



- 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.

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Outline



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

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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.



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HST



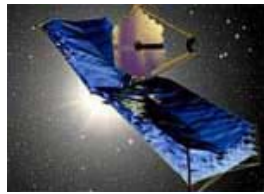
Without the atmosphere, can take much better images of astronomical sources– even with smaller mirror.



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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/gsfsc/spacesci/pictures/20020806ngst/AL-TRW-%20Close%20up%20of%20telesco.mpg>

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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)



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<http://www.vla.nrao.edu/>

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?



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BIMA



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BIMA



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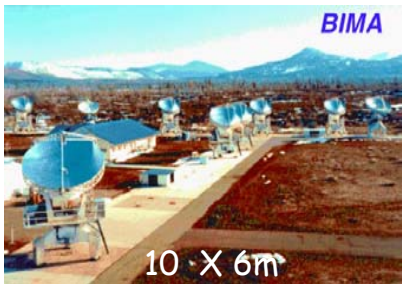
BIMA



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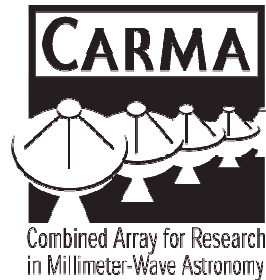
The Future -- 2005



+

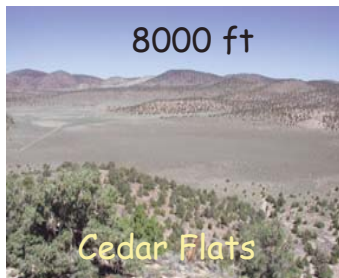


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Combined Array for Research in Millimeter-Wave Astronomy

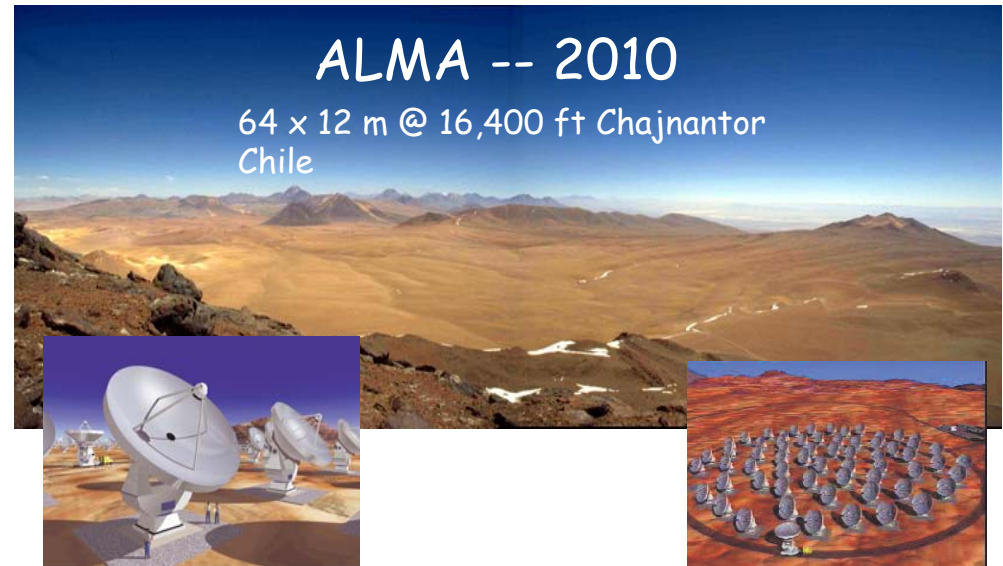
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Future of High Res mm/Sub-mm



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Stratospheric Observatory For Infrared Astronomy SOFIA



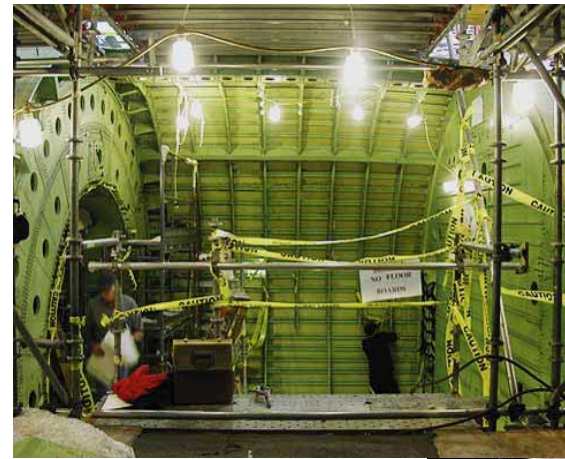
- Modified Boeing 747 SP
- Operation height: 39000 to 45000 ft (11.8 to 13.7 km)
- 2.7m telescope Cassegrain with Nasmyth focus
 - 20000 kg TA (f/19.6 from 0.3 to 1600 μm)
- Image stability goal 0.2" RMS
- Image quality 80% enclosed at 1.5" circle
- First Light - Oct 2004
- 20 year operations (3 to 4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



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

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As

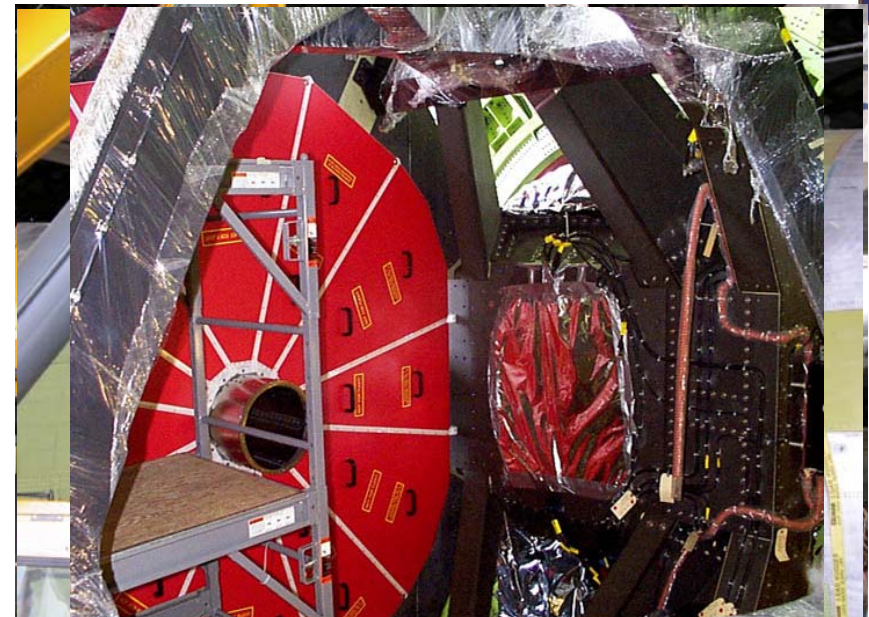


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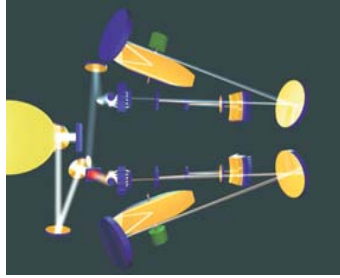
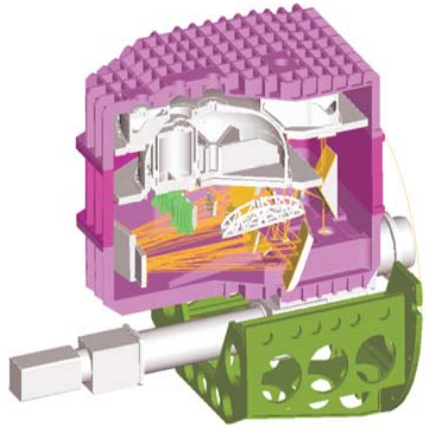
The Mirror



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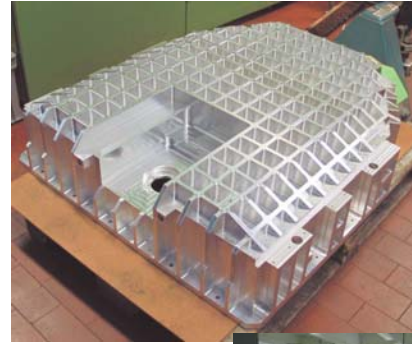
FIFI LS: Far-Infrared Field-Imaging Line Spectrometer



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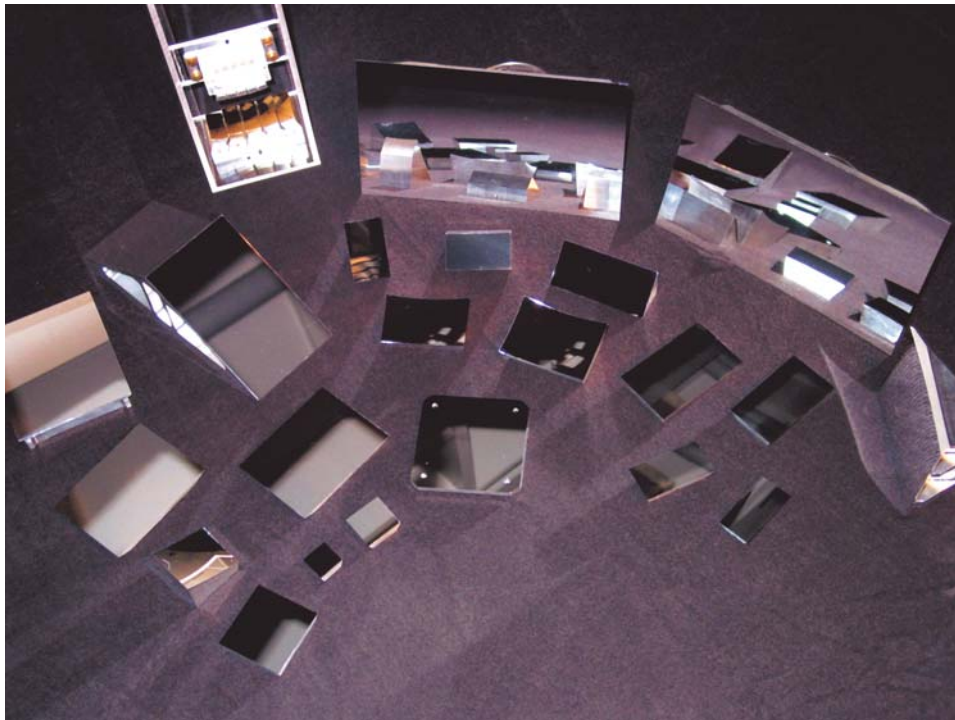
FIFI LS Vacuum Vessel Status



All 3 vessel shells
manufactured

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X-ray Telescopes



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



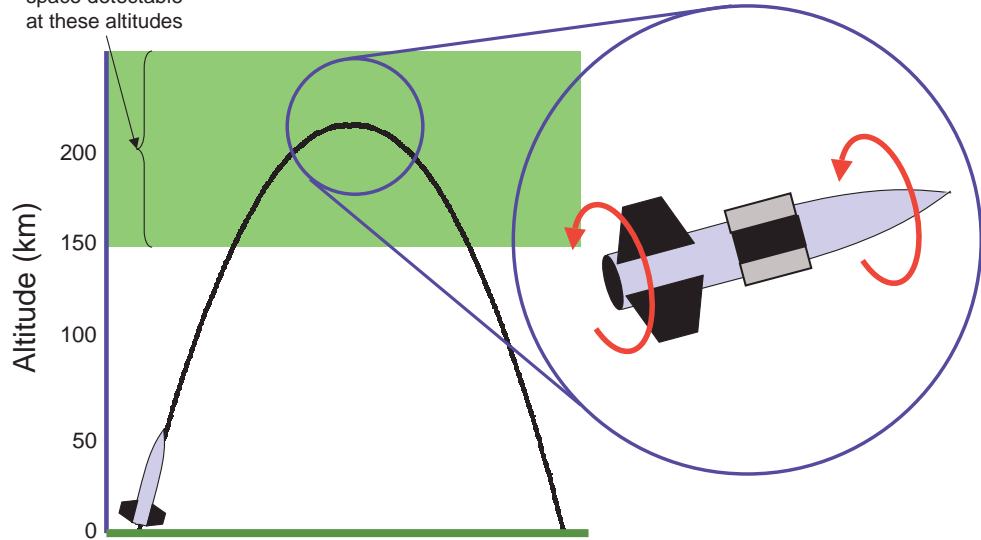
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Sounding rocket observations (1960s)



X-rays from space detectable at these altitudes



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

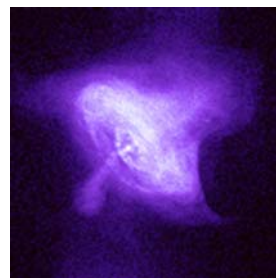
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Chandra X-ray Observatory



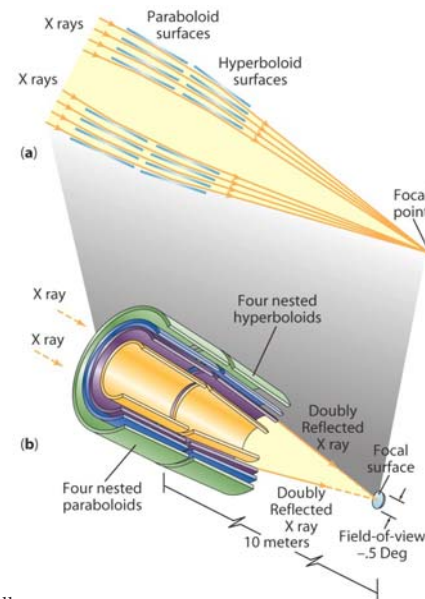
Launched 1999



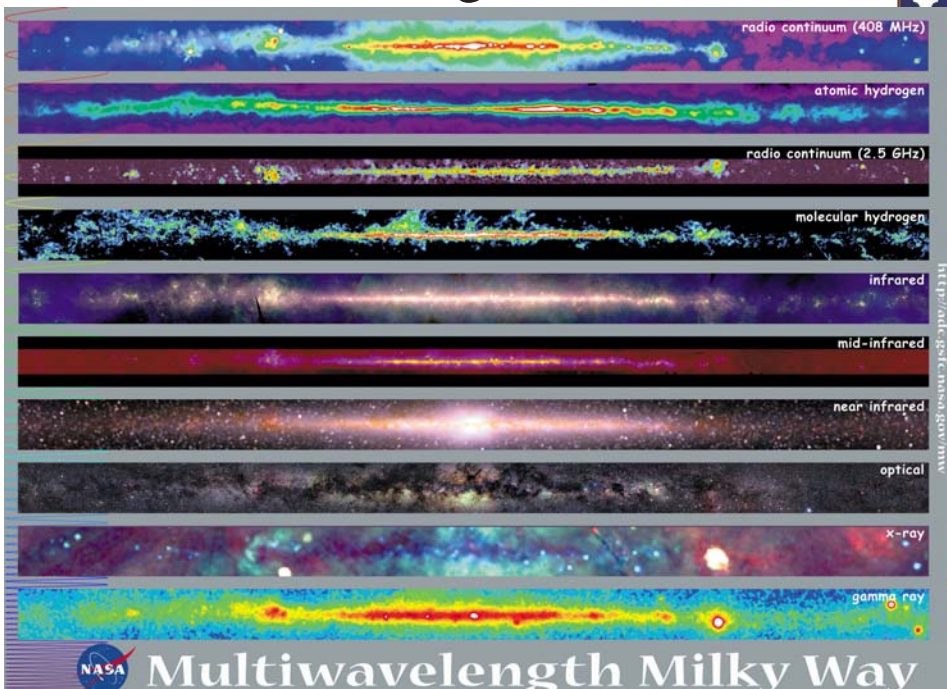
Crab Nebula in X-rays

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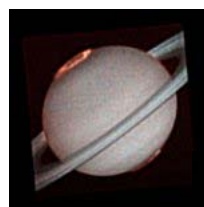


Multi-Wavelength Observations



Multiwavelength Milky Way

The Multi-Wavelength Solar System



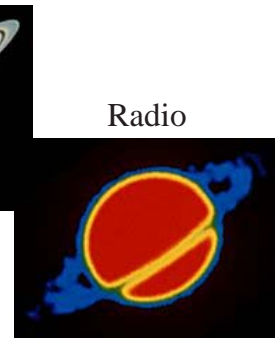
Ultraviolet



Visible



Infrared



Radio

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

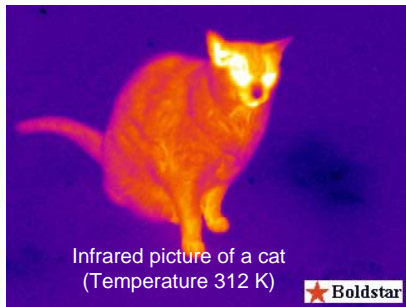
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Blackbody Radiation



- 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)

Boldstar



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

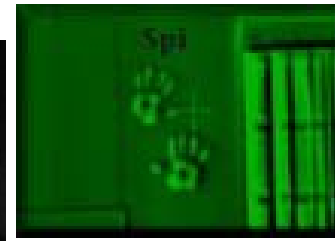
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Glowing Bodies



- 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).

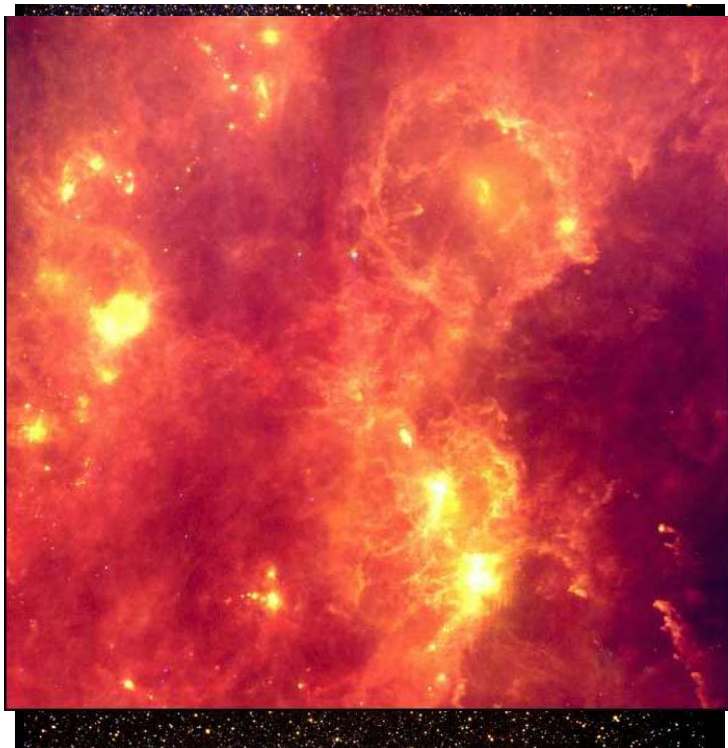


http://www.x20.org/thermal/thermal_weapon_sight_TIWS320.htm

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Orion in Visible and IR

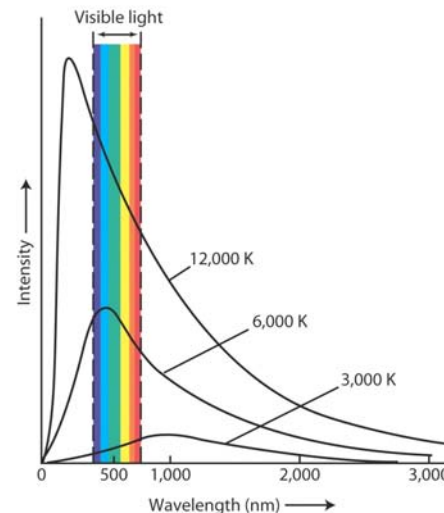


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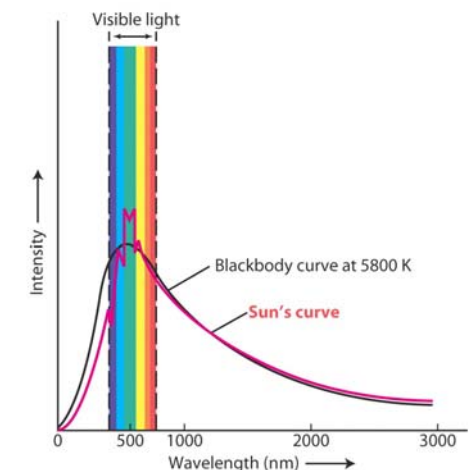
The Spectrum of Blackbody Radiation



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



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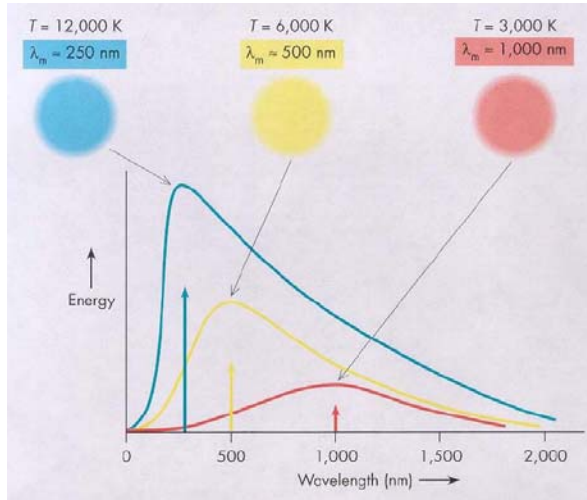


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Wein's Law



- 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?



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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.

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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.



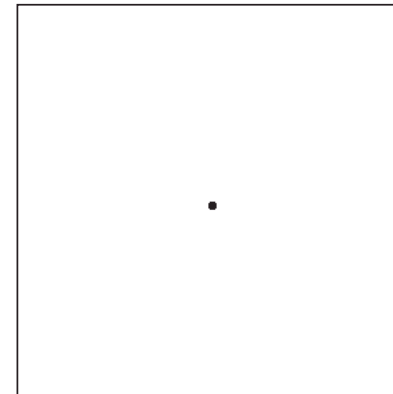
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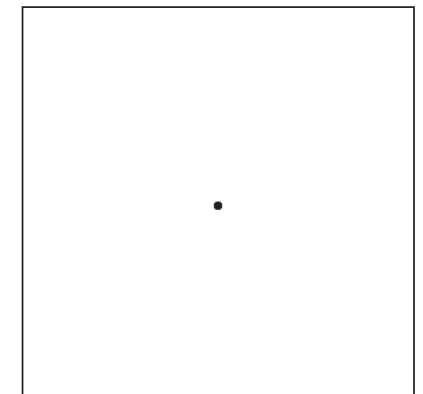
The Doppler Effect



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

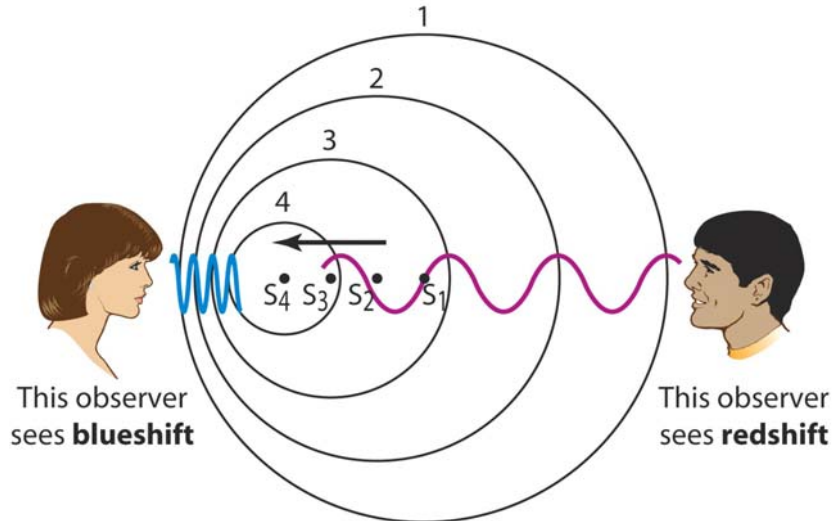
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The Doppler Effect



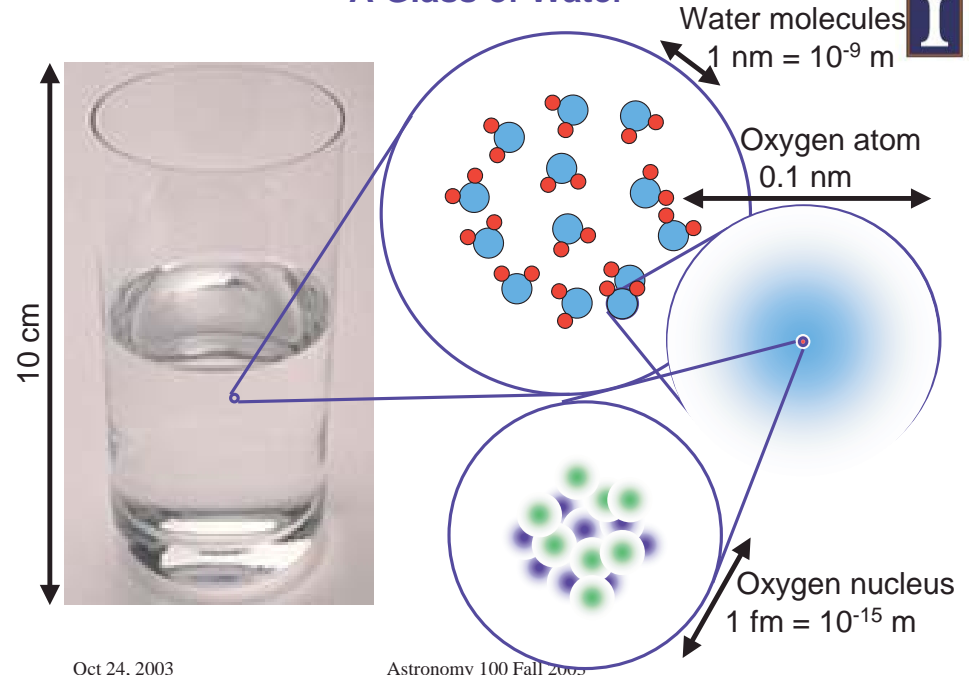
The amount of the shift in wavelength depends on the relative velocity of the source and the observer



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A Glass of Water



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Protons, neutrons, and electrons



- **Electrons**
 Negatively charged (charge -1)
 Lightweight (mass 9.110 x 10⁻²⁸ g)
- **Protons**
 Positively charged (charge +1)
 1832 times as massive as an electron (mass 1.673 x 10⁻²⁴ g)
- **Neutrons**
 No electric charge
 A little more massive than a proton (mass 1.675 x 10⁻²⁴ g)

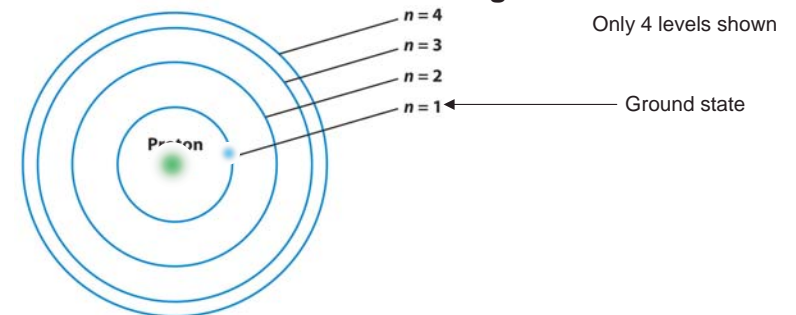
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Atomic Structure



- ▶ 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

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The Periodic Table of the Elements



1 H Hydrogen																	2 He Helium																												
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon																												
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon																												
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton																												
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon																												
55 Cs Cesium	56 Ba Barium	57 La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon																												
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium																																					
<table border="1"> <tr> <td>58 Ce Cerium</td> <td>59 Pr Praseodymium</td> <td>60 Nd Neodymium</td> <td>61 Pm Promethium</td> <td>62 Sm Samarium</td> <td>63 Eu Europium</td> <td>64 Gd Gadolinium</td> <td>65 Tb Terbium</td> <td>66 Dy Dysprosium</td> <td>67 Ho Holmium</td> <td>68 Er Erbium</td> <td>69 Tm Thulium</td> <td>70 Yb Ytterbium</td> <td>71 Lu Lutetium</td> </tr> <tr> <td>90 Th Thorium</td> <td>91 Pa Protactinium</td> <td>92 U Uranium</td> <td>93 Np Neptunium</td> <td>94 Pu Plutonium</td> <td>95 Am Americium</td> <td>96 Cm Curium</td> <td>97 Bk Berkelium</td> <td>98 Cf Californium</td> <td>99 Es Einsteinium</td> <td>100 Fm Fermium</td> <td>101 Md Mendelevium</td> <td>102 No Nobelium</td> <td>103 Lr Lawrencium</td> </tr> </table>																		58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium
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The number of protons in an atom determines the type of element
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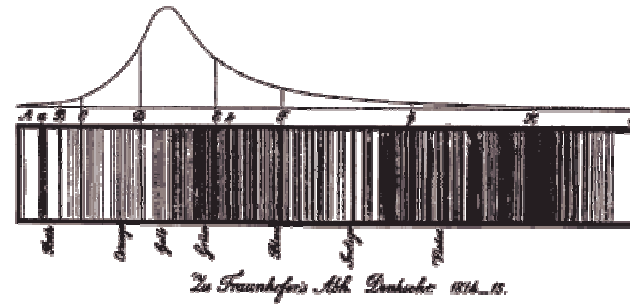
Fraunhofer and Spectral Lines



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



Joseph von Fraunhofer (1787-1826)



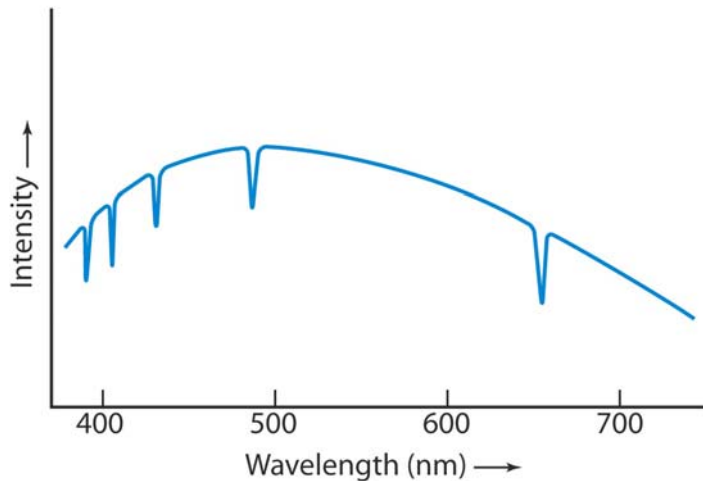
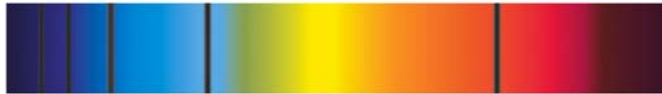
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Prism spectrograph

Absorption Lines



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