Extragalactic High-J CO Observations and their Interpretation

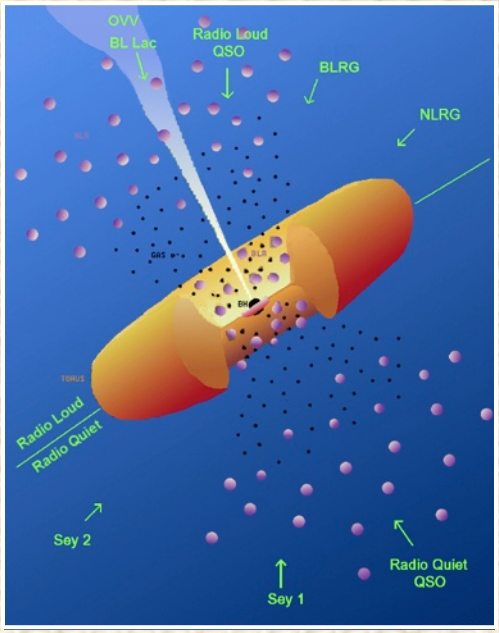
A. Poglitsch

for the

SHINING Consortium

High-J CO in local galaxies with Herschel

- CO SLED observations of "template" galaxies
- Probing AGN environment
- CO line ratios as new diagnostic tool



Extragalactic High-J CO: "Historical" context

Krolik & Lepp (1989):

If the AGN torus exists, it should emit not only in thermal continuum (mid-IR), but also in molecular cooling lines (e.g. FIR)

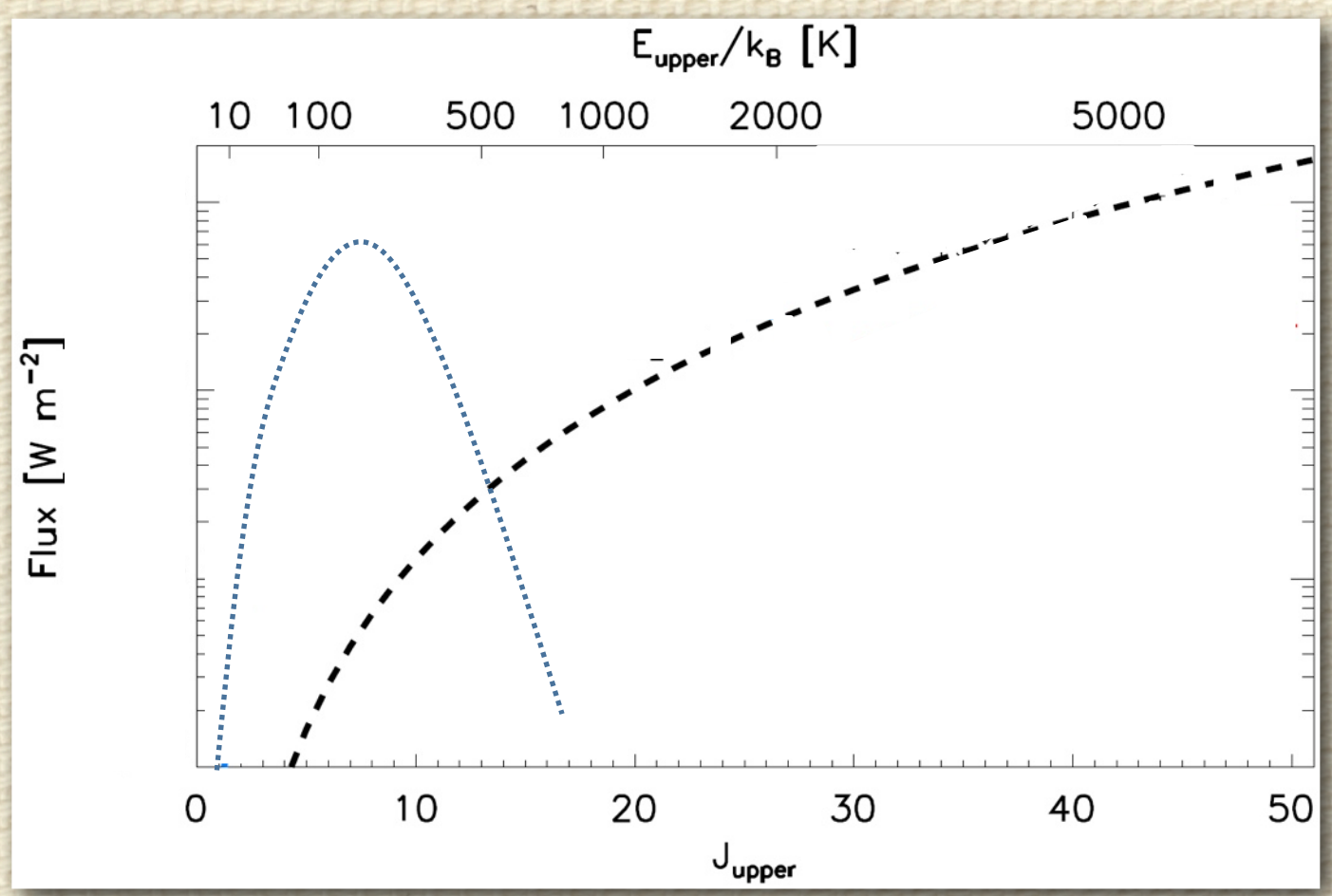
→ detectable fraction of L_{bol} in IR molecular lines (mid-IR H_2, far-IR CO)

Promise of high-J CO lines: strong enough, little extinction, not or only weakly produced in normal star formation regions (i.e. direct tracer of torus)

Krolik & Lepp 1989 – FIR CO lines from the Torus:

$L_{CO} \sim (f_{abs} \times L_{x,44}) \times J^3$

$L_{57} = 7 \times 10^{40} f_{abs} L_{x44}$ ergs^{-1} (J = 58 → 57.46 μm)



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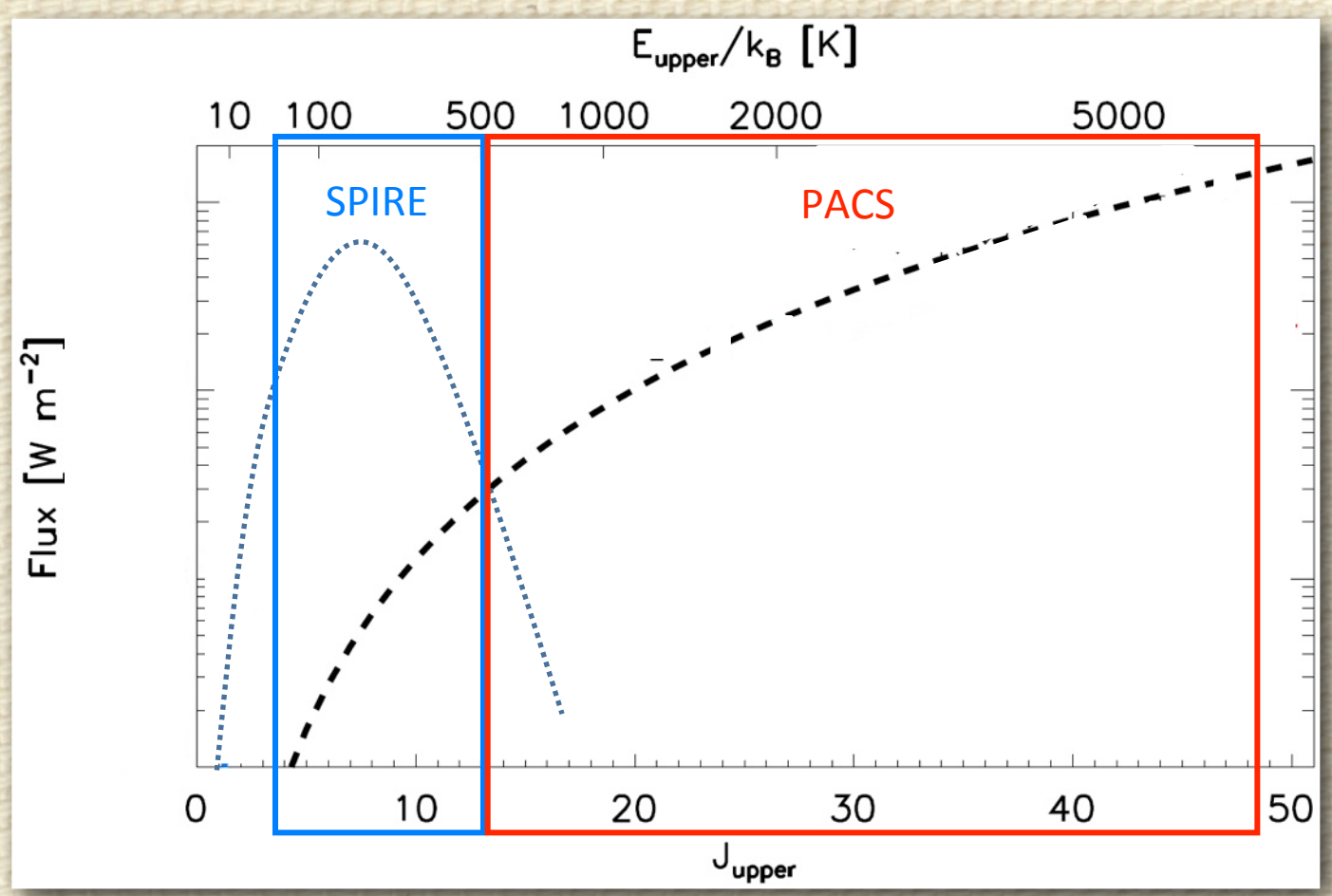
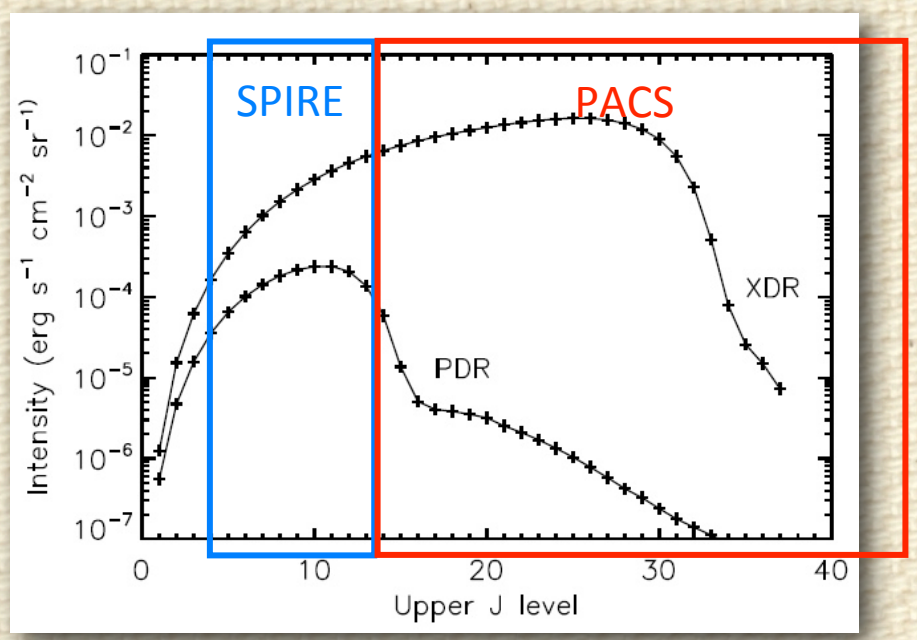
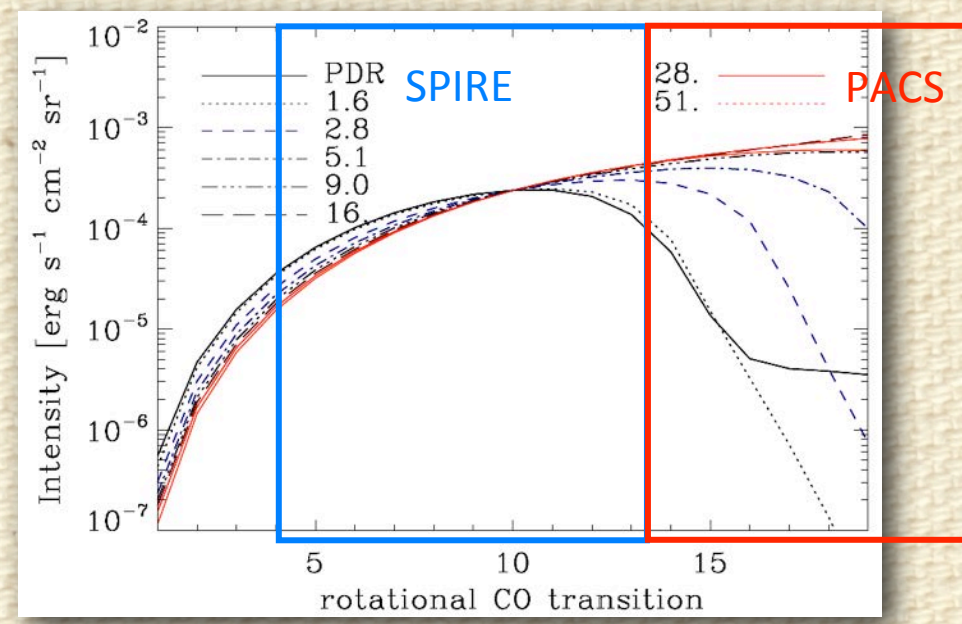


Extragalactic High-J CO: “modern“ context



Spaans & Meijerink 2008

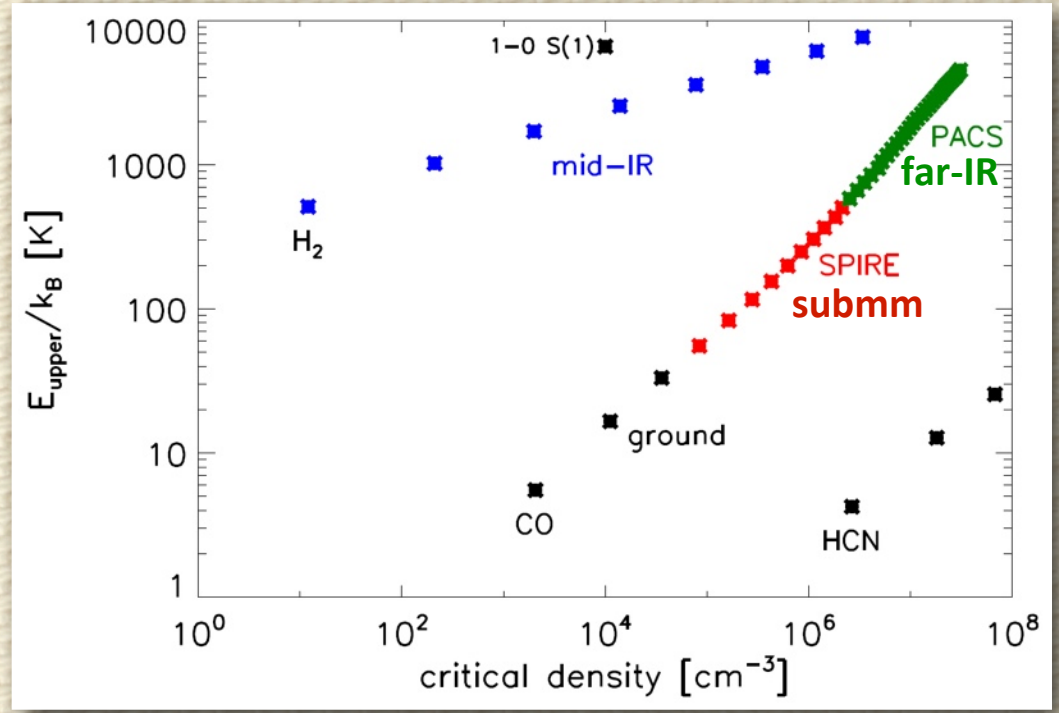


Schleicher+ 2010

High-J CO → A new probe of warm and dense molecular gas

SB, AGN, feedback, galaxy evolution
- UV/X-ray (AGN torus)
- Cosmic rays
- Jets
- Turbulence
- Mergers vs. cold accretion
- Galaxy dynamics
- Outflows

Methods
- Galactic templates
- Non-LTE radiative transfer
- PDR/XDR/shock models
- High resolution spectral imaging

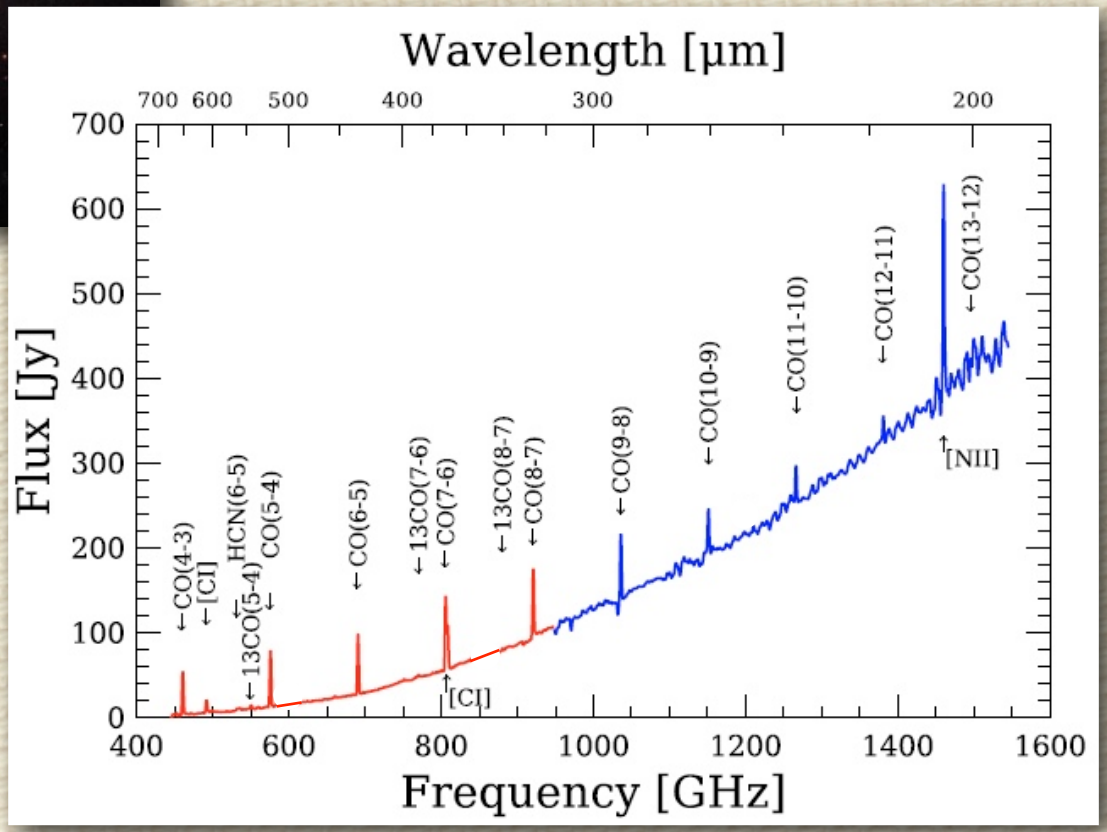


Nearby templates:

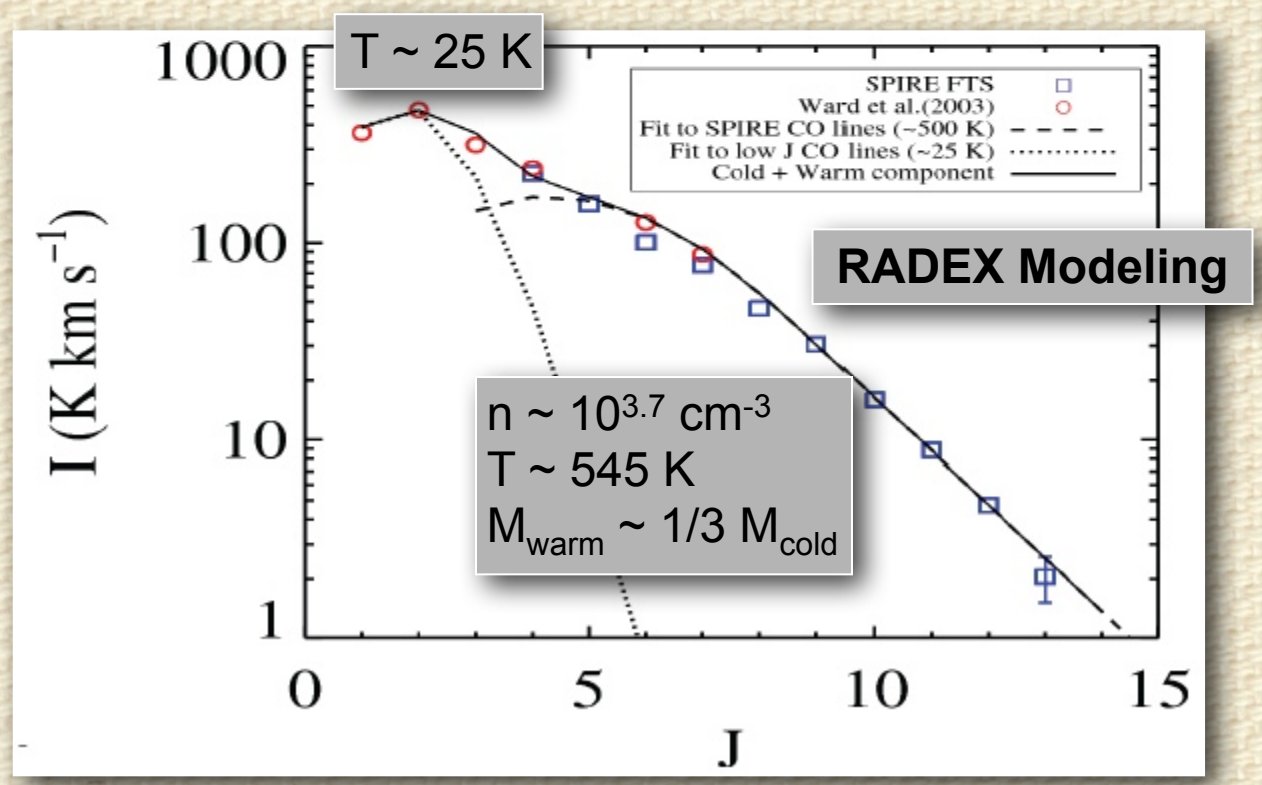
M82(SB)
NGC1068 (Sy)

M82 (Panuzzo+2010, SPIRE)

43.4” beam
~ 830 pc



M82 (SPIRE)



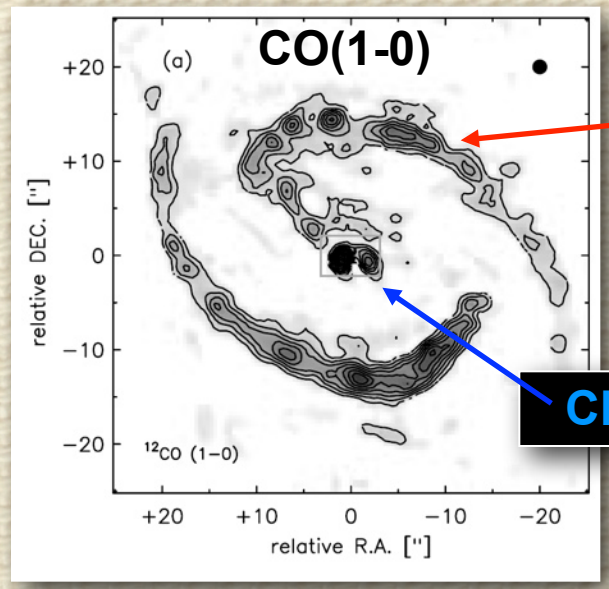
Panuzzo+ 2010,
Kamenetzky+ 2012

- Higher J lines much brighter than PDR predictions
  ⇒*not tracing UV-heated gas*
- Cosmic ray density too low
- Dissipation of turbulence

⇒ ***stellar wind and supernovae***

NGC 1068

Hailey-Dunsheath+2012, PACS
Spinoglio+2012, SPIRE

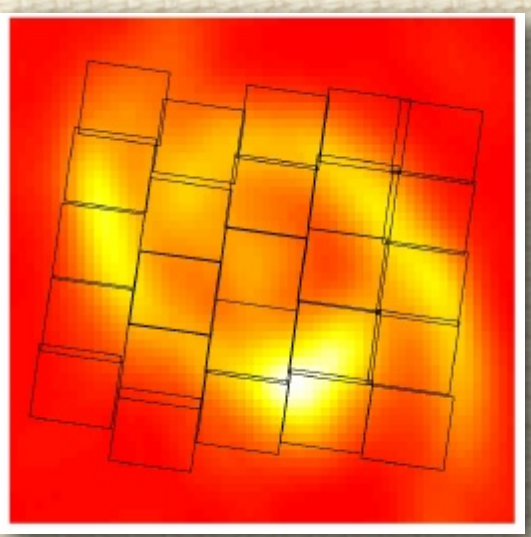


2 kpc

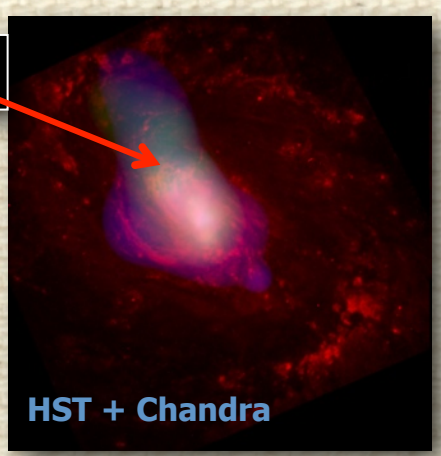
SB ring

CND ~300 pc

Schinnerer+00

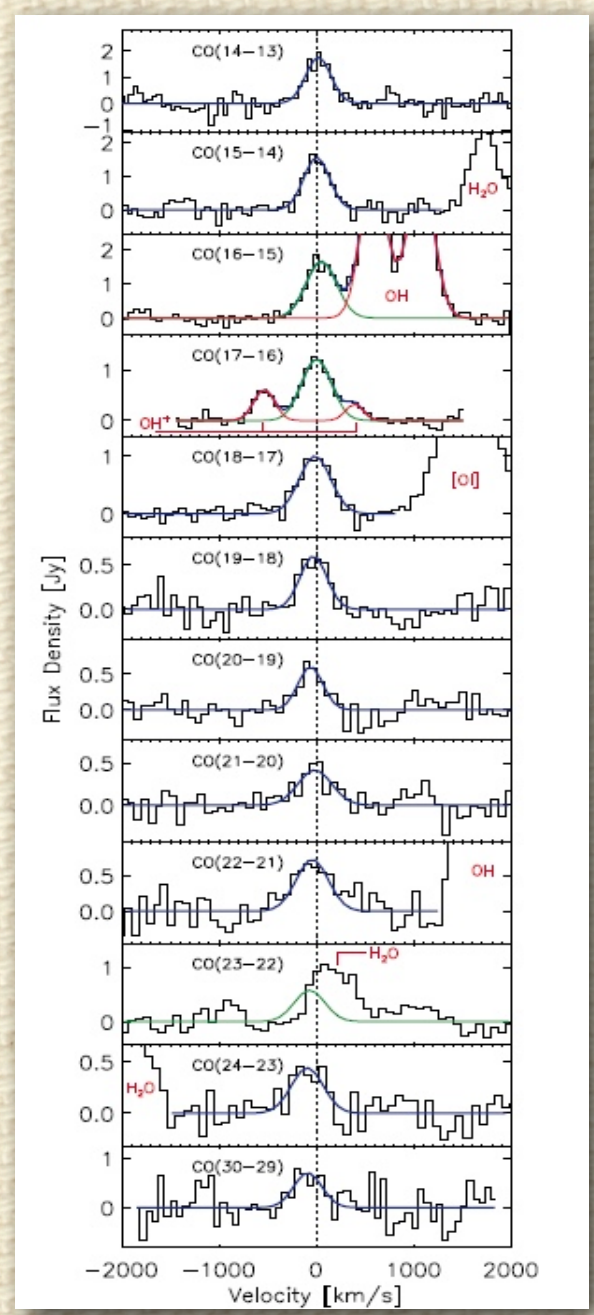


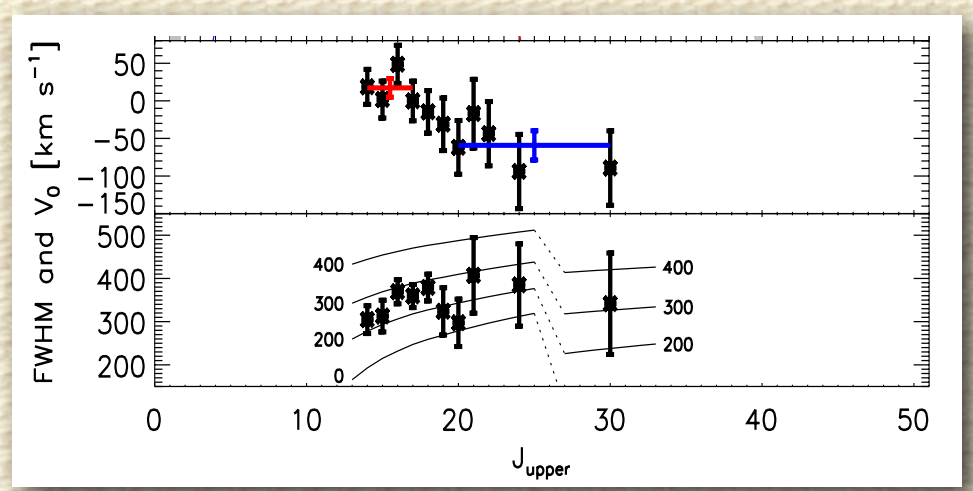
X-rays

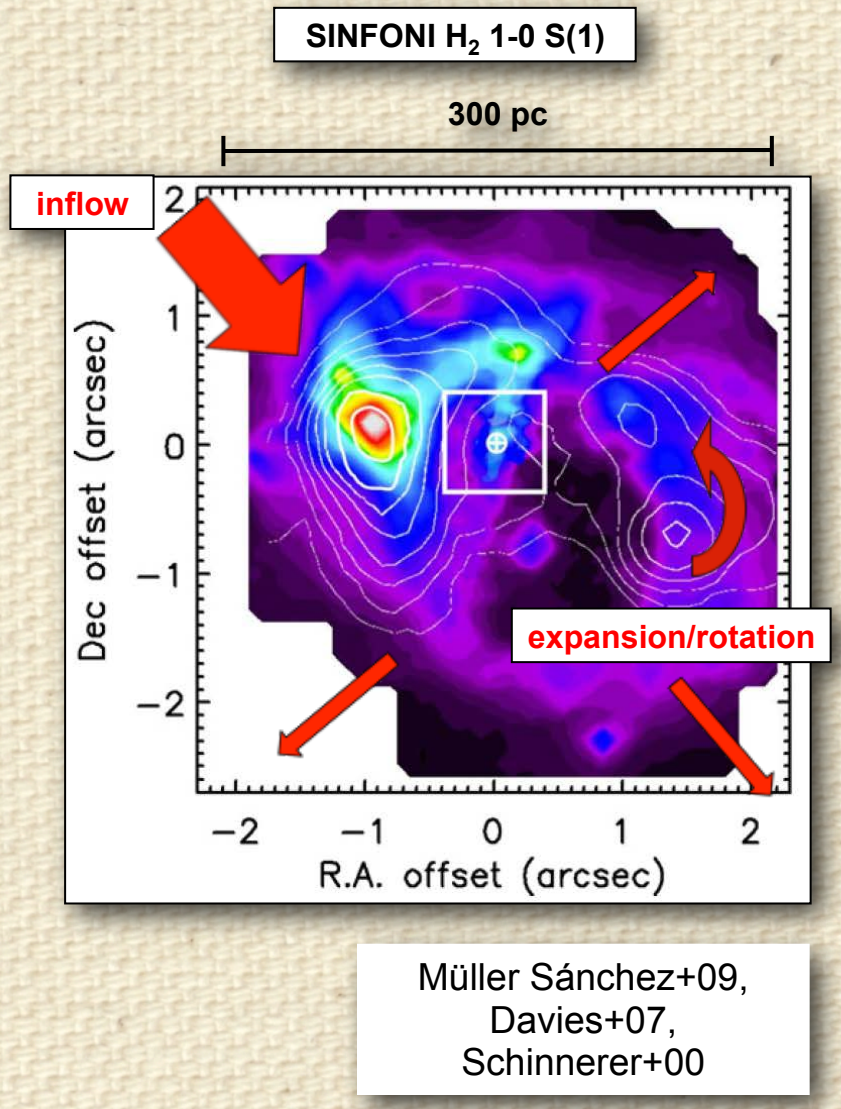


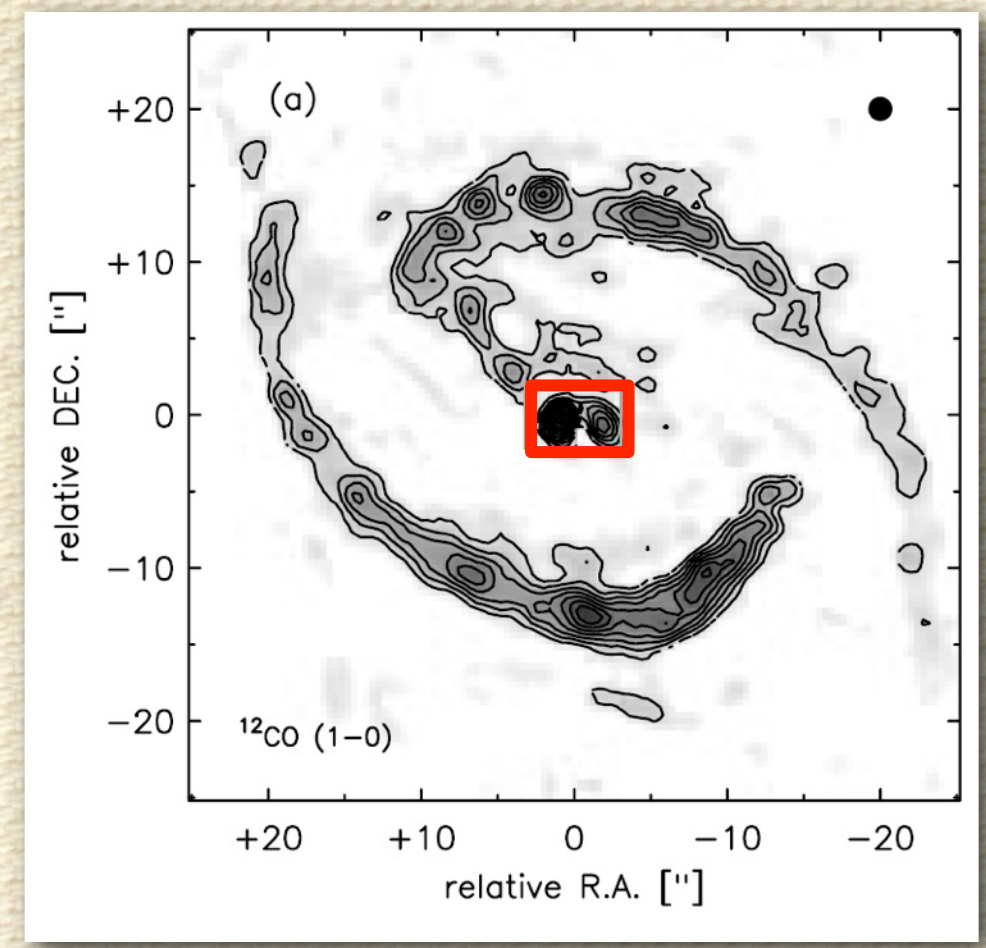
NGC1068

Hailey-Dunsheath+ 2012

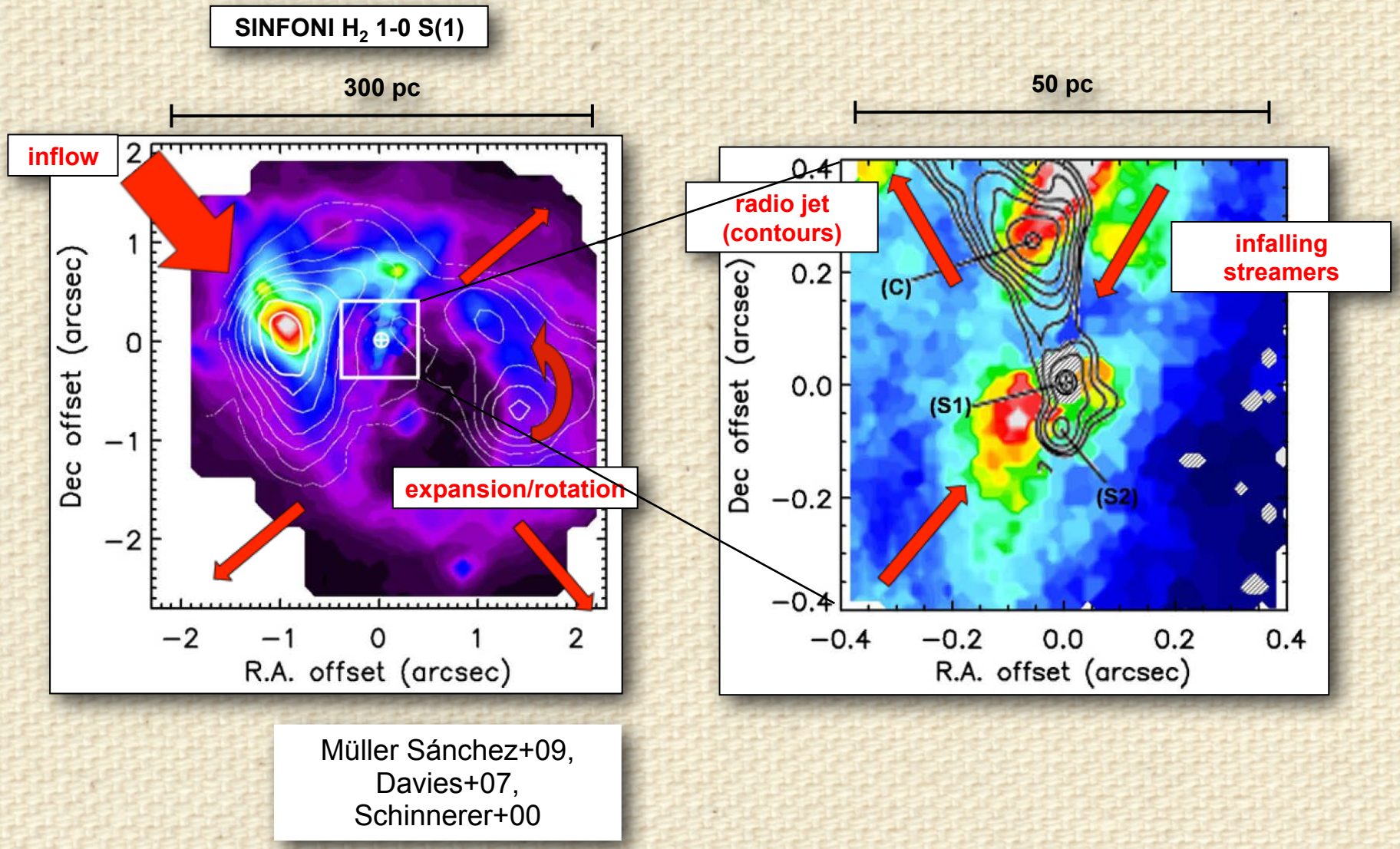








Müller Sánchez+09,
Davies+07,
Schinnerer+00



Müller Sánchez+09,
Davies+07,
Schinnerer+00

Hailey-Dunsheath+ 2012

Janssen+ in prep.

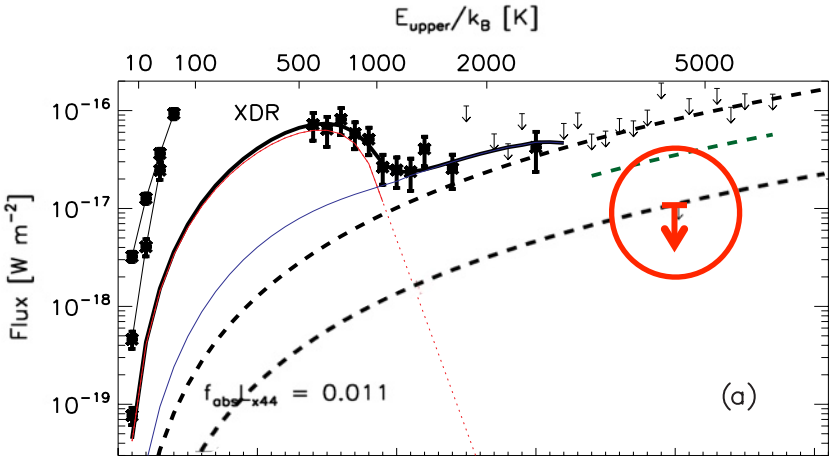
XDR / PDR models:

Meijerink & Spaans 2005

Meijerink + 2007

C-shock models models:

Flower & Pineau Des Forêts 2010



	ME	HE
XDR	$n_H = 10^{5.75}$ cm^{-3} $F_X = 9$ erg cm^{-2} s^{-1} $A \sim (130$ pc$)^2$	$n_H = 10^{5.25}$ cm^{-3} $F_X = 160$ erg cm^{-2} s^{-1} $A \sim (21$ pc$)^2$

XDR Torus(?)

PDR

shock

XDR / PDR models:

Meijerink & Spaans 2005

Meijerink + 2007

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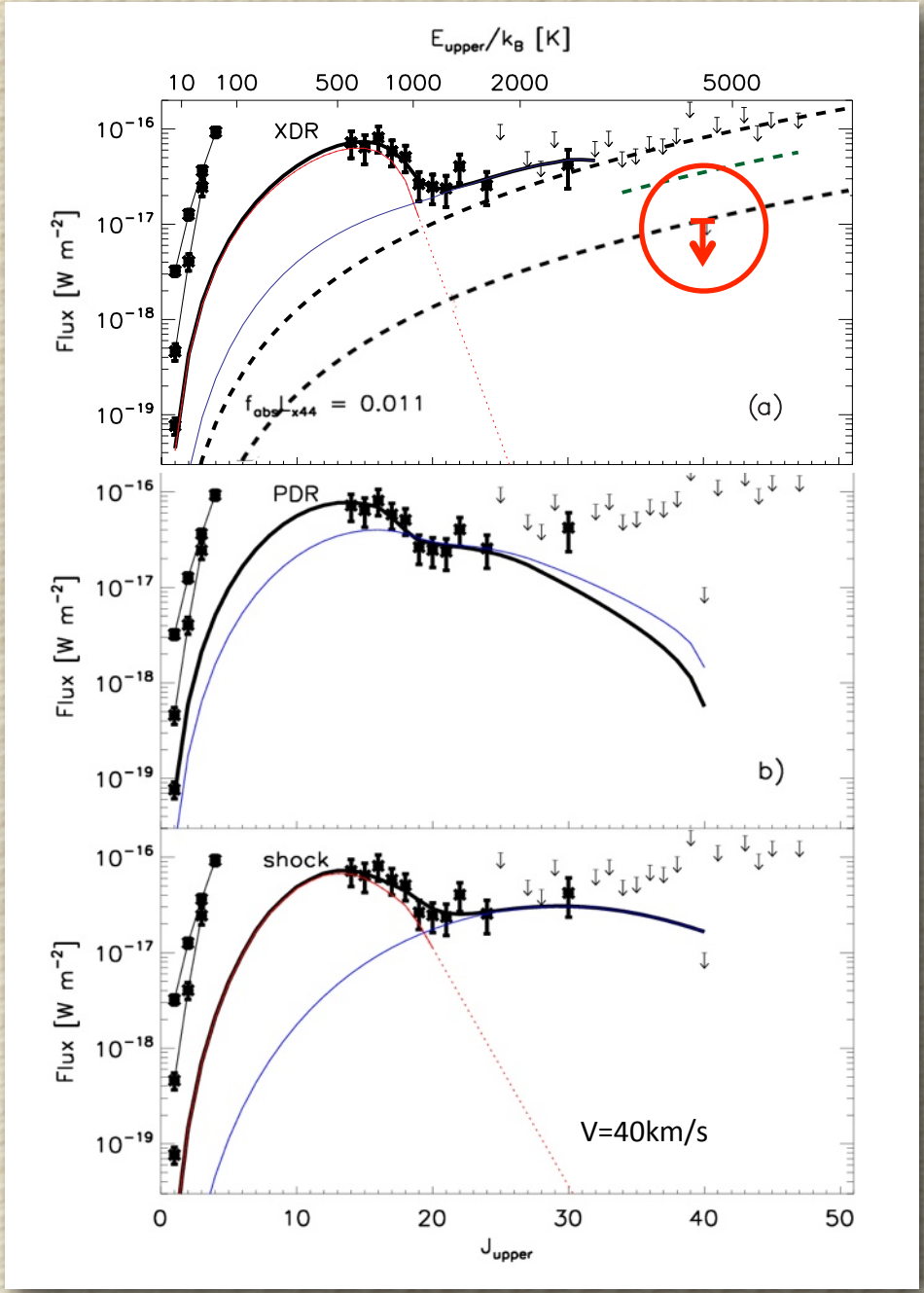

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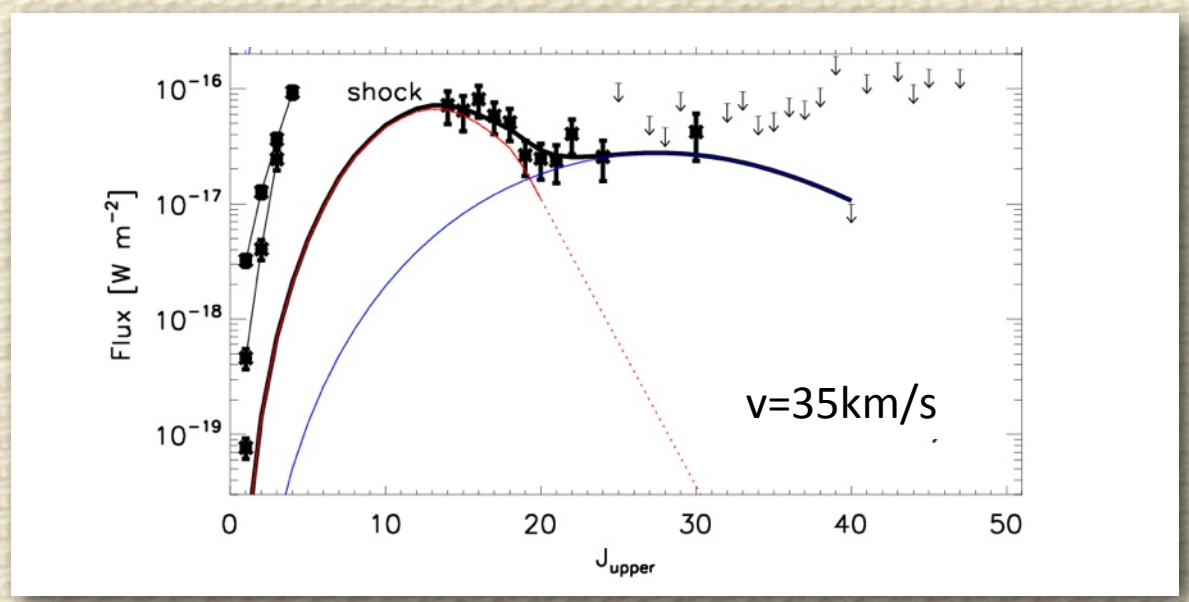
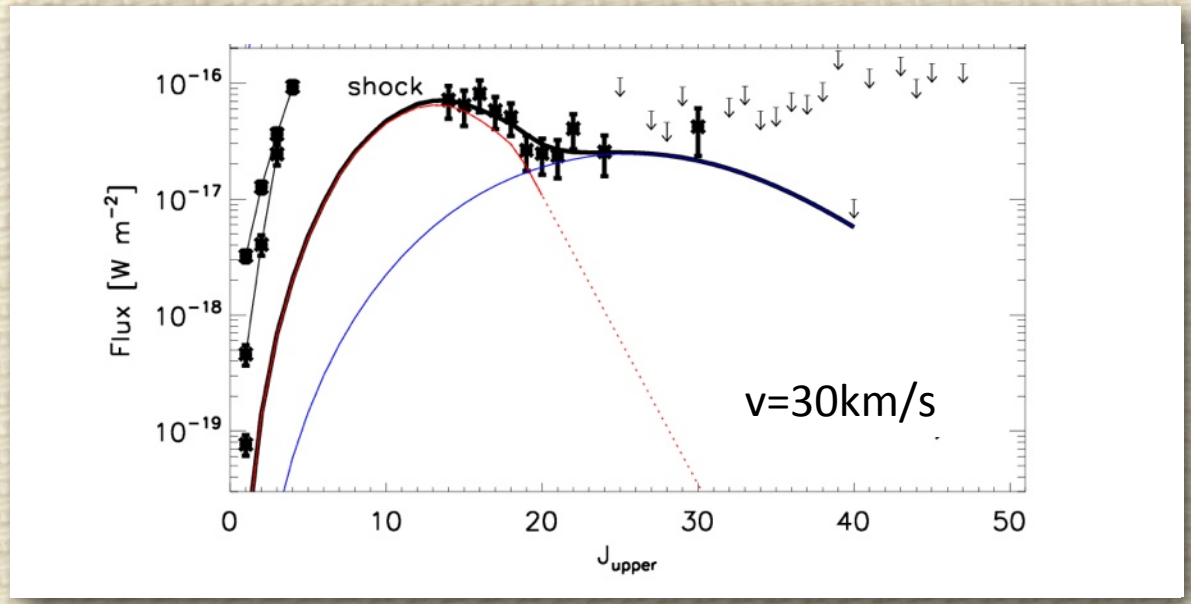
XDR Torus(?)

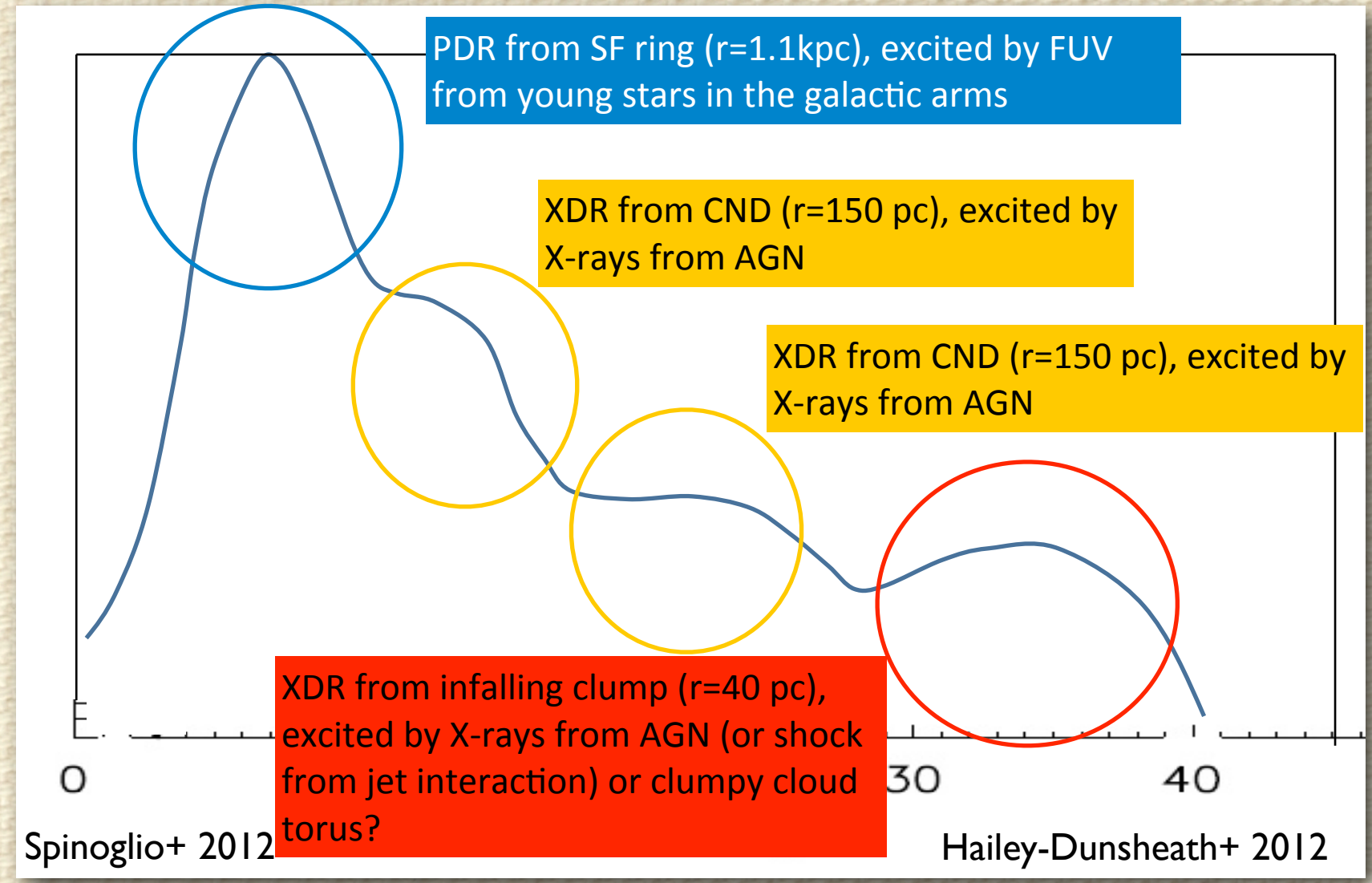
PDR

shock

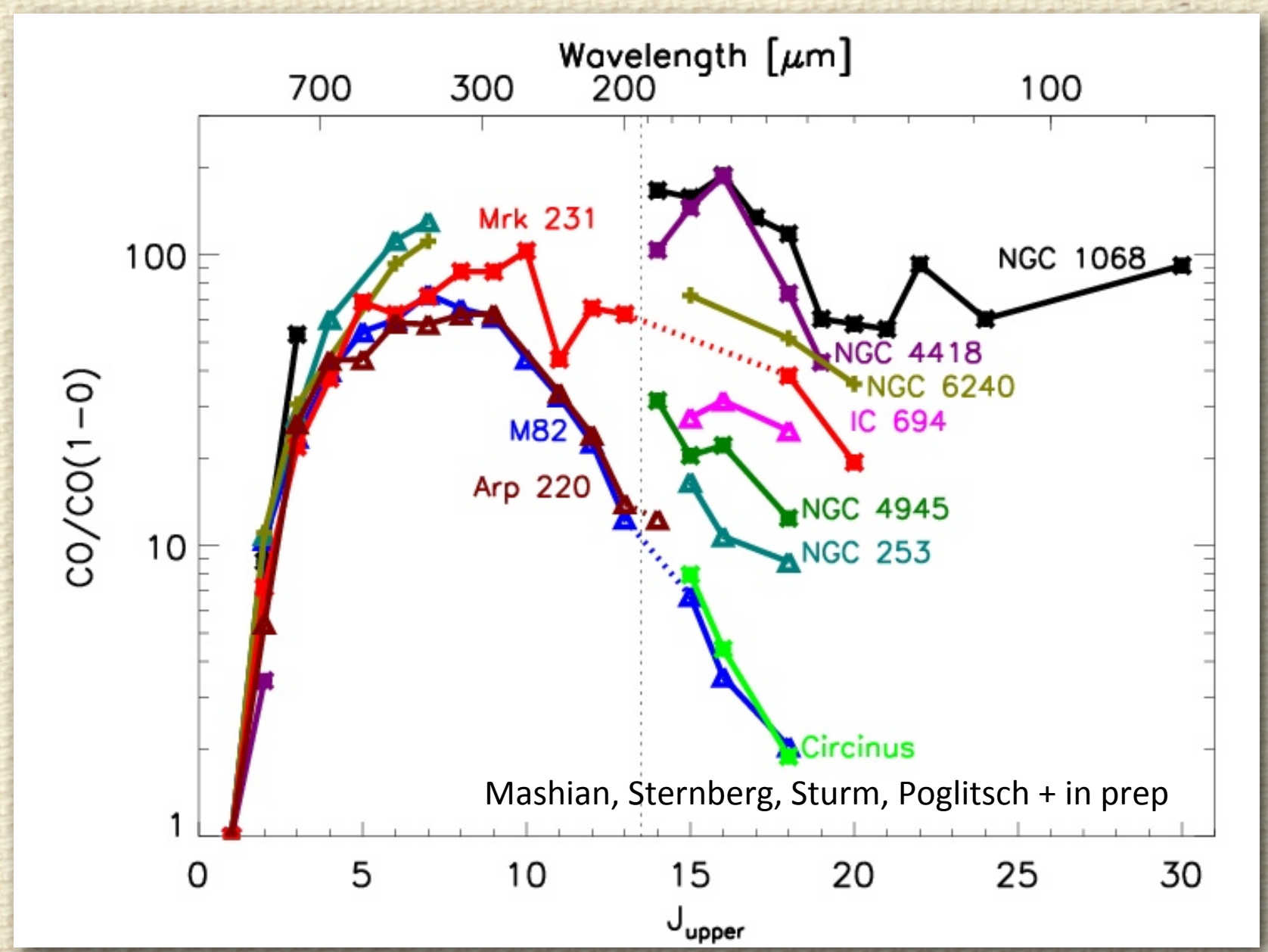

shock
v=35km/s
Flux [W m^{-2}]
10^{-16}
10^{-17}
10^{-18}
10^{-19}
0
10
20
30
40
50
J_{upper}


shock
v=30km/s
Flux [W m^{-2}]
10^{-16}
10^{-17}
10^{-18}
10^{-19}
0
10
20
30
40
50
J_{upper}

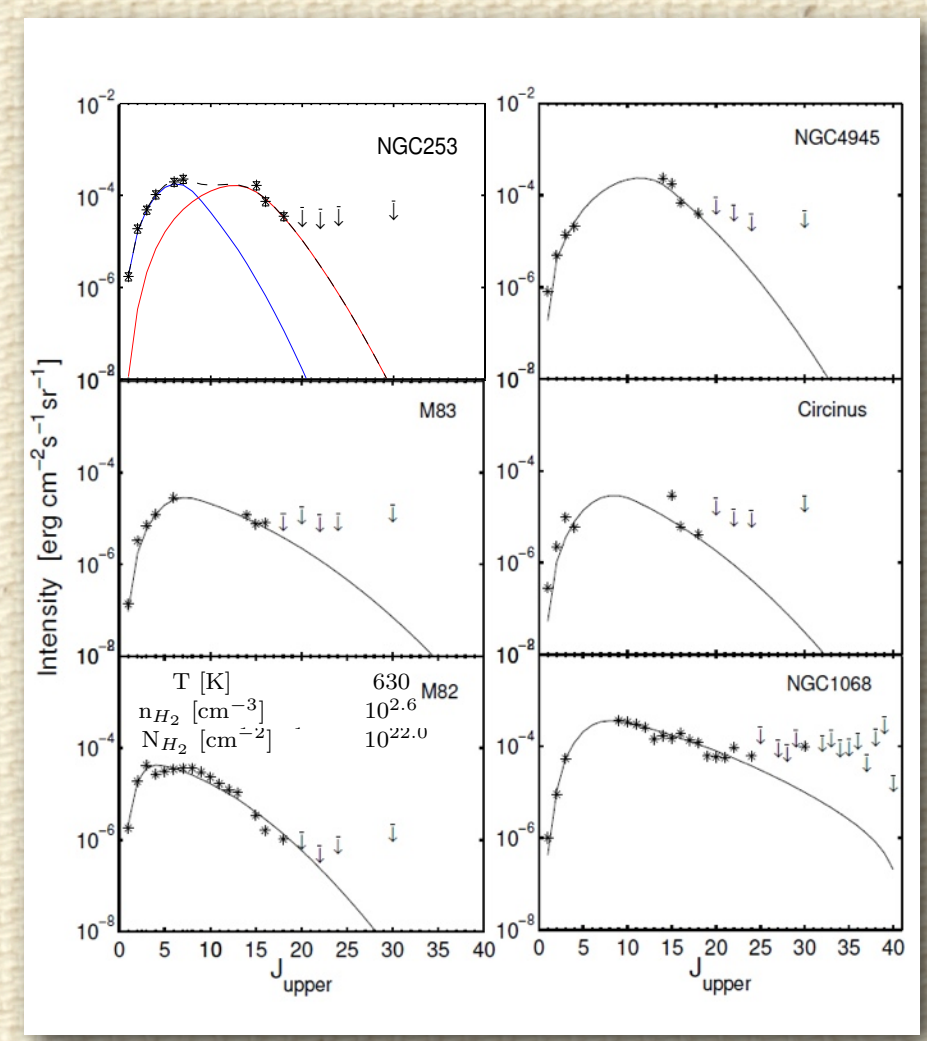
The CO Line-SED of NGC1068 from J=0 ...40

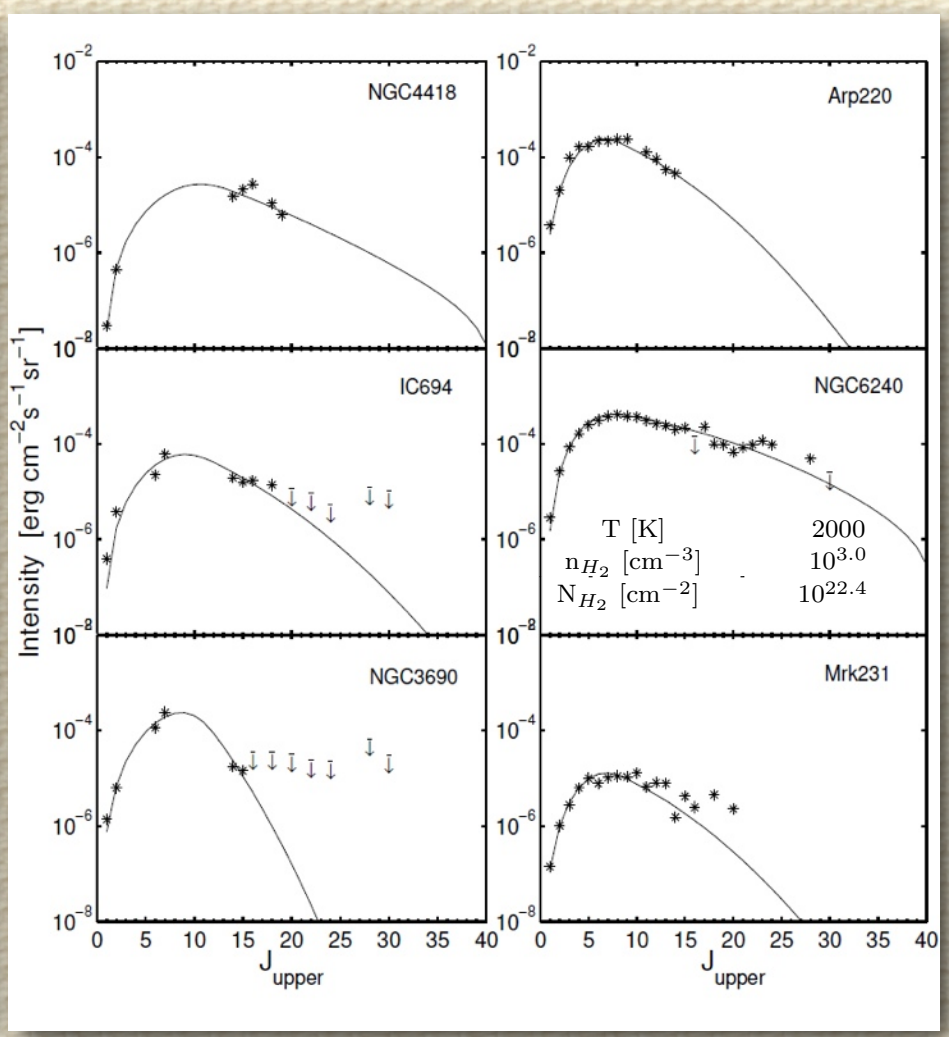


Application to ULIRGs


Wavelength [μm]
700
300
200
100
CO/CO(1−0)
100
10
1
Mrk 231
M82
Arp 220
NGC 1068
NGC 4418
NGC 6240
IC 694
NGC 4945
NGC 253
Circinus
Mashian, Sternberg, Sturm, Poglitsch + in prep
0
5
10
15
20
25
30
J upper

LVG Modeling





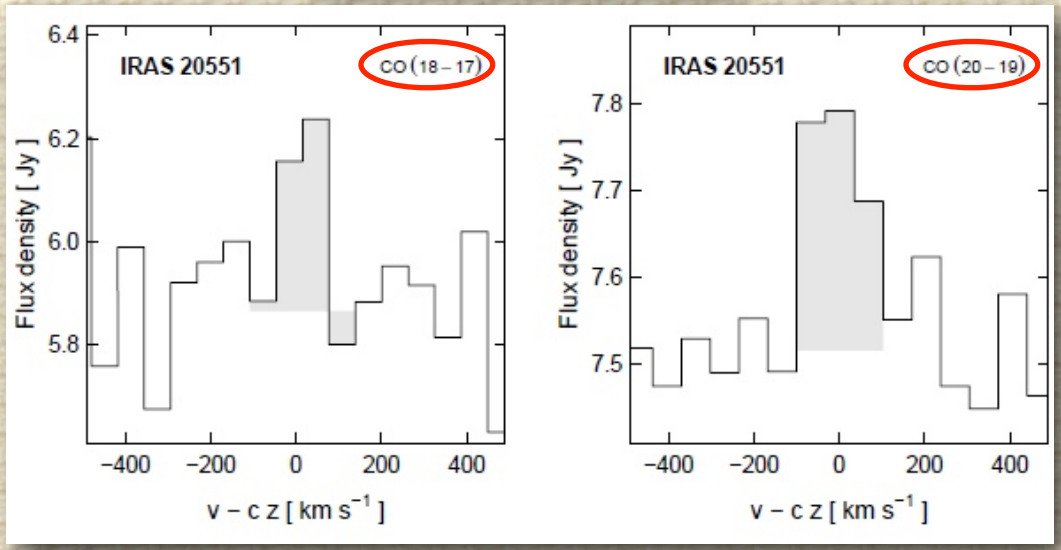
Mashian, Sternberg, Sturm, Poglitsch + in prep

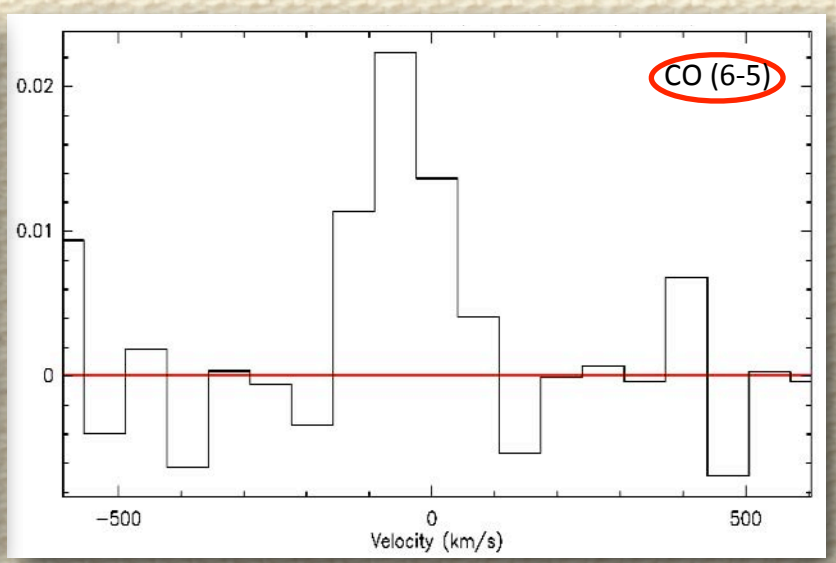
CO Line Ratios in local ULIRGs

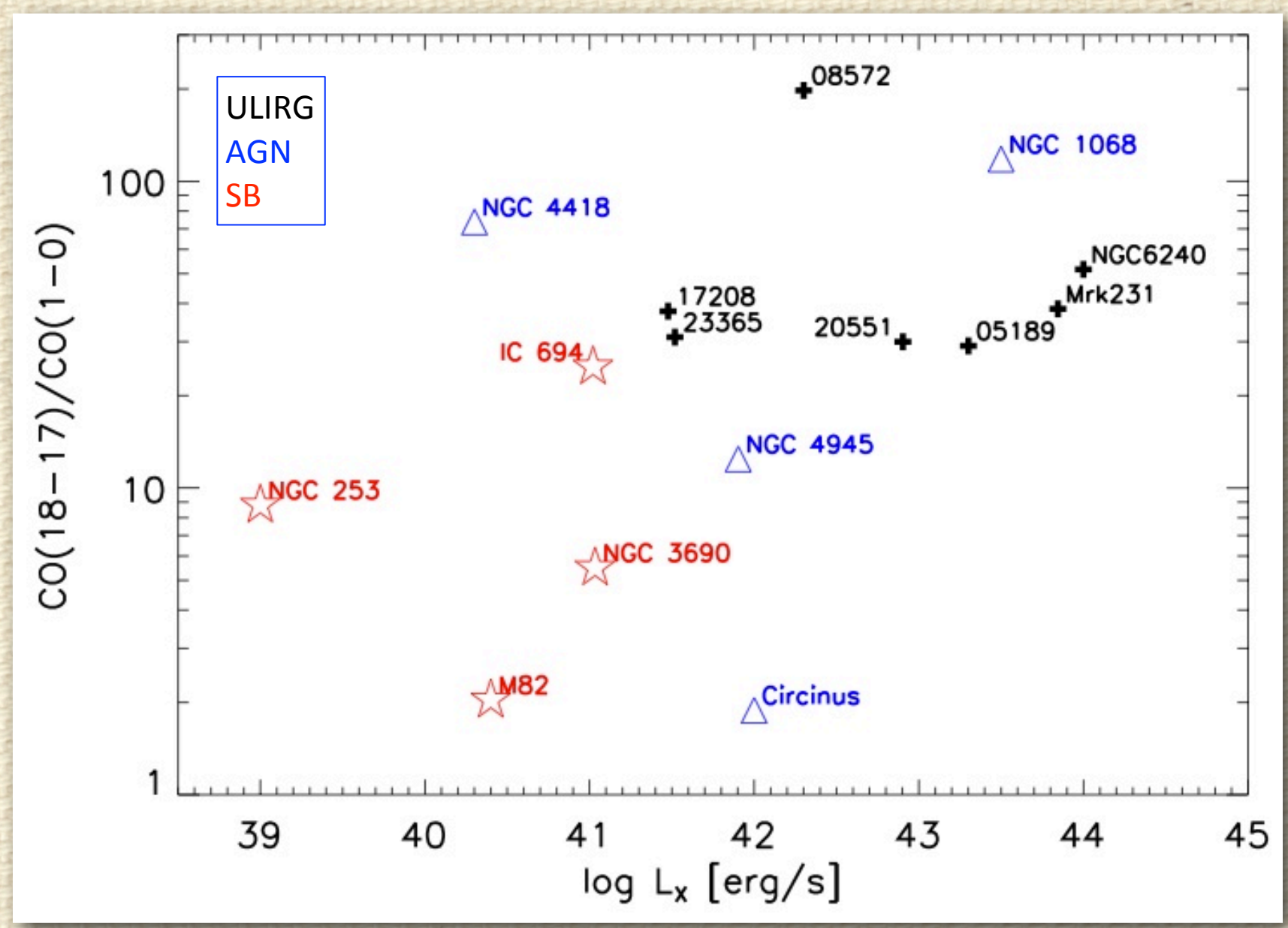
Characterizing the excitation of the molecular gas and the nature of the energy source

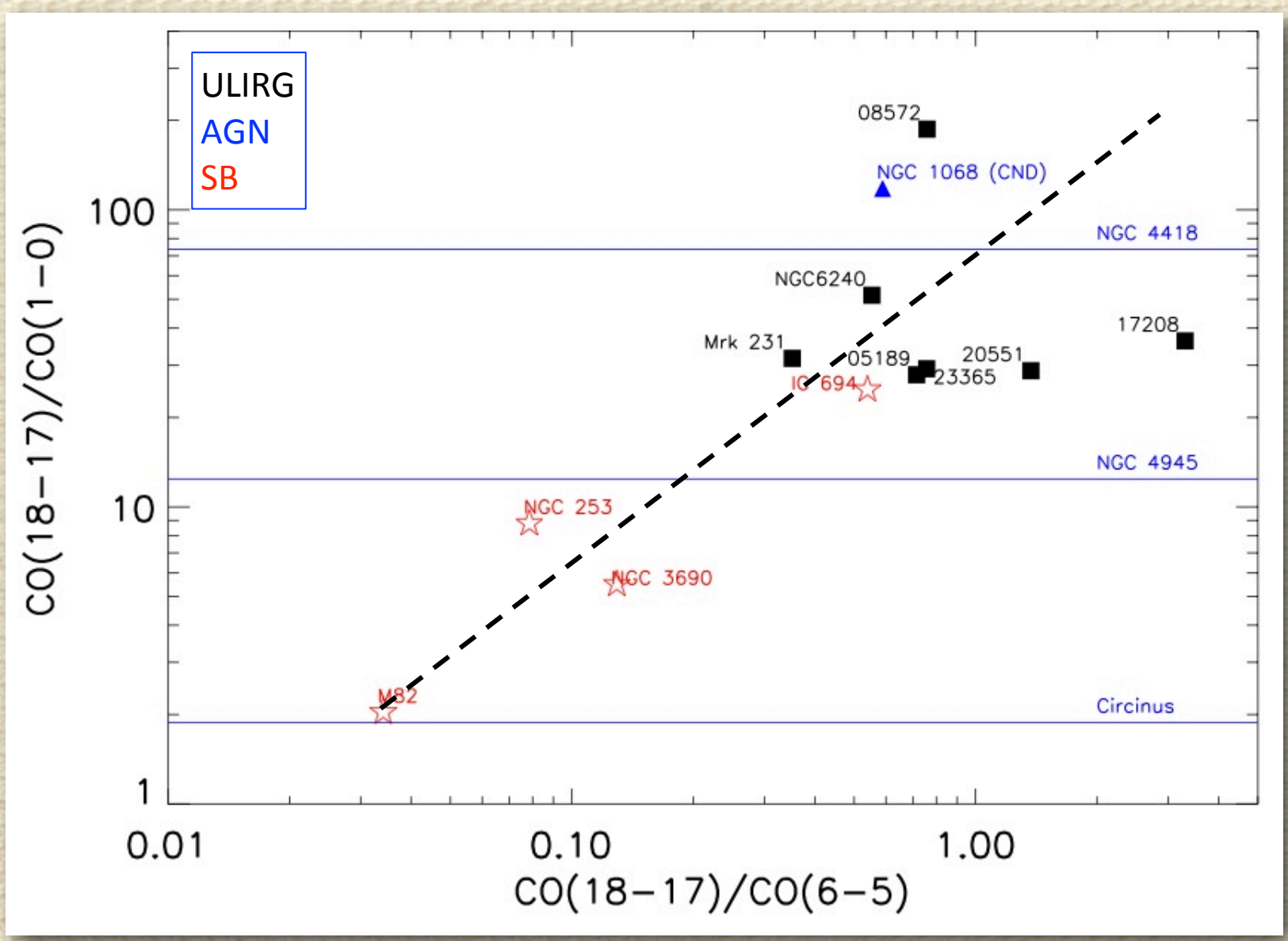
PACS spectra (SHINING)

APEX spectrum

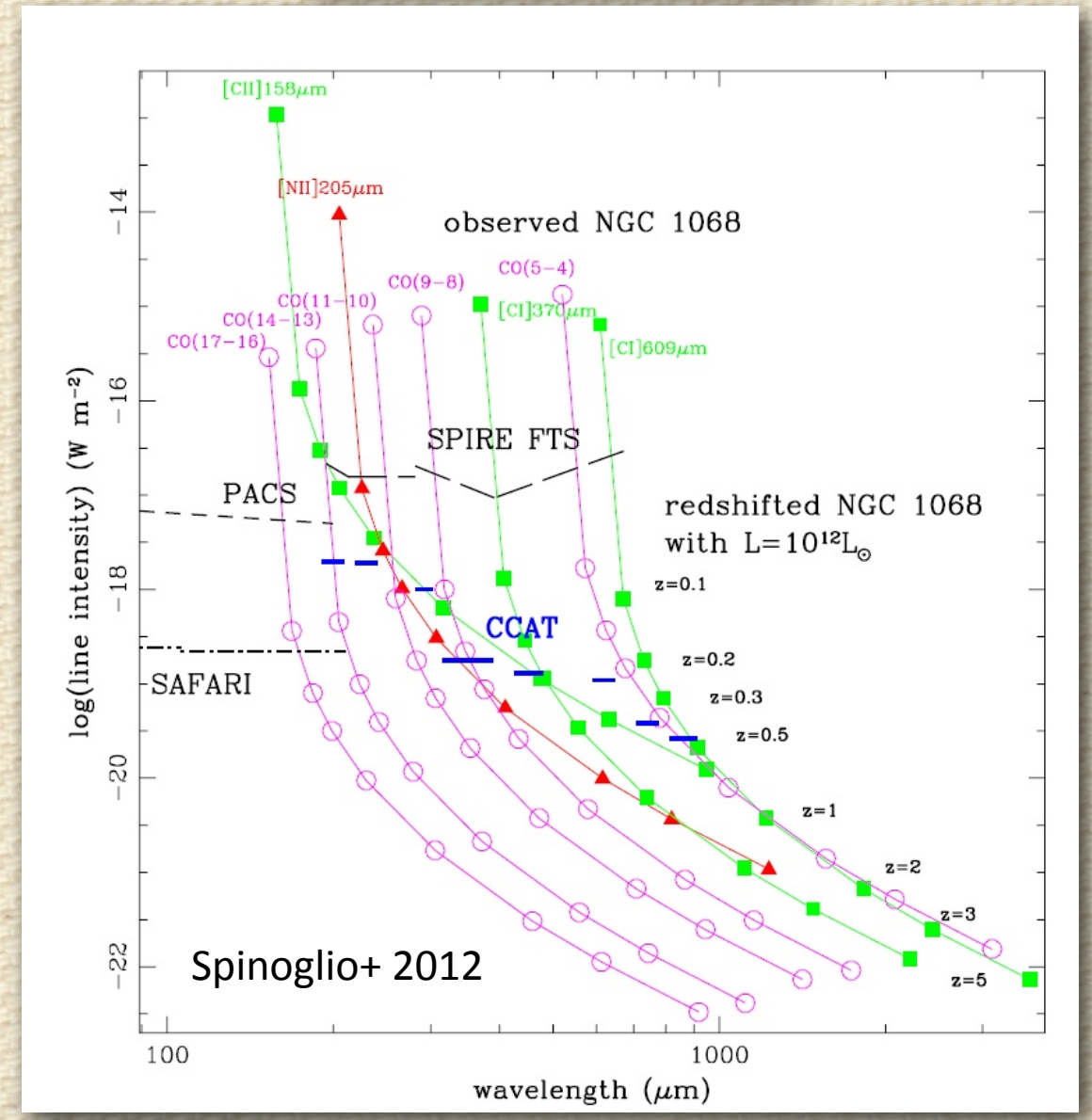




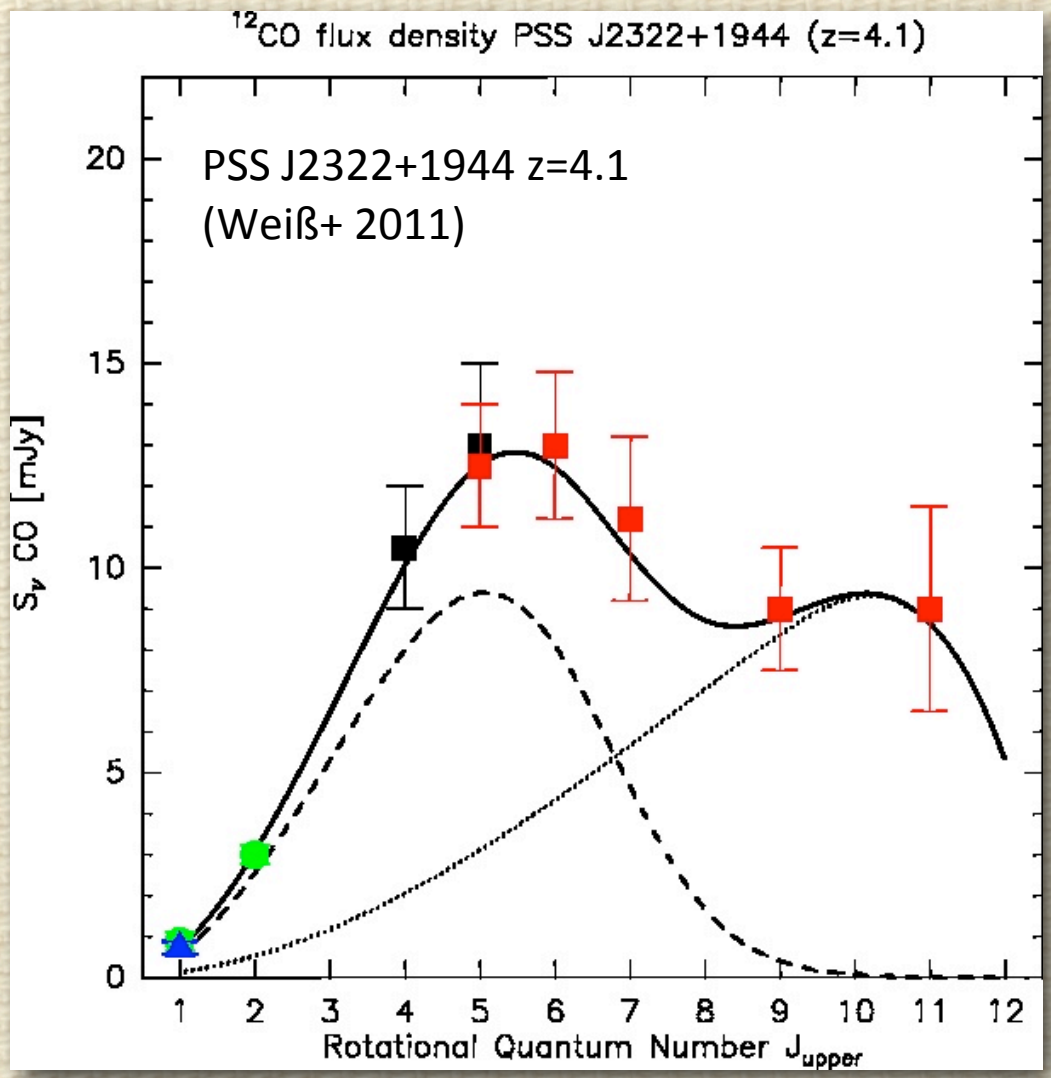

ULIRG
AGN
SB
08572
NGC 1068
NGC 4418
NGC6240
Mrk231
17208
23365
20551
05189
IC 694
NGC 4945
NGC 253
NGC 3690
M82
Circinus
100
10
1
39
40
41
42
43
44
45
CO(18−17)/CO(1−0)
log Lx [erg/s]


ULIRG
AGN
SB
08572
NGC 1068 (CND)
NGC 4418
NGC6240
17208
Mrk 231
05189
20551
23365
IC 694
NGC 4945
NGC 253
NGC 3690
M82
Circinus
100
10
1
0.01
0.10
1.00
CO(18−17)/CO(1−0)
CO(18−17)/CO(6−5)

What next?


[CII]158μm
[NII]205μm
observed NGC 1068
CO(5-4)
CO(9-8)
CO(11-10)
CO(14-13)
CO(17-16)
[CI]370μm
[CI]609μm
SPIRE FTS
PACS
redshifted NGC 1068
with L=10¹²L⊙
z=0.1
CCAT
z=0.2
z=0.3
SAFARI
z=0.5
z=1
z=2
z=3
z=5
Spinoglio+ 2012
log(line intensity) (W m⁻²)
−14
−16
−18
−20
−22
100
1000
wavelength (μm)

CO at high redshifts - Caveats



Summary

- High-J CO lines (together with ionized species like H_2O^+ and OH^+) are a promising tool to help distinguish between XDR, PDR, CDR and shock excitation/chemistry
- However, observationally there is a lot of scatter, and a good sampling of the CO line SED up to really high-J (J≈40 at 65μm) is needed (and expansion of the models)
- Ratio-ratio diagrams (a la CO(18-17)/CO(1-0) vs. CO(6-5)/CO(1-0) must be explored more, both, observationally and theoretically
- Interpretation of high-z high-J CO lines (e.g. CCAT, NOEMA, ALMA) not straightforward!

Summary

- 1 pc torus (basis of Krolik & Lepp 1989) excluded
- "Clumpy Torus" models with slightly larger extension (~10pc) could still work. Testing needs inclusion of gas/line emission in these models, and observations up to really high J
- Further "calibration" of the methods and the models with SPICA – both MCS and SAFARI – at spatially resolved nearby template objects will be critical