Cold gas accretion in galaxies, an update

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Cold gas accretion in galaxies

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Received: 28 January 2008 / Published online: 17 April 2008
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2008 review - main conclusions

‘A large number of galaxies are accompanied by gas-rich dwarfs or are surrounded by HI cloud complexes, tails and filaments. This suggests ongoing minor mergers and recent arrival of external gas. It may be regarded, therefore, as direct evidence of cold gas accretion in the local Universe.

Considerable amounts of extra-planar H I have been found in nearby spiral galaxies. While a large fraction of this gas is undoubtedly produced by galactic fountains, it is likely that a part of it is of extragalactic origin.

We infer a mean “visible” accretion rate of cold gas in galaxies of at least 0.2 $M_\odot$ yr$^{-1}$. In order to reach the accretion rates needed to sustain the observed star formation ($\approx 1 M_\odot$ yr$^{-1}$), additional infall of large amounts of gas from the IGM seems to be required.’
Why should galaxies accrete gas?

Star formation consumes all the gas in a few Gyr. Even quicker at higher redshift

Bigiel et al. 2011
Tacconi et al. 2018
Why should galaxies accrete gas?

The evolution of the number of stars and of the amount of HI do not trace each other

HI cannot provide the gas to compensate for decrease of molecular gas due to star formation

Must be dynamic process involving cooling from ionised CGM

Putman 2016
Accretion

- accretion of gas-rich companions
- reservoir of hot gas cooling onto galaxy
- streams of ‘cold’ gas

- Much observational effort has been done to detect the accreting CGM in HI

- With some success, but observed accretion rates are small
There is a lot of CGM that (could) accrete but is not HI!!
Minor mergers are very common, and bring in fresh HI, but:

Accretion of companions cannot solve the problem: most HI in galaxies is already in large galaxies. There is not enough HI in companions to keep on feeding large galaxies for a long time.

maximum gas accretion rate of 0.28 M⊙ yr⁻¹

di Teodoro & Fraternali 2014
Same is true for large, dark(?) HVC complexes similar to Complex C

A number are known, but not enough to provide sufficient HI

van de Hulst, Sancisi, 1988
New GBT observations show the complex in N2403 is even larger

de Blok+ 2014
Halogas survey (Heald et al.)

HALOGAS Sample: Overview

The WSRT HALOGAS Survey is the first systematic investigation of cold gas accretion in nearby spiral galaxies. It consists of deep (120 hours) WSRT observations of 22 edge-on and moderately-inclined nearby galaxies. Images of the galaxies are shown here, at the same angular scale. The HALOGAS Survey probes neutral hydrogen down to a column density of about $10^{19}$ cm$^{-2}$, and allows the characterisation of faint extra-planar and anomalous-velocity neutral gas with excellent spatial and velocity resolution. HALOGAS data reveal the presence of lagging thick-disk gas, and counterparts to the Milky Way’s high velocity clouds. The data also allow us to study the disk structure and dynamics in unprecedented detail for a sample of this size.
Halogas survey has found some but not many new large HVCs

No evidence of a large population of large HVCs, sufficient to feed star formation
No evidence for extended, diffuse gas on 10 kpc scales

GBT observations of Halogas sample detect the same flux as the WSRT

Very tricky to do…. Early versions of this work concluded the opposite…

Pingel et al. 2018
Most of the HI in the Universe is at high column densities

no room for substantial amounts of low column density HI around galaxies

Braun 2012
But stacking reveals low column density gas on smaller scales.

No edges to the disk. Gas below photo-ionisation limits.

Gas must be clumpy / filamentary, on scales of ~1 kpc.

Resolution GBT is too low.
So maybe it is like M83

filaments of ~1 kpc width out to very large radius

Meerkat should be great for detection this!

Same sensitivity as GBT but at resolution matching the structures
Two components:
- Galactic fountains (IVC) few kpc thick lagging rotation
- Accretion (HVC)

‘Considerable amounts of extra-planar H I have been found in nearby spiral galaxies. While a large fraction of this gas is undoubtedly produced by galactic fountains, it is likely that a part of it is of extragalactic origin.’

Important to understand the origin of this HI

(Now re-discovered as outflows in the optical…)

2008 review

NGC 891
HALOGAS survey shows that lagging, thick HI disks are common and that their properties correlate with star formation.
But N891 is unusual!!!

Separate thin disk H I from thick disk H I

Thin disk model

Lagging thick disk model

Radial extent of thick HI disk is about the same as that of the star formation.

Thick disks indicate very significant gas circulation.

Typical HI masses of thick disks are $10^8 \, M_{\odot}$, so gas circulation of at least $10 \, M_{\odot}/yr$
The role of thick HI disks in accretion

Basic idea: star formation blows gas into halo, gas cools and falls back to disk

*Interaction with hot halo induces cooling of hot gas.*

More cold gas rains down that was shot up!

Induced accretion at rates sufficient to maintain star formation

Fraternali, Marinacci, Marasco, Armilotta,… many papers
Testable using kinematics

Fountain only model without accretion does not fit rotation of thick disk

Fountain+accretion does fit and provides the right amount of accretion

Fountain + accretion: thick disk has radial inflow
Radial motions are detected in thick disk

But not in every galaxy

Disc gas

Extraplanar gas

Fraternali et al. 2004
Radial inflow of thick disk in N4559

(Barbieri et al. 2005)

PV slices along minor axis
NGC 3198 (Halogas)

prominent thick disk but at most subtle signs of inflow…
Perhaps radial motions in M33

Koch et al. 2018
How about accretion in early-type galaxies?

**Atlas$^3$D survey** (Serra et al. 2012)

HI detection rate 40% in field, 10% in Virgo. HI is of low column density, too low for star formation.

Large range in morphology: disks/rings (large and small), strong warps, polar rings, tails, clouds.

Many signs of ongoing accretion, interaction, stripping
Accretion in early-type galaxies

- many early-type galaxies in the field are also accreting small companions. Accretion of small amounts of HI, only small impact on galaxy

- Many field ETGs have gas disks (seen in HI, CO and ionised gas),
- many HI disk are counter rotating, polar or strongly warped
Early-type galaxies

- Surprisingly often these (counter-rotating) disks are huge!!!

NGC 6798

HI disk (100 kpc diameter) counterrotating containing $4 \times 10^9$ M$_\odot$ of HI.

HI column density is low ($<10^{20}$ cm$^{-2}$), so no star formation in these disks, despite the large HI mass.

These disks must be quite old
Such large HI disks are fairly common
Distribution of misalignments is a good test for simulations

Serra+ 2014

Fraction of simulated, aligned galaxies too large

Although this simulation seemed to reproduce the stars, it did not do a good job on the gas,…

Eagle simulations much better. Mainly due to better implementation of feedback (Serra, in progress)
Virgo ETG are HI poor

Differences in star formation history caused by differences in accretion of gas

McDermid et al. 2015
The Future 1

ASKAP & Apertif
Phased array feed front end
very large field of view (~30x larger)
at sensitivity of old WSRT

High survey speed and high resolution

Will be able to image the large areas at 15-30 arc sec resolution with (much) better sensitivity than Alfalfa and HIPASS

Excellent for imaging the HI environment of galaxies and study the changes of HI content
The Future 2

MeerKat and SKA1-Mid

1x resp. 3x sensitivity of EVLA, larger field of view, excellent uv coverage, good resolution (few arcsec) but many short baselines

To better understand the galactic fountains/beards, radial motions and their relevance for accretion, we need something like Halogas survey, but at resolution of a few arc sec.

Much better study on relation star formation and HI halos
The Future 3

SKA1-Mid: 500 m core with high filling factor (‘Imaging Arecibo’)

Will be able to image column densities well below $10^{18}$ cm$^{-2}$ at arcmin resolution

Detect the very faint HI interface with the IGM,
Study gas accretion
Summary

• Plenty of observational evidence for cold gas accretion in galaxies

• But the observed HI accretion rates are below the star formation rates

• Spiral galaxies have thick HI disks, with lower rotation
  • related to star formation (galactic fountains)
  • very significant circulation of gas
  • still some puzzles about the kinematics (radial inflows)

• Many early-type galaxies have accreted gas

• Lack of accretion for Virgo galaxies causes different star formation histories

• Significant progress can be expected from SKA pathfinders

• Relatively modest progress in the last decade
  • will change with the new telescopes soon operational