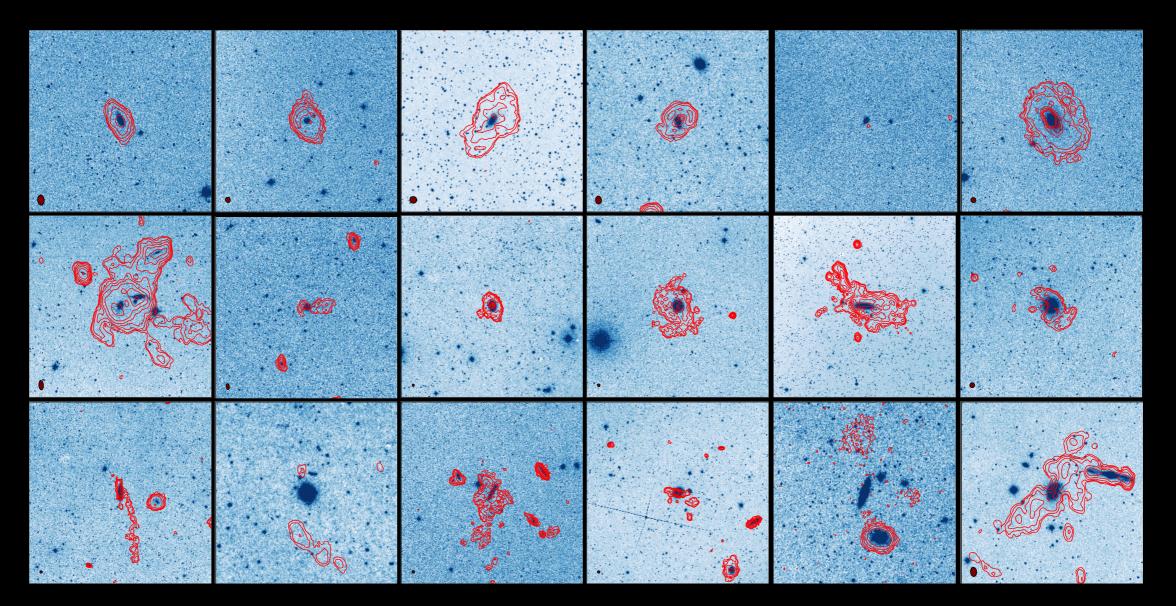
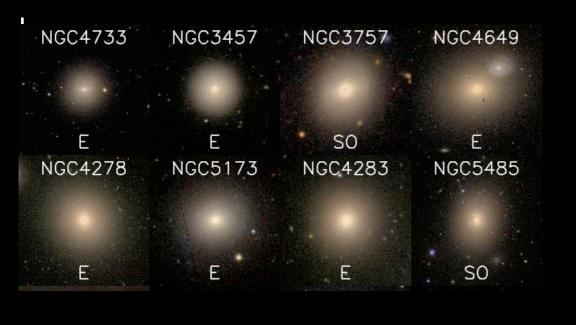
The TF relationship in Early Type Galaxies: results from ATLAS3D

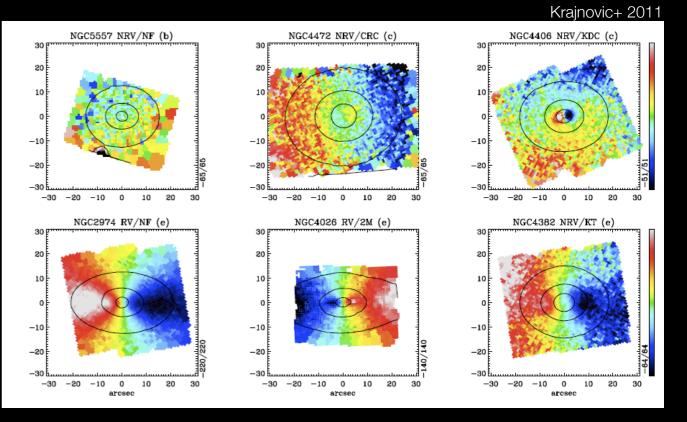


Tom Oosterloo ASTRON & Kapteyn Institute

Raffaella Morganti Paolo Serra Milan den Heijer ATLAS^{3D} collaboration

Early-type galaxies are not the boring gas-poor blobs they appear to





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- Complex structure kinematics suggests complex evolution, involving gas.
- Many ETGs have small, young(ish) population of stars

Despite ETGs being gas poor now,

there are many indications that gas played a role in their evolution

- Different, complementary ways of tackling this problem:
 - single-dish datasets (Knapp, ALFALFA,...)
 - many galaxies, only global information, good for statistics
 - HI imaging (van Gorkom, Schiminovich, ...)
 - fewer galaxies, detailed information on structure and kinematics
 - HIPASS sample 54 galaxies, ATCA, limited sensitivity (10⁸⁻⁹ M₀) detection rate 5-10%. Oosterloo+ 2007
 - SAURON 33 galaxies, WSRT, better sensitivity (10⁶⁻⁷ M_☉).
 detection rate in field 60%. Morganti+ 2006; Oosterloo+ 2010
 lots of complementary data
 - ATLAS3D Superset of SAURON sample, more distant
 166 galaxies, WSRT, (10⁶⁻⁷ M☉). Serra+ 2011
 detection rate in field 45%. Deep follow up on subset (*t* x 10)

- ASKAP, Apertif, MeerKat, EVLA - 100,000+ galaxies, z > 0 2014+

Atlas^{3D} sample: Ellipticals and Lenticulars

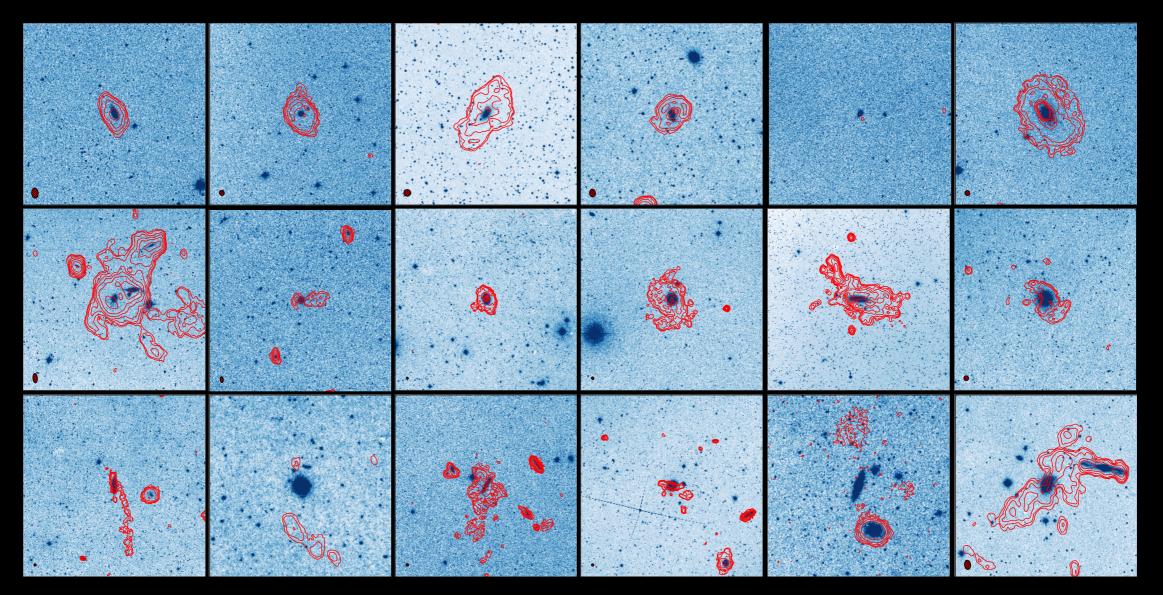
- AST (RON
- Atlas^{3D} sample: volume limited sample: 260 galaxies < 42 Mpc brighter that M_K -21.5. Main selection criterion: no spiral arms or dust lanes, so includes ellipticals *and* lenticulars. No colour selection.
- Large collaboration; optical (2D spec, imaging), CO, HI, UV, Xray, theory, simulations...
 PIs: Cappellari, Emsellem, Krajnovic, McDermid.
 (arXiv:1012.1551, 1102.3801 1102.4444, 1102.4633, 1102.4877, 1104.2326, 1104.3545, 1105.5654, 1105.4076,...)

NGC4733	NGC3457	NGC3757	NGC4649	NGC3073	NGC3379	NGC2679	NGC4382	NGC3412	NGC3384	NGC5839	NGC2950	NGC3605	NGC4754	NGC4340	NGC4429	NGC3230	NGC4684	NGC4255	UGC09519	NGC6547	NGC3245	NGC5342	NGC4546
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E	E NGC4249	E	SO NGC4489	E PGC035754	SO	E NGC4608	SO/a NGC4473	E NGC4459	S0 NGC4612	SO NGC3458	SO NGC4371	SO/a NGC5687	S0 NGC5473	S0 NGC4483	SO : NGC3998	SO	S0 NGC2764	SO	SO NGC0936	E NOCOF 15	SO	S0/a	SO NGC3400
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HI observations of Atlas^{3D} sample

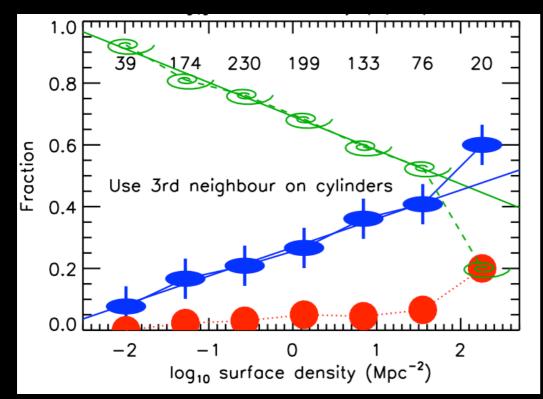


- WSRT observations of those Atlas^{3D} galaxies with δ >20° Serra+ arXiv 1111.4241
 - 12 h per galaxy. Detection limit 10⁶-10⁷ M_☉, n_{HI,lim} 3-5 x 10¹⁹ cm⁻² deep follow up on subset (10x12h)
 - Detection rate 45% in field, 5% in Virgo. HI is of low column density
 - Large range: many disks/rings, strong warps, polar, tails, clouds.
 - Many signs of ongoing accretion but of small amounts. Interaction, stripping
 - Some correlation between HI kinematics and galaxy type (E vs S0)

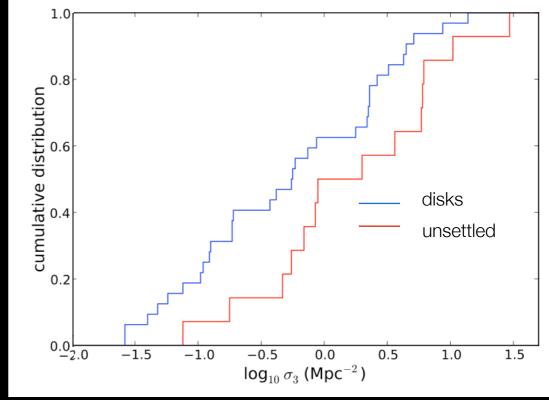


HI morphology depends on small-scale environment AST(RON

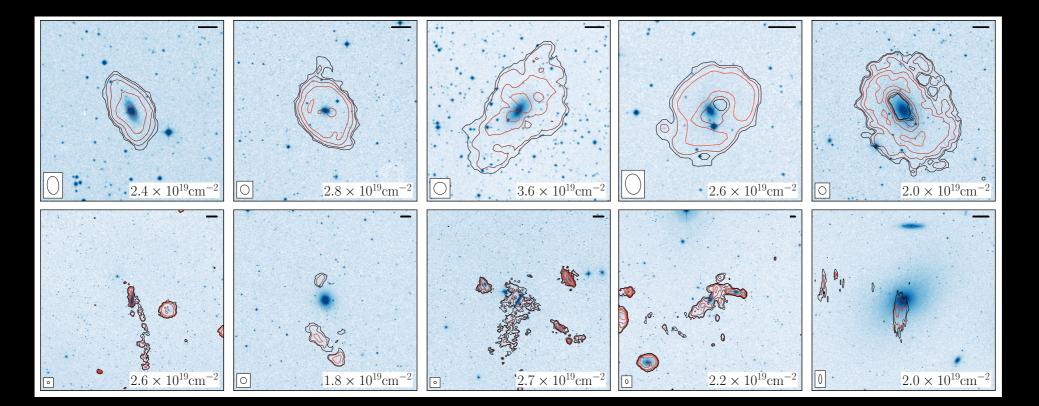
Related to density-morphology relation?



Cappellari et al. paper 7. arXiv: 1104.3545



σ₃ is measure for galaxy density
 on scales of 1 Mpc



low density

high density but field

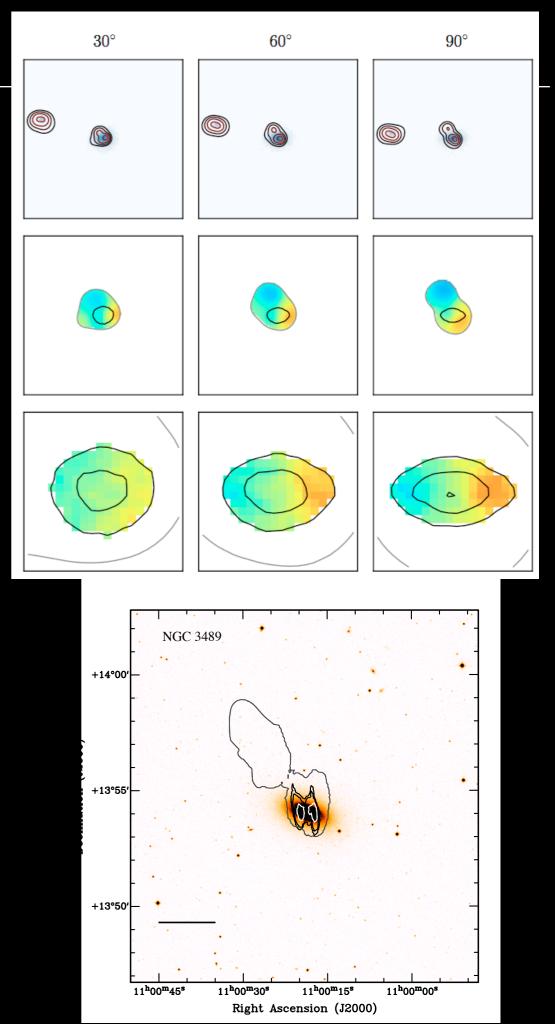
Next step: compare with simulations

Atlas^{3D} group performing cosmological simulations (Naab+)

See same diversity of HI characteristics in (some) simulations

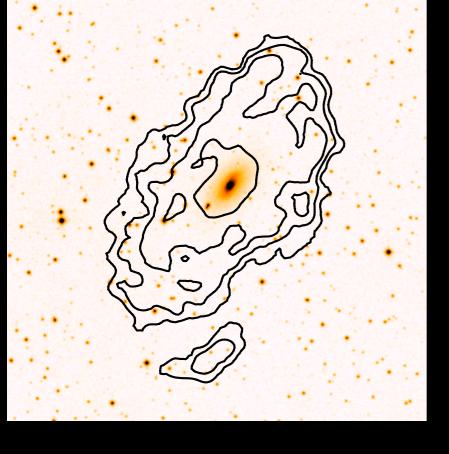
Tracing back the formation of these structures in the simulations will allow us to associate observed HI properties with formation history

example: small inner disks form from accretion of small companion



Many large, regular disks

AST(RON



NGC 6798

Regular disk, 90 kpc diameter. Low column density, 'no' star formation. Large, old HI reservoir with no star formation.

'flat' rotation out to 12 Reff

50

100

radius (arcsec)

150

200

HI velocity field

250

200

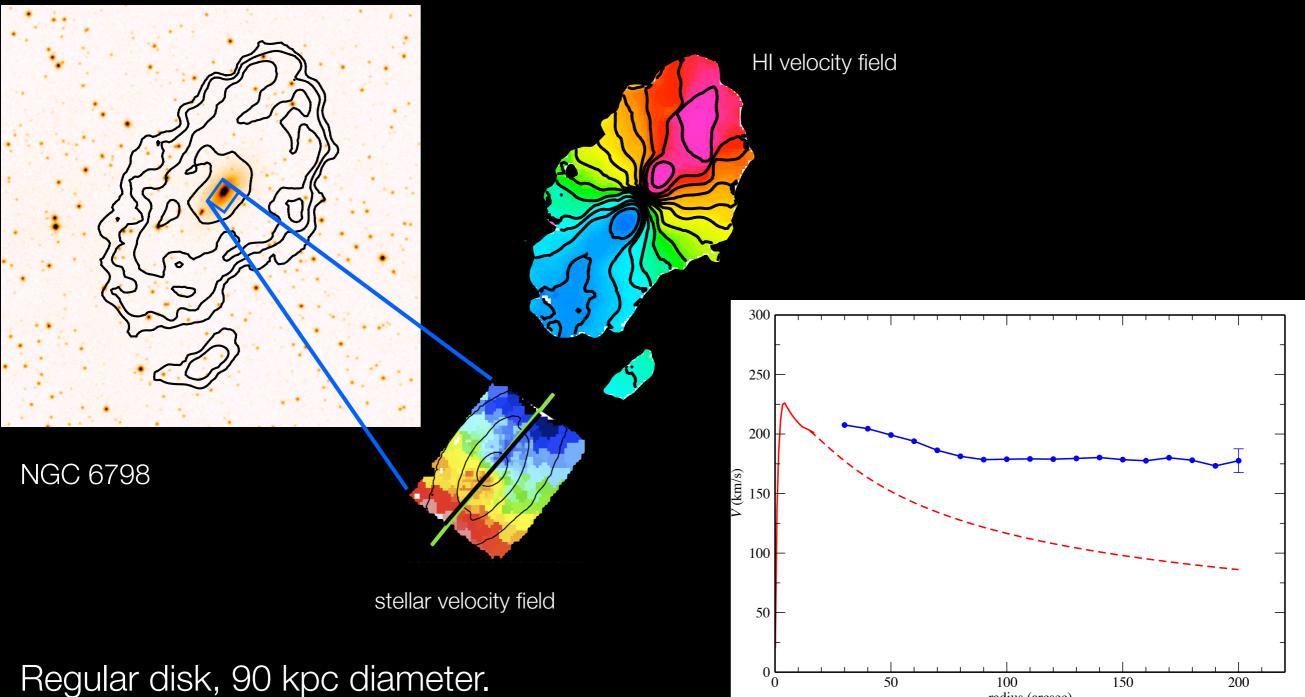
(km/s) 150

100

50

Large, regular disks

AST(RON



Low column density. Large, old HI reservoir with no star formation. Counterrotating. Find several of such disks

'flat' rotation out to 12 Reff

radius (arcsec)

AST(RON

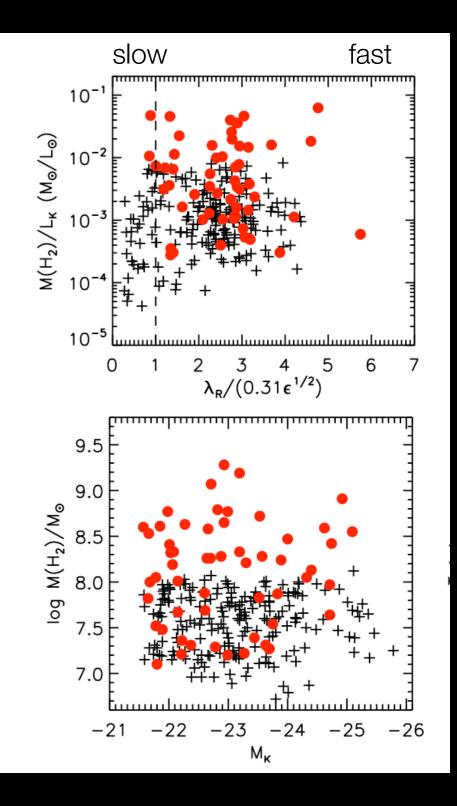
Many ETGs also have CO (Young+ 2011)

detection rate 22% for M_{lim} ~ 10^7- 10^8 M_{\odot}

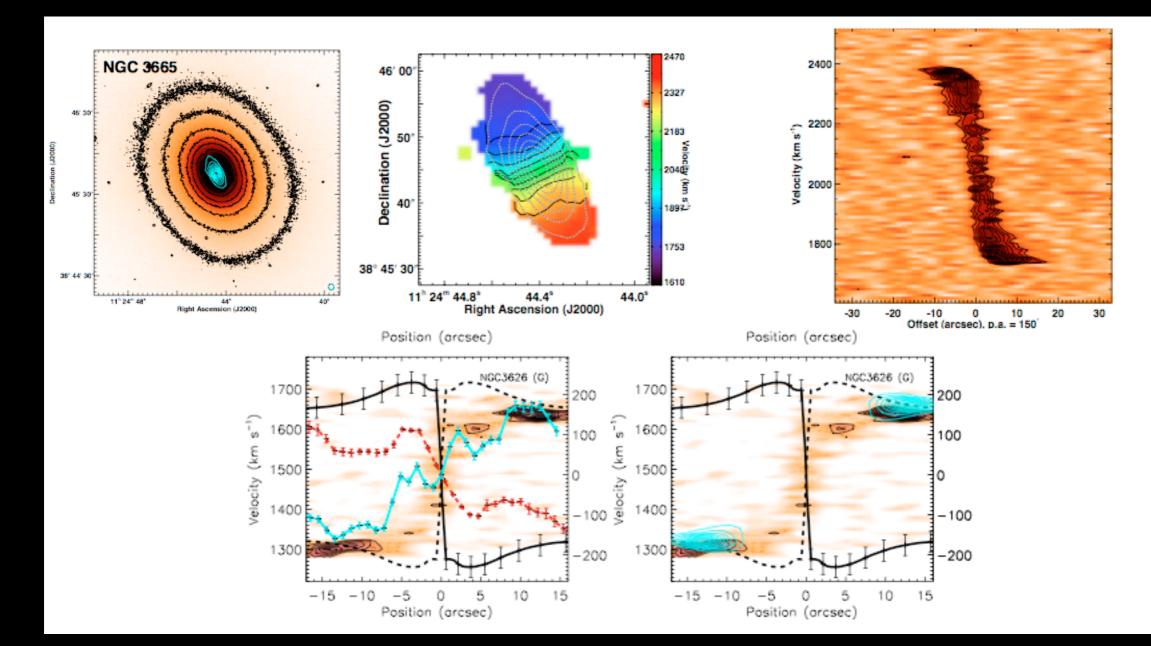
CO independent of stellar mass (like HI), correlates with dynamics

Much less dependent on environment, but H₂ richest systems are in field

In cluster much more often aligned with stars



- CARMA observations (Davis+)
- Small disks, give information on inner regions.
 Often reaching the peak of the rotation curve
- Most cold gas in inner regions is molecular: $M_{H2}/M_{HI} \sim 10$



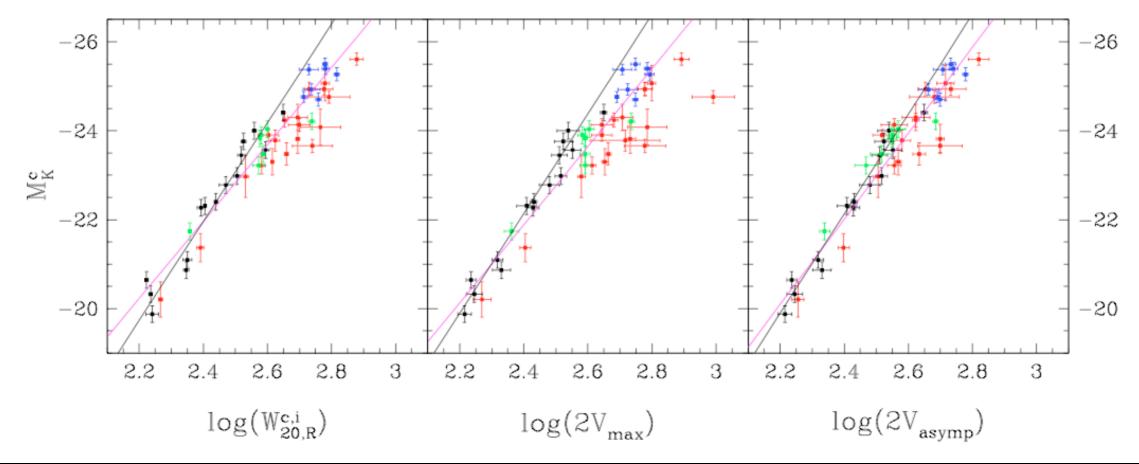
 Comparing TFR for different types of galaxies can give clues on luminosity evolution (fading of stellar populations) and on difference in structure (different size for given mass, different mass distribution)

- Evidence for a systematic offset of the S0 TFR from that of later-type spirals
 - offset seems to be small (Williams+ 2010, Davis+ 2011)
 - corresponds to 1-2 Gyr after star formation stops. Is short...
 - Sa-S0's are smaller for the same mass than later-types?
- Larger offset for massive galaxies? (Noordermeer & Verheijen).
 Differences in shape of rotation curve!
- Complication: be sure you use the same measure of rotation

ETGs have gas disks: can make TFR



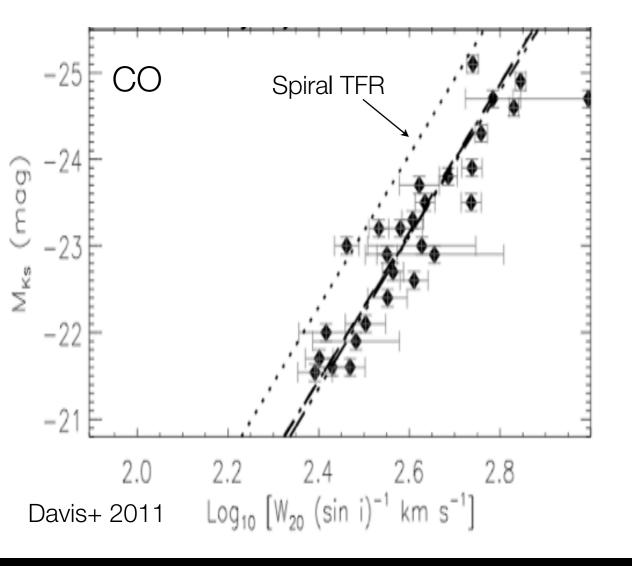
6 E. Noordermeer & M. A. W. Verheijen



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Tully-Fisher relation

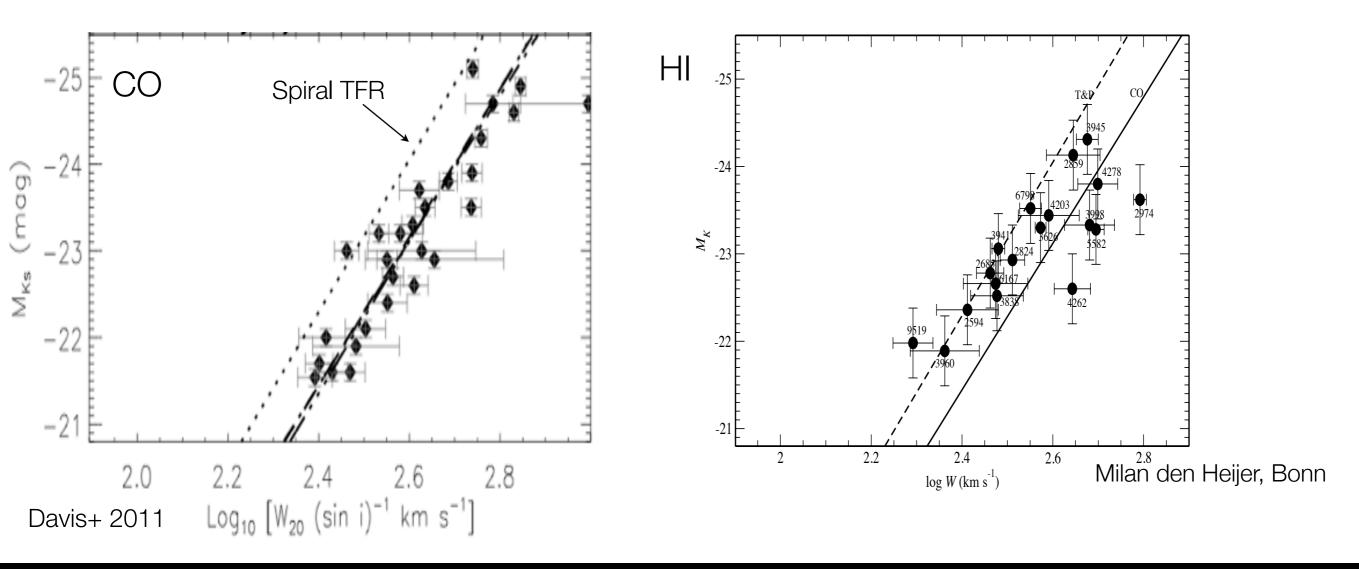




► CO TFR of ETGs offset from spirals (Tully+Pierce 2000). But: CO traces inner regions

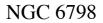
Tully-Fisher relation

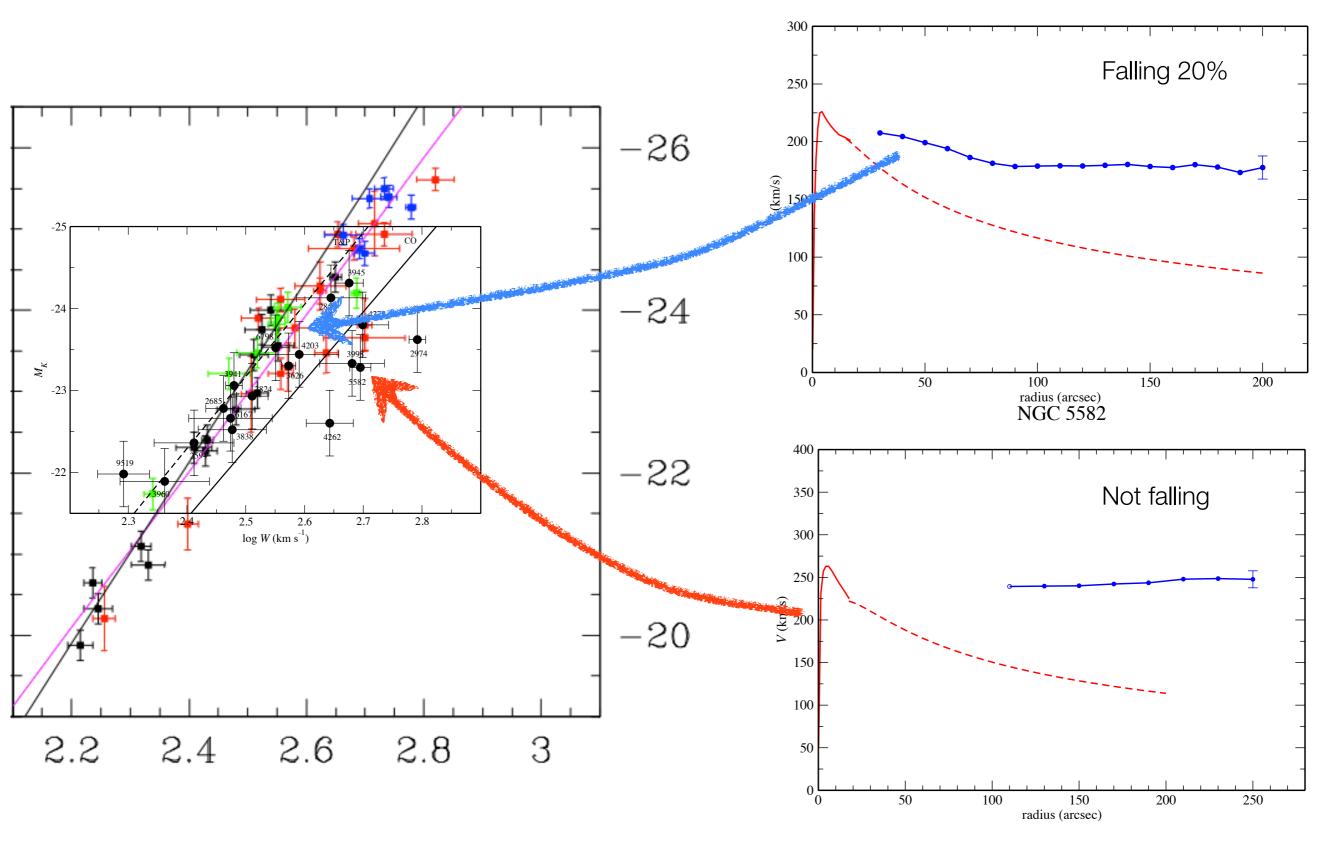




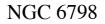
- CO TFR of ETGs offset from spirals (Tully+Pierce 2000). But: CO traces inner regions
- Smaller HI offset due to drop of rotation velocity. Not all galaxies.
 - Important for high z (ALMA)
- Population effect is small. These galaxies have gas!
- Not a very tight HI TFR, large offsets/scatter for more massive galaxies. Why?

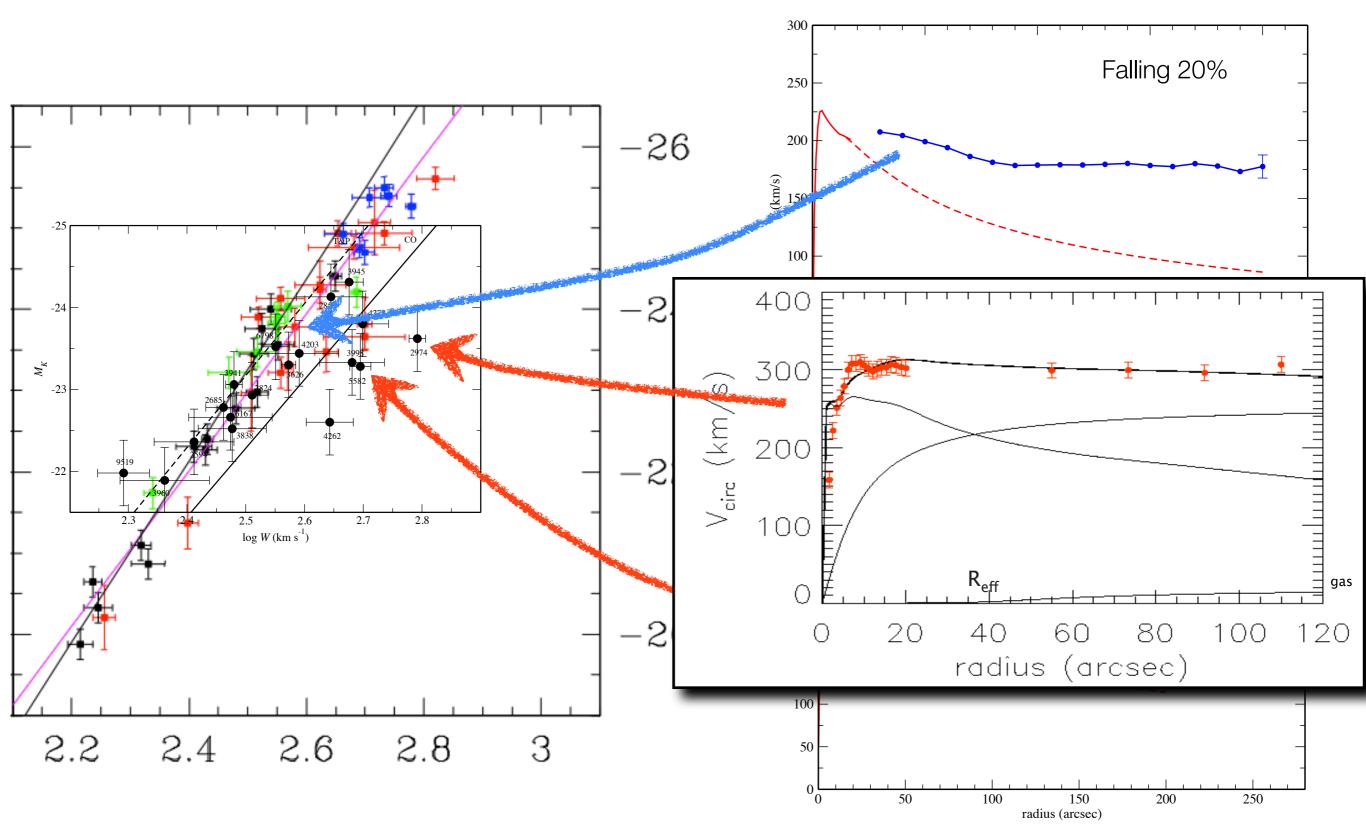
Large offsets are for flat flat rotation curves





Large offsets are for flat flat rotation curves





 ~20% of field early-type galaxies have regular HI disks of low column density, sometimes very large. Many are polar, 90° warps, counter rotating

- ▶ 10-15% of all early-type galaxies have regular CO disks
- Combine with simulations so gas can serve to reconstruct evolution
- Can construct TFR for early-type galaxies.
- Difference of TFR for between CO and HI: declining rotation curve. Important for high-z studies. Most galaxies: small offset from spiral TFR
- Some massive galaxies have large offsets: rotation curve not declining
 - check in simulations; different evolution?