What’s New in Astronomy?

Summary and a grab bag

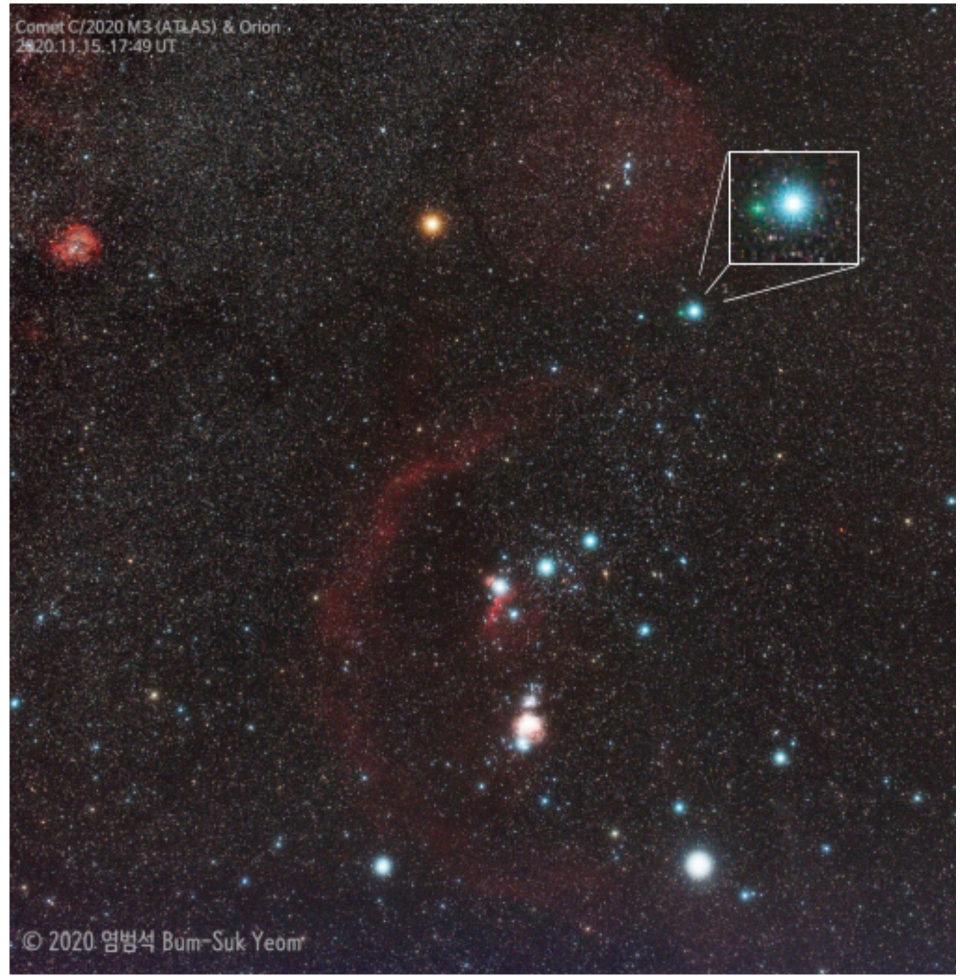
Richard Edgar, Nov 18, 2020

Notes and links and movies: https://RichardJEdgar.github.io

- Outline…
- Gravitational waves, merging black holes & neutron stars.
- Instrumentation: space and ground and airborne
- Pretty pictures taken in multiple wavelength bands by Hubble, the Chandra X-ray Observatory, and other instruments.
- More about the sun, space weather, the heliosphere, and the boundary between that and interstellar space. What's out there between the stars?
- A little about exoplanets (planets orbiting other stars). See Feb 2020 course on my website for six weeks on that topic.
- Some summing up: learning to read science journalism.

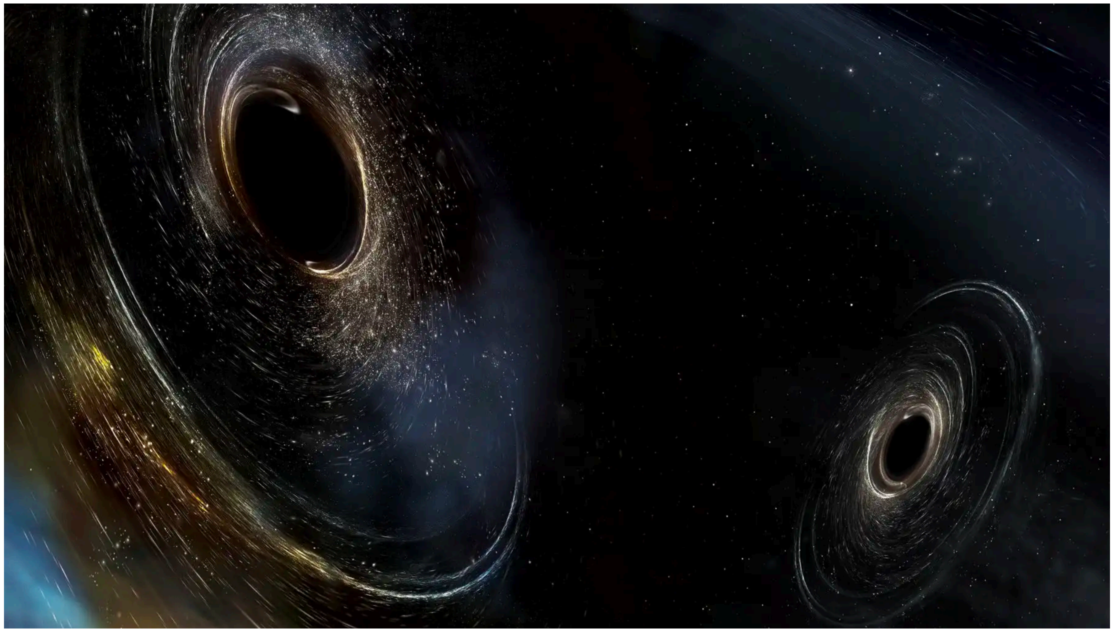
But first…

- Comet ATLAS passes the star Bellatrix in Orion. It’s like 6th magnitude (visible in a telescope from a dark site).



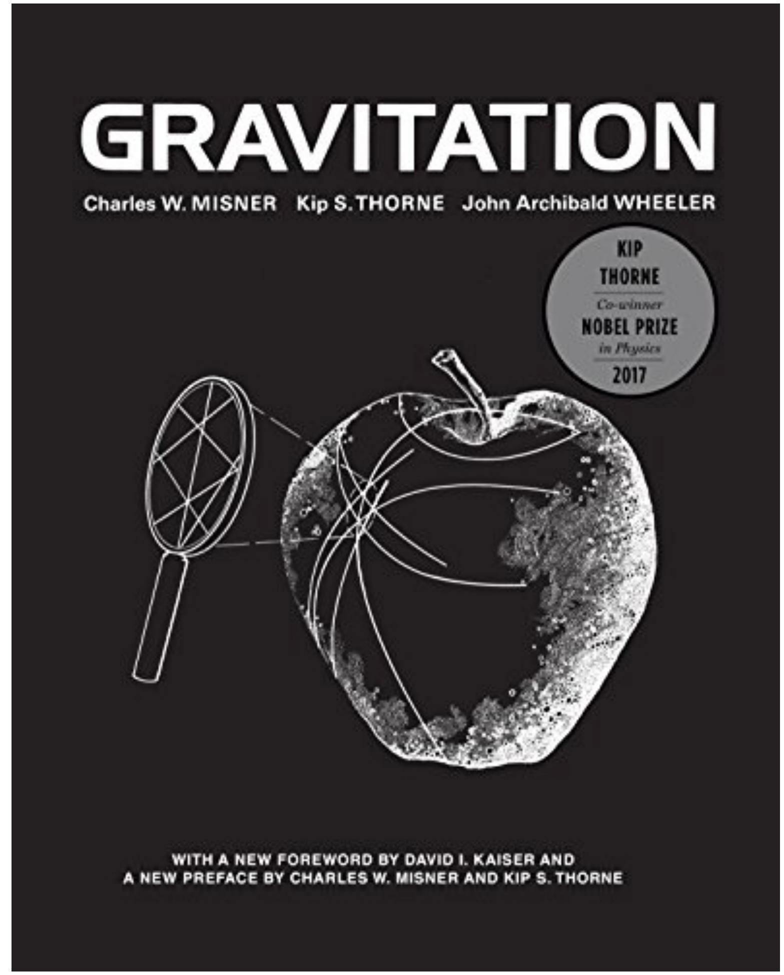
Gravitational Waves

Sources, detection, future prospects



- Analogous to electro-magnetic waves (light, radio, x-ray, etc.) the gravitational field in General Relativity (Einstein's gravity theory) can have waves in it.
- In GR the gravitational field is the curvature of 4-dimensional "space-time"
- Gravitational waves are traveling, periodic distortions in the structure of space (and time) itself.
- They're very weak, leading Einstein himself to say they'd never be detected. They require huge masses with very large accelerations.
- Like, for example, pairs of black holes merging. Or even neutron stars.

- Essentially all physicists had this book on their shelves: Misner, Thorne and Wheeler.
- When Kip Thorne was on the road giving talks to drum up support for a gravitational wave detector, he would point his audience to an exercise in MTW, where the assignment was to show that no such device would ever be possible.
- “And now, here I am trying to convince you we can do it.”

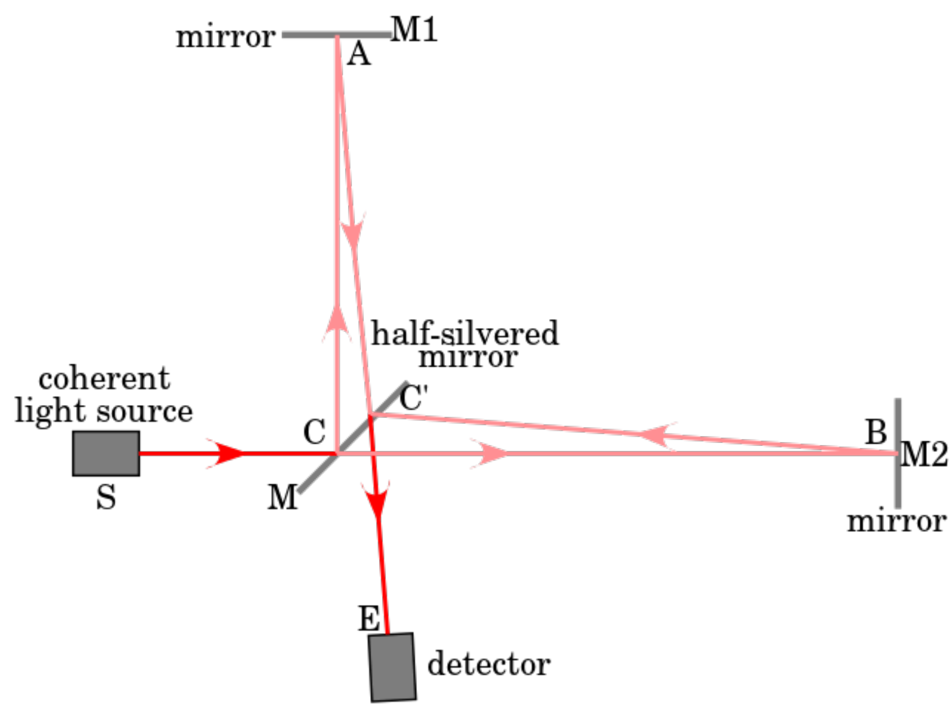


Michelson Interferometer

- Allows the difference in distances AC and BC to be measured to the precision of a fraction of a wavelength of light.

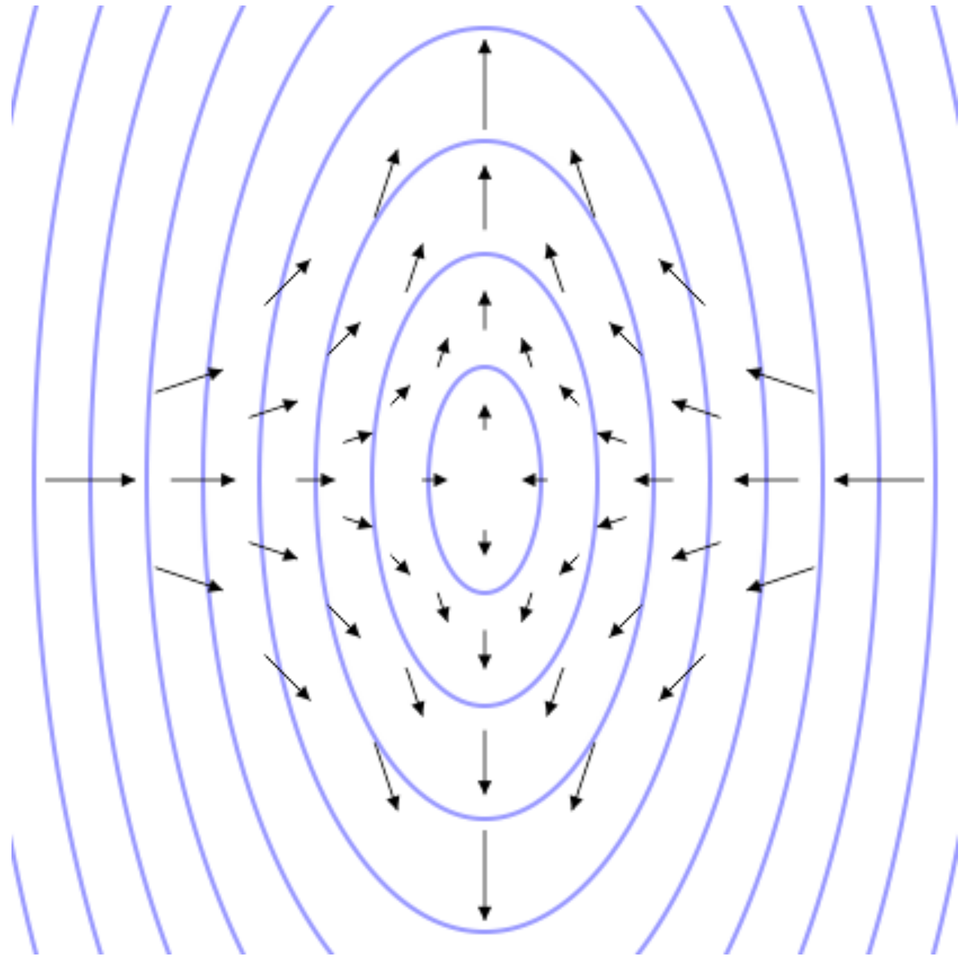
- Used by Michelson and Morley in 1887 to try to measure the speed of the earth relative to whatever medium (“ether”) light is waving in. It failed.

- Einstein took this result and dumped the idea of ether from his theories.



Gravitational Radiation

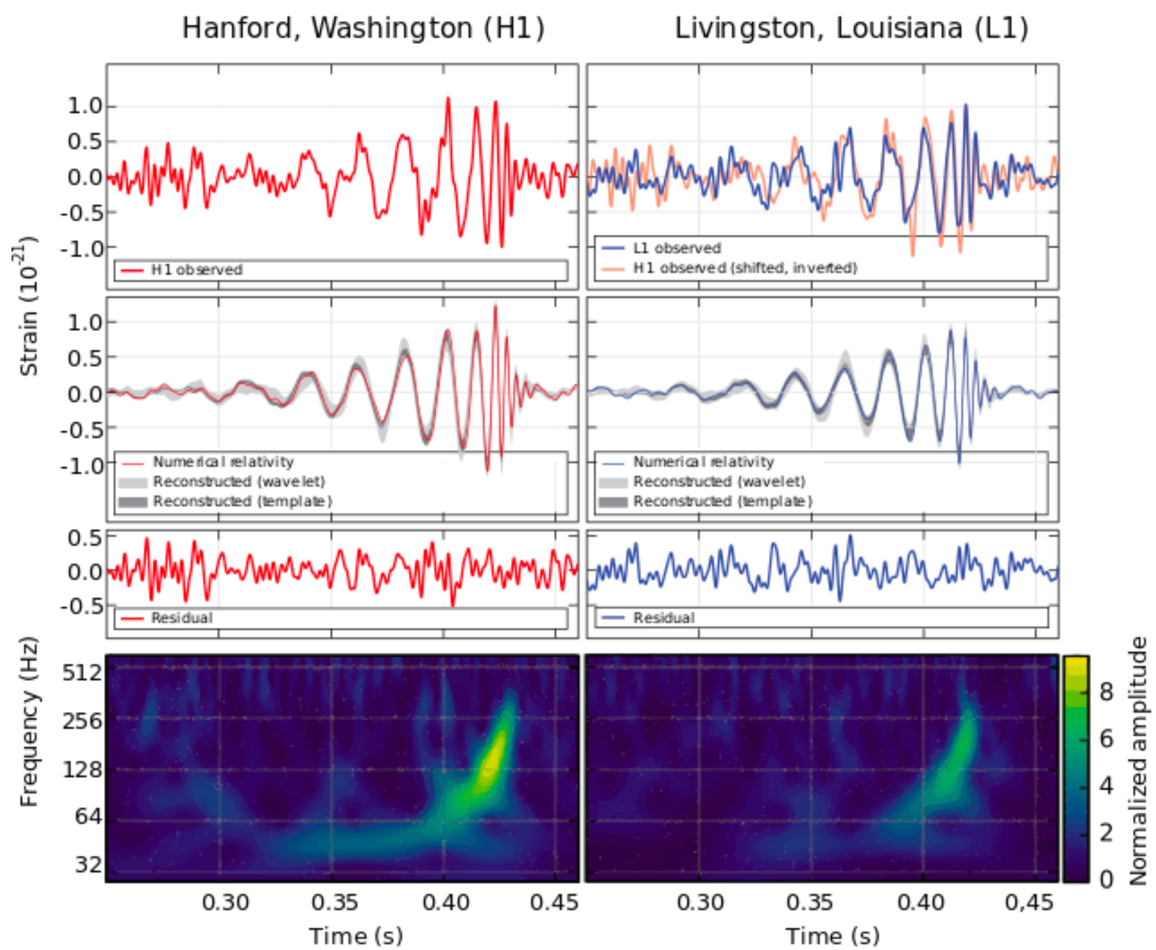
- As the wave moves perpendicular to the diagram, it deforms space in alternating elliptical ways.
- The interferometer tries to measure this by looking at differences in the length of its arms.
- Two detectors were built, in Livingston, LA and Hanford, WA, with follow-on detectors in Europe, Japan, India.



- The LIGO project (Laser Interferometer Gravitational Observatory) detected its first signal on 14 Sept 2015.
- The source, GW150914, came from the merger of two black holes of about 36 and 29 solar masses, yielding a 62 solar mass black hole. The remaining $3M_{sun}c^2$ worth of energy was radiated as gravitational waves.
- The idea is simple enough but the execution needs to be incredibly precise: one part in about 10^{22}.
- Kip Thorne & Barry Barish (CalTech), Rainer Weiss (MIT) were awarded the Nobel Prize in Physics in 2017 for this work.

The actual data

- Real data (top panel), theory (2nd panel) and differences; also a plot of frequency vs. time for each detector.
- The frequency is essentially the orbital period as the two black holes circle each other before merging, radiating energy as gravitational waves, which makes their orbit decay (get tighter and faster).



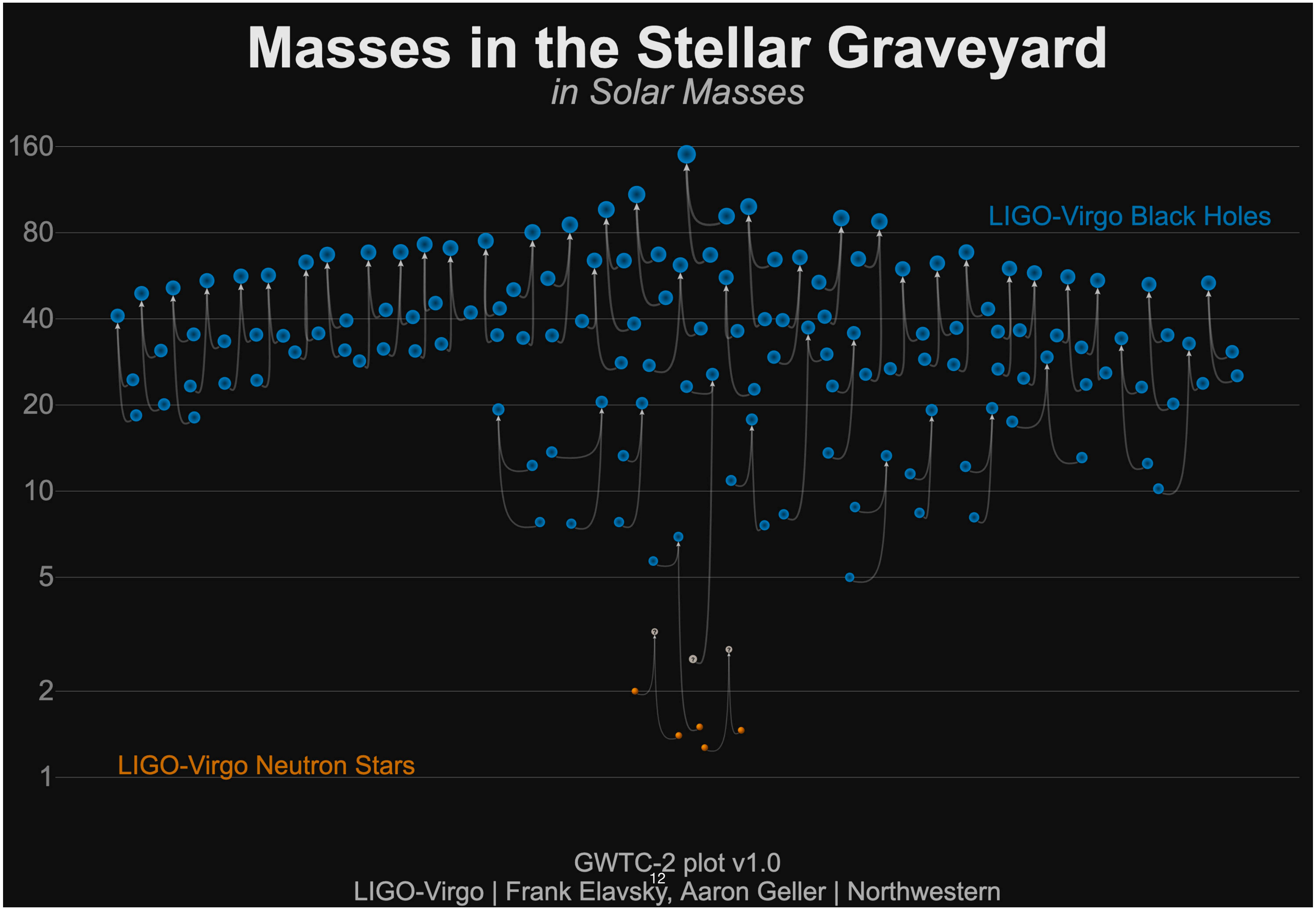
- Multiple detectors and precise timing let you triangulate where in the sky the signal originated.

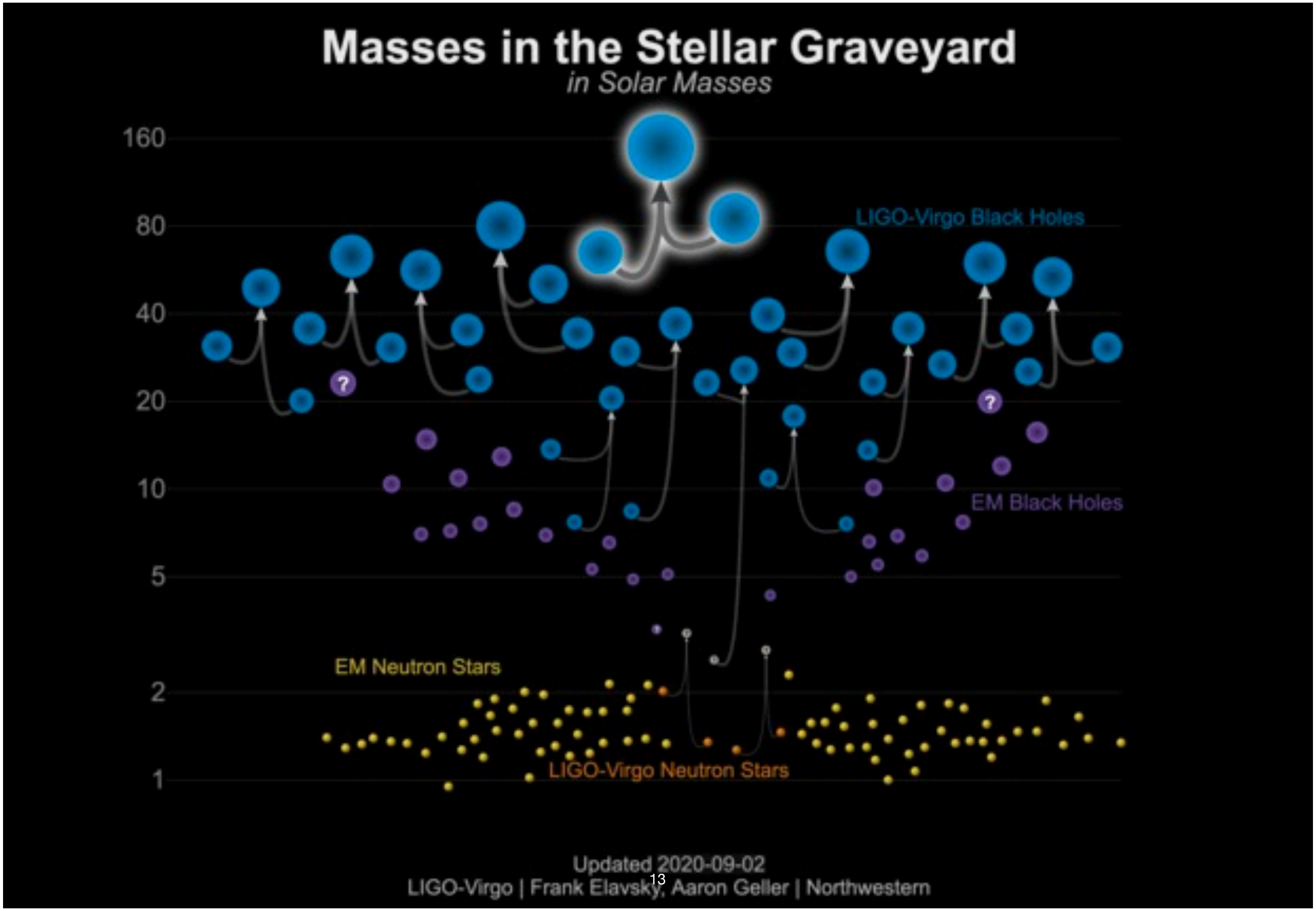
- On 17 Aug 2017, event GW170817 was the merger of two neutron stars. The resulting messy collision produced radio, x-ray, and optical light. It's thought that such "kilonova" events are responsible for synthesizing many of the nuclei heavier than iron.

- There have been about 50 events total, mostly black holes of a few tens of solar masses, but a few neutron star mergers. LIGO and VIRGO (in Europe) have operated together for two of the three observing seasons. Both were shut down due to Covid-19 precautions.

- Distances are typically a few billion light-years.

- New detectors in Japan and India are essentially ready to go.


Masses in the Stellar Graveyard
in Solar Masses
160
80
40
20
10
5
2
1
LIGO-Virgo Black Holes
LIGO-Virgo Neutron Stars
GWTC-2 plot v1.0
LIGO-Virgo | Frank Elavsky, Aaron Geller | Northwestern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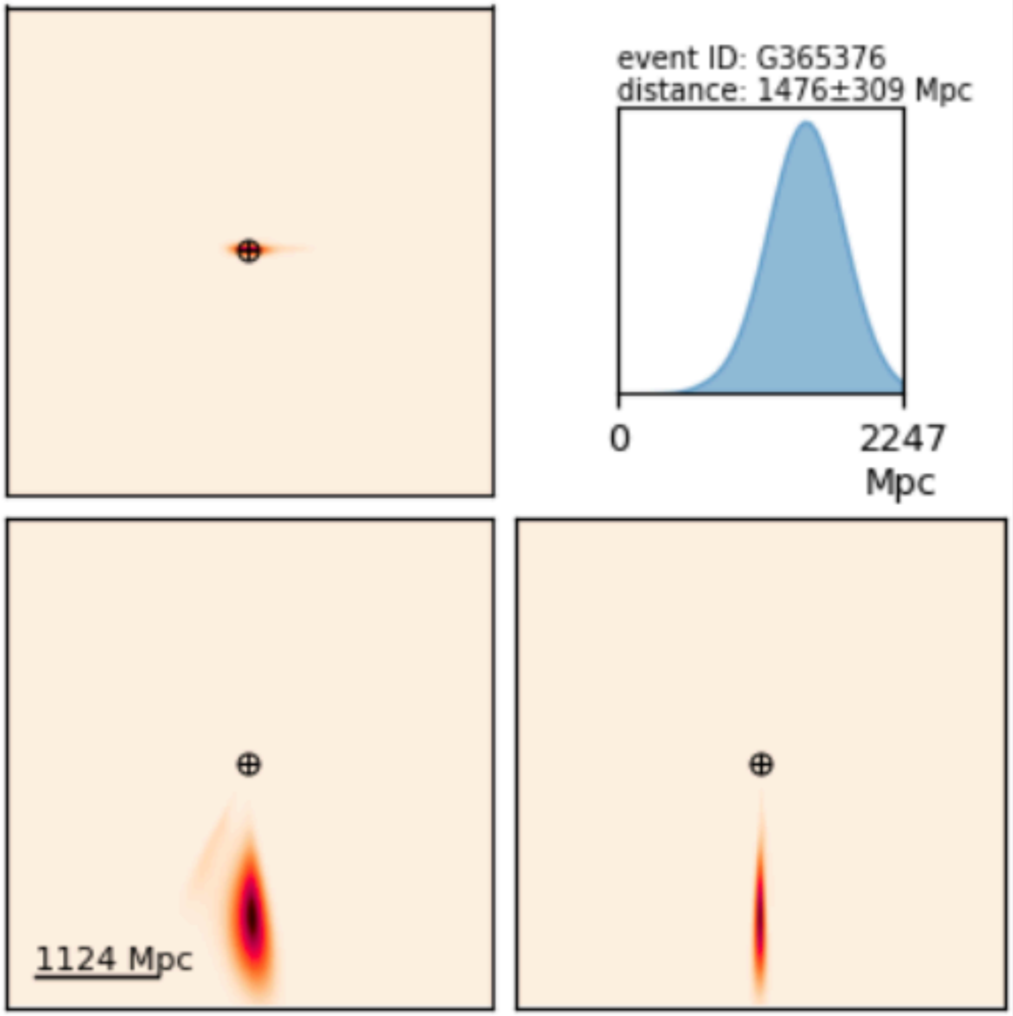
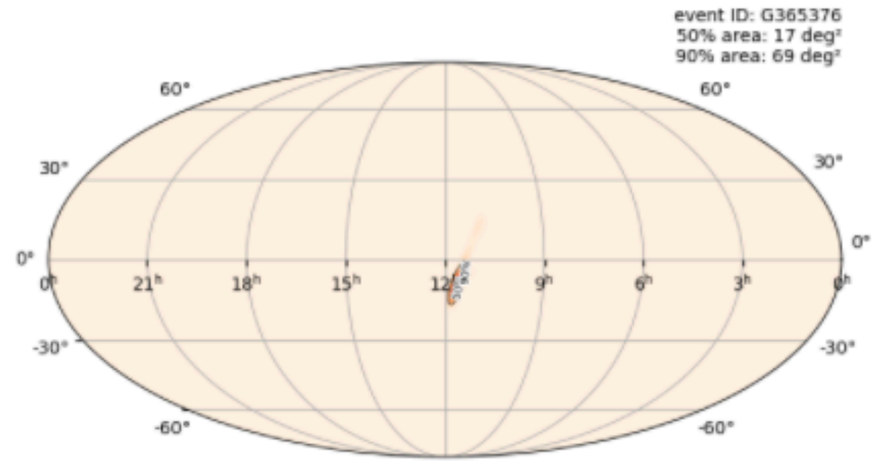
Updated 2020-09-02
LIGO-Virgo | Frank Elavsky, Aaron Geller | Northwestern

Log Image



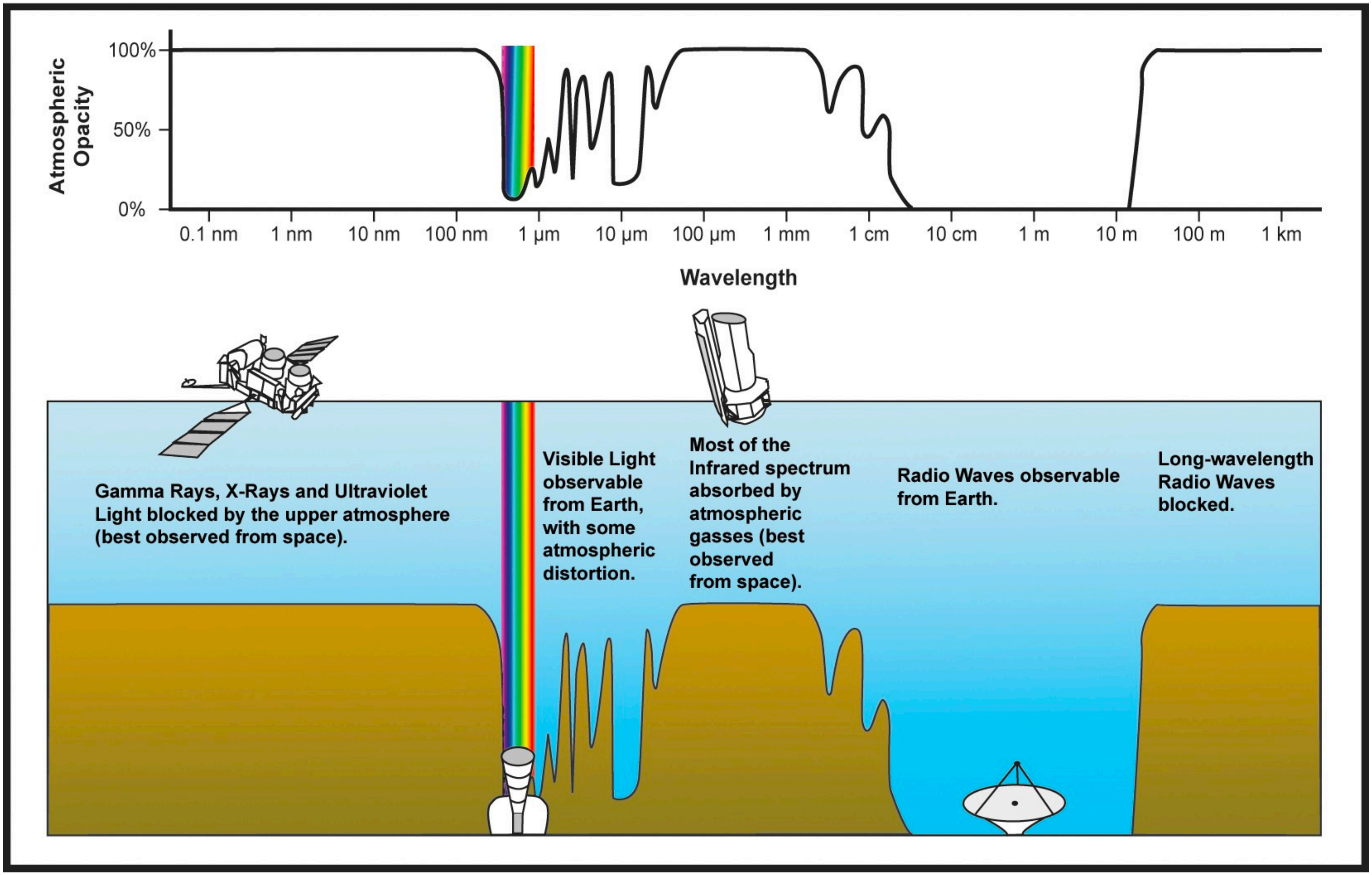
Log Image



Mollweide projection of

- Instrumentation
- You probably want a big telescope
  - ✴ Gathers more light
  - ✴ Diffraction: wavelength / aperture size limits sharpness of images.
  - ✴ Not needed for bright objects
- Detectors work over limited wavelength bands
- Atmospheric absorption is also strongly wavelength dependent.
- Reflective surface needs to be smooth on scales of wavelength / 4

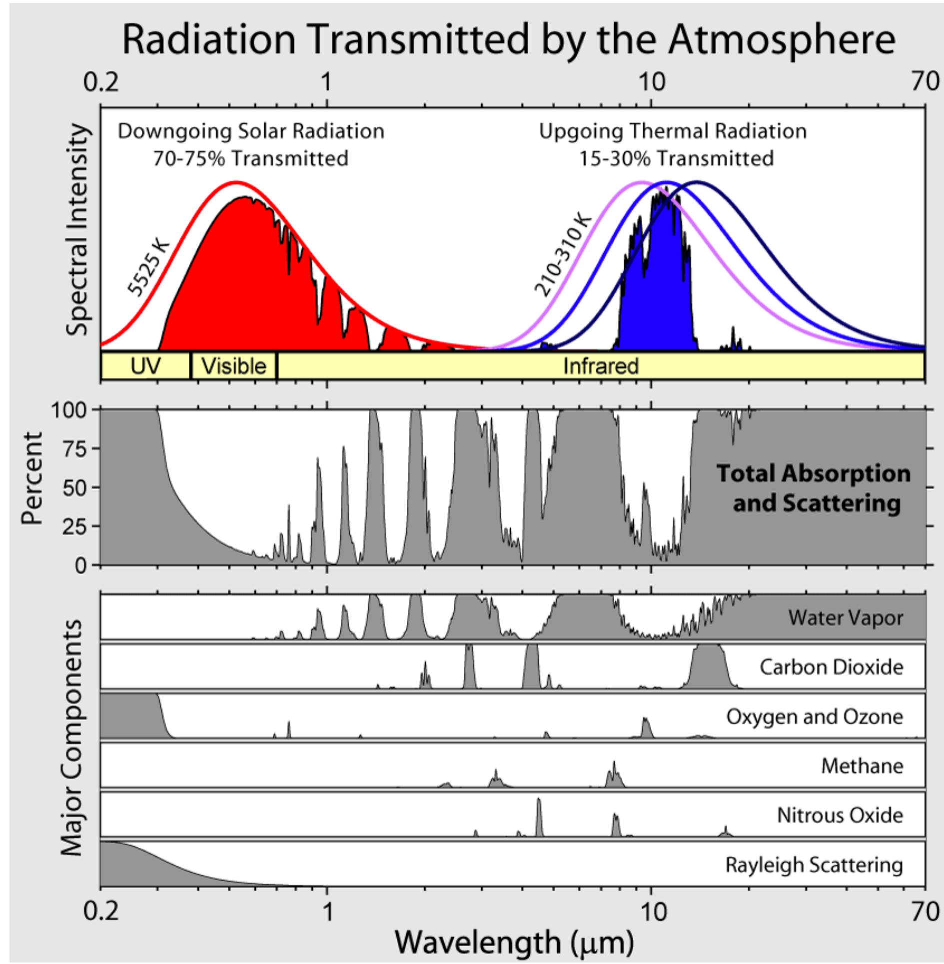
Along with budget cuts came a marked reduction in new discoveries.

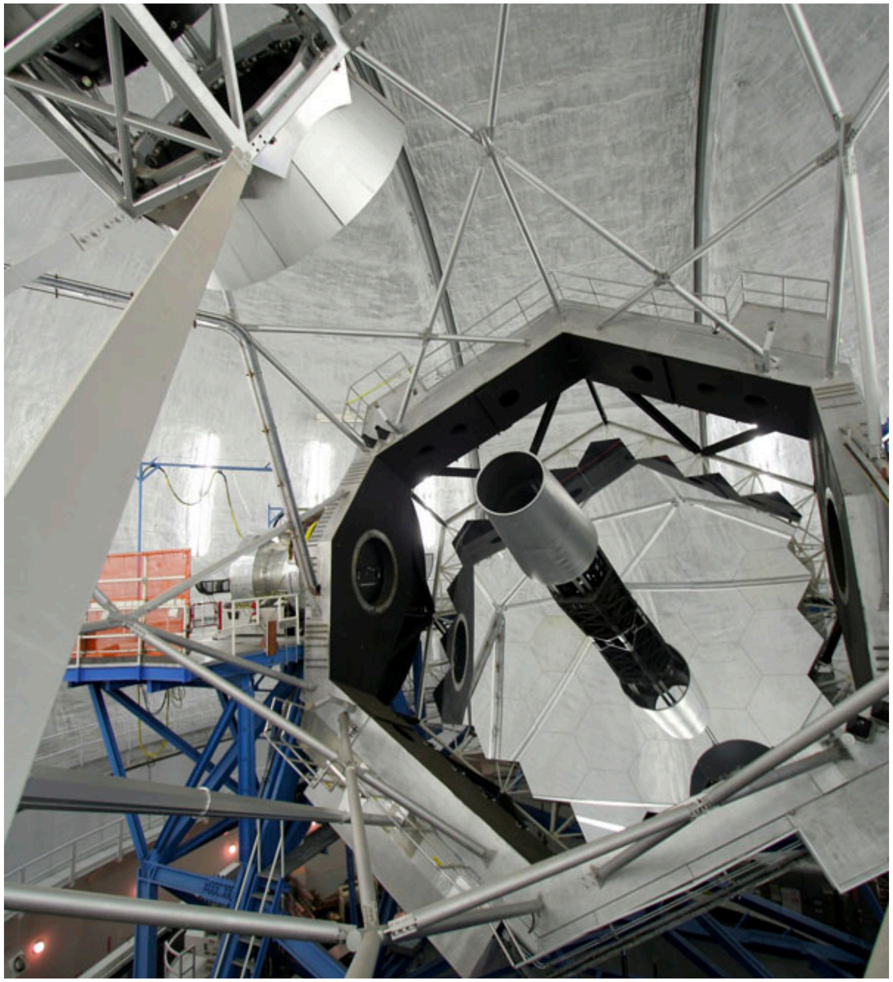


Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

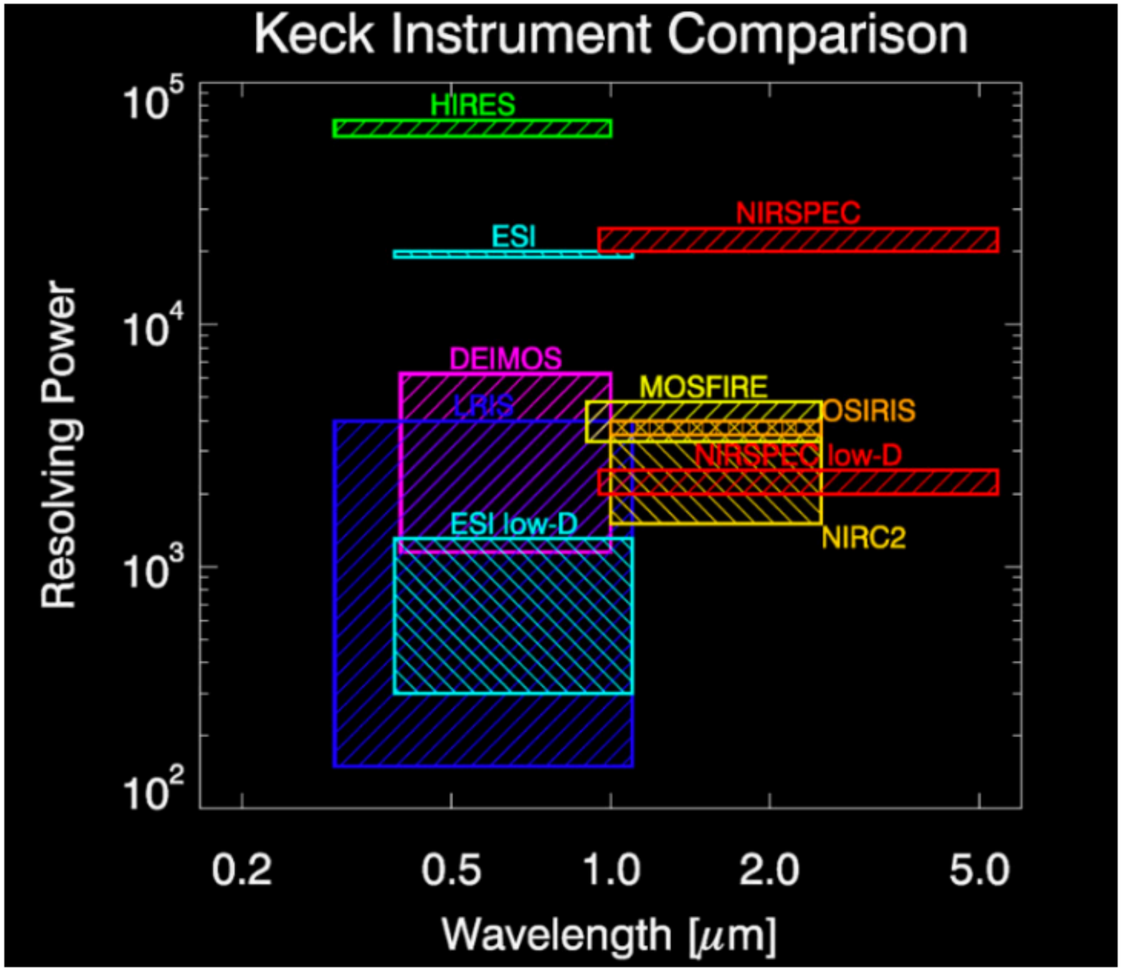
Atmospheric Transmission

- Ozone is opaque in the ultraviolet.
- Water vapor, CO_2, methane are opaque in bands in the infrared.
- The ionosphere is totally reflective at long radio wavelengths.



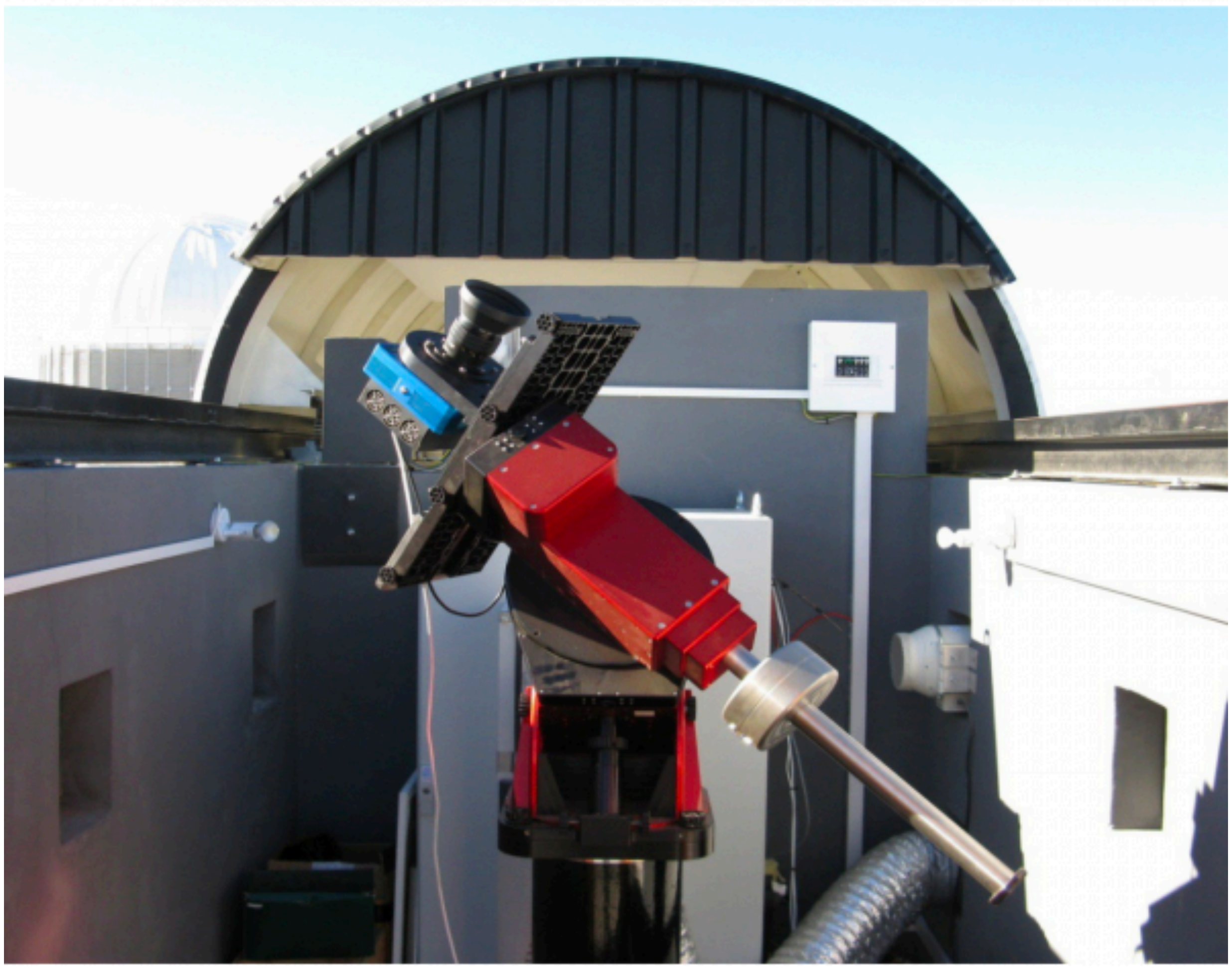


Keck Observatory on Mauna Kea, HI: two 10m optical telescopes (also useful in near infrared).



- Operated by Caltech, U. California system, and U. Hawaii
- Funded by the Keck Foundation, NSF, others
- The two telescopes can be used together as an interferometer (milli-arcsec resolution in IR). Adaptive optics.
- A variety of imaging and spectral instruments are available.

- European Southern Observatory's Very Large Telescope (VLT): four 8.2m telescopes on Mt. Paranal in Chile.
- Interferometer, adaptive optics, large instrument suite.



the Kilodegree Extremely Little Telescope (KELT)

Good CCD cameras on commercial camera lenses.

Used for monitoring bright stars for planetary transits, over a large part of the sky.

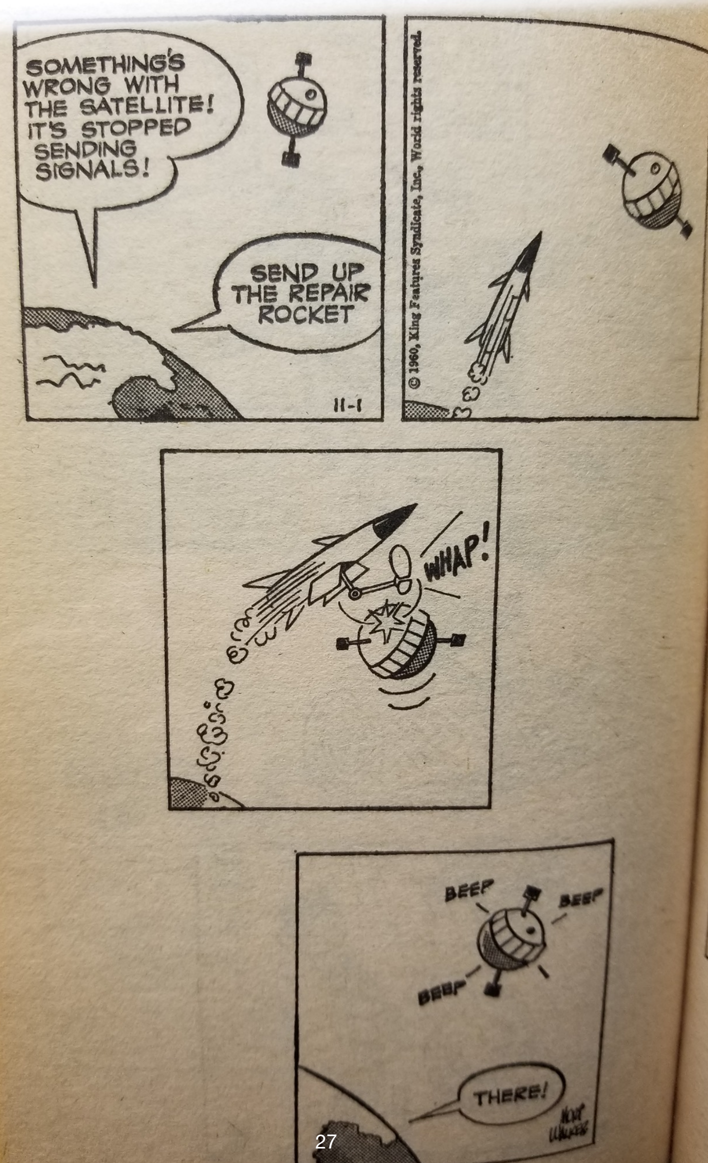
Two copies: Arizona and South Africa.

- Most optical telescopes are useful into the near ultraviolet and near infrared.
- The sky itself is bright in infrared, so things like chopping secondary mirrors (two fields of view, one on-target, one off- and then subtract the sky) are useful. Also the telescope itself glows in the infrared, so cryogenics are useful (also for reducing read noise in detectors.
- Spectrographs precisely measure wavelengths, which can tell us about composition of the source, its velocity, etc.
- Telescopes on high mountains are good because they're above most of the water vapor in the air. Mauna Kea, HI, and the mountains in Chile are both good choices.
- You can go higher in an airplane… enter SOFIA, the Stratospheric Observatory for Infrared Astronomy (a 747 with a 2.4m telescope aboard and a big hole in the side).


SOFIA
STRATOSPHERIC OBSERVATORY
FOR INFRARED ASTRONOMY
DLR
NASA
N747NA

- SOFIA is a modified 747SP aircraft (bought used from United)
- f/1.3 (very short focal length to fit in the airplane)
- Covers 1-655 micrometers wavelength
- Cruising altitude 41,000 ft / 12 km: above most of the atmosphere.
- Mobile (duh)… used for observing Pluto occulting background stars, which like a total eclipse of the sun has a narrow path on the earth.
- This is the observatory that made the “water on the moon” observation that I mentioned in the first lecture. The spectral line of H_2O is in the far infrared.

- Space, the final frontier…
- NASA funded a series of four “Great Observatories” in the 1970s
    - Compton Gamma Ray Observatory (CGRO, 1991-2000)
    - Hubble Space Telescope (HST, launched Apr 24, 1990)
    - Chandra X-ray Observatory (CXO, launched Jul 23, 1999)
    - Spitzer Space Telescope (SST, infrared telescope, 2003-2020)
- The Fermi Gamma Ray Observatory is a follow-on to CGRO
- Other smaller astronomical telescopes are also functioning, often special-purpose. Japan and the European Space Agency have vigorous programs.


SOMETHING'S WRONG WITH THE SATELLITE! IT'S STOPPED SENDING SIGNALS!
SEND UP THE REPAIR ROCKET
11-1
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WHAP!
BEEP
BEEP
BEEP
THERE!

ASTRONOMERS AT WORK
Let's dispel some common beliefs.
I NEVER USE A TELESCOPE
I NEVER GO NEAR A TELESCOPE
I NEVER EVEN LOOK UP.
S. Harris

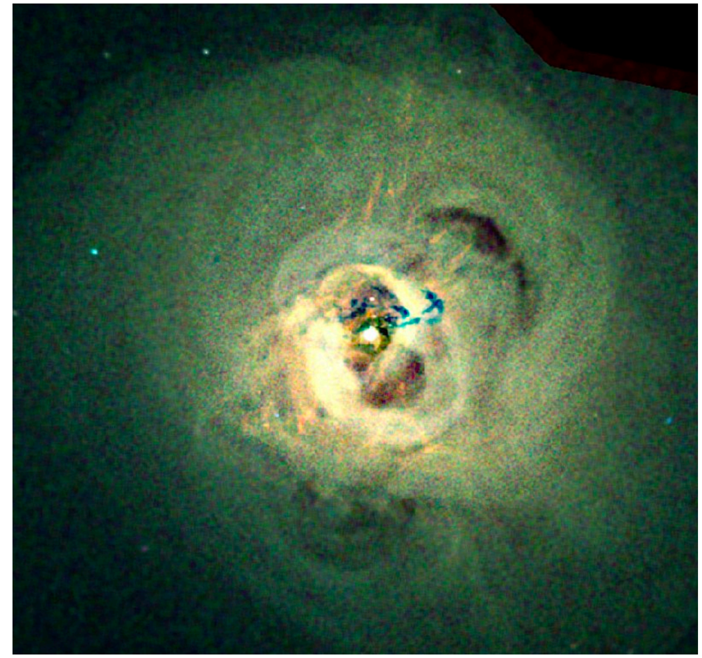
- Why space?

- No atmosphere in the way to blur images or make bright backgrounds (optical, infrared) or just absorb all the light in the last 30 microseconds (as in ultraviolet, x-rays, slices of the infrared)

- It's not just an adventure, it's a JOB! (misquoting a Navy recruiting poster from the 1970s).

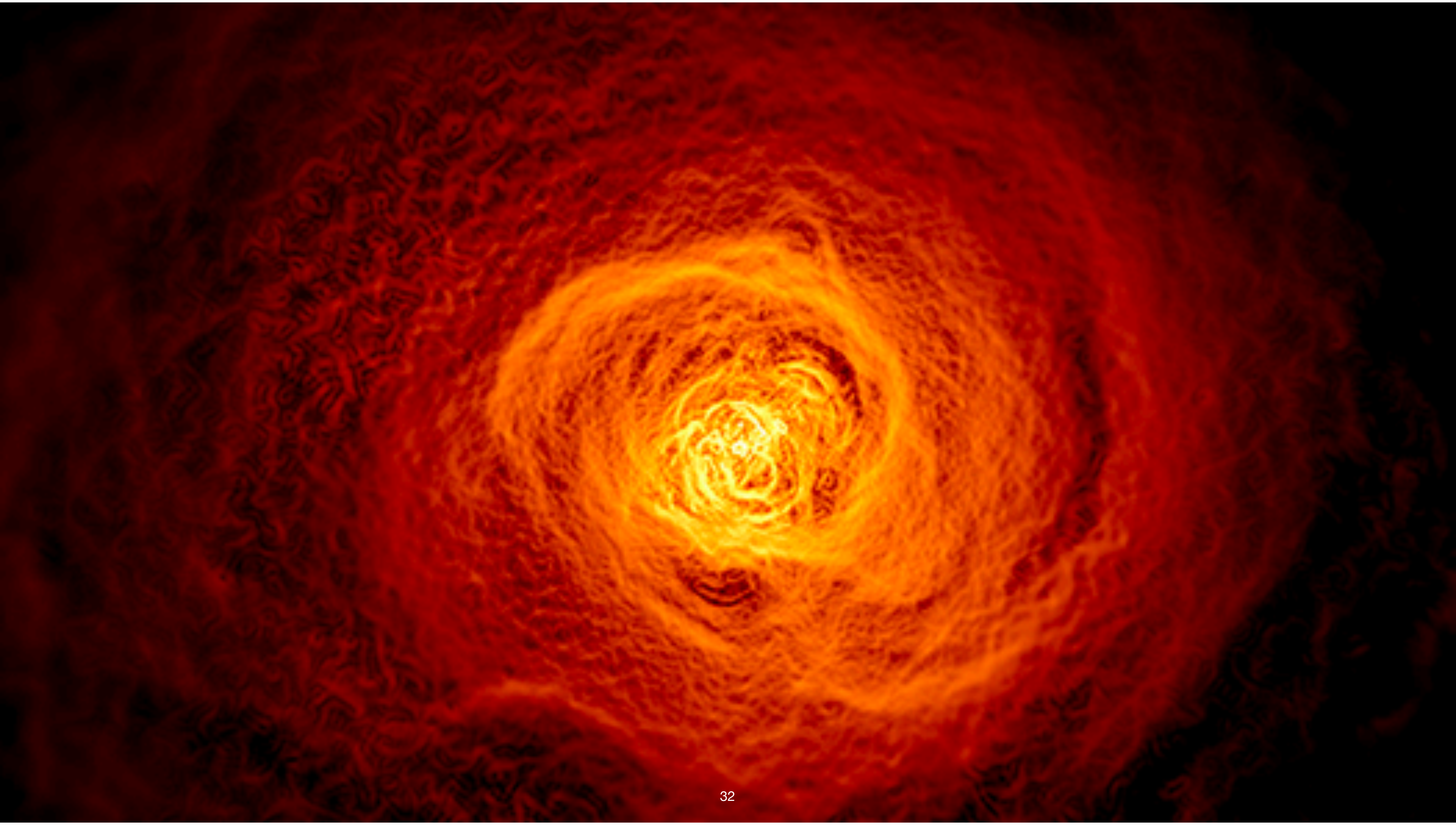
- I spent 25 years working on the Chandra X-ray Observatory, doing calibration and then operations for the prime camera, the Advanced CCD Imaging Spectrograph, ACIS.

- Operated from Cambridge, Mass. by the Smithsonian Astrophysical Observatory (with help from Northrup Grumman) under contract with NASA. Pretty pictures at chandra.si.edu.



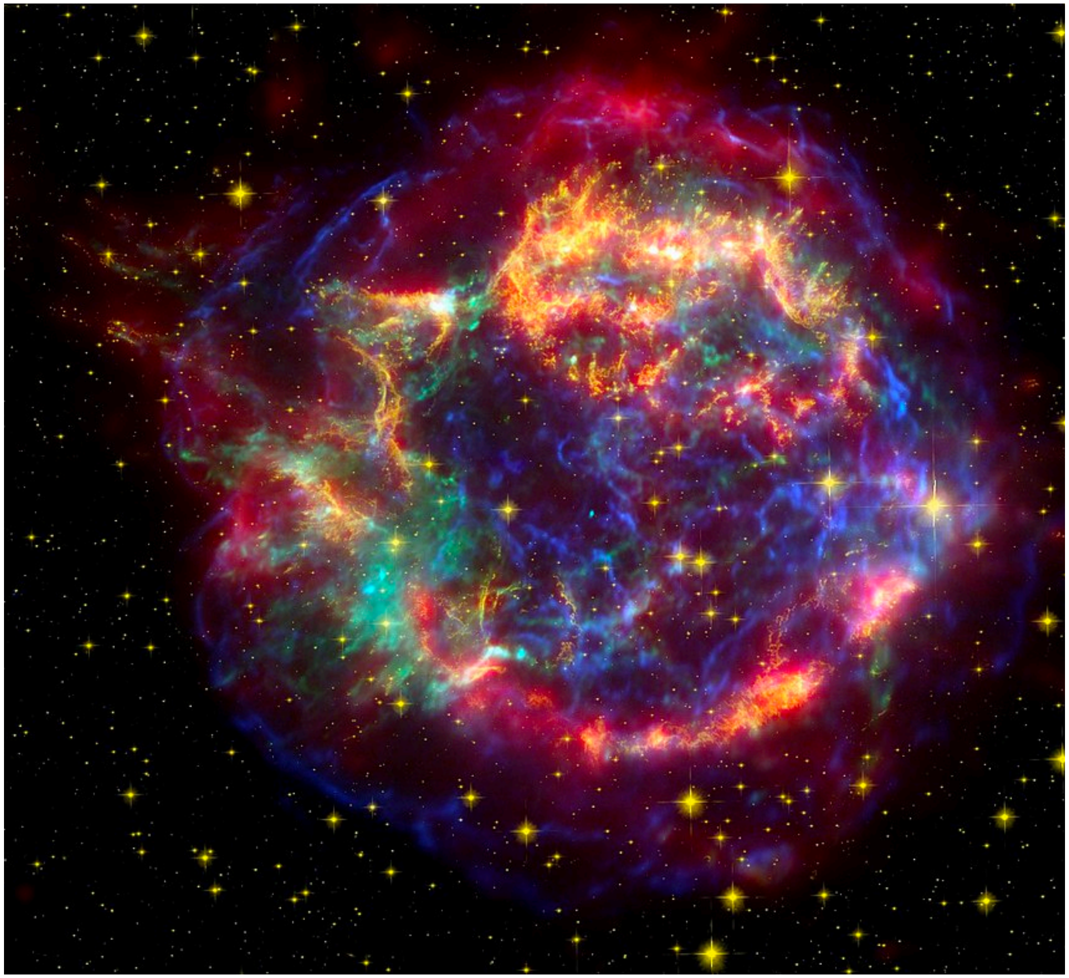
Perseus Cluster of Galaxies

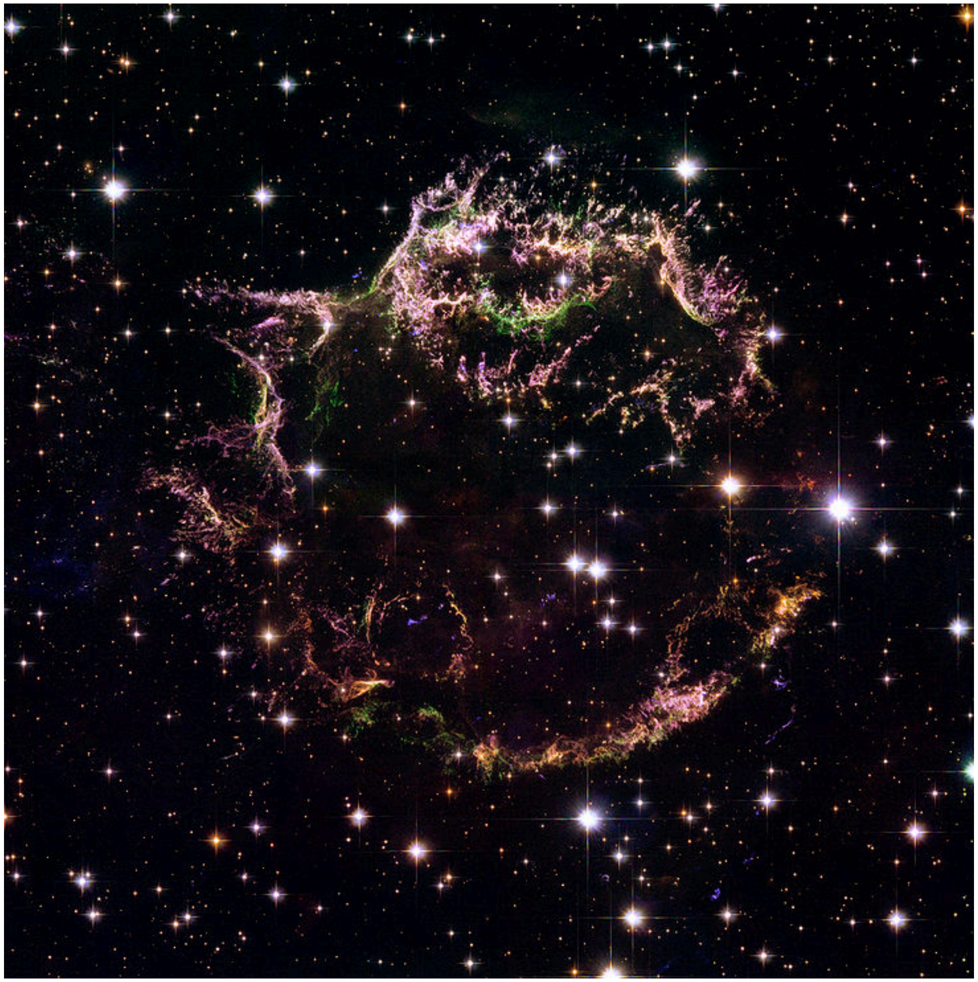
- Composite view, optical, x-ray, radio.
- Previous page: optical (L) and x-ray (R).
- Next page, x-ray with unsharp mask filter showing sound waves.
- Over 1000 galaxies
- Gas stripped from the galaxies has similar velocities to the galaxies themselves, so $T \sim 10^{7\text{-}8}$ K.
- Jets from central black hole carve cavities in the hot gas.

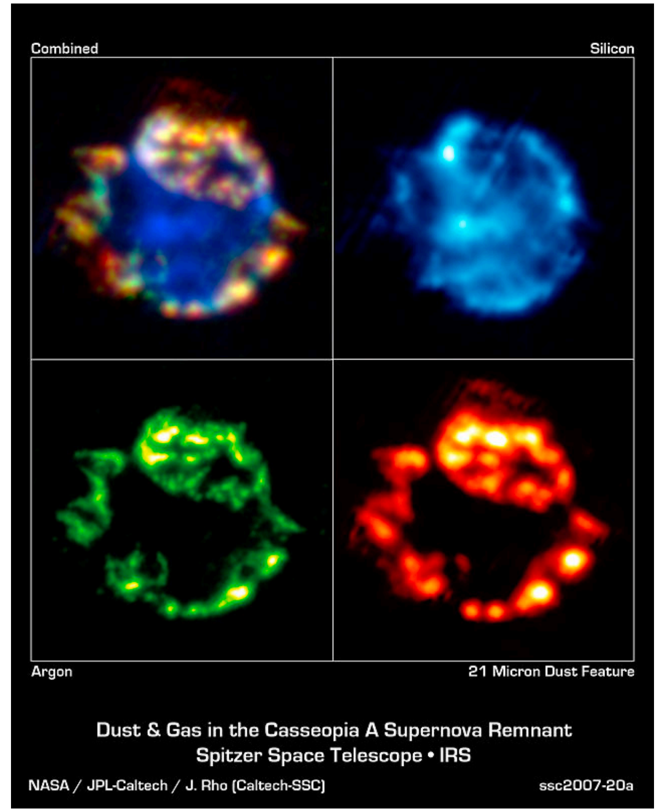


Cassiopea A supernova remnant

- This is x-rays from Chandra, with stars from Hubble optical image.
- Colors depict various elements.
- Next page: Hubble, Spitzer Space Telescope infrared images
- Following: light echoes from the supernova explosion itself.

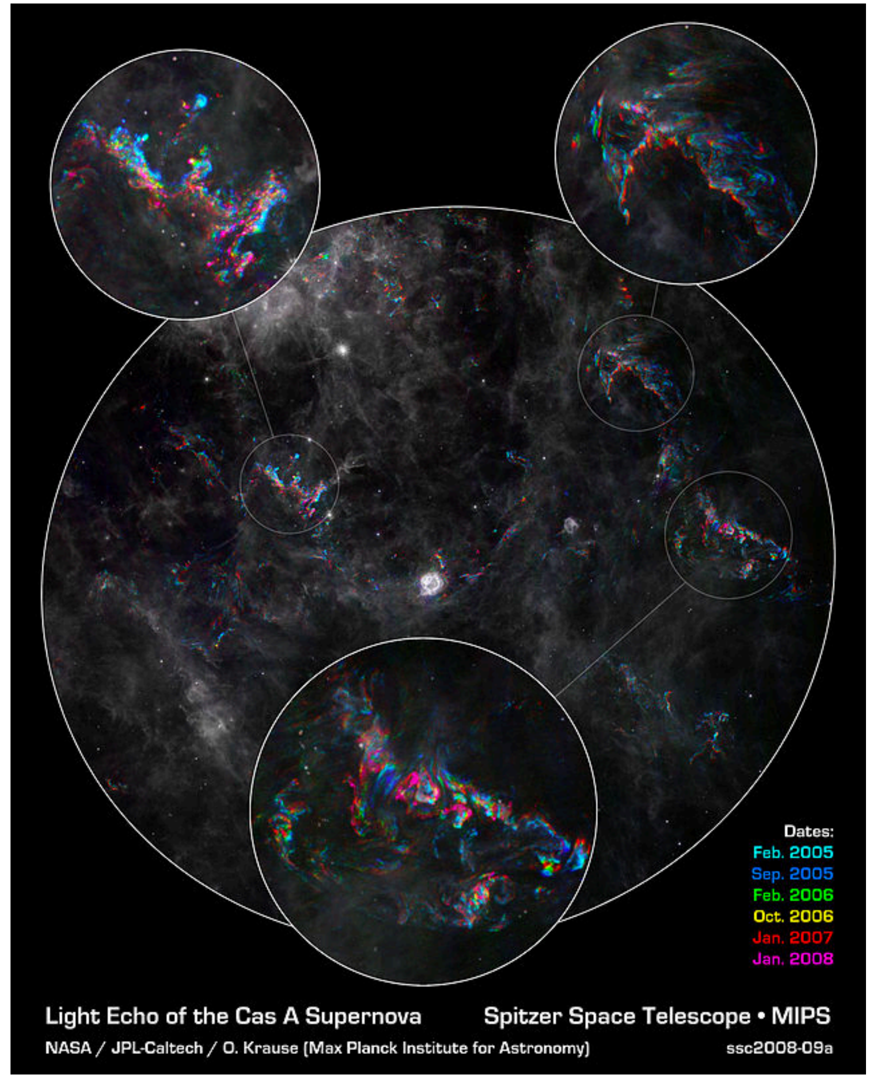


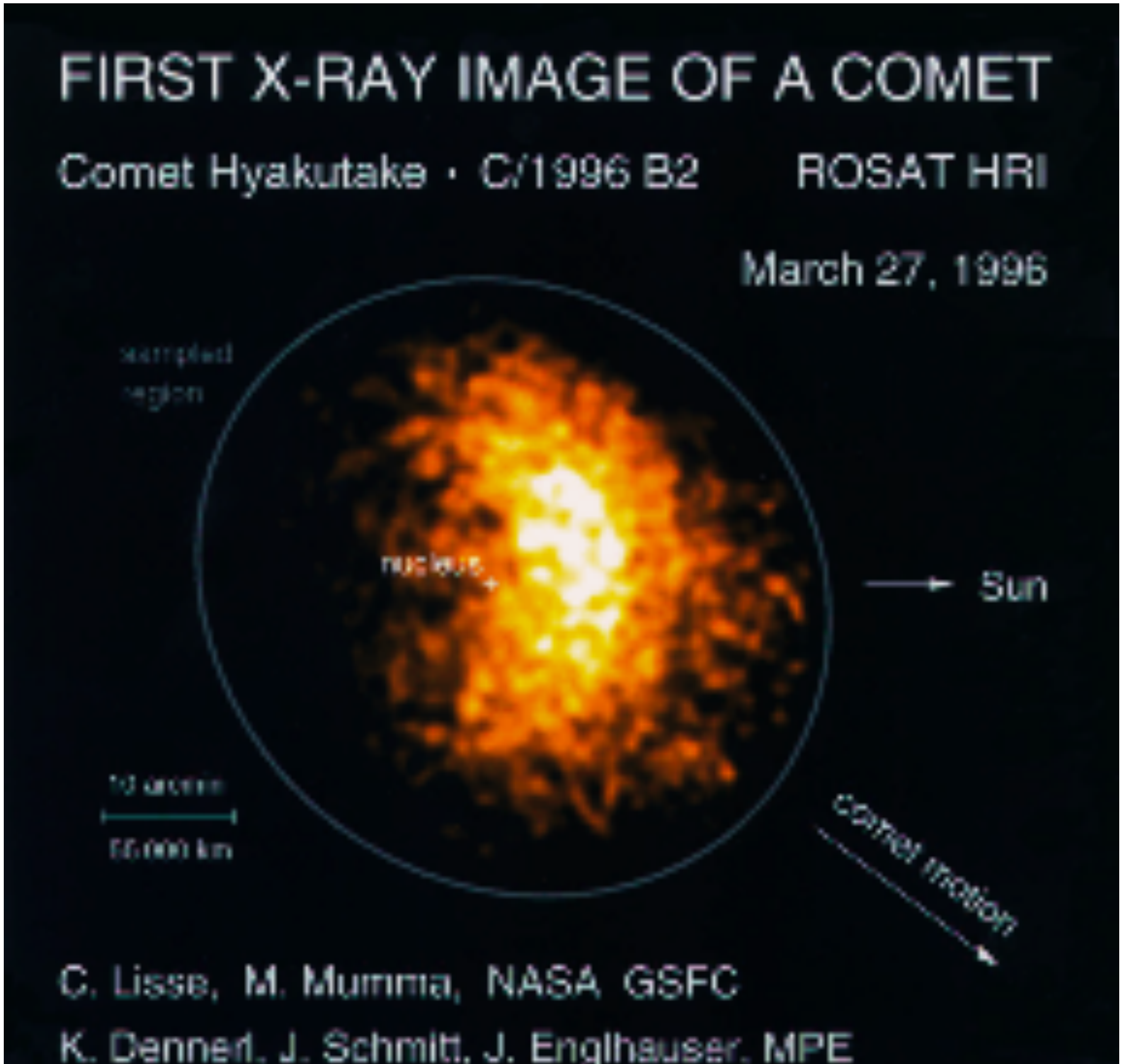


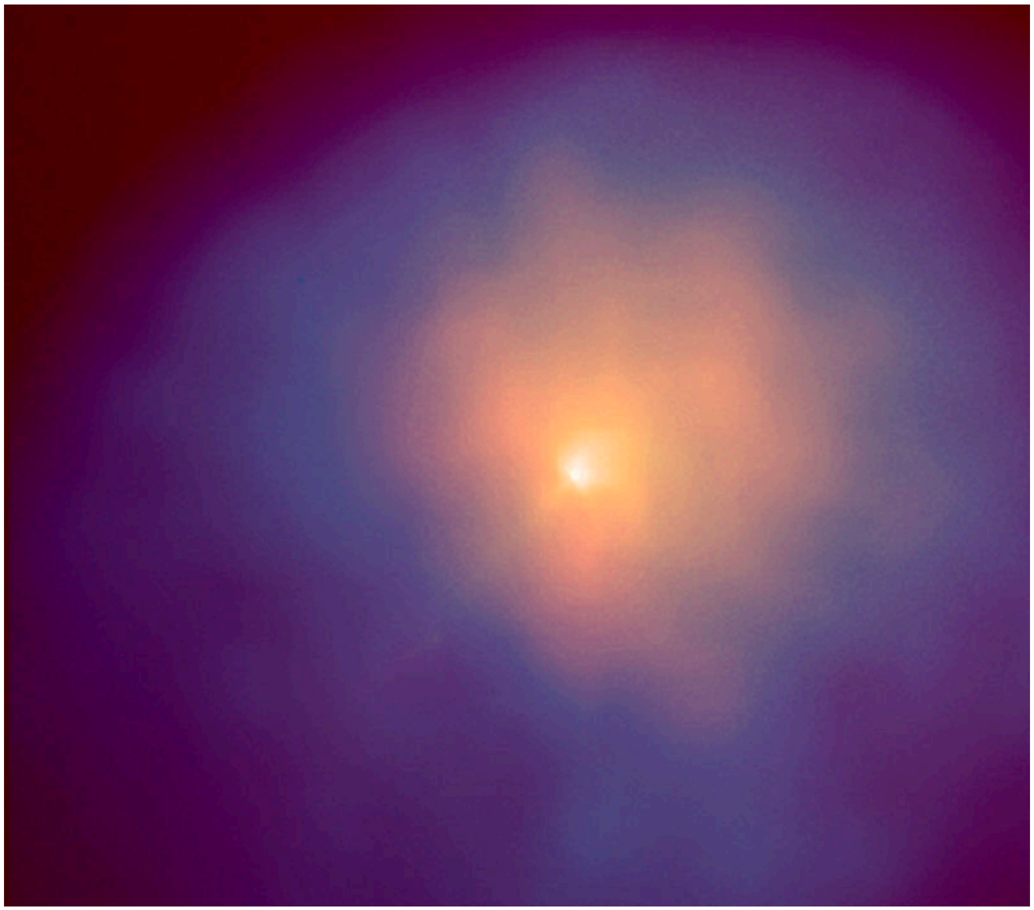

Combined
Silicon
Argon
21 Micron Dust Feature
Dust & Gas in the Casseopia A Supernova Remnant
Spitzer Space Telescope • IRS
NASA / JPL-Caltech / J. Rho (Caltech-SSC)
ssc2007-20a

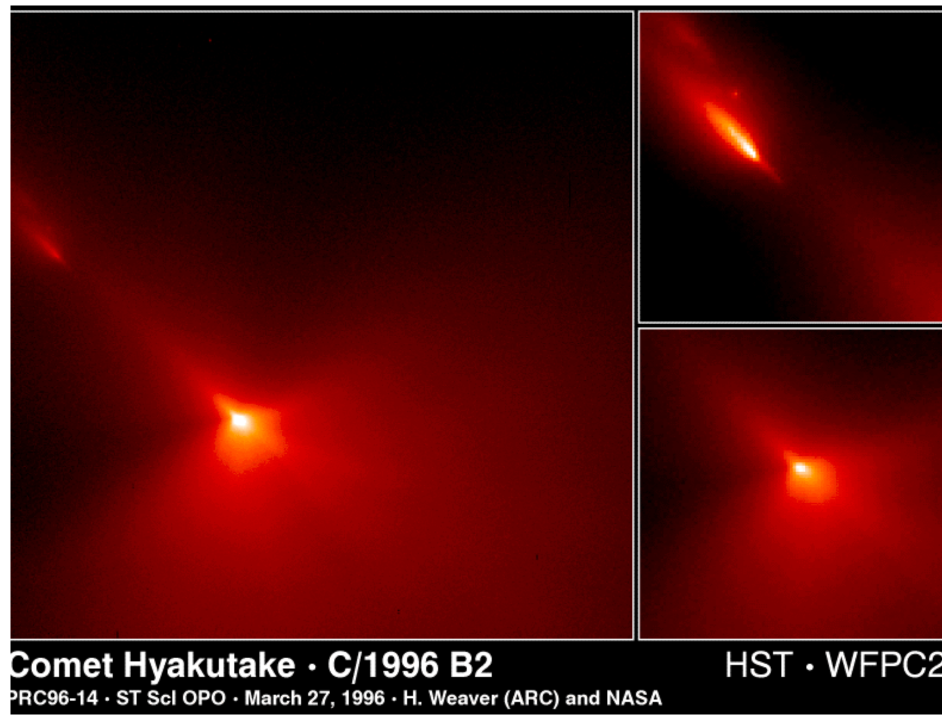
Light Echoes from Cas A

- Light from the supernova explosion c. 1685 reflects off of dust clouds with a better view of the site than ours on earth.
- Path length is hundreds of light years longer, so the light from the supernova (in reflection) is only now arriving.
- The echoes move across the sky as the years go by.
- Data from Spitzer




FIRST X-RAY IMAGE OF A COMET
Comet Hyakutake · C/1996 B2
ROSAT HRI
March 27, 1996
sampled region
nucleus
Sun
comet motion
C. Lisse, M. Mumma, NASA GSFC
K. Dennerl, J. Schmitt, J. Englhauser, MPE




Comet Hyakutake · C/1996 B2
HST · WFPC2
PRC96-14 · ST ScI OPO · March 27, 1996 · H. Weaver (ARC) and NASA

Reading Science Journalism

- What did the scientists actually do?
- Can the basic idea be explained in simple terms?
- “Extraordinary claims require extraordinary proof” —Carl Sagan
- What’s wrong with this picture? Often scientific articles acknowledge problems with the general idea they’re pushing.
- Is the headline over-hyped?
- What news outlet are you reading?
- E.g. NYTimes Science Tuesday, Scientific American, Sky & Telescope, blogs by specialists in the field.