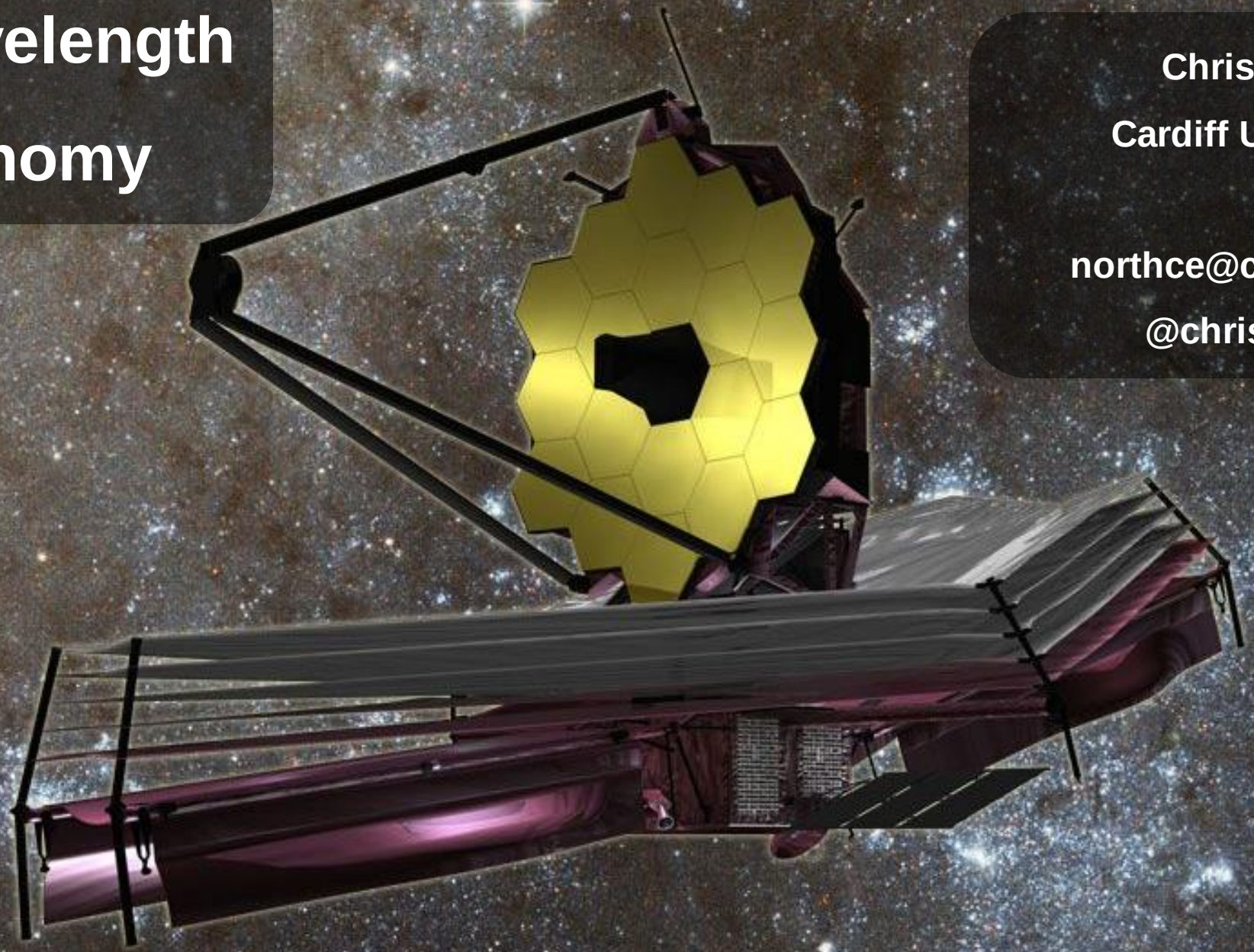
Multiwavelength Astronomy



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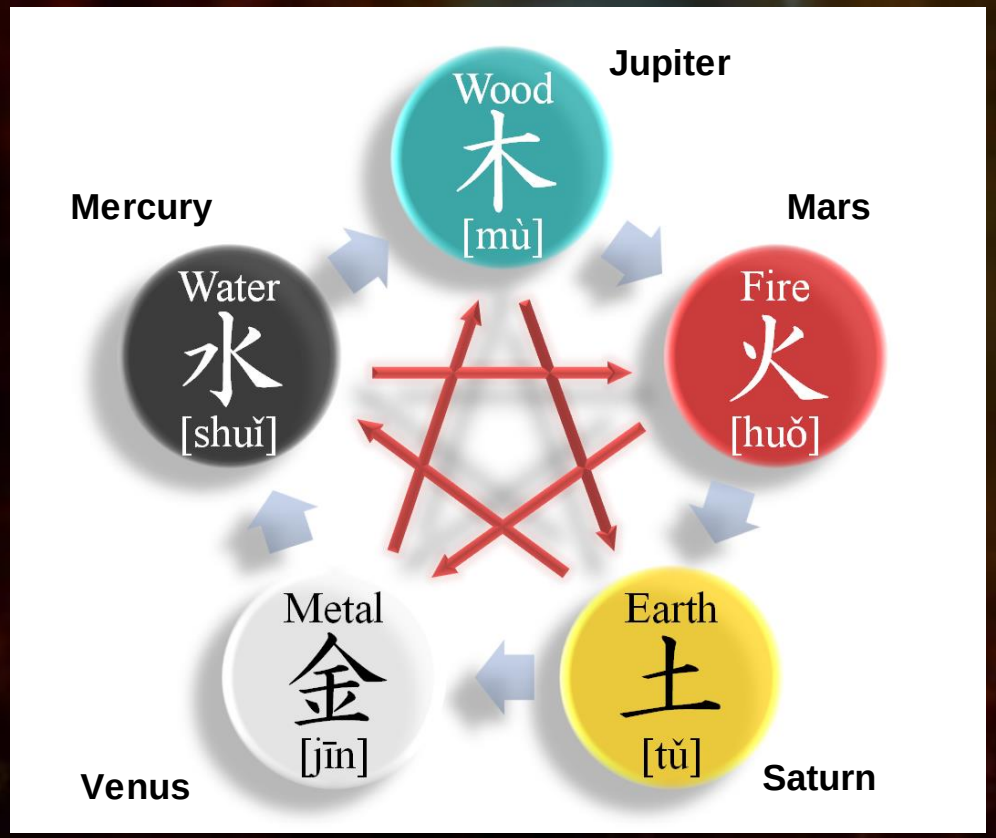
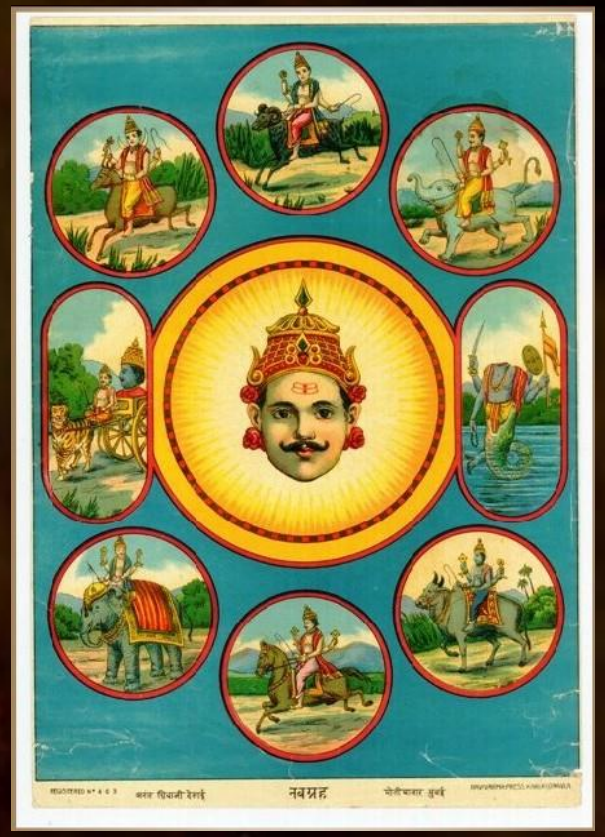
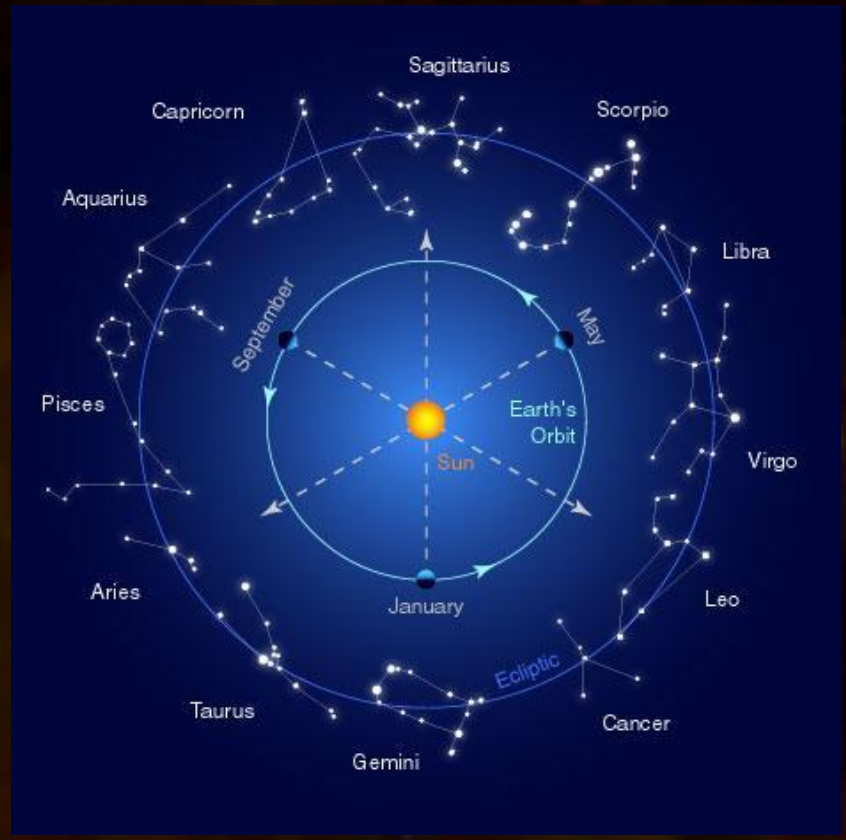
@chrisenorth

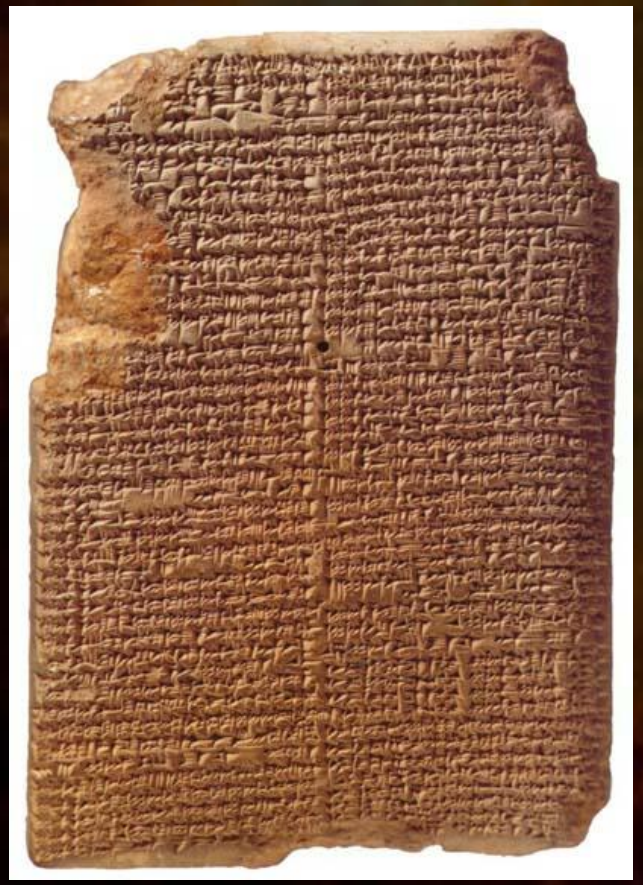
Early Astronomy

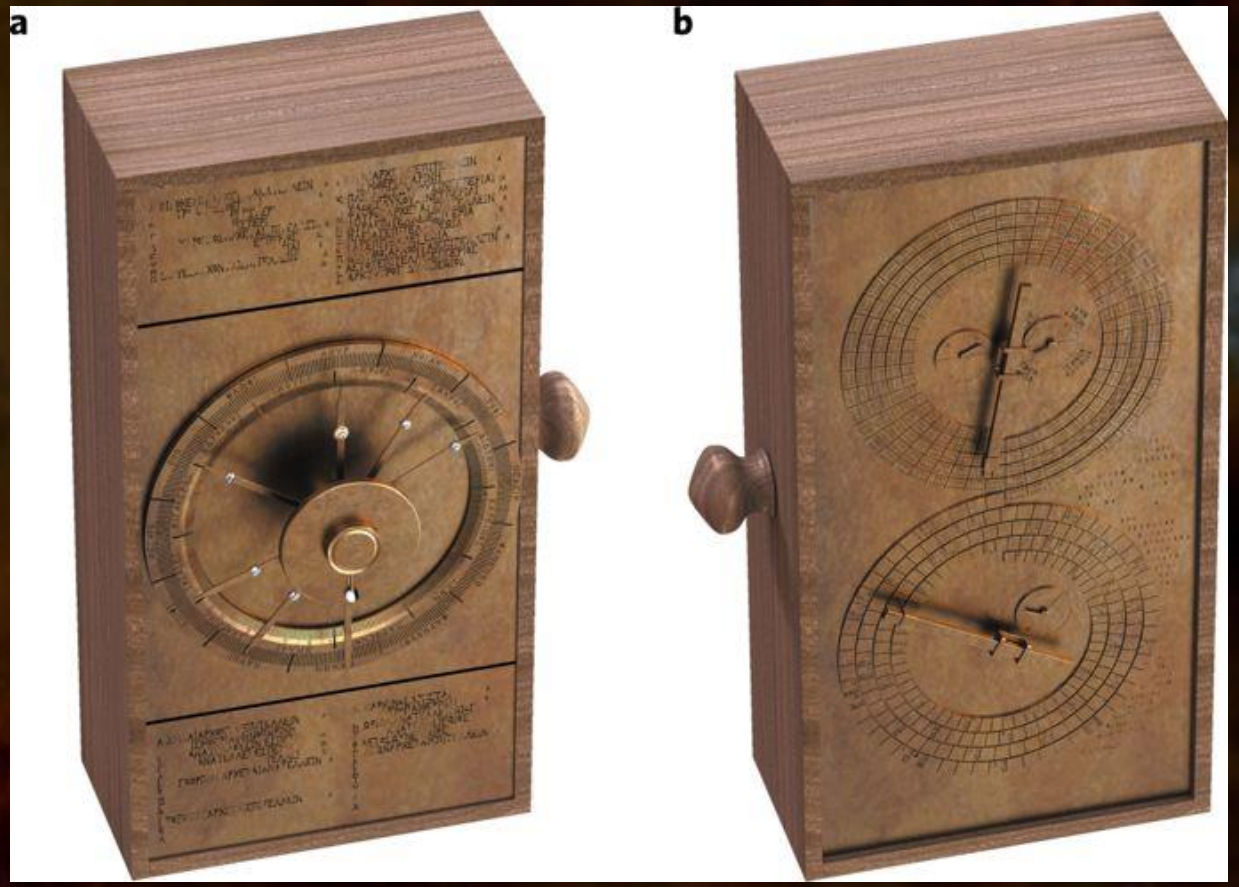






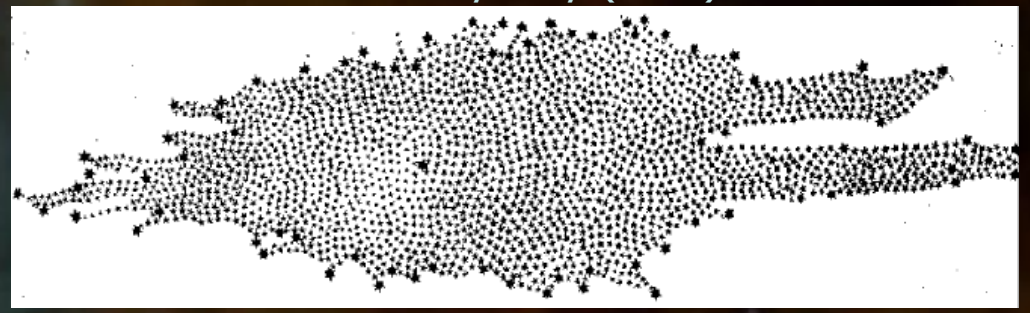
Early Astronomy





The size of the Universe

The Milky Way (1785)

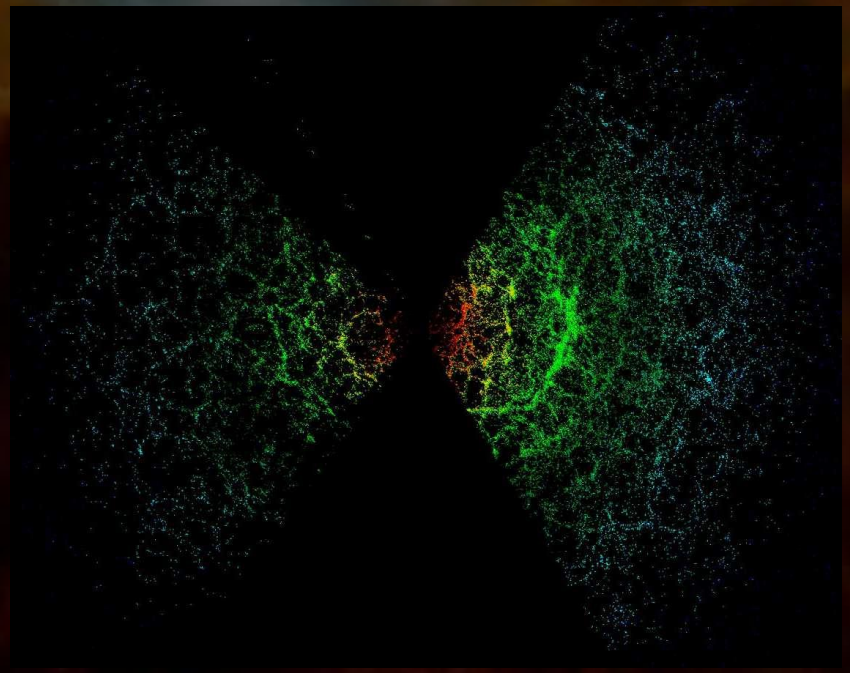


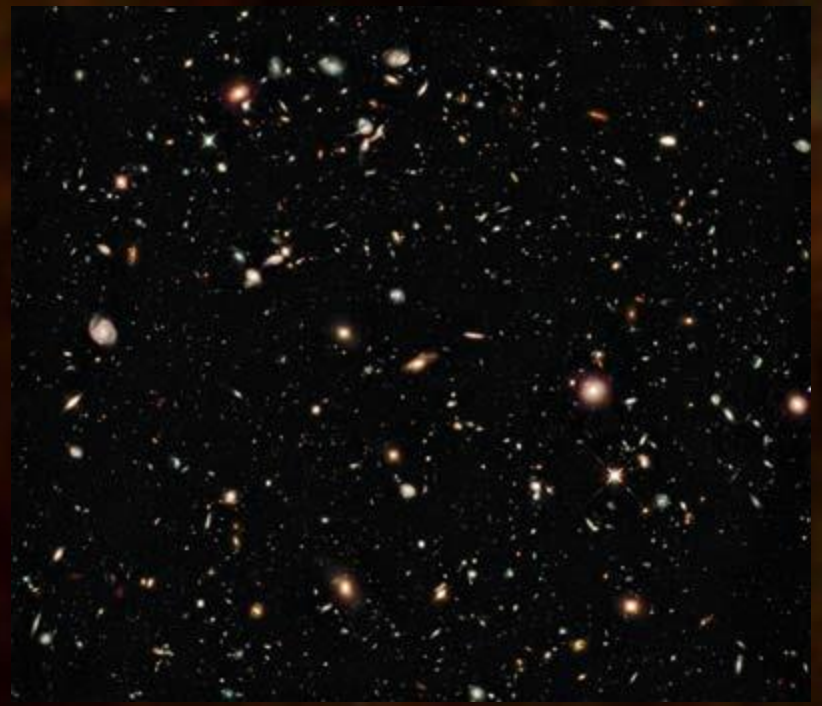
William Herschel

The Great Andromeda Nebula (1887)

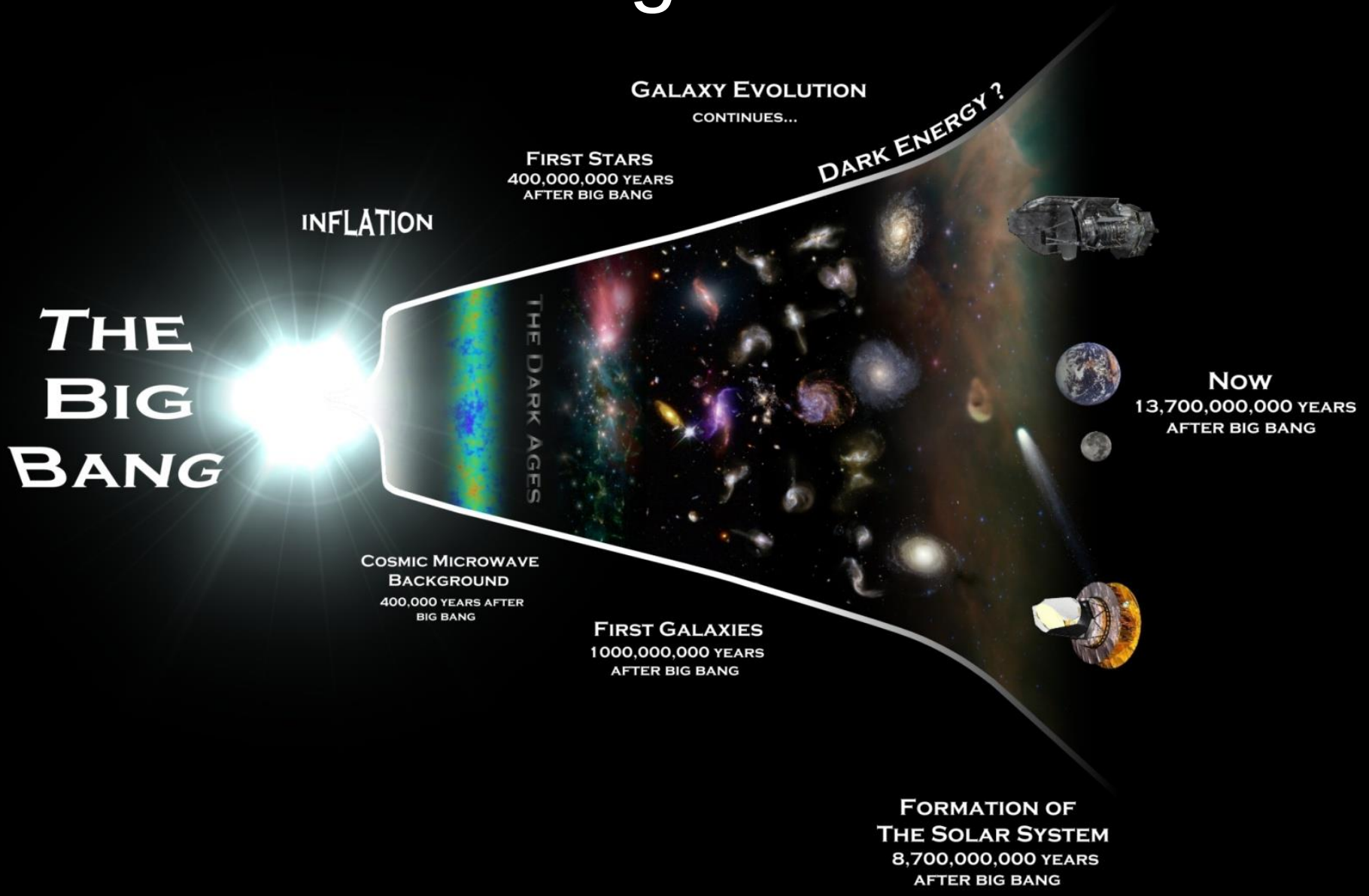
Isaac Roberts

The Distant Universe

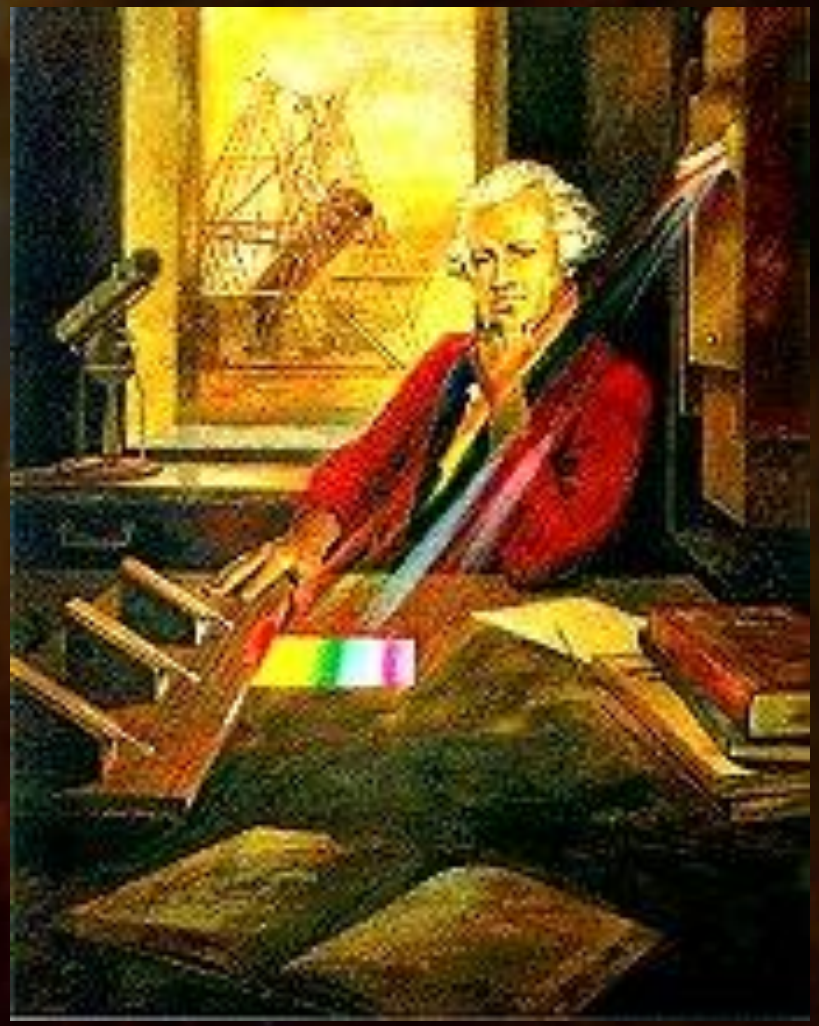




The Big Picture



William Herschel



Electromagnetic spectrum

1800 – Infrared (William Herschel)

1801 – Ultraviolet (Johann Ritter)

1860s – Electromagnetism (James Clerk Maxwell)

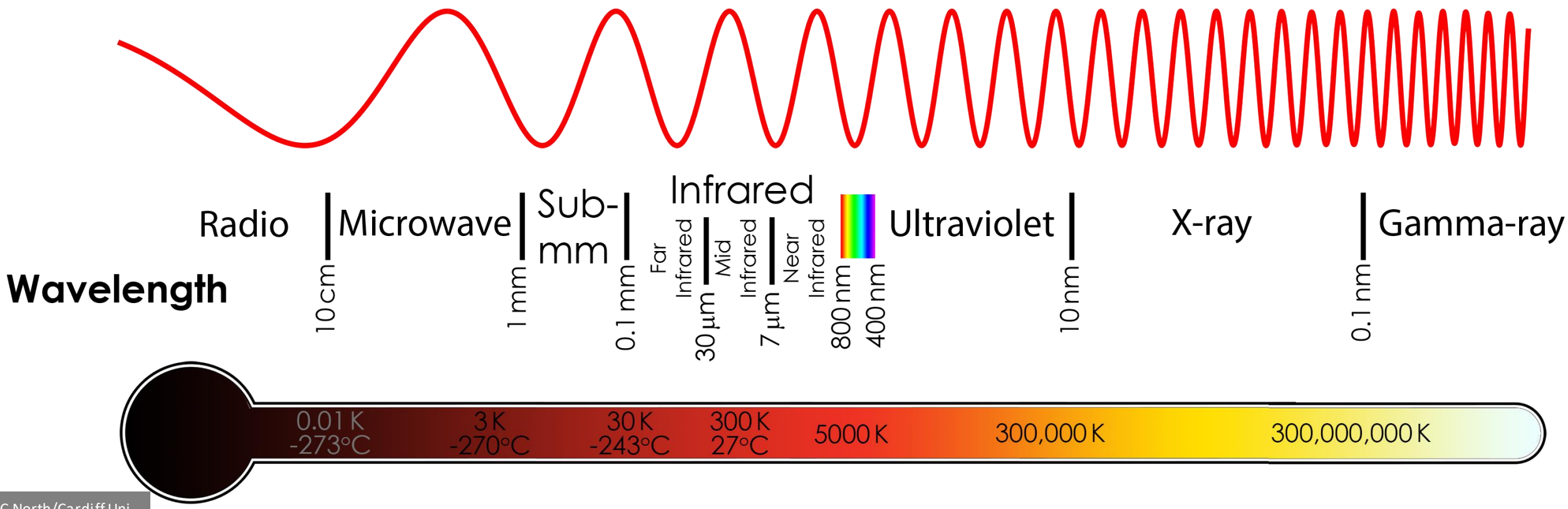
1886 – Radio (Heinrich Hertz)

1895 – X-rays (Wilhelm Roentgen)

1900 – Gamma rays (Paul Villard)

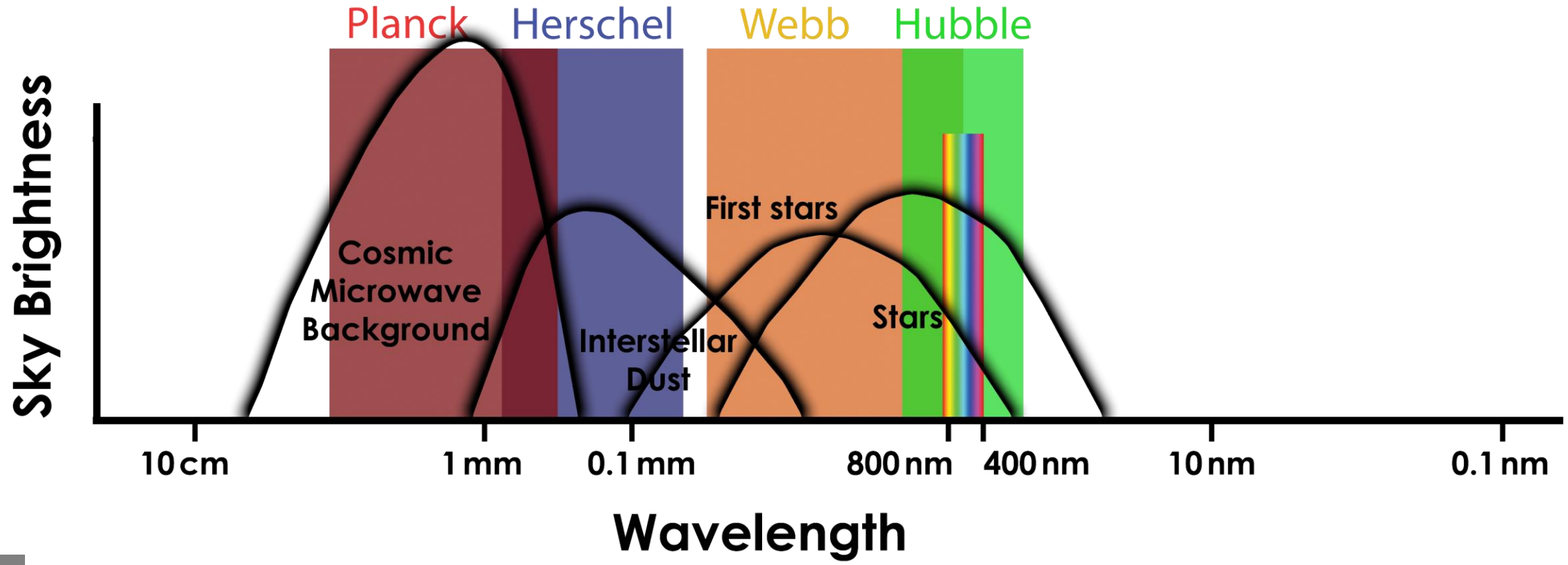
https://blogs.cardiff.ac.uk/physicsoutreach/2014/03/23/illustrative-diagrams/

Electromagnetic spectrum



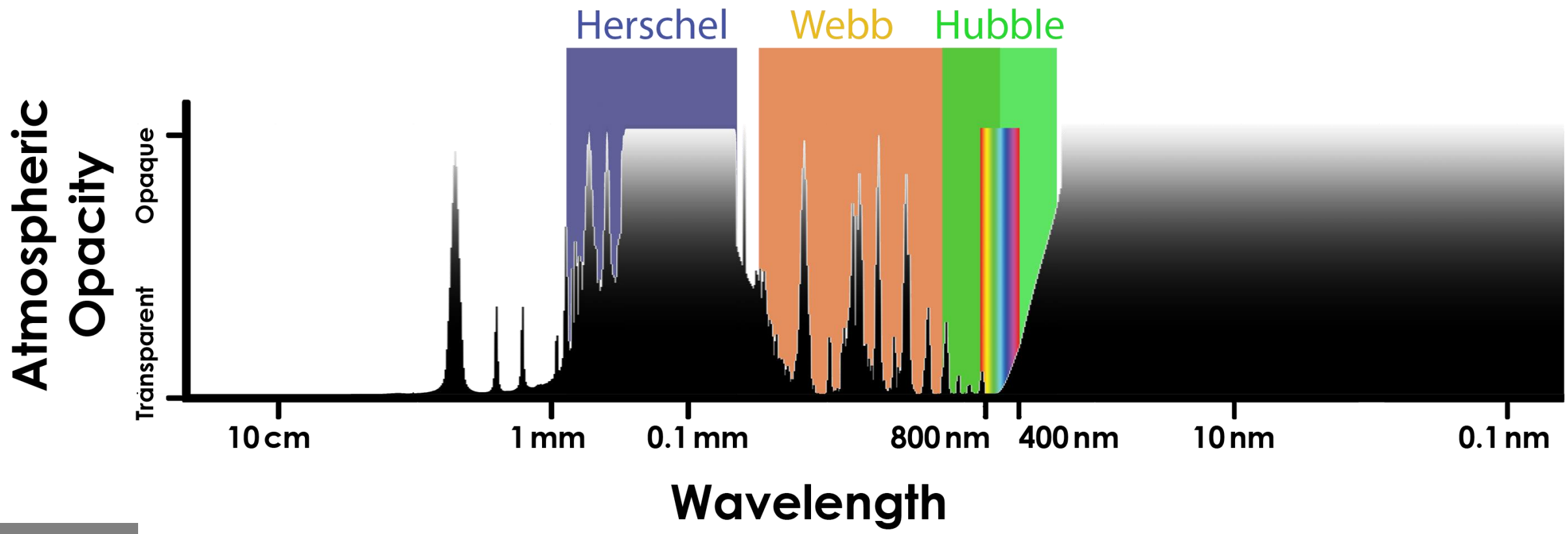
https://blogs.cardiff.ac.uk/physicsoutreach/2014/03/23/illustrative-diagrams/

The Universe



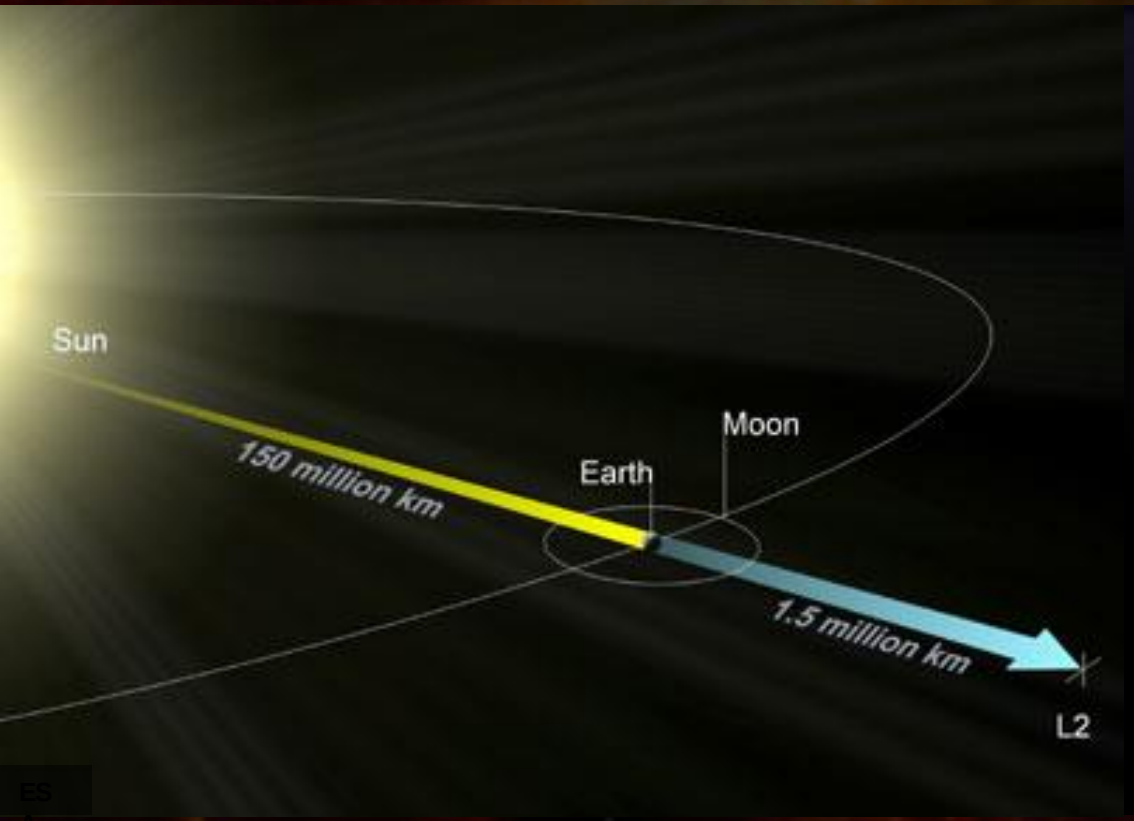
https://blogs.cardiff.ac.uk/physicsoutreach/2014/03/23/illustrative-diagrams/

Earth's atmosphere



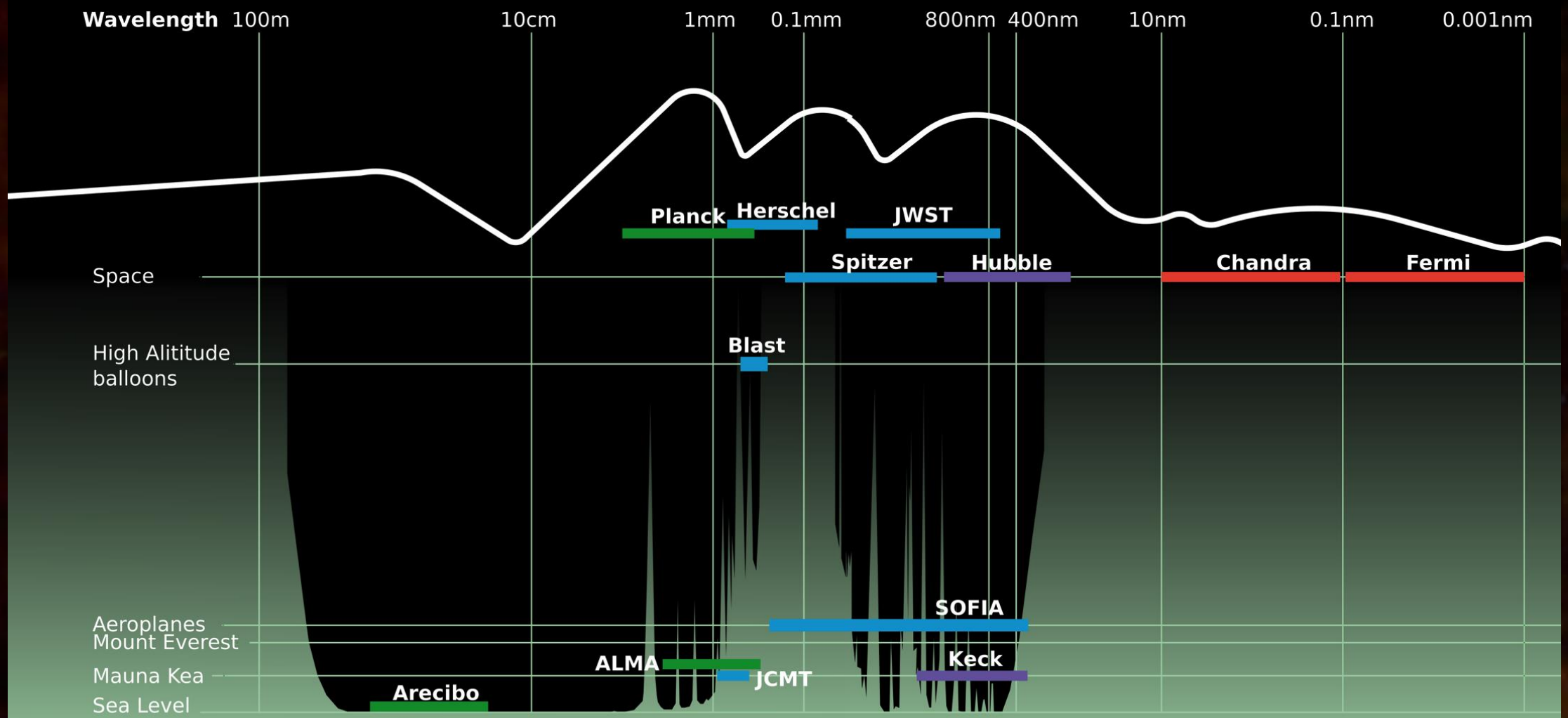
https://blogs.cardiff.ac.uk/physicsoutreach/2014/03/23/illustrative-diagrams/

Not just in space…

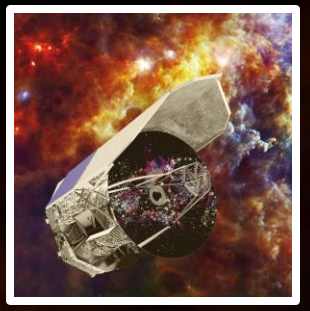
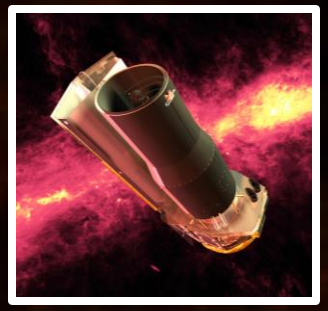
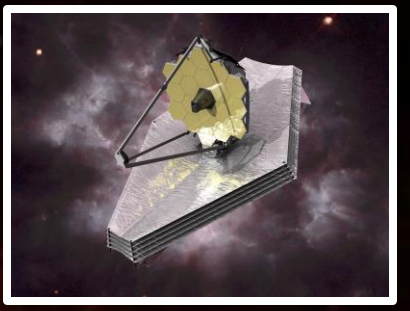
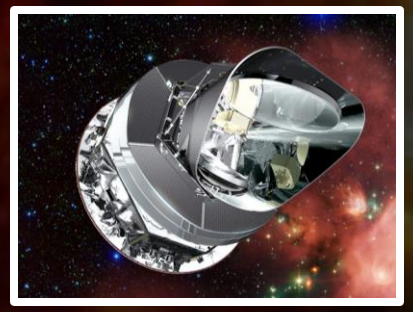


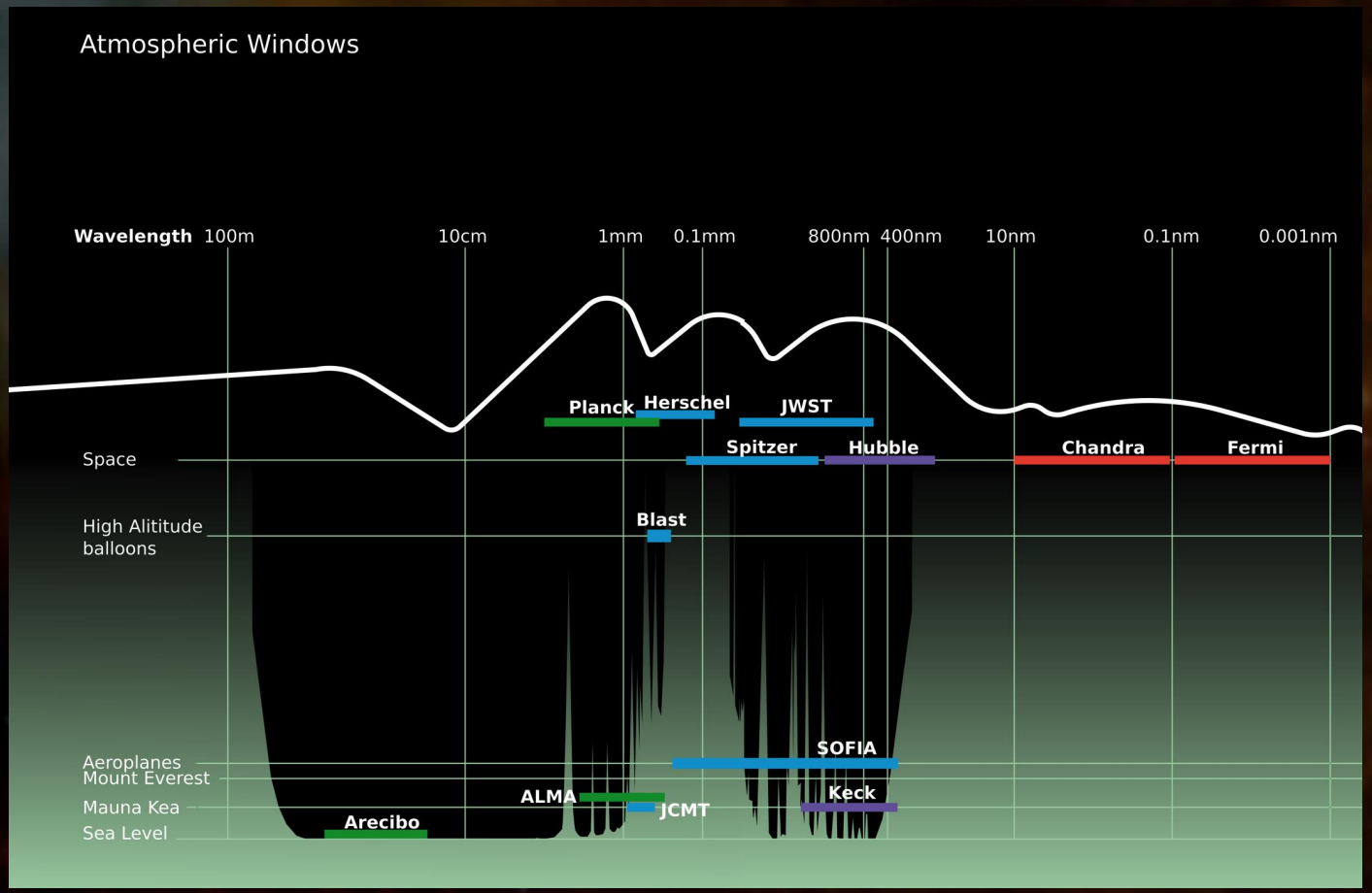
https://youtu.be/6cUe4oMk69E

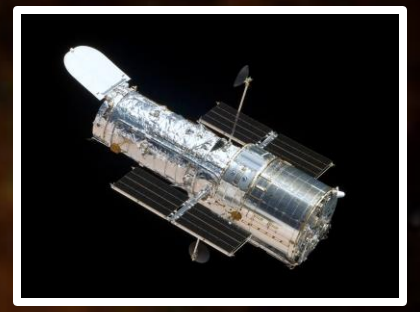
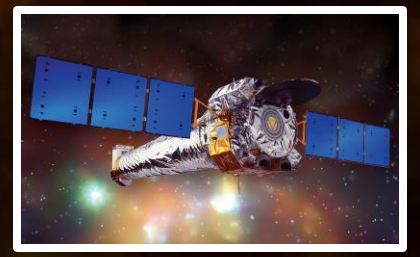
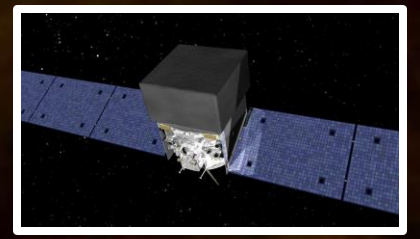
Atmospheric Windows



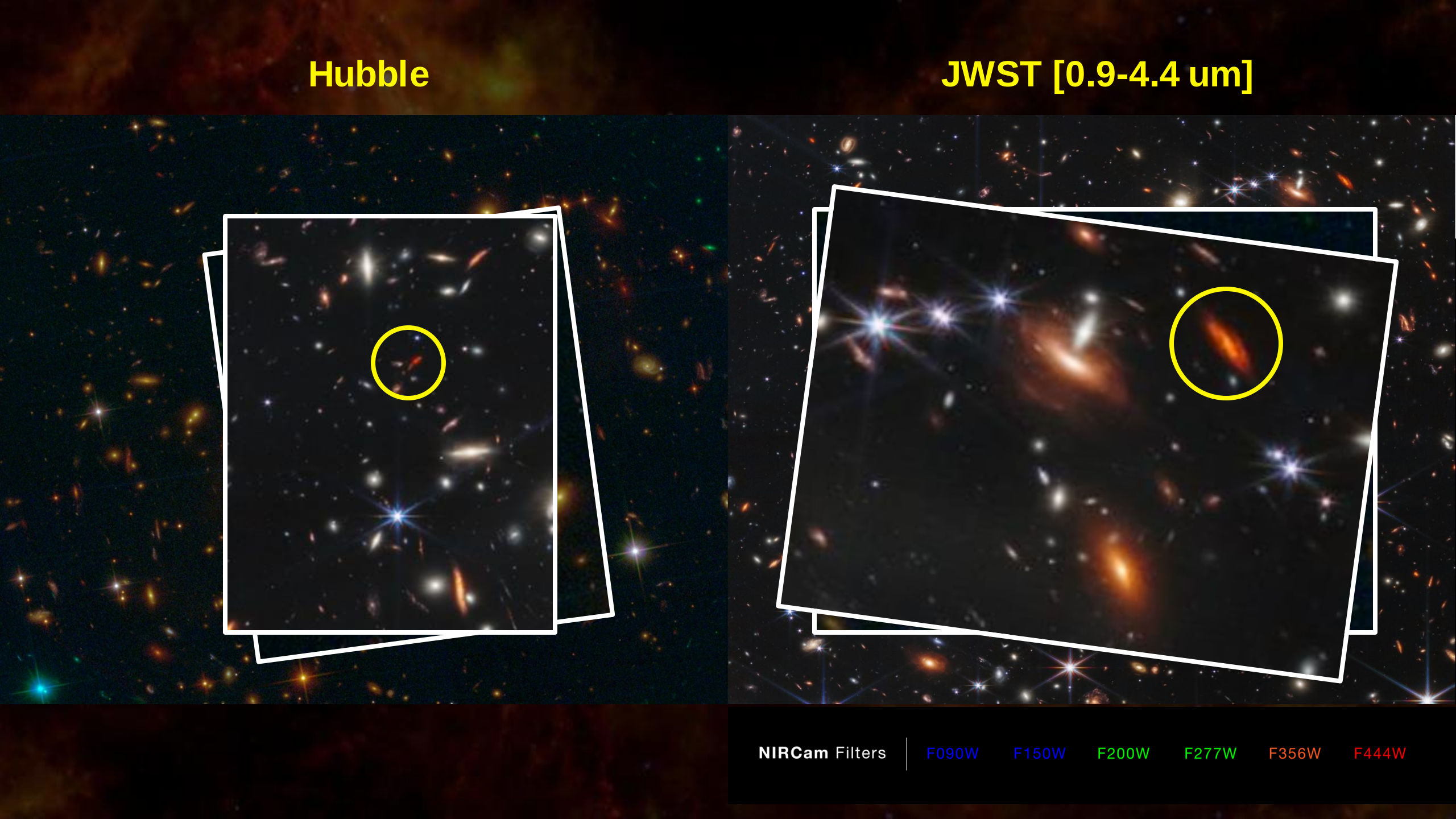


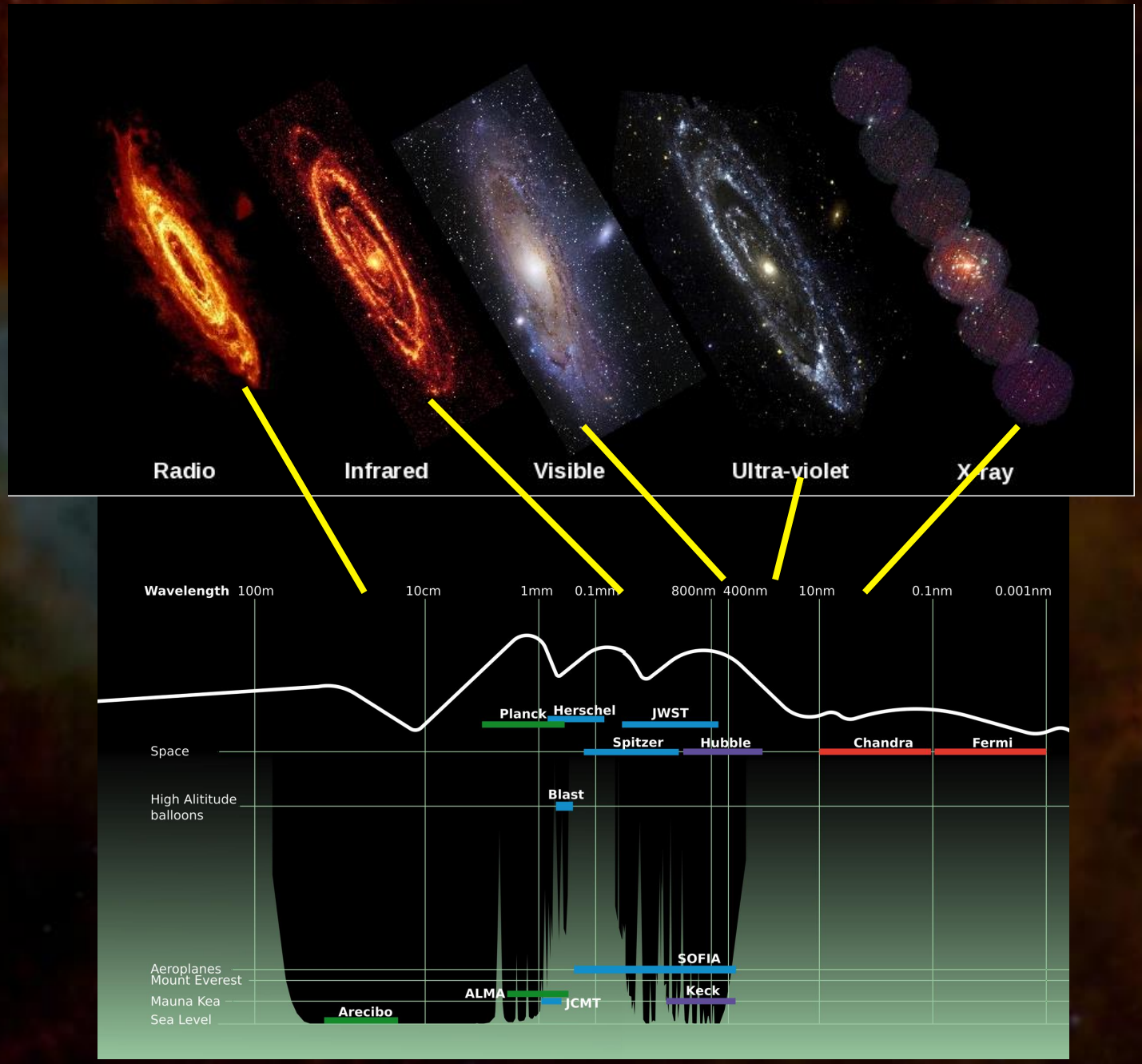


Multicolour Images


Hubble
JWST [0.9-4.4 um]
NIRCam Filters
F090W
F150W
F200W
F277W
F356W
F444W


13.1 billion years
Relative Brightness
6
4
2
0
2
3
4
Wavelength of Light
microns


Radio
Infrared
Visible
Ultra-violet
X-ray
Wavelength 100m
10cm
1mm
0.1mm
800nm
400nm
10nm
0.1nm
0.001nm
Planck
Herschel
JWST
Spitzer
Hubble
Chandra
Fermi
Space
High Alititude balloons
Blast
Aeroplanes
Mount Everest
Mauna Kea
Sea Level
SOFIA
ALMA
JCMT
Keck
Arecibo

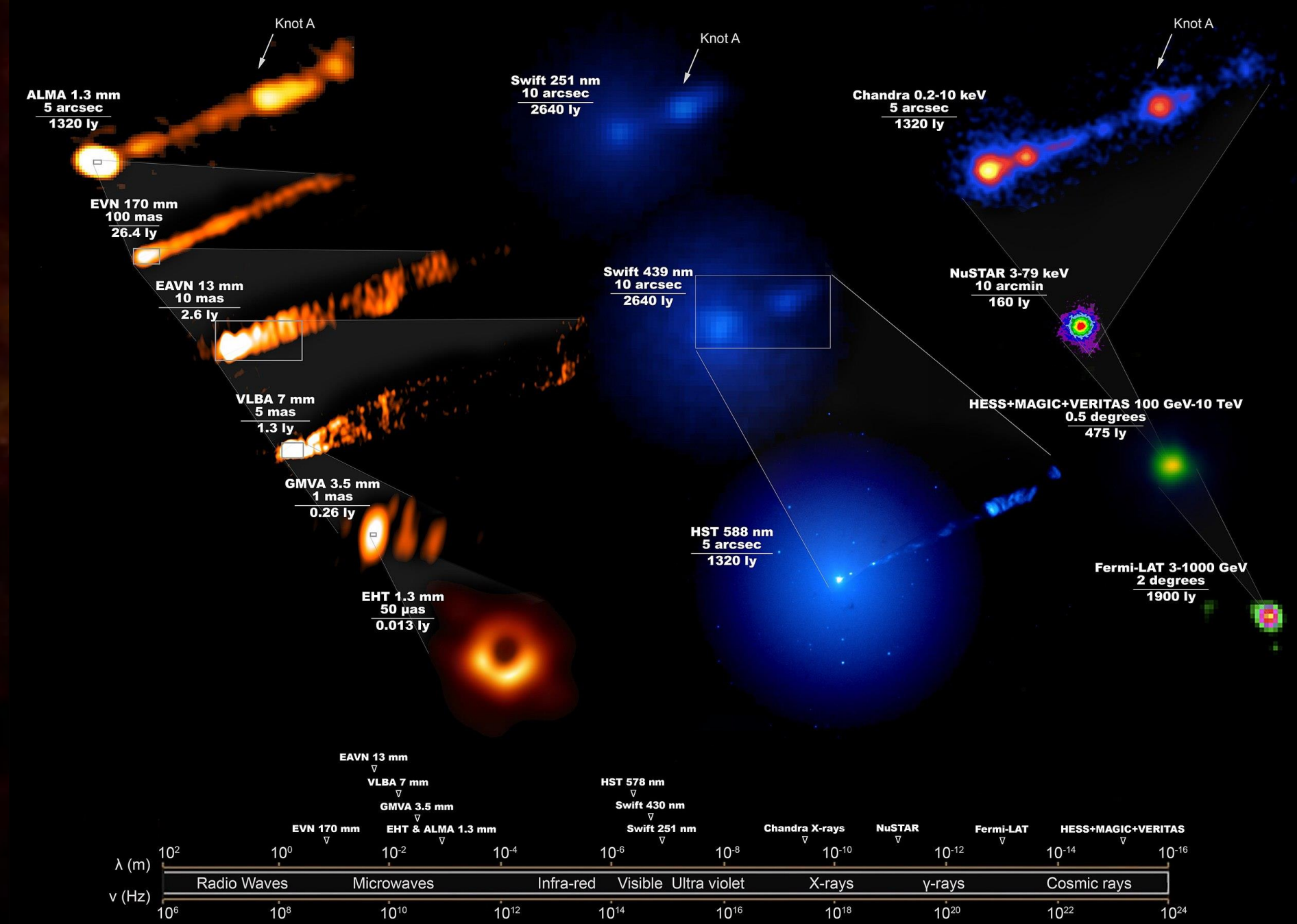
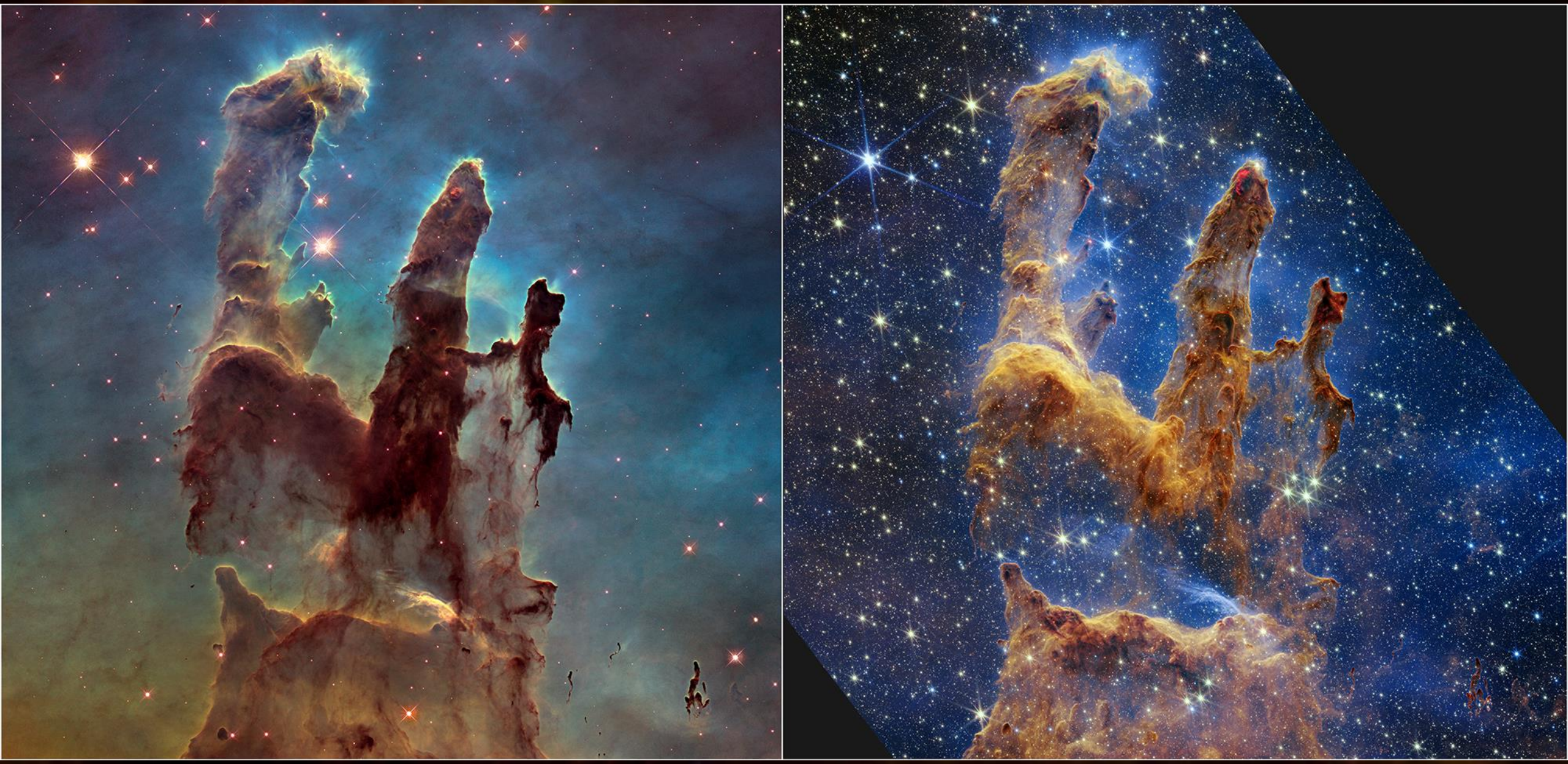
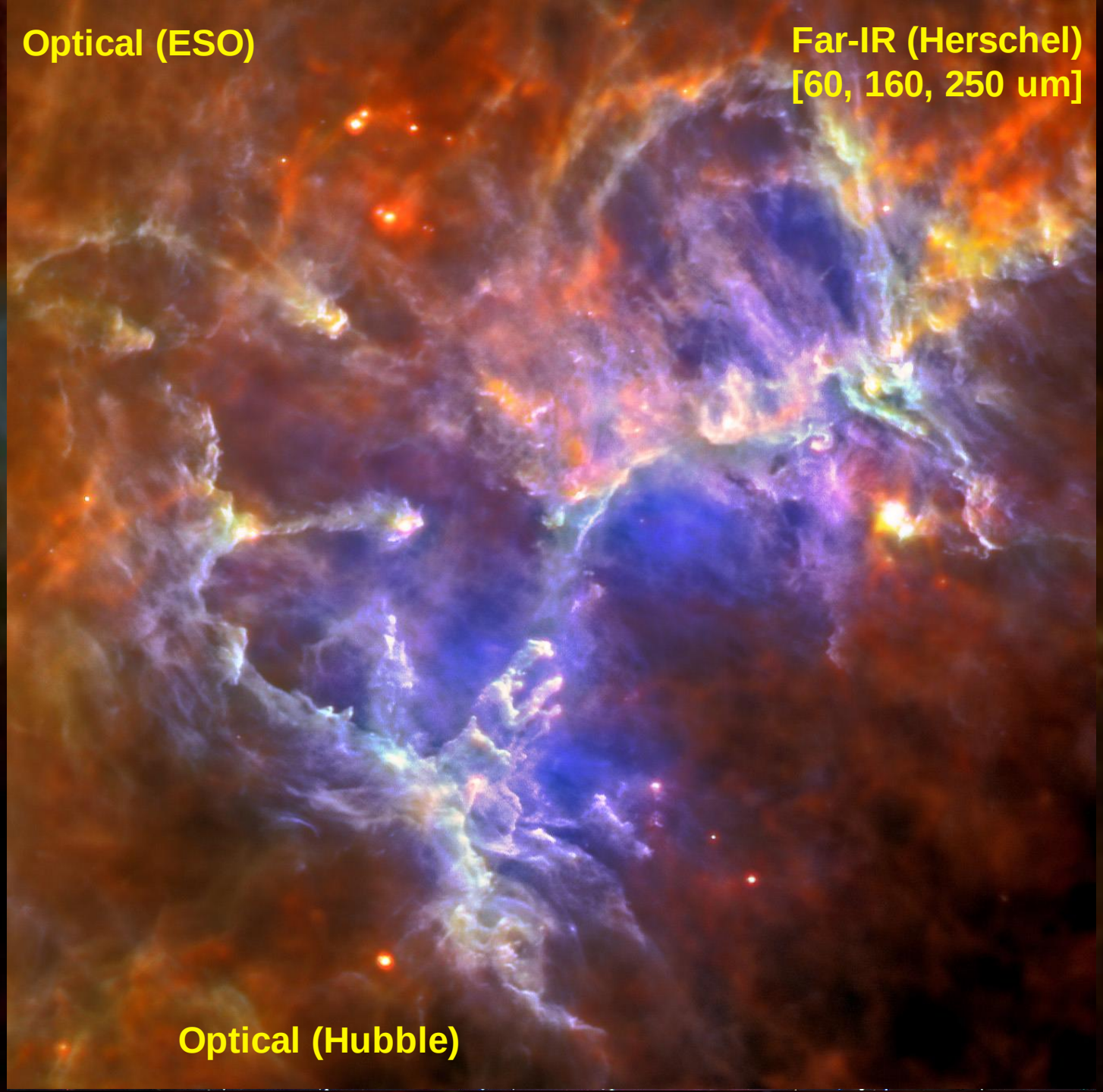


Image Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J. C. Algaba



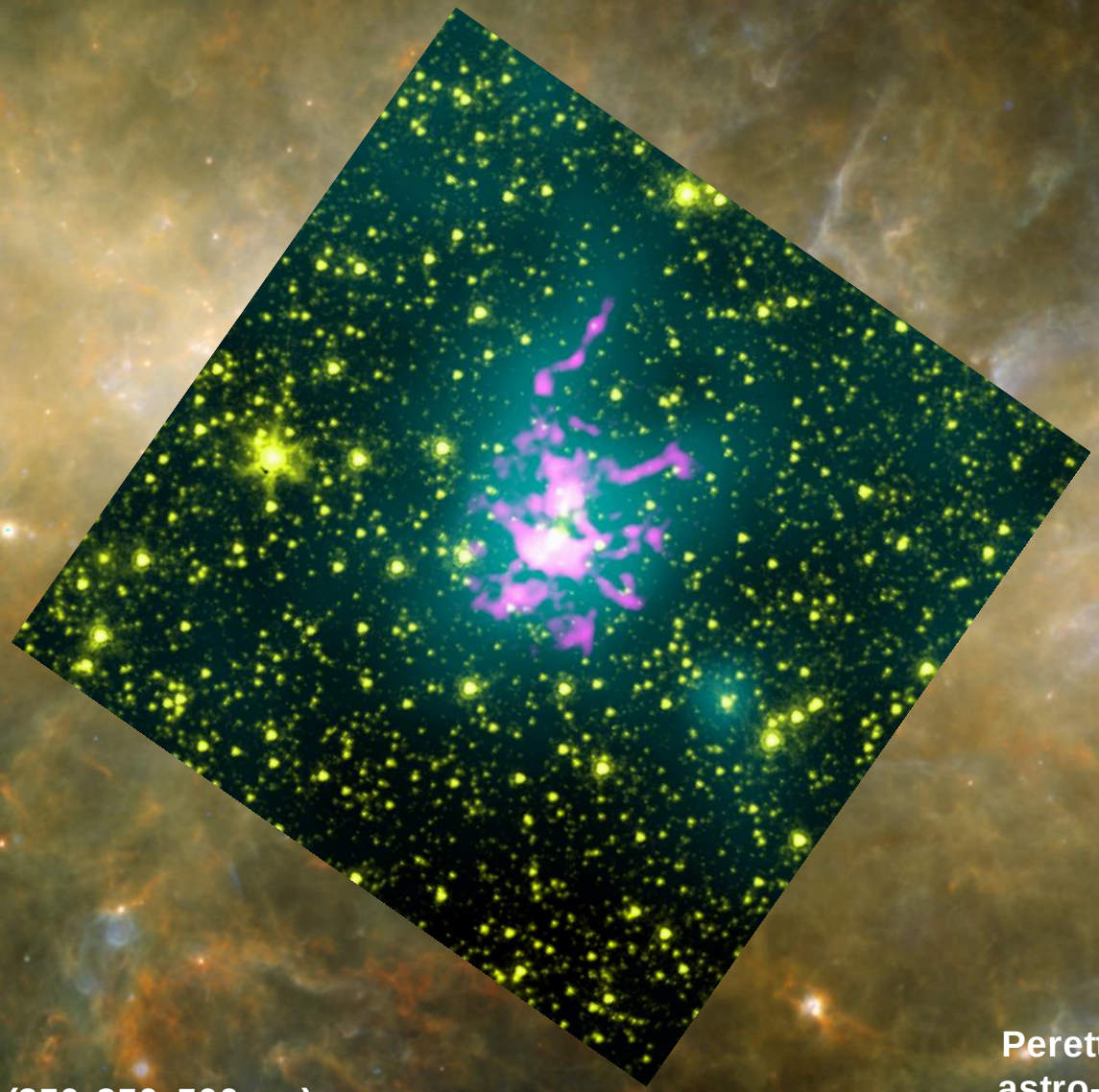

Optical (ESO)
Far-IR (Herschel)
[60, 160, 250 um]
Optical (Hubble)

Spitzer Dark Cloud 335

Spitzer
4.5um

Herschel
350 um

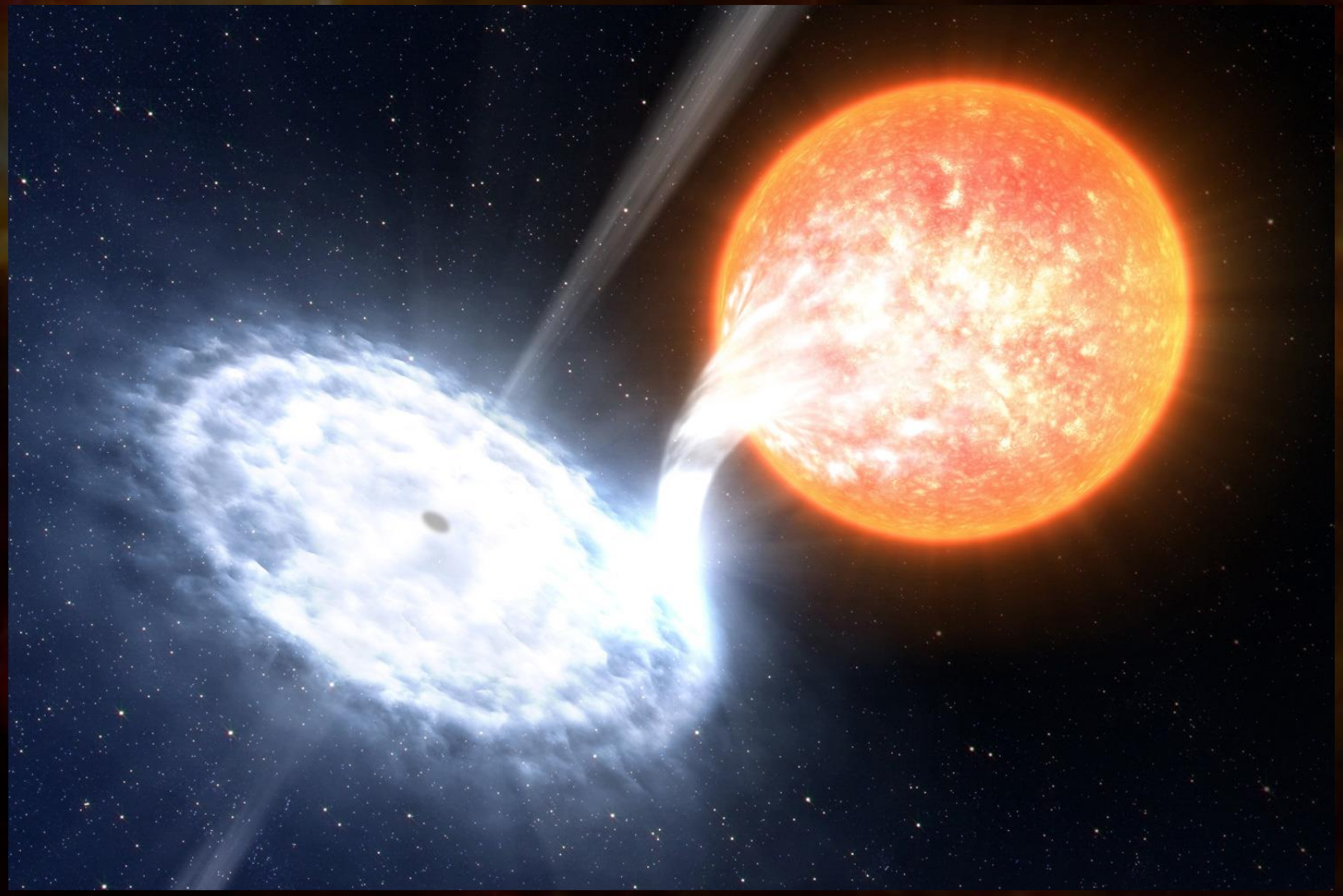
ALMA
3.2mm (CO)

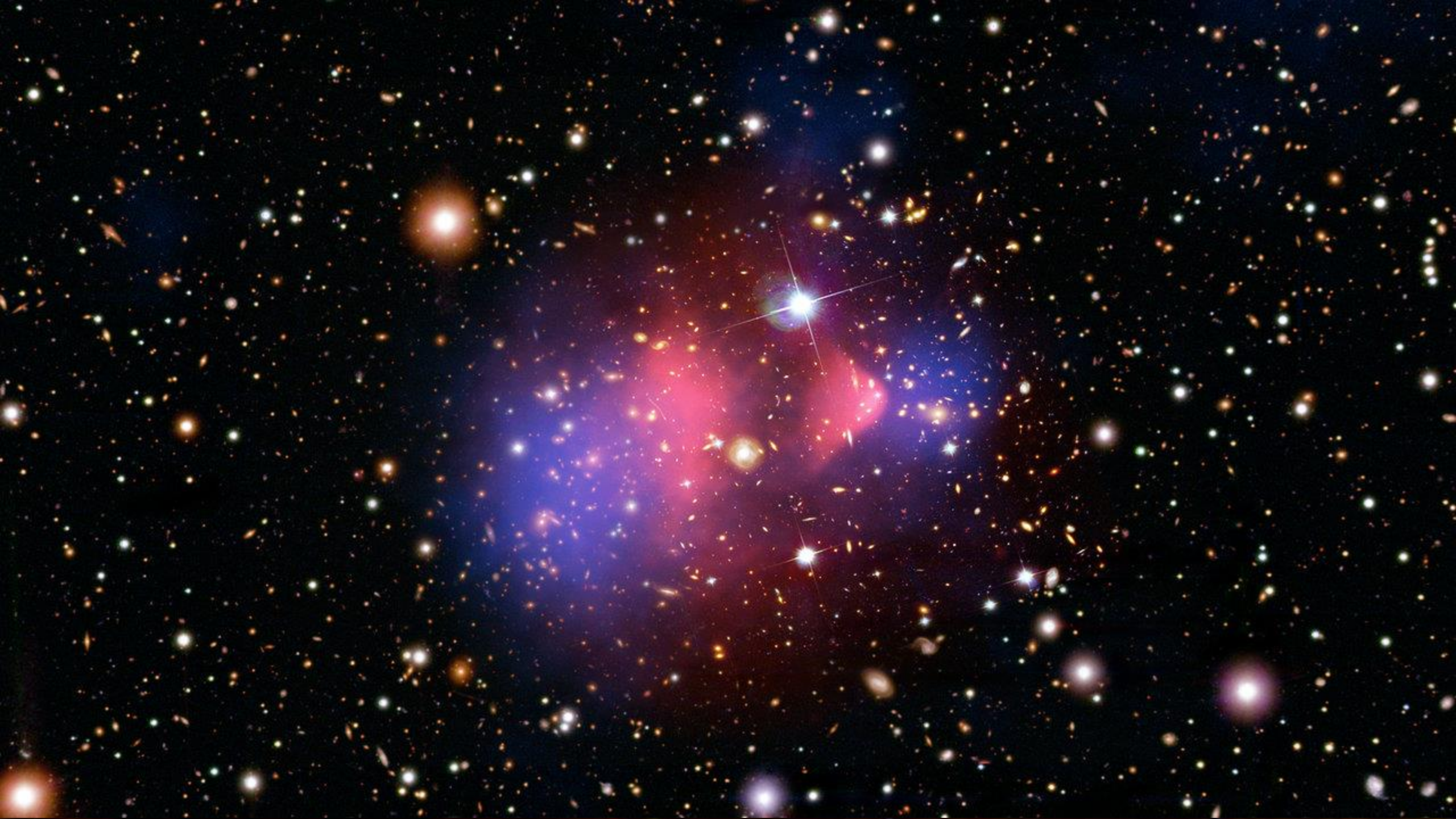


Herschel (250, 350, 500 um)

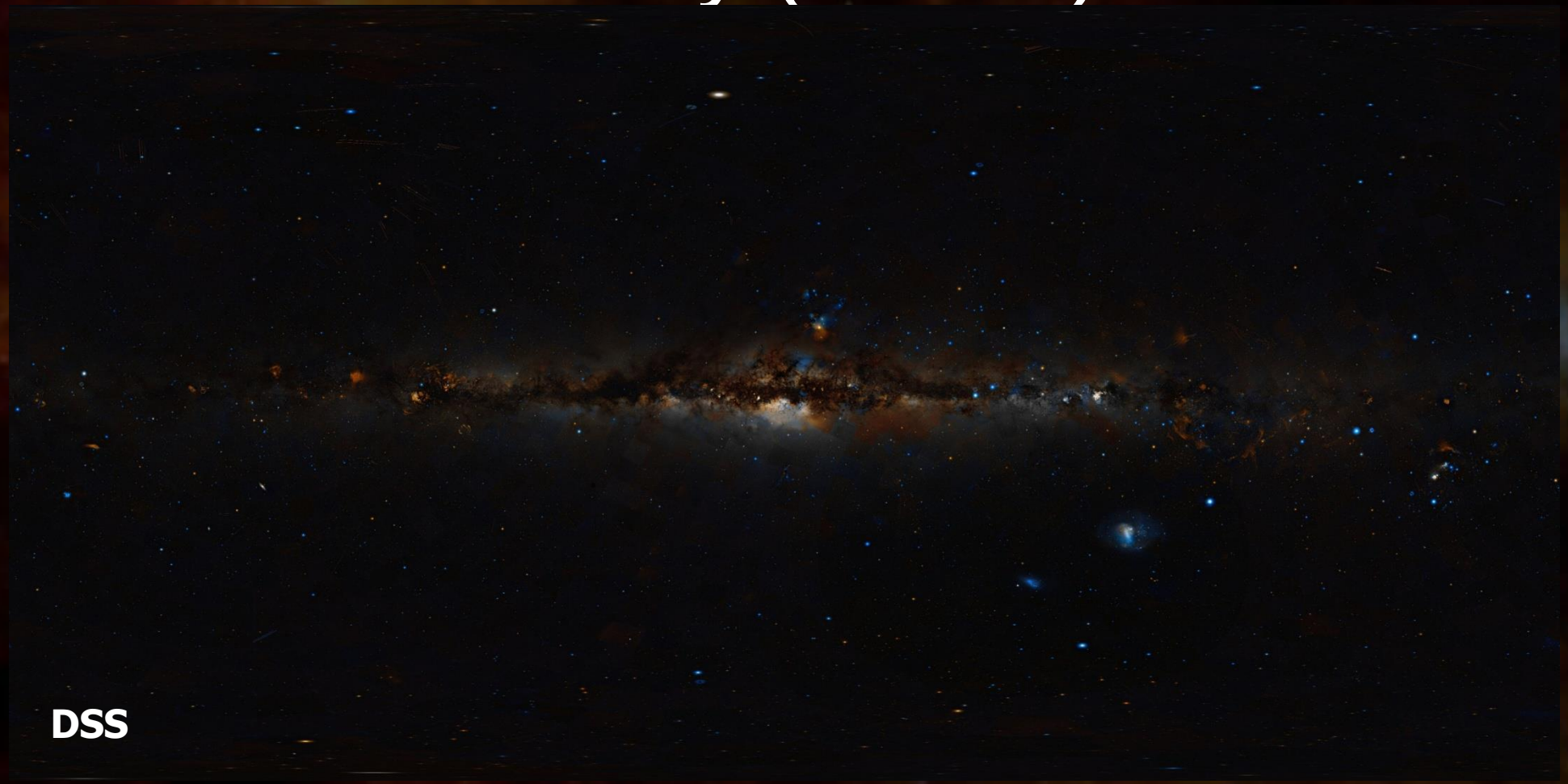
Peretto et al (2013)
astro-ph/1307.2590

X-ray binary stars



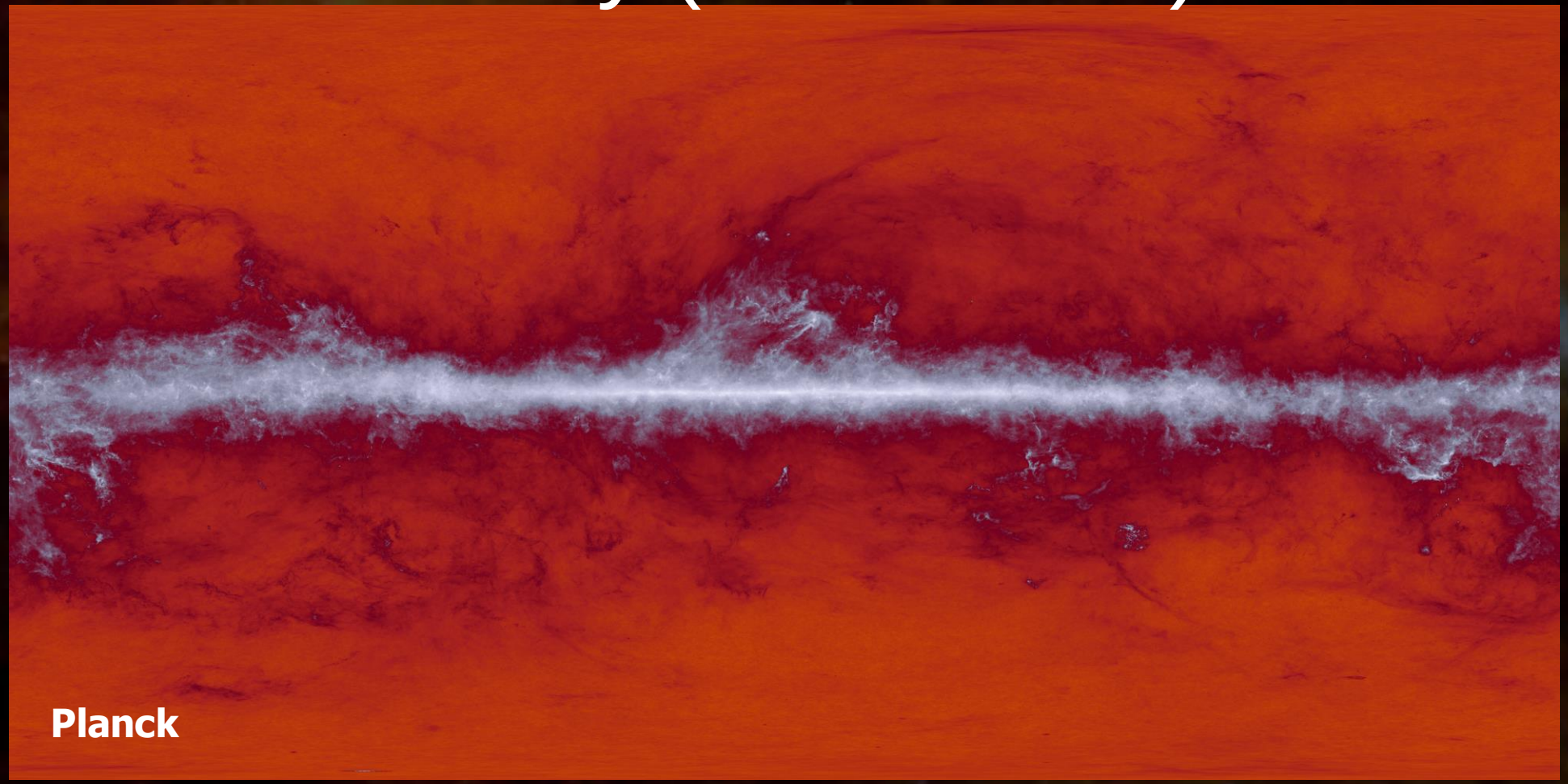


All sky (visible)



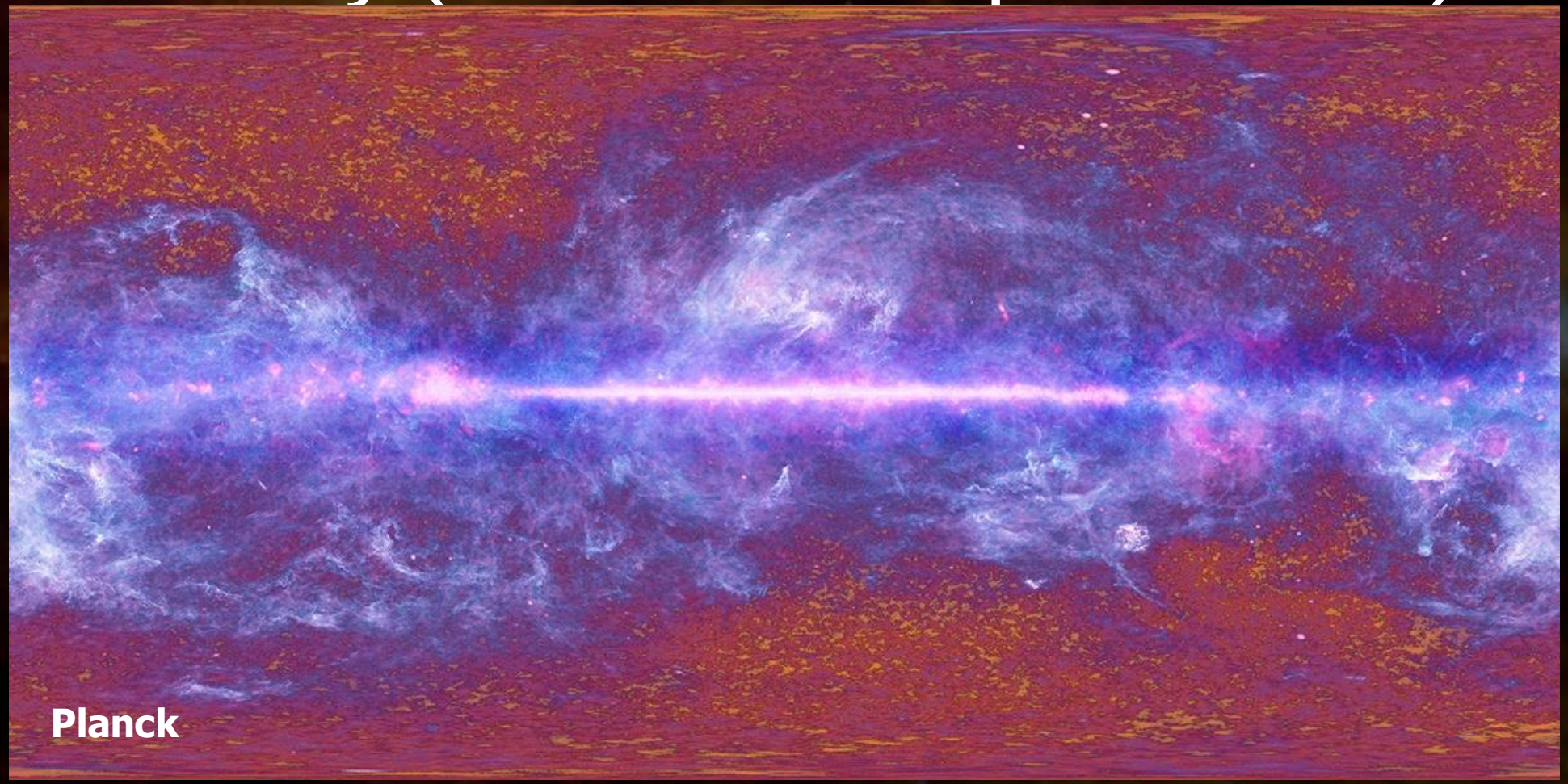
www.chromoscope.net

All sky (far-infrared)



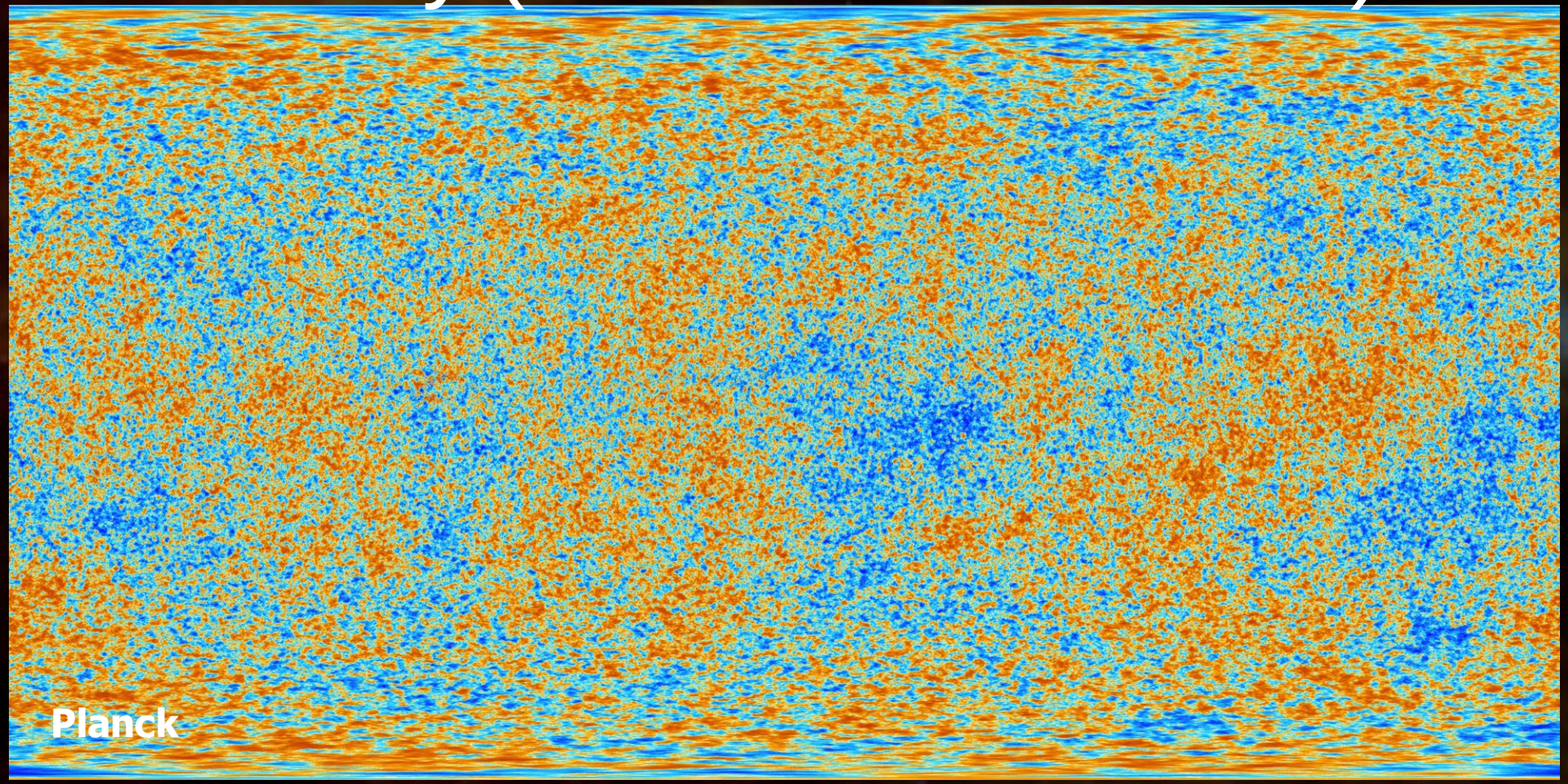
www.chromoscope.net/planck

All-sky (microwave - processed)



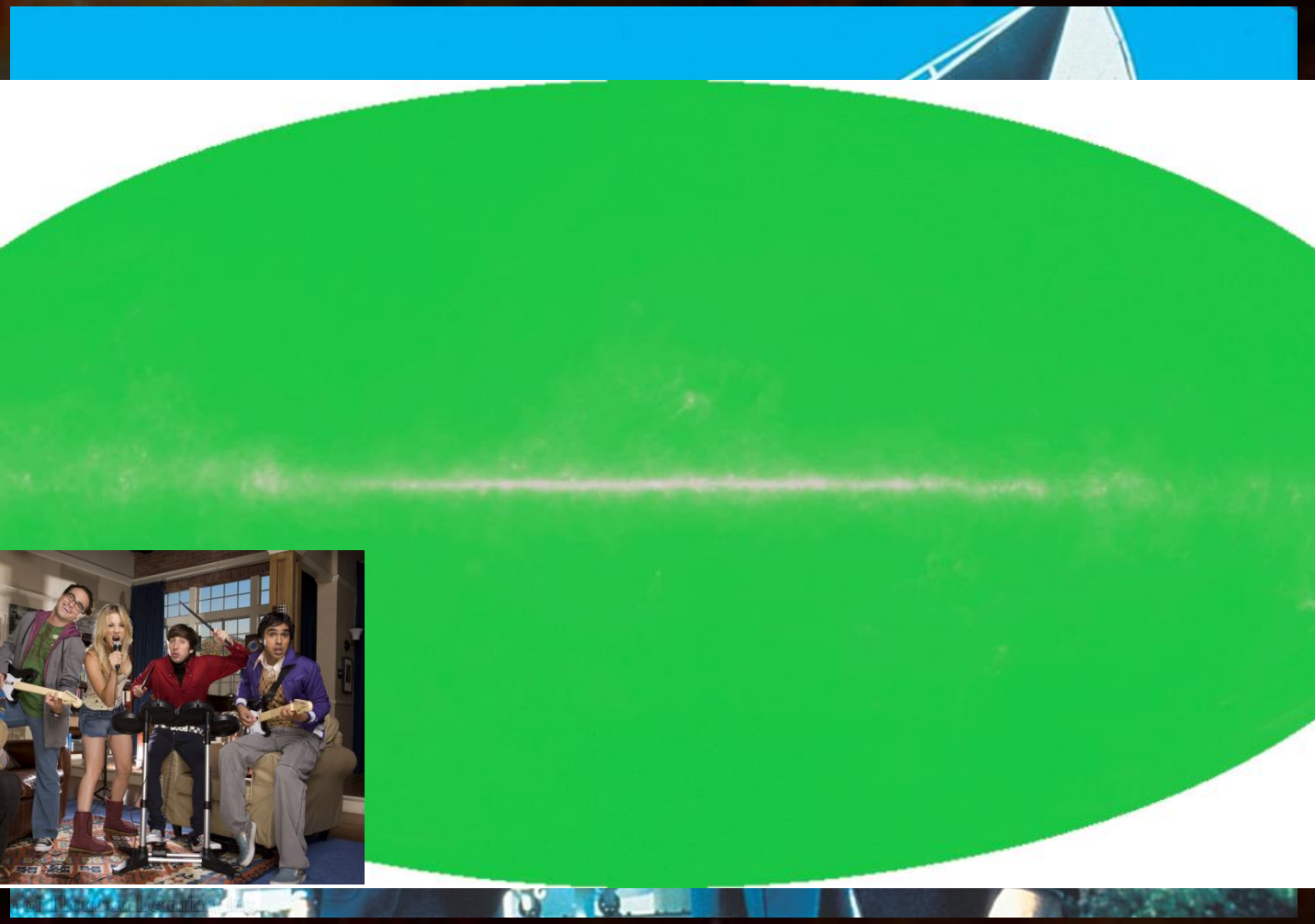
www.chromoscope.net

All-sky (microwave - filtered)

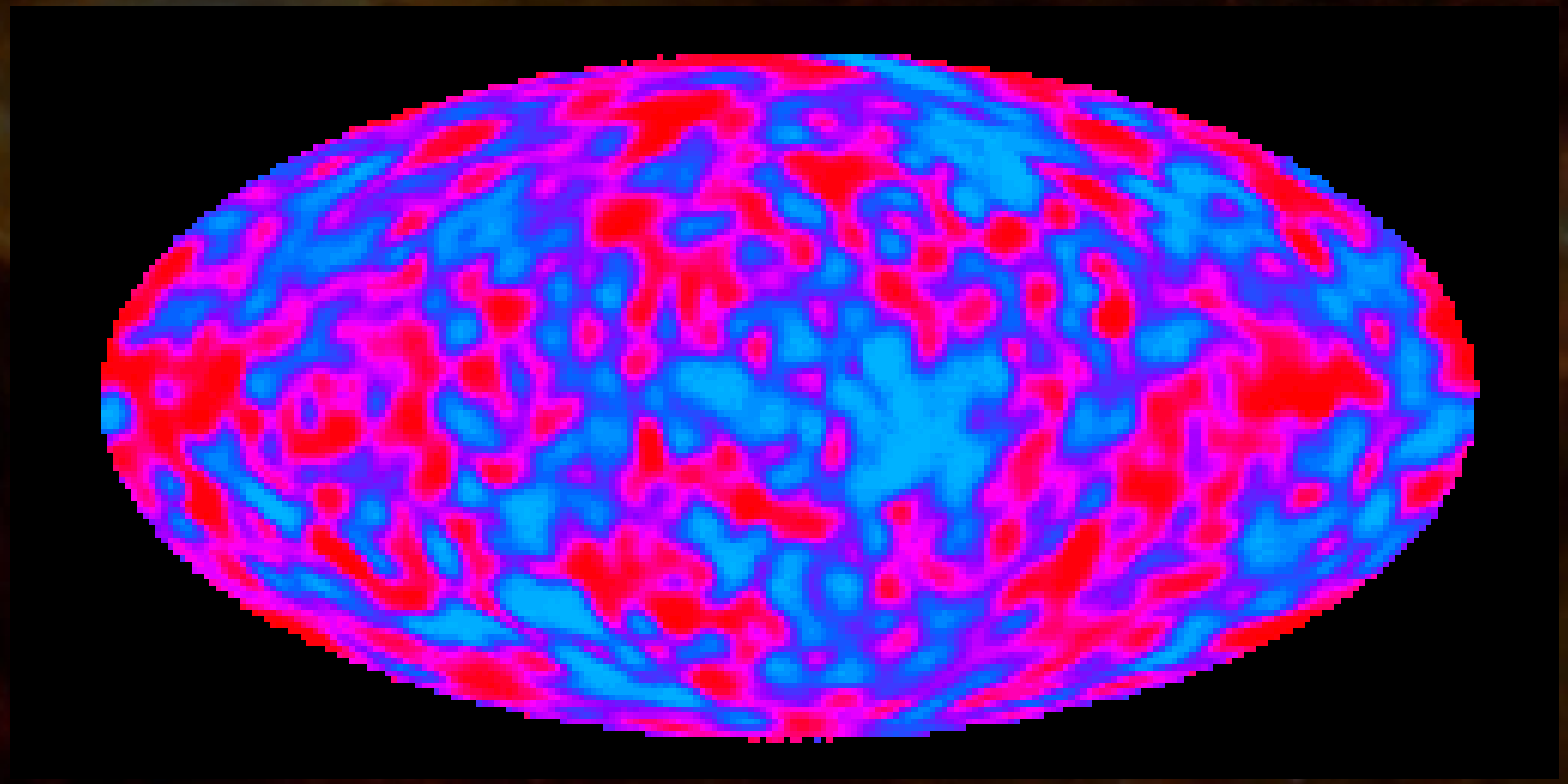


www.chromoscope.net/planck

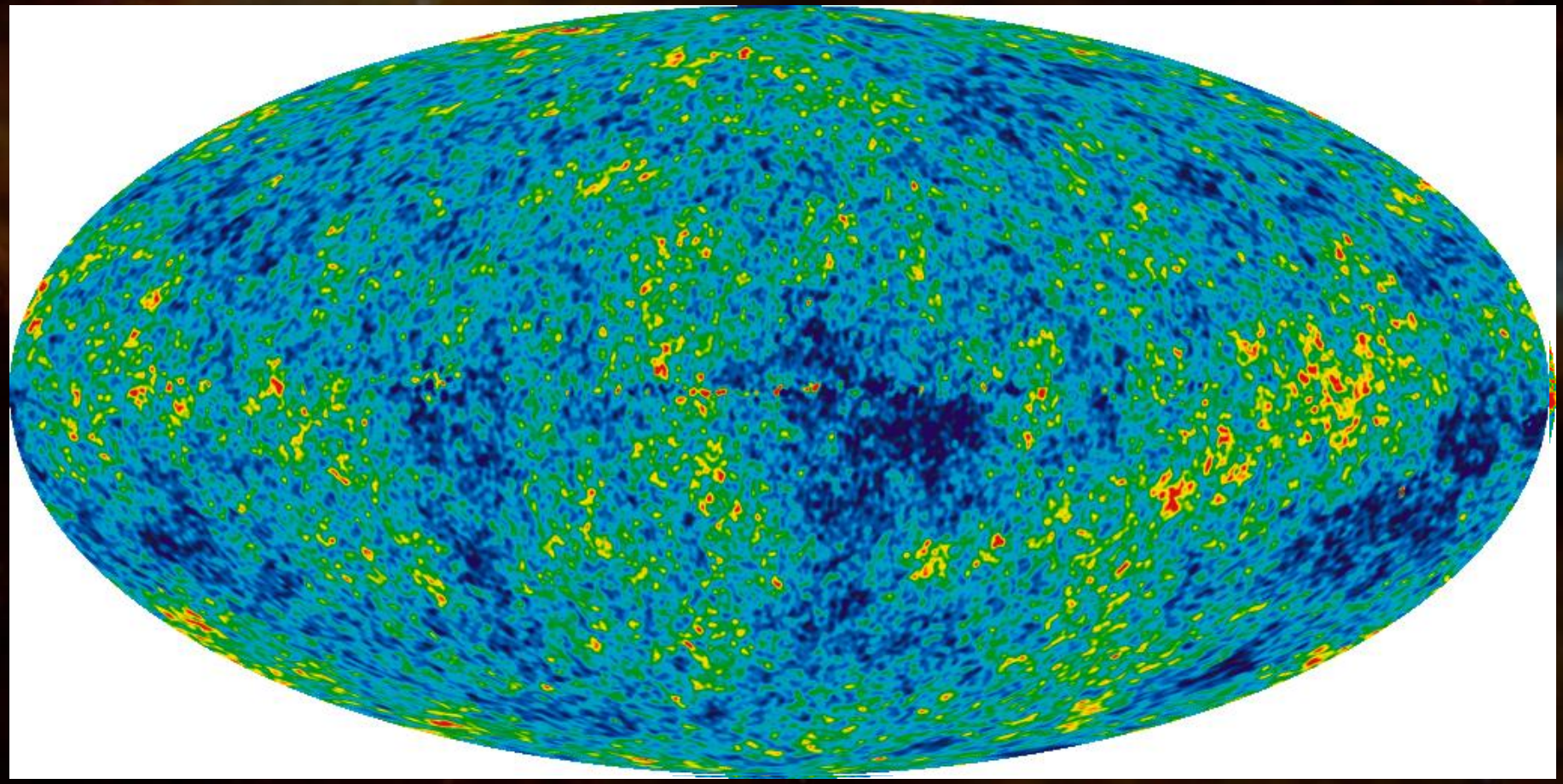
Cosmic Microwave Background



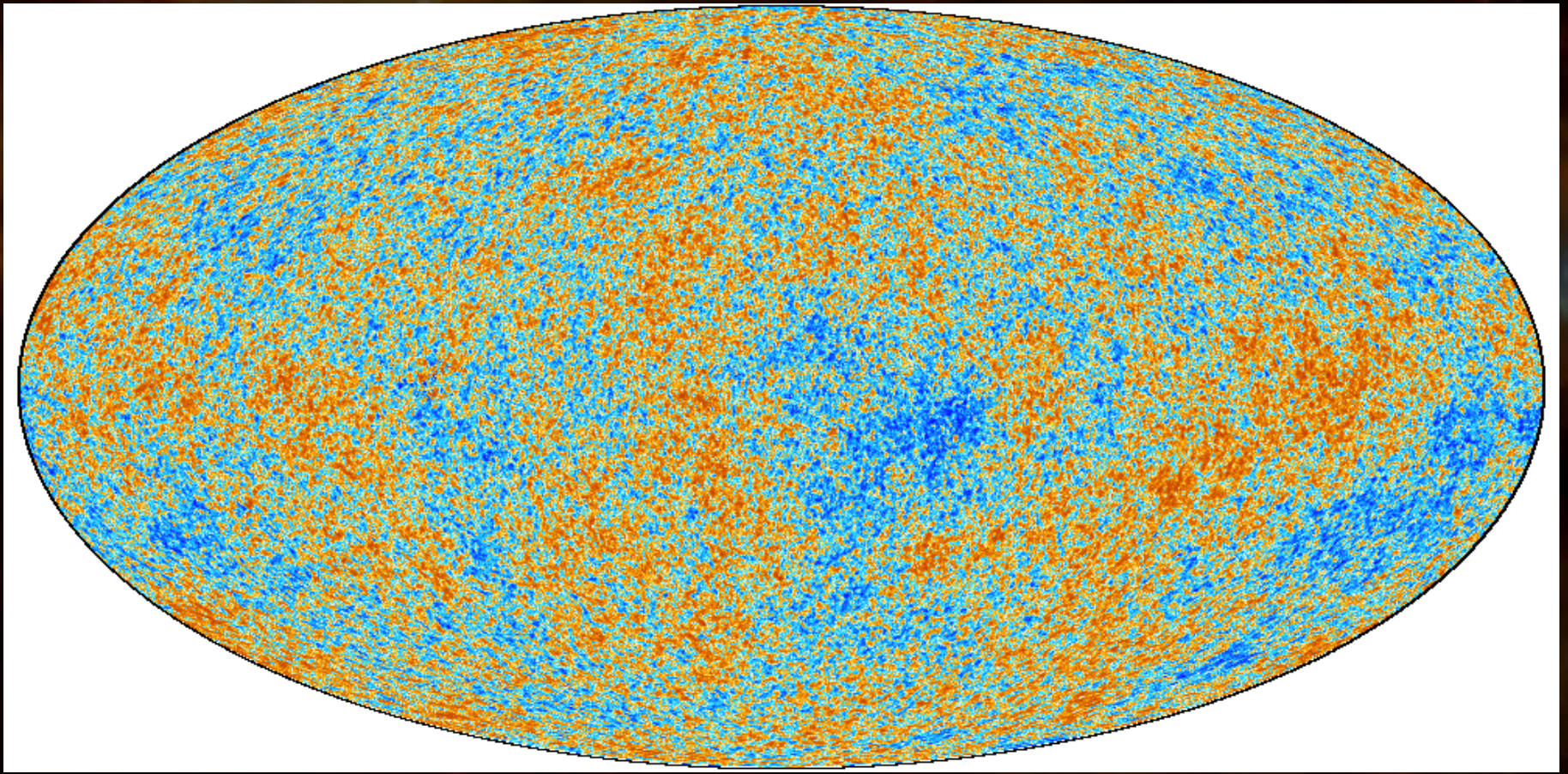
COBE: 1990s



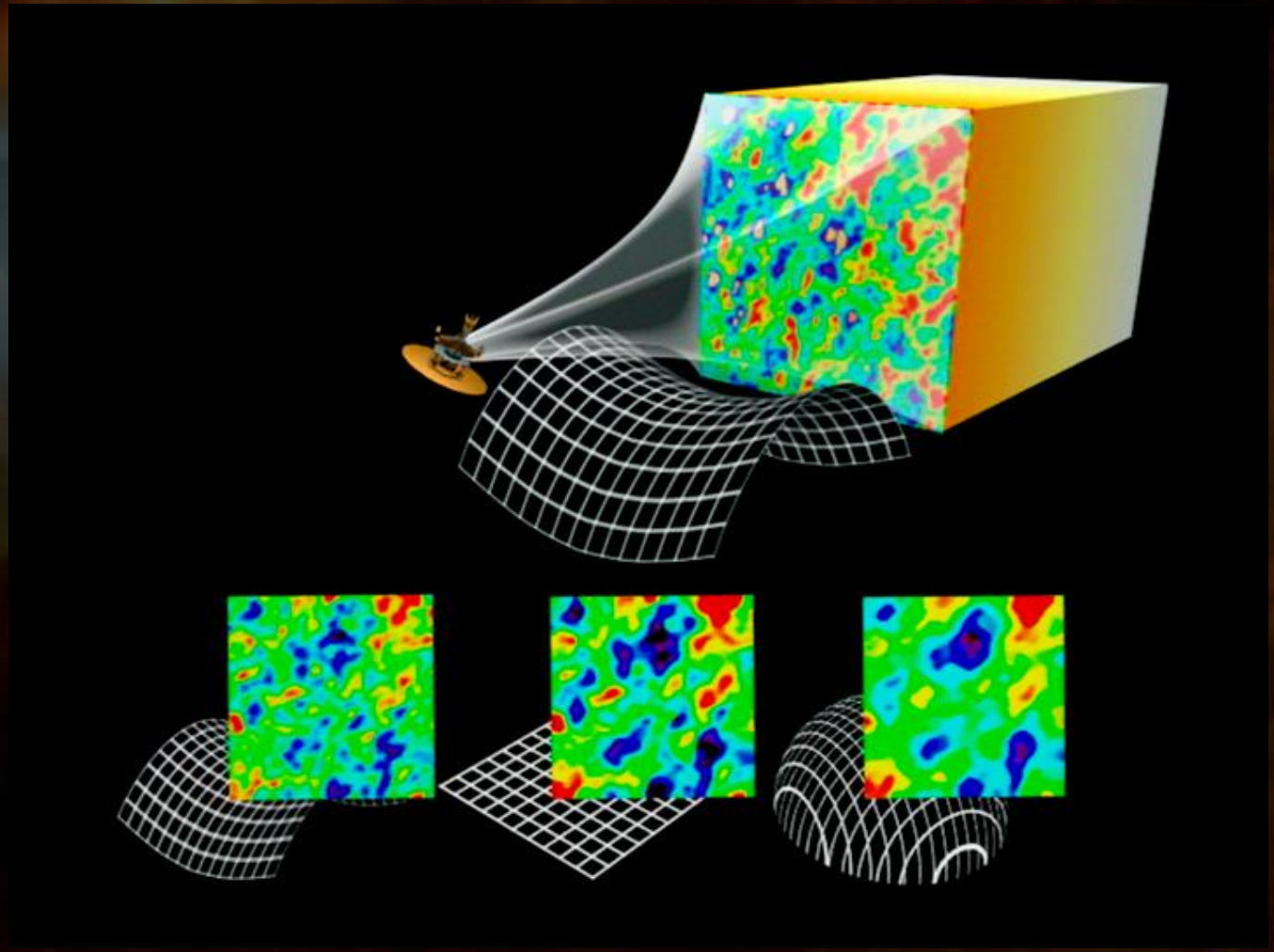
WMAP (2001)



Planck (2013)

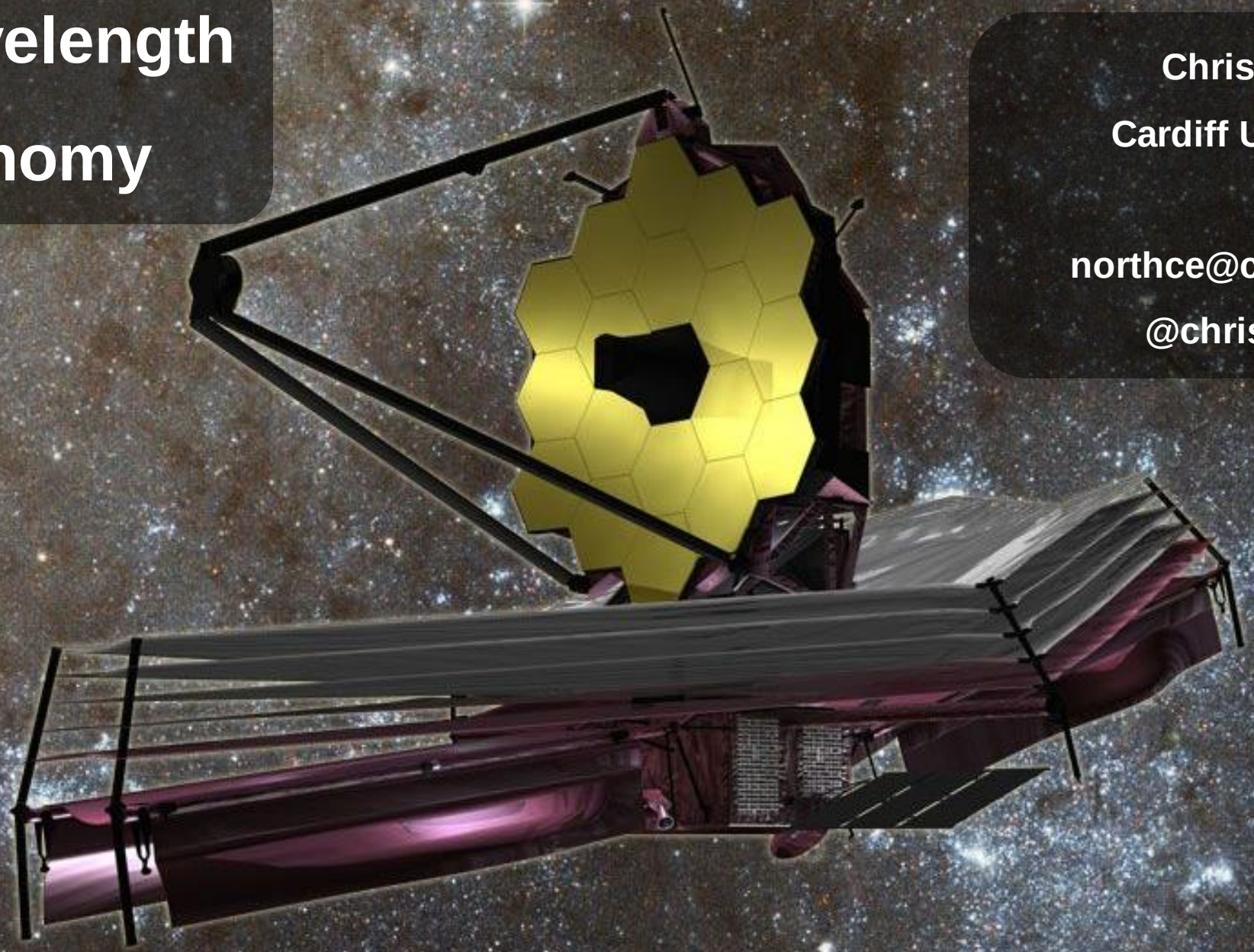


The Geometry of Space



https://plancksatellite.org.uk/cmb-sim/

Multiwavelength Astronomy



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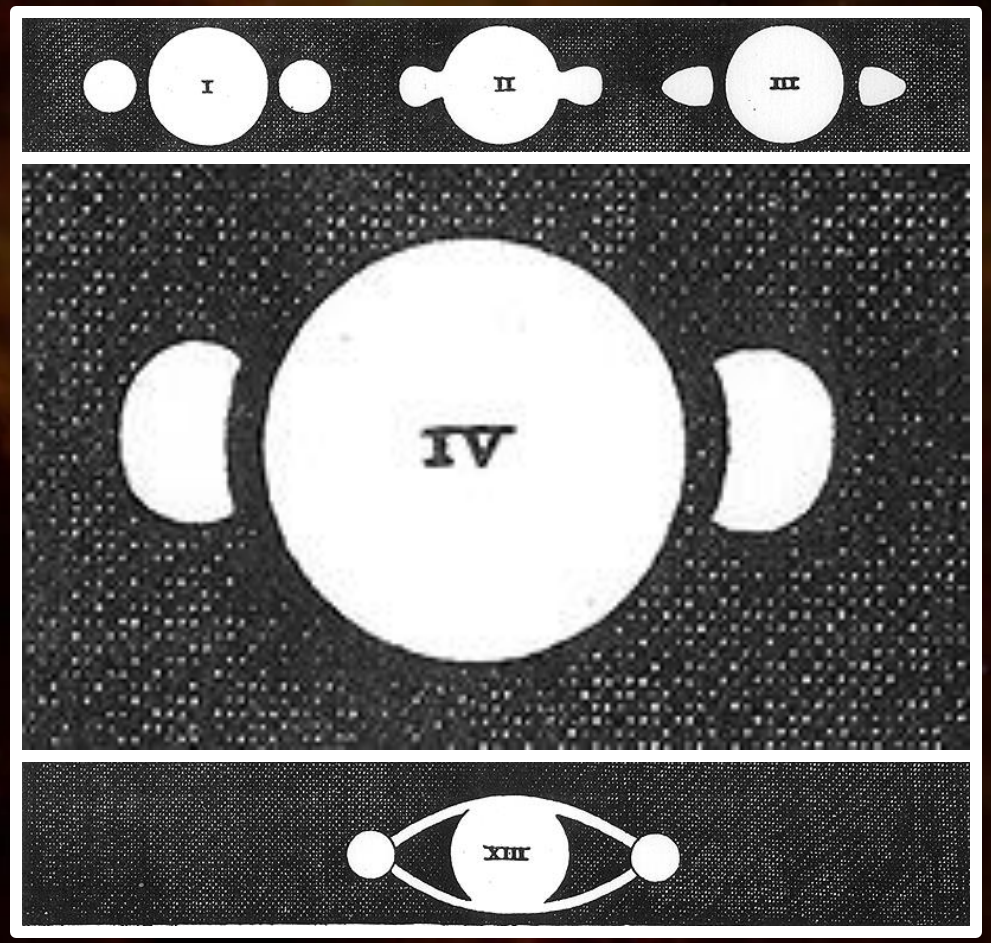
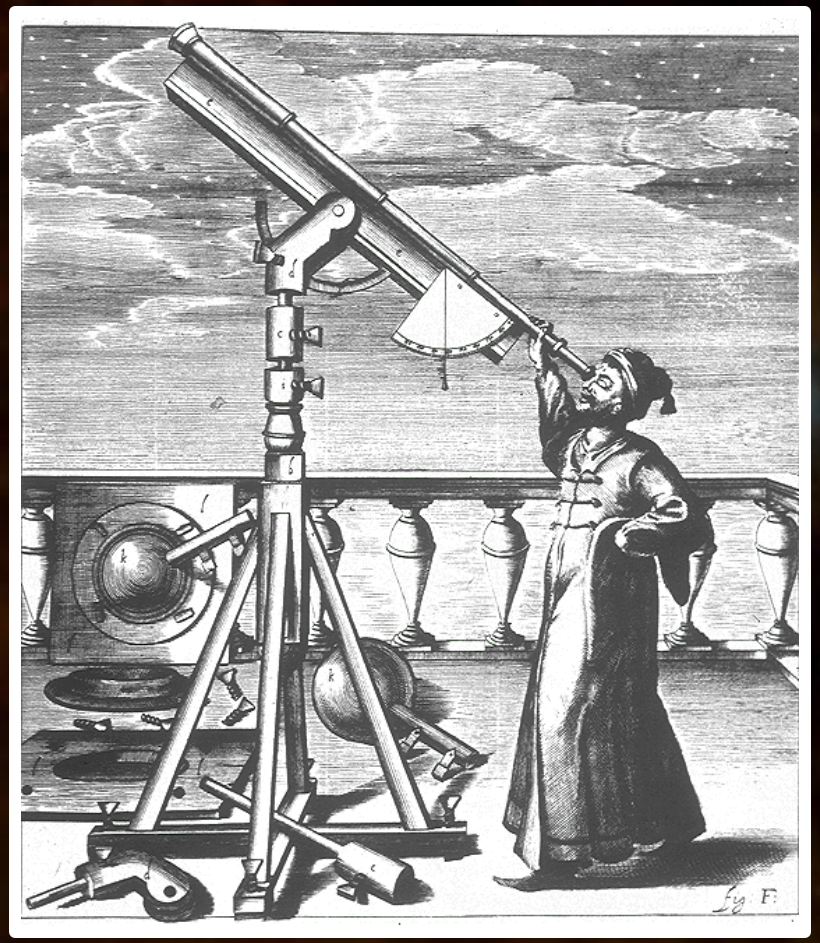
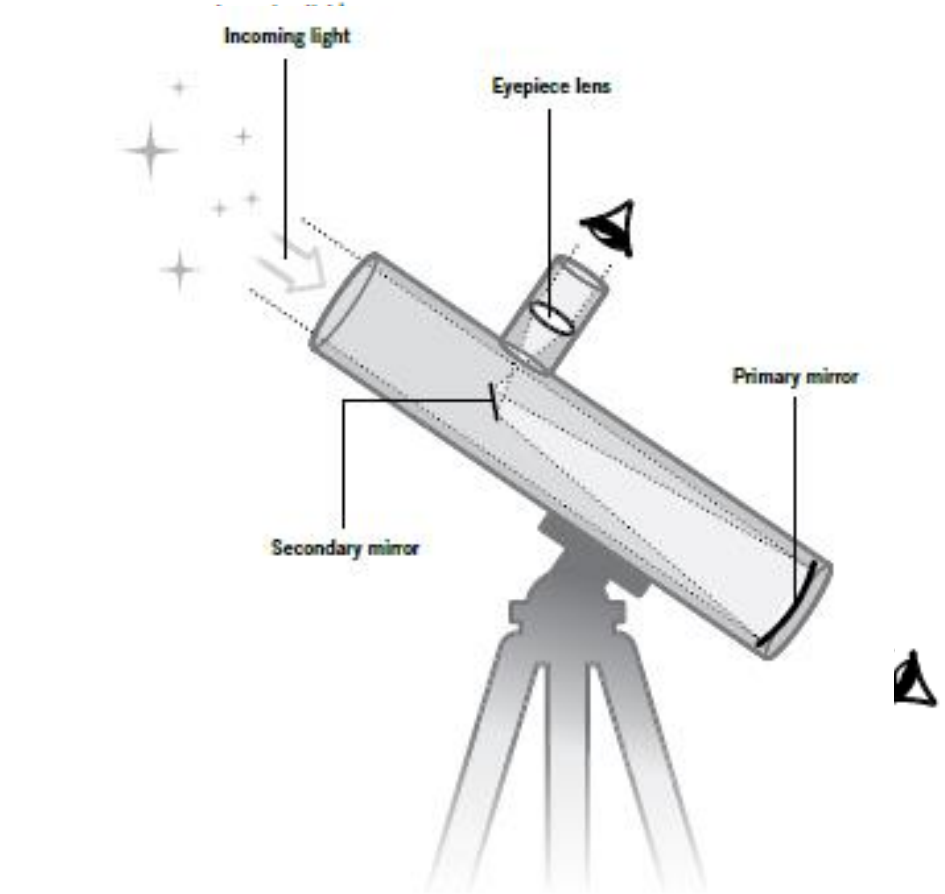
@chrisenorth

The First Telescopes



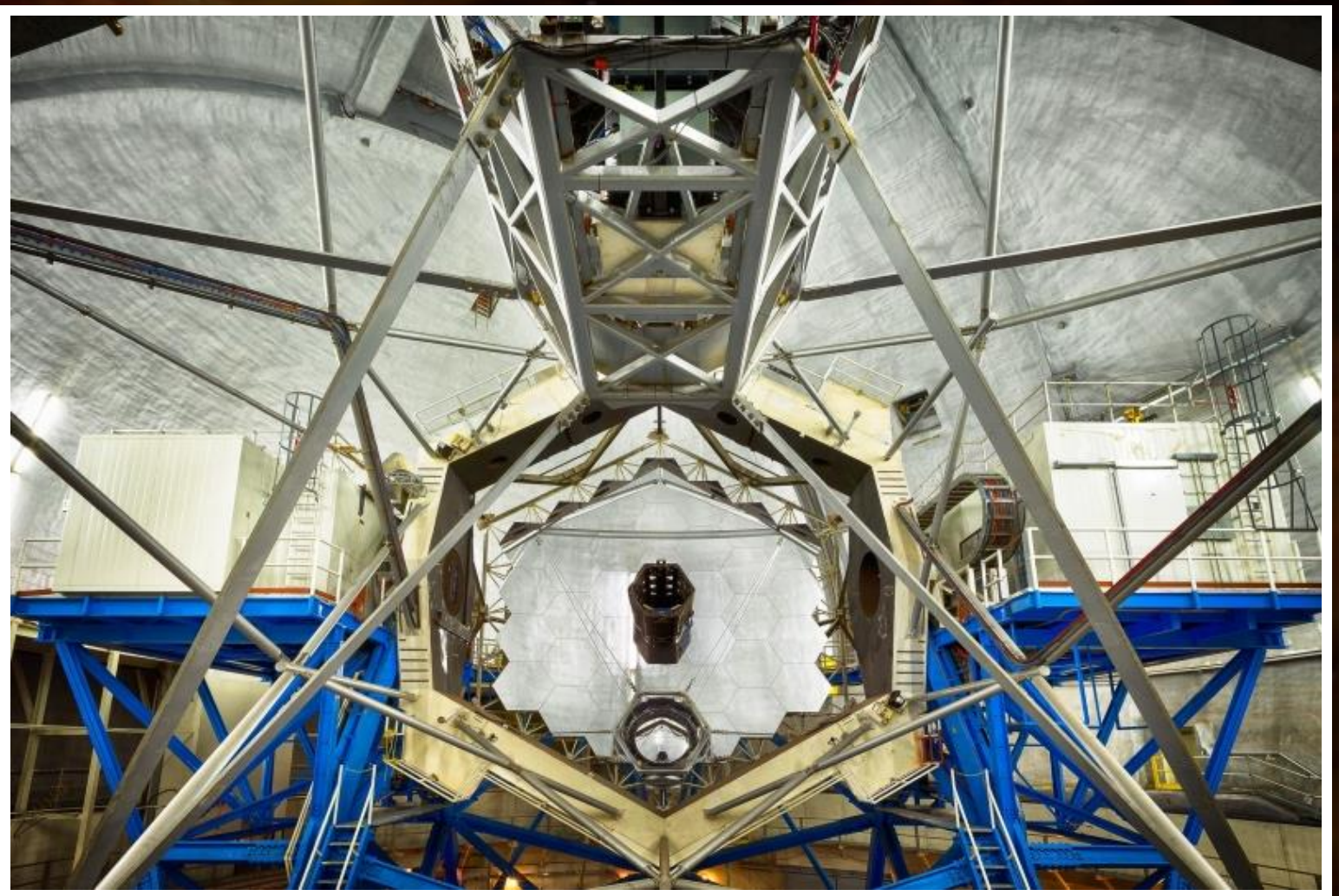


The first telescopes



© Sky at Night: Answers to Questions from Across the Universe,

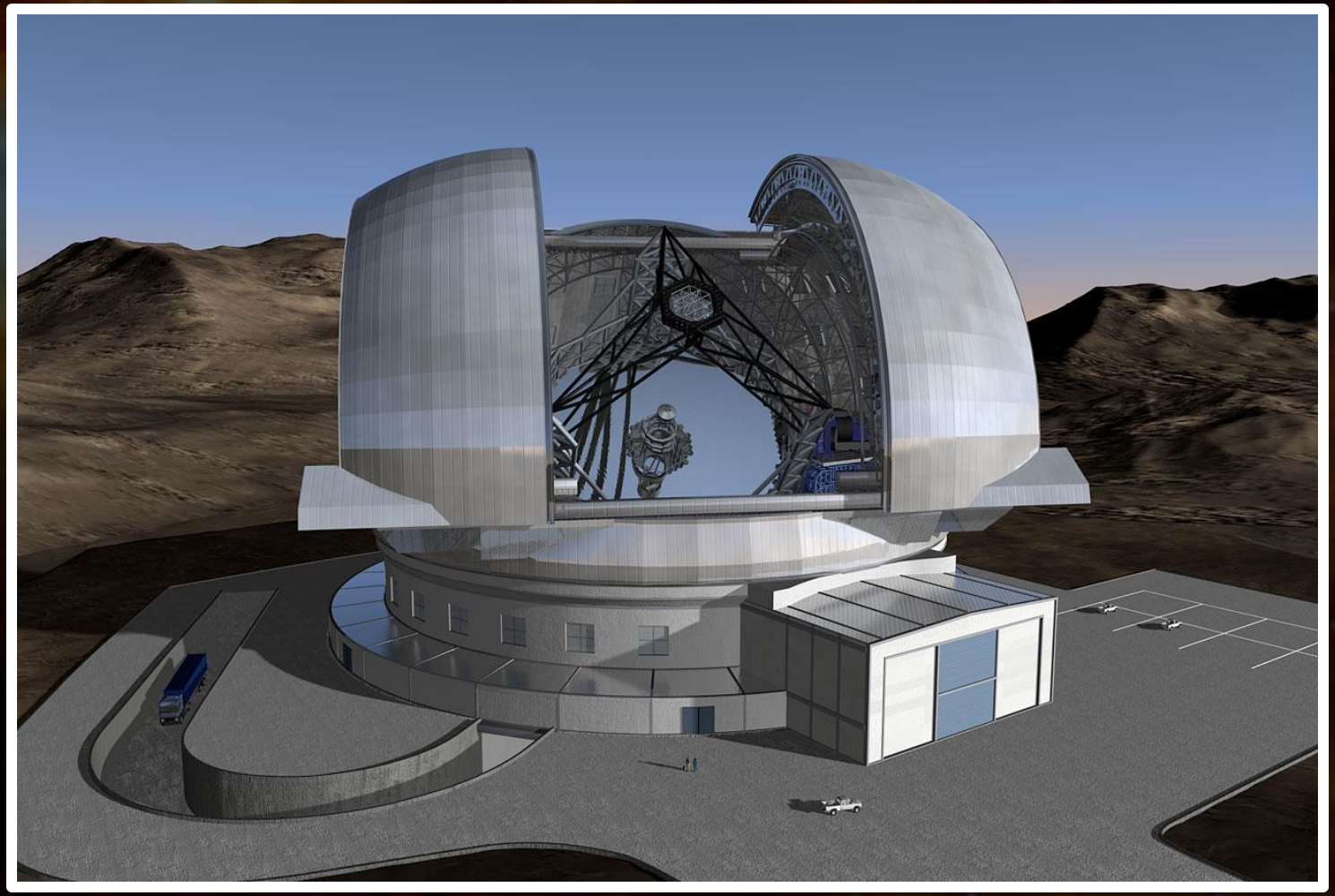
Nikola Smolenski



W. M. Keck Observatory

Very Large Telescope

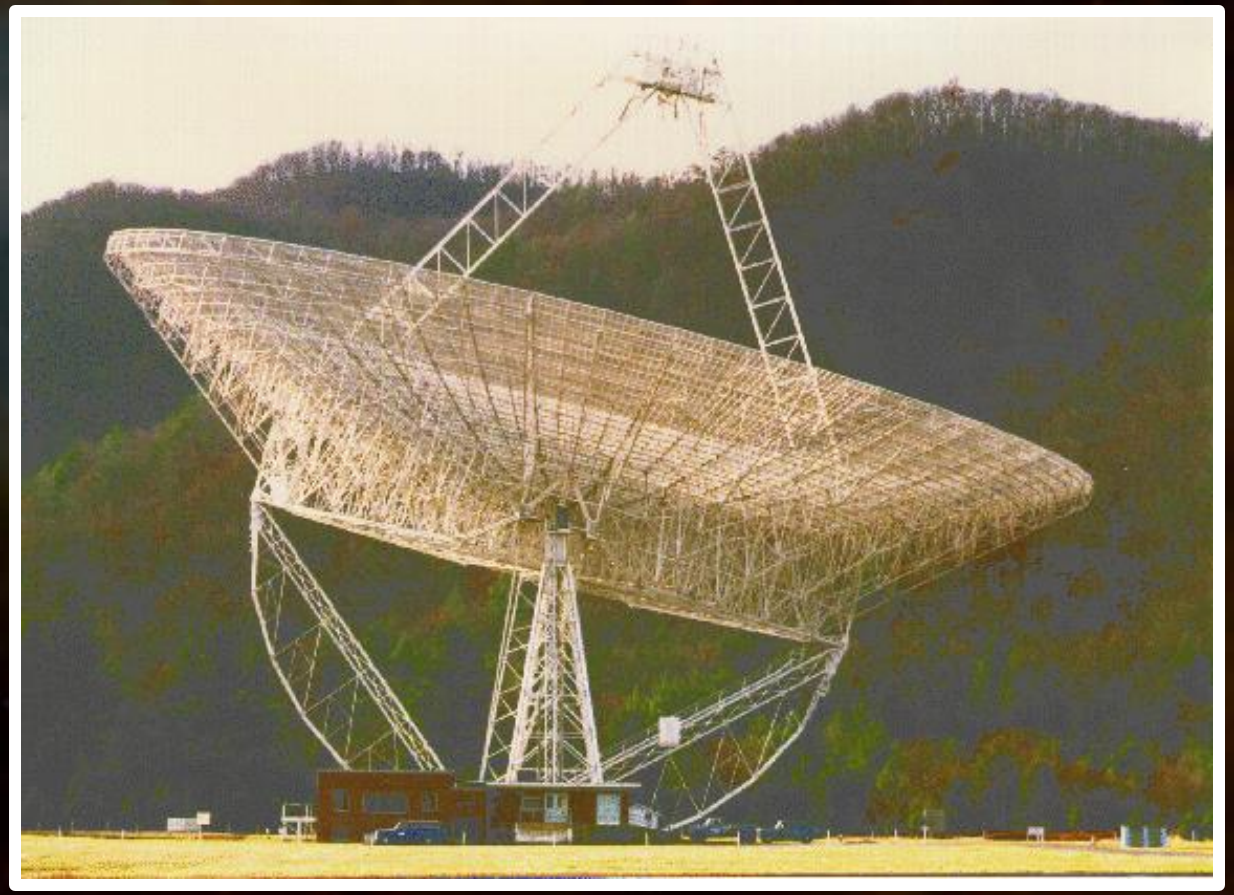
Extremely Large Telescope



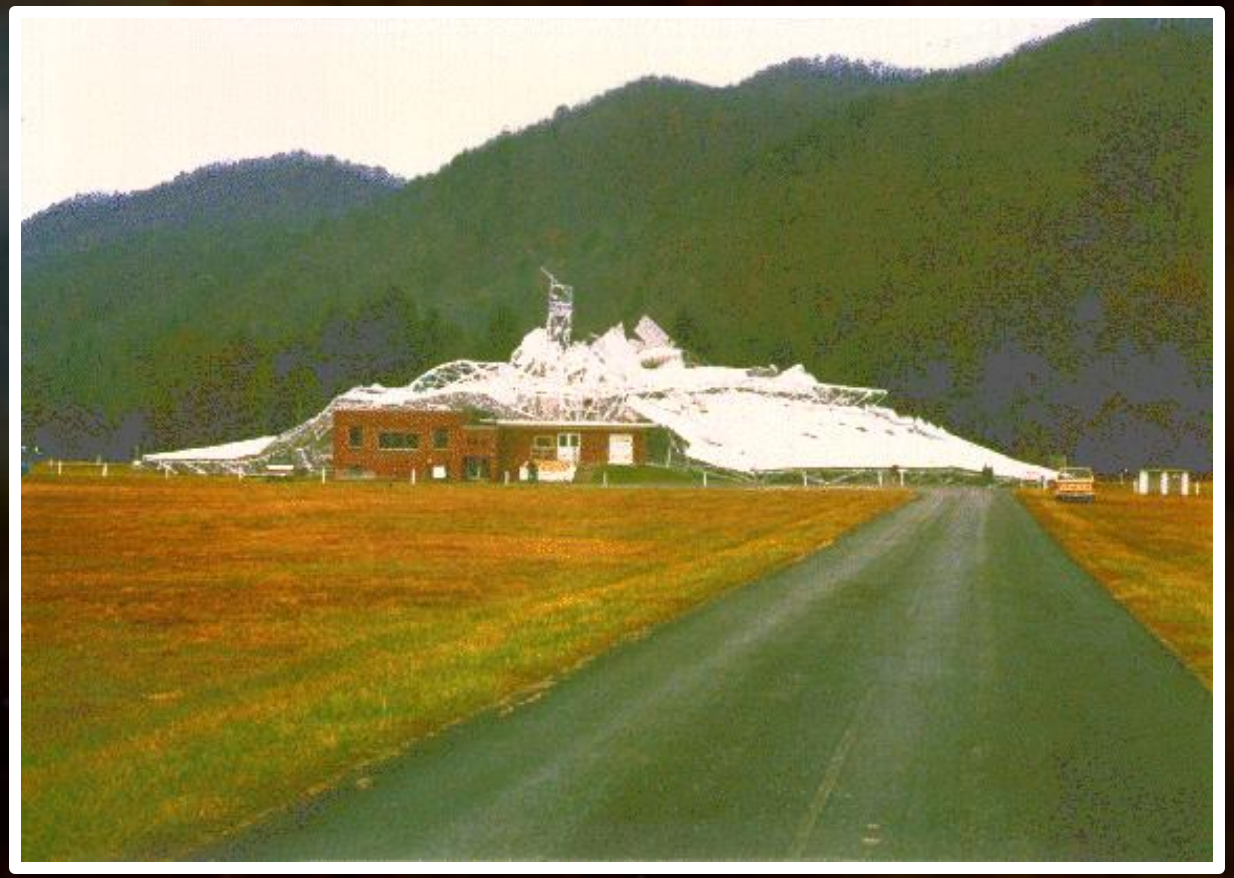
Lovell
Telescope

Effelsberg
telescope

300-foot Green Bank Telescope

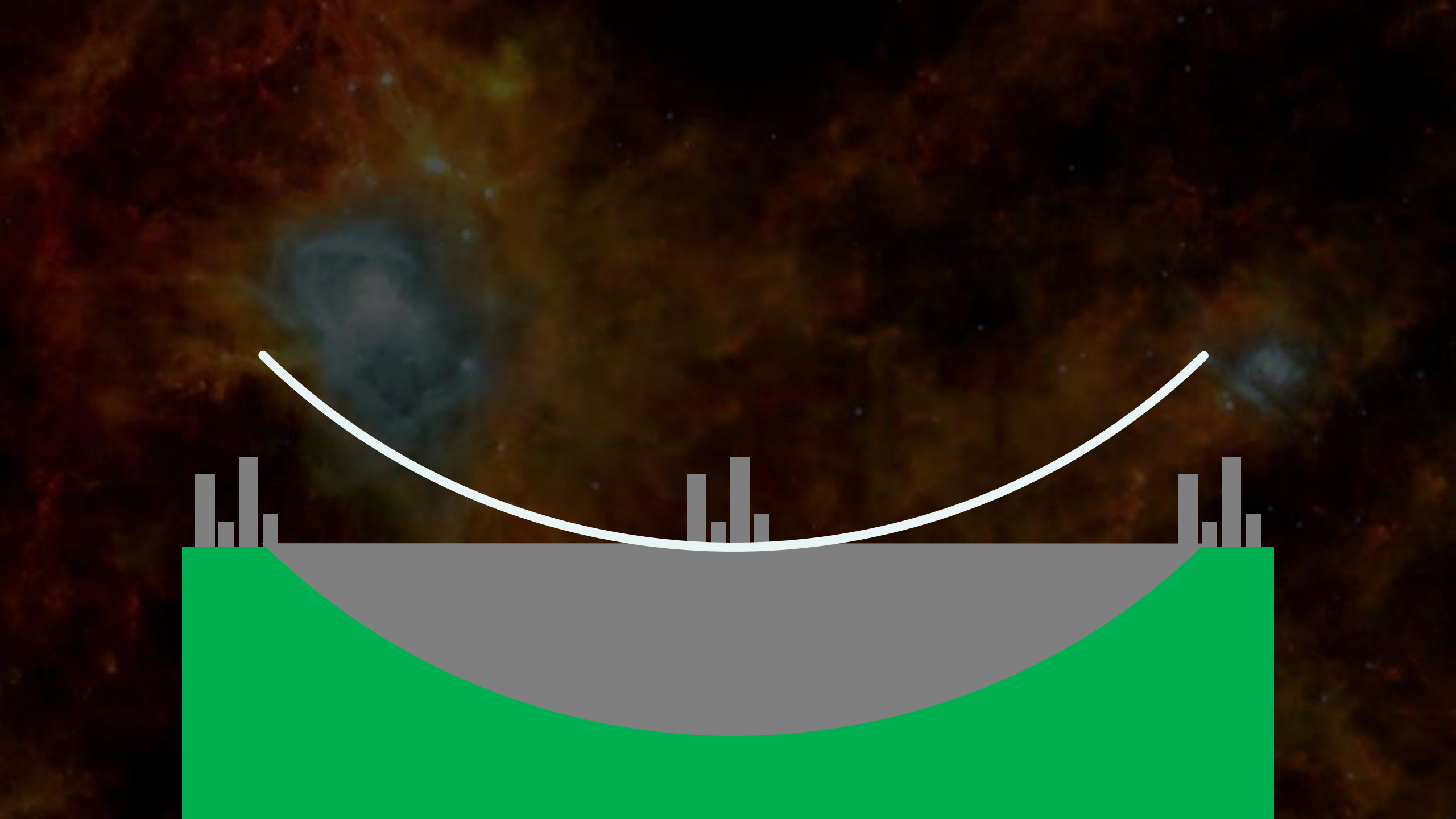


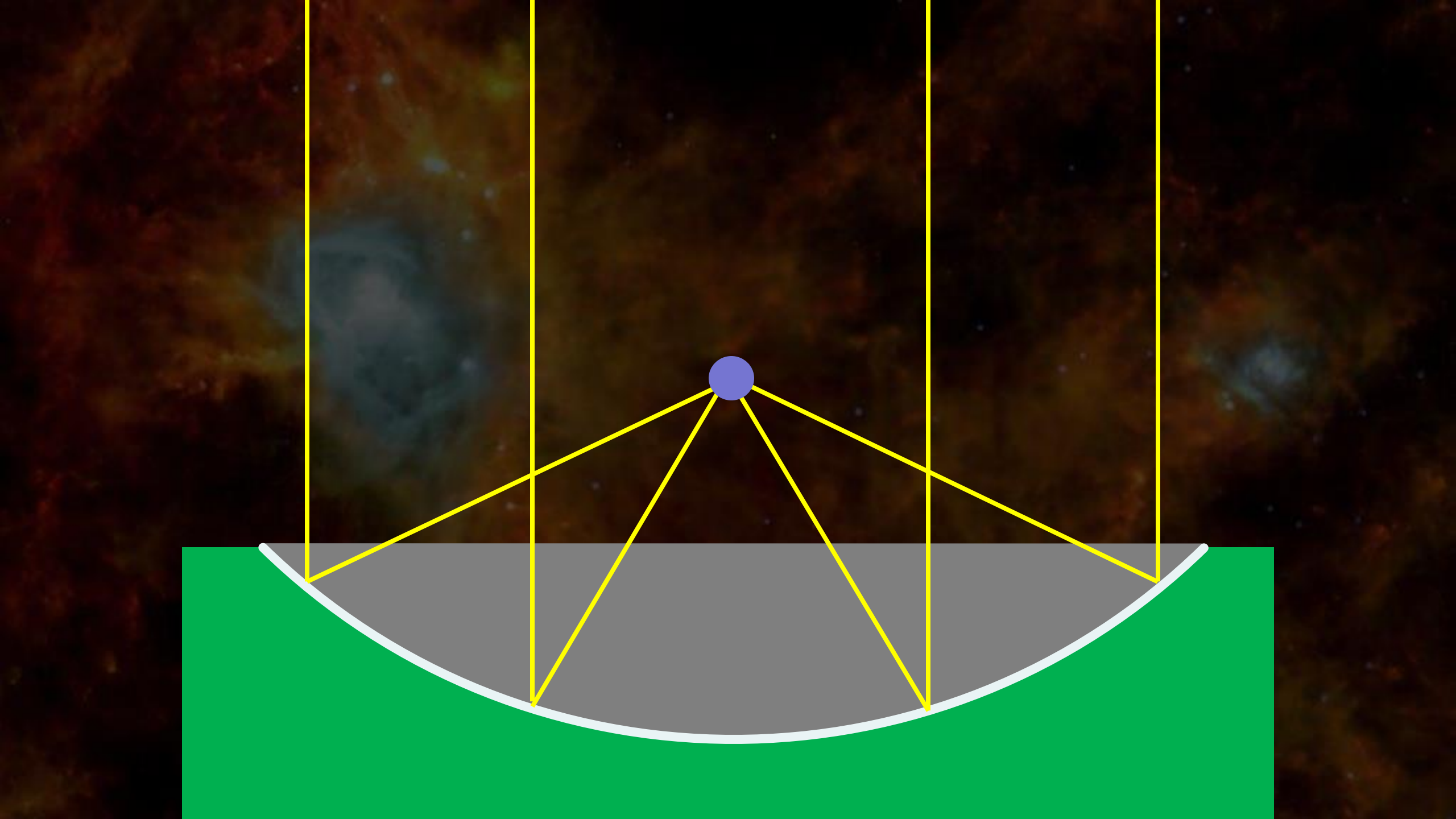
300-foot Green Bank Telescope

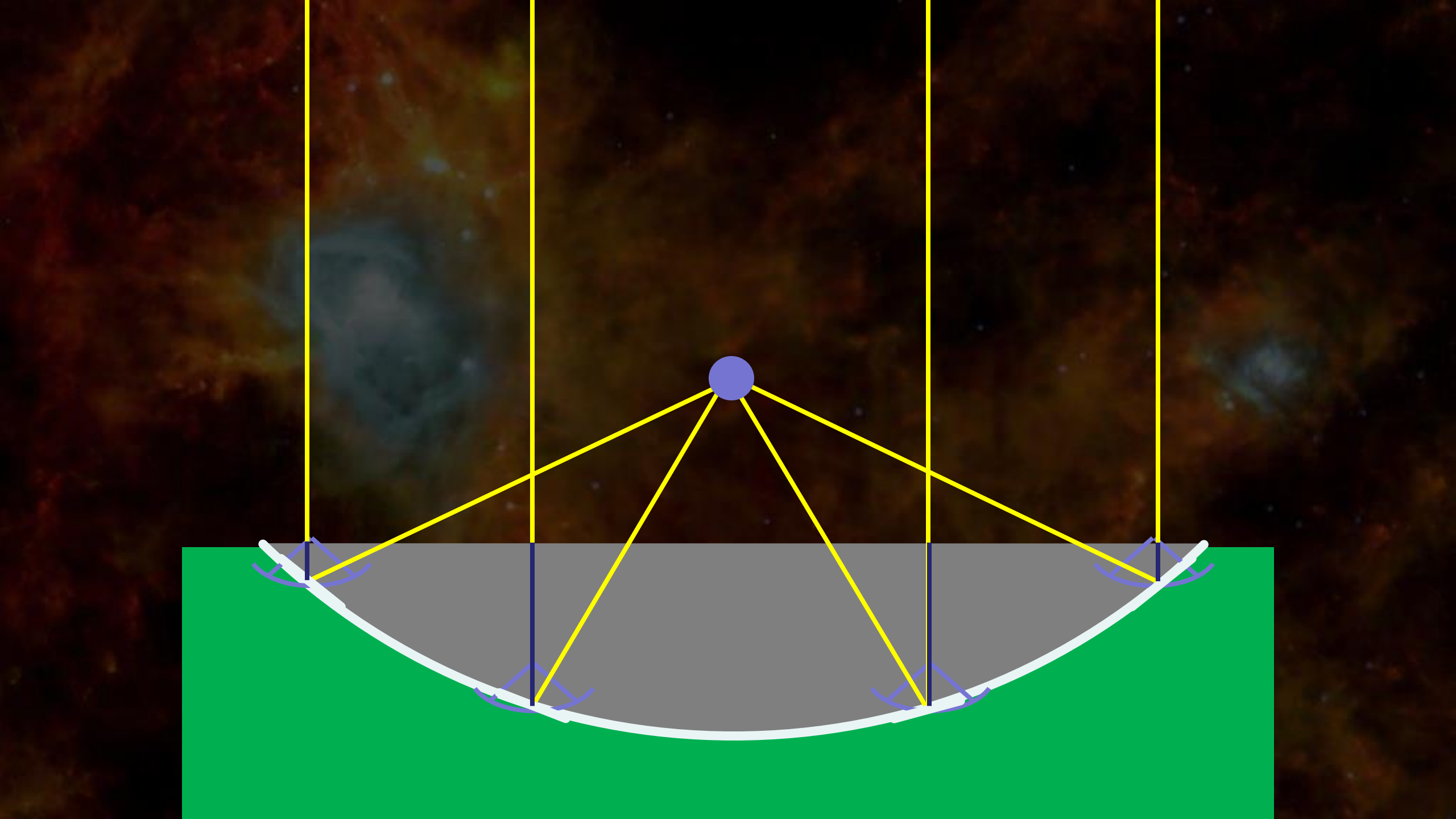


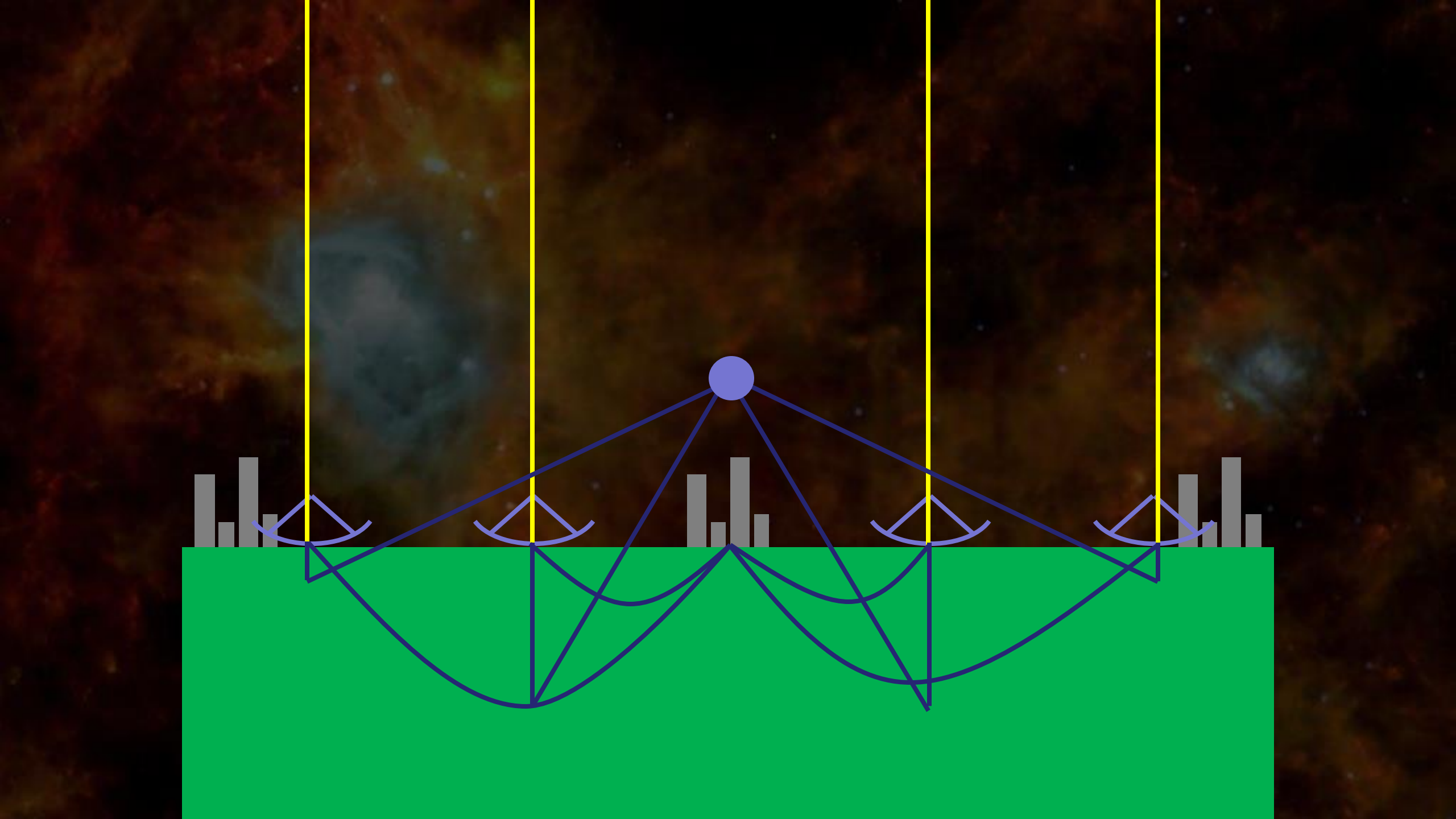
Arecibo Radio Telescope

FAST



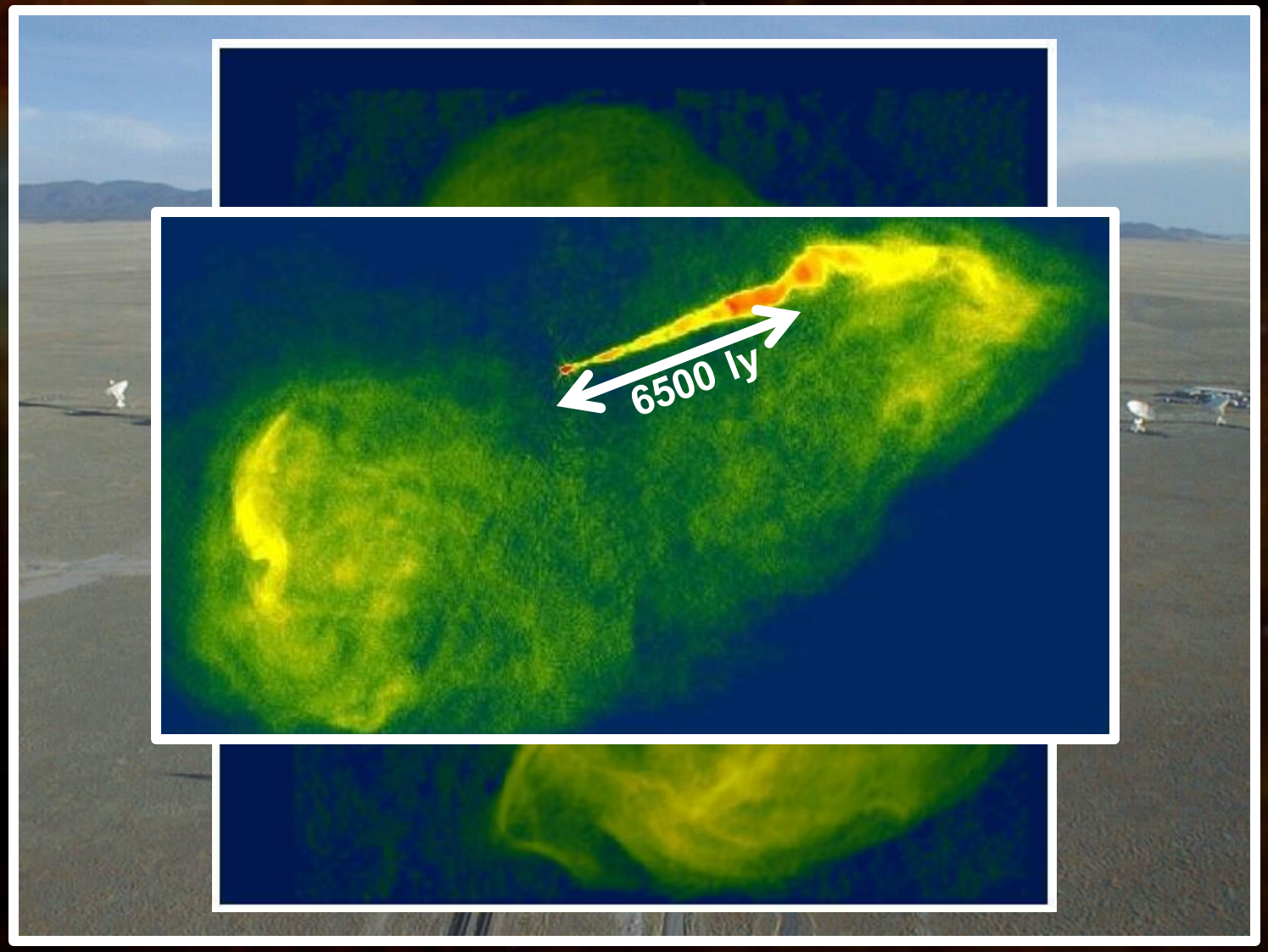


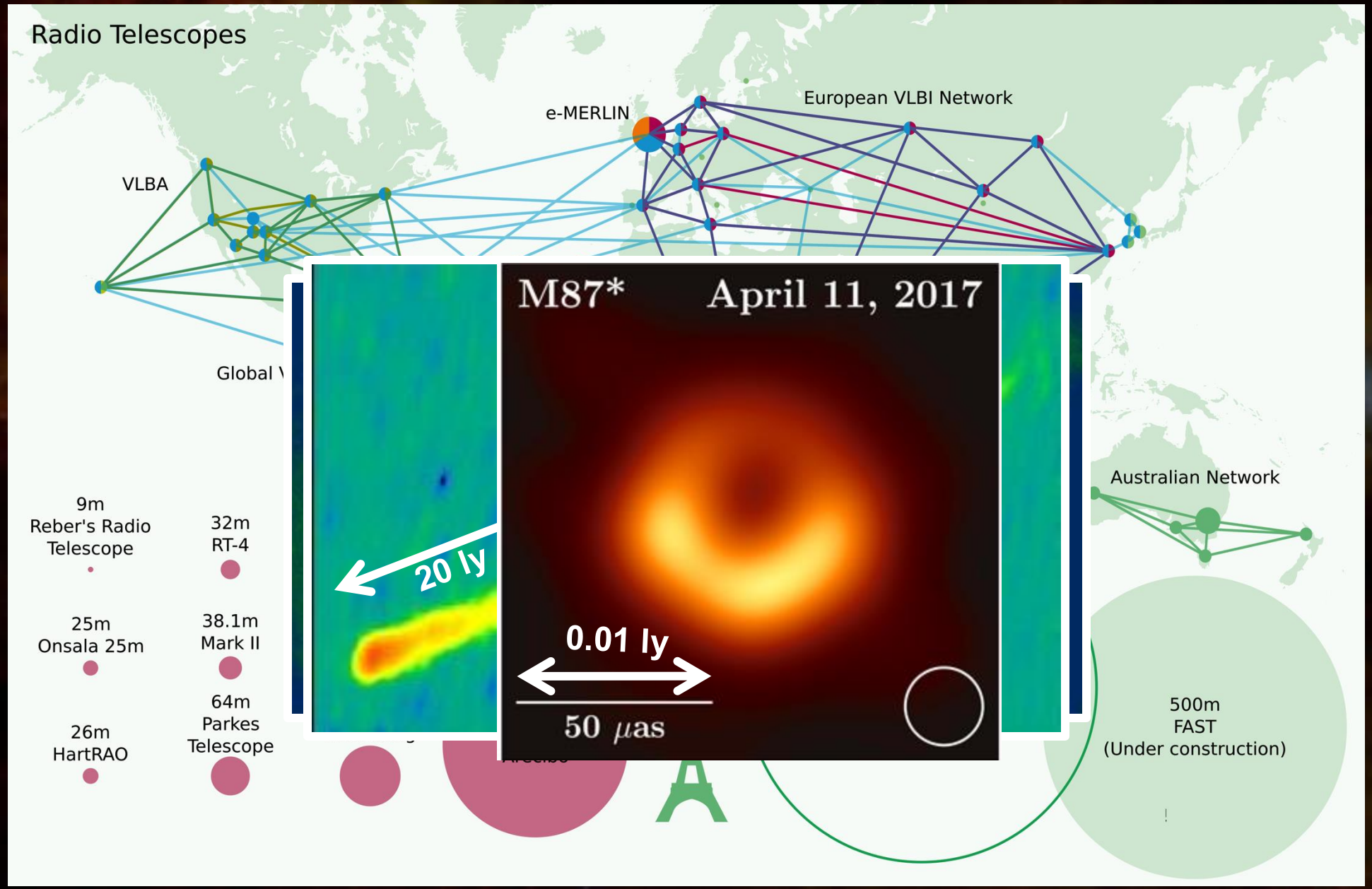




Multi-Element Radio Linked Interferometer Network

Very Large Array

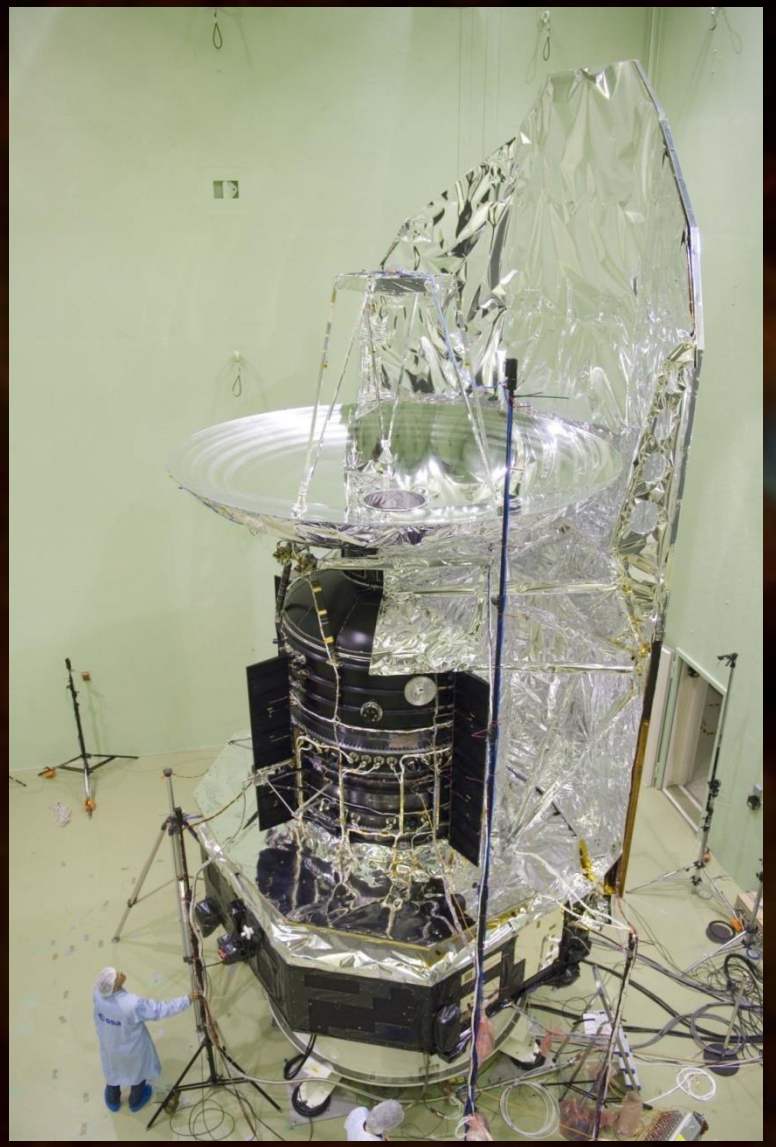



Radio Telescopes
e-MERLIN
European VLBI Network
VLBA
Global V
M87*
April 11, 2017
20 ly
0.01 ly
50 μas
Australian Network
9m
Reber's Radio
Telescope
32m
RT-4
25m
Onsala 25m
38.1m
Mark II
26m
HartRAO
64m
Parkes
Telescope
500m
FAST
(Under construction)

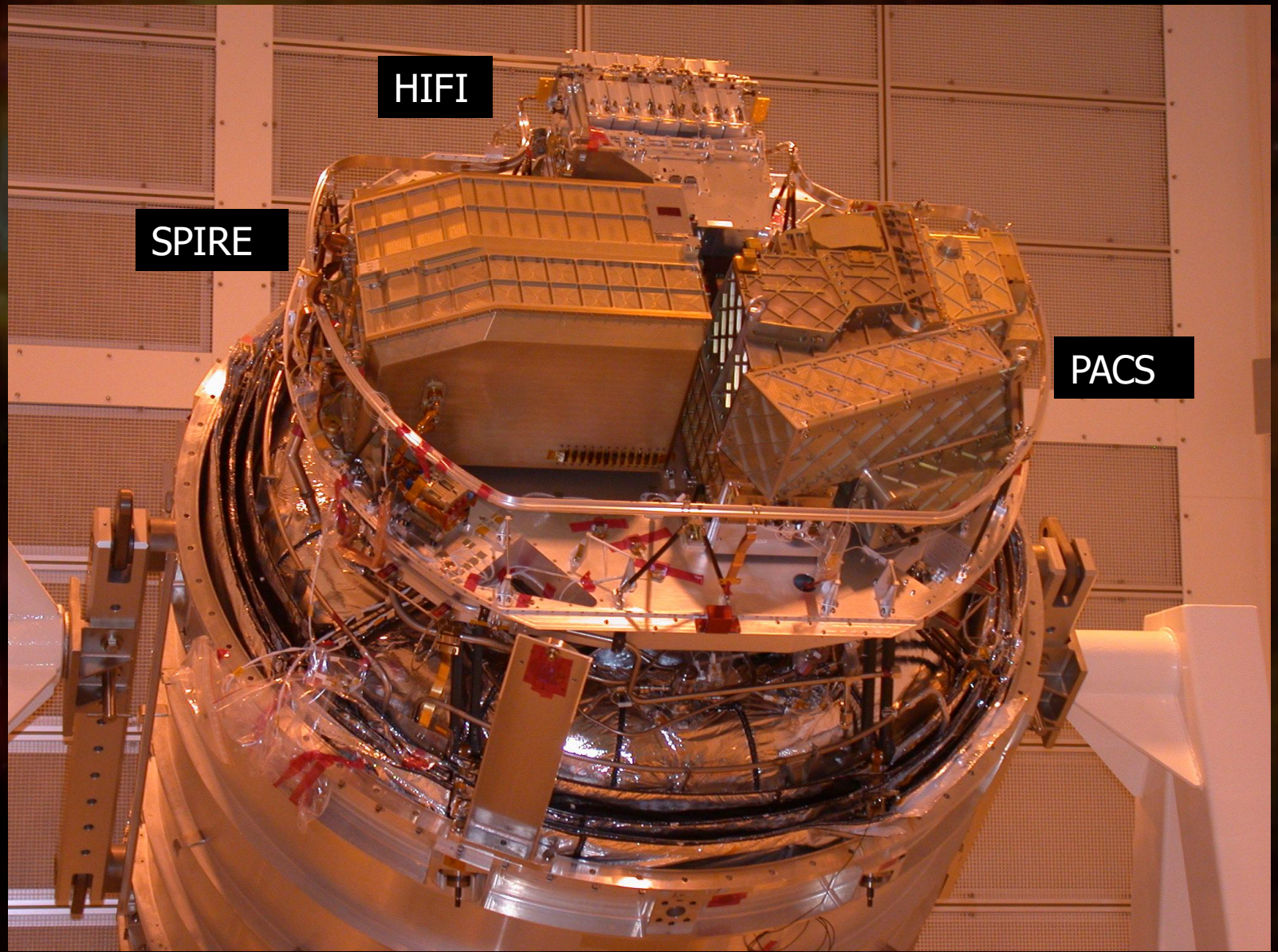
The Herschel Space Observatory

- 8x4x4m
- 4 tonnes on launch
- 3.5m mirror
- 2200 litres of He
- Cooled to 0.3K
- 3 instruments
- 70-700 microns

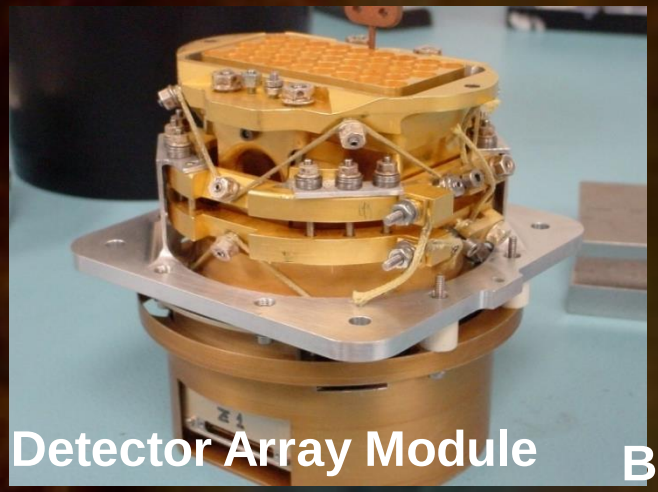

esa

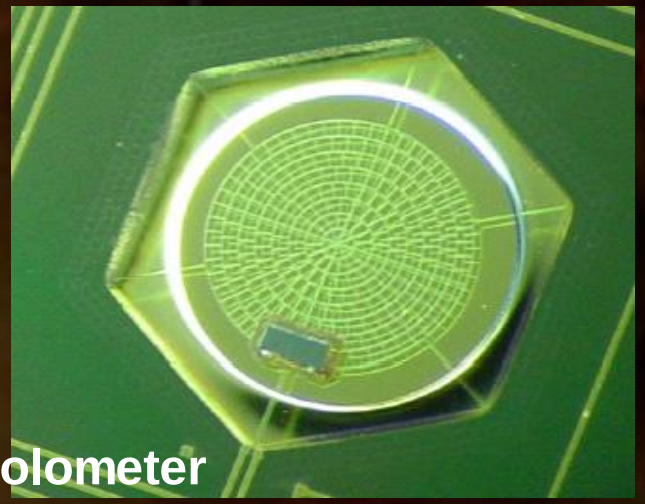


Herschel's Instruments

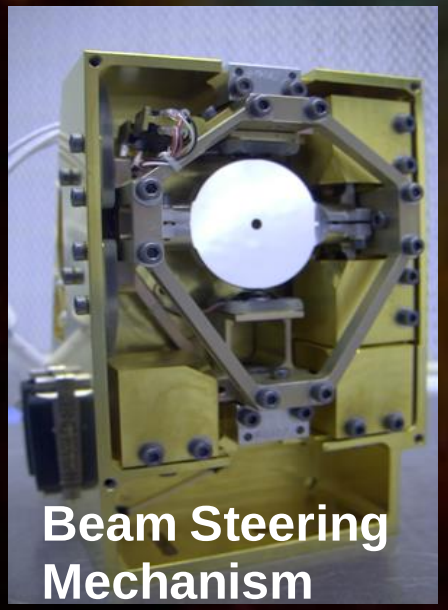


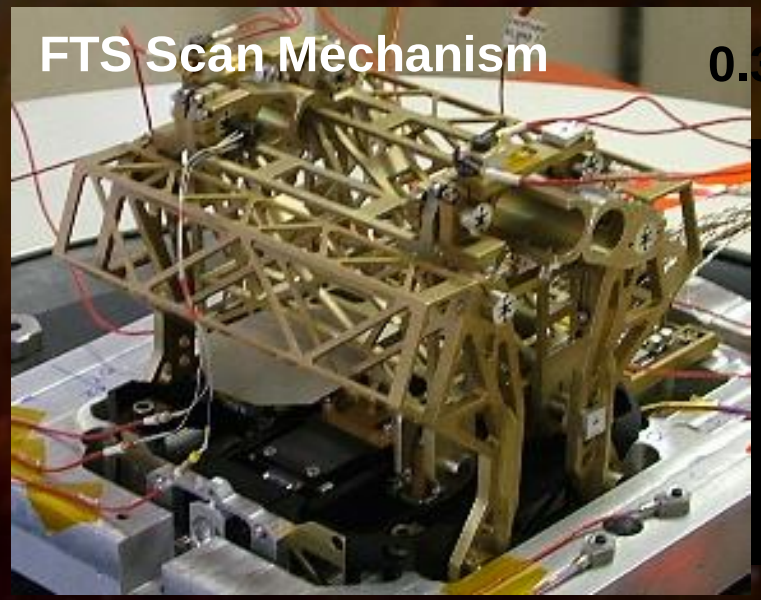
Some SPIRE Subsystems


Detector Array Module

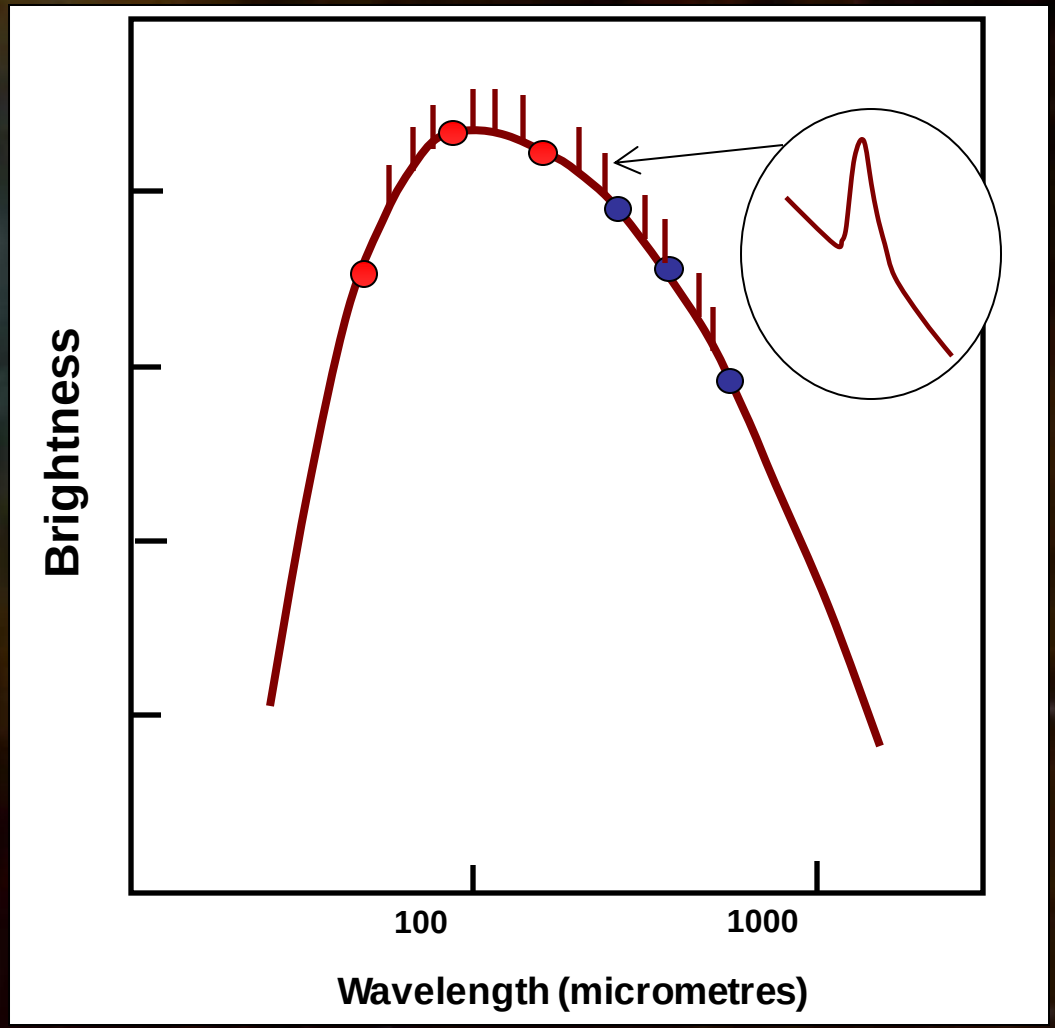

Bolometer


0.3-K Cooler


Beam Steering Mechanism


FTS Scan Mechanism

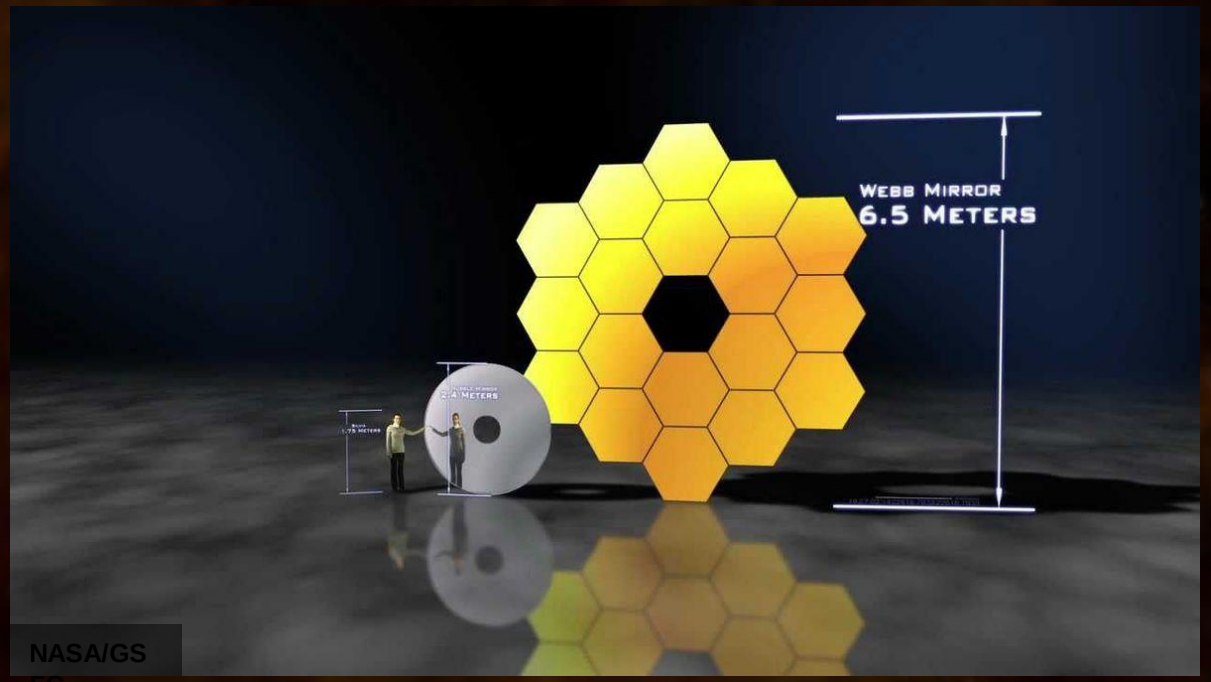
Herschel's Instruments



Multicolour Images

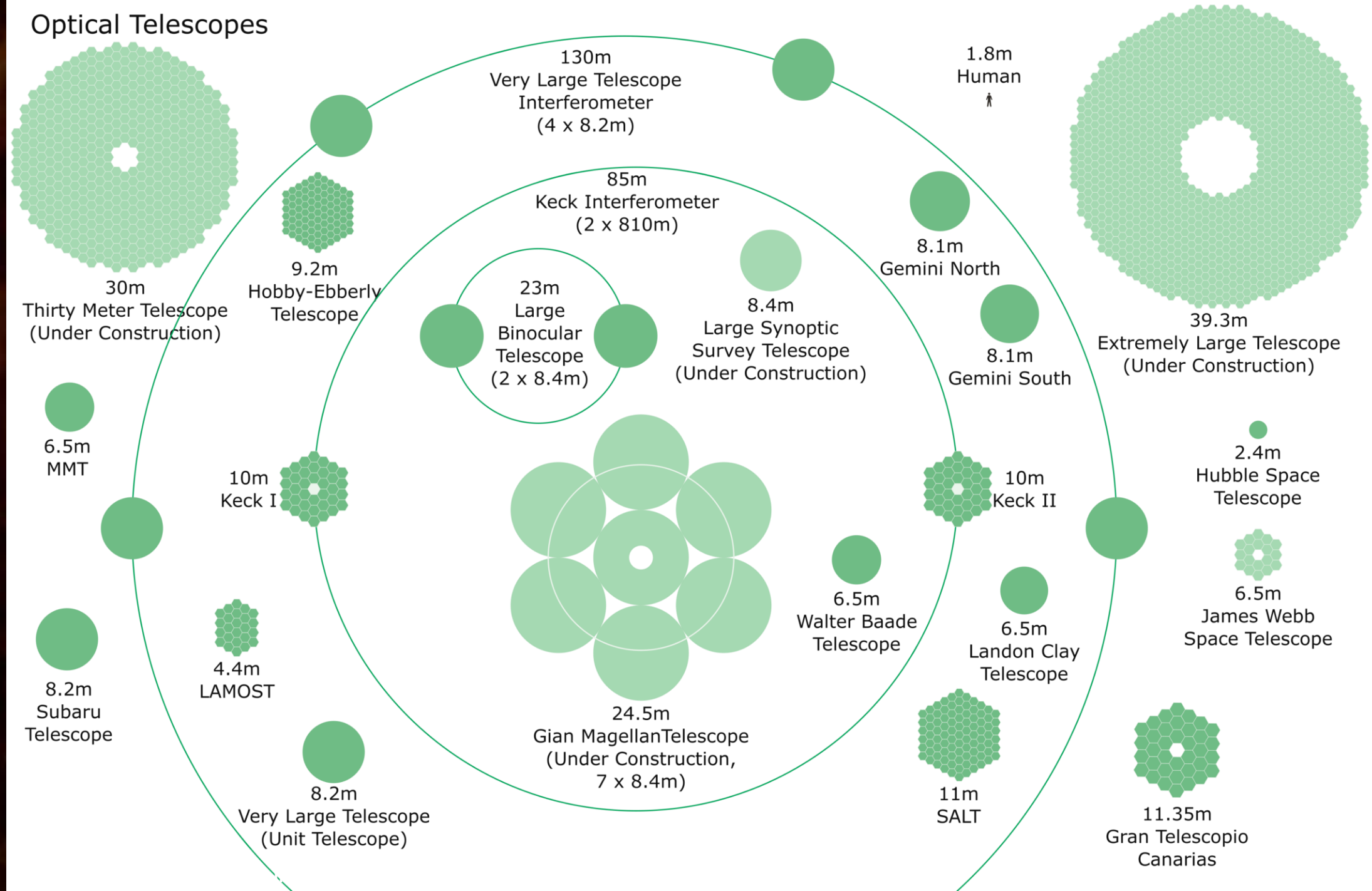
Size matters

ESA/M. Kornmesser

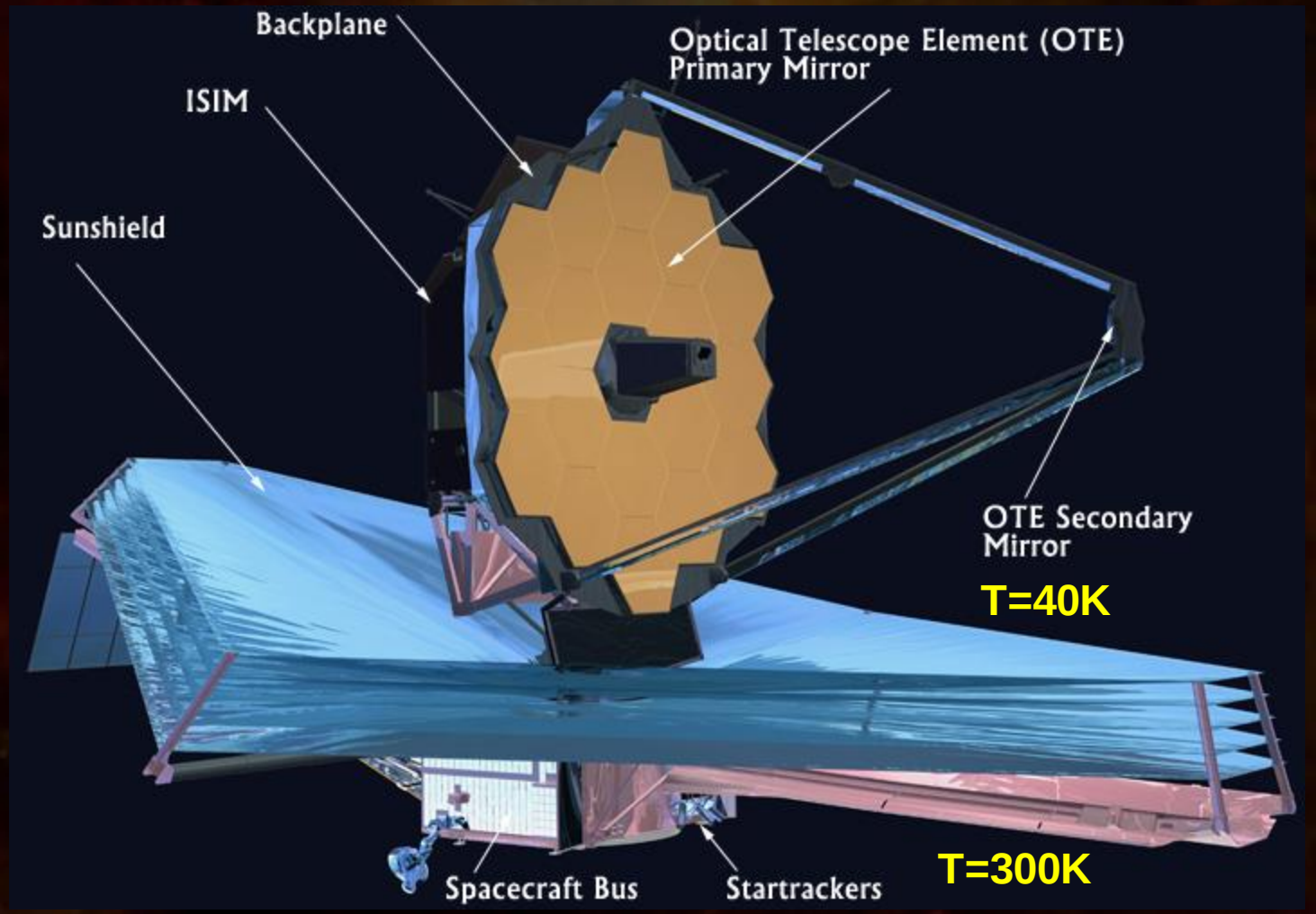


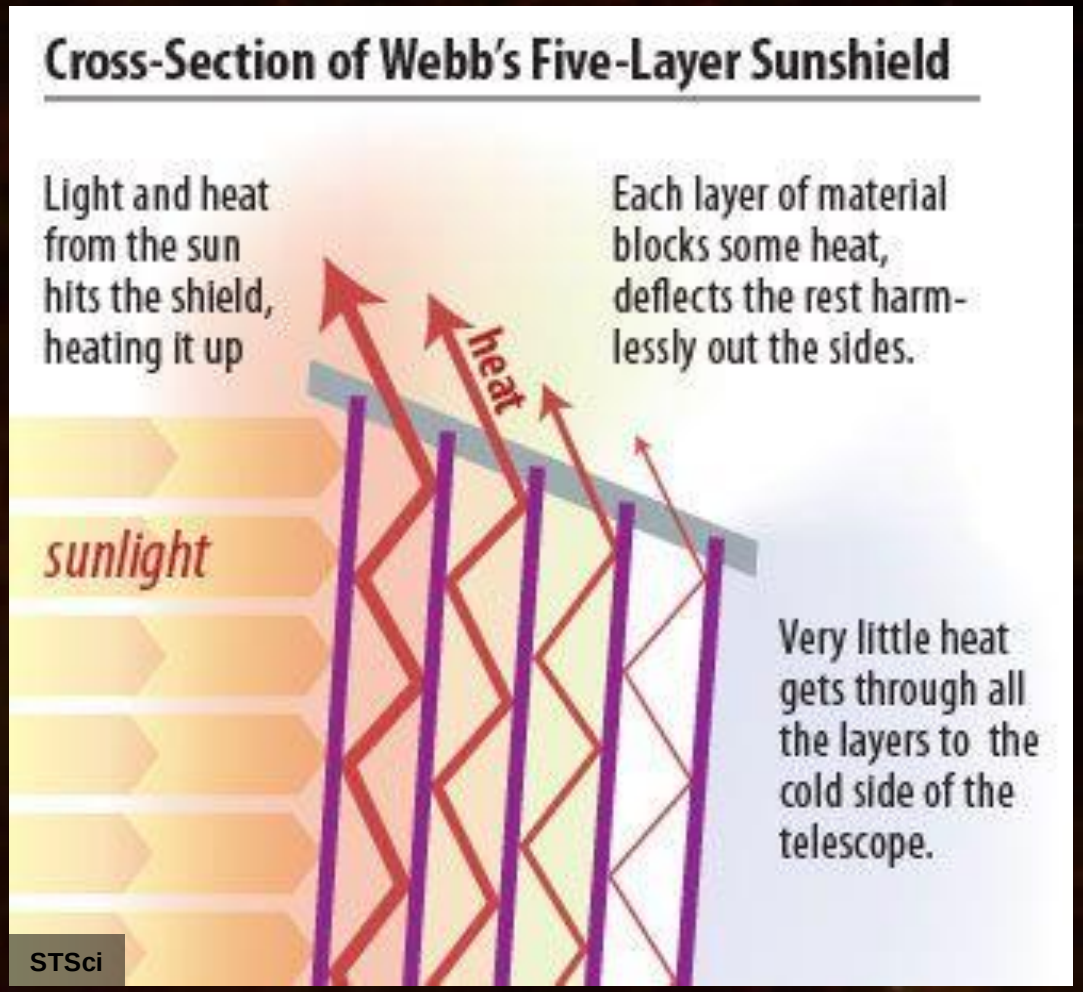
NASA/GSFC

Optical Telescopes

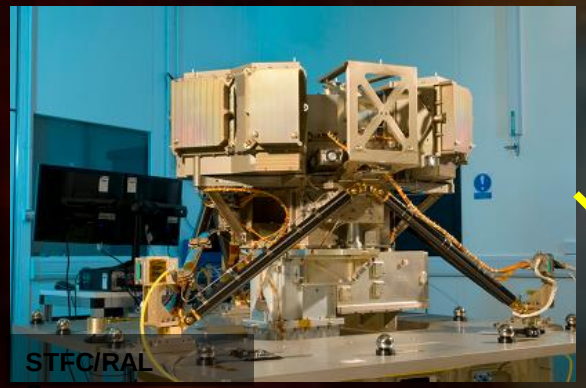


Anatomy of a telescope





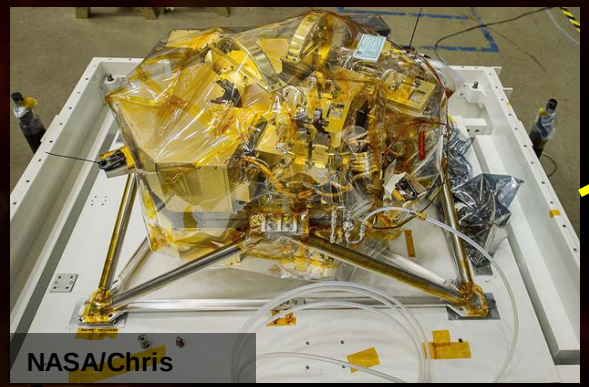
Scientific instruments



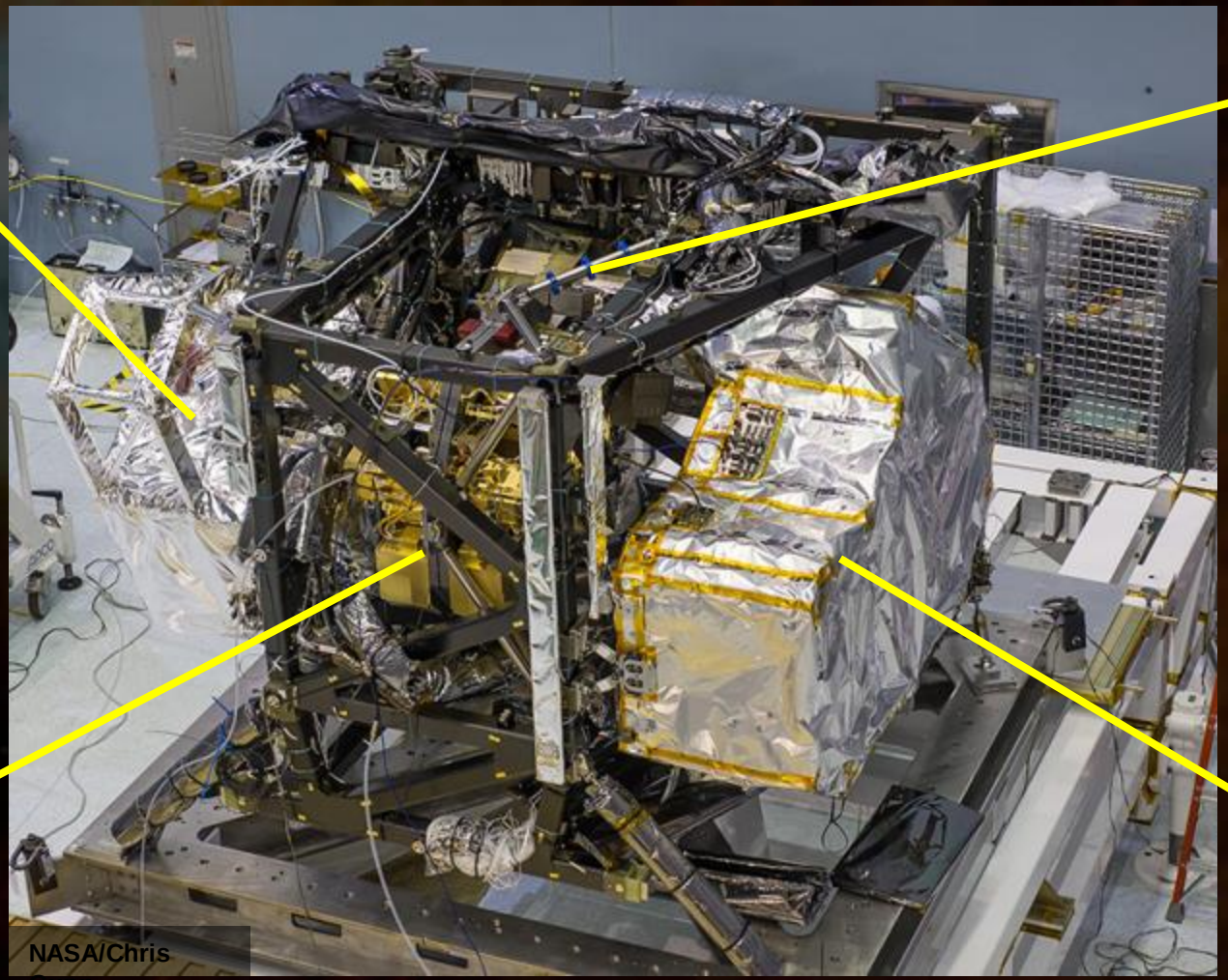
STFC/RAL Space

MIRI

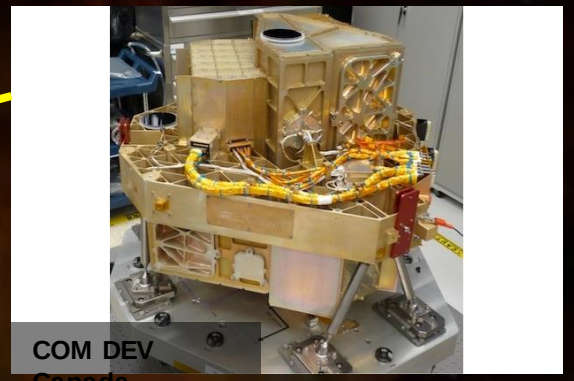
NIRCam



NASA/Chris Gunn



NASA/Chris Gunn



COM DEV Canada

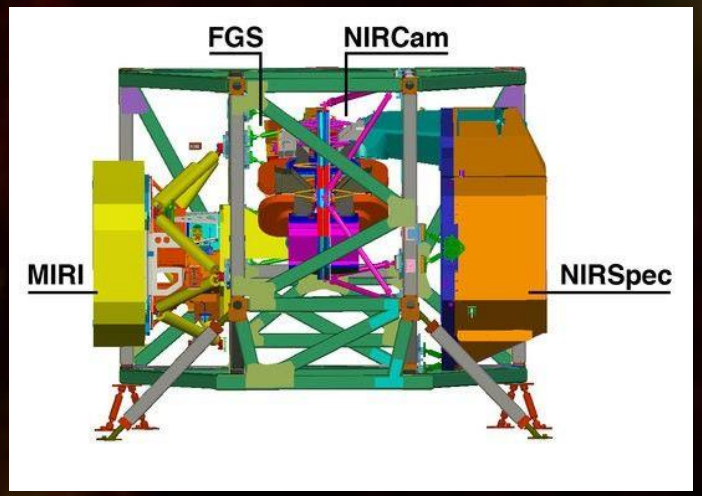
FGS/NIRISS

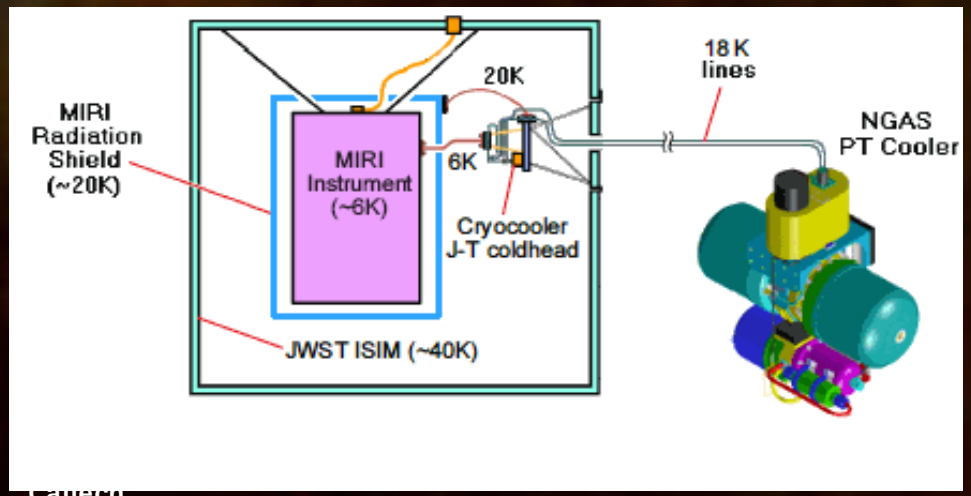
NIRSpec

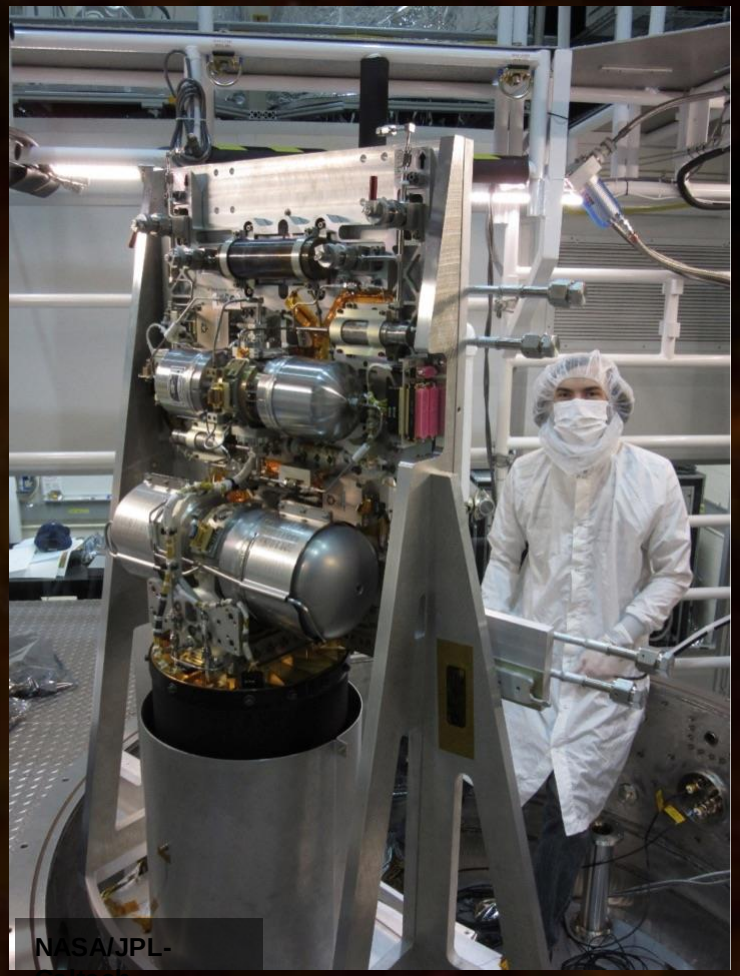
EADS Astrium

How to keep cool in space

- Convection
  - No air!
- Radiation
  - Also heats up (sunlight, hotter parts of surface)
  - can control with reflectivity of surfaces
- Conduction
  - Need to be careful to avoid unwanted conduction!







NASA/JPL-Caltech

Visible light

Far Infrared

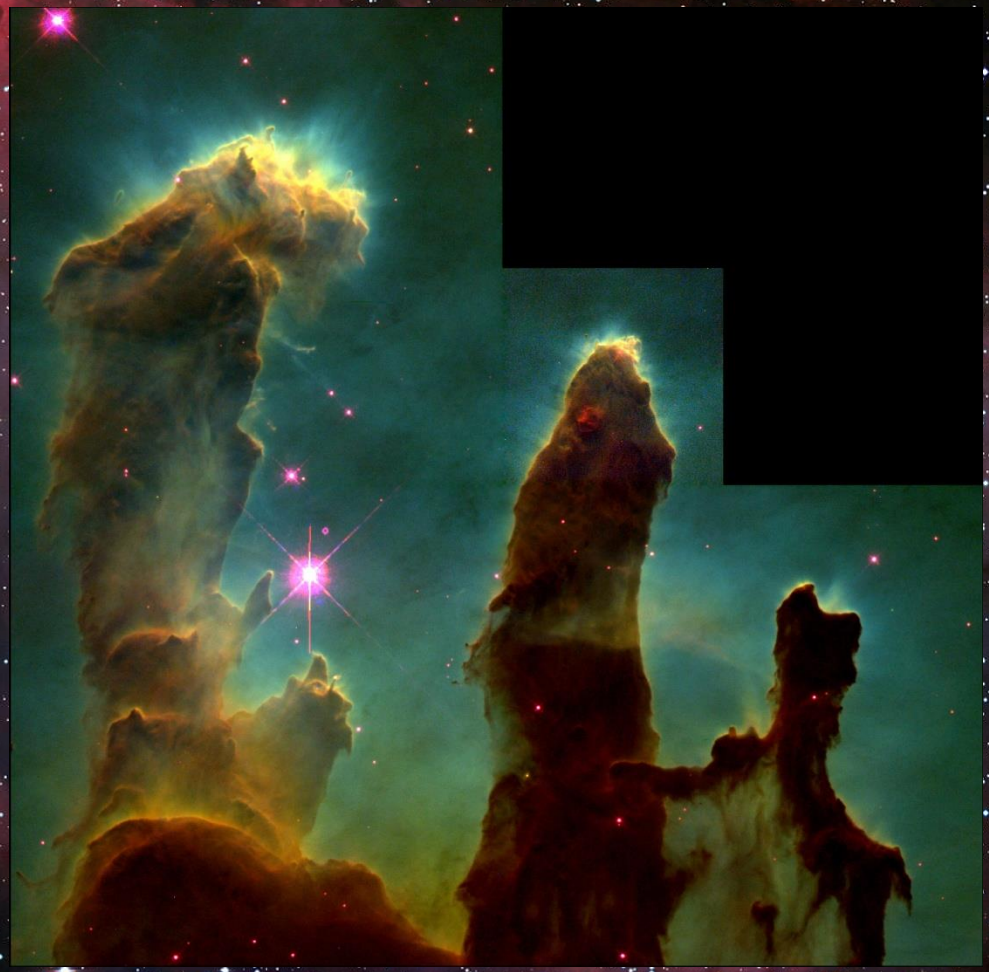
Visible + Far-infrared

Whirlpool Galaxy (M51)

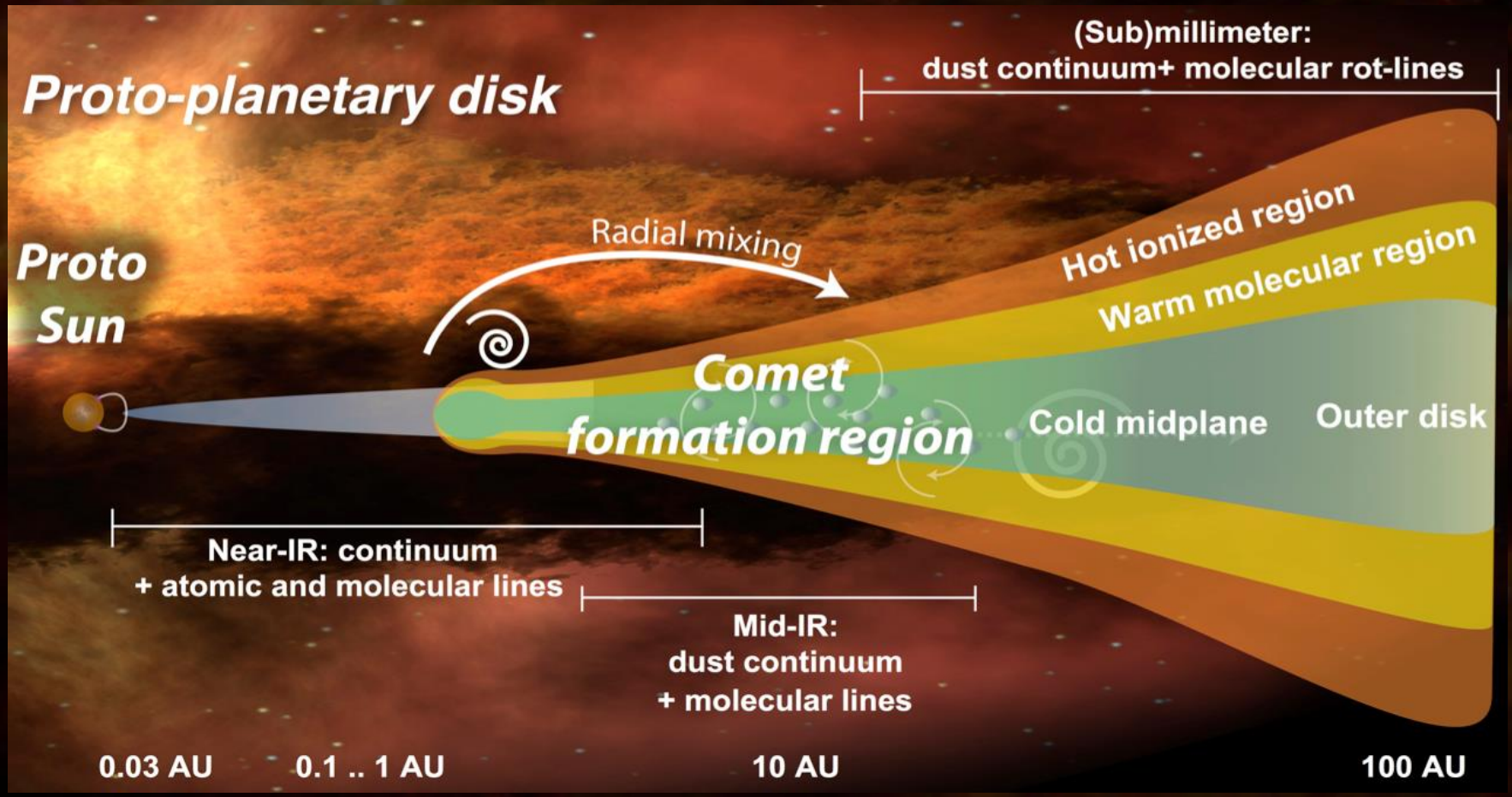
Herschel-PACS

Visible


RCW 120

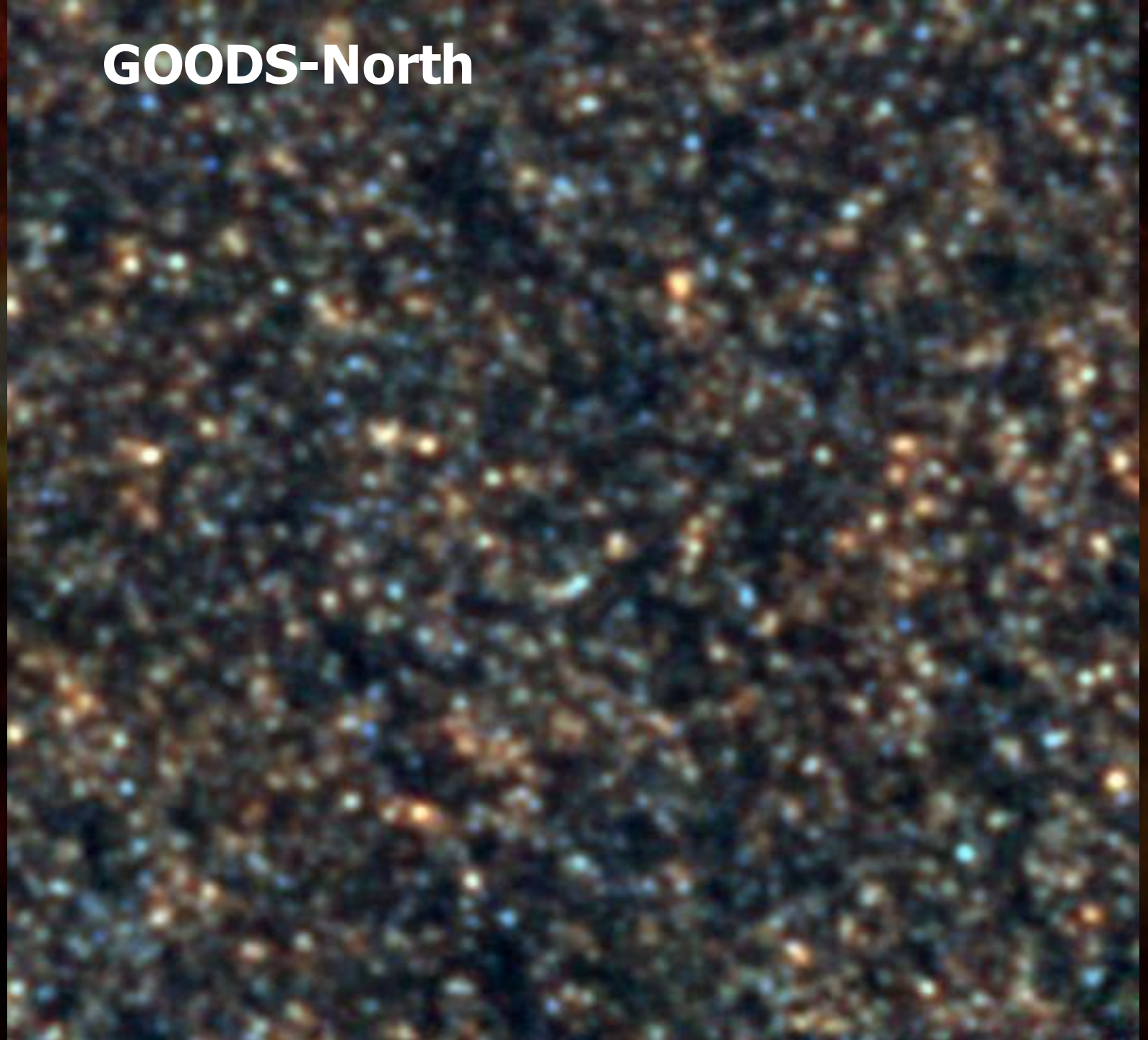


Planet Formation

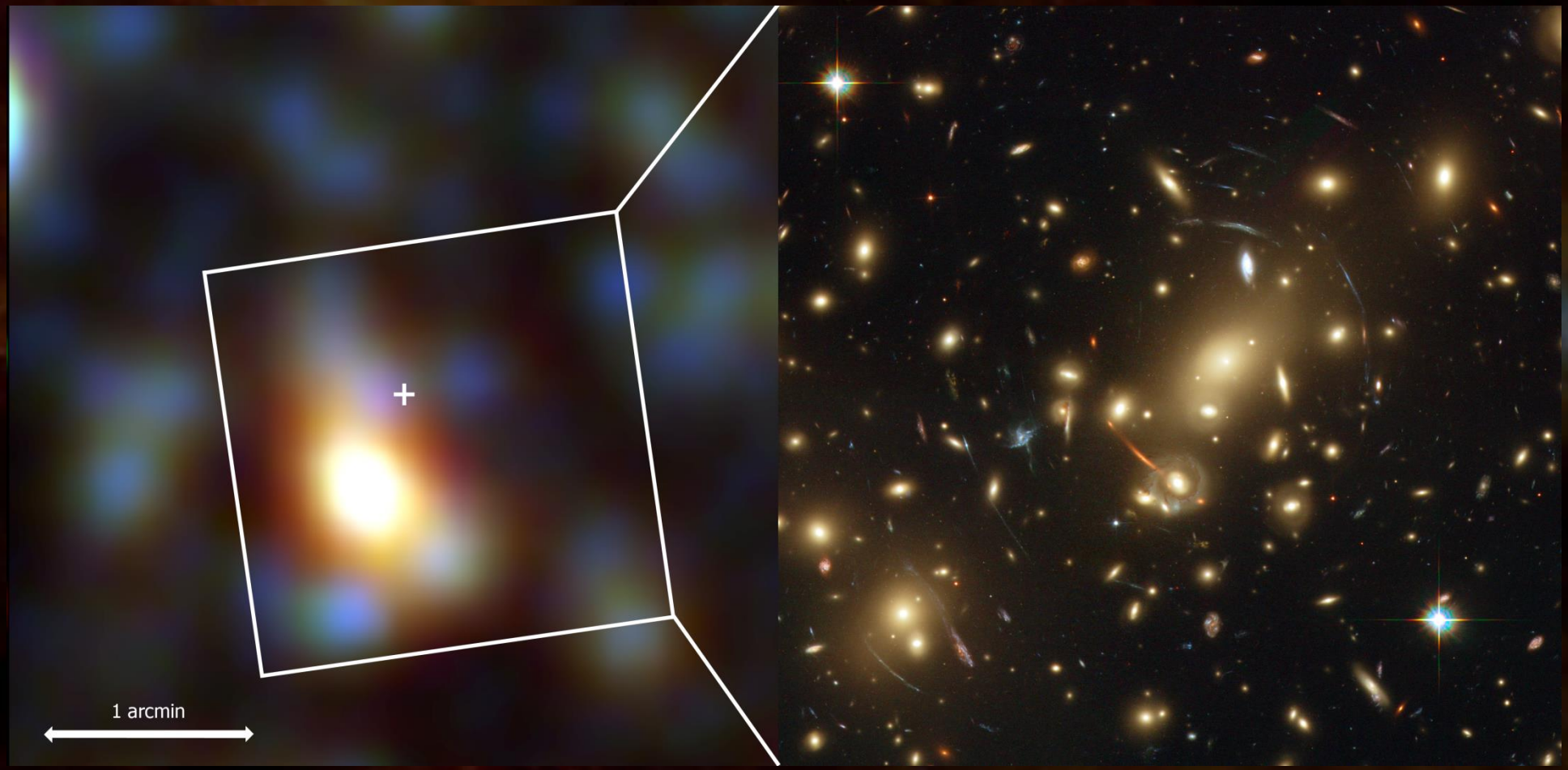


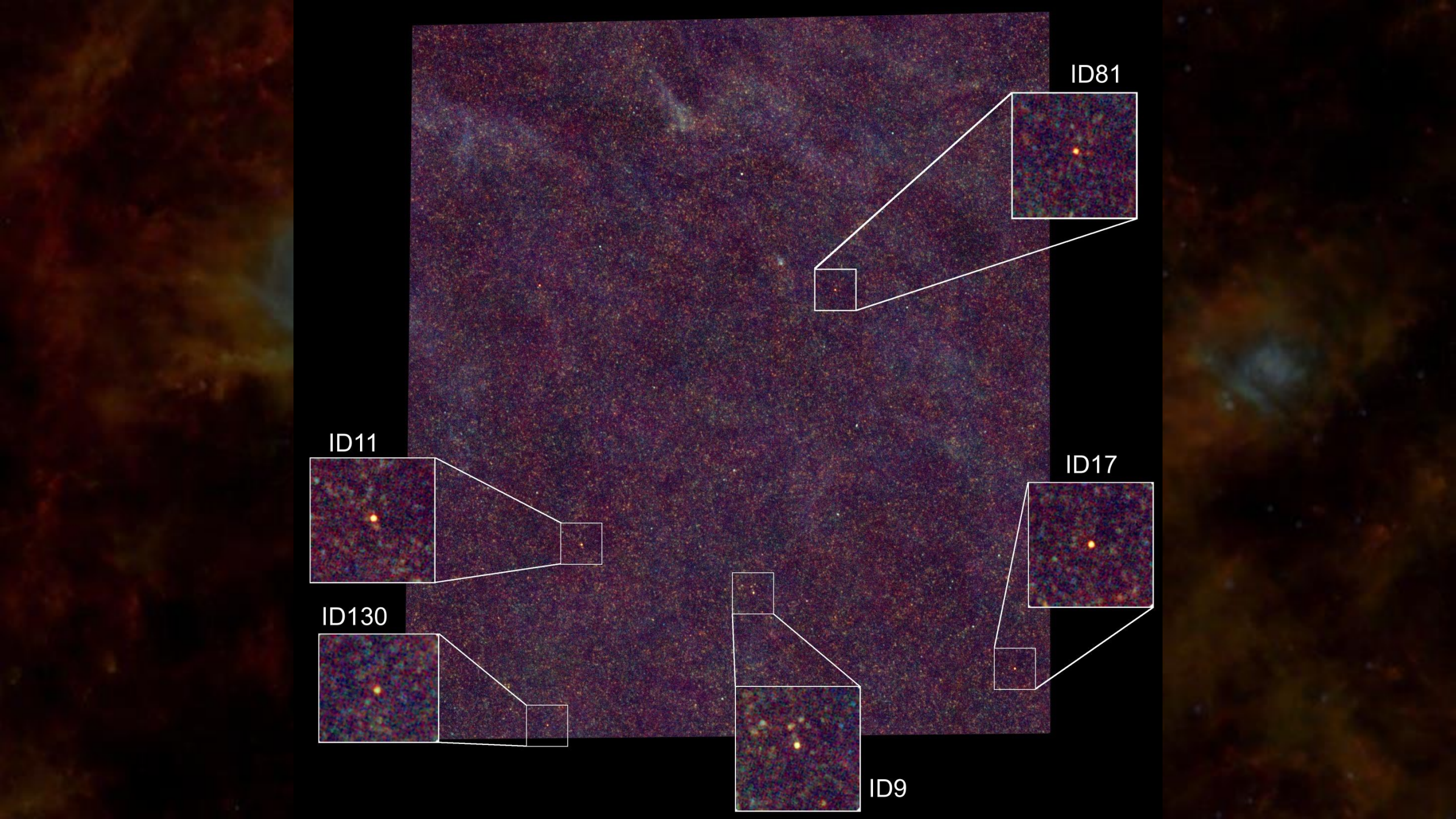
Credit: Villanueva/Mandell (NASA-GSFC)

Hubble Deep Field

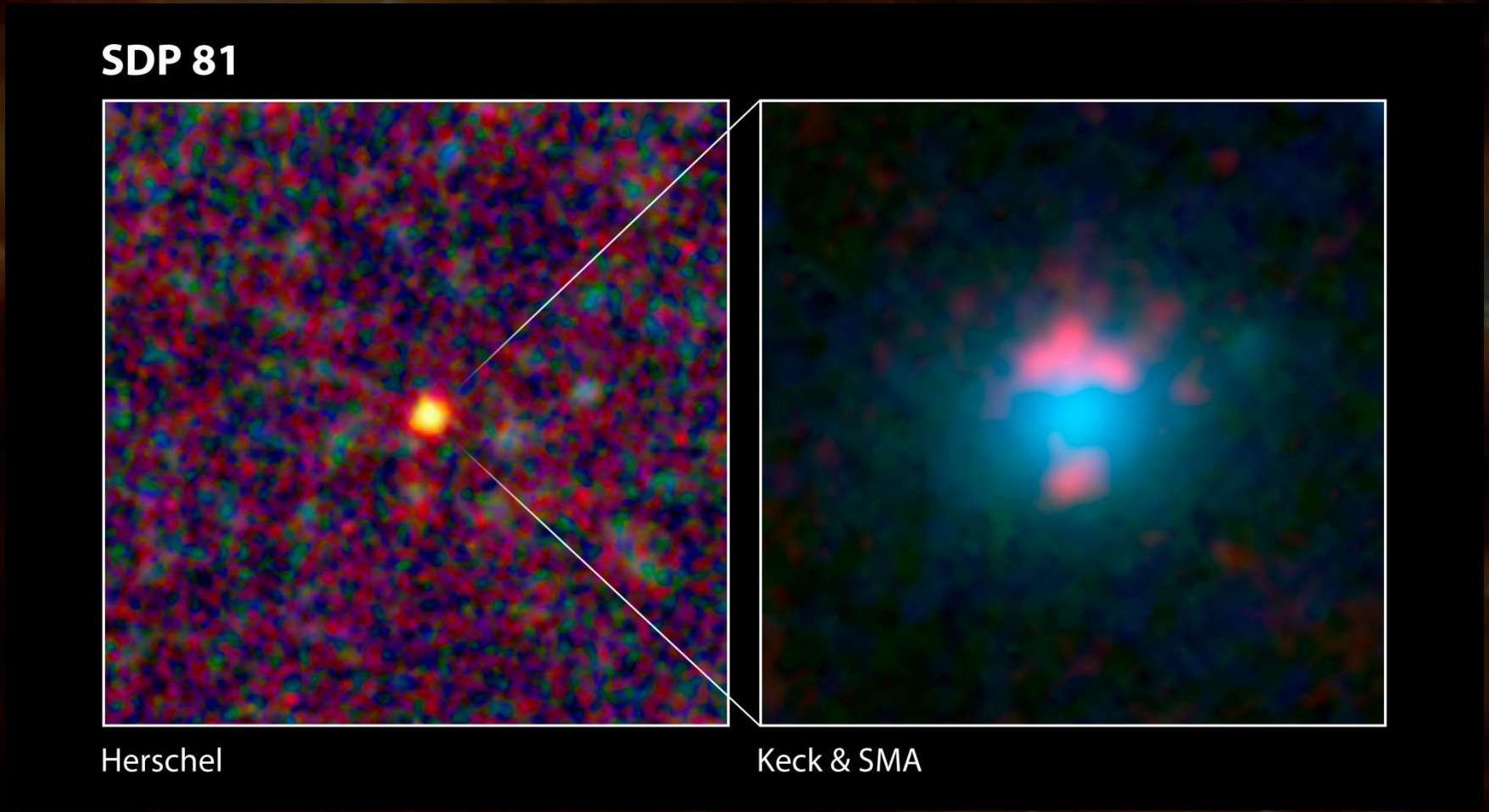

GOODS-North

Abell 2218

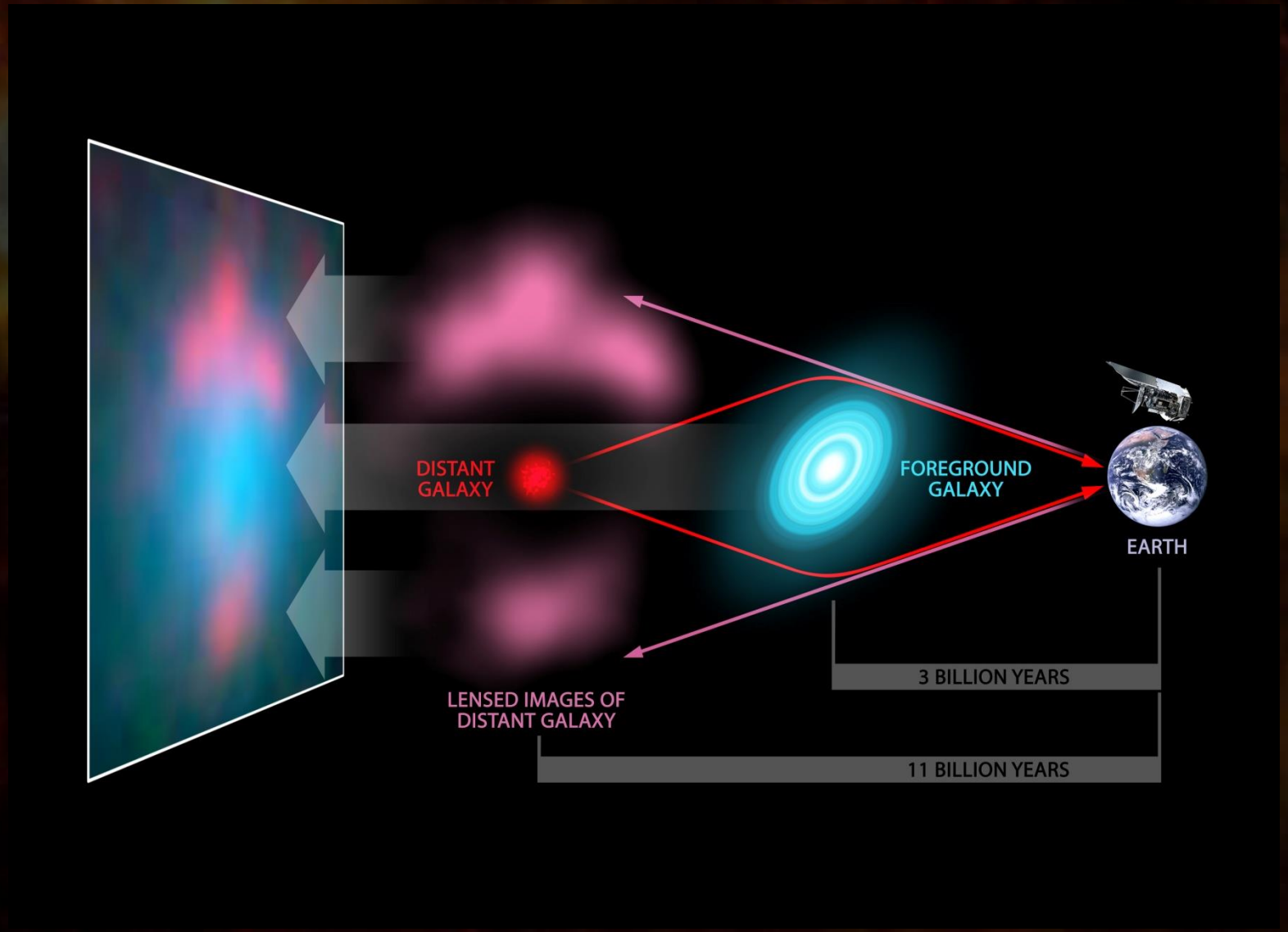



ID81
ID11
ID17
ID130
ID9

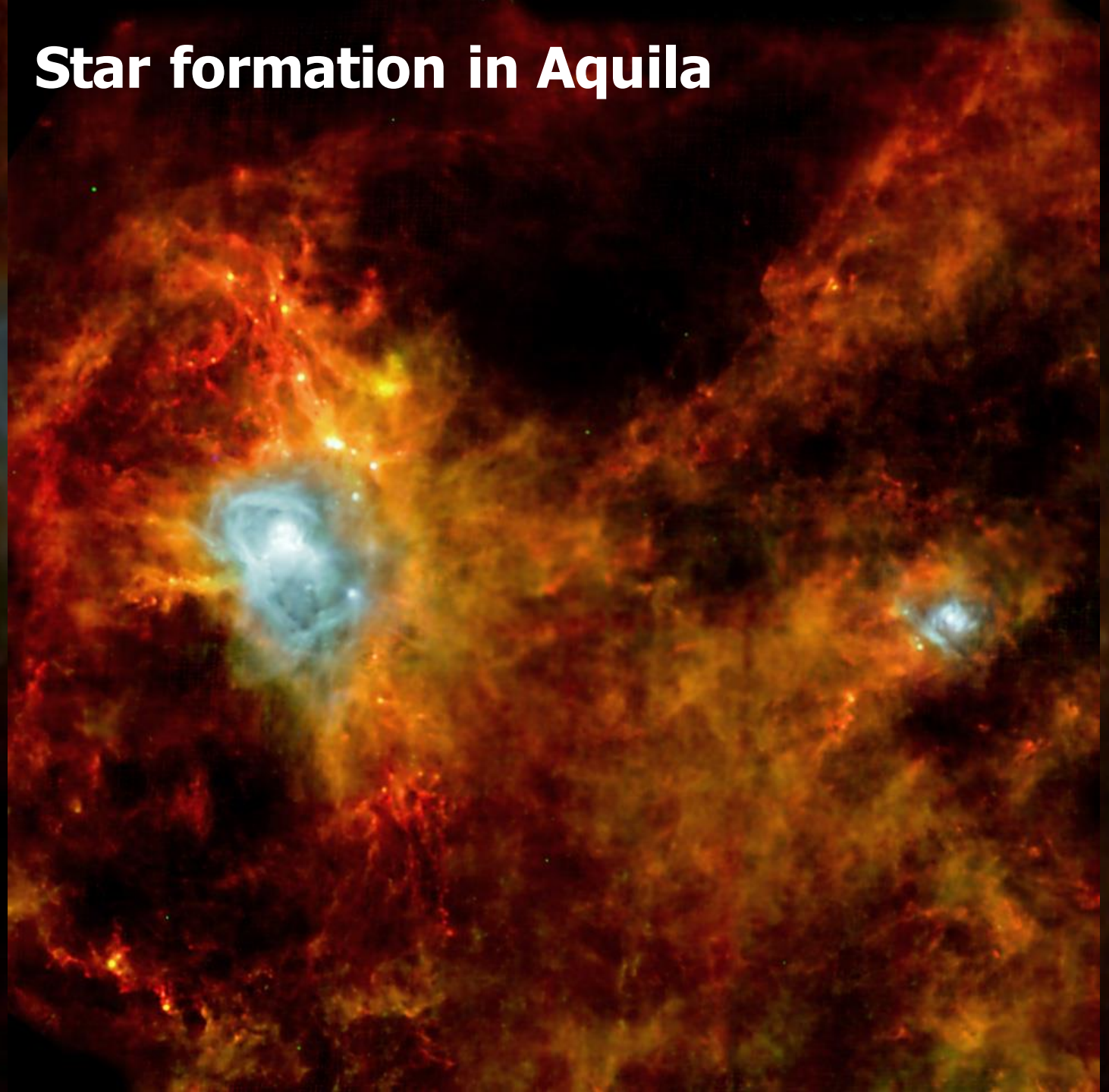
Gravitational Lensing

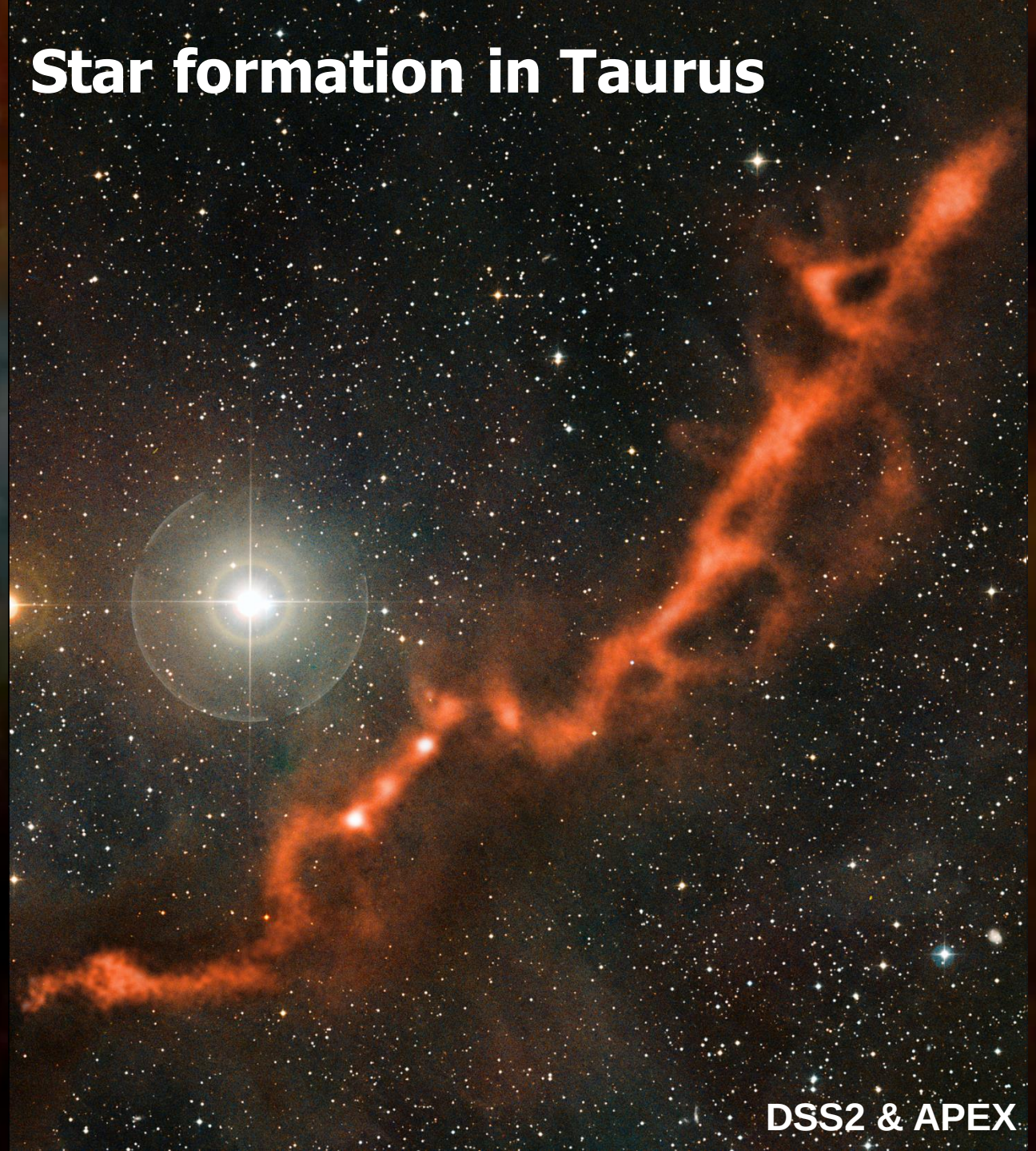


Gravitational Lensing

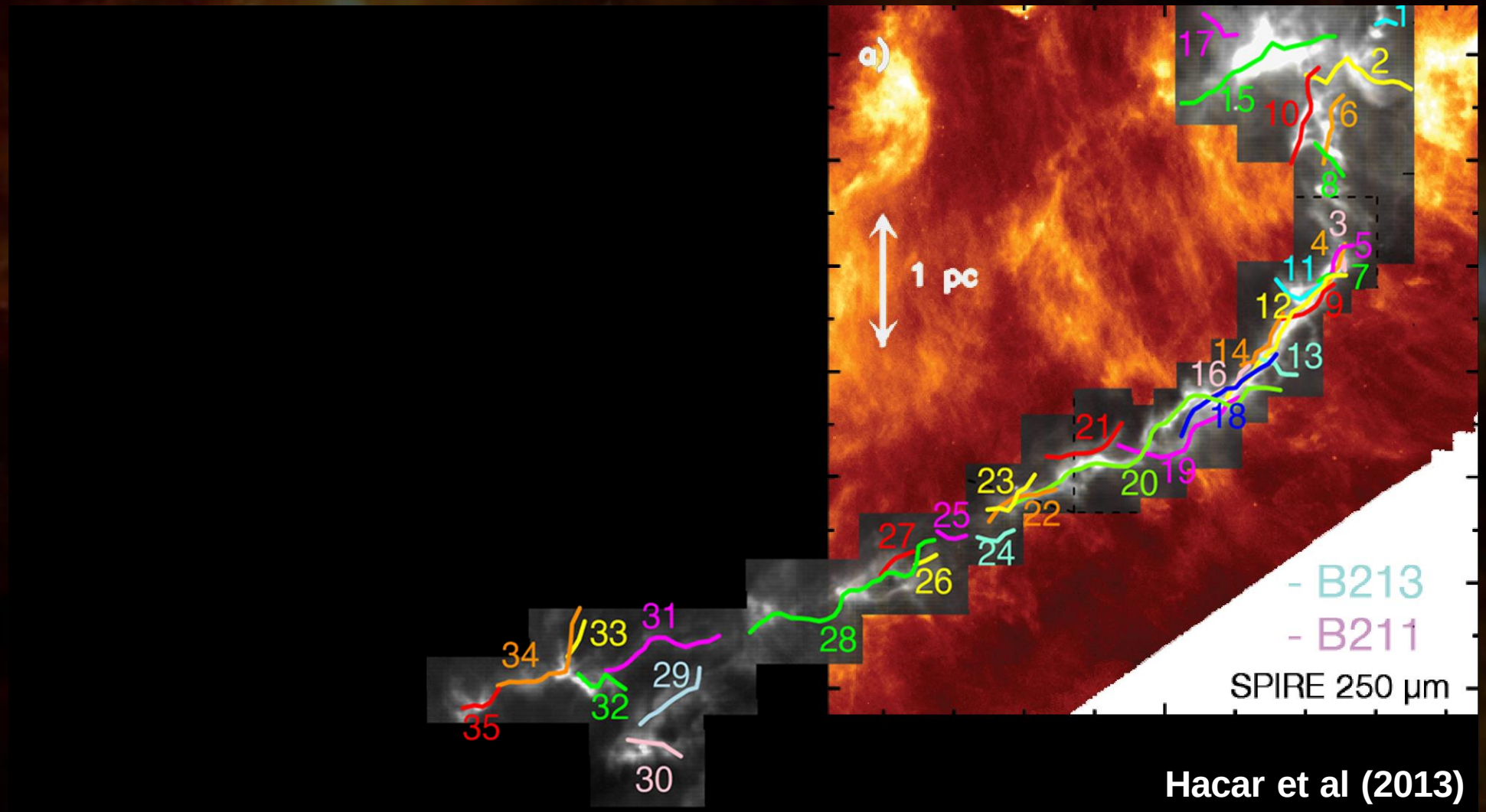


Star formation in Aquila



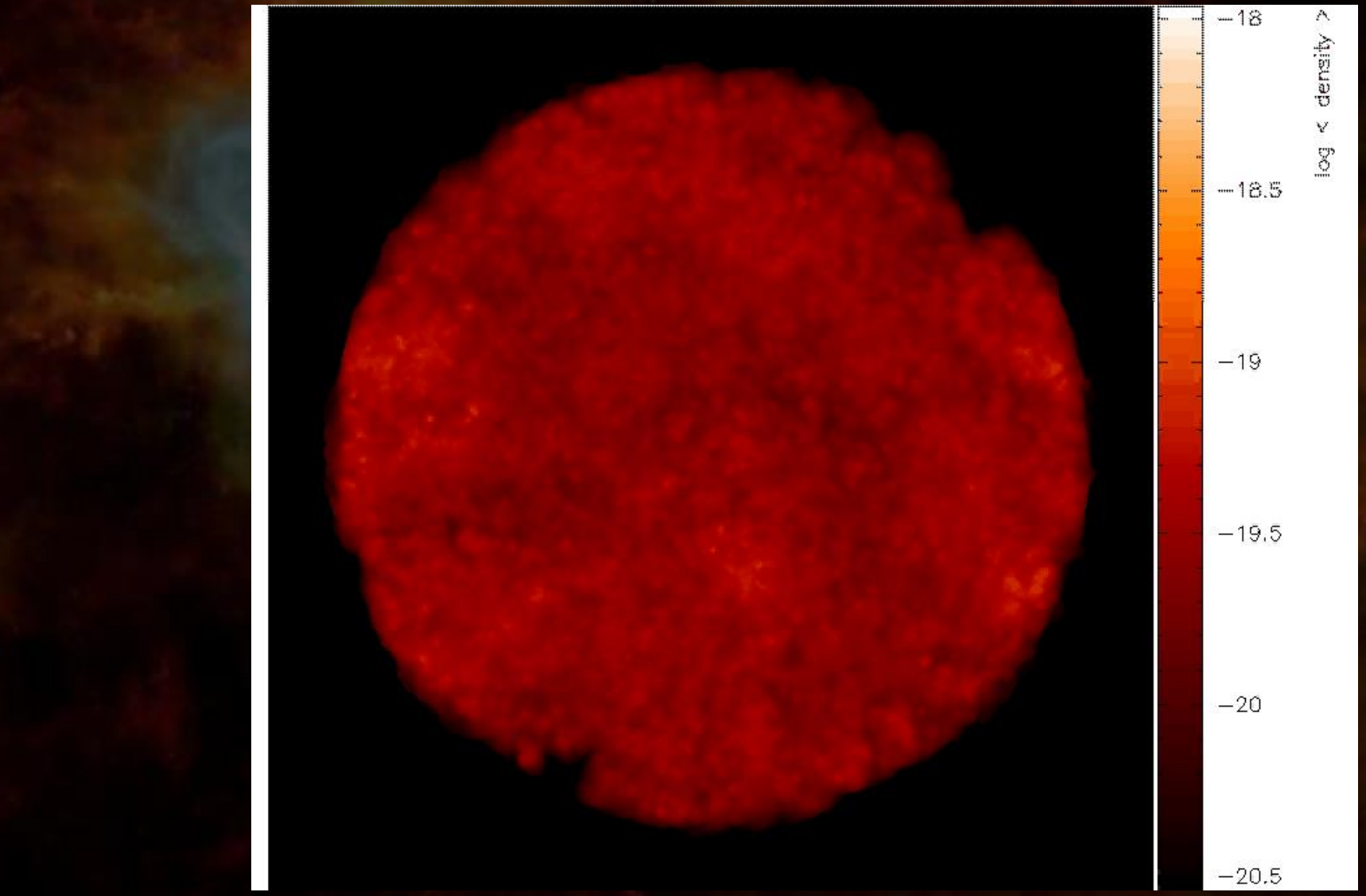

Star formation in Taurus
DSS2 & APEX

Fragmentary filaments



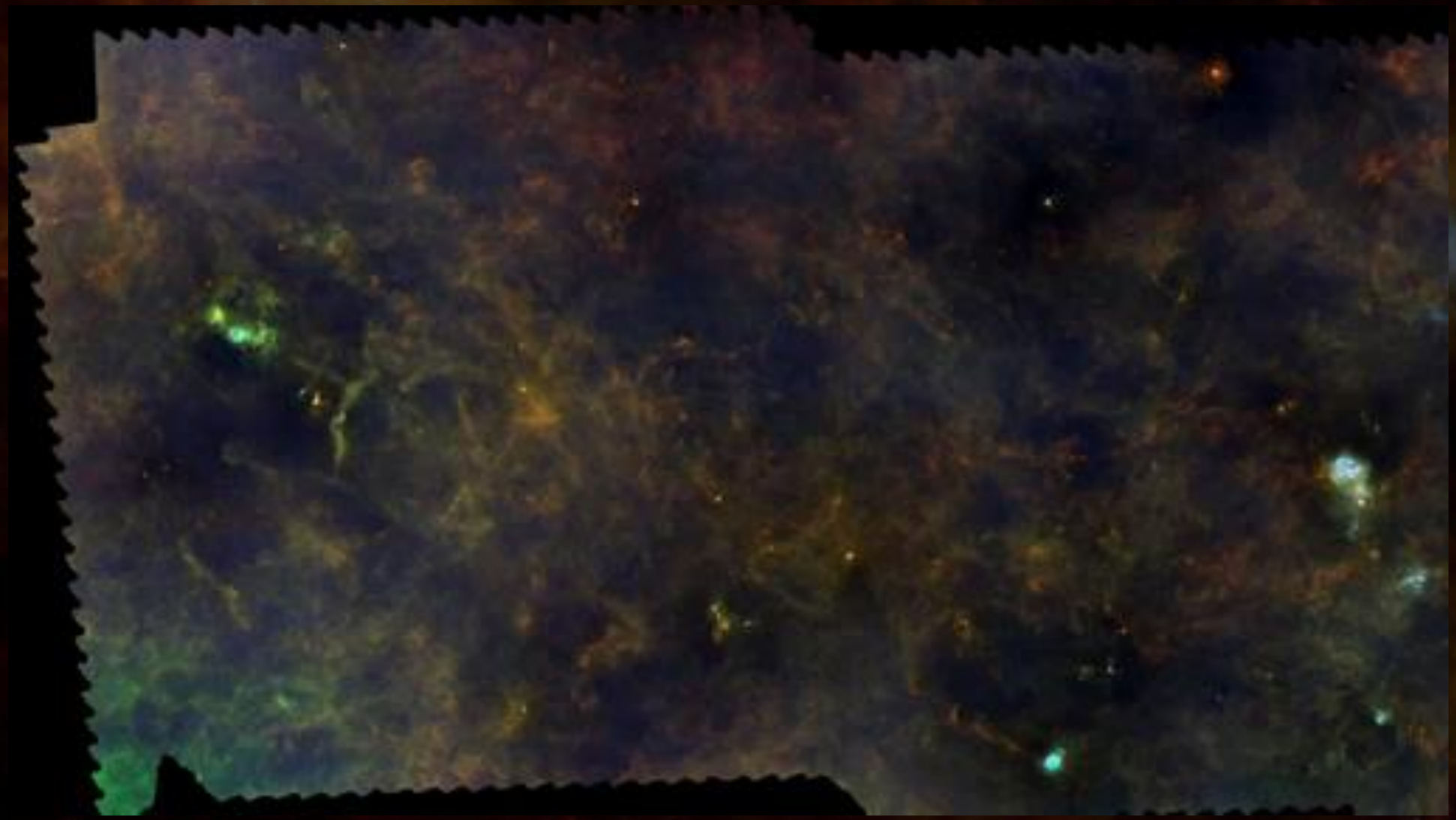
Hacar et al (2013)
astro-ph/1303.2118

Bubble Blowing

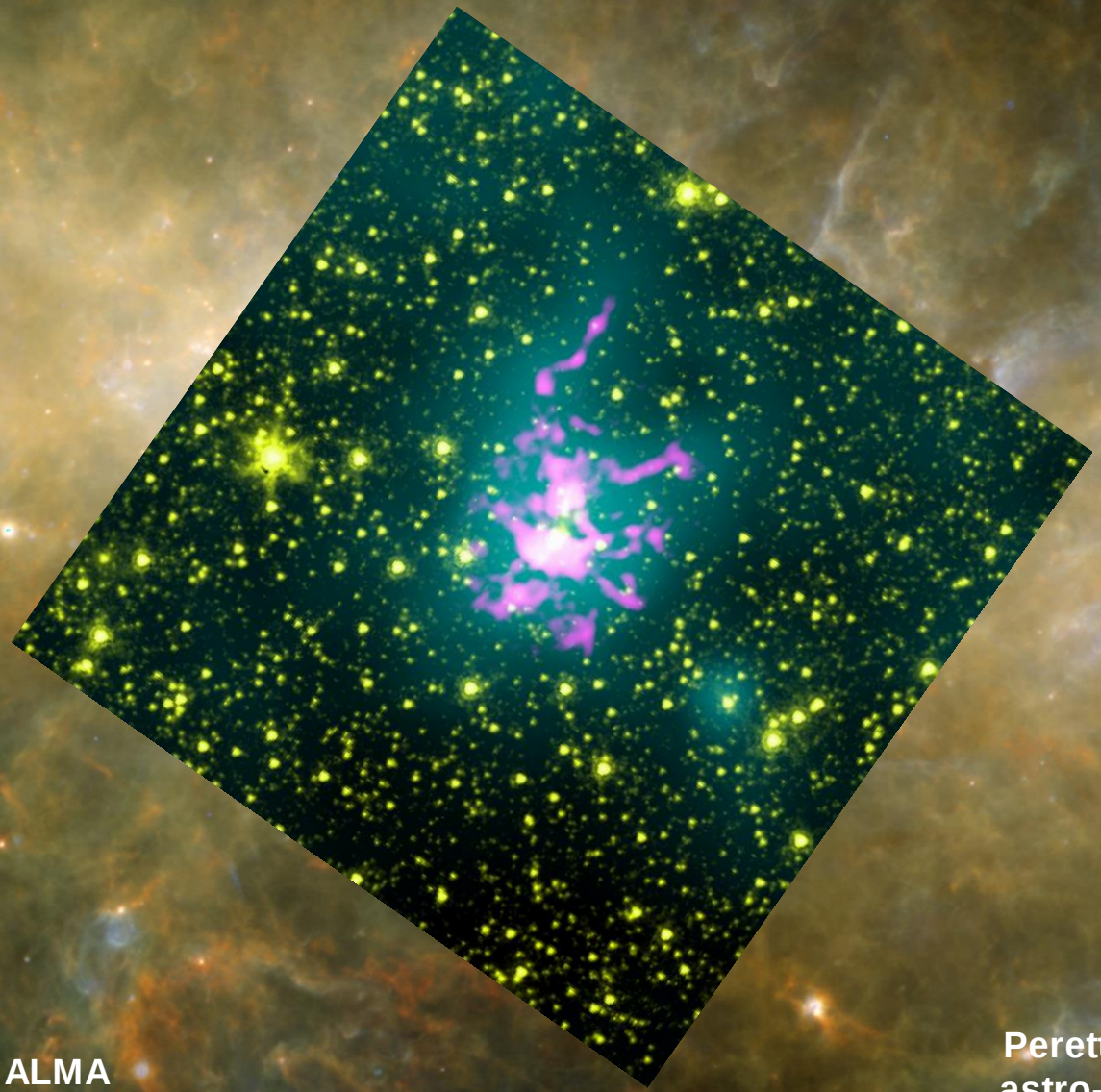


Courtesy Steffi Walch, Ant Whitworth

The Galactic Plane



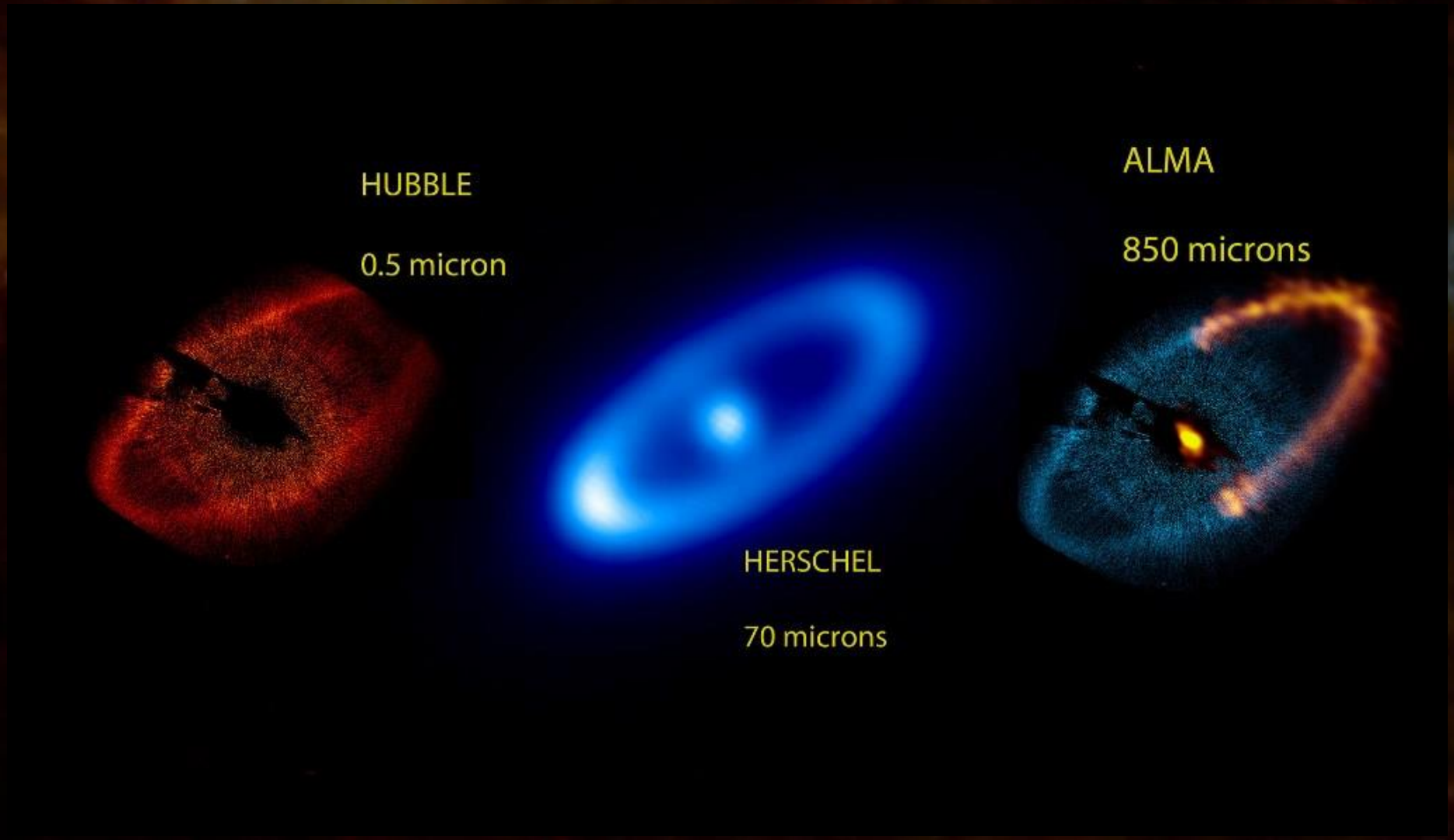
Spitzer Dark Cloud 335



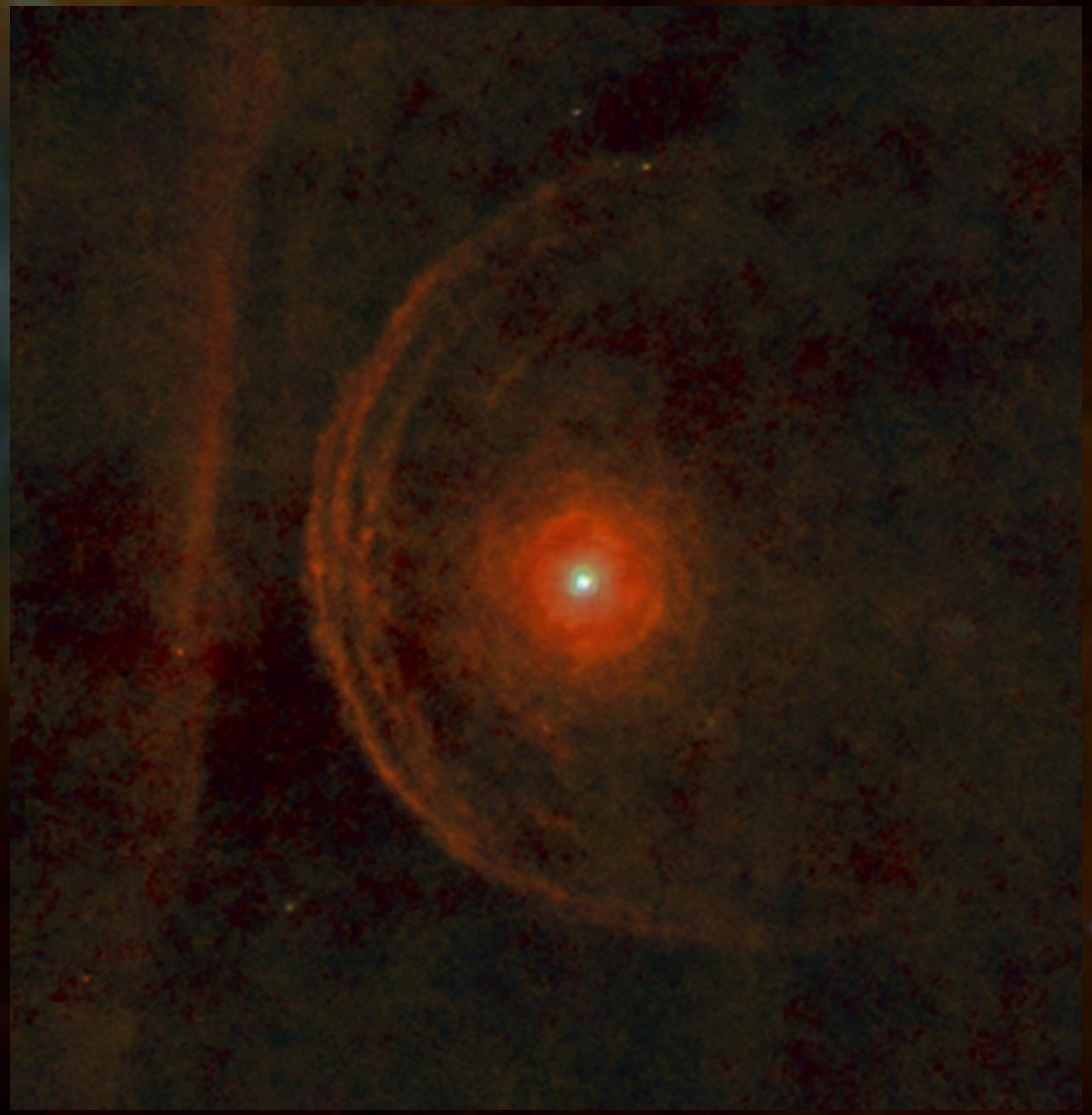
Herschel + ALMA

Peretto et al (2013)
astro-ph/1307.2590

Fomalhaut

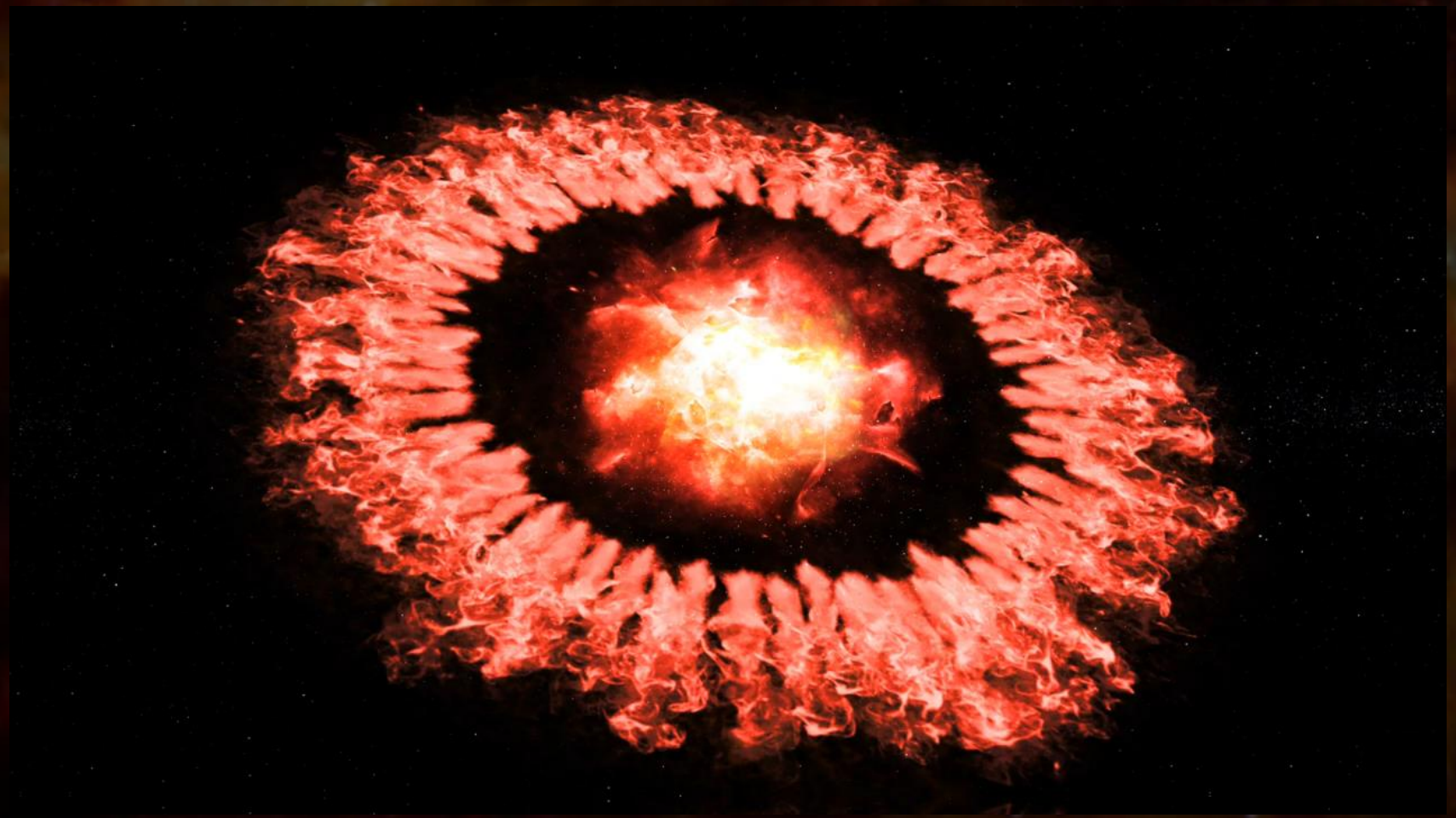


Betelgeuse

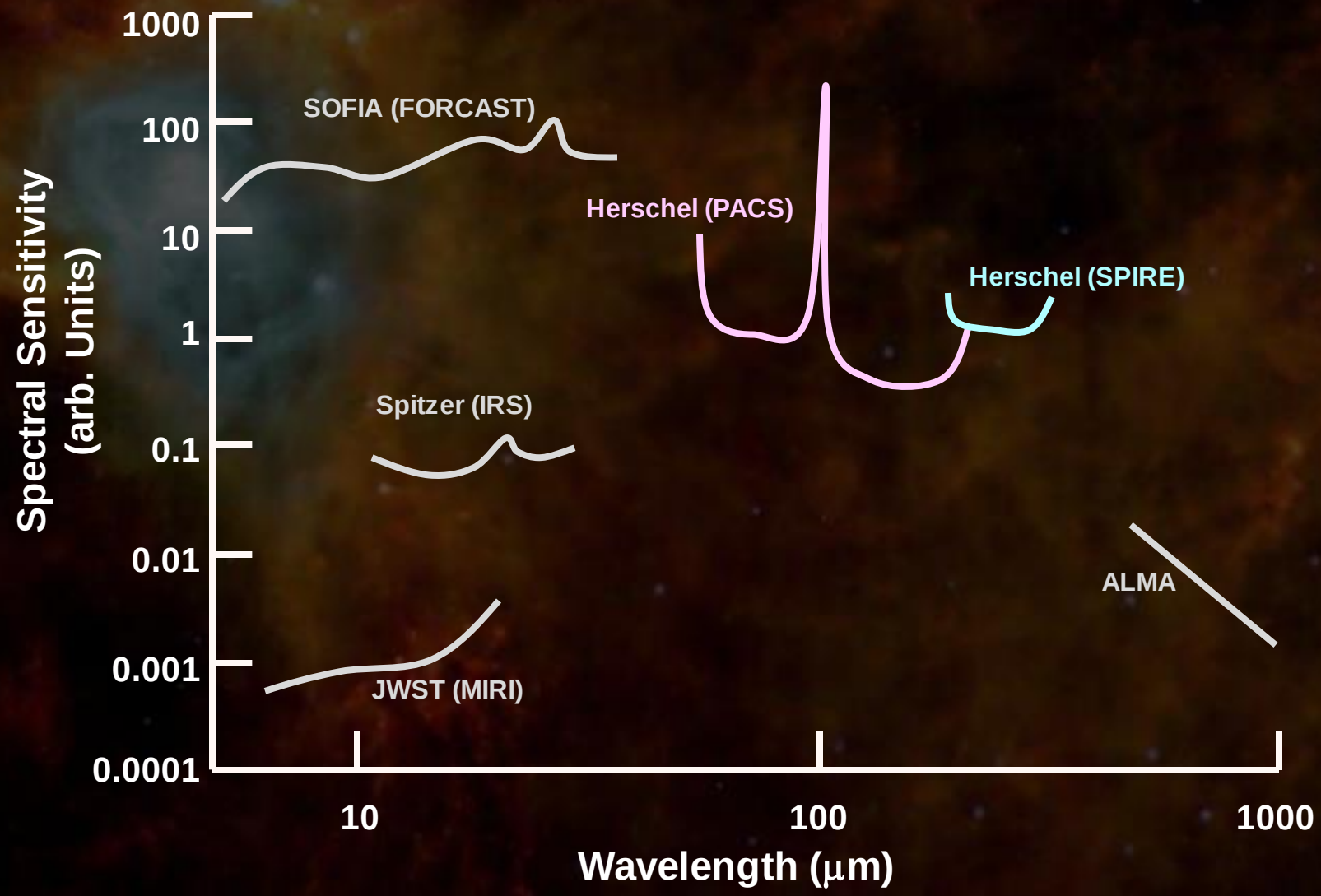


Crab Nebula

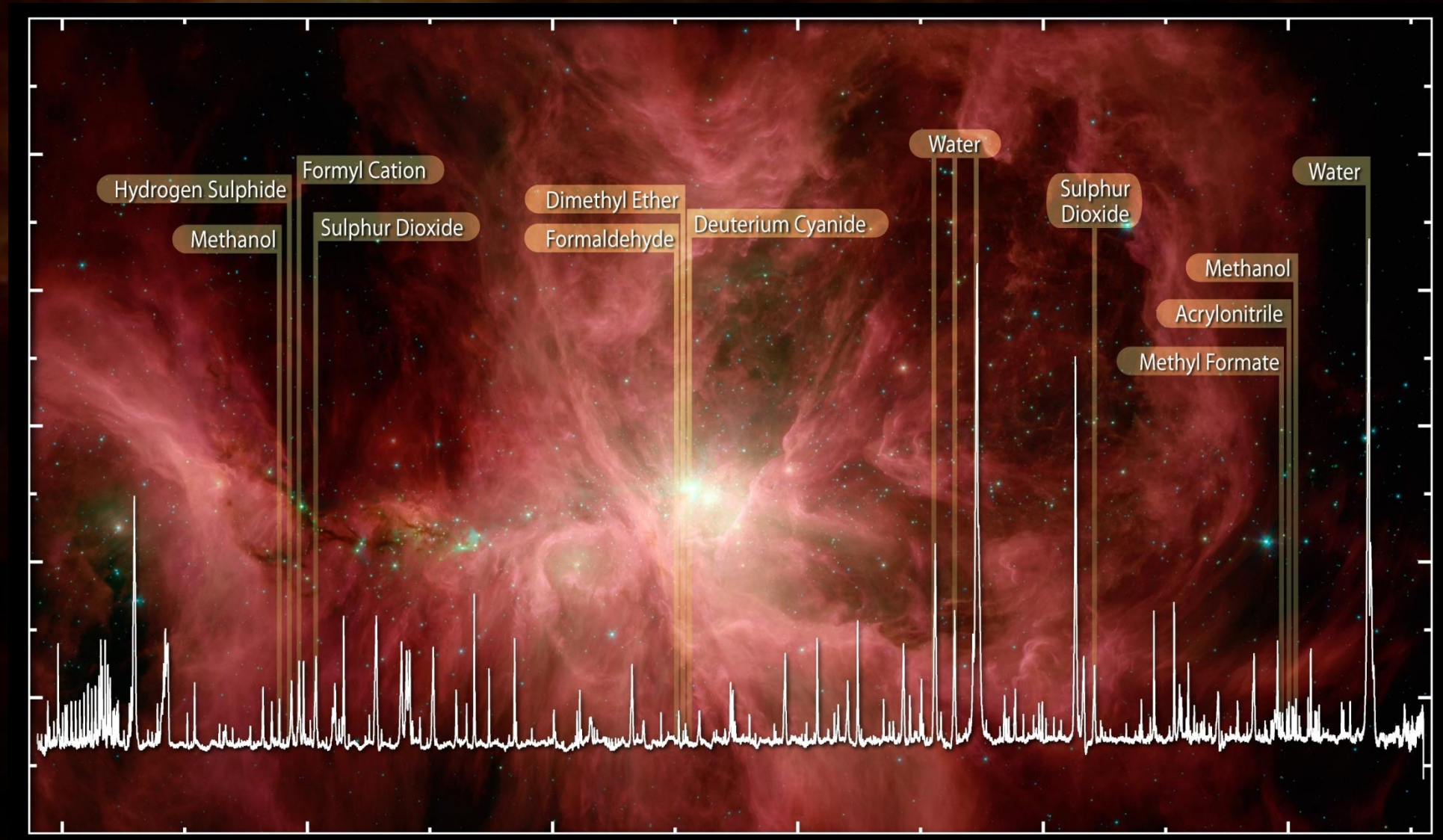
Supernova 1987a



Spectroscopic Sensitivity

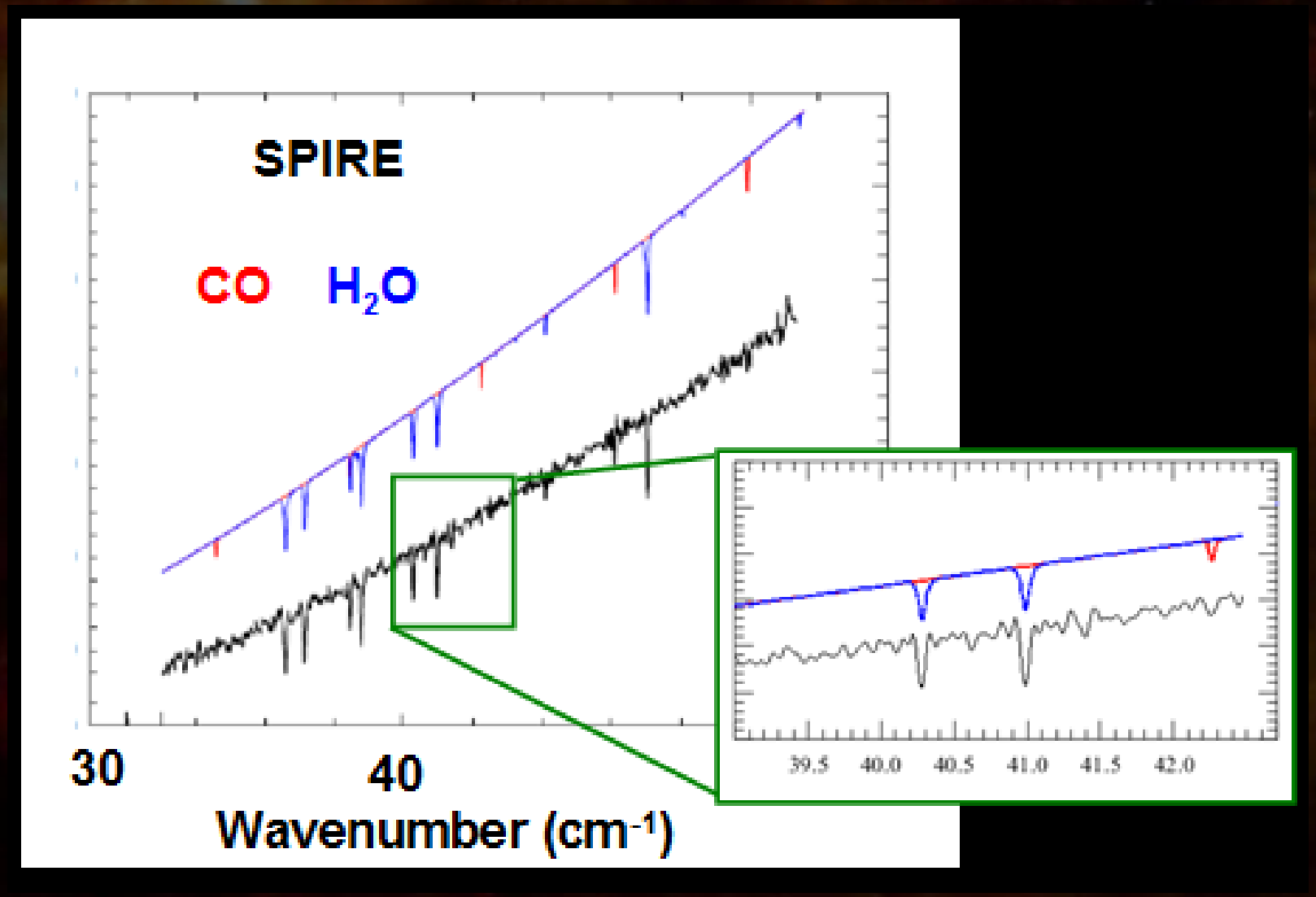


Orion Nebula



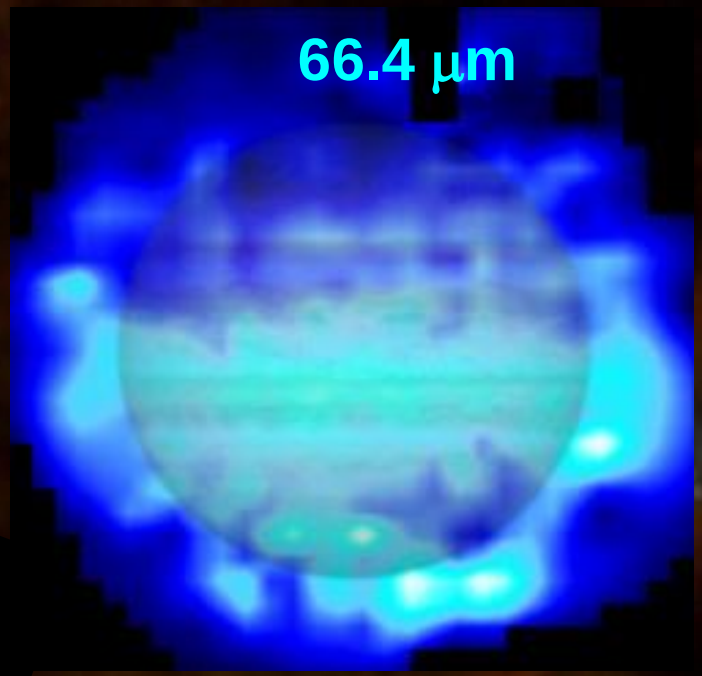
- NH_2CHO
- SiS
- C_2H_5OH
- H_2CS
- NO
- NS
- SO, ^{34}SO, ^{33}SO, $S^{18}O$
- SO_2, $^{34}SO_2$, $^{33}SO_2$
- HCN, $H^{13}CN$, $HC^{15}N$
- HNC, $H^{15}NC$, $HN^{13}C$
- SiO
- CH_3CN, $^{13}CH_3CN$, $CH_3{}^{13}CN$
- NH_3, $^{15}NH_3$, NH_2D
- HCl, $H^{37}Cl$
- H_2S, $H_2{}^{33}S$, $H_2{}^{34}S$
- H_2CO, $H_2{}^{13}CO$, HDCO
- $HCOOCH_3$
- CCH
- CN
- HC_3N
- H_2O, HDO, $HD^{18}O$, D_2O, $H_2{}^{18}O$, $H_2{}^{17}O$
- CH_3OH, $^{13}CH_3OH$, CH_3OD, CH_2DOH
- C_2H_5CN
- HNCO, $HN^{13}CO$
- HCS^+
- H_2CCO
- OCS
- CH_3OCH_3
- CS, $C^{34}S$, $C^{33}S$, ^{13}CS
- CO, ^{13}CO, $C^{17}O$, $C^{18}O$
- HCO^+

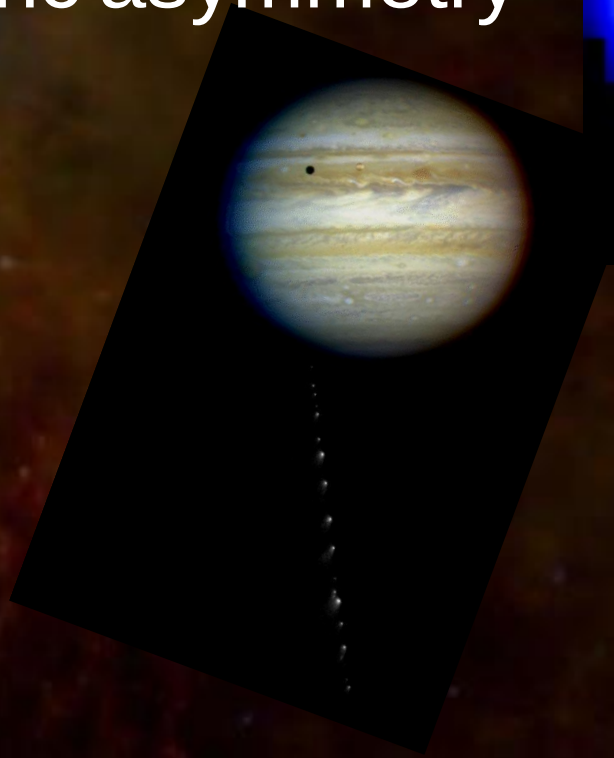
Water on Mars



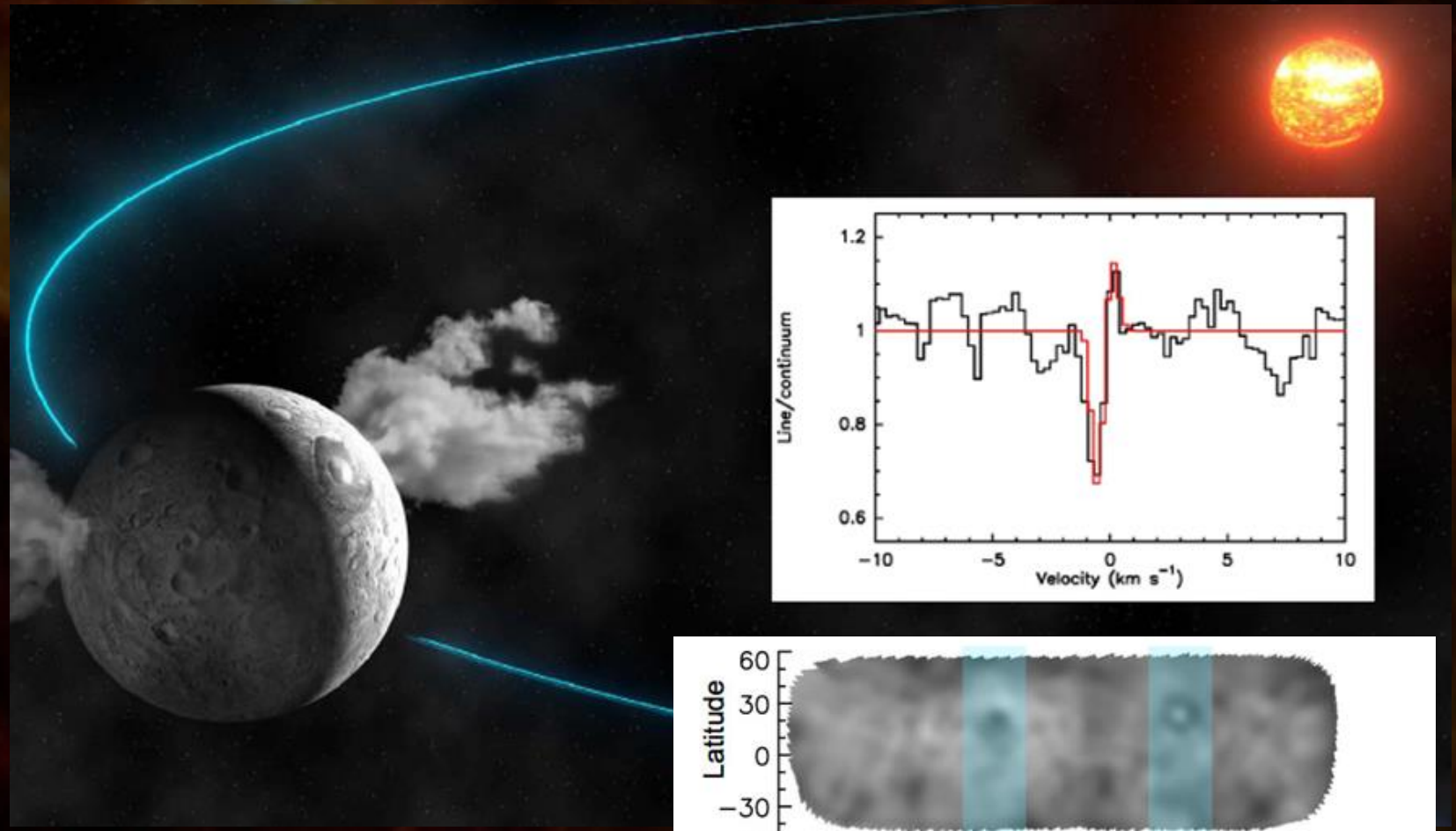
Water in Jupiter's Statosphere

- Vertical and horizontal distribution and hemispheric asymmetry

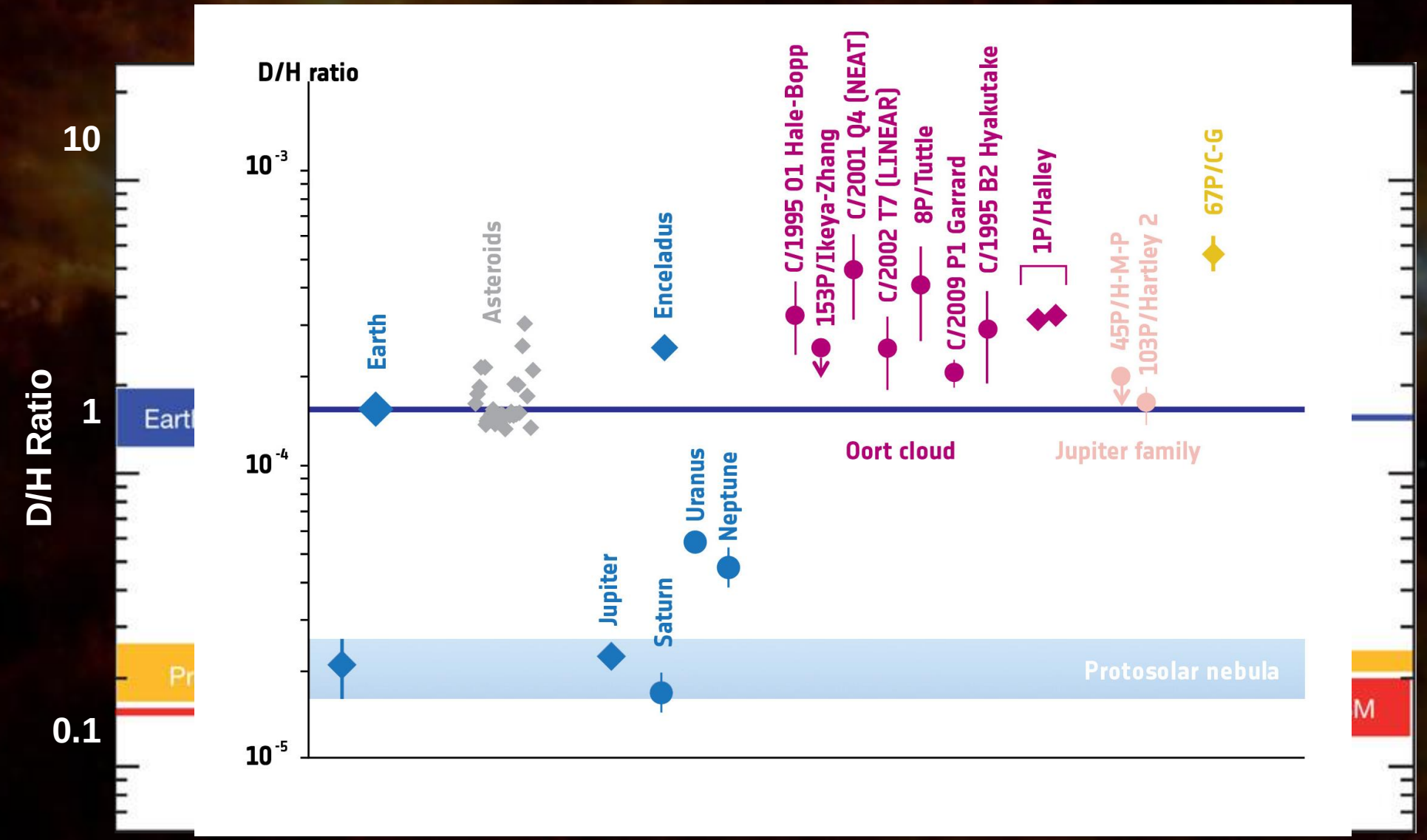




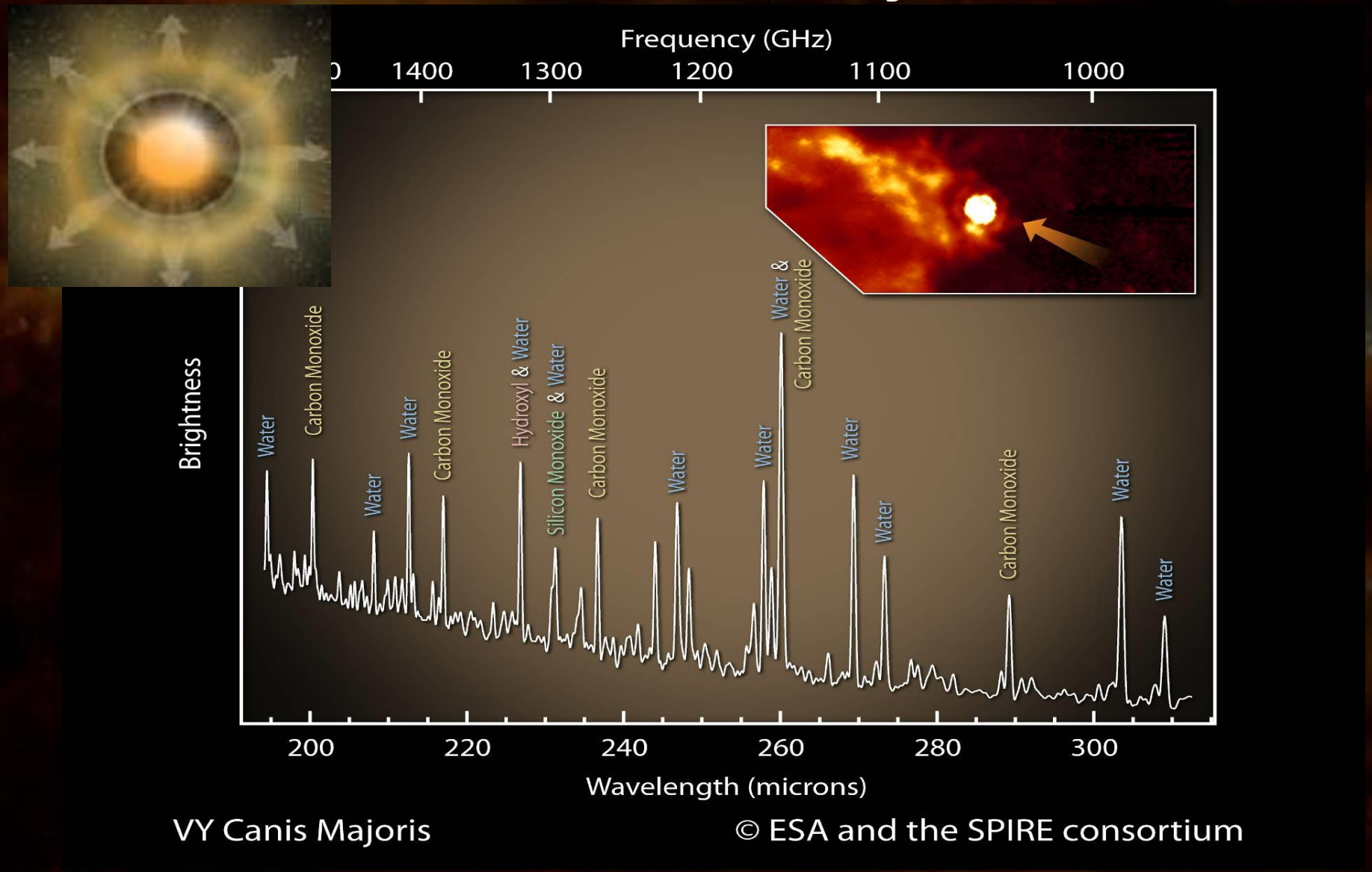
Water on Ceres!



Water composition of comets



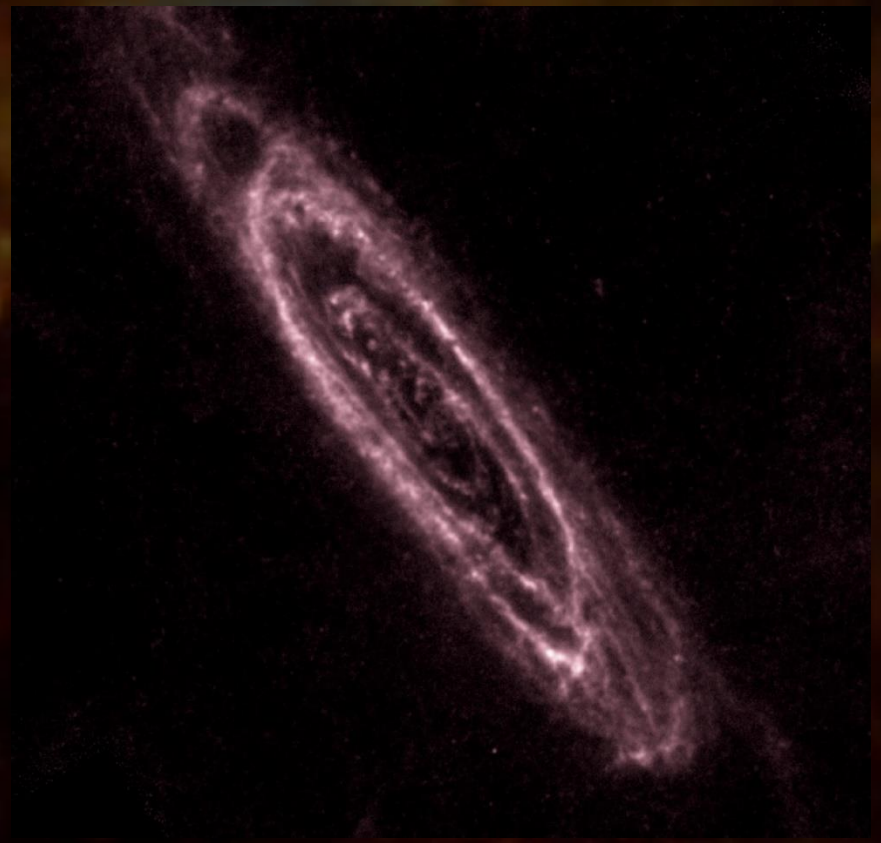
VY Canis Majoris



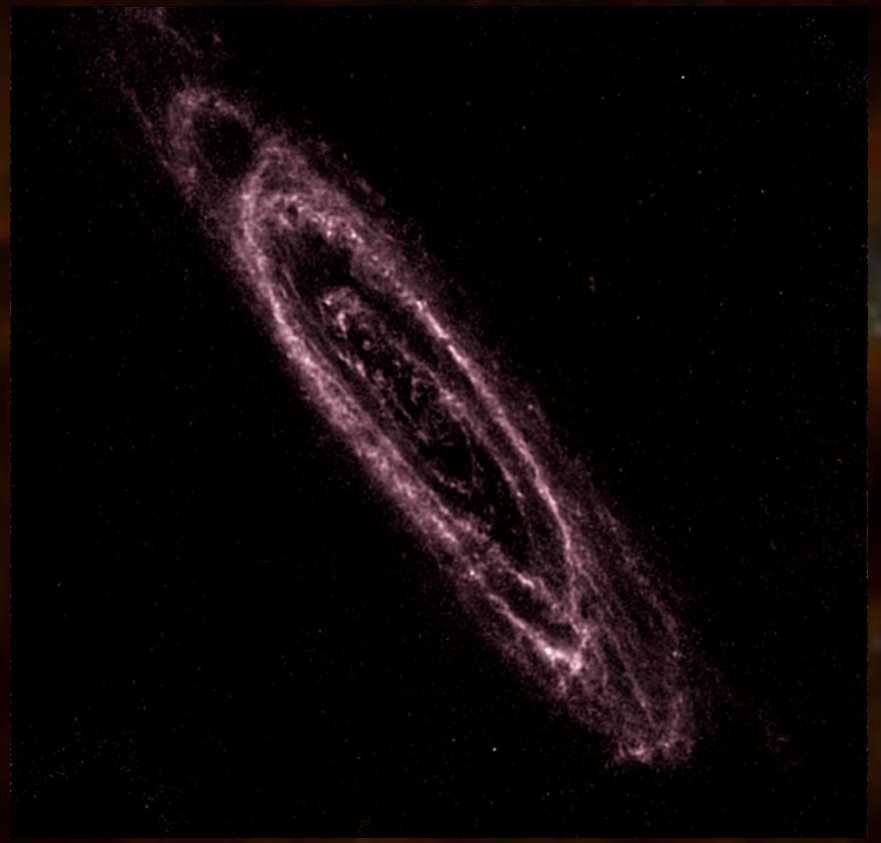
Andromeda Galaxy

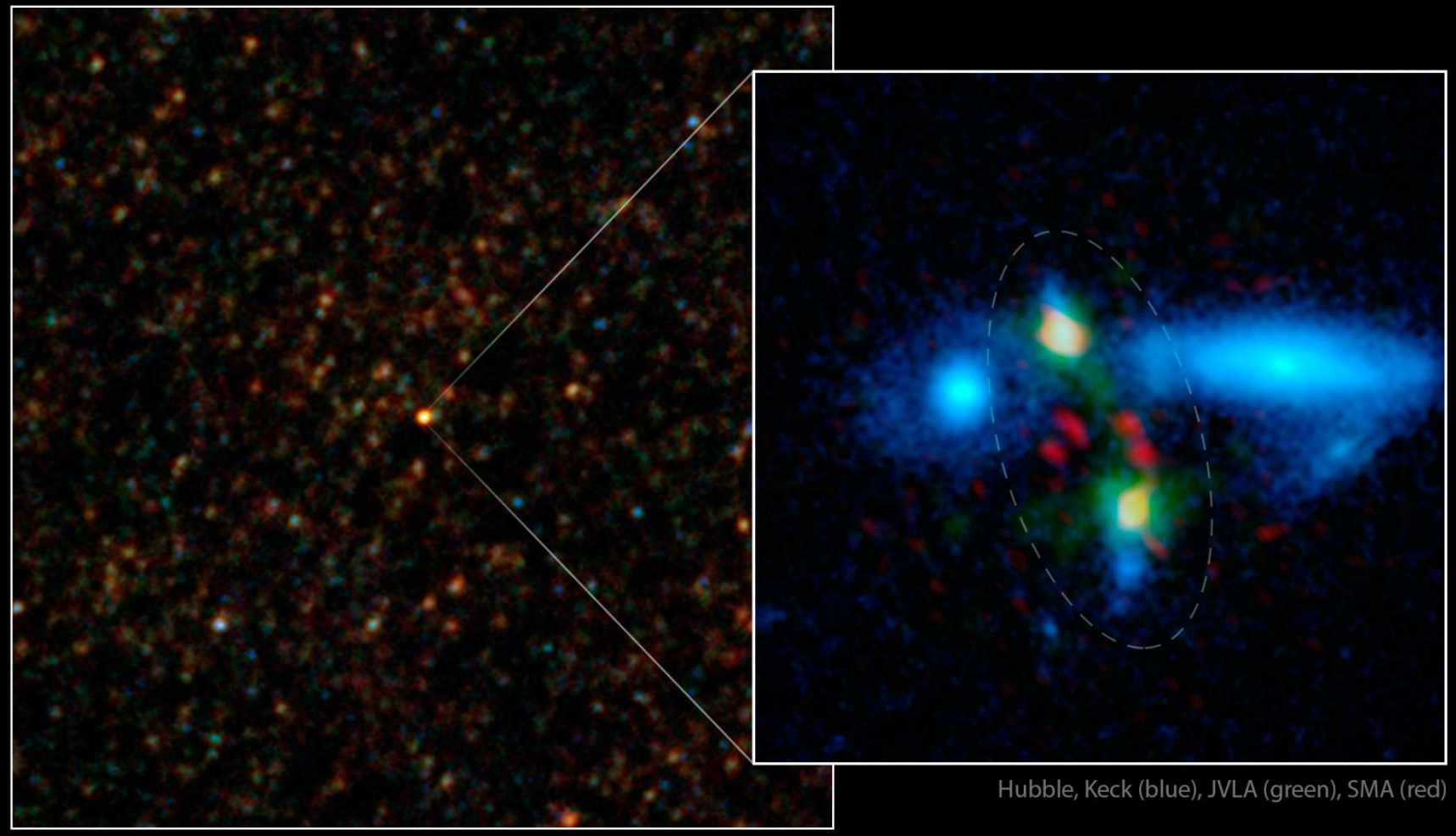
HiRes Maps

M31 500 μm: Nominal



M31 500 μm: HiRes

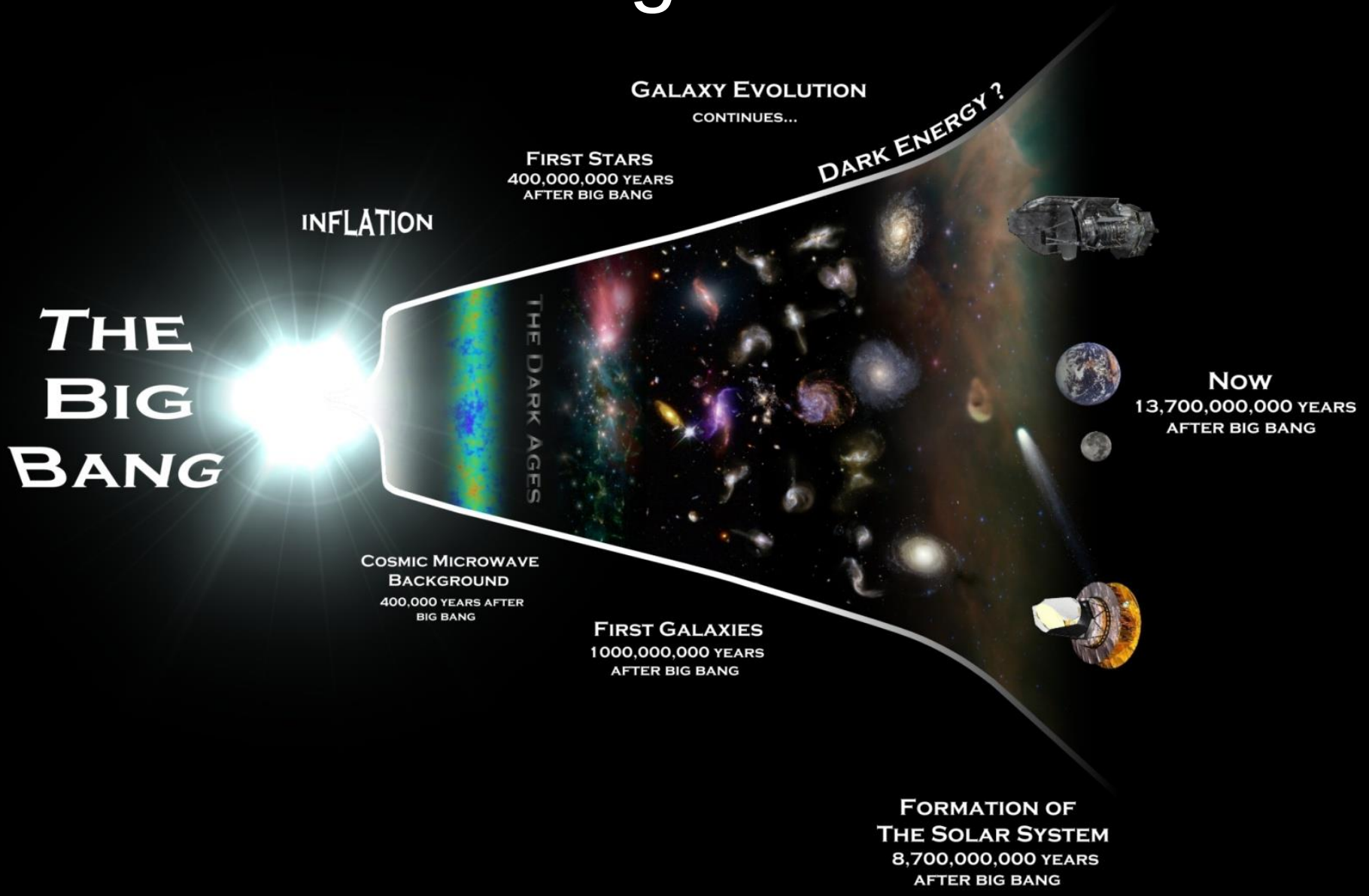




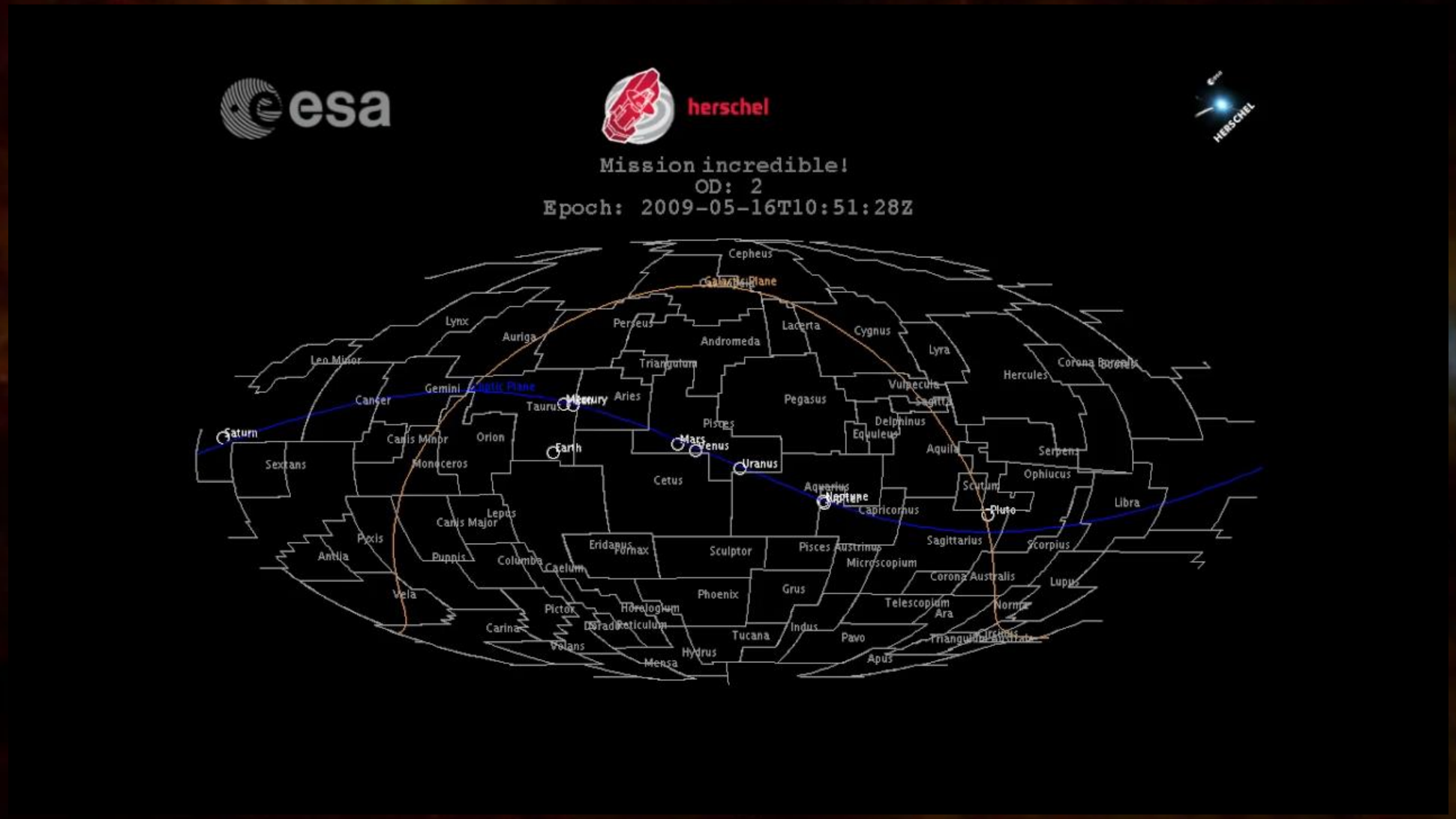
Herschel Space Observatory

Hubble, Keck (blue), JVLA (green), SMA (red)

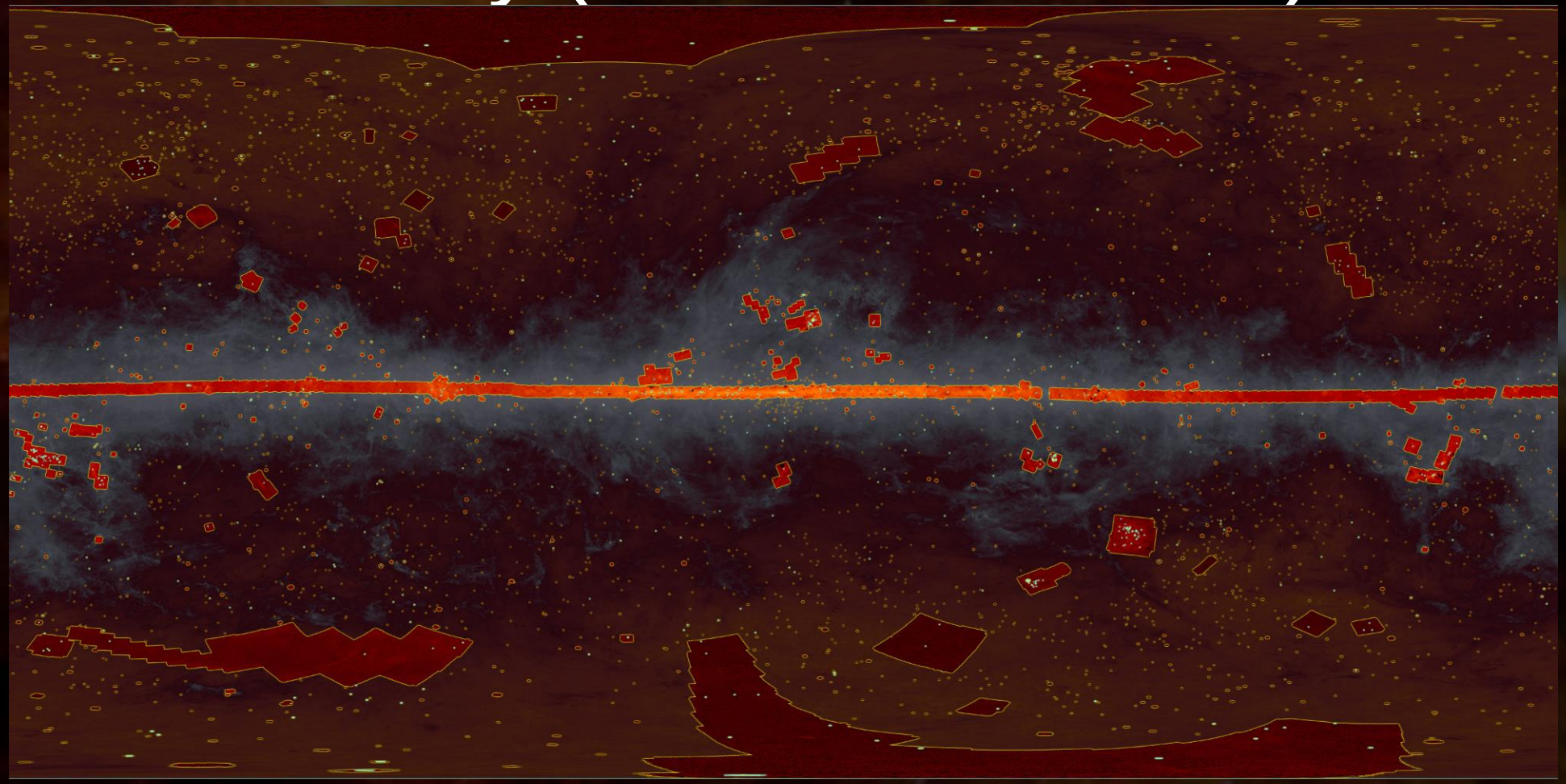
The Big Picture



All Good Things…

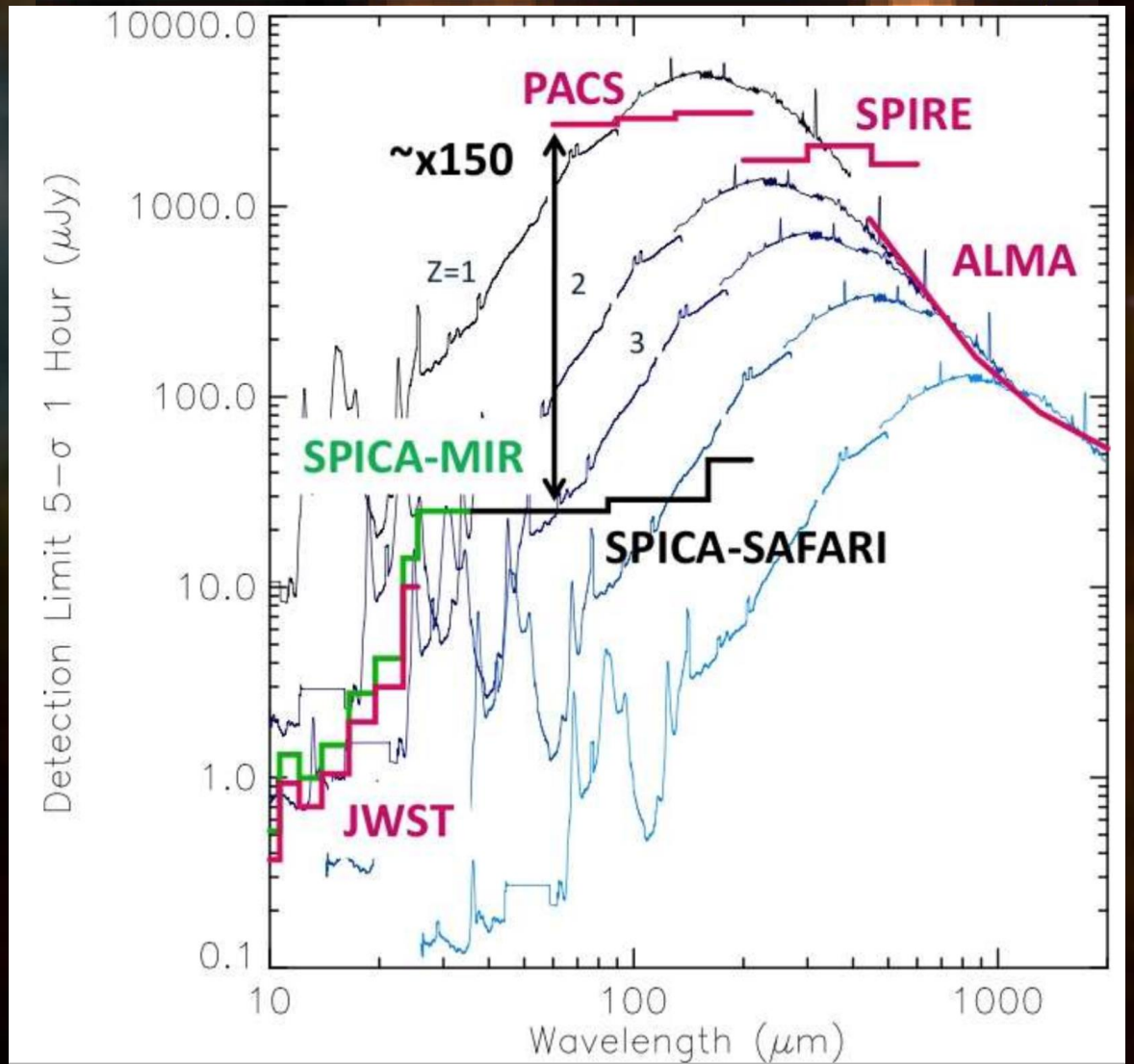

esa
herschel
HERSCHEL
Mission incredible!
OD: 2
Epoch: 2009-05-16T10:51:28Z
Cepheus
Lynx
Perseus
Lacerta
Cygnus
Auriga
Andromeda
Lyra
Leo Minor
Triangulum
Hercules
Vulpecula
Gemini
Cancer
Aries
Pegasus
Taurus
Pisces
Delphinus
Equuleus
Saturn
Canis Minor
Orion
Mars
Venus
Aquila
Serpens
Earth
Sextans
Monoceros
Uranus
Ophiucus
Cetus
Scutum
Neptune
Capricornus
Pluto
Libra
Lepus
Canis Major
Pyxis
Sagittarius
Eridanus
Pomax
Sculptor
Pisces Austrinus
Scorpius
Antlia
Puppis
Columba
Caelum
Microscopium
Corona Australis
Lupus
Vela
Phoenix
Grus
Telescopium
Norma
Pictor
Horologium
Ara
Carina
Reticulum
Tucana
Indus
Pavo
Volans
Hydrus
Mensa
Apus

All-sky (Herschel-SPIRE)

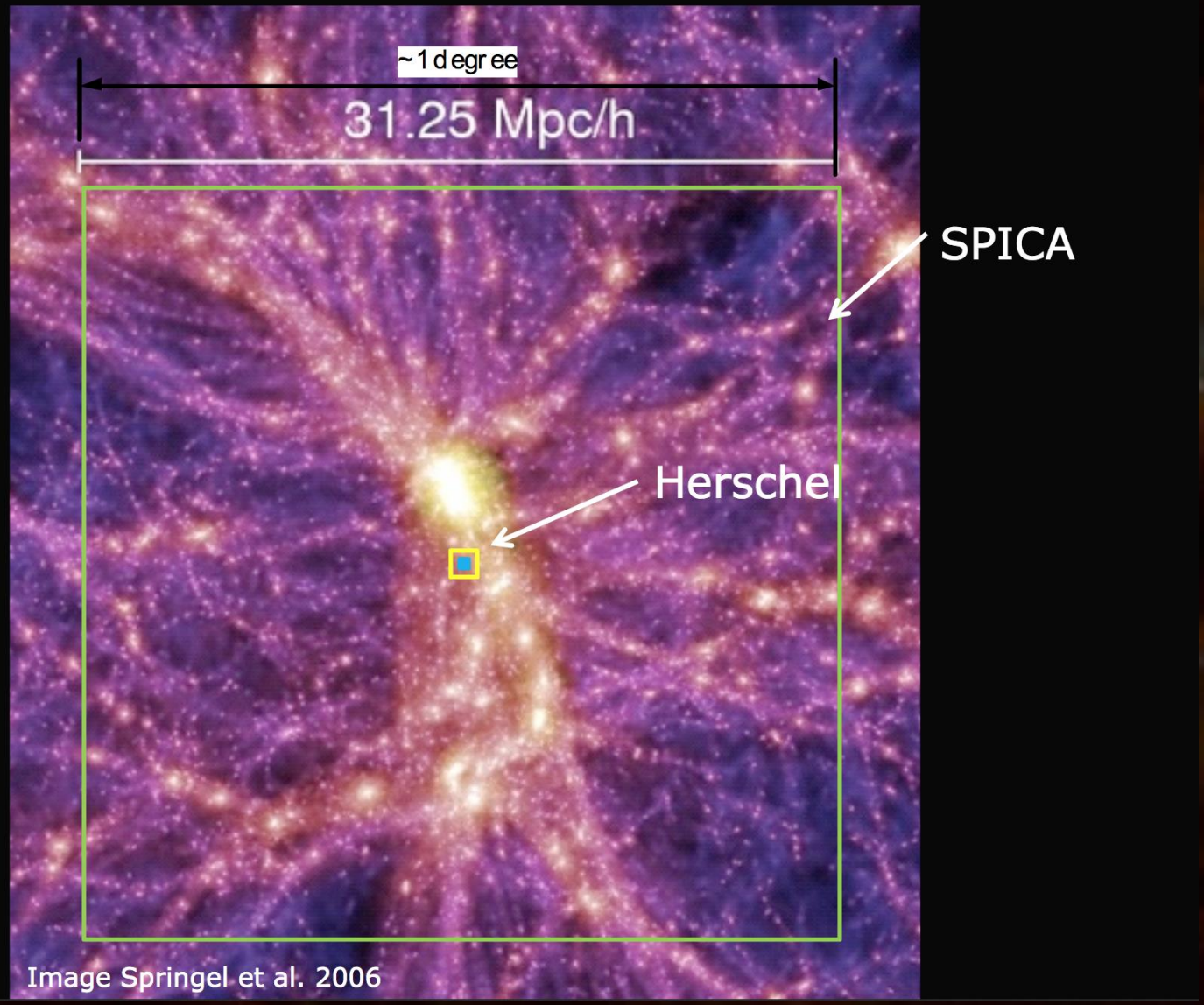


herschel.cf.ac.uk/chromoscope/results

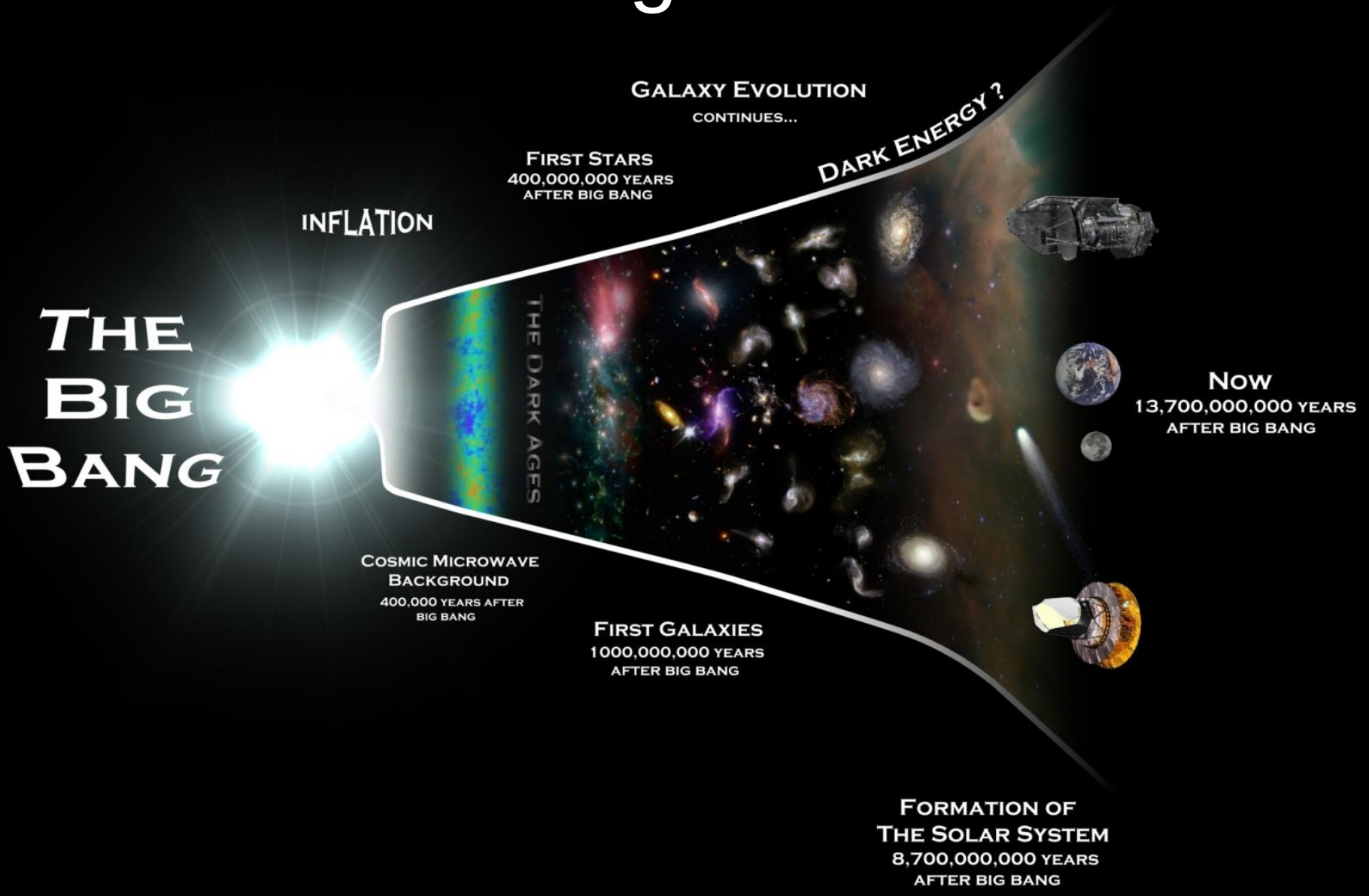
Galaxy Formation and Evolution



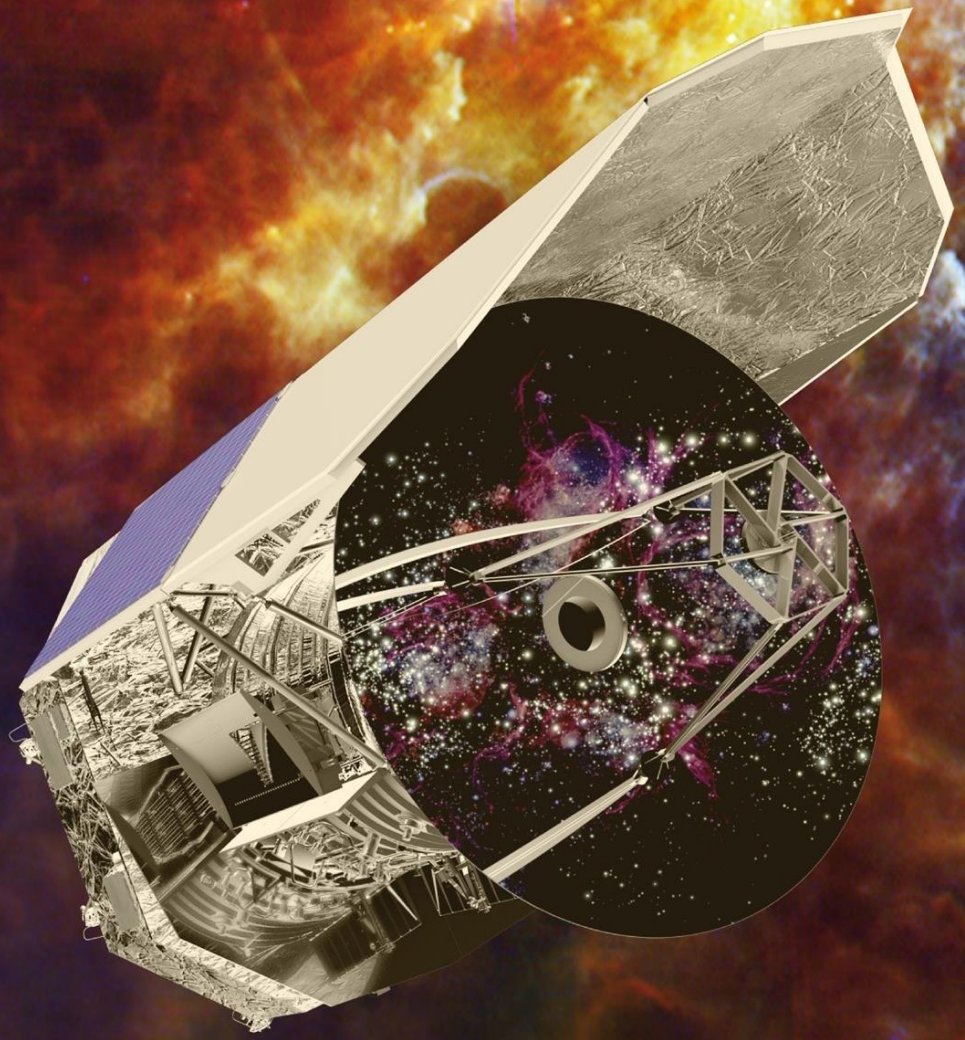
Galaxy Formation and Evolution

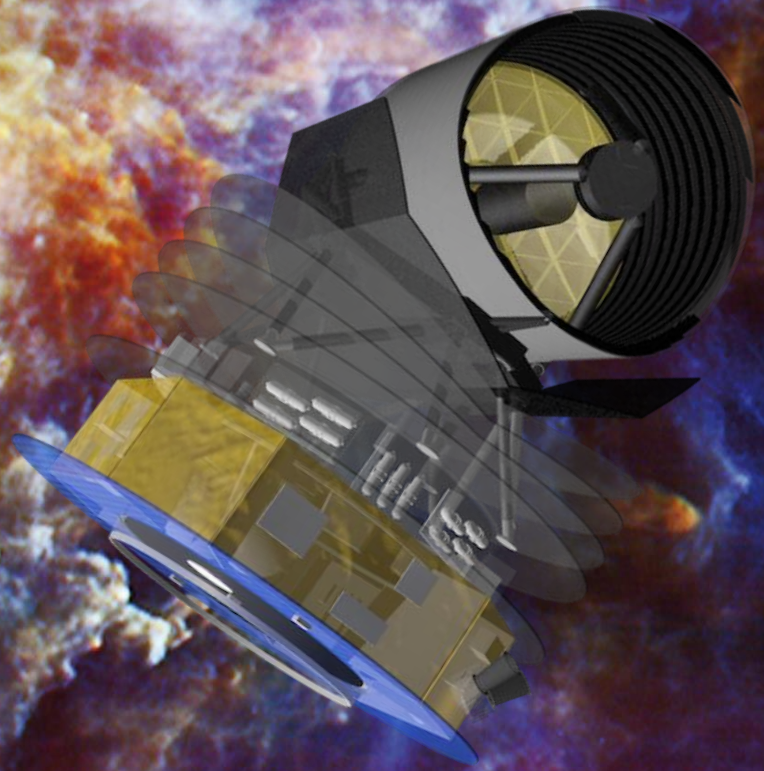


The Big Picture



With thanks to the Herschel Team!





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