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GALAXY INTERACTIONS: OVERVIEW

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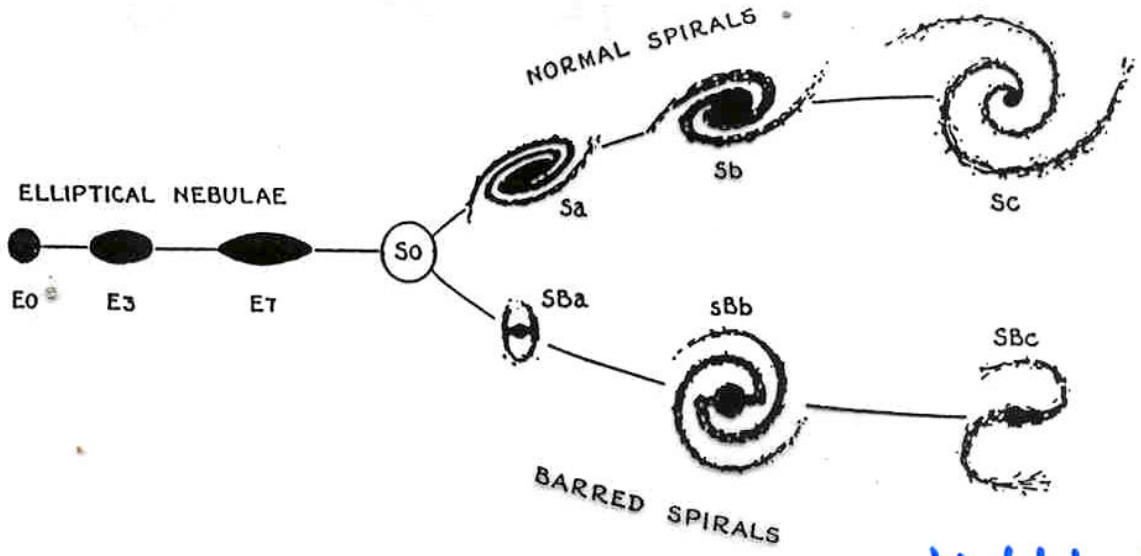
Introduction

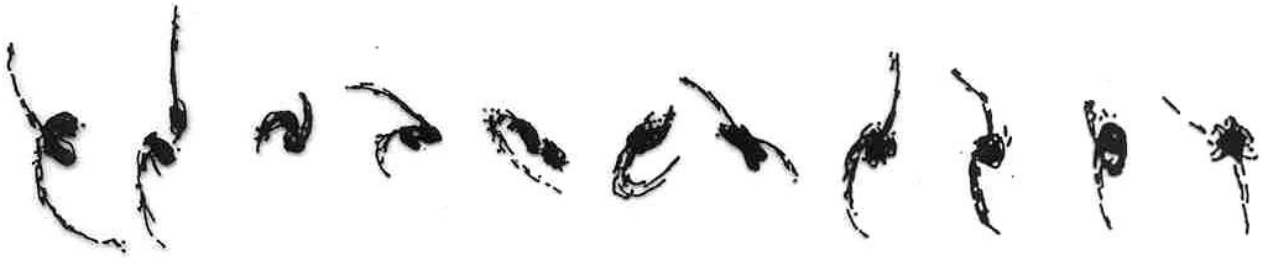
1. **Interactions in the Local Group**
2. **Damaged Disks**
3. **Ellipticals from Wrecked Disks**
4. **I/A at High z and in Clusters**

Support: NSF (**AST**); NASA (**StScI**); Carnegie



Hubble 1936

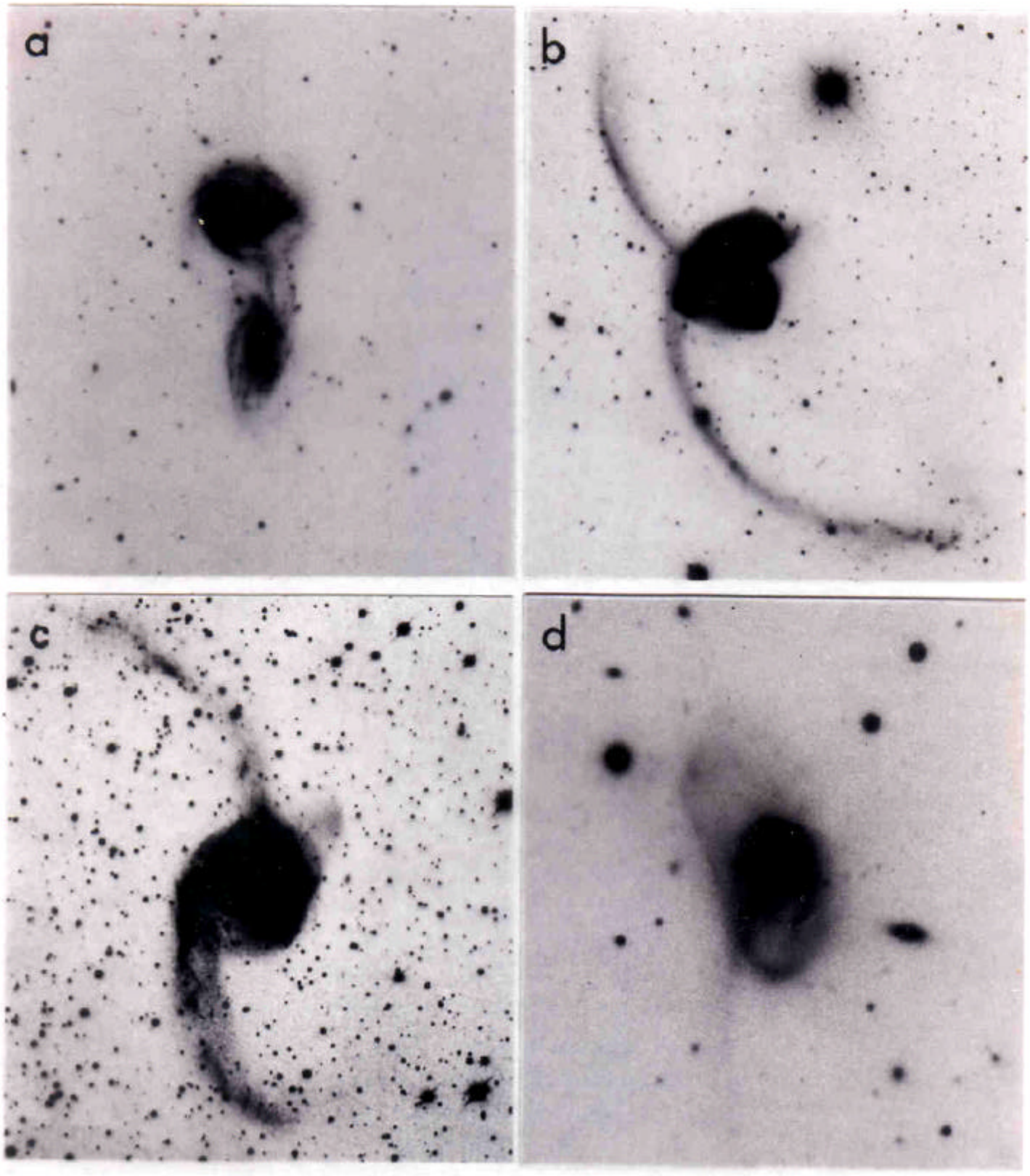
- Why a dichotomy of shapes?
- Meaning of Hubble's morphological sequence?



Toomre 1977

- What dynamical processes drive galaxy evolution?
- Relative importance of interactions, minor mergers, & major mergers in shaping various types of galaxies?

Ellipticals from Wrecked Disks

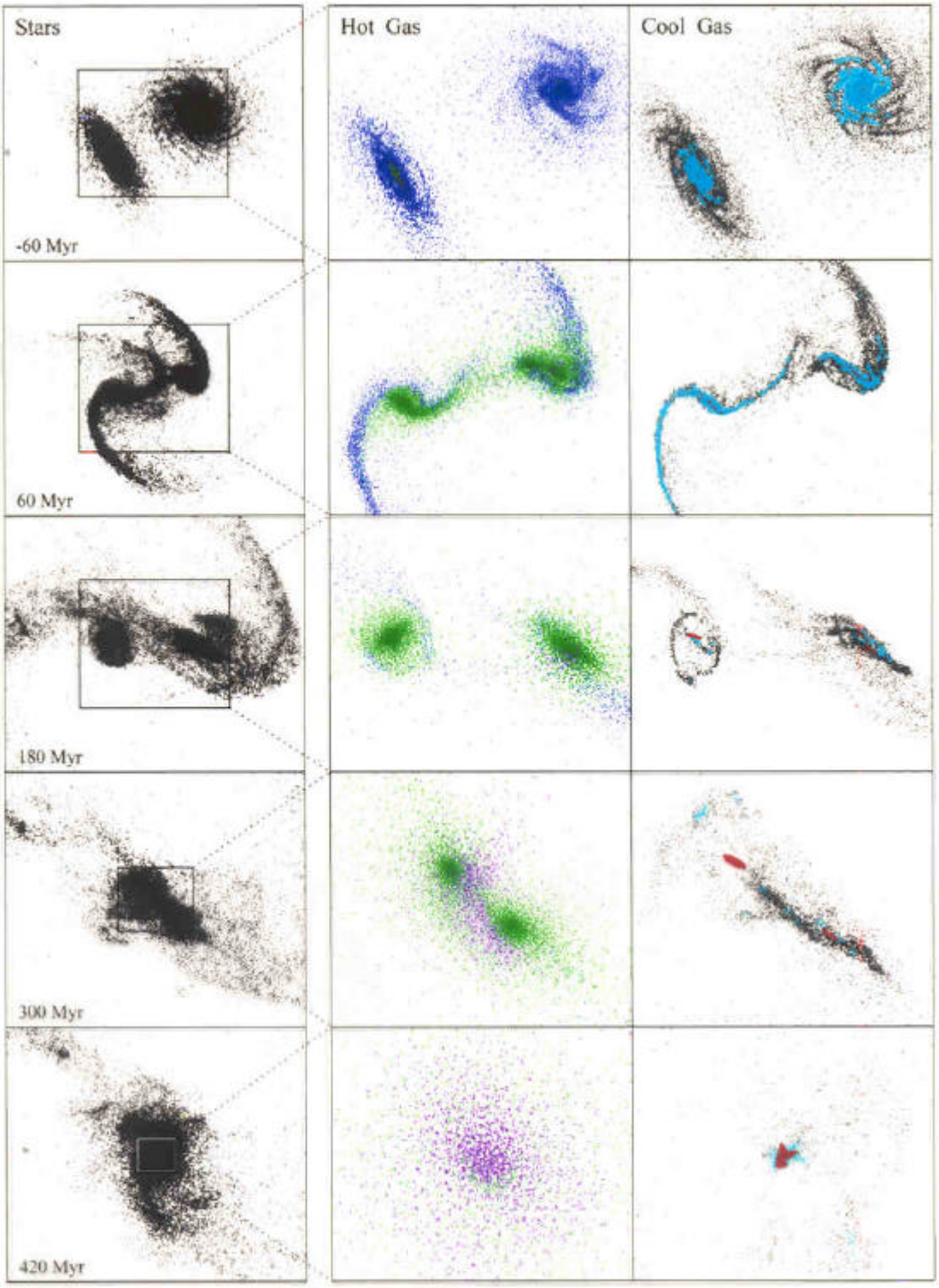


NGC3921, proto elliptical

Barnes (1999)

Simulated Merger of 2 Gas-Rich Disk Galaxie

Stars Hot Gas Cool Gas



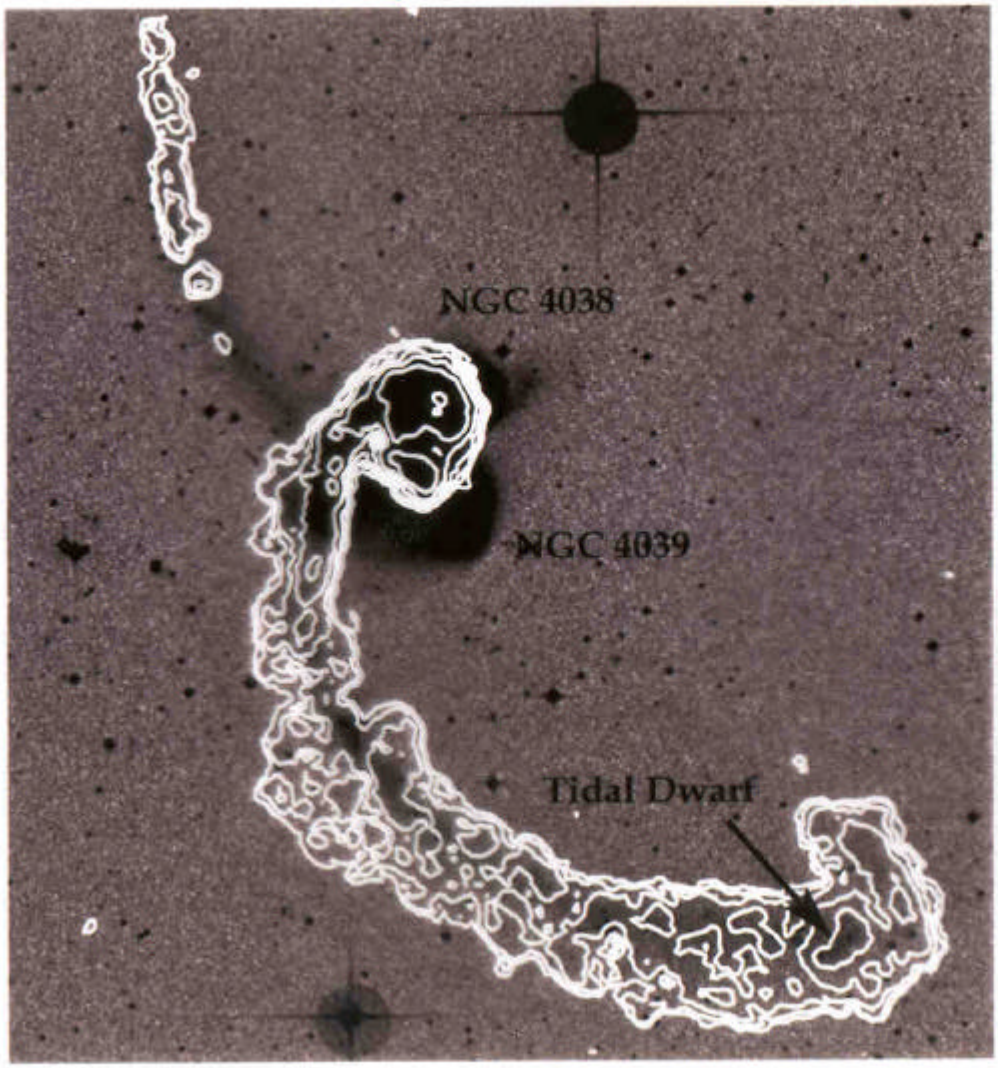
Pericenter at t=0

Hibbard et al (1999)

Signatures of Interactions

Morphological

Kinematic



Optical & HI tails in NGC4038/39

Position-velocity diagram

N 4038/39

N

1" = 1 kpc

A = 19 Mpc
H_0 = 75

Whitmore et al. (1999)

1.

INTERACTIONS AND MERGERS IN THE LOCAL GROUP

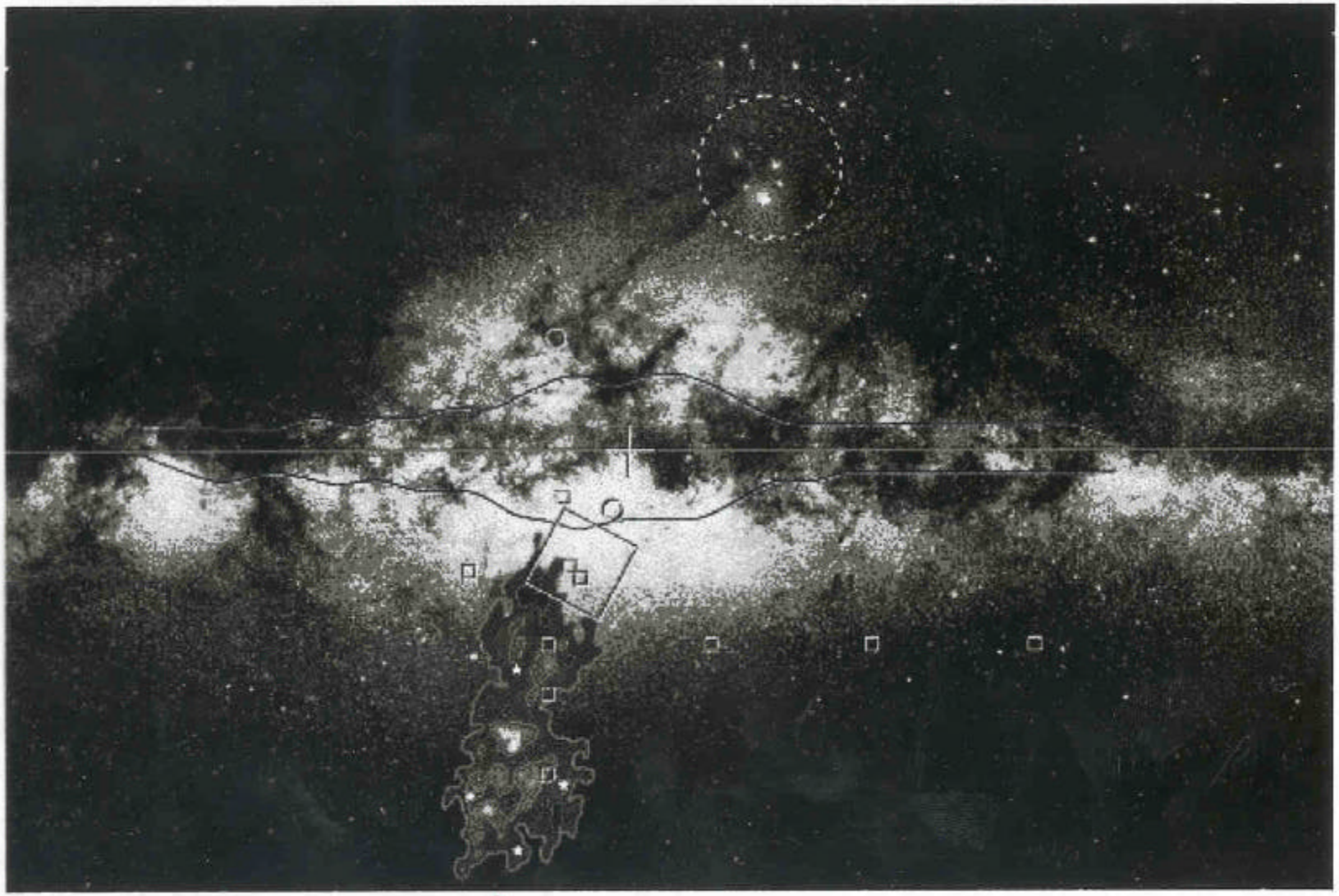
1. **Evidence in Milky Way:** Warp; retrograde orbits of stars and globular clusters; accretion of **Sagittarius Dwarf**; "spaghetti halo"?

2. **The Magellanic Stream**

3. **M 31 and M 32**

4. **M 31 and us**

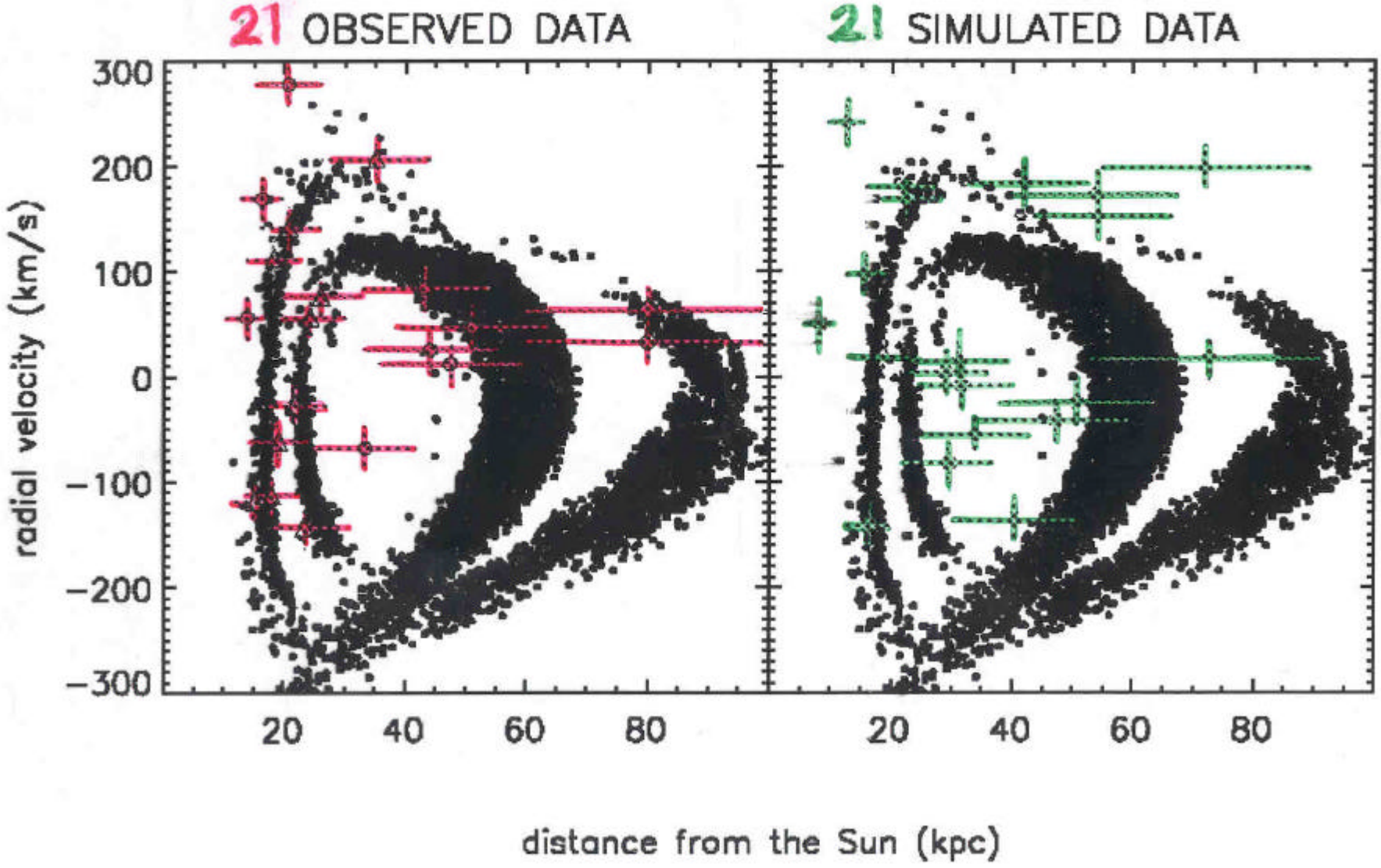
Sagittarius Dwarf (Ibata, Gilmore, & Irwin 1994)



Dohm-Palmer et al. (2001)

• Helmi & White model

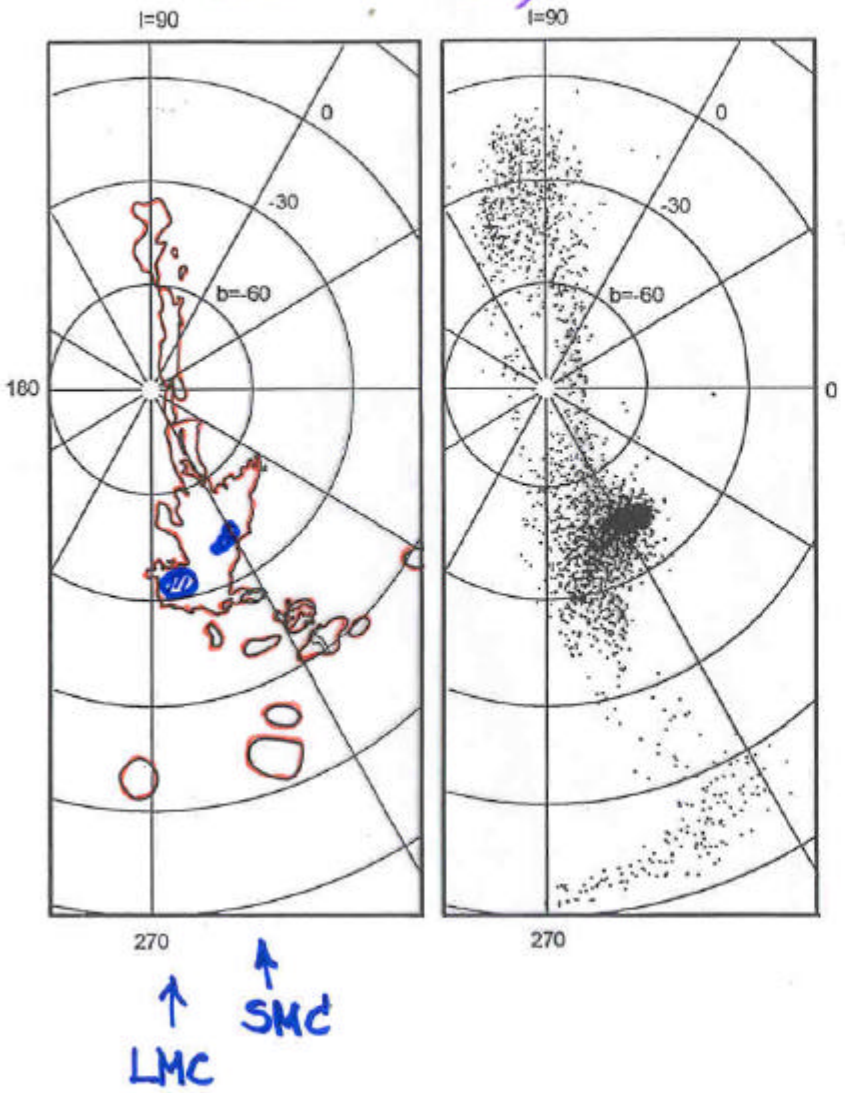
Velocities in Tidal Stream at 60° from Sgr I



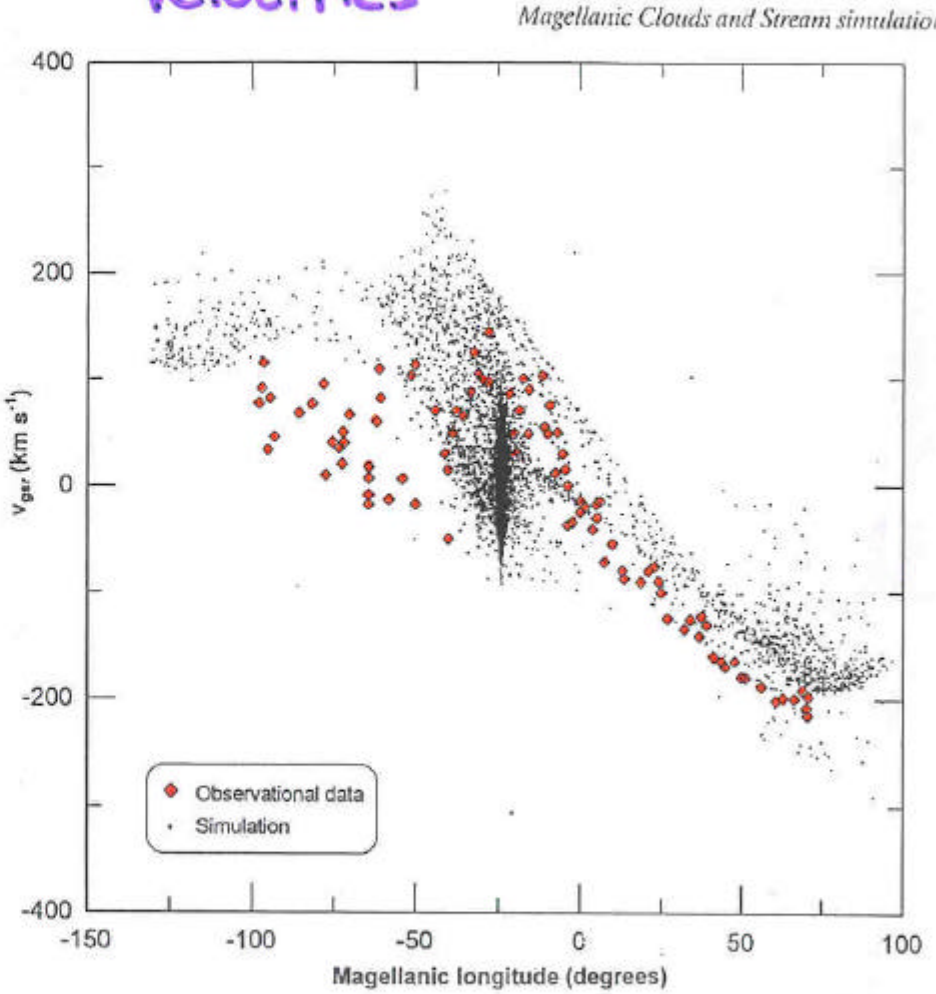
Gardiner & Noguchi '96

Magellanic Stream: Comparison Simulations – Observations

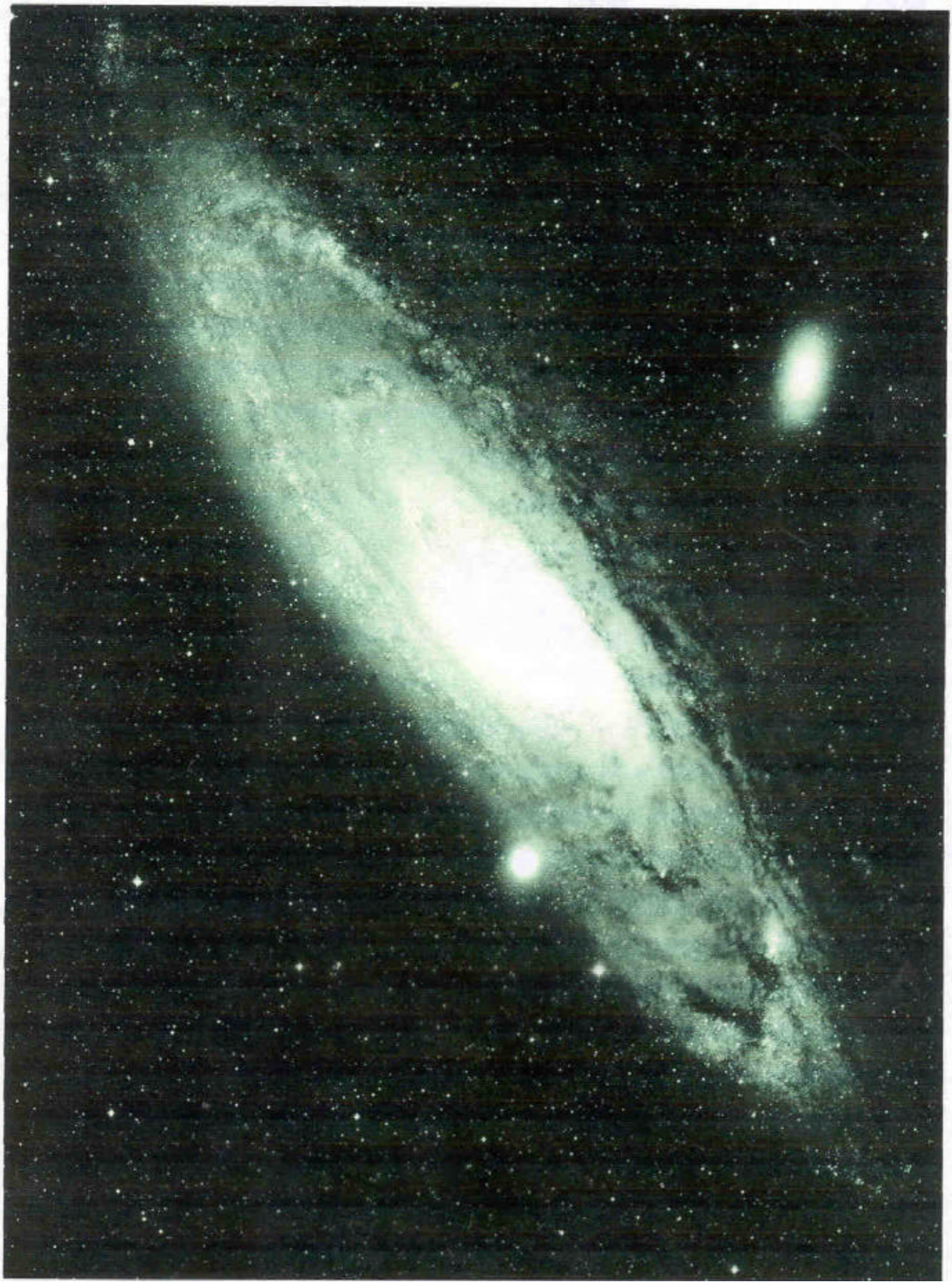
View on Sky



Velocities



M31 and Satellites (Sandage 61)



2.

DAMAGED DISKS

Central issues:

- **How fragile are galaxy disks?** (Tóth & Ostriker 92; Walker+96; Aguerri+01)
- **Can bulges form through minor mergers?** (Aguerri+01: "yes")
- **What fraction of bulges formed in this manner?**

Current status:

1. **Disks with gas are not as fragile as once thought**
2. **Minor mergers do occur in disk galaxies and seem to move them toward earlier Hubble types**
3. **Fraction of bulges built through mergers remains unknown; are there various sequences: disk first, bulge first, and/or mixed?**

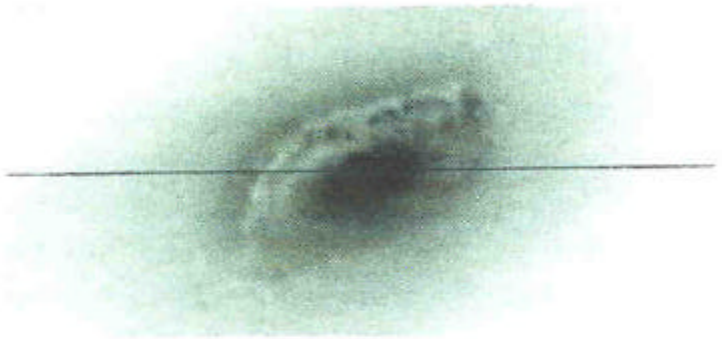
Yun, Ho, & Lo (1994)

Polar Ring Galaxy NGC4650A

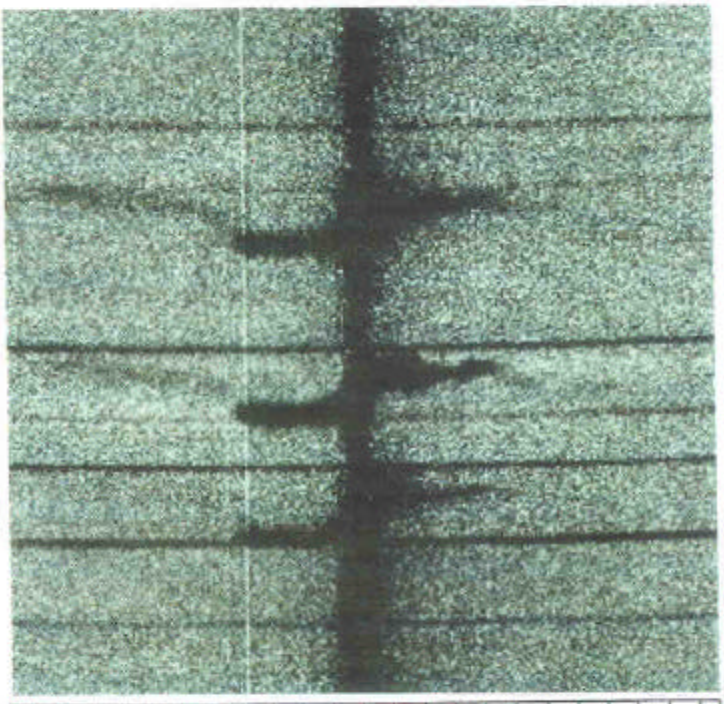
Rubin 94

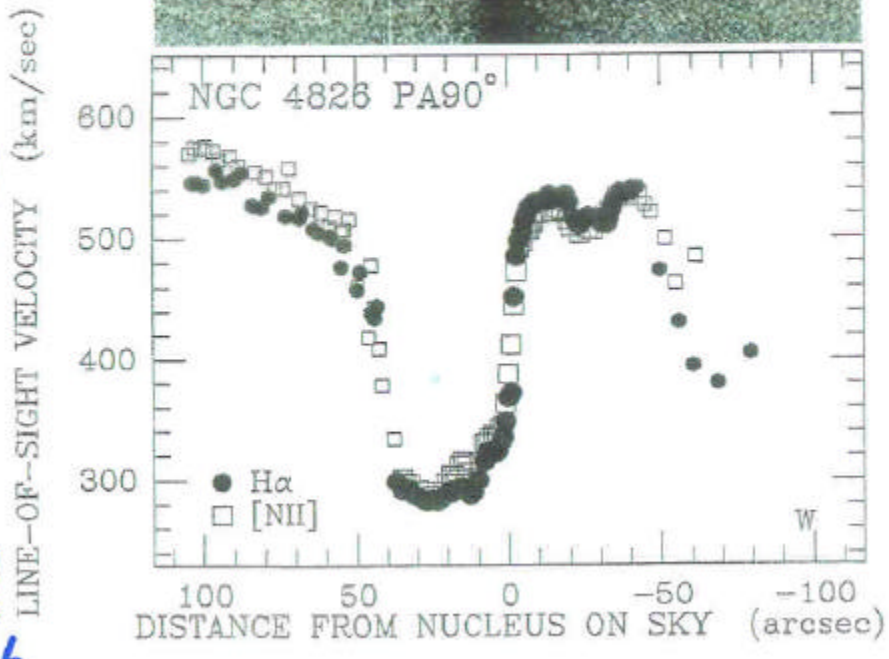
NGC 4826 : Optical Velocities (Sab)

Slit position



Optical spectrum [NII] Hα [NII]





- Velocity reversal in gas is steep
- Stars corotate with inner gas
- In transition reg., evidence for gas infall at ~100 km/s

COUNTERROTATION IN DISK GALAXIES

Counterrotating Gas

S0: **In 33 S0's: 14 co-, 3 skewed-, 9 counter-rotate;**
$\Rightarrow$ **>80% external origin** (Bettoni$^+$91; Bertola$^+$99)

Sa: **In 4 Sa's: Gas decoupled from stars** (Haynes$^+$00)

Sab: **NGC 4826: two counterrotating gas systems**
(Braun$^+$92, 94; Rubin 94)

Counterrotating Disk Stars

S0: **NGC 4550: stars rotate 50/50% pro/retrograde**
(Rubin$^+$92; Rix$^+$92; Kuijken$^+$96)

Sb: **NGC 7217: stars rotate 70/30% pro/retrograde**

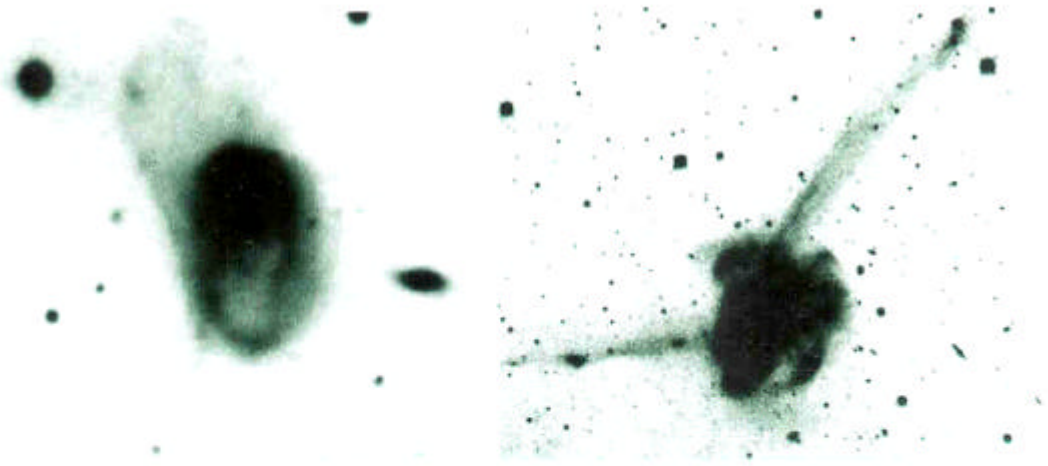
Counter/Orthorotating Bulges!

Sa: **NGC 4698: orthorotating bulge** (Bertola$^+$99)

Sb: **NGC 7331, 2841: counterrotating bulges**
(Prada$^+$96, 99)

3.

ELLIPTICALS FROM WRECKED DISKS



SIMILARITIES: NGC 3921 & 7252 – ELLIPTICALS

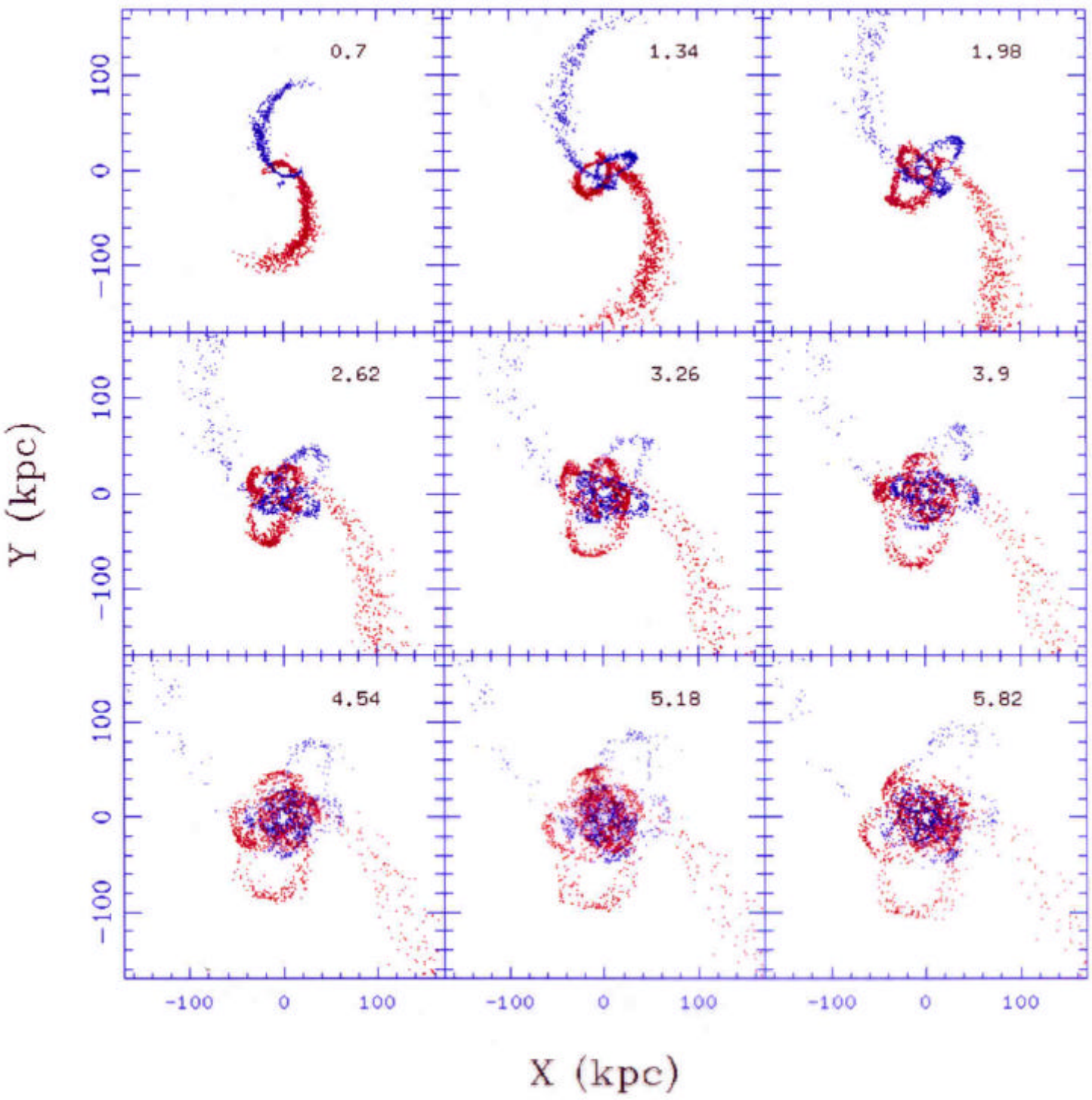
- Single main bodies of $M_V \approx -22.0$ with $r^{1/4}$-type ligh distributions ($\Rightarrow$ violent relaxation)
- Power-law cores, central lumin. density $>10^3\ L_\odot/pc^3$
- Kinematically decoupled core (NGC 7252)
- $UBVI$ color gradients typical of E's
- Velocity dispersions σ_V fit Faber-Jackson
- Fine structure (shells) from returning tidal material
- "E+A" spectra indicative of b = 10%–30% starbursts
- Globular-cluster populations increased by >40%, ~80

$\Rightarrow$ N3921 & 7252 are 0.5 – 1.0 Gyr old protoellipticals.

TT72: Merger rate suggests that ~1/3 – all E's forme this way.

Hibbard & Mihos 95

Ripple ("Shell") Formation in DD Mergers



→ Prolonged return of tidal material forms loops and ripples for several Gyr.

Jedrzejewski & Schechter 88

Major-Axis Rotation Curves for 2 E's

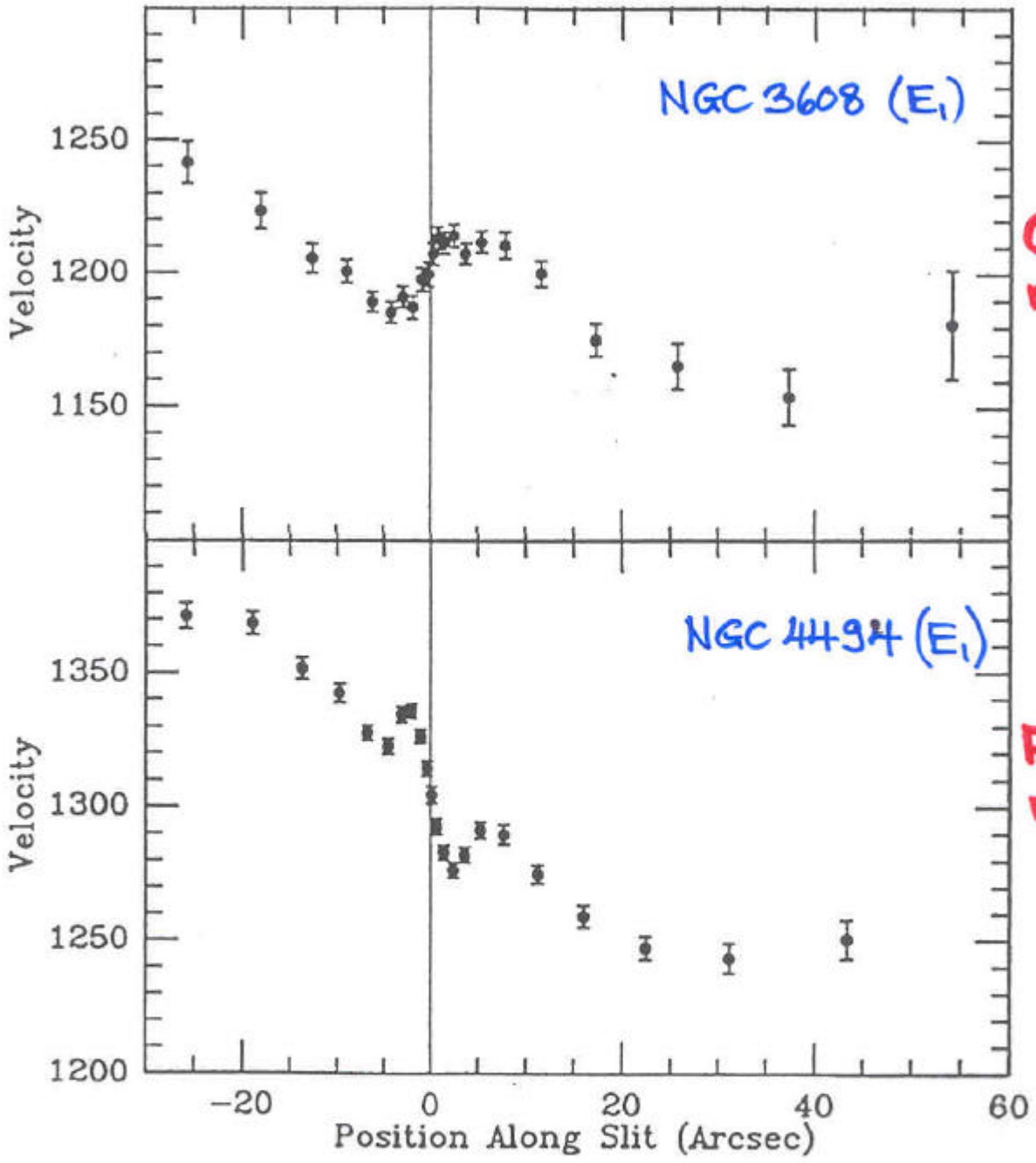


FIG. 7. Stellar velocities as a function of nuclear distance in NGC 3608 (upper) and NGC 4494 (lower) from Jedrzejewski & Schechter (1988). Note that in NGC 3608 the discrete stellar core rotates retrograde; in NGC 4494 it rotates prograde.

(graph assembled by Rubin 94)

NGC 7252 (HST-4, Miller et al. 1997)

~500 candidate clusters $V \leq 26$ mag

32"
10 kpc

(HST)

From Giant Molecular Clouds to Globular Clusters

Dichotomy of Shapes

M100 (Sc)

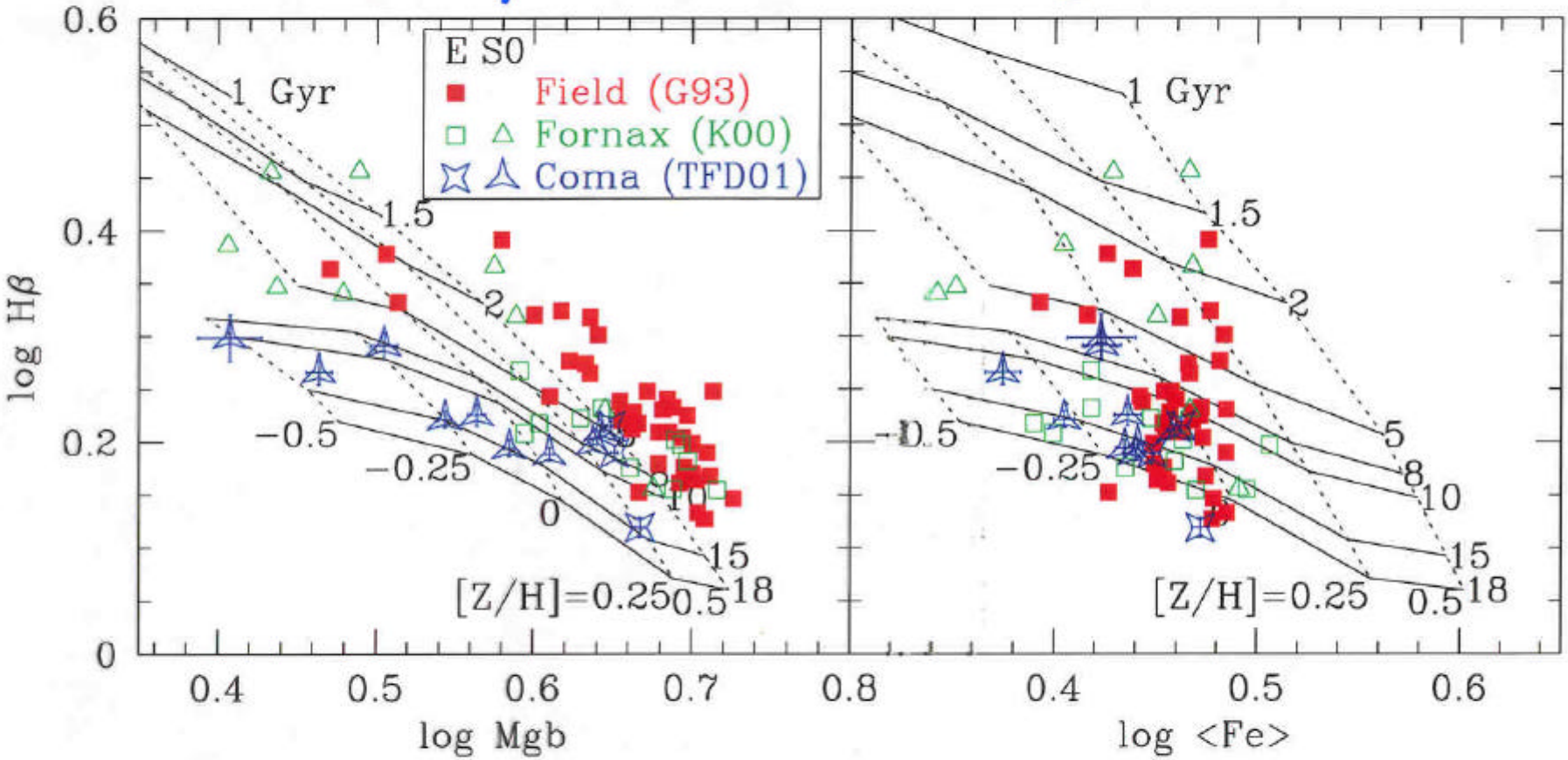
M87 (E0)

D. Malin - AAT

Trager, Faber, & Dressler (2001)

Ages of E+S0 Galaxies

from Hβ (age sensitive) and Mg b, Fe



Results: - Field E have mean-popul. ages of 1.5–18 Gyr

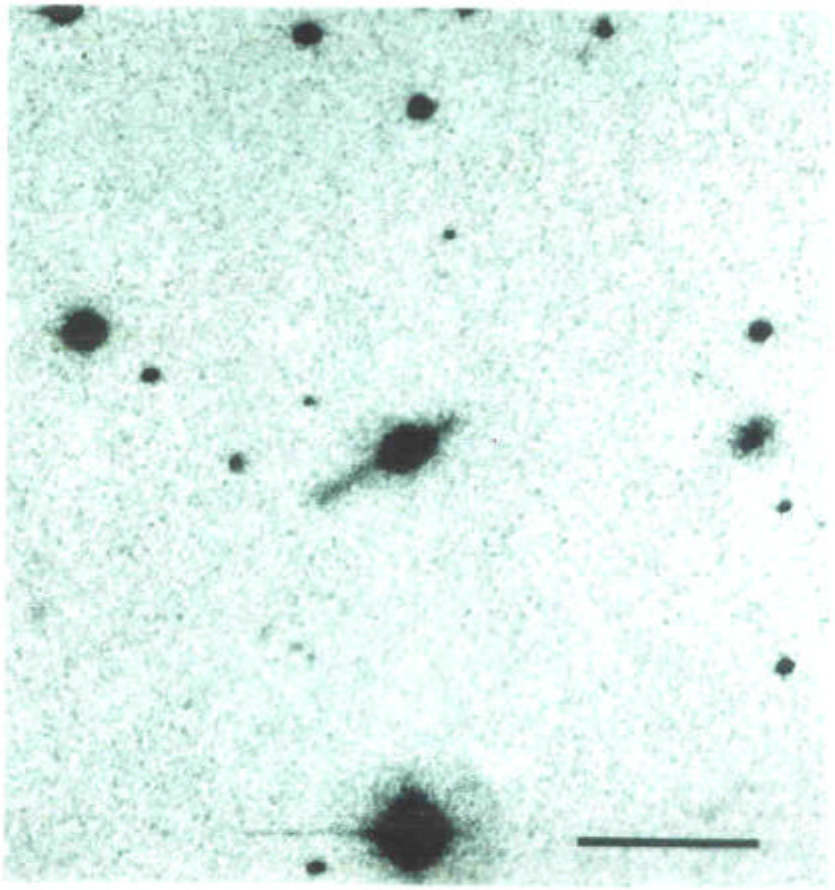
- Coma E+S0 have mean-pop. ages 15–18 Gyr

4.

INTERACTIONS AT HIGH REDSHIFT AND IN CLUSTERS

Stockton + Farnham '91

Recent Merger in QSO OX 169 ($z = 0.21$)

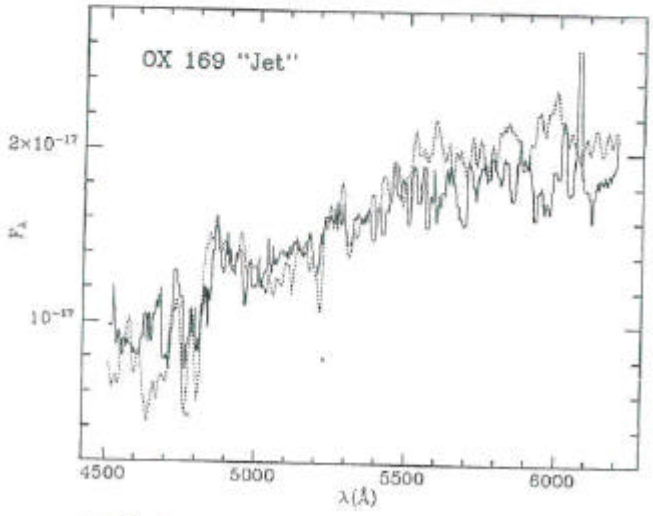


Results:

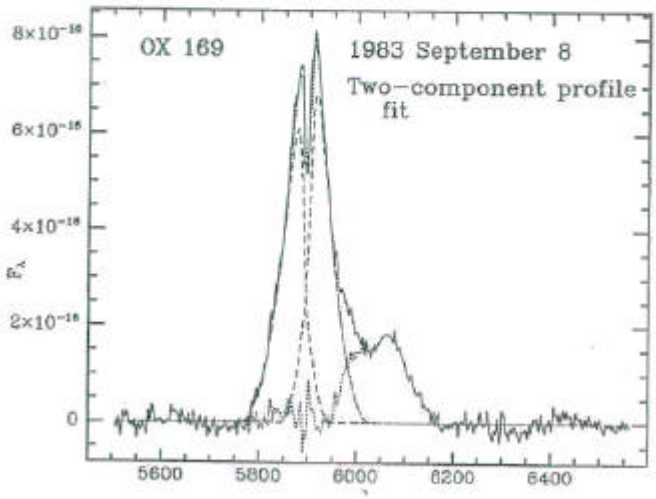
Tidal tail of $l_p \approx 30$ kpc

($H_0 = 75$, $q_0 = 0$)

20″ ≈ 60 kpc



Tail spectrum: Stellar

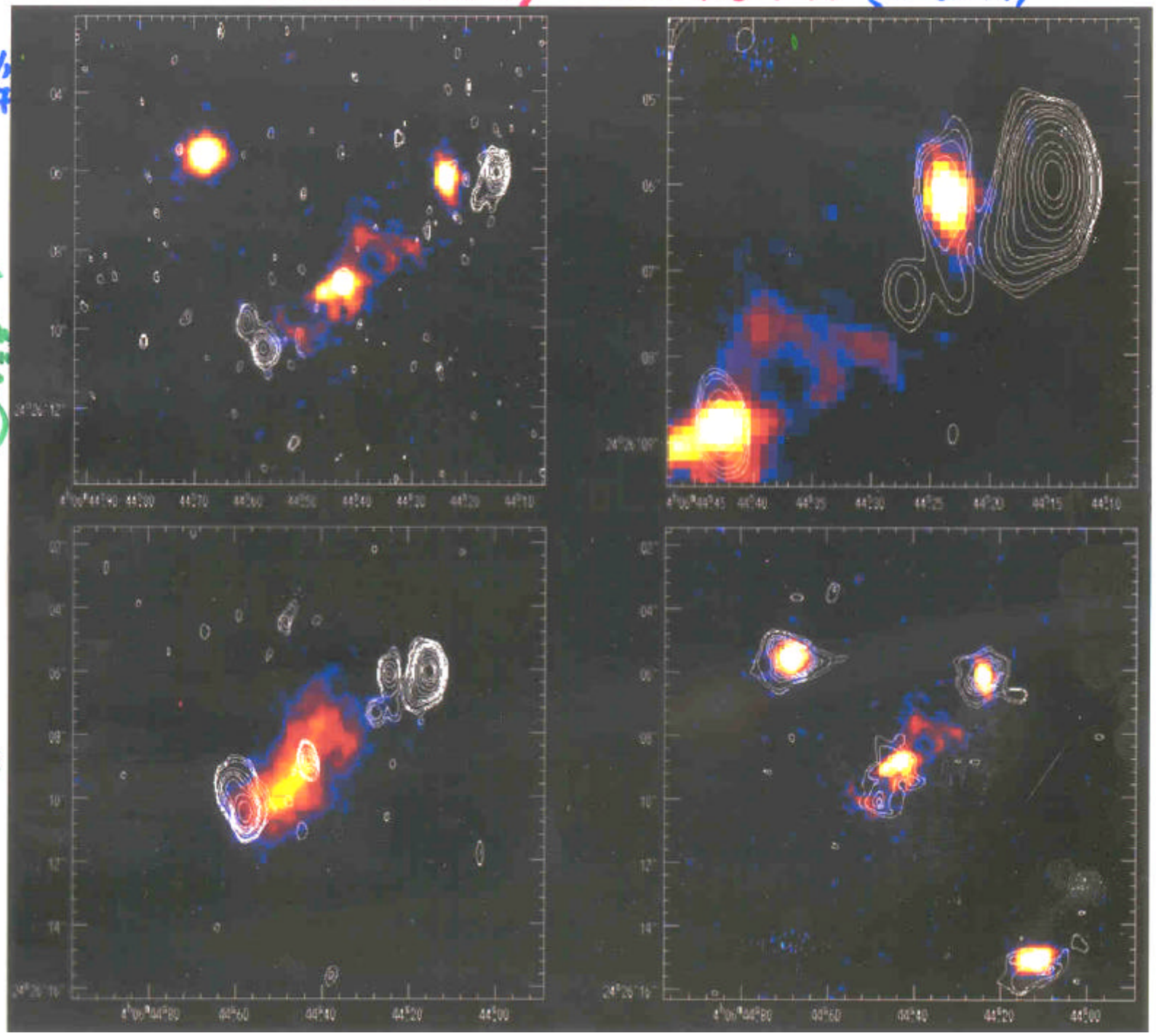


Variable Hβ components

→ 2 different engines ! (?)

Radio Galaxy MRC 0406-244 (z = 2.44)

Rush, McCarthy, et al 1997

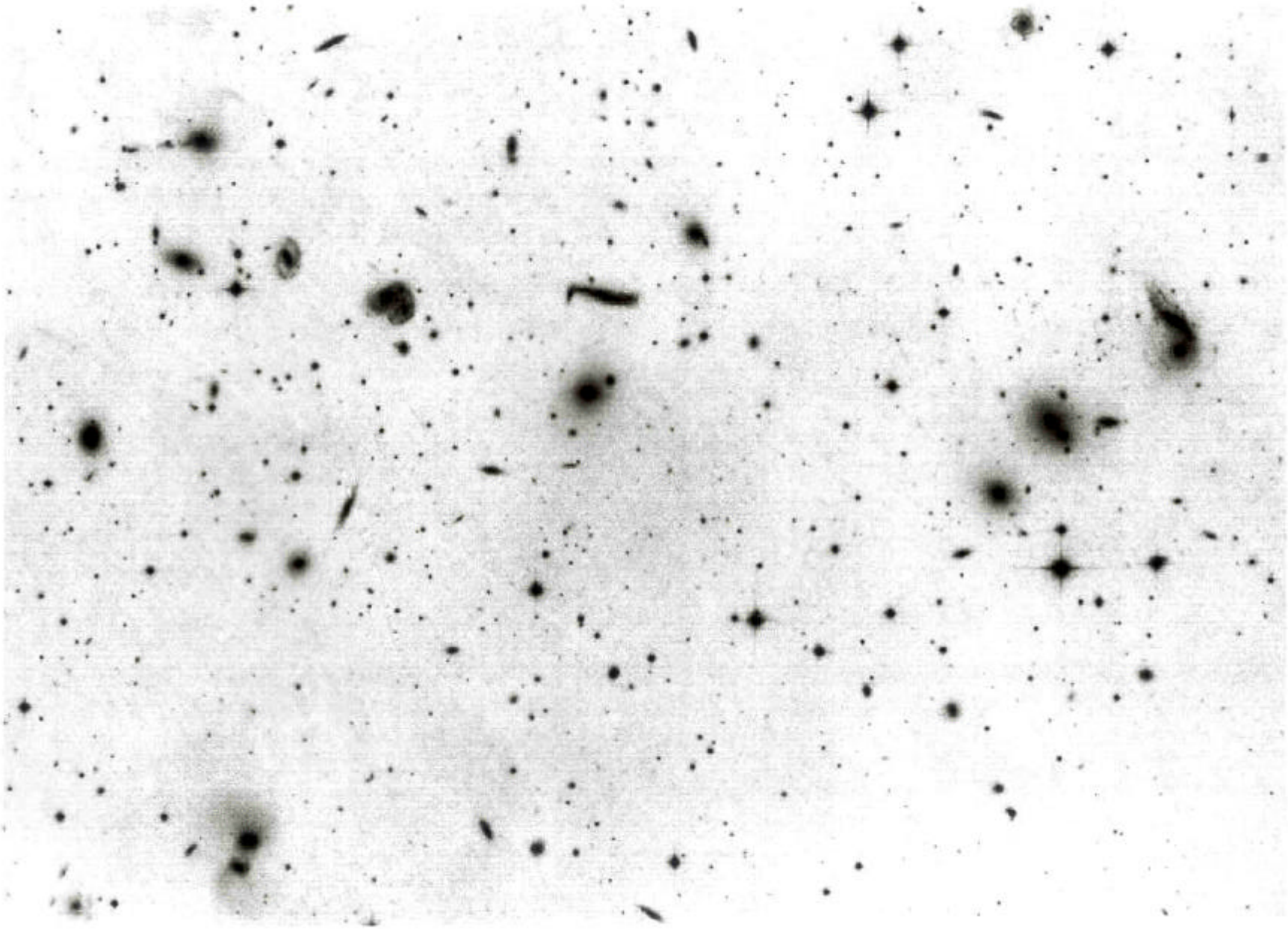


Double nucleus

Two cont. light "tails" (~30 kpc)

Two Lyα bubbles

Mergers in Hercules Cluster ($z = 0.034$)



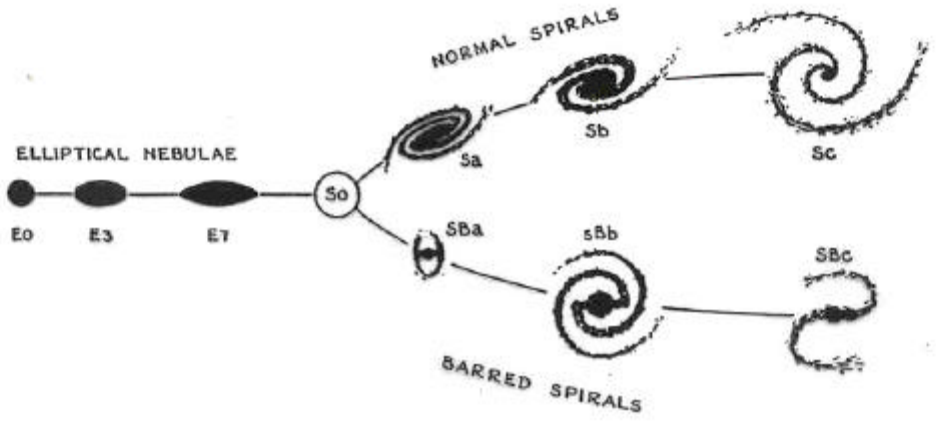
(Las Campanas 2.5m plate, Alan Dressler)

CONCLUSIONS

- Gravitational interactions and mergers are shaping and reshaping galaxies throughout the observable universe. The vast majority involve gas and dissipation.

- The close link between mergers, ULIGs, and QSOs suggests that, like QSO activity, major merging may have peaked around $z = 2$.

- Major disk–disk mergers form ellipticals with kinematic subsystems and bimodal globular-cluster populations. Such mergers occurred relatively early in rich clusters and continue to the present day in poorer clusters and the field.

- Minor mergers tend to move disk galaxies toward earlier morphological types, creating kinematic subsystems and some bulges.

- Hubble's morphological sequence appears to be mainly a sequence of decreasing merger damage.