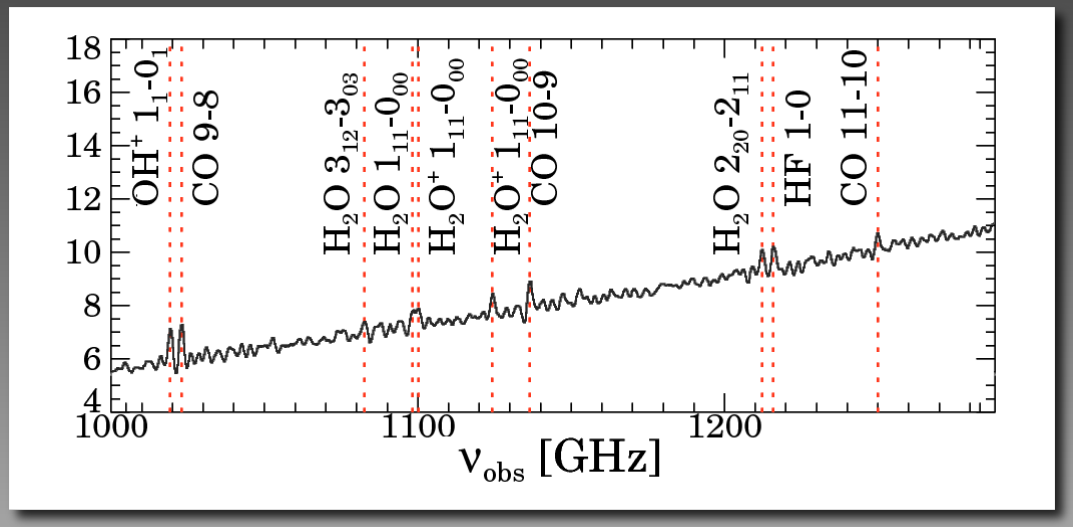
Herschel/SPIRE Spectra of Seyfert Galaxies



Miguel Pereira Santaella

L. Spinoglio, G. Busquet, C. Wilson, J. Glenn, K. Isaak, J. Kamenetzky, N. Rangwala, M. Schirm, M. Baes, M. Barlow, A. Boselli, A. Cooray, D. Cormier

Pereira-Santaella et al. 2013, ApJ 768 55
+ arXiv:1301.3365

ESTEC, October 2013

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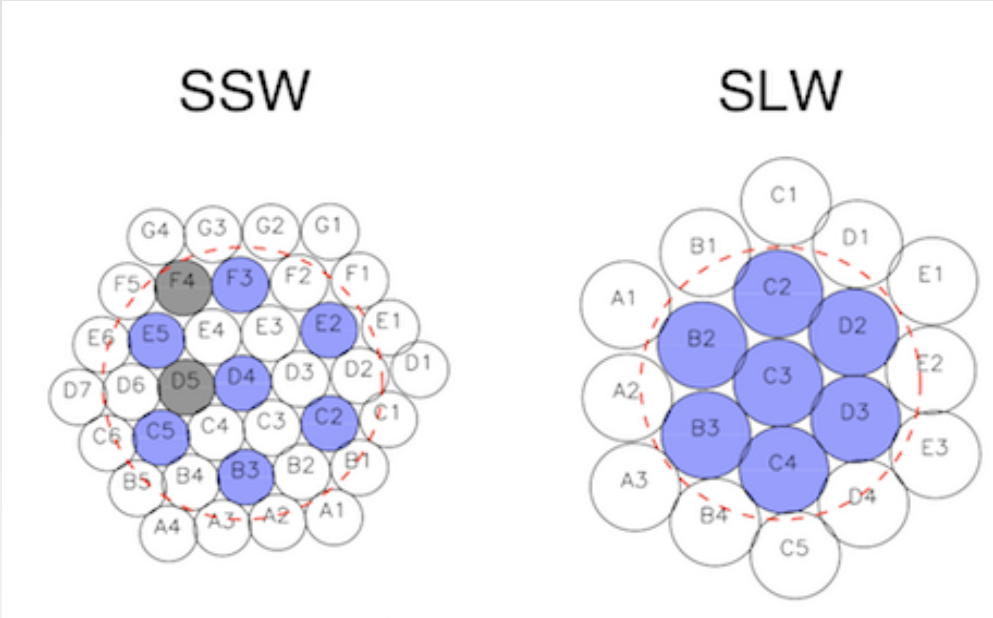
Outline

- Introduction
  - SPIRE/FTS and Sub-mm Spectra
- HF Absorption and Emission
- Mid-J CO Emission
  - LVG Models
  - PDR and XDR models
  - AGN vs Starburst
- Summary

Introduction

SPIRE-FTS

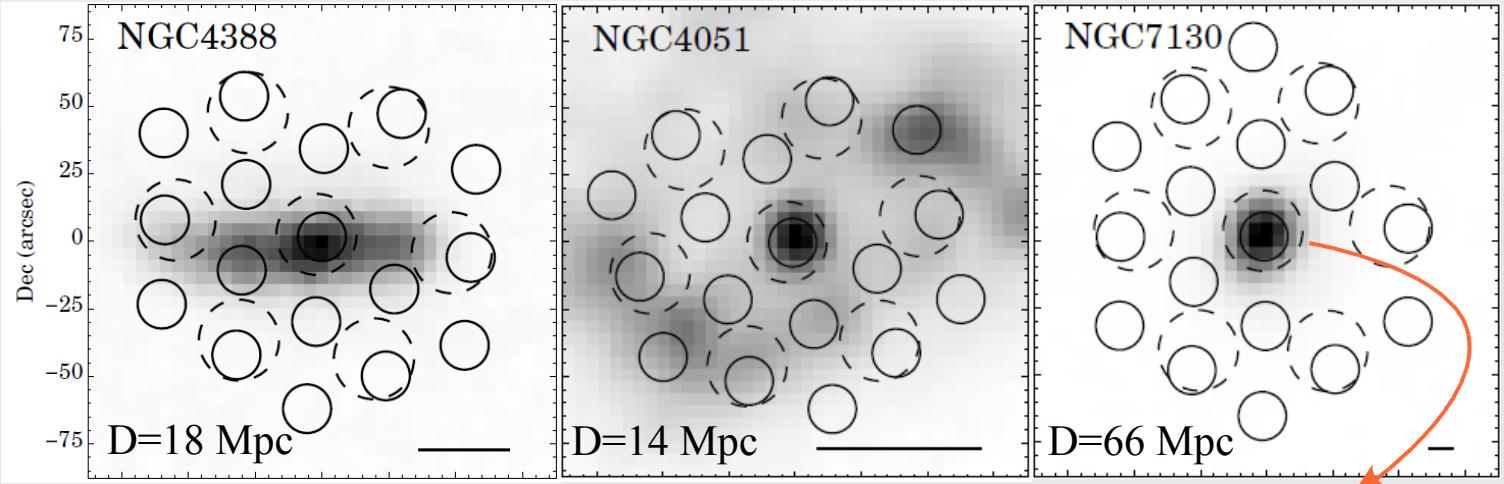
- Fourier Transform Spectrometer (FTS) on-board Herschel



SSW 925-1500 GHz 195-325 μm ~18 arcsec beam
SLW 450-950 GHz 320-670 μm ~30 arcsec beam

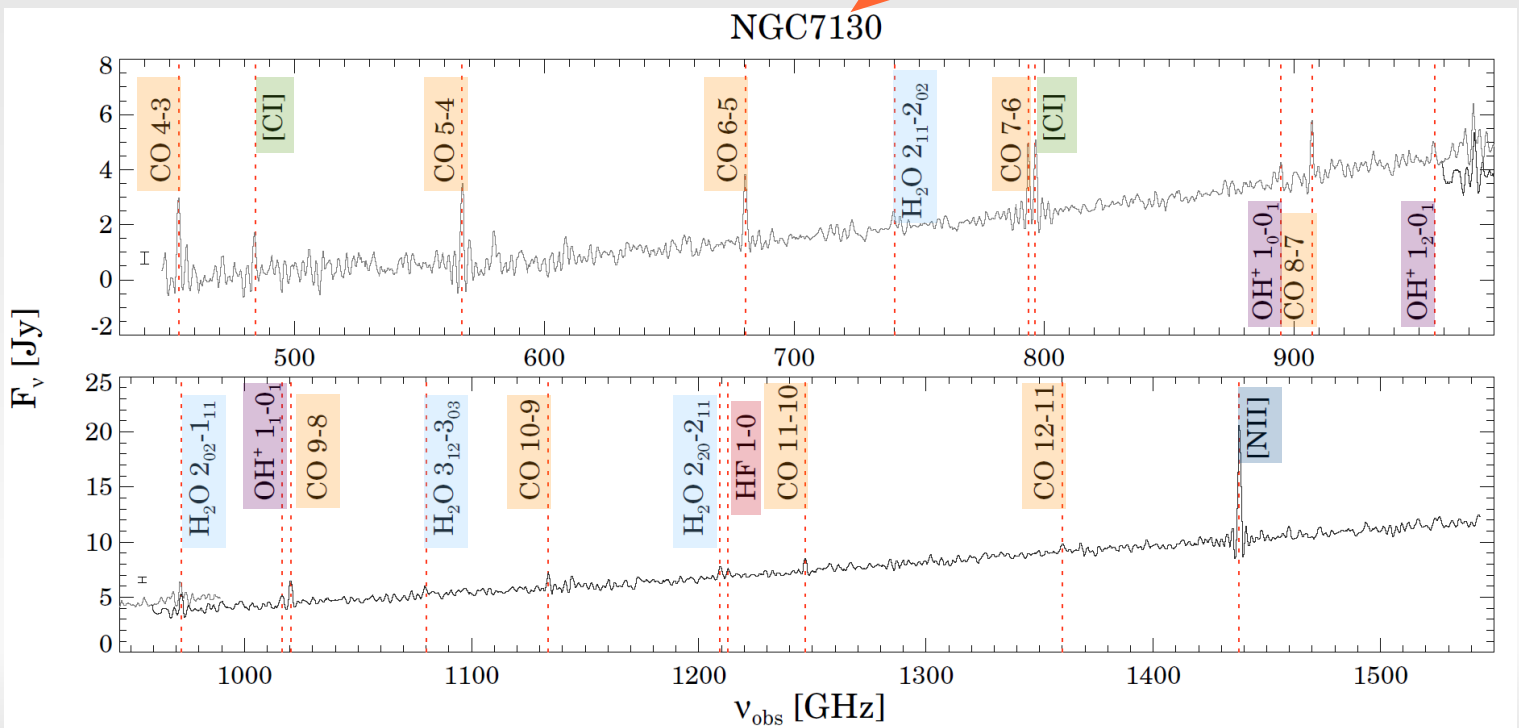
Spectral resolution 1.5 GHz R ~ 300-1000

SPIRE-FTS



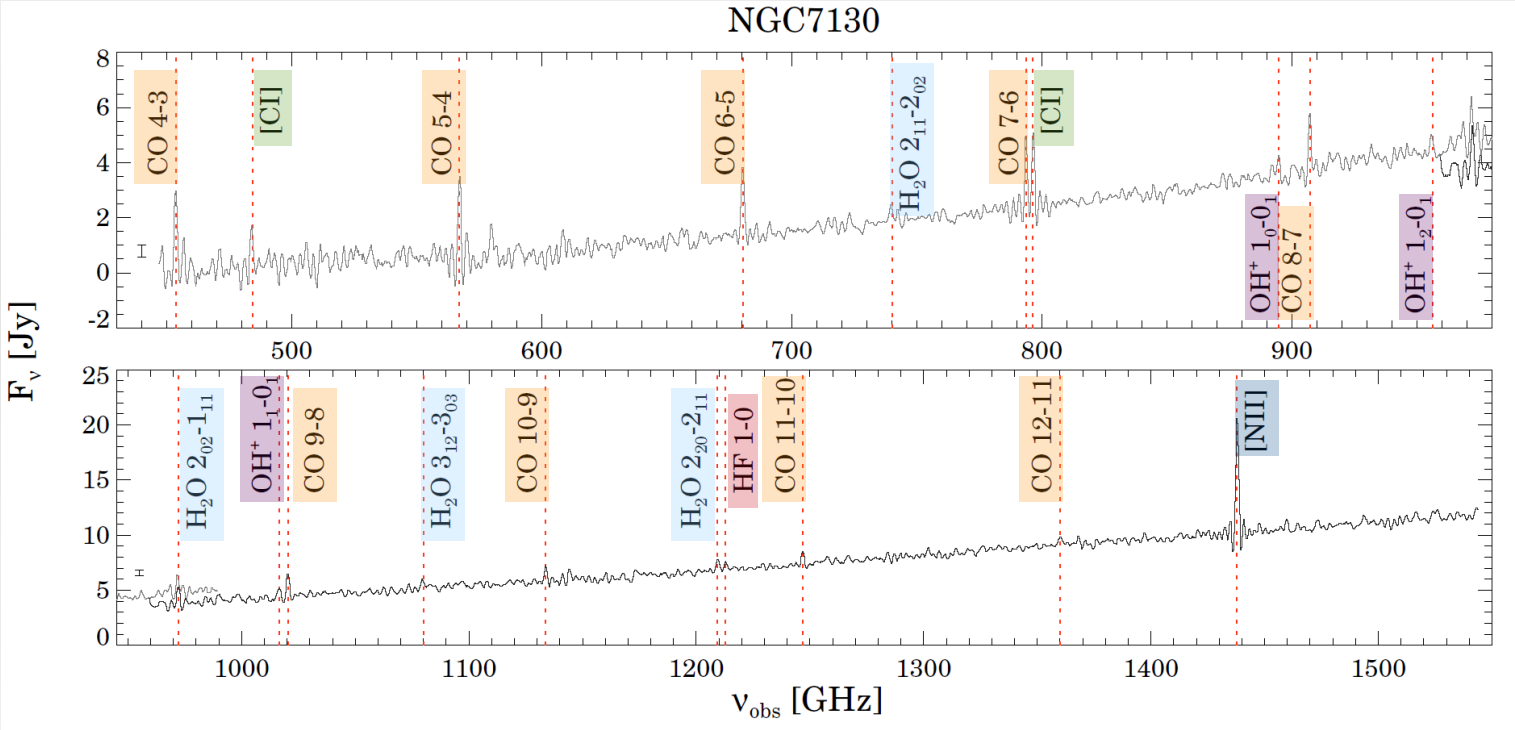
FTS footprint over SPIRE 250μm image

Spectrum central bolometer



Pereira-Santaella+2013

SPIRE-FTS sub-mm Spectrum



Ten mid-J CO ladder from J = 4-3 to J = 13-12
Two [CI] lines at 492 and 809 GHz
A few H_2O and H_2O^+ transitions
CH^+ and OH^+ transitions
HF J = 1-0

} Molecular gas.

[NII] 1461 GHz (205 micron) — Ionized gas.

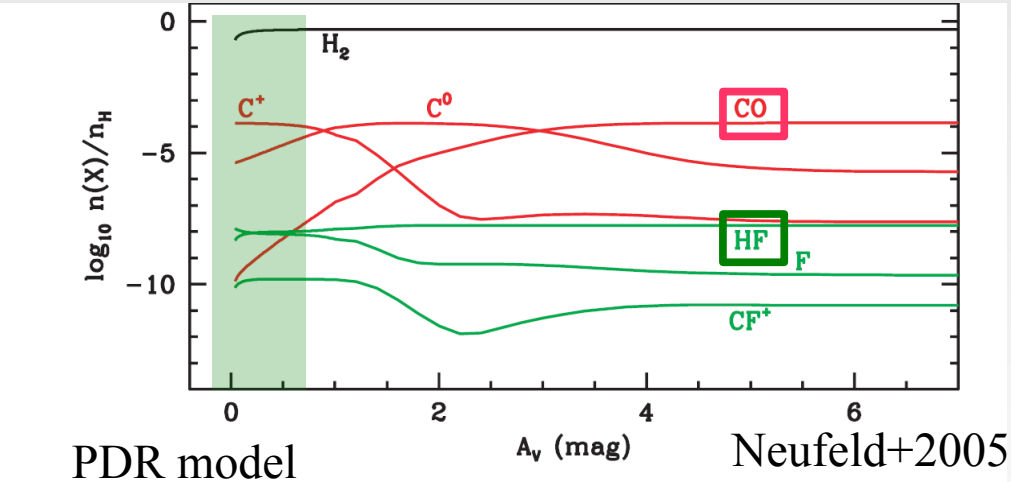
HF 1-0 1232 GHz

Hydrogen Fluoride

- F abundance is low ~10^{-8}

- F forms HF rapidly when H_2 becomes abundant

$$F + H_2 \rightarrow HF + H$$ exothermic

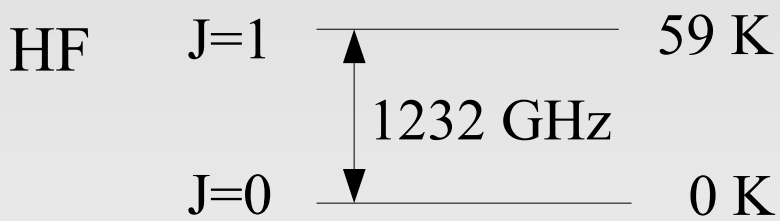


PDR model Neufeld+2005

- HF more abundant than CO for A_v < 1 mag

HF 1-0 at 1232 GHz

For comparison for CO 1-0
τ = 160 days and E_1 = 6 K

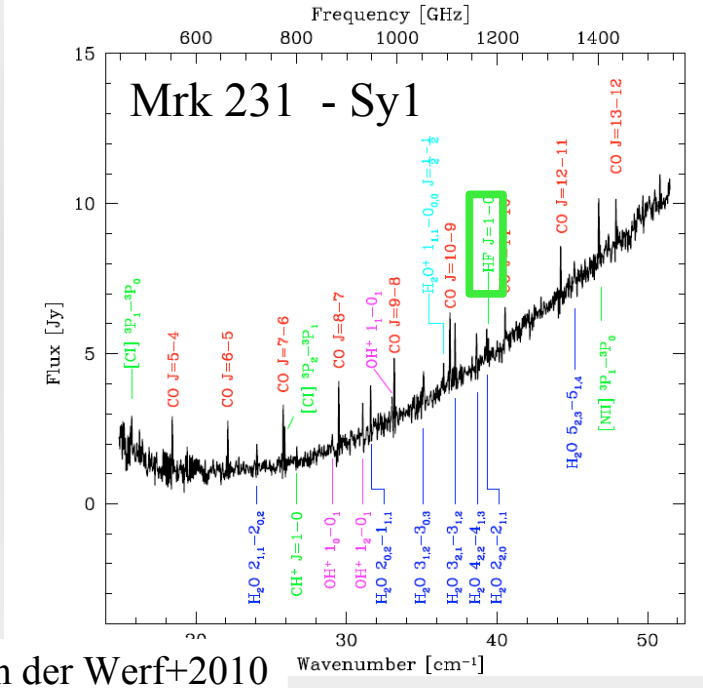


$A_{10} = 2.4 \times 10^{-2}\ s^{-1}$ $\tau = 41$ s

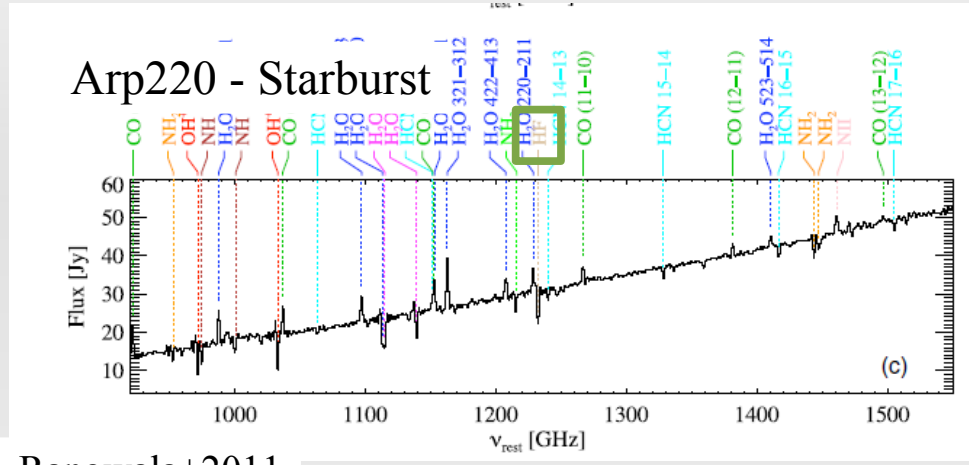
$E_{J=1} = 59$ K & high critical density $n_{H2} \sim 10^{10}\ cm^{-3}$ (at 50 K)

→ Expected in absorption

Herschel detections of HF

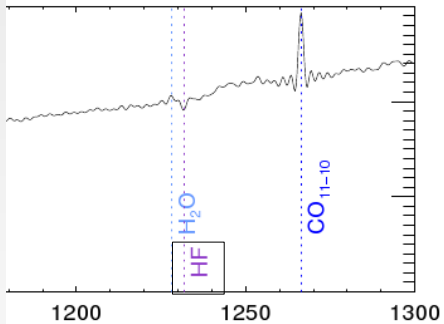


van der Werf+2010

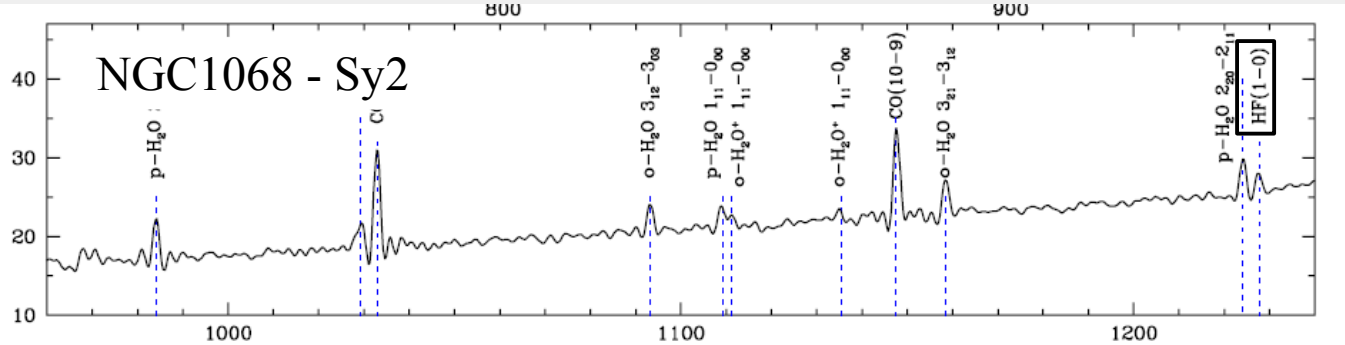


Rangwala+2011

M82 - Starburst

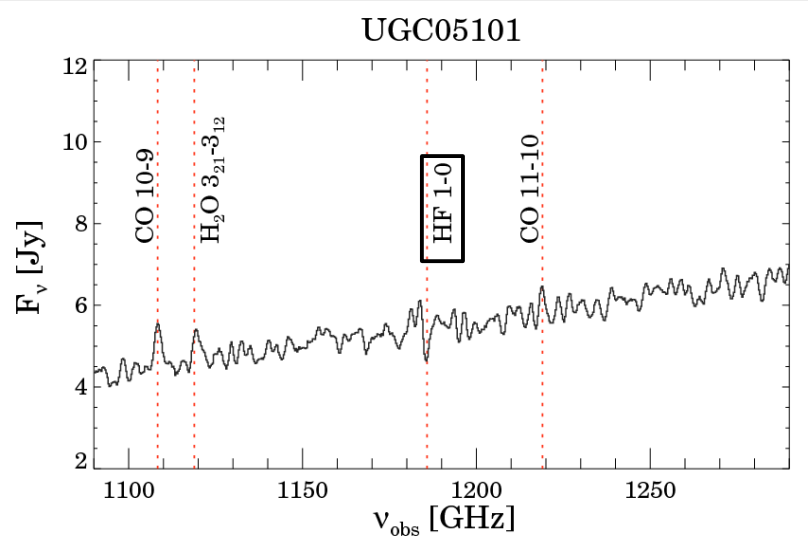


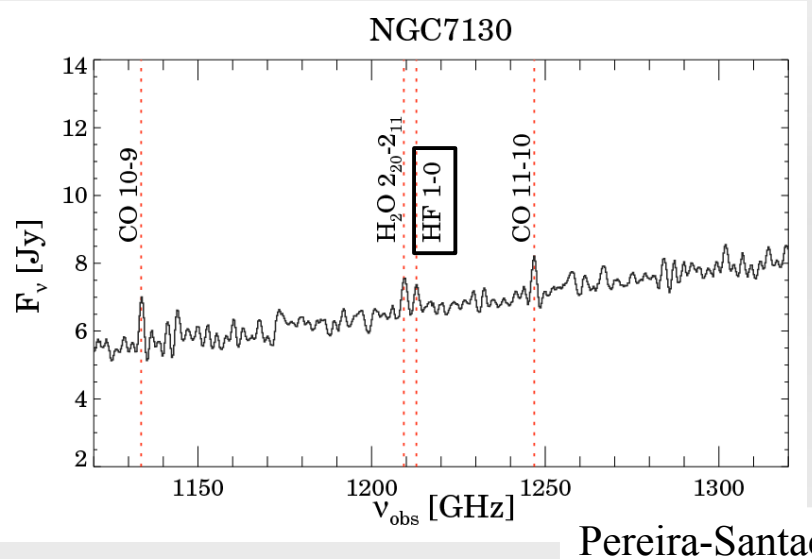
Kamenetzky+2012



Spinoglio+2012

HF in Sy Galaxies





Pereira-Santaella+2013

- 2 detections in our sample
  - UGC05101. LINER. Absorption
  - NGC7130. Sy2. Emission

HF 1-0 Absorption

- UGC05101

$N_{HF} \sim 1.1 \times 10^{14}$ cm^{-2}

For a source size of 10" ⟶ HF abundance ~ 2.6×10^{-8}

- Solar F abundance is 3.5×10^{-8} (Lodders 2003)

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- N_{HF} is a lower limit
  - Only HF in J = 0
  - Only clouds illuminated by the sub-mm continuum source
  - All the continuum measured is actually illuminating these clouds

- N_{H2} is a depends on the CO-to-H2 conversion factor and on the source size

HF 1-0 Emission in NGC7130

- Assuming optically thin emission $N_{J=1} \sim 10^{11}$ cm^{-2}

Again this is a lower limit!

For solar abundance and excitation due to collisions with H2

⬇

>> 20% of the **total** molecular gas $n_{H2} > 10^{10}$ cm^{-3}

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HF 1-0 Emission in NGC7130

- IR Pumping. HF has a vibrational absorption band at 2.5 μm

  To be efficient radiation field T > 730 K ⟶ 10^6 times PDR of O star

  Only the AGN could produce such radiation field

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- Chemical Pumping. HF formed in a excited state

  HF dissociated by intense UV radiation and reformed rapidly

  $\chi > 10^7$ and high density $n_{H2} > 10^7$ cm^{-3} Possible close to the AGN

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  $N_{H2} > 10^{20}$ cm^{-2} of high density molecular gas (H2) with ionized C

  XDR around the AGN?

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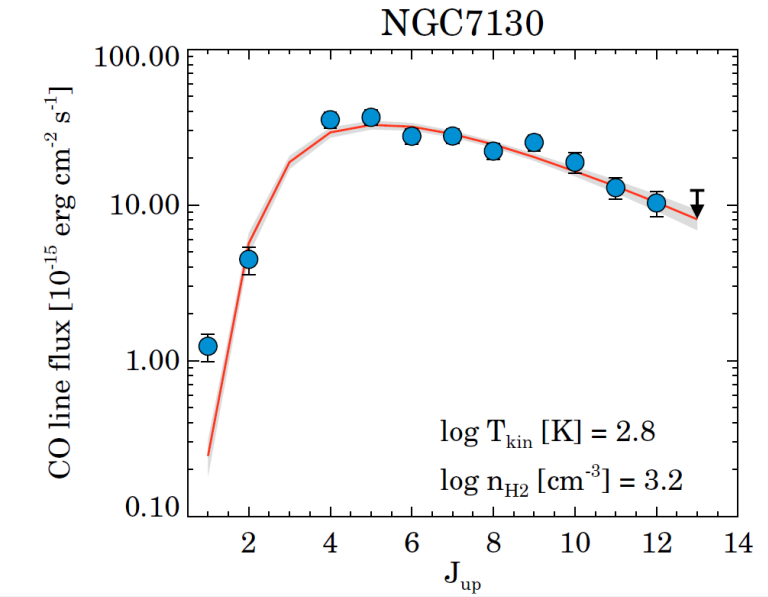
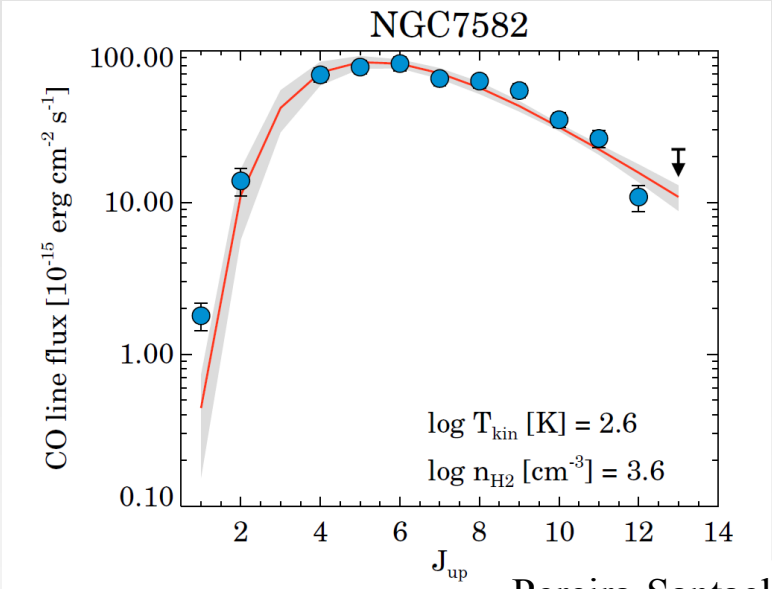
  XDR around the **AGN**?

Mid-J CO Emission

CO Emission

- CO is mainly excited by collisions with H_2
- We use RADEX: non-LTE code to predict the CO line intensities: Kinetic temperature, density and column density

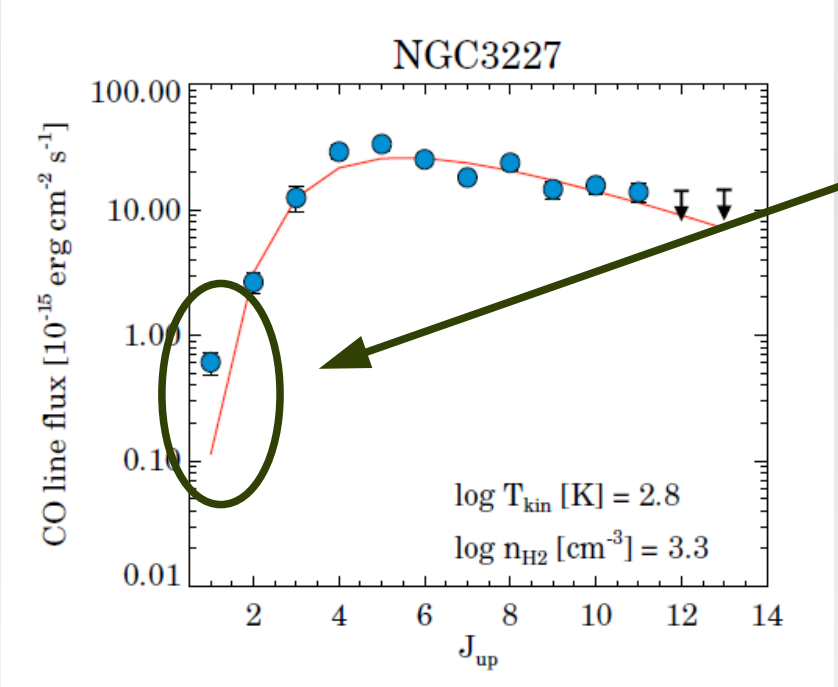




Pereira-Santaella+2013

- The observed CO SLEDs agree with kinetic temperatures ~300-800 K and densities ~10^3-10^4 cm^{-3}
- Warm molecular mass 10^6-10^8 Msun

Cold Molecular Gas



- Excess CO J=1-0 with respect to the model prediction (10-25%)
- Cold molecular gas produces lower-J CO lines (lower excitation temperature)

CO J = 1-0 flux α H_2 mass

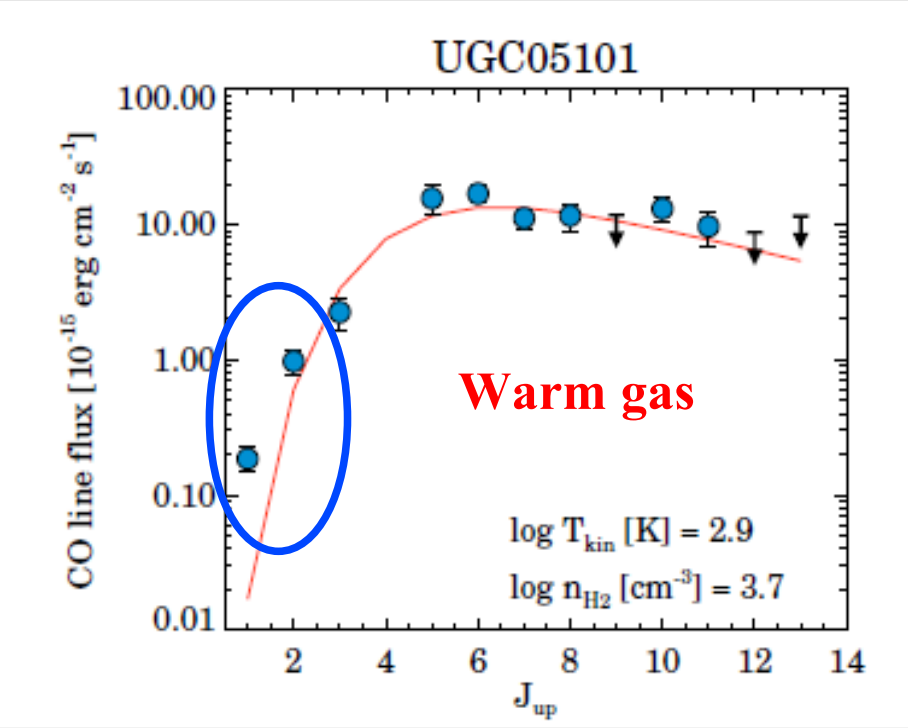
CO-to-H_2 conversion factor

$N(H_2) = 0.5 \times 10^{20}\ I\ (CO\ J = 1\text{-}0)$

Downes & Solomon 2008

Cold molecular mass $10^{7.5}$-$10^{9.6}$ Msun

Cold and Warm Molecular Gas

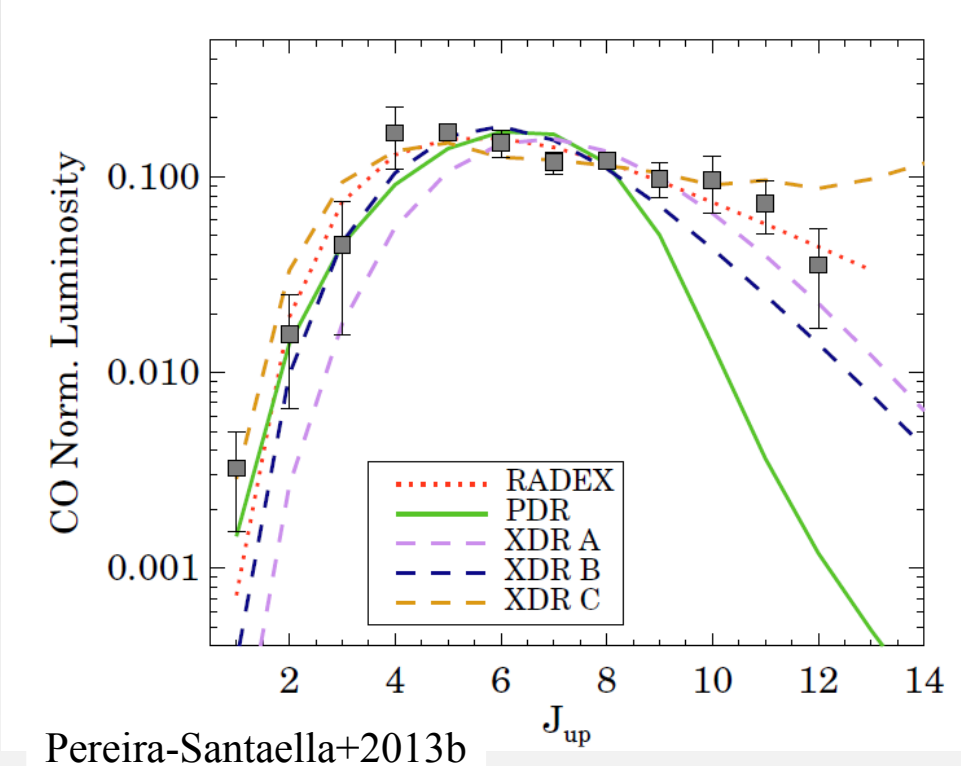


- CO SLED. 2 components
  - Luminosity dominated by the warm component (mid-J CO lines)
  - Mass dominated by the cold component (low-J CO lines)

	Cold	Warm
Luminosity	10%	90%
Mass	95%	5%

PDR or XDR?

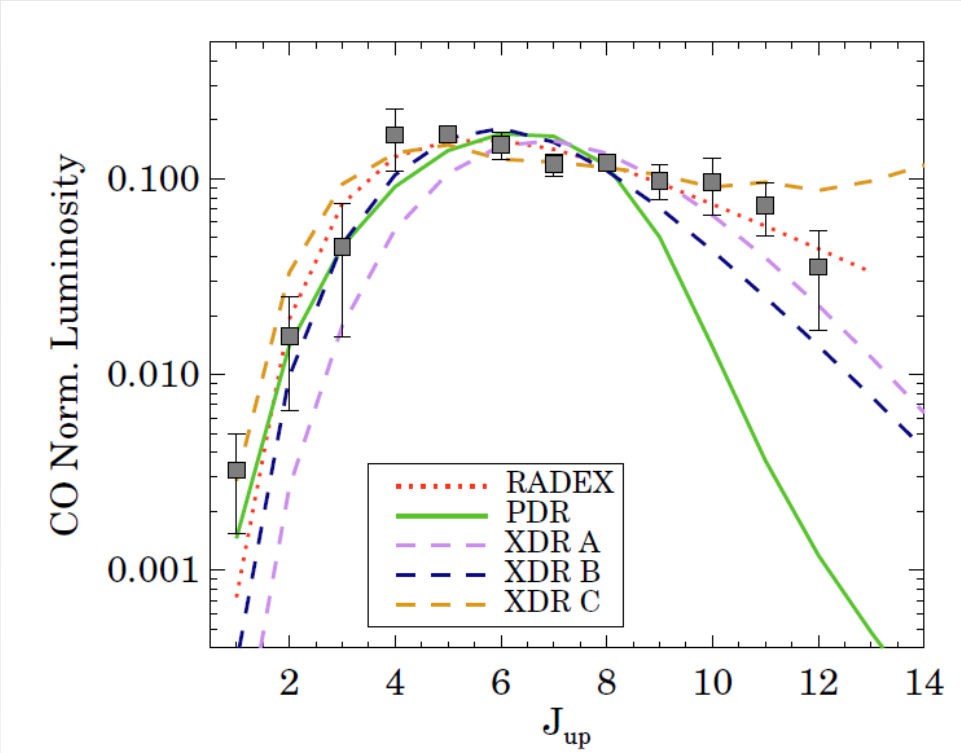
PDR and XDR Models



Pereira-Santaella+2013b

- PDR fits CO J<9. Underpredicts CO J>= 9

PDR and XDR Models



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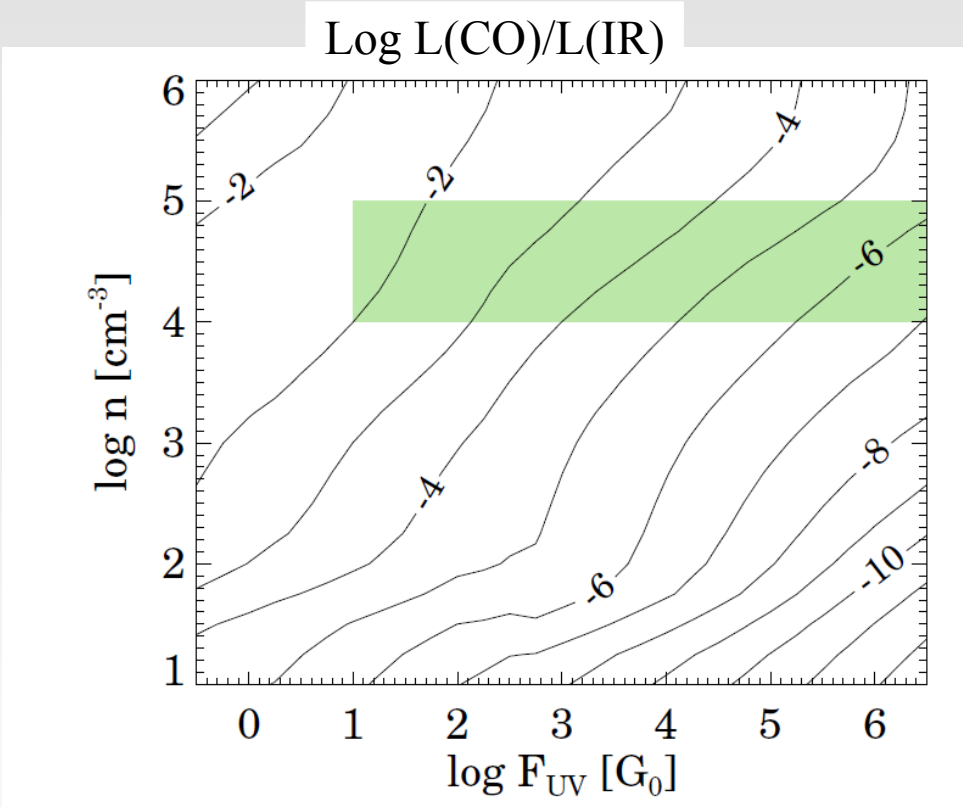
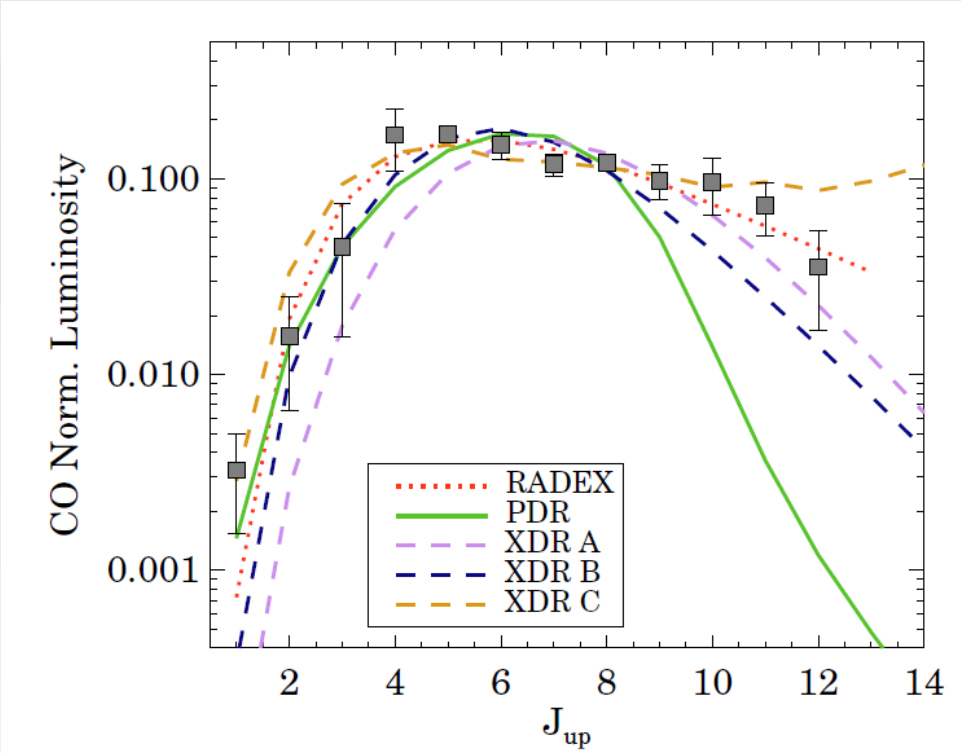


PDR and XDR Models



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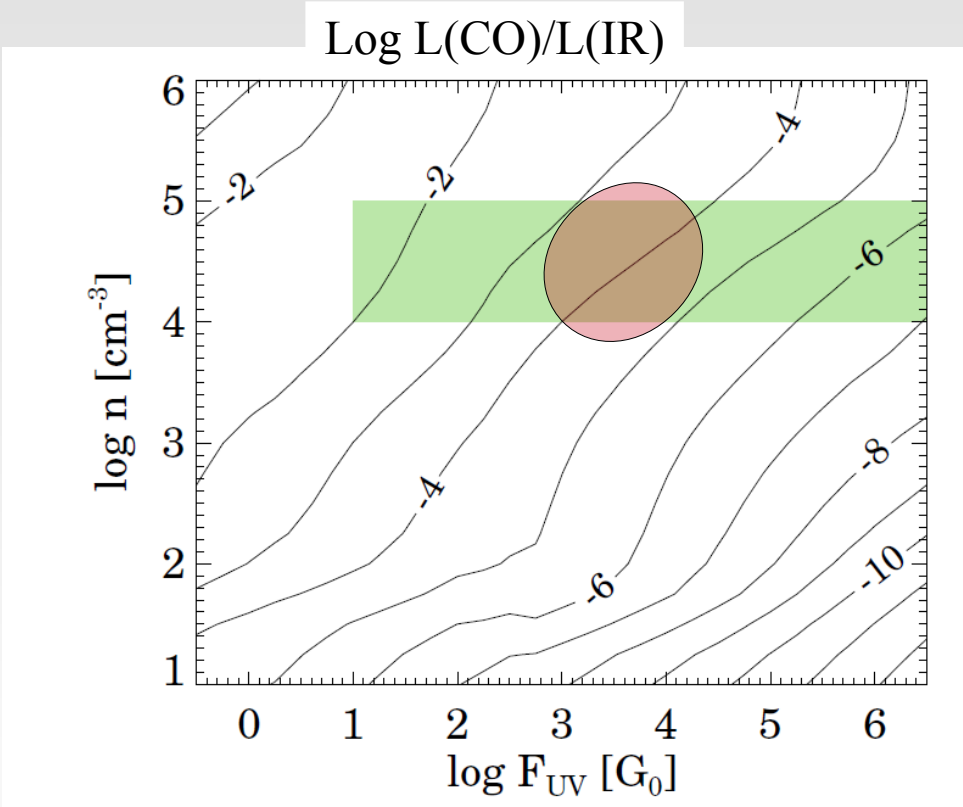
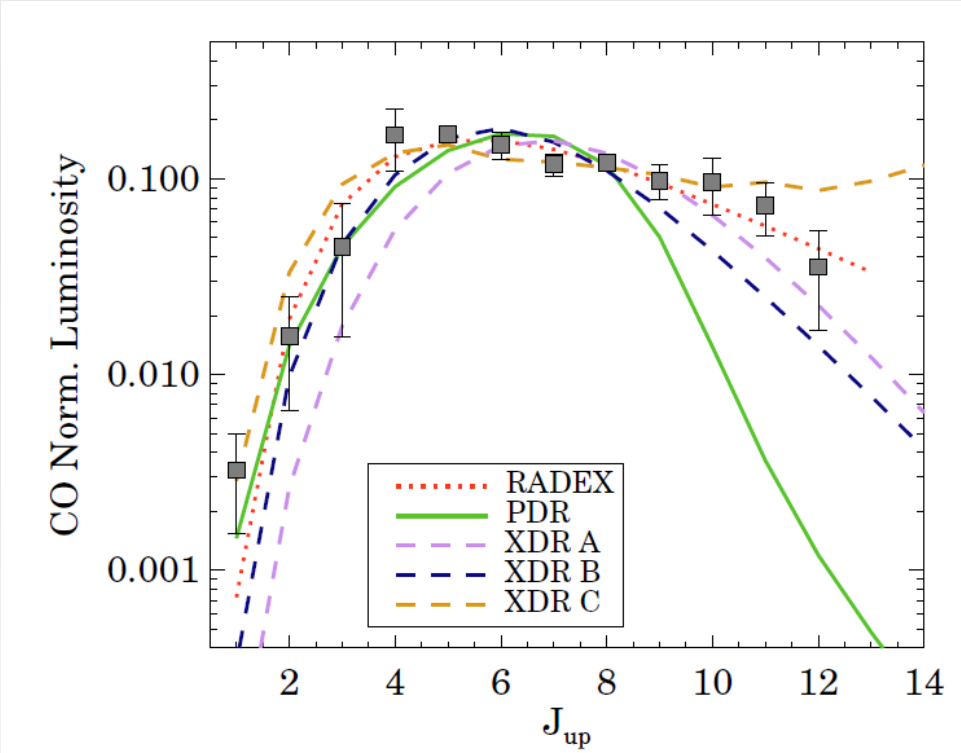


PDR and XDR Models



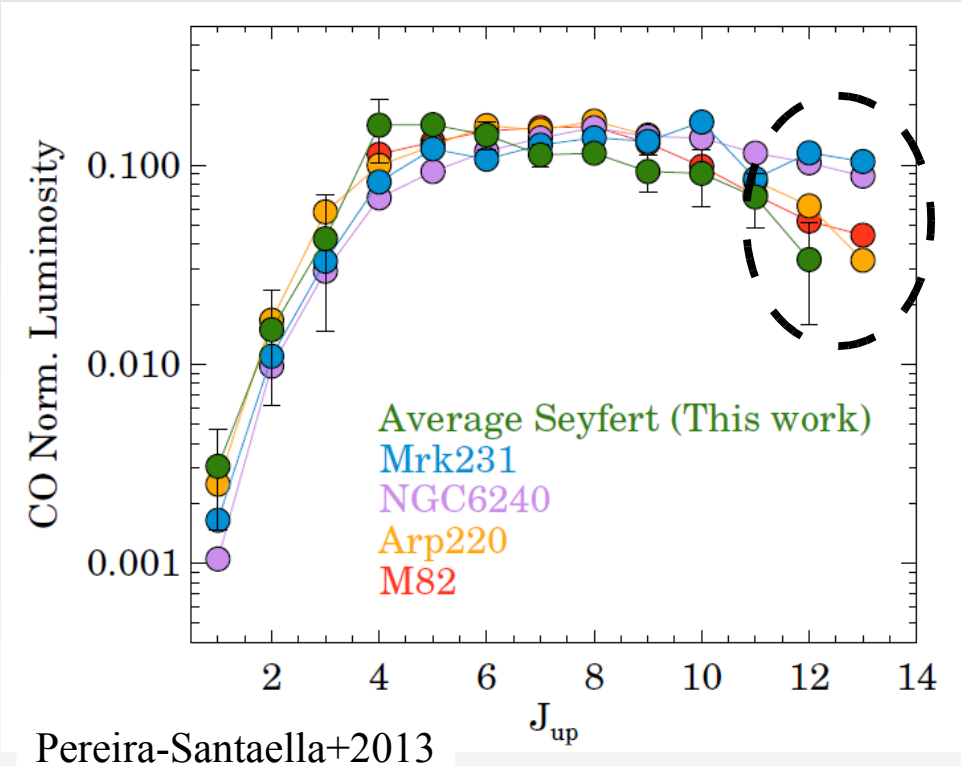
- PDR fits CO J<9. Underpredicts CO J>= 9
- XDR models, in general, fit better higher-J CO lines
  - XDR A High density
  - XDR B Intermediate density

    Models: L(CO)/L(X) ~ 10^{-4}.

    Obs: L(CO)/L(X) ~ 10^{-2}.

  - XDR C Diffuse gas. Low surface brightness (> 100x lower than observed)

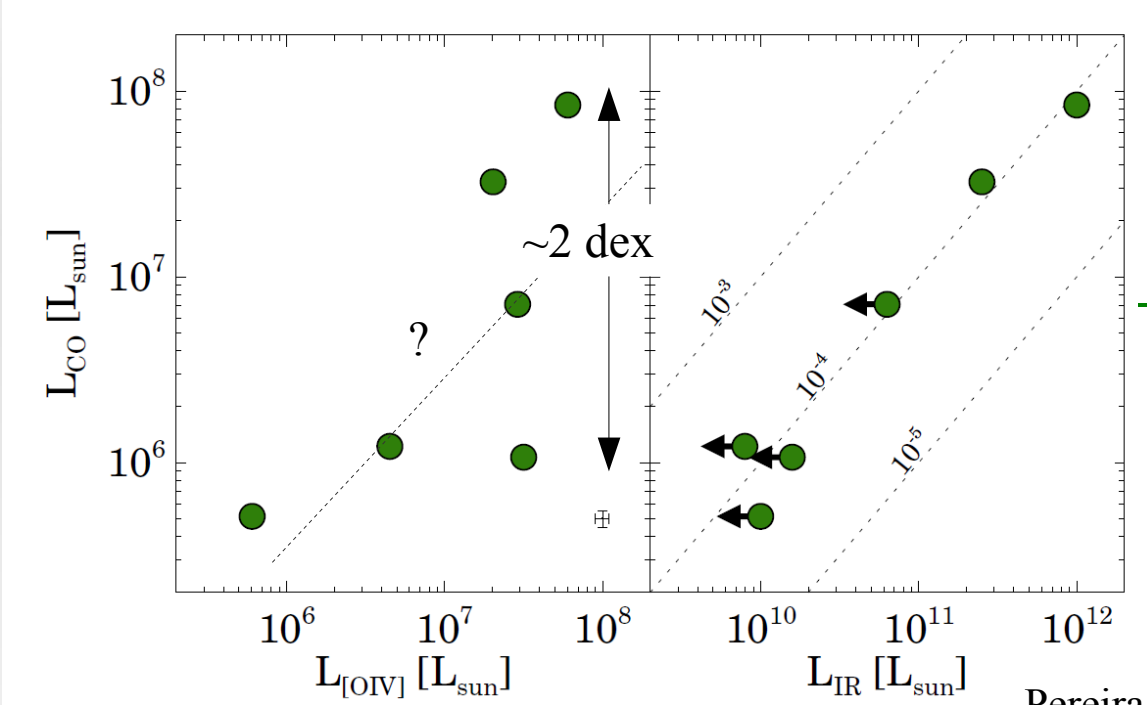
Comparing CO SLEDs



Pereira-Santaella+2013

- Mrk 231. Sy1 LIRG. XDR (van der Werf+2010)
- NGC6240. Sy2 LIRG. Shocks (Meijerink+2013)
- Arp220. ULIRG. No ~~PDR~~, no ~~XDR~~, shocks? (Rangwala+2011)
- M82. Starburst PDR+shocks (Kamenetzky+2012)

AGN or Star-Formation?



Pereira-Santaella+2013

$L_{CO} \sim 10^{-4} L_{IR}$

AGN luminosity

SFR

Likely Star-formation in these galaxies

Summary

- SPIRE/FTS view of warm molecular gas in galaxies
  - HF 1-0 as an AGN tracer
  - PDR? XDR? Shocks? We need more data (higher angular resolution, higher-J CO lines)
  - mid-J CO emission more likely related to SF in these galaxies