HerCULES
Herschel Comprehensive (U)LIRG Emission Survey

Paul van der Werf

Leiden Observatory

Sterrewacht Leiden

ESLAB Conference

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HerCULES in a nutshell

Sterrewacht Leiden

- 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 µm at R ≈ 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

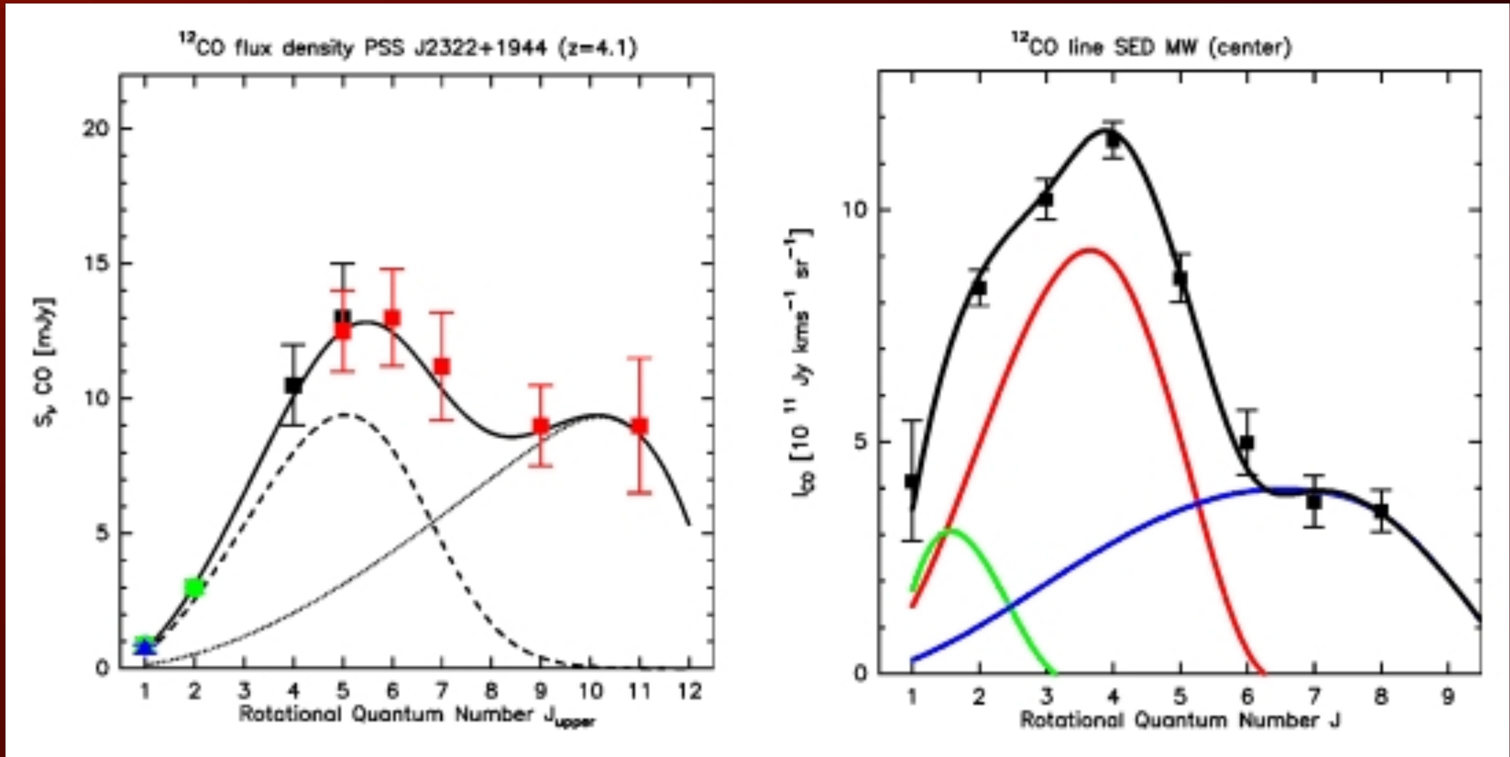
Who is HerCULES?

Paul van der Werf (Leiden; PI)
Susanne Aalto (Onsala)
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/Copenhagen)
Rolf Güsten (MPIfR)
Andy Harris (U Maryland)
Chris Henkel (MPIfR)
Kate Isaak (Cardiff/ESTEC)
Frank Israel (Leiden)
Carsten Kramer (IRAM)
Edo Loenen (Leiden)
Steve Lord (NASA Herschel SC)
Jesus Martín-Pintado (Madrid)
Joe Mazzarella (IPAC)
Rowin Meijerink (Leiden)
David Naylor (Lethbridge)
Padelis Papadopoulos (Bonn)
Adam Rykala (Cardiff)
Dave Sanders (U Hawaii)
Giorgio Savini (Cardiff/UCL)
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 ALMA observations
- spectroscopically probe uncharted territory

A local benchmark for high-z galaxies



(Weiß, Walter *et al.*)

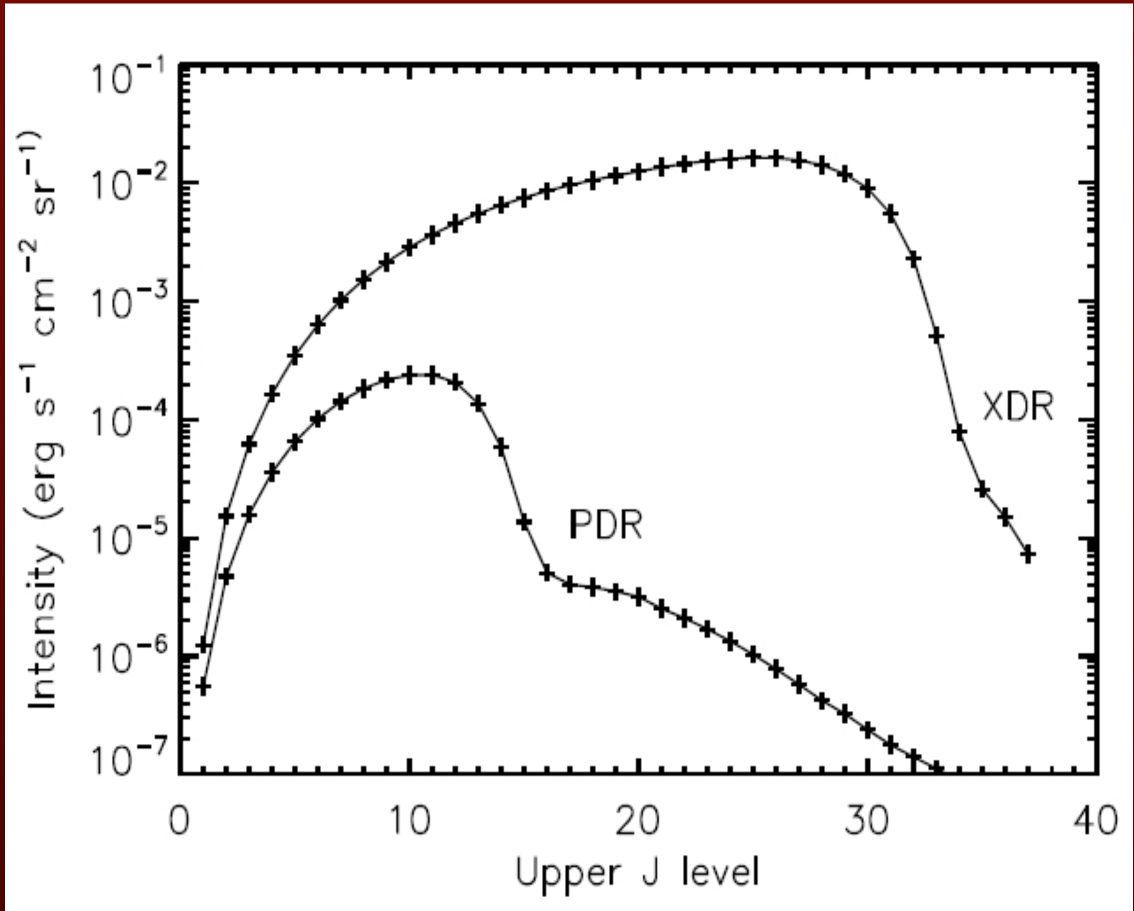
- Even in ALMA era, limited spatial resolution on high-z galaxies, but many lines available
- HerCULES will provide an empirical framework for interpreting these data.

PDRs *vs.* XDRs

Four differences:

- X-rays penetrate much larger column densities than UV photons
- Gas heating efficiency in XDRs is ≈10–50%, compared to <1% in PDRs
- Dust heating much more efficient in PDRs than in XDRs
- High ionization levels in XDRs drive ion-molecule chemistry

PDRs *vs.* XDRs: CO lines



(Spaans & Meijerink 2008)

- XDRs produce larger column densities of warmer gas
- Identical incident energy densities give very different CO spectra
- Very high J CO lines are excellent XDR tracers
- Need good coverage of CO ladder

HerCULES sample

Target	log($L_{\mathrm{IR}}/L_{\odot}$)
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($L_{\mathrm{IR}}/L_{\odot}$)
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

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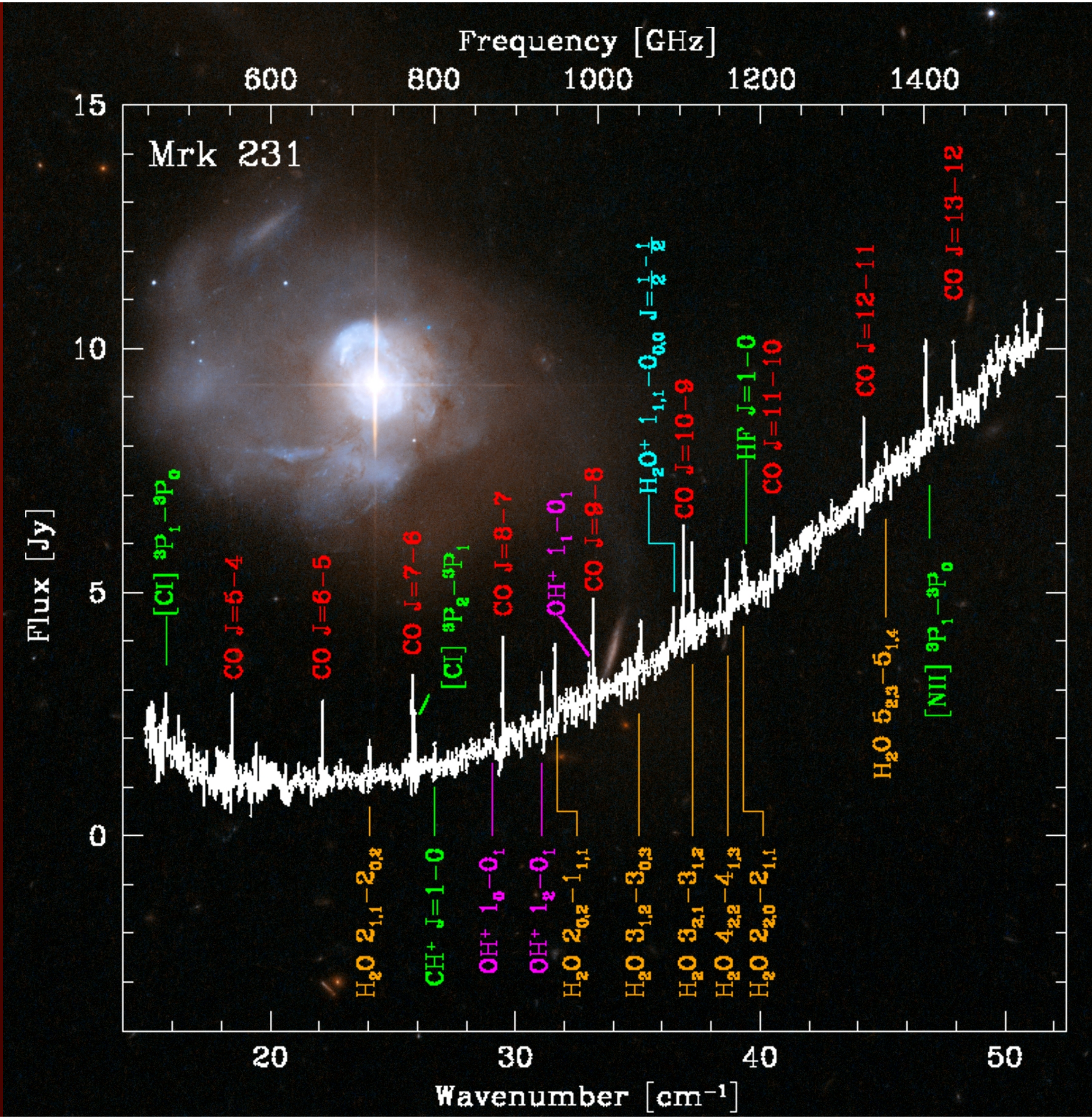
Mrk231 SPIRE FTS



A&A Special Issue papers

LETTER TO THE EDITOR

Loenen talk

Black hole accretion and star formation as drivers of gas excitation and chemistry in Mrk 231

P.P. van der Werf[1 *], K.G. Isaak[2,3], R. Meijerink[1], M. Spaans[4], A. Rykala[2], T. Fulton[5], A.F. Loenen[1], F. Walter[6], A. Weiß[7], L. Armus[8], J. Fischer[9], F.P. Israel[1], A.I. Harris[10], S. Veilleux[10], C. Henkel[7], G. Savini[11], S. Lord[12], H.A. Smith[13], E. González-Alfonso[14], D. Naylor[15], S. Aalto[16], V. Charmandaris[17], K.M. Dasyra[18], A. Evans[19,20], Y. Gao[21], T. Greve[6,22], R. Güsten[7], C. Kramer[23], J. Martín-Pintado[24], J. Mazzarella[12], P.P. Papadopoulos[25], D.B. Sanders[26], L. Spinoglio[27], G. Stacey[28], C. Vlahakis[1], M.C. Wiedner[29], and E. Xilouris[30]

(Affiliations can be found after the references)

LETTER TO THE EDITOR

González-Alfonso poster

Herschel* observations of water vapour in Markarian 231

E. González-Alfonso[1], J. Fischer[2], K. Isaak[3], A. Rykala[3], G. Savini[4], M. Spaans[5], P. van der Werf[6], R. Meijerink[6], F. P. Israel[6], A. F. Loenen[6], C. Vlahakis[6], H. A. Smith[7], V. Charmandaris[8], S. Aalto[9], C. Henkel[10], A. Weiss[10], F. Walter[11], T. Greve[11], L. Spinoglio[12], S. Veilleux[13], A. I. Harris[13], L. Armus[14], S. Lord[14], J. Mazzarella[14], E. M. Xilouris[15], D. B. Sanders[16], K. M. Dasyra[17], M. C. Wiedner[18], C. Kramer[19], P. P. Papadopoulos[20], G. J. Stacey[21], A. S. Evans[22], and Y. Gao[23]

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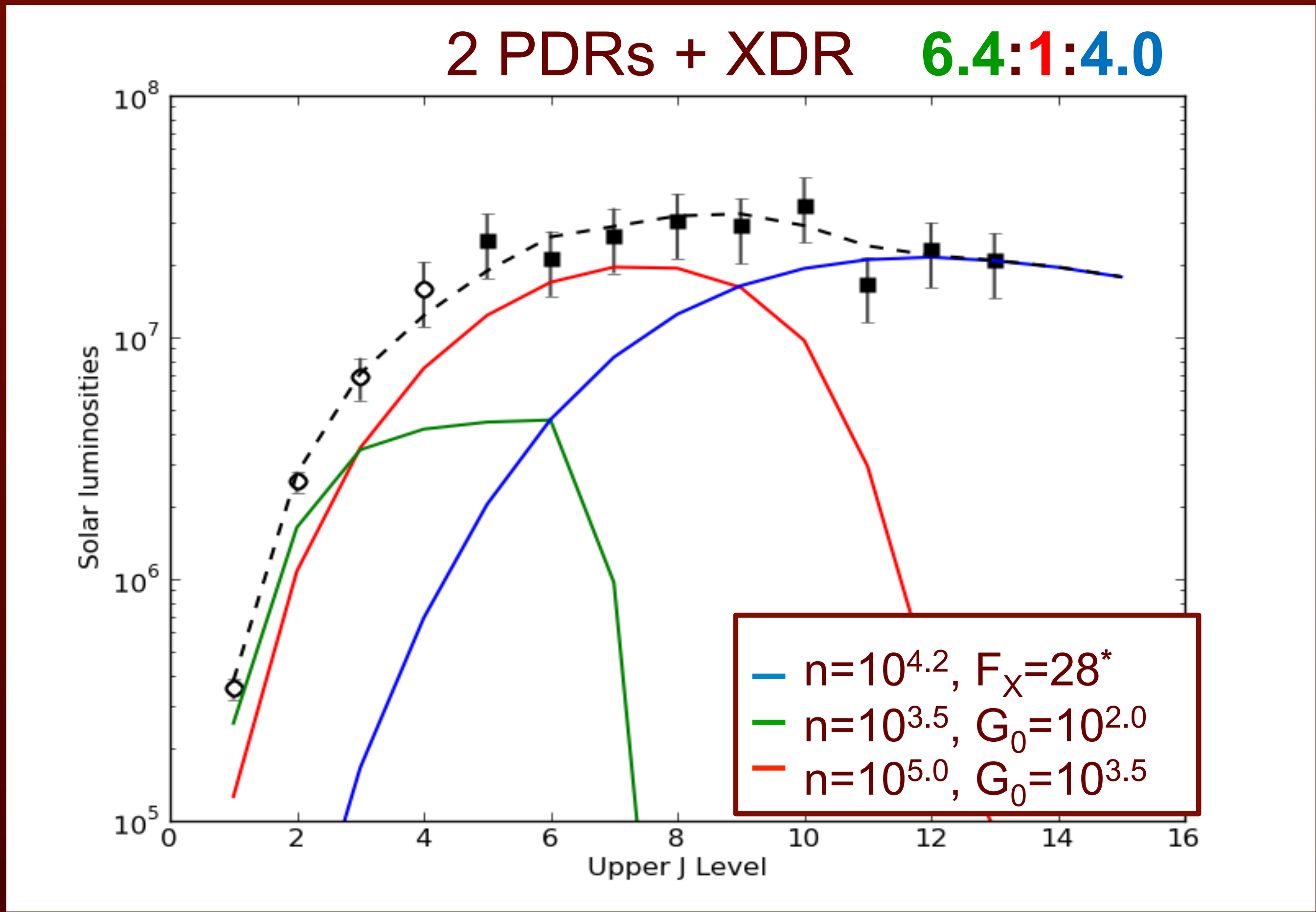
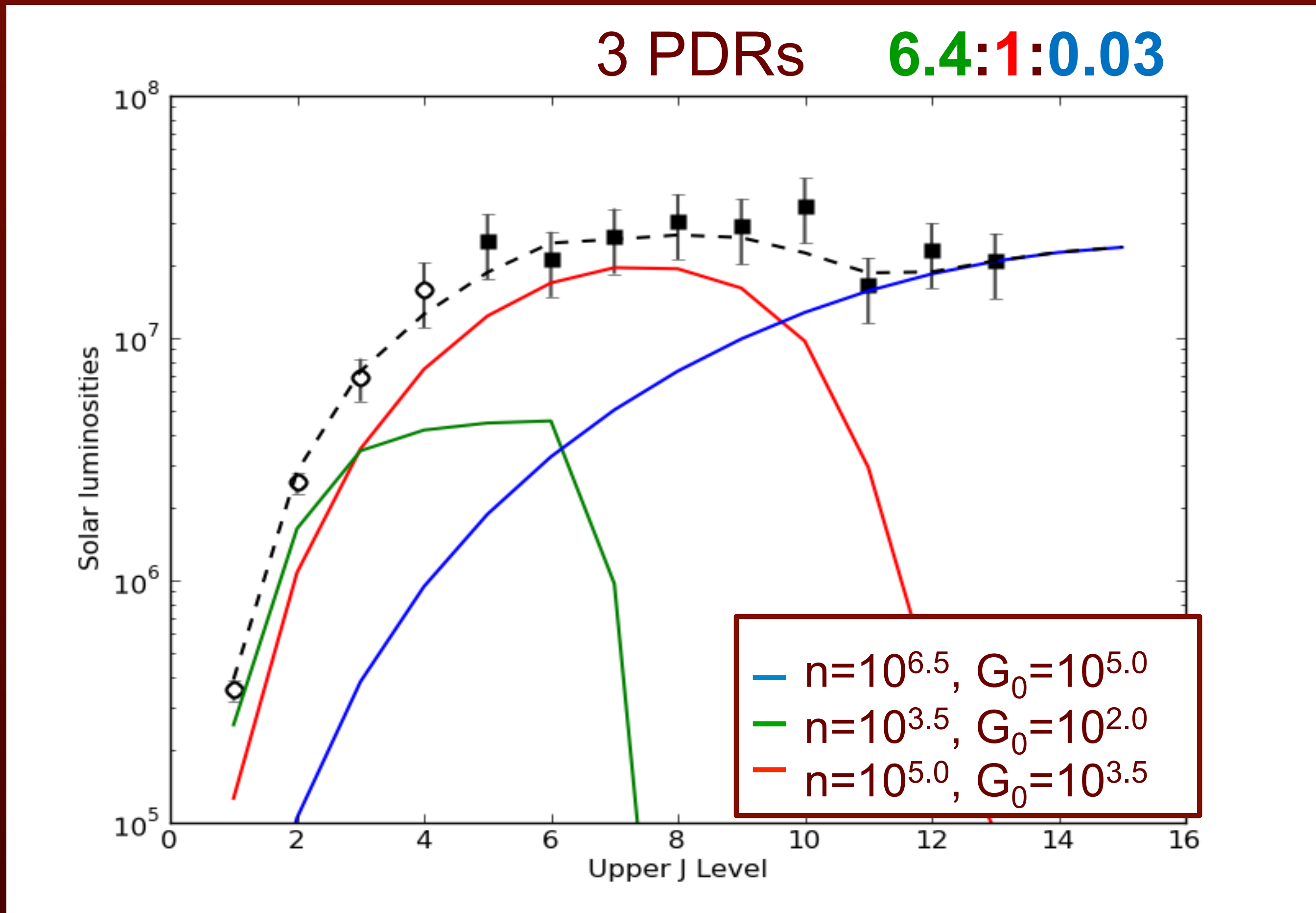
CO excitiation



* 28 erg cm^{-2} s^{-1} → $G_0=10^{4.2}$

CO excitiation



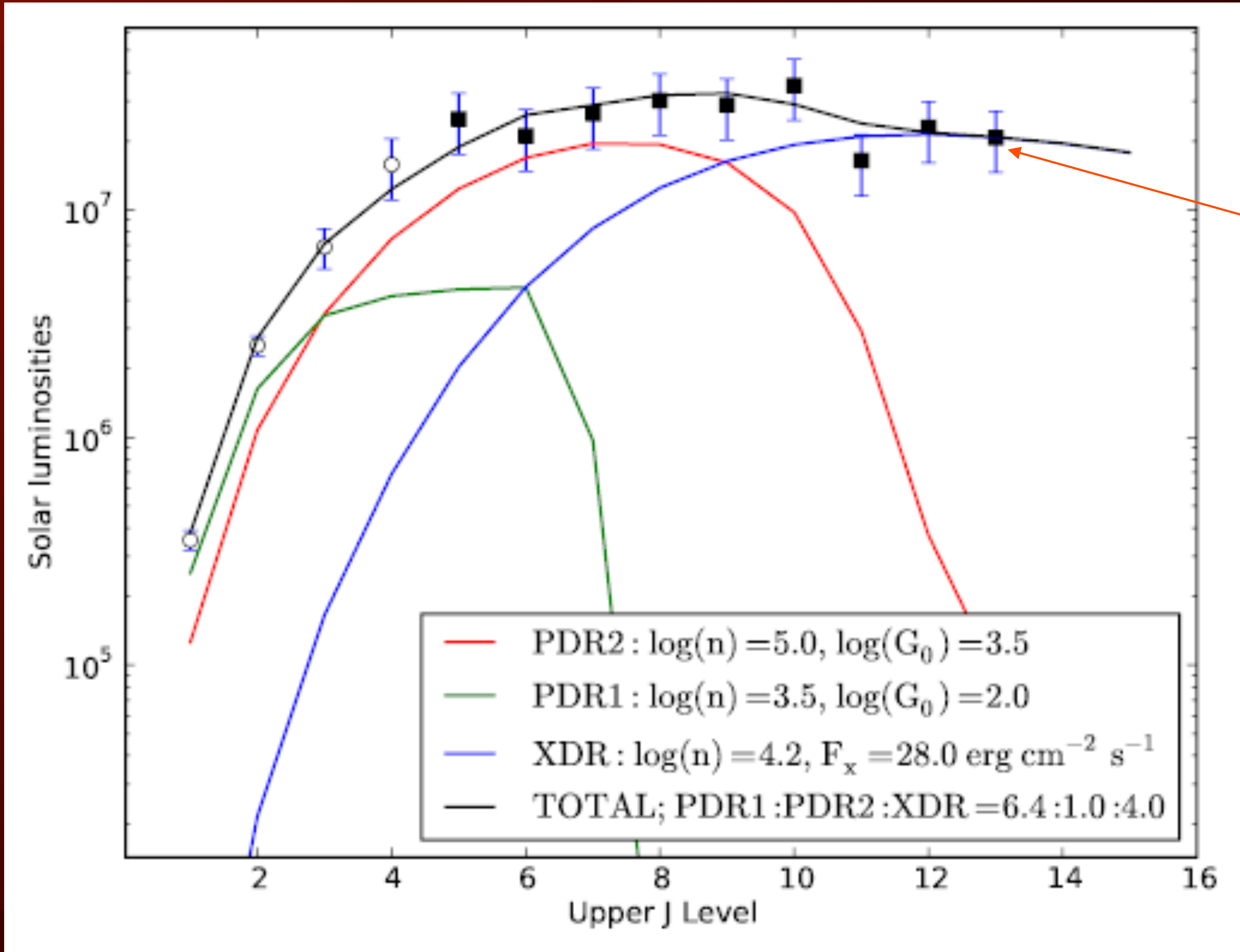
High-*J* lines: PDR or XDR?

- High-*J* CO lines can also be produced by PDR with n=$10^{6.5}$ cm^{-3} and G_0=10^5, containing half the molecular gas mass.

- Does this work?
  - G_0=10^5 only out to 0.3 pc from O5 star; then we must have half of the molecular gas and dust in 0.7% of volume.
  - With G_0=10^5, 50% of the dust mass would be at 170K.
  - [OH^+] and [H_2O^+] > 10^{-9} in dense gas requires efficient and penetrative source of ionization; PDR abundances factor 100–1000 lower

- XDR strongly favoured

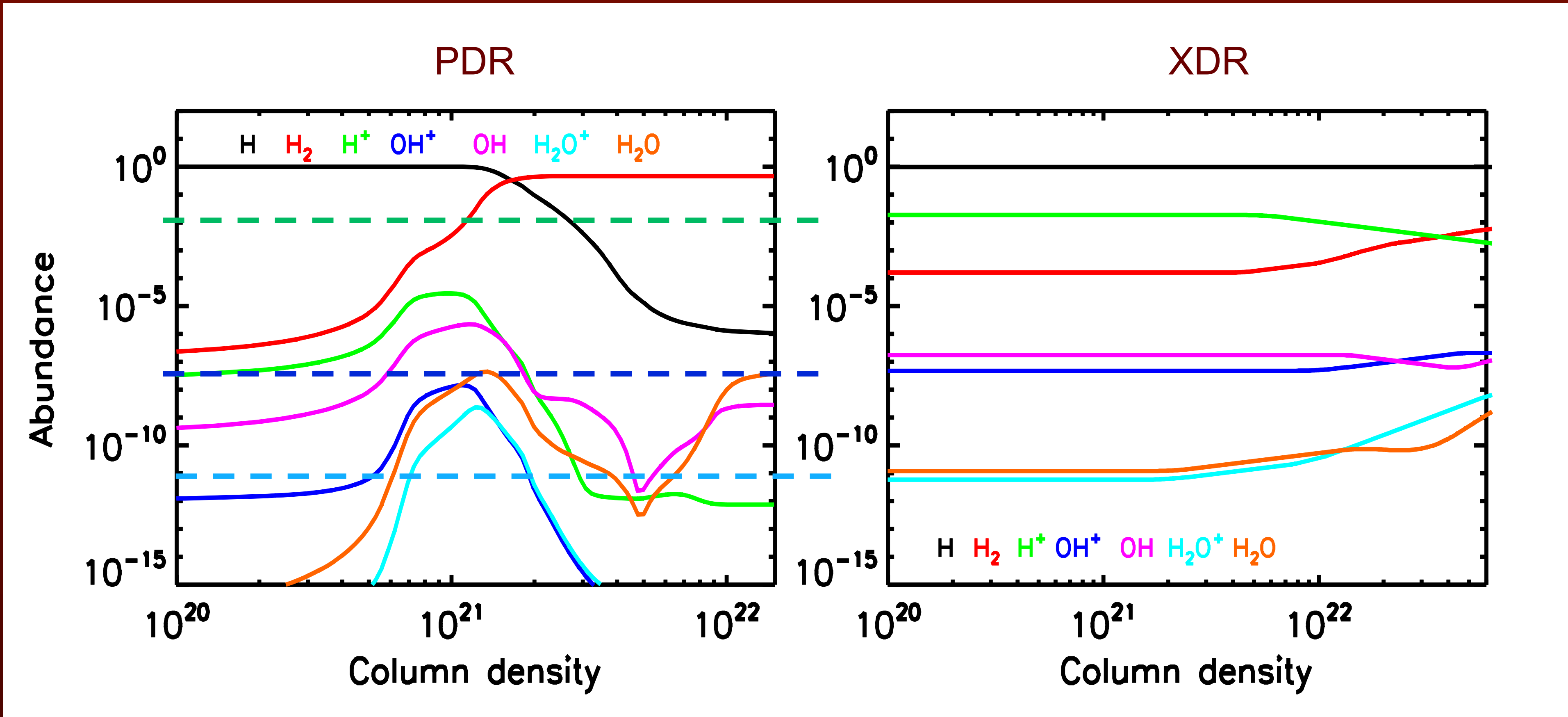
Mrk231 PDR/XDR separation



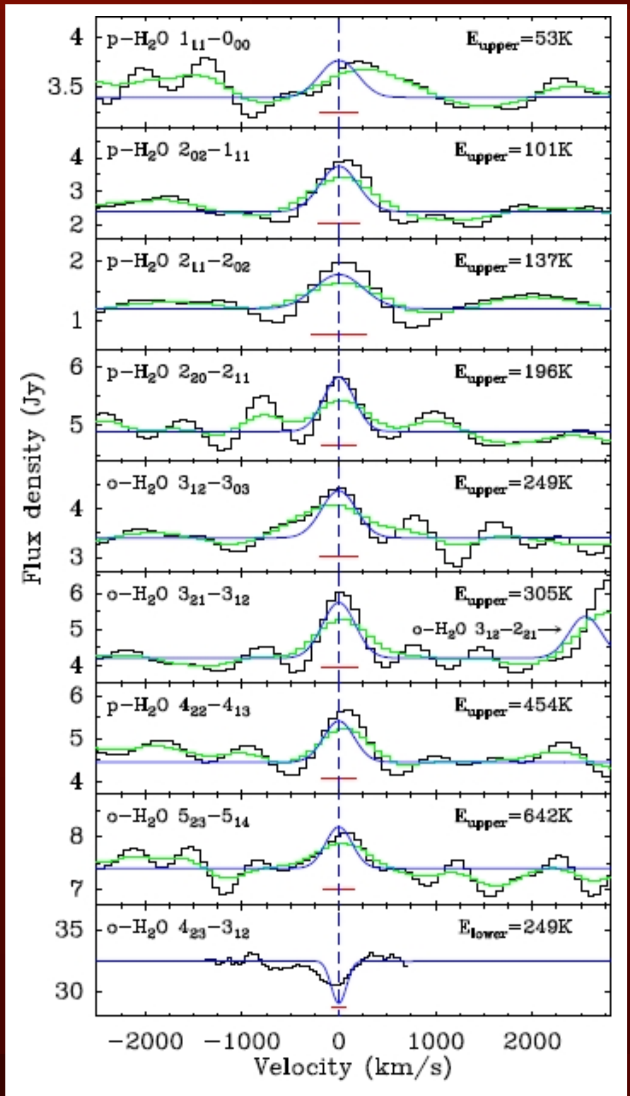
T_{up} = 503 K

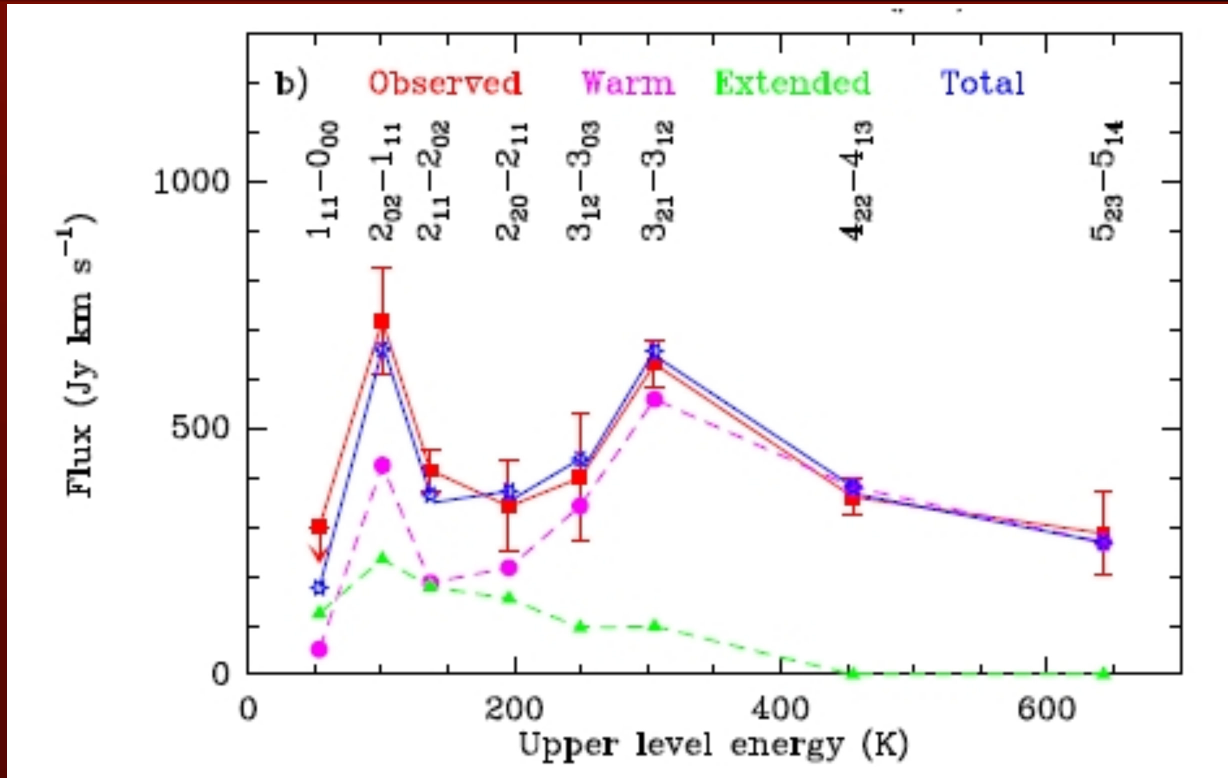
XDR dominates from J=10 upwards!

PDR *vs.* XDR chemistry



H_2O lines in Mrk231

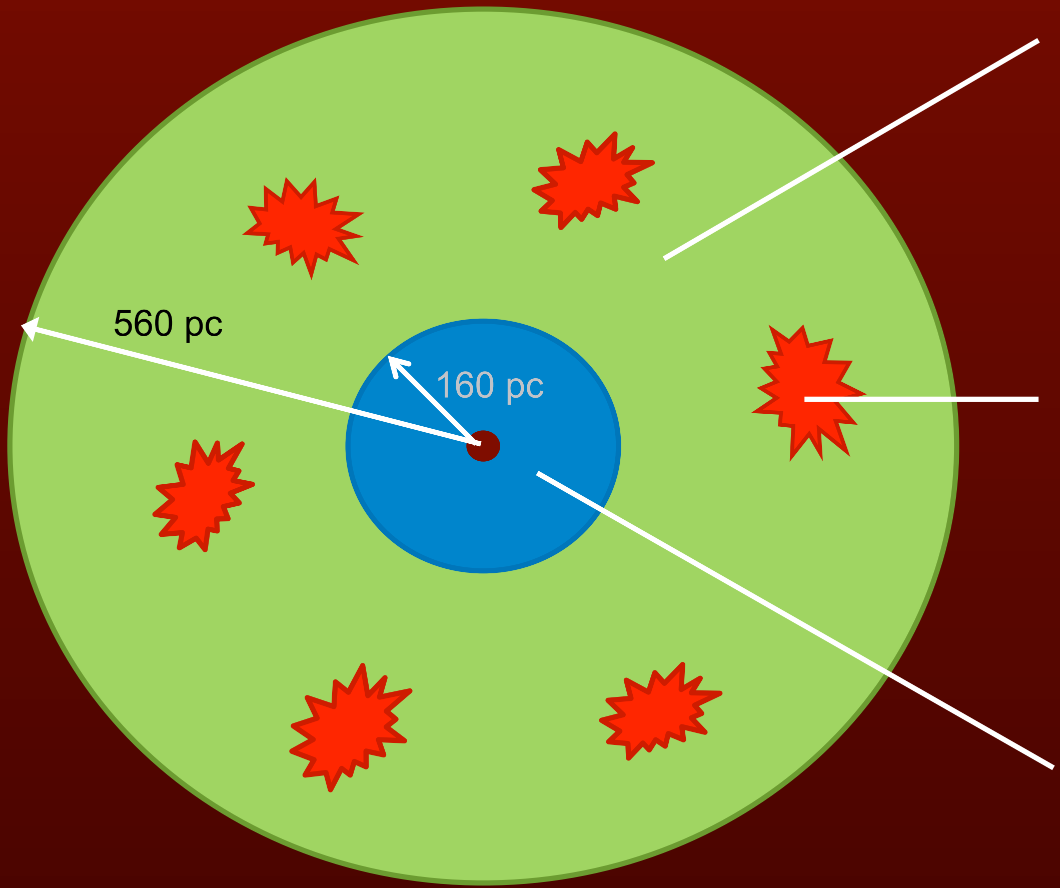




- Low lines: cool extended component
- High lines: warm compact component
- Radiative pumping dominates

(González-Alfonso *et al.*, 2010)

PDR/XDR model



- PDR 1:
  - n=10$^{3.5}$, G_0=10^2, R~500pc
  - Large scale molecular gas
  - → Low-J CO, low H_2O lines
- PDR 2:
  - n=10^5, G_0=10$^{3.5}$
  - Small, dense SF clumps
  - → mid-J CO lines
- XDR:
  - n=10$^{4.2}$, F_X=28, R~150pc
  - Circumnuclear XDR disk
  - → High-J CO, OH^+, H_2O^+, high H_2O lines

HerCULES work in progress

- Comprehensive analysis of Mrk231 data (Meijerink *et al*., in prep.)
- PDR/XDR separation across the HerCULES sample
- H_2 mass determination from CO lines at $J > 1$ (*cf*., ALMA)
- Cooling budget and the [CII] deficit
- …

Future steps with Herschel

- Higher-*J* CO lines (PACS)
- H_2O, H_2O^+, OH^+ line profiles (HIFI)
- What if we integrate 20 hours in stead of 2?
  - ^{13}CO, H_2O, OH, OH^+, H_2O^+, H_3O^+, CH, HCN, HNC, HCO^+, H_2Cl^+, NH, NH_2, NH_3; possibly HeH^+

Connection with high redshift

- H_2O, OH^+, H_2O^+ emission being followed up with IRAM/PdB
- Multi-line approach will be crucial interpreting CO
- High-*J* CO lines are diagnostics for high-*z* black hole formation (e.g., Spaans & Meijerink 2008, Schleicher *et al*., 2010)
- ALMA high-frequency bands crucial for $z \sim 2$ range
- Potential for deriving $f_{\mathrm{Edd}} M_{\mathrm{BH}}$ using XDR modeling