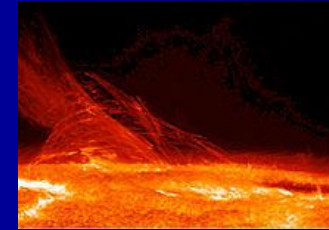
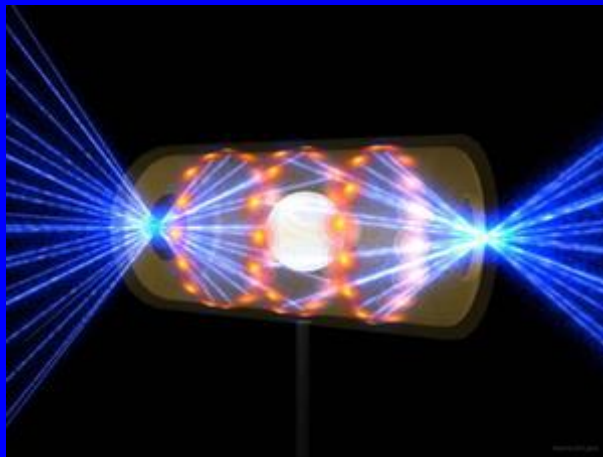


Prof. J. Glošík
KFPP MFF UK

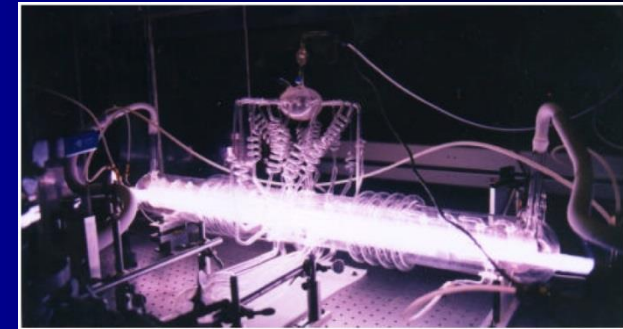
jazyk - česky, slovensky, anglicky, rusky ... v aproximaci



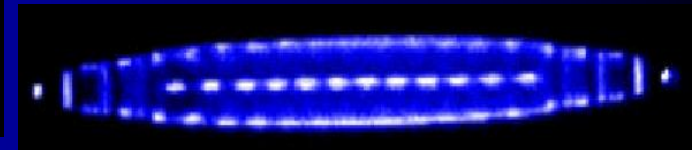
Slunce - vlákna plazmatu



Fusion in a flash. At the National Ignition Facility (NIF) at Lawrence Livermore National Lab, 192 powerful lasers blast a BB-sized fuel pellet inside a metallic cylinder to generate nuclear fusion.



Ultra cold Plasma
Experiment: $T \sim 6$ mK



This presentation is only for students attending the lecture PLASMA PHYSICS at MFF UK,

Not for public use, Preliminary version without references

Scio me nihil scire

**This presentation is only for students attending
the lecture PLASMA PHYSICS at MFF UK,**

**Not for public use,
Preliminary version without references**

Recommended literature :

Úvod do fyziky plazmatu

(Introduction to Plasma Physics)

Francis F. Chen

Academia Praha 1984 (Plenum press 1974)

Základy fyziky plazmy

Viktor Martišovič

Bratislava 2004

Učebný text pre 3. ročník magisterského štúdia

Fundamentals of plasma physics

J. A. Bittencourt

Springer,

Third Edition 2004

Physics of Ionized Gases

Boris M. Smirnov

John Wiley&Sons 2001

Základy klasické a kvantové fyziky plazmatu

„Velký Kracík“

J.Kracík, B. Šesták a L. Aubrecht

Academia Praha 1974

Fyzika plazmatu

J.Kracík, J. Tobiáš

Academia, Praha 1966

„Malý Kracík“

ASTRONOMIE A FYZIKA NA PŘELOMU TISÍCLETÍ

Pod vedením Petra Kulhánka

Aldebaran Group for Astrophysics, 2004

Vybrané kapitoly z fyziky plazmatu

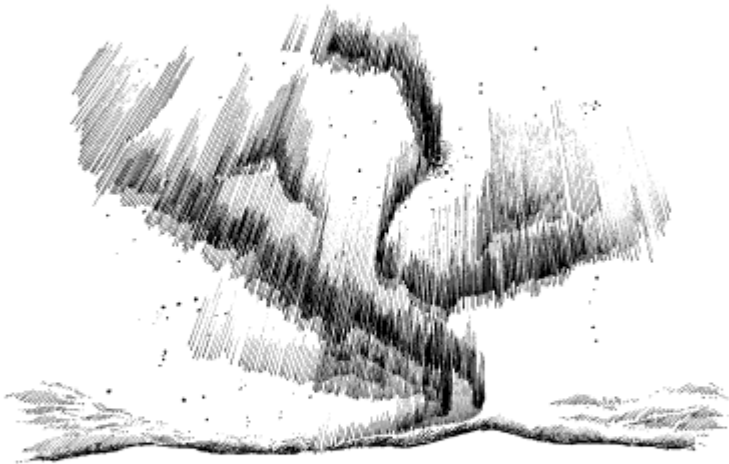
Petr Kulhánek

AGA, Praha 2017

Aldebaran ...

Etc.

Úvod do teorie plazmatu

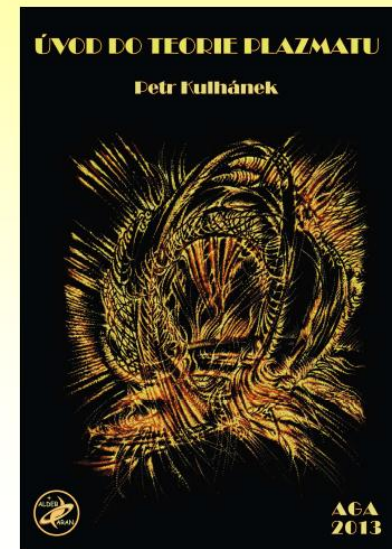


Petr Kulhánek

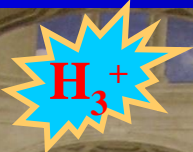
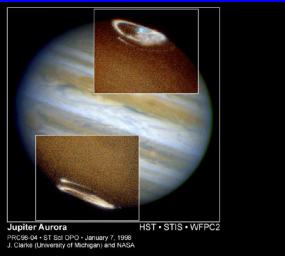
AGA 2020

- V textu byly použity některé obrázky a text z knihy:

P. Kulhánek, Úvod do teorie plazmatu, AGA 2011, Praha.



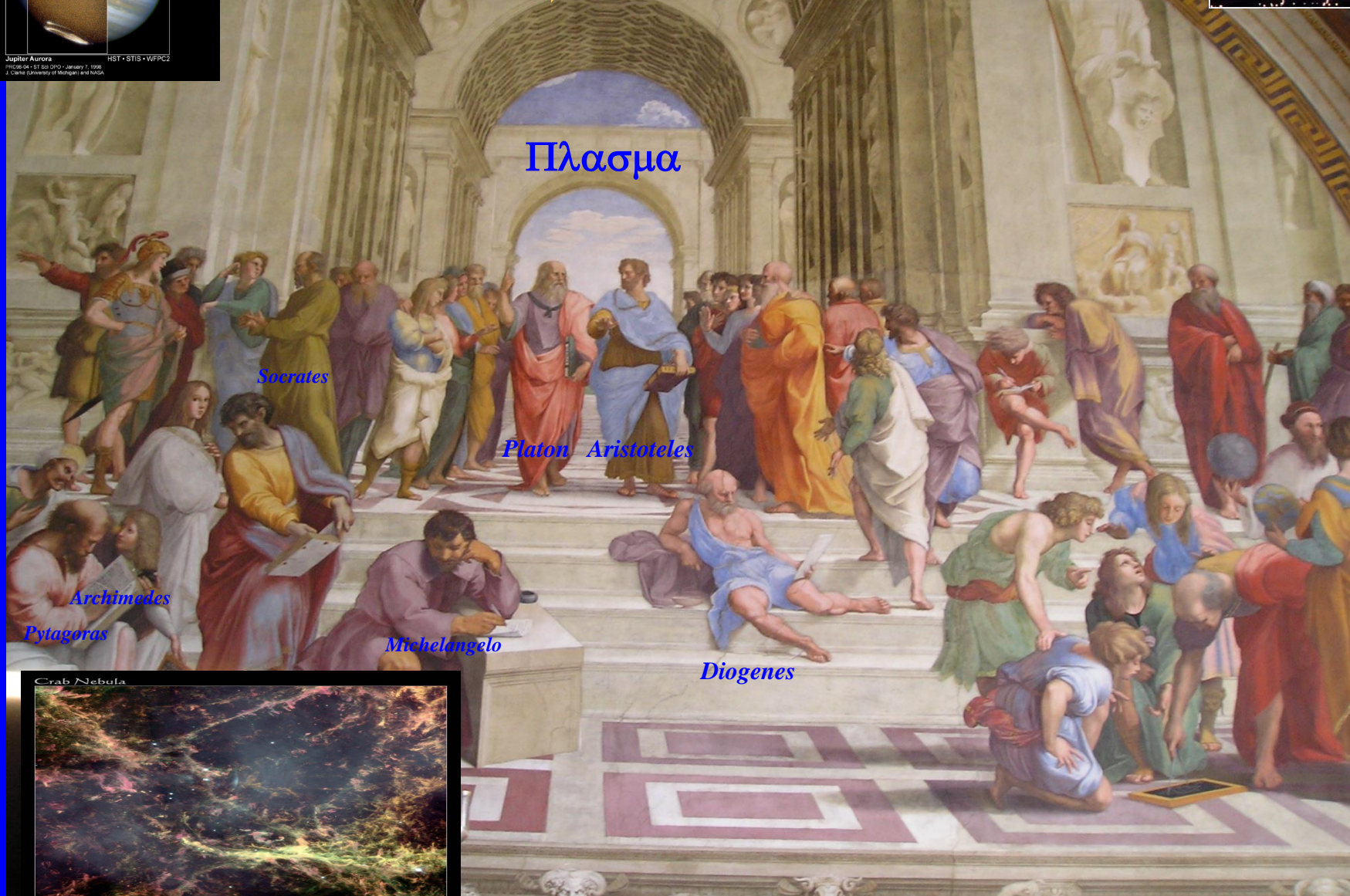
Plasma is everywhere, but where is truth



Scio me nihil scire



Πλασμα



Socrates

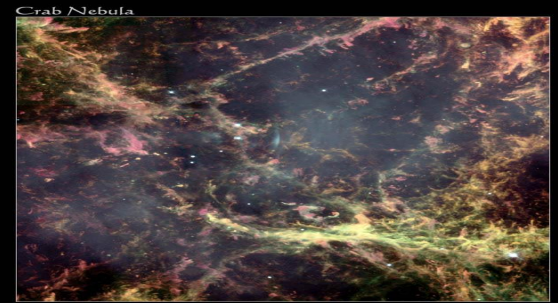
Platon Aristoteles

Archimedes

Pythagoras

Michelangelo

Diogenes

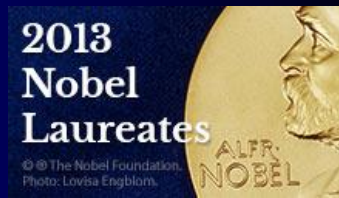


Okomentovaná přednáška pro KFPP MFF UK

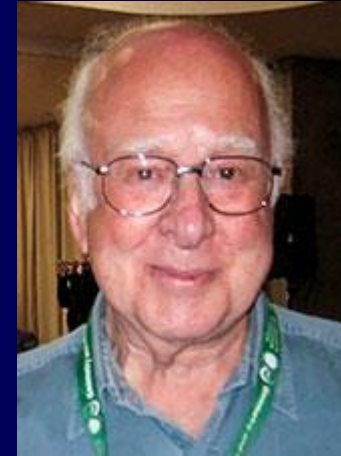
“School of Athens” Rafael, Vatican

Approximation

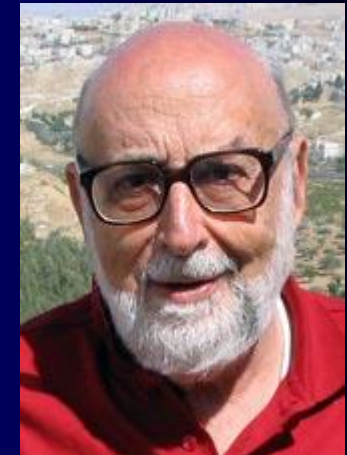
Scio me nihil scire



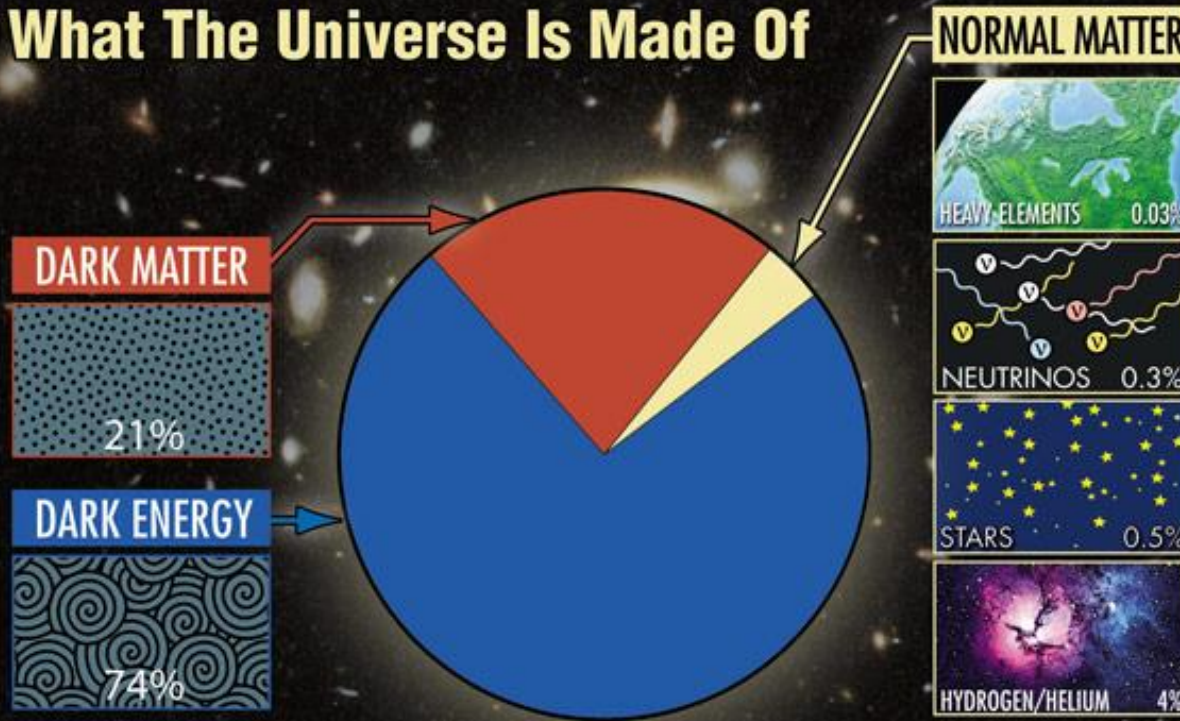
Peter W. Higgs



François Englert



What The Universe Is Made Of

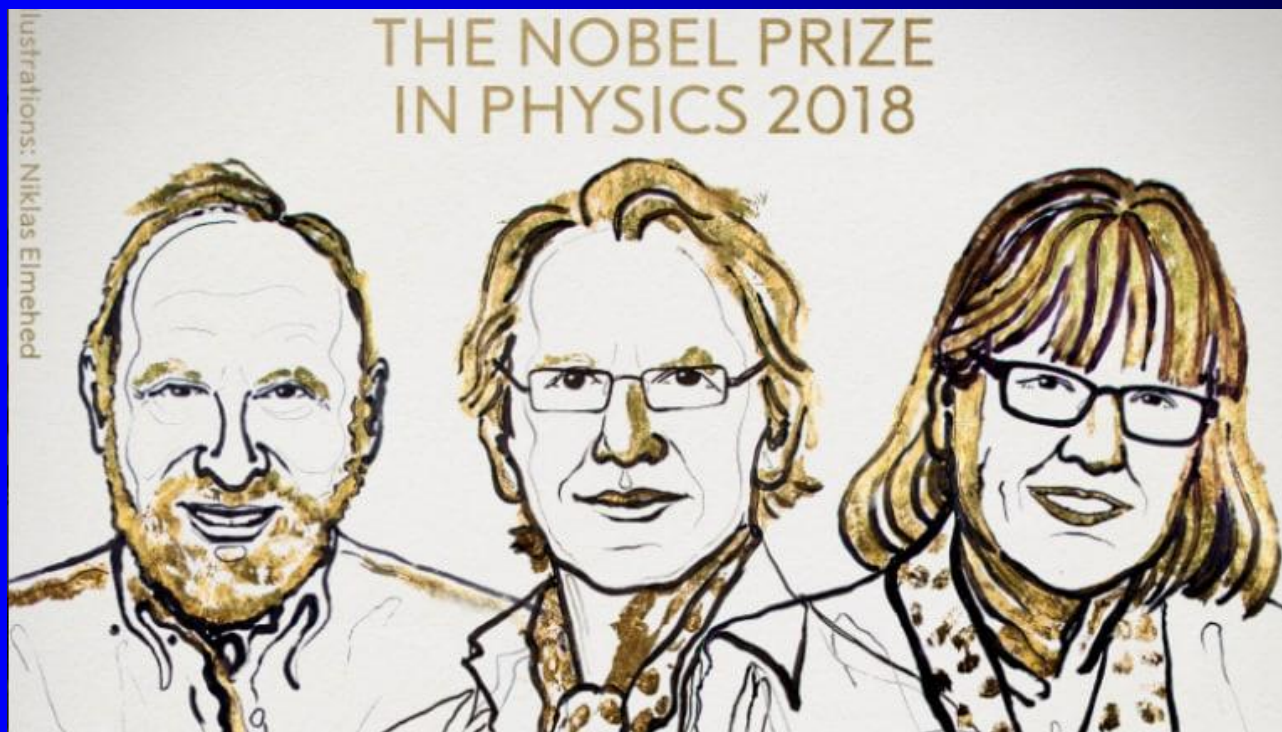


The Nobel Prize in Physics 2013

François Englert and Peter W. Higgs “for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN’s Large Hadron Collider”

Normal matter4.83%

... and now it is clear



The 2018 Nobel Prize in Physics on October 2, 2018, was awarded to Arthur Ashkin of the US, Gerard Mourou of France and Donna Strickland of Canada.

Arthuru Ashkinovi za vynález tzv. optické pinzety a její aplikaci v biologických systémech. druhou polovinu se podělí Francouz Gérard Mourou a Kanadanka Donna Stricklandová, autoři metody generování velmi krátkých optických pulzů s vysokou intenzitou.

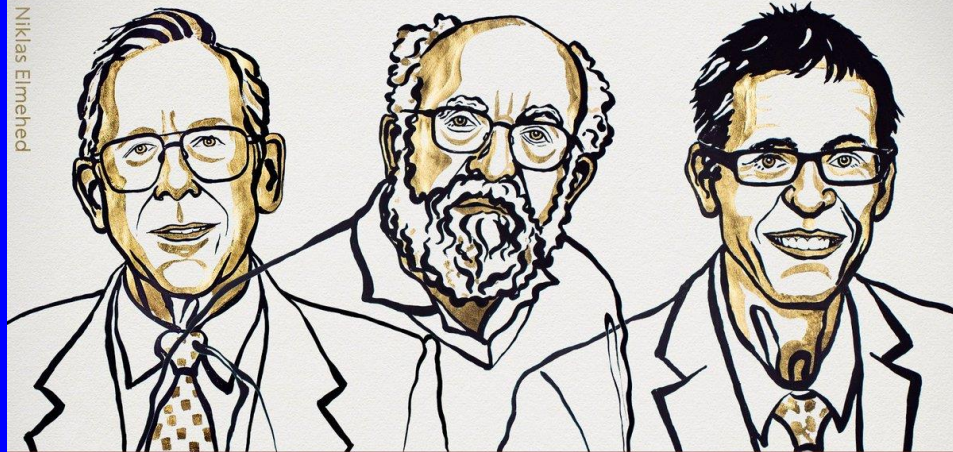
Nobelova cena za fyziku (4)

1903 - Marie Curie-Sklodovská

1963 - Maria Goeppert-Mayer

2018 - Donna Strickland

THE NOBEL PRIZE IN PHYSICS 2019



James
Peebles

“for theoretical
discoveries
in physical
cosmology”

Michel
Mayor

“for the discovery of an exoplanet
orbiting a solar-type star”

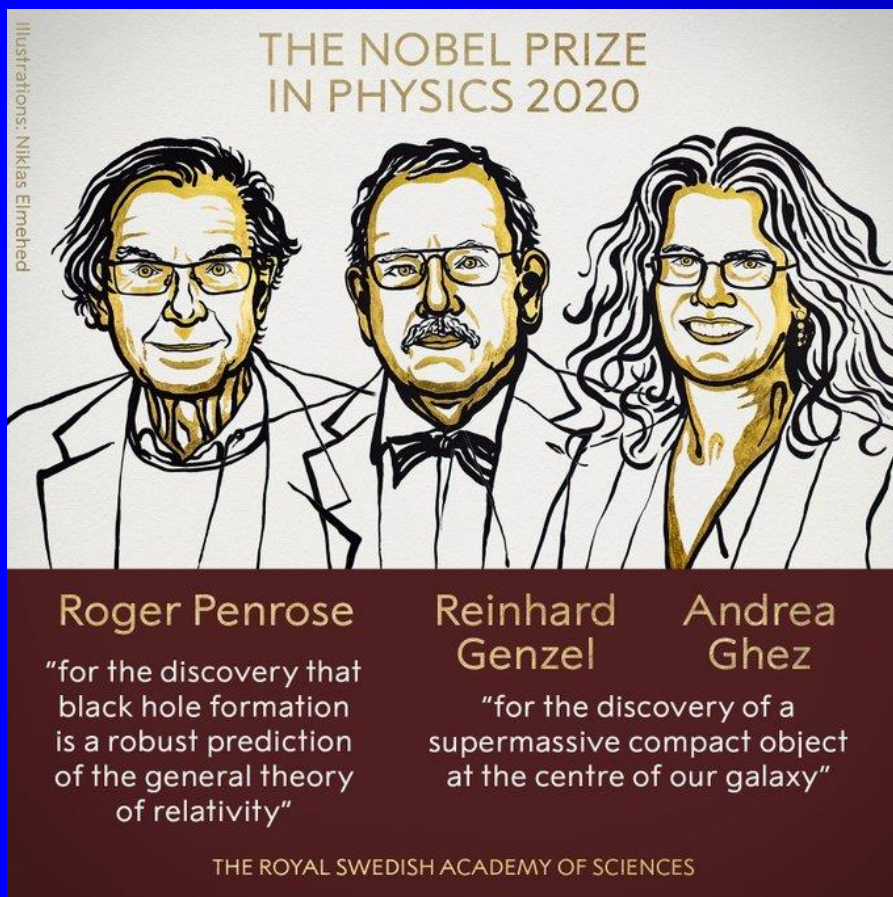
Didier
Queloz

THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Nobel Prize in Physics 2019

“for contributions to our understanding of the evolution of the universe and Earth’s place in the cosmos”

The Nobel Prize in Physics 2020 (6. 10.)



Roger Penrose, born 1931 in Colchester, UK. Ph.D. 1957 from University of Cambridge, UK. Professor at University of Oxford, UK.

Reinhard Genzel, born 1952 in Bad Homburg vor der Höhe, Germany. Ph.D. 1978 from University of Bonn, Germany. Director at Max Planck Institute for Extraterrestrial Physics, Garching, Germany and Professor at University of California, Berkeley, USA.

Andrea Ghez, born 1965 in City of New York, USA. Ph.D. 1992 from California Institute of Technology, Pasadena, USA. Professor at University of California, Los Angeles, USA.

The Nobel Prize in Physics 2020 was divided, one half awarded to Roger Penrose "for the discovery that black hole formation is a robust prediction of the general theory of relativity", the other half jointly to Reinhard Genzel and Andrea Ghez "for the discovery of a supermassive compact object at the centre of our galaxy."

Nobelova cena za fyziku ženy (4x)

1903 - Marie Curie-Sklodowská

1963 - Maria Goeppert-Mayer

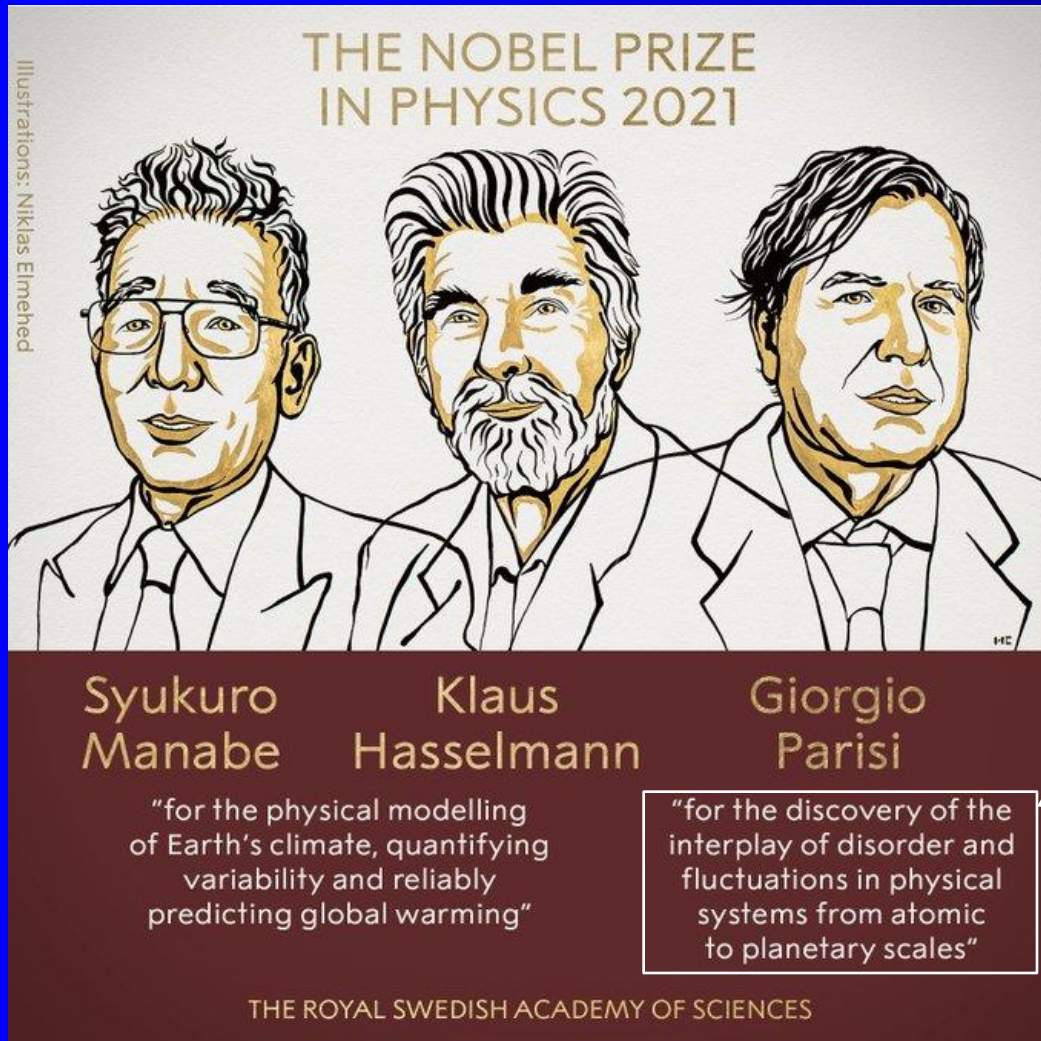
2018 - Donna Strickland

2020 - **Andrea Ghez**

Cenu za fyziku doteraz udelili 212 vedcom.

Doteraz cenu získali tri ženy, Marie Curiová v roku 1903, Maria Goepper-Mayerová v roku 1963 a Donna Stricklandová roku 2018.

BREAKING NEWS: The Royal Swedish Academy of Sciences has decided to award the 2021 Nobel Prize in Physics to Syukuro Manabe, Klaus Hasselmann and Giorgio Parisi “for groundbreaking contributions to our understanding of complex physical systems.”



05. 10. 2021

“It’s clear that for the future generation, we have to act now in a very fast way.” - 2021 physics laureate Giorgio Parisi speaks about the current climate situation at this morning's Nobel Prize press conference.

For discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales.

2021 Nobelova cena za fyziku byla udělena z jedné poloviny společně Syukuro Manabemu a Klausu Hasselmannovi „za fyzikální modelování zemského klimatu, kvantifikaci jeho proměnlivosti a spolehlivou předpověď globálního oteplování“ a z druhé poloviny Giorgiu Parisimu „za objev vzájemného působení neuspořádanosti a fluktuací ve fyzikálních systémech od atomárních po planetární měřítko“.



04. 10. 2022

The Nobel Prize in Physics 2022



Ill. Niklas Elmehed © Nobel Prize Outreach

Alain Aspect

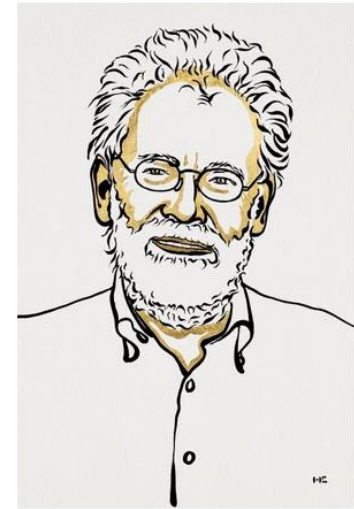
Prize share: 1/3



Ill. Niklas Elmehed © Nobel Prize Outreach

John F. Clauser

Prize share: 1/3

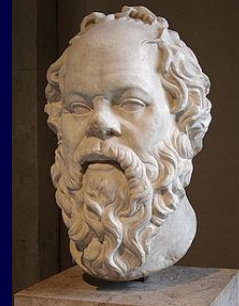


Ill. Niklas Elmehed © Nobel Prize Outreach

Anton Zeilinger

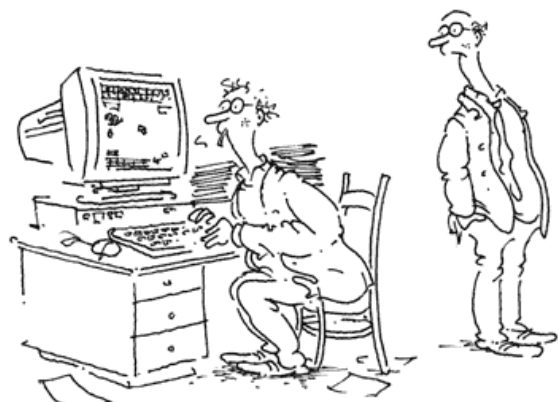
Prize share: 1/3

The Nobel Prize in Physics 2022 was awarded to Alain Aspect, John F. Clauser and Anton Zeilinger "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"



Information

Scio me nihil scire



SPRÁVNĚ, CO MOŽNO NEJVÍC INFORMACÍ! ALE NEPŘEKROČIT HRANICI,
ZA KTEROU SE Z PŘEMÍRY INFORMACÍ ZÁČNE BLBNOUT.

(„Vím, že nic nevím.“ I know that I know nothing)



THE EXPERTS SPEAK[†]

- “There is not the slightest indication that [nuclear] energy will ever be obtained” — *Albert Einstein, 1932*
- “Anyone who expects a source of power from the transformation of these atoms is talking moonshine.” — *Ernest Rutherford, 1933*
- “A few decades hence, [when controlled fusion is achieved], energy will be free — just like the unmetered air.” — *John von Neumann, 1956*
- “Radio has no future.” — *Lord Kelvin, 1897*
- “I think there is a world market for about five computers.” — *Thomas J. Watson, 1943*
- Where a calculator like ENIAC is equipped with 18,000 vacuum tubes and weighs 30 tons, computers in the future may have only 1,000 vacuum tubes and perhaps only weigh $1\frac{1}{2}$ tons.” — *Popular Mechanics, March 1949*
- “640k ought to be enough for anybody.” — *Bill Gates, 1981*

[†] C. Cerf and V. Navasky, Villard, New York, 1998

Motivation:



Just for pleasure.

$$\psi(x) \propto \sum_n A_n e^{ip_n x / \hbar}$$

The Orion molecular clouds

© Royal Observatory, Edinburgh / Anglo-Australian Observatory

92.1% of nucleons in the universe are protons
7.8% are helium nuclei !

H

Mg

Fe

$\begin{matrix} \blacksquare & \blacksquare & \blacksquare & \blacksquare \\ C & N & O & Ne \\ \cdot & \cdot & \cdot & \cdot \\ Si & S & Ar \end{matrix}$

He

Cosmic Abundance
of some elements

| Element | Abundance |
|--------------|-----------|
| hydrogen (H) | 1,000,000 |
| helium | 80,147 |
| oxygen | 739 |
| carbon | 445 |
| neon | 138 |
| nitrogen | 91 |
| magnesium | 40 |
| Silicon | 37 |
| Sulfur | 19 |

The Privilege of Being a Physicist

Victor F. Weisskopf

There are certain obvious privileges that a physicist enjoys in our society. He is reasonably paid; he is given instruments, laboratories, complicated and expensive machines, and he is asked not to make money with these tools, like most other people, but to spend money. Furthermore, he is supposed to do what he himself finds most interesting, and he accounts for what he spends to the money givers in the form of progress reports and scientific papers that are much too specialized to be understood or evaluated by those who give the money—the federal authorities and, in the last analysis, the taxpayer. Still, we believe that the pursuit of science by the

ported by the p
have to look dee
ence to society a
physics only; we
ral sciences, bu
ences, that is, f
formed without



"Intelligent play with simple, natural phenomena, the joys of discovery of unexpected experiences, are much better ways of learning to think than any teaching by rote."

Plasma

History of the term “plasma” In the mid-19th century the Czech physiologist **Jan Evangelista Purkyně** introduced use of the Greek word plasma (meaning “formed or molded”) to denote the clear fluid which remains after removal of all the corpuscular material in blood.

Half a century later, the American scientist **Irving Langmuir** proposed in 1922 that the electrons, ions and neutrals in an ionized gas could similarly be considered as corpuscular material entrained in some kind of fluid medium and called this entraining medium plasma. However it turned out that unlike blood where there really is a fluid medium carrying the corpuscular material, there actually is no “fluid medium” entraining the electrons, ions, and neutrals in an ionized gas. Ever since, plasma scientists have had to explain to friends and acquaintances that they were not studying blood!

Jan Evangelista Purkyně was a Czech anatomist and physiologist. In 1839, he coined the term protoplasm for the fluid substance of a cell. He was one of the best known scientists of his time. [Wikipedia](#)

Purkyně also introduced the scientific terms plasma (for the component of blood left when the suspended cells have been removed) and protoplasm (the substance found inside cells.)

Plasma

- Velmi často se o plazmatu mluví jako o čtvrtém skupenství hmoty
- Název plazma pro ionizovaný plyn poprvé použil Irwing Langmuir (1881–1957) v roce 1928, protože mu chováním tento stav látky připomínal krevní plazmu
- Za své objevy, které byly na pomezí fyziky a chemie (např. Využití atomárního vodíku – svařování atomárním vodíkem), získal v roce 1932 Nobelovu cenu právě za chemii



Langmuir

Plazma 1922 or 1928 ????

- Definice plazmatu je v literatuře celá řada
 - *Plazma je kvazineutrální plyn složený z nabitých a neutrálních částic, vykazující kolektivní chování*
 - *Fyzikální plynné plazma se skládá z různých druhů částic, elektricky nabitých či neutrálních v rozličných kvantových stavech*
- Co je **kvazineutralita**? $n_i = n_e (= n_g)$
- Co je **kolektivní chování**? – rozumí se jím pohyby, které závisí nejen na lokálních podmínkách, ale také na stavu plazmatu ve vzdálených oblastech

Definition of a plasma

Although a plasma is loosely described as an electrically neutral medium of positive and negative particles, a more rigorous definition requires three criteria to be satisfied:

The plasma approximation:

Charged particles must be close enough together that each particle influences many nearby charged particles, rather than just the interacting with the closest particle (these collective effects are a distinguishing feature of a plasma). The plasma approximation is valid when the number of electrons within the sphere of influence (called the *Debye sphere* whose radius is the Debye (screening) length) of a particular particle is **large**. The average number of particles in the Debye sphere is given by the plasma parameter, Λ .

Bulk interactions:

The Debye screening length (defined above) is short compared to the physical size of the plasma. This criterion means that interactions in the bulk of the plasma are more important than those at its edges, where boundary effects may take place.

Plasma frequency:

The electron plasma frequency (measuring plasma oscillations of the electrons) is large compared to the electron-neutral collision frequency (measuring frequency of collisions between electrons and neutral particles). When this condition is valid, plasmas act to shield charges very rapidly (quasineutrality is another defining property of plasmas).

Charged Particle Trajectories Are Different In Plasmas

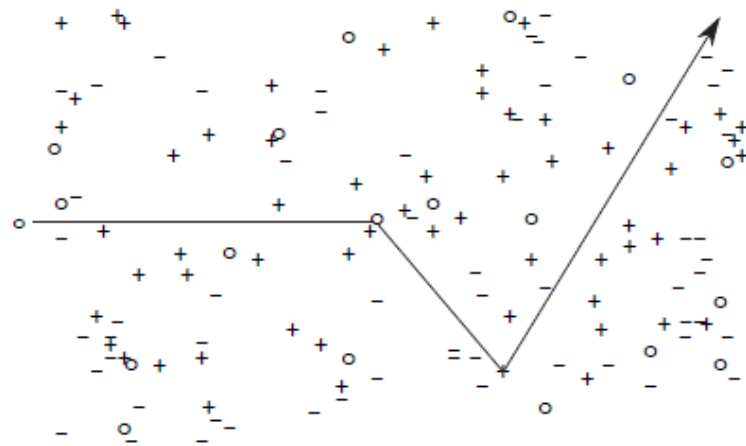


Figure 3: The trajectory of a neutral particle in a partially ionized gas exhibits “straight-line” motion between abrupt atomic collisions. The typical distance between neutral particle collisions is called the collision “**mean free path.**” Symbols: neutrals (circles), electrons (minus signs) and ions (plus signs).

Plasma

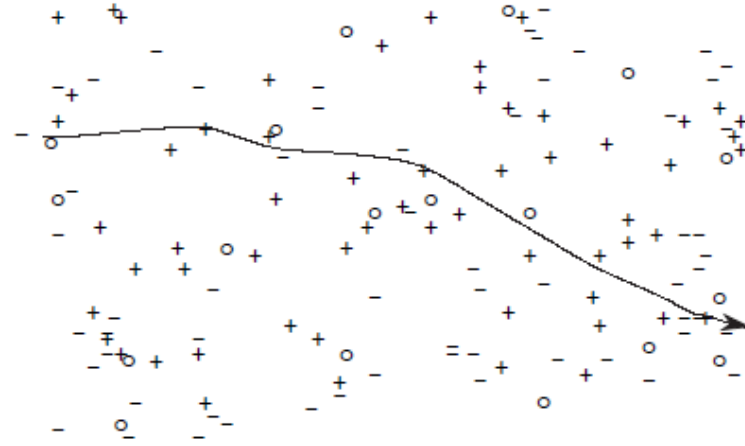
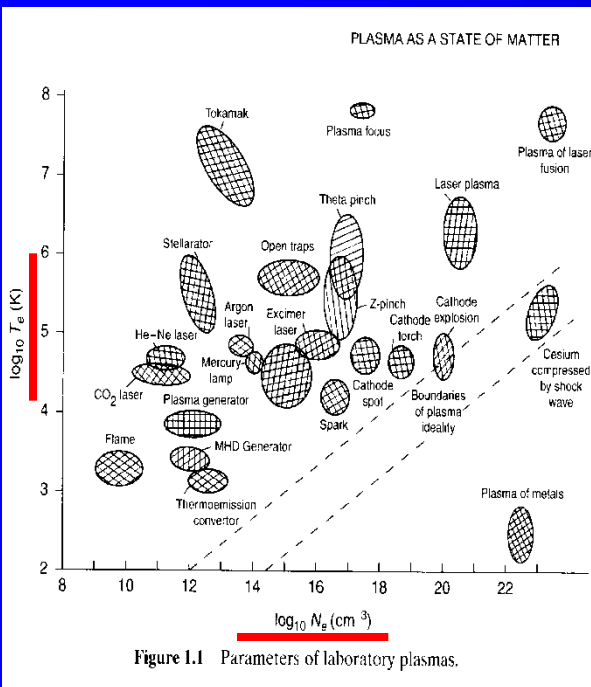
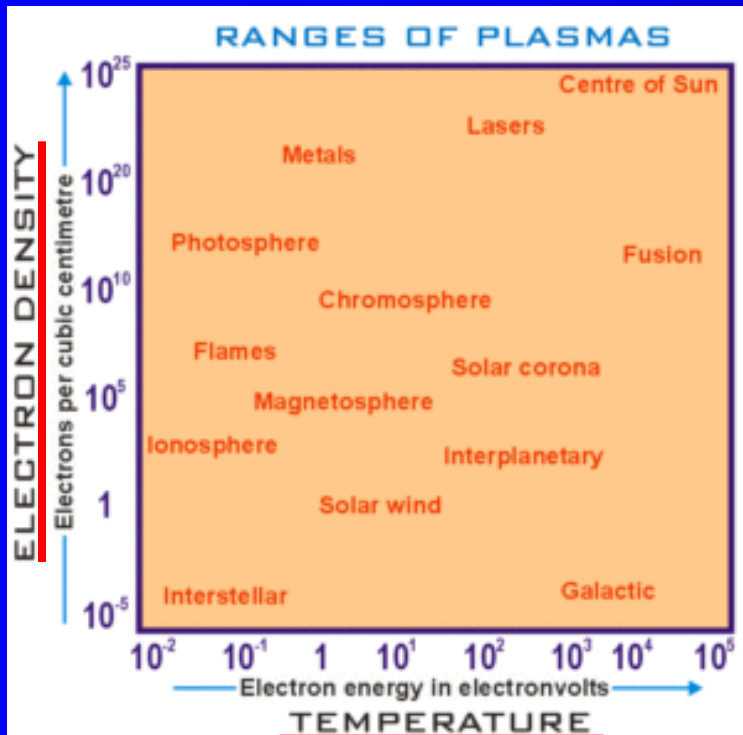


Figure 4: The trajectory of a “test” electron in a plasma exhibits continuous small-angle Coulomb collisional scatterings of its direction of motion. The “**collision length**” is the exponential decay length over which an average charged particle in a plasma loses its initially directed momentum.



Typical ranges of plasma parameters

| Characteristic | Terrestrial plasmas | Cosmic plasmas |
|---|--|---|
| Size in metres | 10^{-6} m (lab plasmas) to 10^2 m (lightning) | 10^{-6} m (spacecraft sheath) to 10^{25} m (intergalactic nebula) |
| Lifetime in seconds | 10^{-12} s (laser-produced plasma) to 10^7 s (fluorescent lights) | 10^1 s (solar flares) to 10^{17} s (intergalactic plasma) |
| Density in particles per cubic metre | 10^7 m $^{-3}$ to 10^{32} m $^{-3}$ (inertial confinement plasma) | 10^0 (i.e., 1) m $^{-3}$ (intergalactic medium) to 10^{30} m $^{-3}$ (stellar core) |
| Temperature in kelvins | ~ 0 K (crystalline non-neutral plasma) to 10^8 K (magnetic fusion plasma) | 10^2 K (aurora) to 10^7 K (solar core) |
| Magnetic fields in teslas | 10^{-4} T (lab plasma) to 10^3 T (pulsed-power plasma) | 10^{-12} T (intergalactic medium) to 10^{11} T (near neutron stars) |



Ranges of plasma parameters

Density increases upwards, temperature increases towards the right. The free electrons in a metal may be considered an electron plasma [11]. Plasma parameters can take on values varying by many orders of magnitude, but the properties of plasmas with apparently disparate parameters may be very similar (see plasma scaling). The following chart considers only conventional atomic plasmas and not exotic phenomena like quark gluon plasmas:

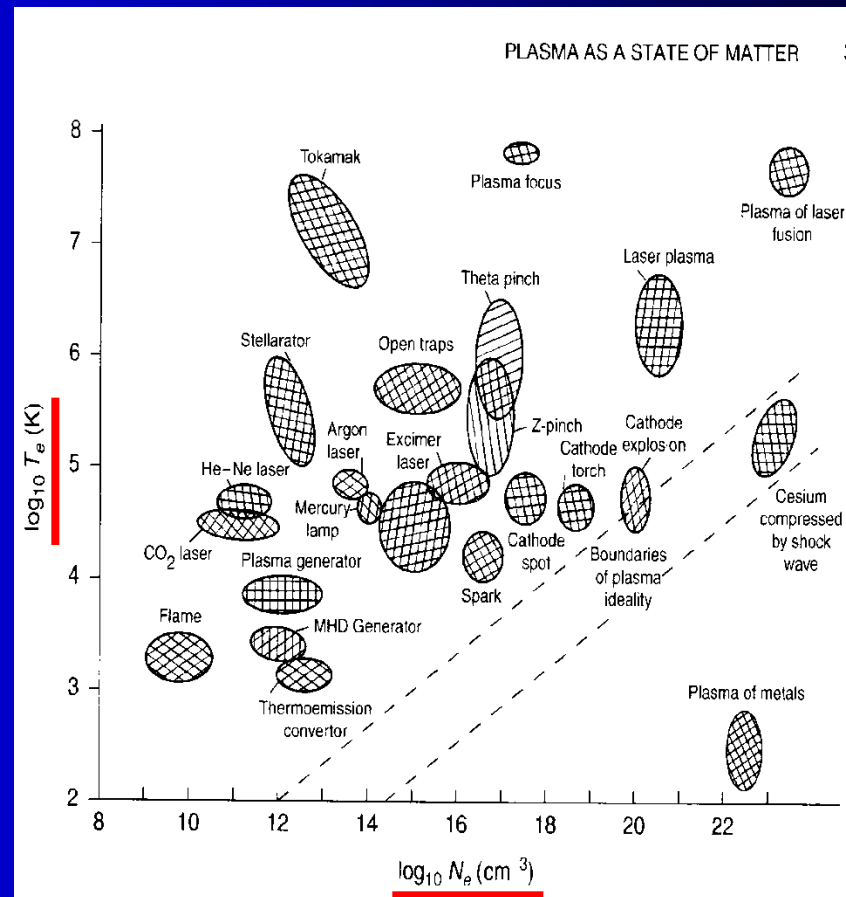


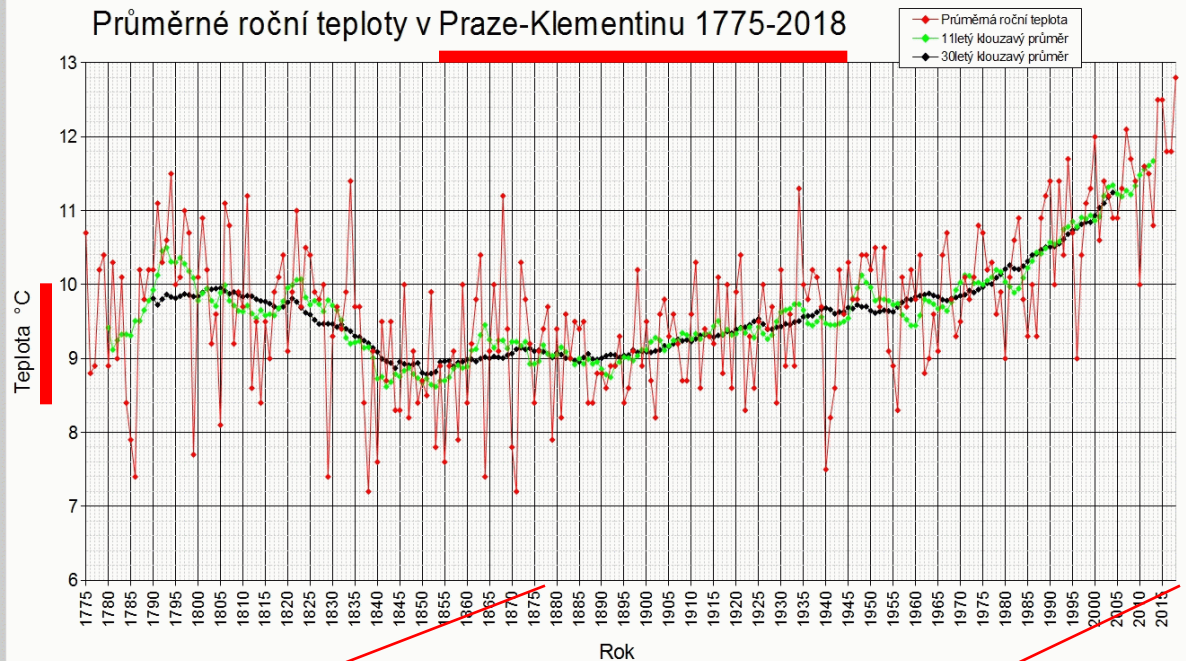
Figure 1.1 Parameters of laboratory plasmas.

05. 10. 2021

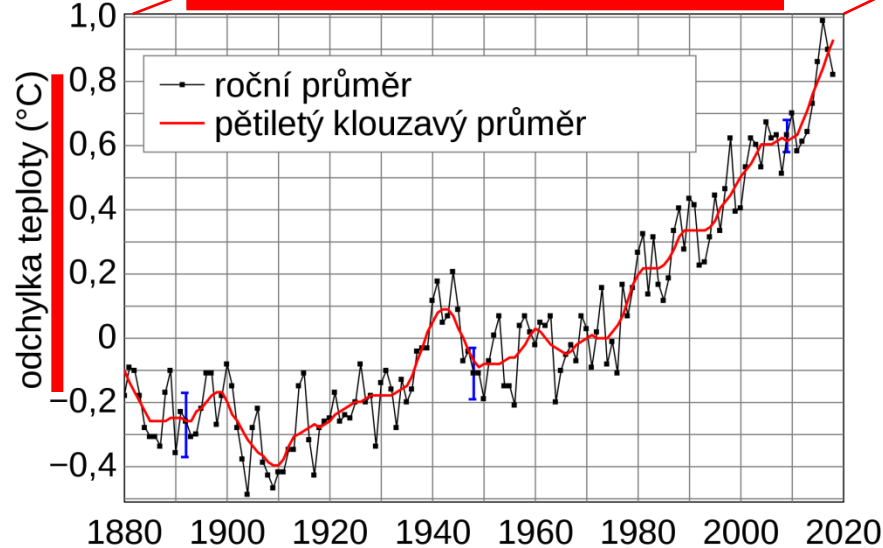
04. 10. 2022

Information

Průměrné roční teploty v Praze-Klementinu 1775-2018



Globální teplotní index pevnina-oceán



“Kdo z vás je bez hříchu, první hod’ na ni kamenem”

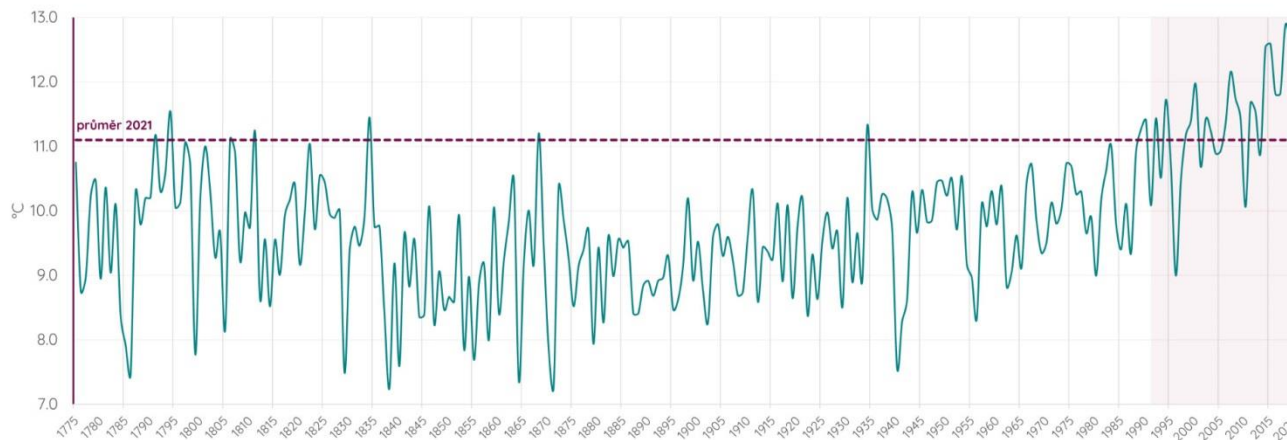
(see ref.: **Nový zákon**, ... Ježíš ... hora Olivetská ...)

Jesus

He that is without sin among you, let him be the first to cast a stone at her.



Průměrná roční teplota 1775–2021, Praha-Klementinum



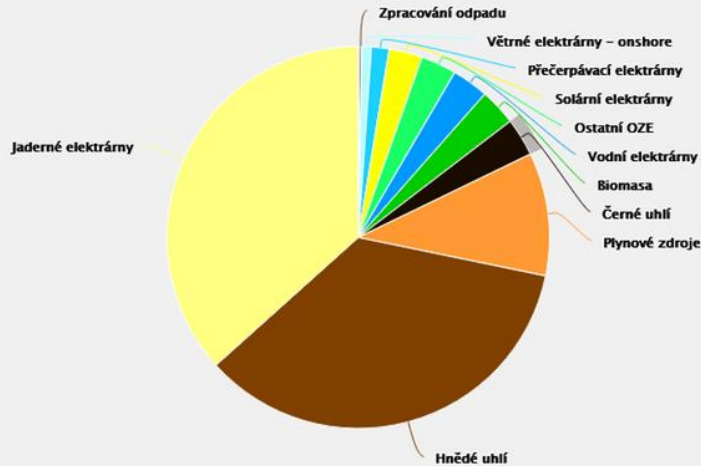
Graf výše ukazuje průměrné roční teploty na stanici Praha-Klementinum za období 1775 až 2020. V grafu je vyznačena přerušovanou čarou hladina průměrné roční teploty za rok 2021 a vyšrafováno je období 1991 až 2020.

Jak ukazuje výše uvedená infografika, v kontextu posledních 30 let (období 1991 až 2020) a zejména pak poslední dekády (2011 až 2020) opravdu byl rok 2021 chladnější. **Při hodnocení klimatu však nejsou podstatné krátkodobé výkyvy, ale dlouhodobý trend.** Z grafu výše je jasně patrné, že **v dlouhodobém hledisku byl i rok 2021 velmi teplý** a do roku 1990 bychom za více než 200 let našly jen 9 roků, které byly v průměru teplejší. Oproti předchozímu tisíciletí 1961–1990 to byl rovněž rok silně nadnormální (+1,1 °C). Trend je zcela zřejmý, a to **dlouhodobé zvyšování teploty**, které se v posledních letech velmi akcelerovalo. To však **neznamená, že se nemůže vyskytnout chladnější rok** (a stejně tak globální oteplování neznamená, že se v zimě nemohou vyskytnout velmi chladné dny, dlouhodobě jich ale ubývá). Ještě lepším příkladem než rok 2021 je v tomto směru rok 1996 a 2010. Ani tyto dva roky ale nelze považovat za velmi chladné z dlouhodobého hlediska. Při pohledu na celkový průběh je patrné, že rok 1996 byl blízko průměru 1775–1990 a rok 2010 byl z dlouhodobého pohledu teplotně nadprůměrný.



Česká republika: Podíl zdrojů na výrobě elektřiny

Data od: 1. 1. 2021 do: 31. 12. 2021

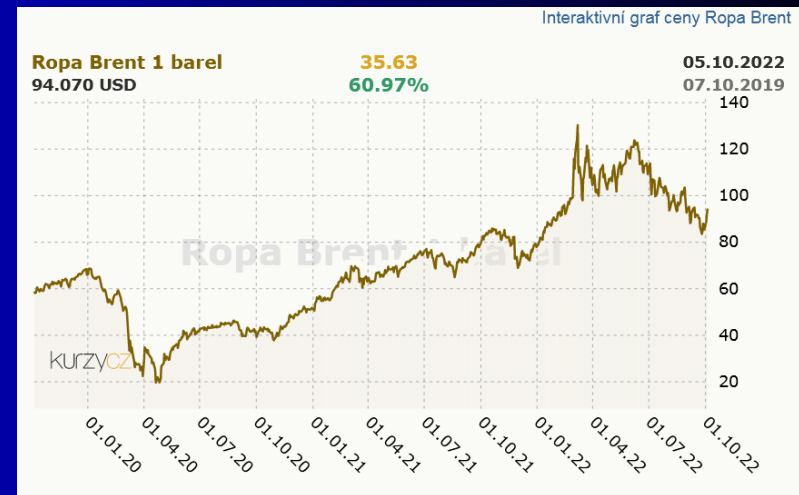


Podíl zdrojů na výrobě elektřiny v roce 2021 (v %)

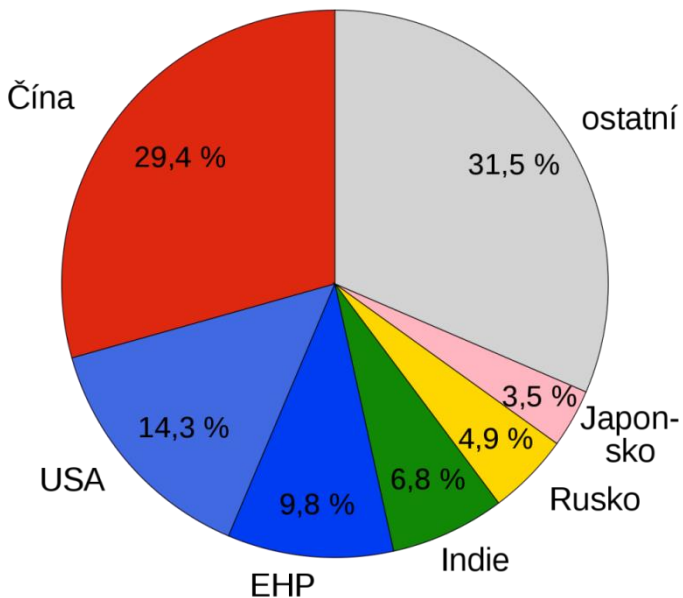
| | Česko | Slovensko | Maďarsko | Rakousko | Německo | Polsko | Francie |
|----------------------------|-------------|-------------|------------|-------------|-------------|-------------|-------------|
| Jaderné elektrárny | 36.6 | 54.3 | 51.2 | 0 | 13 | 0 | 70.4 |
| Hnědé uhlí | 35.1 | 3.5 | 10.3 | 0 | 19.5 | 26.1 | 0 |
| Plynové zdroje | 10.4 | 13.7 | 29.2 | 16.1 | 10.4 | 8 | 6.4 |
| Černé uhlí | 3.2 | 1.3 | 0 | 0 | 10.3 | 50.4 | 0.8 |
| Biomasa | 3.1 | 3.1 | 3.8 | 2.6 | 7.8 | 1.2 | 0.6 |
| Vodní elektrárny | 4.7 | 15.5 | 0.6 | 65.2 | 4.7 | 1.8 | 11.9 |
| Fotovoltaické elektrárny | 2.9 | 2.1 | 0 | 1.6 | 9.4 | 2.9 | 2.7 |
| Větrné elektrárny | 0.9 | 0 | 2.1 | 12.6 | 22.8 | 9.6 | 6.9 |
| Ostatní obnovitelné zdroje | 3 | 1.8 | 0.8 | 1.6 | 1.5 | 0 | 0.3 |
| Ostatní | 0.1 | 4.7 | 2 | 0.3 | 0.6 | 0 | 0 |
| Celkem OZE | 14.6 | 22.5 | 7.3 | 83.6 | 46.2 | 15.5 | 22.4 |

Cui bono?

Qui Bonum

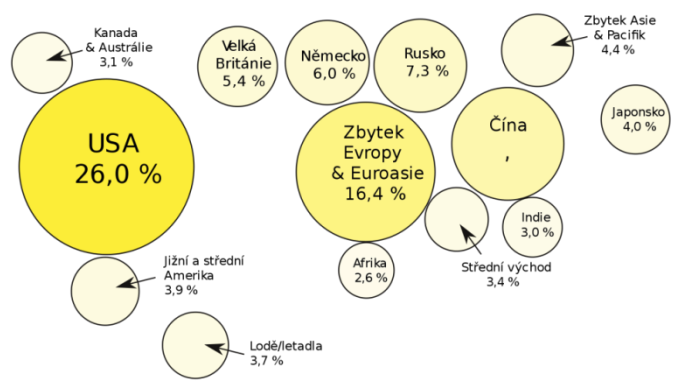


Not actualized, approximation



Největší producenti CO2 na světě

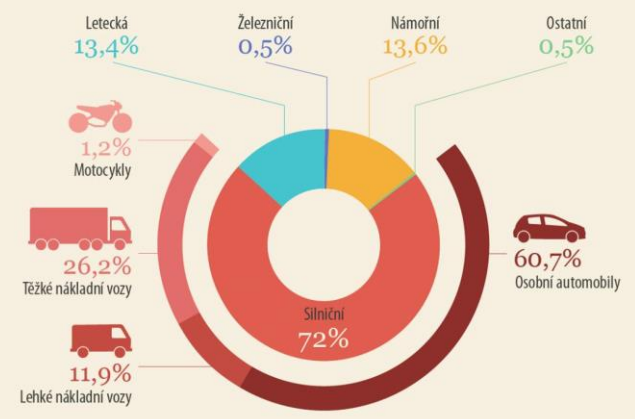
Kumulativní emise₂CO za roky 1751-2012



Podíl na globálních emisích CO₂ mezi roky 1751–2012 podle různých regionů

EMISE CO2 PRODUKOVANÉ V DOPRAVĚ

Podíl emisí podle druhu dopravy (2016)

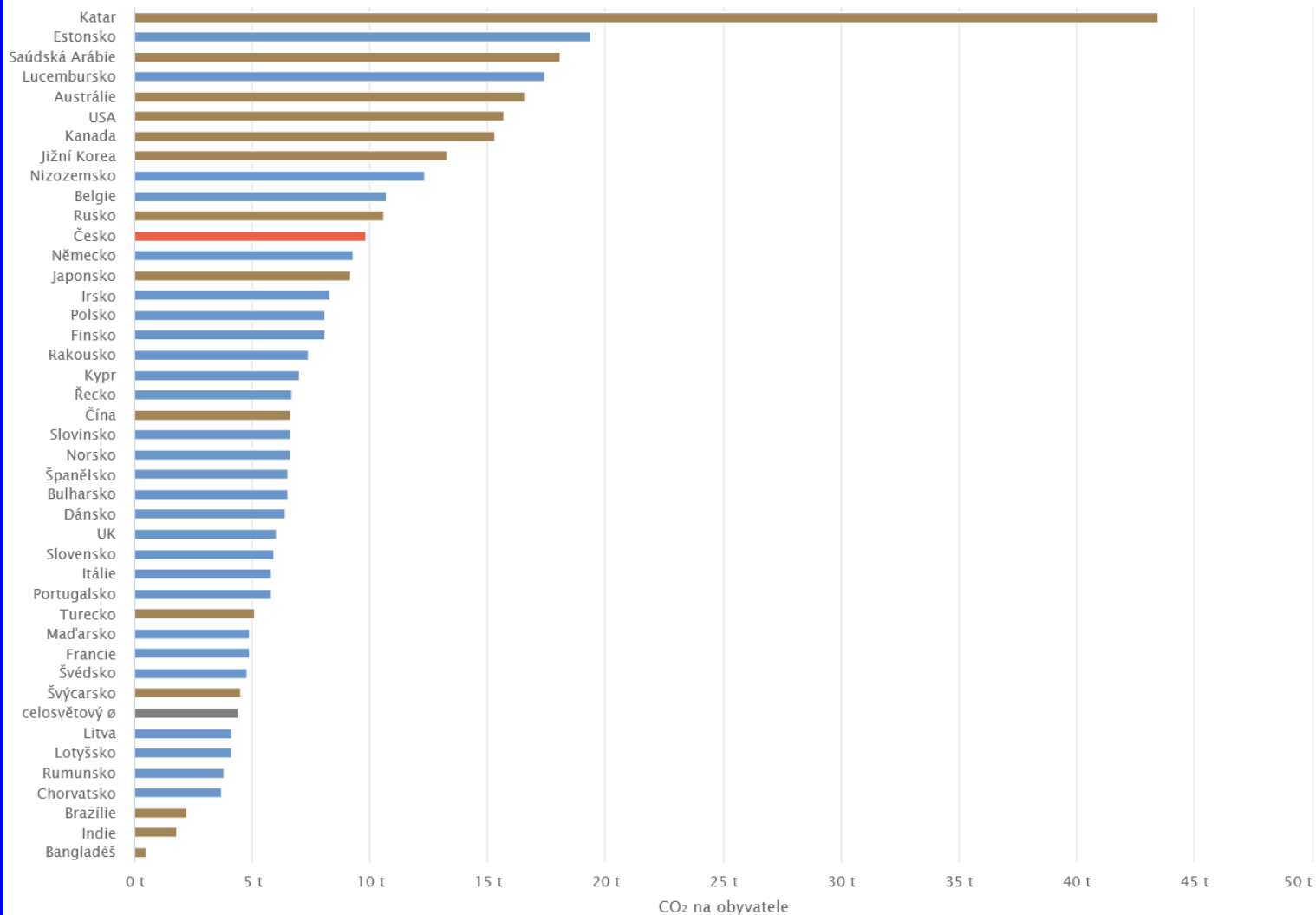


~2019

Kdo z vás je bez hříchu, první hod' na ni kamenem

Emise CO₂ na hlavu

vybrané země, 2017



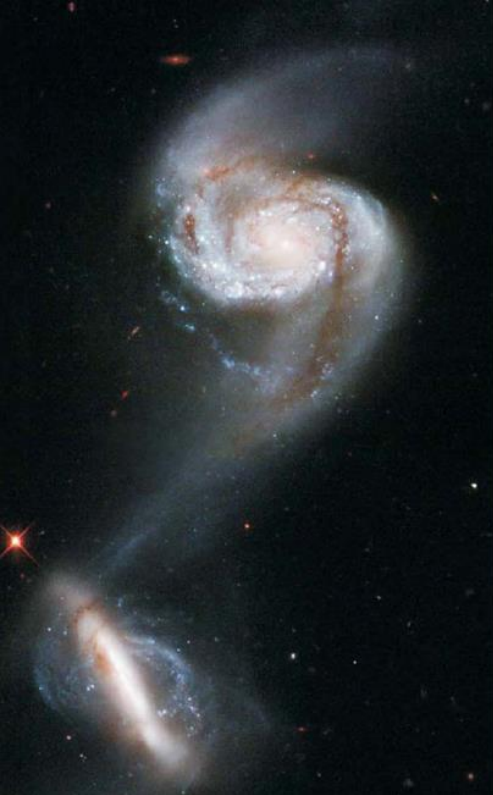
● Česko ● země EU ● země mimo EU ● globální průměr

“Kdo z vás je bez hříchu, první hod’ na ni kamenem”

(see ref.: **Nový zákon**, Jan 8 ... hora Olivetska ...)

Jesus

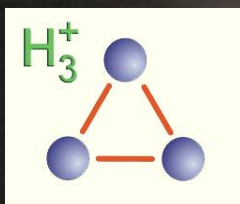
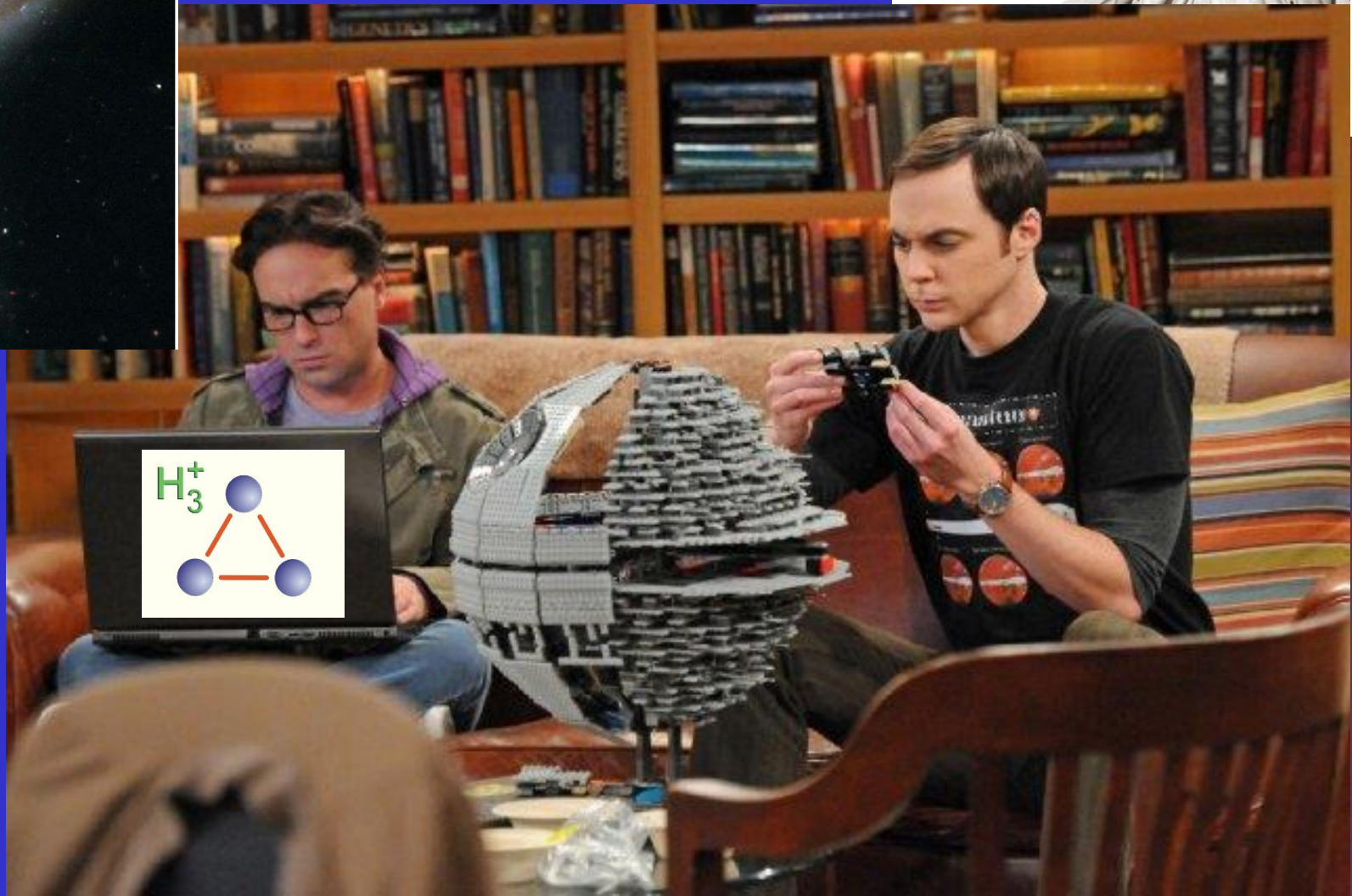
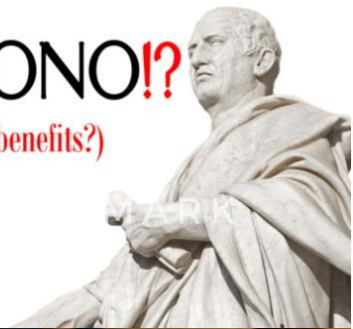
He that is without sin among you, let him be the first to cast a stone at her.



CUI BONO!?

(Who benefits?)

Cicero

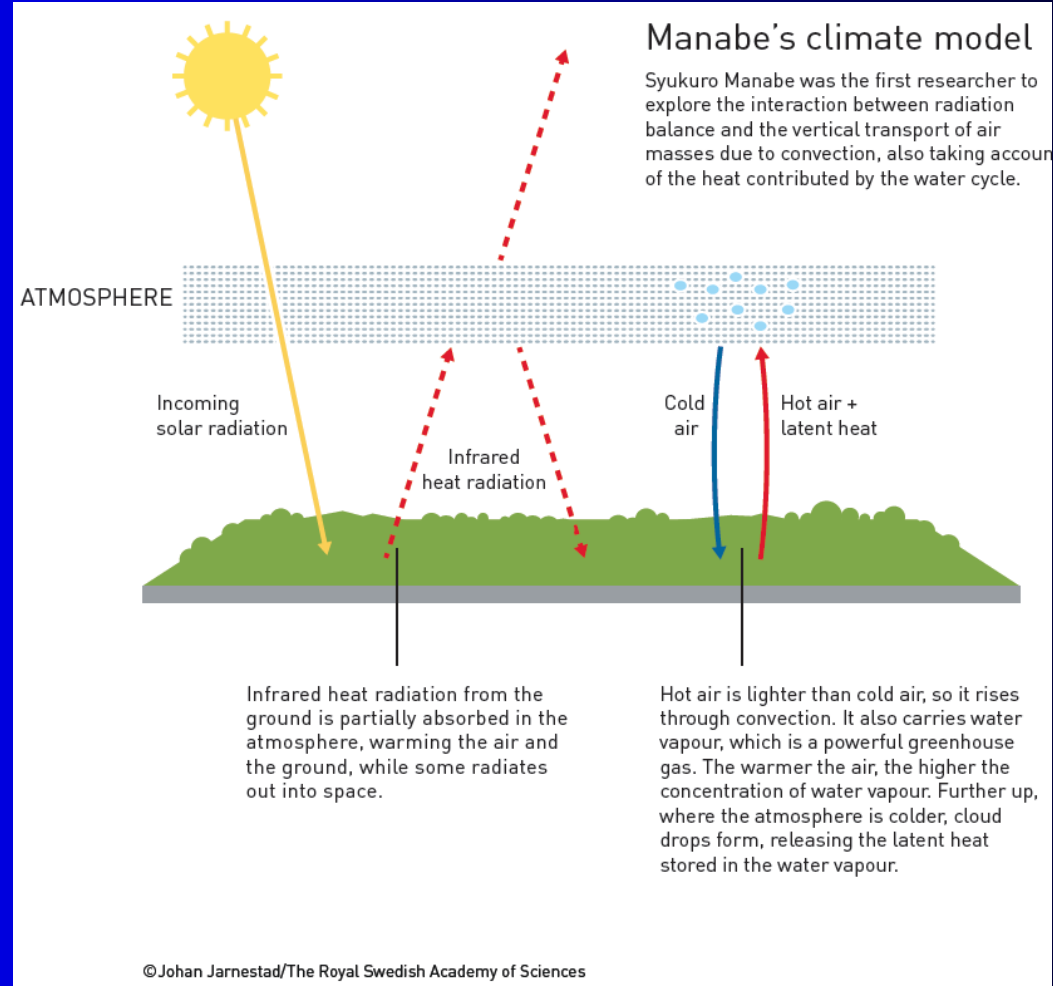


Manabe's work in the 1960s demonstrated how increased levels of carbon dioxide in the atmosphere caused the Earth's temperature to rise. In doing so, he "laid the foundation for the development of current climate models," the Royal Swedish Academy of Sciences said in a statement.

A decade later, Hasselmann "created a model that links together weather and climate."

Parisi's discoveries, meanwhile, "make it possible to understand and describe many different and apparently entirely random complex materials and phenomena." This is not only true for physics but also for other areas, such as mathematics, biology, neuroscience and machine learning, the academy added.

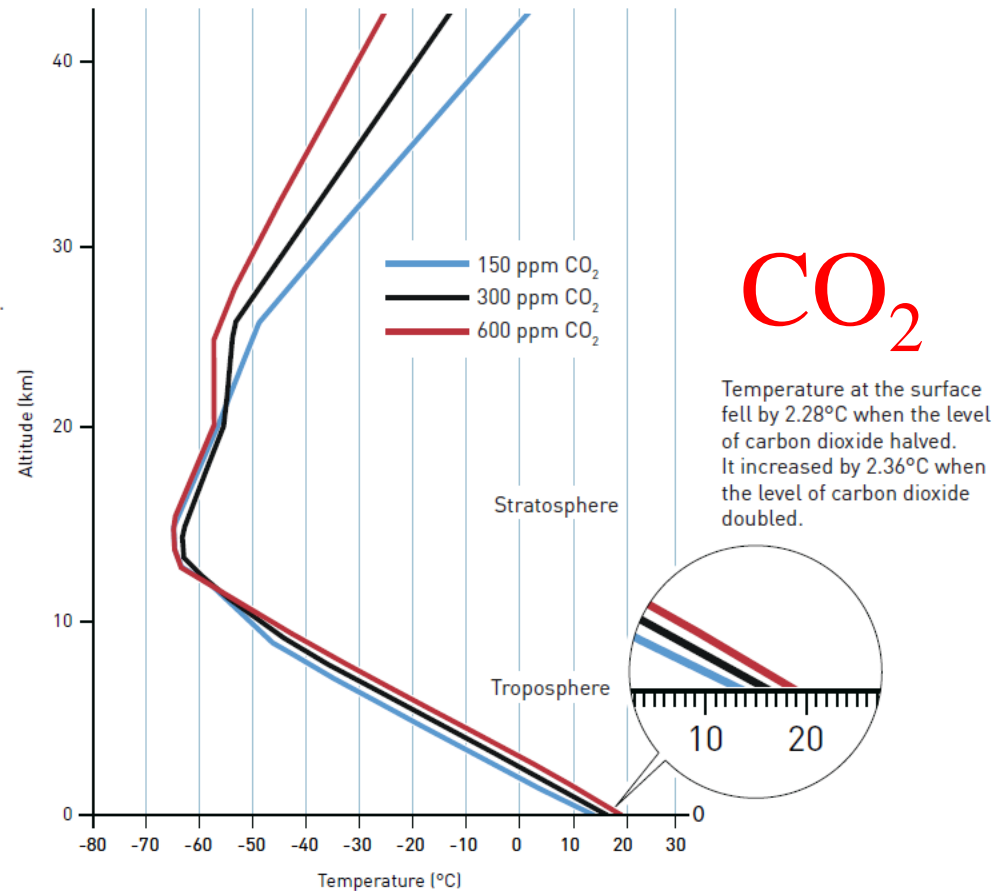
05. 10. 2021



The committee's decision to recognize pioneering work on climate change comes weeks before the world's leaders meet at COP26, [a crucial summit in the United Kingdom.](#)

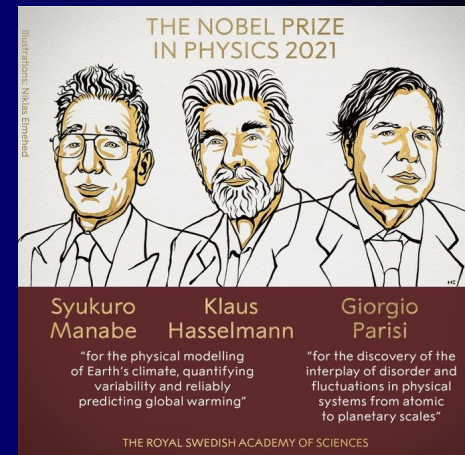
Carbon dioxide heats the atmosphere

Increased levels of carbon dioxide lead to higher temperatures in the lower atmosphere, while the upper atmosphere gets colder. Manabe thus confirmed that the variation in temperature is due to increased levels of carbon dioxide; if it was caused by increased solar radiation, the entire atmosphere should have warmed up.



Source: Manabe and Wetherald (1967) Thermal equilibrium of the atmosphere with a given distribution of relative humidity, *Journal of the atmospheric sciences*, Vol. 24, Nr 3, May.

©Johan Jarnestad/The Royal Swedish Academy of Sciences



Member of the Nobel Committee for Physics Thors Hans Hansson, Secretary General of the Royal Swedish Academy of Sciences Goran K. Hansson, and member of the Nobel Committee for Physics John Wettlaufer announce the winners of the 2021 Nobel Prize in Physics at the Royal Swedish



The committee's decision to recognize pioneering work on climate change comes weeks before the world's leaders meet at COP26, [a crucial summit in the United Kingdom.](#)

For discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales.

24. 09. 2021

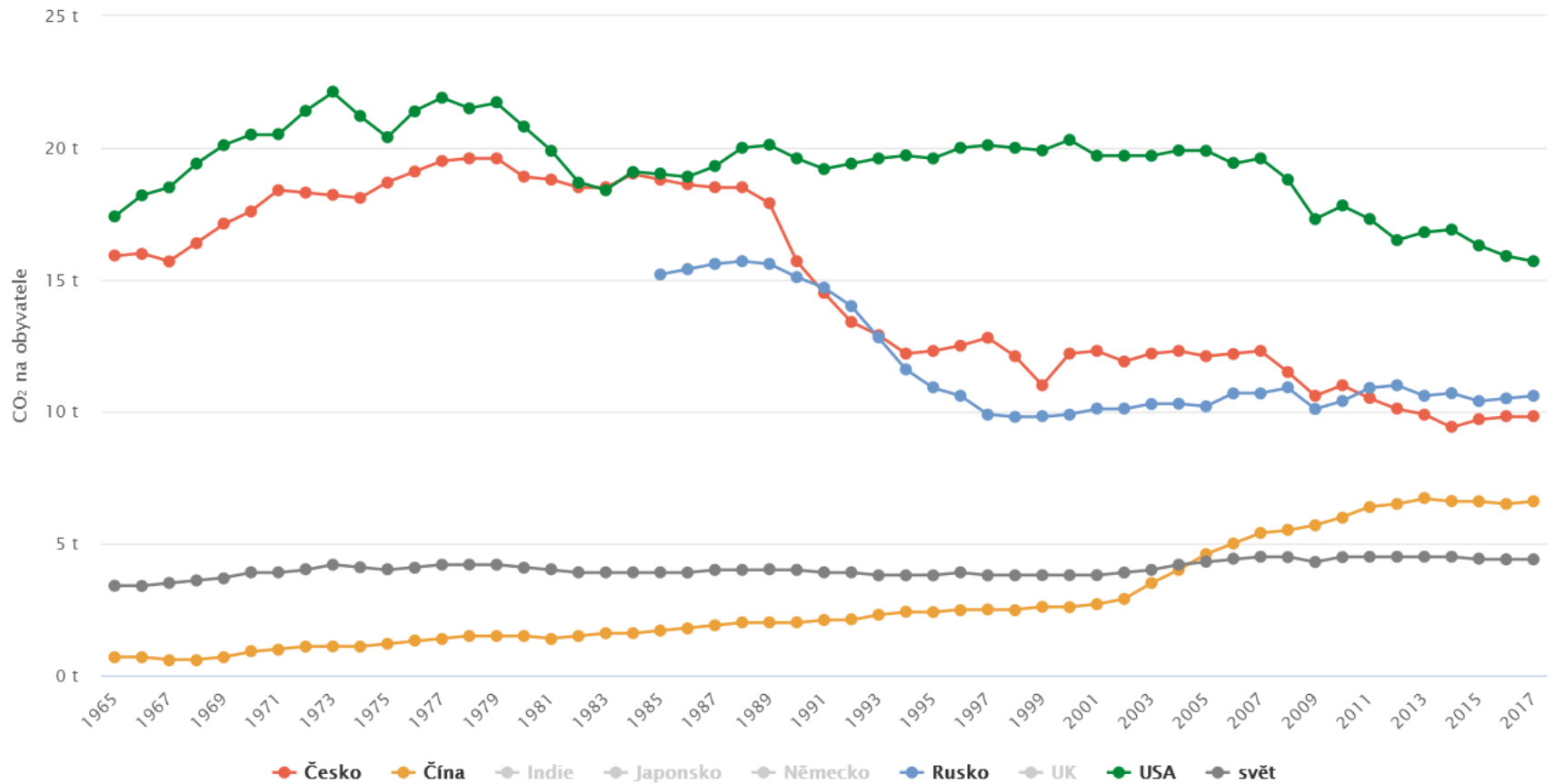
Průzkum: Teenageři se změn klimatu bojí. Protestům fandí, ale nechodí na ně

V Praze se na Malostranském náměstí sešlo kolem 500 lidí, uvedla pro server iROZHLAS na místě policie. Šlo o první studentskou stávku za klima svolanou iniciativou Fridays for Future od loňského září.



Emise CO₂ na hlavu, časová řada

vybrané země, 1965 až 2017



Not actualized, approximation

<https://www.worldometers.info/cz/>

~7 815 369 848

Současná světová populace (8.10. 2019)

~7 897 522 492

Současná světová populace (4. 10. 2021)

8.10.2019 do 13:00

in 1 594 603 663 589

Solární energie dopadající na Zemi dnes (MWh)

out 216 185 179

Energie spotřebovaná dnes (MWh)

out/in ~ 0.00013 negligible

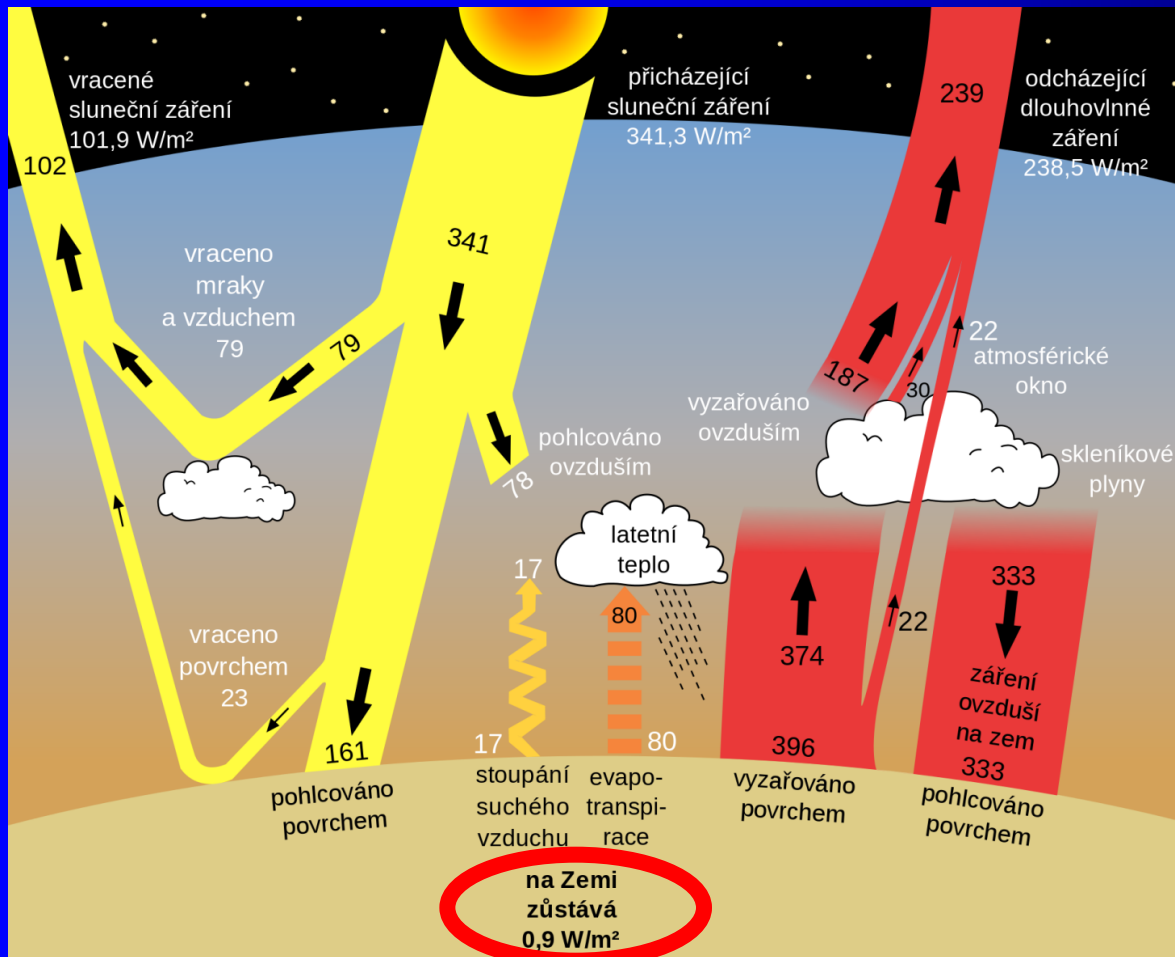
>191 109 298 413

Odeslaných e-mailových zpráv dnes ...

“Kdo z vás je bez hříchu, první hod’ na ni kamenem”

Not actualized, approximation

[wikipedia.org/wiki/Terestriální_záření](https://cs.wikipedia.org/wiki/Terestriální_záření)



Krátkovlnné záření ze Slunce dopadající na zemský povrch a atmosféru. Dlouhovlnná část záření je emitována z povrchu a téměř zcela absorbována do atmosféry.

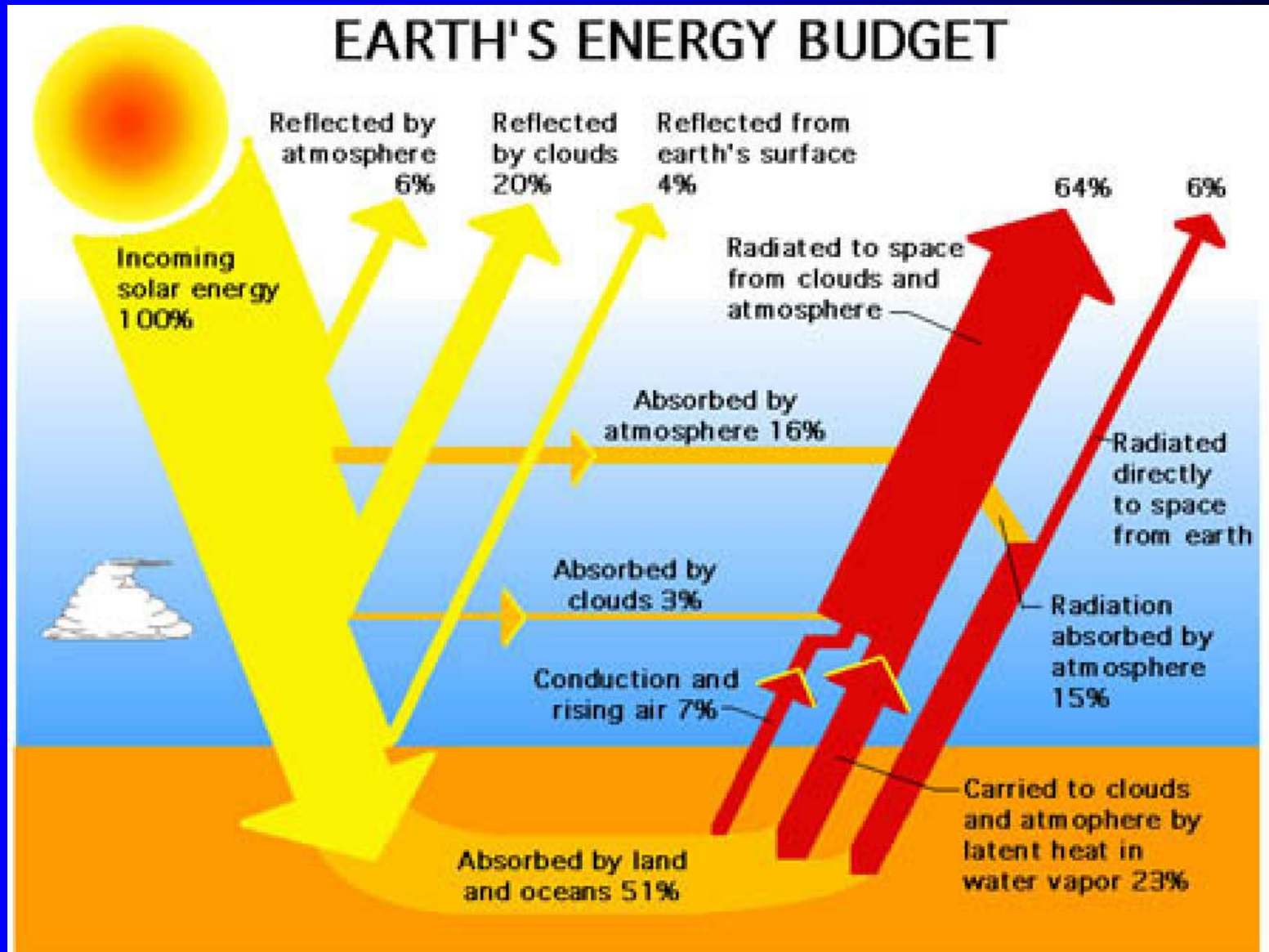
V tepelné rovnováze je absorbovaná energie z atmosféry ~ stejná jako ta vydávaná do vesmíru.

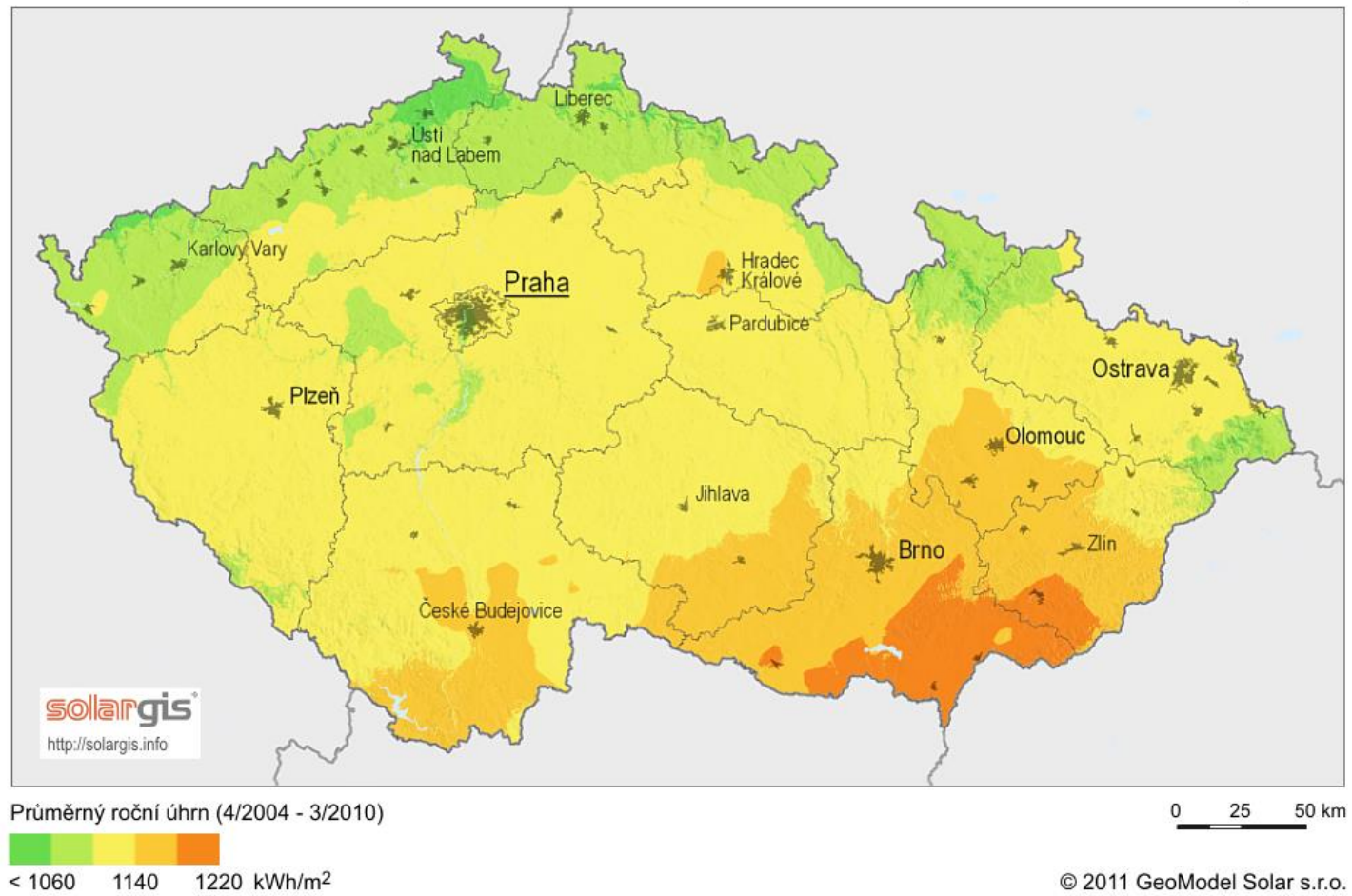
Čísla ukazují výkon záření ve wattch na metr čtvereční v období let 2000–2004

Průměrná hustota toku energie ze zemského povrchu vzhůru činí asi 400 W/m^2 , což odpovídá teplotě 16°C ; hustota toku, který Země vyzařuje do vesmíru, činí ale jen asi 240 W/m^2 a odpovídá to teplotě zhruba 255 K . Terestriální (též terestrické, pozemské) záření je v naprosté většině dlouhovlnné infračervené záření.

<https://cs.wikipedia.org/wiki/>

EARTH'S ENERGY BUDGET



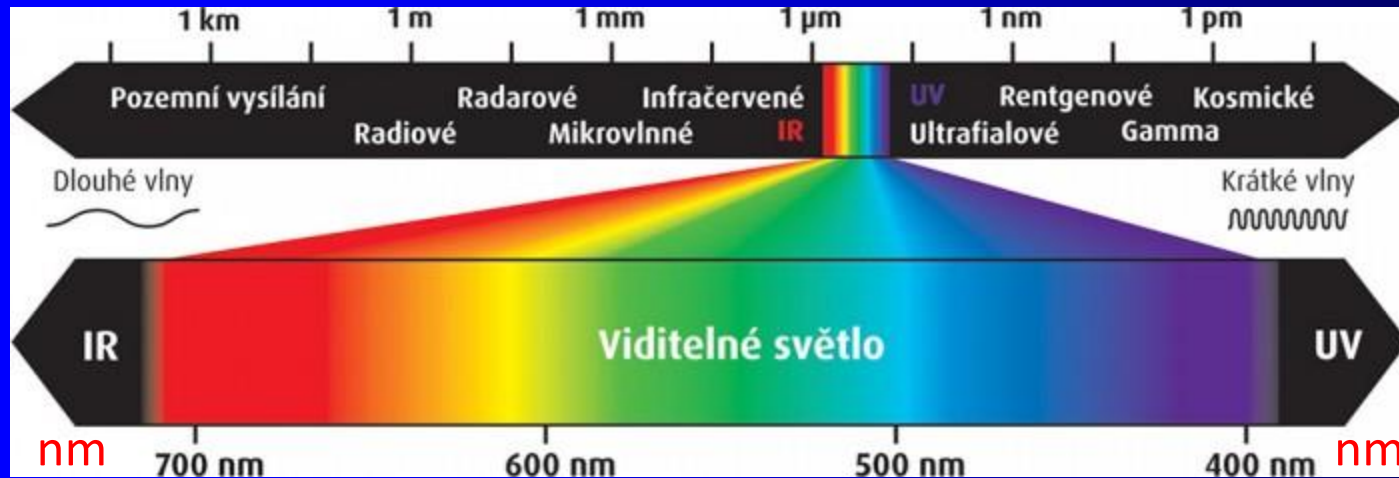


.... elektřiny stanoven na **6 Kč/kWh s DPH**

.... plynu na **3 Kč/kWh s DPH**.

Spektrum elektromagnetického záření

Information



Viditelné světlo - elektromagnetické záření v rozmezí vlnových délek 380–760 nm.

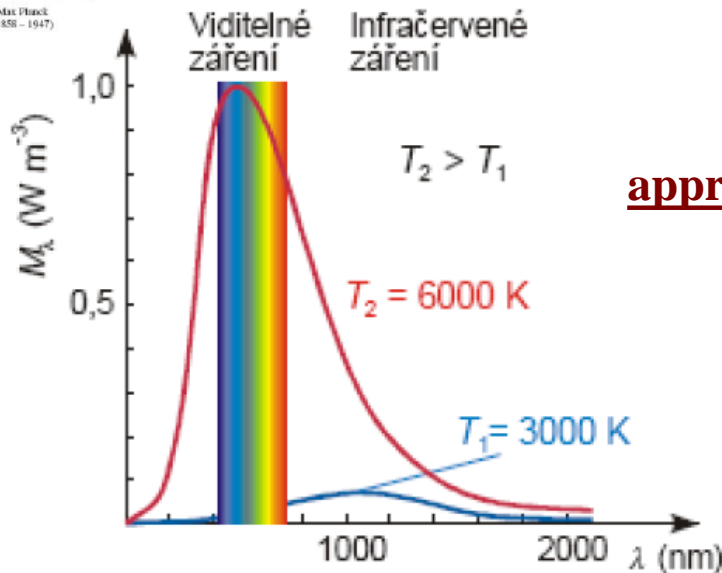
eV





Max Planck
(1858 - 1947)

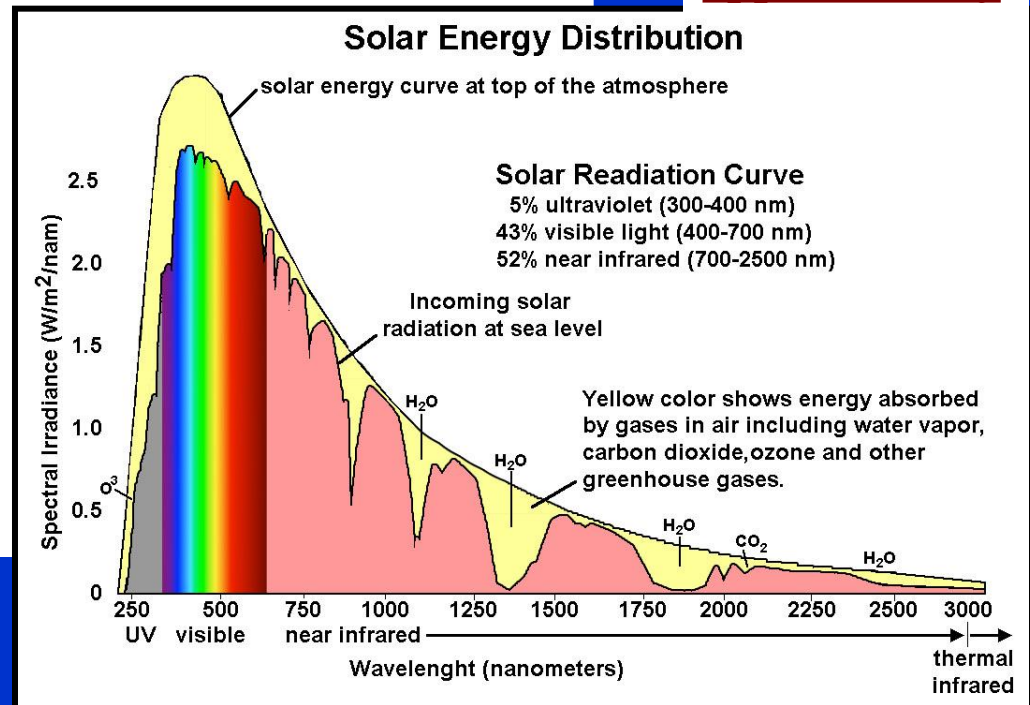
Záření černého tělesa



approximately

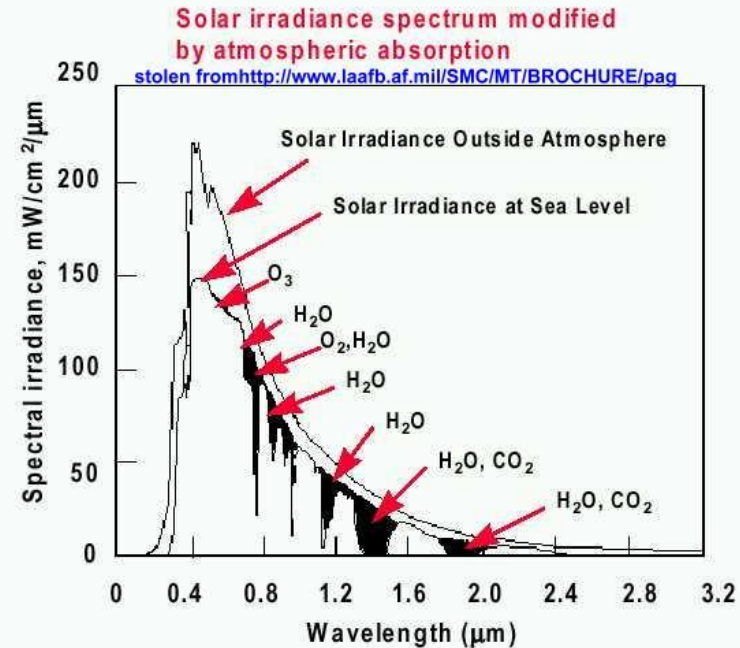
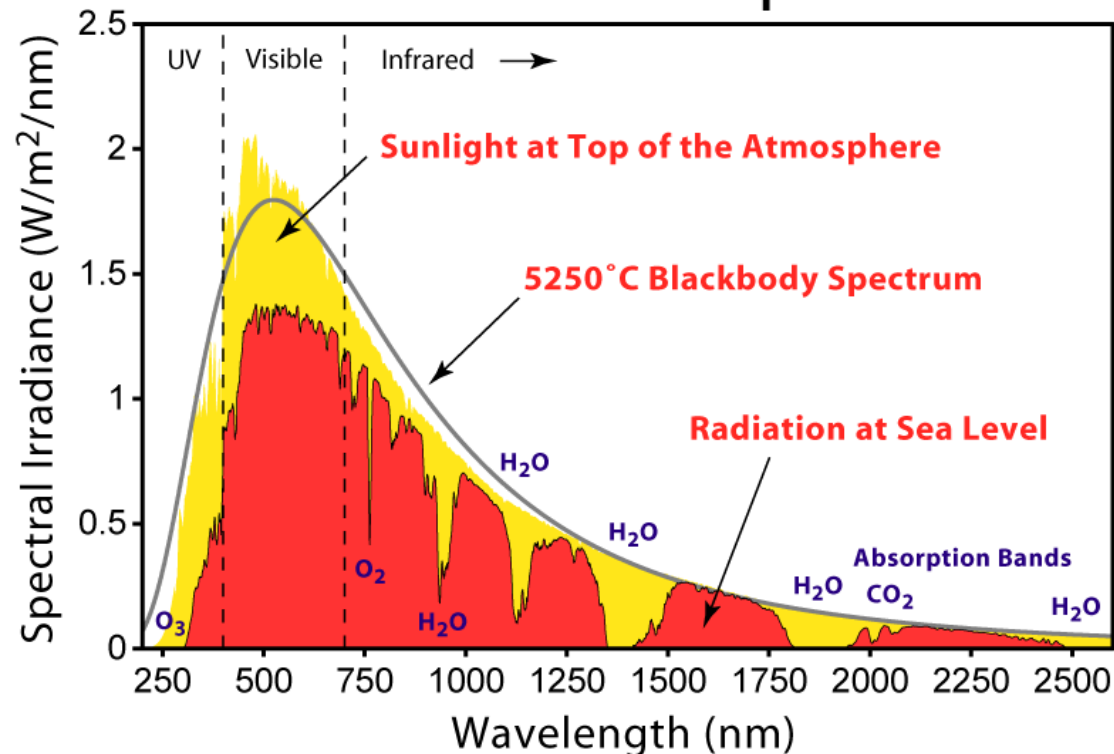
Průběh **spektrální intenzity vyzařování** v závislosti na vlnové délce a teplotě. S rostoucí termodynamickou teplotou tělesa se zvyšuje maximum spektrální intenzity vyzařování a posouvá se směrem k nižší vlnové délce

approximately

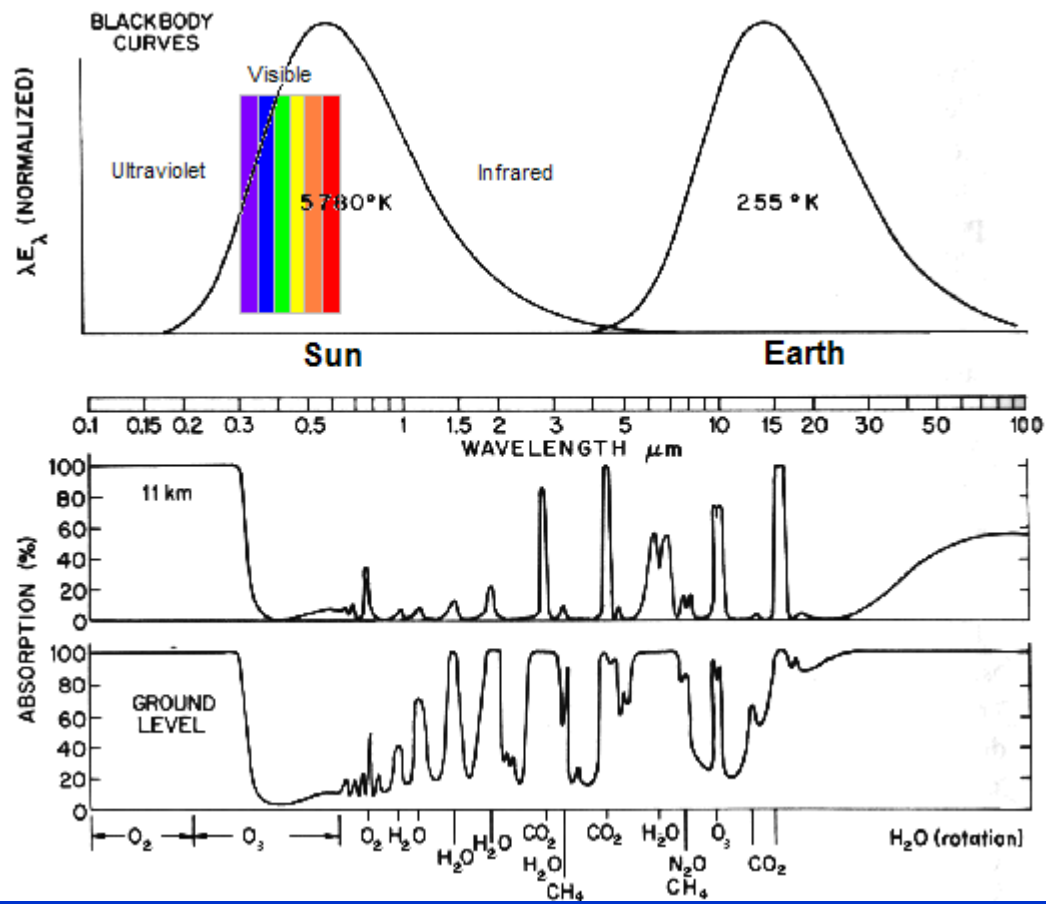
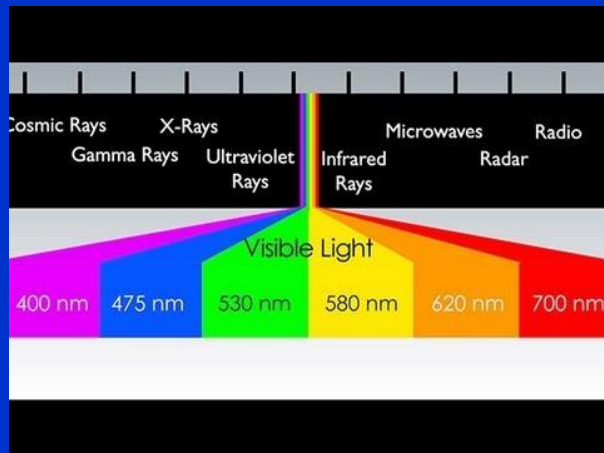


Spectrum of solar radiation modified by atmospheric absorption

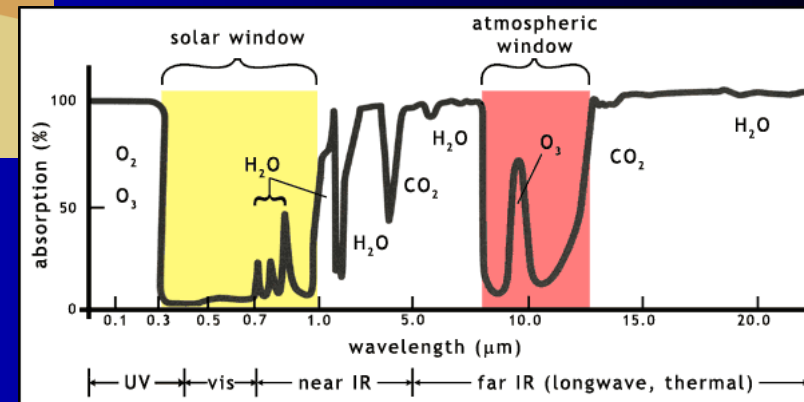
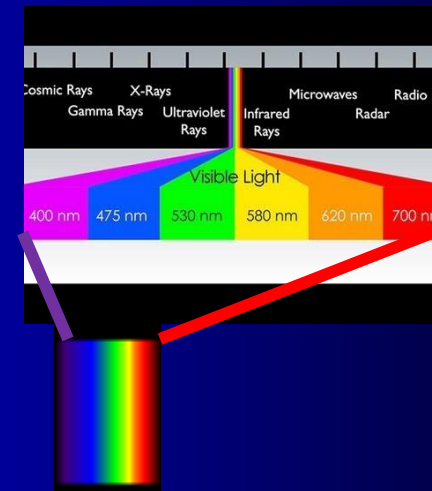
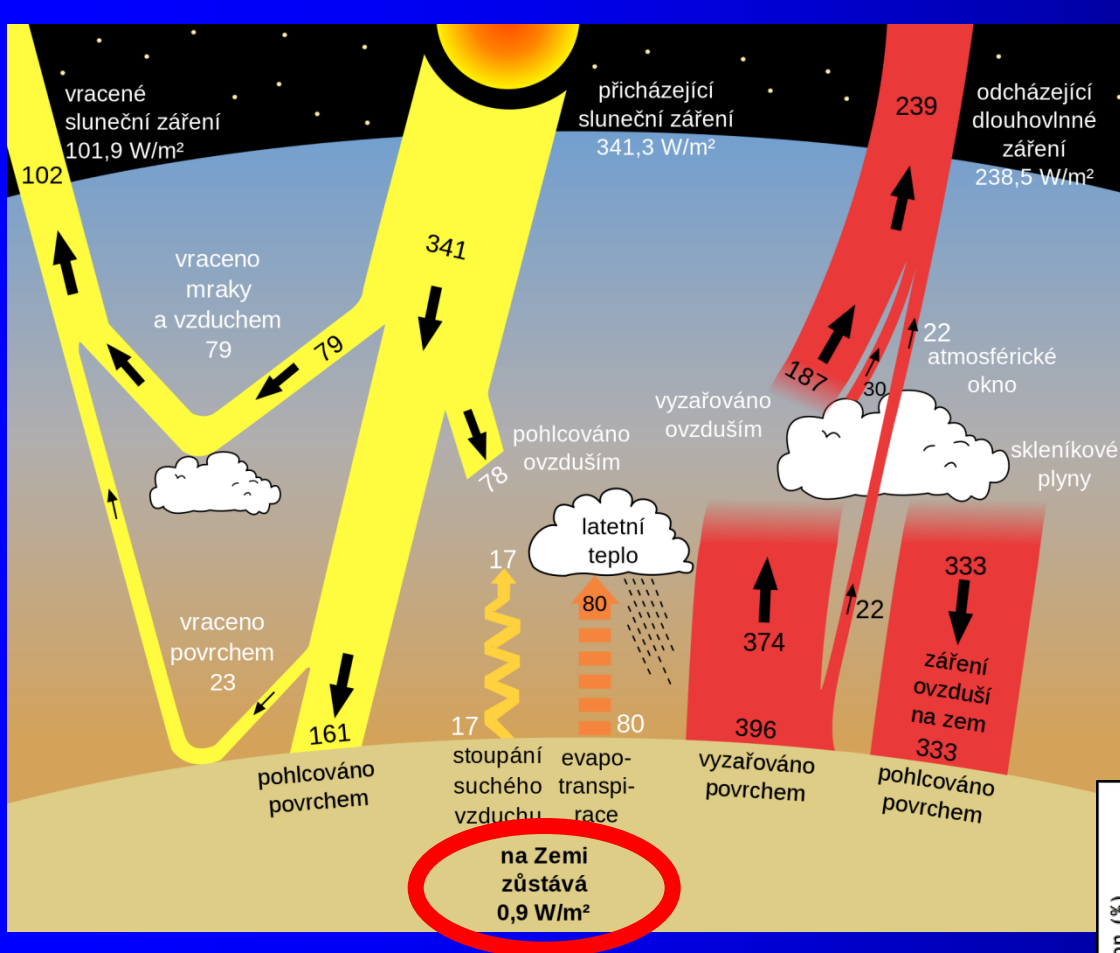
Solar Radiation Spectrum



Absorption



approximation

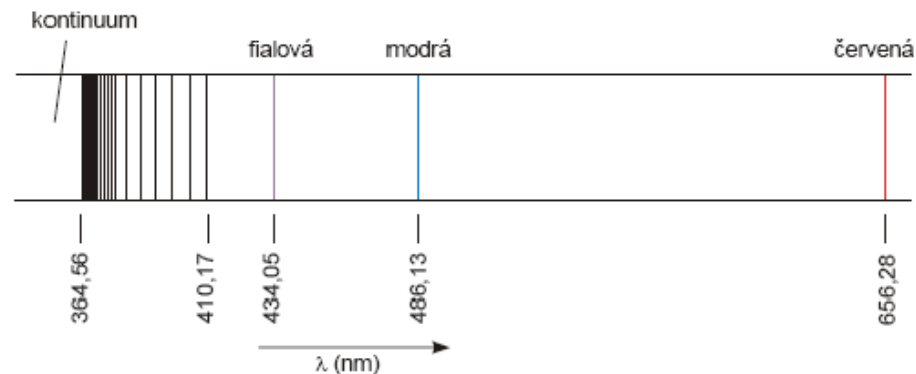
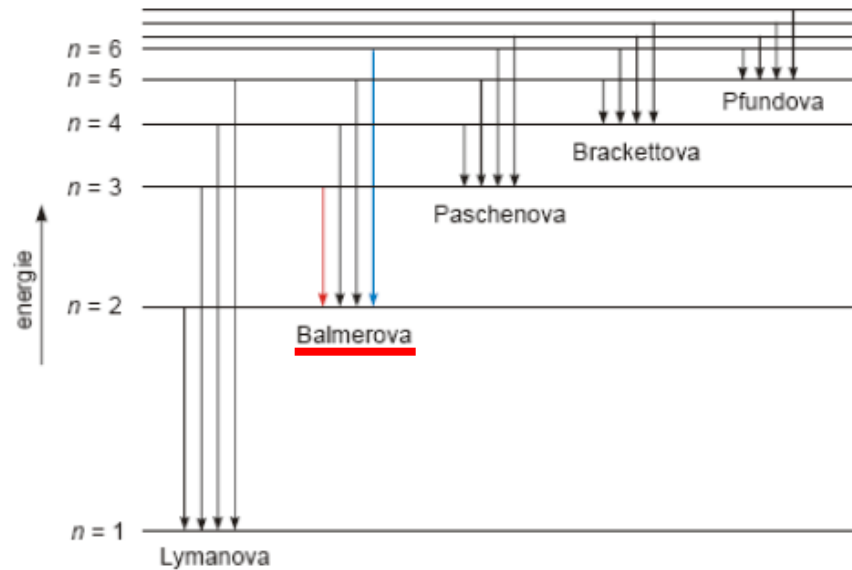
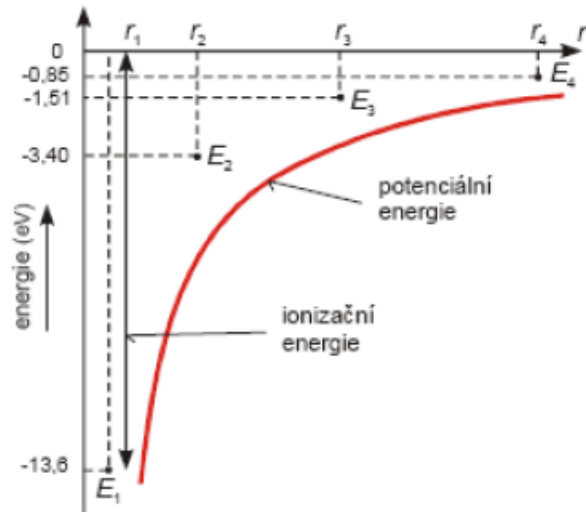


Krátkovlnné záření ze Slunce dopadající na zemský povrch a atmosféru. Dlouhovlnná část záření je emitována z povrchu a téměř zcela absorbována do atmosféry. V tepelné rovnováze je absorbovaná energie z atmosféry stejná jako ta vydávaná do vesmíru. Čísla ukazují výkon záření ve watttech na metr čtvereční v období let 2000–2004



Niels Bohr

Spektrum atomu vodíku



$$h\nu = 13.6 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) [eV]$$

Energy levels H

Grotrian diagram H

Selection rule

$$\Delta l = \pm 1; \quad \Delta m_l = 0, \pm 1$$

Angular momentum of photon is s=1

5.2 Atomic structure and atomic spectra

13.6eV

Fig. 15.12. A Grotrian diagram which summarizes the appearance and analysis of the spectrum of atomic hydrogen. The thicker the line, the more intense the transition.

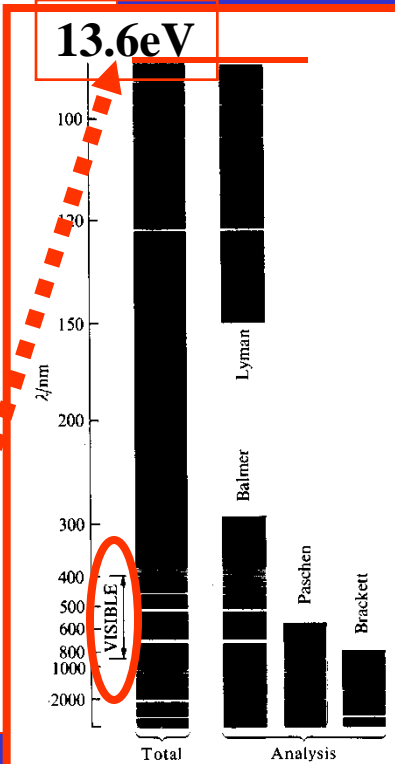
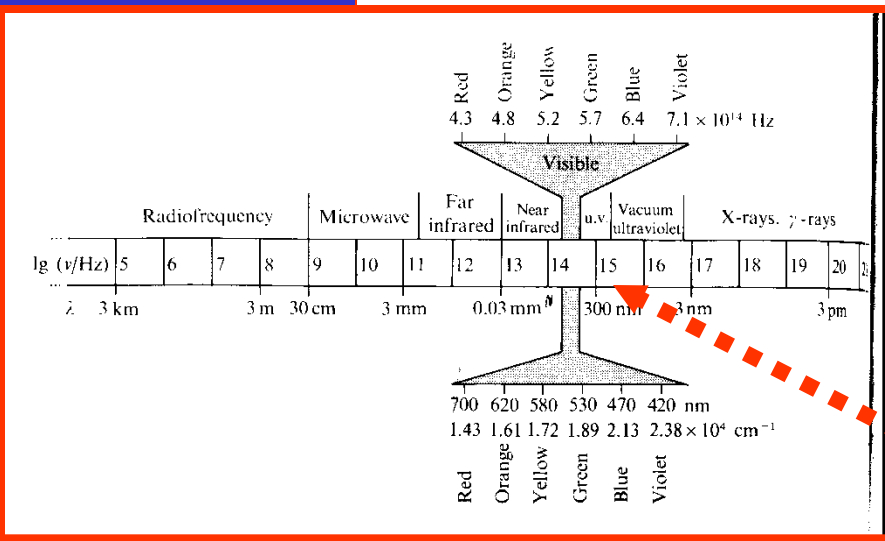
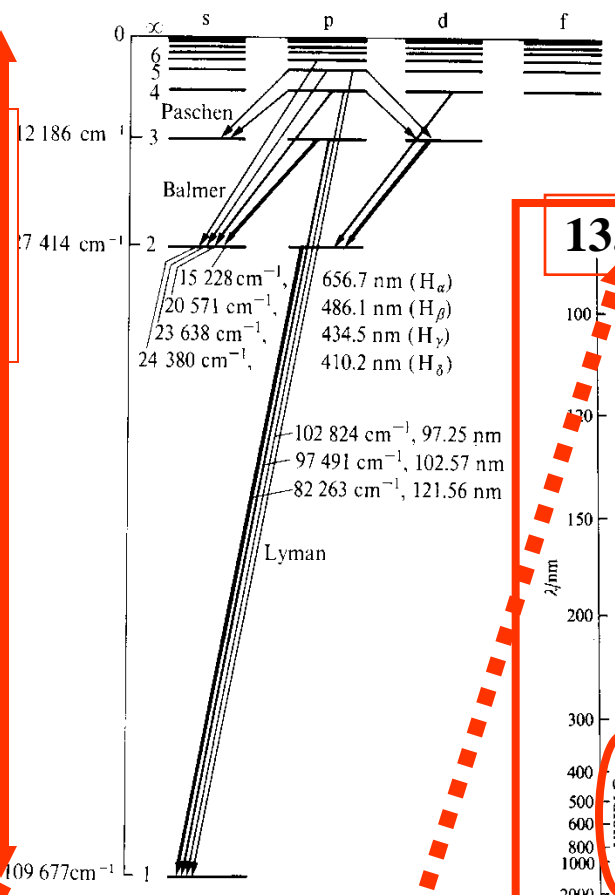


Fig. 15.1. The spectrum of atomic hydrogen. The spectrum is shown on the left, and is analysed into its overlapping series on the right. Note that the Balmer series lies in the visible region.

$$E_n = -\frac{Z^2 \mu e^4}{32 \pi^2 \epsilon_0^2 \hbar^2} x \frac{1}{n^2}$$

$$h\nu = 13.6 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) [eV]$$



$$13.6\text{eV} \times 8065,5 \text{ cm}^{-1} \rightarrow 109000 \text{ cm}^{-1} \rightarrow 91\text{nm}$$

Classical or quantum approach?

Electron:

$$\begin{aligned} 1\text{eV} &\rightarrow v = 5.9 \times 10^7 \text{ cm s}^{-1} \\ \tau &\sim a_0/v \sim 10^{-8} / 5.9 \times 10^7 = 2 \times 10^{-16} \text{ s} \\ \lambda &\sim 2A = 2 \times 10^{-8} \text{ cm} \text{ de Broglie} \\ \text{za } 1\mu\text{s} \dots\dots\dots 1\mu\text{s} \times 5.9 \times 10^7 \text{ cm s}^{-1} &= 59 \text{ cm} \end{aligned}$$

Ar+:

$$\begin{aligned} 1\text{eV} &\rightarrow v = 2 \times 10^5 \text{ cm s}^{-1} \\ \tau &\sim a_0/v \sim 10^{-8} / 2 \times 10^5 \sim 6 \times 10^{-14} \text{ s} \\ \lambda &\sim 9 \times 10^{-11} \text{ cm} \text{ de Broglie} \end{aligned}$$

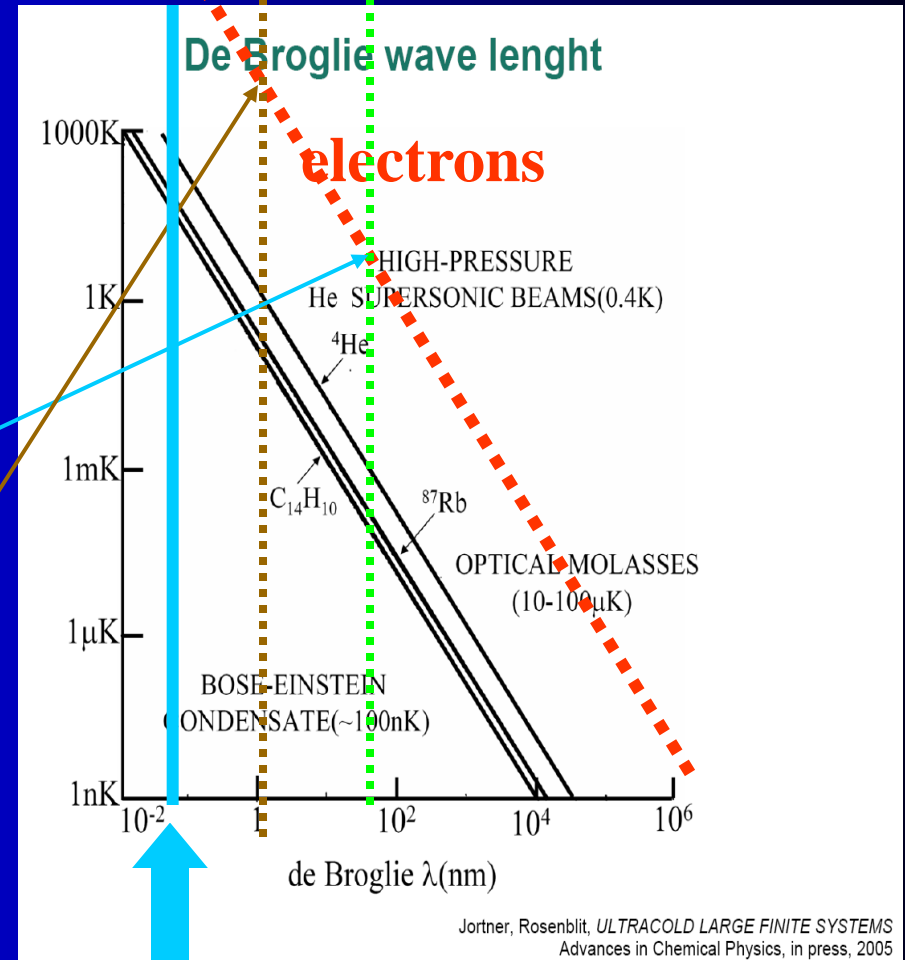
$$40 \times 1800 = 72\,000$$

De Broglie wave length

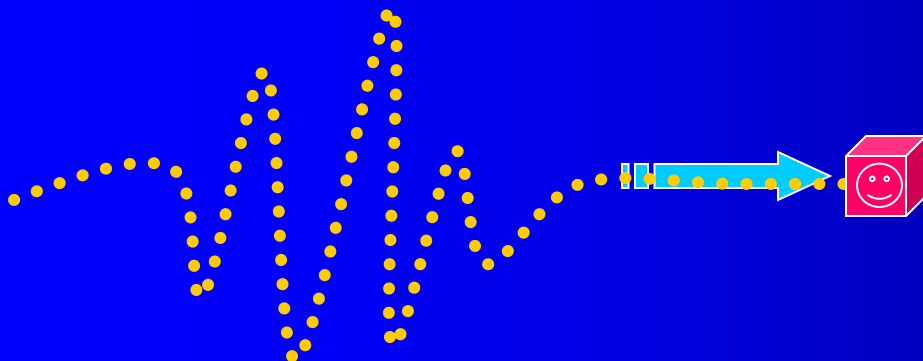
$$\lambda = \frac{h}{p} = \frac{h}{mv} \sqrt{1 - \frac{v^2}{c^2}}$$

$$\lambda_e(4K) \sim 540 \text{ \AA} \sim 54 \times 10^{-9} \text{ m}$$

$$\lambda_e(1\text{eV}) \sim 11.6 \text{ \AA} \sim 1.16 \times 10^{-9} \text{ m}$$

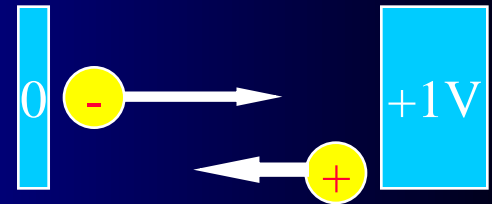


a_0



Electronvolt

$$E \leftrightarrow kT$$
$$1\text{eV} \sim 11\,604.5\text{ K}$$
$$1\text{K} \sim 9 \times 10^{-5} \text{eV}$$



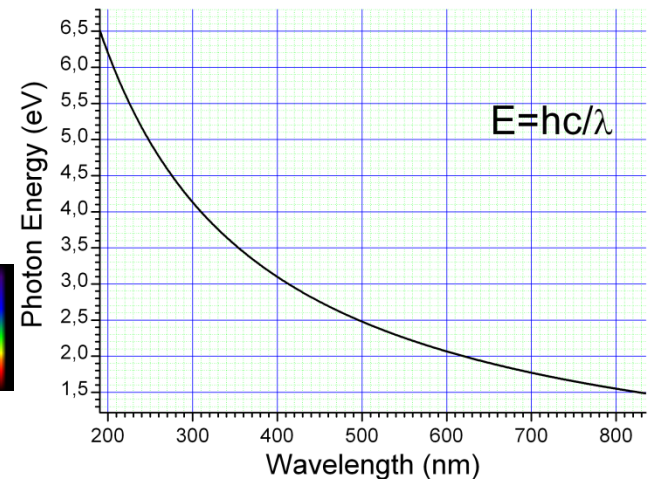
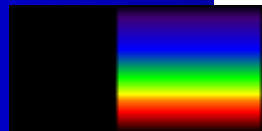
By definition, it is equal to the amount of kinetic energy gained by a single unbound electron when it accelerates through an electric potential difference of one volt

Conversion factors:

1 eV = $1.6021765(40) \times 10^{-19} \text{ J}$ (the conversion factor is numerically equal to the elementary charge expressed in coulombs).

1 eV (per atom) is 96.485 kJ/mol.

1.65 to 3.27 eV: the photon energy of visible light.



13.6 eV: The energy required to ionize atomic hydrogen.
Molecular bond energies are on the order of one eV per molecule

1 TeV: A trillion electronvolts, or $1.602 \times 10^{-7} \text{ J}$, about the kinetic energy of a flying mosquito

14 TeV: the design proton collision energy at the Large Hadron Collider (which has operated at half of the energy since March 30, 2010).

Mol (značka mol) je základní fyzikální jednotka látkového množství.

Jeden mol libovolné látky obsahuje stejný počet částic, jaký je obsažen atomů v 12 g nuklidu uhlíku.

Tento počet udává Avogadrova konstanta, jejíž hodnota je přibližně $6,022 \times 10^{23} \text{ mol}^{-1}$.

Conversion factors

$$E \leftrightarrow kT$$

$$1 \text{ eV} \sim 11\,604.5 \text{ K}$$

$$1 \text{ K} \sim 9 \times 10^{-5} \text{ eV}$$

$$1 \text{ eV}/k = \frac{1 \text{ eV}}{8,617\,333\,262 \times 10^{-5} \text{ eV/K}} = 11\,604,518\,12 \dots \text{ K}$$

$$R\mathcal{F} = 2.4789 \text{ kJ mol}^{-1}$$

$$R\mathcal{F}/F = 25.693 \text{ mV}$$

$$2.3026R\mathcal{F}/F = 59.159 \text{ mV}$$

$$k\mathcal{F}/hc = 207.223 \text{ cm}^{-1}$$

$$V_{\text{m}}^{\ominus} = R\mathcal{F}/p^{\ominus} = 2.4465 \times 10^{-2} \text{ m}^3 \text{ mol}^{-1} = 24.465 \text{ dm}^3 \text{ mol}^{-1}$$

| | | | | | | |
|--------------------------|--------|--------|--------|--------|--------|--------|
| T/K | 100.00 | 298.15 | 500.00 | 1000.0 | 1500.0 | 2000.0 |
| $(kT/kc)/\text{cm}^{-1}$ | 69.50 | 207.22 | 347.51 | 659.03 | 1042.5 | 1390.1 |

$$p^{\ominus} = 100 \text{ kPa} = 1 \times 10^5 \text{ N m}^{-2}$$

$$1 \text{ atm} = 101.325 \text{ kPa} = 1.013\,25 \times 10^5 \text{ N m}^{-2} = 1.013\,25 \times 10^5 \text{ J m}^{-3}$$

$$1 \text{ atm} = 760 \text{ Torr (exactly)}$$

$$1 \text{ Torr} = 133.322 \text{ Pa (exactly)}$$

$$1 \text{ mmHg} = 133.3224 \text{ Pa}$$

$$1 \text{ eV} = 1.602\,19 \times 10^{-19} \text{ J} \triangleq 96.485 \text{ kJ mol}^{-1} \triangleq 8065.5 \text{ cm}^{-1}$$

$$1 \text{ cm}^{-1} \triangleq 1.986 \times 10^{-23} \text{ J} \triangleq 11.96 \text{ J mol}^{-1} \triangleq 0.1240 \text{ meV}$$

1 eV ~ 23.06 kcal

$$hc = 1.986\,48 \times 10^{-23} \text{ J cm}$$

$$hc/k = 1.438\,79 \text{ cm K}$$

$$g/\text{m s}^{-2} = 9.8064 - 0.0259 \cos \{2(\text{latitude})\} = 9.811 \text{ at } 50^\circ$$

$$1 \text{ cal} = 4.184 \text{ J}$$

$$1 \text{ D (debye)} = 3.335\,64 \times 10^{-30} \text{ C m}$$

$$1 \text{ N} = 1 \text{ J m}^{-1} = 10^5 \text{ dyne}$$

$$1 \text{ W} = 1 \text{ J s}^{-1}$$

$$1 \text{ T} = 1 \text{ J C}^{-1} \text{ s m}^{-2}$$

$$1 \text{ J} = 10^7 \text{ erg}$$

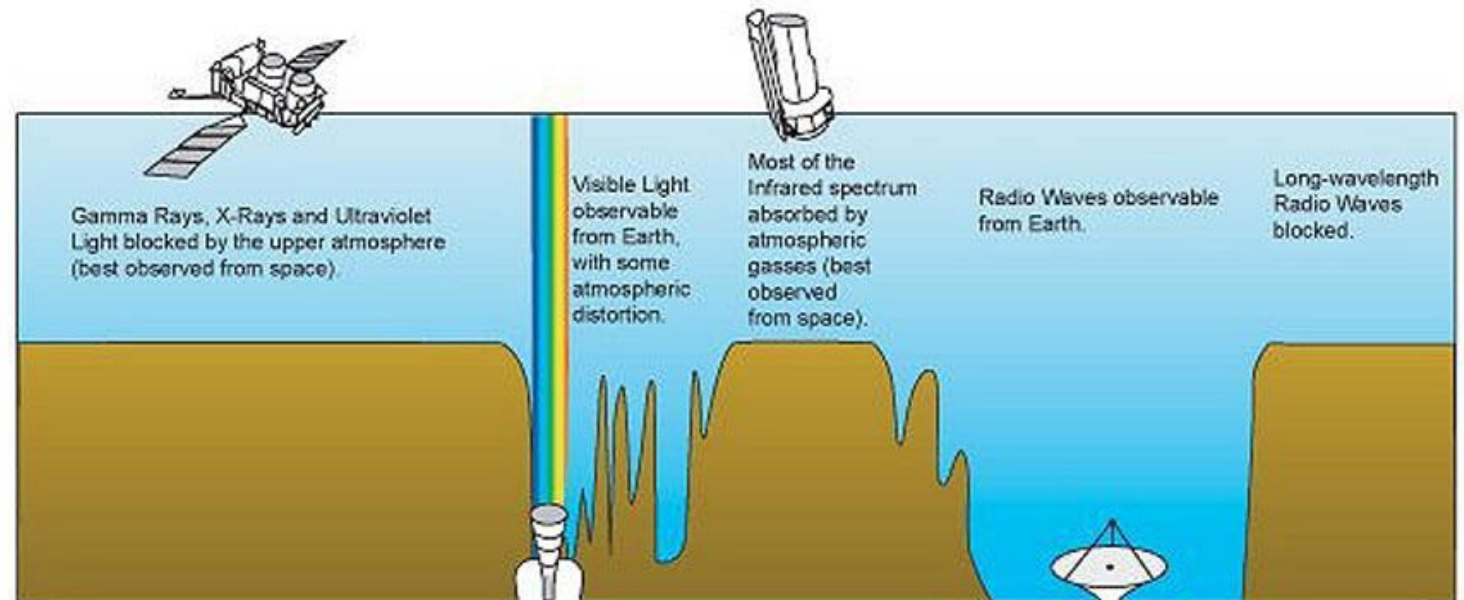
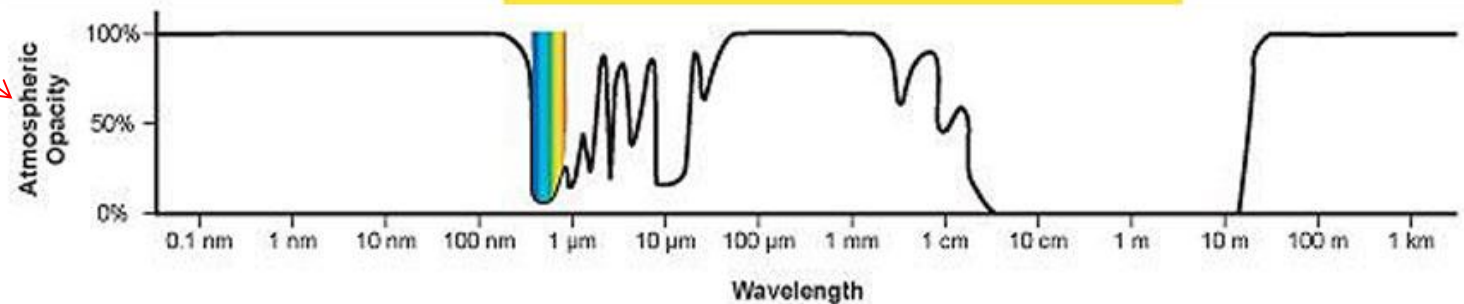
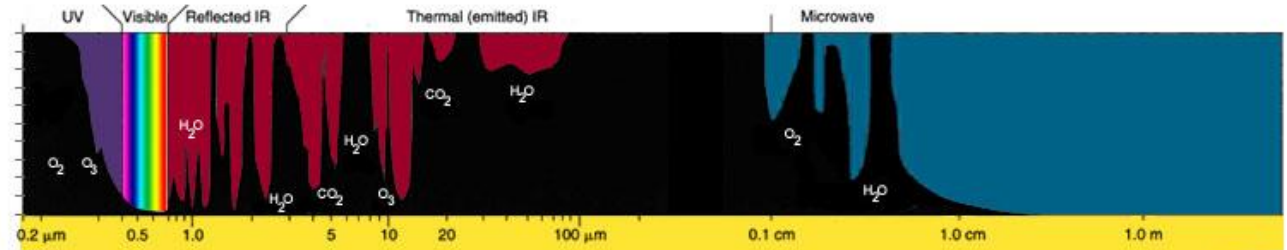
$$1 \text{ A} = 1 \text{ C s}^{-1}$$

$$1 \text{ J} = 1 \text{ A V s}$$



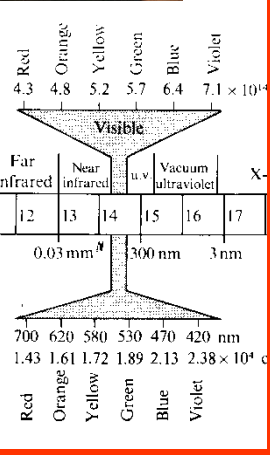
Detail 0.1nm-1 km

Opacity is the measure of impenetrability to electromagnetic or other kinds of radiation, especially visible light.

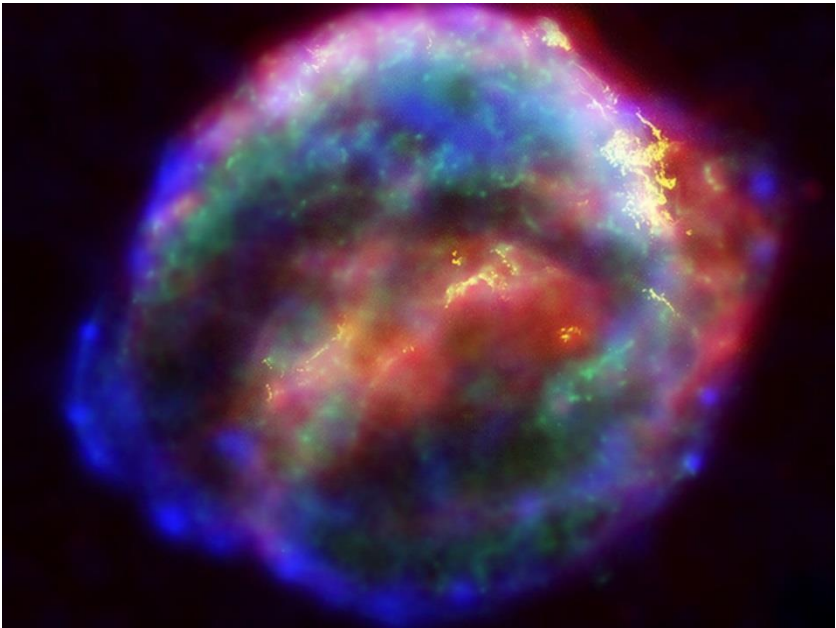
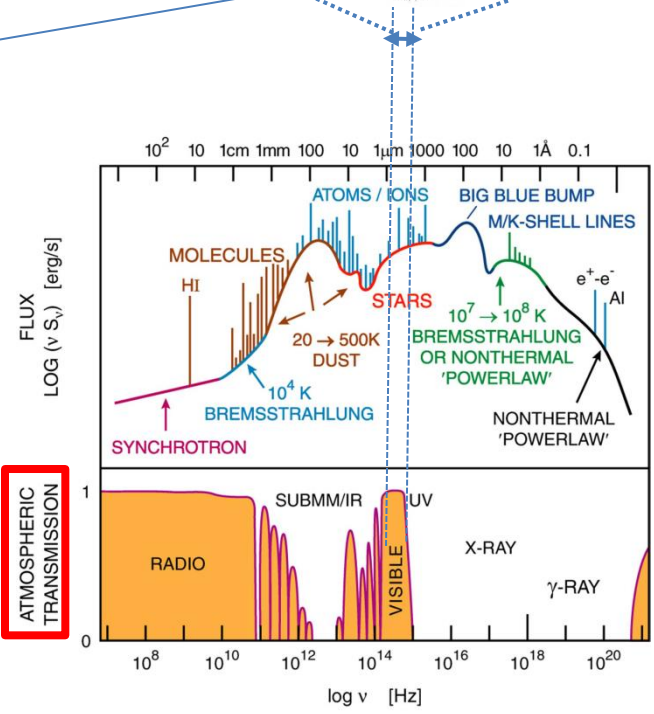


Before

The Supernova of 1604



visible



The first recorded observation was in northern Italy on October 9, 1604. [\[2\]](#) [Johannes Kepler](#) began observing the luminous display while working at the imperial court in [Prague](#) for [Emperor Rudolf II](#) on October 17. [\[3\]](#) It was subsequently named after him because his observations tracked the object for an entire year and because of his book on the subject, entitled *De Stella nova in pede Serpentarii* ("On the new star in Ophiuchus's foot", Prague 1606).

It was the second supernova to be observed in a generation (after [SN 1572](#) seen by [Tycho Brahe](#) in [Cassiopeia](#)). No further supernovae have since been observed with certainty in the Milky Way, though many others outside our galaxy have been seen since [S Andromedae](#) and [SN 1987A](#) in the [Large Magellanic Cloud](#) was visible to the naked eye.

1722



Astronomická věž

socha Atlanta

1722



Věž byla dokončena v roce 1722. Na vrcholu věže stojí socha Atlanta (olověná socha s železnou vnitřní konstrukcí, váha asi 600 kg, výška 2,4 m). Atlas nese nebeskou sféru (průměr asi 1,6 m, váha asi 150 kg) s korouhví.

(Pravděpodobně

Matyáš Braun)

1722



Klementinum and astronomy.

Astronomická věž

socha Atlanta



1722



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(Pravděpodobně

Matyáš Braun)

Golden Age of Astrochemistry



Byla zkonstruována koncem 50. let 20. století Sergejem Koroljovem v Sovětském svazu. Byla vynesena 4. října 1957 19:28 UTC upravenou dvoustupňovou nosnou raketou R-7, která byla z vojenské verze pro kosmonautiku upravena a přejmenována na raketu Sputnik. Odstartovala z kosmodromu Bajkonur na území Kazašské SSR. Vypuštěna byla v rámci Mezinárodního geofyzikálního roku.^[2] Patří do kategorie vědeckých družic.

Družice měla sférický tvar o průměru 58 cm a hmotnost 83,6 kg.

1957 - PES LAJKA



- 3. listopadu 1957 vyslal Sovětský svaz na palubě družice Sputnik 2 na oběžnou dráhu prvního pozemského živého tvora – fenku Lajku.
- Zpátky na Zem se však nevrátila, protože to tehdejší technika ještě neuměla.



Sputnik 2

Lajka

Hmotnost 508 kg

3. listopadu 1957 z kosmodromu Bajkonur.

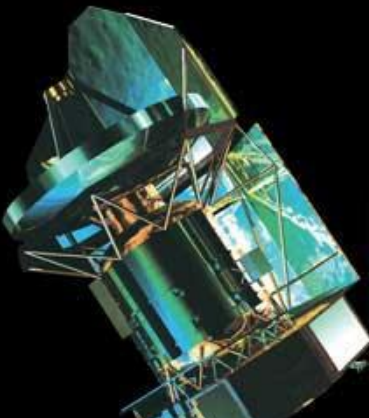
2020

~ 63 rokov

Golden Age of Astrochemistry



Herschel



United Kingdom Infrared Telescope
Mauna Kea, Hawaii

**Five-hundred-meter Aperture Spherical radio
Telescope (China: Tianyan, 2016)**



SOFIA



The Arecibo Observatory
RT in [Puerto Rico](#) (~1960)



Hubble Space Telescope



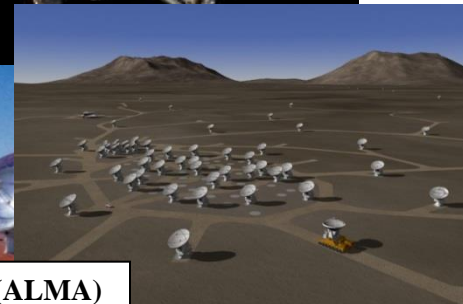
[Třetí nebeský palác](#)

Tiangong, officially the Tiangong space station

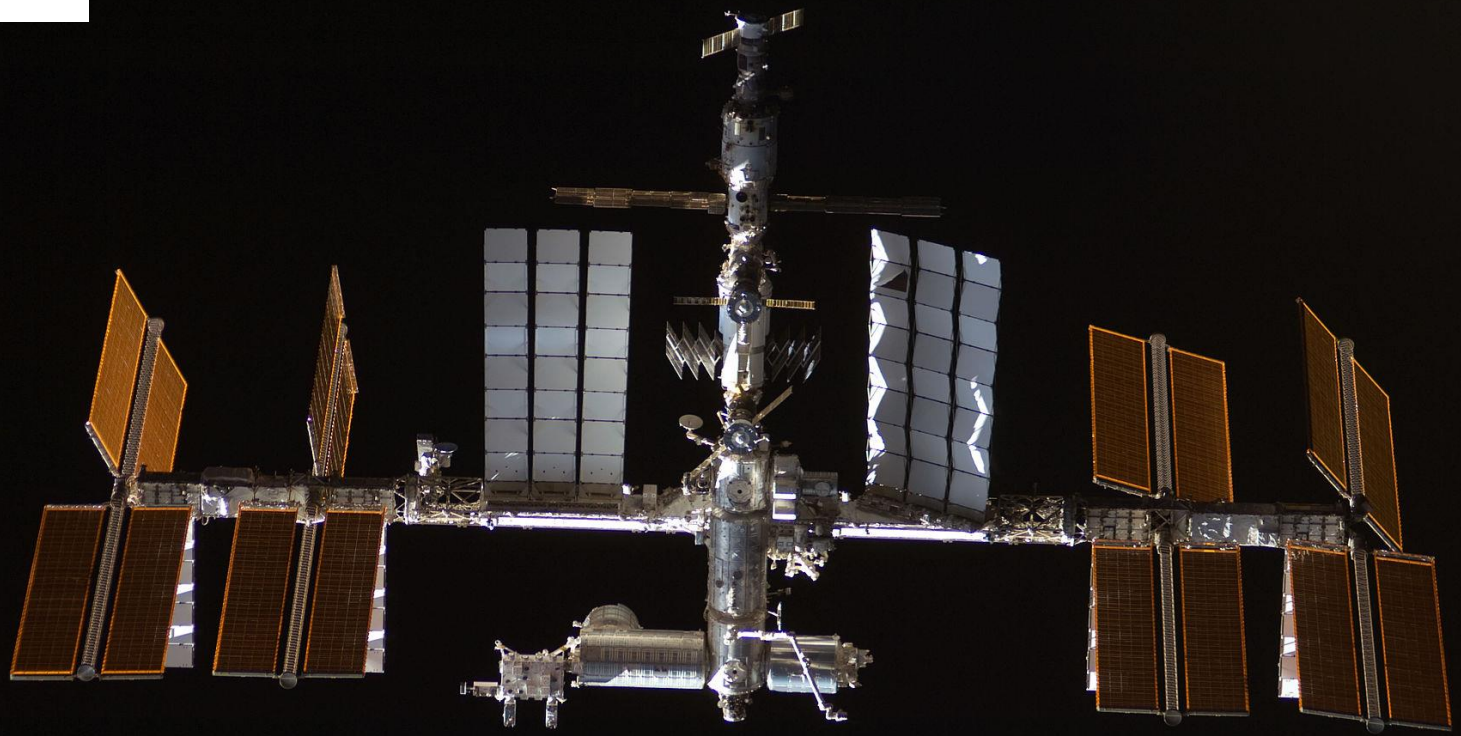
ALMA



The Atacama Large Millimeter/sub-millimeter Array (ALMA)
astronomical interferometer of radio telescopes
Atacama desert of northern Chile



ISS



Hubble Space Telescope



From April 24, 1990

The Hubble Space Telescope is a space telescope that was launched into low Earth orbit in 1990 and remains in operation

The telescope is operating as of 2019, and could last until 2030–2040.

Hubble is the only telescope designed to be maintained in space by astronauts. Five Space Shuttle missions have repaired, upgraded, and replaced systems on the telescope, including all five of the main instruments. The fifth mission was canceled on safety grounds following the [Columbia disaster](#) (2003), but NASA administrator [Michael D. Griffin](#) approved the [fifth servicing mission](#) which was completed in 2009. The telescope was still operating as of April 24, 2020, its 30th anniversary,^[1] and could last until 2030–2040.^[4] One successor to the Hubble telescope is the [James Webb Space Telescope](#) (JWST) which is scheduled to be launched in late 2021.¹

Not actualized, approximation

Hubble má potíže, přestal fungovat čtvrtý gyroskop, který pomáhá s orientací teleskopu

08. 10. 2018

Hubble Teleskopy

V pátek se vesmírný teleskop Hubble přepnul do tzv. safe módu poté, co přestal fungovat jeden z gyroskopů, které teleskopu pomáhají udržet správnou orientaci při pozorování vzdálených cílů ve vesmíru. Hubble měl celkem 6 těchto gyroskopů a potřebuje nejméně tři pro optimální operace. Dva však už delší dobu nefungují a další nefunguje optimálně. Po odchodu čtvrtého tak zbývají pouze dva funkční gyroskopy. Operátoři mise nyní zkoumají možnosti, kterými uvést teleskop zpátky do plného provozu.

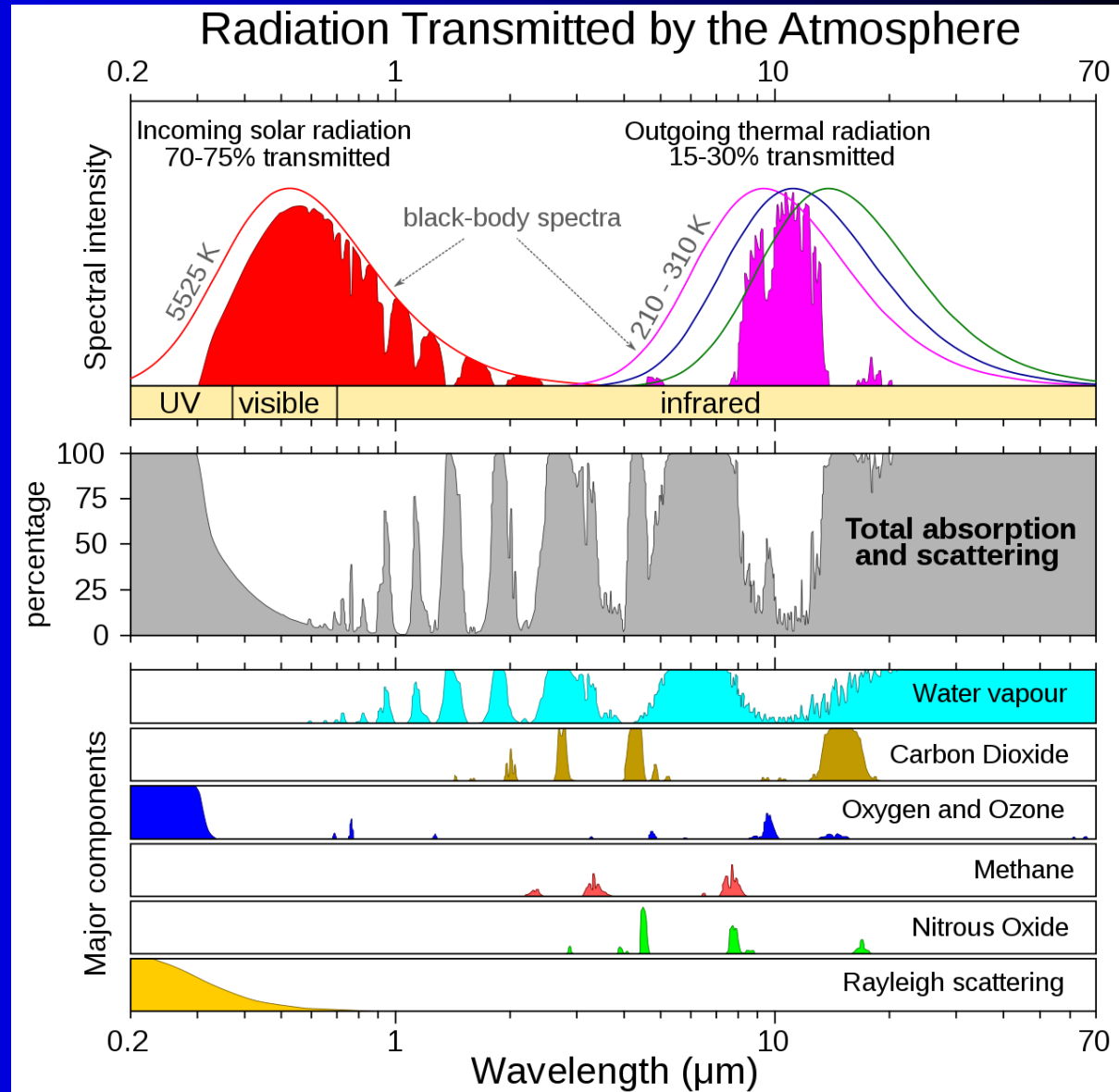
Pokud se nepodaří na dálku opravit porouchaný gyroskop, hodlají operátoři vyzkoušet onen třetí, který nefunguje optimálně. Aktuálně tak hledají cesty, jak teleskop na dálku opravit, pokud se to nepodaří, teleskop může pracovat dál se dvěma, nebo dokonce jedním gyroskopem. Je dokonce pravděpodobné, že pokud se oprava nepodaří, mise bude dále pokračovat pouze s jedním gyroskopem a druhý bude ponechán jako rezerva.

Všech šest gyroskopů teleskopu Hubble bylo vyměněno při poslední misi astronautů k teleskopu v roce 2009. Po dosloužení raketoplánů však teleskop nebyl astronauty navštíven a zatím se neplánuje žádná podobná mise s novými vesmírnými loděmi, které by NASA měla mít v následujících letech k dispozici. Hubble je ve vesmíru od roku 1990.

Vesmírný teleskop Hubble - teleskop Hubble obíhá Zemi od roku 1990 ve výšce asi 540 kilometrů.

ACTUAL October 6. 2021: The telescope completed 30 years in operation in April 2020 and could last until 2030–2040.

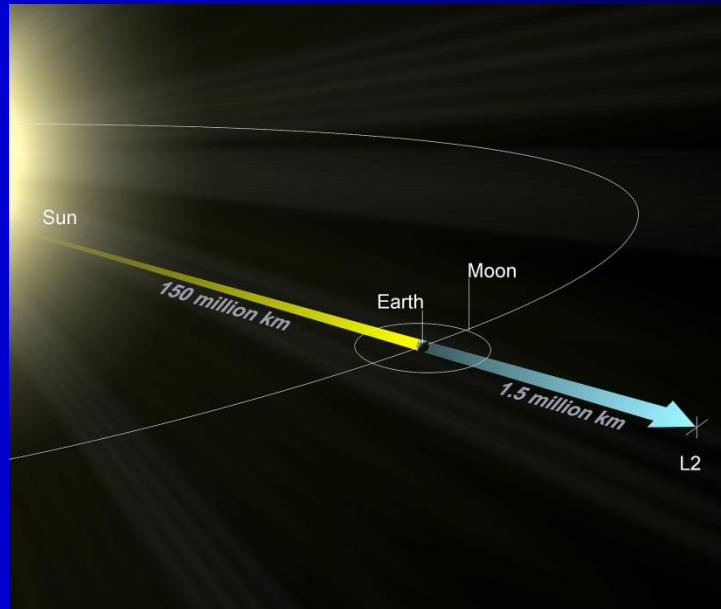
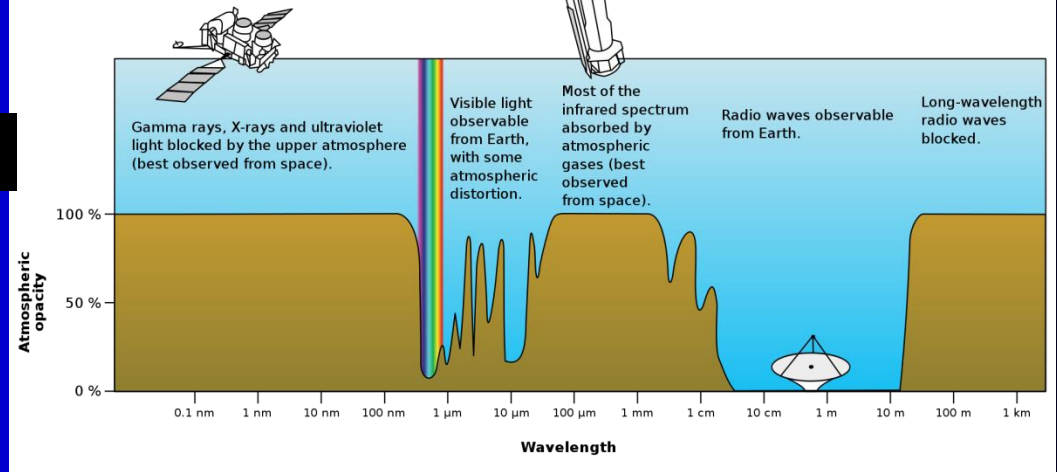
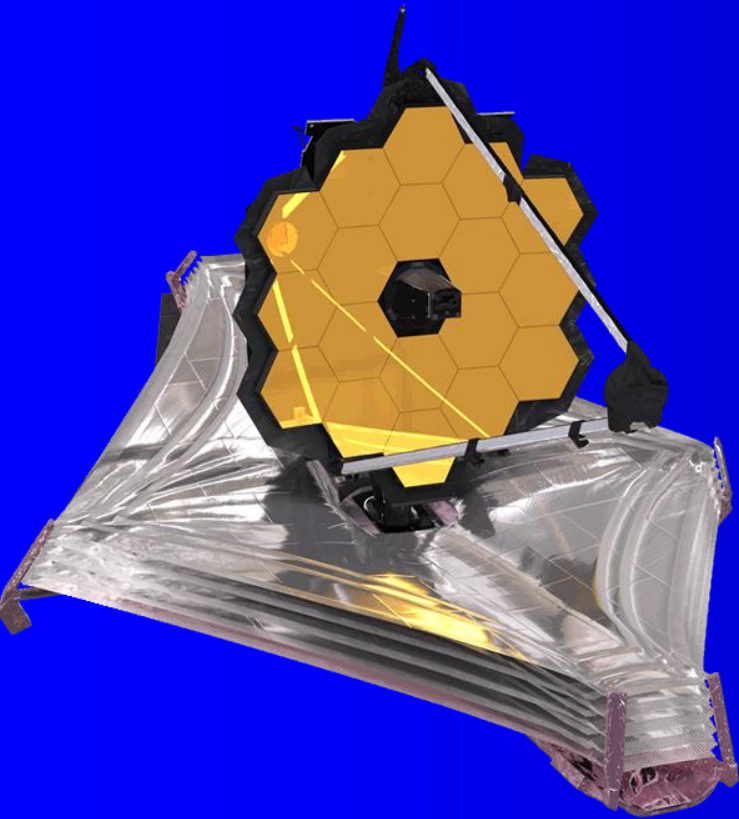
James Webb Space Telescope



Atmospheric windows in the infrared: Much of this type of light is blocked when viewed from the Earth's surface. It would be like looking at a rainbow but only seeing one colour.

infrared astronomy

James Webb Space Telescope (JWST)



The **James Webb Space Telescope (JWST)** is a space telescope which conducts infrared astronomy. As the largest optical telescope in space, its high resolution and sensitivity allow it to view objects too old, distant, or faint for the Hubble Space Telescope. This will enable investigations across many fields of astronomy and cosmology, such as observation of the first stars, the formation of the first galaxies, and detailed atmospheric characterization of potentially habitable exoplanets.

~1/6 of mass is interstellar

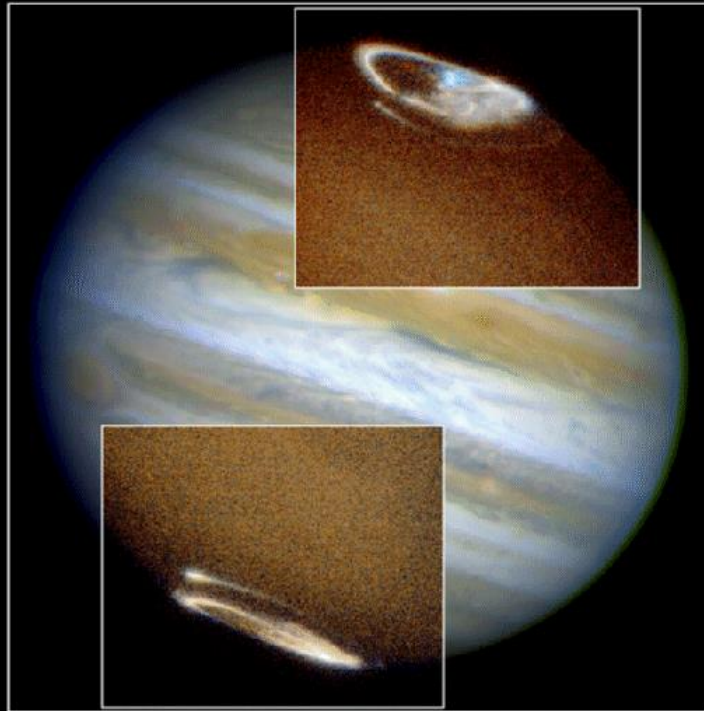
~1/2 of interstellar matter is molecular!



Milky Way has $\sim 10^{66}$ molecules!
Earth has only $\sim 10^{50}$ molecules

Different views of the Milky Way (different wavelengths)

Hydrogen dominated plasma

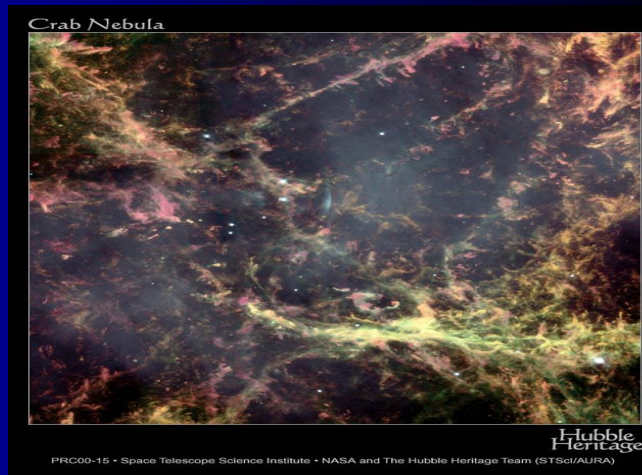


Jupiter Aurora

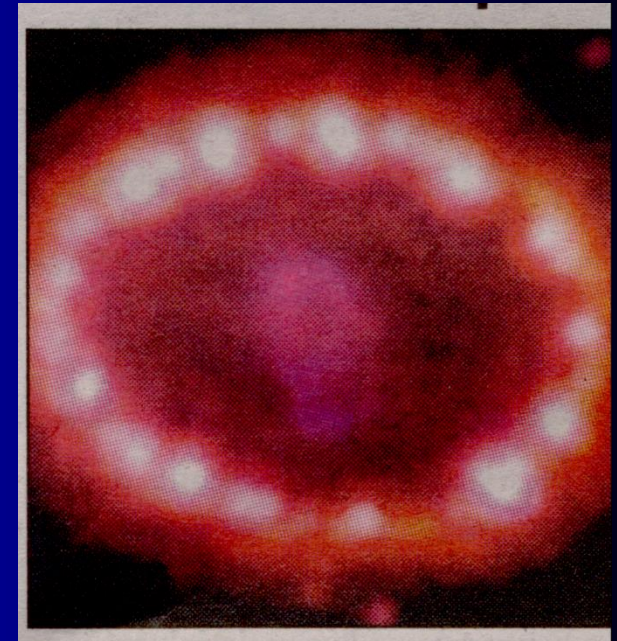
HST • STIS • WFPC2

PRC98-04 • ST Sci OPO • January 7, 1998
J. Clarke (University of Michigan) and NASA

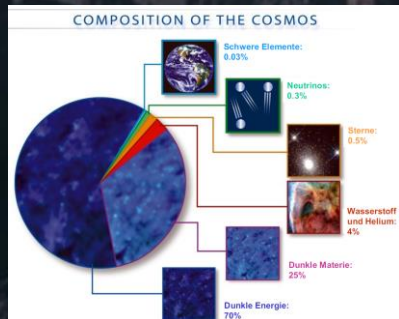
Hydrogen plasma in Jupiter Aurora



Crab Nebula



1994 -Supernova 1987A

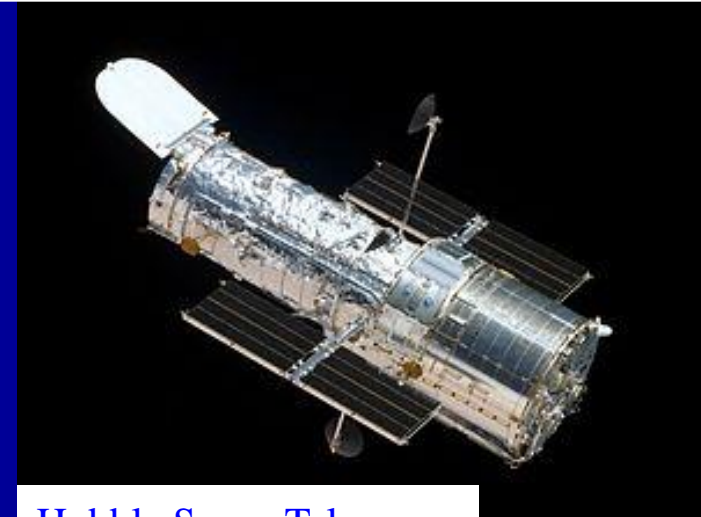


The Herschel Space Observatory was a space observatory built and operated by the European Space Agency. **It was active from 2009 to 2013**, and was the largest infrared telescope ever launched, carrying a 3.5-metre mirror and instruments sensitive to the far infrared and submillimetre wavebands.



Herschel

Herschel (red) and Hubble (blue) composite image of the Crab Nebula. *Credit: ESA/Herschel/PACS/MESS Key Programme Supernova Remnant Team; NASA, ESA and Allison Loll/Jeff Hester (Arizona State Uni)*



Hubble Space Telescope

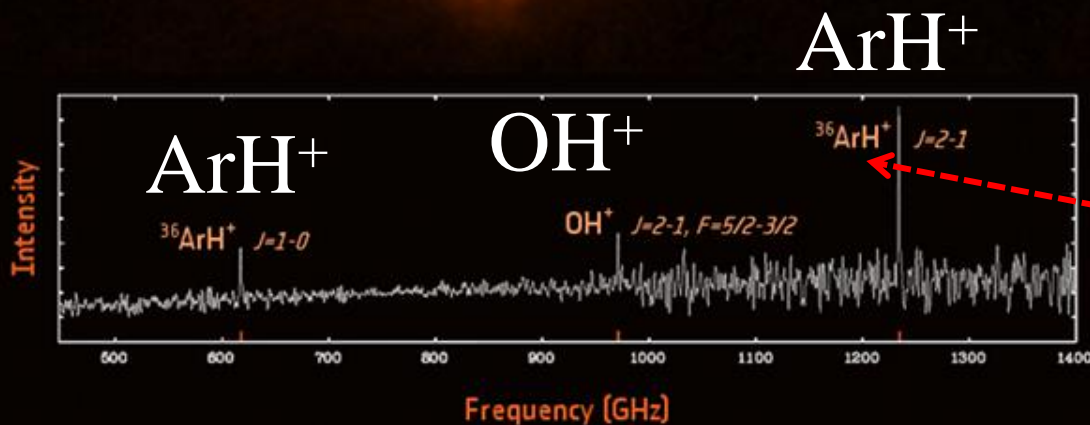
ArH+



The **Crab Nebula** is the remnant of a supernova explosion that was observed by Chinese astronomers in the year 1054.

12 December 2013

Using ESA's Herschel Space Observatory, a team of astronomers has found first evidence of a noble-gas based molecule in space. A compound of argon, the molecule was detected in the gaseous filaments of the Crab Nebula, one of the most famous supernova remnants in our Galaxy. While argon is a product of supernova explosions, the formation and survival of argon-based molecules in the harsh environment of a supernova remnant is an unforeseen surprise.



$$^{36}\text{ArH}^+$$

The results described in this article are reported in "*Detection of a Noble Gas Molecular Ion, $^{36}\text{ArH}^+$, in the Crab Nebula*", by M. J. Barlow et al., published in Science, 342, 6163, 1343-1345, 13 December 2013. DOI: 10.1126/science.124358213.

12 December 2013

 ^{40}Ar

The argon isotope found in the Crab Nebula is different from the one that dominates in Earth's atmosphere, ^{40}Ar , which derives from the decay of a radioactive isotope of potassium (^{40}K) present in our planet's rocks.

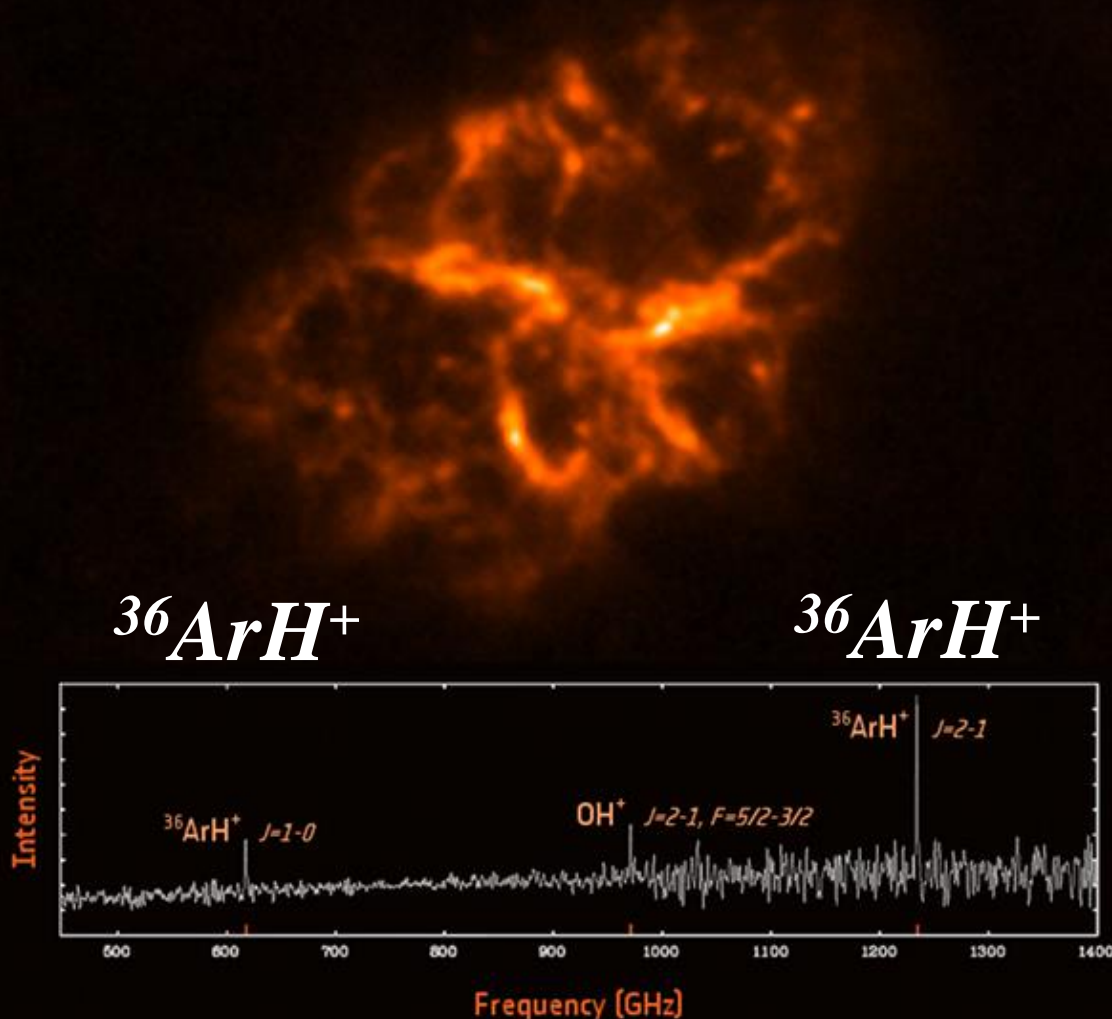
 ^{36}Ar

The Herschel data indicate that the argon hydride found in the Crab Nebula is made up of the argon isotope ^{36}Ar . This is the first time that astronomers could identify the isotopic nature of an element in a supernova remnant.

"Finding that argon in the Crab Nebula consists of ^{36}Ar was not surprising because this is the dominant isotope of argon across the Universe.

"And it's also the main argon isotope to be synthesised in the nuclear reactions during supernova explosions, so its detection in the Crab Nebula confirms that this iconic nebula was created by the explosive death of a massive star," explains Barlow.

On Earth, radioactive potassium-40 decays to argon-40 as the most common isotope. In stars, nucleosynthesis mostly creates the lighter argon-36 and argon-38.



Astrophysical detection of the helium hydride ion HeH^+

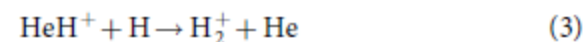
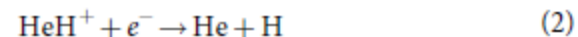
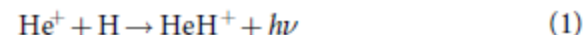
Rolf Güsten^{1*}, Helmut Wiesemeyer¹, David Neufeld², Karl M. Menten¹, Urs U. Graf³, Karl Jacobs³, Bernd Klein^{1,4}, Oliver Ricken¹, Christophe Risacher^{1,5} & Jürgen Stutzki³

During the dawn of chemistry^{1,2}, when the temperature of the young Universe had fallen below some 4,000 kelvin, the ions of the light elements produced in Big Bang nucleosynthesis recombined in reverse order of their ionization potential. With their higher ionization potentials, the helium ions He^{2+} and He^+ were the first to combine with free electrons, forming the first neutral atoms; the recombination of hydrogen followed. In this metal-free and low-density environment, neutral helium atoms formed the Universe's first molecular bond in the helium hydride ion HeH^+ through radiative association with protons. As recombination progressed, the destruction of HeH^+ created a path to the formation of molecular hydrogen. Despite its unquestioned importance in the evolution of the early Universe, the HeH^+ ion has so far eluded unequivocal detection in interstellar space. In the laboratory the ion was discovered³ as long ago as 1925, but only in the late 1970s was the possibility that HeH^+ might exist in local astrophysical plasmas discussed^{4–7}. In particular, the conditions in planetary nebulae were shown to be suitable for producing potentially detectable column densities of HeH^+ . Here we report observations, based on advances in terahertz spectroscopy^{8,9} and a high-altitude observatory¹⁰, of the rotational ground-state transition of HeH^+ at a wavelength of 149.1 micrometres in the planetary nebula NGC 7027. This confirmation of the existence of HeH^+ in nearby interstellar space constrains our understanding of the chemical networks that control the formation of this molecular ion, in particular the rates of radiative association and dissociative recombination.

The deployment of the German Receiver for Astronomy at Terahertz Frequencies (GREAT)⁹ heterodyne spectrometer on board the Stratospheric Observatory for Infrared Astronomy (SOFIA)¹⁰ has now opened up new opportunities. Although the HeH^+ $J = 1-0$ transition at 149.137 μm (2010.183873 GHz; ref. ²¹) cannot be observed from ground-based observatories, skies become transparent during high-altitude flights with SOFIA. The latest advances in terahertz technologies have



We then computed the equilibrium abundance of HeH^+ , including the three reactions identified as being important in the layers in which HeH^+ is most abundant^{7,13}:



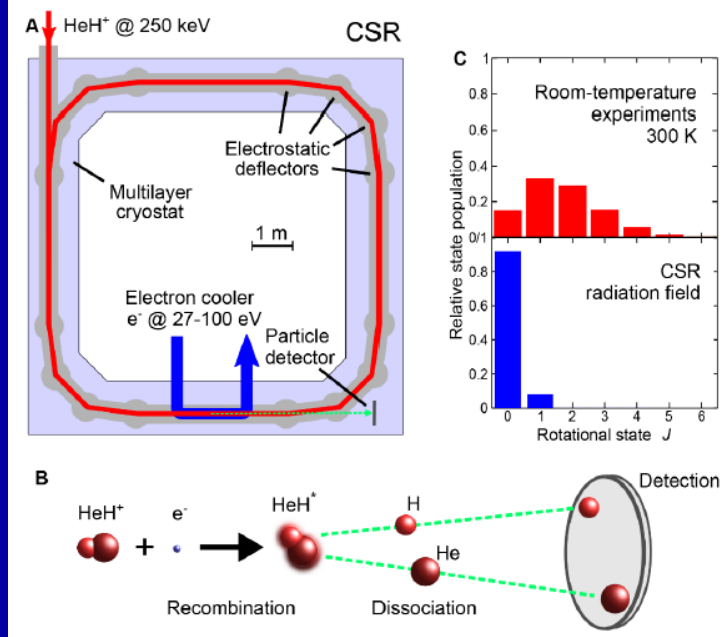
Cite as: O. Novotný *et al.*, *Science*
10.1126/science.aax5921 (2019).

Quantum-state-selective electron recombination studies suggest enhanced abundance of primordial HeH⁺

Oldřich Novotný^{1*}, Patrick Wilhelm¹, Daniel Paul¹, Ábel Kálosi^{1,2}, Sunny Saurabh¹, Arno Becker¹, Klaus Blaum¹, Sebastian George^{1,3}, Jürgen Göck¹, Manfred Grieser¹, Florian Grussle¹, Robert von Hahn¹, Claude Krantz¹, Holger Kreckel¹, Christian Meyer¹, Preeti M. Mishra¹, Damian Muell¹, Felix Nuesslein¹, Dmitry A. Orlov¹, Marius Rimpler¹, Viviane C. Schmidt¹, Andrey Shornikov¹, Aleksandr S. Terekhov⁴, Stephen Vogel¹, Daniel Zajtman⁵, Andreas Wolf⁶

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PHYSICAL REVIEW LETTERS **124**, 043401 (2020)

Dissociative Recombination of Cold HeH⁺ Ions

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(Received 7 October 2019; revised manuscript received 27 November 2019; published 28 January 2020)



2018 Census of Interstellar, Circumstellar, Extragalactic, Protoplanetary Disk, and Exoplanetary Molecules

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Table 1
Commonly Used Facility Abbreviations

| Abbreviation | Description |
|--------------|---|
| ALMA | Atacama Large Millimeter/submillimeter Array |
| APEX | Atacama Pathfinder Experiment |
| ARO | Arizona Radio Observatory |
| ATCA | Australian Telescope Compact Array |
| BIMA | Berkeley-Illinois-Maryland Array |
| CSO | Caltech Submillimeter Observatory |
| FCRAO | Five College Radio Astronomy Observatory |
| FUSE | <i>Far Ultraviolet Spectroscopic Explorer</i> |
| GBT | Green Bank Telescope |
| IRAM | Institut de Radioastronomie Millimétrique |
| IRTF | Infrared Radio Telescope Facility |
| ISO | <i>Infrared Space Observatory</i> |
| KPNO | Kitt Peak National Observatory |
| MWO | Millimeter-wave Observatory |
| NRAO | National Radio Astronomy Observatory |
| OVRO | Owens Valley Radio Observatory |
| PdBI | Plateau de Bure Interferometer |
| SEST | Swedish-ESO Submillimeter Telescope |
| SMA | Sub-millimeter Array |
| SMT | Sub-millimeter Telescope |
| SOFIA | <i>Stratospheric Observatory for Infrared Astronomy</i> |
| UKIRT | United Kingdom Infrared Telescope |

3. Known Interstellar Molecules

Two-atom Molecules

3.1. CH (Methylidyne)

Swings & Rosenfeld (1937) suggested that an observed line at $\lambda = 4300 \text{ \AA}$ by Dunham (1937) using the Mount Wilson Observatory in diffuse gas toward a number of supergiant B stars might have been due to the $^2\Delta \leftarrow ^2\Pi$ transition of CH, reported in the laboratory by Jevons (1932). McKellar (1940) later identified several additional transitions in observational data. The first radio identification was reported by Rydbeck et al. (1973) at 3335 MHz with the Onsala telescope toward more than a dozen sources using estimated fundamental rotational transition frequencies from Shklovskii (1953), Goss (1966), and Baird & Bredohl (1971). The first direct

measurement of the CH rotational spectrum was reported by Brazier & Brown (1983).

3.64. H_3^+

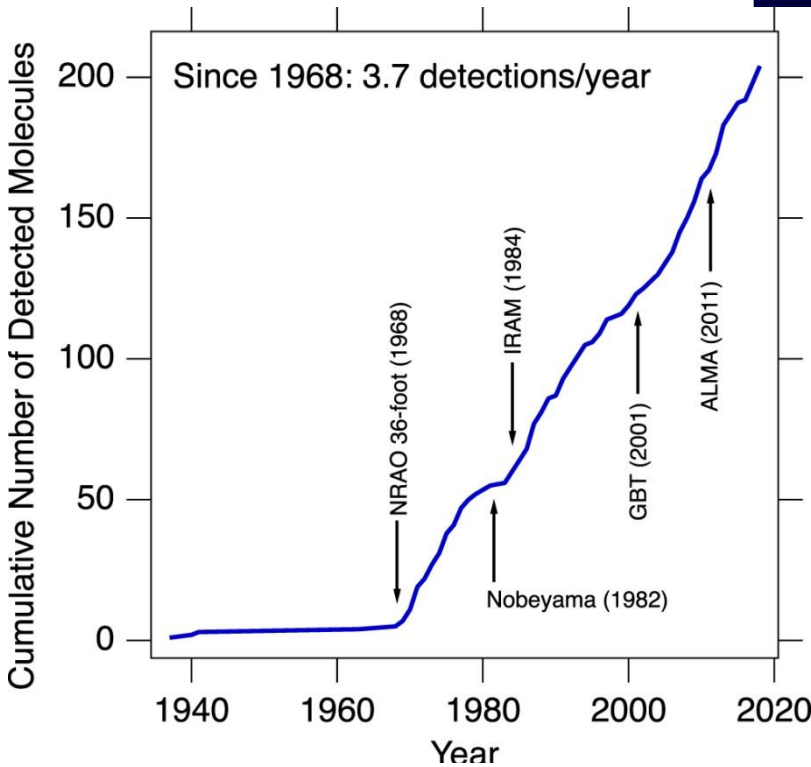
First suggested as a possible interstellar molecule in Martin et al. (1961), H_3^+ was detected 35 years later in absorption toward GL 2136 and W33A by Geballe & Oka (1996) using UKIRT to observe three transitions of the ν_2 fundamental band near $3.7 \mu\text{m}$. The laboratory work was performed by Oka (1980).

Molecules in interstellar space

Not actualized, approximation

| | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 13 |
|-----------------|-------------------------------|----------------------------------|---------------------------------|---------------------------------|-----------------------------------|----------------------------------|------------------------------------|---------------------------------------|-------------------|--------------------|
| H ₂ | C ₃ | c-C ₃ H | C ₅ | C ₅ H | C ₆ H | CH ₃ C ₃ N | CH ₃ C ₄ H | CH ₃ C ₅ N? | HC ₉ N | HC ₁₁ N |
| AlF | C ₂ H | l-C ₃ H | C ₄ H | l-H ₂ C ₄ | CH ₂ CHCN | HCOOCH ₃ | CH ₃ CH ₂ CN | (CH ₃) ₂ CO | | |
| AlCl | C ₂ O | C ₃ N | C ₄ Si | C ₂ H ₄ | CH ₃ C ₂ H | CH ₃ COOH? | (CH ₃) ₂ O | NH ₂ CH ₂ COOH? | | |
| C ₂ | C ₂ S | C ₃ O | l-C ₃ H ₂ | CH ₃ CN | HC ₅ N | C ₇ H | CH ₃ CH ₂ OH | | | |
| CH | CH ₂ | C ₃ S | c-C ₃ H ₂ | CH ₃ NC | HCOCH ₃ | H ₂ C ₆ | HC ₇ N | | | |
| CH ⁺ | HCN | C ₂ H ₂ | CH ₂ CN | CH ₃ OH | NH ₂ CH ₃ | CH ₂ OHCHO | C ₈ H | | | |
| CN | HCO | CH ₂ D ⁺ ? | CH ₄ | CH ₃ SH | c-C ₂ H ₄ O | | | | | |
| CO | HCO ⁺ | HCCN | HC ₃ N | HC ₃ NH ⁺ | CH ₂ CHOH | | | | | |
| CO ⁺ | HCS ⁺ | HCNH ⁺ | HC ₂ NC | HC ₂ CHO | | | | | | |
| CP | HOC ⁺ | HNCO | HCOOH | NH ₂ CHO | | | | | | |
| CSi | H ₂ O | HNCS | H ₂ CHN | C ₅ N | | | | | | |
| HCl | H ₂ S | HOCO ⁺ | H ₂ C ₂ O | | | | | | | |
| KCl | HNC | H ₂ CO | H ₂ NCN | | | | | | | |
| NH | HNO | H ₂ CN | HNC ₃ | | | | | | | |
| NO | MgCN | H ₂ CS | SiH ₄ | | | | | | | |
| NS | MgNC | H ₃ O ⁺ | H ₂ COH ⁺ | | | | | | | |
| NaCl | N ₂ H ⁺ | NH ₃ | | | | | | | | |
| OH | N ₂ O | SiC ₃ | | | | | | | | |
| PN | NaCN | | | | | | | | | |
| SO | OCS | | | | | | | | | |
| SO ⁺ | SO ₂ | | | | | | | | | |
| SiN | c-SiC ₂ | | | | | | | | | |
| SiO | CO ₂ | | | | | | | | | |
| SiS | NH ₂ | | | | | | | | | |
| CS | H ₃ ⁺ | | | | | | | | | |
| HF | SiCN | | | | | | | | | |
| SH | AlNC | | | | | | | | | |
| FeO? | | | | | | | | | | |

16 JULY 2015 | VOL 523 | NATURE | 323

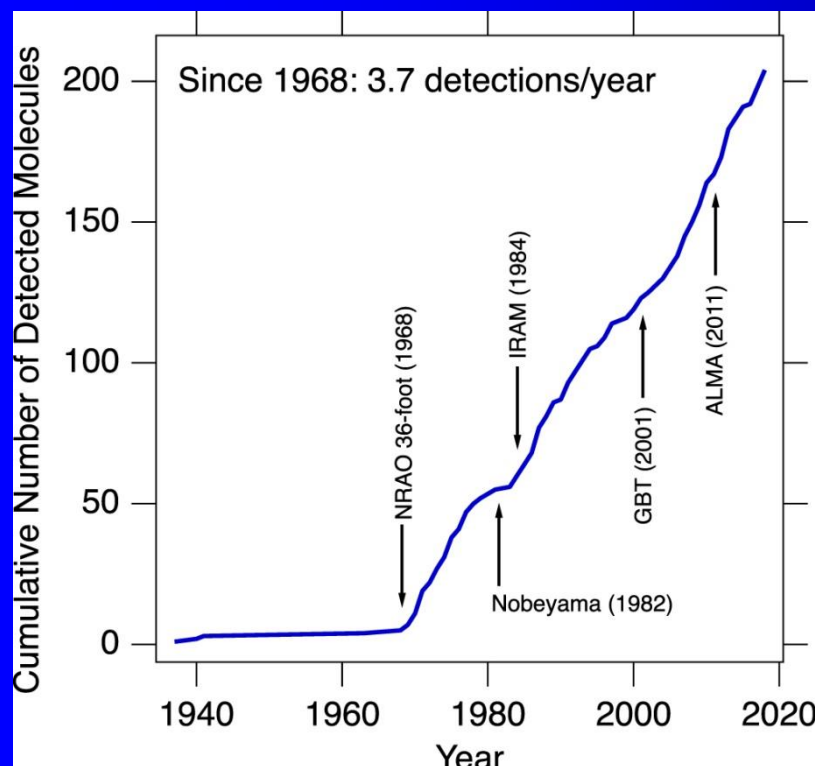


Cumulative number of known interstellar molecules over time. Commissioning dates of major contributing facilities are noted with arrows. [McGuire 2018]

Molecules in interstellar space

Not actualized, approximation

16 JULY 2015 | VOL 523 | NATURE | 323



Cumulative number of known interstellar molecules over time. Commissioning dates of major contributing facilities are noted with arrows. [McGuire 2018]

actualized, approximation 2021

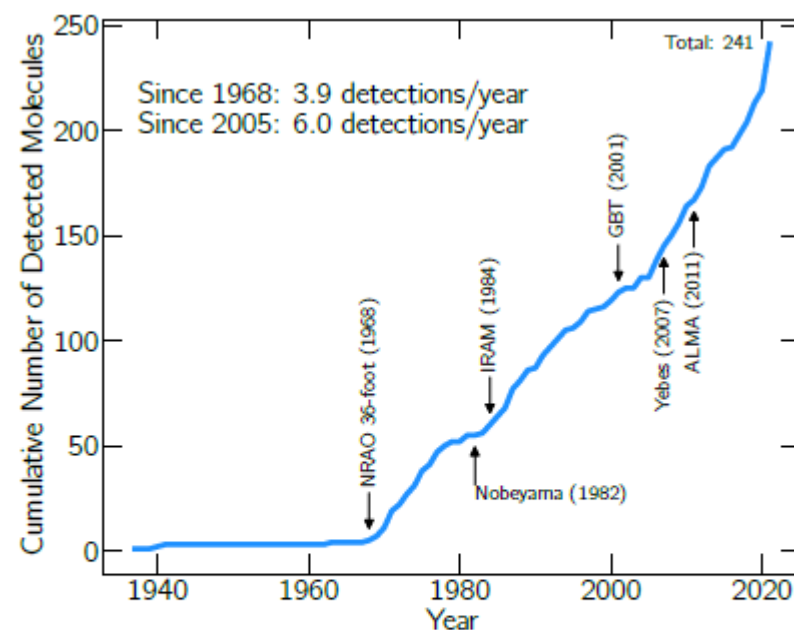


Figure 1. Cumulative number of known interstellar molecules over time. After the birth of molecular radio astronomy in the 1960s, there have been on average 3.9 new detections per year. The commissioning dates of several major contributing facilities are noted with arrows.

DRAFT VERSION OCTOBER 1, 2021
Typeset using L^AT_EX twocolumn style in AASTeX631

2021 Census of Interstellar, Circumstellar, Extragalactic, Protoplanetary Disk, and Exoplanetary Molecules

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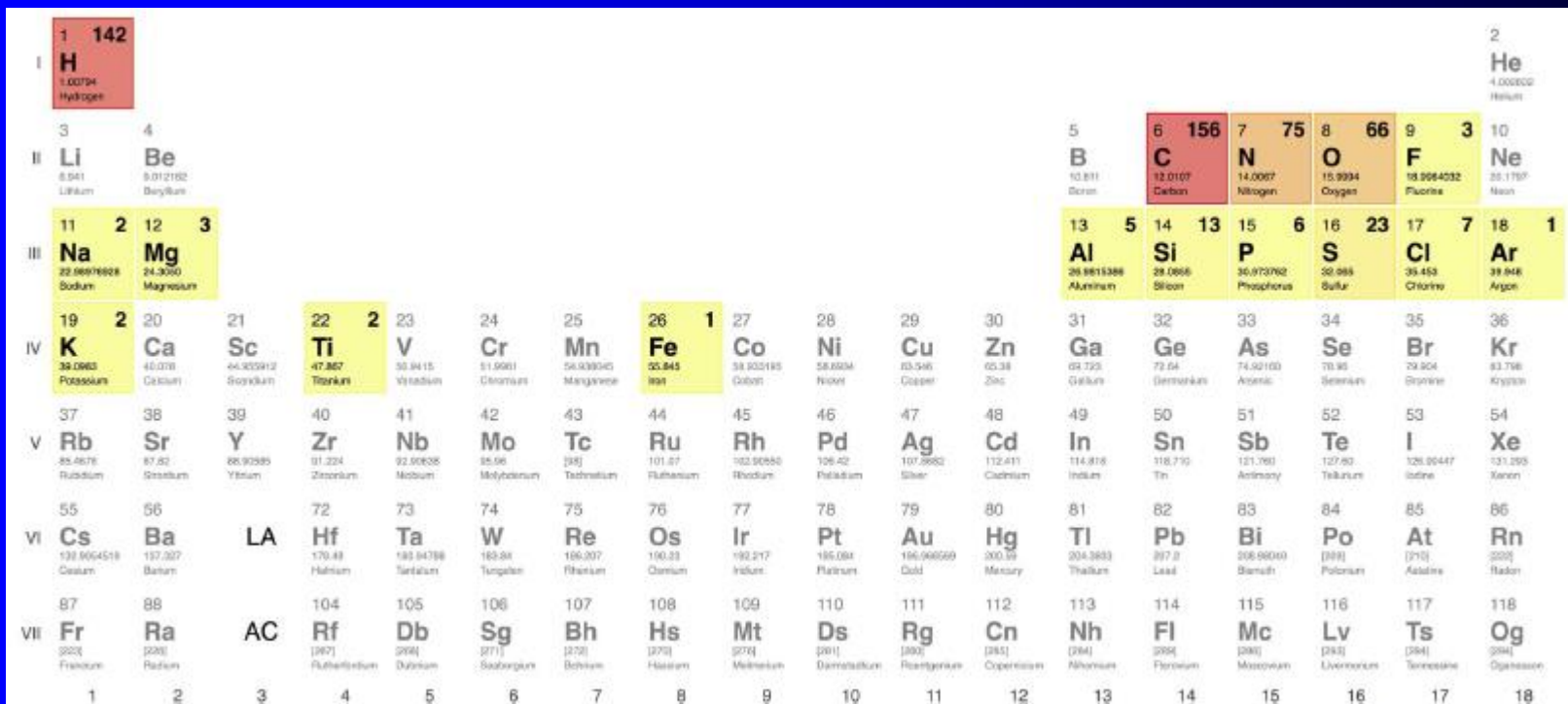



Figure 6. Periodic table of the elements, absent the lanthanide and actinide series, color-coded by number of detected species containing each element. For those elements with detected ISM molecules, that number is displayed in the upper right of each cell.

2018 Census of Interstellar, Circumstellar, Extragalactic, Protoplanetary Disk, and Exoplanetary Molecules

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Interstellar medium

92.1% of nucleons in the universe are protons

7.8% are helium nuclei !

0.1%.....C,N,O,S,Si....

Cosmic abundance

H

He

Mg

Fe

| | | | |
|---------|--------|---------|---------|
| □ C | □ N | □ O | □ Ne |
| □ Si | □ S | □ Ar | |

~0.005%.....D



Andromeda composite

1722



socha Atlanta



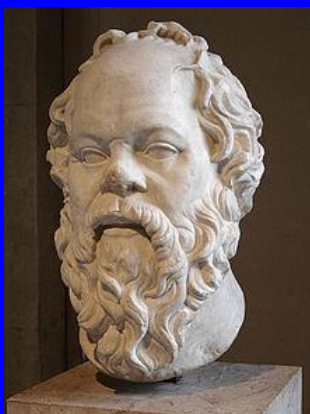
1722



Věž byla dokončena v roce 1722. Na vrcholu věže stojí socha Atlanta (olověná socha s železnou vnitřní konstrukcí, váha asi 600 kg, výška 2,4 m). Atlas nese nebeskou sféru (průměr asi 1,6 m, váha asi 150 kg) s korouhví.

(Pravděpodobně

Matyáš Braun)



Scio me nihil scire

The astrochemistry game plan

Laboratory
astrophysics and
related theory

Spectroscopy

Collisional excitation rate
coefficients

Bimolecular reaction rate
coefficients

Grain surface reactions

Photoionization and
photodissociation cross-
sections

Observations of
astrophysical
molecules

Emission line luminosities

Absorption line optical
depths

Astrochemical
modeling of ...

Diffuse IS cloud

Dense IS clouds

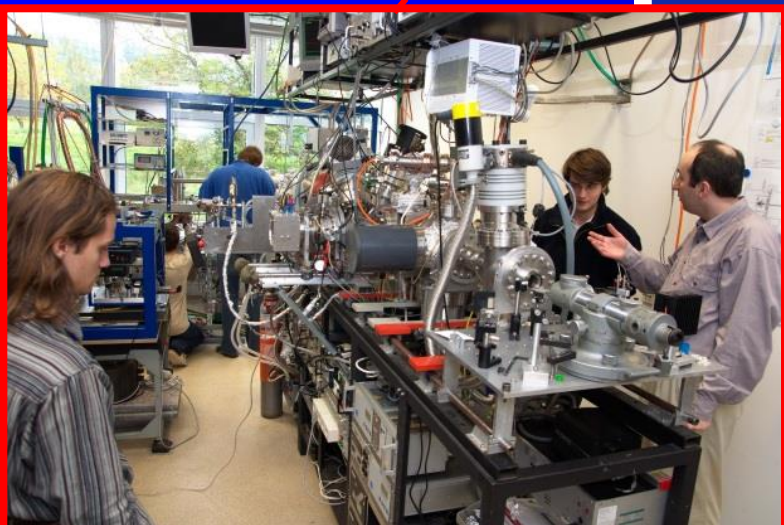
Photodissociation regions

Circumstellar outflows

X-irradiated regions

Excitation and radiative
transfer

Information of general astrophysical interest



KFPP MFF UK

Načo chodiť do školy...

2014

FIRST TIME-DEPENDENT STUDY OF H_2 AND H_3^+ ORTHO-PARA CHEMISTRY IN THE DIFFUSE INTERSTELLAR MEDIUM: OBSERVATIONS MEET THEORETICAL PREDICTIONS*

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The chemistry in the diffuse interstellar medium (ISM)

THE ASTROPHYSICAL JOURNAL, 787:44 (10pp), 2014 May 20

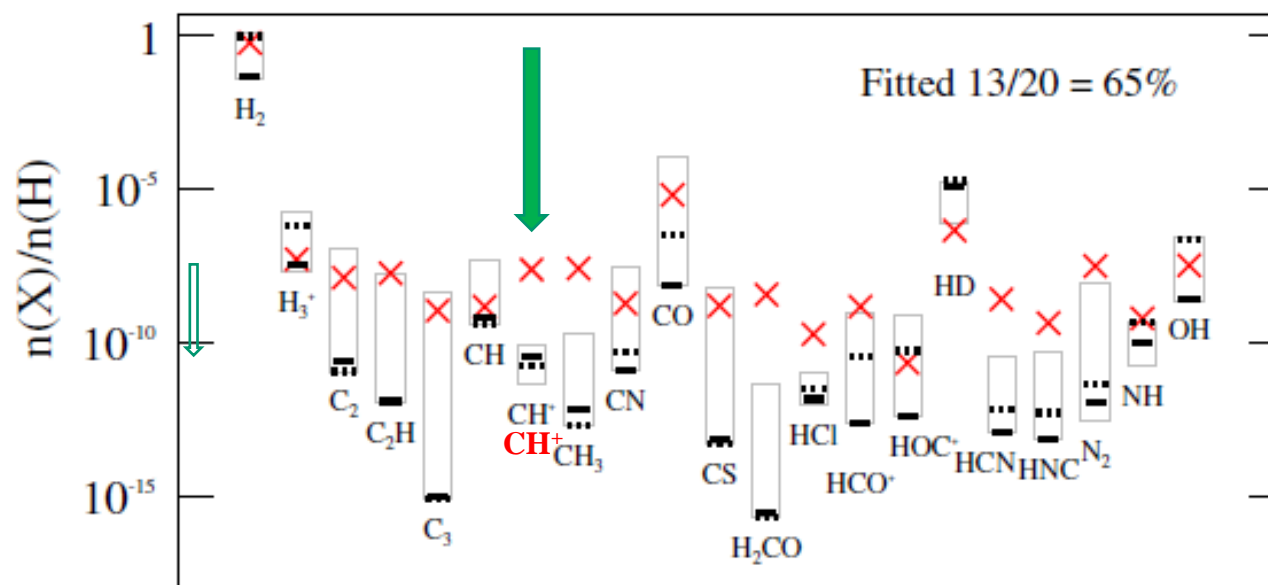


Figure 6. Comparison of observed abundances (red crosses) to modeled values of key species in diffuse clouds. Gray boxes show the range of abundances calculated from the considered models (Table 2) and black lines show abundances from the best-fit model “2X+C15” (30 K, solid line, and 90 K, dotted line).

(A color version of this figure is available in the online journal.)

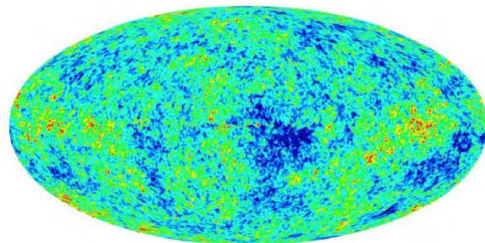
Temperature scale should be logarithmic

Far Infrared Absolute Spectrophotometer (FIRAS)

T

Temperature scale

cosmic microwave background



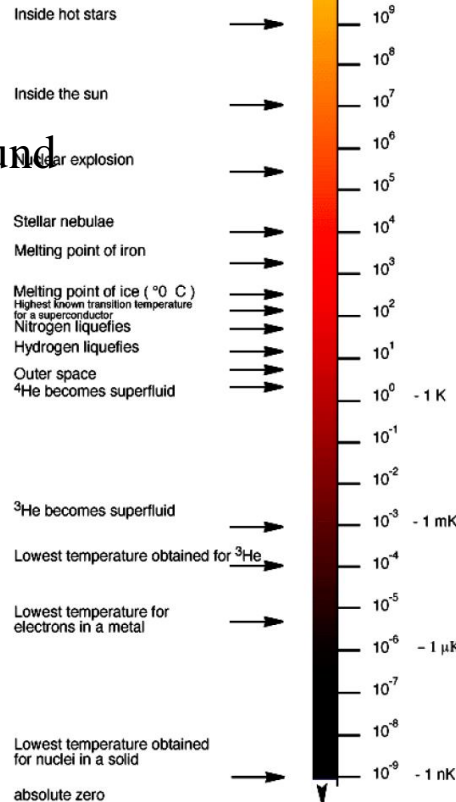
-200 T (μK) +200

$$T_{\text{FIRAS}} = T_0 = 2.730 \pm 0.001 \text{ K}$$

$$T = 2.717 \pm 0.003 \text{ K}$$

monopole and dipole components

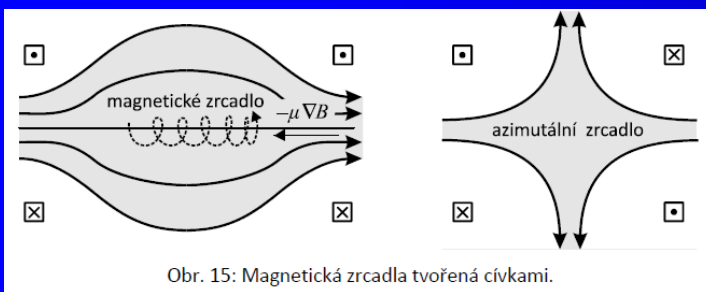
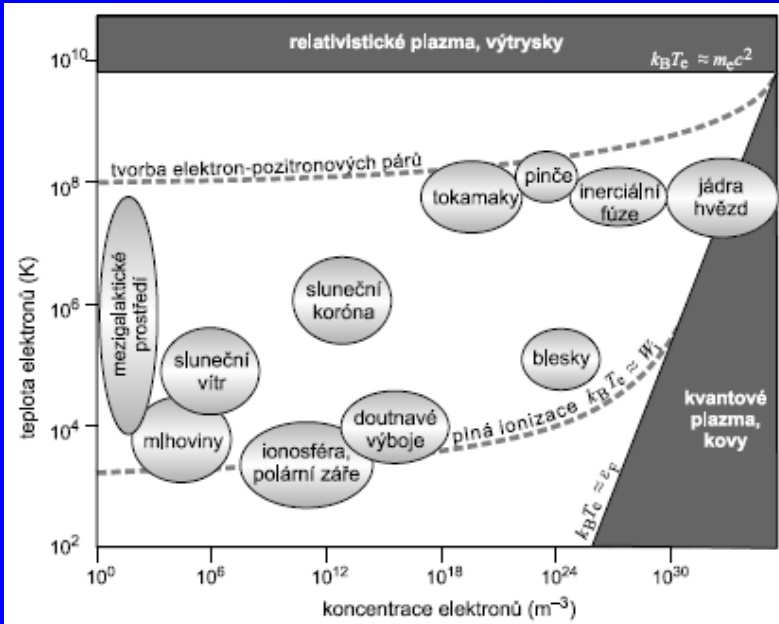
$$\text{anisotropy } 3.353 \pm 0.024 \text{ mK}$$



The **cosmic microwave background (CMB, CMBR)**, **Big Bang** cosmology, is **electromagnetic radiation** which is a remnant from an early stage of the universe, also known as "relic radiation". The CMB is faint **cosmic background radiation** filling all space. It is an important source of data on the early universe because it is the oldest electromagnetic radiation in the universe, dating to the **epoch of recombination**. With a traditional **optical telescope**, the space between stars and galaxies (the *background*) is completely dark. However, a sufficiently sensitive **radio telescope** shows a faint background noise, or glow, almost **isotropic**, that is not associated with any star, galaxy, or other object. This glow is strongest in the **microwave** region of the radio spectrum. The accidental **discovery of the CMB** in 1965 by American radio astronomers **Arno Penzias** and **Robert Wilson**^{[1][2]} was the culmination of work initiated in the 1940s, and earned the discoverers the 1978 **Nobel Prize in Physics**.

Úvod do teorie plazmatu

Petr Kulháněk



Obr. 15: Magnetická zrcadla tvořená cívkami.

Fermiho urychlování druhého druhu

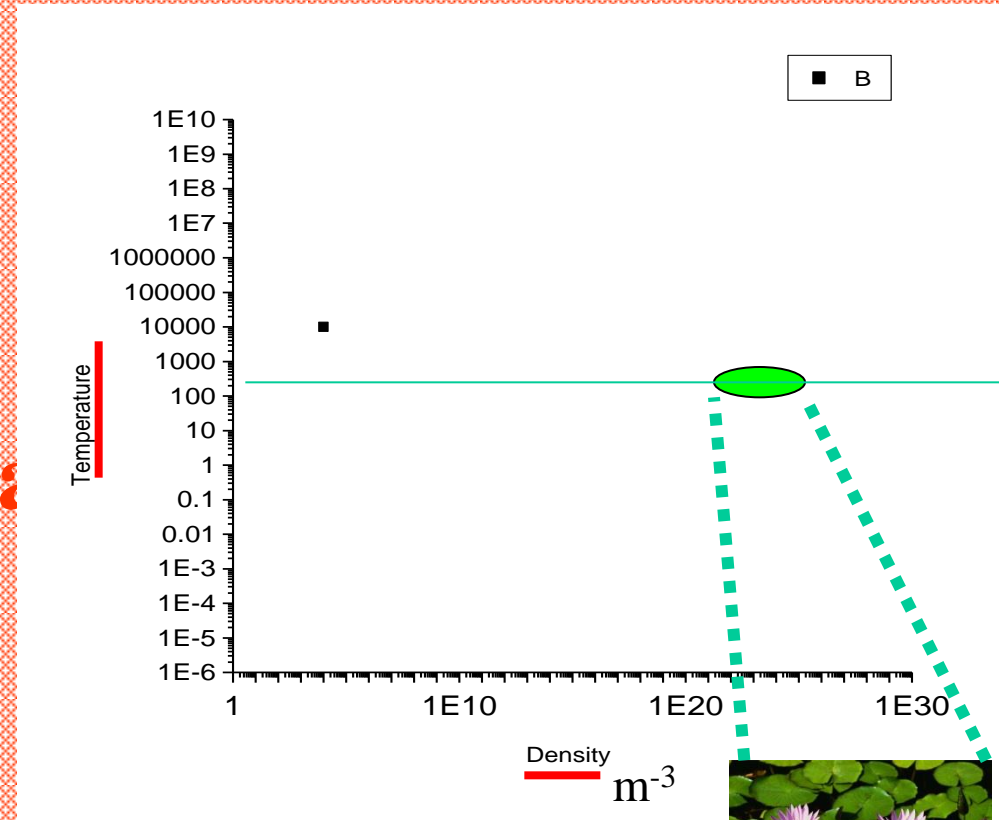
Představme si, že ve vesmíru se pohybují náhodně nabitě částice v prostředí různě se měnících magnetických polí. Nabitá částice bude tu a tam odrážena od magnetických zrcadel polyhujících se náhodným směrem. Díky Fermiho mechanismu bude statisticky někdy urychlena a někdy zpomalena. Rychlostní rozdělení se proto bude rozšiřovat a mezi částicemi se objeví určité procento velmi rychlých částic, které náhodně získaly energii z „příznivých“ odrazů od magnetických zrcadel. Tento mechanismus nazýváme *Fermiho urychlování druhého druhu* a italský fyzik Enrico Fermi se jím pokusil vysvětlit vysoké energie částic kosmického záření.



Obr. 17: Mlhovina Mravenec. Ve vnitřní části je pole dipólové, ve vnějších částech může v náhodných polích docházet k urychlování částic Fermiho mechanismem. HST.

Plasma

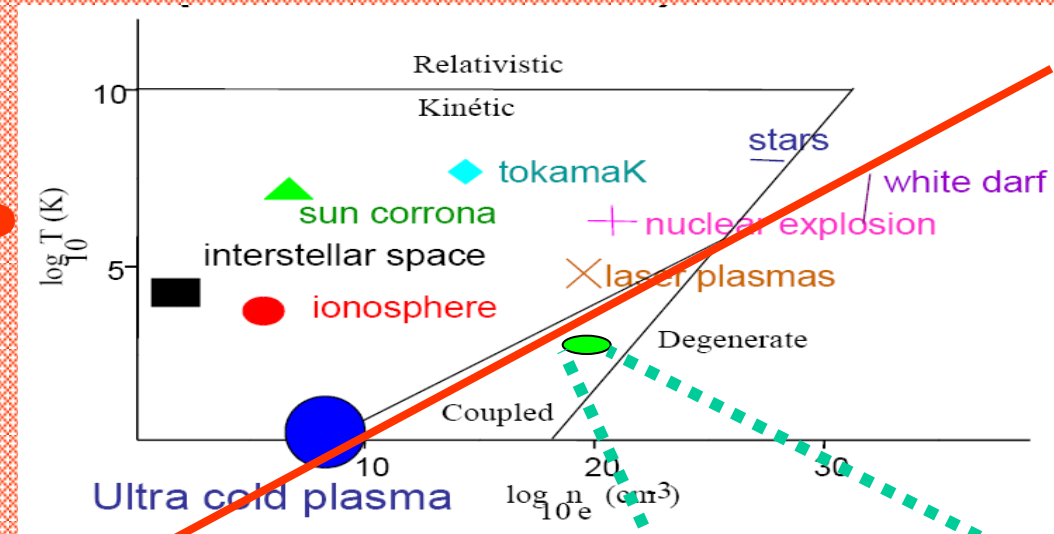
Pla



Not actualized, approximation

Plazma n_e ... T_e T

P



$$n_0 = 2,686\,781\,1(15) \times 10^{25} \text{ m}^{-3}.$$



$$W_{kin} \sim W_{Pot..elektrost}$$

$$\frac{3}{2}kT \sim \frac{e^2}{\epsilon a} \sim \frac{e^2}{\epsilon N^{-1/3}}$$

$$T \sim \frac{10^{-38}}{k\epsilon} N^{1/3}$$

$$T_K = 1K \Rightarrow N_K = 10^9 \text{ m}^{-3}$$

Temperatures and energies

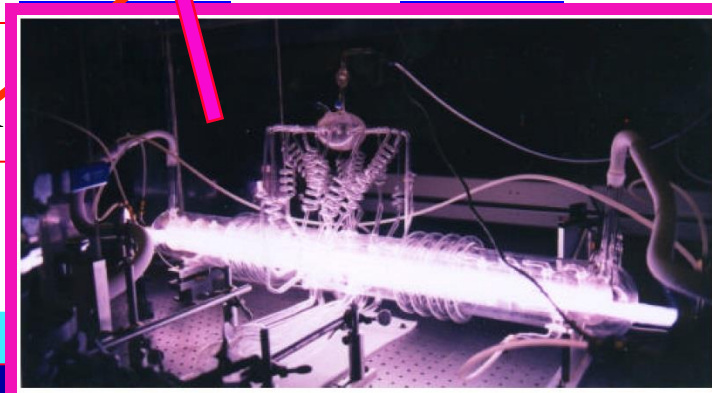
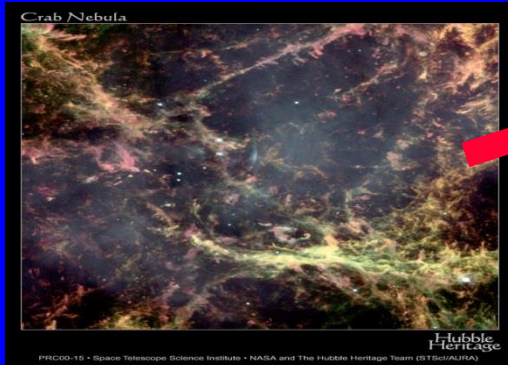
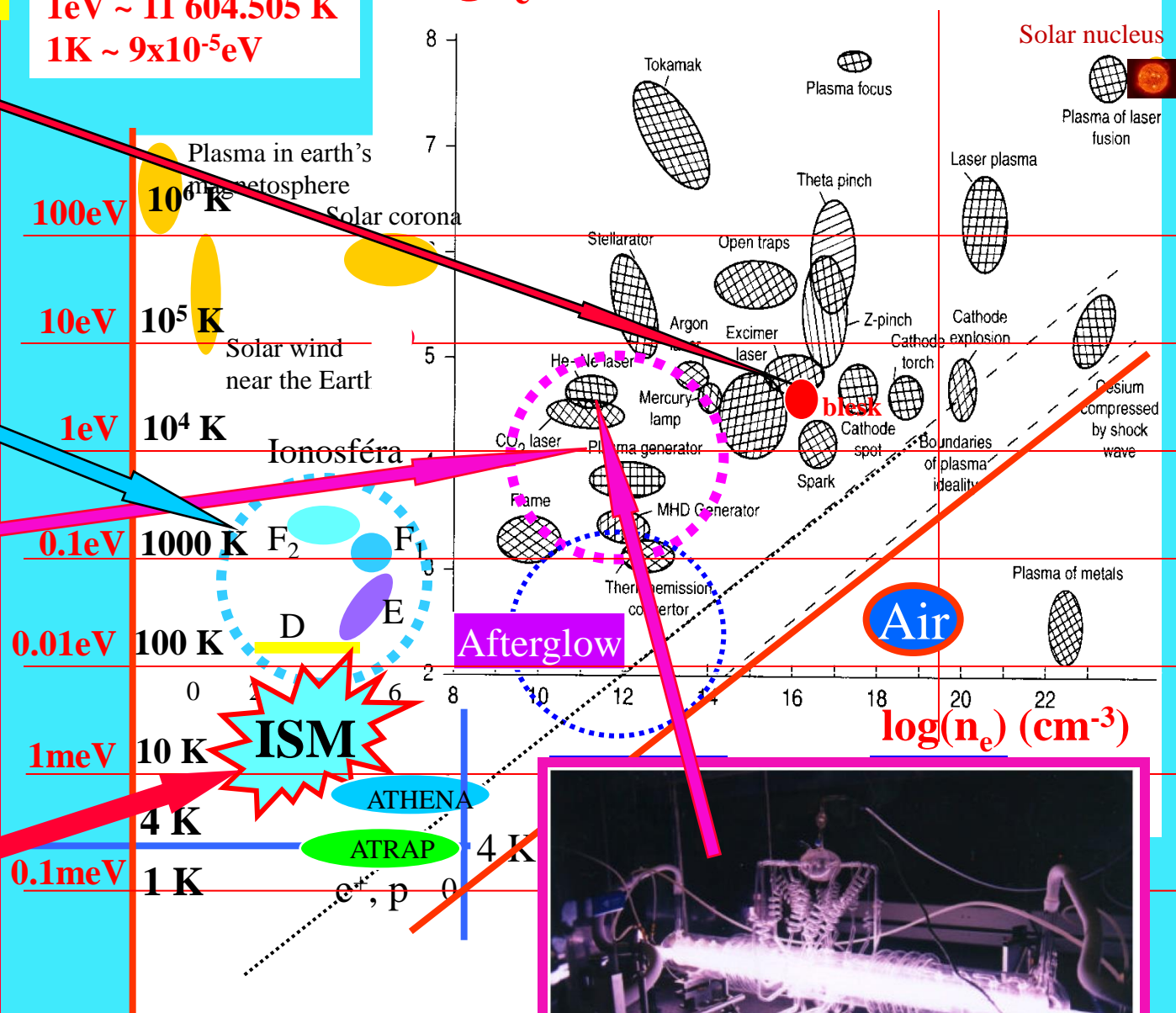
$$E \leftrightarrow kT$$

$$1\text{eV} \sim 11\,604.505\text{ K}$$

$$1\text{K} \sim 9 \times 10^{-5}\text{eV}$$

$\log T_e \text{ (K)}$

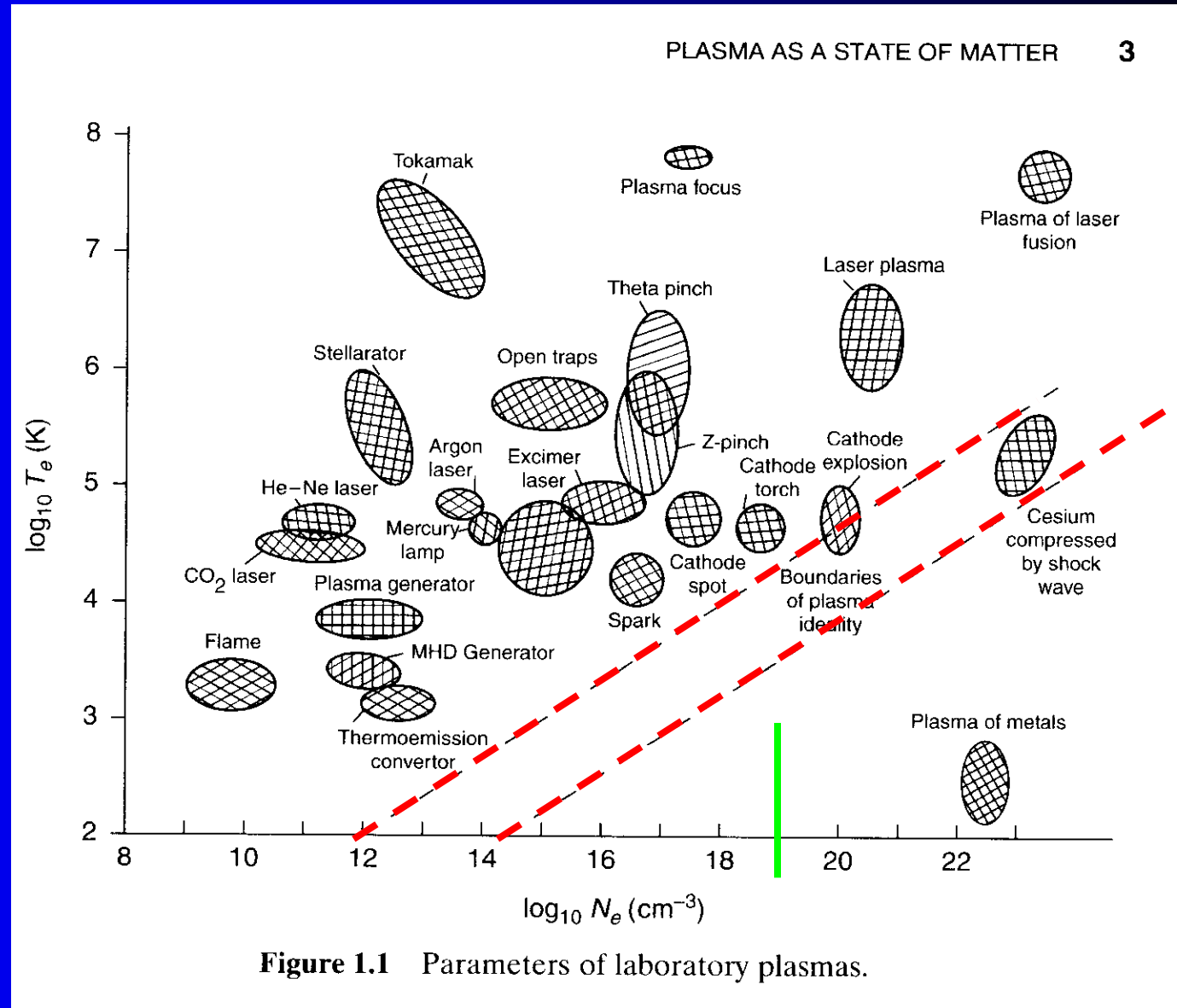
PLASMA AS A STATE OF MATTER



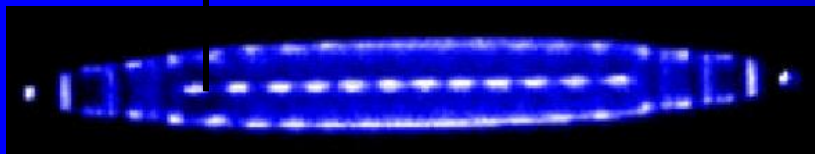
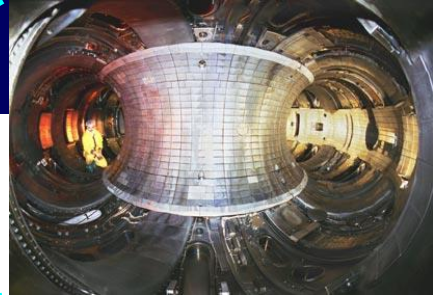
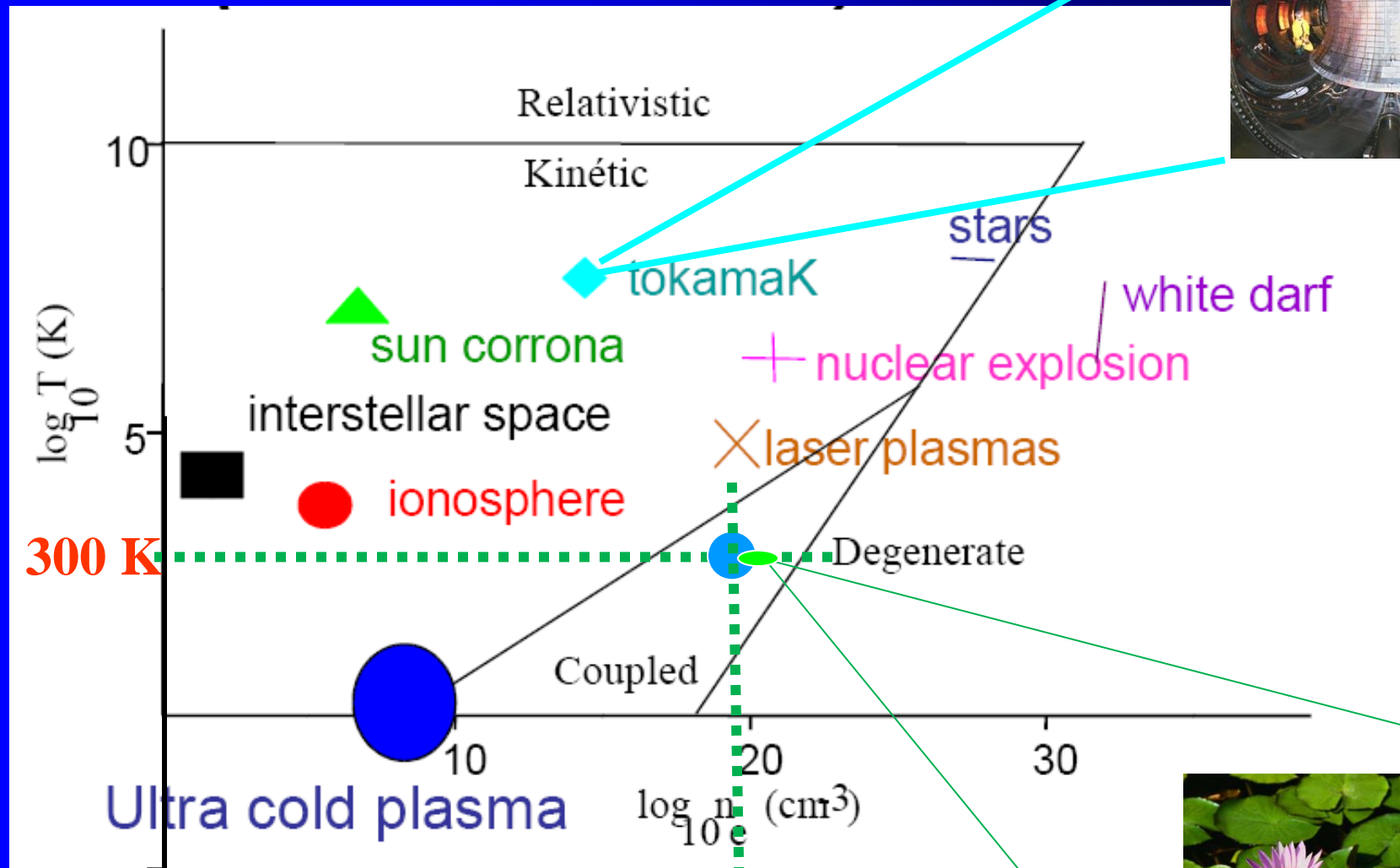
Not actualized, approximation

Parameters of laboratory plasmas

Not actualized, approximation



Electron temperature and electron number density - PLASMA



Experiment: $T \sim 6$ mK

Neutral 1 atm



life

Parameters of plasmas found in nature

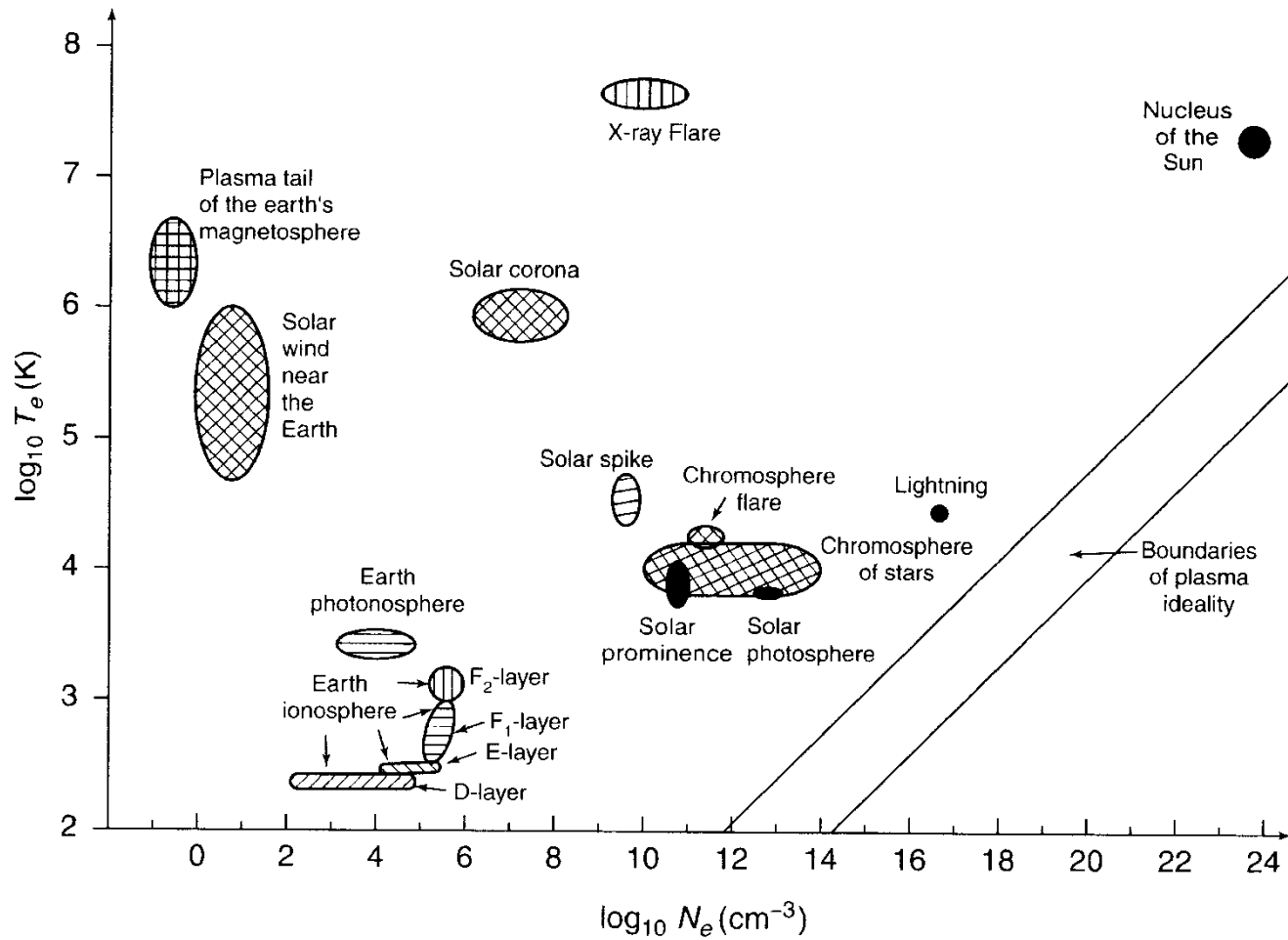


Figure 1.2 Parameters of plasmas found in nature.

Electron and gas temperatures in plasmas

4 PLASMA IN NATURE AND IN LABORATORY SYSTEMS

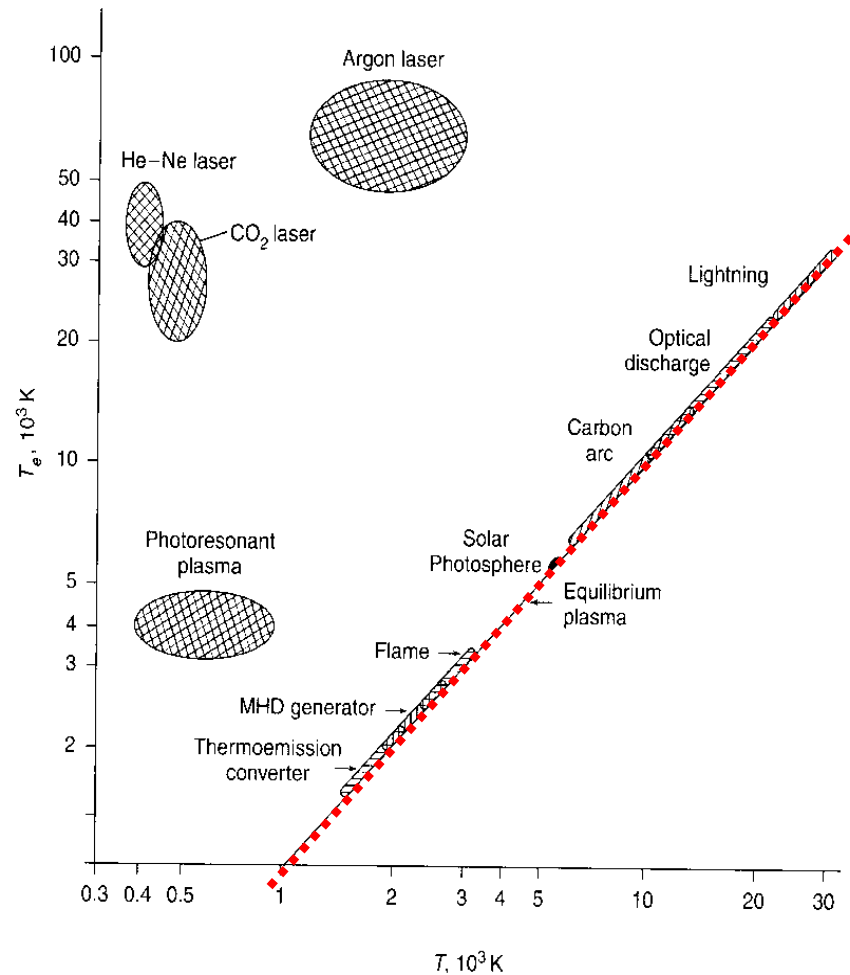


Figure 1.3 Electron and gas temperatures of laboratory plasmas. The straight line corresponds to the equilibrium plasma whose electron and gas temperatures are the same.

Difference in electron, ion and neutral gas temperature in plasma

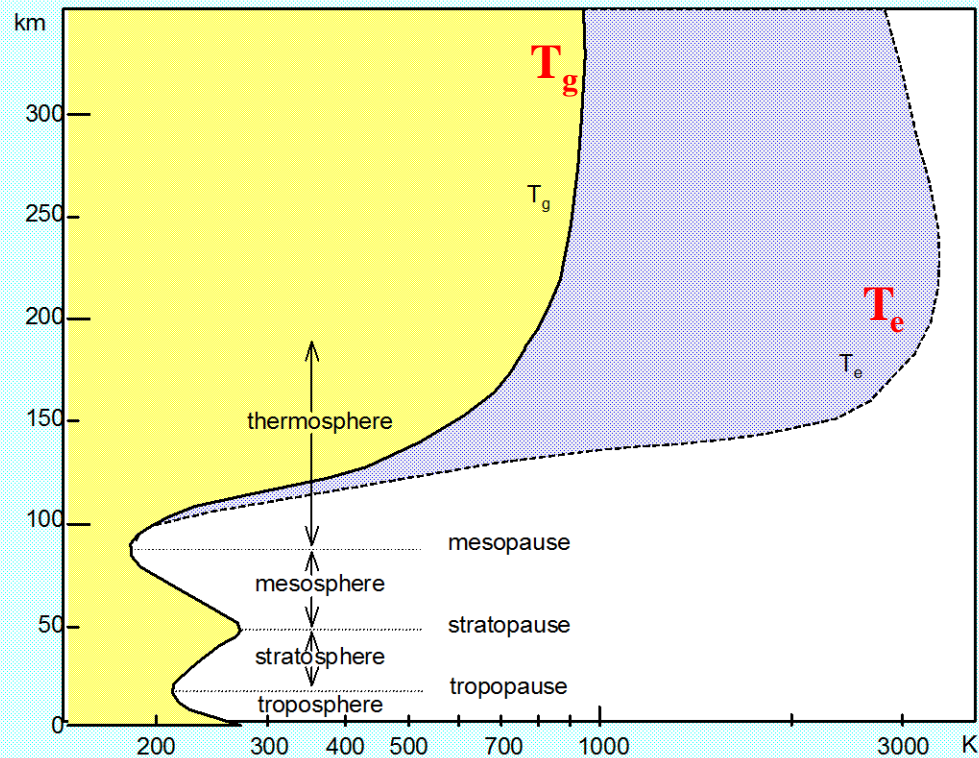
Equilibrium; relaxation time,

Probability of interactions...

Collisional frequency, Energy transfer

cross section

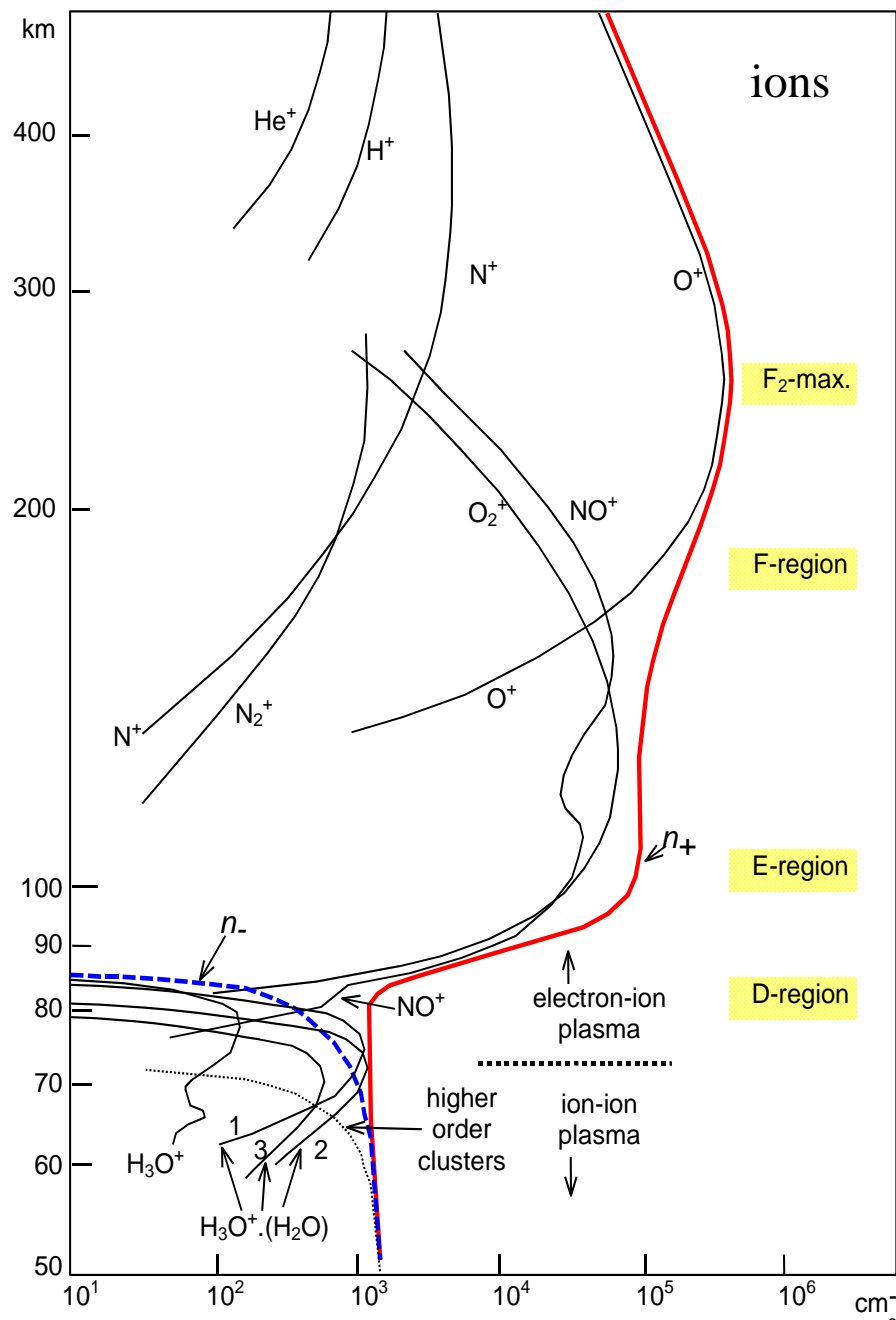
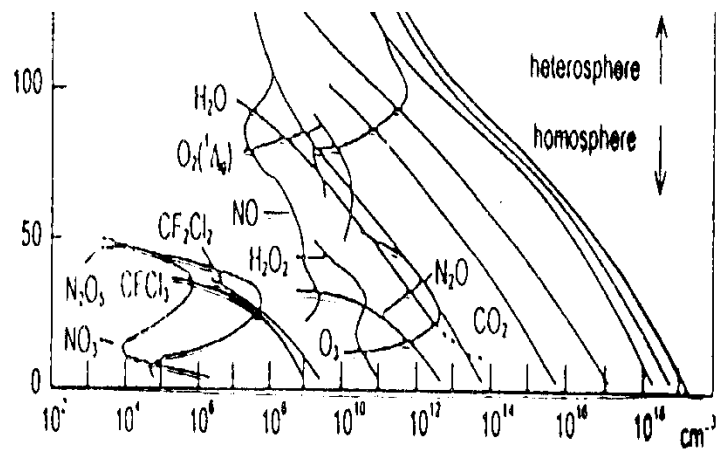
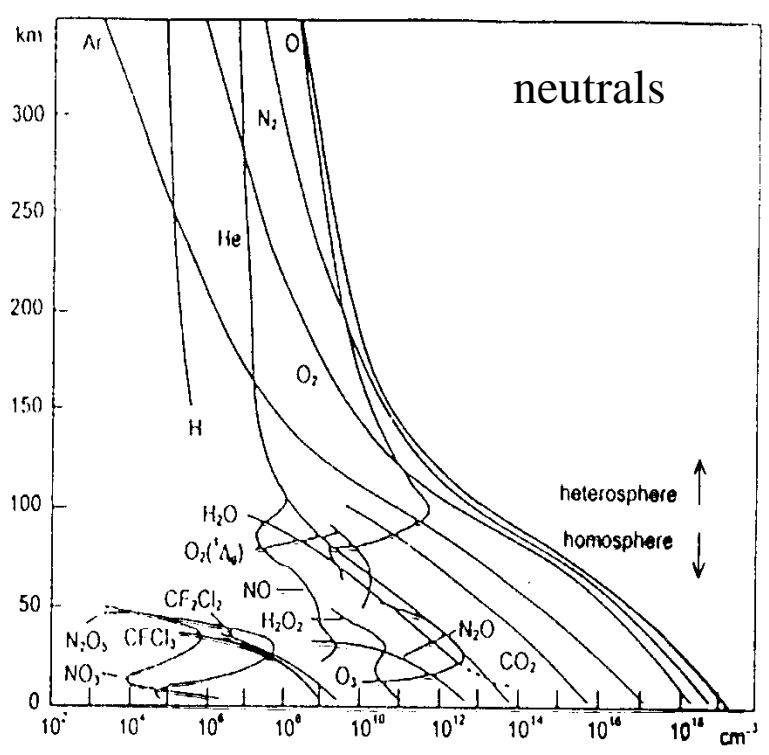
Temperatures in the ionosphere



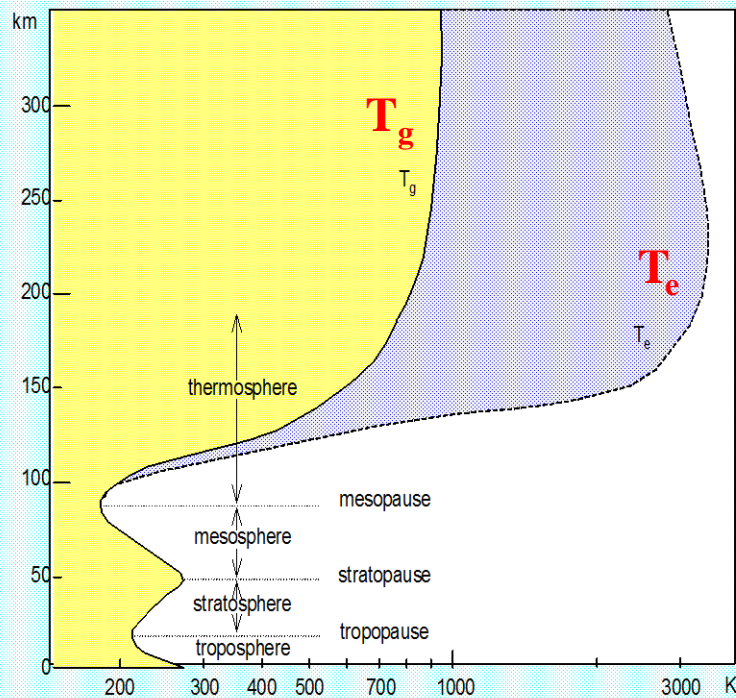
Ions chemistry

$$n_0 = 2,686\,781\,1(15) \times 10^{19} \text{ cm}^{-3}$$

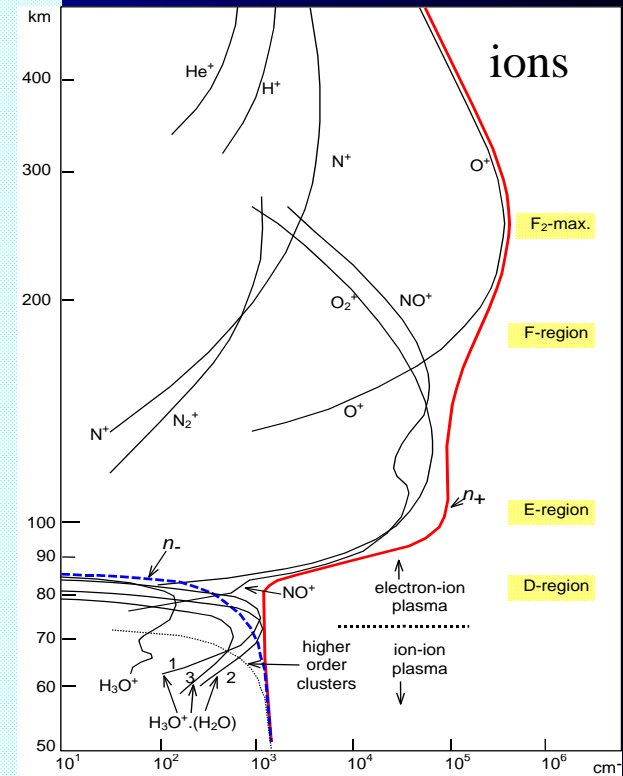
Ions in the terrestrial atmosphere



Temperatures in the ionosphere



Recombination?? $\alpha(T)$



Crab Nebula

ISM

Hydrogen only??

Ions chemistry

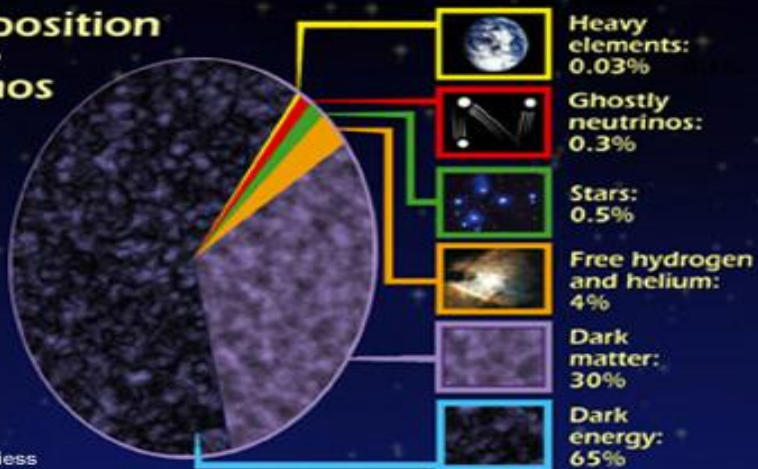
Electron – ion interactions

Negative ions ??

..... ??

Scio me nihil scire

Composition of the Cosmos



NASA/A. Riess

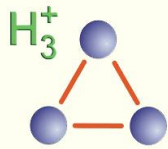
Hubble
Heritage

SA and The Hubble Heritage Team (STScI/AURA)

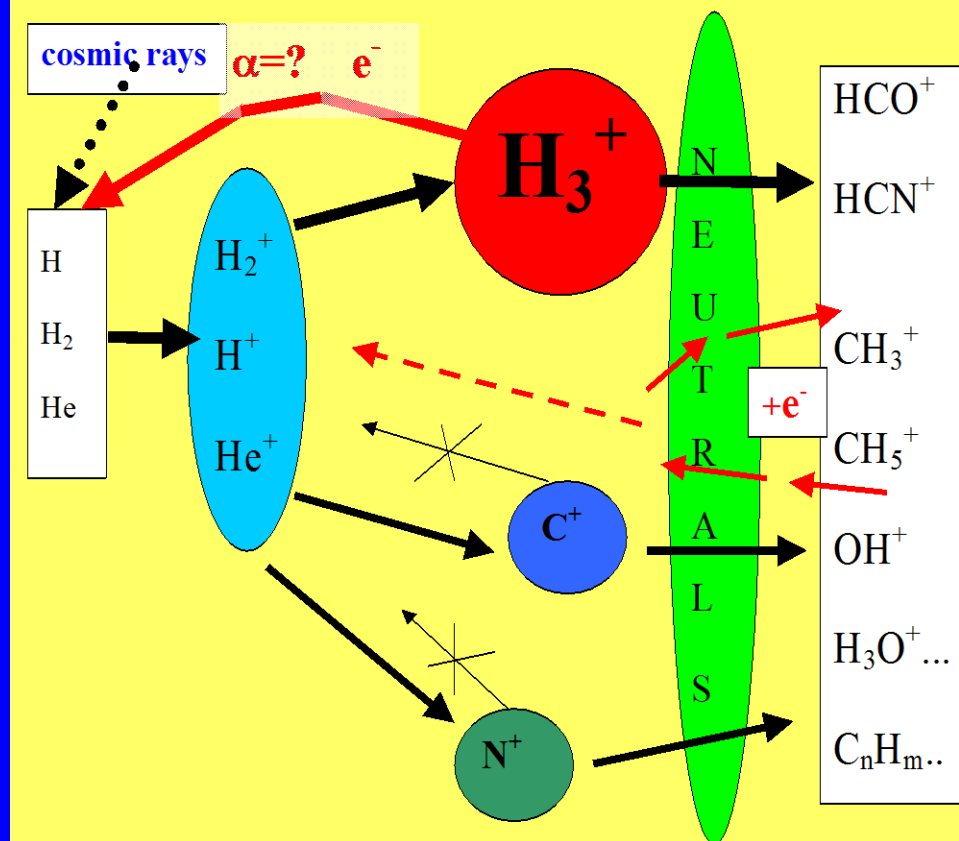
Interstellar medium

Hydrogen only??

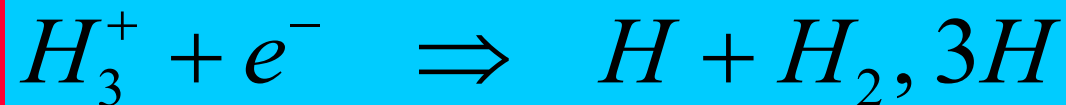
92.1% of nucleons in the universe are protons
7.8% are helium nuclei !



DENSE INTERSTELLAR CLOUDS



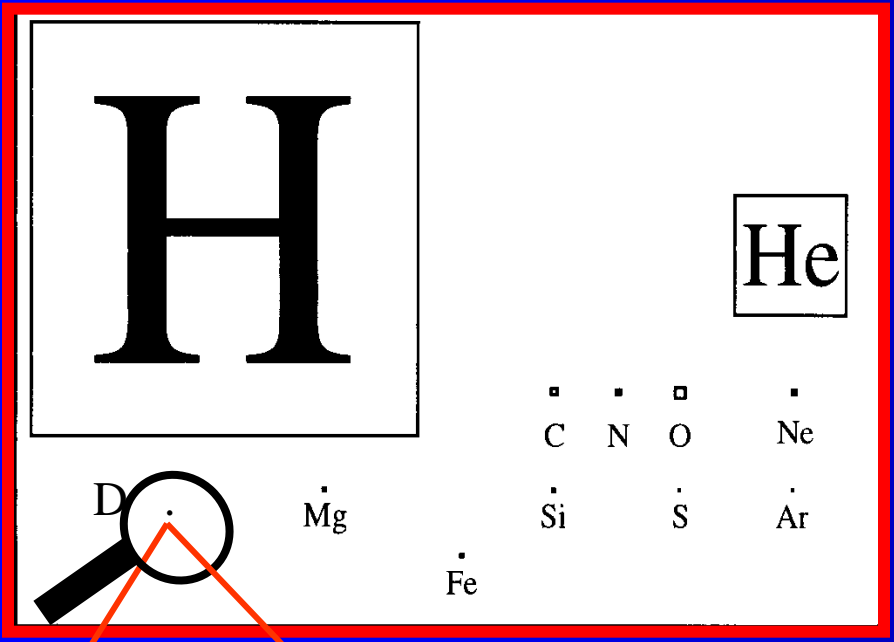
α=?
T~ 10-50K



Interstellar medium, HD role

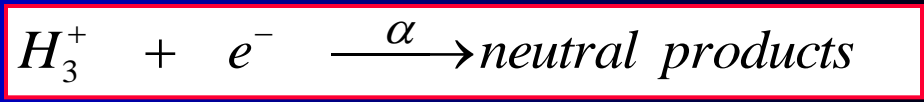
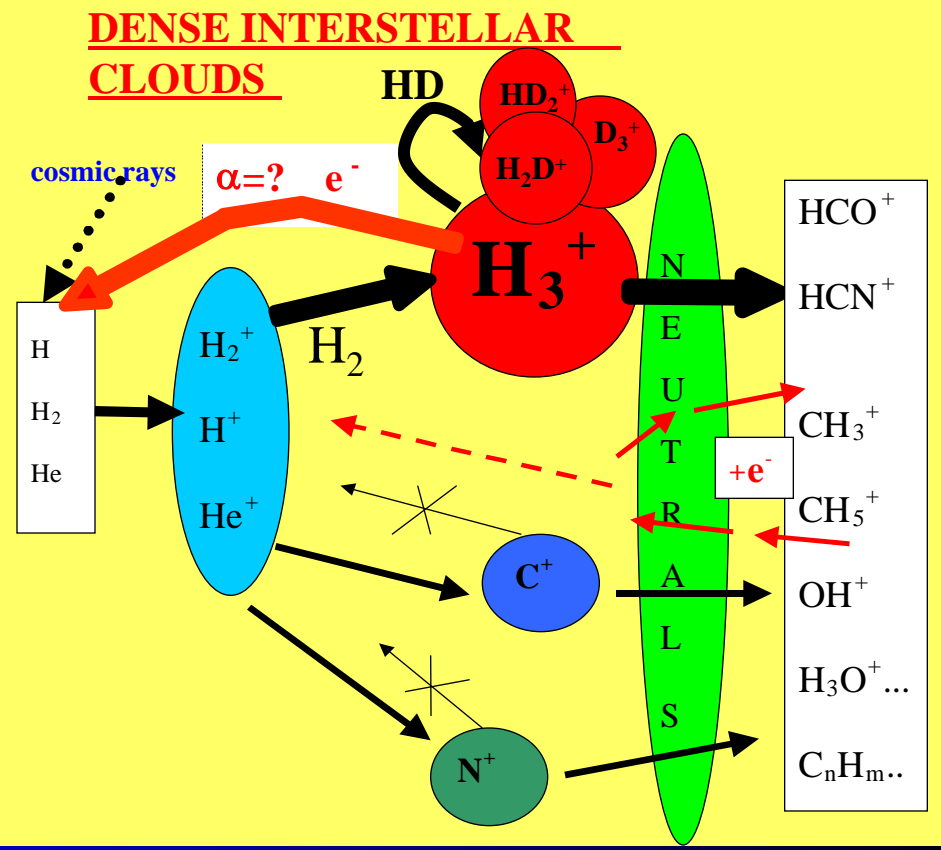
92.1% of nucleons in the universe are protons
7.8% are helium nuclei !
0.1%.....C,N,O,S,Si....

Cosmic abundance



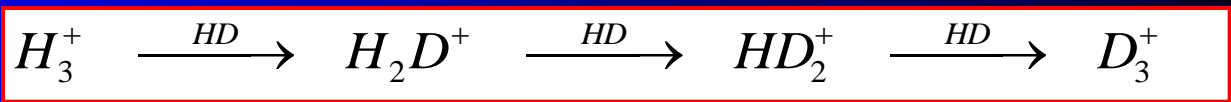
D/H ratio ~ 10⁻⁵

@ 10-50K

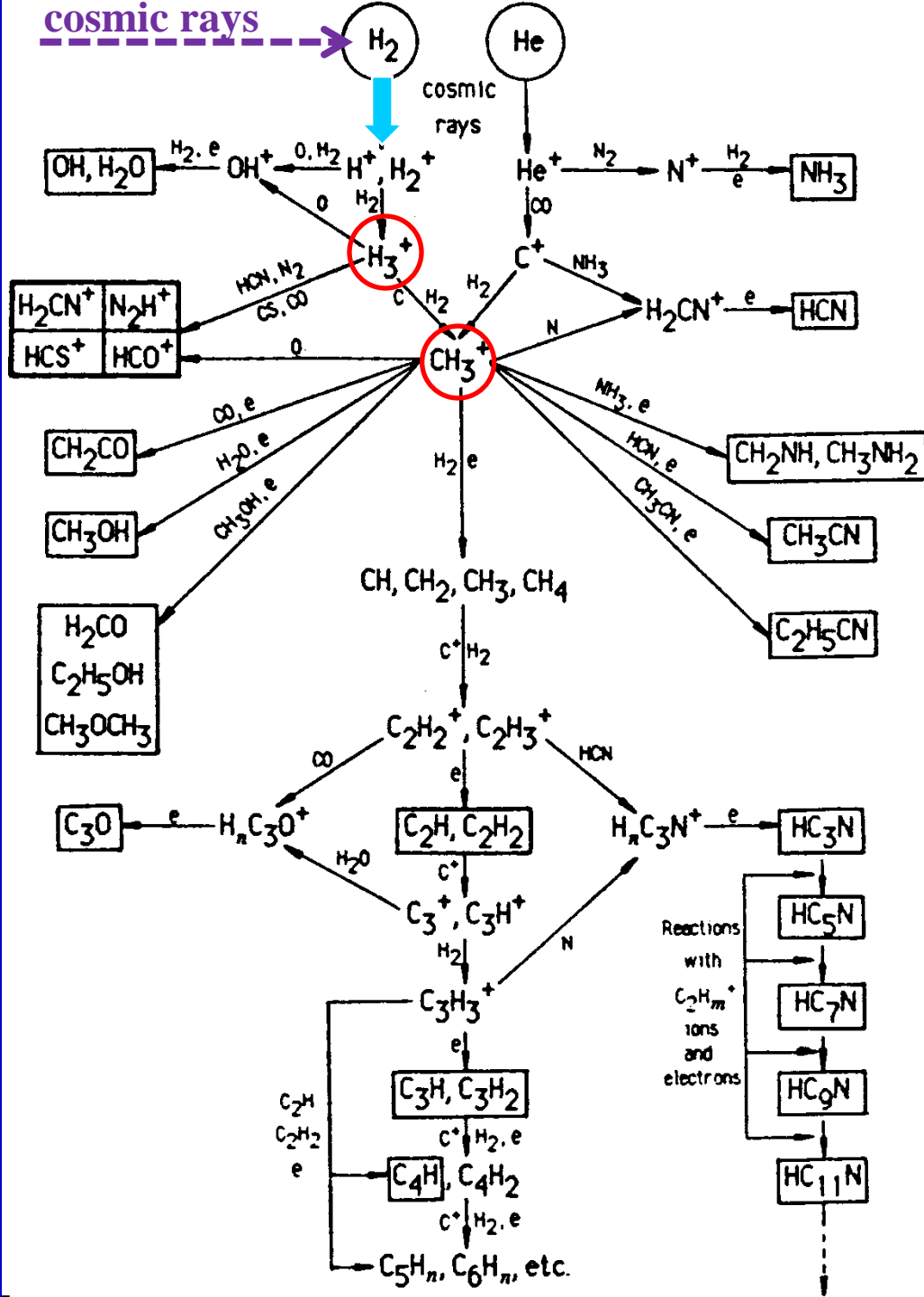
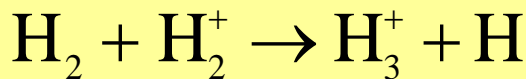
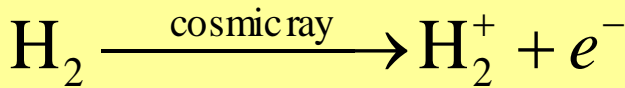


α (10 K) = ????

k (10 K) = ????



H₃⁺ in interstellar space

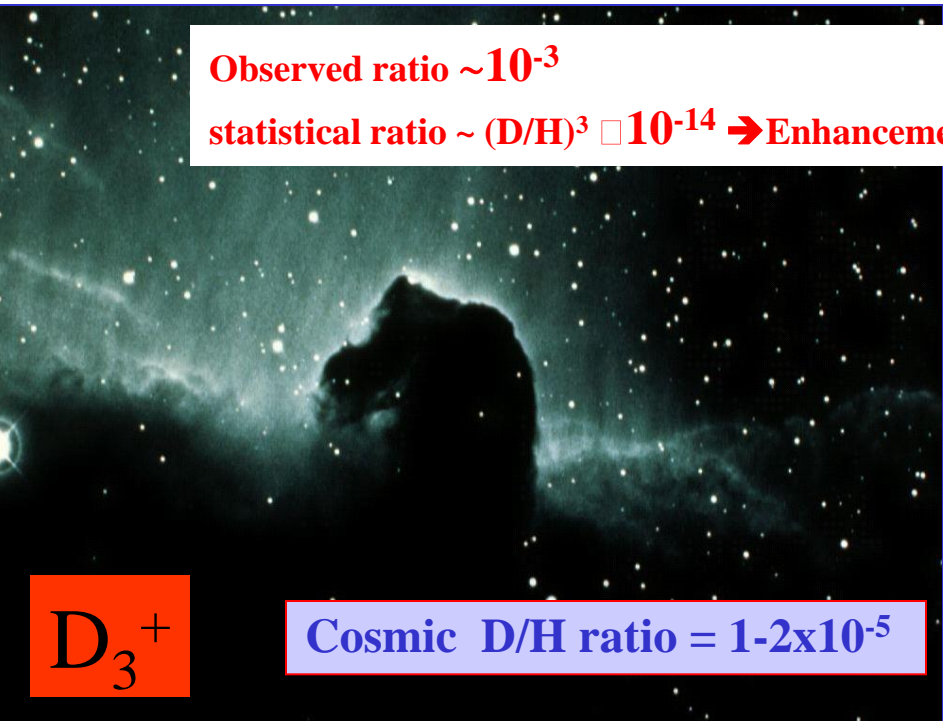


Observation of high population of deuterated molecules

The first detection of deuterated molecules were made in the early 1970s..... Observed enhancement of D in molecules

| | | | |
|-------------------------------------|-------------|--------------|---|
| H ₂ D | Stark | (1999) | 1 ₁₀ -1 ₁₁ transition of ortho- emission from young stellar object NGC 1333 IRAS4A. |
| H ₂ D ⁺ | Caselli | (2003) | detected towards L1544. |
| HD ₂ ⁺ | Vastel | (2004) | the first detection |
| CH ₂ DOH... | Parise | (2003, 2004) | have detected 4 isotopomers of deuterated methanol |
| NHD ₂ /NH ₃ | Roueff | (2000) | |
| | Loinard | (2001) | is 0.005 in the cold cloud L134N and 0.03 in the low-mass protostar 16293 E |
| D ₂ CO/H ₂ CO | Loinard | (2002) | |
| | Bacmann | (2003) | is between 0.01 and 0.4 in a low-mass protostars and prestellar cores |
| NH ₂ D/NH ₃ | J. Hatchell | (2003) | high ratios~4-33% in protostellar cores |

| | | | |
|----------------------------------|-----|--------|---|
| ND ₃ /NH ₃ | Lis | (2002) | ratio ~10 ⁻³ cold dense Barnard 1cloud |
| | Tak | (2002) | Class 0 protostar NGC 1333 IRAS4A |

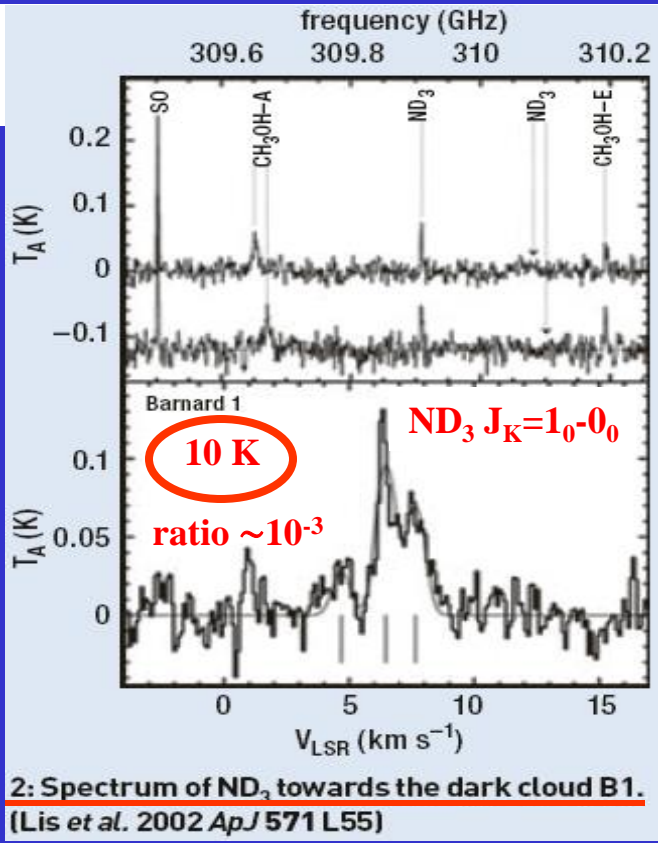


Observed ratio ~10⁻³

statistical ratio ~ (D/H)³ □ 10⁻¹⁴ → Enhancement of 10¹¹

D₃⁺

Cosmic D/H ratio = 1-2x10⁻⁵



High population of deuterated molecules

D_3^+

Cosmic D/H $\approx 10^{-5}$
 XD/XH $\approx 10^{-1}$ - 10^{-3}
 XD₂ / XH₂ $\approx 10^{-2}$
 XD₃ / XH₃ $\approx 10^{-3}$

Cosmic D/H ratio = $1-2 \times 10^{-5}$

H_3^+

H_2D^+

D_2H^+

D_3^+

| | | |
|-------------------------------|-----------------------|---------------------------|
| HD | H_2D^+ | D_2H^+ |
| N ₂ D ⁺ | DCO ⁺ | DCN |
| DNC | HDCS | <u>D₂CS</u> |
| HDO | DC ₃ N | <u>DC₅N</u> |
| C ₃ HD | HDCO | <u>D₂CO</u> |
| CH ₃ OD | CH ₂ DOH | <u>CHD₂OH</u> |
| CD ₃ OH | CH ₂ DCN | <u>NH₂D</u> |
| <u>NHD₂</u> | <u>ND₃</u> | <u>CHD₂CCH</u> |
| <u>CH₃CCD</u> | C ₂ D | <u>C₄D</u> |
| HDS | <u>D₂S</u> | |

Deuterated molecules that have been detected in interstellar clouds as of February 2005.

| Species | Observed ratio |
|--|----------------|
| NH ₂ D/NH ₃ | 0.01 |
| HDCO/H ₂ CO | 0.005-0.11 |
| DCN/HCN | 0.023 |
| DNC/HNC | 0.015 |
| C ₂ D/C ₂ H | 0.01 |
| DCO ⁺ /HCO ⁺ | 0.02 |
| N ₂ D ⁺ /N ₂ H ⁺ | 0.08 |
| DC ₃ N/HC ₃ N | 0.03-0.1 |
| HDCS/H ₂ CS | 0.02 |

Gas phase reactions,

ion-molecule reactions,
recombination

Grain surface reactions

Physics of condensation and evaporation from grain surface

Deuterated gas phase molecules in space

| | | | |
|------------------------|---------------------------|-------------------------------------|--------------------------|
| HD * # | HDCO | H₂D⁺ * | D₂CO |
| HDO * | HDCS | DCO⁺ * | ND₂H |
| DCN * | DC₃N | N₂D⁺ | CHD₂OH |
| DNC | CH₂DOH | | D₂S |
| HDS | CH₃OD | | ND₃ |
| C₂D | DC₅N | | CD₃OH |
| C₄D | CH₂DCCH | | D₂CS |
| C₃HD | CH₂DCN | | |
| NH₂D | CH₃D | | |

- Planets
- Comets
- CS disks
- ISM
- Extragalactic #

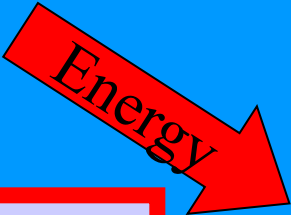
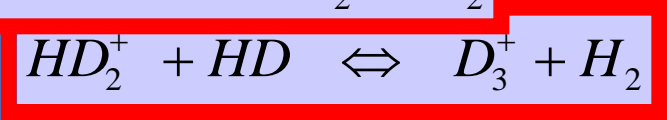
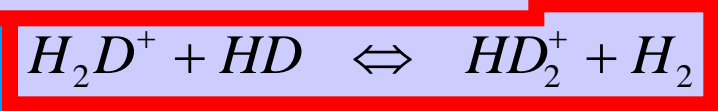
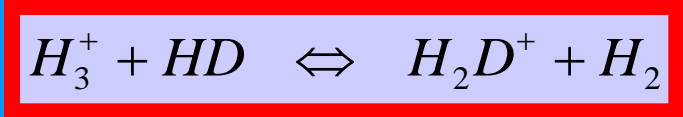
Cosmic D/H ≈ 10⁻⁵

XD/XH ≈ 10⁻¹-10⁻³

XD₂ / XH₂ ≈ 10⁻²

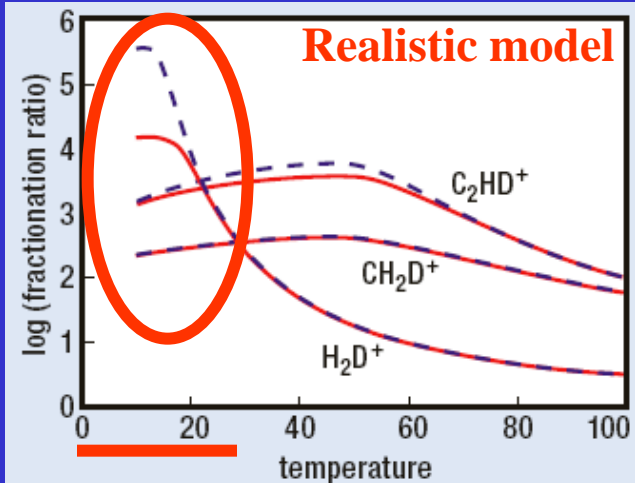
XD₃ / XH₃ ≈ 10⁻³

HD

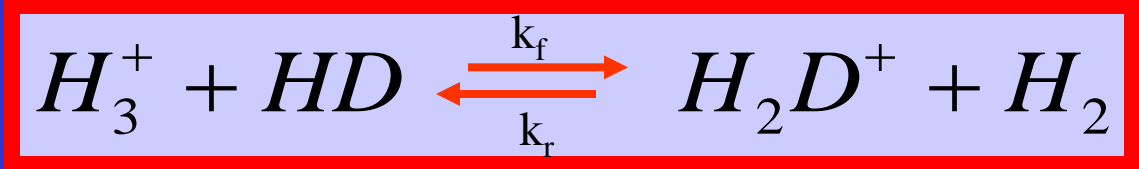


Small differences in zero point energies
for deuterated molecules

$\Delta H / k = -232 \text{ K}$



3: The enhancement in the fractionation of primary ions relative to the HD/H₂ ratio as a function of temperature in interstellar clouds

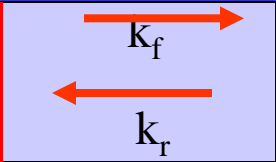


$\frac{k_r}{k_f} \sim \exp(\Delta H / kT) \sim \exp(-232 / T)$

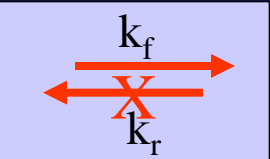
In equilibrium

$$\frac{H_3^+}{H_2D^+} = \frac{H_2}{HD} \frac{k_r}{k_f}$$

$@ 300 \text{ K} \quad \frac{k_r}{k_f} \sim \exp(-1) \sim 0.4$

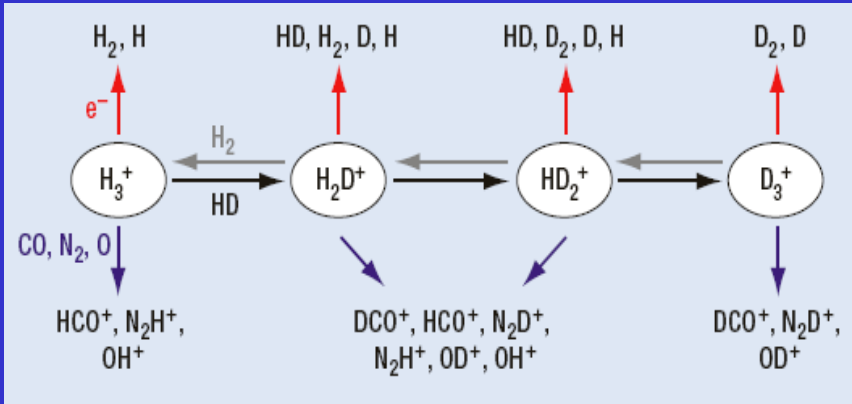
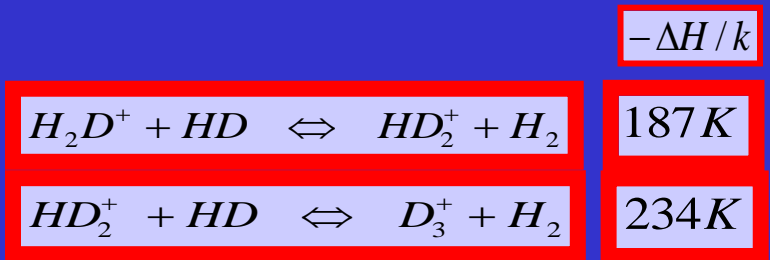


$@ 10 \text{ K} \quad \frac{k_r}{k_f} \sim \exp(-23) \sim 10^{-10}$



$@ 10 \text{ K} \quad \frac{H_3^+}{H_2D^+} = \frac{H_2}{HD} \frac{k_r}{k_f} \sim 10^5 \cdot 10^{-10} = 10^{-5}$

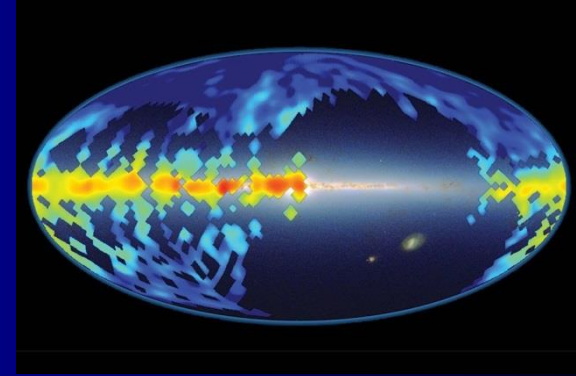
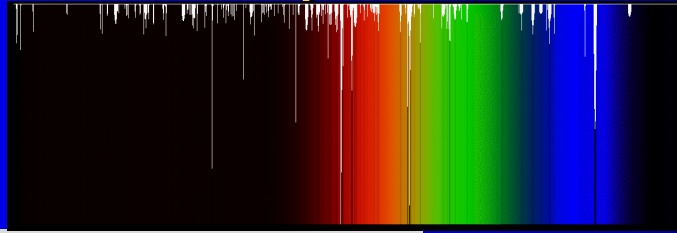
ONLY PARTLY !!!!???



Molecules in interstellar space

DIBs - diffuse bands

1919-1922



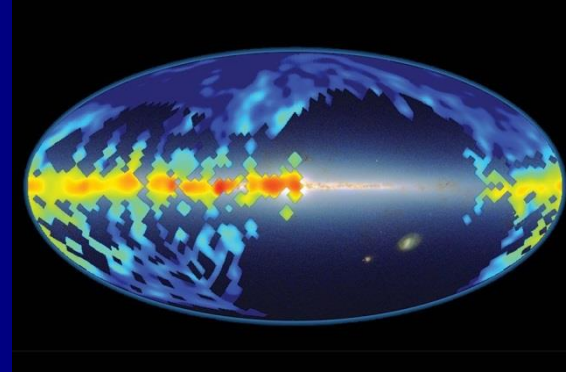
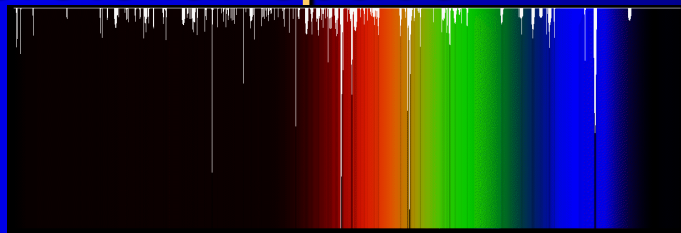
1919-1922 Heger discovers the DIBs

Nearly 100 years ago Mary Lea Heger discovered diffuse bands in the spectra of stars due to some sort of material maybe molecules in the space between stars and Earth. A map of the data from the Sloan Digital Sky Survey, by a team from Johns Hopkins produced this map. Red indicates areas with the most abundant DIB molecules, blue the least.

Molecules in interstellar space

DIBs - diffuse bands

1919-1922



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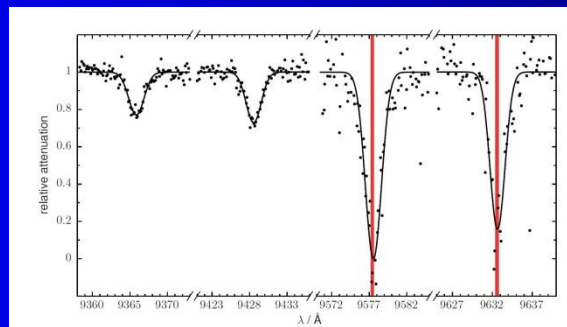
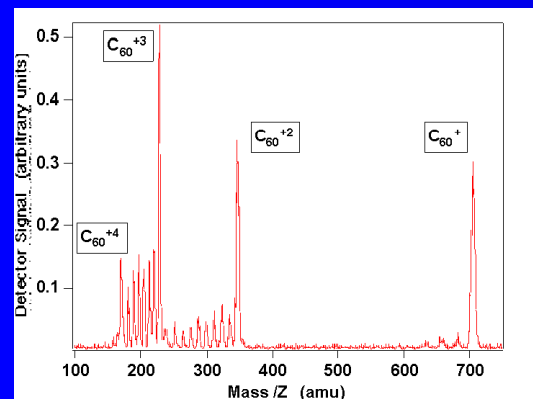
LETTER

2015

doi:10.1038/nature14566

Laboratory confirmation of C_{60}^+ as the carrier of two diffuse interstellar bands

E. K. Campbell¹, M. Holz¹, D. Gerlich² & J. P. Maier¹

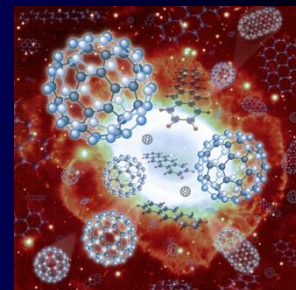
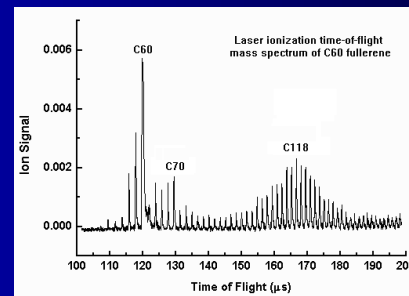
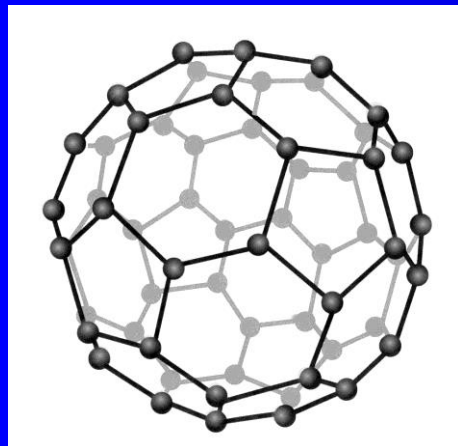


RESEARCH NEWS & VIEWS

ASTROCHEMISTRY

Fullerene solves an interstellar puzzle

Laboratory measurements confirm that a 'buckyball' ion is responsible for two near-infrared absorption features found in spectra of the interstellar medium, casting light on a century-old astrochemical mystery. [SEE LETTER P.322](#)



Observation of H_2O^+

A&A 550, A25 (2013)
DOI: 10.1051/0004-6361/201220466
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2013

Astronomy
&
Astrophysics

Excited OH^+ , H_2O^+ , and H_3O^+ in NGC 4418 and Arp 220*

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A. Poglitsch³, H. Feuchtgruber³, S. Veilleux^{5,6}, A. Contursi³, A. Sternberg⁷, S. Hailey-Dunsheath⁸, A. Verma⁹,
N. Christopher⁹, R. Davies³, R. Genzel³, and L. Tacconi³

* *Herschel* is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA.

Mission duration Planned: 3 years (2009-2012)
Final, to 2013: 4 years, 1 month, 2 days



Herschel

7,5 metru dlouhý a 4 m široký.
Vážil 3400 kg

| | |
|---------------------|--|
| Start | 14. května 2009 v 13:12:02 <u>UTC</u> |
| <u>Kosmodrom</u> | <u>kosmodrom v</u> <u>Kourou, Francouzská</u> <u>Guyana</u> ^[1] |
| <u>Nosná raketa</u> | <u>Ariane 5</u> ^[1] |
| Stav objektu | obíhala <u>Librační bod</u> <u>L2</u> ^[1] |
| ' | <u>17. června 2013</u> |
| Trvání mise | 3 až 4 roky ^[1] |

ABSTRACT

We report on *Herschel*/PACS observations of absorption lines of OH^+ , H_2O^+ and H_3O^+ in NGC 4418 and Arp 220. Excited lines of OH^+ and H_2O^+ with E_{lower} of at least 285 and ~ 200 K, respectively, are detected in both sources, indicating radiative pumping and location in the high radiation density environment of the nuclear regions. Abundance ratios $\text{OH}^+/\text{H}_2\text{O}^+$ of 1–2.5 are estimated in the nuclei of both sources. The inferred OH^+ column and abundance relative to H nuclei are $(0.5\text{--}1) \times 10^{16} \text{ cm}^{-2}$ and $\sim 2 \times 10^{-8}$, respectively. Additionally, in Arp 220, an extended low excitation component around the nuclear region is found to have $\text{OH}^+/\text{H}_2\text{O}^+ \sim 5\text{--}10$. H_3O^+ is detected in both sources with $N(\text{H}_3\text{O}^+) \sim (0.5\text{--}2) \times 10^{16} \text{ cm}^{-2}$, and in Arp 220 the pure inversion, metastable lines indicate a high rotational temperature of ~ 500 K, indicative of formation pumping and/or hot gas. Simple chemical models favor an ionization sequence dominated by $\text{H}^+ \rightarrow \text{O}^+ \rightarrow \text{OH}^+ \rightarrow \text{H}_2\text{O}^+ \rightarrow \text{H}_3\text{O}^+$, and we also argue that the H^+ production is most likely dominated by X-ray/cosmic ray ionization. The full set of observations and models leads us to propose that the molecular ions arise in a relatively low density ($\gtrsim 10^4 \text{ cm}^{-3}$) interclump medium, in which case the ionization rate per H nucleus (including secondary ionizations) is $\zeta > 10^{-13} \text{ s}^{-1}$, a lower limit that is several $\times 10^2$ times the highest current rate estimates for Galactic regions. In Arp 220, our lower limit for ζ is compatible with estimates for the cosmic ray energy density inferred previously from the supernova rate and synchrotron radio emission, and also with the expected ionization rate produced by X-rays. In NGC 4418, we argue that X-ray ionization due to an active galactic nucleus is responsible for the molecular ion production.

Modeling observations of the interstellar medium (ISM)

David Neufeld
Johns Hopkins University

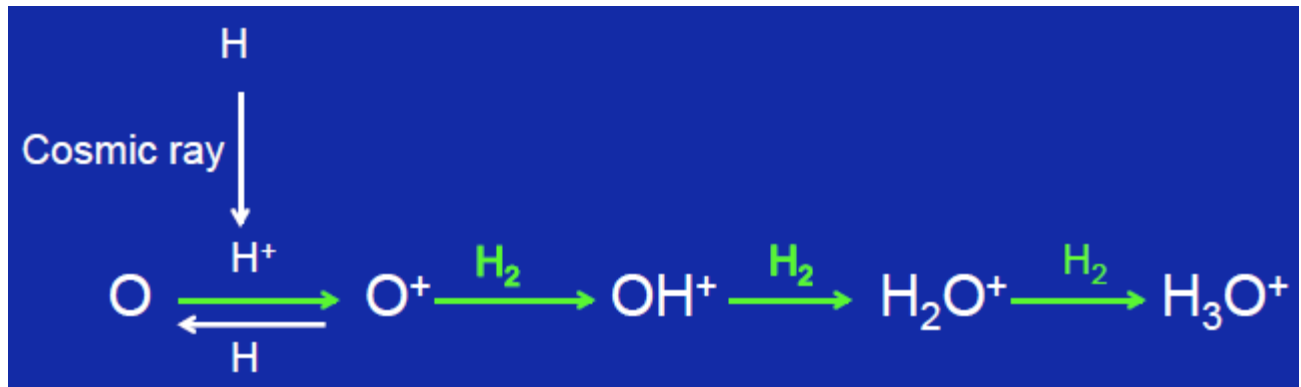
Measuring the cosmic-ray ionization rate with OH^+ and H_2O^+

Unlike C^+ and S^+ , O^+ does react with H_2 at low temperature. But O is not ionized by UV radiation longward of the Lyman limit, so OH^+ and H_2O^+ formation must be initiated by cosmic ray ionization

Recent discoveries of molecules in the diffuse ISM

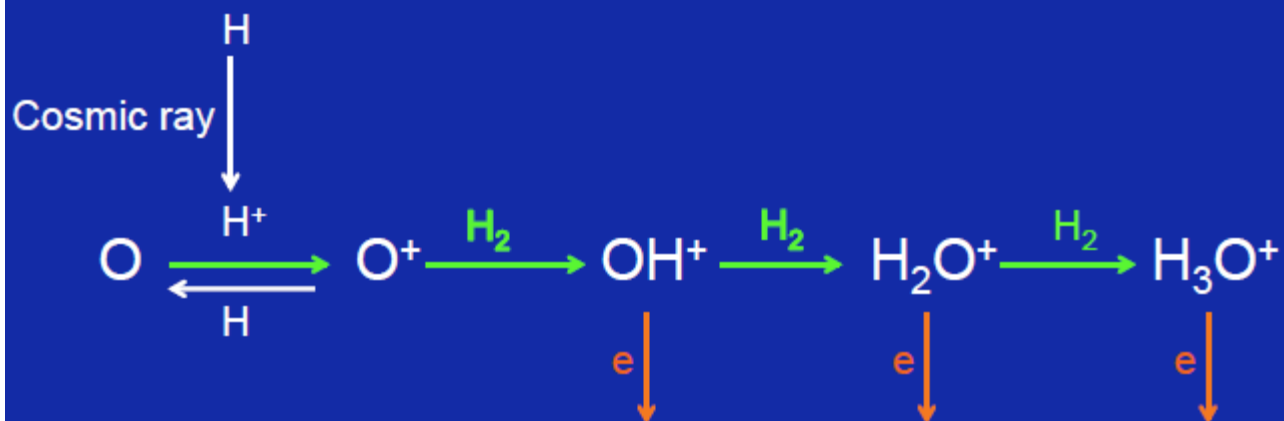
| | | |
|-------------------------|----------------------|----------|
| OH^+ | Wyrowski et al. 2010 | APEX |
| SH^+ | Menten et al. 2011 | APEX |
| H_2O^+ | Gerin et al. 2010 | Herschel |
| HF | Neufeld et al. 2010 | Herschel |
| HCl^+ | de Luca et al. 2013 | Herschel |
| H_2Cl^+ | Lis et al. 2010 | Herschel |
| SH | Neufeld et al. 2012 | SOFIA |
| ArH^+ | Schilke et al. 2014 | Herschel |

All hydrides with high frequency rotational transitions that are unobservable from the ground or observable only from superb submillimeter sites



Determining the molecular fraction in the diffuse ISM

The $\text{OH}^+/\text{H}_2\text{O}^+$ ratio reflects a competition between reaction of OH^+ with H_2 and reaction with electrons



Observed $\text{OH}^+/\text{H}_2\text{O}^+$ ratios ~ 3 to 15 imply that only 2 – 10 % of the H is typically in H_2

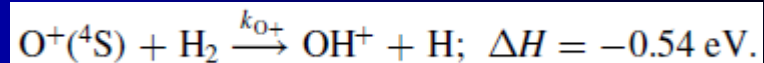


OH⁺ Formation in the Low-temperature O⁺(⁴S) + H₂ Reaction

Artem Kovalenko , Thuy Dung Tran , Serhiy Rednyk , Štěpán Roučka , Petr Dohnal , Radek Plašil ,
Dieter Gerlich , and Juraj Glosík

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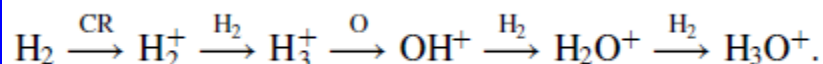
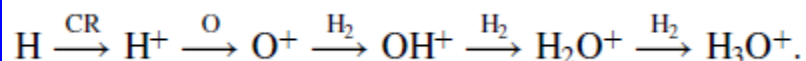
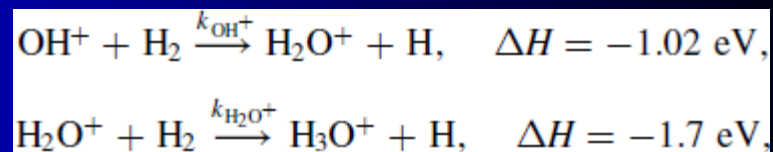


Formation of H₂O⁺ and H₃O⁺ Cations in Reactions of OH⁺ and H₂O⁺ with H₂: Experimental Studies of the Reaction Rate Coefficients from $T = 15$ to 300 K

Thuy Dung Tran , Serhiy Rednyk , Artem Kovalenko , Štěpán Roučka , Petr Dohnal , Radek Plašil ,
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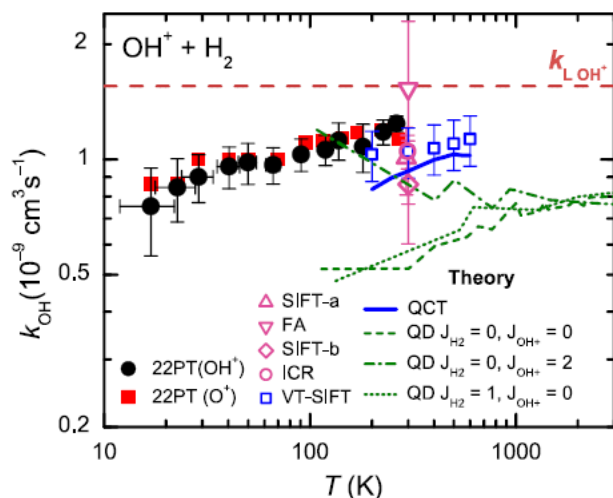


Figure 4. Temperature dependence of the rate coefficient k_{OH^+} of the reaction of OH^+ with normal hydrogen. The averaged data obtained in experiments with OH^+ and O^+ ions injected into the trap are indicated by full circles and squares, respectively. The systematic error due to pressure measurement is 20%. The dashed horizontal line ($k_{\text{L,OH}^+}$) indicates the Langevin collisional rate coefficient. The previous results at 300 K are FA (Fehsenfeld et al. 1967), ICR (Kim et al. 1975), SIFT-a (Jones et al. 1981), and SIFT-b (Shul et al. 1988). The temperature dependencies of k_{OH^+} calculated (QCT) and measured (VT-SIFT) by Martinez et al. (2015) are indicated by the full line and open squares, respectively. The dashed, dotted, and dash-dotted lines represent the phenomenological rate coefficients ($\nu\sigma$) derived from the theoretical QD cross-sections (Song et al. 2016a) corresponding to different rotational states of reactants as indicated in the legend.

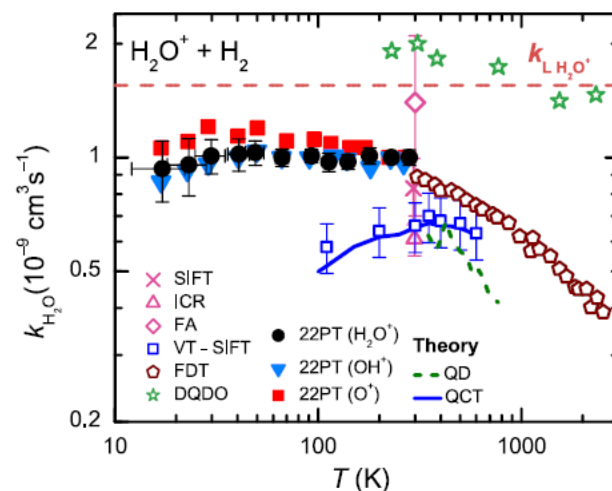


Figure 5. Temperature dependence of the reaction rate coefficient $k_{\text{H}_2\text{O}^+}$ of the reaction of H_2O^+ with normal hydrogen. The averaged data obtained in experiments with H_2O^+ , OH^+ , and O^+ ions injected into the trap are indicated by full circles, triangles, and squares, respectively. The systematic error due to pressure determination is 20%. The dashed horizontal line ($k_{\text{L,H}_2\text{O}^+}$) indicates the Langevin collisional rate coefficient. The previous results at 300 K are FA (Fehsenfeld et al. 1967), ICR (Kim et al. 1975), FDT (Dotan et al. 1980), and SIFT (Jones et al. 1981). The values measured (VT-SIFT) and calculated (QCT) by Ard et al. (2014) are indicated by the open squares and by the full line (QCT), respectively. The dashed line and stars represent the phenomenological rate coefficients ($\nu\sigma$) derived from the theoretical QD, and experimental DQDO cross-sections (Song et al. 2016b). The uncertainty of the DQDO results is 50%.

Interstellar Hydrides

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and Javier R. Goicoechea⁵

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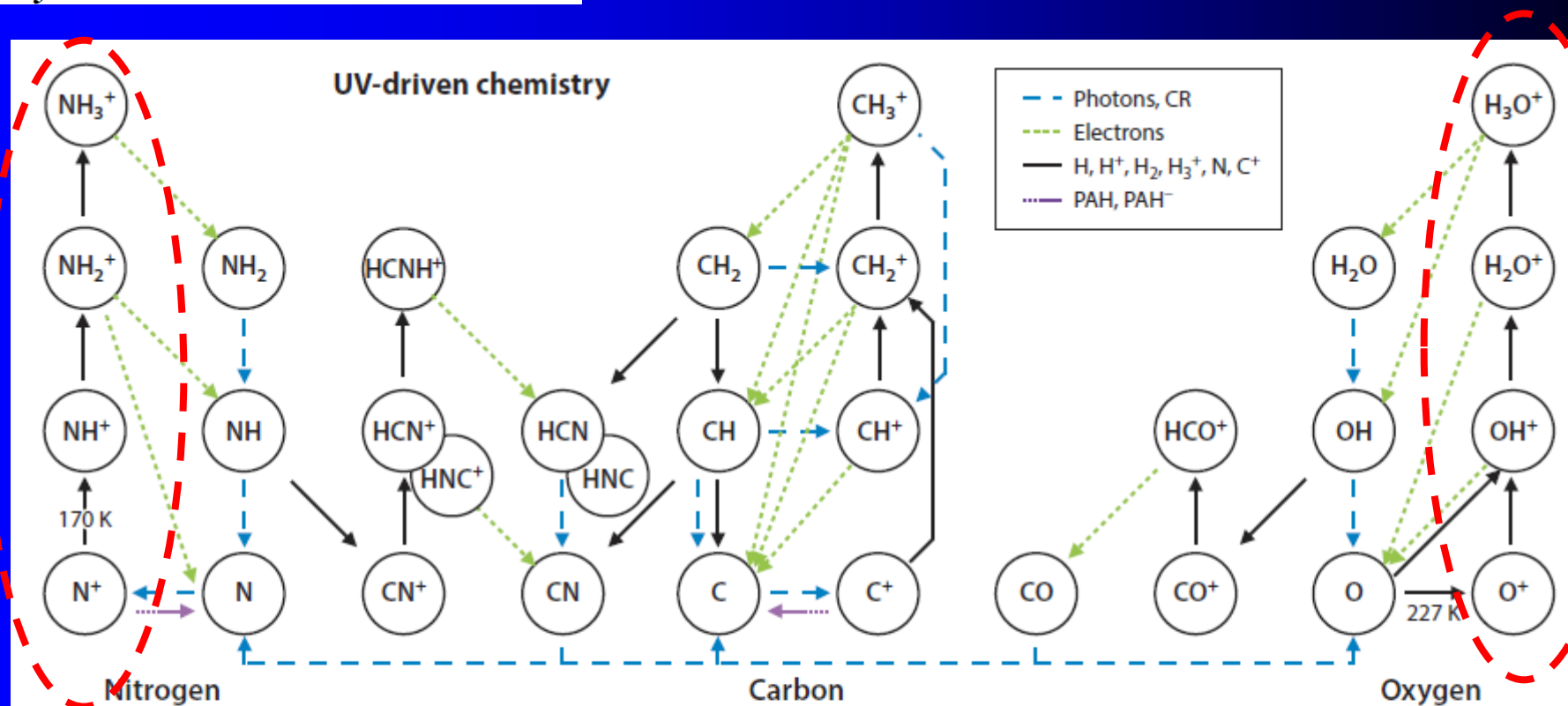


Figure 3

Illustration of the chemical network initiating the carbon, oxygen, and nitrogen chemistry in diffuse cloud conditions ($n_{\text{H}} = 50 \text{ cm}^{-3}$, $A_V = 0.4 \text{ mag}$, $\chi = 1$). The black arrows show the reactions with H, H⁺, H₂, H₃⁺, C⁺, and N, with values of the endothermicity for the reaction between N⁺ and H₂ and for the charge exchange reaction between O and H⁺. Note that CH₂⁺ is formed in the slow radiative association reaction between C⁺ and H₂. The dashed blue arrows indicate the reactions induced by FUV photons or cosmic rays (CR). Dissociative recombination reactions with electrons are shown with green dotted arrows. Purple arrows show the neutralization reactions on dust grains and polycyclic aromatic hydrocarbons (PAHs). Adapted from Godard et al. (2014) with permission.

Koniec skutočnej prednášky 1A 06. 10. 2022 ?