The continuing formation of early-type galaxies: an HI view

HI observations of SAURON galaxies

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Gas and early-type galaxies

- Early-type galaxies: diversity of properties that goes beyond simulations do not constitute a uniform class

- Hierarchical galaxy formation:
  - mass ratio of the merging components
  - feedback on the gas
  - amount of dissipation during the merger

Is gas (partly) responsible for this? Cold accretion important?
H I-rich early-type galaxies: shallow survey (HIPASS & ATCA)

Morganti et al. 1997
Oosterloo, Sadler, Morganti
H I-rich early-type galaxies: shallow survey (HIPASS & ATCA)

- 5-10% (in field galaxies) have $10^9 - 10^{10} \, M_\odot$ on scale of hundred kpc
- $M_{HI}/L_B \sim 0.1 - 1$ (i.e. like spirals!)
- **Regular structures (disks), very large, more than $10^9$ yr old:**
  - Often strongly warped
  - Dark matter content; similarity with spirals
  - Low surface density ($0.5 - 1 \, M_\odot/pc^2$)

  so do not form (many) stars (i.e. the H I is not used up quickly),
  these H I structures can stay around for a very long time!
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These early-type galaxies likely form through a major merger

IC4200: Event that happened about 2 Gyr ago and originated both
the H I structure and the central starburst: major merger – time not
long enough for accretion of IGM.
What is the next step?

Higher sensitivity for deeper HI observations

Complementary information on the ionised/molecular gas and stellar population essential for a complete picture

WSRT observations of galaxies of the SAURON sample (dec>10°)

- 12h spent on each target
- resolution few kpc (at the distance of typical SAURON galaxies)
- follow-up (additional 3x12h) for the HI detected galaxies
The WSRT-HI survey of SAURON galaxies

- detection rate in field ~60%
- strong dependence on the environment:
  - 20 field galaxies ➔ 12 (+2?) detections
  - 13 cluster galaxies ➔ 1 detection
- mass limit few \( \times 10^6 \, M_\odot \)
- variety of HI morphologies: information about morphology important


Oosterloo et al. in prep
• Half of the HI detected early-type galaxies have the gas distributed (mainly) in disk/ring structures

• Some of them have also tails suggesting on-going accretion or interaction

• The remaining show unsettled structures \( \Rightarrow \) HI does not manage to form a disk

• Cases with large offset HI-target: what is the actual relation with the target?

\[ \sim 5 \times 10^8 M_\odot \]

\[ \sim 5 \times 10^7 M_\odot \]
Unique dataset to compare/correlate with other 3D datasets ➤ optical and CO data

- Ionised data occurrence/morphology/kinematics
- Stellar population
- Host galaxy properties
- Dark matter
- CO data
- Radio AGN

as function of HI occurrence but also HI morphology
Kinematics of the gas and the stars:
galaxies with regular HI disks also have extended,
kinematically regular structures in the ionised gas

M_{HI} = 1.8 \times 10^9 M_{sun}

M_{HI} \approx 2 \times 10^8 M_{sun}

M_{HI} = 2 \times 10^8 M_{sun}

M_{HI} = 6 \times 10^8 M_{sun}

M_{HI} = 4 \times 10^7 M_{sun}

NGC 3414

NGC 4278

NGC 2685

NGC 4150

Morganti et al. 2006
Galaxies with offset (or complex) H\textsubscript{I}

NGC 5982

NGC 5198

NGC 1023

NGC 7332

Galaxies with no H\textsubscript{I}

NGC 2549

NGC 2768

NGC 5308

NGC 7457
There is more in the data: looking at the full datacube

NGC4278
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NGC4278
Example of what we can do with these data: NGC 2974


Sauron + VLA

Mass model combining HI rotation curve with the central kinematics of the ionised gas.
Increase M/L ⇒ dark matter (M/L from 4.3 to 8.5 M_S/L_* between 1 and 5 R_e)

Galex & H I

Star formation at large radii
Jeong, Bureau et al. 2007
HI and Stellar population: no trivial link!

Values of the (luminosity weighted) stellar age from Harald Kuntschner

**HI**

- Very different region sampled by the HI and the optical data
- Large radial gradients in stellar populations
- Efficiency with which gas is turned in stars varies strongly with details of interaction/accretion (see e.g. de Matteo et al. 2007)
- From GALEX data: young at large r in some objects

**Ionised gas** (Emsellem et al. 2006)

Trend between mass of the ionised gas and presence of "young" stars

see also talk of Paolo Serra
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H I

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NGC 3489
NGC 4150
NGC 3032

Centrally concentrated galactic-size HI disks

red: Tully < 2

\log(\text{age})

\log(\text{M}_{\text{HI}}/L_{\text{K}})
Centrally concentrated galactic-size HI disks

KDC detected in the very inner part - gas co-rotating with that

McDermid et al. 2007
NGC 3489
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Gas decoupled from young stars!!
HI and the host galaxy

from SAURON stellar kinematics: fast- and slow-rotator classification (Cappellari et al. 2007)
presence AND morphology of the HI

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presence AND morphology of the HI

from Cappellari et al. 2007

NGC 3414

slow
HI presents both in slow and fast rotators

BUT

Possible trend with the HI morphology
Slow rotators do not have regularly rotating structures of HI?
Origin of these galaxies?

Too few cases of slow rotators to derive some clear conclusions ▶️ ATLAS3D
Preliminary result: relation to radio continuum

- Detection rate higher for galaxies with HI
- Independent from the HI morphology
Comparison with the molecular gas

NGC 3032 CO

M(H$_2$)/M(HI)≈6

NGC 4150 - HI

M(H$_2$)/M(HI)>4


M(H$_2$)/M(HI)=23

Crocker et al. MNRAS 2008
Comparison with the molecular gas

No strong correlation in the detection of CO and HI. Tendency of the CO to be detected in systems with centrally concentrated HI.

$M(H_2)/M(HI) = 23$


$M(H_2)/M(HI) > 4$

$M(H_2)/M(HI) \approx 6$
• 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. in prep.
Conclusions

- HI common characteristic of early-type galaxies in field
- In half of the detections, HI in regular structures (wide range of HI mass)
- HI nicely connected to the ionised gas (morphology and kinematics)
- Galactic-size HI disks found in galaxies with the younger stellar population - cases of young stars at large-r associated with peaks of HI
- Possible difference in HI morphology between fast and slow rotators?
- Detection of radio continuum (AGN?) higher in galaxies where also HI is detected (regardless morphology)
- Comparison with CO - cases of high values of M(H$_2$)/M(HI)
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Machinery (and time allocation!) in place for the study of a much larger sample ➔ ATLAS$^{3D}$