BRLSI: 25 October 2018

The Formation of the Universe, the Chemical Elements and Life

A story told in colour

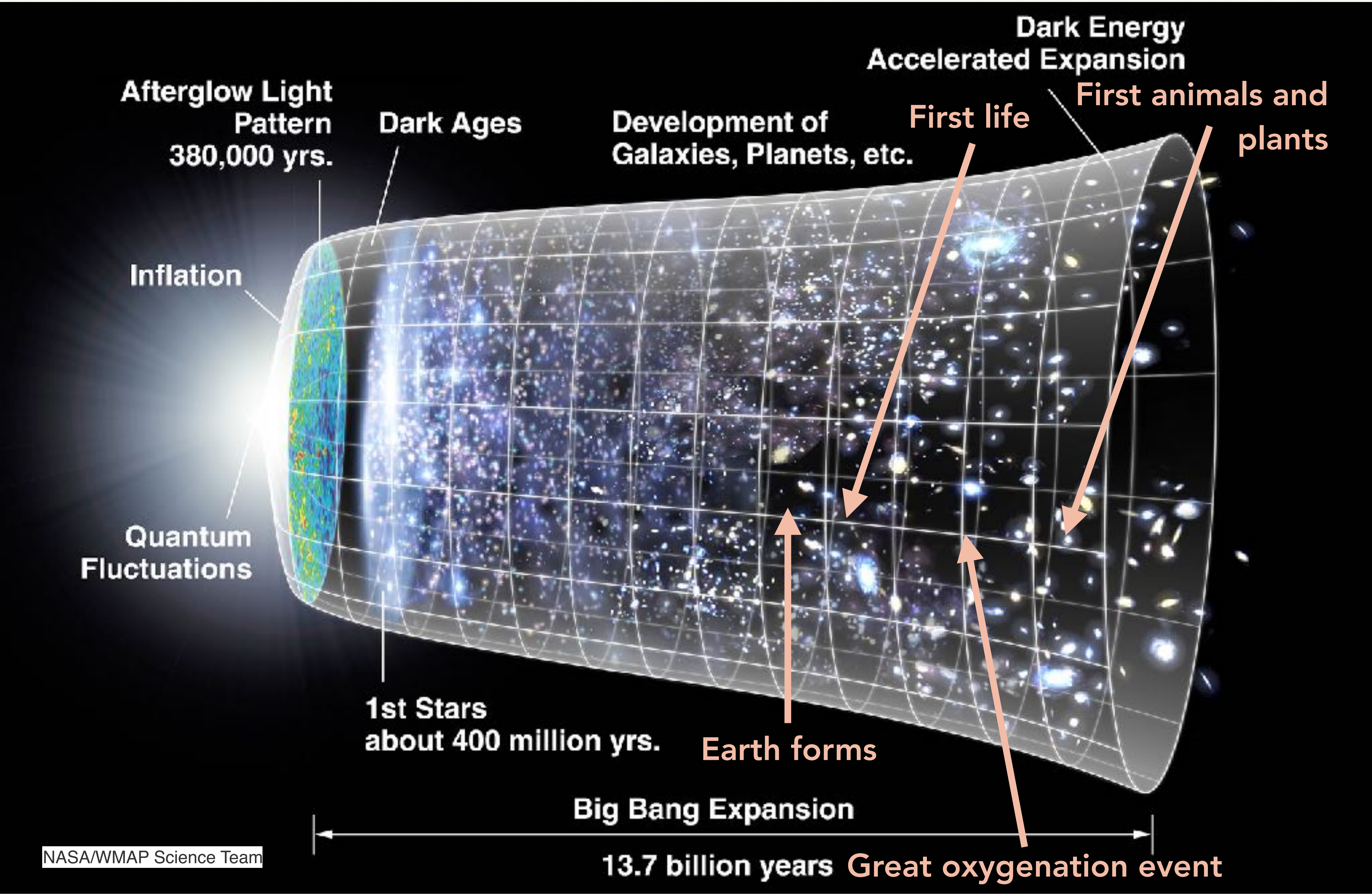
Bob Fosbury
European Space Agency
European Southern Observatory
Institute of Advanced Study — University of Durham
Institute of Ophthalmology — University College London

https://www.flickr.com/photos/bob_81667/

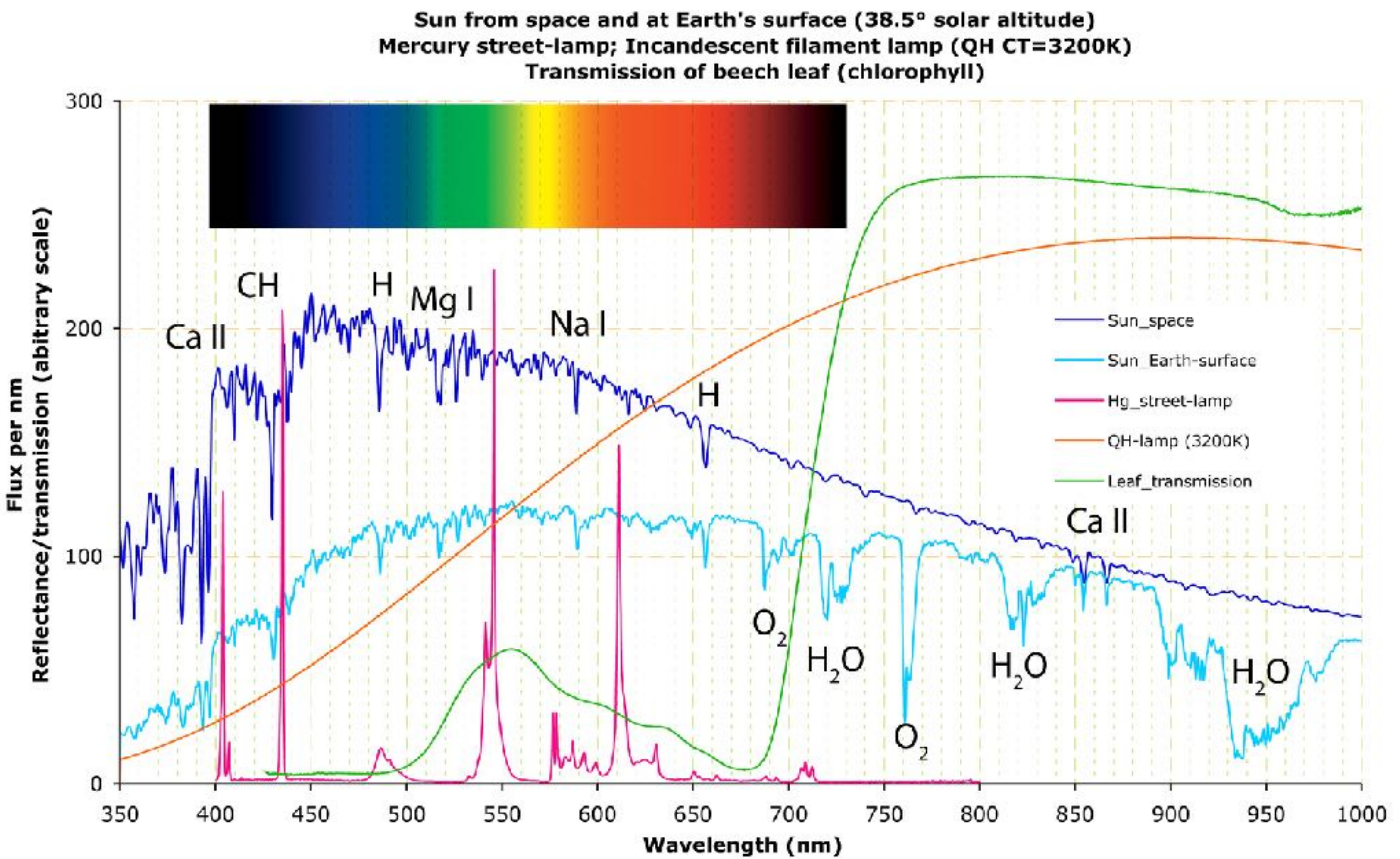
Plan of talk

- Asides on the Universe timeline and spectroscopy
- The colour of the Big Bang
- Building the Periodic Table of the elements
- The beginning of life on Earth
- The colours of life

The timeline of the universe



What is a spectrum?



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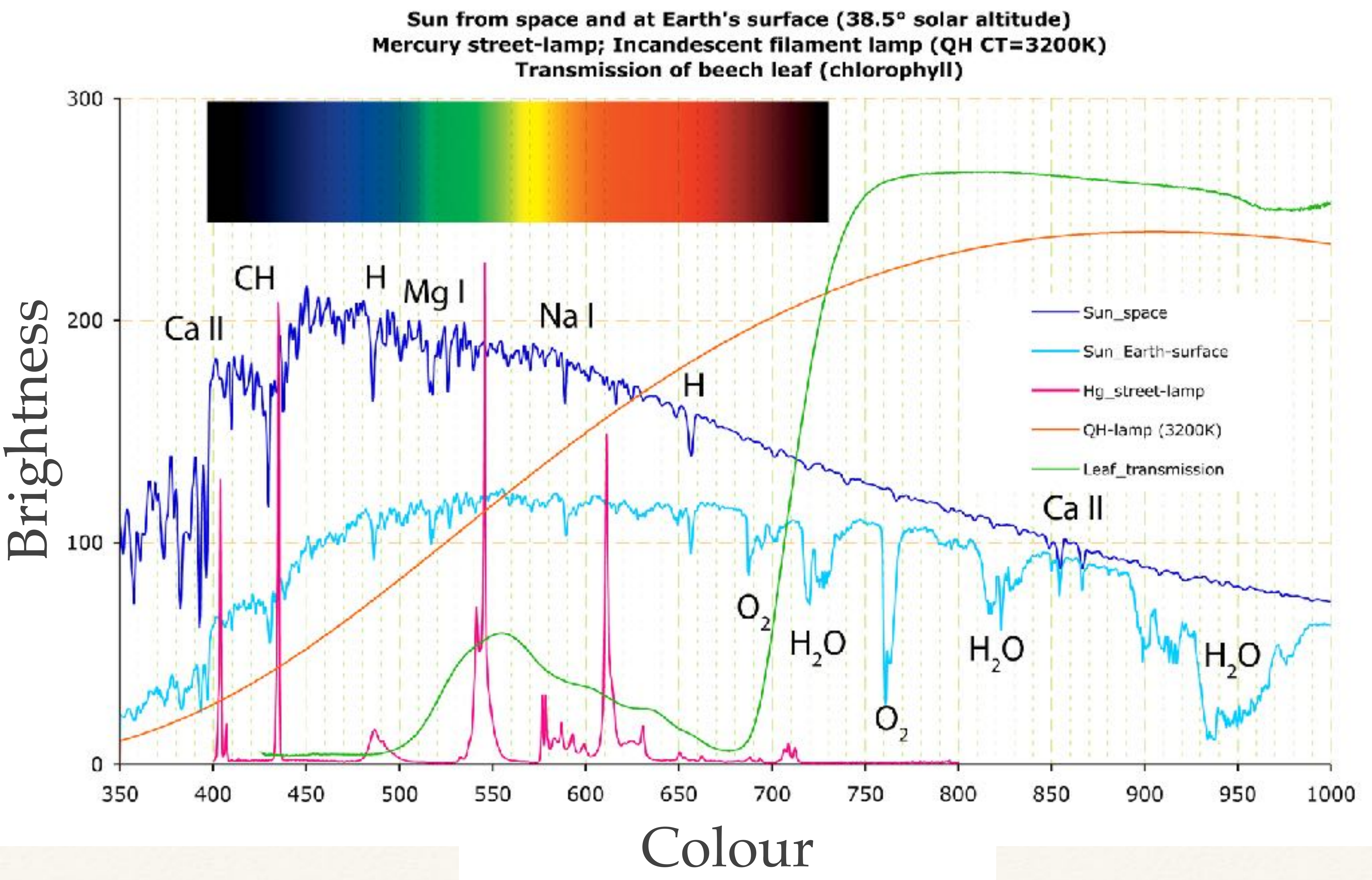
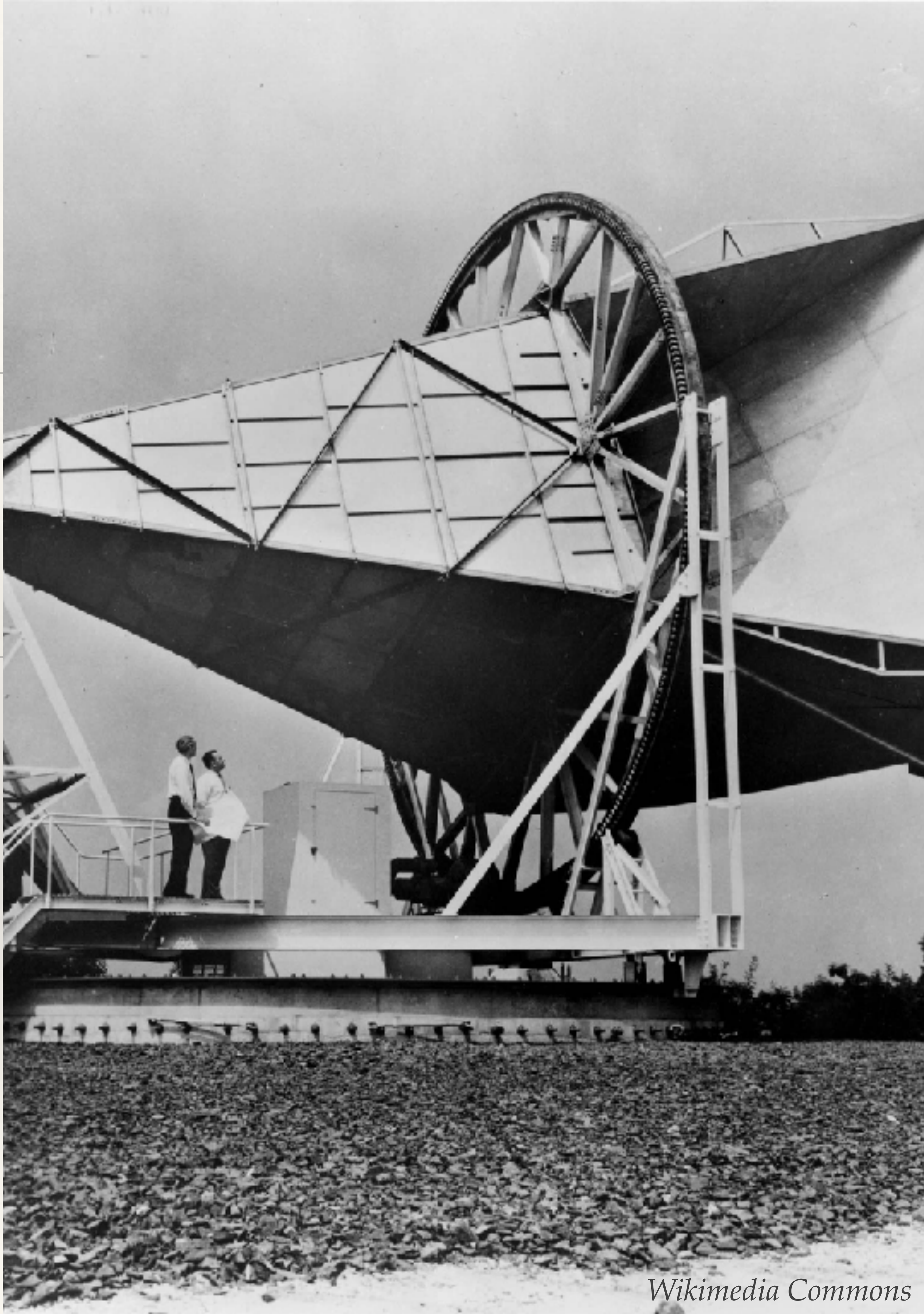


The Big Bang

Can we see the cosmic fireball?

Yes, it was first detected by Penzias & Wilson in 1966 and became known as the Cosmic Microwave Background Radiation (CMBR).

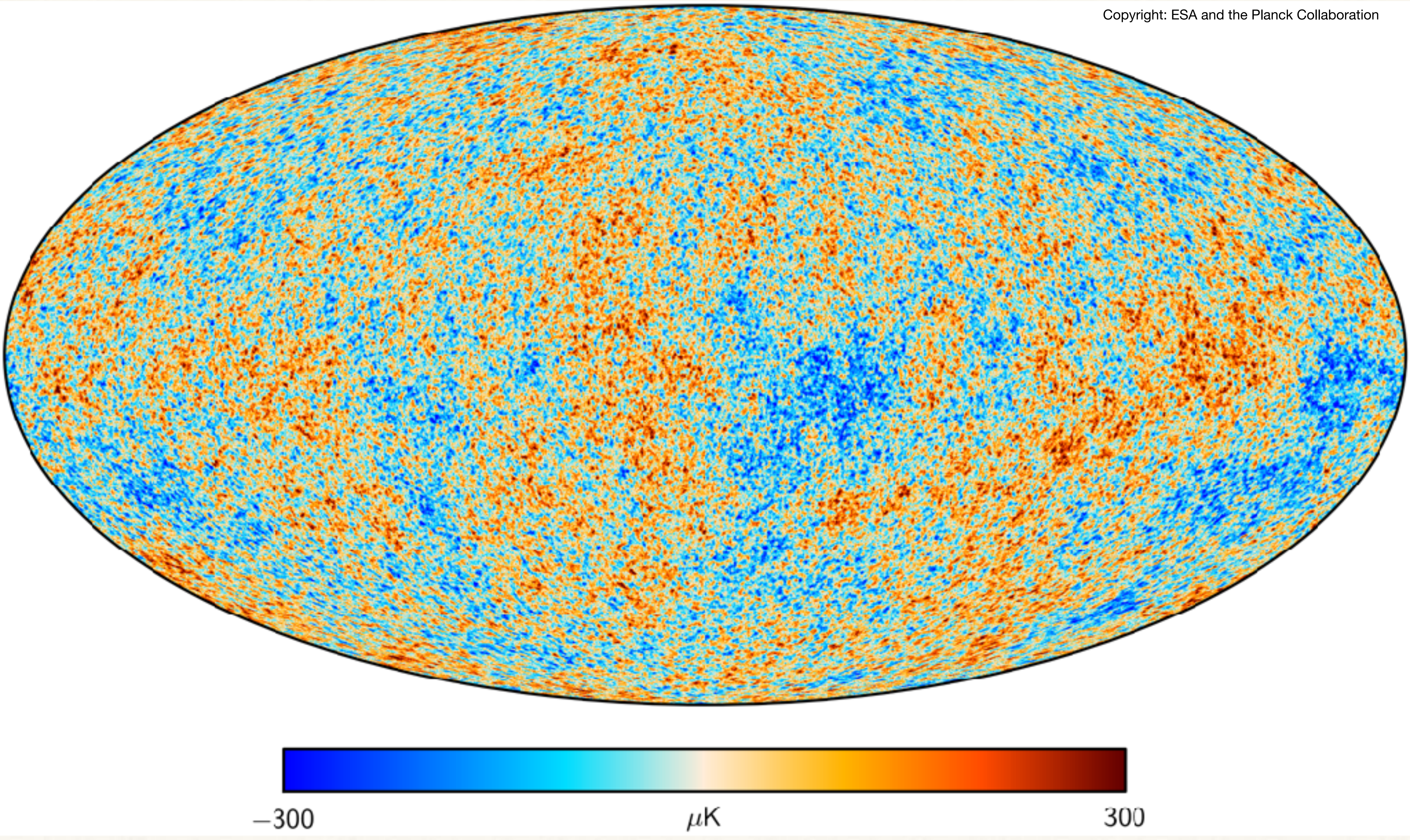
This radiation has been travelling to us for nearly 14 billion years What colour was it when it was emitted?

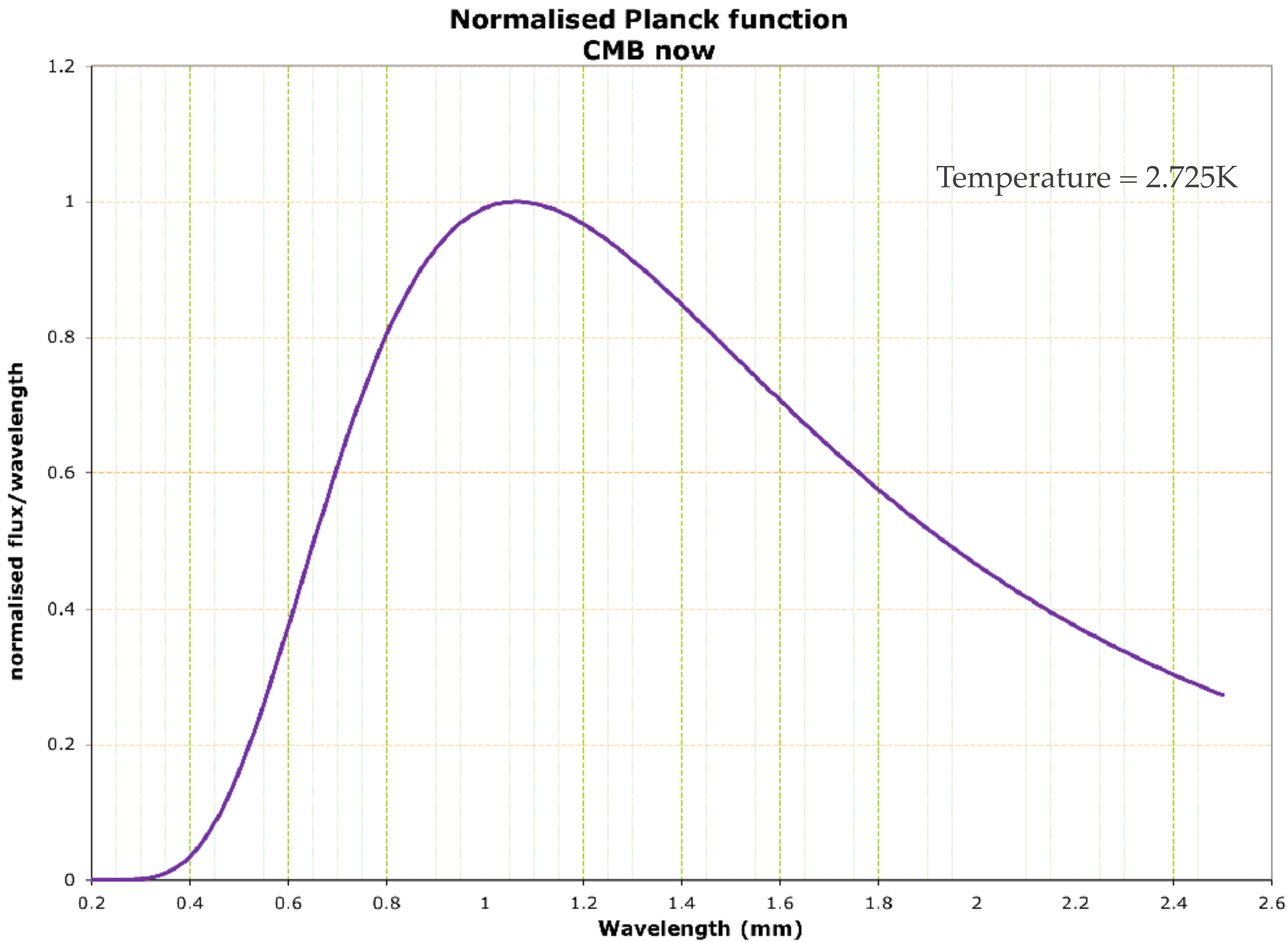


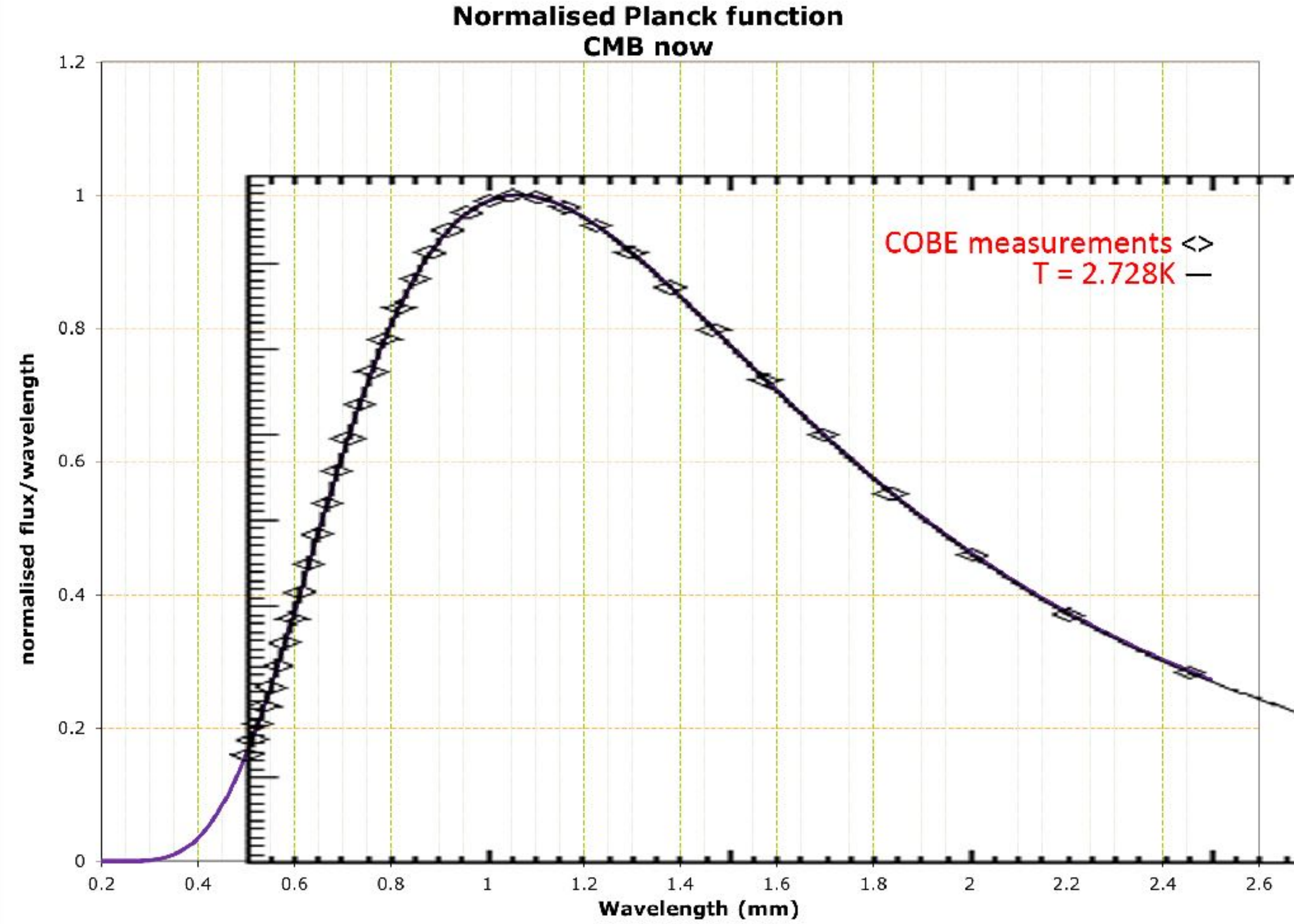
Wikimedia Commons

All-sky map of the CMBR measured by the Planck satellite (ESA) and published in 2013

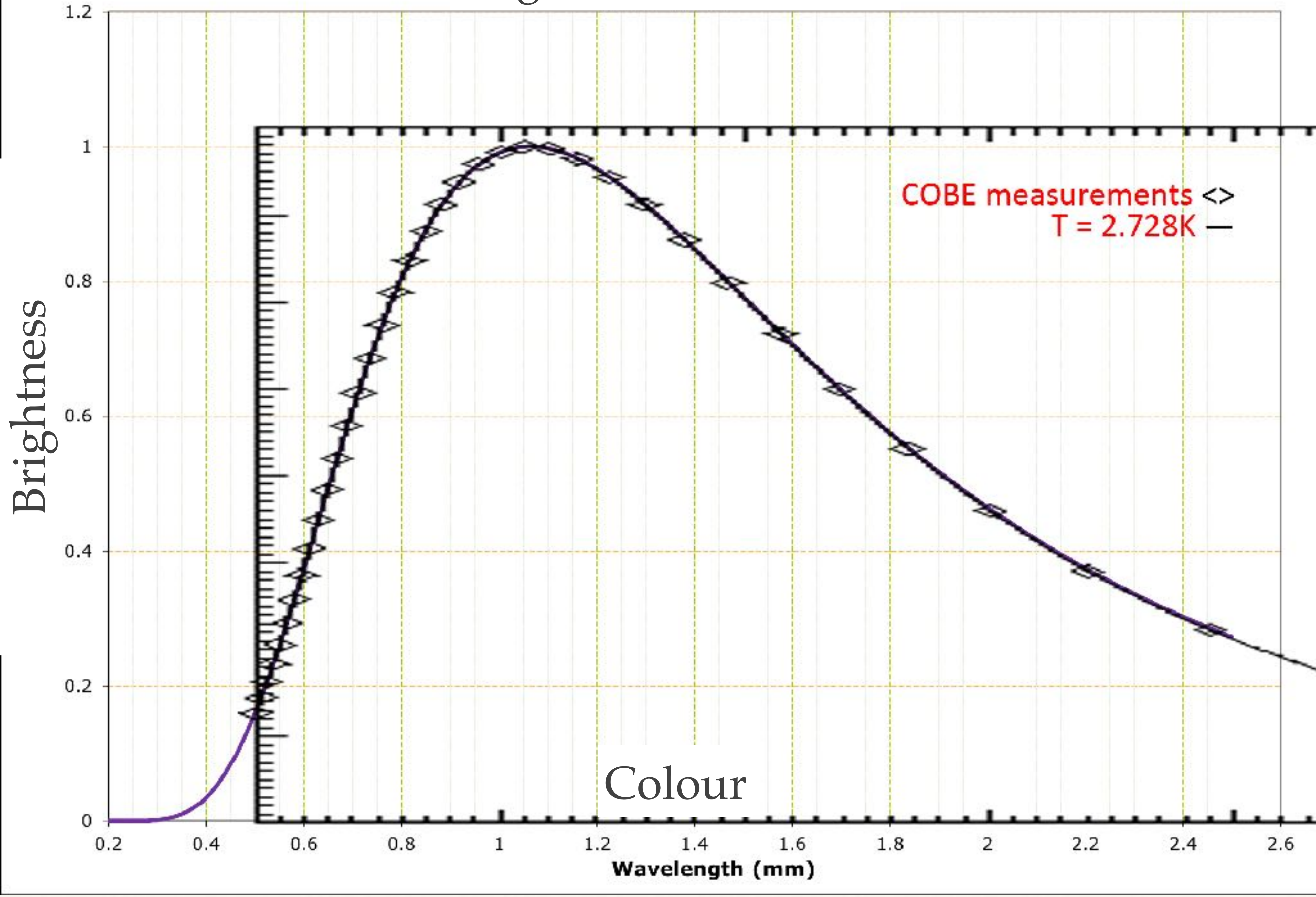
The colours represent tiny temperature differences imprinted on the young Universe by quantum fluctuations



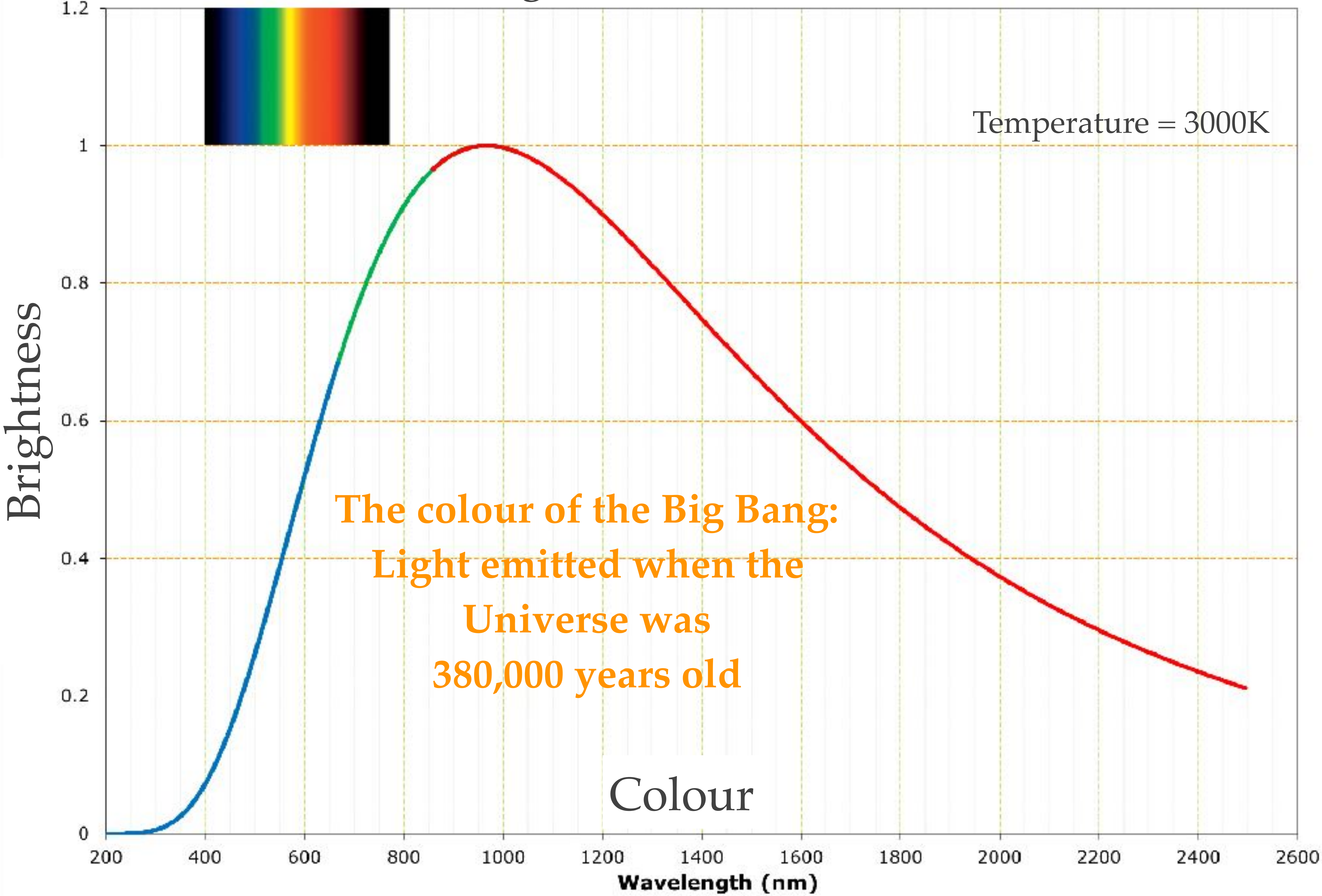

Normalised Planck function
CMB now
Temperature = 2.725K
normalised flux/wavelength
Wavelength (mm)
0
0.2
0.4
0.6
0.8
1
1.2
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6


Normalised Planck function
CMB now
COBE measurements <>
T = 2.728K —
normalised flux/wavelength
Wavelength (mm)
1.2
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6

Brightness vs. Colour

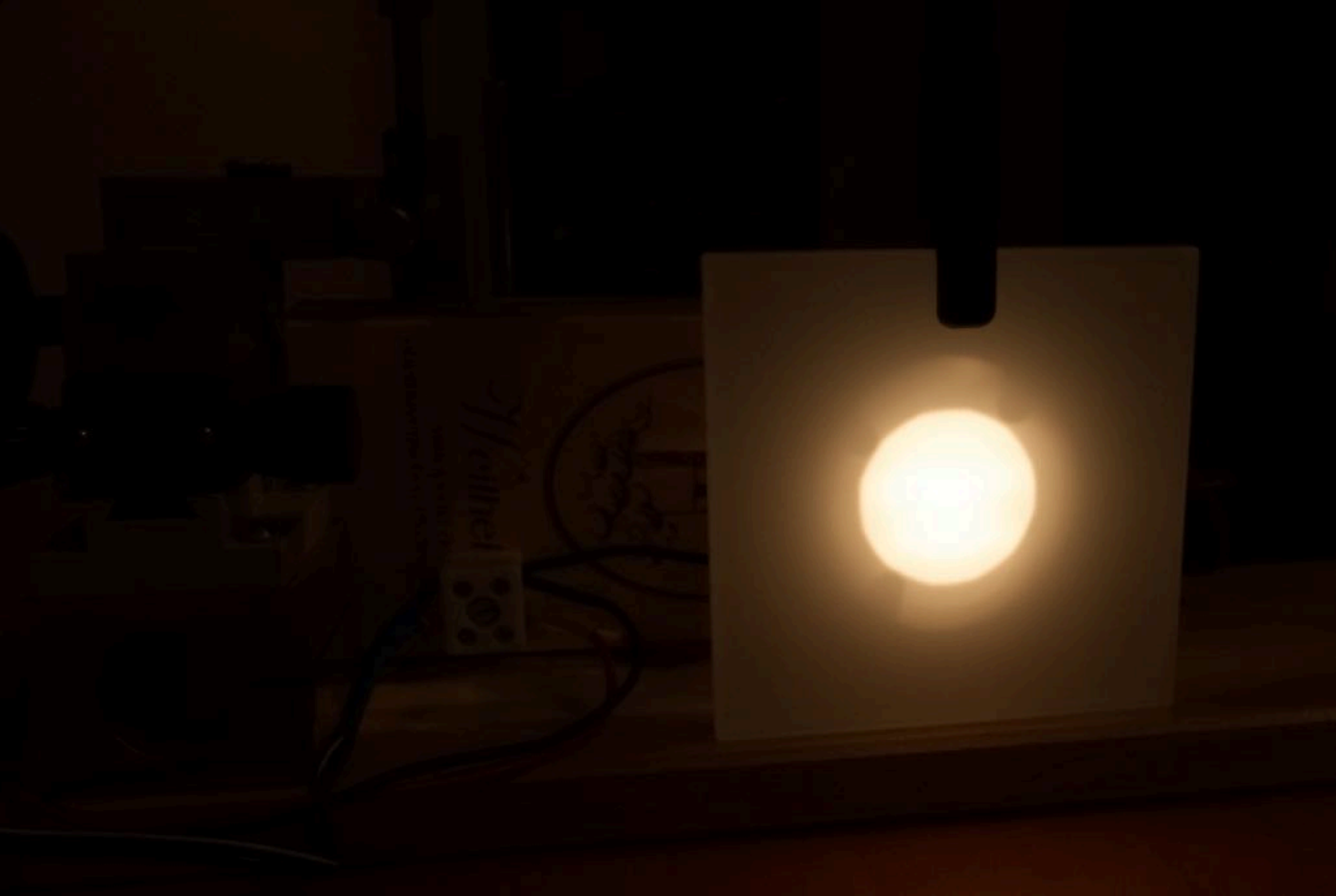


Brightness vs. Colour

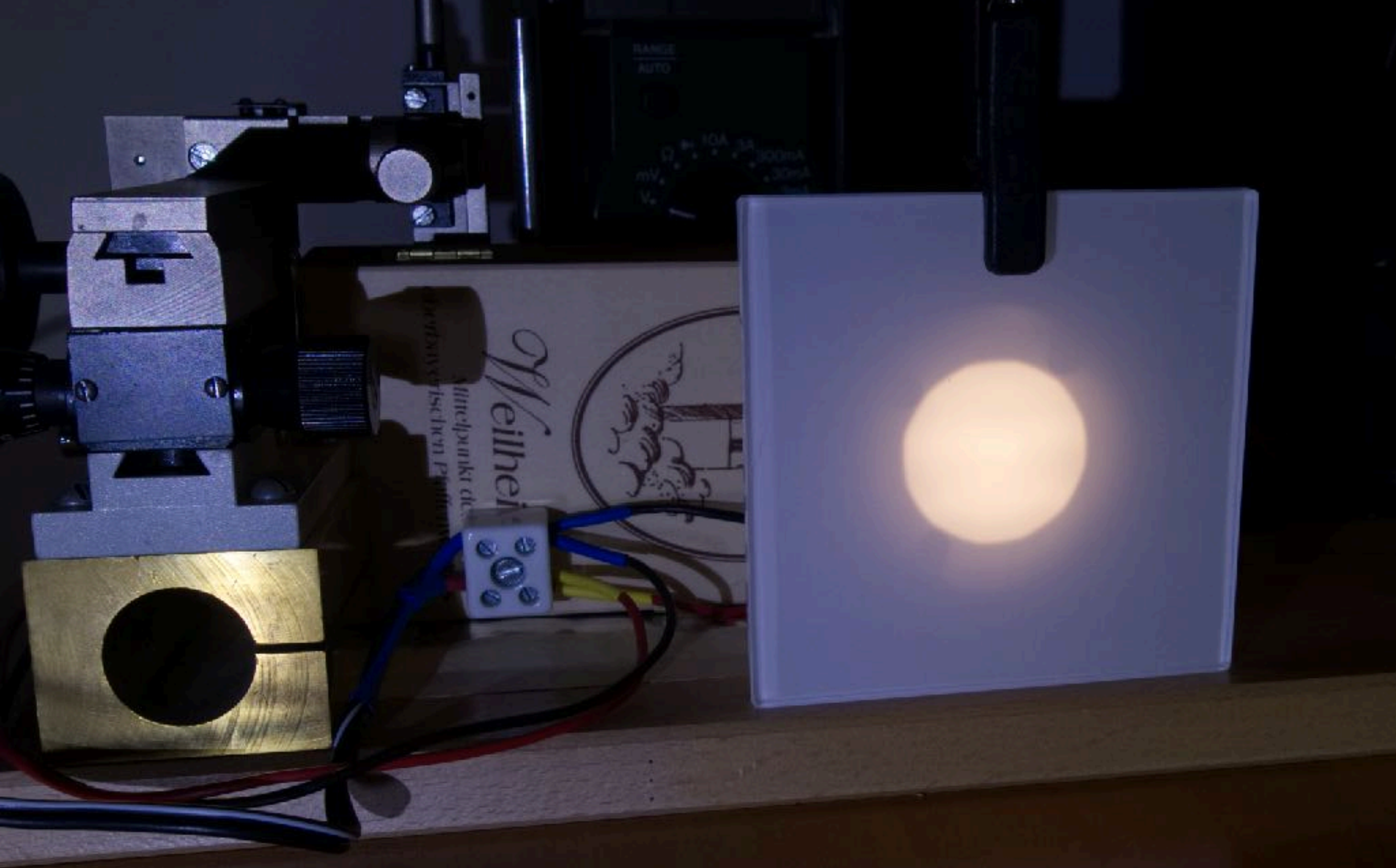



HALOGEN
DISPLAY/OPTIC
LAMP
OSRAM

The colour of the Big Bang at 380,000 years



The colour of the Big Bang at 380,000 years
Compared with sunlight

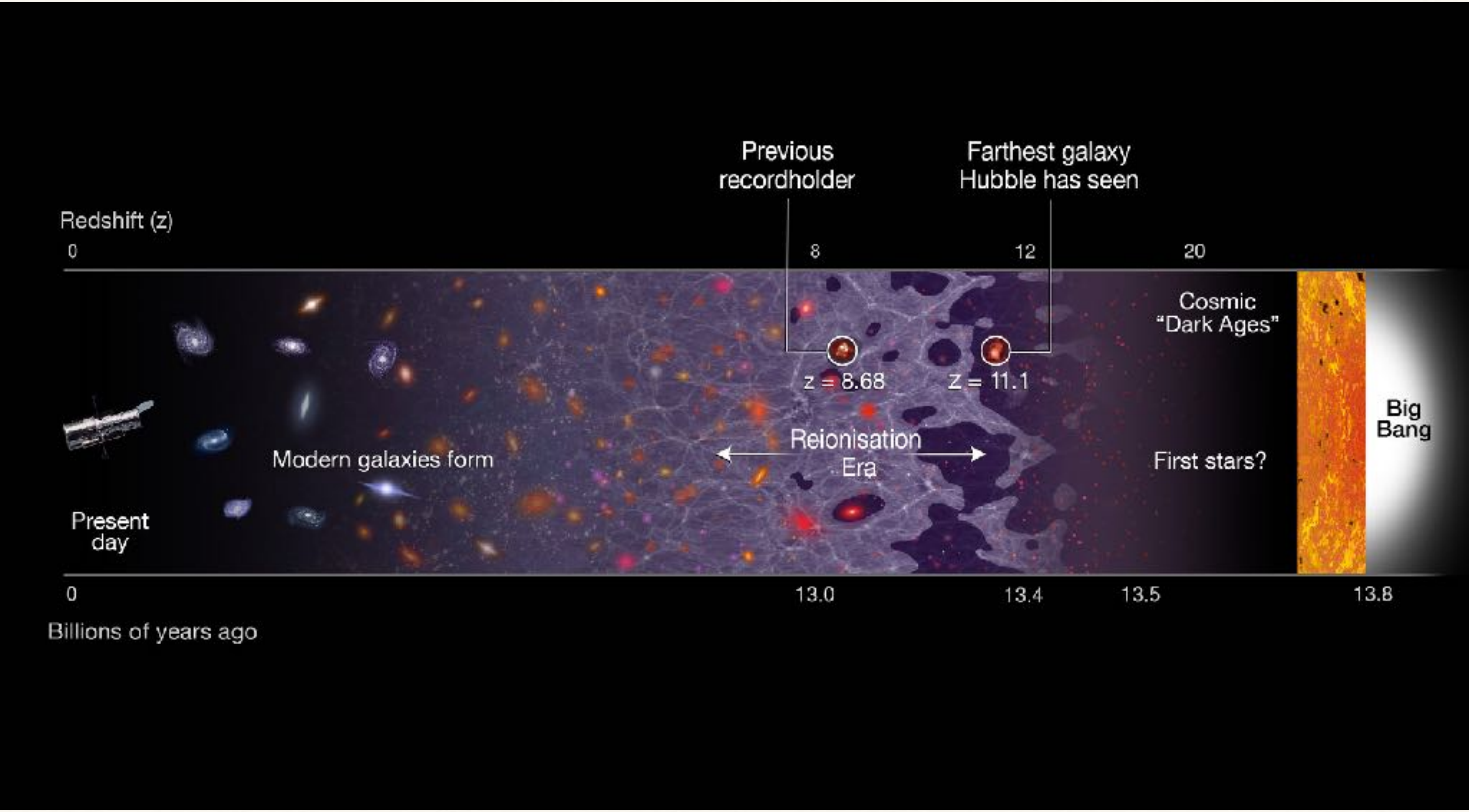


The most distant galaxy

Video at: https://www.spacetelescope.org/videos/heic1604a/ Credit: NASA, ESA, and G. Bacon (STScI)

GN-z11, Oesch et al. (2016): WFC3 Grism

Penetrating to the era of the first stars
The first elements heavier than helium being forged



Our local neighbourhood

https://www.eso.org/public/images/potw1834a/ Credit: P. Horálek/ESO

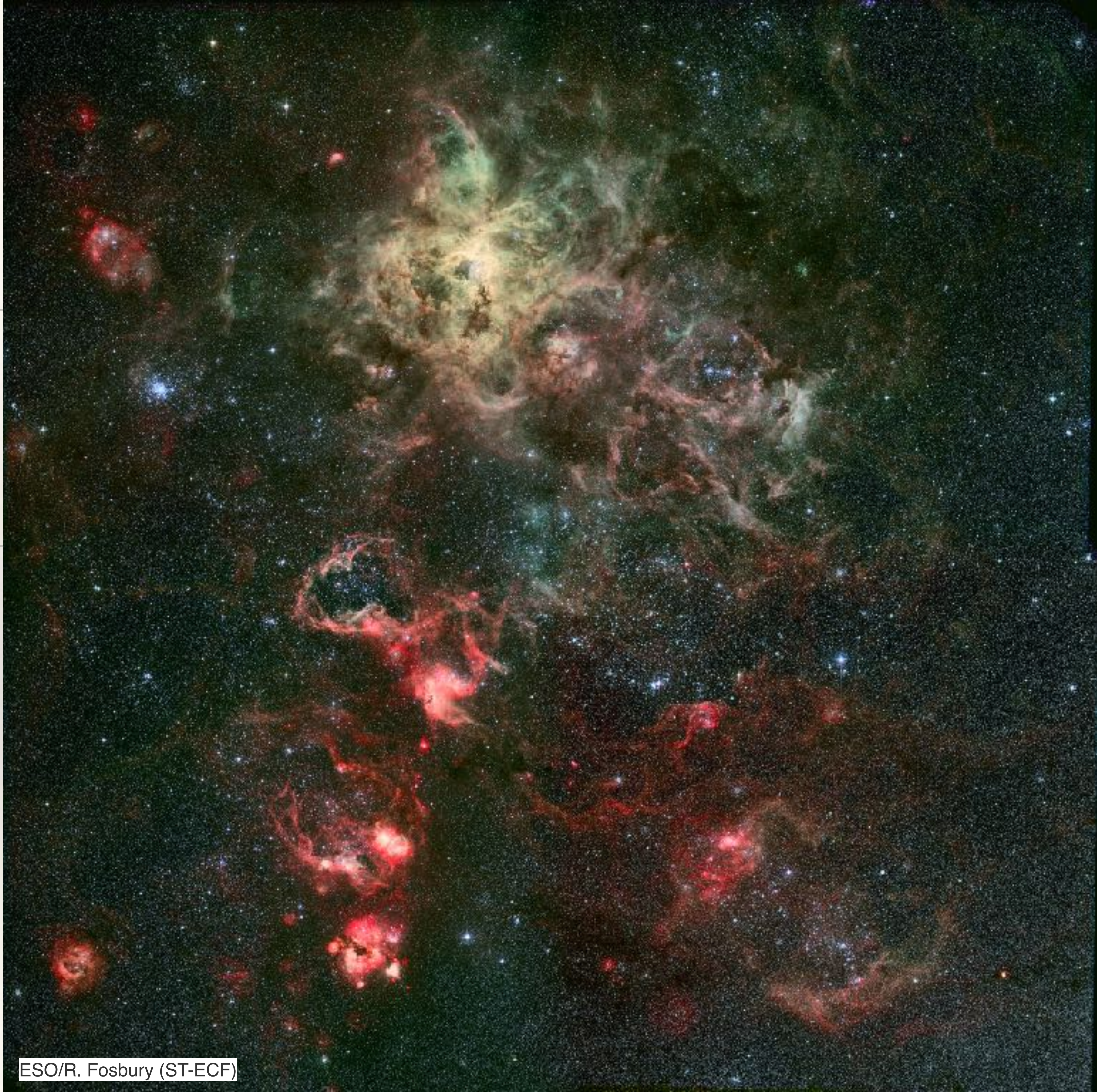
Where we find the 'fossil' record of the distant past

Our local element factory

The Tarantula nebula

Time sequence of star formation and recycling

Four colour filters:
B, V, [OIII], H-alpha



Our local element factory

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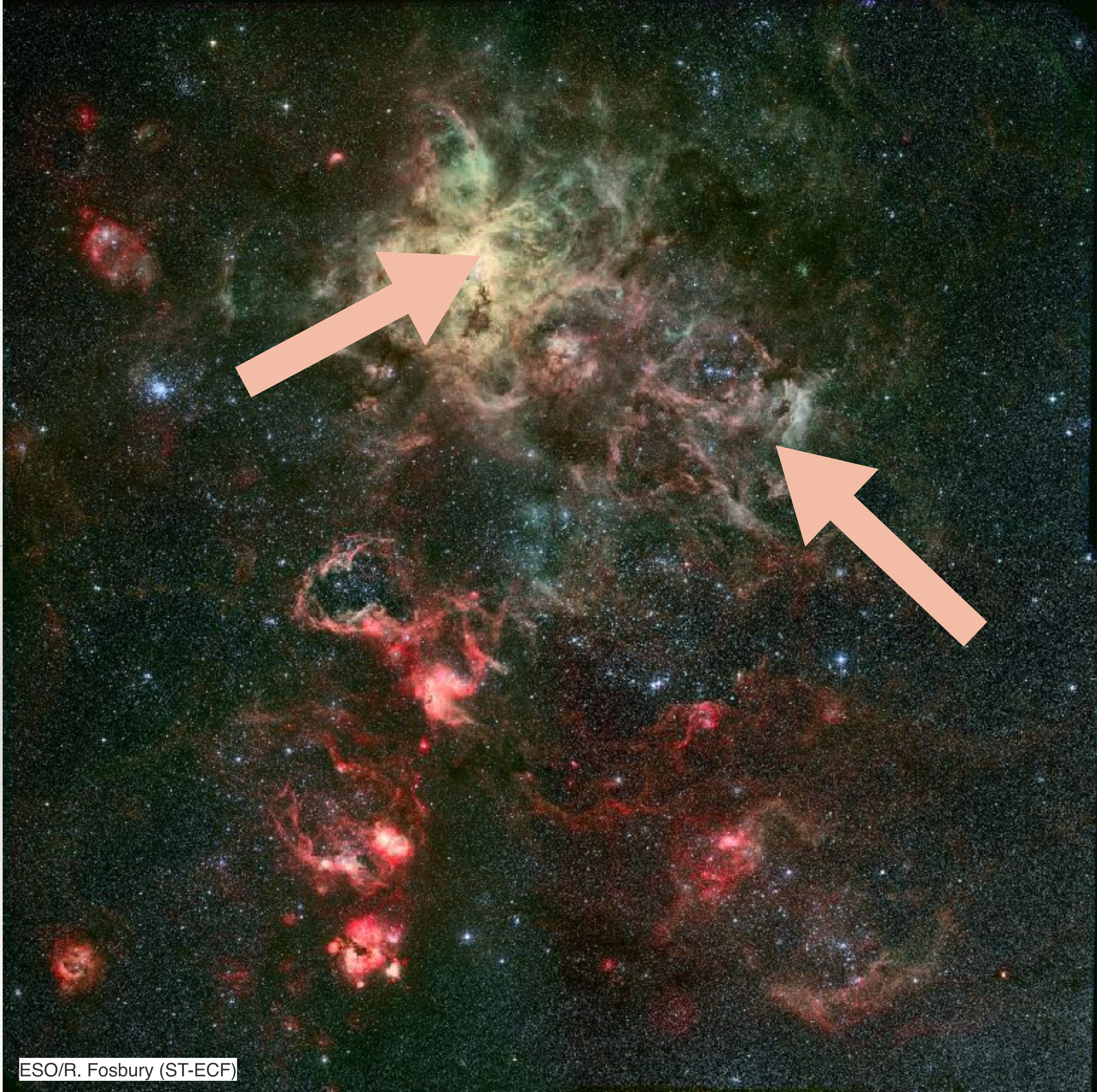
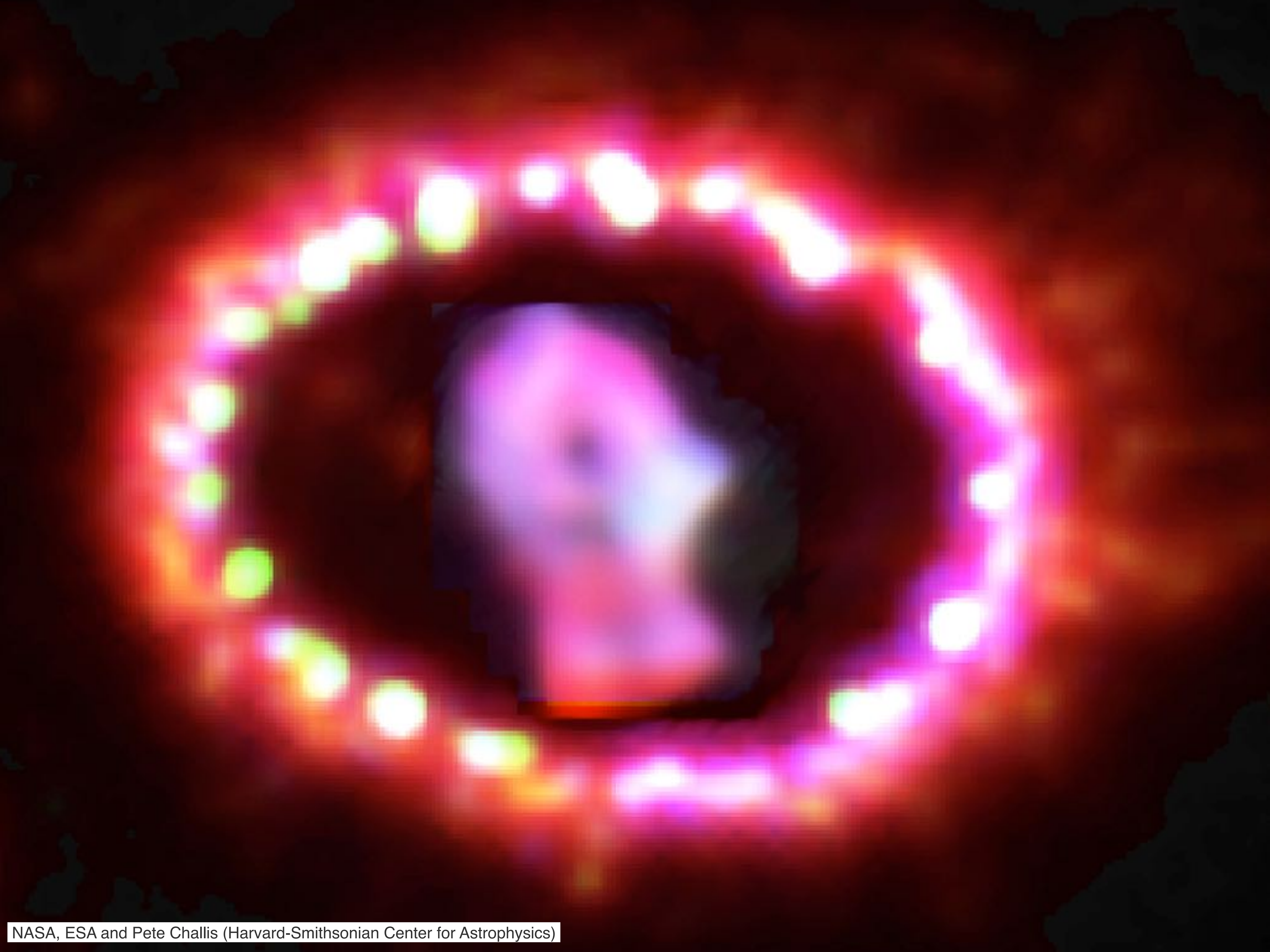
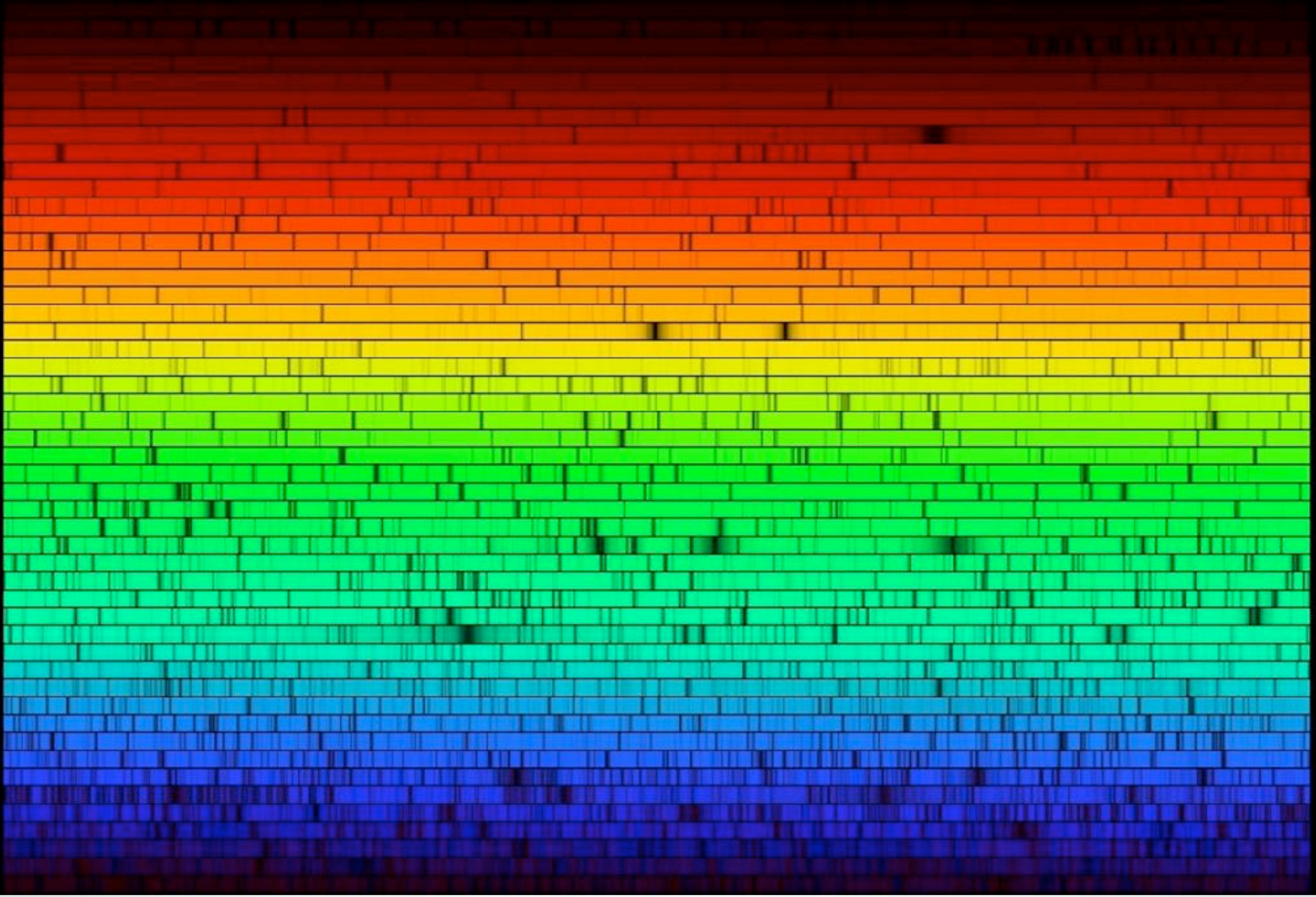


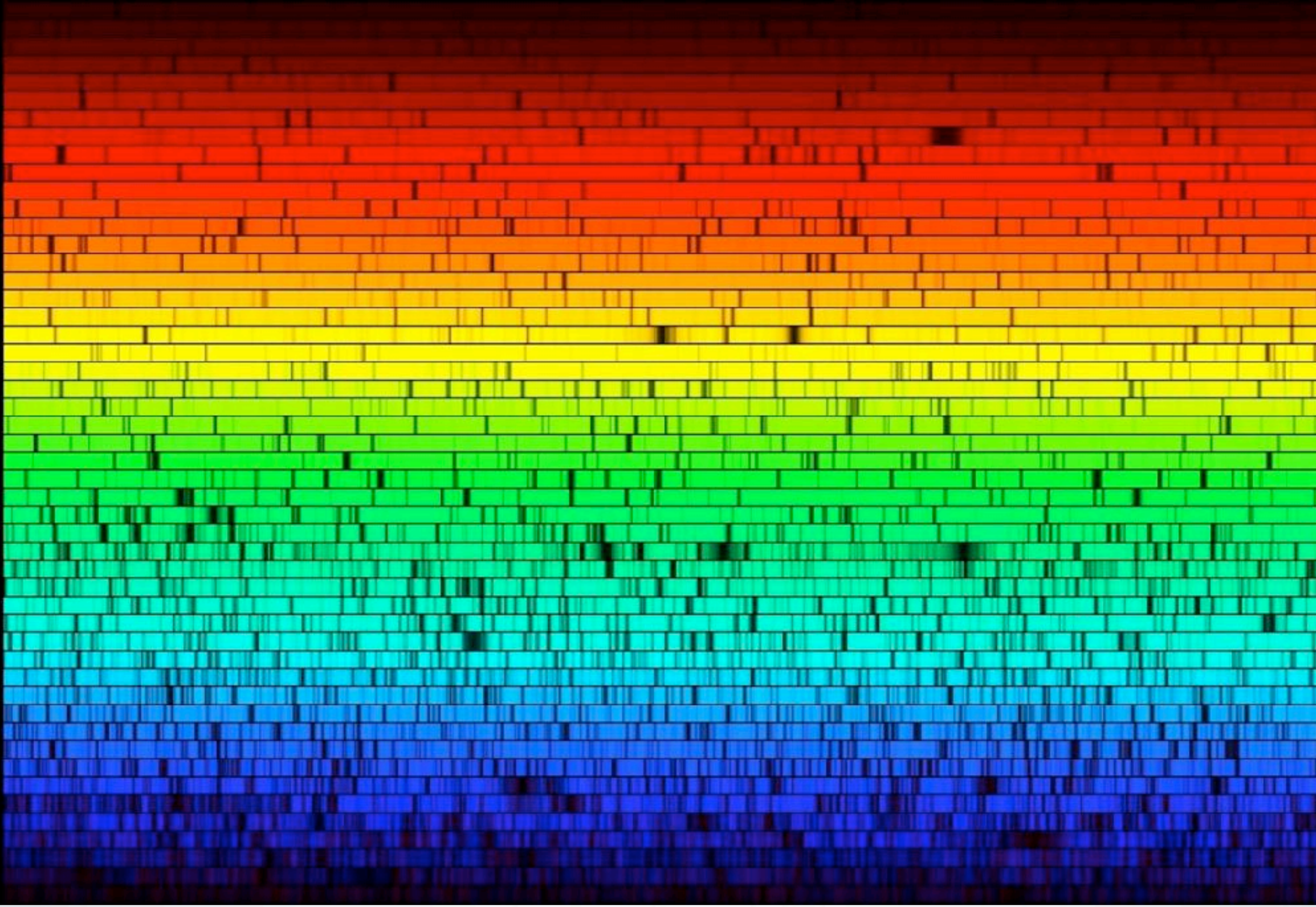


NASA, ESA and Pete Challis (Harvard-Smithsonian Center for Astrophysics)



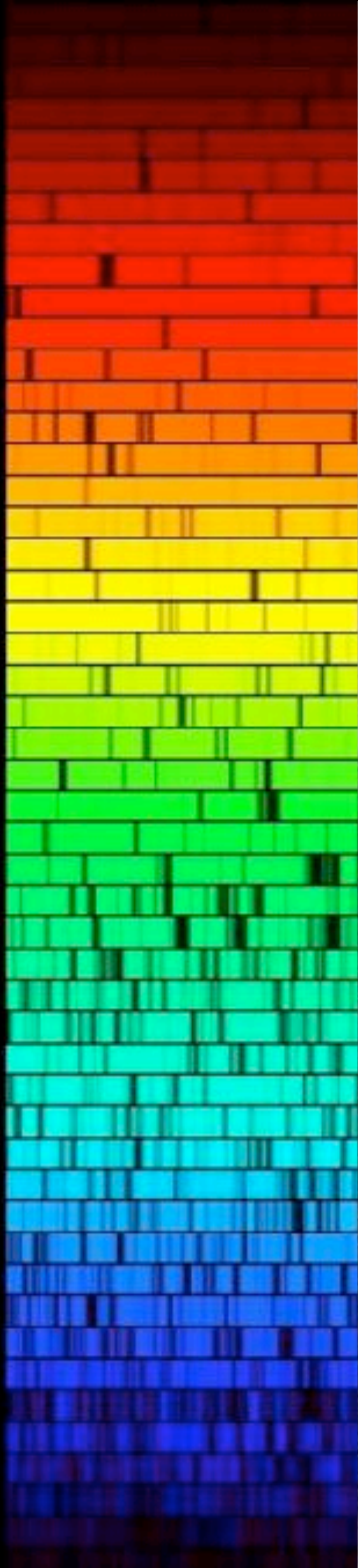
Courtesy NOAO

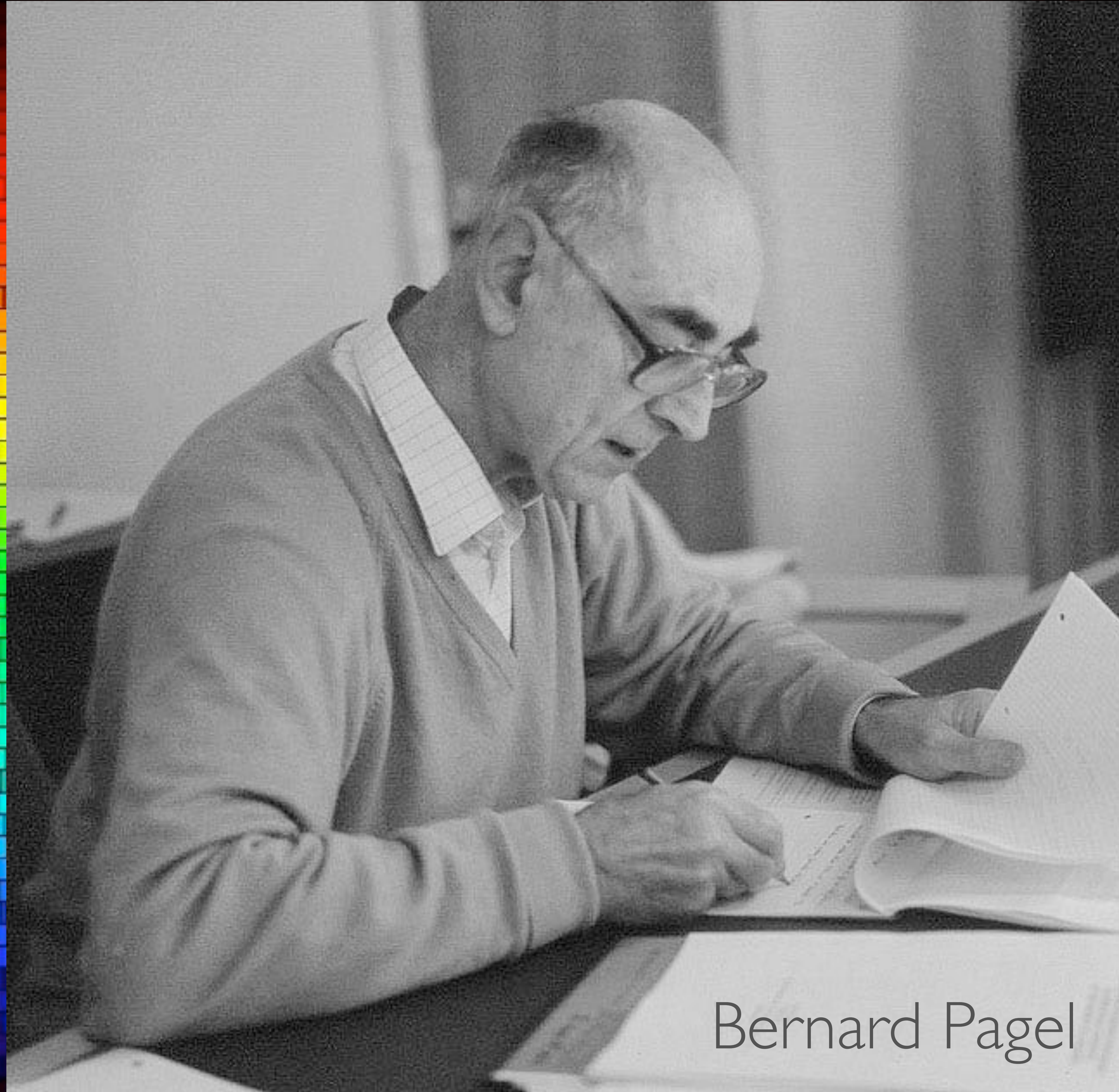
Sun

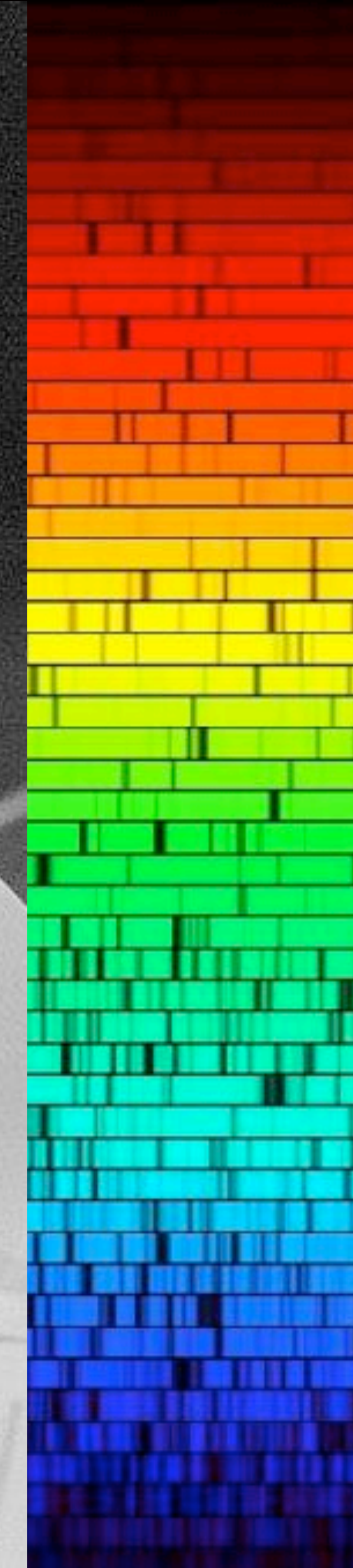


Courtesy NOAO

Arcturus (brighter but cooler)







Courtesy NOAO

Arcturus (brighter but cooler)

William Henry Fox Talbot and the Foundations of Spectrochemical Analysis: Study at Lacock

Building the elements

What the colours tell us

When stars explode at the end of their lives, they ‘export’ the elements they have ‘manufactured’ to form the next generation of stars and planets.

The colours of the explosion remnants reveal the ‘catalogue’ of products.

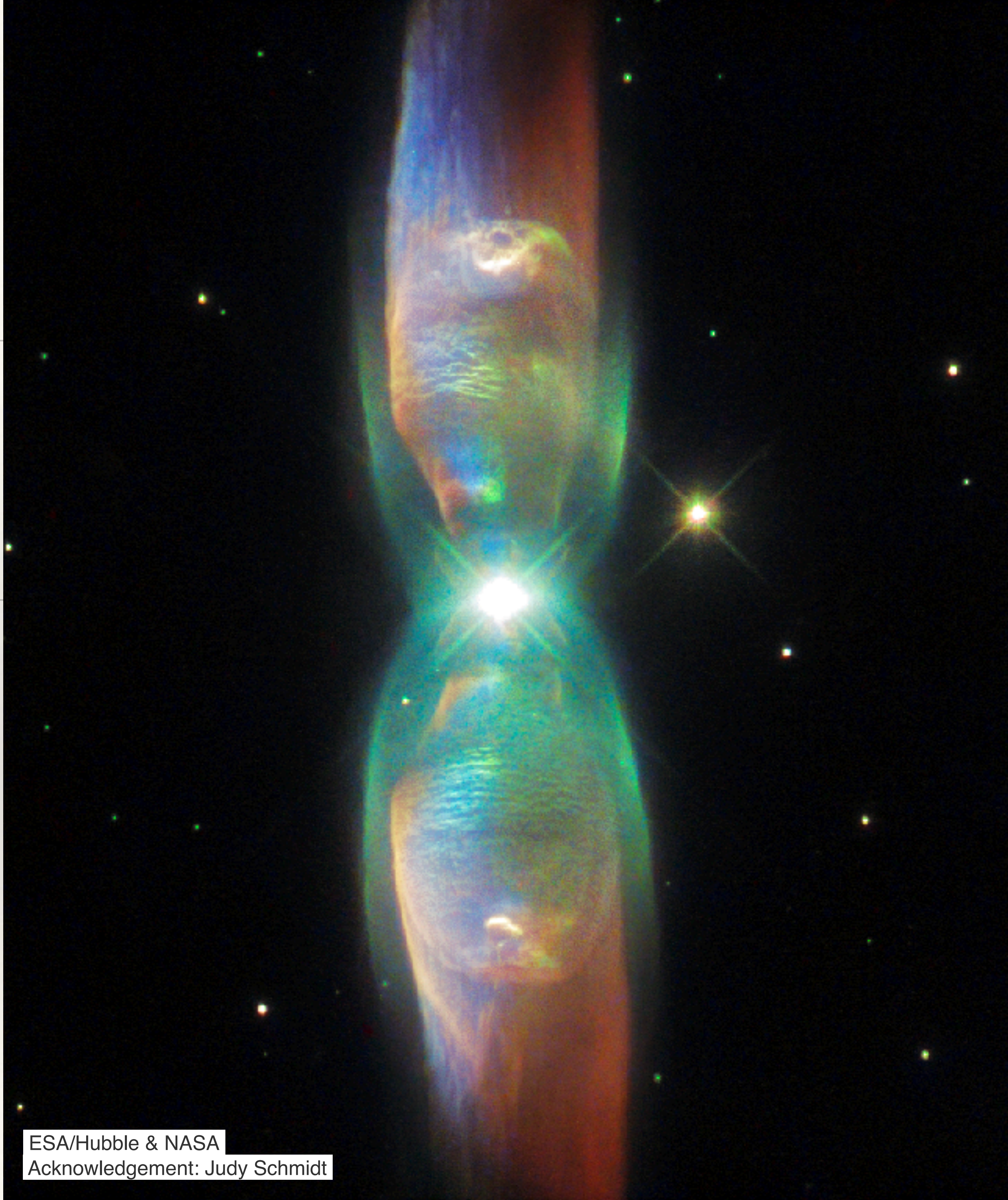
The Veil nebula in Cygnus
A supernova remnant

A planetary nebula

The Twin Jet nebula

Recycling at the death of a low-mass star like the Sun: actually this object is a binary star system

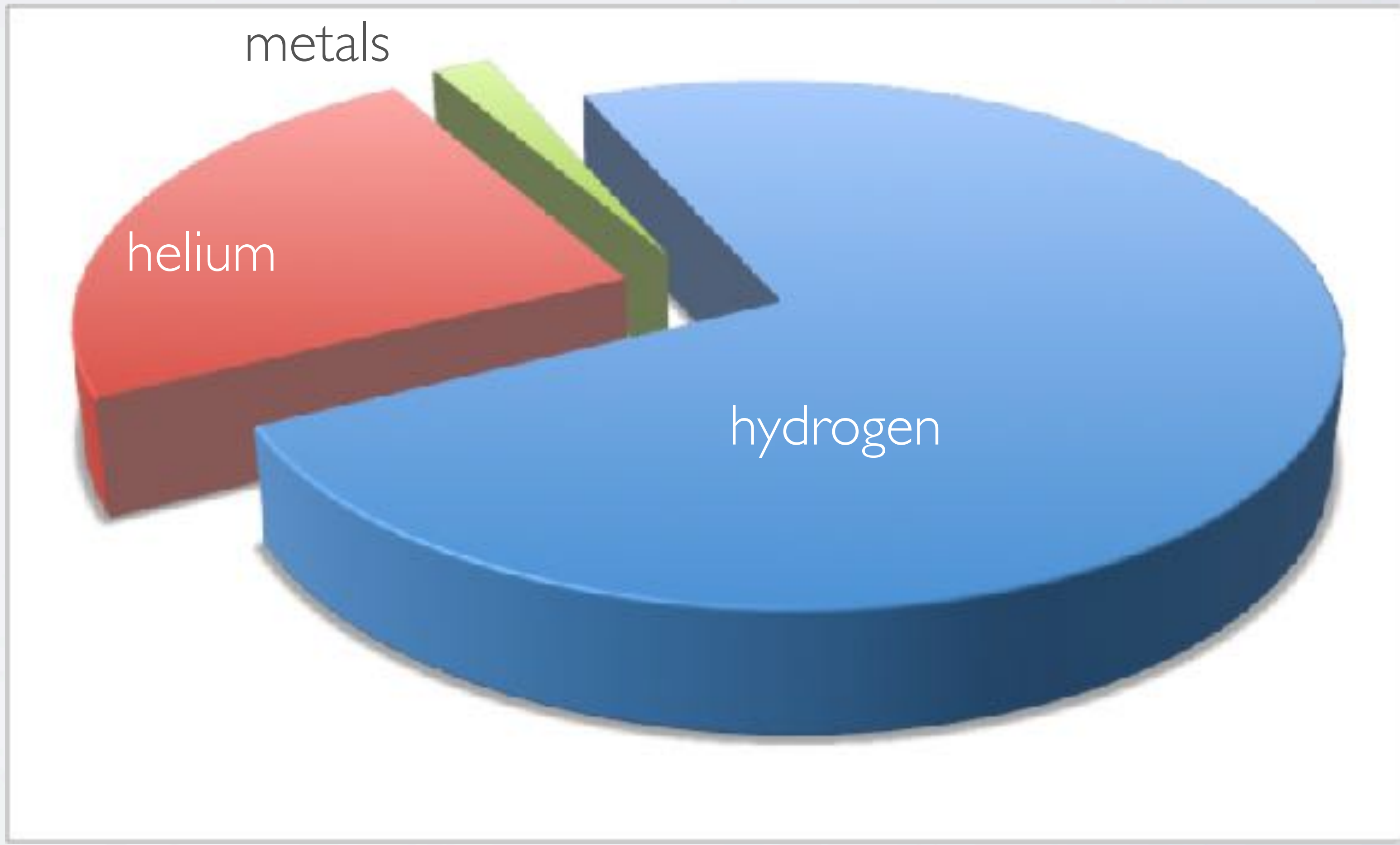
Three colour filters:
V, [OIII], [SII]



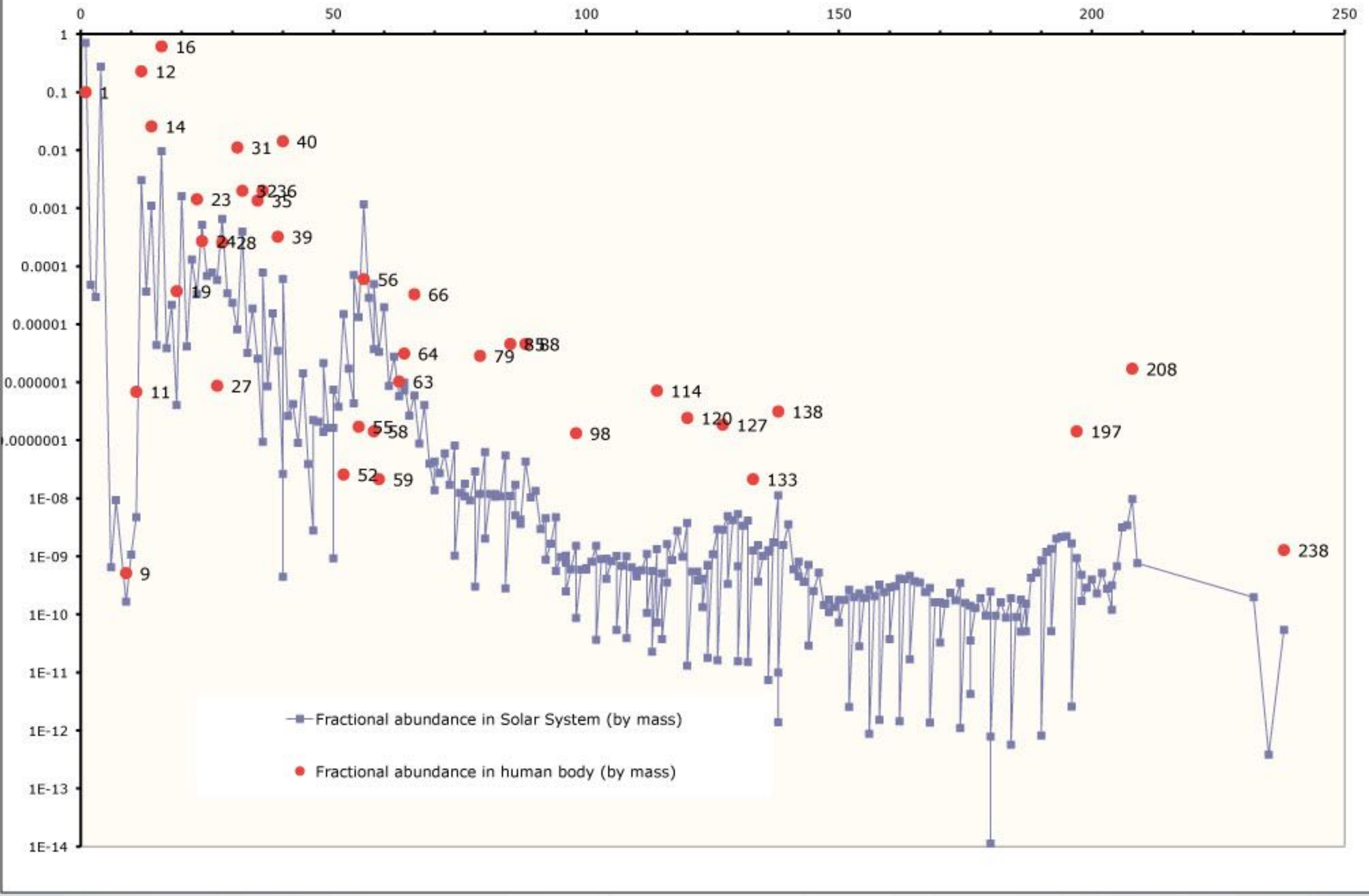
By doing 100 years of spectroscopy and detailed studies of samples from the Solar System, geophysicists and astronomers have built up a table containing the
"Cosmic abundance of the elements"

This varies in detail with time and place but the pattern is pretty similar (except at very early epochs)

Nowadays, we have →



Number of protons + neutrons in the nucleus



The principal players

Particles

 Proton (p): nucleus of hydrogen atom, electric charge +1

 Neutron (n): bit like a proton but with charge 0

Electron (e): nearly 2000 times less massive than proton, charge -1

 Photon (γ): no mass or charge but carries energy at “light speed”

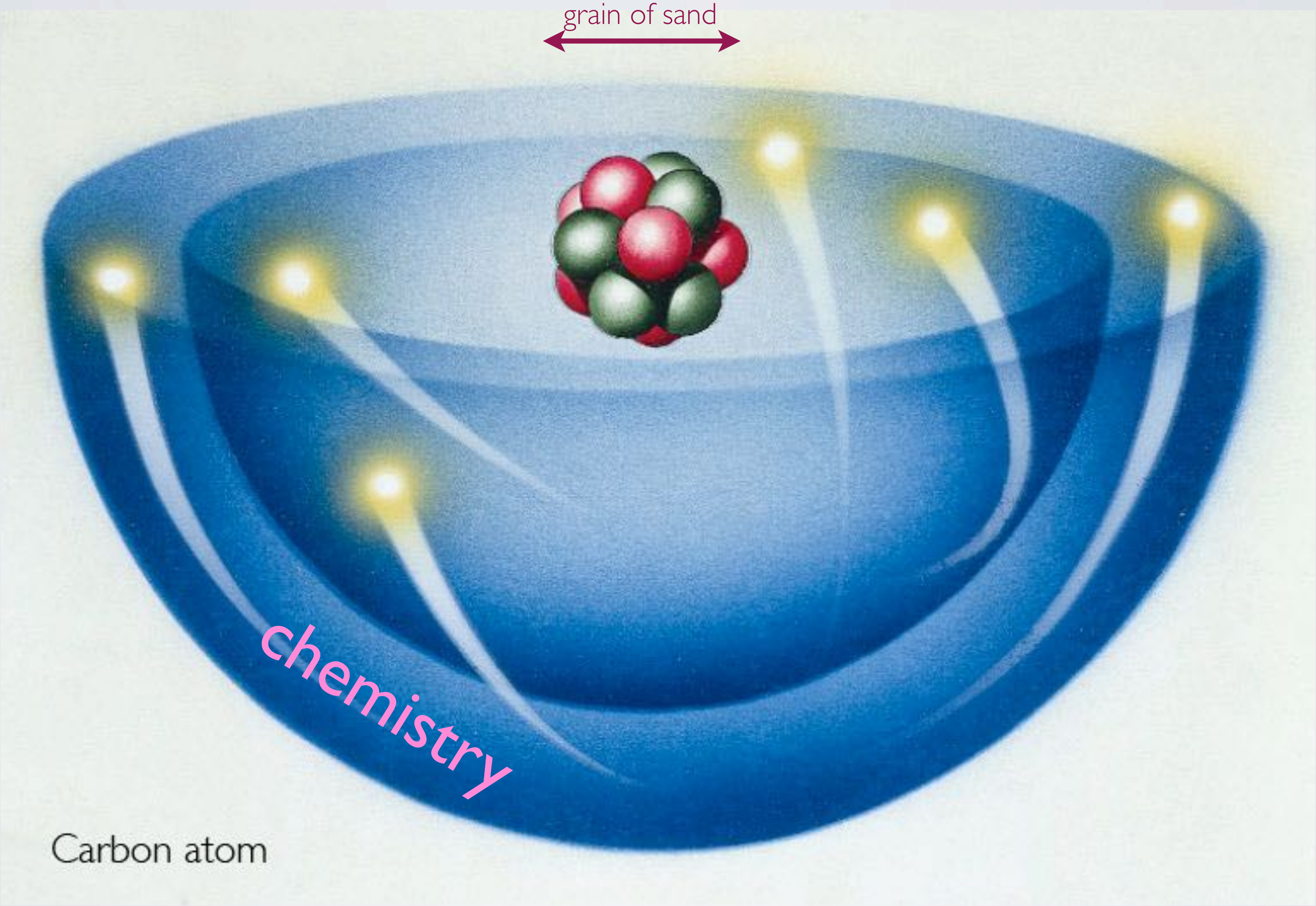
Neutrino (ν): little mass, does not like to interact with anything*

 Alpha-particle (α) = helium nucleus = 2p + 2n, charge +2

* trillions pass through your body every second

AN ATOM

Queen Square



To play alchemist and transmute* elements, we need to put protons and neutrons together (*fusion*) or split them apart (*fission*)

The story of how to do this forms our 20/21 century "Creation Myth"

It took well over a century to figure it out

* *transform from one to another*

REVIEWS OF
MODERN PHYSICS

VOLUME 29, NUMBER 4 — OCTOBER, 1957

Synthesis of the Elements in Stars*

E. MARGARET BURBIDGE, G. R. BURBIDGE, WILLIAM A. FOWLER, AND F. HOYLE

Kellogg Radiation Laboratory, California Institute of Technology, and Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California

"It is the stars, The stars above us, govern our conditions";
(*King Lear*, Act IV, Scene 3)

but perhaps

"The fault, dear Brutus, is not in our stars, But in ourselves,"
(*Julius Caesar*, Act I, Scene 2)

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* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

B²FH

107 pages — and one of the GREAT papers in astrophysics.
Fowler shared the Nobel prize for physics in 1983

Burbidge, Burbidge, Fowler and Hoyle
Took the stars and made them toil:
Carbon, copper, gold and lead
Formed in stars, is what they said.

Shell structure in a massive star

Nuclear ‘burning’ is happening at the shell boundaries

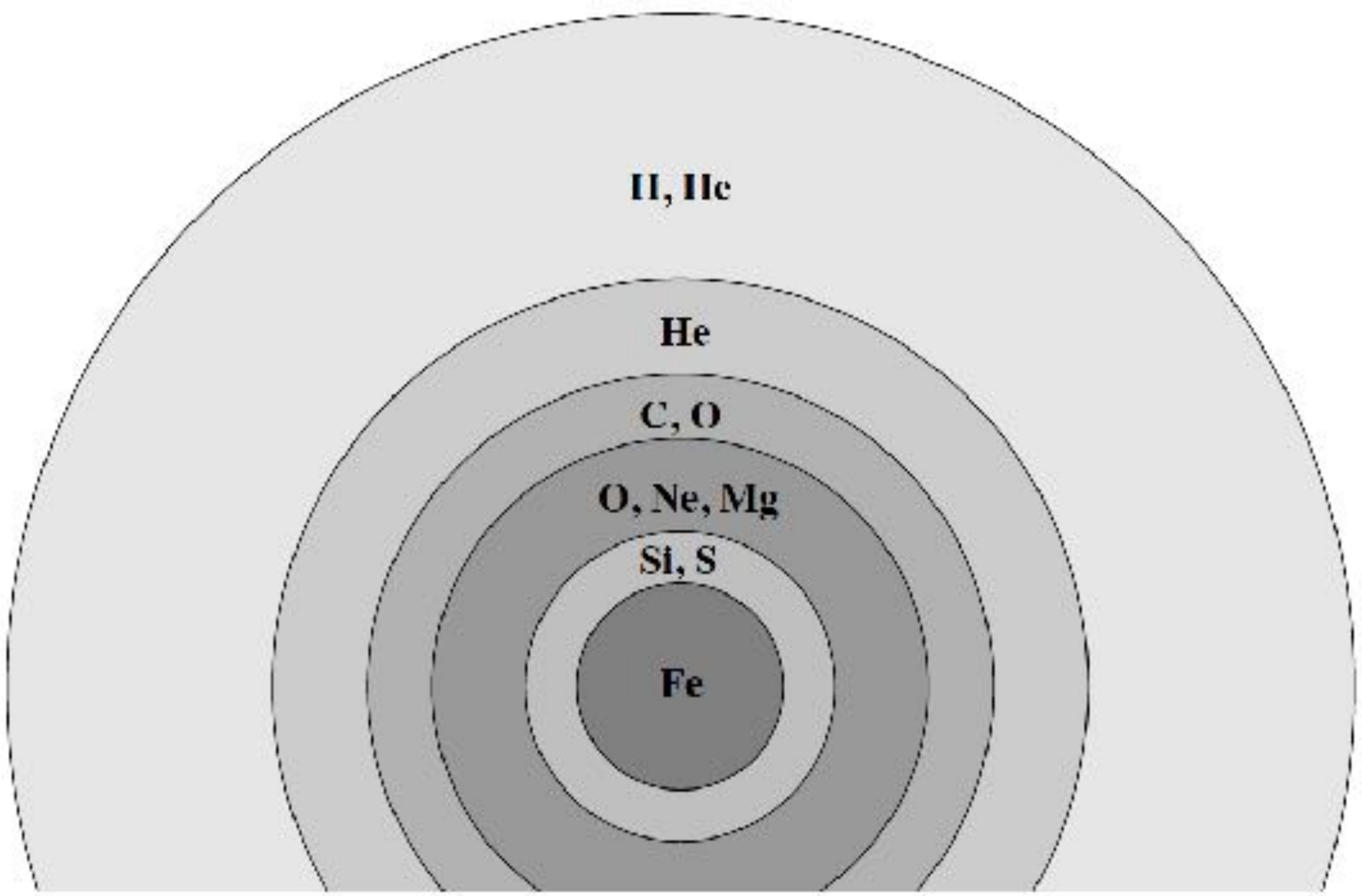
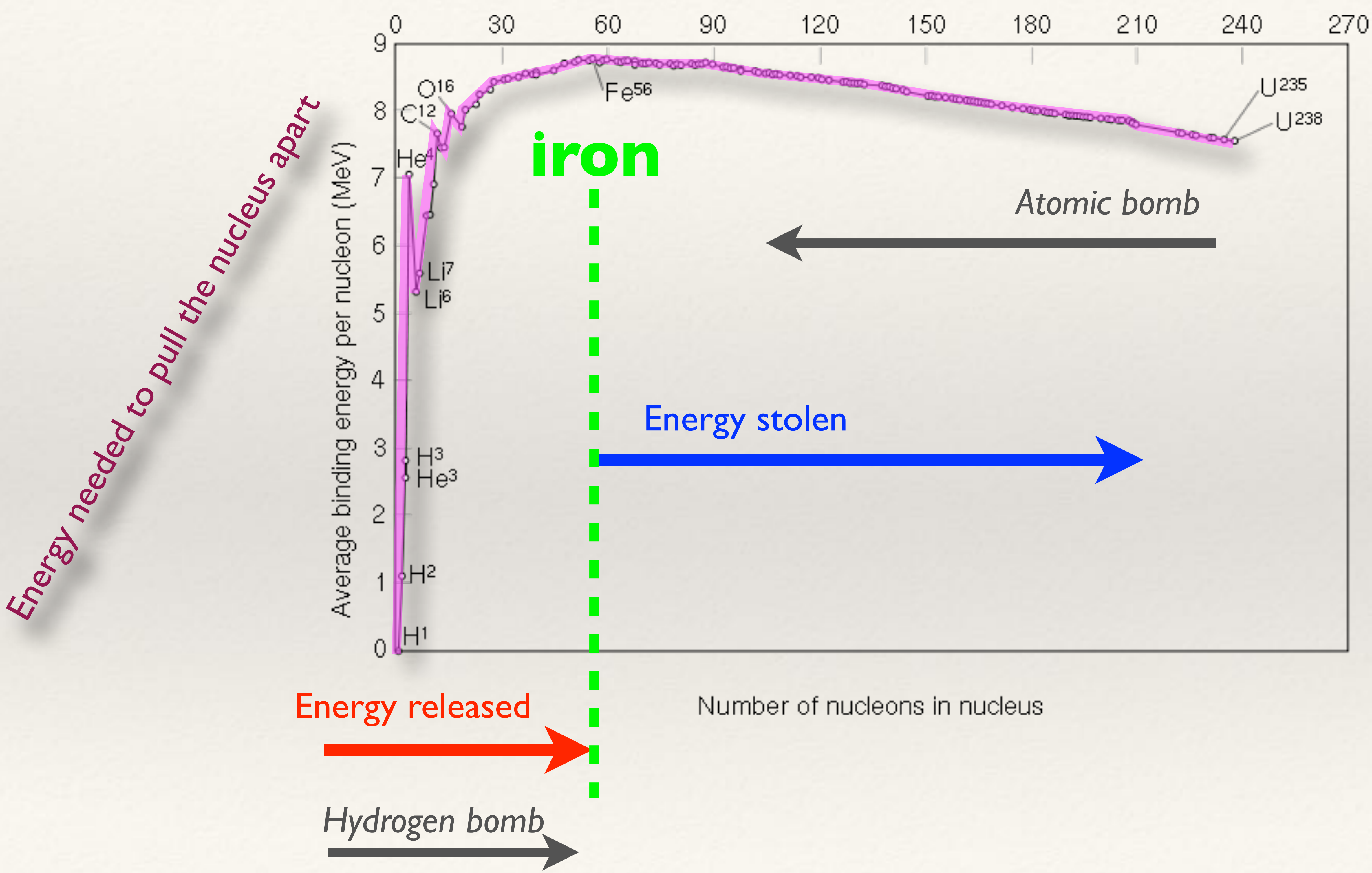
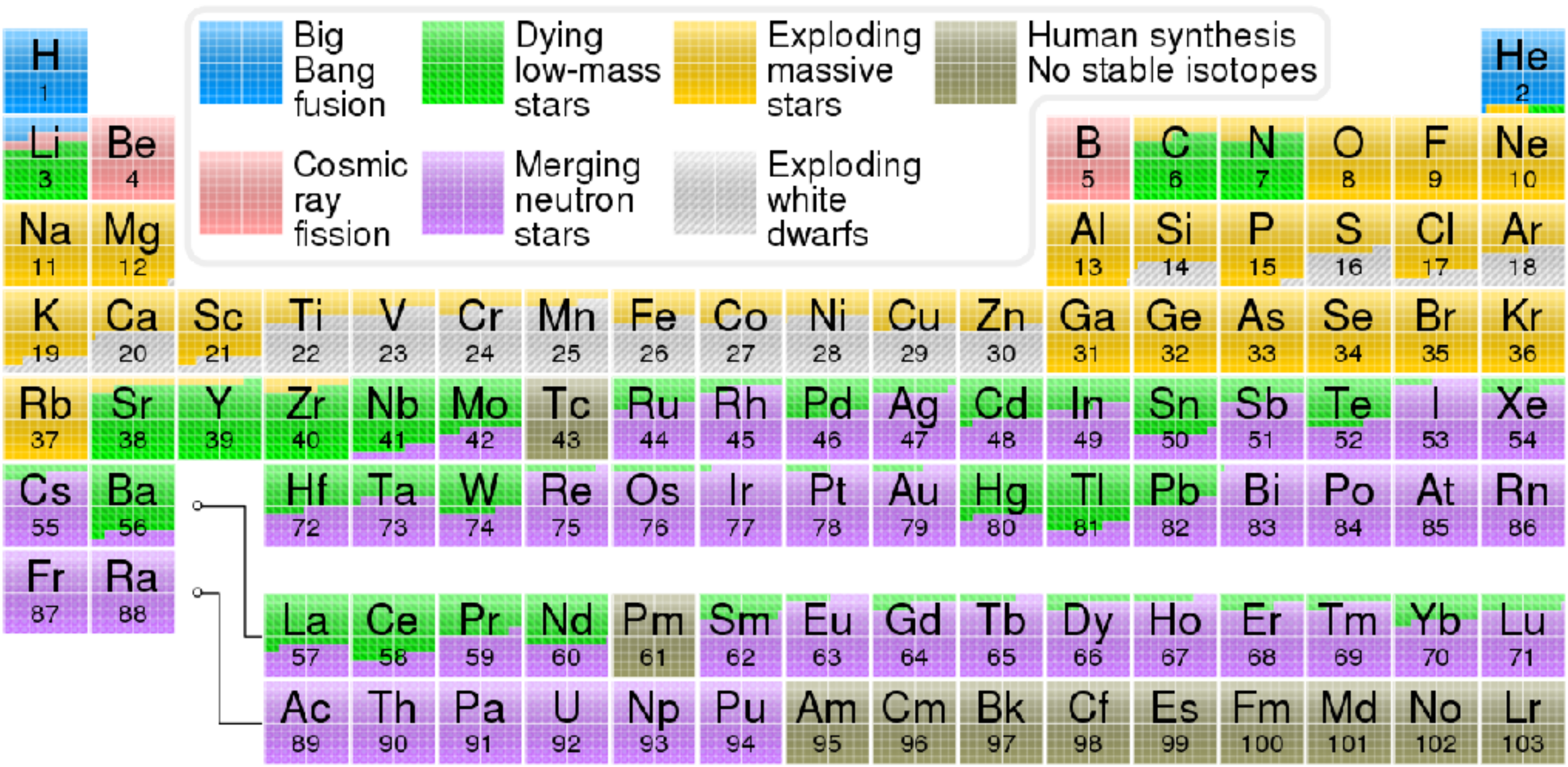


Figure 12.8. Schematic overview of the onion-skin structure of a massive star at the end of its evolution.

Norbert Langer, University of Bonn

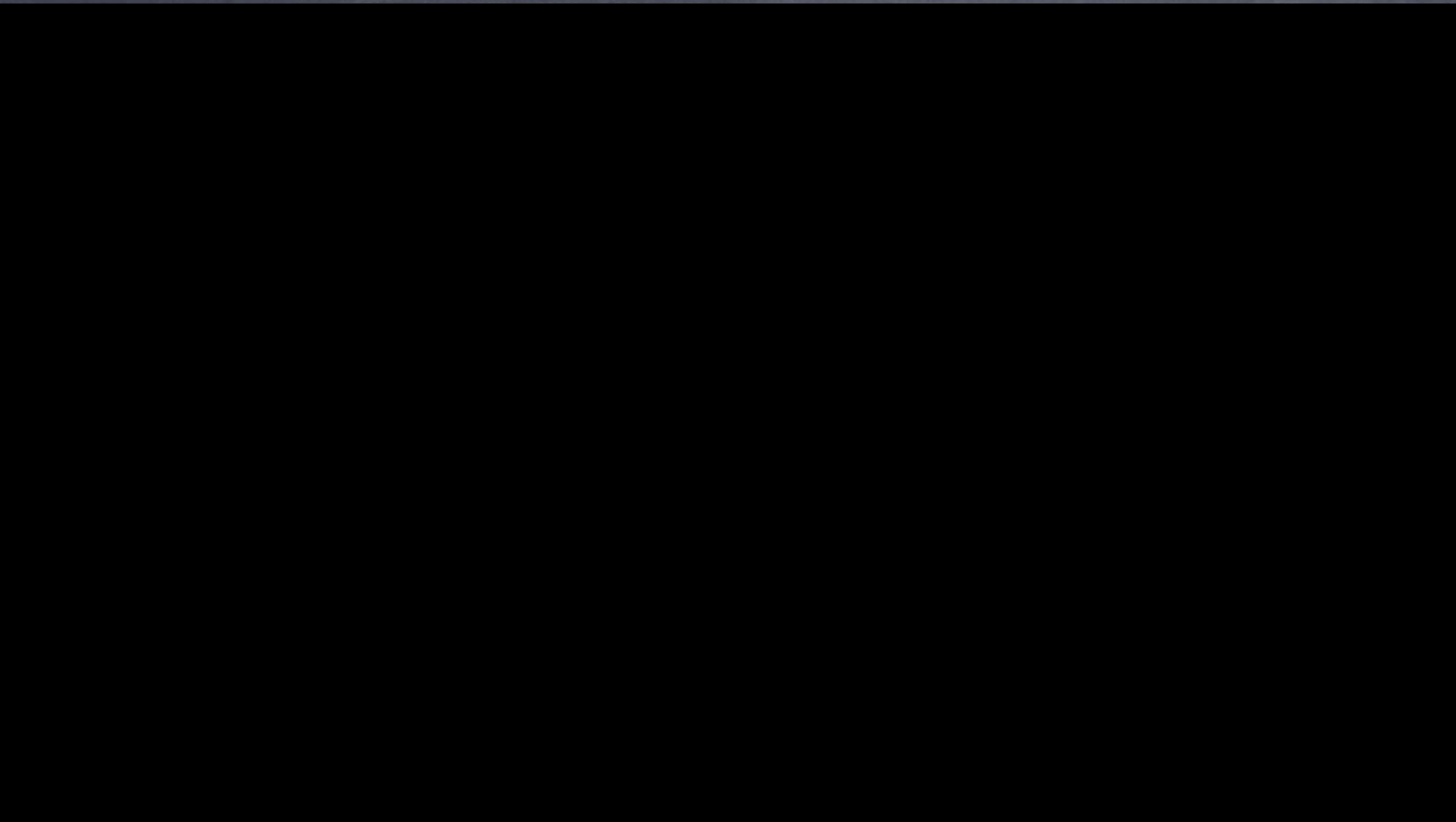
All you need to know about nuclear physics





Periodic table showing origin of elements in the Solar System

based on data by Jennifer Johnson at Ohio State University



Video and credit at: https://www.spacetelescope.org/videos/heic1717a/

Early times

The Lynx arc

A distant* galaxy studied in detail using a 'gravitational telescope' with a combination of Hubble and ground-based telescopes

* 5.7×10^{23} miles (570,000,000,000,000,000,000,000 or five hundred and seventy thousand trillion miles)

Fosbury et al. (2003)

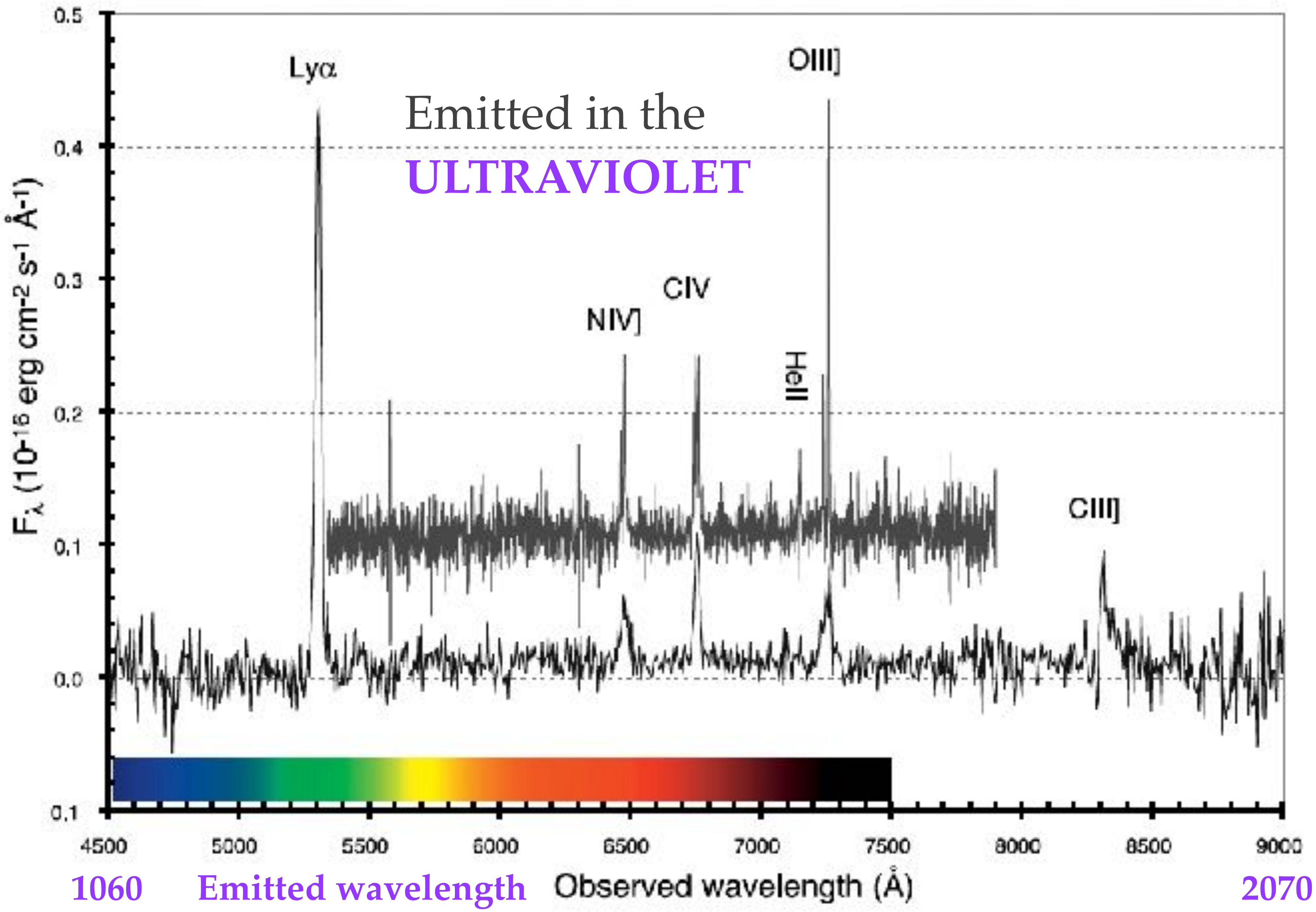


FIG. 2.—LRIS spectra of the arc. The higher resolution spectrum has been shifted by 0.1 units of the flux scale (10^{-16} ergs cm^{-2} s^{-1} Å^{-1}). Both spectra have been scaled by the photometric correction factors described in the text and so represent the sum of components A and B. [*See the electronic edition of the Journal for a color version of this figure.*]

thousand trillion miles)

Fosbury et al. (2003)

https://www.flickr.com/photos/bob_81667/7682569442/

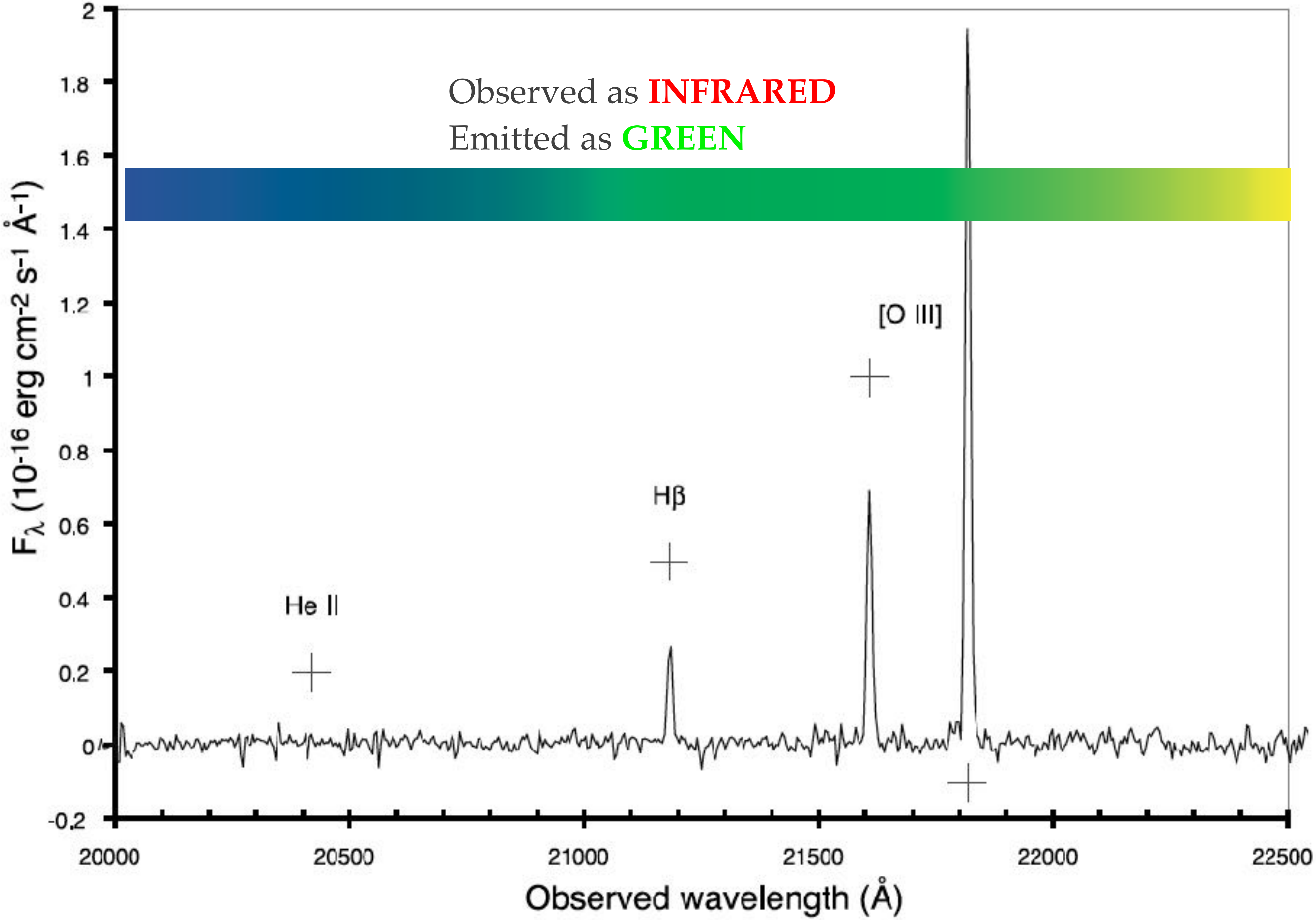


FIG. 4.—NIRSPEC *K*-band spectrum of the arc. Plus signs mark the positions of the He II, Hβ, and the [O III] lines.

THE ASTROPHYSICAL JOURNAL, 596:797–809, 2003 October 20

MASSIVE STAR FORMATION IN A GRAVITATIONALLY LENSED H II GALAXY AT $z = 3.357$[1,2,3]

R. A. E. FOSBURY[4]
ST-ECF, Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany; rfosbury@eso.org

M. VILLAR-MARTÍN AND A. HUMPHREY
University of Hertfordshire, Hatfield, Hertfordshire AL10 9AB, UK

M. LOMBARDI AND P. ROSATI
European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany

D. STERN
Institute of Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, Livermore, CA 94550

R. N. HOOK[5]
Space Telescope Science Institute, Baltimore, MD 21218

B. P. HOLDEN AND S. A. STANFORD
Department of Physics, University of California, Davis, CA 95616

G. K. SQUIRES
SIRTF Science Center, California Institute of Technology, Pasadena, CA 91125

M. RAUCH
The Observatories of the Carnegie Institution of Washington, 813 Santa Barbara Street, Pasadena, CA 91101

AND

W. L. W. SARGENT
California Institute of Technology, Pasadena, CA 91125
Received 2003 March 21; accepted 2003 July 4

ABSTRACT

The Lynx arc, with a redshift of 3.357, was discovered during spectroscopic follow-up of the $z = 0.570$ cluster RX J0848+4456 from the *ROSAT* Deep Cluster Survey. The arc is characterized by a very red $R-K$ color and strong, narrow emission lines. Analysis of *HST* WFPC2 imaging and Keck optical and infrared spectroscopy shows that the arc is an H II galaxy magnified by a factor of $\sim$10 by a complex cluster environment. The high intrinsic luminosity, the emission-line spectrum, the absorption components seen in Lyα and C IV, and the rest-frame ultraviolet continuum are all consistent with a simple H II region model containing $\sim 10^6$ hot O stars. The best-fit parameters for this model imply a very hot ionizing continuum ($T_{\rm BB} \simeq 80,000$ K), a high ionization parameter ($\log U \simeq -1$), and a low nebular metallicity ($Z/Z_\odot \simeq 0.05$). The narrowness of the emission lines requires a low mass-to-light ratio for the ionizing stars, suggestive of an extremely low metallicity stellar cluster. The apparent overabundance of silicon in the nebula could indicate enrichment by past pair-instability supernovae, requiring stars more massive than $\sim 140\ M_\odot$.

Subject headings: cosmology: observations — galaxies: abundances — galaxies: high-redshift — gravitational lensing — H II regions — stars: formation

On-line material: color figures

1. INTRODUCTION

During a multiwavelength study of the cluster RX J0848+4456 ($z = 0.570$) and its slightly lower redshift (0.543) companion, which we call CL J0848.8+4455, from the *ROSAT* Deep Cluster Survey, Holden et al. (2001) discovered a gravitational arc at $\alpha = 08^{\rm h}48^{\rm m}48\overset{\rm s}{.}76$, $\delta = +44°55'49\overset{''}{.}6$ (J2000.0). This shows an unusual narrow emission line spectrum identified with ultraviolet H, He, C, N, and O lines at a redshift of $z = 3.36$. Using arguments based on photoionization modeling, these authors suggested that the emission arises from low-metallicity gas ionized, at a high ionization parameter (U = photon/matter density), by a source with a blackbody temperature of

[1] Based partly on observations with the NASA/ESA *Hubble Space Telescope*, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy (AURA), Inc., under NASA contract NAS 5-26555.

[2] Some of the data presented herein were obtained at the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California, and NASA. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation.

[3] Based partly on observations obtained by the staff of the Gemini Observatory, which is operated by the AURA, Inc., under a cooperative agreement with the National Science Foundation on behalf of the Gemini partnership: the NSF (United States), the Particle Physics and Astronomy Research Council (United Kingdom), the National Research Council (Canada), CONICYT (Chile), the Australian Research Council (Australia), CNPq (Brazil), and CONICET (Argentina).

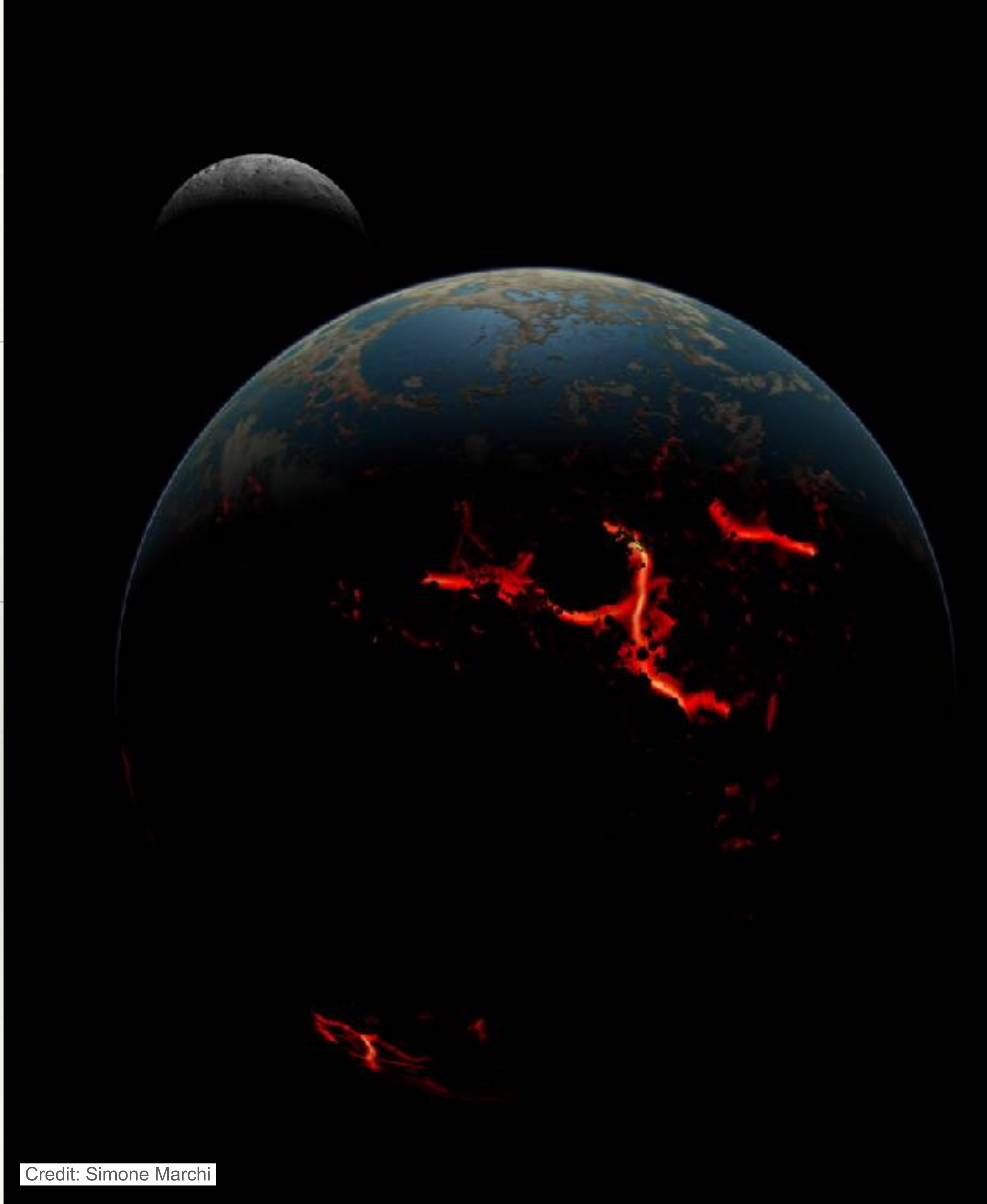
[4] Also the Space Telescopes Division, Research and Space Science Department, European Space Agency.

[5] Seconded from ST-ECF, Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany.

4.6 – 4 billion years ago

Early Earth

Many impact events
Liquid oceans
Volcanic activity
Atmosphere probably opaque

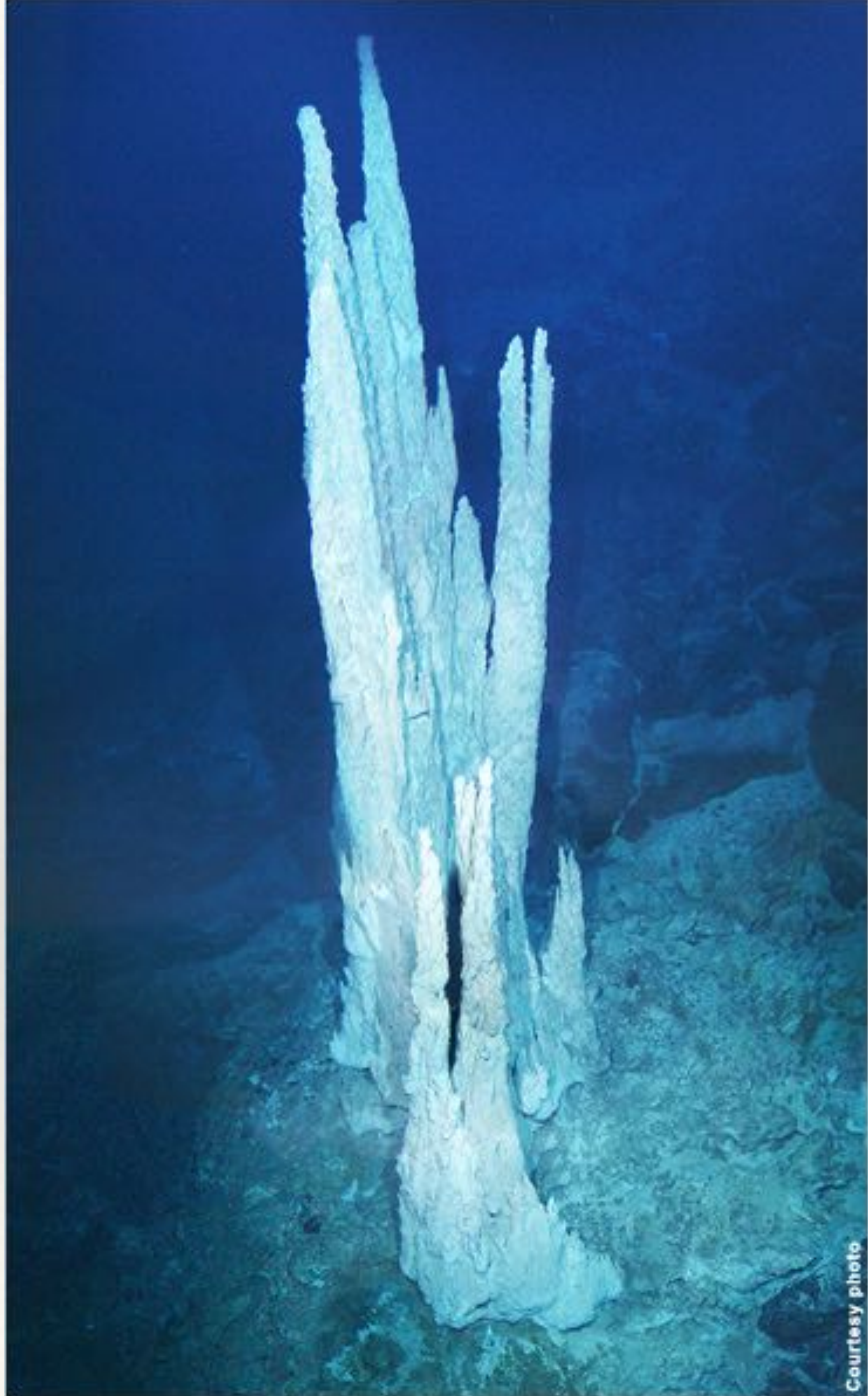

Credit: Simone Marchi

Deep sea alkaline hydrothermal vents

First life

"The Vital Question"
Nick lane
Profile Books, 2015

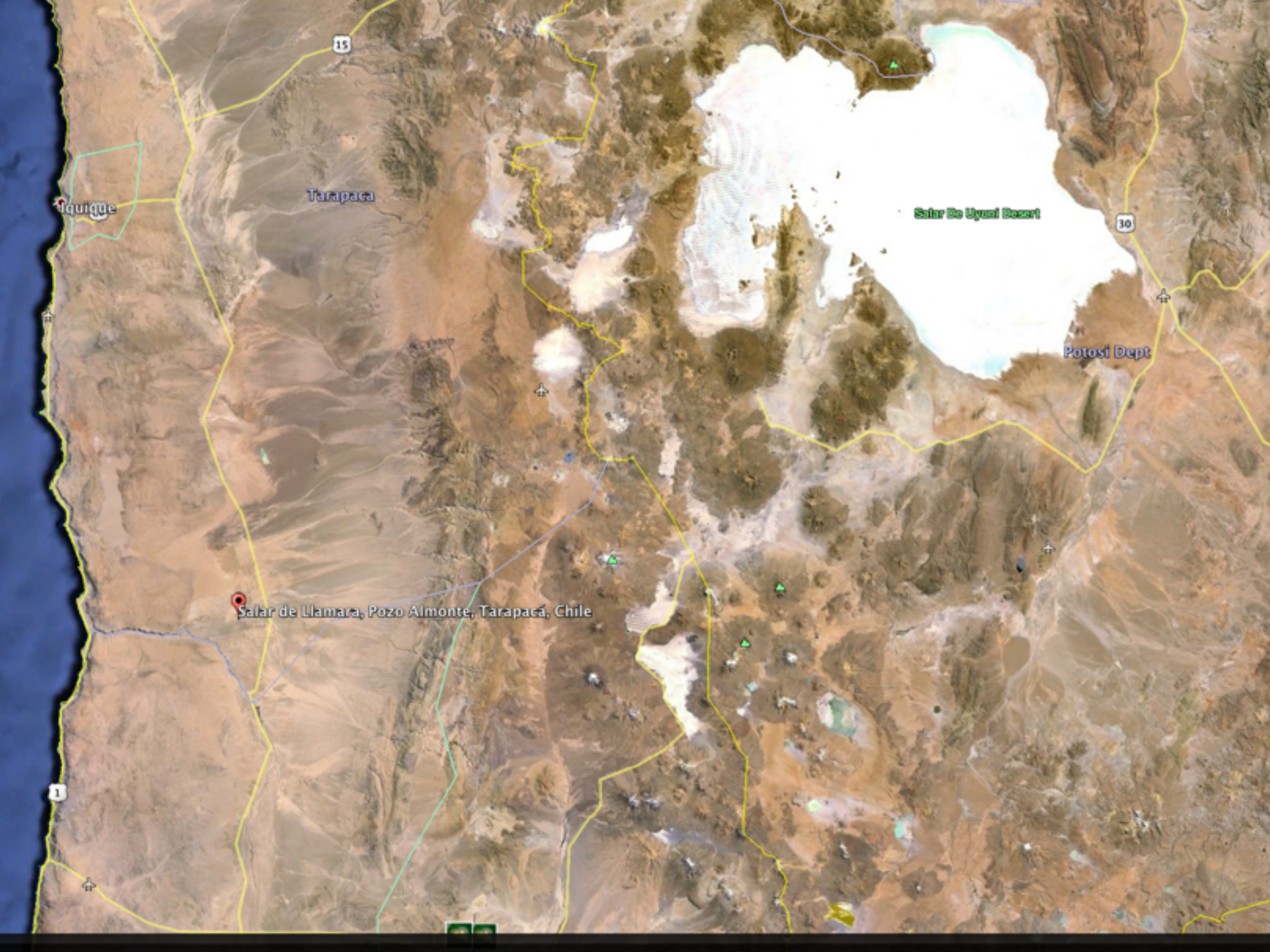
http://jayarava.blogspot.co.uk



Banded Iron Formation @ NHM


Image credit: Emma Fosbury


Cordillera Occidental Mountains
Lake Titicaca
La Paz
Bolivia
The Andes
Cordillera Real Mountains
Iquique
Salar De Uyuni Desert
San Juan
Laguna Colorada
Sol de Manana
Laguna Blanca
Laguna Verde
Lascar volcano
Desierto De Atacama Desert
Alto Parag
Boqueron
Pa
Salta

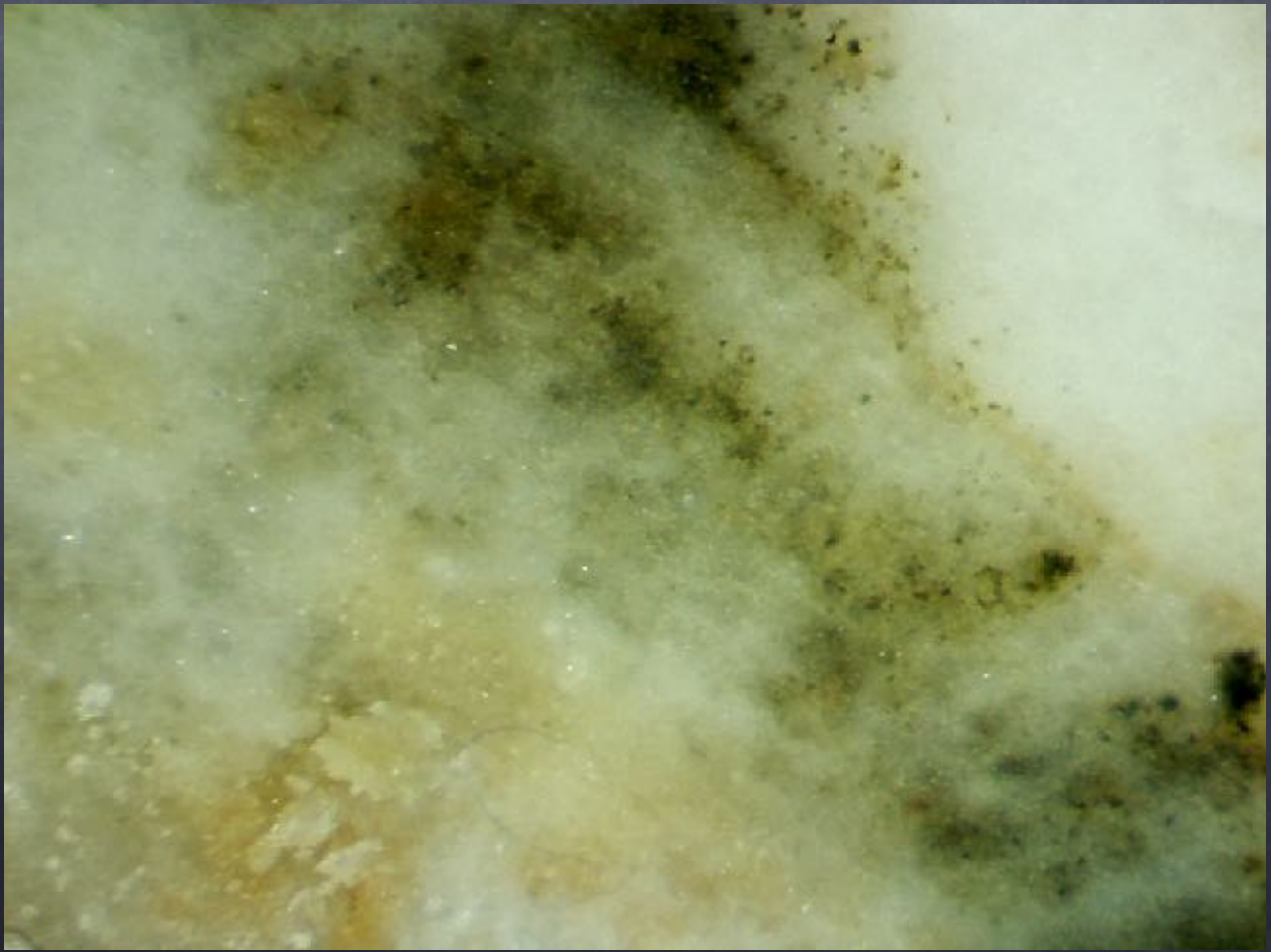


15
Tarapaca
Iquique
Salar De Uyuni Desert
30
Potosi Dept
Salar de Llamara, Pozo Almonte, Tarapacá, Chile
1


Salar de

The primitive Earth
Early ‘greening’ bacteria

Extremophile cyanobacterium: **Chroococcidiopsis**
Populates extremely arid cold and hot deserts
from Antarctica to the Atacama (Chile)
Originated more than 2.5 Gya (billion years ago)
Could probably live on Mars — it possibly even came from Mars to Earth!



Extremophile cyanobacterium: **Chroococcidiopsis**
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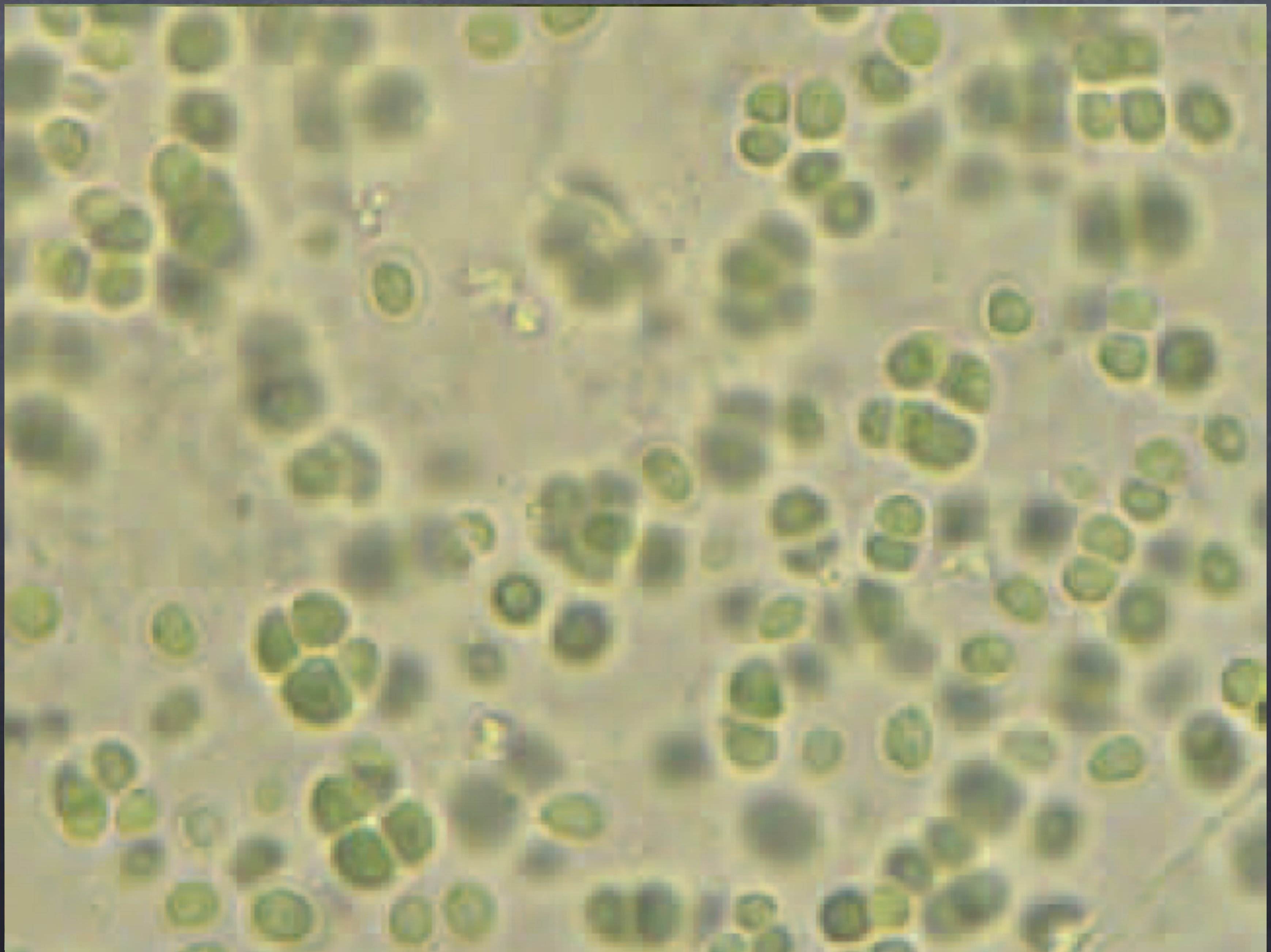
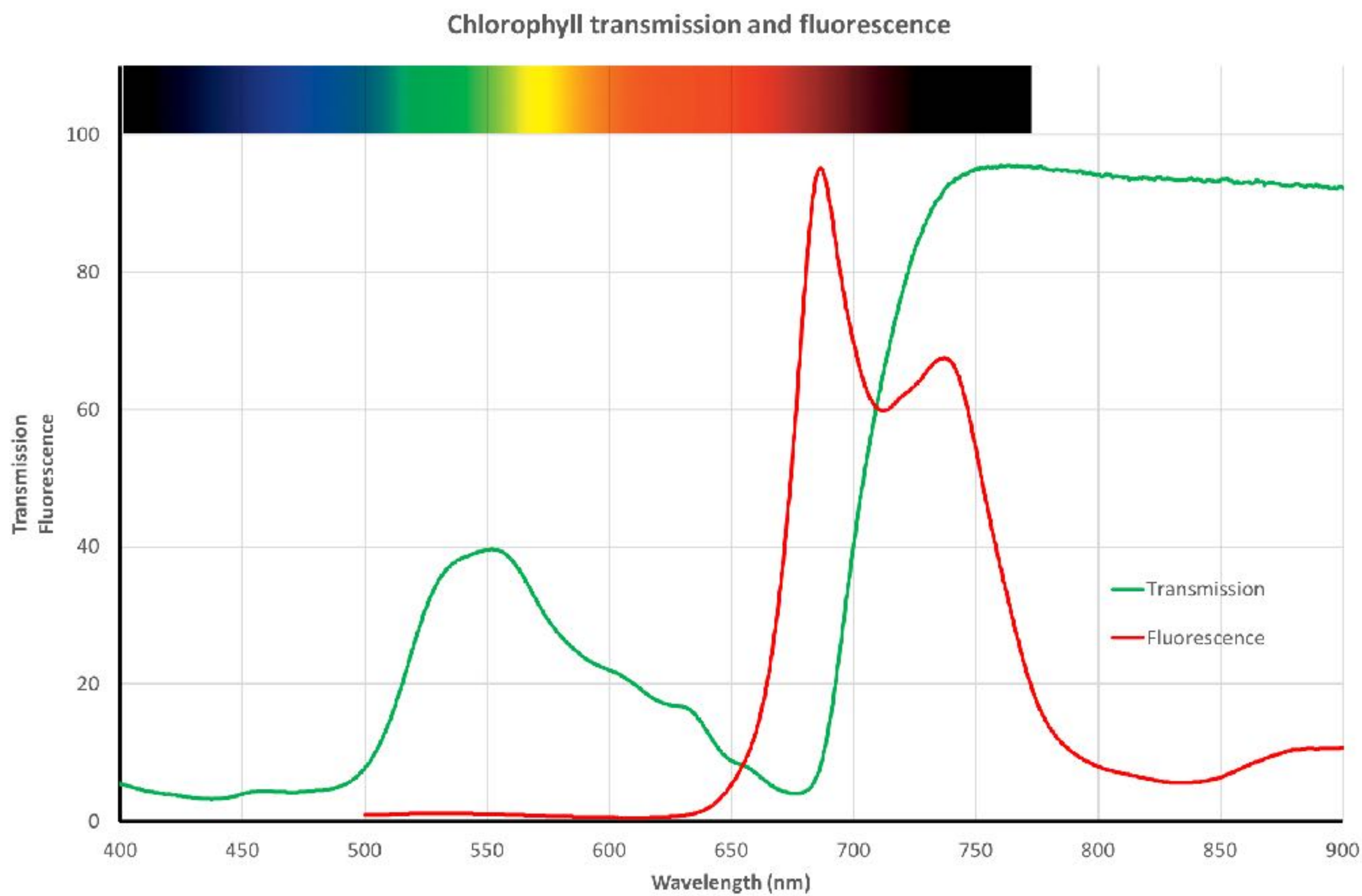
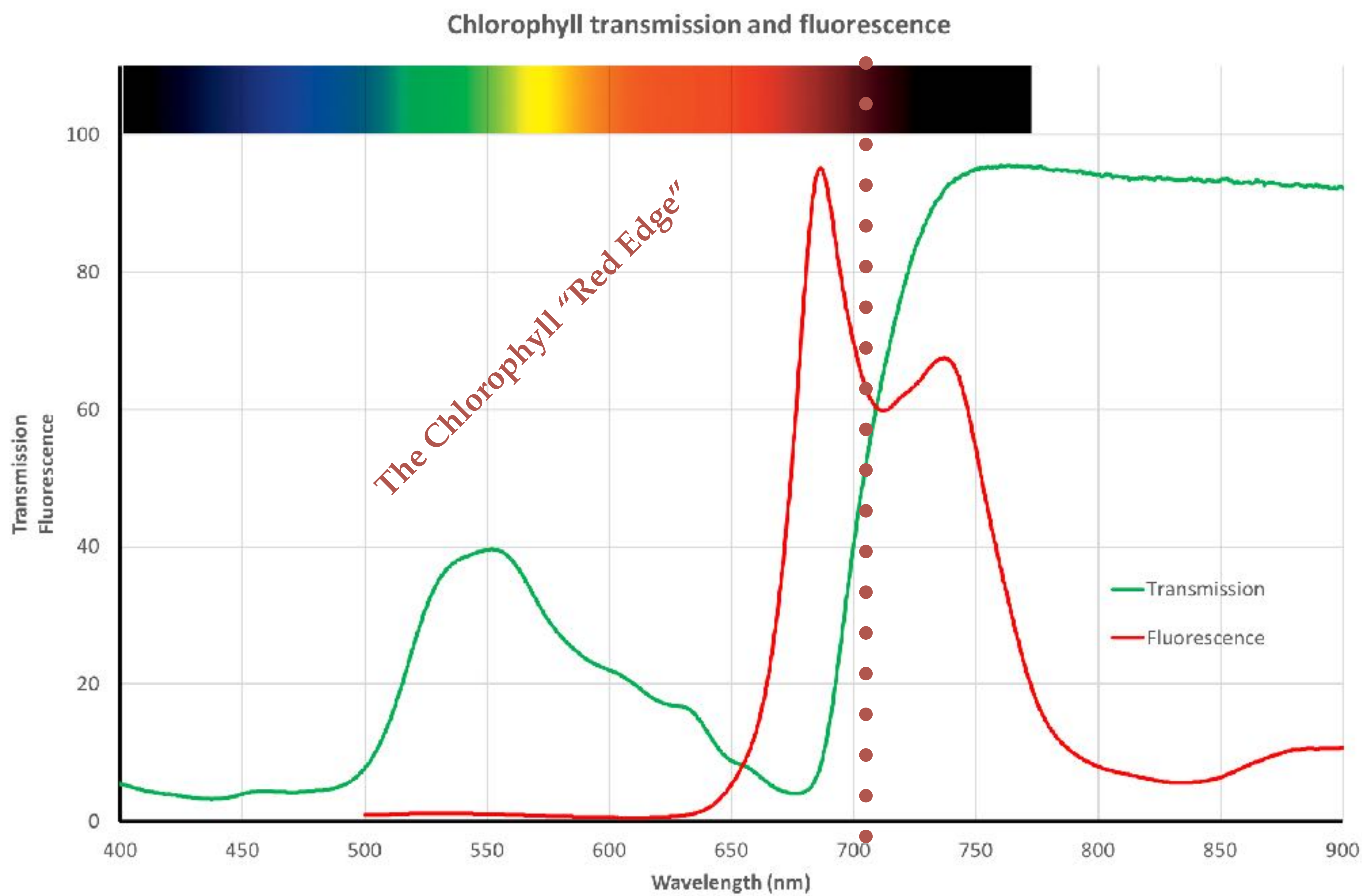


Chlorophyll in organic solvent

White light (left); UV light (right)

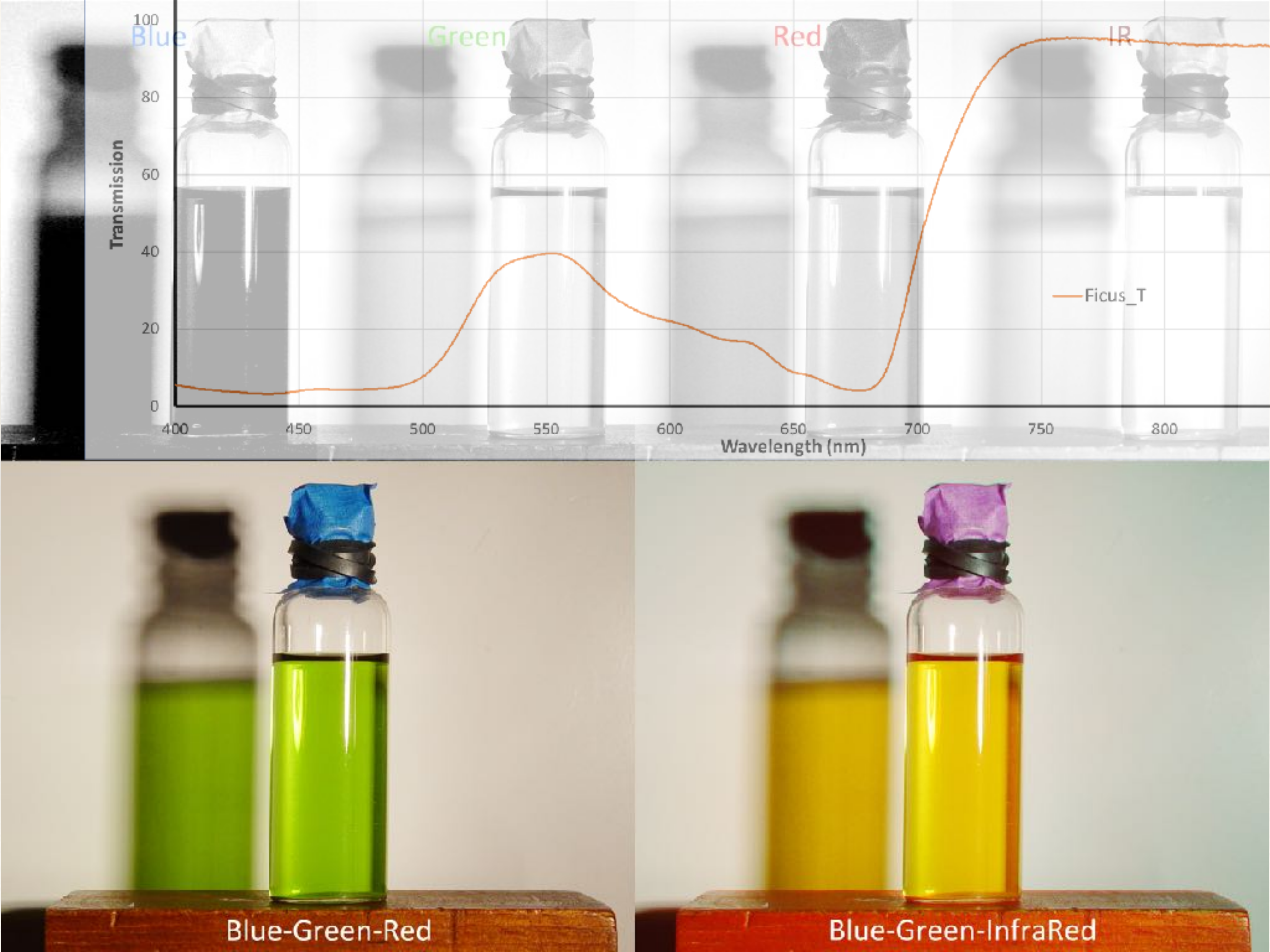


Chlorophyll transmission and fluorescence
Transmission
Fluorescence
100
80
60
40
20
0
400
450
500
550
600
650
700
750
800
850
900
Wavelength (nm)
Transmission
Fluorescence



Chlorophyll transmission and fluorescence
The Chlorophyll "Red Edge"
Transmission
Fluorescence
Transmission
Fluorescence
Wavelength (nm)
0
20
40
60
80
100
400
450
500
550
600
650
700
750
800
850
900


Blue
Green
Red
IR
Blue-Green-Red
Blue-Green-InfraRed


Blue
Green
Red
IR
Transmission
100
80
60
40
20
0
400
450
500
550
600
650
700
750
800
Wavelength (nm)
Ficus_T
Blue-Green-Red
Blue-Green-InfraRed

Geranium leaves under UV light

Video and credit at: https://www.nasa.gov/topics/solarsystem/features/epoxi_transit.html

What does the Earth look like from 50 million km?

Video and credit at: https://www.nasa.gov/topics/solarsystem/features/epoxi_transit.html

Lunar Transit of Earth

NASA's EPOXI Spacecraft

Range to Earth = 31 million miles

Red-Green-Blue Color Composite

Landscape above the chlorophyll "red-edge"

Blue–Green–Red


Blue–Green–Infra-Red

Infra-Red

Video and credit at: https://www.nasa.gov/topics/solarsystem/features/epoxi_transit.html

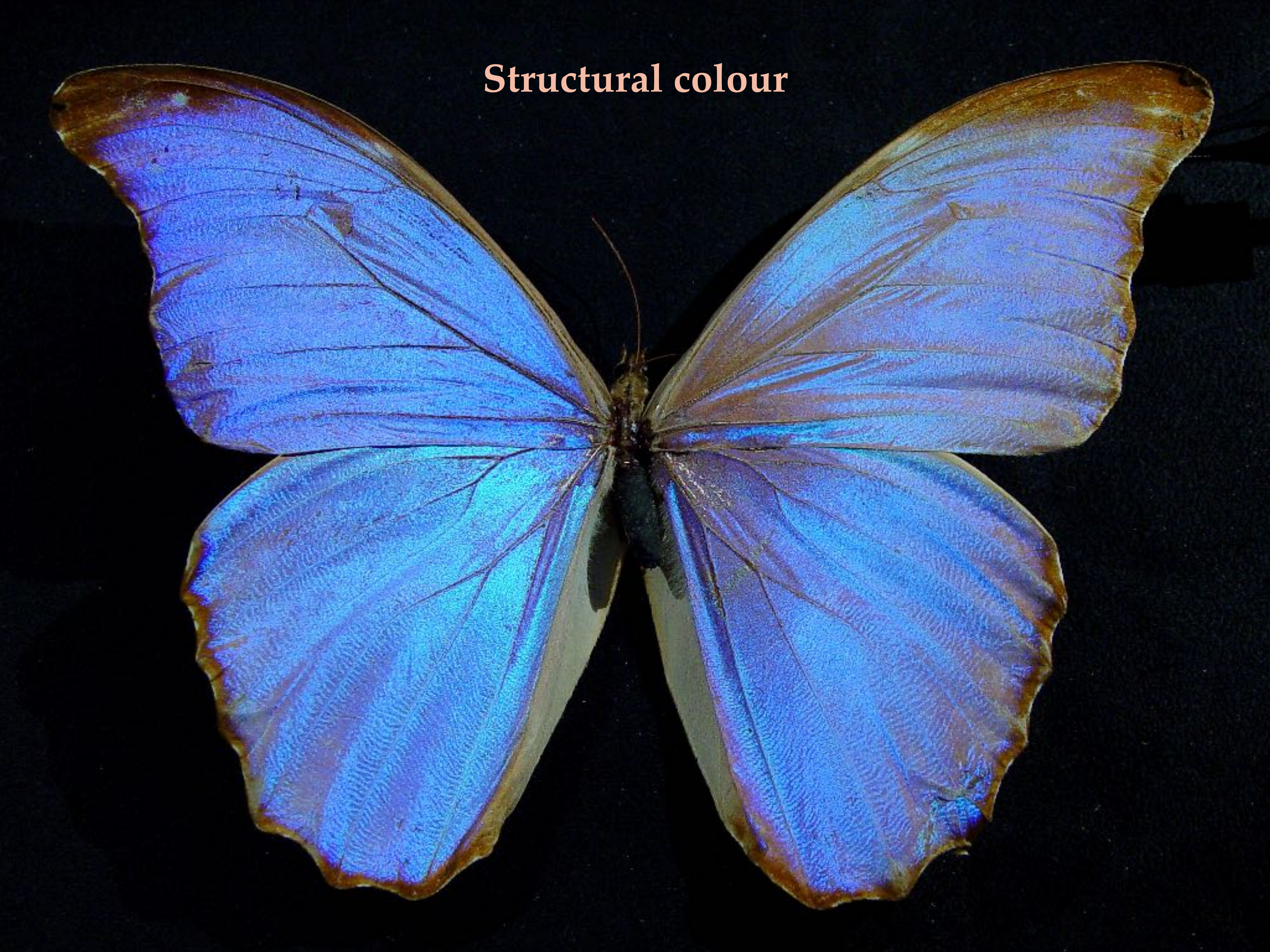
Lunar Transit of Earth

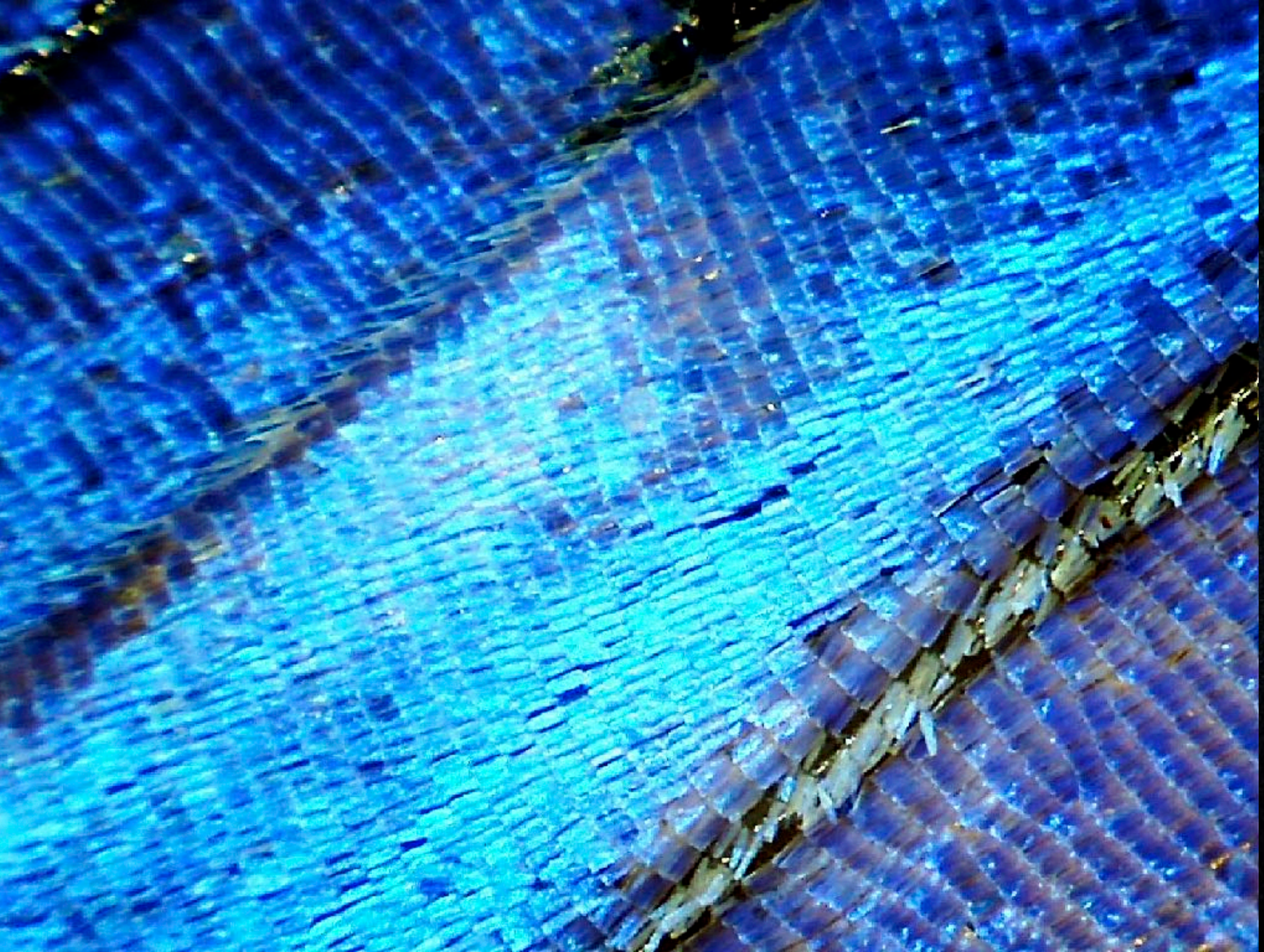
NASA's EPOXI Spacecraft

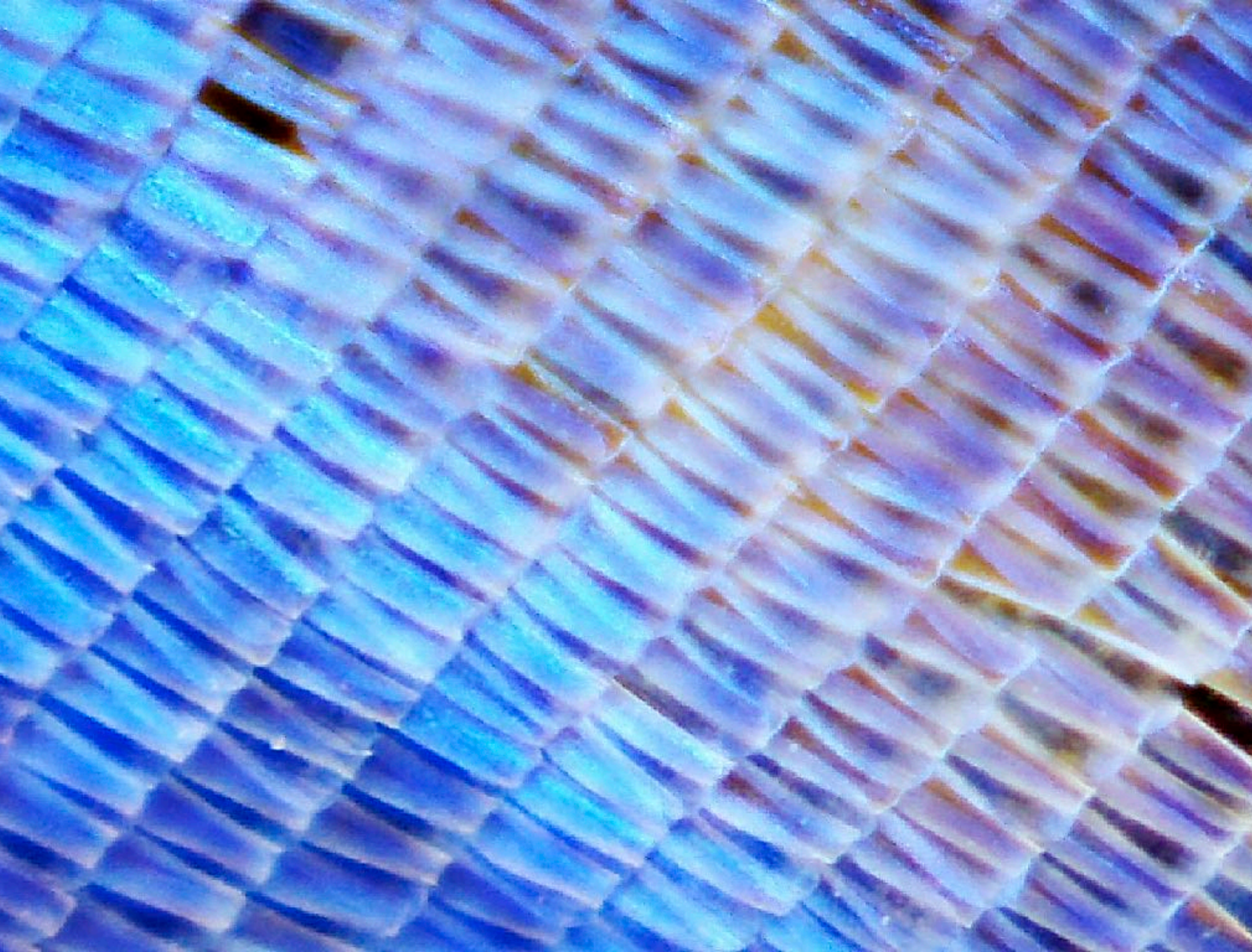
Range to Earth = 31 million miles

Infrared-Green-Blue Color Composite

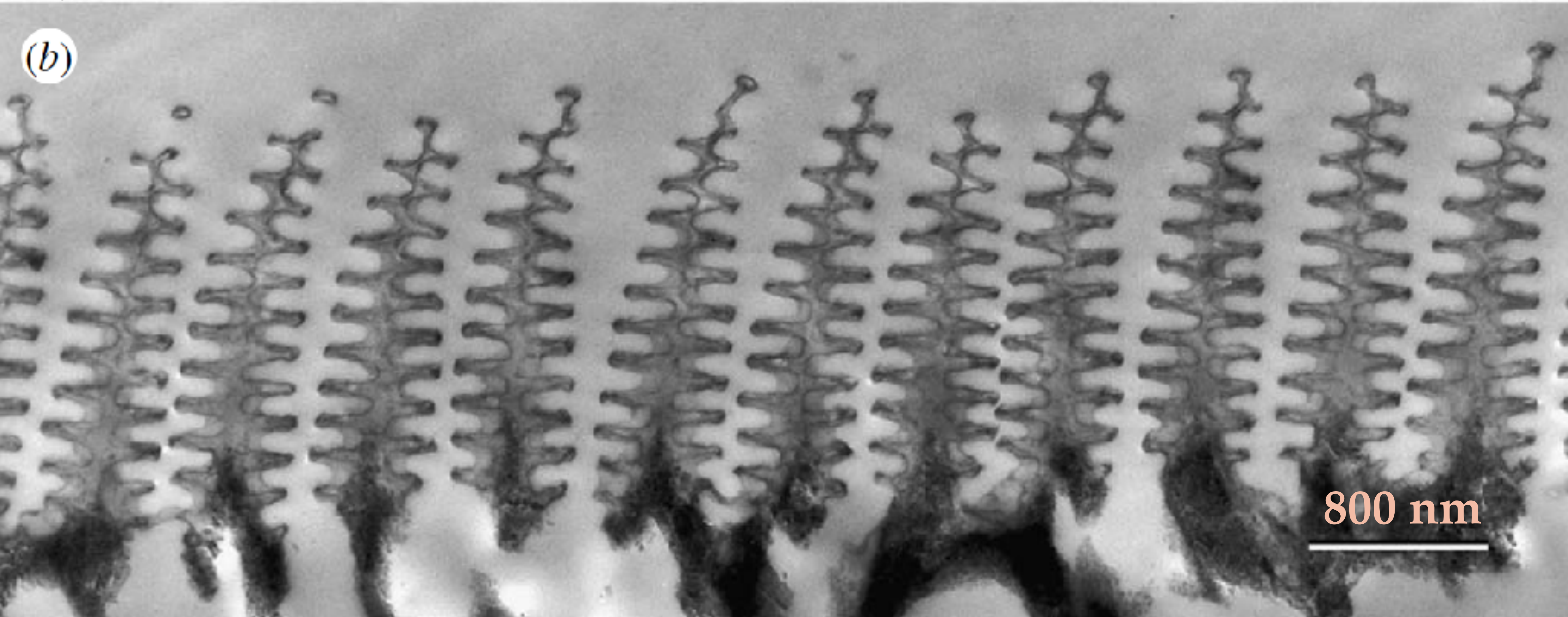
Structural colour







Credit: Peter Vukusic



Reindeer Tapetum Lucidum (winter)

The active use by intelligent life of the complex building blocks that have evolved and been optimised over a period of more than four billion years may well usher in the next major transition to a yet more complex phase of the Universe.

Biological lifeforms, as the carrier of advanced intelligence, could then pass into history.

The End