

# Methanol Maser associated with the Molecular Ring around Binary System giving birth to Strong Molecular Outflow Ori-S6

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Warszawa 2012

**Microwave**

**Amplification by**

**Stimulated**

**Emission of**

**Radiation**

$$I = I_0 \exp(-\tau)$$

if  $\tau < 0$  matter

**amplifies background**

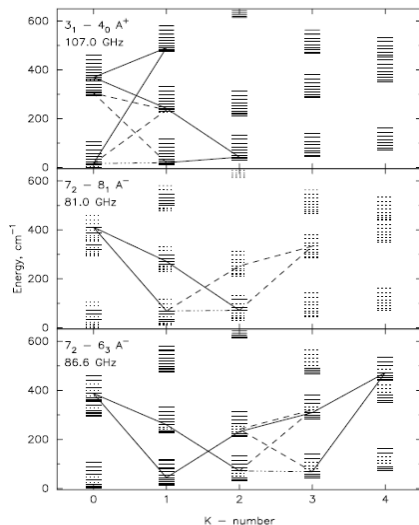
**instead of obscuring it**

Maser effect is realized due to

**the pumping mechanism**

**which reflects the balance between**

**population transfer processes**



# RadioAstron project

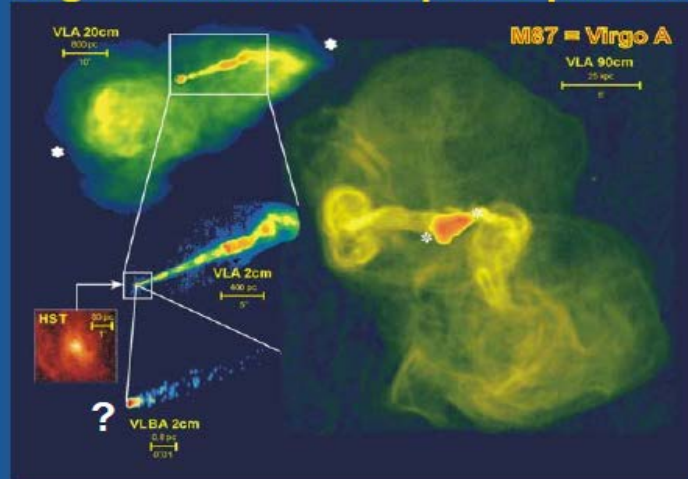
**1 year anniversary of launch today!**

<http://www.asc.rssi.ru/radioastron/index.html>

## Main Parameters of the RadioAstron Mission

Frequency band [GHz]	0,327	1,665	4,83	18 - 25
Bandwidth, 2-pol. [MHz]	2 x 4	2 x 32	2 x 32	2 x 32
Fringe size at 350.000 km baseline [micro arcsec]	540	106	37	7 - 10
Detection limit 1- $\sigma$ [mJy] (ground radio telescope GBT, 16/4 MHz bandwidth, 300 s integration)	42	4	4	10

**The unprecedented super high angular resolution up to 1  $\mu$ arcsec**



# ATCA



# MERLIN



# SMA



# VLA





# class II maser pumping: surveys and models (see Sobolev et al. 2001, Cragg et al 2005)

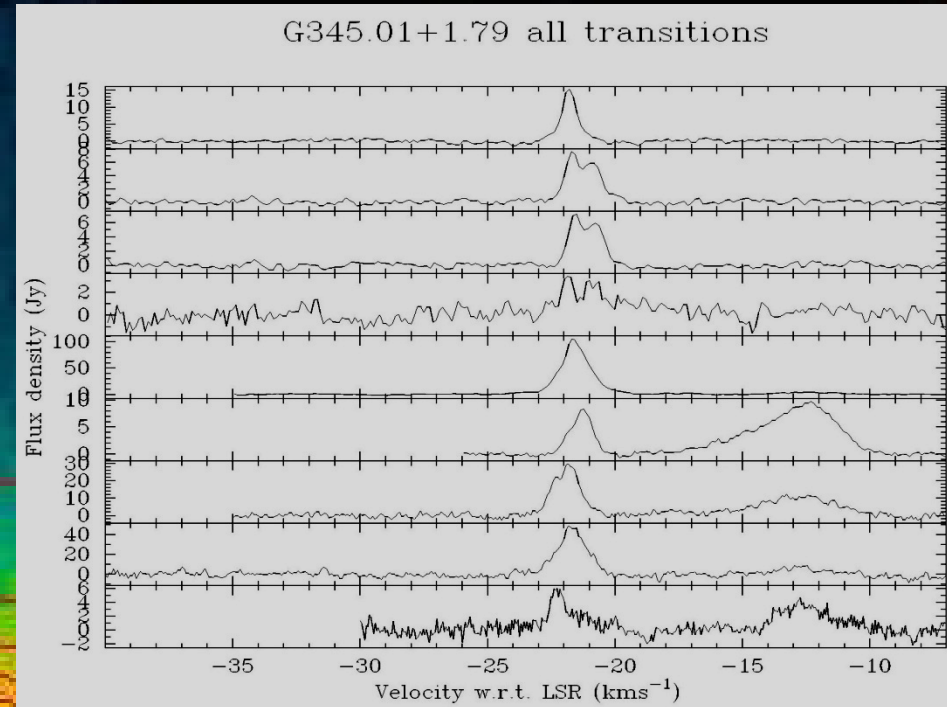


Cragg

107, 156, 23,  
19, 37, 38, 86,  
93, etc. GHz



Ostrovskii



Caswell



Ellingsen

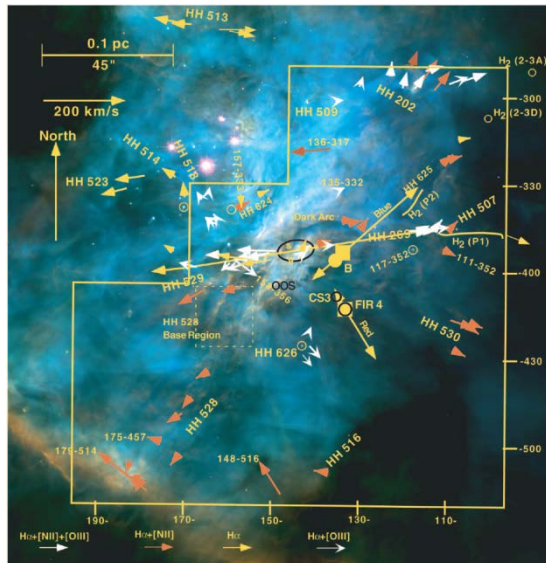


Henkel



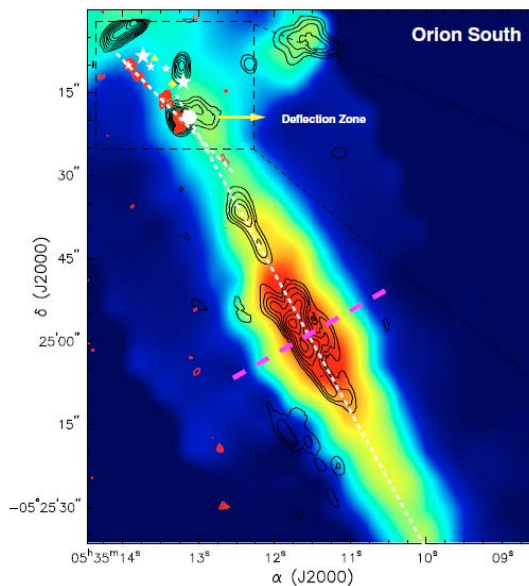
Voronkov

Ori-S 3 arcmin



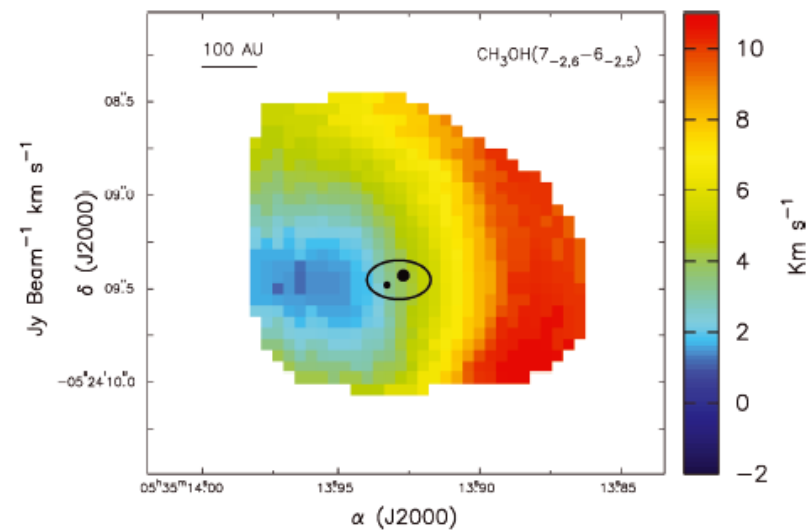
(O'Dell & Doi 2003)

Ori-S6 outflow 1.5 arcmin



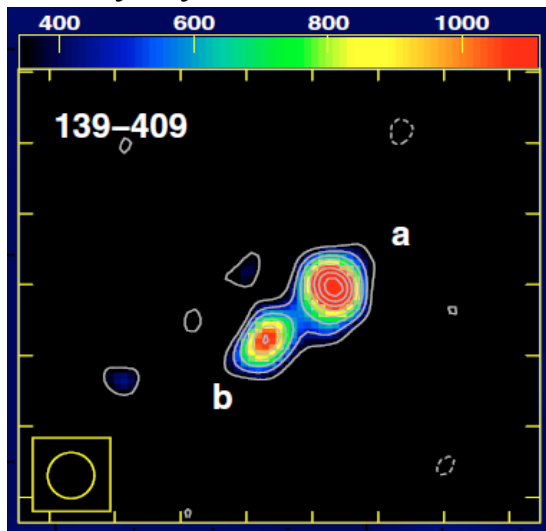
(Zapata et al. 2010)

Rotating ring 2.5 arcsec



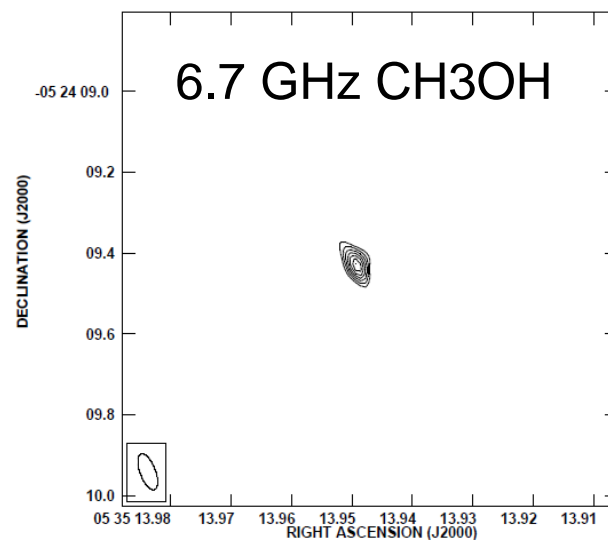
(Zapata et al. 2009)

Binary system 0.6 arcsec



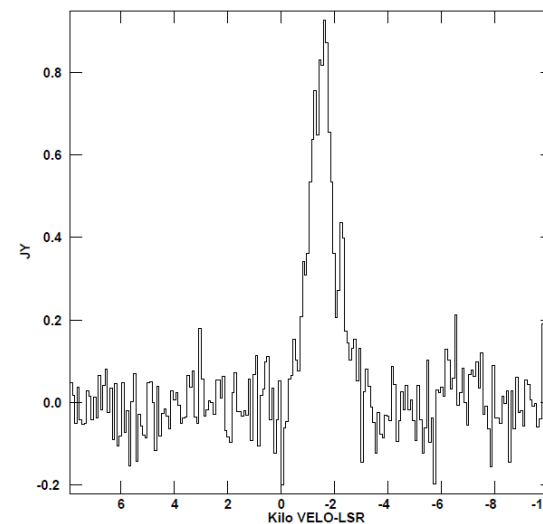
(Zapata et al. 2007)

Maser 1.2 arcsec



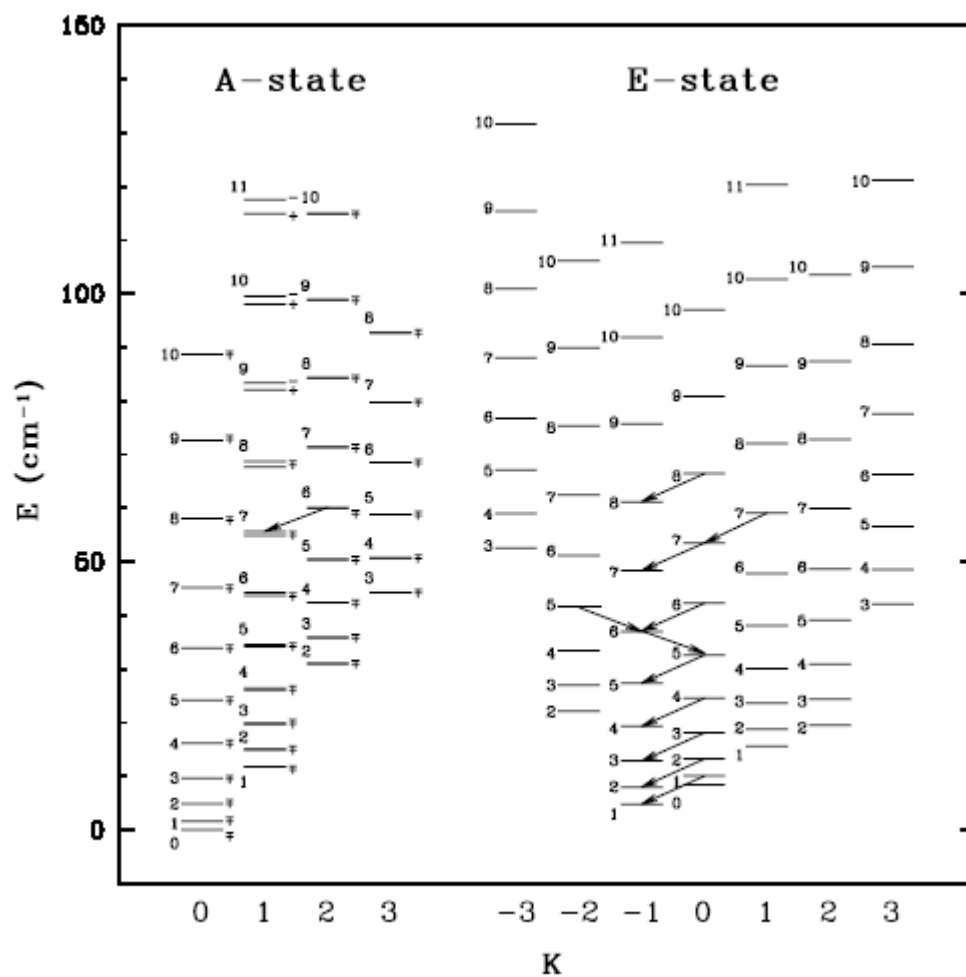
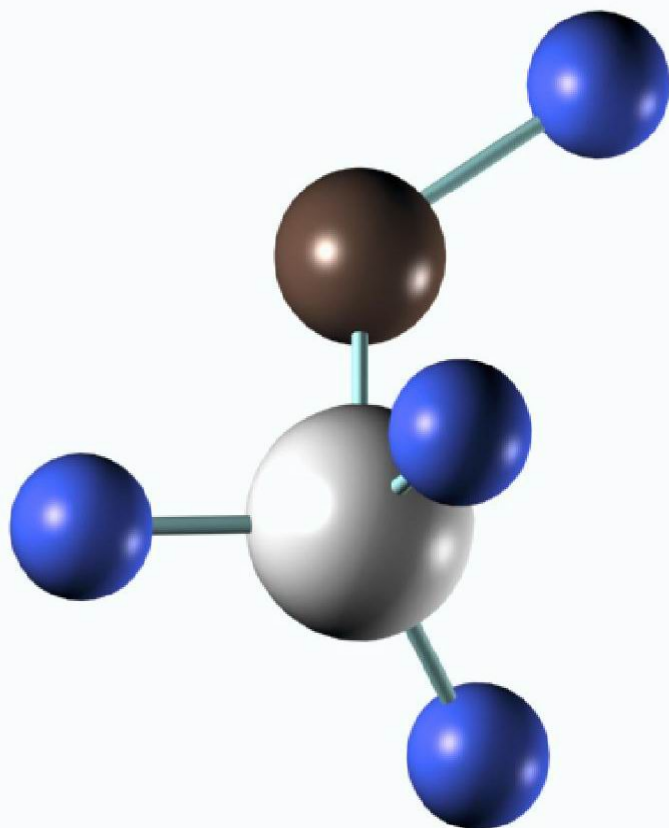
this work

Maser line spectrum



this work

# Methanol

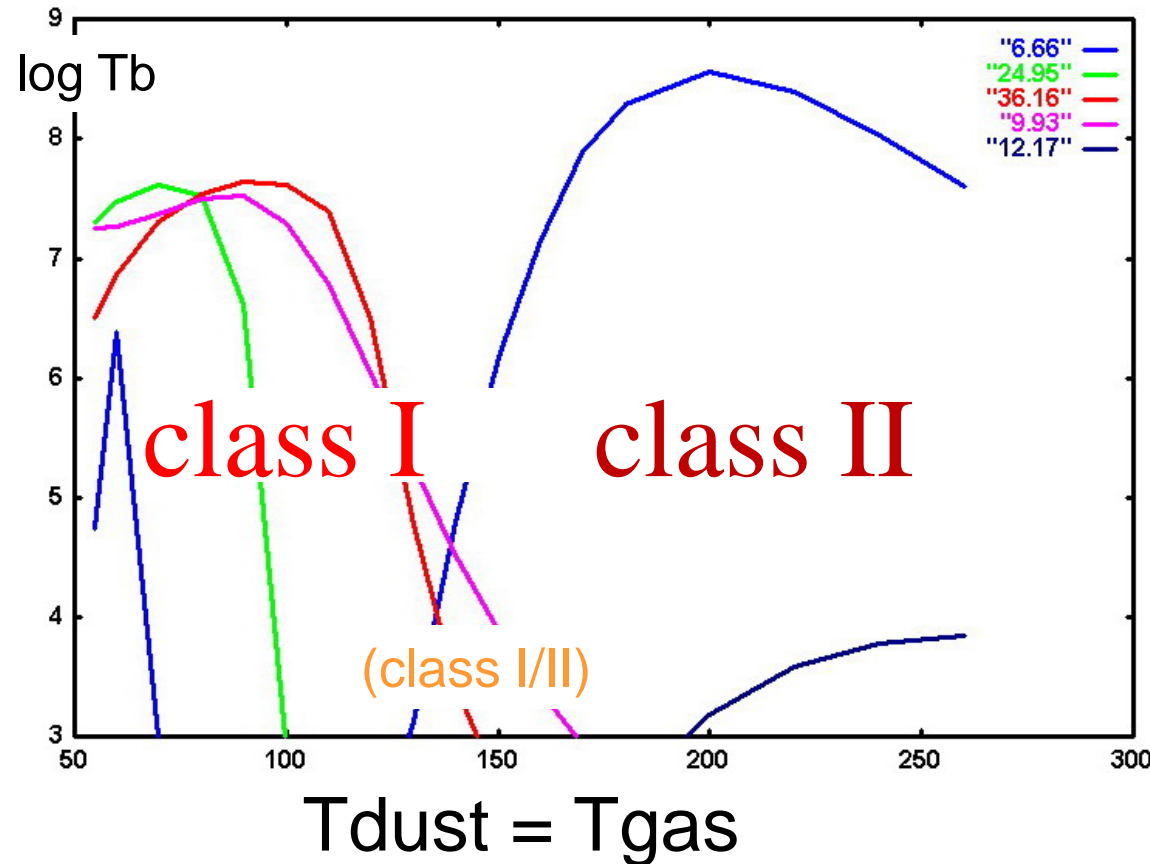
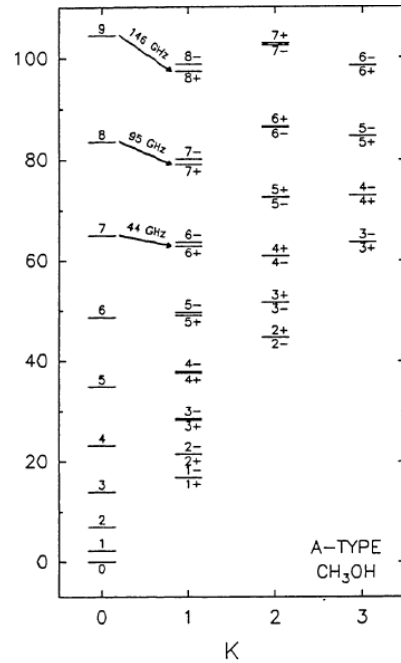
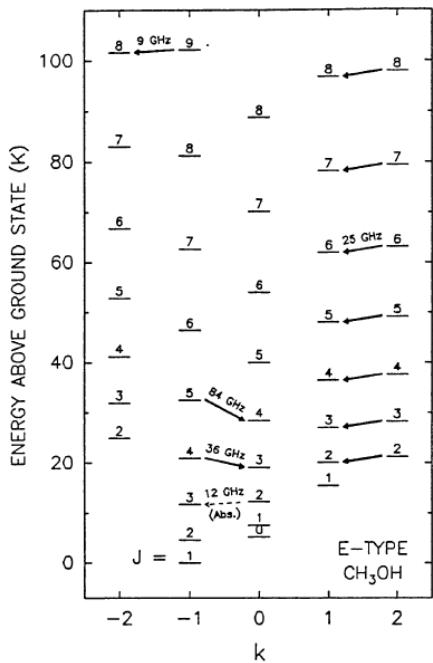




# Different classes of Methanol Masers display strong emission in different transitions:

**class I – at 25 GHz, 44 GHz, 36 GHz, etc.**

**class II – at 6 GHz, 12 GHz, 157 GHz, etc.**

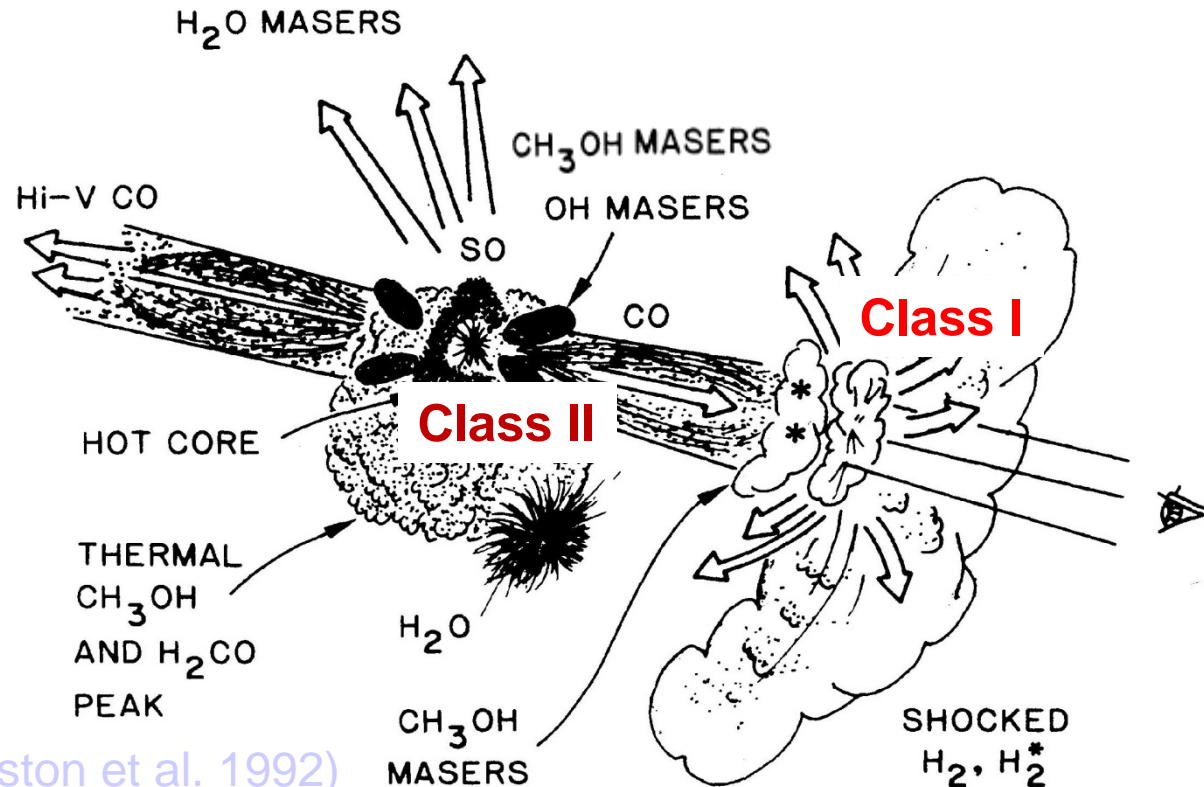




# Strong Methanol Masers are found in vicinity of Massive Stars

There are 2 classes of Methanol Masers:

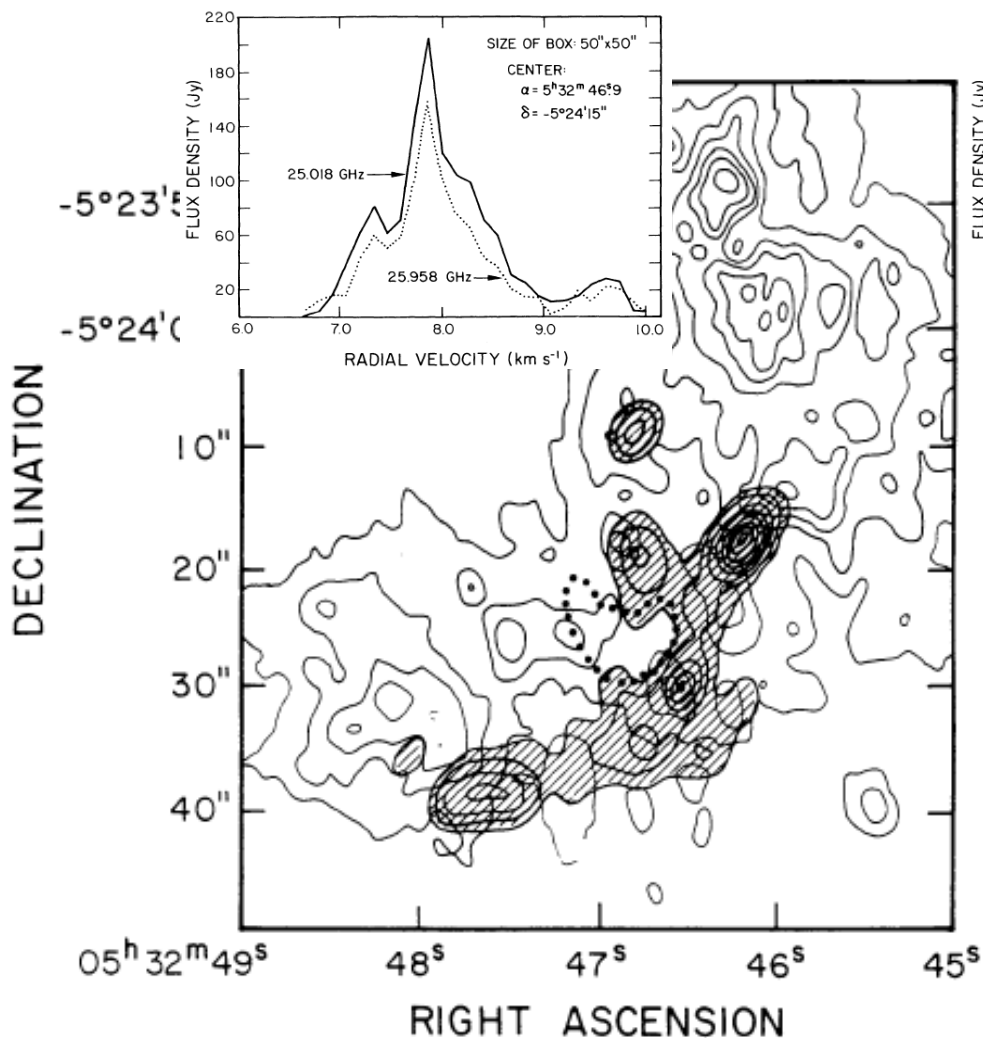
**class I trace the shocks**  
**class II are close to YSOs**



(Johnston et al. 1992)

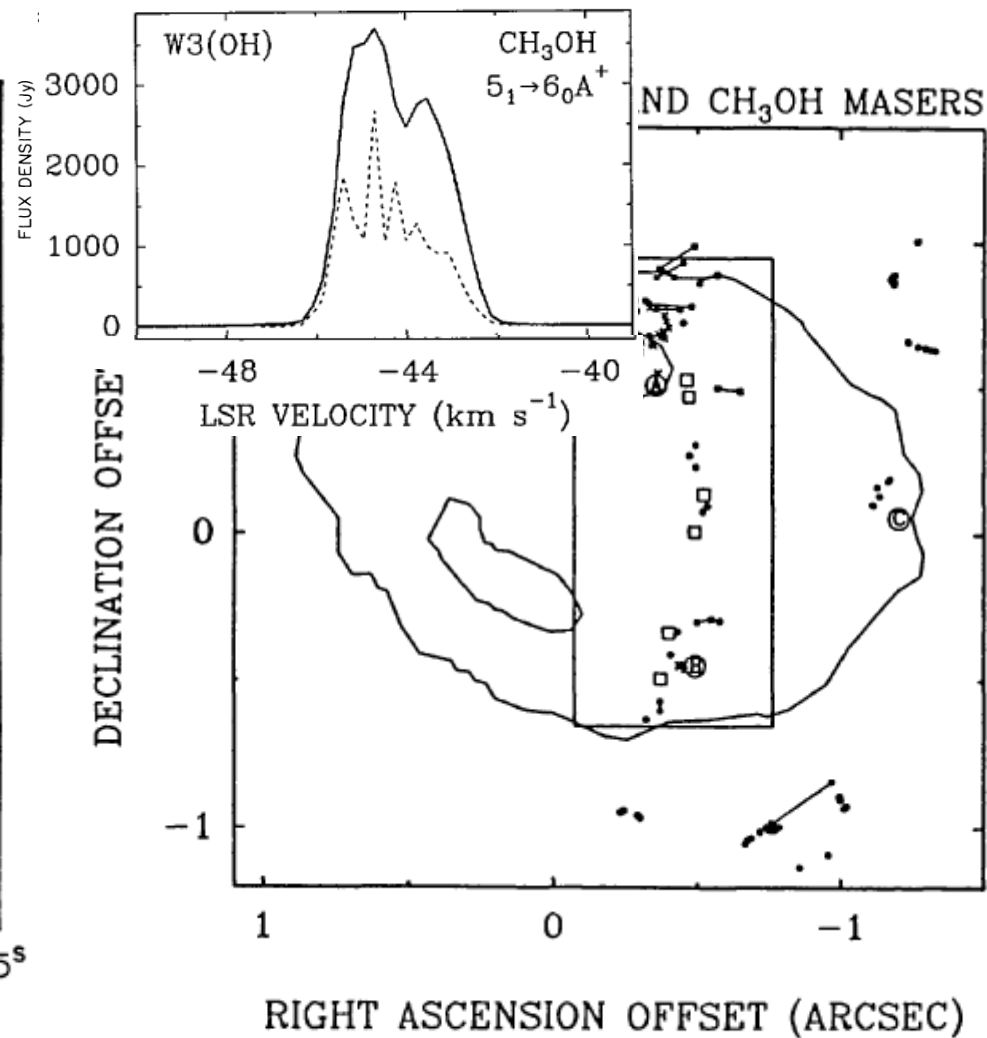
# Ori-KL Class I masers ONLY

$T_b > 10^5 K$  (Johnston et al. 1992)



# W3(OH) Class II masers ONLY

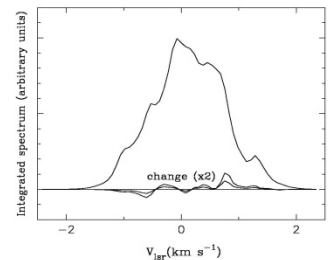
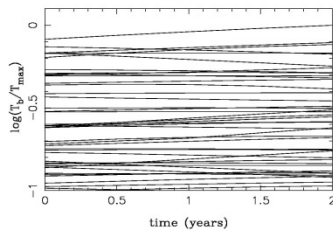
$T_b > 10^{12} K$  (Menten et al. 1991)



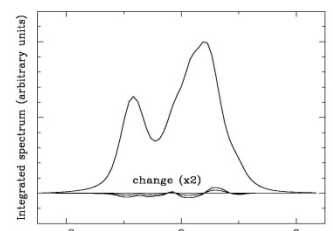
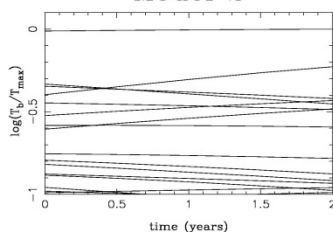
# class I masers at 25 GHz in OMC-1

(Sobolev, Wallin & Watson 1998)

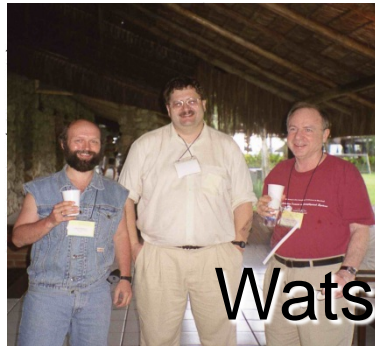
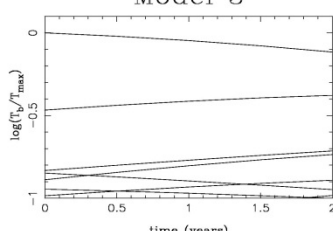
Model 1



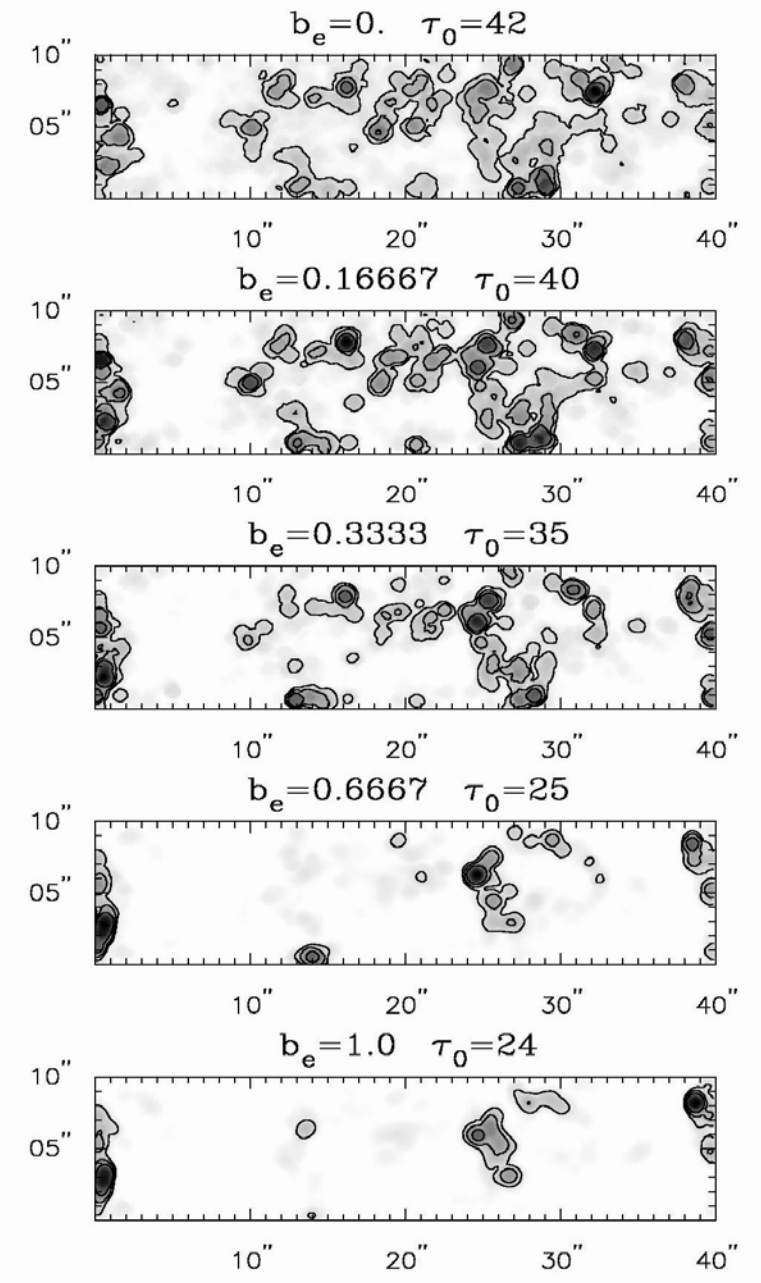
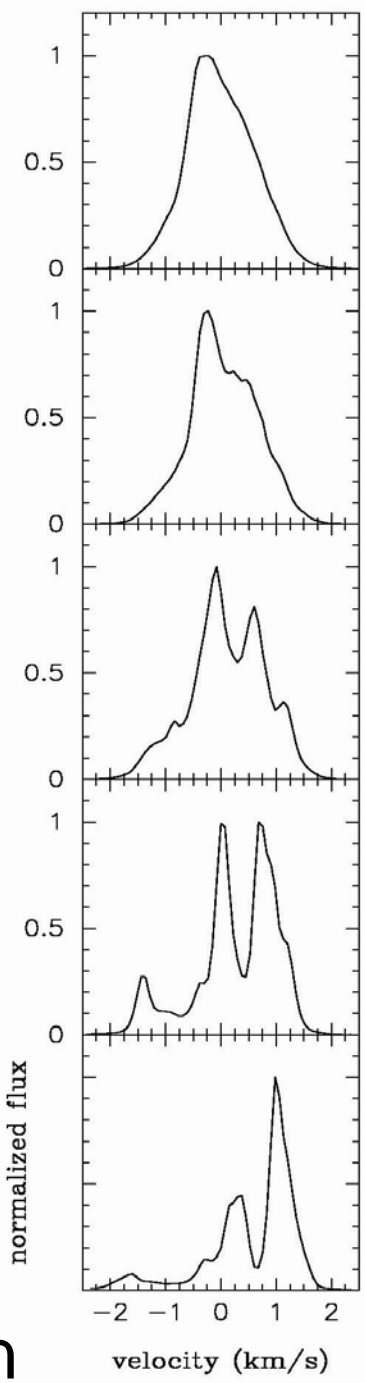
Model 2



Model 3



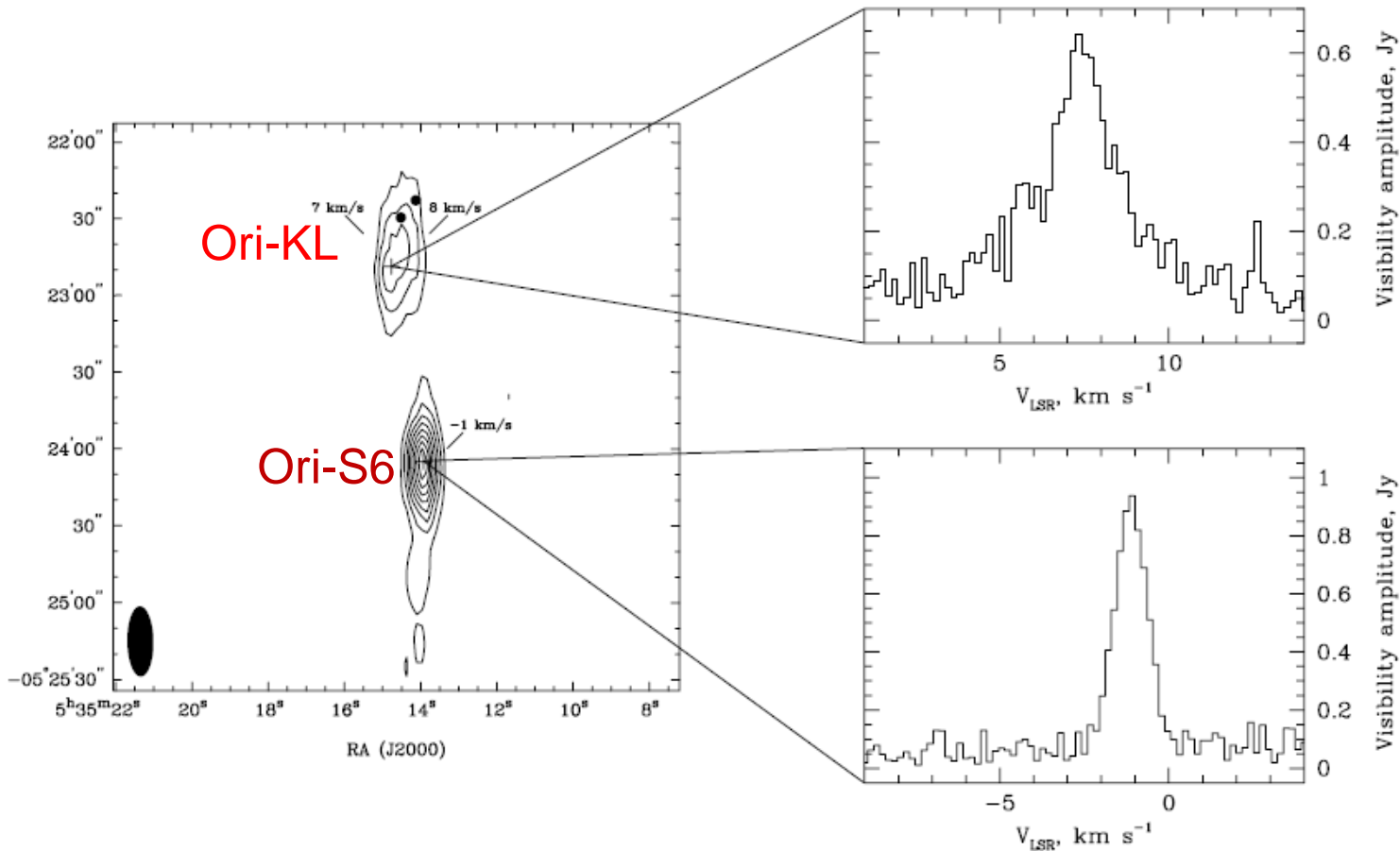
Watson



maps filtered with 1.1''



# ATCA was used to map 6.7 GHz CH<sub>3</sub>OH emission (Voronkov, Sobolev et al. 2005)



normal  
 $V_{\text{lsr}}$  and  $\Delta V$

**unusual**

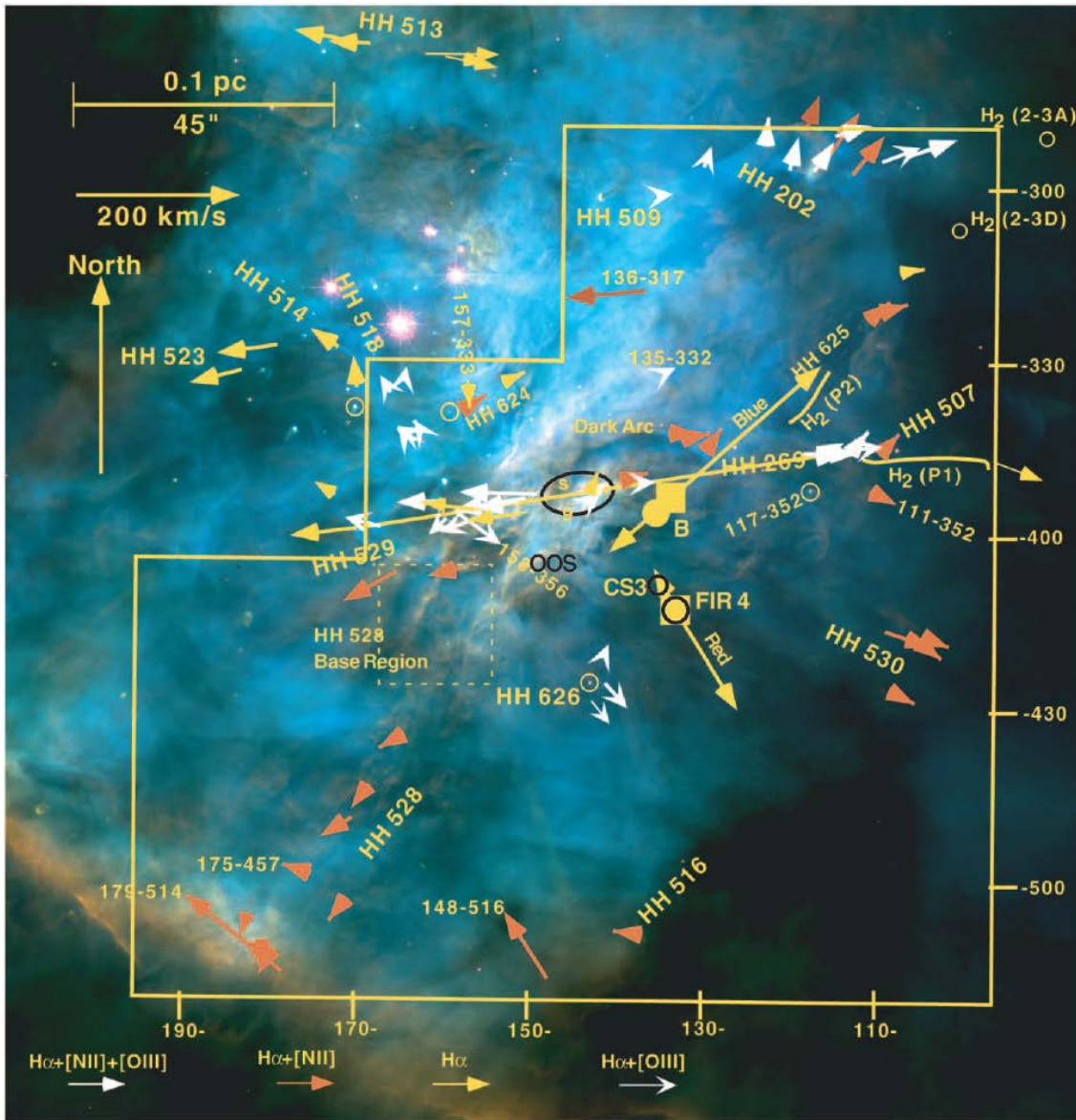
$V_{\text{lsr,mas}} - V_{\text{lsr,th}} \sim -8 \text{ km/s}$

$\Delta V$  is too narrow

# Orion-S

high proper motion features

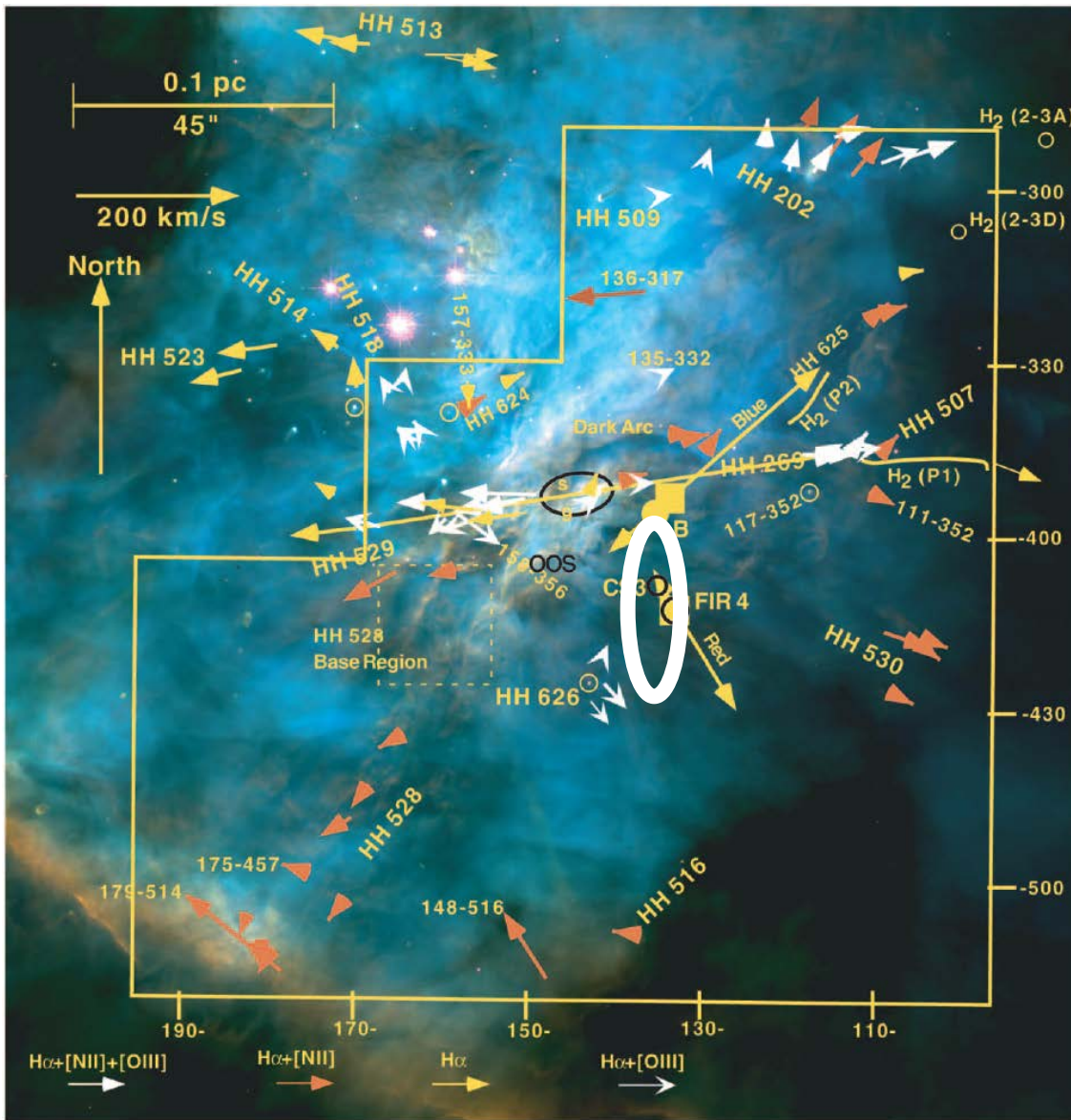
(O'Dell & Doi 2003)



Red is [N II], green is H $\alpha$ , and blue is [O III]

# Orion-S

high proper motion features  
(O'Dell & Doi 2003)



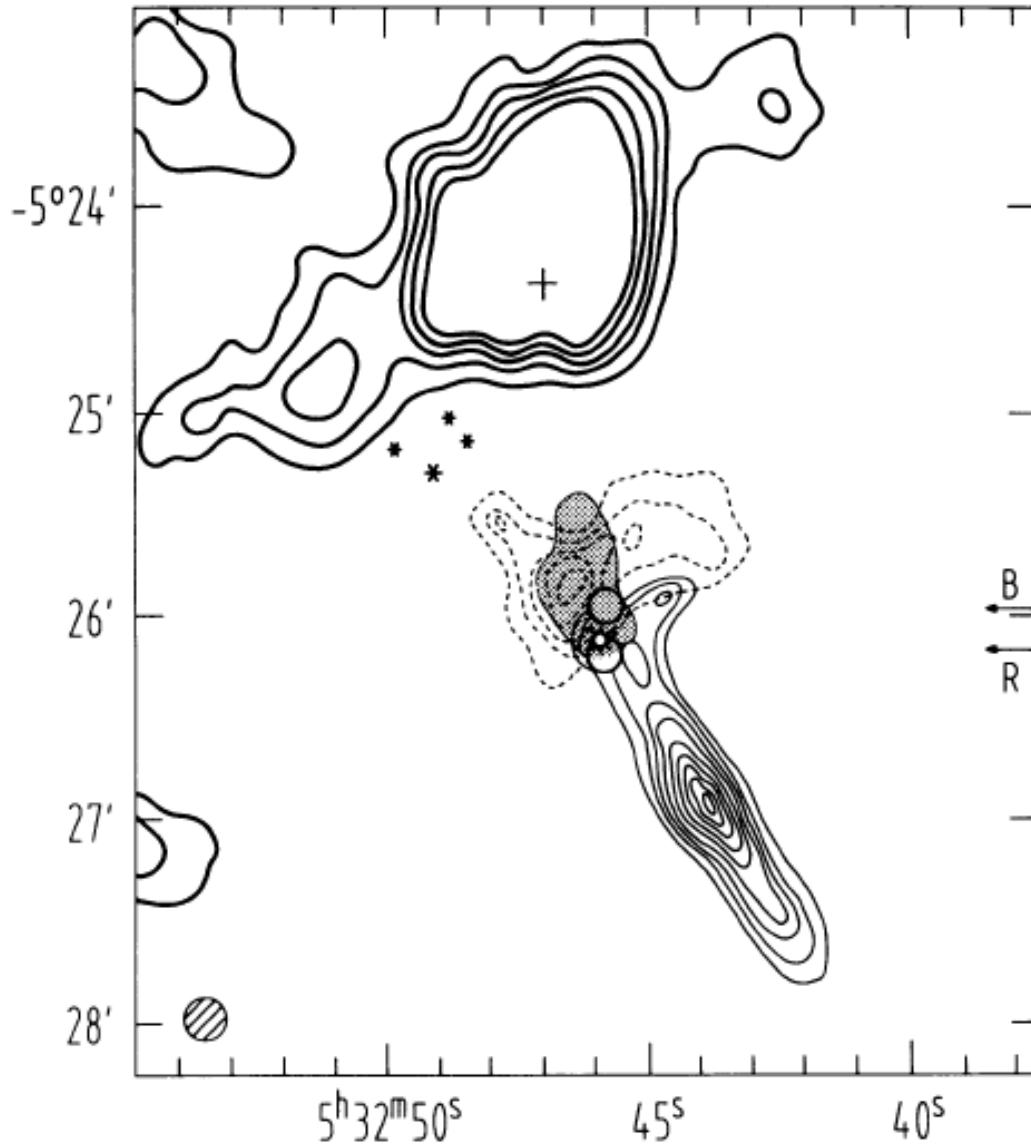
Red is [N II], green is  $H\alpha$ , and blue is [O III]



# Orion-S

## CO outflow

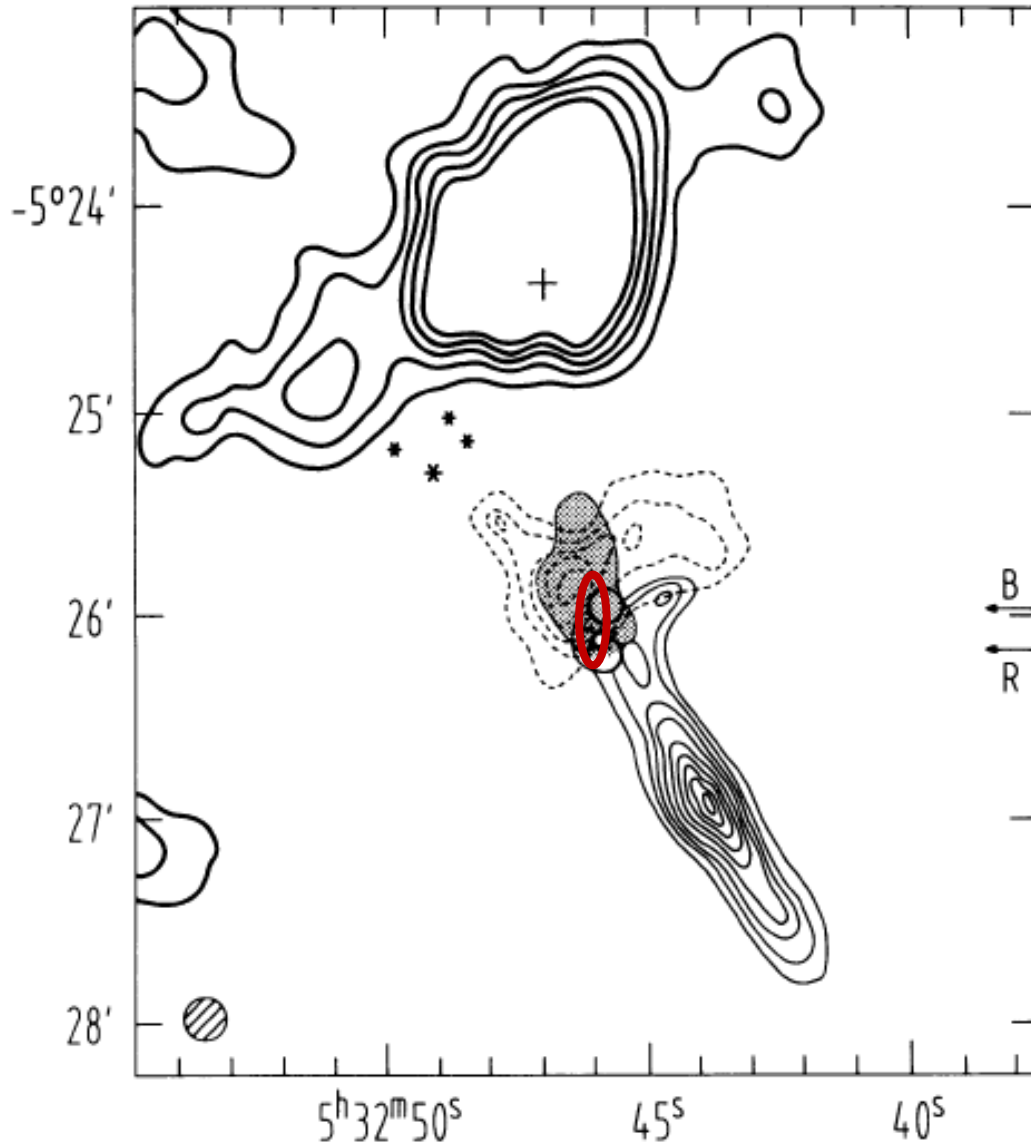
(Schmid-Burgk et al. 1990)



# Orion-S

## CO outflow

(Schmid-Burgk et al. 1990)

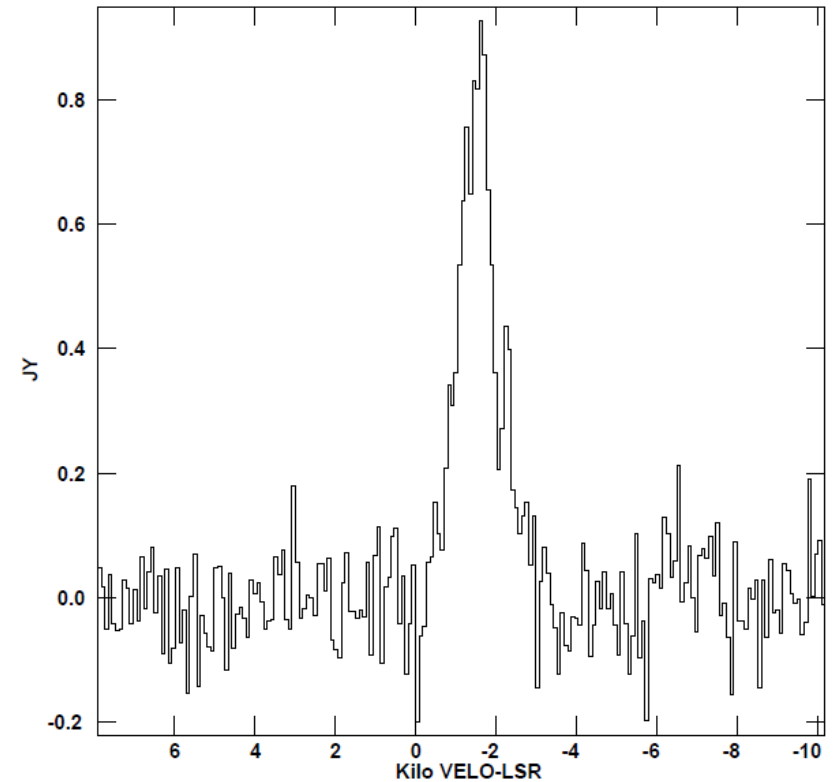
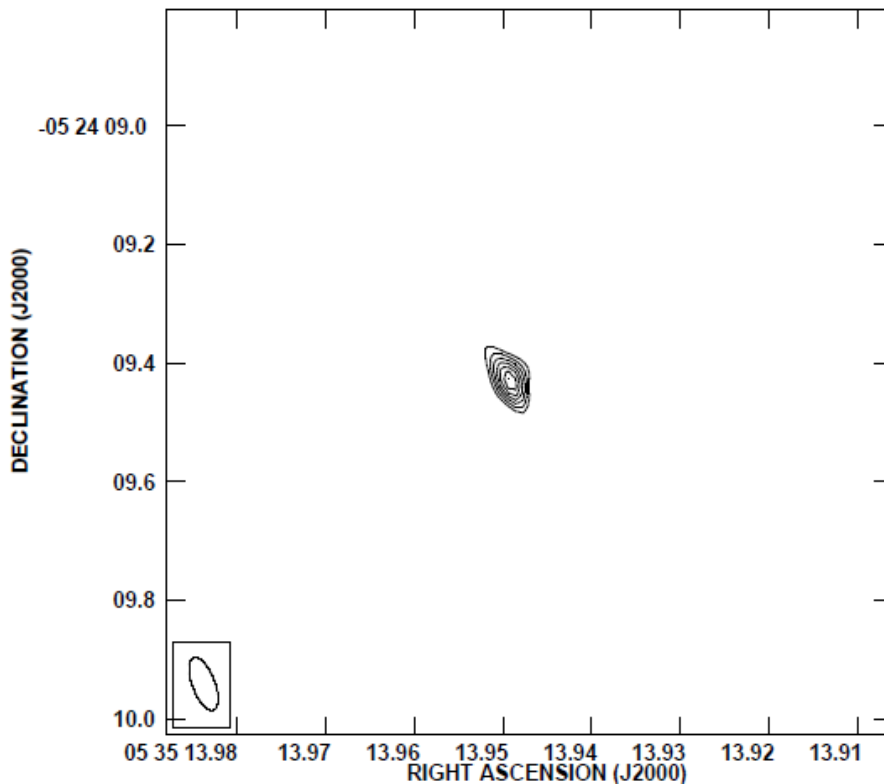


# MERLIN was used to map 6.7 GHz $\text{CH}_3\text{OH}$ emission



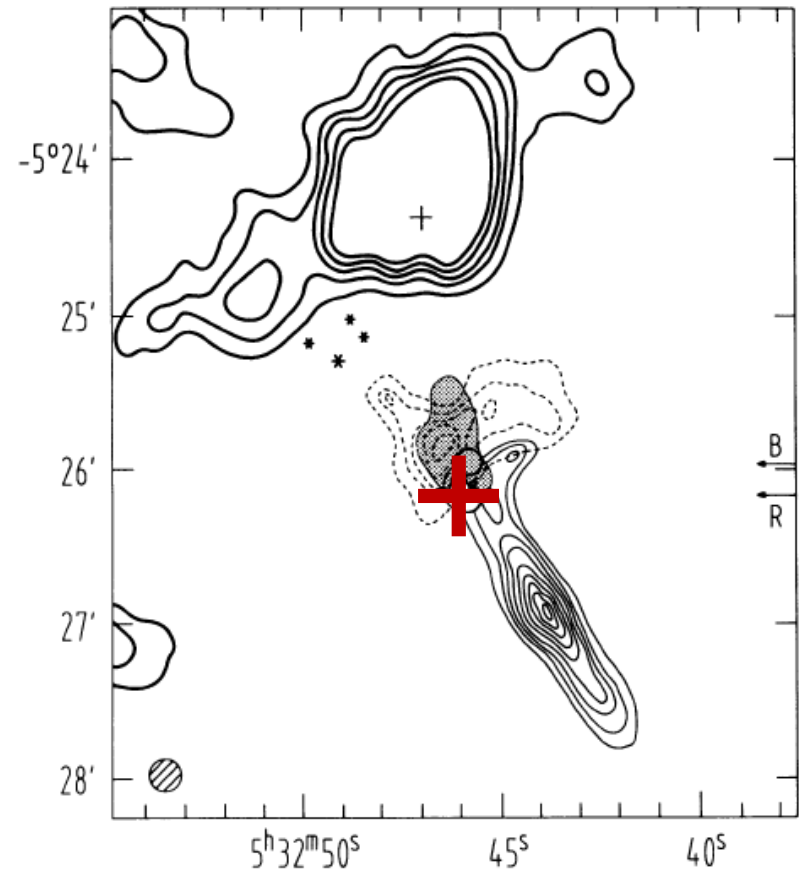
RA 05 35 13.94847 +/- 0.00011; DEC -05 24 09.4408 +/- 0.0037

achieved accuracy of position is 0.004" (!)

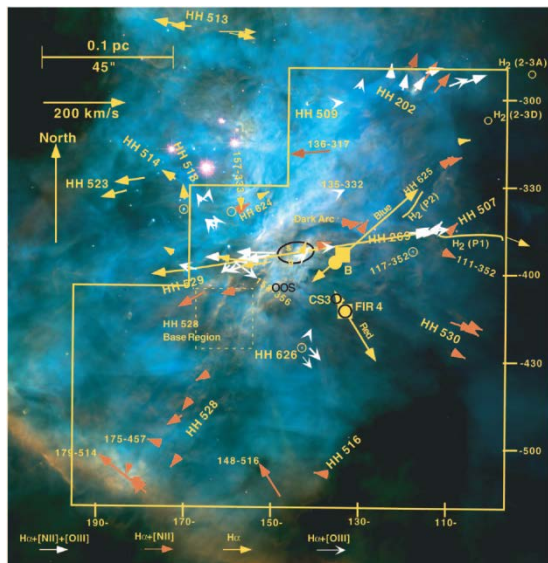




# Improved maser position

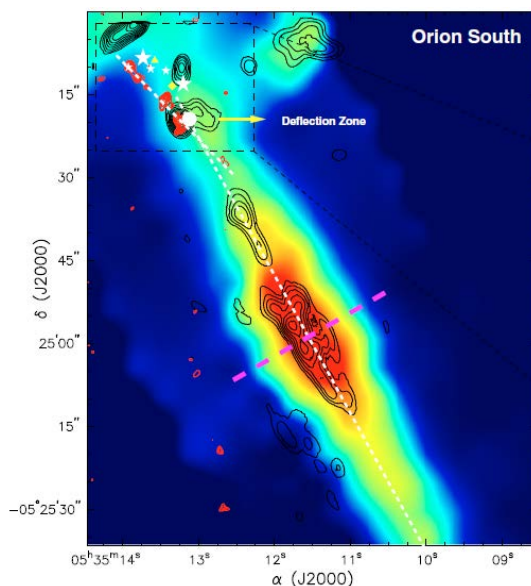


**Ori-S 3 arcmin**



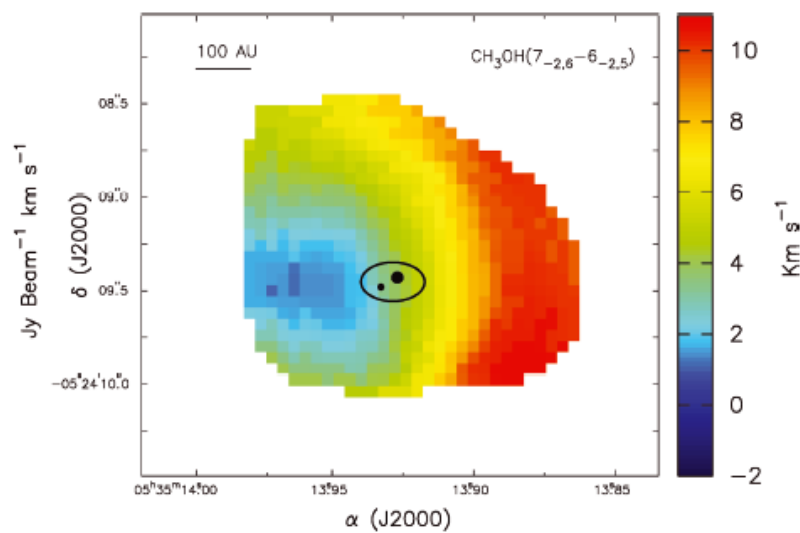
(O'Dell & Doi 2003)

**Ori-S6 outflow 1.5 arcmin**



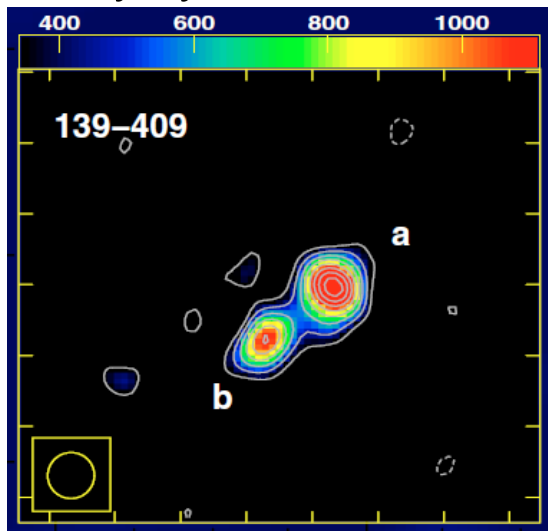
(Zapata et al. 2010)

**Rotating ring 2.5 arcsec**



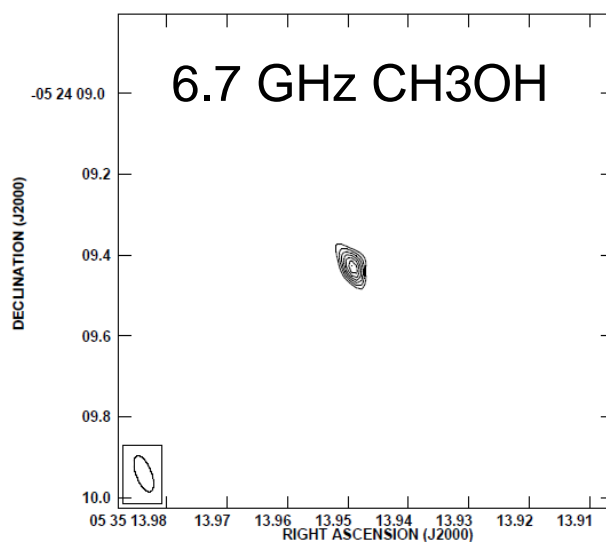
(Zapata et al. 2009)

**Binary system 0.6 arcsec**



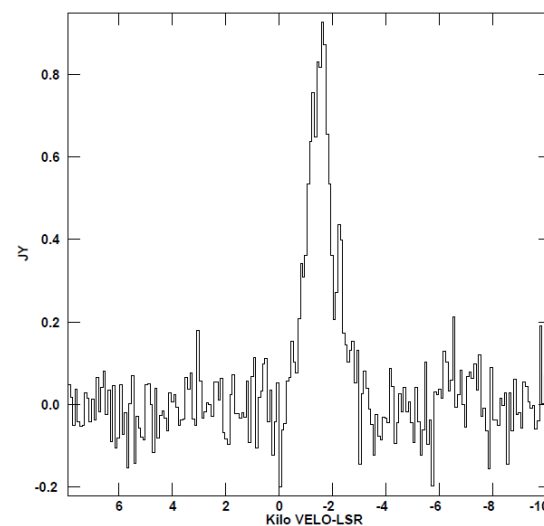
(Zapata et al. 2007)

**Maser 1.2 arcsec**

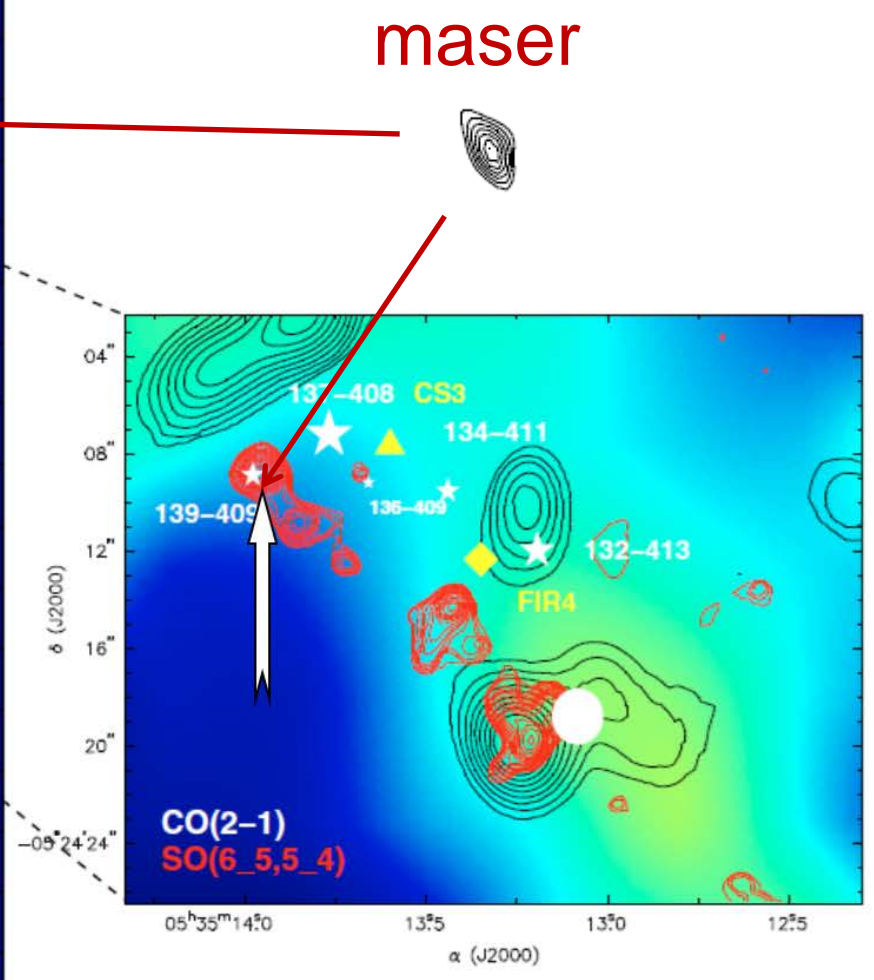
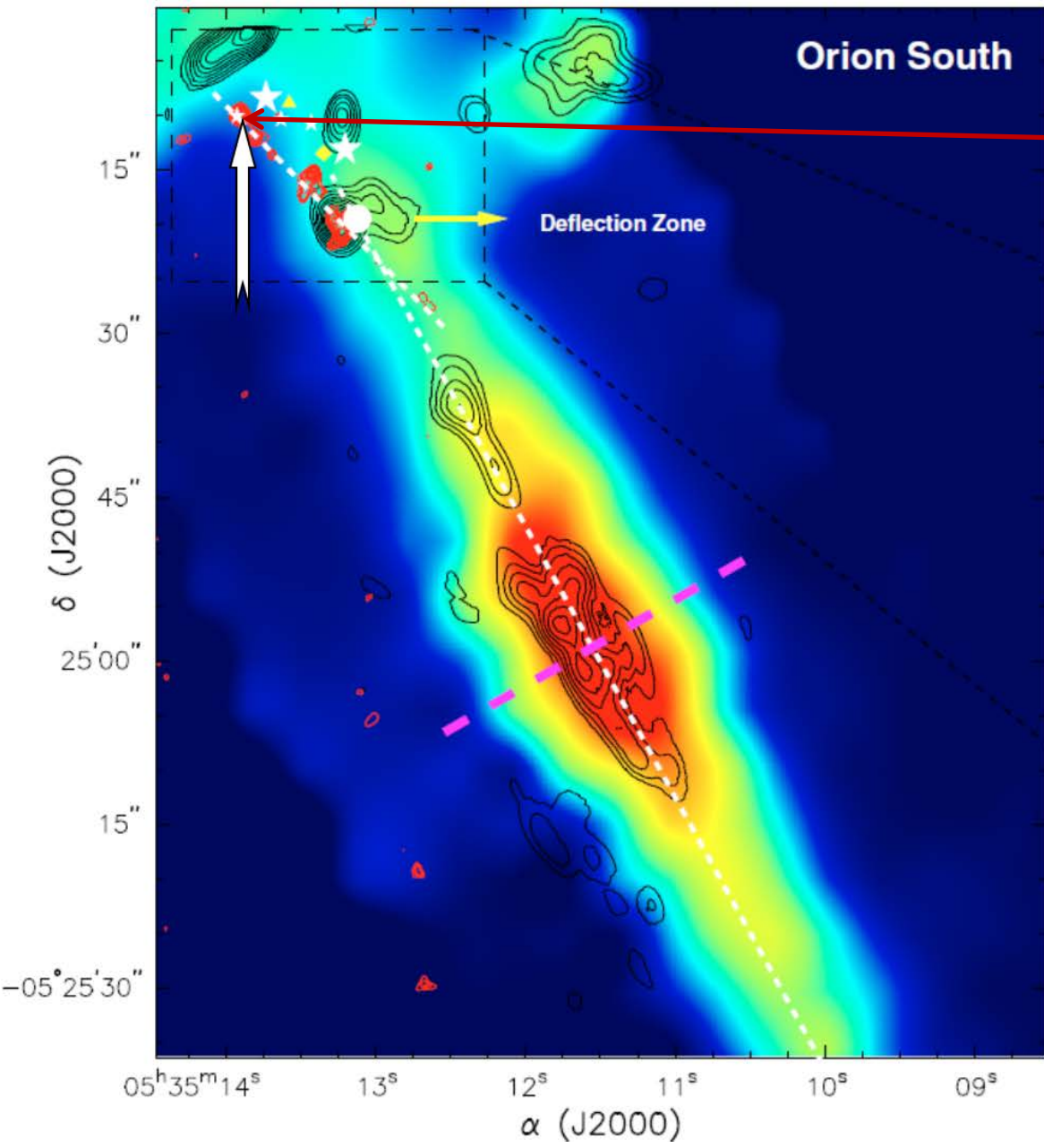


this work

**Maser line spectrum**

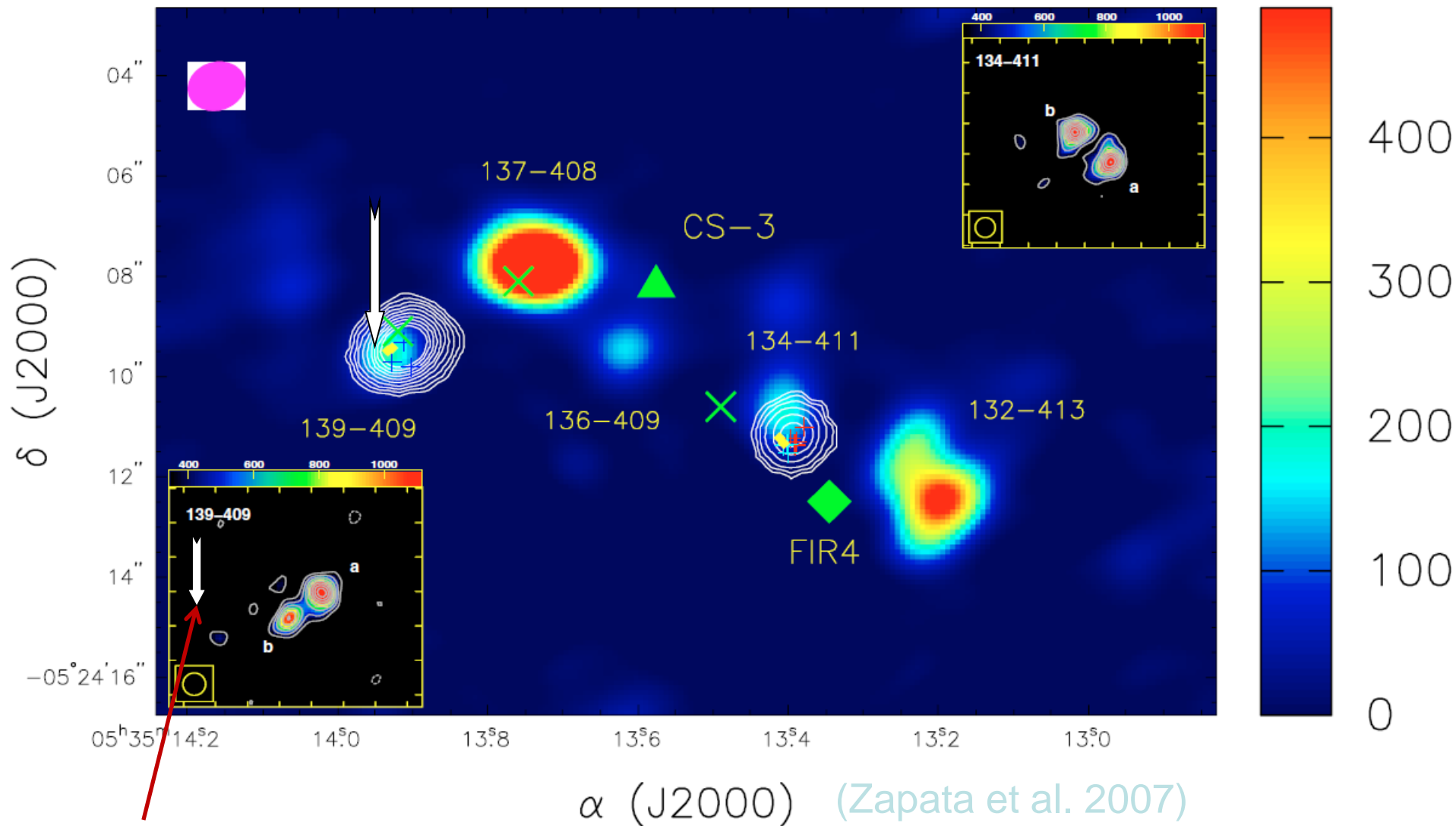


this work



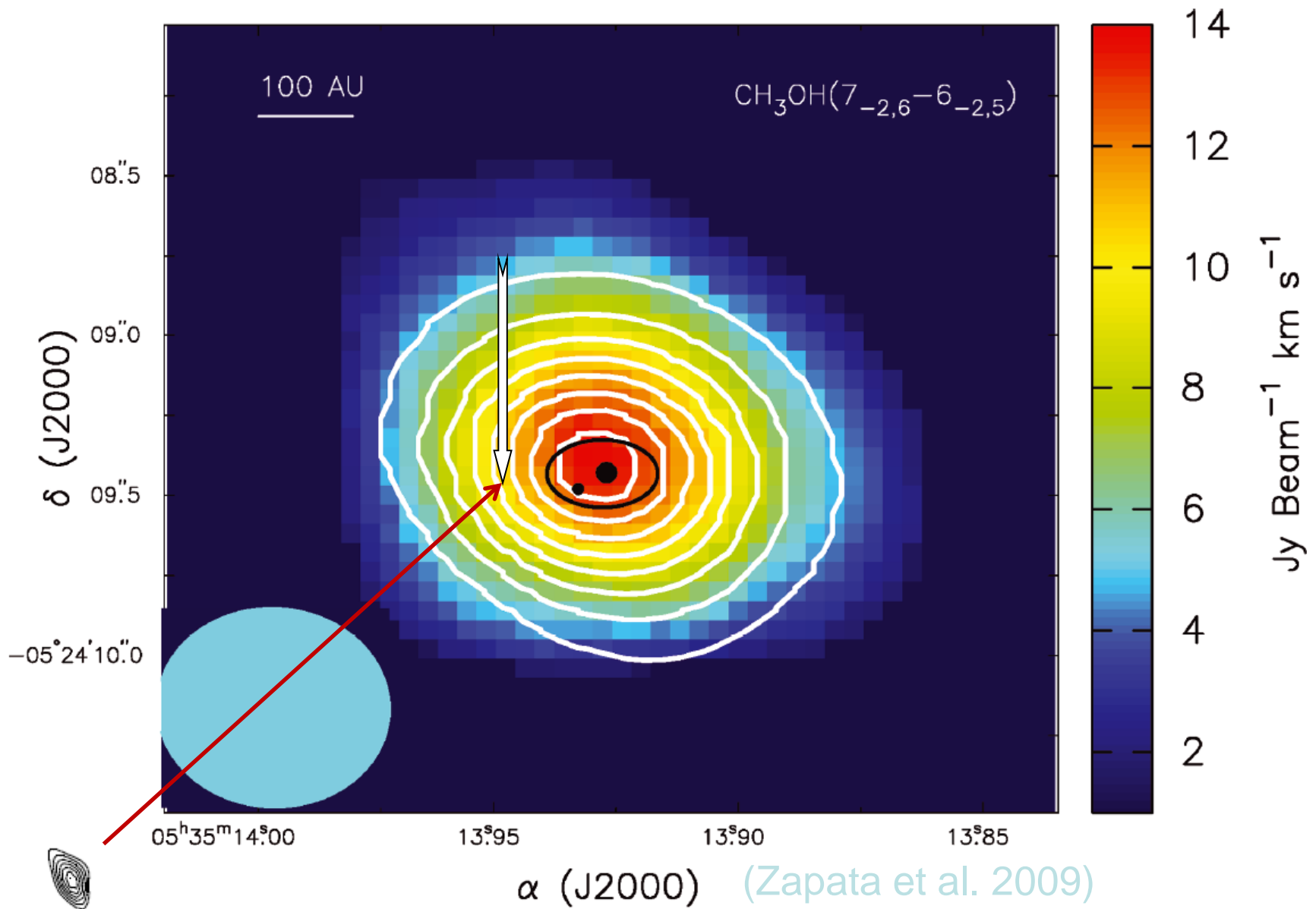
(Zapata et al. 2010)





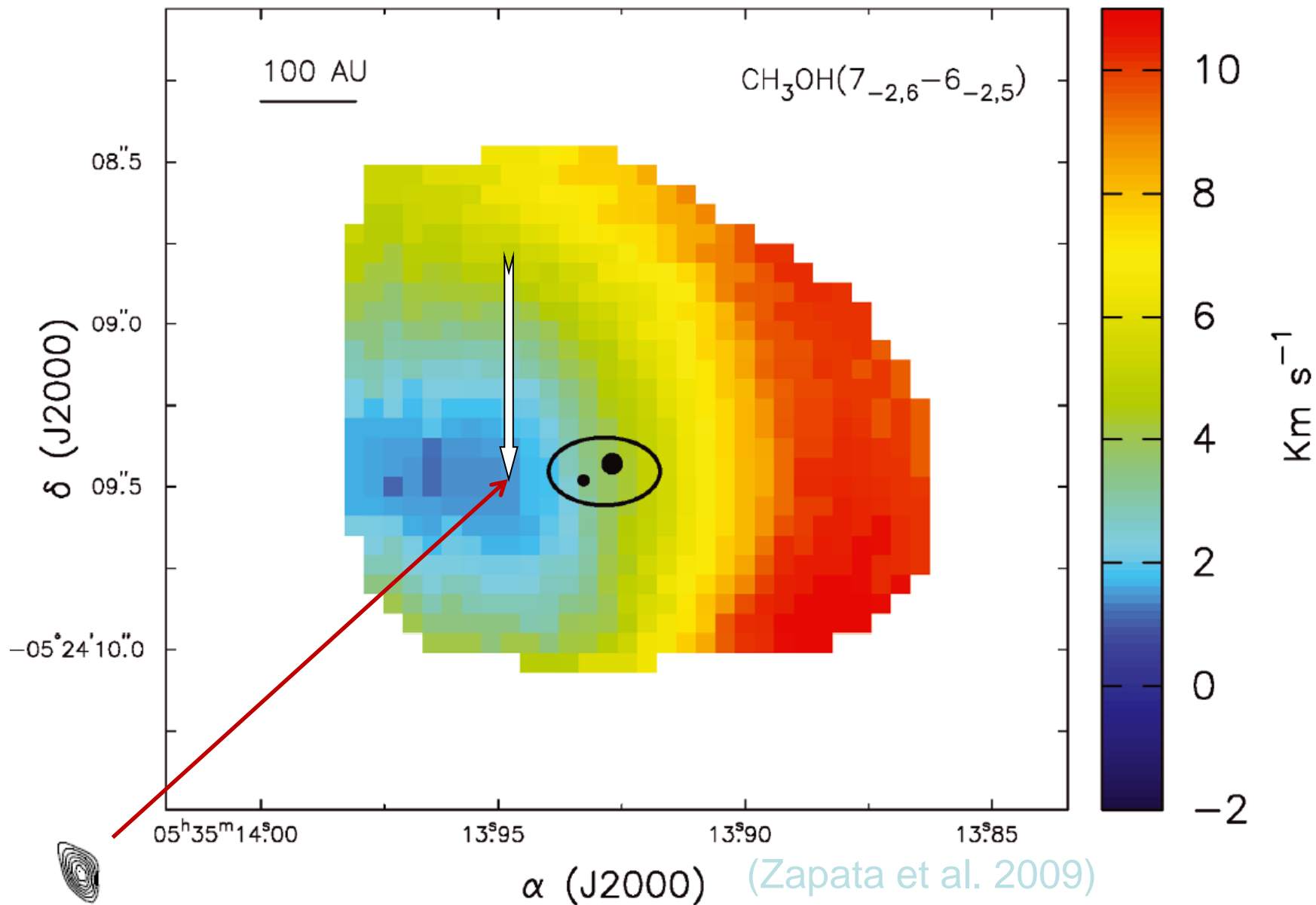
## Map of the outflow origin.

1.3 mm color image with overlaid CH<sub>3</sub>CN line contours.  
 Inserts (0.6"x0.6") show 7 mm cont. emission

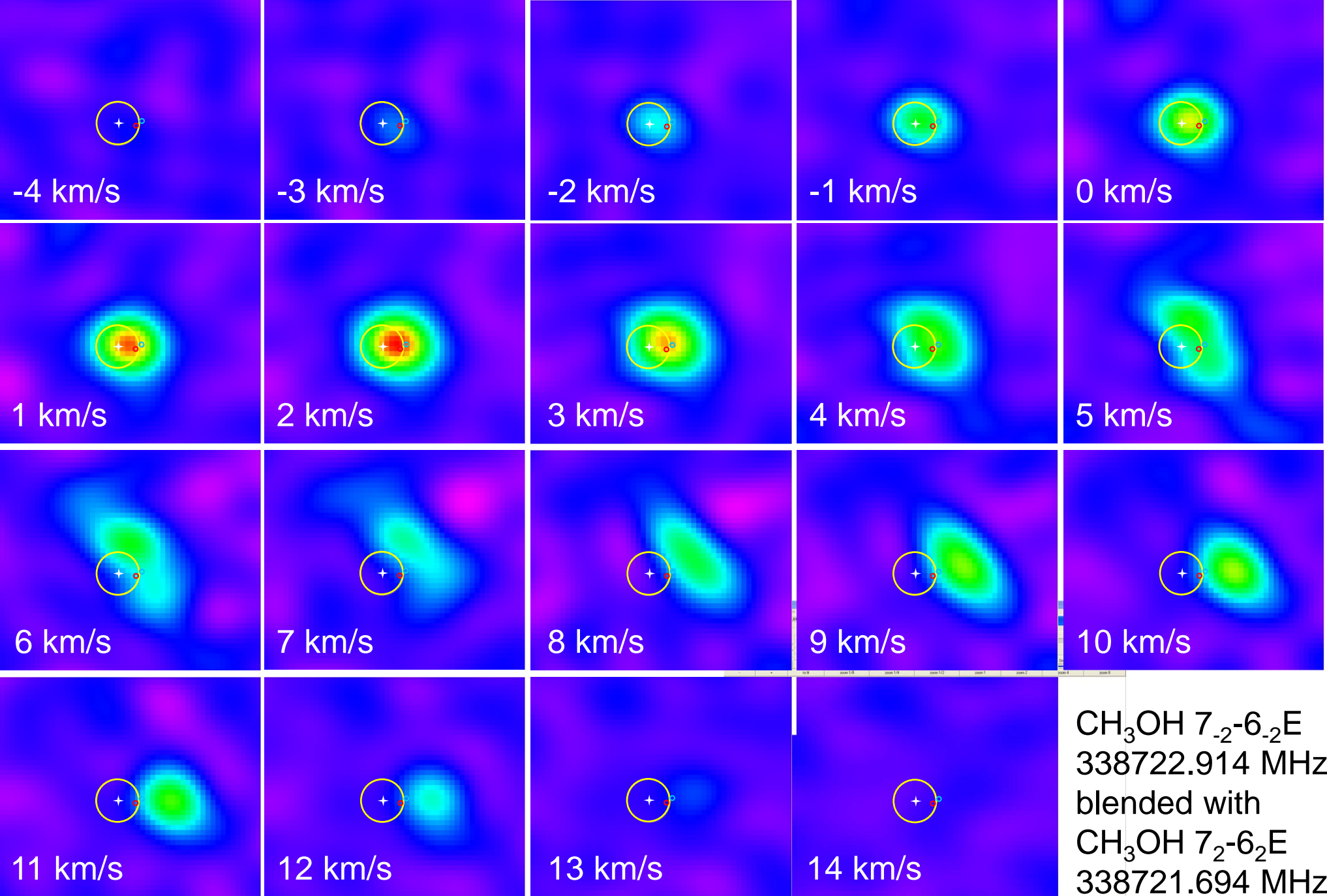


maser

Map of flux density of the thermal methanol line emission from the hot core (circumbinary ring) around 139-409

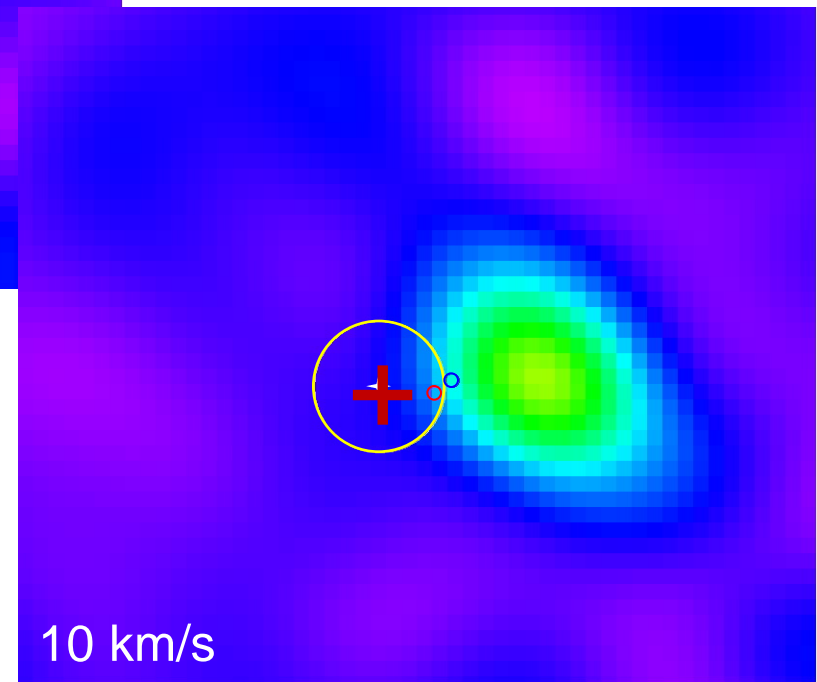
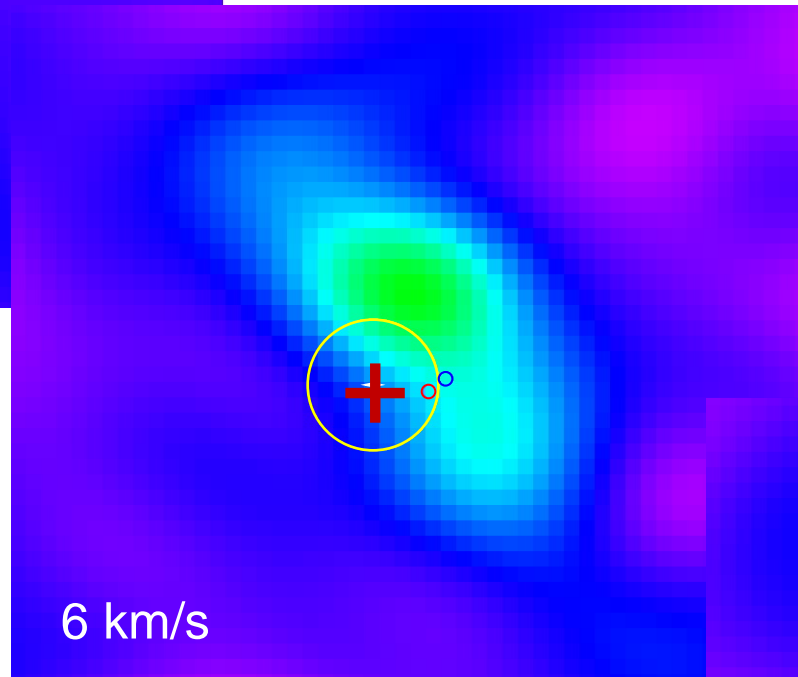
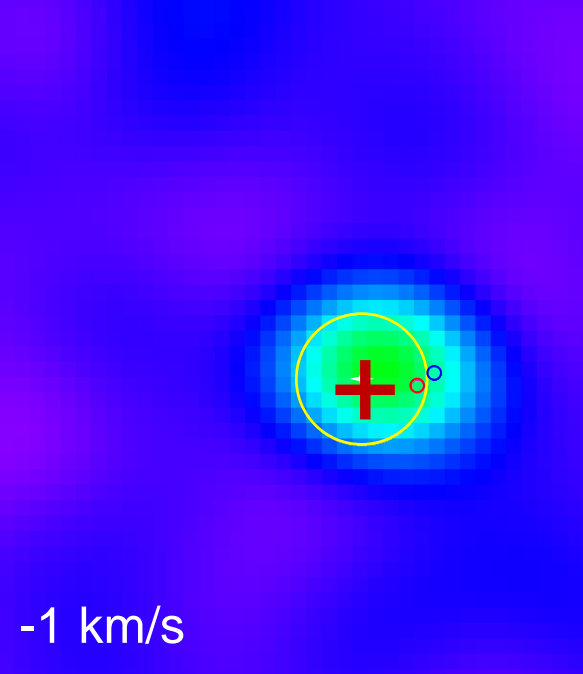


Map of velocity of the thermal methanol line emission from the hot core (circumbinary ring) around 139-409



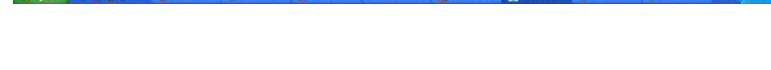
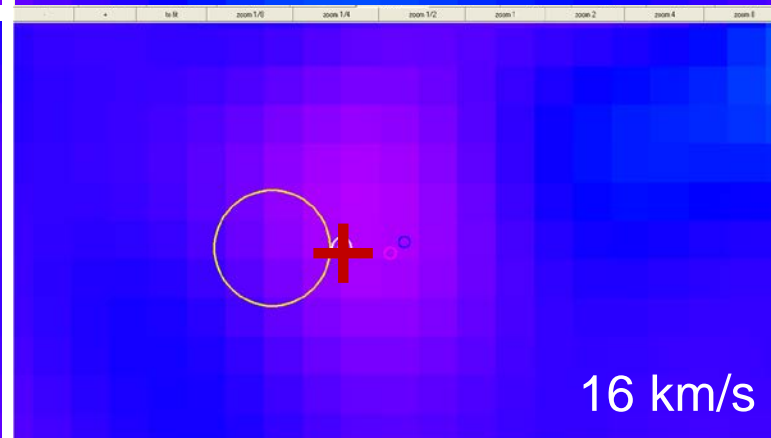
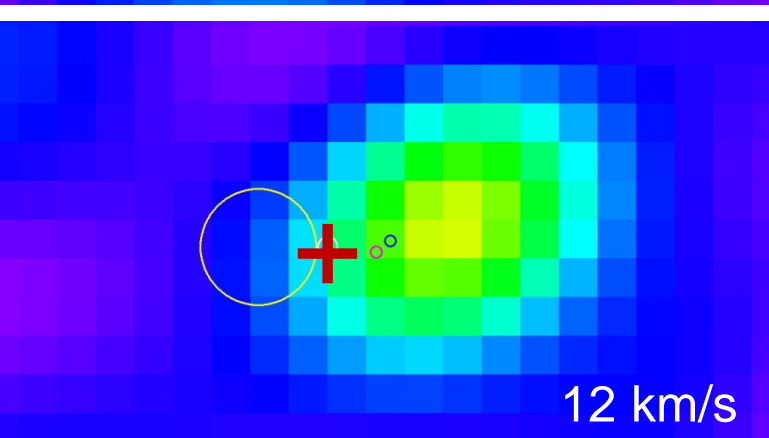
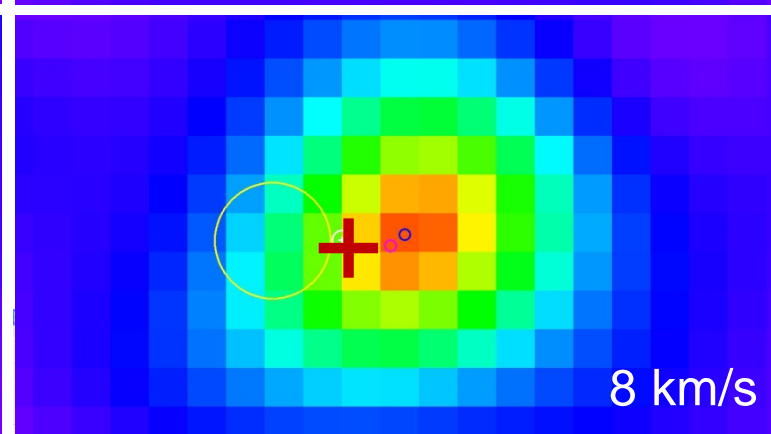
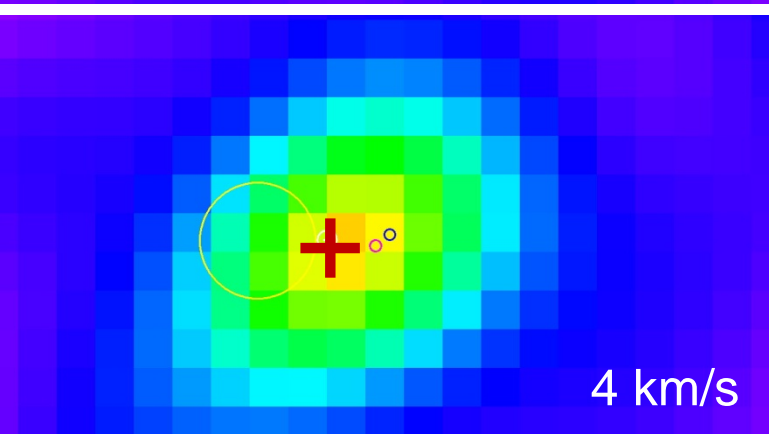
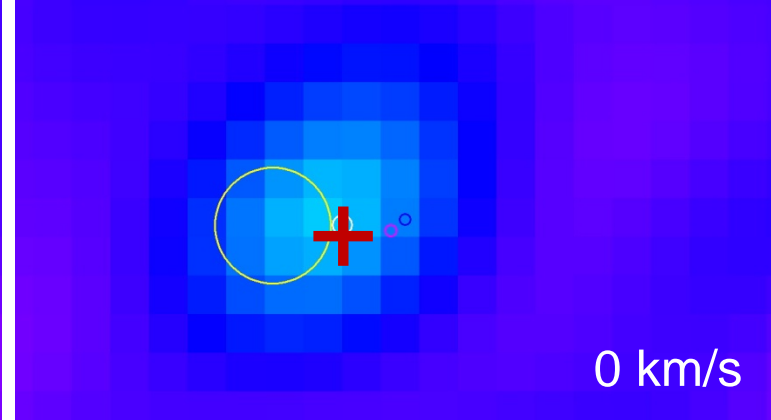
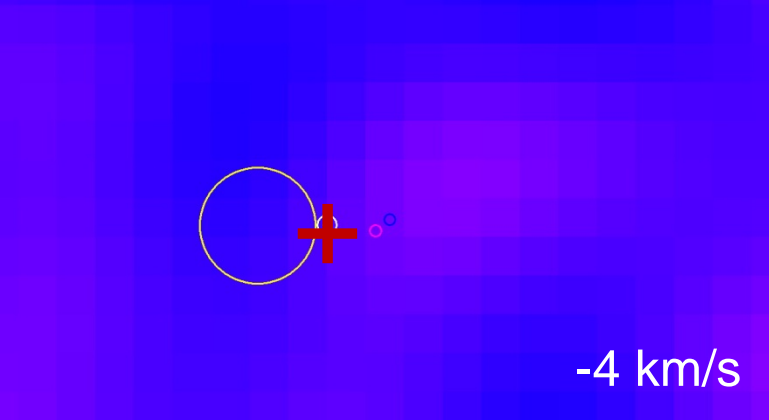


CH<sub>3</sub>OH 7<sub>-2</sub>-6<sub>-2</sub>E  
338722.914 MHz  
blended with  
CH<sub>3</sub>OH 7<sub>2</sub>-6<sub>2</sub>E  
338721.694 MHz  
(1.1 km/s difference)



Ori-S6  
Source 139-409

$\text{CH}_3\text{CN } 12_4-11_4\text{E}$   
220679 GHz



# Summary

- 6.7 GHz CH<sub>3</sub>OH maser is found in Ori-S6 at the origin of the strongest outflow in the region
- maser is projected close to very young binary system 139-409
- both position and velocity of the maser correspond to the part of the circumbinary ring moving toward us
- dynamical mass of 139-409 binary is about 9 M<sub>o</sub> and binary components are likely to have similar masses

# Importance for maser research

- First association of the 6.7 GHz CH<sub>3</sub>OH maser with stars of intermediate mass
- First clear association of the CH<sub>3</sub>OH maser with the multiple stellar system
- First clear association of the CH<sub>3</sub>OH maser with the unique object – circumbinary molecular ring



# Importance for studies of circumstellar formations and jet forming regions

- constraints on the physical parameters of molecular material in the circumbinary ring

through class II methanol maser model estimates given in Sobolev et al. (2007) and Cragg, Sobolev & Godfrey (2005):

$$10^5 < n_{\text{H}} [\text{cm}^{-3}] < 10^8$$

$$T_{\text{d}} [\text{K}] > 100$$

$$3 \cdot 10^{11} < N_{\text{M}}/\Delta V [\text{cm}^{-3}\text{s}] < 10^{14}$$

# Importance for studies of circumstellar formations and jet forming regions

- constraints on the physical parameters of molecular material in the circumbinary ring:
- association with maser provides possibility to measure accurate distances using trigonometric parallax method and study kinematics.

EVN





**Dziękuję bardzo!**

**Спасибо!**

**Thank you very much!**

**¡Muchas gracias!**

**Vielen Dank!**