HERSCHEL/HIFI observations of water in nuclei of actively star forming galaxies

Axel Weiss (MPIfR Bonn Germany)

on behalf of the HexGal consortium

R. Güsten (PI)
S. Gracia-Burillo, A. Harris, F. Israel, T. Klein
C. Kramer, S. Lord, J. Martin-Pintado,
M. Requena-Torres, M.Roellig, J. Stutzki,
R. Szezerba, P. van der Werf
with associates and affiliates

The HexGal project:

HexGal:
Aims to study the physical and chemical composition of the ISM in galactic nuclei using HIFI spectroscopy

o ISM in the galactic center region
- detailed investigation of the GC region

o Gas excitation in starbursts and ULIRGs
- CO & fine structure line excitation
- The extragalactic water trail
…

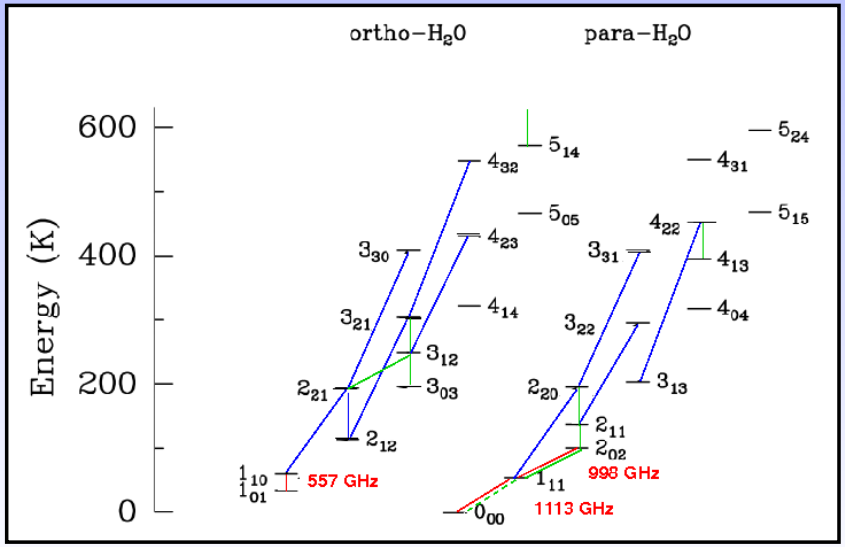
o Chemical complexity of extragalactic nuclei
- Line surveys of selected sources
- Absorption line study in selected source
…

Extragalactic Water so far:
SWAS & ODIN not sensitive enough

ISO: detections of H_2O in extragalactic objects, but no observations below 1.5 THz

=> only high excitation lines

HexGal water trail:
First systematic survey for H_2O low-level transitions in active galaxies



Water trail sample:

Sample:

all flavors of nuclear activity in different evolutionary stages:

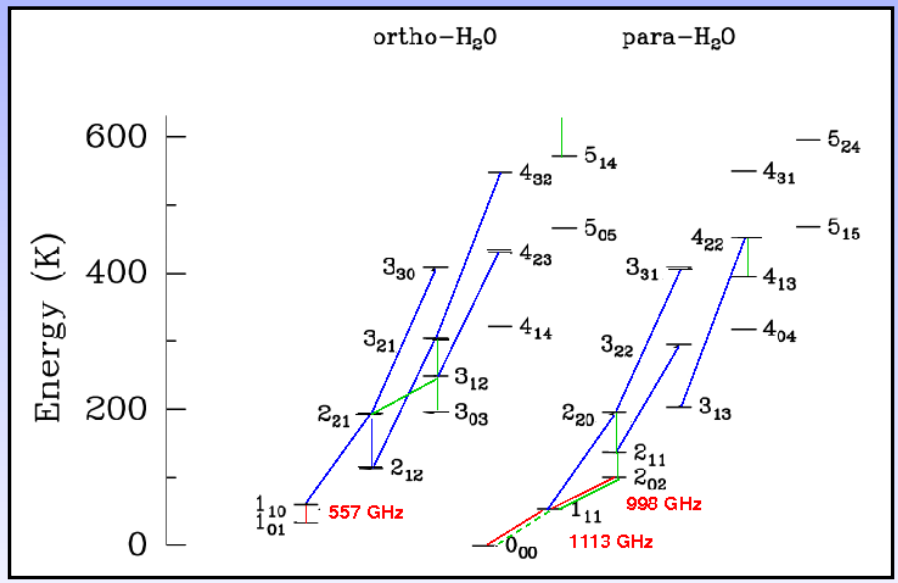
M82	nuclear SB	LIRG
NGC 253	nuclear SB	LIRG
M83	nuclear SB/AGN	LIRG
NGC 4945	nuclear SB/AGN	LIRG
Centaurus A	nuclear SB/AGN	LIRG
Mrk273	SB/AGN Major Merger	ULIRG
Arp220	SB/AGN Major Merger	ULIRG
Arp299	SB/AGN Major Merger	LIRG
NGC 4038/39	SB Major Merger	LIRG
NGC1068	AGN/SB	LIRG
Mrk 231	AGN/SB	ULIRG
NGC6240	AGN/SB	LIRG

Lines:

p-H_2O (1_{11}-0_{00}) 1113 GHz
p-H_2O (2_{02}-1_{11}) 988 GHz

o-H_2O (1_{10}-1_{01}) 557 GHz

(p-$H_2{}^{18}O$ (1_{11}-0_{00}) 1102 GHz)



Water observations in M82:

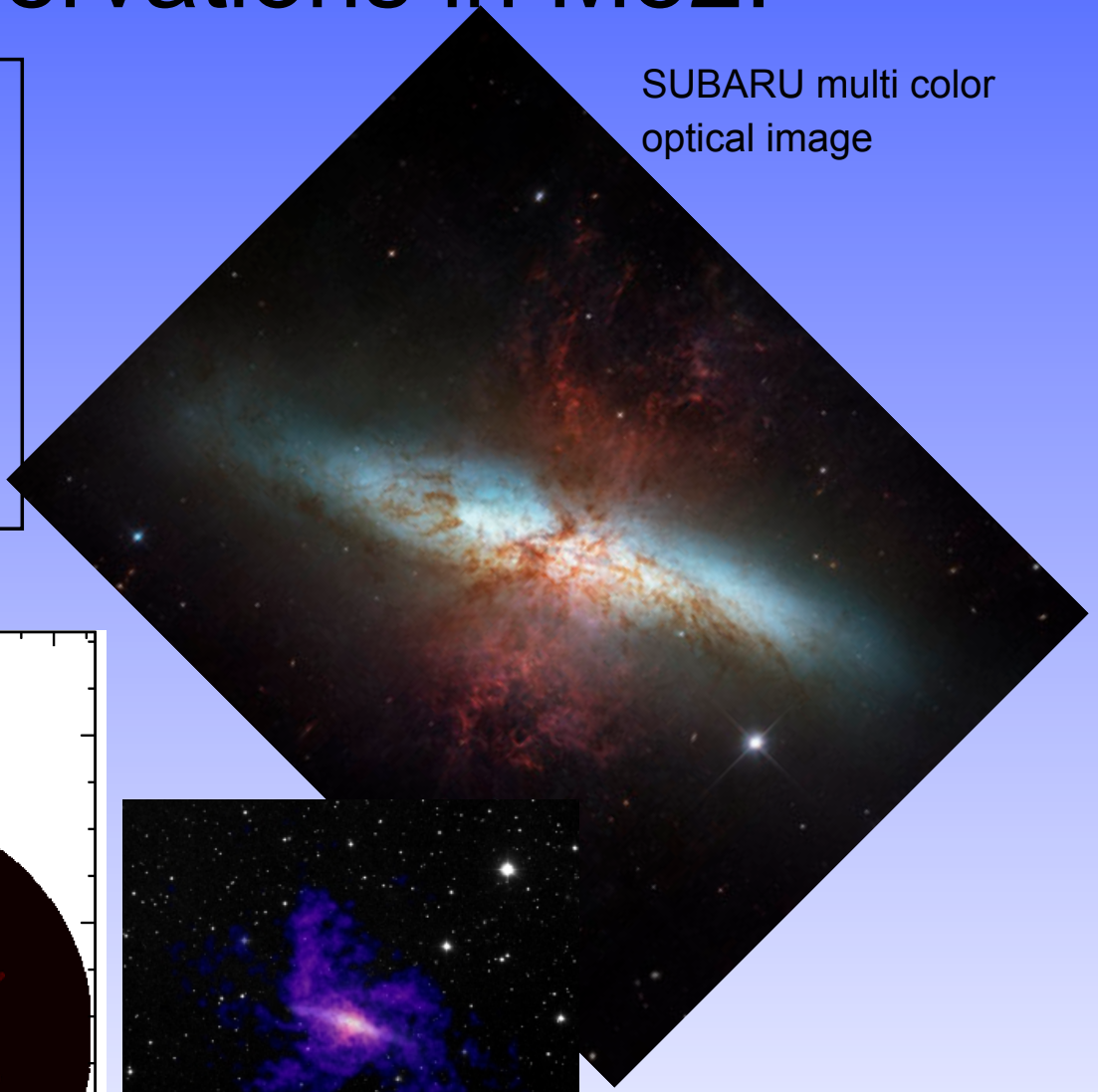
Lines:

p-H_2O (1_{11}-0_{00}) 1113 GHz
p-H_2O (2_{02}-1_{11}) 988 GHz

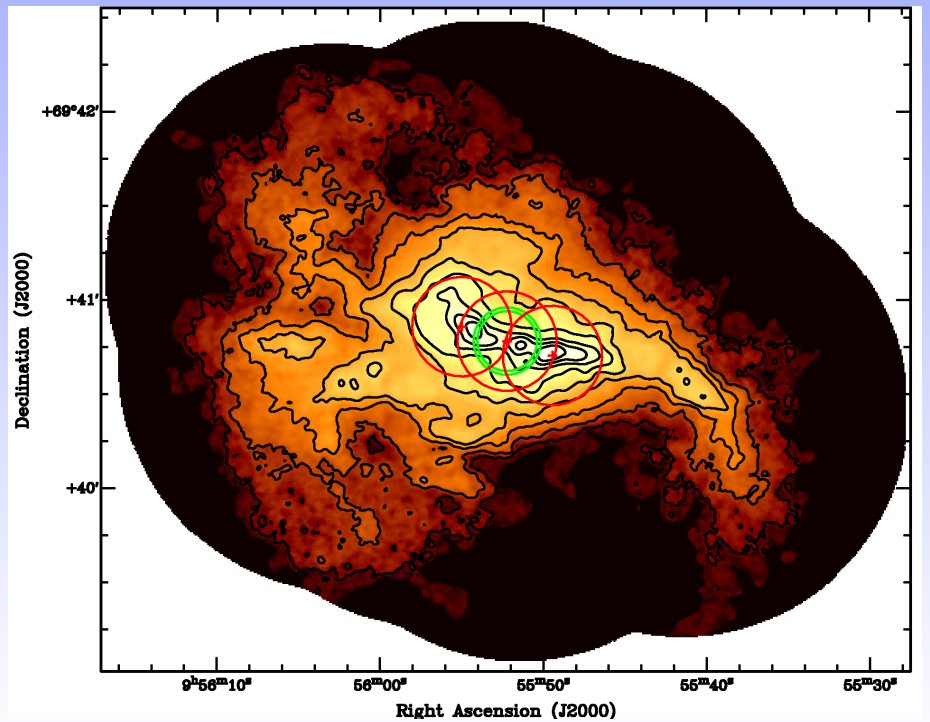
o-H_2O (1_{10}-1_{01}) 557 GHz yesterday

(p-$H_2{}^{18}O$ (1_{11}-0_{00}) 1102 GHz) pending

SUBARU multi color optical image



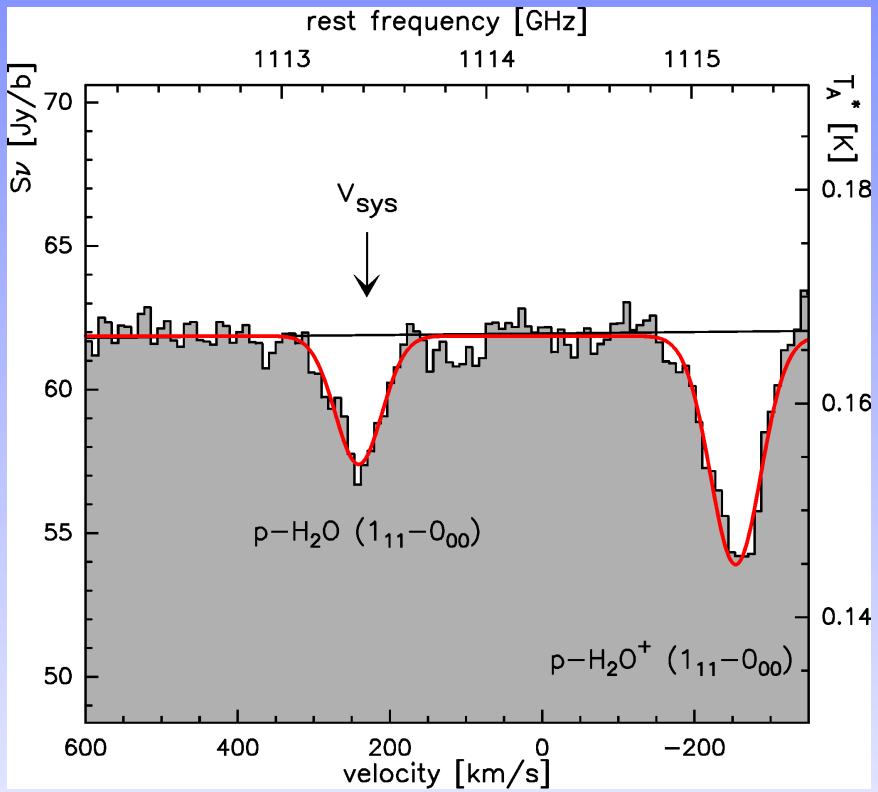
CO(1-0) OVRO+30m Walter etal 2002



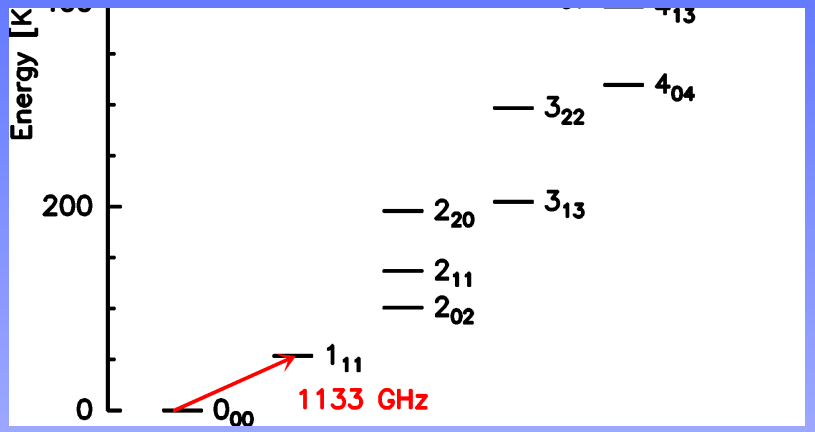
VLA HI
Yun etal 1998

HIFI p-H_2O 1113 GHz results:

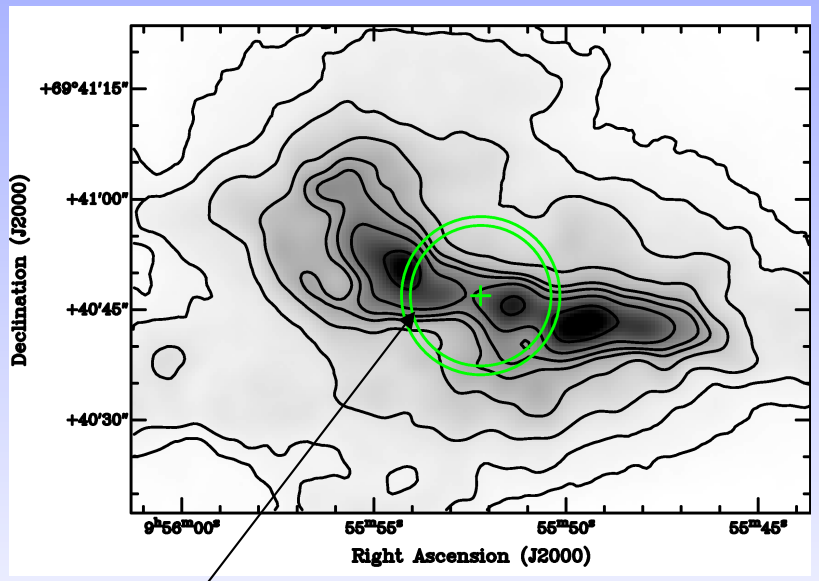
Chop/Nod observations (fast chopping)
5600s (2280 on source)
rms: 1.6mK @ 8 km/s resolution (H+V)
HIPE level 2 reduction: OK



First detection of H_2O and H_2O^+
Surprise: H_2O^+ absorption stronger than H_2O



CO(1-0) beam: 3.5”

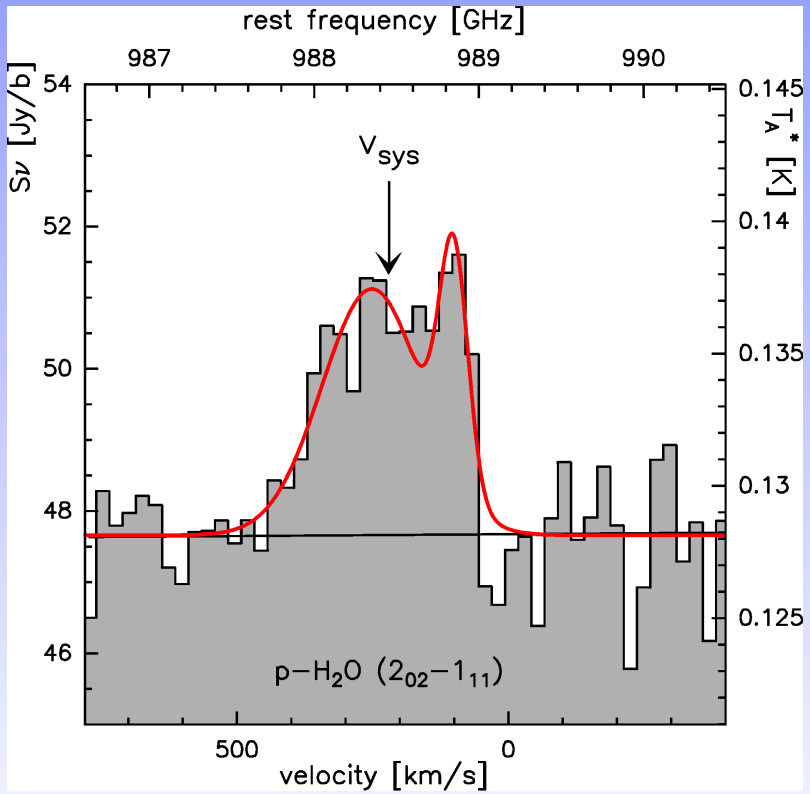


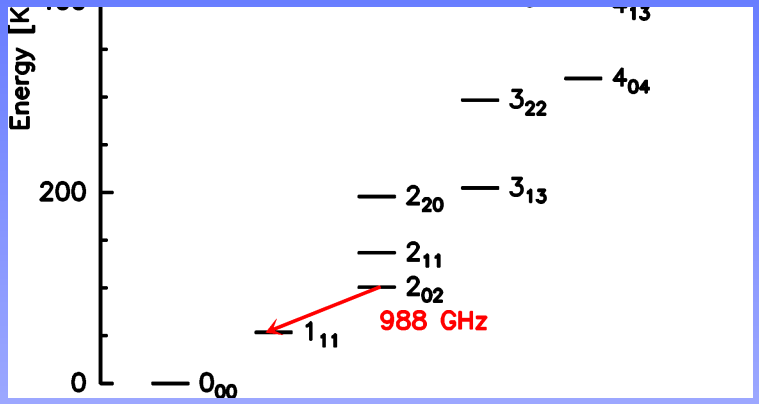
HIFI beam:
19” for p-$H_2O(1_{11}$-$0_{00})$

HIFI p-H_2O 988 GHz results:

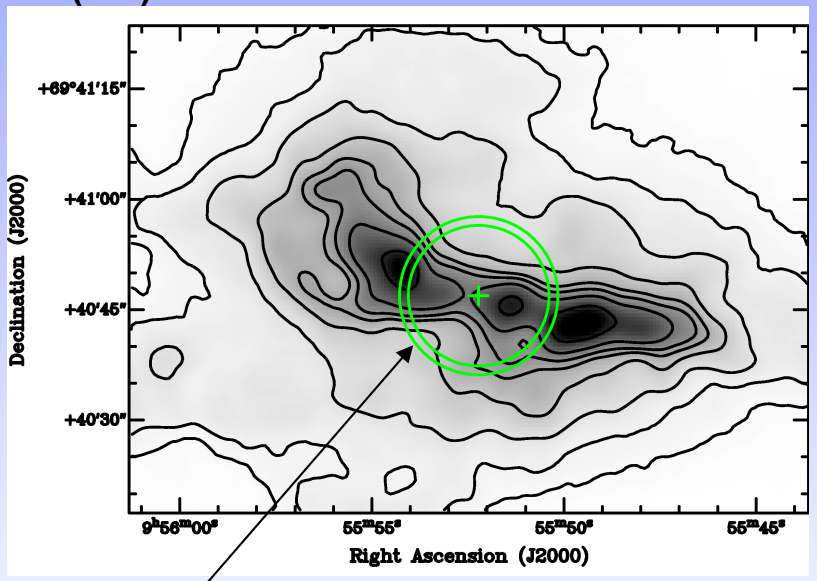
Chop/Nod observations (fast chopping)
3680s (1510 on source)
rms: 2.0mK @25 km/s resolution (H+V)

Parts of the data affected by baseline instabilities - HIPE 1 level + Class processing





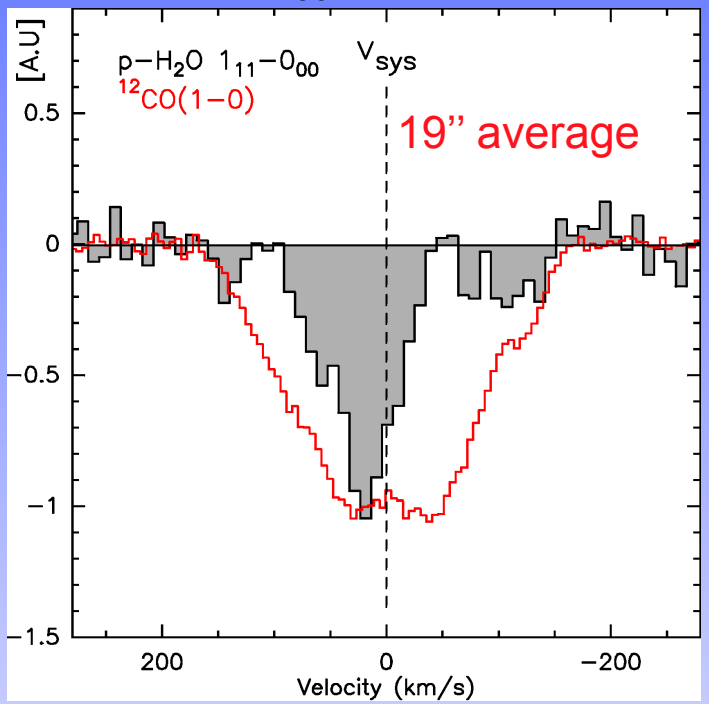
CO(1-0) beam: 3.5”



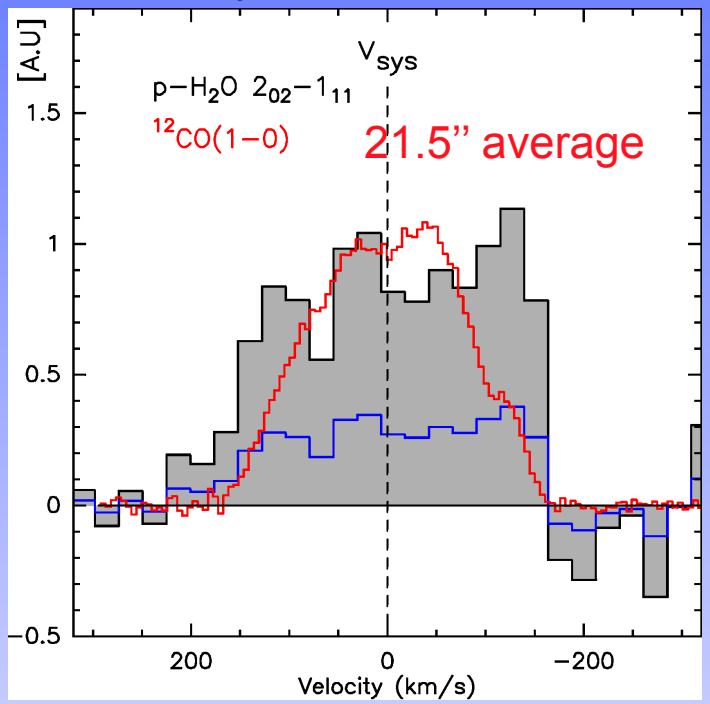
HIFI beam:
21”.5 for p-$H_2O(2_{02}$-$1_{11})$

Comparison to CO line profiles

p-H_2O (1_{11}-0_{00}) 1113 GHz



p-H_2O (2_{02}-1_{11}) 988 GHz



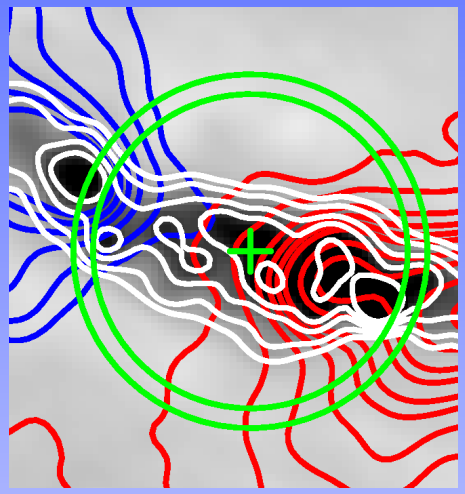
Water absorption detected in the line wings as well as red-wards of the systemic velocity

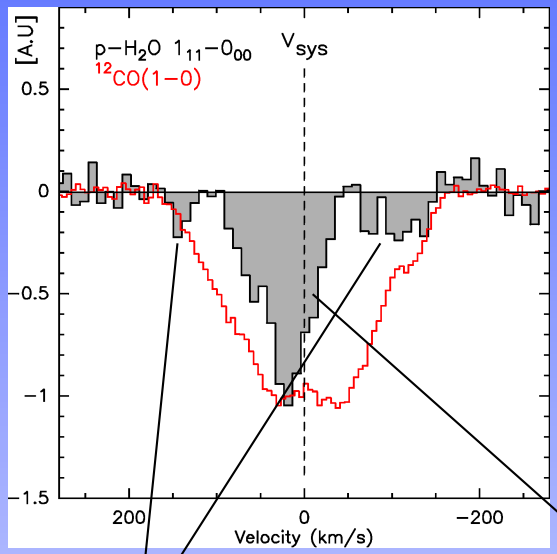
The lack of absorption is most likely due to geometry (e.g. located behind the continuum)

Water emission detected at all velocities where CO emission is detected.

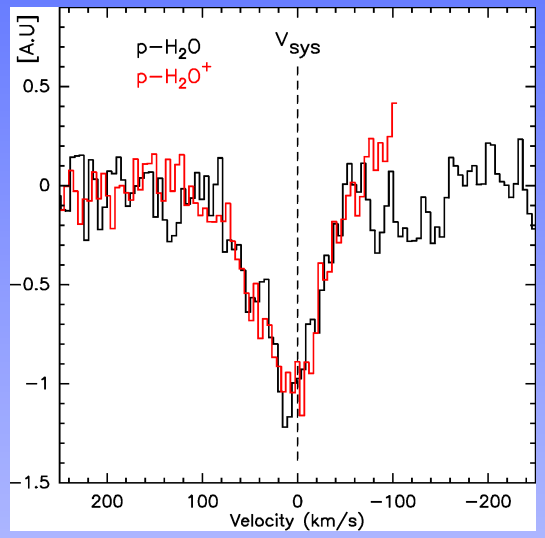
⇒H_2O abundant in the gas phase at all nuclear velocities

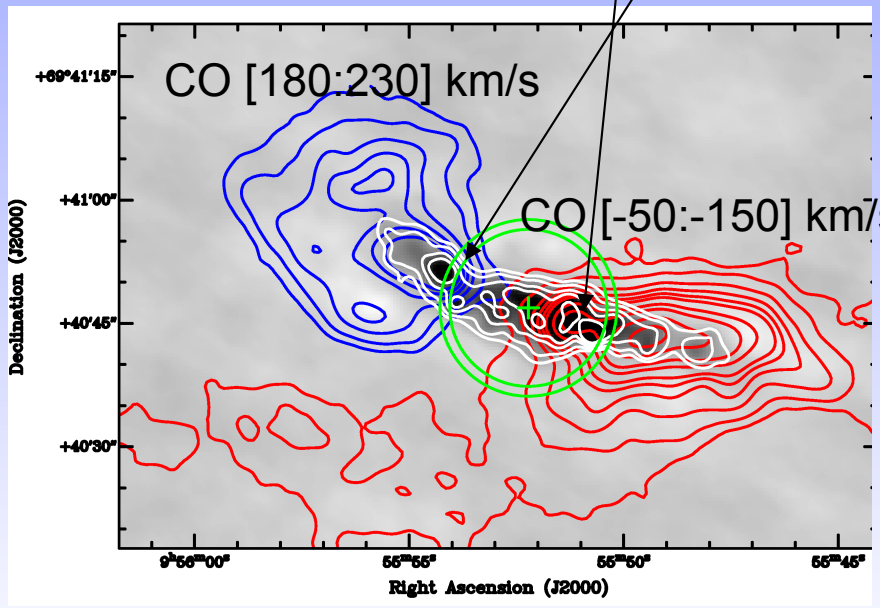
On the origin of the water absorption



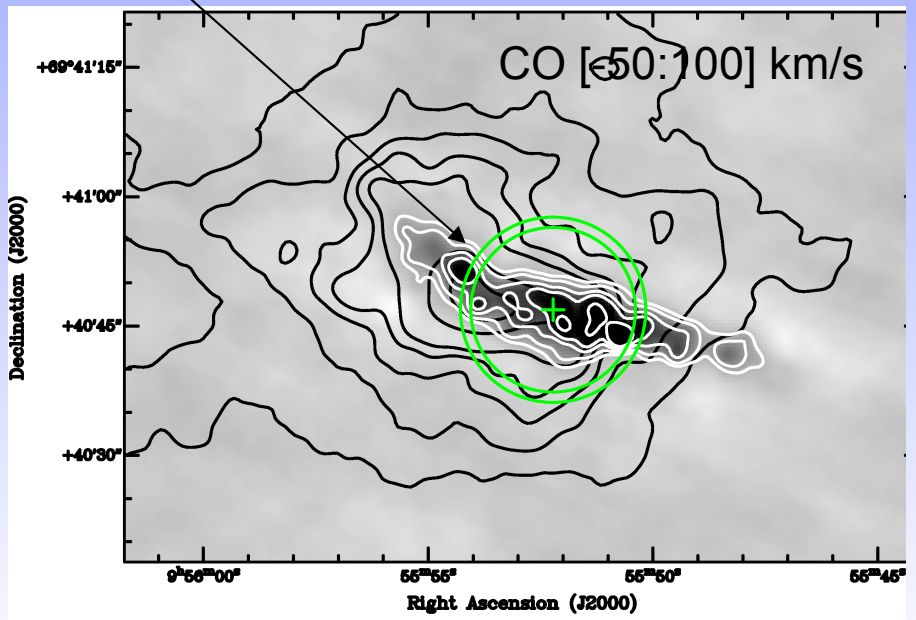


H_2O/H_2O^+ line profiles



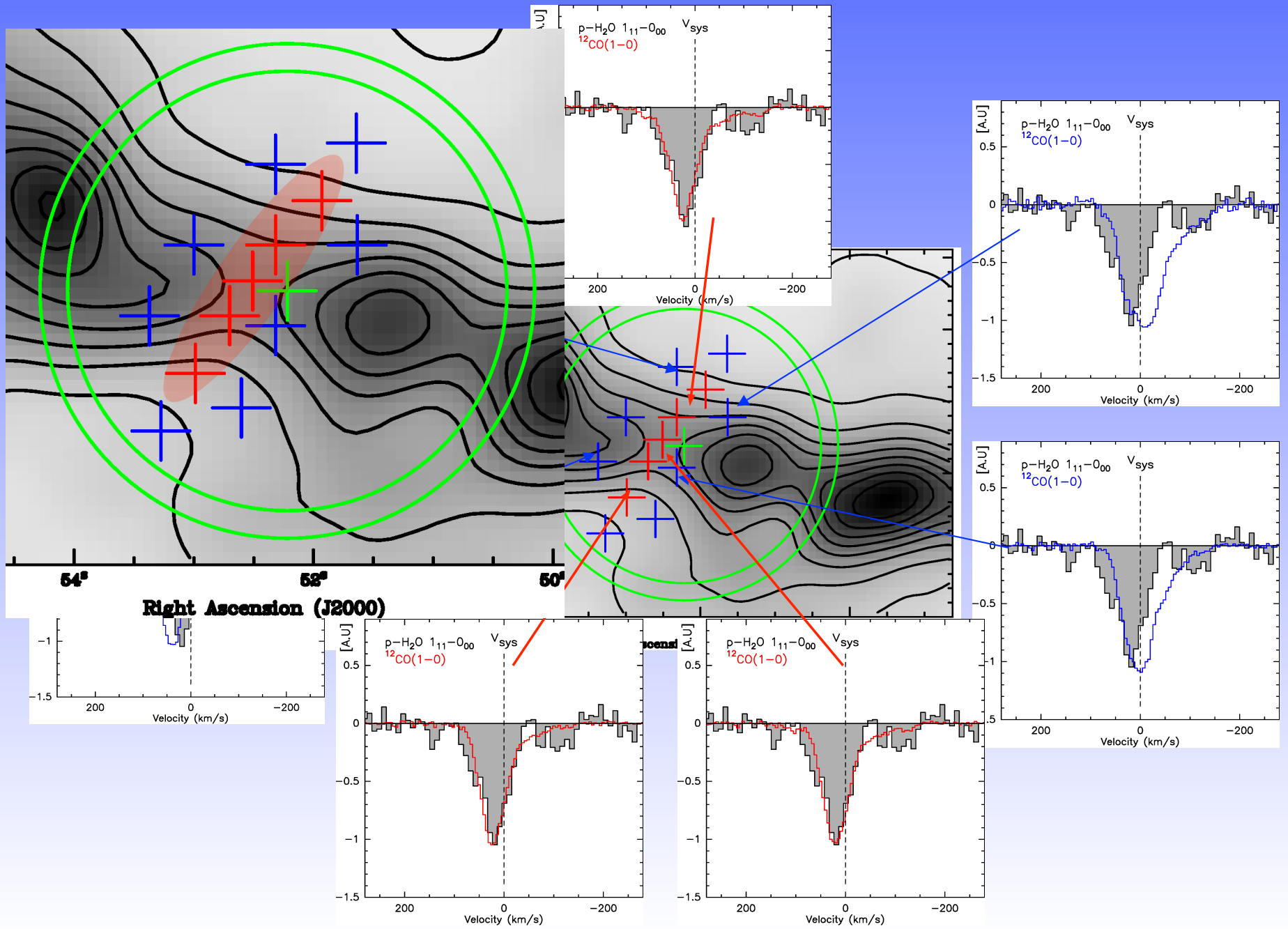


Grey scale & white contours VLA 1.4GHz



Grey scale & white contours VLA 1.4GHz

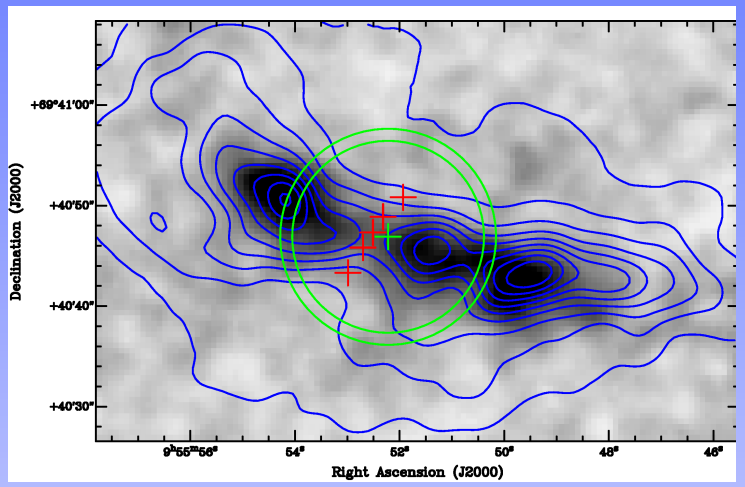
H_2O absorption region



Comparison to other wavelength

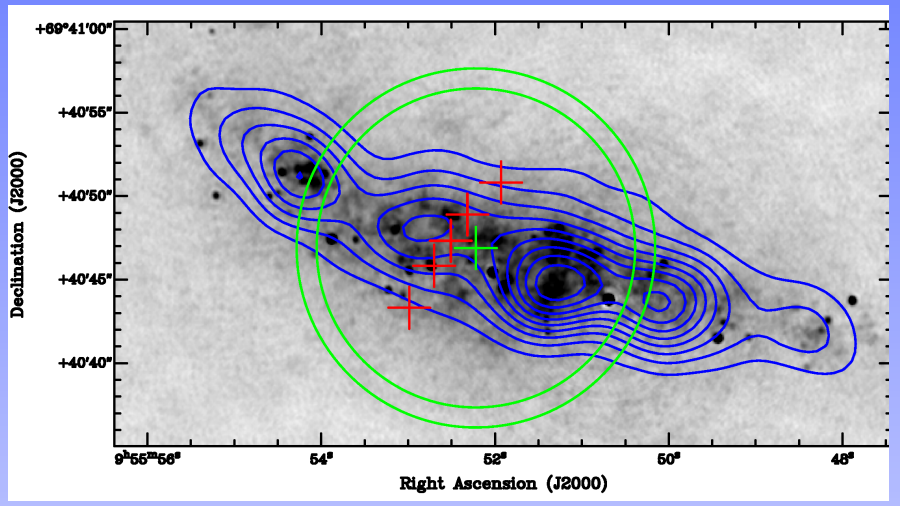
Dense Gas:

greyscale: $H^{13}CO+$ Garcia-Burillo etal 2002
contours: CO(1-0)



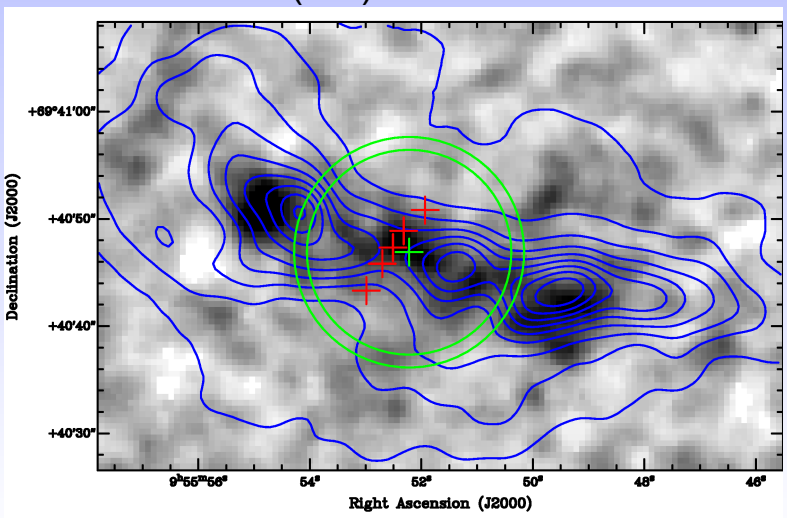
Continuum:

greyscale: 1.4GHz continuum Wills etal 1998
contours: 3mm continuum Weiss etal 1999



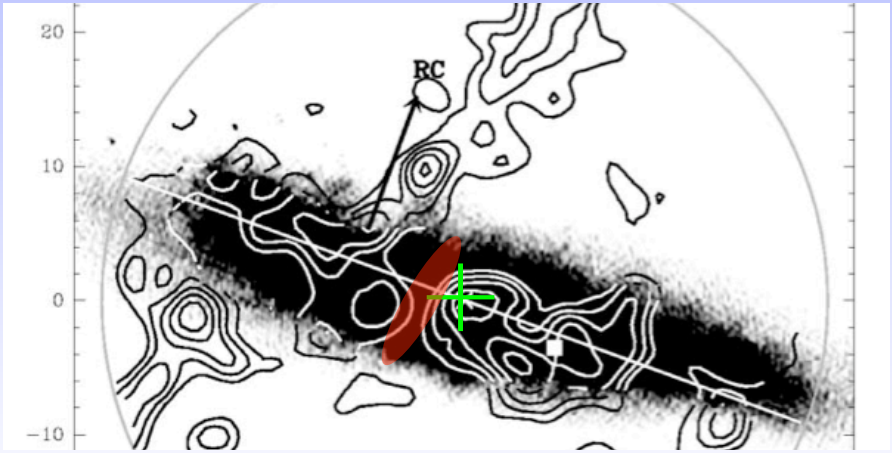
PDRs:

greyscale: HCO Garcia-Burillo etal 2002
contours: CO(1-0)



Shocks:

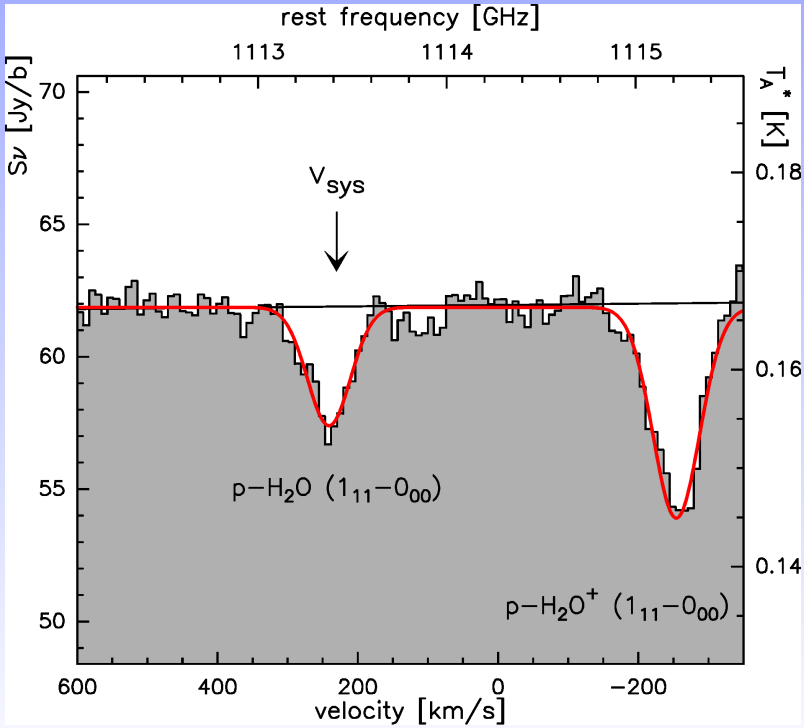
contours: SIO Garcia-Burillo etal 2001



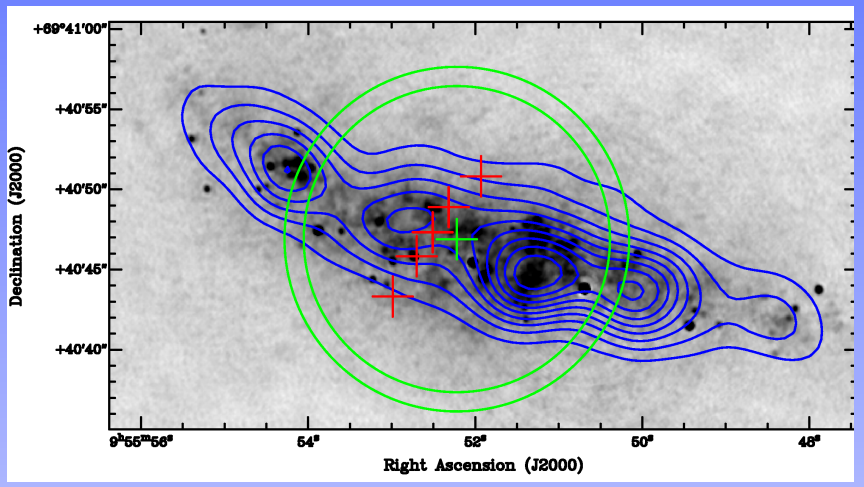
Water continuum covering factor

Continuum: 61.9 Jy/b
(SED model & 3mm distribution: 66Jy/b)

Absorption:
H_2O (1_{11}-0_{00}): 4.5 Jy/b
H_2O^+ (1_{11}-0_{00}): 8.0 Jy/b



M82 3mm continuum



for τ>>1 absorption depth ~ fc

Continuum covering factor:

1) random distribution in beam
   => H_2O : fc = 7%
   => H_2O^+ : fc = 13%

2) Limited to the region determined from the CO line profiles:
   => H_2O : fc ~ 45% !
   => H_2O^+ : fc ~ 80% !

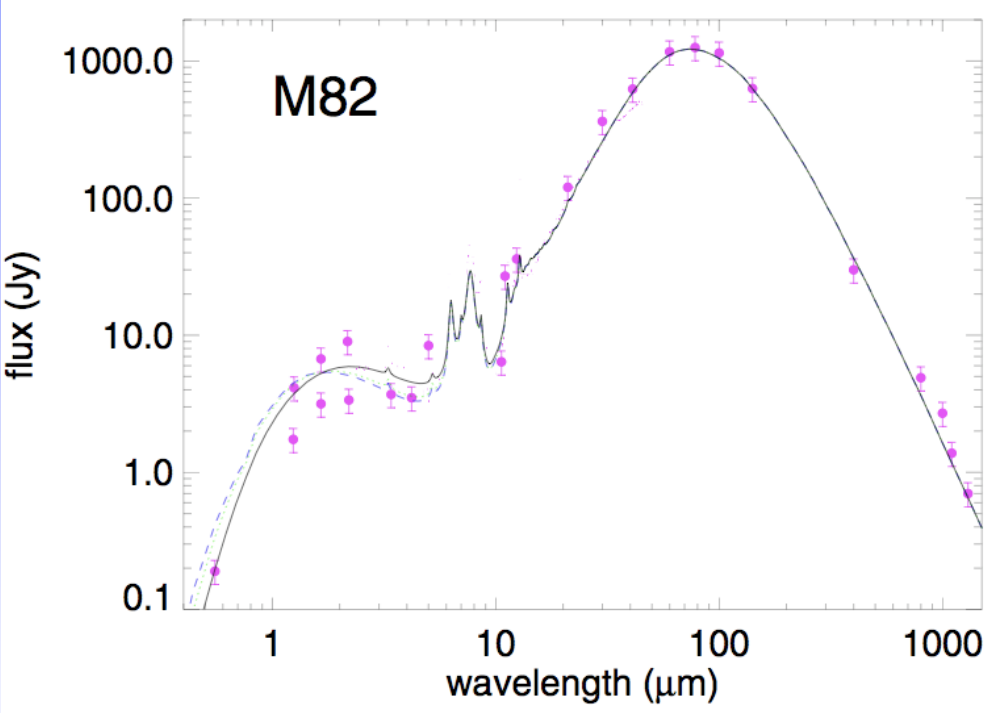
Water excitation - first steps

$T_{line} \sim f_c \, (J(\nu,T_{ex}) - J(\nu,T_{bg})) \, (1-e^{-\tau})$

Line absorption => $J(\nu,T_{ex}) < J(\nu,T_{bg})$

Background derived from dust SED models

Siebenmorgen & Kruegel 2007



Result depends on dust model, in particular the clumpiness of medium (this determines the opacity)

fit to the cold gas with $\beta = 1.8$
and a dust filling factor of 30% yields:

$T_{dust} = 45$ K and
τ@1113GHz = 0.19
$\tau = 1$ @ 120μm (quite long λ, max. T_{ex})

$\Rightarrow$**$T_{ex} < 20$ K**

for H_2O $(1_{11}\text{-}0_{00})$ and
H_2O^+ $(1_{11}\text{-}0_{00})$

Implications & Conclusions

p-H_2O ground transition sub-thermally excited
=> in agreement with spatial distribution of the H_2O absorption (avoids dense gas)

H_2O/H_2O^+ absorption in M82 associated with diffuse gas which could have a PDR origin. H_2O^+ more wide spread than H_2O

HIFIs spectral resolution highly required

Relation to H_2O emission not clear yet
$\Rightarrow$o-H_2O will shed more light on its origin

But:
Water excitation is complex (IR pumping important). Higher excited H_2O line (e.g. from SPIRE) highly desirable.

Larger sample of galaxies required…

Mrk 231 SPIRE
van der Werf etal. 2010