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Presence of gas in early-type galaxies as a signature of minor mergers

or the continuing assembly of early-type galaxies

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ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

Netherlands Institute for Radio Astronomy

Minor merging as a driver of galaxy evolution, JENAM-11: 7 July 2011, St Petersburg

Why study gas in gas-poor galaxies?





Complex kinematical structure suggests complex evolution.

Saturday, 23 July 2011

Krajnovic+ 2011



Why study gas in gas-poor galaxies?

Other issues:

Many ETGs have small, young(ish) population of stars Density-morphology relation; Gas content \rightleftharpoons environment What is feeding the AGN?

> What is the role of gas in all this? What are the gas properties of ETGs?





Why study gas in gas-poor galaxies?

Other issues:

Many ETGs have small, young(ish) population of stars • Density-morphology relation; Gas content \rightleftharpoons environment ► What is feeding the AGN?

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This talk: results from HI studies

Detecting and tracing HI in early-type galaxies

Different, complementary ways are used and planned for tackling this problem

MAIN issues:

it requires deep observations ➡ the features we are looking for (signs of minor merger and/or accretion) are there but are faint!

and

imaging capability IP crucial for the morphology and kinematics

and

data from other wavebands I correlation between different indicators



The role of the HI in ETGs:a brief history

- 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





The past

< 2000: general perception was that ETGs are gas poor

- HI detection rates of ~10% mostly single dish work (e.g. Knapp), not sensitive
- Some suggestion that presence of HI is connected to merging (e.g. Knapp; van Gorkom, Schiminovich)

erican Astronomical Society • Provided by the NASA Astrophysics Data System

NGC 2865 Schiminovich+ 1995

Saturday, 23 July 2011



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FIG. 1a.—A morphological association between gas and stars is evident in the total H 1 overlay on an optical image of NGC 2865. Inner shells, diffuse outer shells, and "jet" are clearly visible in the optical image. The H 1 peaks to the outside of the southern and easern outer shells and to the outside of the northern loop. The H 17 southeast of the galaxy center corresponds to an edge-on dwarf companion, or shred. The H 1 contour levels are 1.9, 3.8, 7.6, and 11.4 × 10¹⁹ cm⁻². The optical image is from photoamplified AAT IIIa-J plates. The 73" × 40" VLA beam is shown in the lower right-hand comer of the image.

SCHIMINOVICH et al. (see 444, L78)

PLATE L2

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

> LARGE REGULAR DISKS! A lot of HI!! Possibly the result of major mergers?





The role of the HI in ETGs:a brief history

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 - 54 galaxies, ATCA, limited sensitivity ($10^{8-9} M_{\odot}$) - HIPASS sample detection rate 5-10%. Oosterloo+ 2007
 - SAURON - 33 galaxies, WSRT, better sensitivity (10^{6-7} M $_{\odot}$). detection rate in field 60%. Morganti+ 2006; Oosterloo+ 2010 lots of complementary data - ATLAS3D - Superset of SAURON sample, slightly more distant 166 galaxies, WSRT, $(10^{6-7} \text{ M}_{\odot})$. Serra+ 2011 detection rate in field 45%. Deep follow up on subset ($t \ge 10$)



- WSRT observations of SAURON sample
 - 33 galaxies, 'representative sample', field and cluster
 - optical 2D spectroscopy of stars and ionised gas, + lots of other data (e.g. CO, FIR, UV)
 - all galaxies above $\delta > 10^{\circ}$ (33)
 - detection limit 10^{6} - 10^{7} M $_{\odot}$, $n_{\text{HI,lim}}$ 3-5 x 10^{19} cm⁻²

- Much higher detection rate: $\sim 60\%$ in field; $\sim 2\%$ in Virgo. For CO the field and cluster detection rates are about the same!
- Environmental effects stronger than for spirals. Older cluster population, more affected by ICM?





Morganti+ 2006; Oosterloo+ 2010



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Morganti+ 2006; Oosterloo+ 2010



HI characteristics

- Diverse morphologies
- Again many disks, ~50% of detections
- But: recent or on-going accretion ubiquitous (also for gas disks).
 But of small amounts
- Some but no strong relation between HI disks and stellar dynamics
- Galaxies with large HI disks also show 'fast' stellar rotation





Morganti R., deZeeuw T., Oosterloo T. et al. (2006) Oosterloo et al. 2010

Accretion

- Accretion very common (>50%), smaller amounts than spirals, ≤ 0.1 M_☉ per yr.
 No major direct effect on galaxy
- See many cases of formation of small inner disk which is also seen in CO.
 Connection with KDC



NGC3489

Remnant tail pointing to inner disk

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Small counterrotating CO disk in N3032, also seen in HI



Other examples







CO(1-0) data from Young et al. 2008
 Optical data from Sarzi et al. 2006
 HI from Morganti et al. 2006 and Oosterloo et al. 2010

Atlas^{3D} sample: Ellipticals and Lenticulars

- 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...
- Pls: Cappellari, Emsellem, Krajnovic, McDermid. (arXiv:1012.1551, 1102.3801 1102.4444, 1102.4633, 1102.4877, 1104.2326, 1104.3545, 1105.5654, 1105.4076,...)

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HI observations of Atlas^{3D} sample

- WSRT observations of those Atlas^{3D} galaxies with δ >10°
 - 12 h per galaxy. Detection limit 10^6 - 10^7 M $_{\odot}$, $n_{\text{HI,lim}}$ 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





Serra, Oosterloo, Morganti et al. 2011 almost ready!

Many regular disks/rings (50% of detections)



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



irregular features at

AST(RON A continuum of HI morphologies sequence Serra et al. 2011

Sequences of HI-rich ETGs with increasingly less regular gas configurations

NGC 3945 (D)



Shows how the HI structures form and evolve: accretion

NGC 5422 (d)



HI distribution of size very large compared to the stellar body

NGC 7280 (u) NGC 2768 (u) • 2.1 (3.1) $\times 10^{19} \text{ cm}^{-1}$ $3.3 \times 10^{19} \mathrm{cm}^{-2}$ 0

HI distribution of size similar to the stellar body

Environment

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

0

2.7 (3.0) ×10¹⁹ cm⁻²

low density



0

2.7 ×10¹⁹ cm⁻²

ŀО





Cappellari et al. paper 7. arXiv: 1104.3545

Do not see evidence of effect of intergalactic radiation field on HI disks

'Expected': below column densities of a several x 10^{19} cm⁻² HI disks should be ionised. Should see truncation of outer HI disk.

Do not observe such edges of HI disks. Outer HI disks consist of clumps of accreting material?

Very similar to outer regions of spirals





Deep HI observations

Evidence of accretion/interaction in all galaxies





7)



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Spiral-like streaming motions, HI still settling. Timescale few x 10^9 yr (z ~ 0.3-0.5)

More signs of accretion

HI disk (90 kpc diameter) counterrotating to stars - co-rotating with ionised gas NGC 6798

Not your regular S0

HI disk (90 kpc diameter) counterrotating



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HI velocity field



stellar velocity field

Many polar gas rings and 90-degree warps

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

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HI and radio continuum

- Many galaxies also detected in radio continuum (most at mJy level)
- ► Star formation or AGN?
- Use high-res radio data to look for AGN



Oosterloo et al. 2010

SFR from radic

Galaxies with central HI are more likely to be detected in continuum. Due to star formation, not AGN.





SFR from Spitzer

Follow radio-FIR relation

- Young stellar population detected in ~30% of radio galaxies: likely fraction of galaxies resulting from major mergers (Tadhunter et al. 2011)
- but sign of interaction/accretion in the majority of the galaxies (Ramos Almeida et al. 2011)
-but is the interaction really responsable for the triggering of the AGN?
- ► Two cases: NGC1167 and Centaurus A



NGC1167: many accretion of small satellites?

Disrupted satellite?



- Huge HI disk \rightarrow ~170 kpc with more than 10¹⁰ M_{\odot} of cold gas
- Very regular kinematics \rightarrow but disturbances in the outer parts and evidence for a disrupted satellite
- No "diffuse" accretion from small gas cloud, no HI halo
- No widespread starformation
- A large fraction of the HI disk was built up via minor mergers (and interactions) in the course of several Gyr
- Any relation between these mergers and the AGN activity?

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B2 0258+35: recurrent activity and large reservoir of gas



Struve, Sancisi, Oosterloo, Morganti 2010 Shulevski in prep.

 Recurrent radio emission => young radio source (10⁶ yr) plus a large structure possible left over of previous phase of activity (at least 10⁸ yr)

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• What is the trigger of these different phases of activity? Same minor mergers likely forming the HI disk?

• No particular features in the HI distribution: cannot have been a large event

• Study of the central HI (absorption) in progress

HI in Centaurus A: latest news

Struve, Oosterloo & Morganti 2010



 Regular kinematics inside 5 kpc Asymmetries and filaments at larger radius No need for non-circular orbits between <5 kpc Reproduces H I kinematics & shape dust disk (and stellar ring)

• $M_{HI}/L_B = 0.01$, so H I disk might well be the result of accretion of

Saturday, 23 July 2011



Modelling of the HI

llar ring) Accretion of



Merger/accretion and activity

- Difficult to reconcile time scales?
- ► Age merger few x 10⁸ yr (consistent with other indicators, e.g. warp structure, stars associated with the young blue tidal stream → 300 Myr, Peng et al. 2002)
- Too old for triggering recent AGN activity? 10⁶ yr inner lobe (Croston et al.), >10⁷ yr outer lobes
- Connected to previous episode of AGN activity?
- Merger actually disrupted the plasma flow (Saxton, Sutherland, Bicknell 2001)?

The delay would represent the time to recover from this!?



APoD 13 April 2011 Centaurus A - 1.4GHz ATCA Feain et al.



oung stars outer filamen inner filamen Optical image from D. Malin

Summary

- ▶ ~50% of field ETGs have HI (detection limit 10^{6} - 10^{7} M_☉); 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, $\leq 0.1 \, \text{M}_{\odot}$ 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 .
- 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
- relation to AGN?

Next step: ASKAP, Apertif, MeerKat, EVLA - 10,000++ galaxies not only local Universe



2014+