Homework #3

Handed out Oct 31st (after exam)

Due **Nov 14**

Last time...

Types of Stellar Temperature

Excitation - ratio of atoms in different states of excitation, defined by Boltzmann equation

Ionization - ratio of atoms in different stages of ionization, defined by Saha equation

Kinetic - Maxwell-Boltzmann distribution

Color - blackbody assumption

Effective - at the "surface" of a star

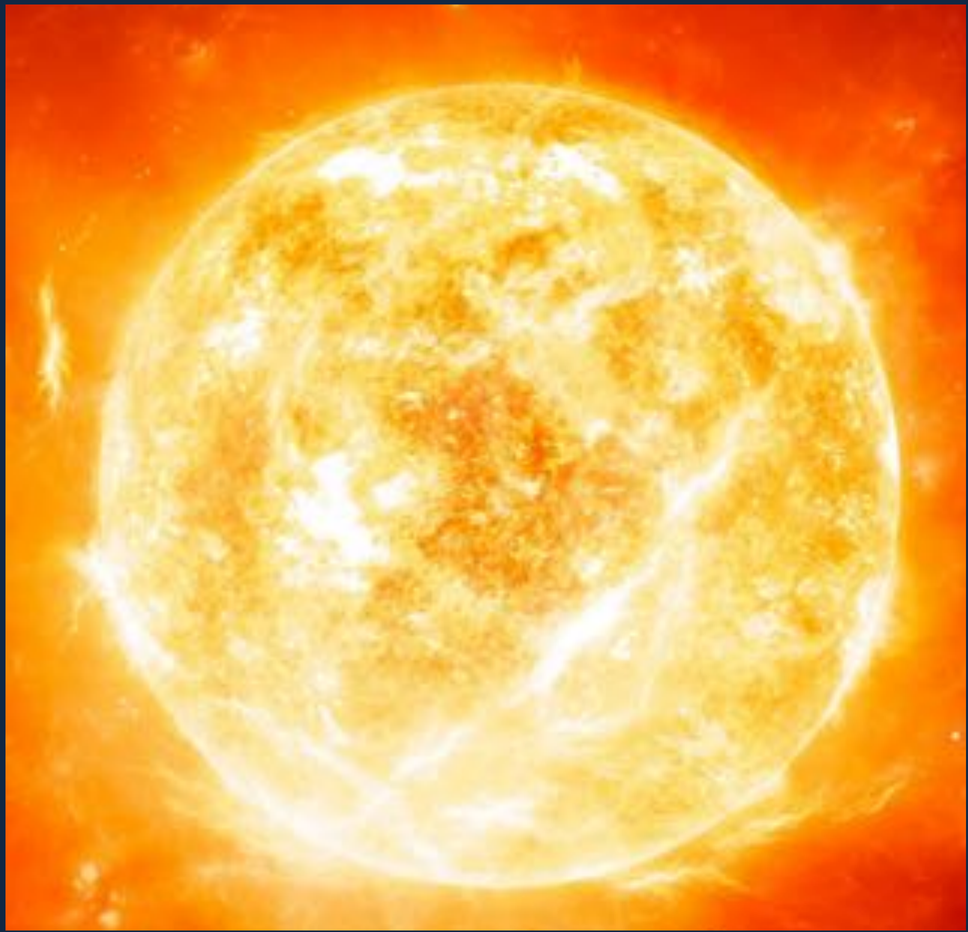
$$L = 4\pi R^2 \sigma T^4$$

Properties of Stars - Temperature

Types of Stellar Temperature

Why aren’t these all the same?

Excitation
Ionization
Kinetic
Color
Effective



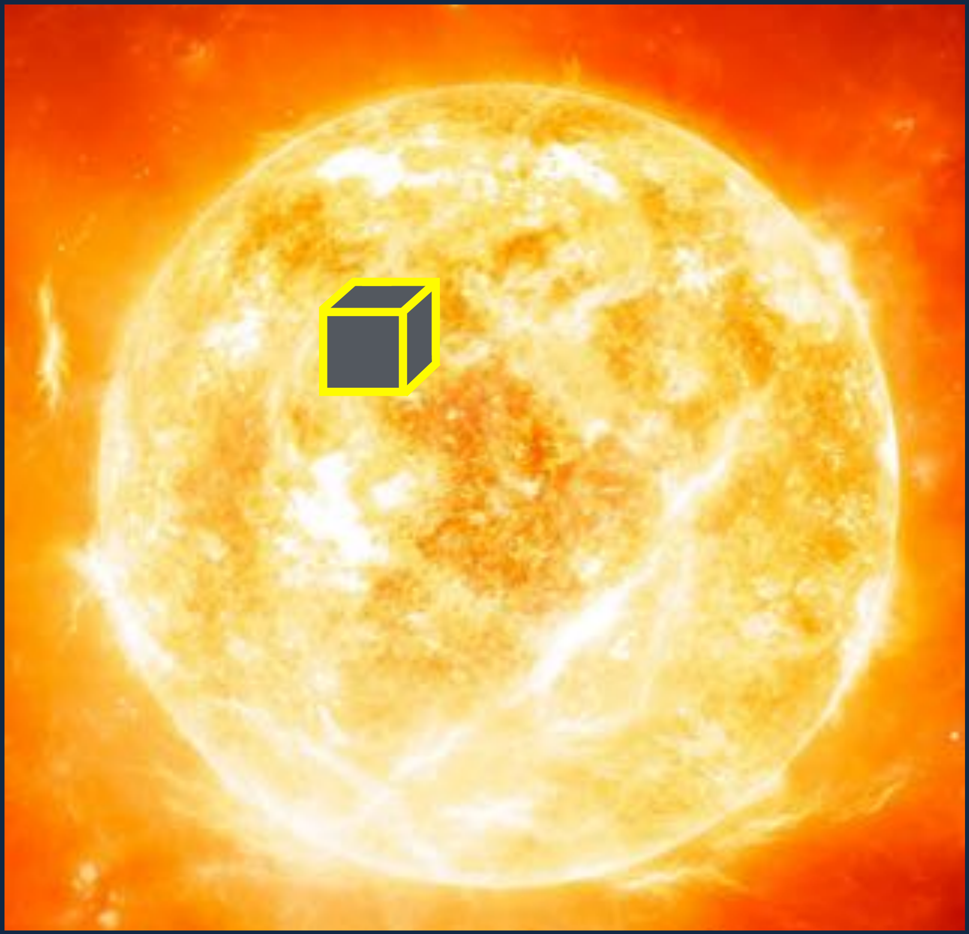
Properties of Stars - Temperature

Types of Stellar Temperature

Stars aren't in thermodynamic equilibrium…

…but can approximate:

Local
Thermodynamic
Equilibrium



Excitation
Ionization
Kinetic
Color
Effective

Properties of Stars - Mass

1) Distance - parallax, Cepheids
2) Velocity - proper motion, radial velocity
3) Brightness - magnitudes, luminosity
4) Temperature - effective temp (usually)
5) Mass
6) Radius

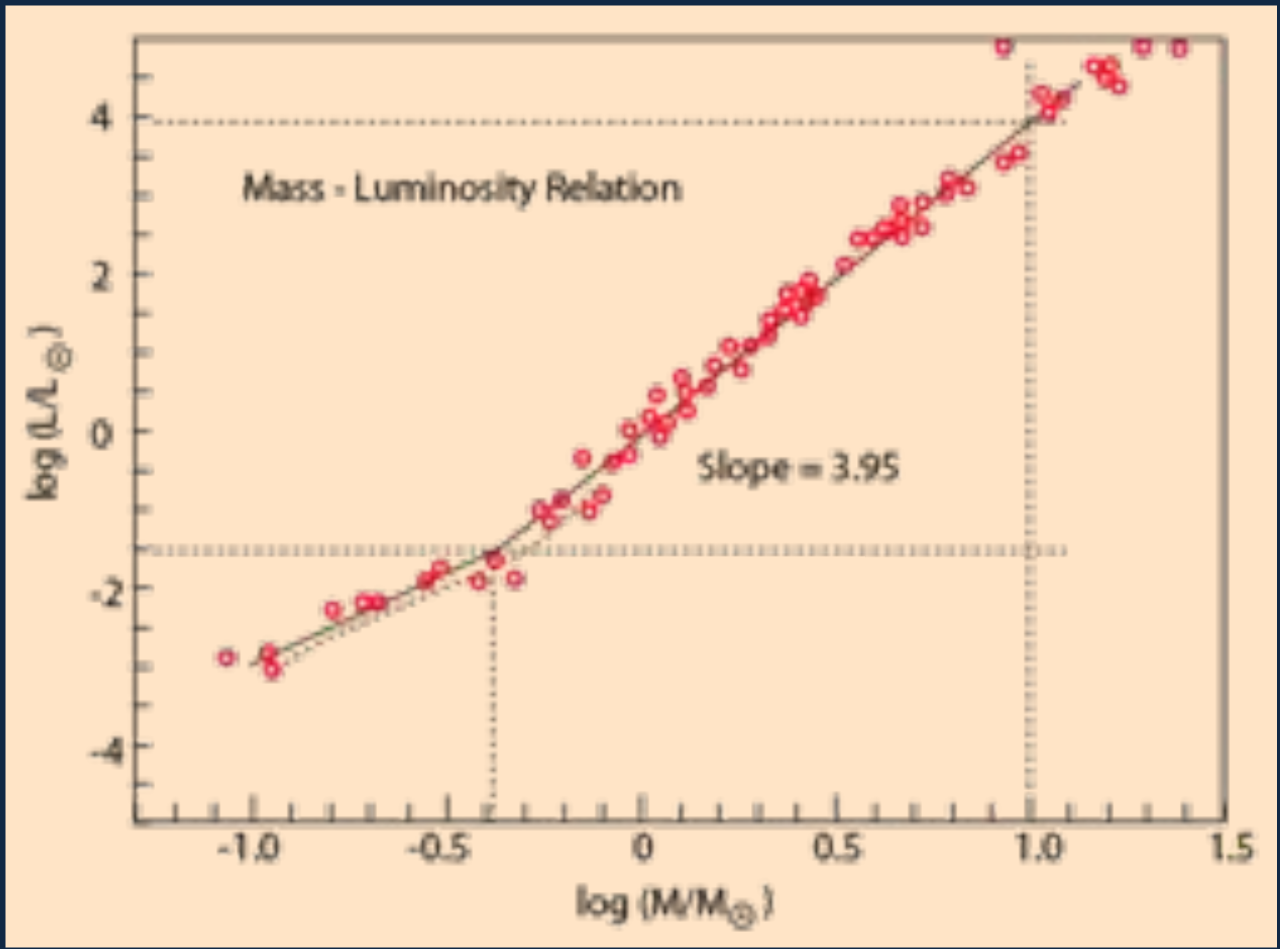
Properties of Stars - Mass

Determining Stellar Mass

For much of a star's lifetime it follows the **mass-luminosity relation**.

$$L = L_{sun}\left(\frac{M}{M_{sun}}\right)^{a}$$

$3 \lesssim a \lesssim 4$



Properties of Stars - Mass

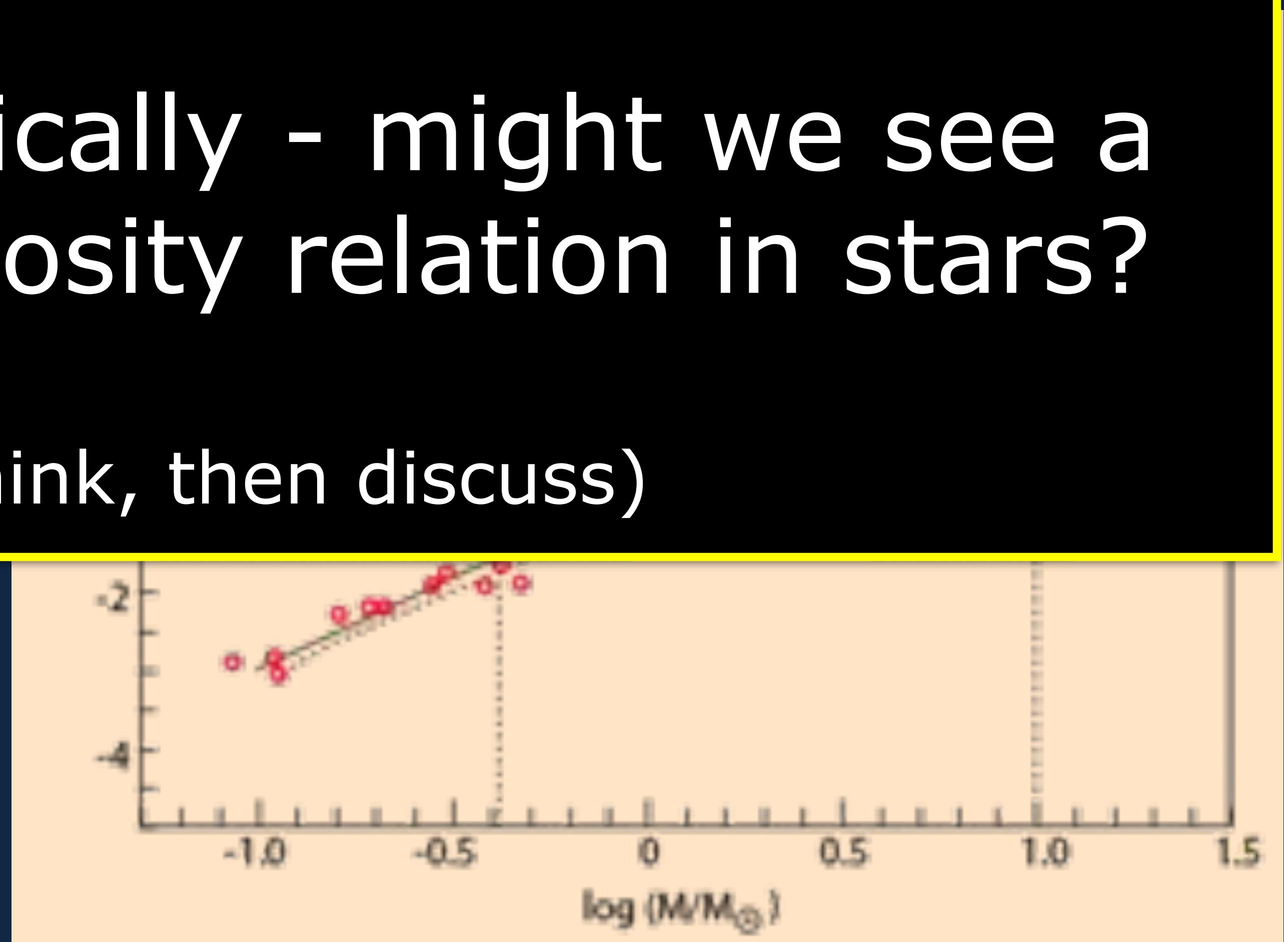
Determining Stellar Mass

For much of a star’s lifetime it follows the

Discussion Question

Why - physically - might we see a mass-luminosity relation in stars?

(think, then discuss)



Properties of Stars - Mass

Determining Stellar Mass

For much of a star's lifetime it follows the **mass-luminosity relation**.

$$L = L_{sun}\left(\frac{M}{M_{sun}}\right)^{a}$$

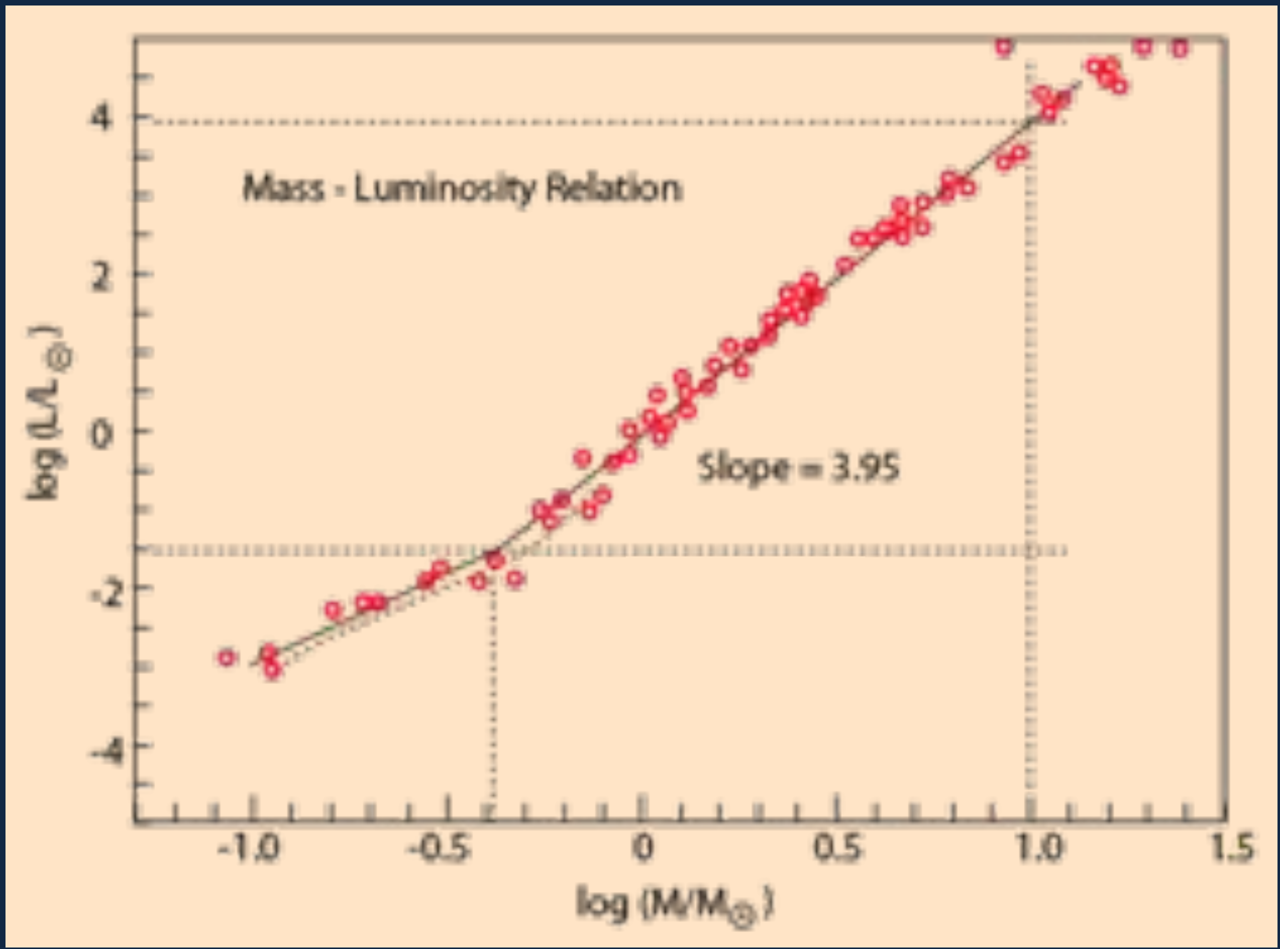
$3 \lesssim a \lesssim 4$

Most massive:

$\sim 100\ M_{sun}$ (ish)

Least massive:

$\sim 0.01\ M_{sun}$



Properties of Stars - Mass

Determining Stellar Mass

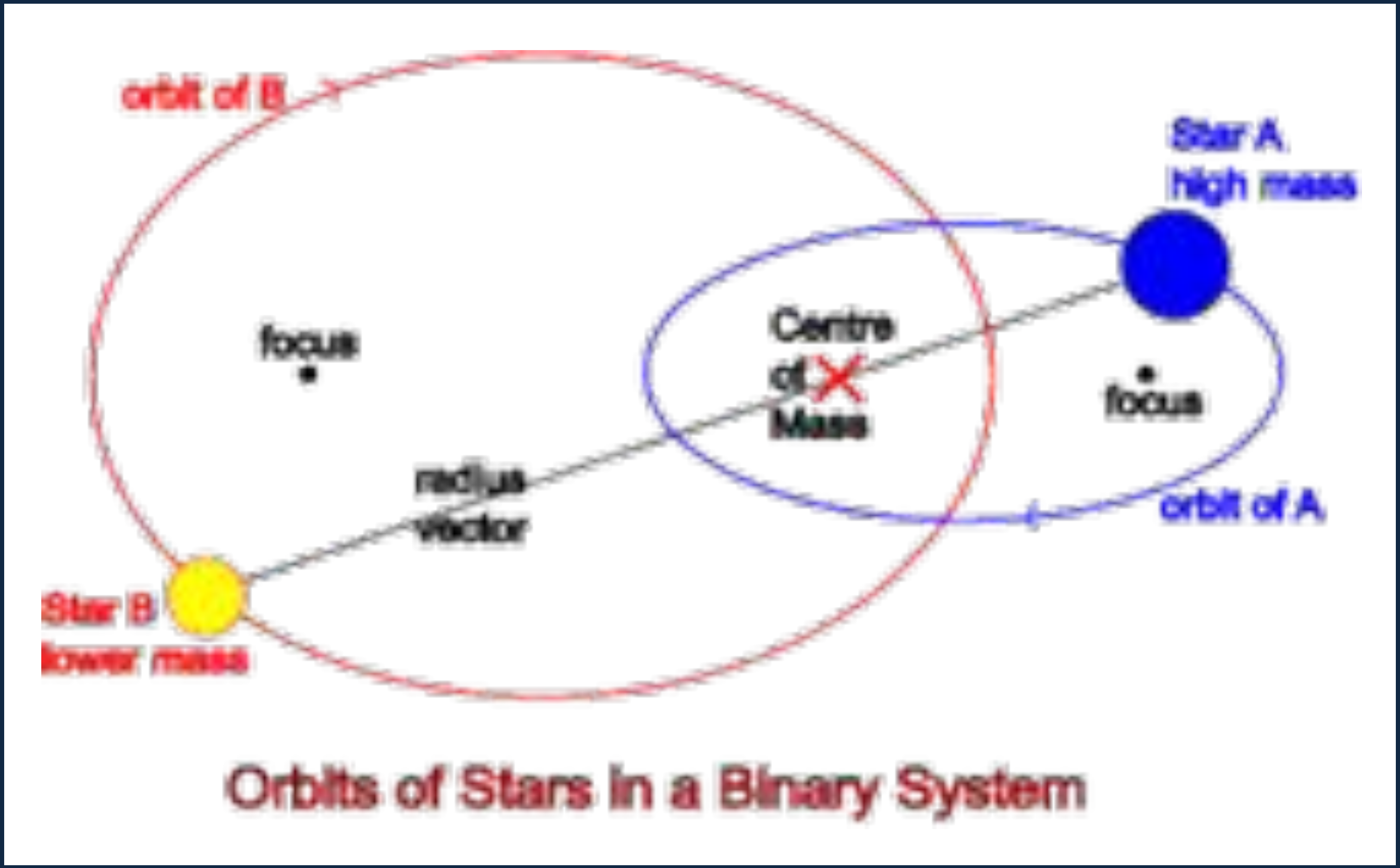
Masses can be determined very precisely for stars in **spectroscopic binaries**.


Alcor
AV5 + MV
Mizar
Mizar A & B
A2V + A2V
A1 + A5V

Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:



Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:

$$m_1 d_1 = m_2 d_2$$

$$v = 2\pi d/P \text{ so } d = vP/2\pi$$

$$m_1 v_1 P/2\pi = m_2 v_2 P/2\pi$$

Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:

$$m_1 d_1 = m_2 d_2$$

$$v = 2\pi d/P \text{ so } d = vP/2\pi$$

$$\frac{m_1}{m_2} = \frac{v_2}{v_1}$$

Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:

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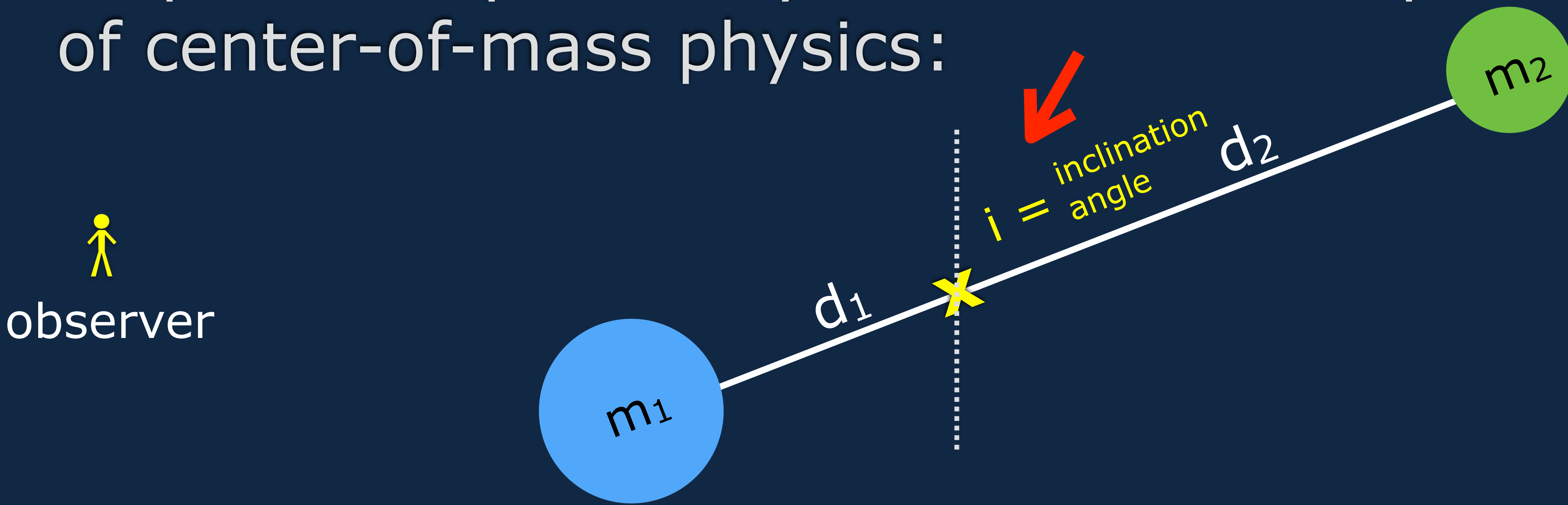
Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:



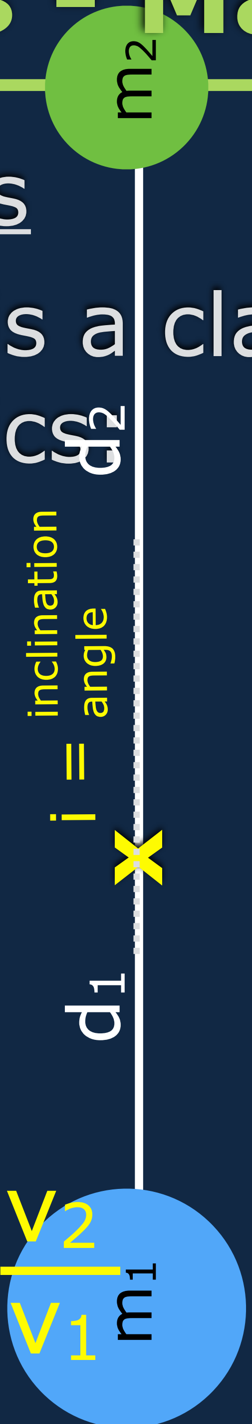
$$\frac{m_1}{m_2} = \frac{v_2}{v_1}$$

Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics.

observer



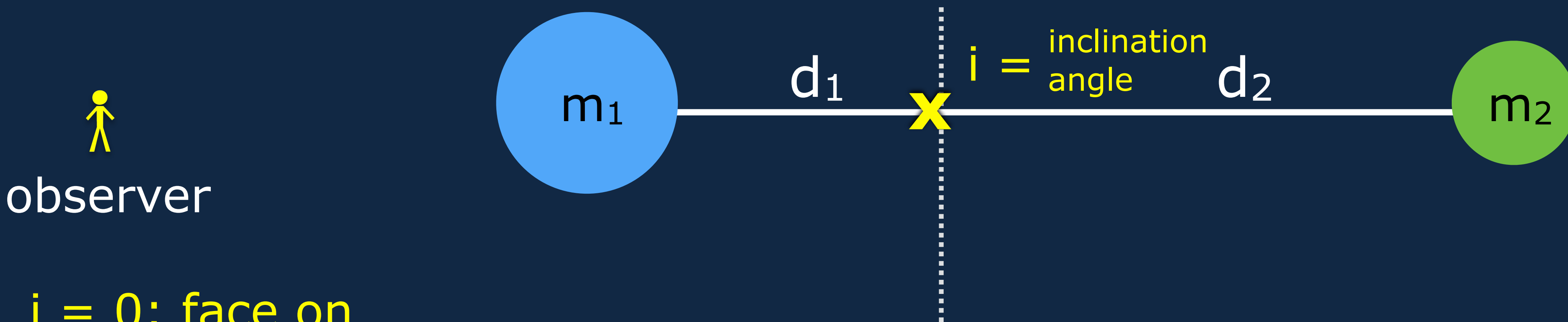
i = 0: face on

$$\frac{m_1}{m_2} = \frac{v_2}{v_1}$$

Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:



i = 0: face on

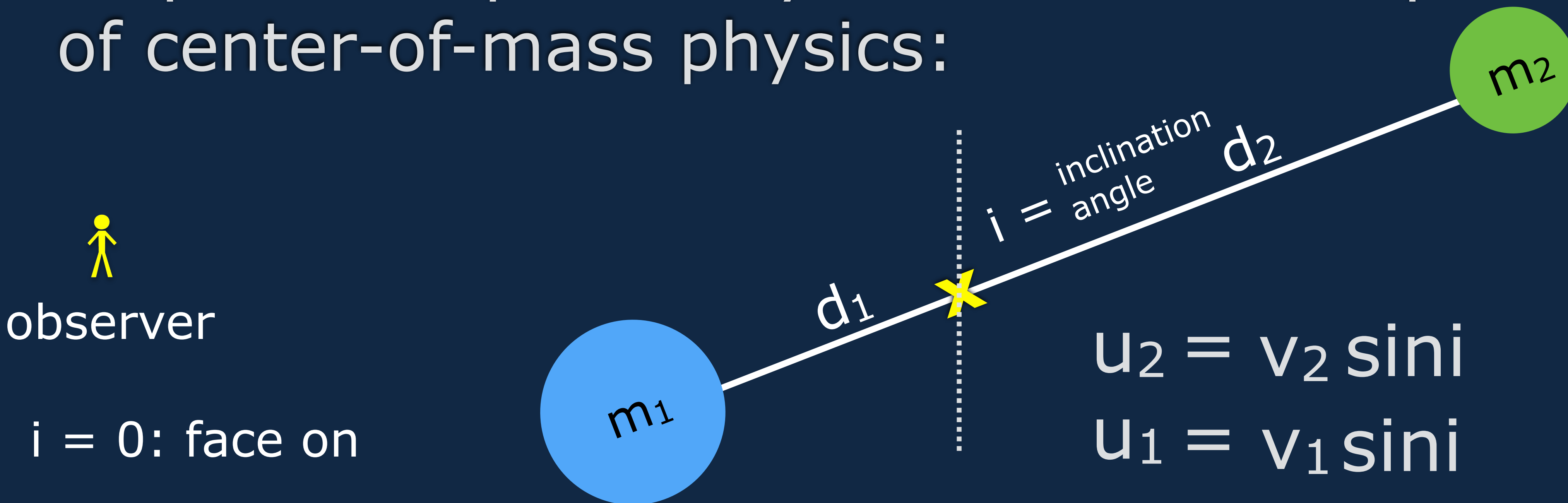
i = 90: along orbital plane

$$\frac{m_1}{m_2} = \frac{v_2}{v_1}$$

Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:



$u_2 = v_2 \sin i$

$u_1 = v_1 \sin i$

i = 0: face on

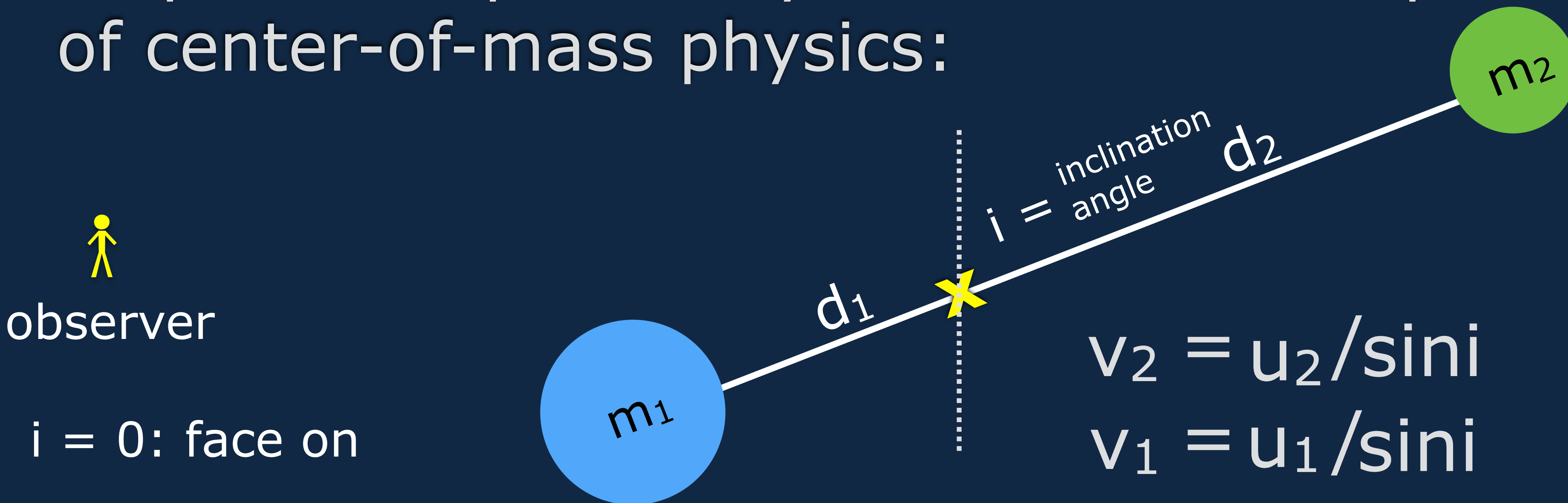
i = 90: along orbital plane

$$\frac{m_1}{m_2} = \frac{v_2}{v_1}$$

Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:



$$v_2 = u_2/\sin i$$
$$v_1 = u_1/\sin i$$

i = 0: face on

i = 90: along orbital plane

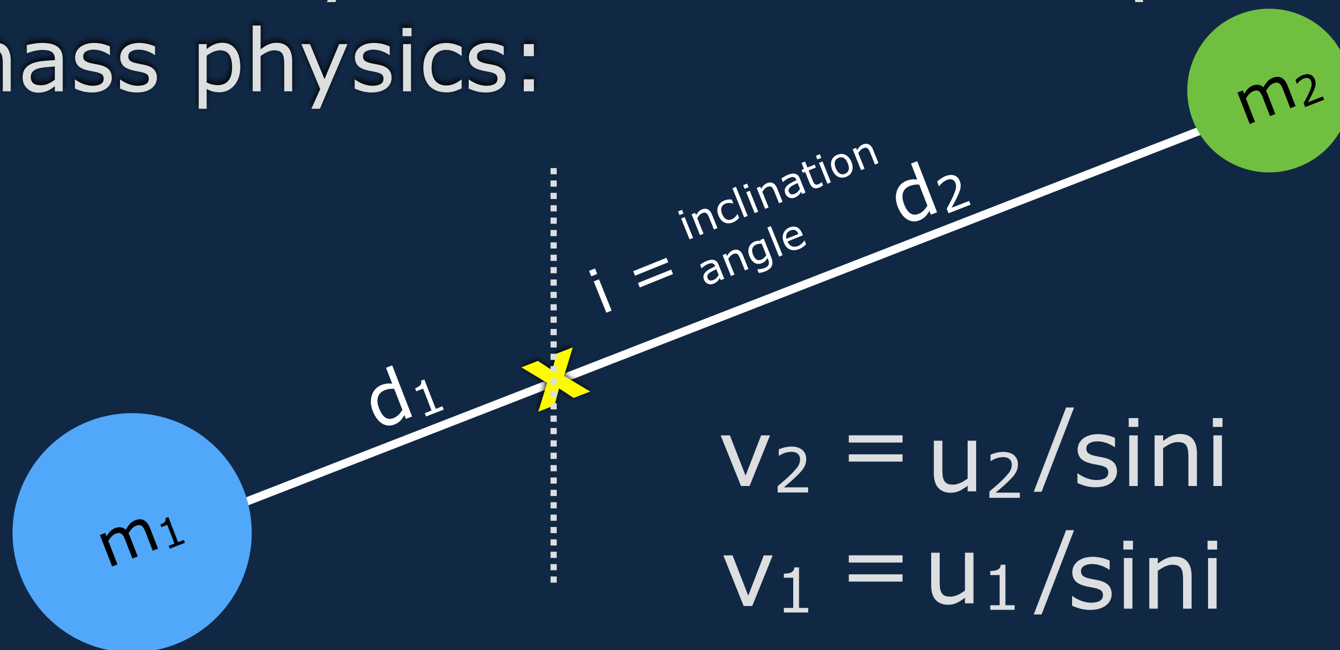
$$\frac{m_1}{m_2} = \frac{v_2}{v_1}$$

Properties of Stars - Mass

Determining Stellar Mass

A spectroscopic binary is a classic example of center-of-mass physics:

observer



$v_2 = u_2/\sin i$

$v_1 = u_1/\sin i$

i = 0: face on

i = 90: along orbital plane

$$\frac{m_1}{m_2} = \frac{v_2}{v_1} = \frac{u_2}{u_1}$$

Properties of Stars - Mass

Determining Stellar Mass

$$\frac{m_1}{m_2} = \frac{v_2}{v_1} = \frac{u_2}{u_1} \;,\; v_1 = u_1/\sin i$$

Properties of Stars - Mass

Determining Stellar Mass

$$\frac{m_1}{m_2} = \frac{v_2}{v_1} = \frac{u_2}{u_1} \ , \ v_1 = u_1/\sin i$$

We also know Kepler's 3rd Law:

$$m_1 + m_2 = \frac{4\pi^2 (a_1 + a_2)^3}{GP^2} \ , \ v_1 = \frac{2\pi a_1}{P}$$

where a_1 and a_2 are the semimajor axes of the two masses' elliptical orbits.

Properties of Stars - Mass

Determining Stellar Mass

$$\frac{m_1}{m_2} = \frac{v_2}{v_1} = \frac{u_2}{u_1} \;,$$

$$m_1 + m_2 = \frac{4\pi^2 (a_1 + a_2)^3}{GP^2} \;,$$

$$\frac{2\pi a_1}{P} = u_1/\sin i$$

Properties of Stars - Mass

Determining Stellar Mass

$$\frac{m_1}{m_2} = \frac{v_2}{v_1} = \frac{u_2}{u_1} \quad ,$$

$$m_1+m_2 = \frac{4\pi^2 (a_1+a_2)^3}{GP^2} \quad ,$$

$$a_1 = \frac{u_1 P}{2\pi \sin i}$$

$$a_2 = \frac{u_2 P}{2\pi \sin i}$$

Properties of Stars - Mass

Determining Stellar Mass

$$\frac{m_1}{m_2} = \frac{v_2}{v_1} = \frac{u_2}{u_1} \;,$$

$$m_1 + m_2 = \frac{4\pi^2 (a_1 + a_2)^3}{GP^2} \;,$$

$$a_1 + a_2 = \frac{(u_1 + u_2)\, P}{2\pi \sin i}$$

Properties of Stars - Mass

Determining Stellar Mass

$$\frac{m_1}{m_2} = \frac{v_2}{v_1} = \frac{u_2}{u_1} \;,$$

$$m_1 + m_2 = \frac{4\pi^2 \left(\frac{(u_1 + u_2)\,P}{2\pi \sin i} \right)^3}{G P^2}$$

Properties of Stars - Mass

Determining Stellar Mass

$$\frac{m_1}{m_2} = \frac{u_2}{u_1}$$

$$m_1 + m_2 = \frac{P\,(u_1 + u_2)^3}{2G\pi \sin^3 i}$$

Properties of Stars - Mass

Determining Stellar Mass

$$\boxed{\frac{m_1}{m_2} = \frac{u_2}{u_1}}$$

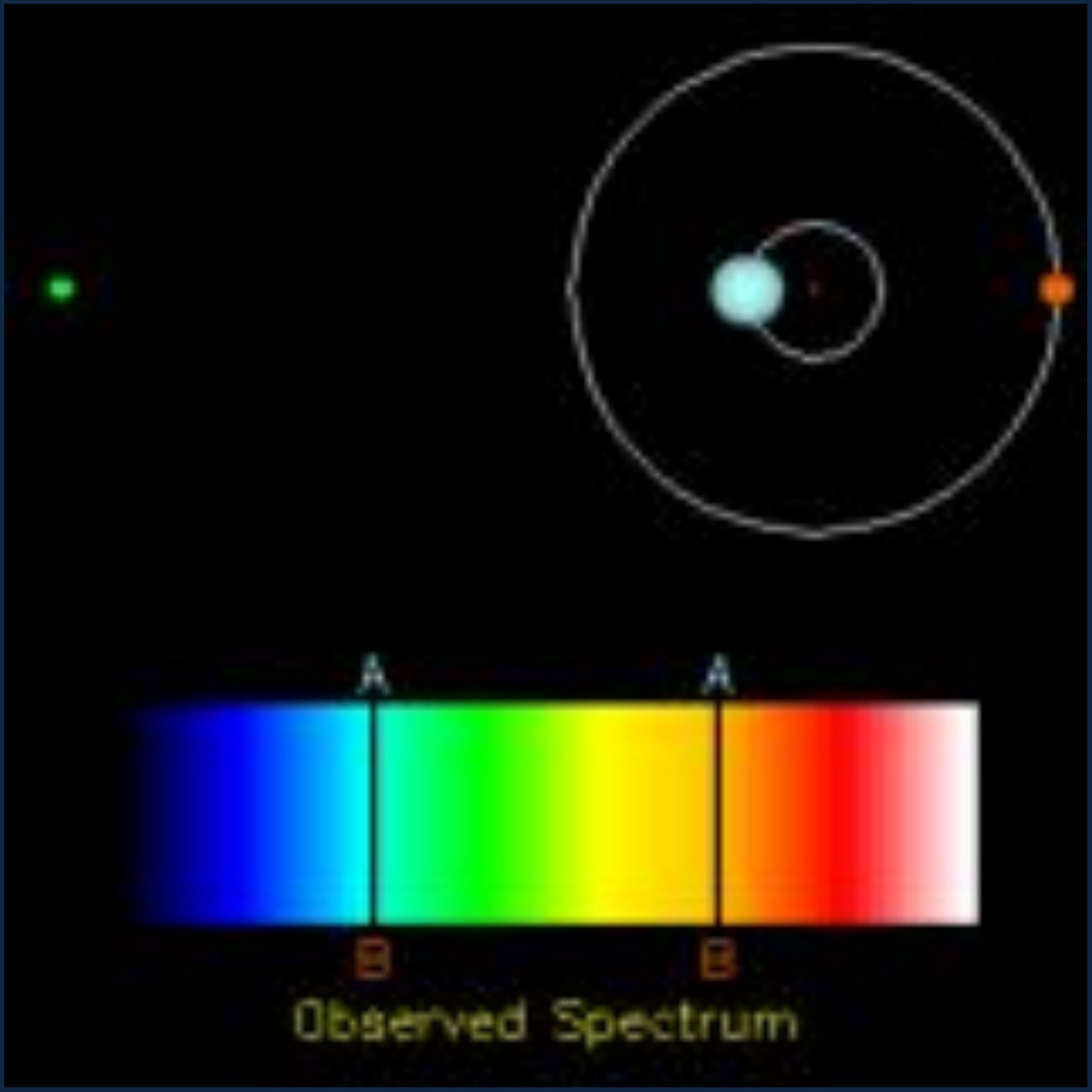
and

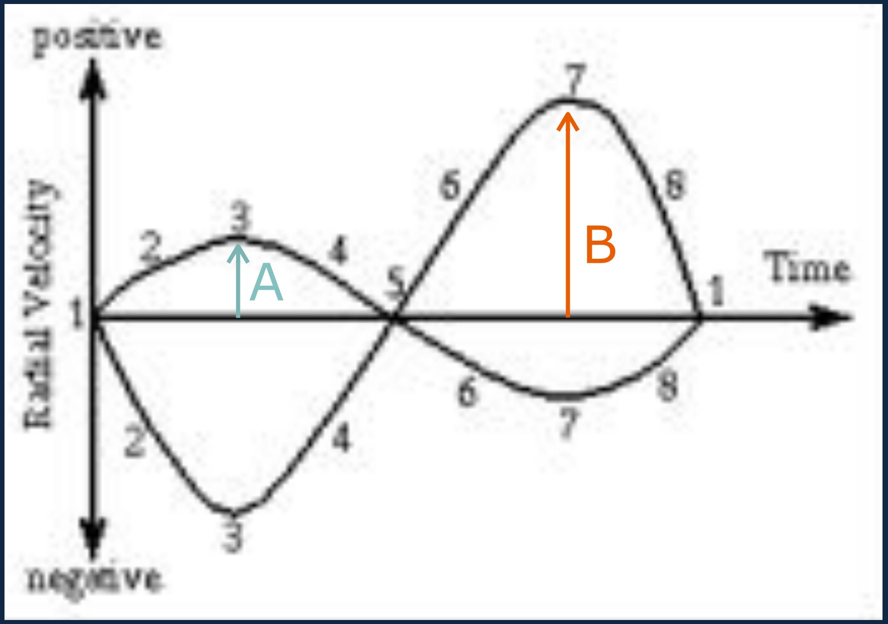
$$\boxed{m_1 + m_2 = \frac{P\,(u_1 + u_2)^3}{2G\pi \sin^3 i}}$$

give us masses from a spectroscopic binary

Properties of Stars - Mass

Determining Stellar Mass





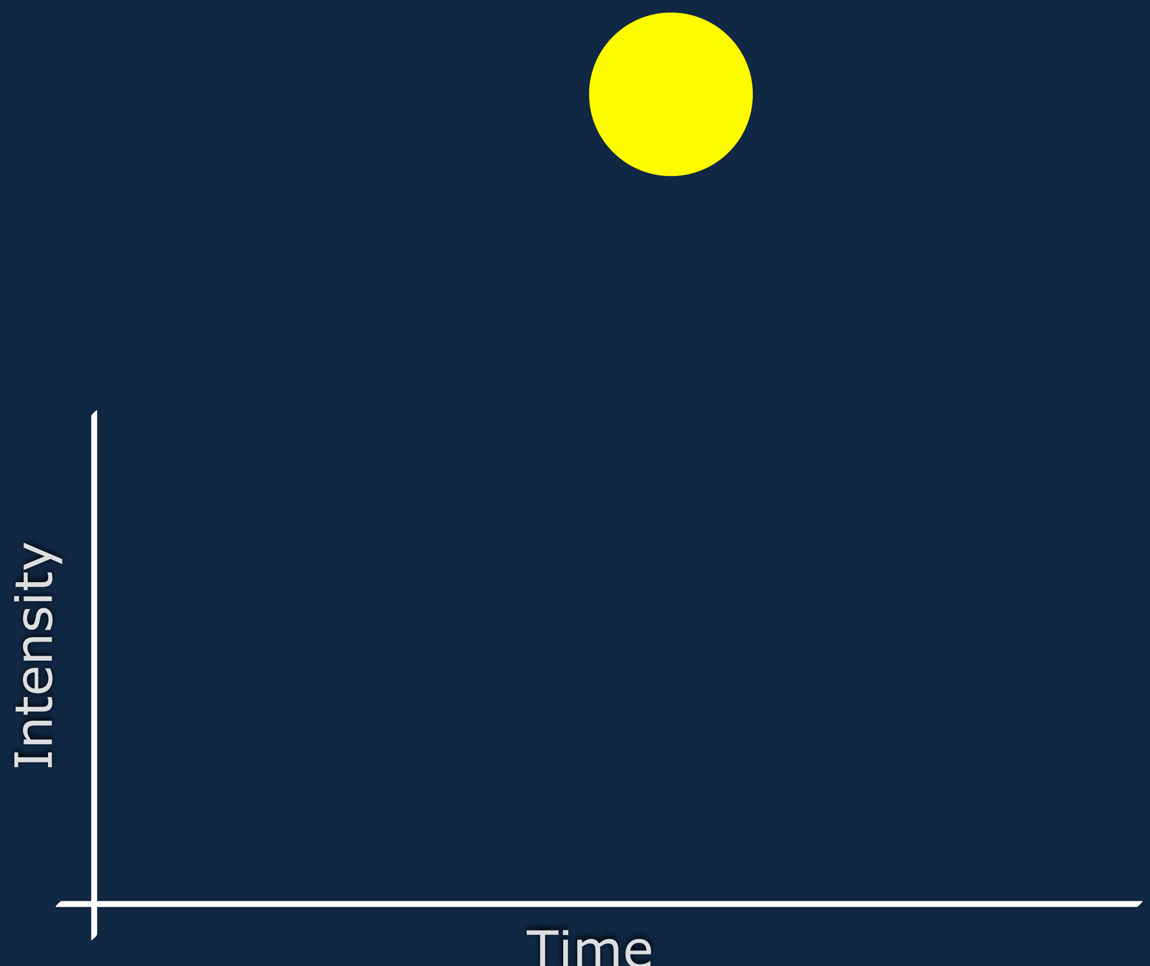
Properties of Stars - Radius

1) Distance - parallax, Cepheids
2) Velocity - proper motion, radial velocity
3) Brightness - magnitudes, luminosity
4) Temperature - effective temp (usually)
5) Mass - luminosity, binaries
6) Radius

Properties of Stars - Radius

Determining Stellar Radius

Lunar occultation



Properties of Stars - Radius

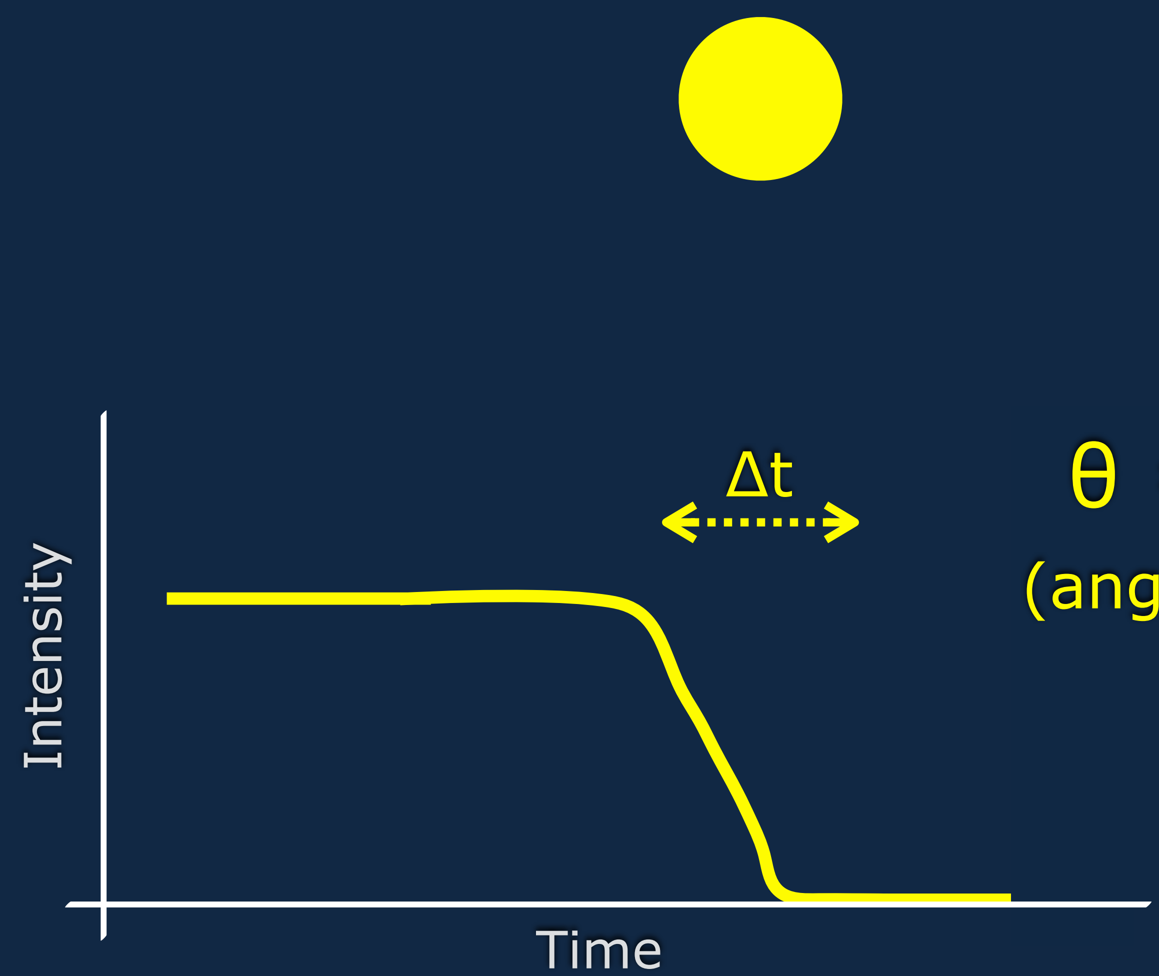
Determining Stellar Radius

Lunar occultation

Properties of Stars - Radius

Determining Stellar Radius

Lunar occultation



$\theta = v_{Moon}\Delta t$

(angular distance)

Properties of Stars - Radius

Discussion Question

Which of the following factors limit the use of the lunar occultation technique?

I: star brightness

II: star size

III: star position

IV: star temperature

A) II and III

B) I, II, and III

C) III only

D) all of the above

Time

Properties of Stars - Radius

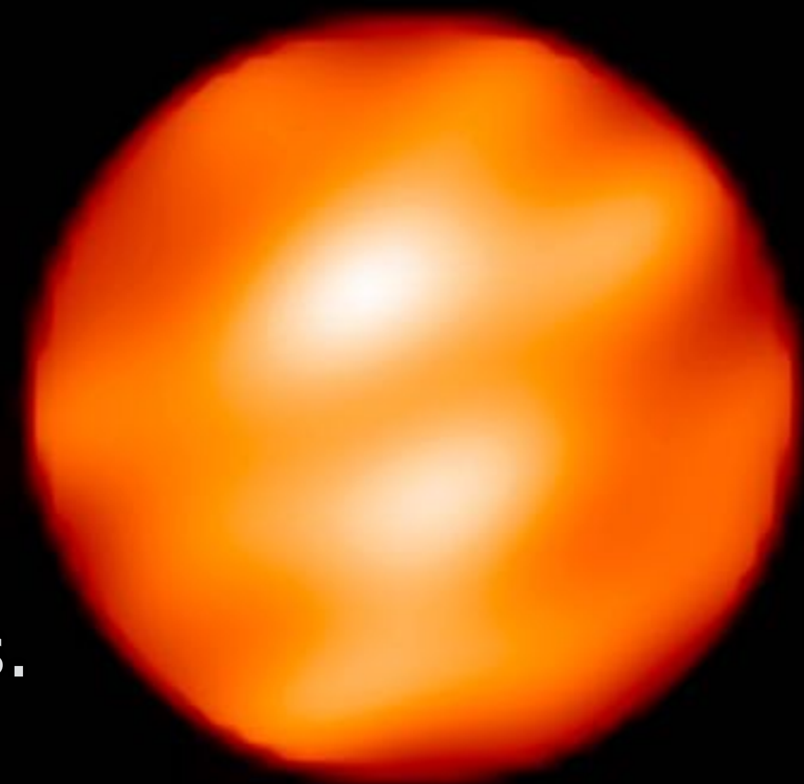
Determining Stellar Radius

Lunar occultation

Interferometry

We can use interferometry to push down towards diffraction-limited astro and image very large stars.

Easier at longer wavelengths.



Betelgeuse in the IR

10 mas

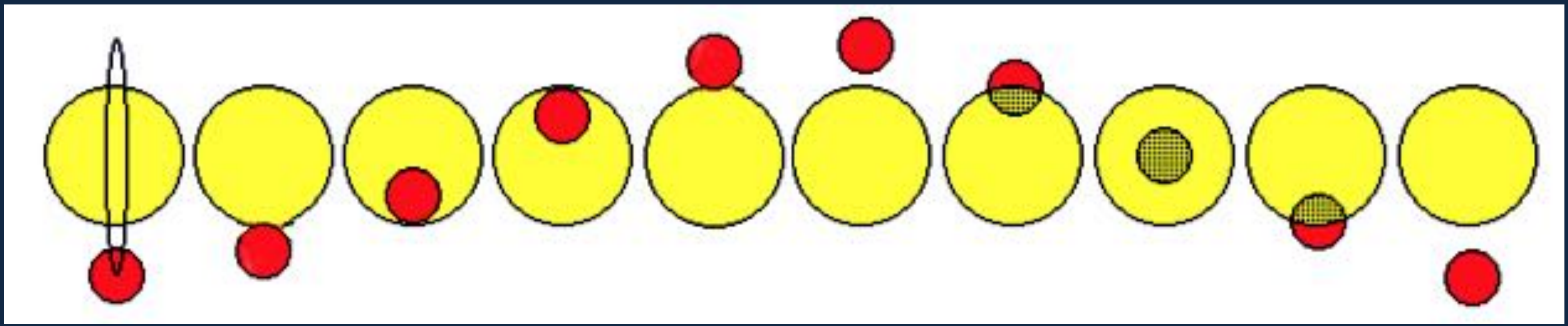
Properties of Stars - Radius

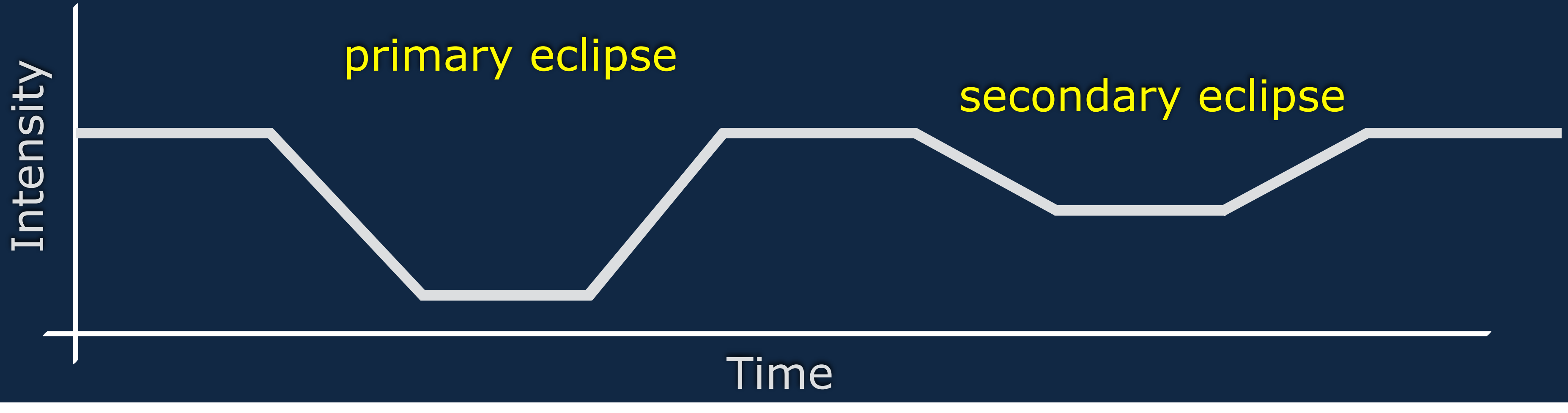
Determining Stellar Radius

Lunar occultation

Interferometry

Eclipsing binaries





Properties of Stars - Radius

<u>Determining Stellar Radius</u>

Lunar occultation

Interferometry

Eclipsing binaries

from T and L ($L = 4\pi R^2 \sigma T^4$)

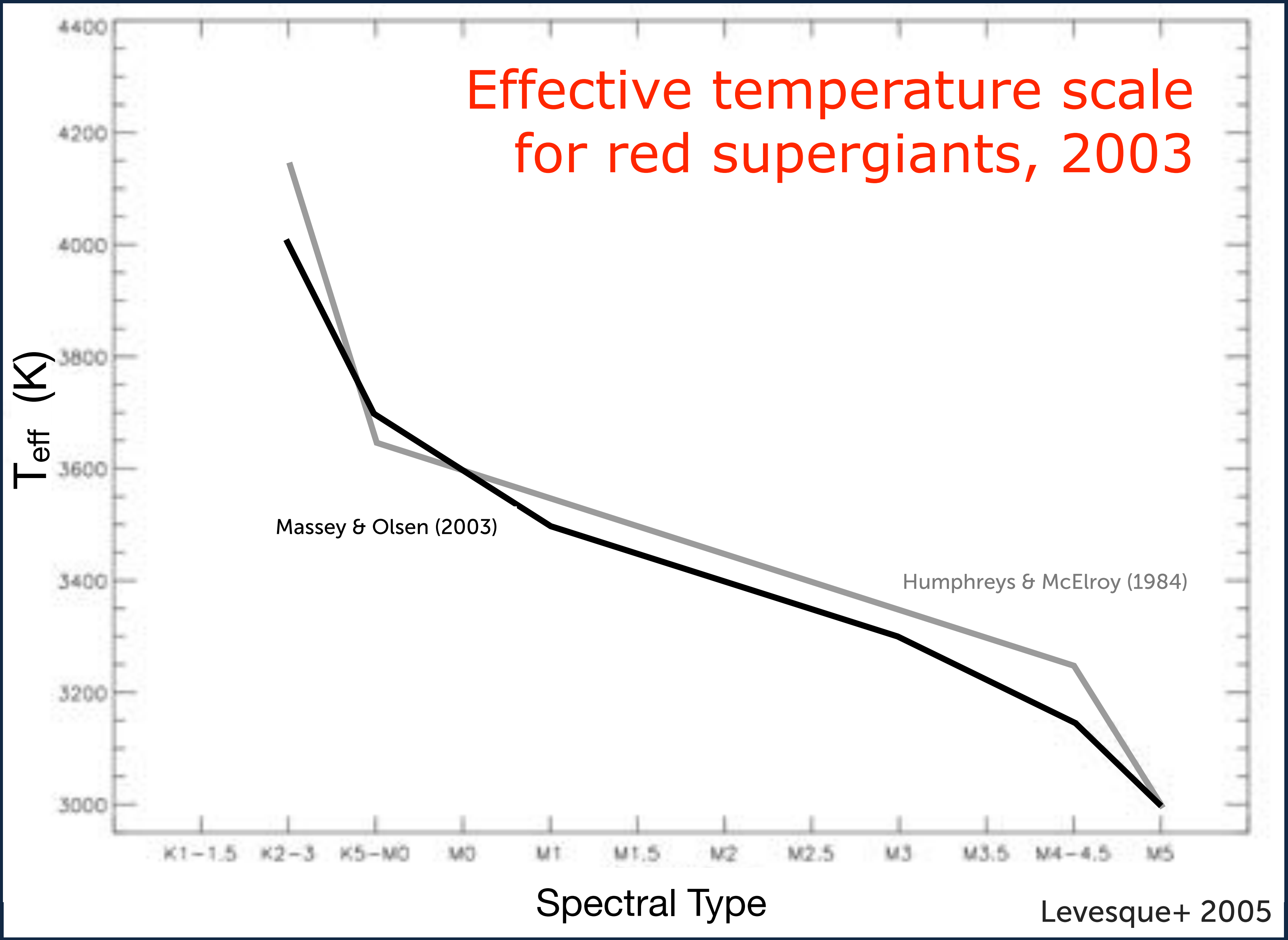
Properties of Stars - Radius

Determining Stellar Radius

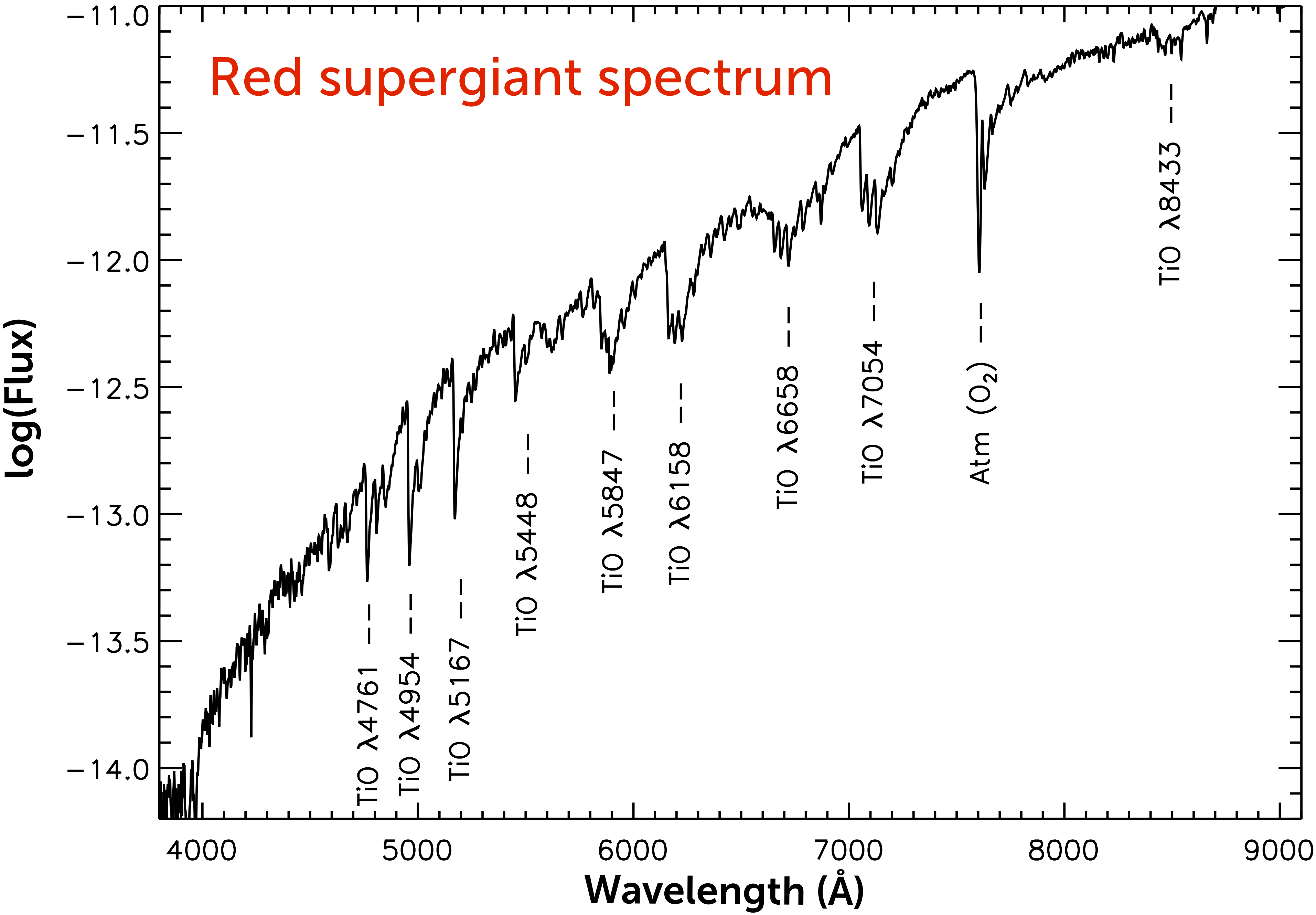
Smallest stars: neutron stars; ~city of Seattle

Largest stars: red supergiants…

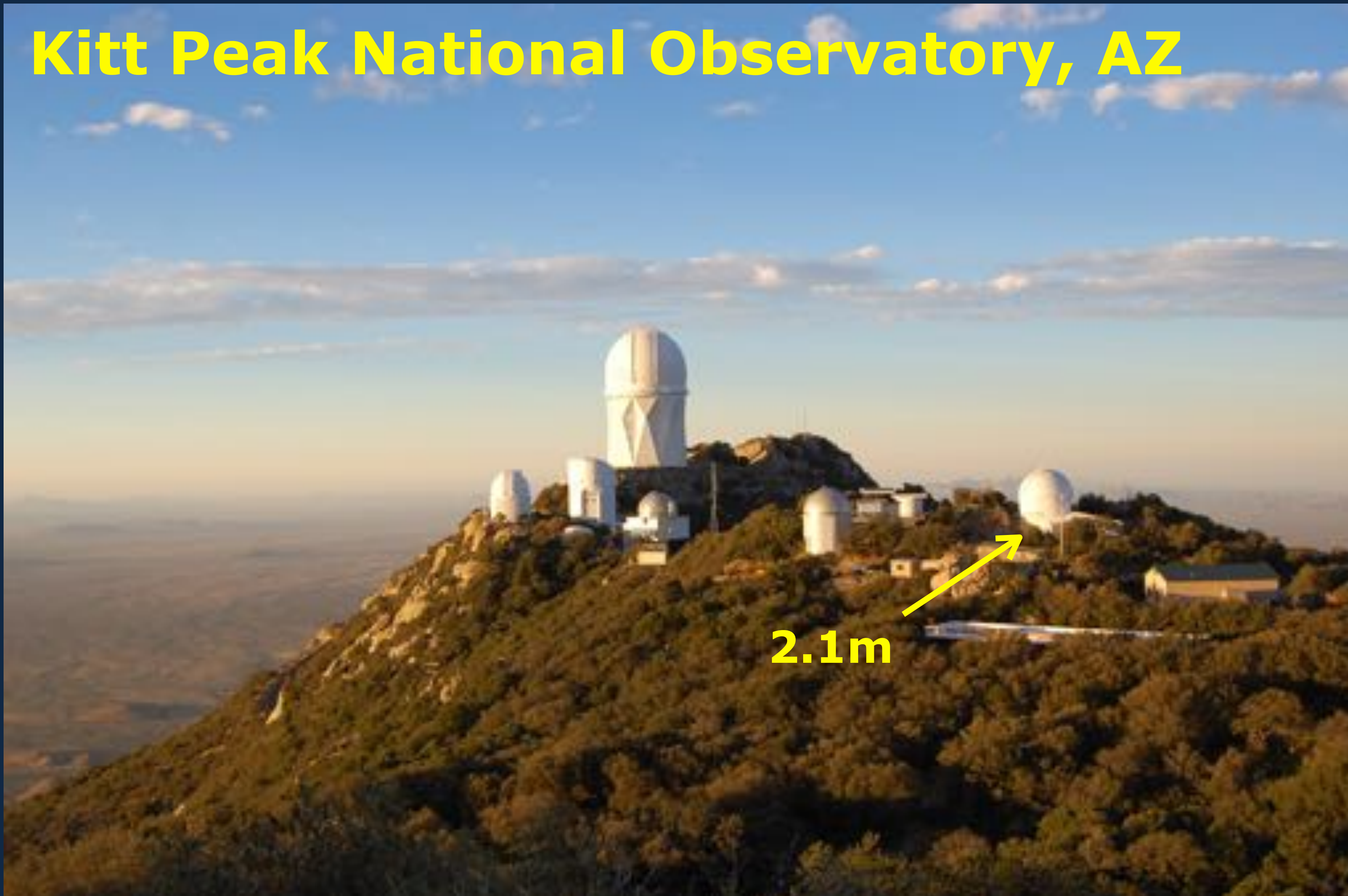
Properties of Stars - Radius



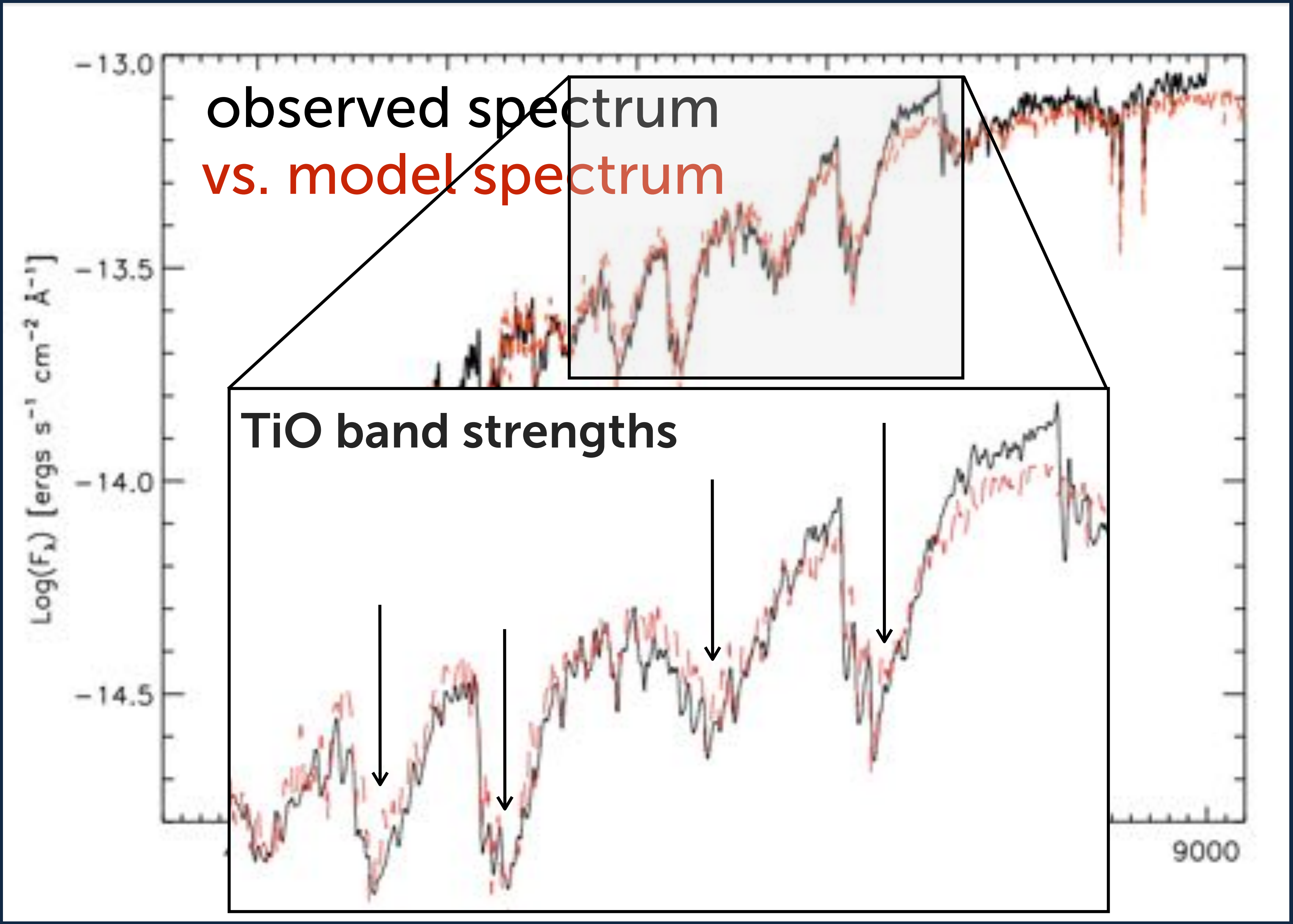
Properties of Stars - Radius



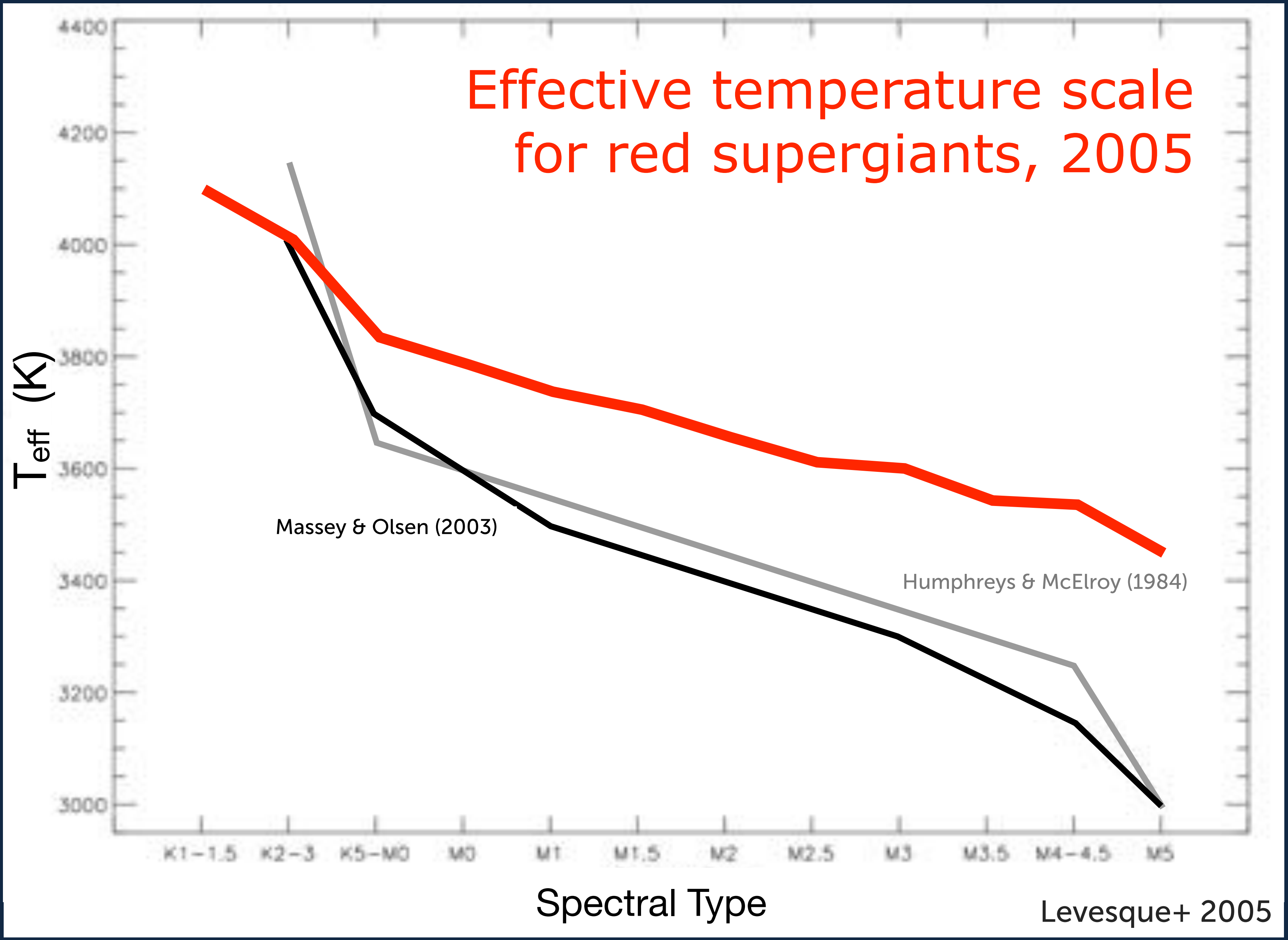
Properties of Stars - Radius



Properties of Stars - Radius



Properties of Stars - Radius



Properties of Stars - Radius

$$L = 4\pi R^2 \sigma T^4$$

Star	Sp Type	V	B-V	m-M	T_{eff} (K)	M_{bol}	R/R_{sun}
HD 90382	M3-M4 I	7.45	2.21	11.7	3550	-8.27	1060
HD 91093	M2 I	8.31	2.21	11.9	3625	-8.26	640
HD 303250	M2 I	8.92	2.51	11.9	3625	-7.60	750
HD 93420	M4 I	7.55	1.87	12.0	3525	-7.60	790
HD 94096	M2 I	7.38	2.24	12.0	3650	-8.08	920
HD 95687	M3 I	7.35	2.12	11.6	3625	-7.63	760
HD 95950	M2 I	6.75	2.04	11.6	3700	-7.54	700
V396 Cen	M3-M4 I	7.85	2.15	11.6	3550	-8.29	1070
HD 160371	K2.5 I	6.14	1.82	8.4	3900	-3.63	100
KY Cygni	M3-M4 I	10.57	3.64	11.0	3500	-10.36	2850
HD 339034	K3 I	9.36	3.05	11.8	4000	-8.63	980

Levesque et al. (2005)

Properties of Stars - Radius

Determining Stellar Radius

Smallest stars: neutron stars; ~city of Seattle

Largest stars: red supergiants; ~orbit of Jupiter

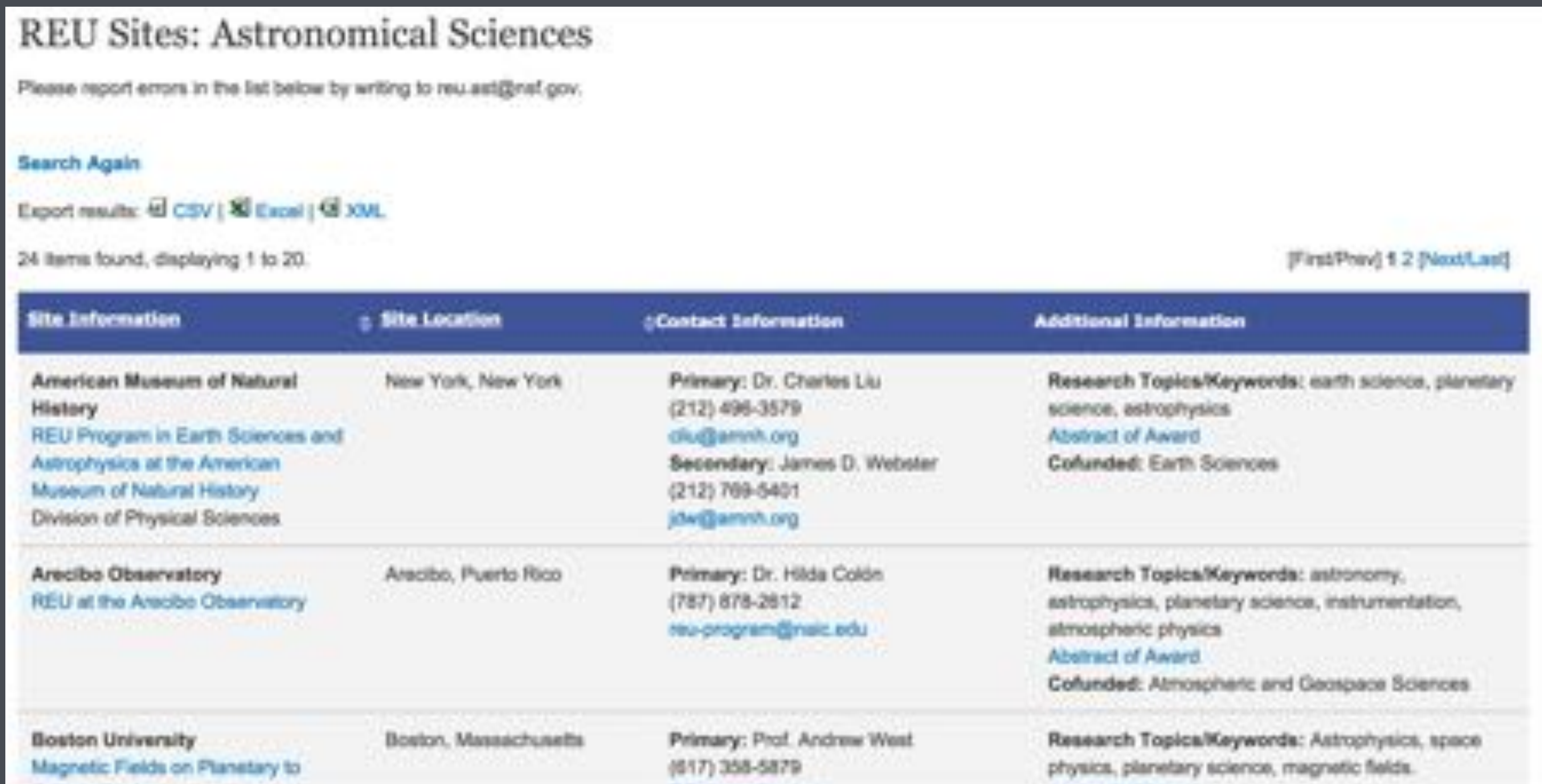
Properties of Stars - Radius

NSF REU Programs in Astronomy

- ~2-month summer research internships at research sites around the world
- **paid** research with an REU adviser or group
- apply directly to specific sites; typical application includes essay, transcripts, and reference letters
- most deadlines are ~Jan-Feb
- *excellent* opportunity to present, publish, and strengthen graduate school applications

Properties of Stars - Radius

NSF REU Programs in Astronomy



REU Sites: Astronomical Sciences

Please report errors in the list below by writing to reu.ast@nsf.gov.

Search Again

Export results: CSV | Excel | XML

24 items found, displaying 1 to 20.

[First/Prev] 1 2 [Next/Last]

Site Information	Site Location	Contact Information	Additional Information
American Museum of Natural History REU Program in Earth Sciences and Astrophysics at the American Museum of Natural History Division of Physical Sciences	New York, New York	**Primary:** Dr. Charles Liu (212) 496-3579 cliu@amnh.org **Secondary:** James D. Webster (212) 769-5401 jdw@amnh.org	**Research Topics/Keywords:** earth science, planetary science, astrophysics Abstract of Award **Cofunded:** Earth Sciences
Arecibo Observatory REU at the Arecibo Observatory	Arecibo, Puerto Rico	**Primary:** Dr. Hilda Colón (787) 878-2612 reu-program@naic.edu	**Research Topics/Keywords:** astronomy, astrophysics, planetary science, instrumentation, atmospheric physics Abstract of Award **Cofunded:** Atmospheric and Geospace Sciences
Boston University Magnetic Fields on Planetary to	Boston, Massachusetts	**Primary:** Prof. Andrew West (617) 358-5879	**Research Topics/Keywords:** Astrophysics, space physics, planetary science, magnetic fields.

Link on class website!

Saturn

Properties of Stars

1) Distance - parallax, Cepheids
2) Velocity - proper motion, radial velocity
3) Brightness - magnitudes, luminosity
4) Temperature - effective temp (usually)
5) Mass - luminosity, binaries
6) Radius - lunar, interferometry, binaries, L & T

Exam #1 - Policies

PAA A10

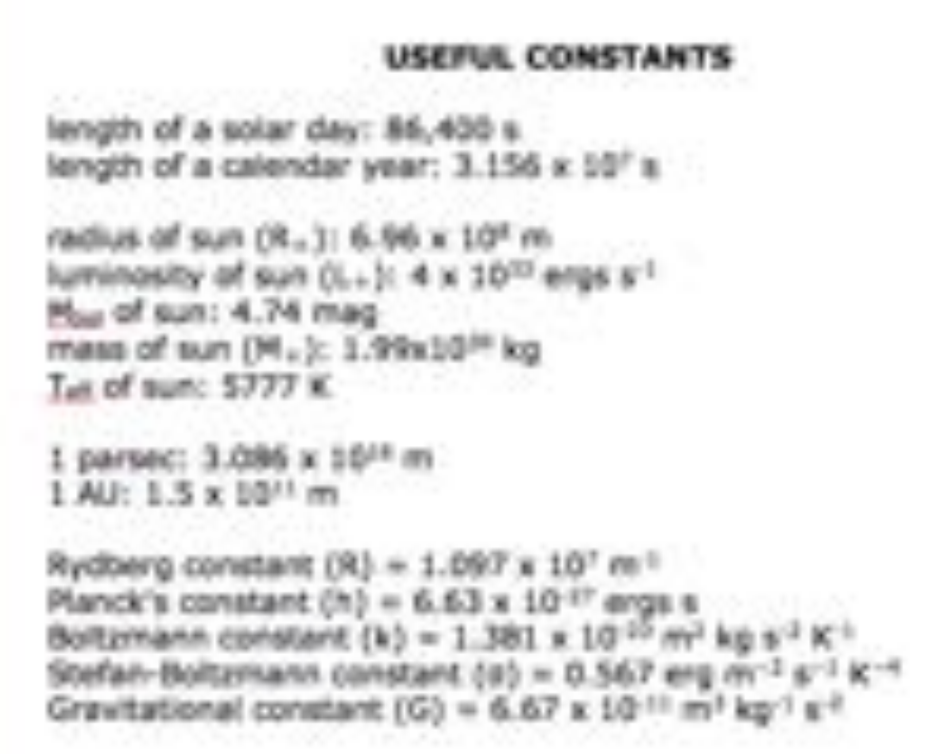
— format: short answers (problems, paragraphs)

— exam goes from 1:30pm - 2:50pm

— scientific calculators are the **only** devices allowed

— one 8.5x11 page of notes (both sides) is allowed

You will be given this:



USEFUL CONSTANTS

length of a solar day: 86,400 s
length of a calendar year: 3.156×10^{7} s

radius of sun ($R_\odot$): 6.96×10^{8} m
luminosity of sun ($L_\odot$): 4×10^{33} ergs s^{-1}
M_{bol} of sun: 4.74 mag
mass of sun ($M_\odot$): 1.99×10^{30} kg
T_{eff} of sun: 5777 K

1 parsec: 3.086×10^{16} m
1 AU: 1.5×10^{11} m

Rydberg constant (R) = 1.097×10^{7} m^{-1}
Planck's constant (h) = 6.63×10^{-27} ergs s
Boltzmann constant (k) = 1.381×10^{-23} m^2 kg s^{-2} K^{-1}
Stefan-Boltzmann constant (σ) = 0.567 erg m^{-2} s^{-1} K^{-4}
Gravitational constant (G) = 6.67×10^{-11} m^3 kg^{-1} s^{-2}

You will **not** be given:

— equations

— relations

— basic units (microns, angstroms, Hz)

Coming up next...

Thursday, Oct 26: exam review

slidecast; link on class website!

exam prep: extra office hours

Mon Oct 30: 10-11am, 1-4pm

Tuesday, Oct 31: Exam #1