A search for gravitationally lensed water masers

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with

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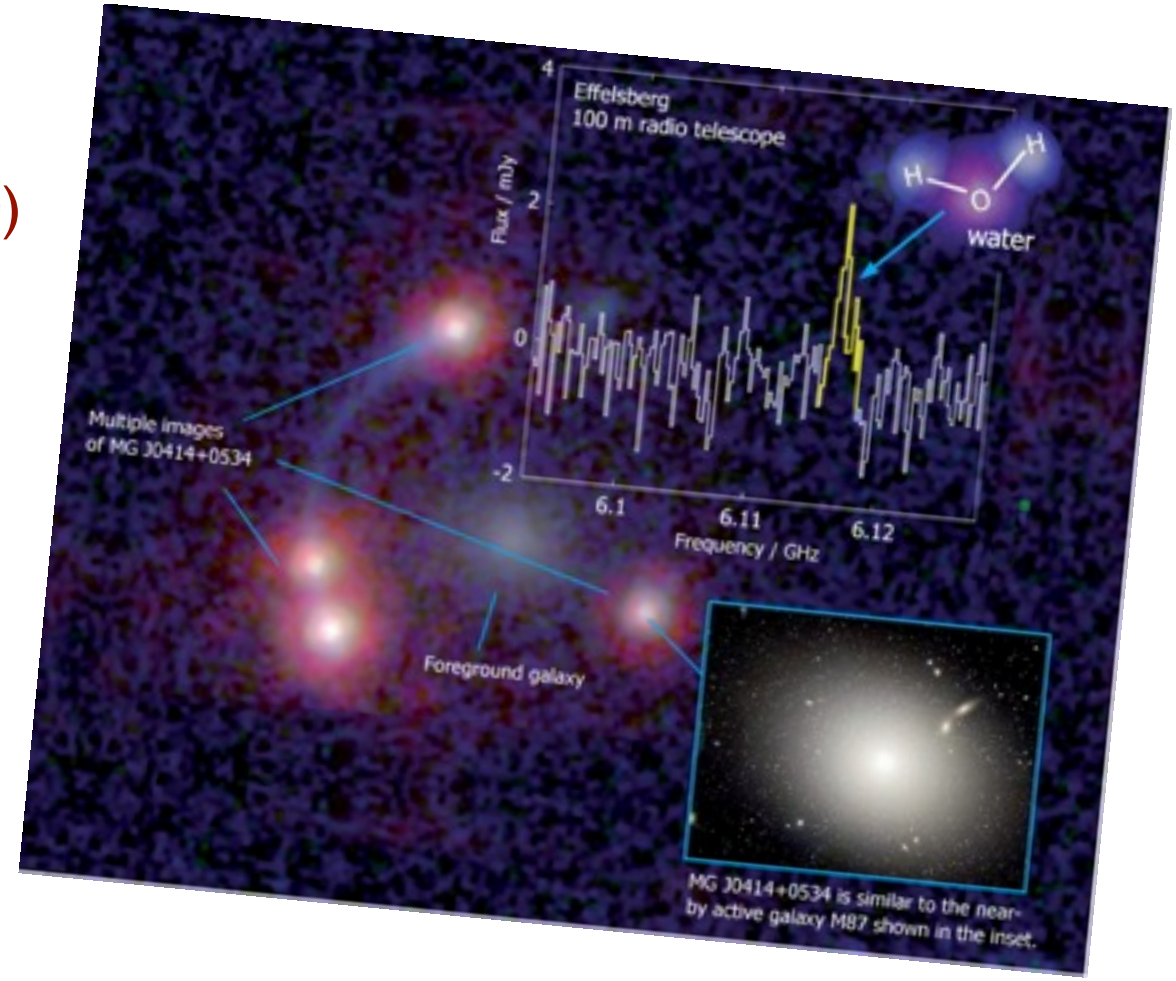
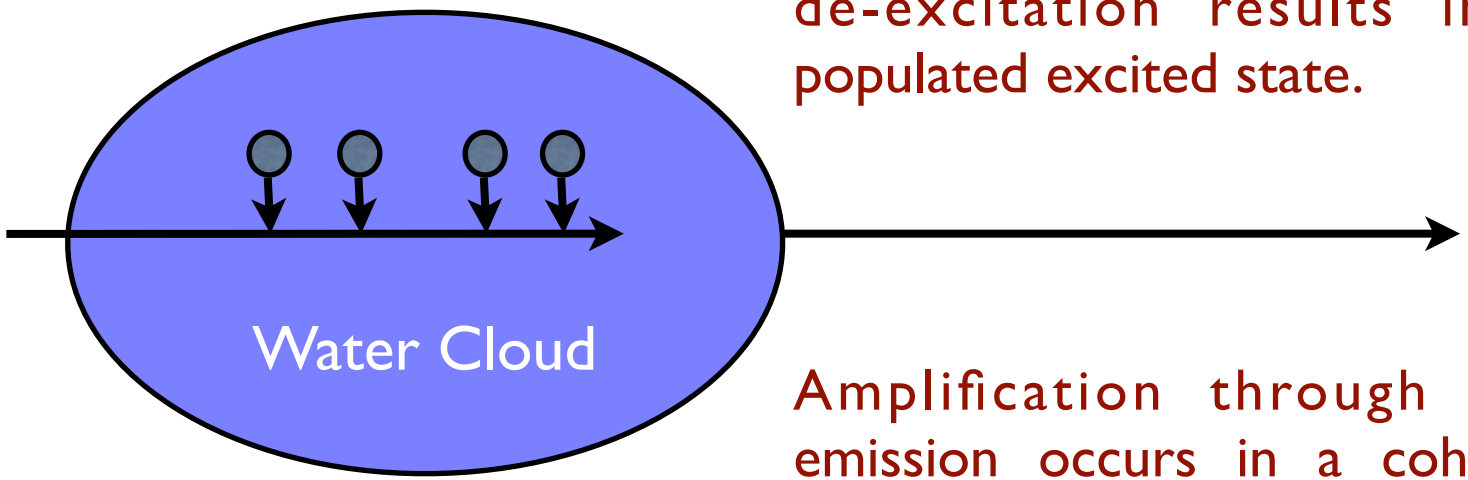


Water Masers

Maser emission ($6_{12} - 5_{23}$) from water is seen at 22.2 GHz (rest frame.)



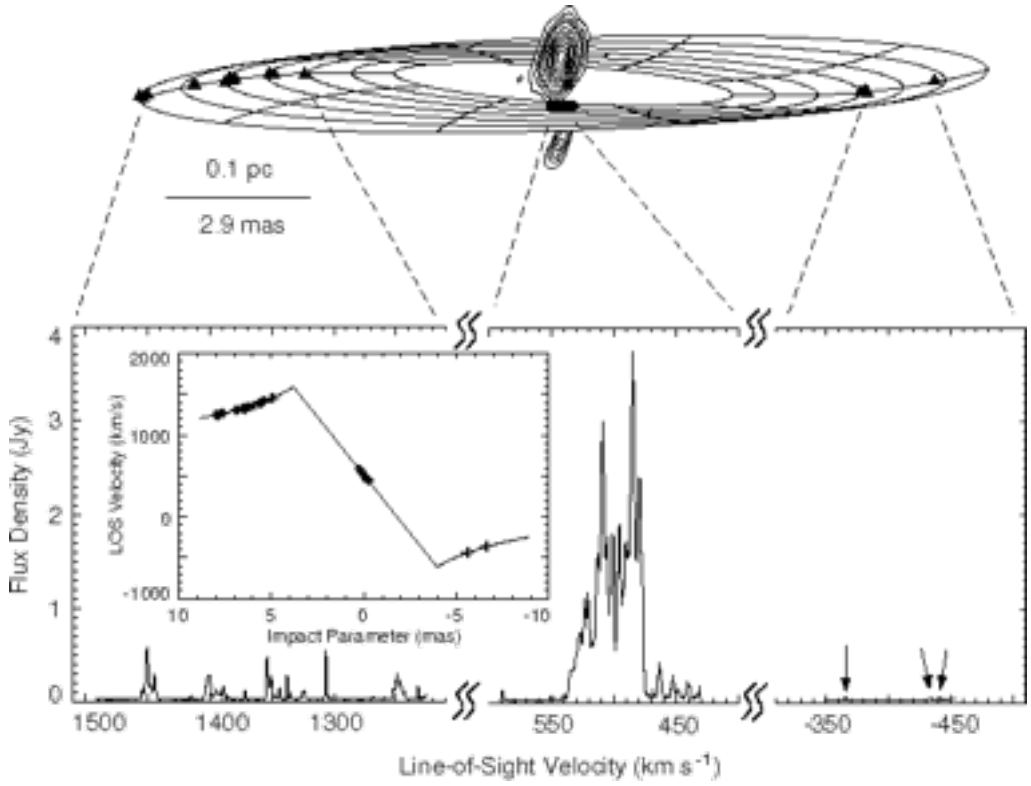
Collisional excitation and low radiative de-excitation results in an over populated excited state.

Amplification through stimulated emission occurs in a coherent (freq/ velocity) gain medium.

Radiation has a very high surface brightness and is beamed to the observer.

Found in regions of dense gas ($10^{7\text{-}11}$ cm^{-3}) => most luminous (> 10 $L_{\odot}$) are found very close to the super-massive black hole of an AGN.

Probing AGN - I



Blueshifted, redshifted and systemic components.

Tend to have narrow emission lines (<1--3 km s^{-1}.)

Estimate Black hole mass,

$$\frac{dv}{dt} = \frac{v^2}{r} = \frac{GM_{BH}}{r^2}$$

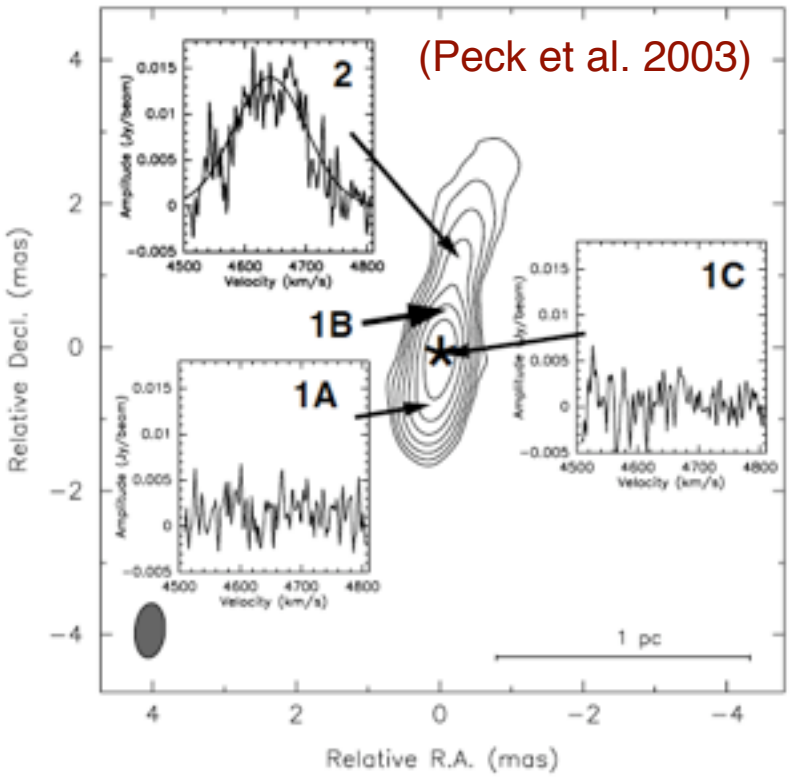
NGC 4258 M_{BH} = 3 x 10^7 M_{solar} (Miyoshi et al. 1995).

With VLBI accurate geometrical distances can be found (e.g. Herrnstein et al. 1999).

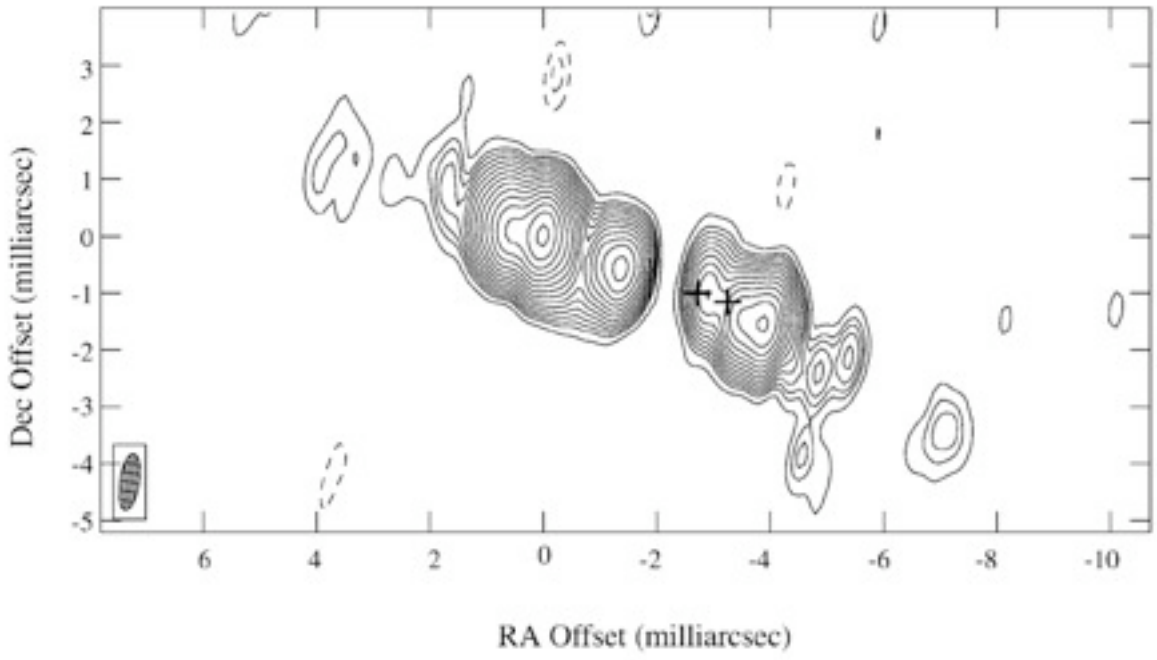
NGC 4258 distance = 7.2 ± 0.3 Mpc.

High-z water masers can be used to find H_0 (see MCP of NRAO).

Probing AGN - II



NGC 1052 (Claussen et al. 1998)

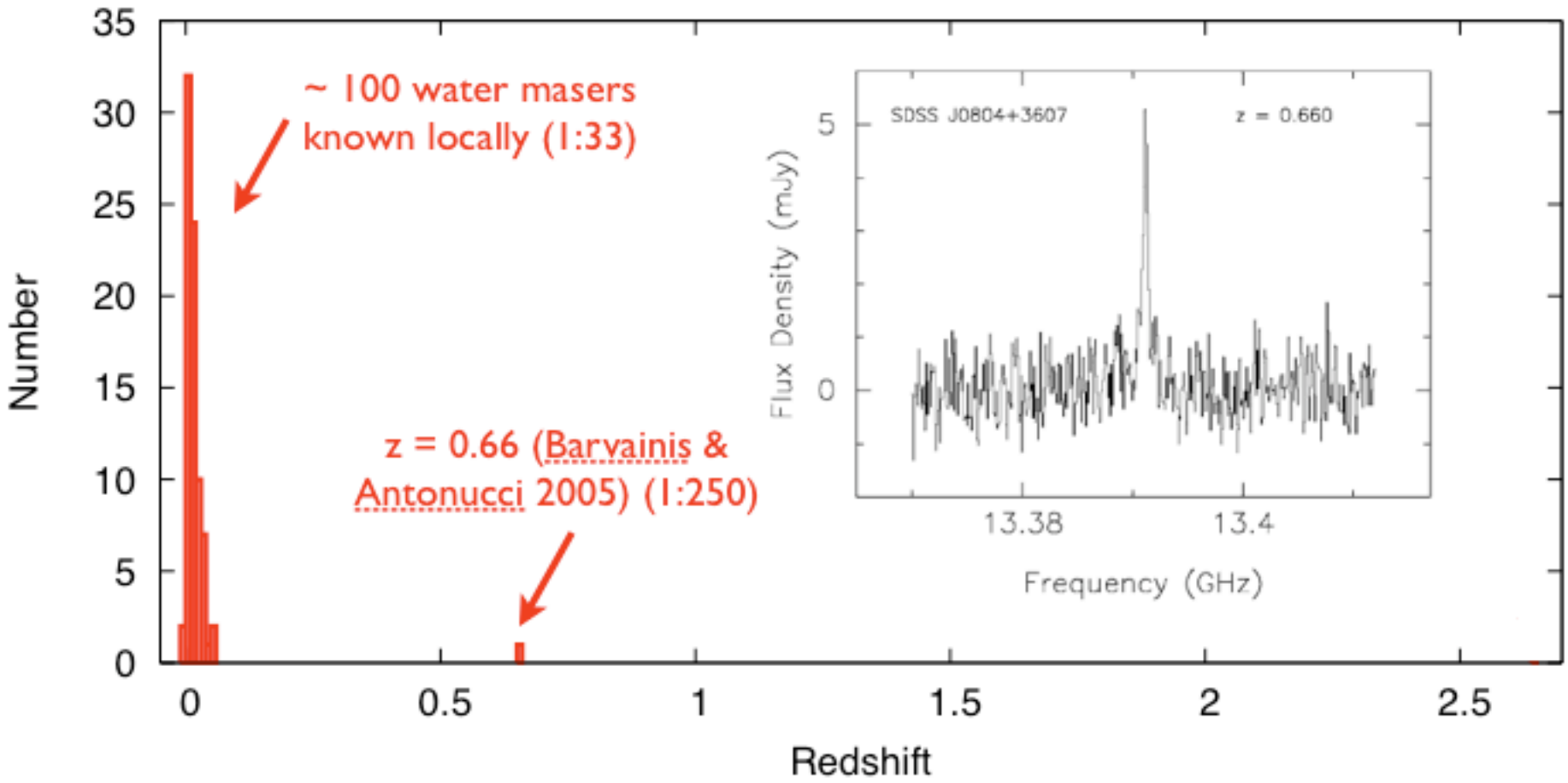


Broad line (<100 km s^{-1}) emission in the radio jet out to 30 pc from the core.

Due to interaction of the jet with a molecular cloud.

Used to study e.g. shock speeds (~ 300 kms^{-1}) and jet densities (100 cm^{-3}) for MRK 348.

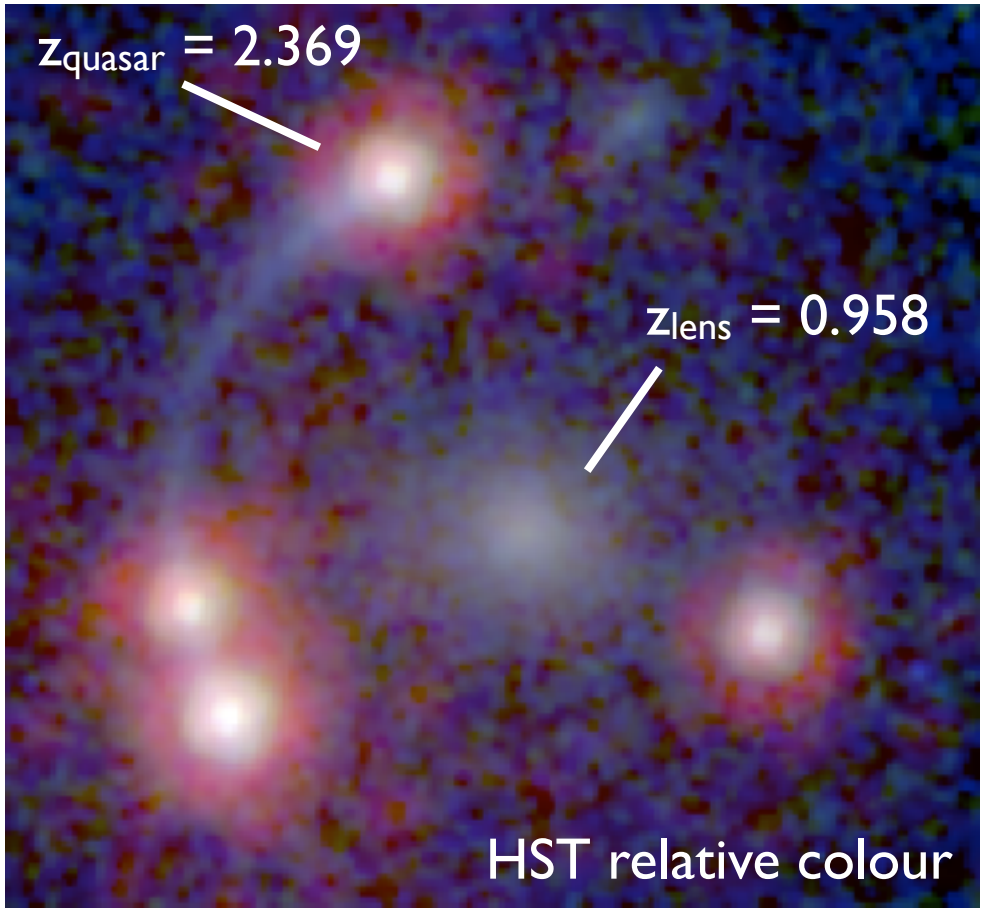
Almost all found locally

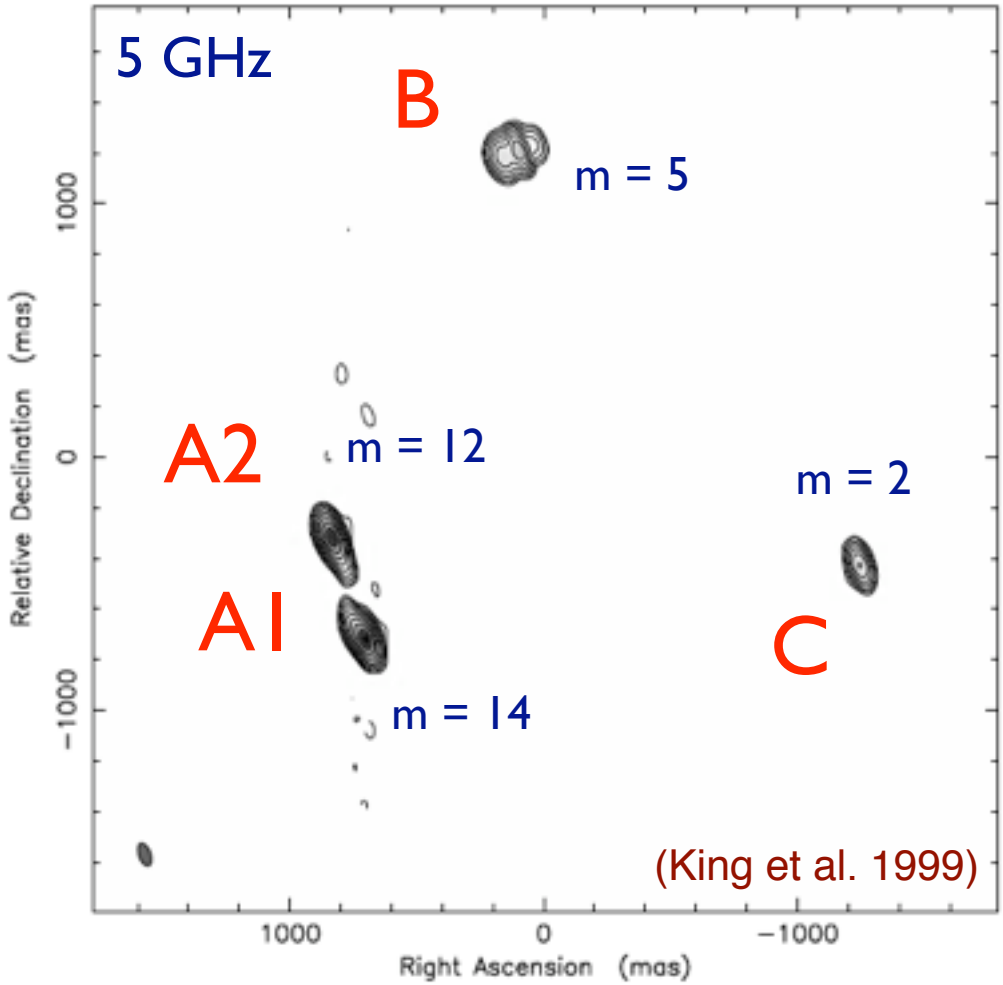


Almost all associated with Seyfert 2 or LINER galaxies at z << 0.06.

Most distant and luminous water maser at z = 0.66 (type 2 quasar; L ~ 23 000 $L_{\odot}$)

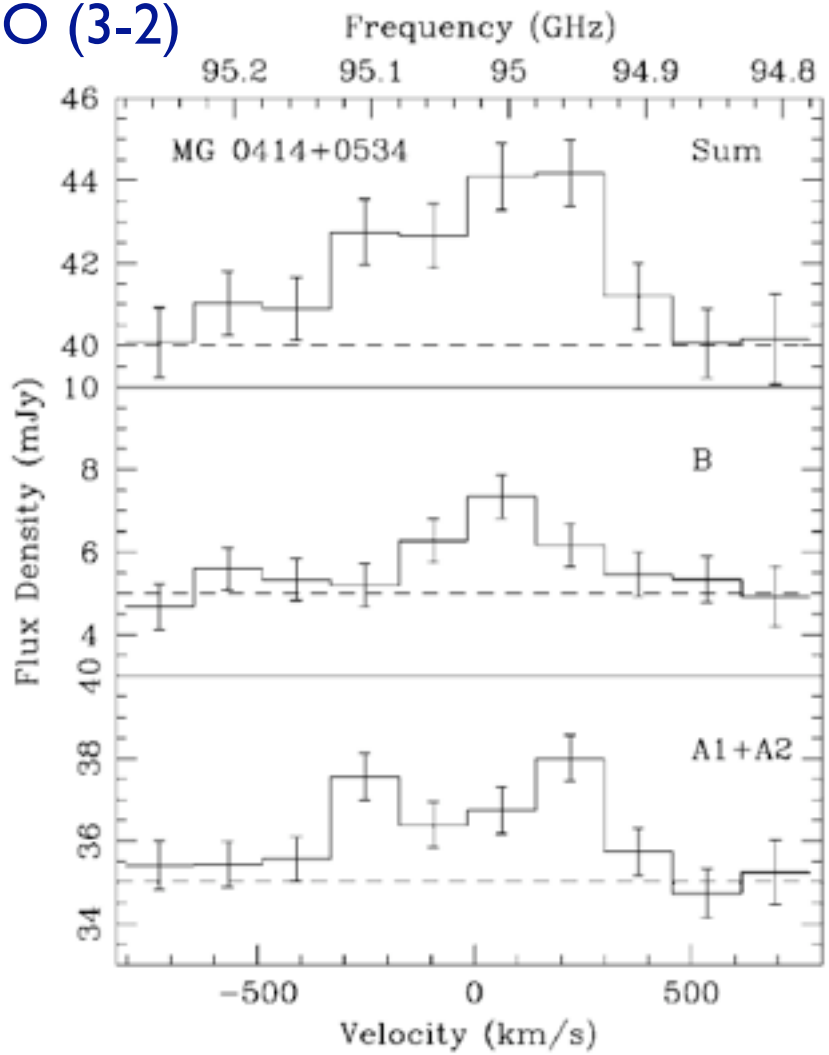
Water from MG J0414+0534



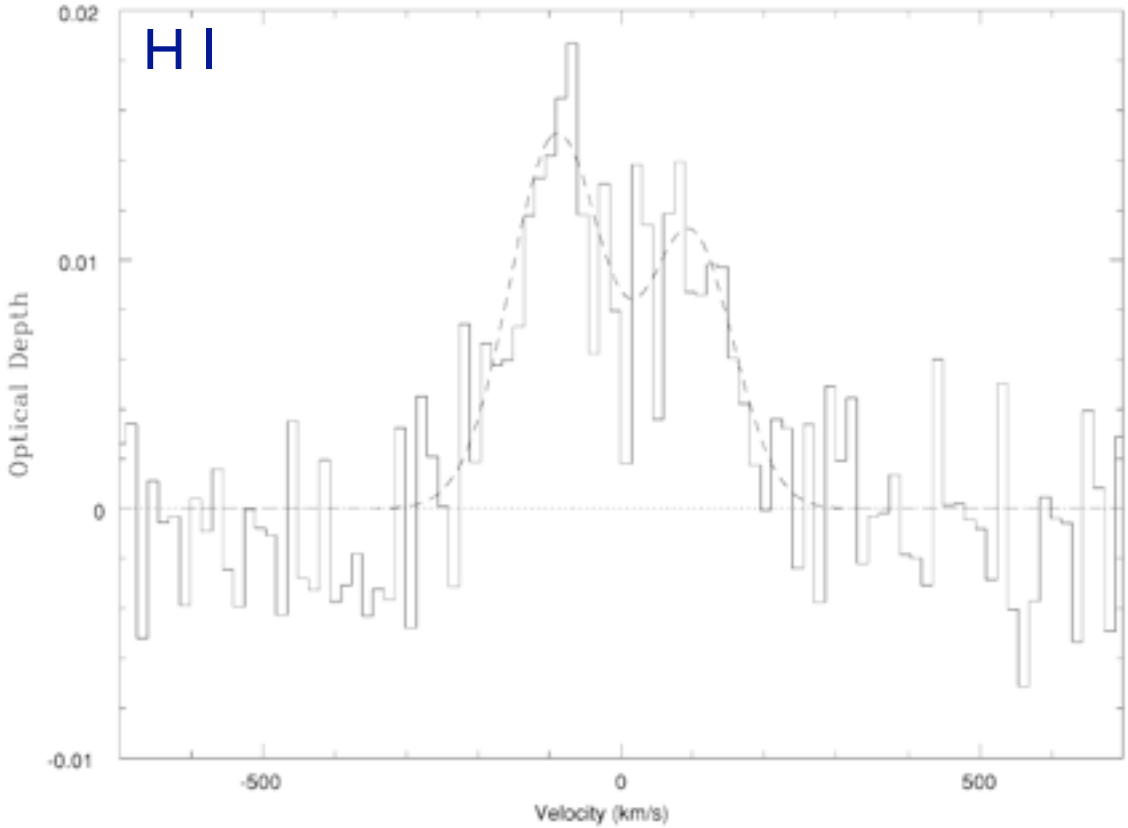


Rich molecular environment

CO (3-2)



H I



Lensed quasar has a dusty host galaxy rich in molecules.

CO emission at ±300 km s^{-1} (Barvainis et al. 1998) around the systemic.

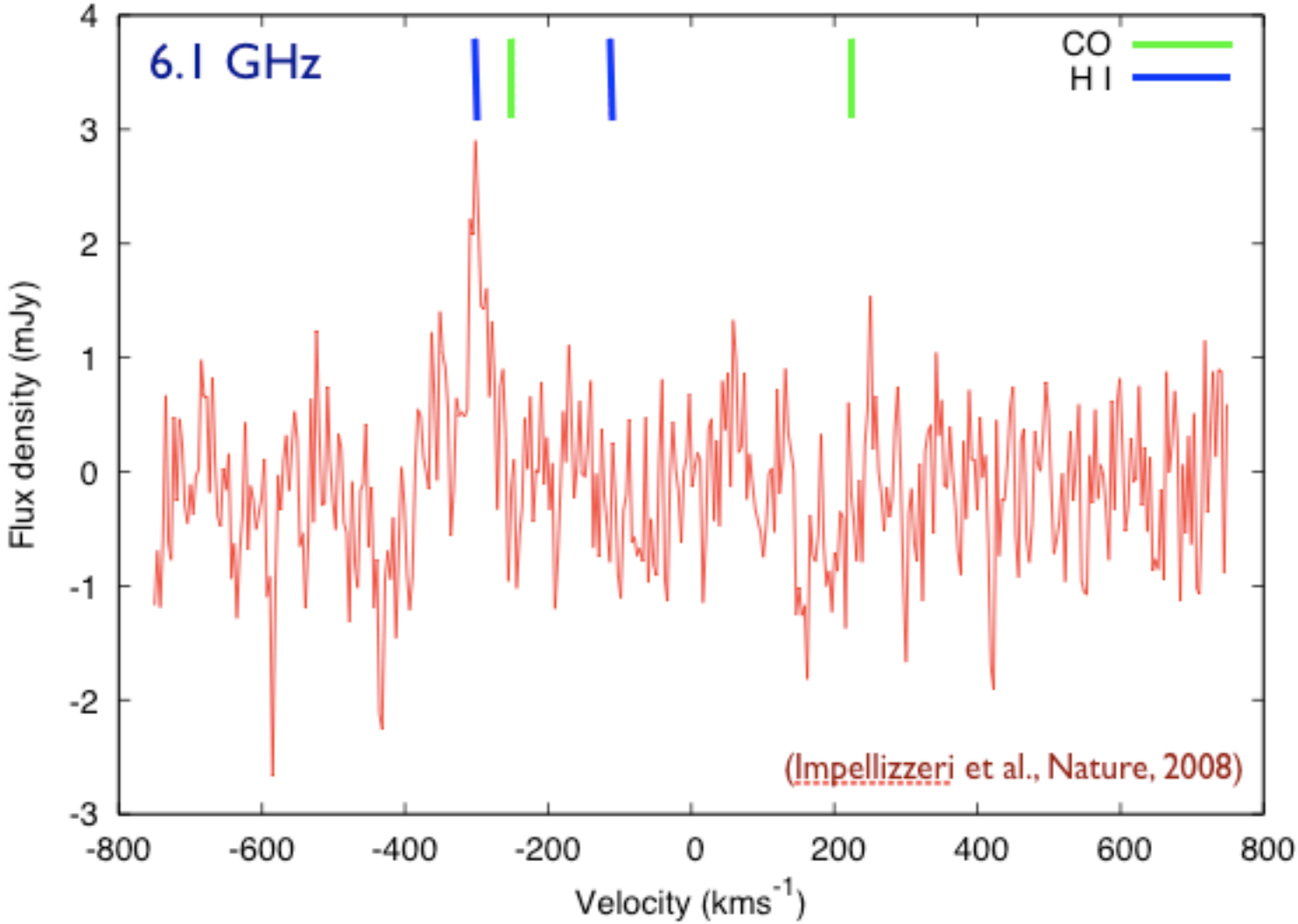
HI absorption at −300 km s^{-1} (Moore et al. 1999).

Effelsberg Radio Telescope

Total integration time 14 h.

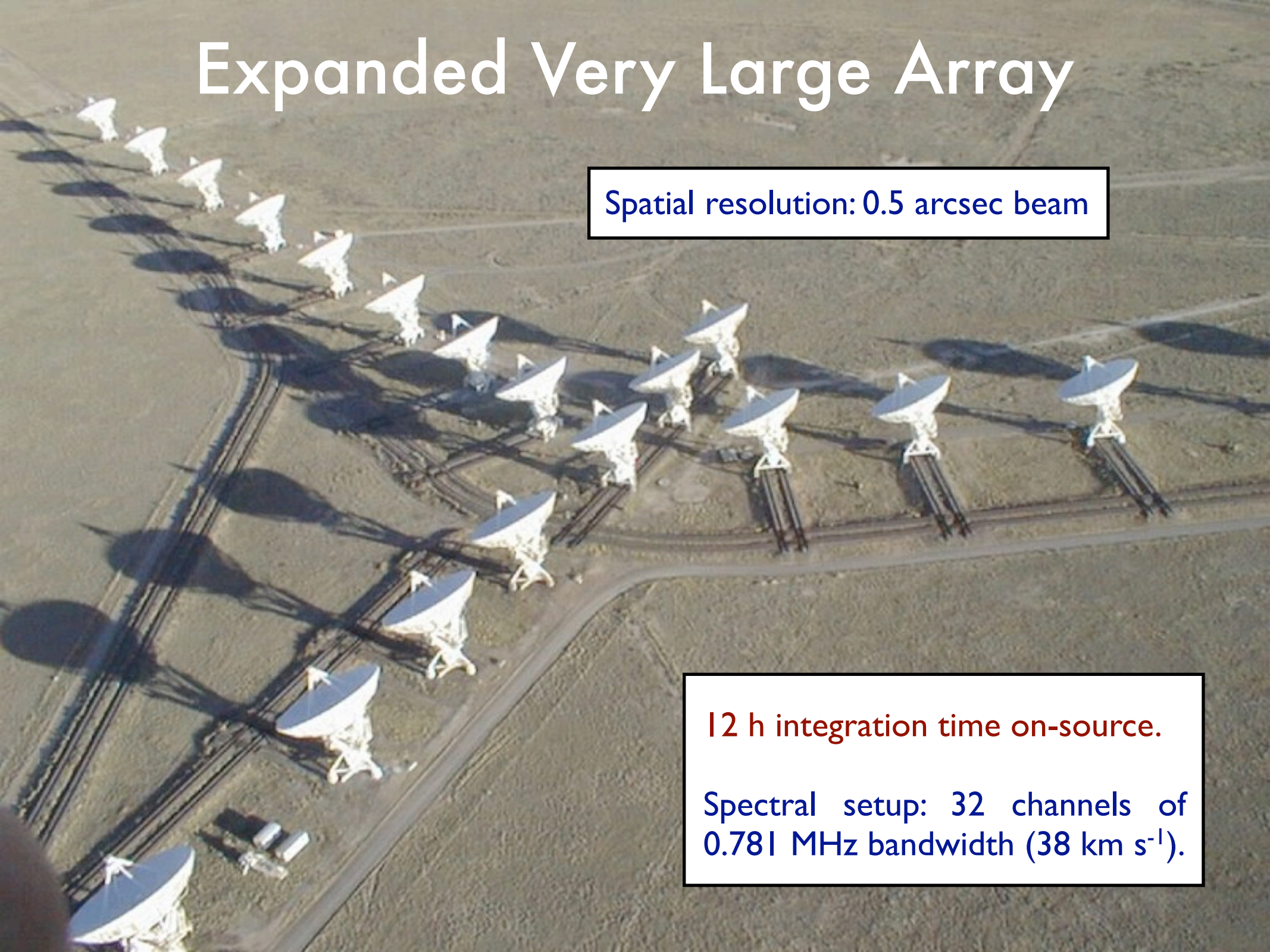
rms ~ 0.6 mJy in 3.8 km s^{-1} channel.

Effelsberg spectrum



The estimated unlensed (isotropic) luminosity is ~10 000 $L_{\odot}$.

Expanded Very Large Array



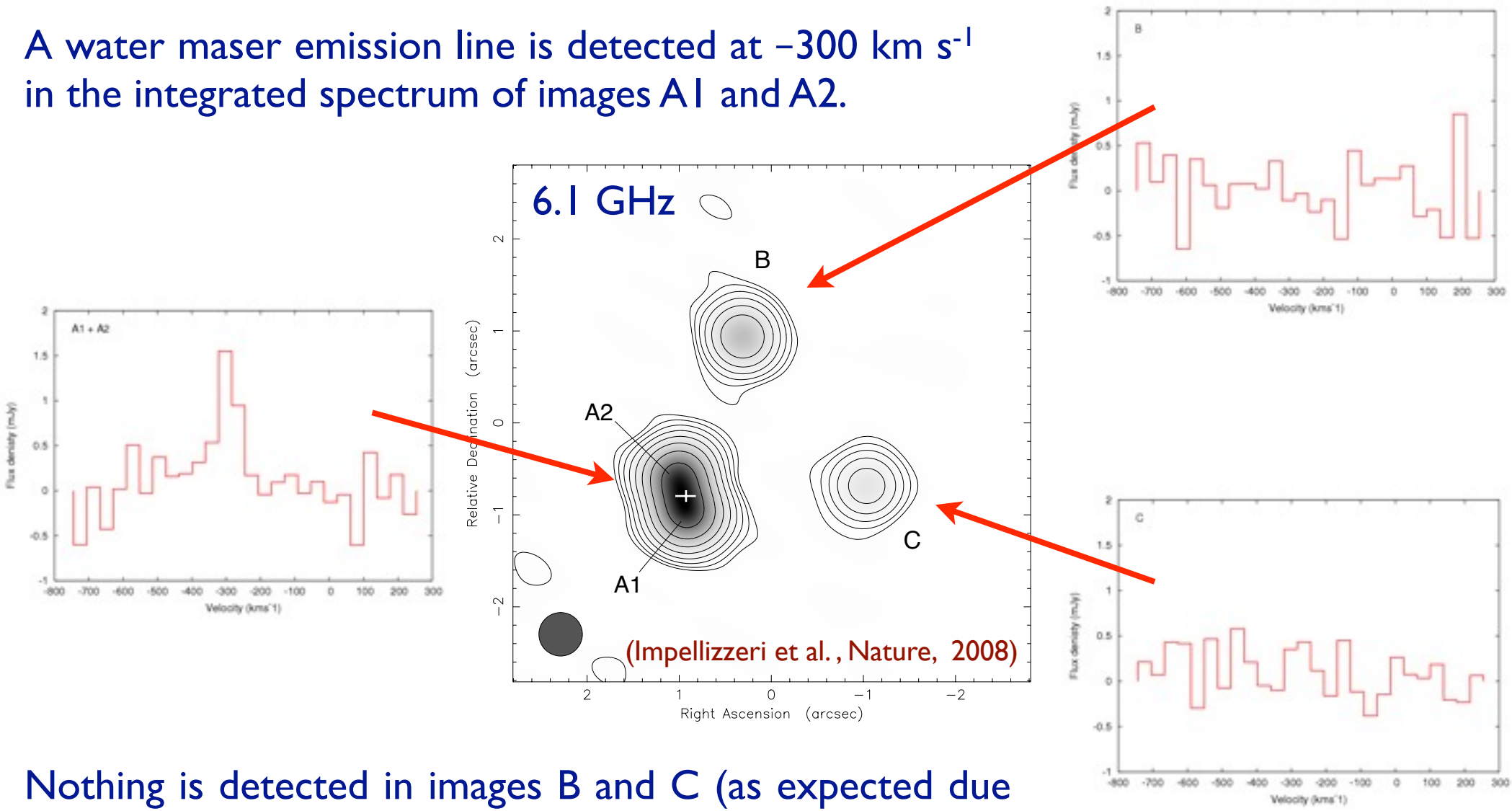
Spatial resolution: 0.5 arcsec beam

12 h integration time on-source.

Spectral setup: 32 channels of 0.781 MHz bandwidth (38 km s^{-1}).

EVLA spectra

A water maser emission line is detected at −300 km s^{-1} in the integrated spectrum of images A1 and A2.



Nothing is detected in images B and C (as expected due to their lower image magnifications).

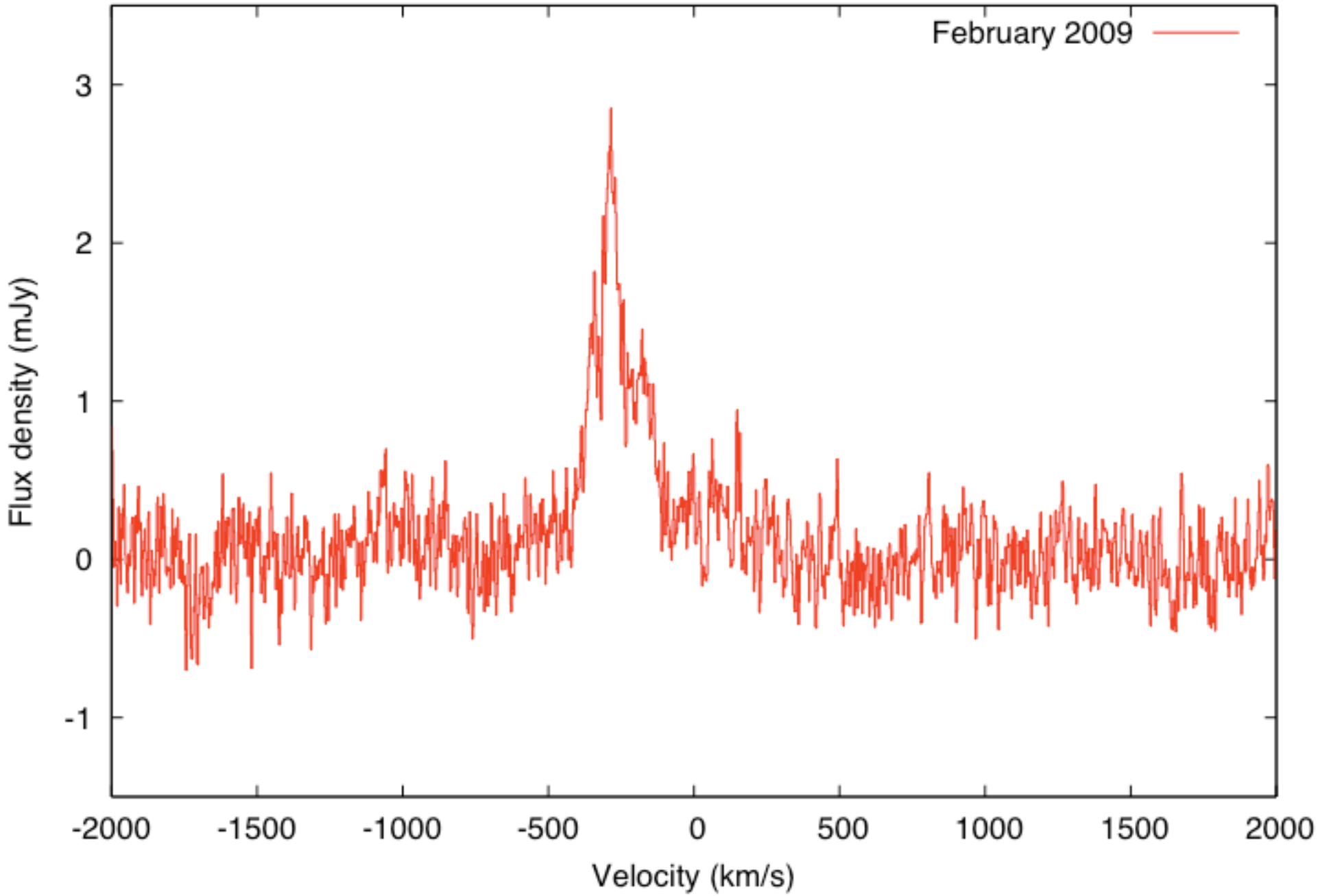
Aricebo Monitoring

High sensitivity/spectral resolution

4 hour integration time on-source per epoch.

One visit per month.

New Aricebo spectrum



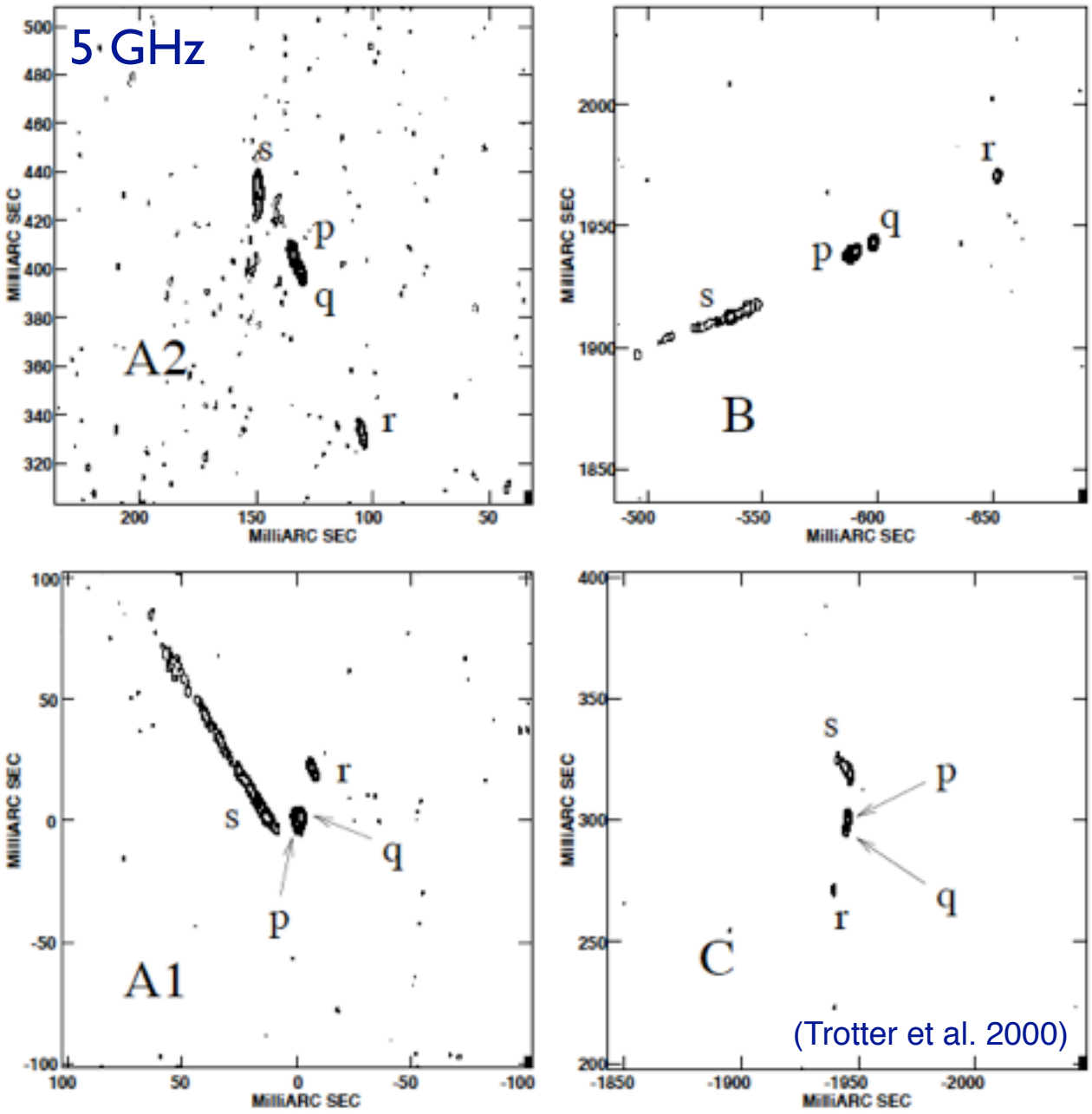
Jet or disk maser?

- ★ Maser line is broad (FWHM ~ 40-90 km s^{-1}).
- ★ Line offset from the systemic velocity (−300 km s^{-1}).
- ★ MG 0414+0534 type 1 radio-loud quasar.

★ Jet maser scenario seems most likely ★

- ★ VLBI spectral line observations at 6.1 GHz (June 2008).
- ★ VLBI continuum observations at 1.7 and 8.46 GHz (June 2008/Oct 2008).

Lensing Magnifies



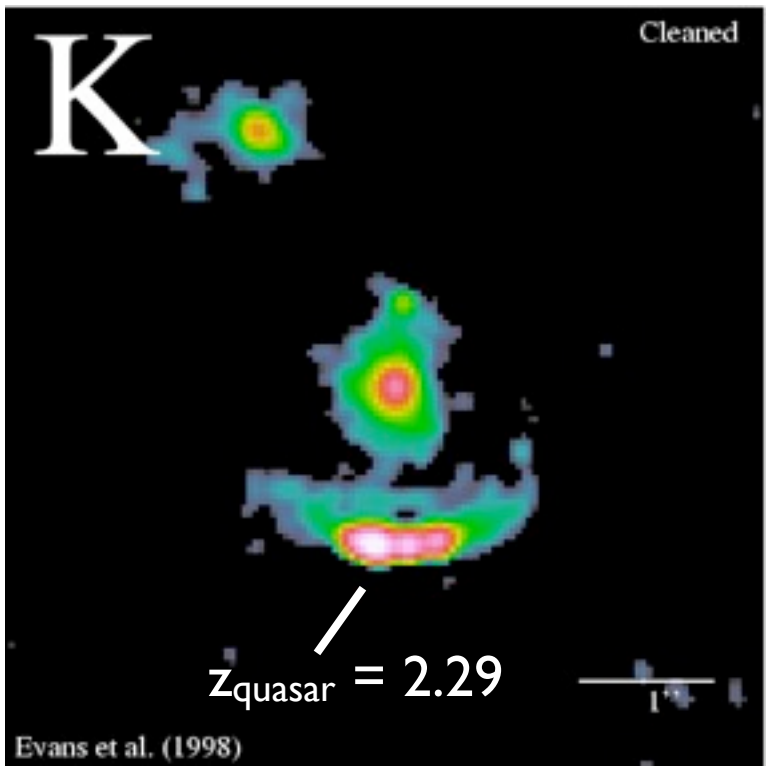
VLBI at 6.1 GHz has 1-2 milliarcsecond resolution.

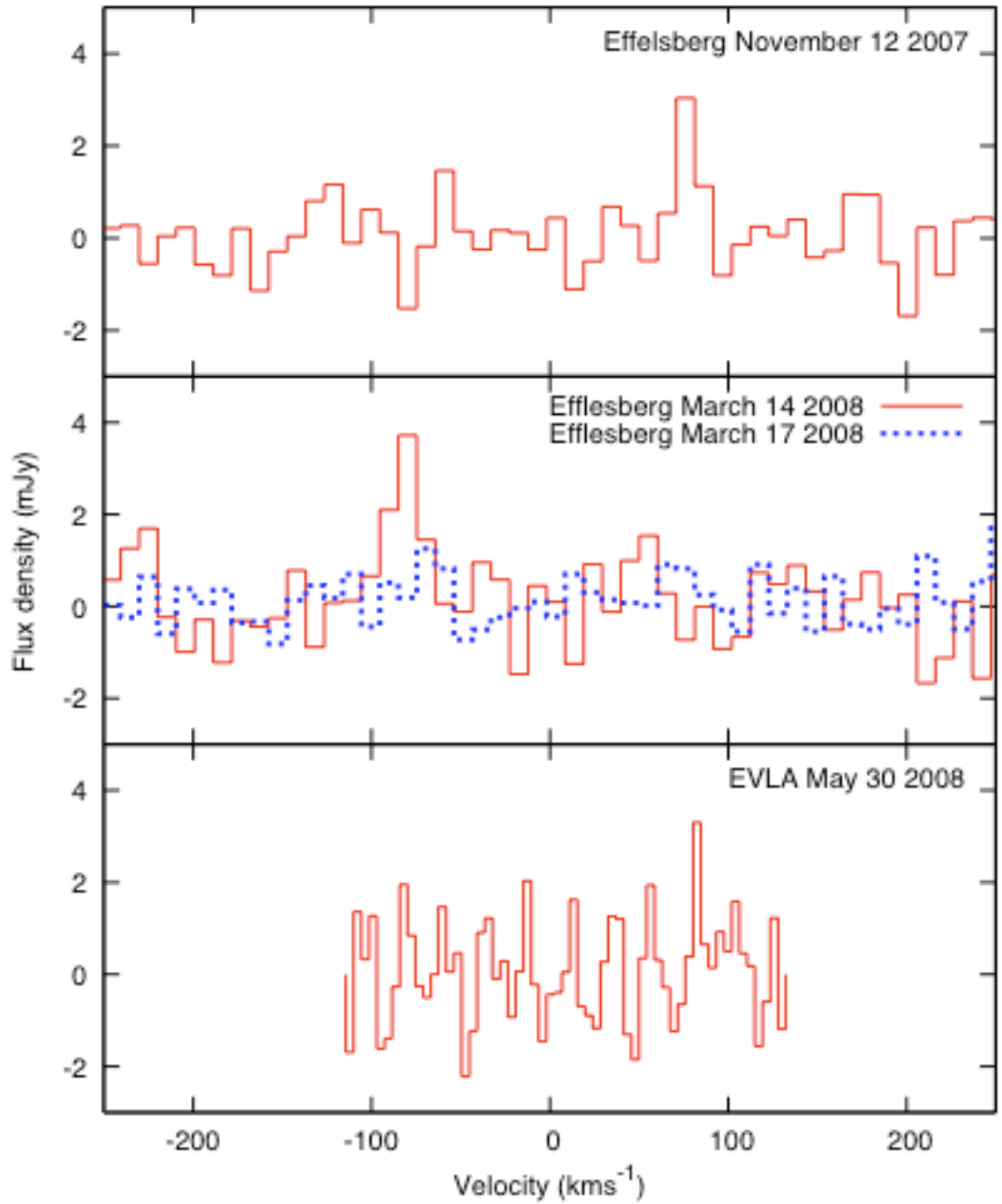
~1 parsec (unlensed) at redshift 2.64.

IRAS 1021+4724

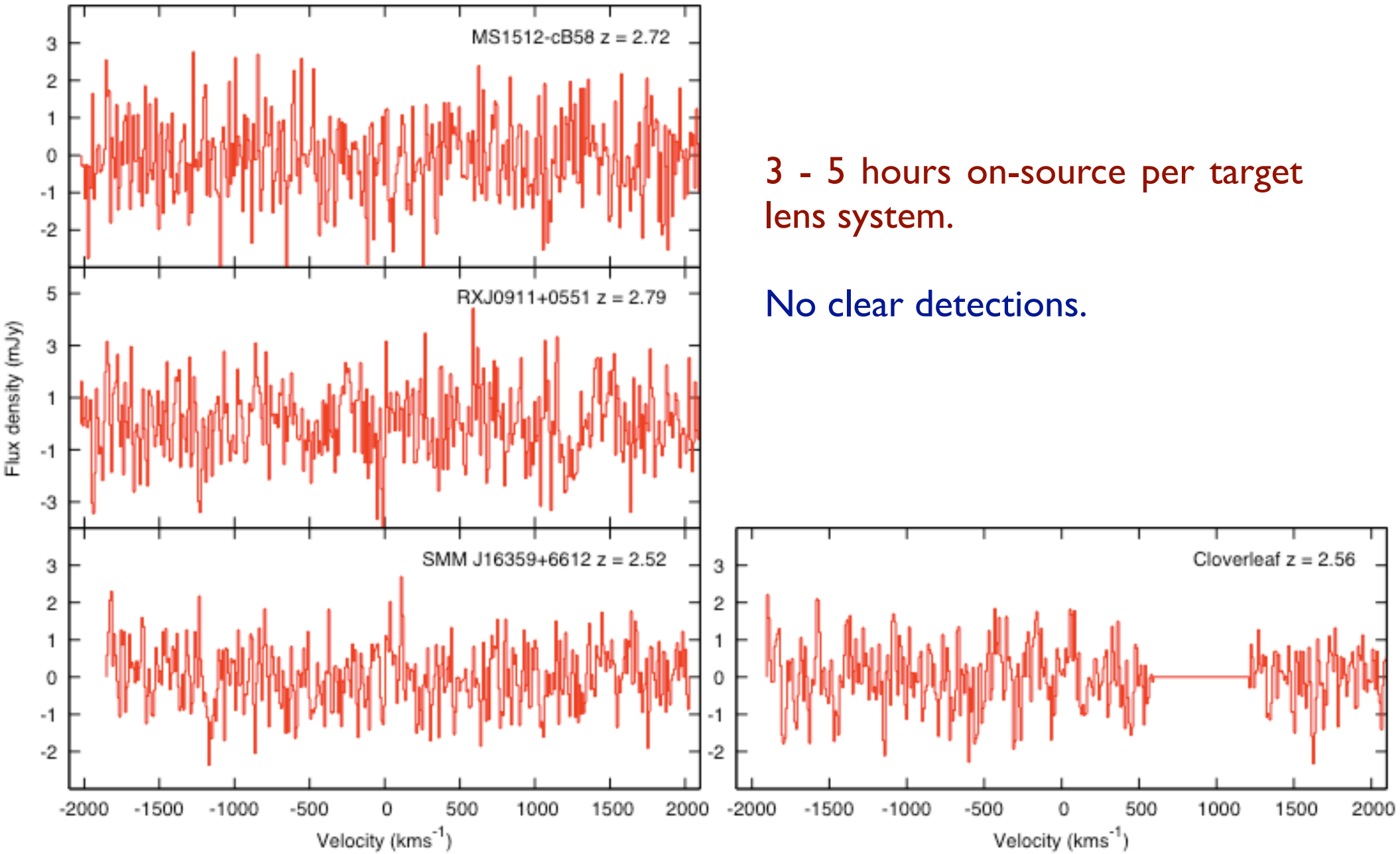
Effelsberg survey of dusty (high S_{FIR}) galaxies at redshift 2.3 to 2.8.

Tentative (unconfirmed) detection of water from luminous IR galaxy at z = 2.29.





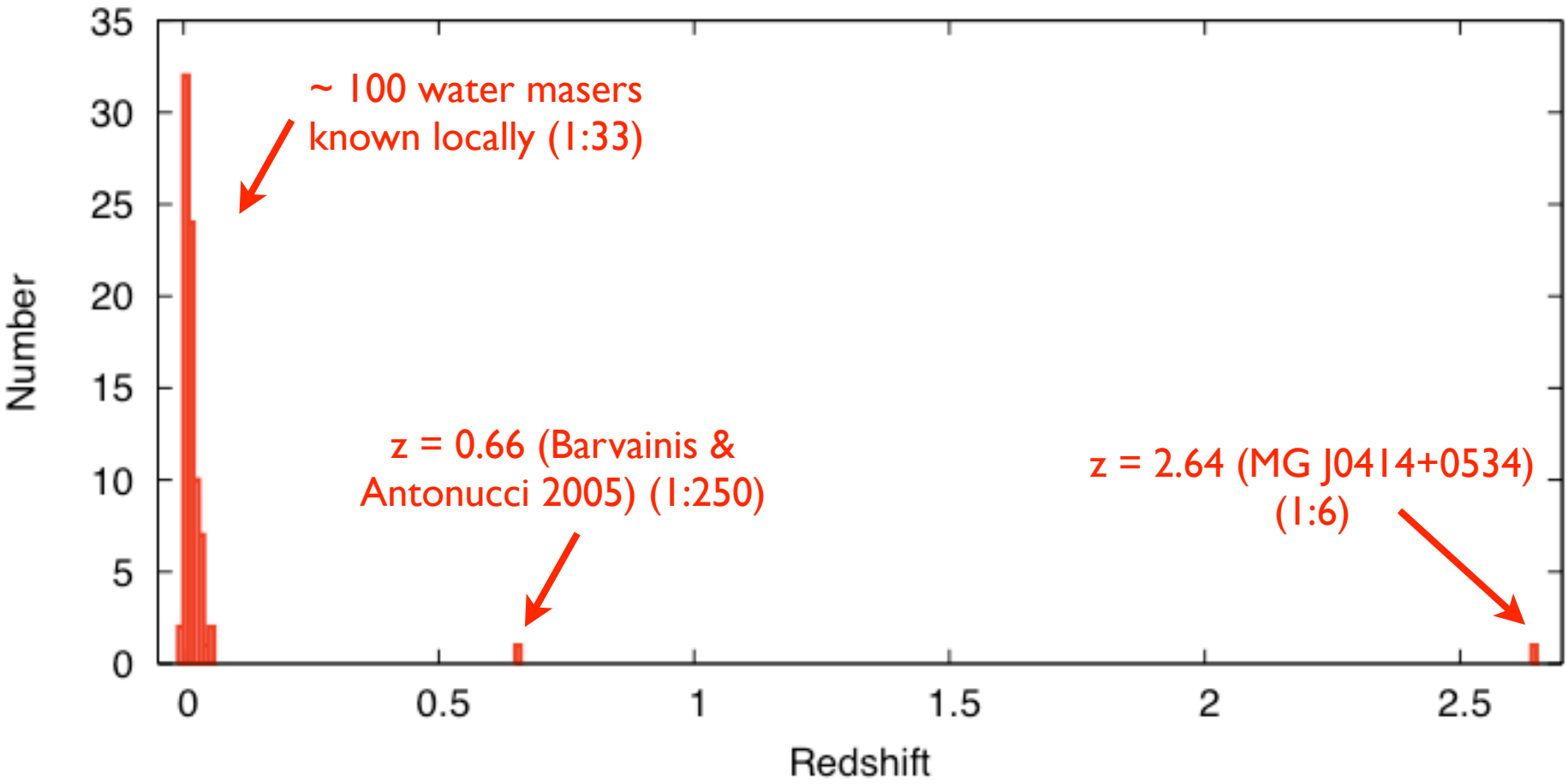
Results from Effelsberg survey



3 - 5 hours on-source per target lens system.

No clear detections.

Water in the early Universe

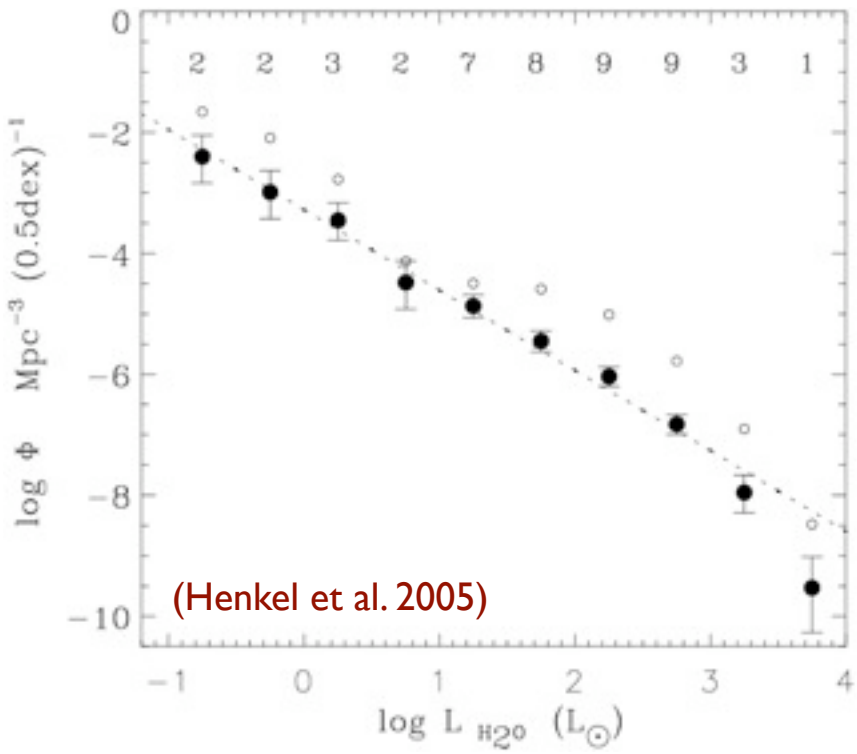


MG J0414+0534 is by far the most distant source water has been detected

(lensing decreases the integration time needed by ~1150; 1.8 years with Effelsberg).

The water maser transition requires gas temperatures > 300 K and $n(H_20) > 10^7$ cm^{-3}.

Abundance at high redshift



Detection from a single pointed observation.

→ Common occurrence.

Probability of detecting >10000 $L_\odot$ from an AGN is,

~10^{-6}

★ Evolution of the water maser luminosity function?

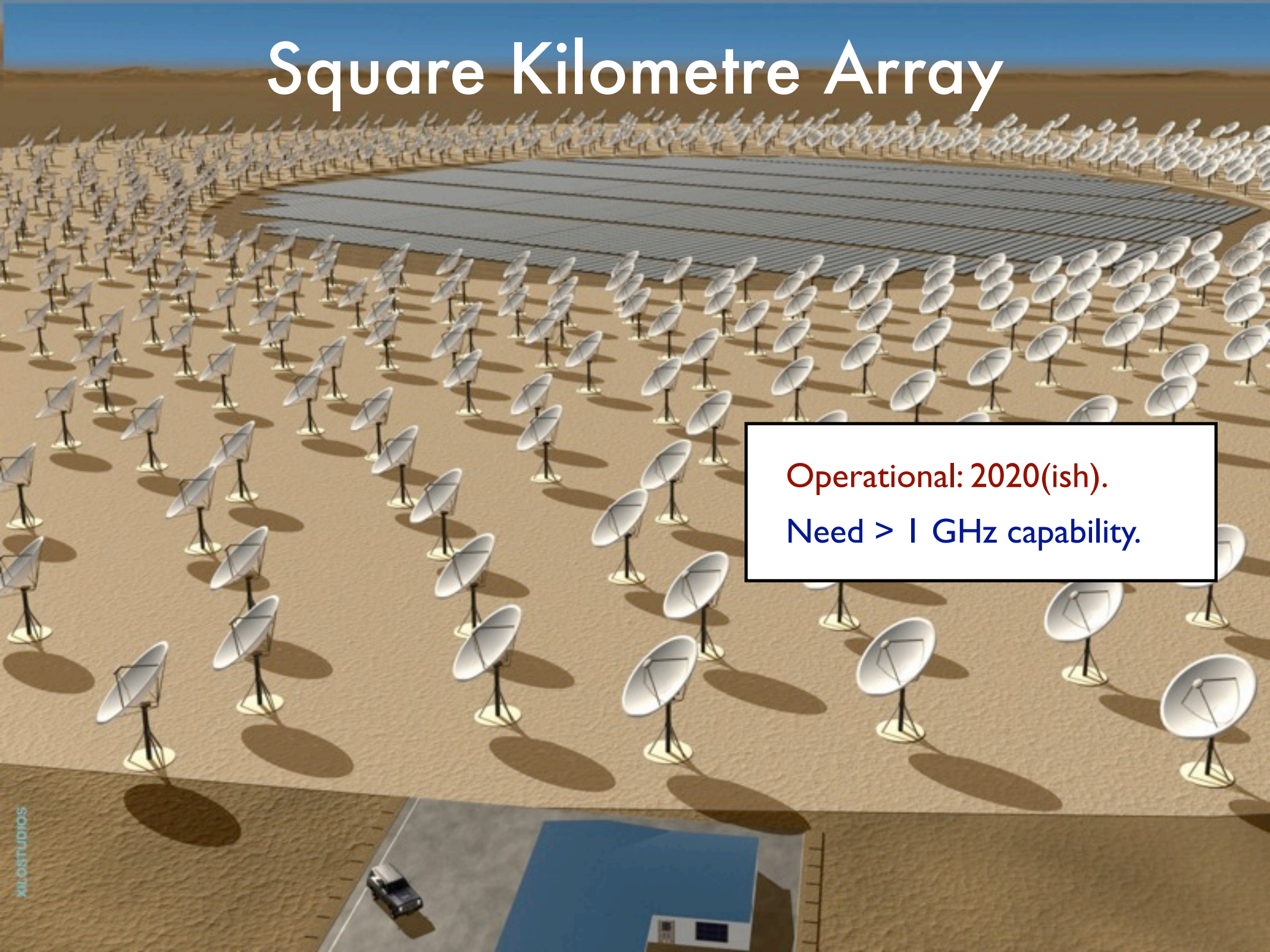
★ Slope of −0.7 and moderate evolution of $(1 + z)^4$.

★ Selection effect?

★ Radio-loud AGN with powerful jets.

★ Dust and gas rich galaxy.

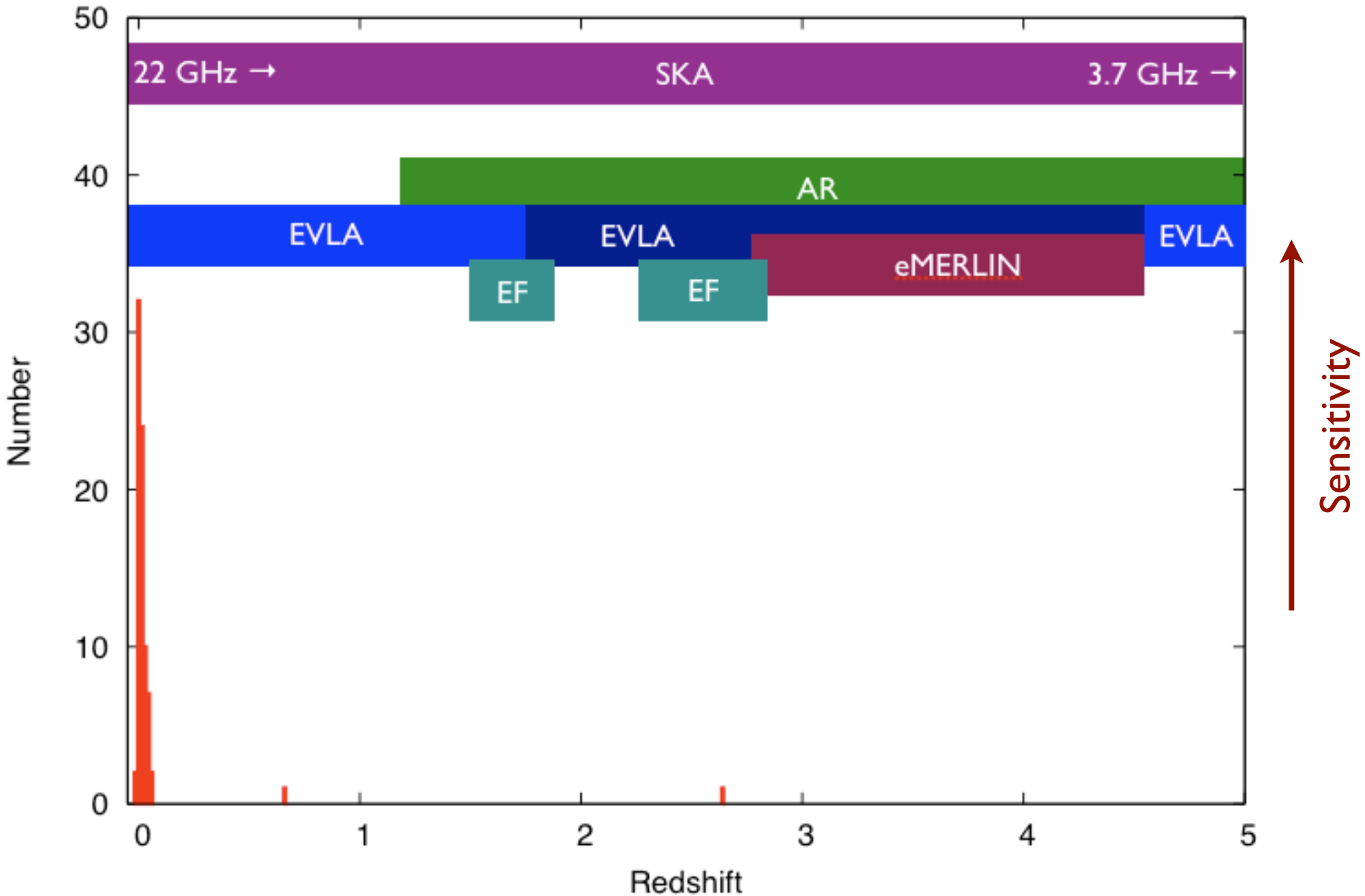
Square Kilometre Array



Operational: 2020(ish).

Need > 1 GHz capability.

Next generation of surveys



Summary

- ★ Water detected from the gravitationally lensed type 1 quasar MG 0414+0534 at z = 2.64 (look-back time 11.2 Gyr).
- ★ Its existence implies that water masers are much more abundant at high redshift than previously thought.
- ★ Arecibo survey of 25 lens systems approved (10 times deeper than with Effelsberg; 50 hrs + 50 hrs)
- ★ ...and what about other tracers i.e. OH