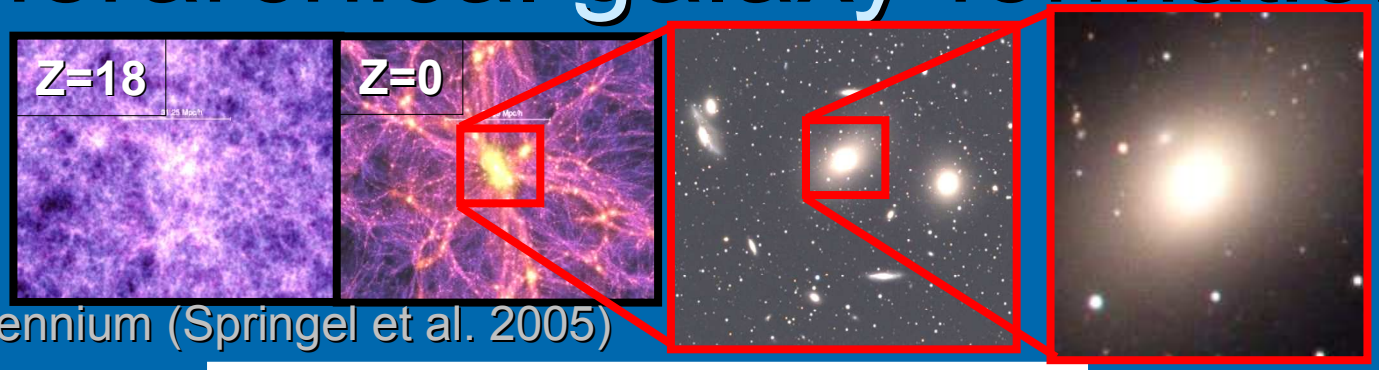
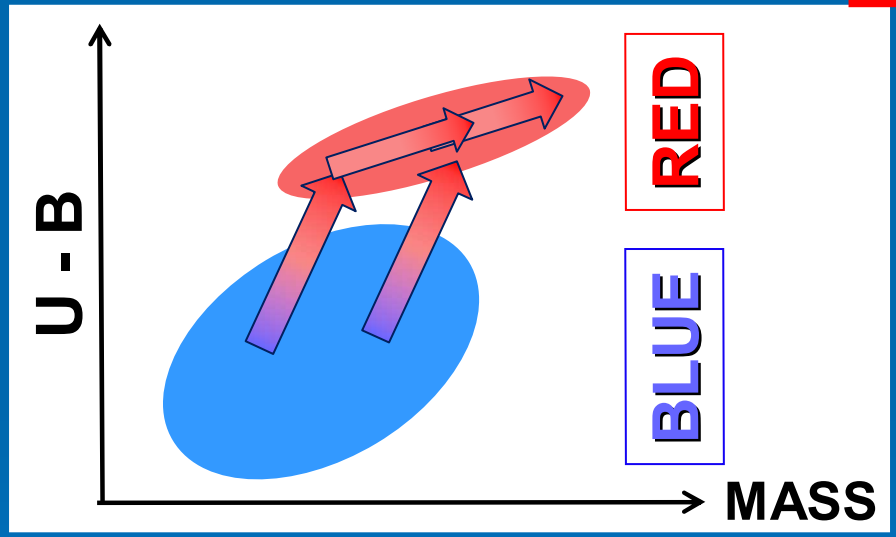
Gas and the formation of early-type galaxies: SAURON + WSRT

Michele Cappellari

Hierarchical galaxy formation



Millennium (Springel et al. 2005)



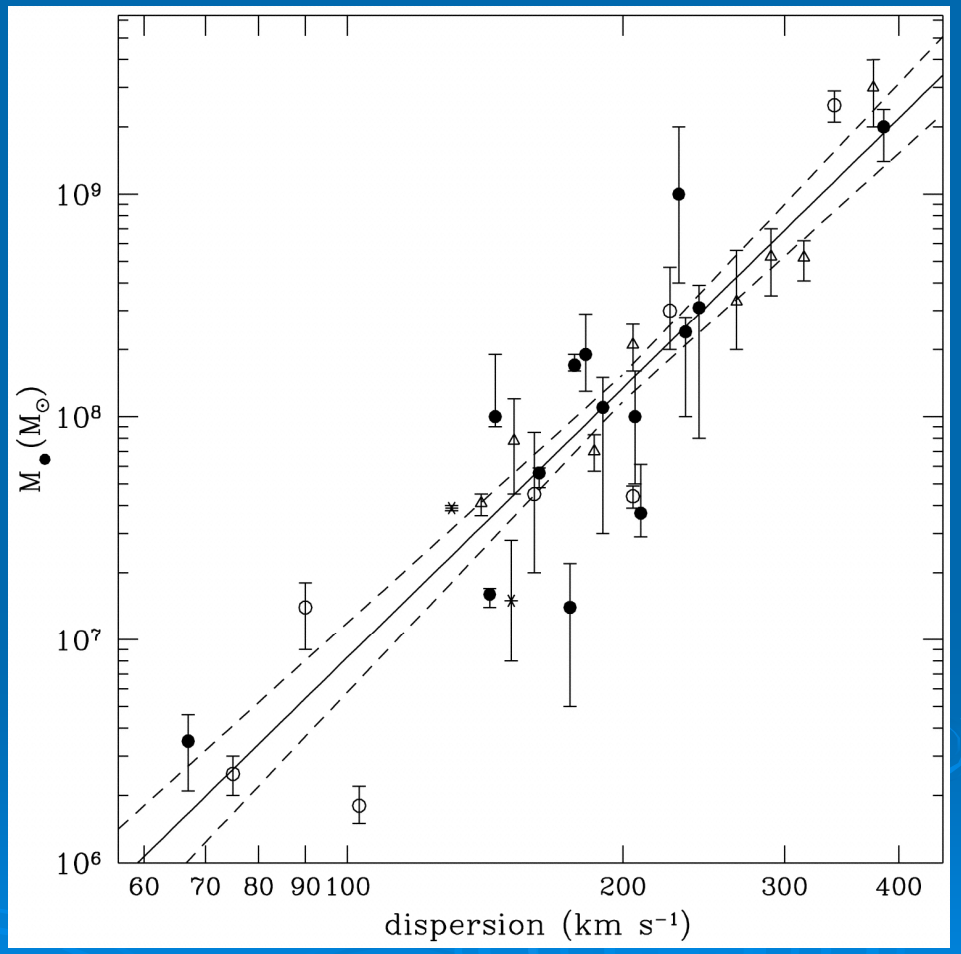
(see Faber et al. 2007)

- Dark matter clumps via gravitational instability
- Bimodal galaxy colour distribution
- Mergers of blue-cloud galaxies → Red-sequence galaxies
- Feedback required for quick transition: blue → red

M_{BH}-σ relation

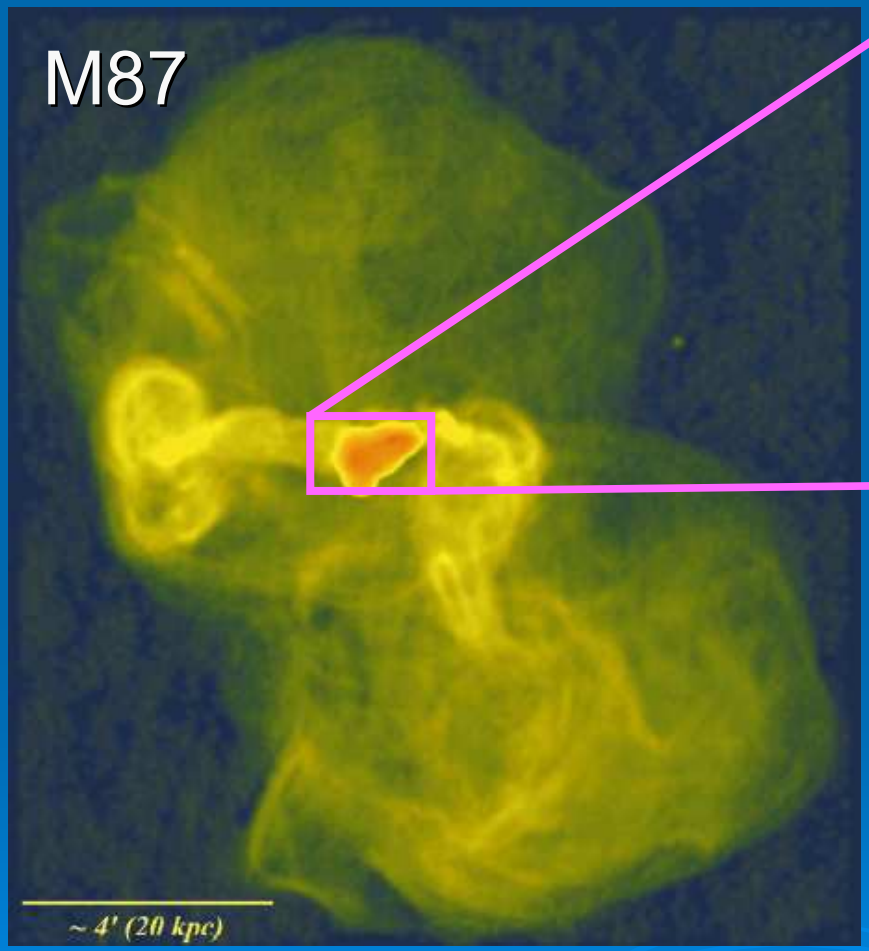
- A decade of HST observations
- Dramatic modeling improvements
- ~30 BH masses
- Clear correlation with global galaxy properties
- Link galaxy-BH formation

  (Magorrian et al. 1998; Gebhardt et al. 2000; Ferrarese & Merritt 2000)

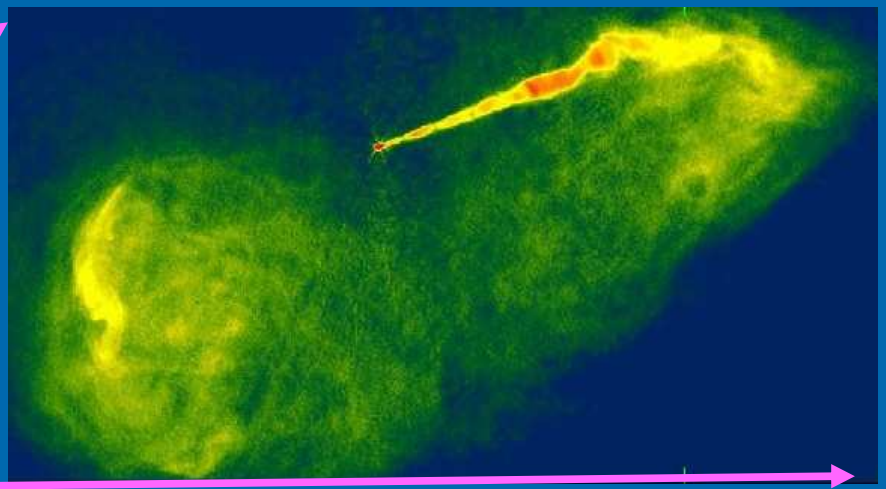


(Tremaine et al. 2002)

Feedback from AGN in action



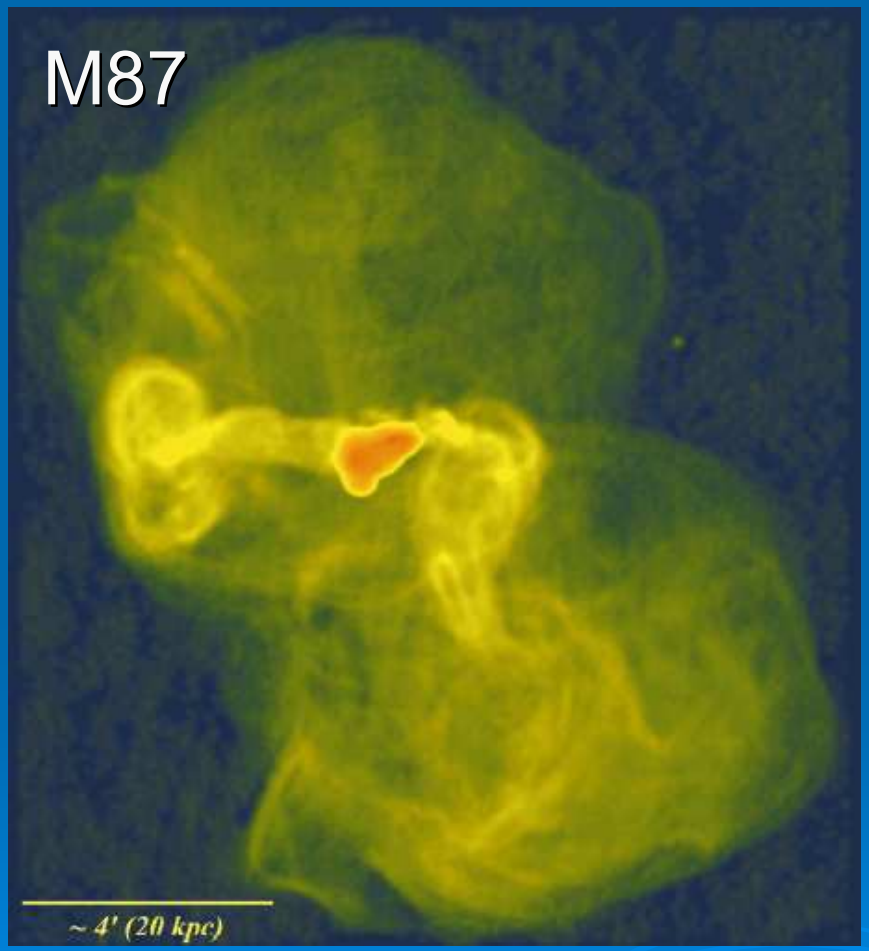
VLA at 90 cm (Owen et al. 2000)



VLA at 2 cm

- AGN can distribute energy on galaxy cluster scales
- Heating of gas by AGN may provide self-regulation of BH mass growth

Feedback from AGN in action



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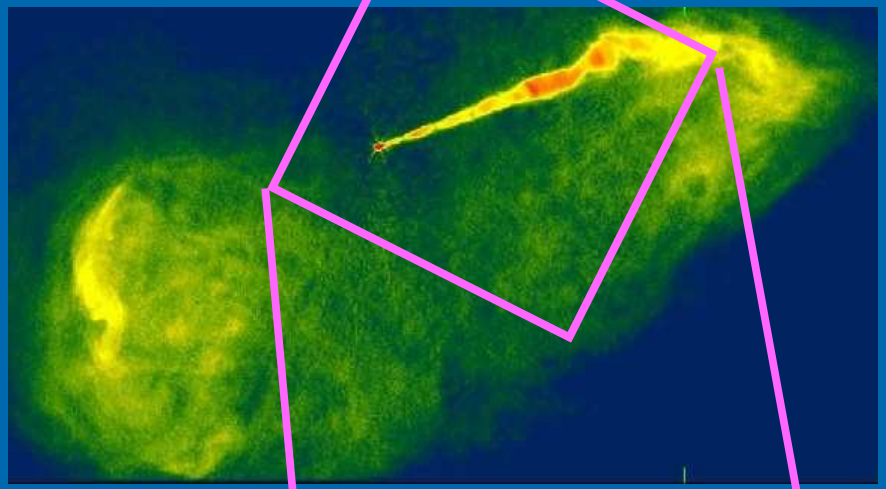
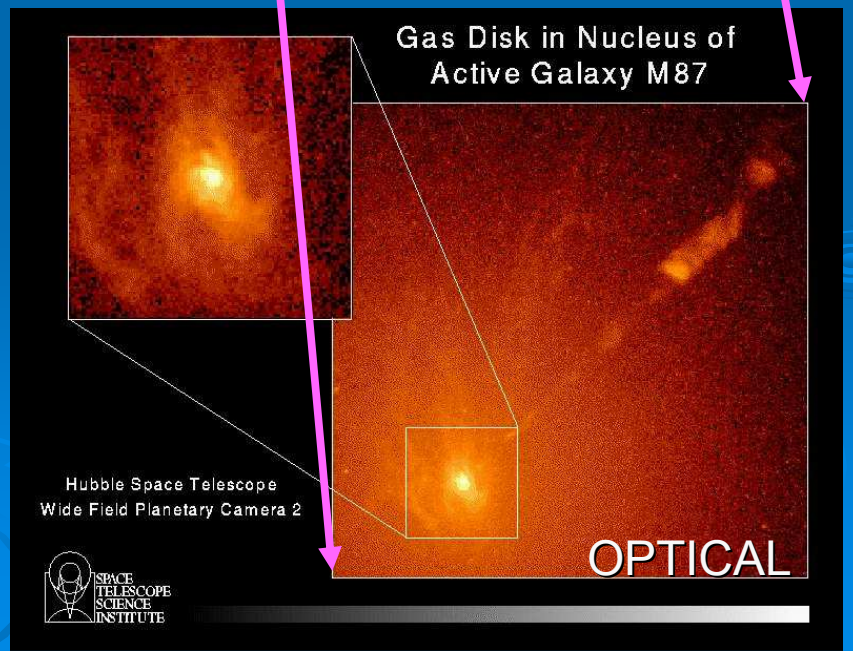
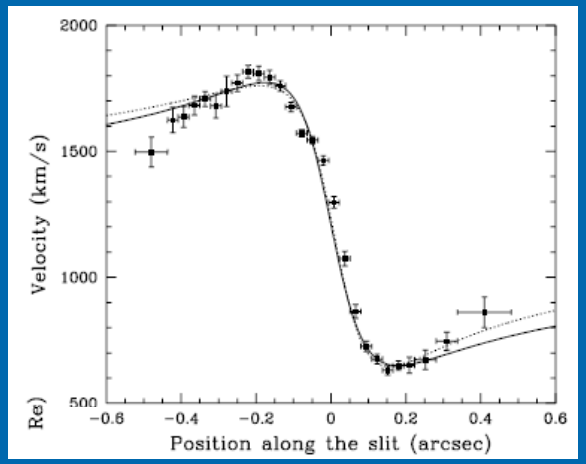
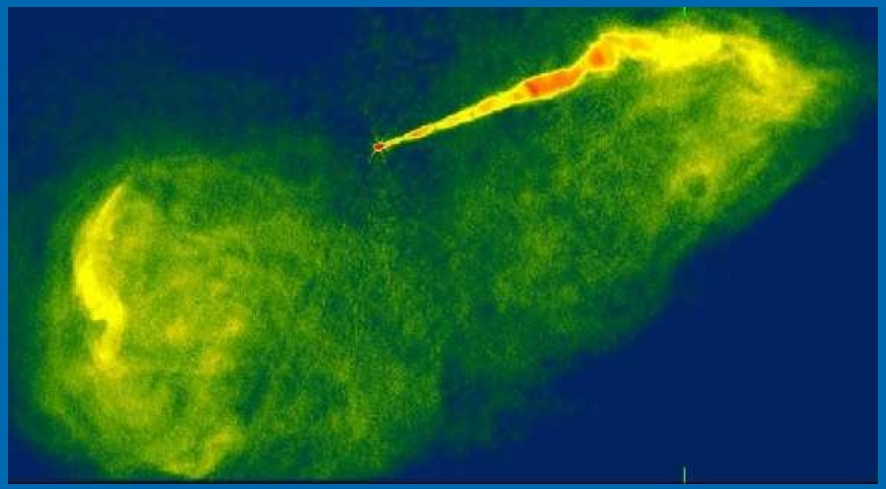


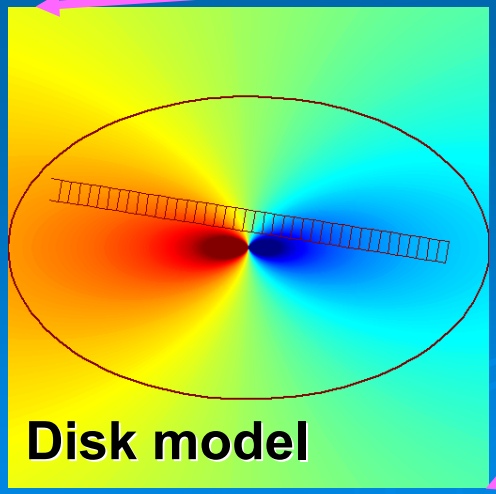


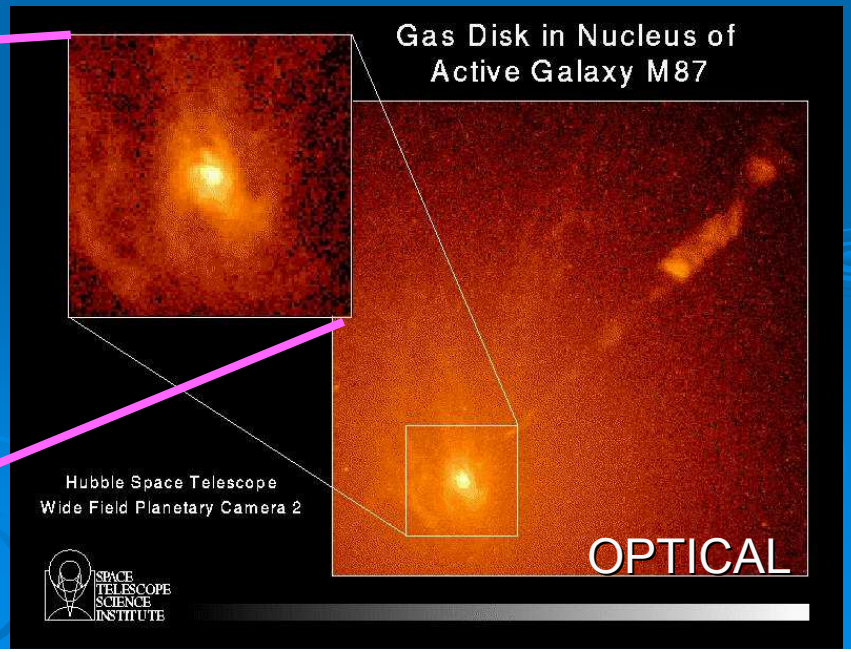
Feedback from AGN in action



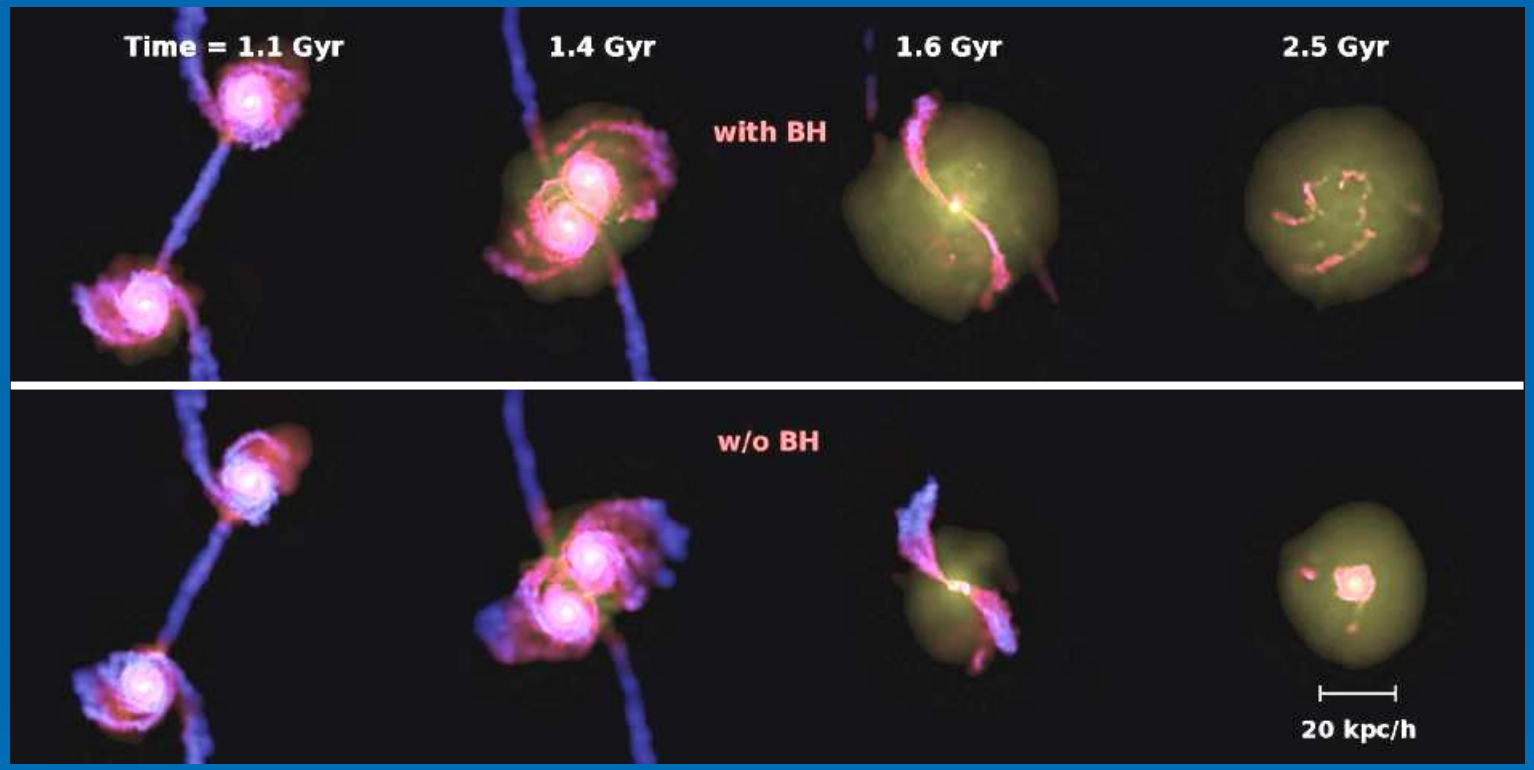
Gas velocity along the slit
Macchetto et al. (1997)







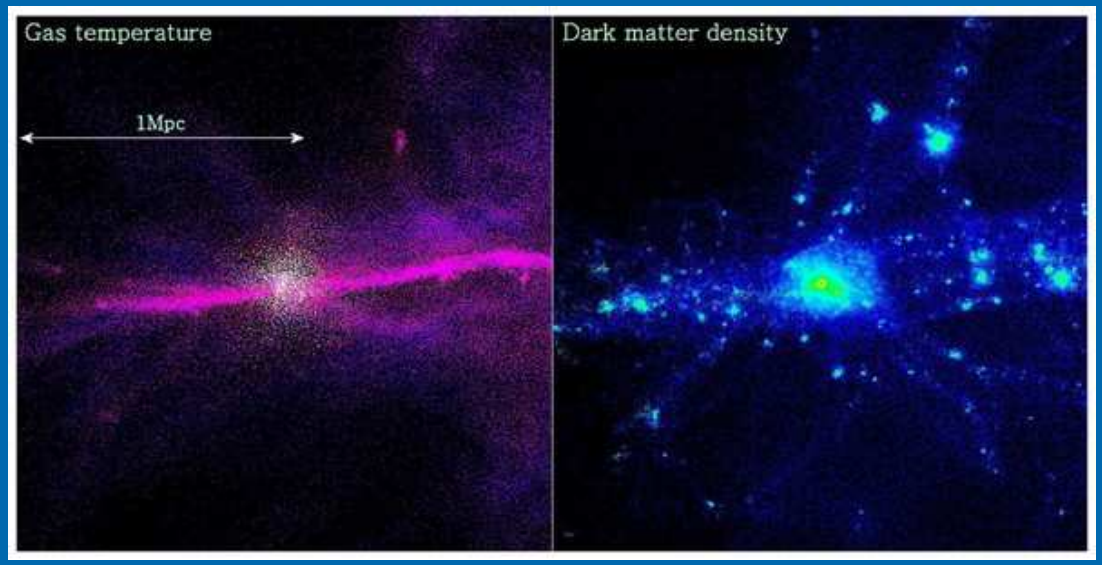
Simulating AGN feedback



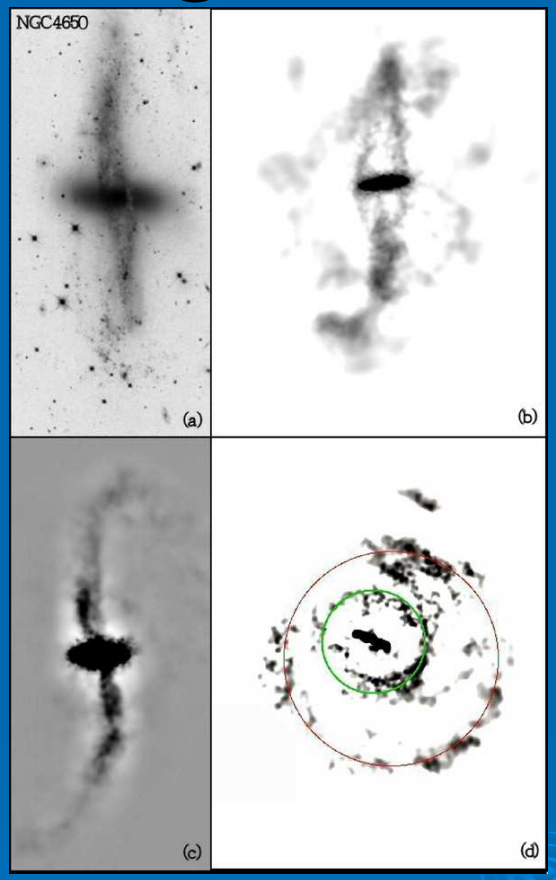
Di Matteo et al. (2005)

- Without BH all gas collapses to the center
- With BH gas is expelled ad heated up
- But simulations not realistic: AGN energy input not isotropic

Not all happens by mergers



Macciò, Moore, Stadel (2006)



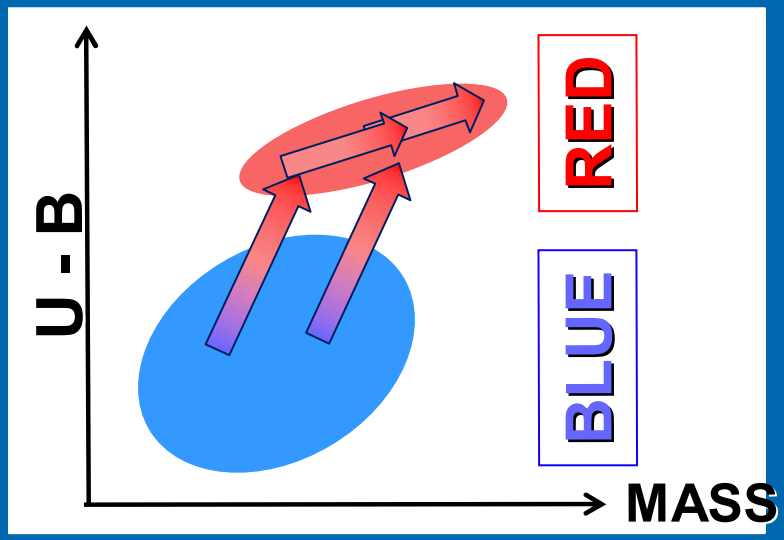
- Models predict cold accretion important
- Slow accretion of significant amount of primordial gas
- Some observational support to this picture

Expected relics of galaxy formation

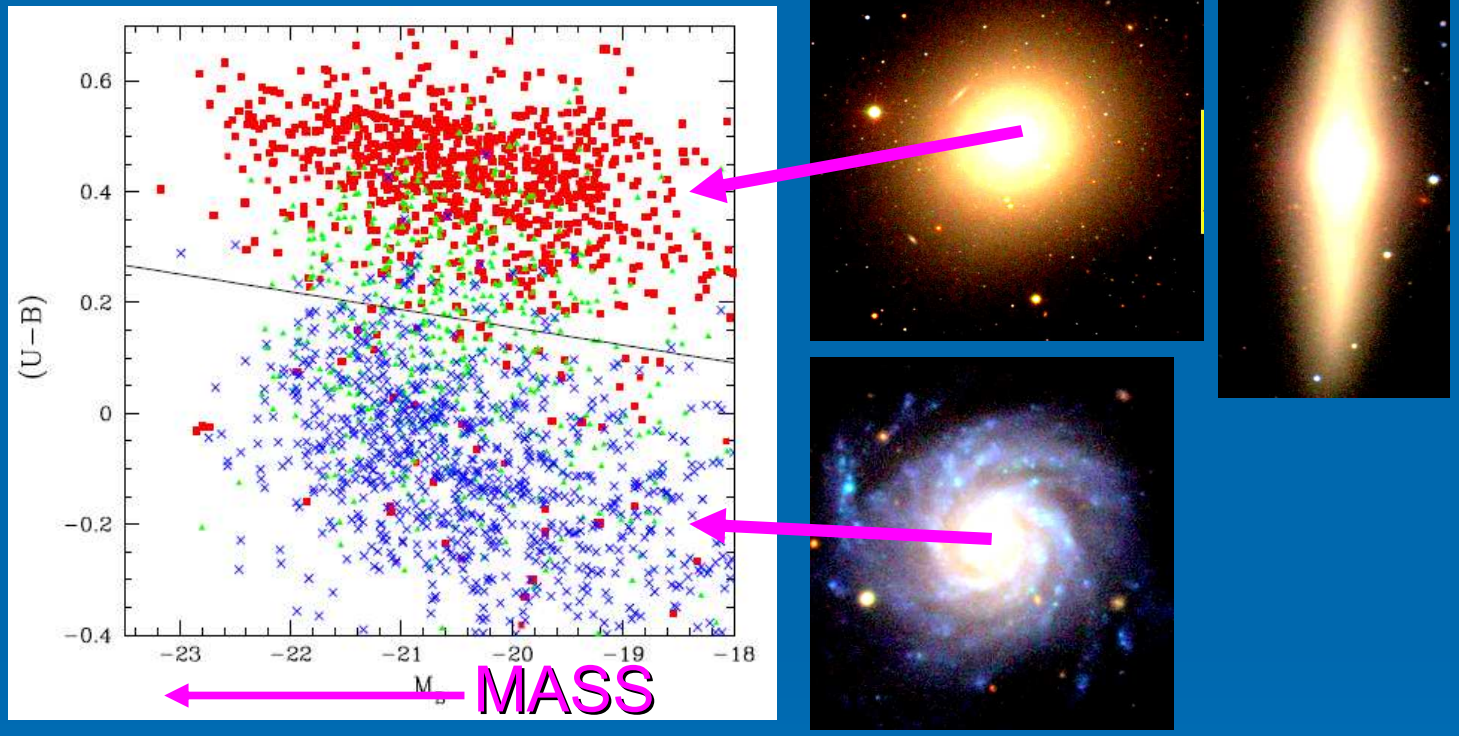
- Spiral galaxies on blue sequence
  - Gas and dust rich
  - Actively star forming
- Lenticulars on low-mass red sequence
  - Faded spirals?
  - Minor mergers?
  - Gas rich mergers + slow accretion?
  - AGN feedback likely not important

  → Fast rotating
- **True** ellipticals on high-mass red sequence
  - Major mergers
  - Collisionless mergers?
  - Gas rich mergers + strong AGN feedback feedback?

  → Slowly rotating



Galaxy morphology and color

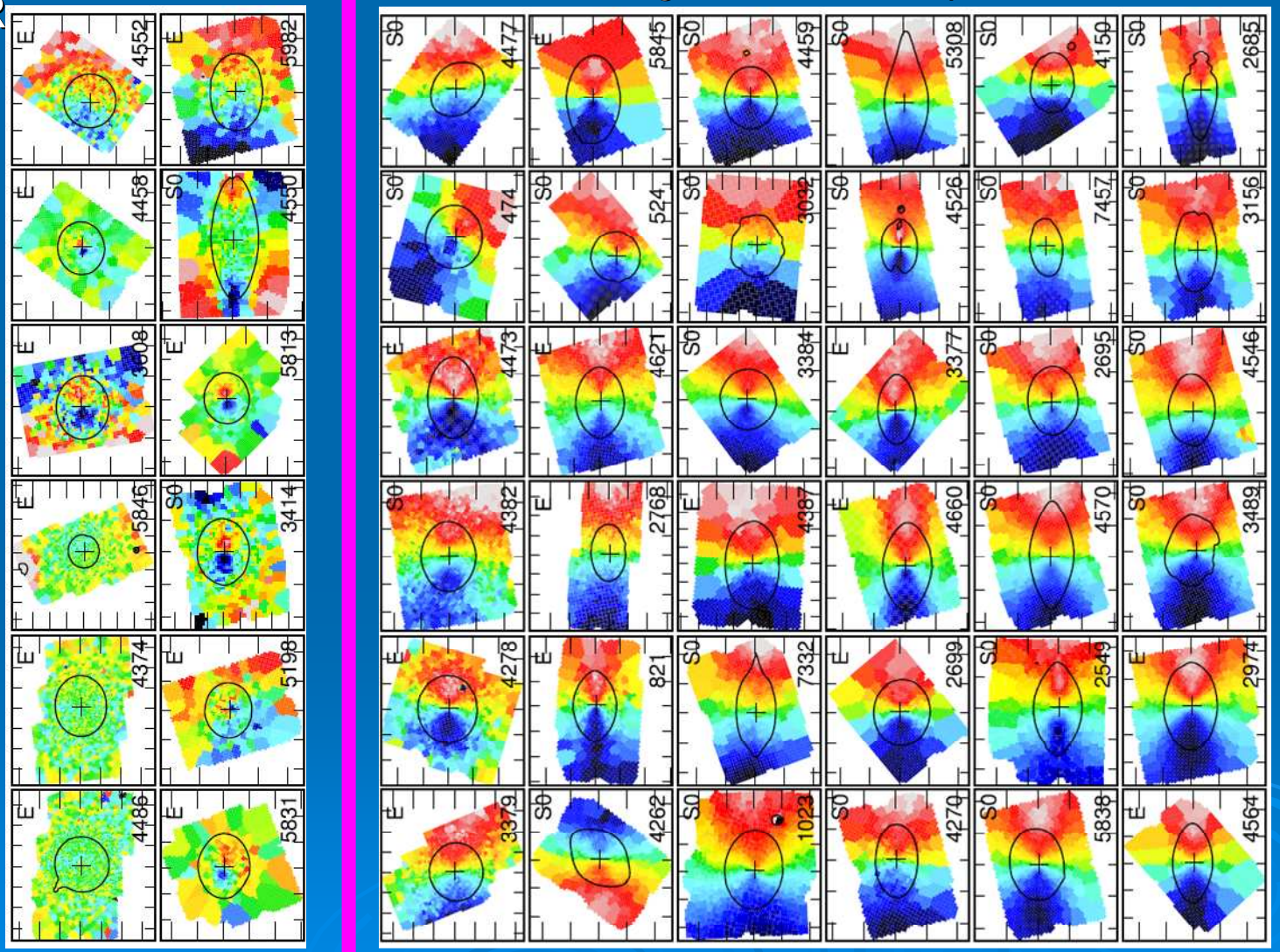


(Strateva et al. 2001; Conselice 2006; van den Bergh 2007)

- Clear connection morphology-colour
- E/S0 on red sequence
- Spirals on blue sequence

Two classes of early-type galaxies

λ_R → Angular momentum per unit mass

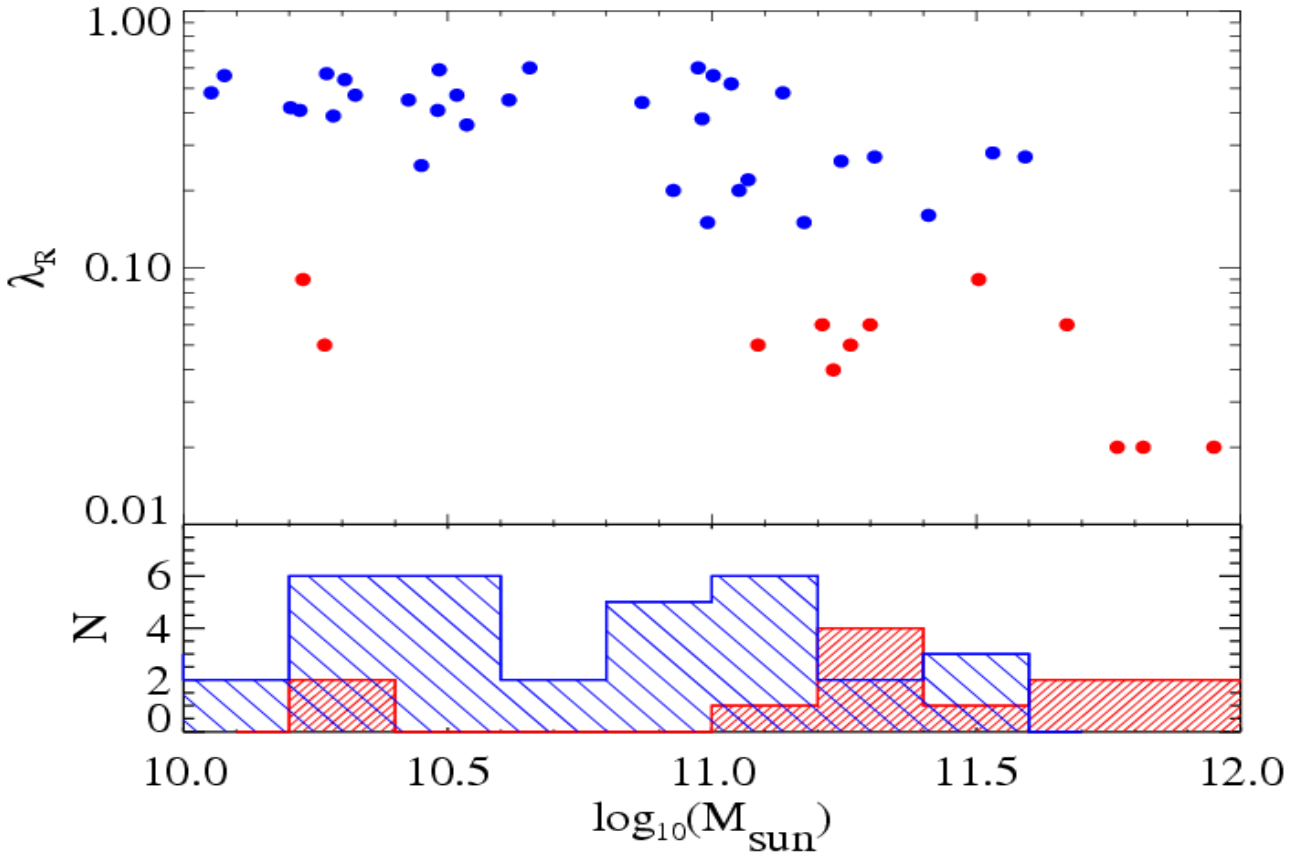


From SAURON survey (de Zeeuw et al. 2002)

"Slow-rotator" λ_R=0.1 **"Fast-rotator"**

Mass Assembly

Angular momentum per unit mass



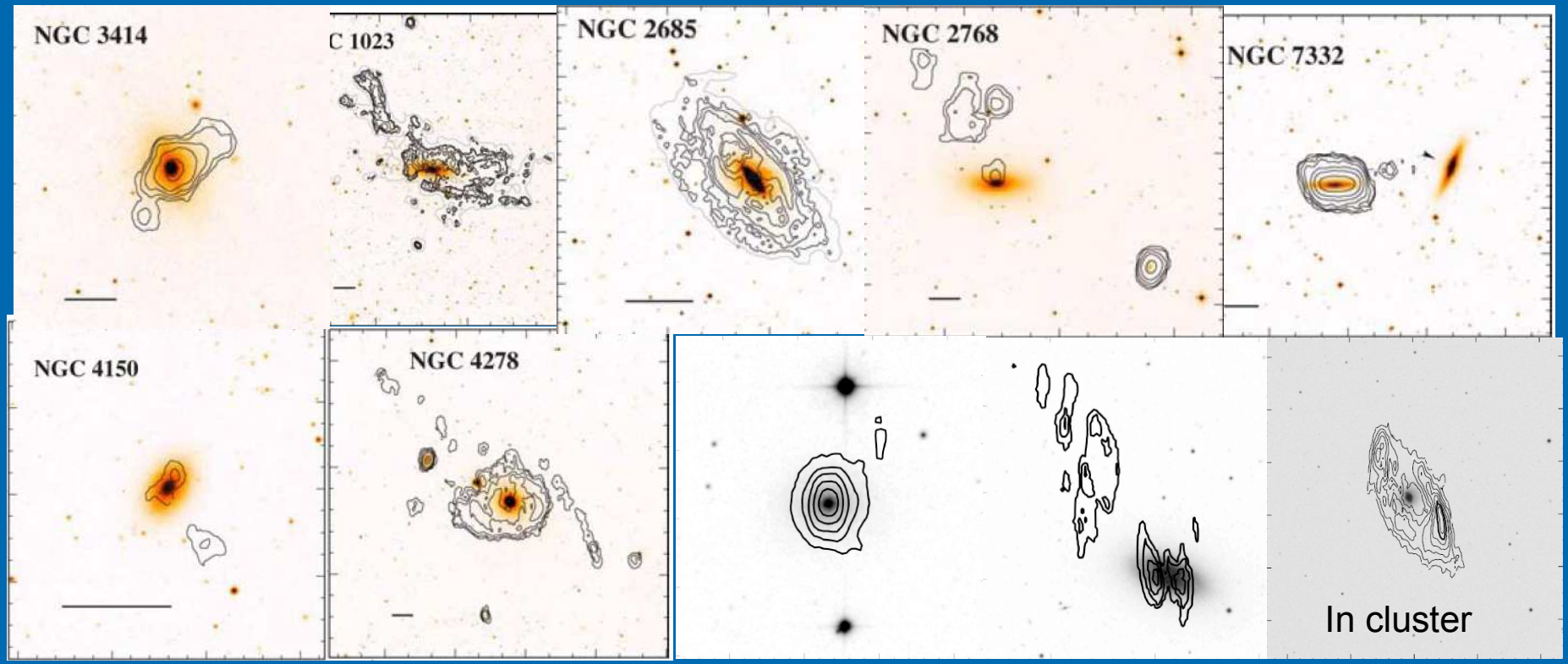
(Emsellem et al. 2007)

- **Fast-rotators:** Broad range of masses
- **Slow-rotators:** More massive. End point of mass evolution?

HI in early-types with WSRT

- Previous surveys (mainly) single-dish: HI detection rate 5 - 20%
  - HI seems unimportant for early-types
- WSRT observations of 12 (field) SAURON galaxies:
  - Surprising 60% detection (Morganti et al. 2006)
  - HI common in (field) early-type galaxies if we look deep enough!
- New WSRT observations bring sample to 33
  - Confirm high detection (Oosterloo et al. in prep)

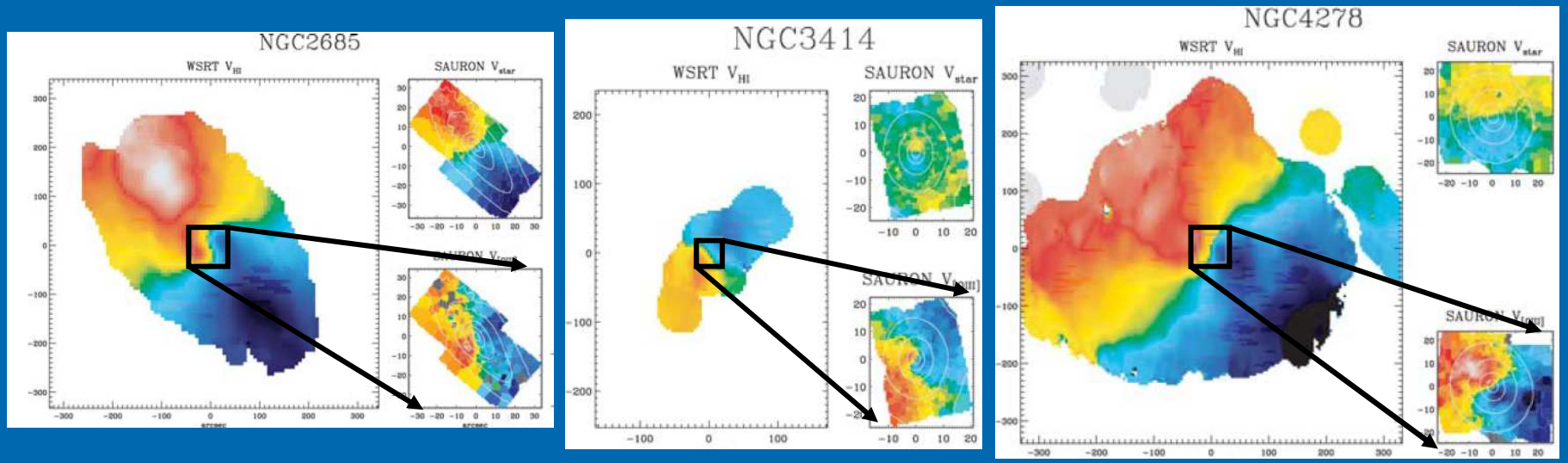
HI in Fast-rotators



(Morganti et al. 2006, Oosterloo et al. in prep)

- HI present in 55% (10/18) of the cases
- When HI is detected
  - Often in organized disk-like rotating structure
  - Present down to the one effective radius

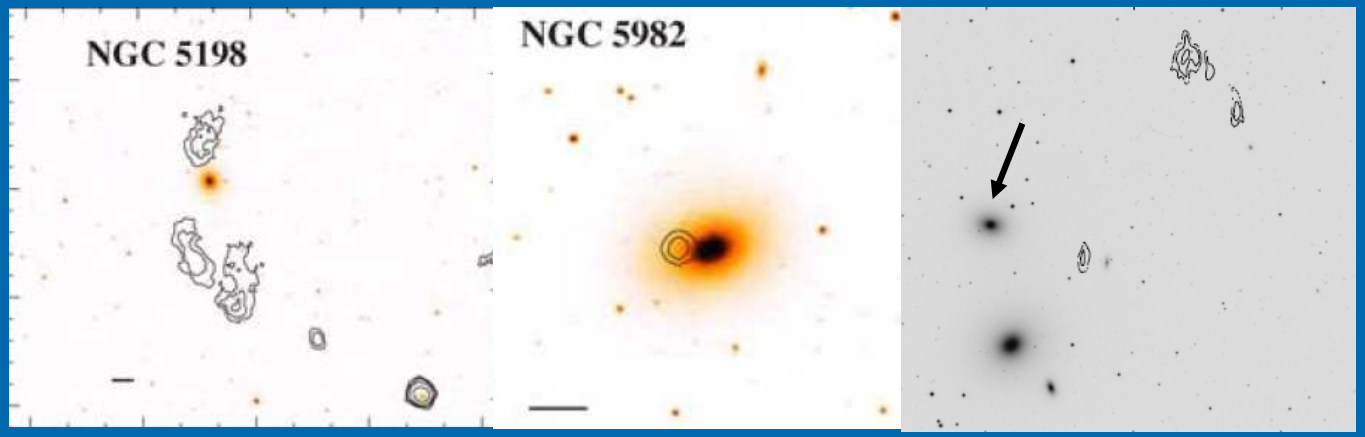
HI and ionized gas



HI: Morganti et al. (2006)
Ionized: Sarzi et al. (2006)

- When HI disk is present
  - HI kinematics matches smoothly with ionized one
  - Two phases of the same structure
- Gas kinematics important to study dark-matter (Weijmans et al. 2008)

HI in Slow-rotators



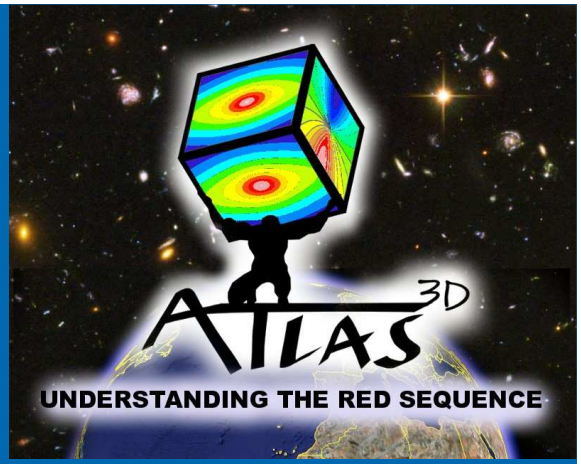
(Morganti et al. 2006, Oosterloo et al. in prep)

- Detected all (3/3) of the objects in field
- However when HI present
  - Never reaches the central regions
  - Never in an ordered rotating structure
  - Not obvious association with the galaxy

A possible scenario

- In Fast-rotators
  - Gas is relics of last gas accretion event
  - Or comes from slow accretion
  - Contributed to formation of stellar disk
- In Slow-rotators
  - Large scale HI residual of major gas mergers
  - Feedback from AGN heated the gas
  - Most of the gas is in hot halo
  - Prevent significant further accretion
- But very small number statistics!
- Strongly biased sample!
- SAURON sample not representative of early-type galaxy population

New quantitative survey:



- Atlas^{3D} project (PIs: Cappellari, Emsellem, Krajnovic, McDermid)
- Volume limited sample (D<41Mpc) Oxford Lyon Oxford Gemini
- K-band selected (M_K<-21.5)
  → ~1,000 galaxies of all morphologies
- We observed all 265 E/S0 galaxies in the volume
- Integral-field observations with SAURON (all completed!)
- IRAM 30m single-dish CO of full sample (2/3 completed) (Bureau/Young)
- Planned CO interferometry of detections with CARMA
- HI survey of ~150 northern galaxies (excl. Virgo) (Morganti/Oosterloo/Serra)
- Complete 8-bands photometry (2MASS, SDSS, INT)
- Additional archival data (Chandra, XMM, GALEX, HST, Spitzer)
- Web: http://www-astro.physics.ox.ac.uk/atlas3d