Australian National University

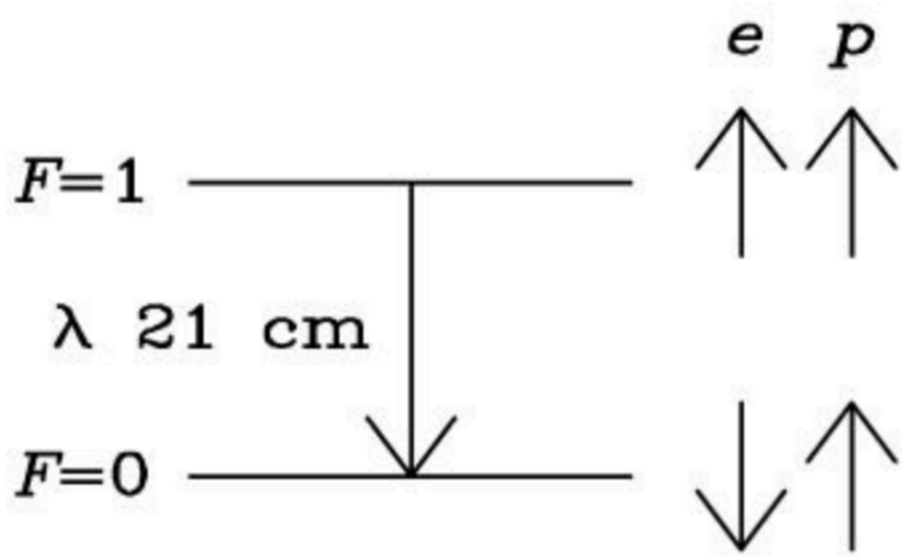
ASTR2013 – *Foundations of Astrophysics*

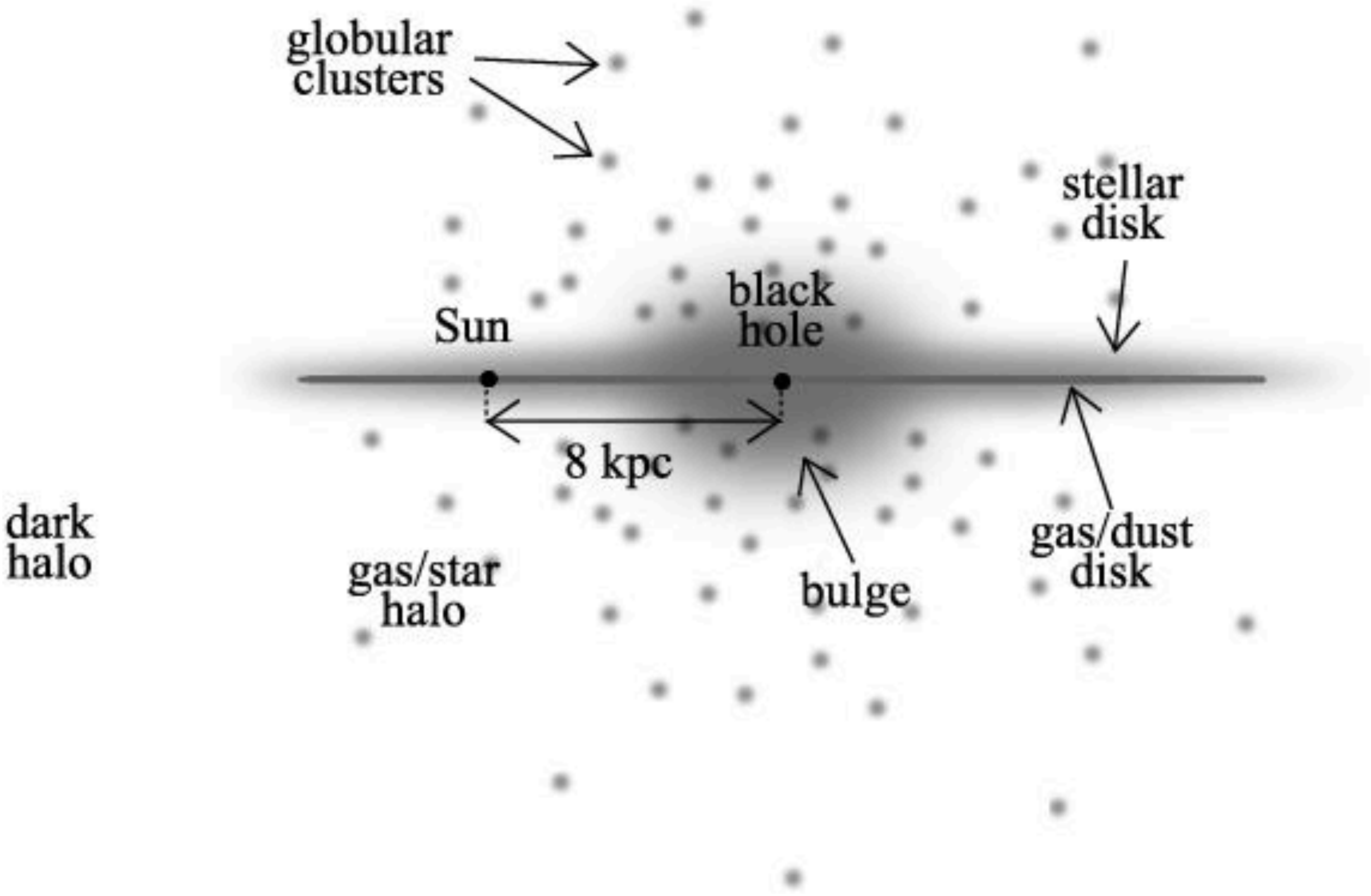
Week 9: Other Galaxies and Active Galactic Nuclei

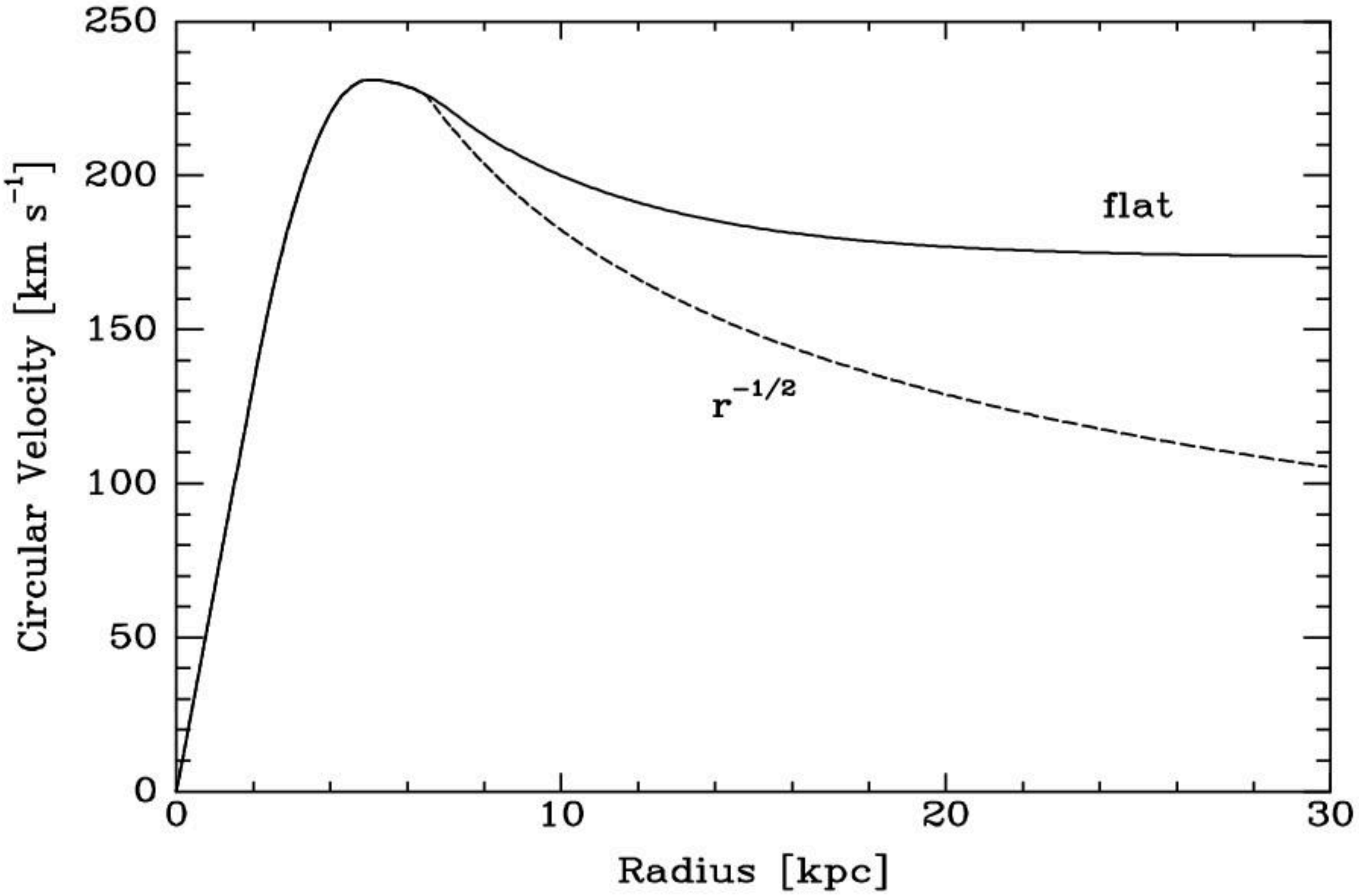
Mike Ireland

HI Emission

- HI is so important because all neutral hydrogen emits at this wavelength. Ionised and molecular hydrogen can be difficult to detect.
- The transition rate is 3 x 10^{-15} Hz from upper to lower energy level – i.e. 10^7 years on average to emit a photon.
- Very close to 50% of H is always in upper state – *emission measures mass.*




globular
clusters
stellar
disk
black
hole
Sun
8 kpc
dark
halo
gas/star
halo
bulge
gas/dust
disk



250
200
150
100
50
0
Circular Velocity [km s^{-1}]
0
10
20
30
Radius [kpc]
flat
$r^{-1/2}$

Australian National University

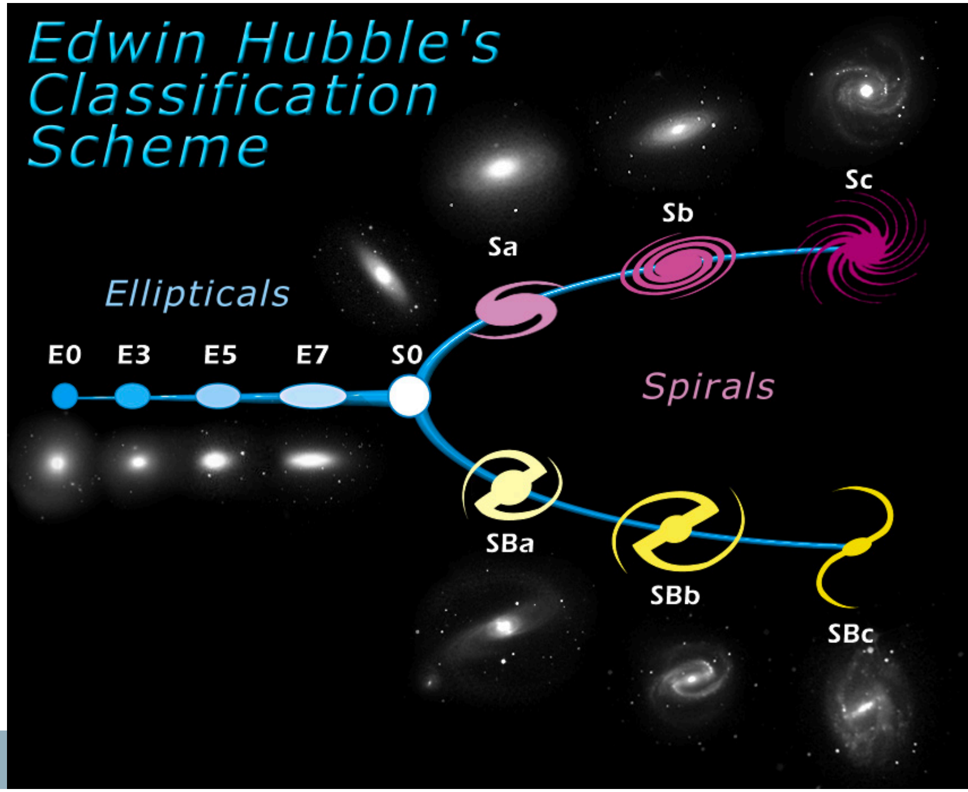
Week 9 Summary

Textbook: Sections 7.2, 4.6.1, 4.6.2, 7.3, 7.4 (2nd edition – 1st edition has 1 fewer chapters)

- Other Galaxies have historically been classified morphologically – irregular galaxies, spirals and ellipticals. The reason for morphology remains complex.
- Galaxy luminosity is described by a *Schechter* function, with our Milky Way being at around the exponential cutoff mass.
- Galaxy evolution is intimately tied in to evolution of their AGN/Quasars/Supermassive black holes. Accretion rates are (roughly) limited by the *Eddington limit.*
- The distribution of galaxies is observed to be highly structured, in *groups* and *clusters*.

Historical Classification

- Edwin Hubble created in 1926 a classification from *early* to *late* type galaxies: terms which have nothing to do with evolution.
- In ASTR2013, we will only consider the broad definitions of Irregular, Spiral and Elliptical Galaxies.



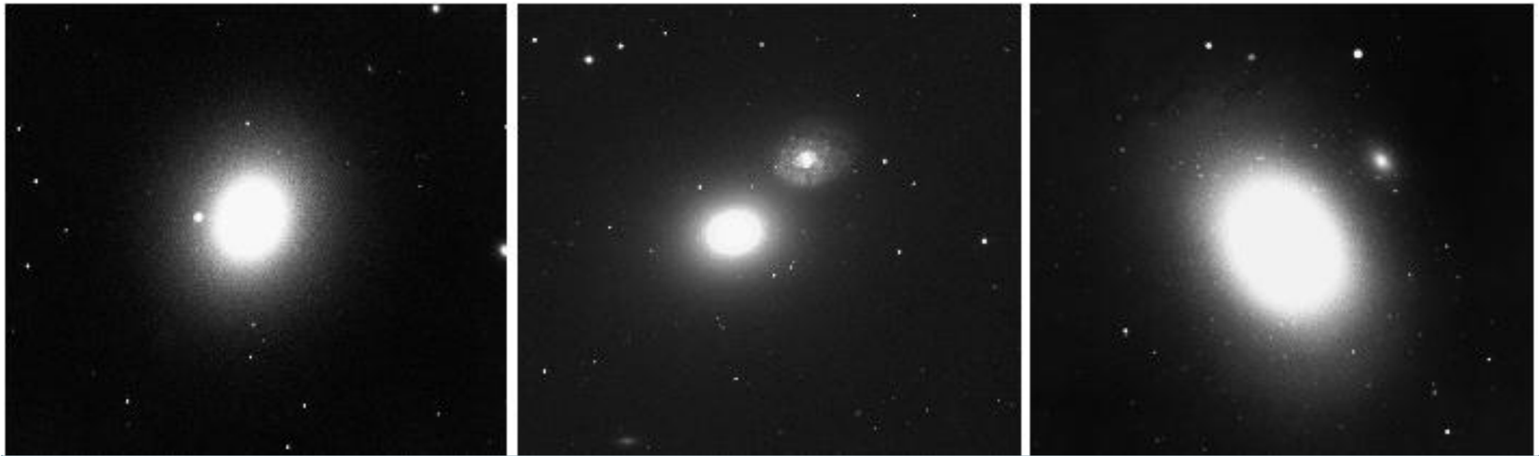
NASA/STSci/ Wikipedia

Irregular Galaxies

Irregular galaxies, with a combination of young and old stars and some gas/star formation are the most common Galaxy type: e.g. LMC and SMC.

Elliptical Galaxies

- Elliptical galaxies have no cool gas to collapse and form new stars: they have *old stellar populations.*
- Although not all elliptical galaxies are massive, the most massive galaxies are giant ellipticals.

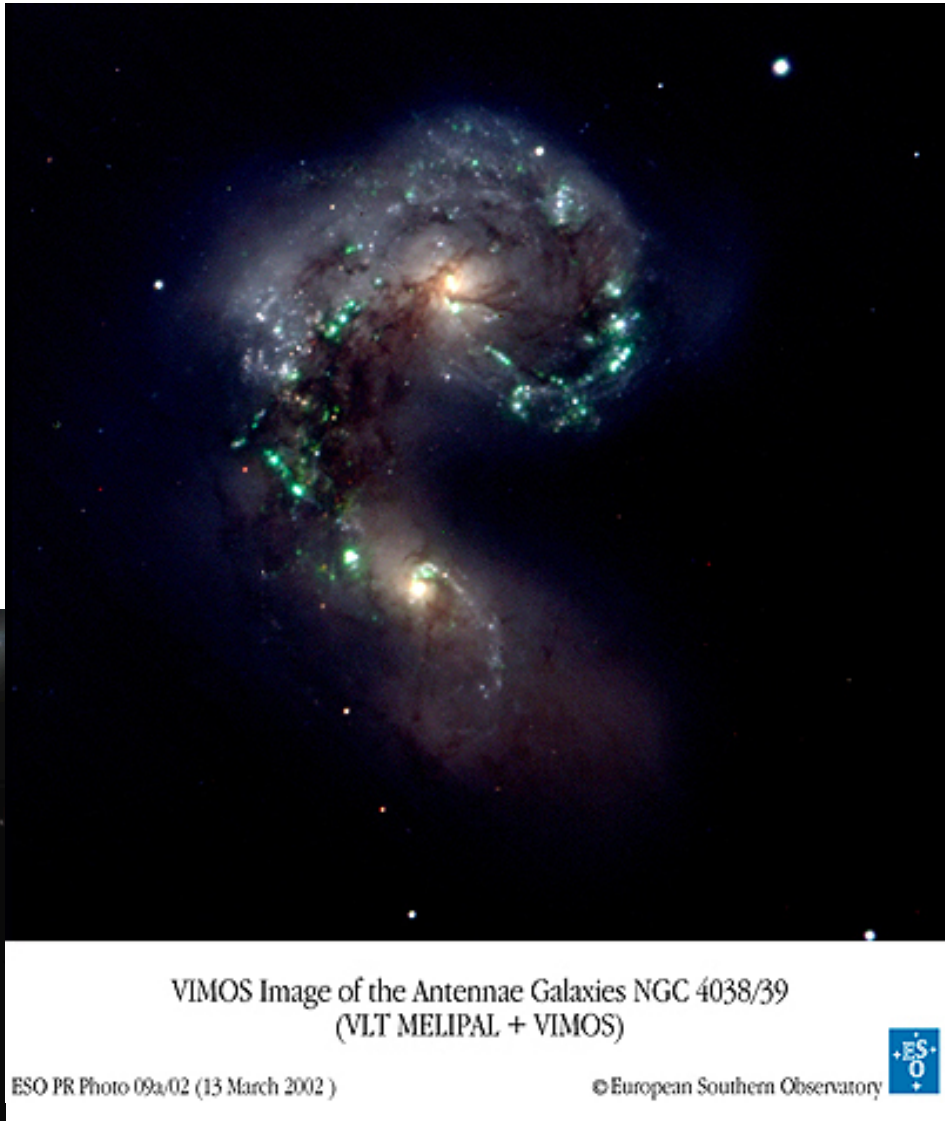


Virgo cluster ellipticals: M49, M60 and M86

Galaxy Collisions

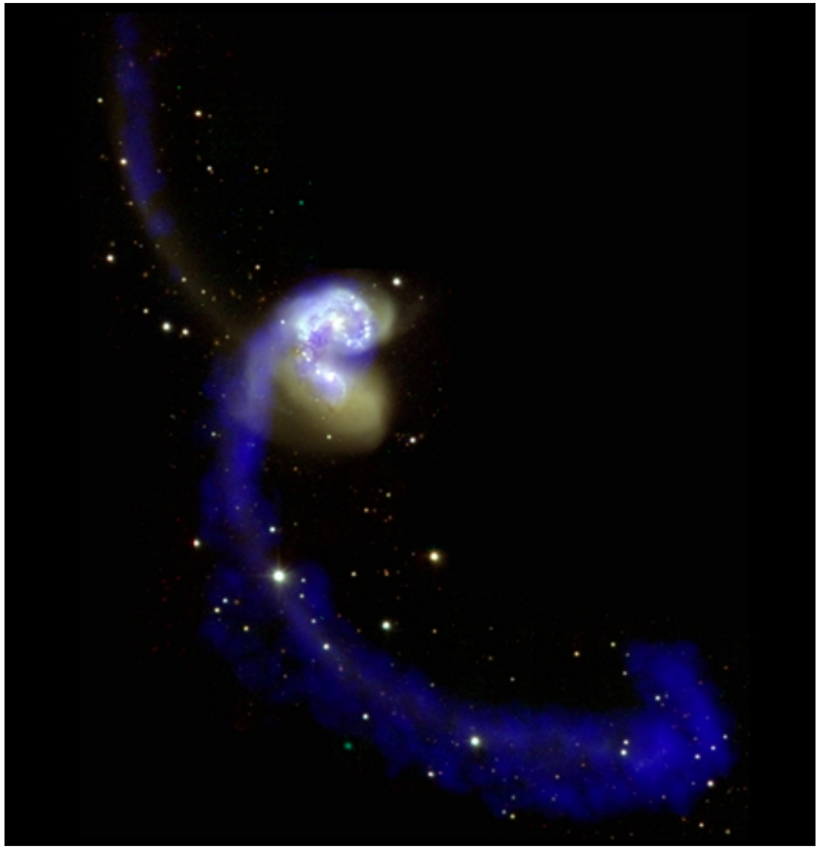
NGC 4038/4039 zoom in (right)

NGC 4676 (bottom)



Galaxy Collisions

Interacting and colliding galaxies are likely important in forming massive ellipticals: gas collides but stars flow through each other (but tidally disrupt).



NGC 4038 and 4039

Colliding Spirals Simulation

Credit: Josh Barnes (University of Hawaii) and John Hibbard (National Radio Astronomy Observatory) [also NASA/Hubble press release in 2002]

Galaxy Luminosity Function

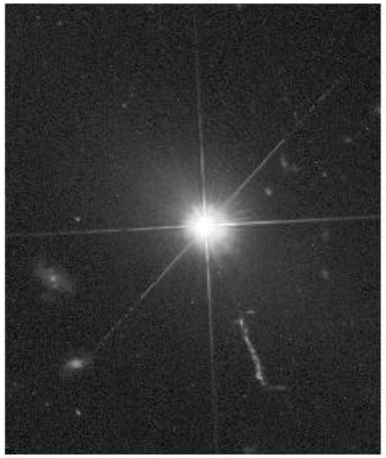
- The distribution of galaxy luminosities is approximately described by the *Schechter* function (at least within a factor of 100 of the Milky Way luminosity).
- [ϕ is the number per unit L and volume]

$$\phi(L)\,dL \approx \phi(L_*)\left(\frac{L}{L_*}\right)^{-1}\exp\left(-\frac{L}{L_*}\right)dL.$$

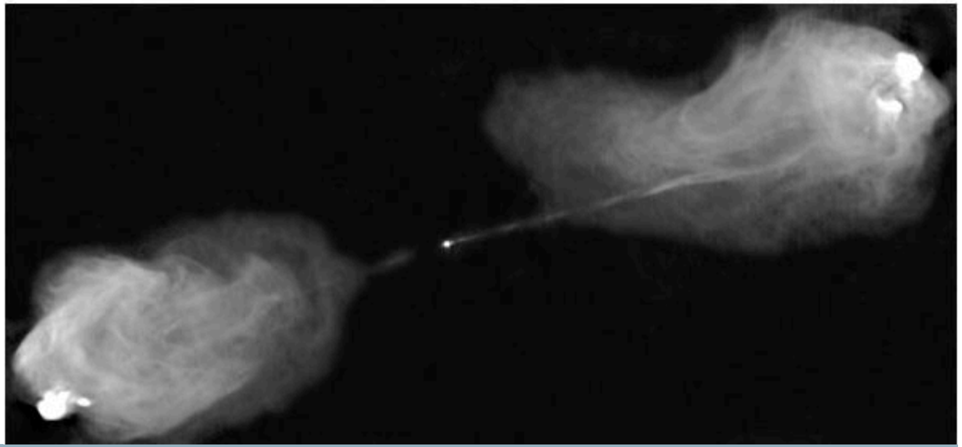
- The critical turning point in this distribution, L_*, is approximately the Milky Way.
- The distribution of lower luminosities can be described as *uniform in log(L).*

Quasars

- Quasars are “quasi-stellar” objects, observationally defined as being point-like but at moderate redshift (i.e. not in the Galaxy)
- They are generally associated with strong ratio emission from jets that travel close to the speed of light.
- Quasars are now known to be supermassive black holes accreting gas rapidly at the center of galaxies: *Active Galactic Nuclei (AGN)*

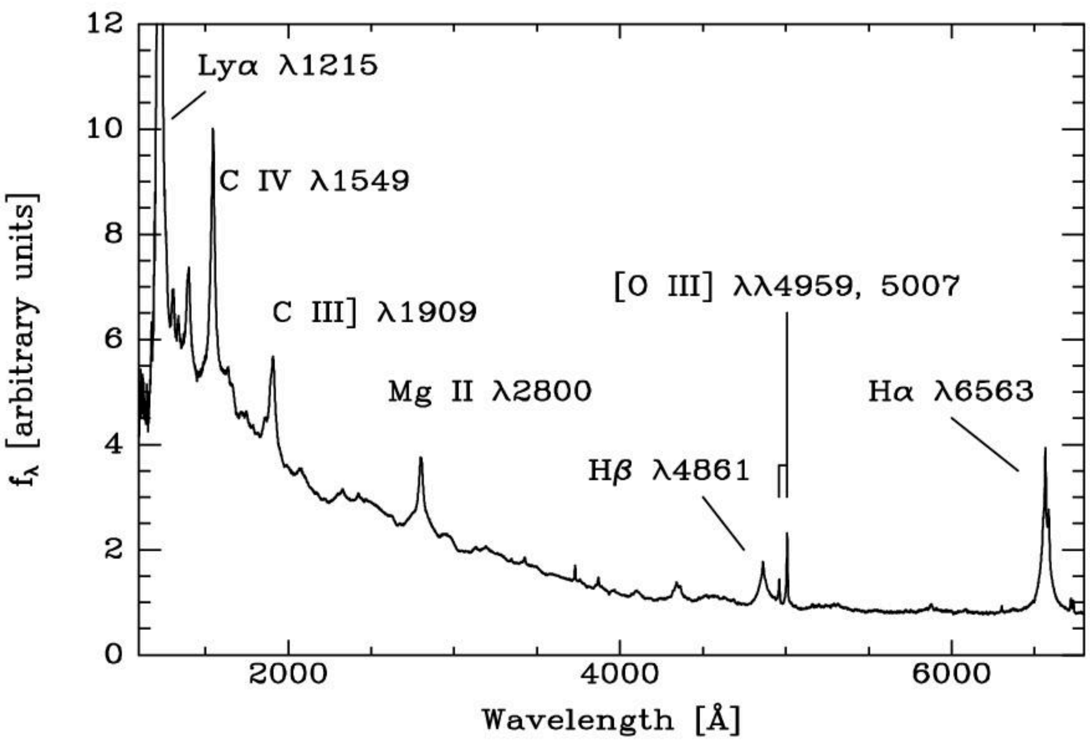


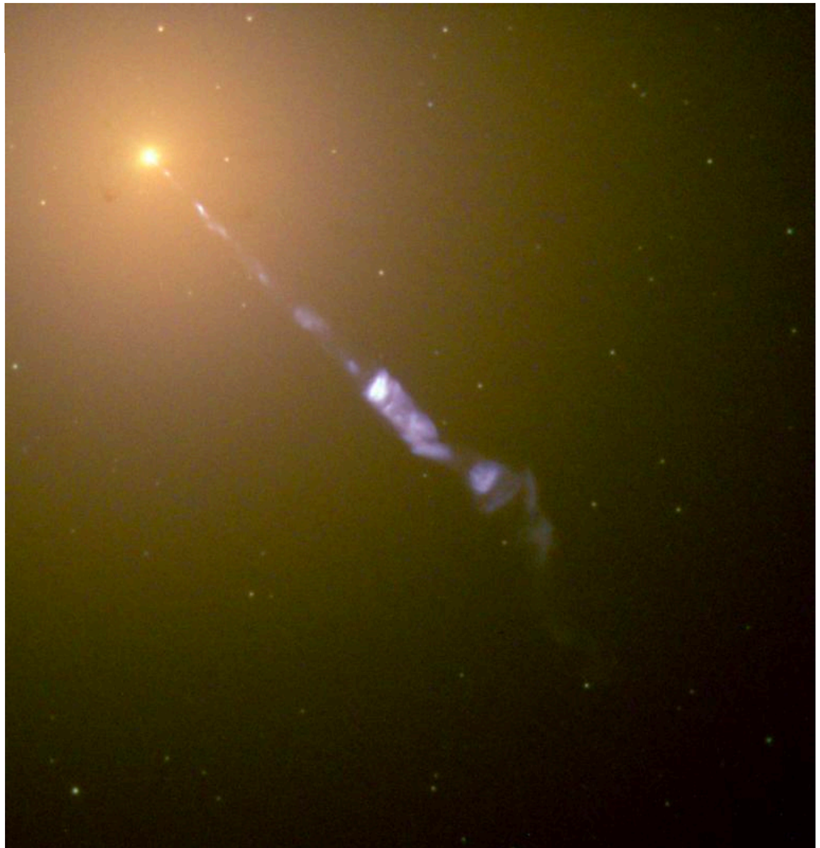
- A supermassive black hole is only an AGN if it is accreting rapidly.
- An AGN is only a quasar if it is seen from the right angle – if seen edge on, dust (e.g. in a Torus shape) gets in the way.



Quasars

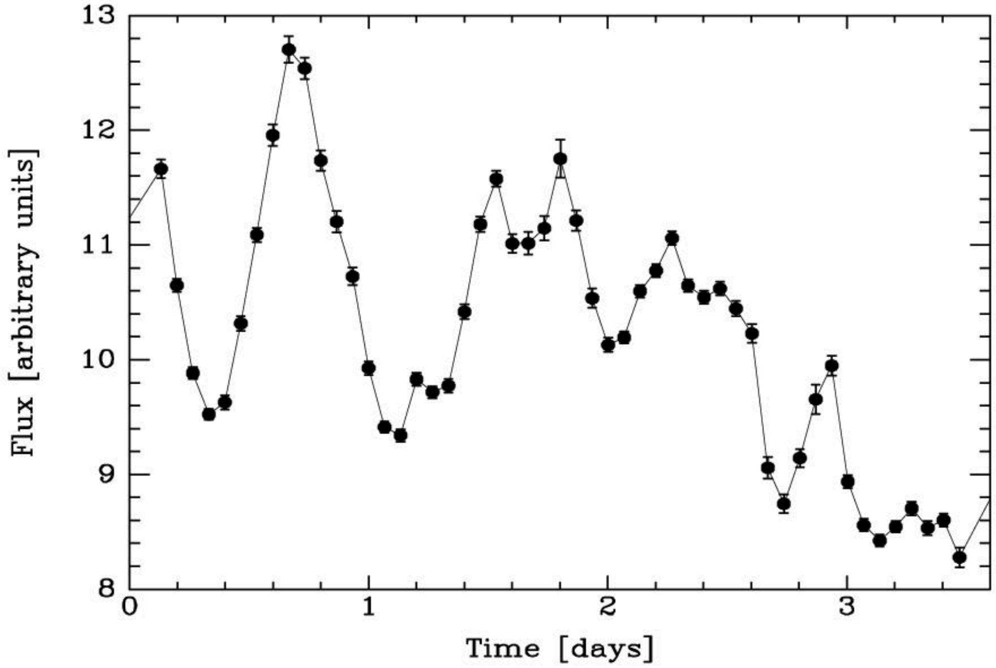
Quasars have a characteristic spectrum, with emission at all wavelengths as occurs in an accretion disk, and emission lines of highly ionized elements.

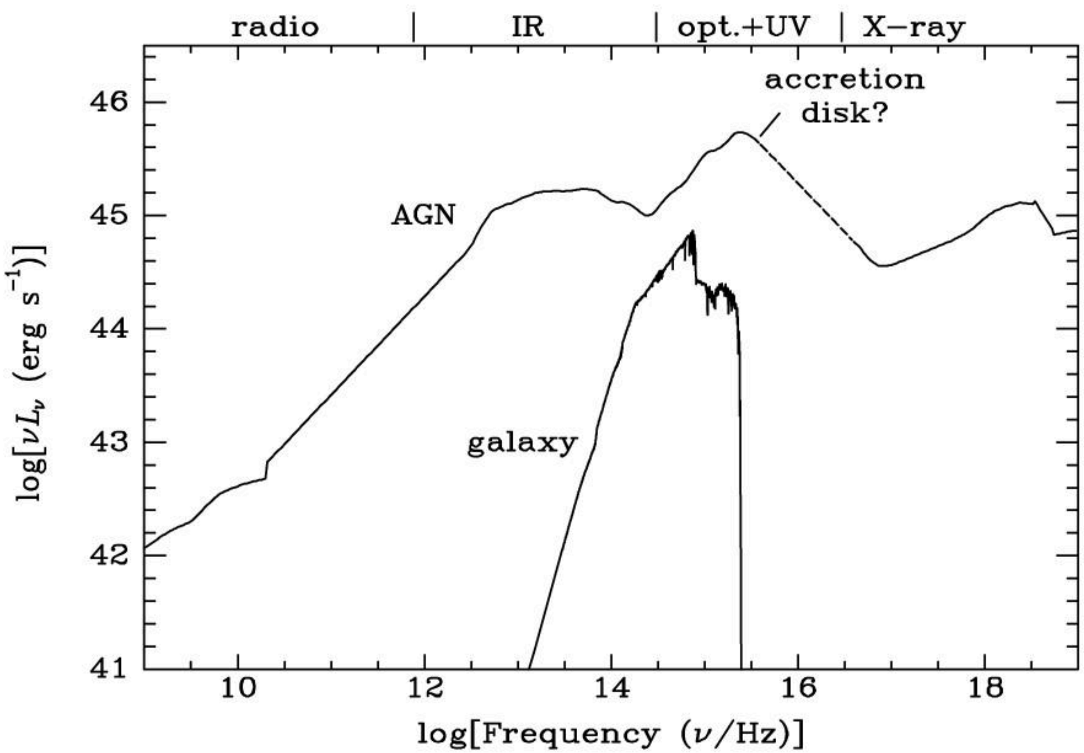




Quasar variability (top) and spectrum (bottom) are very different to a galaxy.

discuss





Eddington Luminosity

- Ignoring the geometry of the accretion disk, we can estimate the maximum possible accretion rate when the force per atom due the outgoing radiation due to accretion is equal to the gravitational force.
- We take the highly ionized opacity – the Thompson scattering cross section:

$$L = L_E = 1.3 \times 10^{38}\ \mathrm{erg\ s^{-1}}\ \frac{M}{M_\odot}$$

$$\frac{GMm_p}{r^2} = \frac{L_E \sigma_T}{4\pi r^2 c}$$

$$L_E = \frac{4\pi c G M m_p}{\sigma_T}$$

Derive on board!

Eddington-Limited Accretion

- Equate the energy radiated to the energy lost to the last stable orbit:

$$L \approx \frac{1}{2}\frac{GM\dot{M}}{r_{\rm in}} = \frac{\dot{M}c^2}{12}$$

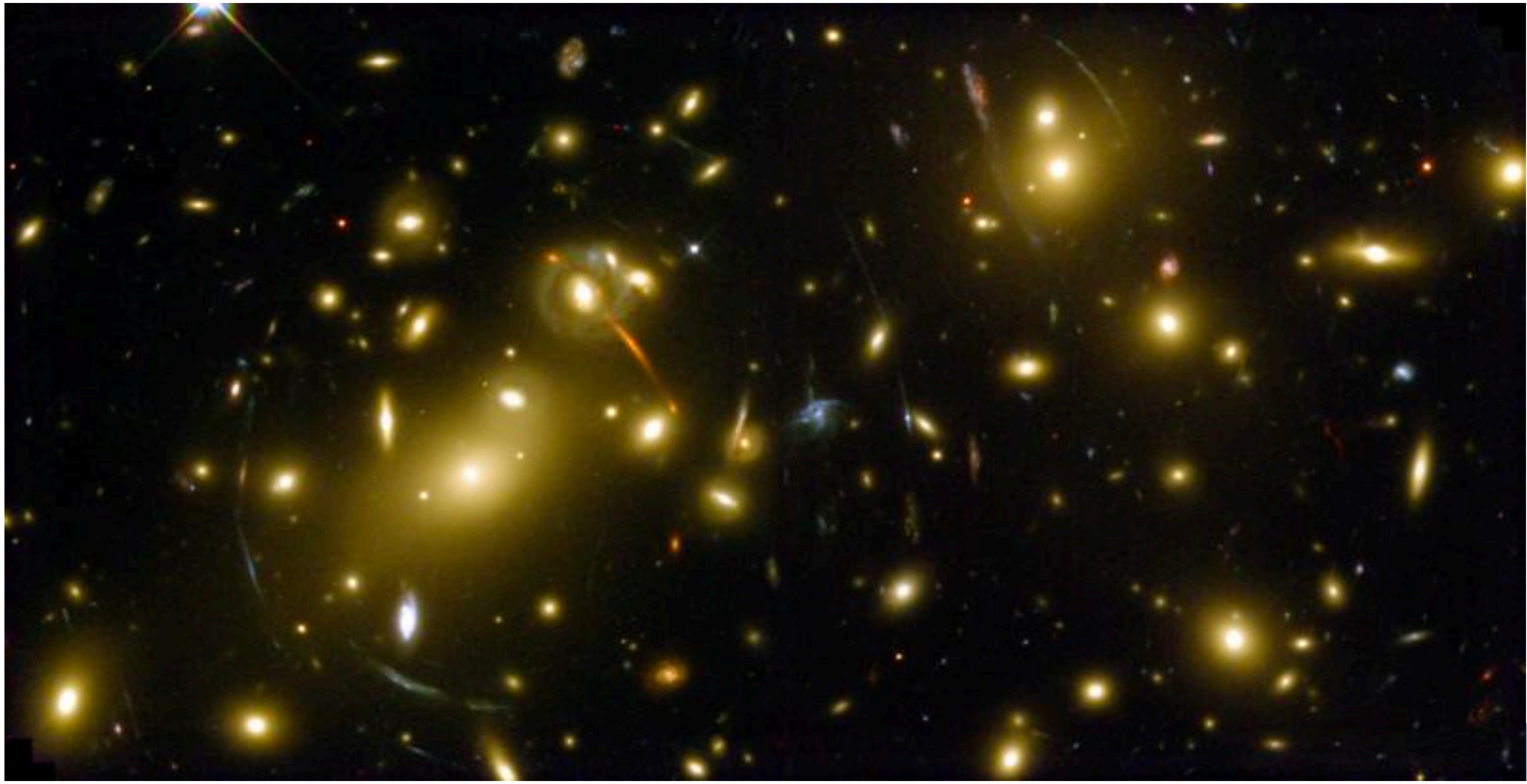
- After taking into account a small correction for general relativistic effects, we arrive at:

$$L = 0.057\dot{M}c^2$$

- Accretion can be “super-Eddington” e.g. through a disk, or if matter falls onto the black hole without radiating, but it is difficult to significantly exceed this limit.

Galaxy Clusters and Groups

- Galaxies are found in groups (e.g. Andromeda and the Milky Way) and in clusters (e.g. Virgo, Coma).
- The most massive galaxy clusters show strong gravitational lensing of background galaxies



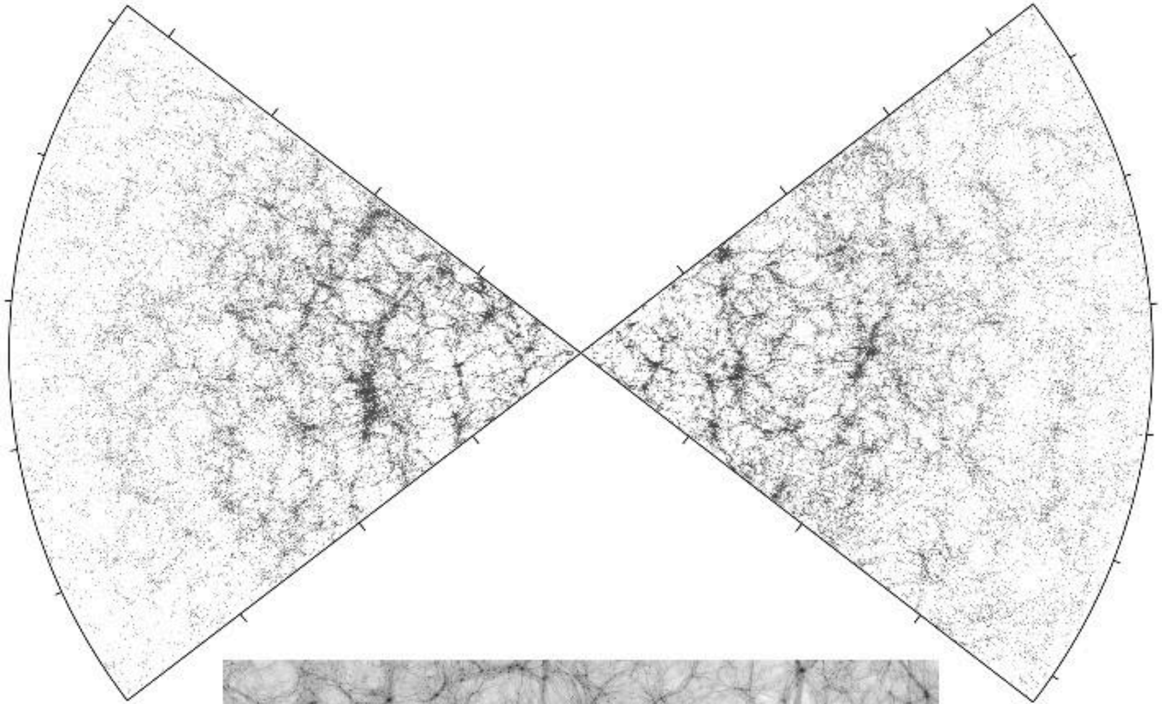
Abell 2218
(NASA/textbook)

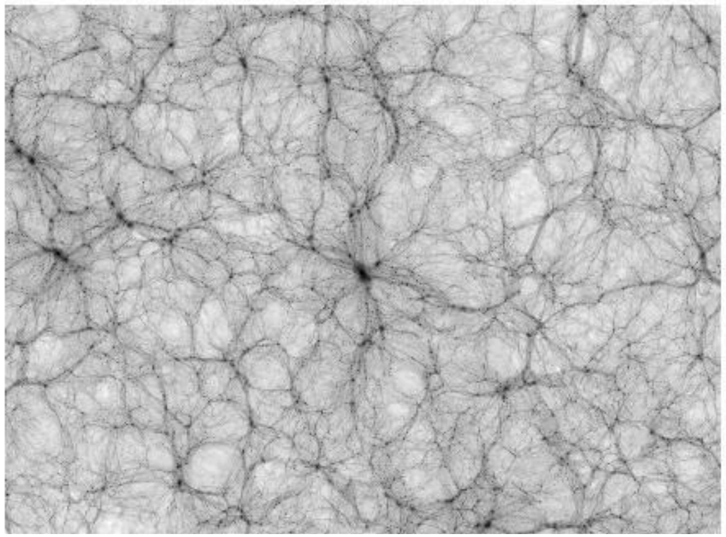
Galaxy Cluster Mass

- We can measure galaxy velocities within a cluster and its size.
- This gives a crossing timescale of ~1 Gyr – much less then the Universe age.
- This means that the cluster is *virialized*, i.e. that motions are random enough that the virial theorem should apply, implying cluster masses of order 10^{14} M_{sun}.

$$M \approx \frac{\sigma_v^2 r_{cl}}{G}$$

Large Scale Structure





Observed large scale structure of Galaxies (2dF, top) match simulations (bottom).

Very large voids i-between clusters and fillaments… more on this in 2 weeks!

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