VLBA+Y27 Images of the Formaldehyde Masers in NGC 7538 and G29.96-0.02

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Future Directions in High Resolution Astronomy:
A Celebration of the 10th Anniversary of the VLBA
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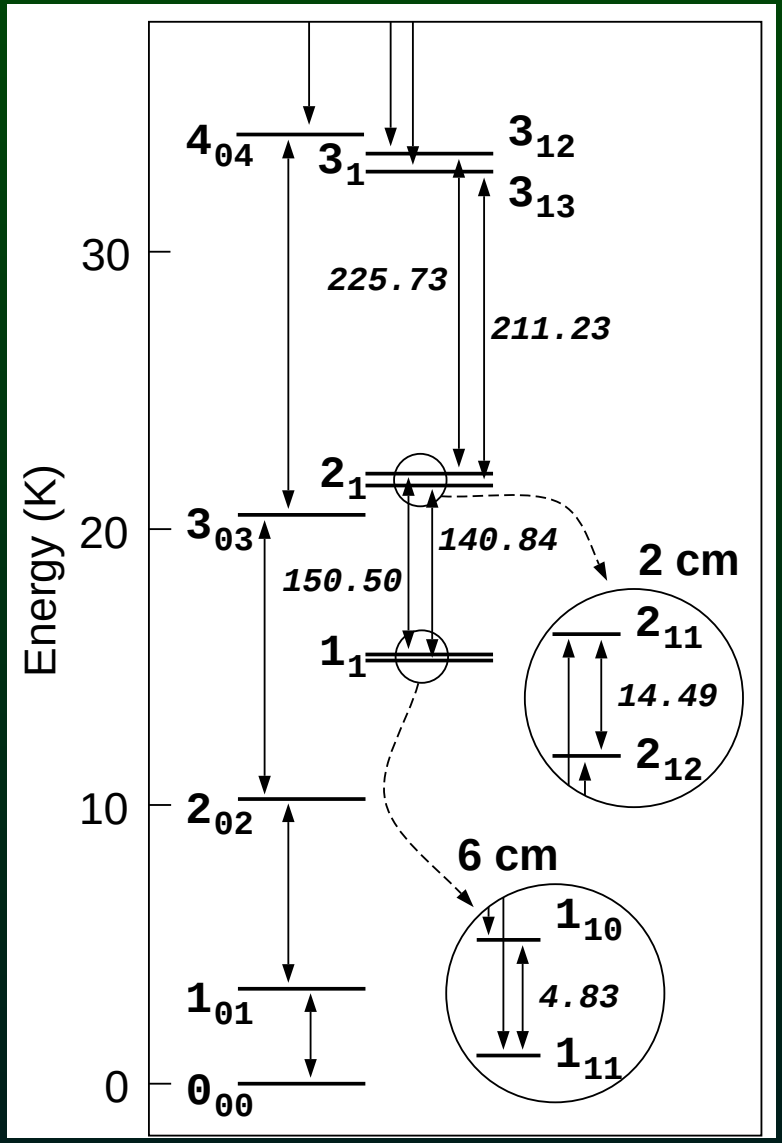
H_2CO Maser Observational History

- only *four* Galactic sources known
  - NGC 7538 (1974)
  - Sgr B2 (1985)
  - G29.96-0.02 (1994)
  - IRAS 18556+0408 (2003)
- emission noted in NGC 7538 by Downes & Wilson (1974)
- maser nature shown by Forster et al. (1980), Rots et al. (1981)
- masers found angularly unresolved and spectrally blended

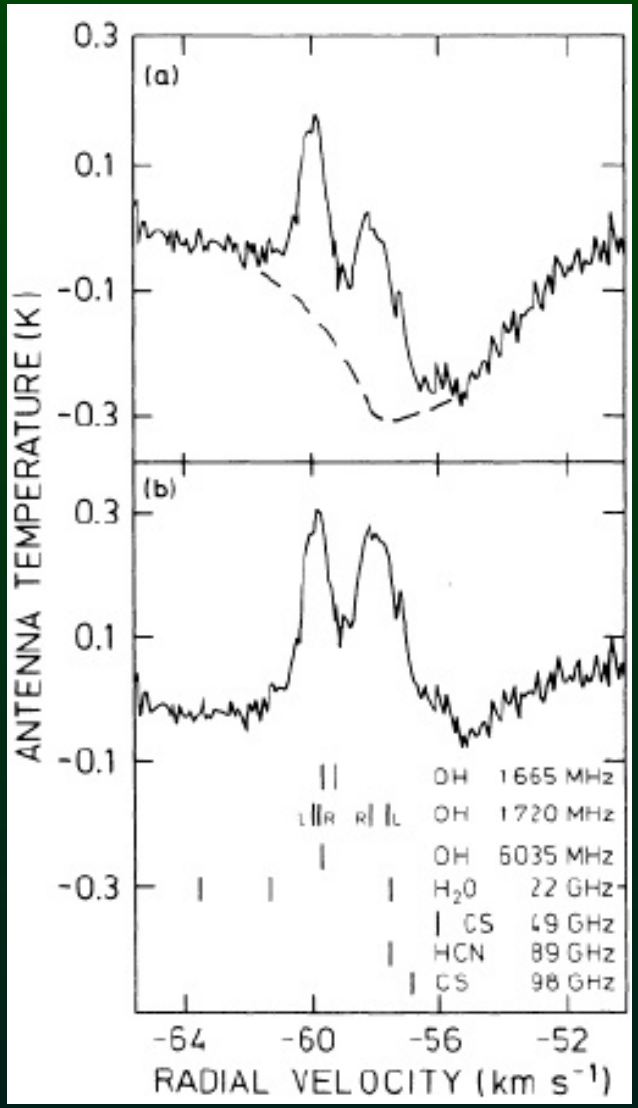
H_2CO Maser Theoretical History

- only one pump model
- Boland & de Jong (1981)
  - radiative pump
    cm turnover
  - HII continuum radiation
    $EM \simeq 10^{8-10}\,\mathrm{cm}^{-6}\,\mathrm{pc}$
  - close proximity
    $<$ 2000 AU
  - physical conditions
    $n < 10^5\,\mathrm{cm}^{-3}$
    $T \approx 20$ K
  - predicts $T_B \approx 2 \times 10^4$ K
  - predicts 2 cm maser
- *relatively ubiquitous conditions*
  survey!



H_2CO Maser Survey History

- single dish H_2CO absorption field
  - presumably insensitive
  - *e.g.* Sgr B2
- interferometric surveys
  - $>$ 40 HII regions searched
  - many other observations sensitive
  - 4 masers found
  - $<$ 5% of HII regions
- *rare and mysterious!!*

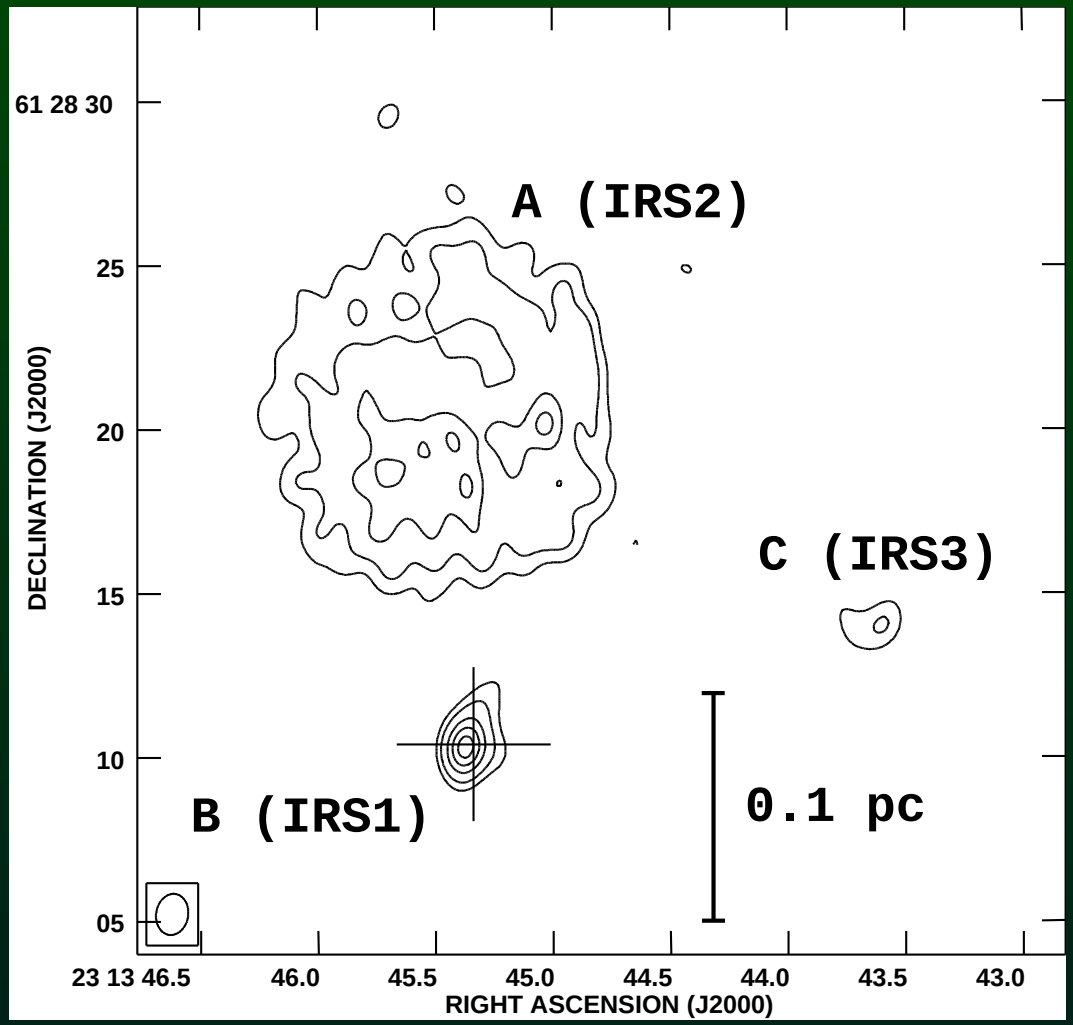


Formaldehyde Questions

- empirical questions
  - **+** what is the [transverse] size of the masers?
  - **+** what is the brightness temperature (*i.e*. gain)?
  - **+** what is the true velocity structure?
  - **-** are there 2 cm masers?
  - **+** where are the masers located relative to other HII region masers?
- theoretical questions
  - **+** does the current pump model work?
  - **+** how are H_2CO masers related to other, more common masers?
  - **?** why are H_2CO masers so rare?!

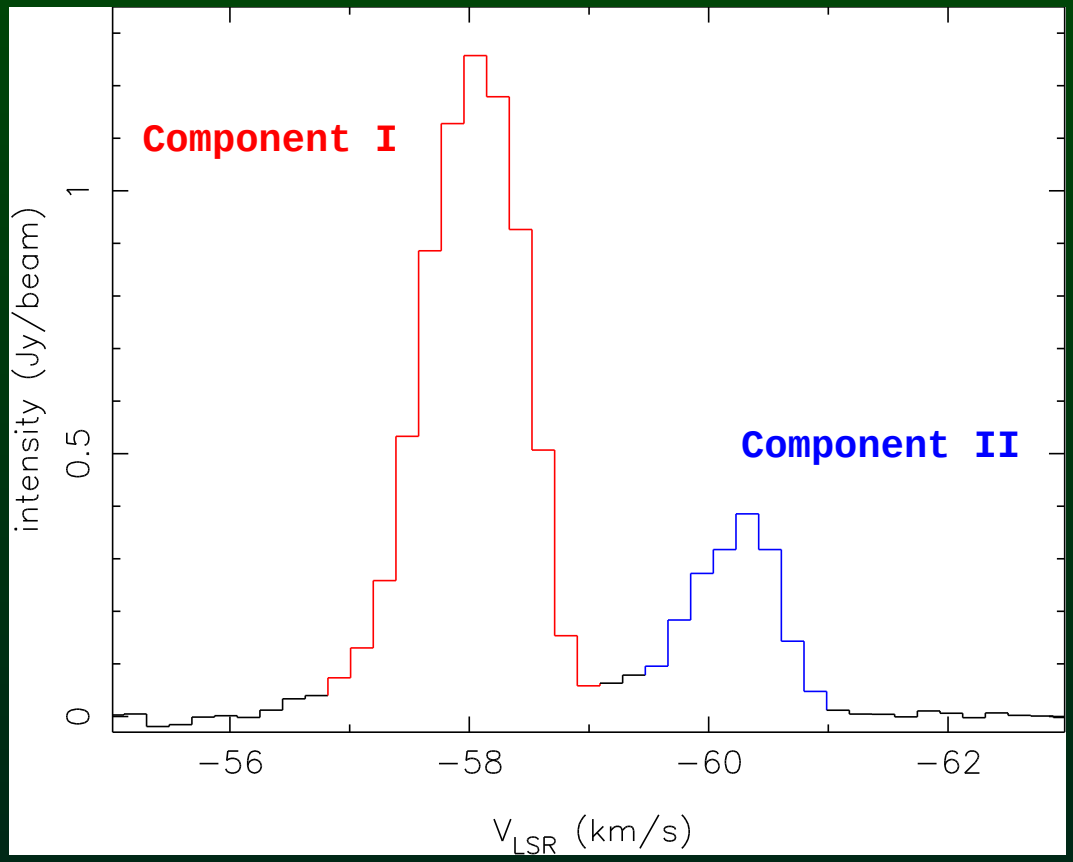
NGC 7538 VLA ‘B’

- 6 cm continuum
- complex region
- well-studied
- $d \approx 3$ kpc



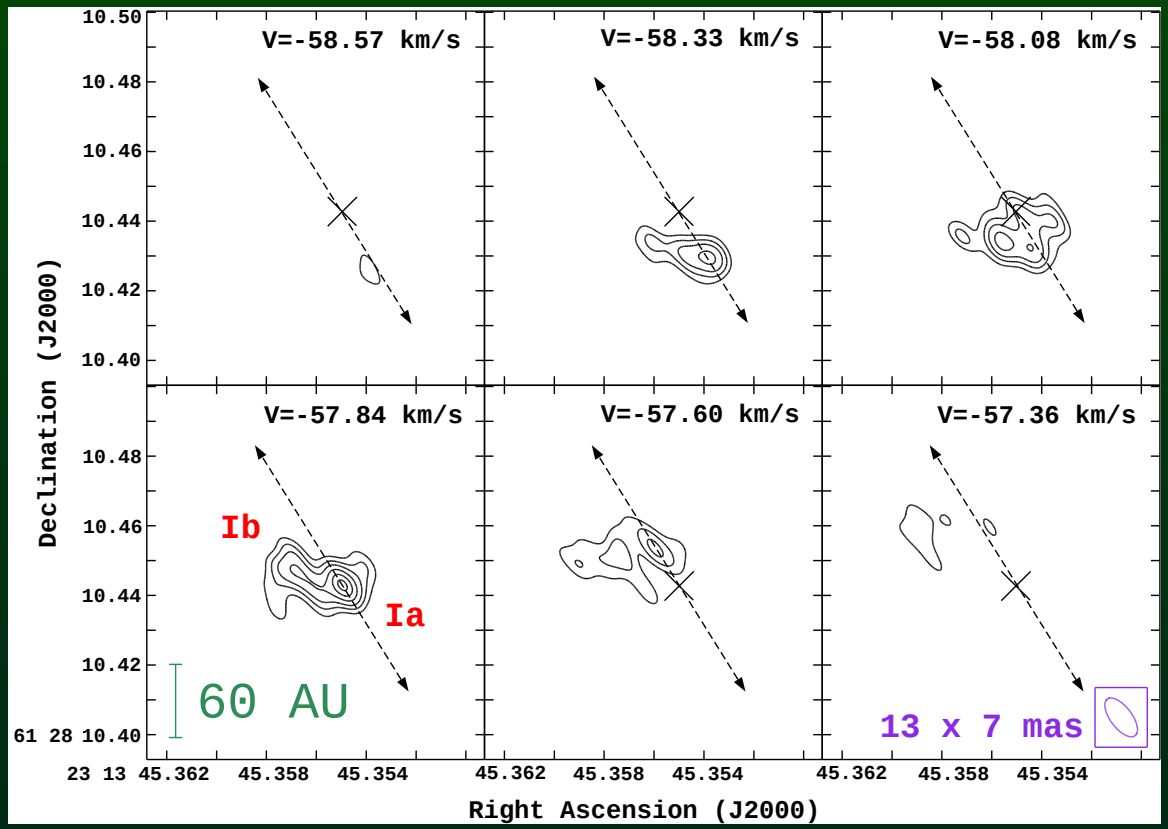
NGC 7538 VLA ‘B’

- two components
- both variable
- spectrally blended
- displaced 80 mas



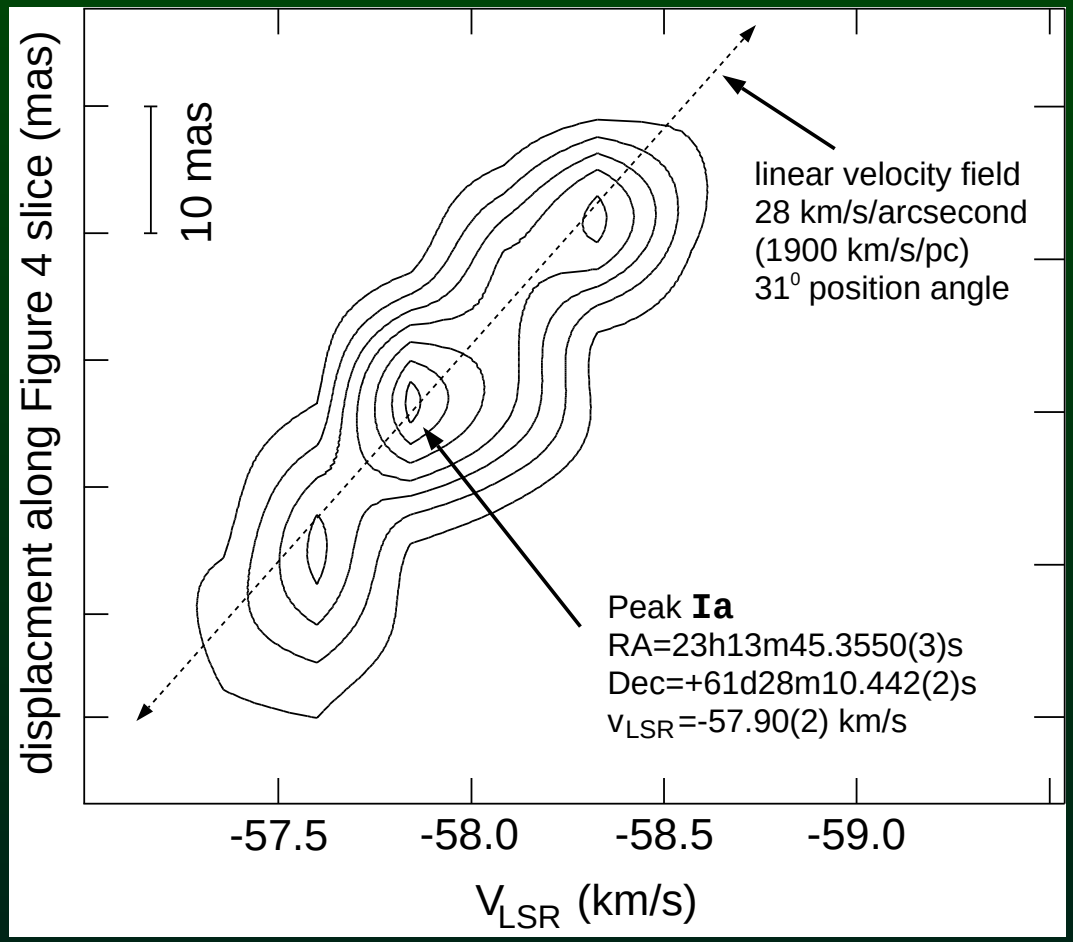
NGC 7538 VLBA+Y27

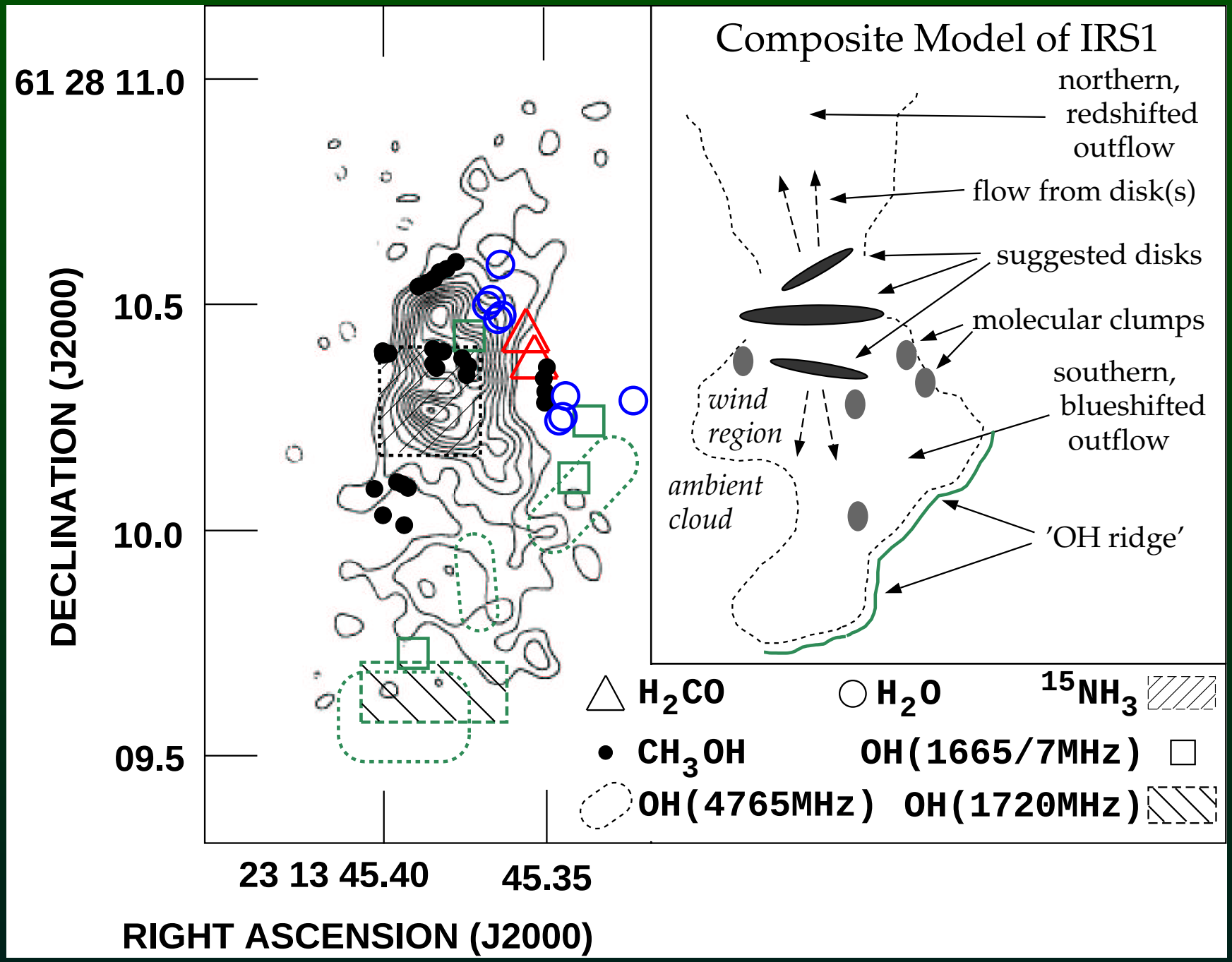
- channel images
- velocity gradient
- no comp. II



NGC 7538 VLBA+Y27

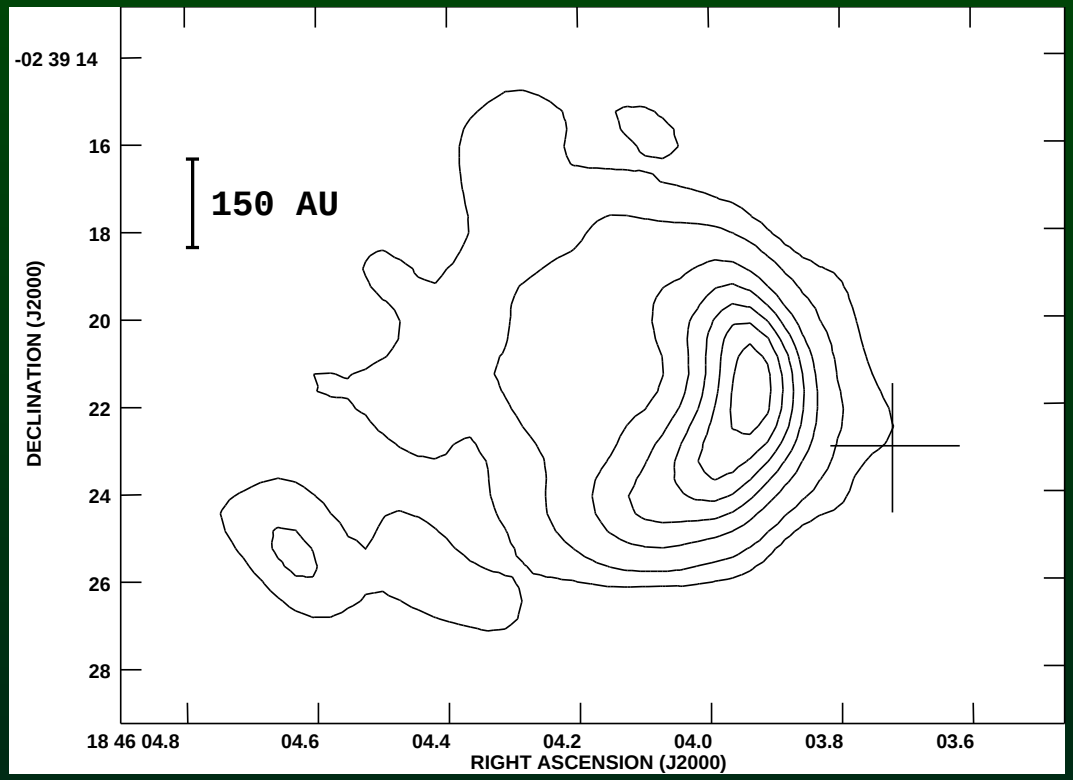
- linear gradient
- velocity structure




61 28 11.0
10.5
10.0
09.5
DECLINATION (J2000)
23 13 45.40
45.35
RIGHT ASCENSION (J2000)
Composite Model of IRS1
northern, redshifted outflow
flow from disk(s)
suggested disks
molecular clumps
southern, blueshifted outflow
wind region
ambient cloud
'OH ridge'
H2CO
H2O
15NH3
CH3OH
OH(1665/7MHz)
OH(4765MHz)
OH(1720MHz)

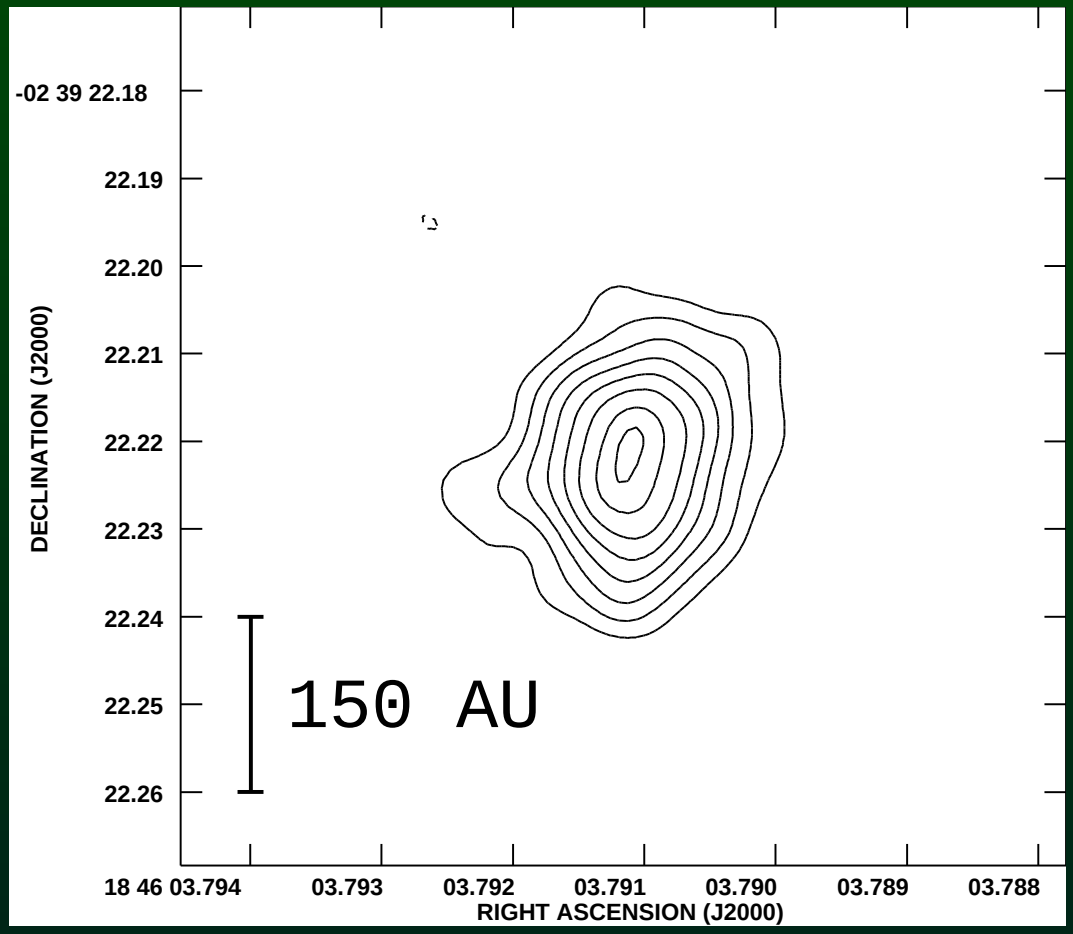
G29.96-0.02 VLA ‘C’

- 2 cm continuum
- cometary
- masers in ‘hot core’
- $d \approx 7$ kpc



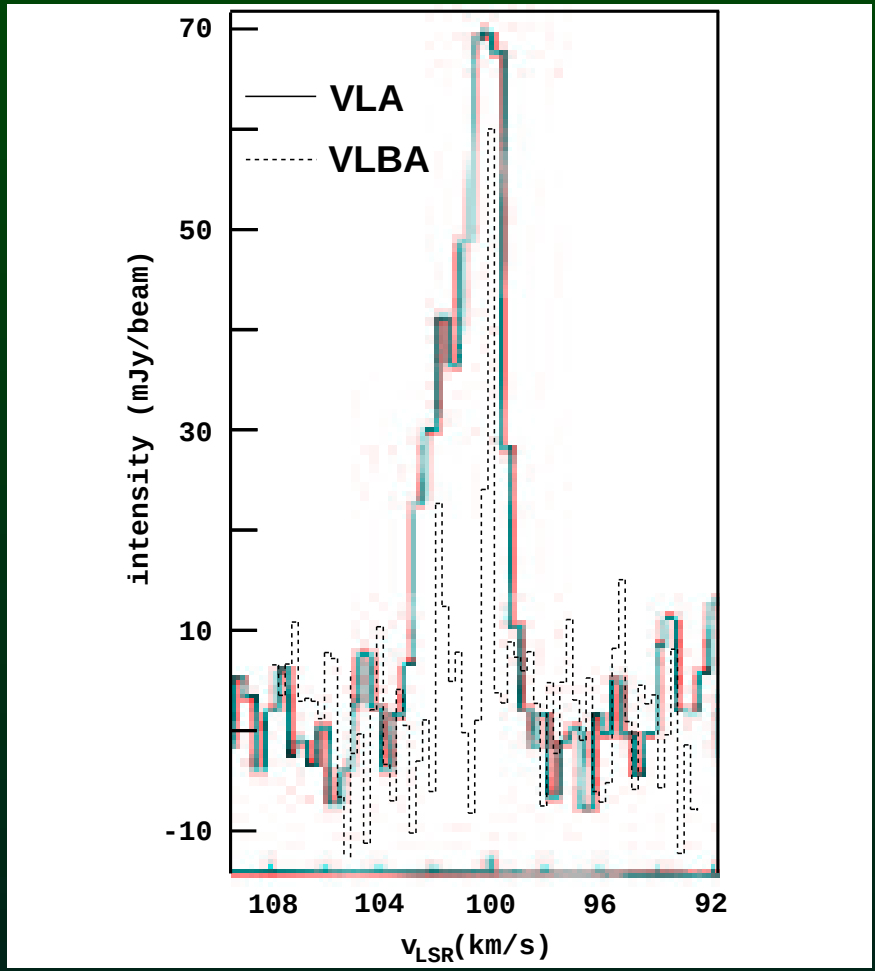
G29.96-0.02 VLBA+Y27

- 15 mas
- 100 AU



G29.96-0.02 VLA ‘A’ v. VLBA

- two components
- no observed variability
- coincident on sky
- atypical angular distribution
- weakest Galactic VLBI maser image

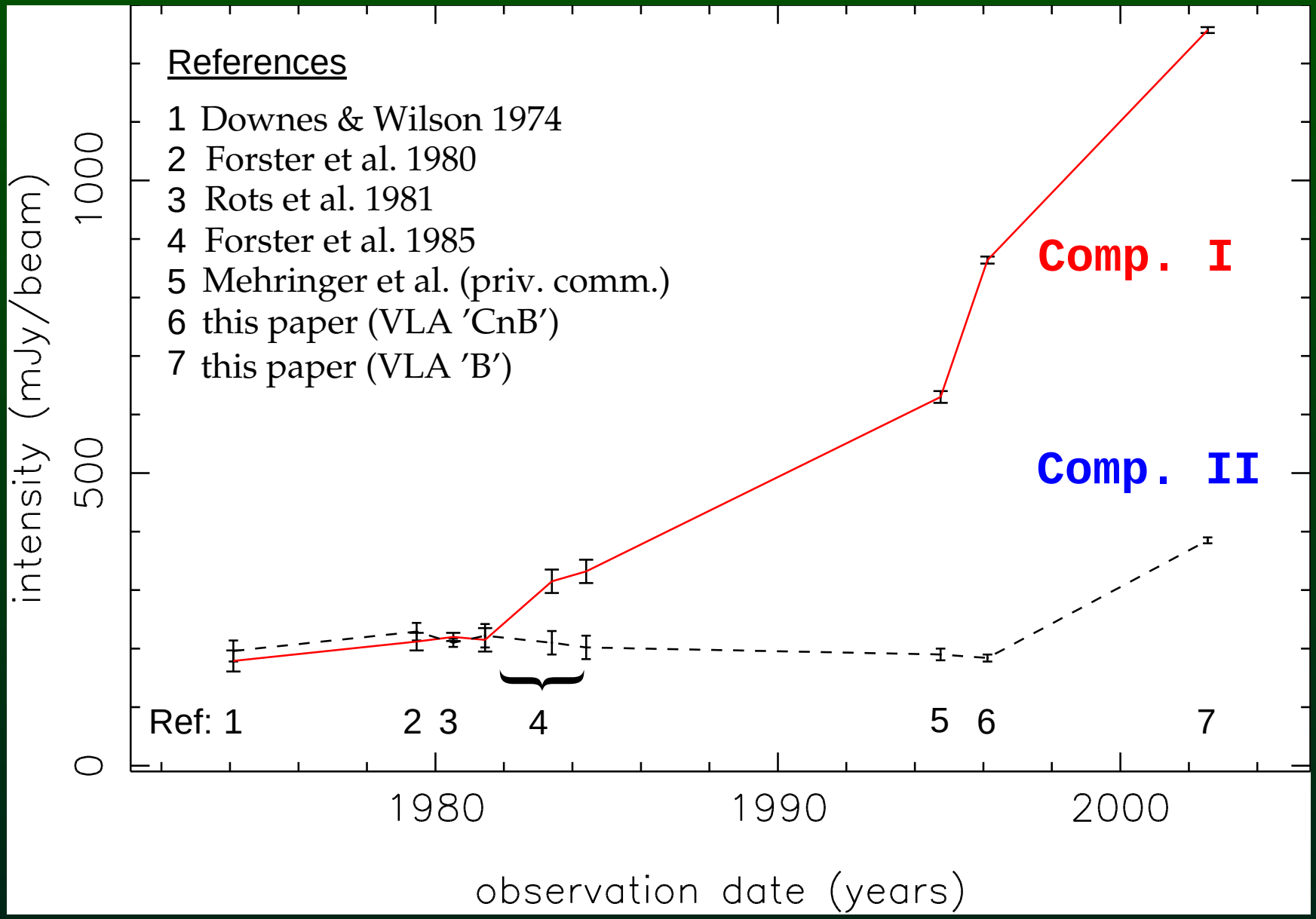


Formaldehyde Answers

- empirical answers
  - what is the size of the masers? 30 - 100 AU
  - what is the brightness temperature (*i.e.* gain)? $\sim 10^8$ K
  - what is the true velocity structure? gradient; narrow width
  - are there 2 cm masers? no
  - where are the masers located? in with the rest
- theoretical answers
  - does the current pump model work? no
  - how are H_2CO masers related to other, more common masers? ?
  - why are H_2CO masers so rare?! ?

VLBI Contributions

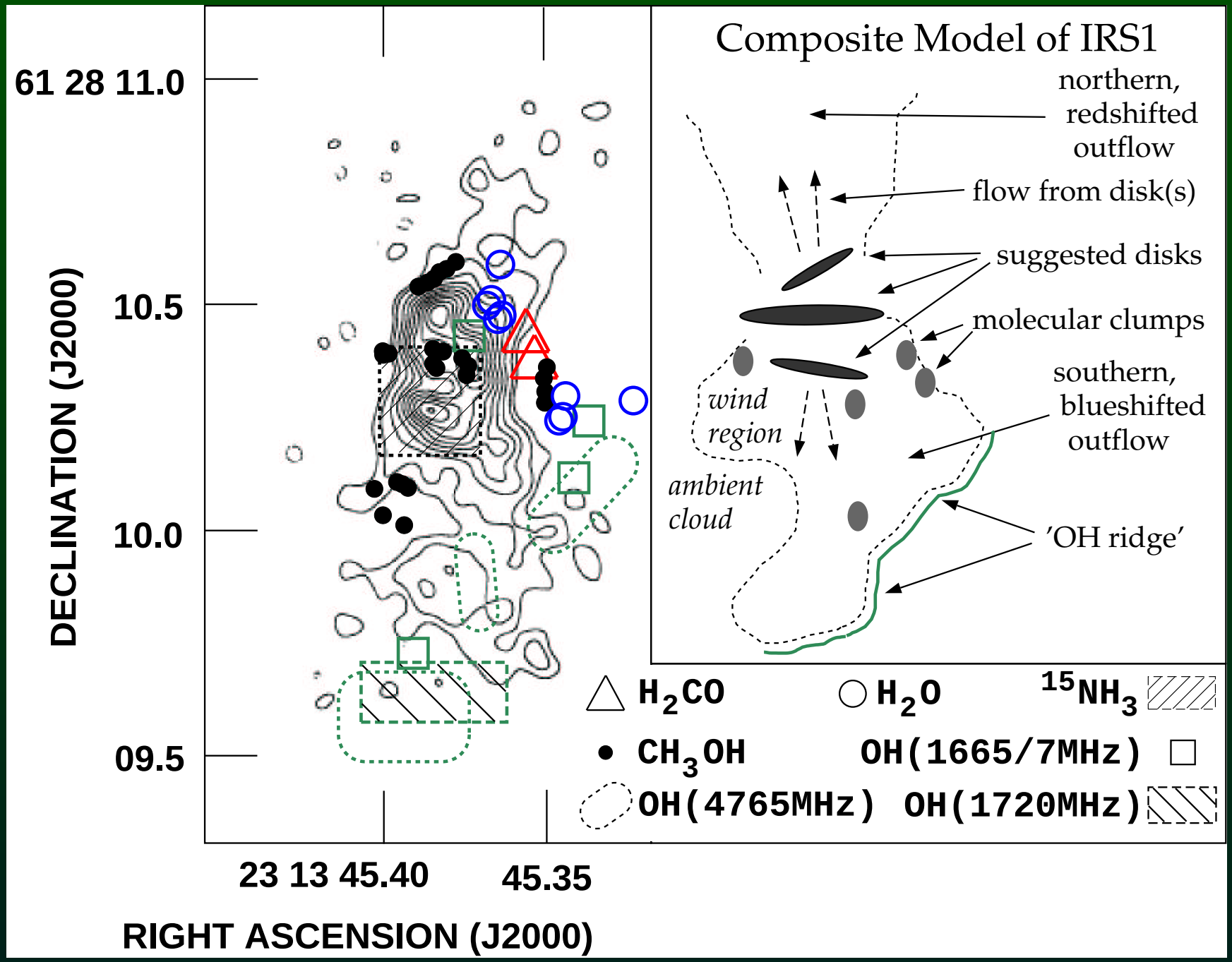
- the H_2CO/maser field is again picking up
  critically constraining 10-25 year old theories for the first time
  developing phase-referencing and wide/narrow band techniques for continued progress
- future observations yielding true position and velocity structure
  - common masers
    H_2O, CH_3OH, OH
  - rare masers
    H_2CO, NH_3 (9,6)


References
1 Downes & Wilson 1974
2 Forster et al. 1980
3 Rots et al. 1981
4 Forster et al. 1985
5 Mehringer et al. (priv. comm.)
6 this paper (VLA 'CnB')
7 this paper (VLA 'B')
Comp. I
Comp. II
Ref: 1 2 3 4 5 6 7
intensity (mJy/beam)
0
500
1000
1980
1990
2000
observation date (years)

Pump Ideas

- need rare conditions
  perhaps collisions with excited species (H*, H_2*)
  but no cross sections available
- shock crossing (Hill & Hollenbach 1978; Bertoldi & Driane 1996)
  dissociation wave v. ionization wave
  wave velocities and relative evolution depend on:
    - density
    - age
    - magnetic field
    - ambient clumpiness (H_2O masers)

  NGC 7538 lies in this sparse parameter space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