H_2O in (Ultra)luminous Infrared Galaxies at low and high z

Paul van der Werf

Leiden Observatory

ESTEC

April 15, 2016

Credits

Saskia van den Broek (Leiden)
Marco Spaans (Kapteyn Astronomical Institute)
Eduardo González-Alfonso (Henares)
Rowin Meijerink (Leiden Observatory)
Alicia Berciano Alba (Leiden Observatory)
Alain Omont (IAP)
Axel Weiß (MPI für Radioastronomie)
Mark Swinbank (Durham)
+ the HerCULES team &c

See also talks by Chentao Yang & Daizhong Liu, & poster by Saskia van den Broek

Extragalactic water

- Gas-phase H_2O can be abundant.
- Affected by UV photons, X-rays, cosmic rays, shocks,...
- Excitation in various ways

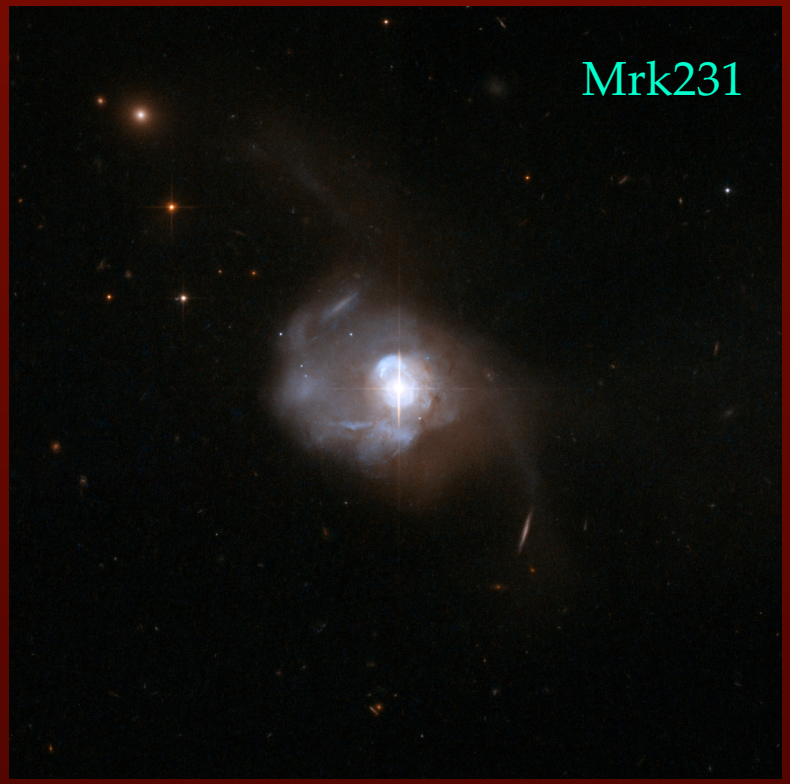
Herschel image of (part of) the Rosetta Molecular Cloud

- Requires multiple lines and spatial resolution!

Outline

- Extragalactic H_2O at low and high z
- Radiatively excited H_2O as a probe
- Spatially resolved H_2O emission at high z

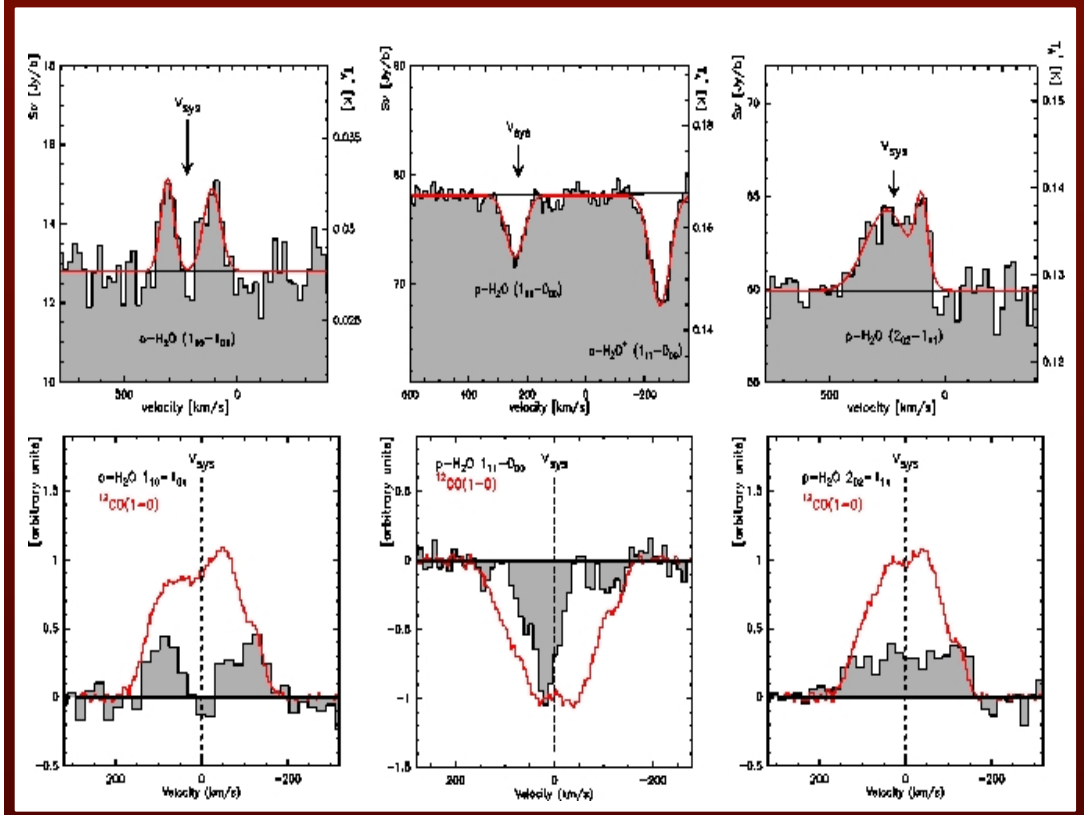
Low-z H_2O: M82 *vs.* Mrk231



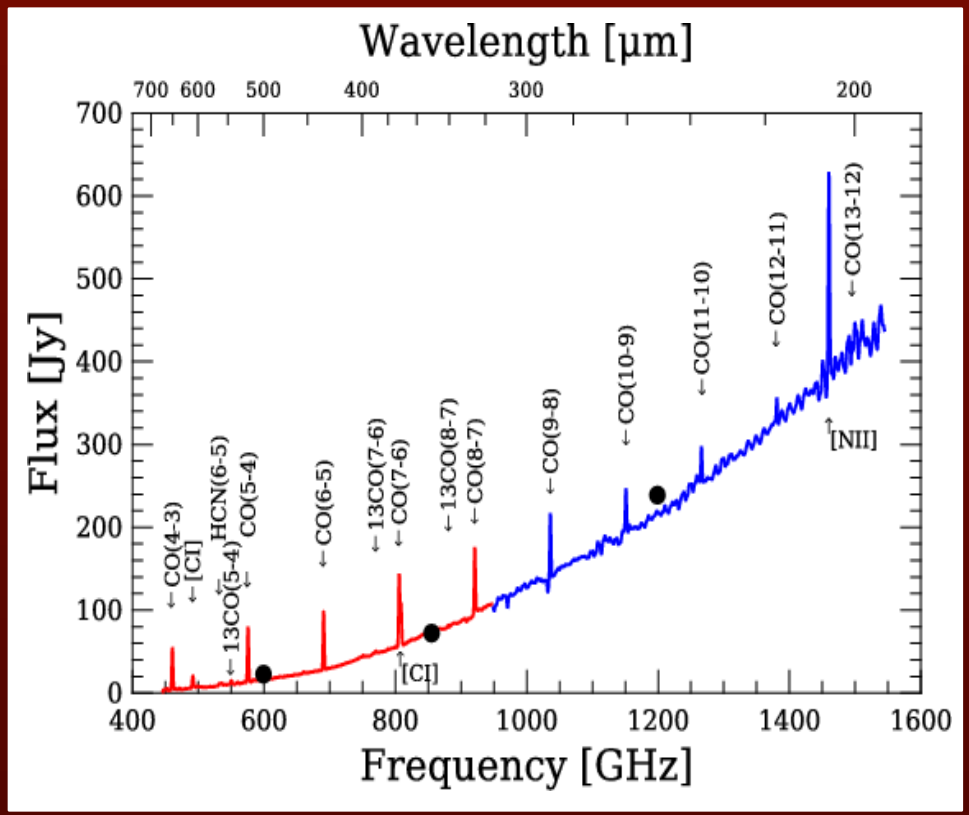
- At D = 3.9 Mpc, one of the closest starburst galaxies
- With $L_{IR} = 3 \cdot 10^{10}\, L_{\odot}$, a very moderate starburst

- At z=0.042, one of the closest QSOs (D_L=192 Mpc)
- With $L_{IR} = 4 \cdot 10^{12}\, L_{\odot}$, the most luminous ULIRG in the IRAS Revised bright Galaxy Sample

H_2O lines in M82

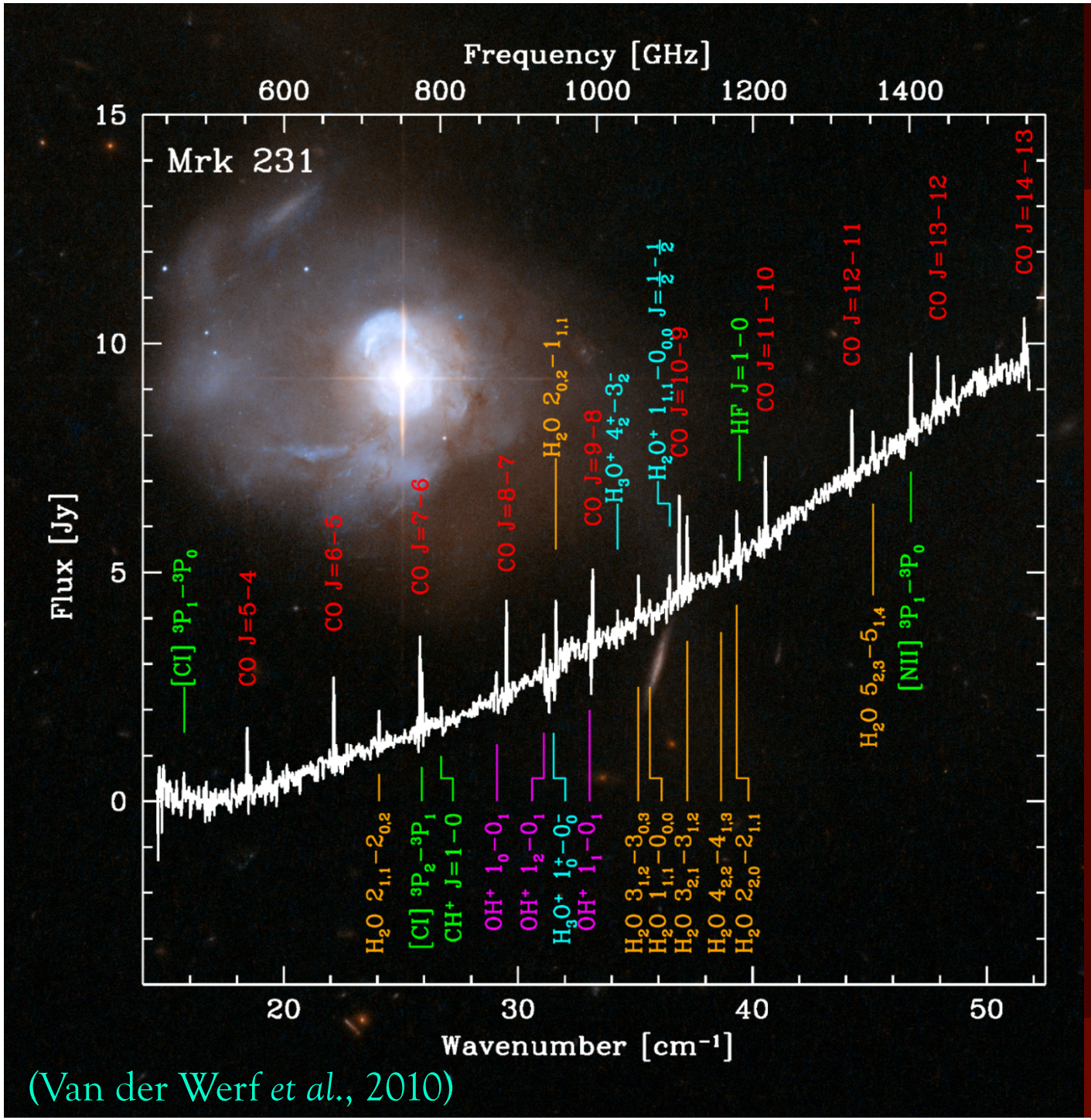


(Weiß *et al.*, 2010)



(Panuzzo *et al.*, 2010)

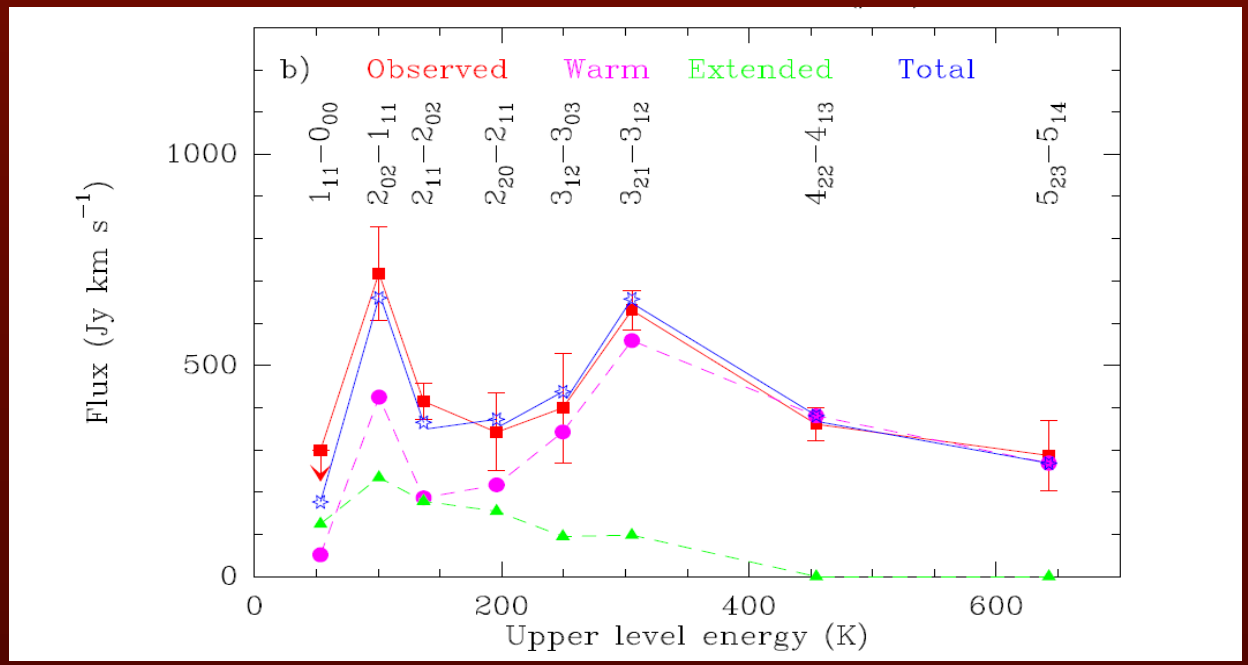
- Faint lines, complex profiles
- Only lines of low excitation



(Van der Werf *et al.*, 2010)

Mrk231 SPIRE FTS

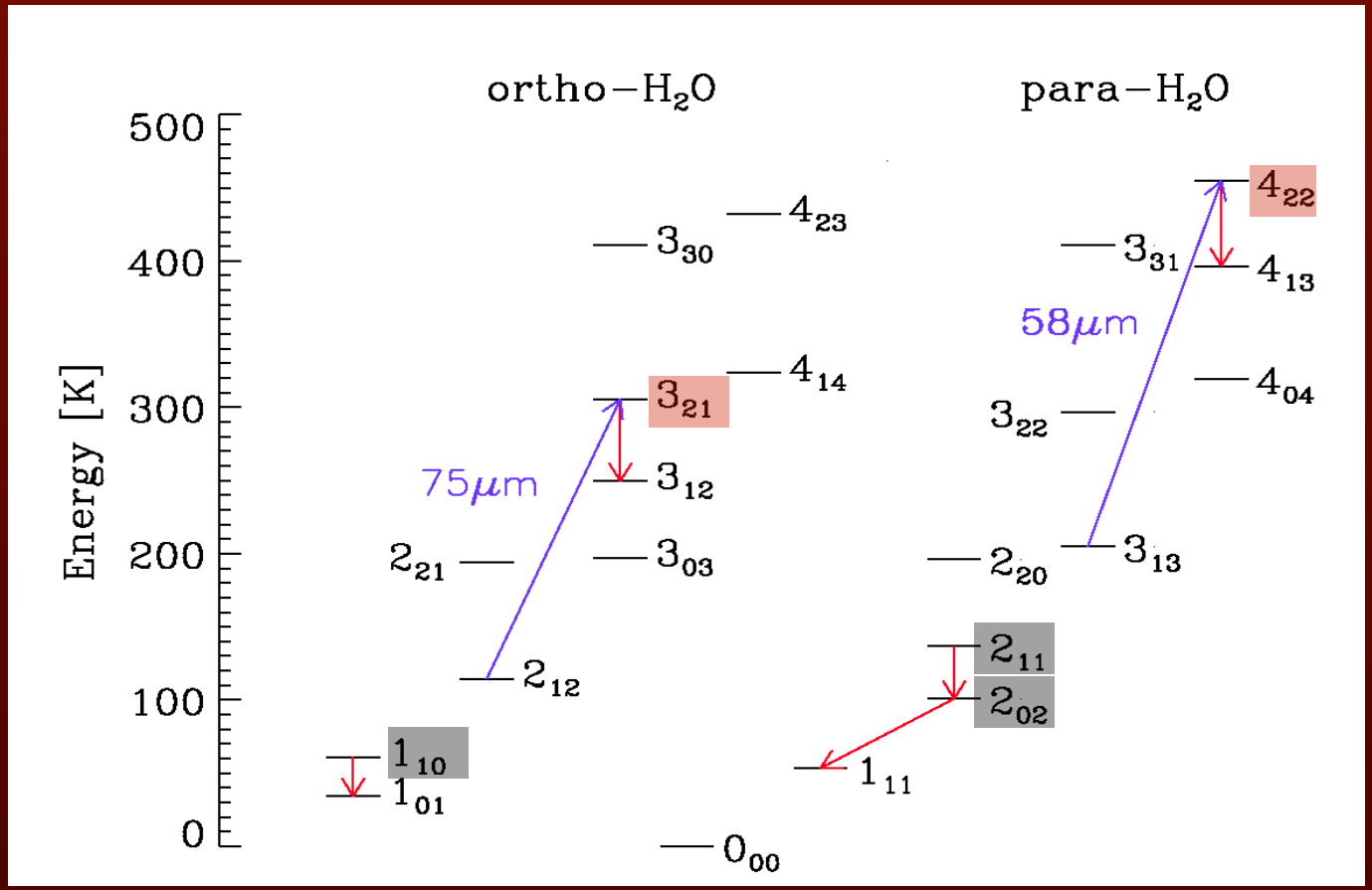
H_2O lines in Mrk231



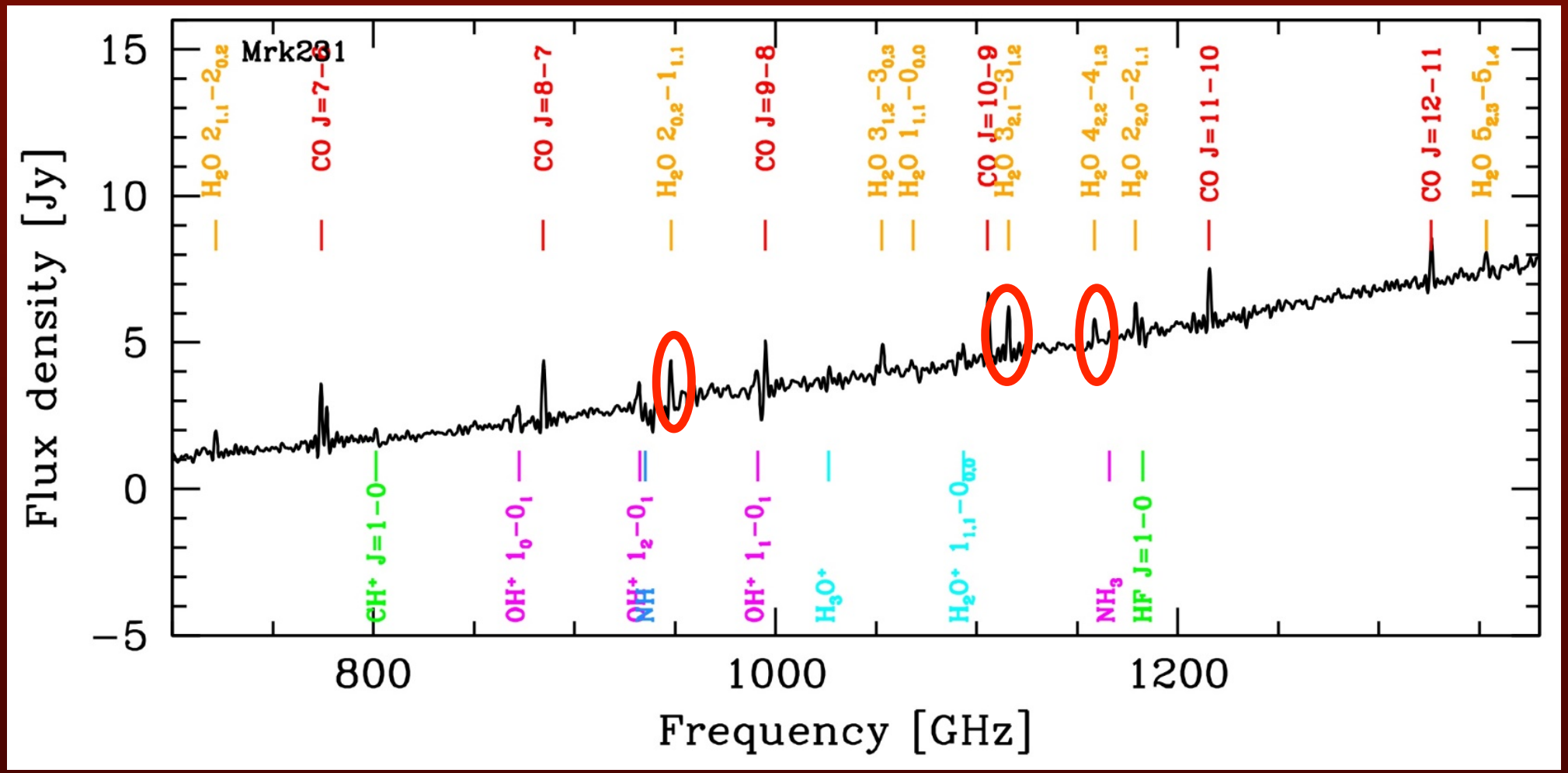
- Low lines: pumping by cool IR component + some collisional excitation
- High lines: pumping by warm IR component
- Radiative pumping dominates.

(González-Alfonso *et al.*, 2010)

Radiative excitation of H_2O lines



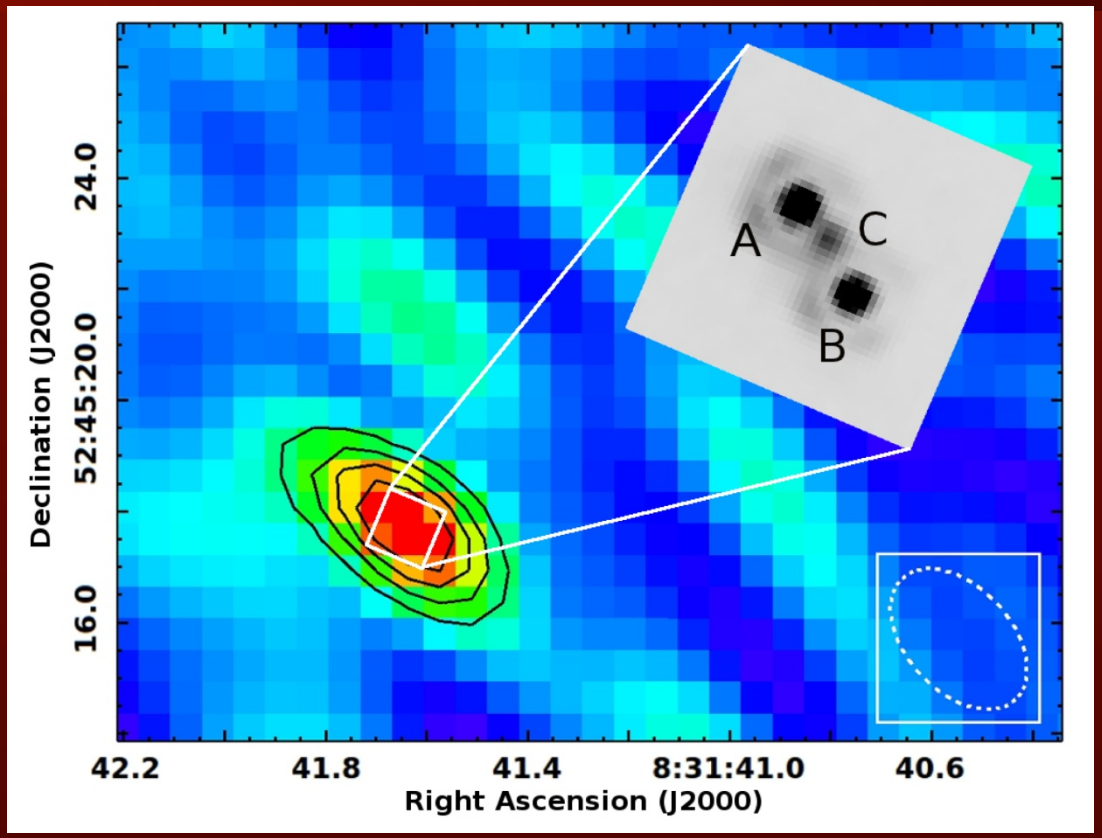
Key diagnostic H_2O lines

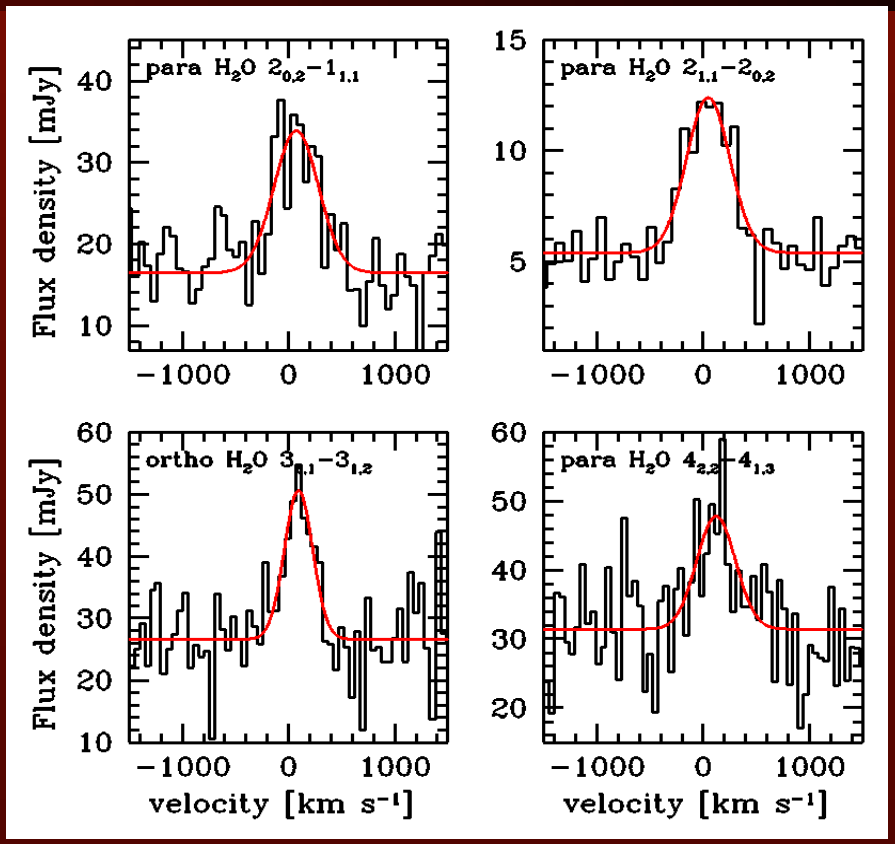


Outline

- Extragalactic H_2O at low and high z
- Radiatively excited H_2O as a probe
- Spatially resolved H_2O emission at high z

High-z connection: H_2O at z=3.9

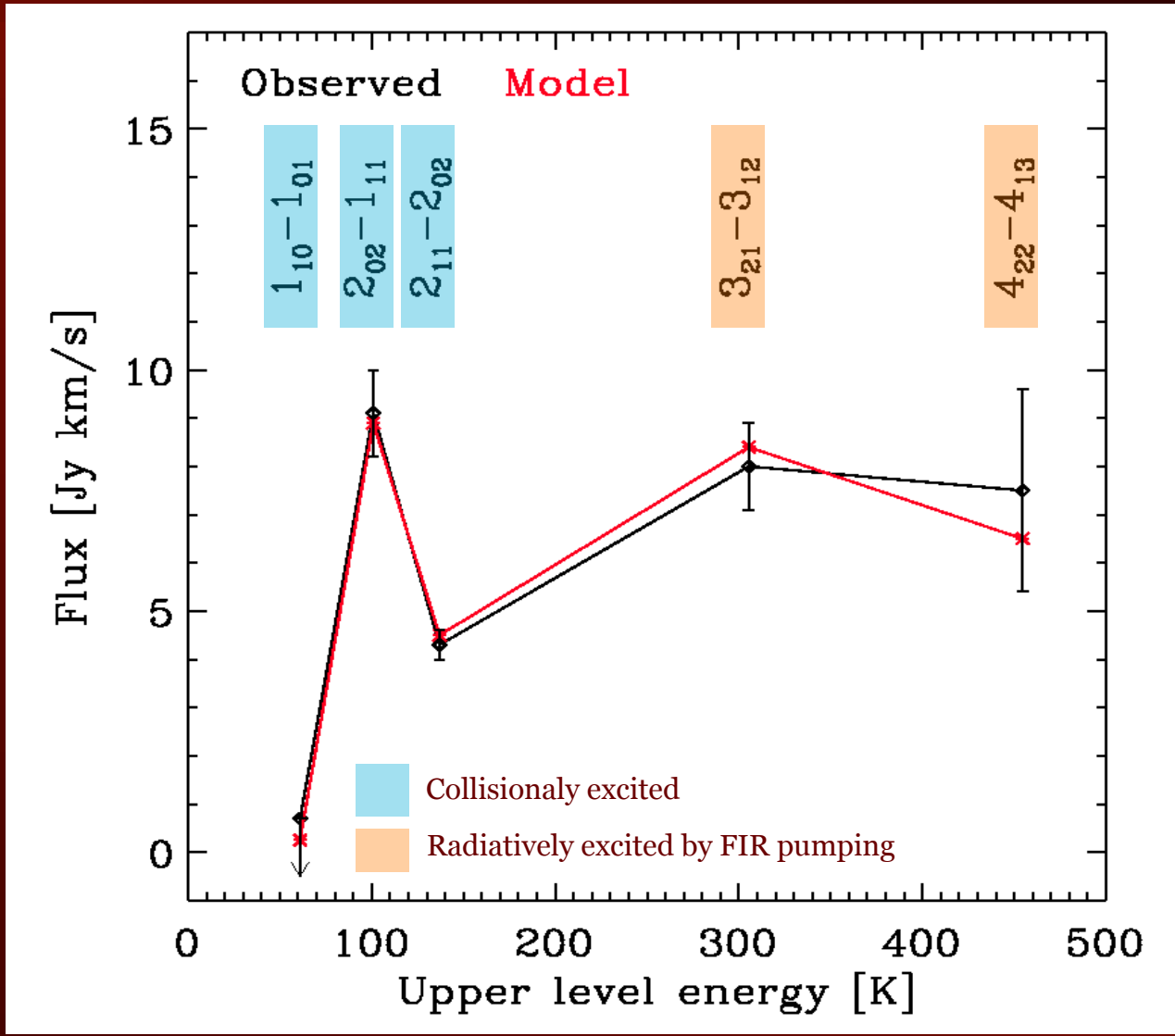




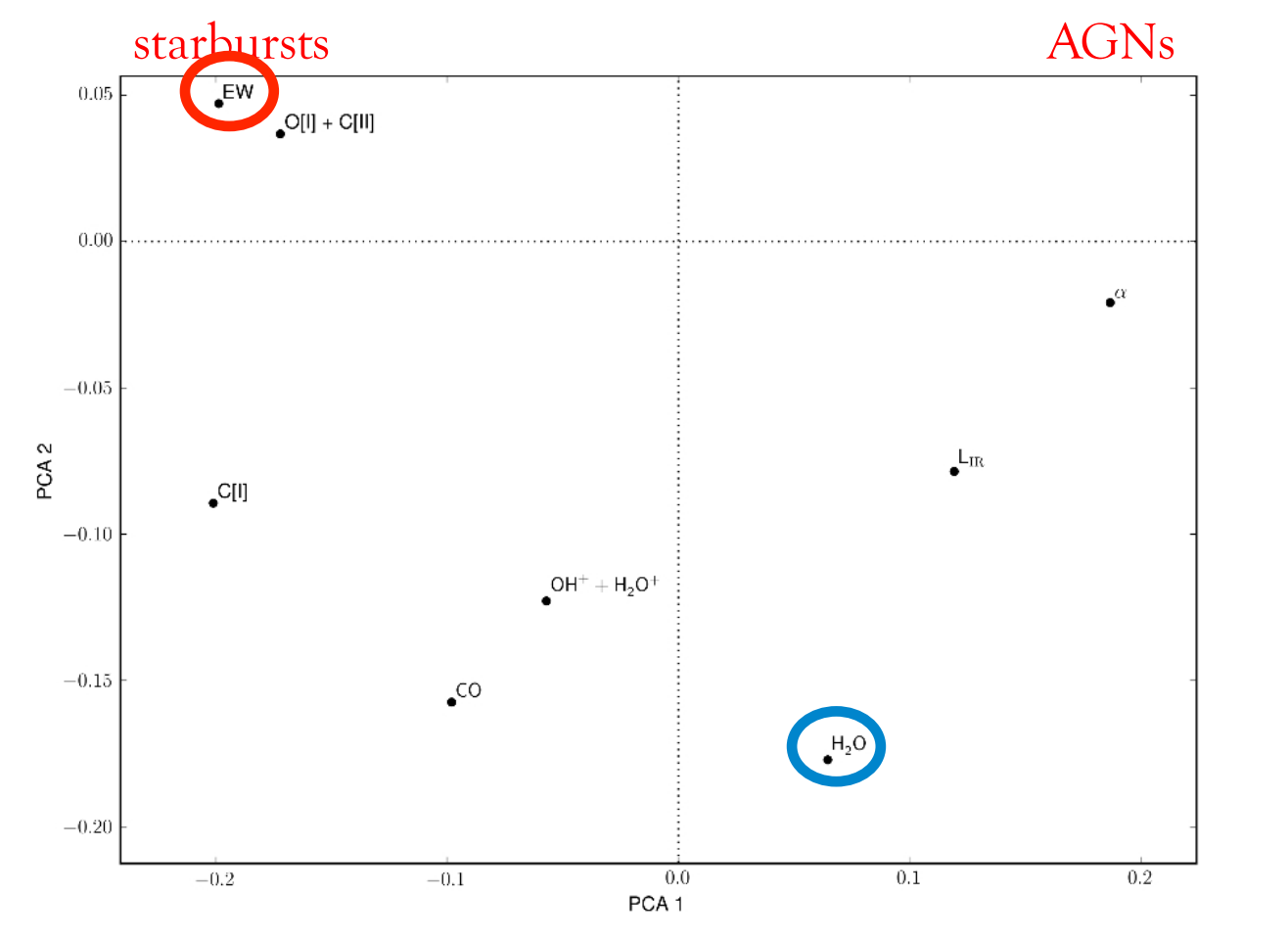
Van der Werf *et al.*, 2011

- Line ratios similar to Mrk231
- FIR pumping dominates, implies 100 μm-opaque disk

Model result



H_2O as a tracer of what?



- CO excitation is the best AGN indicator
- ([CII]+[OI])/FIR high in starbursts
- OH^+ and H_2O^+ do not prefer AGNs
- H_2O/FIR correlates with L_{IR} & has some preference for AGNs

(see poster by Saskia van den Broek)

Water as a probe

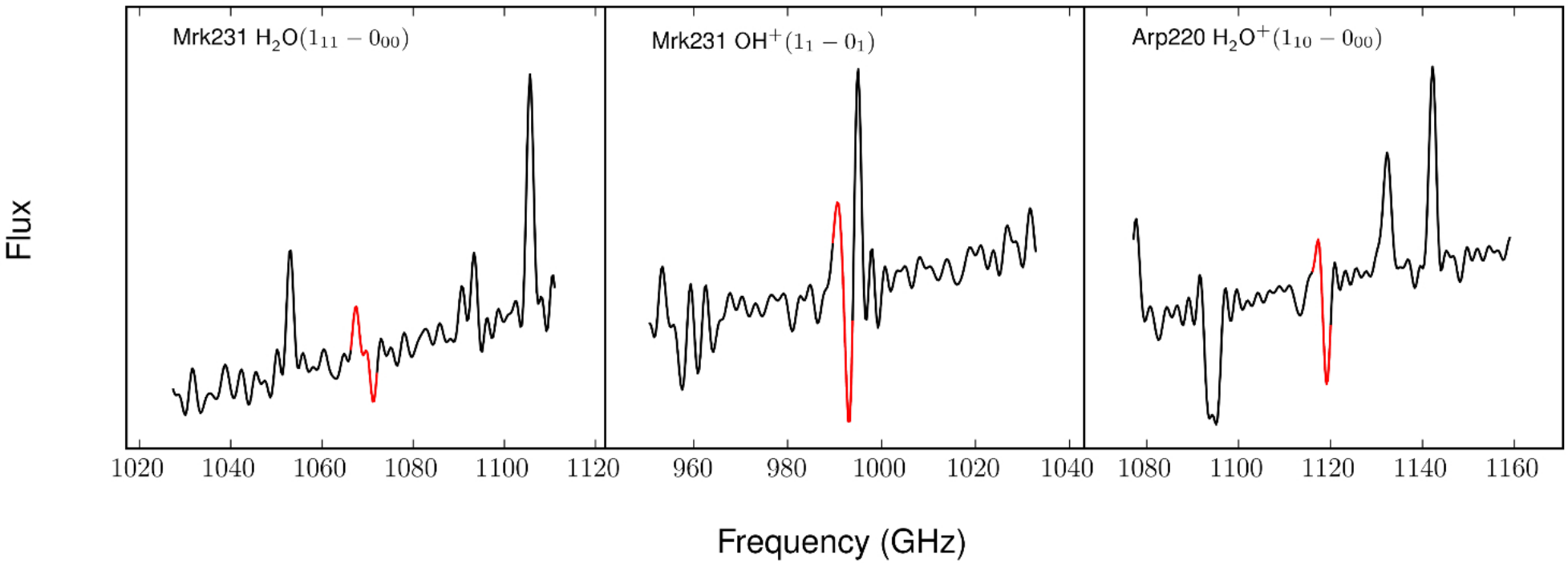
Herschel image of (part of) the Rosetta Molecular Cloud

- Radiative pumping of H_2O lines: derive local FIR flux
- Combine with T_d: implies emission at the blackbody limit
- ⇒ Infrared-opaque ($\tau_{100\mu m} \approx 1$) central regions
- Radiation pressure from the strong IR radiation field:

$$P_{\rm rad} \approx \tau_{100} \sigma T_{\rm d}^4 / c$$

- Can be dominant pressure term and source of local turbulence

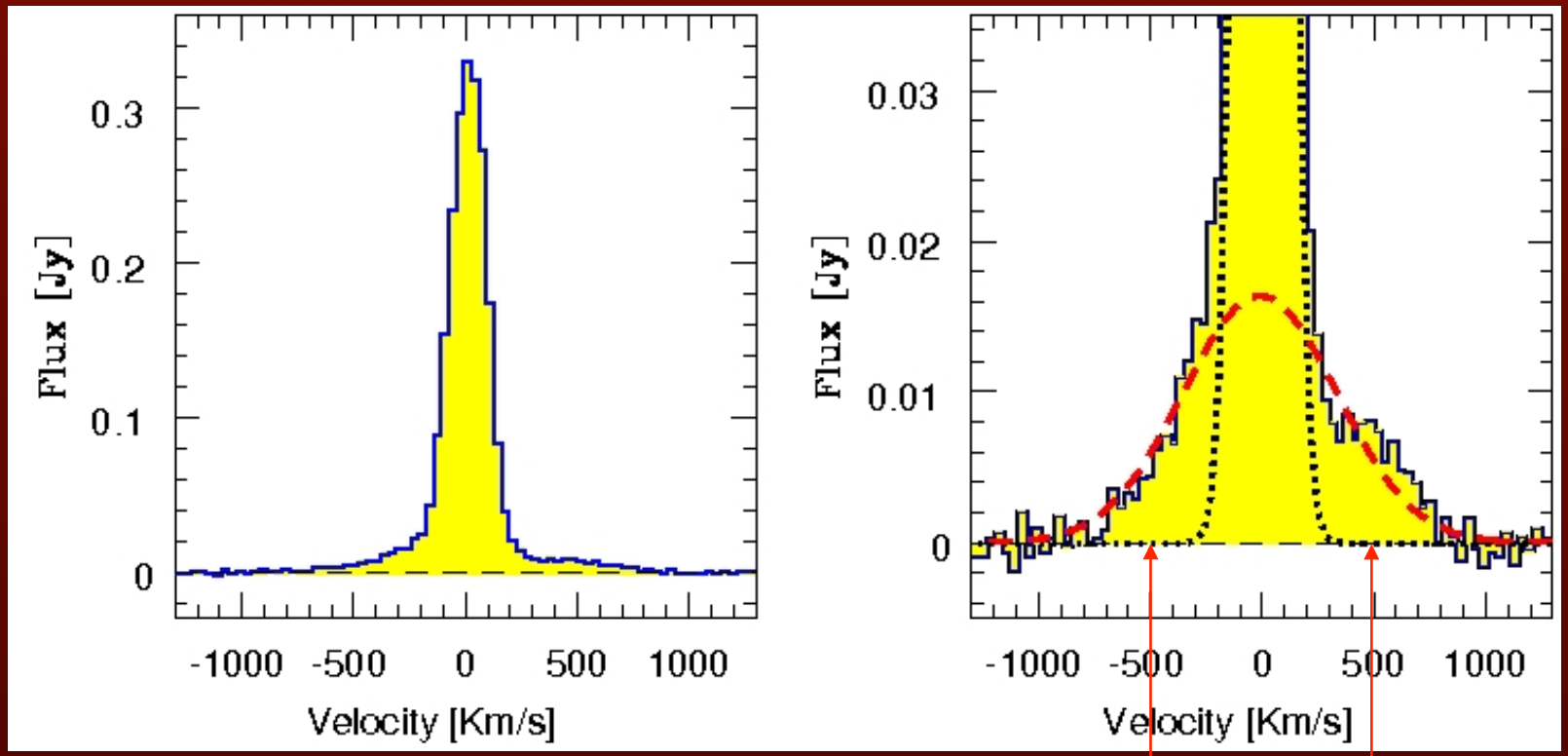
Outflow tracers



(see poster by Saskia van den Broek)

- P-Cygni profiles on many low-lying lines (also CH^+, HF, others)
- OH^+ and CO(9–8) in one ALMA subband – direct velocity comparison
- H_2O in Mrk231: outflow velocity of ≈500 ± 100 km s^{-1}

Mrk231 outflow in CO



(Feruglio *et al.*, 2010)

H_2O absorption

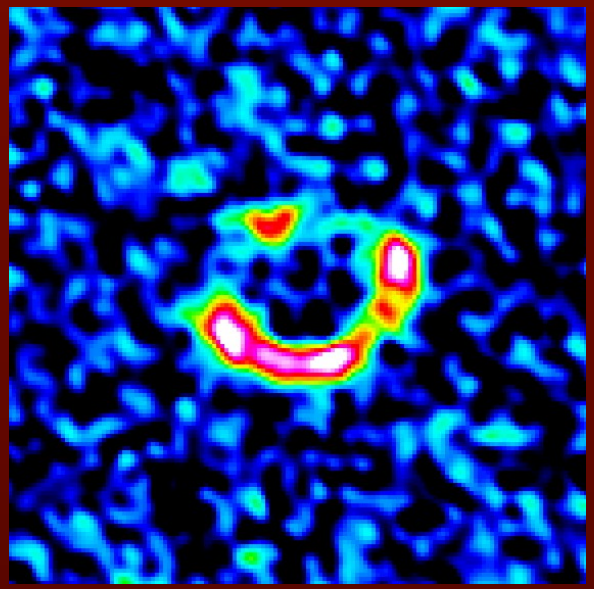
H_2O emission

Outline

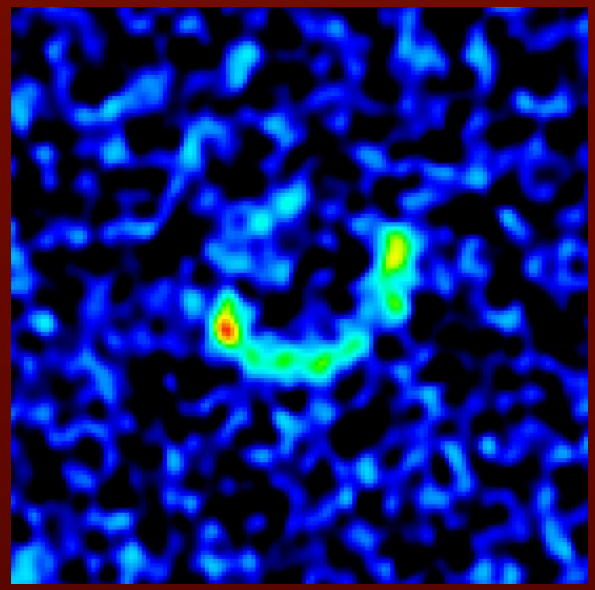
- Extragalactic H_2O at low and high z
- Radiatively excited H_2O as a probe
- Spatially resolved H_2O emission at high z

Spatially resolved H_2O in the Cloverleaf quasar (z=2.56)

Continuum Band 7



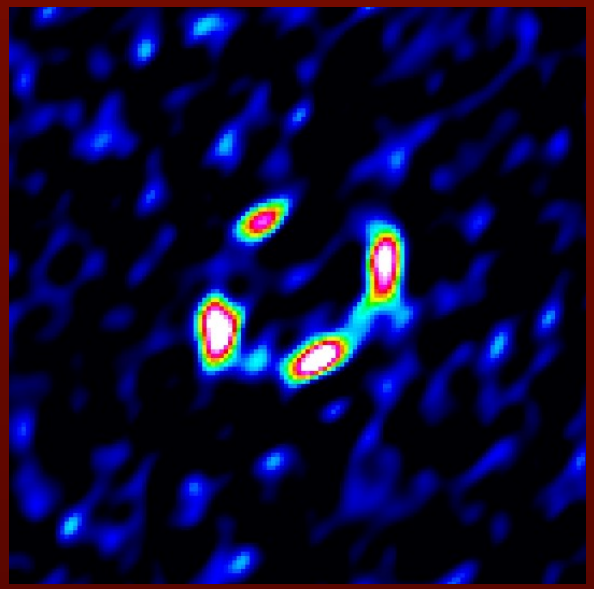
CO 9-8



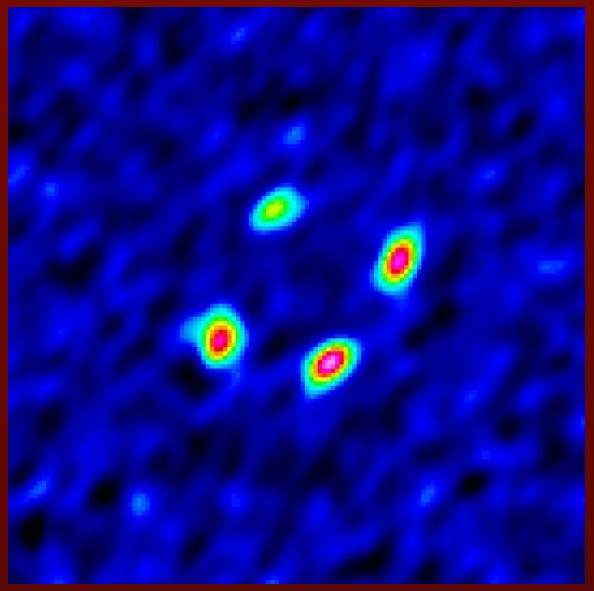
H_2O $2_{0,2}$-$1_{1,1}$

Spatially resolved H_2O in the Cloverleaf quasar (z=2.56)

Continuum Band 7

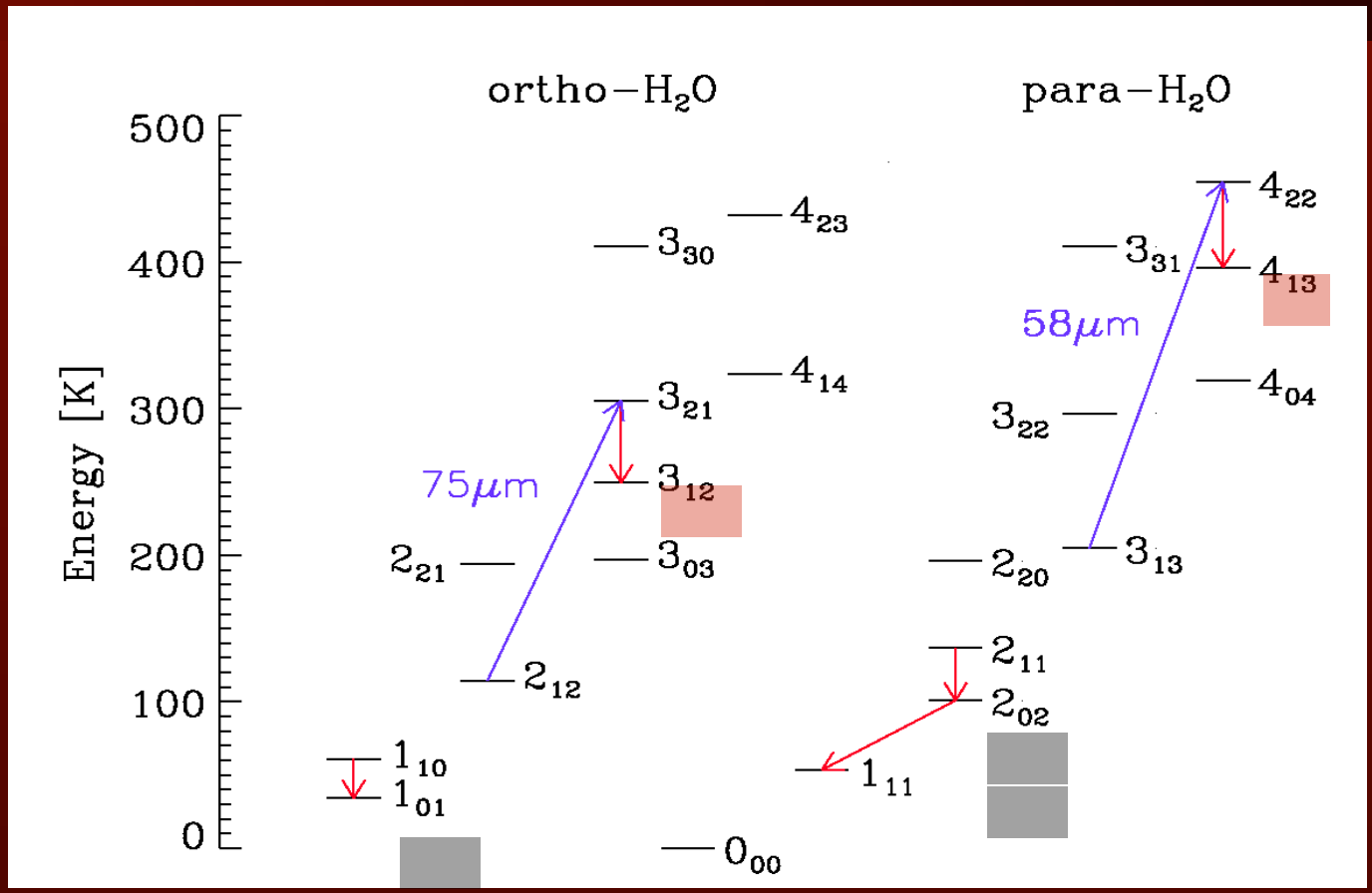


$H_2O\ 3_{2,1}$-$3_{1,2}$



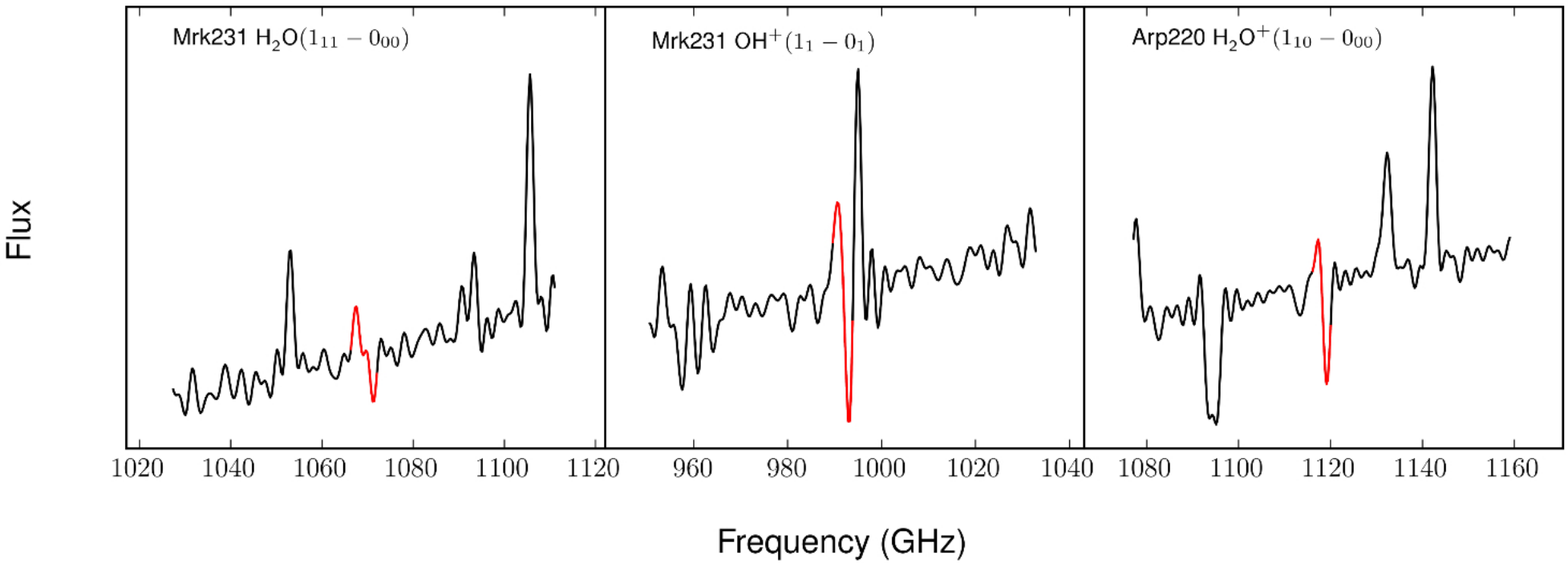
$H_2O\ 4_{2,2}$-$4_{1,3}$

Cloverleaf: implications



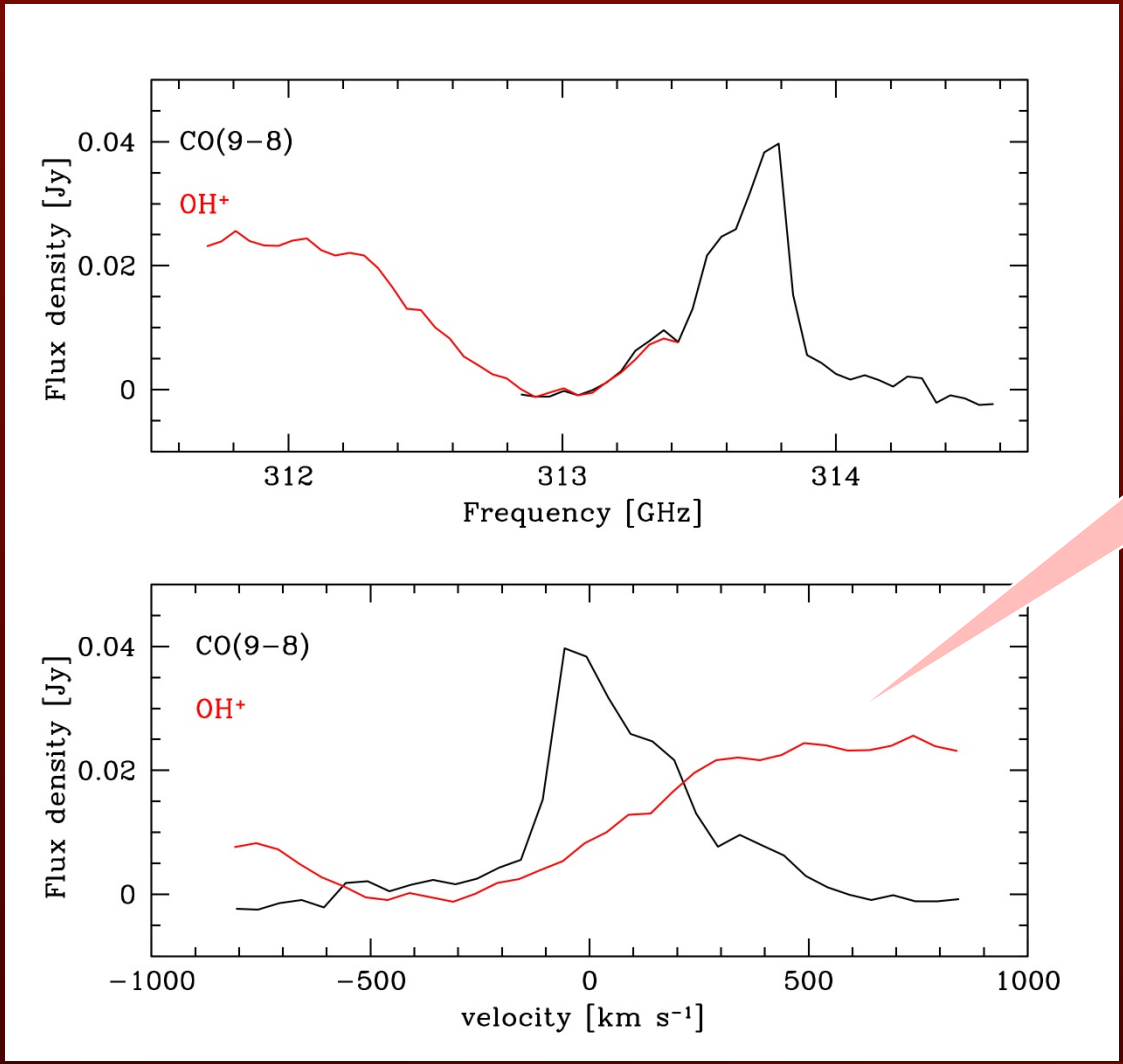
- Radiative excitation near AGN nucleus
- Increasingly hot radiation field near nucleus

Outflow tracers



Can we use OH^+ and CO(9–8) to trace high-z outflows?

OH^+ outflow at $z > 2$



Preliminary!

Summary

- Luminous H_2O lines trace infrared-opaque nuclear disks and reveal Eddington-limited circumnuclear conditions.
- Luminous H_2O emission correlates with strong local IR radiation field, without caring too much whether an AGN is present or not.
- Lines of different levels of excitation can be distributed differently, depending on local IR field intensity and colour.
- High-excitation H_2O lines probe a hot IR radiation field, which may be AGN-dominated.
- OH^+ is a very promising tracer of outflows at high z