Dense gas and star formation on sub-kiloparsec scale in nearby star-forming galaxies

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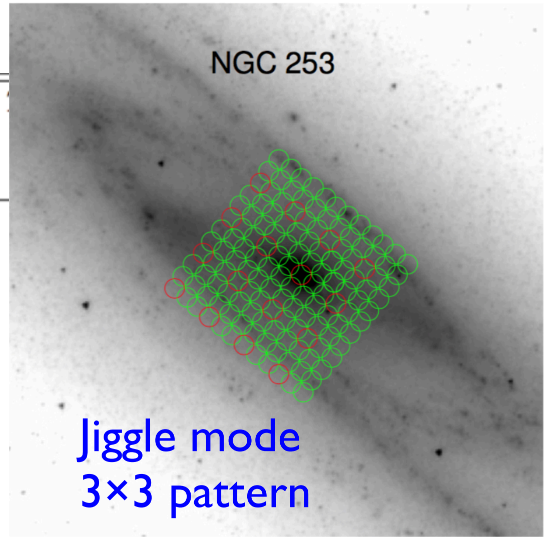
Outline

- Introduction
- Preliminary results
  - HCN(4-3) and HCO+(4-3) line emission
  - CO archival data
  - Infrared photometry
- Data analysis
- Summary

N (1)	Source Name (2)	R.A. (J2000) (3)	Decl. (J2000) (4)	Distance (Mpc) (5)	Diameter (arcmin) (6)	$f_{60\mu m}$ (Jy) (7)	$f_{100\mu m}$ (Jy) (8)	$\log L_{fir}$ ($L_\odot$) (9)	$\log \Sigma_{SFR}$ ($M_\odot yr^{-1} kpc^{-2}$) (10)	$T_{peak}^{(HCN10)}$ (mK) (11)
1	**∗NGC 253**	00 47 33.1	−25 17 18	2.5	27.5×6.8	967.81	1288.15	10.29	0.05	330
2	∗NGC 660	01 43 02.4	13 38 42	14.0	8.3×3.2	65.52	114.74	10.38	0.37	4[c]
3	∗NGC 891	02 22 33.4	42 20 57	10.0	13.5×2.5	66.46	172.23	10.18	-1.76	16
4	Maffei 2	02 41 55.0	59 36 15	2.8	5.82×1.57	135	225	10.00	0.42	150
5	**∗NGC 1068**[a]	02 42 40.7	−00 00 48	16.7	7.1×6.0	196.37	257.37	10.89	1.92	35[d]
6	NGC 1097	02 46 19.0	−30 16 30	16.4	9.3×6.3	53.35	104.79	10.59	-0.08	30[e]
7	∗NGC 1365[a]	03 33 36.4	−36 08 25	20.8	11.2×6.2	94.31	165.67	10.86	0.55	10[c]
8	**∗IC 342**	03 46 48.5	68 05 47	3.7	21.4×20.9	180.80	391.66	10.01	-2	45[c]
9	NGC 1808[a]	05 07 42.3	−37 30 47	10.5	6.5×3.9	105.55	141.76	10.55	0.61	18[f]
10	∗NGC 2146	06 18 37.7	78 21 25	15.2	6.0×3.4	146.69	194.05	10.93	0.44	30
11	∗NGC 2903	09 32 10.1	21 30 03	6.2	12.6×6.0	60.54	130.43	10.05	-1.22	15
12	**∗M82**[b]	09 55 52.7	69 40 46	3.5	11.2×4.3	1480.42	1373.69	10.61	1.05	100
13	∗NGC 3079	10 01 57.8	55 40 47	16.2	7.9×1.4	50.67	104.69	10.65	-0.4	6[c]
14	NGC 3521	11 05 48.6	−00 02 09	8.2	11.0×5.1	49.19	121.76	9.84	-1.55	12
15	∗NGC 3627	11 20 14.9	12 59 30	8.1	9.1×4.2	66.31	136.56	10.24	-1.43	4[c]
16	∗NGC 3628	11 20 17.0	13 35 23	9.6	14.8×3.0	54.80	105.76	10.14	-0.85	10[c]
17	Arp 299	11 28 30.4	58 34 10	54.1	...	113.05	111.42	11.74	0.3	12
18	∗NGC 4631	12 42 08.0	32 32 29	8.1	15.5×2.7	85.40	160.08	10.10	-1.9	3.5[c]
19	NGC 4736	12 50 53.0	41 07 14	4.8	11.2×9.1	71.54	120.69	9.59	-1.01	10
20	M51	13 29 52.7	47 11 43	7.6	11.2×6.9	97.42	221.21	10.31	-1.78	50
21	**∗M83**	13 37 00.9	−29 51 56	3.7	12.9×11.5	265.84	524.09	9.94	-1.44	23[c]
22	NGC 5457	14 03 12.5	54 20 56	5.2	28.8×26.9	88.04	252.84	10.13	-2.14	10
23	**∗NGC 6946**	20 34 52.3	60 09 14	5.5	11.5×9.8	129.78	290.69	10.01	-1.68	17[c]



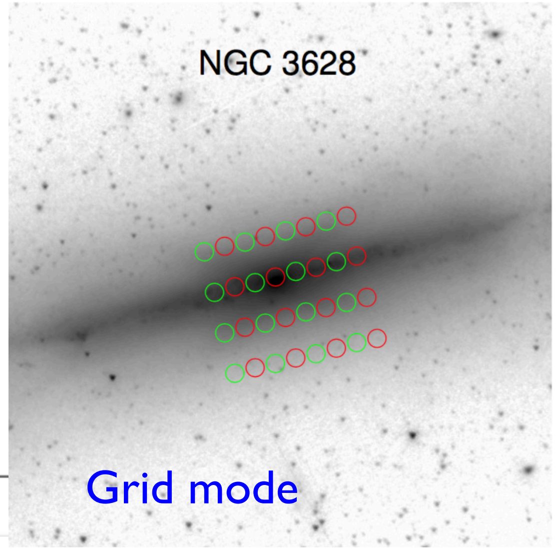
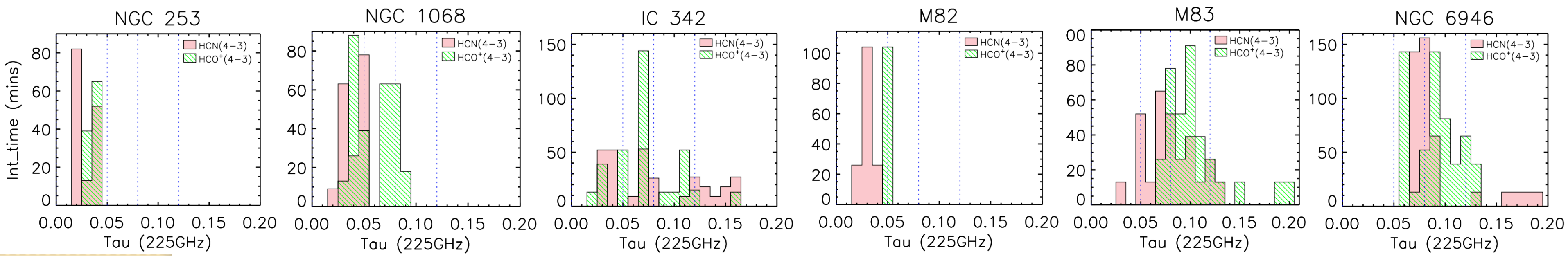




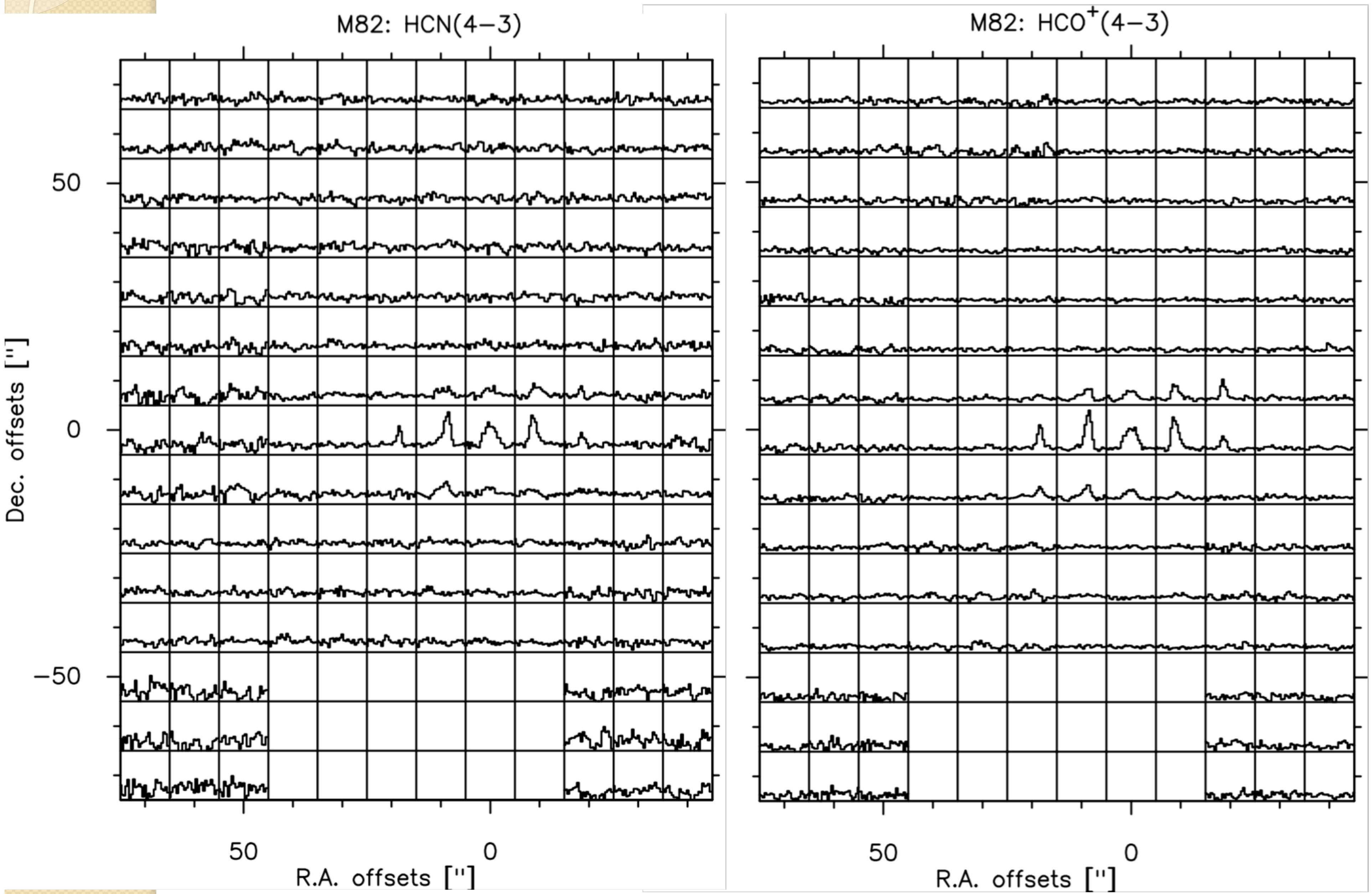



Table 2. Summary of observing parameters

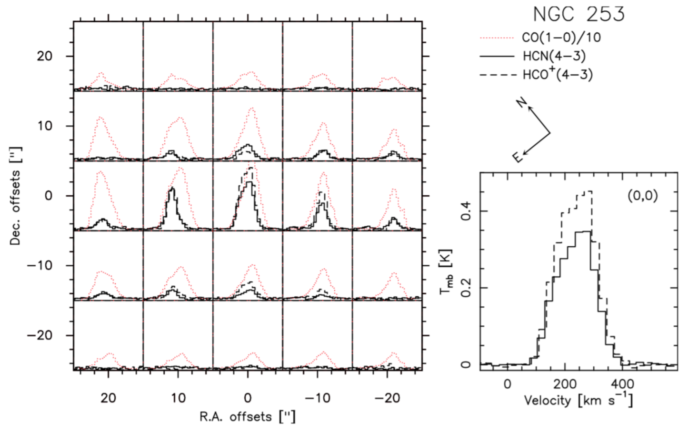
Galaxy	Molecule	Obs.Dates	$f_{\rm obs}$ (GHz)	ROT_PA (deg)	$\overline{T_{\rm sys}}$ (K)	$\overline{\tau}$ (225 GHz)	$t_{\rm int}$ (min)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NGC 253	HCN $J=4\to3$	2015-(1202,1210,1211)	354.223	51, −39	231	0.024	142
	$HCO^+ J=4\to3$	2015-1212	356.447	51, −39	281	0.036	100
NGC 1068	HCN $J=4\to3$	2015-(1213,1230,1231),2016-1114	353.191	0	246	0.046	250
	$HCO^+ J=4\to3$	2015-(1212,1213),2016-(0210,0623,1009)	355.411	0	328	0.072	287
IC 342	HCN $J=4\to3$	2015-(1202,1212,1216),2016-(1008,1009)	354.474	90	458	0.076	300
	$HCO^+ J=4\to3$	2015-(1213,1216,1220,1221,1224),2016-1007	356.701	90	453	0.070	352
M82	HCN $J=4\to3$	2015-(1210,1212)	354.265	65, 155	270	0.031	150
	$HCO^+ J=4\to3$	2015-1213	356.494	65, 155	338	0.051	100
M83	HCN $J=4\to3$	2016-(0622,0625,0712,0713,0714)	353.954	−45	459	0.075	300
	$HCO^+ J=4\to3$	2016-(0626,0711,0715,0716,0717,0718,0731)	356.132	−45	619	0.097	350
NGC 6946	HCN $J=4\to3$	2016-(0504,0615,0711,0712)	354.458	109	409	0.082	450
	$HCO^+ J=4\to3$	2016-(0505,0506,0616,0712,0713,0714,0715)	356.681	109	472	0.091	553

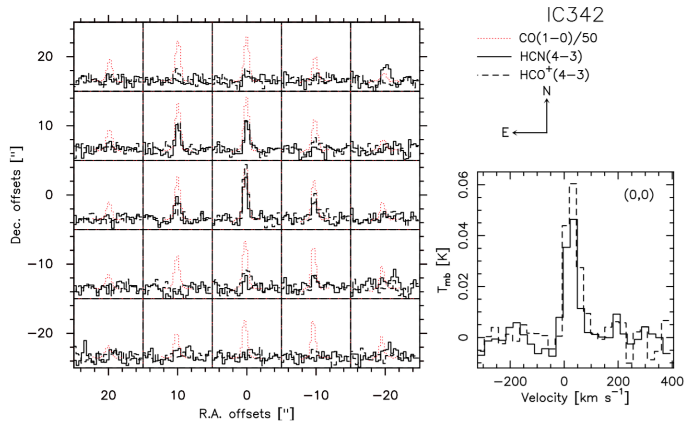


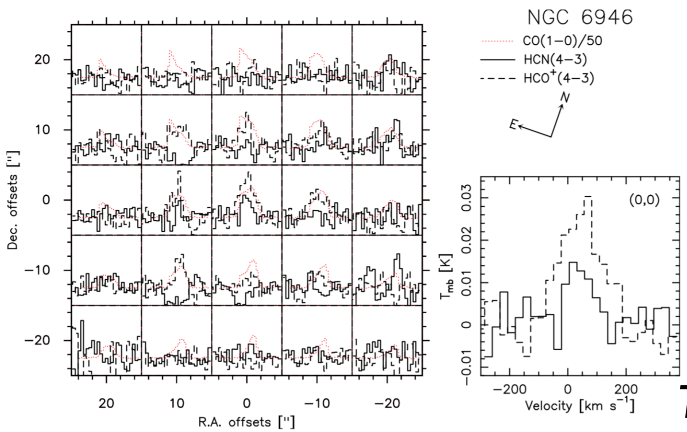
HCN (4-3) & HCO$^+$(4-3) spectra of M82

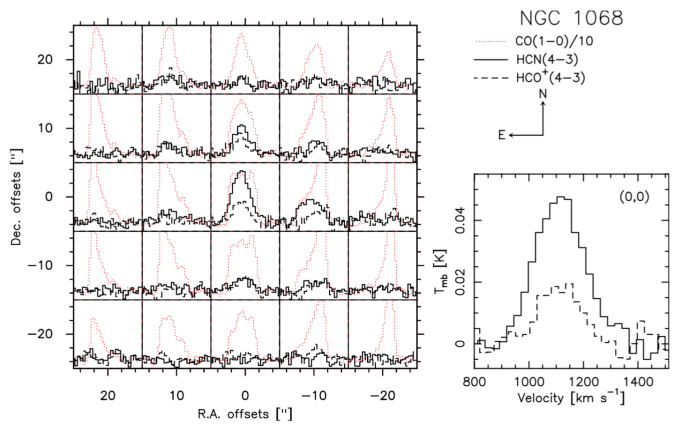


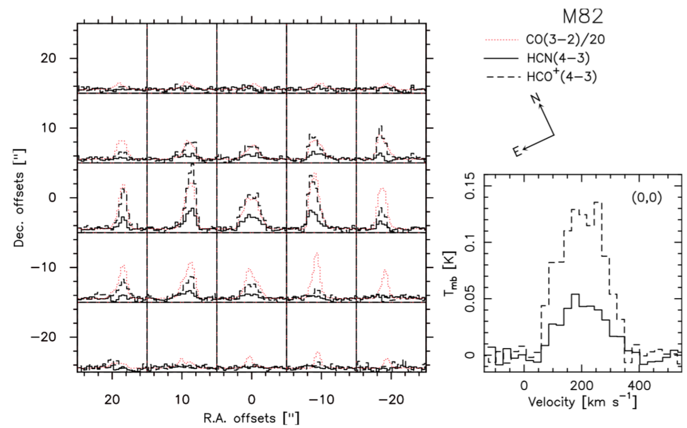
HCN, HCO+, & CO spectra

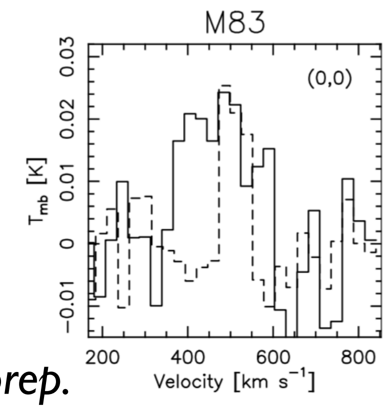








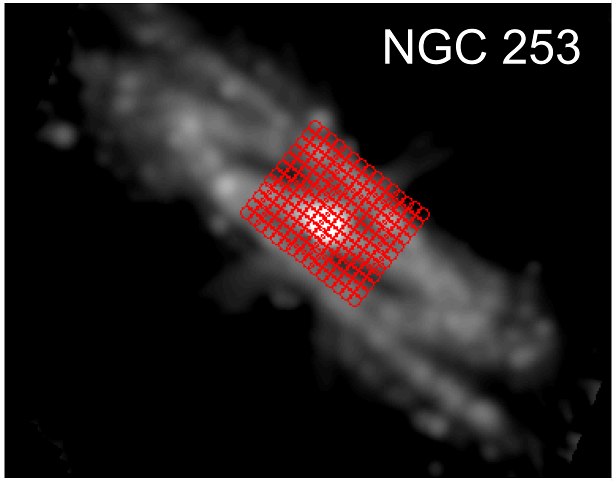




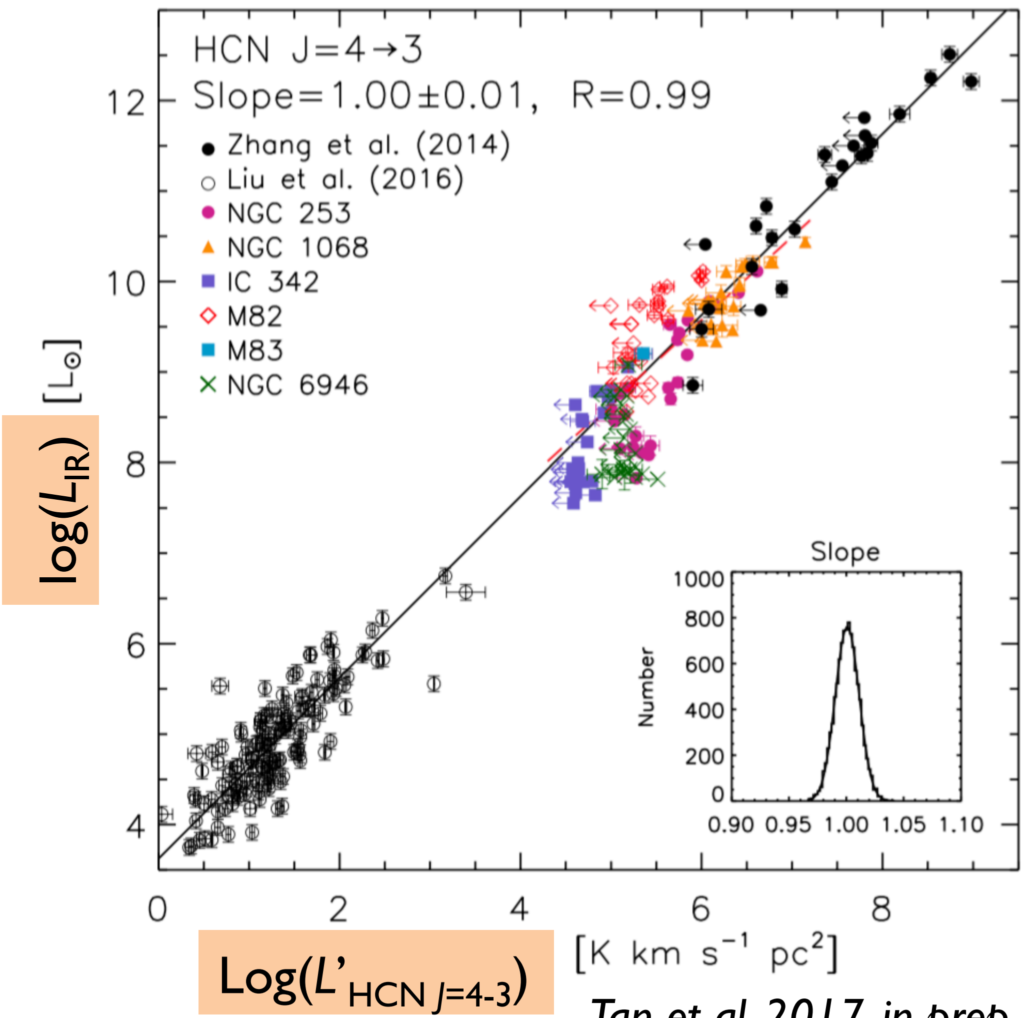
Tan et al. 2017, in prep.

Infrared photometry

- Convolve the infrared maps to the JCMT resolution (14")
  - Spitzer/MIPS & Herschel/PACS images
  - Convolution kernels: Aniano et al. (2011)
- Aperture photometry
  - IDL rountine: APER
  - Fix the sky value as the average of sky area
- Calculate IR luminosity
  - LTIR calibration: Galametz et al. (2013)



The $L'_{\text{dense gas}} - L_{\text{IR}}$ correlation



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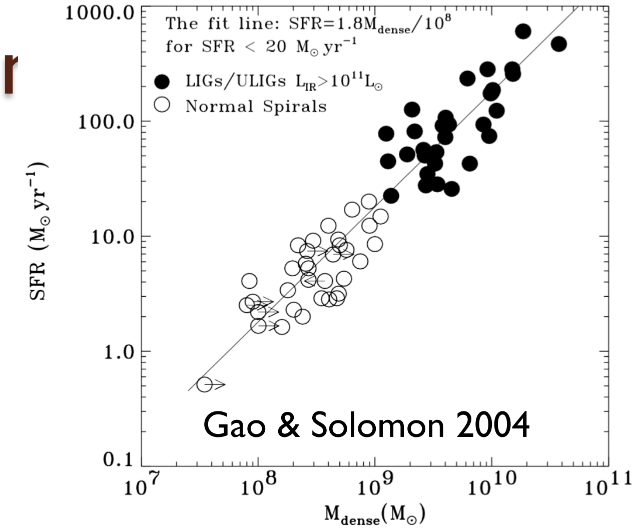
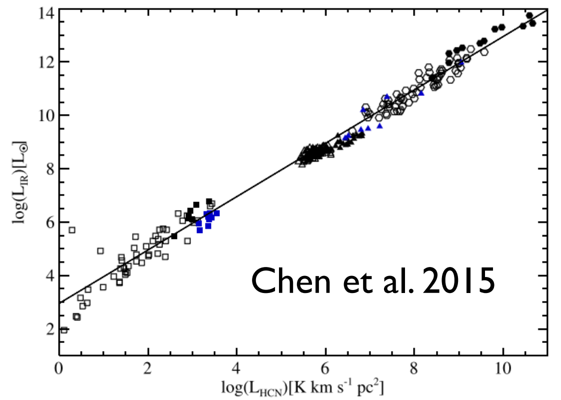
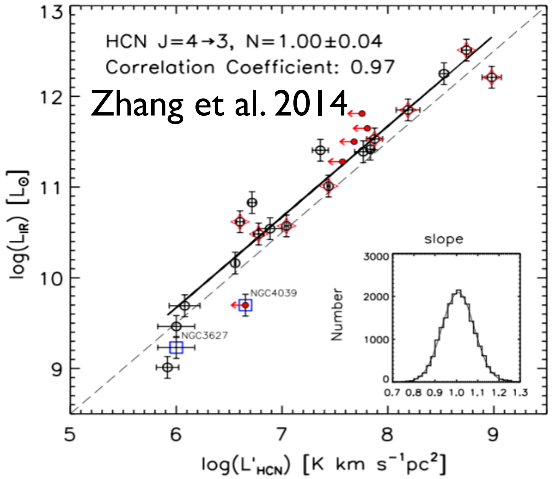
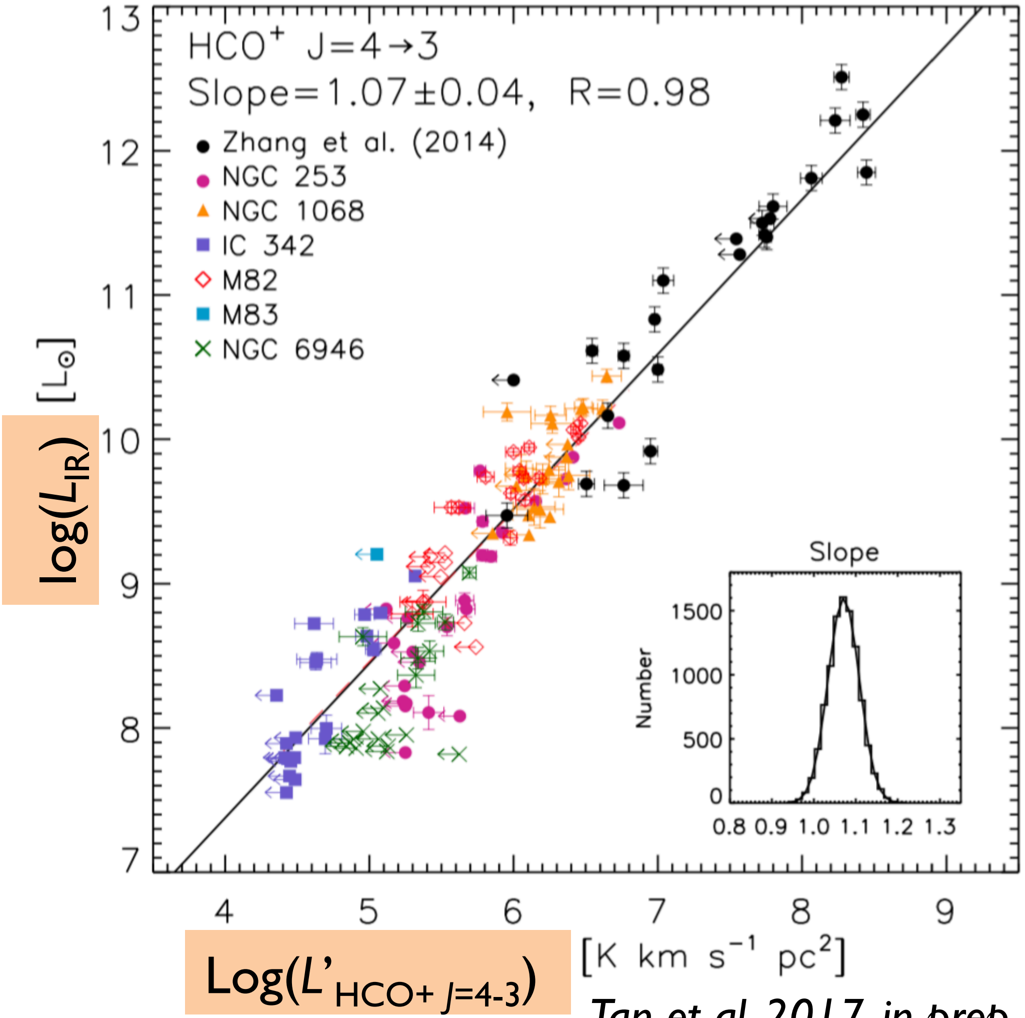






- fill the gap between GMC and galaxy scale
- verify the global SF law for nearby galaxies

The $L'_{\text{dense gas}} - L_{\text{IR}}$ correlation



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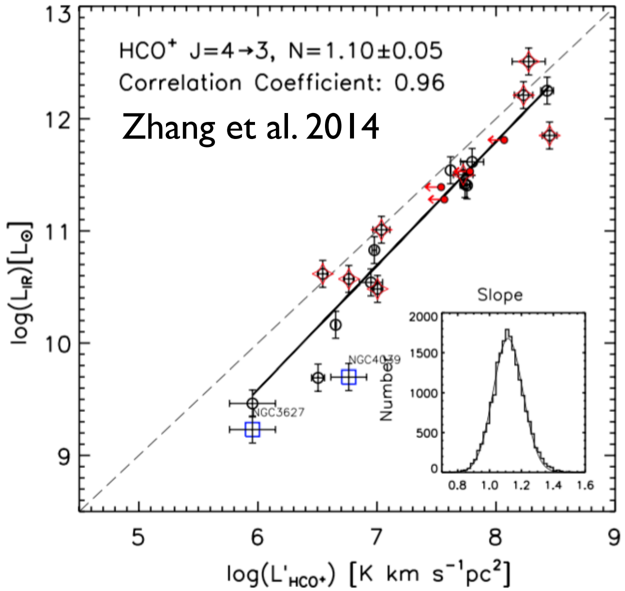
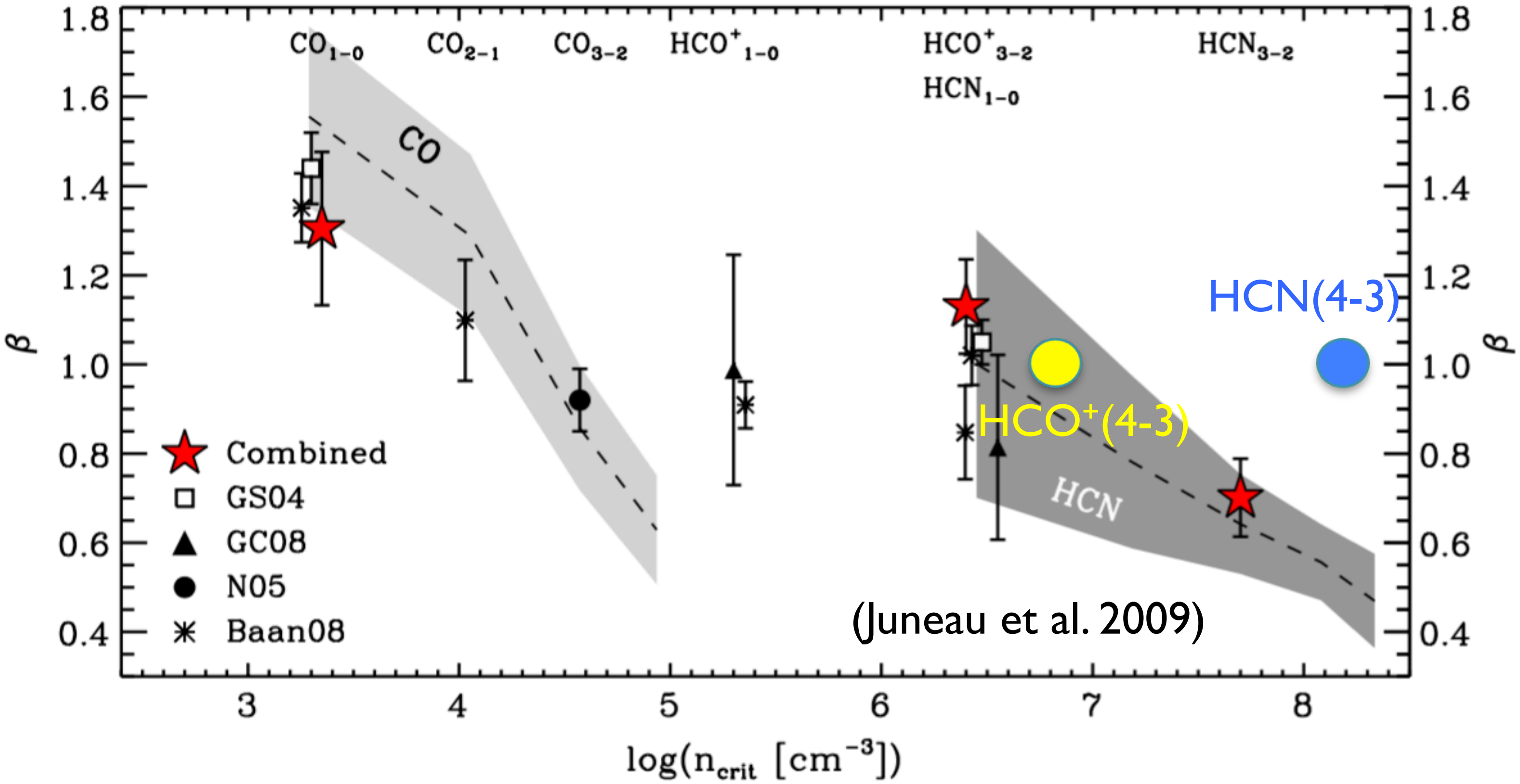
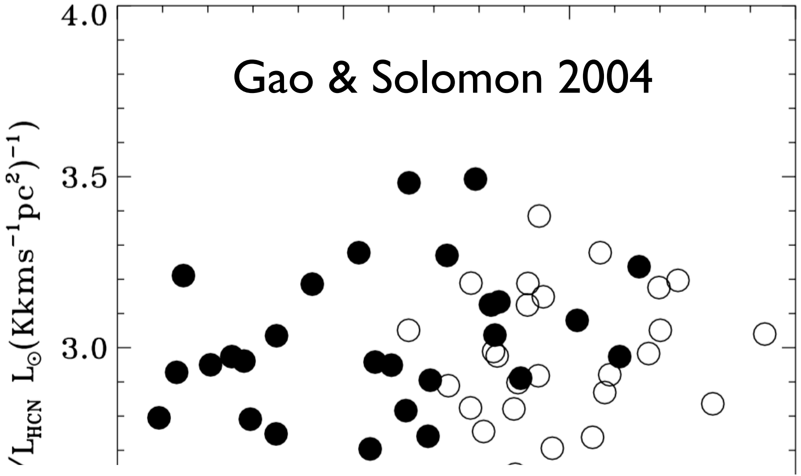


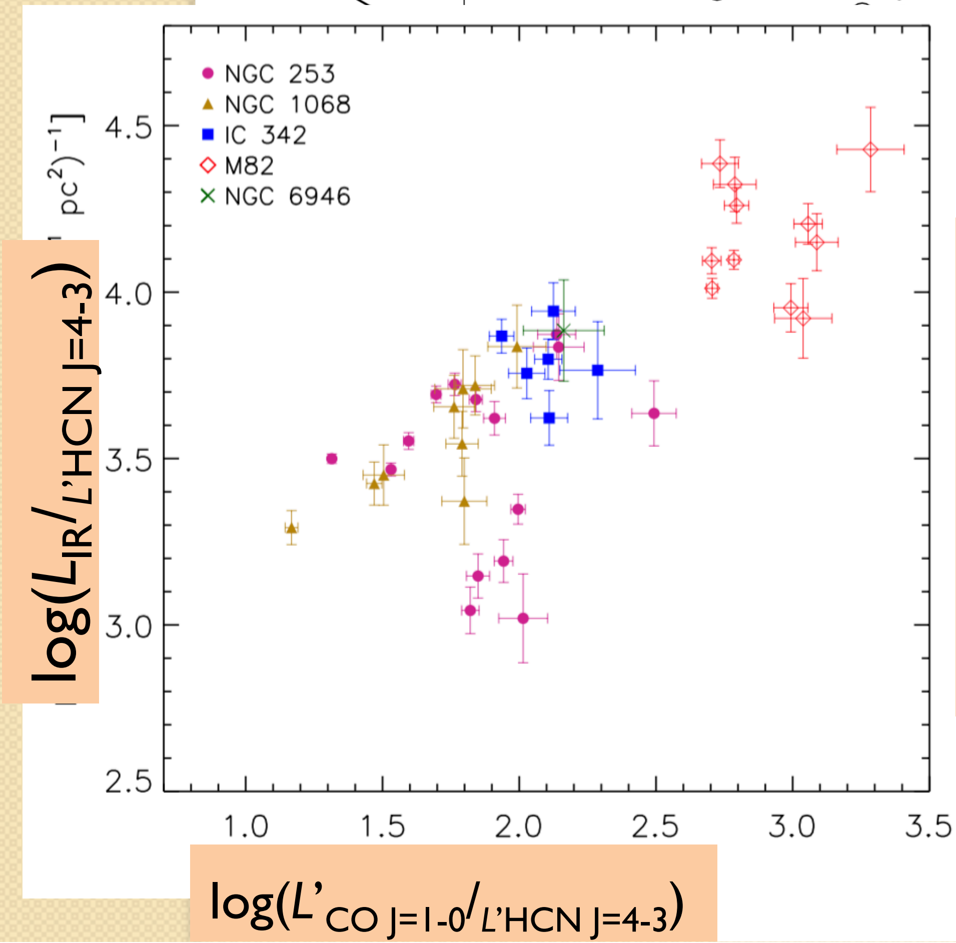
Slope of log(L_{IR})-log(L'_{gas}) vs. molecular line critical densities

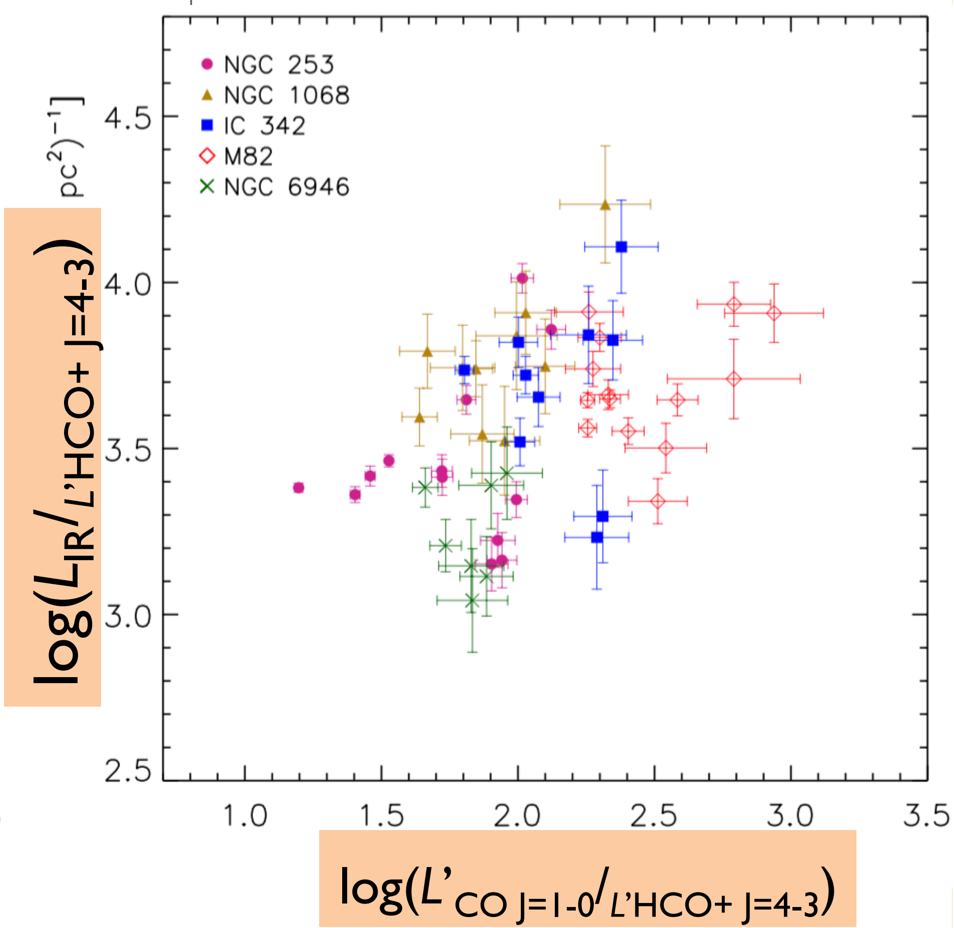


- Numerical simulations predict decreasing slopes against increasing critical density (i.e., Narayanan et al. 2008; Juneau et al. 2009)
- Our new data confirm the finding revealed by Zhang et al. (2014), the linear correlations between L'gas – LIR hold for all densities > 10^4 cm^{-3}.

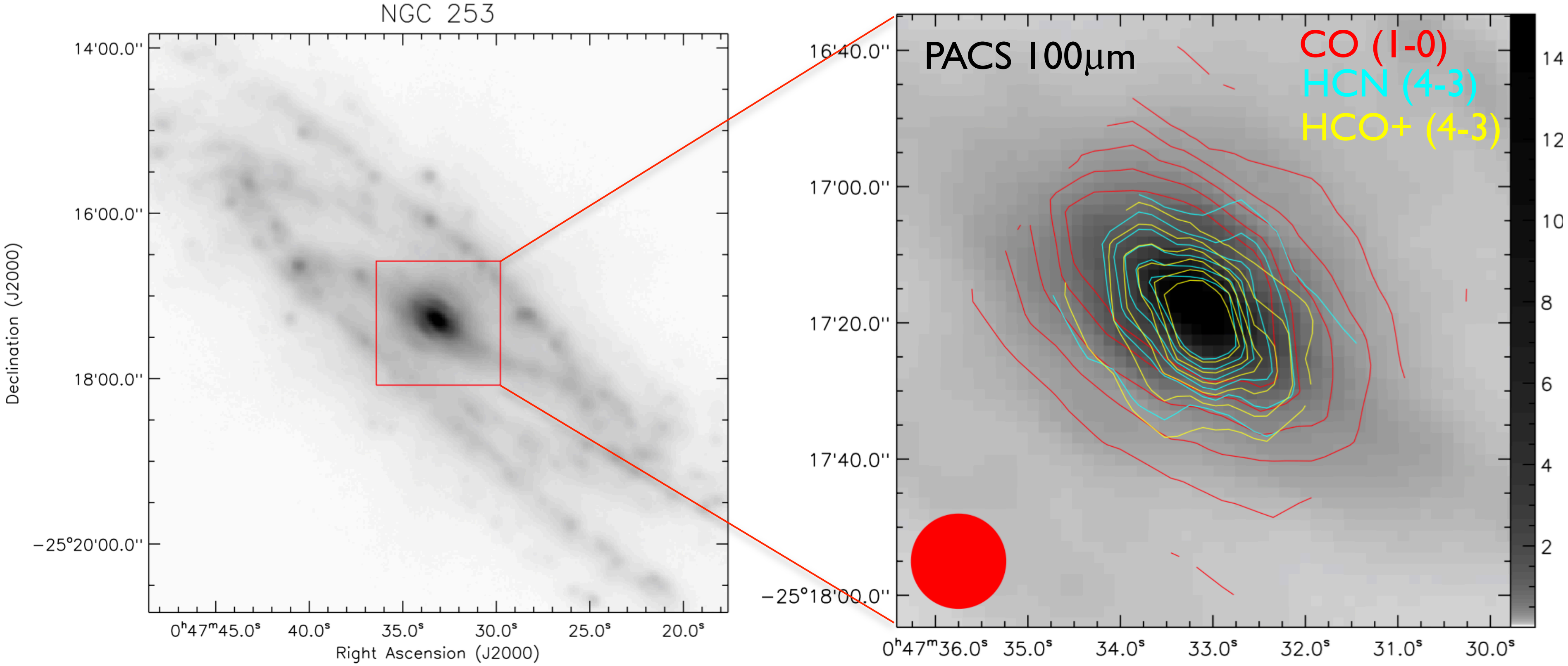


No correlation is found between *L*IR/*L*HCN and *L*CO/*L*HCN!





The distribution of star formation and gas emission



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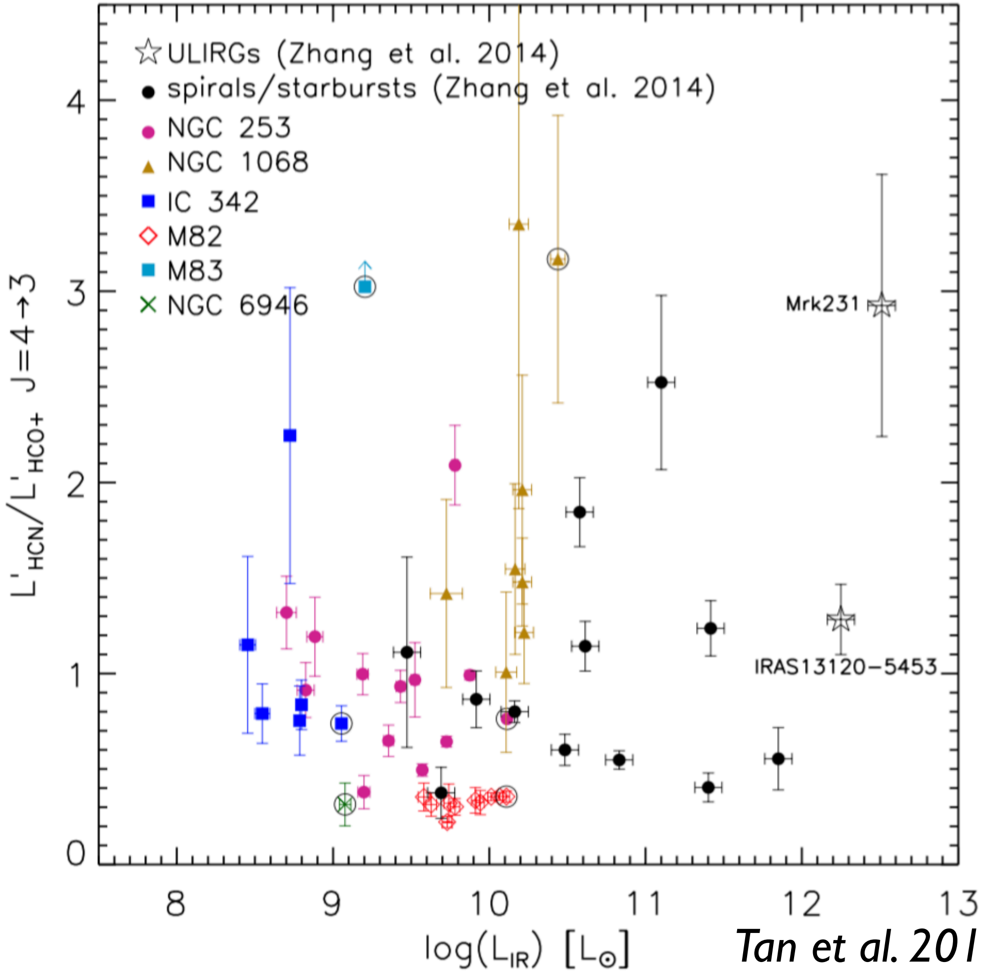
- CO emission extend to a larger area than that of dust and dense molecules
- The distribution of SF is better matched with dense gas, rather than the total molecular gas!

Ratio of L'_{HCN} / L'_{HCO+} vs. Infrared luminosity



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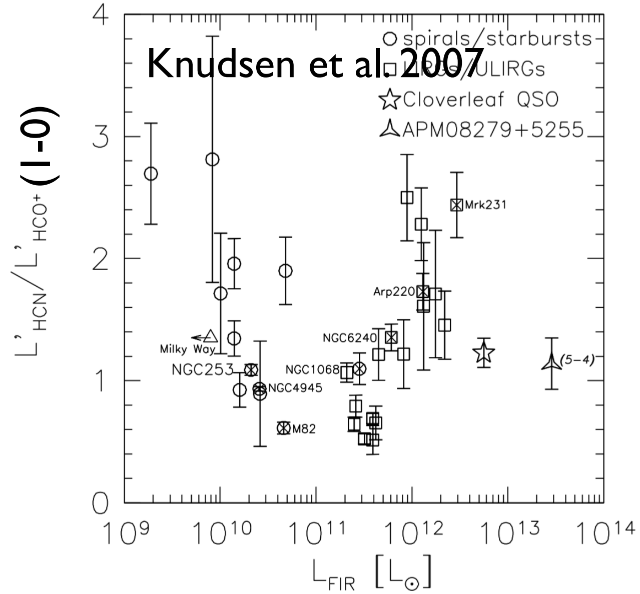

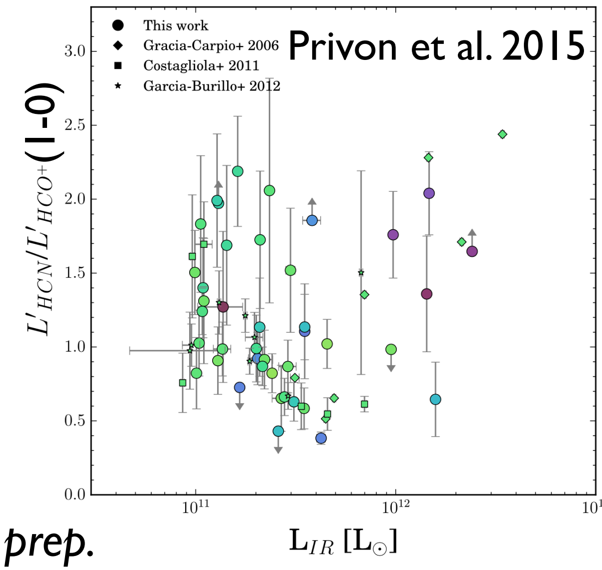

The variation of L'_{HCN} / L'_{HCO+} ratio reflect the different physical and chemistry conditions between galaxies.

Summary

- The mapping data in **sub-kiloparsec scale** fill the gap between GMC and galaxy, **verify the global dense gas SF law**.
- The **distribution of SF** is found to be **better consistent with dense gas** instead of the total molecular gas, providing direct evidence for the **true physical relationship** between **star formation** and **dense gas emission**.

Thank you!