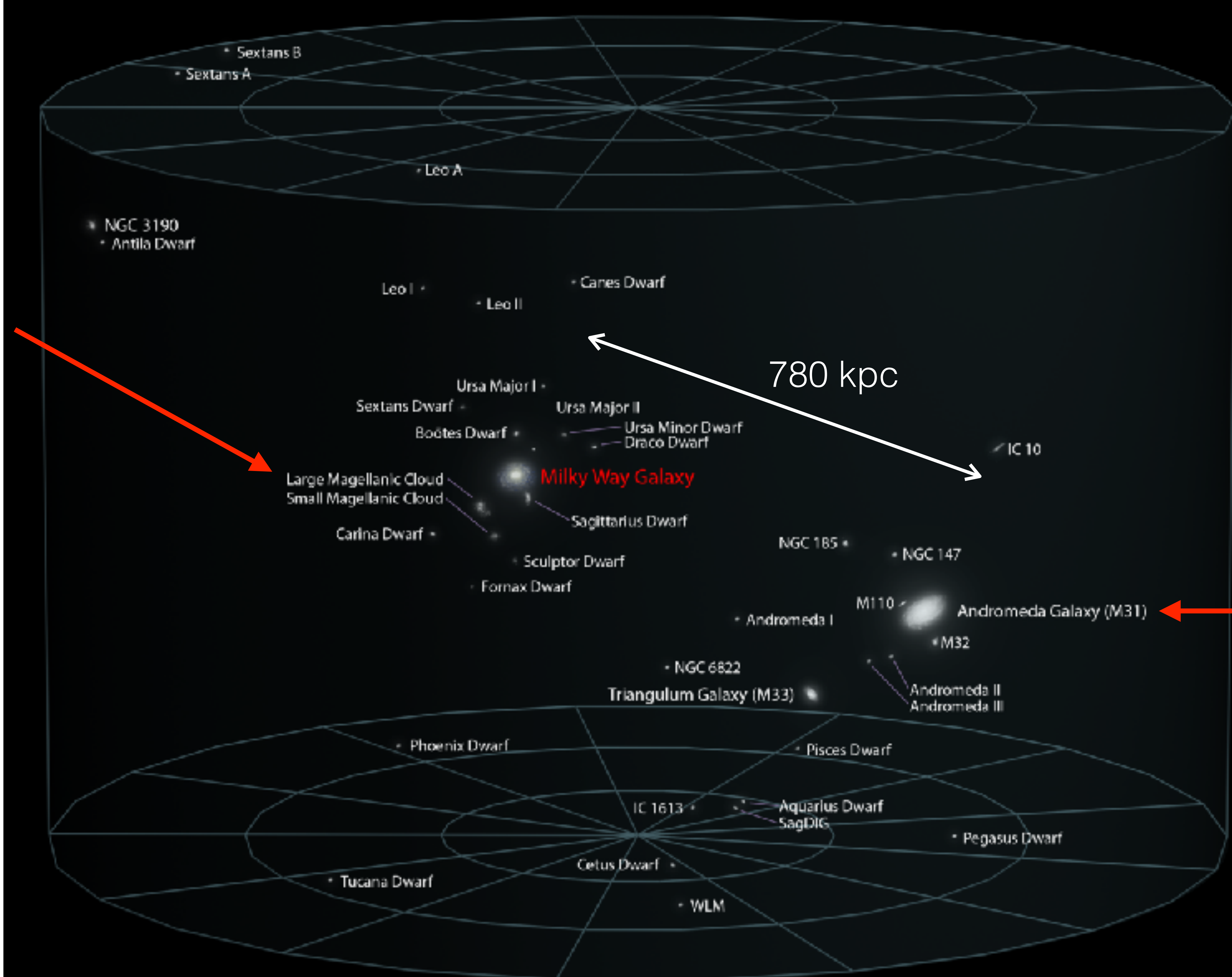
Dynamical friction, galaxy mergers, and AGN

Local Galactic Group



Orbital decay of LMC due to dynamical friction in MW halo, for two different halo models and different velocity measurements

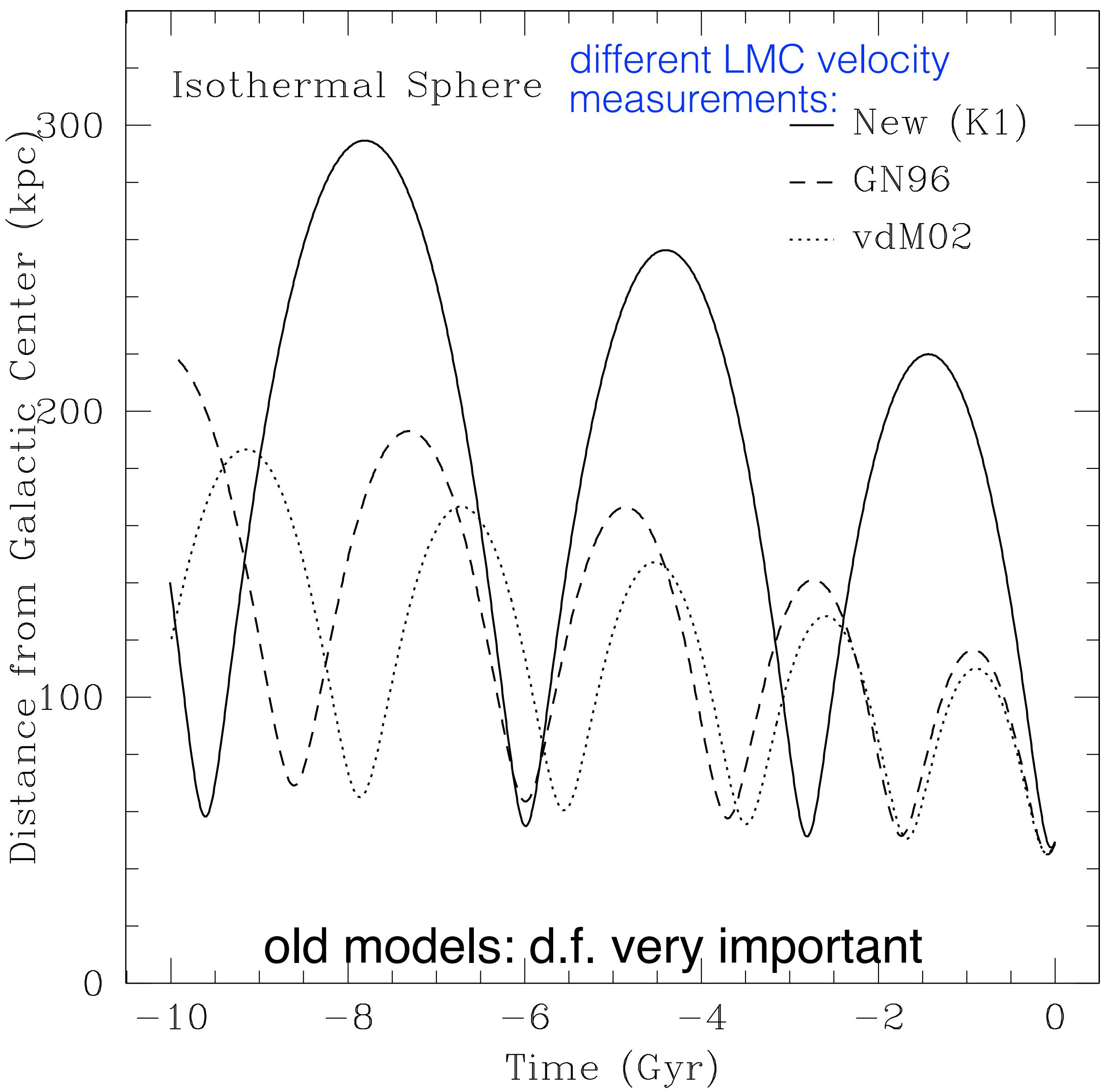


FIG. 1.—Galactocentric radial distance plotted as a function of time in the past for the mean K1 (*solid line*), GN96 (*dashed line*), and vdM02 (*dotted line*) values, where $T = 0$ corresponds to today. The MW dark matter halo is modeled as an isothermal sphere and the effect of dynamical friction is approximated using the Chandrasekhar formula with Coulomb logarithm $\ln \Lambda = 3$. Even in this idealized case, the apogalacticon distance reached using the mean K1 values is ∼2 times larger than the GN96 or vdM02 results and the orbital period has increased to ∼3 Gyr.

→ future minor merger (mass ratio ~1:40)

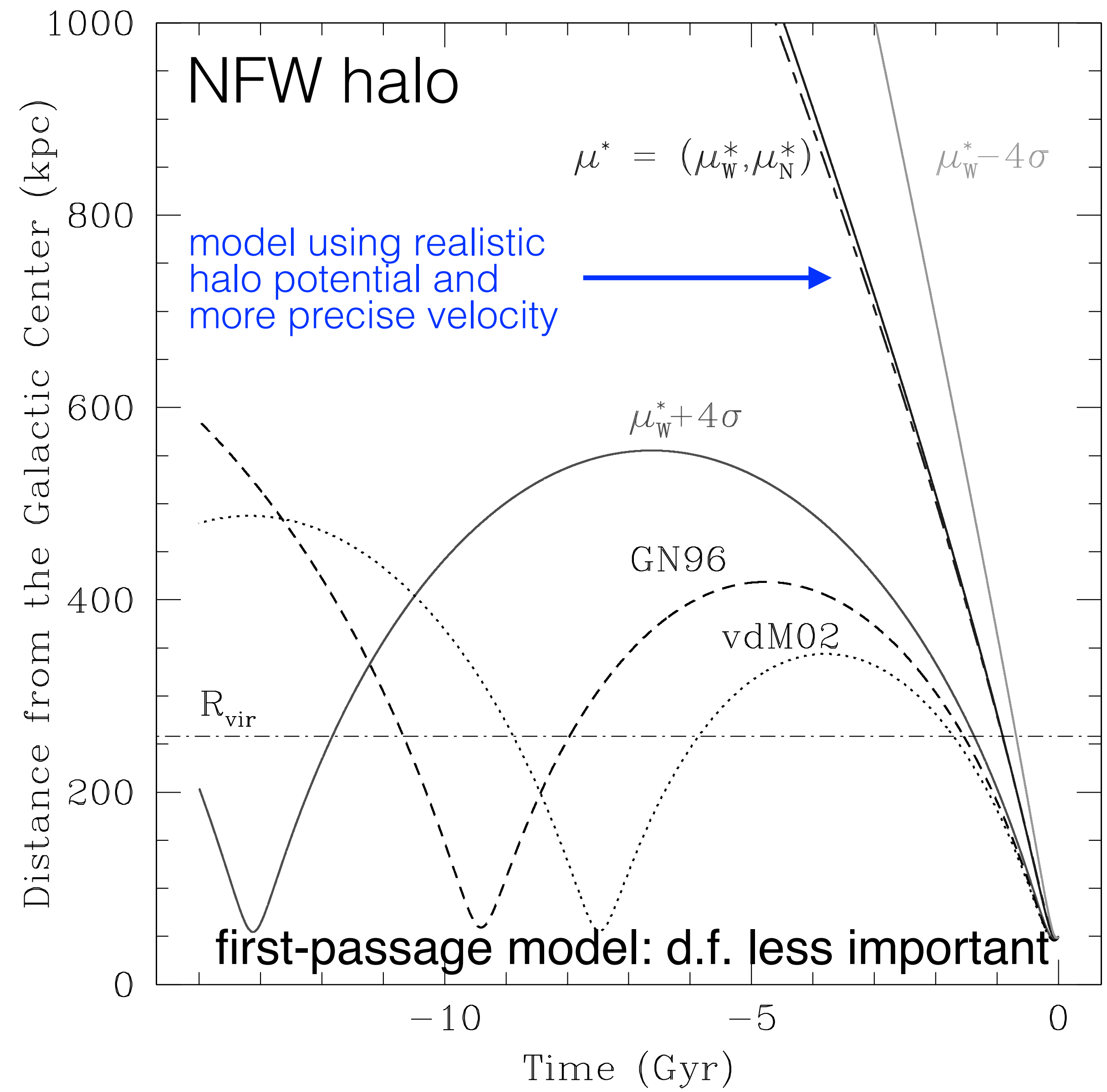


FIG. 4.—Orbital evolution of the LMC plotted as a function of time in the past, where $T = 0$ corresponds to today. The dash-dotted line indicates the virial radius of the halo (258 kpc). All allowed orbits are constrained by the lines marked $\mu_W = \mu^*_W \pm 4\sigma$, which indicate the outer boundary of the green regions in Fig. 3. The two lines indicated by μ^* represent the orbital evolution of the LMC if the mean values are used [$\mu^* = (-2.03,\ 0.44)$]: the long-dashed(solid) line illustrates the orbit ignoring(including) dynamical friction. Even in the best-case scenario, the LMC completes only one orbit within t_H and reaches an apogalacticon distance of 550 kpc. The short-dashed and dotted lines indicate the orbits traced by the old GN96 and vdM02 values, respectively, in our fiducial model. [*See the electronic edition of the Journal for a color version of this figure.*]

Besla+07

Milky Way-Andromeda major merger

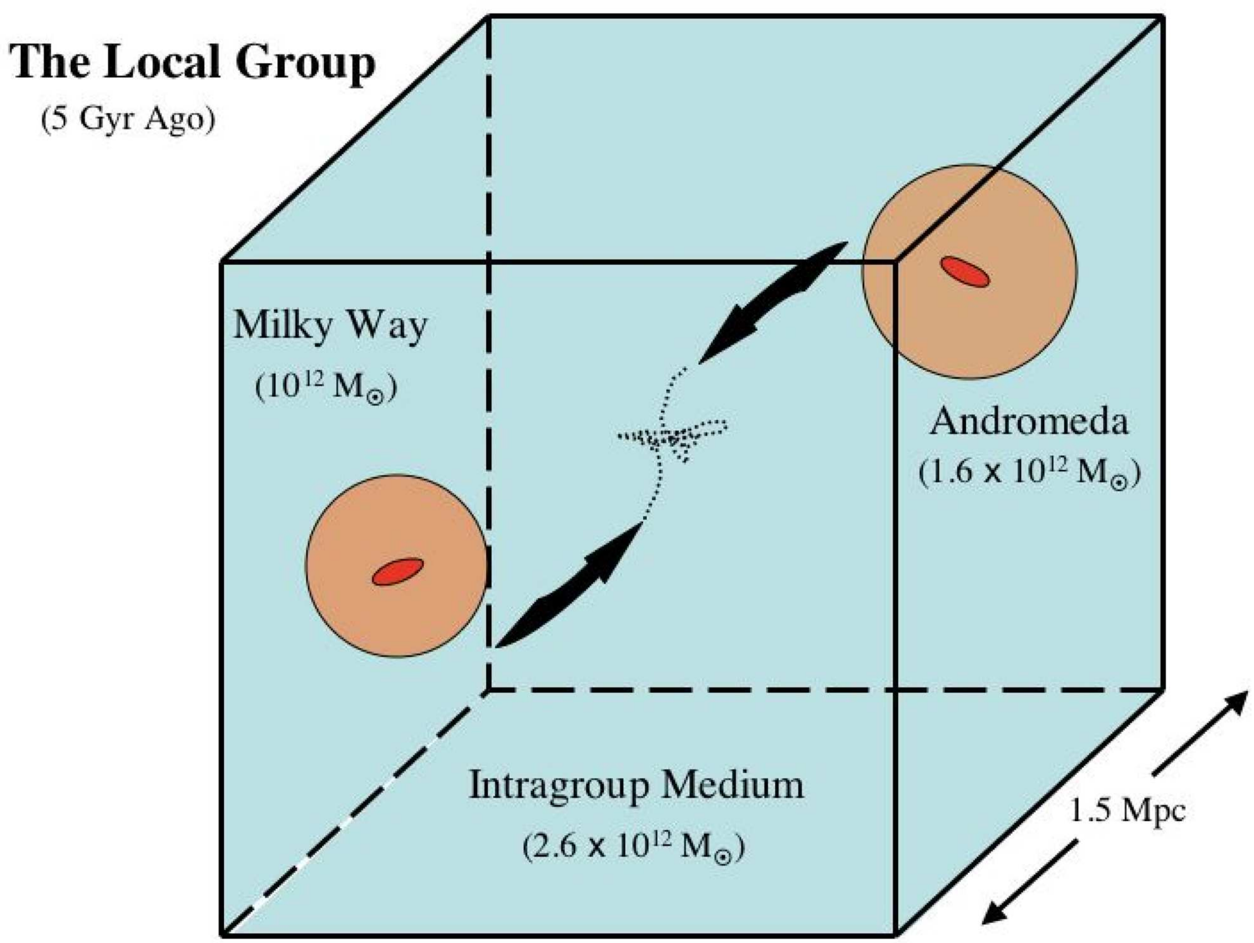


Figure 1. Sketch of the initial configuration of our Local Group model, which consists of the MW and Andromeda embedded in a diffuse, constant-density intragroup medium of equivalent mass. See the text in Section 2 and Table 1 for more details.

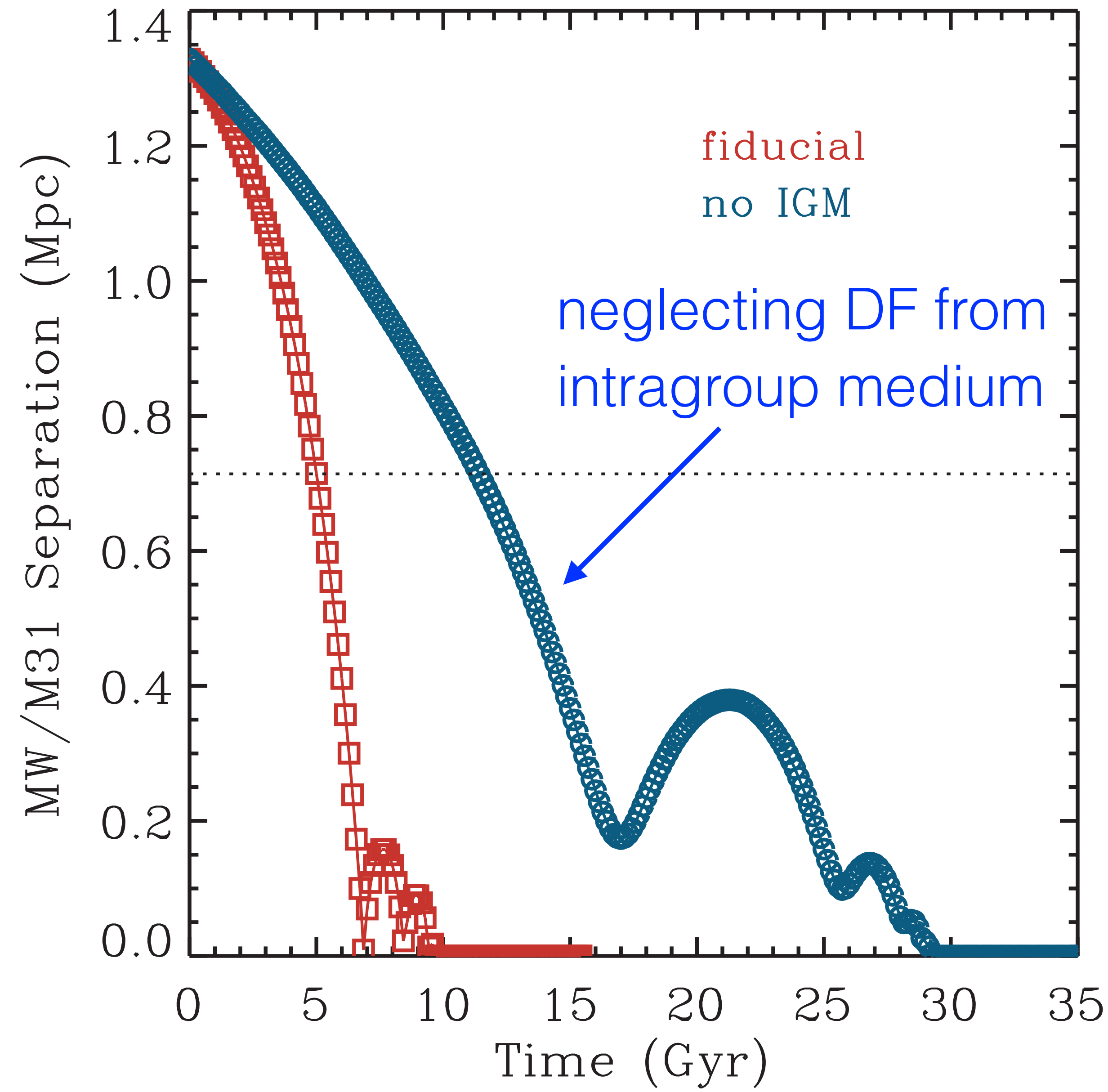
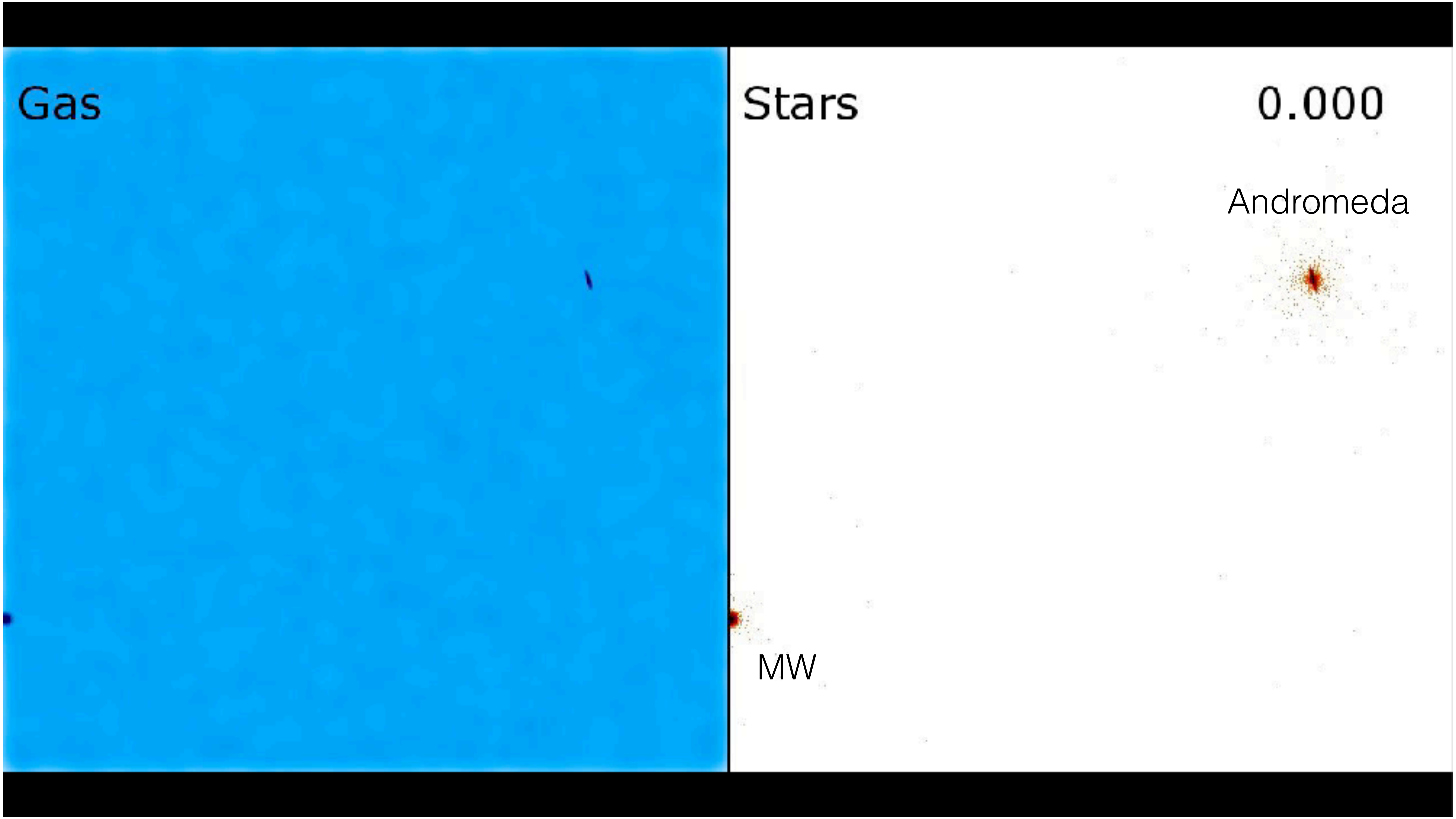


Figure 8. The separation between Andromeda and the MW during the course of their merger. Our fiducial model in red is compared to a case with no intragroup medium (dark matter + gas) in blue. Dynamical friction on the diffuse medium shortens the MW/M31 coalescence time by a factor of a few. The present time is 5 Gyr after the start of the simulation.

galaxies can merge absent d.f. (but more slowly) because tidal forces can transfer orbital energy into internal energy of the galaxies

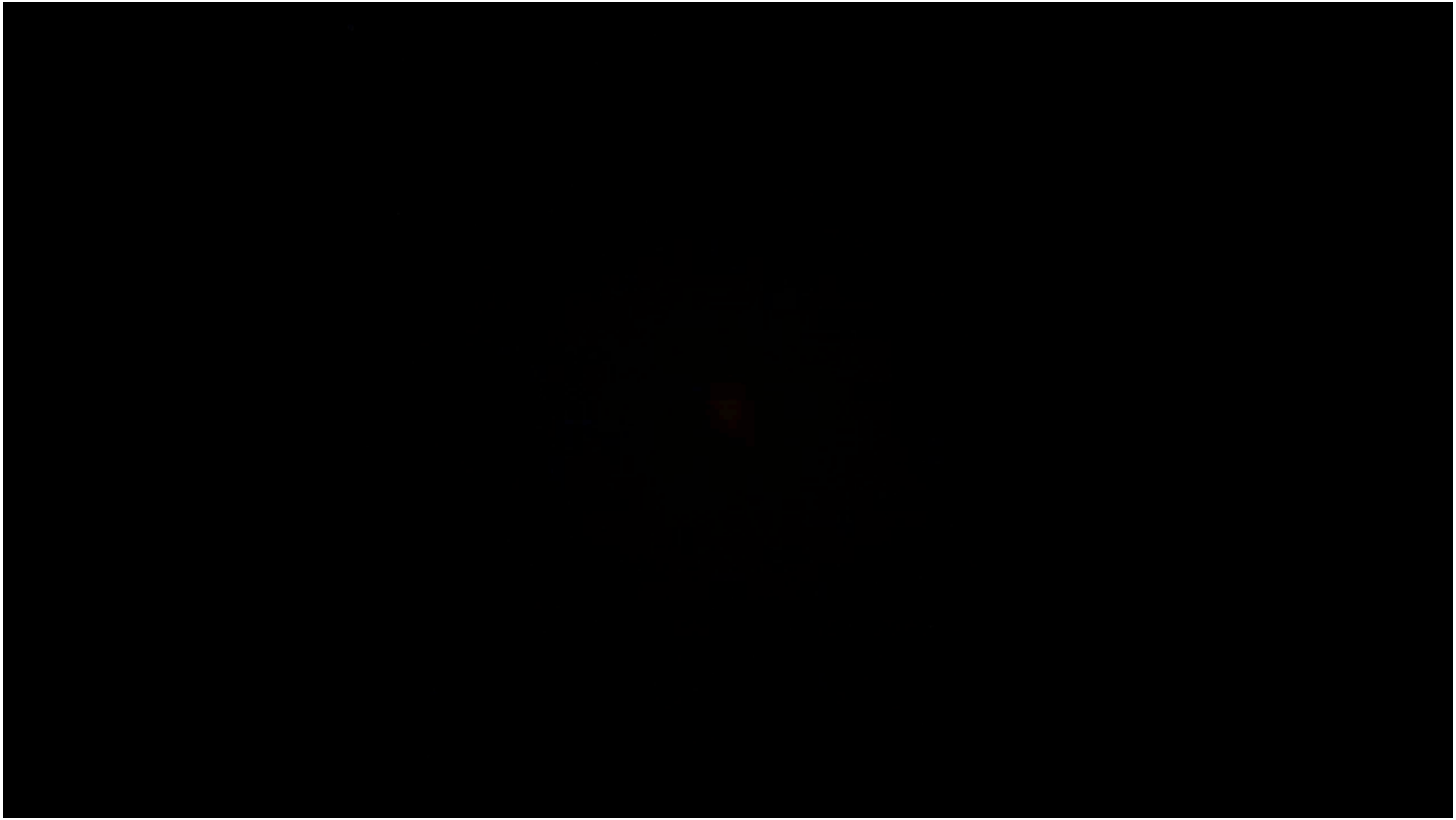
Cox & Loeb 08

Elliptical galaxy formation in MW-Andromeda merger



Cox & Loeb 08

Better animation of formation of ellipticals by major mergers of two disk galaxies



Blue=young stars
Red=old stars

Viz credit:Jonsson

Major mergers are relatively common

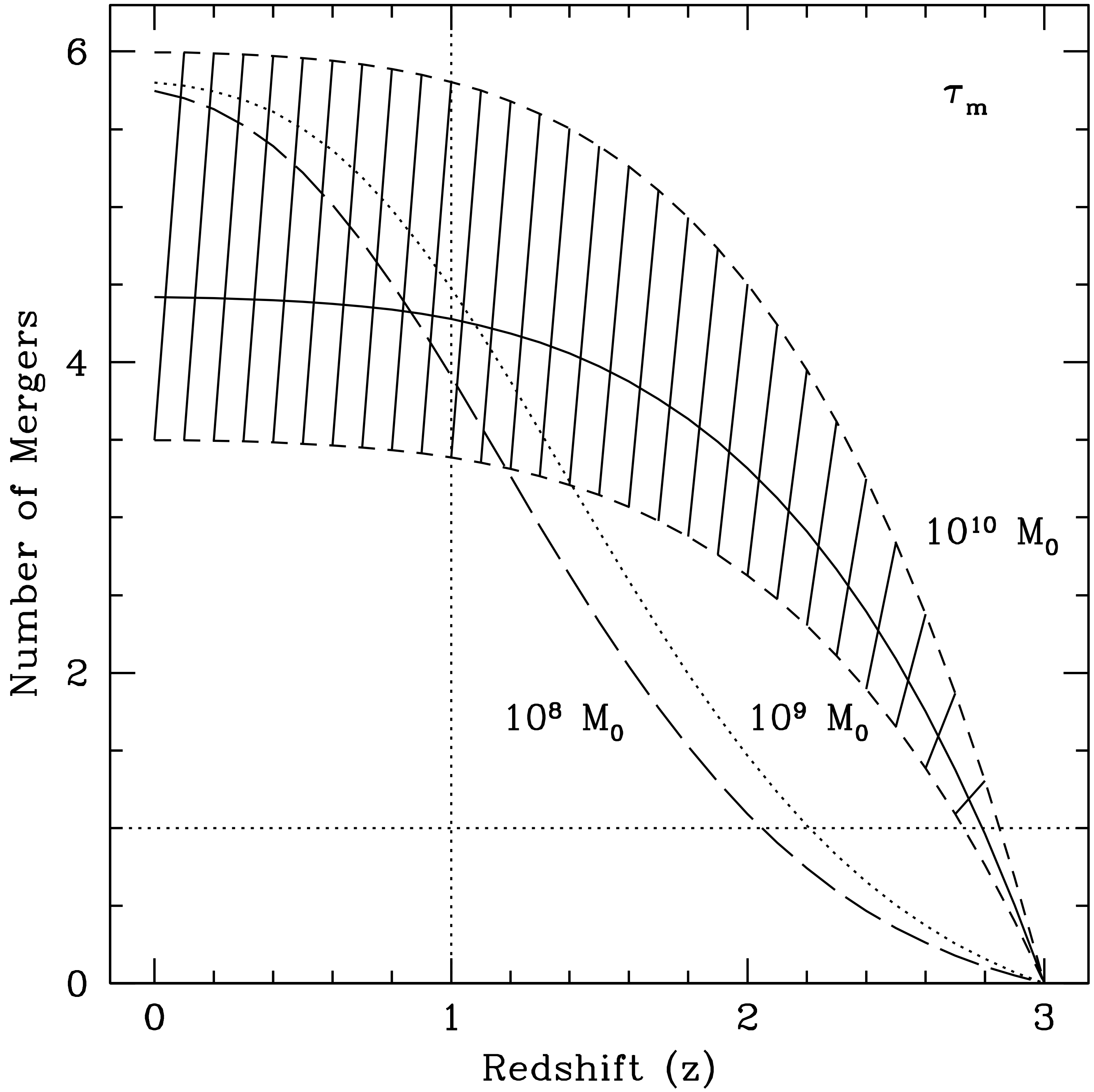


FIG. 6.—Cumulative number of major mergers (1:3 or lower mass ratios) for galaxies starting from $z = 3$ for systems with different initial stellar masses. The solid line shows the evolution in the cumulative number of mergers for an average galaxy with an initial mass of 10^{10} $M_{\odot}$, with the hatched region showing the 1 σ range of possible outcomes. This 1 σ range includes uncertainties in the merger timescales as well as uncertainties in the measured merger fractions. For lower mass galaxies, the number of mergers is shown as the dashed line for systems with $M_* > 10^8$ $M_{\odot}$ and the dotted line for systems with $M_* > 10^9$ $M_{\odot}$.

Conselice 06

Galactic bridges & tails as relics of close encounters

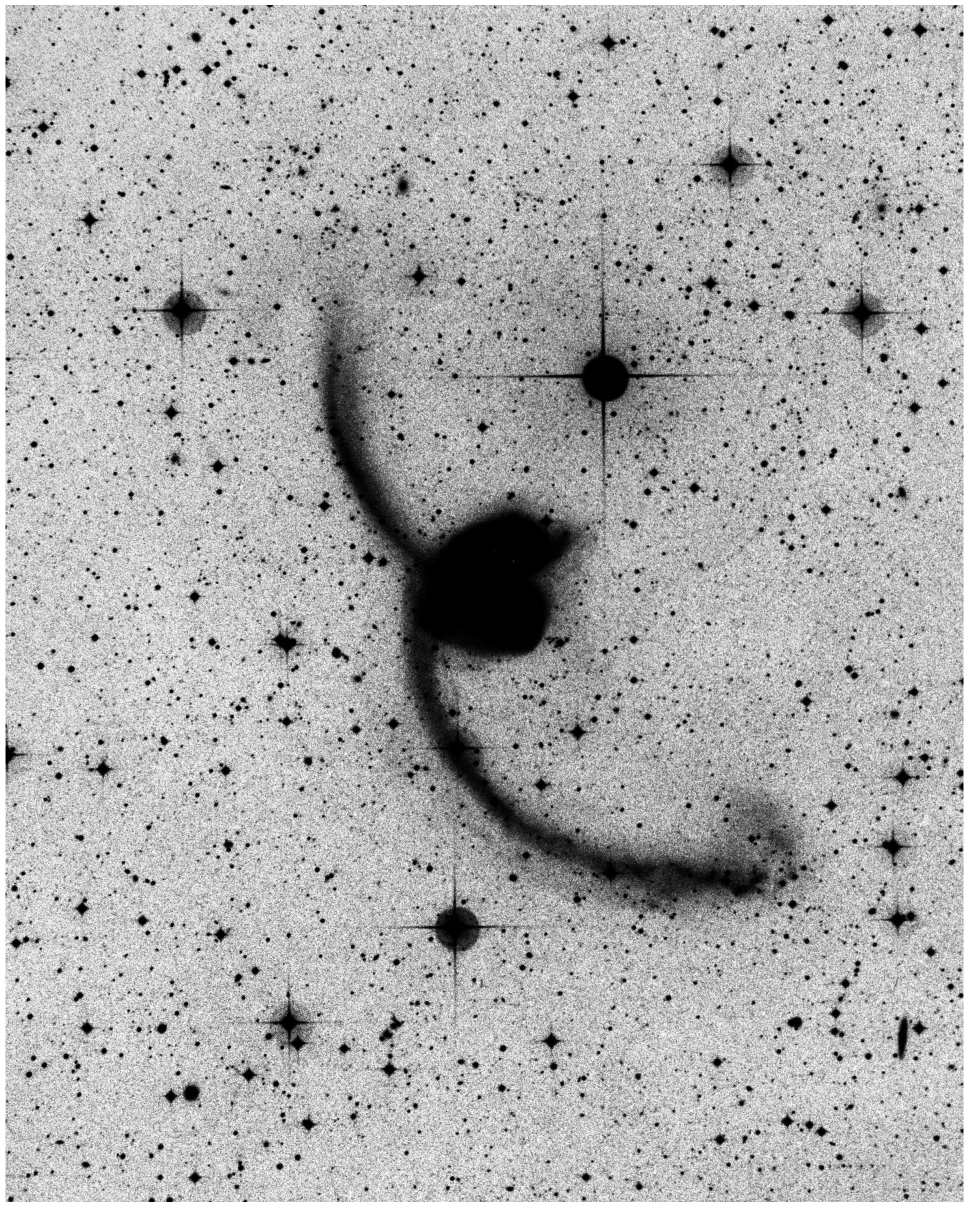


Figure 8.13 The interacting galaxies NGC 4038 and NGC 4039, the "Antennae." This is an overexposed image to emphasize the low surface-brightness tidal tails. The distance from the overlapping blobs at the center to the bright star above and to the right of them is 40 kpc. Courtesy of D. F. Malin and the Anglo–Australian Telescope Board.

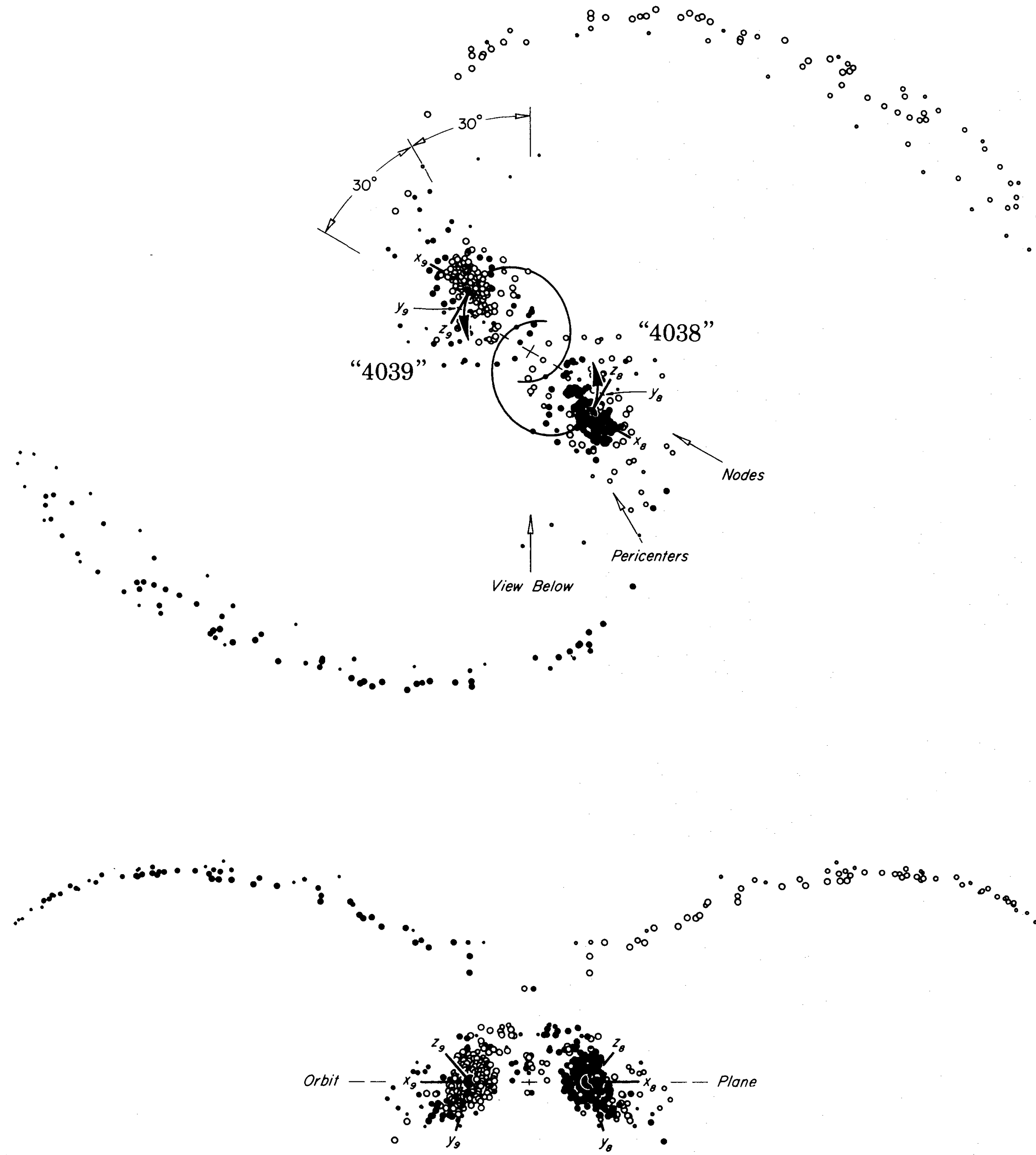
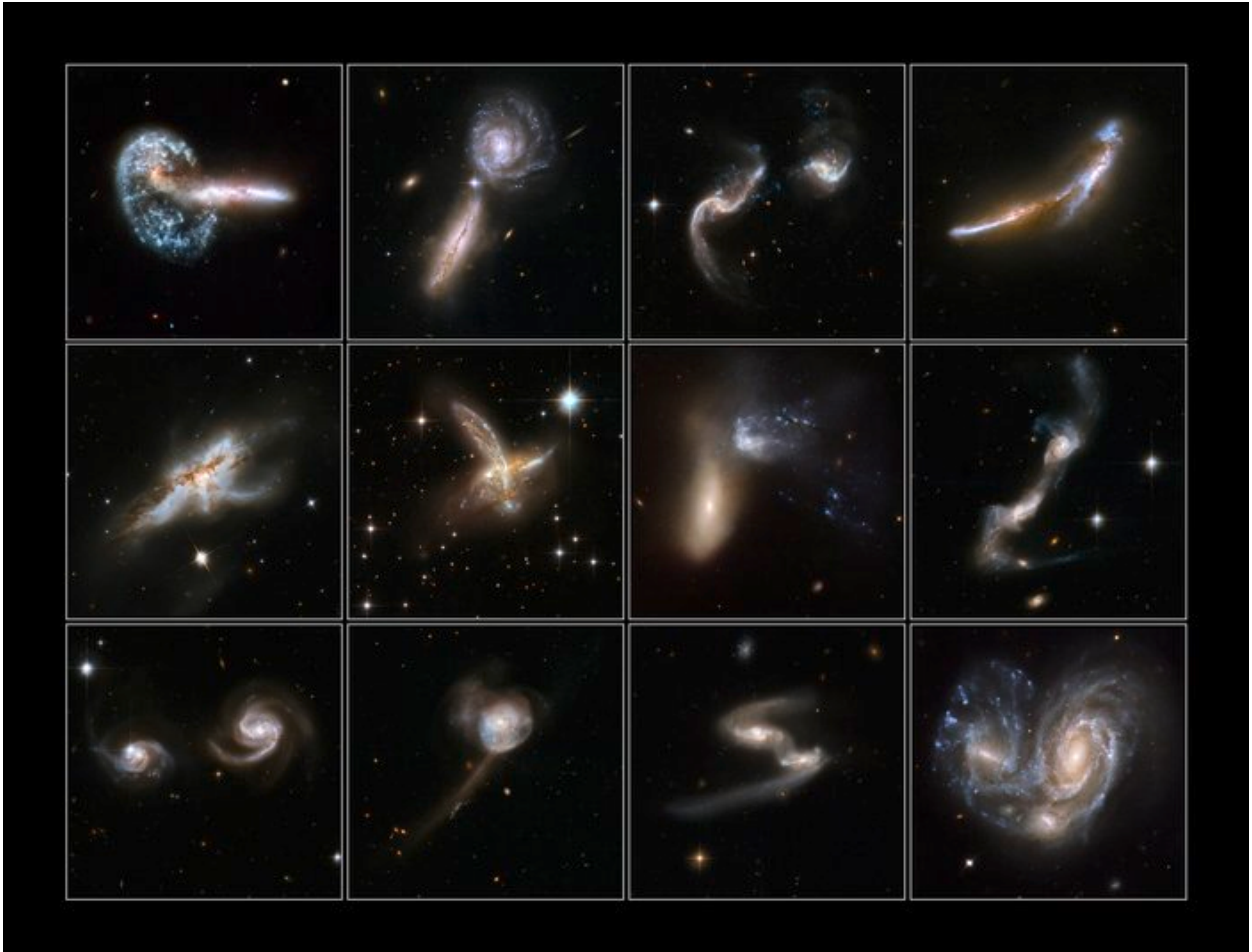


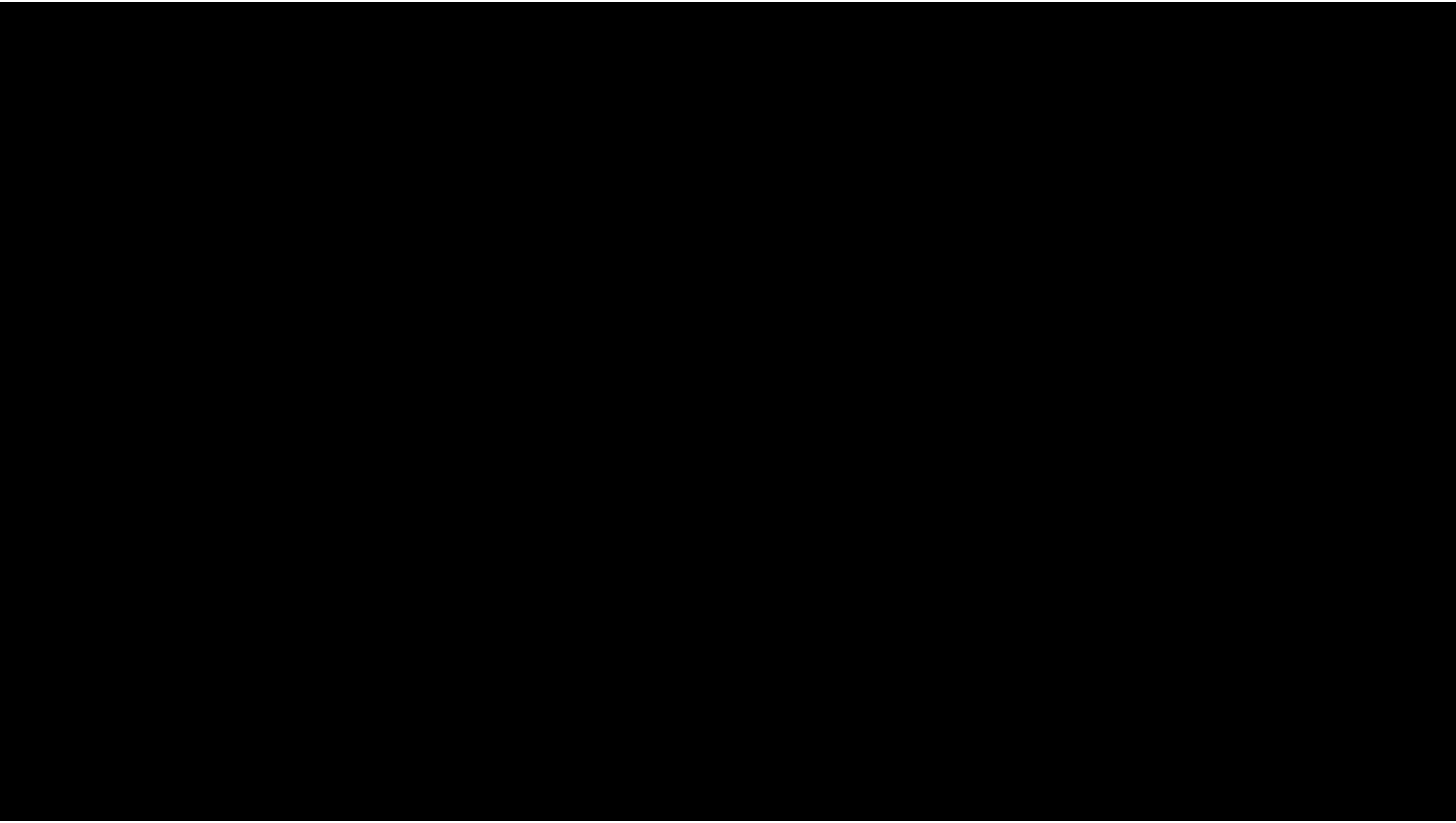
Figure 8.14 A model of the NGC 4038/4039 pair by Toomre & Toomre (1972). Reproduced by permission of *The Astrophysical Journal.*

Toomre & Toomre 72 explained features of many observed 'peculiar galaxies' in encounters of two point masses + tracer particles

Interacting galaxies observed by HST

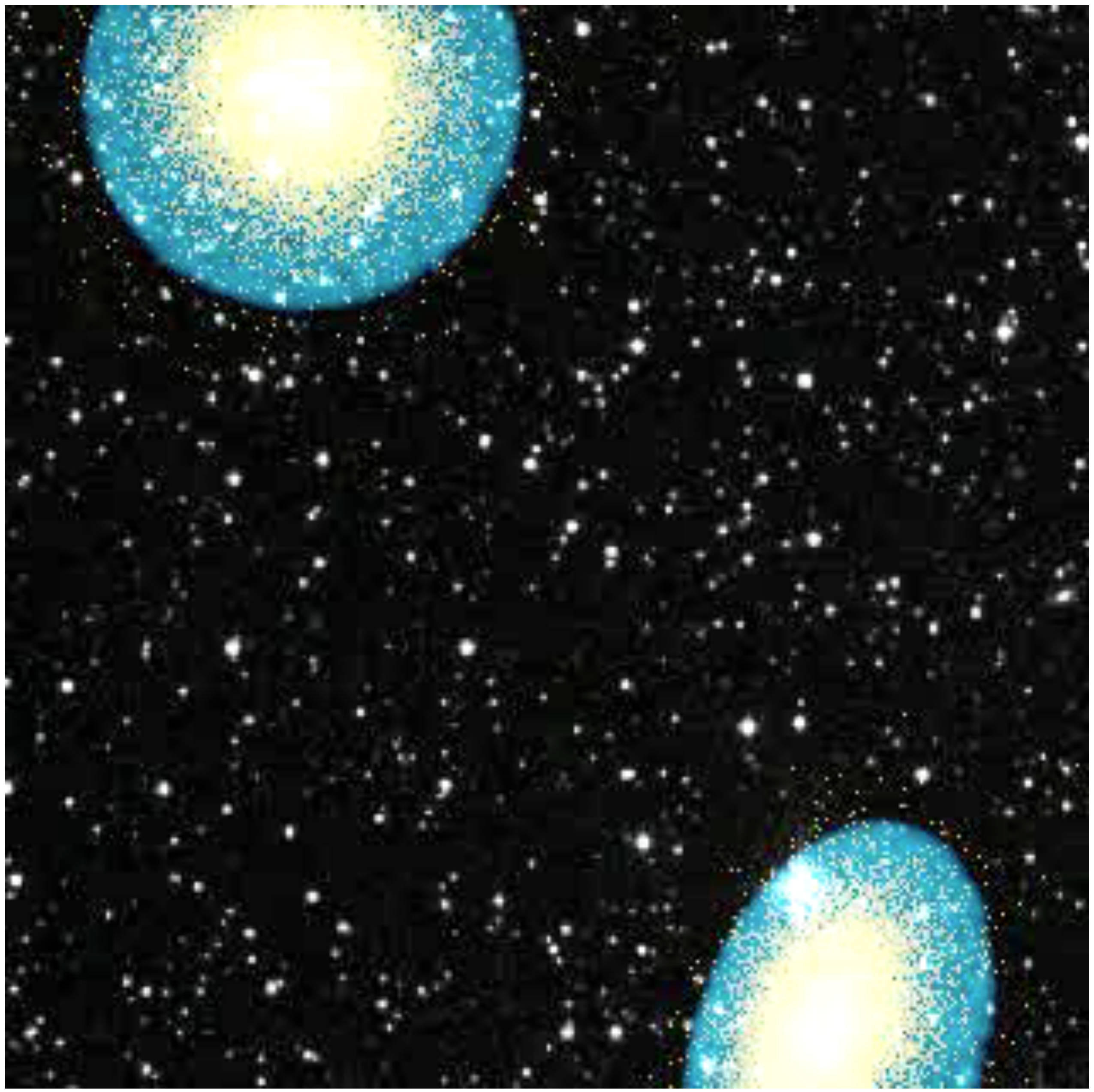


Matching peculiar galaxies with stages of mergers in modern simulation



Toggling between galaxy merger simulation and HST images

Angular momentum transport and the funneling of gas into the nucleus in major mergers



Blue=gas
Yellow=stars

Strong asymmetries induced by tidal forces

+

offsets between gas & stars (stellar orbits can cross but gas orbits can't)

$\Longrightarrow$ strong gravitational torques efficiently drive gas to nucleus ($\lesssim$100 pc), SFR enhanced by up to factor ~100

Mihos & Hernquist 96

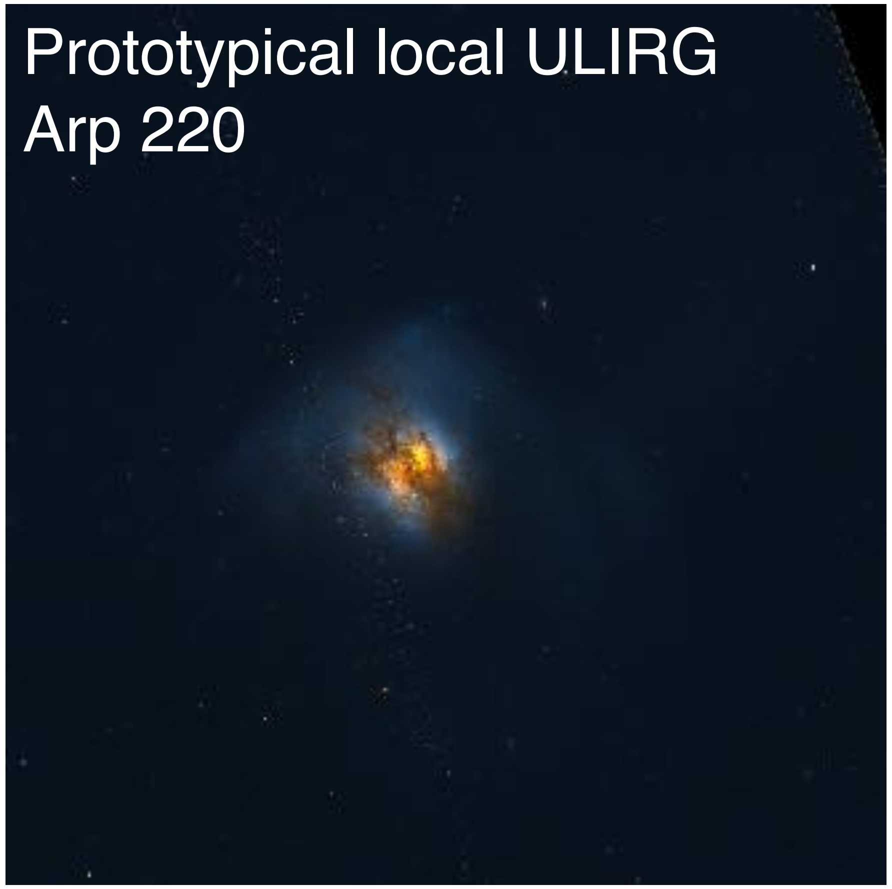
(Ultra-)luminous infrared galaxies

Starburst galaxies:

- LIRG: $L_{\rm IR}>10^{11}$ $L_{\rm sun}$
- ULIRG: $L_{\rm IR}>10^{12}$ $L_{\rm sun}$

In the local Universe (but not necessarily at high redshift), ULIRGs appear always associated with signs of a recent major merger (shells, tidal tails, complex velocity fields, …)

Most ULIRGs have non-thermal nuclear spectra indicative of an AGN excitation source (rather than star formation)



The major “merger sequence”

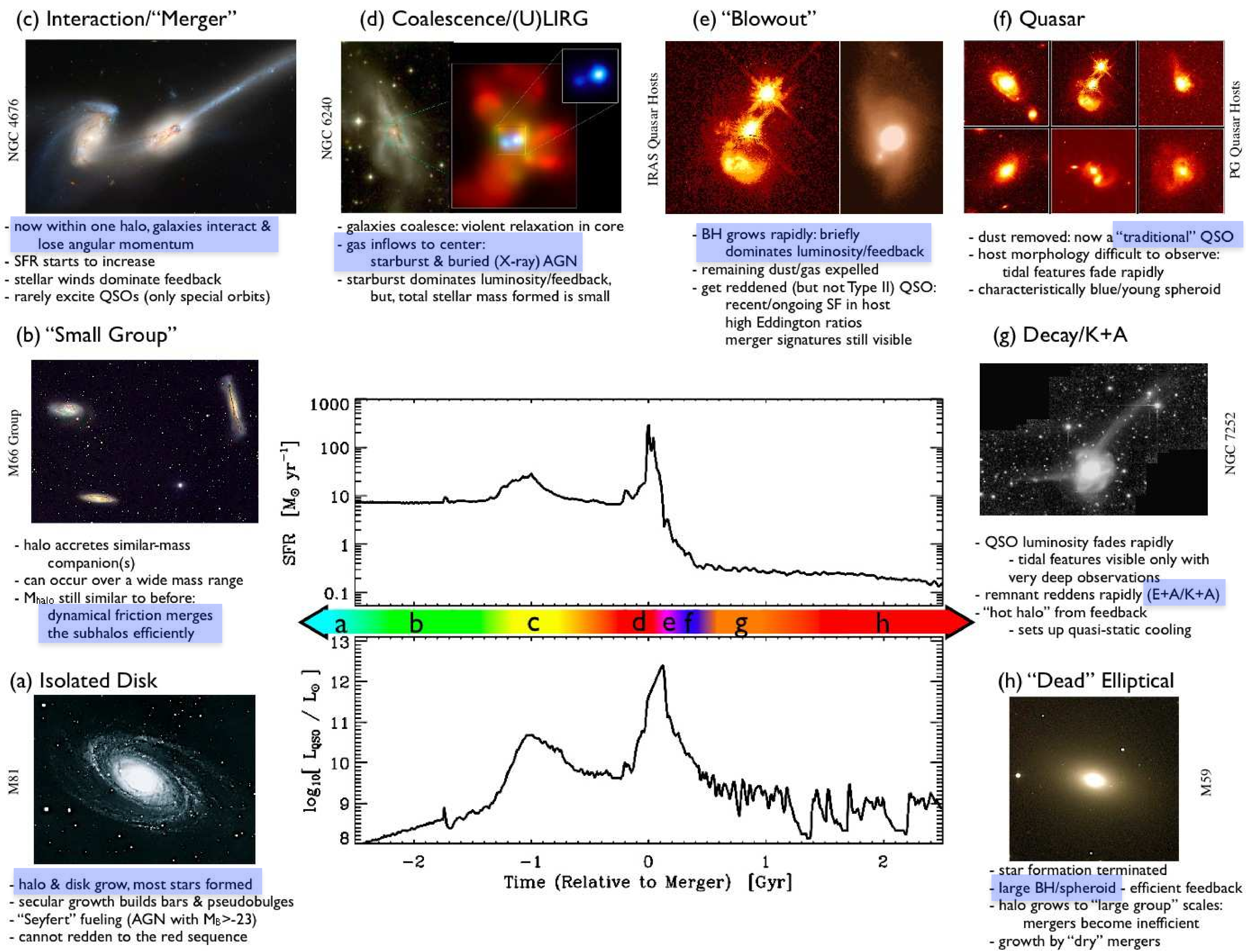


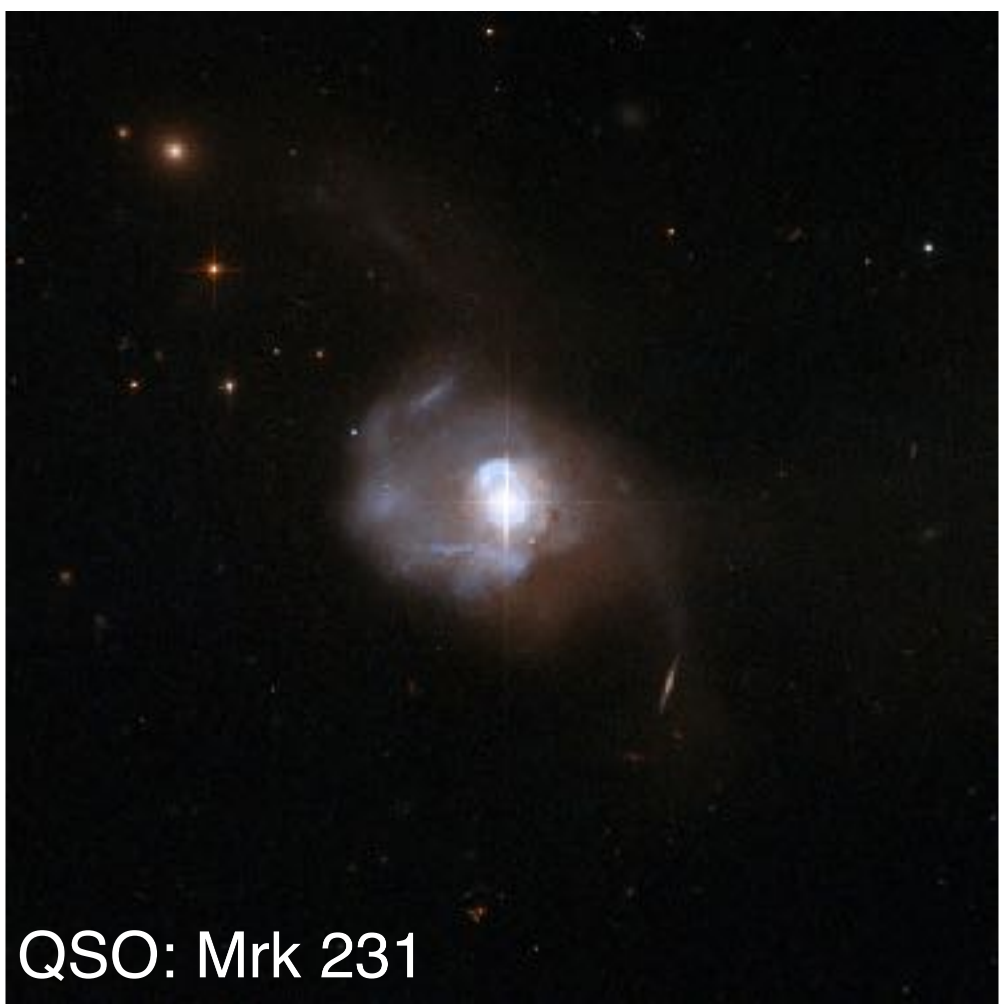
FIG. 1.— An schematic outline of the phases of growth in a “typical” galaxy undergoing a gas-rich major merger. *Image Credit:* (a) NOAO/AURA/NSF; (b) REU program/NOAO/AURA/NSF; (c) NASA/STScI/ACS Science Team; (d) Optical (left): NASA/STScI/R. P. van der Marel & J. Gerssen; X-ray (right): NASA/CXC/MPE/S. Komossa et al.; (e) Left: J. Bahcall/M. Disney/NASA; Right: Gemini Observatory/NSF/University of Hawaii Institute for Astronomy; (f) J. Bahcall/M. Disney/NASA; (g) F. Schweizer (CIW/DTM); (h) NOAO/AURA/NSF.

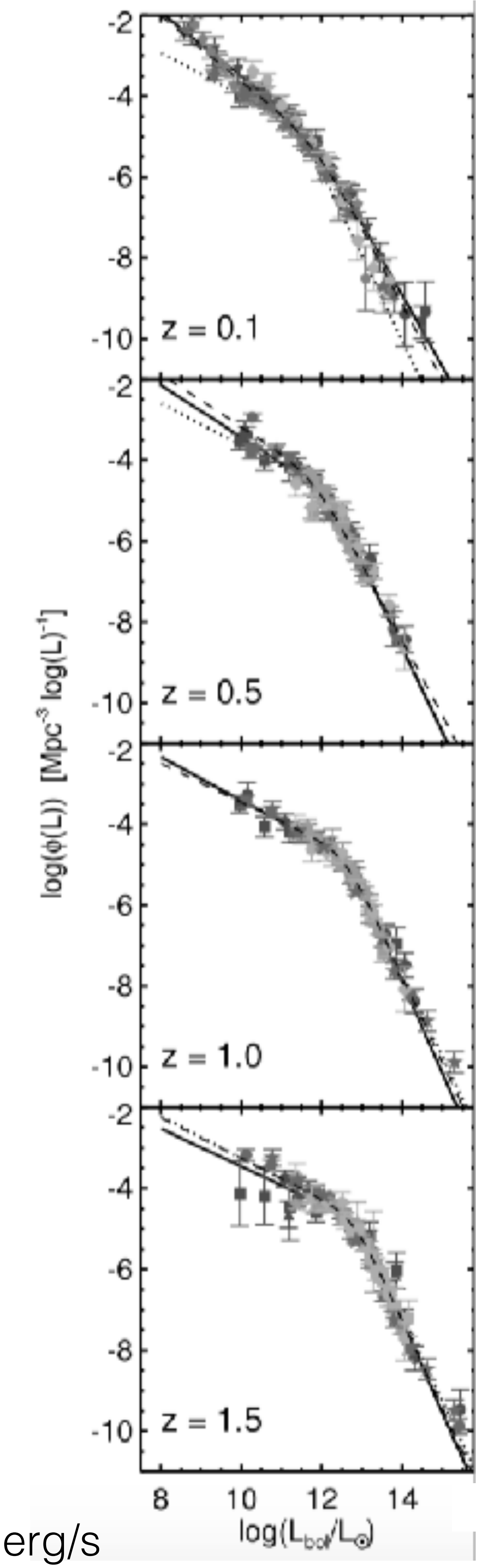
Hopkins+08, following Toomre & Toomre 72, Sanders+88

The AGN luminosity function: Quasars vs. Seyferts

AGN luminosity function is broad

- "Quasars"/"QSOs" refer to the most luminous AGN
- Lower-luminosity AGN referred to as "Seyferts"





AGN bolometric luminosity function from Hopkins+07 compilation; 1 L_{sun}=3.8×10^{33} erg/s

Secular AGN fueling in Seyferts

Low-luminosity Seyferts typically *not* associated with mergers. Instead: weaker galaxy-galaxy interactions or secular fueling by bars, spirals, …

Type I: nucleus directly visible in the optical

Type II: AGN nucleus obscured by dusty "torus," AGN inferred from off-nuclear recombination lines or radio, X-rays that pass through the torus