Unravelling Atomic ISM Physics Across the Local Group

Eric Koch

SMA Postdoctoral Fellow

Erik Rosolowsky, Adam Leroy, Jonathan Braine, Jeremy Chastenet, I-Da Chiang, Julianne Dalcanton, Megan Johnson, Amanda Kepley, Jay Lockman, Snezana Stanimirovic, Andreas Schruba, Karin Sandstrom, Dyas Utomo, Tom Williams

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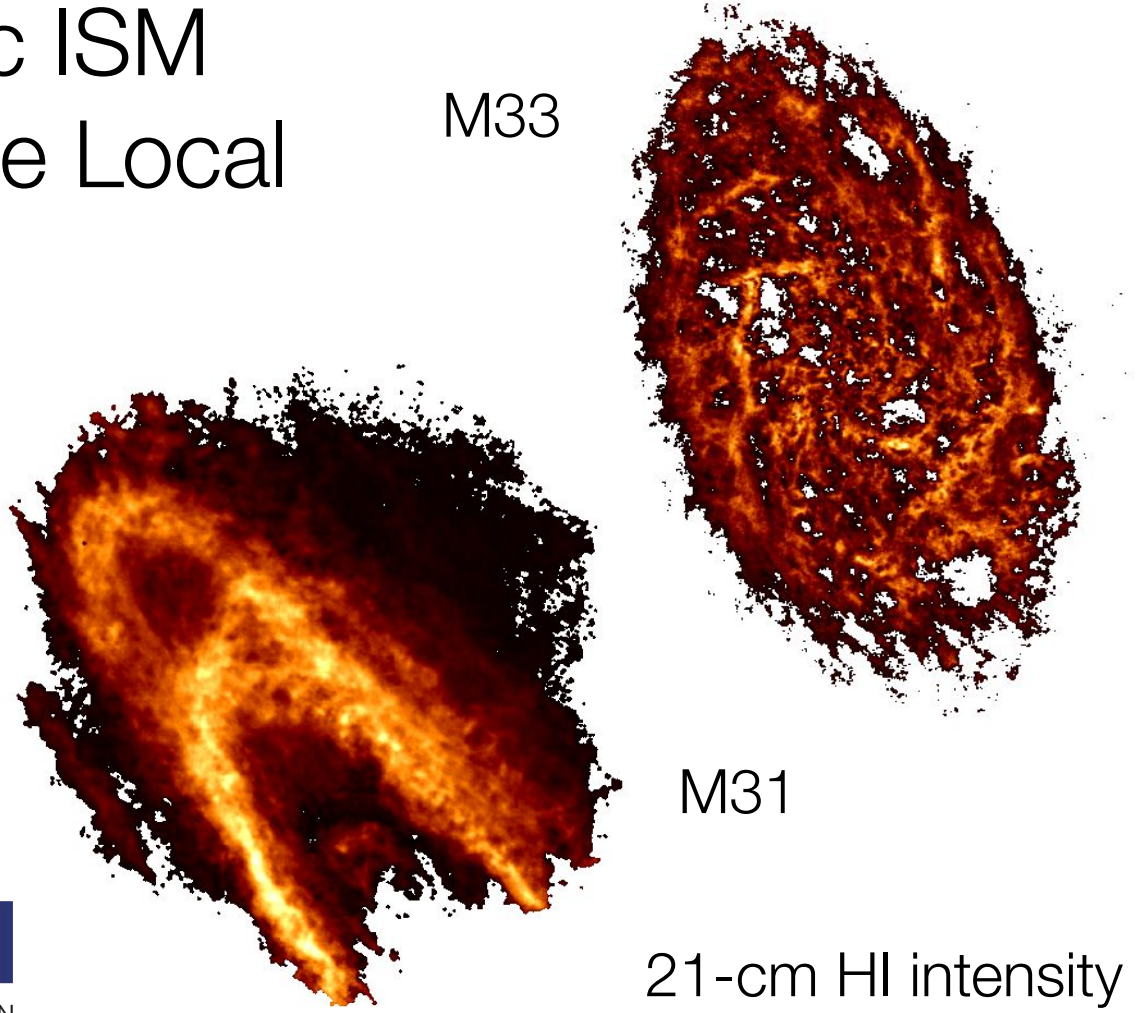
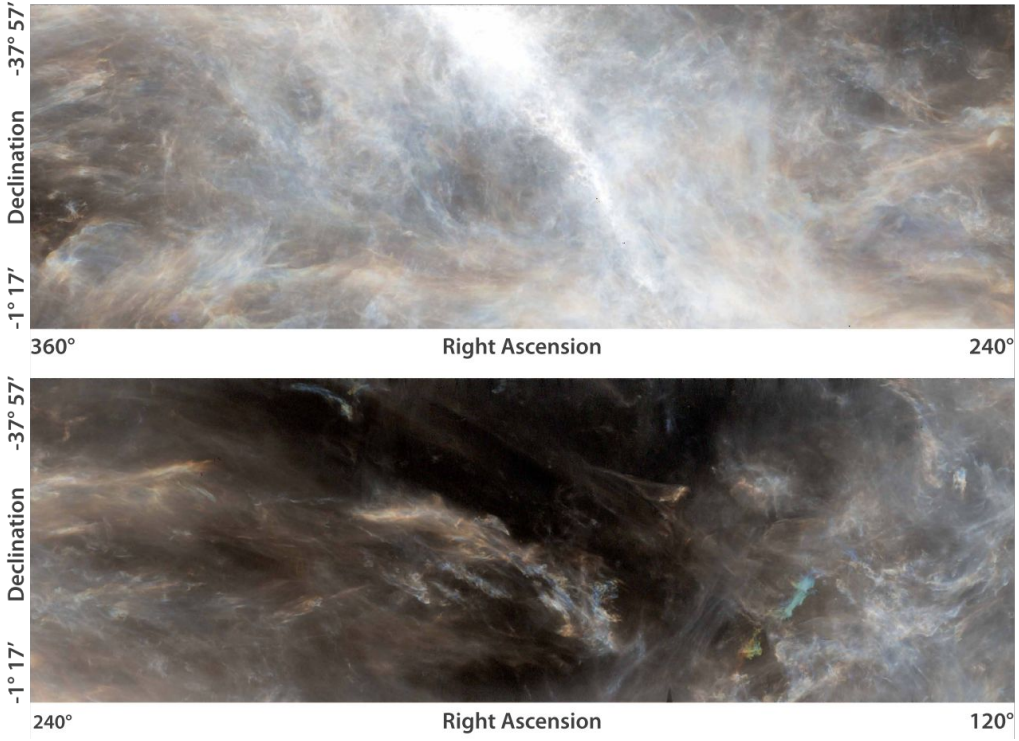
HARVARD & SMITHSONIAN

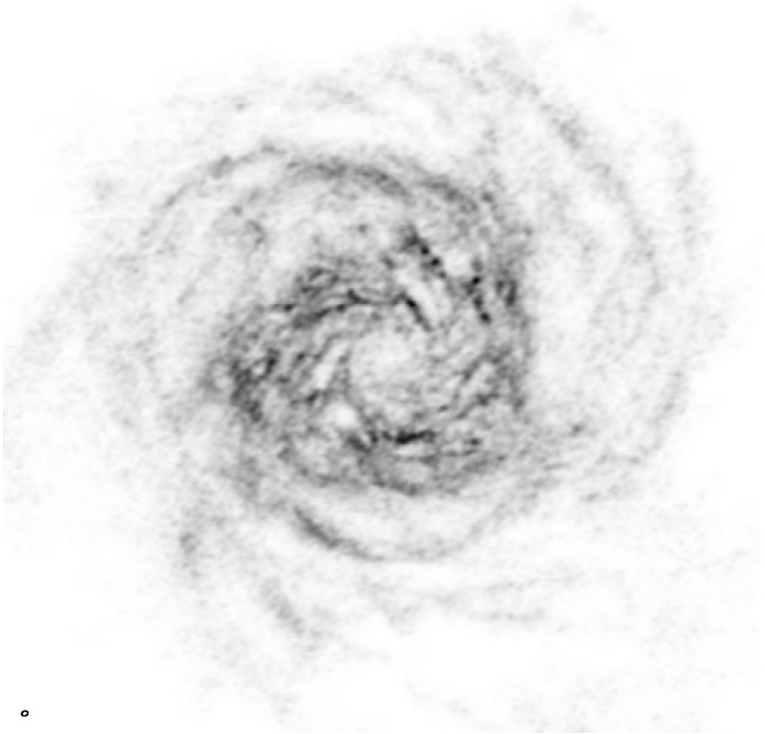


Galactic HI



(GALFA DR2; Peek+2018)

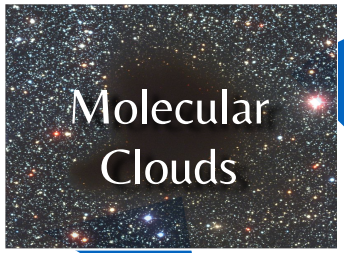
Extragalactic HI (NGC 628)



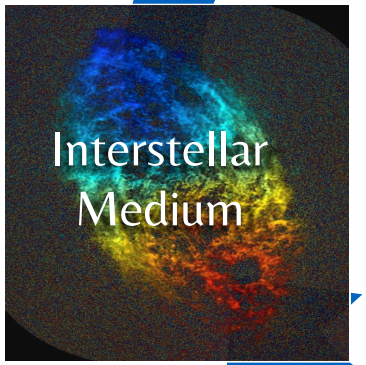
(THINGS; Walter+2008)

The galactic ecosystem

Photo Credits: R. Gendler, the FORS Team, D. Malin, SAO/Chandra, D. Thilker



Low-mass stars

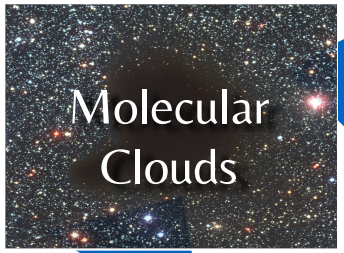


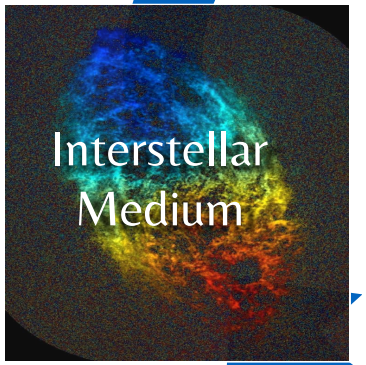
Galaxy accretion

Galaxy winds & outflows

Many processes affect the atomic ISM

Photo Credits: R. Gendler, the FORS Team, D. Malin, SAO/Chandra, D. Thilker



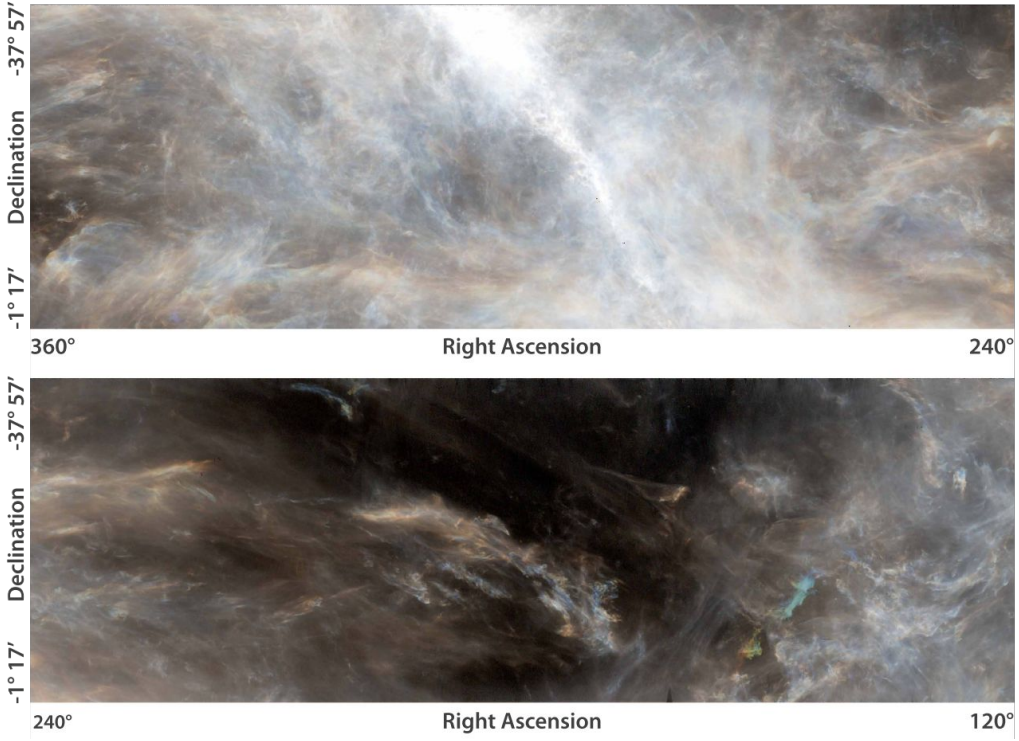


Each process contributes to 21-cm HI line observations

Galaxy accretion

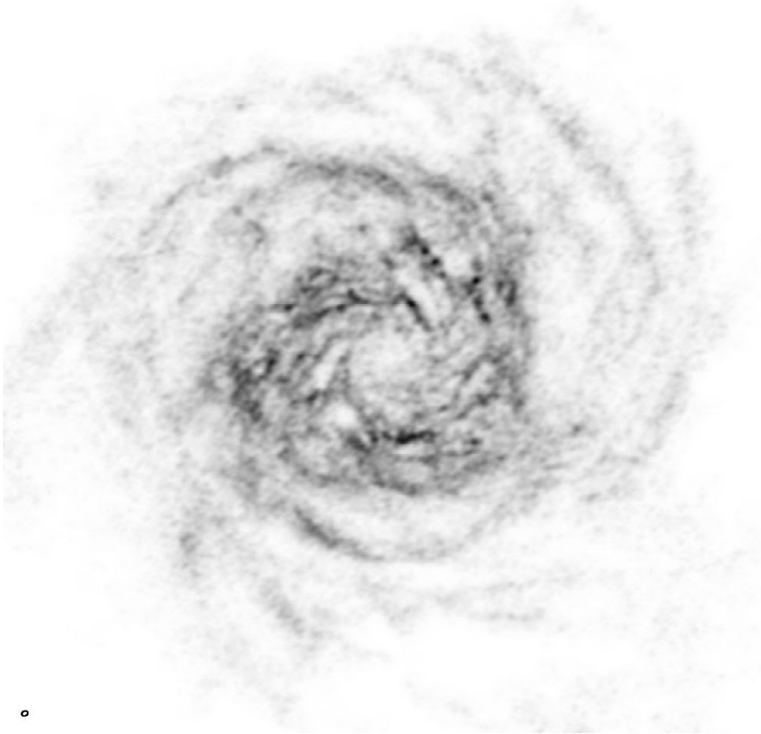
Galaxy winds & outflows

Galactic HI



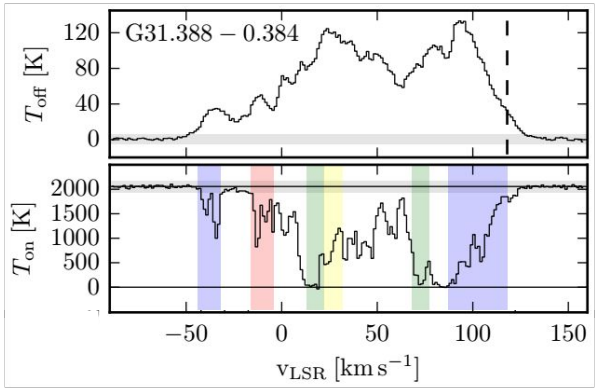
(GALFA DR2; Peek+2018)

Extragalactic HI (NGC 628)



(THINGS; Walter+2008)

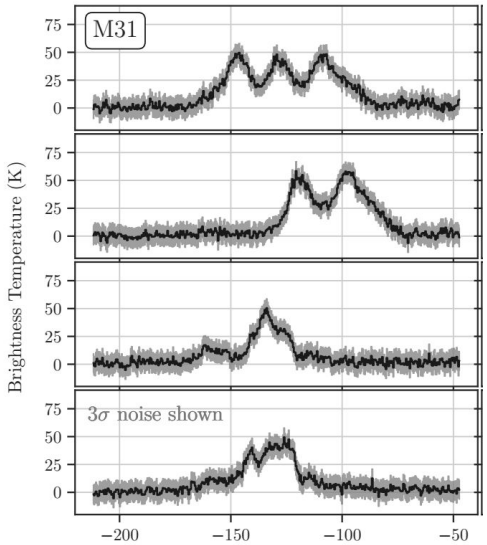
Spectrally sharpening our view of the atomic ISM

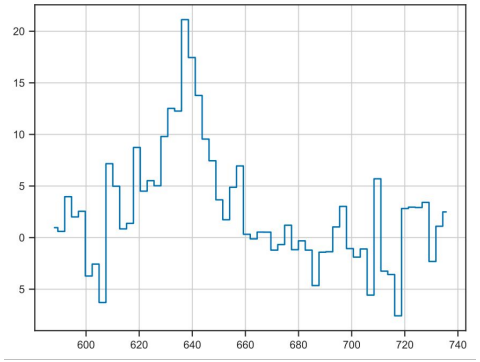


Milky Way ~pc scales

VLA THOR (Bihr+2016)

Local Group (<1 Mpc)
>20 pc scales





Nearby galaxies (<10 Mpc)
>200 pc scales

VLA THINGS (Walter+2008)

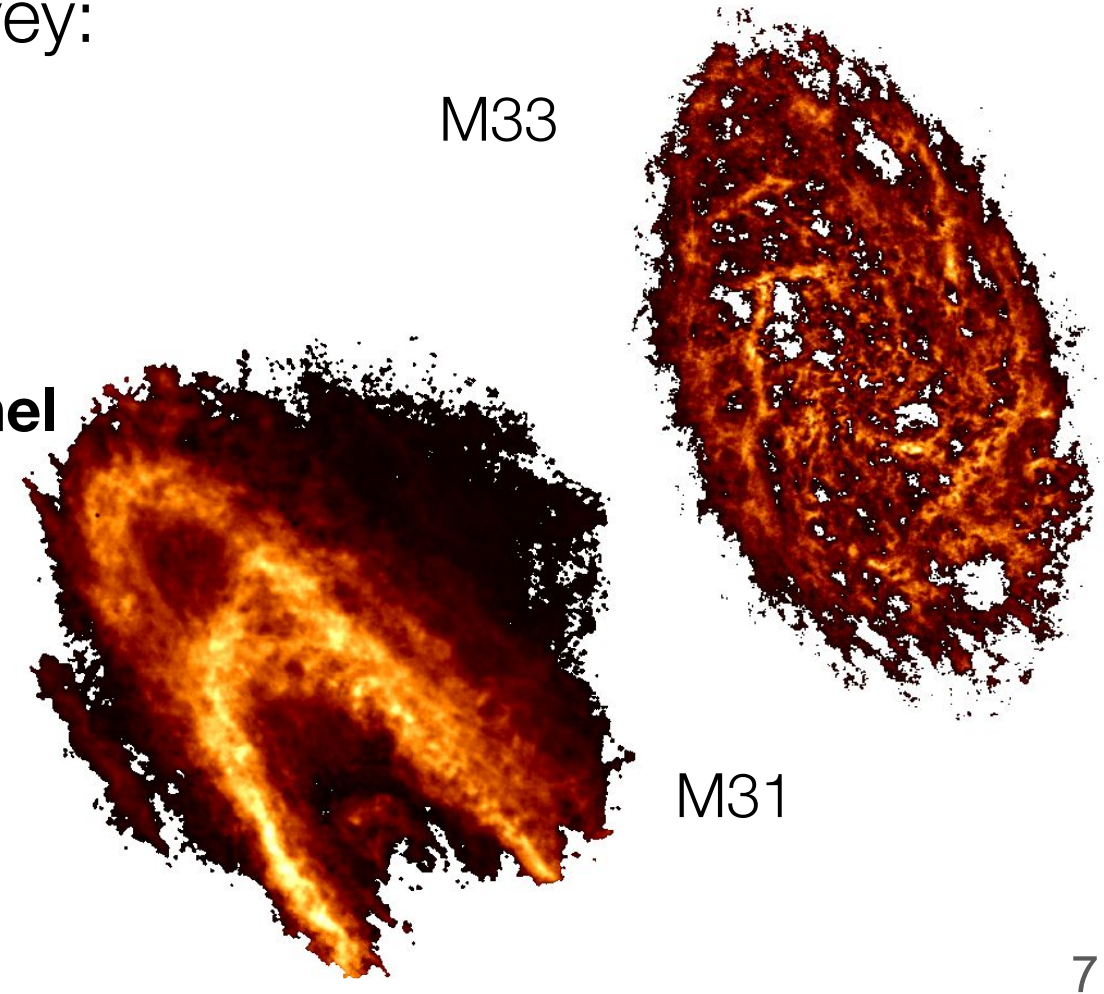
VLA Local Group Survey: Initial Observations

~80 pc spatial resolution

0.4 km/s spectral resolution

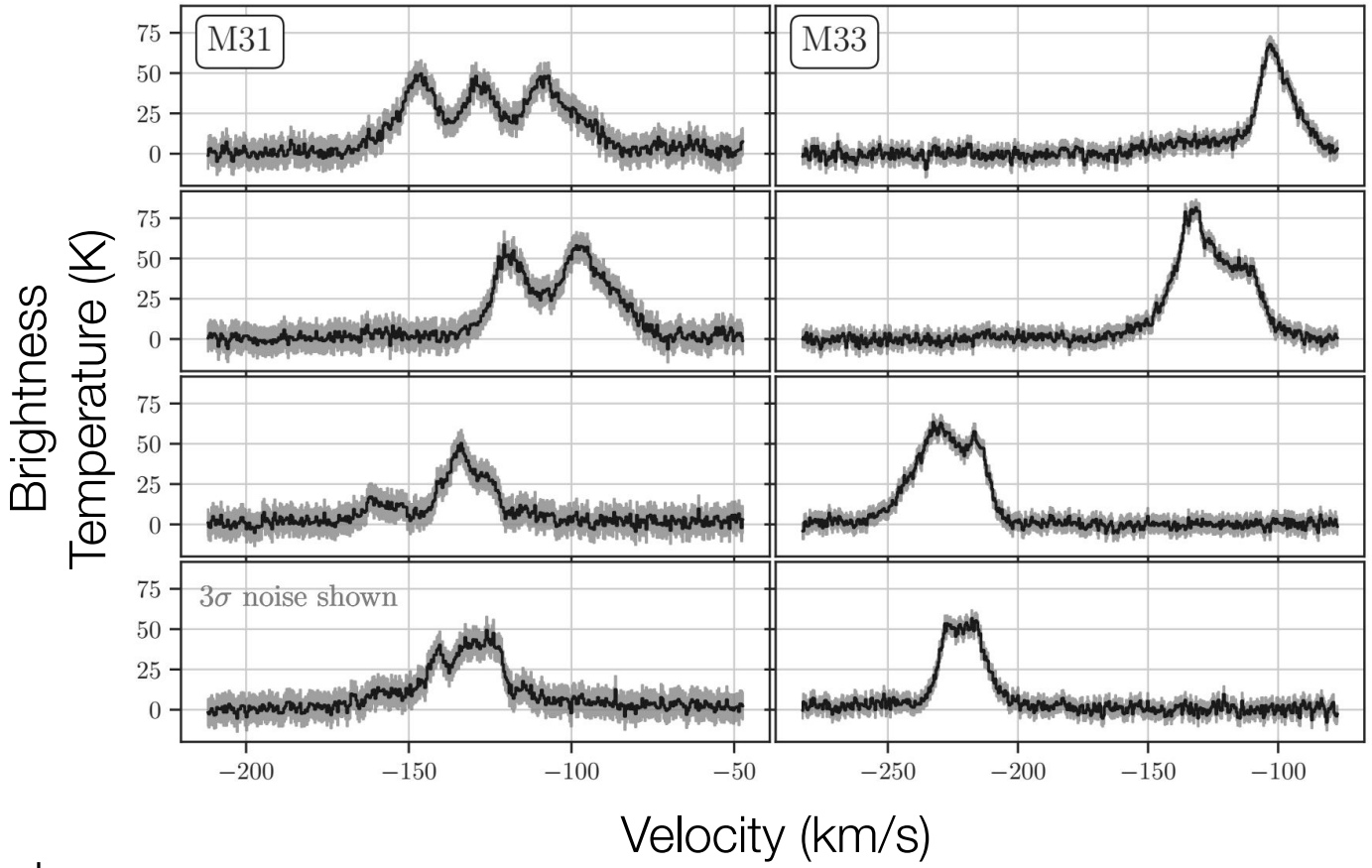
5σ=1x10^{19} cm^{-2} per channel

GBT/EBHIS short-spacing



Koch+2018, 2021

Ubiquitous HI spectral complexity on 80 pc scales

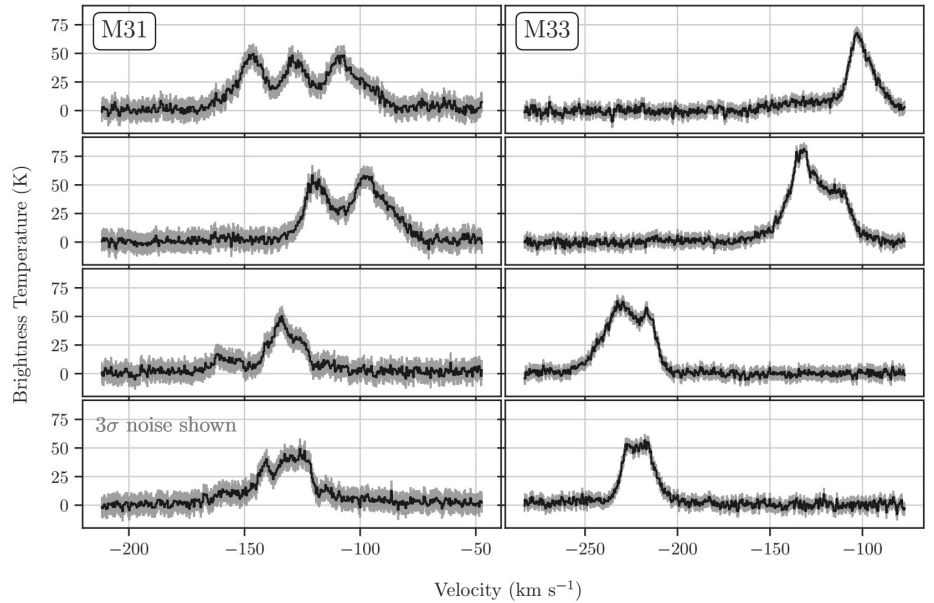


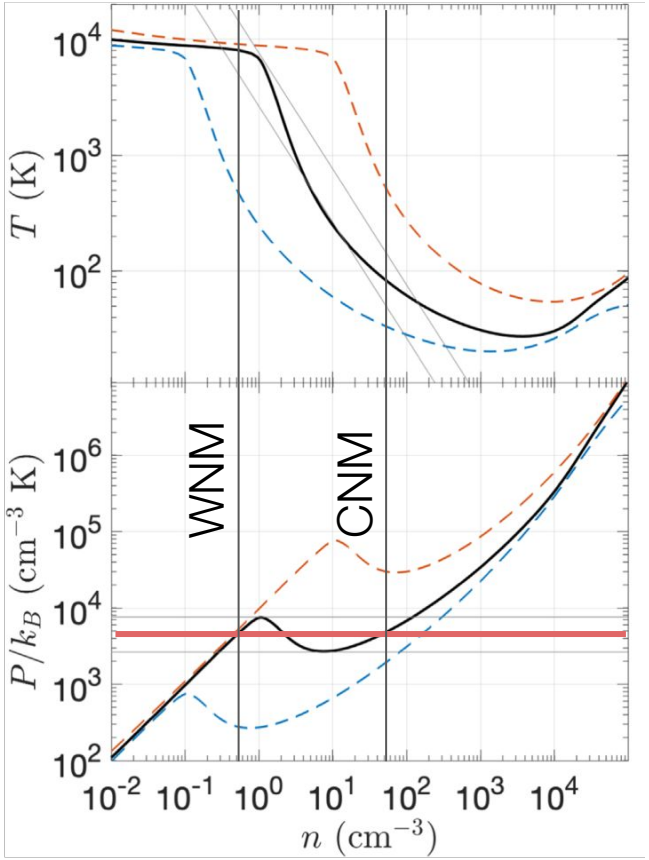
Koch+18, 21

What are we learning from complex HI spectra?

1. Where is cold, opaque HI? How much mass is there?

2. Which atomic gas is associated with molecular clouds?





Where is cold, opaque HI?

Two-phase atomic ISM model.

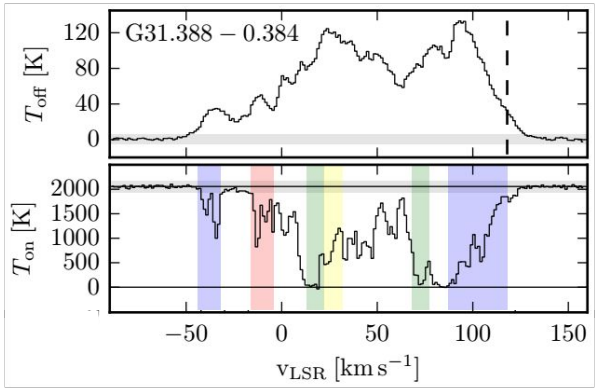
Warm Neutral Medium (WNM) remains optically-thin.

Cold Neutral Medium (CNM) likely becomes optically-thick.

Accurate atomic ISM masses need to account for HI line opacity.

(Bialy & Sternberg 2019)

Galactic HI



Emission: warm *and* cold

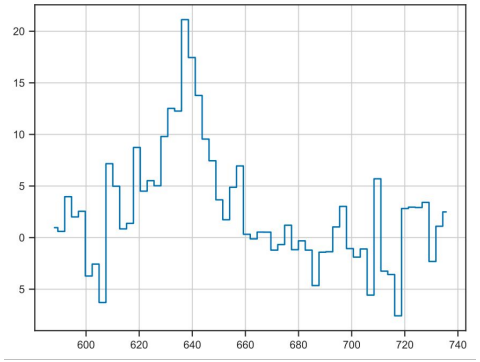
Absorption: cold

Ensemble of clouds along line-of-sight. Model for line opacity.

(THOR; Bihr+2015)

We know extragalactic atomic ISM masses are underestimated.

Extragalactic HI (NGC 628)



Velocity (km/s)

Volume-filling gas with non-thermal motion. Assume optically-thin.

(THINGS; Walter+2008)

Are complex HI spectra due to opaque, cold atomic gas? Braun+09,12

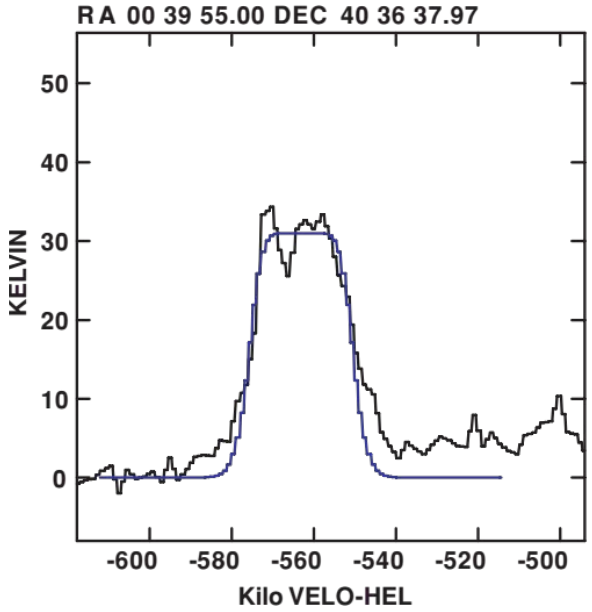
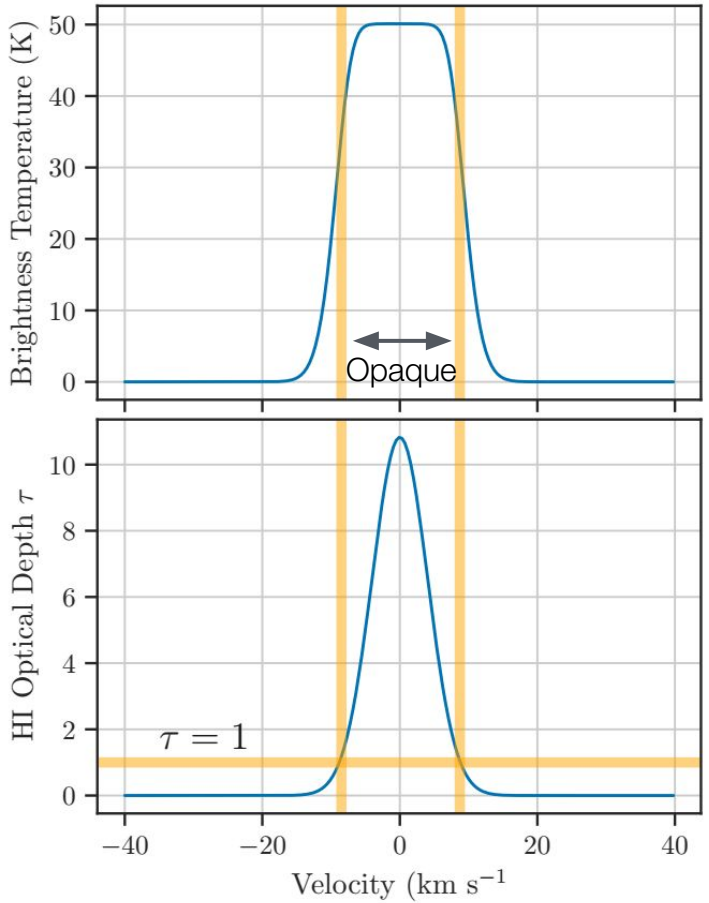
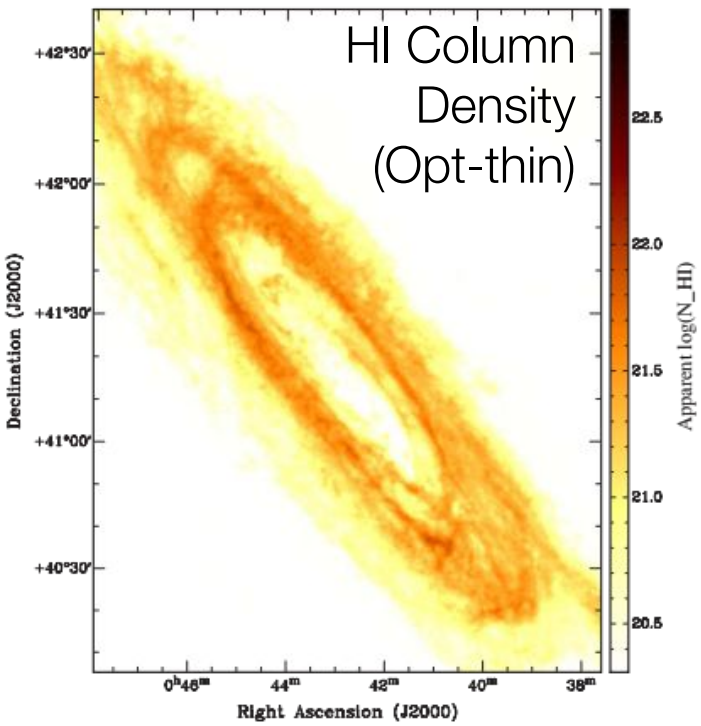
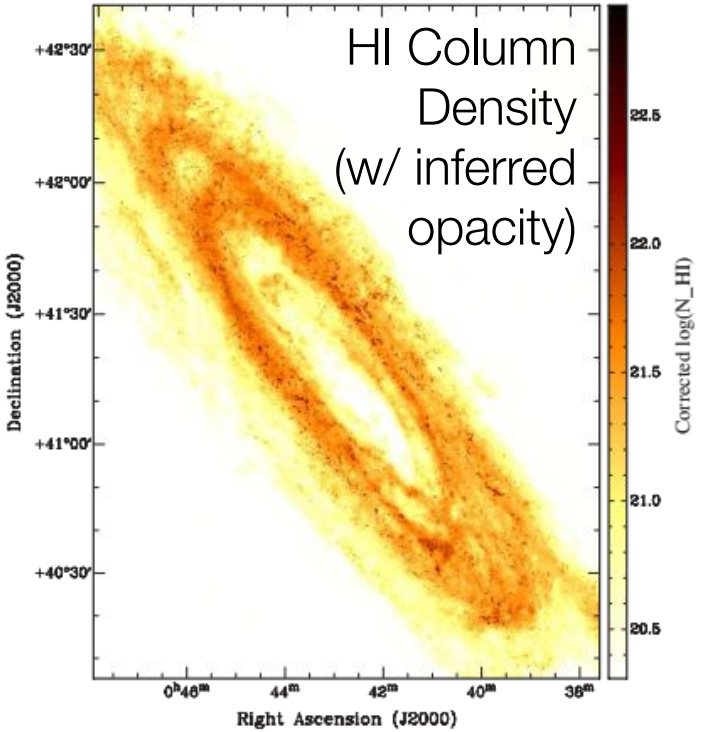


Figure from Braun+09



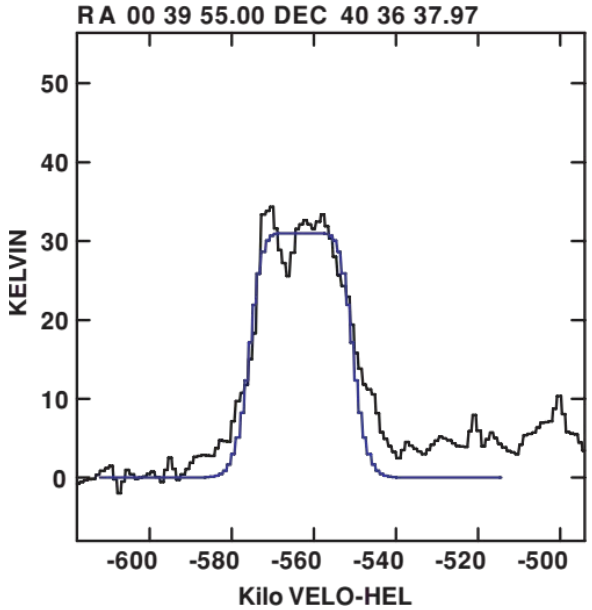
Are complex HI spectra due to opaque, cold atomic gas? Braun+09,12



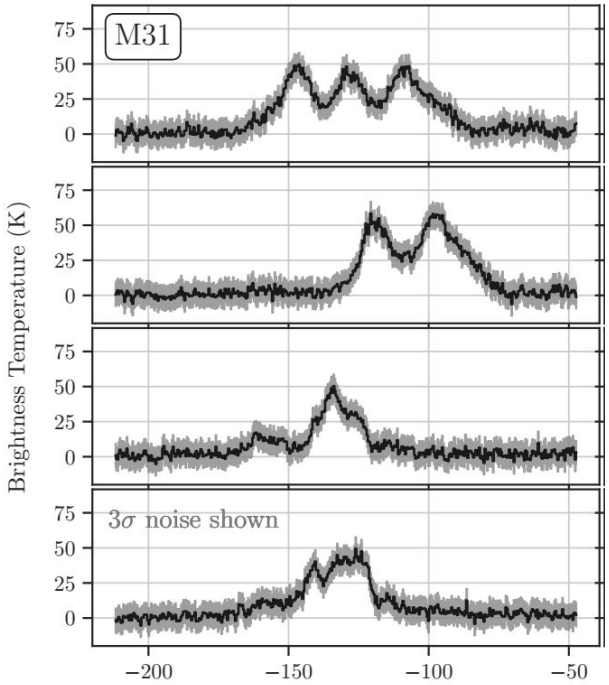


Infer **35%** of HI mass is missing.

Opaque “top-hats”? Or blended components?



From Braun+09



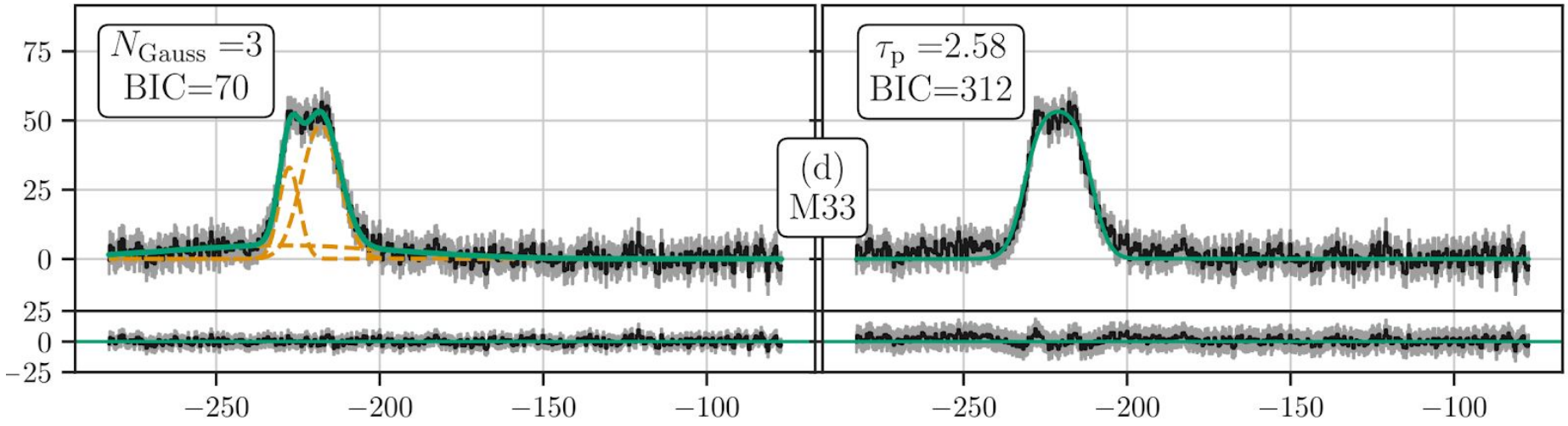
Koch+2021

Also see: Rohlfs+1972; Peek+2011

Model test: opaque vs. multi-component Gaussian

Multi-Gaussian

Opaque single-component

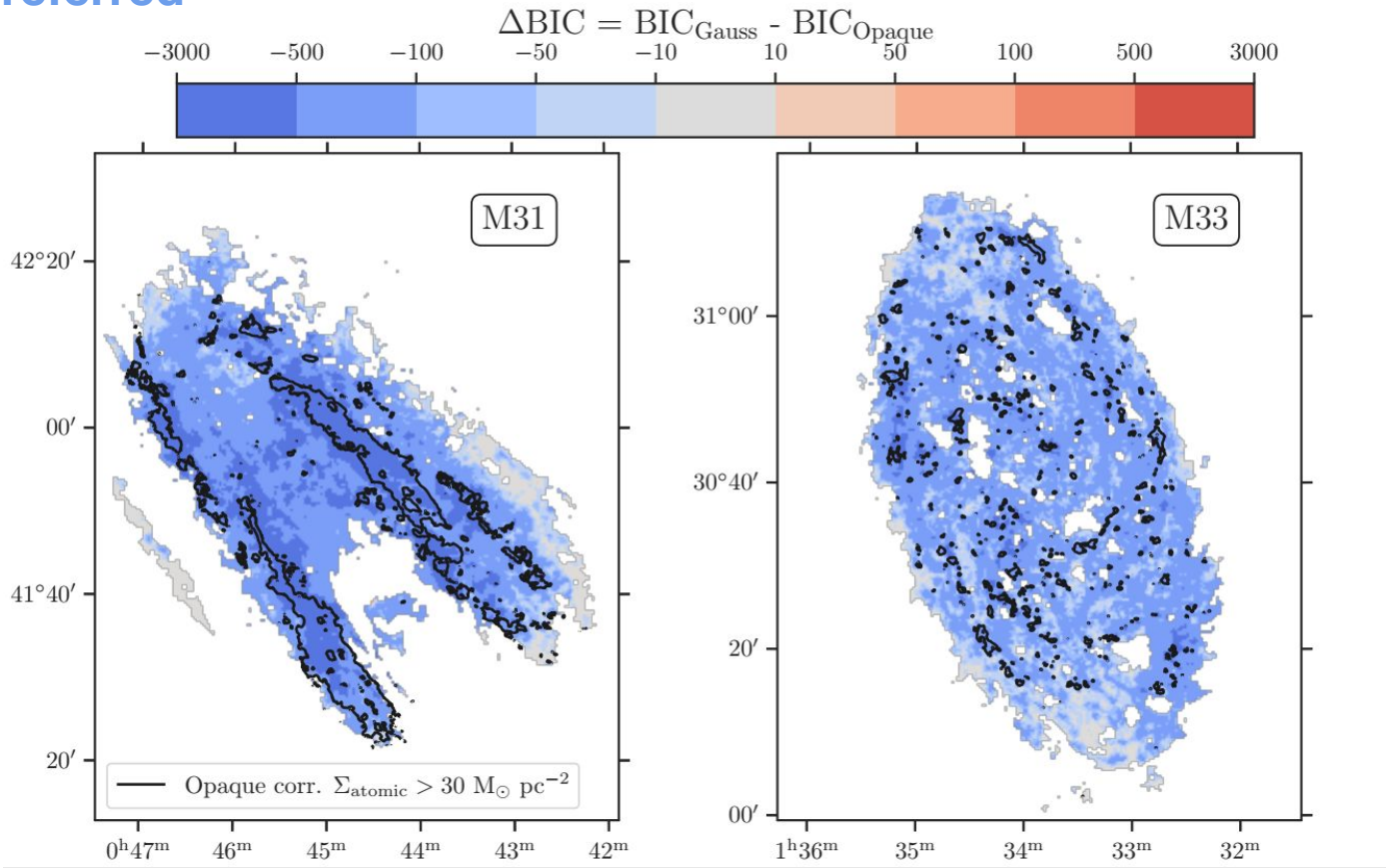


GaussPy (Lindner+15)

Preferred model has the smaller BIC statistic.

Multi-component model preferred

Opaque model preferred



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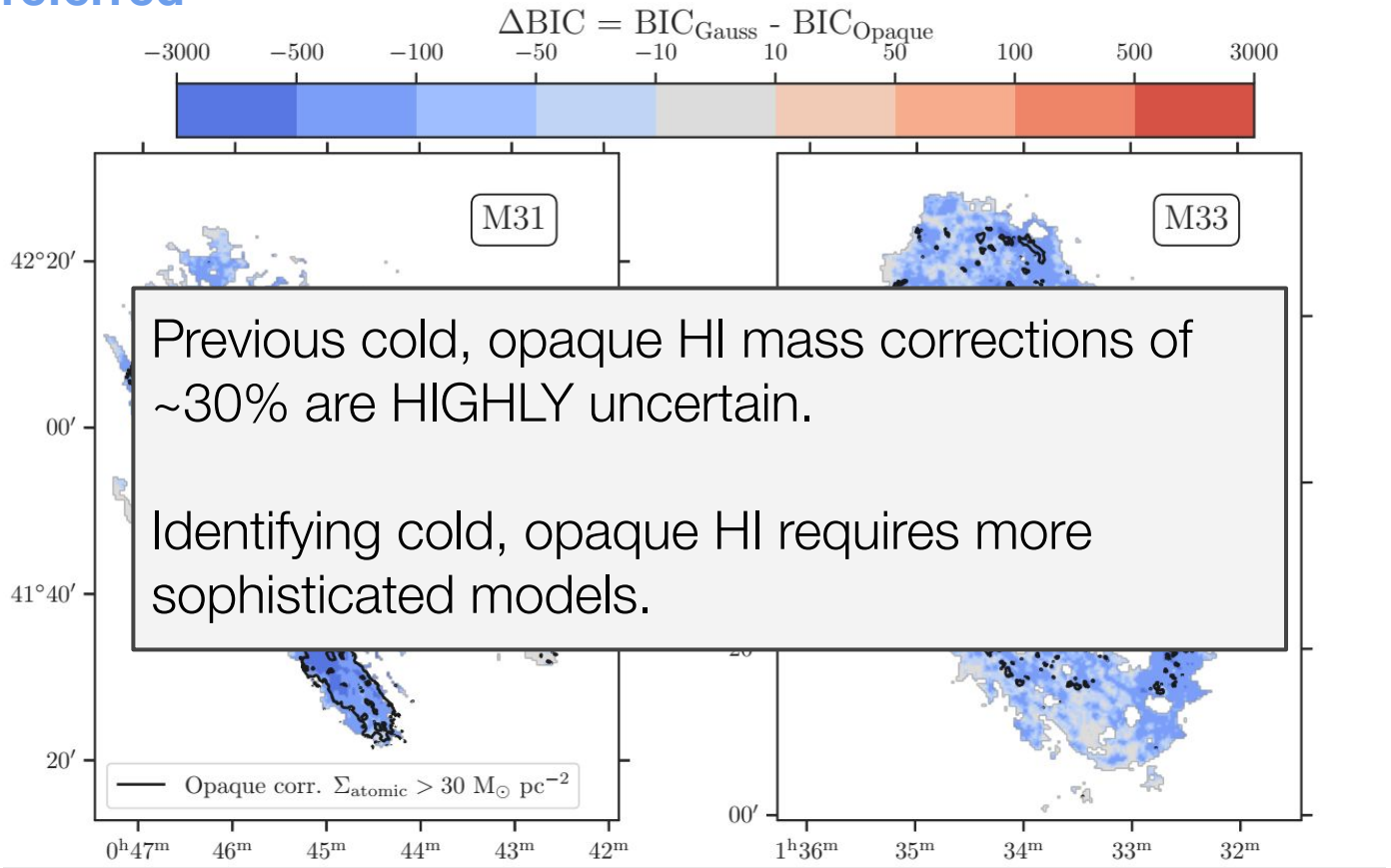
Koch+2021

Multi-component model preferred

Opaque model preferred



Previous cold, opaque HI mass corrections of ~30% are HIGHLY uncertain.

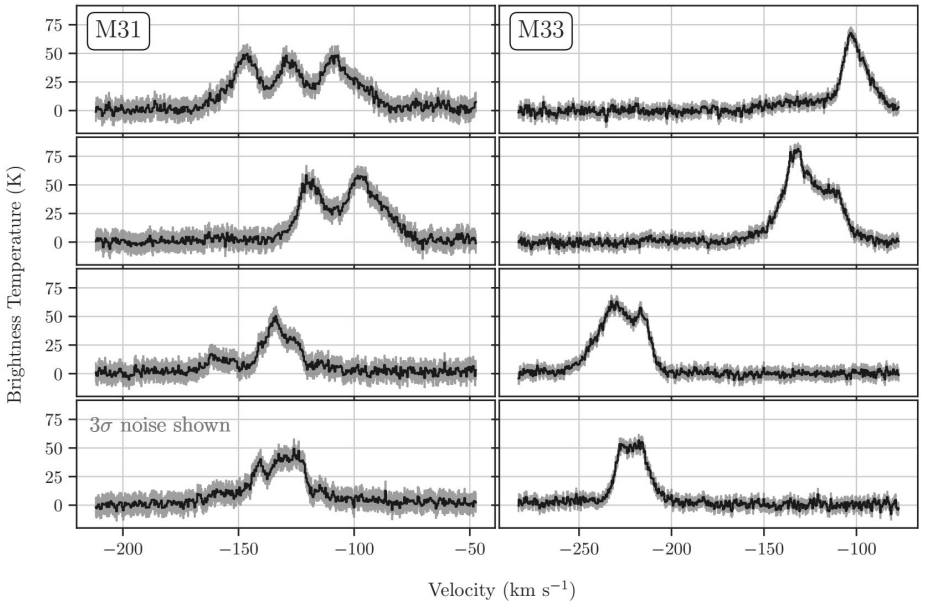
Identifying cold, opaque HI requires more sophisticated models.

What are we learning from complex HI spectra?

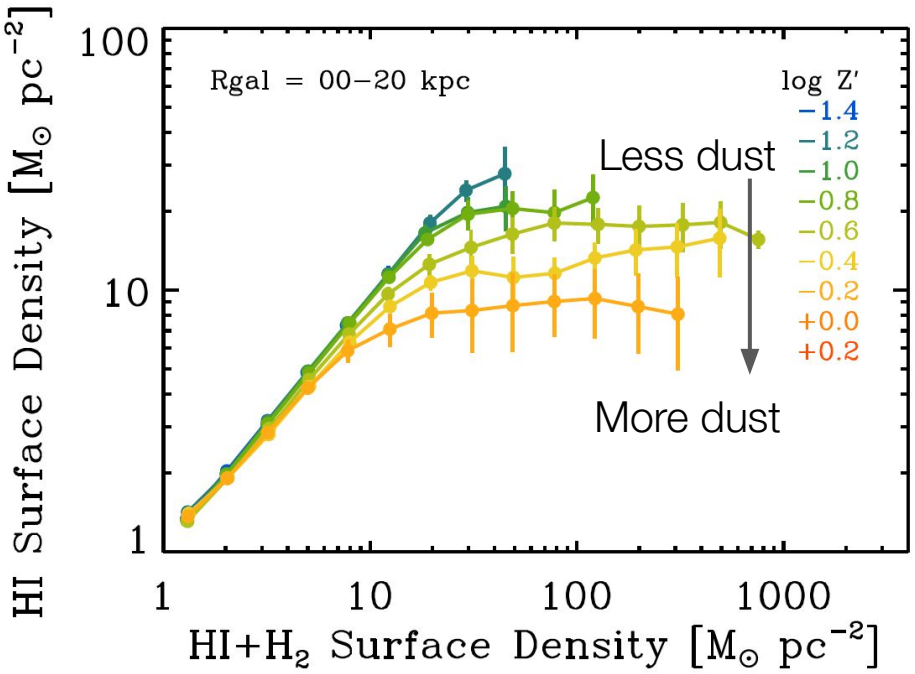
1. Where is cold, opaque HI?
   How much mass is there?

Requires improved modeling.

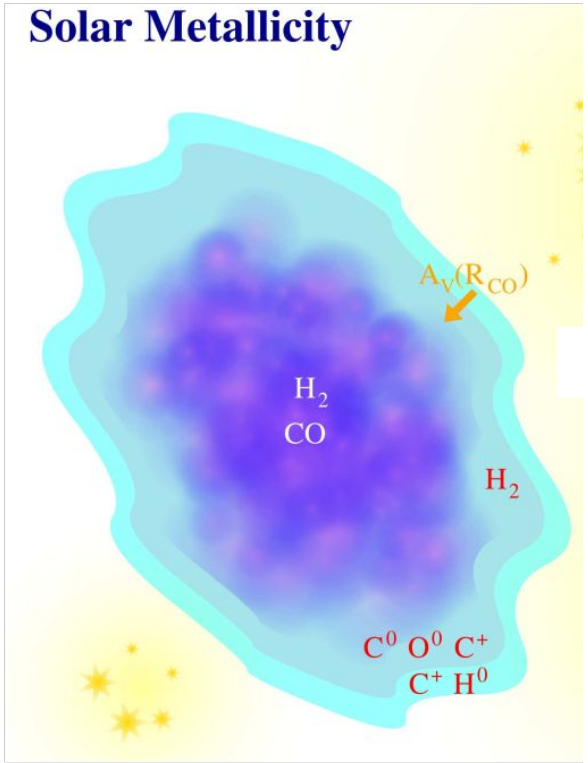
2. Which atomic gas is associated with molecular clouds?



70 nearby galaxies on 100s pc scales



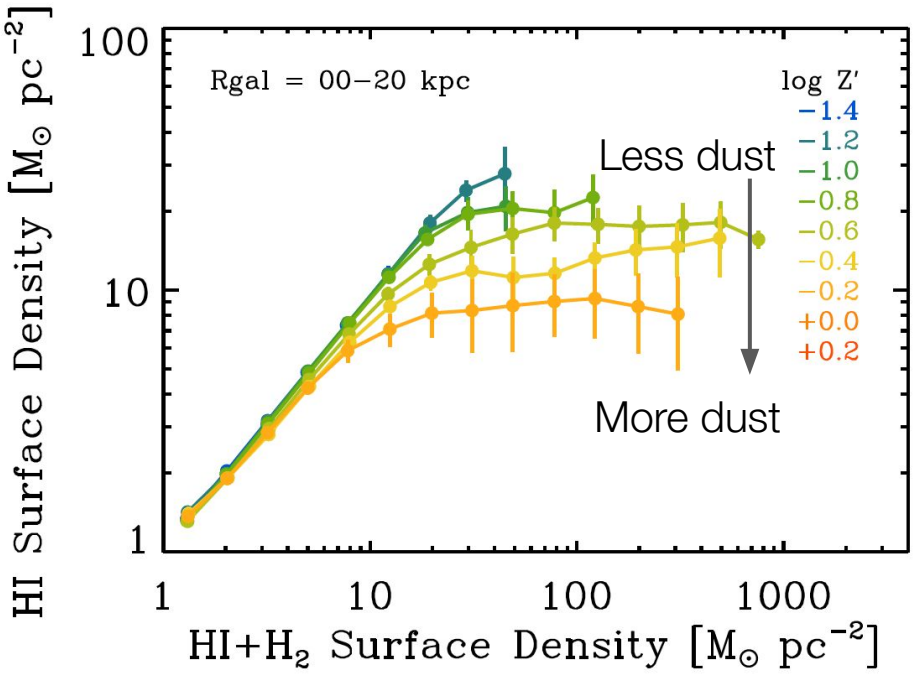
Schruba+2018



From Madden+2020

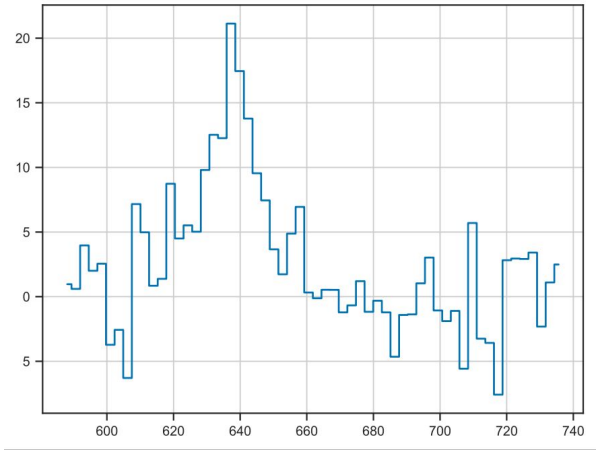
See also Krumholz+2009,2013; Ostriker+2011; Sternberg+2014 and more

70 nearby galaxies on 100s pc scales



Schruba+2018

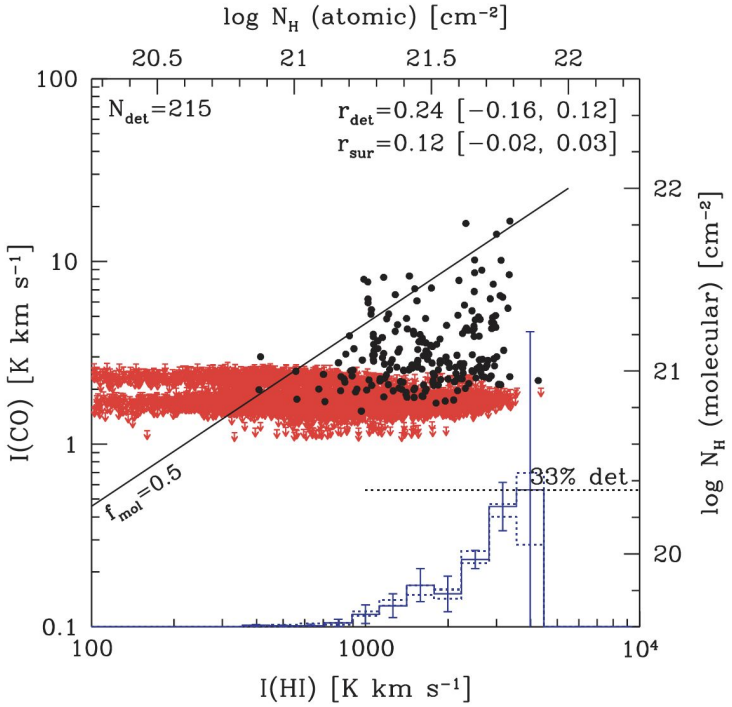
Extragalactic HI (NGC 628)



(THINGS; Walter+2008)

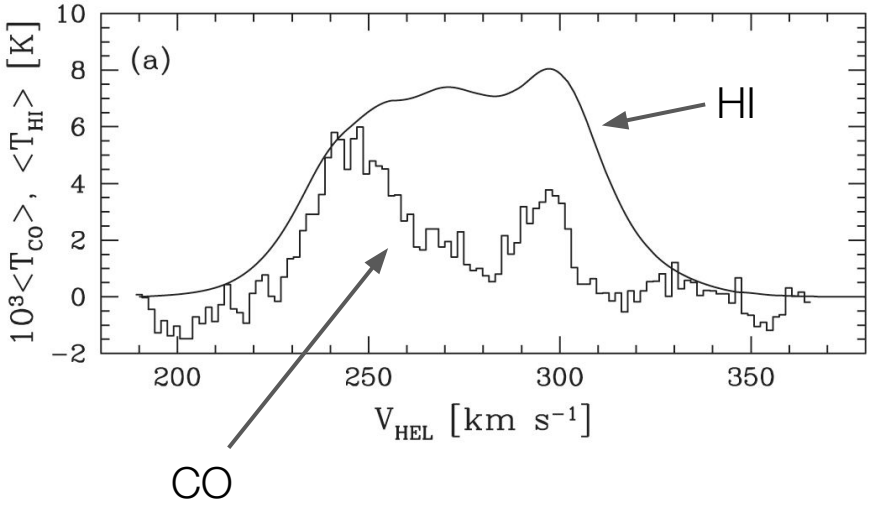
Is *all* HI associated with H_2?

HI and CO in the LMC at 30 pc scales

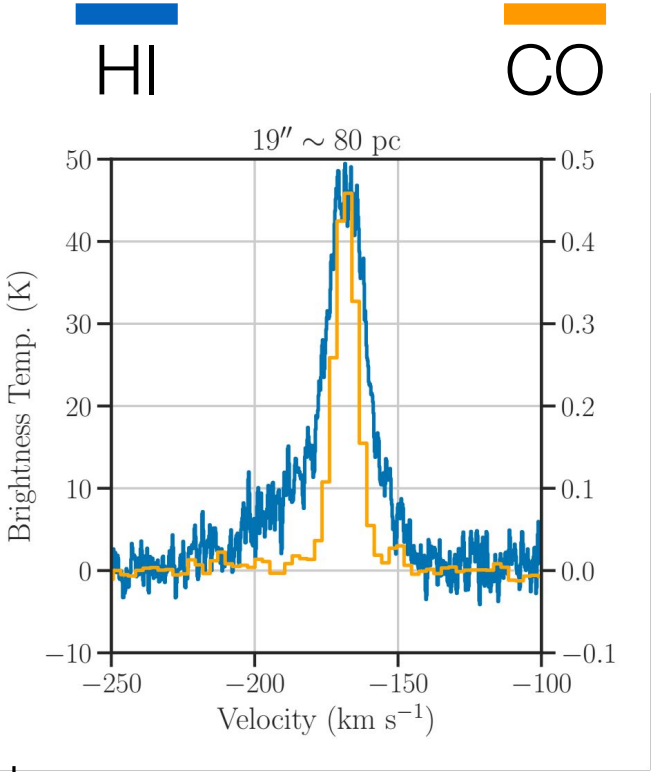


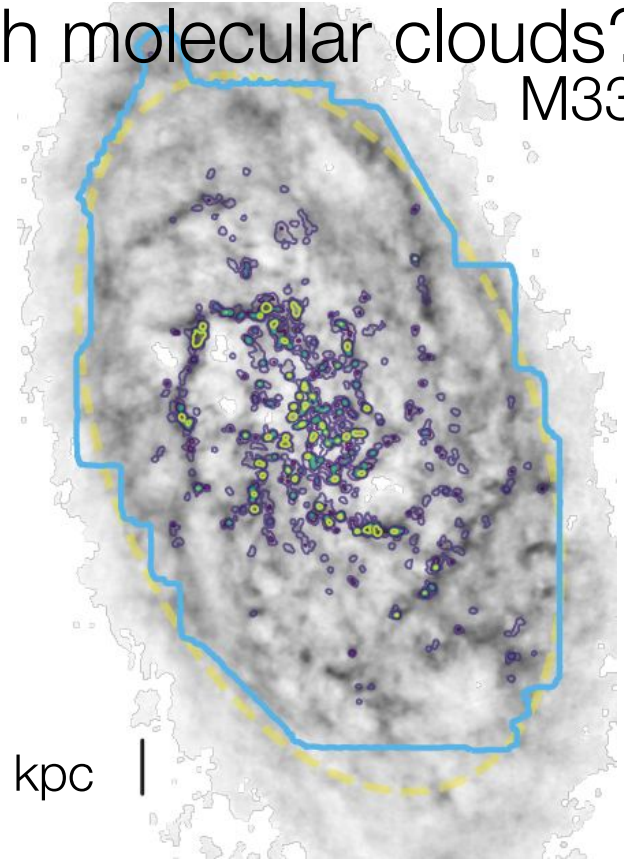
Wong+2009; Fukui+2009

Averaged HI and CO LMC spectrum



Which atomic gas is associated with molecular clouds?





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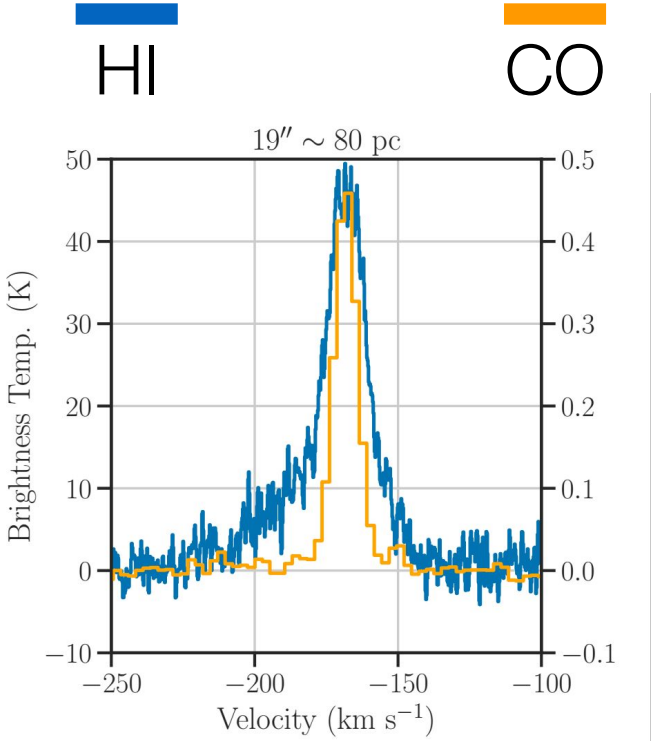
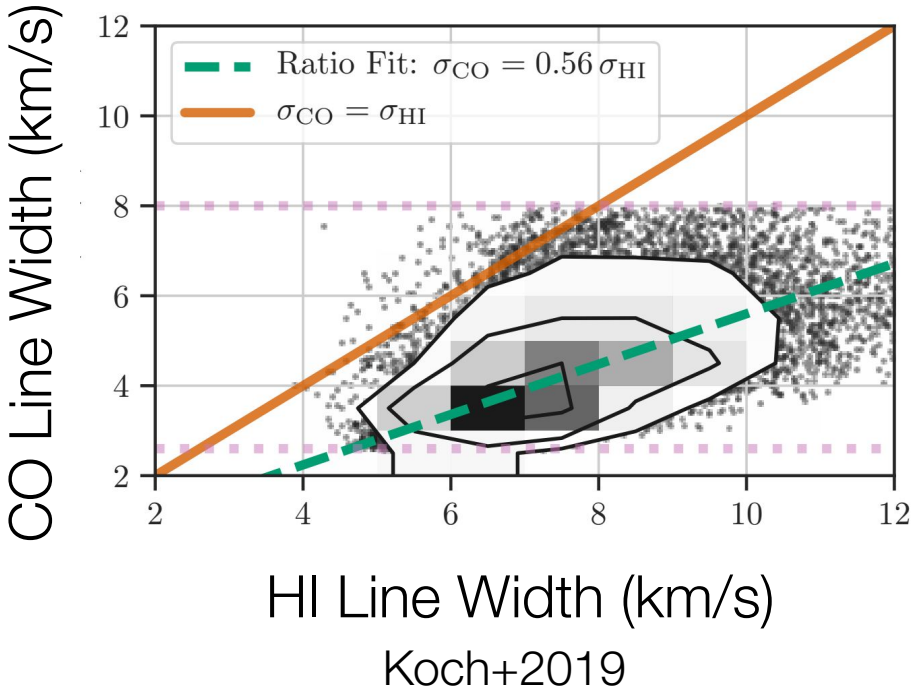
Koch+19

CO from Druard+14

Strong line width correlation using HI assoc. with CO

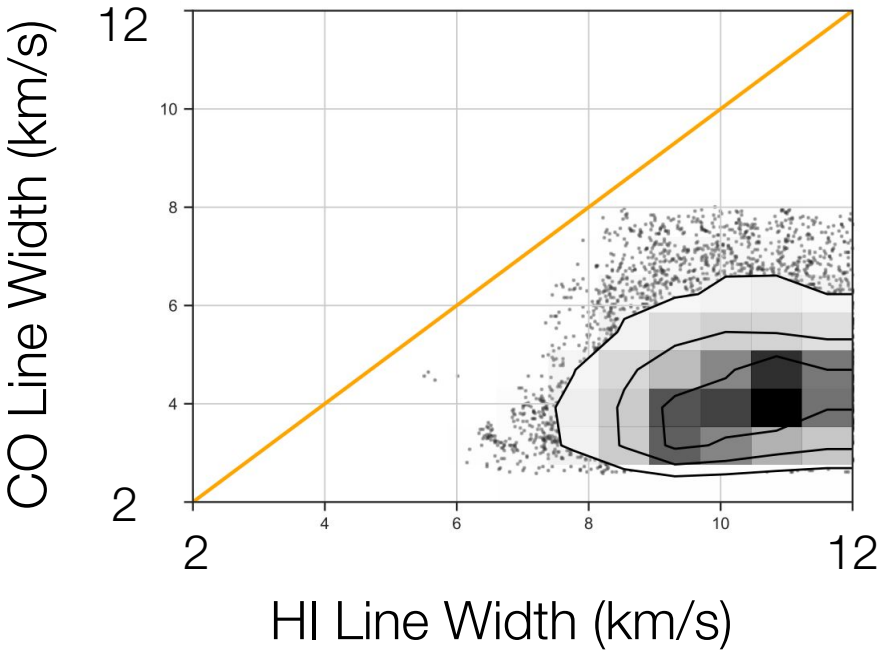




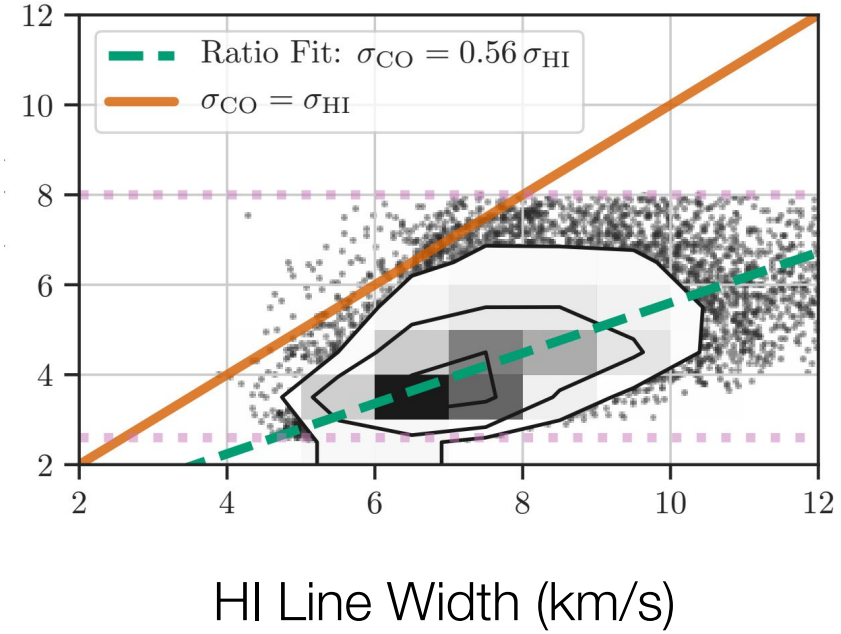
Koch+2019

LMC: Wong+2009; Fukui+2009

Using whole HI spectrum



Using single HI component



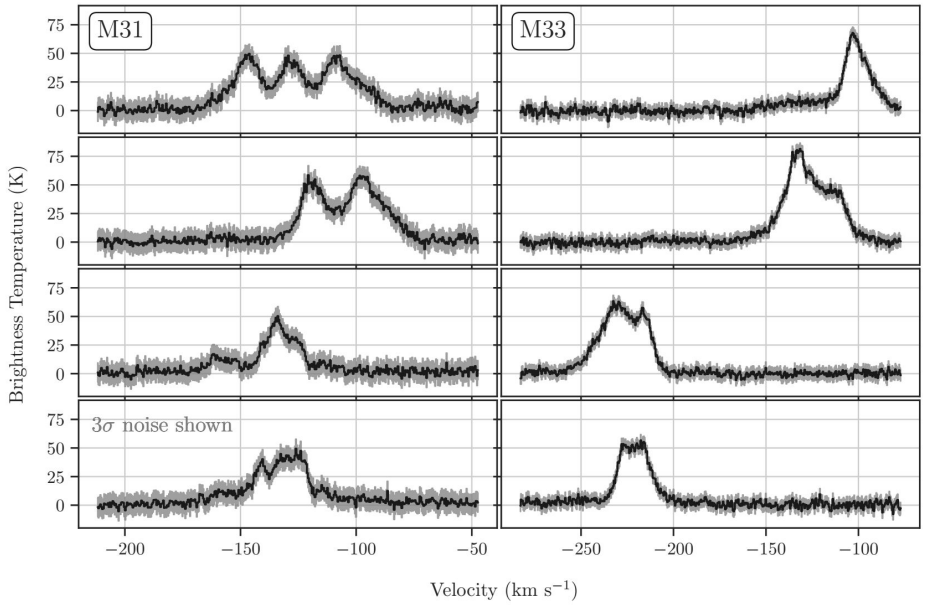
What are we learning from complex HI spectra?

1. Where is cold, opaque HI? How much mass is there?

Requires improved models.

2. Which atomic gas is associated with molecular clouds?

HI and CO *components* strongly linked.

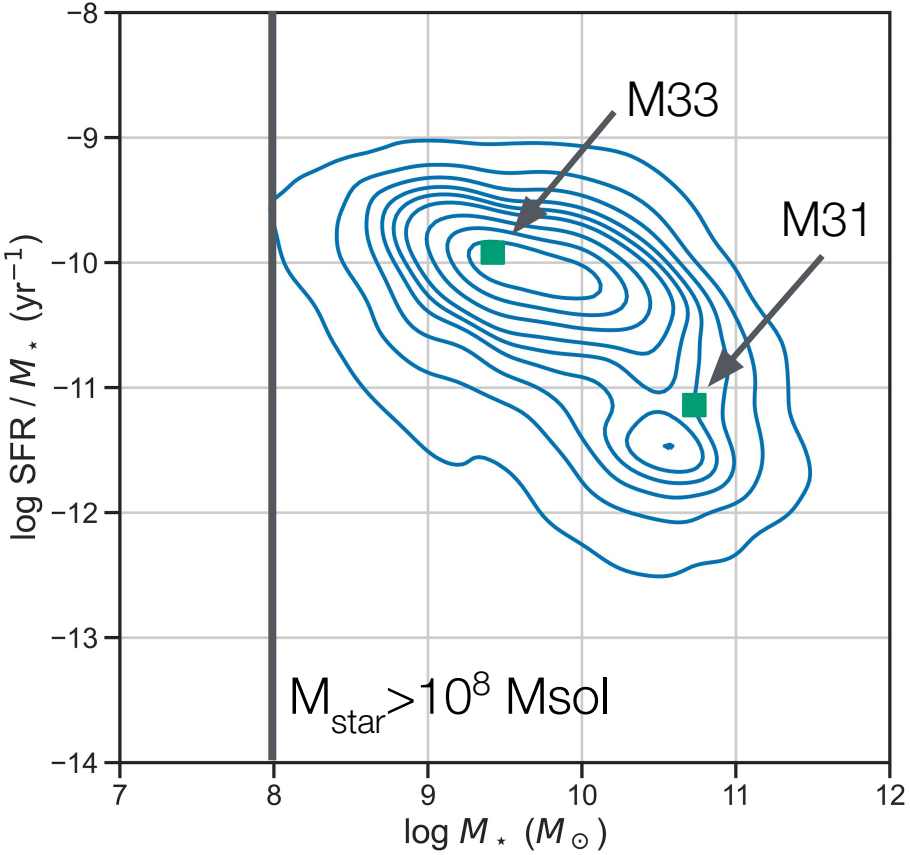


SKA-mid & ngVLA: Atomic ISM physics across the SFMS

D<1 Mpc

20” ~ 100 pc

2 galaxies



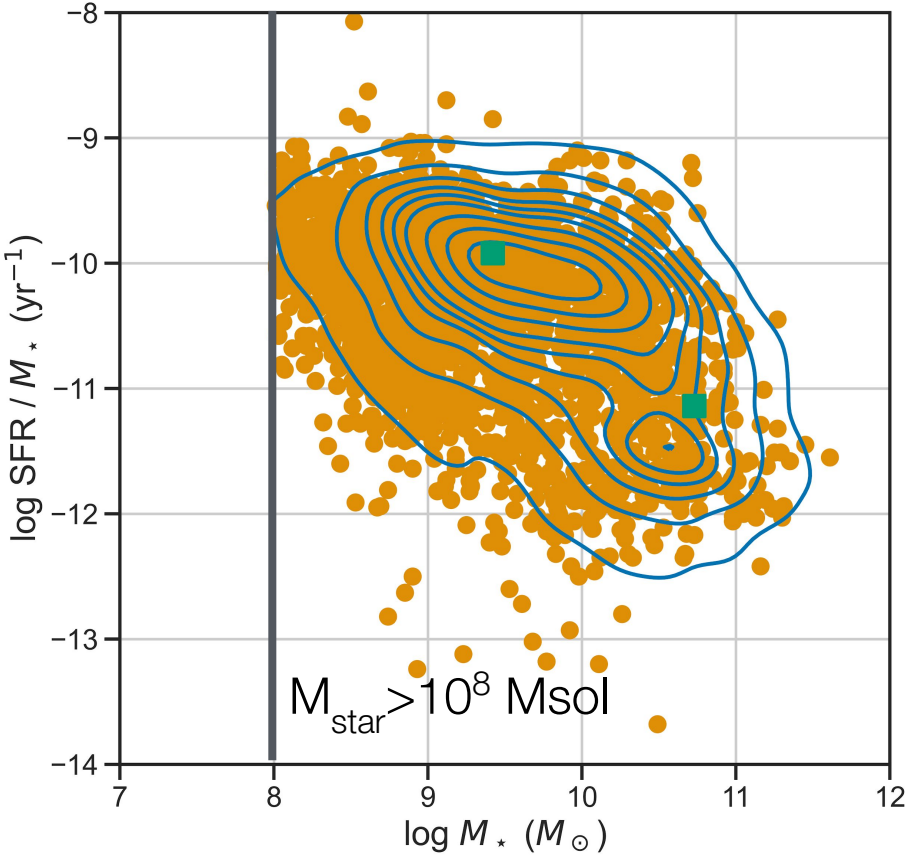
z0mgs
WISE+GALEX
Leroy+2019

SKA-mid & ngVLA: Atomic ISM physics across the SFMS

D<25 Mpc

0.8” ~ 100 pc

~2000 galaxies



z0mgs
WISE+GALEX
Leroy+2019

Unravelling Atomic ISM Physics Across the Local Group

- 21-cm HI traces many processes. Modeling complex HI spectra *sharpens* our view of the atomic ISM.
- Simple cold, opaque HI models cannot capture this complexity: previous mass estimates cannot be trusted.
- HI and CO components are more strongly linked compared to the entire line-of-sight.

CENTER FOR ASTROPHYSICS
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Eric Koch

koch.eric.w@gmail.com