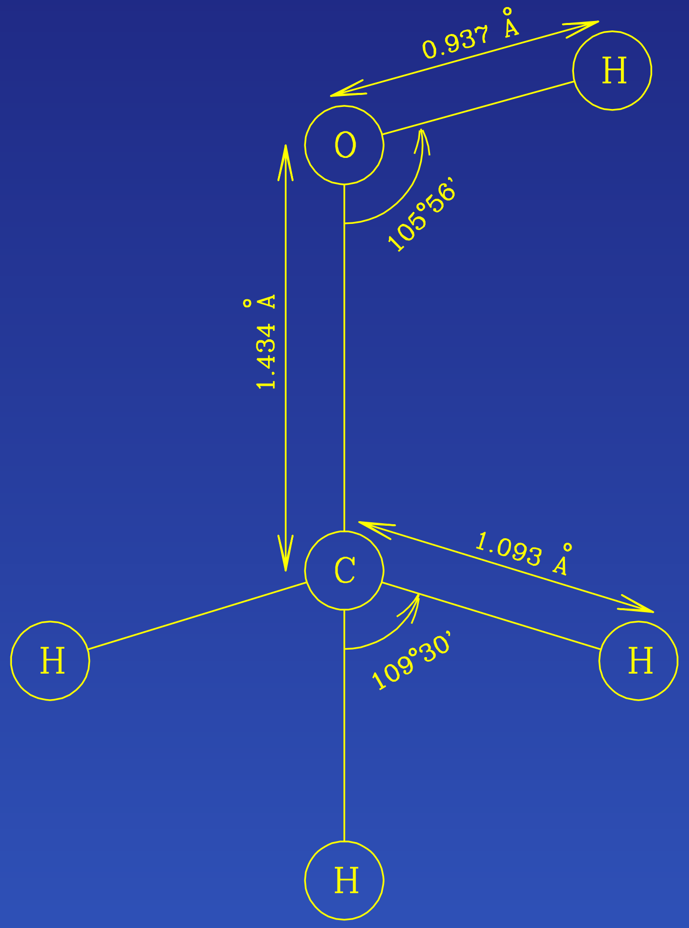


Methanol masers at 7mm

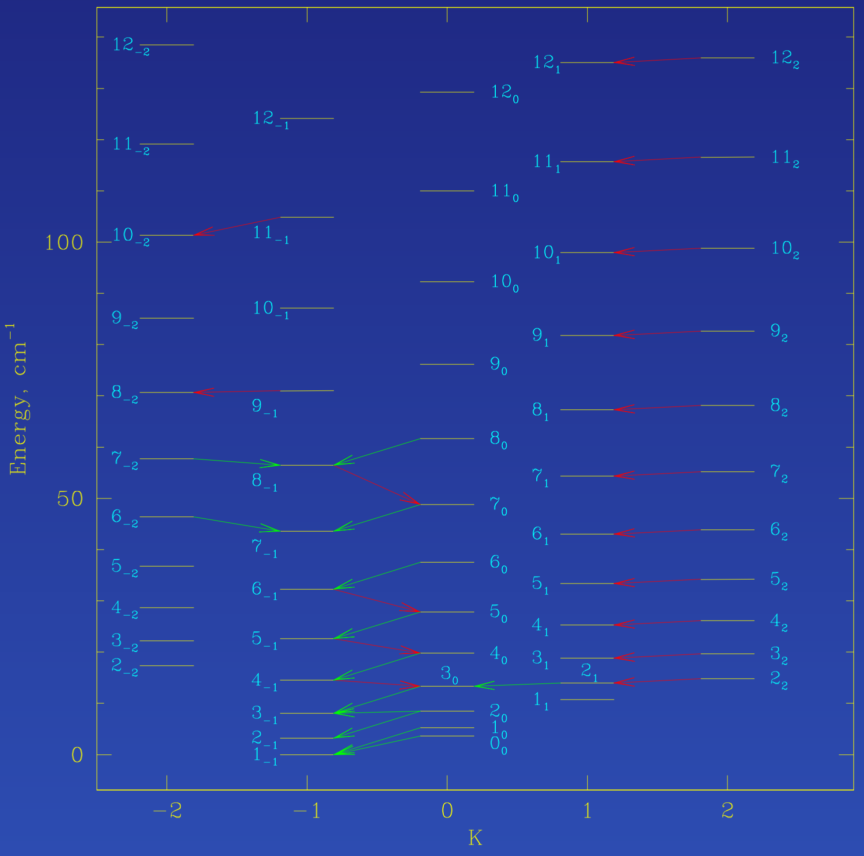
7mm workshop

Maxim Voronkov

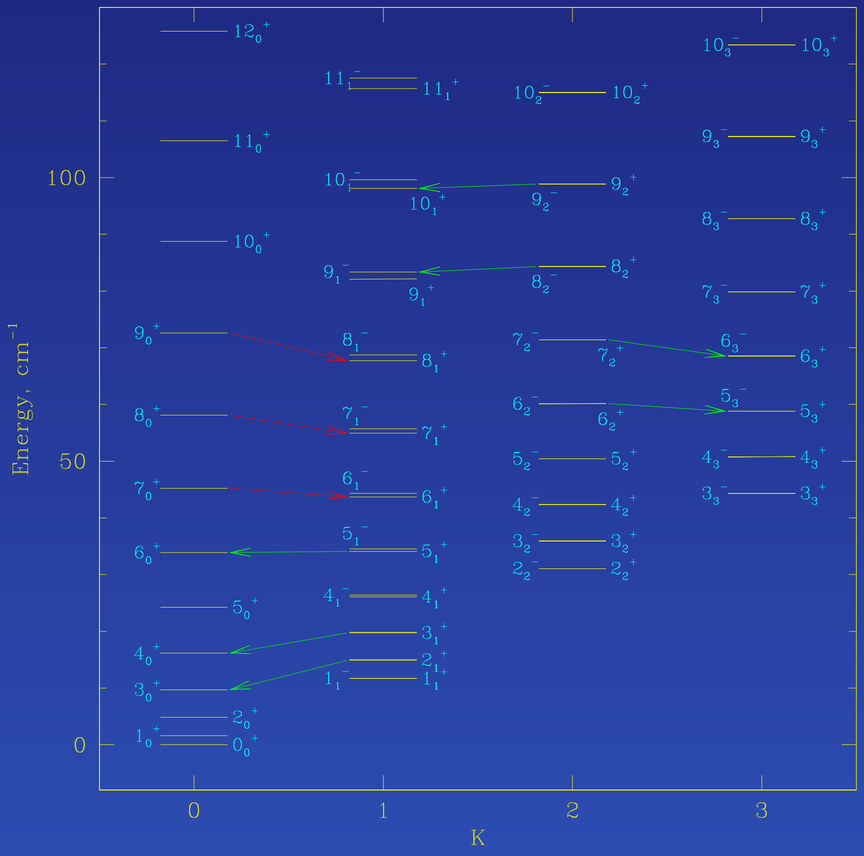
Australia Telescope National Facility

Energy levels

E-methanol



A-methanol



$$\Delta J = 0, \pm 1 \; ; \; \Delta K = \pm 1$$

$$\Delta J = \pm 1 \; ; \; \Delta K = 0$$

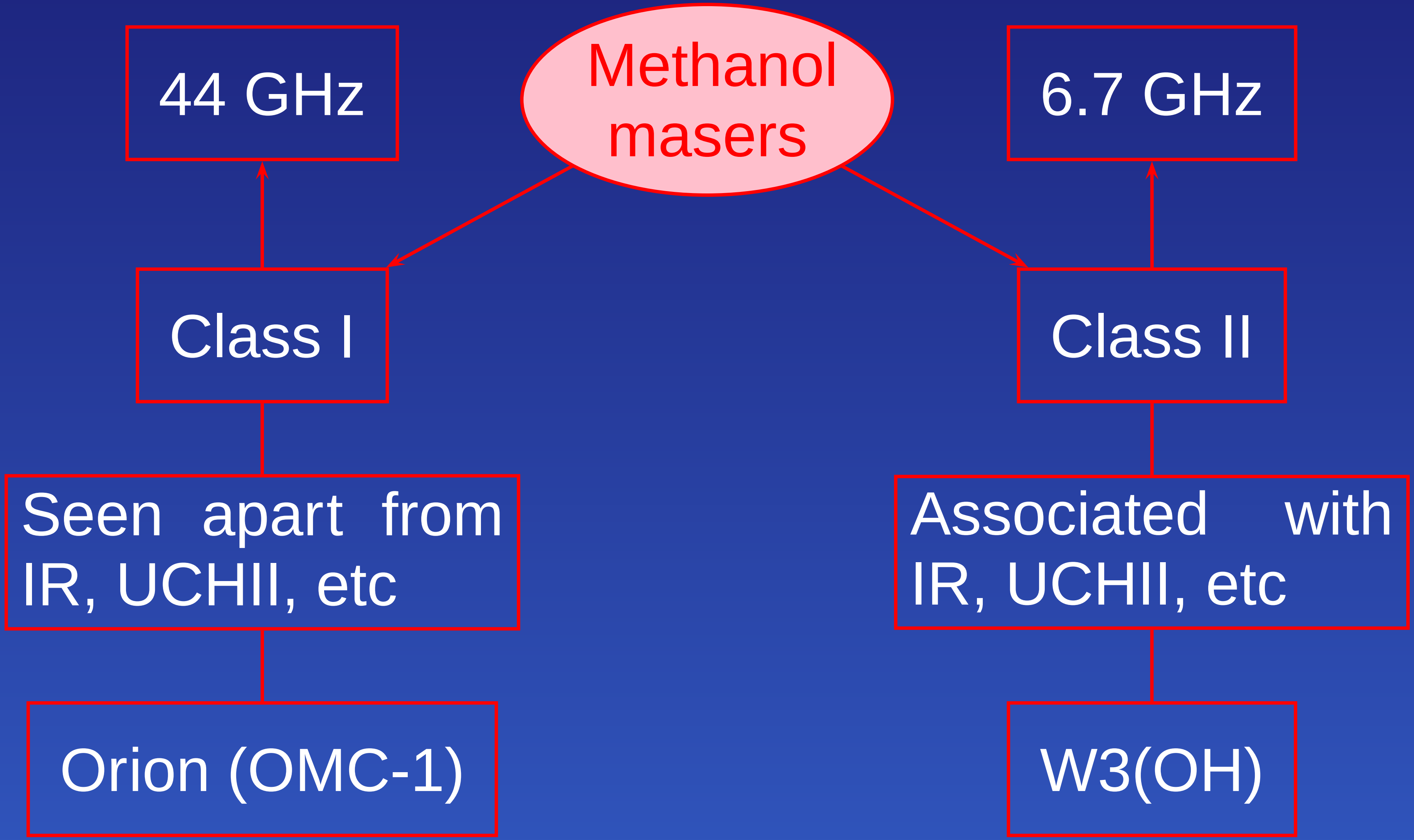
$J_{-2} - J_1$ series at $\sim$ 101 GHz

$$\Delta J = 0, \pm 1 \; ; \; \Delta K = \pm 1 \; ; \; A^{\pm} \leftrightarrow A^{\pm}$$

$$\Delta J = \pm 1 \; ; \; \Delta K = 0 \; ; \; A^{\pm} \leftrightarrow A^{\pm}$$

$$\Delta J = 0 \; ; \; \Delta K = 0 \; ; \; A^{\pm} \leftrightarrow A^{\mp}$$

Two classes of methanol masers



Methanol masers

44 GHz

Class I

Seen apart from IR, UCHII, etc

Orion (OMC-1)

6.7 GHz

Class II

Associated with IR, UCHII, etc

W3(OH)

Known Class I maser transitions

	Transition	Frequency GHz	Reference
●	$9_{-1} - 8_{-2}$ E	9.9	Slysh et al. (1993)
→	$J_2 - J_1$ E series	$>$24.9	Barrett et al. (1971); Menten et al. (1986)
→	$4_{-1} - 3_0$ E	36	Turner (1972)
→	$7_0 - 6_1$ A^+	44	Haschick et al. (1990)
●	$5_{-1} - 4_0$ E	84	Zuckerman et al. (1972)
●	$8_0 - 7_1$ A^+	95	Ohishi et al. (1986)
●	$11_{-1} - 10_{-2}$ E	104	Voronkov et al. (2005)
●	$6_{-1} - 5_0$ E	133	Slysh et al. (1997)
●	$9_0 - 8_1$ A^+	146	Menten (1991a)
●	$8_{-1} - 7_0$ E	229	Slysh et al. (2002)

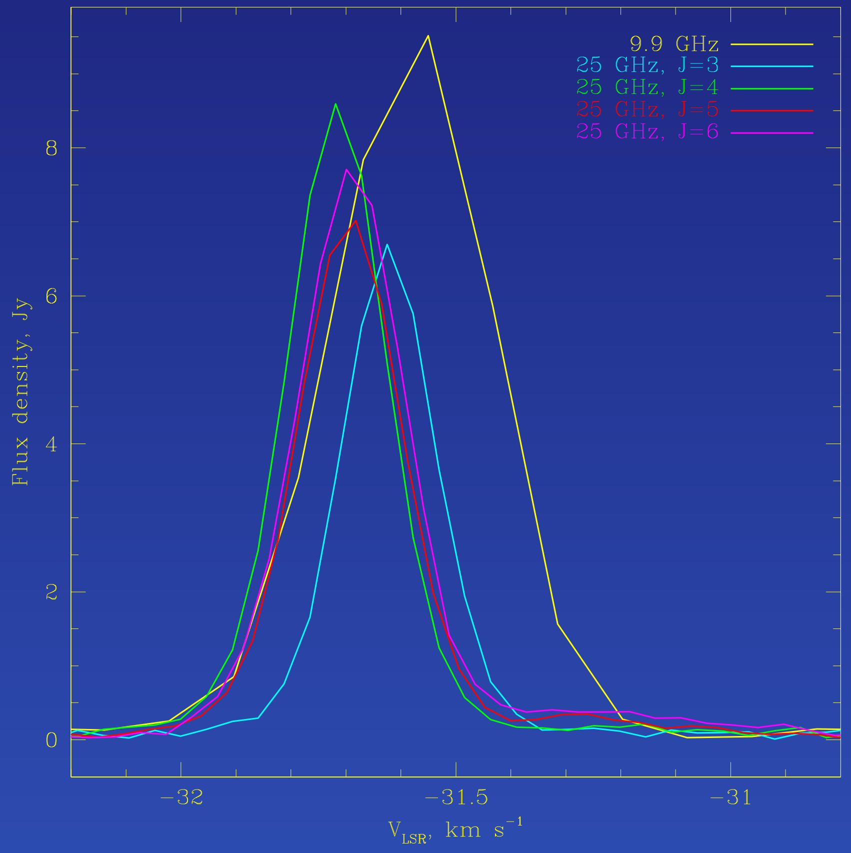
Known Class II maser transitions

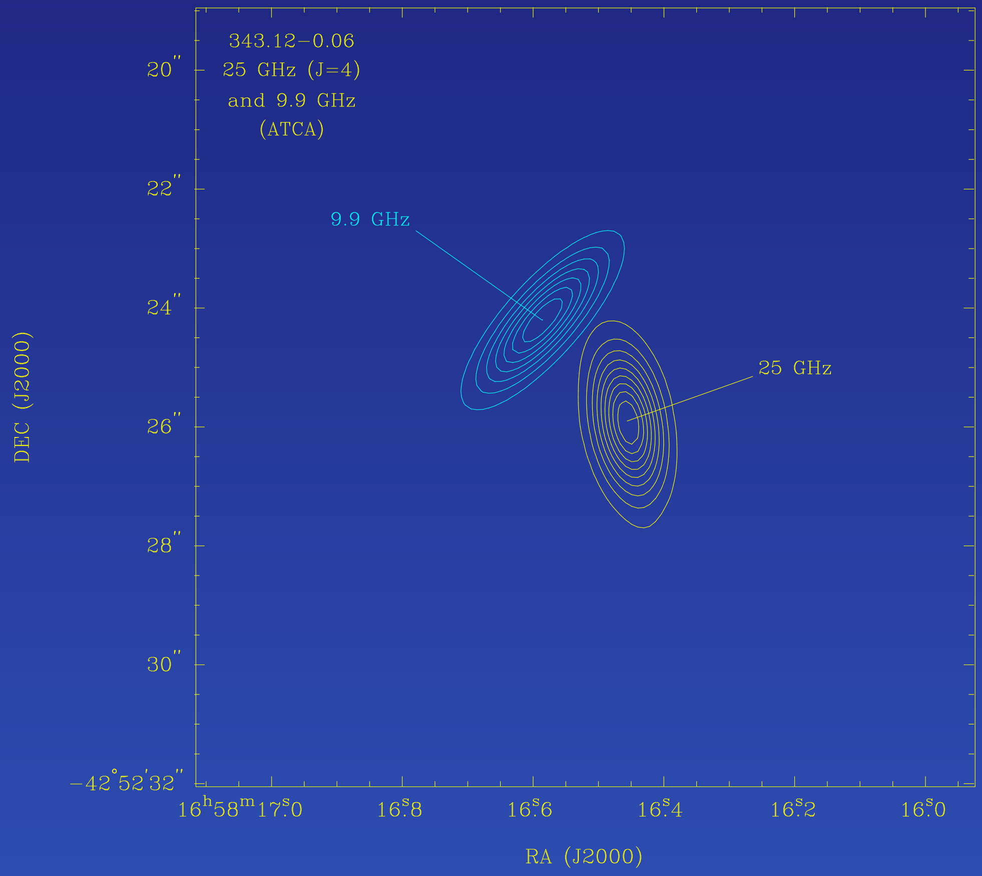
	Transition	Frequency, GHz	Reference
●	$5_1 - 6_0$ A$^+$	6.7	Menten (1991b)
●	$2_0 - 3_{-1}$ E	12.2	Batrla et al. (1987)
●	$2_1 - 3_0$ E	19.9	Wilson et al. (1985)
●	$9_2 - 10_1$ A$^+$	23.1	Wilson et al. (1984)
→	$8_2 - 9_1$ A$^-$	28.9	Wilson et al. (1993)
→	$7_{-2} - 8_{-1}$ E	37.7	Haschick et al. (1989)
→	$6_2 - 5_3$ A$^-$	38.2	Haschick et al. (1989)
→	$6_2 - 5_3$ A$^+$	38.4	Haschick et al. (1989)
●	$6_{-2} - 7_{-1}$ E	85.5	Cragg et al. (2001)
●	$7_2 - 6_3$ A$^-$	86.6	Cragg et al. (2001)
●	$7_2 - 6_3$ A$^+$	86.9	Cragg et al. (2001)
●	$3_1 - 4_0$ A$^+$	107	Val'tts et al. (1995)
●	$0_0 - 1_{-1}$ E	108	Val'tts et al. (1999)
●	$2_1 - 3_0$ A$^+$	156.6	Slysh et al. (1995)
●	J$_0$−J$_{-1}$ E series	$\sim$157	Slysh et al. (1995)

What can be learned?

- The greater the number of observed transitions, the stronger the constraints on the model. Potentially, the modelling can give estimates of the physical parameters like temperature and density. The ATCA is a very attractive instrument for such studies because it has a great flexibility and the southern location.
- Interferometric observations give the source position and size estimate. Positions are necessary for identification between different maser spots.
- The ATCA has a very good spectral resolution. By observing simple sources one can improve the accuracy of the rest frequencies and, hence, the Hamiltonian of the molecule.
- Untargeted surveys can reveal new sites of the massive star formation at probably their earliest stages.

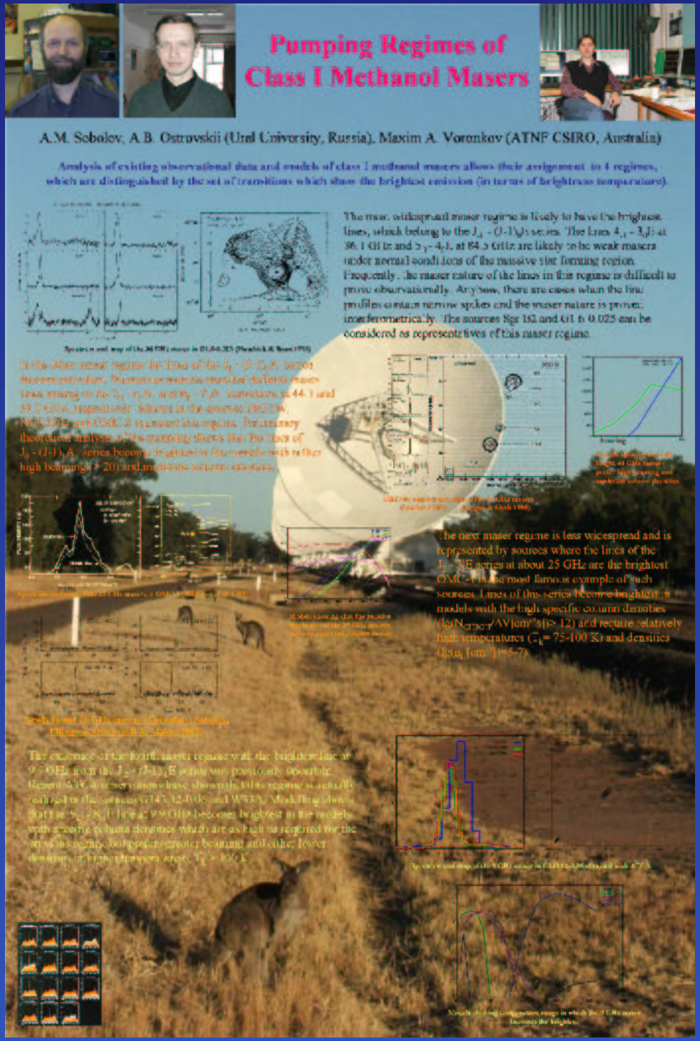
Some examples





- More precise rest frequencies can be determined
- Interferometer is required even for sources which look simple

4 regimes of the Class I methanol masers



Pumping Regimes of Class I Methanol Masers

A.M. Sobolev, A.B. Ostrovskii (Ural University, Russia), Maxim A. Voronkov (ATNF CSIRO, Australia)

Analysis of existing observational data and models of class I methanol masers allows their assignment to 4 regimes, which are distinguished by the set of transitions which show the brightest emission (in terms of brightness temperature).

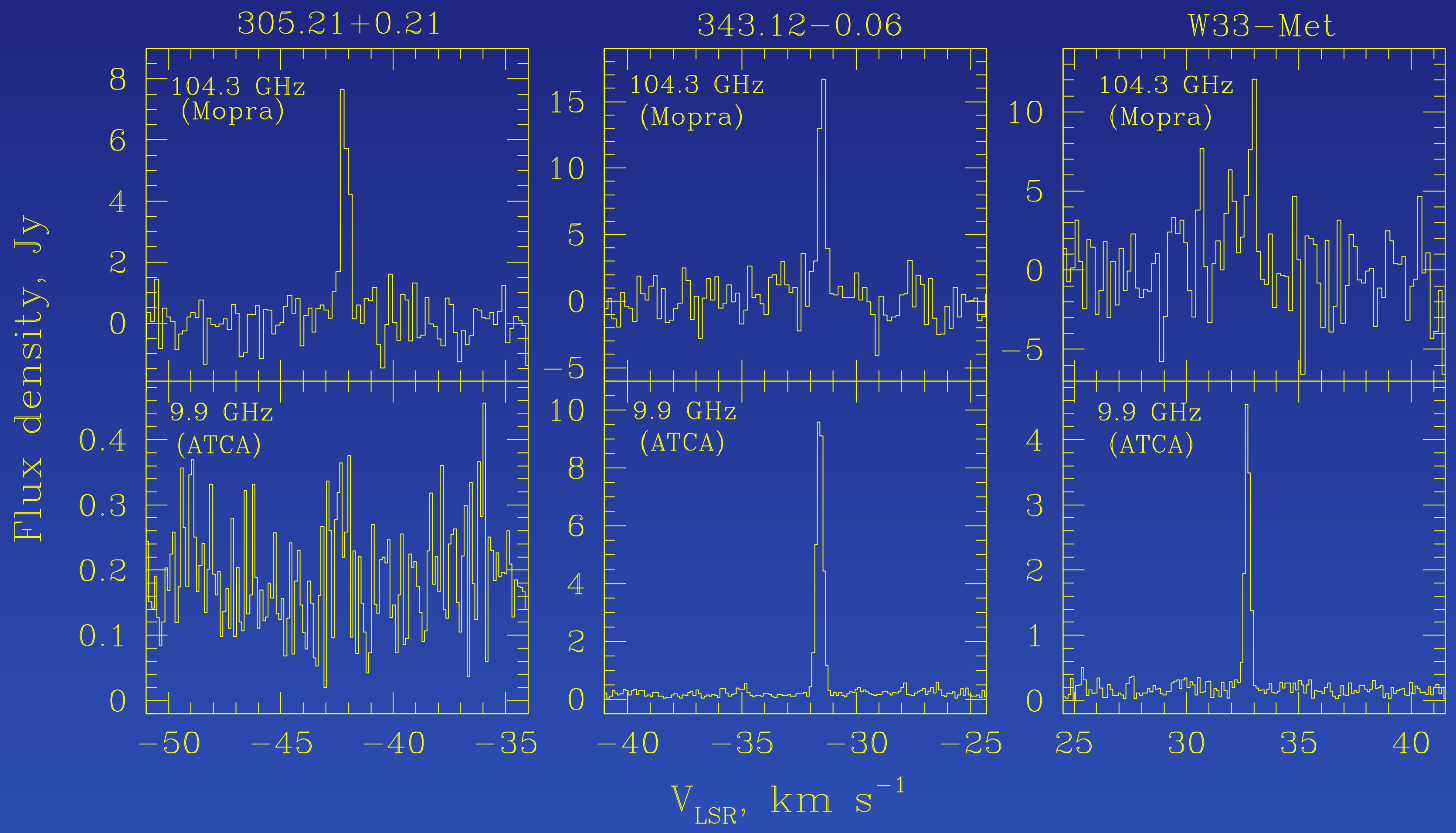
The most widespread maser regime is likely to have the brightest lines, which belong to the J_{-1} - $(J-1)_0E$ series. The lines 4_{-1} - 3_0E at 36.1 GHz and 5_{-1} - 4_0E at 84.5 GHz are likely to be weak masers under normal conditions of the massive star forming region. Frequently, the maser nature of the lines in this regime is difficult to prove observationally. Anyhow, there are cases when the line profiles contain narrow spikes and the maser nature is proven interferometrically. The sources Sgr B2 and G1.6-0.025 can be considered as representatives of this maser regime.

The next maser regime is less widespread and is represented by sources where the lines of the J_2 - J_1E series at about 25 GHz are the brightest. OMC-1 is the most famous example of such sources. Lines of this series become brightest in models with the high specific column densities ($\lg(N_{CH_3OH}/\Delta V[cm^{-3}s]) > 12$) and require relatively high temperatures (T_k = 75-100 K) and densities ($\lg(n_{H_2}[cm^{-3}])$=5-7).

Poster at IAUS227 (Sobolev et al.)

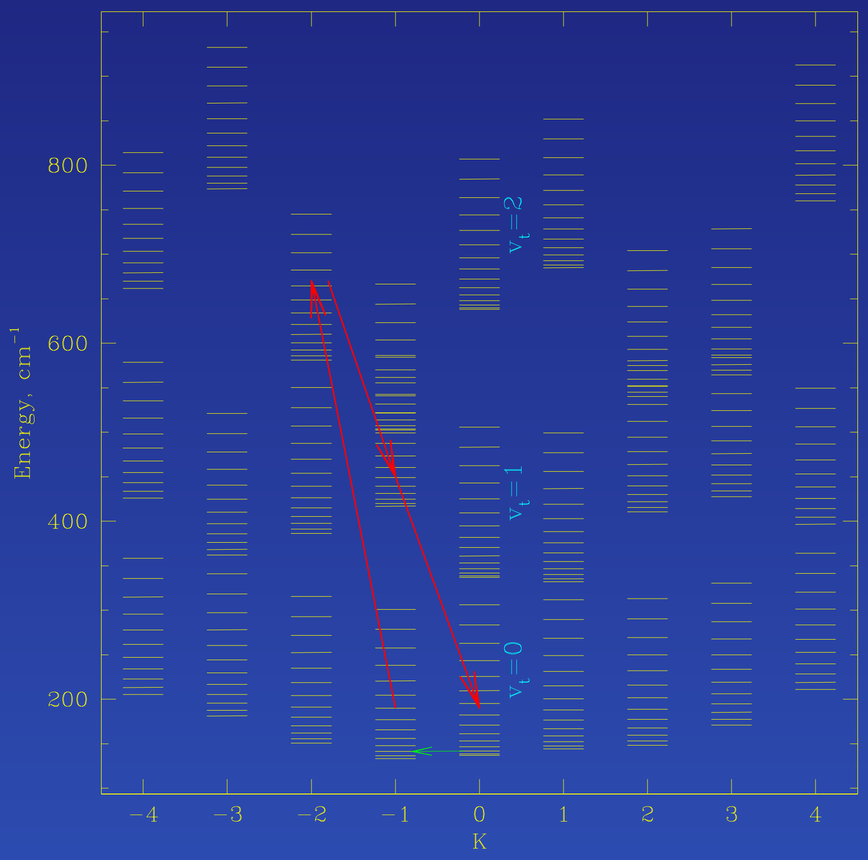
1. The 36 GHz and 84 GHz transitions are the brightest. This is the most widespread regime, but masers are weak.
2. The 44 GHz and 95 GHz transitions are the brightest. This regime requires a high beaming (elongated geometry).
3. The transition series near 25 GHz is the brightest. This is a rare regime and requires a high methanol column densitiy and relatively high temperature and hydrogen density.
4. The 9.9 GHz and 104 GHz transitions are the brightest. The parameters are similar to the previous case, but a greater beaming and either lower density or higher temperature are required.

104 and 9.9 GHz data



- The fluxes of the masers belonging to the same transition series do not necessarily correlate.

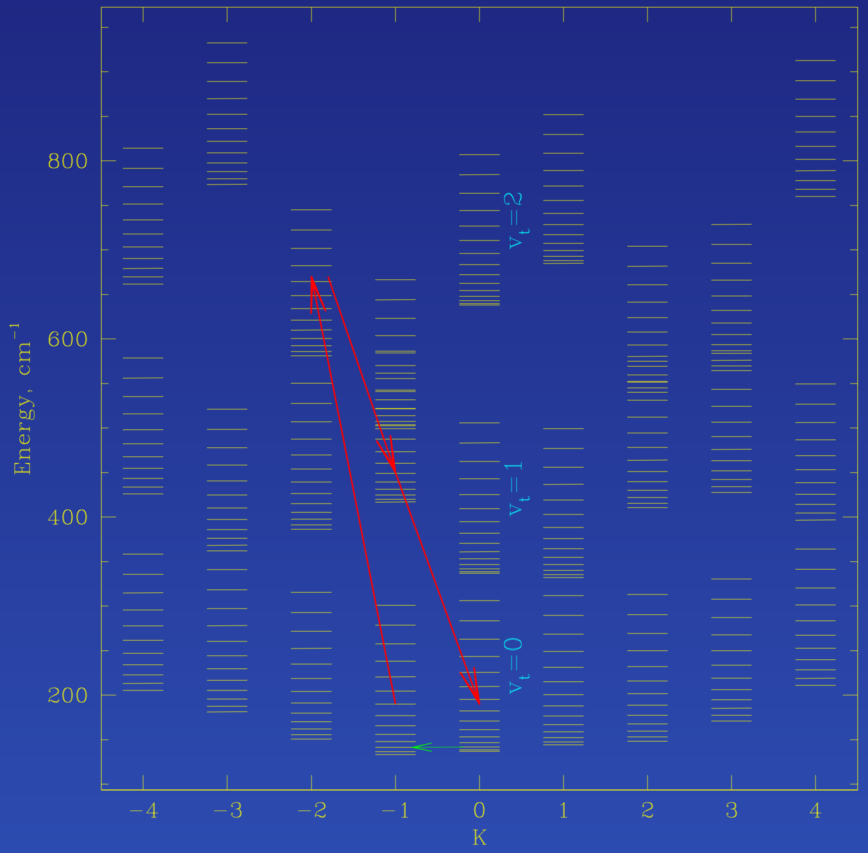
Torsional pumping



- For the pumping to be efficient the dust temperature should be higher than 175 K

- VLBI: Masers at 6.7 GHz and 12.2 GHz have very high brightnesses reaching 2×10^{10} K and 3×10^{12} K, respectively (Menten et al.; ApJ, 1988, 333, L83 and ApJ, 1992, 401, L39)
- It is difficult to get if the model involves rotational levels of the molecule only
- Sobolev & Deguchi (A&A, 1994, 291, 569): Pumping via first and second torsionally excited states can significantly increase the model brightnesses for Class II masers and explain the observed value.

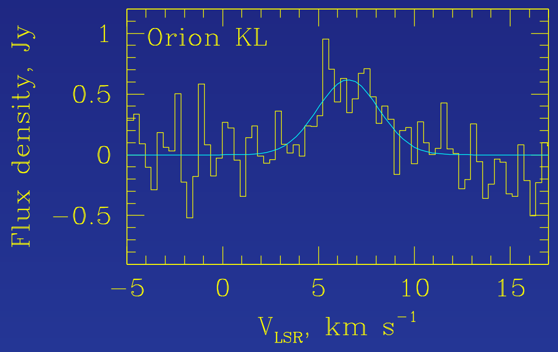
Torsional pumping

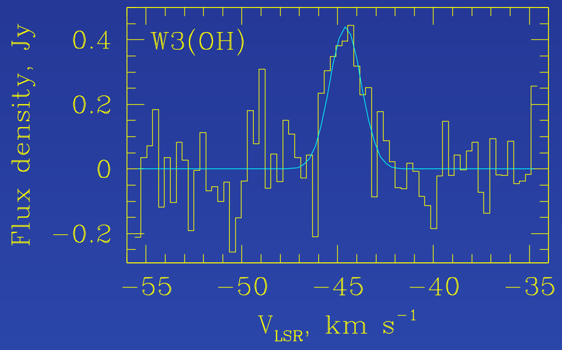


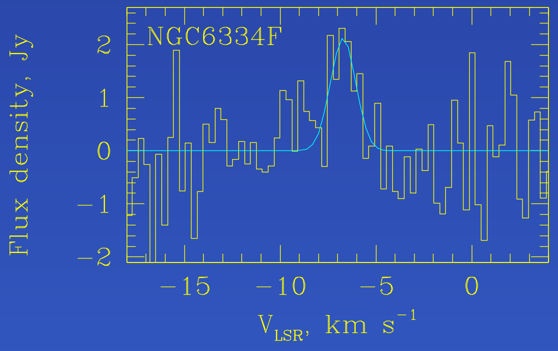
- The lack of interferometry does not allow to check whether the position is the same at different frequencies.

- As for Class I masers, a larger number of observed transitions can result in a better model.
- Sutton et al. (2001, ApJ, 554, 173) developed a good model of the methanol masers in northern source W3(OH).
- Transitions at the frequency range from 28 GHz to 38 GHz are crucial for model testing
- The 86 GHz and 107 GHz masers apparently trace higher densities/temperatures, while the 28 GHz-38 GHz masers trace lower densities/temperatures.

Torsionally excited maser?







- Model can be checked by searching for predicted torsionally excited maser in the $2_0 - 3_1$ E, $v_t = 1$ transition at 44.9558 GHz.
- Such observations have been done using the 37-m Haystack radiotelescope (Voronkov et al., 2002, A&A, 387, 310).
- Line was detected in Orion KL, W3(OH) and probably in NGC6334F
- It was shown that the line in W3(OH) is a low gain maser
- Interferometric observations of such sources make it easier to proove that the observed transitions are masers (strong limit on the brightness temperature).

Summary

- It is highly desireable for methanol maser researches to be able to observe the following frequencies: 36.16929, 37.70370 and 44.06948 GHz
- The 36 and 84 GHz transitions are basically unstudied in the southern hemisphere, although a good target list exists. Surveys at these frequencies can be used for statistical analysis to check the predictions of the theory
- The 44 GHz transition and probably the 36 GHz one are good candidates for a blind survey
- Thermal lines (e.g. 48.1–48.4 GHz) and weak maser lines exist throughout the whole frequency range of 26–50 GHz