A Survey of the vibrationally excited H_2O lines in nearby massive YSOs

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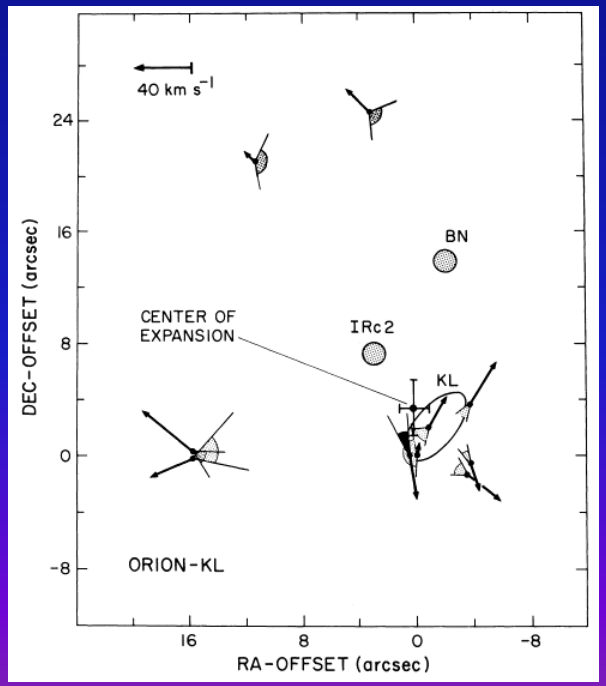
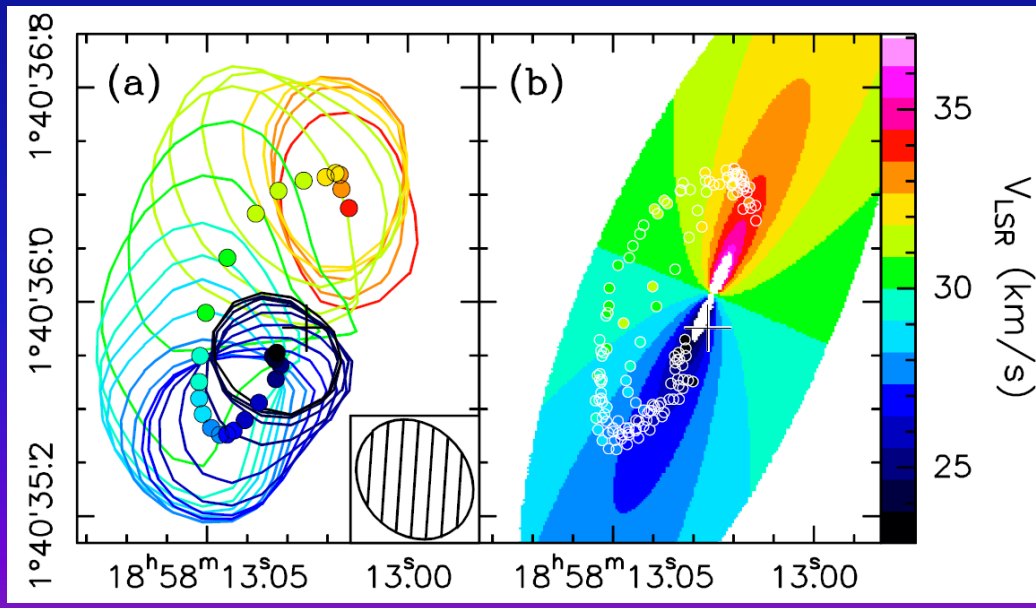
Introduction

- **High-resolution study of high-mass star-formation**
  - ***How can high mass accretion rate be achieved?***
  - ***How do high-mass YSOs associated with disk/outflow evolve?***
  - ***What are differences from low-mass star-formation?***



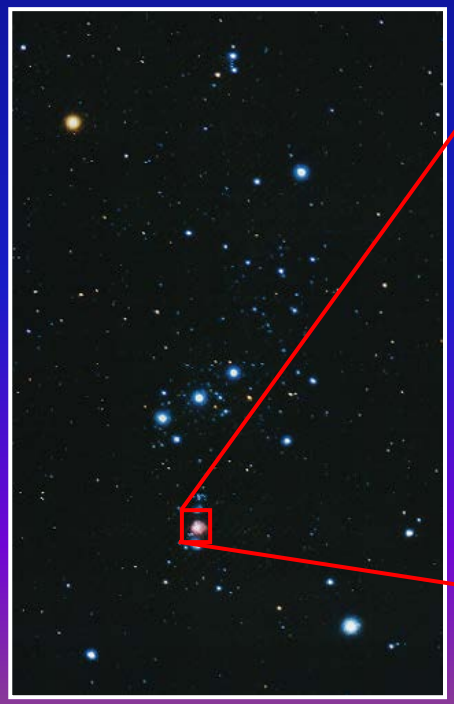
VLBI map of 22 GHz H_2O masers in Orion KL (Genzel et al. 1981)

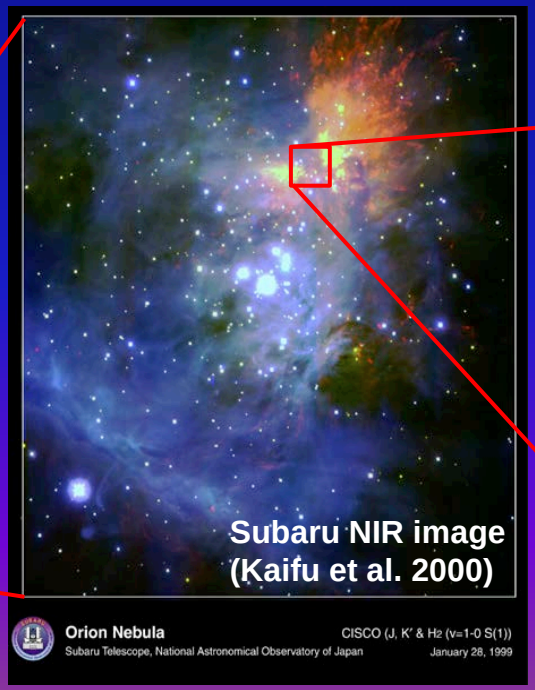


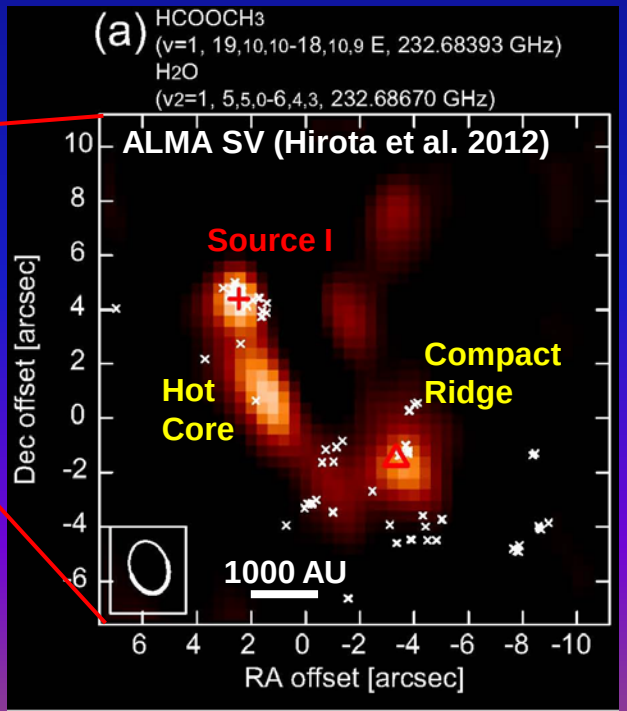
ALMA image of circum-binary disk around G35.20-0.74N (Sanchez-Monge et al. 2013)

Orion KL

- Nearest high-mass star-forming region
  - 420 pc (Hirota et al. 2007, Menten et al. 2007, Kim et al. 2008)
  - One of the best targets for high-mass star-formation study
  - One of the most studied sources for astrochemistry

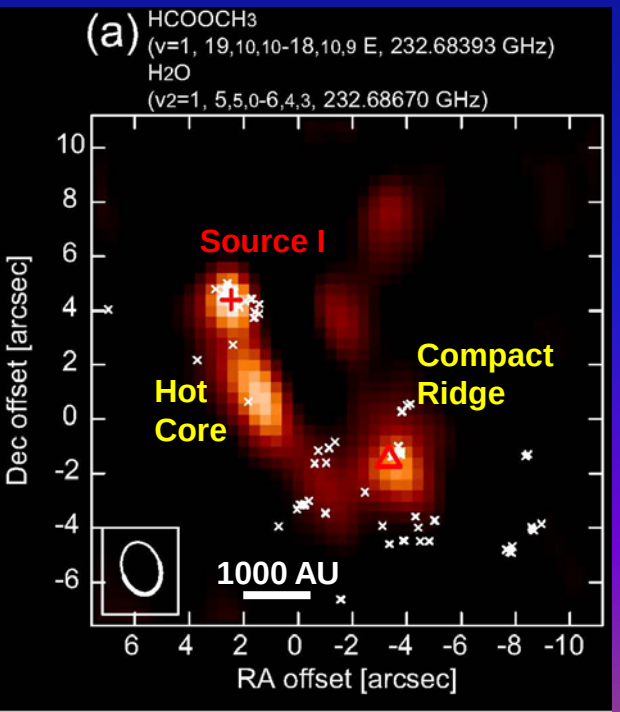


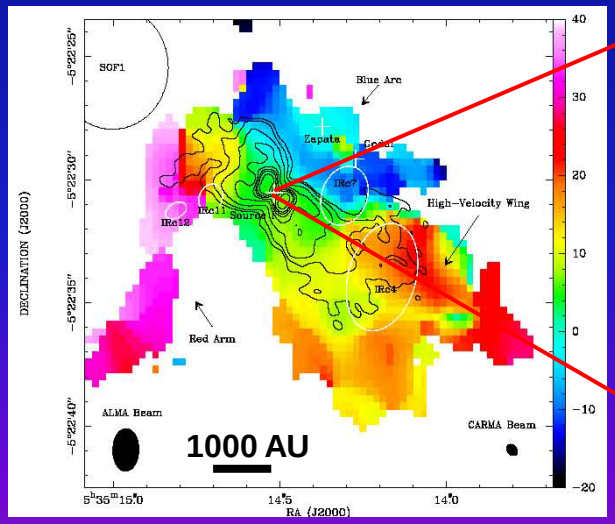




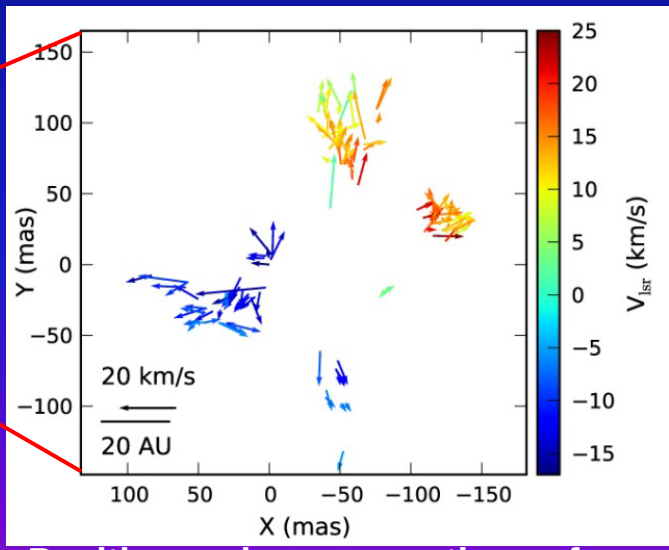
Orion KL; zoom-in

- **Low-velocity (~18 km s^{-1}) NE-SW outflow**
  - **Traced by thermal SiO lines (Plambeck et al. 2009, Zapata et al. 2012, Niederhofer et al. 2012, etc.)**
  - **Perpendicular to high-velocity explosive outflow**
  - **SiO masers at the center (Kim et al. 2008, Matthews et al. 2010)**





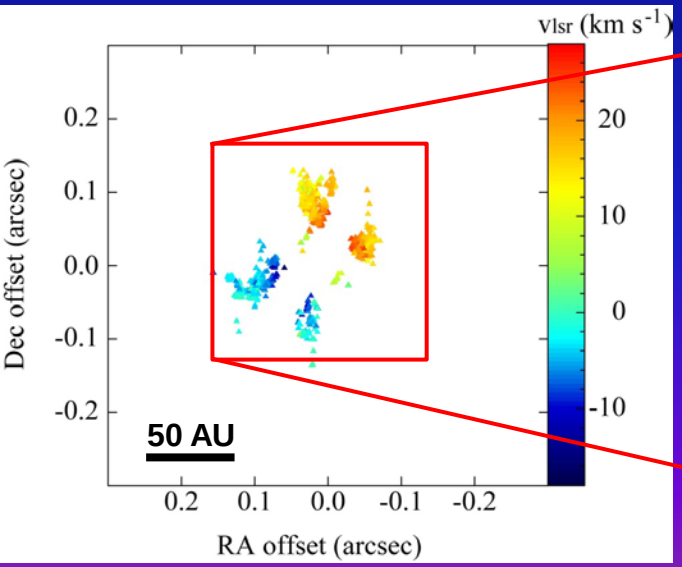
SiO thermal by ALMA SV (Niederhofer et al. 2012)



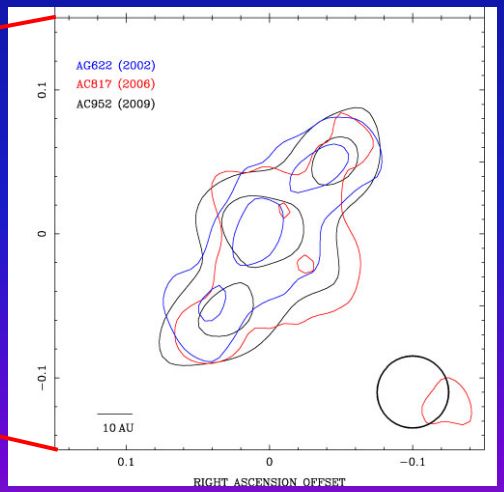
Position and proper motions of 43 GHz SiO maser map by VERA (Kim et al. 2008)

Radio Source I

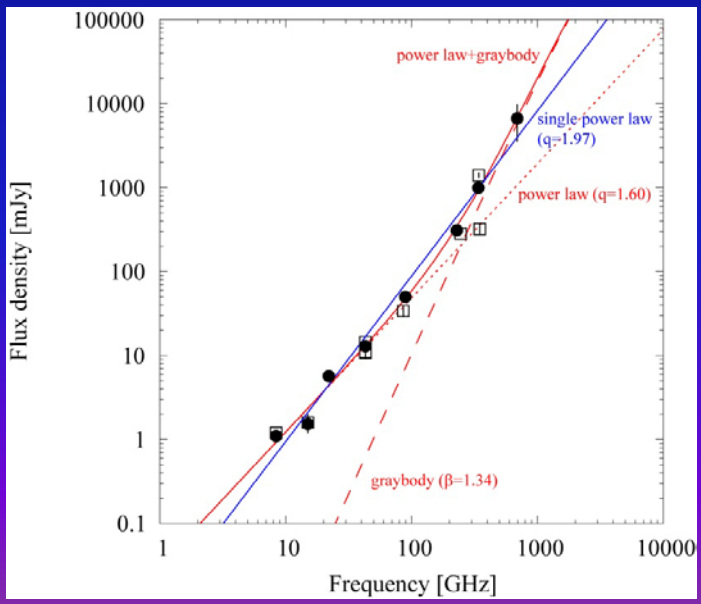
- **Strong continuum source only visible in cm-submm**
  - **NW-SE elongation perpendicular to the NE-SW outflow**
  - **Coincident with SiO maser emission (Menten & Reid 1995)**
  - **Edge-on rotating disk with optically thick H^- free-free radiation *but still controversial* (Beuther et al. 2006, Reid et al. 2007, Goddi et al. 2011, Plambeck et al. 2013)**



43 GHz SiO maser map by VERA (Kim et al. 2008)



43 GHz continuum by VLA (Goddi et al. 2011)



SED of source I (Hirota et al. 2015)

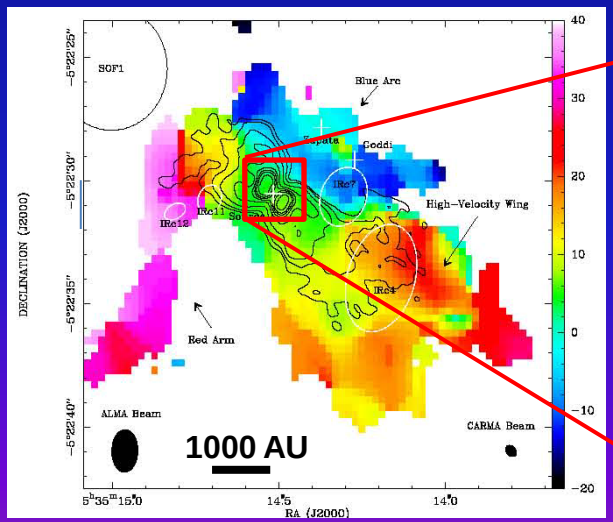
ALMA observations

- **Band 7 in cycle 0**
  - **Sum of 3 epochs, 5 min on-source for each**
  - **0.37” resolution (maximum baseline length of 400 m)**
  - **321 GHz ($10_{2,9}$-$9_{3,1}$, E_l=1846 K)**
  - **336 GHz (v=1, $5_{2,3}$-$6_{1,6}$, E_l=2939 K)**

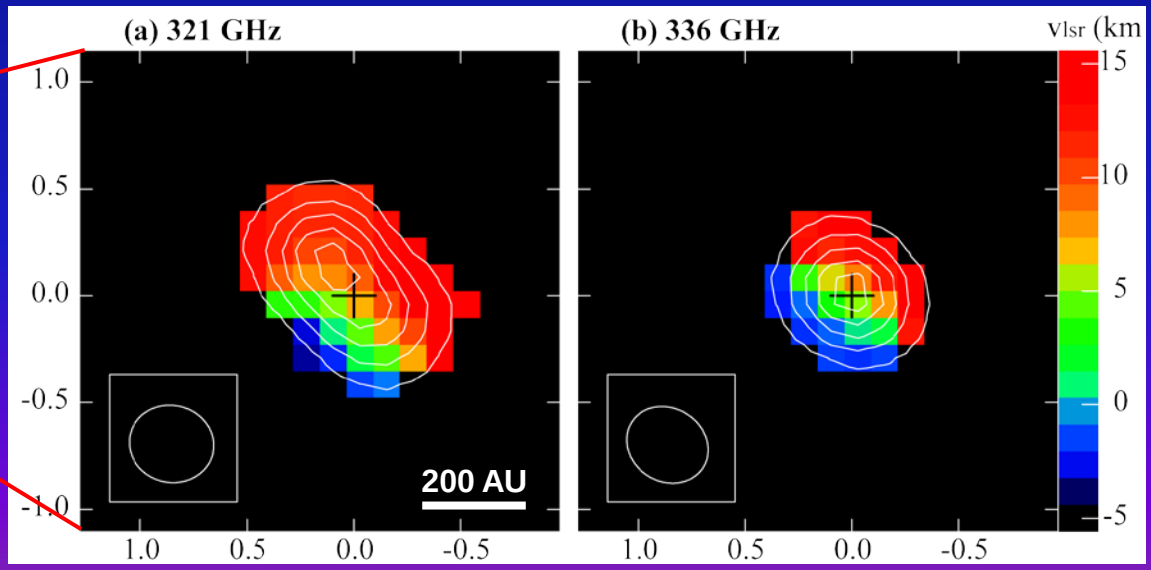
0.1” resolution = 42 AU at Orion KL

Moment maps

- Common velocity gradient perpendicular to outflow
- 321 GHz ($10_{2,9}$-$9_{3,1}$, E_l=1846 K)
  - NE-SW elongation possibly tracing base of the outflow
- 336 GHz (v=1, $5_{2,3}$-$6_{1,6}$, E_l=2939 K); unresolved structure
  - Suggesting compact rotating structure --- disk



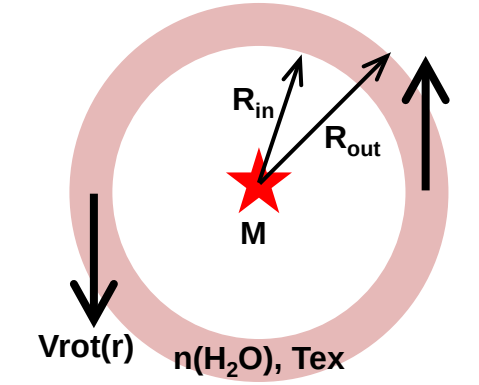
SiO thermal by ALMA SV (Niederhofer et al. 2012)

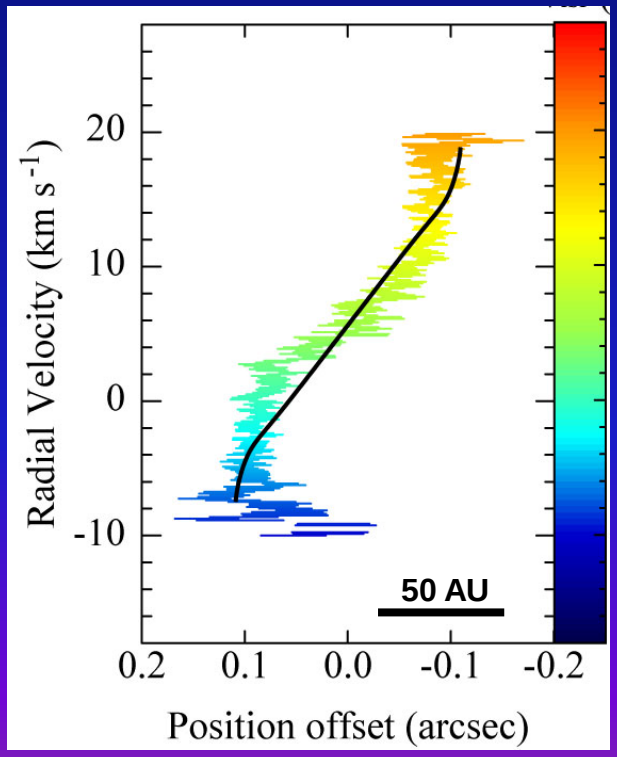


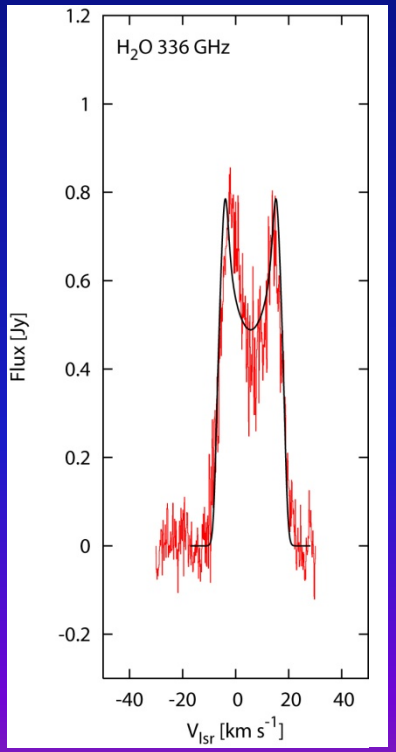
Moment 0 (contour) and 1 (color) maps for 321/336 GHz lines (Hirota et al. 2014)

Position-velocity diagram

- Quasi-linear velocity gradient found in 336 GHz line
  - Simple model of edge-on rotating ring-like structure
  - T_{ex}>3000 K, thermal excitation (e.g. Alcorea & Menten 1993)
  - $n(H_2O)$~5 X10^5 cm^{-3}
  - R_{in}~45 AU, R_{out}~50 AU
  - M ~ $7M_{Sun}$







PV diagram and spectrum of 336 GHz H_2O line (Hirota et al. 2014)

JCMT project

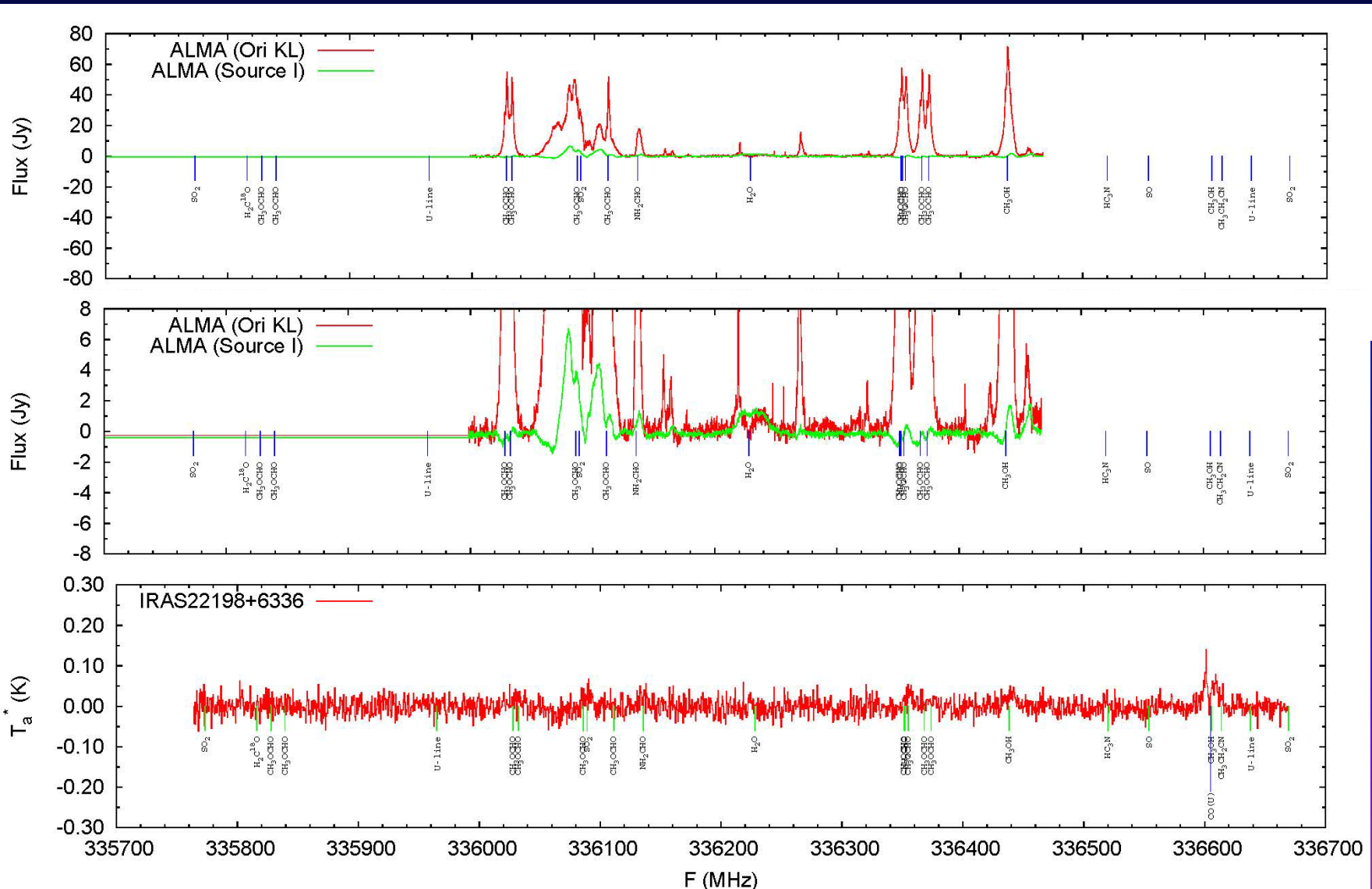
- ***Is Source I peculiar?***
  - **Associated with SiO masers**
  - **Submillimeter H_2O lines**
  - **Optically thick H^- free-free emission**
- **Yes**
  - **Why?**
- **No**
  - **We can study disk/outflow system around HM-YSOs with H_2O lines at high resolution even without SiO masers (i.e. H_2O is ubiquitous in SFRs)**

JCMT observations

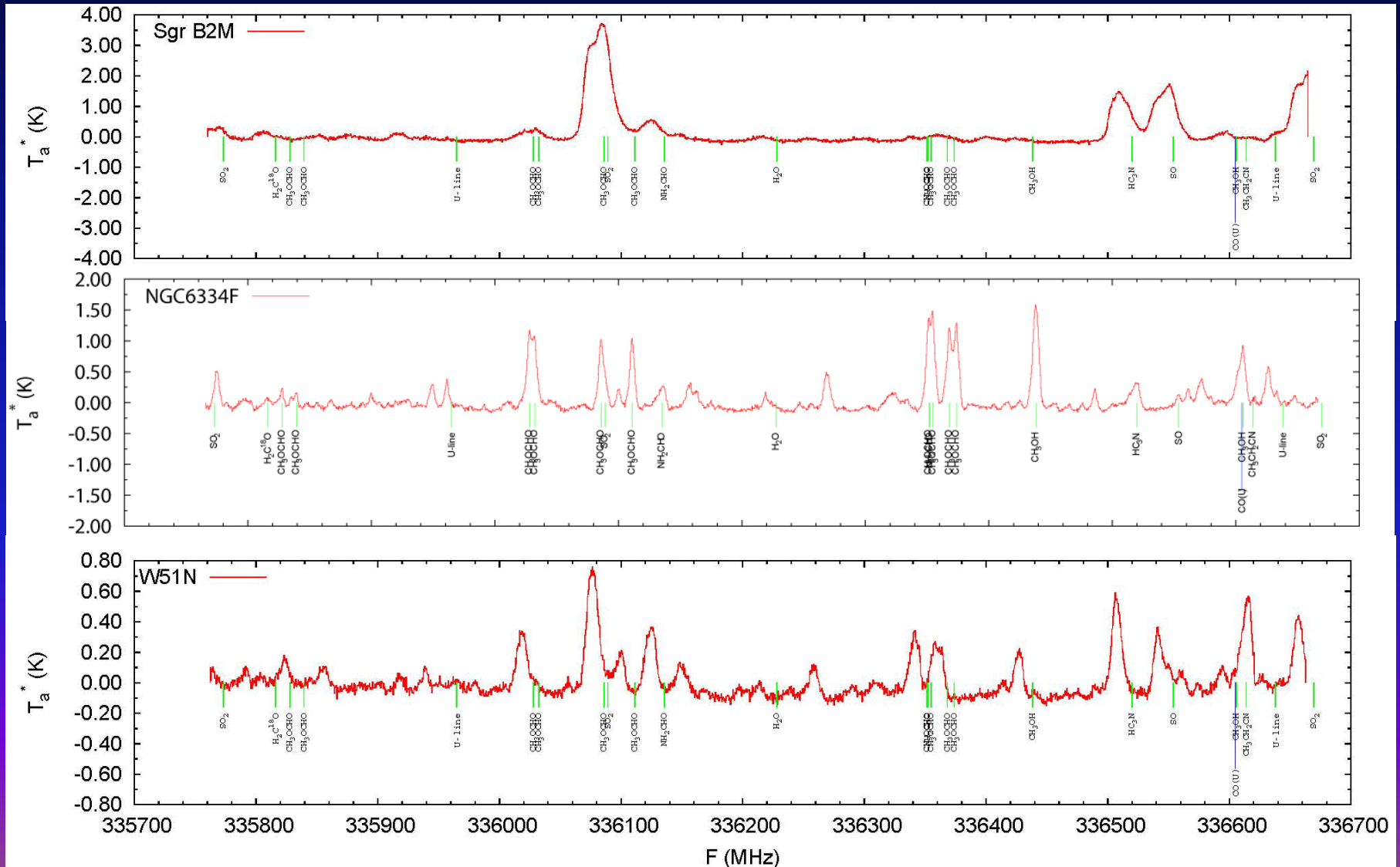
- Target line; 336 GHz H_2O (v=1)
  - HARP receiver (but used only one receiver)
  - ~2 hours/each source
- Target sources; high-mass YSOs
  - Possibly associated with disk traced by 6.7 GHz CH_3OH masers
  - Nearby (<2 kpc) to resolve structures with ALMA
  - M15ai037; LST 17-19h (southern sources)
  - M15bi003; LST 20-24h (northern sources)
  - Total 13 sources observed (not all proposed sources)

Ta*=1 K corresponds to ~30 Jy (is it correct?)

Results (negative)



Results (positive?)



Summary

- We have carried out survey of sub-mm vibratinoally excited H_2O line at 336 GHz toward high-mass YSOs
- A few sources show possible detection?
- Future ALMA observations will be able to confirm detection and to reveal circumstellar structures at ~100 AU scale (but not in cycle 4 …)
- Survey of new H_2O lines will be important not only for high-resolution follow-up observations but also statistical studies

- We would like to thank support of EAO and JCMT staff!