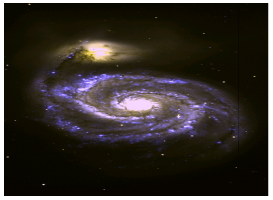
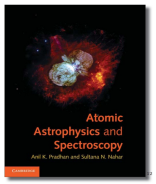
THE OHIO STATE UNIVERSITY

"SEARCHING FOR CLUE OF LIFE IN EXOPLANETS"

SULTANA N. NAHAR

Astronomy, The Ohio State University, Columbus, Ohio

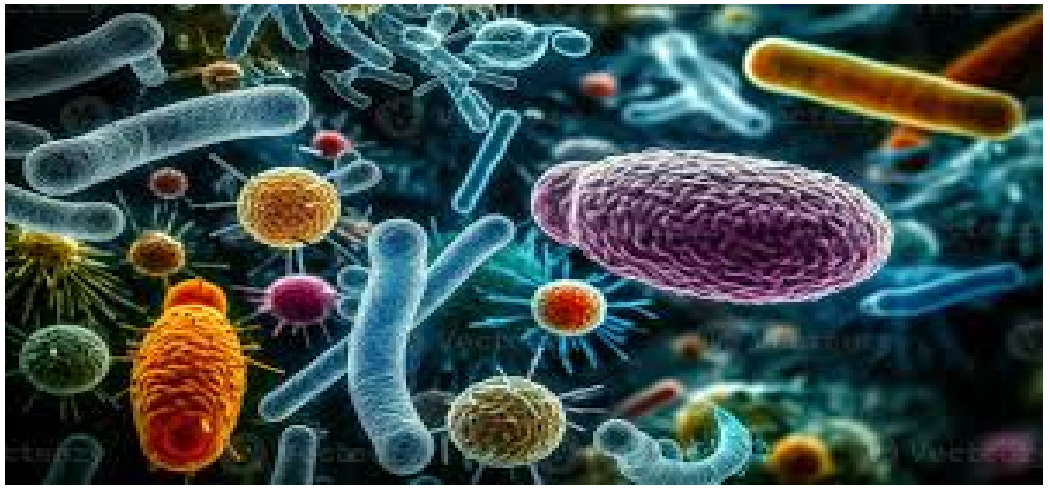
Email: nahar.1@osu.edu

http://www.astronomy.ohio-state.edu/nahar.1/

Delaware, Ohio, January 18, 2025

SUPPORT: (DOE), , Supercomputer Center

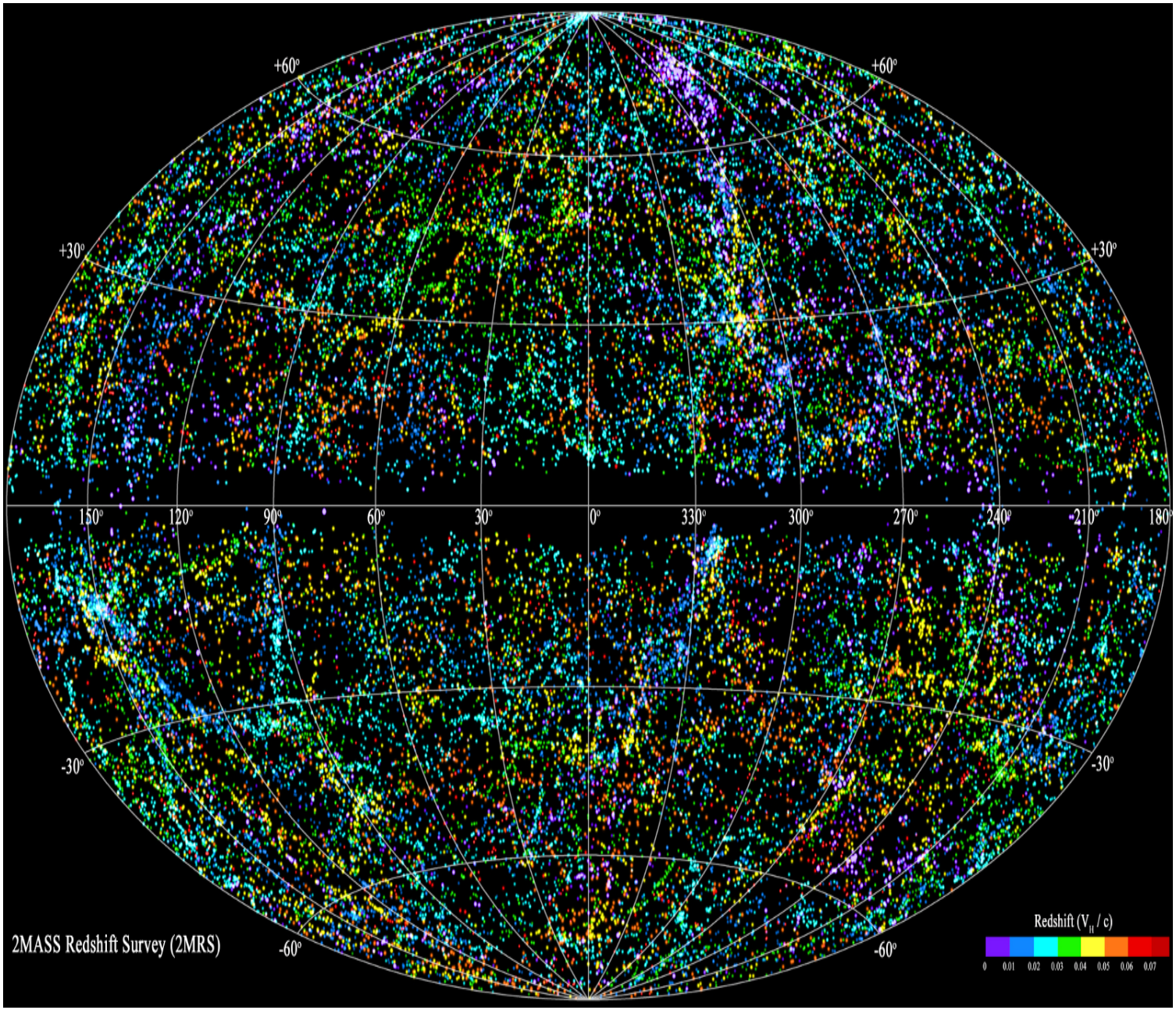
EARTH HAS INTELLIGENT LIFE FORMS ALL AROUND



- Our earth is filled with intelligence beings - from highly creative human beings to animals, microbes. Are we unique to the universe!

WE MAY NOT BE ALONE IN THE UNIVERSE!

(By 2MASS mapping over 3 decades)



- The 2-Micron All-Sky Survey includes 43,000 galaxies within 380 million Ly
- There are 2 trillion galaxies in the universe

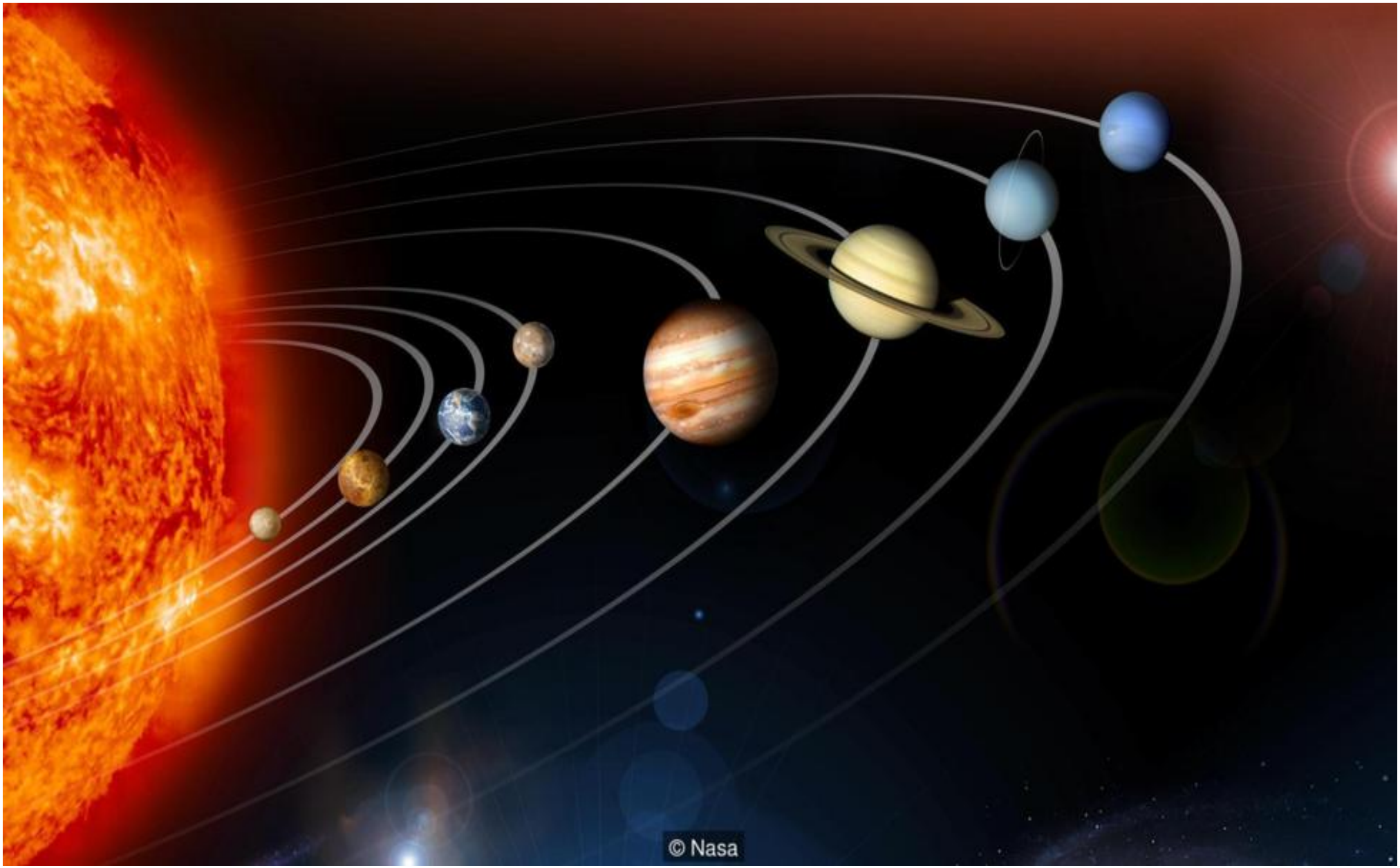
ASTRONOMY: Anything beyond our earth - but important to study. Our galaxy: MILKY WAY (stable one)

- **Has 200-400 billion stars. How do we study them?**

- Analyzing the light coming from them.

Light or radiation is emitted by excited or "HOT" atoms,

The SUN, our STAR (diameter: 110 x Diameter-earth)

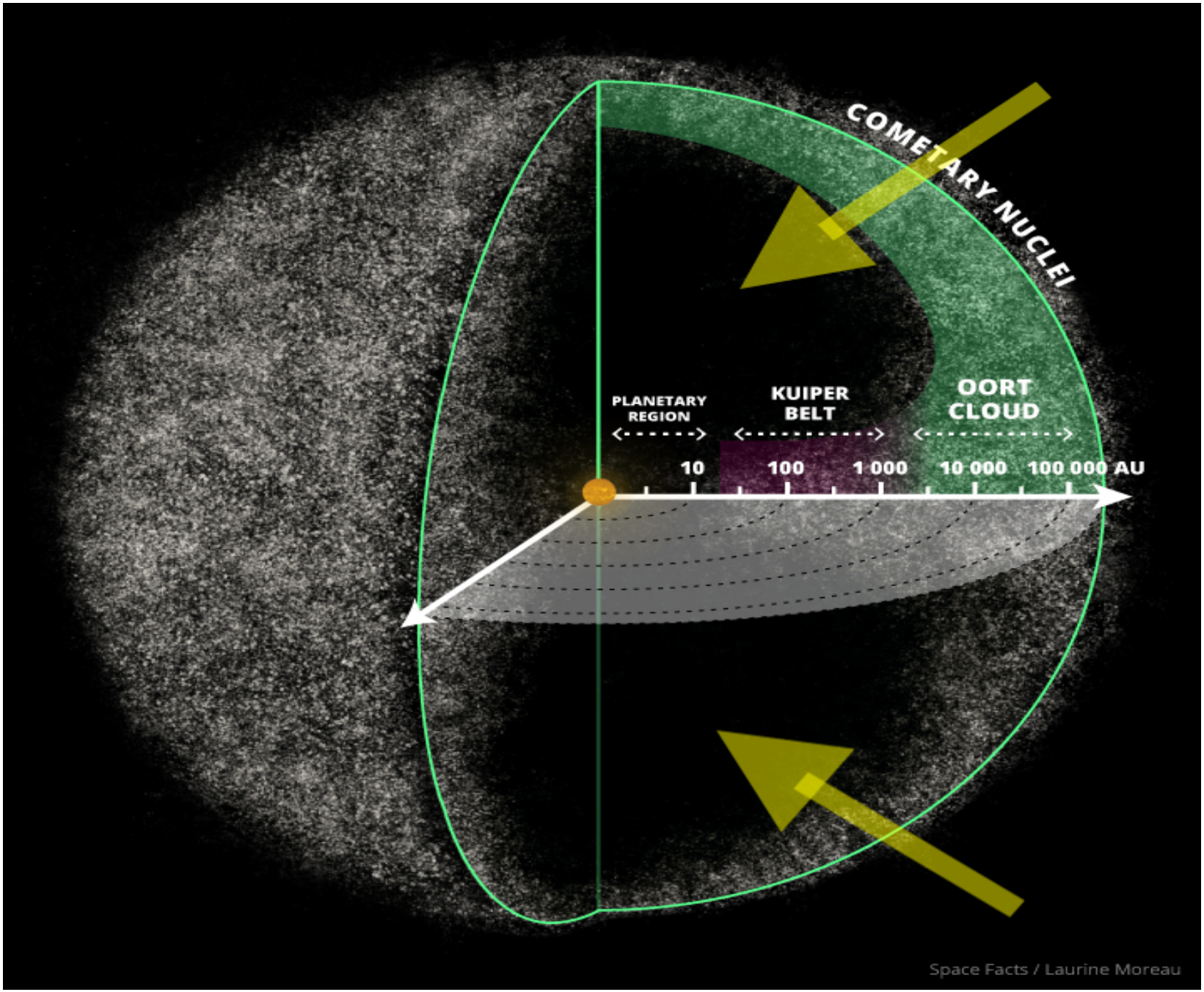


- The Sun has 8 planets (M-V-E-M terrestrial, J-S-U-N gaseous)
- It is an extremely dense and hot ball of plasma, gives out huge amount of radiation, Only small fraction of sun's radiation reaches the earth. The Sun is the source of energy for us

"The Pale Blue Dot": our Earth by Voyager I 1990 from 4 BM

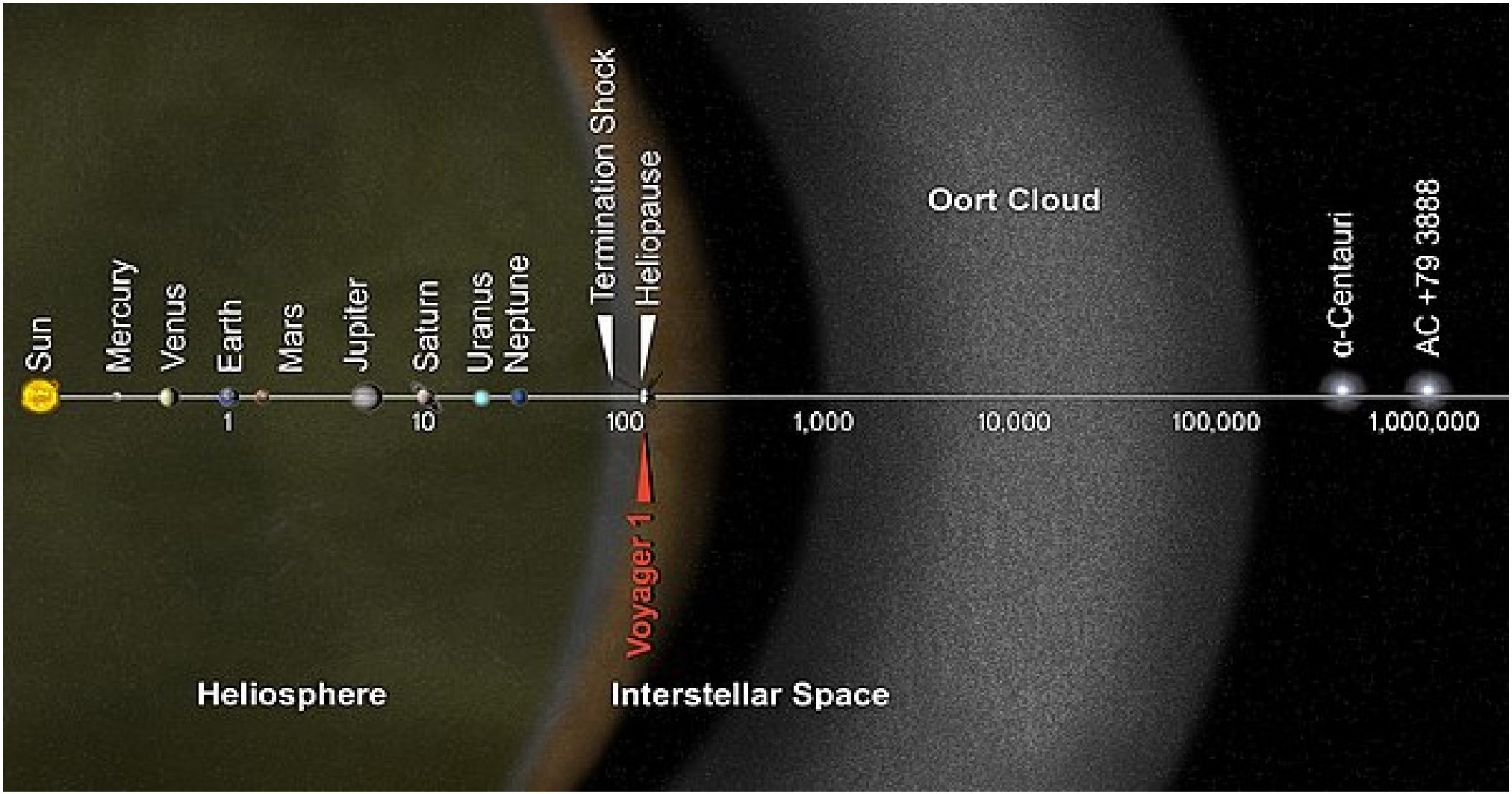
- The "Pale Blue Dot" picture of Planet Earth was acquired by Voyager 1 probe 30 years, Feb 14, 1990. This is our home.
- Occupying only a tiny dot in the vast universe, we can not be unique

SUN'S INFLUENCE: KUIPER BELT and OORT CLOUD



- Kuiper belt started beyond Neptune. It ends at Sun's region of magnetic fields, called "Heliopause" (more than 10 billion miles).

VOYAGERS AND SOLAR INFLUENCE



- The red arrow indicates the projected location, in 2025-2027, of the space probe Voyager 1, which may reach the Oort cloud about 300 years later
- Voyager 1 will not approach another star (Alpha Centurai, the closest stars after the Sun) for nearly 40,000 years

Search for Extraterrestrial Intelligence (SETI) signals 1984

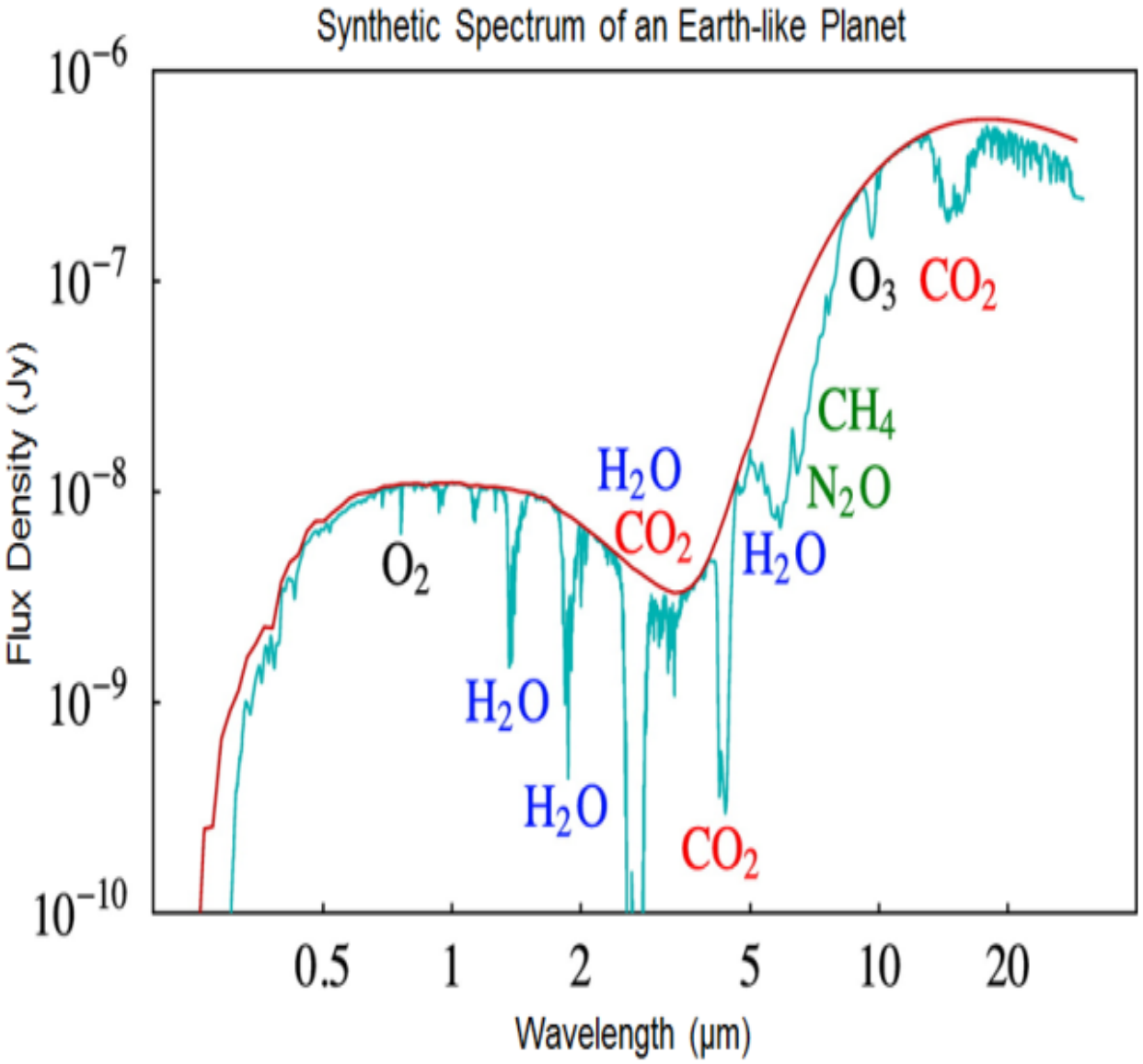
- Aim: Detect any consistent, patterned signal message from outside
- Since started in 1984, SETI (based in California) has not confirmed detection of any ETI signals except some - e.g. of SHGb02+14a in 2004 that needs analysis (exoplanets - not a topic)
- It is searching 20,000 red dwarf stars for signs of intelligent life and hopes to a confirmation by 2040.

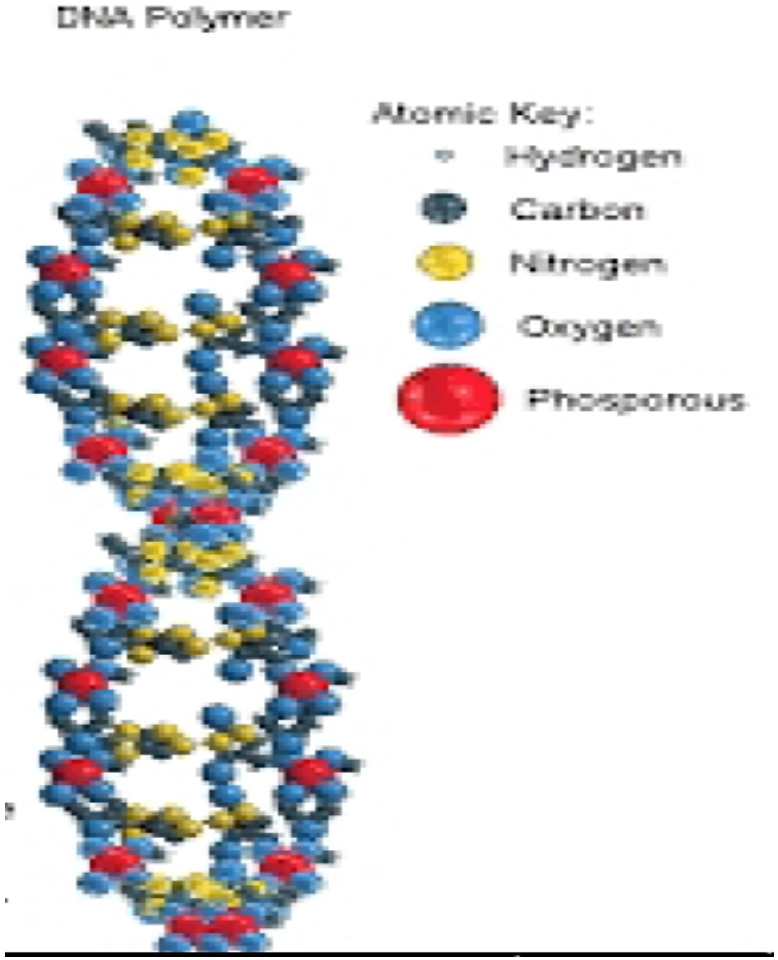
"EXTRA-TERRESTRIAL LIFE"

- We make our own judgment and imagination for the ET life
- They may be searching for us
- Distances are too great! Need warp speed (squeezing the front space and expanding the back space to move faster than light) and find worm holes (to travel in shortest path)!

SPECTROSCOPY: CLUE FOR BIO-SIGNATURE ELEMENTS

- Biosignatures: H_2O, CH_4, CO_2, CN, H_2C_6, NO_3, NH_3
- Basic element of evolution: C, N, O, K, Ca, Fe, .., P
- Phosphorus, a component of DNA, RNA, ATP, cells, teeth, bone



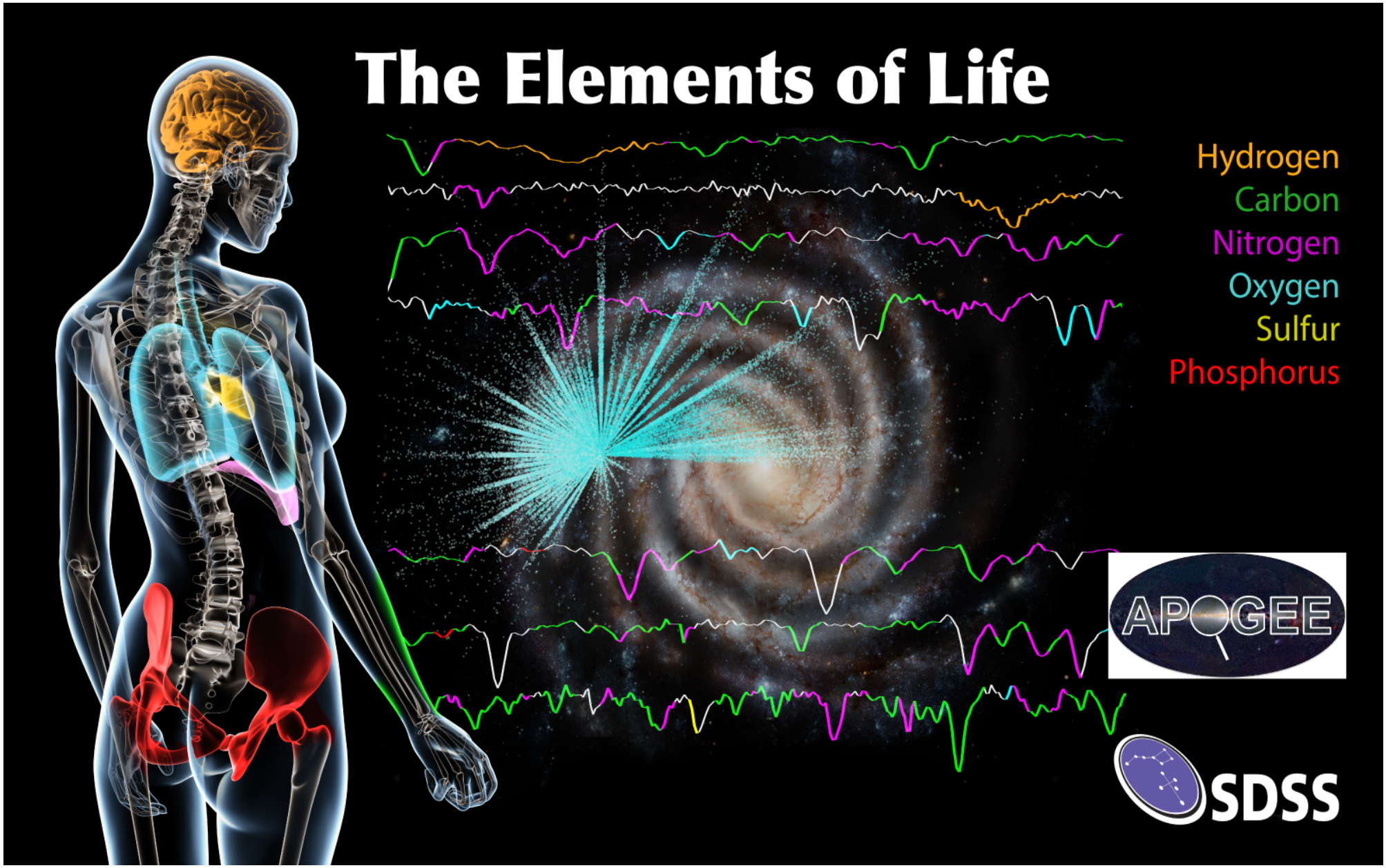


"OUR COSMIC SELVES": (NY Times, April 13, 2015)

Astronomer Prof. Carl Segan promoted: "We are made of star dusts"
- so should the aliens!

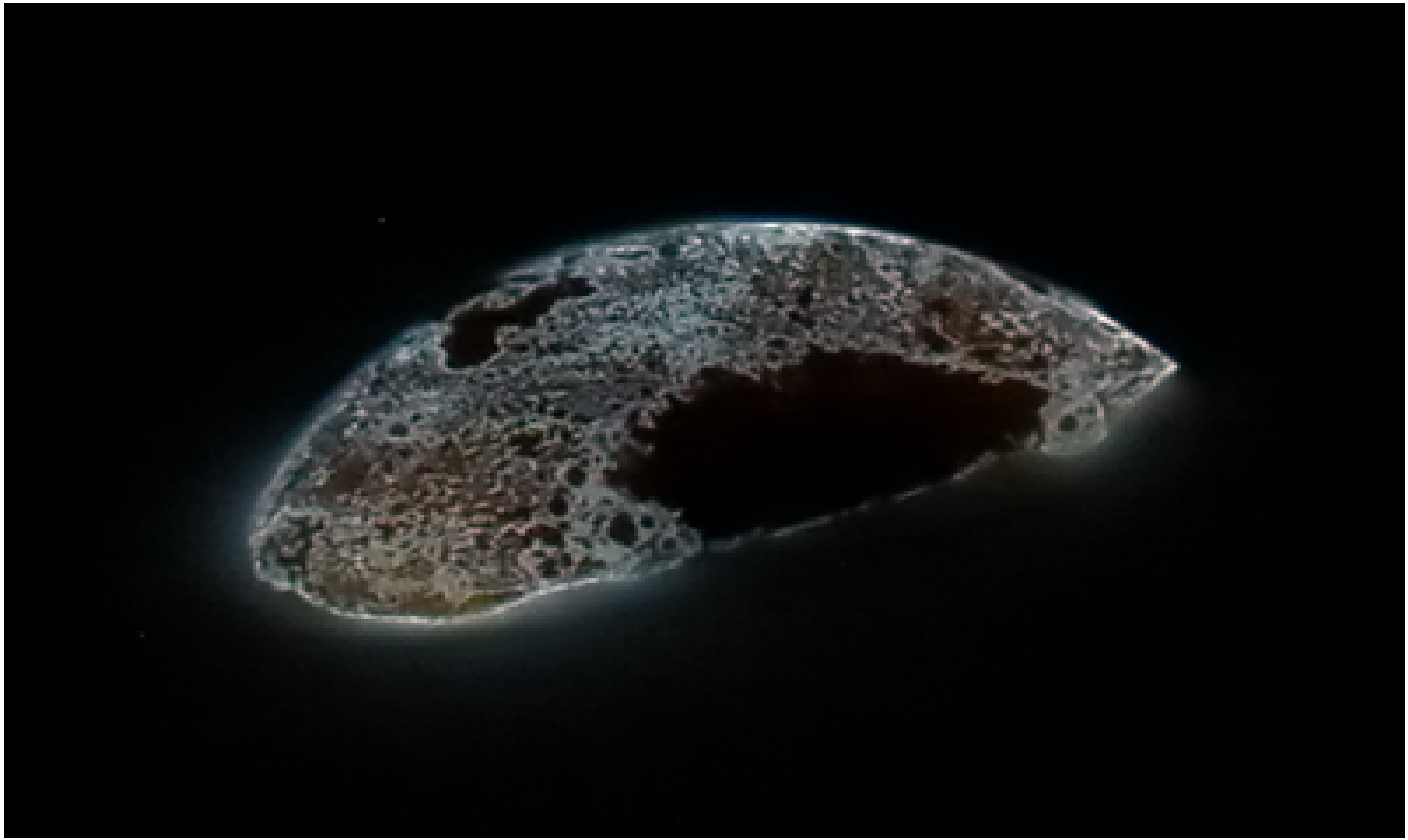
- Article: Found abundance of bio-elements in space: C, N, O, Fe, Ca

APOGEE project of SDSS: P (red)



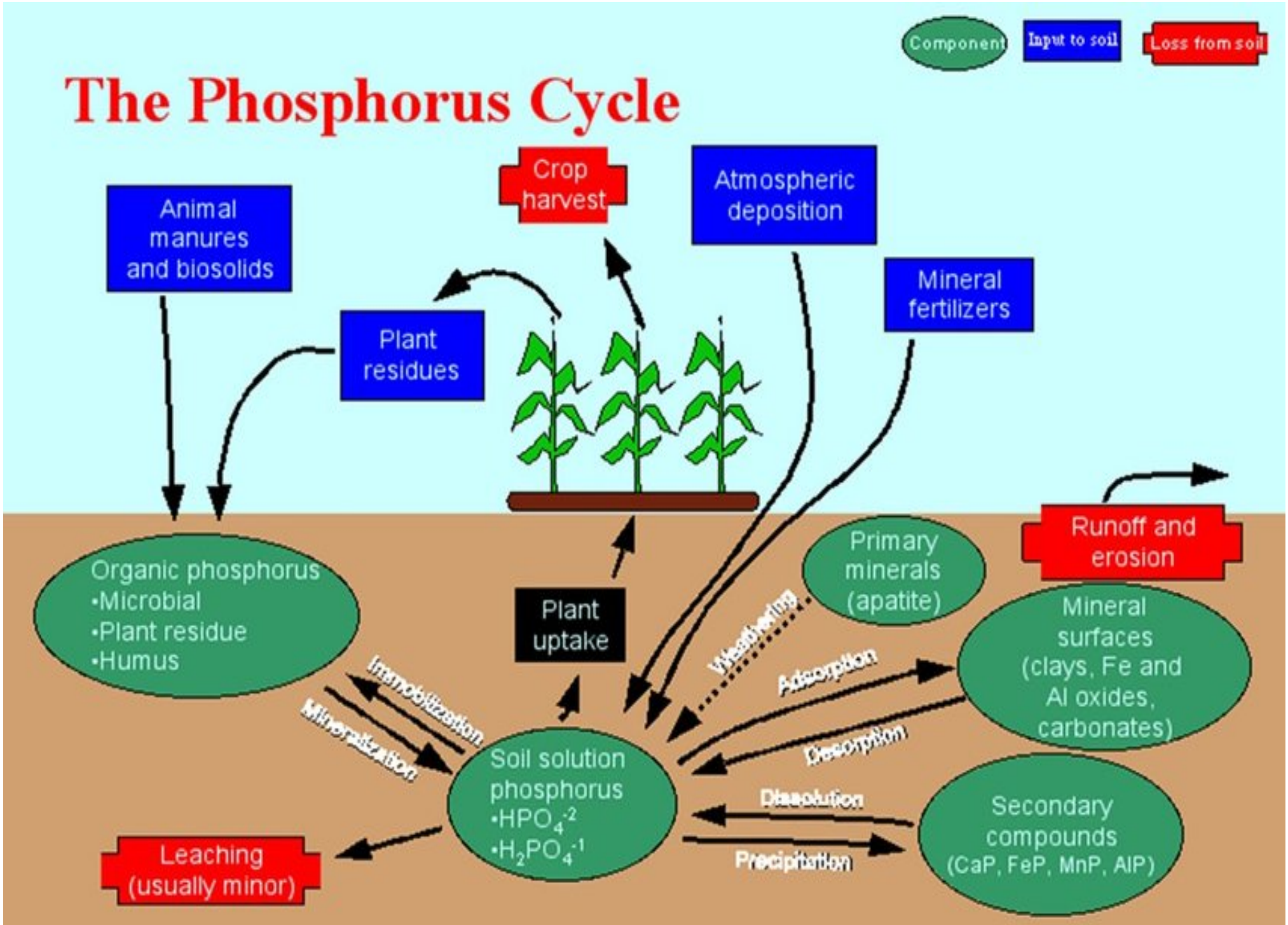
- P is abundant in the solar system but not in others.
- How do we determine the existence of elements is space - through spectroscopy

PHOSPHORUS: A HIGHLY REACTIVE ELEMENT

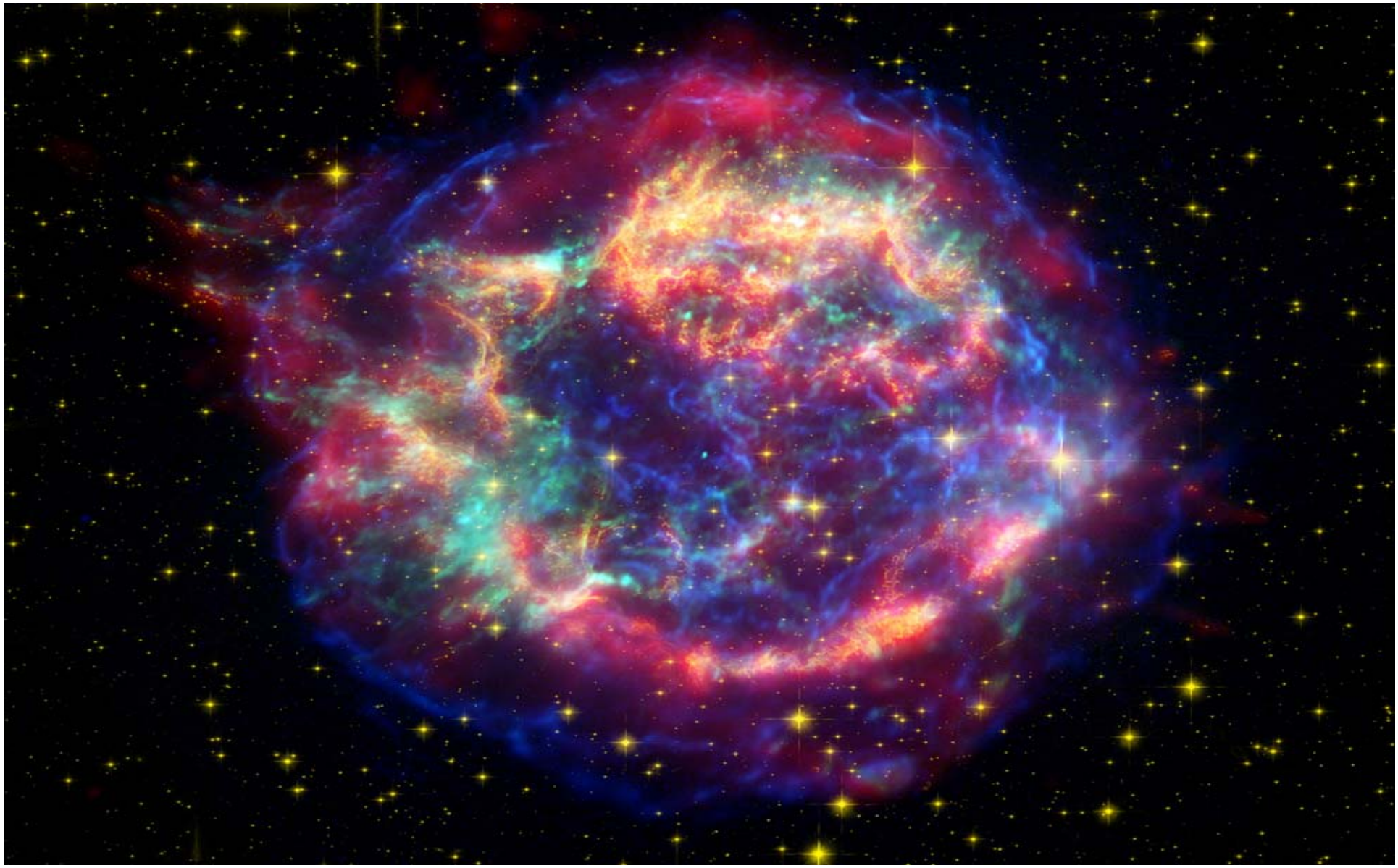


- It glows when exposed to air
- It is used extensively in industries, fertilizers, detergents, pesticides, plasticizers, etc
- The least studied element - was not seen in space

PHOSPHORUS CYCLE ON EARTH - SCARCE IN SPACE



SUPERNOVA REMNANT CASSIOPEIA A - P IS FOUND

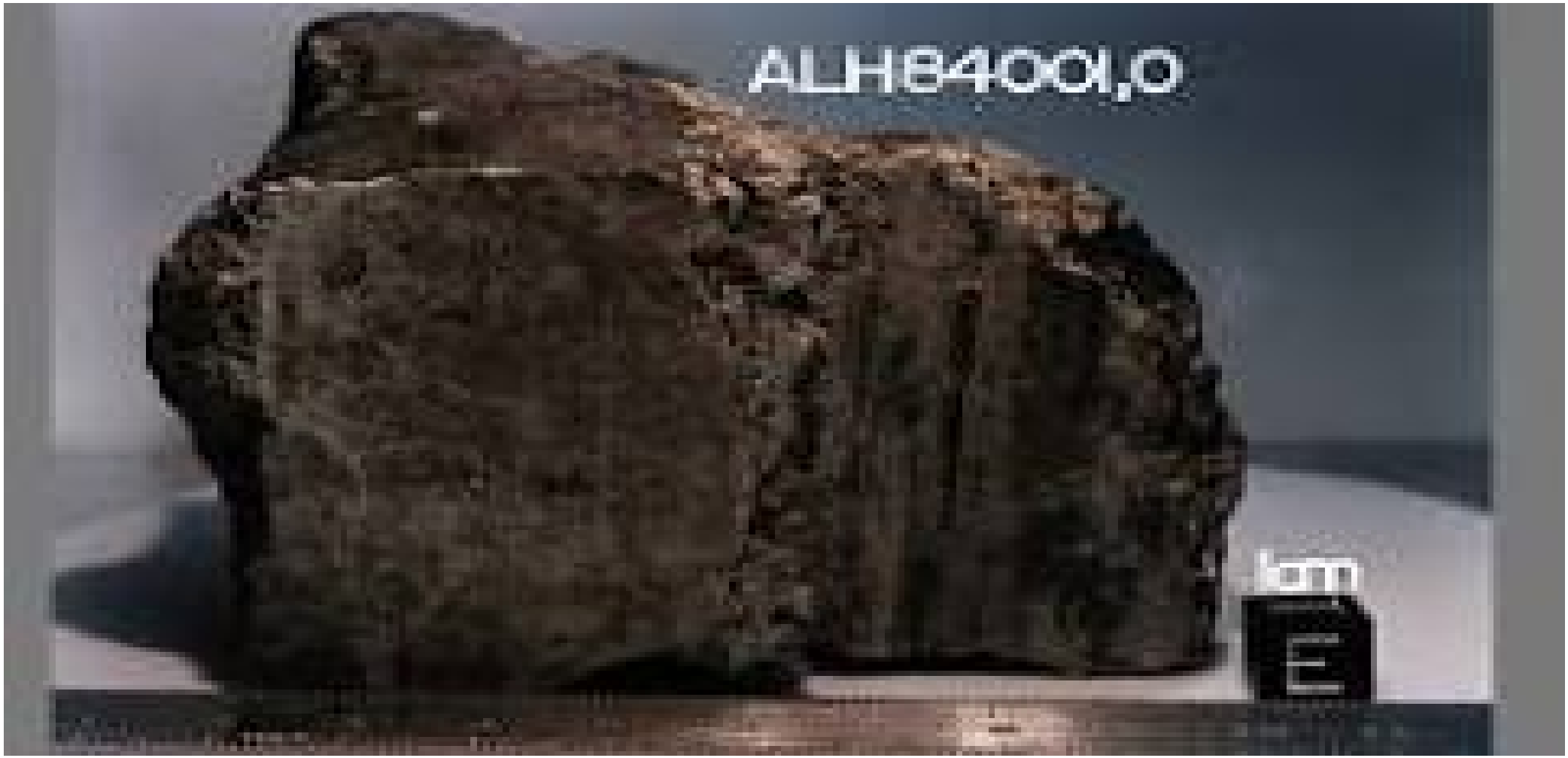


• Photometric Observation: Spitzer (Infrared - red), Hubble (Visible - yellow), Chandra (X-ray - green & blue)
• In 2013, astronomers detected phosphorus in Cassiopeia A, which confirmed that this element is produced in supernovae as a byproduct of supernova nucleosynthesis. • Heavier elements - Supernova explo-

Life on the earth - started in water. We are ∼75% water

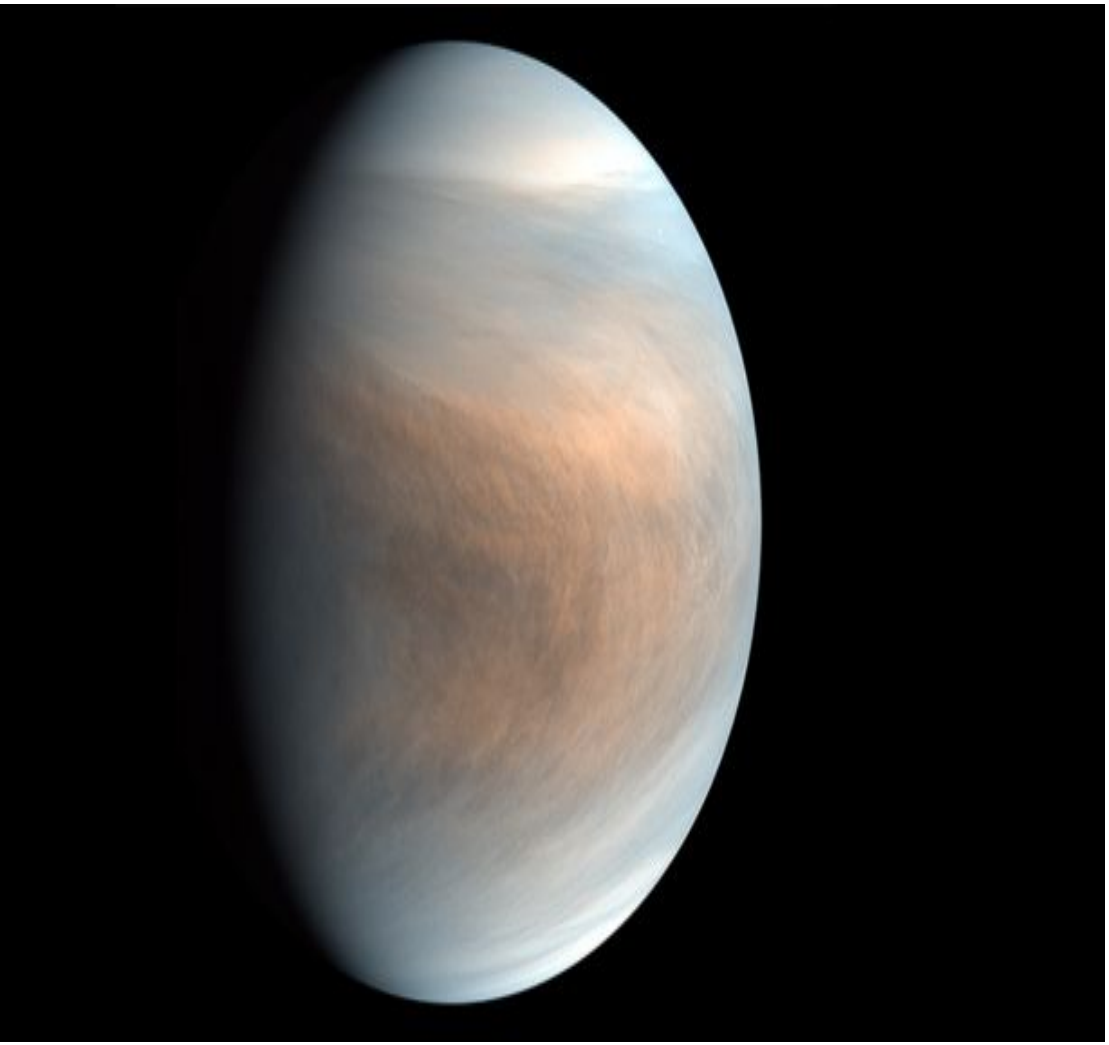
• Extraterrestrial life could be similar to Trichoplax (3 cells), one of the first animals on Earth originated in water 550 Myrs ago or highly intelligent. Trichoplax has no mouth, no stomach, no muscles, no blood, no veins, no front or back. It is nothing but a flat sheet of cells,

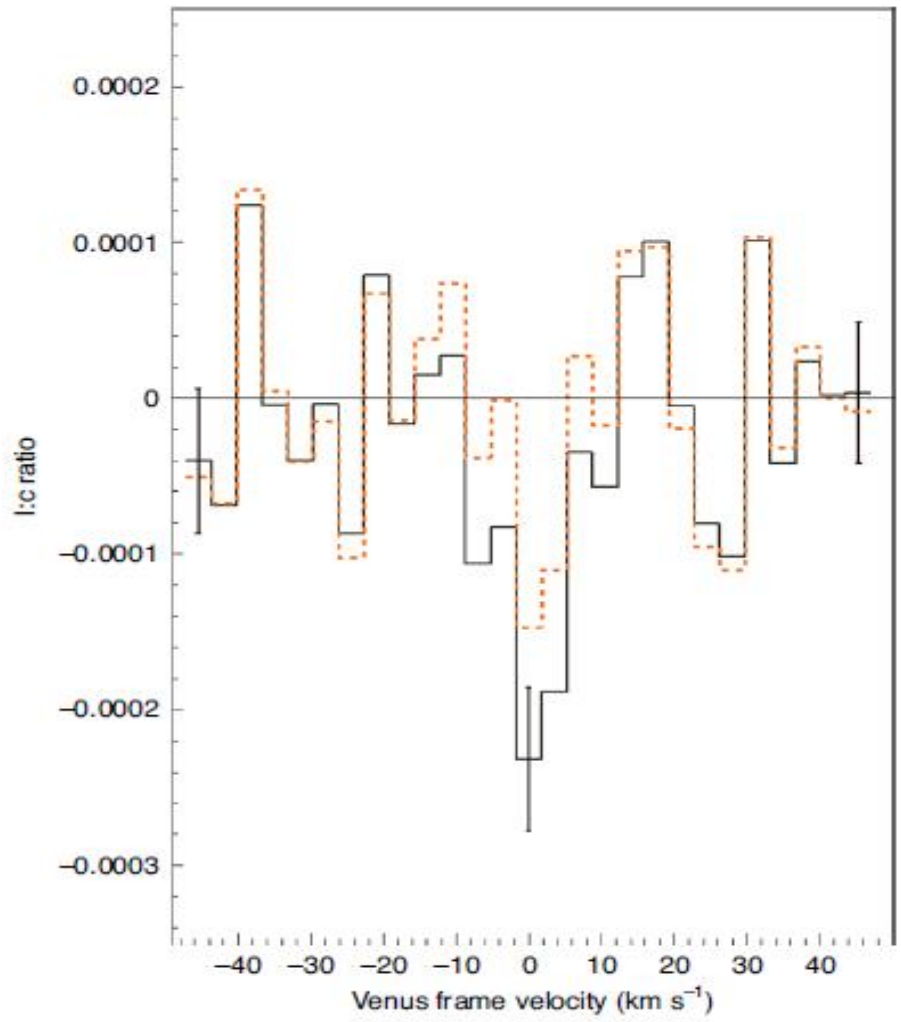
"MARTIAN METEORITE ALH840010"



- Two incidents got extensive media attention - Meteorite ALH840010 ejected from Mars and landed in Antarctica in 1984. Identified as a basalt rock, which is formed from volcanic activity on Mars
- Attention due to claims made in the 1990s that it contained evidence of carbon fossil of ancient microbial life on Mars but may also have formed from deposit of surrounding mineral - inconclusive

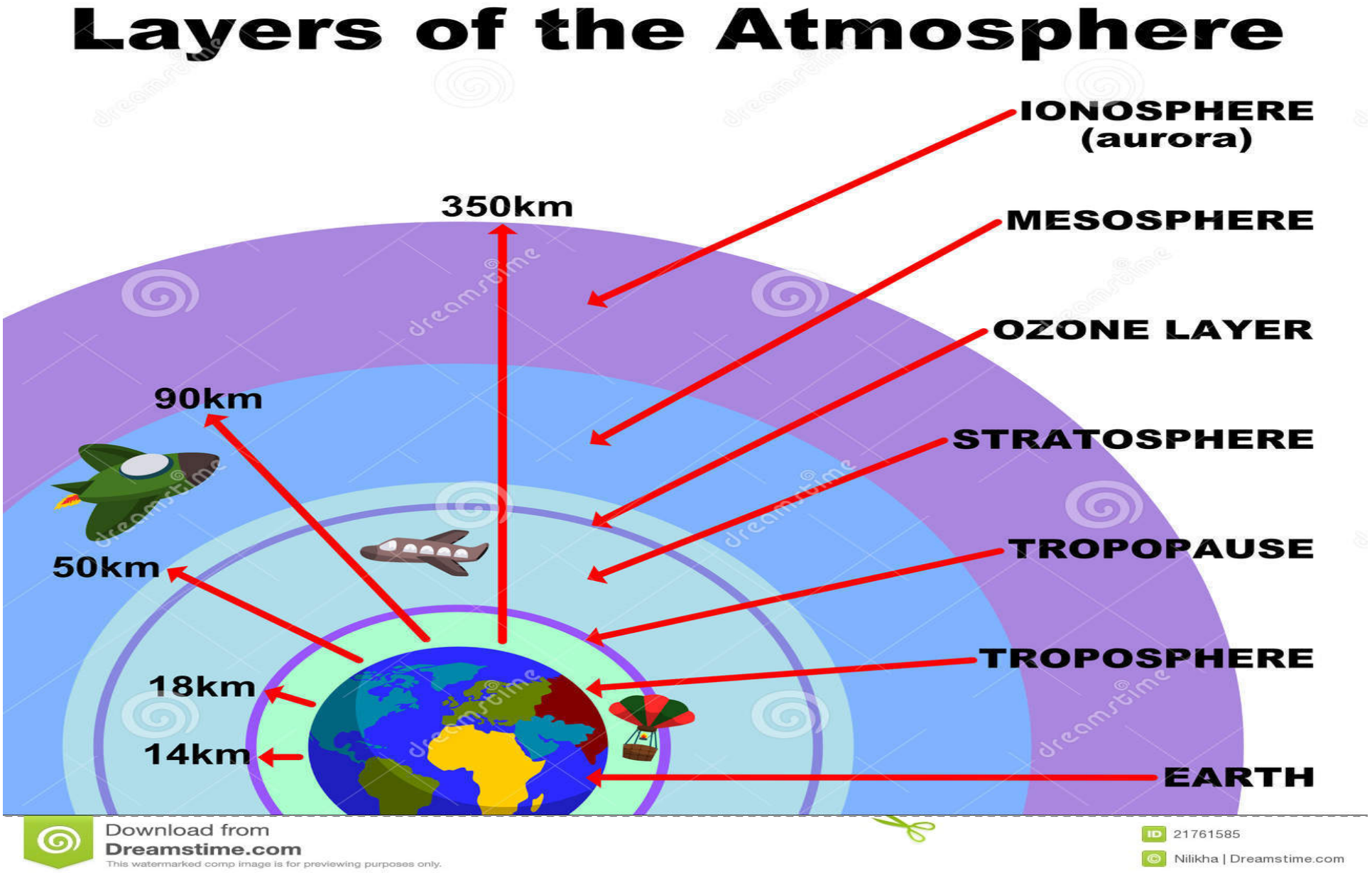
"is ALIEN life living in the clouds of Venus", Sep 2020 news





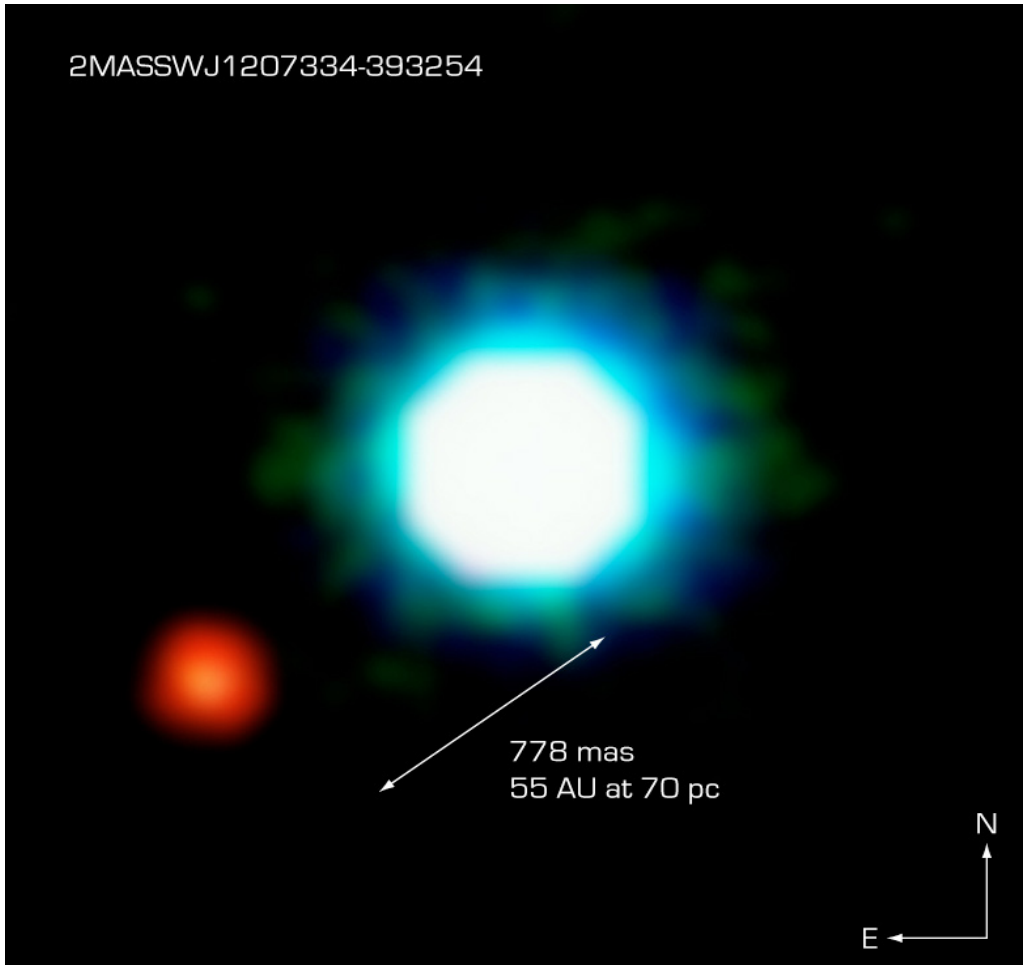
• Phosphine (PH3), created by living forms, found in Venus atmosphere (2020)!!! • L) Venus Surface; T = 900 K, Density = 90 × Earth, CO2, Sulfuric acid, hostile to living form, upper atmosphere: cooler & high velocity gas. Fig. R: Spectra of PH_3 1-0 in Venus atmosphere, 50 km up, as observed with ICNT (Greaves et al 2020)
Predicted maximum photo-chemical production of PH_3 found to be insufficient to explain observations by more than 4 orders of magnitude.

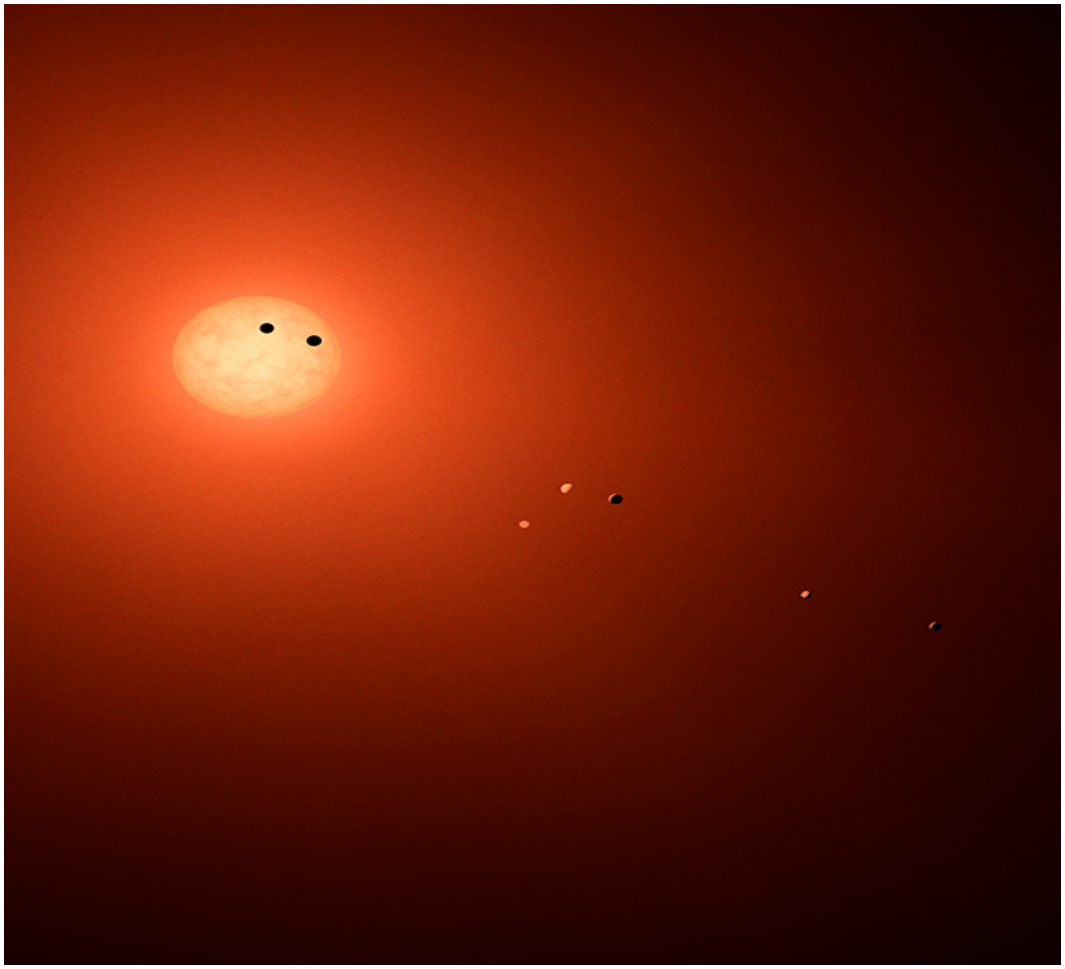
PHOSPHINE IN VENUS AND EARTH'S ATMOSPHERE



- Microbes are found 60-70 km above the earth surface.
- Grazing theory: Asteroid carried earth microbes to Venus (Siraj and Loeb 2020)

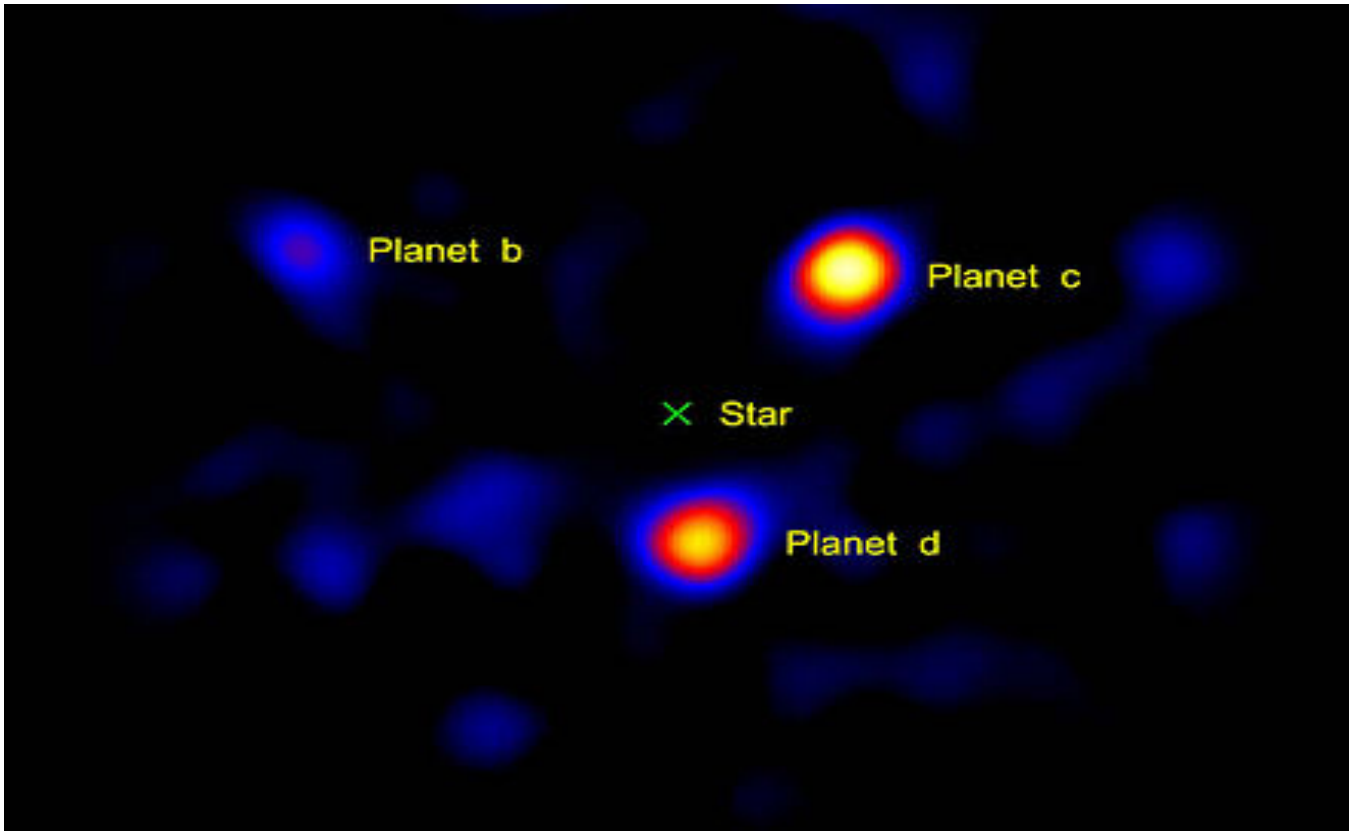
STARS WITH EXOPLANETS





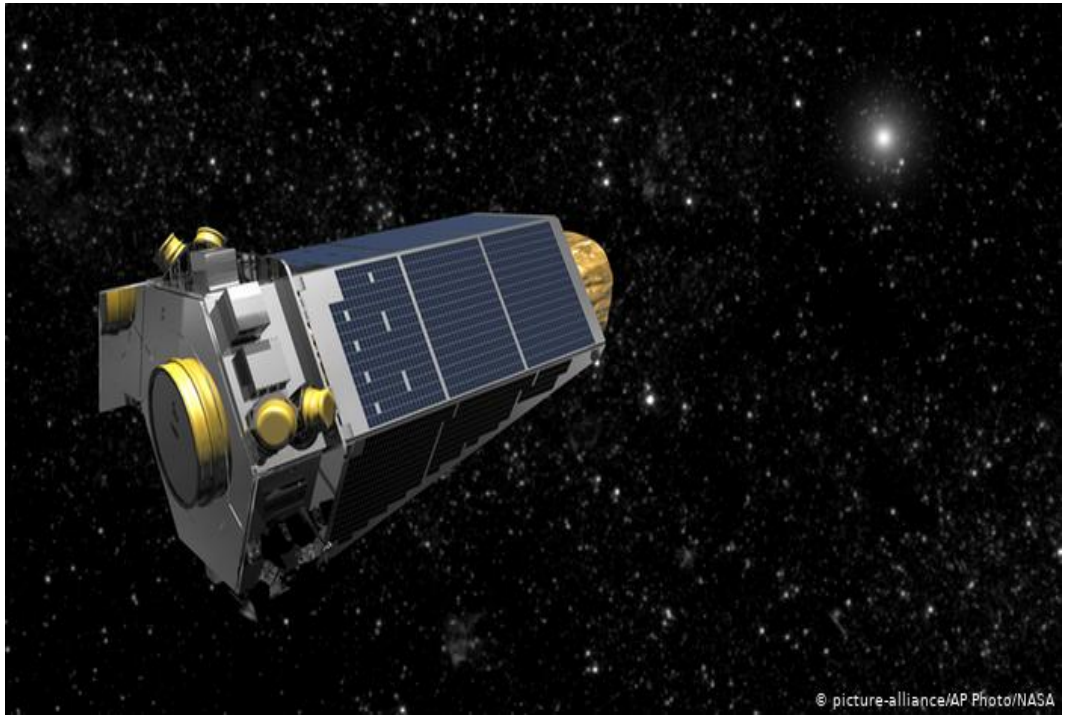
•: Discoveries of exoplanets led to a boost to investigation for ET life •: Planets are around our sun. Exo-Planets those moving around a star not the sun. • There were claims for exoplanets, but existence was confirmed in 1992. • L: The first direct picture of an exoplanet, 2M1207b-ESO2004, by ESO telescope HARPS in Chile in 2004 (radial velocity method). • R: Seven planets of TRAPPIST I (transit method) • Since 1988, now January 2025, there have been 5811 confirmed exoplanets

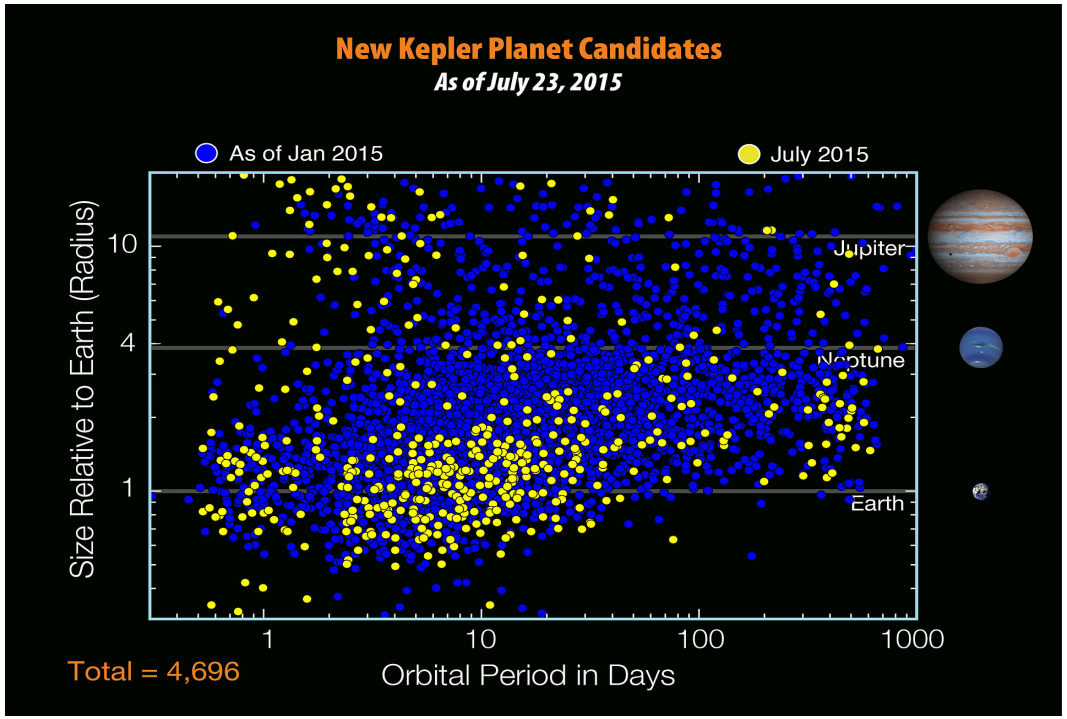
EXTRA-TERRESTRIAL (ET) LIFE AND EXOPLANETS

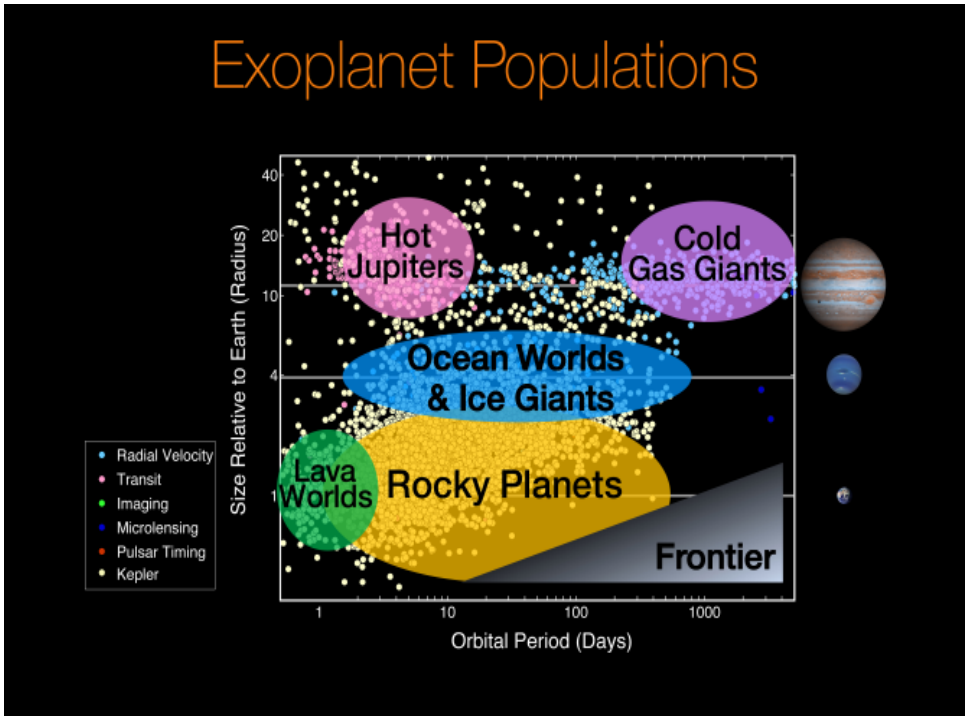


• In the figure, light of the host star is blocked to see the exoplanets. Exoplanets are named with suffixes b, c, d etc while the host star suffix is "a" whose name is often the name of the telescope /observatory that detected it. • With 200 billion stars in the Milky Way, one can hypothesize that there are i) 40 billion exo-planets orbiting the numerous red dwarfs and ii) 11 billion of them are potentially habitable Earth-sized planets. Habitable planets: Rocky, H_2O, O_2, right T, safe distance from stellar radiation

EXOPLANETS HUNTING TELESCOPES: Ex: KEPLER, TESS



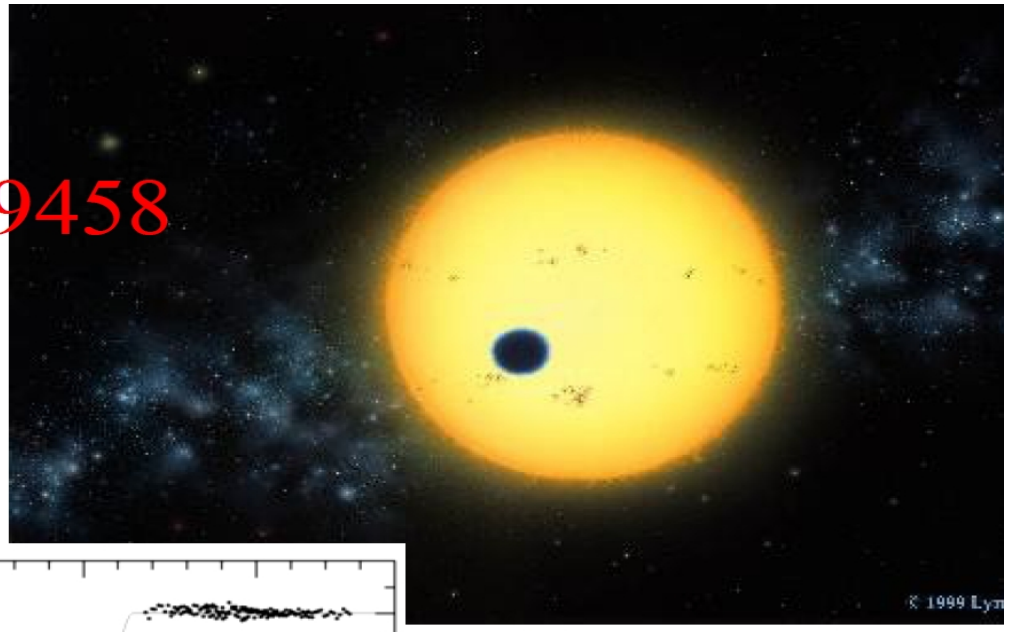


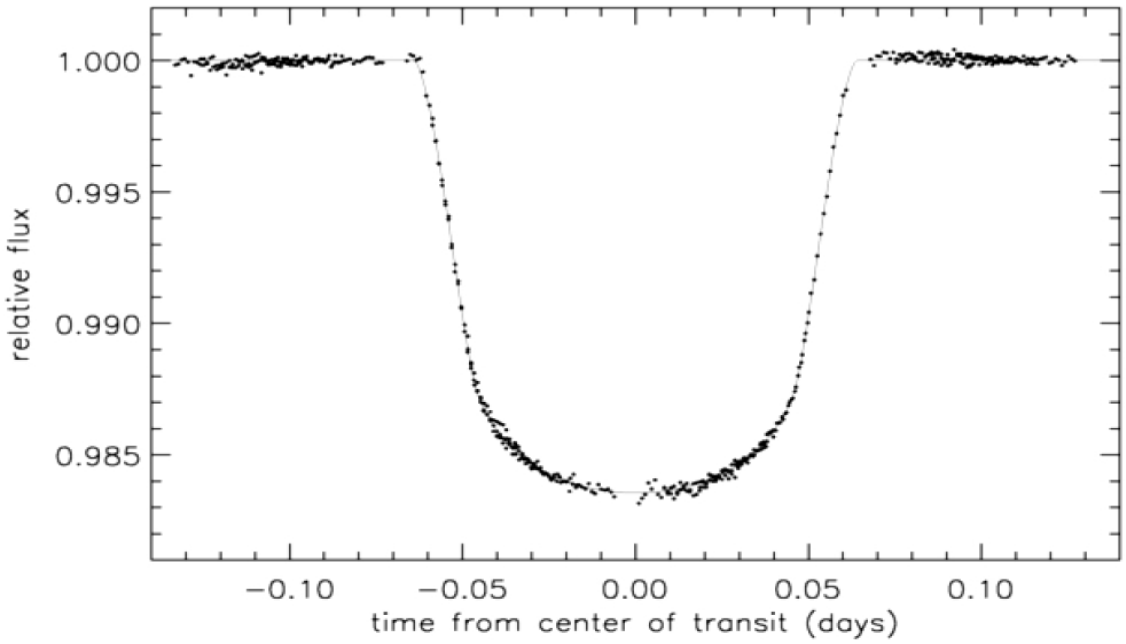


- Over 5800 confirmed exoplanets

DETECTION SPECTROSCOPY OF EXOPLANETS: TRANSIT METHOD

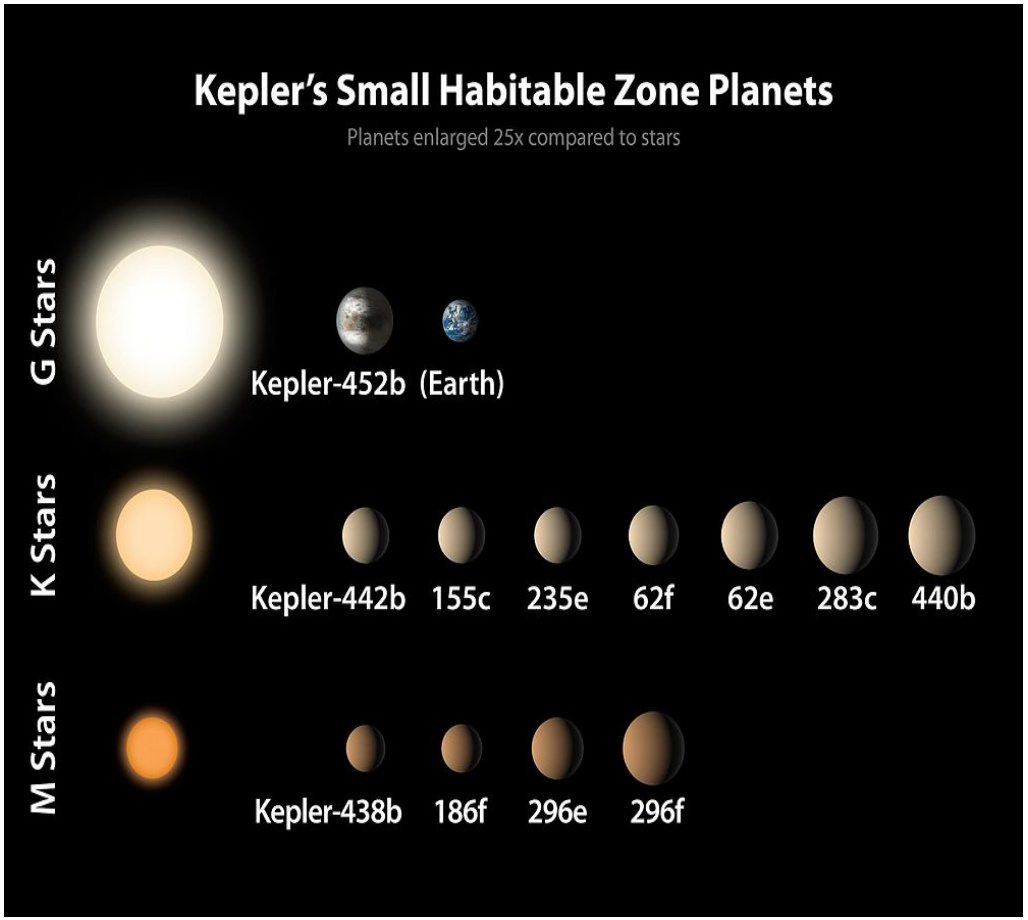
planetary transit
in the star HD 209458

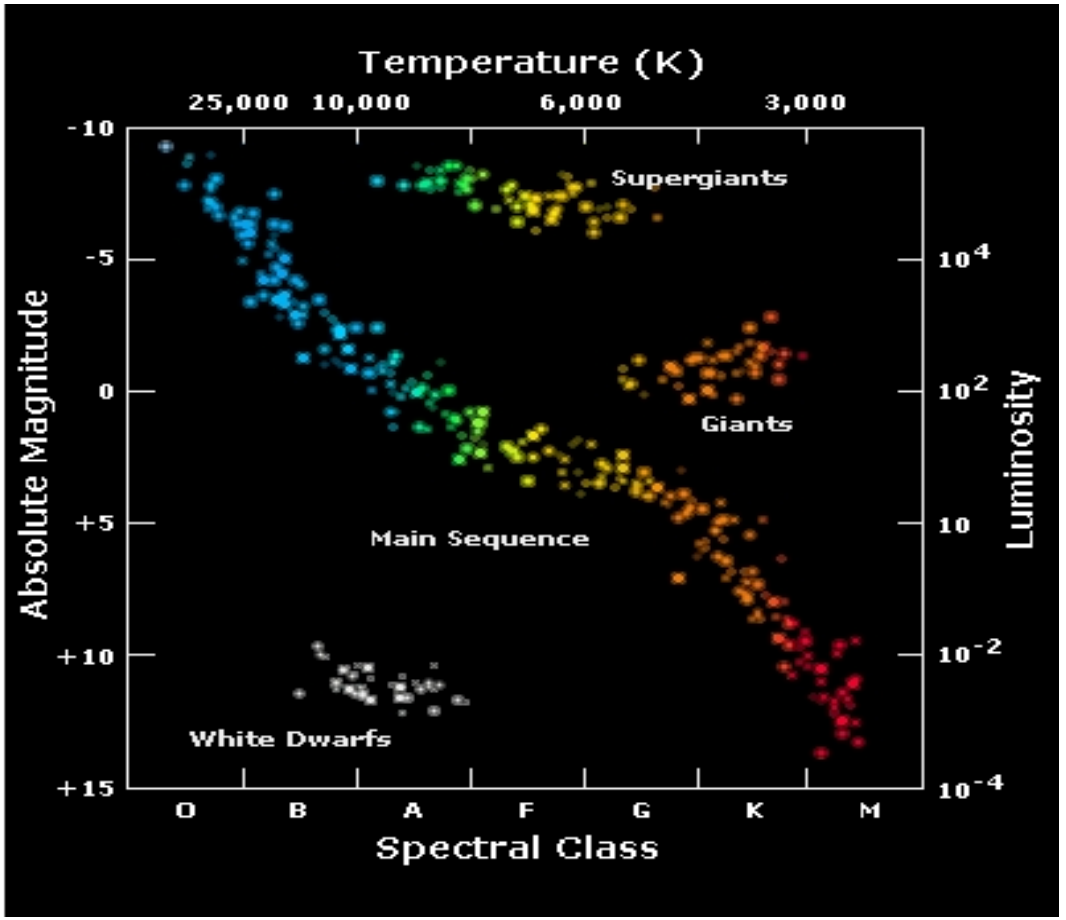




- **L: Transit method:** Most common, via photometry as intensity varies up to of a few percent
  - Ex: Simply identifying "Proxima b", was a considerable challenge

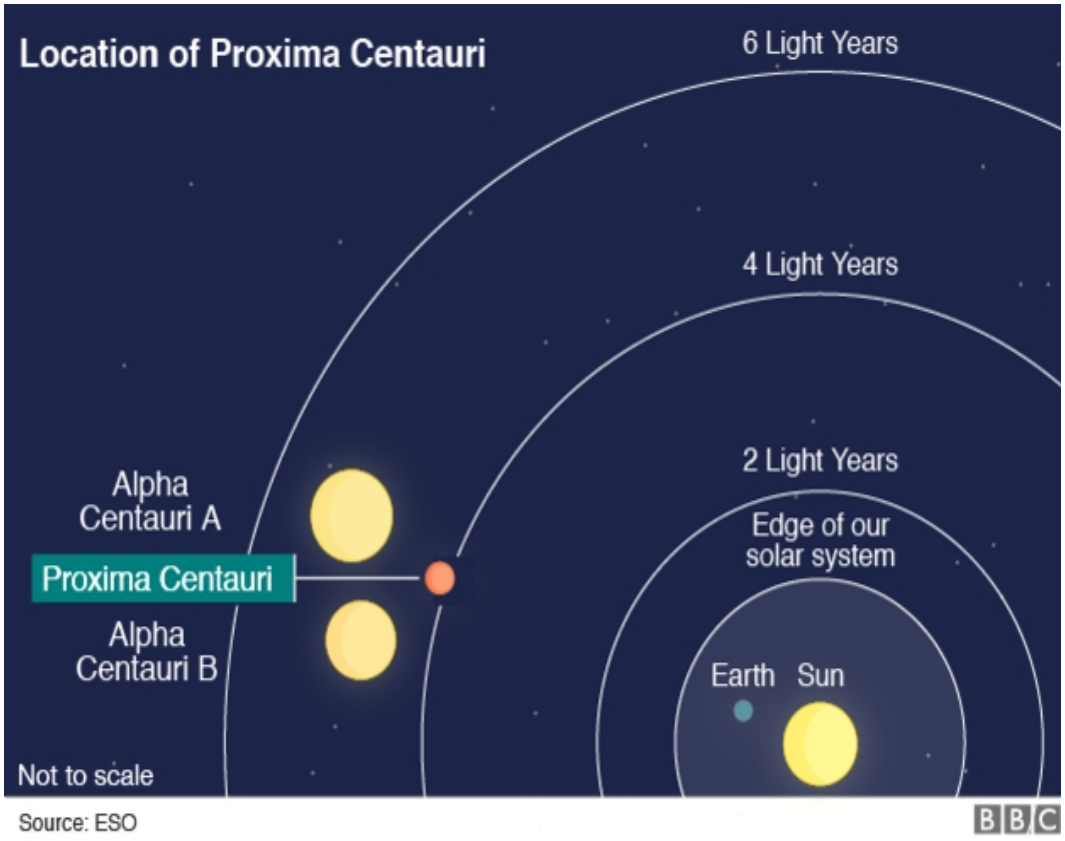
HR DIAGRAM FOR EXOPLANETARY HOST STARS

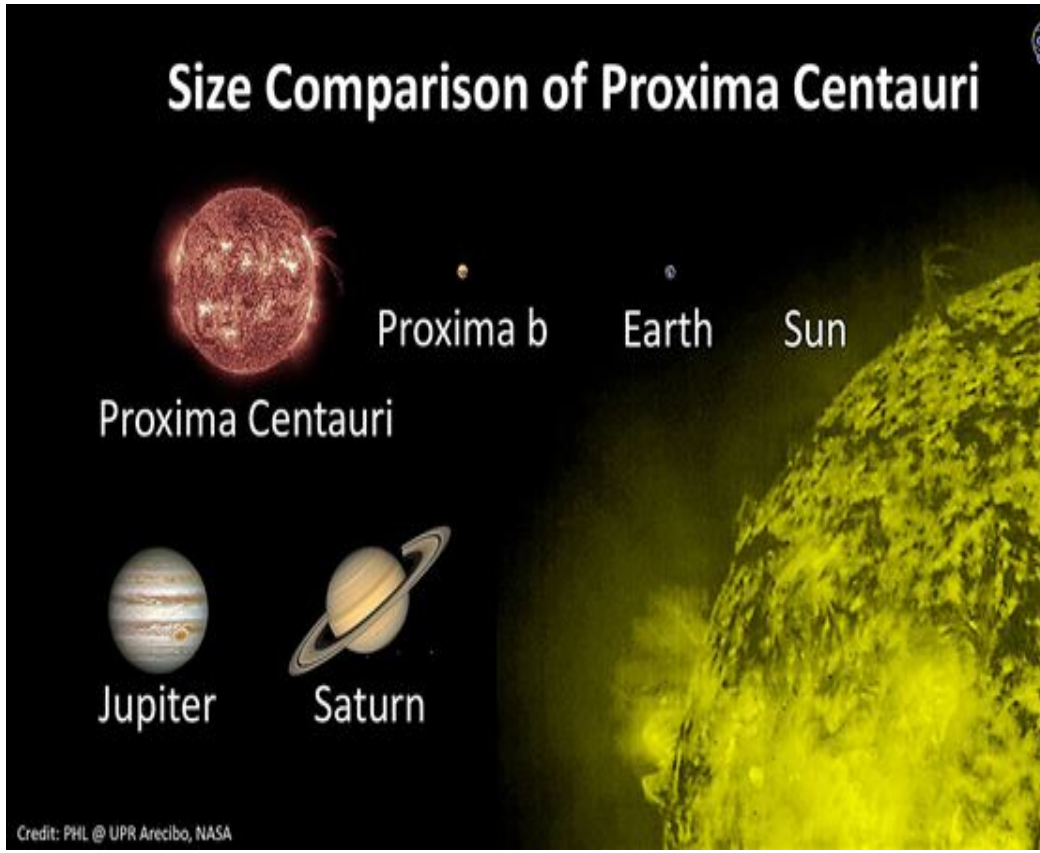




- L: All habitable planets are largely belong to G, K, & F, M stars
- R: Mainly cool stars yellow to red in the HR diagram
- However, current model spectra of cool stars do not accurately reproduce observed fluxes even for the Sun. The problem lies in the attenuation of transmitted flux due to the opacity of the stellar plasma

NEAREST HABITABLE EXOPLANET





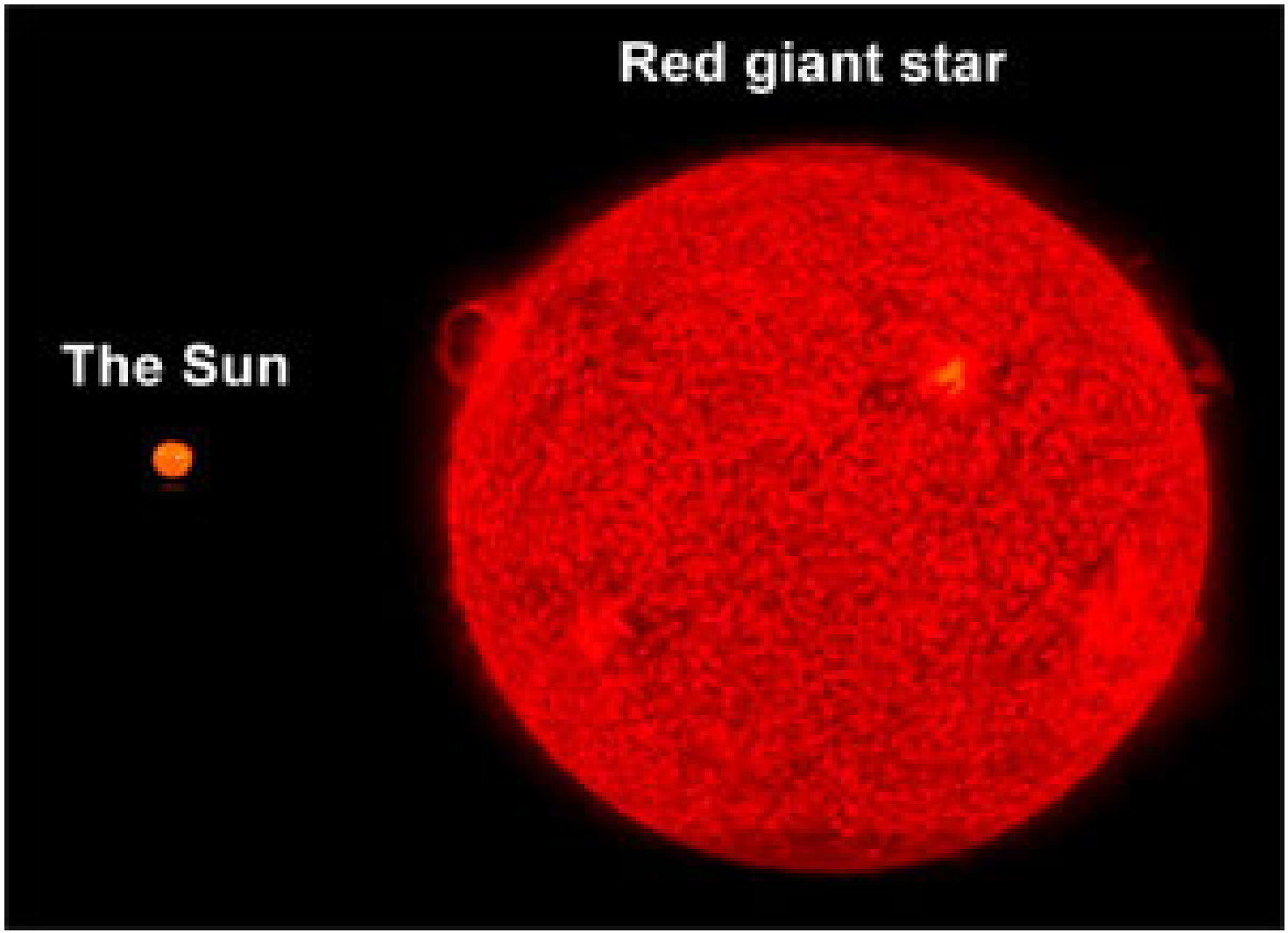
- Habitable planets where liquid water may exist
- Proxima b, exoplanet to our closest star Alpha Centauri (4 ly away: Earth-like in size, hard & rocky surface, possibility of liquid water & temperature similar to us

- But a spacecraft using current technology will take 18 thousands of years to reach it → New idea for 20 years

- 1 in 5 sun-like stars have an earth-sized planet in the habitable • Milky Way has as 200-400 billion stars

size, hard and rocky surface, possibility of liquid water,

LIFE OF OUR SUN: RED GIANT IN 6-7 BYR

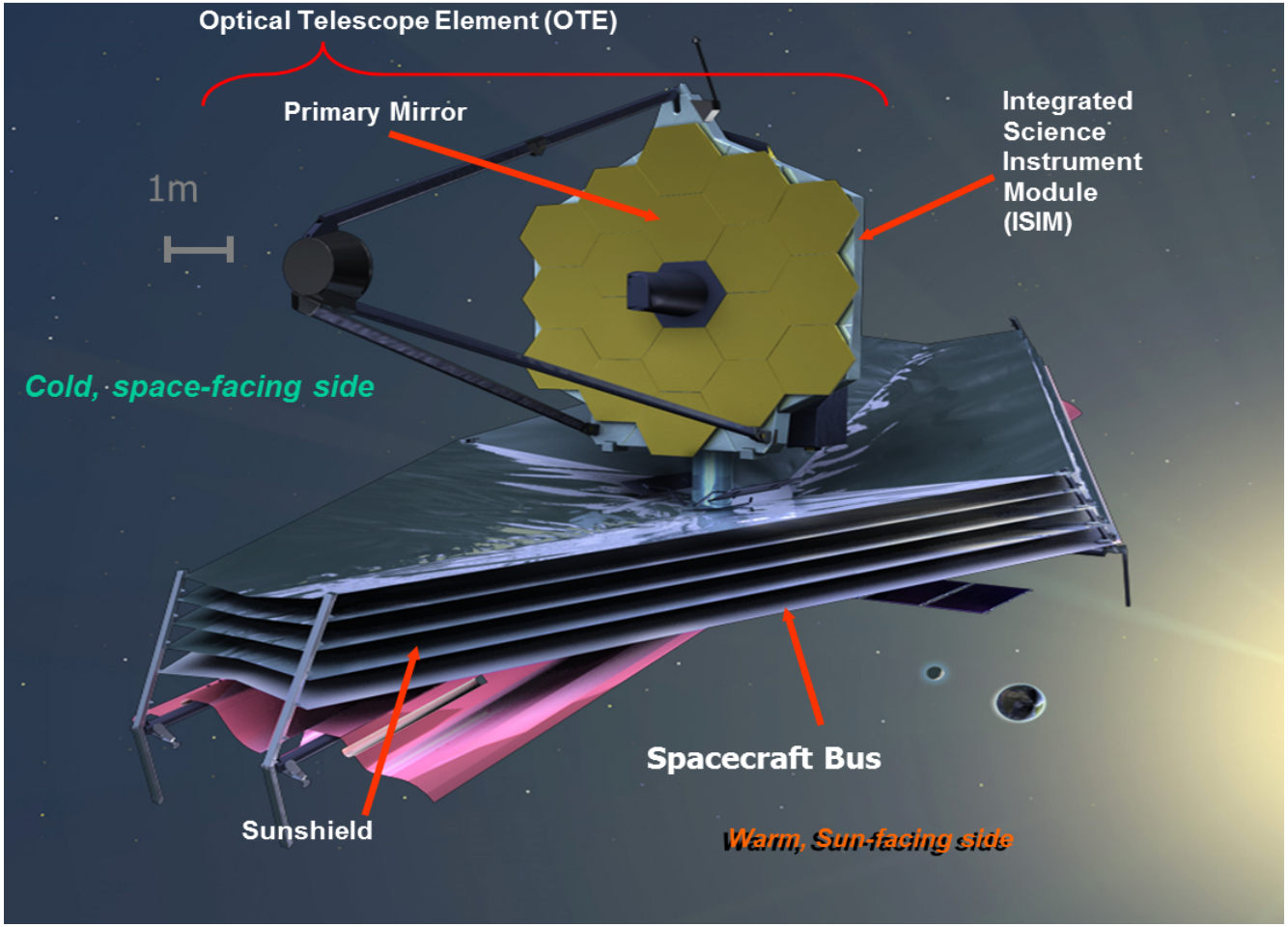


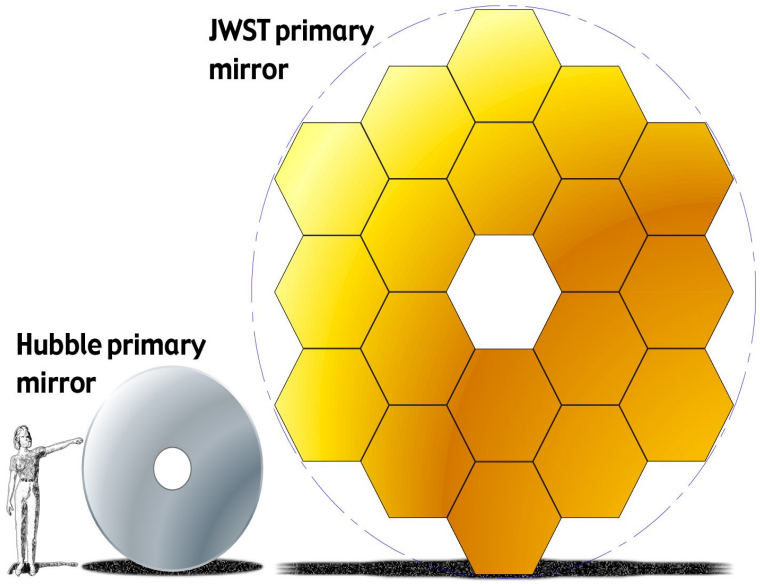
• SUN: 4.5 BYr old, live for another 6-7 BYr. The current age of the universe $\sim$ 13.8 BYr

• It will become a Red Giant, a dying expanded star with H fuel gone

• The heat, radiation, electrons will push materials out to form a red giant. • Red giant will slowly become planetary nebulae and ultimately white dwarf. Over 90% stars will end up to white dwarf and lot of diamond in them $\rightarrow$ earth will be engulfed, we will need another home

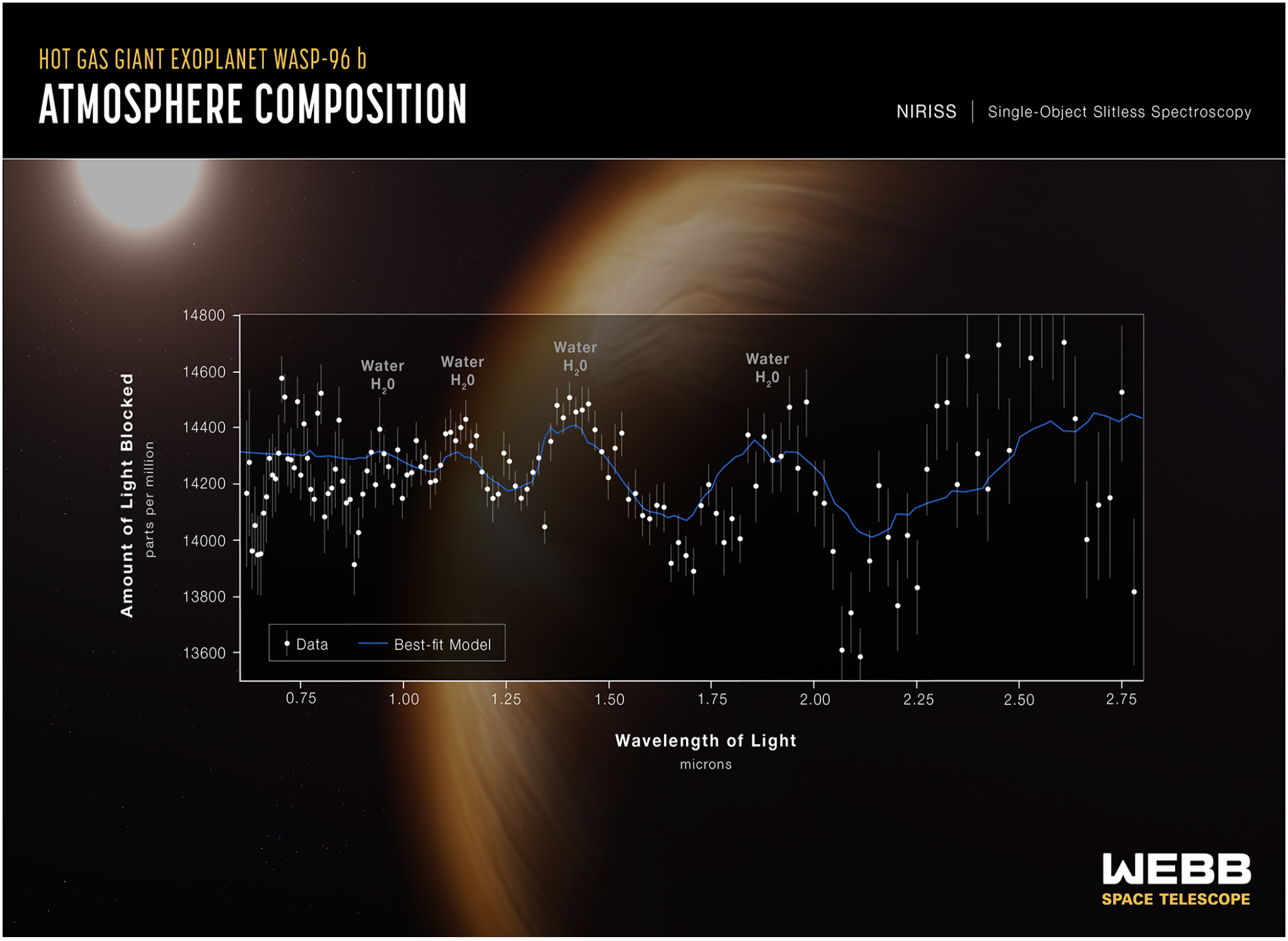
James Webb Space Telescope (JWST): Infrared 0.6 - 28.5 μm



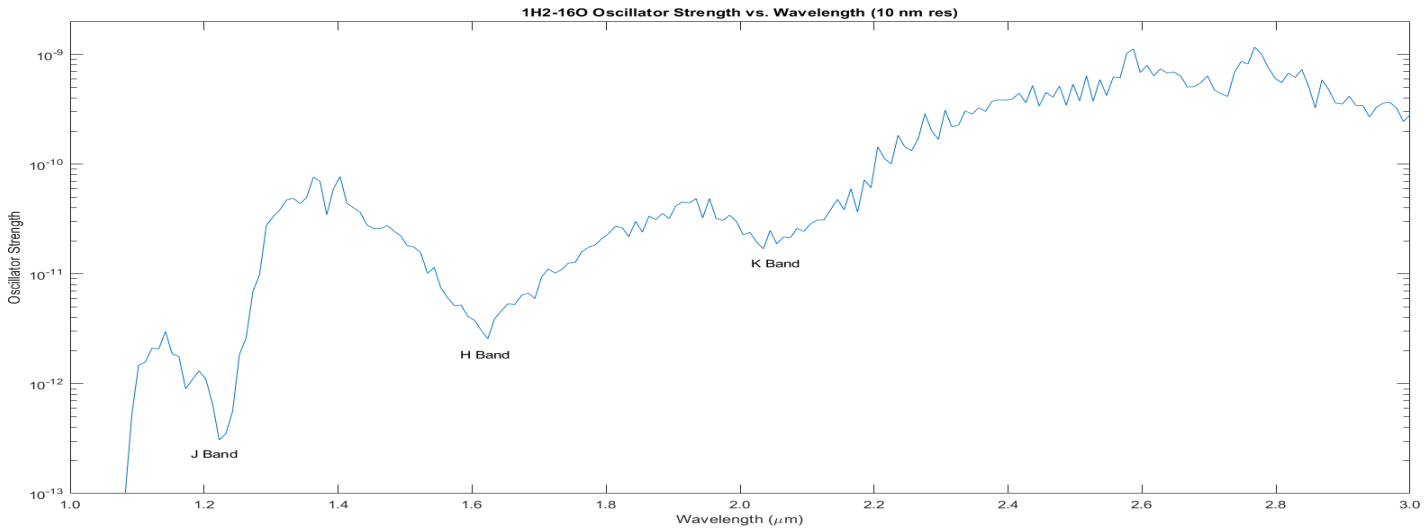


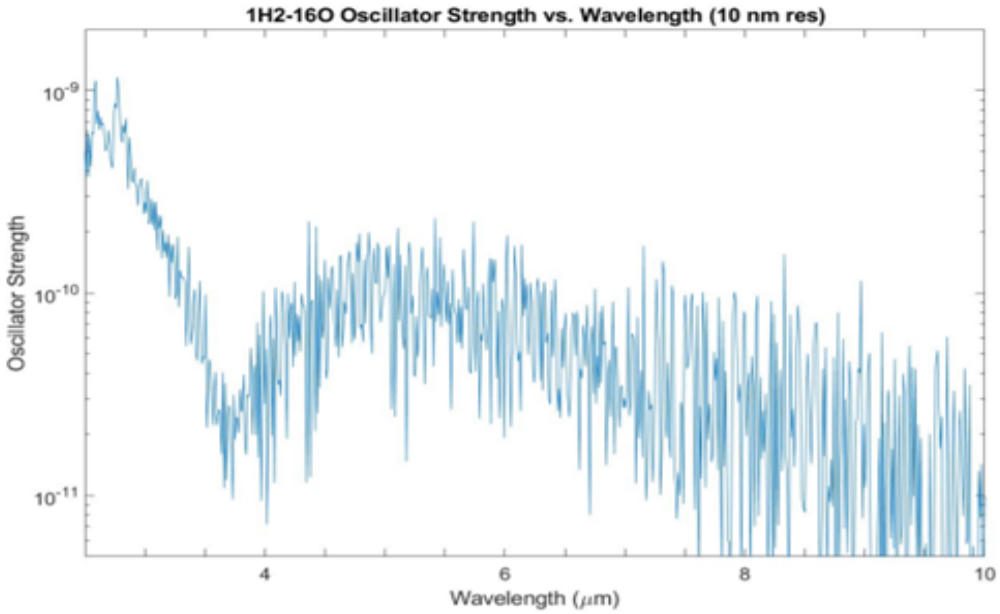
- 18 mirrors combine to create 6.5m - Hubble: 2.4m diameter lens
- Mass: 6500 kg - Launched: December 25, 2021
- Two main objectives: Origin of the universe and Characterize exoplanets - find existence of any life form

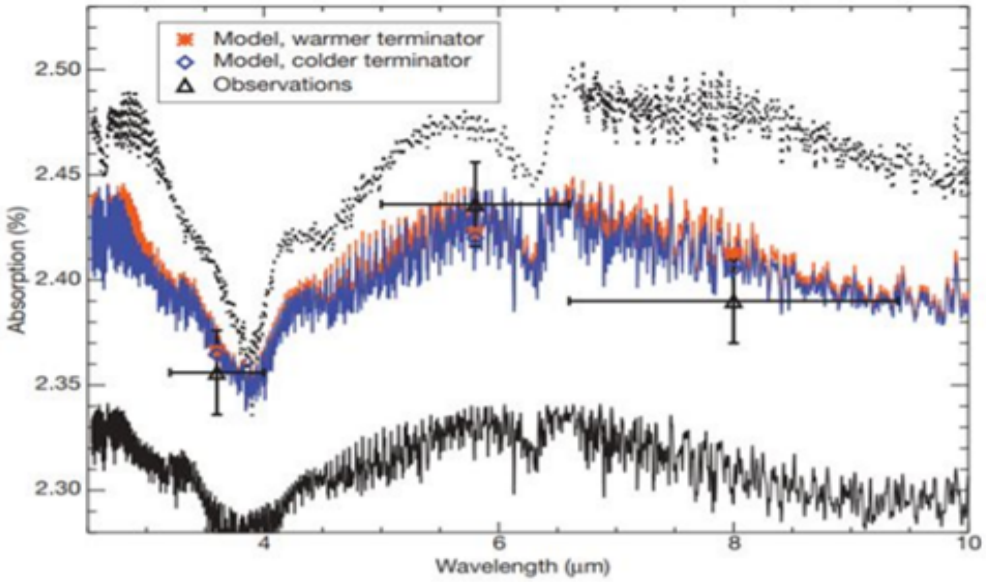
JWST (James Webb Space Telescope) SPECTRUM SHOWING WATER IN EXOPLANET WASP



Group research: 2. H_2O in atmosphere: Rothman, Sep 27, 2021

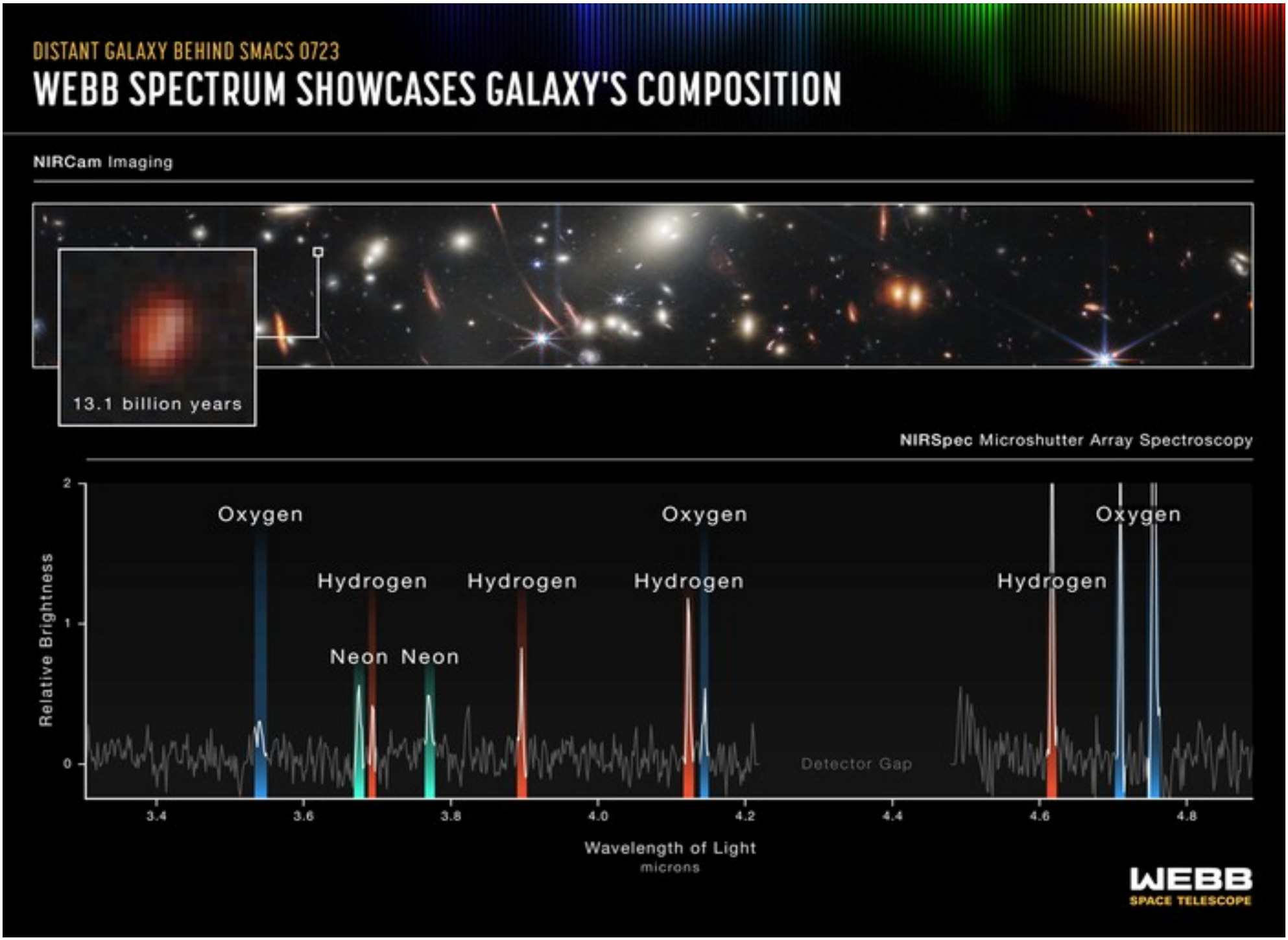




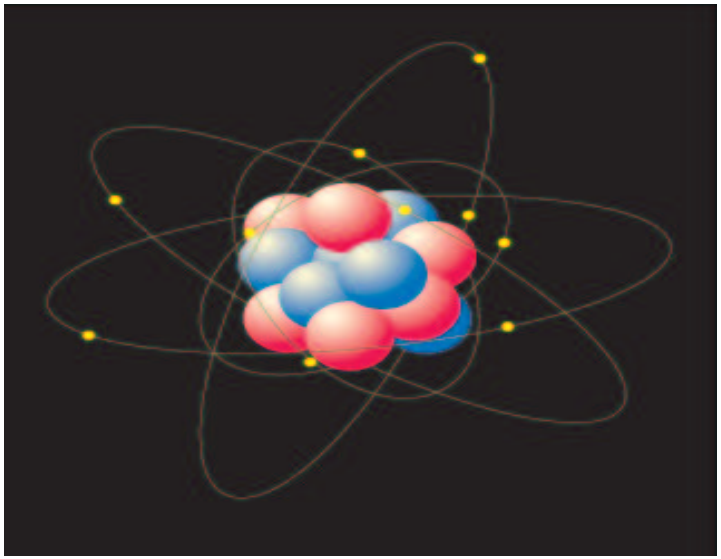


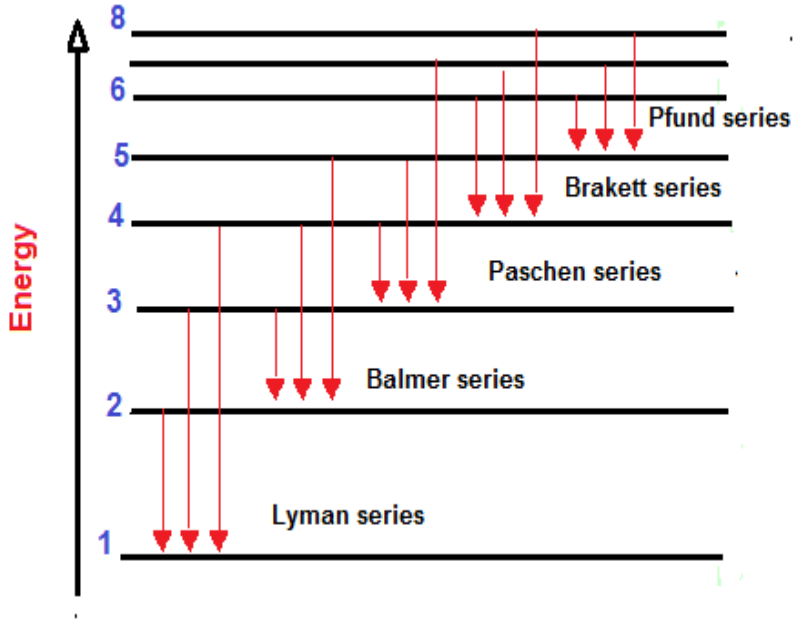
- Lower Left: Synthetic spectrum of H_2O: J-H-K band absorption using radiative transitions. Right: Observed H2O lines (with crosses) are compared with calculated spectra.

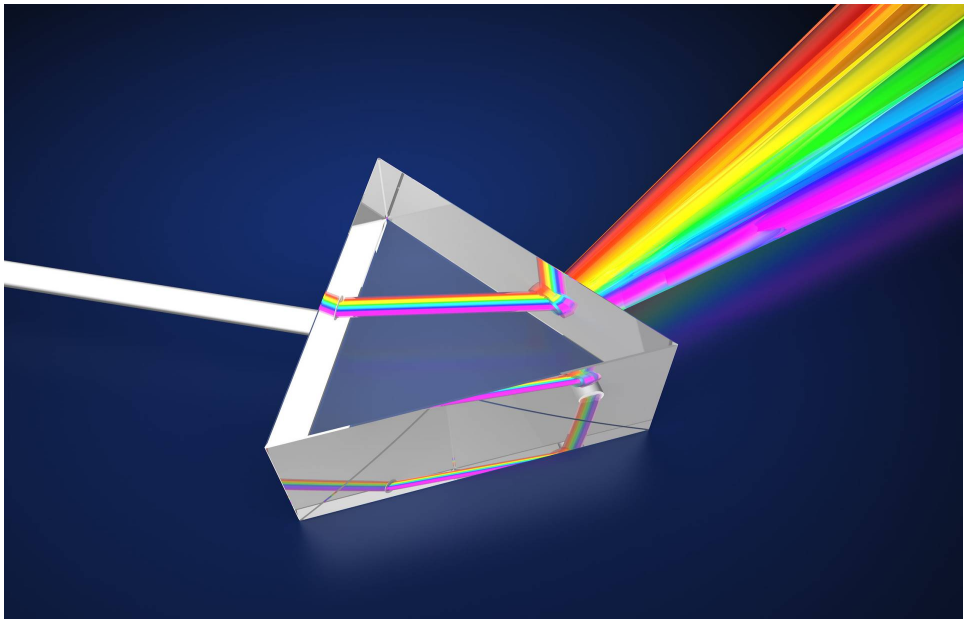
JWST SPECTROSCOPY DETECTING 13.1 BYr OLD PHOTONS OF H, O, N

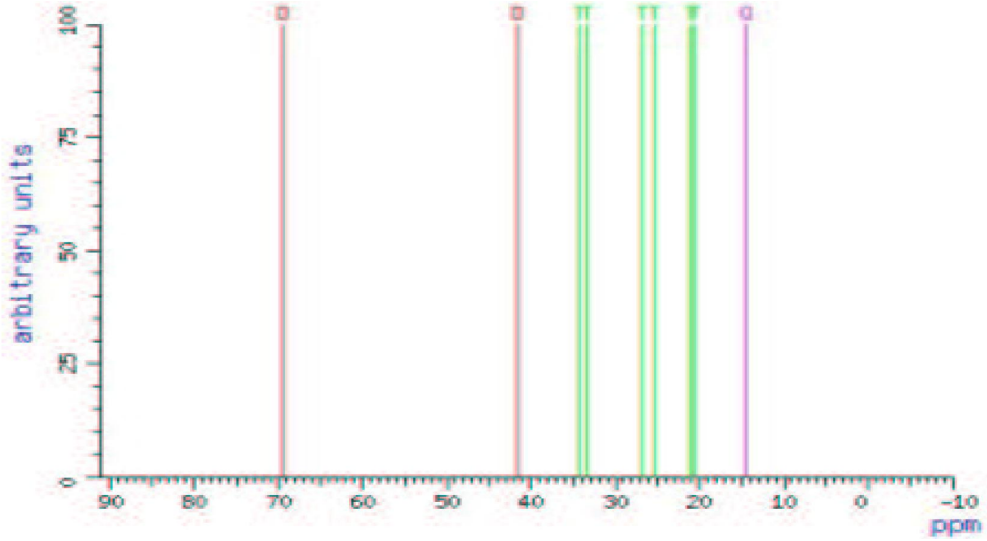


RADIATION FROM ATC







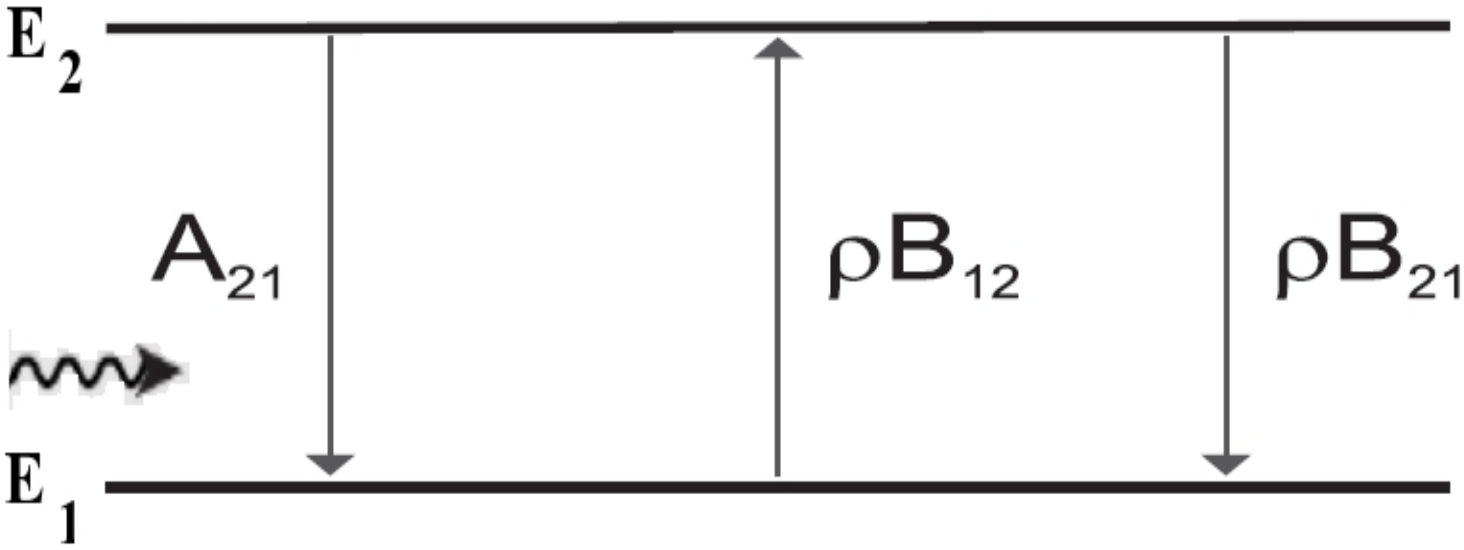


- Energy levels are quantized. There are infinite number of levels.
- An electron can be excited to higher levels. While dropping down, it gives out a photon. Radiation contains photons of many energies
- SPECTRUM: Splitting the radiation in to its colors: Rainbow, C lines

ATOMIC PROCESS FOR LINE FORMATION IN PLASMA

1. PHOTO-EXCITATION & DE-EXCITATION:

$$X^{+Z} + h\nu \rightleftharpoons X^{+Z*}$$



- Atomic quantities:

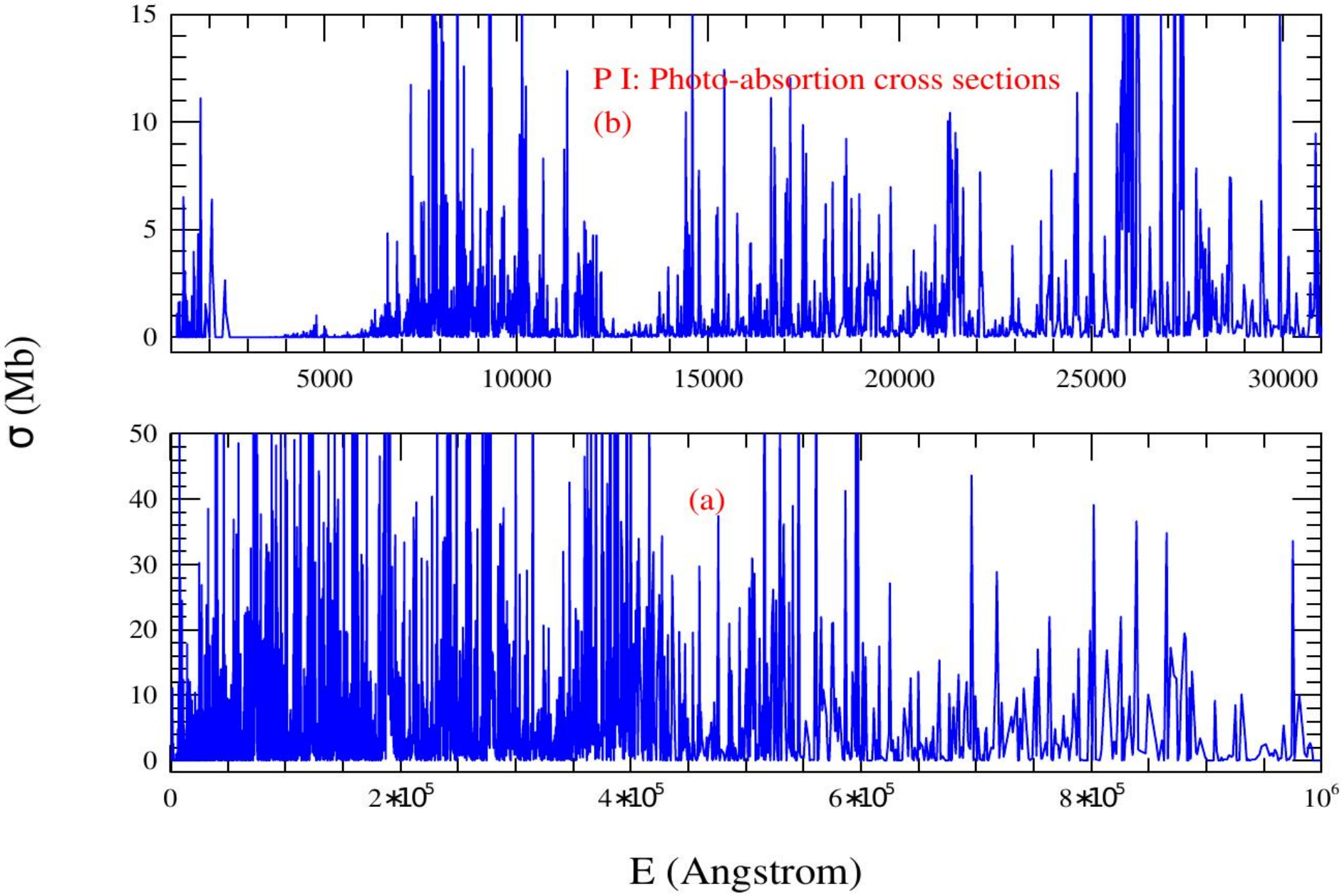
- A_{21} for Spontaneous Decay or Radiative Decay Rate
- f (Oscillator Strength) or B_{12} for Excitation

- Monochromatic opacity (κ_ν) depends on f_{ij}

$$\kappa_\nu(i \rightarrow j) = \frac{\pi e^2}{mc} N_i f_{ij} \phi_\nu$$

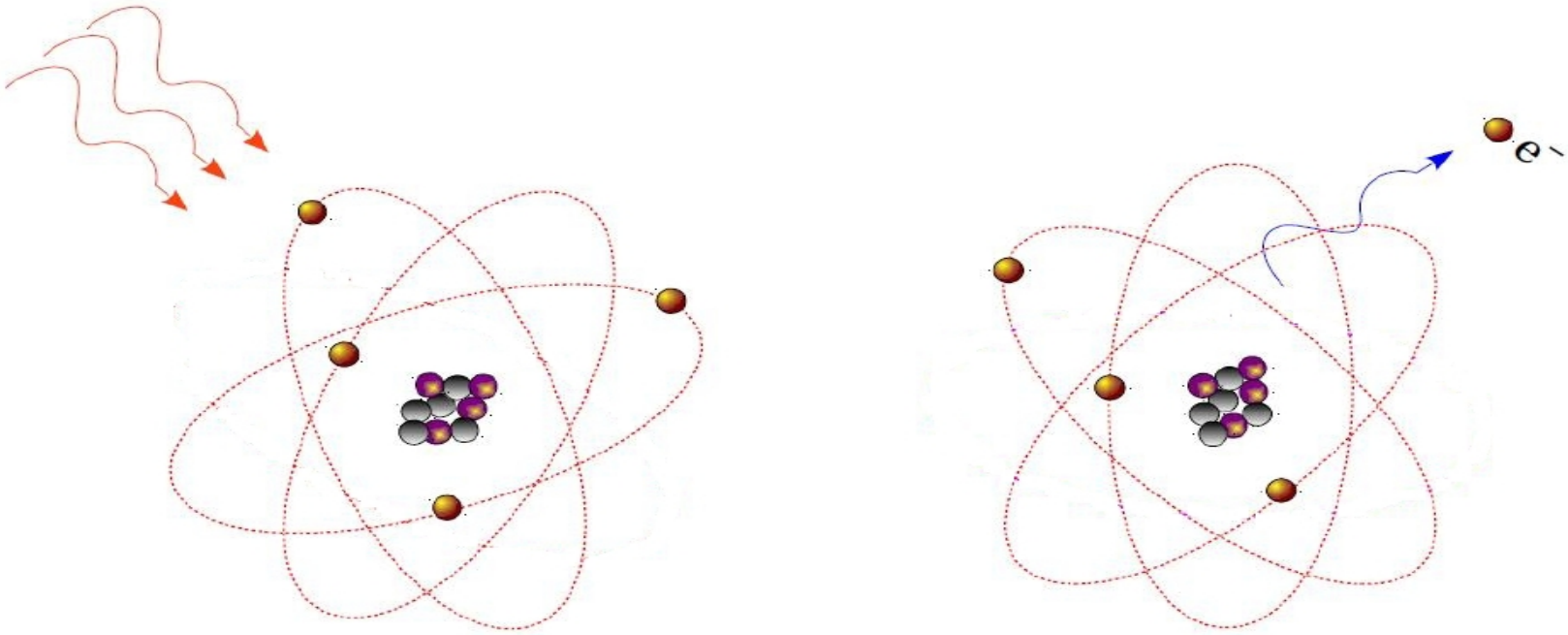
N_i = ion density in state i, ϕ_ν = profile factor

PHOTOABSORPTION SPECTRUM: P I (Nahar & Shafique 2024



- Spectrum of 32,678 fine structure transitions in 343 bound states: Range covers from X-ray to infrared Bottom: Full spectrum, TOP: Details up to 30,000 $\AA$.
- Covers detection range of JWST (0.6 - 28 μm)

3. PHOTOIONIZATION (PI):



i) Direct Photoionization (background):

$$\mathbf{X^{+Z} + h\nu \rightleftharpoons X^{+Z+1} + \epsilon}$$

ii) Resonant Photoionization: an intermediate state before ionization → "Autoionizing state" → RESONANCE

$$\mathbf{X^{+Z} + h\nu \rightleftharpoons (X^{+Z})^{**} \rightleftharpoons X^{+Z+1} + \epsilon}$$

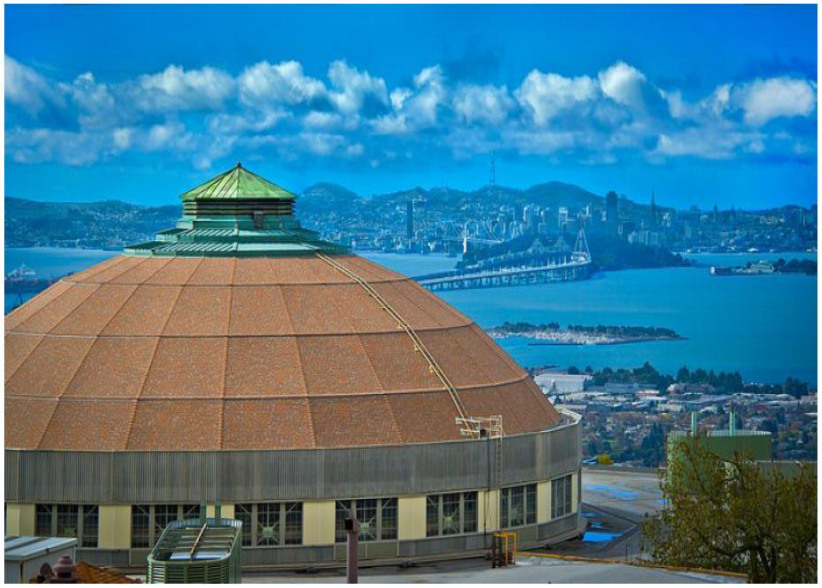
- κ_ν depends on photoionization cross section $\sigma_{\mathbf{PI}}$

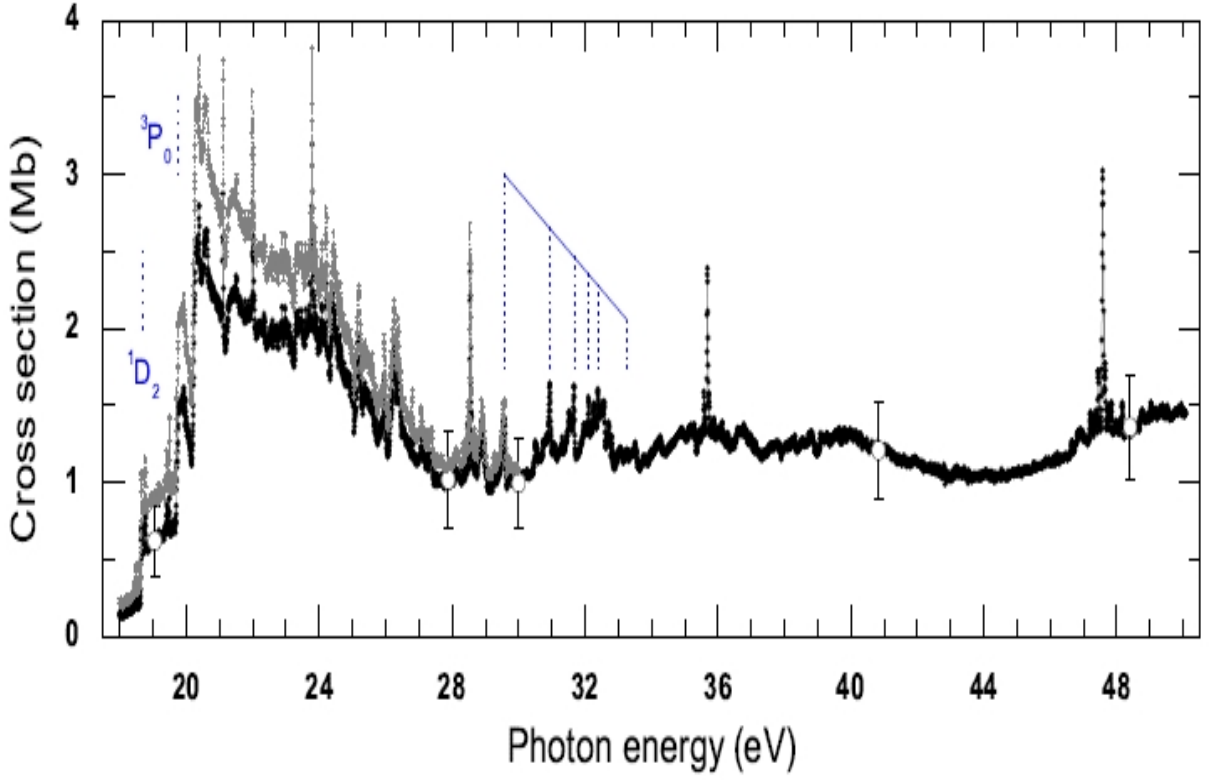
$$\kappa_\nu = \mathbf{N_i}\sigma_{\mathbf{PI}}(\nu)$$

PHOTOIONIZATION OF P II: Experiment (ALS, Berkeley)

(Guillermo et al. 2015

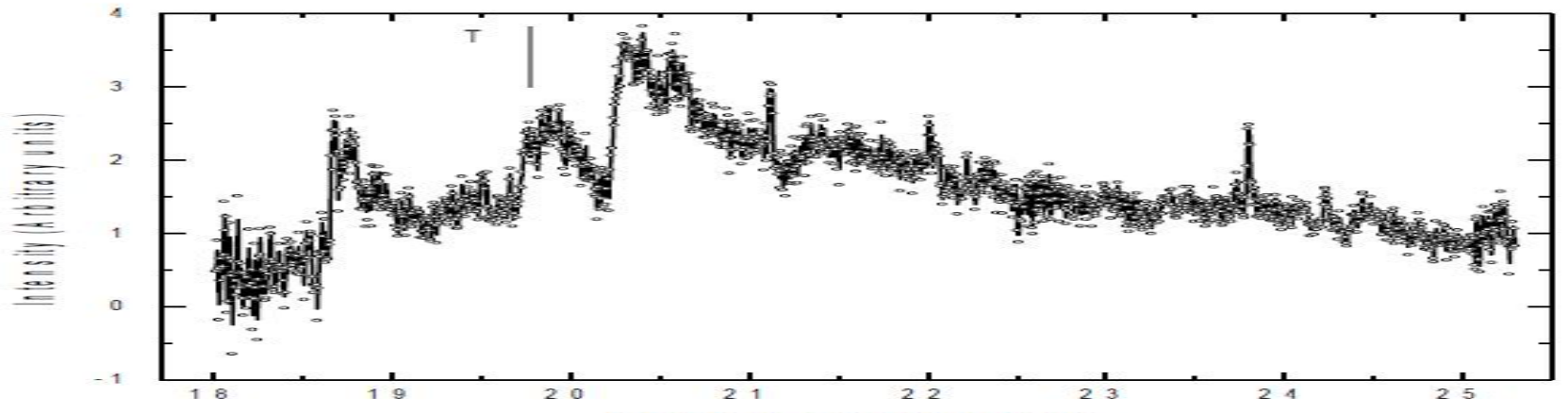
The ALS at Lawrence Berkeley National Laboratory



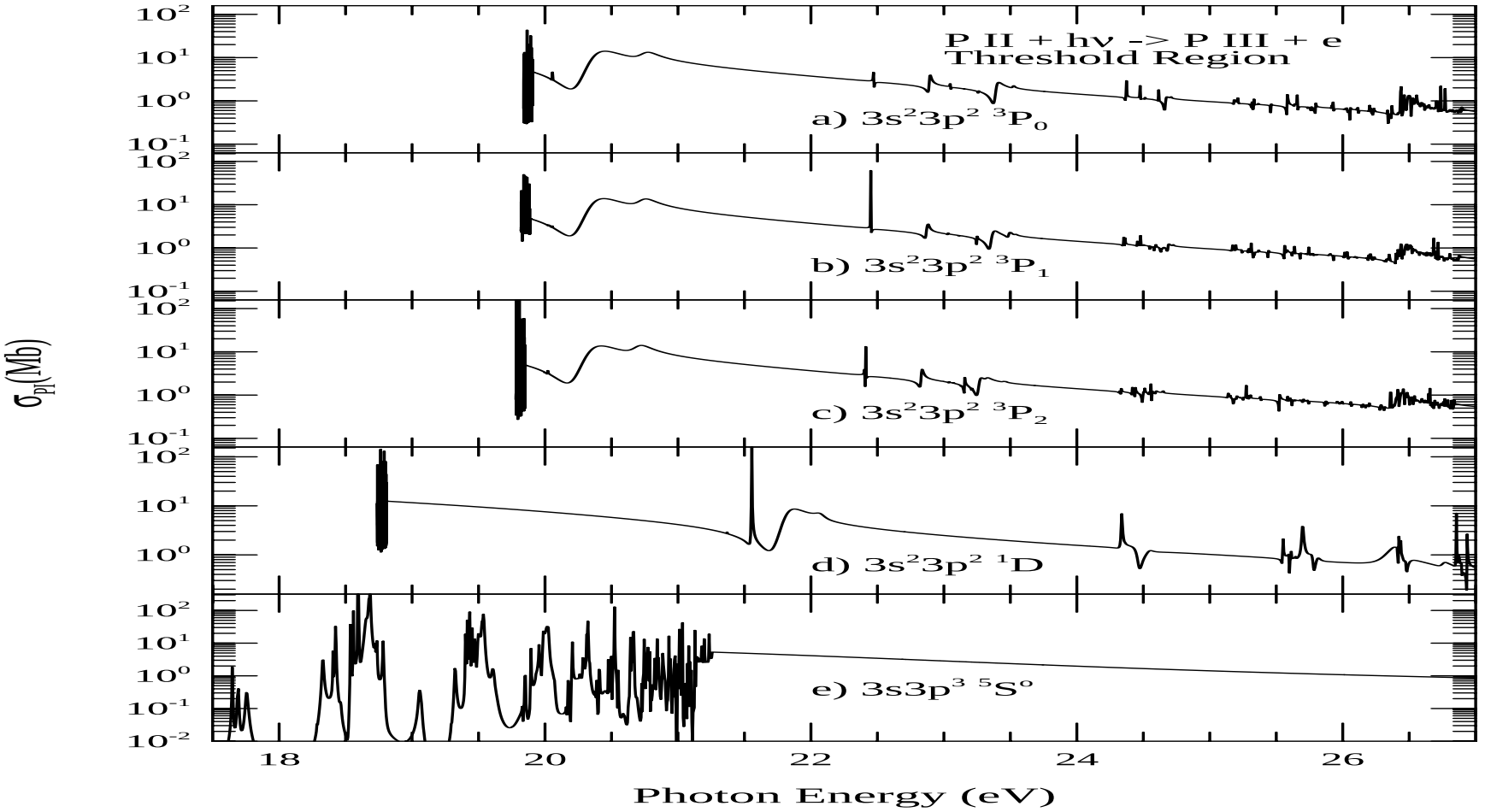


- Synchrotron based Advanced Light Source (ALS) produces high resolution photoionization spectra
- Figure shows combined features of states in target beam
- Needs theoretical spectral analysis for identification of features and abundance of states

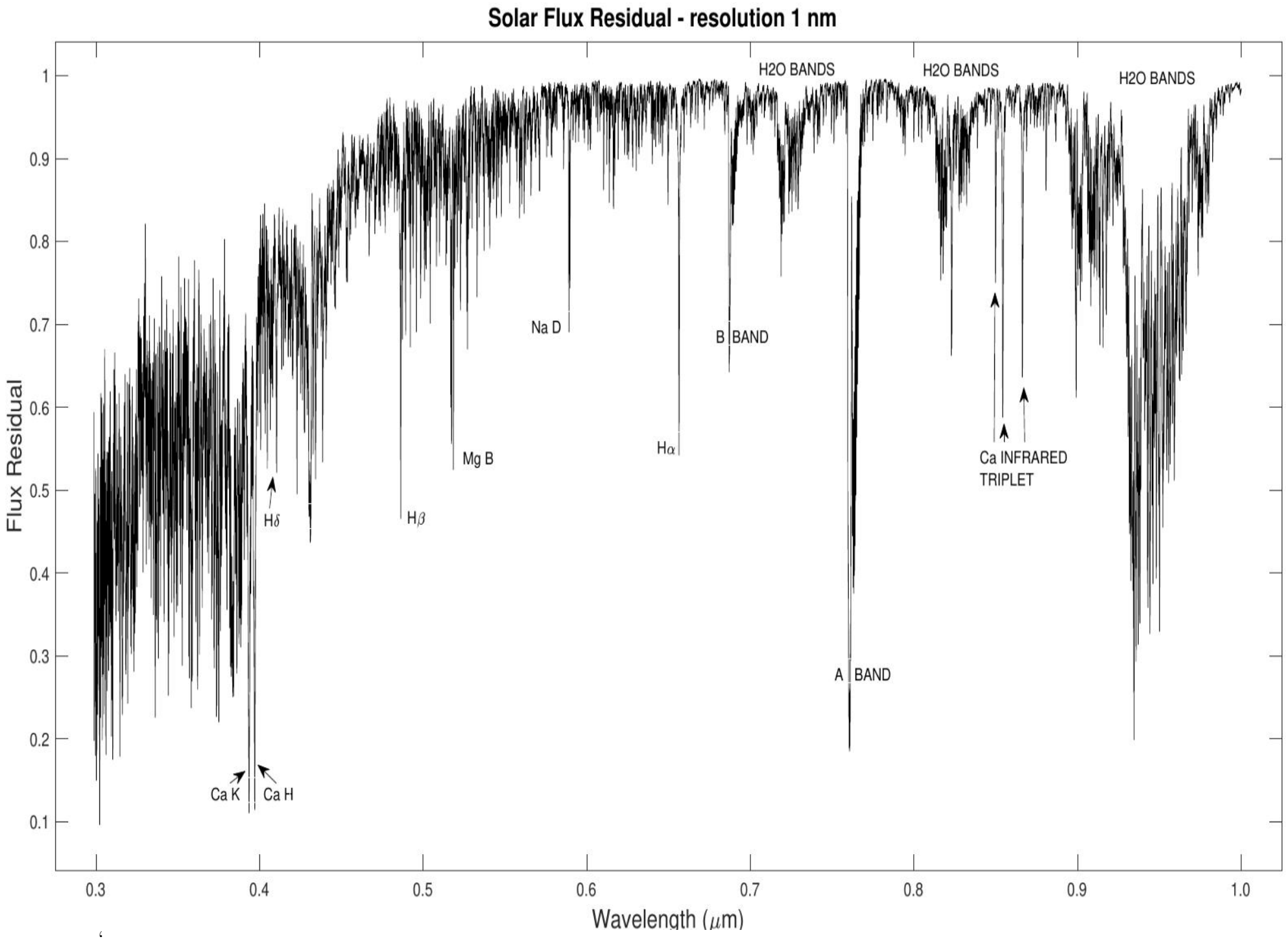
MEASURED PHOTOIONIZATION CROSS SECTIONS OF P II: BENCHMARK WITH R-MATRIX METHOD (Nahar et al 2016)



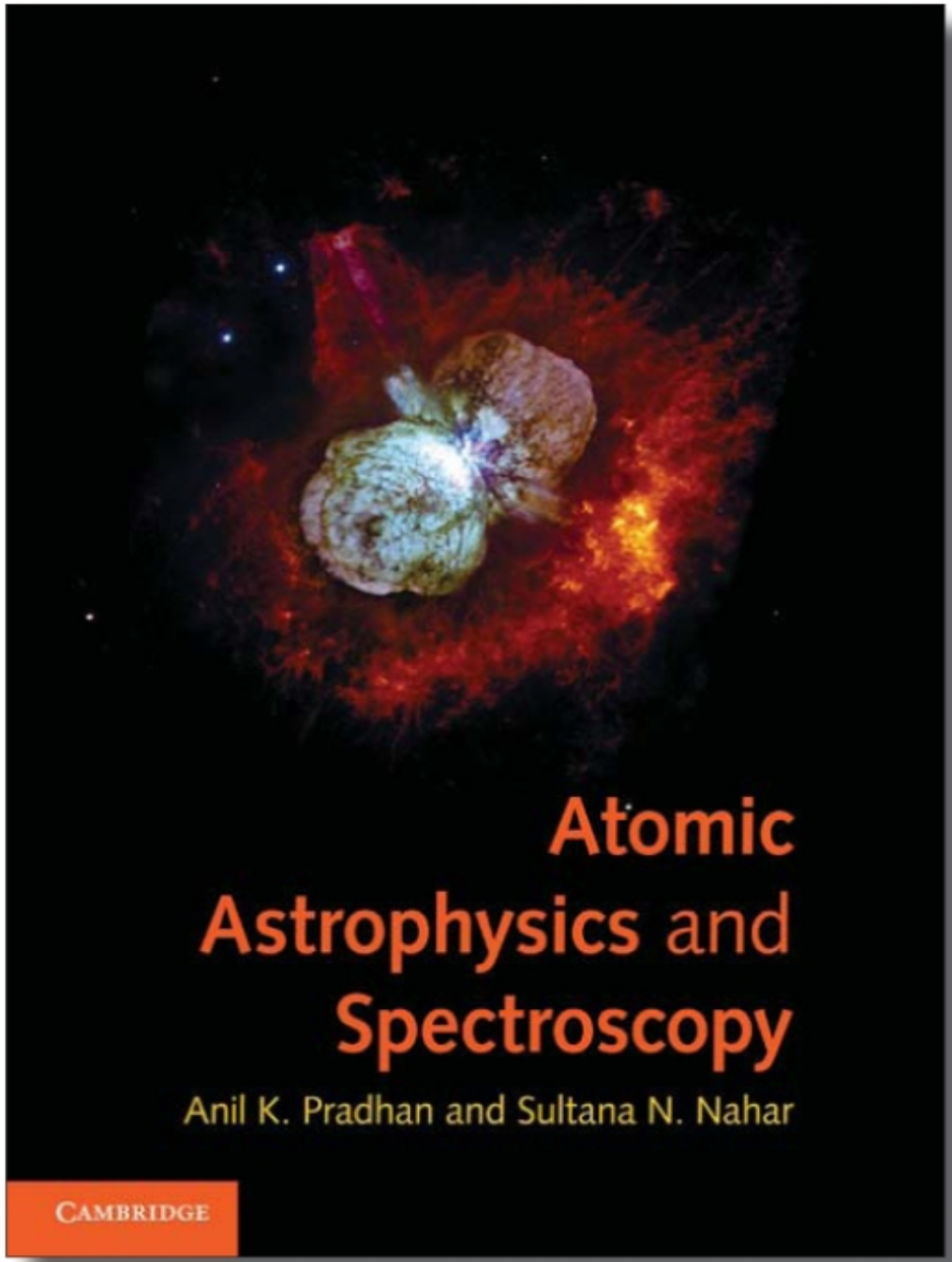
Photoionization Cross sections of P II at Thresholds



Research: Study for exoplnetary atmosphere with phosphorus



TEXTBOOK (Cambridge University press, 2011)y



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