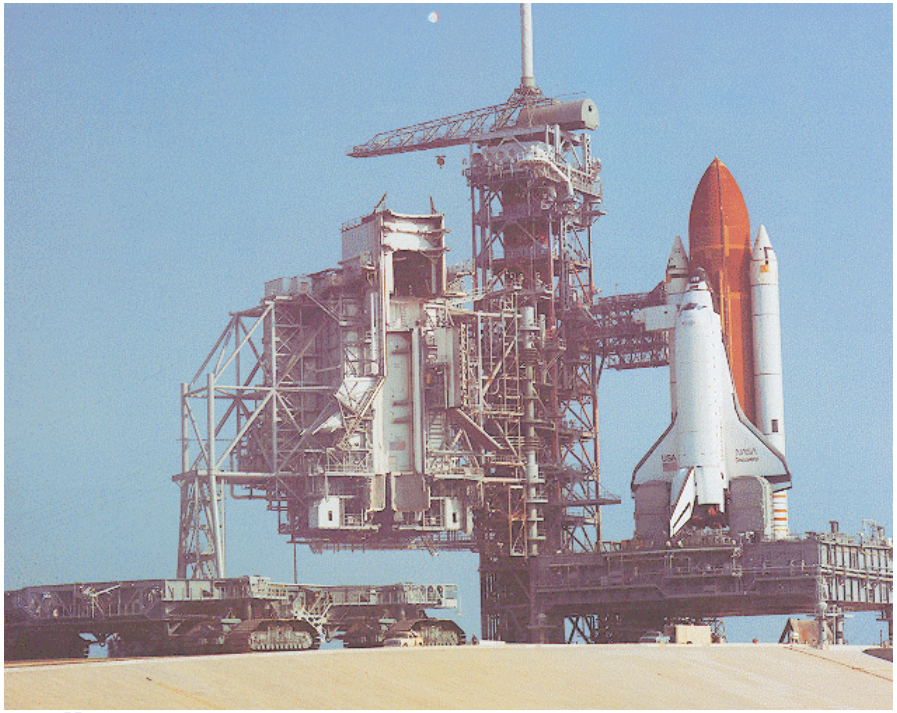
- Homework #5 was due today.
- Next homework is #6– due next Friday at 11:50 am.
- There will be another make-up nighttime observing session in November. Stay tuned.
- I will be teaching Paul's class on Monday, so my office hours will be cancelled.

Outline

- HST & JWST
- CARMA and ALMA
- SOFIA
- Chandra
- Blackbodies
  - Wavelength of light corresponds to temperature
  - Brightness of light corresponds to temperature
- Doppler Effect

HST

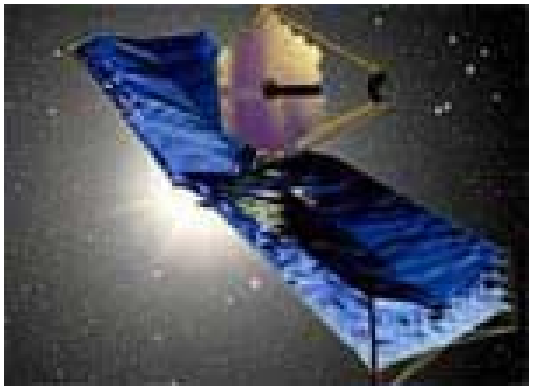
- Hubble Space Telescope was launched April 24, 1990, 8:33:51 a.m– pad B.
- Is a 2.5 m reflecting telescope.
- Initially had a mirror error, but it was fixed by serving mission.



HST

Without the atmosphere, can take much better images of astronomical sources– even with smaller mirror.

JWST



- The next space telescope– 2011
- The James Webb Space Telescope
- Observe in the near and mid-infrared
- Will be the biggest telescope in space– 6 meters! (Must fold up for launch)
- Mirror is expected to weigh 1/3rd as much as HST
- Will take 3 months to reach position– no service missions
- http://www.gsfc.nasa.gov/gsfc/spacesci/pictures/20020806ngst/AL-TRW-%20Close%20up%20of%20telesco.mpg

Very Large Array

- Radio observatory of 27 antennas each 25 meters (82 ft) weighing 230 tons in Socorro, NM

- Longest separation is 36 km (22 miles)

BIMA

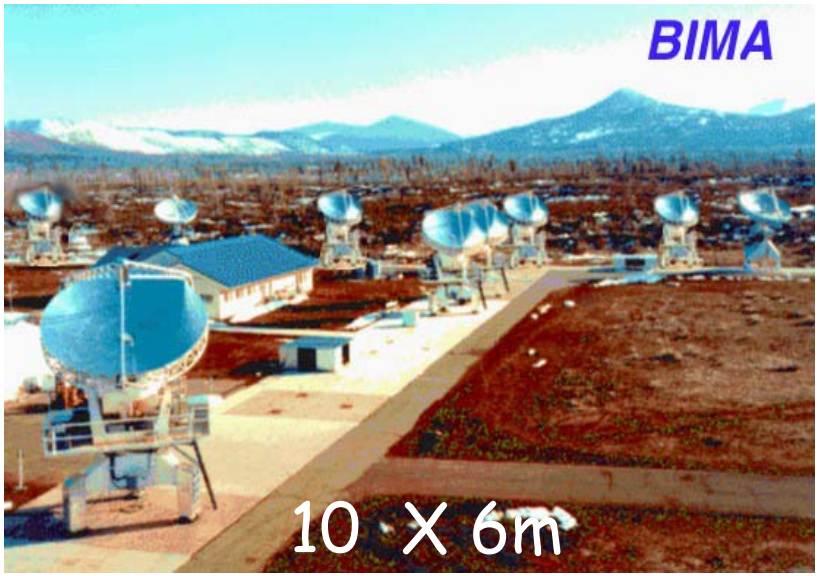
A millimeter array of telescopes owned and operated by UC Berkeley, UIUC, and UMd in Hat Creek, California. Wavelength of 3 millimeters – frequency of 115 GHz. Works night and day. Why?

BIMA

BIMA

BIMA

The Future -- 2005



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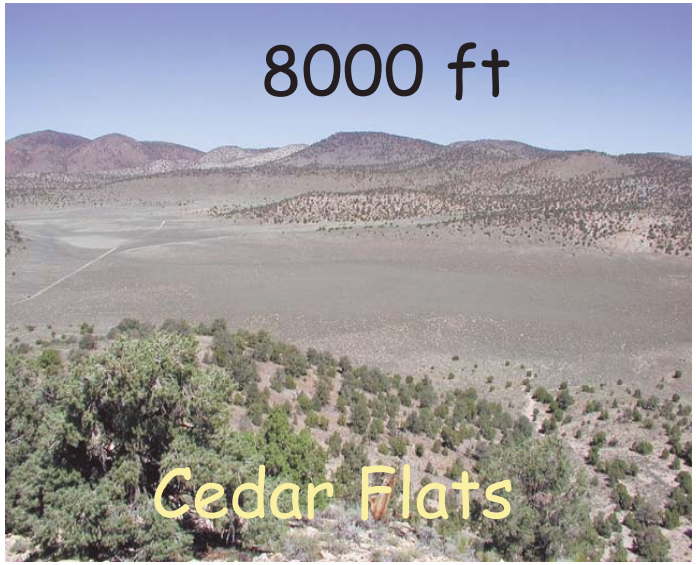

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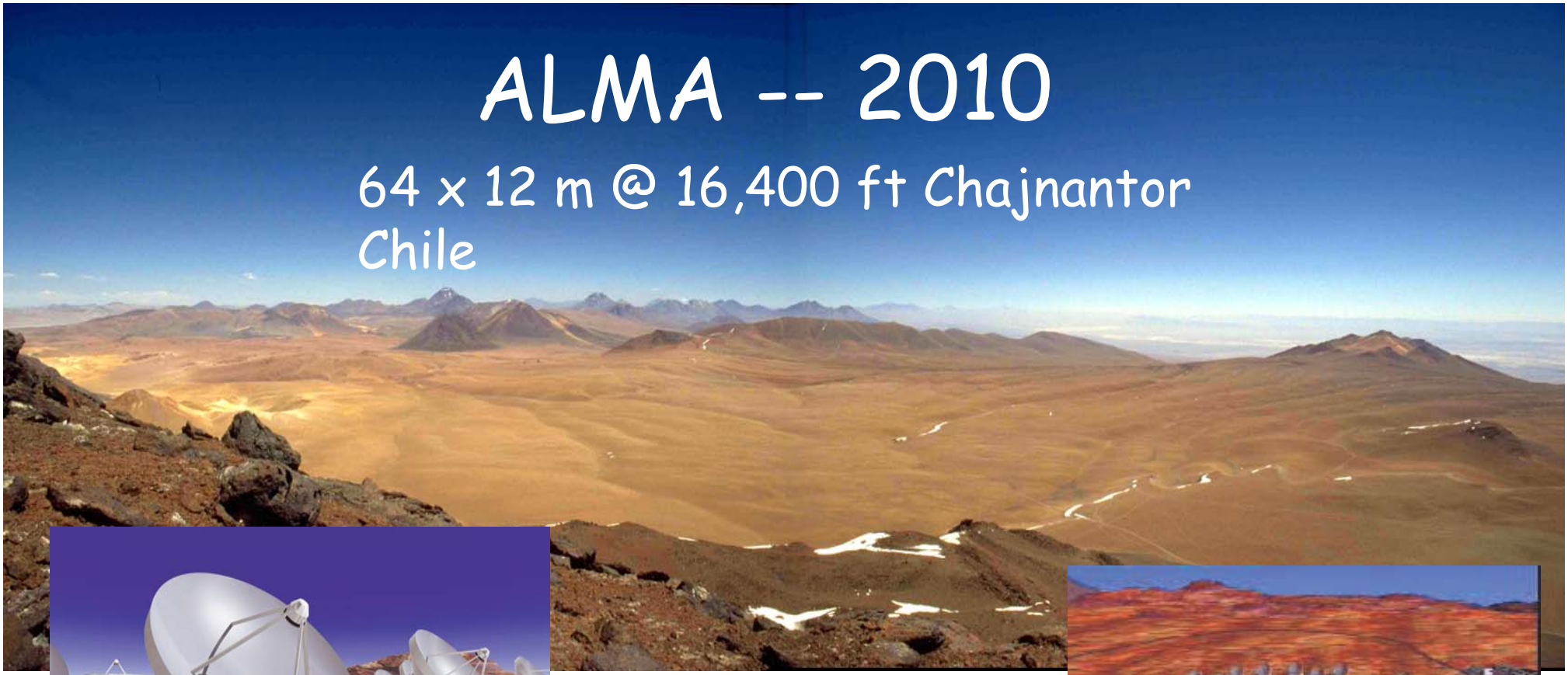
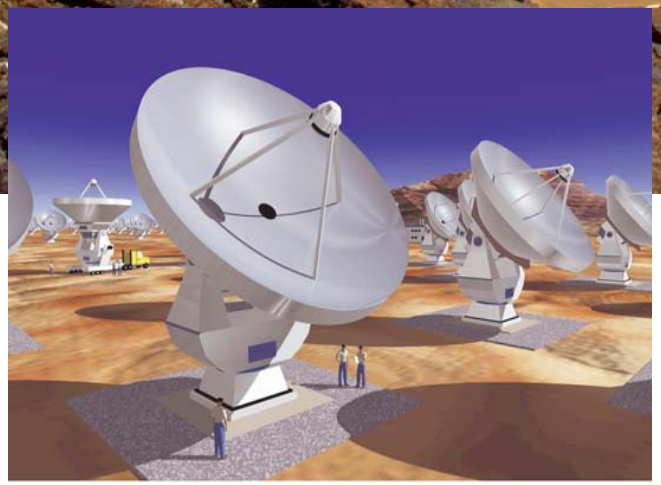
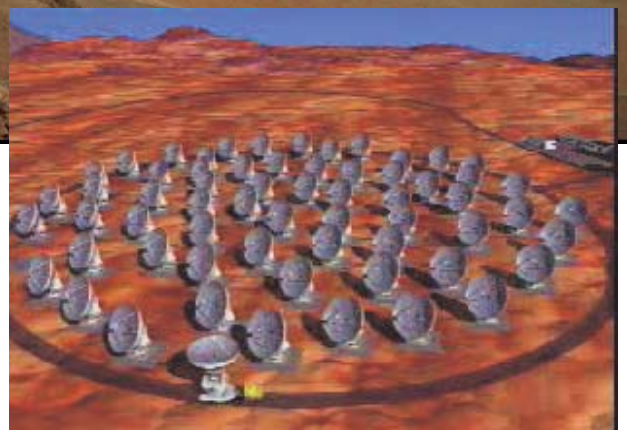
CARMA

Combined Array for Research in Millimeter-Wave Astronomy

Future of High Res mm/Sub-mm



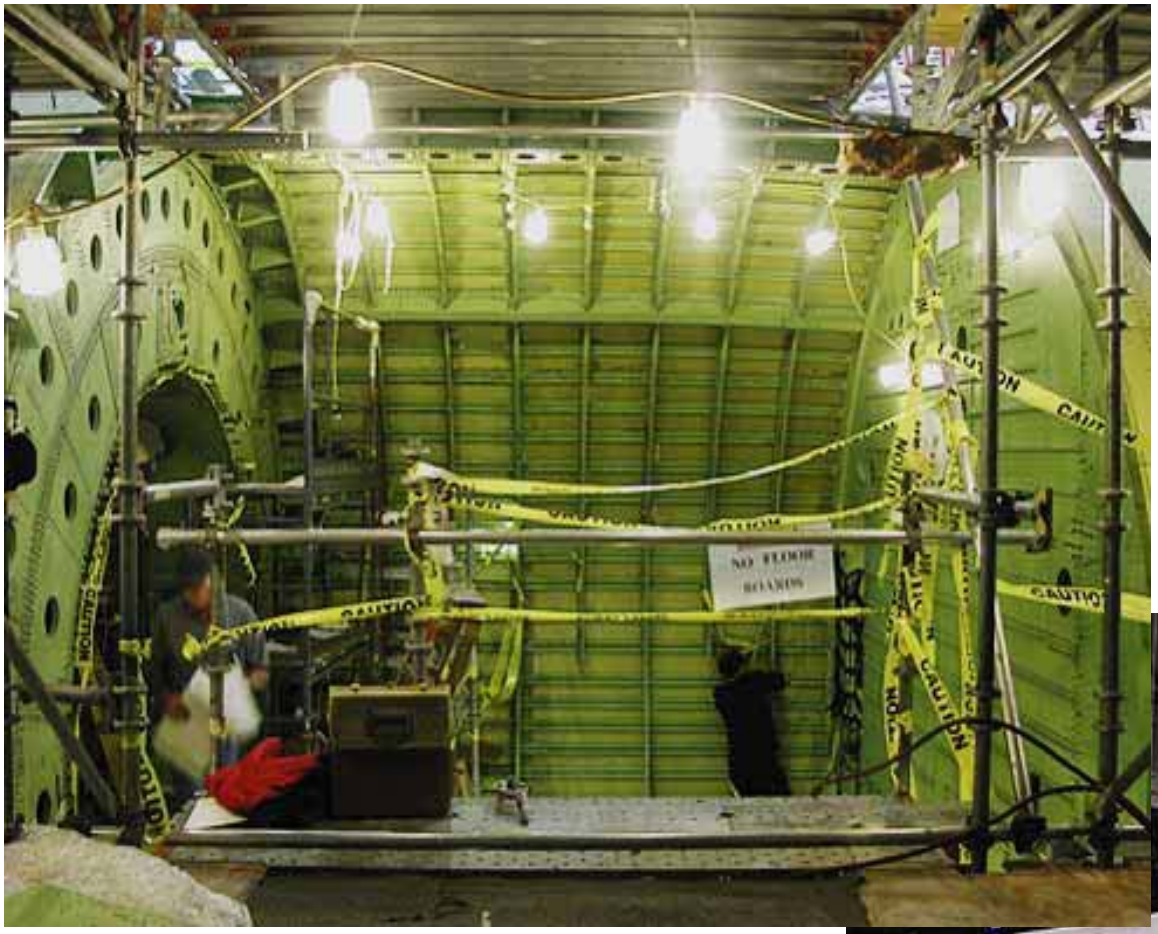




Stratospheric Observatory For Infrared Astronomy
SOFIA

- Modified Boeing 747 SP
- Operation height: 39000 to 45000 ft (11.8 to 13.7 km)
- 2.7m telescope Cassegrain with Nasmyth focus
  - 20000 kg TA (f/19.6 from 0.3 to 1600 μm)
- Image stability goal 0.2" RMS
- Image quality 80% enclosed at 1.5" circle
- First Light – Oct 2004
- 20 year operations (3 to 4 flights per week)

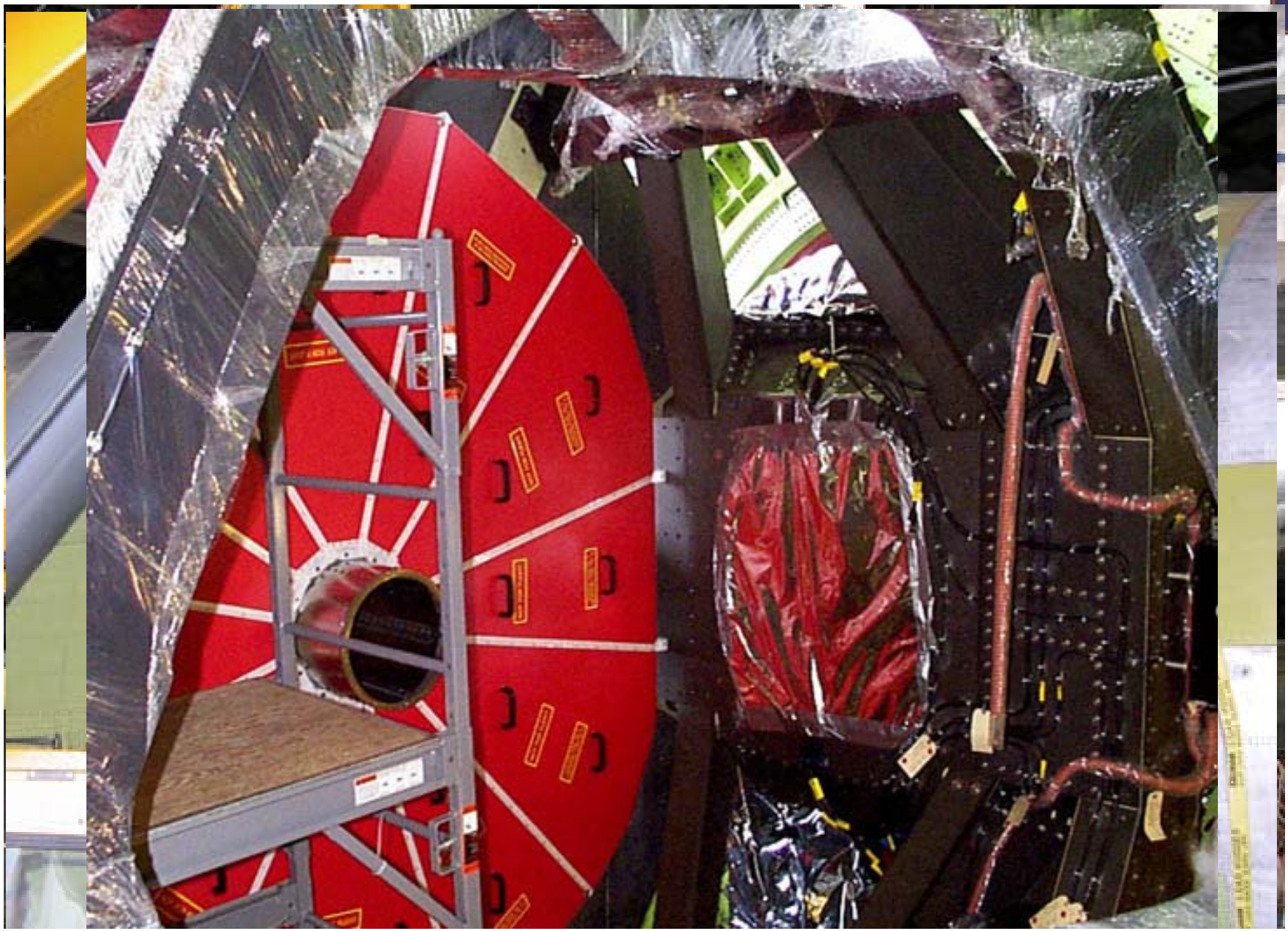
http://www.united-sofia.com/Farout_2_frm.htm


CAUTION
NO FLOOR
BEYOND

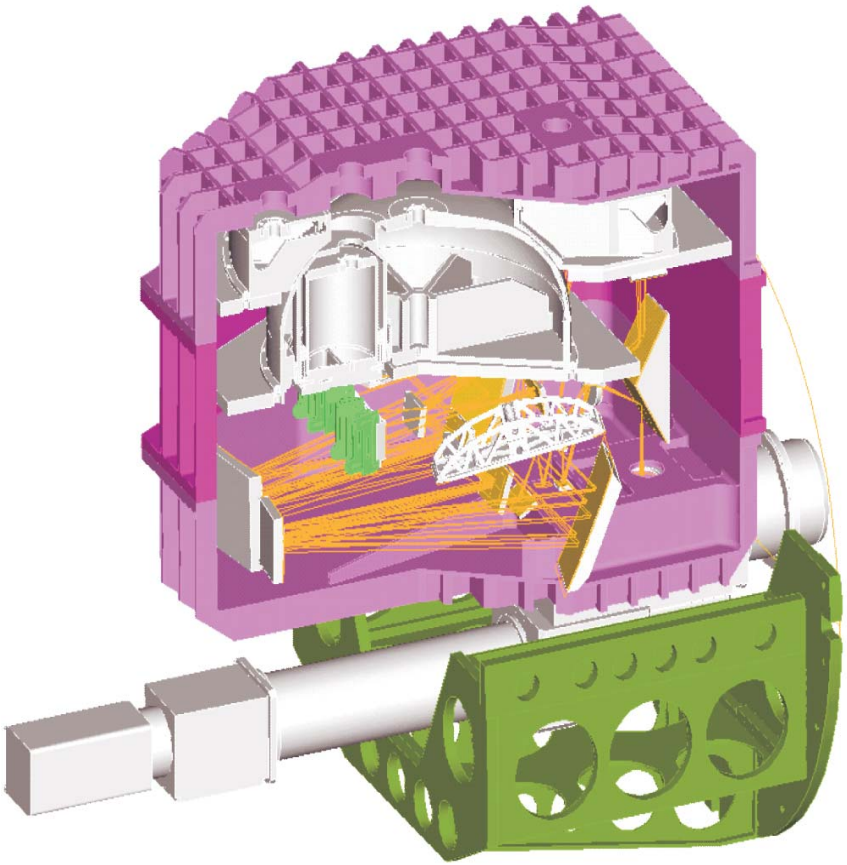

GROVE

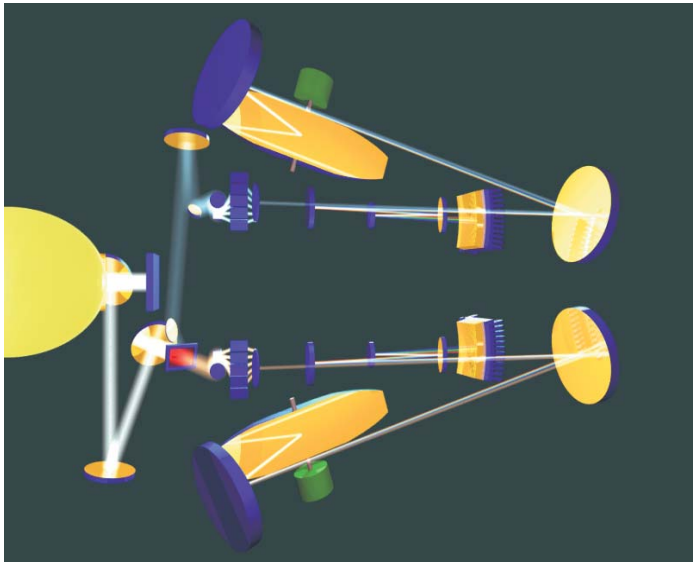

GROVE

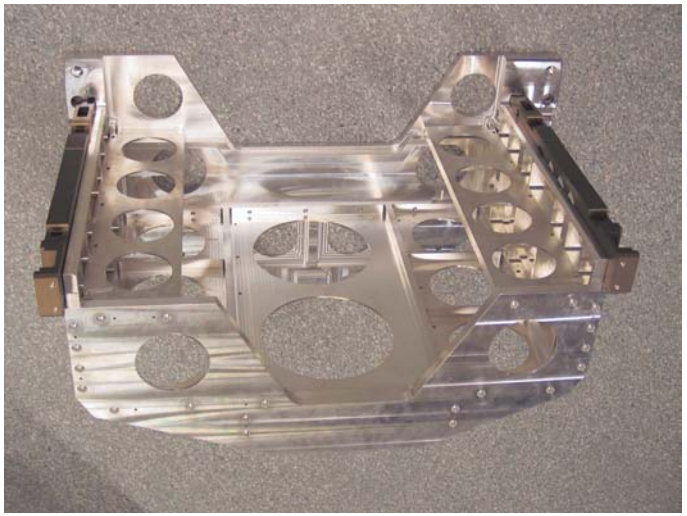
The Mirror



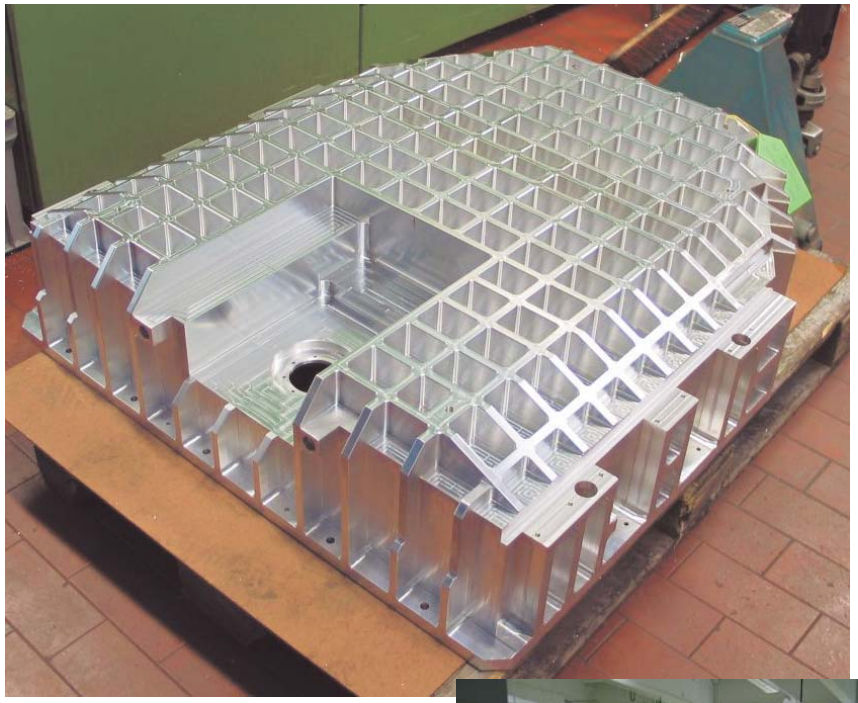
FIFI LS: Far-Infrared Field-Imaging Line Spectrometer



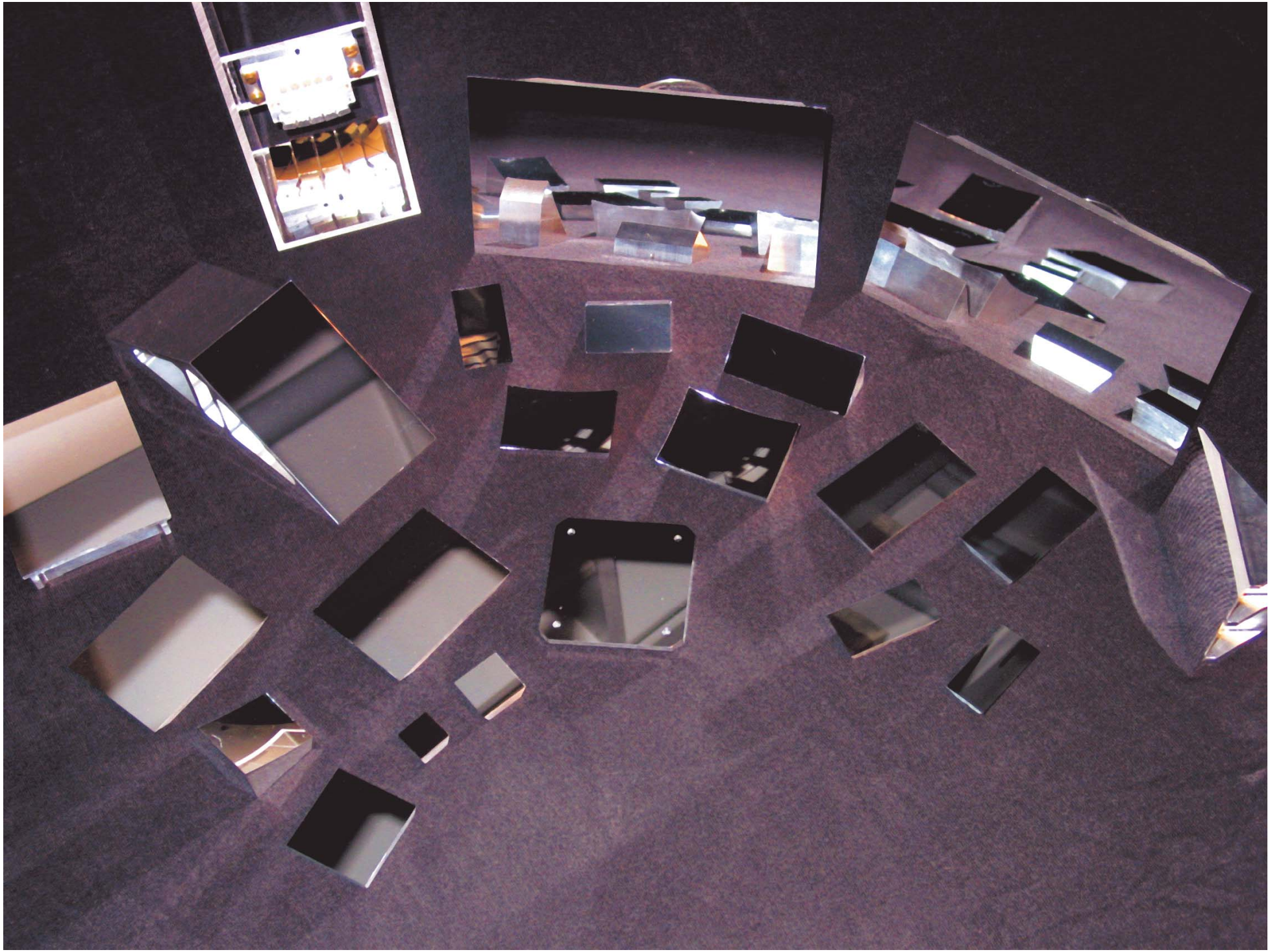




FIFI LS Vacuum Vessel Status



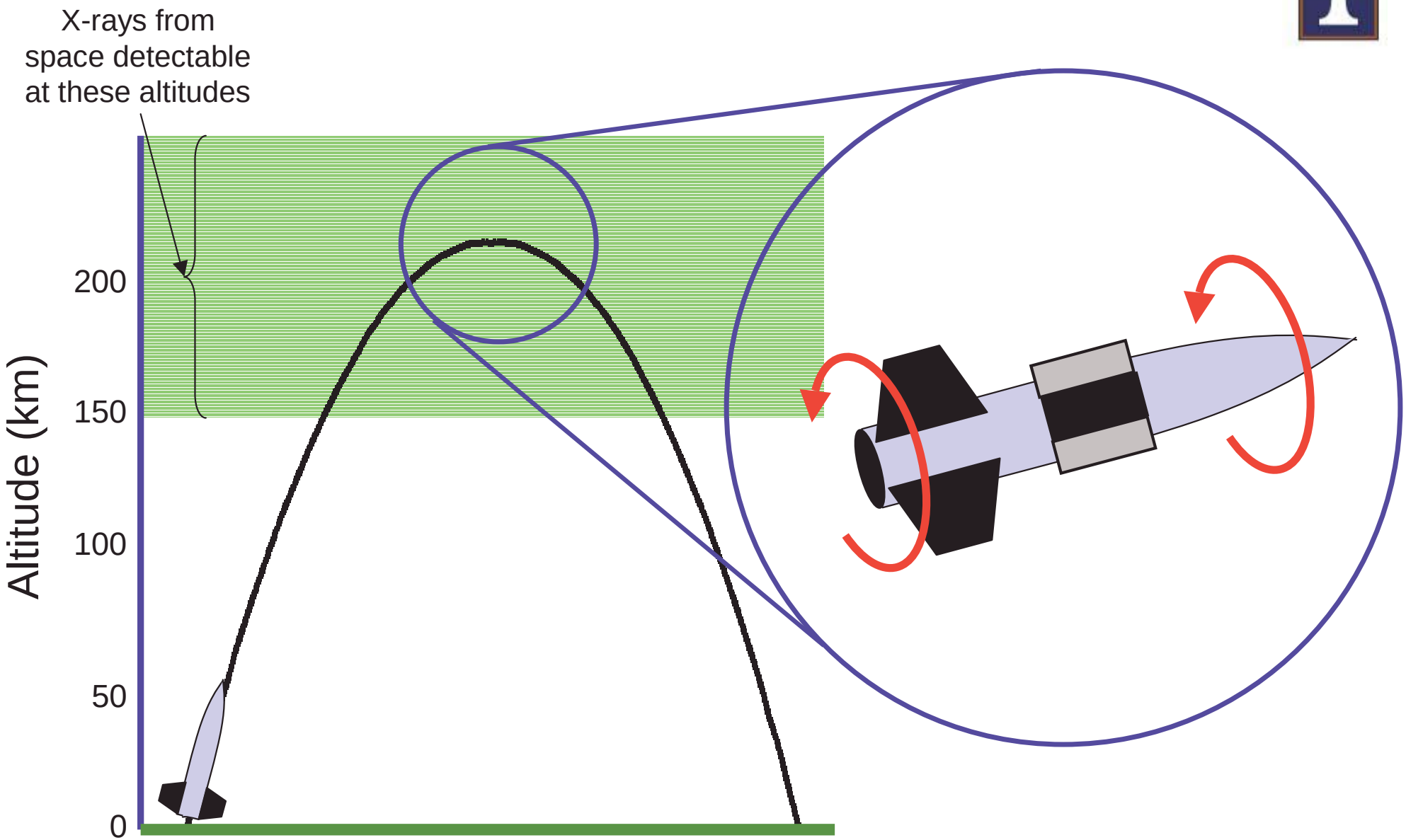
All 3 vessel shells manufactured



X-ray Telescopes

Riccardo Giacconi – discovery of extrasolar X-ray sources (1962) and construction of the first imaging X-ray telescope (1963)

Sounding rocket observations (1960s)

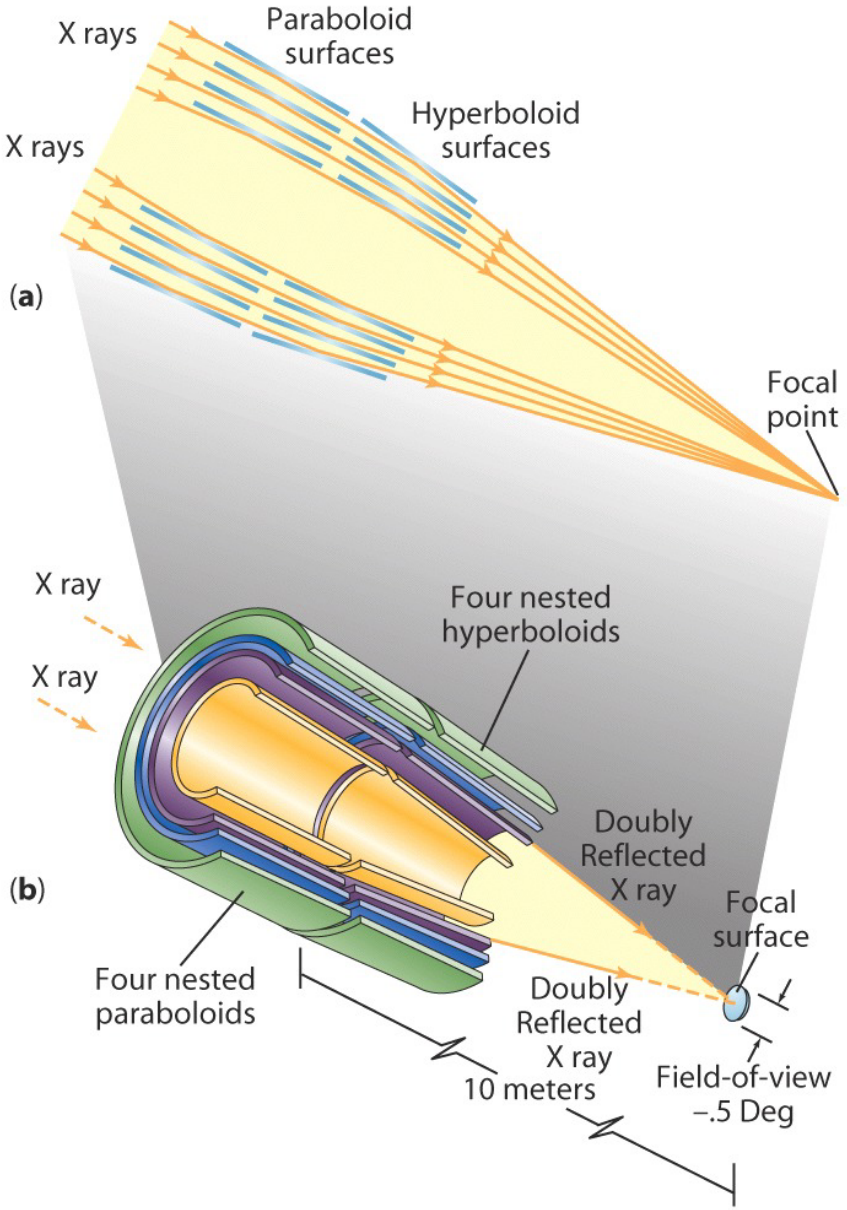


http://www.boulder.swri.edu/~hassler/rocket/movie_gallery/36_171_onboard.mov

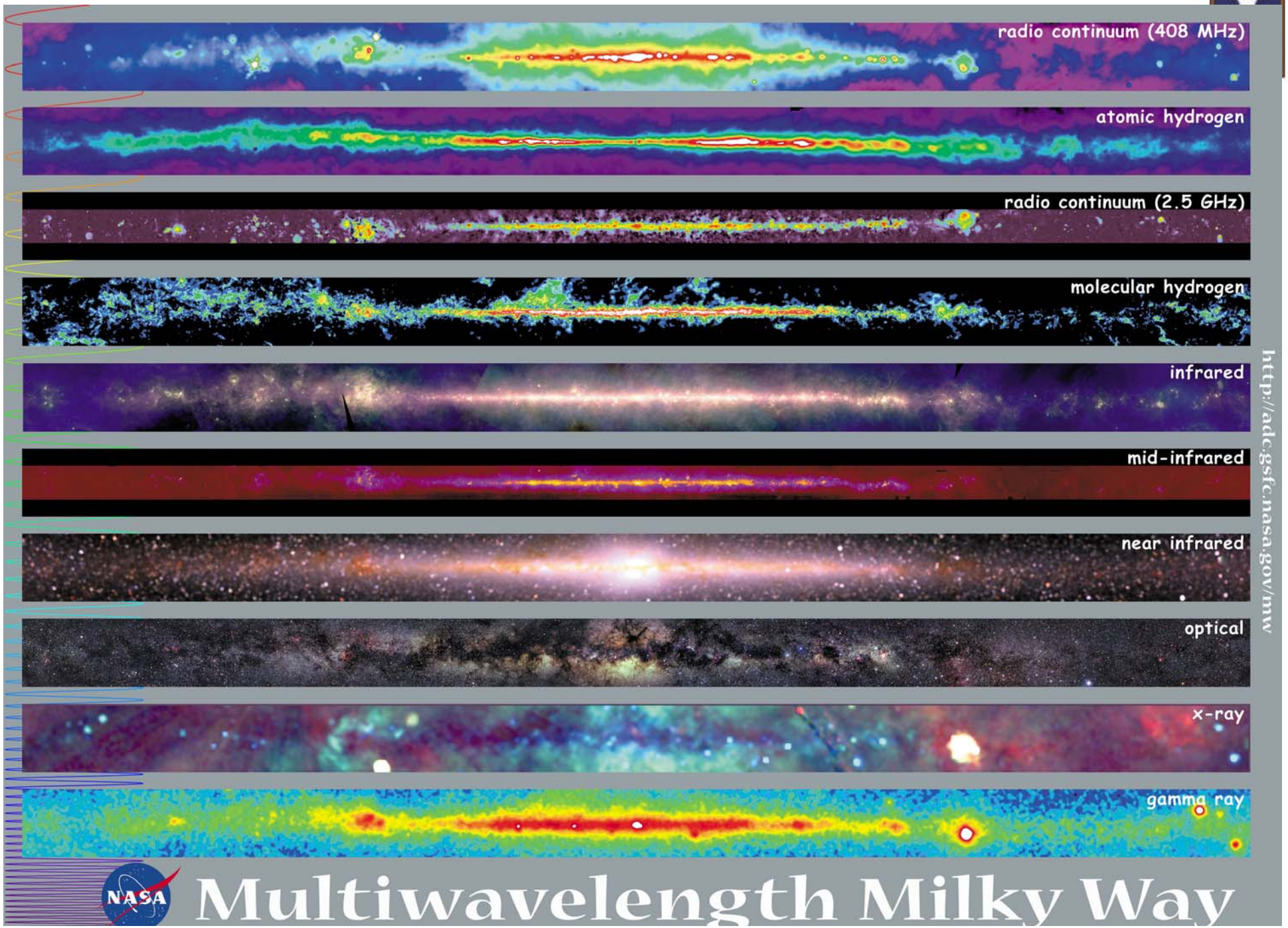
Chandra X-ray Observatory

Launched 1999

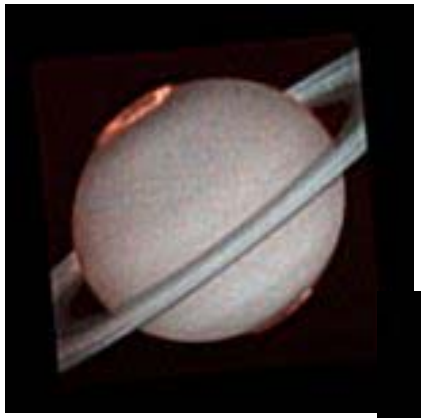
Crab Nebula in X-rays



Multi-Wavelength Observations

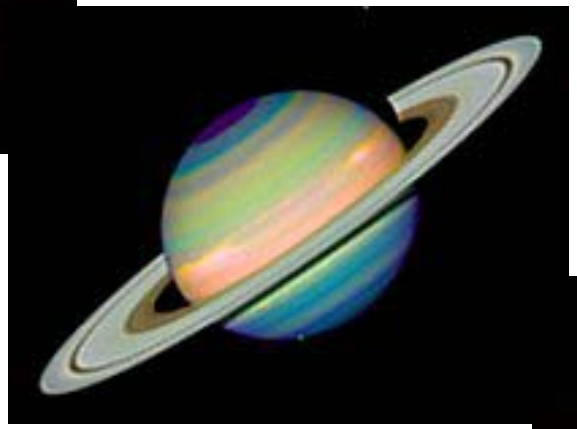


The Multi-Wavelength Solar System

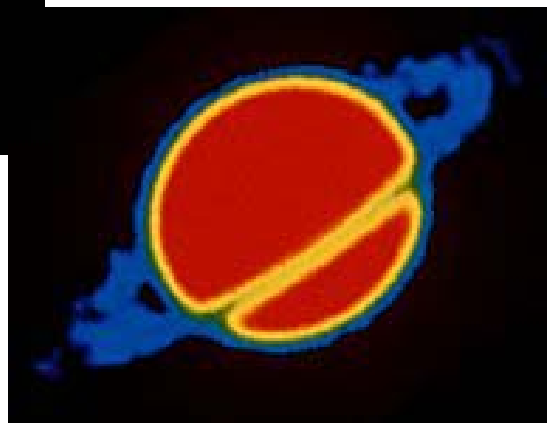


Ultraviolet

Visible



Infrared

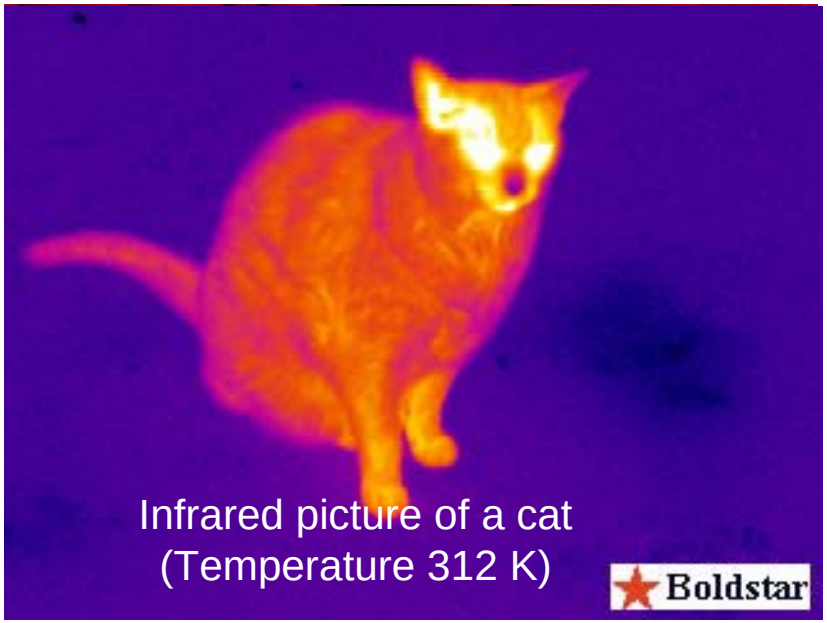


Radio

http://www.ipac.caltech.edu/Outreach/Multiwave/gallery.html

Blackbody Radiation

- Light that objects emit because of their temperature is called **blackbody radiation**
- Blackbody radiation is composed of a continuous spectrum of wavelengths
- The **hotter** an object gets, the **more intense** and **shorter wavelength** (bluer) its blackbody radiation becomes

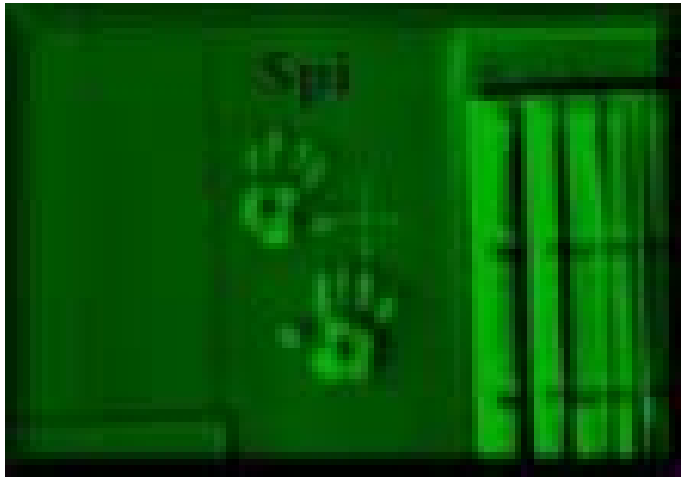


Infrared picture of a cat
(Temperature 312 K)

Visible-light picture of a stove element
(Temperature ~ 400 K)

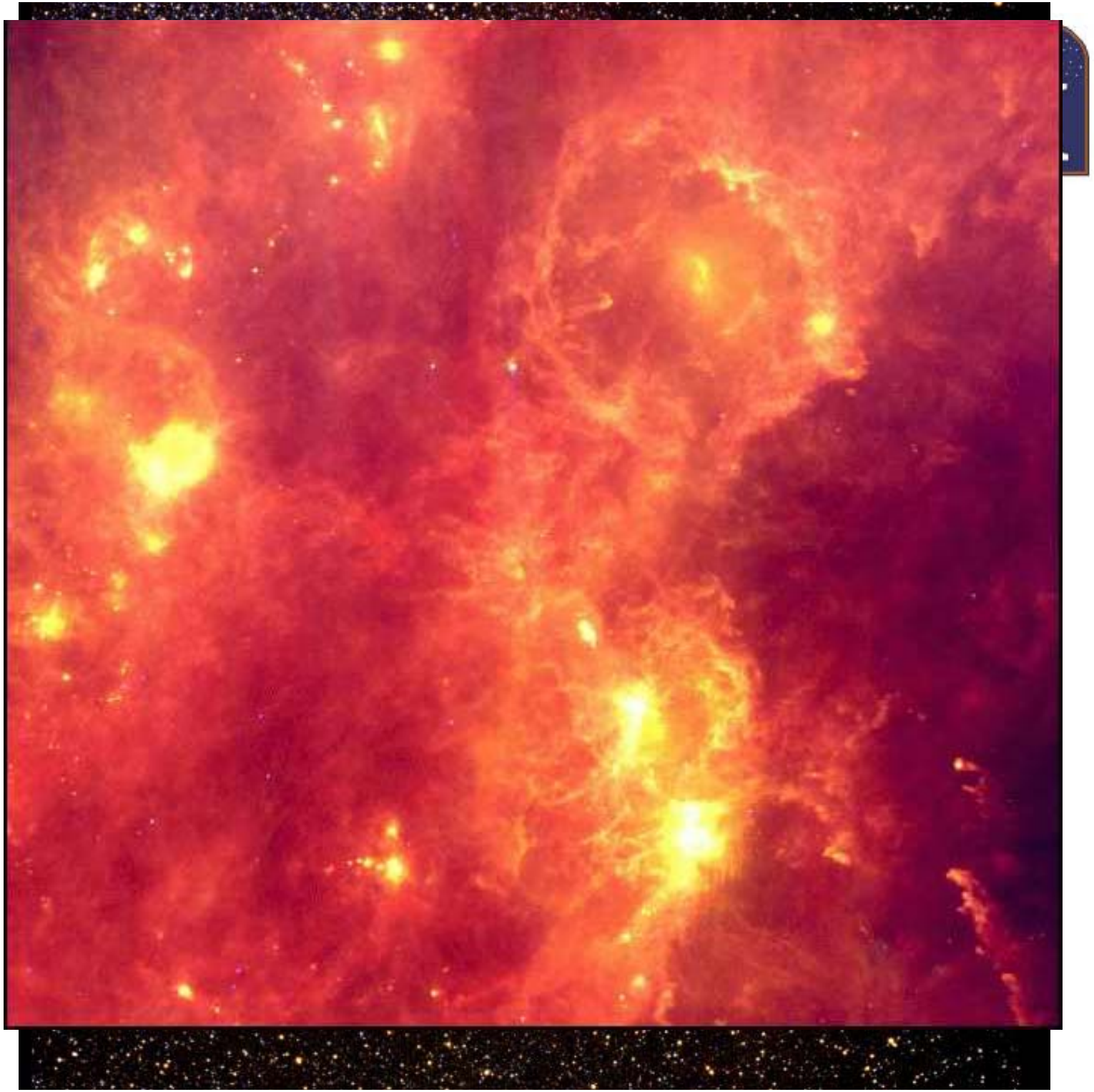
Glowing Bodies

- So, everything we know is in fact giving off light– as long as it has a temperature, it is glowing.
- The higher the temperature the shorter the wavelength it glows in– compare the person in the bottom left (near infrared) and a light bulb (in the visible).



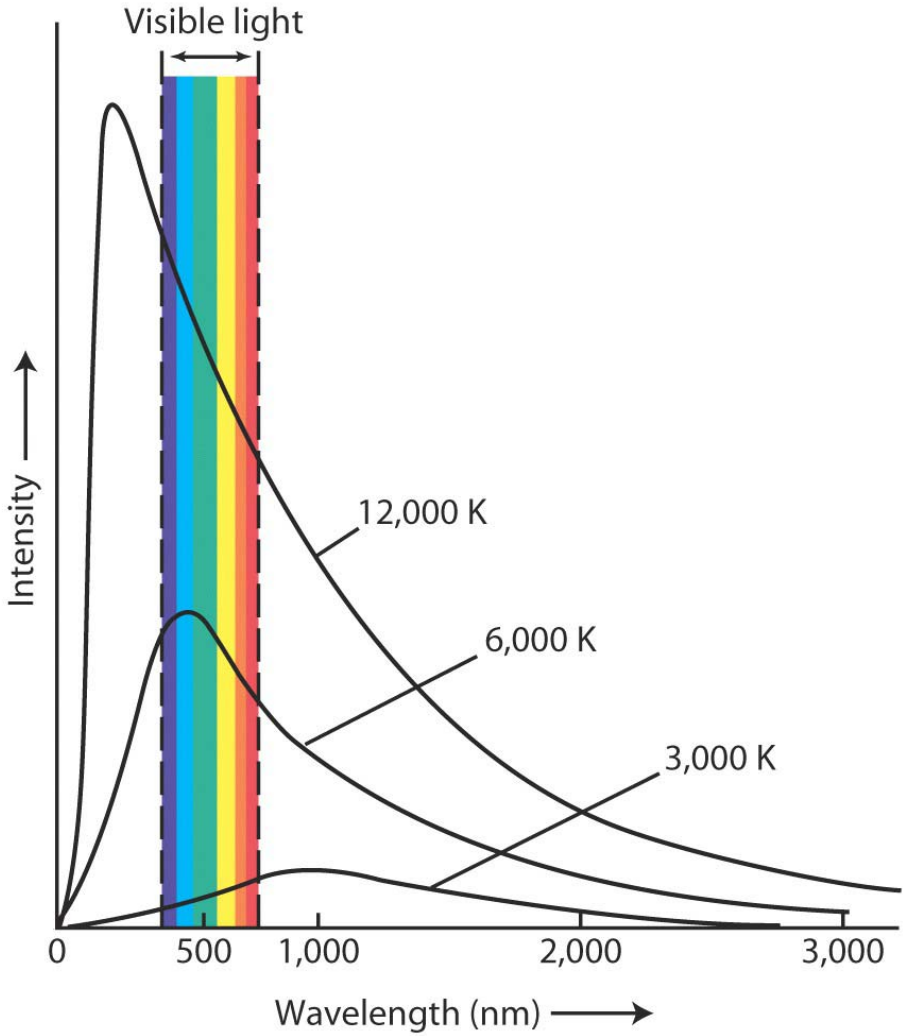
http://www.x20.org/thermal/thermal_weapon_sight_TIWS320.htm

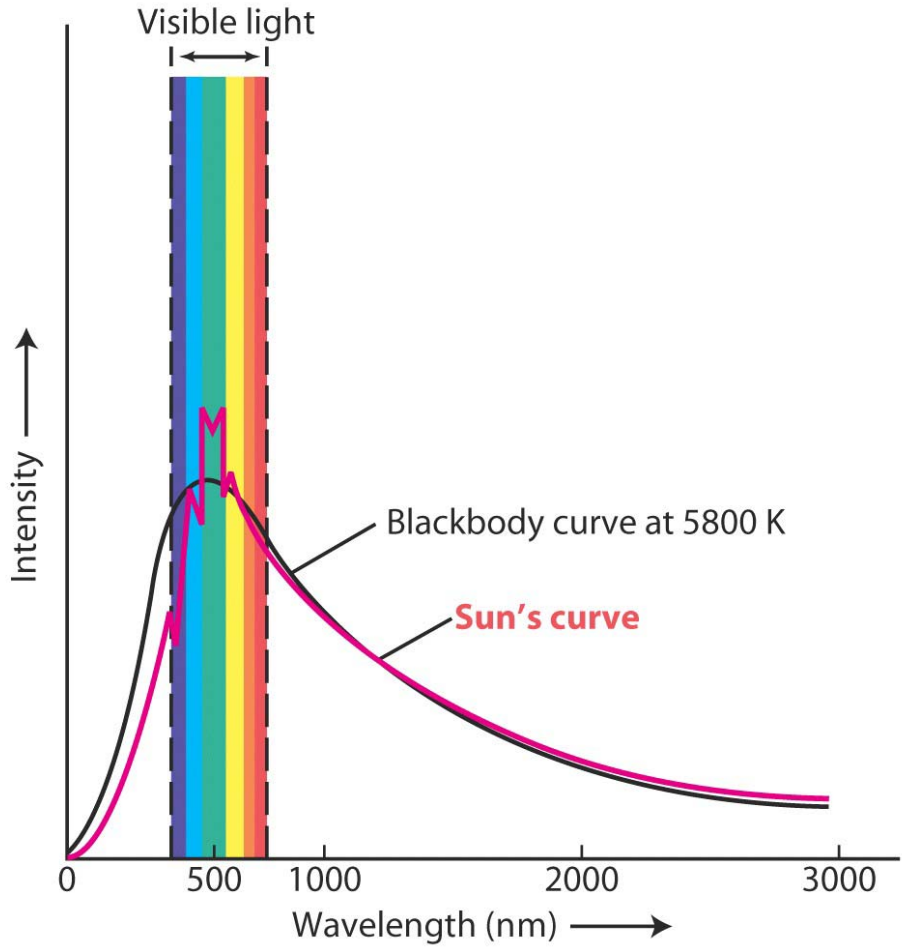
Orion in Visible and IR



The Spectrum of Blackbody Radiation

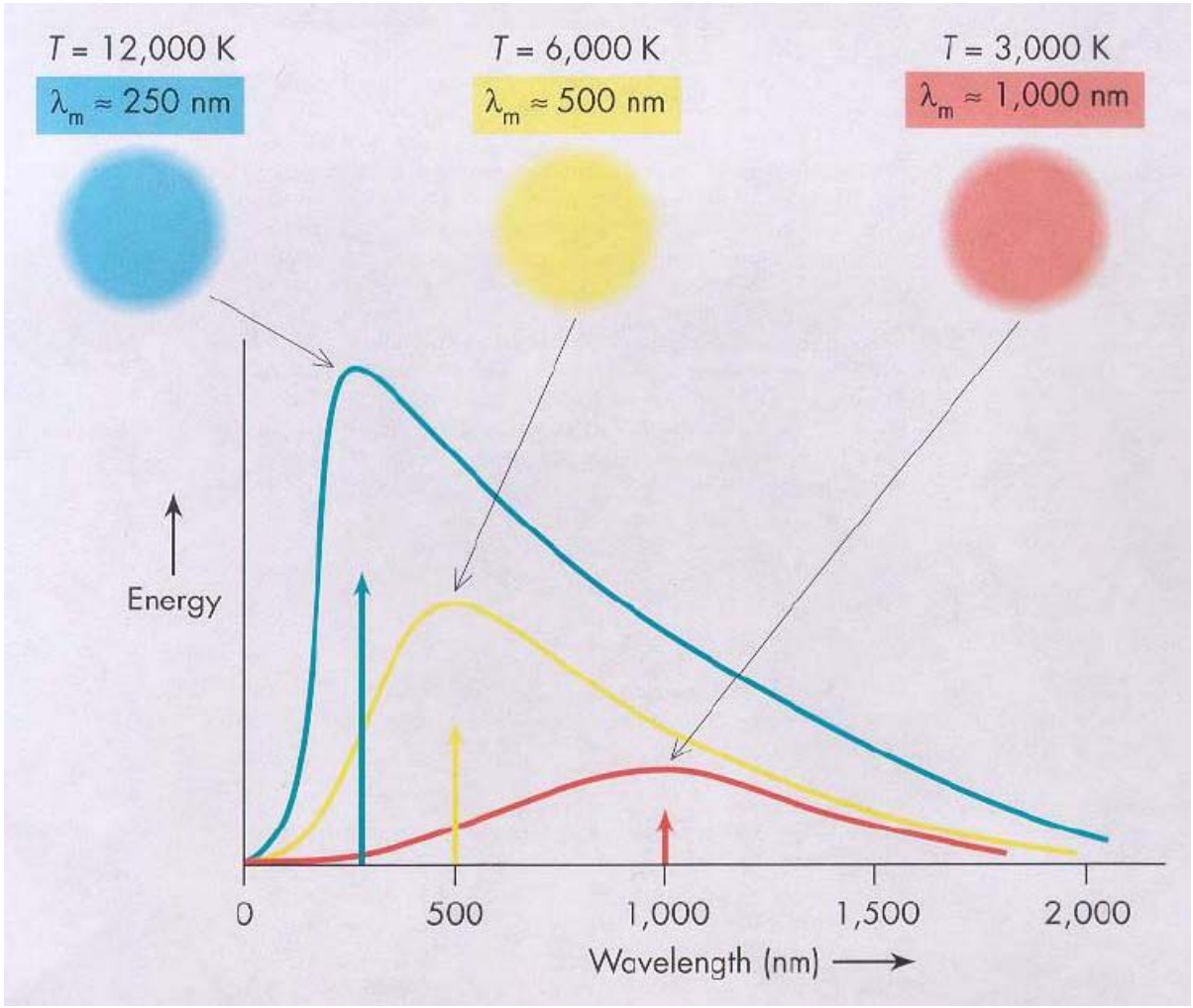
- As temperature increases, peak shifts to shorter wavelengths
- The Sun's spectrum looks almost like a 5800 K blackbody





Wein's Law

- The peak of the blackbody emission is inversely related to the temperature
- The hotter the object, the stronger it emits light in the shorter wavelengths.
- The Sun's Photosphere is around 5800 K
- Red hot? Or Blue hot? Color of stars?



Stephan-Boltzmann Law

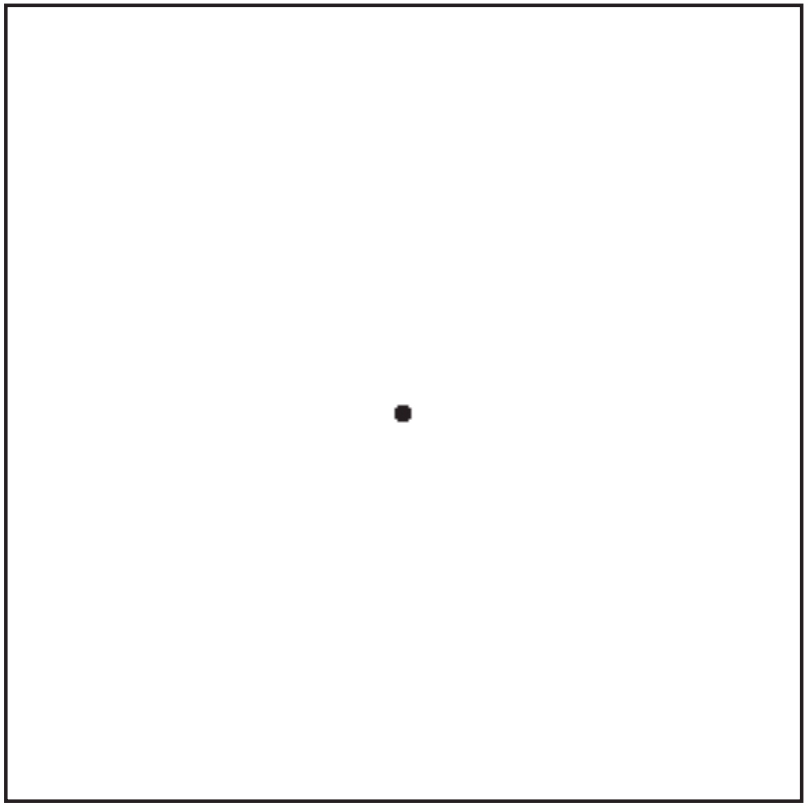
- For blackbodies, the brightness, or intensity, or output energy, is proportional to T^4 (in Kelvin).
- If a star was the same size as the Sun, but was twice as hot, it would be 16 times as bright.

Doppler Effect

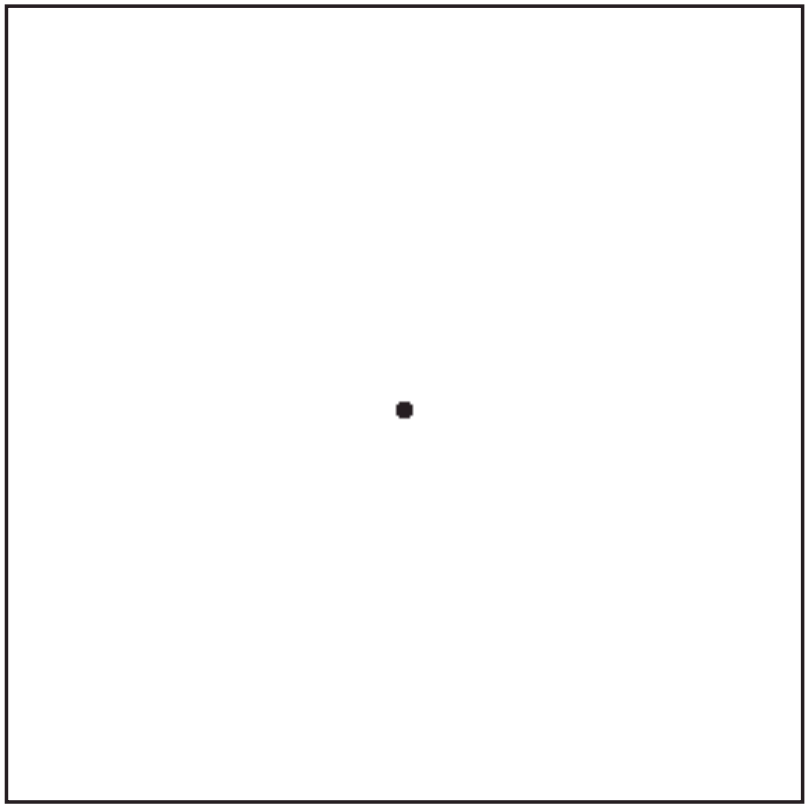
Those of you use to racing events like the Indy 500, or the sound of a police siren, are use to the Doppler effect.

The Doppler Effect

The effect arises from the relative motion of the observer and the source of light, sound, etc. The waves get squashed in the direction of motion and stretched in the opposite direction.



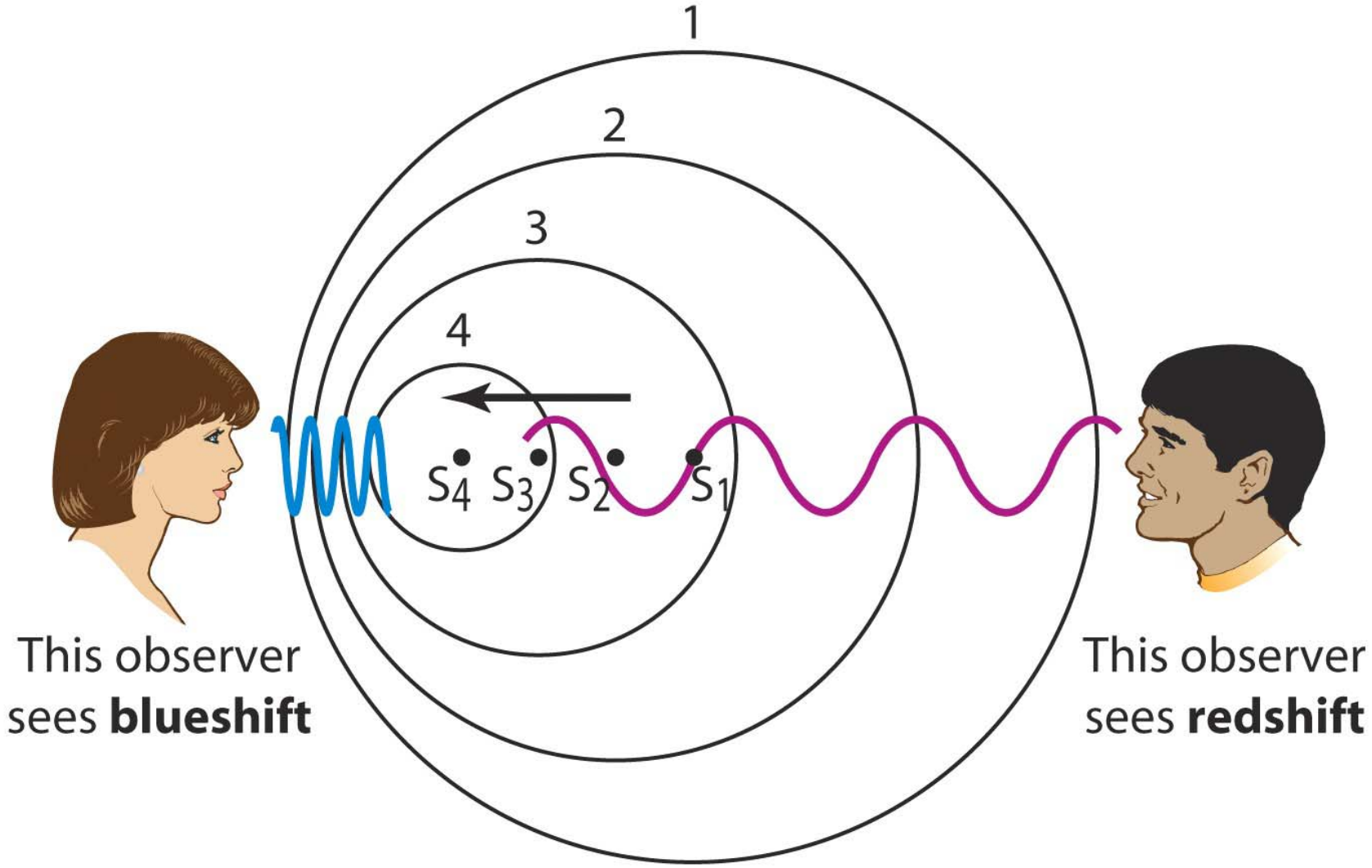
Source standing still



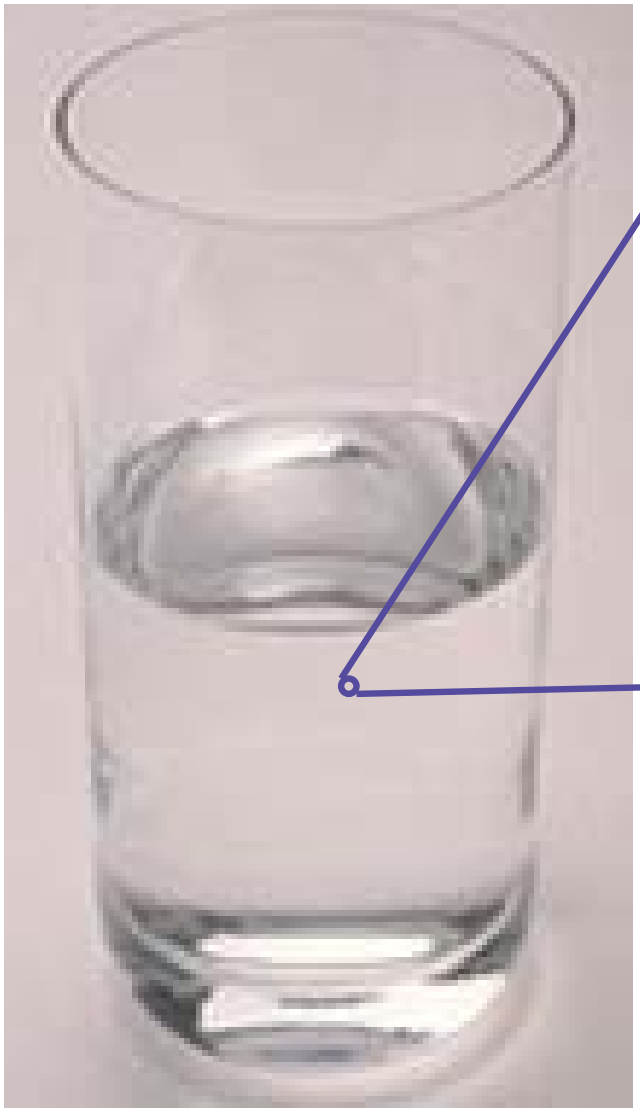
Source moving to right

The Doppler Effect

The amount of the shift in wavelength depends on the relative velocity of the source and the observer



A Glass of Water



10 cm

Water molecules
1 nm = 10^{-9} m

Oxygen atom
0.1 nm

Oxygen nucleus
1 fm = 10^{-15} m

Protons, neutrons, and electrons

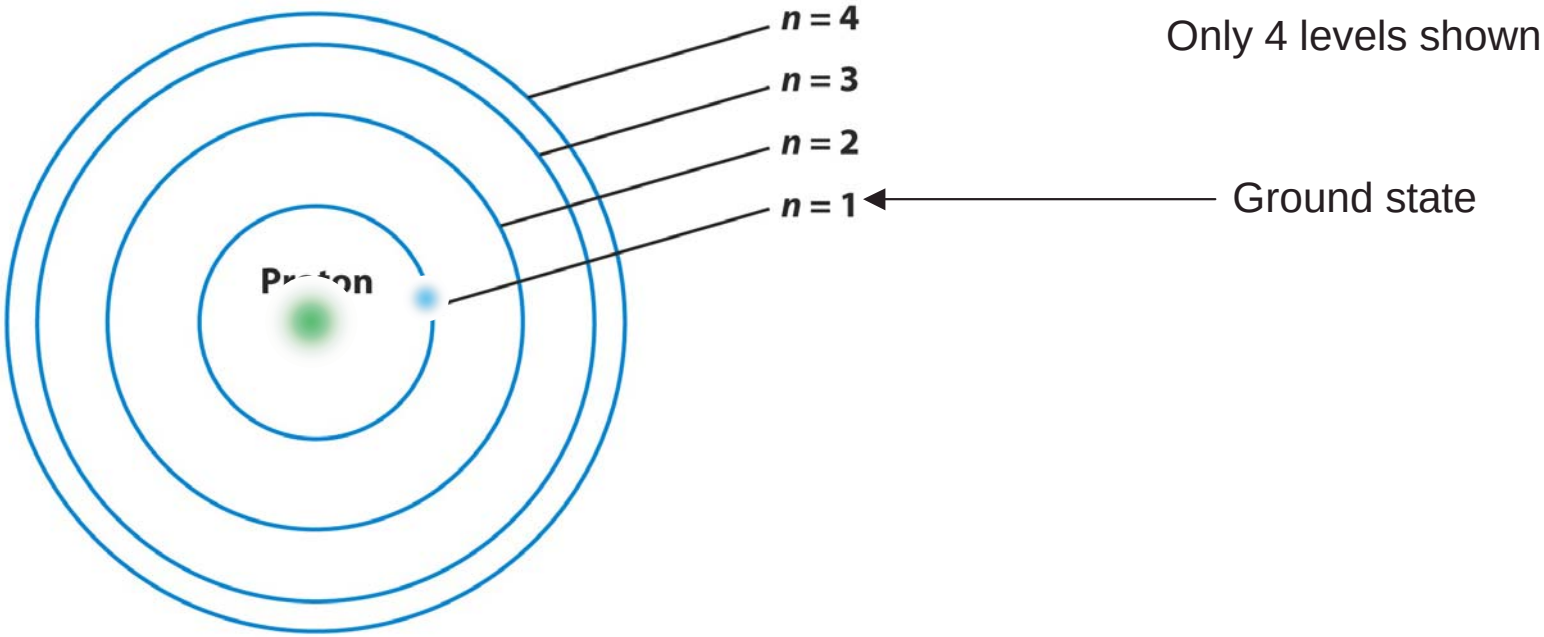
- **Electrons**
  Negatively charged (charge -1)
  Lightweight (mass 9.110×10^{-28} g)

- **Protons**
  Positively charged (charge +1)
  1832 times as massive as an electron (mass 1.673×10^{-24} g)

- **Neutrons**
  No electric charge
  A little more massive than a proton (mass 1.675×10^{-24} g)

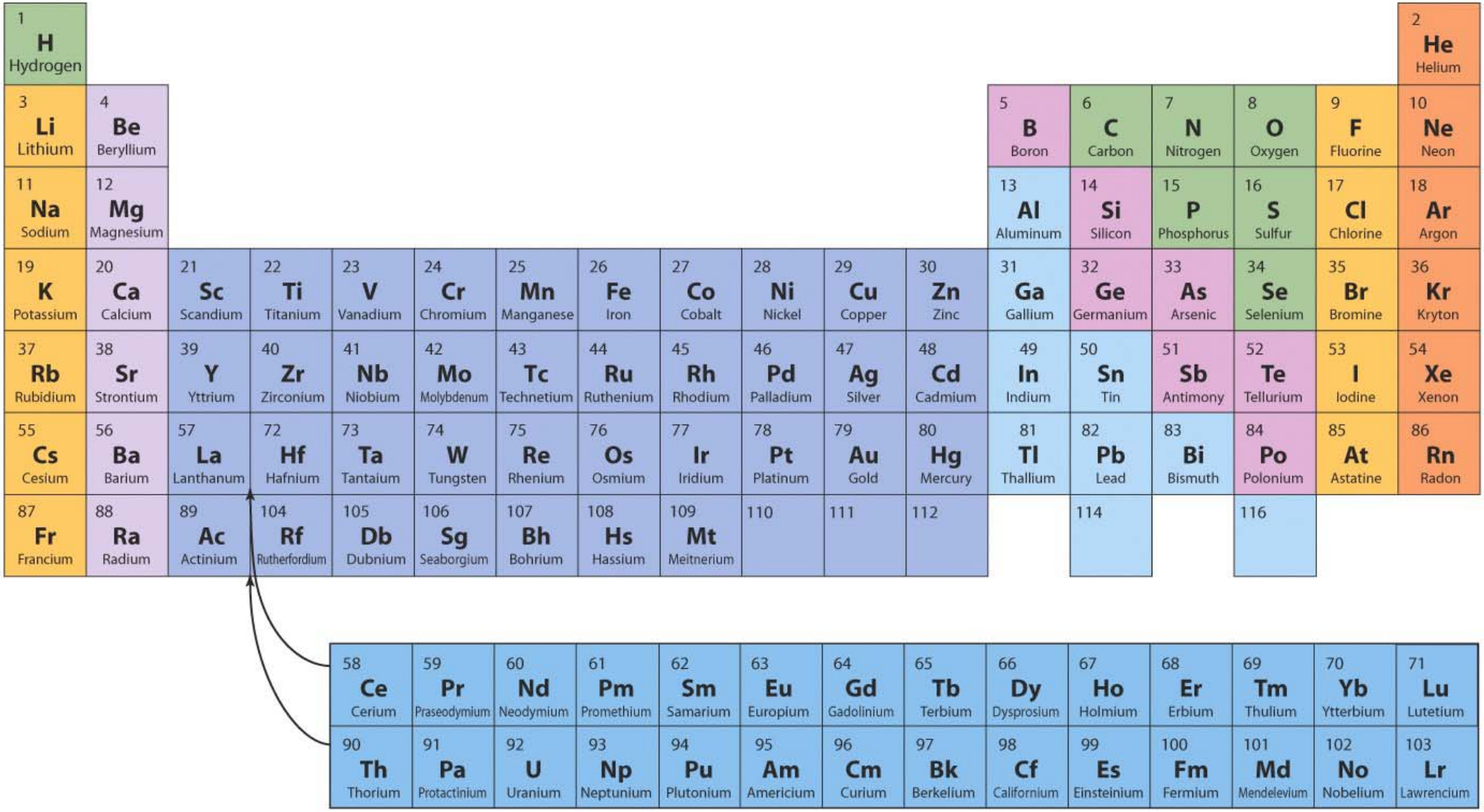
Atomic Structure

- Electrons orbit the **nucleus** of each atom (a little like planets around the Sun)
- The nucleus consists of protons and neutrons
- Number of protons = number of electrons (so total charge is 0)
- The electrons can only have special orbits called **energy levels** – the lowest energy level is the **ground state**



Hydrogen atom

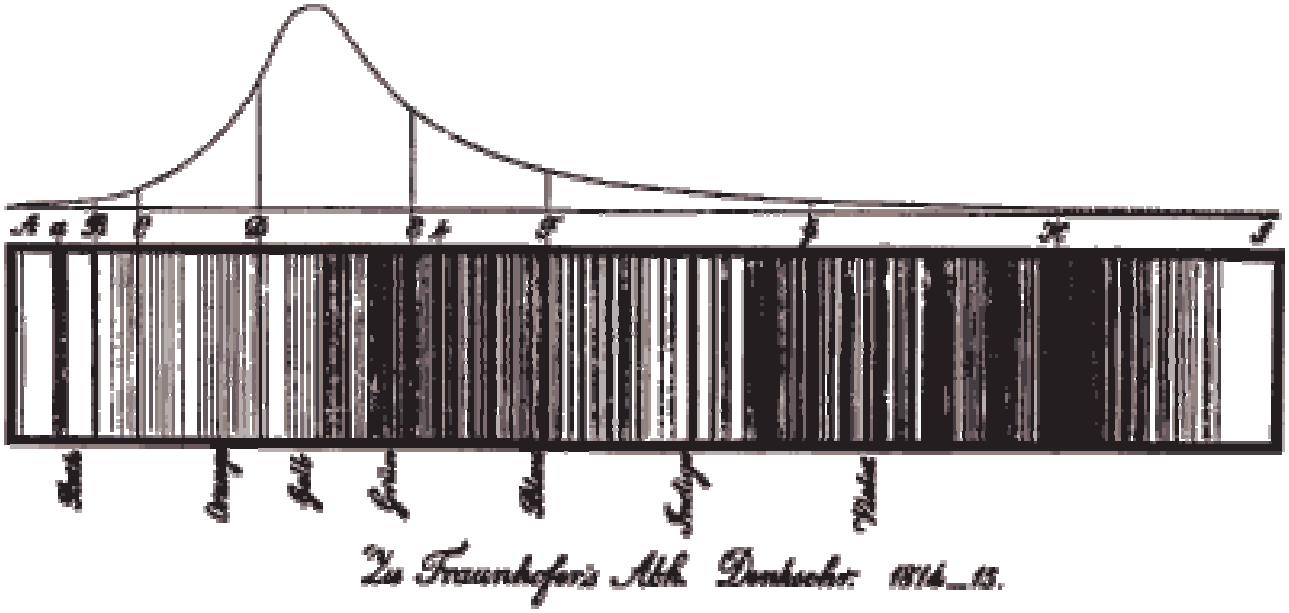
The Periodic Table of the Elements



The number of protons in an atom determines the type of element

Fraunhofer and Spectral Lines

Discovered that Sun's spectrum contained narrow gaps (**spectral lines**) when viewed at high resolution (1814)



Joseph von Fraunhofer
(1787-1826)

Prism spectrograph

Absorption Lines