

Physics 681: Solar Physics and Instrumentation – Lecture 2

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Kepler's 3rd Law

$$\vec{v} \perp \vec{r} \Rightarrow \begin{cases} r_p = a(1-e) \text{ (perihelion)} \\ r_a = a(1+e) \text{ (aphelion)} \end{cases} \Rightarrow L = \mu r v \Leftrightarrow \mu r_p v_p = \mu r_a v_a$$

$$\Rightarrow \frac{v_p}{v_a} = \frac{1+e}{1-e} \text{ and } \frac{1}{2} \mu v_p^2 - G \frac{M \mu}{a(1-e)} = \frac{1}{2} \mu v_a^2 - G \frac{M \mu}{a(1+e)}$$

$$\Rightarrow v_p^2 = \frac{GM}{a} \left(\frac{1+e}{1-e} \right) \text{ and } v_a^2 = \frac{GM}{a} \left(\frac{1-e}{1+e} \right)$$

$$\Rightarrow L = \mu r_p v_p = \mu \sqrt{GMa(1-e^2)}$$

Virial Theorem

$$\Rightarrow E = \frac{1}{2} \mu v_p^2 - G \frac{M \mu}{r_p} = -G \frac{M \mu}{2a} = -G \frac{m_1 m_2}{2a} = \frac{1}{2} \langle U \rangle$$



Kepler's 3rd Law (cont.)

$$E = -G \frac{M \mu}{2a} = \frac{1}{2} \mu v^2 - G \frac{M \mu}{r}$$

$$\Rightarrow v^2 = G(m_1 + m_2) \left(\frac{2}{r} - \frac{1}{a} \right)$$

$$A = \int_0^P \frac{dA}{dt} dt = \int_0^P \frac{1}{2} \frac{L}{\mu} dt = \frac{1}{2} \frac{L}{\mu} \int_0^P dt = \frac{1}{2} \frac{L}{\mu} P$$

$$\Rightarrow P^2 = \left(\frac{2A\mu}{L} \right)^2 = \frac{4\pi^2 a^2 b^2 \mu^2}{L^2} = \frac{4\pi^2 a^2 b^2 \mu^2}{\mu^2 (GMa(1-e^2))} = \frac{4\pi^2}{GM} a^3$$

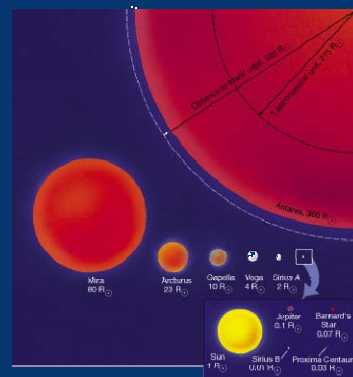
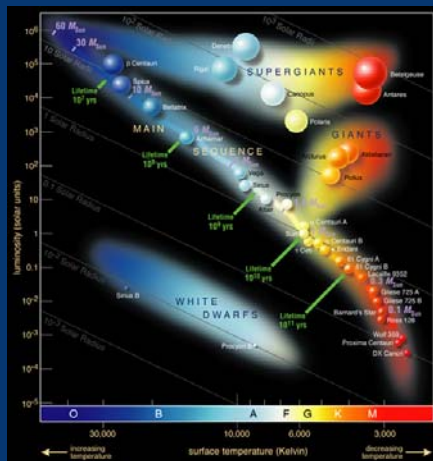
Virial Theorem:
For gravitationally bound systems in equilibrium, it can be shown that the total energy is always one-half of the time averaged potential energy.

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Hertzsprung-Russell Diagram



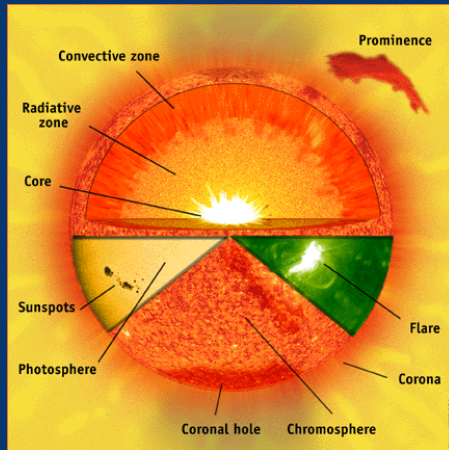
<http://www.physics.sjsu.edu/tomley/Planck.html>

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Sun – Overview



Mass (kg)	1.99e+30
Mass (Earth = 1)	332,830
Equatorial radius (km)	695,000
Equatorial radius (Earth = 1)	108.97
Mean density (gm/cm ³)	1.410
Rotational period (days)	25-36
Escape velocity (km/sec)	618.02
Luminosity (ergs/sec)	3.827e33
Magnitude	-26.8
Mean surface temperature	6,000°C
Age (billion years)	4.5
Principal chemistry	
Hydrogen	92.1%
Helium	7.8%
Oxygen	0.061%
Carbon	0.030%
Nitrogen	0.0084%
Neon	0.0076%
Iron	0.0074%
Silicon	0.0031%
Magnesium	0.0024%
All others	0.0036%

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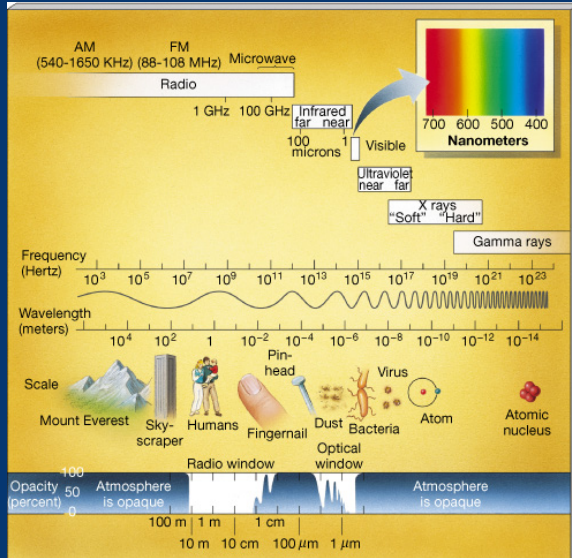
Parameters

- Astronomical unit [AU]: $A = 149,597,870 \pm 2 \text{ km}$ (perihelion in January: $1.471 \times 10^{11} \text{ m}$; aphelion in July: $1.521 \times 10^{11} \text{ m}$)
- Travel time: $\tau_A = 499.004782 \pm 0.000006 \text{ s}$
- Velocity of light: $c = 299,792,458 \text{ m s}^{-1}$
- Constant of gravitation: $(6.67259 \pm 0.00085) \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$
- Mass of the Sun: $m_{\odot} = (1.9889 \pm 0.0003) \times 10^{30} \text{ kg}$
- Radius: $r_{\odot} = (6.960 \pm 0.001) \times 10^8 \text{ m}$
- Mean density: $\rho = 1.408 \text{ g cm}^{-3}$
- Gravitational acceleration: $g_{\odot} = 274 \text{ m s}^{-2}$
- Solar constant: $S = 1367 \pm 3 \text{ W m}^{-2}$
- Luminosity: $L_{\odot} = (3.844 \pm 0.010) \times 10^{26} \text{ W}$
- Magnitude: $M_{\odot} = 4.74$ (absolute) and $m_{\odot} = -26.74$ (apparent)
- Effective temperature: $T_{\text{eff}} = 5778 \pm 3 \text{ K}$

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Electromagnetic Spectrum



Group Problem:

List a few solar phenomena that you know!

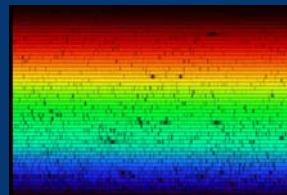
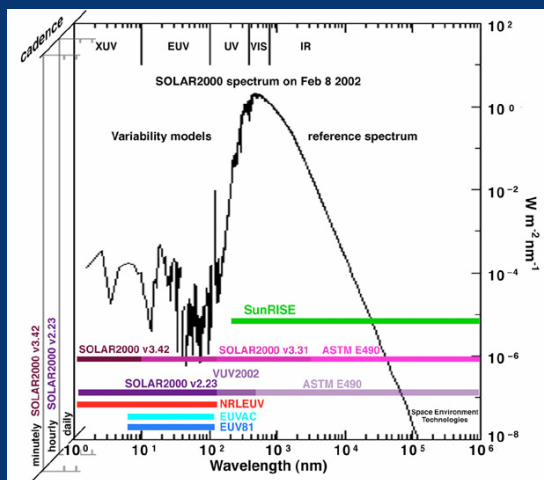
Where in the solar spectrum would you try to observe these solar phenomena?



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Solar Spectrum



http://www.noaa.gov/image_gallery/html/im0600.html

http://www.spacewx.com/solar_spectrum.html



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Planck Function

(<http://scienceworld.wolfram.com/physics/PlanckLaw.html>)

- Wavelength form: $B_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$
- Frequency form: $B_{\nu}(T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1}$
- Wien displacement law: $\lambda_{\max} = \frac{hc}{4.965kT} = \frac{2.898 \times 10^{-3} \text{ K m}}{T}$
- Rayleigh-Jeans law: $B_{\nu}(T) = 2kT\nu^2 / c^2$ for $(h\nu \ll kT)$
- Wien law: $B_{\nu}(T) = (2h\nu^3 / c^2)e^{-h\nu/kT}$ for $(h\nu \gg kT)$
- Stefan-Boltzman law: $F = \sigma T^4$ with $\sigma = 2\pi^5 k^4 / (15c^2 h^3)$

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