44 GHz methanol maser emission around SNR G27.4-0.16 and new detections of class I methanol masers in the direction of high-mass protostellar candidates

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- **Nowadays methanol (CH_3OH) along with the OH and H_2O is the most studied interstellar molecule.**
- **Methanol is widely spread in the interstellar medium. It plays an important role in the interstellar chemical processes for it is an intermediate in the synthesis of more complex molecules from simpler. This molecule is second the most common among the interstellar dust after H_2O.**
- **The CH_3OH formula is on fig.1**
- **It is weakly asymmetrical spinner. Its asymmetry is due to the movement of the hydrogen atom around the axis of the molecule, which lifts the degeneracy of energy levels.**

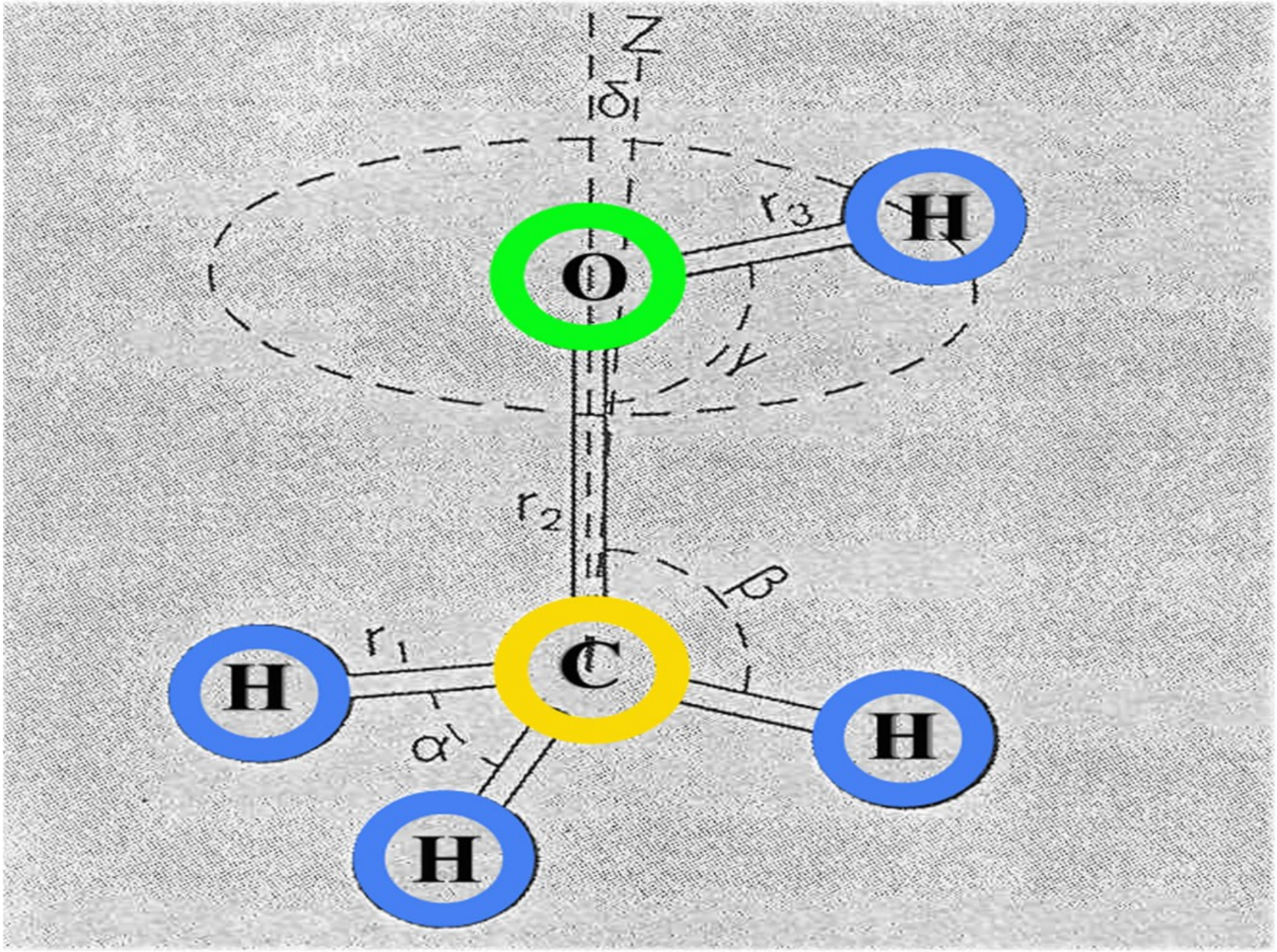


Fig. 1. Scheme of methanol molecule CH_3OH.

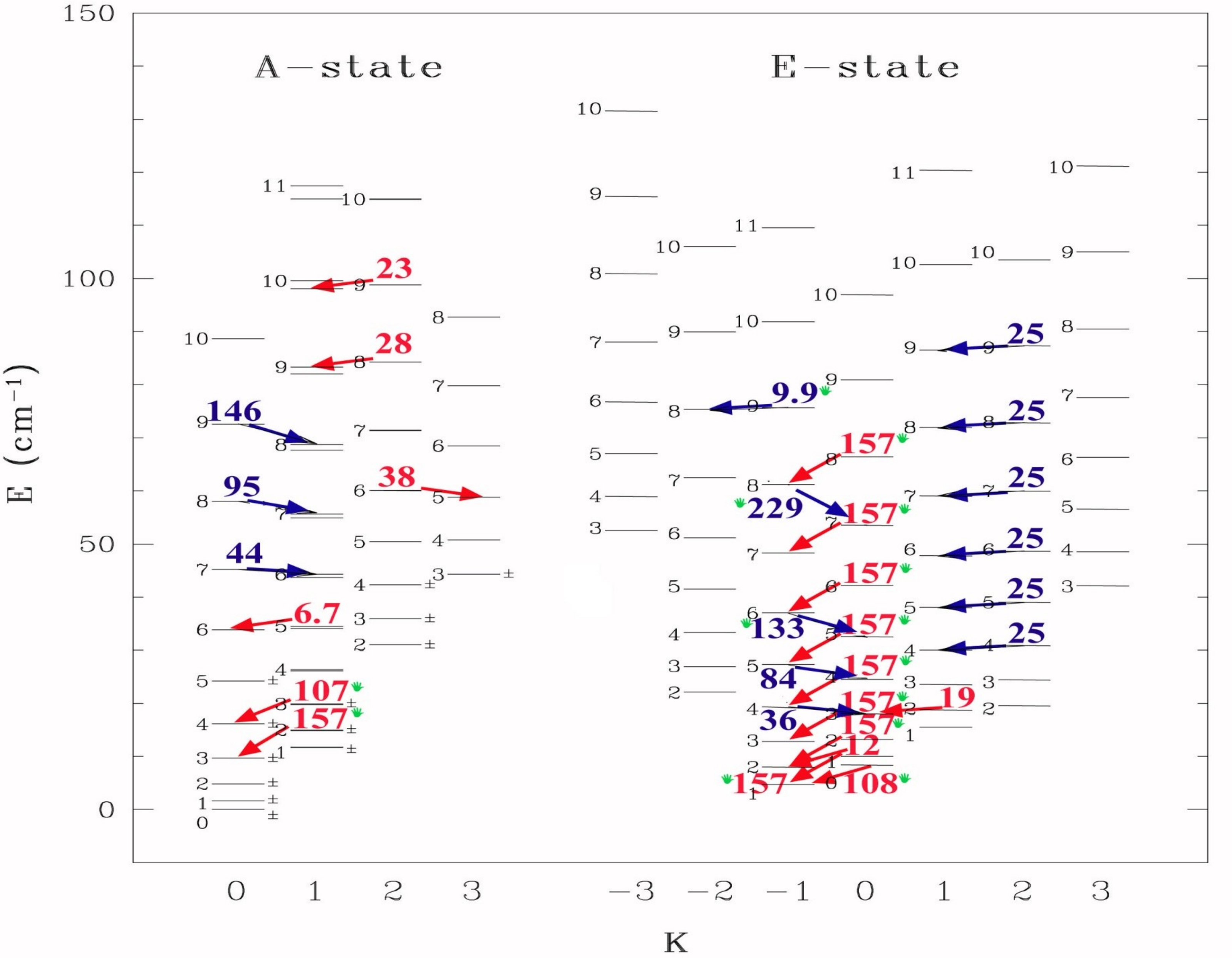


Fig. 2. Energy-level diagram of the methanol molecule. The numbers near quantum levels are the values of the rotational quantum number J. On axis X defer quantum number K, that corresponding projection of the rotational quantum number on the axis of the molecule, on axis Y - energy levels. The numbers near the arrow show shows the transition frequencies in GHz.

Classification attributes of methanol masers, class I (MMI)

1. **Emissions in transitions 7_0-6_1A^+ (44 GHz), 8_0-7_1A^+ (95 GHz), 9_0-8_1A^+ (146 GHz), J_2-J_1E (25 GHz), 4_{-1}-3_0E (36 GHz), 5_{-1}-4_0E (84 GHz), absorption at on frequencies 2_0-$3_{-1}E$ (12.2 GHz) and и 5_1-6_0A^+(6.7 GHz);**
2. **Offset position and isolation from UCHII-regions zones, IRAS sources of IRAS, OH and H_2O masers;**
3. **Possible link with bipolar outflows;**

1. **Collisional pumping mechanism.**

Prototype sources are

Ori KL, OMC2, NGC2264, W51, DR21West.

Classification attributes of methanol masers, class II (MMII)

1. Emissions in transition 2_0-$3_{-1}E$ (12 ГГц), 5_1-6_0 A^+(6.7 ГГц);
2. Association with UCHII-zone, infrared sources and OH and H_2O masers;

1. Collisional-radiative pumping mechanism.

Prototype sources are

W3(OH), NGC7538, NGC6334E,F

- **Collisional pumping mechanism of class I methanol masers are now considered essential.**
- **There have been predictions (*Menten 1991, Catarzi et al. 1992, Bachiller et al. 1995*) that the shock wave front from a bipolar flow (a phenomenon often accompanies the process birth of stars) can triggered class I methanol masers.**
- **The remnants of shock fronts accelerated by supernova explosions can be possible candidates for class I methanol maser searches, too; in this case the collisional pumping is provided by shock wave propagates through the adjacent cloud.**
- **OH maser emission at 1720 MHz, collisionally pumped, is an obvious sign of interaction of SNR with molecular clouds.**
- **24 OH(1720 MHz) masers related to SNRs (so-called ME SNR - i.e. "maser-emitting").**
- **No special search for methanol emission towards SNRs have been done before.**

Observations

- December 2-15, 2009

- Onsala, Sweden
- 20-m telescope

- Frequency 44069.4900 MHz
- Methanol transition $7_0\text{-}6_1A^+$

- Half power beamwidth 88" at 44 GHz
- Aperture efficiency 0.53 (18 Jy/K)
- System temperature ~200K

- <u>Spectrometer characteristics:</u>
- total bandwidth – 20 MHz
- number of channels – 1600 (800 in one polarization)
- channel separation – 25kHz (0.18 km/s at 44 GHz)

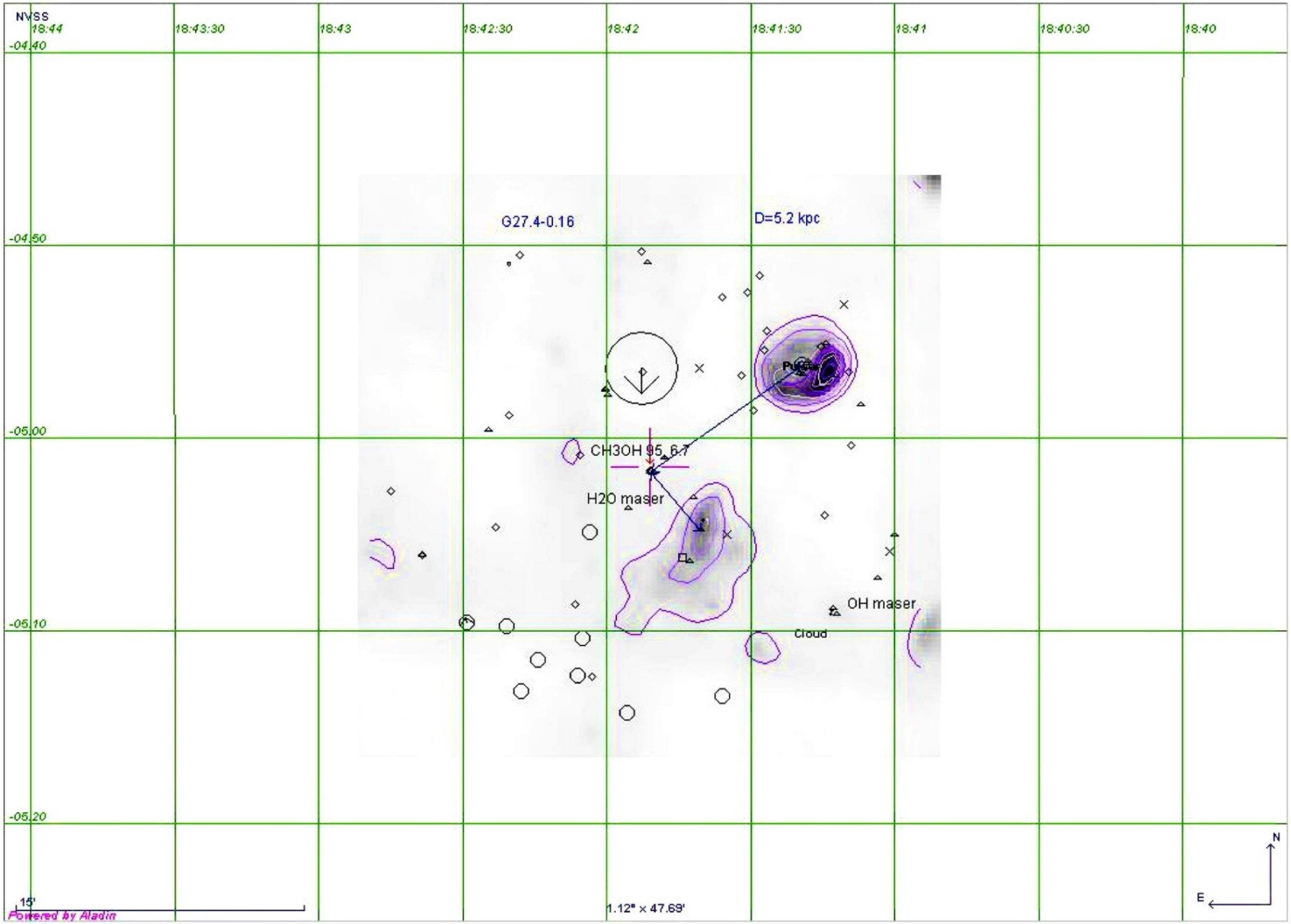
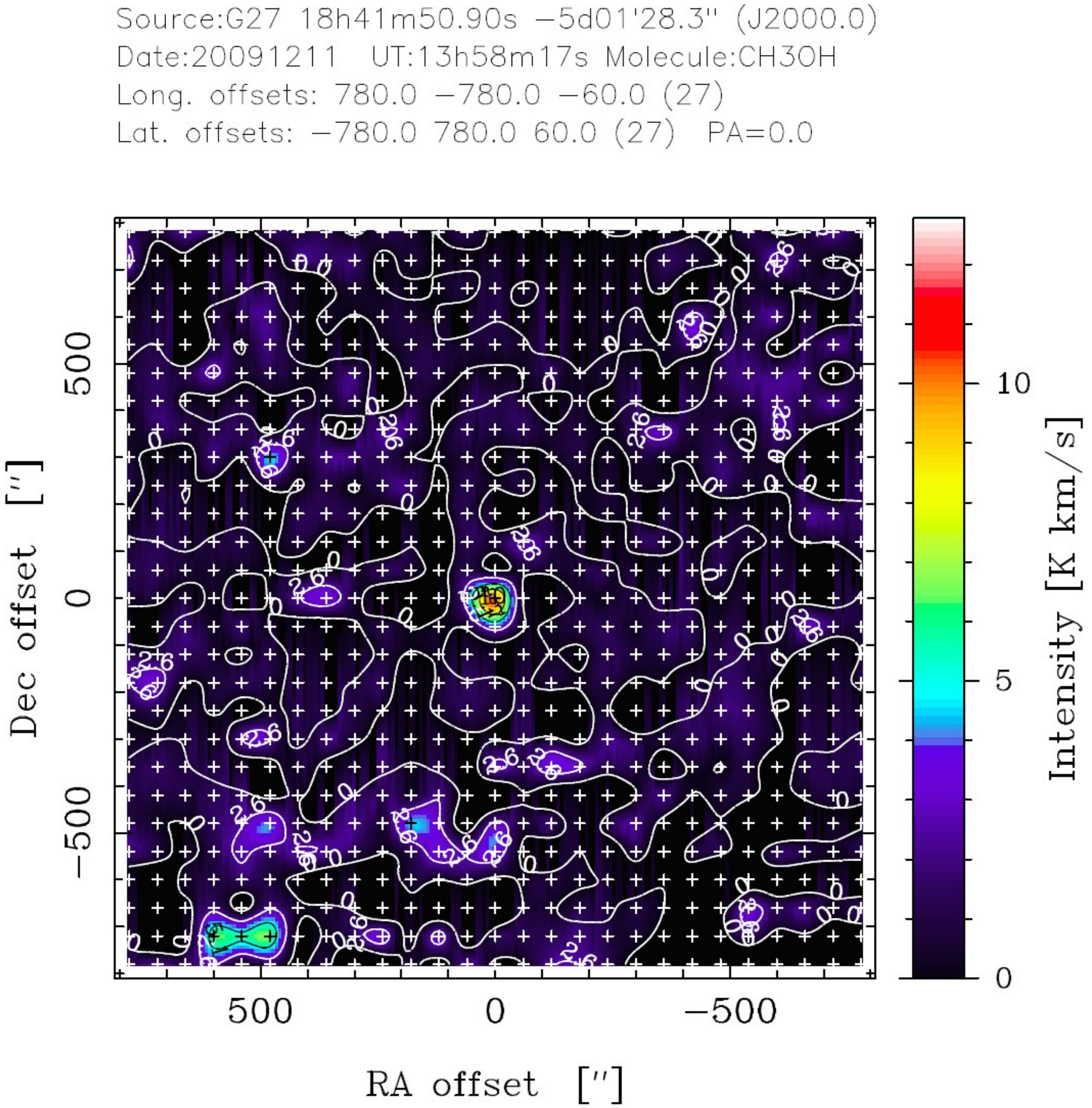


Fig. 3. The region (30′x30′) around the site of class I methanol maser G27.4-0.16, firstly observed at 95 GHz using 22-m millimeter antenna at Mopra, ATNF by *Ellingsen 2005*. The picture was composed with the help of interactive software sky atlas superimposing entries SIMBAD and NVSS (NRAO VLA Sky Survey, Radio 21-cm – contours and grey-scale continuum.

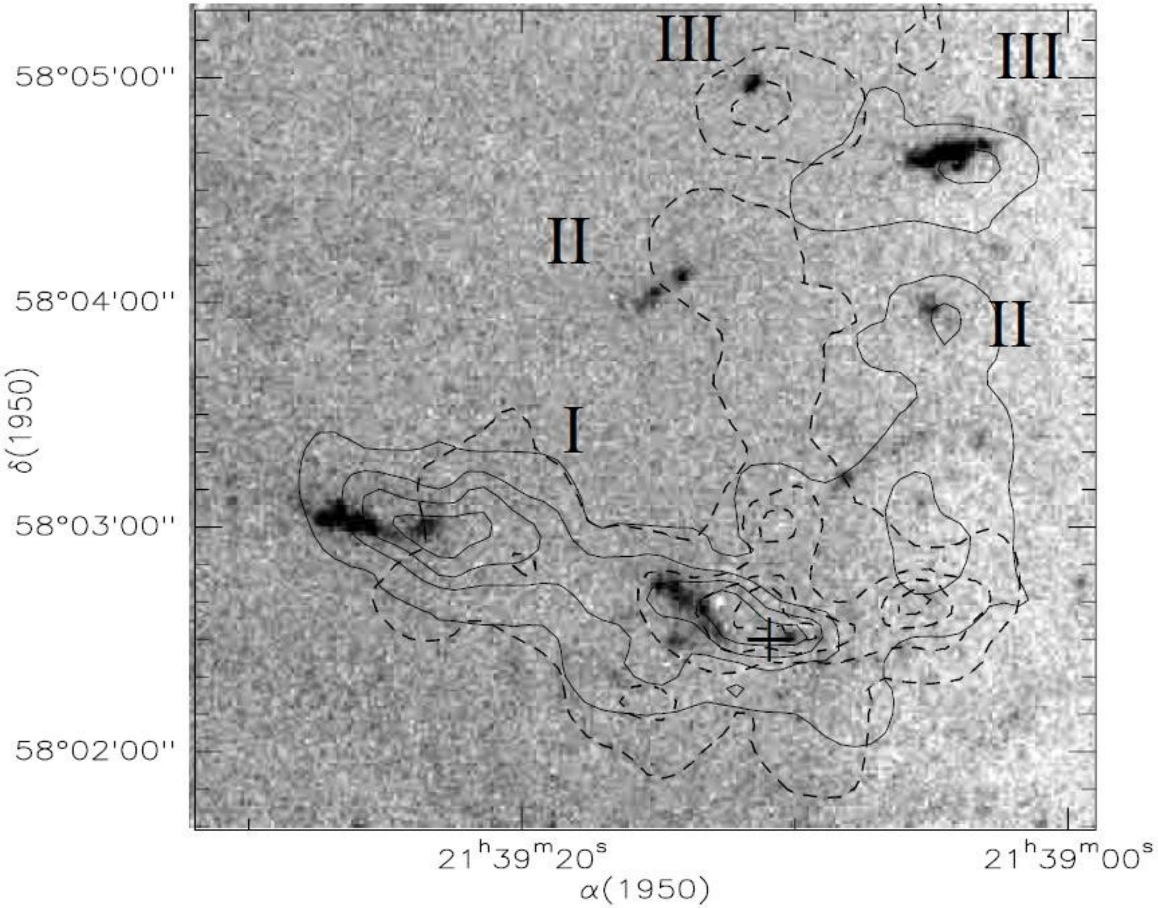
Map at 44 GHz of class I methanol maser around SNR G27.4-0.16



Future directions

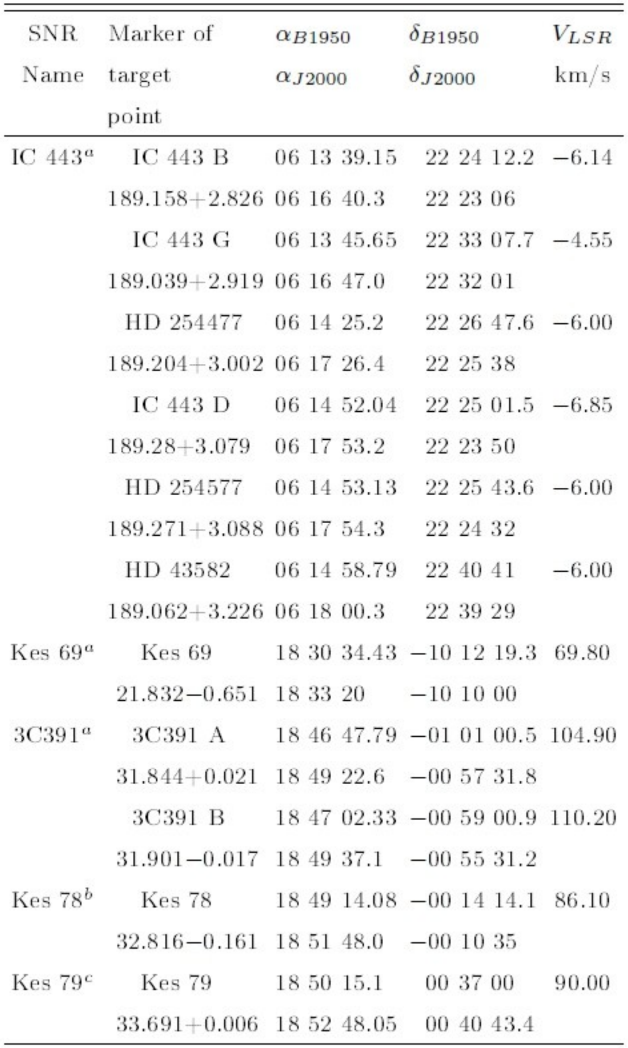
To confirm the hypothesis that the maser G27.4-0.16 excitation produced by the shock waves from SNR, it is desirable to conduct the following observations:

- **Observations of CO emission, which is a tracer of the high-velocity outflows.**
- **Observations of H_2 emission in the line 1-0 S(1) λ=2.122 μm with narrow filter (Δλ=0.021 μm). This line is excites by the same mechanism as class I methanol masers.**
- **For example such observations have been provided for IC 1396-N by *Nisini et al. 2001*, where class I methanol maser at 44 GHz firstly was observed in Spain with 14-m radio telescope by *Kalenskii et al. 1992* at the position of cold IRAS source.**



Continuum subtracted H_2 2.12 μm image (dark spots) superimposed CO(2-1) map of high velocity gas (counters) . From *Nisini et al.* 2001.

Table of observed points in ME SNR at 44 GHz.



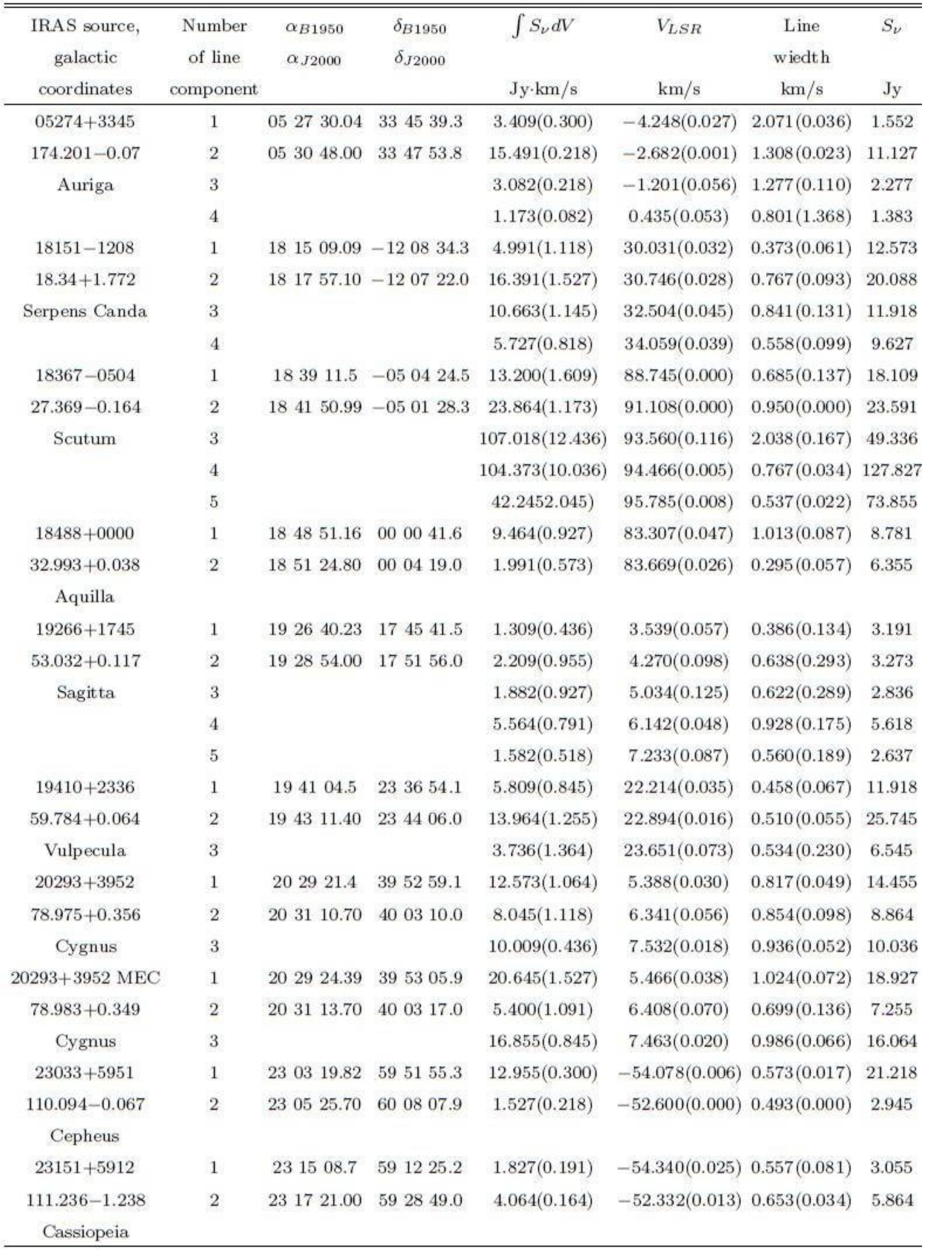
SNR Name	Marker of target point	α_{B1950} α_{J2000}	δ_{B1950} δ_{J2000}	V_{LSR} km/s
IC 443[a]	IC 443 B	06 13 39.15	22 24 12.2	−6.14
	189.158+2.826	06 16 40.3	22 23 06	
	IC 443 G	06 13 45.65	22 33 07.7	−4.55
	189.039+2.919	06 16 47.0	22 32 01	
	HD 254477	06 14 25.2	22 26 47.6	−6.00
	189.204+3.002	06 17 26.4	22 25 38	
	IC 443 D	06 14 52.04	22 25 01.5	−6.85
	189.28+3.079	06 17 53.2	22 23 50	
	HD 254577	06 14 53.13	22 25 43.6	−6.00
	189.271+3.088	06 17 54.3	22 24 32	
	HD 43582	06 14 58.79	22 40 41	−6.00
	189.062+3.226	06 18 00.3	22 39 29	
Kes 69[a]	Kes 69	18 30 34.43	−10 12 19.3	69.80
	21.832−0.651	18 33 20	−10 10 00	
3C391[a]	3C391 A	18 46 47.79	−01 01 00.5	104.90
	31.844+0.021	18 49 22.6	−00 57 31.8	
	3C391 B	18 47 02.33	−00 59 00.9	110.20
	31.901−0.017	18 49 37.1	−00 55 31.2	
Kes 78[b]	Kes 78	18 49 14.08	−00 14 14.1	86.10
	32.816−0.161	18 51 48.0	−00 10 35	
Kes 79[c]	Kes 79	18 50 15.1	00 37 00	90.00
	33.691+0.006	18 52 48.05	00 40 43.4	

[a] Hewitt, Yusef-Zadeh & Wardle 2008

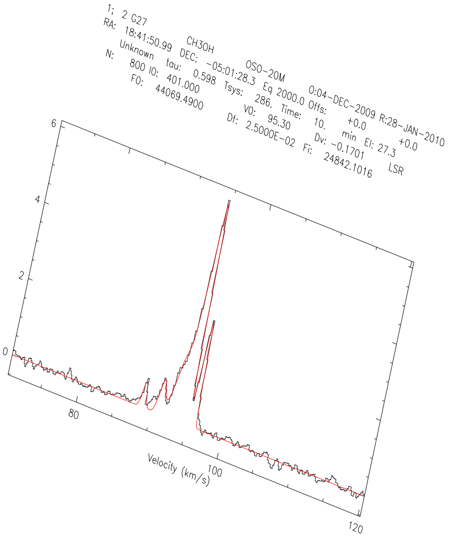
[b] Koralesky et al. 1998

[c] Zubrin, Shulga 2008

New masers detected in the direction of high-mass star-forming regions.



IRAS source, galactic coordinates	Number of line component	α_{B1950} α_{J2000}	δ_{B1950} δ_{J2000}	$\int S_\nu dV$ Jy·km/s	V_{LSR} km/s	Line wiedth km/s	S_ν Jy
05274+3345	1	05 27 30.04	33 45 39.3	3.409(0.300)	−4.248(0.027)	2.071(0.036)	1.552
174.201−0.07	2	05 30 48.00	33 47 53.8	15.491(0.218)	−2.682(0.001)	1.308(0.023)	11.127
Auriga	3			3.082(0.218)	−1.201(0.056)	1.277(0.110)	2.277
	4			1.173(0.082)	0.435(0.053)	0.801(1.368)	1.383
18151−1208	1	18 15 09.09	−12 08 34.3	4.991(1.118)	30.031(0.032)	0.373(0.061)	12.573
18.34+1.772	2	18 17 57.10	−12 07 22.0	16.391(1.527)	30.746(0.028)	0.767(0.093)	20.088
Serpens Canda	3			10.663(1.145)	32.504(0.045)	0.841(0.131)	11.918
	4			5.727(0.818)	34.059(0.039)	0.558(0.099)	9.627
18367−0504	1	18 39 11.5	−05 04 24.5	13.200(1.609)	88.745(0.000)	0.685(0.137)	18.109
27.369−0.164	2	18 41 50.99	−05 01 28.3	23.864(1.173)	91.108(0.000)	0.950(0.000)	23.591
Scutum	3			107.018(12.436)	93.560(0.116)	2.038(0.167)	49.336
	4			104.373(10.036)	94.466(0.005)	0.767(0.034)	127.827
	5			42.2452.045)	95.785(0.008)	0.537(0.022)	73.855
18488+0000	1	18 48 51.16	00 00 41.6	9.464(0.927)	83.307(0.047)	1.013(0.087)	8.781
32.993+0.038	2	18 51 24.80	00 04 19.0	1.991(0.573)	83.669(0.026)	0.295(0.057)	6.355
Aquilla							
19266+1745	1	19 26 40.23	17 45 41.5	1.309(0.436)	3.539(0.057)	0.386(0.134)	3.191
53.032+0.117	2	19 28 54.00	17 51 56.0	2.209(0.955)	4.270(0.098)	0.638(0.293)	3.273
Sagitta	3			1.882(0.927)	5.034(0.125)	0.622(0.289)	2.836
	4			5.564(0.791)	6.142(0.048)	0.928(0.175)	5.618
	5			1.582(0.518)	7.233(0.087)	0.560(0.189)	2.637
19410+2336	1	19 41 04.5	23 36 54.1	5.809(0.845)	22.214(0.035)	0.458(0.067)	11.918
59.784+0.064	2	19 43 11.40	23 44 06.0	13.964(1.255)	22.894(0.016)	0.510(0.055)	25.745
Vulpecula	3			3.736(1.364)	23.651(0.073)	0.534(0.230)	6.545
20293+3952	1	20 29 21.4	39 52 59.1	12.573(1.064)	5.388(0.030)	0.817(0.049)	14.455
78.975+0.356	2	20 31 10.70	40 03 10.0	8.045(1.118)	6.341(0.056)	0.854(0.098)	8.864
Cygnus	3			10.009(0.436)	7.532(0.018)	0.936(0.052)	10.036
20293+3952 MEC	1	20 29 24.39	39 53 05.9	20.645(1.527)	5.466(0.038)	1.024(0.072)	18.927
78.983+0.349	2	20 31 13.70	40 03 17.0	5.400(1.091)	6.408(0.070)	0.699(0.136)	7.255
Cygnus	3			16.855(0.845)	7.463(0.020)	0.986(0.066)	16.064
23033+5951	1	23 03 19.82	59 51 55.3	12.955(0.300)	−54.078(0.006)	0.573(0.017)	21.218
110.094−0.067	2	23 05 25.70	60 08 07.9	1.527(0.218)	−52.600(0.000)	0.493(0.000)	2.945
Cepheus							
23151+5912	1	23 15 08.7	59 12 25.2	1.827(0.191)	−54.340(0.025)	0.557(0.081)	3.055
111.236−1.238	2	23 17 21.00	59 28 49.0	4.064(0.164)	−52.332(0.013)	0.653(0.034)	5.864
Cassiopeia							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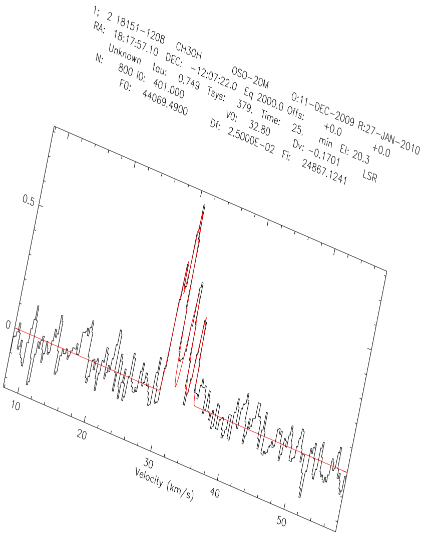
Unknown tau: 0.598 Tsys: 286. Time: 10. min El: 27.3
N: 800 I0: 401.000 V0: 95.30 Dv: -0.1701 LSR
F0: 44069.4900 Df: 2.5000E-02 Fi: 24842.1016
6
4
2
0
80
100
120
Velocity (km/s)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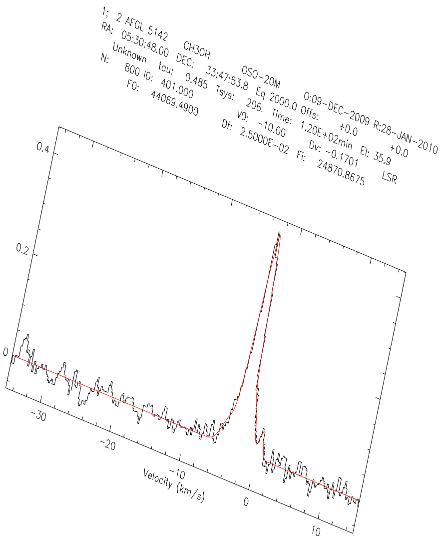
RA: 18:17:57.10 DEC: -12:07:22.0 Eq 2000.0 Offs: +0.0 +0.0
Unknown tau: 0.749 Tsys: 379. Time: 25. min El: 20.3
N: 800 I0: 401.000 V0: 32.80 Dv: -0.1701 LSR
F0: 44069.4900 Df: 2.5000E-02 Fi: 24867.1241
0.5
0
10
20
30
40
50
Velocity (km/s)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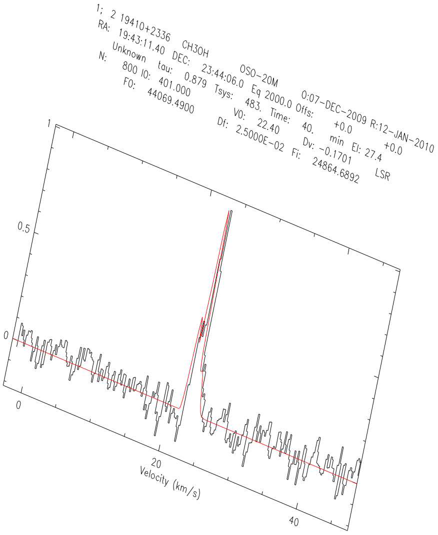
RA: 05:30:48.00 DEC: 33:47:53.8 Eq 2000.0 Offs: +0.0 +0.0
Unknown tau: 0.485 Tsys: 206. Time: 1.20E+02min El: 35.9
N: 800 I0: 401.000 V0: -10.00 Dv: -0.1701 LSR
F0: 44069.4900 Df: 2.5000E-02 Fi: 24870.8675
0.4
0.2
0
-30
-20
-10
0
10
Velocity (km/s)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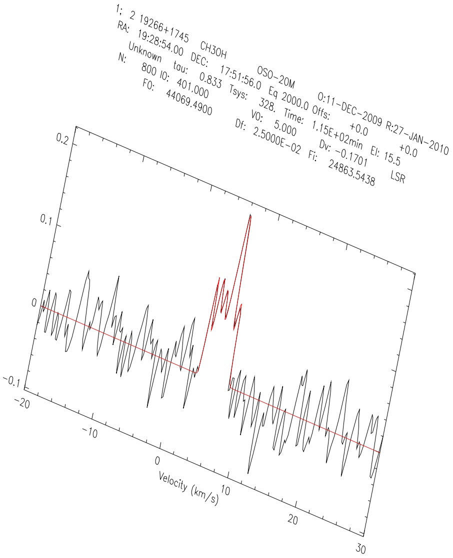
RA: 19:43:11.40 DEC: 23:44:06.0 Eq 2000.0 Offs: +0.0 +0.0
Unknown tau: 0.879 Tsys: 483. Time: 40. min El: 27.4
N: 800 I0: 401.000 V0: 22.40 Dv: -0.1701 LSR
F0: 44069.4900 Df: 2.5000E-02 Fi: 24864.6892
1
0.5
0
0
20
40
Velocity (km/s)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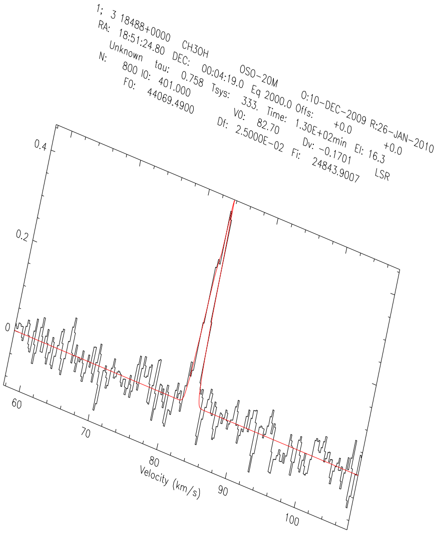
Unknown tau: 0.833 Tsys: 328. Time: 1.15E+02min El: 15.5
N: 800 I0: 401.000 V0: 5.000 Dv: -0.1701 LSR
F0: 44069.4900 Df: 2.5000E-02 Fi: 24863.5438
0.2
0.1
0
-0.1
-20
-10
0
10
20
30
Velocity (km/s)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Unknown tau: 0.758 Tsys: 333. Time: 1.30E+02min El: 16.3
N: 800 I0: 401.000 V0: 82.70 Dv: -0.1701 LSR
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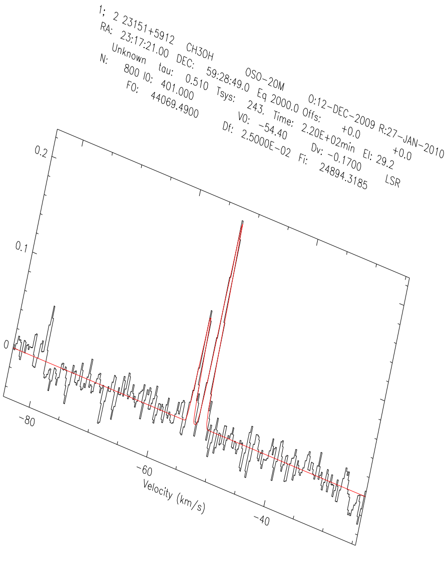
0.4
0.2
0
60
70
80
90
100
Velocity (km/s)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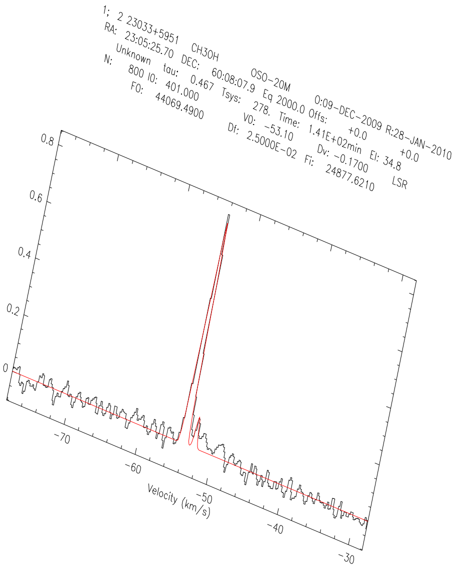
Unknown tau: 0.510 Tsys: 243. Time: 2.20E+02min El: 29.2
N: 800 I0: 401.000 V0: -54.40 Dv: -0.1700 LSR
F0: 44069.4900 Df: 2.5000E-02 Fi: 24894.3185
0.2
0.1
0
-80
-60
-40
Velocity (km/s)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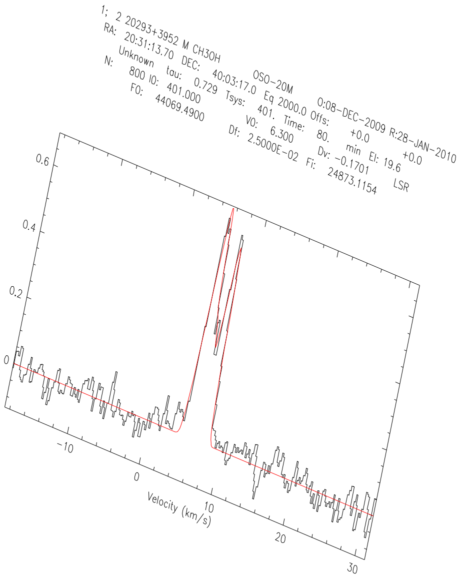
RA: 23:05:25.70 DEC: 60:08:07.9 Eq 2000.0 Offs: +0.0 +0.0
Unknown tau: 0.467 Tsys: 278. Time: 1.41E+02min El: 34.8
N: 800 I0: 401.000 V0: -53.10 Dv: -0.1700 LSR
F0: 44069.4900 Df: 2.5000E-02 Fi: 24877.6210
0.8
0.6
0.4
0.2
0
-70
-60
-50
-40
-30
Velocity (km/s)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Unknown tau: 0.729 Tsys: 401. Time: 80. min El: 19.6
N: 800 I0: 401.000 V0: 6.300 Dv: -0.1701 LSR
F0: 44069.4900 Df: 2.5000E-02 Fi: 24873.1154
0.6
0.4
0.2
0
-10
0
10
20
30
Velocity (km/s)

Conclusions

- **Successful observations of class I methanol masers at 44 GHz have been carried out.**
- **The map of class I methanol maser emission around SNR G27.4-0.16 was obtained.**
- **To confirm the hypothesis of excitation of class I methanol masers by shock waves in the vicinity of SNR we plan to make observations in the lines CO and H_2 1-0 S(1).**
- **9 new class I methanol masers at 44 GHz were detected in the direction of high-mass star-forming regions from the lists of *Shridharan 2002.***

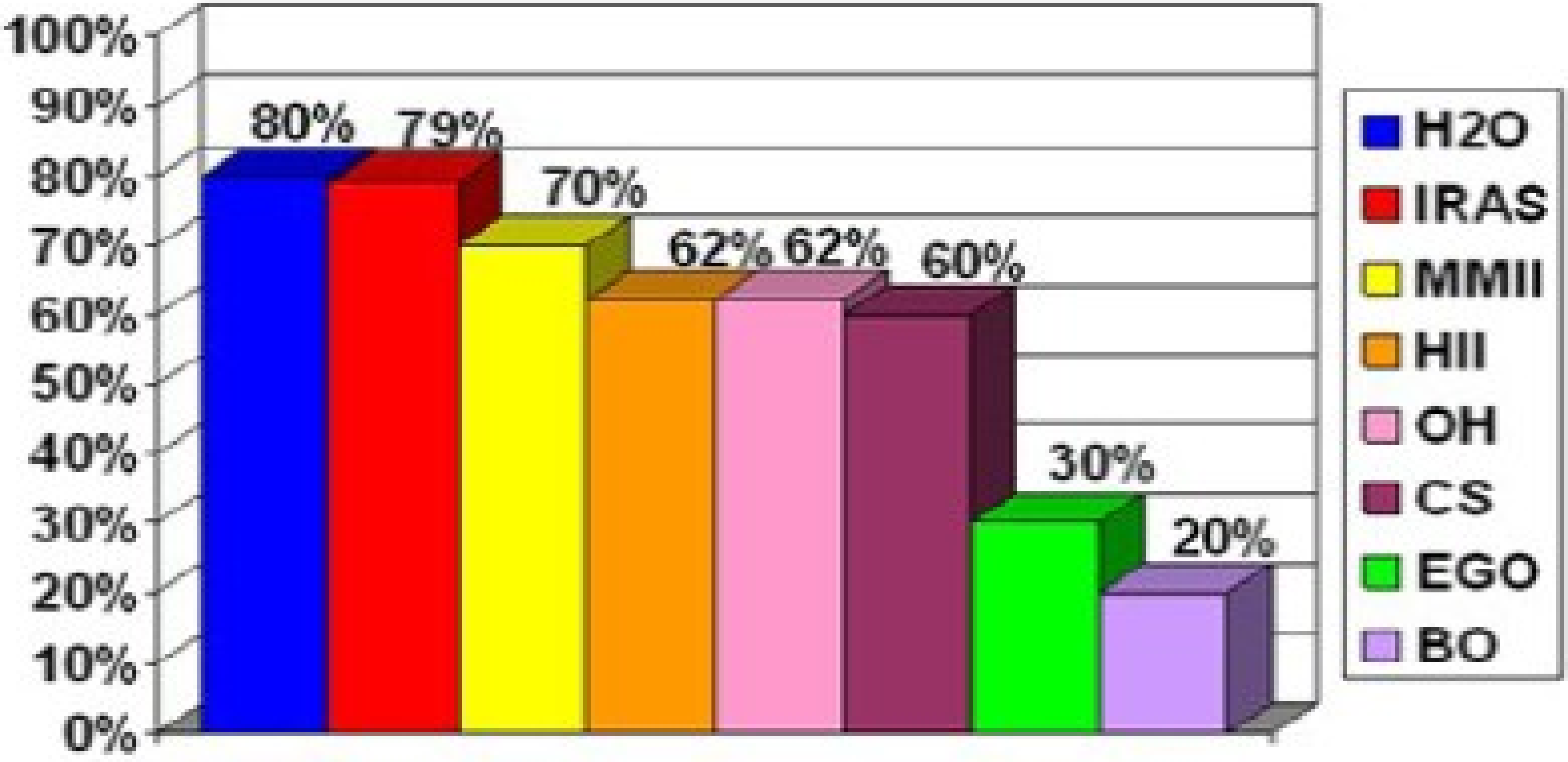

Fig.4. Histogram showing the results of the statistical analysis of the data for class I methanol maser and their environment (from "General Class I Methanol Maser Catalog", by *Val'tts, Larionov, & Bayandina*, http://asc.rssi.ru/MMI) .