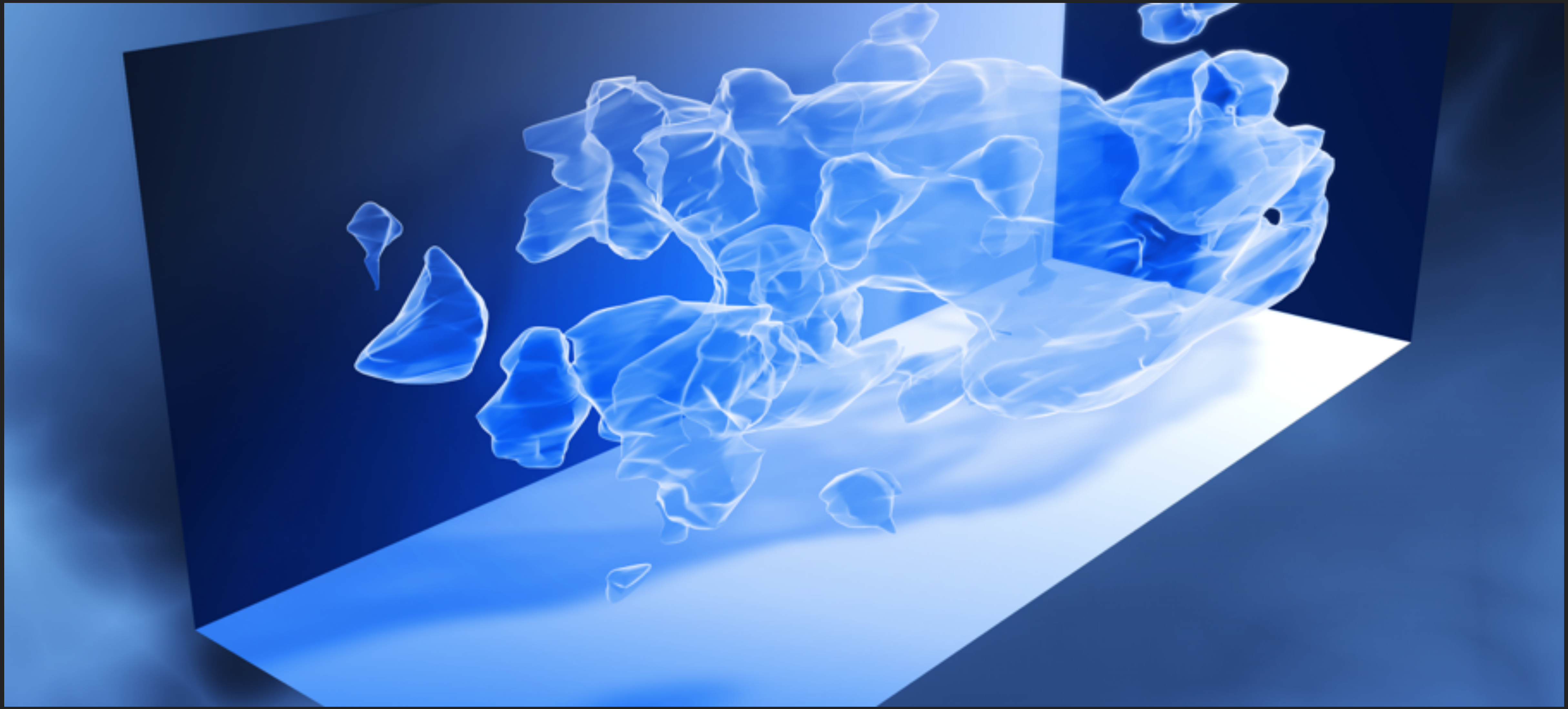


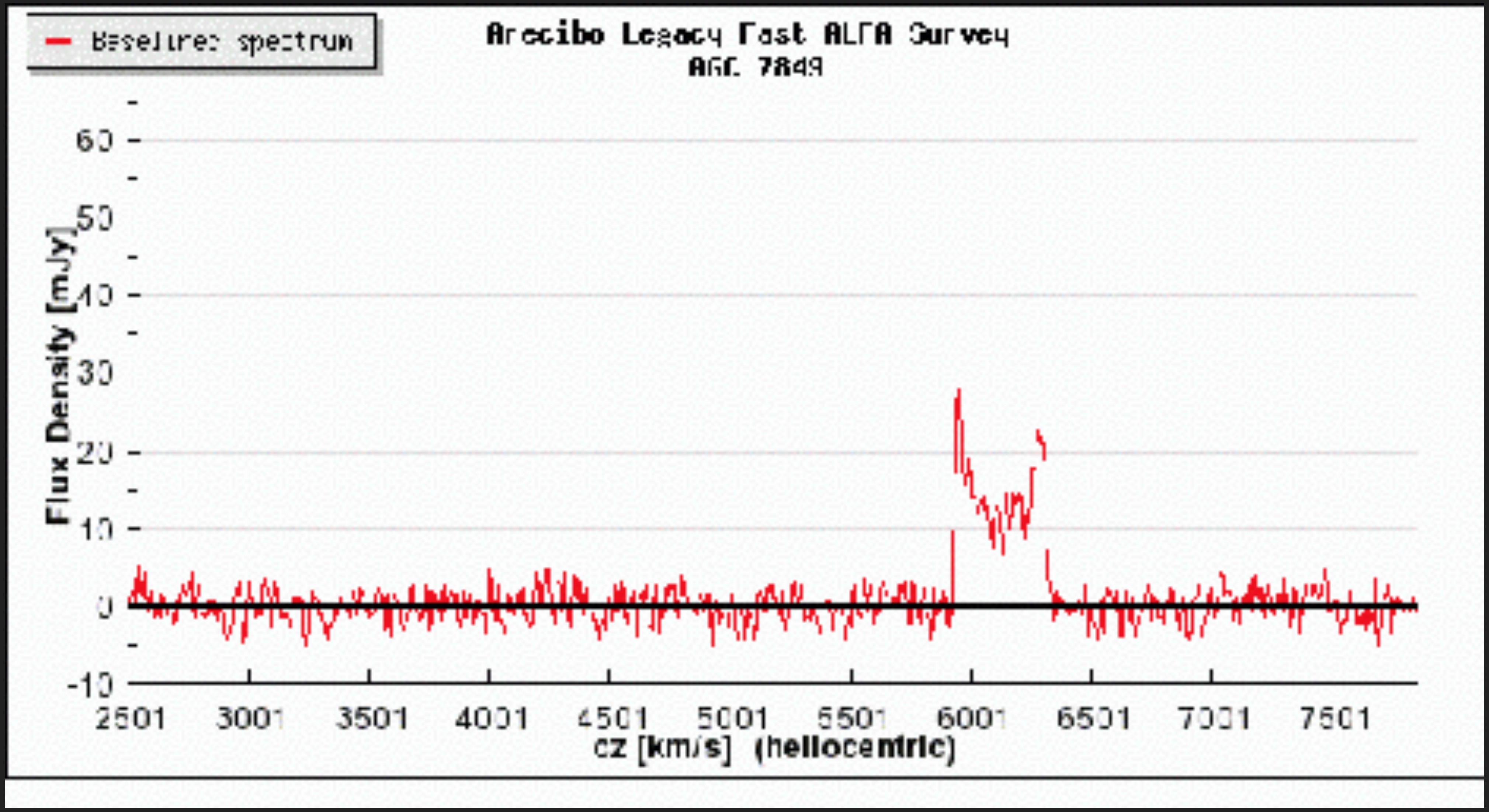
WOLFGANG KLASSEN

DARK MATTER

"Hubble Maps the Cosmic Web of "Clumpy" Dark Matter in 3-D" (Press release). NASA. 7 January 2007.

CONTENTS

TULLEY-FISHER RELATION



- Observational relationship relates mass to light
- Mass is obtained from the rotation velocity, found from graphs like the above

Image: UGC 7849, Cornell ALFALFA archive

A GOOD CORRELATION BETWEEN DISTANCE-INDEPENDENT OBSERVABLES, GLOBAL HI PROFILE WIDTHS AND ABSOLUTE MAGNITUDES . . . OFFERS A NEW EXTRAGALACTIC DISTANCE TOOL, AS WELL AS POTENTIALLY BEING FUNDAMENTAL TO AN UNDERSTANDING OF GALACTIC STRUCTURE.

Brent Tulley, Richard Fisher

TULLEY-FISHER RELATION

- The width of the HI distribution, ΔV, can be seen to correlate well with absolute magnitude
- This works even though the rotation velocity is dictated largely by non-visible mass
- This can be used to measure the distance to galaxies, by calculating a distance modulus

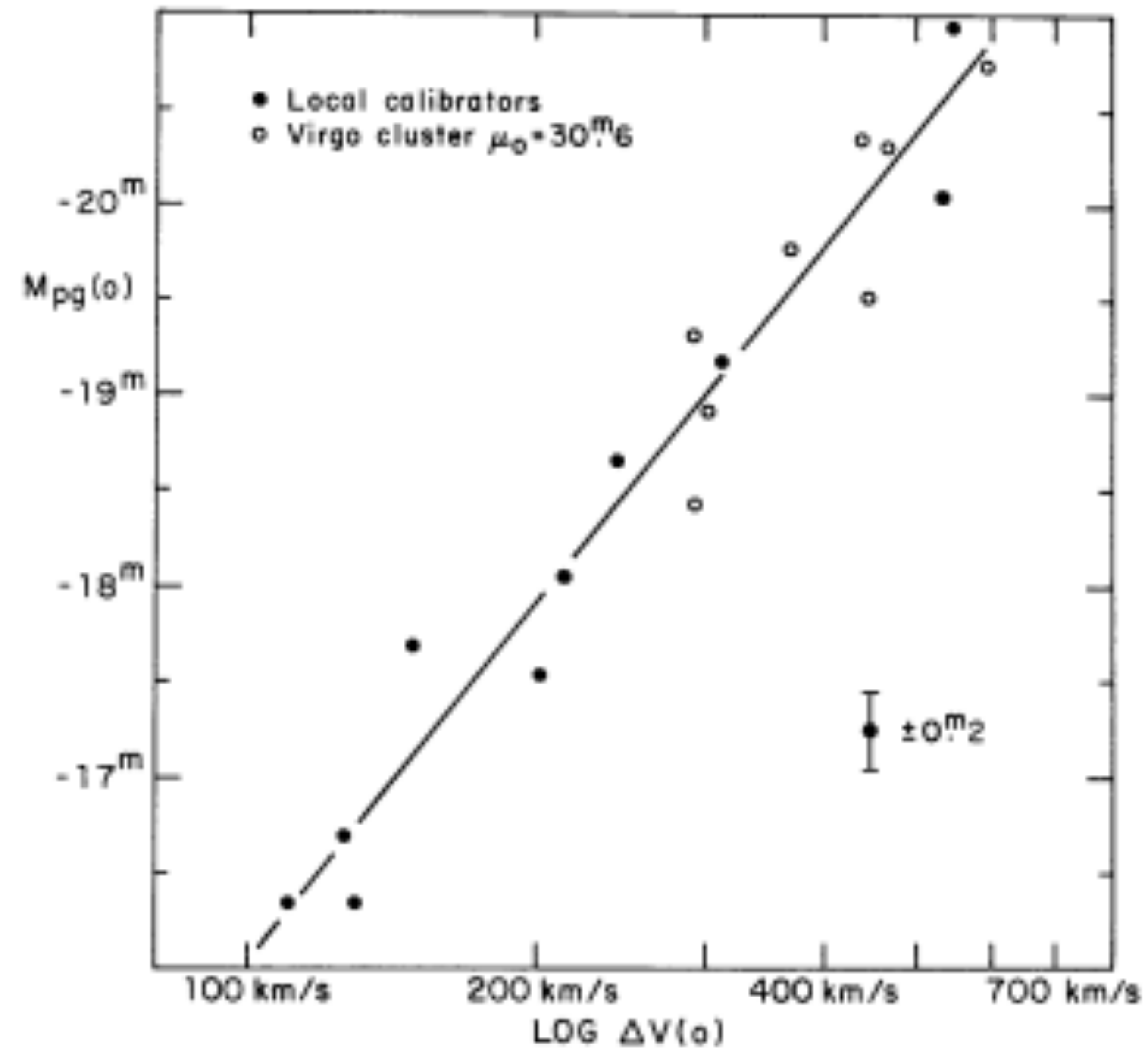


Fig. 5 (a) Absolute magnitude – global profile width relation produced by overlaying Figure 3 on Figure 1, adjusting Figure 3 vertically to arrive at a best visual fit with a distance modulus of $\mu_0 = 30^m.6 \pm 0^m.2$

Tully, R. B. and Fisher, J. R., "A new method of determining distances to galaxies". Astronomy and Astrophysics, vol. 54, no. 3, Feb. 1977, pp. 661–673

MASS-TO-LIGHT RATIOS : ϒ

- We can estimate the mass of luminous material in a galaxy by calculating how many suns would be required to produce the observed light
- Obviously, not all matter in a galaxy is the same as the sun
- Different material has different mass-to-light ratios
- We can call the mass found using this ratio the “luminous mass”

MASS-TO-LIGHT RATIOS : ϒ

- We can also measure mass using other methods, discussed later
- When we use these methods we start to see more mass than luminous mass
- The larger the ratio of mass-to-light, the harder it is to account for mass using visible material
- For $\Upsilon > \sim 5$, we need to invoke dark matter to explain the mass

Michael Merrifield on Mass-to-light ratios:

https://www.youtube.com/watch?v=f83AwpY9zhc

ROTATION CURVES

- First year kinematics:

$$F_{centripetal} = F_{gravity}$$
$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$
$$M(< R) = \frac{Rv^2}{G}$$

- Estimates the amount of mass contained in a radius required to keep gas/stars in the observed orbits
- Known as Dynamical Mass: M_{Dyn}

VERA RUBIN

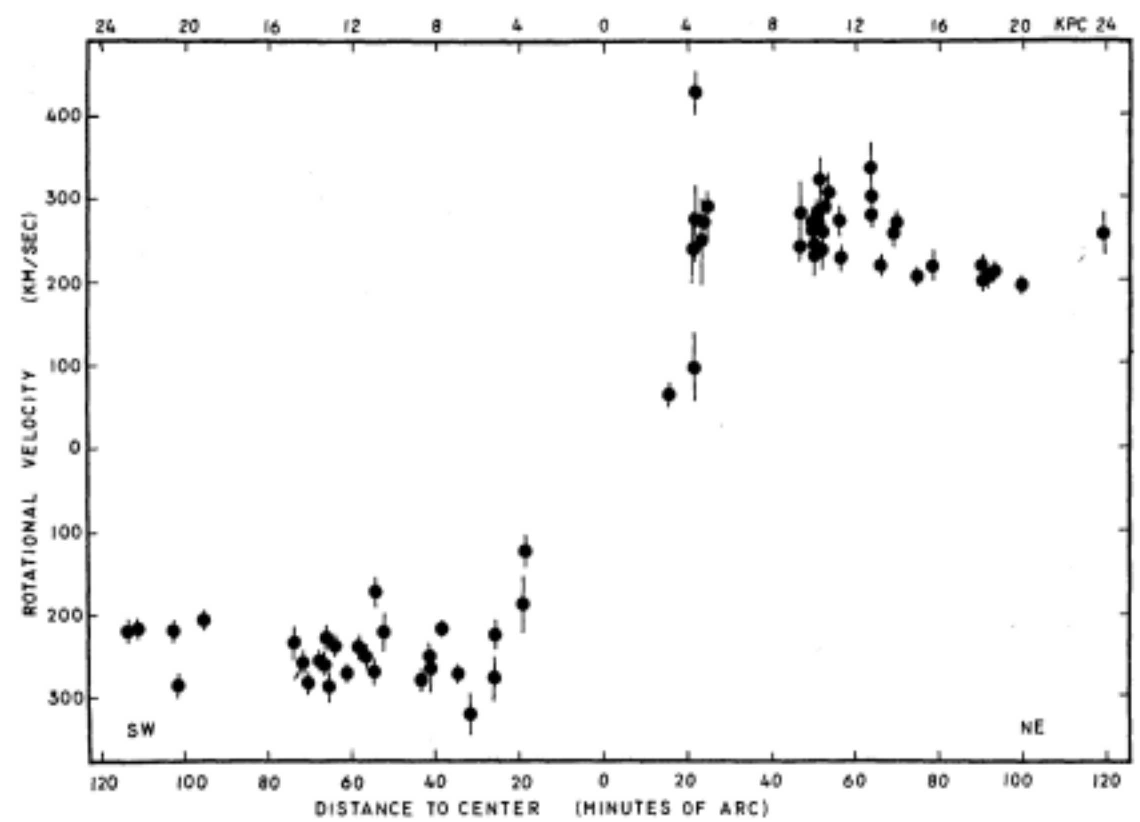


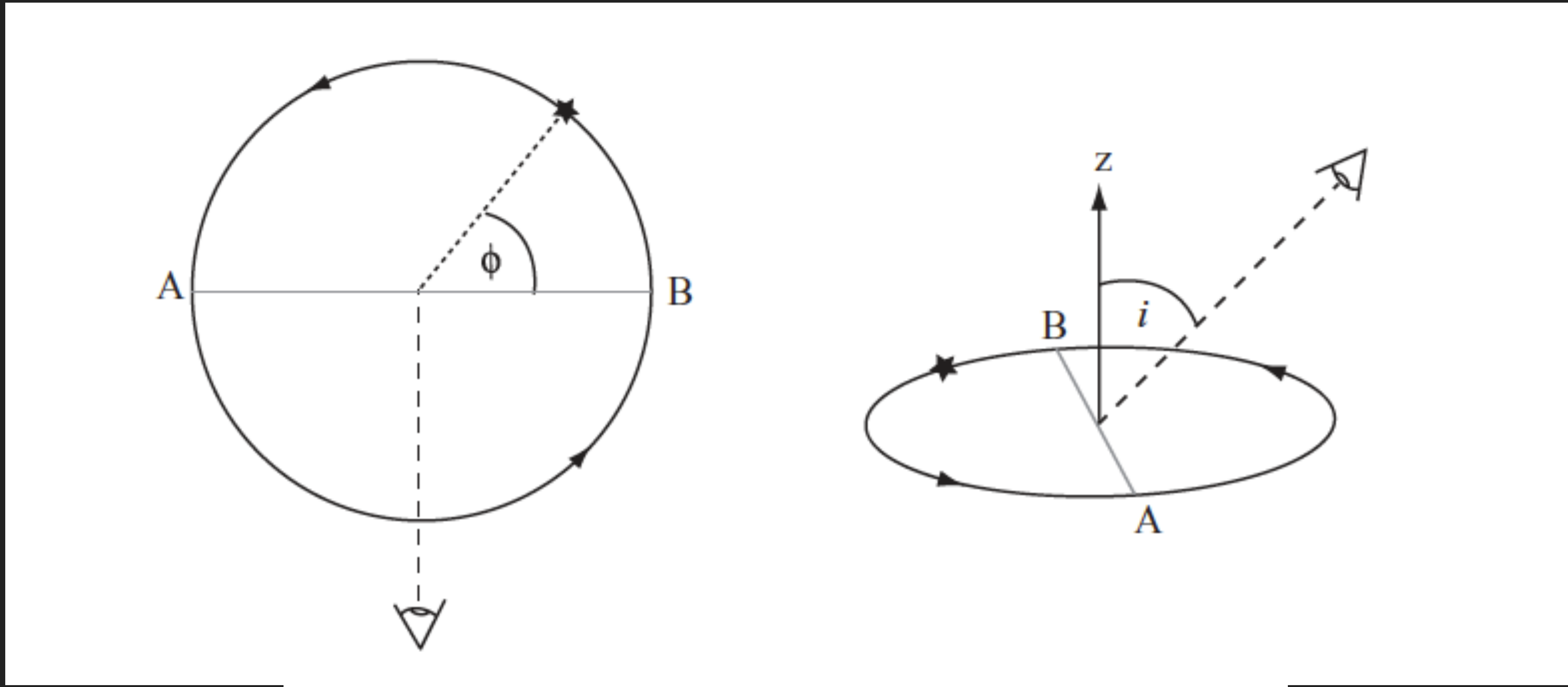
FIG. 3.—Rotational velocities for sixty-seven emission regions in M31, as a function of distance from the center. Error bars indicate average error of rotational velocities.

- Followed work done by Babcock and Oort to show that the rotation curve of Andromeda out to 24 kpc from the centre does not match the predicted angular momentum given by the luminous mass

Rubin, Vera; Ford, Jr., W. Kent (1970). "Rotation of the Andromeda Nebula from a Spectroscopic Survey of Emission Regions". Astrophysical Journal. 159: 379–404

ROTATION CURVE VS POSITION-VELOCITY PLOT

- Velocity is dependent on the inclination of the galaxy
- Also dependant on the position of the observed star on the disk

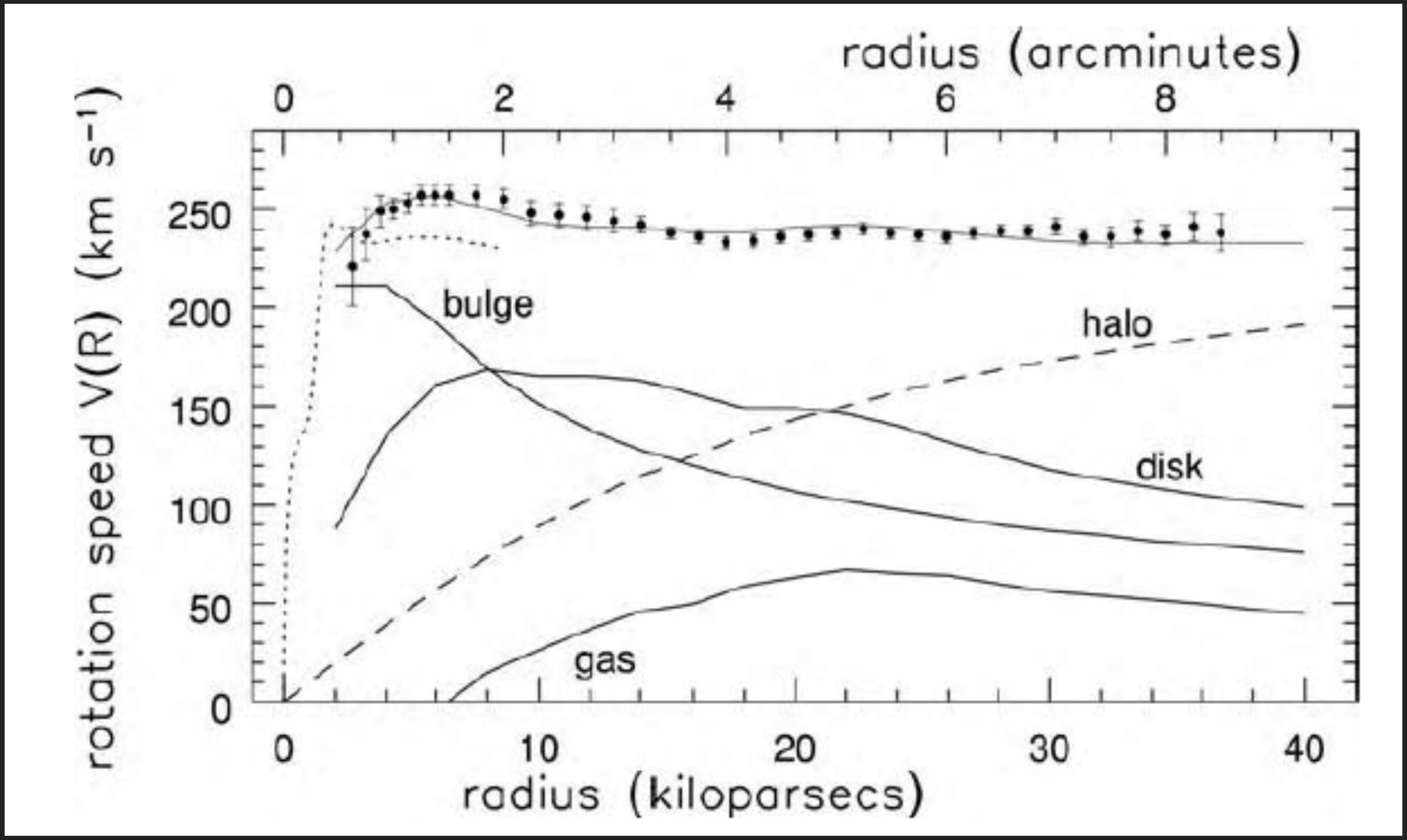


$$V_{\mathrm{r}}(R, i) = V_{\mathrm{sys}} + V(R) \sin i \cos \phi .$$

RADIO HI

- More thorough calculations of the gravitational potential of a galaxy may have reconciled the data found by Rubin
- Radio HI data made this impossible
- The existence of non-luminous matter is now widely accepted as a viable theory
- Dynamical mass is more "trusted" as a measurement for total mass than the mass-to-light ratio. As far as we know, GR is pretty solid

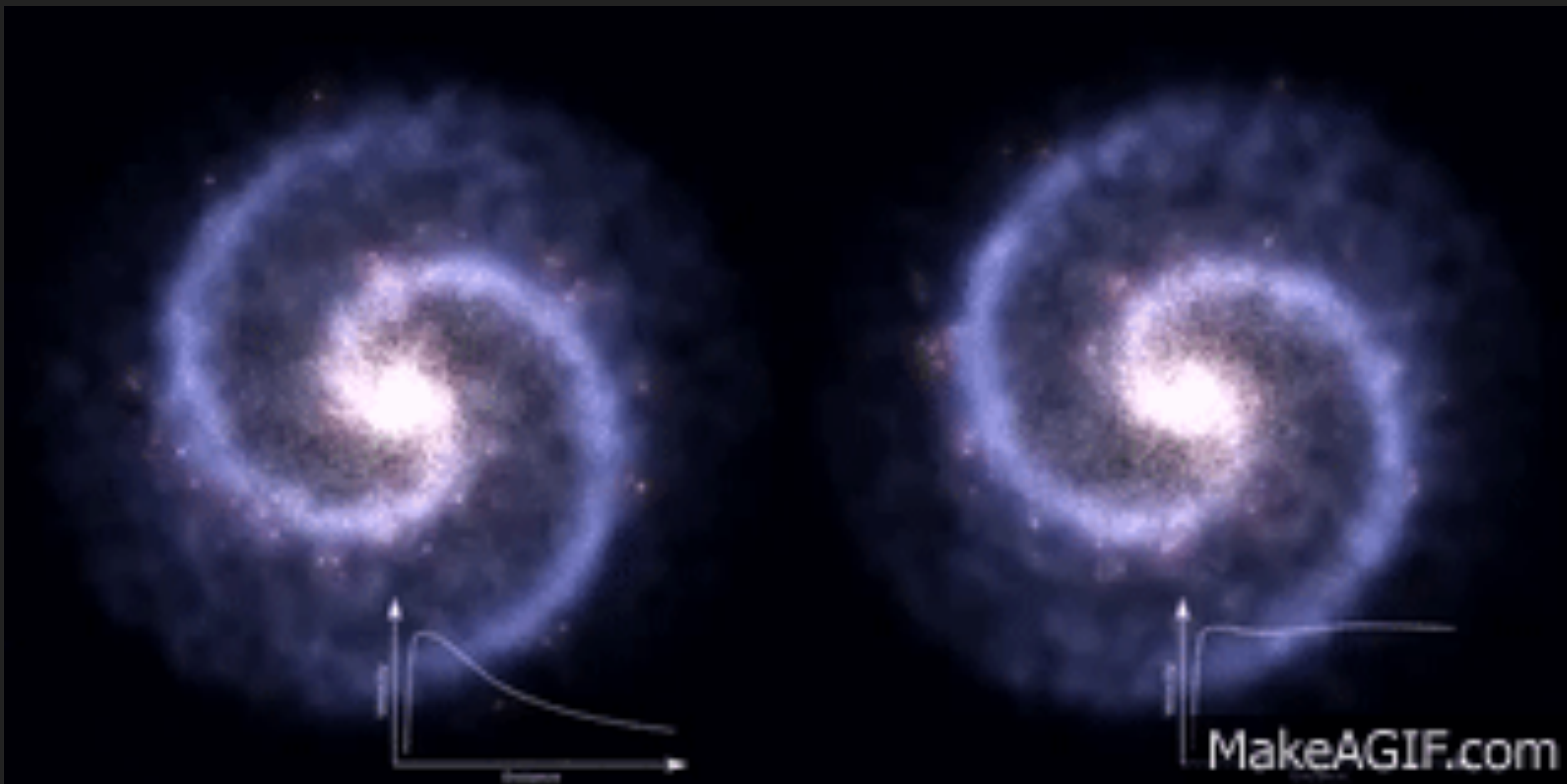
RADIO HI

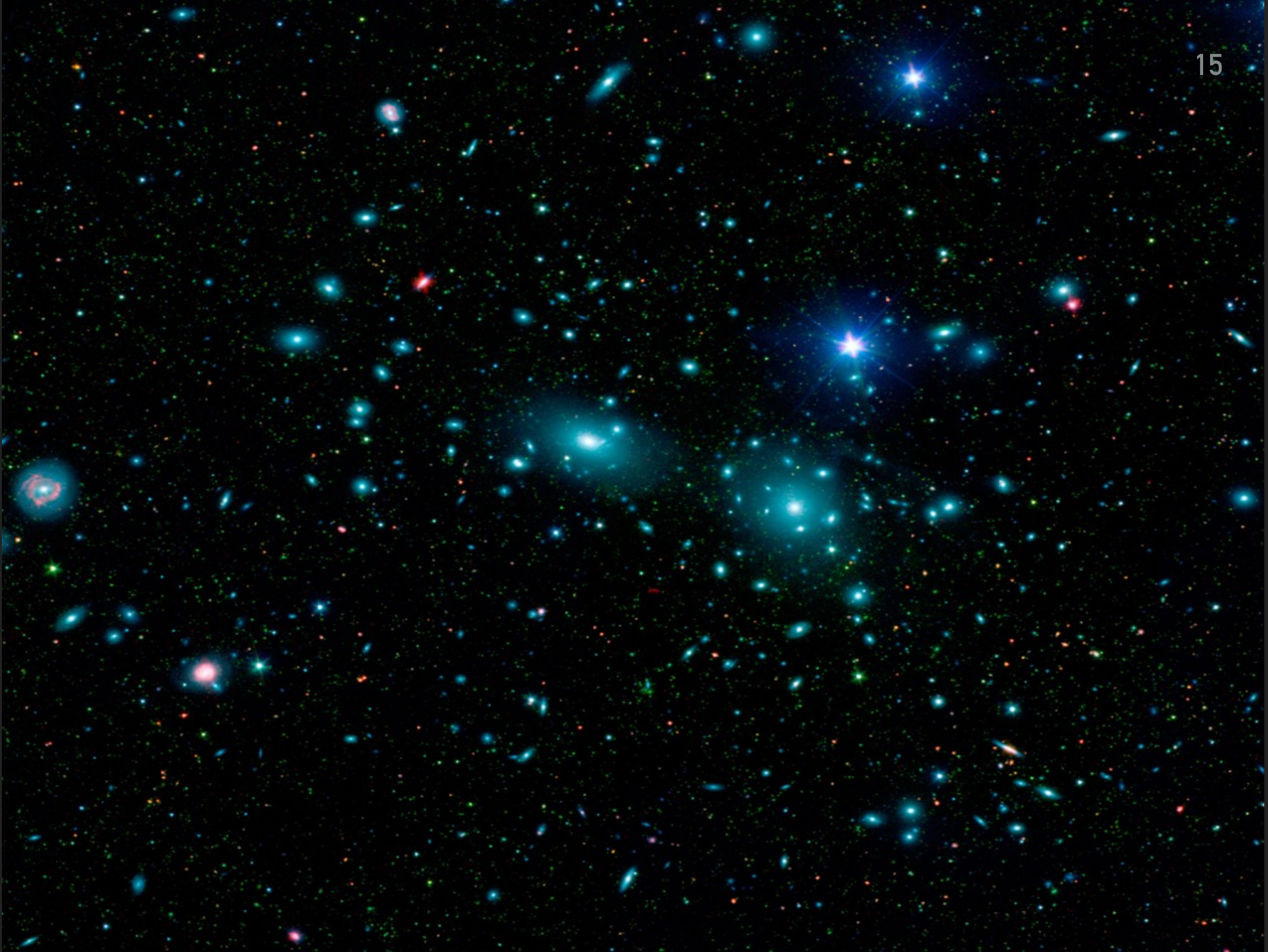


- Dynamical mass is the mass calculated from the observed dynamics of the system, the line at the top
- The predicted rotation curve due to luminous mass is shown below, and is insufficient to account for the total mass. The dashed line must be added

Sparke & Gallagher, p.217

THE DIFFERENCE





GALACTIC CLUSTERS

- The further out we look for mass, the more we find
- While looking at the Coma galaxy cluster, Zwicky found much more mass than was observed from light
- He calculated a mass-to-light ratio of ~500 for this cluster
- Modern estimates are lower(>100), but still much more than can be explained by luminous material, and higher than that of individual galaxies (~10)

GALACTIC CLUSTERS

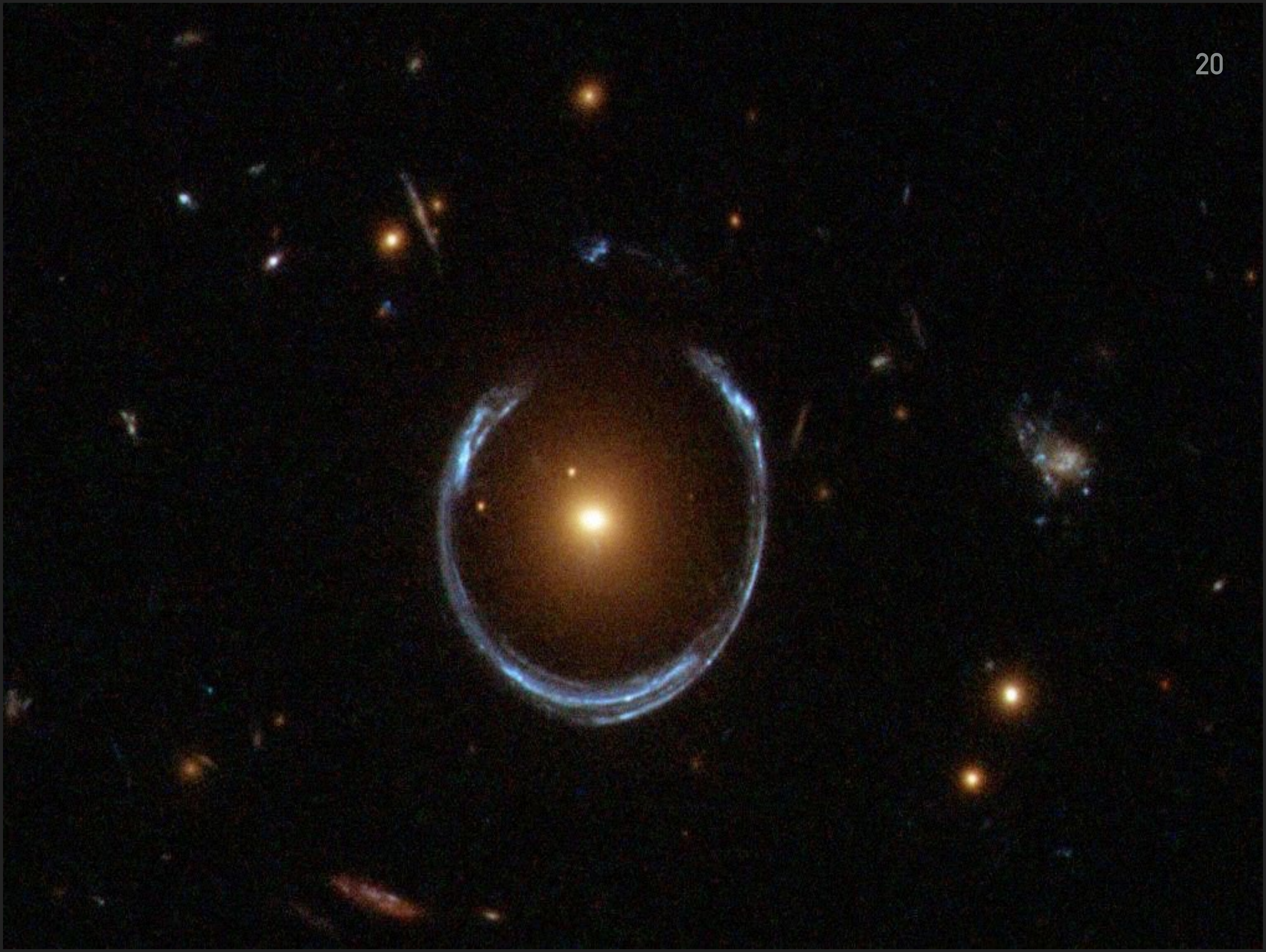
- We can measure mass by the dynamics of clusters, as well as the gravitational lensing of clusters

GRAVITATIONAL LENSING

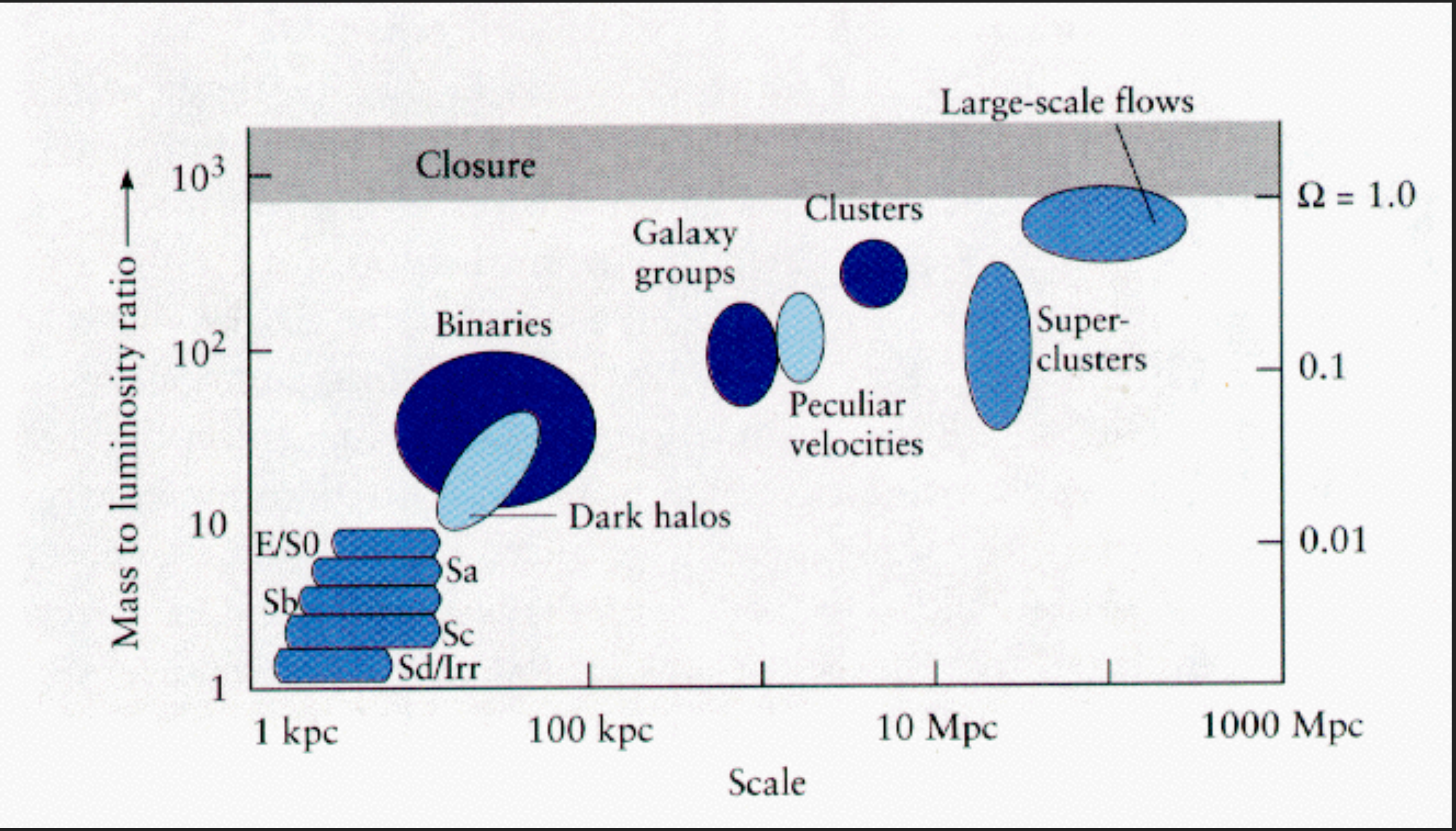
- Prediction of Einsteins General Relativity
- Anything that changes the direction of travelling particles should be able act as a lens
    - Glass bends the path of light in optical systems
    - EM and B fields bend the path of particles in CRTs, Mass spectrometers, etc.
    - Water bends the path of light
- In the same way, if gravity acts on photons, massive enough systems should act as lenses

GRAVITATIONAL LENSING

- The amount of bending is proportional to the mass of the system
- Again we can use information from light to “weigh” an object
- Easiest to see in very massive objects, i.e. clusters
- Also seen in single galaxies, meaning we can measure the mass of signal galaxies as well



MASS-TO-LIGHT RATIOS IN THE UNIVERSE

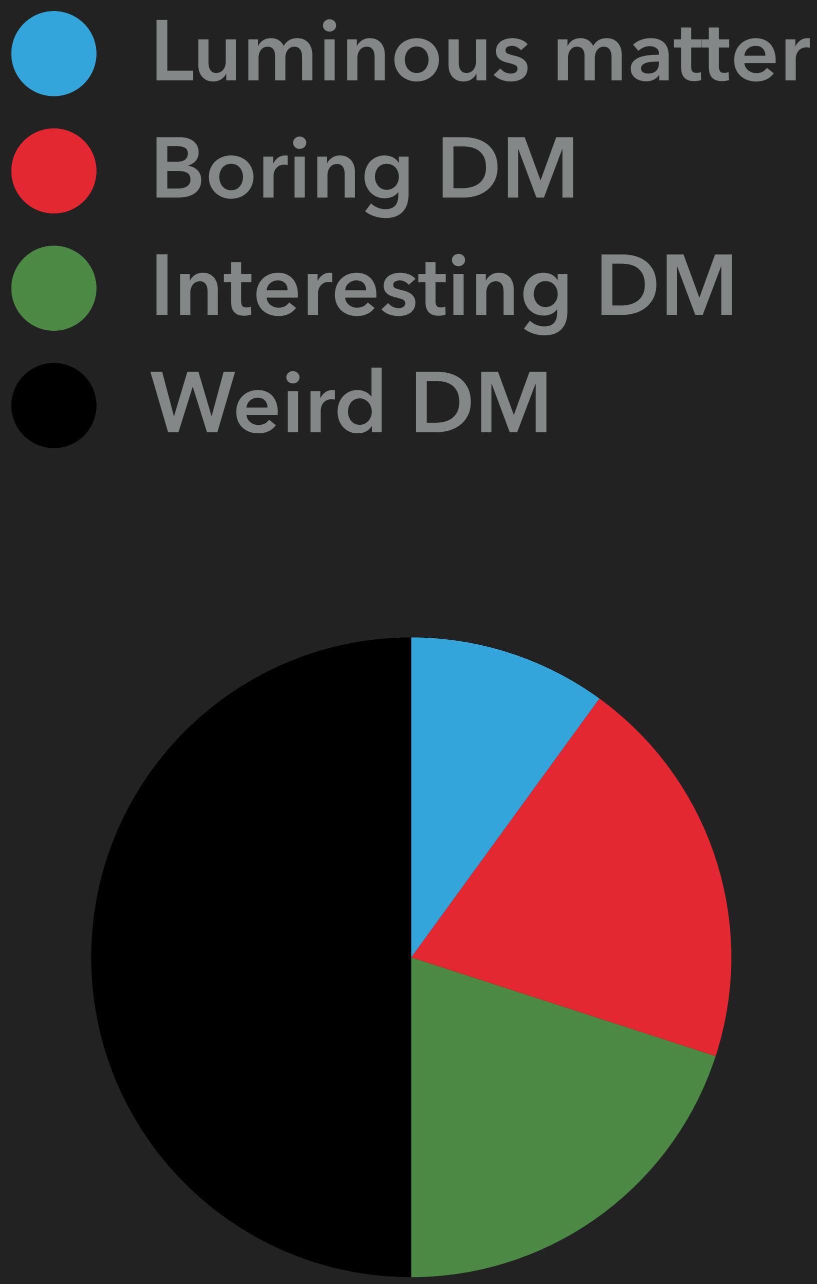


- The larger scale we look at, the more M/L begins to look like the number derived by cosmological models

Image: lecture given by James Schombert

WHAT COULD IT BE?

- Properly classified into Cold, Warm, and Hot Dark Matter, based on its speed.
- I classify it as boring, interesting, and weird Dark Matter



WHAT COULD IT BE?

- Luminous matter is what we can see, based on the mass-to-light ratios
- Boring dark matter is just regular matter that happens to not emit light we can see: cold gas, dust, MACHOs(small stars, BH, brown dwarfs)
- Interesting dark matter is non-baryonic matter, such as WIMPs (neutrinos, sterile neutrinos, axions)
- Weird dark matter is the stuff we can't really even speculate about too well. This includes "hidden sector" particles, which only interact via gravity

Luminous matter
Boring DM
Interesting DM
Weird DM

WHERE IS IT?

- Models such as the Navarro-Frenk-White profile and the Einasto profile have had some success replicating the observed rotation curves in simulation
  - These are parametrized models, meaning we fit them to the observed data. There is no hard theory to explain the distribution.
- Polar ring galaxies give us a way to measure two axis of the distribution of DM
- Current models generally predict an oblate spheroid or ellipsoid, characterized by the lengths of the axes.

END