ASTR2013 – *Foundations of Astrophysics*

Week 1: Making Astronomical Observations. Basic observations of Stars.

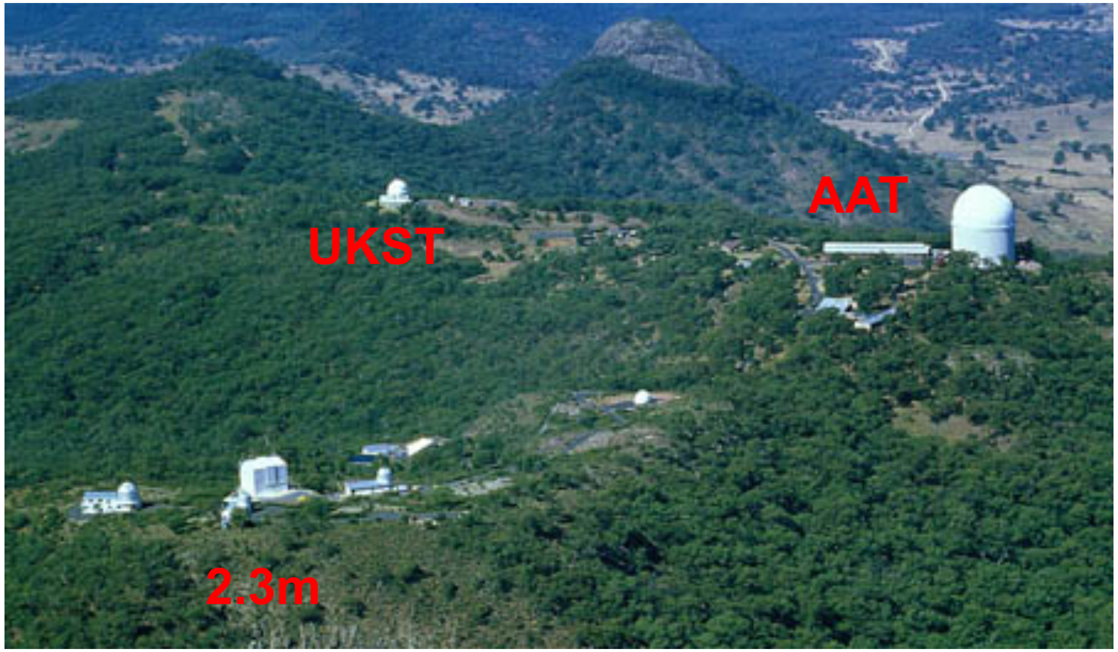
Mike Ireland

Intro to RSAA

- Established as Commonwealth Solar Observatory in 1924
- Became part of the Australian National University in 1954
- Established Siding Spring Observatory in 1960
- We are ranked as one of the top 10 research institutes in the world for astronomy and space science.
- Our staff have been recognized with major prizes including the 2011 Nobel Prize for Physics.

Offices, Labs, Observatories

- As Canberra grew, “dark sky” astronomy moved to Siding Spring observatory.
- At 6.5 hours driving time, you can only go there on a vacation project or… the ASTR2013 field trip!



New Astrophysics Major

- ASTR2013 leads into ASTR3002, ASTR3007, ASTR3013, ASTR8011 and other honours/Masters subjects.
- Not a pre-requisite yet, but will almost certainly become one in time (esp. for ASTR3007).
- Most important for a successful 3rd year research project! (ASTR3005 or PhB)

36 units from completion of the following courses:

PHYS1101 Physics 1

PHYS1201 Physics 2

PHYS2013 Quantum Mechanics

PHYS2020 Thermal and Statistical Physics

ASTR2013 Foundations of Astrophysics

ASTR3013 Astrophysical Processes

A minimum of 6 units from completion of one of the following courses:

ASTR3002 Galaxies and Cosmology

ASTR3007 Stars

A maximum of 6 units from completion of one of the following courses:

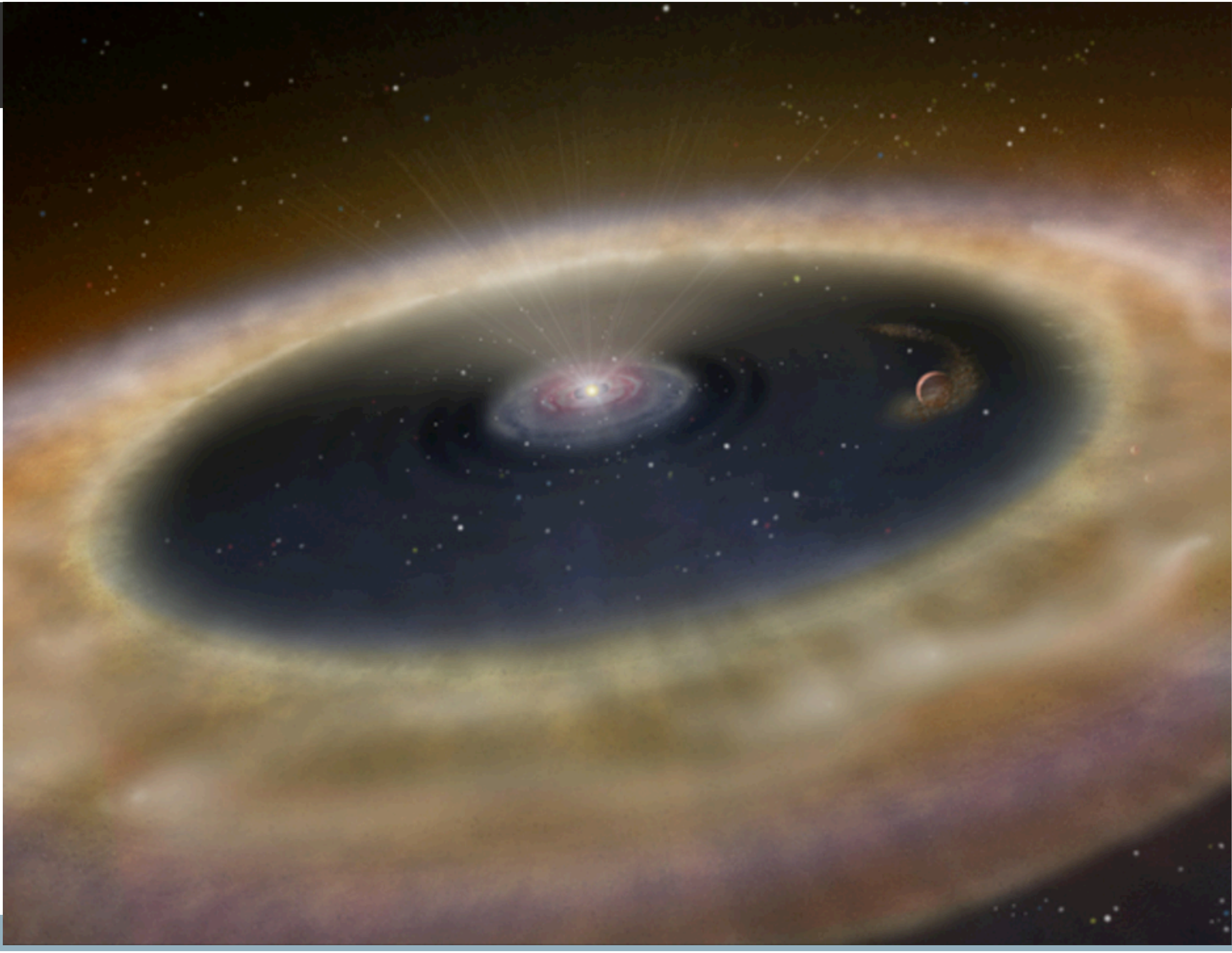
ASTR3005 Astrophysics Research Topic

EMSC3022 Planetary Science

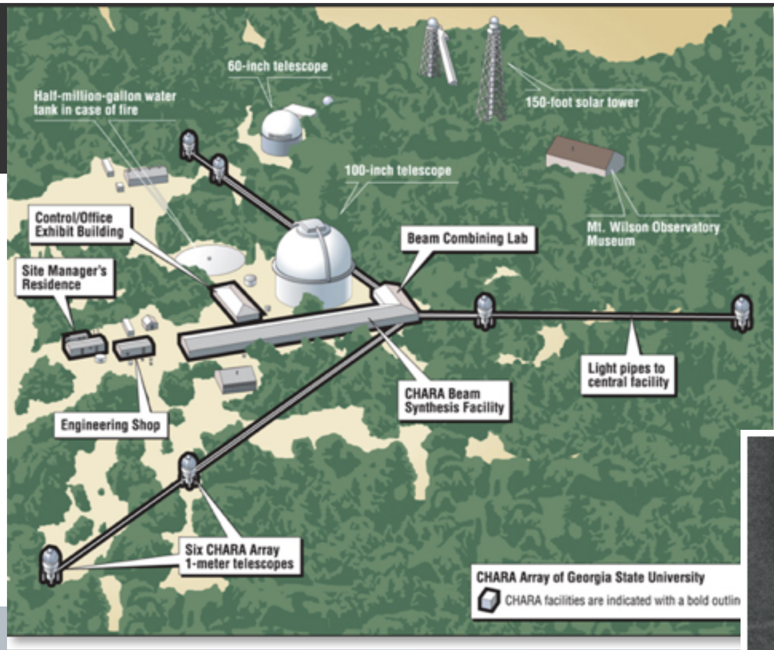
PHYS3057 Optical Physics

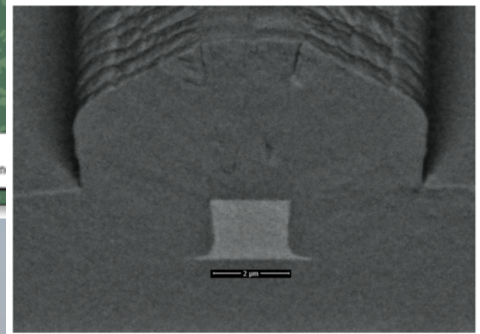
Intro to Me and your Tutors

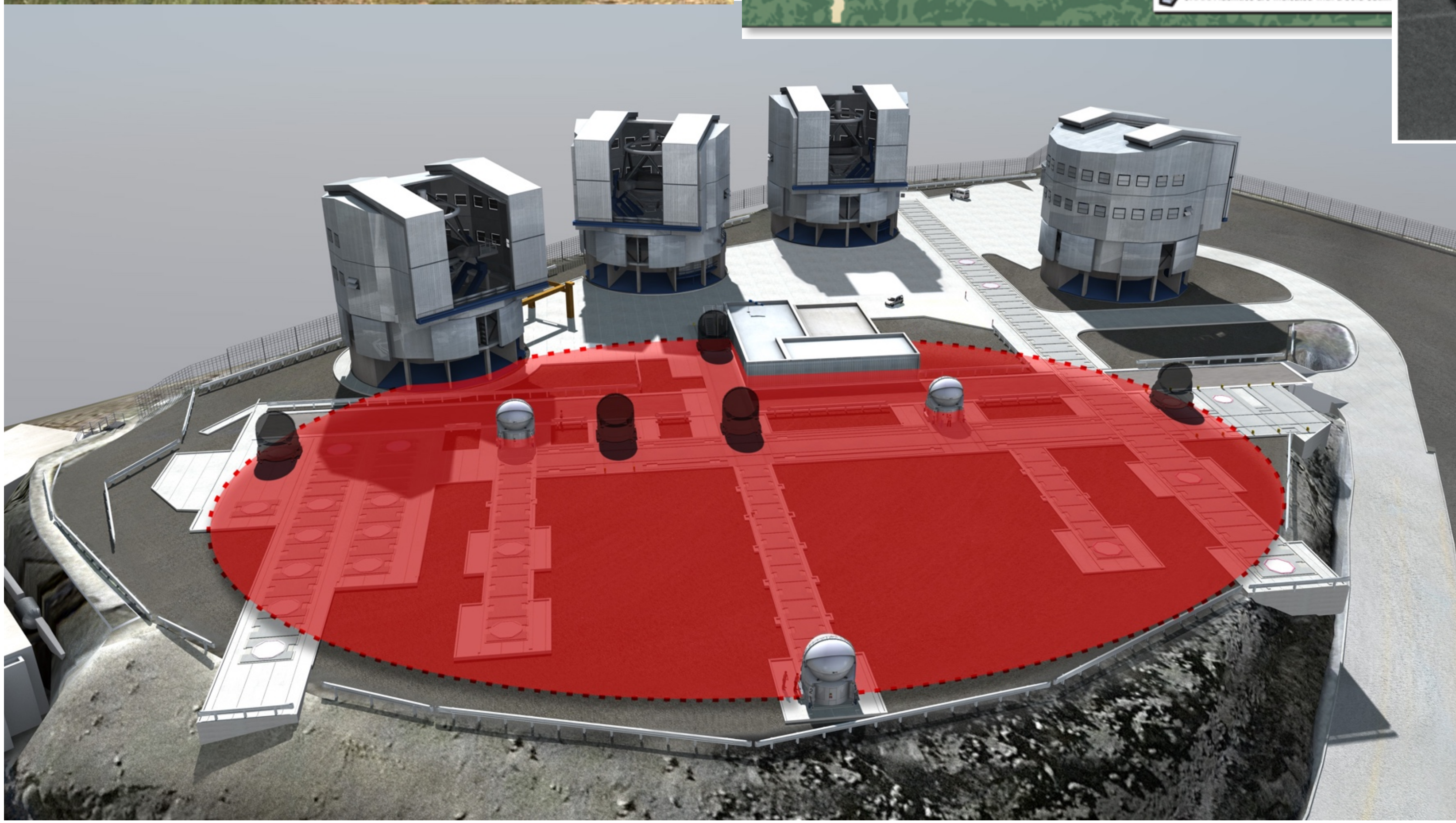
- I'm ~40% an observational stellar and planetary astrophysicist, 40% a scientist developing new instruments for telescopes, and 20% "other".
- See http://www.mso.anu.edu.au/~mireland, Google Scholar and NASA ADS.
- Rotating Tutors are current PhD students:
  - Jack Livingston (radio observations of diffuse gas in the Galaxy and environs)
  - Stephanie Monty (galactic archaeology, metal poor stars and new instruments)
  - Abdu Abohalima (3D computational models of stars)
  - Jamie Soon (instrumentation and infrared bright supernovae)




SYDNEY UNIVERSITY STELLAR INTERFEROMETER
SUSI
AUSTRALIA


60-inch telescope
150-foot solar tower
Half-million-gallon water tank in case of fire
100-inch telescope
Mt. Wilson Observatory Museum
Control/Office Exhibit Building
Beam Combining Lab
Site Manager's Residence
Light pipes to central facility
CHARA Beam Synthesis Facility
Engineering Shop
Six CHARA Array 1-meter telescopes
CHARA Array of Georgia State University
CHARA facilities are indicated with a bold outlin





Course Structure and Expectations

- See the “Class Summary” for Key details of timeline, assessment and policies…
- Schedule largely follows the text:

  Dan Maoz: Astrophysics in a Nutshell.

Class Schedule

WEEK/SESSION	SUMMARY OF ACTIVITIES	ASSESSMENT
1	Week 1 Making Astronomical Observations. Basic observations of Stars.	
2	Week3 2-3 Stellar Physics	
3	Weeks 4-5 Stellar Evolution	
4	Week 6 Practical Astronomical Observations and Coordinate Systems	
5	Week 7 The Interstellar Medium and Star Formation	
6	Week 8 Structure and Dynamics of the Milky Way	
7	Week 9 Other Galaxies and Active Galactic Nuclei	
8	Week 11 Big Bang Cosmology (NB Week 10 a Public Holiday)	
9	Week 12 Special Topic in Astrophysics	

Course Structure and Expectations

- Assessment is split between by problem sets (first one given out later today), final exam and the field trip.
- Field trip will be ~9am on 2 Sep to 6pm on 5 Sep, and includes using the ANU 2.3m telescope in small groups. Cost is $200, with more official details later this week (but please ask questions now!)

Assessment Summary

ASSESSMENT TASK	VALUE	DUE DATE	RETURN OF ASSESSMENT
Problem Sets	40 %	02/08/2019	01/11/2019
Field Trip Report	20 %	20/09/2019	11/10/2019
Participation and Performance during Field Trip	10 %	05/09/2019	13/09/2019
End of Semester exam	30 %	31/10/2019	28/11/2019

Course Structure and Expectations

- The 3 hours per week face to face plus ~14 hours compulsory assessable activities on the field trip makes up less than half the time you're expected to spend on this course.
- Each week, you'll should spend at least an hour reading the applicable textbook sections, some time revising and the rest on the problems sets and assessments.
- Every second tutorial will provide and opportunity to discuss the assessable problem sets with tutors and peers. Work is expected to be your own, but we will cover related problems in tutorials and you're certainly free to ask questions.
- We will also need 2 class representatives to provide feedback, and I'll be hoping for volunteers during tutorial.

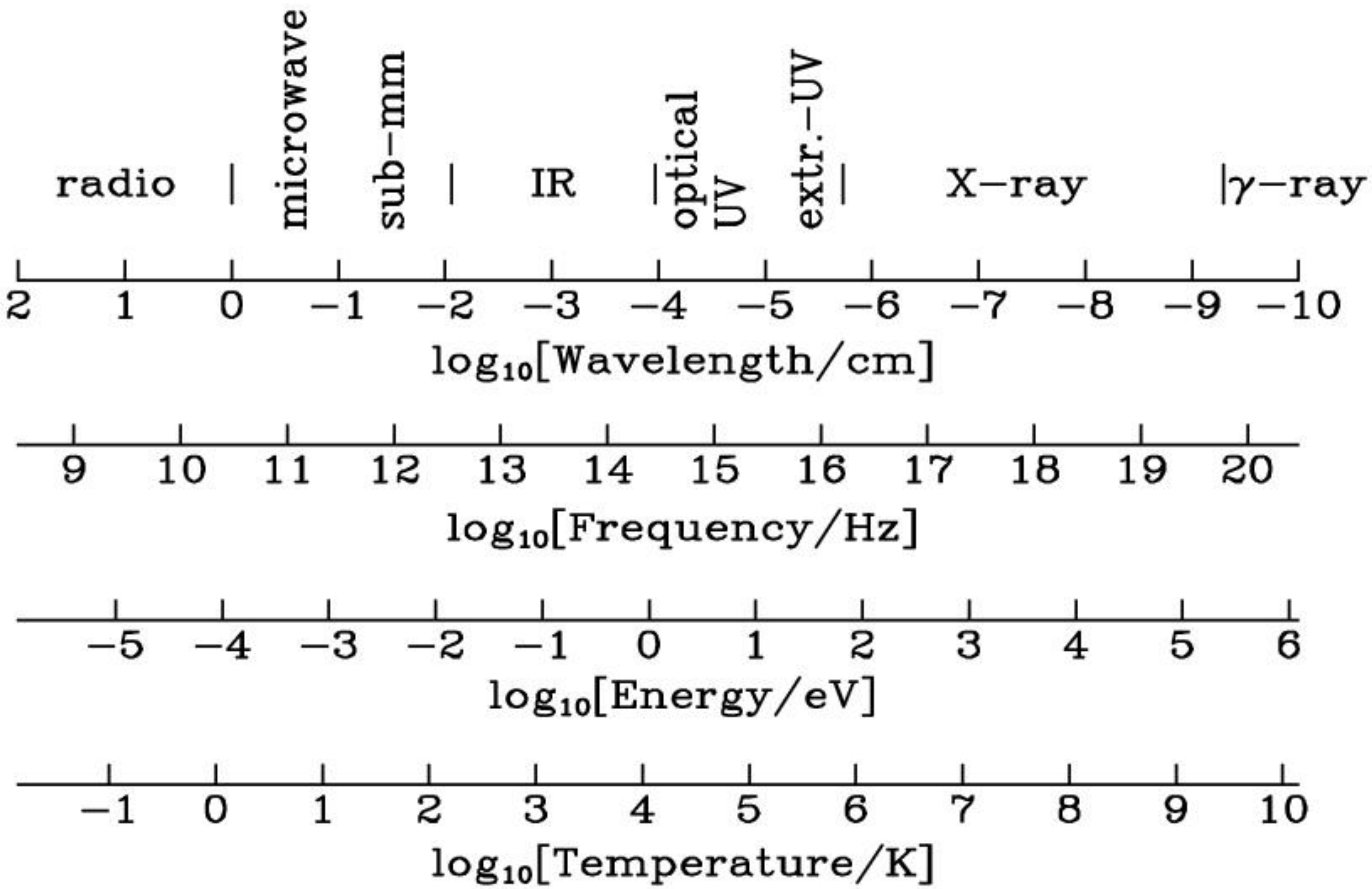
Questions now?

Week 1 Summary

Textbook: Sections 1.1, 2.1 and 2.2.

1. Angular resolution and Diffraction Limit.
2. Telescopes as photon counters.
3. Blackbody radiation
   a) Energy density.
   b) Specific Intensity and Flux.
   c) Asymptotic forms (Wien and Rayleigh-Jeans)
4. Three main observation types:
   a) Photometry: counting photons.
   b) Spectroscopy: measuring photon wavelength or frequency.
   c) Astrometry: measuring photon angle of arrival.

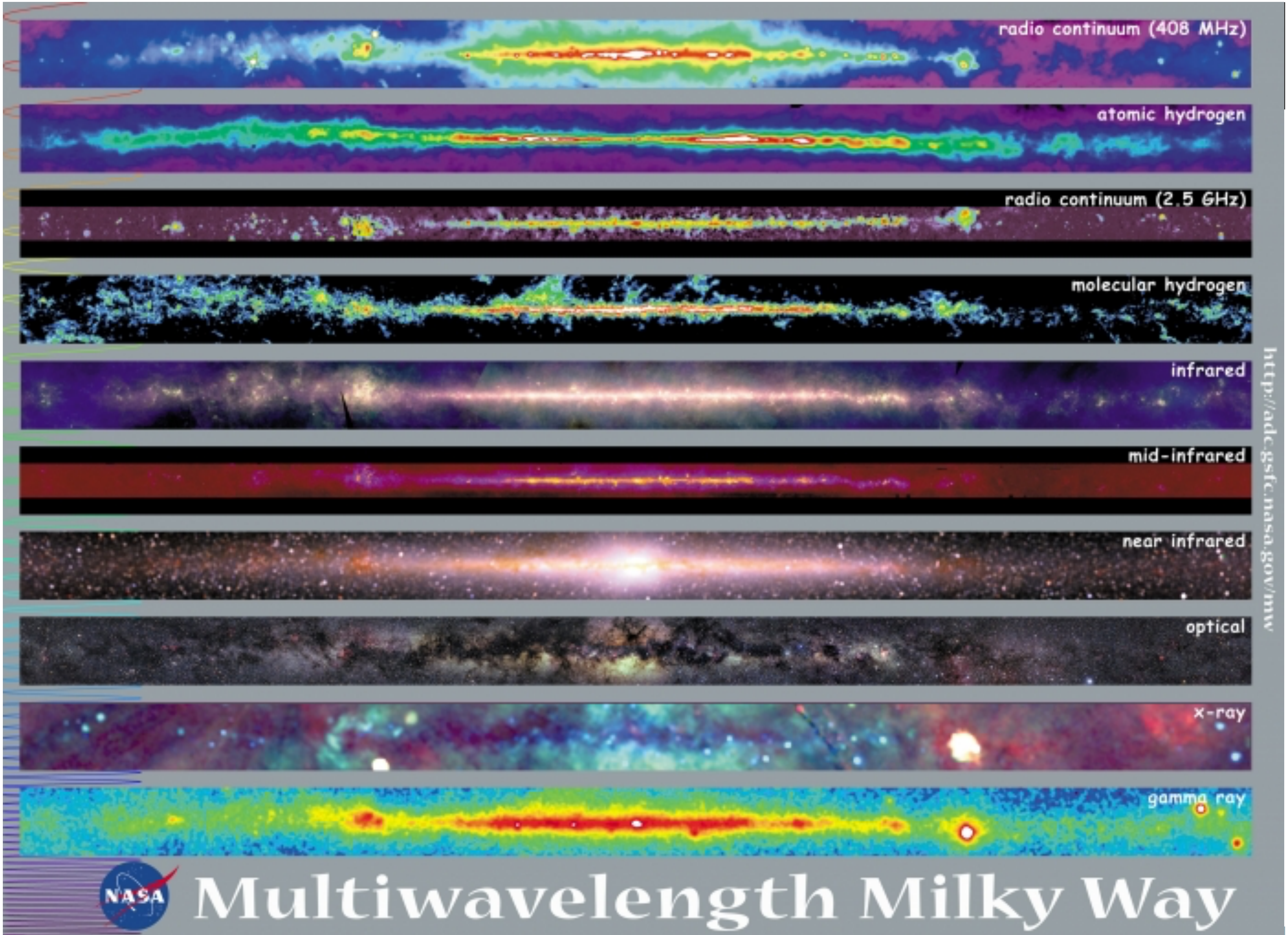
Electromagnetic Waves as Primary Probes



$$\lambda = \frac{c}{\nu}$$

$$E = h\nu$$

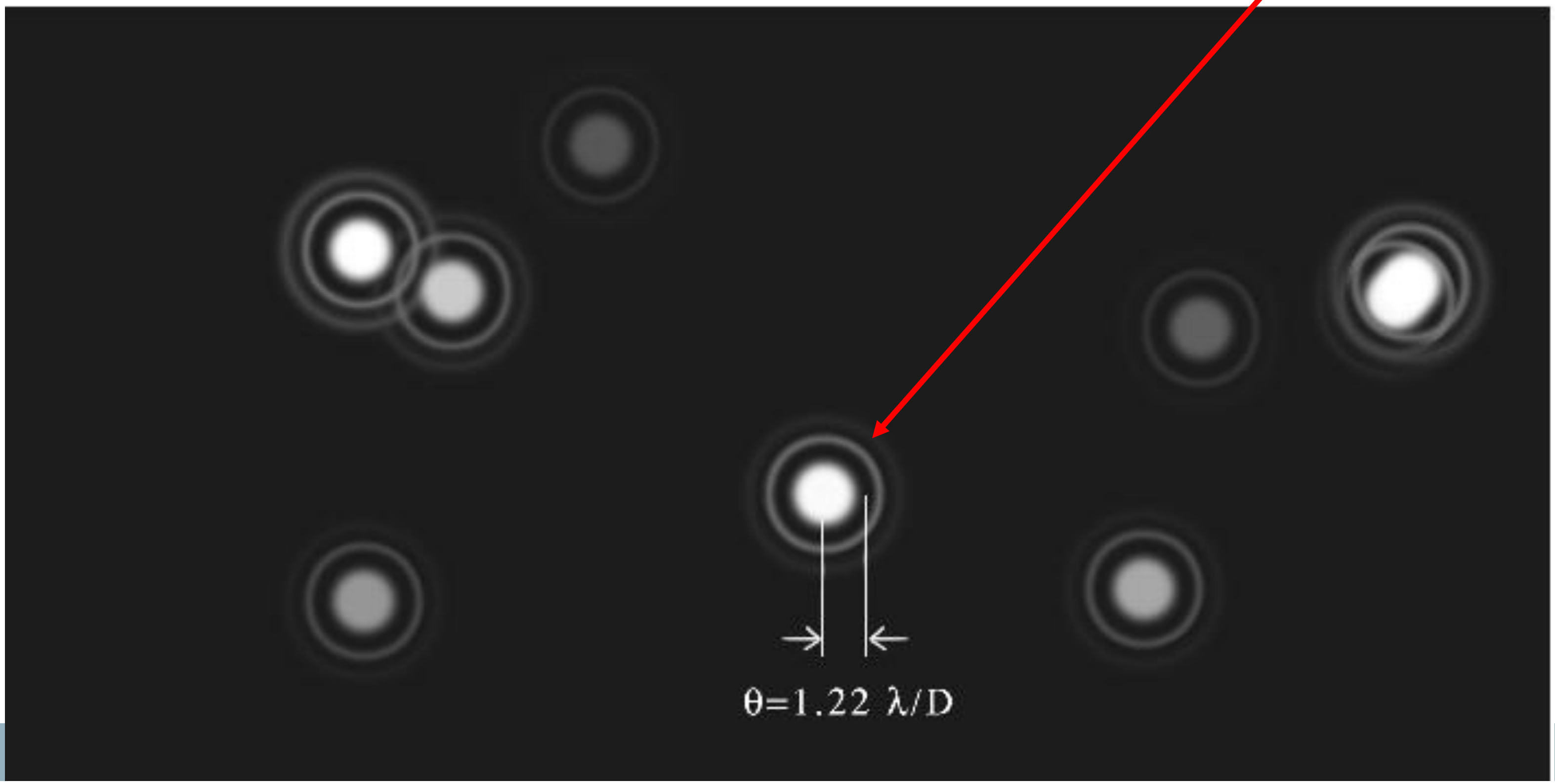
$$E = k_B T$$


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way

Diffraction Limit

- Wave nature of light means that an aperture of size ~λ diffracts light by about a radian.
- Larger circular apertures are described by *Fraunhofer Diffraction.*

“Airy Disk” (described by Bessel Functions)



Photons and Quantum Mechanics

- Whenever we want to add up the energy in an electromagnetic wave, we can only do so in discrete units - photons. Each photon has an energy equal to:

$$\begin{aligned} E &= h\nu \\ &= \frac{hc}{\lambda}. \end{aligned}$$

- Many astronomical measurements are about counting photons - the rate of photons arriving in a range of wavelengths (or frequency) tells us the about the energy output of the astronomical source at that wavelength (frequency) range.
- Although photons are the observed units of energy, there are other more general definitions we have to consider…

Poisson Statistics In More Detail

- Applies only to light in the particle approximation…
- If the number of photons expected to arrive in a particular aperture from a particular range of angles in a particular wavelength (frequency) range is *r*, then the actual number of detected photons has a Poisson distribution:

$$P(N = k) = \frac{r^k e^{-r}}{k!}$$

- Importantly, the variance of *N* is *r*, the standard deviation is $\sqrt{r}$, so:

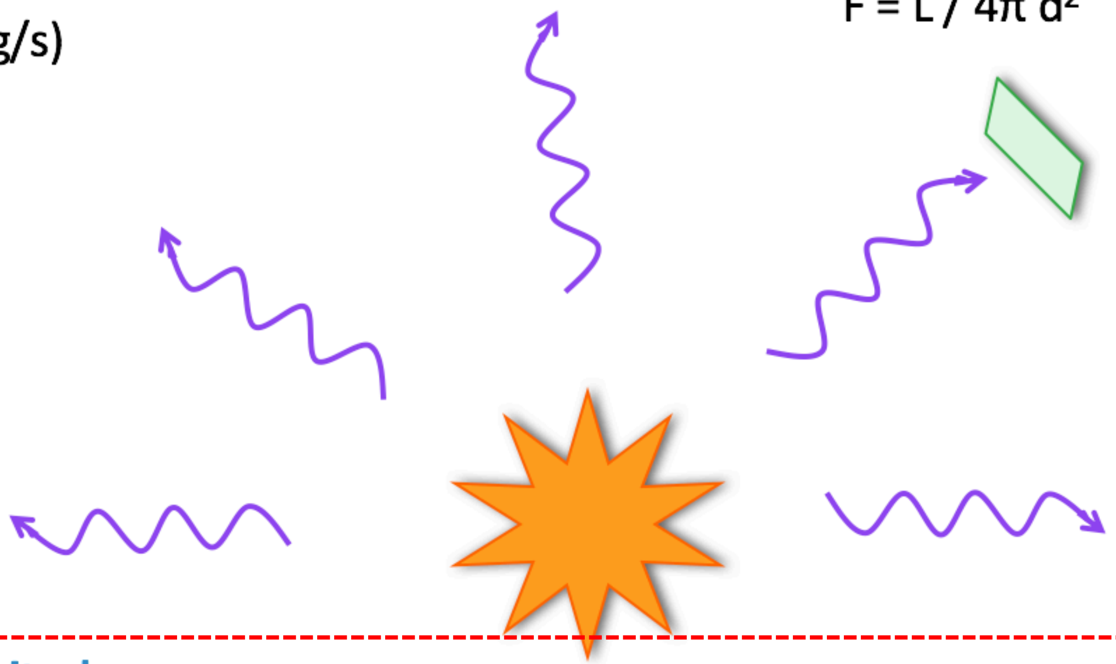
$$S/N = \sqrt{r} \approx \sqrt{N}$$

See python example

Luminosity and Flux

intrinsic **luminosity**
L = energy emitted
per second (erg/s)

flux F = energy received
per unit area
$F = L / 4\pi d^2$ (erg/s/cm^2)



apparent magnitude m =
measure of flux relative to
chosen standard

$m_1 - m_2 = -2.5 \log_{10} (F_1/F_2)$

Week 6…

distance modulus
$m - M = 5 \log_{10} (d/10\text{pc})$

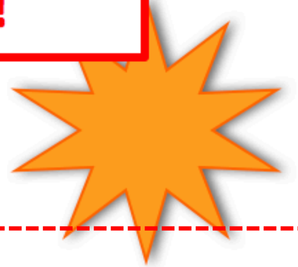
absolute magnitude M = measure of flux
you would see if you were 10 pc away

Luminosity and Flux

intrinsic **luminosity**
L = energy emitted
per second (erg/s)

Luminosity can be either in a given band or
"**bolometric**" = covering all wavelengths

But remember these are all a function of wavelength!



flux F = energy received
per unit area
$F = L / 4\pi d^2$ (erg/s/cm^2)

flux density = flux per
unit wavelength or per
unit frequency

F_λ = erg/s/cm^2/Å
F_ν = erg/s/cm^2/Hz or
Jansky (Jy) =
10^{-26} W/m^2/Hz

Week 6…

apparent magnitude m =
measure of flux relative to
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$m_1 - m_2 = -2.5 \log_{10} (F_1/F_2)$

distance modulus
$m - M = 5 \log_{10} (d/10pc)$

absolute magnitude M = measure of flux
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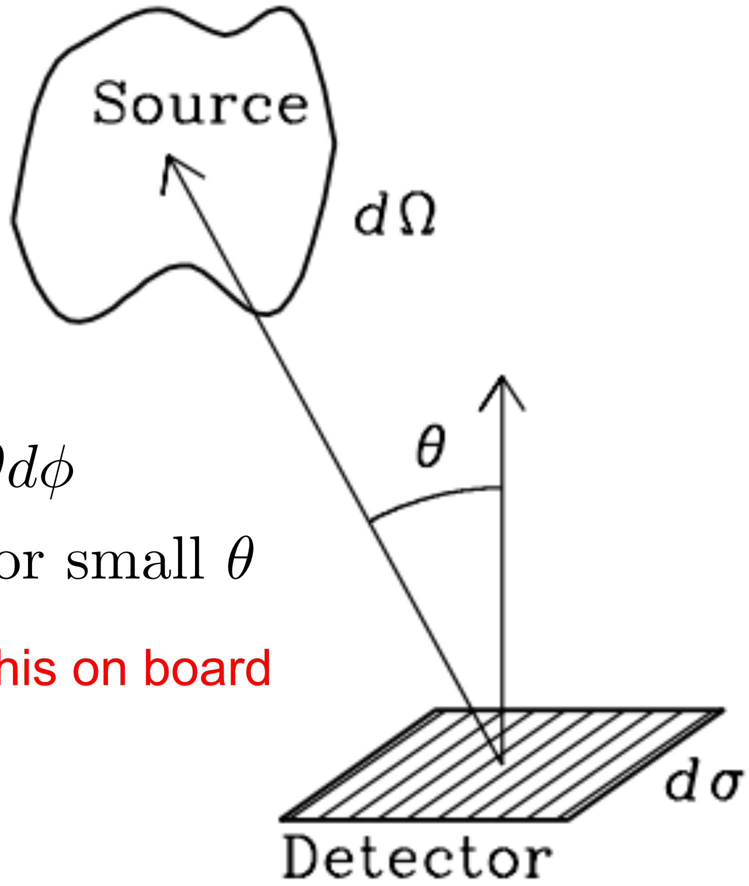
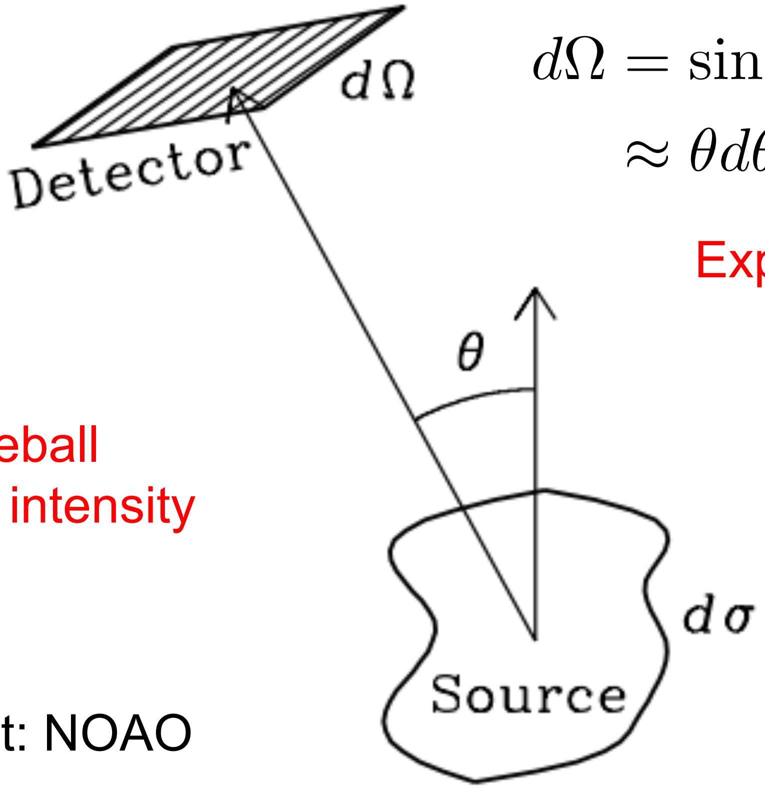
Flux Units

- Units are either based on SI, or “cgs” (centimeters-grams-seconds). I will try to *mostly* stick with SI units, but will not be completely consistent.
- 1 erg = 10^{-7} Joule.
- Energy received through a telescope from a given source depends on wavelength (frequency), bandpass and telescope size.
- f_λ is the energy per unit time, per unit telescope area per unit wavelength.
- f_ν is the energy per unit time, per unit telescope area per unit frequency.
- The Jy = 10^{-26} $Wm^{-2}Hz^{-1}$, a standard unit of f_ν , originally from radio astronomy.

Specific Intensity or Surface Brightness

- Specific intensity is flux density per unit solid angle.
- Specific intensity is conserved in a lossless optical system (including free space).





$$d\Omega = \sin(\theta) d\theta d\phi$$
$$\approx \theta d\theta d\phi \text{ for small } \theta$$

Explain this on board

Play eyeball specific intensity game

Credit: NOAO

$$dW_\nu = \underbrace{\overbrace{I_\nu(\nu)}^{\text{received}}}_{\text{emitted}} \, d\Omega \, \cos\theta \, d\sigma \, d\nu$$

Specific Intensity to Flux

- If we have a specific intensity of an object being viewed at near-normal incidence to an aperture, simply multiply by the solid angle being integrated over to get flux. i.e.

$$F_\nu = \int I_\nu d\Omega \approx I_\nu \Delta\Omega$$

- If we have an isotropic radiation field, e.g. a black-body, then we can find the specific intensity from the flux (tutorial question or problem for board):

$$I_\nu = F_{\nu,\mathrm{isotropic}}/\pi$$

Energy Density and Specific Intensity

- We can also think of a radiation field as local energy flow at the speed of light.
- Then I_ν/c is the energy density of radiation for a small solid angle $d\Omega$, and we can find the total energy density by:

$$u_\nu = \frac{1}{c}\int I_\nu d\Omega$$

(I find this more intuitive than the textbook's differential form)

- For an *isotropic* radiation field:

$$u_\nu = \frac{4\pi}{c} I_\nu$$

Blackbody Radiation

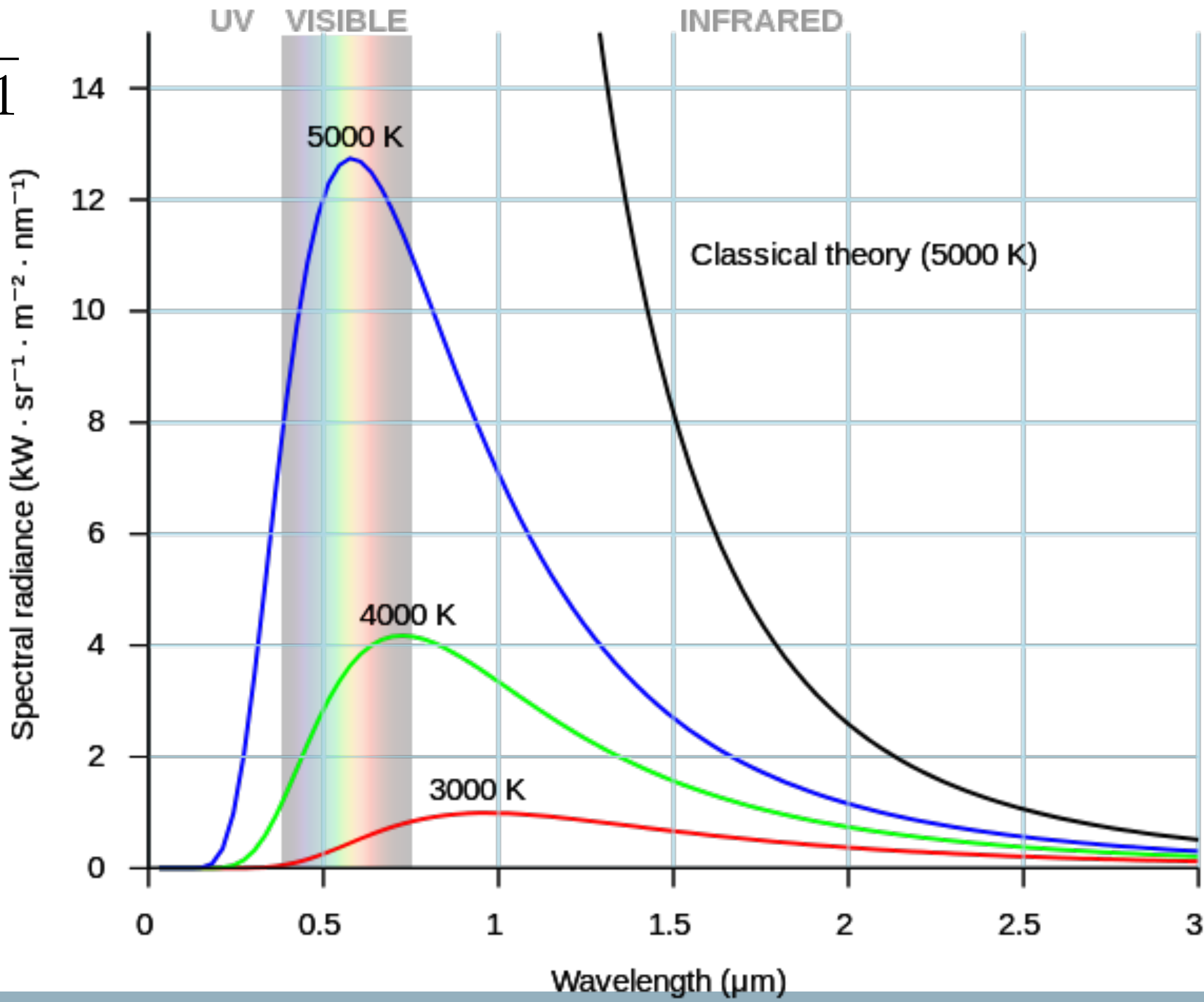
- One of the easiest ways to determine an objects temperature is to look at the radiation it emits. *Blackbody radiation* is the radiation emitted from a body that has perfect emissivity.
- One way to get near-perfect blackbody radiation is to punch a small hole in a cavity of uniform temperature. This evens out the effects of albedo variations.
- Astrophysics doesn't have perfect cavities... but we can talk about:
  - The *effective temperature* of a surface is the temperature of an blackbody that would emit the same total radiation.
  - The *brightness temperature* of a surface at wavelength λ is the temperature of a blackbody that would emit the same specific intensity at that wavelength.

Planck's Formula – Blackbody Radiation

$$\frac{dn}{d\nu} = \frac{1}{\exp(h\nu/k_B T) - 1} \text{ photons/s/Hz/mode}$$

$$f_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{\exp(hc/\lambda k_B T) - 1}$$

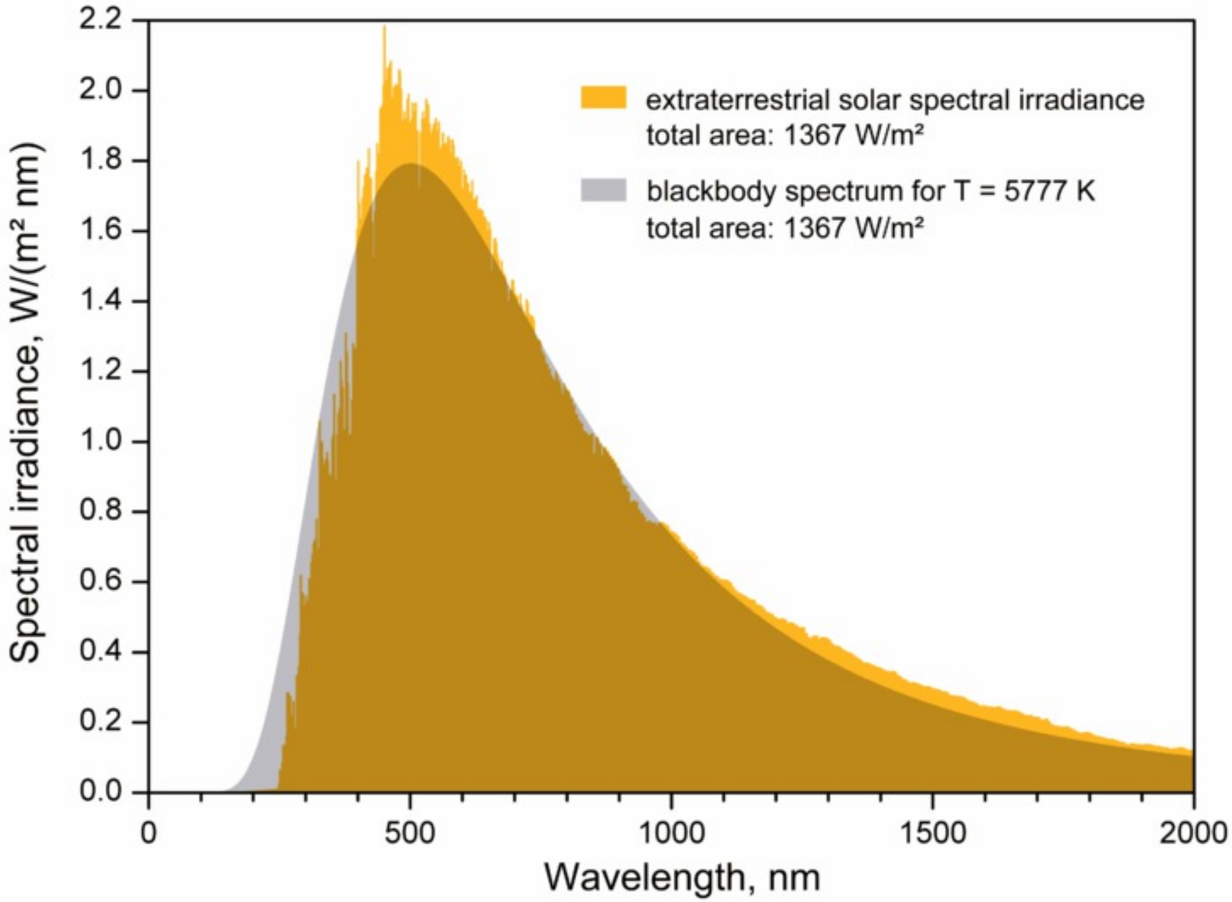
$$f_\nu = \frac{2h\nu^3}{c^2} \frac{1}{\exp(h\nu/k_B T) - 1}$$



More on this in the tutorial…

Solar Radiation

- Given that the sun varies, we now define *nominal* values for the sun's properties (IAU):



$$T^{N}_{\mathrm{eff}\odot} = 5772\,\mathrm{K}$$

$$S^{N}_{\odot} = 1361\,\mathrm{W\,m^{-2}}$$

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Inspiring Picture: Zodiacal Light (APOD 0902)