Kinematics of H_2O masers in high-mass star forming regions

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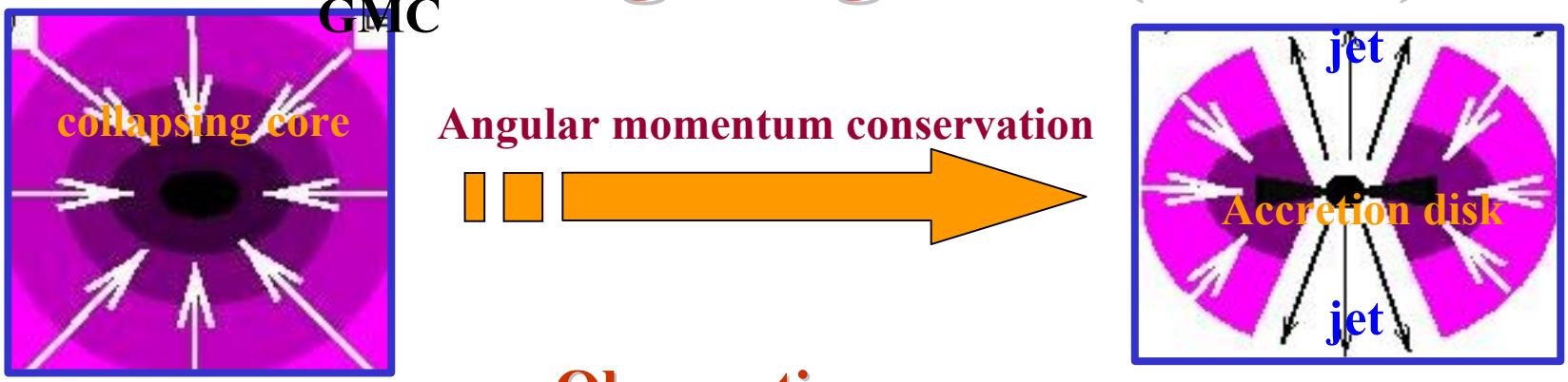
Star Forming Regions (SFRs)

Theory:



Observations

Low-mass YSOs: the existence of disk/jet systems *confirmed* by observations

High-mass YSOs:
- ✓ distant from the Sun (≥1 kpc): high-angular resolution needed!
- ✓ on the ZAMS phase enshrouded in the placental cloud

($M > 8\ M_\odot$, $L > 10^3\ L_\odot$) ➔ optical (and NIR) observations *impossible*

A powerful diagnostic tool

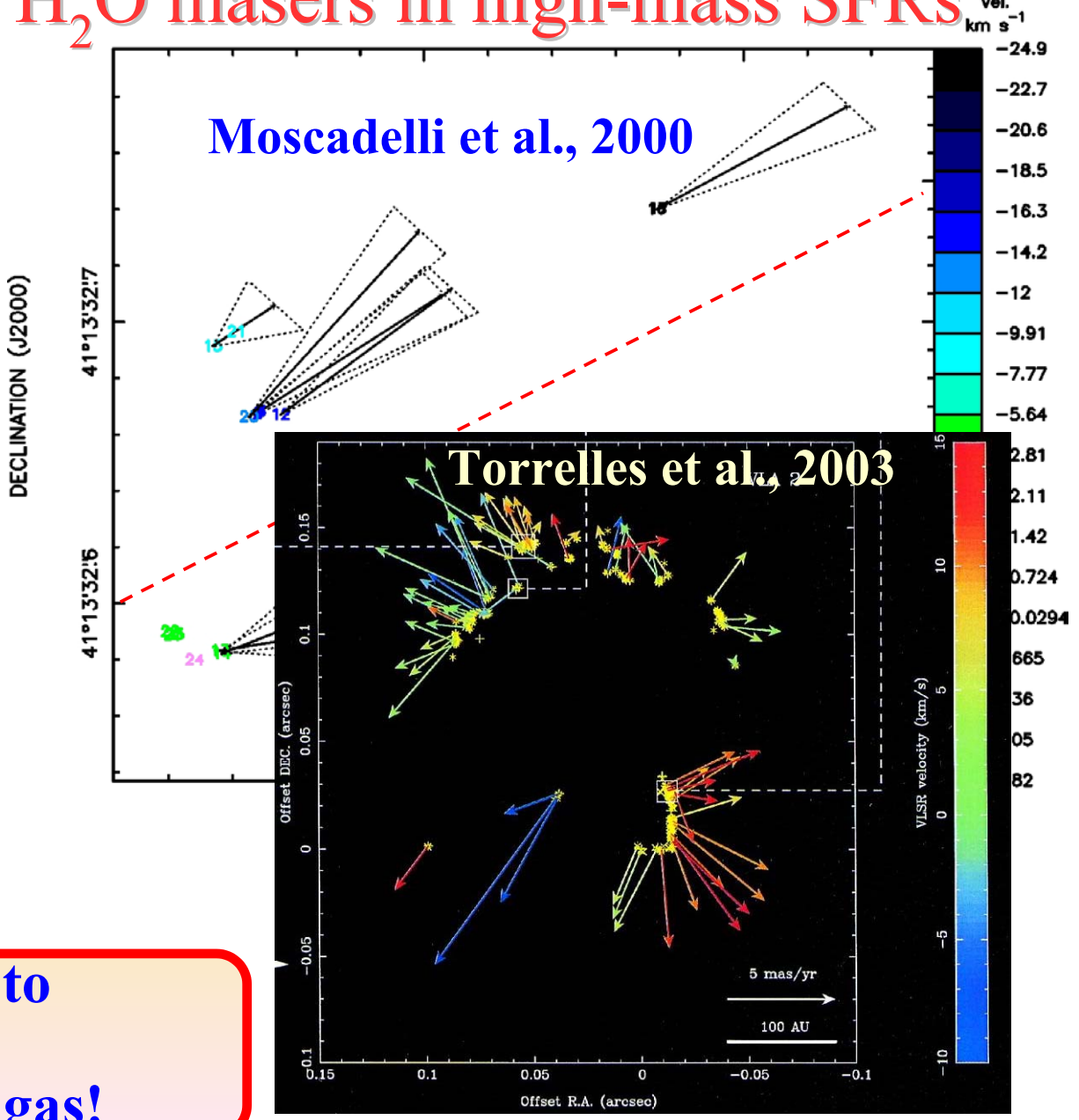
VLBI observations of maser lines (e.g., **22 GHz H_2O**; 6.7 and 12 GHz CH_3OH):

- ➢ linear resolution of few AU: disk/jet systems resolvable even at 1 kpc
- ➢ *multi*-epoch observations: 3-d velocity distribution of the masing gas

The only technique able to derive the gas kinematics nearby the YSO!

Kinematics of 22.2 GHz H_2O masers in high-mass SFRs

- ✓ **Collimated flows of gas:**
  e.g., IRAS 20126+4104
- ✓ **Accretion rotating disks:**
  AFGL 5142 (Goddi et al., 2004)
- ✓ **Expanding spherical shells**:
  e.g., W75N-VLA2



Proper motions are essential to derive the kinematics of the masing gas!

So far, only few (~10) high-mass YSOs studied with *multi-epoch VLBI* observations of water masers!

The sample

Multi-epoch **VLBI** observations of the **22 GHz H_2O masers** towards a sample of candidates as **high-mass YSOs:**

- **EVN: S255 IR**, **WB89-234**, **AFGL 5142**
- **VLBA: AFGL 5142**

Observational parameters

EVN

Antennas: Medicina, Cambridge, Onsala, Noto, Effelsberg, Metsahovi, Jodrell and Shanghai

Observational epochs: **Oct 1996, and Jun, Sep, Nov 97**

Bandwidth = 1-2 MHz

Spectral channels = 112

Velocity resolution = 0.12 km s^{-1}

Correlator = MKIII (Bonn, Germany)

VLBA

Antennas: full array (10)

Observational epochs: **Oct and Nov 2003, Jan and Feb 2004** (separat ~1 month)

Bandwidth = 16 MHz

Spectral channels = 1024

Velocity resolution = 0.21 km s^{-1}

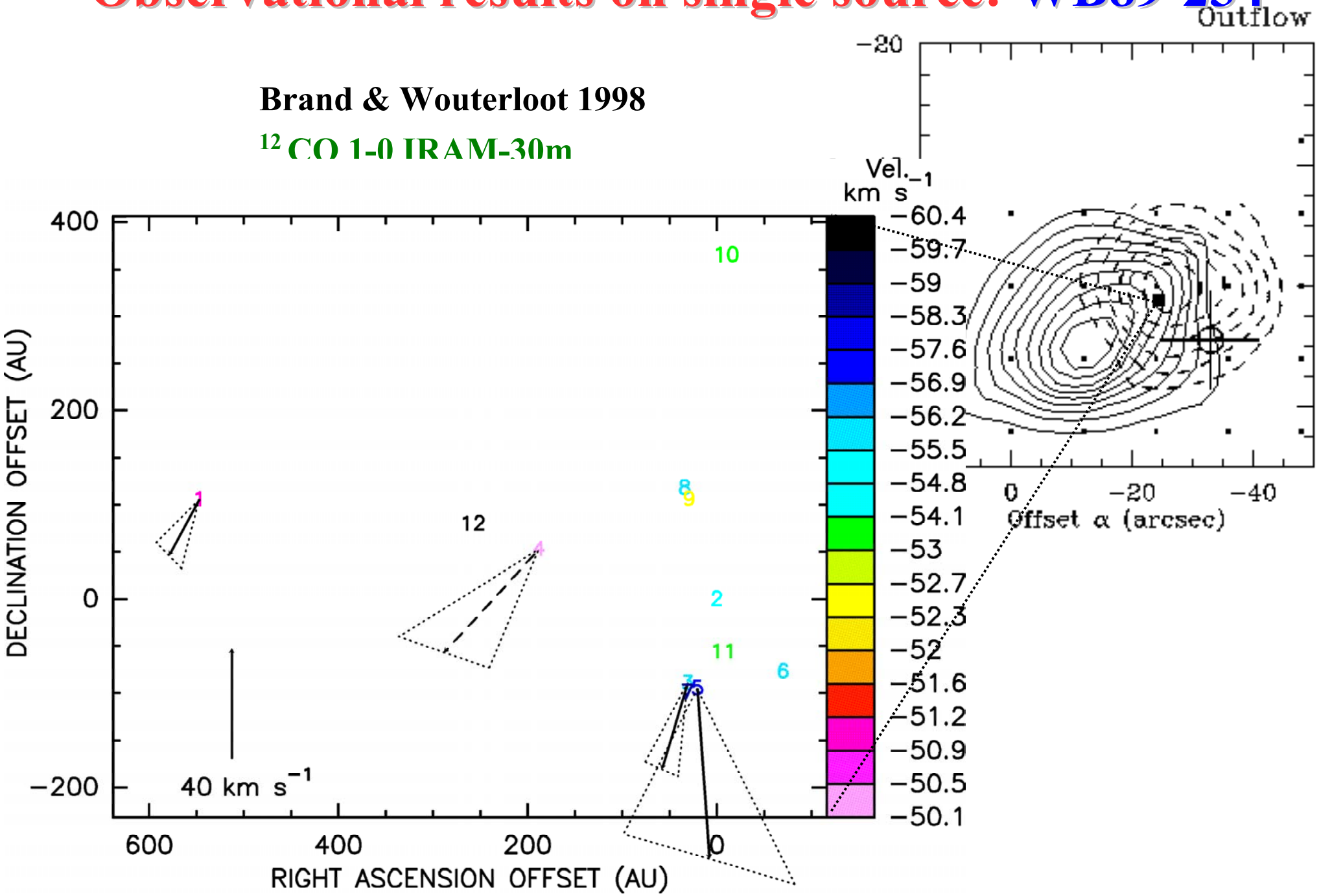
Correlator =VLBA (Socorro,NewMexico)

Phase-reference = **ABSOLUTE position**

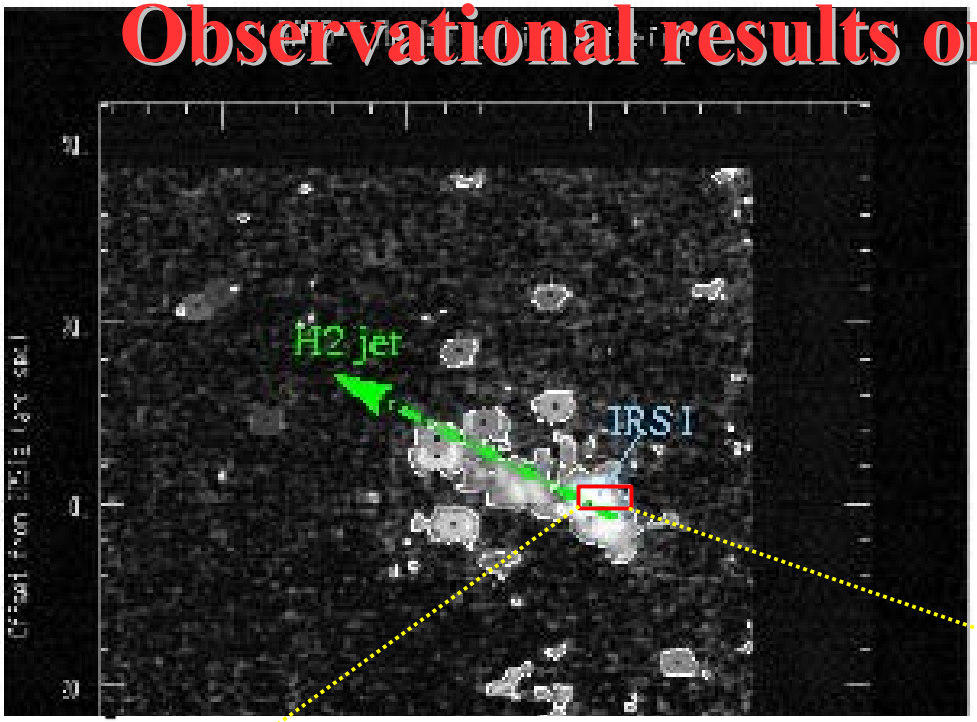
Observational results on single source: WB89-234

Brand & Wouterloot 1998

^{12}CO 1-0 IRAM-30m



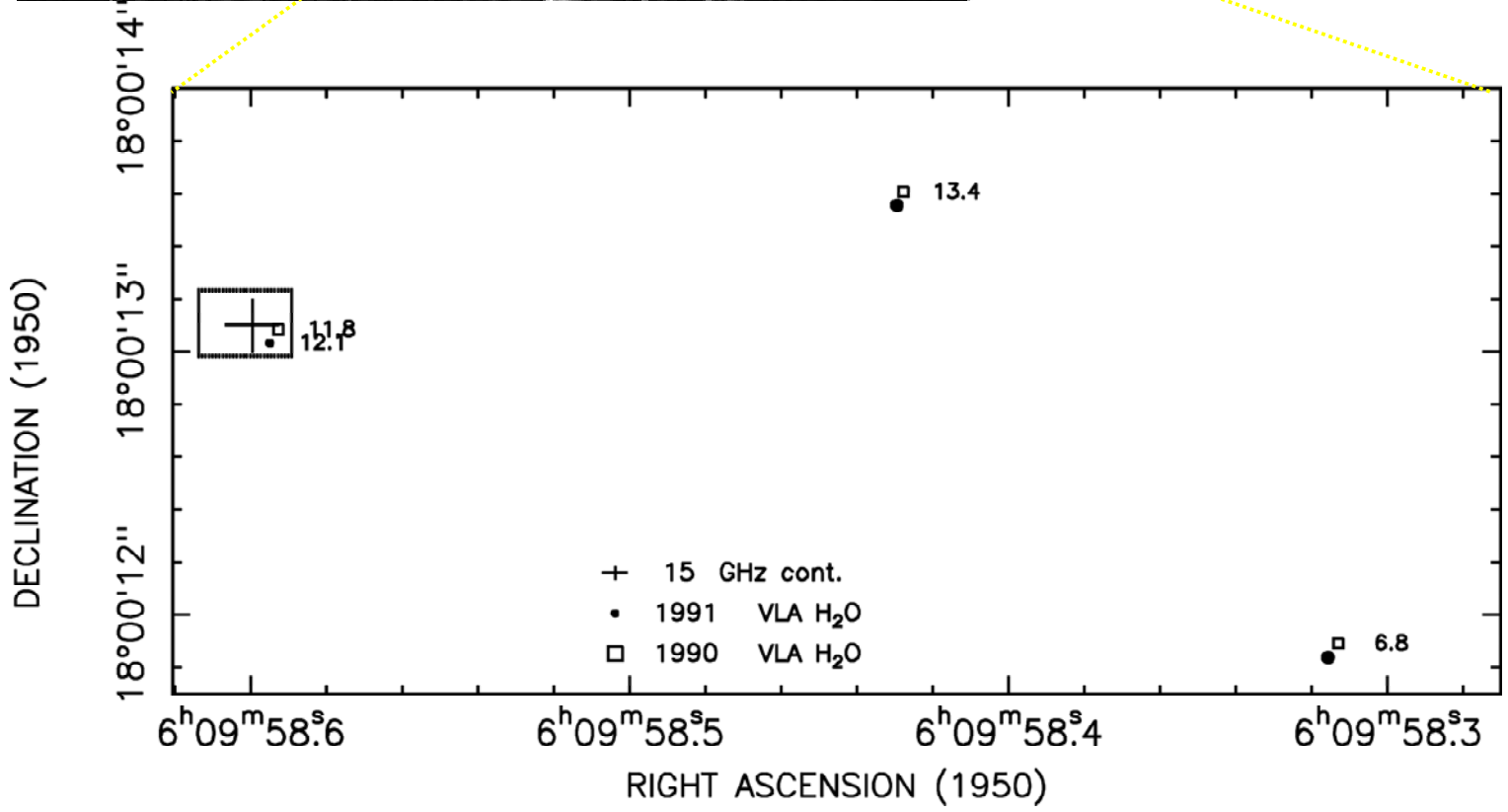
Observational results on single source: S255 IRS1



Howard et al. 1997

Brγ (2.17 μm) – continuum

H_2 $\nu = 1\text{-}0$ (2.12 μm) jet



Cesaroni (unpubl.)

VLA 22 GHz maser

Rengarajan (1996)

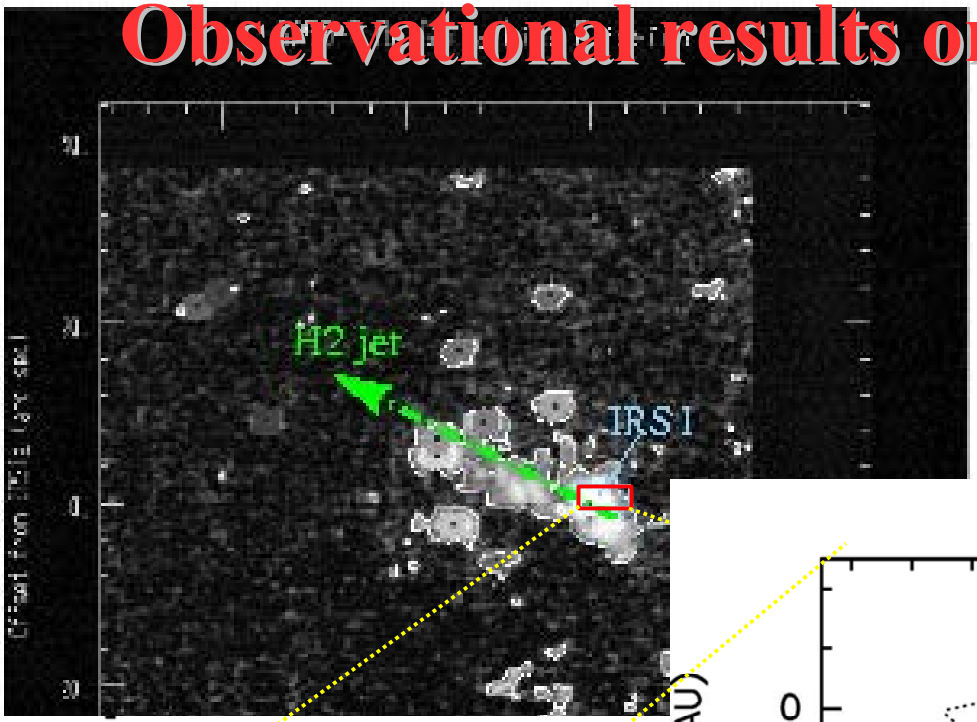
+ VLA 15 GHz cont.

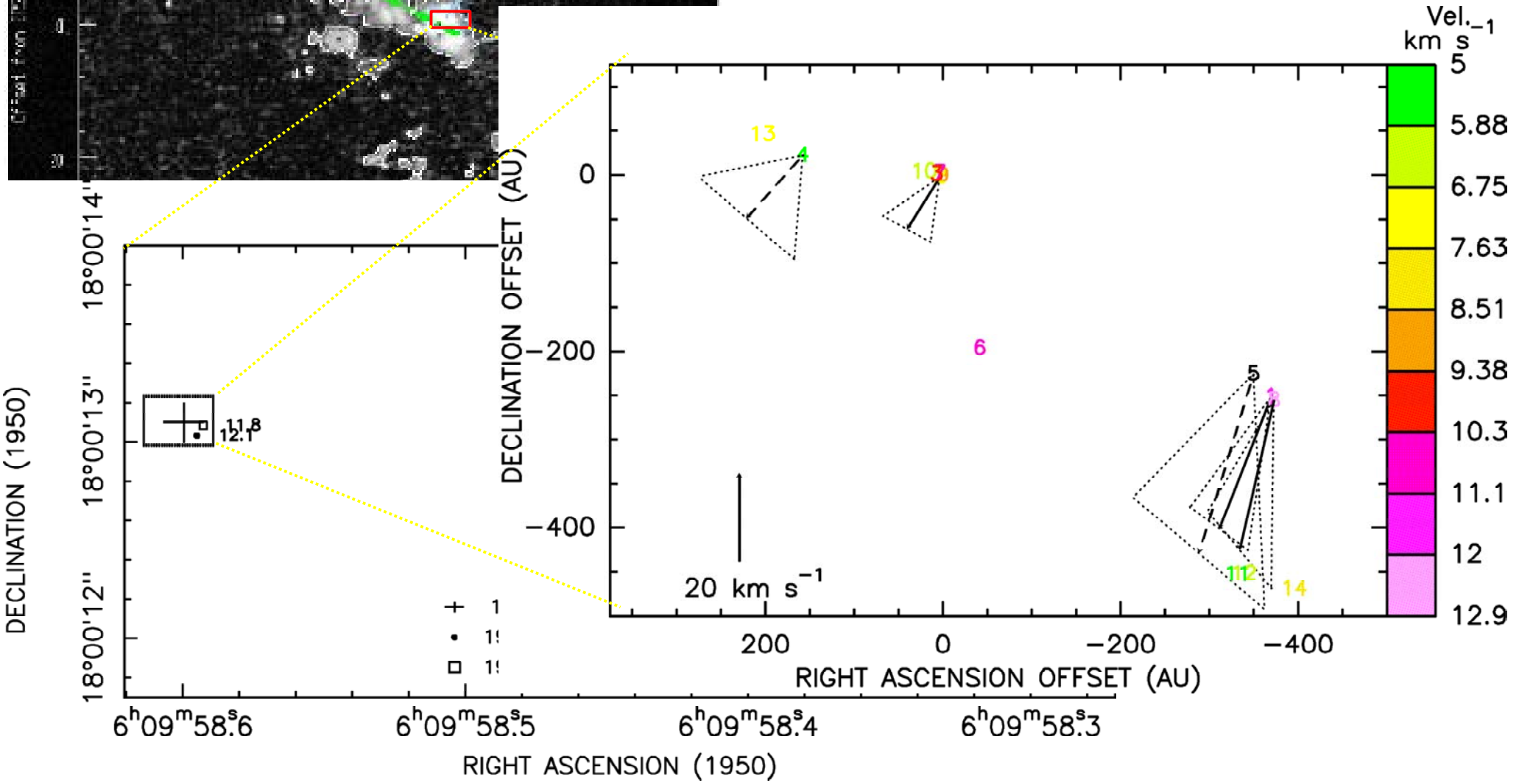
Observational results on single source: S255 IRS1

Howard et al. 1997

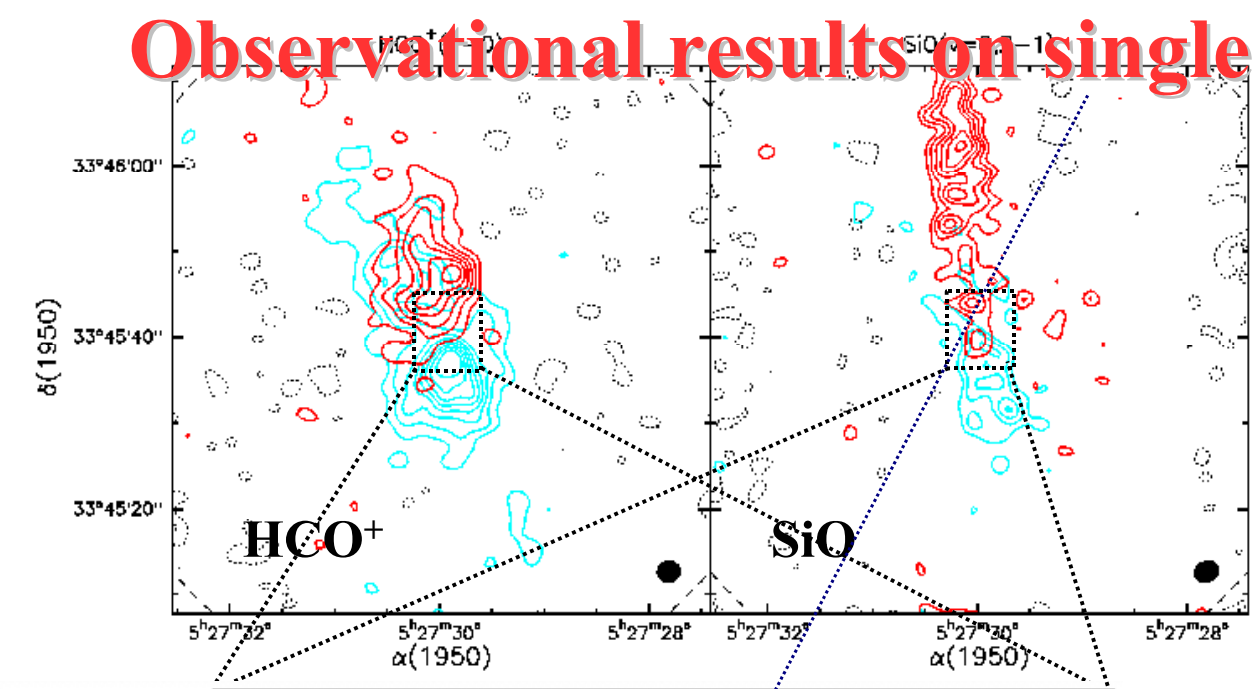
Brγ (2.17 μm) – continuum

H_2 ν = 1-0 (2.12 μm) jet





Observational results on single source: AFGL 5142



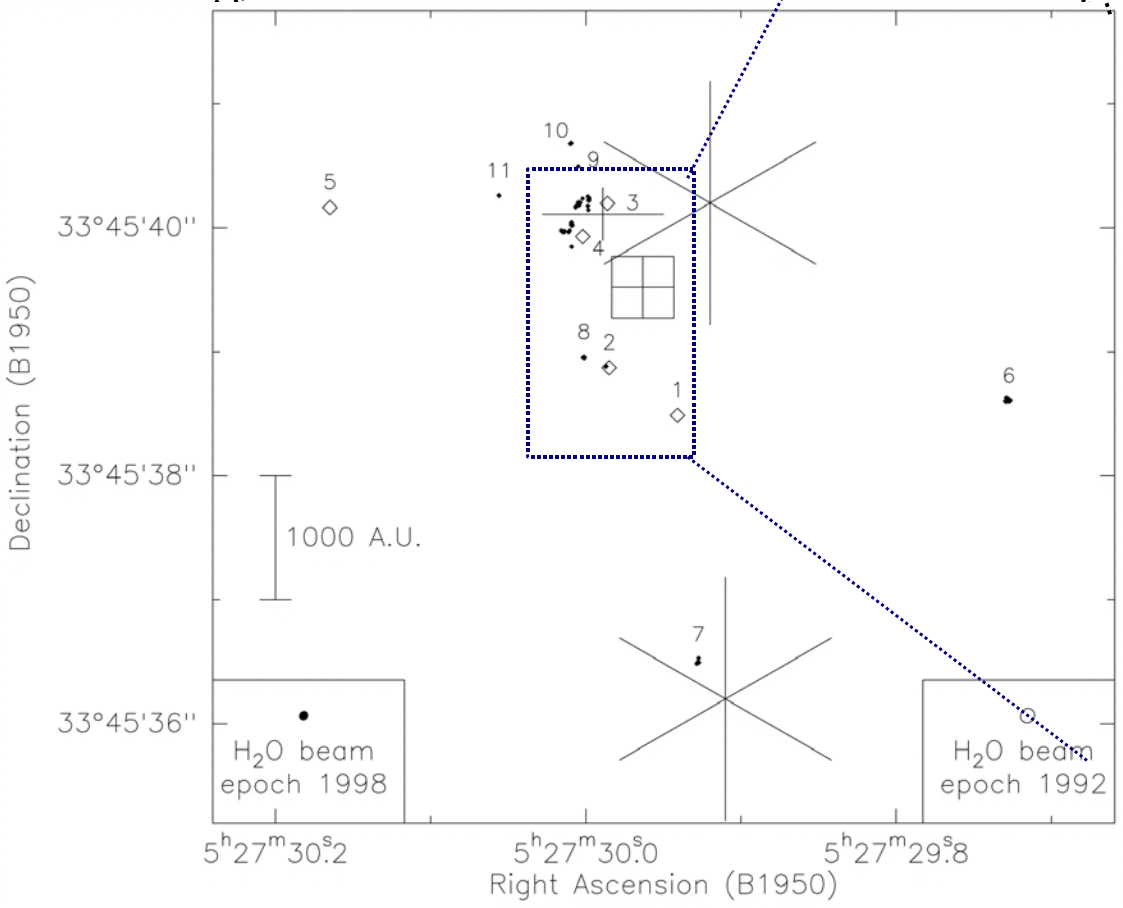
Hunter et al. 1999

OVRO HCO^+ (1→0) outflow

OVRO SiO (ν=0, 2→1) jet

OVRO 88 GHz cont.

VLA 22 GHz water

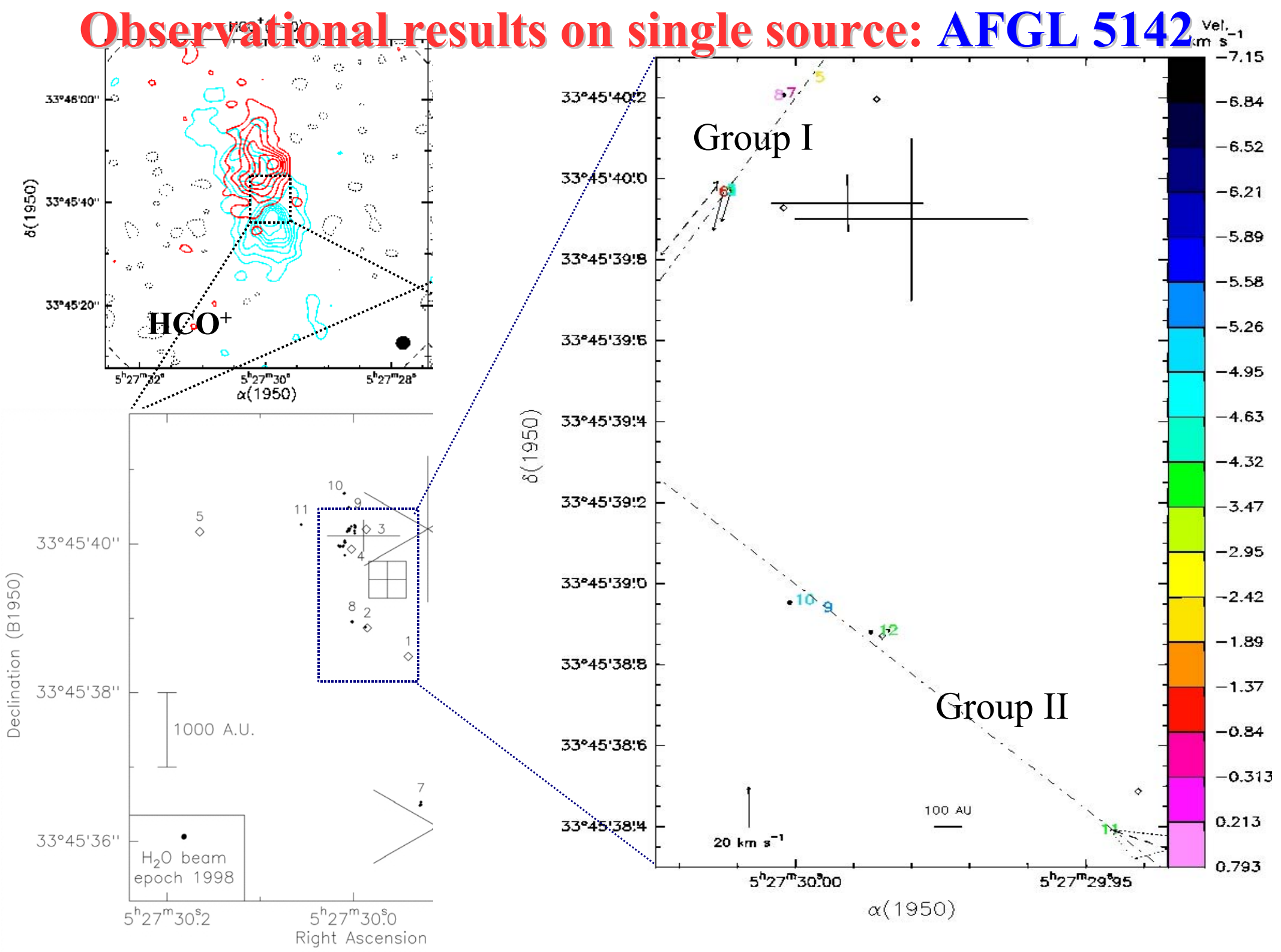


Hunter et al. 1995

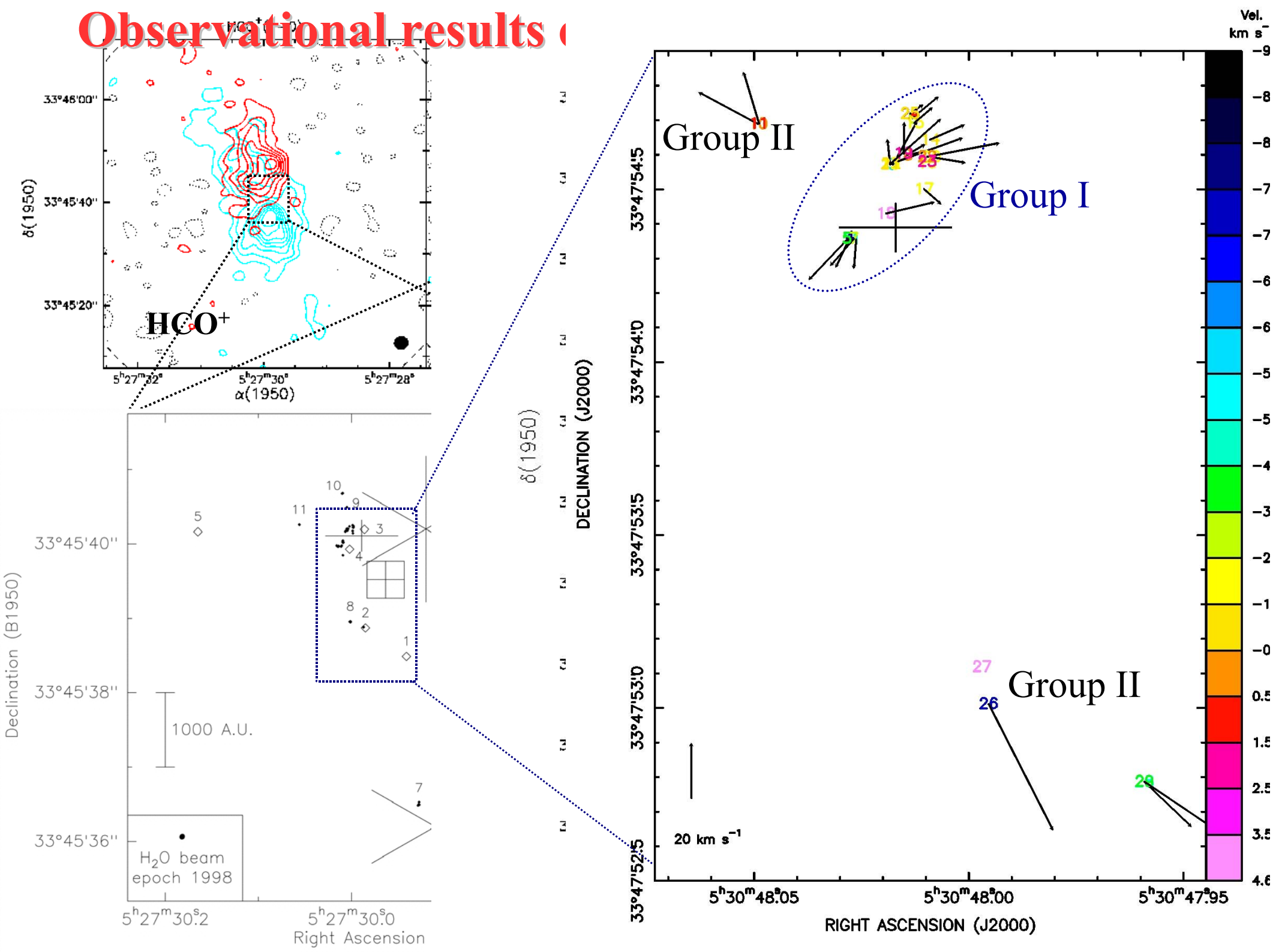
VLA 8.4 GHz cont.

VLA 22 GHz water

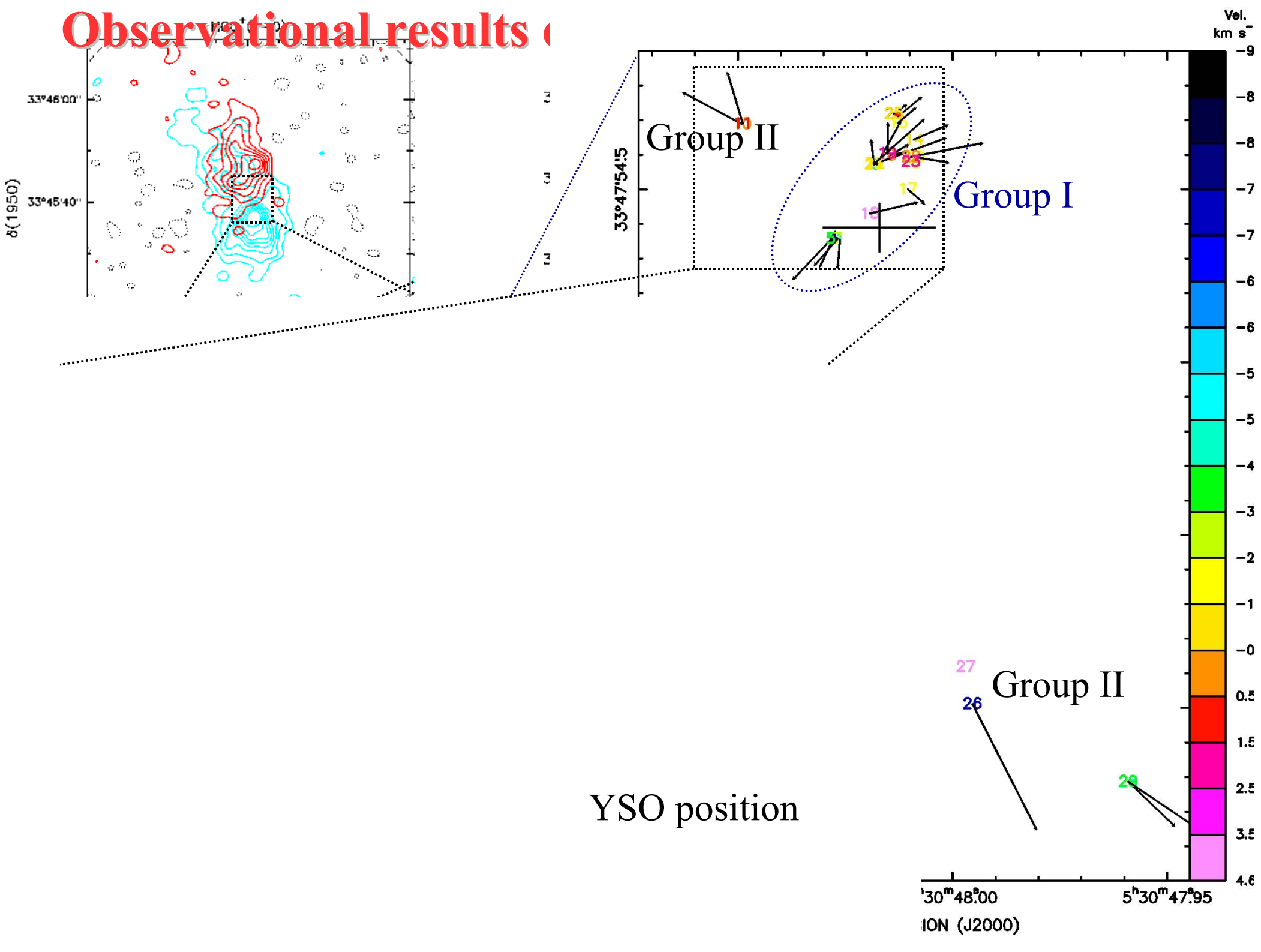
Observational results on single source: AFGL 5142



Observational results



Observational results



Kinematics of the masing gas

Common features between the studied YSOs:

- ✓ A large-scale molecular outflow detected towards each of the studied SFRs
- ✓ Good agreement of LOF velocities between outflows and H_2O masers
- ✓ Measured proper motions consistent with a general expansion.

Simple interpretation:

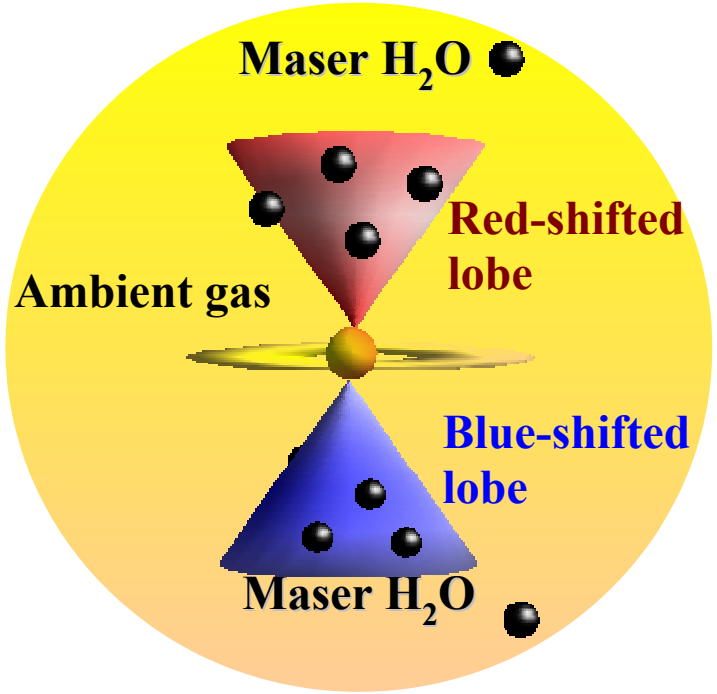
The detected masers are tracing the innermost portion of the molecular outflow

BUT:

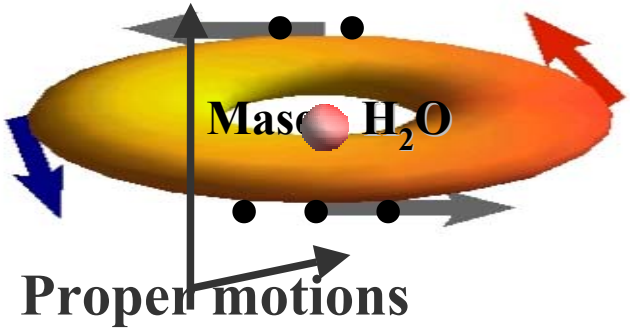
The overall ***spatial*** and ***velocity*** distribution of the H_2O masers ***seems*** not in agreement with a model of ***collimated*** flow

Kinematical Models

Conical outflow



Keplerian disk



Hubble motion: $v = a \cdot r$

Keplerian Motion: $V = (GM/R^2)^{1/2}$

Results:

- ✓ **Conical outflow: a solution for S255 and WB89-234**
- ✓ **Keplerian disk: a solution for AFGL 5142**

S255 IRS1 and WB89-234

Best fit solutions of conical model

- Estimated parameters in agreement with large-scale outflows
- Modeled conical jets with large opening angles
  - **wide-angle winds**

AFGL 5142

Two distributions of masers nearly perpendicular to each other:

- **Multiple outflows**
  - supported by the measured proper motions
  - evidence in other massive (proto)stars (eg, Beuther2003)
    - → binary/multiple star system
  - higher sensitivity and resolution observations (from radio to NIR frequencies) needed to confirm

- **Disk/jet system**

Group I fitted with the ***keplerian disk*** model:

- Disk **edge-on** and parallel with the maser elongation axis
- Disk radius: **≥ 800 AU**
- **M_{YSO}= 14 $M_{\odot}$**: in agreement with L_{bol} (4×10^3 $L_{\odot}$)

Group II proper motion orientation:

- close to the HCO^+ outflow axis
- indicating outflow motion from the YSO

Conclusions

- **S255 IRS1 and WB89-234**
  - **Masers trace preferably outflow rather than rotation**
  - **Jets driven possibly by wide-angle winds**

- **AFGL 5142**
  - **massive YSO associated with a disk/ jet system**
    ➔Star formation process is similar for low and high-mass stars?
  - **Multiple star system associated with distinct outflows**

Follow-up observations

✓ Multi-frequency radio continuum with the **VLA** for **AFGL 5142**

✓ 22 GHz water masers with the **VLBA** for **WB89-234** and **S255**