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Netherlands Institute for Radio Astronomy

Presence of gas in early-type galaxies as a signature of minor mergers

or the continuing assembly of early-type galaxies

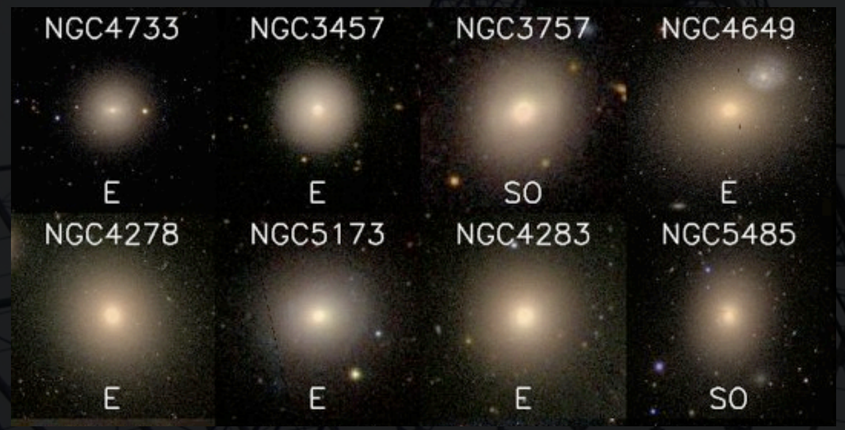
Raffaella Morganti

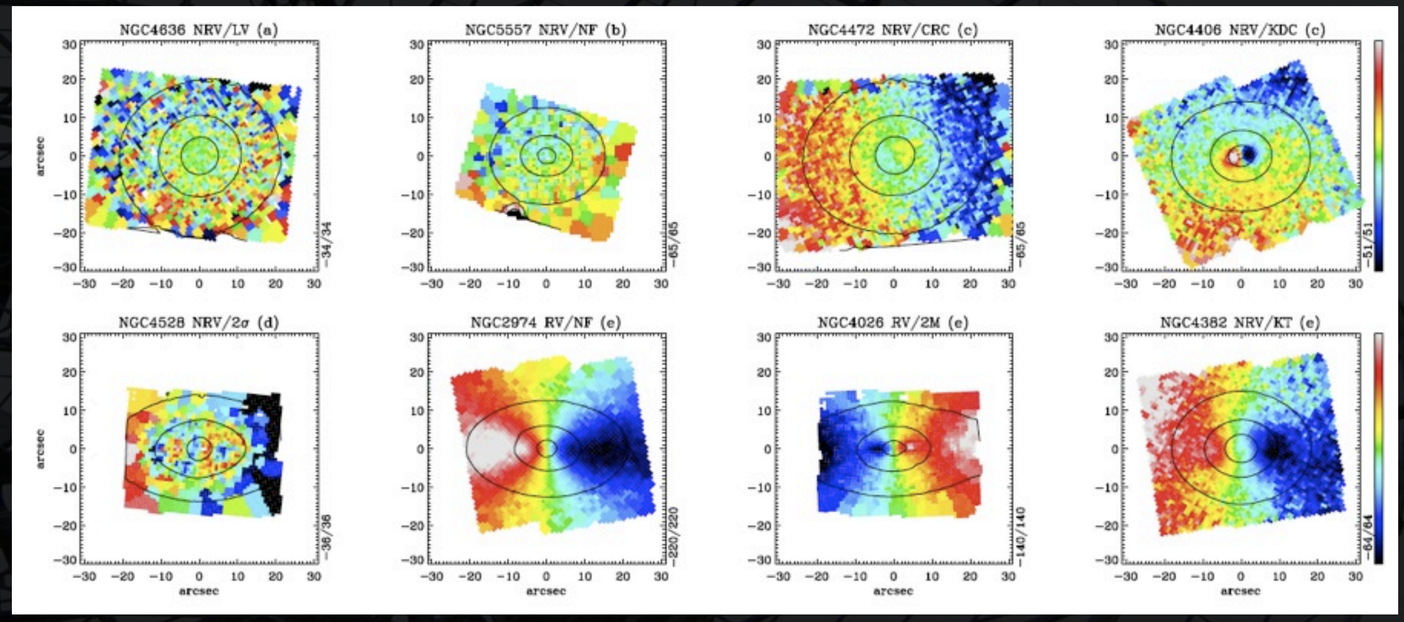
ASTRON (Netherlands Institute for Radio Astronomy &
Kapteyn Institute, Groningen (NL)

ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

Minor merging as a driver of galaxy evolution, JENAM-11:
7 July 2011, St Petersburg

Why study gas in gas-poor galaxies?





Krajnovic+ 2011

Complex kinematical structure suggests complex evolution.

Why study gas in gas-poor galaxies?

Other issues:

- Many ETGs have small, young(ish) population of stars
- Density-morphology relation; Gas content ⇄ environment
- What is feeding the AGN?
- ...

What is the role of gas in all this?
What are the gas properties of ETGs?

Why study gas in gas-poor galaxies?

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This talk: results from HI studies

Detecting and tracing HI in early-type galaxies

- Different, complementary ways are used and planned for tackling this problem

MAIN issues:

it requires deep observations ➪
the features we are looking for (signs of minor merger and/or accretion)
are there but are faint!

and

imaging capability ➪ crucial for the morphology and kinematics

and

data from other wavebands ➪ correlation between different indicators

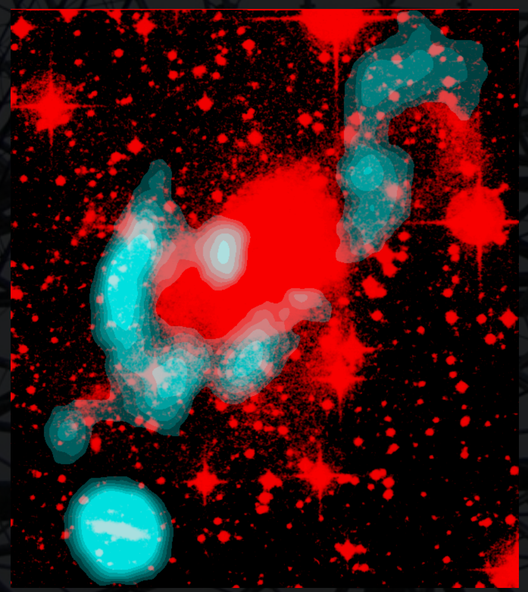
The role of the HI in ETGs:a brief history

- Different, complementary ways of tackling this problem:
  - single-dish datasets (Knapp, ALFALFA,…)
    - many galaxies, only global information, higher *z*
  - HI imaging (van Gorkom, Schiminovich, …)
    - fewer galaxies, detailed information on internal structure and kinematics

The past

< 2000: general perception was that ETGs are gas poor

- HI detection rates of ~10% - mostly single dish work (e.g. Knapp), not sensitive
- Some suggestion that presence of HI is connected to merging
  (e.g. Knapp; van Gorkom, Schiminovich)



NGC 2865 Schiminovich+ 1995

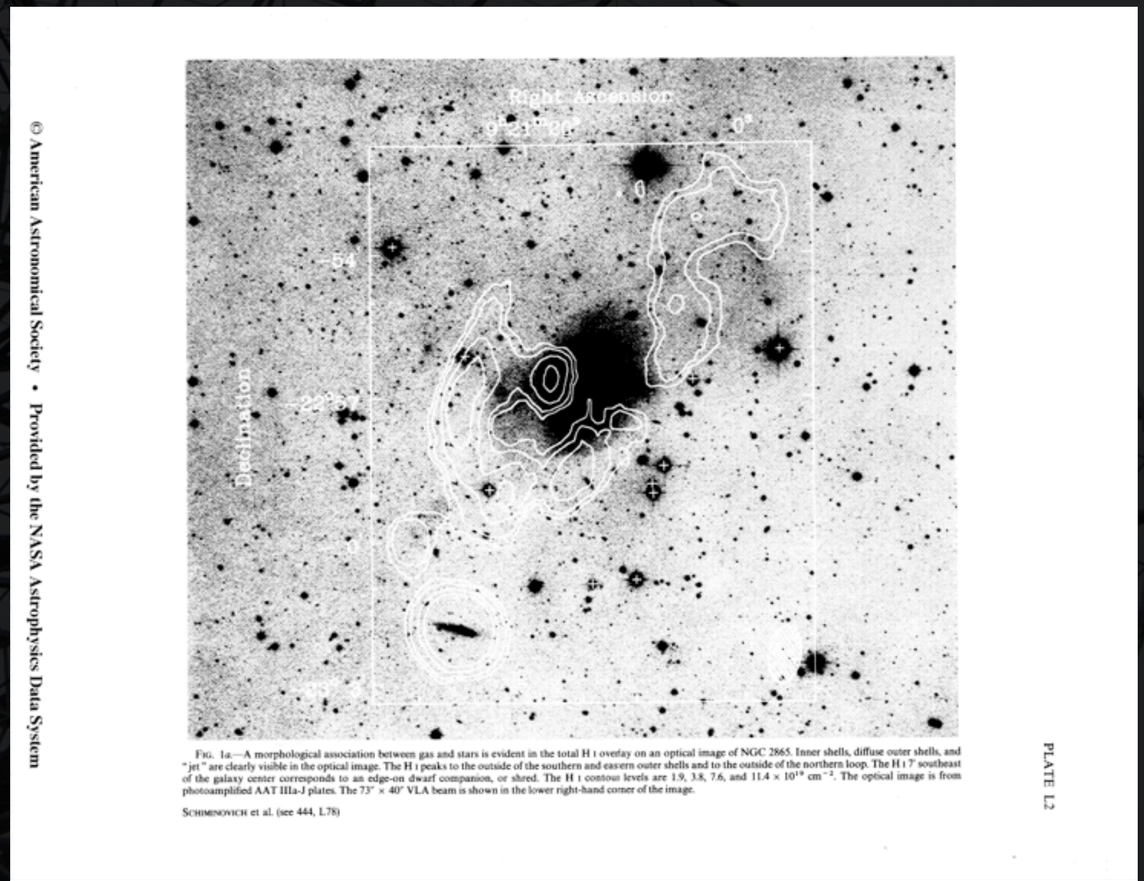


FIG. 1a.—A morphological association between gas and stars is evident in the total H I overlay on an optical image of NGC 2865. Inner shells, diffuse outer shells, and "jet" are clearly visible in the optical image. The H I peaks to the outside of the southern and eastern outer shells and to the outside of the northern loop. The H I 7' southeast of the galaxy center corresponds to an edge-on dwarf companion, or shred. The H I contour levels are 1.9, 3.8, 7.6, and 11.4 × 10^{19} cm^{-2}. The optical image is from photoamplified AAT IIIa-J plates. The 73" × 40" VLA beam is shown in the lower right-hand corner of the image.

SCHIMINOVICH et al. (see 444, L78)

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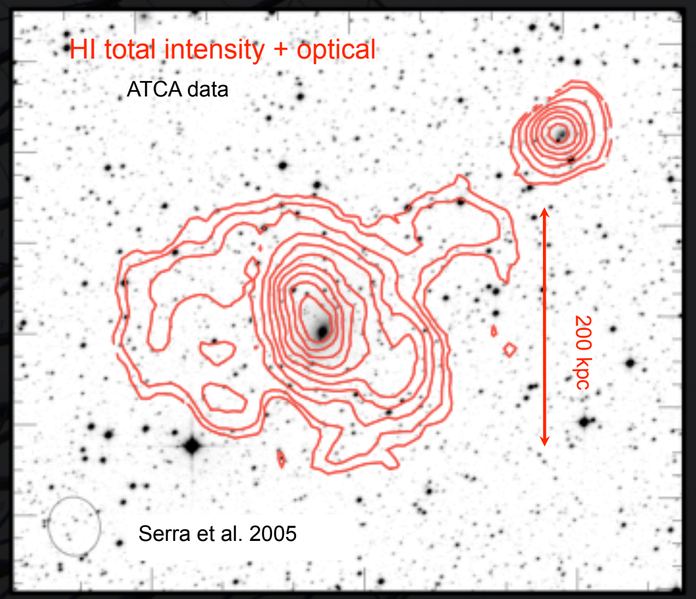
- HIPASS sample - 54 galaxies, ATCA, limited sensitivity ($10^{8\text{-}9}$ $M_\odot$)
  detection rate 5-10%. Oosterloo+ 2007

LARGE REGULAR DISKS! A lot of HI!!
Possibly the result of major mergers?



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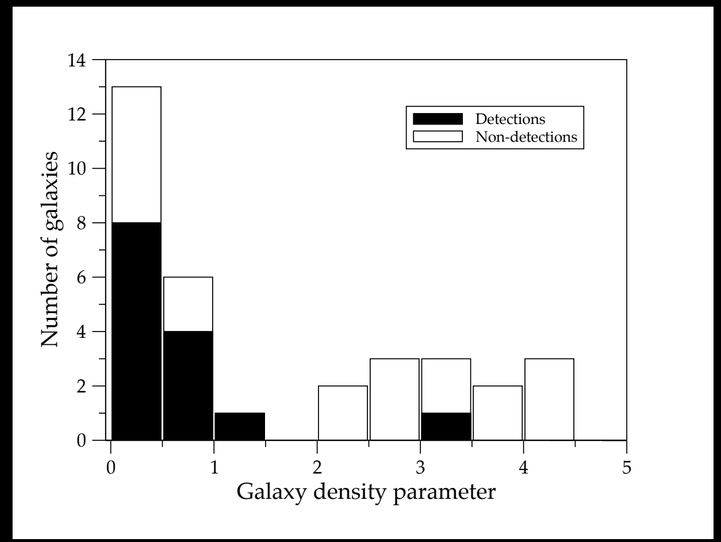
- SAURON - 33 galaxies, WSRT, better sensitivity ($10^{6\text{-}7}$ $M_\odot$).
  detection rate in field 60%. Morganti+ 2006; Oosterloo+ 2010
  lots of complementary data

- ATLAS3D - Superset of SAURON sample, slightly more distant
  166 galaxies, WSRT, ($10^{6\text{-}7}$ $M_\odot$). Serra+ 2011
  detection rate in field 45%. Deep follow up on subset (*t* x 10)

Going deeper: WSRT observations of SAURON sample

- WSRT observations of SAURON sample
  - 33 galaxies, ‘representative sample’, field and cluster
  - optical 2D spectroscopy of stars and ionised gas, + lots of other data (e.g. CO, FIR, UV)
  - all galaxies above δ>10˚ (33)
  - detection limit 10^6-10^7 $M_\odot$, $n_{HI,lim}$ 3-5 x 10^{19} cm^{-2}

Morganti+ 2006; Oosterloo+ 2010



- Much higher detection rate: ~60% in field; ~2% in Virgo.
  For CO the field and cluster detection rates are about the same!
- Environmental effects stronger than for spirals. Older cluster population, more affected by ICM?

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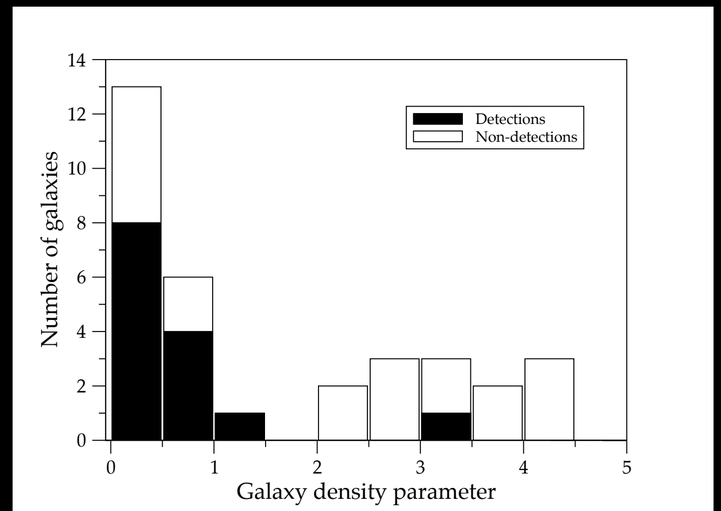

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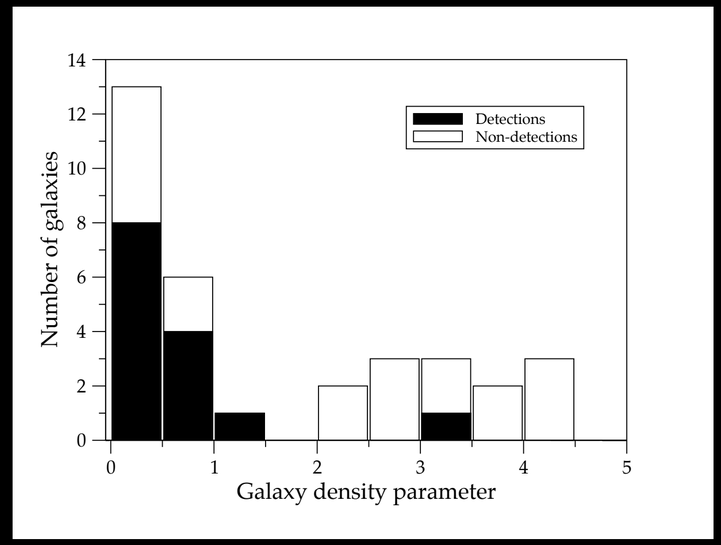

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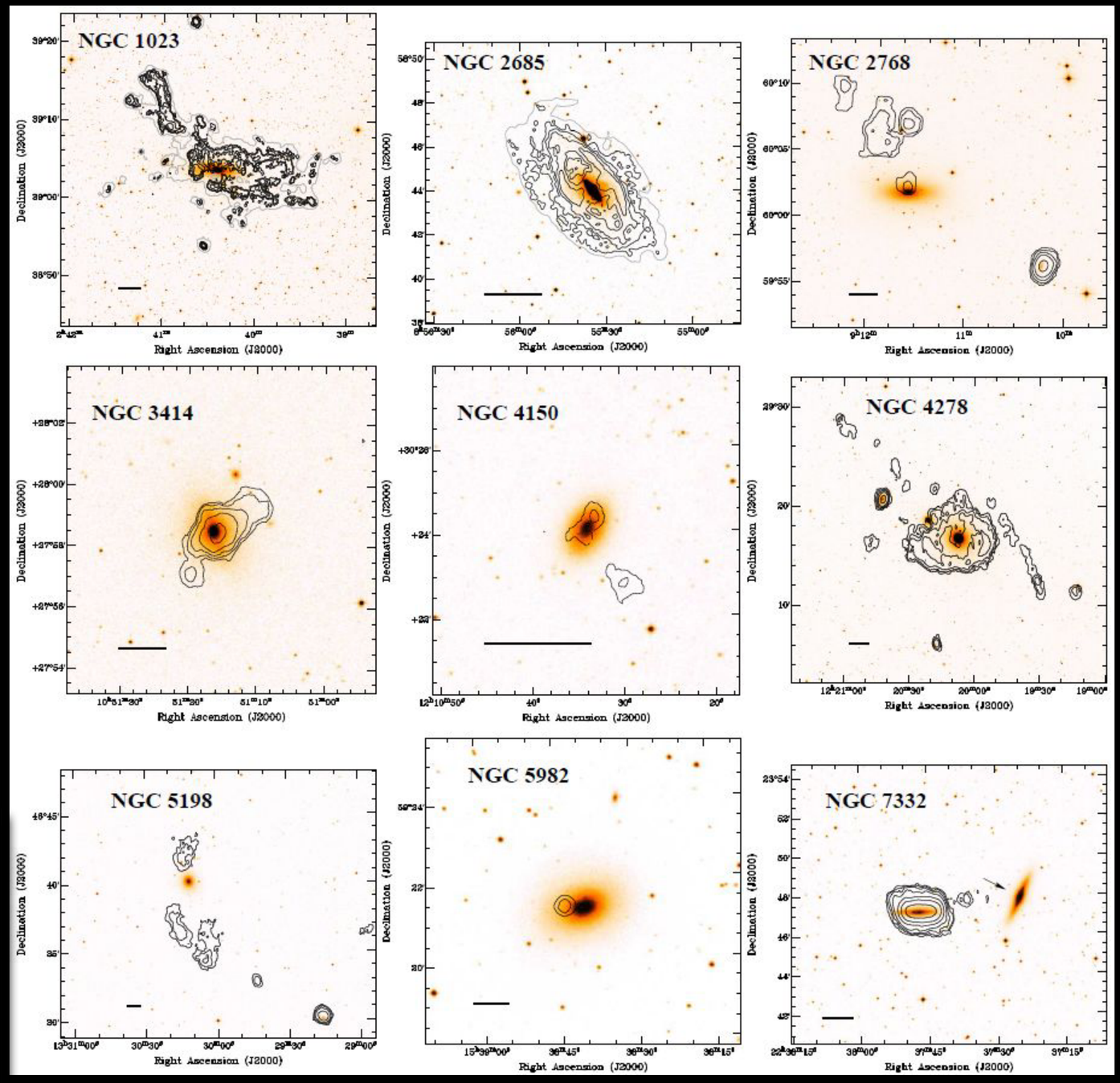
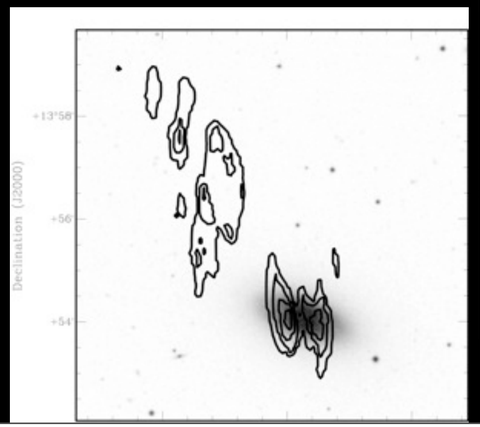
HI characteristics

- Morganti R. , deZeeuw T. , Oosterloo T. et al. (2006)
- Oosterloo et al. 2010

- Diverse morphologies
- Again many disks, ~50% of detections
- But: recent or on-going accretion ubiquitous (also for gas disks). But of small amounts
- Some but no strong relation between HI disks and stellar dynamics
- Galaxies with large HI disks also show ‘fast’ stellar rotation



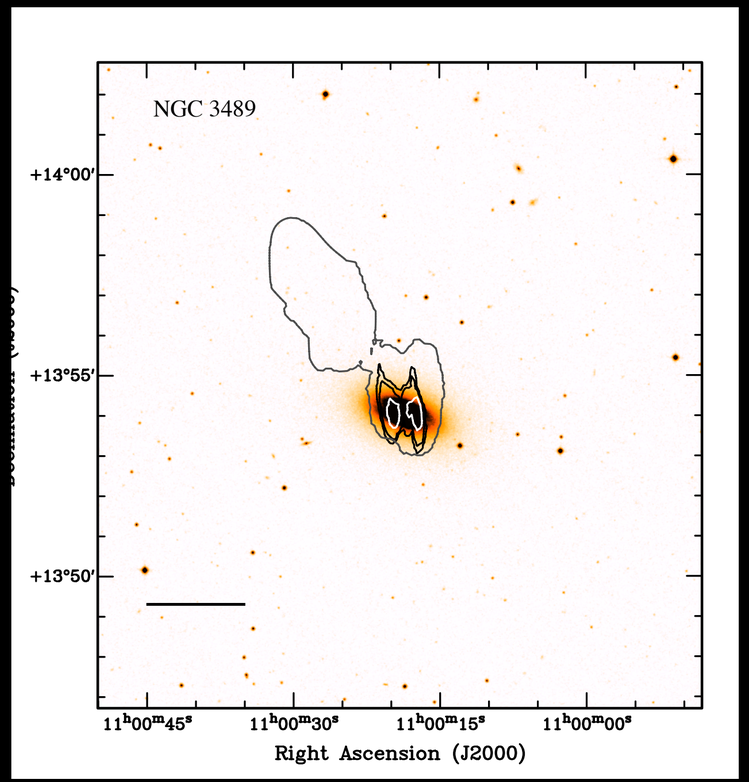


Accretion

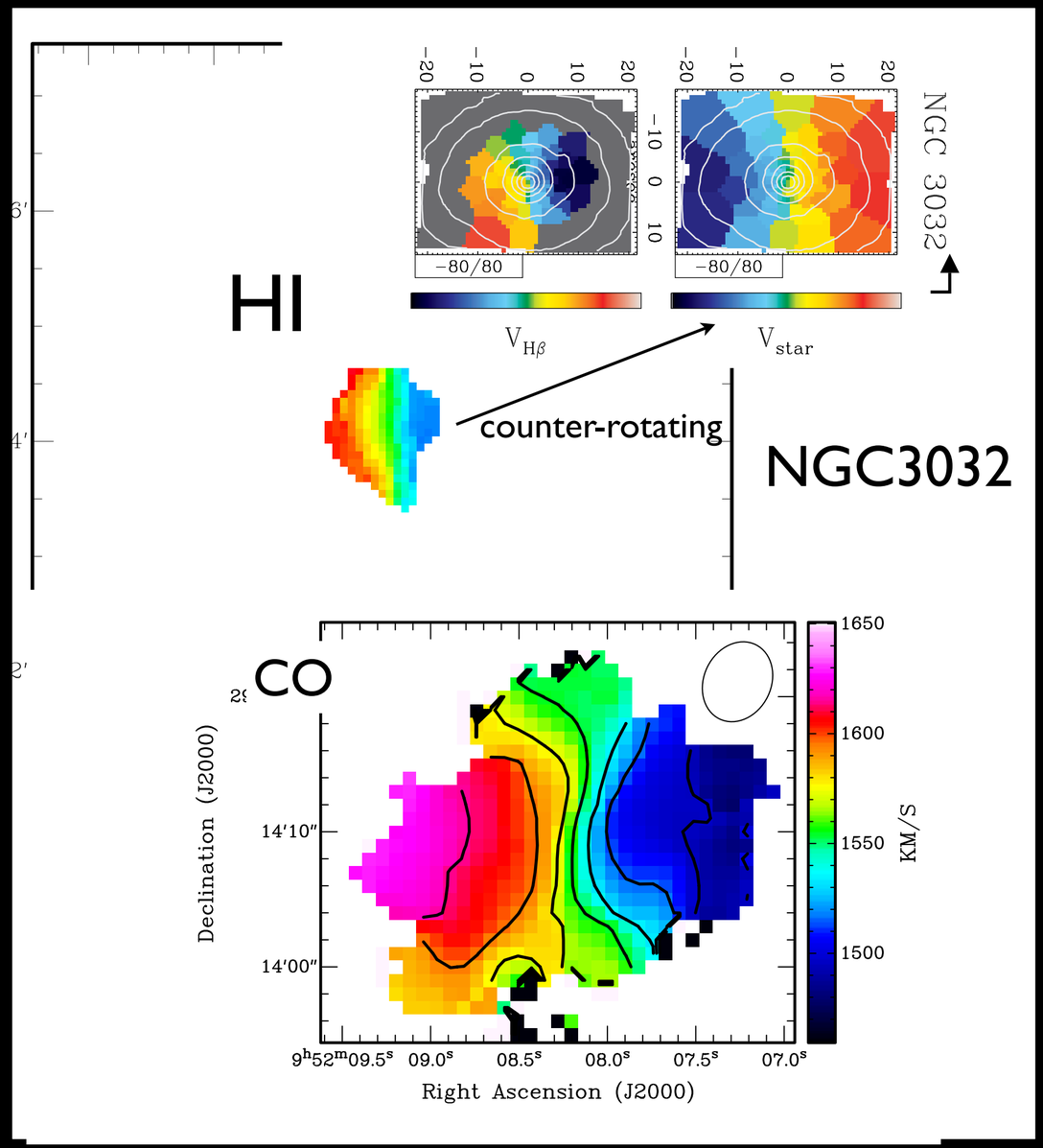
- Accretion very common (>50%),
  smaller amounts than spirals, ≲ 0.1 $M_\odot$ per yr.
  No major direct effect on galaxy
- See many cases of formation of
  small inner disk which is also seen in CO.
  Connection with KDC

NGC3489

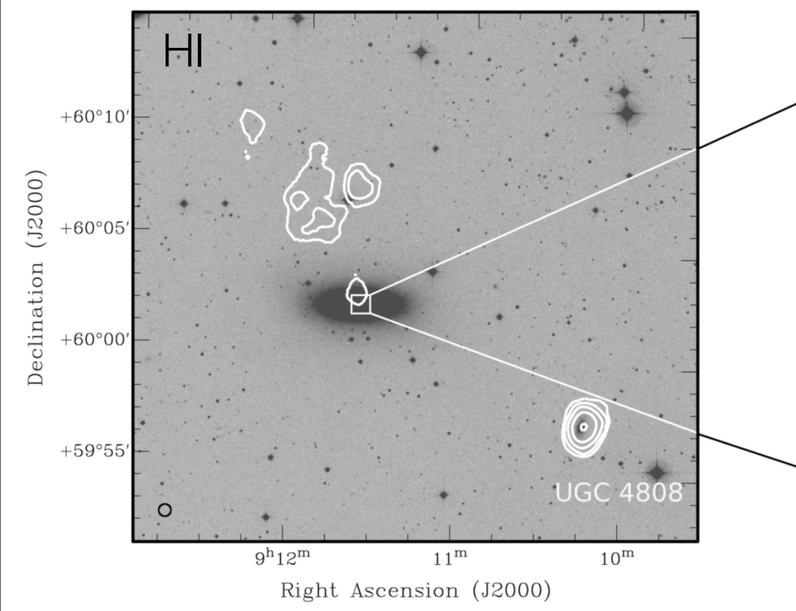
Remnant tail pointing to inner disk

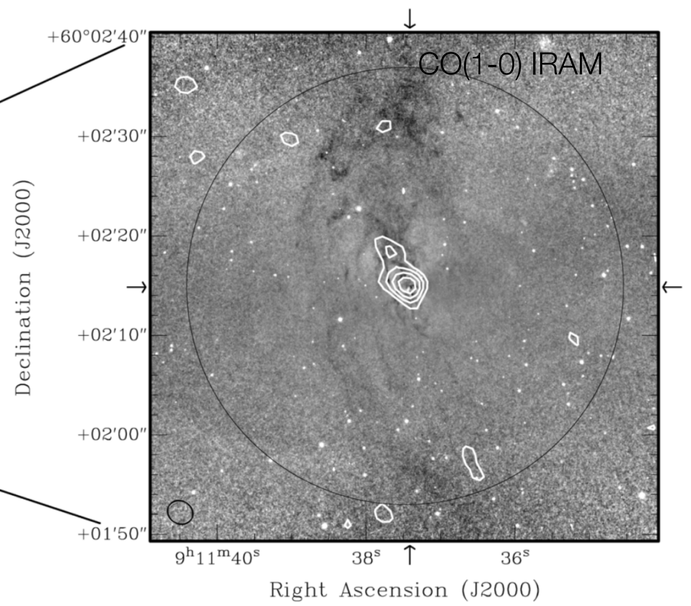


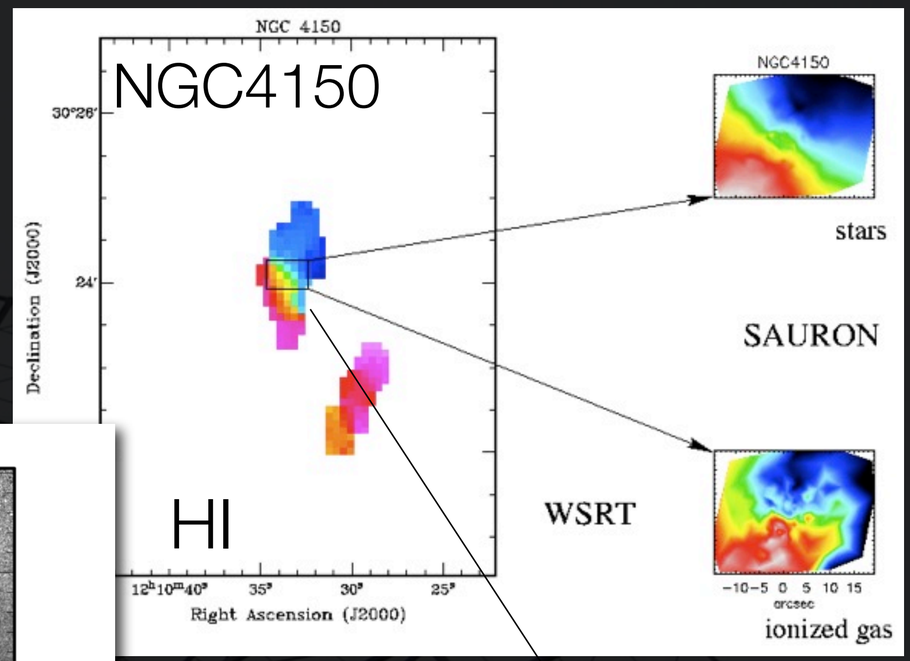
Small counterrotating CO disk in N3032,
also seen in HI

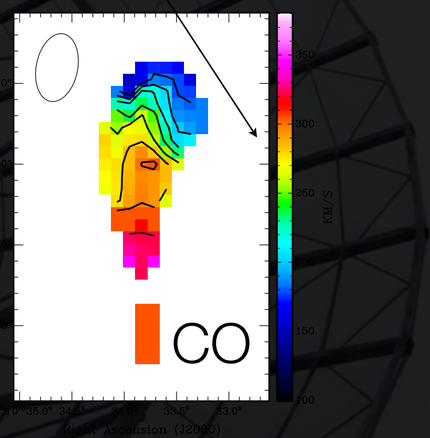


Other examples









- CO(1-0) data from Young et al. 2008
- Optical data from Sarzi et al. 2006
- HI from Morganti et al. 2006 and Oosterloo et al. 2010

Atlas^{3D} sample: Ellipticals and Lenticulars

- Problem with SAURON sample:
  - small; perhaps not as representative as one would like it to be
- Atlas^{3D} sample: volume limited sample: 260 galaxies < 42 Mpc brighter that M_K -21.5.
  Main selection criterion: no spiral arms or dust lanes (Sandage 1961, 1975),
  so include ellipticals and lenticulars. No colour selection
  Comprehensive study of ETGs;
  Large collaboration; optical (2D spec, imaging), CO, HI, UV, Xray, theory, simulations…
- PIs: Cappellari, Emsellem, Krajnovic, McDermid.

(arXiv:1012.1551, 1102.3801 1102.4444, 1102.4633, 1102.4877, 1104.2326, 1104.3545,1105.5654, 1105.4076,...)

Data……

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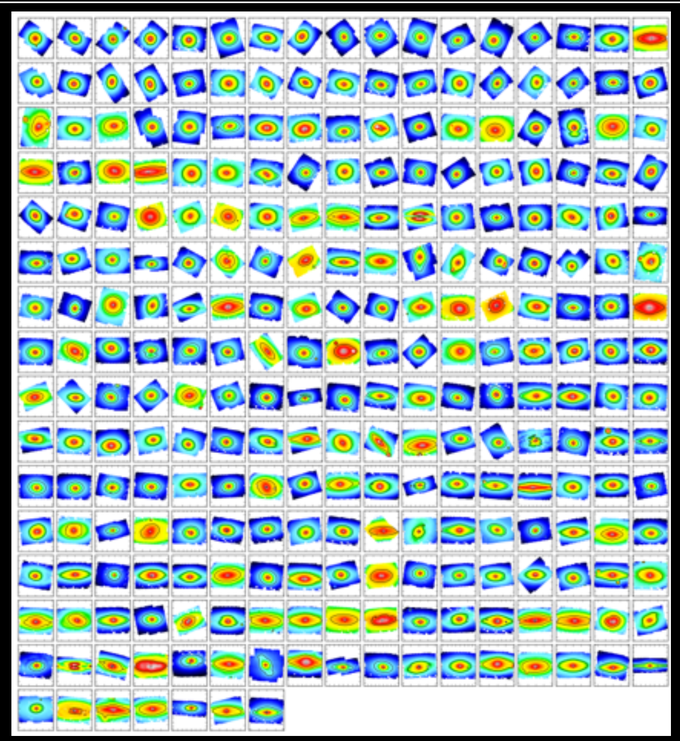

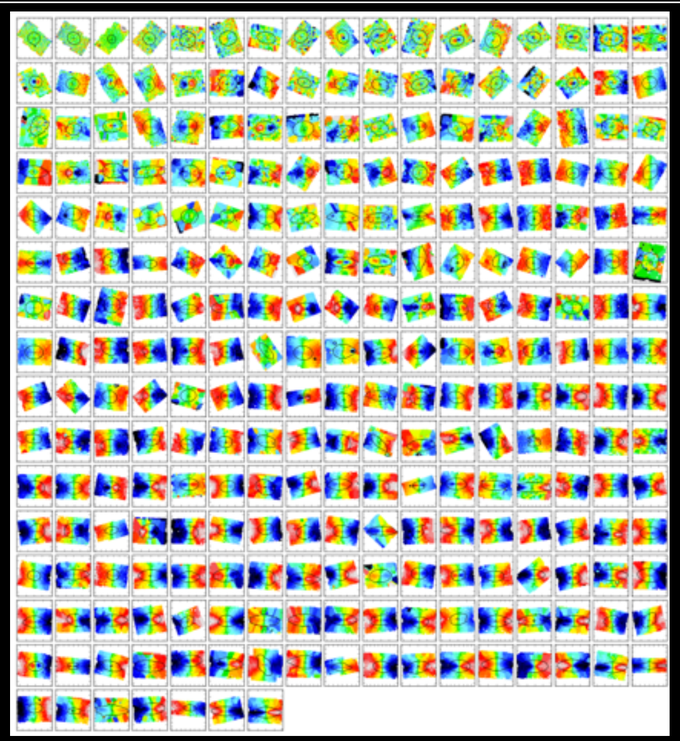

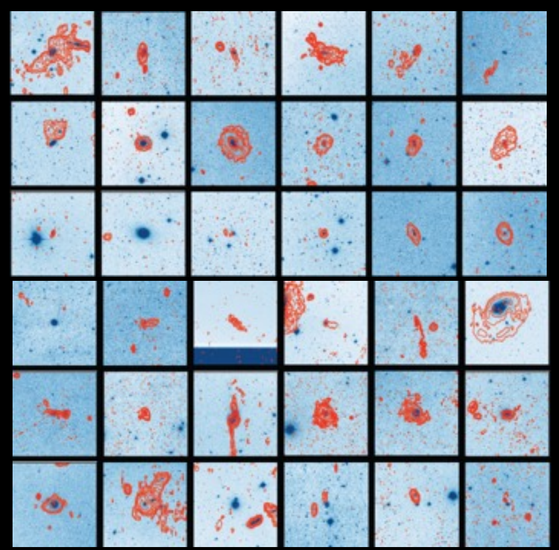

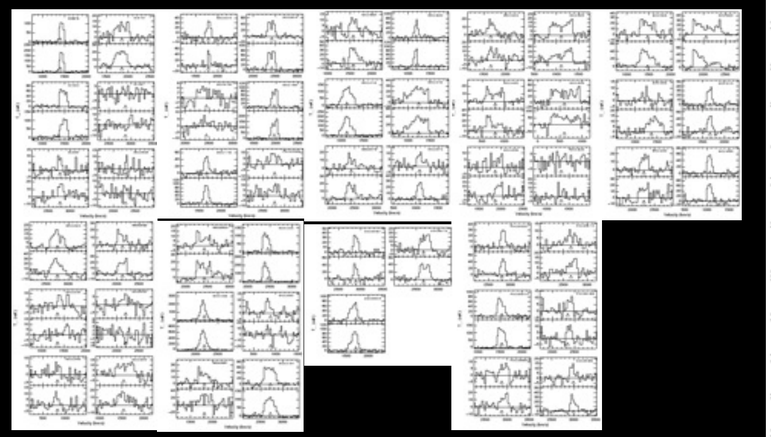

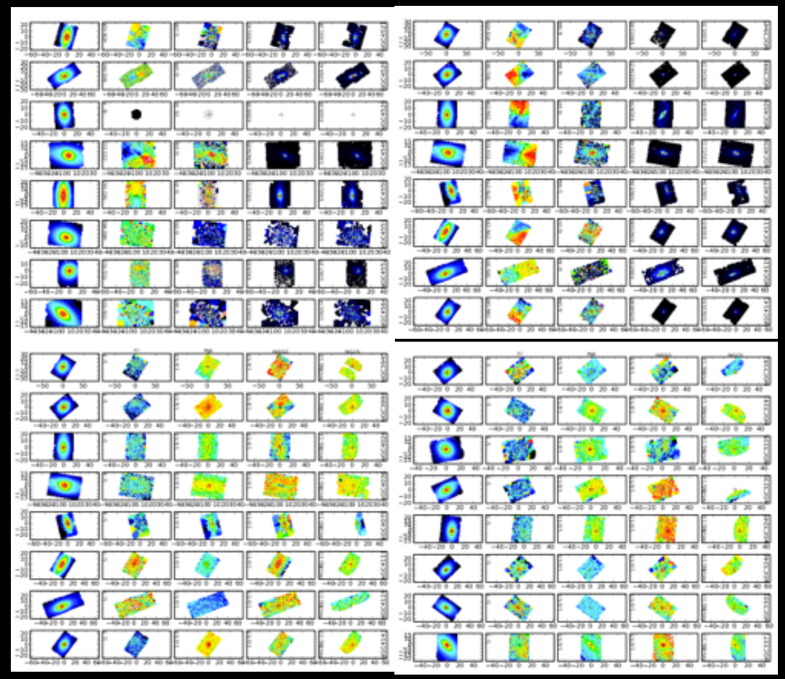

HI observations of Atlas^{3D} sample

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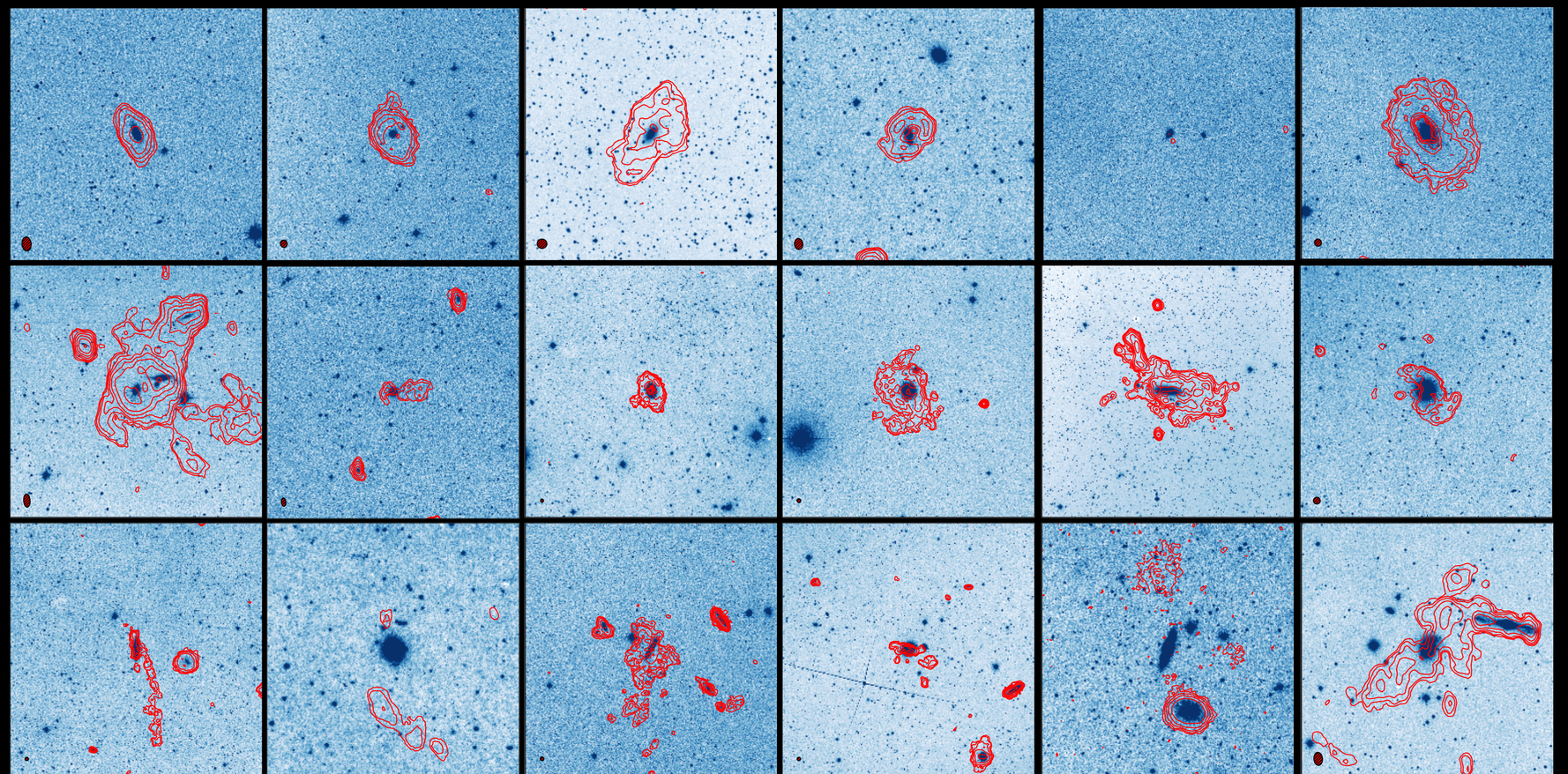
- WSRT observations of those Atlas^{3D} galaxies with δ>10°
  - 12 h per galaxy. Detection limit 10^6-10^7 $M_\odot$, $n_{HI,lim}$ 3-5 x 10^{19} cm^{-2}
    deep follow up on subset (10x12h)
  - Complements CO observations
  - large range in morphologies, many disks/rings (large and small), tails, clouds



Serra, Oosterloo, Morganti et al. 2011 almost ready!

Many regular disks/rings (50% of detections)

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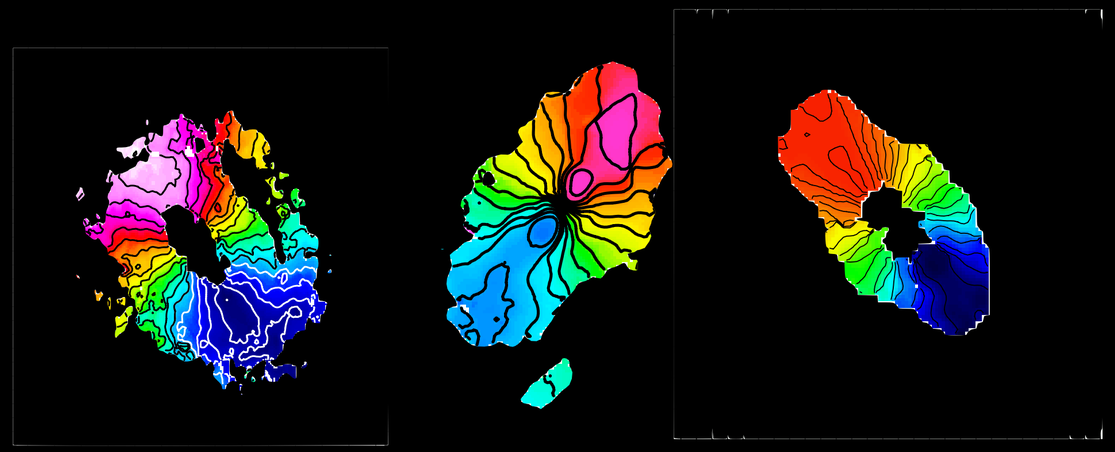
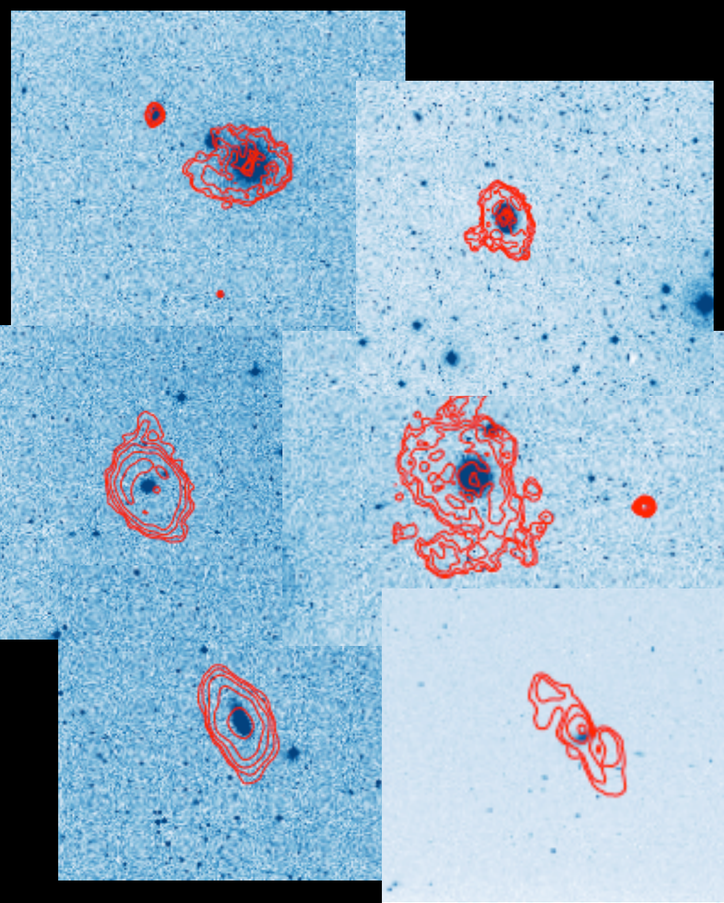
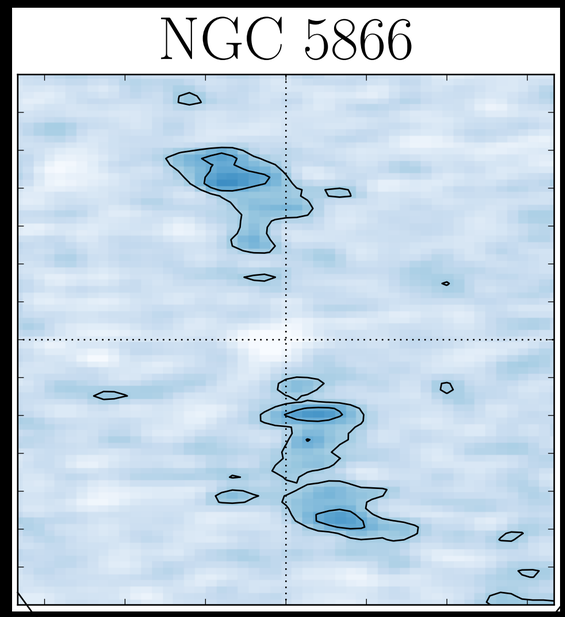


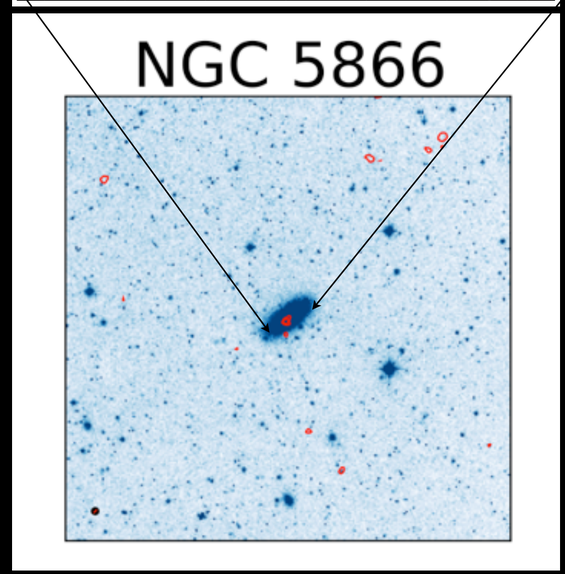


many are large
(many 10s kpc)

Note the small, irregular features at large radius

some are small,
few kpc
(and are also detected in CO)

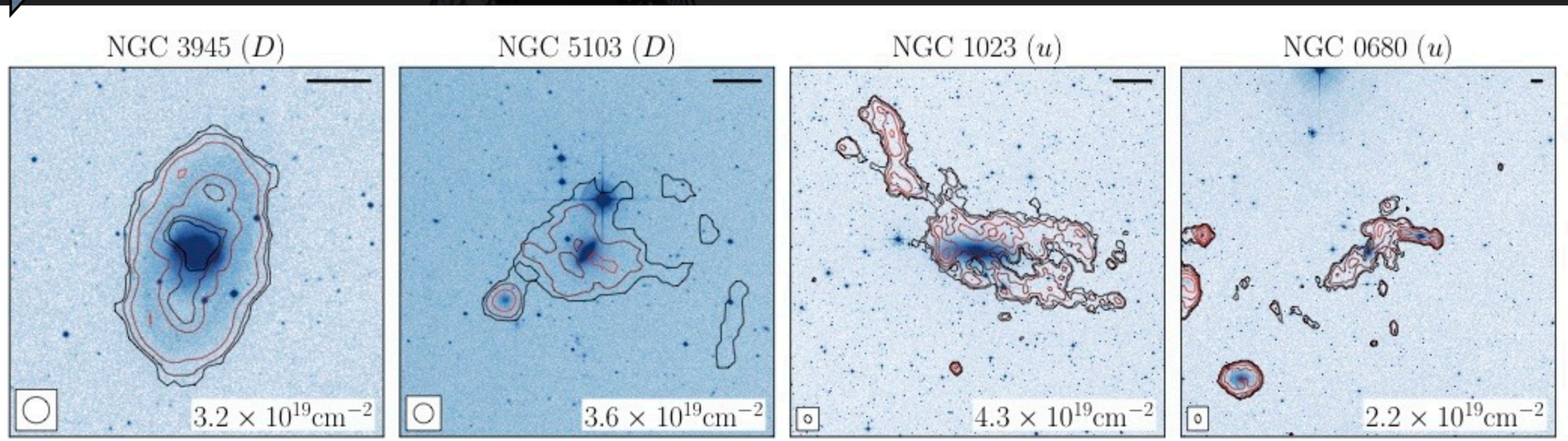




A continuum of HI morphologies sequence

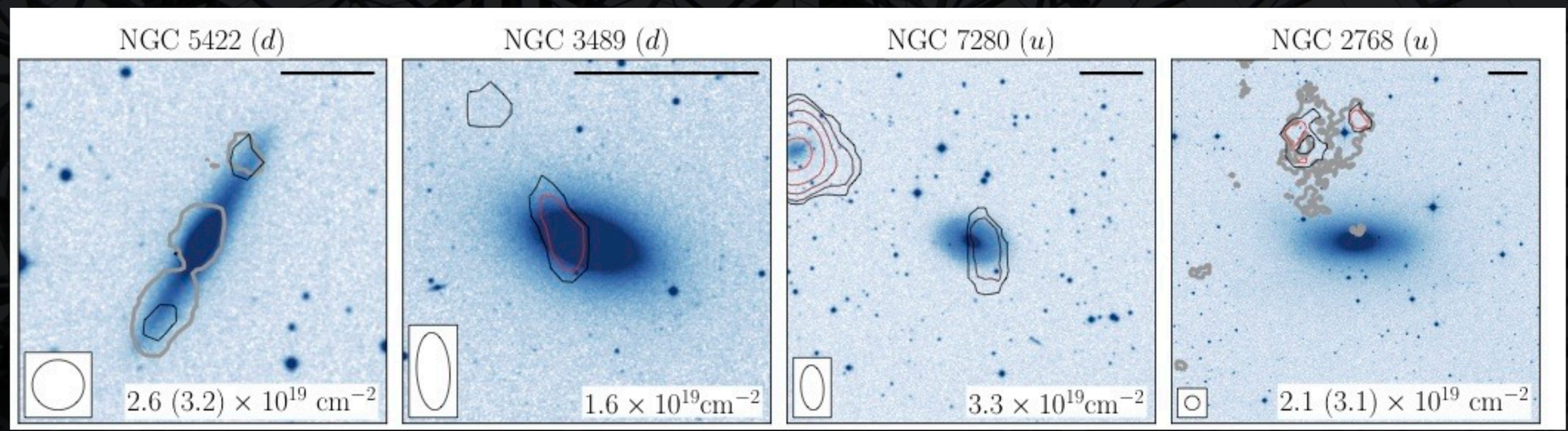
Serra et al. 2011

Sequences of HI-rich ETGs with increasingly less regular gas configurations



HI distribution of size very large compared to the stellar body

Shows how the HI structures form and evolve: accretion

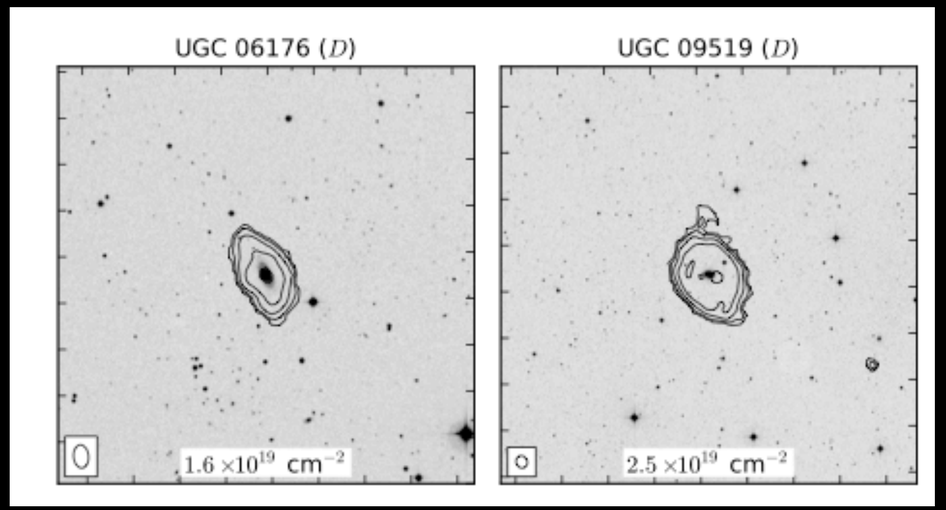


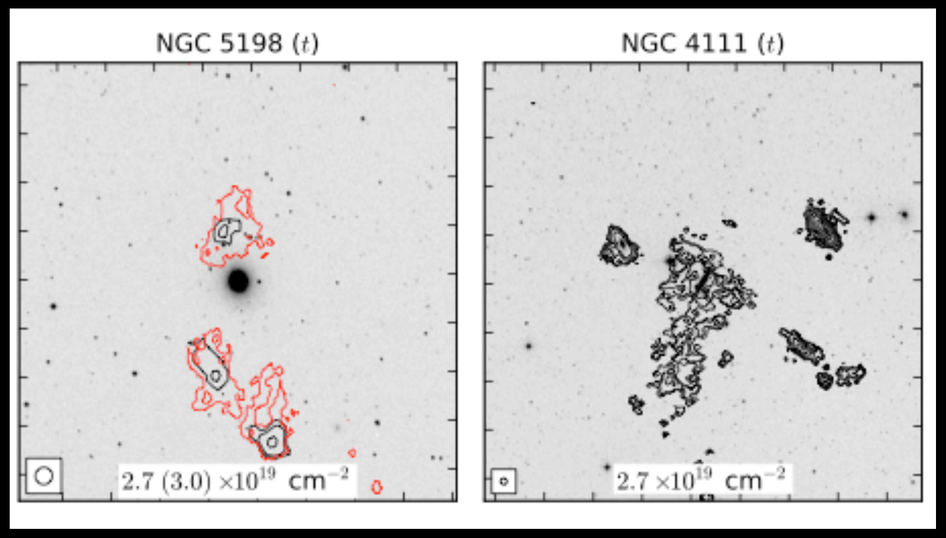
HI distribution of size similar to the stellar body

Environment

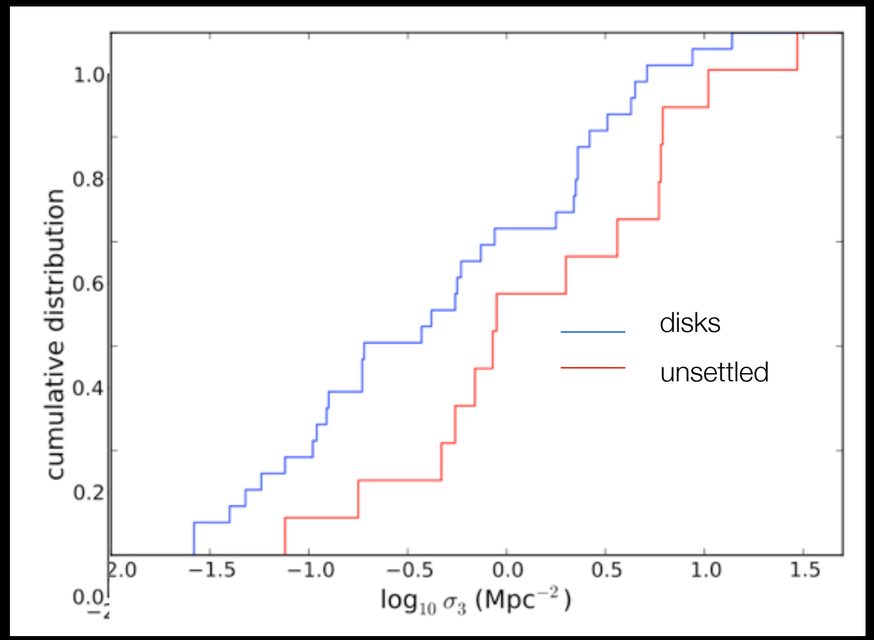
- HI morphology depends on small-scale environment
- Related to density-morphology relation?

low density

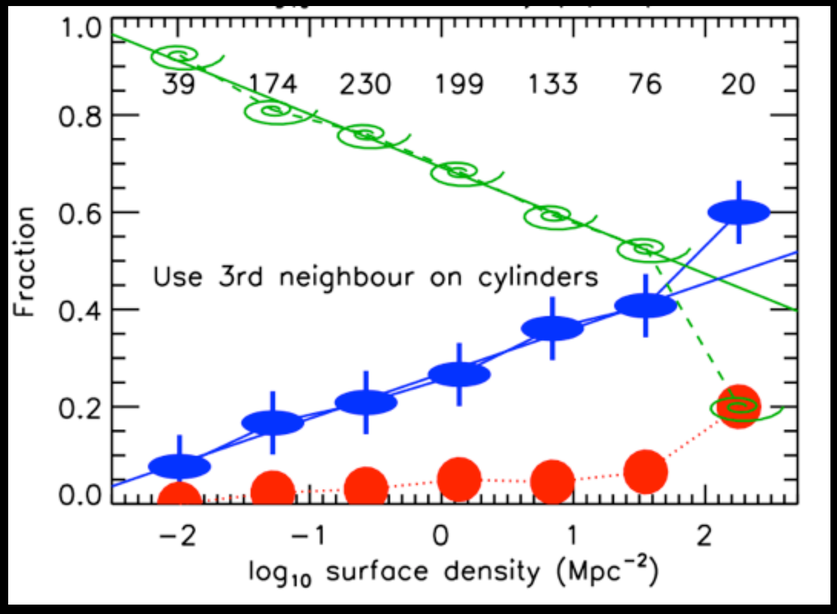




field, but high density



σ_3 is measure for galaxy density on scales of 1 Mpc



Cappellari et al. paper 7. arXiv: 1104.3545

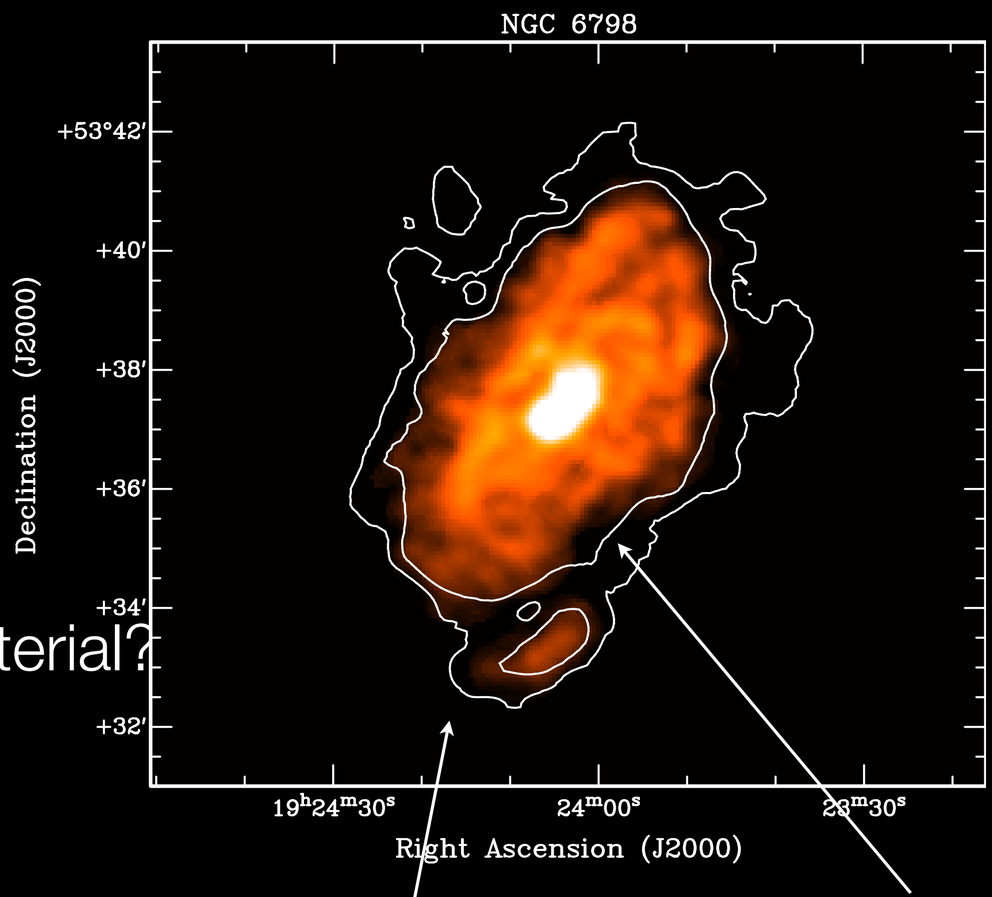
Even Deeper HI observations for some selected objects

Do not see evidence of effect of intergalactic radiation field on HI disks

'Expected': below column densities of a several x 10^{19} cm^{-2} HI disks should be ionised. Should see truncation of outer HI disk.

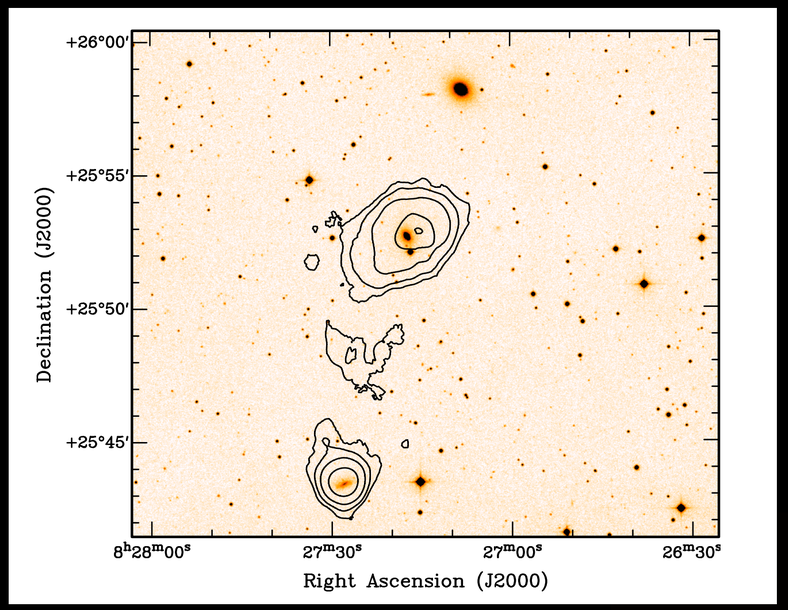
Do not observe such edges of HI disks.
Outer HI disks consist of clumps of accreting material?

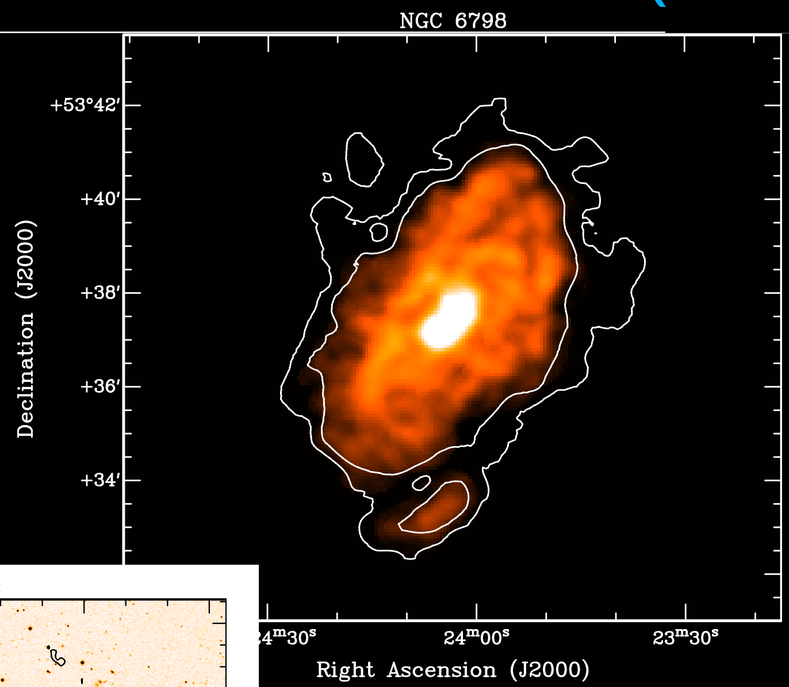
Very similar to outer regions of spirals

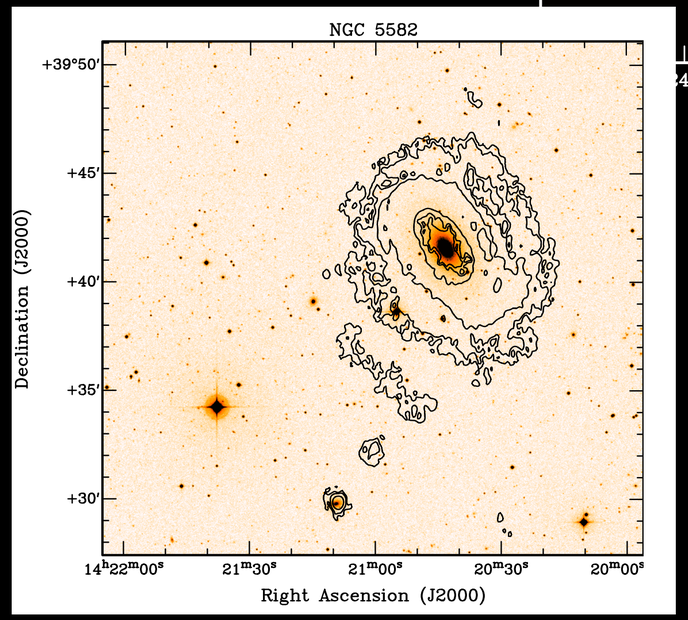


Deep HI observations

Evidence of accretion/interaction in all galaxies







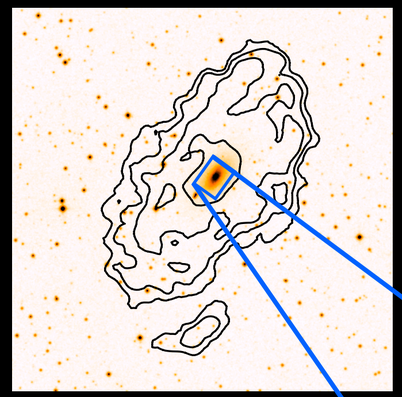
Spiral-like streaming motions, HI still settling.
Timescale few x 10^9 yr (z ~ 0.3-0.5)

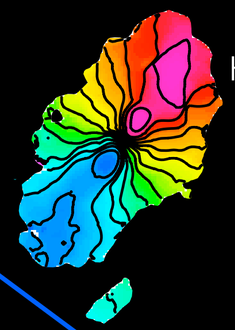
More signs of accretion

HI disk (90 kpc diameter) counterrotating to stars - co-rotating with ionised gas

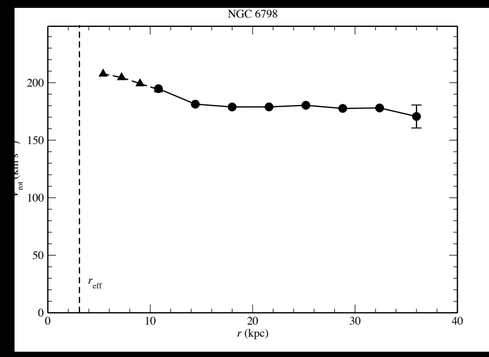
Not your regular S0

NGC 6798

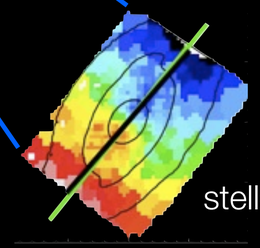




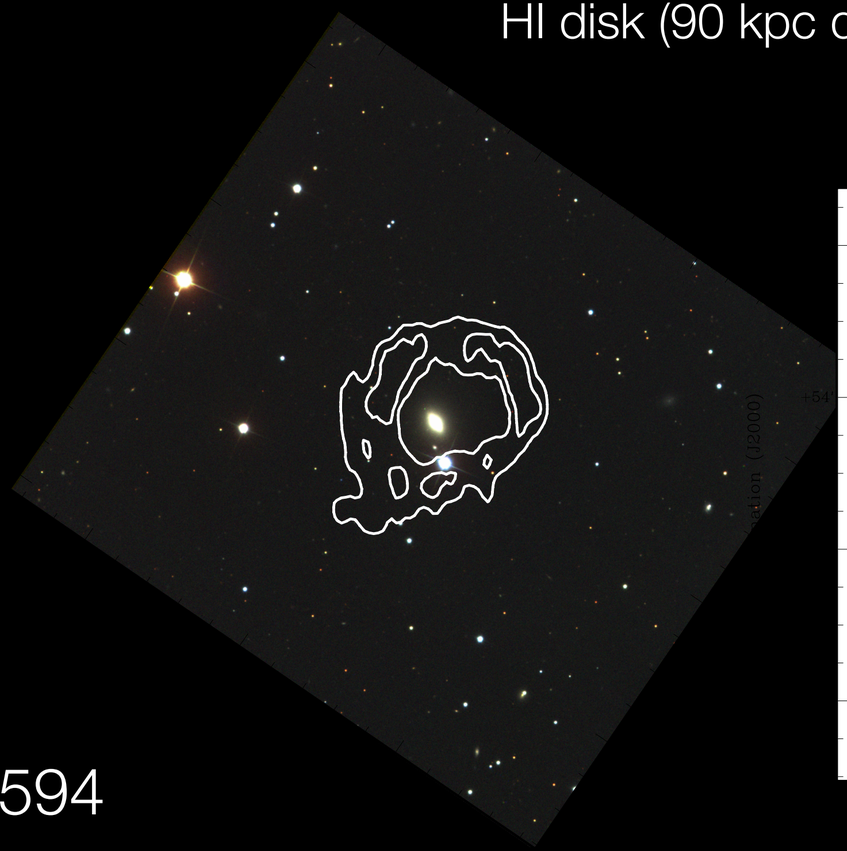
HI velocity field

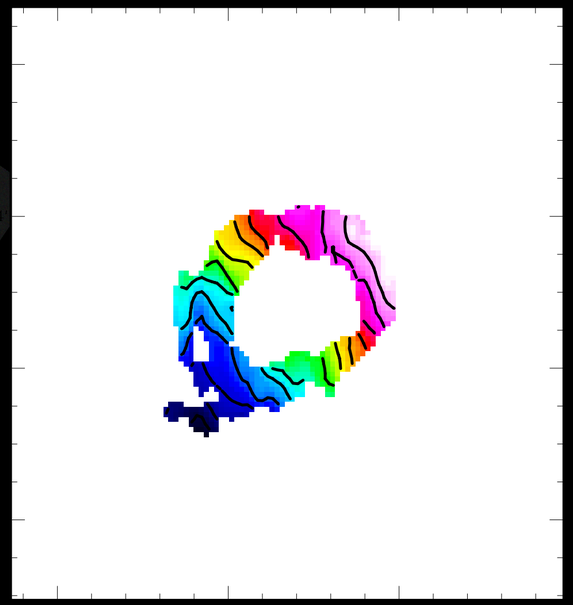


HI disk (90 kpc diameter) **counterrotating**



stellar velocity field





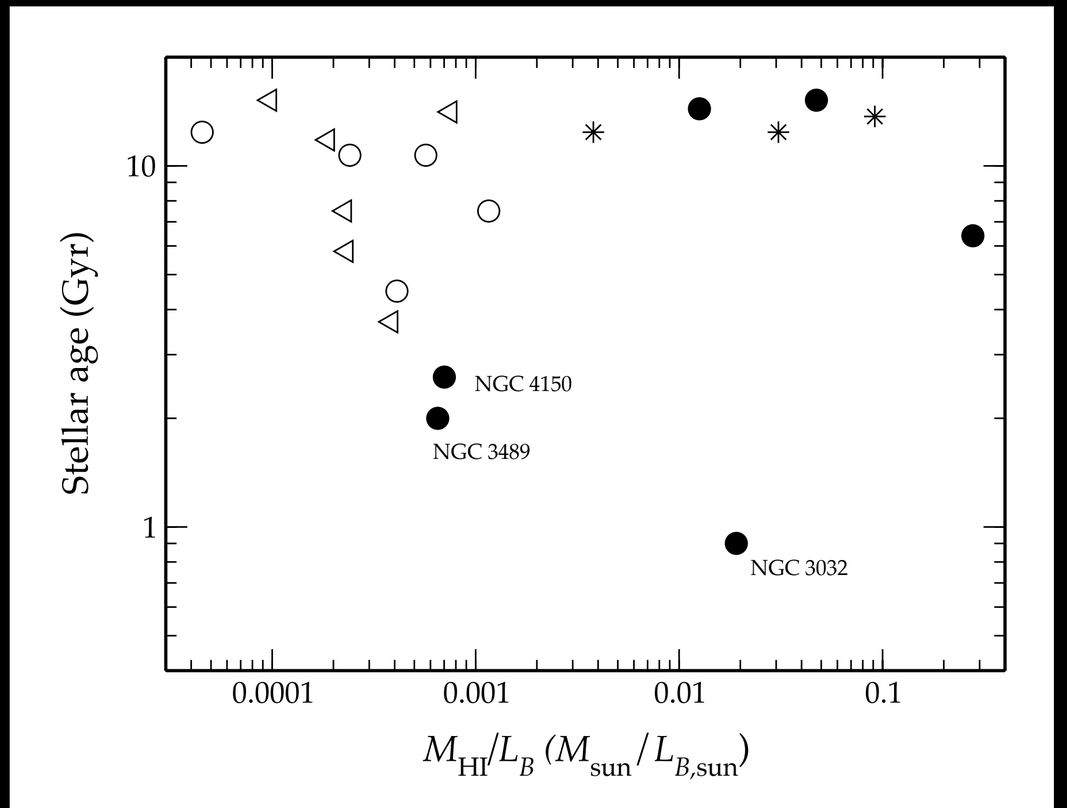
NGC 2594

Many polar gas rings and 90-degree warps

Stellar population

- Continuing accretion may have influence on stellar pop, but no strong trend with current HI content

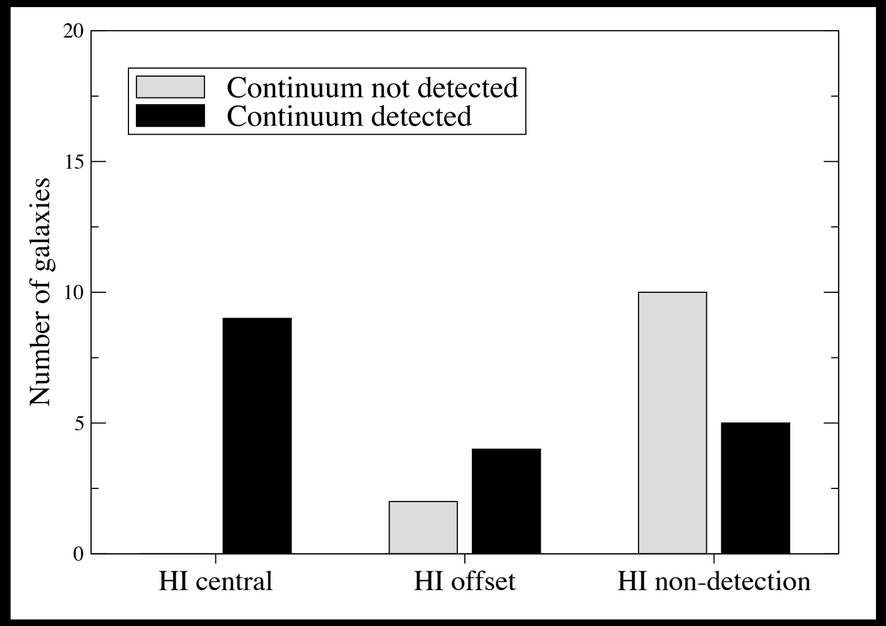
Some galaxies are (very) gas rich, but have old stellar population



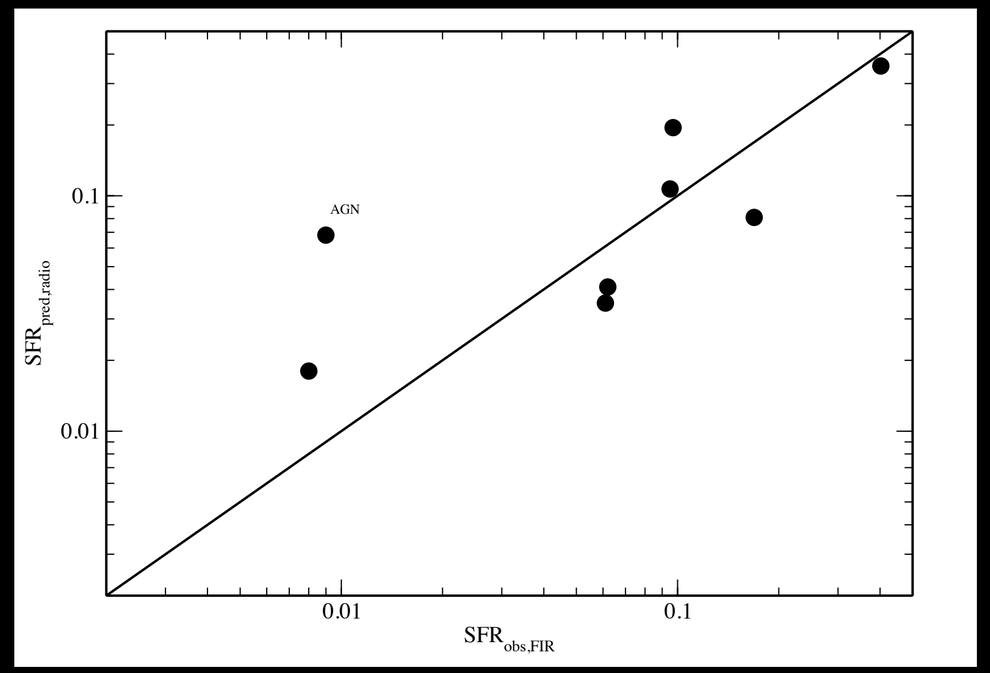
- Exception: galaxies with small inner gas disk have young stars in centre

HI and radio continuum

- Many galaxies also detected in radio continuum (most at mJy level)
- Star formation or AGN?
- Use high-res radio data to look for AGN



Oosterloo et al. 2010



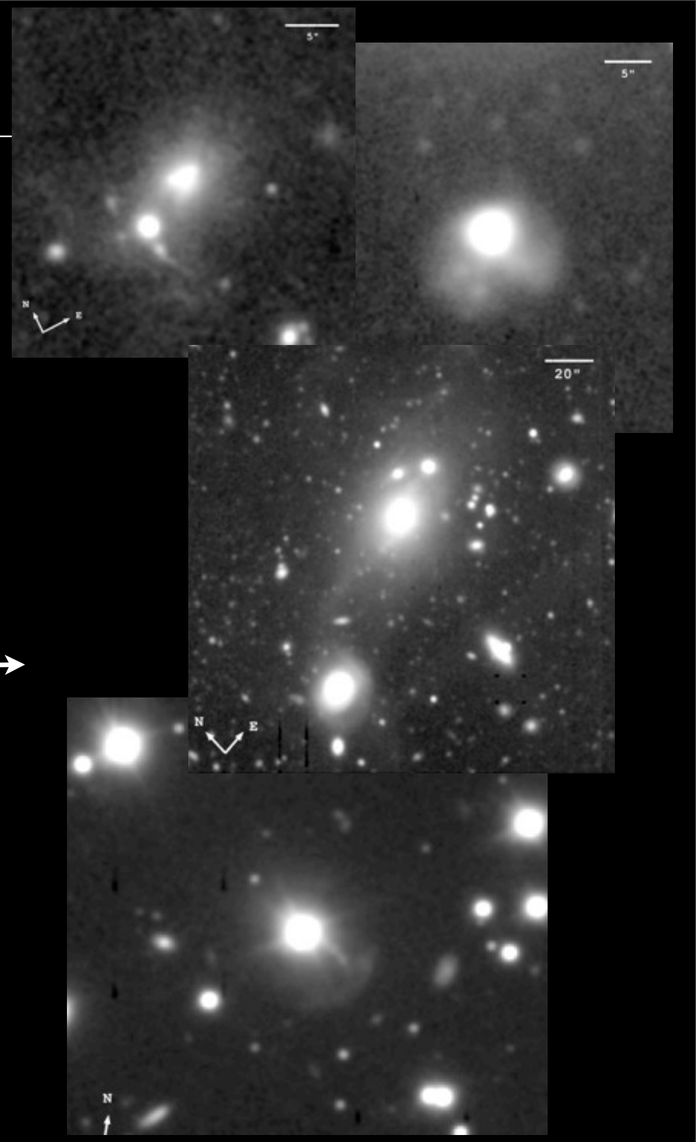
SFR from Spitzer

Follow radio-FIR relation

Galaxies with central HI are more likely to be detected in continuum.
Due to star formation, not AGN.

Radio galaxies and minor mergers

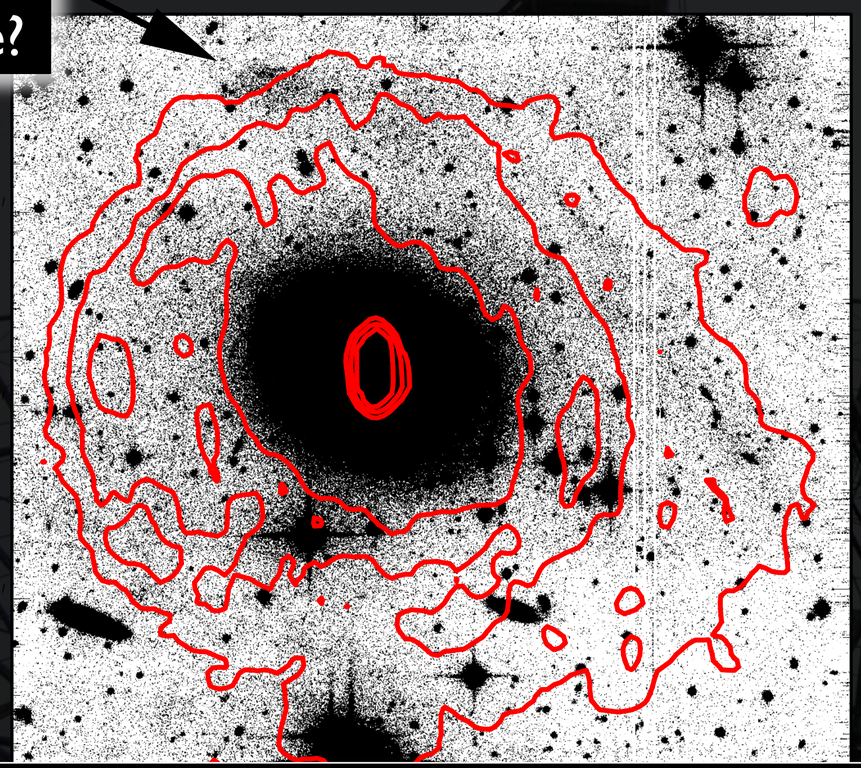
- Young stellar population detected in ~30% of radio galaxies: likely fraction of galaxies resulting from major mergers (Tadhunter et al. 2011)
- but sign of interaction/accretion in the majority of the galaxies (Ramos Almeida et al. 2011)
- ....but is the interaction really responsable for the triggering of the AGN?
- Two cases: NGC1167 and Centaurus A



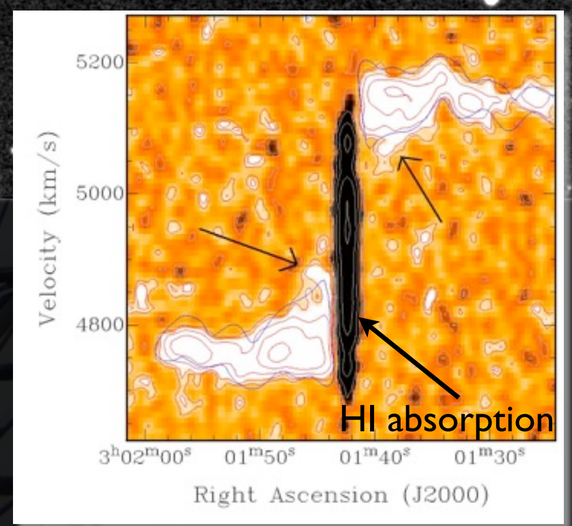
NGC1167: many accretion of small satellites?

Struve, Oosterloo, Sancisi, Morganti, Emonts A&A 2010

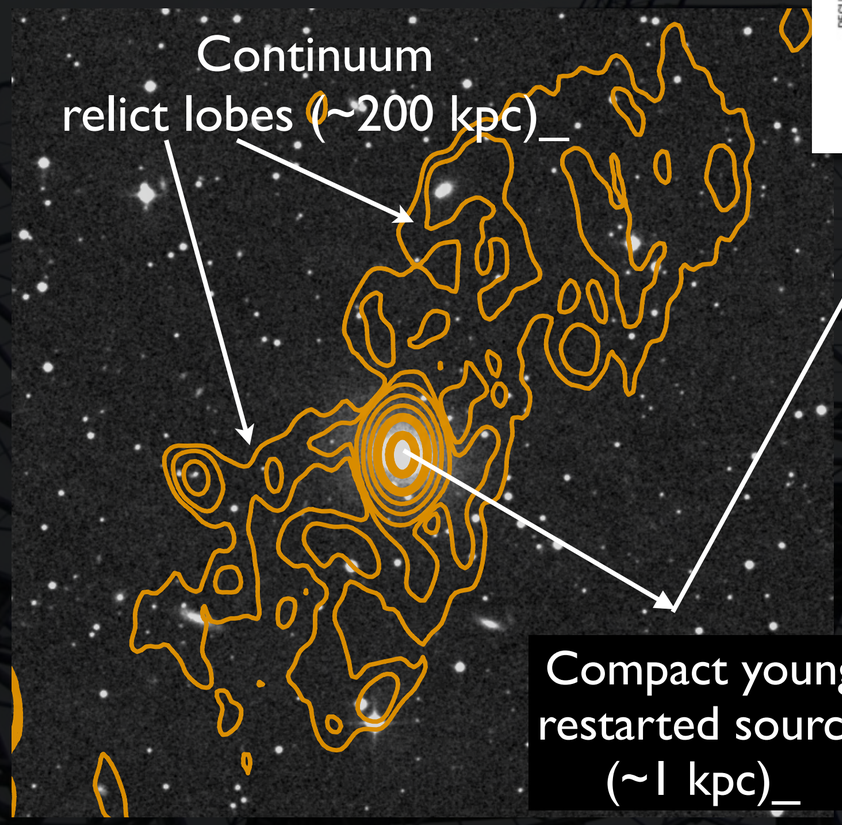
Disrupted satellite?

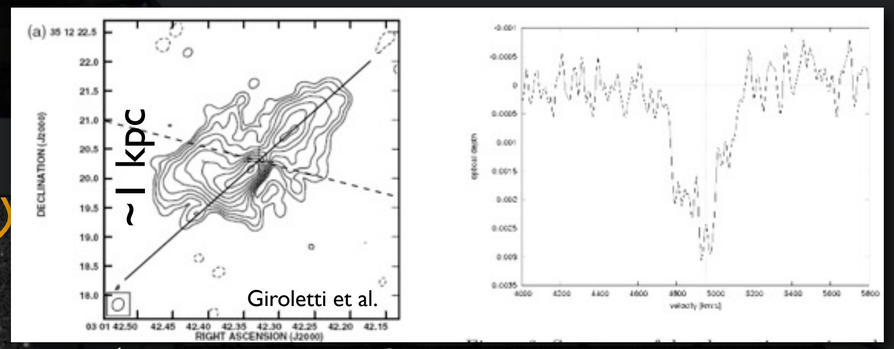


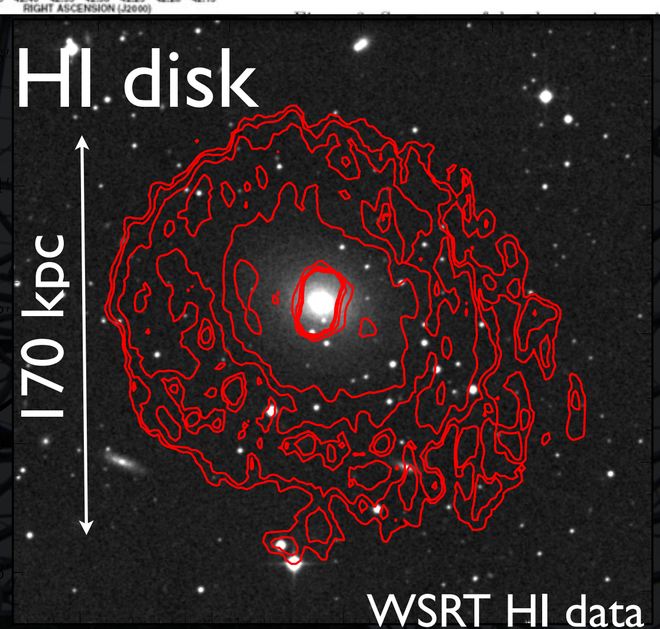
- Huge HI disk → ~170 kpc with more than 10^{10} $M_\odot$ of cold gas
- Very regular kinematics → but disturbances in the outer parts and evidence for a disrupted satellite
- No "diffuse" accretion from small gas cloud, no HI halo
- No widespread starformation
- A large fraction of the HI disk was built up via minor mergers (and interactions) in the course of several Gyr
- Any relation between these mergers and the AGN activity?



B2 0258+35: recurrent activity and large reservoir of gas







Struve, Sancisi, Oosterloo, Morganti 2010
Shulevski in prep.

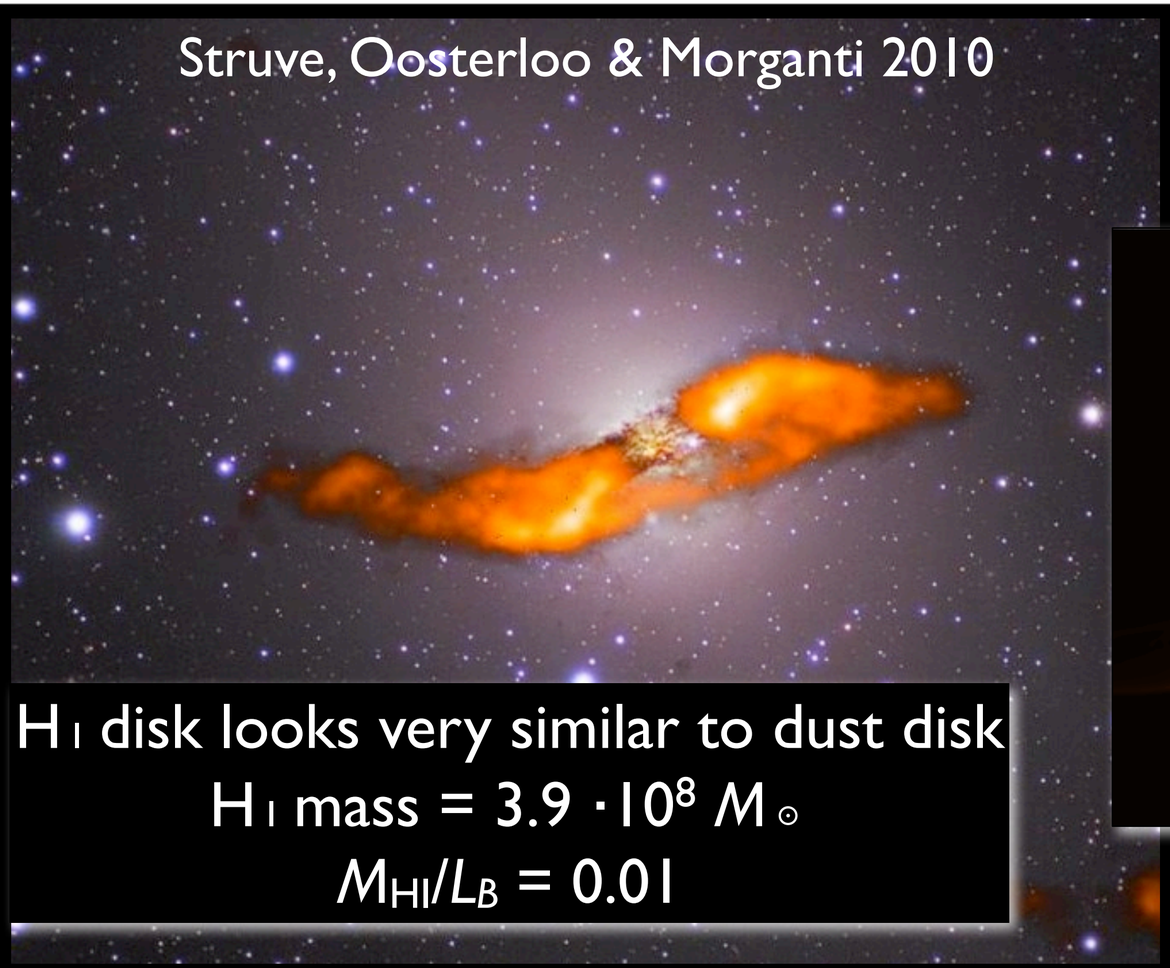
- Recurrent radio emission => young radio source (10^6 yr) plus a large structure possible left over of previous phase of activity (at least 10^8 yr)

- What is the trigger of these different phases of activity? Same minor mergers likely forming the HI disk?

- No particular features in the HI distribution: cannot have been a large event

- Study of the central HI (absorption) in progress

HI in Centaurus A: latest news

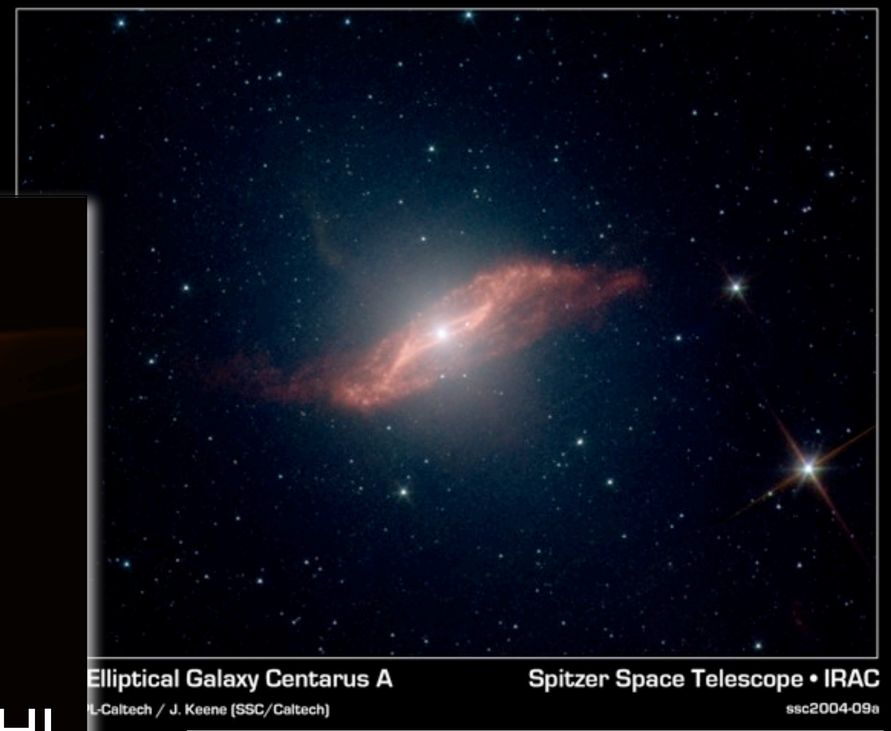


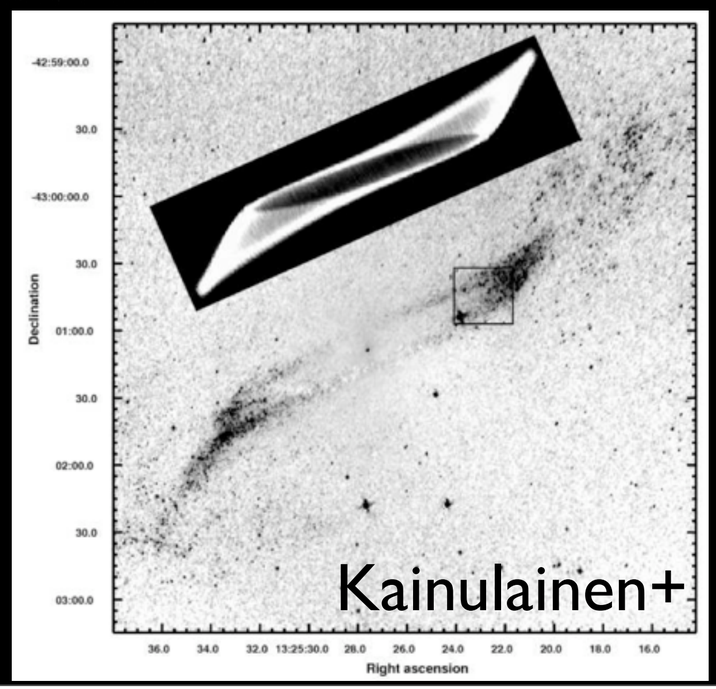
H I disk looks very similar to dust disk

H I mass = $3.9 \cdot 10^8 M_\odot$

$M_{HI}/L_B = 0.01$

Modelling of the HI



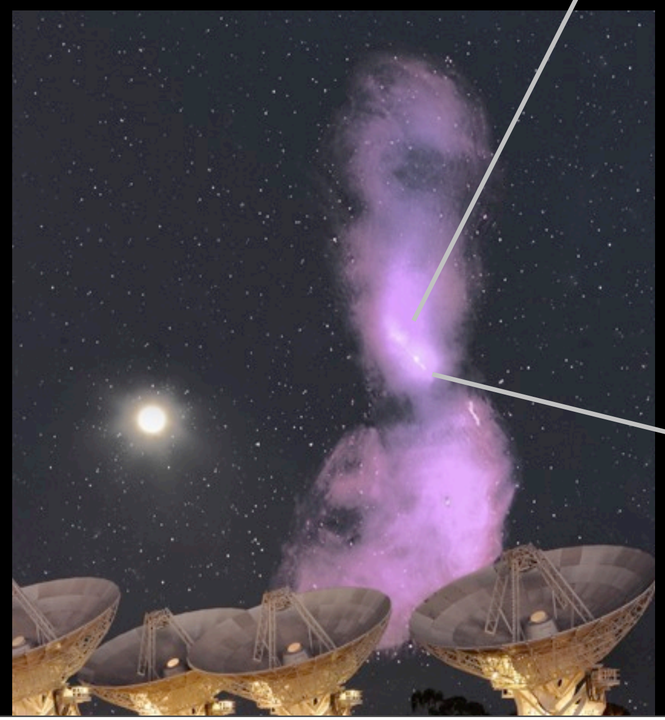


- Regular kinematics inside 5 kpc
  Asymmetries and filaments at larger radius
  No need for non-circular orbits between <5 kpc
  Reproduces H I kinematics & shape dust disk (and stellar ring)
- $M_{HI}/L_B = 0.01$, so H I disk might well be the result of **accretion of small (SMC-like?) galaxy**

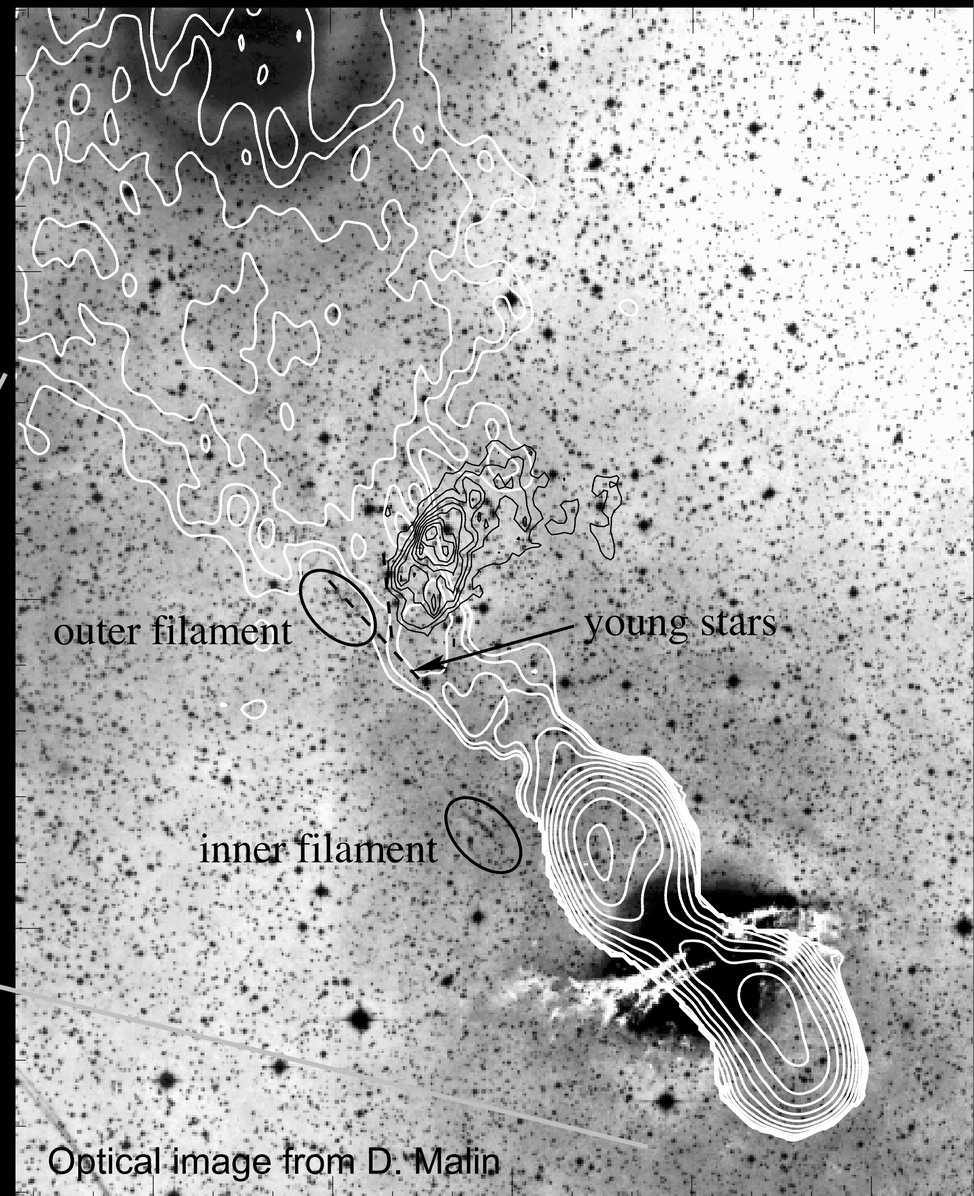
Merger/accretion and activity

- Difficult to reconcile time scales?
- Age merger few x 10^8 yr (consistent with other indicators, e.g. warp structure, stars associated with the young blue tidal stream ➔ 300 Myr, Peng et al. 2002)
- Too old for triggering recent AGN activity? 10^6 yr inner lobe (Croston et al.), $>10^7$ yr outer lobes
- Connected to previous episode of AGN activity?
- Merger actually disrupted the plasma flow (Saxton, Sutherland, Bicknell 2001)?

The delay would represent the time to recover from this!?



APoD 13 April 2011
Centaurus A - 1.4GHz ATCA
Feain et al.



Summary

- ~50% of field ETGs have HI (detection limit 10^6-10^7 $M_\odot$); only few % of ‘cluster’ ETGs have HI. HI mass function is flat; HI has low column density. Environment very important
- Diverse HI characteristics. 50% have HI in regular HI disks of low column density. Lenticulars more often have HI disks, but exceptions exists
- Field: accretions very common, but of small amounts, $\lesssim$ 0.1 $M_\odot$ per yr. Only subtle effects on galaxy, only after long time. Do see formation of inner disks and KDCs;
- No strong relation between HI and stellar pop. Some galaxies are very HI rich but no young stars. Exception: small inner disks .
- Most cold ISM in centre is molecular (10:1)
- Galaxies with central HI are more likely to be detected in radio continuum. Due to star formation, no connection with AGN
- relation to AGN?

Next step: ASKAP, Apertif, MeerKat, EVLA - 10,000++ galaxies not only local Universe 2014+