Astronomical Images

Goals for today: you should be able to...

* Identify problems that cause real-world data to be non-ideal, and methods for eliminating those problems

Preparing for projects: basic properties of imaging data in astronomy

- Let's start by considering the simplest case:

1) Light is emitted by an object in the direction of a telescope. Every photon emitted towards it is captured.

2) The telescope/system stays perfectly the same over time

3) All the photons that reach the telescope are focused without distortion on a single plane, all moving perpendicular to some detector

4) We place a filter in front of this plane which selects a single wavelength of light (or 100% of light over some well-known range, and 0% otherwise)

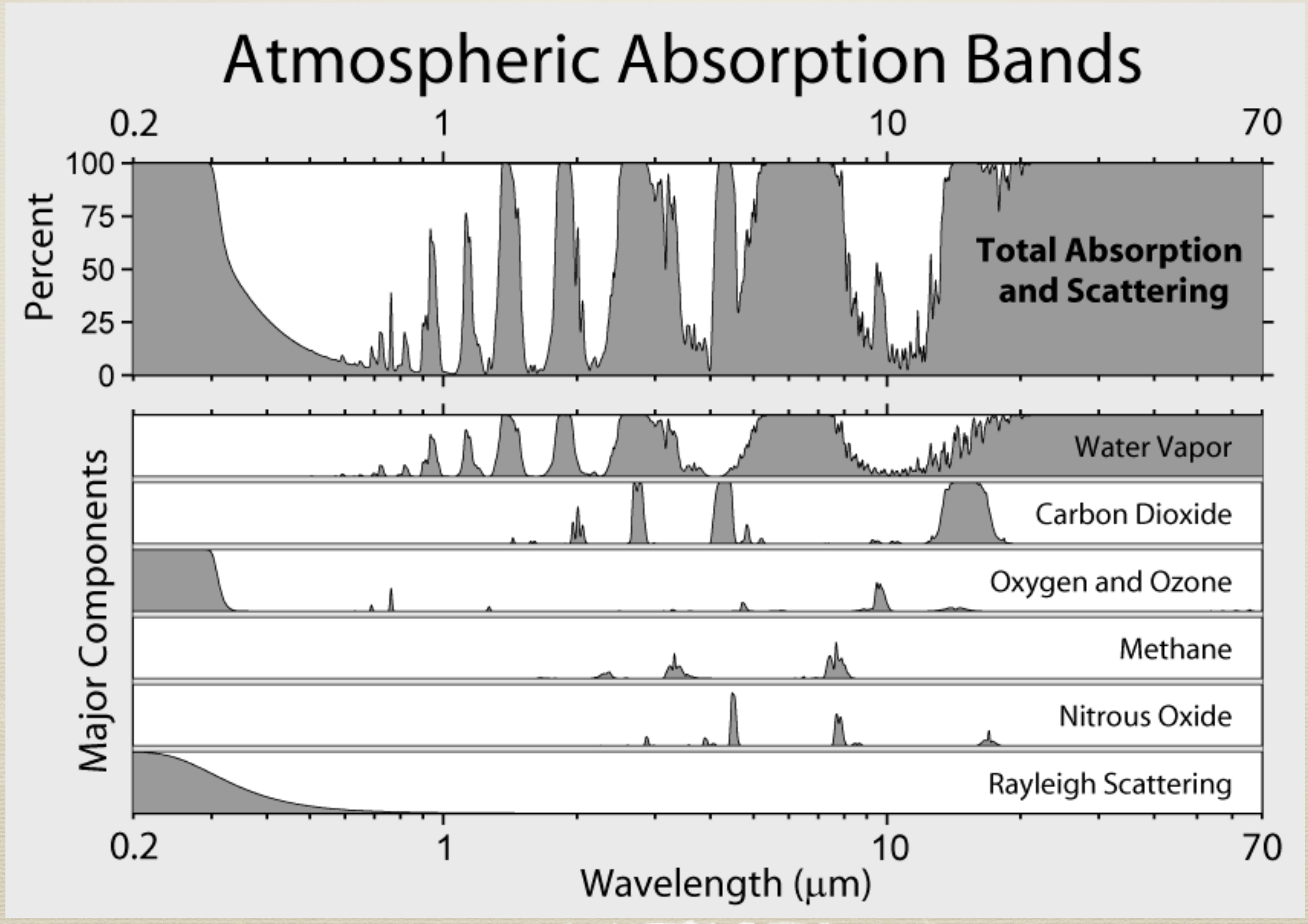
5) We have a detector which then reports to us the number of photons that hit it at each position over some range of time, telling us the intensity of light at that wavelength at that position on the sky

We'll see where this goes wrong. Many of these issues will affect CCD images in general..

What goes wrong?

1) Light is emitted by an object in the direction of a telescope. Every photon emitted towards it is captured.

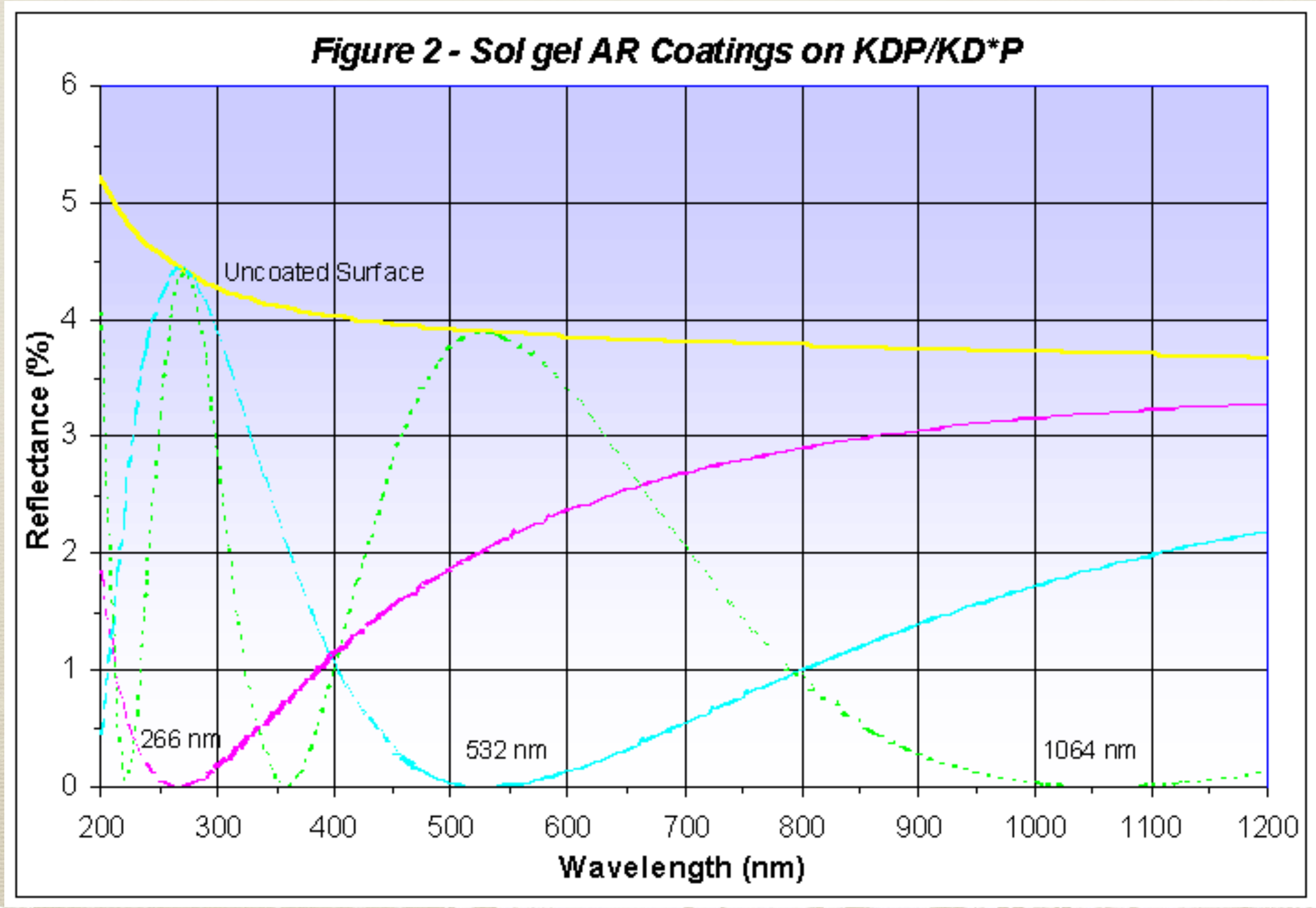
- The atmosphere absorbs light at specific wavelengths in molecular bands, and scatters light at short wavelengths



What goes wrong?

1) Light is emitted by an object in the direction of a telescope. Every photon emitted towards it is captured.

- Light also is lost to scattering off telescope superstructure, reflections from lenses, or absorption on mirrors

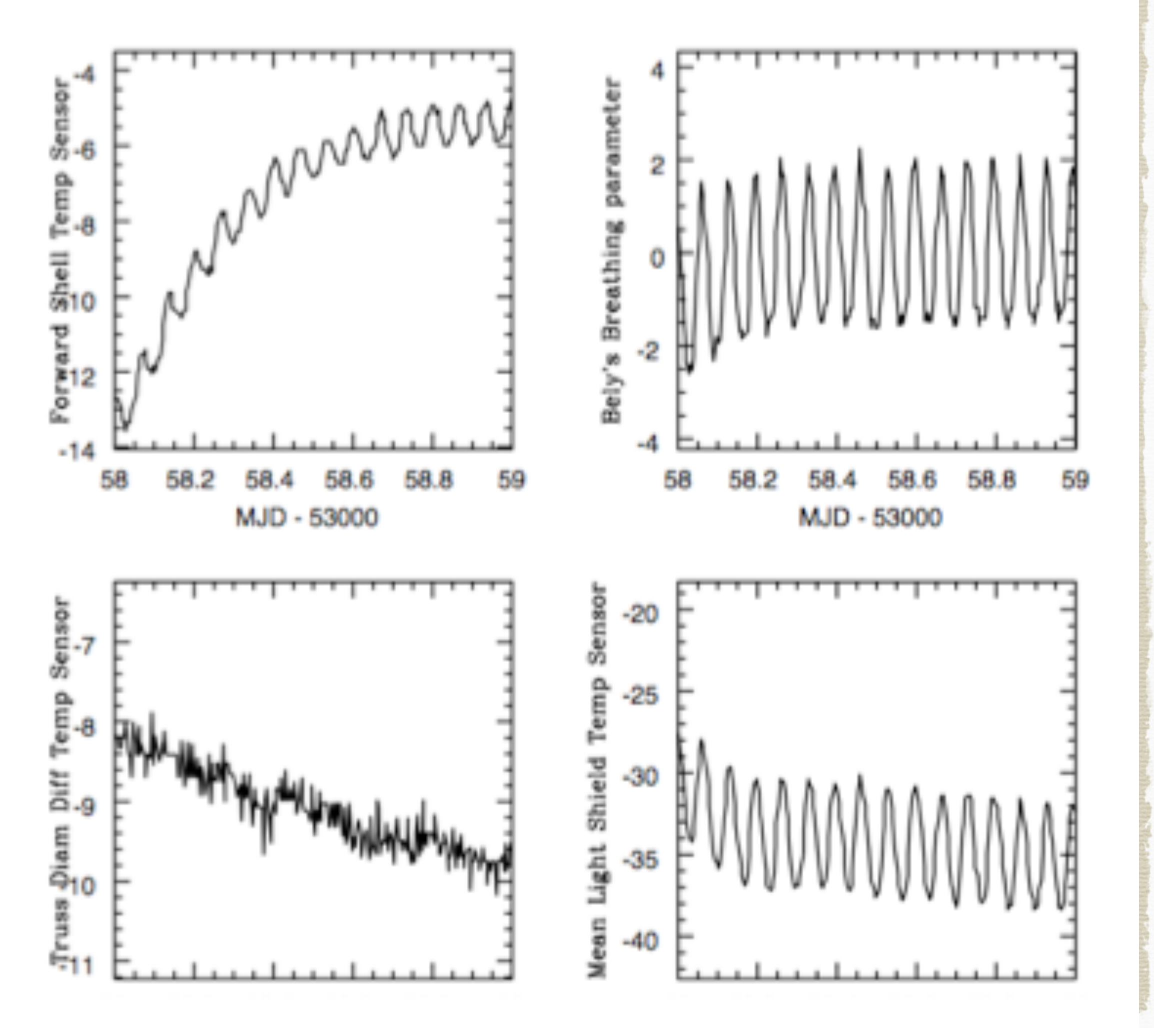


What goes wrong?

2) The telescope/system stays perfectly the same over time

- Metal, glass, etc. all expand or contract as temperature varies, changing the focal length over time

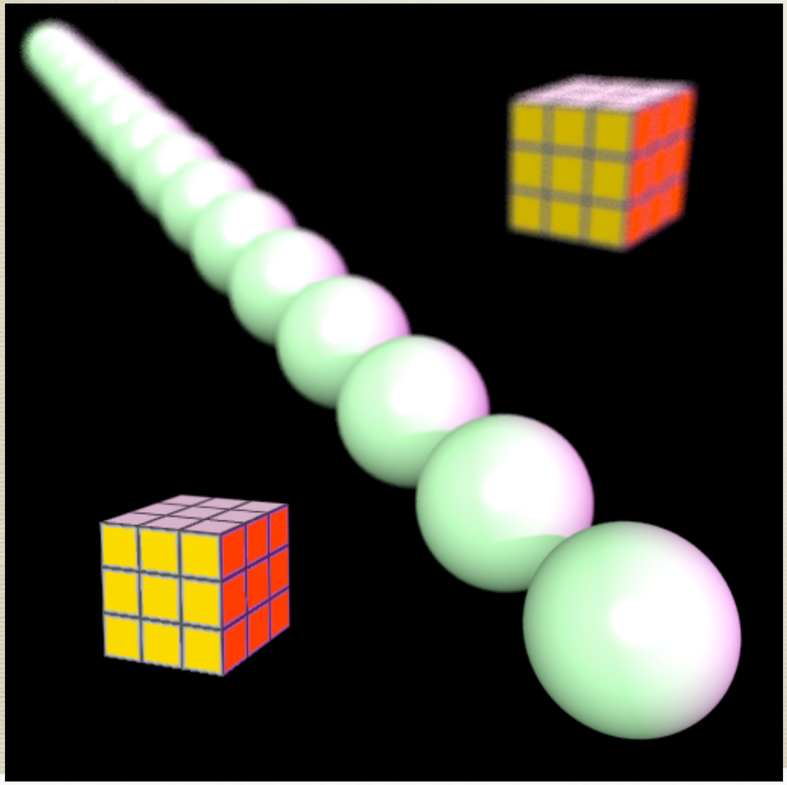
- Additionally, detector sensitivities depend on their ambient temperature, voltages applied, etc. - could sometimes go wonky.

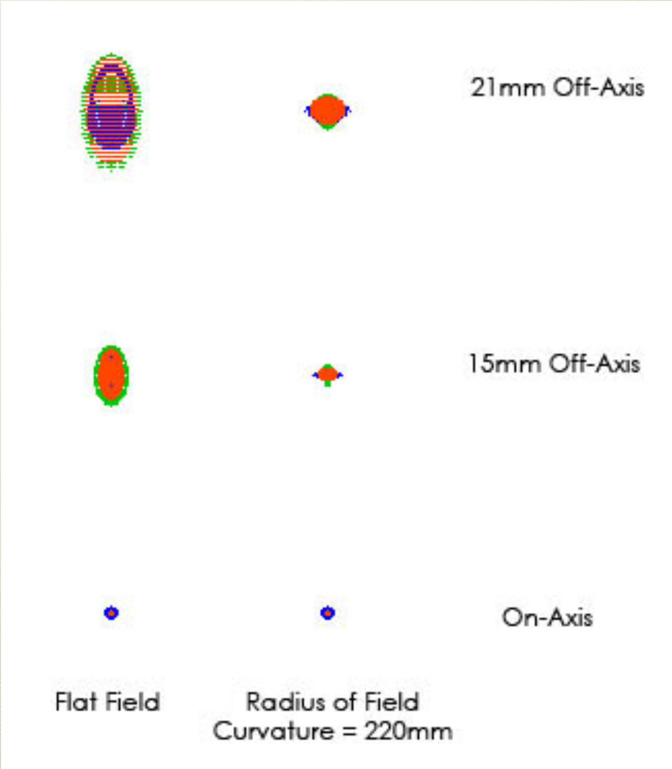


What goes wrong?

3) All the photons that reach the telescope are focused without distortion on a single plane, all moving perpendicular to some detector

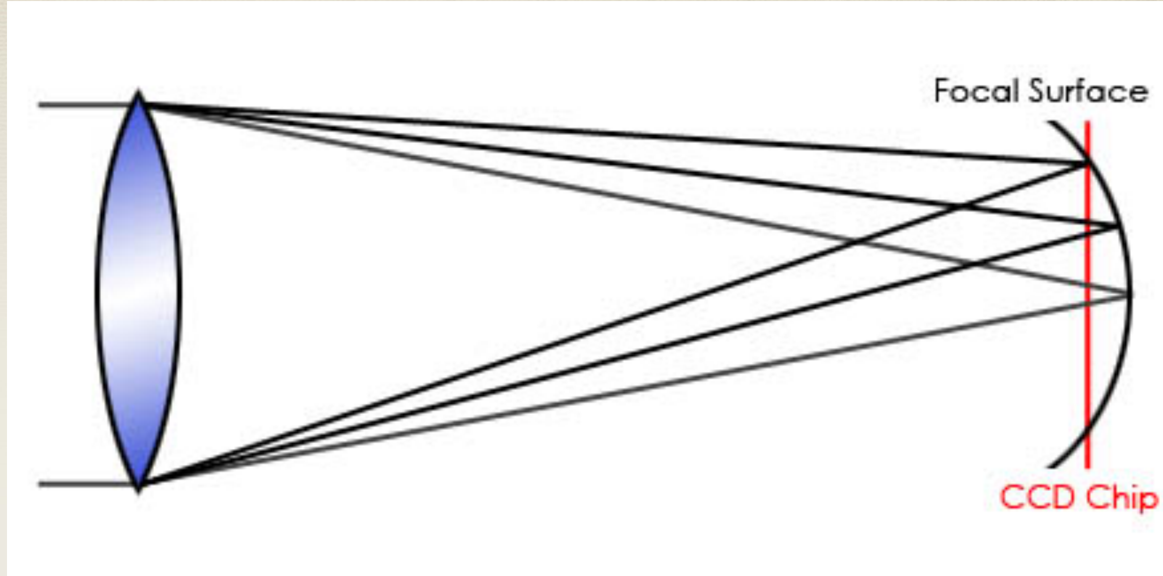
- Focal planes are curved, not flat. If we adjust the optics so one part of a plane detector (like a single CCD) is perfectly focused, another part will not be



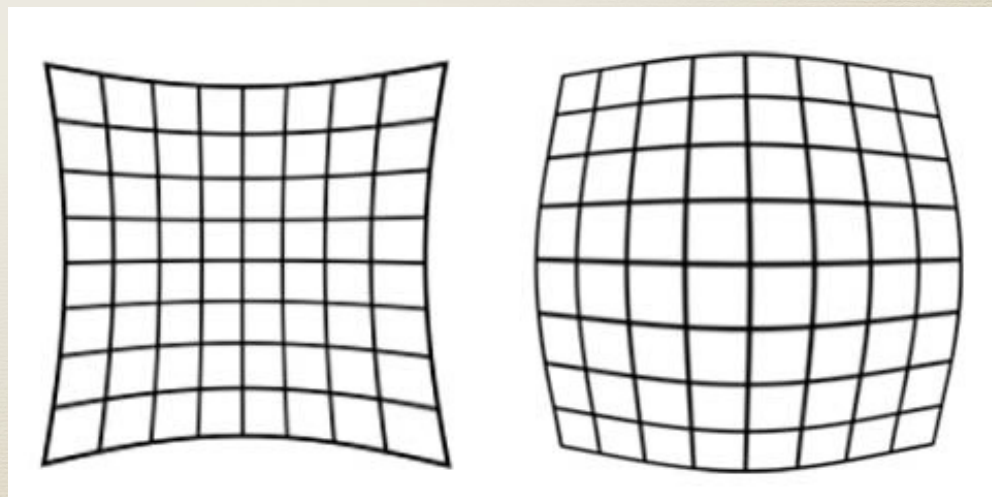


Field curvature & distortions

- Since focal surfaces are not flat, images on a flat detector will be variably in or out of focus



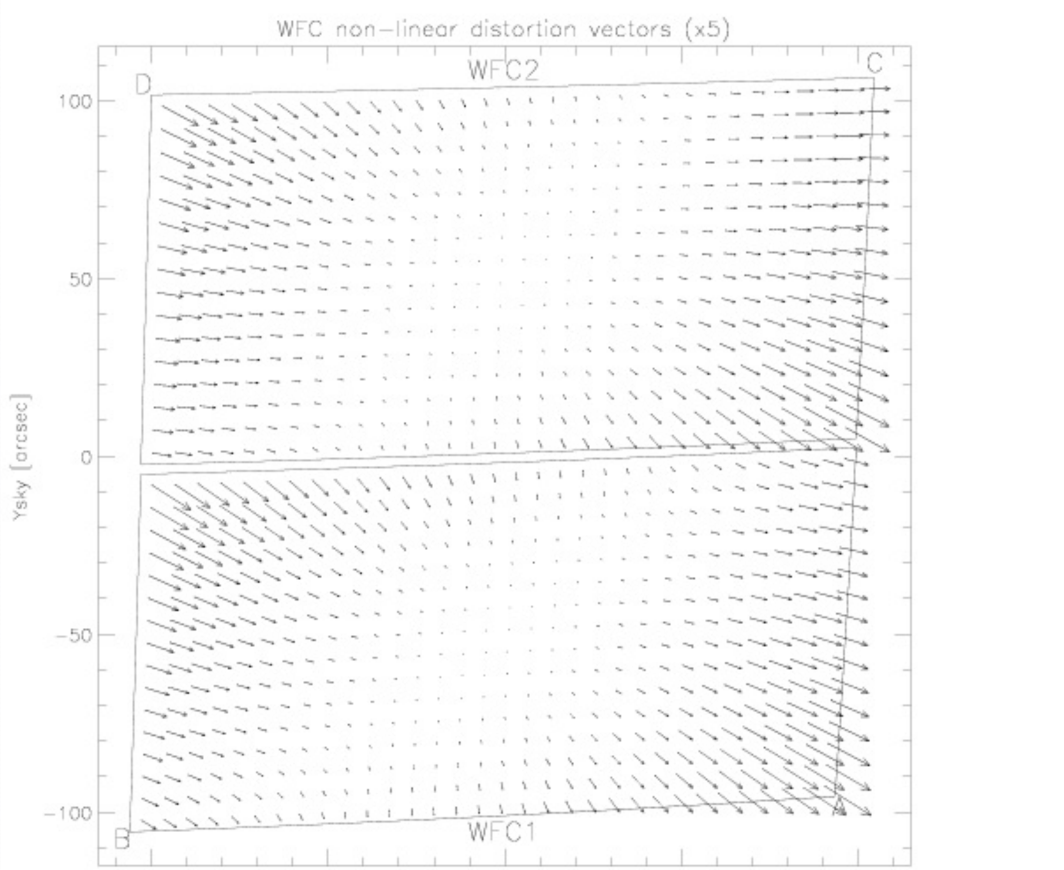
- This leads to distortions as well - we have to take this out in software.

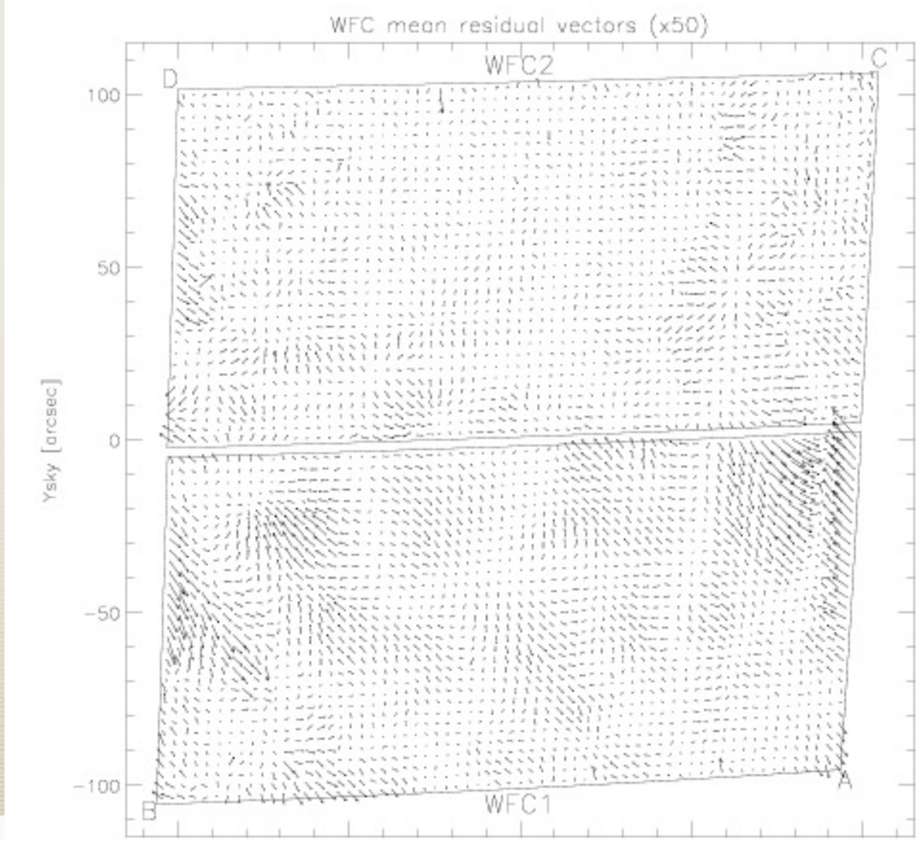


What goes wrong?

3) All the photons that reach the telescope are focused without distortion on a single plane, all moving perpendicular to some detector

- All optical systems exhibit some sort of distortion. Here are a fit to distortions for ACS (the best optical camera HST has had) and residuals about the fit

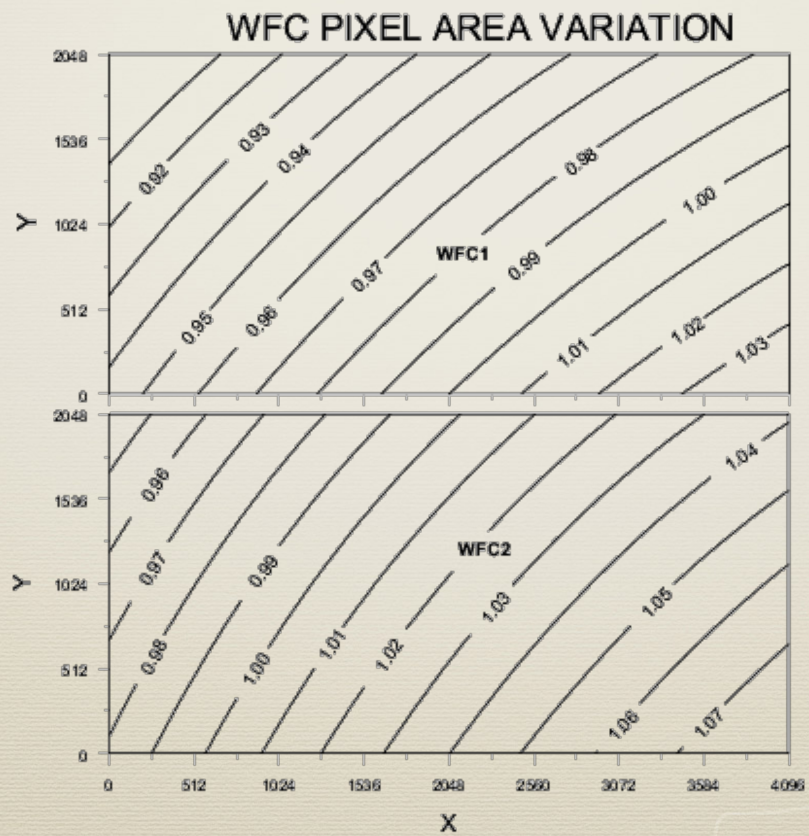




What goes wrong?

3) All the photons that reach the telescope are focused without distortion on a single plane, all moving perpendicular to some detector

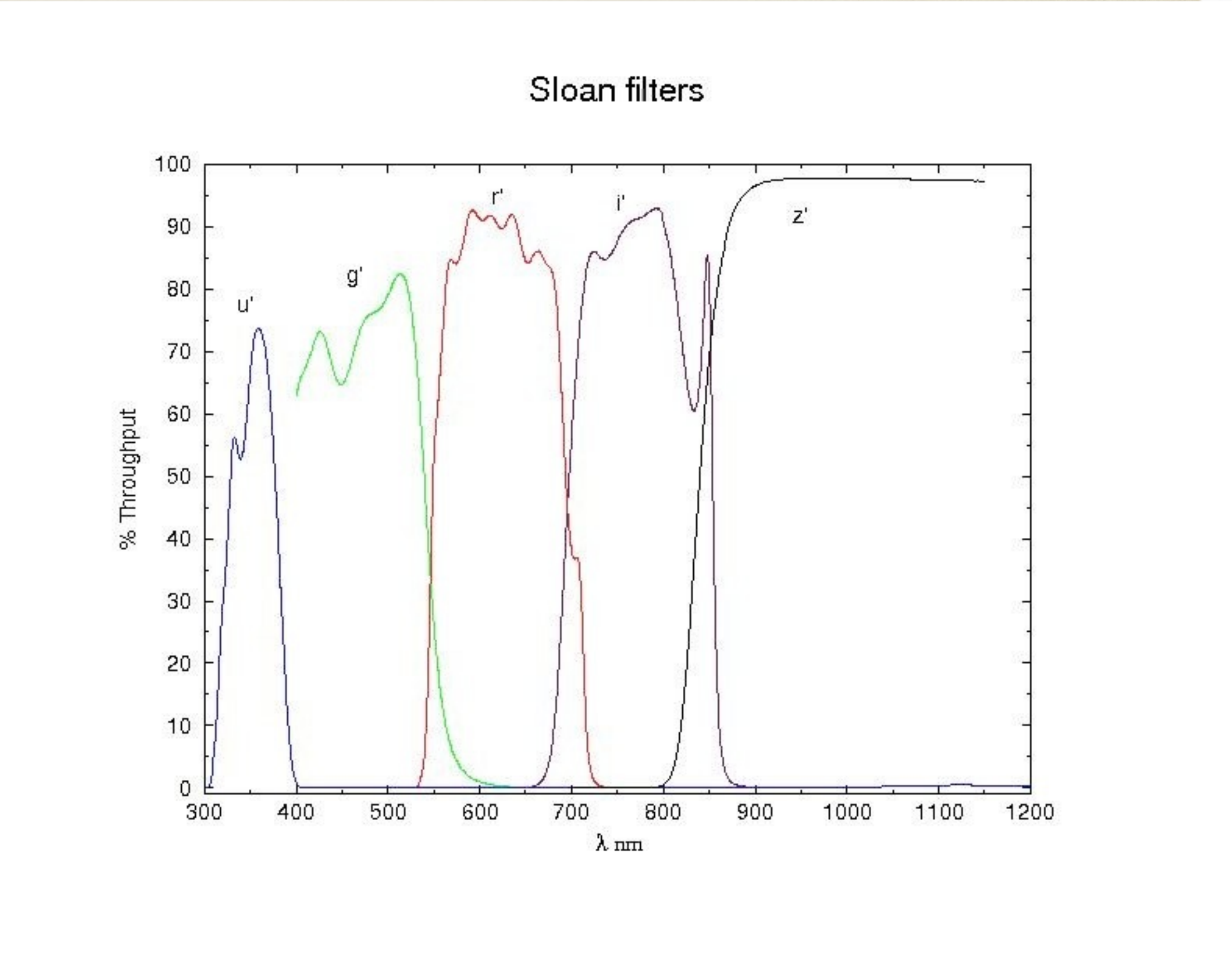
- A consequence of distortions & curvature is that the effective area on the sky for a constant area on the detector varies



What goes wrong?

4) We place a filter in front of this plane which selects a single wavelength of light (or 100% of light over some well-known range, and 0% otherwise)

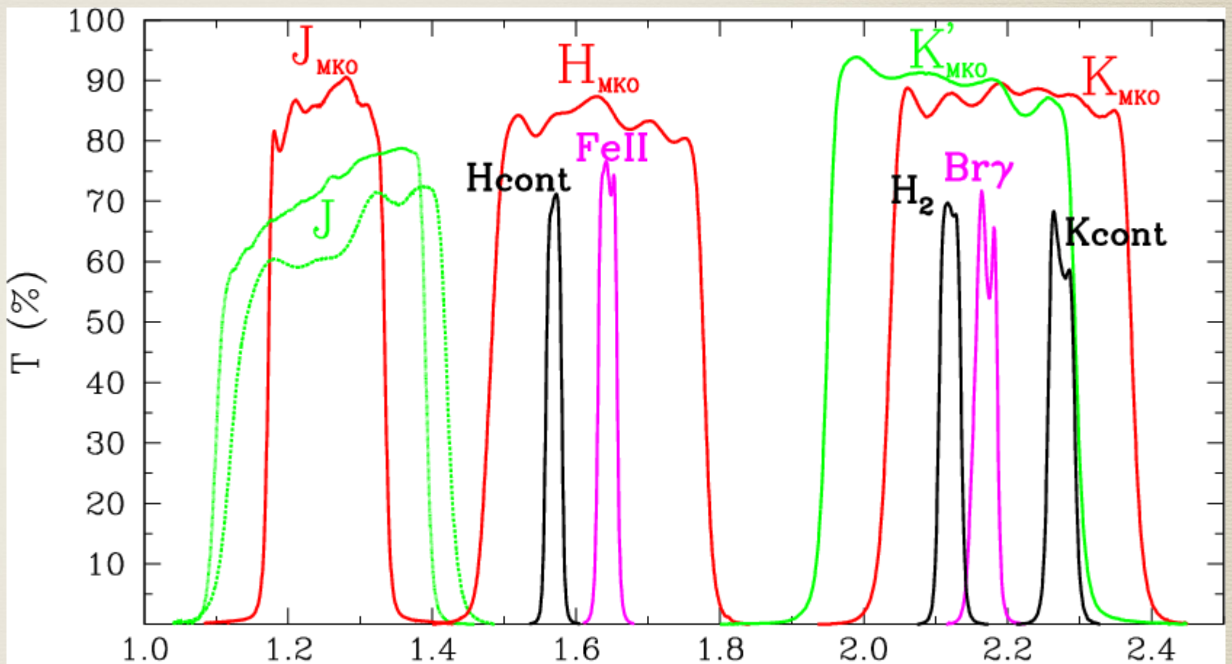
- 'Filter curves' rarely reach 100%, and generally have a number of features

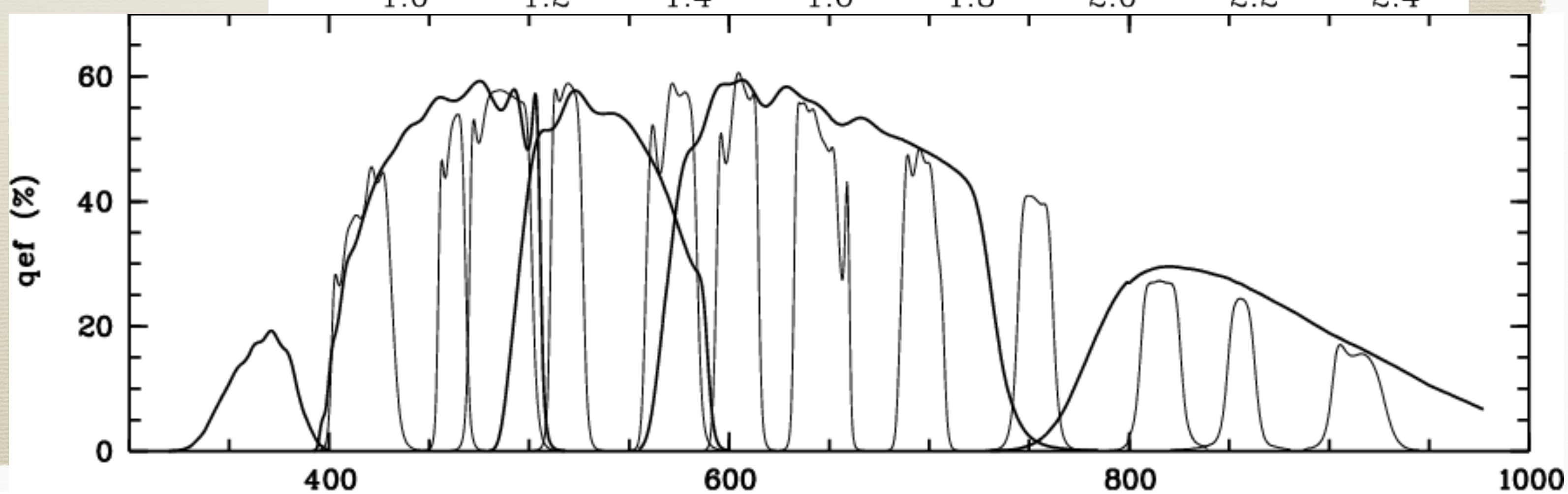


What goes wrong?

4) We place a filter in front of this plane which selects a single wavelength of light (or 100% of light over some well-known range, and 0% otherwise)

- Narrower filters often offer worse performance as a tradeoff (in addition to letting a smaller fraction of photons through)

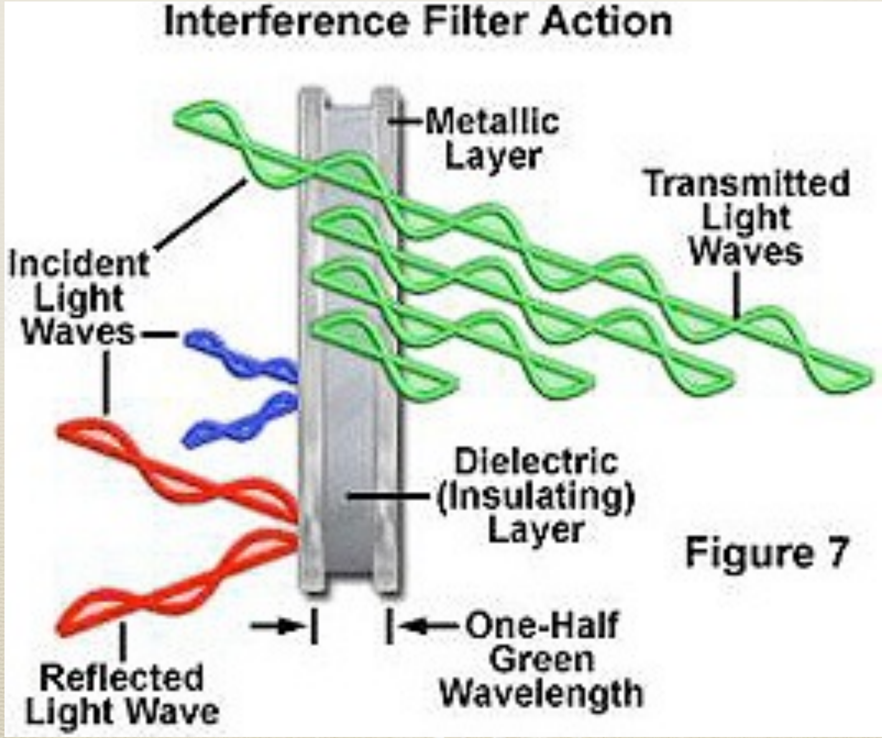




What goes wrong?

4) We place a filter in front of this plane which selects a single wavelength of light (or 100% of light over some well-known range, and 0% otherwise)

- Most filters today are interference filters, which select wavelengths to pass through or reflect by tuning constructive and destructive interference as they pass through layers with different refractive index

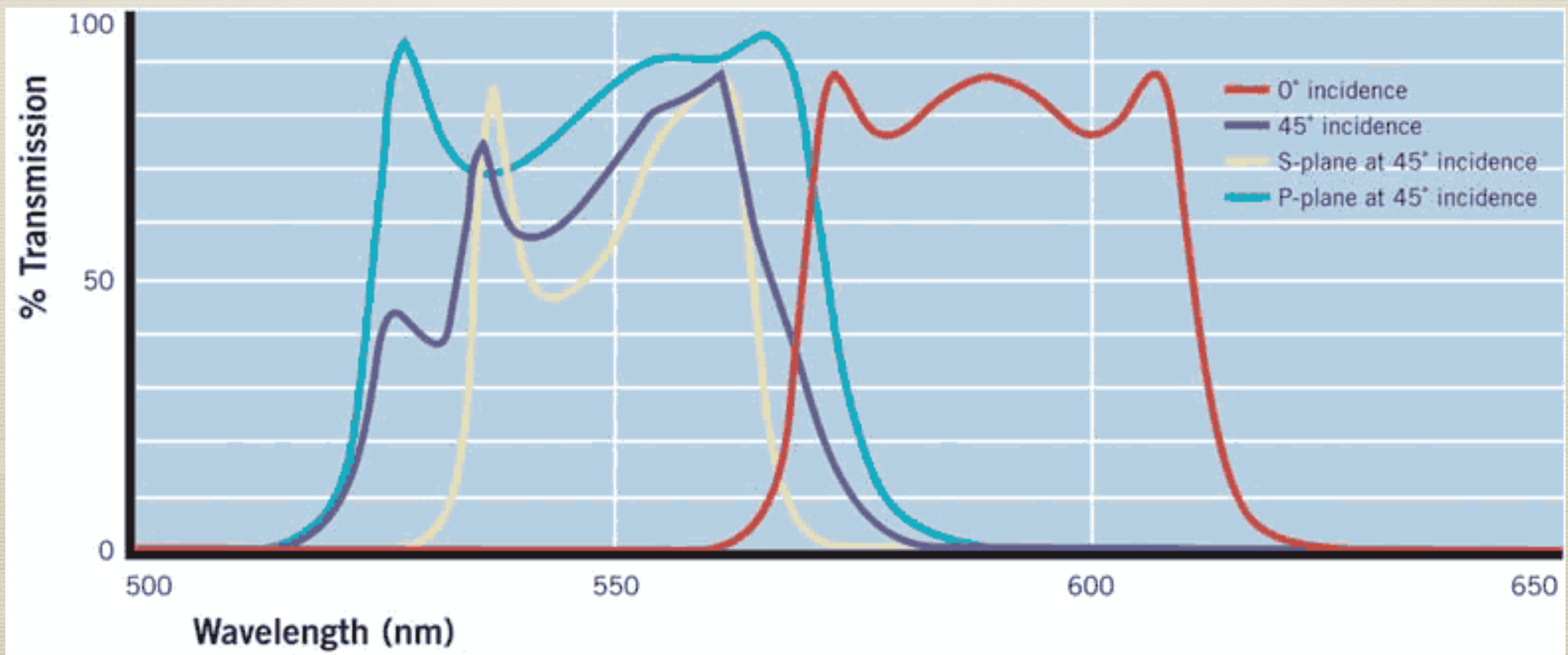


What goes wrong?

4) We place a filter in front of this plane which selects a single wavelength of light (or 100% of light over some well-known range, and 0% otherwise)

- At an angle to an interference filter, different wavelengths pass through!

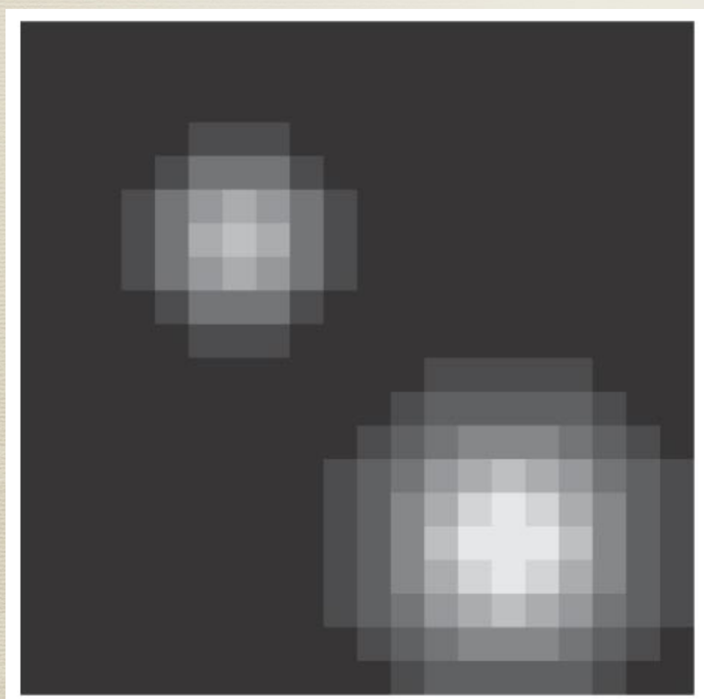
- To check out the effect go to: http://micro.magnet.fsu.edu/primer/java/filters/interference/index.html



What goes wrong?

5) We have a detector which then reports to us the number of photons that hit it at each position over some range of time, telling us the intensity of light at that wavelength at that position on the sky.

- In the ideal case, we have some detector which splits the focal plane into individual elements - *pixels*. We can measure how many photons hit a pixel in a set amount of time, and use that, along with the known wavelength/frequency & collecting area, to tell us the intensity in ergs/sec/cm^2/Hz.



0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
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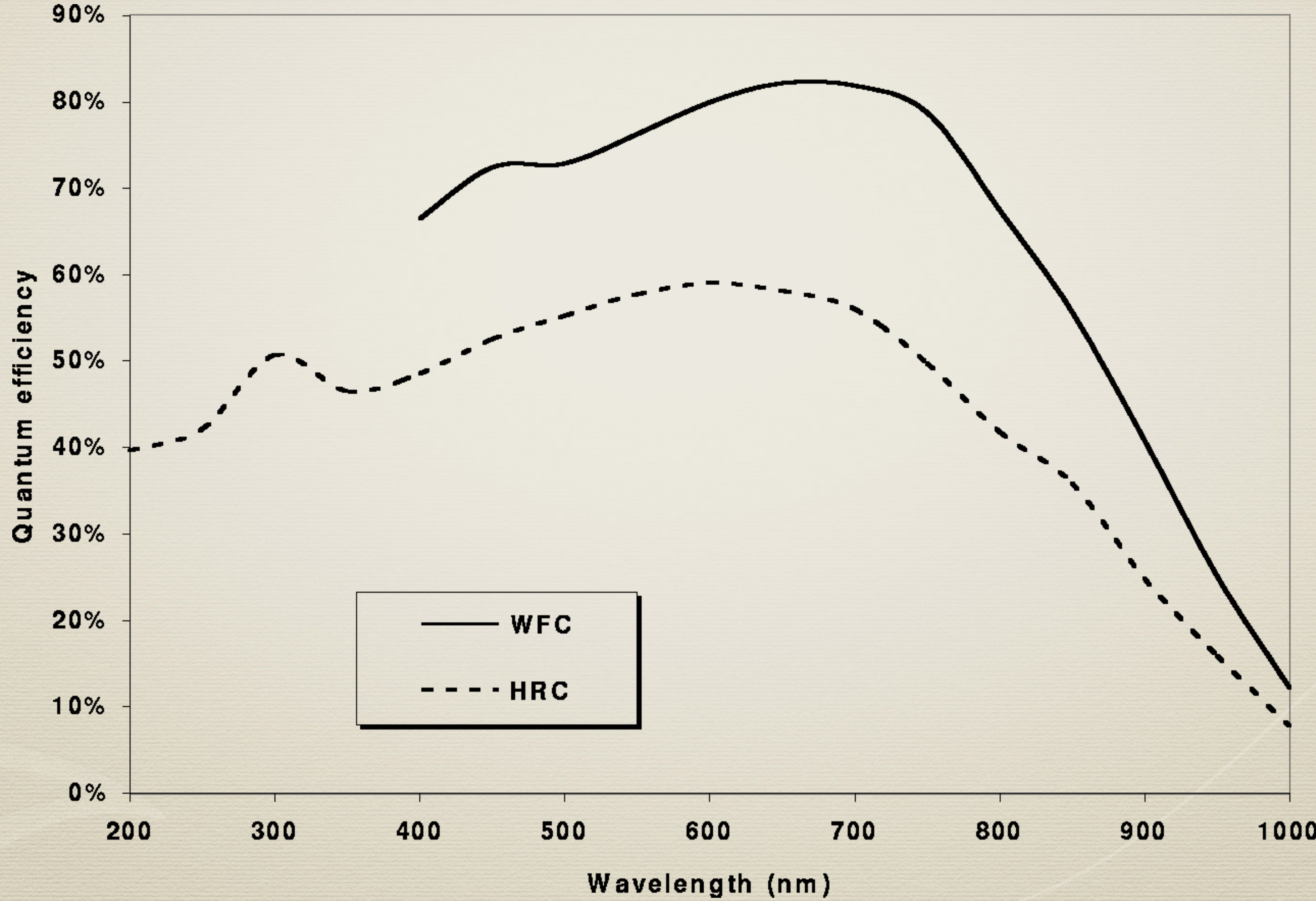
0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	1	0	0

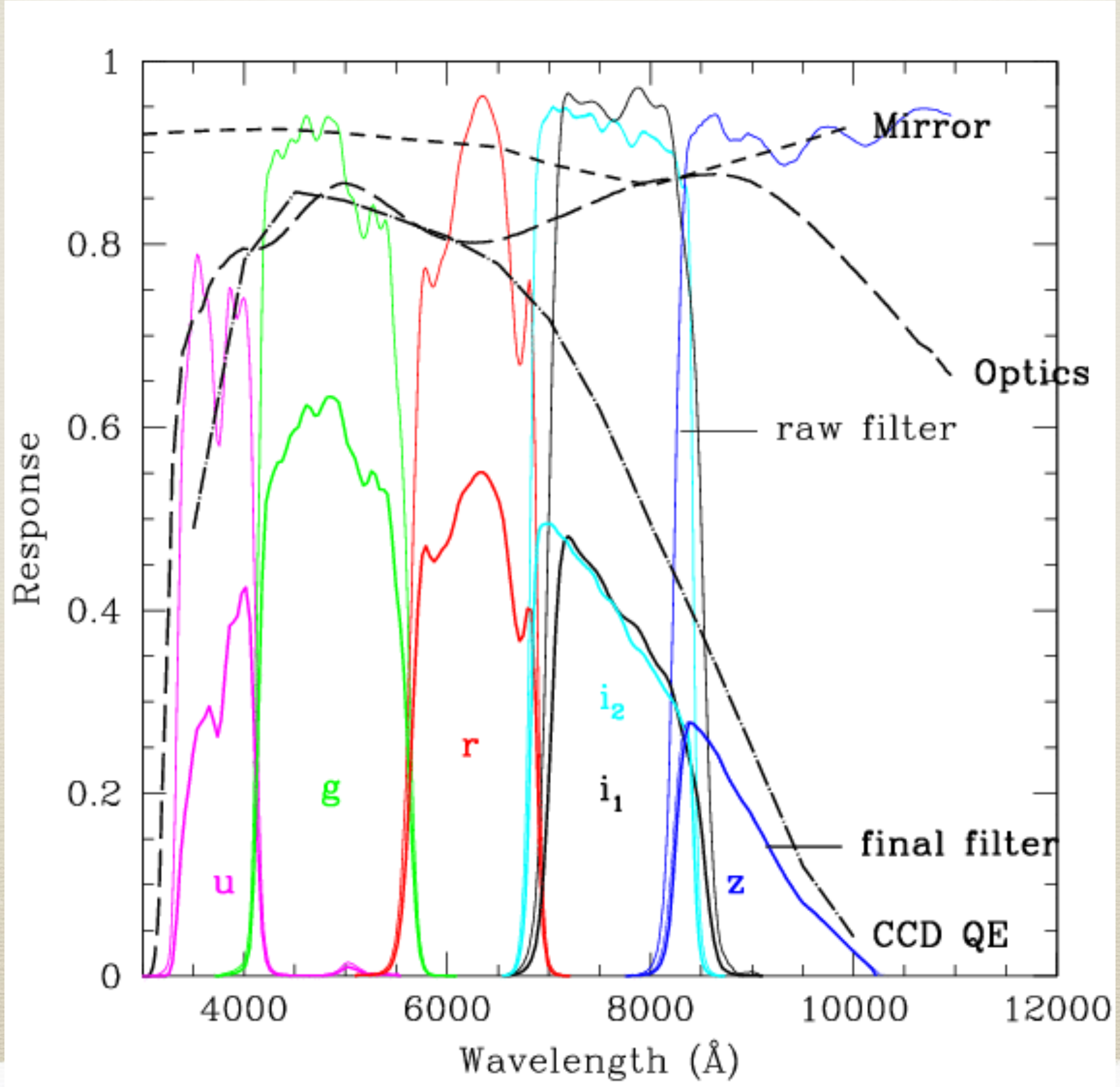
Quantum efficiency

- Most detectors will only detect a fraction of the photons that hit them, depending on energy. This fraction is called the *quantum efficiency* or QE.



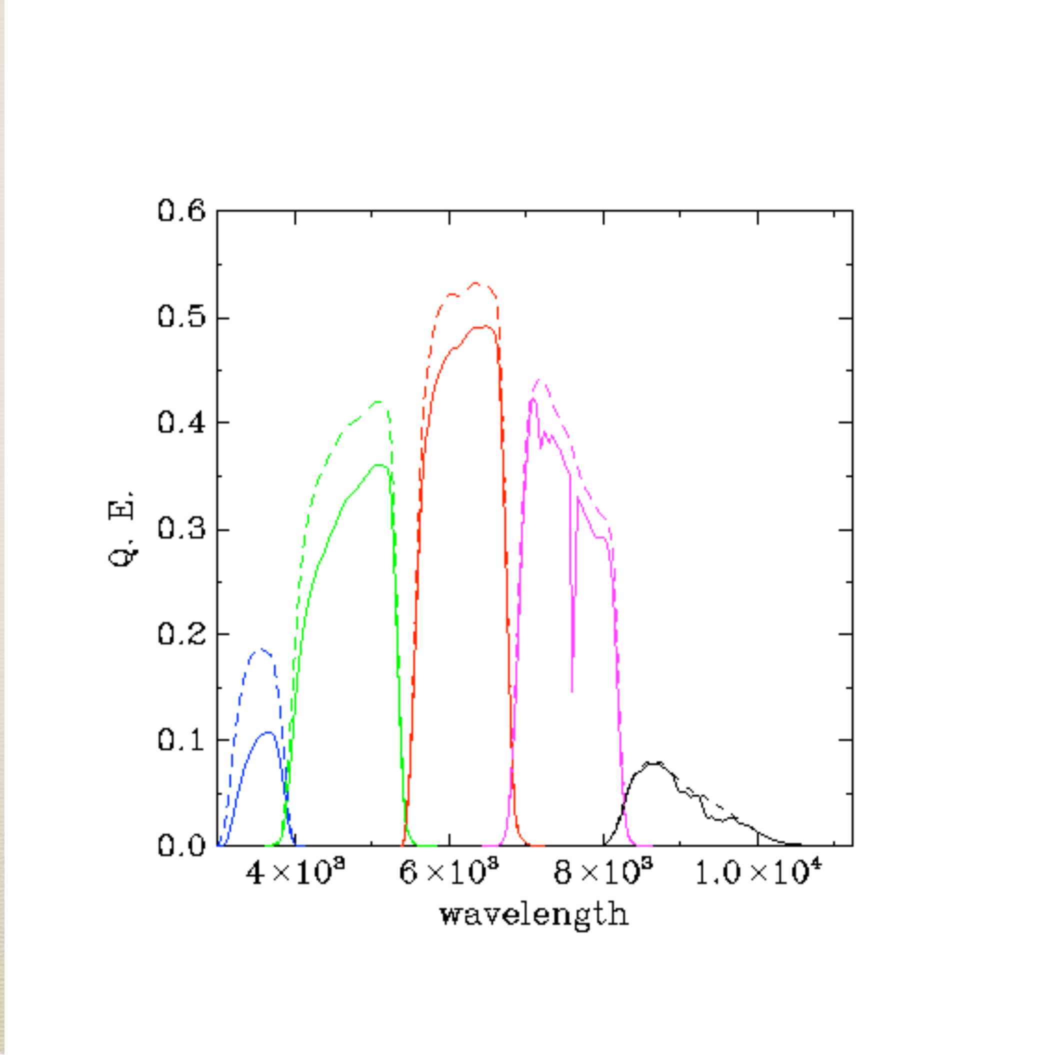
Throughput

- The *throughput* of an instrument is the net fraction of photons that reach the telescoped that are counted by it, after losses to mirrors, filters, QE...



That plot skipped losses to the atmosphere...

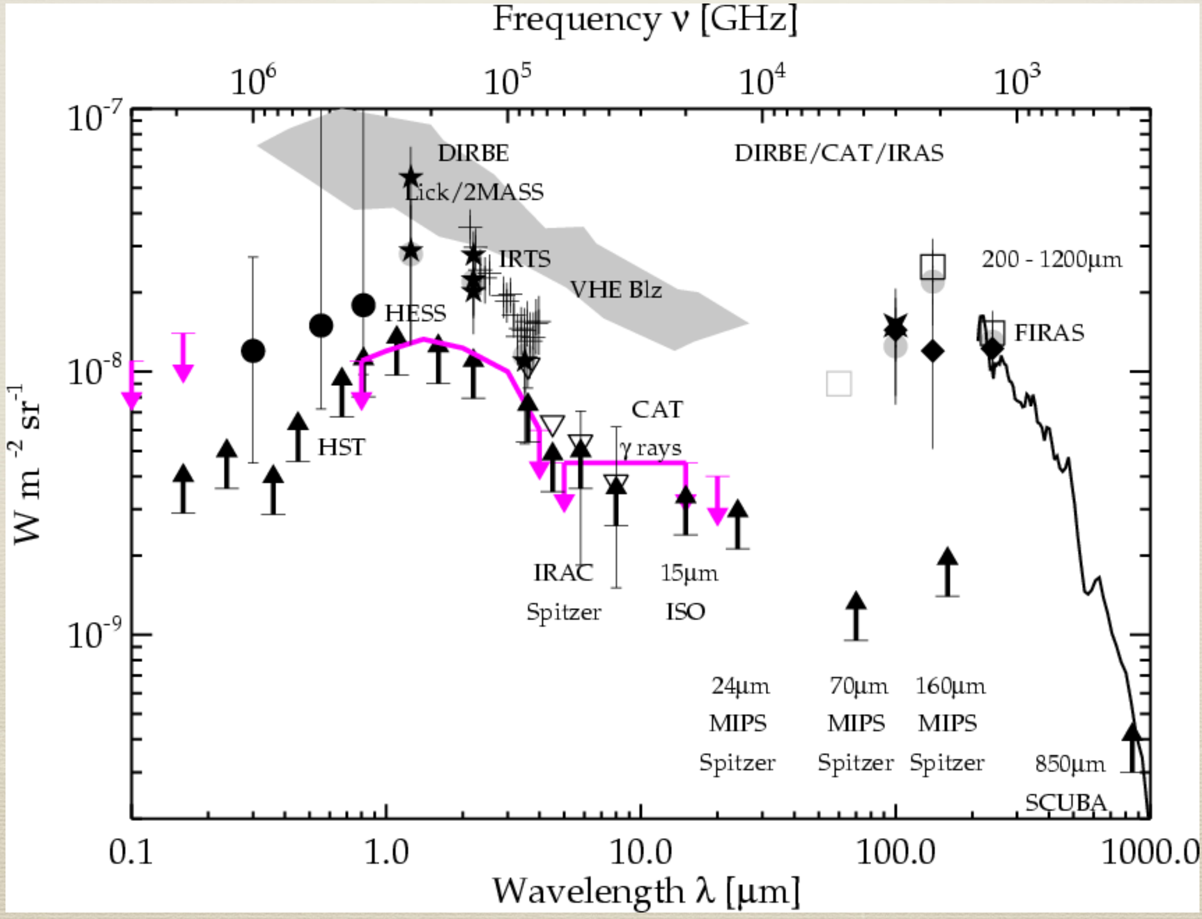
- A fraction of the photons that hit the upper atmosphere are lost to scattering as they head to the telescope, especially in the blue



Backgrounds

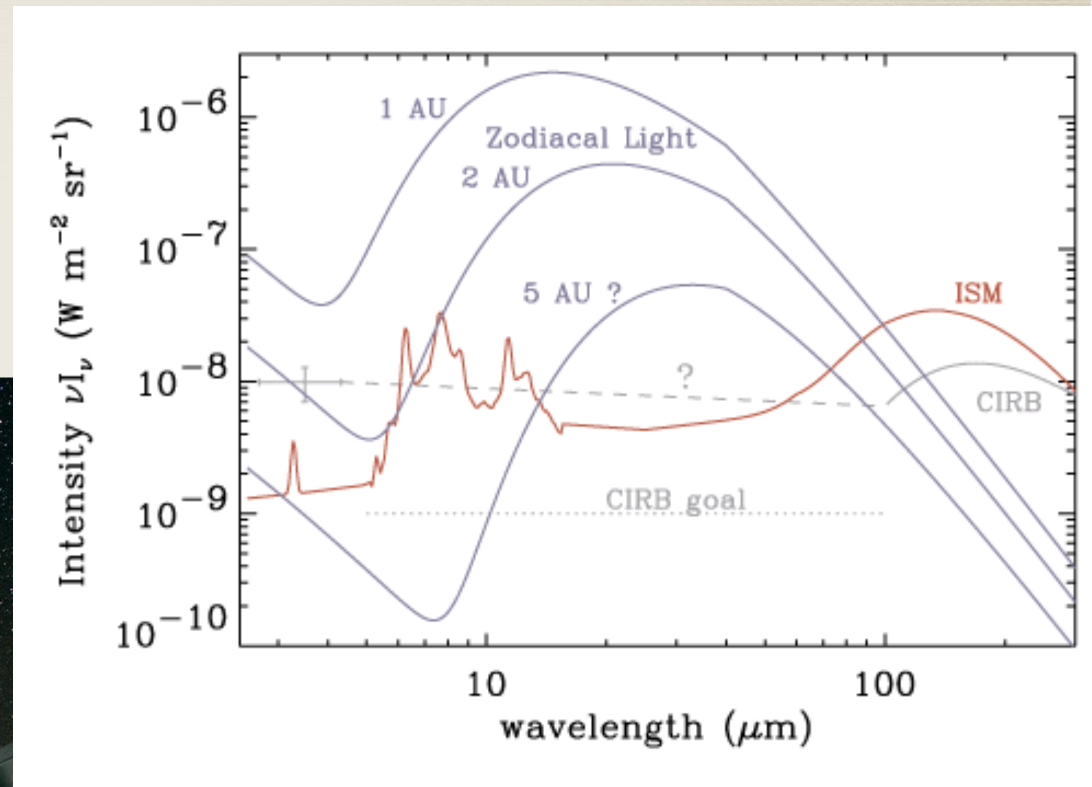
- Not all photons at a given position come from the objects we're interested in, though.

- In space, we have to deal with light from unresolved, very distant sources (*cosmic backgrounds*)...



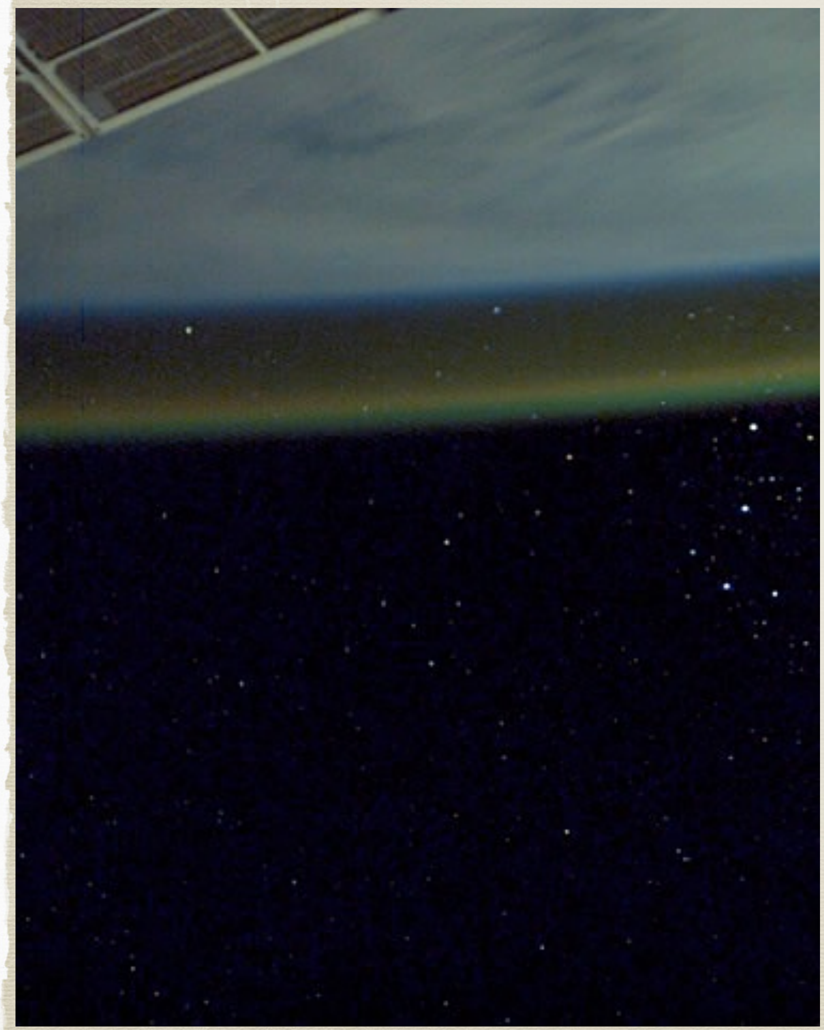
Backgrounds

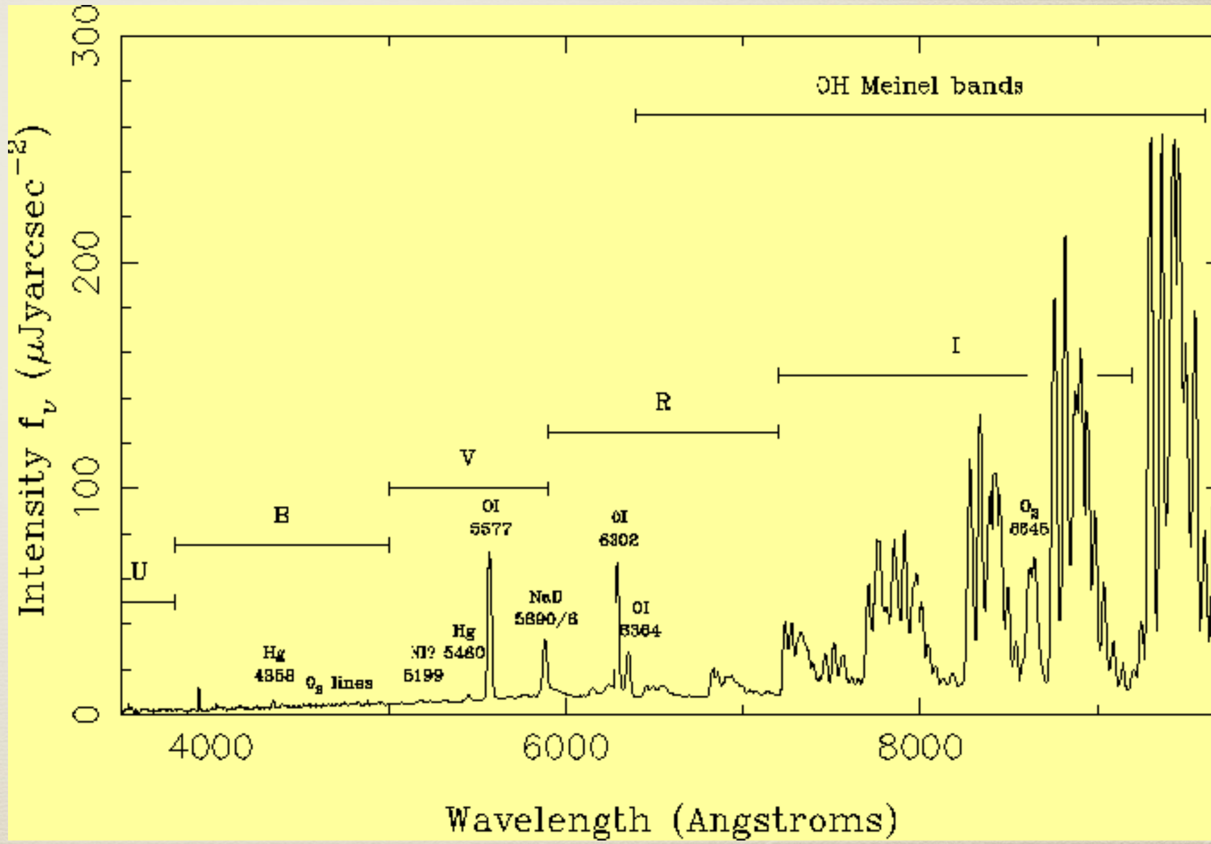
… along with the *zodiacal light,* light scattered or emitted by dust in the Solar System



Backgrounds

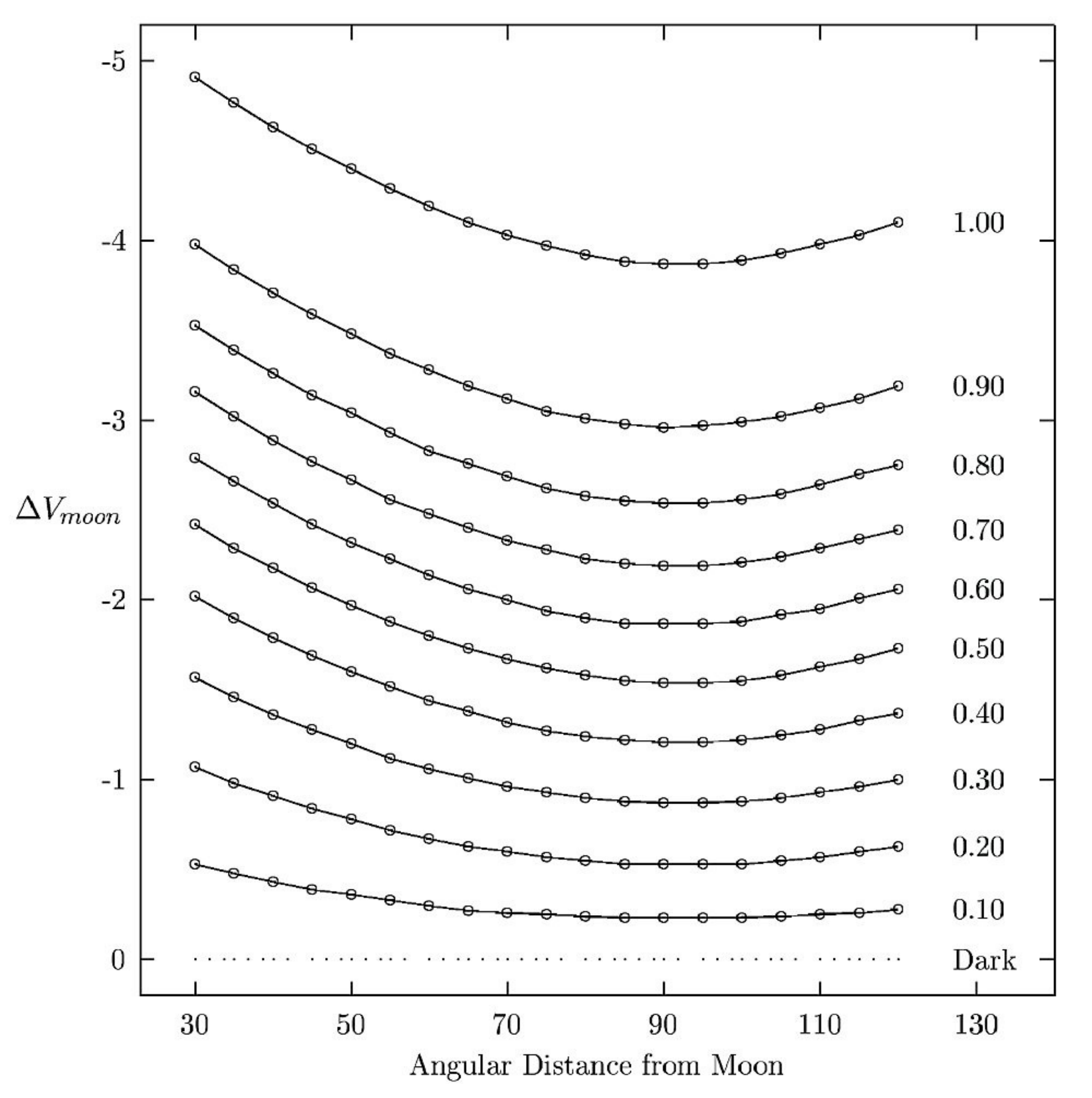
- From the ground, the biggest problem in the infrared is emission by molecules in the upper atmosphere (~90 km up)





Backgrounds

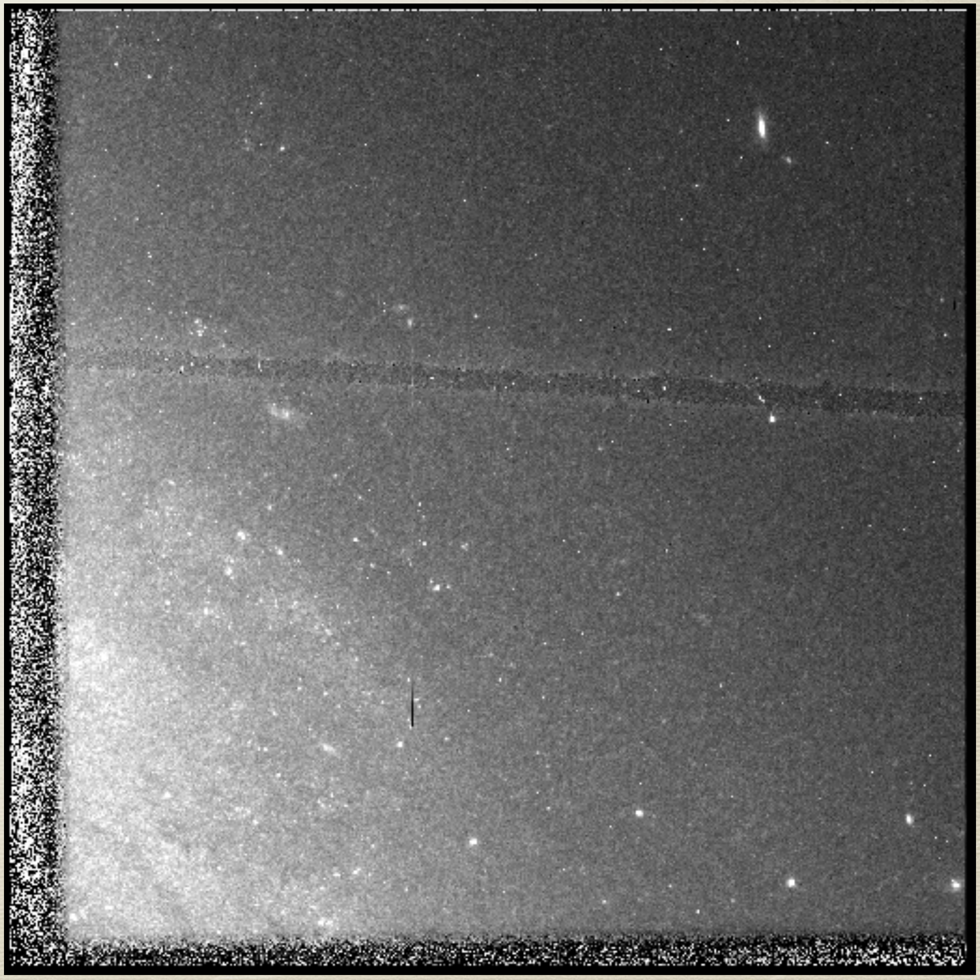
- At bluer wavelengths, scattered light from the Moon is more of a problem, if it is up



Cosmic rays

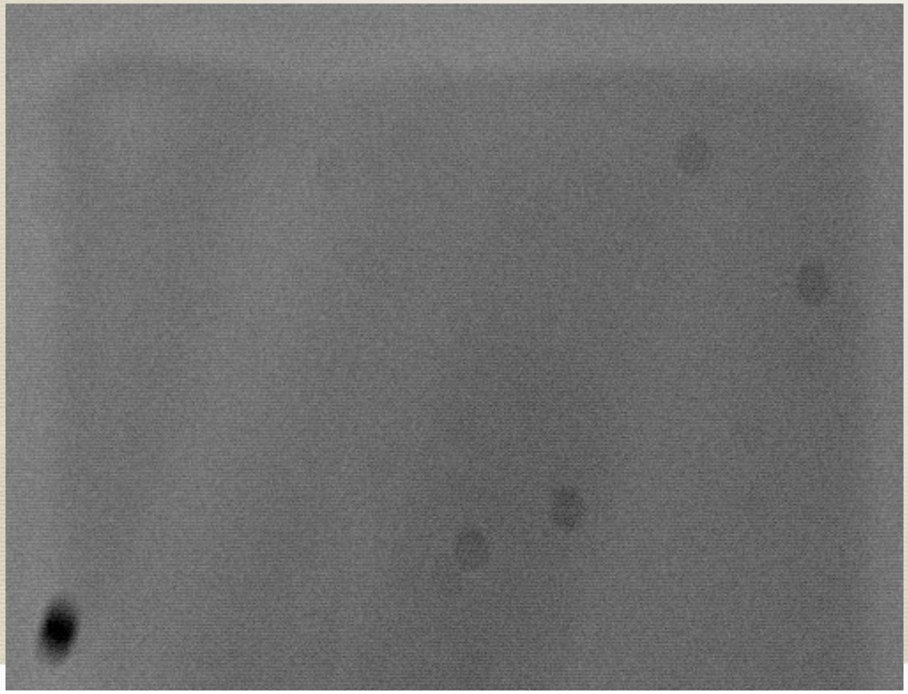
- As a further problem, the detectors we use are not sensitive only to photons... Cosmic rays (and particles from natural radioactivity) will also contribute to the observed counts.

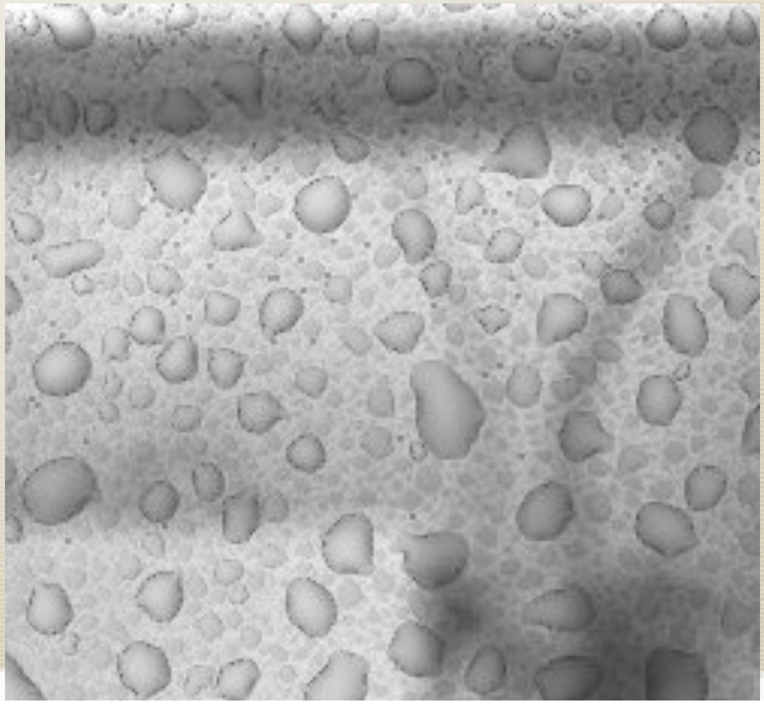
- Satellite trails pose similar problems...



Other problems

- Detectors count electrons, not photons; the #s of each are not linearly related when traps start to fill up
- There is noise in detector readouts
- Baseline level may not be 0 electrons, and may change over time with accumulated currents
- Dust or condensation can accumulate in front of our detectors, blocking some light





Other problems

- QE may vary amongst multiple chips in a camera, or amongst pixels on a chip

- Pixels may not all be the same physical size

- For red light hitting thin detectors, interference patterns can cause variations in sensitivity across the detector : "fringing"