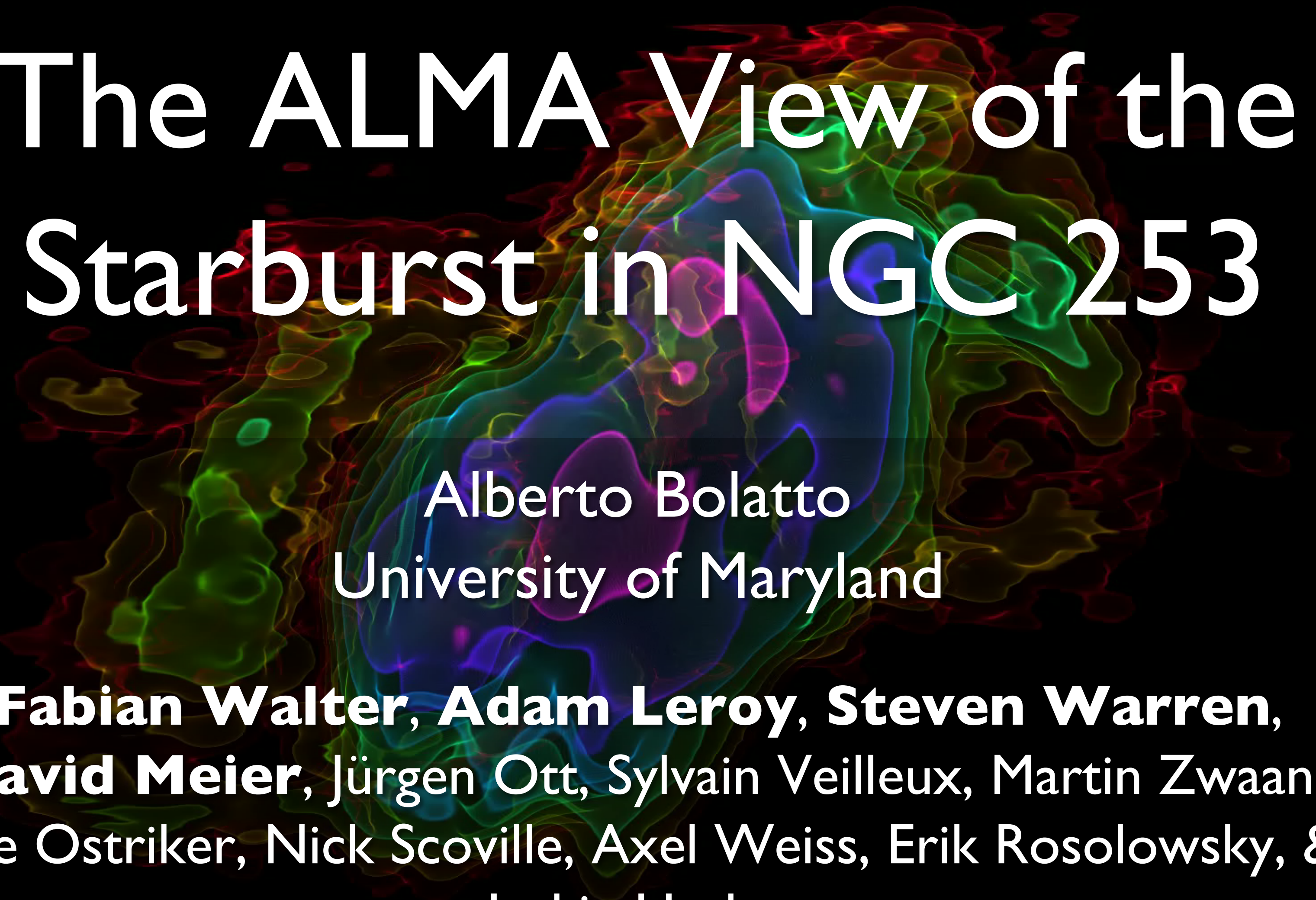
The ALMA View of the Starburst in NGC 253



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Outline

- Motivation: why is this interesting?
  - Relevant "KS" questions
  - Nuclear starbursts offer a prototype for processes at work in young "main sequence" z~1-2 galaxies (e.g., Tacconi+ 2013)
- ALMA's view of the dense ISM in NGC 253 (Leroy+ submitted)
- ALMA's view of the resolved spectroscopic complexity in NGC 253 (Meier, Walter+, submitted)
- ALMA's view of the wind in NGC 253 (Bolatto, Warren+ 2013, Nature)

Evolution of the Interstellar Medium and Star formation over Cosmic Time

a) Is there a common Schmidt-Kennicutt law at all redshifts and all scales?

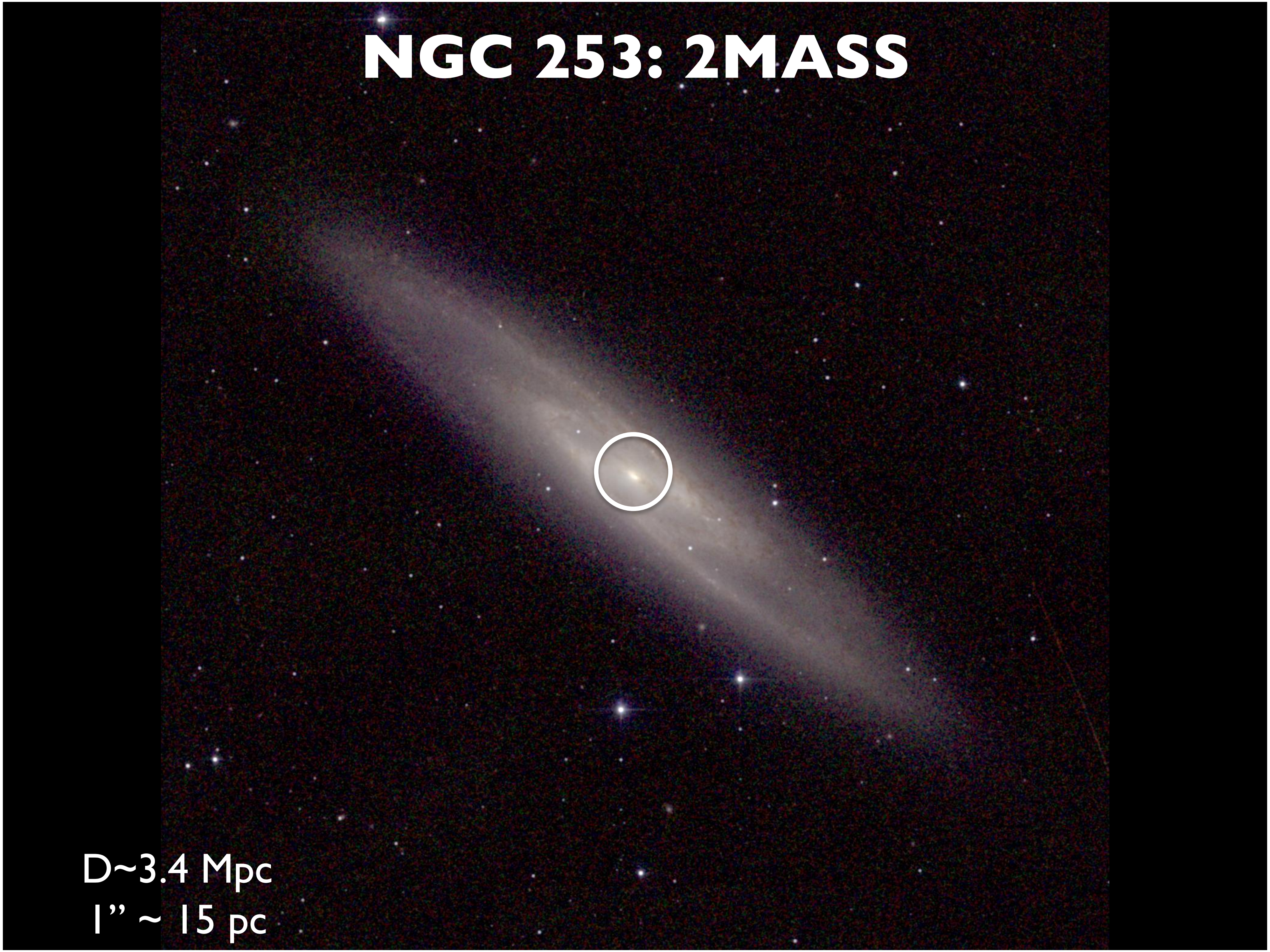
b) Can models reproduce the KS law and what are the limitations in the models? Is there any predictive test of models or the KS law that should or can be tested with ALMA and other telescopes?

c) How well do we understand the feedback from starbursts and outflows? What role can ALMA play in better constraining feedback?

d) What have we or will we learn about the chemical evolution of galaxies over cosmic time with ALMA, JWST and other telescopes? What molecular and atomic species have we detected with ALMA and how have they helped us better understand the composition and evolution of galaxies?

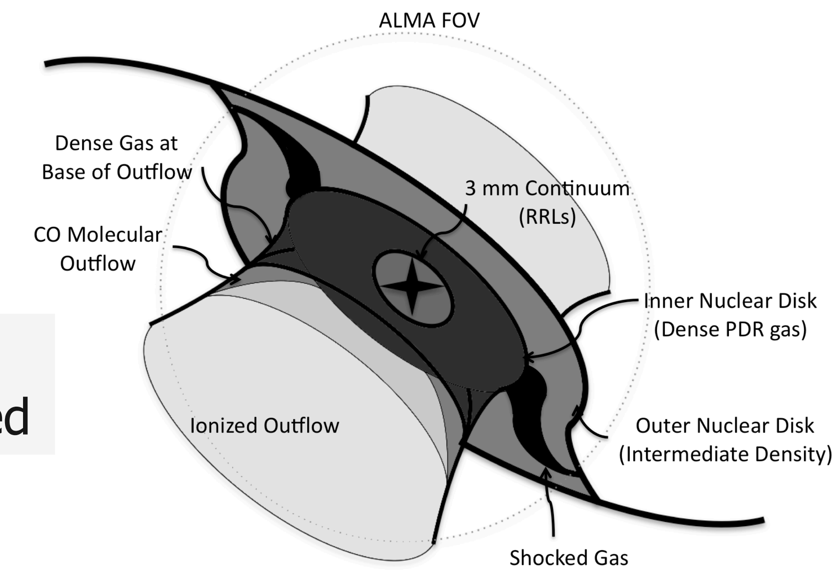
See S. Warren's talk about the molecular wind on Wednesday

See R. Herrera-Camus' talk about the prospects for using [CII] on Thursday


NGC 253: 2MASS
D~3.4 Mpc
1" ~ 15 pc

cycle0+cycle1
+ACA+Mopra

cycle0+Mopra

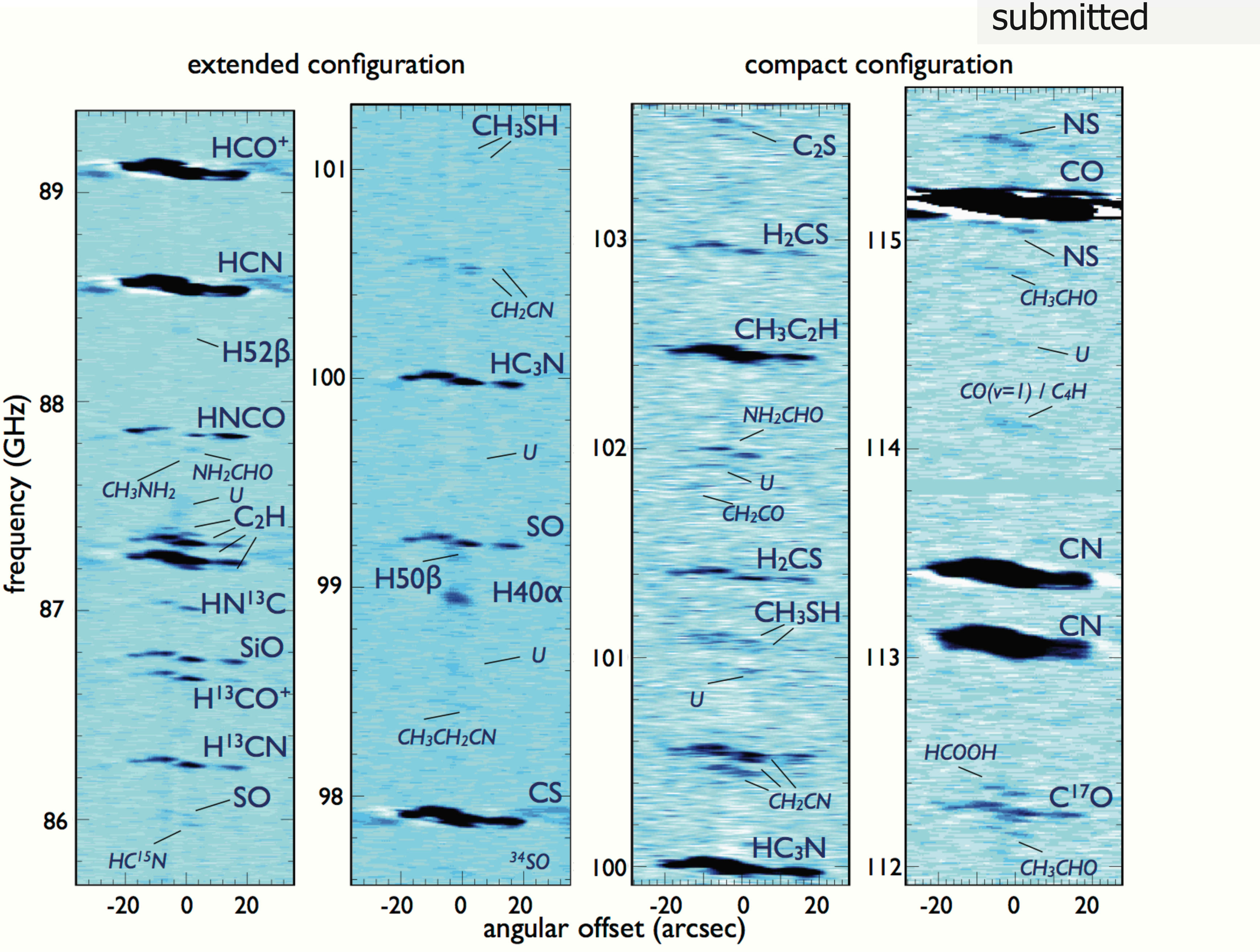


Sketch from Meier,
Walter, et al., submitted

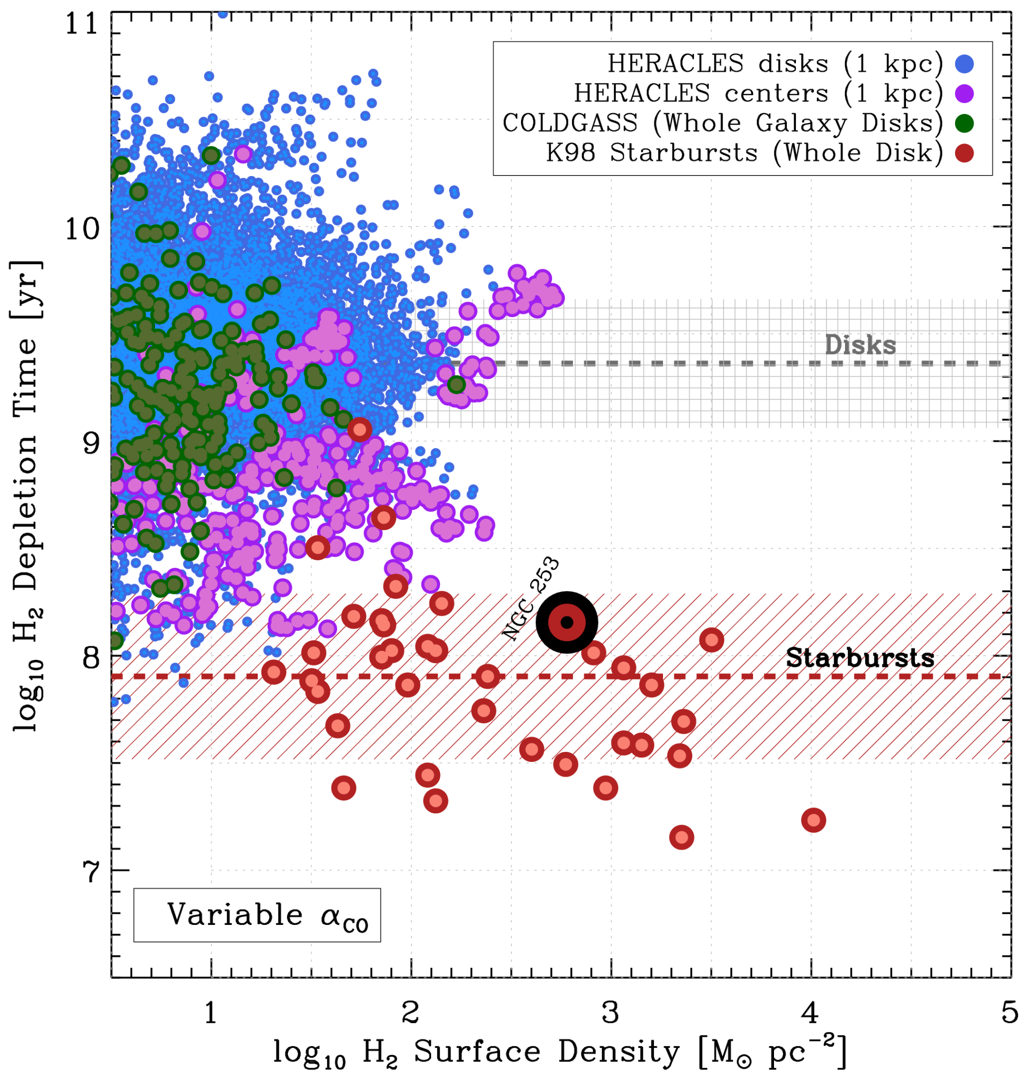
CO data

But not just CO

Meier, Walter, et al., submitted



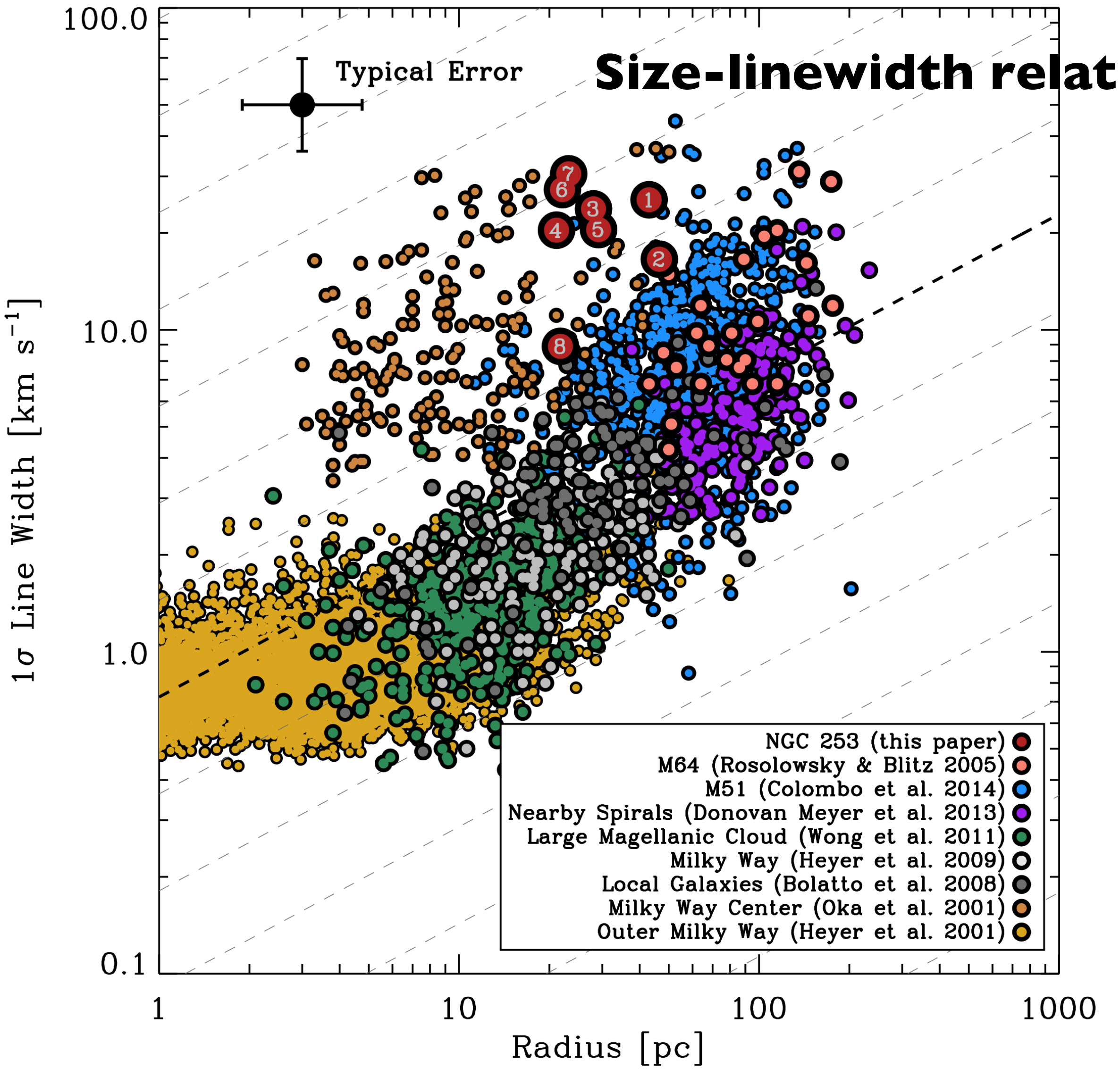
A bona fide starburst



- SFR ~ 3 $M_\odot$/yr/kpc^2
- Short gas consumption time, << Hubble time
- Much higher "efficiency" than normal disks
- The nuclear SFR density is ~ a few tens of solar masses per year per kpc^2
- AGN may or may not exist, but currently it is energetically unimportant (Forbes+ 2000, Weaver+ 2002)

Leroy et al., submitted

GMCs, the site of star formation

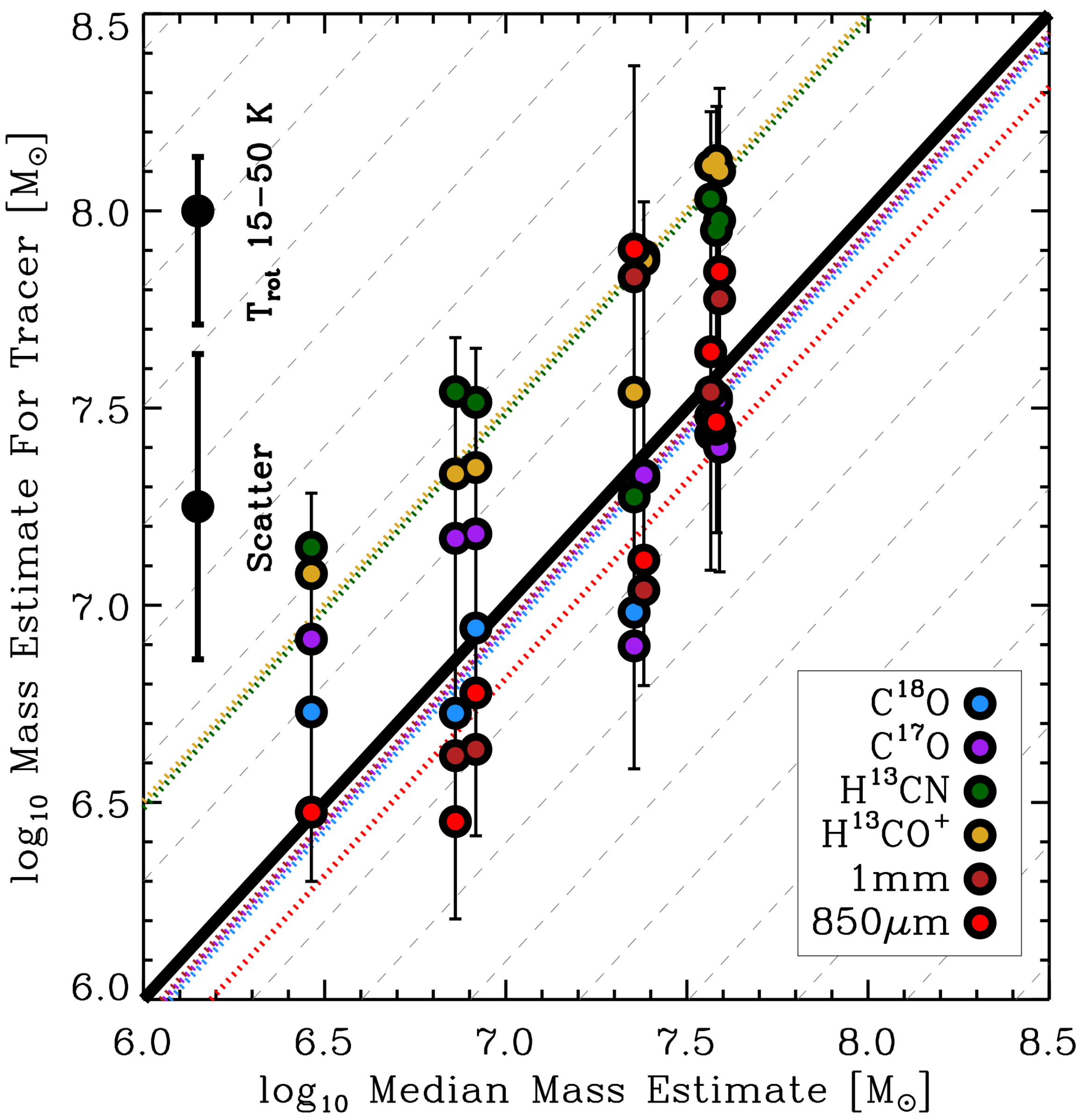


Size-linewidth relation

- For virialized GMCs, the coefficient is proportional to surface density
- The NGC 253 GMCs are over the Galactic relation, suggesting high surface densities
- But are they virialized? Or is it high external pressure? That requires an independent estimate of their mass

Leroy et al., submitted

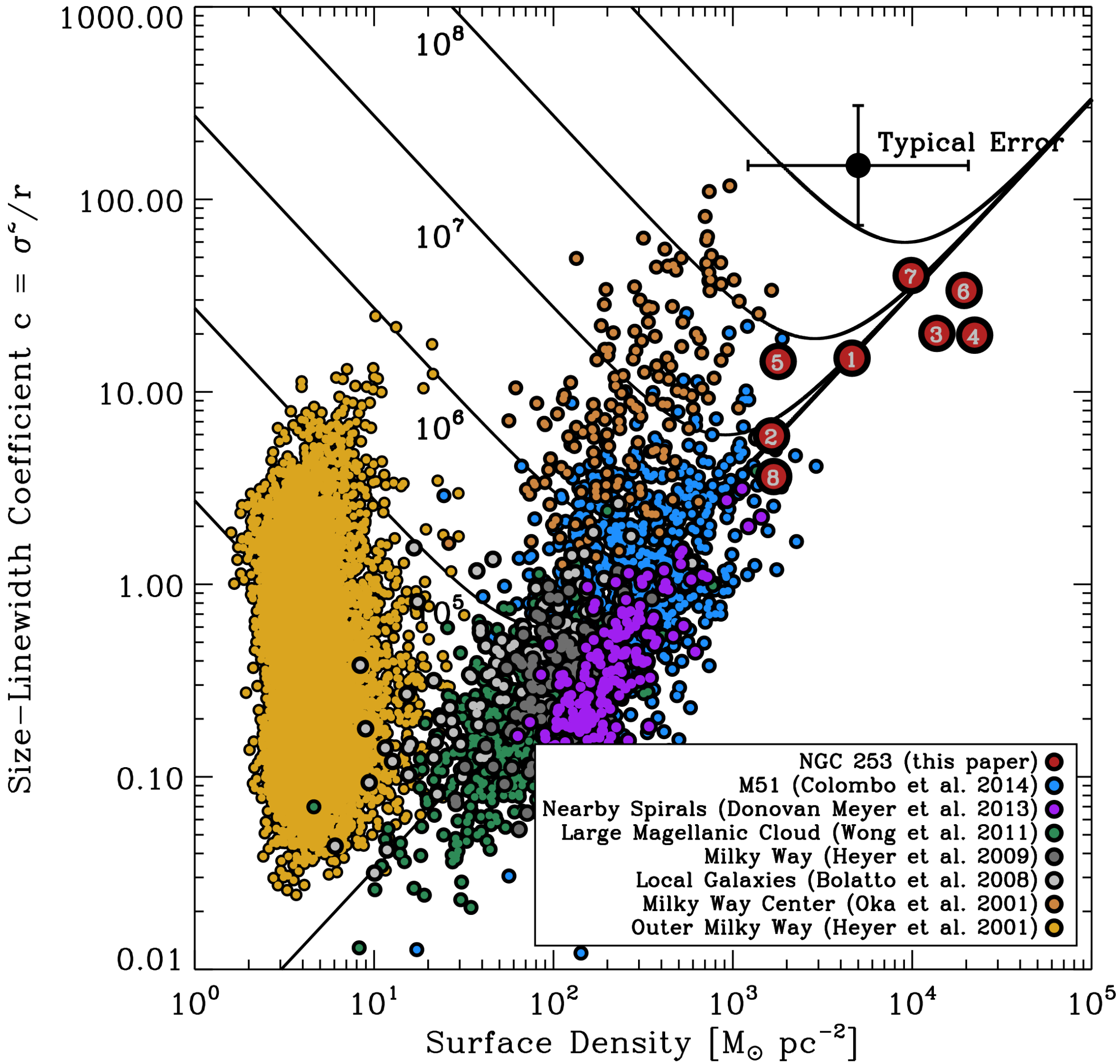
Independent cloud mass estimates



- Independent mass estimates from optically thin emission tracers
- Dependent on temperature, abundance assumptions
- On average ~±0.3 to 0.4 dex scatter
- Fine for our purposes

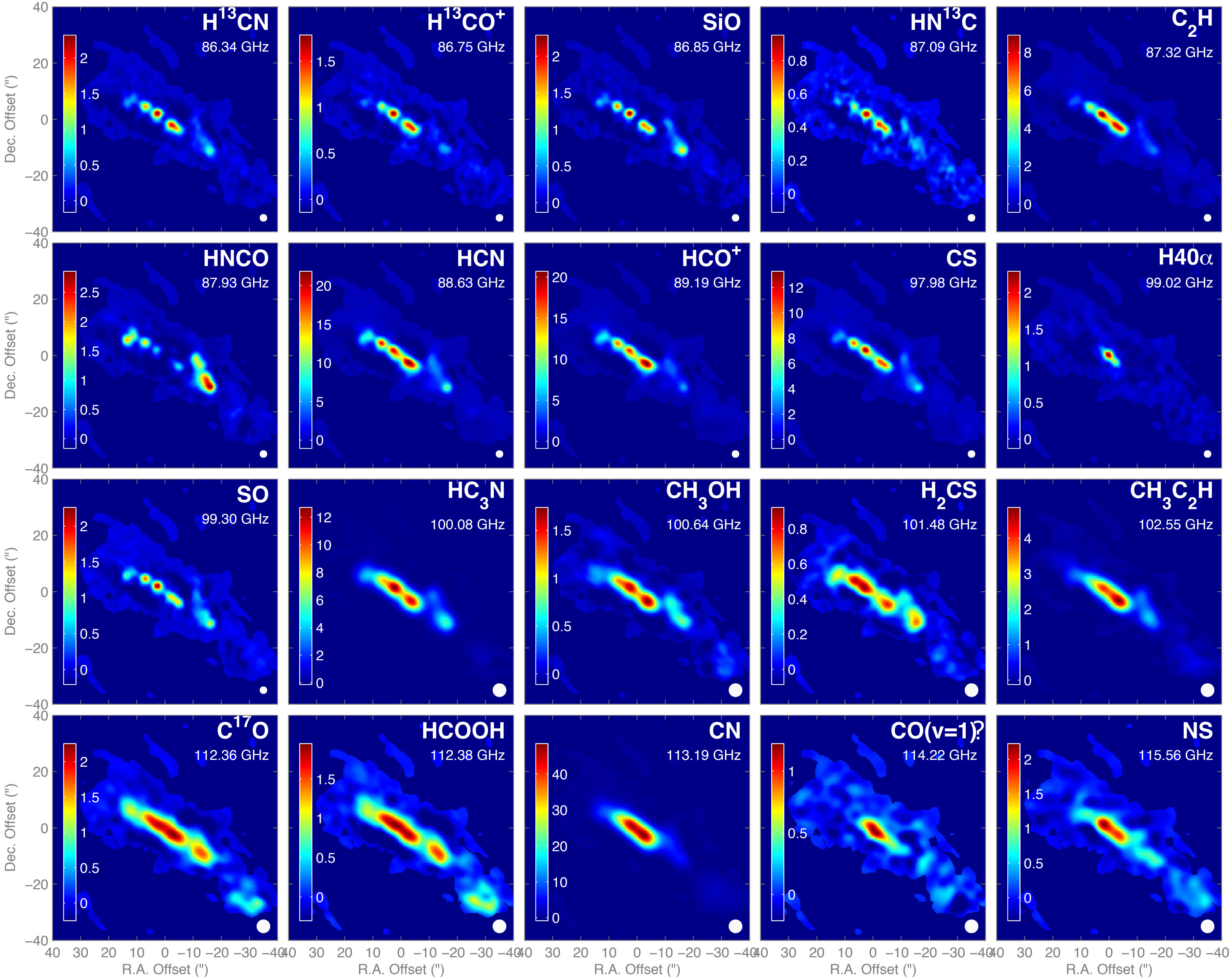
Leroy et al., submitted

Size-linewidth vs. Surface density



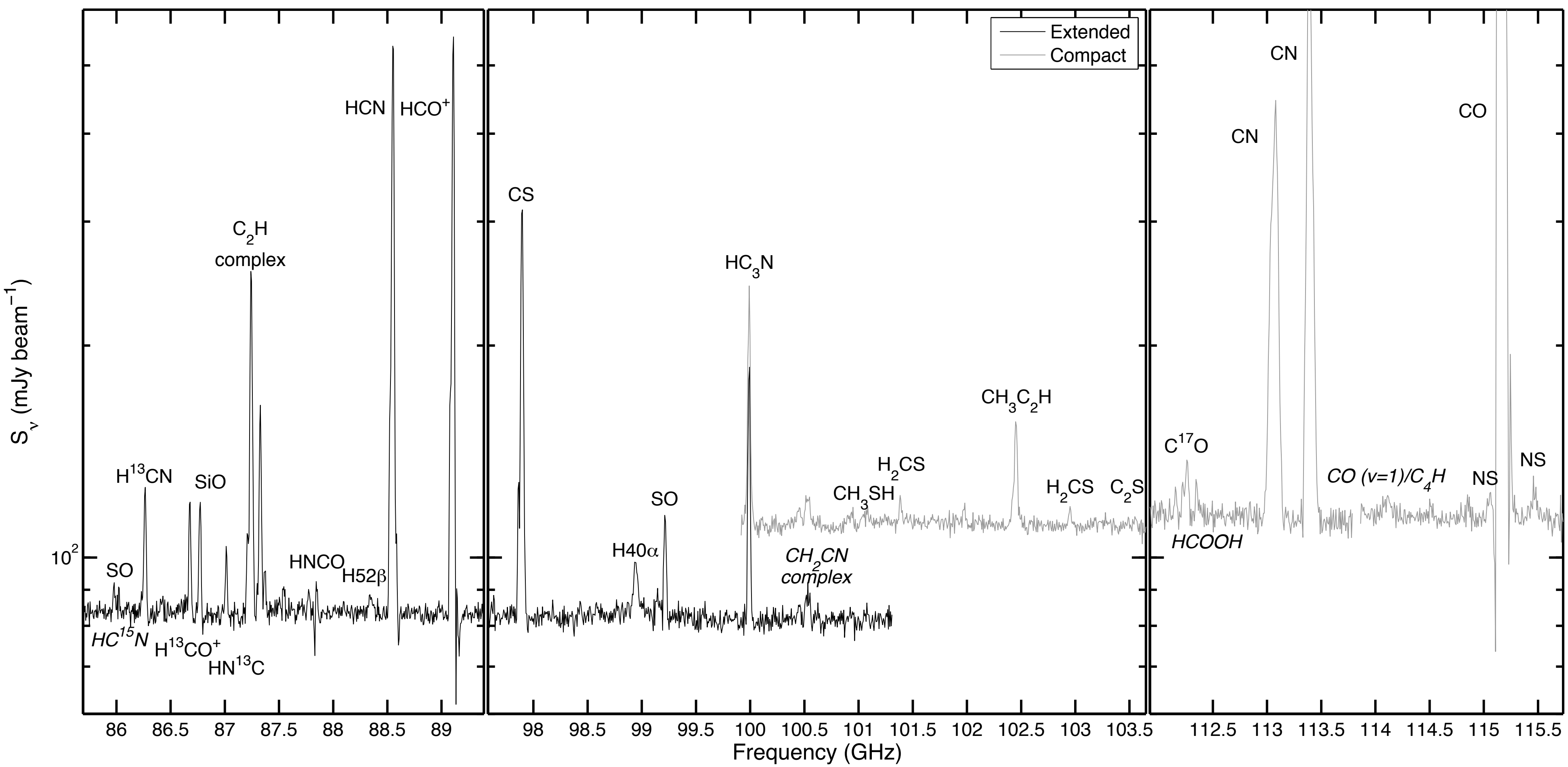
- We can now place the NGC 253 GMCs in the context of all GMCs
- Comparing to Field, Blackman, & Keto (2011) models for PVE
- Linewidths are consistent with virial equilibrium, not external pressure
- Much higher densities than "normal" GMCs!
- Implies short free-fall and sound-crossing times ($\sim\rho^{-1/2}$)

Leroy et al., submitted



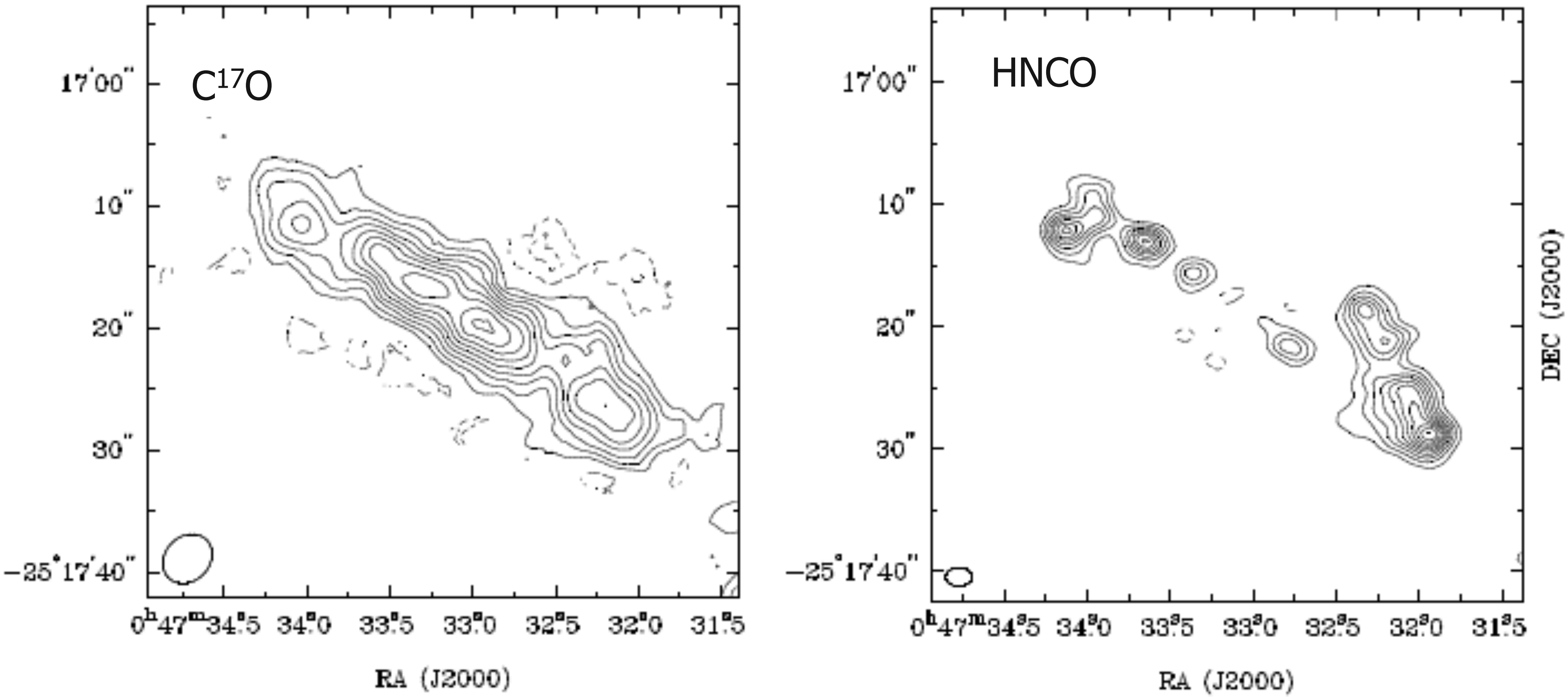
H13CN
86.34 GHz
H13CO+
86.75 GHz
SiO
86.85 GHz
HN13C
87.09 GHz
C2H
87.32 GHz
HNCO
87.93 GHz
HCN
88.63 GHz
HCO+
89.19 GHz
CS
97.98 GHz
H40α
99.02 GHz
SO
99.30 GHz
HC3N
100.08 GHz
CH3OH
100.64 GHz
H2CS
101.48 GHz
CH3C2H
102.55 GHz
C17O
112.36 GHz
HCOOH
112.38 GHz
CN
113.19 GHz
CO(v=1)?
114.22 GHz
NS
115.56 GHz
Dec. Offset (")
R.A. Offset (")

Spectrum example



Meier, Walter, et al. submitted

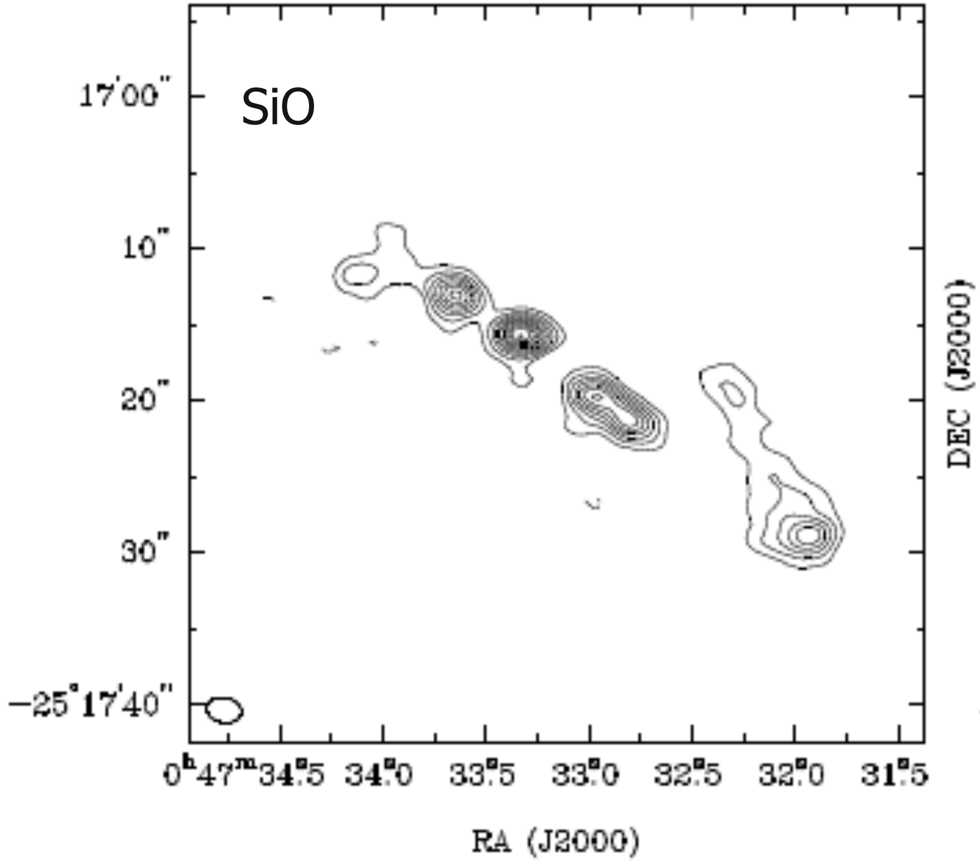
Total column and shocks

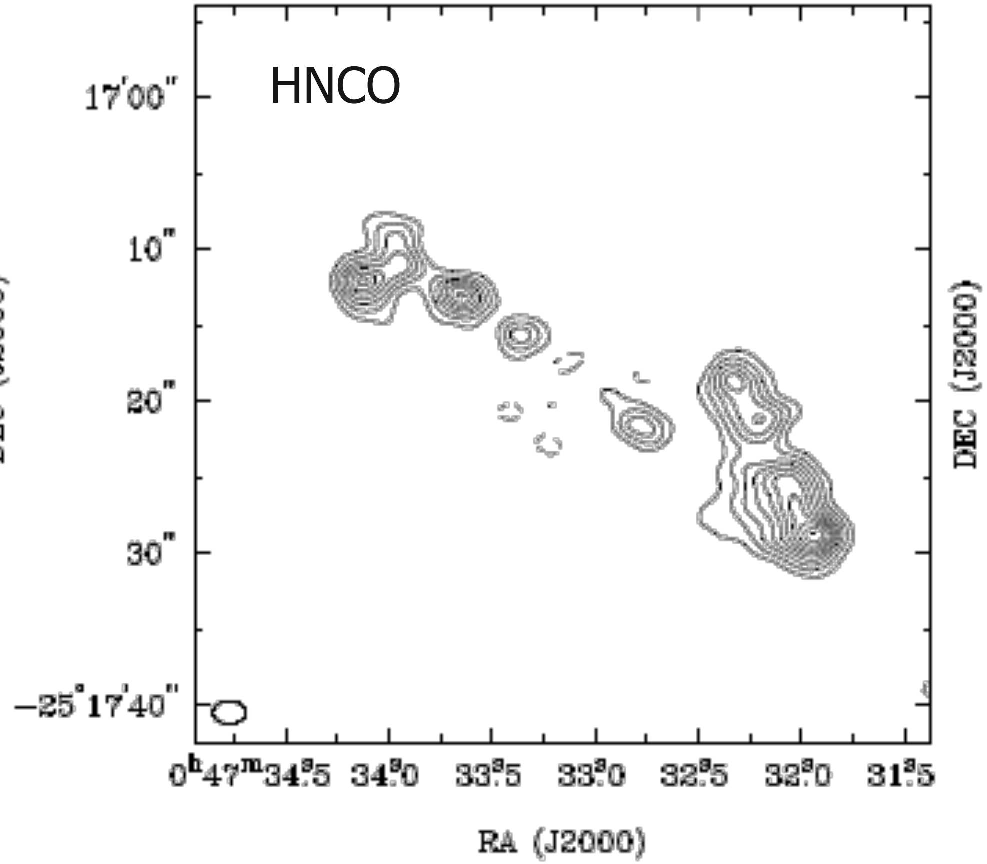


- $C^{17}O$ must be optically thin, with $^{16}O/^{17}O$~1000-2000
- This suggests τ_{CO}~2-5
- HNCO is released from grain mantles/surfaces in slow (v<15 km/s) shocks

Meier, Walter, et al. submitted

Shock strength

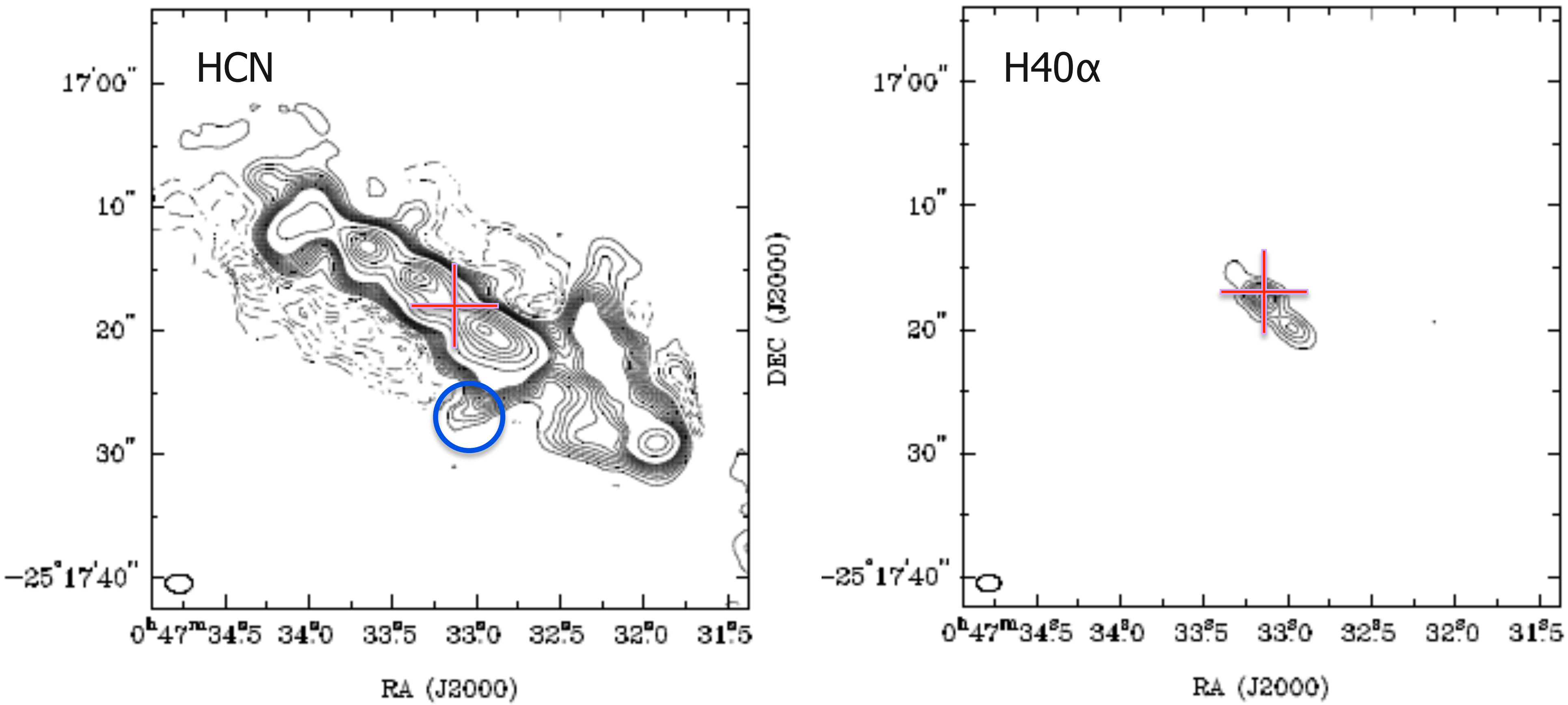




- SiO is also a shock tracer, but SiO is put in the gas phase by sputtering/shattering of the grain
- It traces higher velocity shocks, so SiO/HNCO is a measure of shock strength
- Photodissociation complicates the picture

Meier, Walter, et al. submitted

Dense and ionized gas



- Surprisingly, HCN/H^{13}CN~CO/^{13}CO, suggesting similar optical depth!
- The H40α line is broad and peaks at the kinematic center (see also Kepley+ 2012 EVLA maps). The SW extension is a known SSC
- No relation to the dense gas!

Meier, Walter, et al. submitted

- ALMA affords unique new insights into the inner workings of galaxies
- The sensitivity and resolution allow us to observe the physics at the root of the KS law in a starburst
  - Very high Σ_{H2}, resulting in short $t_{free\text{-}fall}$
- The bandwidth and sensitivity are such that "involuntary" line surveys will be common, enabling spatially-resolved astrochemical probes on a new scale
  - Shock, PDR, density, temperature tracers
  - Enormous value in archive