Observational Studies of H_2O Maser Burst in Orion KL with ALMA and VERA

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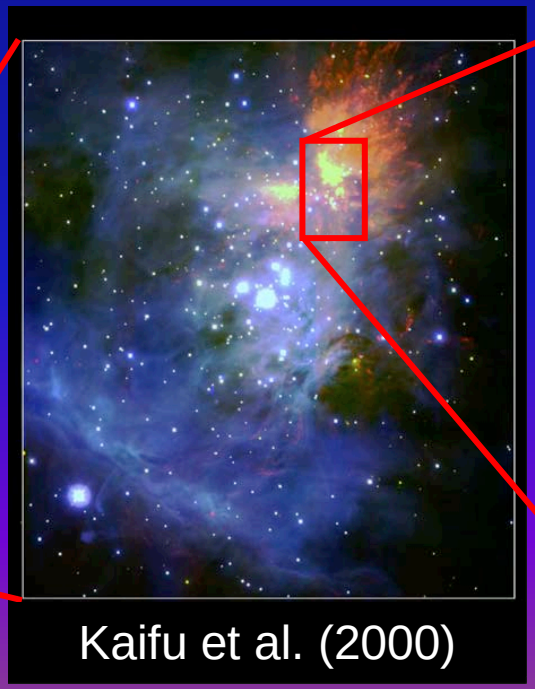
Scientific topics

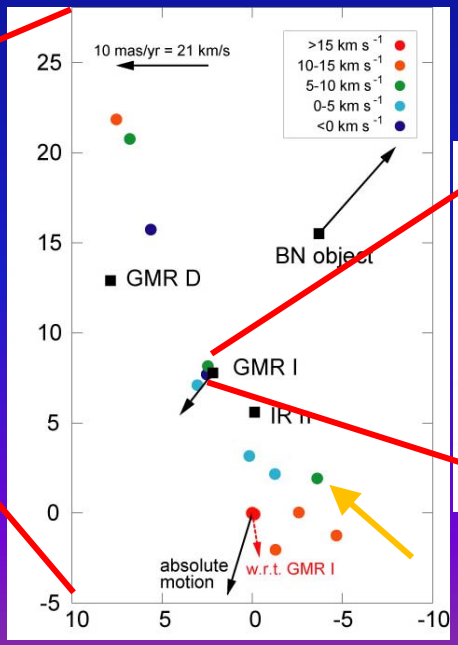
- Variability
  - The latest results of monitoring of H_2O maser burst in Orion KL with VERA and ALMA
  - Behaviors, patterns and periodicity of its flux variability
  - Simultaneous variability of sub-mm H_2O lines
- VLBI
  - Resolution of the structure of bursting maser features
  - Possible relation with disks and/or outflows
- ~~Magnetism~~
  - ~~Possible relation of magnetism with maser burst (e.g. Garay et al. 1989)~~

Orion KL region

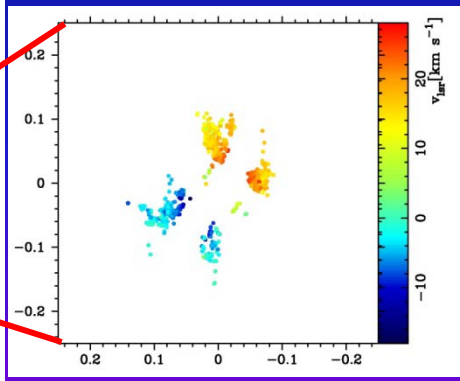
- Nearest massive star-forming region
  - D=420 pc measured by VLBI astrometry
    (Kim et al. 2008, Menten et al. 2007)
  - Complex structure of outflow/disk system (e.g. next talk)



Kaifu et al. (2000)



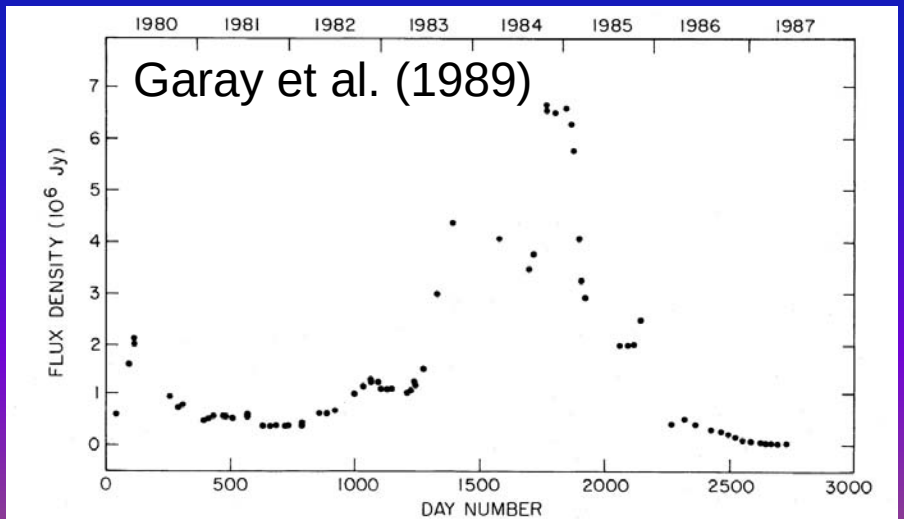
Hirota et al. (2007)

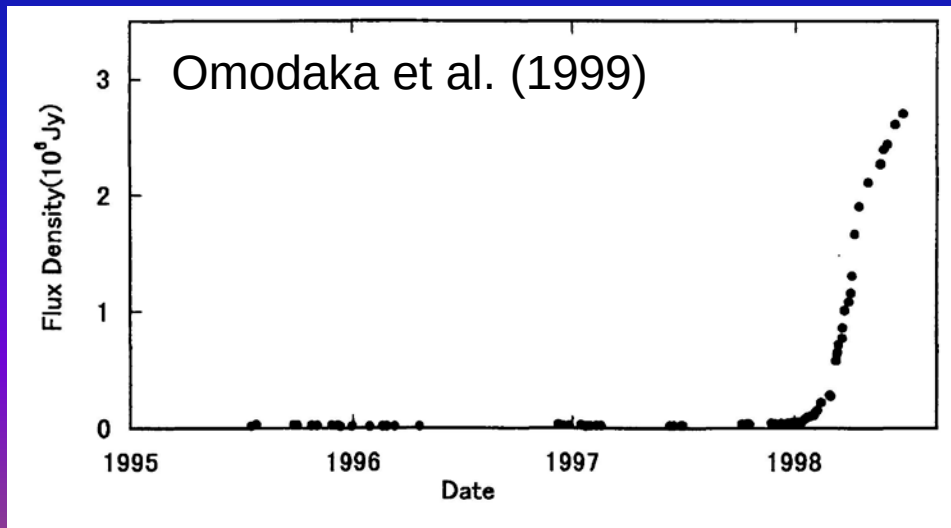


Kim et al. (2008)

H_2O maser flare/burst in Orion KL

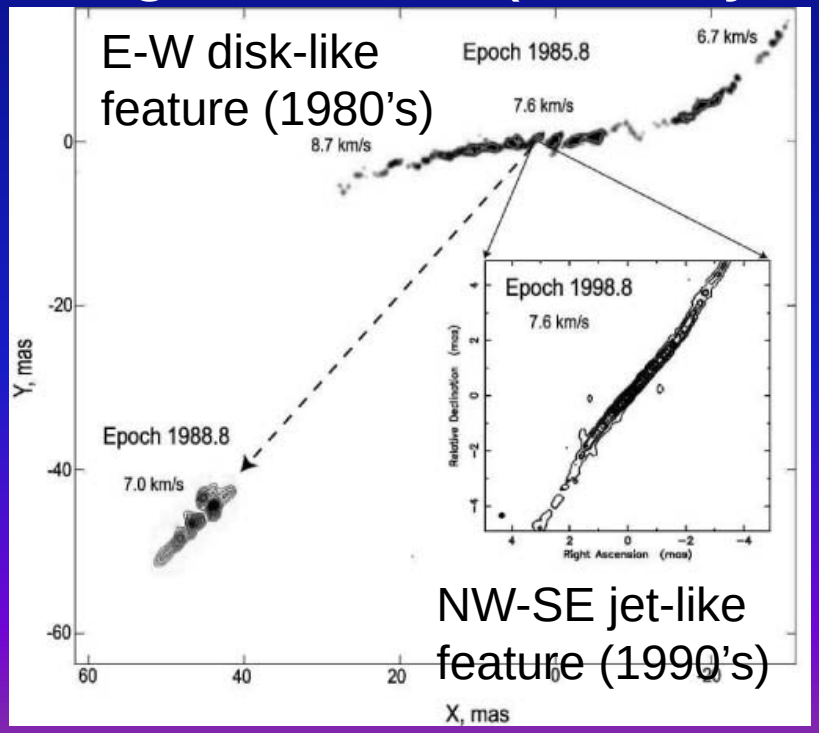
- History of maser burst
  - 1979-1985 (Matveenko et al.1988, Garay et al. 1989, …)
  - 1998 (Omodaka et al. 2004, Shimoikura et al. 2005, …)
  - 2011 February (Tolmachev 2011); 13-year periodicity?
    - 1973 (Baudry et al. 1974) corresponding feature ~100 Jy
    - 1975-76 (Forster et al. 1978) no higher than ~500 Jy

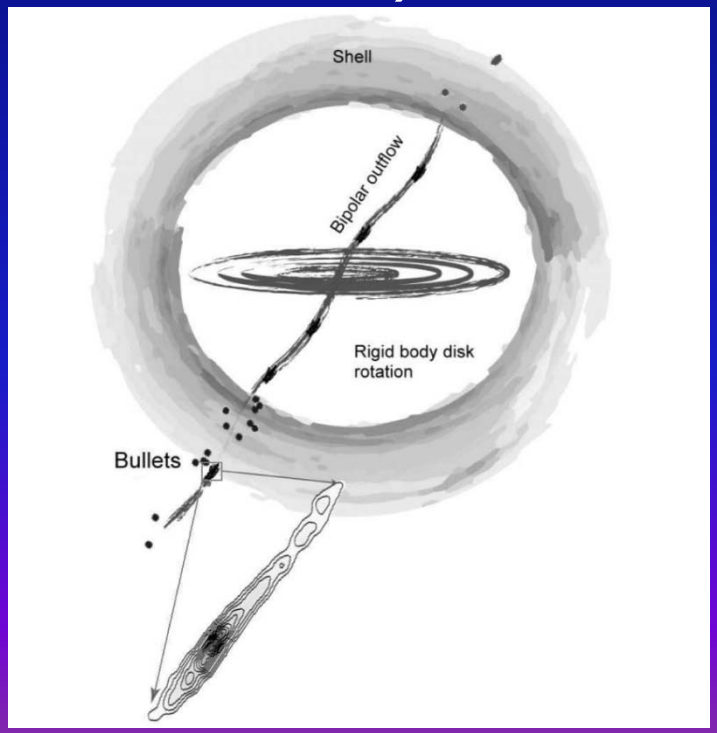




Possible mechanism of maser burst

- Outflow/shock (Garay et al. 1989)
- Jet (Matveenko et al. 2004)
- Edge-on disk (Matveyenko et al. 1988)

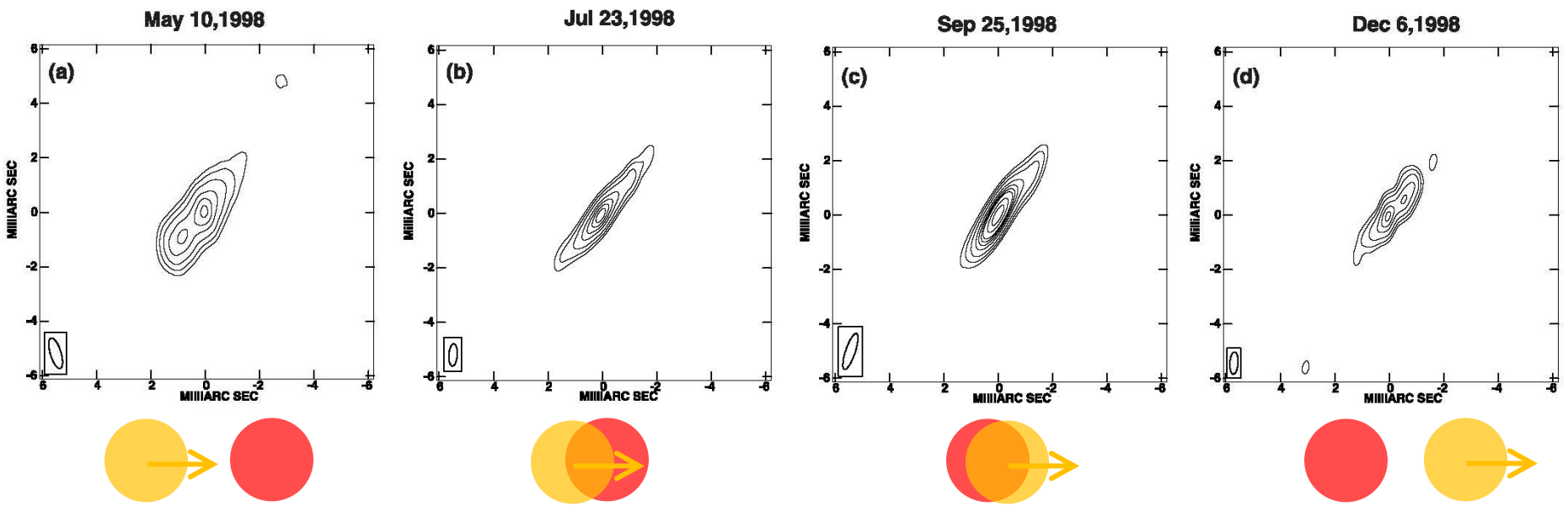




VLBA/global VLBI mapping by Matveyenko (Demichev et al. 2009)

Possible mechanism of maser burst

- Overlapping model
  - Overlapping of two different clouds
    (Deguchi et al. 1989, Shimoikura et al. 2005)



VLBA Mapping (Shimoikura et al. 2005)

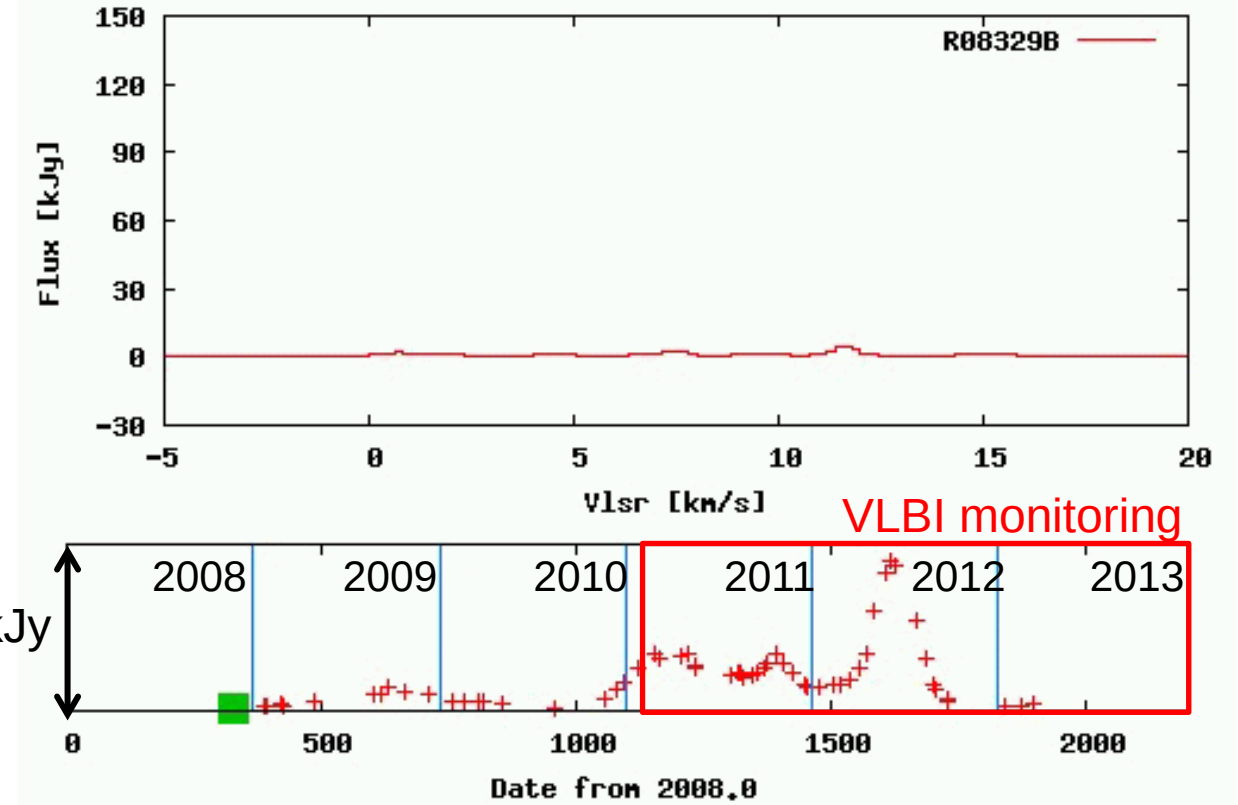
Monitoring observations with VERA

- Aim
  - Identify its powering source
  - Reveal 3D velocity and spatial structure
  - Investigate possible relation with star-formation activities
  - Verify relationship with previous bursts, periodicity
- Detail
  - VERA 4 station

    Beam size=1.7masX0.9mas
  - Dual-beam astrometry
  - Since Mar 09 2011
- See Hirota et al. (2011)

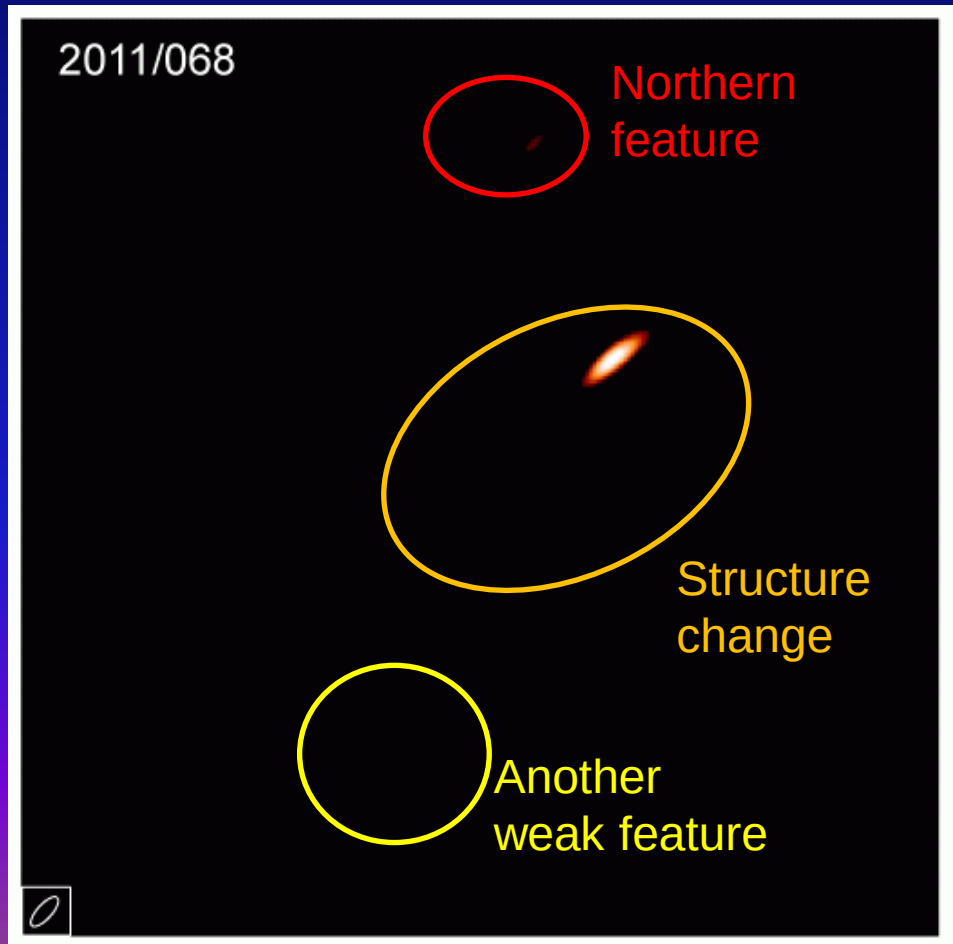
Flux monitoring

- Monitoring of total flux since 2008 (~once/month)
  - Peak~150kJy(~10^{14} K); far below previous bursts (<0.1)
  - Duration ~1.5yr; already finished? To be monitored



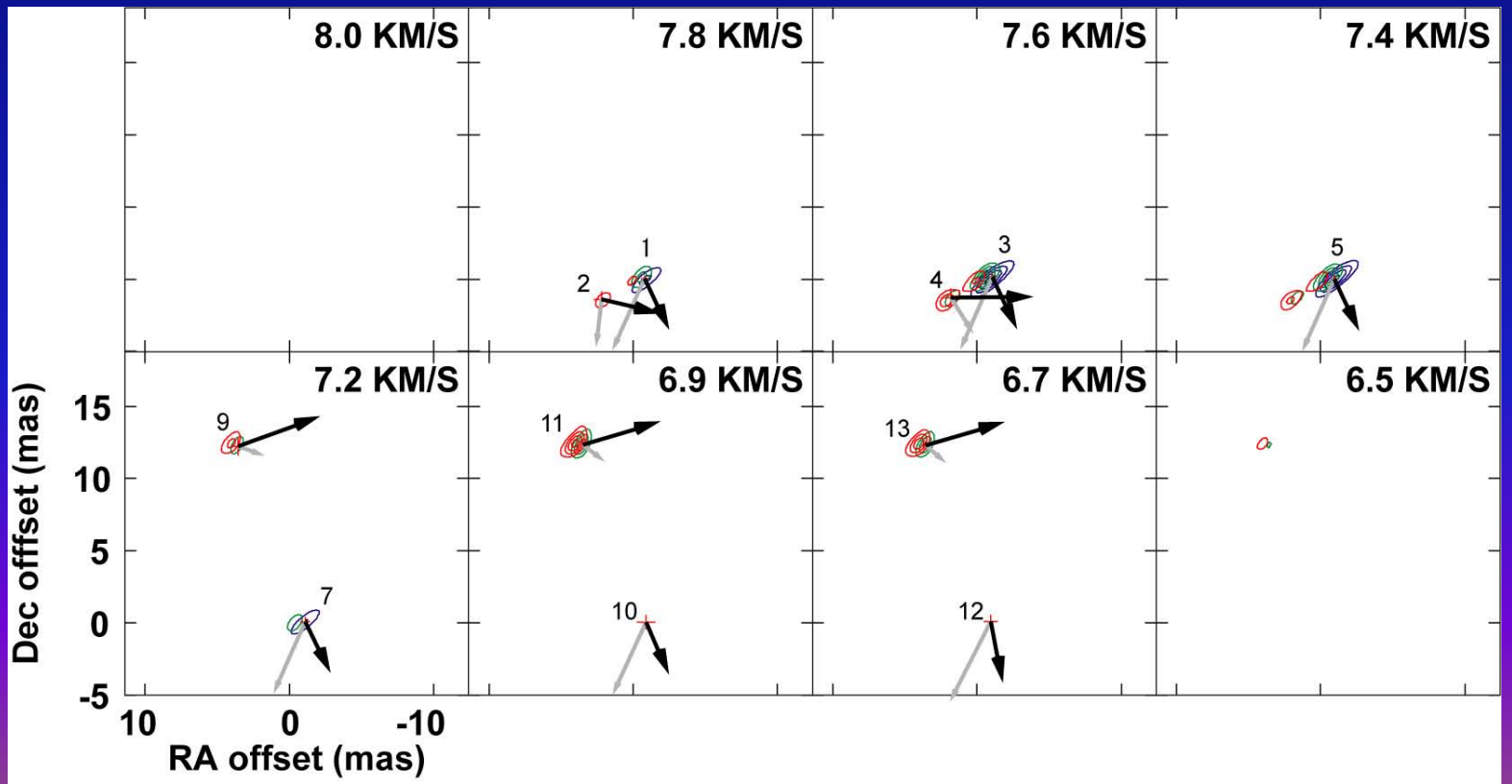
Phase-referenced images

- Multiple spatially distinct features
  - Significant change in structure, not a localized phenomenon for a single feature
  - Elongation along NW-SE as seen in previous bursts (Shimoikura et al. 2005, Demichev et al. 2009)



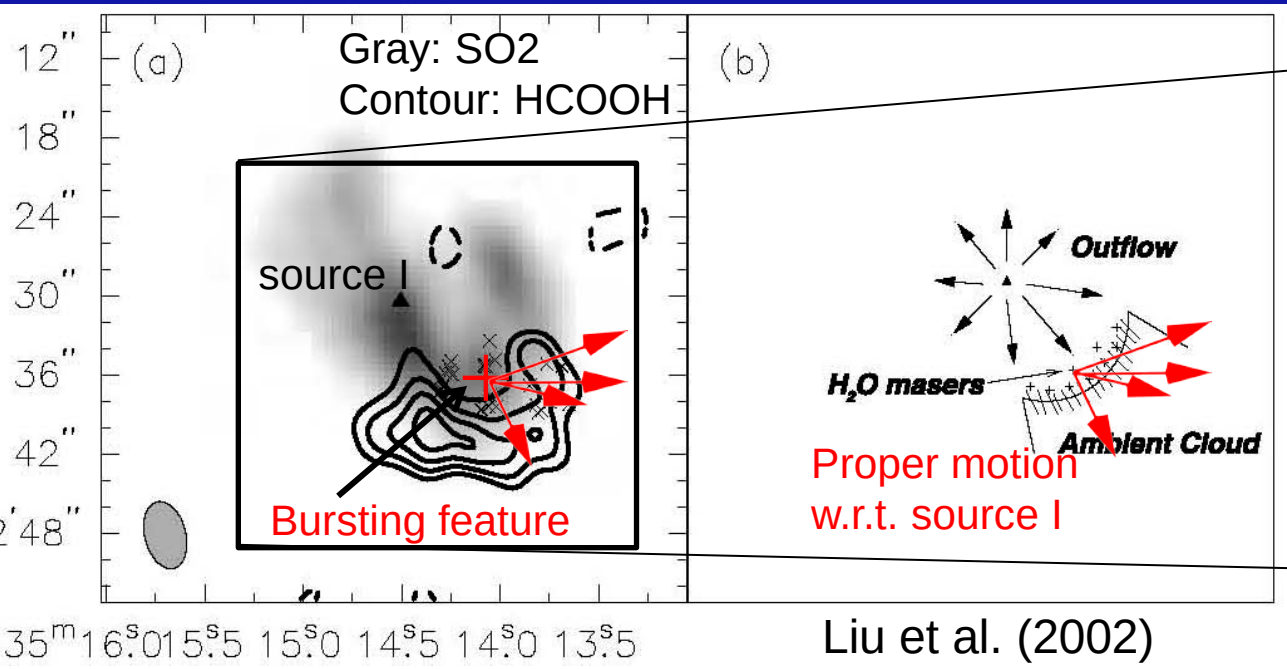
Proper motions

- Proper motions w.r.t. Source I (Goddi et al. 2011)
  - 10-20 km s^{-1} toward S-W, almost parallel to outflow axis
  - Almost perpendicular to the elongation of maser features

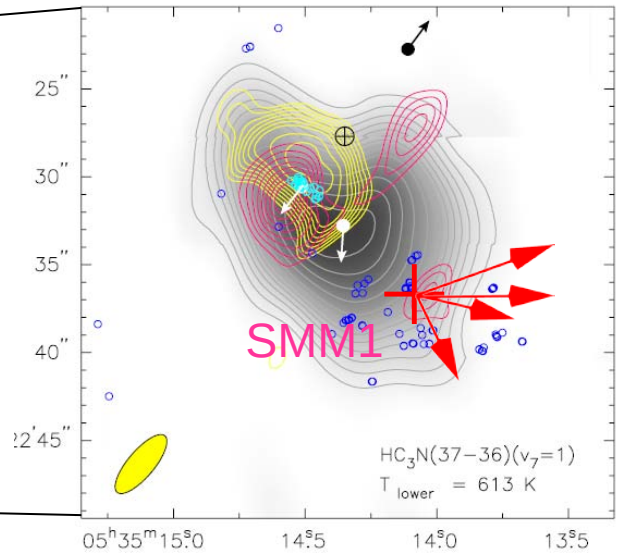


Possible origin of the burst

- Located at Compact Ridge as in previous bursts
  - Proper motions along the low-velocity outflow axis (S~W)
  - Explained by shock (Liu et al. 2002, Favre et al. 2011)
  - Source I or another YSO? (SMM1, Zapata et al. 2011)



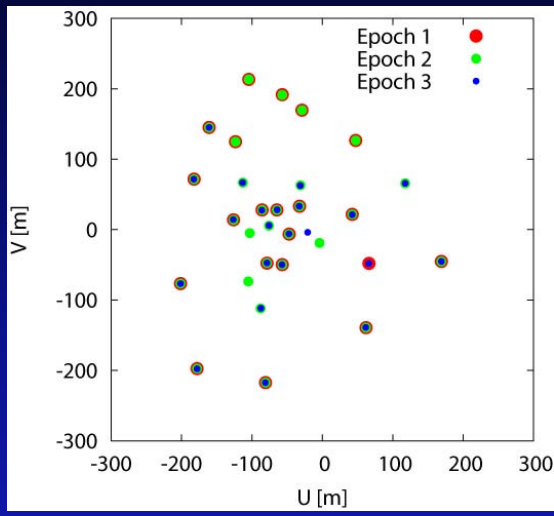
Liu et al. (2002)



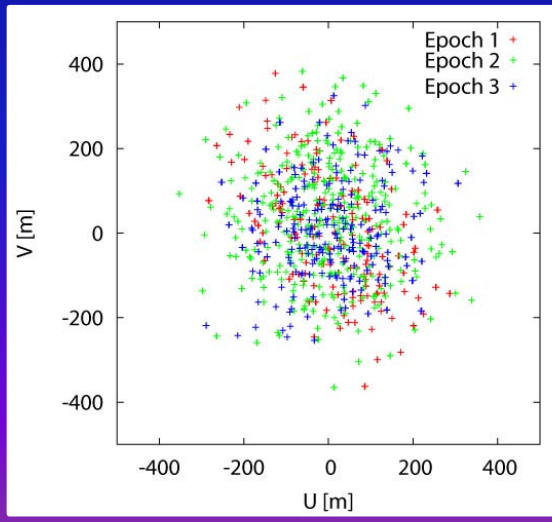
Zapata et al. (2011)

Follow-up by ALMA cycle 0

- Aim
  - Identify the powering source
  - Investigate multi-transitions from centimeter to submillimeter
- Details
  - Extended configuration (~0.5” beam)
  - Continuum emission at band 6/7
    - Tsys~100 K@B6, 150K@B7
    - On-source 30s (total 20min)
  - Spectral line at band 7
    - Tsys~150-200 K@B7
    - On-source 100s (total 20min)



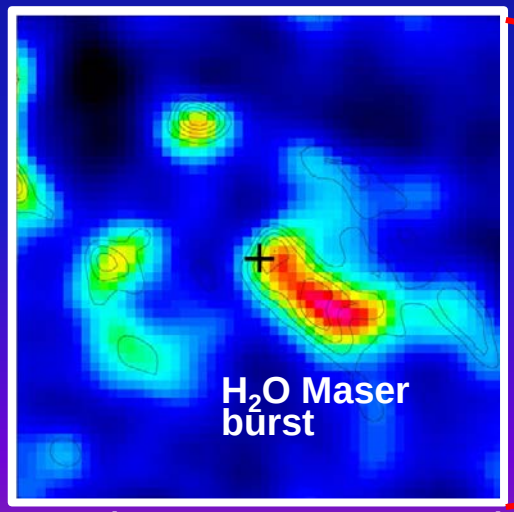
Array configuration

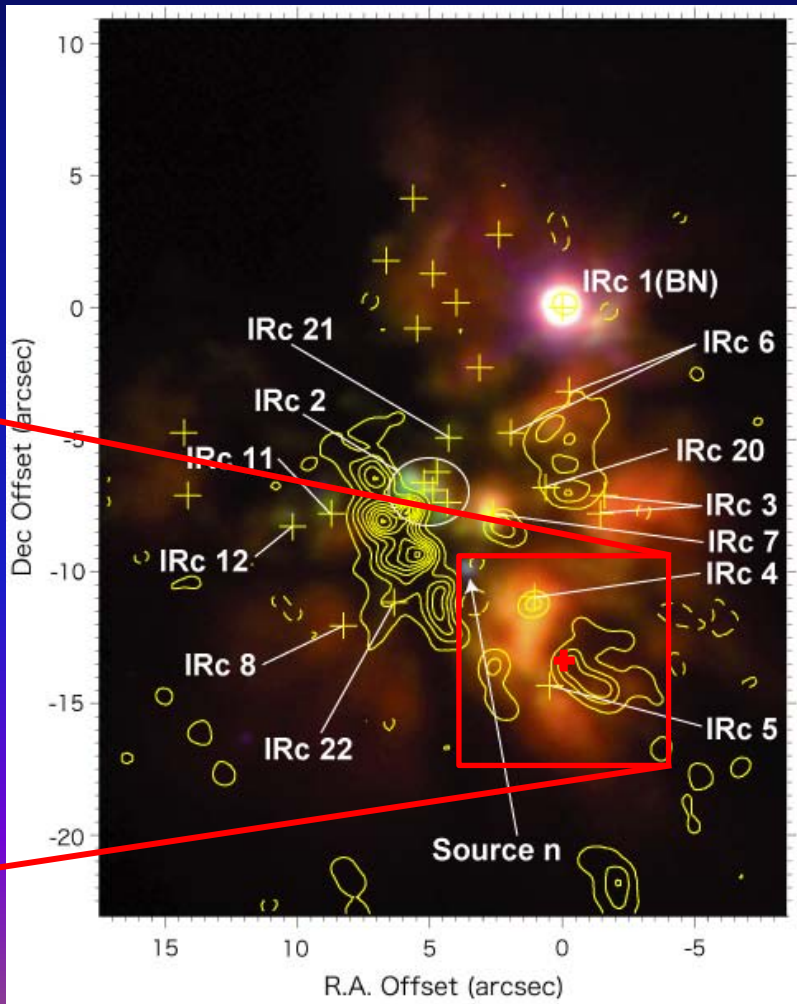


UV coverage

Continuum emission

- Coincident with continuum peak in Compact Ridge
  - Zapata et al. (2009) SMM1
  - Favre et al. (2011) MF1/Cb1
  - To be studied with SED at ALMA bands 6, 7, and 9

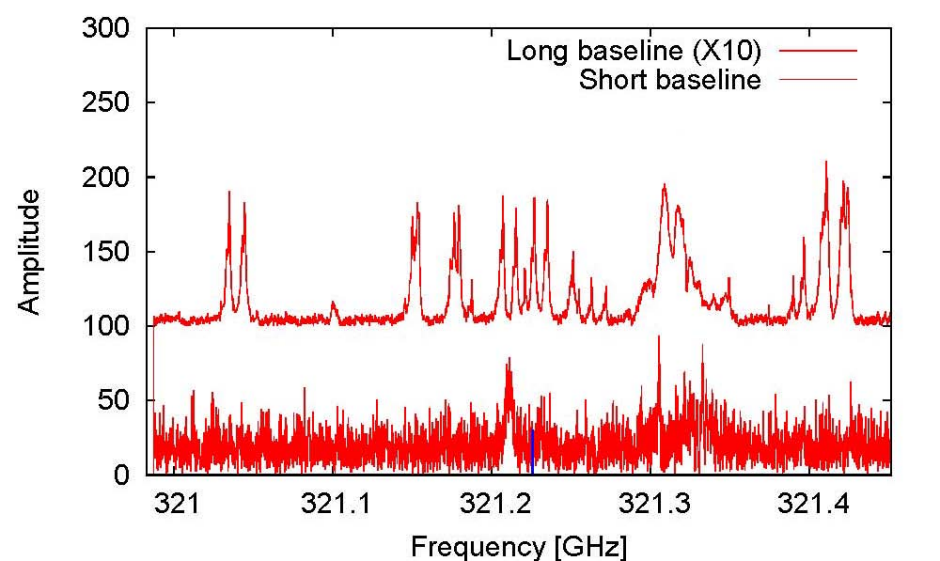


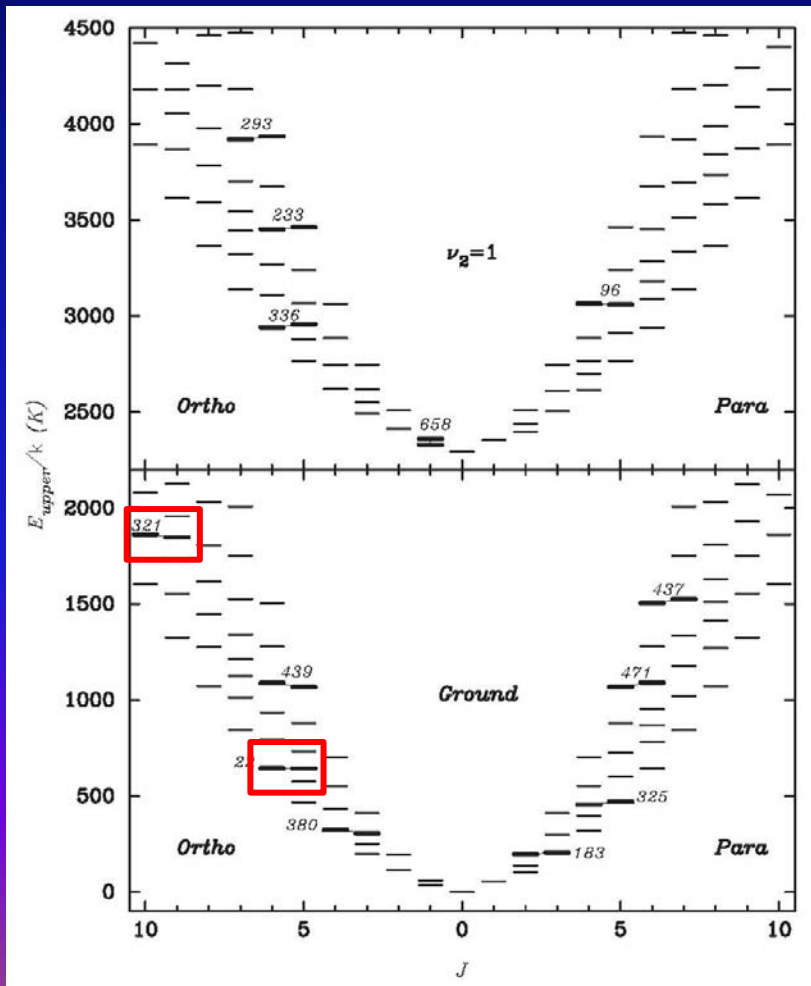


Band 7 (330 GHz) continuum superposed on the Subaru image (Okumura et al. 2011)

The 321 GHz H_2O maser

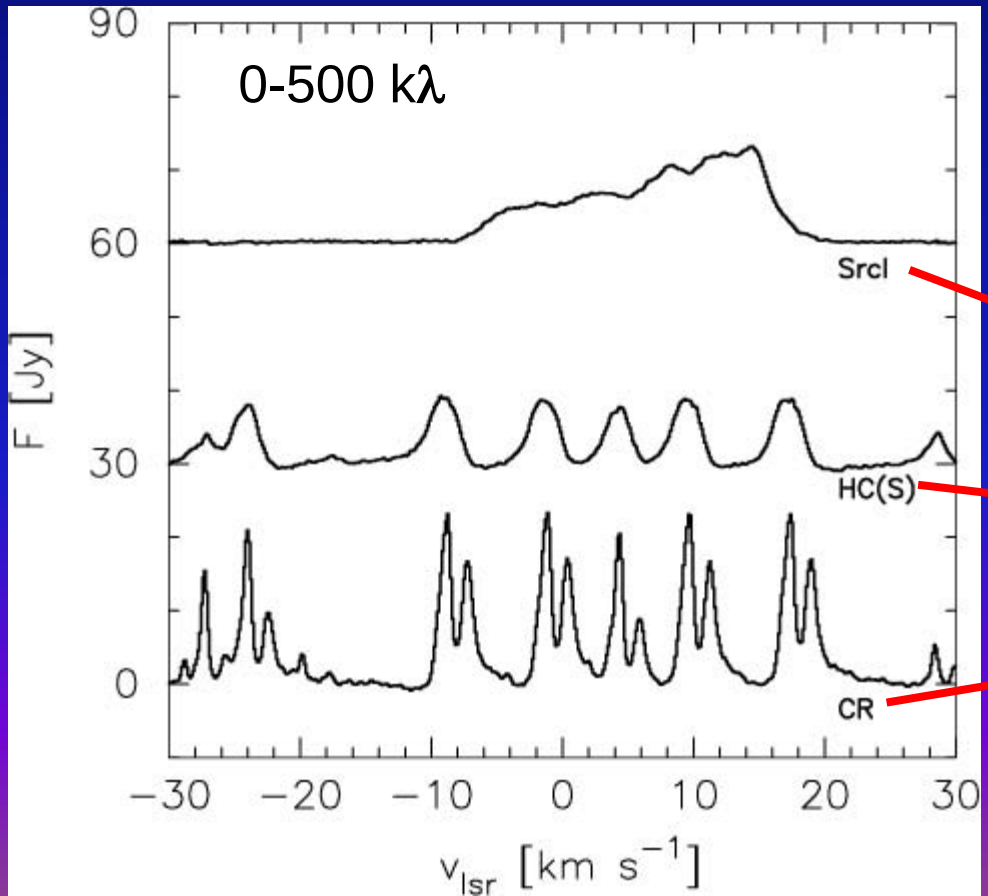
- One of the bright submillimeter masers with higher excitation energy (Menten et al. 1990)
- Detected even in the longest baselines

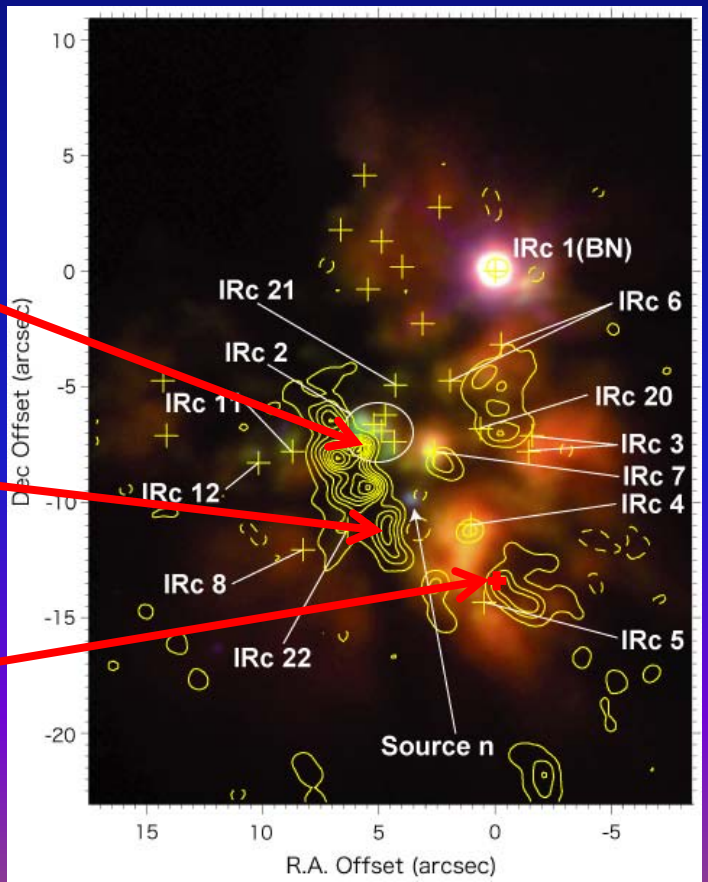




The 321 GHz H_2O maser

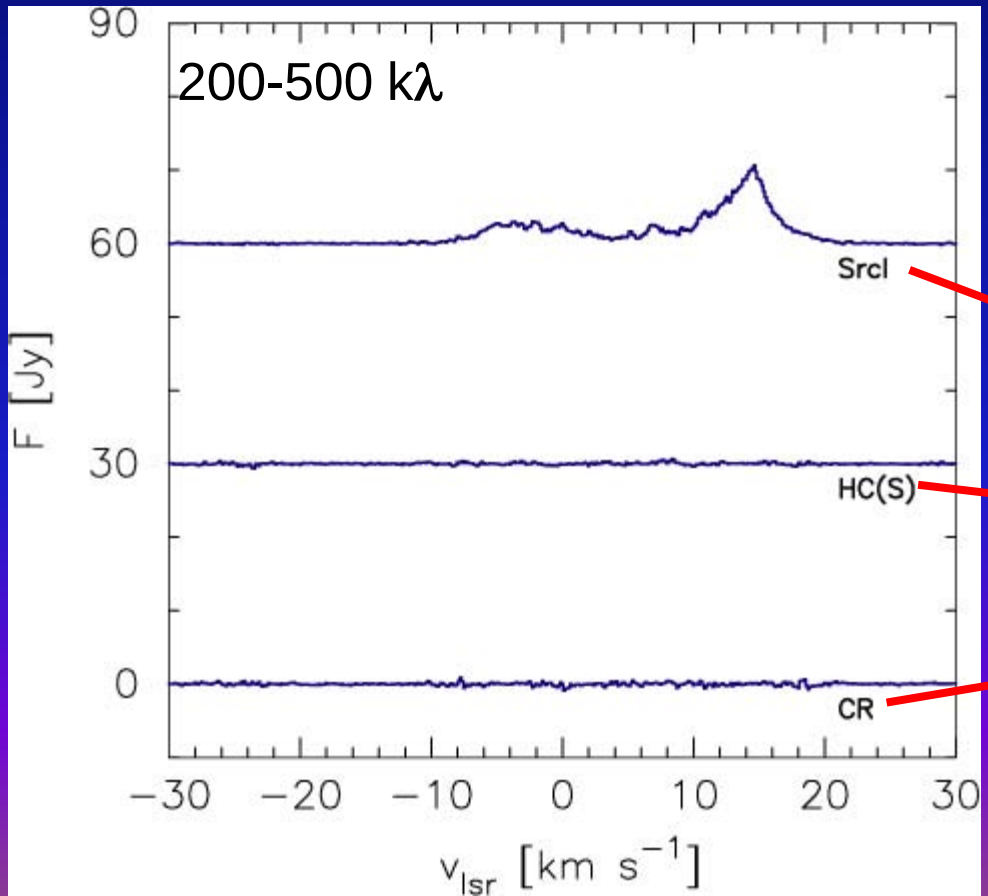
- Confusion with other molecular lines
  - $HCOOCH_3$ are dominant in Hot Core and Compact Ridge

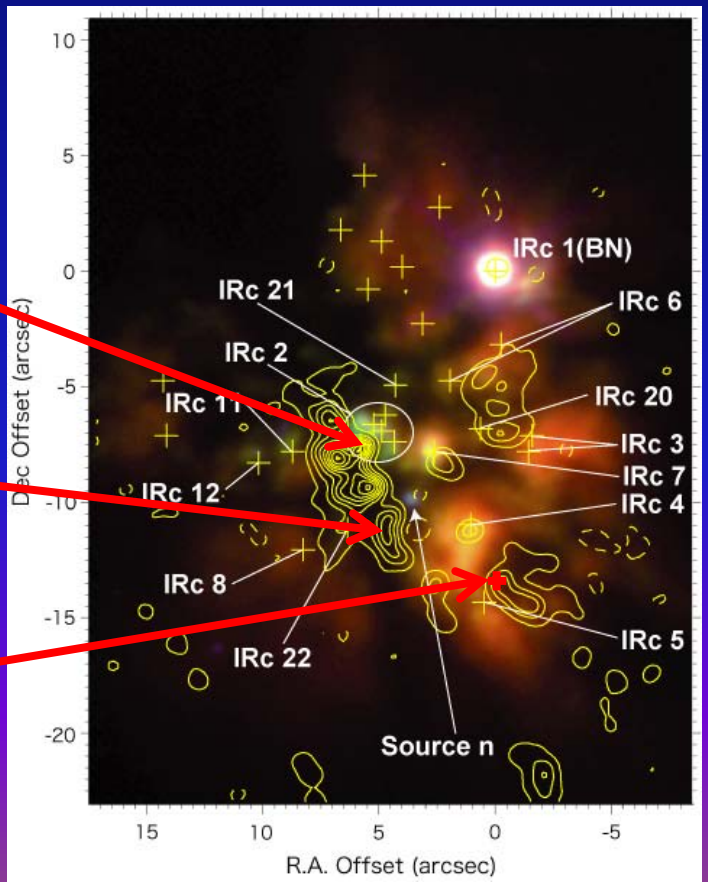




The 321 GHz H_2O maser

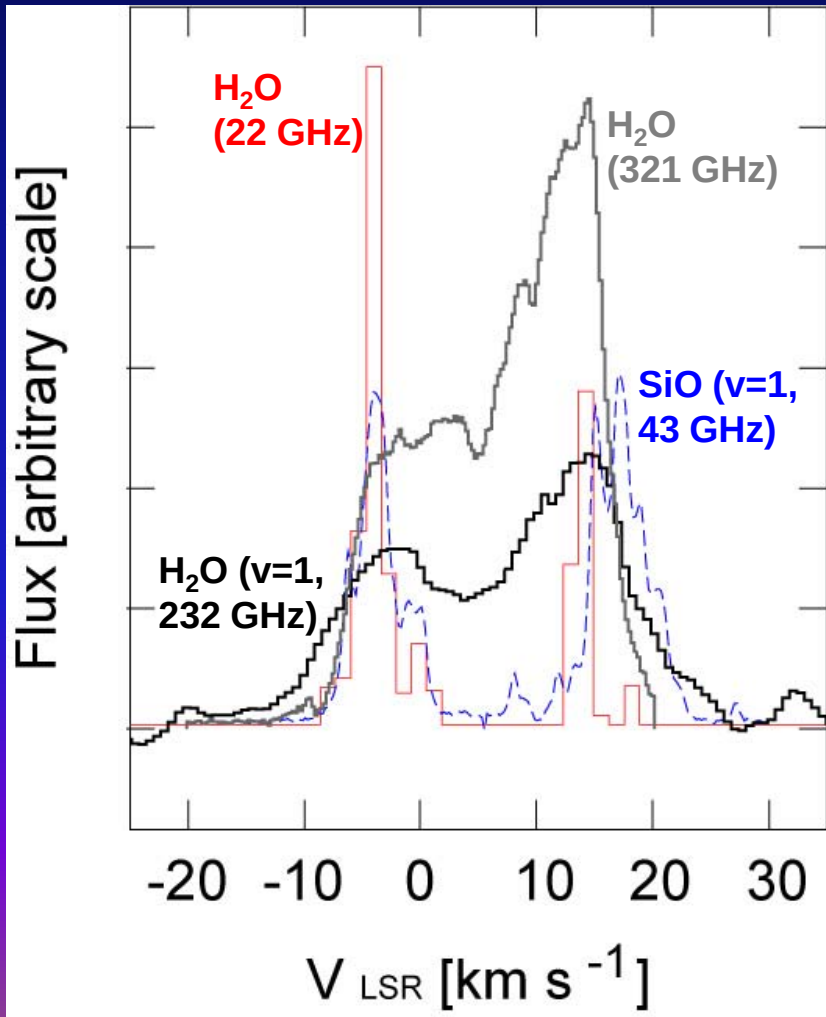
- But, no strong 321 GHz maser in Compact Ridge
  - $HCOOCH_3$ are resolved out, only Source I unresolved





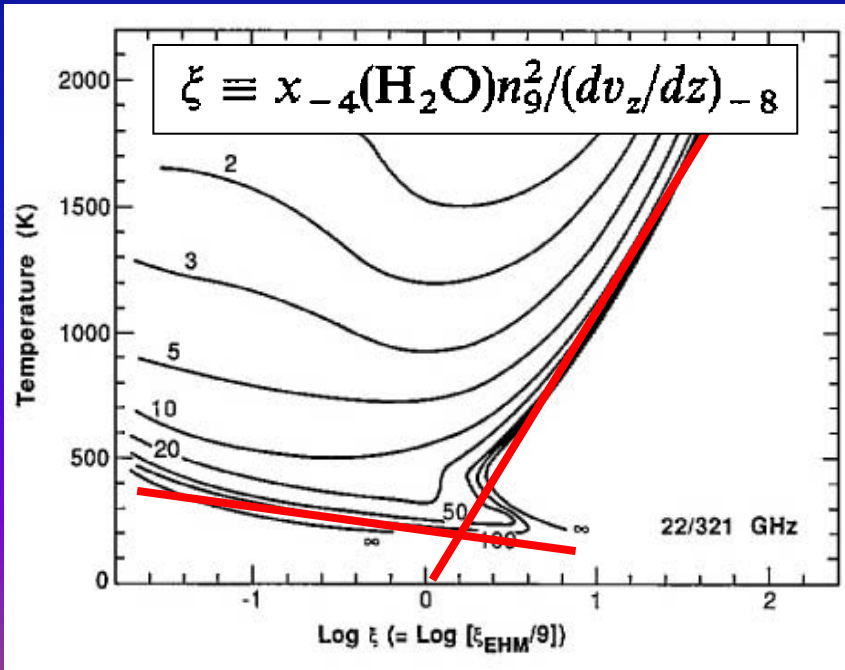
(Sub)millimeter H_2O in Source I

- The 321 GHz H_2O line is detected in Source I
  - Compact, unresolved with ~0.5” beam
  - Analogous to SiO masers (next talk, Kim et al. 2008, Goddi et al. 2009, etc)
  - See Hirota et al. (2012) for the 232 GHz vibrationally excited lines observed by ALMA Science Verification



Multi-transition analysis

- Photon luminosity ratio (Neufeld & Melnick 1990)
  - Good probe of H_2O abundance, density, velocity gradient, and/or temperature
  - e.g. L_{22}/L_{321} = 5-150 (W3, W49, W51; Menten et al. 1990)
  - At least one of the following condition would be required
    - Low temperature (<400 K)
    - High density (>$10^{9.5}$ cm^{-3})
    - High H_2O abundance (>$10^{-4.5}$)
    - Small velocity gradient/width
    - Long path length



Summary

- The 22 GHz H_2O maser burst in Orion KL has been observed with VERA.
- Positions, structures, and proper motions of bursting features could be explained by interaction with the shocked gas and ambient cloud in the Compact Ridge.
- Physical properties of host cloud core and masing clump will be investigated with new ALMA data.
- Future multi-transition observations of masers with VLBI and ALMA will be powerful tools to explore physical and dynamical properties of MYSOs.