Cold gas and star formation in galaxies

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Thanks!!

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GASS students at Arecibo (Fabello, Lemonias, Hummels, Wu)
The HI window on galaxy evolution

- Dominant component of ISM
- Reservoir for future star formation
- Kinematical tracer
- Best tracer of tidal interactions and environmental effects

M81 group, Yun et al. (1994)

http://www.spica-mission.org/science_galaxies.xhtml
**HI-blind surveys**: HIPASS done, ALFALFA started

- **HIPASS**: HI Parkes All-Sky Survey (Barnes+ 01), z<0.04, N~6,000
- **ALFALFA**: Arecibo Legacy Fast ALFA survey (Giovanelli+ 05), z<0.06, N~30,000

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**Main issues:**

- Lack of multi-wavelength coverage
- Samples small (cf. optical/IR,UV…), biased, limited to local Universe

→ Little gas constraints for galaxy formation and evolution models
Need for deep cold gas surveys

http://www.spica-mission.org/science_galaxies.xhtml
Need for deep HI surveys

HI-blind surveys best suited to study HI-rich regime processes (with detections)
Quenching processes (e.g., gas stripping) → deep observations, stacking
1. Deep cold gas surveys of stellar-selected samples
Representative samples for cold gas studies

xGASS: the extended GALEX Arecibo SDSS Survey
Areecibo large programs: ~1300 hrs, ~1200 galaxies. Selection:
- GASS: 0.025< z<0.05, 10< log M*/M⊙<11.5
- GASS-low: 0.01< z<0.02, 9< log M*/M⊙<10.2
- Gas fraction limited: M_HI/M_* > 1.5%

http://xgass.icrar.org

xCOLD GASS: the extended CO Legacy Database for GASS
CO follow up of xGASS
IRAM large programs: ~950 hrs, ~500 galaxies (Saintonge+11, 17)

http://www.star.ucl.ac.uk/xCOLDGASS/

Deepest observations of cold gas in the local Universe
xGASS: the extended GASS survey

 Designed to probe from the gas-rich to the gas-poor regime
Atomic and molecular hydrogen scaling relations


HI and H$_2$ behave differently at low masses!
The physics is in the scatter!

Does the presence of a bulge affect the cold gas reservoir? (R. Cook’s PhD thesis at ICRAR/UWA)

Interesting outliers: a population of “red and dead” galaxies with a huge HI reservoir

Geréb, Catinella et al. (2016)
Gas scaling relations and galaxy models

SAMs

Hydro

Test subgrid physics in cosmological simulations
2. Exploiting HI-blind surveys with spectral stacking
Scaling relations with spectral stacking

- cosmic HI density up to $z\sim0.4$ (Lah+ 2007, 2009; Rhee+ 2013)
- gas scaling relations in nearby galaxies (Fabello+ 2011, Brown+ 2015, Meyer+ 2016)
- powerful technique to exploit HI-blind surveys well below their sensitivity limits
The gas fraction-stellar mass relation is a consequence of galaxy bimodality.
Gas and environment

SF quenching → need to know about the gas!

Gomez et al. (2003), SDSS

Peng et al. (2010)

HI-deficient galaxies in Virgo

Chung et al. (2009)
HI stripping across environments

~11,000 satellite galaxies binned by halo mass

Gradual decrease of gas content with group size (no threshold)
Reduction of gas fraction also at fixed sSFR.
HI removed faster than SF quenched → stripping!

Brown, Catinella, Cortese+ 2017
Comparison with models

Models reproduce slopes reasonably well, but galaxies are too gas poor, even in absence of cold gas stripping!
3. Beyond $z \sim 0$: exploring the very gas-rich Universe
Cold gas at z>0

H$_2$-rich disks at z~1-2 (CO on HST)

Saintonge et al. 2013

Tacconi et al. 2013

HI: 1 gal @ z=0.17, WSRT (Zwaan+ 01)
BUDHIES: 2 clusters at z~0.2 with WSRT, >1200 hrs (Yaffe’+ 2014)
CHILES: COSMOS field, z<0.5 with JVLA, 1000 hrs (Fernandez+ 2015)

Highest-z HI emission to date: z=0.37 (Fernandez+ 2016)
HIGHz Arecibo survey

- Selection: SDSS, Hα emission, exponential disk profile, isolated
- On-source integration time of **1-5 hr per object**; ~400 hrs
- Radio frequency interference (RFI) a serious challenge

- ~40 HI detections, 0.17 < z < 0.25
- Stellar mass > $10^{10} M_\odot$
- SFR = 3-35 $M_\odot$/yr

Catinella+ 2008, 2015

Catinella & Cortese 2015

H1ghMass: Huang+ 2014

Catinella+ 2008, 2015

Catinella & Cortese 2015

H1ghMass: Huang+ 2014
HIGHz Arecibo survey: ALMA data

Huge gas reservoirs:

\[ M(H_2) = 0.4 - 2 \times 10^{10} \, M_\odot \]
\[ M(HI) = 2 - 8 \times 10^{10} \, M_\odot \]

Regular, rotating disks, high \( V/\sigma \)

Cortese, Catinella + 2017
Galaxies up to $z \approx 0.2$ still HI-dominated

Cortese, Catinella + 2017

HIGHz doubled the number of galaxies with HI and H$_2$ at $z \approx 0.2$!
A few take-home messages

- **Cold gas** key to understand galaxies and their transformations, but **multi-wavelength info** (stellar masses, SFRs, environment…) also essential

- Deep observations of HI and H\textsubscript{2} from xGASS, xCOLD GASS providing **reference sample at z=0**

- Local (z<0.05) galaxies are HI-dominated; HI/H\textsubscript{2} varies by 2 orders of mag, scatter driven by HI variations. Galaxies at z~0.2 still HI-dominated (HIGHz)

- Some of the most interesting results coming from HI stacking:
  - when it comes to gas, M\textsubscript{*} is not king
  - evidence for HI depletion in groups at fixed M\textsubscript{*} and sSFR
SKA and its precursors will revolutionise HI astronomy:

✦ **unprecedented statistics** in the local Universe from all-sky, shallow surveys
✦ **evolution of HI with cosmic age** from deep surveys