Gas Flows around Early-type Galaxies - the ATLAS^{3D} view

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and the ATLAS^{3D} team

Outline

- The **ATLAS^{3D}** survey, and the paradigm shift from E/S0s to Fast and Slow rotators
- The Warm and Cold gas content of early-type galaxies
- **Gas IN**

  - On the origin of the gas. External accretion vs. recycling
- **Gas OUT**

  - Ending up in stars. Modes of star-formation in ETGs

  - Pushed away by AGN feedback? Perhaps…

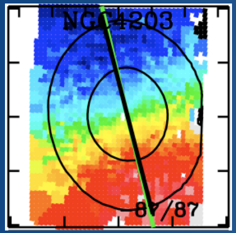
  - Joining the hot ISM. Different hot-gas content of Fast and Slow rotators

The ATLAS^{3D} survey

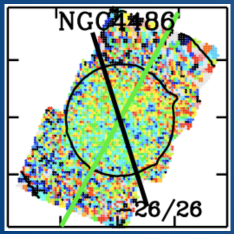
ATLAS^{3D} is a volume-limited (D<42Mpc) ***SAURON*** integral-field spectroscopic survey of 260 ETGs (Cappellari et al. 2011), which builds on a previous representative effort (48 ETGs, de Zeeuw et al. 2001) and provides consistently compiled or derived:

- Distances, K-band luminosities, apparent flattening and galactic environment
- Degree of rotational support, through the λ_R parameter (Emsellem et al. 2007)
- Dynamical Mass, through Jeans modeling (Cappellari et al. 2013)
- Single-dish and synthesis CO map with IRAM and CARMA (Young et al 2011, Alatalo et al. 2013)
- HI maps from Westerbork (Serra et al. 2012)
- Deep imaging with MegaCam at the CFHT (e.g. Duc et al. 2011)

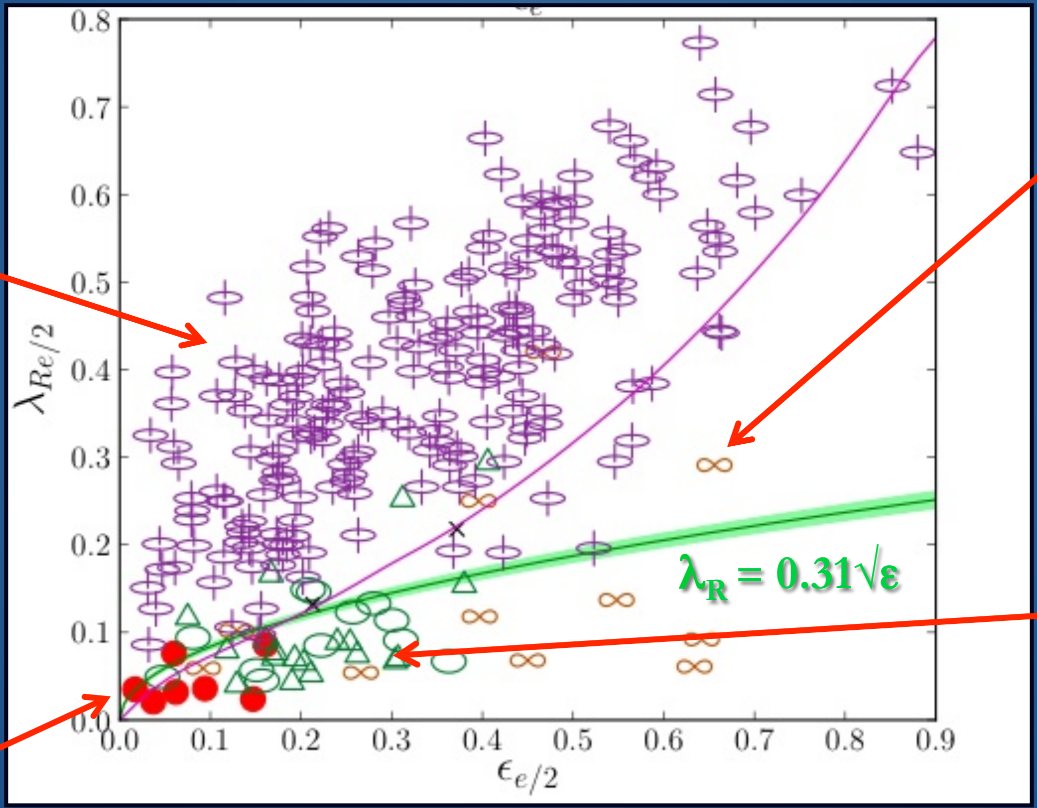
From E-S0 to Fast and Slow rotators



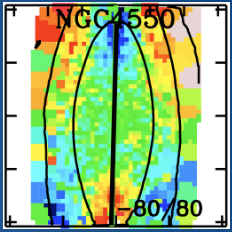
Fast-Rotators



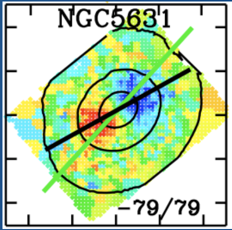
Non-Rotators



Emsellem et al. (2011, but see also Emsellem et al. 2007 and Cappellari 2007)

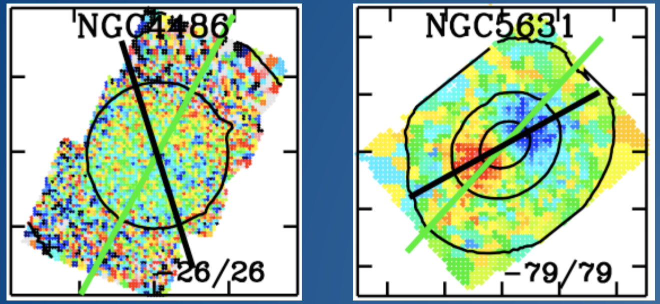


Double-disks masquerading as Slow-Rotators



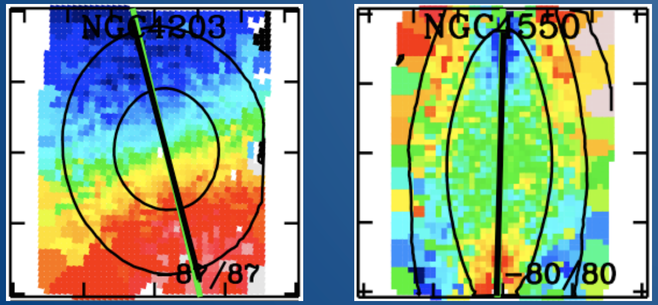
Slow-Rotators with KDC

From E-S0 to Fast and Slow rotators



Non-Rotators or Slow-Rotators with KDCs

Made exclusively of old stars, generally round and massive. In other words, your proto-typical dead and old "Elliptical", except that only 14% of ETGs are Slow-Rotators



Fast-Rotators or double-Disks

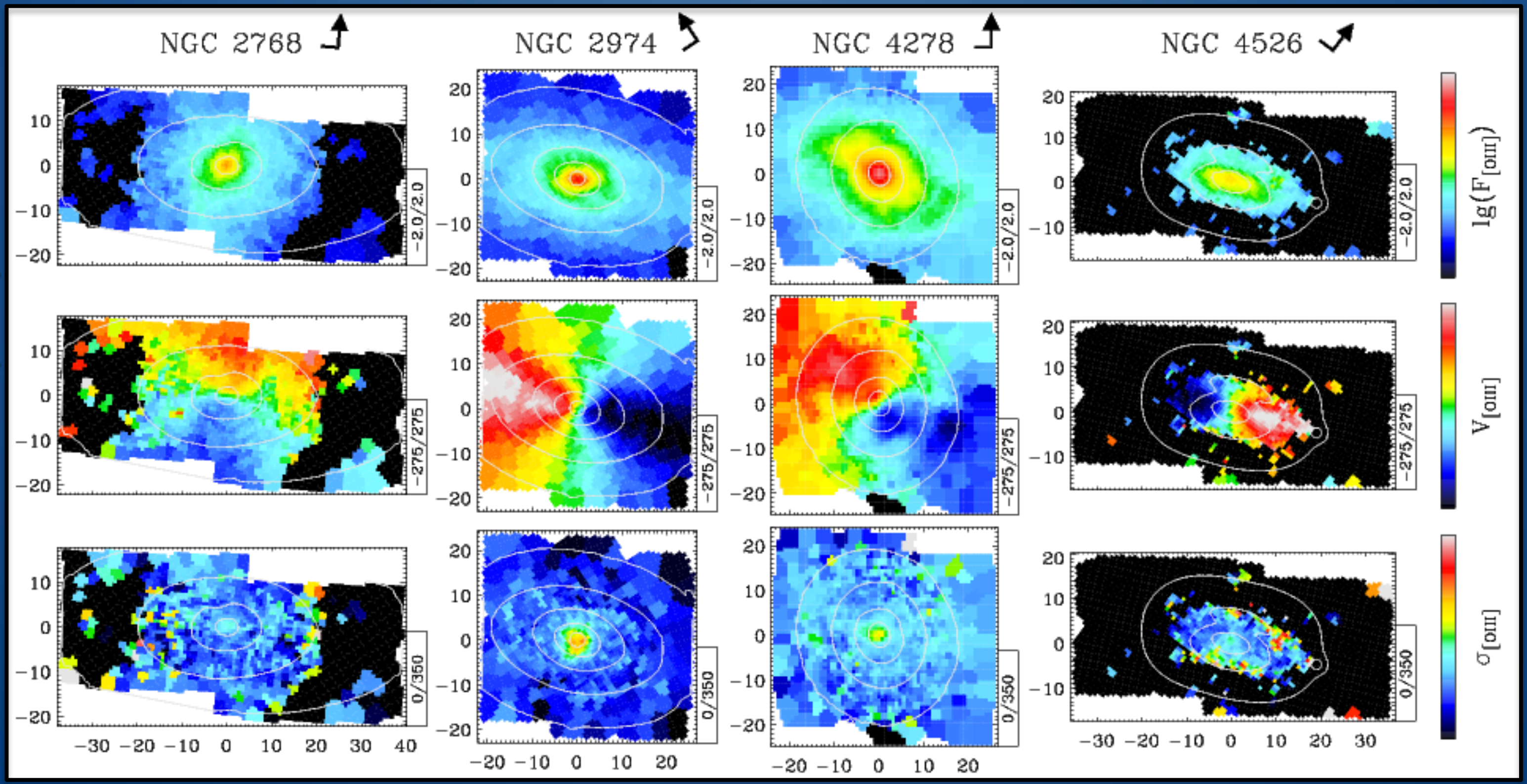
Can show sign of recent stars formation, can be very flat and span a large range of masses. May link to faded spiral galaxies, and made up 86% of ETGs

Cold and Warm Gas content of ETGs

Cold and Warm Gas content of ETGs

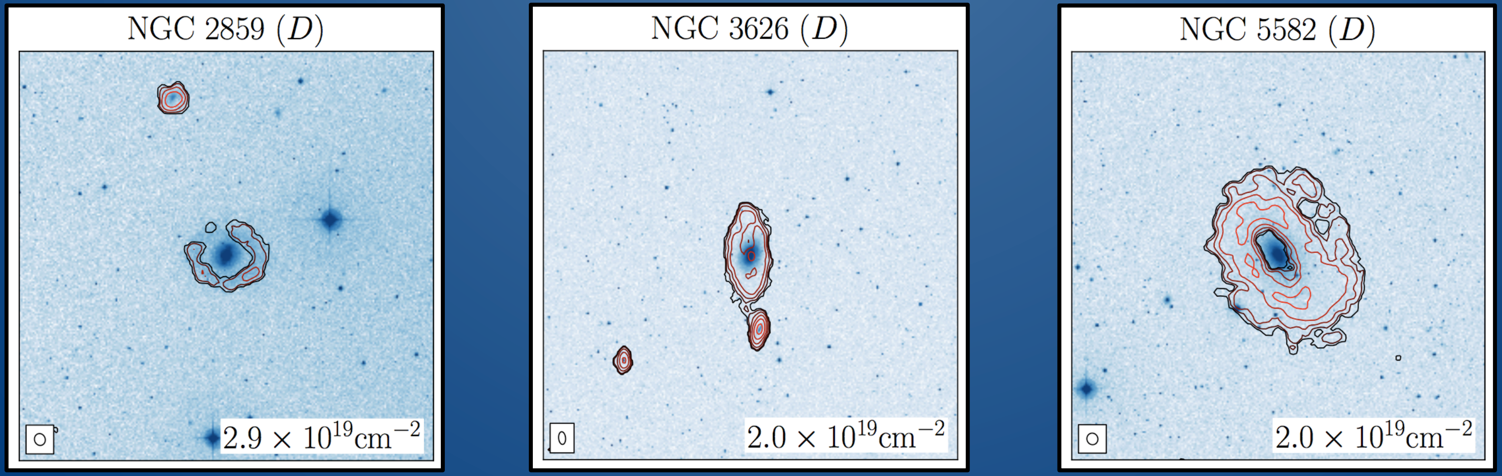
Ionised: in ~70% of ETGs, is nearly always extended, and comes with masses between 10^4 and 10^5 $M_\odot$ Incidence drops to ~50% in Virgo. No noticeable in the detection rate of SR and FR

Sarzi et al (2006)



Cold and Warm Gas content of ETGs

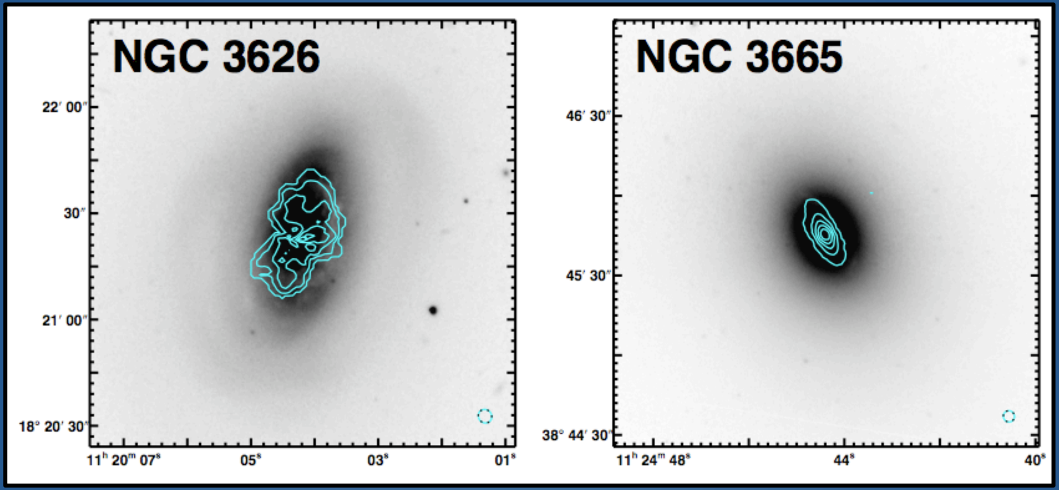
Neutral: in ~40/10% of ETGs outside/inside Virgo. ETGs have either small or very extended discs, and with masses between 10^8 and few 10^9 $M_\odot$. Detection rate somehow drops around SR.



Serra et al (2012)

Cold and Warm Gas content of ETGs

Alatalo et al (2013)

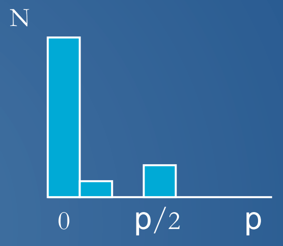


Molecular: in ~20% of ETGs, irrespective of environment. Generally confined to optical regions, with masses between 10^7 and 10^9 $M_{\odot}$. Incidence drops dramatically in SR.

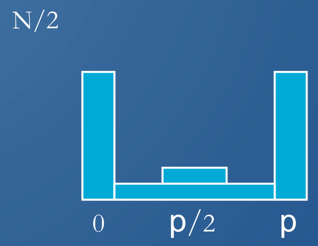
Cold and Warm Gas always share the same kinematics, at the same scales, as expected in the case of pressure equilibrium.

Gas IN - the origin of the gas in ETGs

Clues from the Gas-Star Misalignment



internal triaxial



external triaxial

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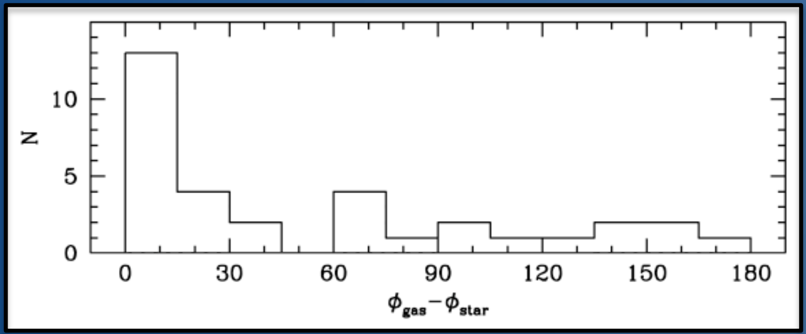
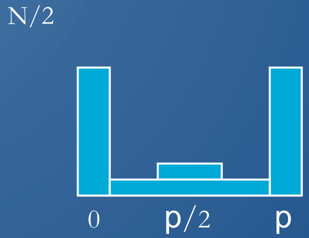
Sarzi et al (2006)



internal triaxial



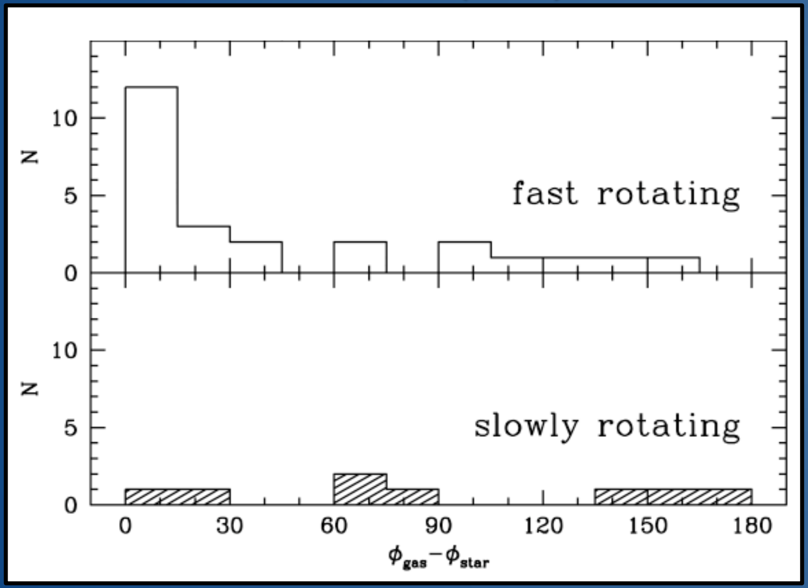
external triaxial

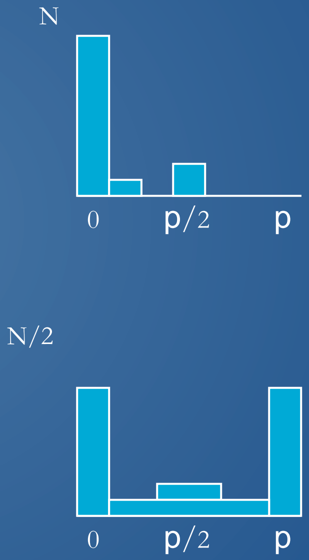
The *SAURON* representative sample revealed fewer counter- or orthogonal rotations. Both internal and external origin needed!

Gas IN - the origin of the gas in ETGs

Clues from the Gas-Star Misalignment

Sarzi et al (2006)





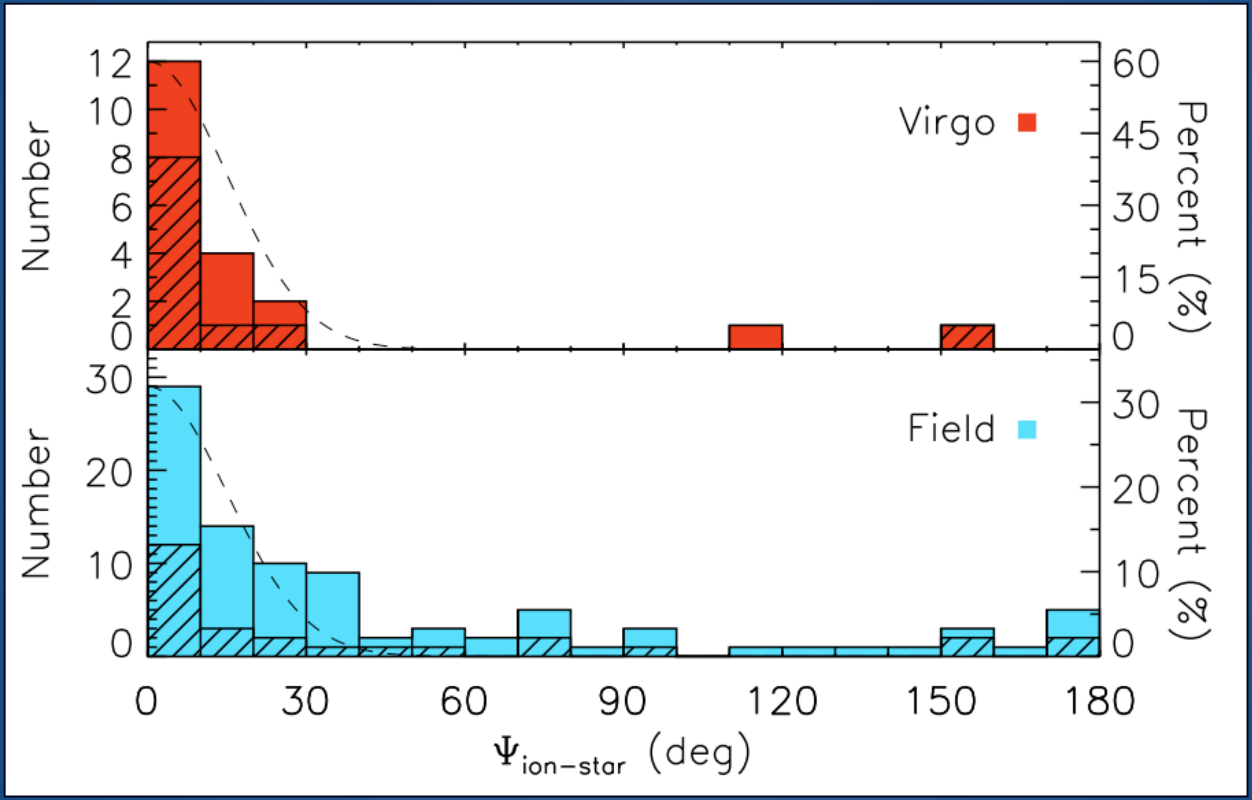
internal triaxial

external triaxial

And it was already recognised that slow-rotators mainly accrete their gas.

Gas IN - the origin of the gas in ETGs

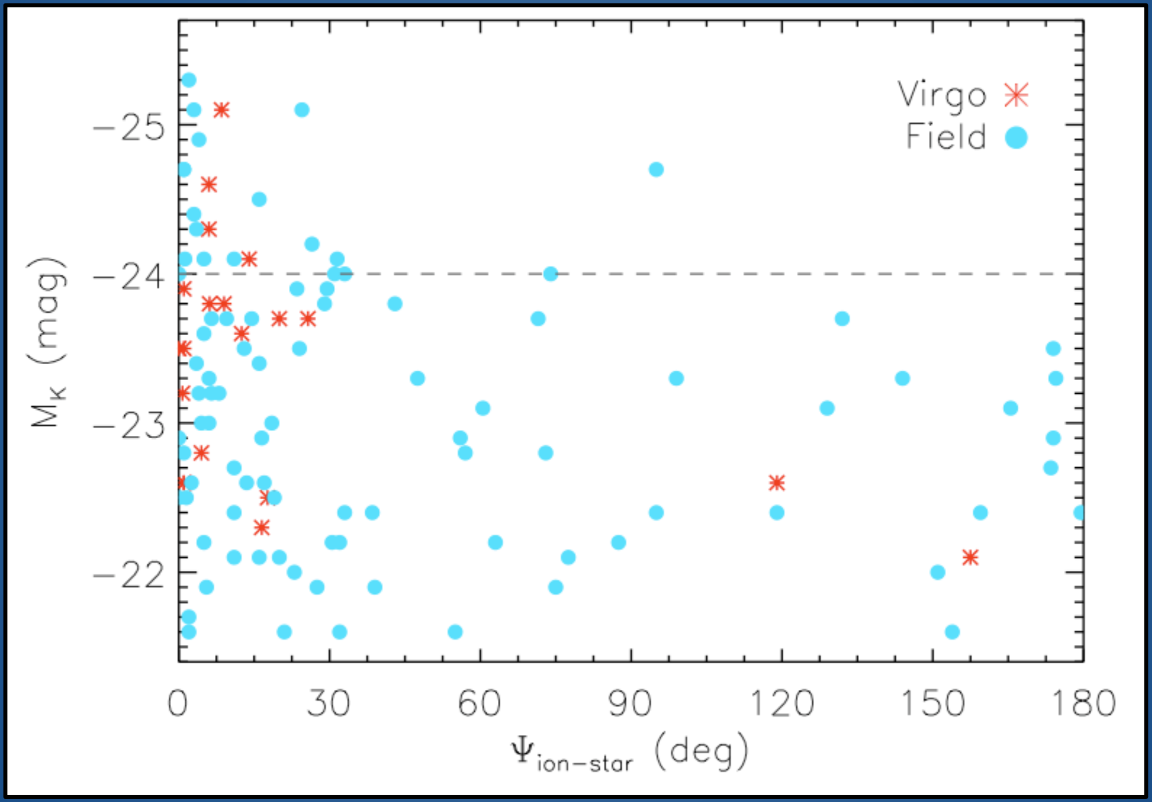
Clues from the Gas-Star Misalignment



With **ATLAS^{3D}** we further find that fast rotators can accrete gas only in field environments (Davis et al. 2011)

Gas IN - the origin of the gas in ETGs

Clues from the Gas-Star Misalignment



And that accretions also seem not to occur in the most massive fast rotators (M_K<-24; Davis et al. 2011)

Gas OUT – star-formation in ETGs

Star formation is currently on-going in ~15% of the **ATLAS^{3D}** sample. It only occurs in Fast Rotators, however, and in two modes.

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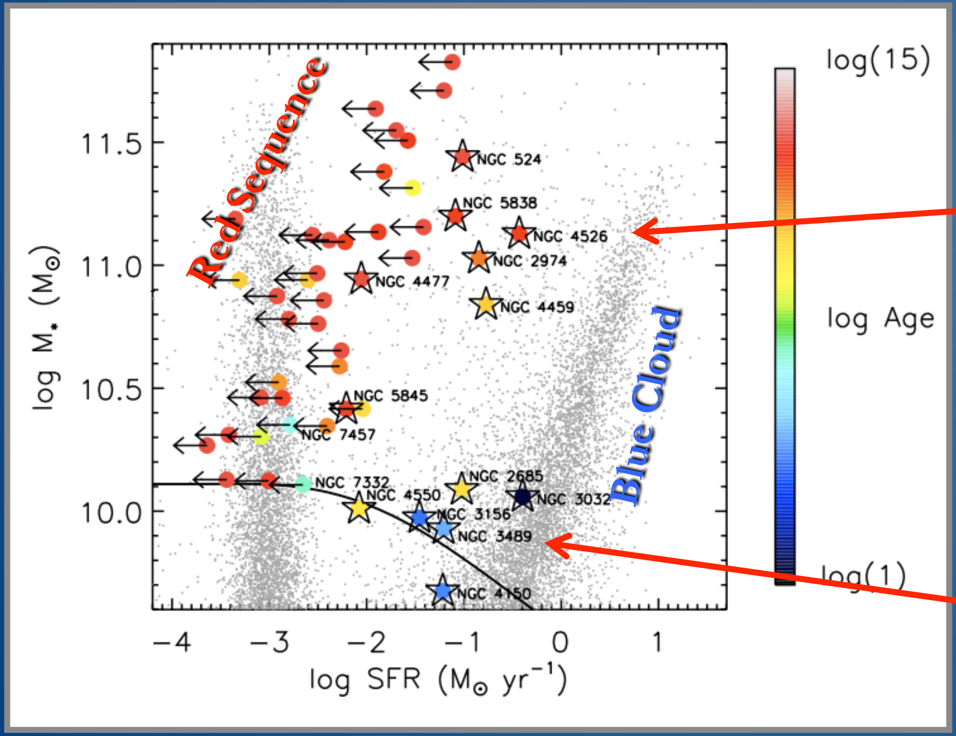
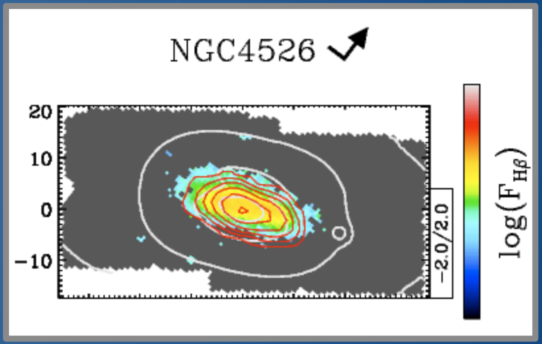
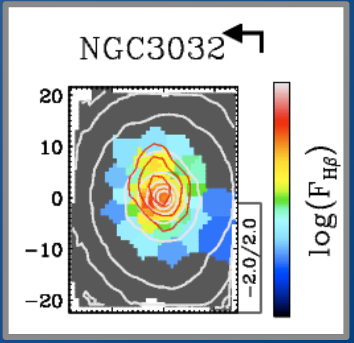


Shapiro et al (2009, SFR from PAHs)

Concentrated Star formation



Pervasive Star formation



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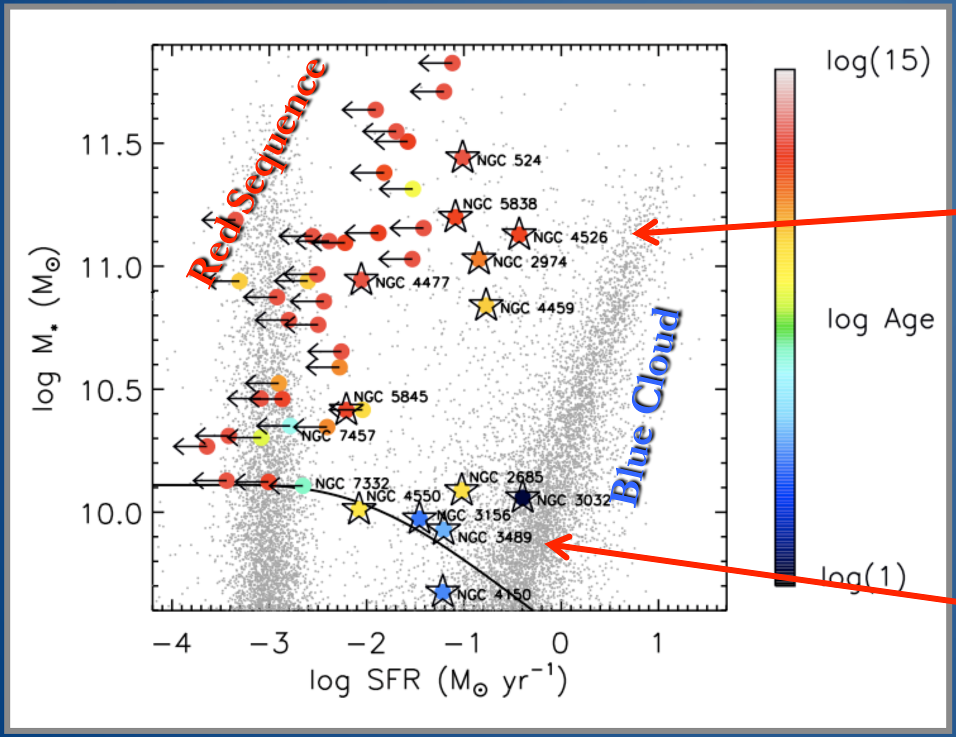
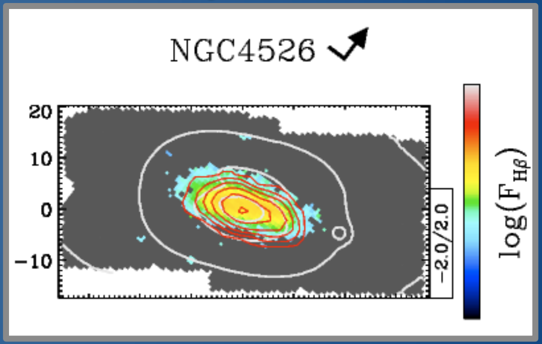
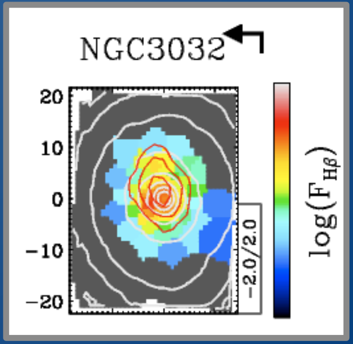


Shapiro et al (2009, SFR from PAHs)

Mostly co-rotating systems



Accreted material



Gas OUT – star-formation in ETGs

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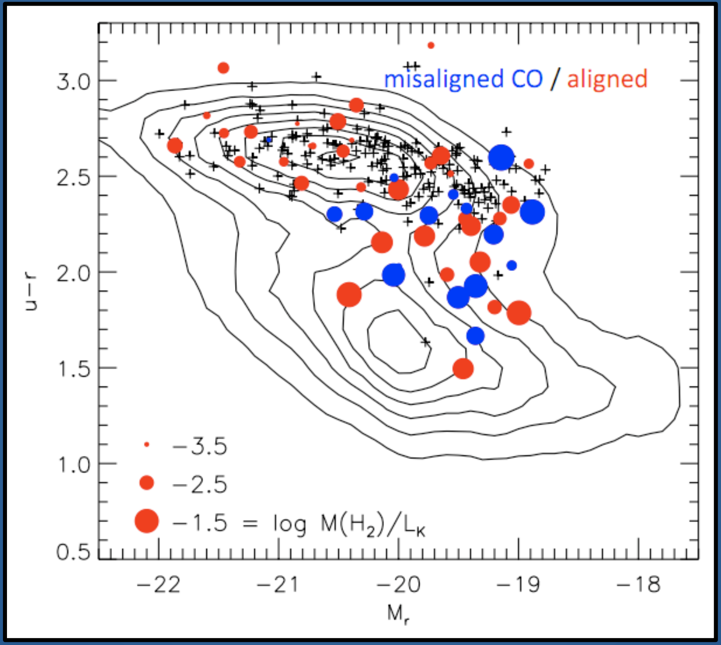


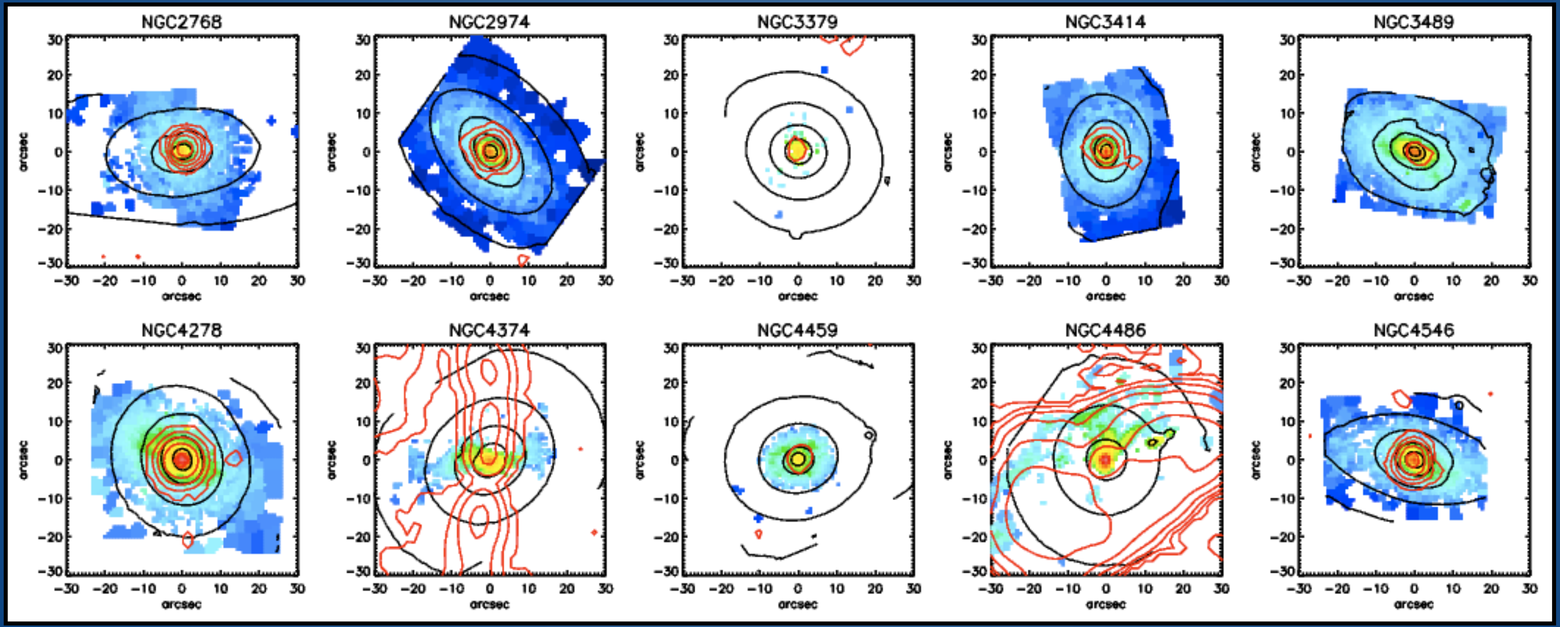
Lisa Young et al. in prep

The kinematics and specific content of molecular gas also supports an external origin for the new material forming stars in low-mass fast rotators

Gas OUT – AGN feedback?

Many **ATLAS^{3D}** galaxies have radio jets and core, but this does not seem to disturb the distribution of the ionised gas.

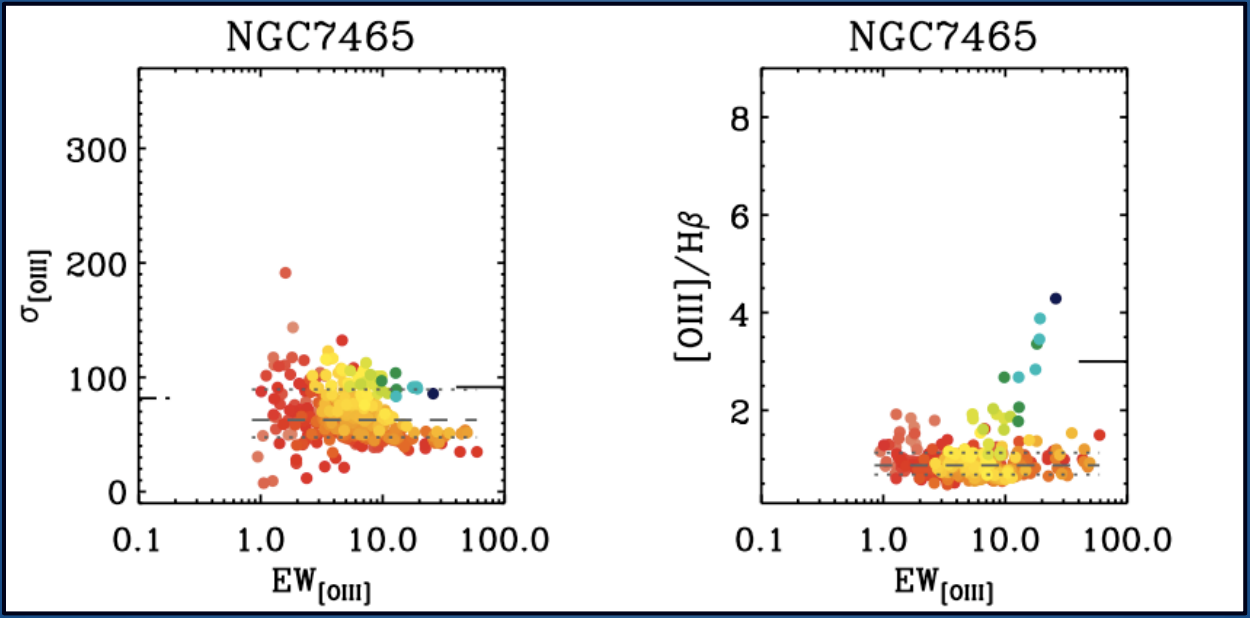
Sarzi et al (2010)



Most likely, this may act on the hot-gas around these galaxies, possibly affecting the dynamics of the warm gas only in the nuclear regions…

Gas OUT – AGN feedback?

What we see in **ATLAS^{3D}** is an impact of LINERs activity on the central ionised-gas dynamics.



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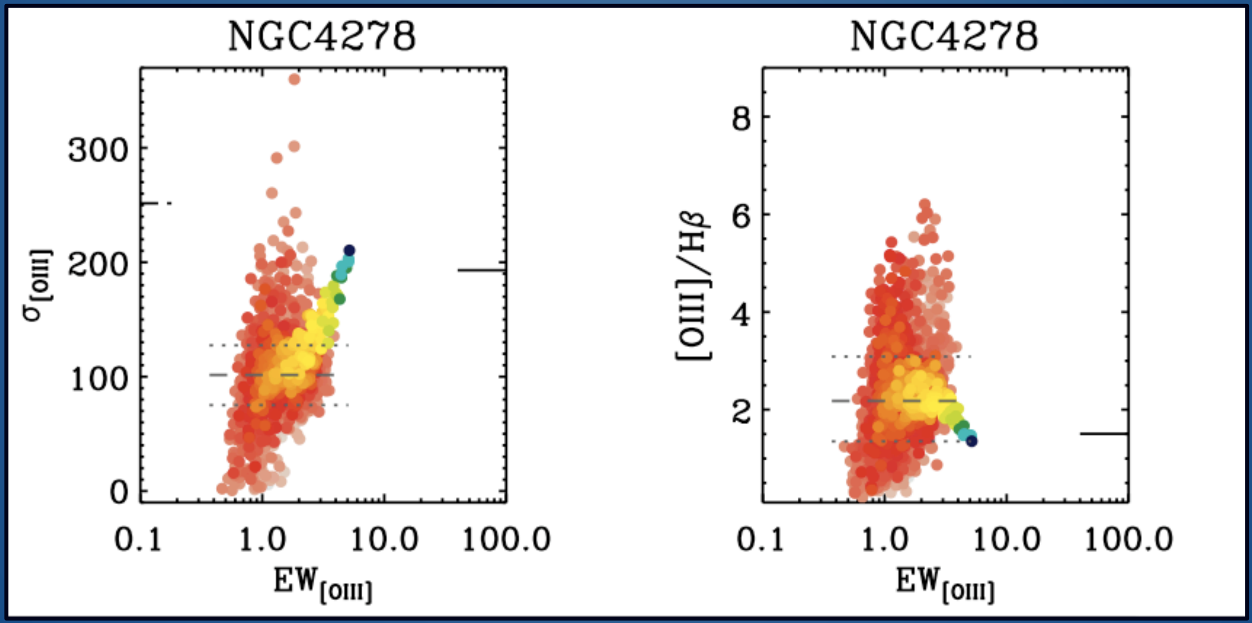

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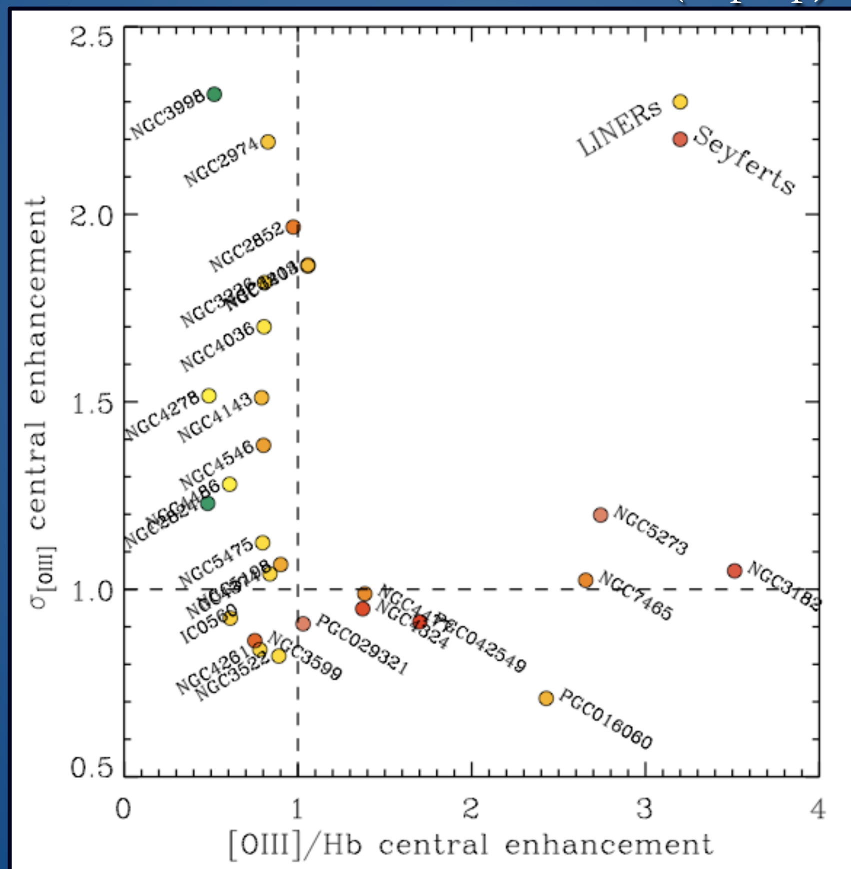
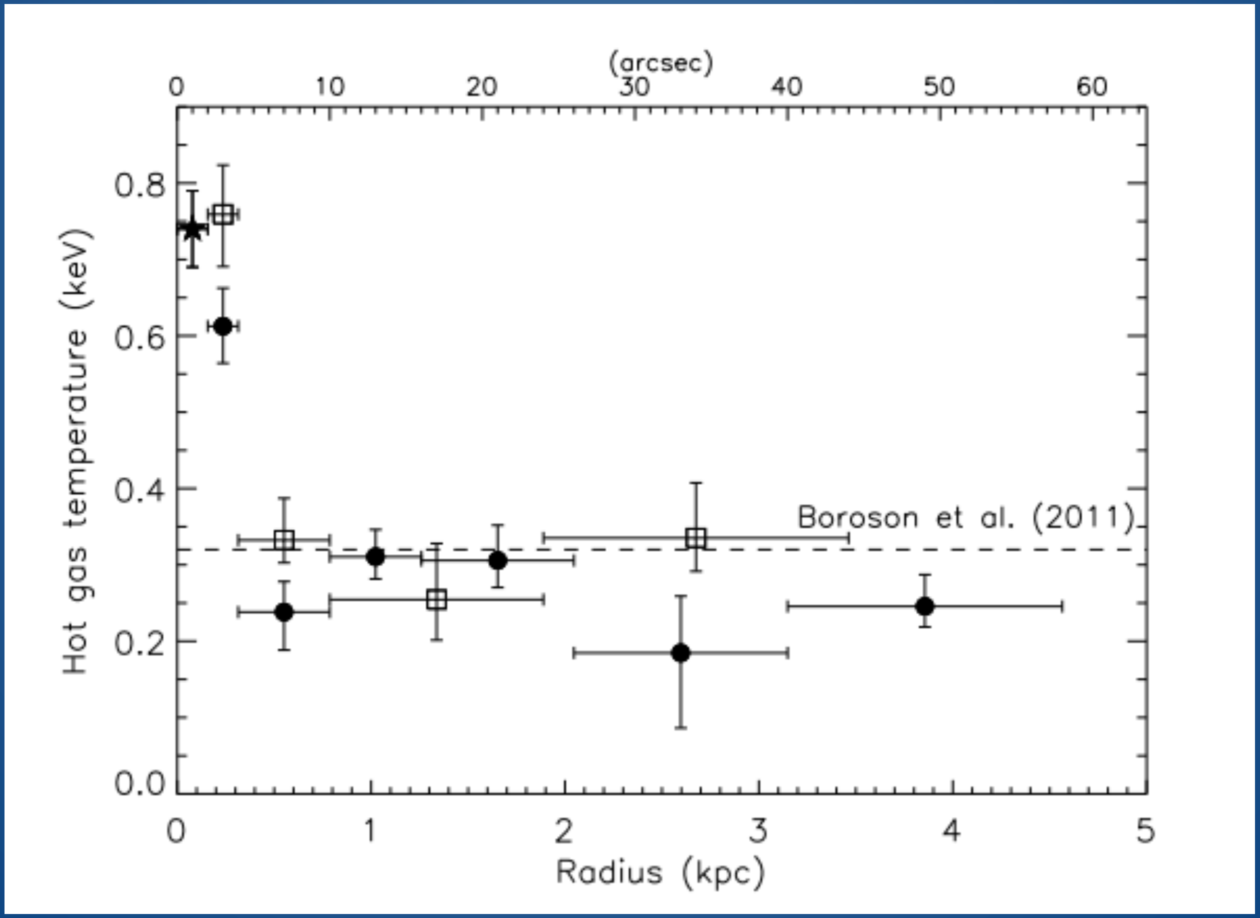
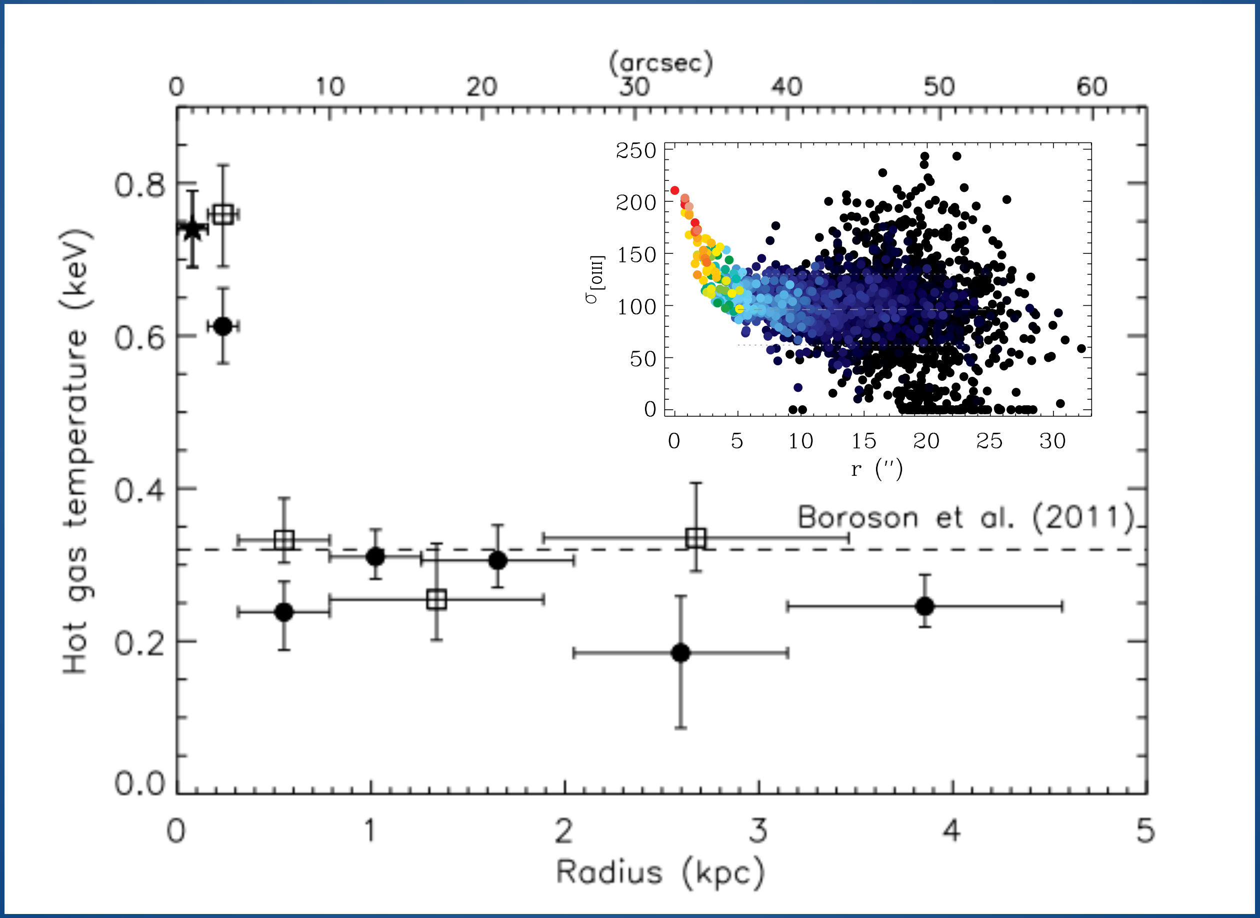


LINERs in action on both the Hot and Warm gas

Pellegrini et al (2012)



LINERs in action on both the Hot and Warm gas



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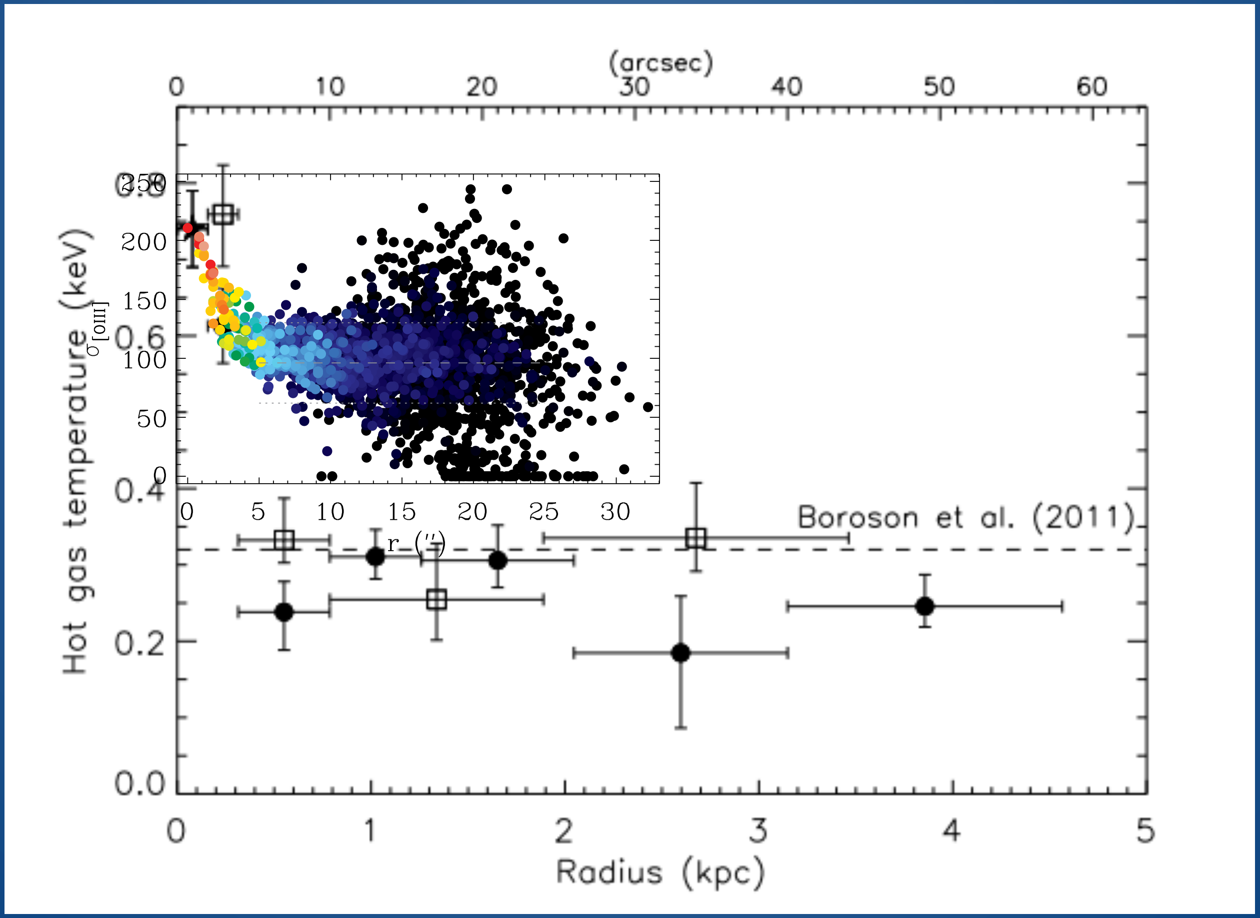

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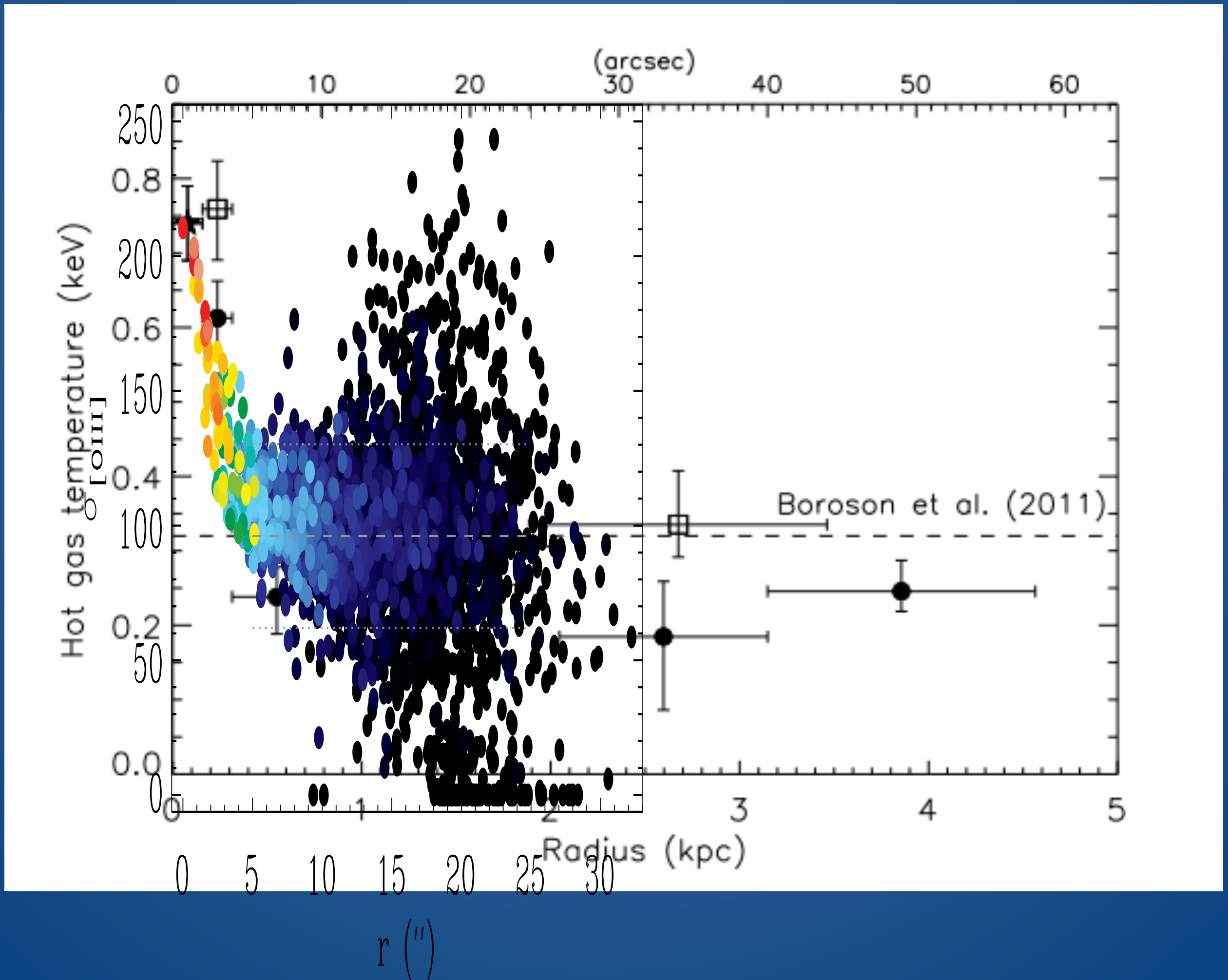
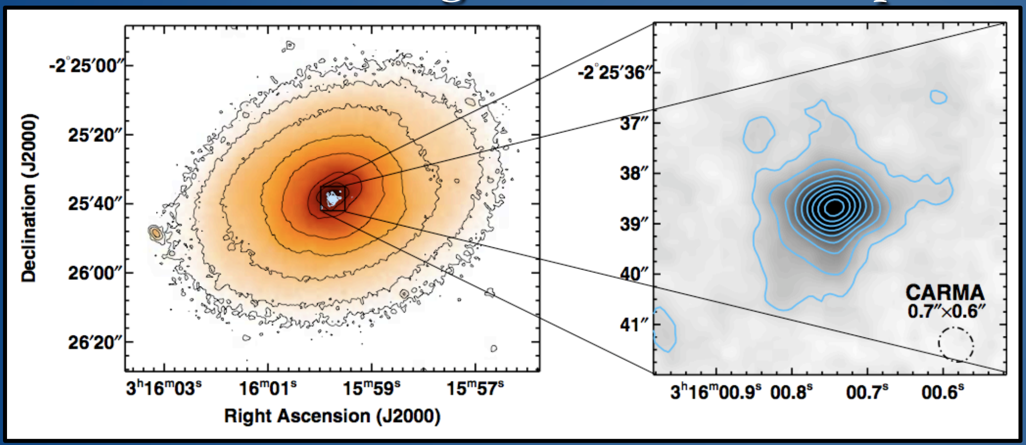


Gas OUT – AGN feedback?

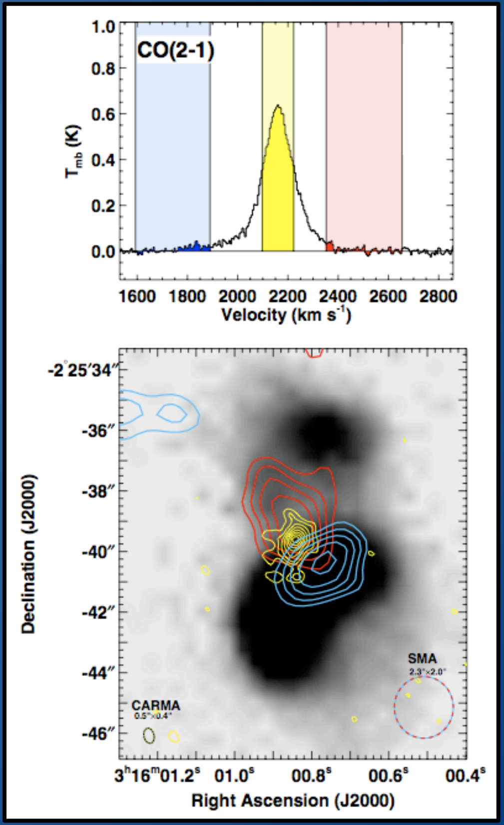
Nonetheless, in **ATLAS^{3D}** we found one very rare case of an AGN properly removing gas from a ETGs (Alatalo et al 2011, Davis et al. 2012)

R-band image **CO maps**



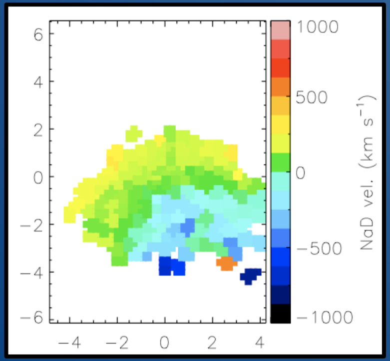
CO outflow

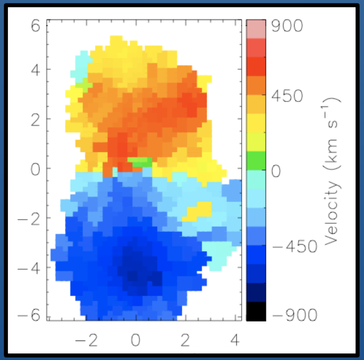
CARMA



NaD outflow **Ha outflow**

GMOS



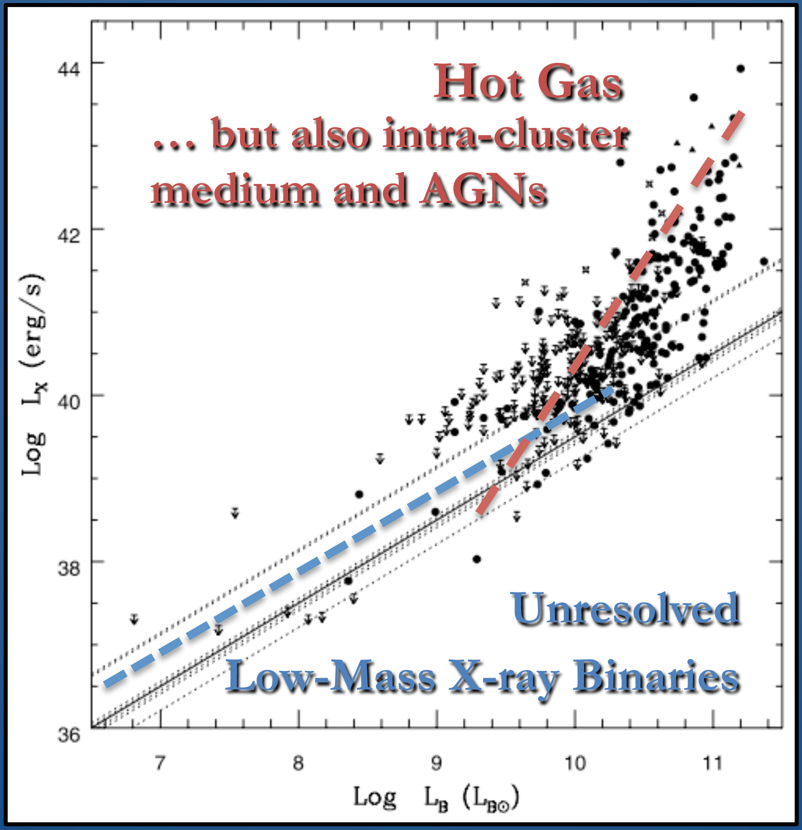


Gas OUT – joining the Hot Gas

For ETGs, the ability to sustain a corona of hot, X-ray emitting gas could have played a key role in quenching their past star formation history. An halo of hot gas can indeed act as an effective shield against the acquisition of cold gas and can quickly absorb any stellar mass loss material.

Gas OUT – joining the Hot Gas

But what is the exact hot-gas content of ETGs? This is no new problem… it's a question that has been around since the first observations with the *Einstein* X-ray telescope



From O'Sullivan et al. (2001)

Gas OUT – joining the Hot Gas

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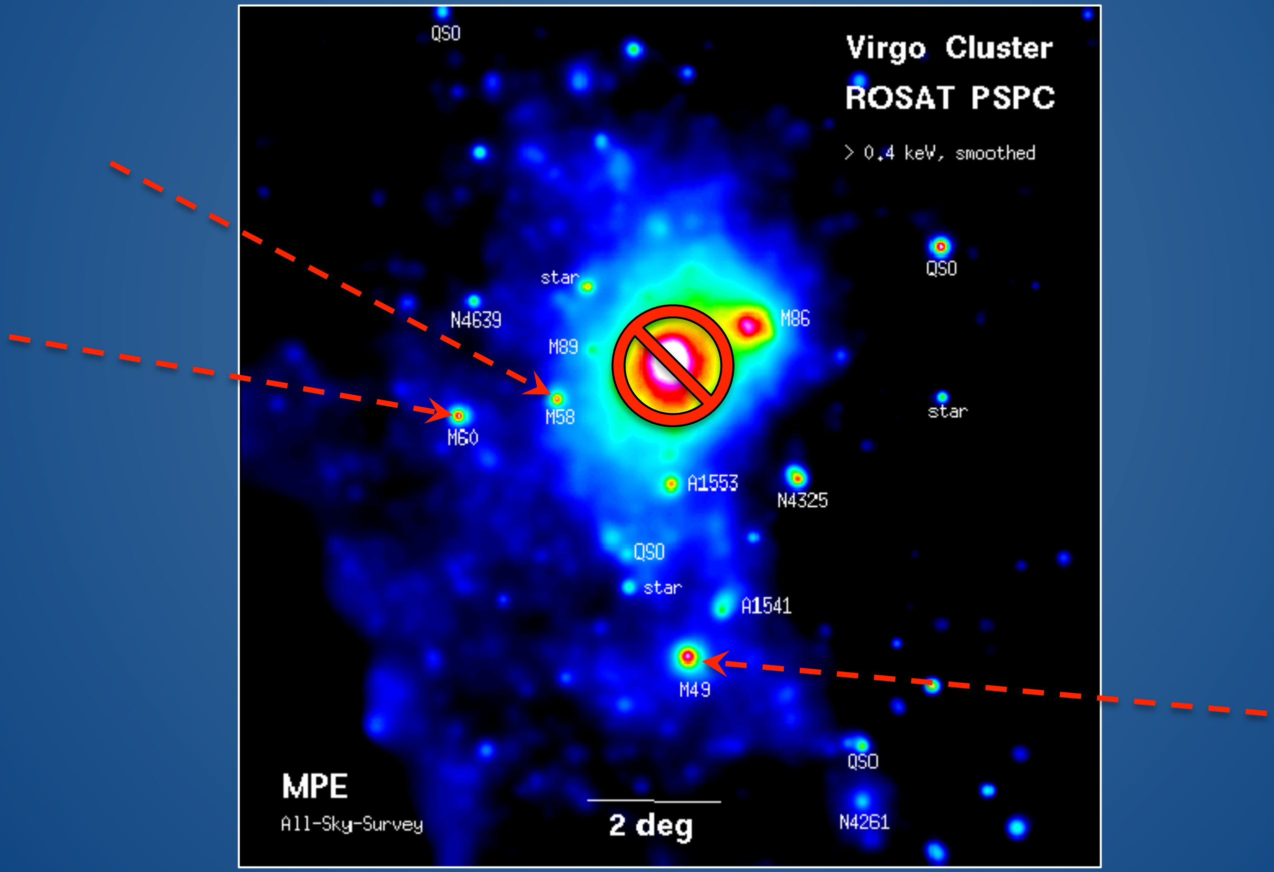
To address this issue, we have combined *Chandra* X-ray measurements (from Boroson, Kim & Fabbiano 2010) with our *SAURON* integral-field spectroscopic measurements, excluding BCGs.

Gas OUT – joining the Hot Gas

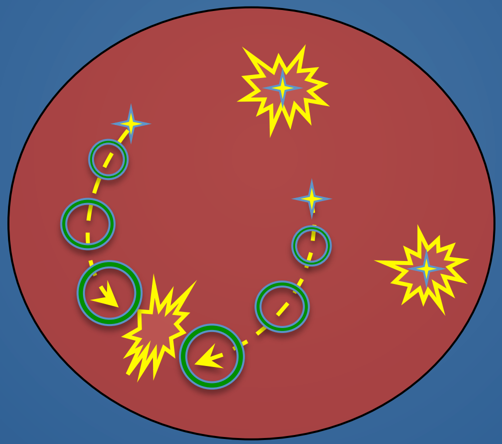
This is not about the Cluster or Group Medium



Origin of X-ray Halos around ETGs

The "standard" idea is that in ETGs the hot gas mostly comes mostly from stellar mass-loss material heated by

① The injection of the kinetic energy from SNe

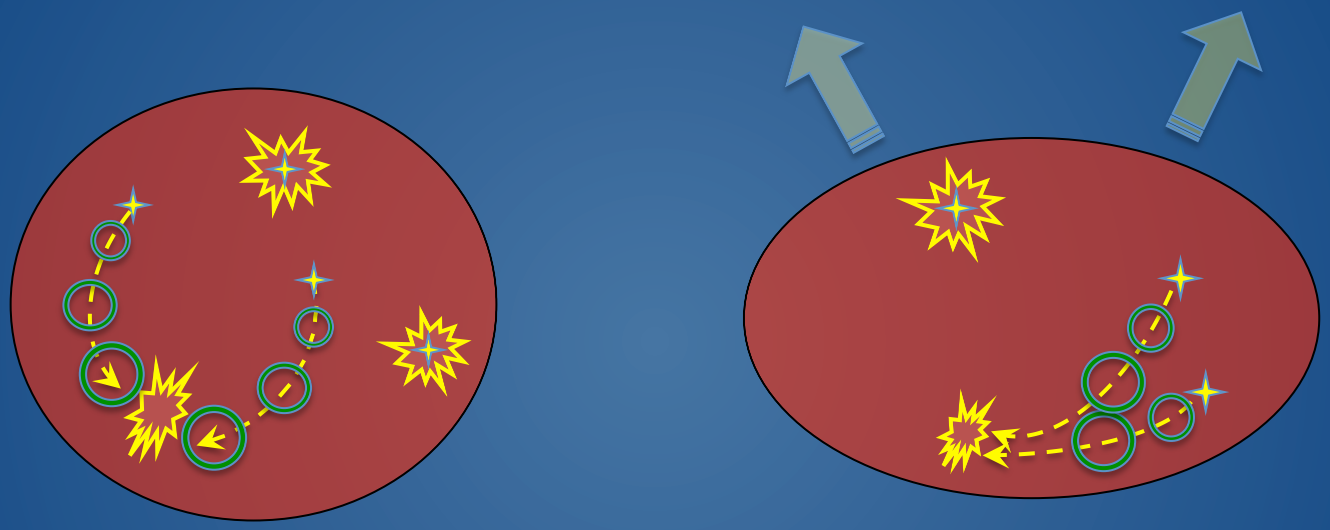


② The thermalisation of the stellar kinetic energy inherited by the stellar ejecta.

The decreasing rate of SN II and Ia vs. the accumulation of mass-loss material is what drives the evolution of hot-gas content

Origin of X-ray Halos around ETGs

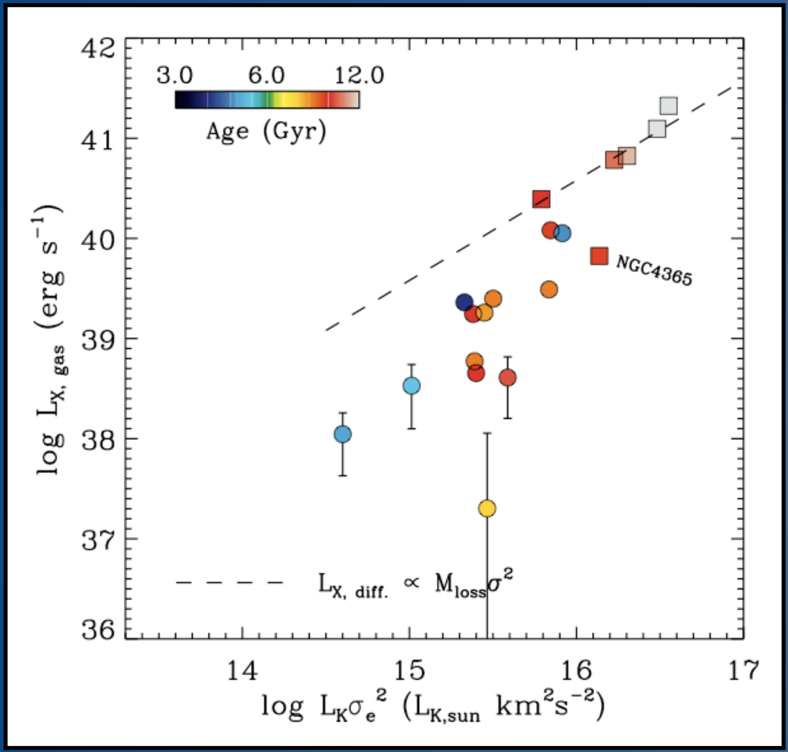
the role of flattening

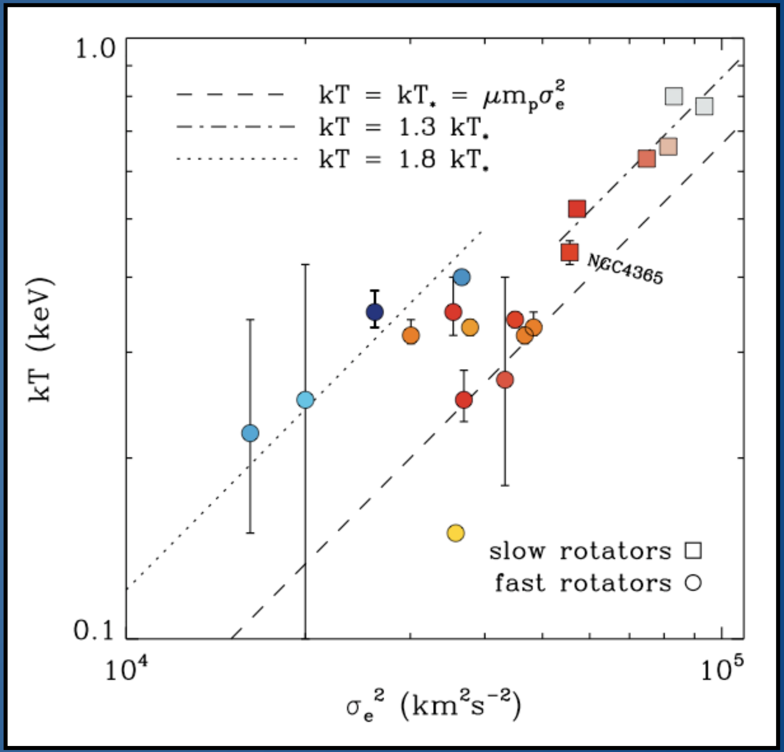


Flat galaxies have an harder time in retaining their hot gas, which may cause them to be systematically L_X underluminous compared to their rounder counterparts. This was first suggested by Ciotti & Pellegrini (1996) following the observations of Eskridge, Fabbiano & Kim (1995)

Gas OUT – joining the Hot Gas

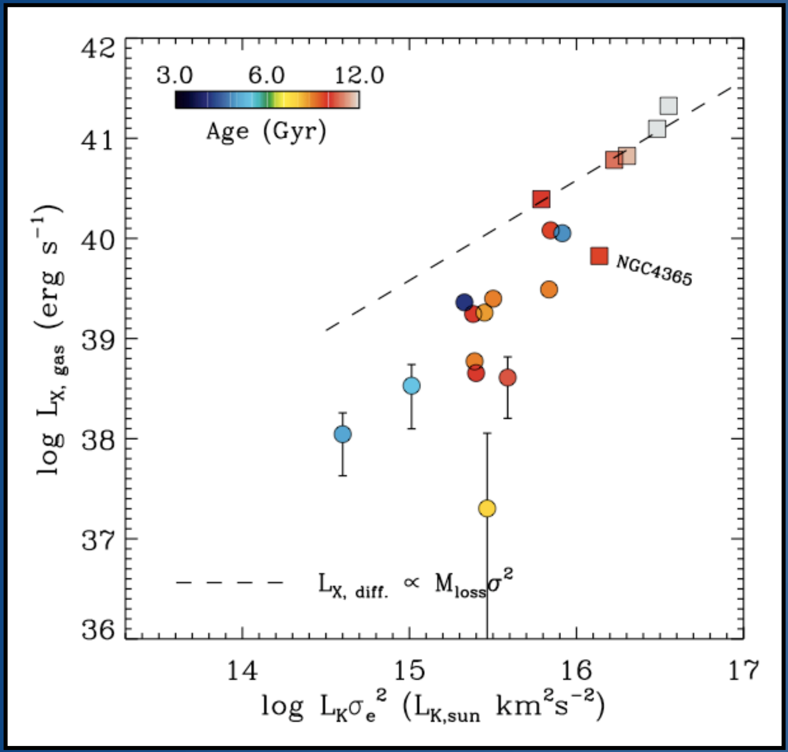
Sarzi et al (2013)

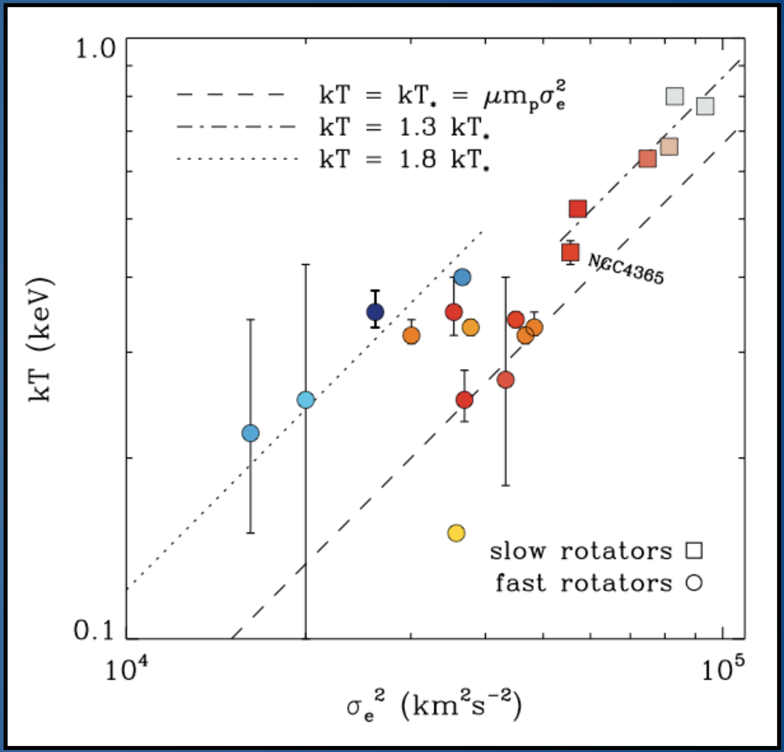




Slow-rotators have X-ray haloes with L_X and T_X values consistent with what expected if the hot-gas emission is sustained by the thermalisation of the kinetic energy carried by the stellar mass loss material.

Gas OUT – joining the Hot Gas

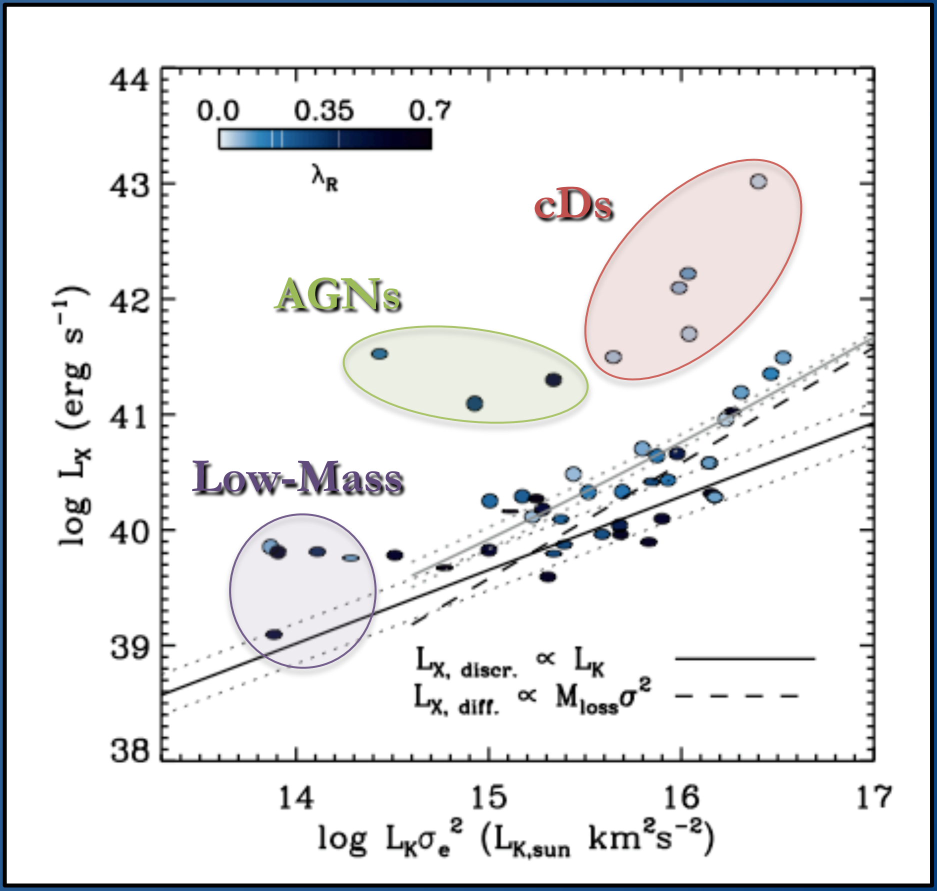




Fast rotators appear systematically under-luminous in X-ray and show no clear T_X trend. Younger Fast rotators would seem hotter and brighter in X-rays, possibly due to more recent SNe energy injection

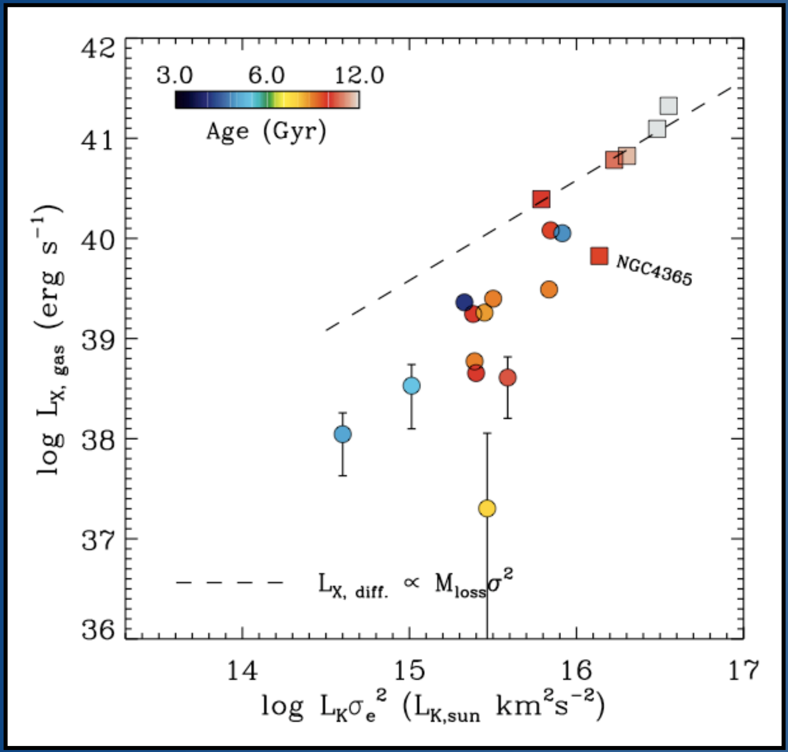
Gas OUT – joining the Hot Gas
ROSAT & ATLAS^{3D}

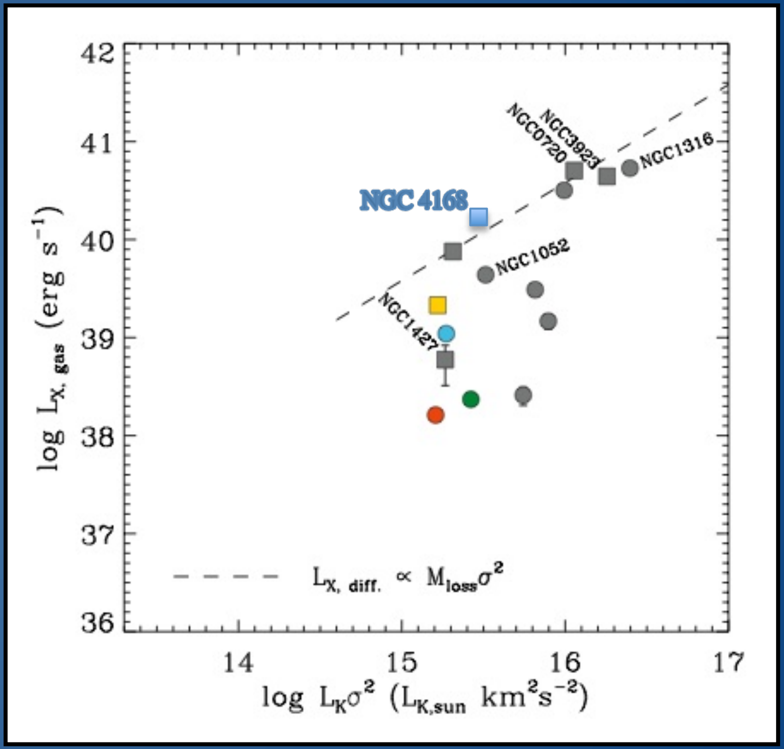
Excluding low-mass objects or those most likely contaminated by the ICM or a central AGN we observe a similar trend with flattening and λ_R also in low X-ray resolution data



X-ray Halos around ATLAS^{3D} ETGs

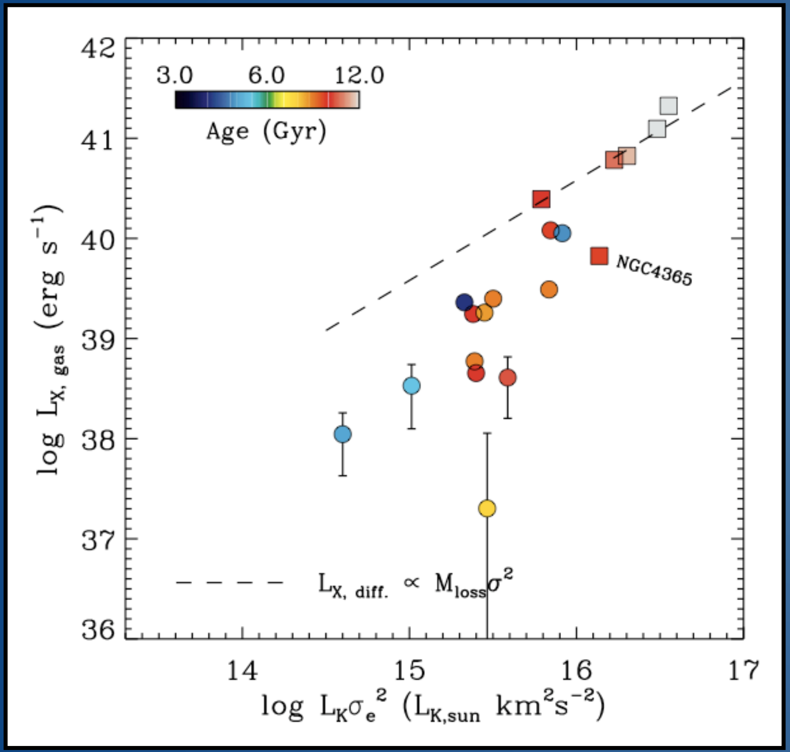
Chandra & ATLAS^{3D}

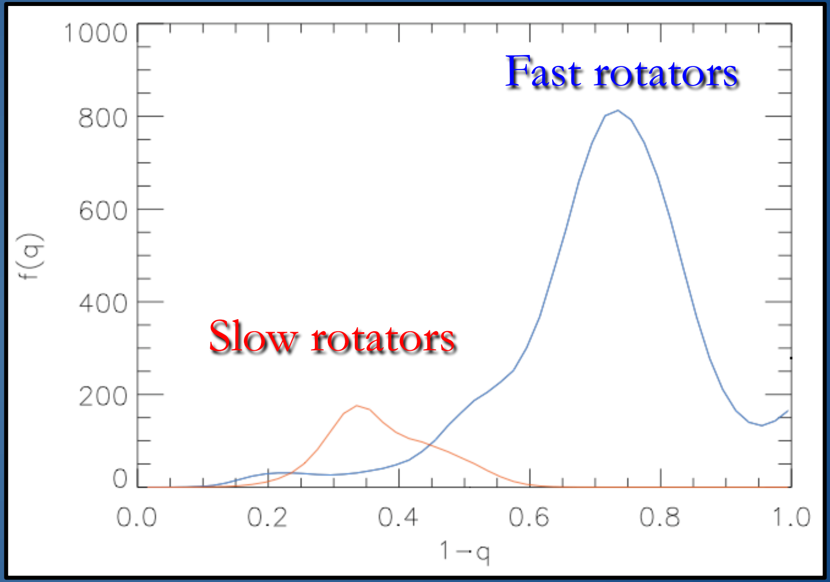




Bringing more objects, further suggest that the X-ray deficiency of Fast-Rotator would appear to reduce, or even disappear, for the most massive objects.

Gas OUT – joining the Hot Gas

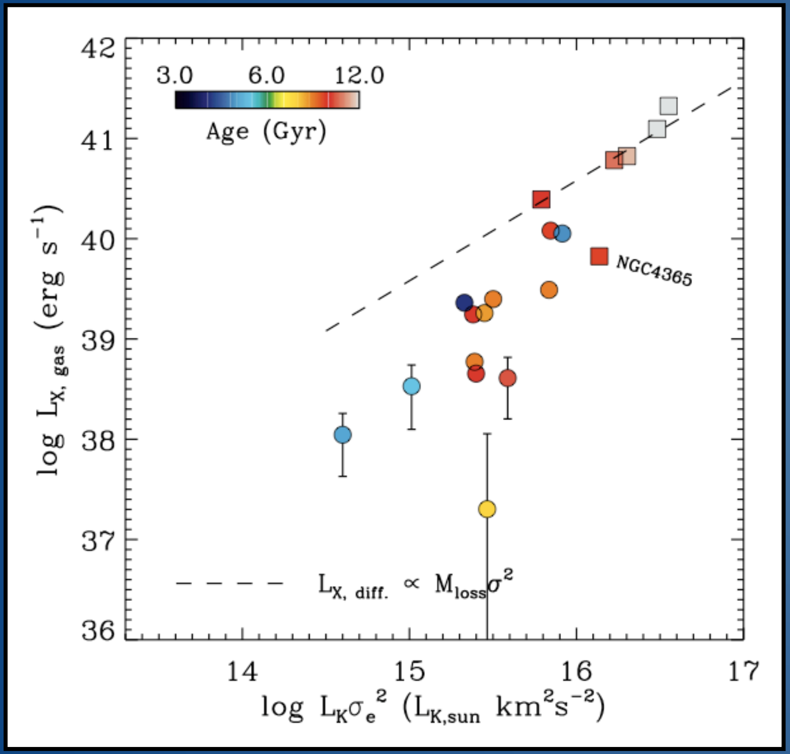




from Weijmans et al. (in prep)

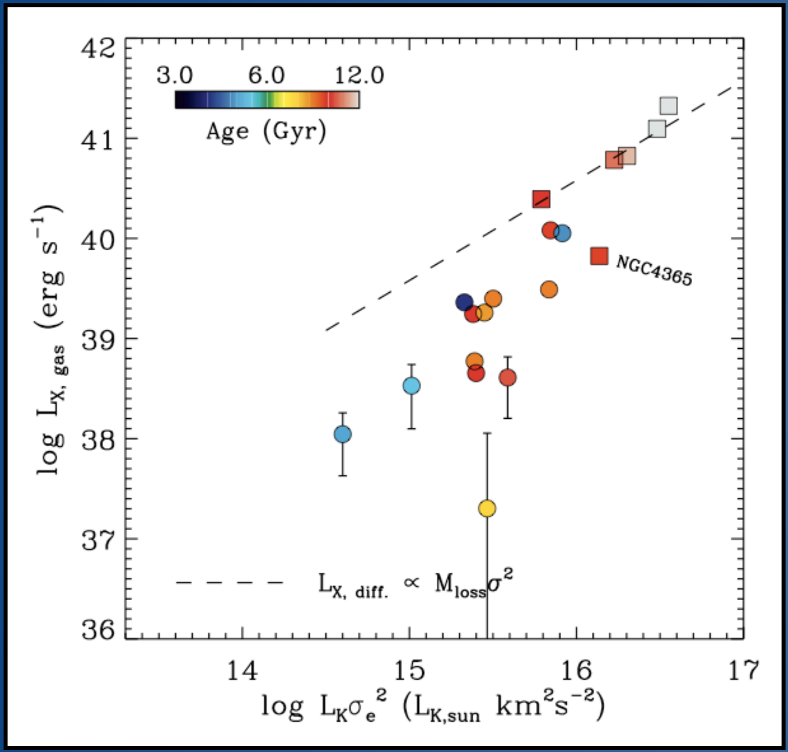
Since Fast Rotators are likely to be intrinsically flatter than Slow Rotators, their X-ray deficiency would support the idea of Ciotti & Pellegrini (1996) that flat galaxies find it harder to retain their hot gas

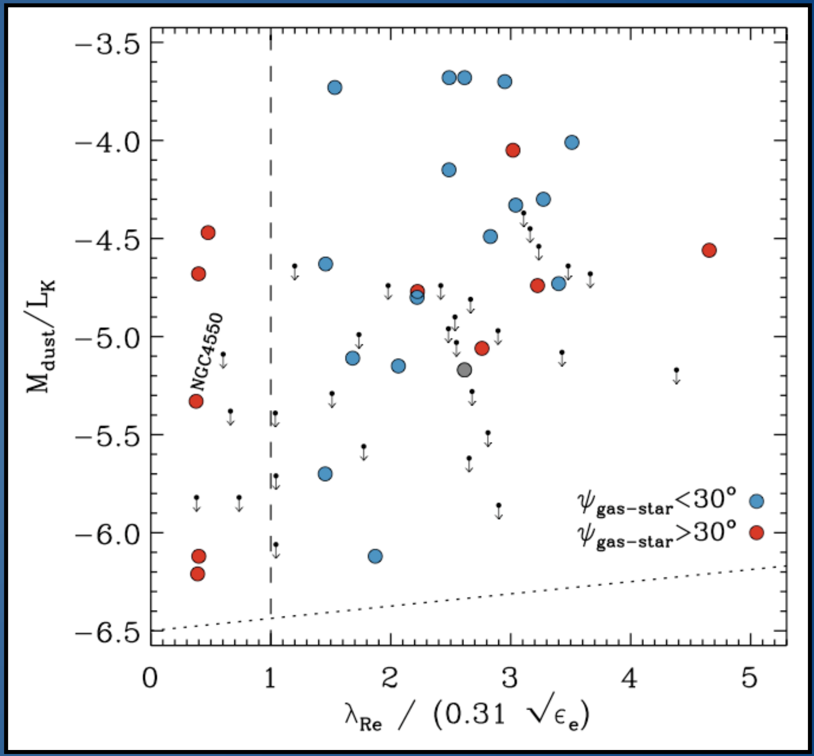
Gas OUT – joining the Hot Gas



That Fast Rotators are X-ray deficient could mean that they may recycle more efficiently their stellar-mass losses, which on the other hand would quickly fizzle in the hot-gas of Slow Rotators

Gas OUT – joining the Hot Gas





In fact, Fast Rotator have a larger dust content (from Herschel data of Smith et al. 2012) than Slow Rotators, in particular considering that most of far IR emission of these systems is due to acquired material.

Wrap Up - origin and fate of gas in Slow and Fast Rotators

- In Slow Rotators the presence of hot gas prevents the recycling of stellar mass loss material as this quickly joins the hot ISM. Accreted material would also suffer the same fate. This is why Slow Rotators stay red and dead.

- Fast Rotators have gentler X-ray environments and can recycle their stellar mass loss (which is why they are dustier) and, in particular in the field, acquire gas. This is why rejuvination is only witnessed in Fast Rotators.

- That massive Fast Rotators do not seem to acquire gas is harder to explain. One possibility is that their hot halo could inherit some of stellar spin (as suggested Marinacci et al. 2011), thus ending up exerting more ram-pressure on any acquired counter-rotating material, effectively absorbing the latter.

A last question

This is all very nice, but it is also work in progress… in particular one key element is missing in this picture: how come some ETGs seem totally devoid of gas?