ASTRON 449: Stellar (Galactic) Dynamics

Fall 2014

In this course, we will cover

- the basic phenomenology of galaxies (including dark matter halos, stars clusters, nuclear black holes)
- theoretical tools for research on galaxies: potential theory, orbit integration, statistical description of stellar systems, stability of stellar systems, disk dynamics, interactions of stellar systems
- numerical methods for *N*-body simulations
- time permitting: kinetic theory, basics of galaxy formation

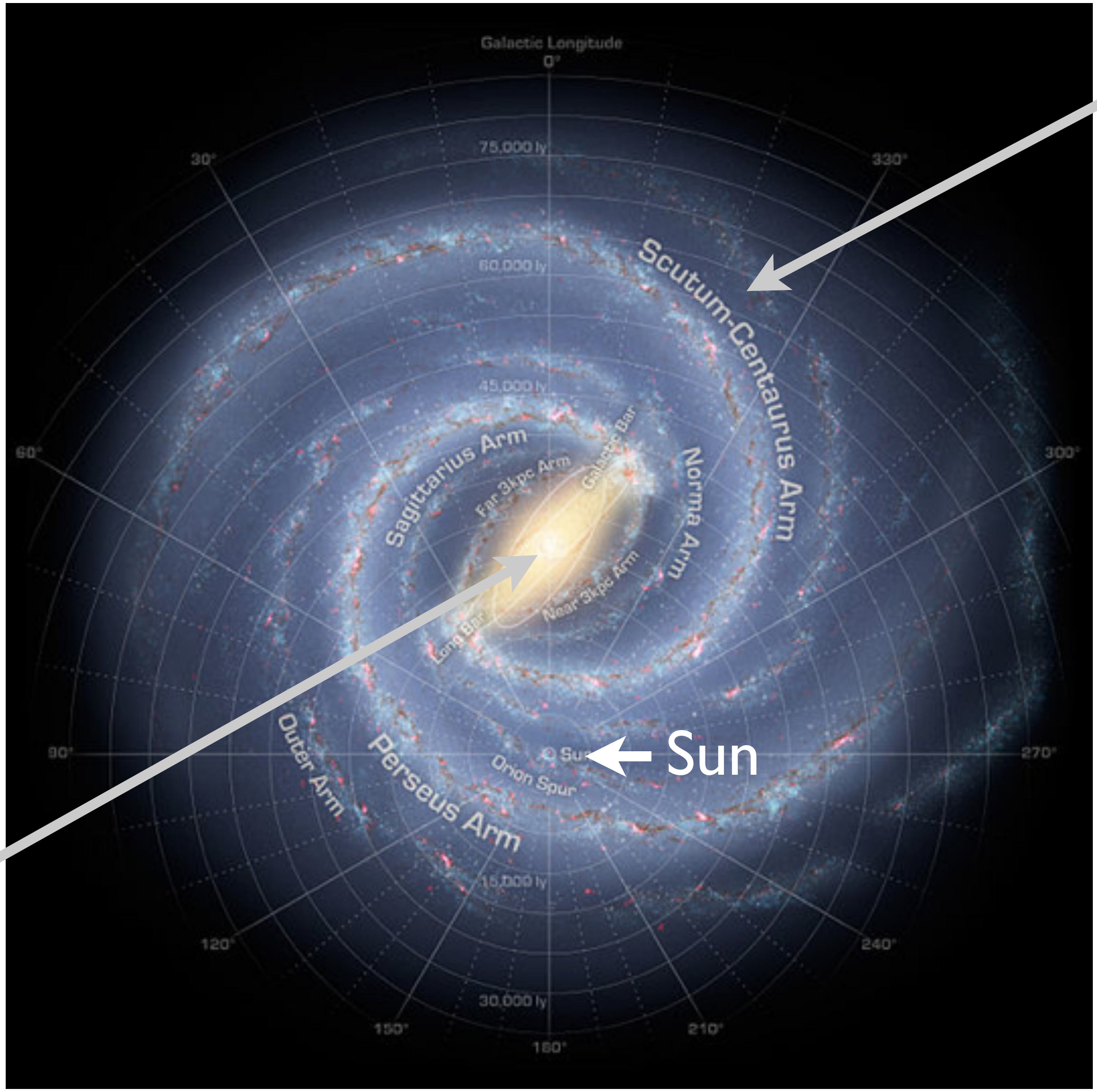
This will allow us, e.g.

- to measure the masses of stellar systems and massive black holes
- understand the origin of spiral structure in galactic disks and the formation of elliptical galaxies
- understand how the dynamics of galaxies differ from the dynamics of dense star clusters
- prepare for research on galaxies, and in many other areas of astrophysics

Galaxy phenomenology

Reading: BT2, chap. 1 intro and section 1.1

What is a galaxy? The Milky Way



disk of stars,
dust, and gas
$\sim 10^{11}$ stars

8 kpc
1 pc≈3 lyr

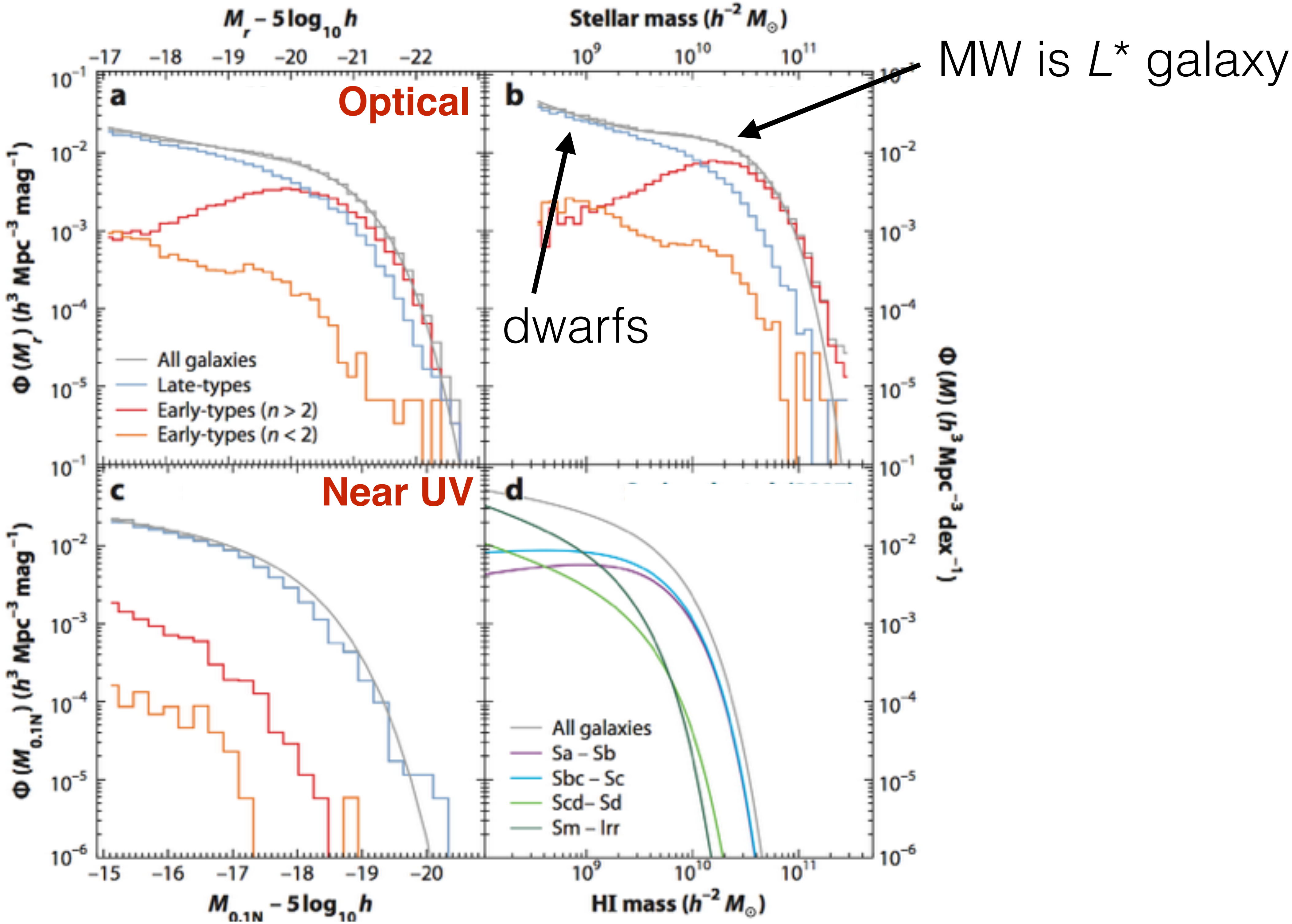
4×10^{6} M_{sun}
black hole

Gravity turns gas into stars

(all in a halo of dark matter)


Galaxies are the building blocks of the Universe
Hubble Space Telescope
Ultra-Deep Field

Luminosity and mass functions



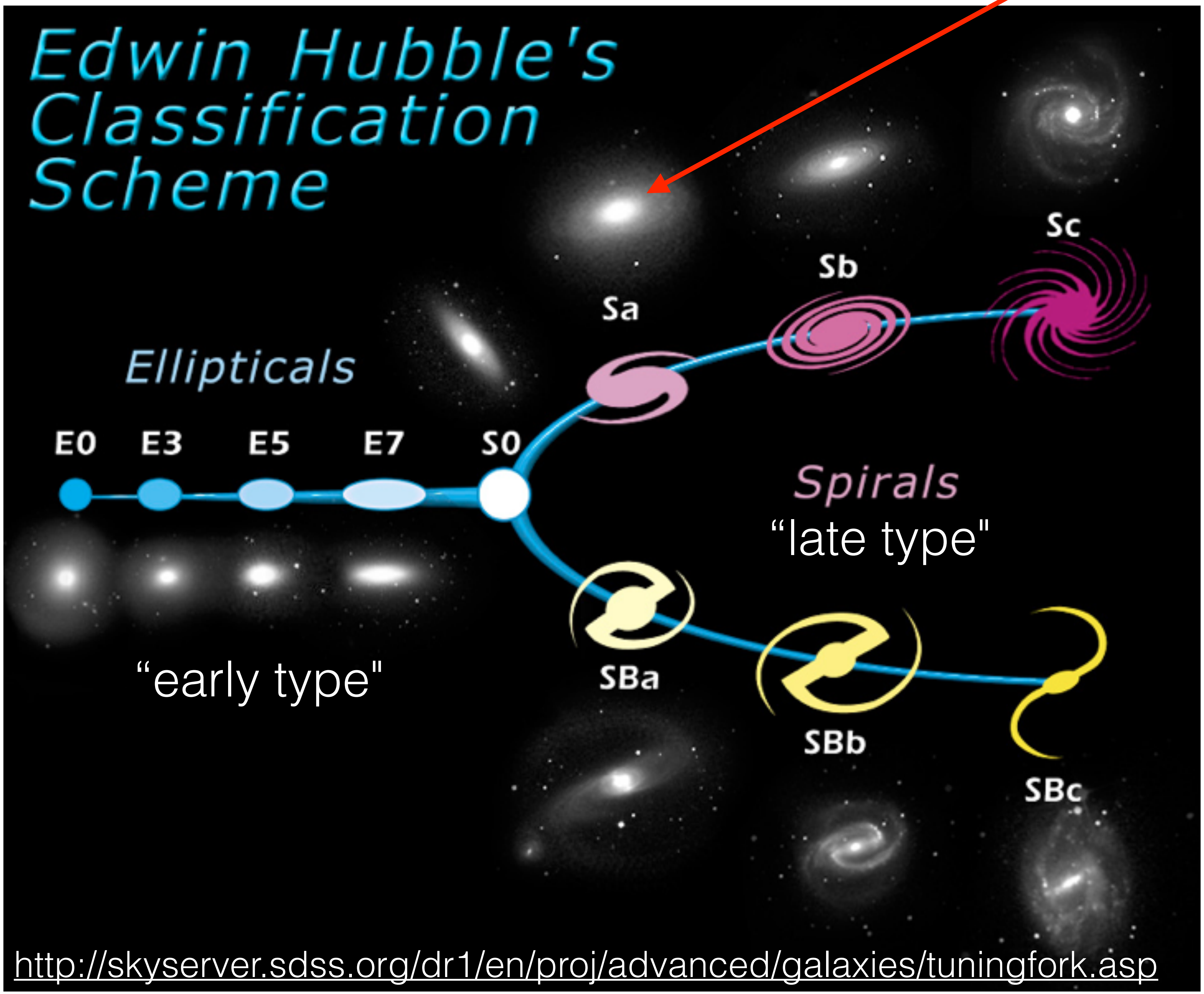
Schechter fits: $\Phi(L)dL = \frac{dL}{L_*}\exp(-L/L_*)\left[\phi_{*,1}\left(\frac{L}{L_*}\right)^{\alpha_1} + \phi_{*,2}\left(\frac{L}{L_*}\right)^{\alpha_2}\right]$

$M = -2.5\log_{10}L + const.$

Local galaxies from SDSS; Blanton & Moustakas 08

Hubble's morphological classes

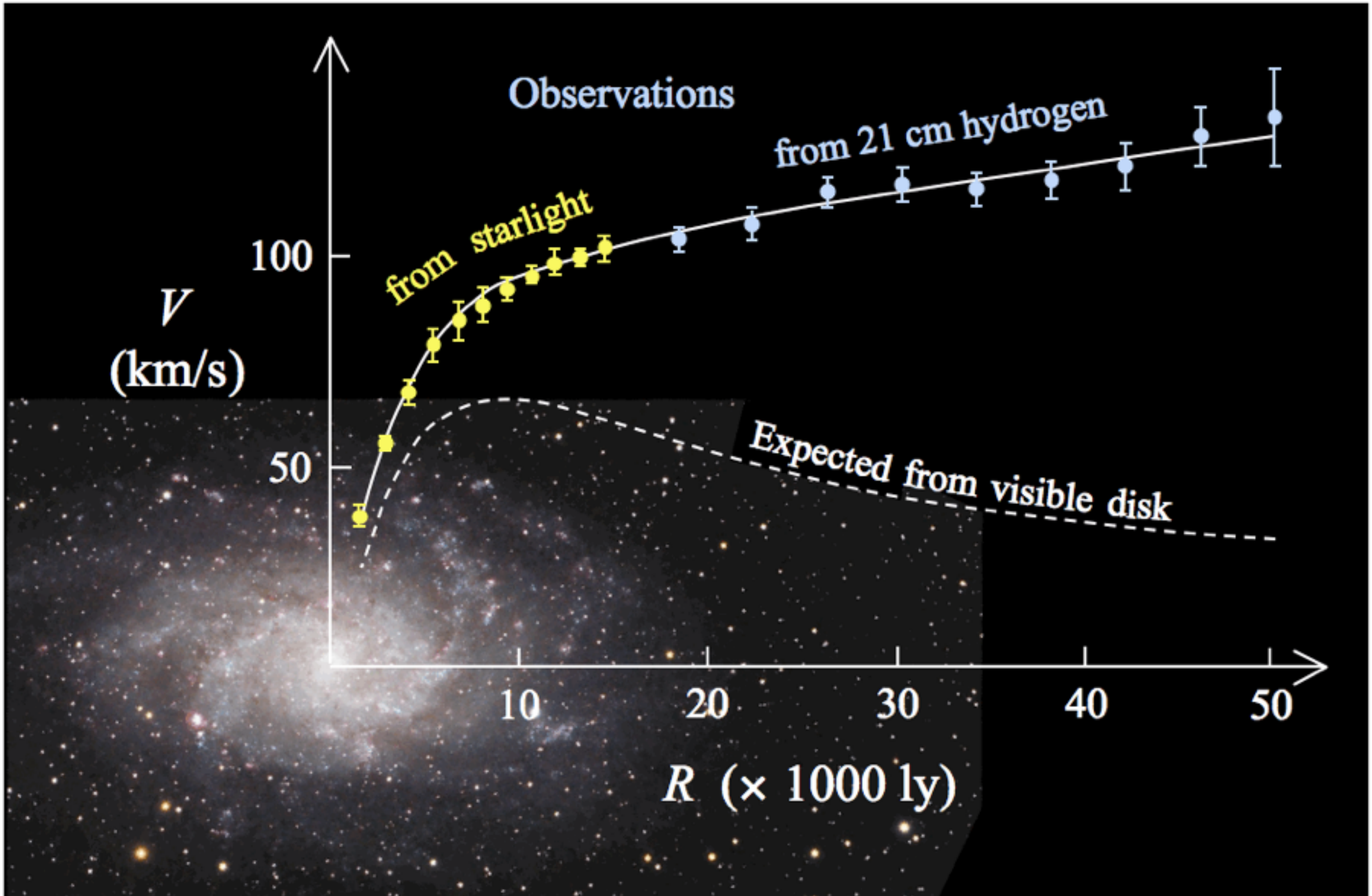
bulge or spheroidal component



barred

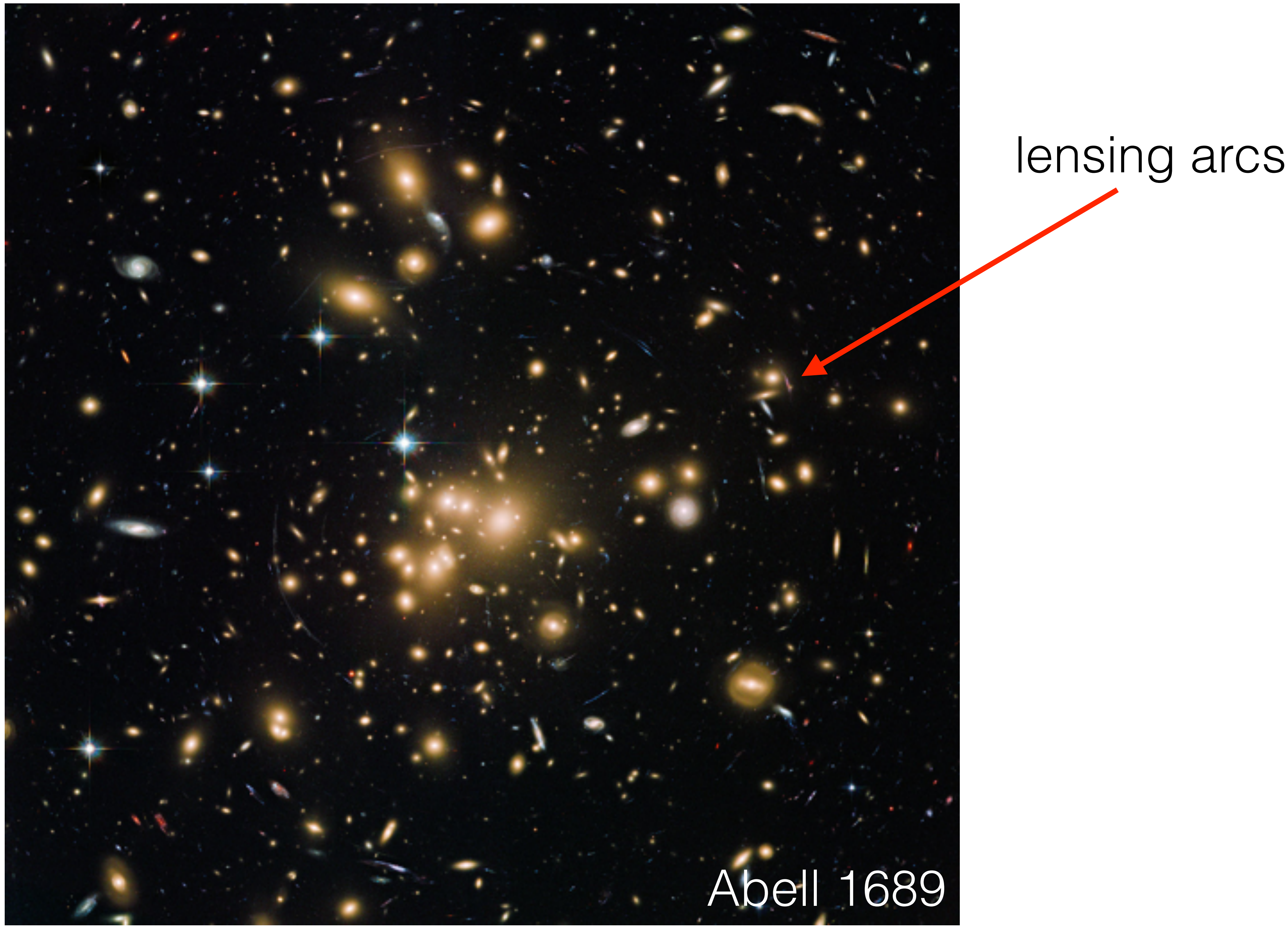
Not a time or physical sequence

Galaxy rotation curves: evidence for dark matter



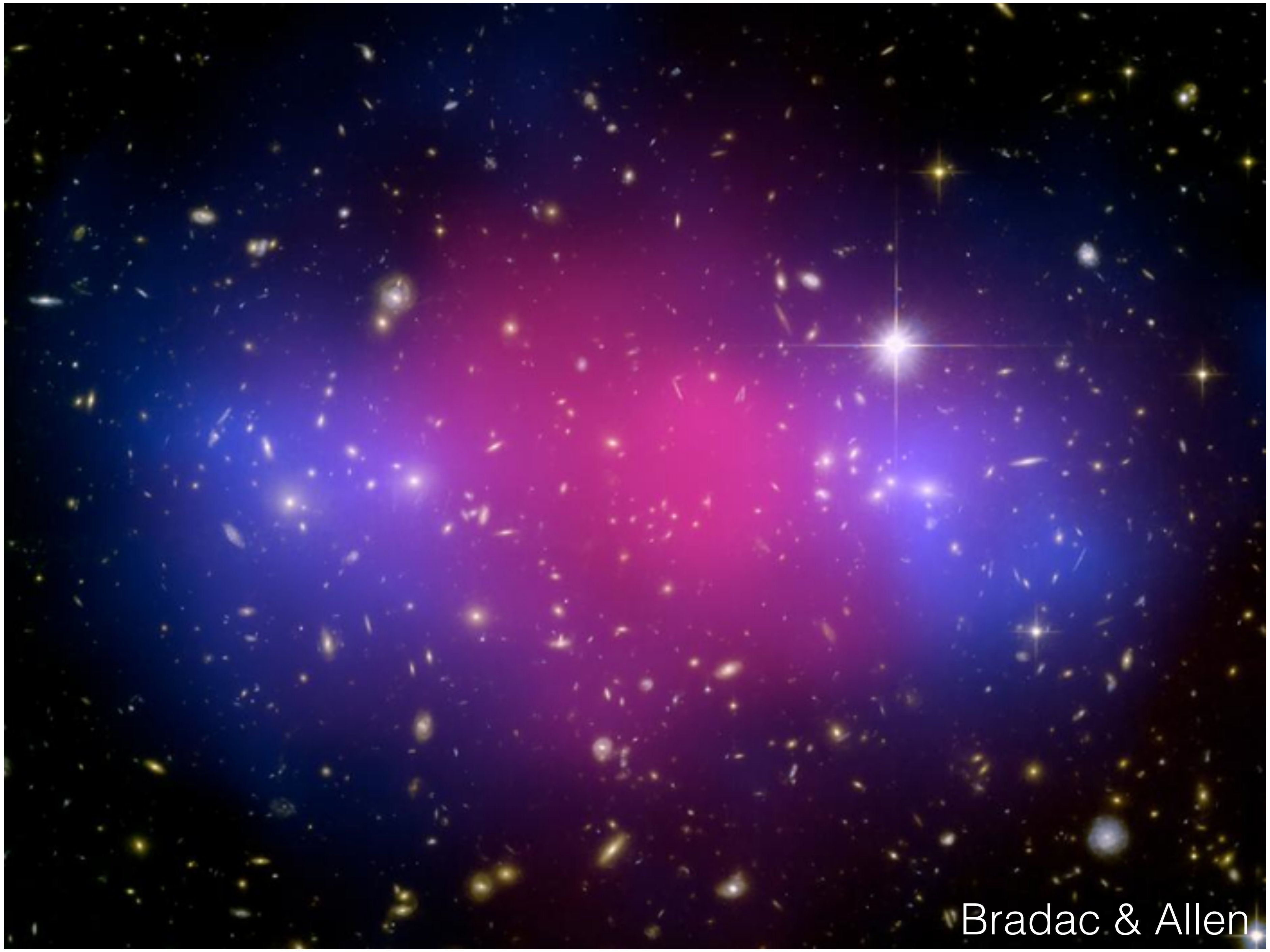
M33 rotation curve from http://en.wikipedia.org/wiki/Galaxy_rotation_curve

Galaxy clusters

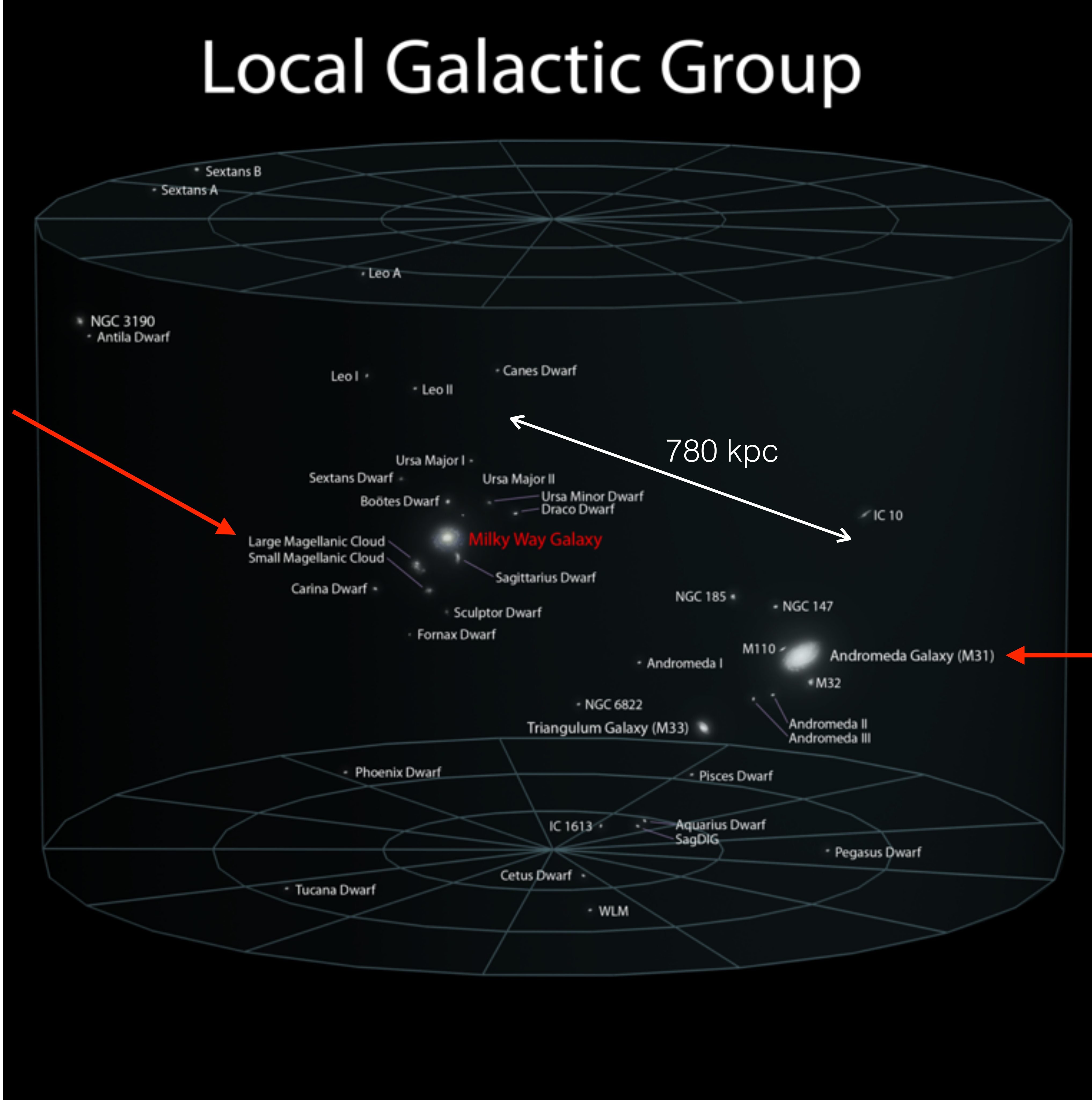


- most massive gravitational bound objects in the Universe
- contain up to thousands of galaxies
- most baryons intracluster gas, $T \sim 10^7$-10^8 K gas
- smaller collections of bound galaxies are called 'groups'

Bullet cluster: more evidence for dark matter



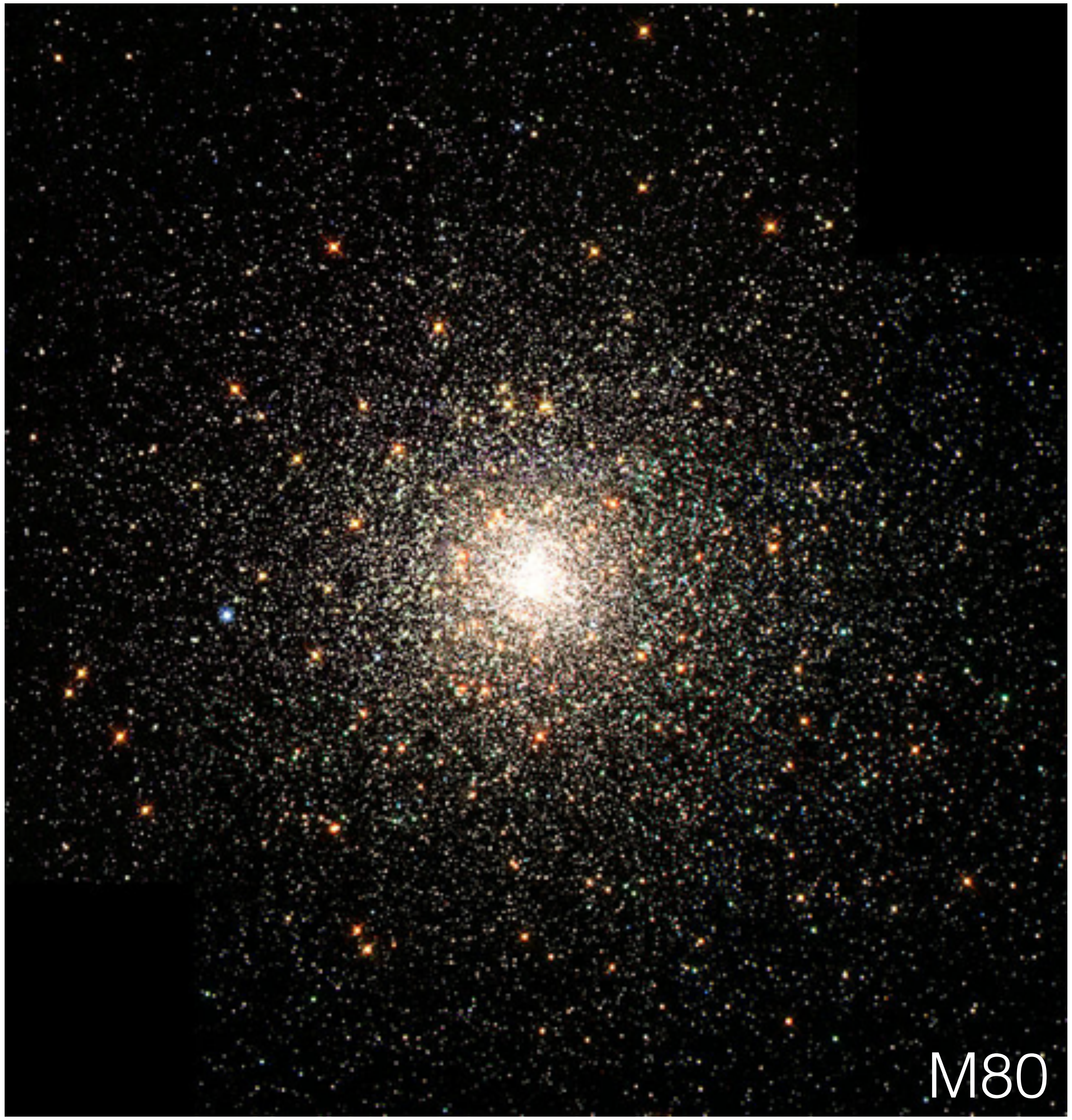
- two clusters that recently collided
- gravitational mass traced by weak lensing (blue)
- gas (collisional) stuck in middle


Local Galactic Group
Sextans B
Sextans A
Leo A
NGC 3190
Antila Dwarf
Canes Dwarf
Leo I
Leo II
780 kpc
Ursa Major I
Sextans Dwarf
Ursa Major II
Boötes Dwarf
Ursa Minor Dwarf
Draco Dwarf
IC 10
Large Magellanic Cloud
Small Magellanic Cloud
Milky Way Galaxy
Sagittarius Dwarf
Carina Dwarf
NGC 185
NGC 147
Sculptor Dwarf
Fornax Dwarf
M110
Andromeda Galaxy (M31)
Andromeda I
M32
NGC 6822
Triangulum Galaxy (M33)
Andromeda II
Andromeda III
Phoenix Dwarf
Pisces Dwarf
IC 1613
Aquarius Dwarf
SagDIG
Pegasus Dwarf
Cetus Dwarf
Tucana Dwarf
WLM
well-studied MW satellites
most massive

Open clusters

- ~10^2-10^4 stars, irregular
- most younger than 1 Gyr, in disk
- most stars probably formed in open clusters, which have since dissolved

Globular clusters



- $\sim 10^4$-10^6 stars, nearly spherical
- little dust, gas, young stars, or dark matter
- central stellar density 10^4 M_{sun} pc^{-3} (compared to 0.05 M_{sun} pc^{-3} for solar neighborhood) $\Longrightarrow$ direct interactions between stars (collisional effects)

Galaxy collisions

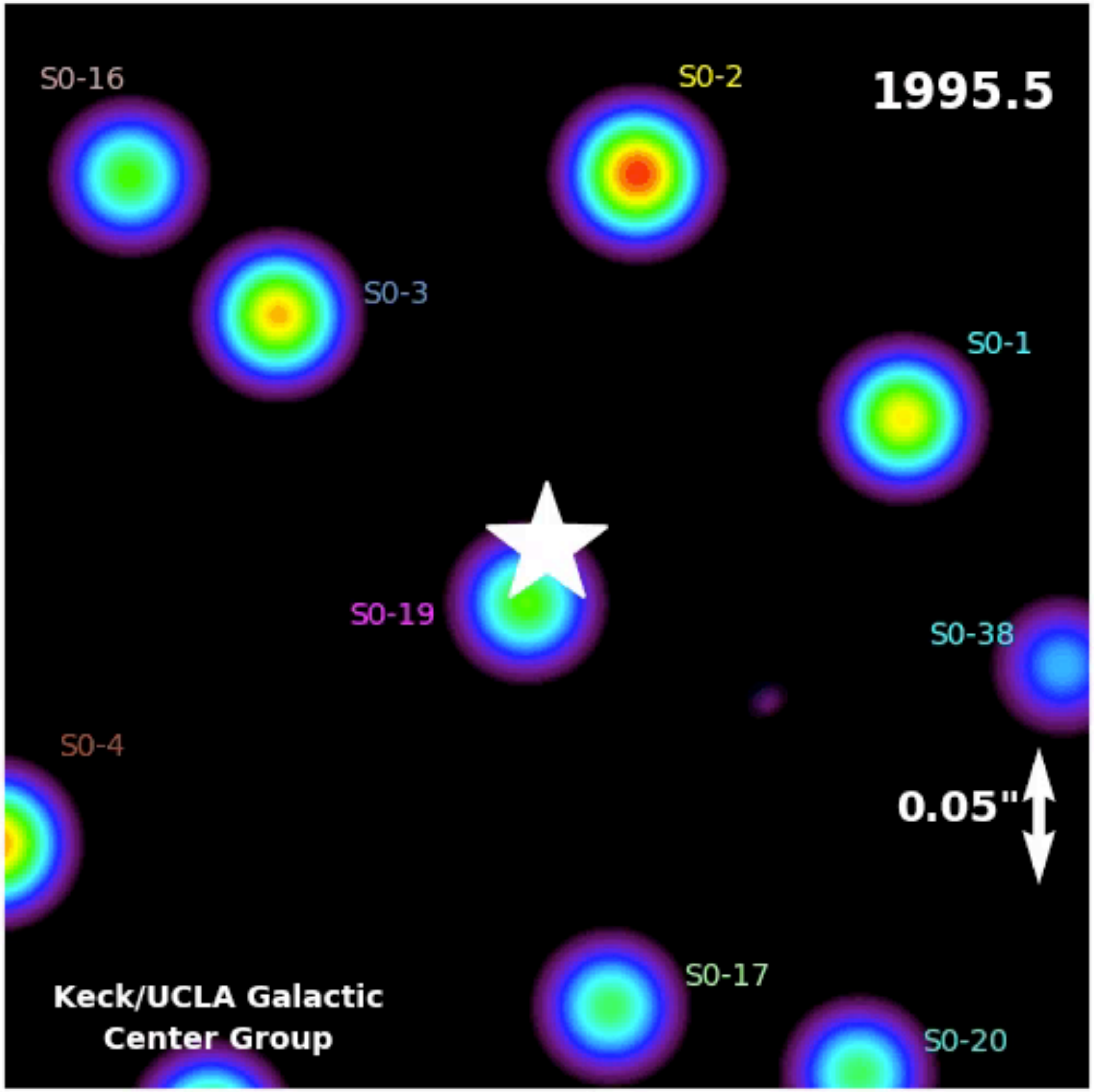
- collisions between galaxies are common, e.g. MW and Andromeda will merge in ~3 Gyr
- mass ratio >1:3 → major merger (otherwise, minor)
- create tidal features, stellar bulges

Formation of ellipticals by major mergers of two disk galaxies

N-body simulation (viz credit: Patrik Jonsson)

Note: stars typically do *not* collide in a galaxy collision (collisionless dynamics)!

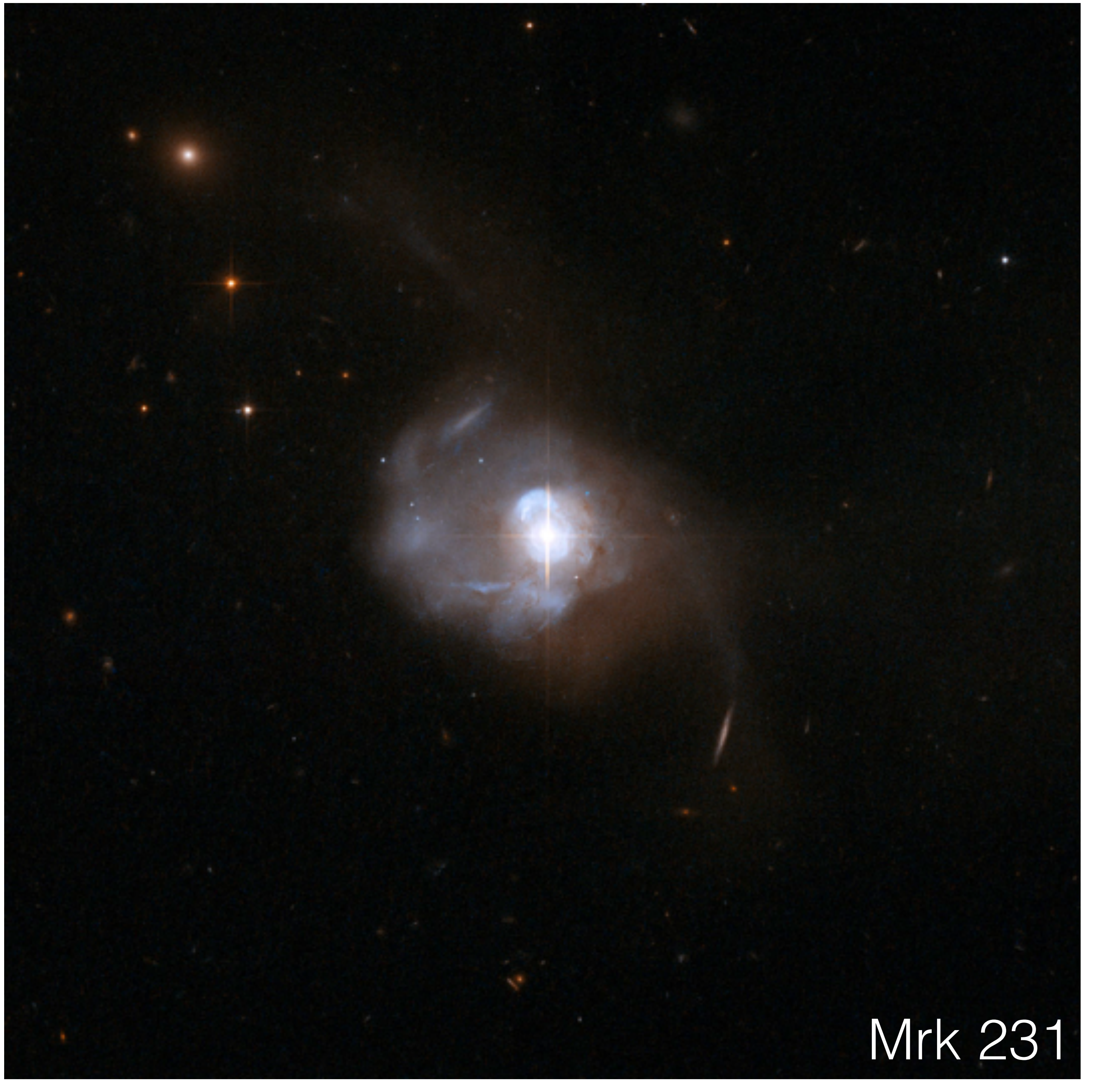
Nuclear black holes



10^{-4} pc

- all (massive) galaxies appear to have one
- in MW (Sgr A*), $M_{BH}=4\times10^6$ M_{sun}, measured using individual stellar orbits

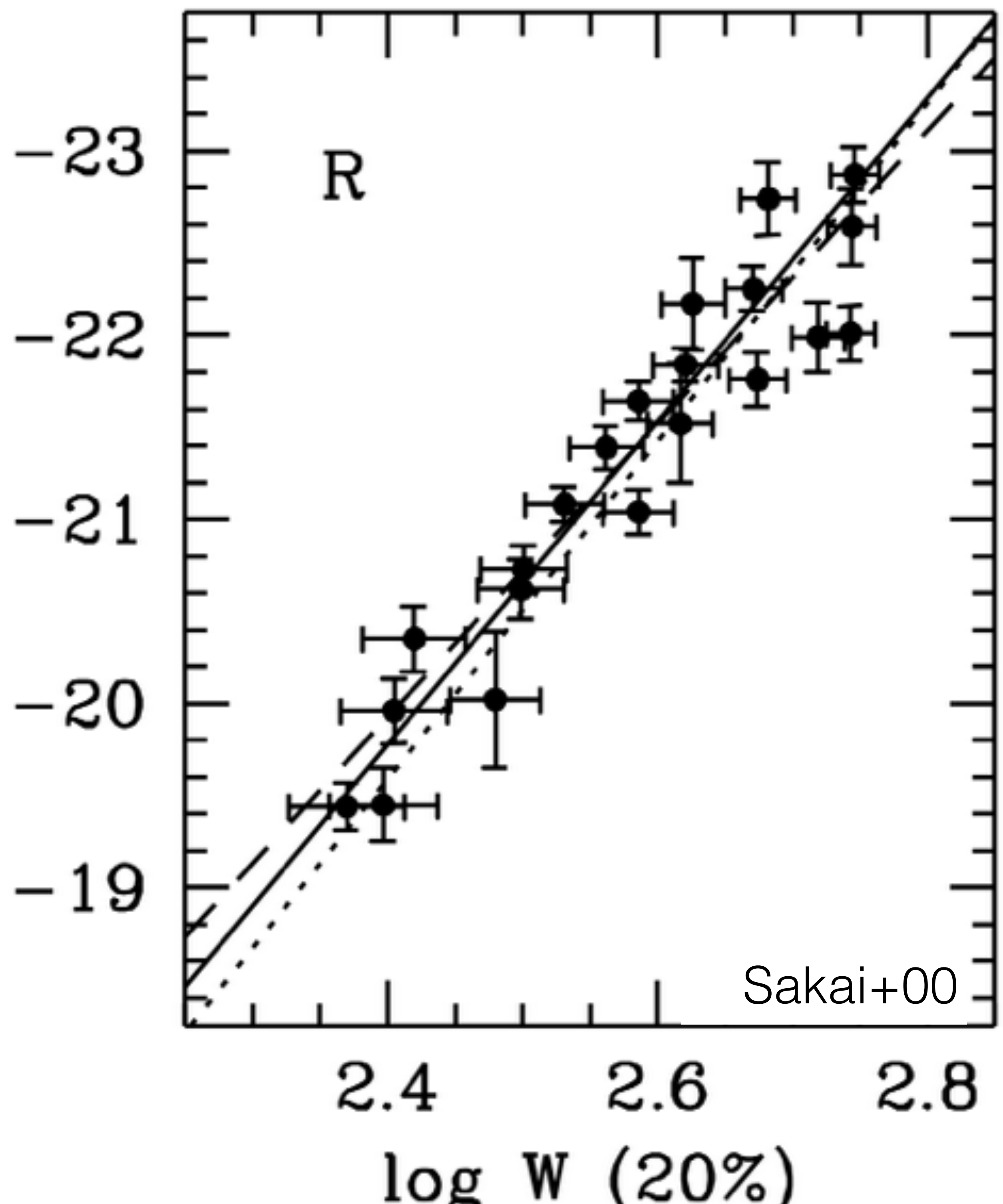
Active galactic nuclei



- accreting nuclear black holes visible as AGN
- the most luminous AGN are called quasars (can outshine entire host galaxy)
- in local Universe, quasars are associated with galaxy mergers

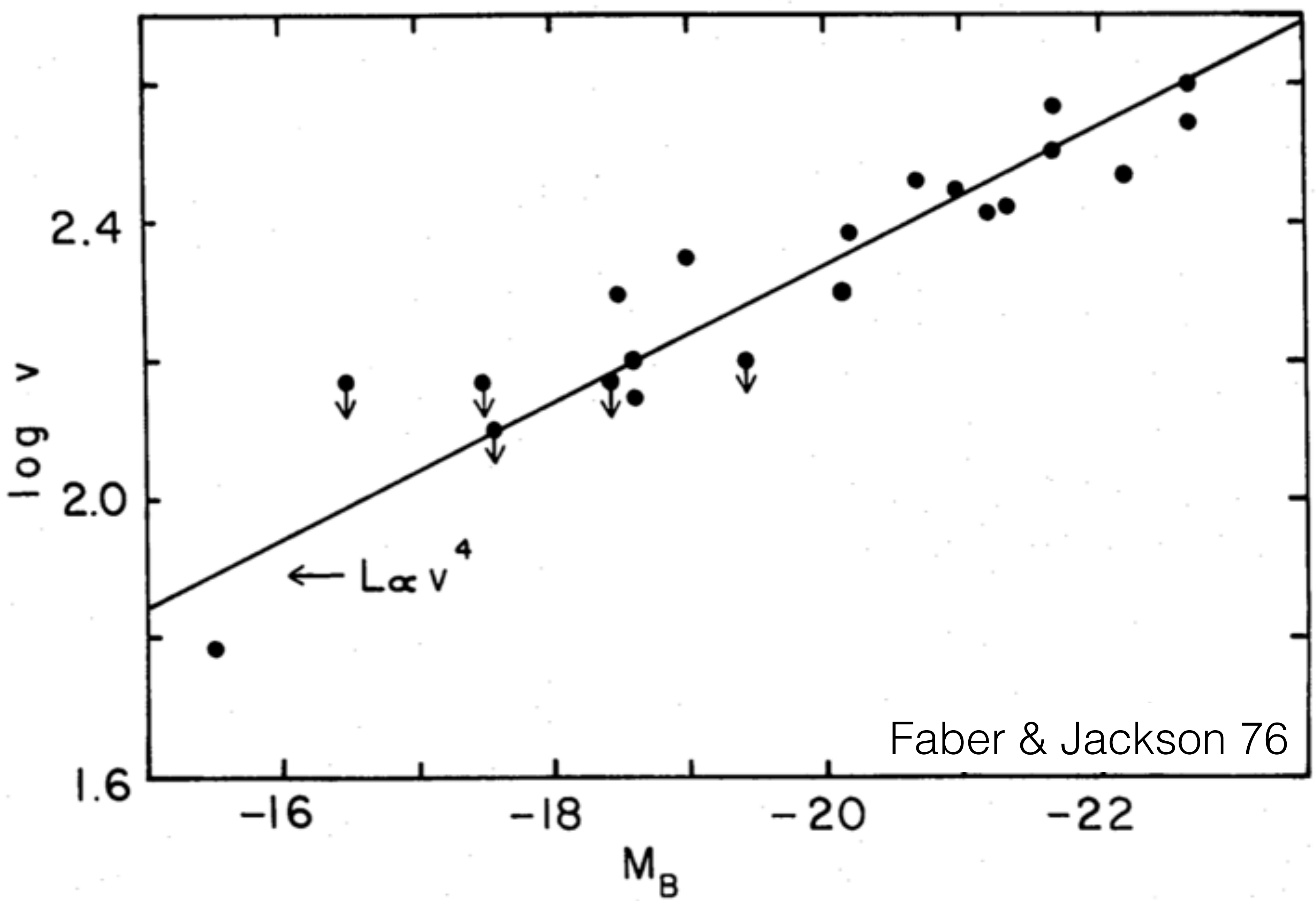
Scaling relations, and other correlations

Tully-Fisher: luminosity - circular velocity for spirals



$$\log_{10}\left(\frac{L_{\rm R}}{10^{10}\ L_\odot}\right) = 3.5\log_{10}\left(\frac{v_{\rm c}}{200\ \rm km\ s^{-1}}\right) + 0.5$$

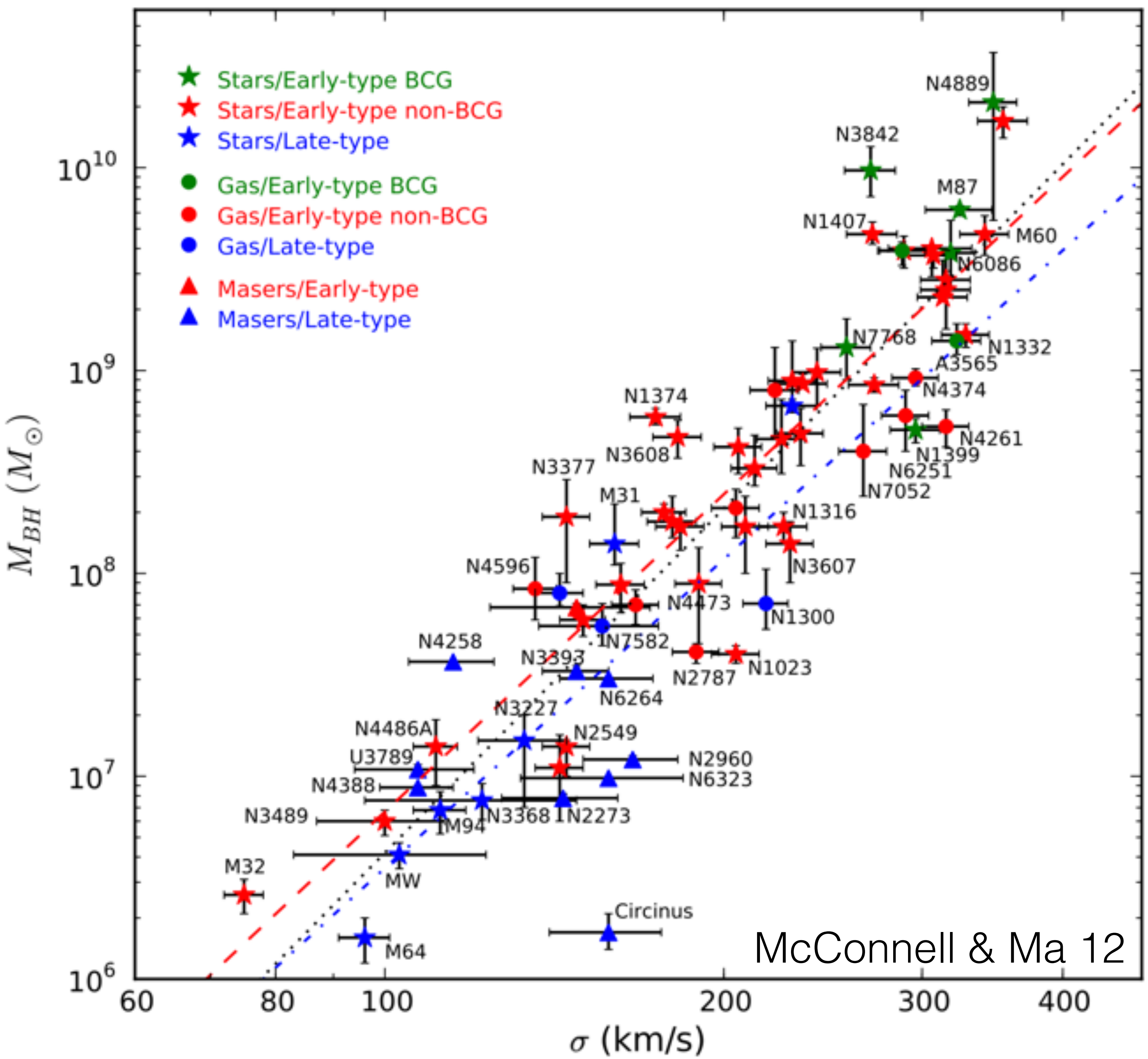
Faber-Jackson: luminosity - velocity dispersion for ellipticals



$$\log_{10}\left(\frac{\sigma_{||}}{150\ km\ s^{-1}}\right) = 0.25\log_{10}\left(\frac{L_{\rm R}}{10^{10}\ {\rm M}_{\odot}}\right)$$

Projection of tighter 'fundamental plane' for ellipticals in effective radius-velocity dispersion-surface brightness space (see BT2, p. 23)

M-σ: black hole mass - stellar bulge velocity dispersion

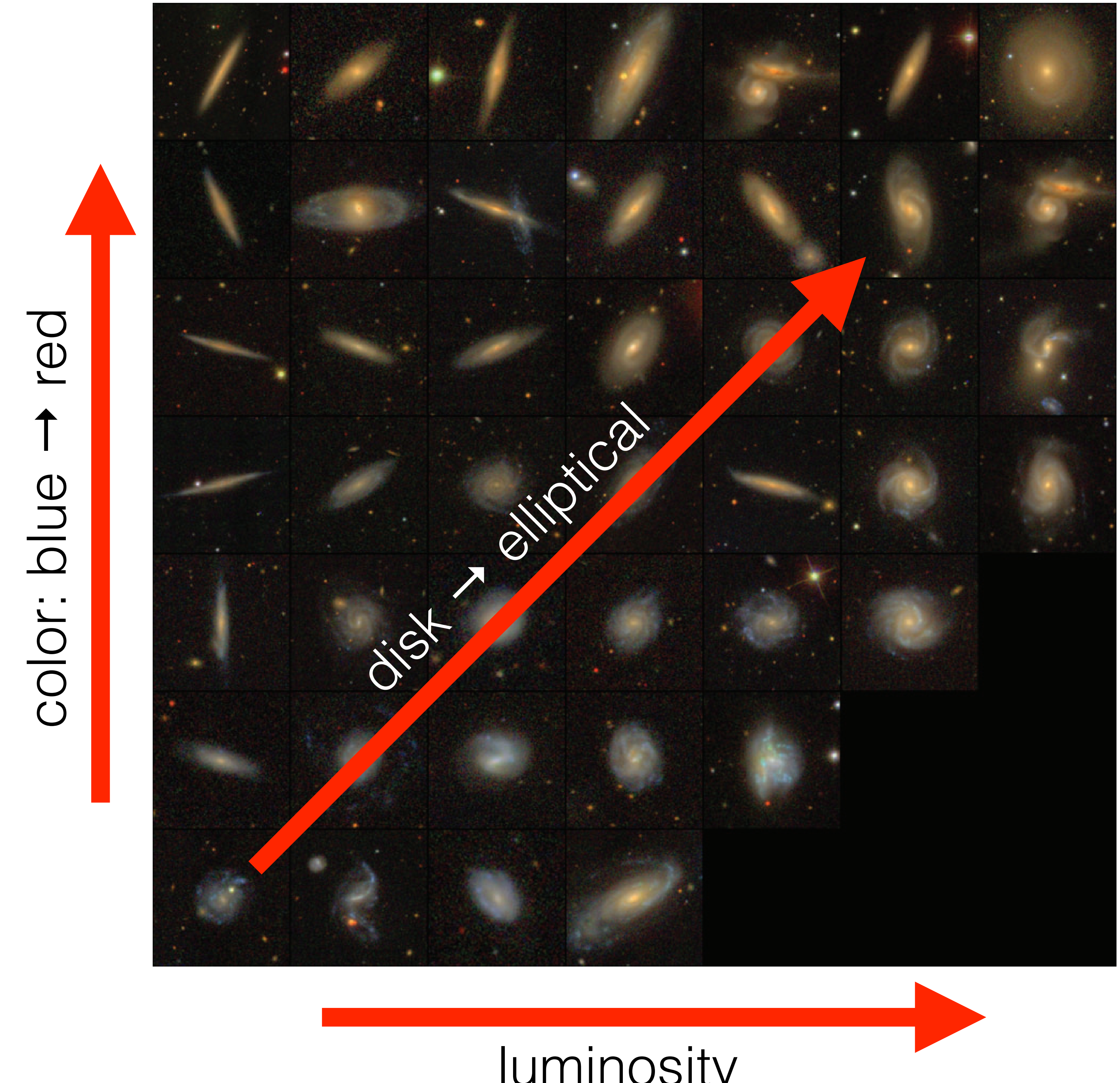


Magorrian:

$M_{\rm BH} \sim 0.002\, M_{\rm bulge}$

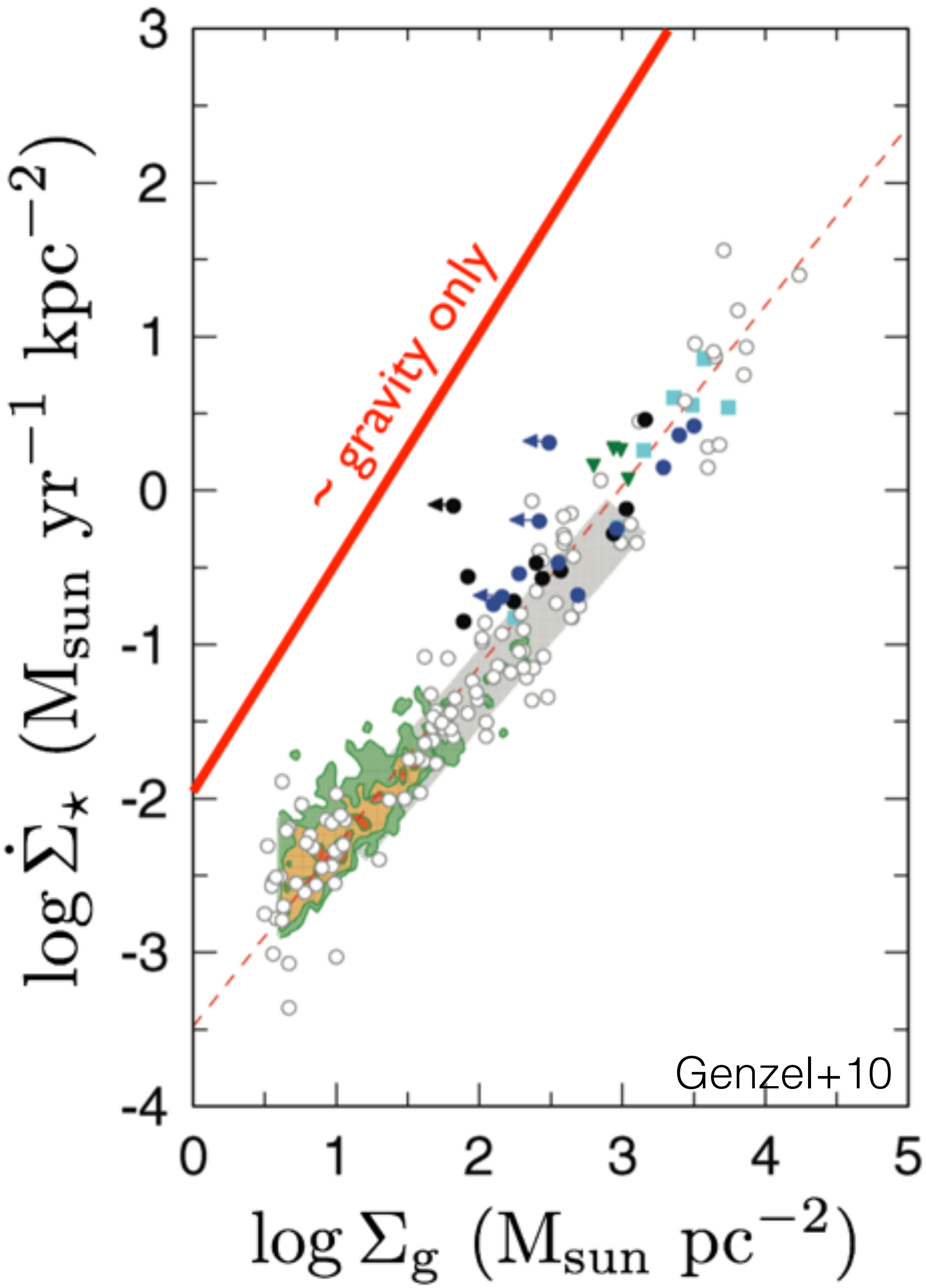
$$\log_{10}(M_\bullet / M_\odot) = 8.32 + 5.64 \log_{10}(\sigma / 200\, \mathrm{km\, s^{-1}})$$

Color, luminosity, morphology correlations



Blanton & Moustakas 08

Kennicutt-Schmidt law: star formation rate - gas mass surface density



Gravity only:

$$\text{Star form. rate} \approx \frac{\text{Gas mass}}{\text{Free fall time}}$$

$\Longrightarrow$ stellar feedback

Redshift evolution

Cosmological simulations of galaxy formation

- Follow dark matter, gas, and stars from Big Bang initial conditions
- Reveal complex formation histories (smooth gas accretion, galaxy mergers, effects of feedback)
- Galaxies change with redshift: clumpy → smooth