

# 6.7 GHz Methanol Maser Survey in Outer Galaxy beyond the Galactic Center

S. Kanazawa, K. Fujisawa, K. Hachisuka, K. Niinuma, K. Motogi (Yamaguchi University)

## Abstract

Study of the area beyond the Galactic Center is poor. Since objects in the area are far from the sun, they are difficult to be observed in terms of angular size and flux density. The area beyond the Galactic Center has not been well considered in the studies of the star formation and Galactic astronomy. Recently, however, new spiral arm was found in the Galactic First Quadrant beyond the Outer Arm, and it is called as Outer Scutum - Centaurus Arm. HII regions and molecular clouds were also found in the arm. Only a few 6.7 GHz methanol maser sources have been found in the Outer Galaxy beyond the Galactic Center region. We have made a 6.7 GHz methanol maser survey toward Outer Galaxy beyond the Galactic Center, Outer Scutum - Centaurus Arm in the range of  $350^\circ < l < 25^\circ$  using Yamaguchi 32m telescope and VERA for determining the distance to Outer Scutum - Centaurus Arm. As a result, 11 methanol maser sources were detected, of which one was new detection. The detected sources are probably in the inner Galaxy because of their line-of-sight velocities. Bright sources like W3(OH) was not found in this survey, and it is likely that bright source does not exist in the Outer Scutum - Centaurus Arm.

## Introduction

Structure of Milky Way is thought to be a barred spiral Galaxy (Fig.1). These arms are called as Near and Far 3kpc Arm, Sagittarius Arm, Norma-Outer Arm, Perseus Arm and Scutum - Centaurus Arm, respectively. Structures of these arms are still unclear because observations of the area beyond Galactic Center have not been performed well. Since distance to object beyond the Galactic center is far from the sun, and therefore studies of such a distant source is more difficult than that of neighborhood. However, recent studies of Our Galaxy's structure discovered a new spiral arm beyond the outer arm in the Galactic First Quadrant. This arm was defined as an extension of Scutum - Centaurus Arm (Dame & Thaddeus 2011). In addition, kinematic distance towards several HII regions within  $|l| < 30^\circ$  were resolved using radio recombination line and HI absorption spectra and these HII regions are located beyond Galactic center (Jones et al. 2012, 2013). Furthermore a few methanol maser sources were also found beyond Galactic Center region. Our Galaxy has been mapped by maser VLBI astrometry using VERA since 2007 (Honma et al. 2012), the area beyond Galactic center has not been mapped yet. Because there is no maser source in there which is good for the VLBI astrometry.

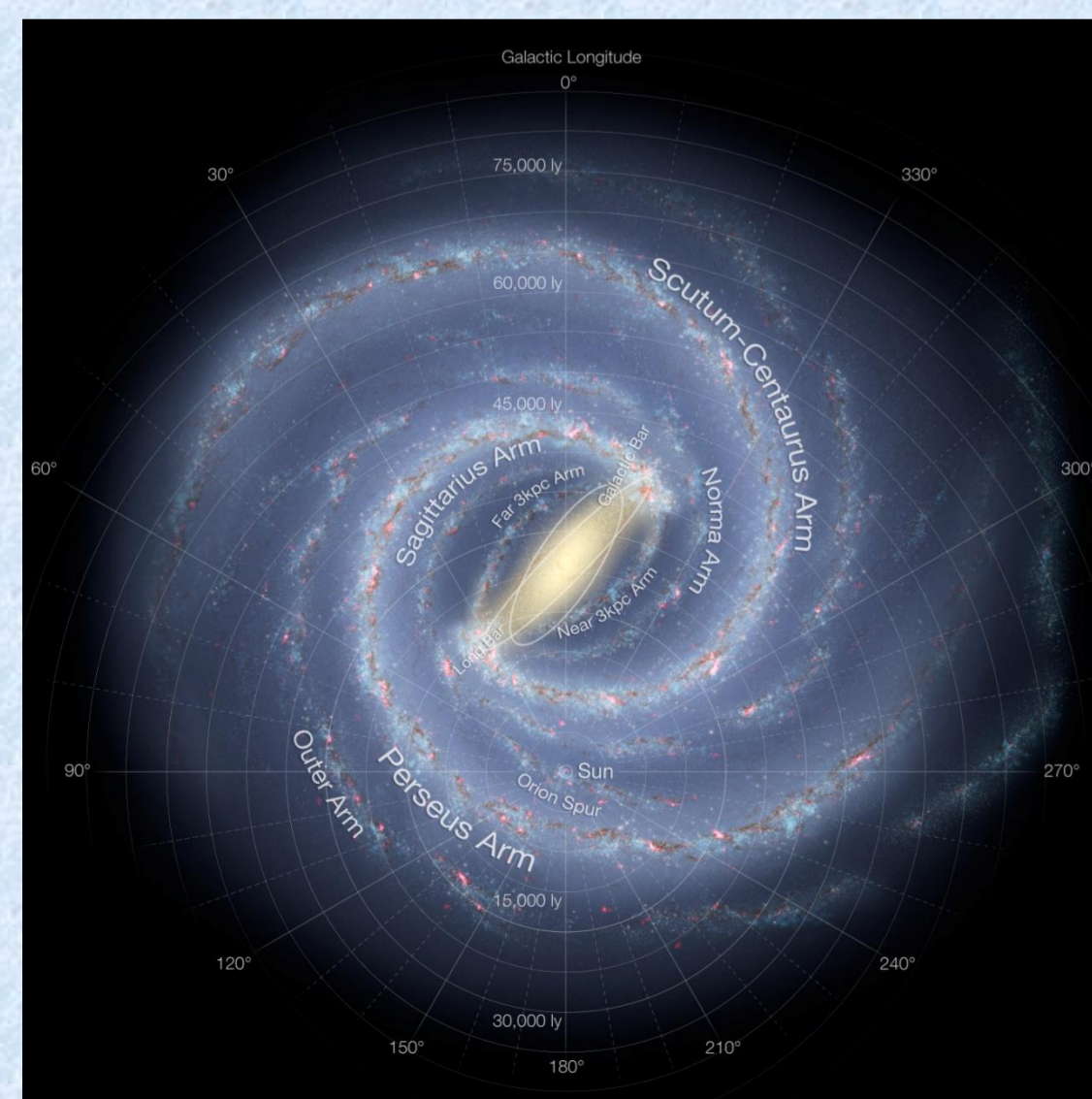


Fig.1 Picture of Milky Way



Fig.2 Observable area of VERA.

We would like to observe the area beyond Galactic Center using VERA.

## Purpose

We proposed to search new 6.7 GHz methanol maser sources toward HII regions in outer Galaxy beyond the Galactic center region. If maser sources were found, it would be possible to reveal structure of the arm in Outer Scutum - Centaurus Arm at Galactic First Quadrant by the observations of these sources. If we can measure a distance of the arm, it will help to determine the diameter of Our Galaxy.

## Observations

We selected possible distant HII regions (yellow circles in Fig.3) from the HII region catalog by C. Jones et al. (2012, 2013).

- Observation range :  $355^\circ < l < 24^\circ$
- The number of target source : 25
- Observation date: May 19 ~ May 28
- Observation method : position switching

Table 1 Observation Parameters

Aperture	32 m
Beam size	5'
System temperature	~ 60 K
Velocity resolution	0.044 km/s
bandwidth	8 MHz
Spectral channels	8192
rms noise level $1\sigma$	~0.2 Jy
Integration time	3600 s

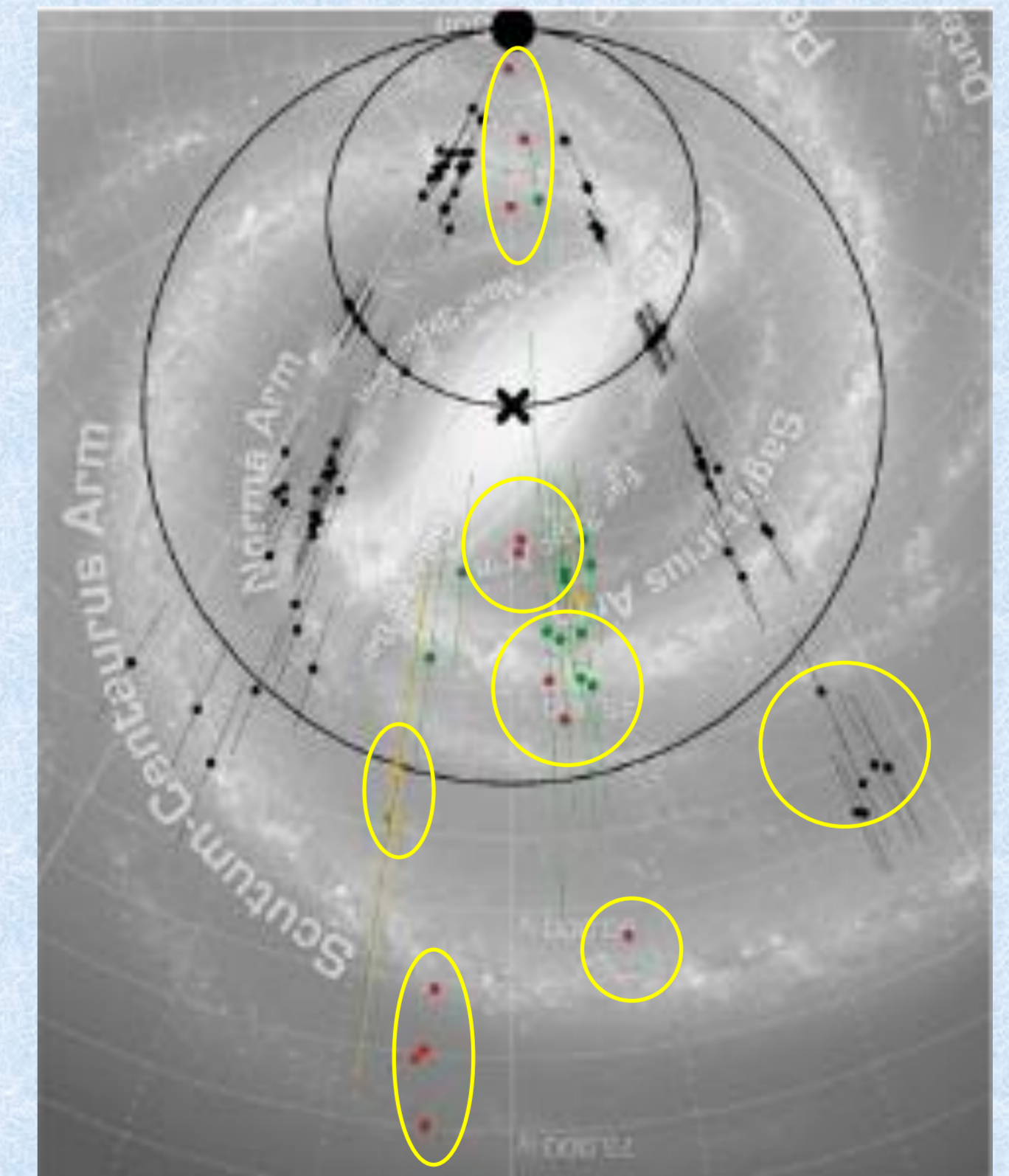


Fig.3 Distribution of distant HII regions (Jones et al. 2013). The yellow circles were observed in this survey.



# Result

- rms noise level  $1\sigma$  after 8 channel bind is 0.06 – 0.1 Jy  
→ Sensitivity was better than the Methanol Multibeam (MMB) survey (0.17 Jy).
- We detected in 11 of 25 sources, of which one maser (25.151-00.667) is a new detection.  
→ 8 methanol maser sources were known sources (MMB survey)[4][5].

**I found this one !!!!**

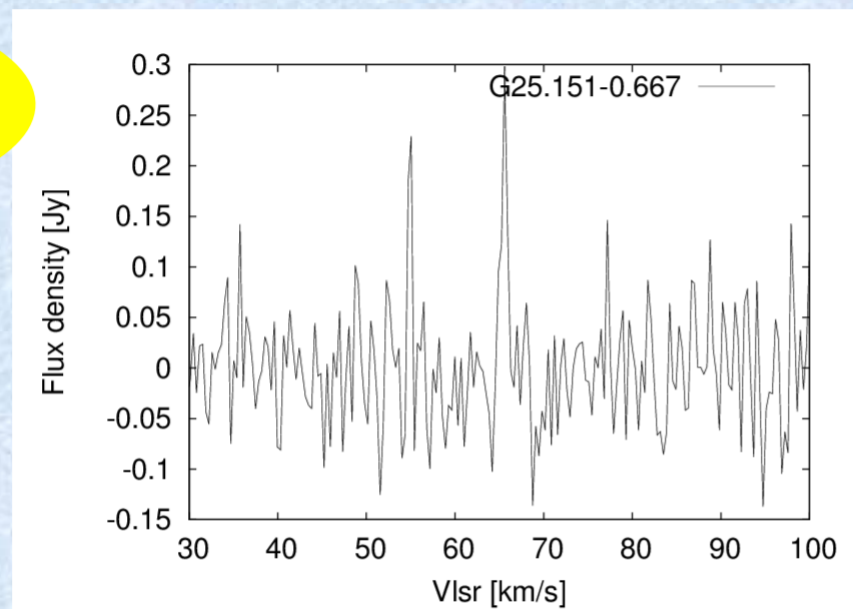


Fig.4 New methanol maser G25.151-00.667 of first detection.

- Almost of them would be neighborhood, but two sources, G355.242+00.096 and G355.344+00.145 might located in the outer Scutum – Centaurus Arm by their LSR velocity (Dame and Thaddeus 2011). Note that water maser has been detected in G355.344+00.145 (Walsh et al. 2011).

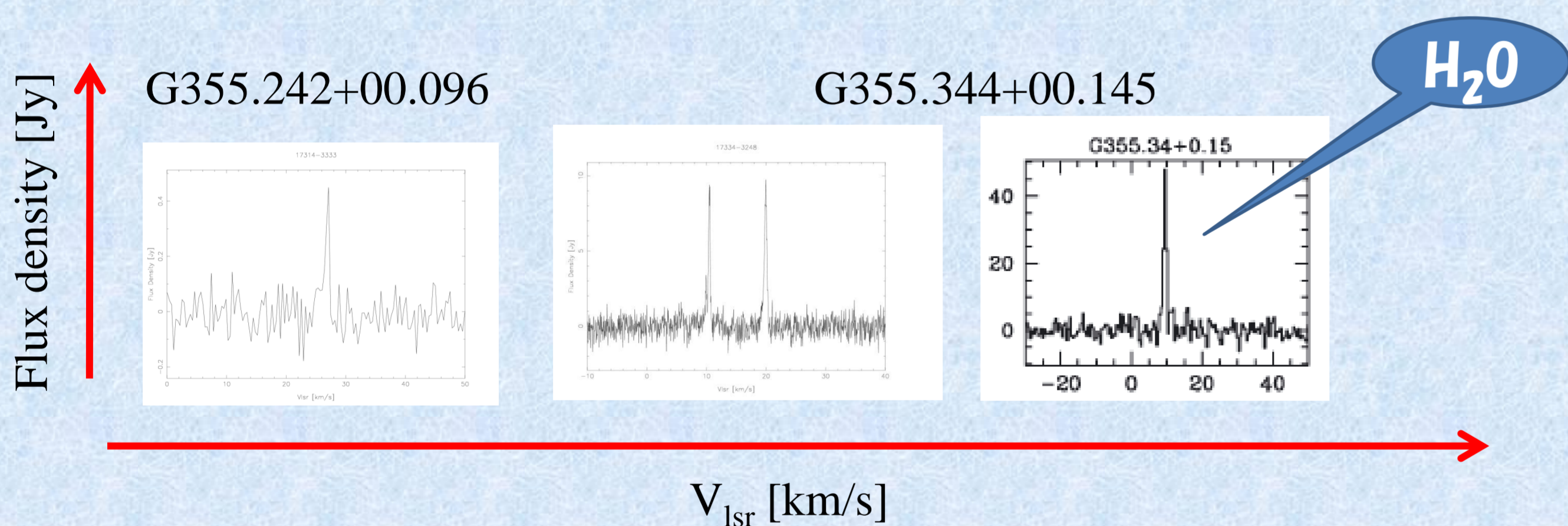


Fig.5 G355.242+00.096 and G355.344+00.145 spectral. The right picture is Water maser spectral ( Walsh et al. 2011).

# Future

- We are searching 6.7 GHz methanol maser in Perseus Arm at  $350^\circ < l < 10^\circ$ ,  $40^\circ < b < 70^\circ$ .  
→ Only a few maser sources have been mapped in this area by VERA, therefore these area are still unclear. We would like to help VERA project by discovery new maser sources in this are.
- As a first step of VLBI astrometry for distant maser source, we would like to propose observation of G355.242+00.096 and G355.344+00.145 in VERA.  
→ They may be located in the area beyond the Galactic Center.

# Discussion

- These sources that we were detected in this survey are shown in Fig.6. It is assumed that the flat Galactic rotation curve (Honma et al. 2012).

Table 2. Information of detected methanol maser sources.

Distance  $r$  is kinematic distance which is assumed flat rotation curve. The distance of G354.486+00.085 and G355.344+00.145 are unclear, however these sources is thought to be beyond the Galactic Center.

Source Name	RA <sup>h m s</sup>	Dec <sup>° ' "</sup>	$S_p$ [Jy]	$V_{LSR}$ [km/s]	$r$ [kpc]
G000.838+00.189	17 46 52.15	-28 07 19	4.3	3.6	4.1
G005.889-00.427	18 00 38.8	-24 04 51	3.3	9.7	2.3
G025.395+00.030	18 37 31.2	-06 41 24	0.9	94.8	4.9
G025.151-00.667	18 39 34	-07 13 34	0.39	65	3.7
G026.610-00.210	18 40 37.3	-05 43 13	4.3	115	5.7
G350.813-00.019	17 21 53.6	-36 29 30	3.9	-10.5	1.8
G351.028+00.155	17 21 47.3	-36 22 57	3.9	-10.5	1.8
G351.192+00.708	17 20 00.1	-35 55 57	10.6	-5.2	1.0
G351.358+00.666	17 20 38.4	-35 49 13	90.3	-10.4	1.8
G354.486+00.085	17 31 29.7	33 33 08	0.8	27.1	~16
G355.344+00.145	17 33 29.7	-32 48 02	9.7	19.9	~16

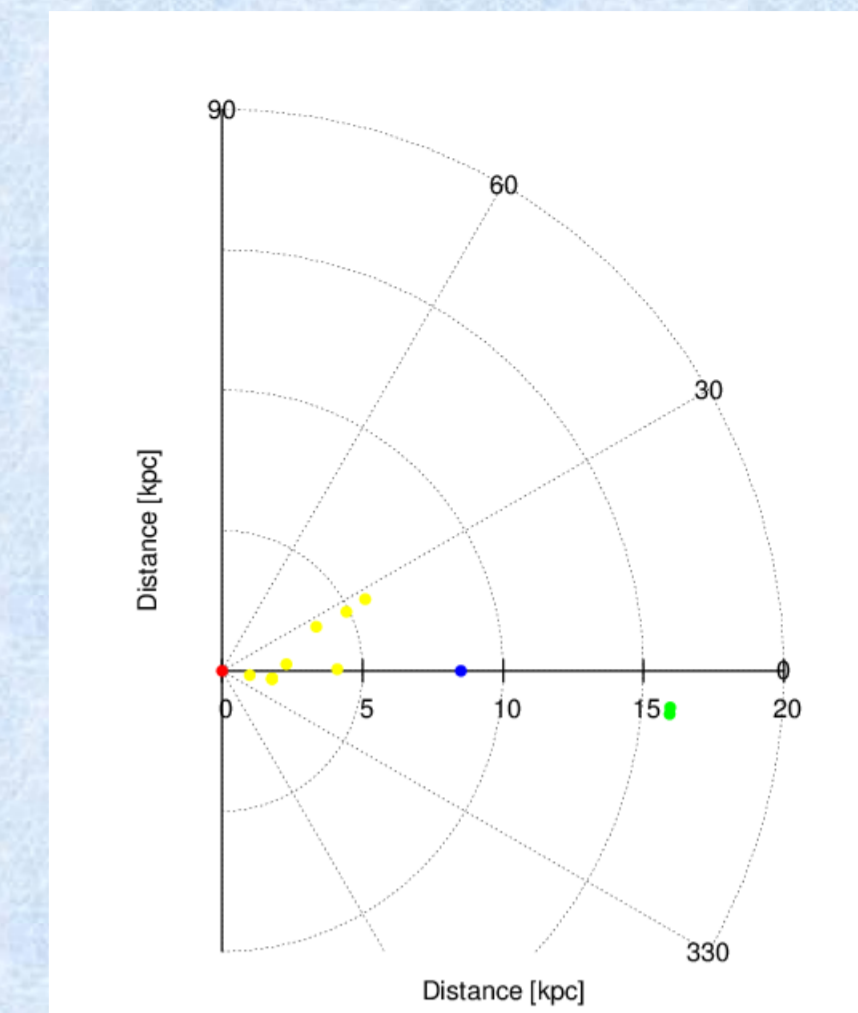
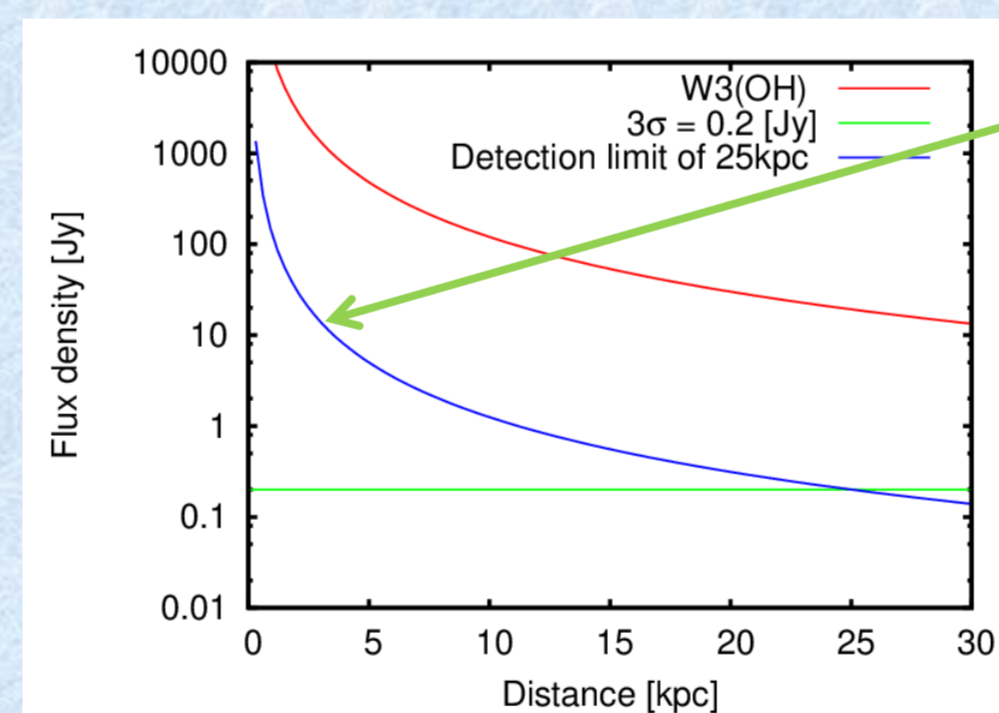


Fig.6 Distance from the sun to the sources in this survey.

Red point is the sun, blue point is Galactic Center, yellow points are detected sources when there are near-side distance, and green points are located in 16 kpc from the sun that there are assumed to be a far side distance.

- Bright sources like W3(OH), the distance is 2 kpc from the sun and the flux density of a single dish is 3000 Jy, are not found in this observation. Assuming that W3(OH) is moved from 2 to 25 kpc, the flux density is about 20 Jy. We think that massive star formation rate beyond Outer Arm maybe lower than inner Galaxy. Actually, the bright methanol maser source is not found in this area.



**If it is 2 kpc, flux density is about 30 Jy and luminosity is about  $10^{-7}L_0$  !**

Fig.7 Yamagichi 32 m telescope's detection limit at 1hour.

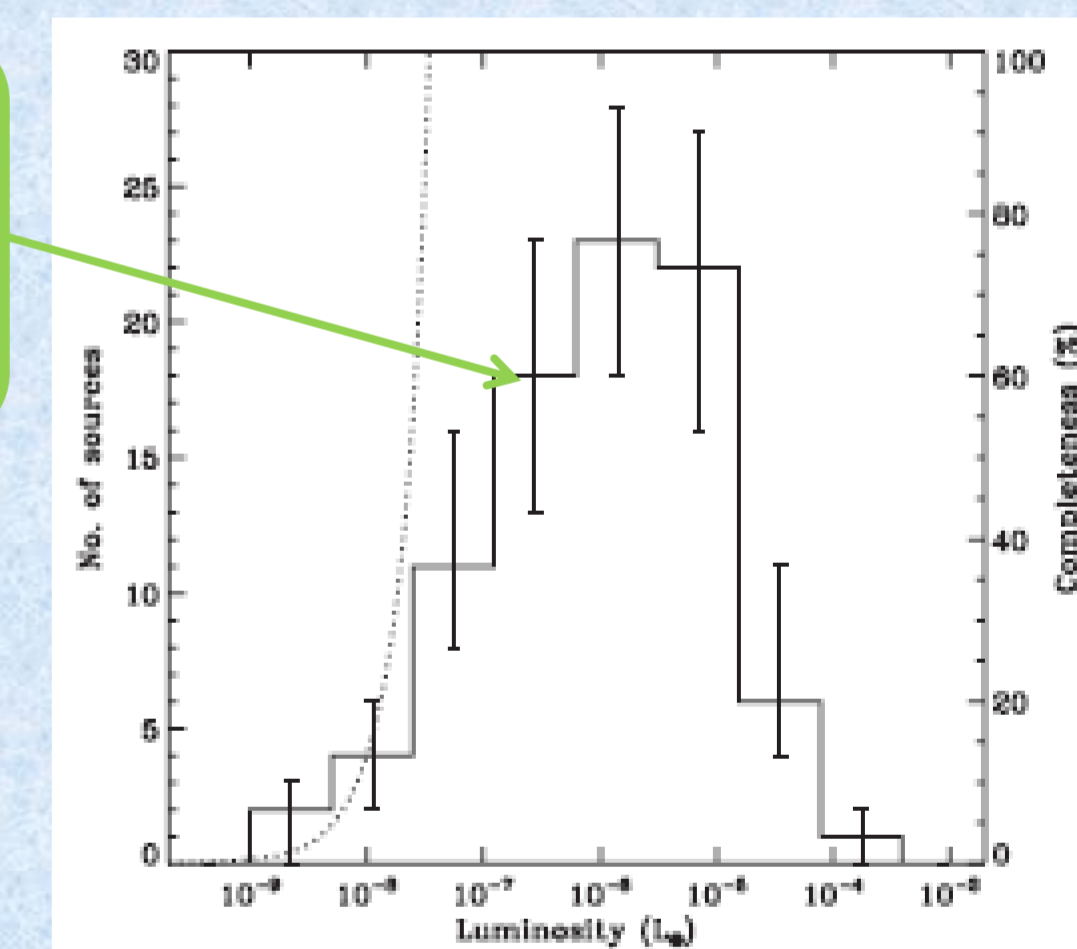


Fig. 8 Luminosity function of 6.7 GHz methanol maser. (Pandian et al. 2009)

# Reference

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