

# HerCULES

## Herschel Comprehensive (U)LIRG Emission Survey



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Leiden Observatory



**ESAC**

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# Credits!



- Data processing: Trevor Fulton  
Kate Isaak  
Adam Rykala
- Modeling: Rowin Meijerink  
Marco Spaans  
Edo Loenen  
Eduardo Gonzalez-Alfonso  
Axel Weiß

NB: data taking December 13  
data processing December 14-17  
modeling December 18  
this talk December 19

# HerCULES in a nutshell



- HerCULES will uniformly and statistically measure the neutral gas cooling lines in a flux-limited sample of (U)LIRGs.
- Sample:
  - all IRAS RBGS ULIRGs with  $S_{60} > 12.19$  Jy (6 sources)
  - all IRAS RBGS LIRGs with  $S_{60} > 16.8$  Jy (23 sources)
- Observations:
  - SPIRE/FTS full high-resolution scans: 200 to 670  $\mu\text{m}$  at  $R \approx 600$ , covering CO 5–4 to 13–12 and [CI] (+ other lines?)
  - PACS line scans of [CII] and both [OI] lines
  - All targets observed to same (expected) S/N
  - Extended sources observed at several positions

# Who is HerCULES?



Paul van der Werf (Leiden; PI)  
Susanne Aalto (Onsala)  
Peter Ade (Cardiff)  
Lee Armus (Spitzer SC)  
Vassilis Charmandaris (Crete)  
Kalliopi Dasyra (CEA)  
Aaron Evans (Stony Brook)  
Jackie Fischer (NRL)  
Yu Gao (Purple Mountain)  
Eduardo Gonzalez-Alfonso (Henares)  
Thomas Greve (MPIA)  
Rolf Güsten (MPIfR)  
Andy Harris (U Maryland)  
Chris Henkel (MPIfR)  
Kate Isaak (Cardiff)  
Frank Israel (Leiden)  
Carsten Kramer (Cologne)  
Edo Loenen (Leiden)  
Steve Lord (NASA Herschel SC)  
HerCULES

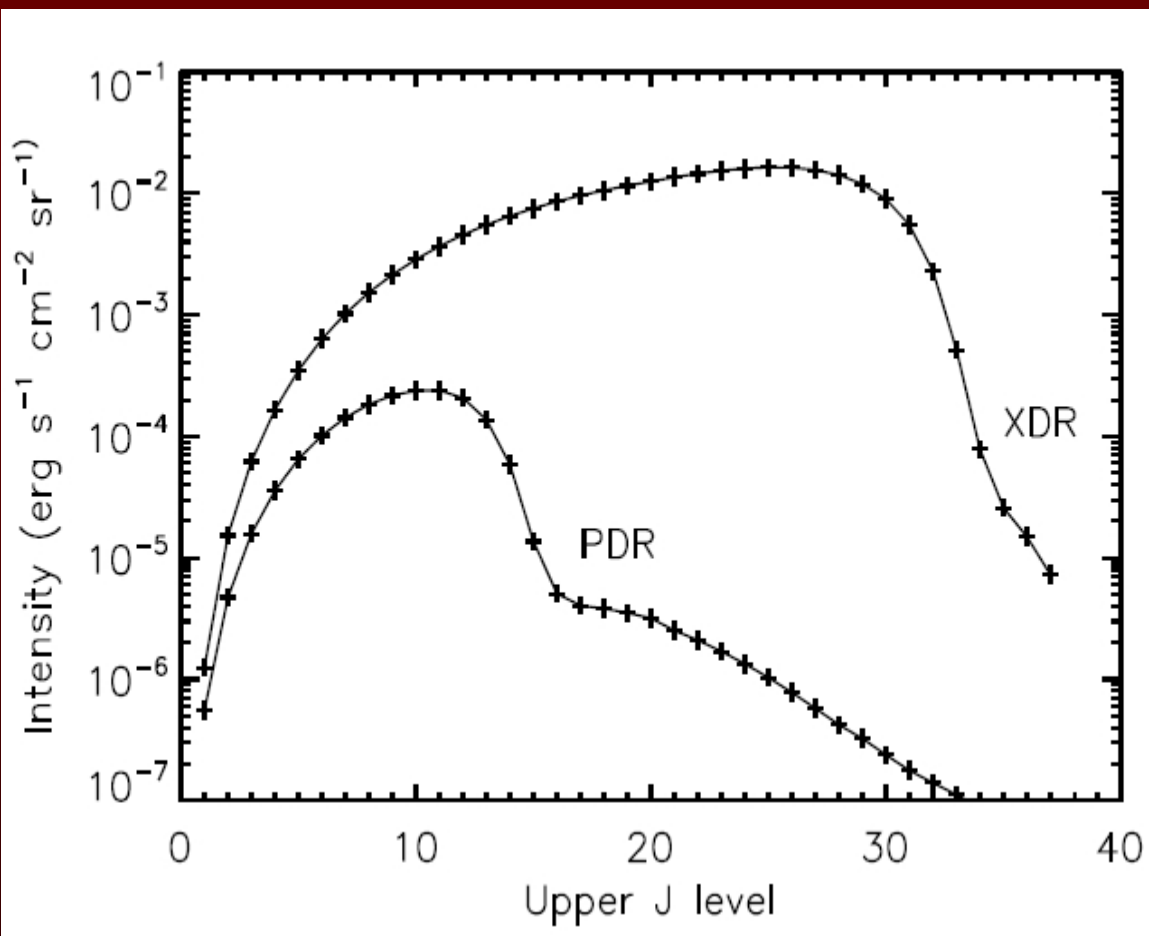
Jesus Martín-Pintado (Madrid)  
Joe Mazzarella (IPAC)  
Rowin Meijerink (Leiden)  
David Naylor (Lethbridge)  
Padelis Papadopoulos (Bonn)  
Sabine Philipp (DLR)  
Adam Rykala (Cardiff)  
Dave Sanders (U Hawaii)  
Giorgio Savini (Cardiff)  
Howard Smith (CfA)  
Marco Spaans (Groningen)  
Luigi Spinoglio (Rome)  
Gordon Stacey (Cornell)  
Sylvain Veilleux (U Maryland)  
Cat Vlahakis (Leiden)  
Fabian Walter (MPIA)  
Axel Weiß (MPIfR)  
Martina Wiedner (Paris)  
Manolis Xilouris (Athens)

# Aims of HerCULES



- develop use of the CO rotational ladder as a diagnostic
- inventory of neutral gas cooling
- statistically robust approach
- low- $z$  benchmark for future ALMA observations

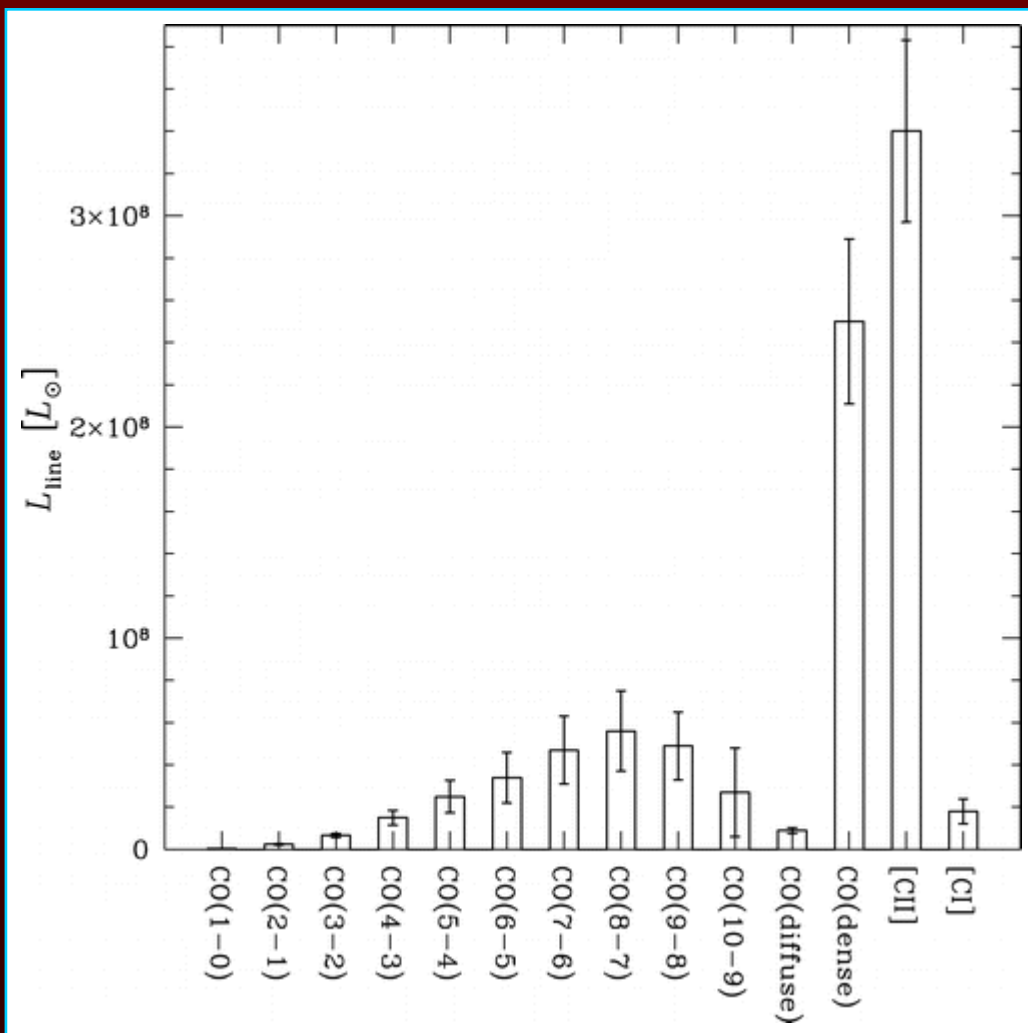
# PDRs vs. XDRs



- Identical incident energy densities give very different CO spectra
- Very high J CO lines are unique XDR tracers
- Need full coverage of CO ladder in real galaxies

(Spaans & Meijerink 2008)

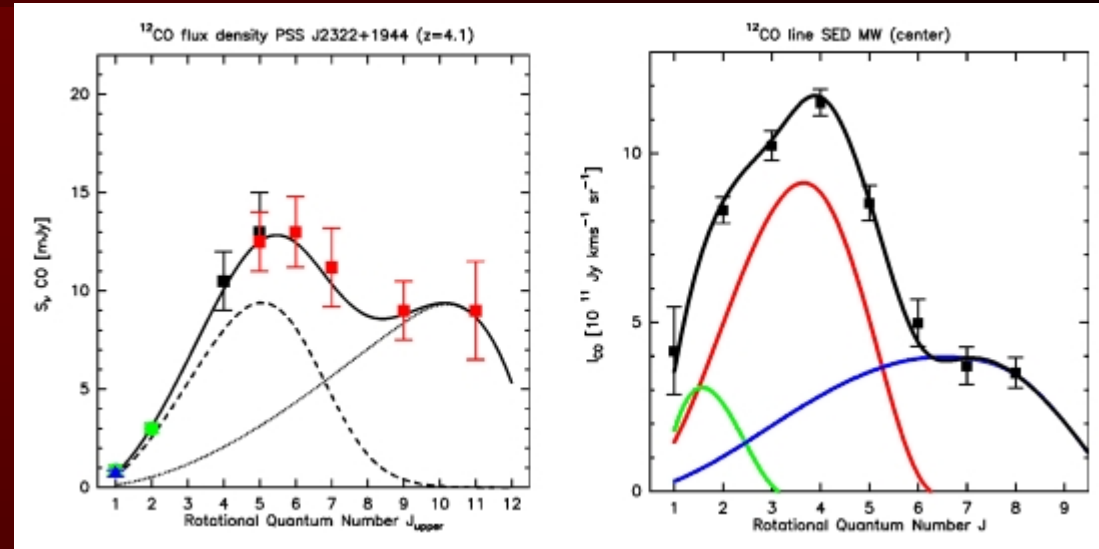
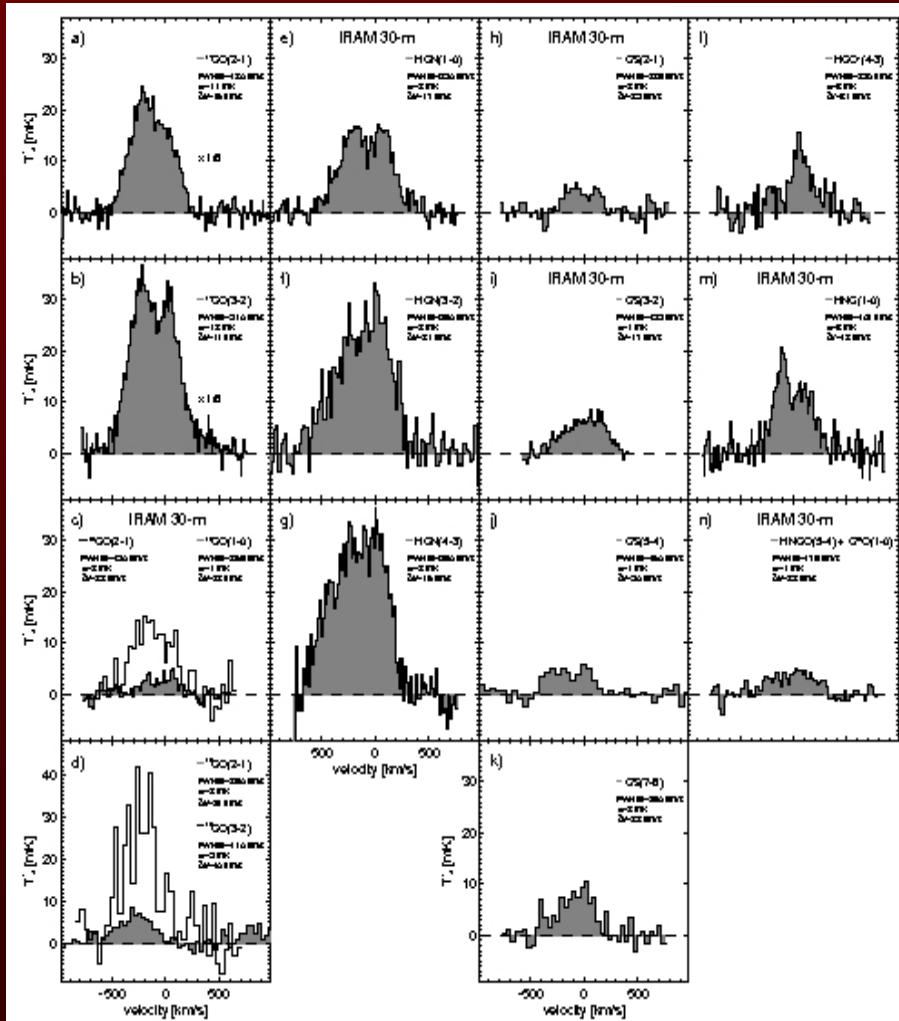
# Cooling budget in Mrk231



Line	$L_{\text{line}} [L_{\odot}]$
[C II] 158 $\mu\text{m}$	$3.6 \cdot 10^8$
[C I]	$3.4 \cdot 10^6$
CO diffuse	$5.8 \cdot 10^6$
CO dense	$>1.5 \cdot 10^8$

- CO cooling from the dense phase approaches [C II] cooling
- Consistent with dense PDRs
- **Solution to the [C II] problem**
- **Full understanding crucial in ALMA era**

# A local benchmark for high- $z$ galaxies



(Walter, Weiß *et al.*)

- Even in ALMA era, often limited spatial resolution on very high  $z$  galaxies, but many lines available
- HerCULES will provide an empirical framework for interpreting these data.

# HerCULES sample

Target	$\log(L_{\text{IR}}/L_{\odot})$
Mrk 231	12.51
IRAS F17207—0014	12.39
IRAS 13120—5453	12.26
Arp 220	12.21
Mrk 273	12.14
IRAS F05189—2524	12.11
Arp 299	11.88
NGC 6240	11.85
IRAS F18293—3413	11.81
Arp 193	11.67
IC 1623	11.65
NGC 1614	11.60
NGC 7469	11.59
NGC 3256	11.56

Target	$\log(L_{\text{IR}}/L_{\odot})$
IC 4687/4686	11.55
NGC 2623	11.54
NGC 34	11.44
MCG+12—02—001	11.44
Mrk 331	11.41
IRAS 13242—5713	11.34
NGC 7771	11.34
Zw 049.057	11.27
NGC 1068	11.27
NGC 5135	11.17
IRAS F11506—3851	11.10
NGC 4418	11.08
NGC 2146	11.07
NGC 7552	11.03
NGC 1365	11.00



# HerCULES SDP



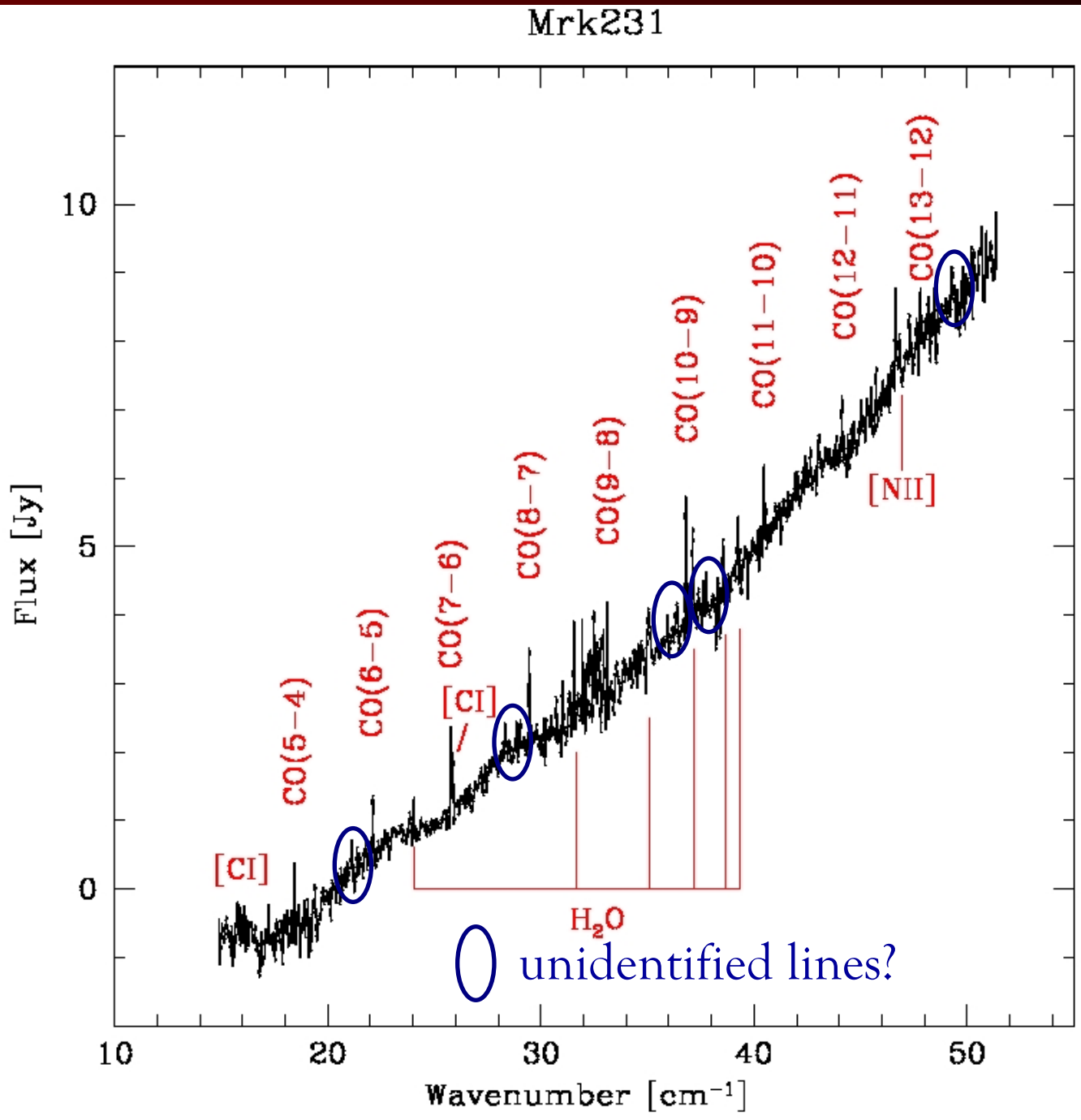
- 1 target observed in SDP: Mrk231 (SPIRE/FTS only)
- 18 lines detected at good S/N
- FTS sensitivity better than expected by factor 2

# The bottom line

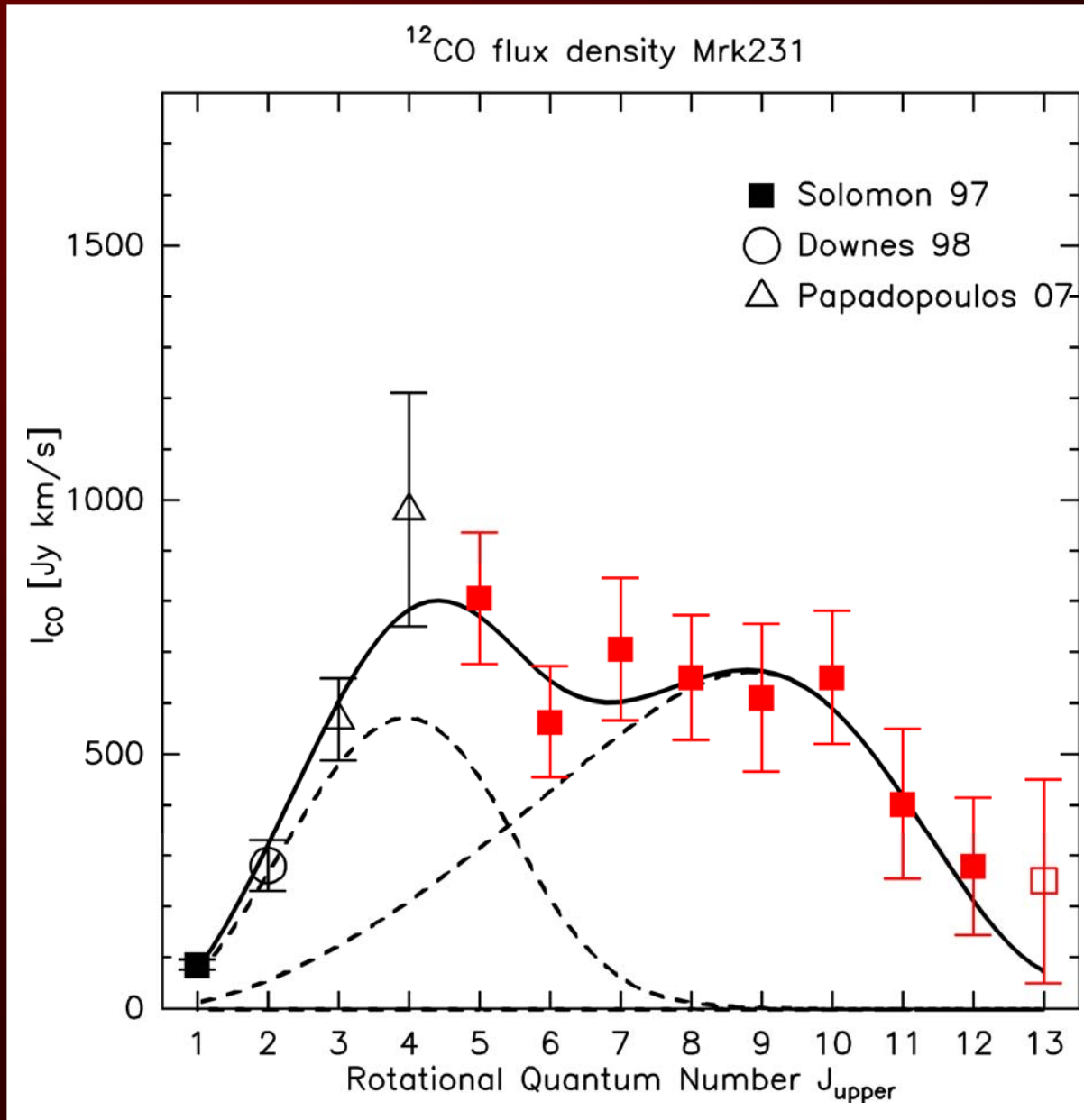


- CO lines in Mrk231 require PDR (low-J lines) + XDR (high-J lines)
- Modeling CO lines enables separation of starburst and AGN contribution to  $L_{\text{IR}}$

# Mrk231 SPIRE FTS

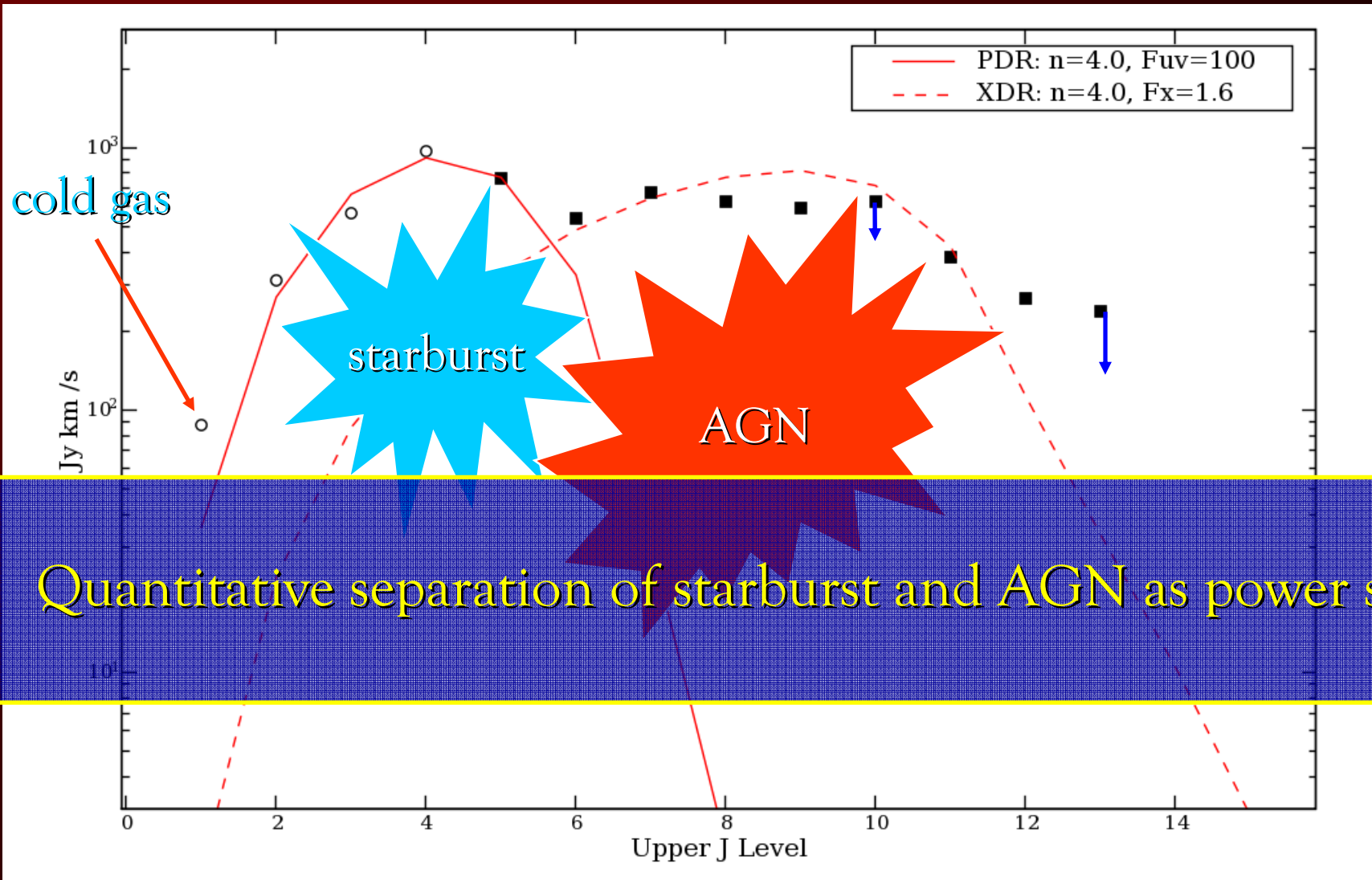


# Mrk231 CO excitation



(Weiß,  
yesterday)

# Mrk231 PDR/XDR separation



Quantitative separation of starburst and AGN as power source!

# Water lines



- All water lines are in emission
- Water lines IR-pumped, provides constraints on the continuum as well as on emitting medium
- Best-fitting model:
  - warm component:  $T=100$  K,  $R=100$  pc (56% of  $L_{\text{IR}}$ )
  - cool component:  $T=47$  K,  $R=350$  pc (22% of  $L_{\text{IR}}$ )
  - $M(\text{H}_2)_{\text{warm}} \approx 0.1 M(\text{H}_2)_{\text{cool}}$
  - emitting gas and dust mixed

(Gonzalez-Alfonso, yesterday)

# To be done



- Improved FTS processing to get to thermal noise
- Modeling extreme PDR to reproduce maximum number of CO lines
- Verify and identify unidentified lines
- Go *really* deep with the FTS on a number of targets
- Compare/coordinate with PACS
- Follow-up H<sub>2</sub>O lines (and others?) with HIFI

# Conclusions



- CO lines in Mrk231 require PDR (low-J lines) + XDR (high-J)
- Modeling CO lines enables separation of starburst and AGN contribution to  $L_{\text{IR}}$
- New template for high-z galaxies including H<sub>2</sub>O lines!
- Water lines IR-pumped, helps constrain physical models
- 7 unidentified lines?
- Stay tuned for more!