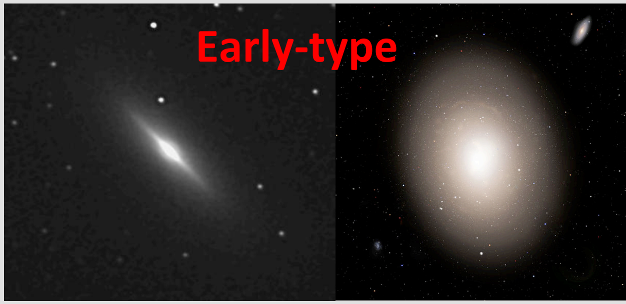
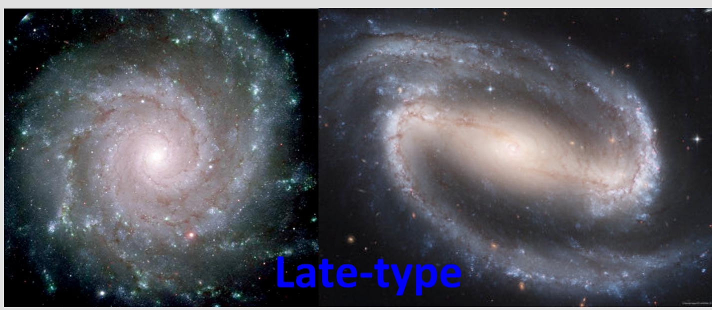
Probing the cold phase ISM in early-type galaxies

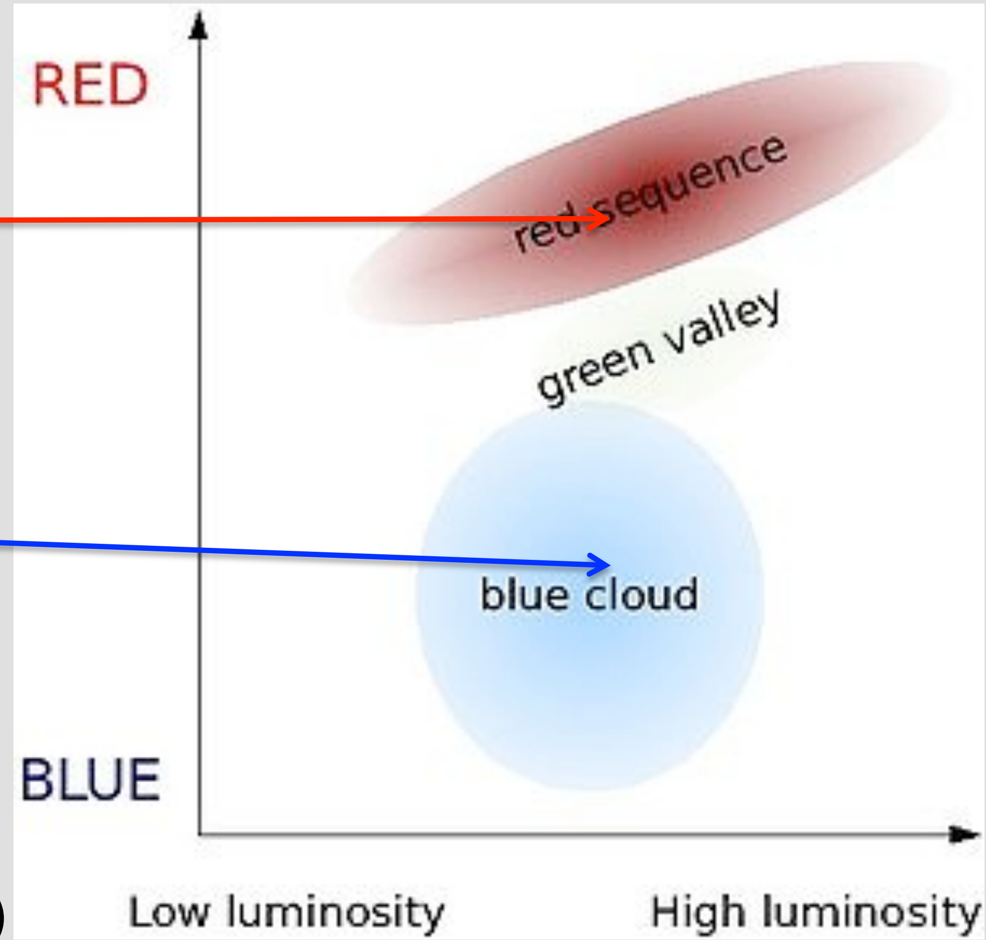
Timothy A. Davis – ESO Fellow

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

Probing the cold phase ISM in early-type galaxies







The red sequence is very tight:

Conclusions:

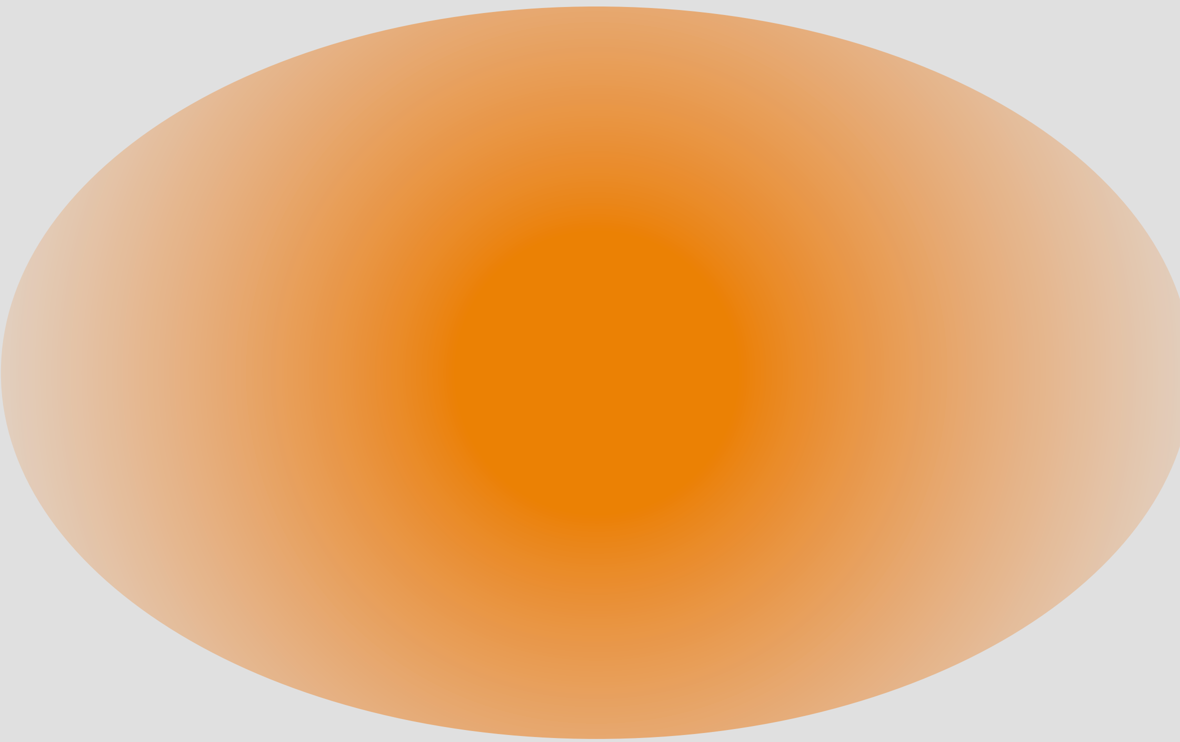
• Galaxies exhaust star-forming gas quickly (lack of galaxies in green valley!)

• No ongoing star-formation in the red sequence

ETGs~ **50%** of (SDSS) mass
[Bernardi et al. 2009]

Probing the cold phase ISM in early-type galaxies

Meet a early-type galaxy…



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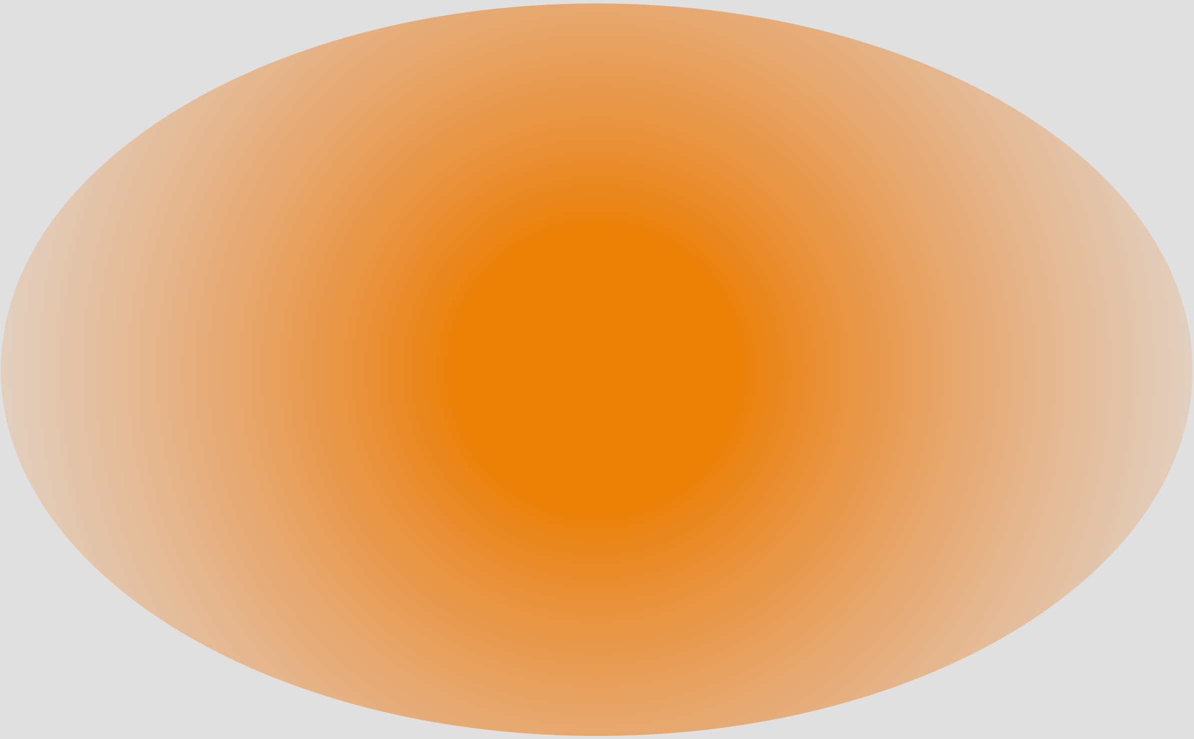


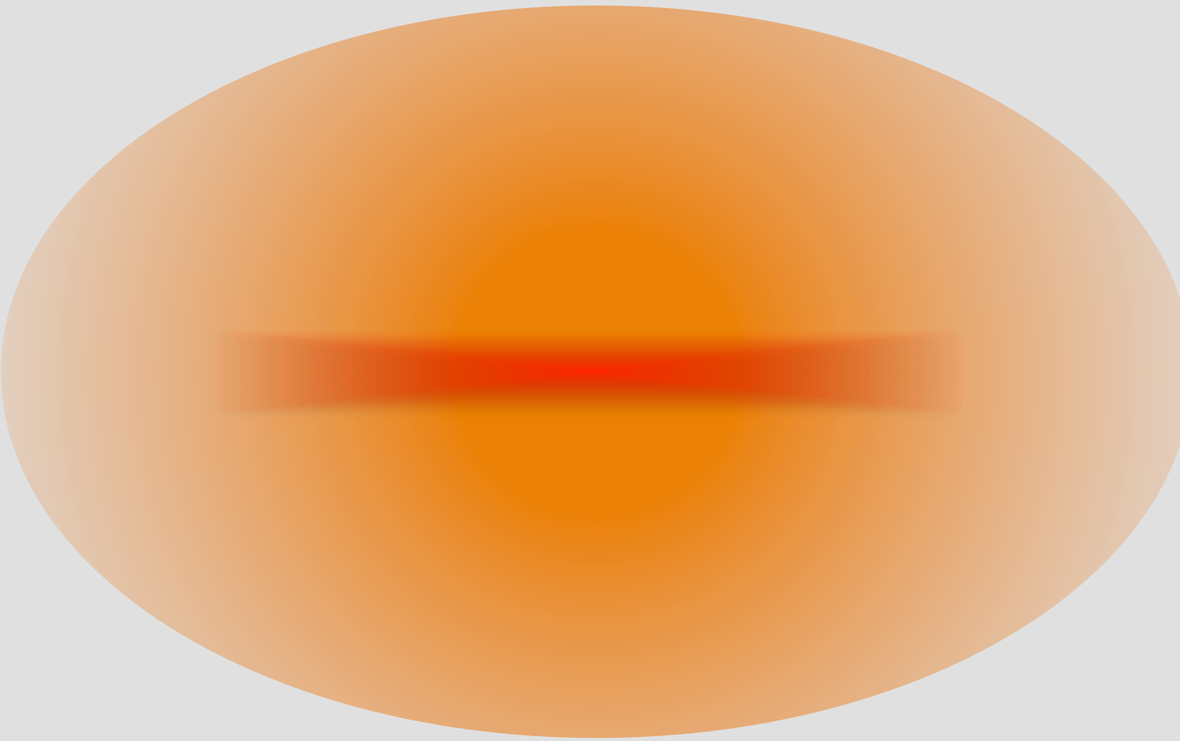
Textbook knowledge:

ETGs:

- “have no axis of rotation”
- “many are pure spheroids”
- “no ISM”
- “no ongoing star-formation”
- “really really boring”

Probing the cold phase ISM in early-type galaxies

Meet a early-type galaxy…



Textbook knowledge:

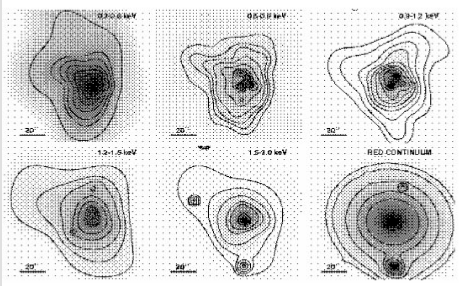
ETGs:

- “have no ~~a[illegible]ation~~”
  90% of ETGs rotate!
  e.g. Emsellem et al., 2011
- “many are ~~[illegible]eroids~~”
  ~90% have imbedded stellar disks! Krajnovic et al., 2013
- “no ISM”
- “no ongoing star-formation”
- “really really boring”

Probing the cold phase ISM in early-type galaxies

The hot ISM

Massive ETGs have large X-ray halos



e.g. O'Sullivan et al., 2001

The hot ISM

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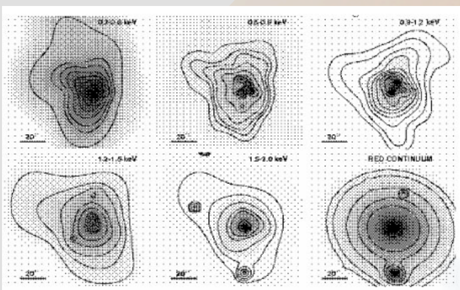

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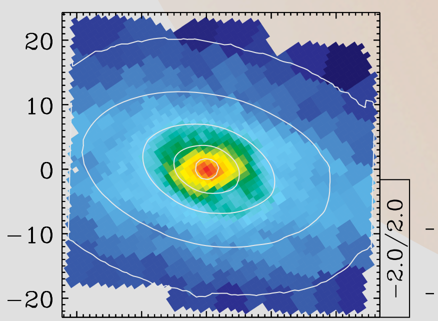
~70% of ETGs have ionised gas disks



e.g. Sarzi et al., 2006

Probing the cold phase ISM in early-type galaxies

The hot ISM

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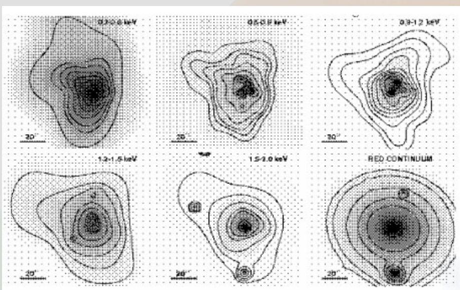

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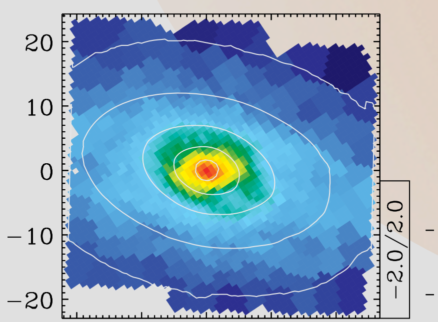
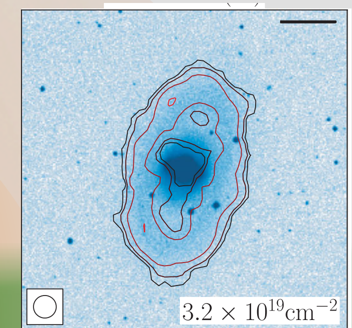


e.g. Sarzi et al., 2006

The cold ISM

~40% of ETGs have HI reservoirs

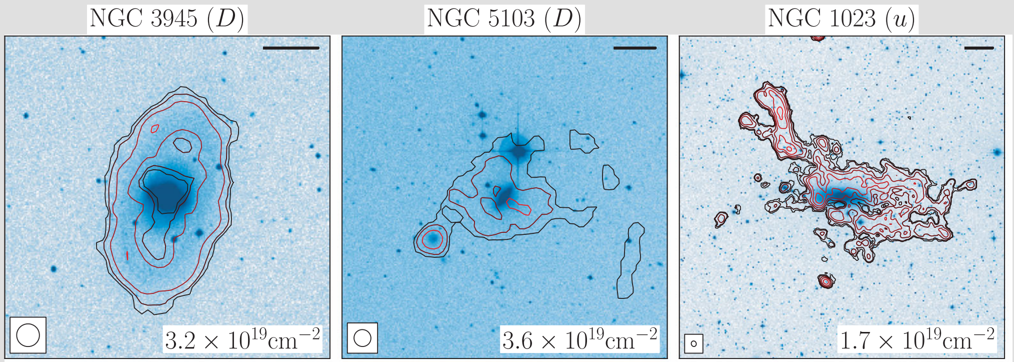


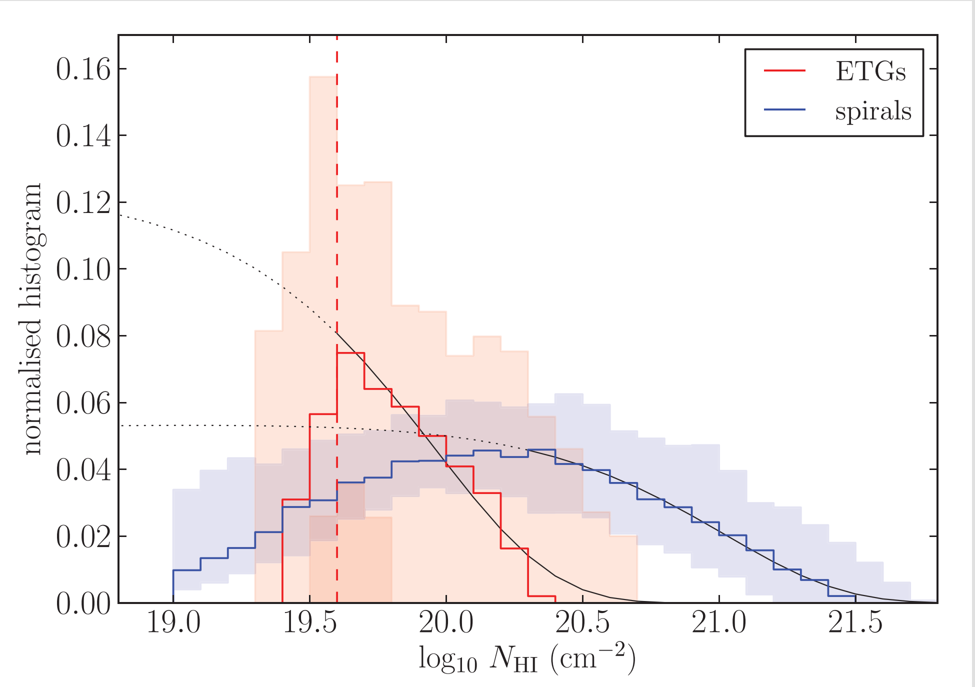
e.g. Serra et al., 2011

Probing the cold phase ISM in early-type galaxies

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





Probing the cold phase ISM in early-type galaxies

The hot ISM

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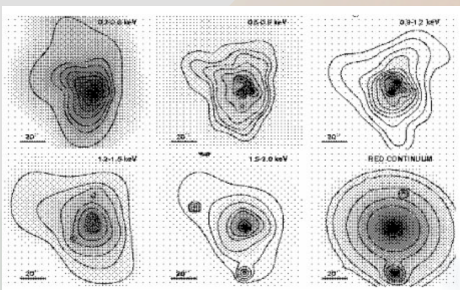
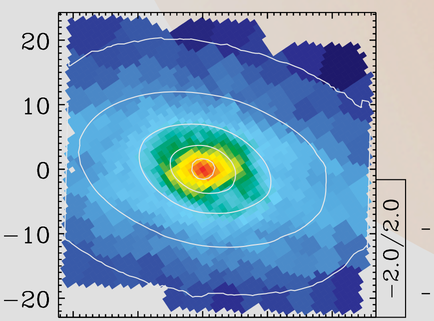


e.g. O'Sullivan et al., 2001

~70% of ETGs have ionised gas disks



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The cold ISM

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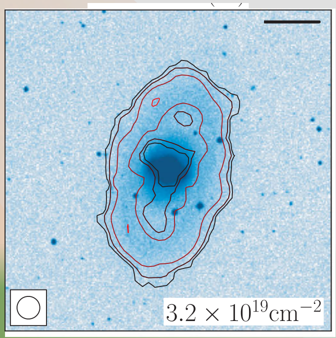
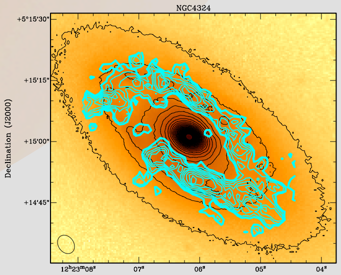


e.g. Serra et al., 2011

~23% of ETGs have molecular gas



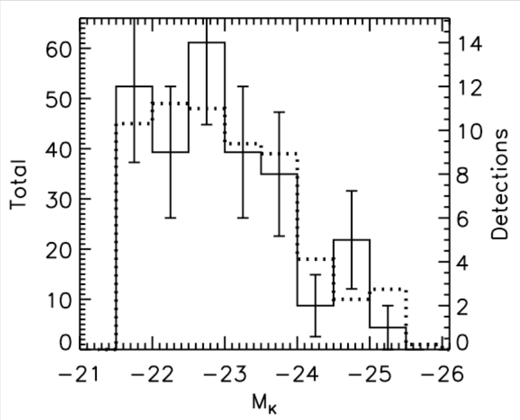
e.g. Young et al., 2011

Probing the cold phase ISM in early-type galaxies

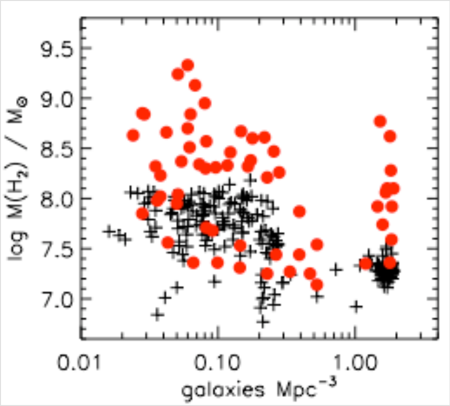
Molecular gas in Early-Type Galaxies

- **Detection rate: 22%**
- Molecular gas masses in range 10^7 to 10^9 Msolar
- Molecular gas fractions: 7% to 0.02% (Msolar/L_K)
- No detections of molecular gas in slow rotators
- Detection rate independent of luminosity!

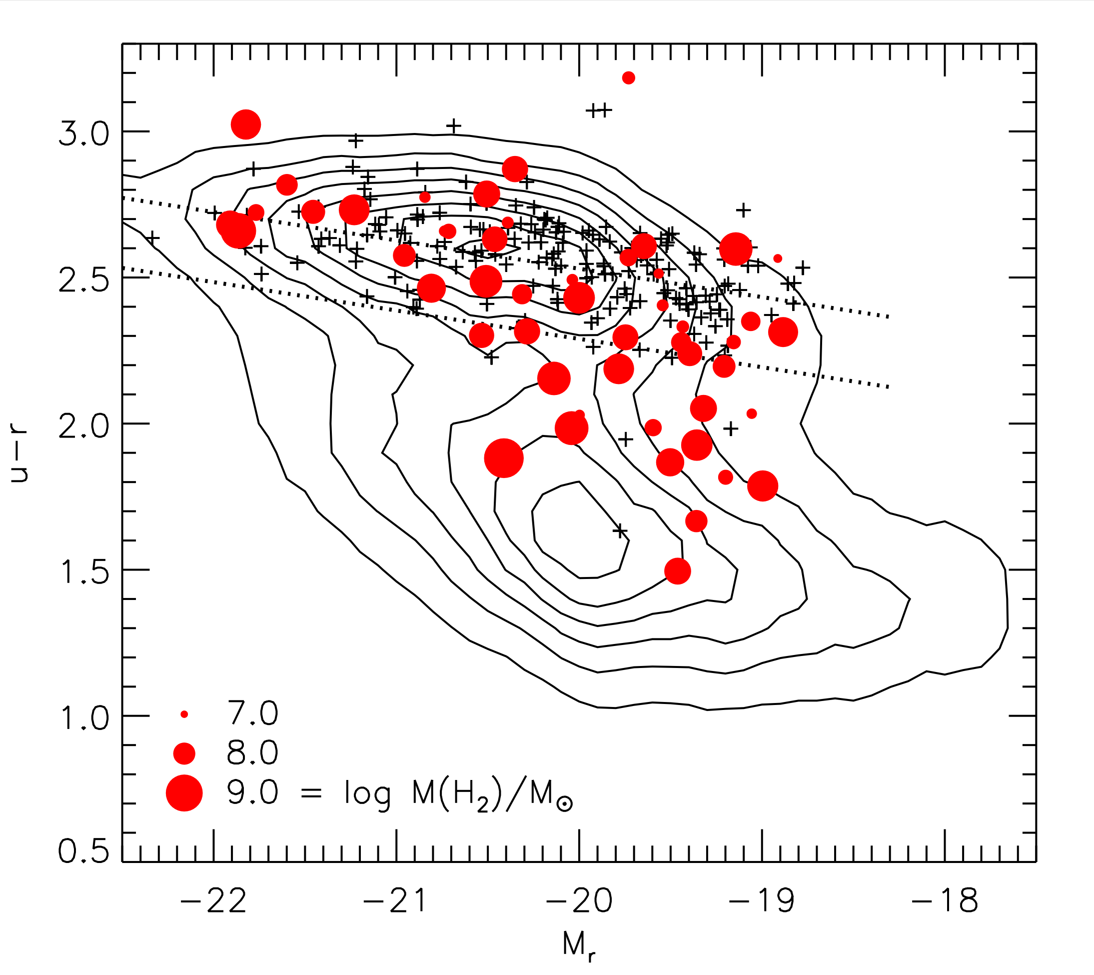
Young et al, 2011



Detection rate also seems to be independent of environment!



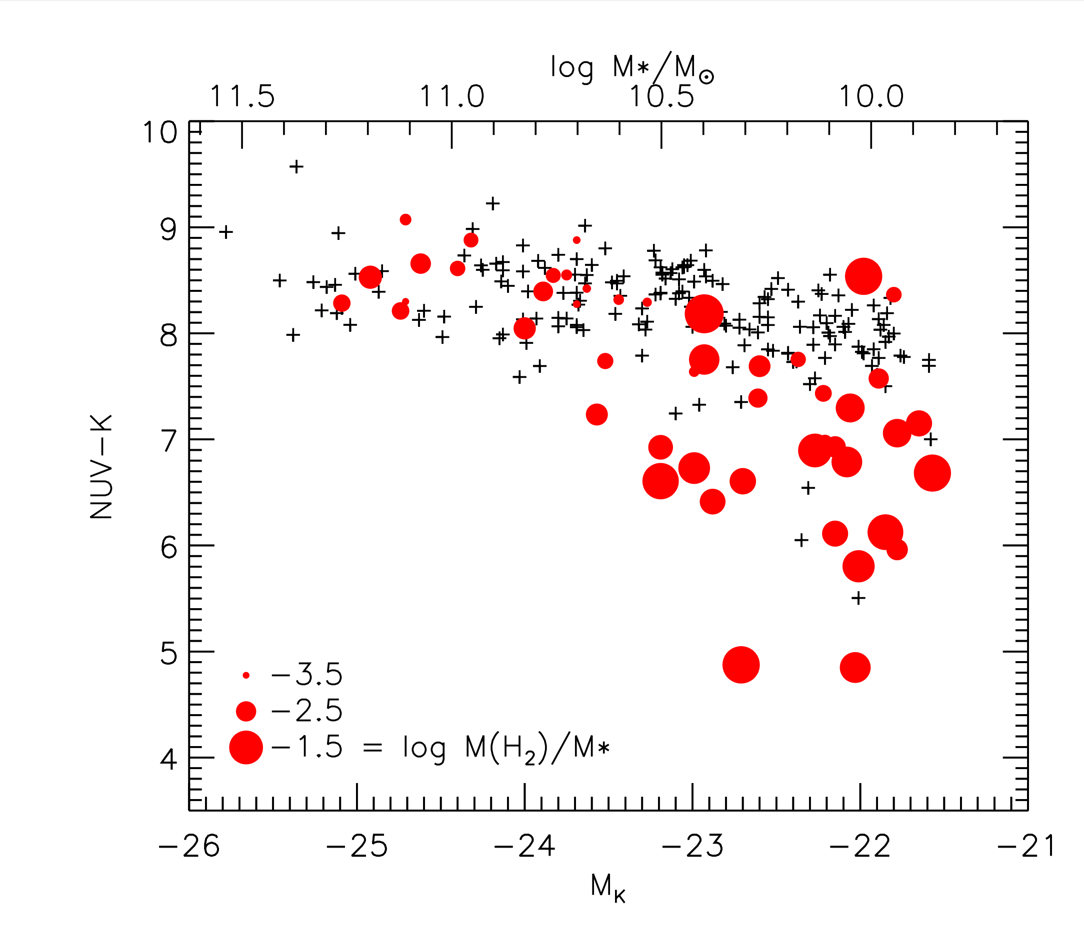
Probing the cold phase ISM in early-type galaxies



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

→ You cannot select galaxies by colour and expect ISM/star-formation free samples!!

Probing the cold phase ISM in early-type galaxies



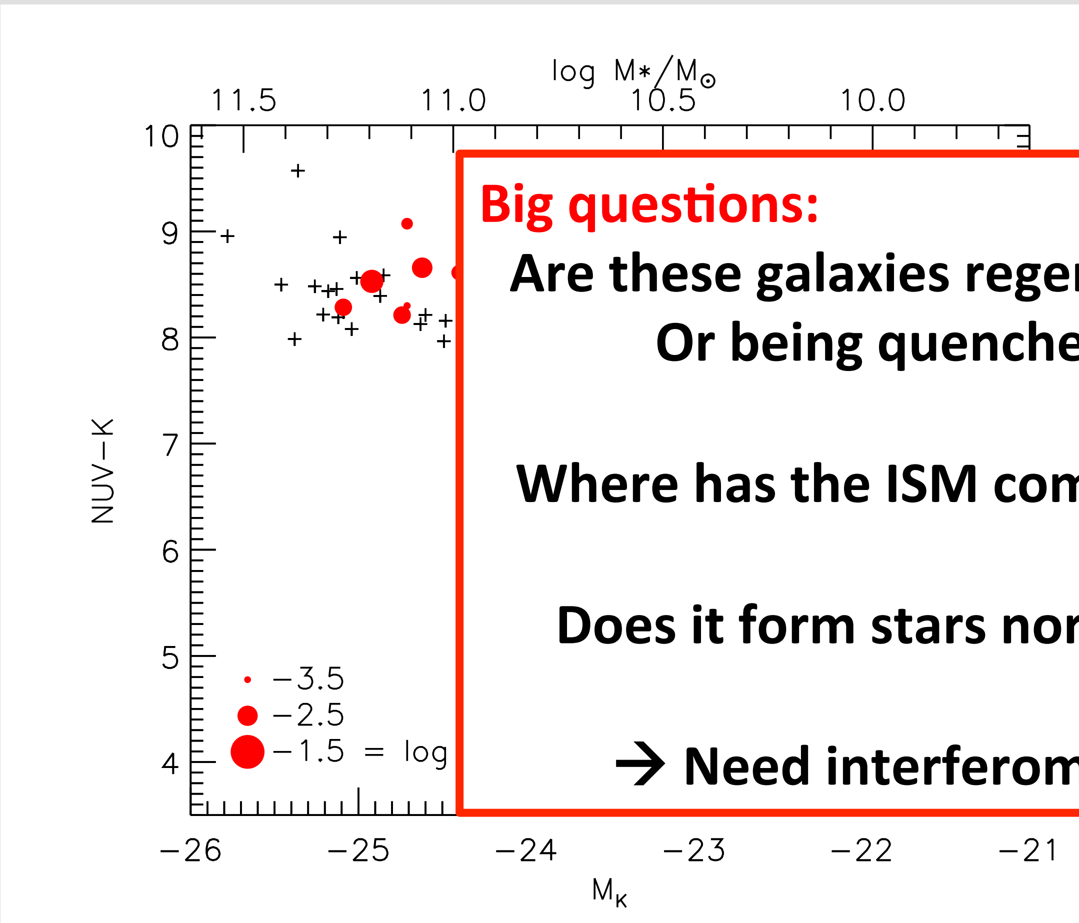
- Detections do not avoid the red sequence
- Mass fractions also don't depend on optical colour

→ You cannot select galaxies by colour and expect ISM/star-formation free samples!!

Even NUV-IR colours cannot be used to select ISM free samples!

(but can help avoid high gas fraction objects)

Probing the cold phase ISM in early-type galaxies



Big questions:

Are these galaxies regenerated?
Or being quenched?

Where has the ISM come from?

Does it form stars normally?

→ Need interferometry

- Detections do not avoid the red sequence
  fractions also don't
  d on optical colour

nnot select galaxies
r and expect ISM/star-
n free samples!!

V-IR colours cannot
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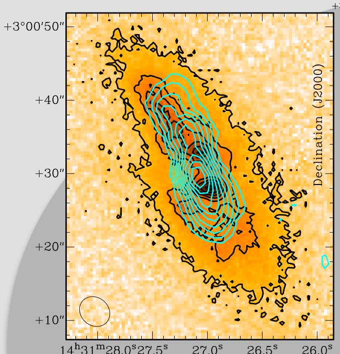
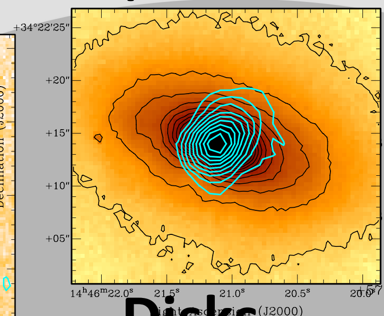
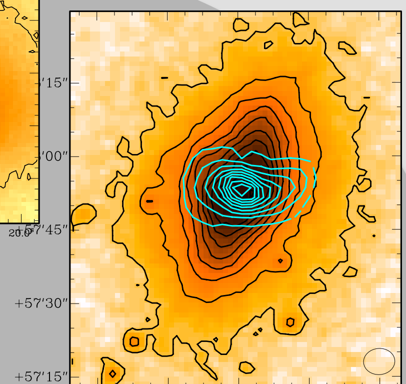
samples!

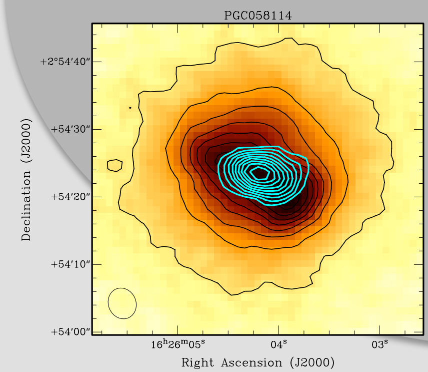
(but can help avoid high gas fraction objects)

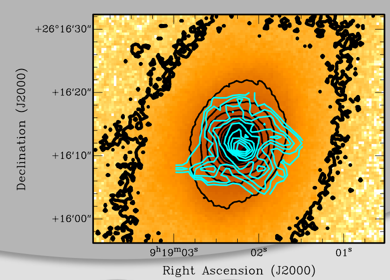
Probing the cold phase ISM in early-type galaxies

CARMA survey- Example Gas Morphologies

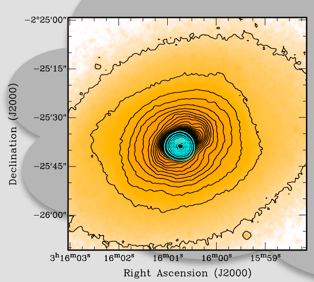
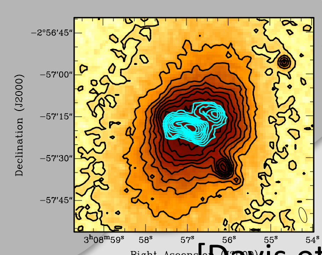




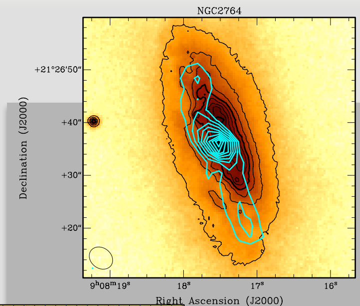
Disks (~55%)

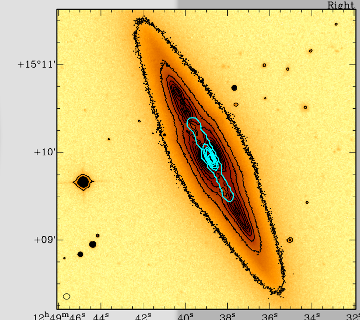
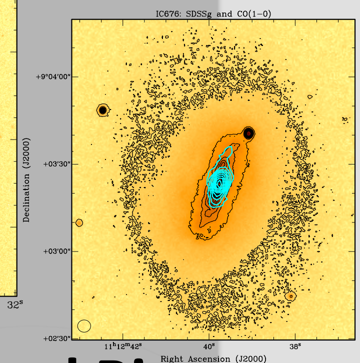




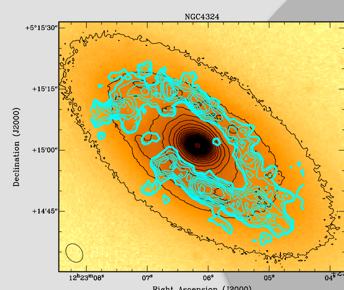
Disturbed Distributions (~10%)

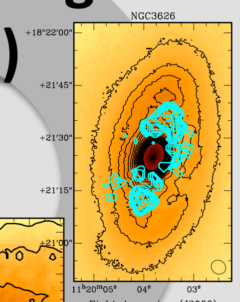



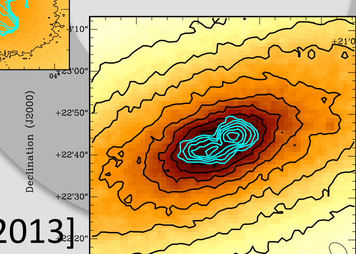


Bars and Rings (~35%)

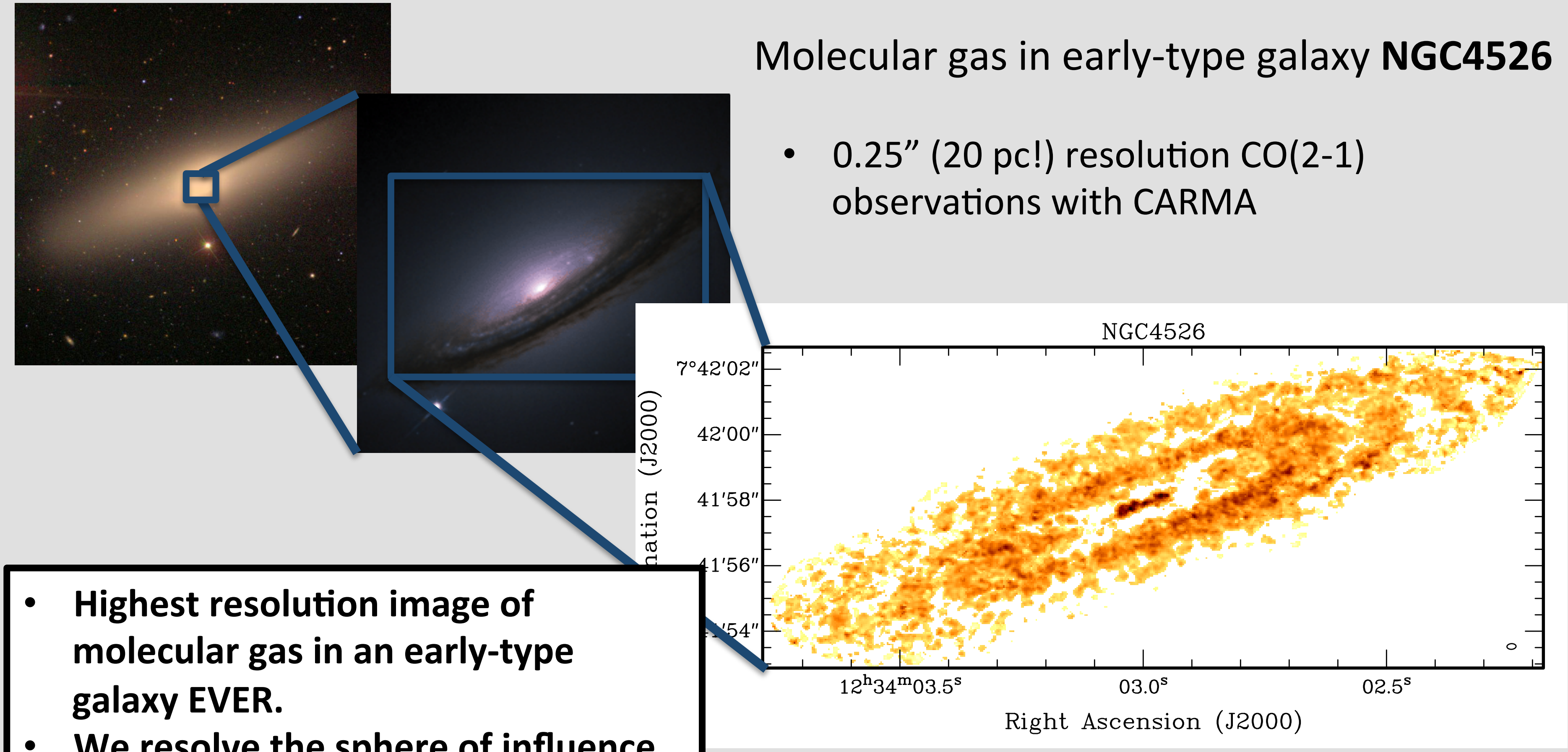






[Davis et al., 2011, 2013, Alatalo et al., 2013]

Probing the cold phase ISM in early-type galaxies



Molecular gas in early-type galaxy **NGC4526**

- 0.25" (20 pc!) resolution CO(2-1) observations with CARMA

Davis et al., Nature, 2013, 494, 328-330

- **Highest resolution image of molecular gas in an early-type galaxy EVER.**
- **We resolve the sphere of influence of the black-hole**
- **Shows importance of resonances/ spirals at small scales**

Probing the cold phase ISM in early-type galaxies

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

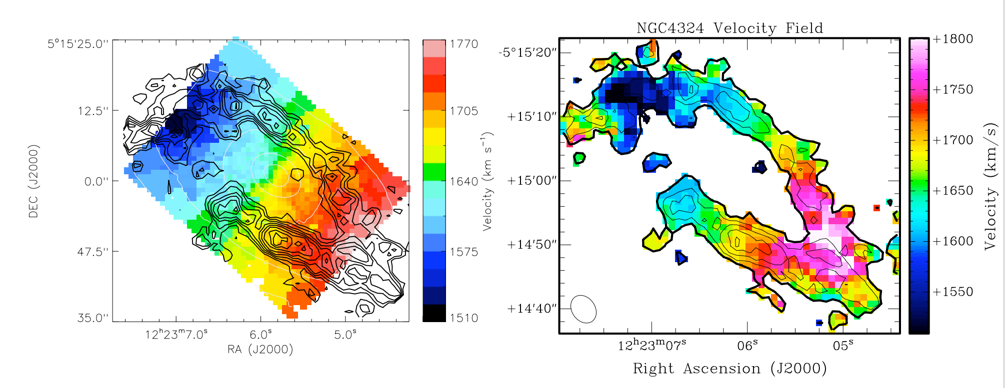
Two main possibilities:
- Internal stellar mass loss
- External accretion/cooling

Both leave traces in molecular gas kinematics.

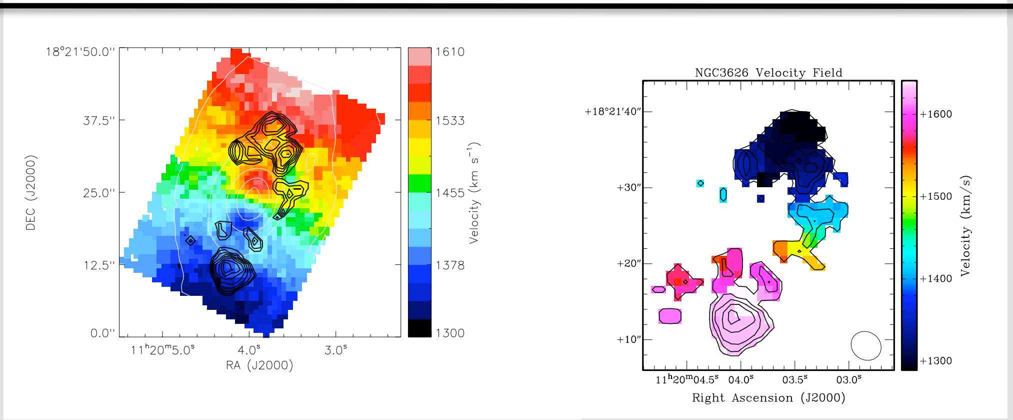
Internal stellar mass loss -> gas rotates like stars

External -> gas can rotate in any sense

Use our large statistical sample to see which is dominant:



ALIGNED



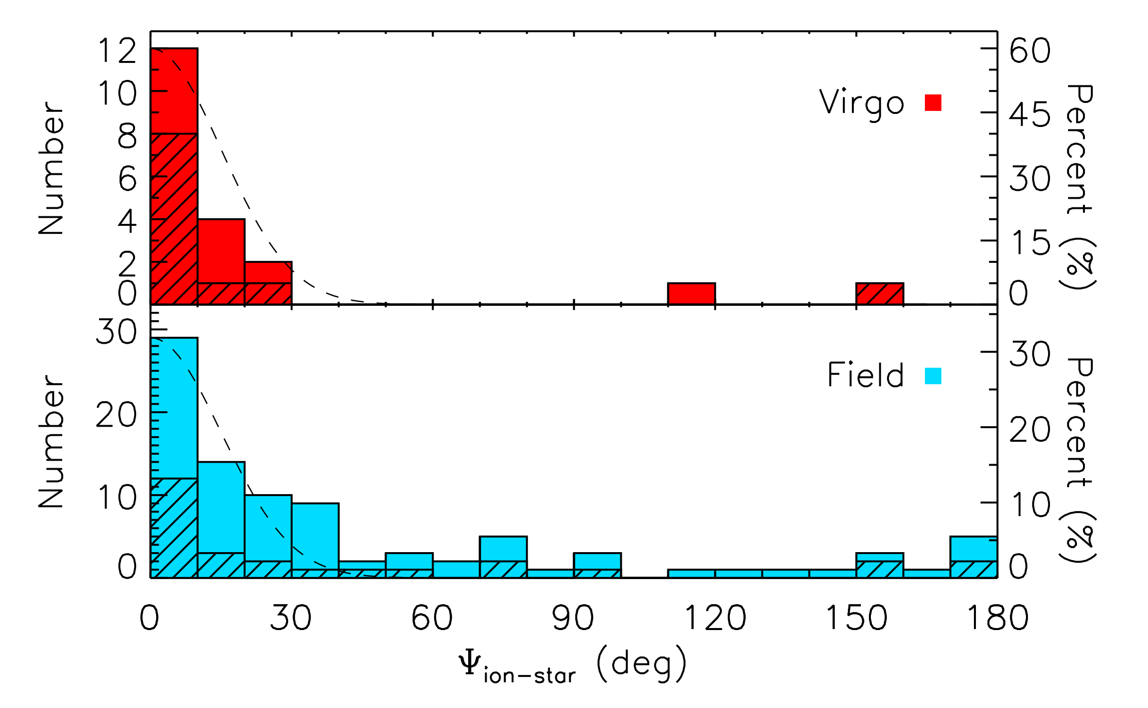
MISALIGNED

Davis et al., 2011b

Probing the cold phase ISM in early-type galaxies

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

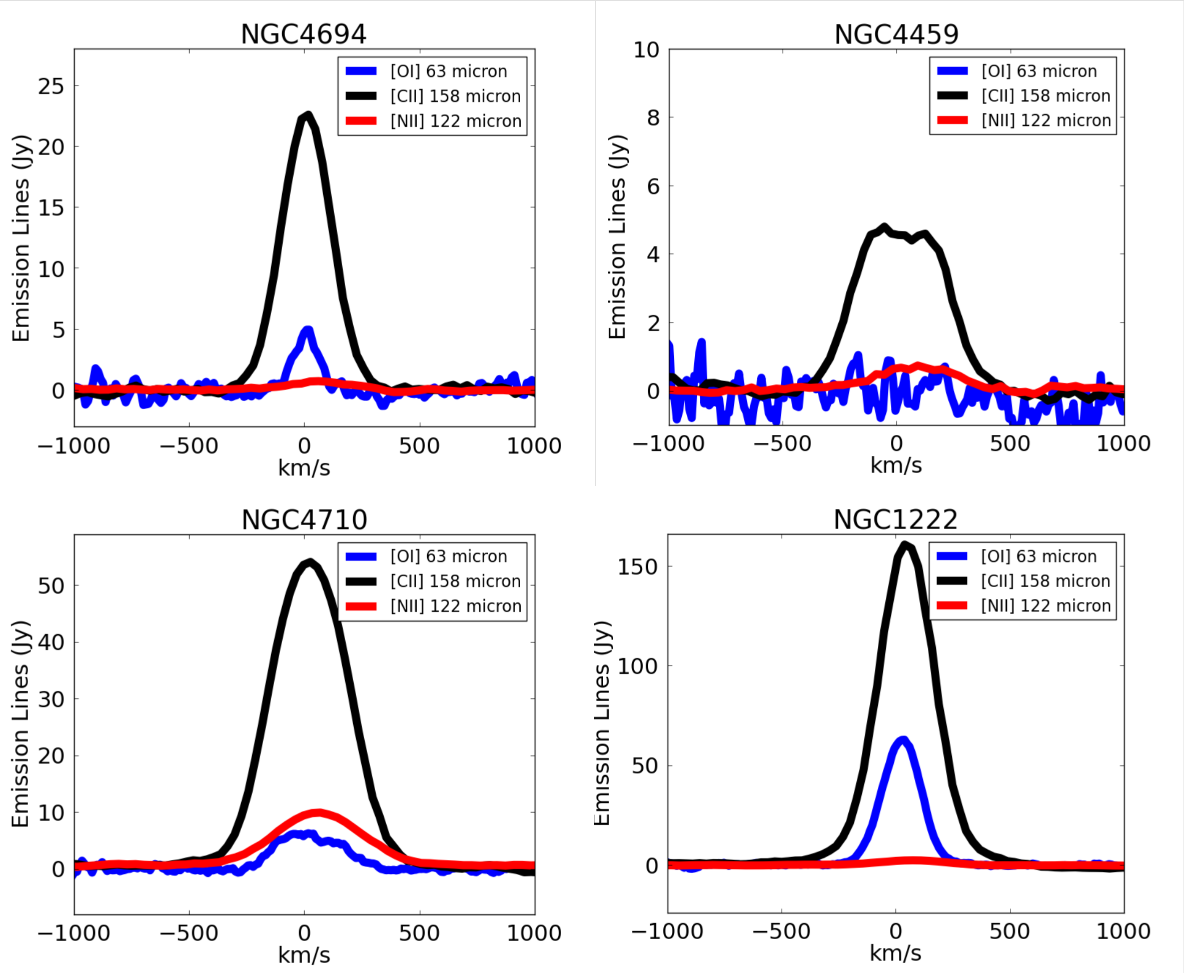
- >35% of cold ISM accreted!
- >50% of ISM accreted in the field galaxies!
- Cluster objects have aligned ISM
  (ISM not accreted, or relaxed?)
- High mass objects have aligned ISM
  (supressed accretion in high mass objects?)



Davis et al., 2011b

Probing the cold phase ISM in early-type galaxies

Atomic gas chemistry



R. Lapham/L. Young et al., in prep

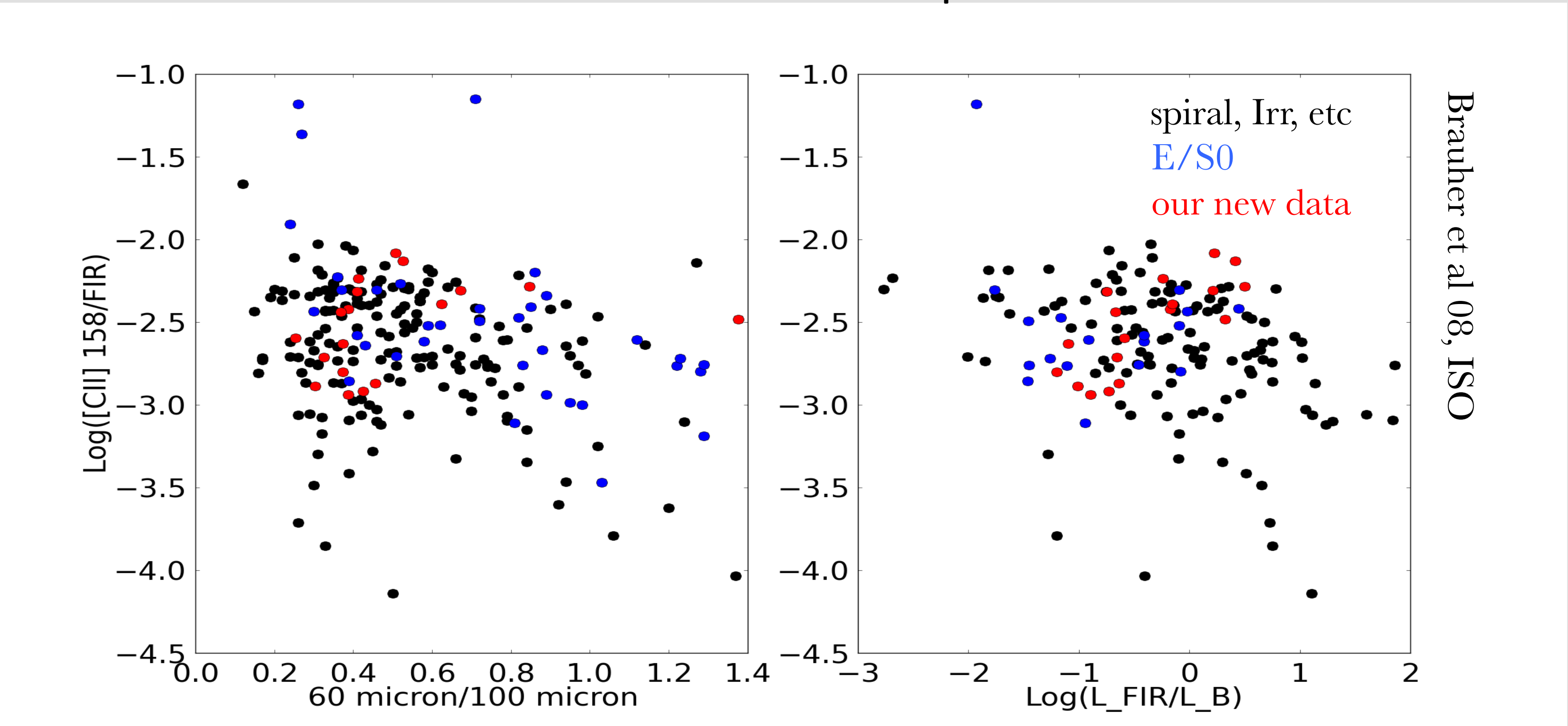
PACS [C II], [O I] 63 μm, [NII] 122 μm for 20 galaxies

SPIRE FTS for 9 galaxies

Probing the cold phase ISM in early-type galaxies

Atomic gas chemistry

FIR line ratios in early-type galaxies are broadly similar to those in spirals.



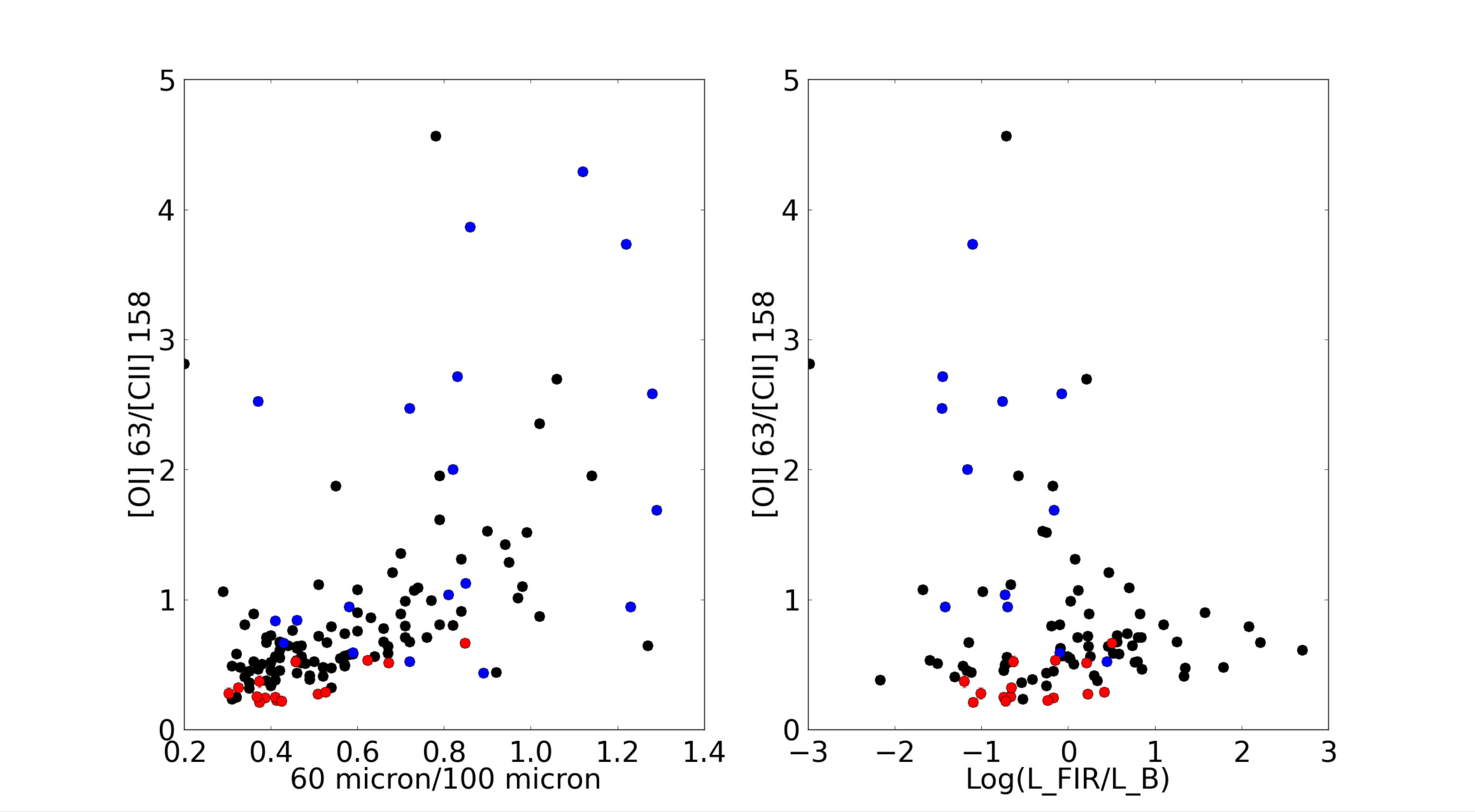
Also: [C II]/FIR vs FIR/H_2 consistent with "normal" galaxies -- Gracia-Carpio et al 2011

R. Lapham/L. Young et al., in prep

Probing the cold phase ISM in early-type galaxies

Atomic gas chemistry

But… ATLAS[3D] galaxies have systematically lower [O I] 63 / [C II].



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Probing the cold phase ISM in early-type galaxies

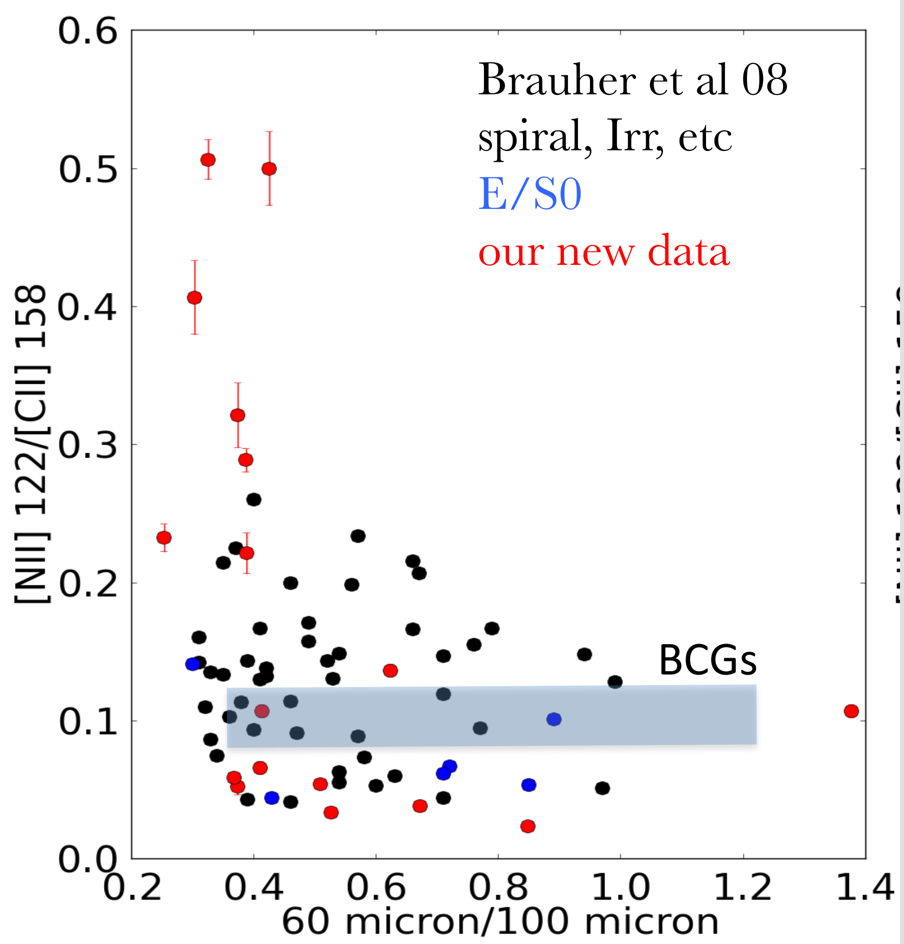
Atomic gas chemistry

And… Surprisingly high [N II] 122 / [C II].

• the high [N II]122/[C II] galaxies are all Virgo Cluster members;
• they are also HI-deficient (Serra et al 2012; Lucero & Young 2013)
• $M(H_2)/M(H\ I)$ >80
•[N II]205 also strong

• stripping of diffuse atomic gas in the intracluster medium?

• BUT compare observations of the central galaxies of cooling flow clusters (Edge et al 2010; Mittal et al 2011, 2012)



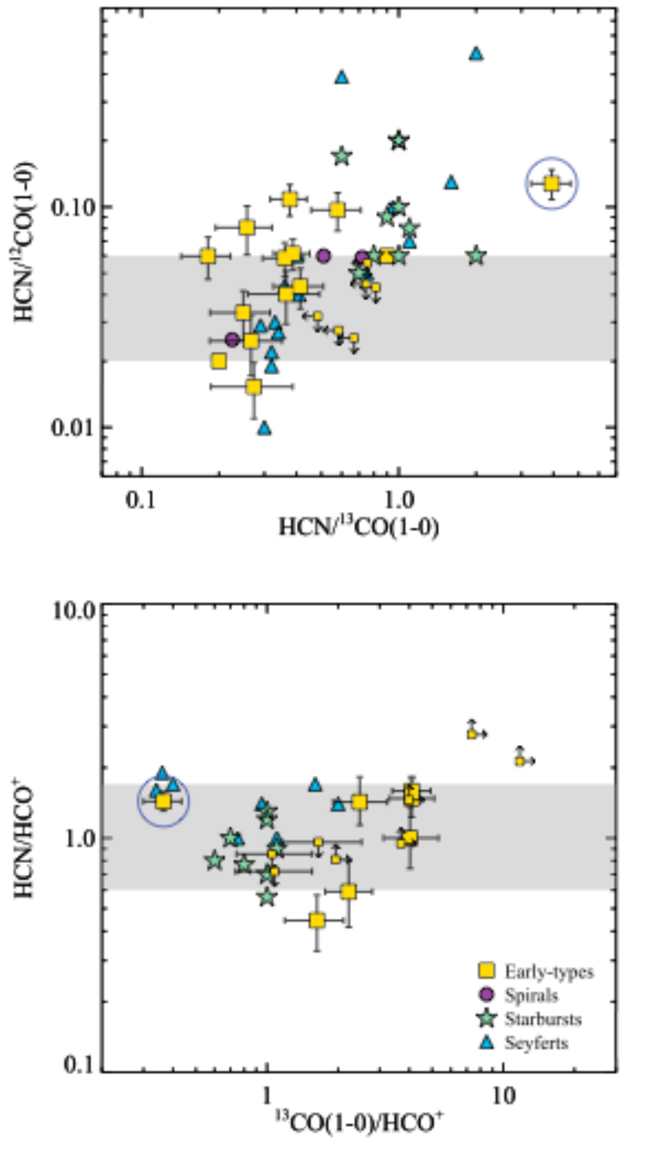
R. Lapham/L. Young et al., in prep

Probing the cold phase ISM in early-type galaxies

Molecular chemistry

- 12CO, 13CO, HCN, HCO+ Crocker et al 2012;
- CS, CH_3OH – Davis et al., 2013b
- CO J=3-2 Bayet et al 2012;
- chemical network modeling with specific applications to early-type galaxies
  - enhanced cosmic ray ionization
  - high metallicity, α-enhanced abundances

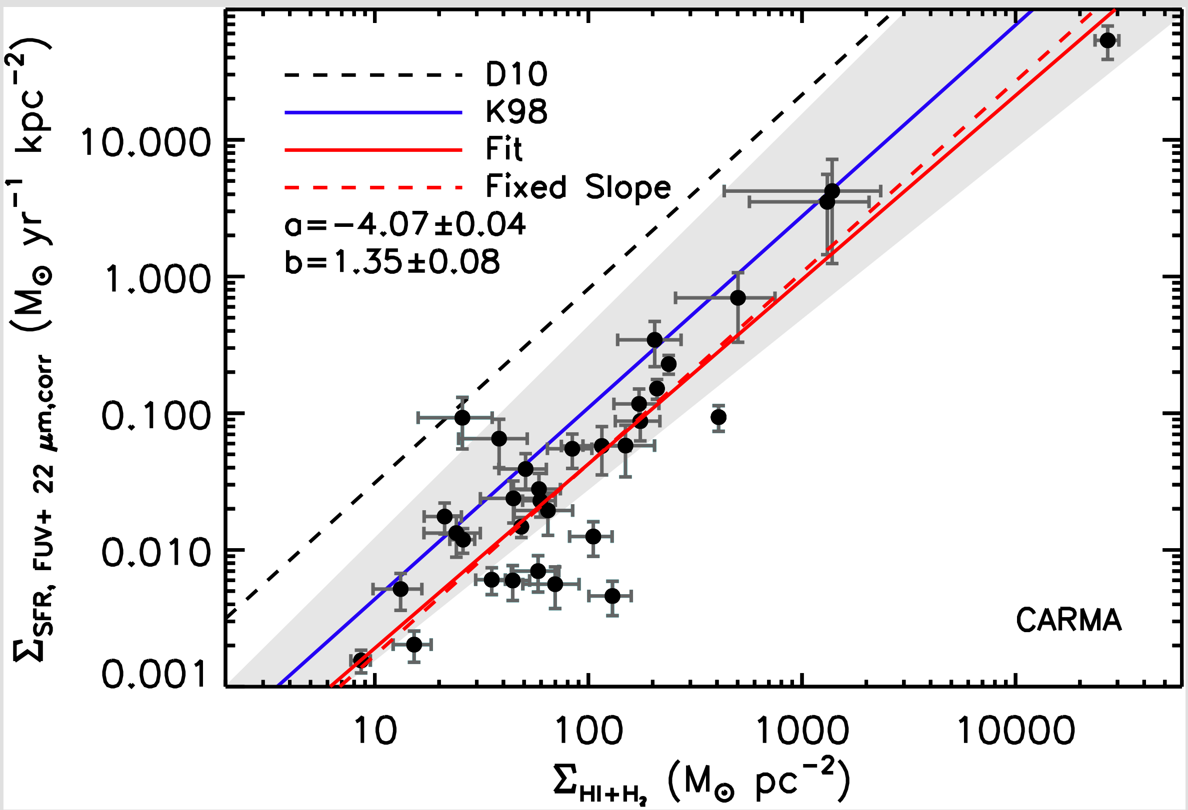
(Bayet et al 2012)



Probing the cold phase ISM in early-type galaxies

Star formation - (Davis et al, in prep)

→ SFR density (GALEX+WISE 22um) →



→ Gas Density (HI+H2 – WSRT+CARMA) →

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

Could this effect be driven by different physical conditions in the ISM?

(Deep potential, harsh irradiation, high metallicity, alpha-enhancements, high shear…)

Probing the cold phase ISM in early-type galaxies

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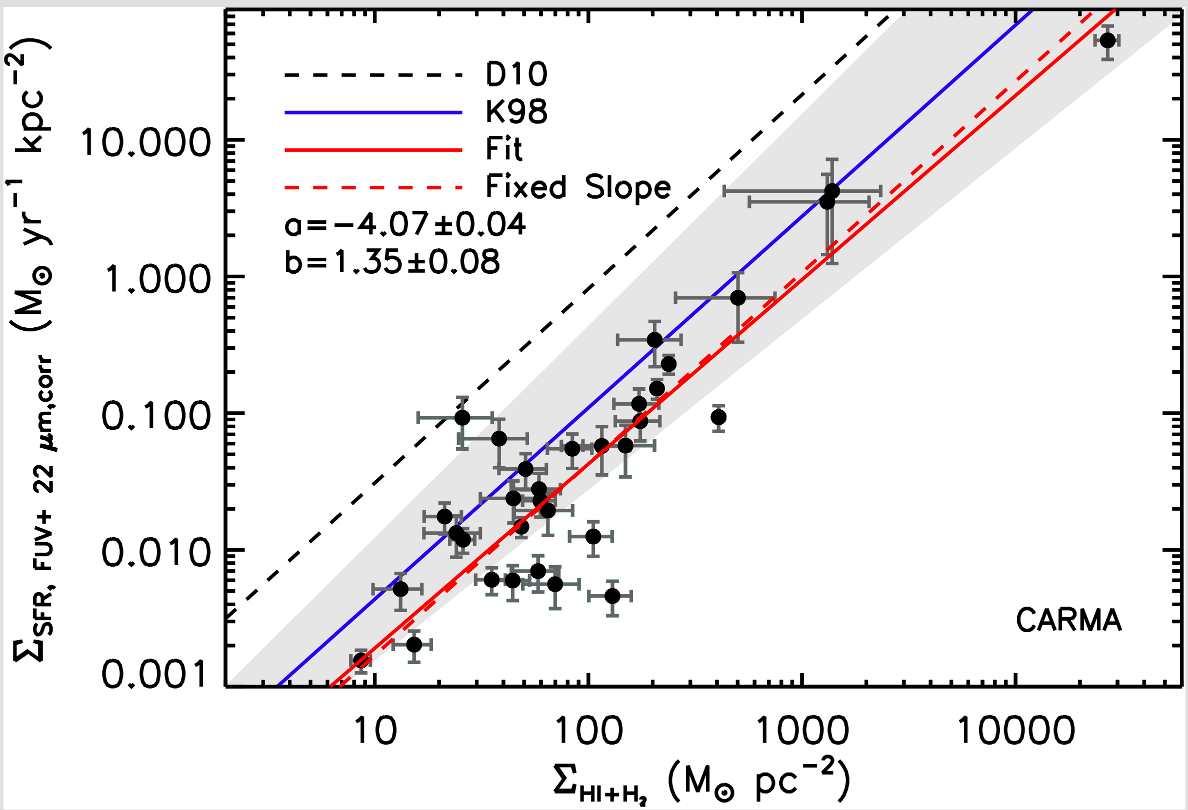

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(caution! Xco… systems are high metallicity however…)

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Star formation - (Davis et al, in prep)

(caution! SFR calibrations derived in spirals!)

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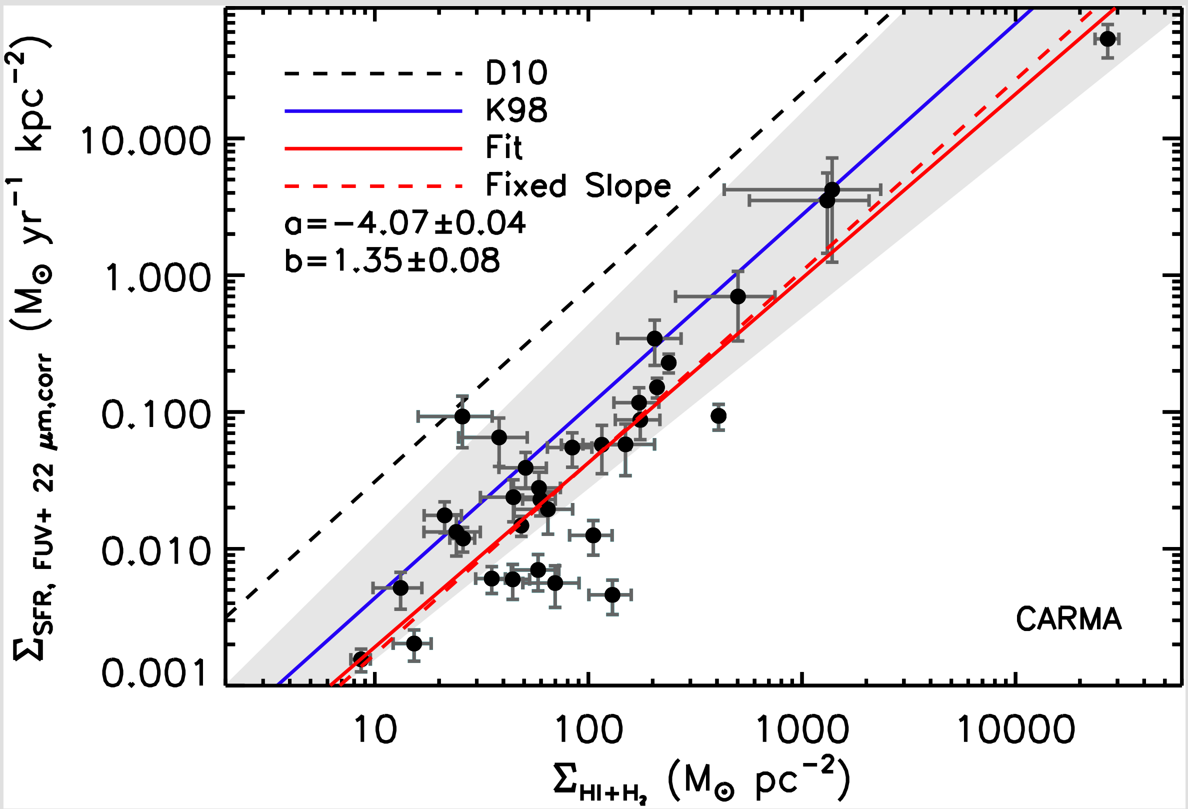

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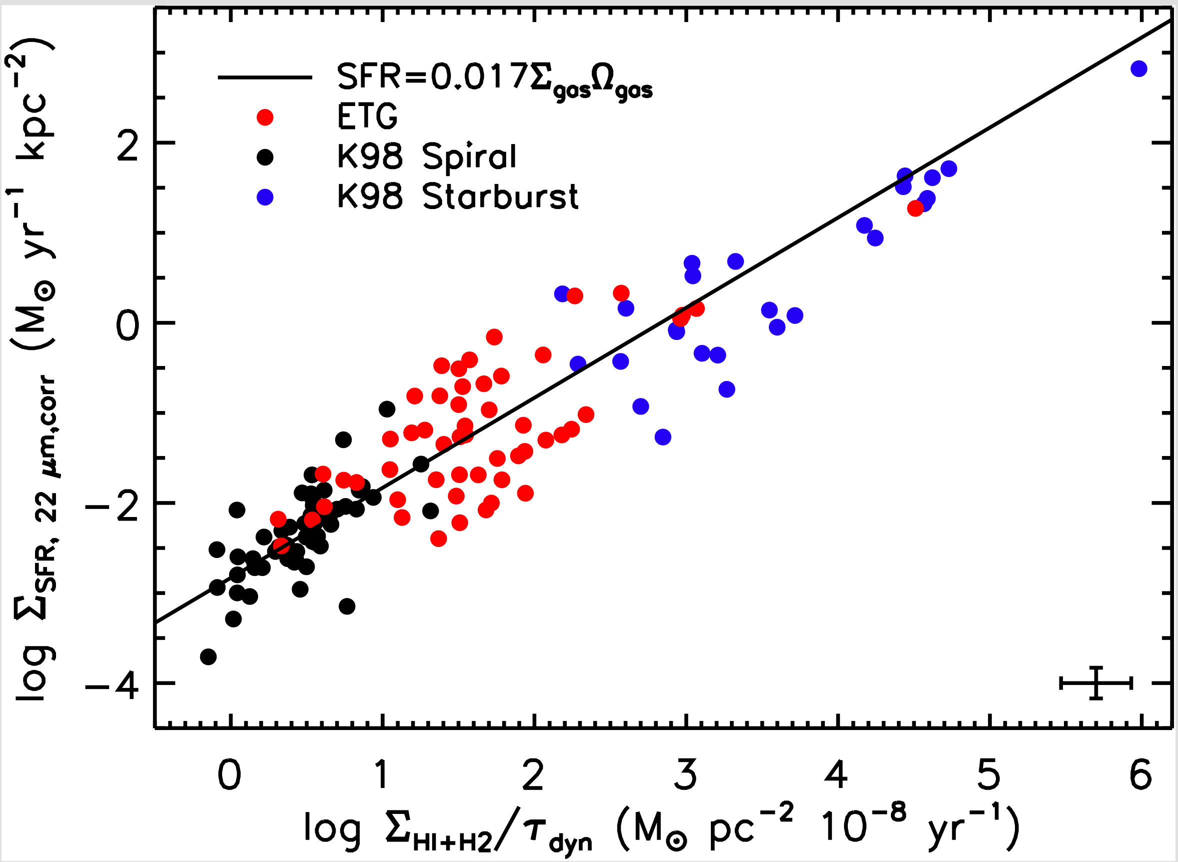


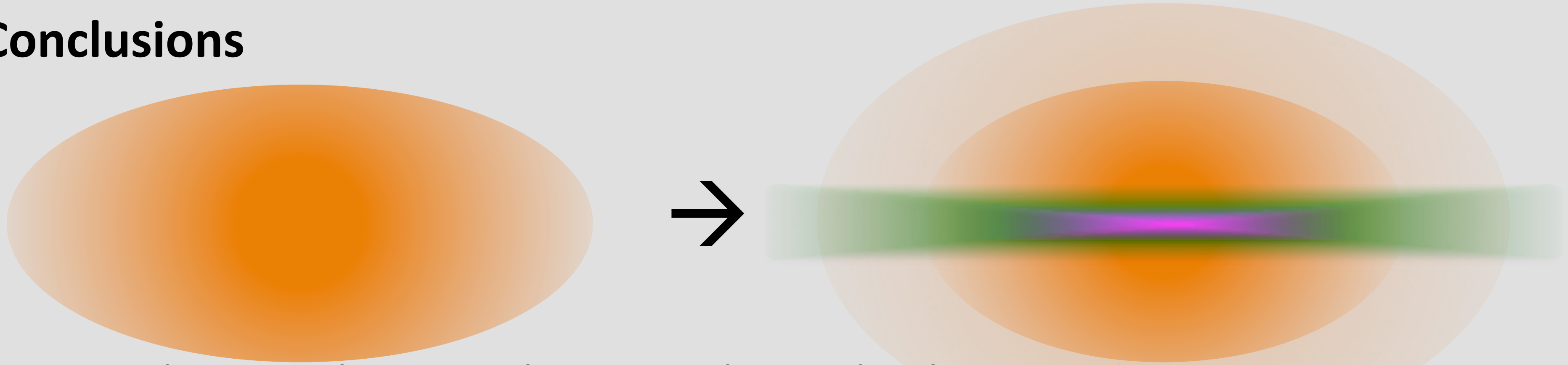
→ Gas Density/Tdyn (HI+H2 – WSRT+CARMA) →

HOWEVER:

- **ETGs form the same amount of stars per unit dynamical time as spirals/starbursts/high-z objects!**
- global dynamic star-formation regulation?
- Or simply a manifestation of a local dynamical model?
  (c.f. Krumholtz, Dekel, McKee 2012)

Probing the cold phase ISM in early-type galaxies

Conclusions



- Early type galaxies can have complex, multi-phase ISMs!
  → Hot, warm and cold gas detected, dust also present in large quantities

- Much of the gas is accreted
  → What happens to stellar mass loss?!

- Environment has a strong effect on the morphology, kinematics and chemistry of the ISM

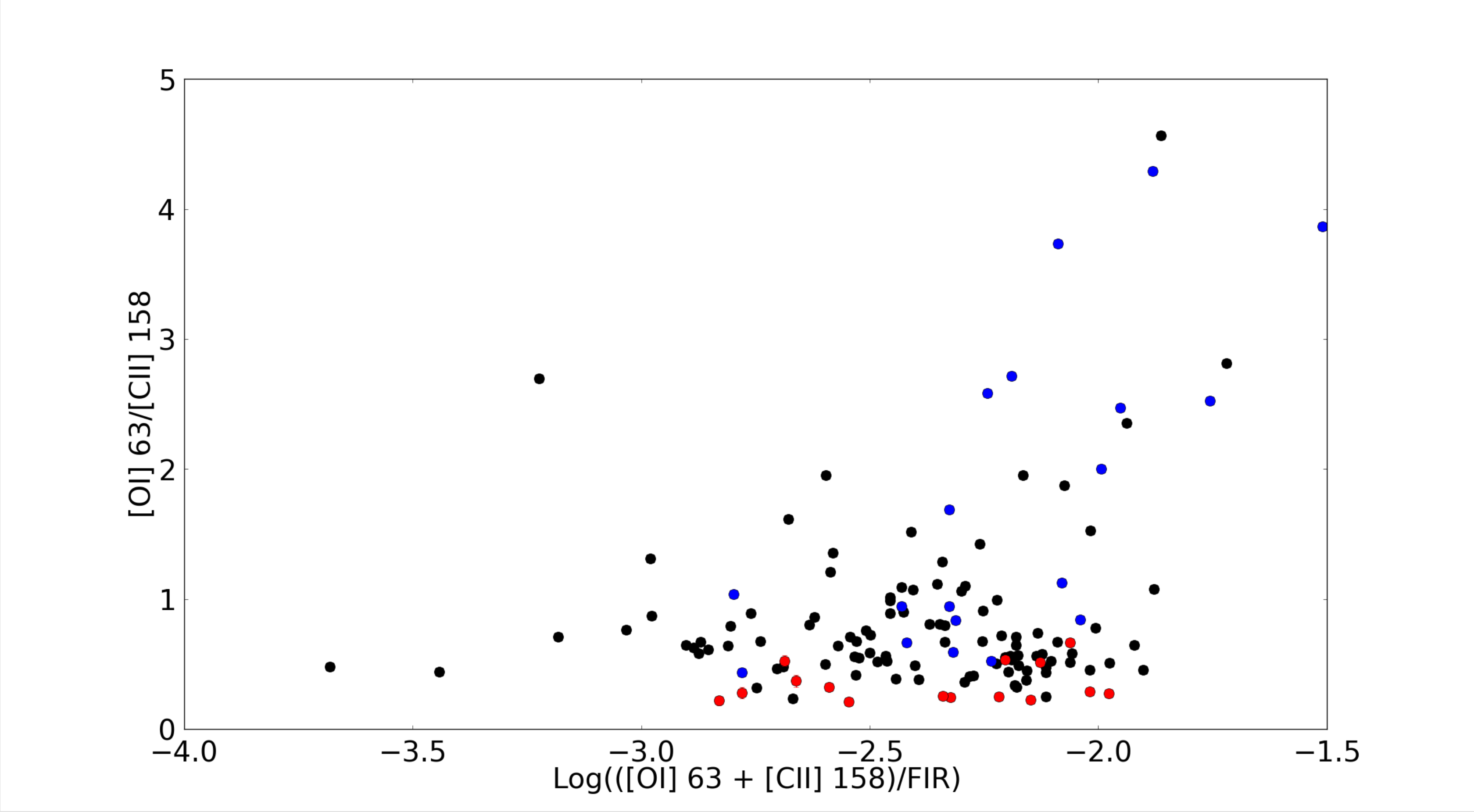
- Star formation efficiencies low in early-type galaxies
  → Star formation appears to be dynamically regulated


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

Probing the cold phase ISM in early-type galaxies

Atomic gas chemistry

But… ATLAS^{3D} galaxies have systematically lower [O I] 63 / [C II].



R. Lapham/L. Young et al., in prep