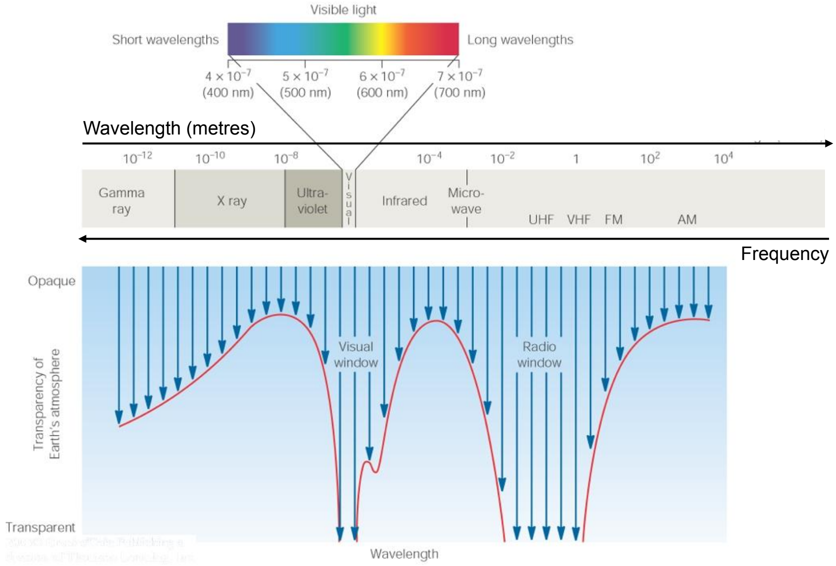
Space-based Observing

Advantages of observing from space
Limitations of observing from space
Comparison of current/recent space observatories

Space-based Observing

- Advantages:
  - Earth's atmosphere is opaque to X-ray, UV, and far-IR radiation
  - Improved signal-to-noise ratio and angular resolution for optical and near-infrared observations
- Limitations:
  - Background radiation from Zodiacal light and infrared cirrus
  - Radiation damage from charged particles in magnetosphere
  - Weight restrictions limit mirror size and diffraction limit
  - Evaporation of coolants limit duration of mission

The Electromagnetic Spectrum



Diffraction versus Seeing

$$\Delta\theta = \frac{1.22\lambda}{D}$$

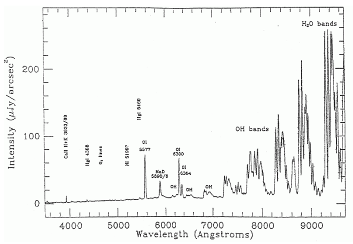
Keck telescope
- D=10m, FWHM>~0.5arcsec (seeing), λ=500nm
- Δθ = 1.22x500nm/10m = 0.51x10^{-7} radians
  = 0.01arcsec
- Keck is seeing limited

Hubble Space Telescope
- D=2.4m, FWHM~0.1arcsec (seeing), λ=500nm
- Δθ = 1.22x500nm/2.4m
  = 2.54x10^{-7} radians = 0.05arcsec
- Hubble is seeing limited – but only just!

Arecibo
- D=305m, FWHM~10arcsec (seeing), λ=21cm
- Δθ = 1.22 x 21cm / 305m
  = 8.4x10^{-4} radians
  = 173arcsec
- Arecibo is diffraction limited

Atmospheric Emission

- The atmosphere also emits radiation at optical wavelengths:
  - Rayleigh scattered moonlight and starlight
  - Emission from excited atoms and molecules in upper atmosphere (airglow)
- Airglow:
  - dominated by the hydroxyl radical OH^-
  - Increases rapidly in strength beyond 700nm
- The sky brightness is a strong function of wavelength:



Filter	λ(um)	mag/arcsec^2	photons/cm^2/s/um/arcsec^2
U	0.36	21.6	1.74x10e-2
B	0.44	22.3	1.76x10e-2
V	0.55	21.1	3.62x10e-2
R	0.64	20.3	5.50x10e-2
I	0.79	19.2	1.02x10e-1
J	1.23	14.8	2.49
H	1.66	13.4	4.20
K	2.22	12.6	3.98

Resolution, Background, S/N

- Consider a CCD for which the dark current is **D** electrons/pixel/sec and the read noise is **R** electrons
- This CCD is used to observe a star for a total of **t** seconds
- A total of **F** photons/sec are detected from the star in a measurement aperture of **N** pixels
- The sky background is measured to be **B** photons/sec/pixel

$$\text{Signal} = S = Ft$$

$$\sigma_{\text{Poisson}} = \sqrt{Ft}$$

$$\sigma_{\text{Dark}} = \sqrt{DNt}$$

$$\sigma_{\text{Sky}} = \sqrt{BNt}$$

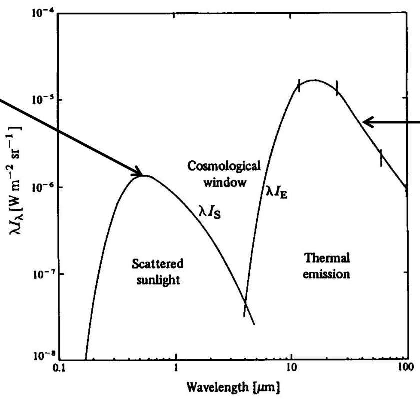
$$\sigma_{\text{RN}} = R\sqrt{N}$$

$$\frac{S}{N} = \frac{Ft}{\sqrt{\sigma_{\text{Poisson}}^2 + \sigma_{\text{Dark}}^2 + \sigma_{\text{Sky}}^2 + \sigma_{\text{RN}}^2}}$$

$$\frac{S}{N} = \frac{Ft}{\sqrt{(F + DN + BN)t + R^2 N}}$$

Zodiacal Light

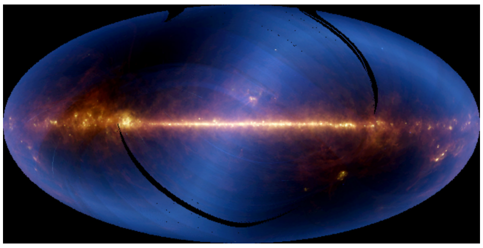
If the Sun is a black body then what wavelength do you expect this curve to peak at?



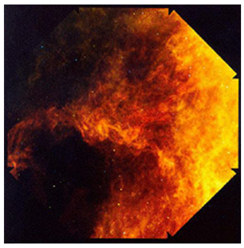
Use this curve to estimate the temperature of the dust that is orbiting round the Sun

The scattered sunlight has the same colour as the Sun. What scattering process is at work here?

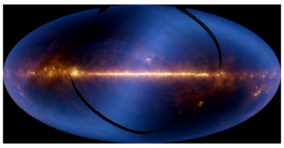
Infrared Cirrus



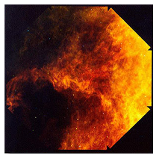
IRAS all-sky image of dust in the MW from IR thermal emission from dust grains.



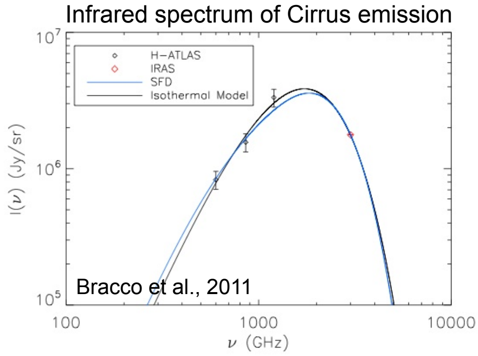
IRAS infrared cirrus at the north galactic pole, based on 12, 60 and 100 µm observations wavelengths.



Infrared Cirrus



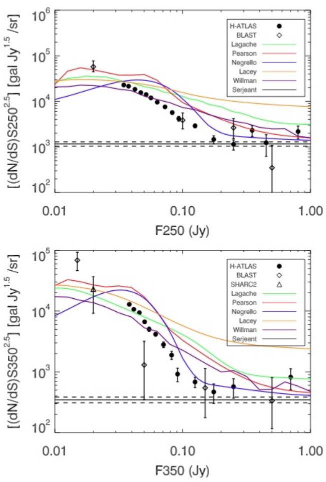
Infrared spectrum of Cirrus emission



At what wavelength does the cirrus emission peak?

Estimate the dust temperature.

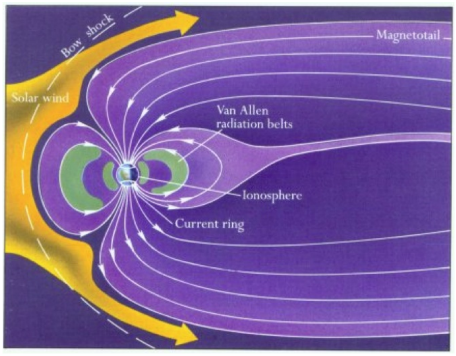
How does the cirrus emission compare with the signal from galaxies at z=2?



Clements et al., 2010

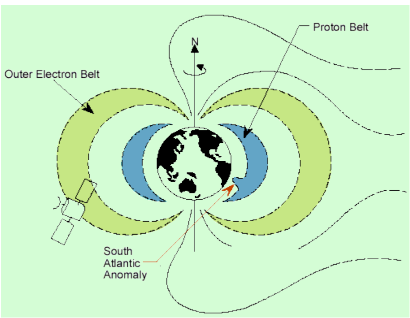
Van Allen Radiation Belts

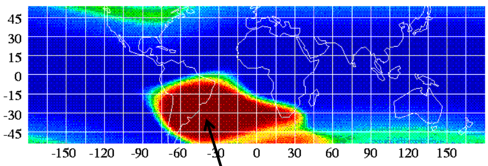
- High energy particles trapped in the Earth's magnetic field at tropical/temperate latitudes
- Inner belt:
  - ~300–3,000 miles altitude
  - dominated by high-energy protons
- Outer belt
  - ~6,000–20,000 miles altitude
  - dominated by high-energy electrons
- Many satellites orbit at ~200 – 500m altitude!



South Atlantic Anomaly

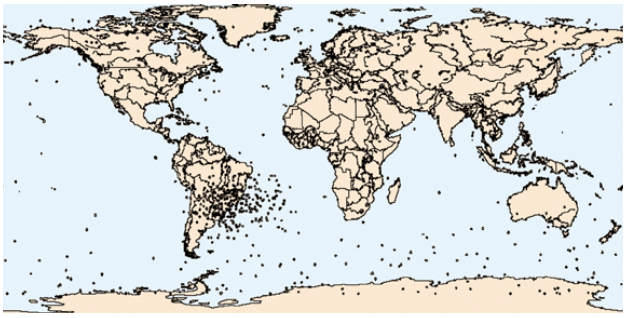
- A dip in the Earth's magnetic field over the South Atlantic allows cosmic rays and charged particles to reach the lower atmosphere
- This anomaly interferes with communication with satellites, aircraft, and the Space Shuttle
- The enhanced particle flux also strongly affects space-borne astronomy detectors (e.g. damage to HST/ACS CCDs)





South Atlantic Anomaly

South Atlantic Anomaly



1300 single-event upsets from one computer on the TAOS mission shows that nearly 50 percent occurred in the South Atlantic Anomaly, whereas only 5 percent of orbital time was spent there.

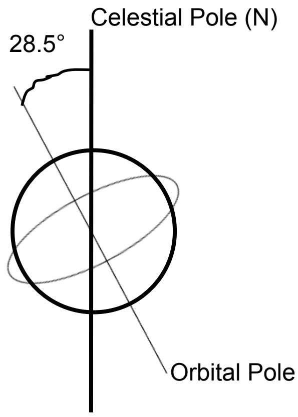
For example, the German X-ray satellite ROSAT's PSPCs had to be turned off during passage through the South Atlantic Anomaly to prevent severe damage.

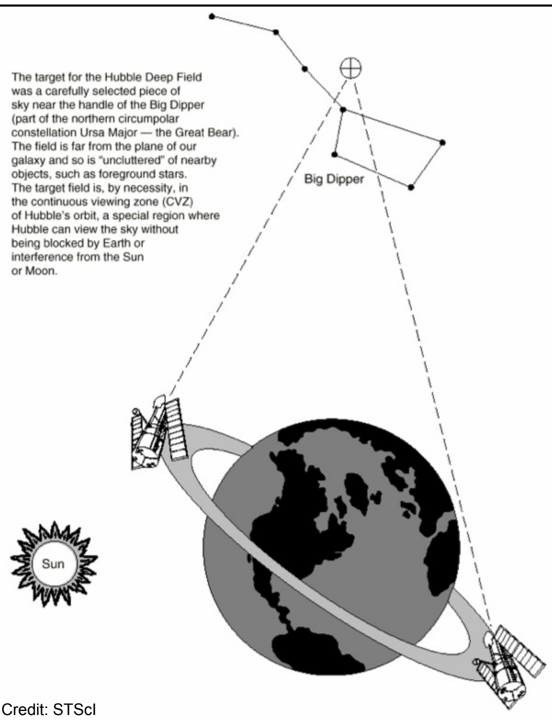
Modern Space Telescopes Compared

	Chandra	**Hubble**	**Spitzer**	**Herschel**
Duration of mission	1999–	1990–	2004–2009	2010–2013
Wavelength range	0.12–15nm	0.1–1.6um	3.6–160um	60–670um
Photon energy	0.1–10keV	0.8–12eV	8–350meV	2–21meV
Mirror diameter	15–30cm	2.4m	85cm	3.3m
Angular resolution	~0.5"	0.1" (1um)	30" (100um)	7" (100um)
Ambient temperature	~150K	~150K	34K	85K
Instrument temperature	…	…	5.6K	0.3–1.65K
Coolant	[Passive]	[Passive]	Liquid He	Superfluid He
Primary background	Solar flares	Thermal	Thermal	Thermal
Orbit	10^4–1.4×10^5km	600km	Earth-trailing	L2
Orbital period	63.5hrs	96mins	1 year	1 year
Observing efficiency	0.7	~0.5	0.9	~0.8
Max uninterrupted observ'n	48hrs	~8hrs	24hrs	18hrs

Hubble Space Telescope

- South Atlantic Anomaly
  - Telescope shuts down during SAA passage
  - SAA responsible for CCD damage and CTE degradation
- Continuous Viewing Zone
  - Orbital pole precesses around celestial pole every 56 days
  - Targets within 24° of orbital poles are not occulted by Earth at any time during the orbit

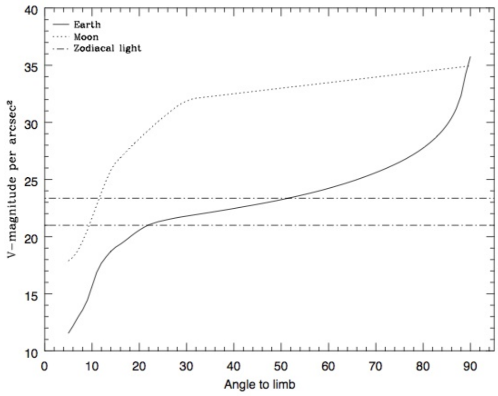




Credit: STScI

Hubble Space Telescope

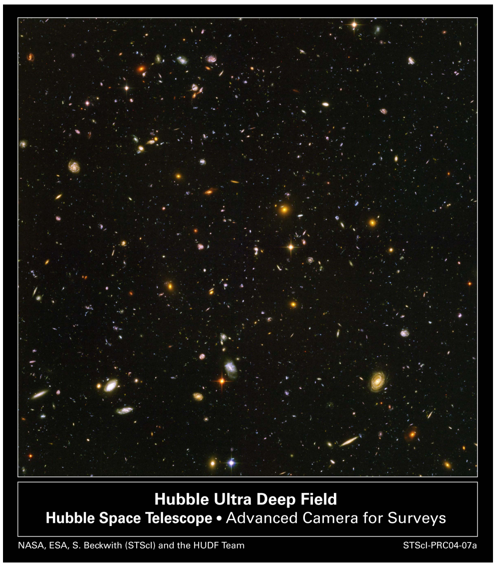
Figure 9.2: Background contributions in V magnitude per arcseconds^2 due to the zodiacal light, Moon, and the sunlit Earth, as a function of angle between the target and the limb of the Earth or Moon.



The two zodiacal light lines show the extremes of possible values.

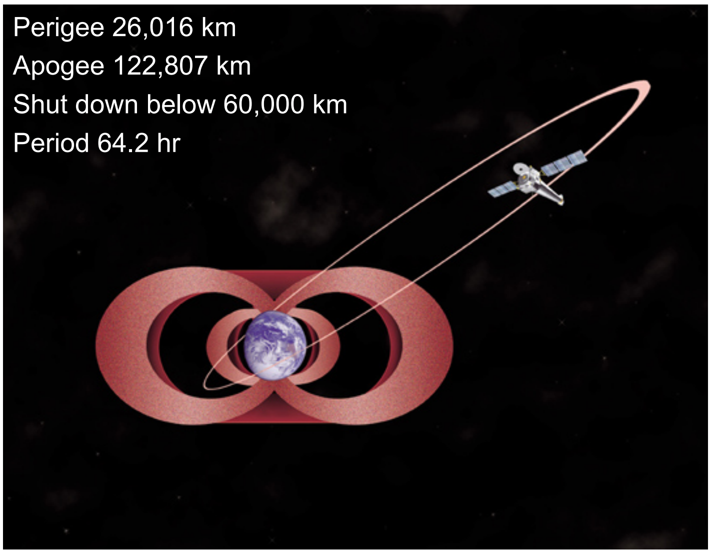
Hubble Ultra Deep Field

Our deepest view of the universe to date

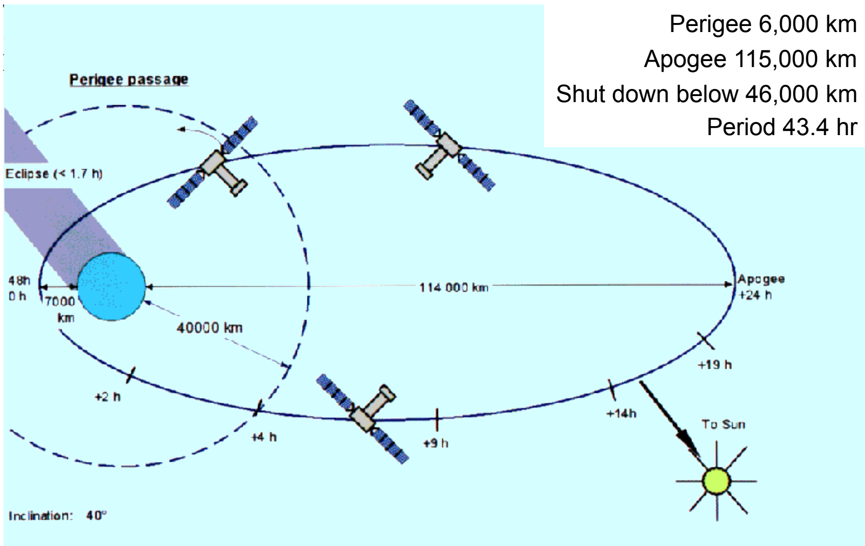


- 1 million seconds (312 orbits)
- "Blank" field in CVZ (Fornax cluster)
- BVIz filters reaching ~29th magnitude
- 0.1x diameter of moon
- Main science highlight:
  - discovery of galaxies at z>7
  - (see Group Study, next year)

Chandra

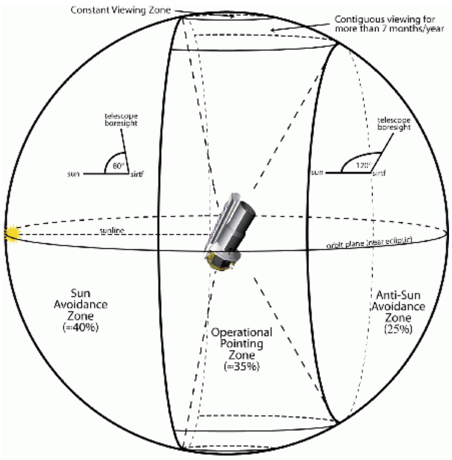


XMM-Newton

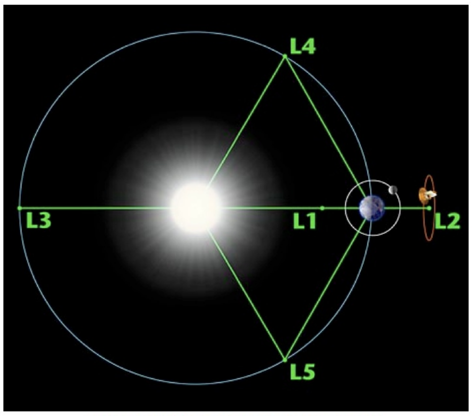


Spitzer

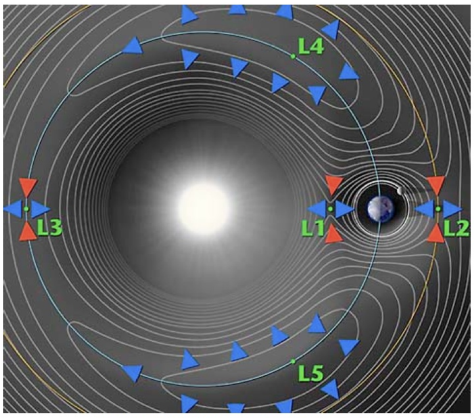
- Earth trailing orbit
- Currently 0.58AU from earth
- Recedes at 0.12AU/year
- Data transfer strategy needs to change over time
- Very efficient radiative cooling:
  - Away from heat of Earth
  - Points permanently away from Sun
- Solar panels point permanently towards Sun
- Not affected by Van Allen belts nor South Atlantic Anomaly



Herschel @ L2



Lagrange Points of the Earth-Sun system (not drawn to scale!).



A contour plot of the effective potential (not drawn to scale!).