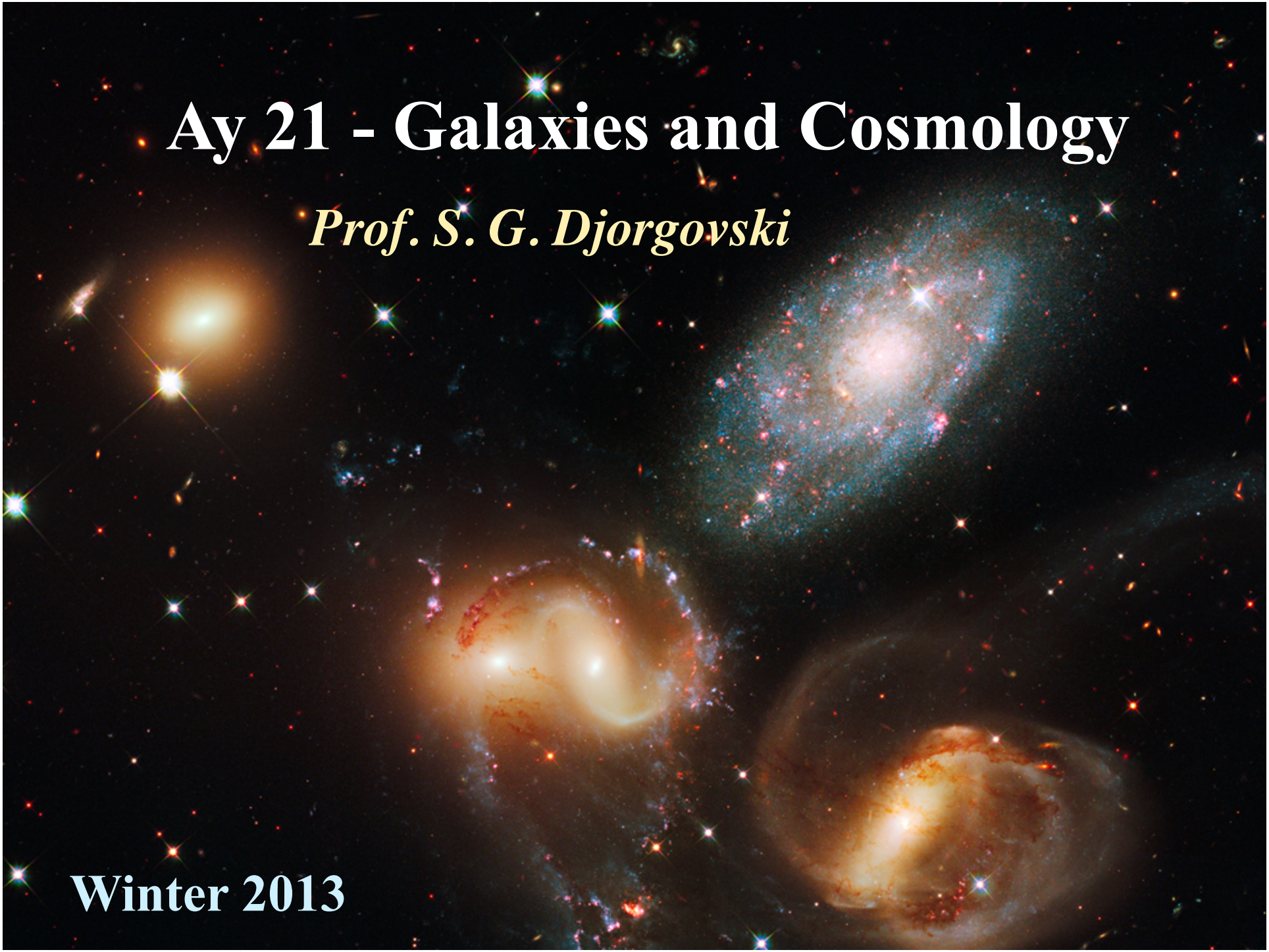

Ay 21 - Galaxies and Cosmology

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Cosmology* as a Science

- A study of the universe as a whole, its global geometry, dynamics, history, fate, and its major constituents - galaxies and large-scale structures, their formation and evolution
- A basic assumption: the physical laws are the same at all times and everywhere
  - Some aspects of this are testable
  - But a new and unexpected physics can show up, e.g., dark matter, dark energy
- Only one object of study, and all we can do is look at the surface of the past light cone
- Observations tend to be difficult, and subject to biases and selection effects

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* From Greek *kosmos* = order; see also *cosmetology* …

The Evolution of the Cosmological Thought

… From magical and arbitrary to rational and scientific

Folklore to theology to philosophy to physics

… Away from anthropocentric/anthropomorphic

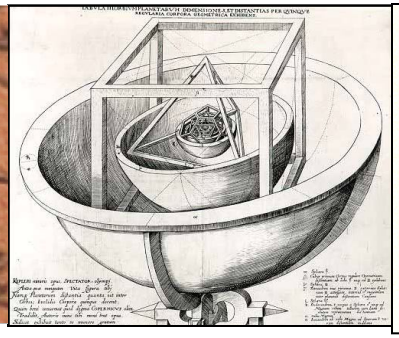
The Copernican revolution

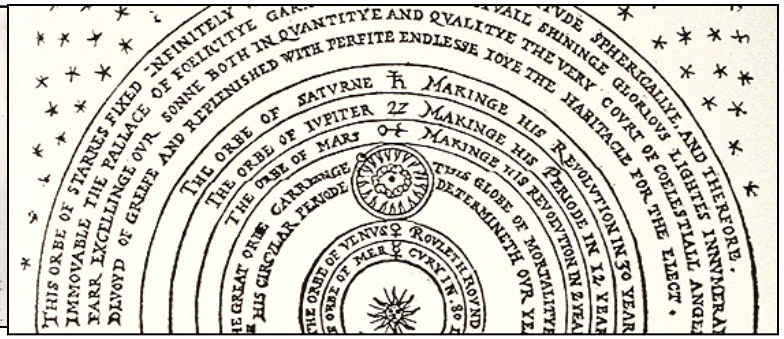
… From final and static to evolving and open-ended

The Darwinian revolution

… From absolute certainty to an ever expanding sphere of knowledge and a boundary of unknown

Cosmology today is a branch of physics





Dust Off Your Astronomical Units!

- Distance:
  - Astronomical unit: the distance from the Earth to the Sun, 1 au = 1.496×10^{13} cm
  - Light year: c $\times$1 yr, 1 ly = 9.463×10^{17} cm
  - Parsec: the distance from which 1 au subtends an angle of 1 arcsec, 1 pc = 3.086×10^{18} cm = 3.26 ly = 206,264.8 au
- Mass and Luminosity:
  - Solar mass: 1 $M_\odot$ = 1.989×10^{33} g
  - Solar luminosity: 1 $L_\odot$ = 3.826×10^{33} erg/s

Fluxes

Real detectors are sensitive over a finite range of λ (or ν). Fluxes are always measured over some finite bandpass.

Total energy flux: $F = \int F_\nu(\nu) d\nu$ Integral of f_ν over all frequencies

Units: erg s^{-1} cm^{-2} Hz^{-1}

A standard unit for specific flux (initially in radio, but now more common):

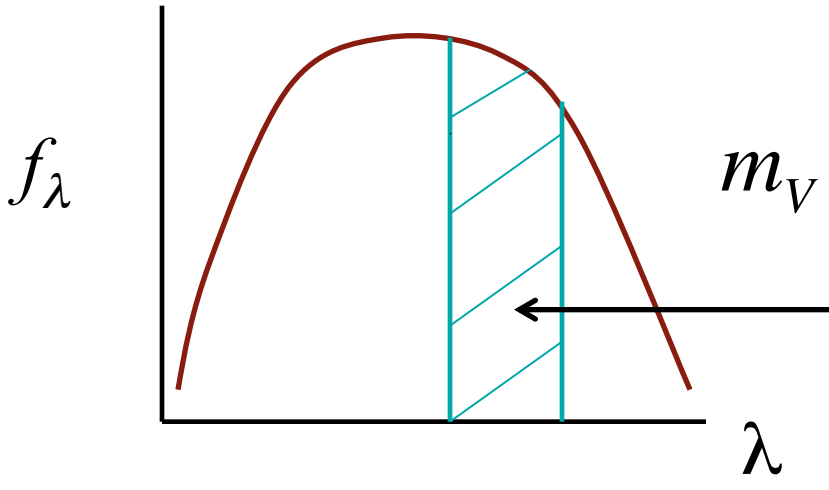
1 Jansky (Jy) = 10^{-23} erg s^{-1} cm^{-2} Hz^{-1}

f_ν is often called the ***flux density*** - to get the ***power,*** one integrates it over the bandwith, and multiplies by the area

Fluxes and Magnitudes

For historical reasons, fluxes in the optical and IR are measured in magnitudes: $m = -2.5 \log_{10} F + \text{constant}$

Usually integrated over some finite bandpass, e.g., V band ($\lambda \sim$ 550 nm):

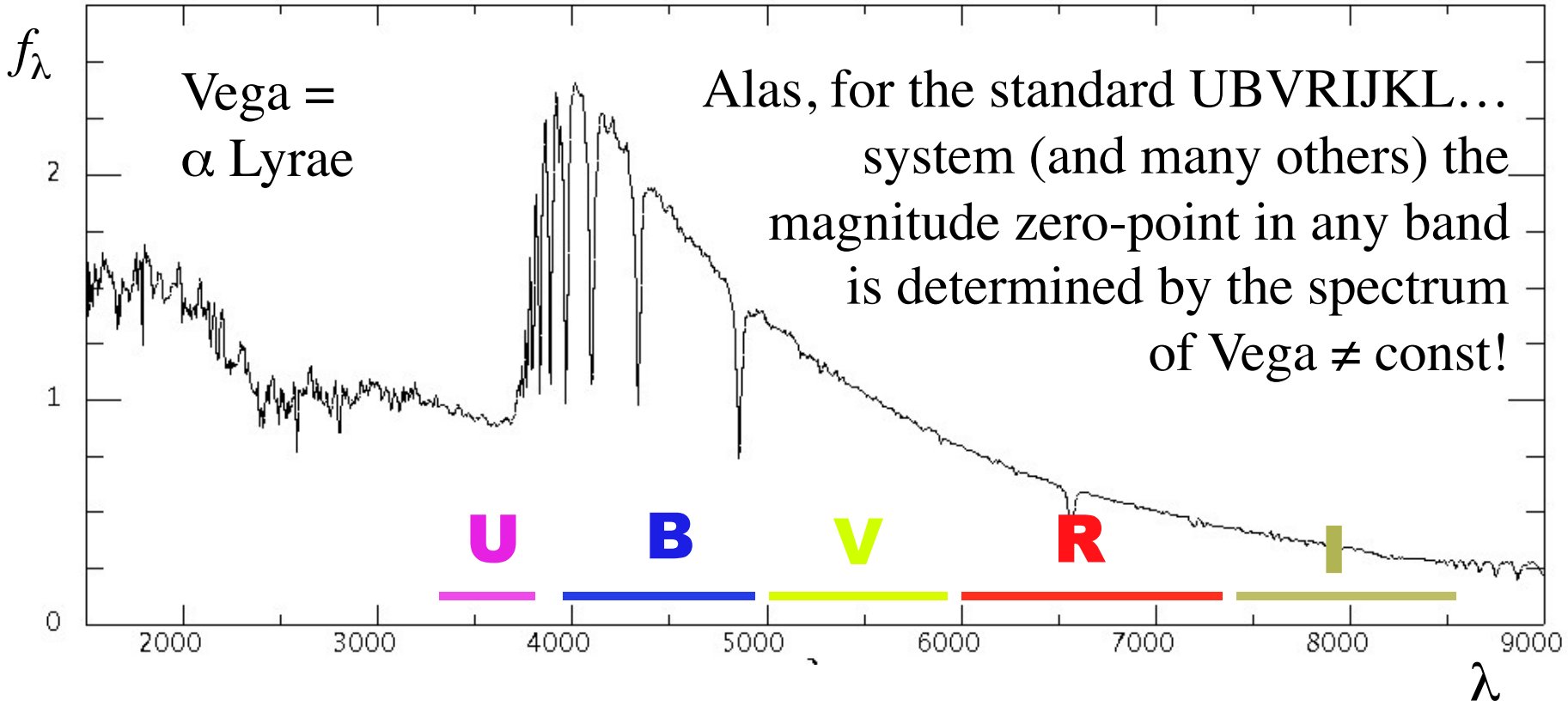


$$m_V = -2.5 \log_{10} F + \text{constant}$$

flux integrated over the range of wavelengths for this band

If the flux is integrated over the entire spectrum, then m is the *bolometric magnitude*.

Magnitude Zero Points



Vega calibration ($m = 0$): at $\lambda = 5556$: $f_\lambda = 3.39 \times 10^{-9}$ erg/cm²/s/Å

$f_\nu = 3.50 \times 10^{-20}$ erg/cm²/s/Hz

$N_\lambda = 948$ photons/cm²/s/Å

A more logical system is AB_ν magnitudes:

$$AB_\nu = -2.5 \log f_\nu \text{ [cgs]} - 48.60$$

Using Magnitudes

Consider two stars, one of which is a hundred times fainter than the other in some waveband (say *V*).

$$m_1 = -2.5 \log F_1 + \text{constant}$$

$$\begin{aligned} m_2 &= -2.5 \log(0.01 F_1) + \text{constant} \\ &= -2.5 \log(0.01) - 2.5 \log F_1 + \text{constant} \\ &= 5 - 2.5 \log F_1 + \text{constant} \\ &= 5 + m_1 \end{aligned}$$

Source that is 100 times **fainter** in flux is five magnitudes fainter (**larger** number).

Faintest objects detectable with *HST* have magnitudes of ~ 29 in R/I bands. The sun has $m_V = -26.75$ mag

Apparent vs. Absolute Magnitudes

The absolute magnitude is defined as the apparent mag. a source would have if it were at a distance of 10 pc:

$$M = m + 5 - 5 \log d/\mathrm{pc}$$

It is a measure of the **luminosity** in some waveband.

For Sun: $M_{\odot B} = 5.47$, $M_{\odot V} = 4.82$, $M_{\odot bol} = 4.74$

Difference between the apparent magnitude m and the absolute magnitude M (any band) is a ***measure of the distance*** to the source

$$\underbrace{m - M}_{\text{Distance modulus}} = 5 \log_{10}\left(\frac{d}{10\ \mathrm{pc}}\right)$$

The Olbers Paradox (1826): Why is the sky dark at night?

Assume:

- The universe is infinite
- The universe is filled uniformly with stars
- The universe is eternal and unchanging

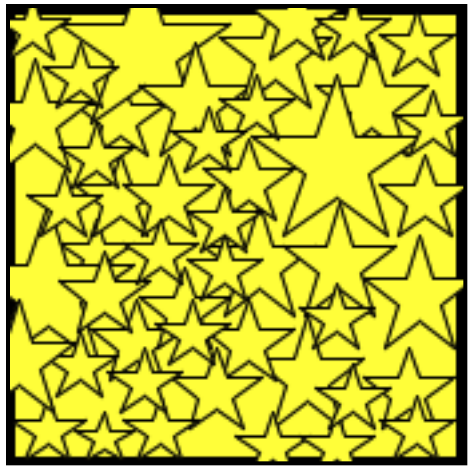
Deriving the Olbers Paradox:

Total flux we receive from a star $\propto 1/d^2$

Angular area of a star $\propto 1/d^2$

Surface brightness (light per unit area on sky)

= total flux / angular area = constant



If every line of sight ends on a star, the sky should be as bright as the sun!

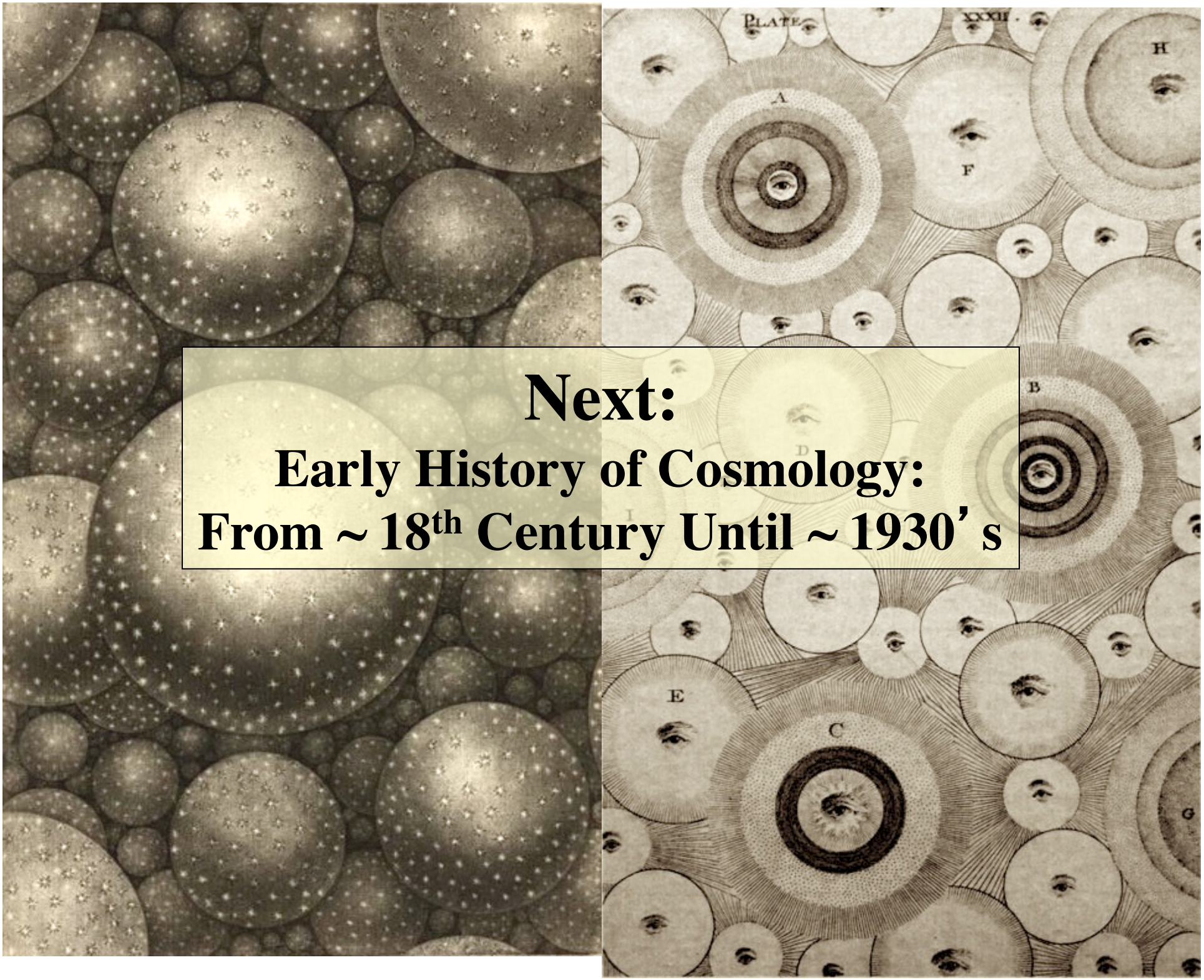
The equivalent paradox applies to gravity - infinite tidal forces?!

Solving the Olbers Paradox

- Opaque universe? - *No, the energy is still there*
- Redshift? - *Not enough*
- Hierarchical universe? - *Possible, but not true*

The actual explanation:

- The universe has a finite extent, age, and energy content: there isn't enough radiative energy in it to make the sky as bright as the surface of a star
  - In fact, the sky is ablaze - but the temperature of the radiation is only 2.7° K (CMBR)
  - All starlight ever emitted amounts only to a few percent of the CMBR energy density



Next:

Early History of Cosmology:
From ~ 18th Century Until ~ 1930's