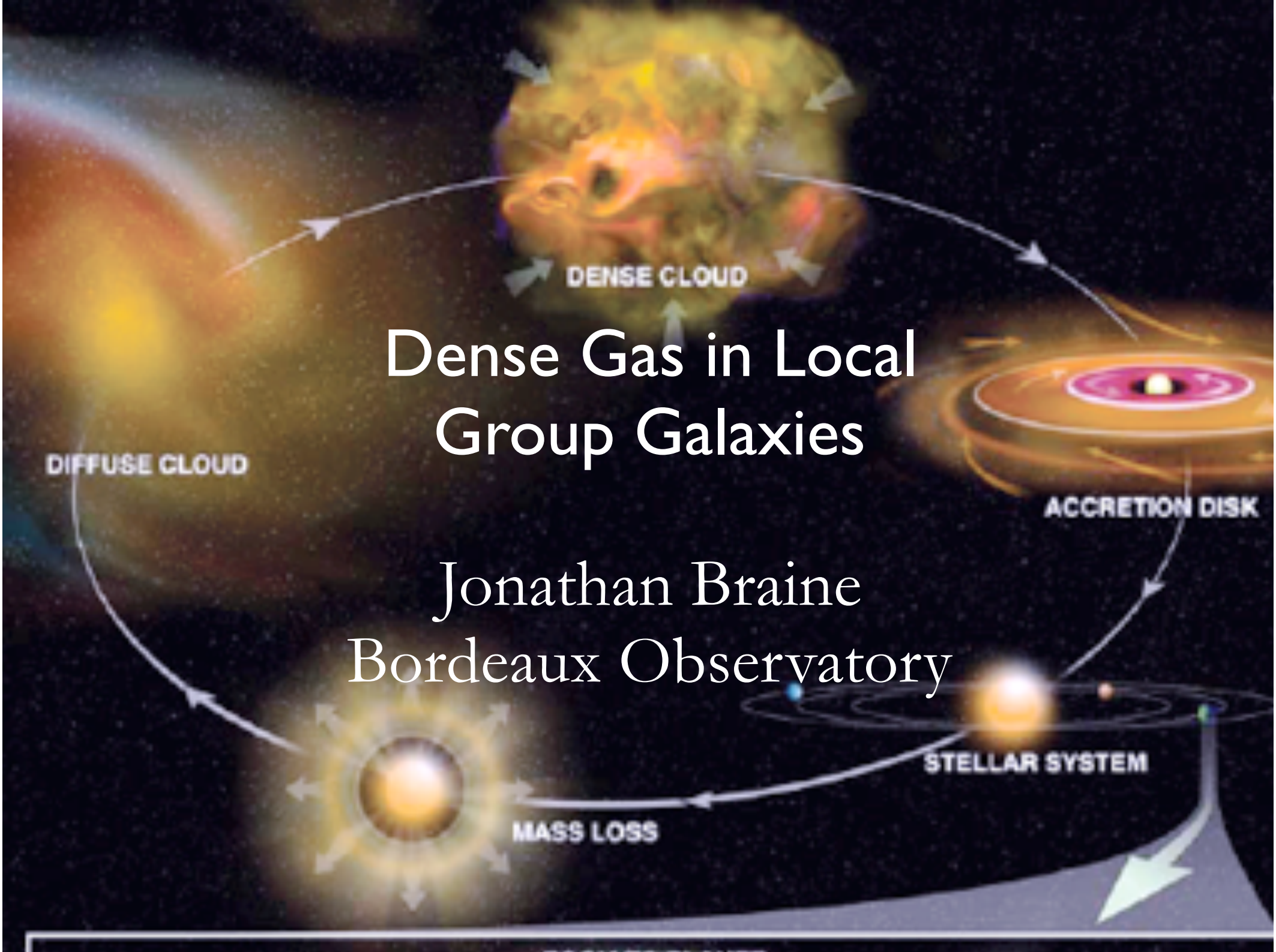


Dense Gas in Local Group Galaxies

Jonathan Braine
Bordeaux Observatory

Many open questions about dense gas and star formation

How can we estimate the dense gas mass? *HCN(1-0) best?*

Does this work for all galaxies/clouds?

How can we estimate the star formation rate (Msun/yr) ? *Hα, FIR*

Depends critically on IMF ==> how constant is IMF? ????

Do clouds naturally create a constant mass fraction of dense cores?

Do dense cores naturally create stars with the same efficiency?

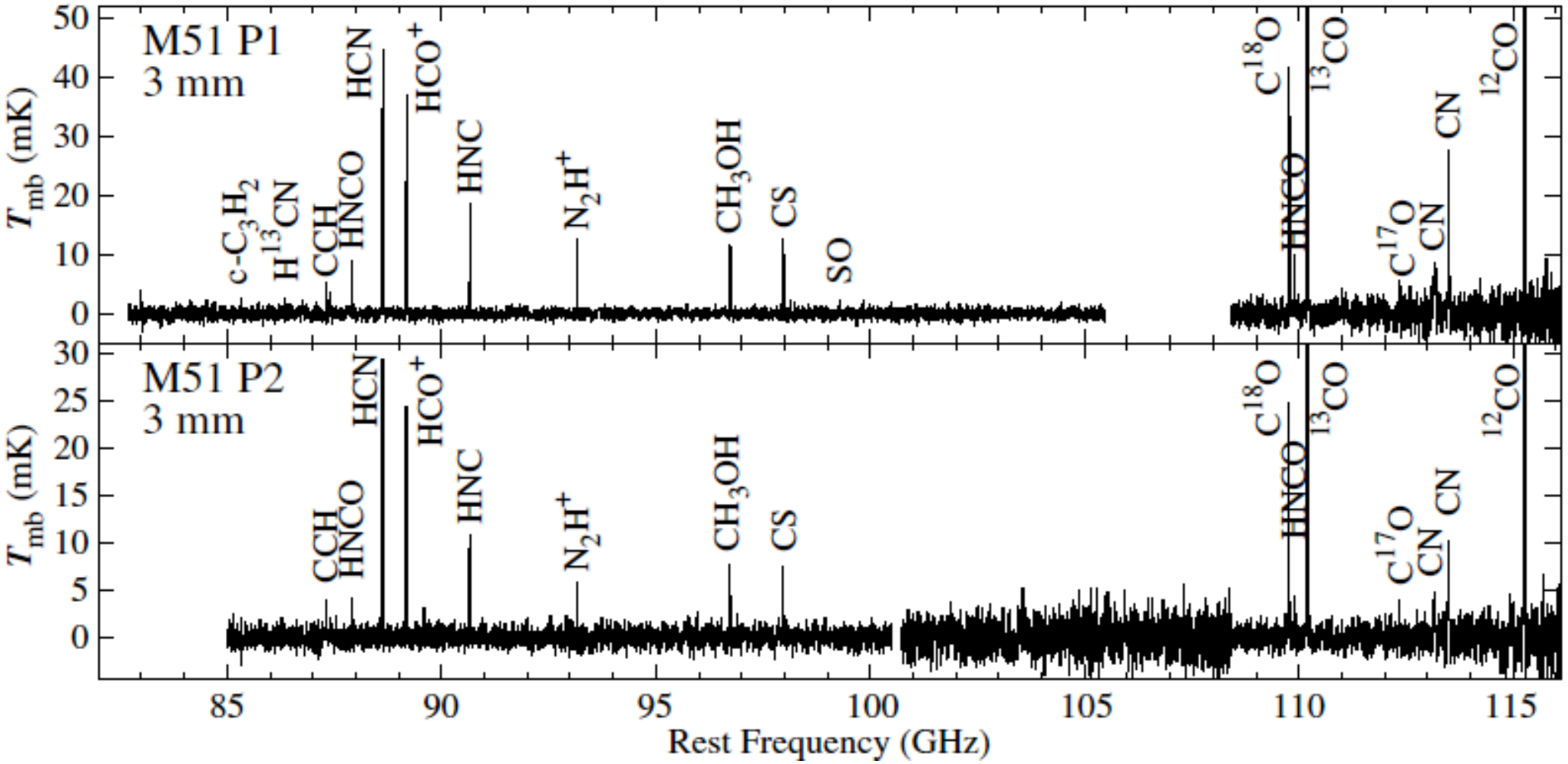
Are the answers redshift and/or metallicity dependent?

==>observe HCN/HCO+ in local analogues

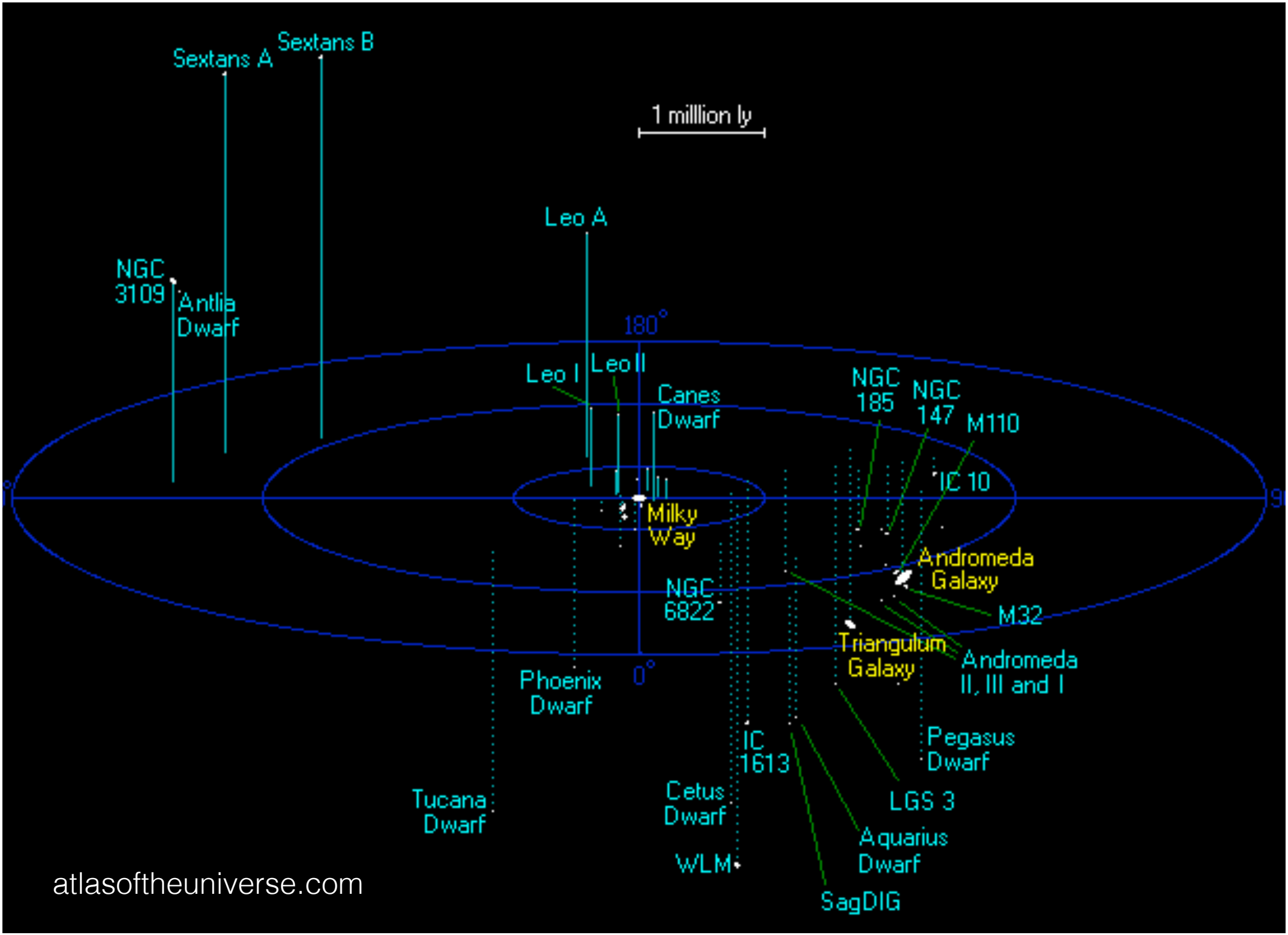
Mol cloud mass traced by CO and/or dust emission (problem at very low metallicity). Core mass more difficult: short free-fall time, depletion onto grains, broad range in densities, rich chemistry.

Telescopes now equipped with broadband receivers and backends

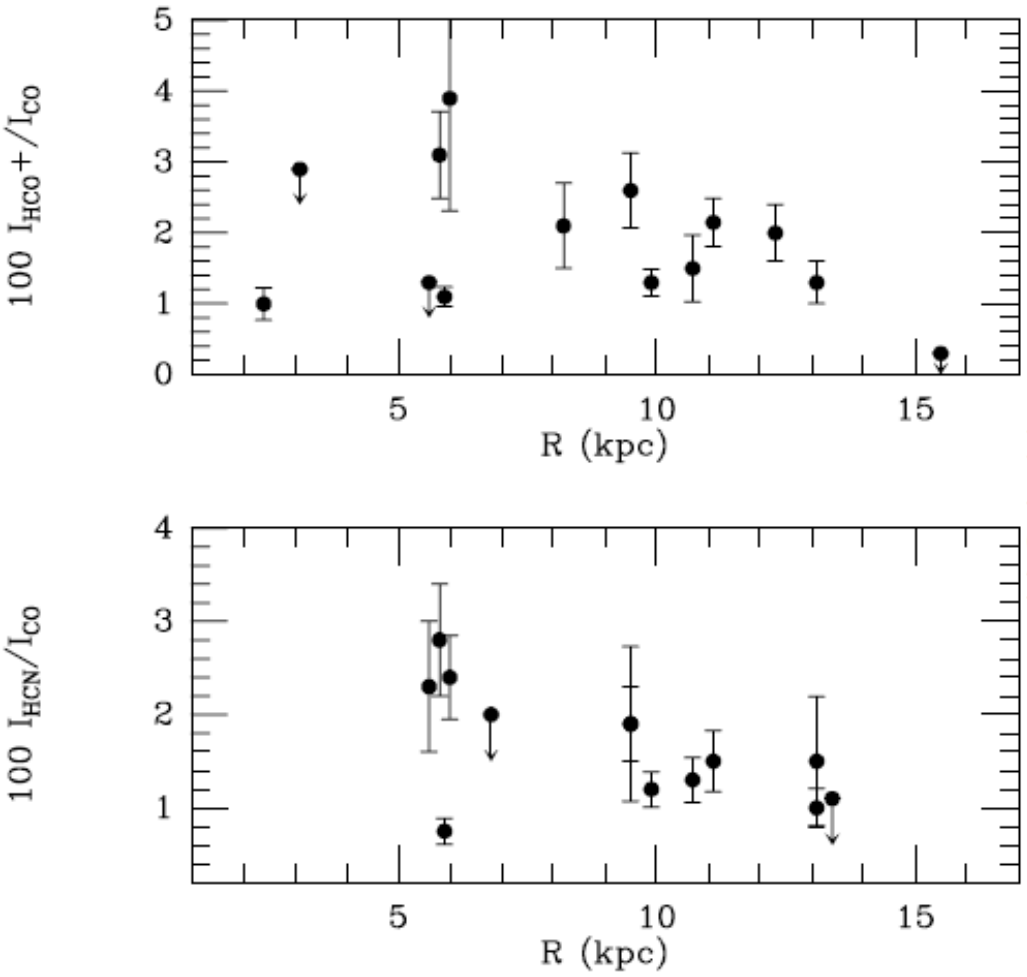
==> observe many molecules simultaneously



Two positions near the center of M51 by Watanabe +2014.
Note presence of N2H+, HNCO, C18O
HCN/HCO+ > 1


Sextans A
Sextans B
1 milllion ly
Leo A
NGC 3109
Antlia Dwarf
180°
Leo I
Leo II
Canes Dwarf
NGC 185
NGC 147
M110
IC 10
Milky Way
Andromeda Galaxy
M32
NGC 6822
Triangulum Galaxy
Andromeda II, III and I
Phoenix Dwarf
0°
IC 1613
Pegasus Dwarf
Tucana Dwarf
Cetus Dwarf
LGS 3
Aquarius Dwarf
WLM
SagDIG
atlasoftheuniverse.com

Brouillet et al (2005) on M31



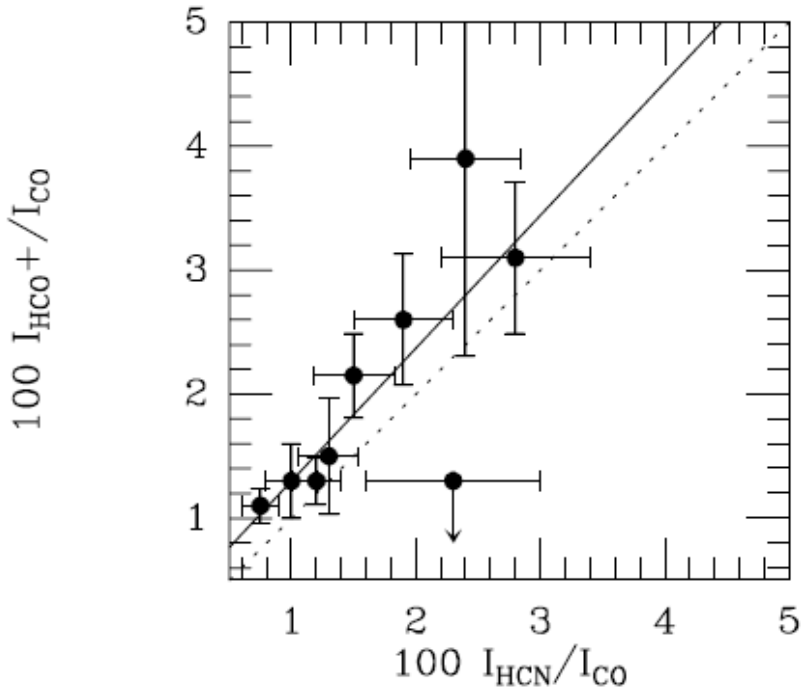
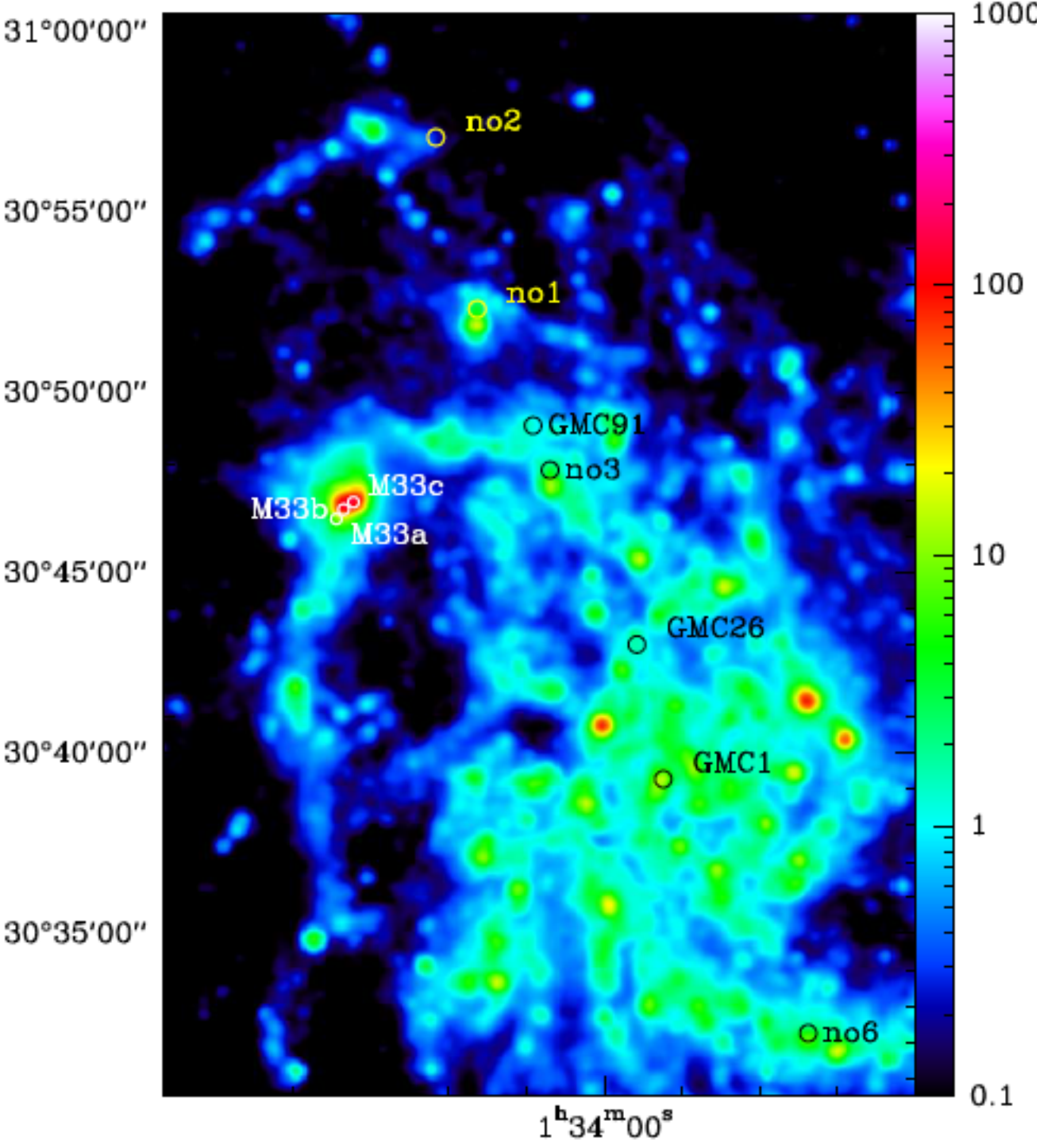


Fig. 2. χ_{O^+} as a function of χ_N. The dotted line represents $I_{HCO^+}/I_{CO} = I_{HCN}/I_{CO}$ and the solid line a least-square linear fit to the data ($\chi_{O^+} = 1.07\chi_N + 0.23$) without taking into account position F (upper limit).

possible radial variation of HCO+/HCN, due to metallicity gradient?



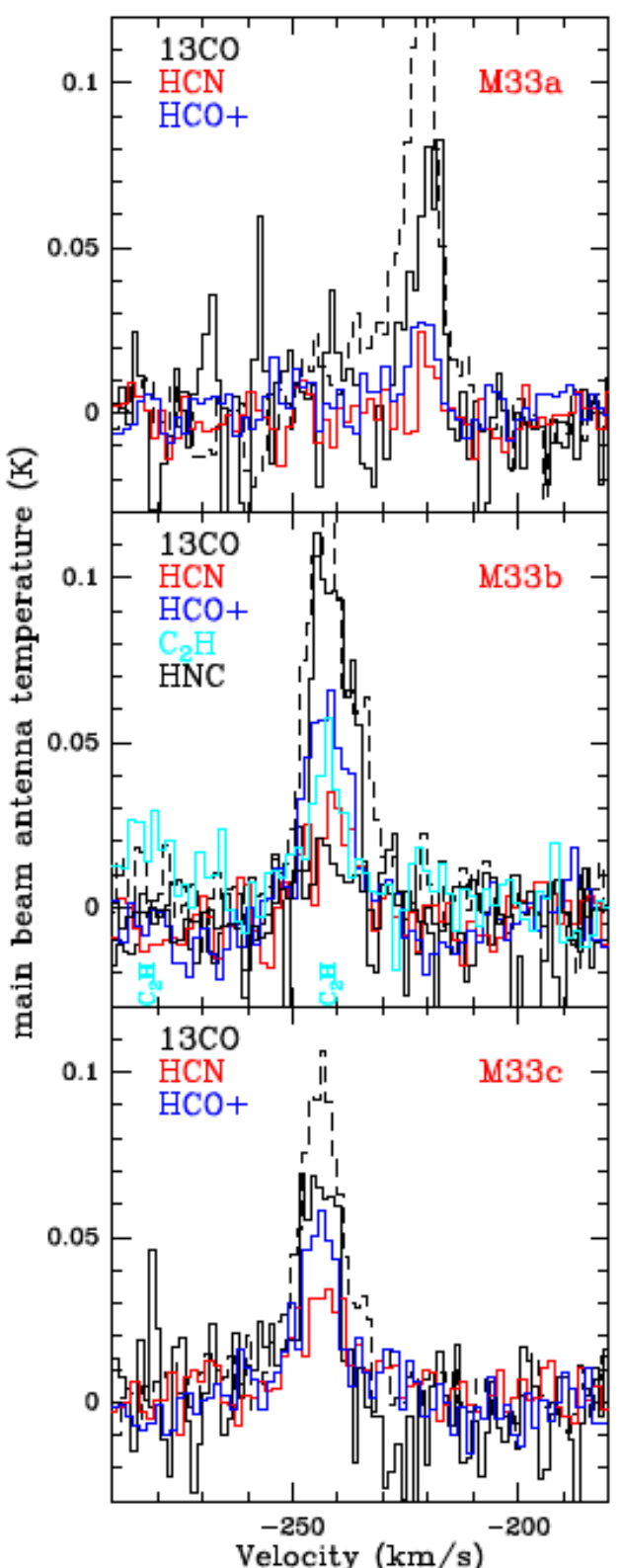
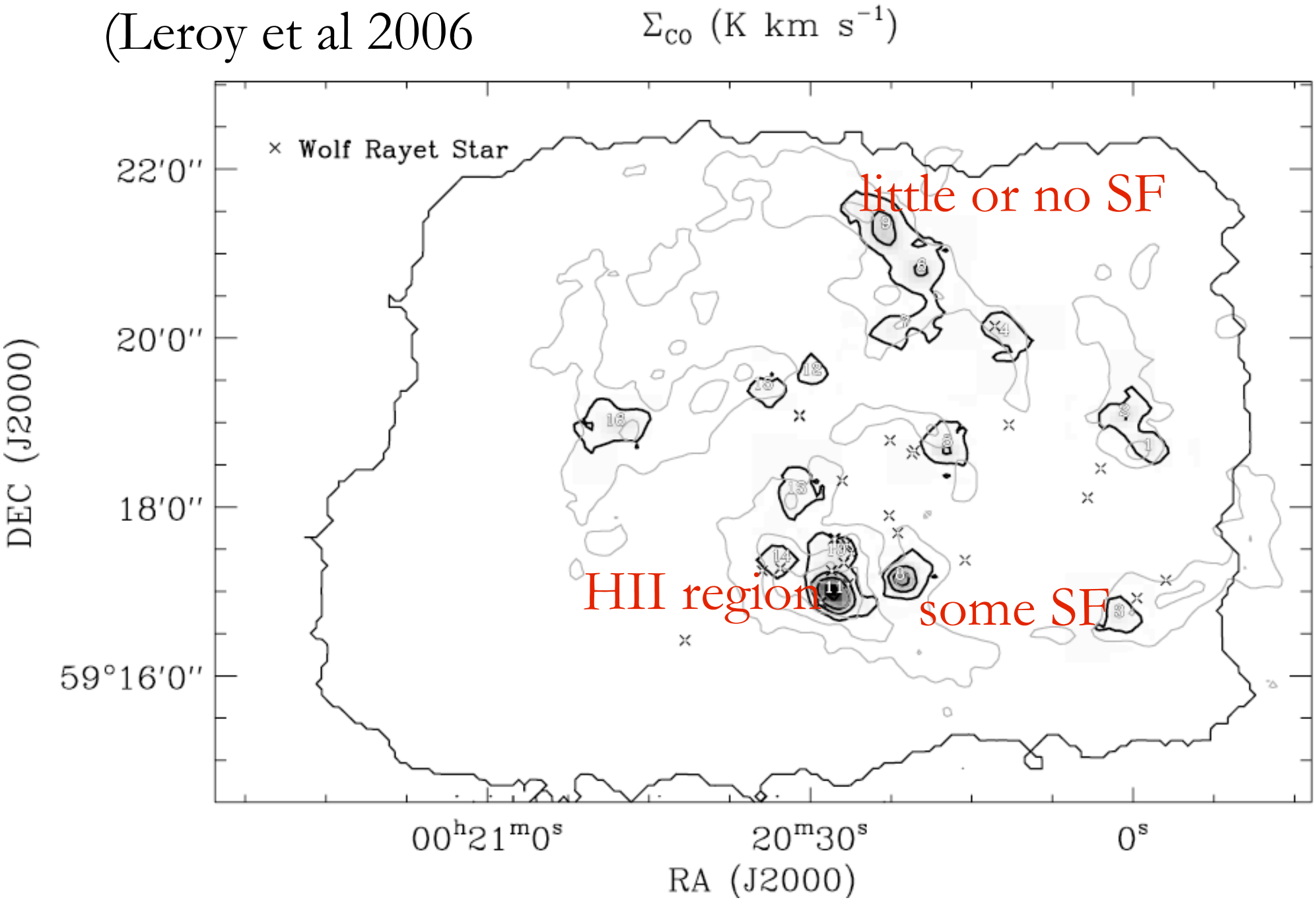
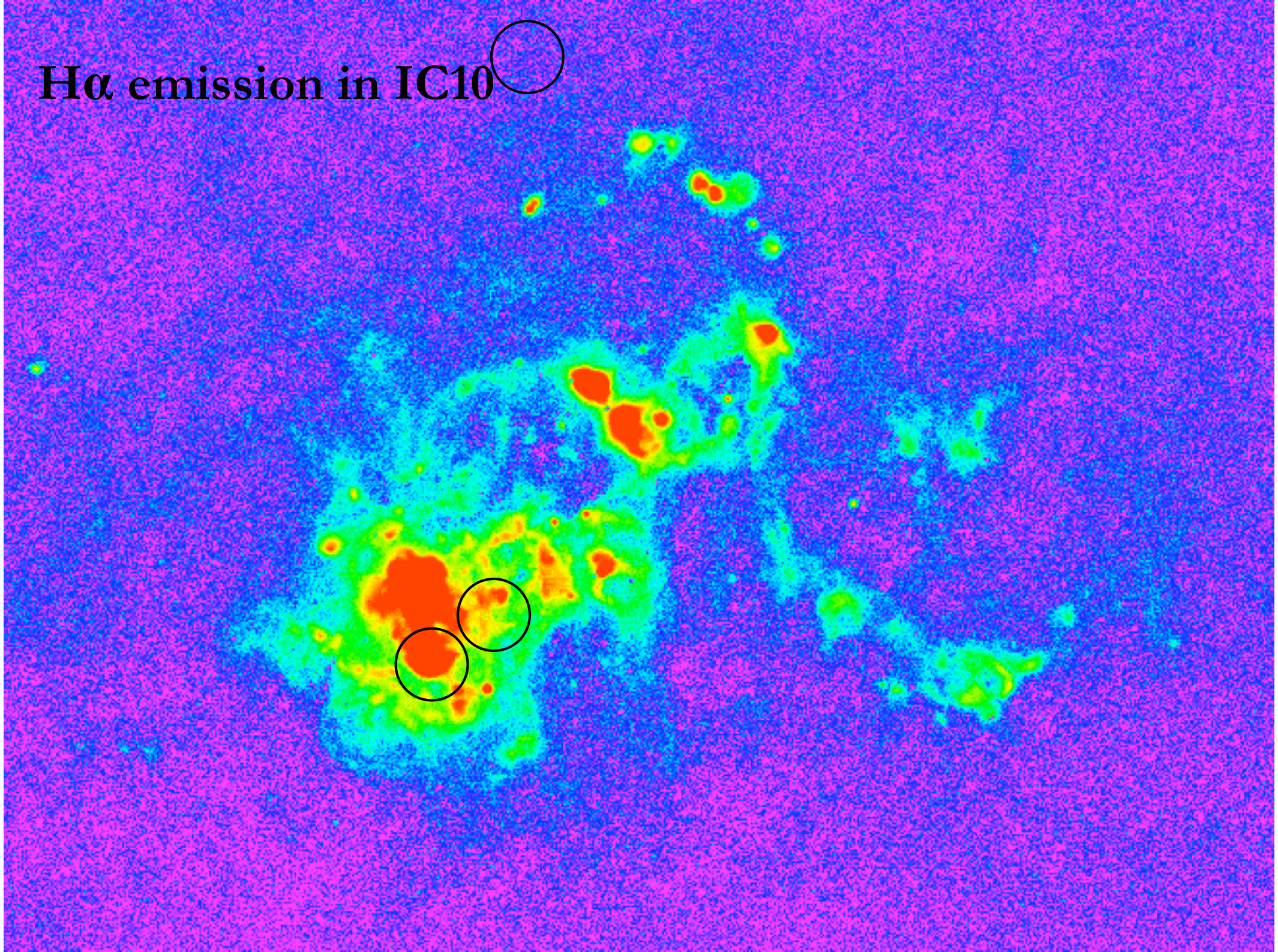


Fig. 3. Observed positions on a Spitzer 24μm map of M 33. The

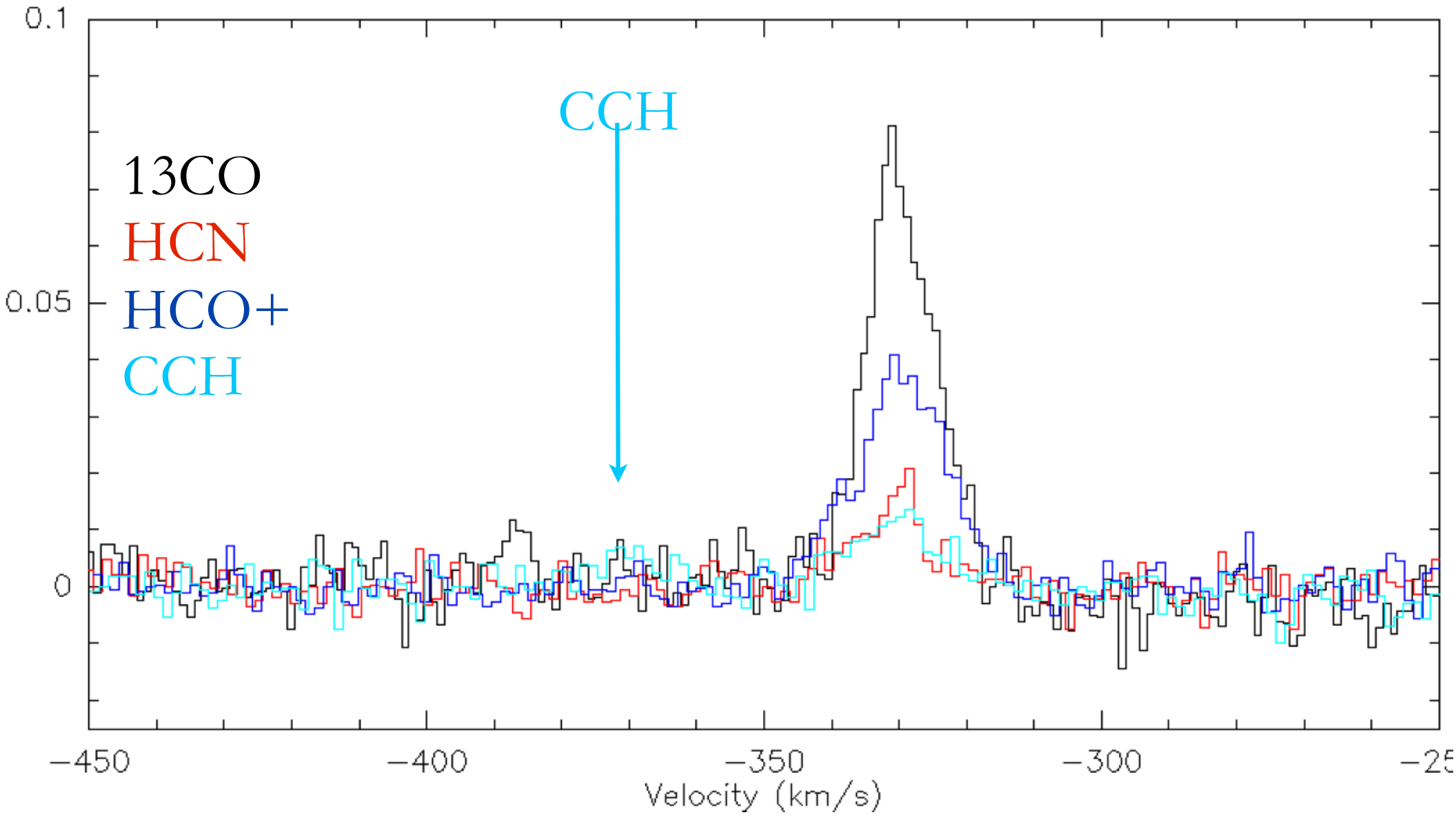
Braine et al. 2017

CO emission in IC10
(Leroy et al 2006




Hα emission in IC10

Region B11 in IC10



HCO+/HCN ≈ 2.5

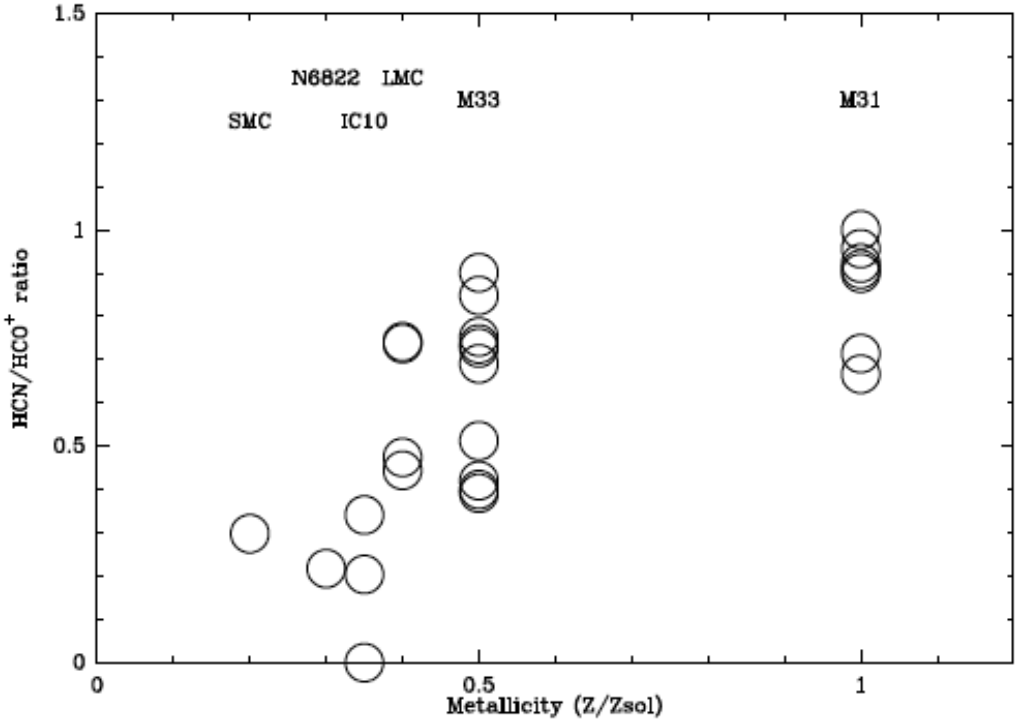


Fig. 8. Variation of the HCN/HCO$^+$ ratio with metallicity. References are Brouillet et al. (2005); Chin et al. (1997, 1998) for M 31 and the Magellanic Clouds, Buchbender et al. (2013) and the present work for M 33, and this work for IC 10 and NGC 6822. Typical uncertainties for individual points are 0.2 dex for the metallicity and 0.3 in the HCN/HCO$^+$ ratio.

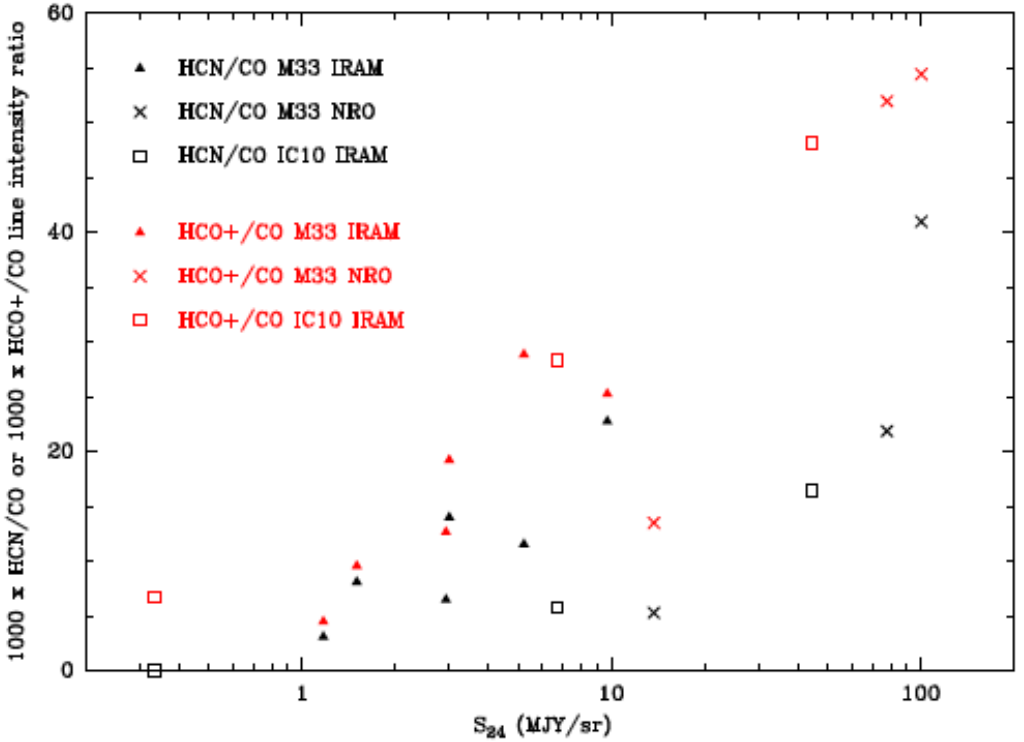


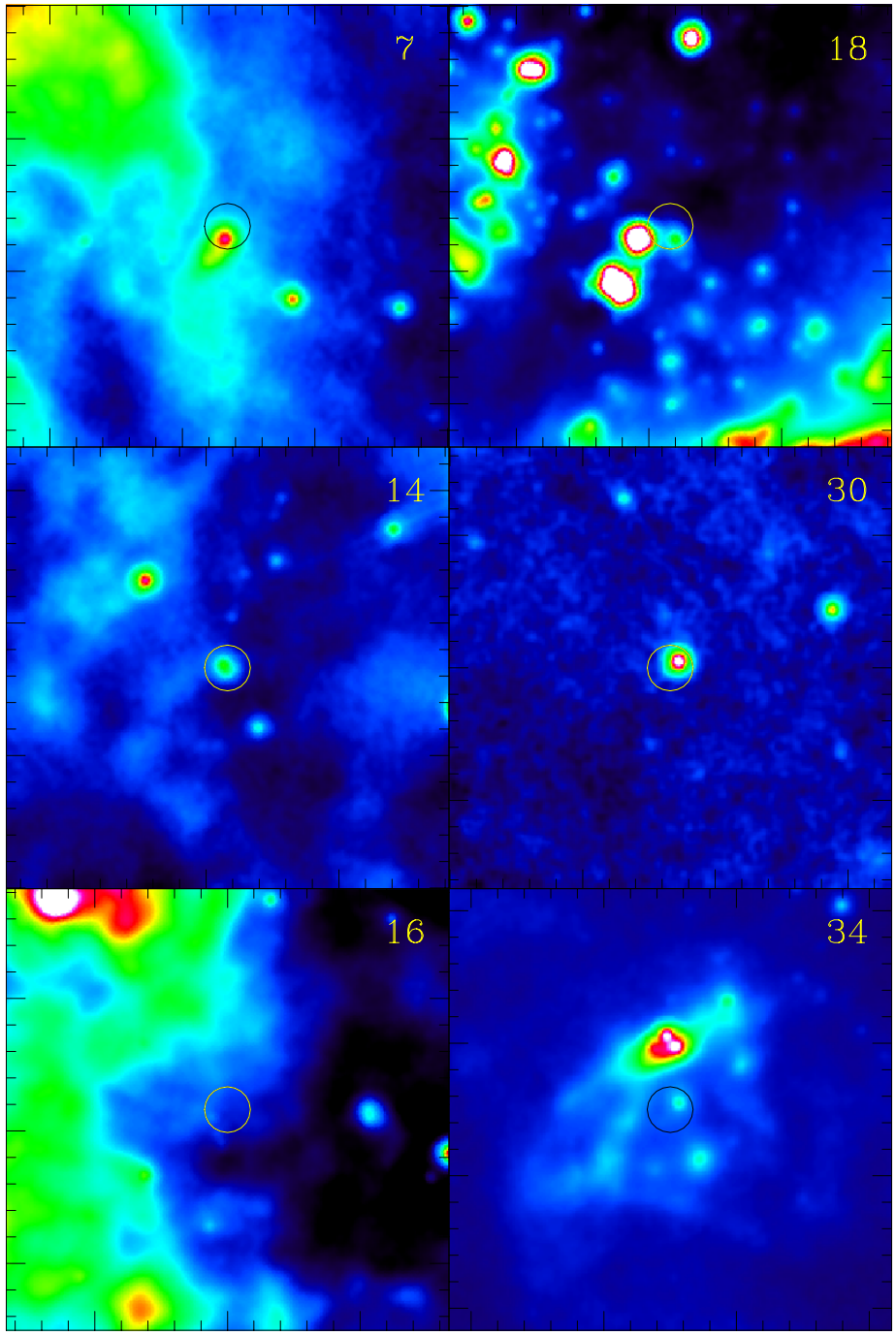
Fig. 9. Link between dense gas fraction and star formation rate. The HCN/CO and HCO$^+$/CO ratios are used to trace the fraction of dense molecular gas and the 24μm intensity is used as a proxy for the SFR. HCN/CO is in black and HCO$^+$/CO is in red. Observations are from Buchbender et al. (2013) and the present work. Typical uncertainties are 20% for HCO$^+$/CO and 25% for the HCN/CO ratio.

Next step: Observations of outer galaxy clouds, near-solar metallicity with low radiation field.

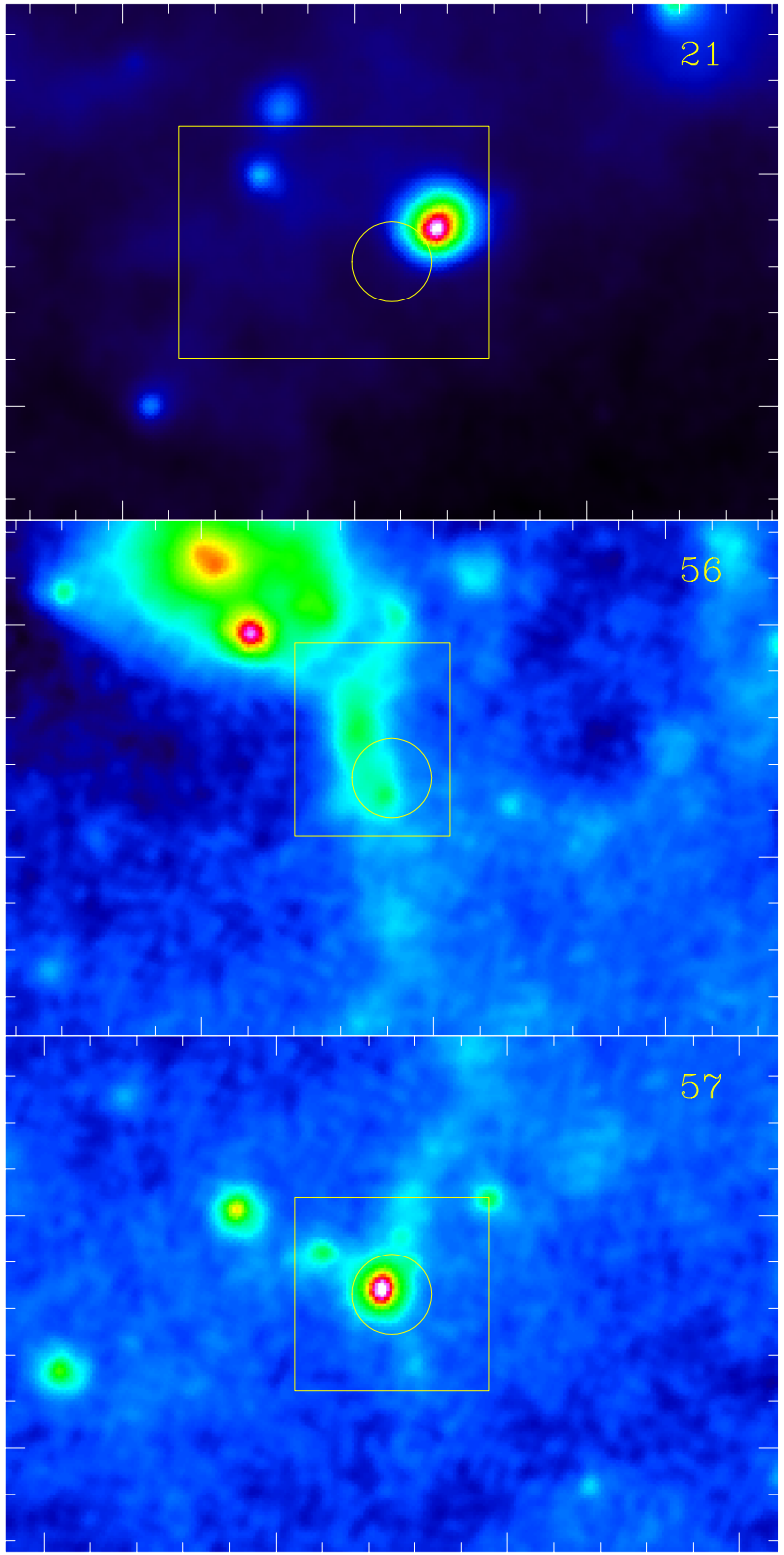
Delingha: 14meter millimeter-wave radiotelescope in western China at 3200m. Clouds to be observed in HCN and HCO^+ taken from a broad ^{12}CO and ^{13}CO survey of outer galaxy. ^{13}CO peaks chosen.

Work in progress with Yu Gao, Yan Sun, Hao Chen, Min Fang, and Y. Shimajiri & Ph. André

DLH Outer Galaxy observations



WISE 22 μm images



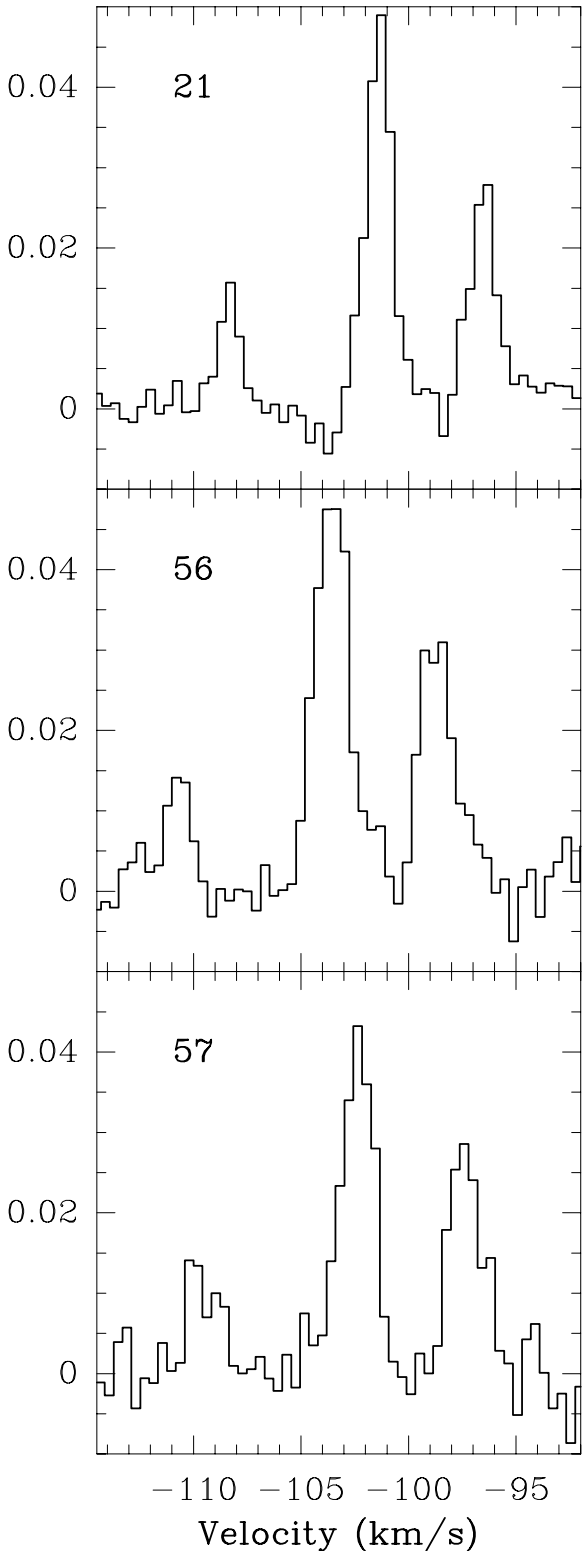
Mapping with DLH

Summing spectra enables measure of HCN hyperfine structure ==> ***optical depth***

==> HCN column $N_{HCN} \lesssim 3 \times 10^{12} cm^{-2}$

==> HCN really traces dense gas
==> dense gas fraction ~constant
$S_{HCN} \sim 0.5\ S_{HCO+}$ consistent with density $n(H_2) \sim 3 \times 10^5\ cm^{-3}$. *Not* consistent with same origin for CO and ^{13}CO emitting gas.

CO/HCN intensity ratio ~ 75, ^{13}CO/HCN ~10
HCO+ alose traces dense gas
Metallicity of very distant clouds poorly known.
From Luck+2011 gradient, factor 2.5 in Z between cloud 21 and clouds 56 & 57 but no sign of this.



Some conclusions:

HCN becomes weaker with respect to HCO+ and 13CO as metallicity decreases ==> problem at high redshift?
Nitrogen abundance N/O ~ O/H but C/O ~ constant.
$HCN/HCO^+ \sim Z/Z_\odot$ (*approximately*)

HCN/CO ~ SFR but probably also varies with galactic radius.

In outer Galaxy clouds, unlike denser regions generally observed, the narrow lines enable an *estimation of the optical depth: HCN is optically thin.* HCN is weak (half HCO+ and ~1.5% of CO). HCO+ appears to trace the same gas and is easier to detect
==> good dense gas tracer

To use HCN to trace dense gas mass, need to take Z into account. Very preliminary, observations of higher transitions required.