ASTRON 449: Stellar Dynamics

Winter 2017

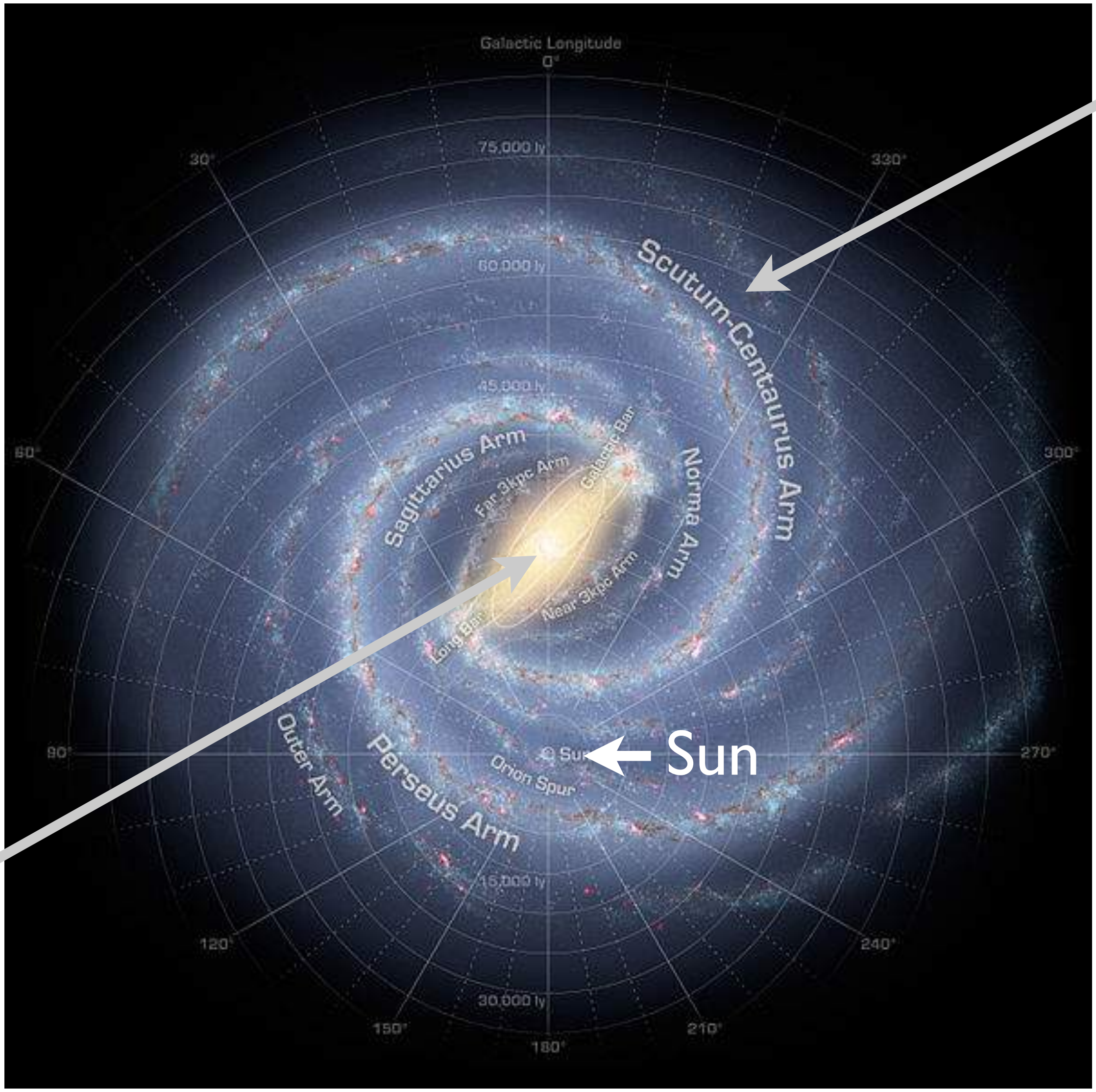
In this course, we will cover

- 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

Galaxy phenomenology

Reading: BT2, chap. 1 intro and section 1.1

What is a galaxy? The Milky Way



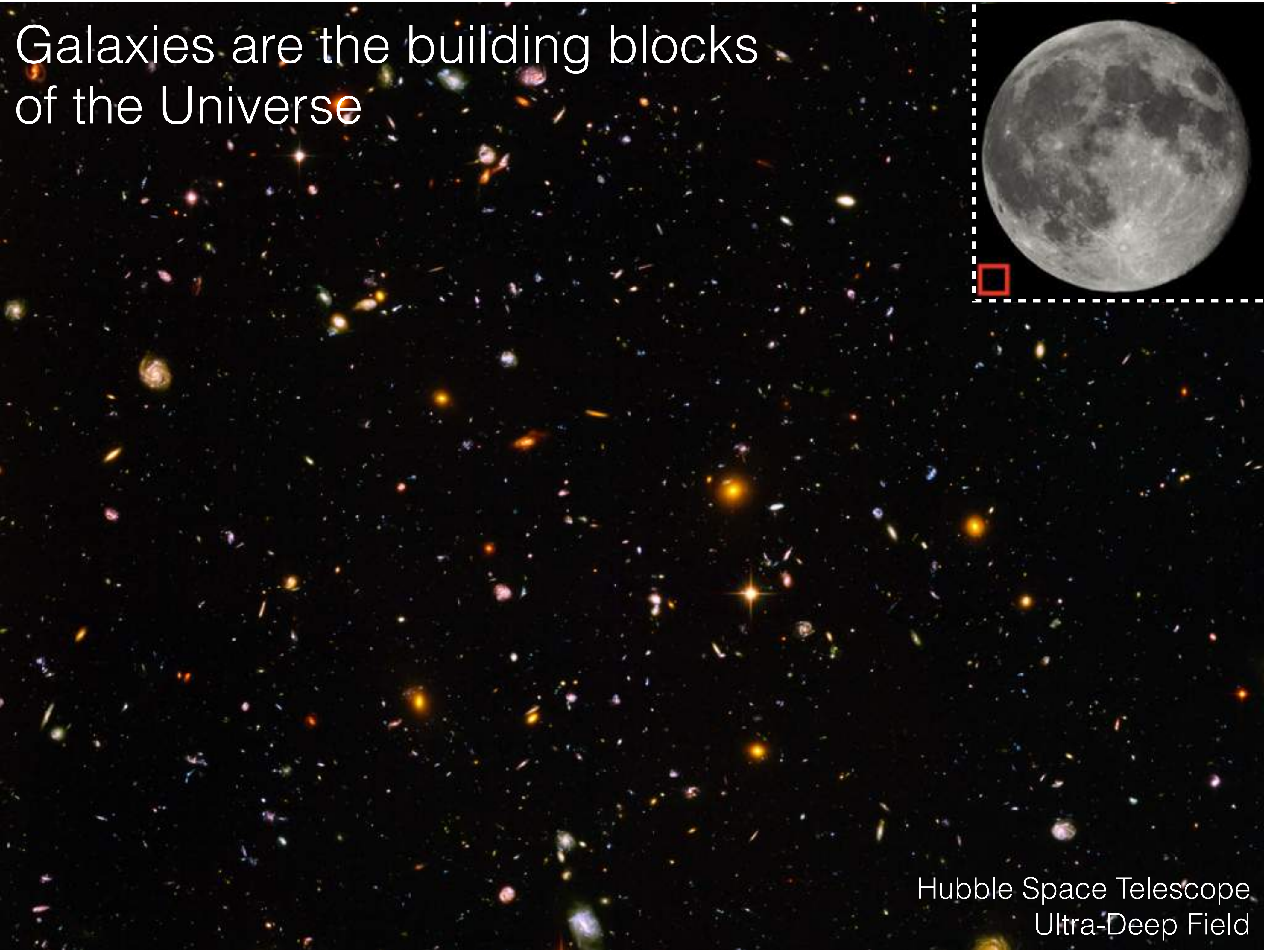
disk of stars,
dust, and gas
$\sim 10^{11}$ stars

8 kpc
1 pc≈3 lyr

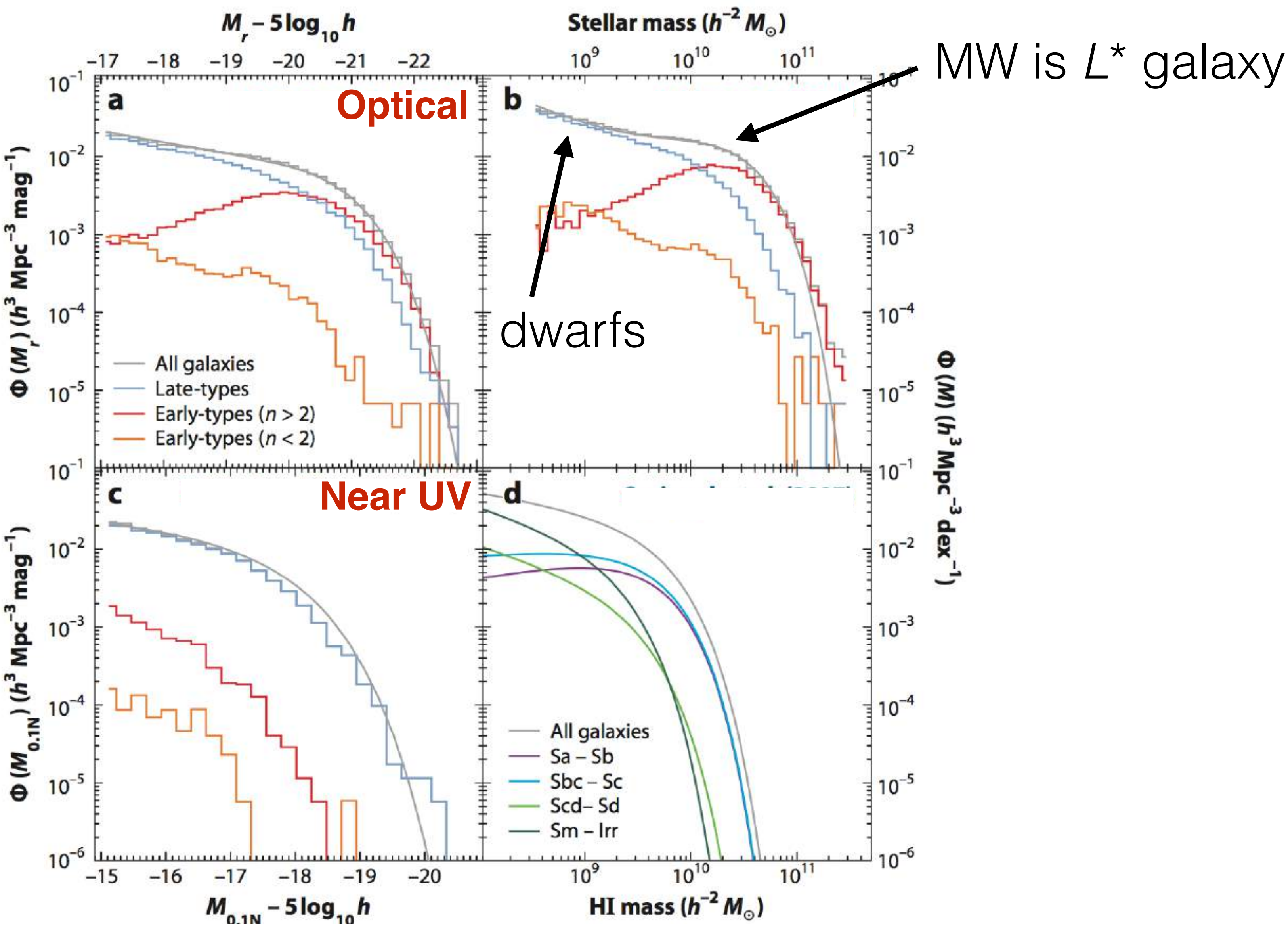
4×10^6 M_{sun}
black hole

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



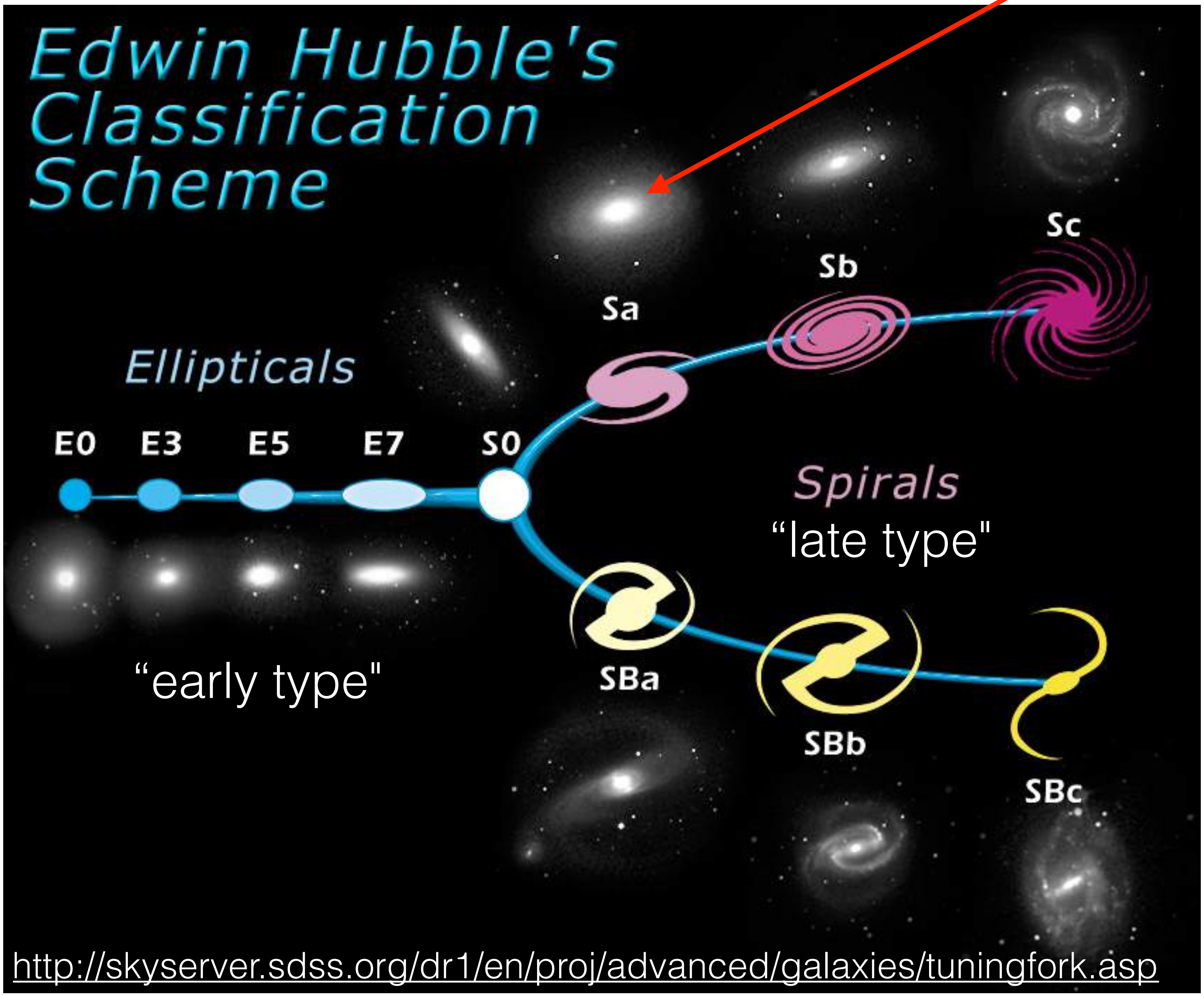
Schechter fits: $\Phi(L)dL = \frac{dL}{L_*}\exp(-L/L_*)\left[\phi_{*,1}\left(\frac{L}{L_*}\right)^{\alpha_1} + \phi_{*,2}\left(\frac{L}{L_*}\right)^{\alpha_2}\right]$

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

Local galaxies from SDSS; Blanton & Moustakas 08

Hubble's morphological classes

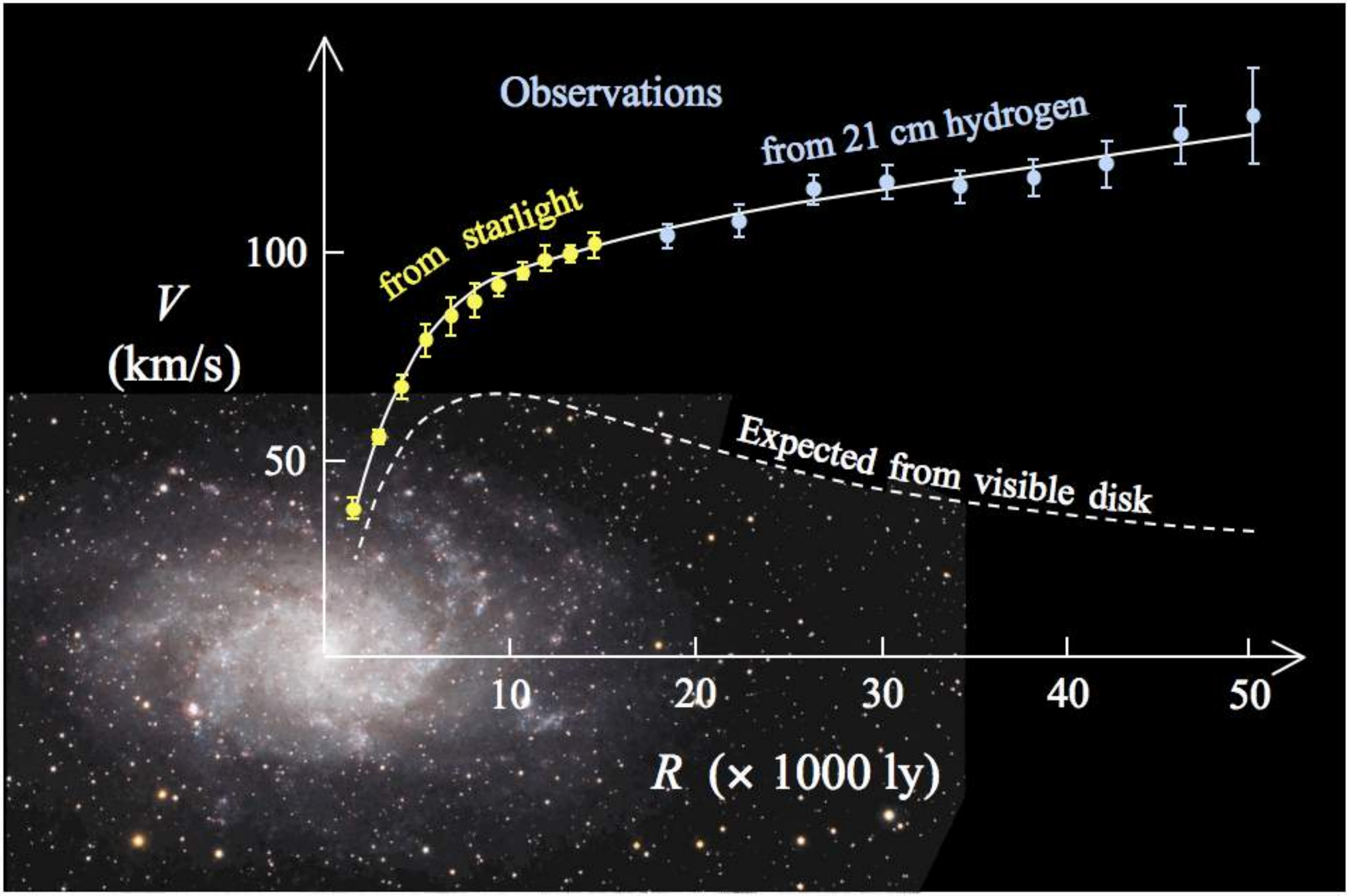
bulge or spheroidal component



barred

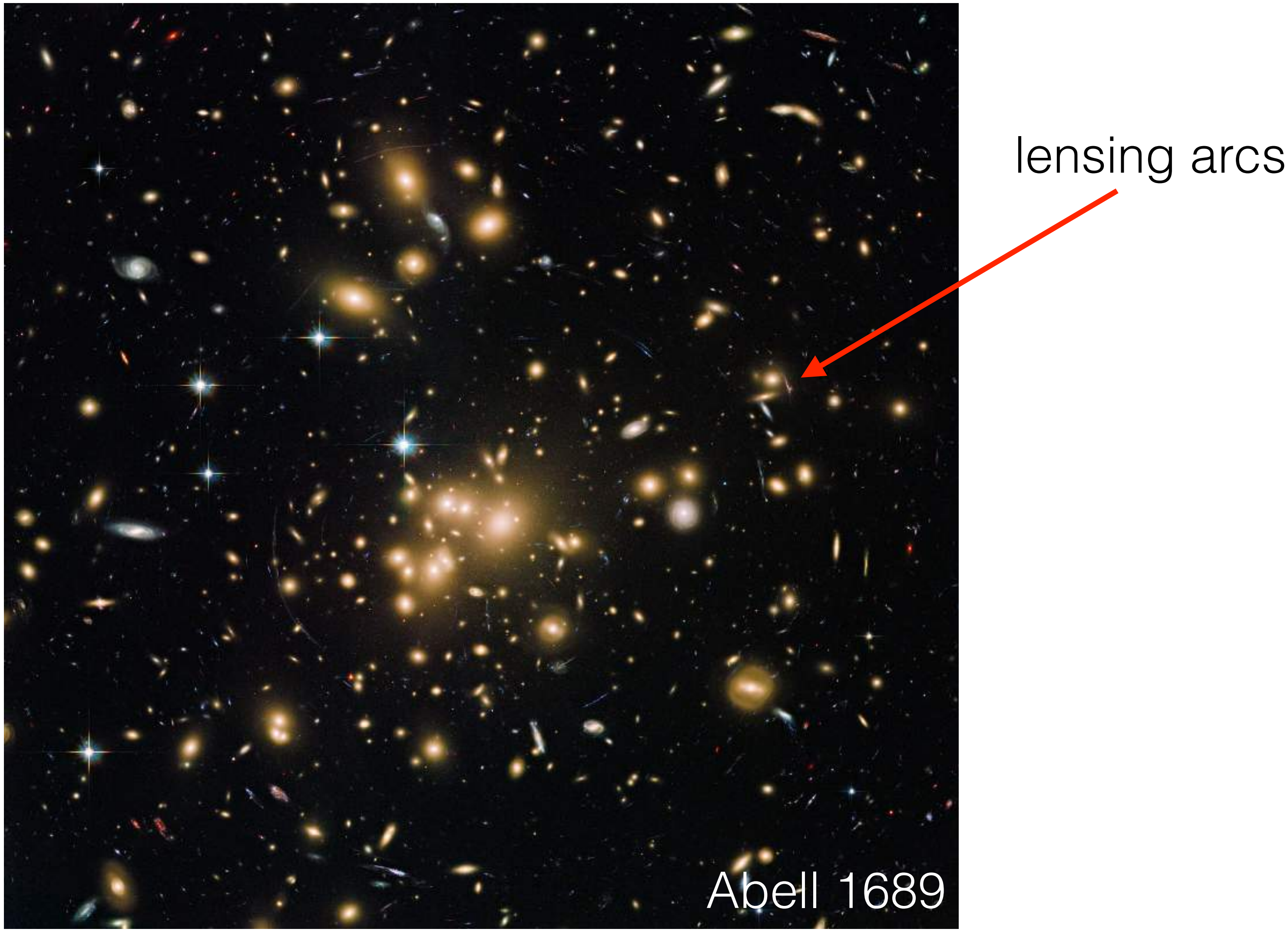
Not a time or physical sequence

Galaxy rotation curves: evidence for dark matter



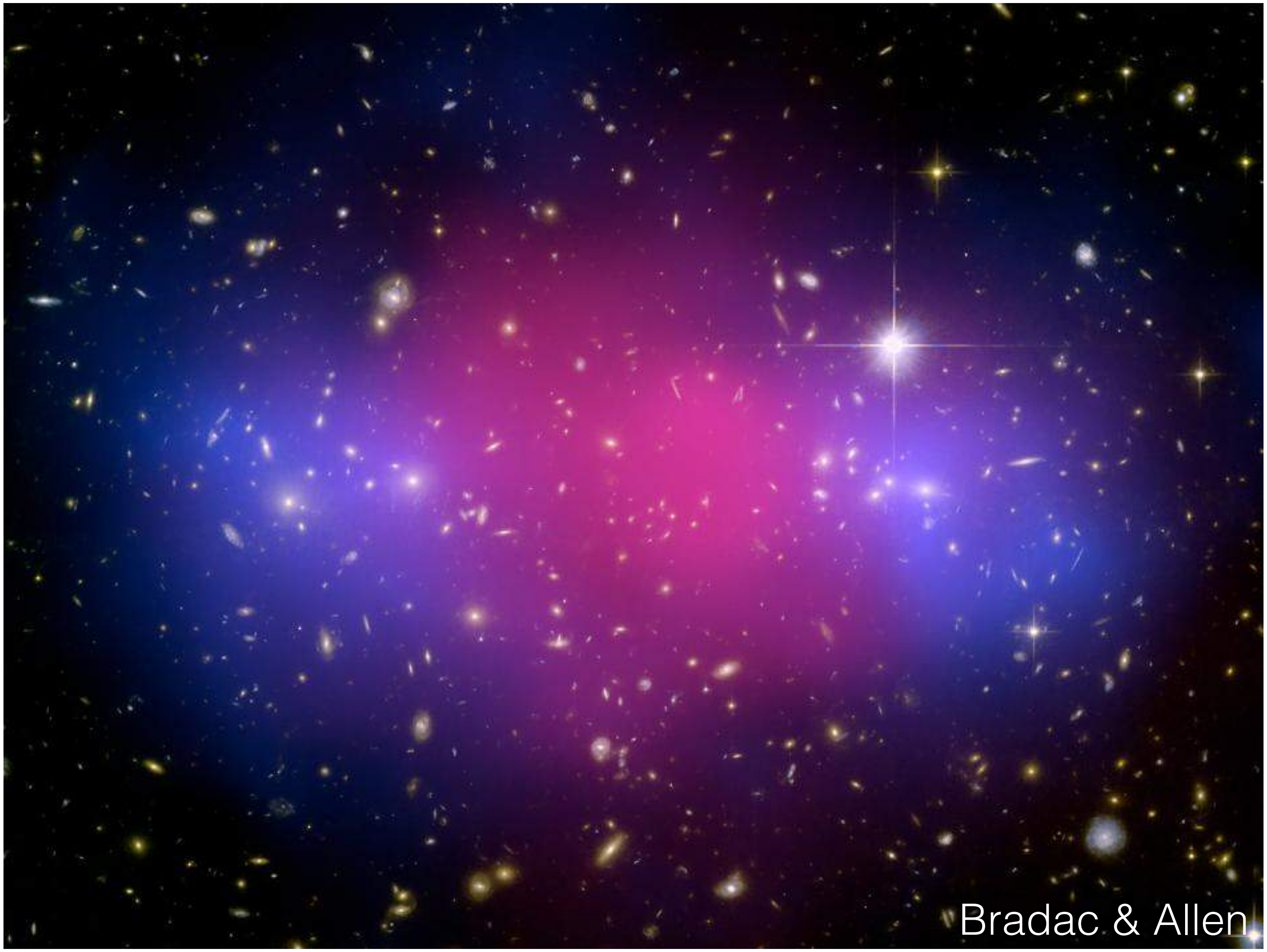
M33 rotation curve from http://en.wikipedia.org/wiki/Galaxy_rotation_curve

Galaxy clusters



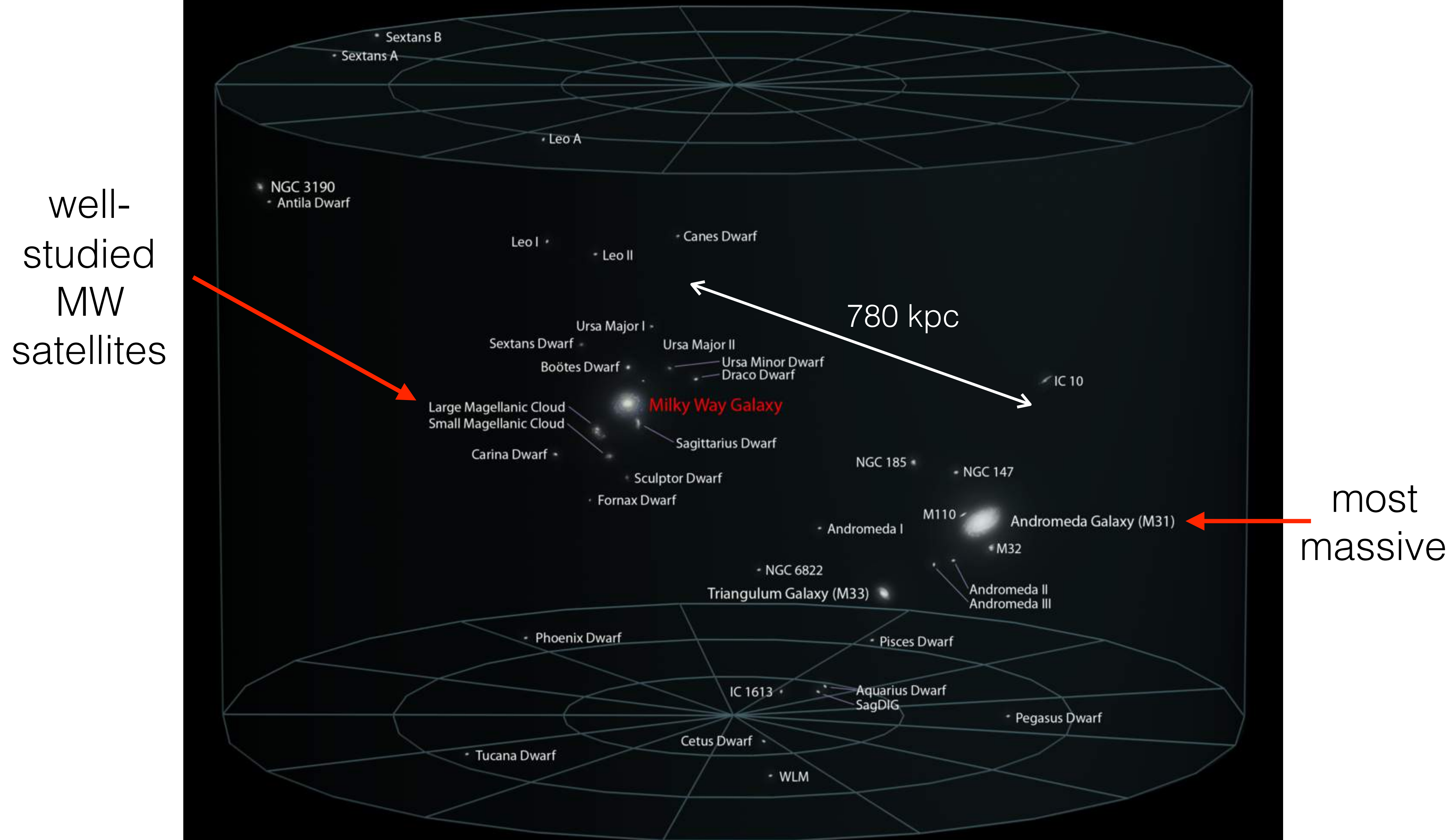
- most massive gravitational bound objects in the Universe
- contain up to thousands of galaxies
- most baryons intracluster gas, $T \sim 10^7$-10^8 K gas
- smaller collections of bound galaxies are called 'groups'

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

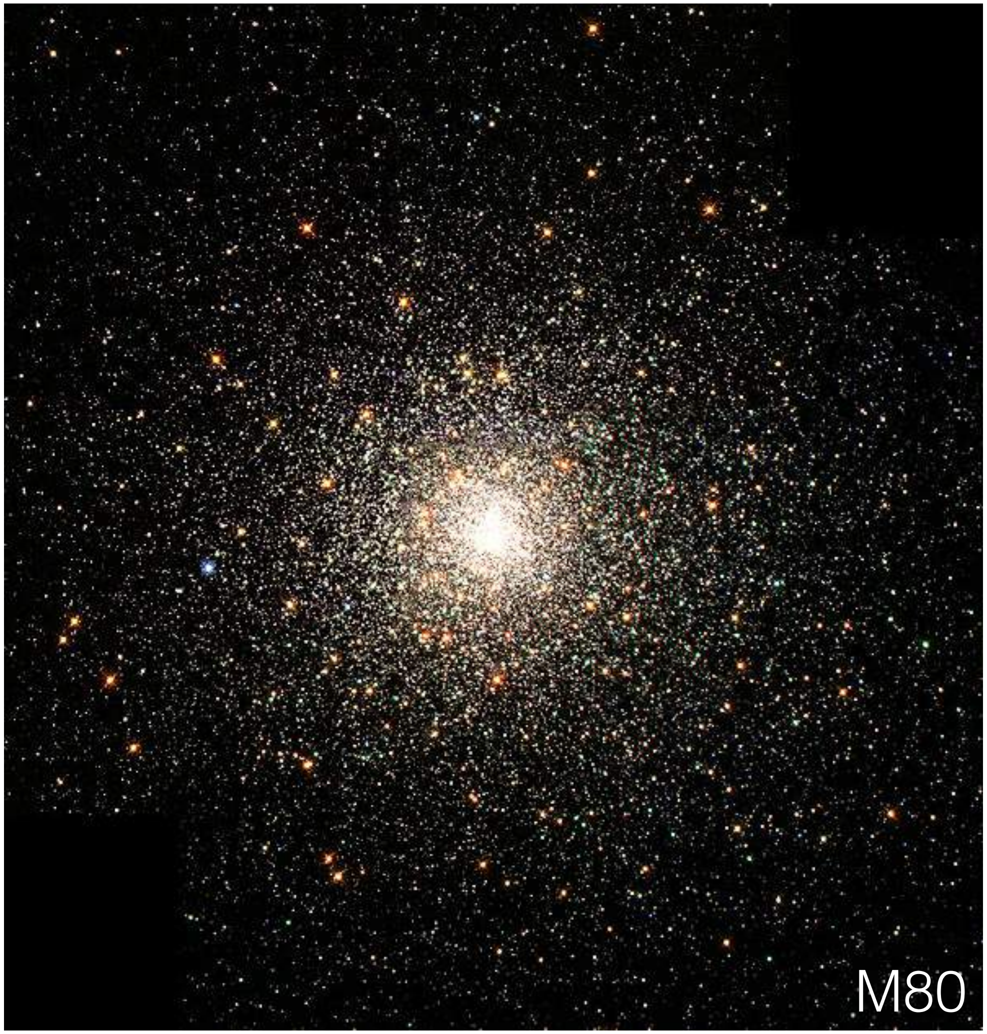


Note: potential of lowest-mass dwarfs is dominated by dark matter — internal dynamics cleanly probe dark matter distribution

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



- ~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

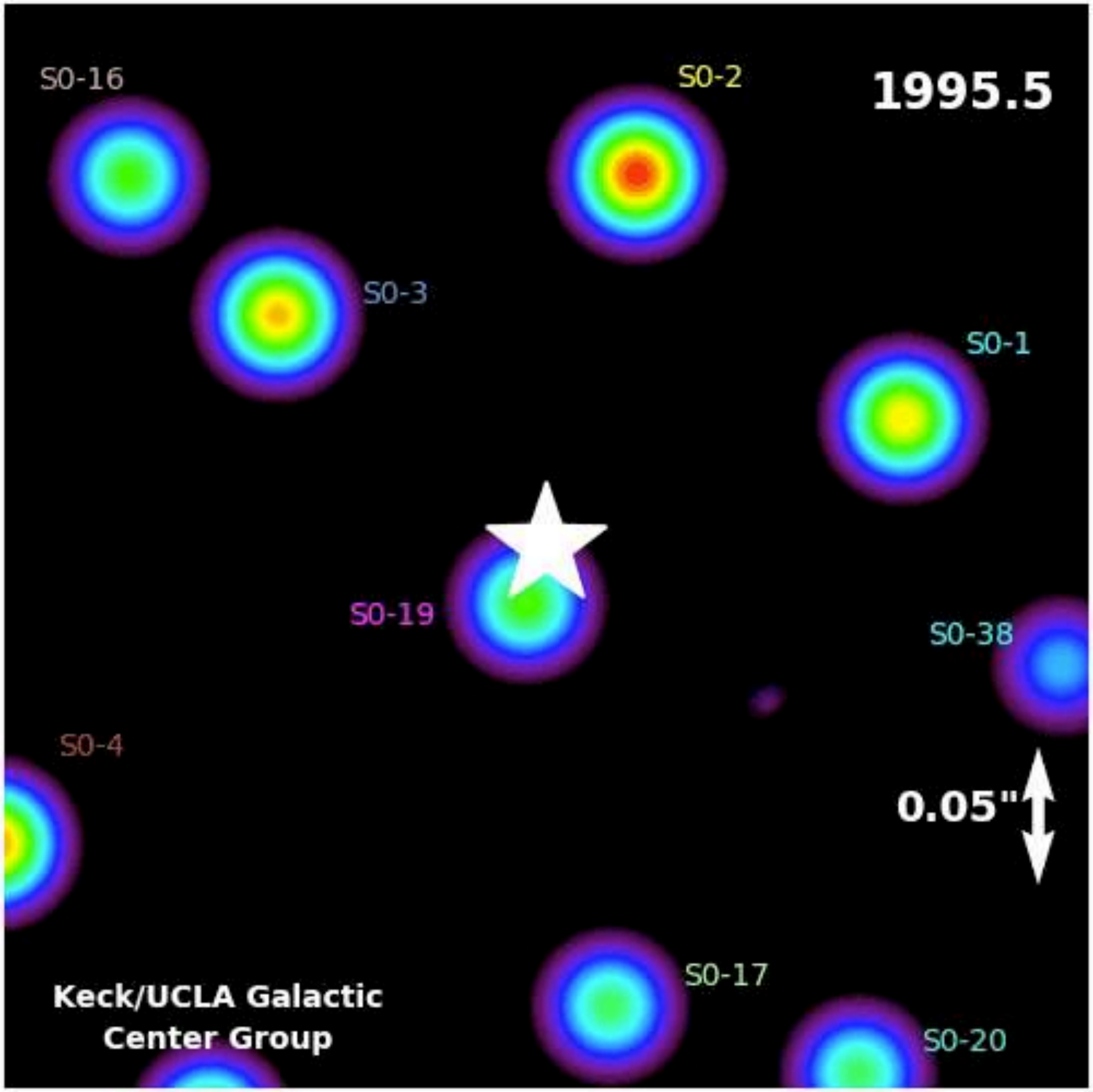
- collisions between galaxies are common, e.g. MW and Andromeda will merge in ~3 Gyr
- mass ratio >1:3 → major merger (otherwise, minor)
- create tidal features, stellar bulges

Formation of ellipticals by major mergers of two disk galaxies

N-body simulation (viz credit: Patrik Jonsson)

Note: individual stars very rarely collide in a galaxy collision (collisionless dynamics)!

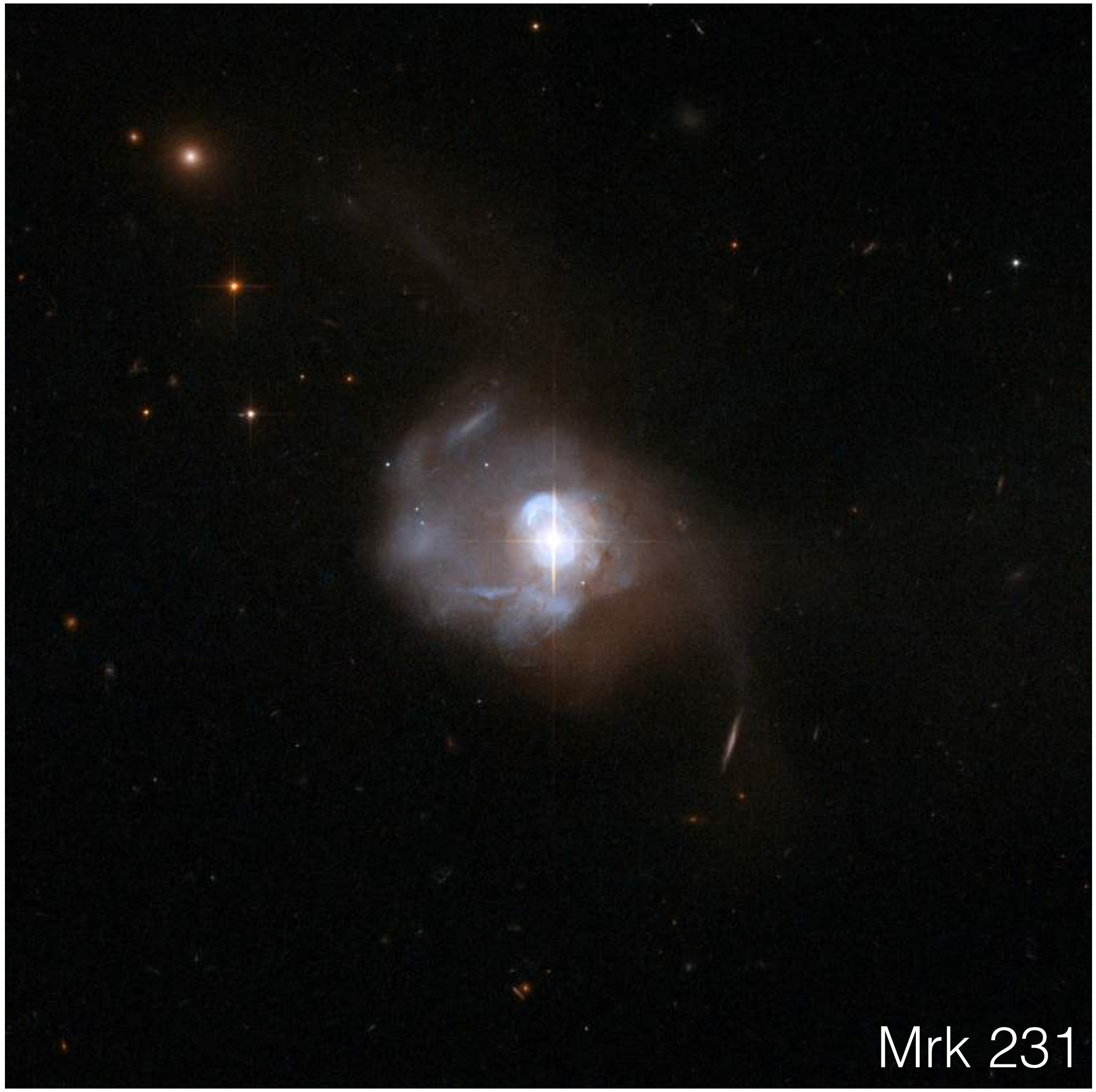
Nuclear black holes



10^{-4} pc

- all (massive) galaxies appear to have one
- in MW (Sgr A*), $M_{\rm BH}$=4×10^6 $M_{\rm sun}$, measured using individual stellar orbits

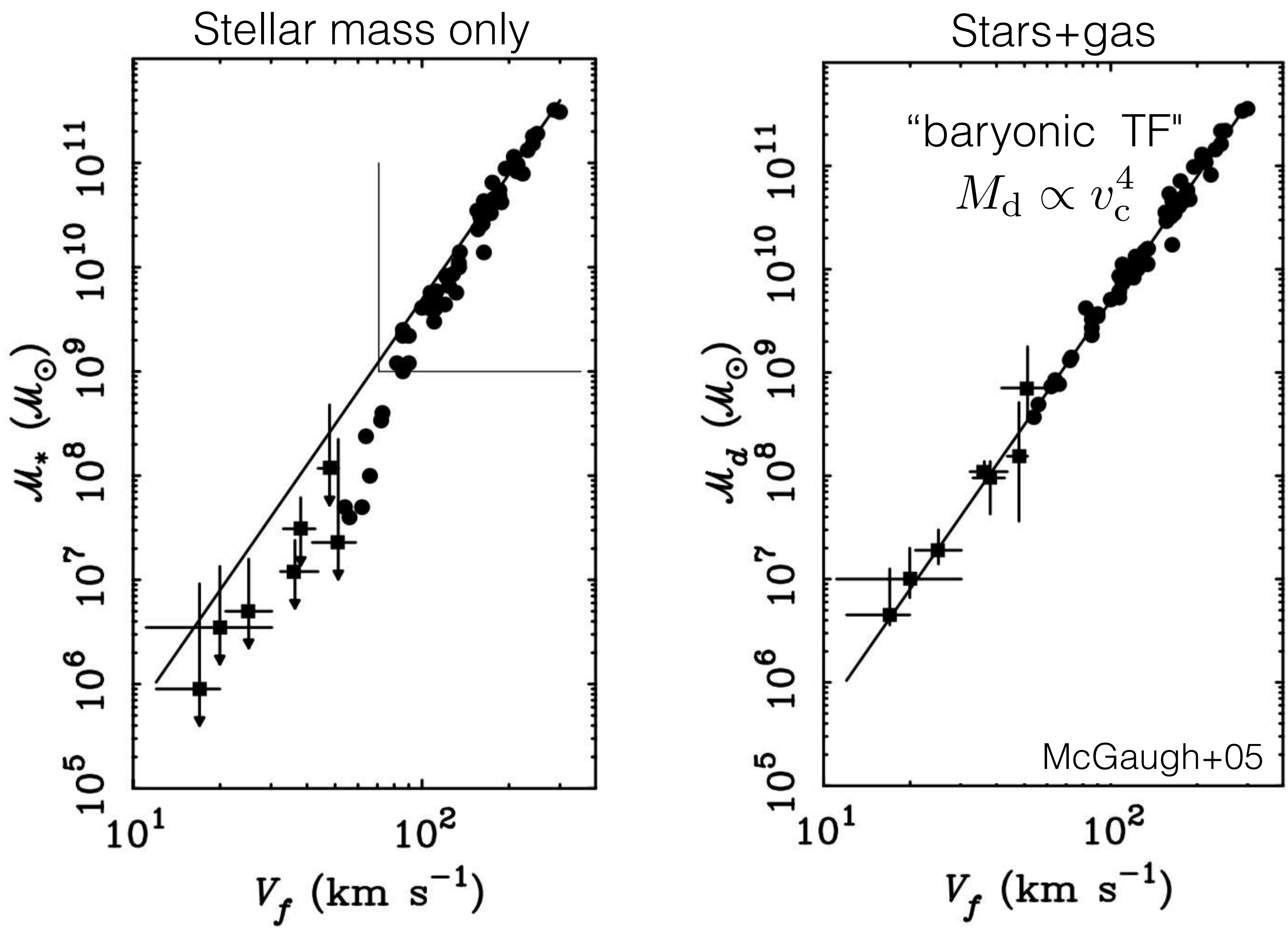
Active galactic nuclei



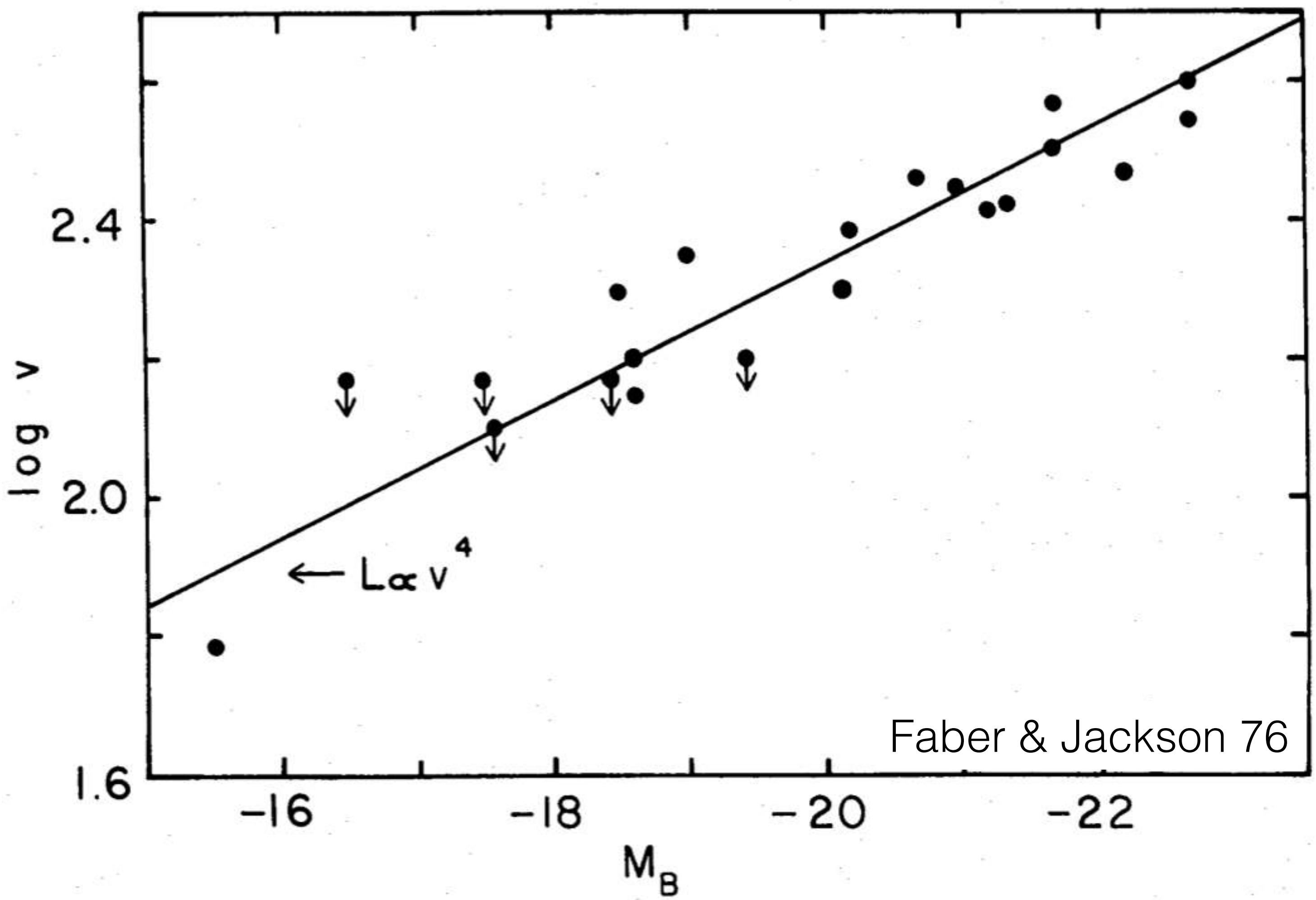
- accreting nuclear black holes visible as AGN
- the most luminous AGN are called quasars (can outshine entire host galaxy)
- in local Universe, quasars are associated with galaxy mergers

Scaling relations, and other correlations

Tully-Fisher: luminosity/mass - circular velocity for spirals



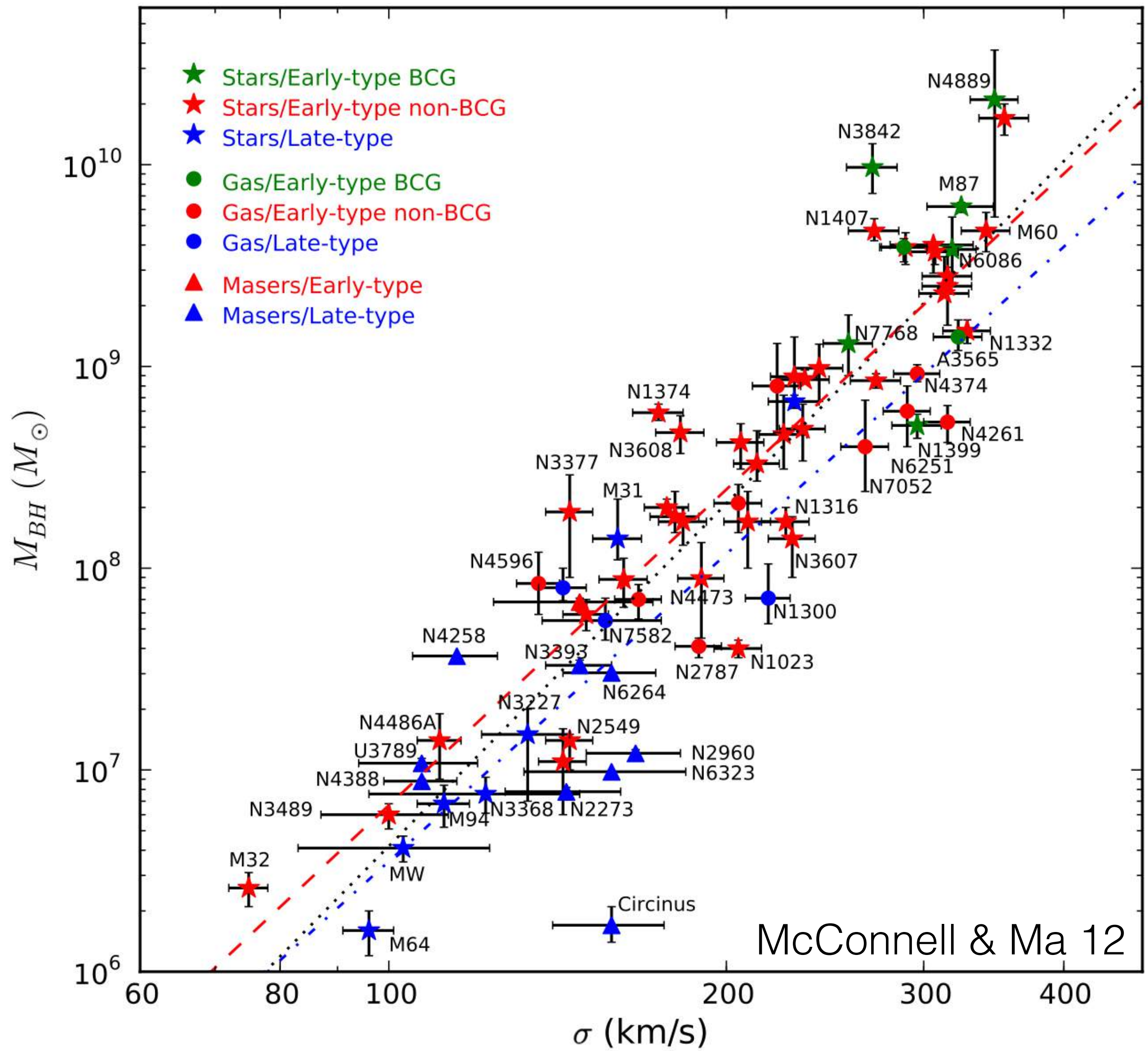
Faber-Jackson: luminosity - velocity dispersion for ellipticals



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

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

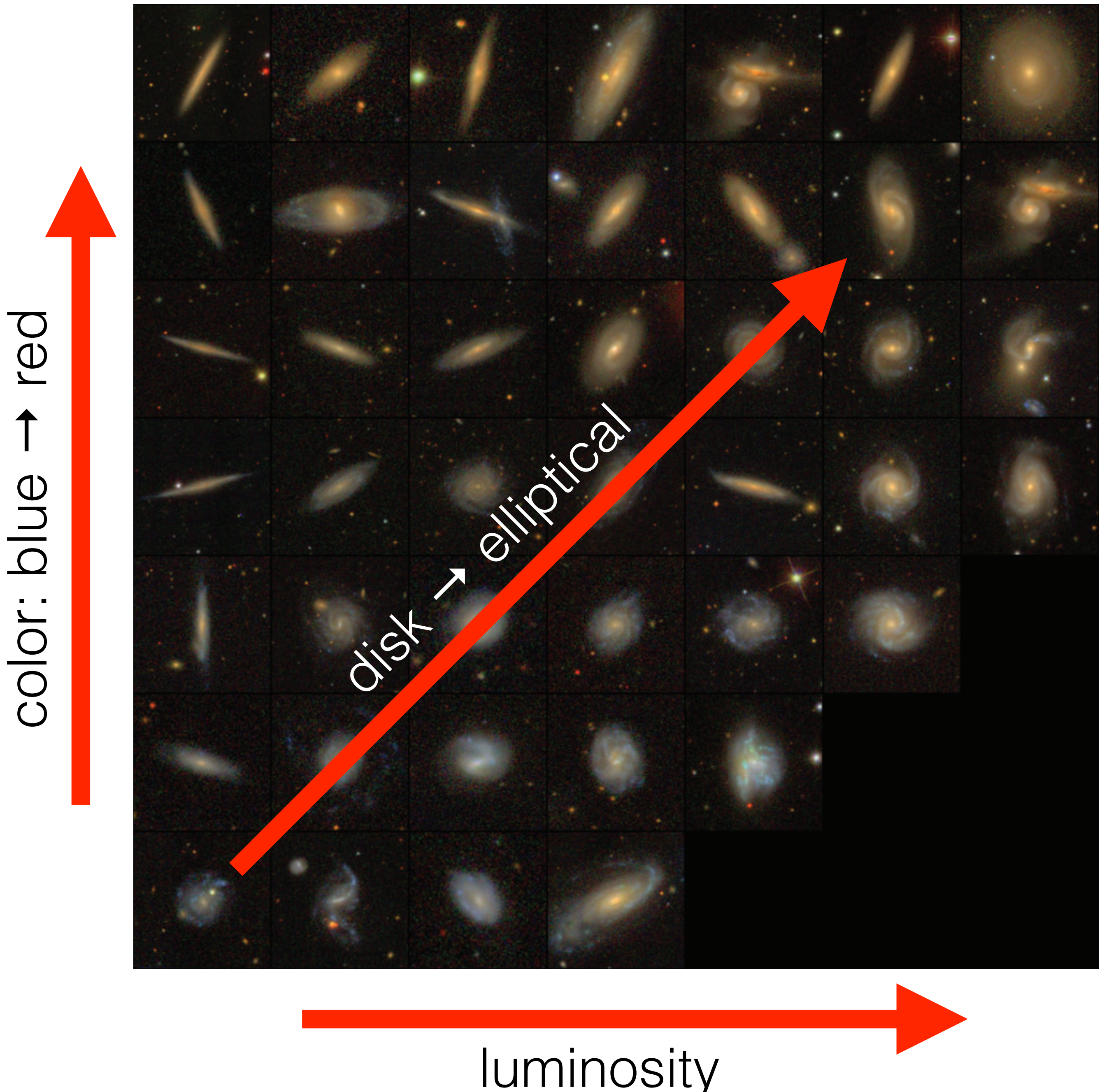


Magorrian:

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

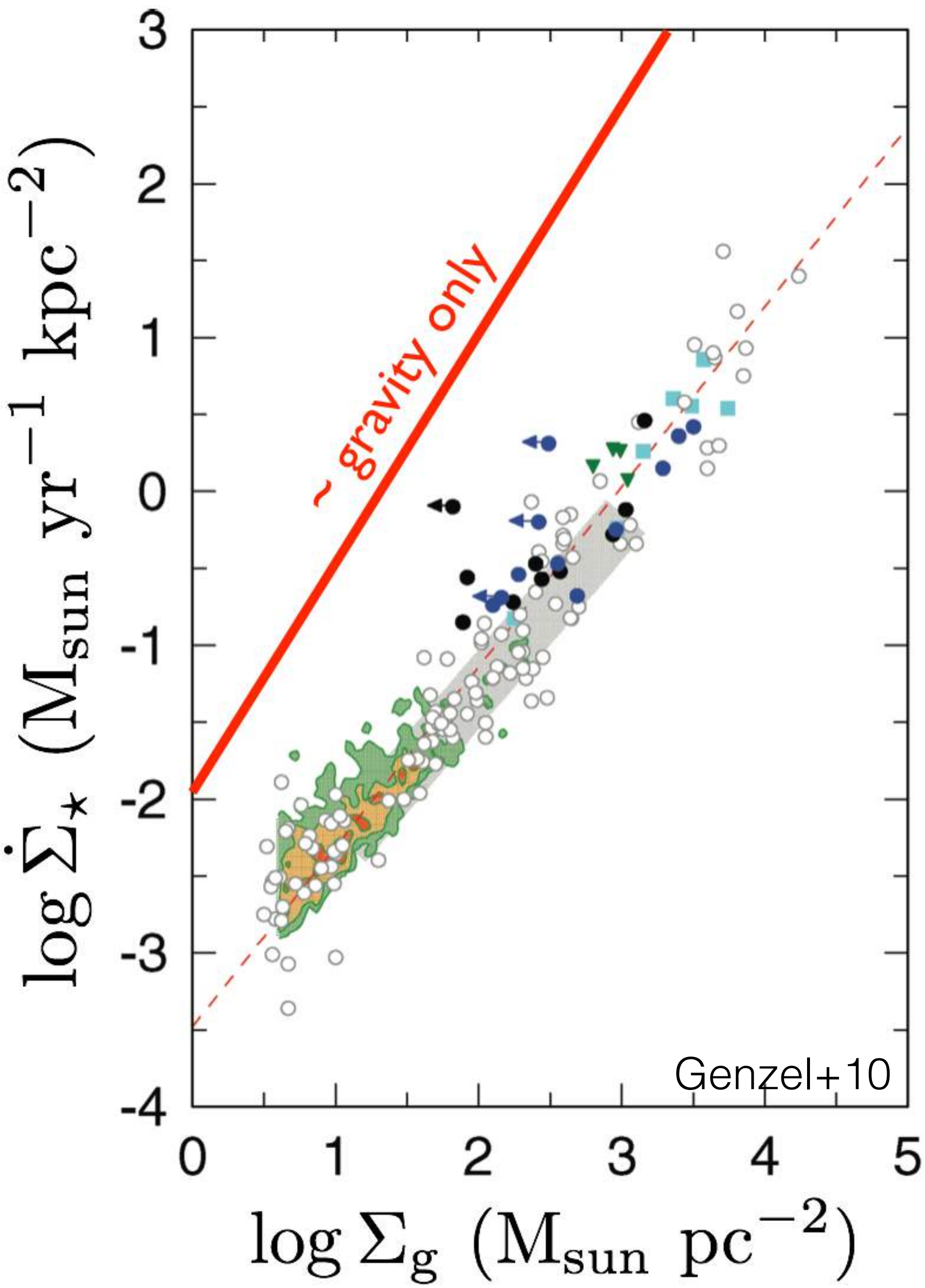
$$\log_{10}(M_\bullet/M_\odot) = 8.32 + 5.64\log_{10}(\sigma/200\,\mathrm{km\,s^{-1}})$$

Color, luminosity, morphology correlations



Blanton & Moustakas 08

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



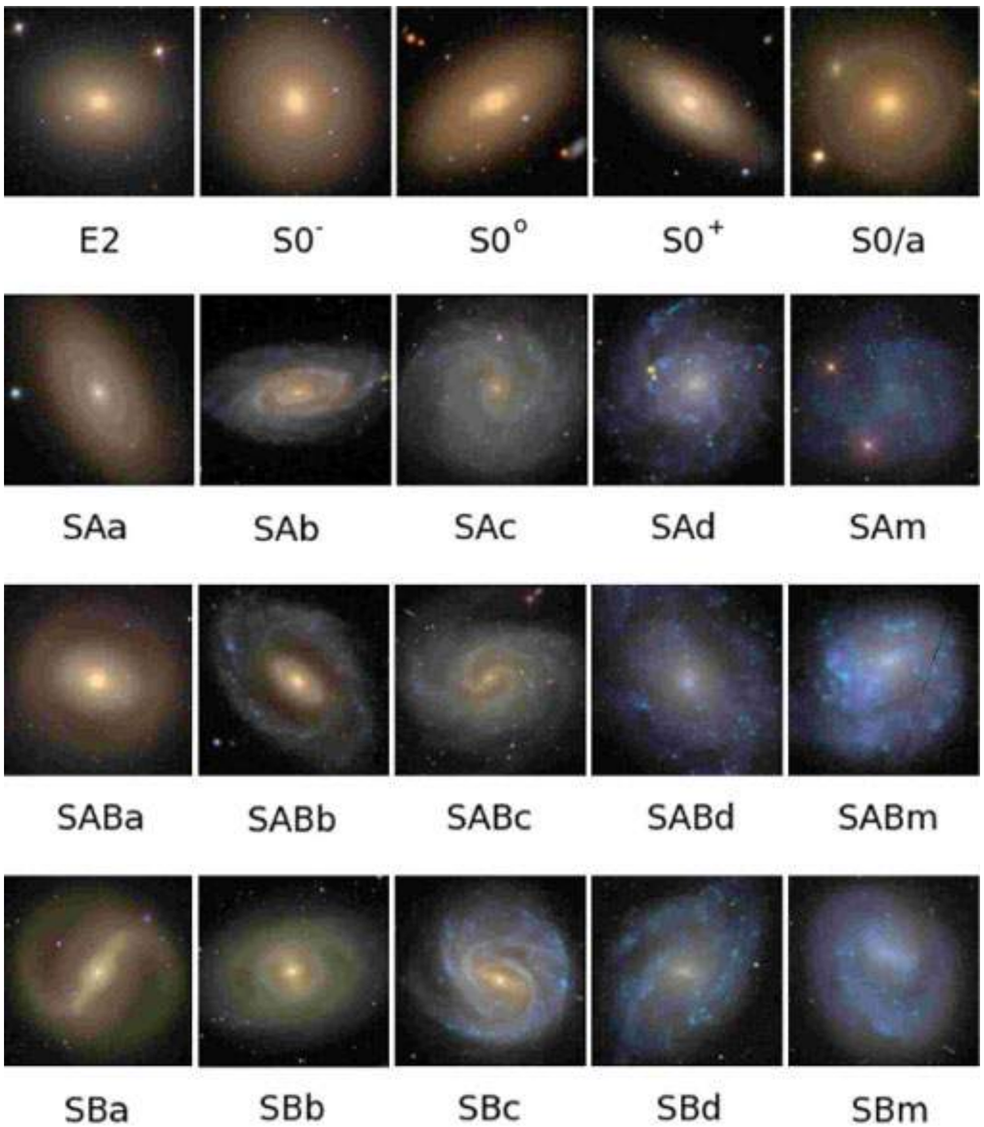
Gravity only:

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

$\Longrightarrow$ stellar feedback

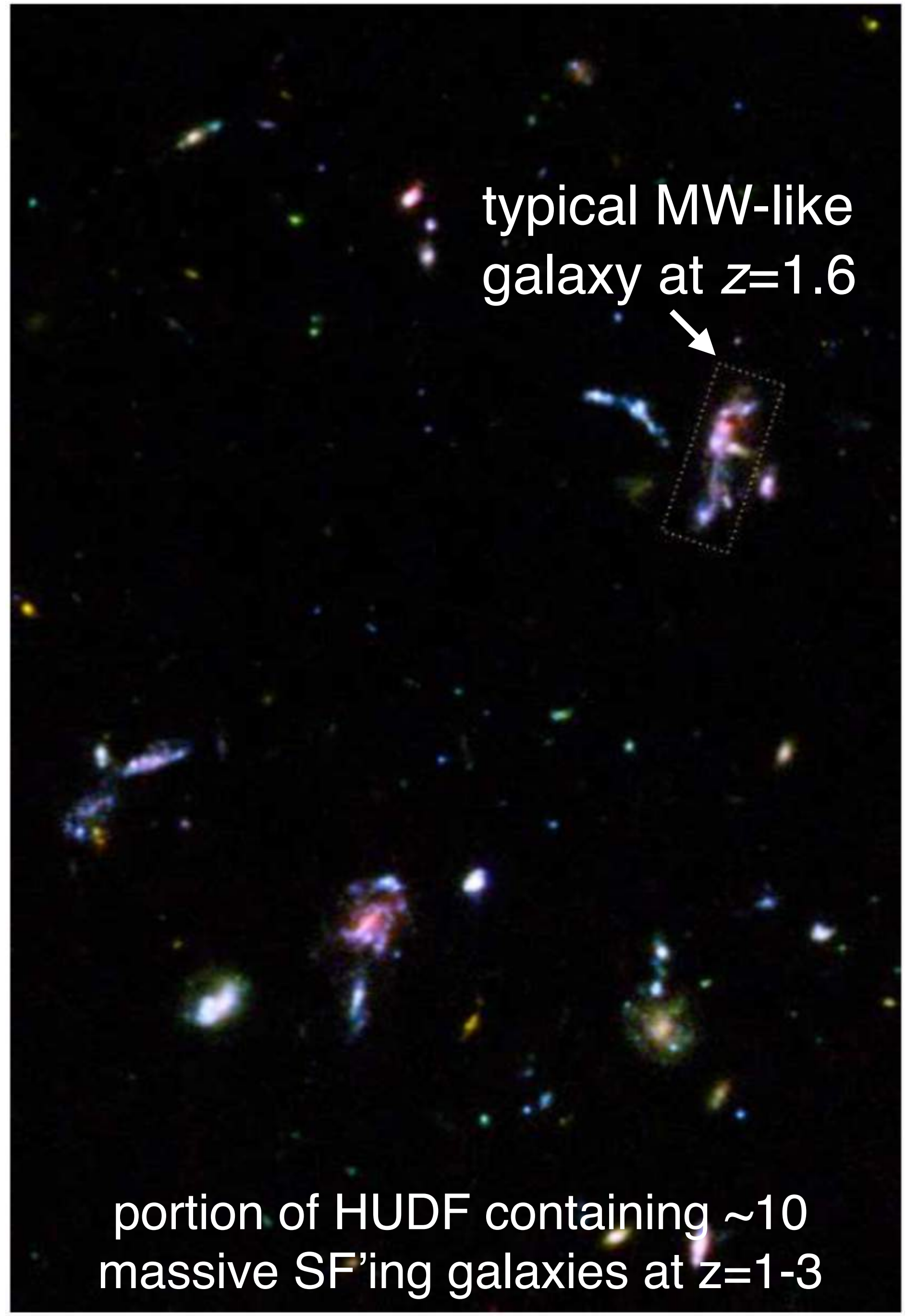
Redshift evolution

Local galaxies



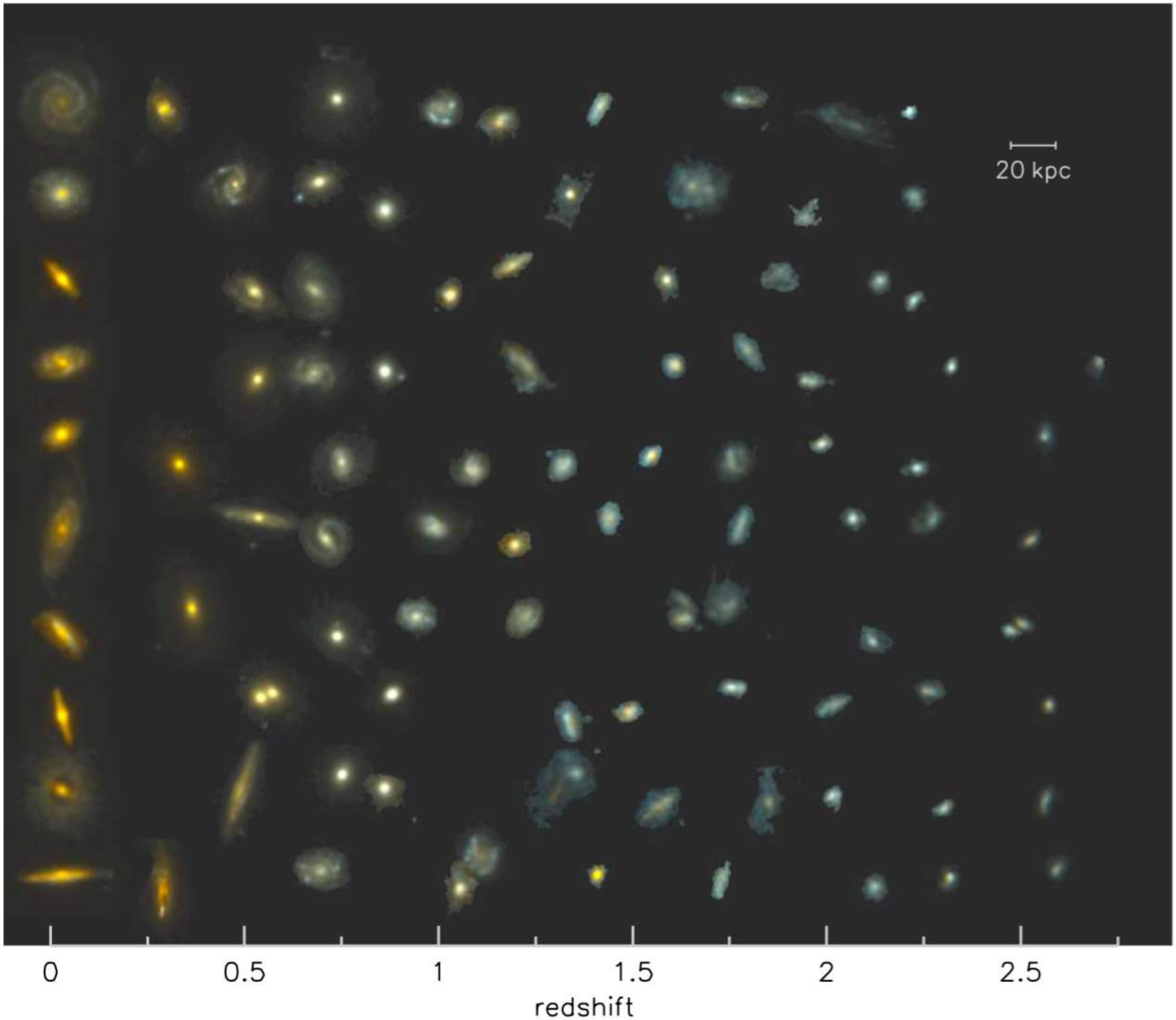
Buta 2011

High redshift



Bournaud 2015

Tracing progenitors of MW-mass galaxies using number density



van Dokkum+13

At high z, galaxies are:

- smaller (even at same mass)
- clumpier (esp. in UV — young stars)
- bluer (younger stellar populations, higher SFRs)

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)
- Morphological evolution from clumpy to well ordered (for massive galaxies)