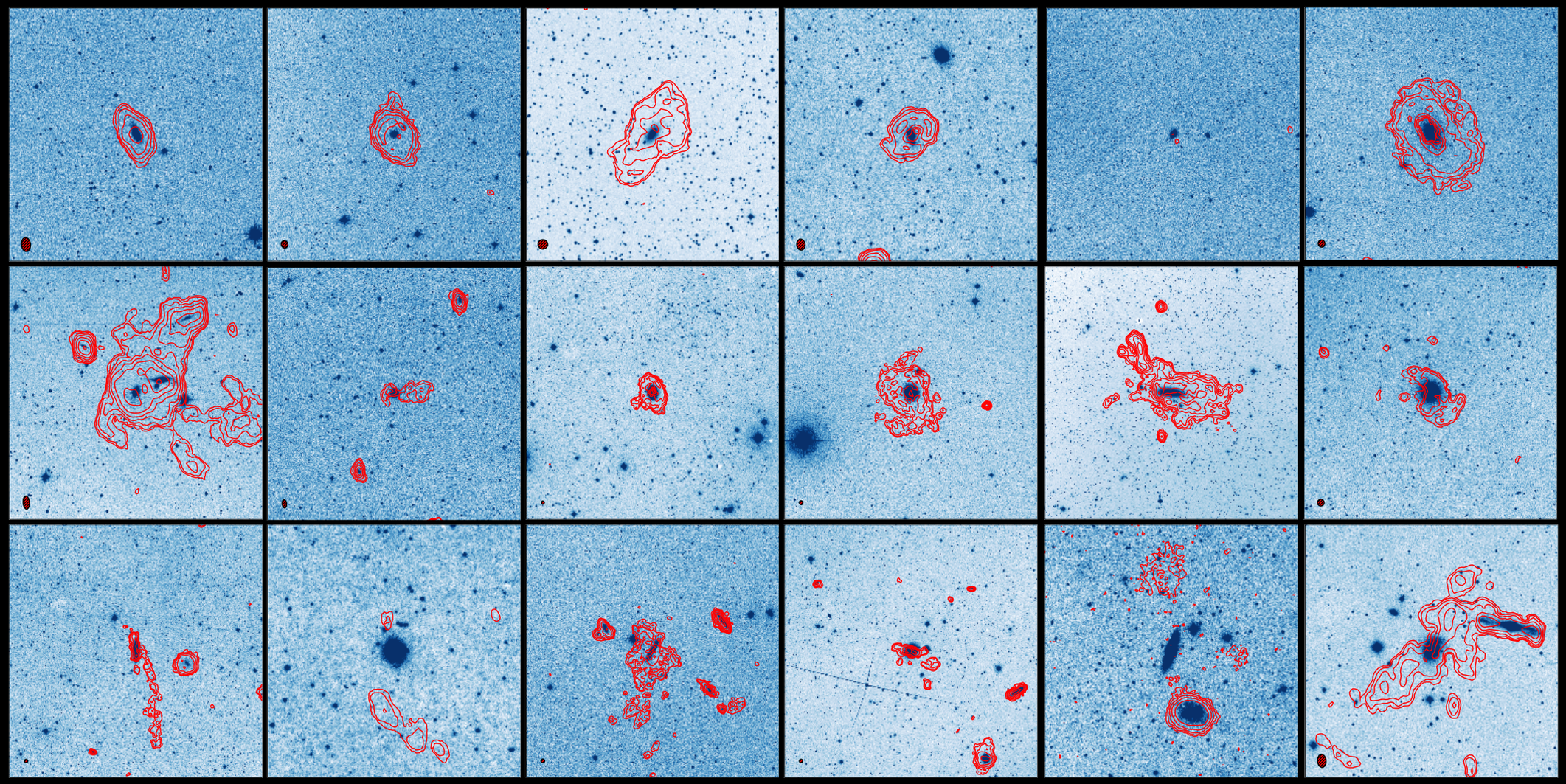
Neutral hydrogen in early-type galaxies: results from ATLAS^{3D}



Tom Oosterloo
ASTRON & Kapteyn Institute

Raffaella Morganti
Paolo Serra
ATLAS^{3D} collaboration

Why study gas in gas-poor galaxies?

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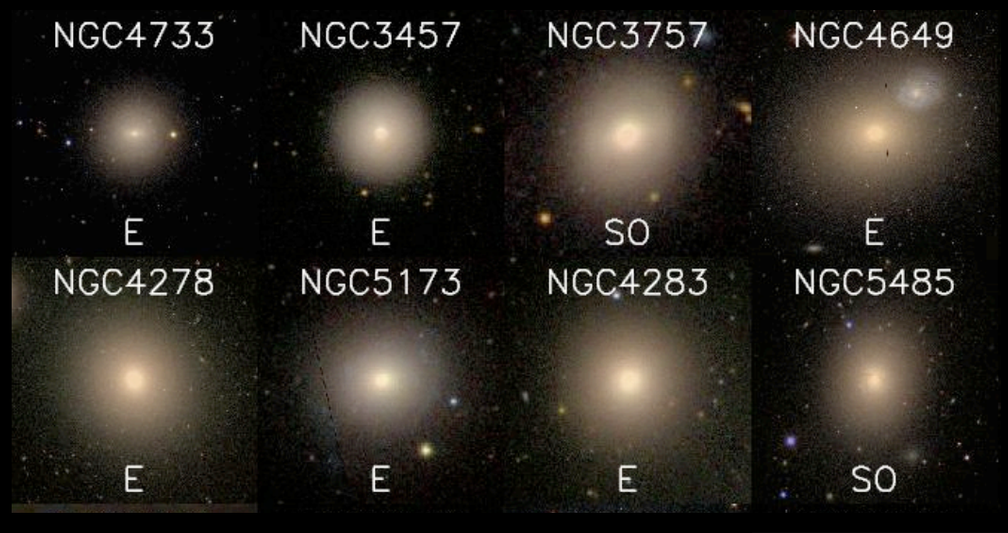
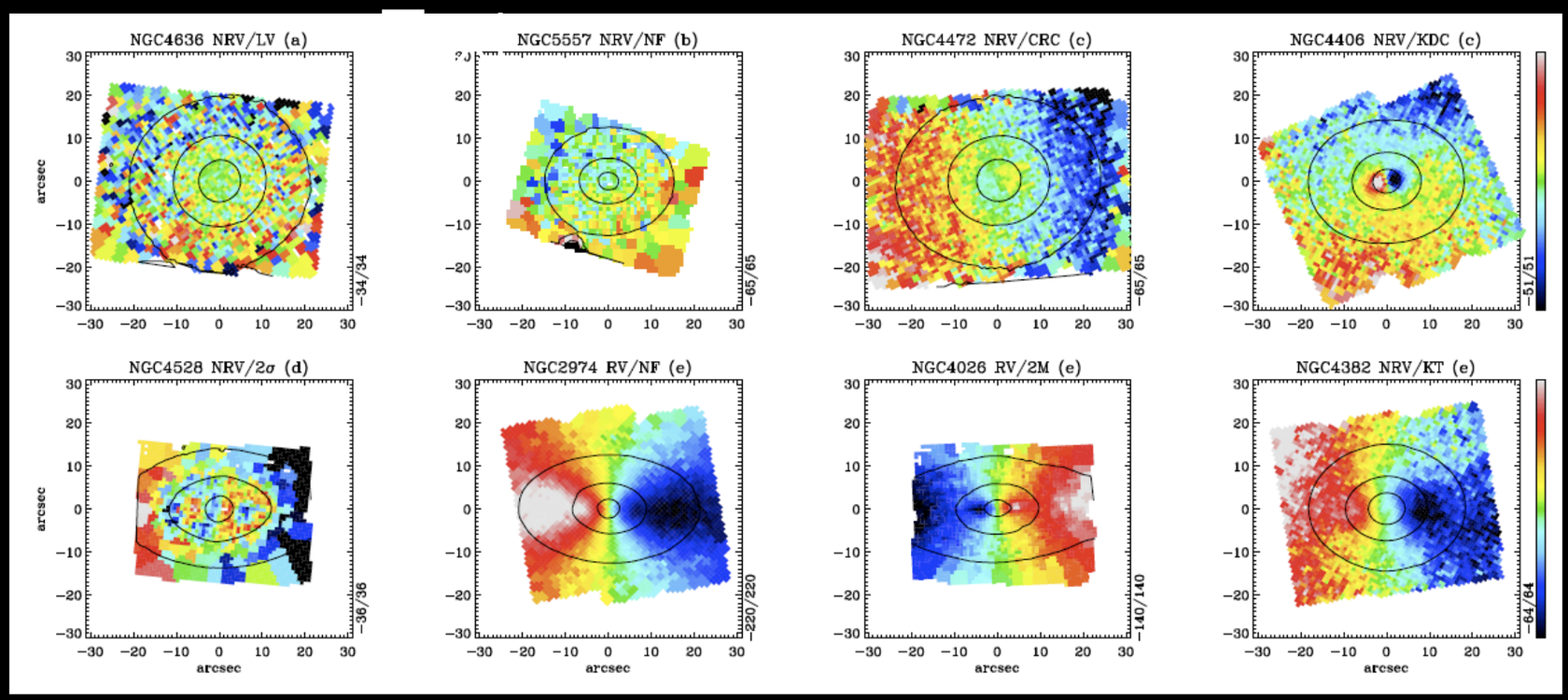
Early-type galaxies are not the amorphous blobs they appear to be





Krajnovic+ 2011

Complex kinematical structure suggests complex evolution.

Why study gas in gas-poor galaxies?

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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?

The role of HI in the evolution of ETGs

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- 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

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

- ASKAP, Apertif, MeerKat, EVLA - 10,000++ galaxies, z > 0 2014+

Atlas^{3D} sample: Ellipticals and Lenticulars

ASTRON

- 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,...)

Atlas^{3D} sample: Ellipticals and Lenticulars

ASTRON

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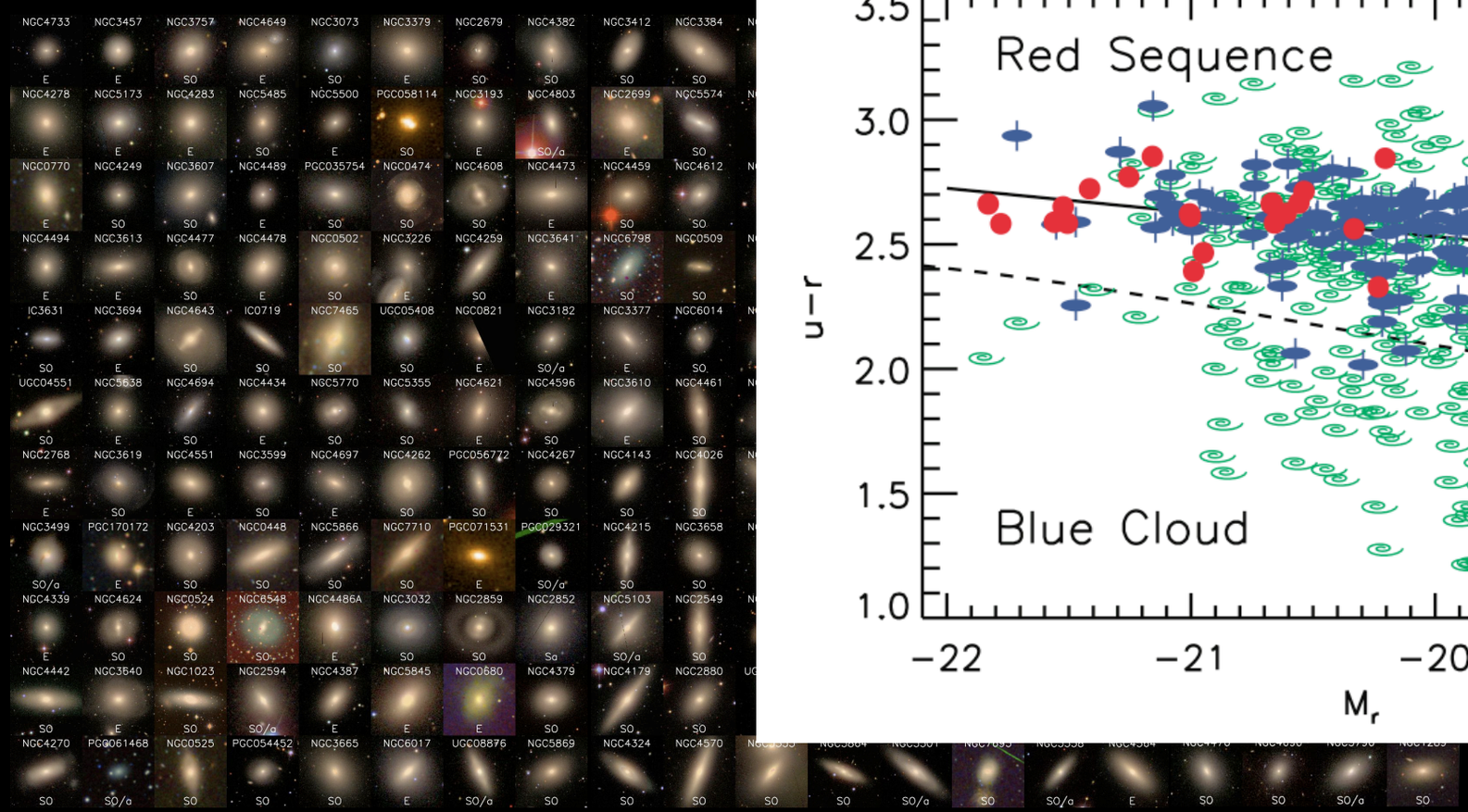
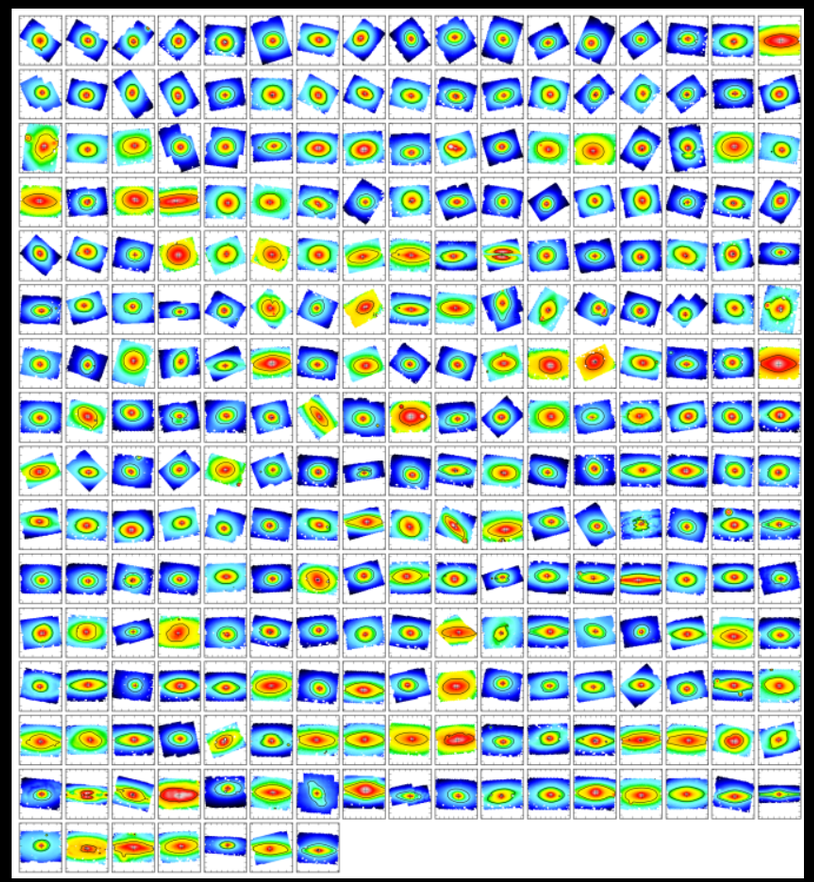
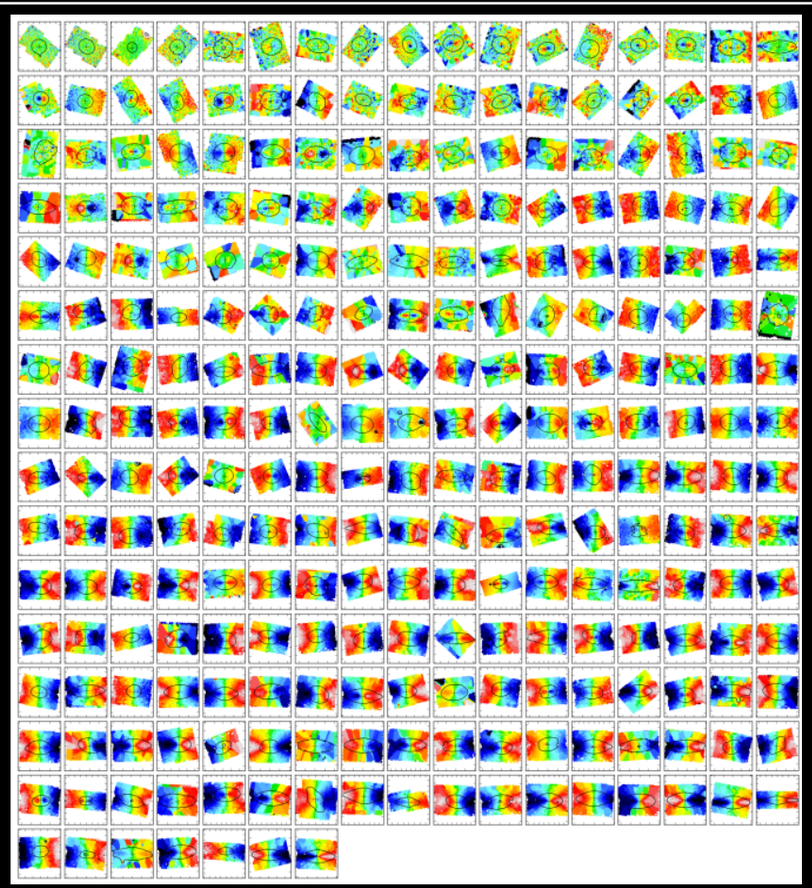
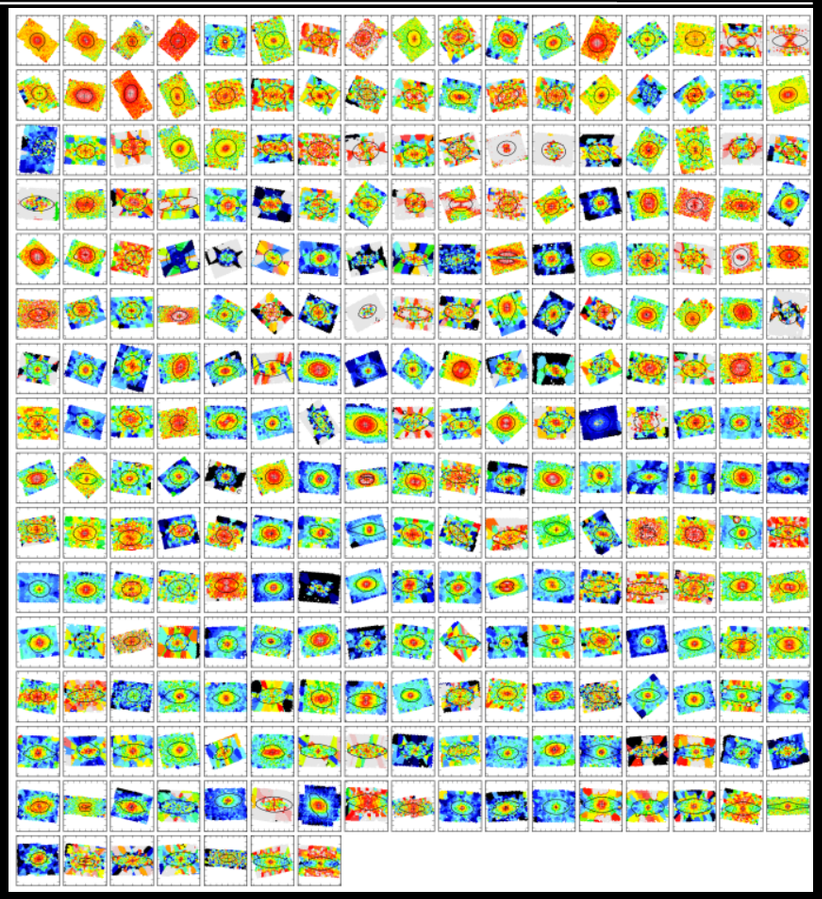


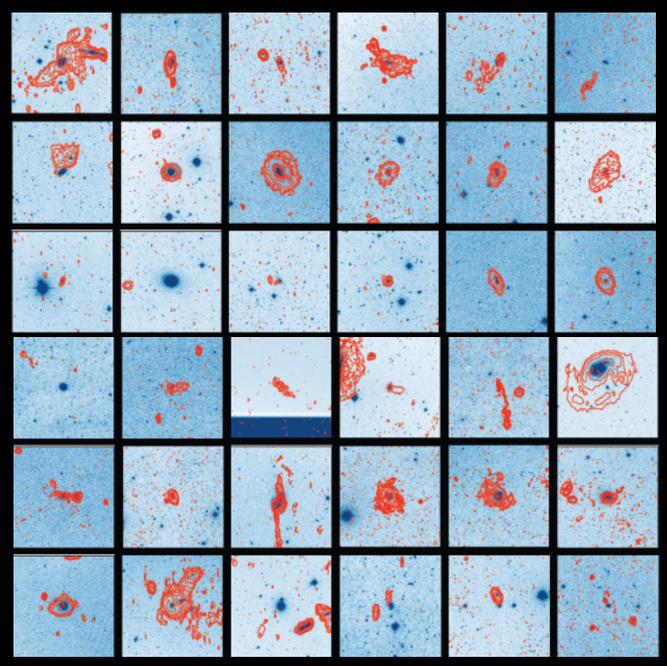
Data……

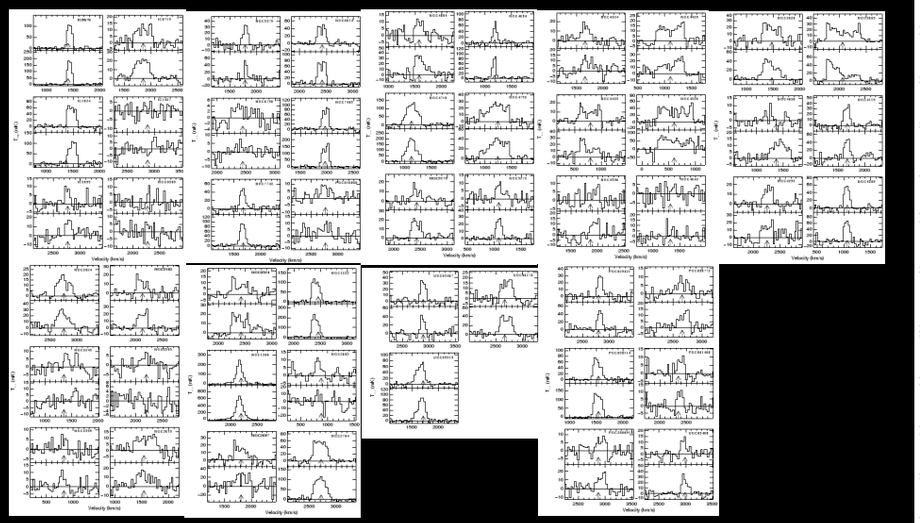
ASTRON

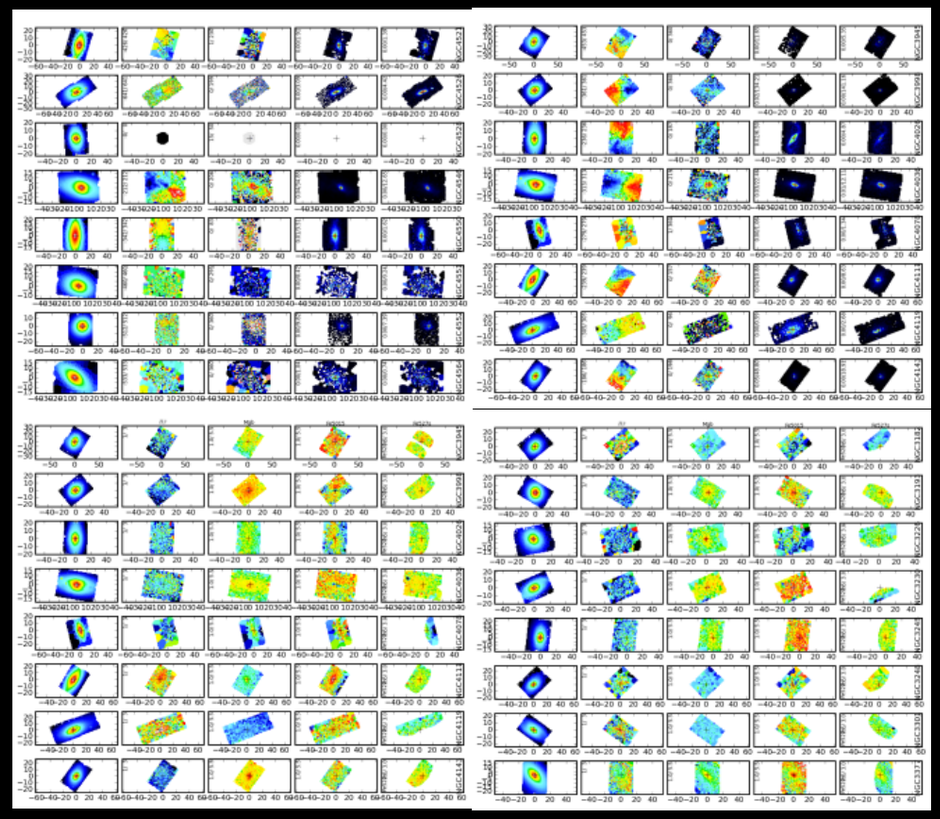












HI observations of Atlas^{3D} sample

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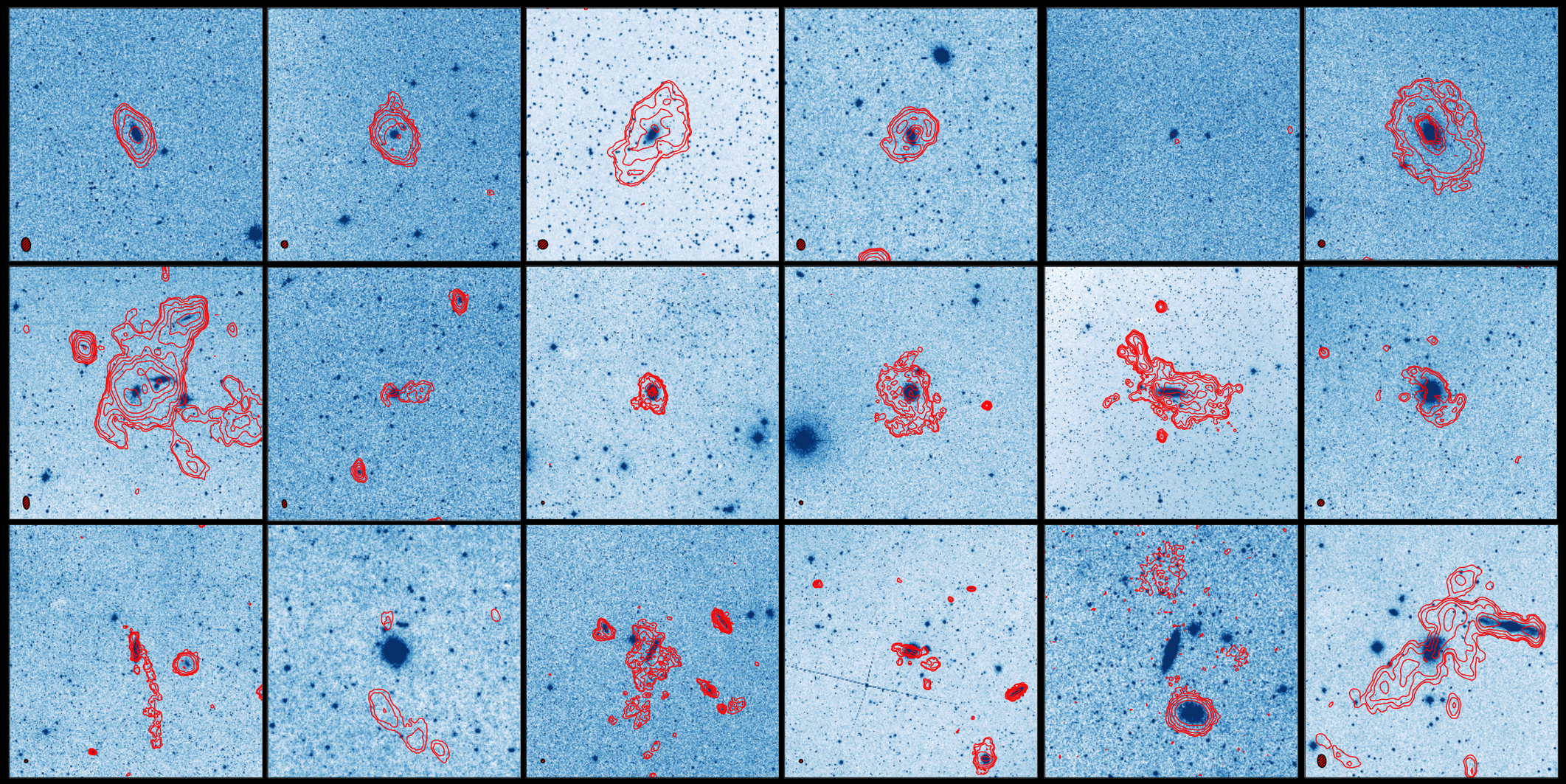
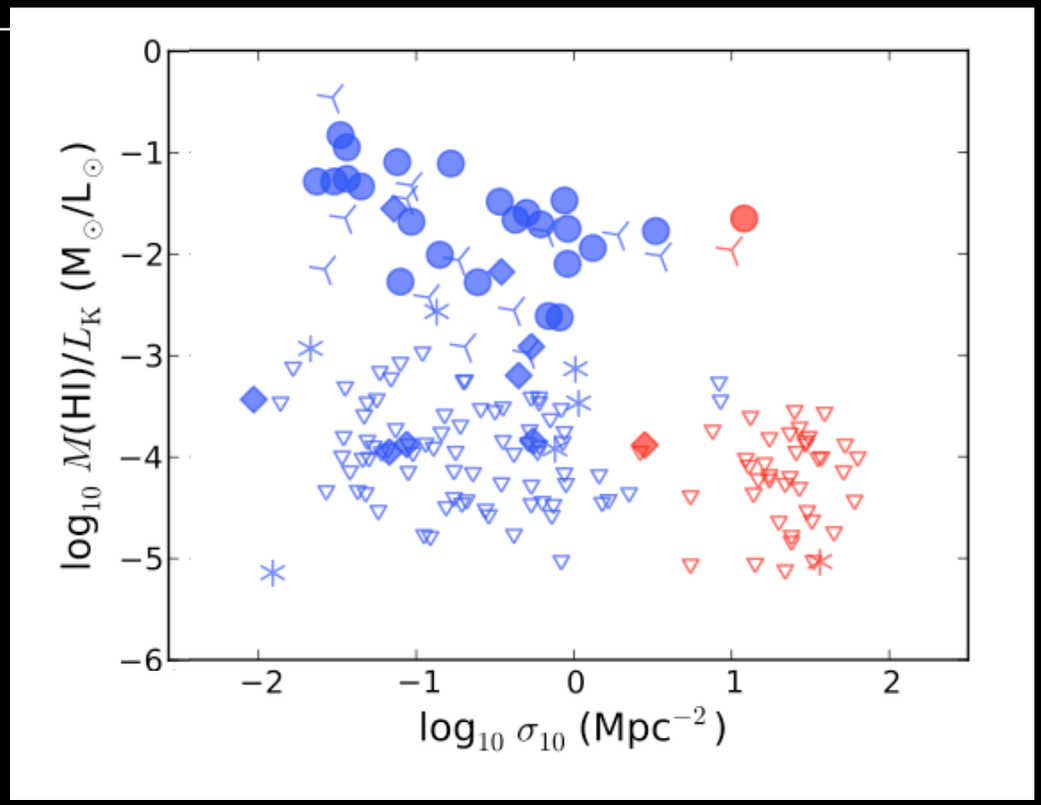
- WSRT observations of those Atlas^{3D} galaxies with δ>20˚
  - 12 h per galaxy. Detection limit 10^6-10^7 $M_\odot$, $n_{HI,lim}$ 3-5 x 10^{19} cm^{-2}
    deep follow up on subset (10x12h)
  - Complements CO observations
  - large range in morphologies, many disks/rings (large and small), tails, clouds



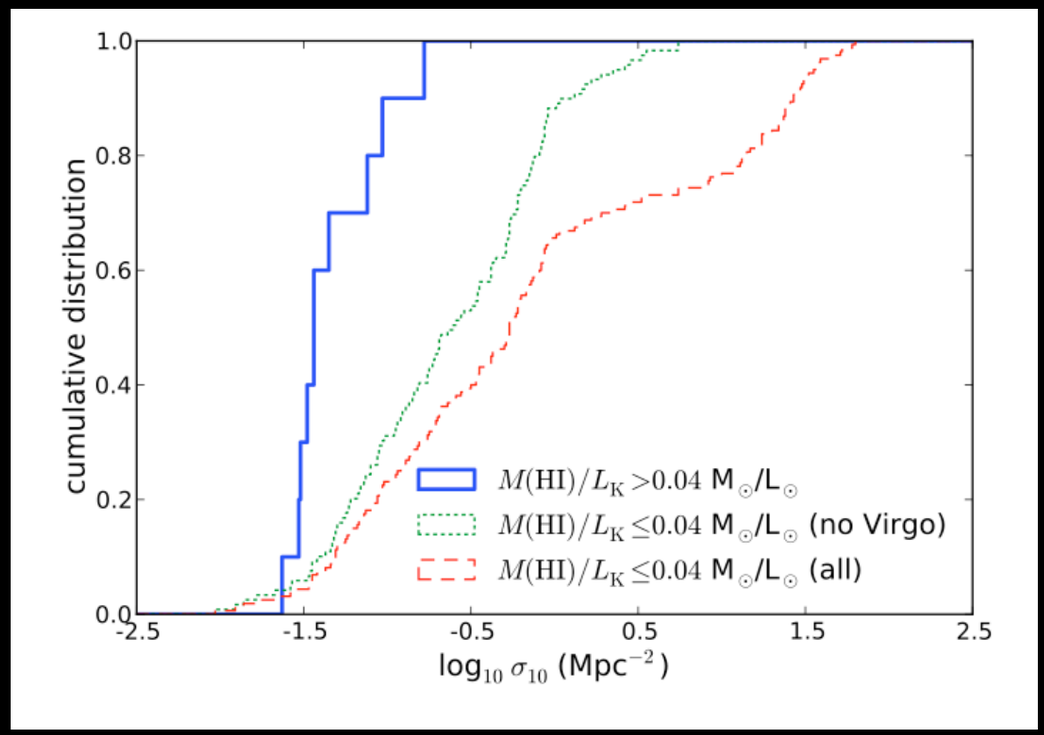
Main factor: environment

- Detection rate 45% in field, 5% in Virgo, stronger contrast than seen for spirals. ETGs are older cluster population?
- Different from CO:
  CO detection rate in field and cluster are more or less the same (for 10^7 $M_\odot$),
  (but galaxies most H_2-rich are in the field and Virgo CO disks are aligned with stellar body, while many misalignments in field)



σ_{10} is measure for galaxy density on scales of several Mpc

- Gas stripping is more effective at large galaxy radius



- Environment also important outside Virgo

ETGS are very different from spirals, also in HI

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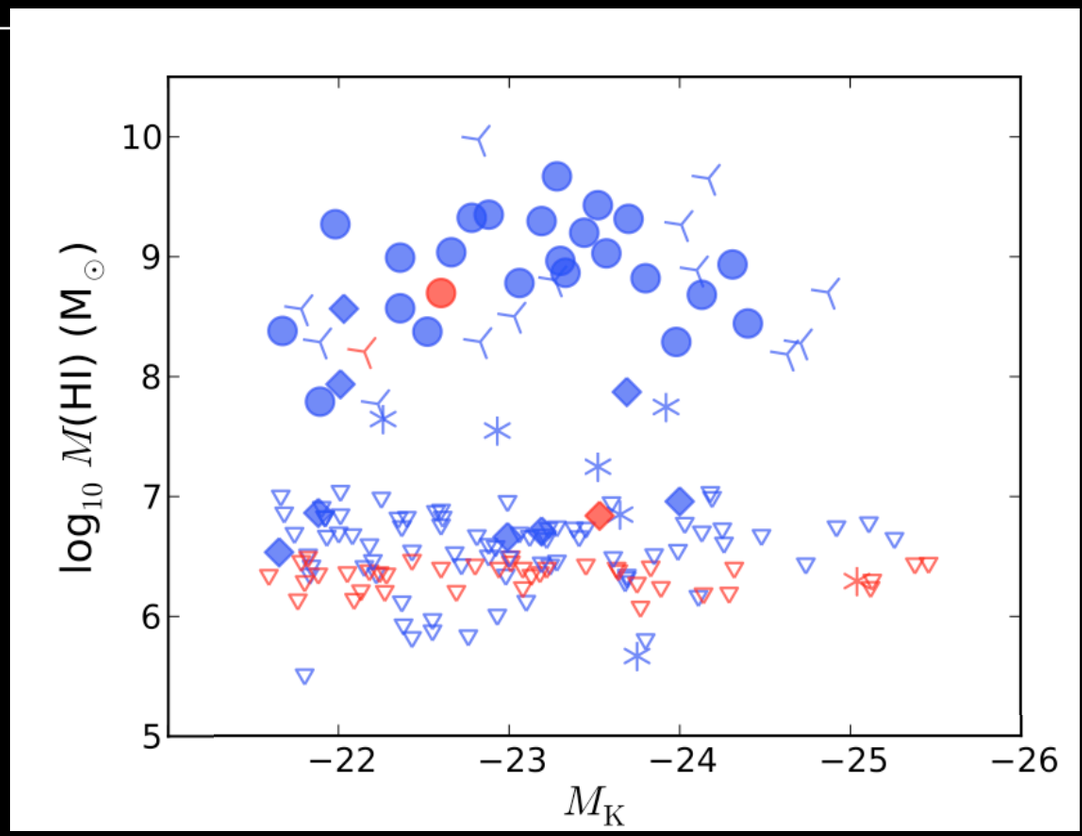
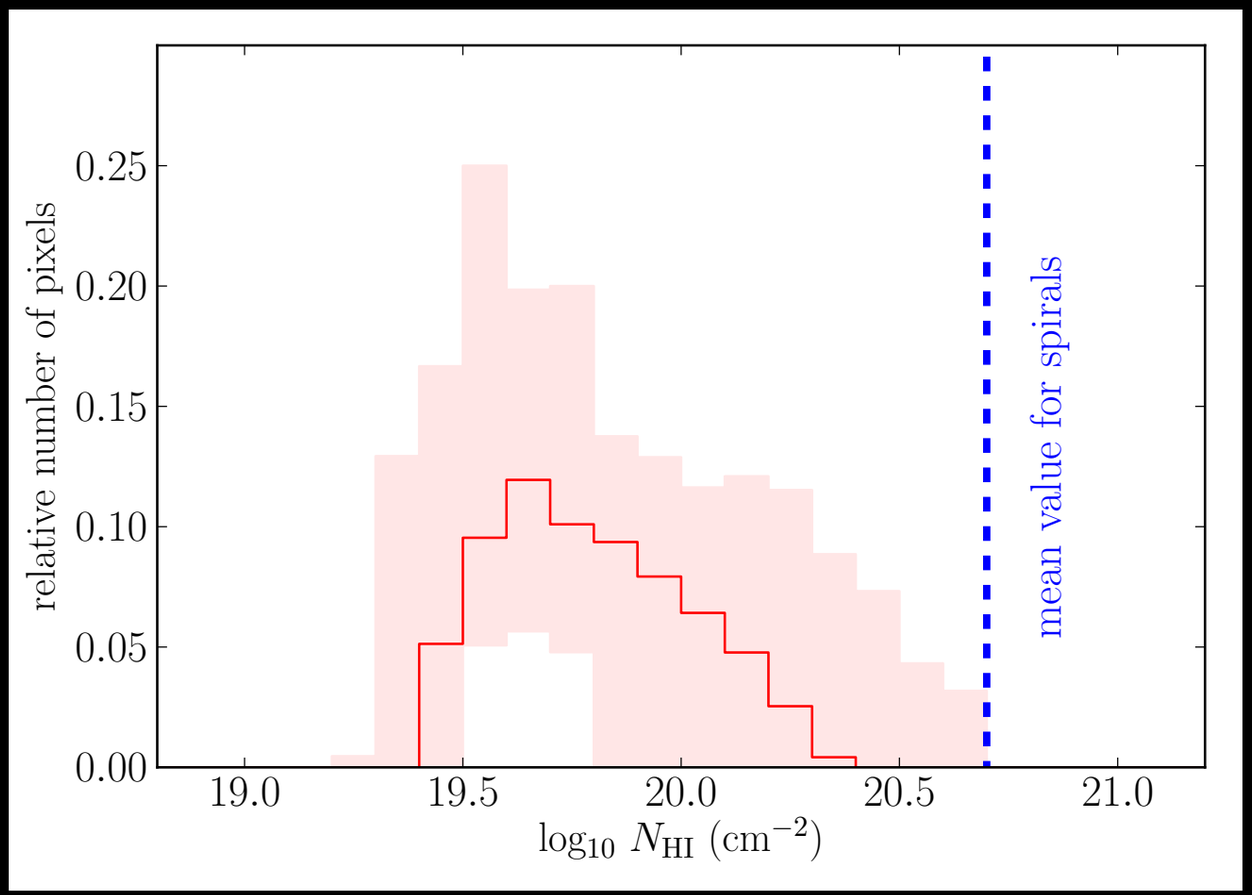
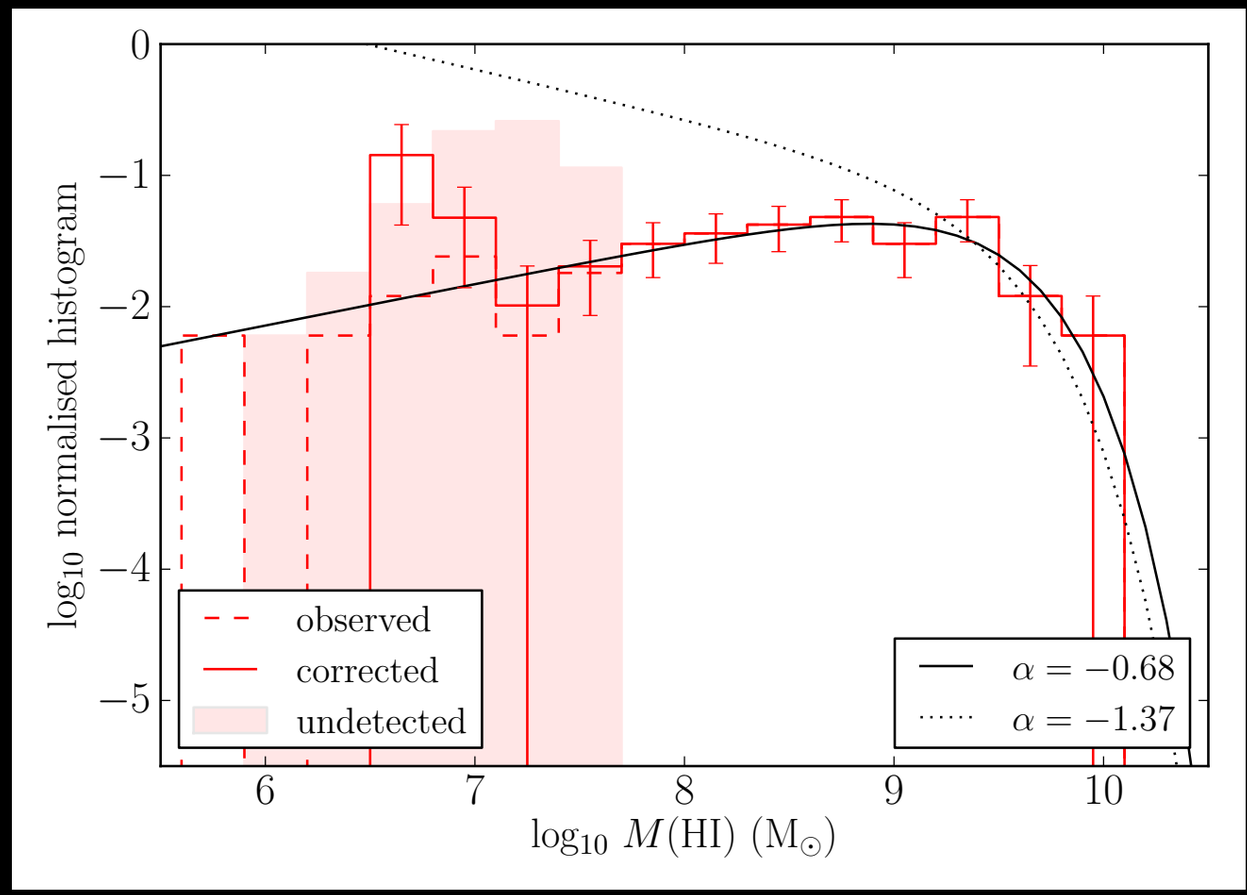
- HI mass independent of luminosity, except for most luminous galaxies. Same seen in CO.
- HI mass function is flat
- Some galaxies have a lot of HI, but is always of low column density



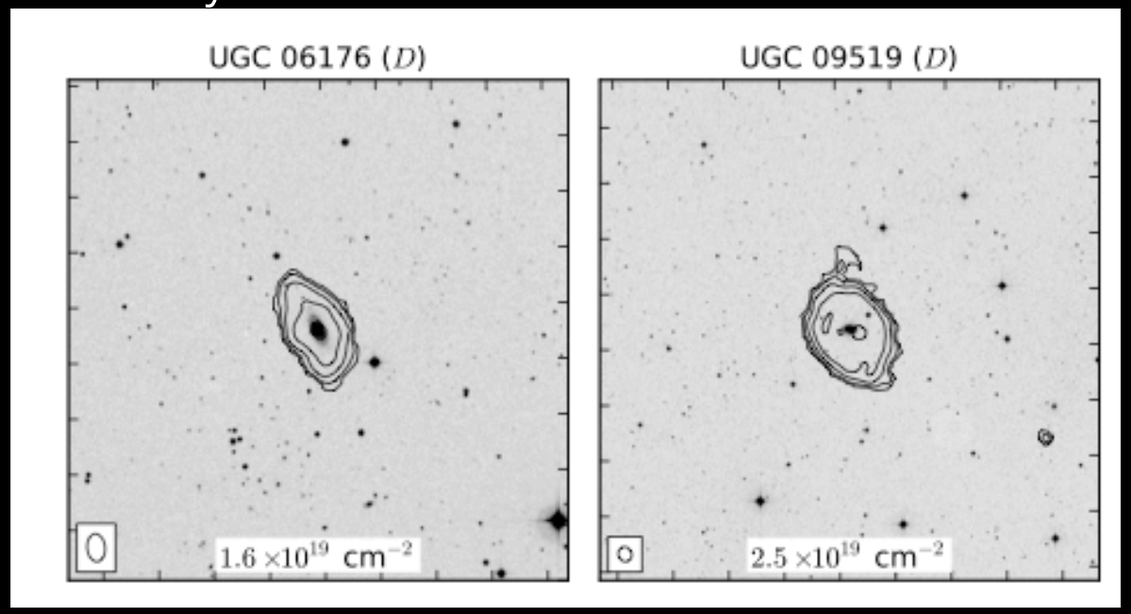


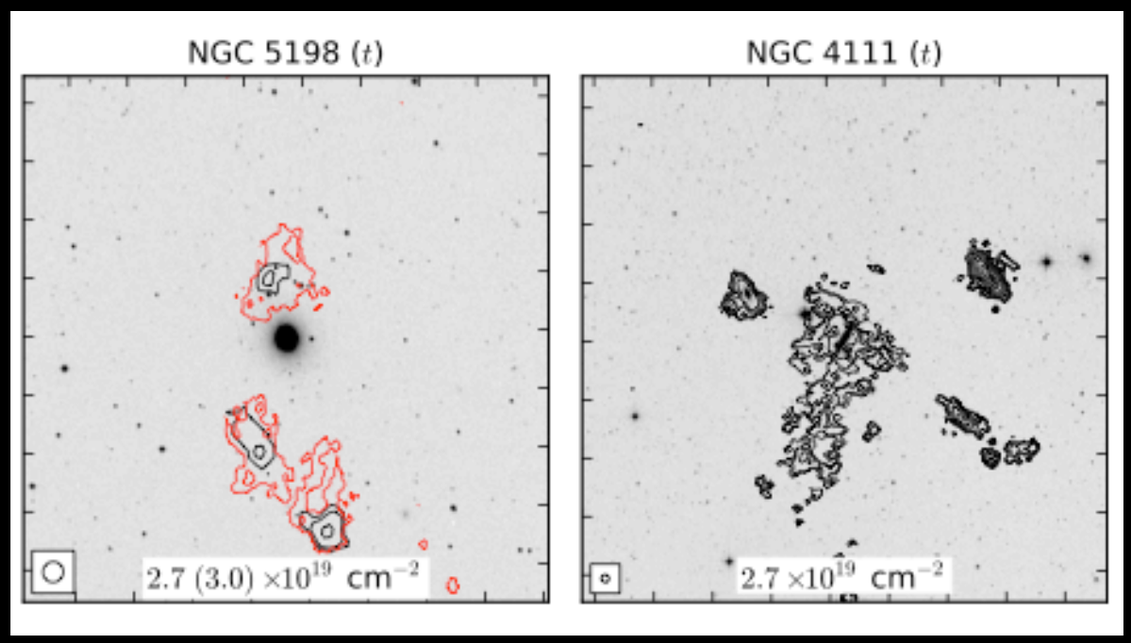


Environment

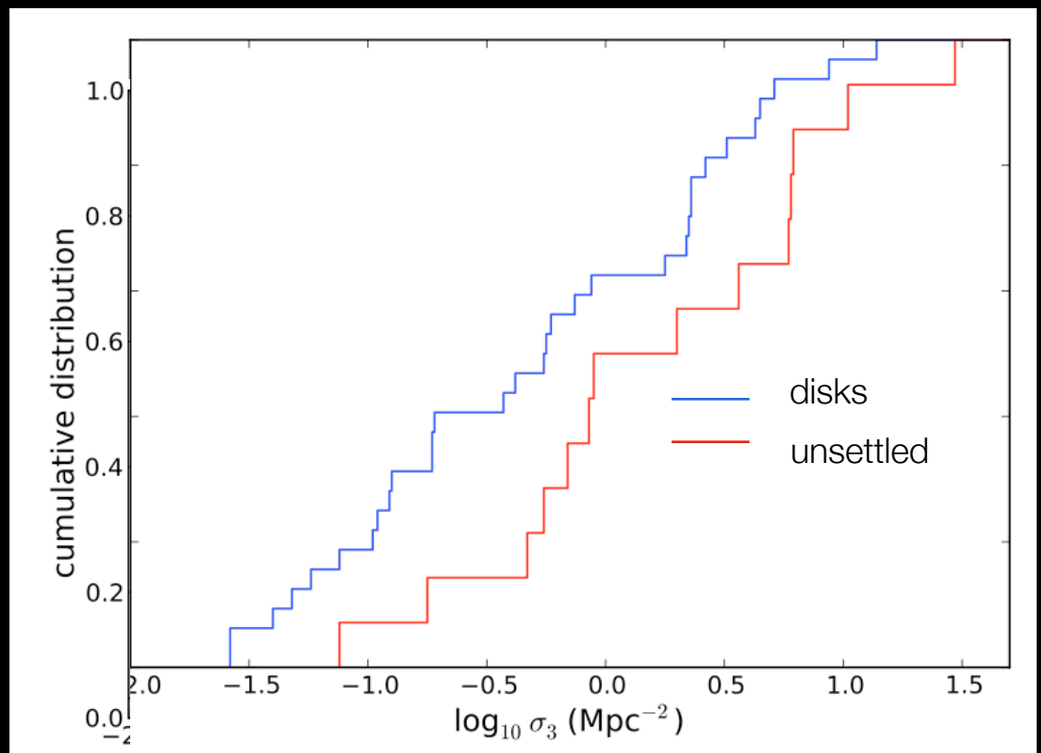
- HI morphology depends on small-scale environment
- Related to density-morphology relation?

low density

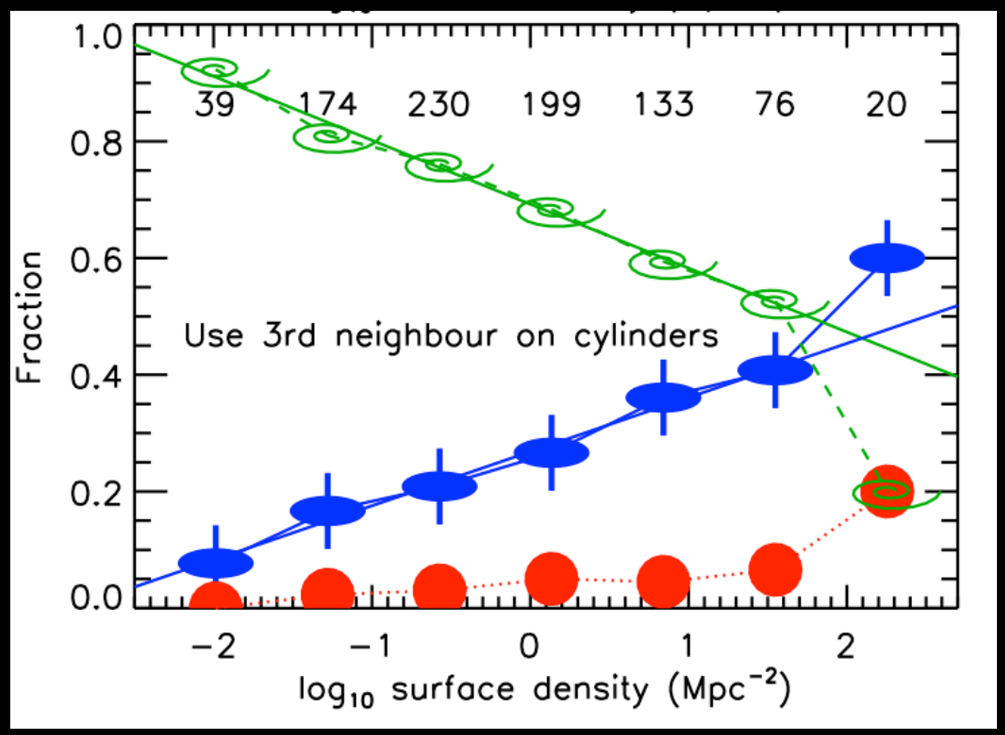




field, but high density

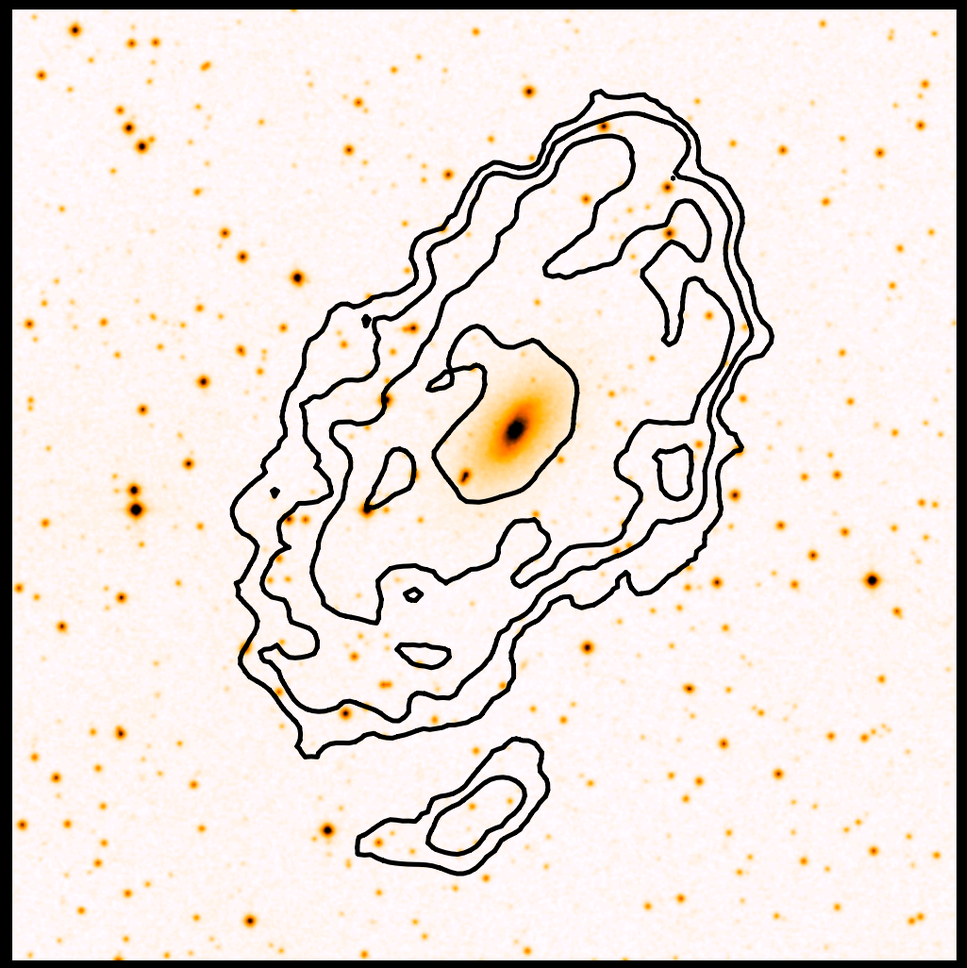


σ_3 is measure for galaxy density on scales of 1 Mpc



Cappellari et al. paper 7. arXiv: 1104.3545

many dead disks



NGC 6798

out to 12 R_{eff}
peak column density ~10^{20} cm^{-2}
no sign of young population
some (but little) star formation in outer disk

Many regular disks/rings (50% of detections)

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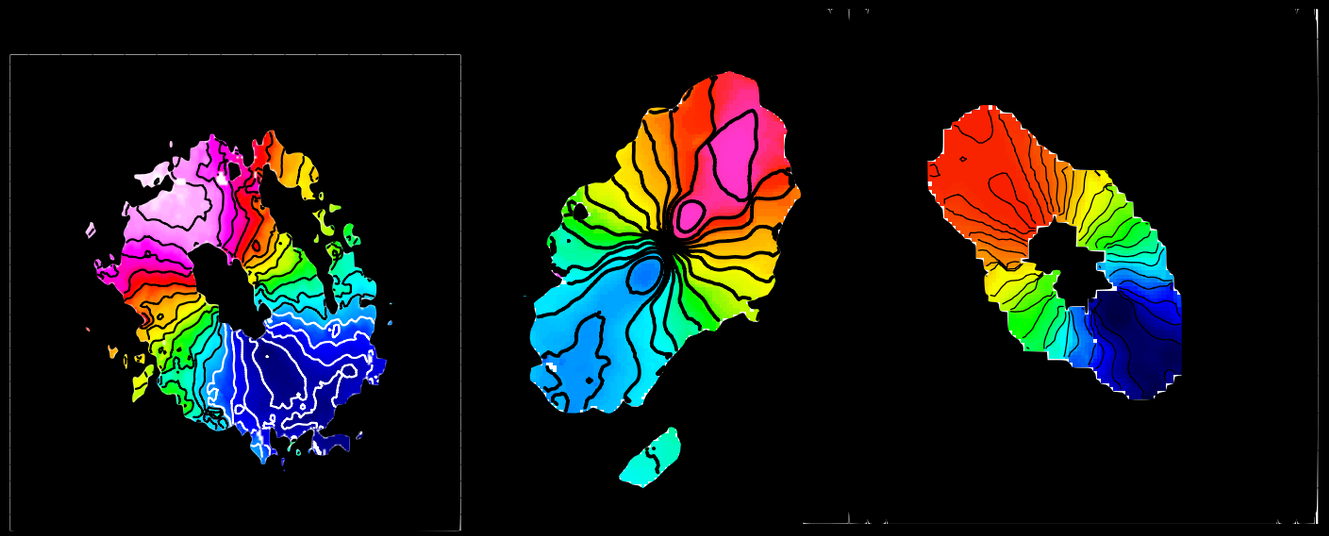
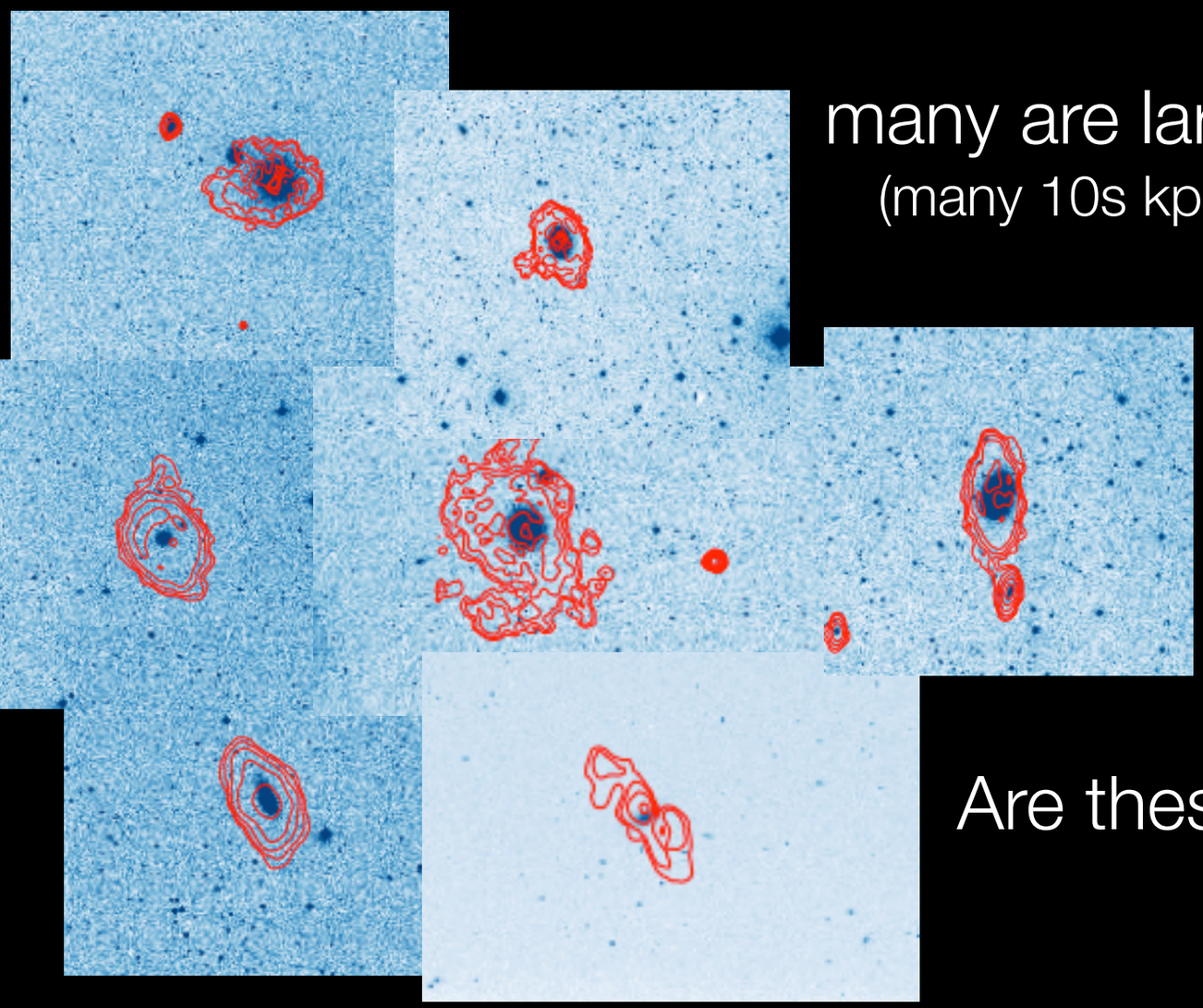
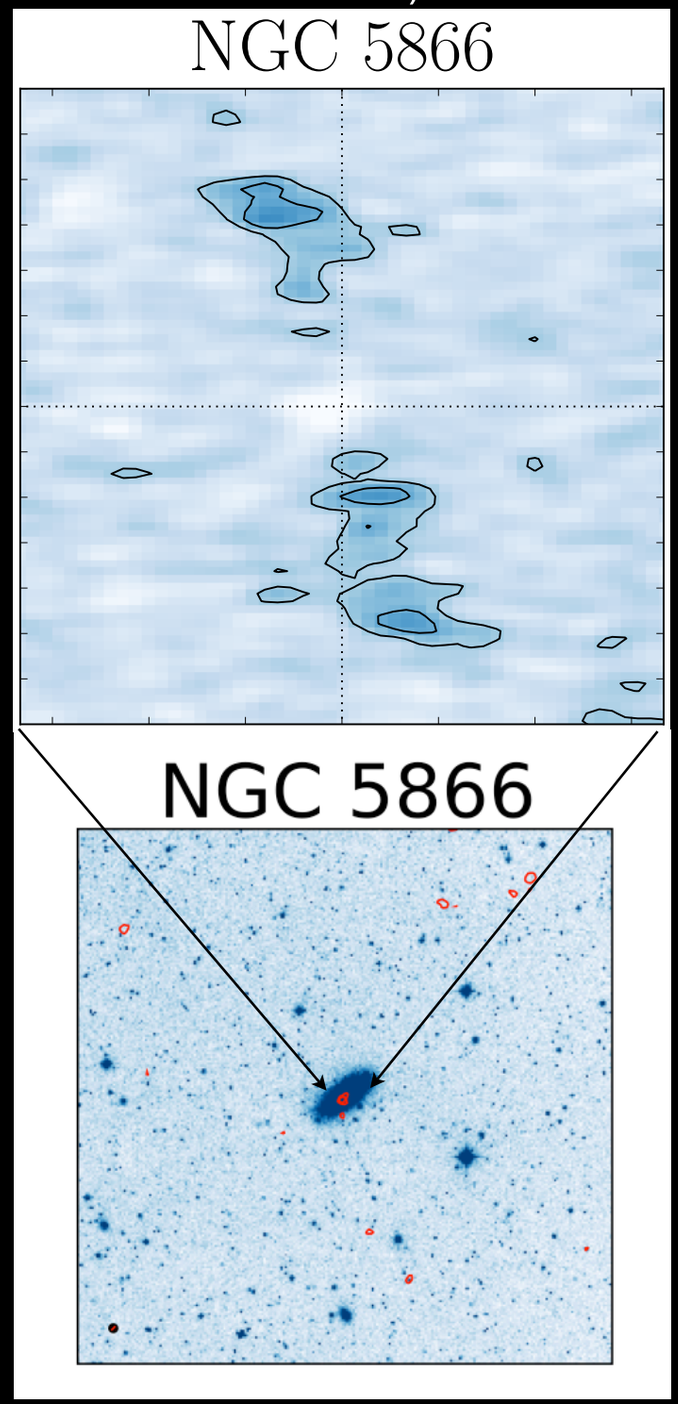




many are large
(many 10s kpc)

Are these the S0s?

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



E vs S0 : Fast vs Slow rotation

Disk-like Rotators

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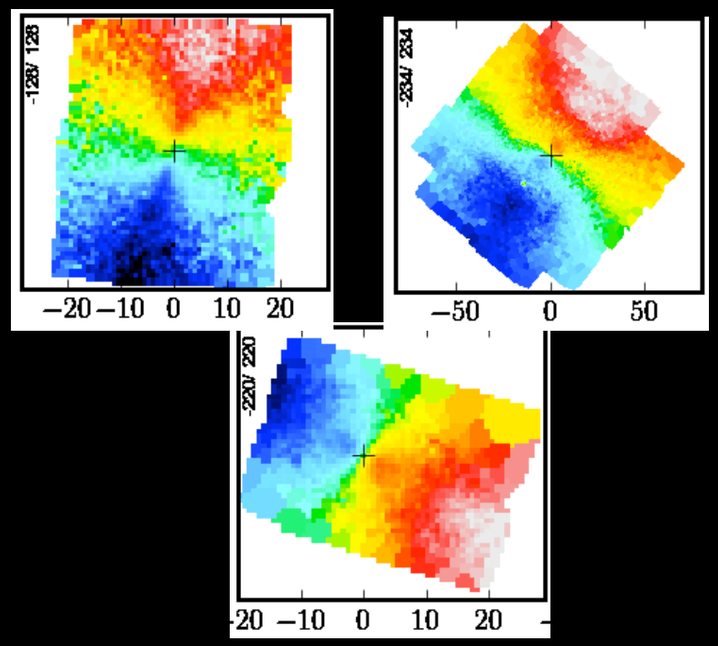
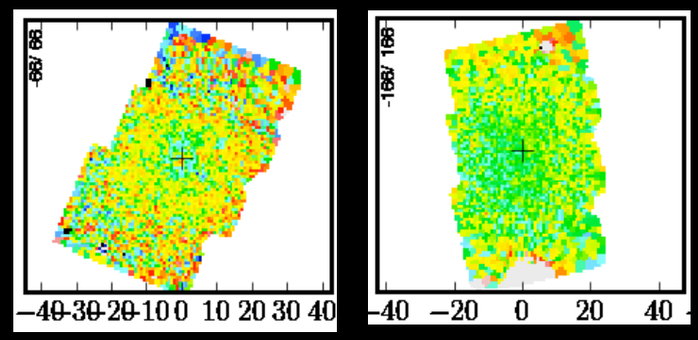
Fast
- regular rotation
- consistent with disk-like rotation
- oblate rotators

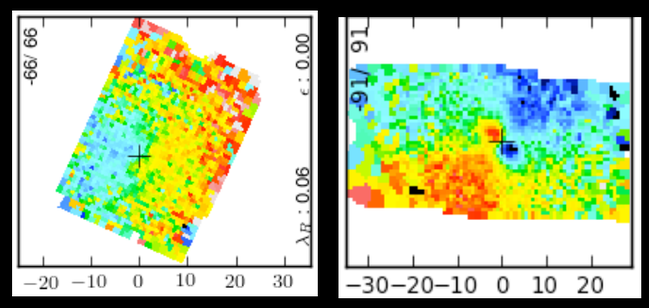


Slow
- no or little rotation
- misalignments
- KDC
- triaxial



Non-rotators

Non Disk-like rotators



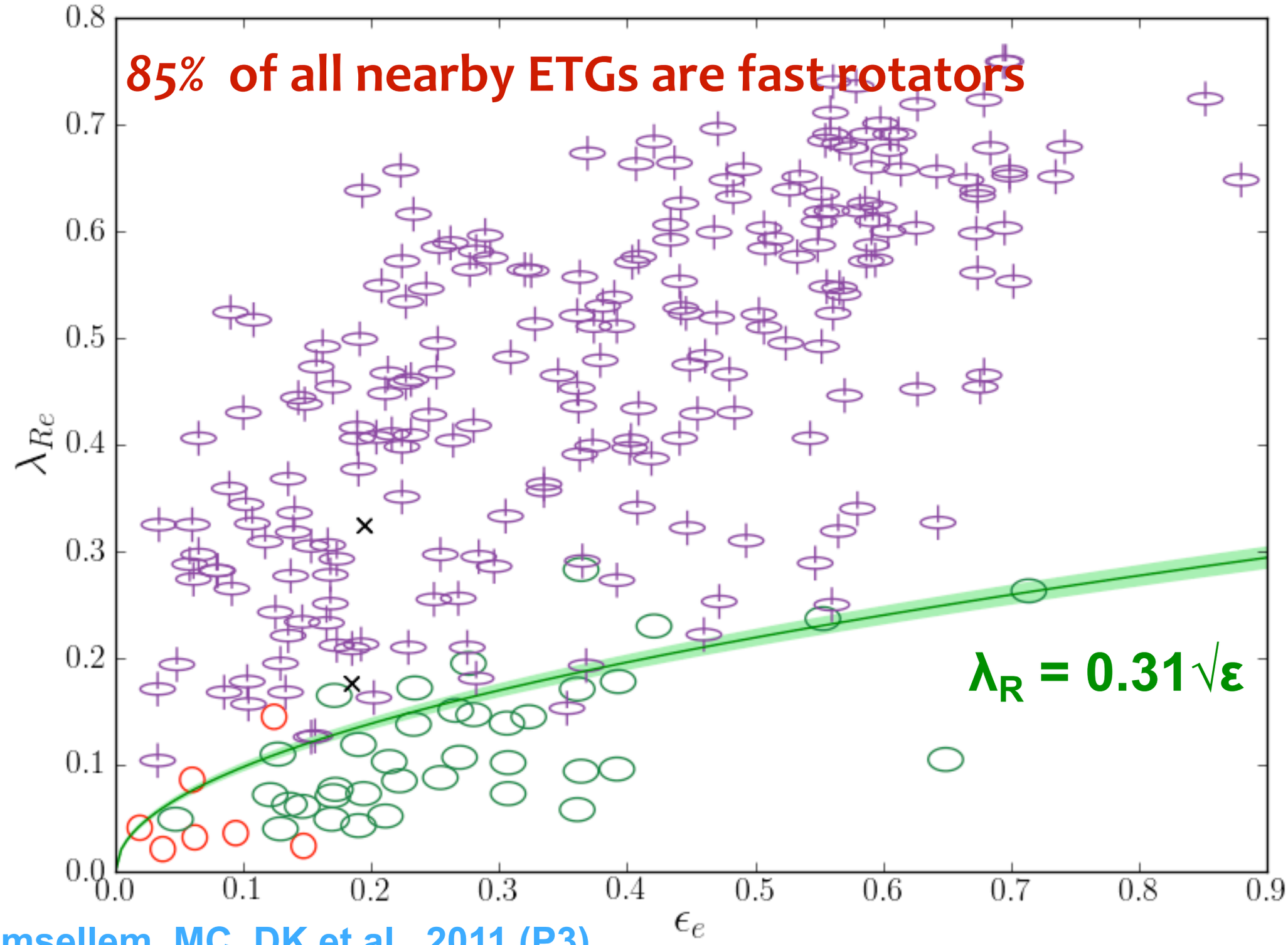
86% of sample are fast rotators

66% of E are fast rotators
20% of fast rotators are E

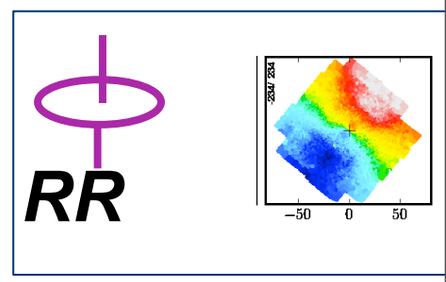
Morphology not a good indicator for dynamics

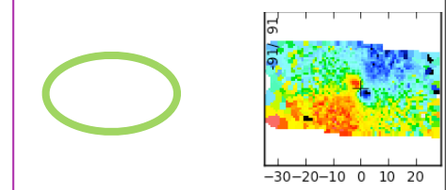
Emsellem et al. paper 3. arXiv: 1102.4633

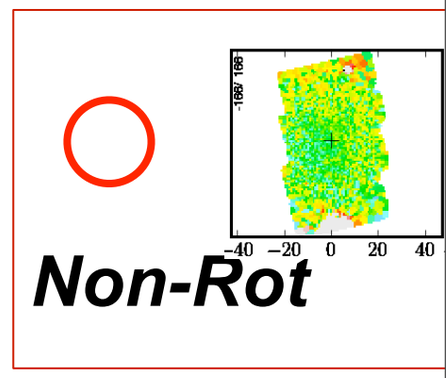
λ_R: Stellar angular momentum



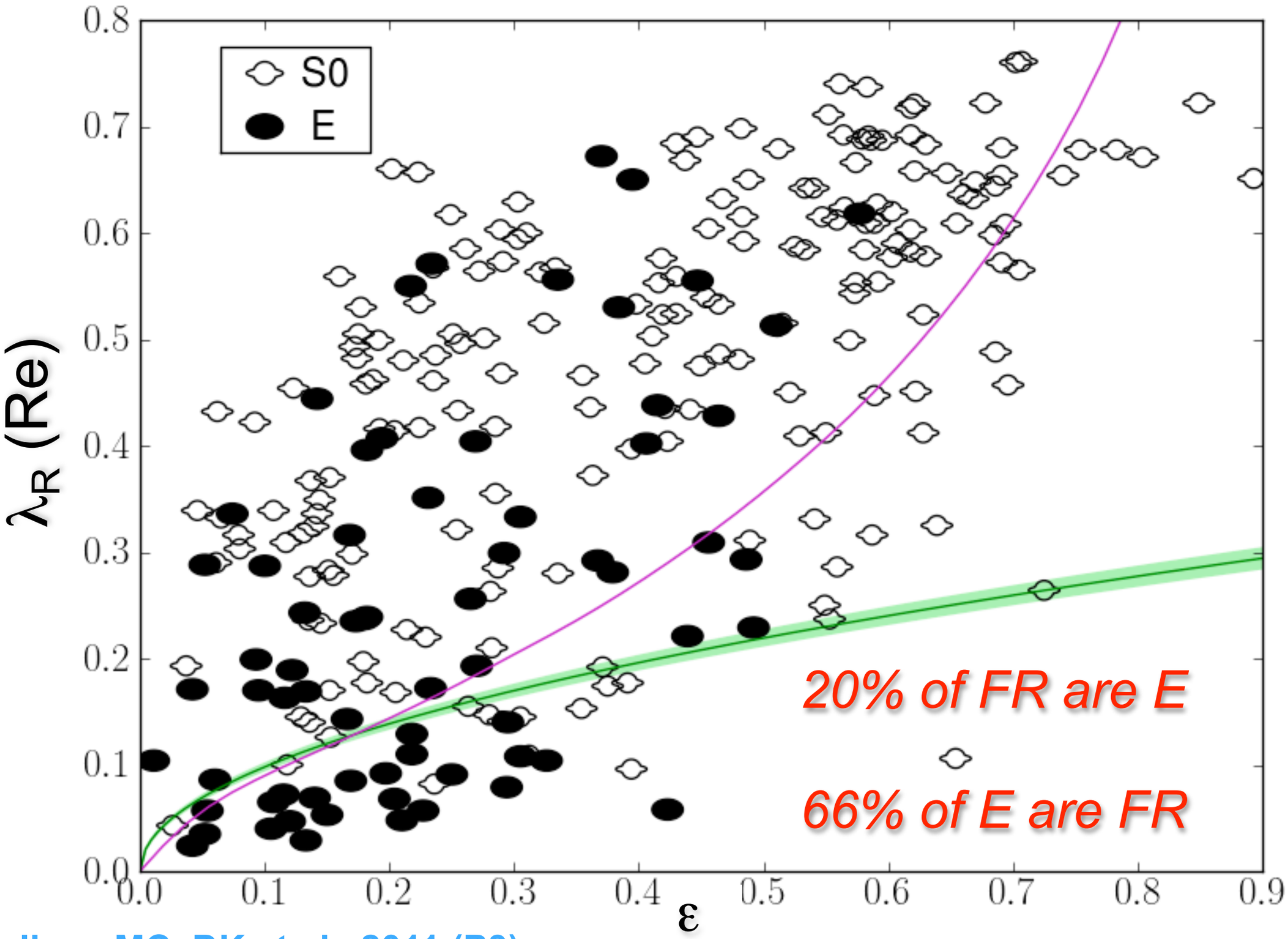
Emsellem, MC, DK et al., 2011 (P3)







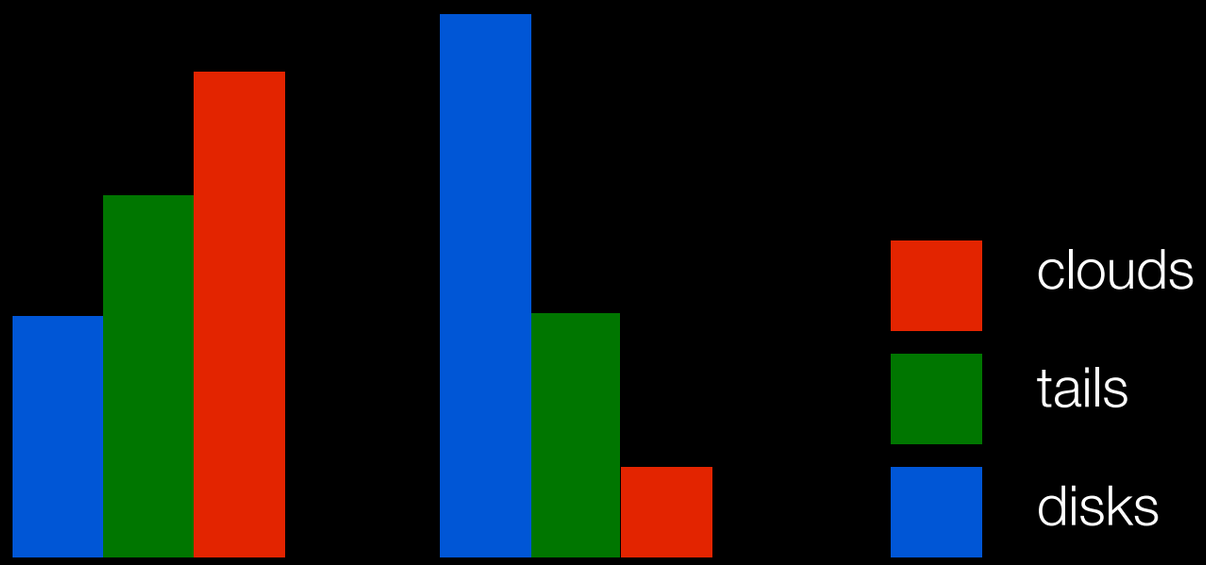
What about the Hubble classes?



Emsellem, MC, DK et al., 2011 (P3)

Disks vs dynamics

- ~half of detections are disks. Are they the S0's?



HI disks have the same kinematics as the disks of ionised and of molecular gas. Often misaligned with stellar kinematics.

50% of HI disks also detected in CO
20% of of non HI disk have CO

- HI disky-ness correlates with stellar kinematics.
- But there are exceptions!!! Slow rotators have less HI in centre
- Better correlation for CO: no CO detections for slow rotators

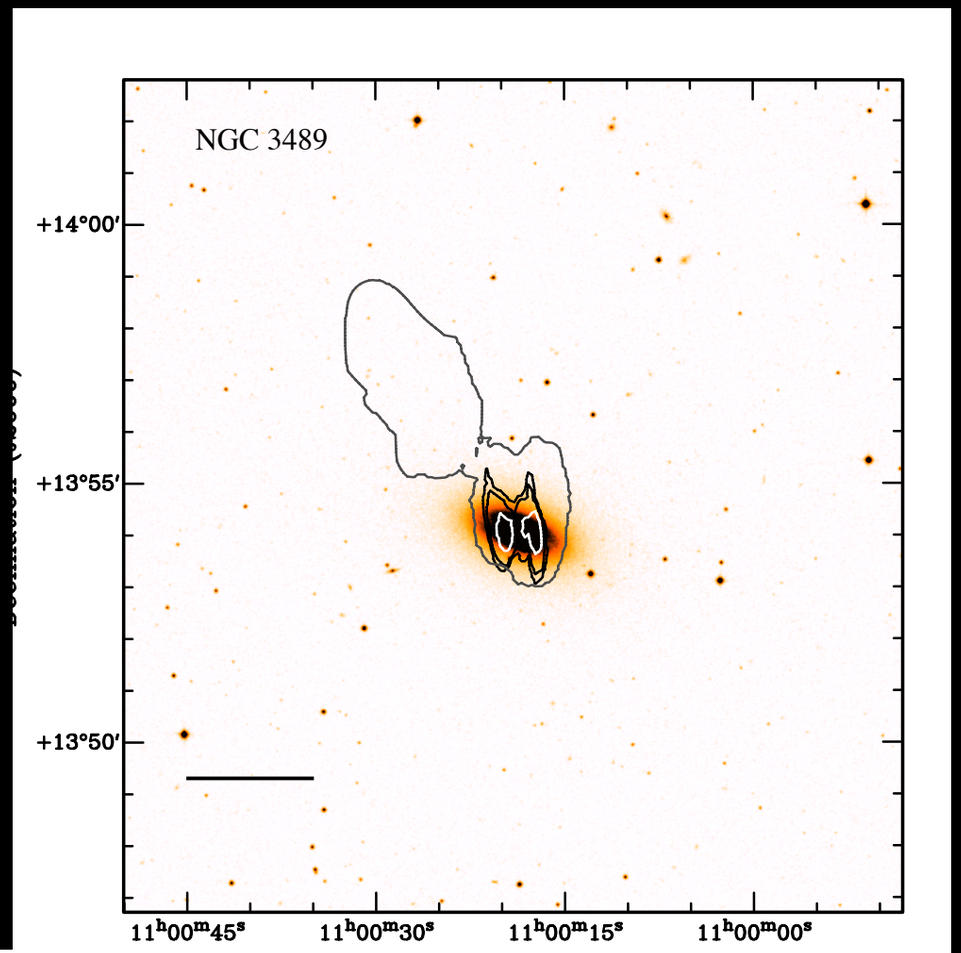
Accretion

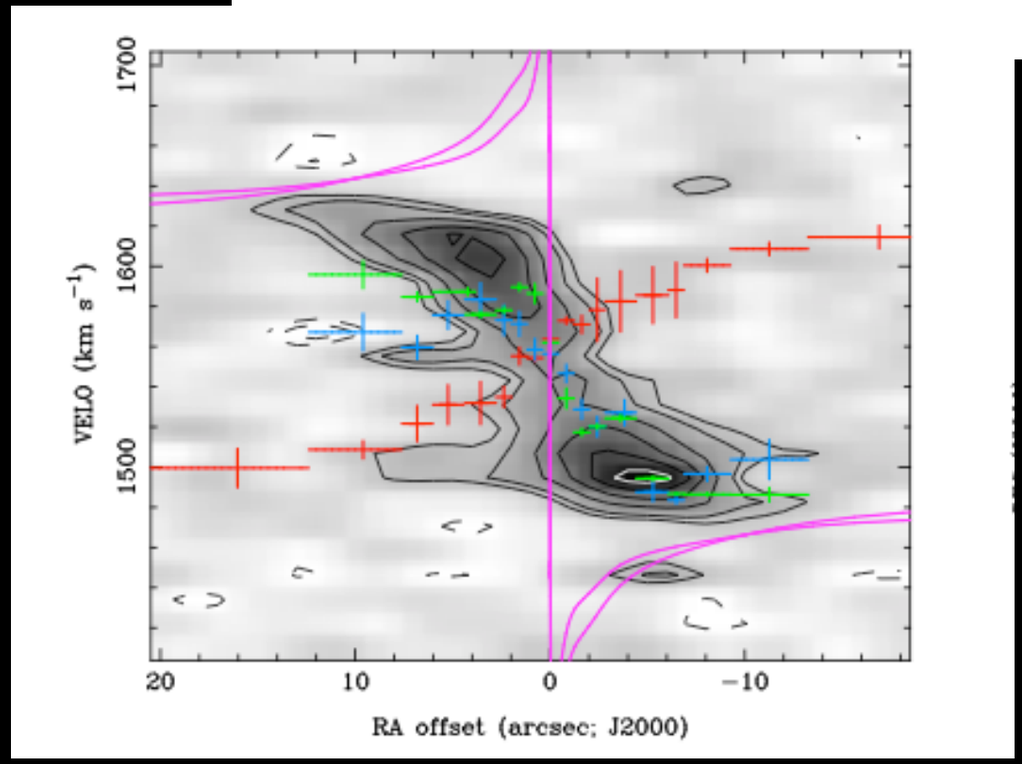
- Accretion very common (>50%),
  smaller amounts than spirals, ≲ 0.1 $M_\odot$ per yr.
  No major direct effect on galaxy

- Many cases of formation of
  small inner disk which is also seen in CO.
  Connection with KDC

Small counterrotating CO disk in N3032,
also seen in HI

- Most cold gas in inner regions is
  molecular: M_{H2}/M_{HI} ~ 10





More signs of accretion

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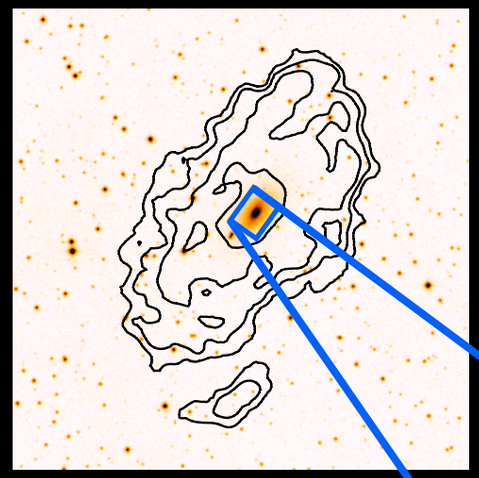
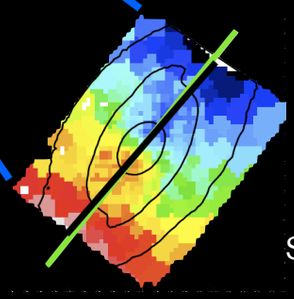
NGC 6798

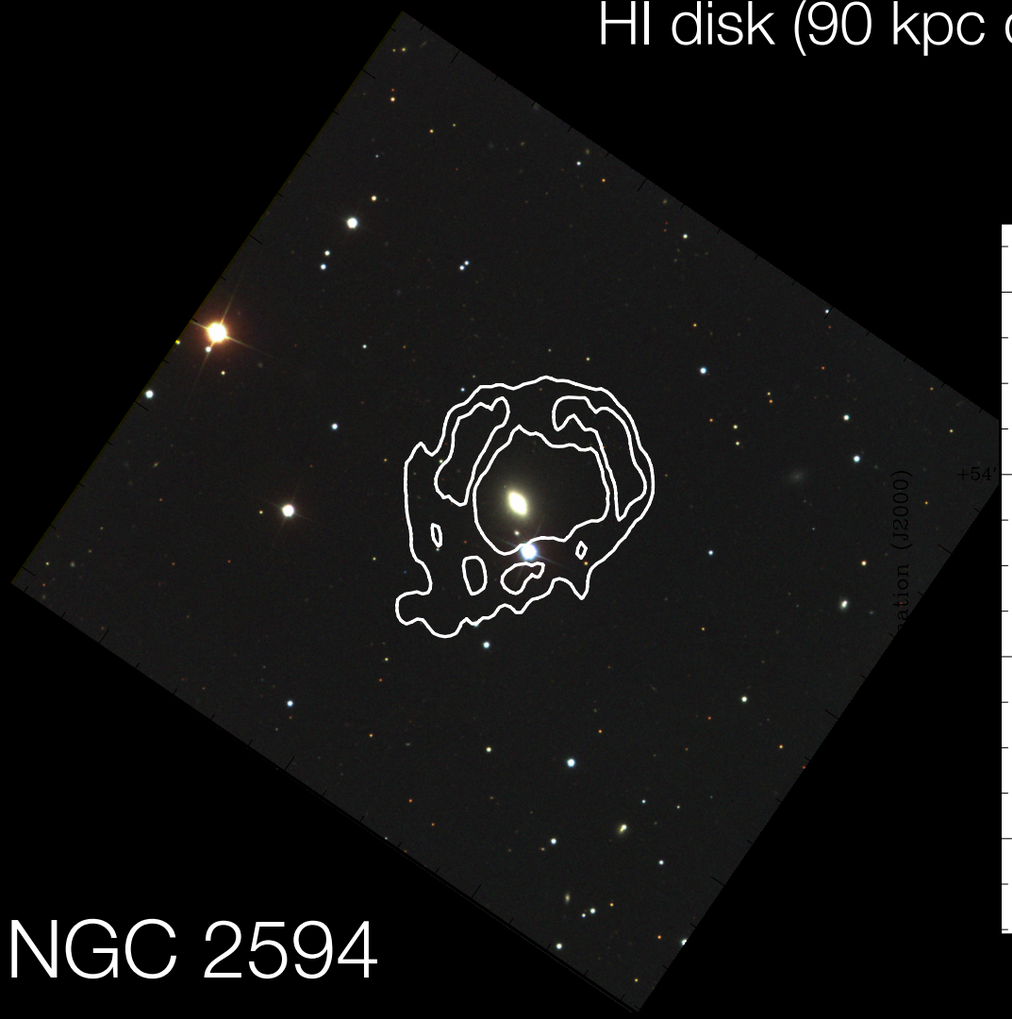


HI velocity field

HI disk (90 kpc diameter) counterrotating



stellar velocity field

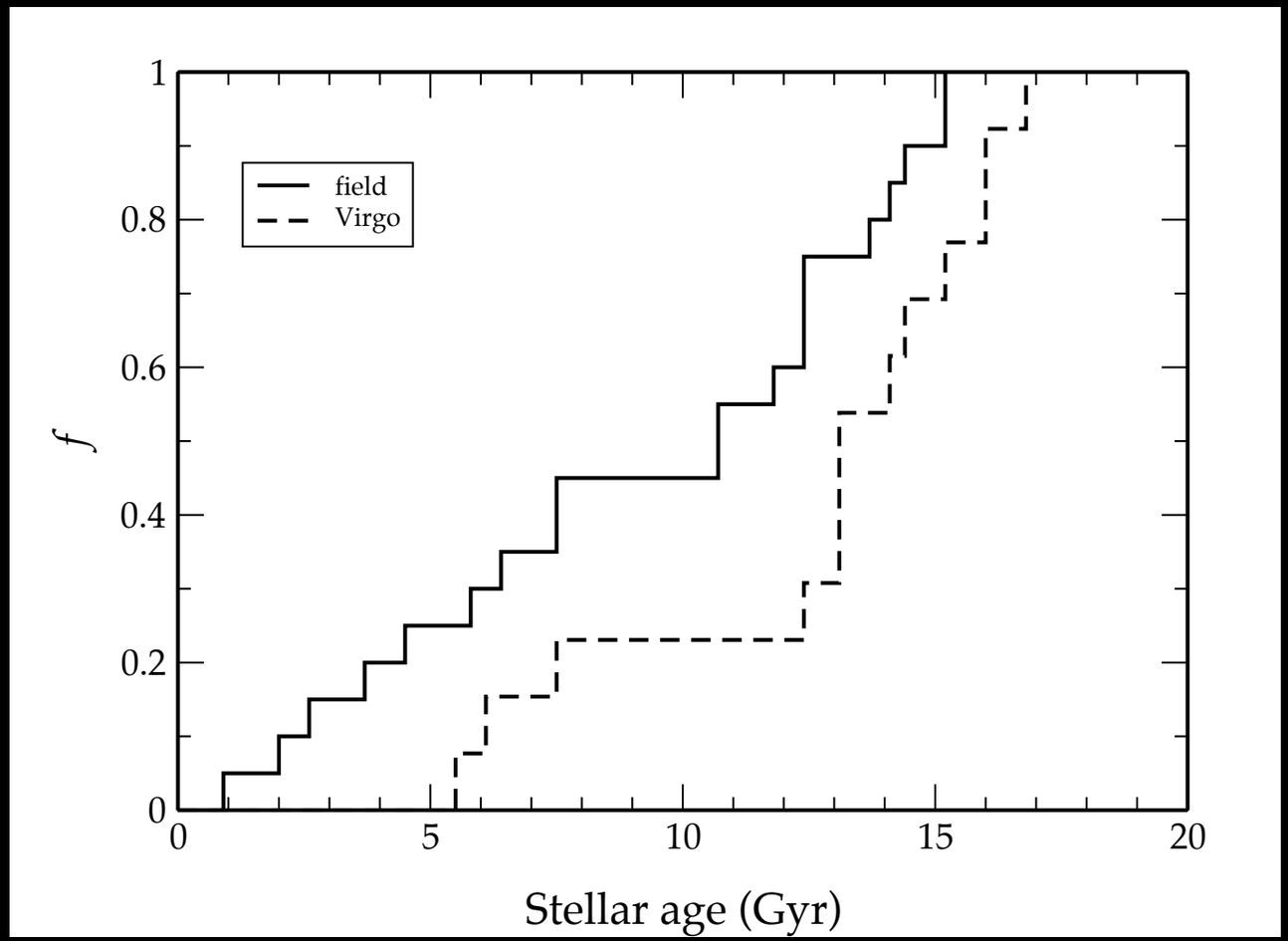


Many polar gas rings
and 90-degree warps

NGC 2594

Environment

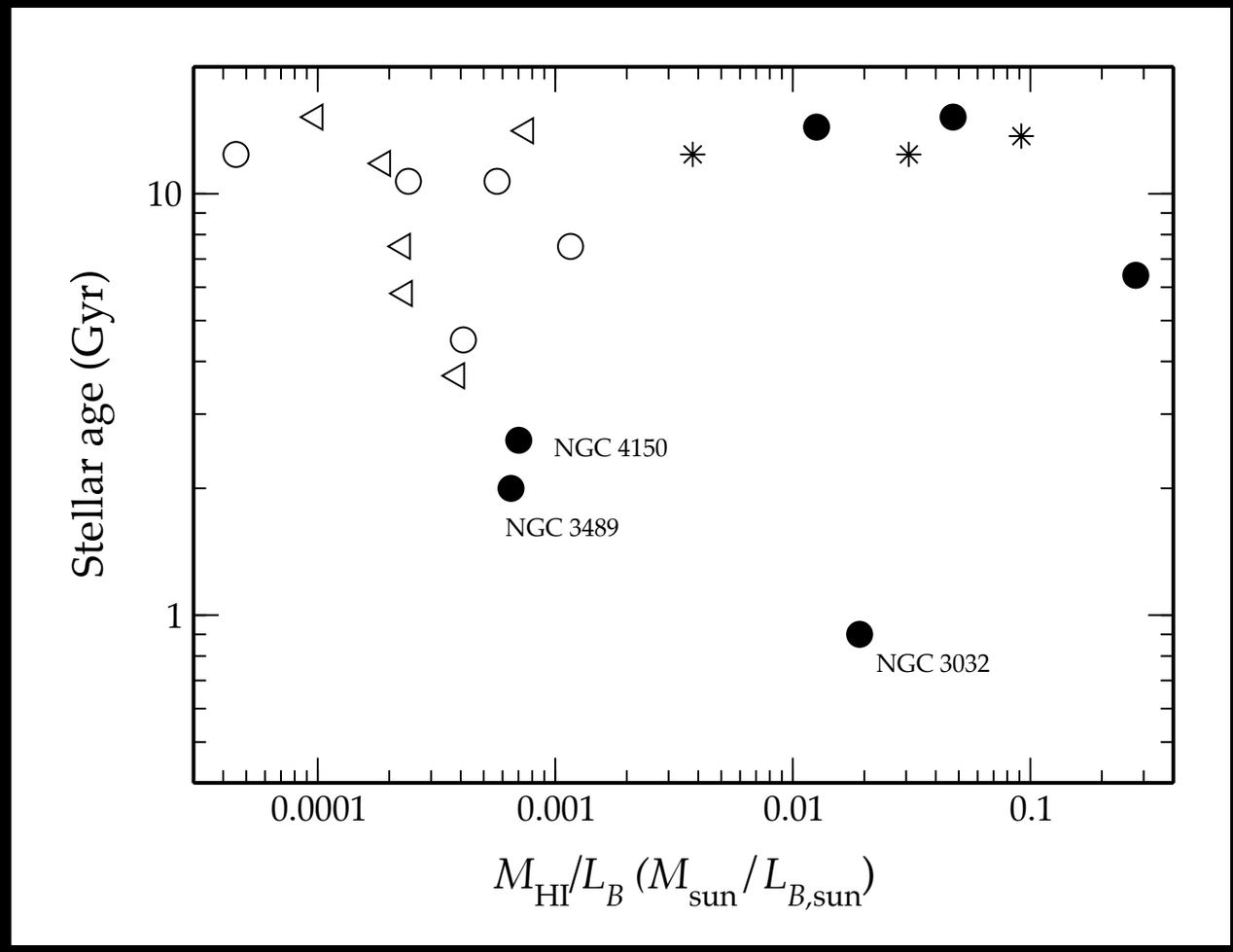
- No accretions seen in Virgo (no HI, CO aligned)
- Connected to difference in stellar population?
- Small accretions in field galaxies have cumulative effect on stellar population?



Stellar population

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

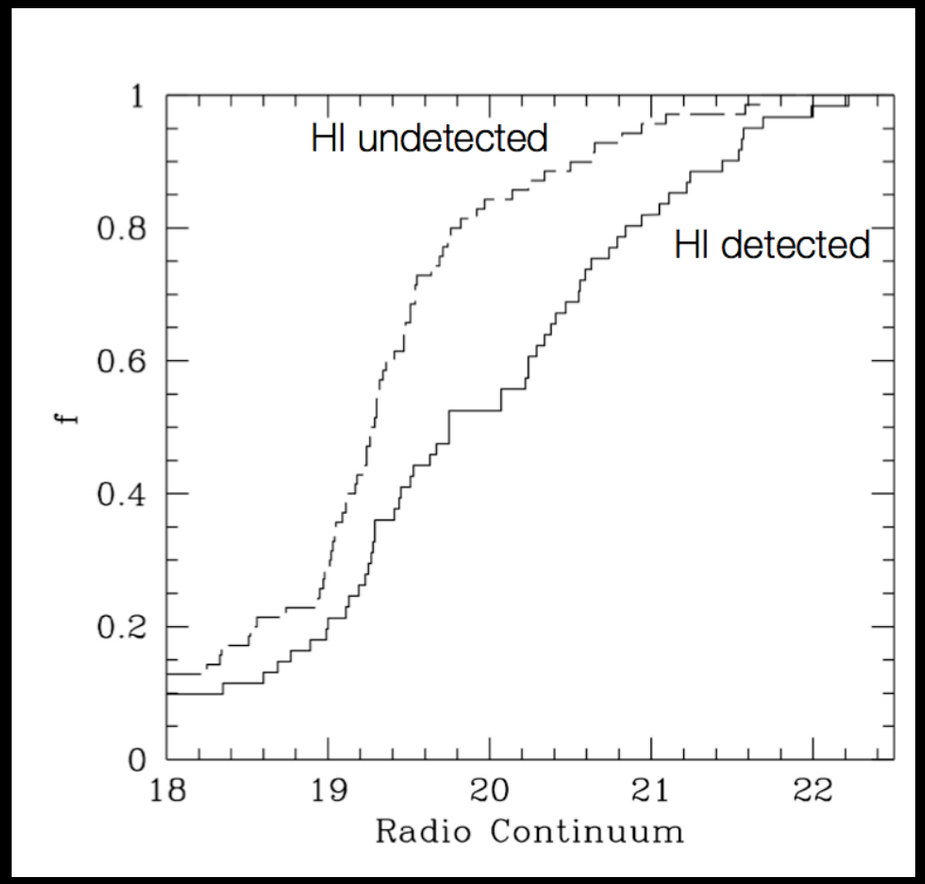
Some galaxies are (very) gas rich, but have old stellar population

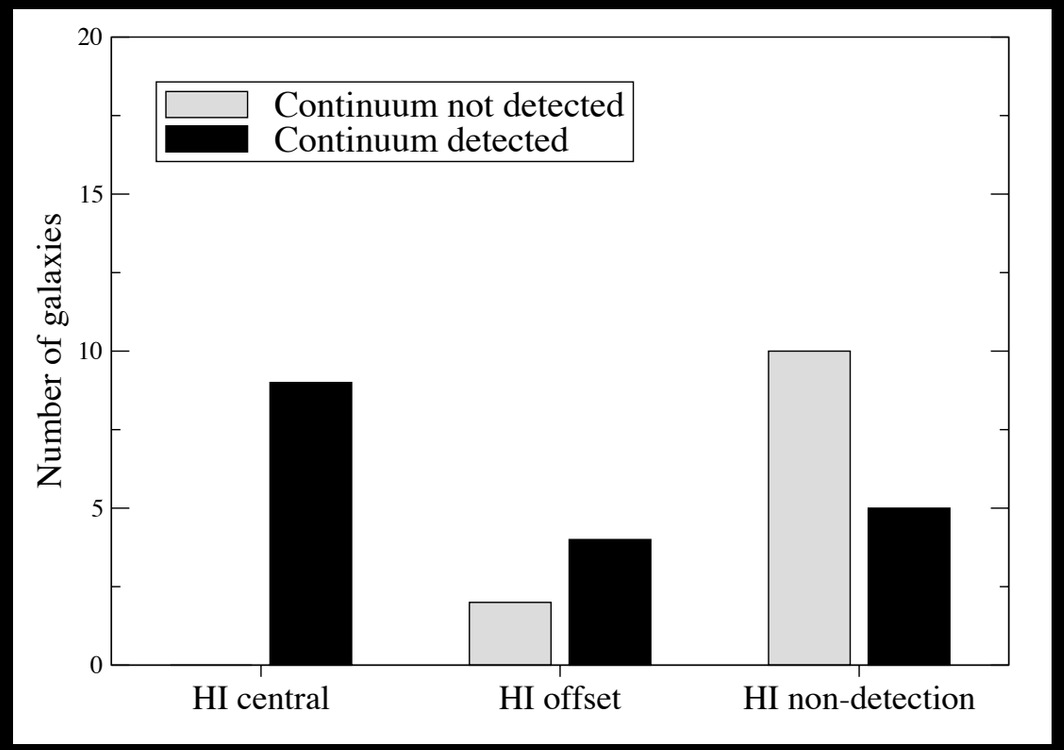


- Exception: galaxies with small inner gas disk have young stars in centre

Radio continuum

- Galaxies detected in HI are stronger in radio, in particular those with HI in the centre

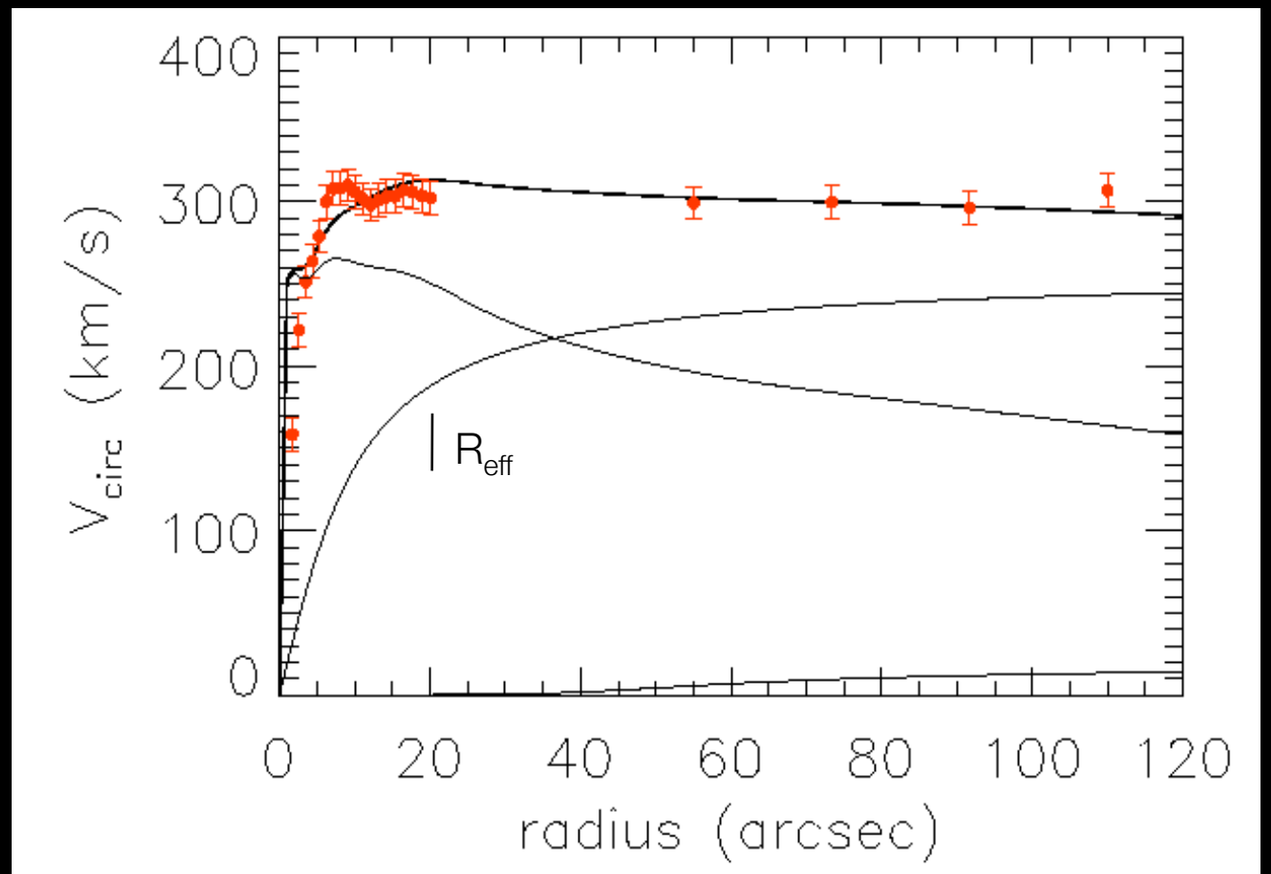




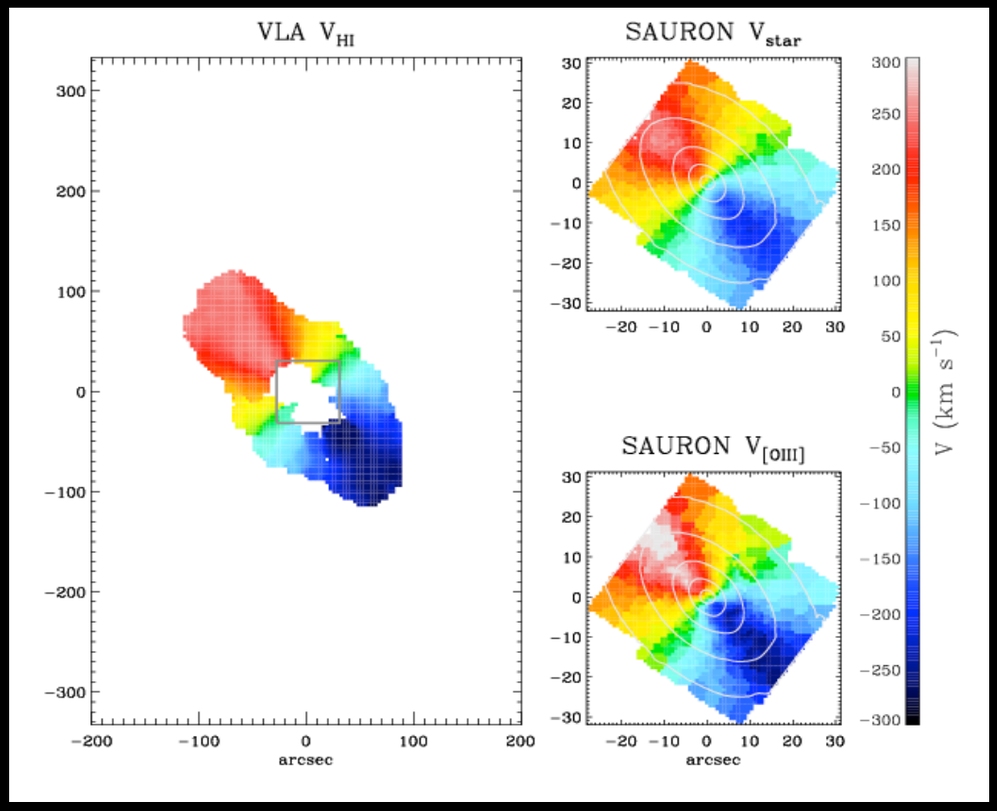
- Use high-res radio data to separate AGN from star formation
  ⇒ correlation is due to star formation, not to AGN

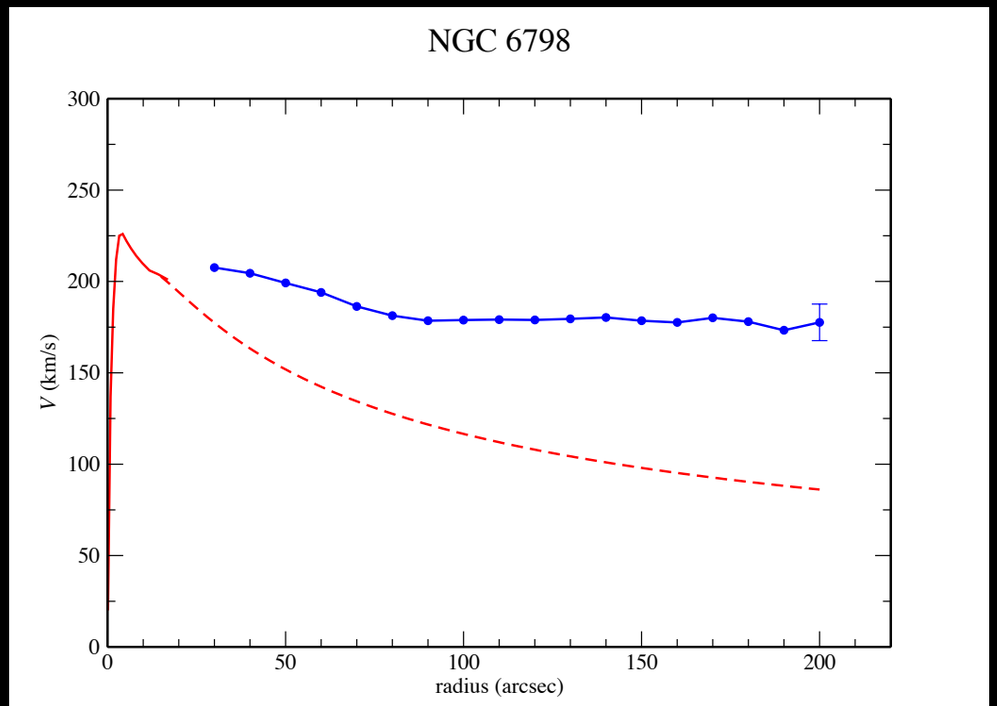
Dark matter

- Large, regular HI disks allow to probe DM well outside optical body.
  Difficult to do with other techniques
- Combination with optical data very powerful
- Rotation curve out to many R_{eff}: flat (with decline)



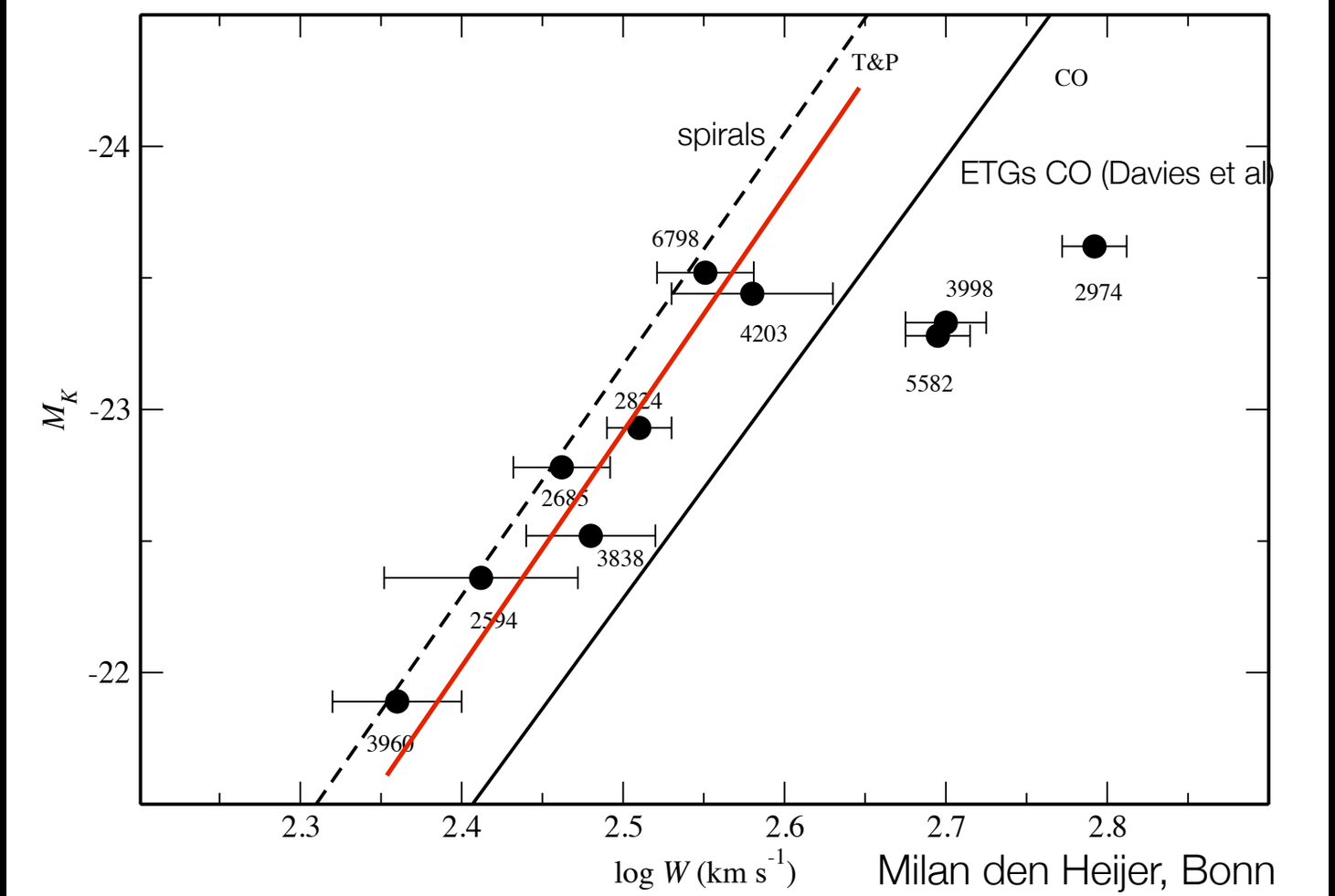
NGC 2974
Weijmans+ 2008





Tully-Fisher relation

- TFR slightly offset from spiral TFR.
- Offset smaller than of CO TFR for ETGs. CO traces inner regions. Smaller HI offset due to drop of rotation velocity
- Large offset for massive galaxies?



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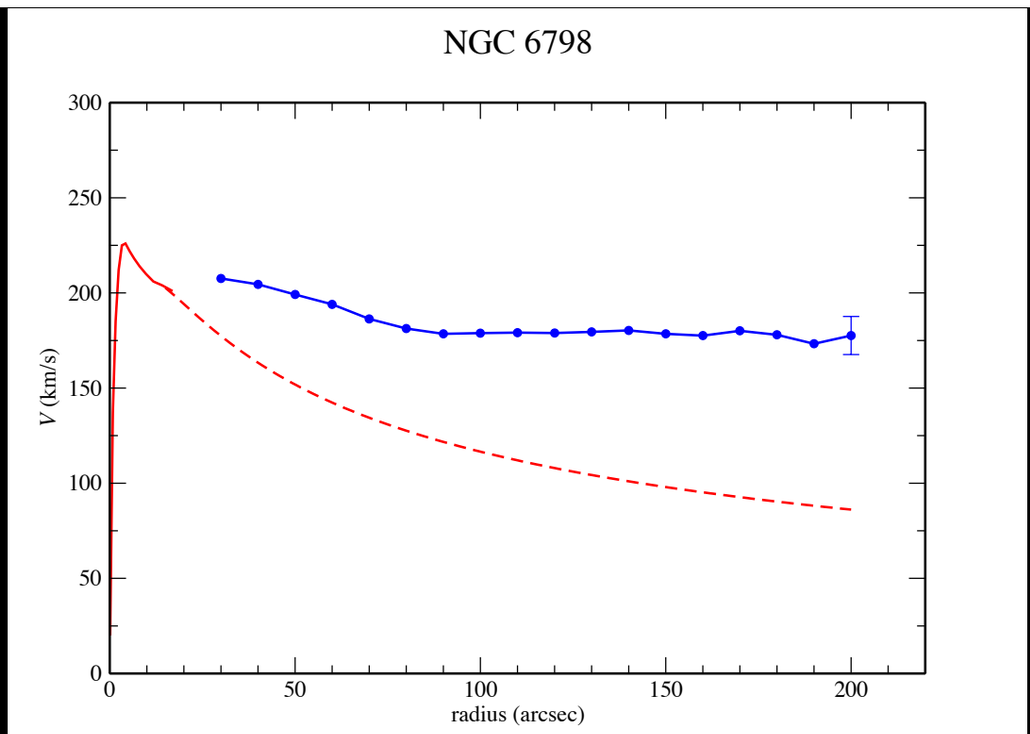

Summary

ASTRON

- ~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 .
- Cluster: no accretions: related to difference in stellar pop?
- 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
- Rotation curves are flat out to > 10 $R_{\rm eff}$
- TFR has small offset from that of spirals, but less than CO TFR; Massive galaxies have large offset?
- HI imaging reveals a lot about ETGs - will learn a lot from ASKAP, Apertif, MeerKat & EVLA surveys