A SEARCH FOR MOLECULAR GAS IN LOW LUMINOSITY RADIO SOURCES

Prandoni[1], R. Laing[2], P. Parma[1], H.R. de Ruiter[3], T. Wilson[2], F. Montenegro[1]

[1]Istituto di Radioastronomia del CNR, Bologna, Italy

[2]European Southern Observatory, Garching, Germany

[3]Osservatorio Astronomico di Bologna, Italy

Summary

We discuss CO spectral line data for a volume-limited sample of 23 nearby ($z<0.03$) low luminosity radio galaxies, selected from the B2 catalogue

Most of such objects (16/23) have HST imaging available

Our aims are:

A) to establish the distribution of molecular gas masses in low luminosity radio galaxies, in comparison with other samples.

B) to establish targets for future CO interferometric imaging

C) to determine the relation between CO and the dusty disks observed with HST in most of such objects, and confirm the suggestion that the CO is in ordered rotation.

Observations & Line Measurements

Telescope used: IRAM 30 m at Pico Veleta

Emission lines searched for: (1→0) and (2→1) transitions of ^{12}CO

Receivers and rms noise levels (outputs summed & Δv_{res}~40 km/s):

A100/B100 → 0.5 – 1 mK   A230/B230 → 1 – 2 mK

Number of sources observed: 9   (July and October 2005)

Data reduction: CLASS package

Line measurements: channels summed in the line profile (at FWHM)

Detection criteria: both CO lines detected ($T_{peak}/T_{rms} > 2$)
AND at least one sure detection ($T_{peak}/T_{rms} > 3$)

Upper limits → $T_{mb} dv < 3T_{rms} \Delta v_{FWHM} \sqrt{(\Delta v_{FWHM} / \Delta v_{res})}$

where $\Delta v_{FWHM} = 500$ km/s (av. FWHM line width of detected sources)
$\Delta v_{res} = 42$ km/s (velocity resolution after smoothing)

$M(H_2)$ → $M(H_2) = 11.2 \times 10^{18} K/[\eta_a (H_0 D)^2] \{[(1+z) - \sqrt{(1+z)}]^2/(1+z)\} \Sigma T_a^* dv$

where D = 30 m (telescope diameter); K = 1 (for point sources);
$\eta_a = B_{eff} * 0.79$ (telescope efficiency at obs. frequency);

(Lim et al. 2000)

Observed Dataset

Source	$^{12}CO(1\rightarrow0)$ $\Sigma T_a^* dv$ (K km/s)	$^{12}CO(1\rightarrow0)$ Δv_{FWHM} (km/s)	$^{12}CO(1\rightarrow0)$ T_{peak}/T_{rms}	$^{12}CO(2\rightarrow1)$ $\Sigma T_a^* dv$ (K km/s)	$^{12}CO(2\rightarrow1)$ Δv_{FWHM} (km/s)	$^{12}CO(2\rightarrow1)$ T_{peak}/T_{rms}
0120+33	<0.35	-	-	<0.61	-	-
0149+35	1.34	545	5.4	3.15	551	7.7
0258+35	0.88	382	6.6	0.21	127	2.4
0326+39	<0.35	-	-	0.64	171	1.9
0331+39	1.35	807	3.6	0.90	679	3.4
1122+39	6.84	670	23.0	5.93	672	16.7
1217+29	0.58	346	3.3	0.87	335	3.1
1321+31	<0.35	-	-	1.24	297	2.7
1615+35	<0.35	-	-	0.52	129	4.1

NB: *undetected sources *detected sources (see Figures 1 e 2)

Figure 1 - $^{12}CO(1 \rightarrow 0)$ spectra

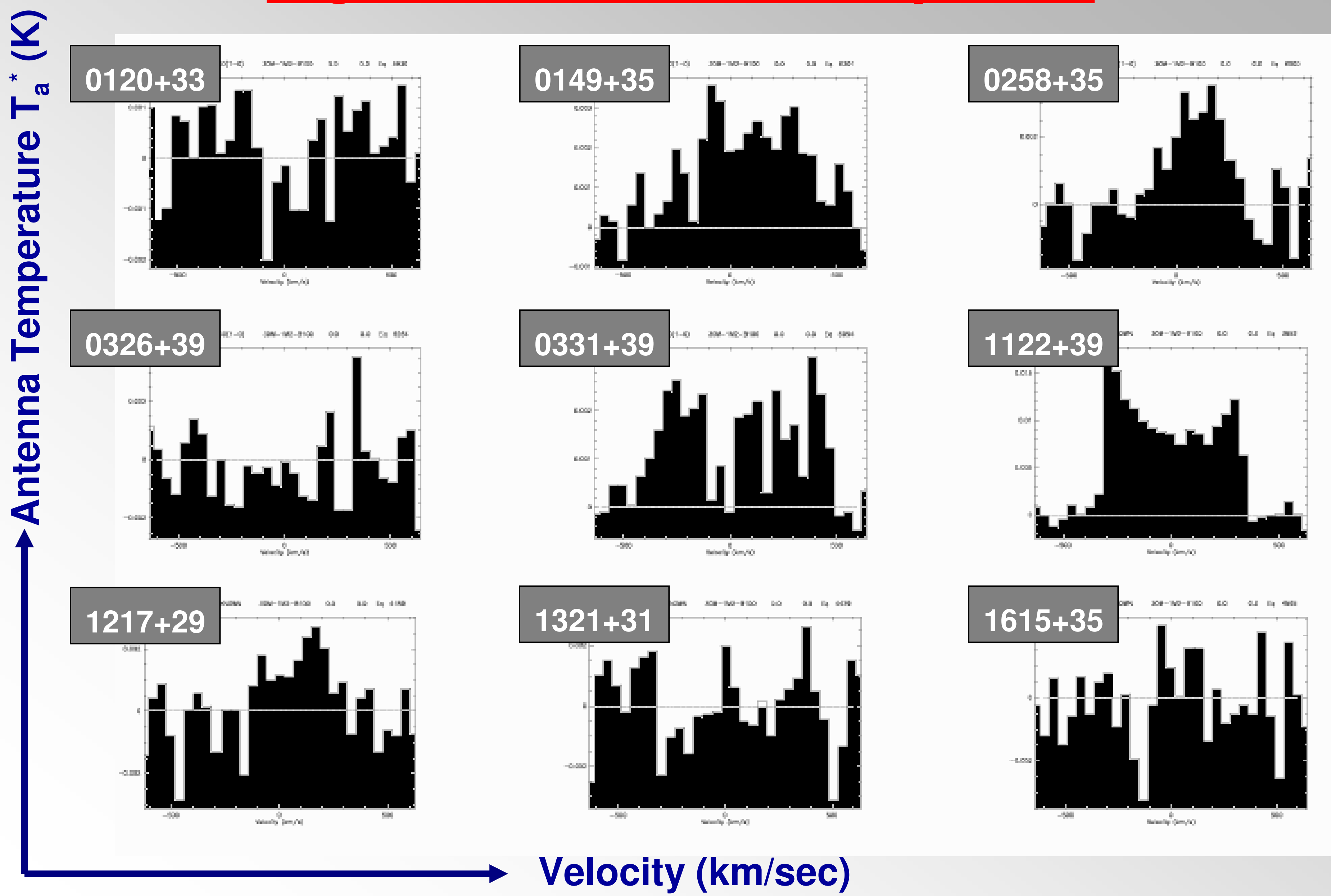
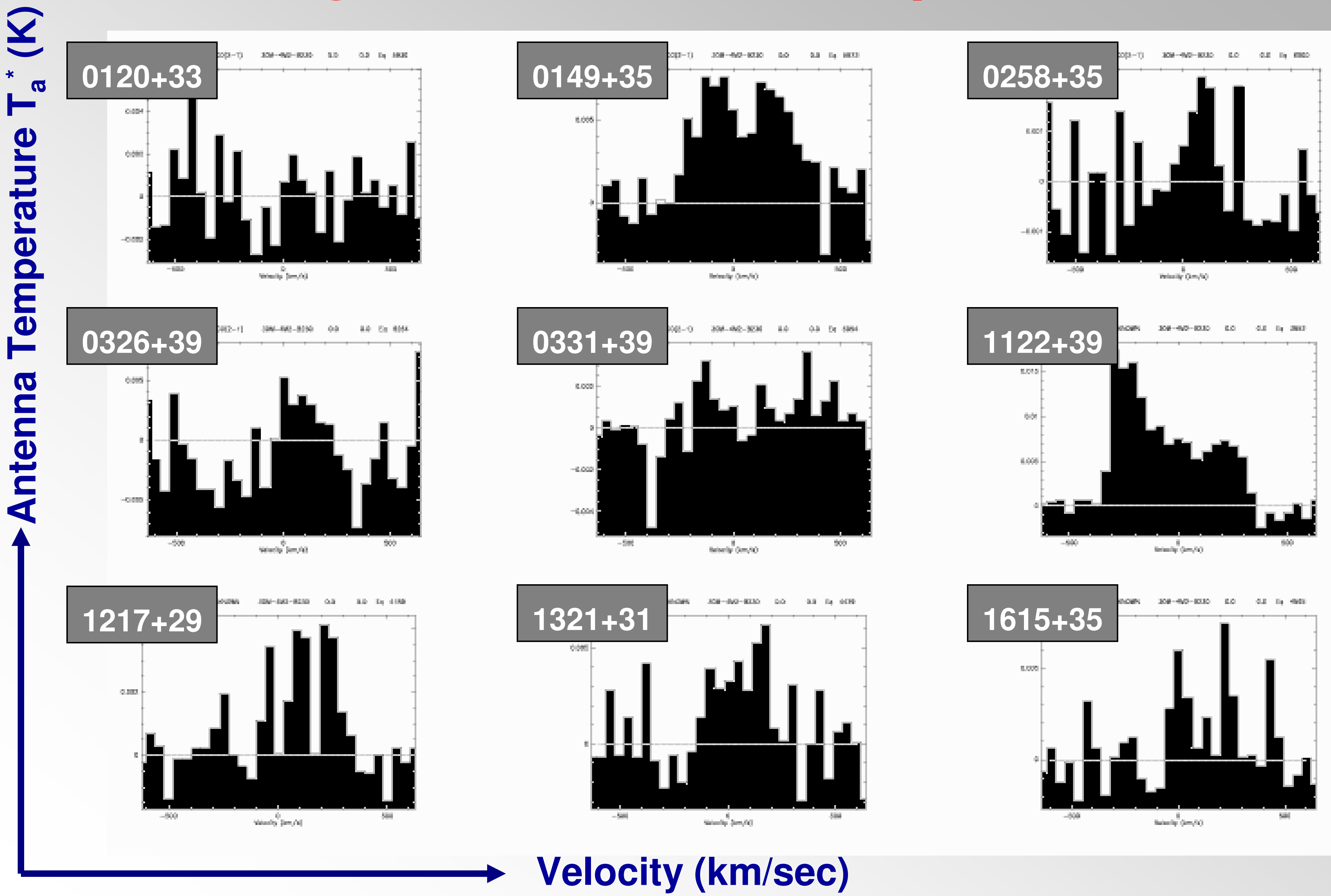


Figure 2 - $^{12}CO(2 \rightarrow 1)$ spectra



A) The B2 z<0.03 sample

			IRAS(1)			CO obs		HST obs(2)	
Source	z	$lgP_{1.4GHz}$	$S_{60\mu}$	$S_{100\mu}$	lgM_{dust}	Ref.	$lgM(H_2)$	lgM_{dust}	Dust morph.
		W/Hz	mJy	mJy	M_{sun}		M_{sun}	M_{sun}	
005530	0.017	24.08	363	586	5.9	UGC	8.1	2.9	disk
010432	0.017	24.21	444	1720	6.4	UGC	8.7	5.1	disk
012033	0.016	22.30	<140	<347	<5.7	B2	<7.7	-	no dust
014935	0.016	22.33	273	1247	6.2	B2	8.3	4.4	disk
020738	0.018	22.59	-	-	-	-	-	-	-
025835	0.016	23.67	177	<441	<5.8	B2	8.1	-	-
032639	0.024	24.06	<140	<410	<6.1	B2	<8.0	-	-
033139	0.020	23.69	<140	<410	<6.0	B2	8.5	-	-
092430	0.027	23.52	<126	<315	<6.1	-	-	-	no dust
110138	0.030	23.97	181	361	6.2	-	-	-	?(*)
112239	0.007	21.81	1813	7014	6.2	B2	8.2	-	disk(**)
121729	0.002	21.24	618	2041	4.7	B2	6.1	2.6	complex
125427	0.025	22.63	-	-	-	-	-	-	-
125628	0.022	23.05	<25	<85	<5.4	-	-	2.6	disk
125728	0.024	23.08	<25	<85	<5.4	-	-	-	no dust
132131	0.016	23.85	<140	<347	<5.7	B2	<7.7	3.6	disk
132236	0.018	24.55	<153	<378	<5.8	UGC	<8.3	3.3	disk

A) The B2 z<0.03 sample – Cont'd

Source	z	$lgP_{1.4GHz}$	$S_{60\mu}$	IRAS([1]) $S_{100\mu}$	lgM_{dust}	CO obs Ref.	$lgM(H_2)$	HST obs ([2]) lgM_{dust}	Dust morph.
		W/Hz	mJy	mJy	M_{sun}		M_{sun}	M_{sun}	
161535	0.030	24.30	<112	<284	<6.1	B2	<8.2	–	–
162639	0.030	24.49	<38	<113	<5.7	3C	<8.1	4.9	filament
211626	0.016	22.79	538	1276	6.3	UGC	8.2	4.7	disk
222939	0.018	24.03	186	1029	6.3	UGC	8.1	4.3	disk
223635	0.028	23.47	<140	<347	<6.2	–	–	–	no dust
233526	0.030	24.88	149	<198	<6.0	3C	<8.2	3.8	disk

Notes:

([1]) Impey & Gregorini 1993 ([2]) de Ruiter et al. 2002

CO obs ref. → UGC = Leon et al. 2003 3C = Lim et al. 2003
B2 = our IRAM obs - = not available

(*) not determined because Bl Lac

(**) Dust morphology from ground observations

Source 020738: only Spiral in the sample

For H_2 mass det.: $\Sigma T_a^* dv$ for $^{12}CO(1 \rightarrow 0)$; H_0 = 100 km/s/Mpc; $\Omega = 1$

The B2 z<0.03 sample → Dust vs. H_2 Mass

- ● M_{Dust} from IRAS
- ▼ Upper limits for M_{dust}
- ● M_{Dust} from HST
- ◀ Upper limits for $M(H_2)$

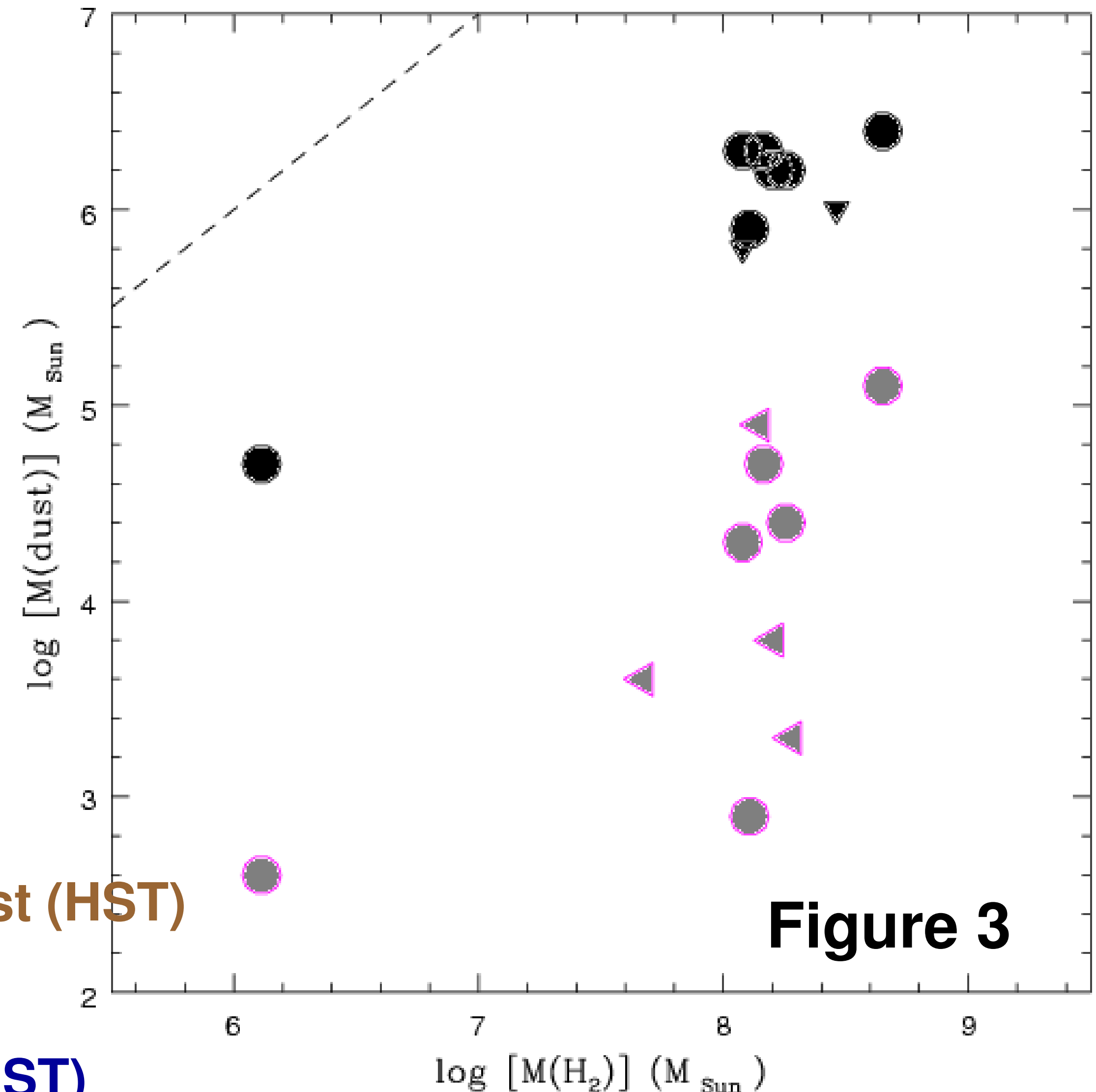


Figure 3

We notice (Figure 3):

→ Objects detected in IRAS always detected in CO

→ Objects detected in CO always show optical dust (HST) (see also Fig. 4)

→ $M(H_2)>M_{dust}(IRAS)>M_{dust}(HST)$

1) M_{dust}(IRAS) ~ 10-100 M_{dust}(HST) → due to different scales probed

whole galaxy for IRAS FIR observations

inner galaxy core for HST high resolution observations

2) CO obs. approx. sensitive to same scale as HST

[<5-10 kpc at $^{12}CO(1-0)$ obs. frequency]

➔ probe same structures

- see examples in Figures 5 and 6
- see few existing interferometric CO obs. showing CO rotating disks which coincide with HST dusty disks (Okuda et al. 2005)

Figure 4 - CO line detection → dust in galaxy core

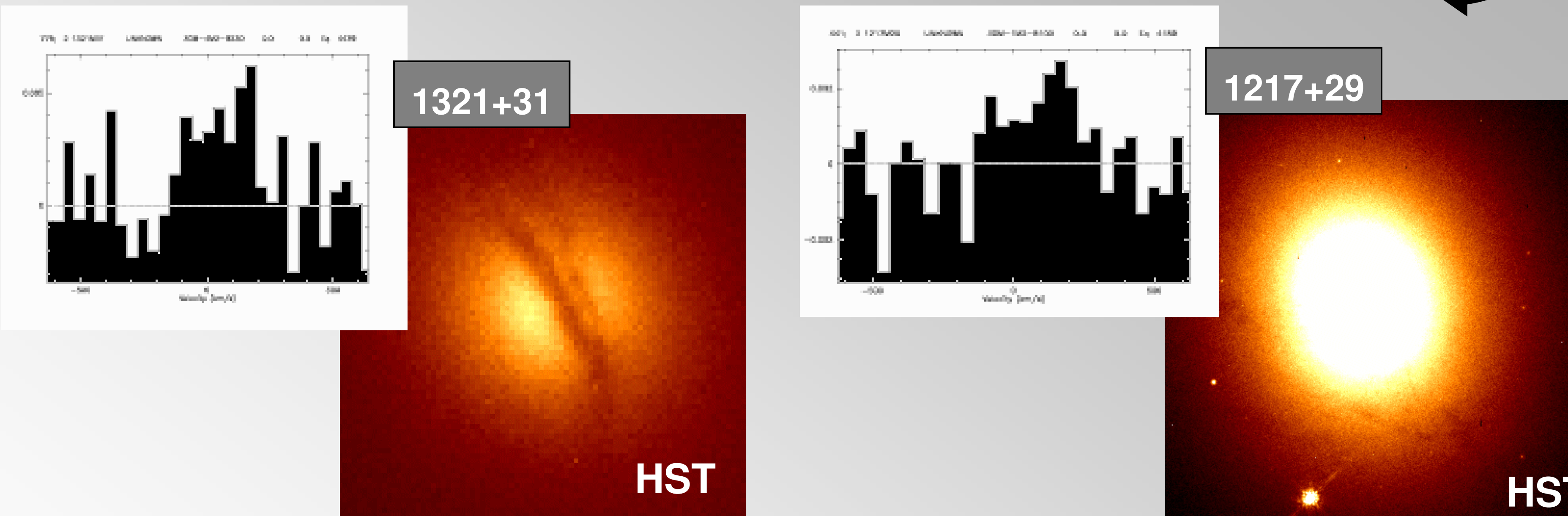


Figure 5

No dust in galaxy core
→ no CO detection

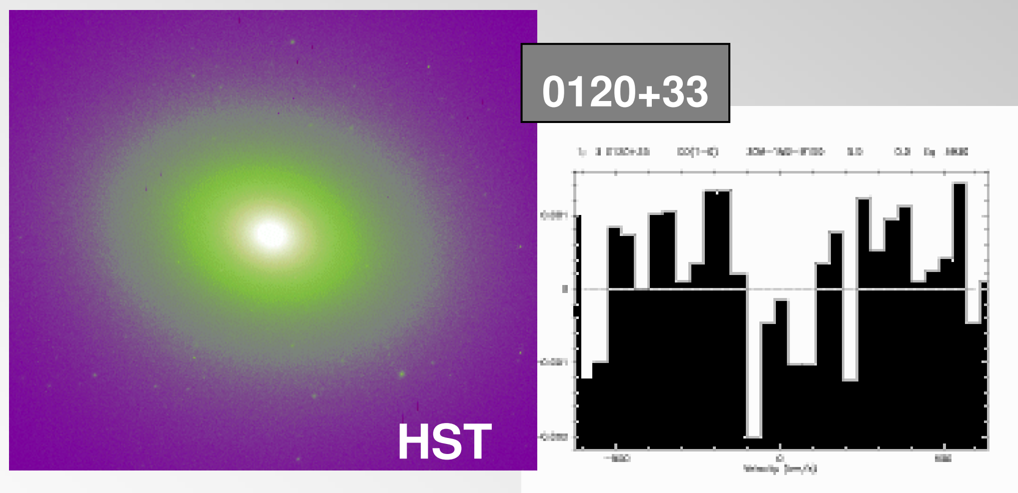
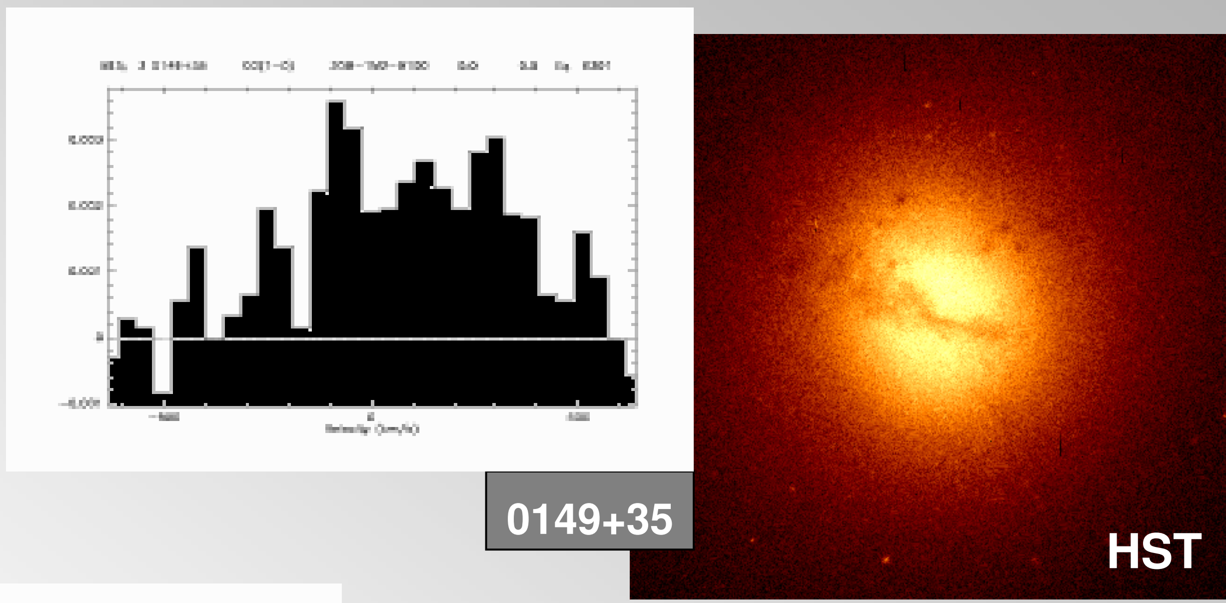
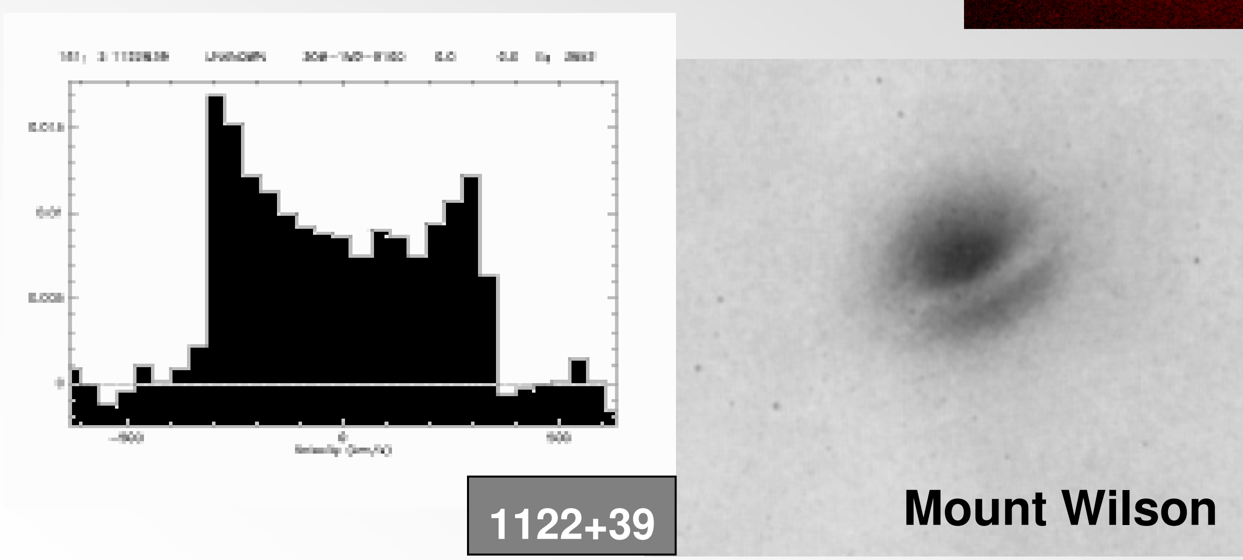


Figure 6 - double-horn CO lines associated to rotating dusty disks





Comparison Samples

B) 3C: All radio galaxies with $z<0.03$

volume limited sample of 23 objects

Ref. → Lim et al. 2003

C) UGC: All galaxies with:

- → $v<7000$ km/s ($z<0.0233$)
- → optical diameter > 1 arcmin
- → radio jets

volume limited sample of 18 objects

Ref. → Leon et al. 2003

NB: Samples A, B and C are partially overlapping

Redshift distribution & CO detection rates

A) **B2:** most at z <0.023 → N_{tot} =23 N_{obs}=16 N_{det}=9

B) **3C:** most at z >0.02 → N_{tot} =23 N_{obs}=22 N_{det}=4

C) **UGC:** all at z<0.0023

Samples probe different volumes

→comparison in same reshift range

at z <0.023:

A) N_{tot} =14 N_{obs}=12 N_{det}=9

→ N_{det}/N_{obs}= 75 ± 25%

B) N_{tot} =13 N_{obs}=12 N_{det}=4

→ N_{det}/N_{obs}= 33 ± 17%

C) N_{tot} =18 N_{obs}=17 N_{det}=8

→ N_{det}/N_{obs}= 47 ± 17%

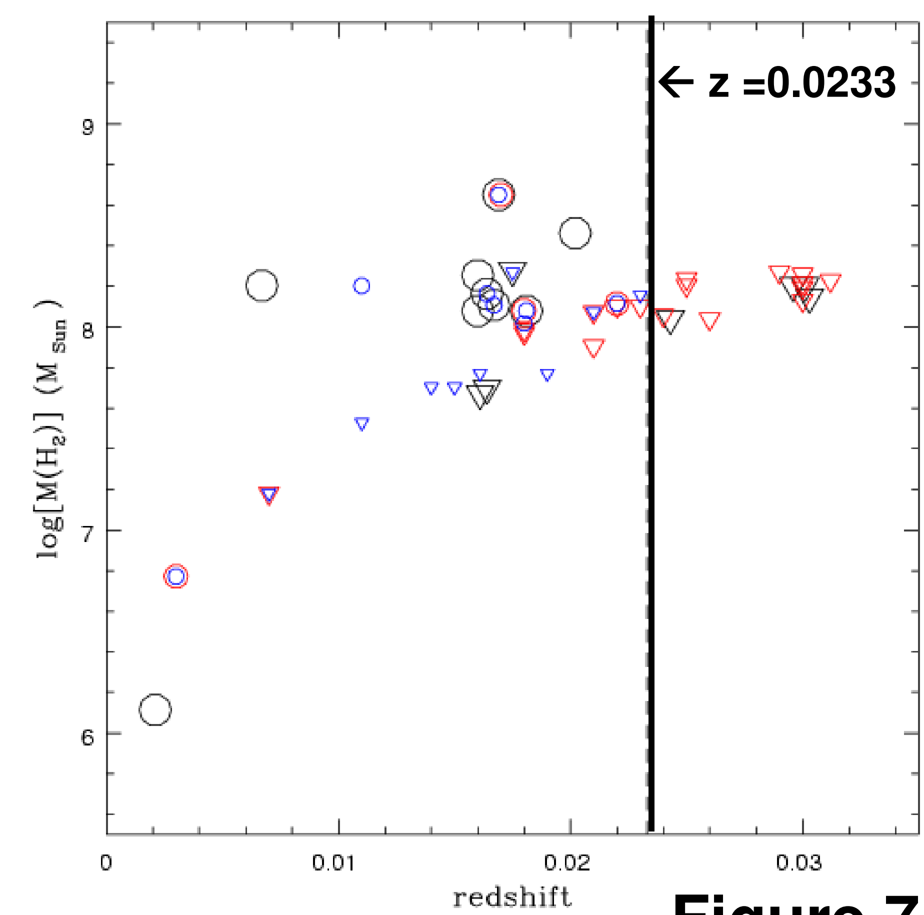


Figure 7

Conclusions

1) Evidences for a relation between CO and the dusty disks observed with HST

   ➔ Detected sources will be proposed for CO interferometry to confirm such evidences

2) No significant difference in detection rates among different samples of local radio sources

   once corrected for volume effects

3) No correlation between radio power $P_{1.4\ GHz}$ and molecular gas mass $M(H_2)$

   Caveat: radio power range is here very limited

   NB: a correlation between M_{dust}(HST) and $P_{1.4\ GHz}$ found by de Ruiter et al. 2002