Cool gas inside early-type galaxies

Timothy A. Davis – ESO Fellow

M. Bureau, K. Alatalo, L. Young, R. Lapham, E. Bayet, A. Crocker, L. Blitz, M. Cappellari, M Sarzi & the ATLAS^{3D} team

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Defining ETGs:

In this talk my ETGs are from the ATLAS^{3D} survey:

They are selected such that:

- Mk < -21.5 ~ log(Msun) > 9.3
- Within 42 Mpc
- Visually classified as early-type (classical Hubble definition)
- Observable with the WHT

→ Volume limited sample of 260 ETGs

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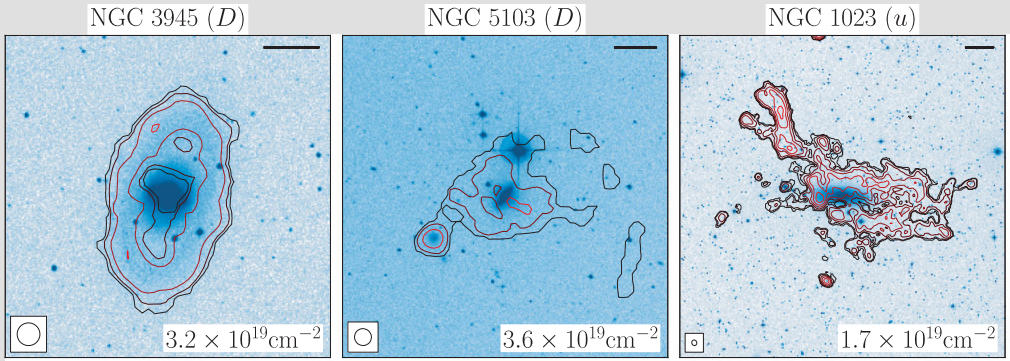
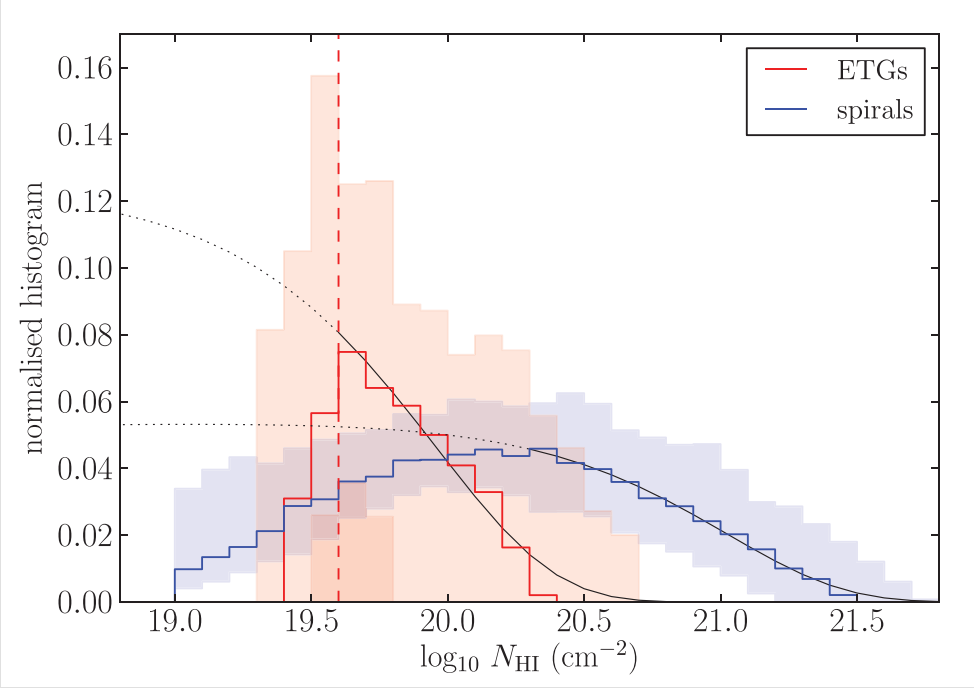
HI in Early-Type Galaxies

- **40%** of field ETGs detected
  - <10% of cluster ETGs
- Detection rate independent of galaxy mass
- HI Masses: **10^7** to **10^{10}** Msun!
  - → significant fraction of all ETGs as H I-rich as spiral galaxies!
  - → … but typical density is lower
- Majority of HI in disks/rings
- Most dynamically relaxed





Morganti et al., 06, Oosterloo et al., 10, Serra et al., 12

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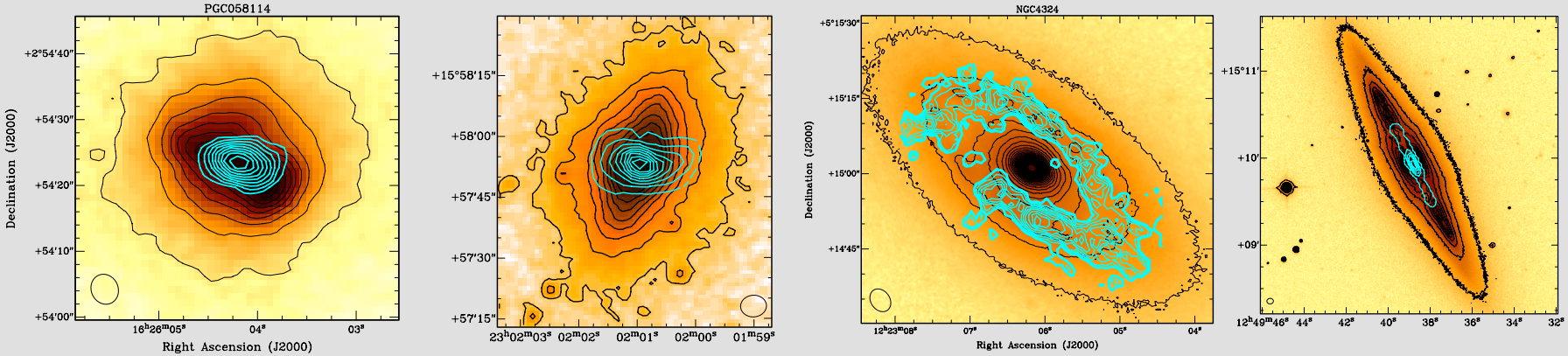
Molecular Gas in ETGs

- **Detection rate: 22%** (Young et al., 11)
- Molecular gas masses in range 10^7 to 10^9 Msolar
- Upper limits down to 6.3×10^6 Msolar
- Molecular gas fractions: 7% to 0.02% (Msolar/L_K)
- No detections of molecular gas in slow rotators

- Detection rate independent of luminosity and environment!
- Molecular gas relaxed, dynamically cold, in disks/rings (Davis+ 11a,b, 13a, Alatalo+ 13)



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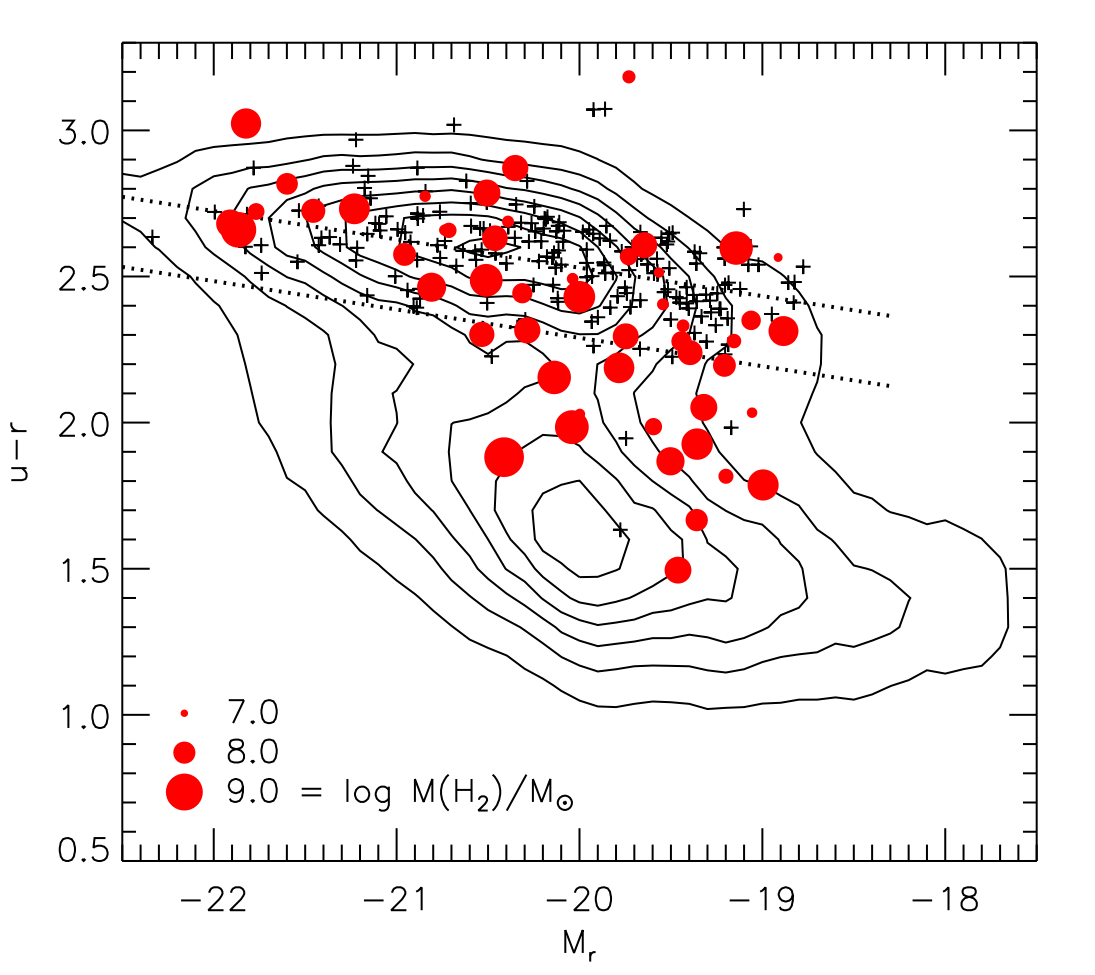

- Detections do not avoid the red sequence
- Mass fractions also don't depend on colour

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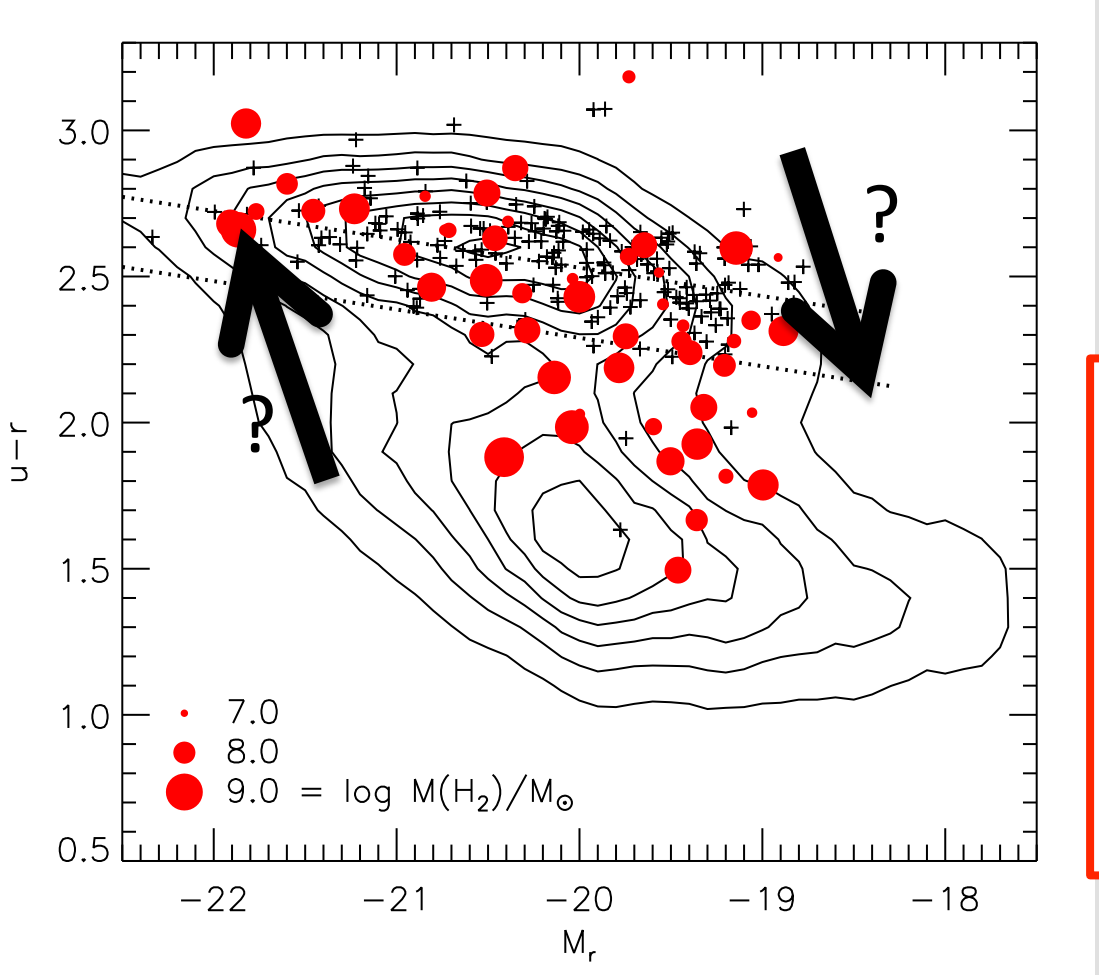

- Detections do not avoid the red sequence
- Mass fractions also don't depend on colour

Big questions:

- **Are these galaxies regenerated? Or being quenched?**
- **Where is the gas coming from?**
- **Is it forming stars?**

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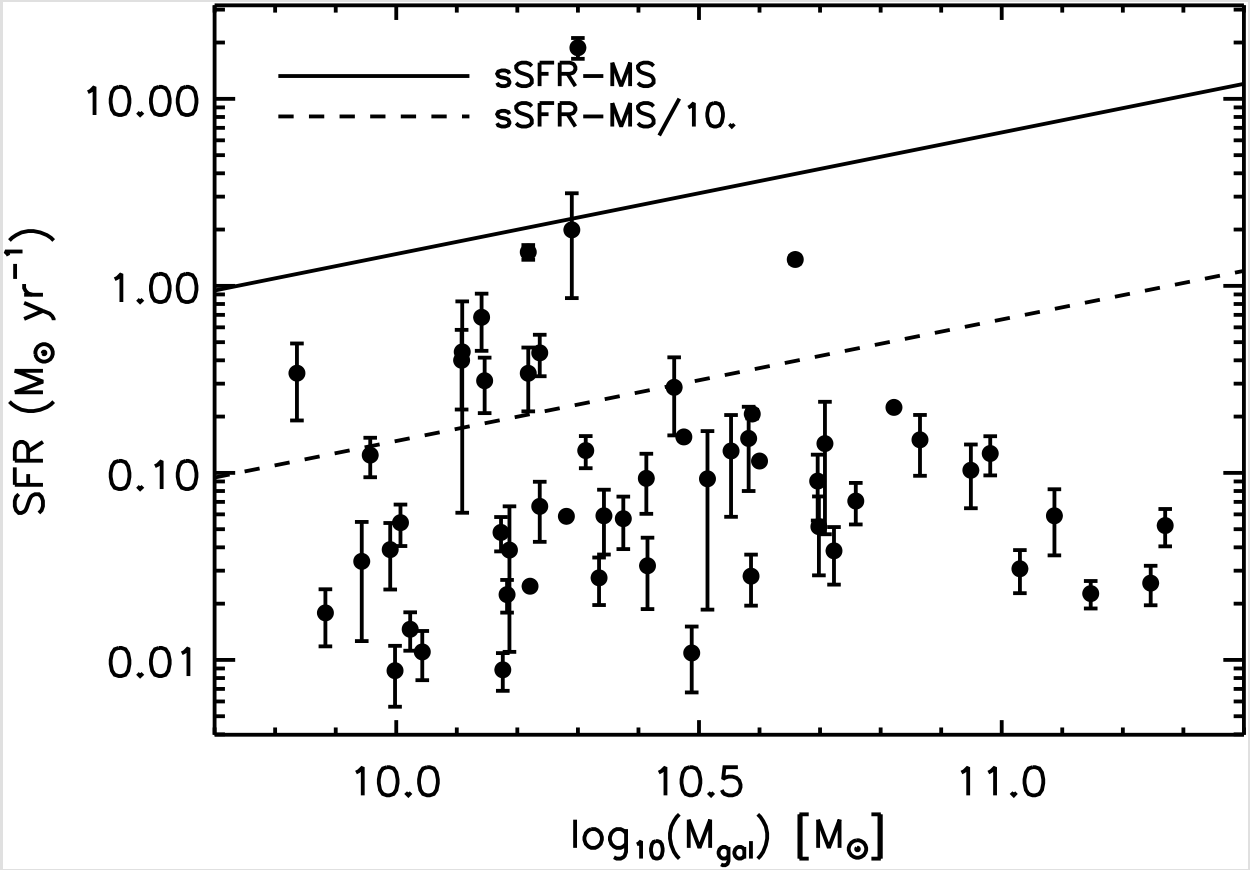
Aside: Are these objects "quiescent"

Depends how you define it…

But:

- Many are in the red sequence
- **80%** are >10x below the sSSR "main sequence"
- Similar fraction would be selected in a "passive" colour wedge



Davis et al., 14

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Big questions:

1. **Are these galaxies regenerated? Or being quenched?**

2. Where is the gas coming from?

3. Is it forming stars?

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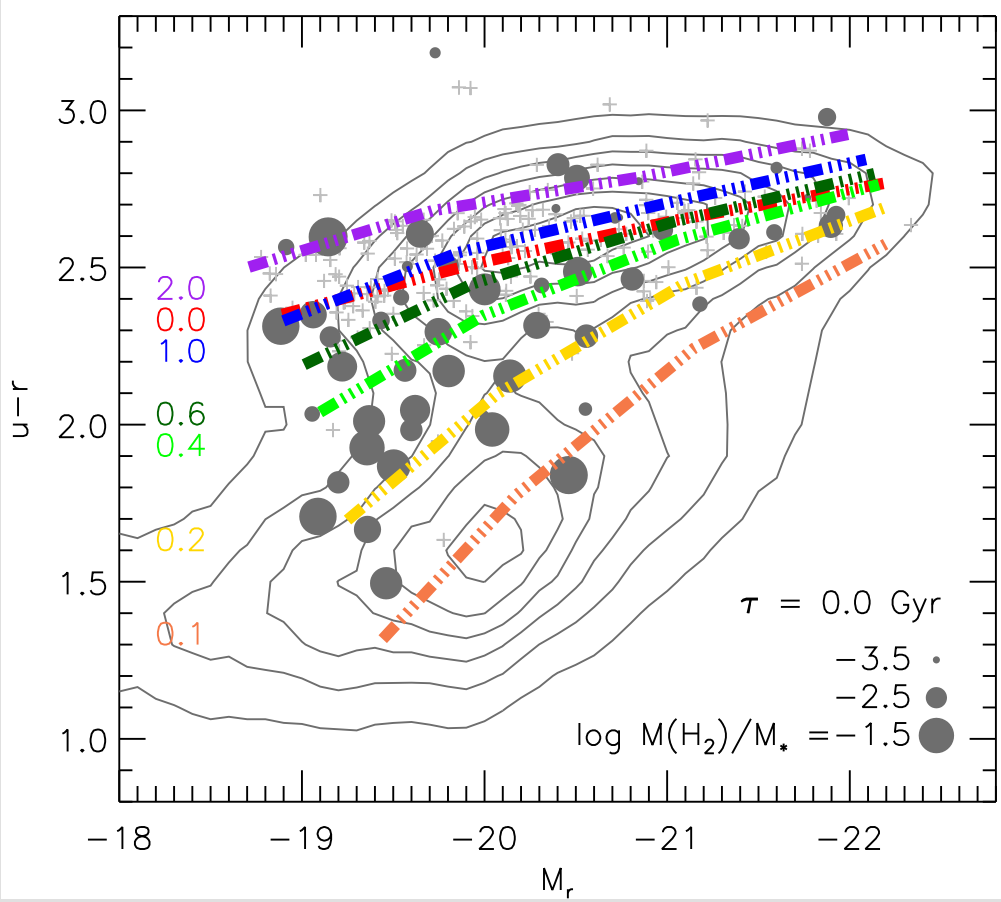
Regenerated? Or being quenched?

- Gas hosting galaxies *almost* indistinguishable from gas poor galaxies (e.g. same B/T, same environments, same masses…)

- Colour distribution entirely consistent with galaxies from the red sequence that have been ***regenerated***

→ Whatever mechanism keeps galaxies quiescent has *failed* in up to 40% of cases…



Young et al., 2013

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Big questions:

1. **Are these galaxies regenerated? Or being quenched?**
   - Regeneration most likely
   - Mechanisms that keep galaxies quiescent have *failed* ~40% of cases

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Key Question:
What is the origin of the cold gas?

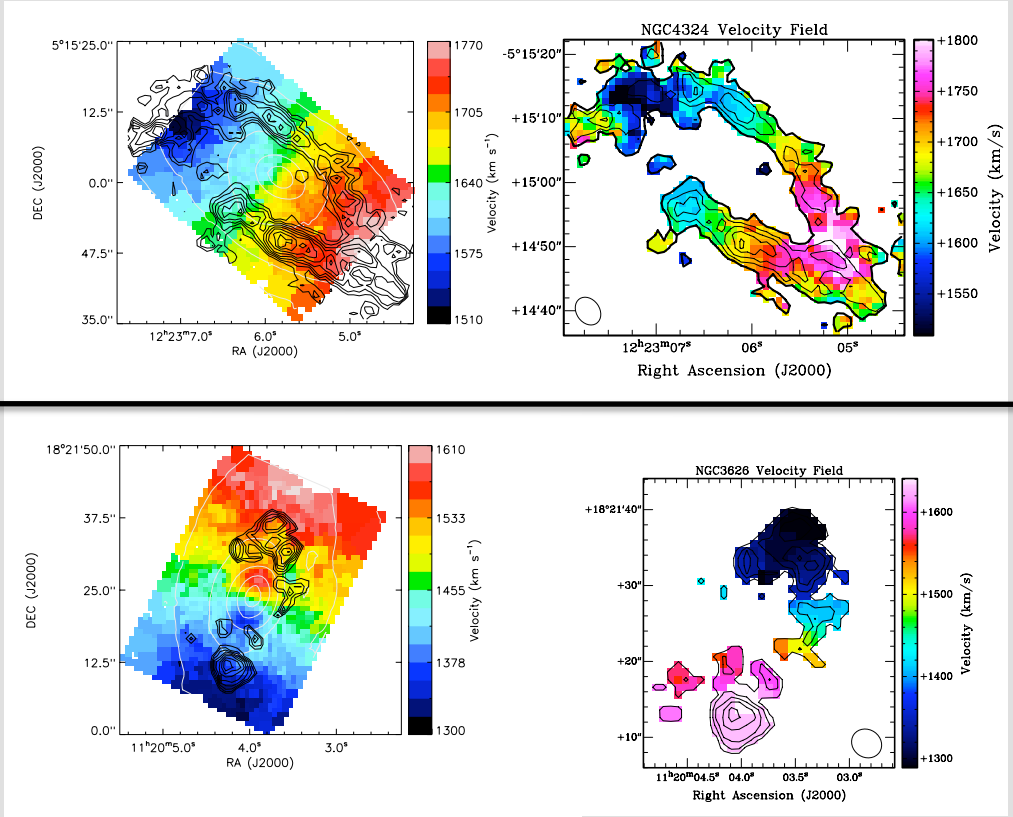
Two main possibilities:
- Internal stellar mass loss
- External accretion/cooling

Both leave traces in molecular gas kinematics.

Internal stellar mass loss -> gas rotates like stars

External -> gas can rotate in any sense

Use our large statistical sample to see which is dominant:



Davis et al., 2011 (Paper X)

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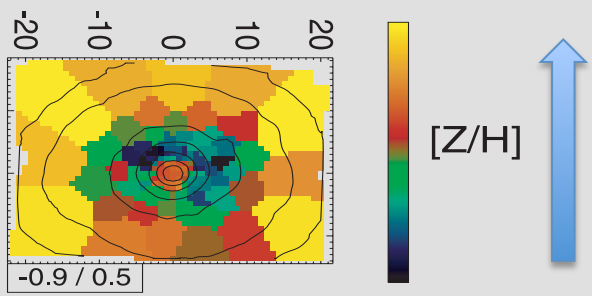
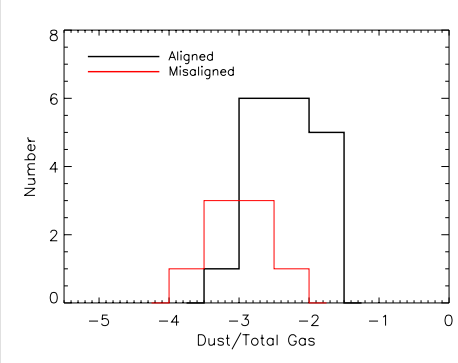
In total:
- Aligned gas → 2/3 of galaxies
- Misaligned accretion/cooling → 2/3 of galaxies

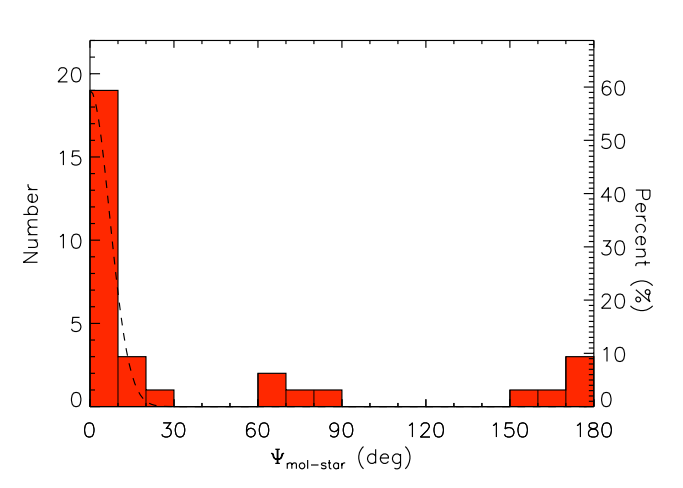
However- there is a strong environmental dependence
→ In field environments >50% of gas misaligned!!

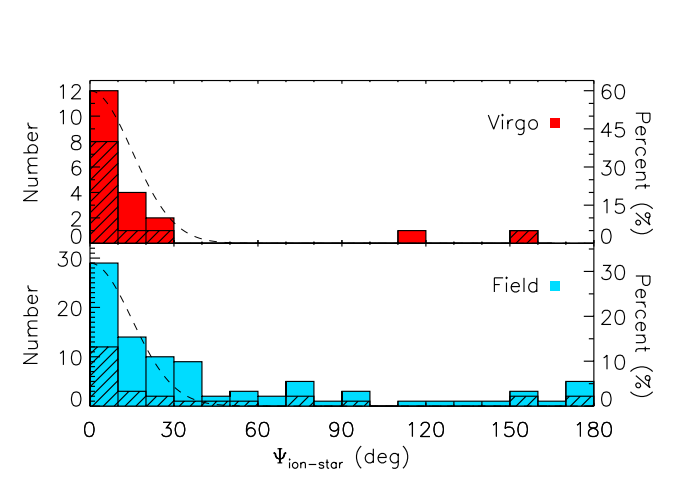
This misaligned gas is typically:
- Lower metallicity & has a lower dust content

→ Suggests accretion from *minor mergers* dominates in the field









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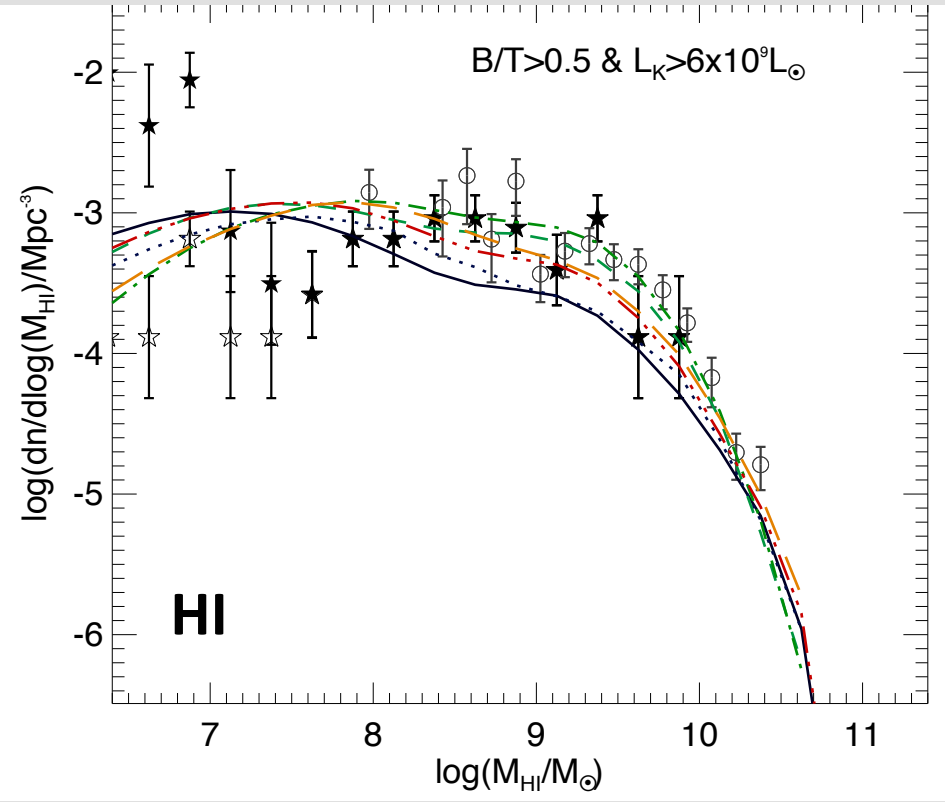
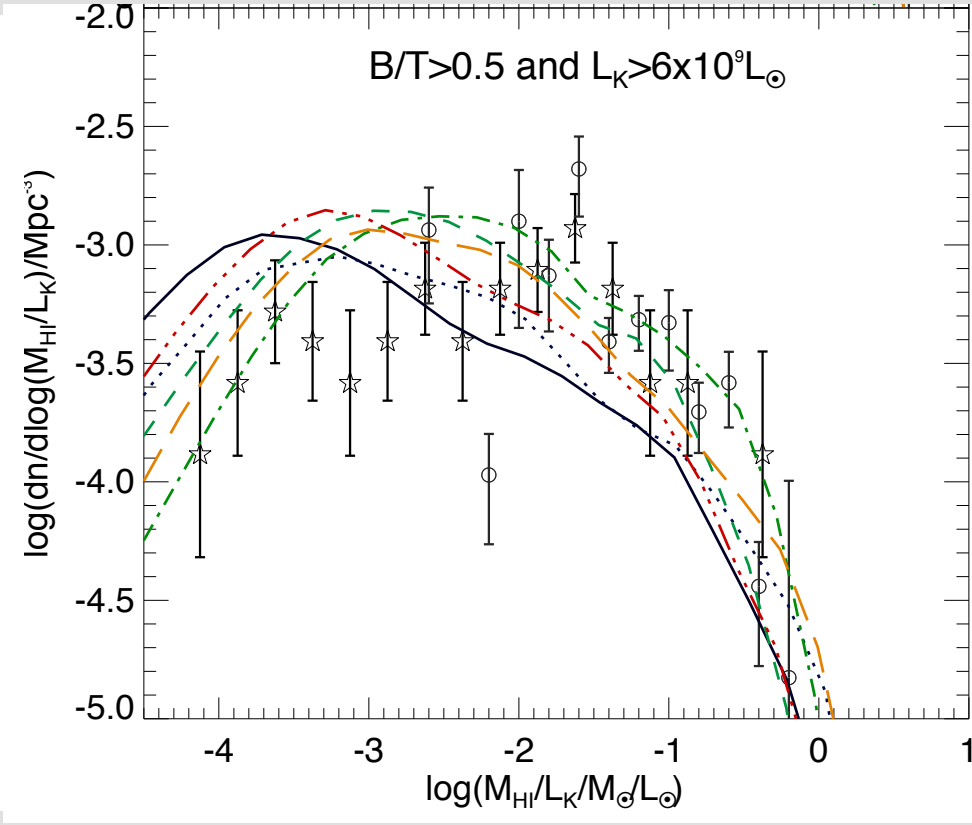
Theoretically:

- State of the art semi-analytic models successfully predict HI and H2 mass functions in ETGs, and mass fraction distributions (Lagos et al., 14)





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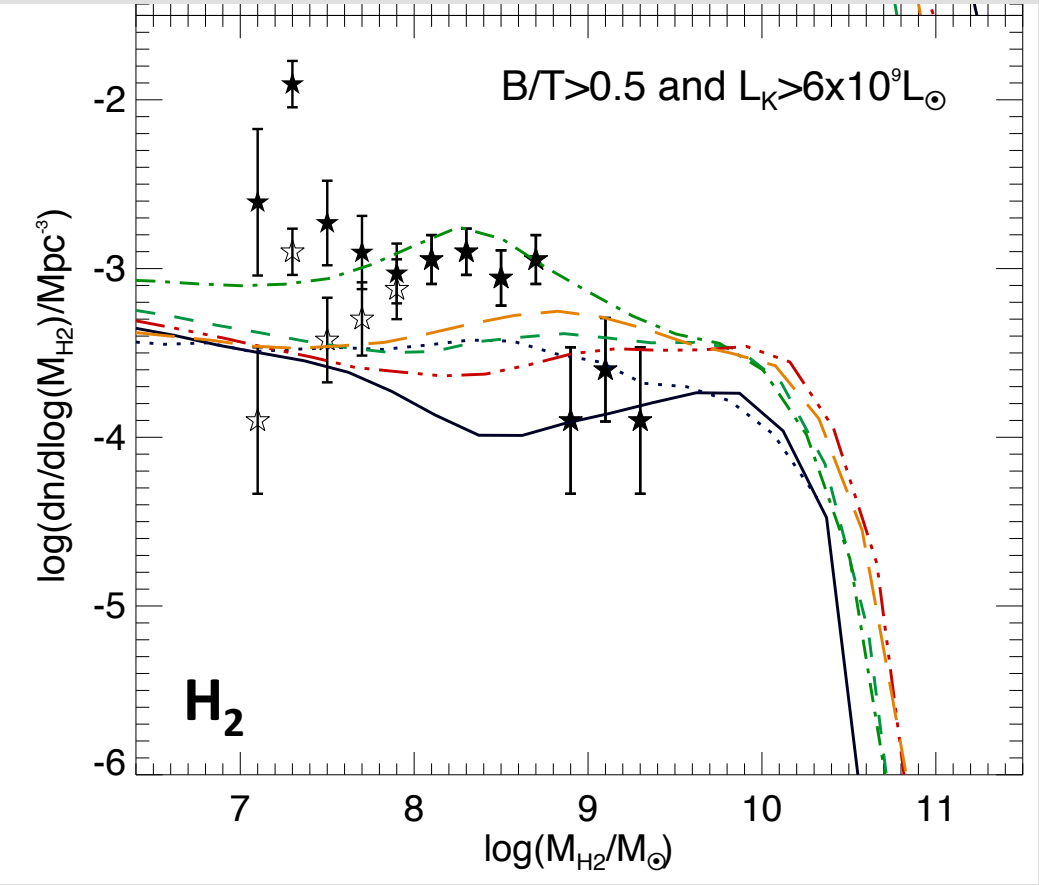

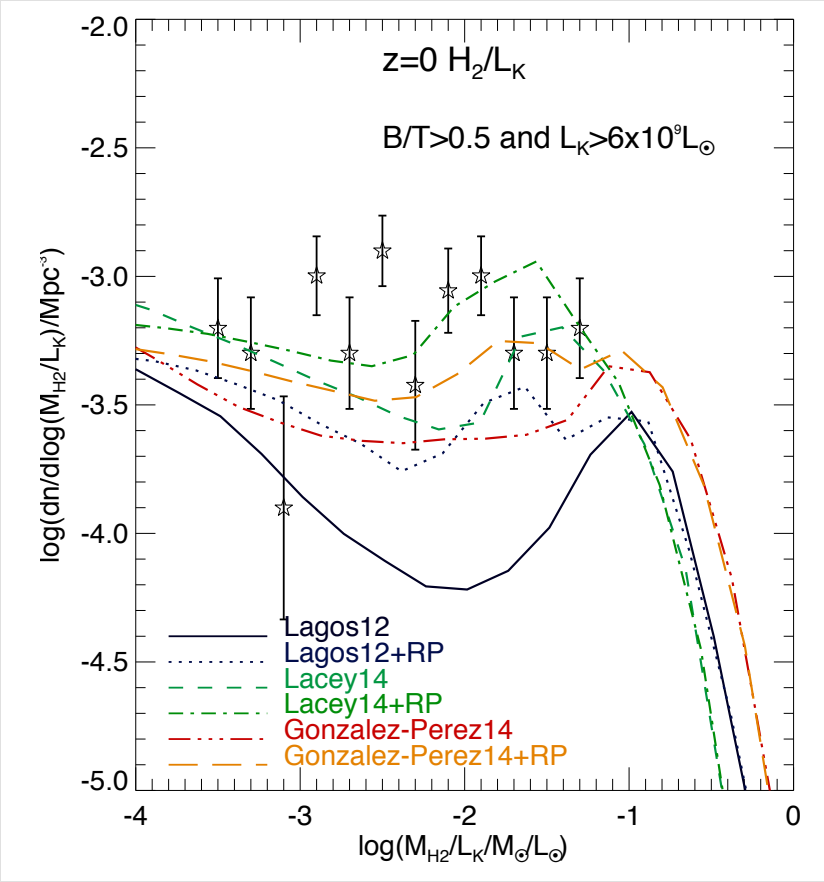

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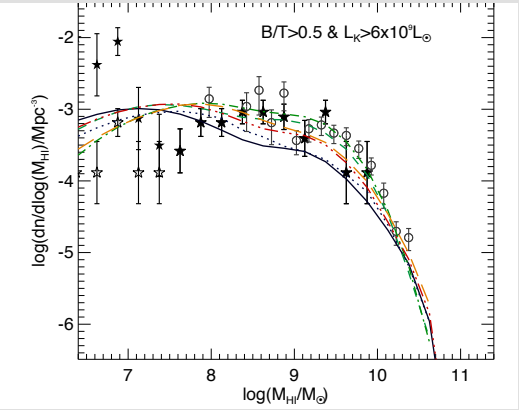

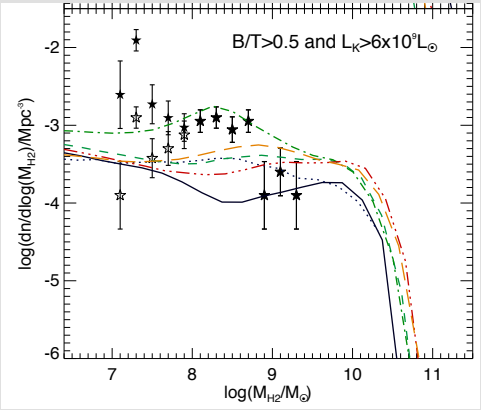

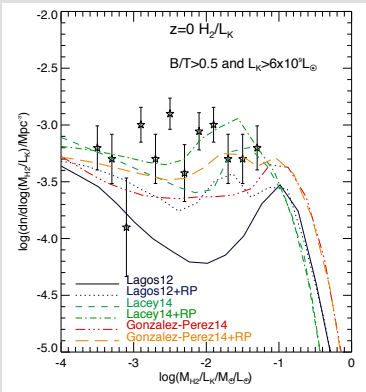

BUT SAMs suggest the majority of the gas cools from the hot halo

→ **Requires hot halos to have angular momentum, and be misaligned from galaxies >50% of the time…**

→ **OR gas rich minor mergers to be more common than predicted, and cooling suppressed?**

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Is this reasonable?

New semi-analytic treatment follows the spin flips of halos

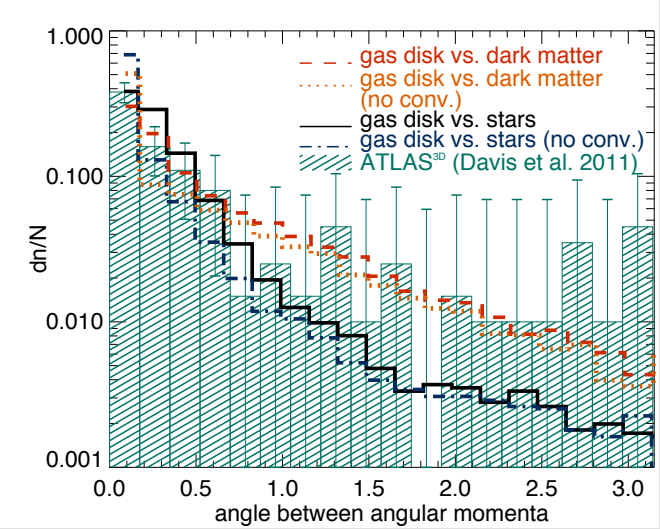
→ Predicts large fraction of misaligned hot gas halos

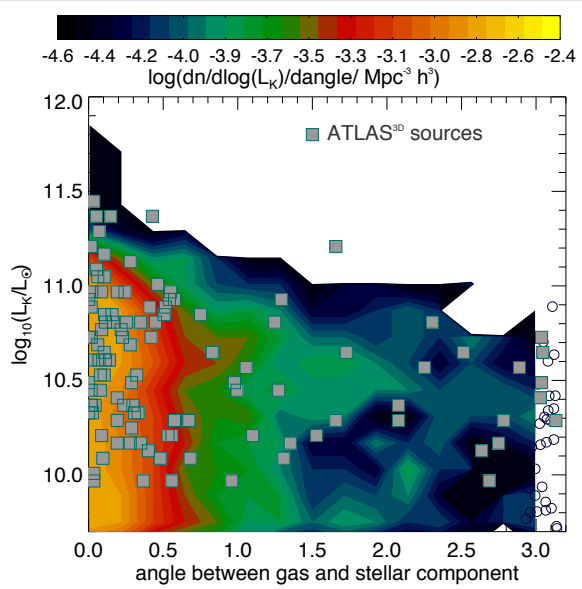
→ Can reproduce the observed misalignment distributions

→ Also predicts the correct mass dependence

Watch for Lagos, Padilla, Davis et al., 2014

In the future ASTRO-H will have to spectral resolution to observe rotation of hot halos in X-ray lines…





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   - Regeneration most likely
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2. **Where is the gas coming from?**
   - Field environments → Accretion from minor mergers and cooling from misaligned hot halos(?)
   - Cluster environments → stellar mass loss cooling?

3. **Is it forming stars?**

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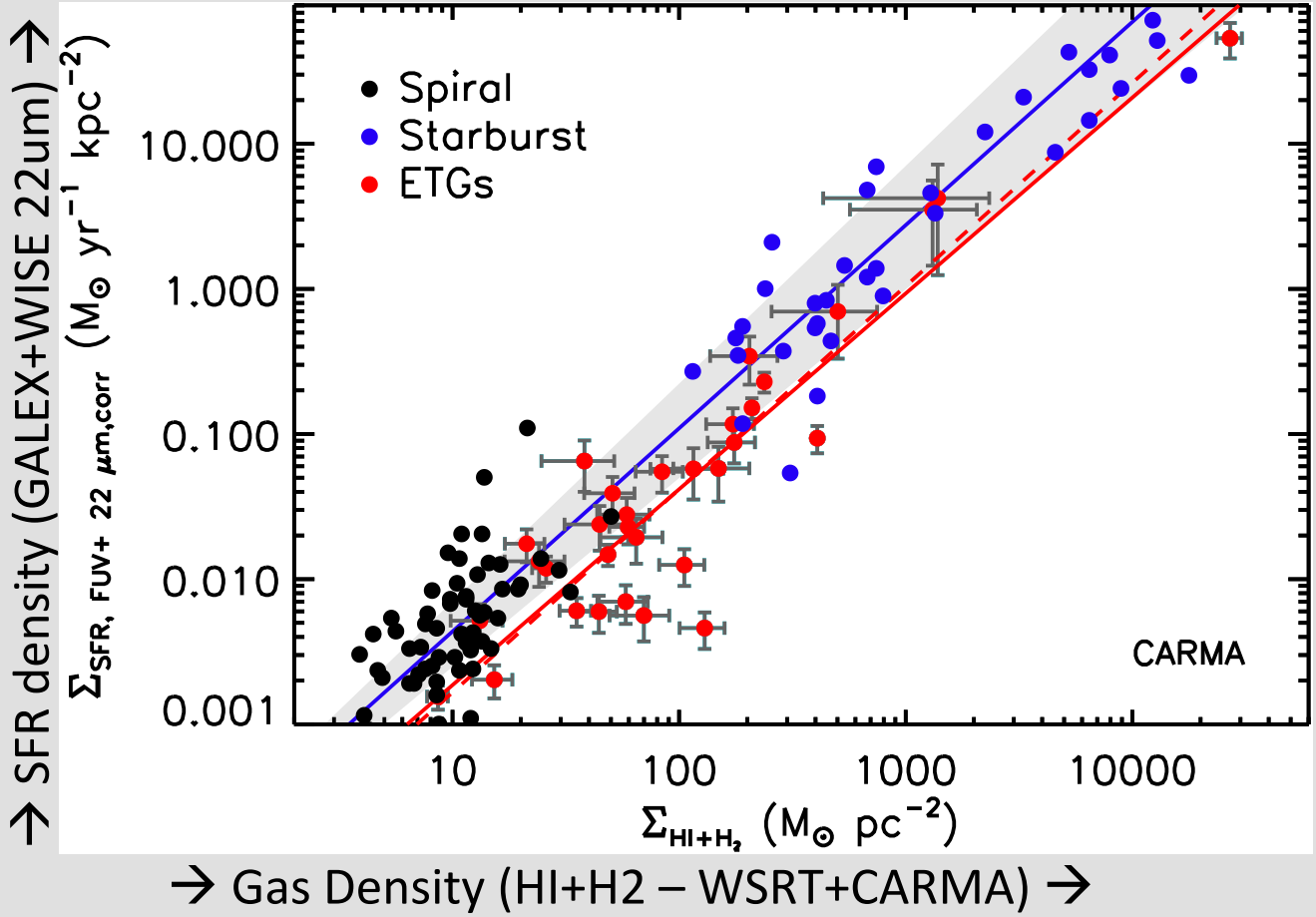
Star formation - (Davis et al, 2014)



- **ETGs form stars less efficiently than spirals!**
- SFE lower by a factor **~2.5**!

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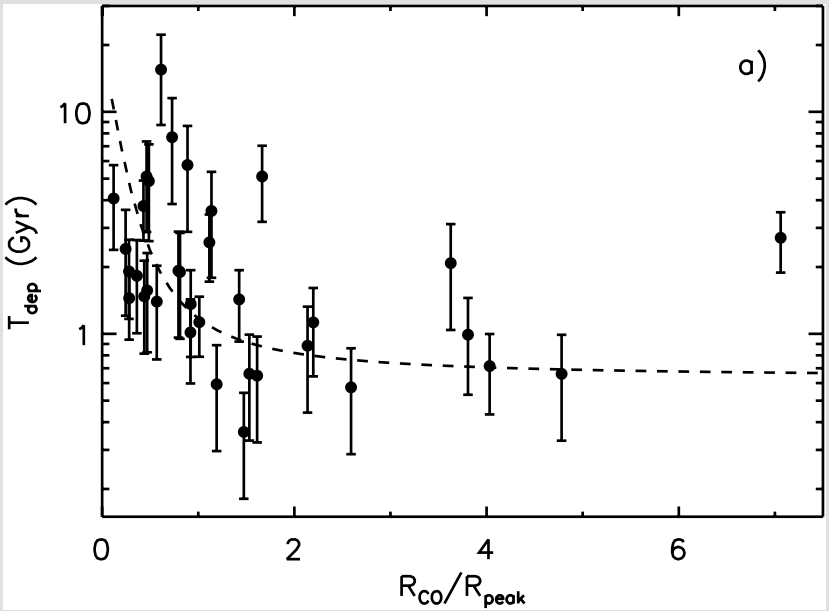
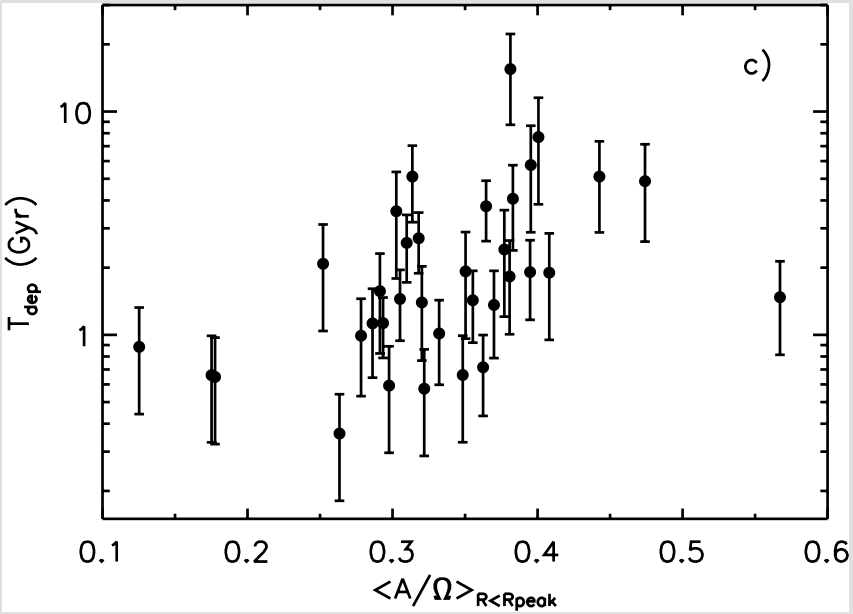
Star formation - (Davis et al, 2014)



- **Depletion time correlates with shape of potential!**
- **If most of the gas is in the rising part of the rotation curve you get SFE suppression!**



- **Torque rate in low SFE objects higher**
  → Clouds pulled apart?

Clearly *resolved* studies will be required to determine fully the physical cause

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3. **Is it forming stars?**
   - Yes → building galaxy substructure
   - Star formation efficiency low
   - Dynamical quenching mechanism?

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Conclusions:

- At least 22% of early type galaxies have molecular gas – not "red and dead"!
- At 40% of field ETGs have substantial HI reservoirs
  → Quenching has failed to stop cold gas forming/surviving in ~50% of ETGs!

- This gas comes from the environment (and cooling from misaligned halos?) in the field
- In clusters secular mechanisms dominate

- The gas is forming stars, building up kinematic substructure
- … but with low efficiency!
- Dynamical quenching mechanisms may be at work? General importance?

The Future:

1) What fundamental process suppresses star formation in local ETGs?
   → Dynamics? Gas chemistry? Star-formation calibrations?
2) From where does the cold inter-stellar medium (ISM) in ETGs originate, and what is the role of minor-mergers, and cooling from hot X-ray halo gas?
   → ASTRO-H, simulations (hydro and SAMs), gas observations of other clusters


Thanks for Listening!
Any questions?
CARMA in winter: mmarray.org