The ionization rates of galactic nuclei and disks: HIFI observations of H_2O, H_2O^+, and OH^+

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A&A, submitted

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Physical conditions in ISM of galaxies

SFR tied to ISM conditions
- density sets free-fall time
- temperature sets mass scale

dusty media: need long wavelengths

Water ions: trace ionization rate
- dynamical importance of B-field
- major gas heating mechanism
- top-heavy IMF?

Today: pilot study of 5 nearby AGN / starbursts

$L = 2 \times 10^{10} .. 2 \times 10^{12} L_0$

d = 3 .. 72 Mpc: 20'' = 0.35 - 7 kpc

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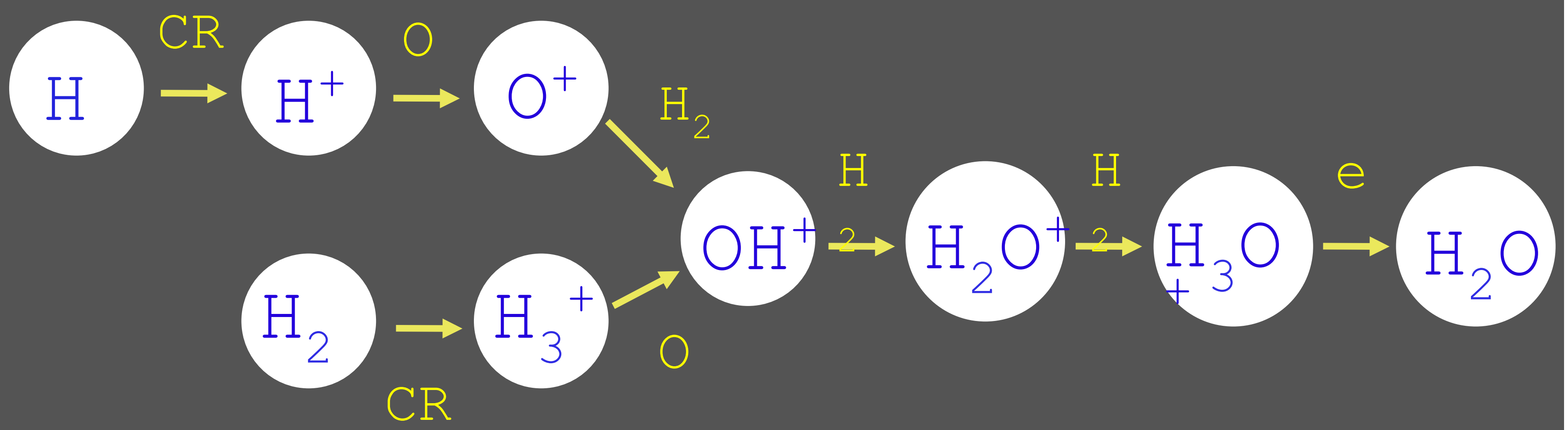
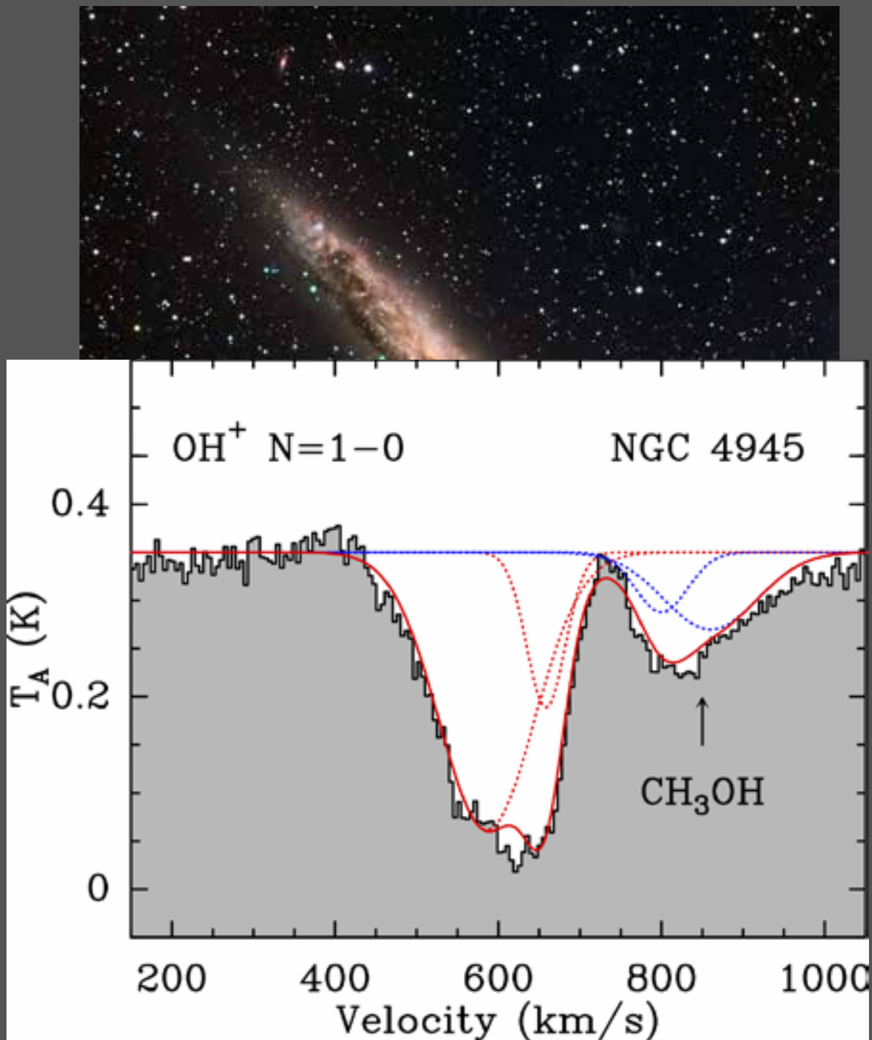
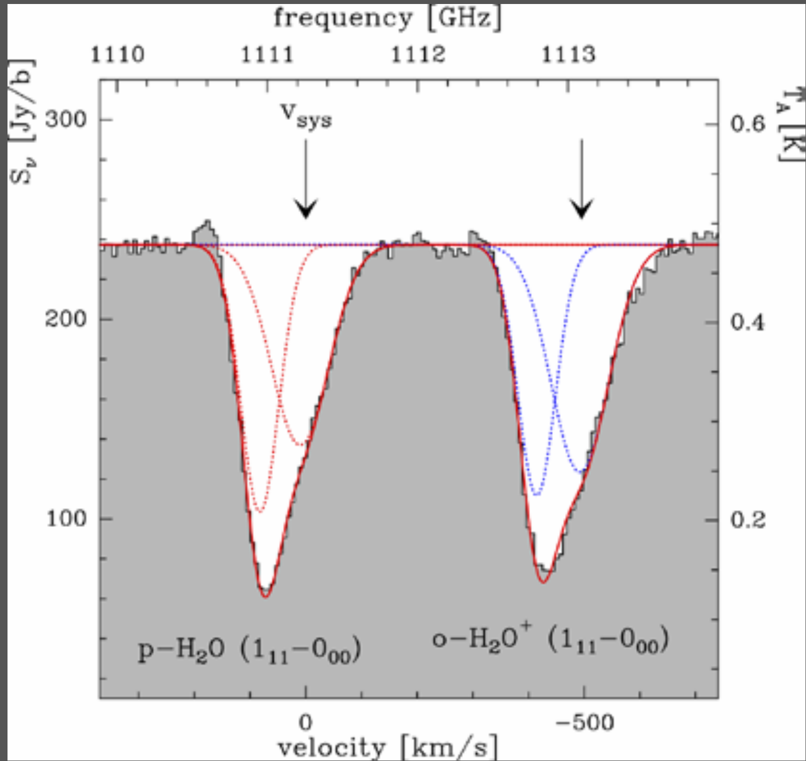
The two ways to make H_2O in cold gas



Use OH^+ / H_2O^+ ratio to infer H/H_2 ratio (Neufeld et al 2010)

NGC 4945: Dust-enshrouded Seyfert nucleus





-Similar shapes of all lines

-Redshifted gas: infall?

like HF & HI: Monje et al 2014

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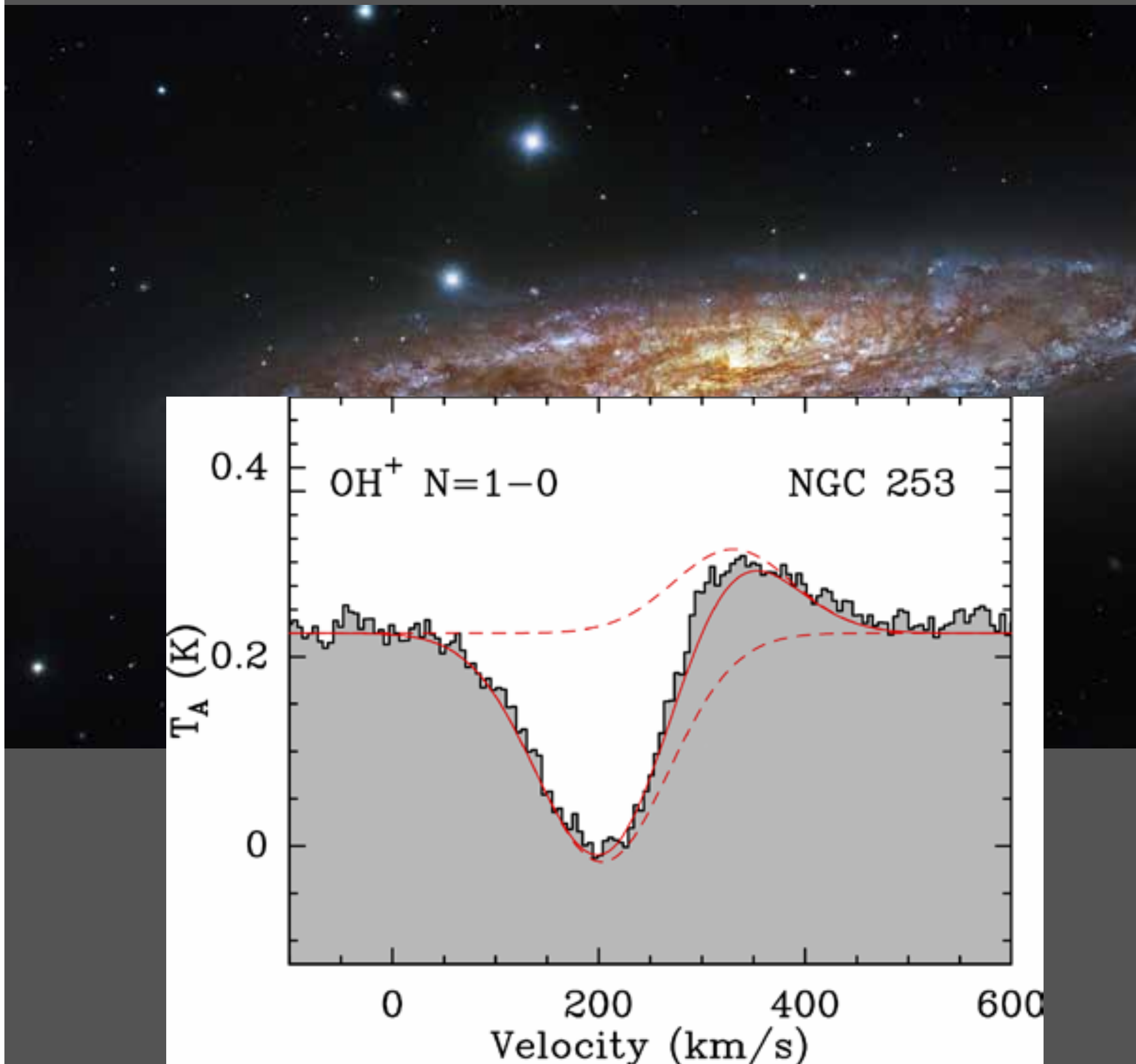
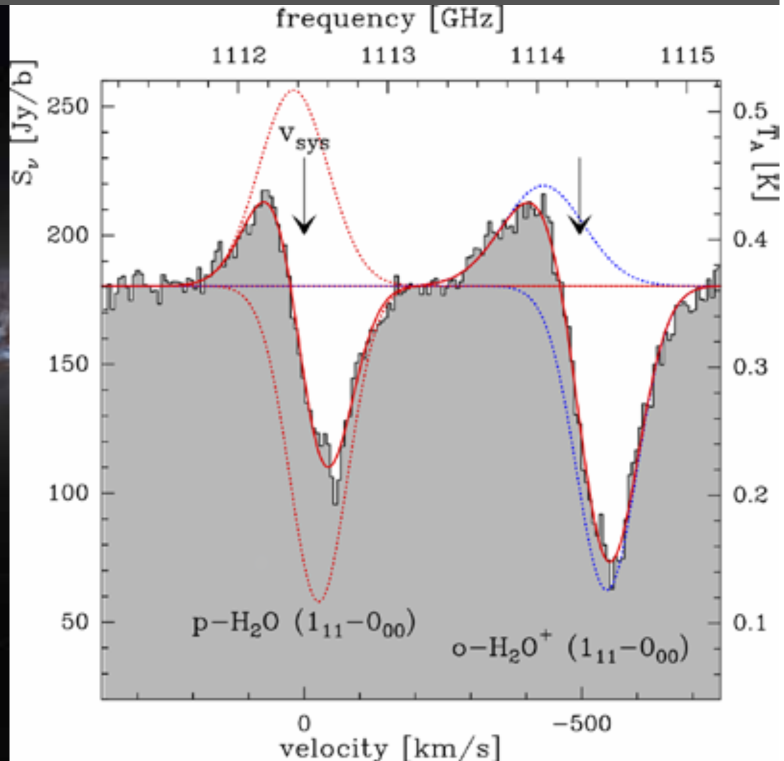
NGC 253: Starburst nucleus





Red emission
+ blue absorption
= P Cygni wind

like HF (& HI): Monje et al 2014

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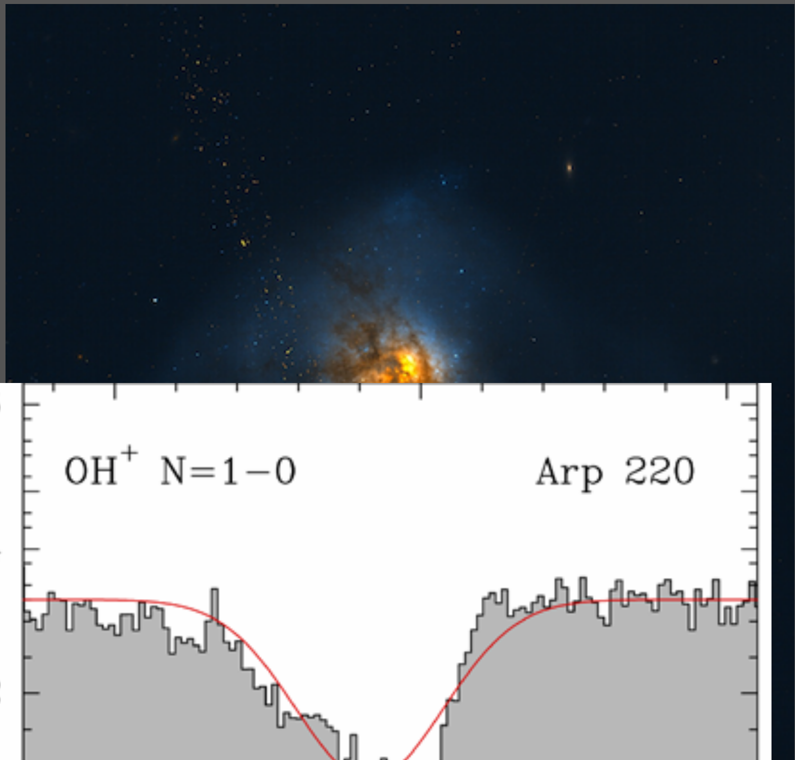
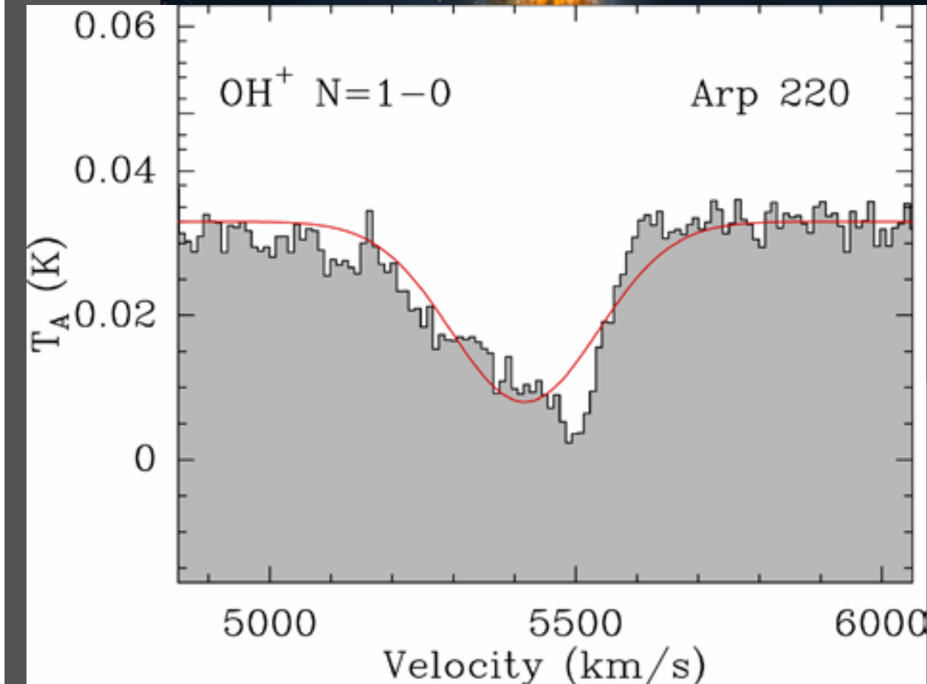
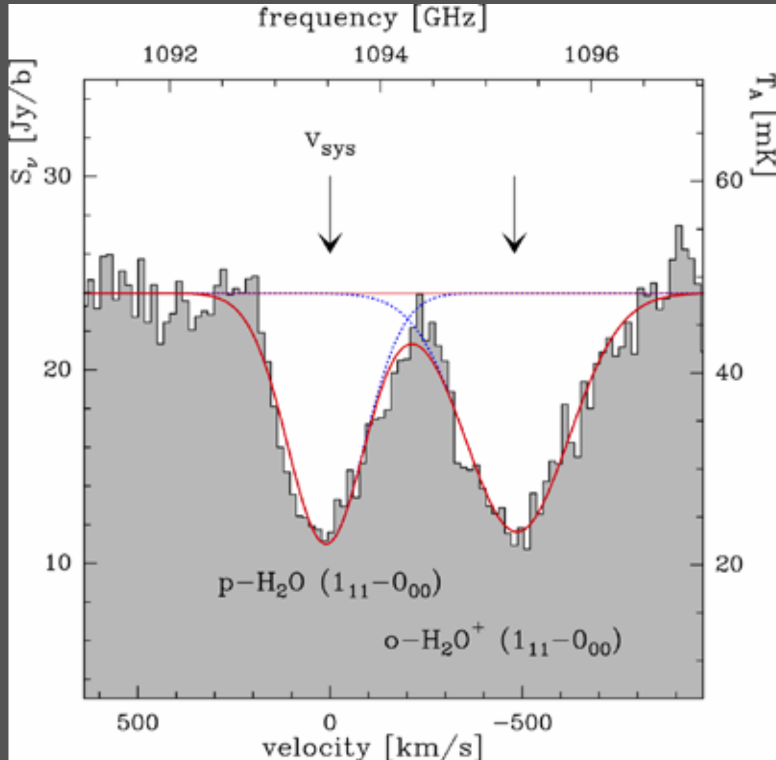
Arp 220: Ultraluminous merger with SMBH







Single broad absorption

V_0~5500 km/s: origin in W nucleus (Aalto et al 2007)

OH^+: wind / 2nd nucleus

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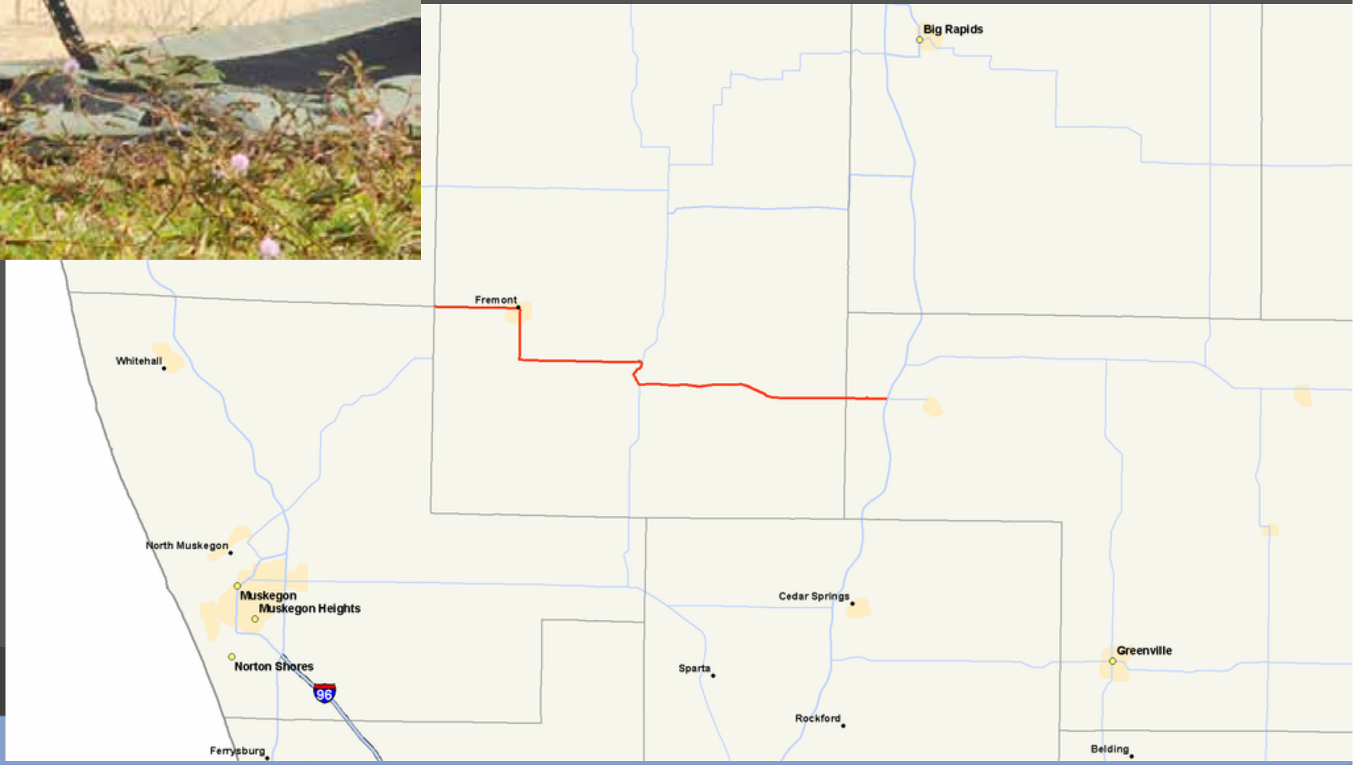
M 82: Semi-automatic rifle & Michigan highway



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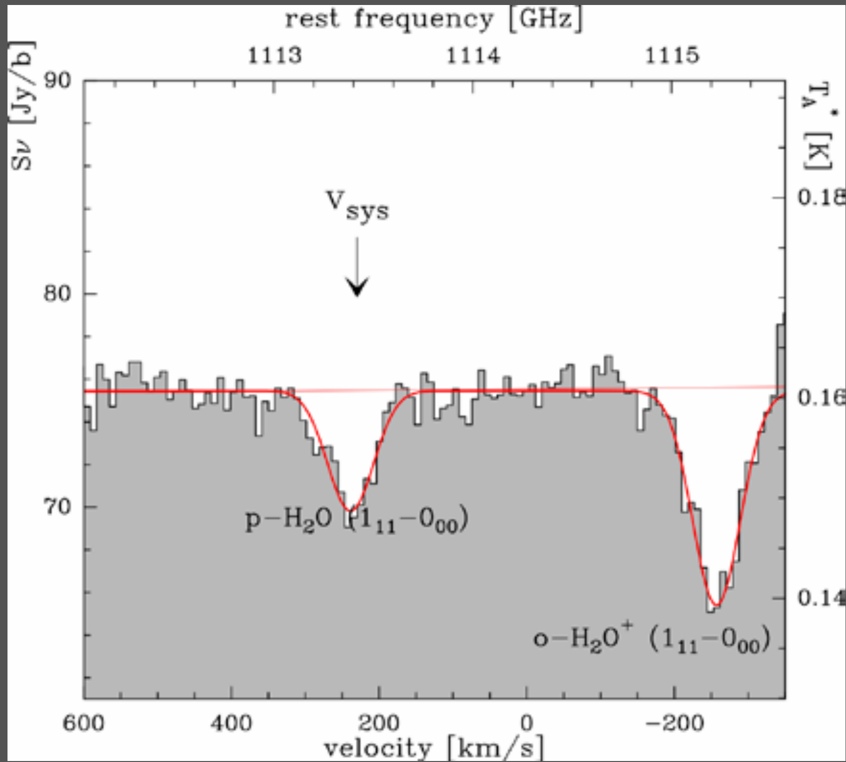
M 82: Starburst disk



Single narrow absorption
in both species

V_0: origin between NE lobe and central CO peak
(Weiss et al 2010)

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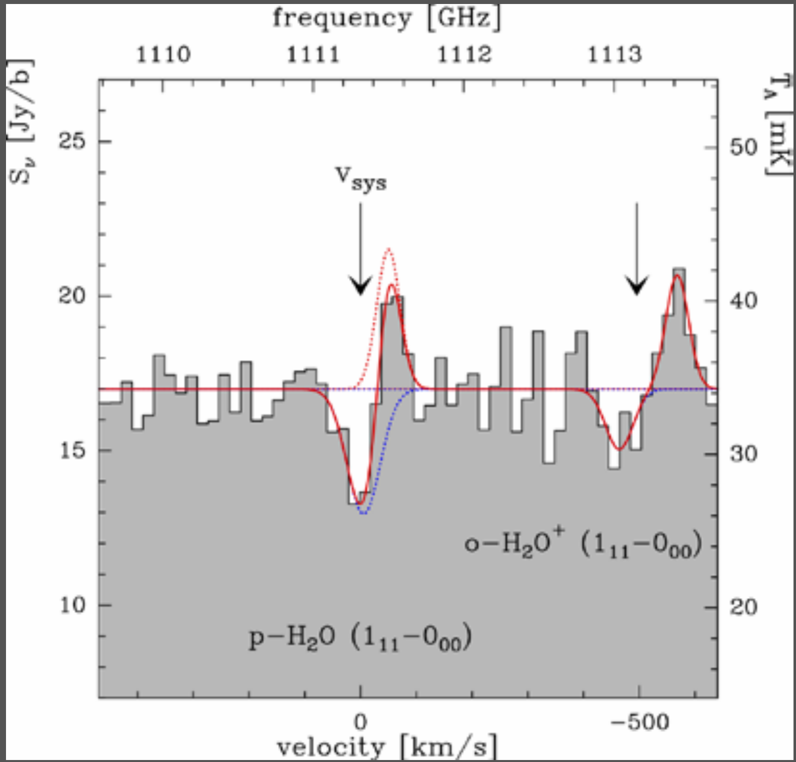
Cen A: Radio AGN



Red absorption
+ blue emission
= infall signature

narrow line: origin in "extended thin disk"

(Israel et al 2014)

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Estimating column densities

- Absorption features: assume excitation negligible
  - only ground state populated
  - ortho/para ratio of 3 *(as observed by Flagey / Schilke et al 2013)*
- Emission features: model collisional excitation
  - radiative rates: from CDMS/JPL spectroscopy
  - collisional rates H_2O, OH^+ known *(cf talk Alex Faure)*
- For H_2O^+ use scaled radiative rates
  - assuming strong coupling H_2 - ion
- Use RADEX for T_k = 10-100 K & $n(H_2) = 10^4$-10^6 cm^{-3}
  - find T_{ex} = 5-10 K

  Alternative: radiative pumping (T_{ex} ~100 K)
  - lowers column density by ~15x

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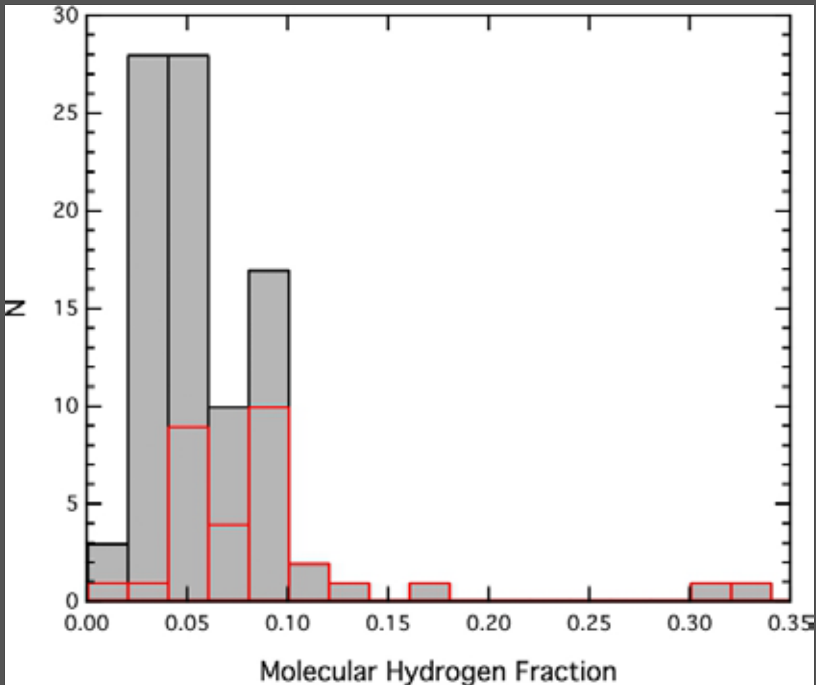
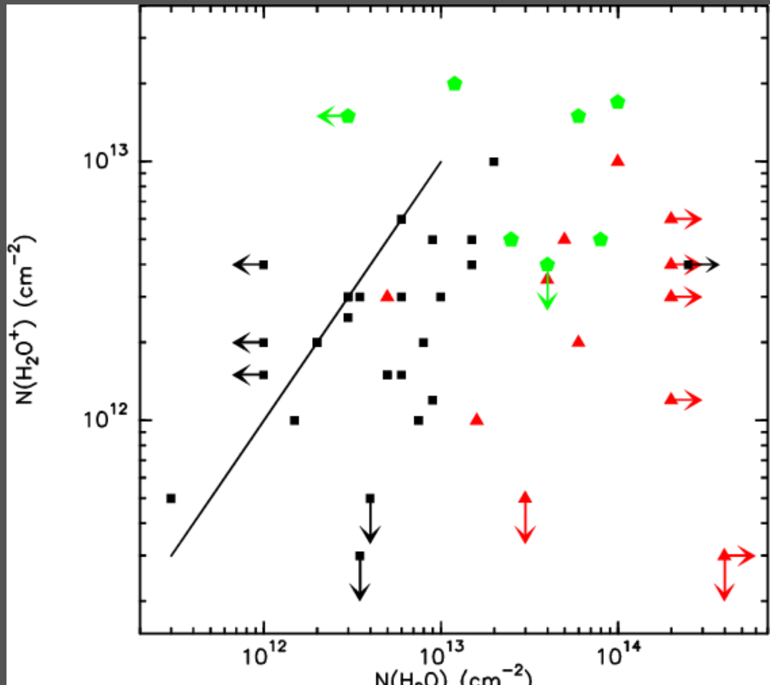
Results

Column densities range from $\sim 10^{13}$ to $\sim 10^{15}$ cm^{-2}

- absorption ~ emission: nucleus does not contribute much
- low H_2O / H_2O^+ ratio: origin in diffuse gas
- OH^+ / H_2O^+ ratio: $f(H_2)$ ~11% ~ 3x Galactic average



Indriolo et al 2015



Wyrowski et al 2010

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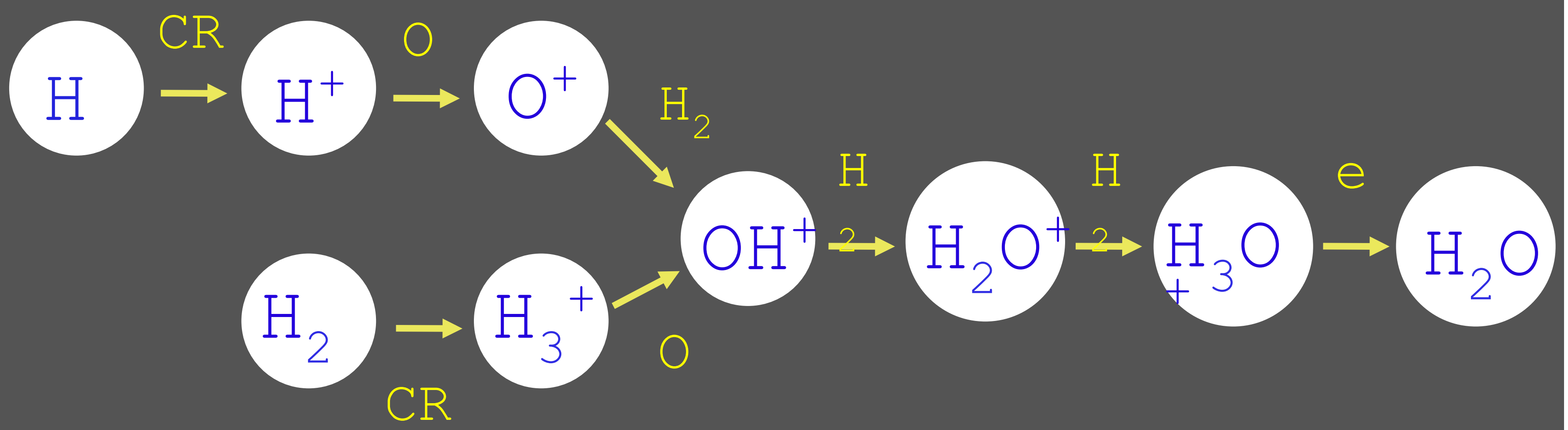
The two ways to make H_2O in cold gas



The ionization rate

- Steady state:

$$\epsilon\zeta_{\rm H} = \frac{N({\rm OH^+})}{N({\rm H})} n_{\rm H} \left[\frac{f_{\rm H_2}}{2} k_4 + x_e k_5 \right]$$

  - diffuse absorbers: take x_e = 1.5 x 10^{-4}; n_H = 35 cm^{-3}
  - adopt Galactic ionization efficiency ε = 7% (Indriolo et al 2012)

One parameter left:

- the atomic H column

$$f_{\rm H_2} = \frac{2x_e k_7/k_4}{N({\rm OH^+})/N({\rm H_2O^+}) - k_6/k_4}$$

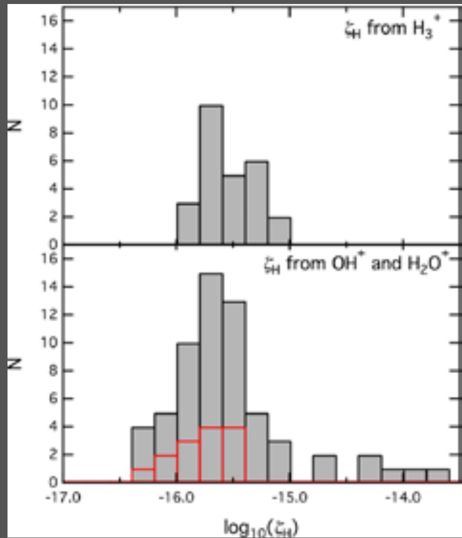
The HI column

- Matched-beam data exist for M82 (Yun) & Cen A (v.d. Hulst)
  - N(H) 3-5x below $N(H_2)$
  - integrated over LOS, most gas is dense
- But OH^+/H_2O^+ ratio indicates $f(H_2)$ ~11%
  - locally in H_nO^+ absorbers, most gas is diffuse
  - OH^+ & H_2O^+ profiles similar to H_2O & HI: phases mixed
  - absorption in 'bubbles' in sea of dense gas

Discussion

Find ζ_H = 6 x 10^{-17} ... 8 x 10^{-16} s^{-1}

- like Galactic disk, 1/10 of Galactic center (Goto et al 2014)
- 1/100 of AGN estimates from H_3O^+ (González-Alfonso et al 2013)

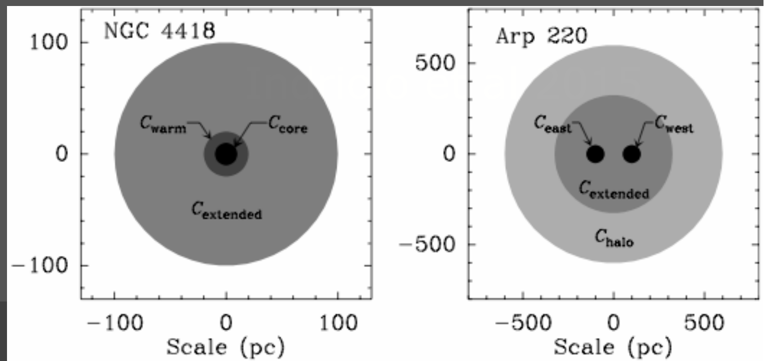


Low excitation & ionization: disk not nucleus

- physically distant from AGN/SB?
- more likely shielded by dust
- infall/outflow motions support

Ionization rates are not constant across galaxies

- variation ~10x between disk & nucleus
- as seen before in our Galaxy
- active nuclei with normal disks



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