

Parallax and proper motions measurement toward the CMZ

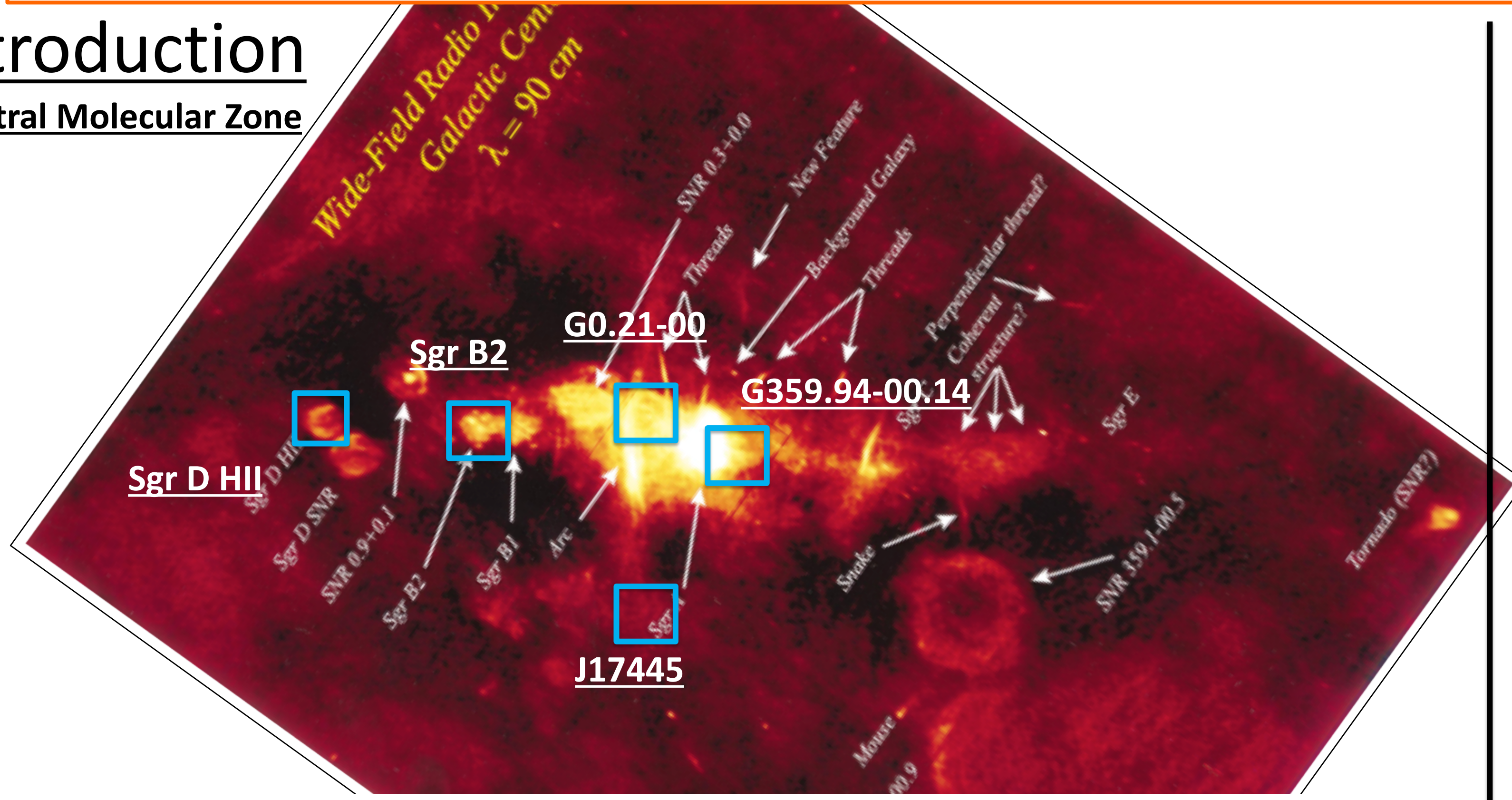
Daisuke Sakai, Tomoaki Oyama, Takumi Nagayama, Mareki Honma, Hideyuki Kobayashi (NAOJ)

The Central Molecular Zone (CMZ) in the Galactic center region shows outstanding non-circular motion unlike the Galactic disk. Although several models describing this non-circular motion are proposed, an uniform kinematic model of the CMZ orbit is not appeared. Three dimensional velocity information including proper motions will be critical to constrain the orbital models of the CMZ because most of models proposed are devised to reproduce the line-of-sight velocity profiles of the molecular clouds in this region.

To reveal the dynamics of the Galactic center region, we conducted VLBI astrometric observations of 22 GHz water maser sources toward the Galactic center with VERA. By measuring parallaxes and proper motions, we can identify whether each source is actually located in the CMZ or not, and identify the three dimensional positions and velocities in the non-circular orbit if the source is located in the CMZ. We show the results of astrometric study for several maser sources associated with molecular clouds toward the Galactic center including Sgr B2 complex and Sgr D HII region. The parallax measurement toward Sgr B2 obtained the parallax of 0.133 mas +/- 0.038 mas, and its proper motions indicated that Sgr B2 complex is moving toward the positive Galactic longitude with $V=100$ km/s relative to Sgr A*.

Introduction

Central Molecular Zone



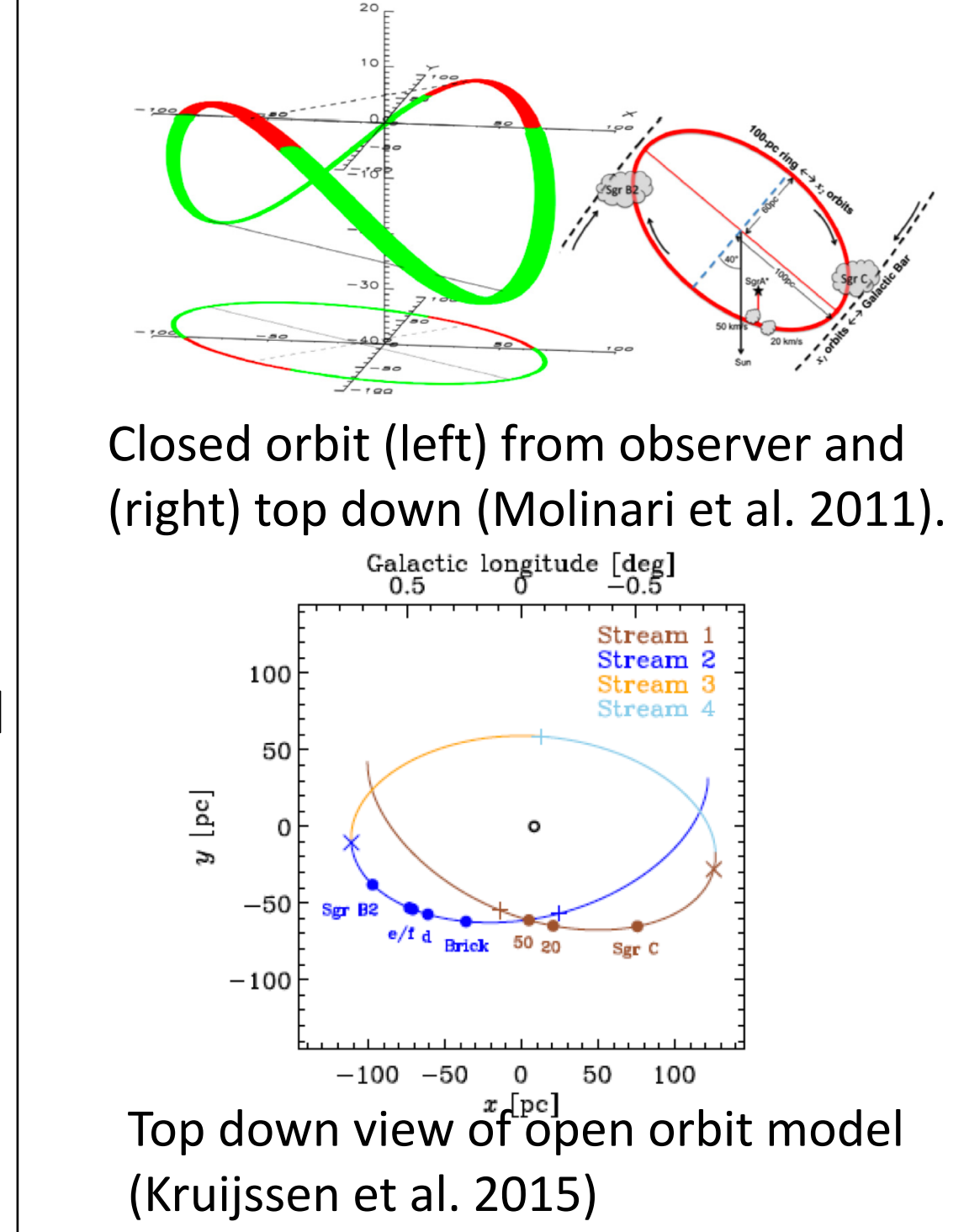
90 cm radio continuum image taken by VLA (Larosa 2000). Rectangles indicate sources which we conducted VLBI astrometric observations with VERA.

Dynamical model problems

There are some competitive models which explains dynamical orbit in Central Molecular Zone,

1. Closed elliptical model (Molinari et al. 2011)

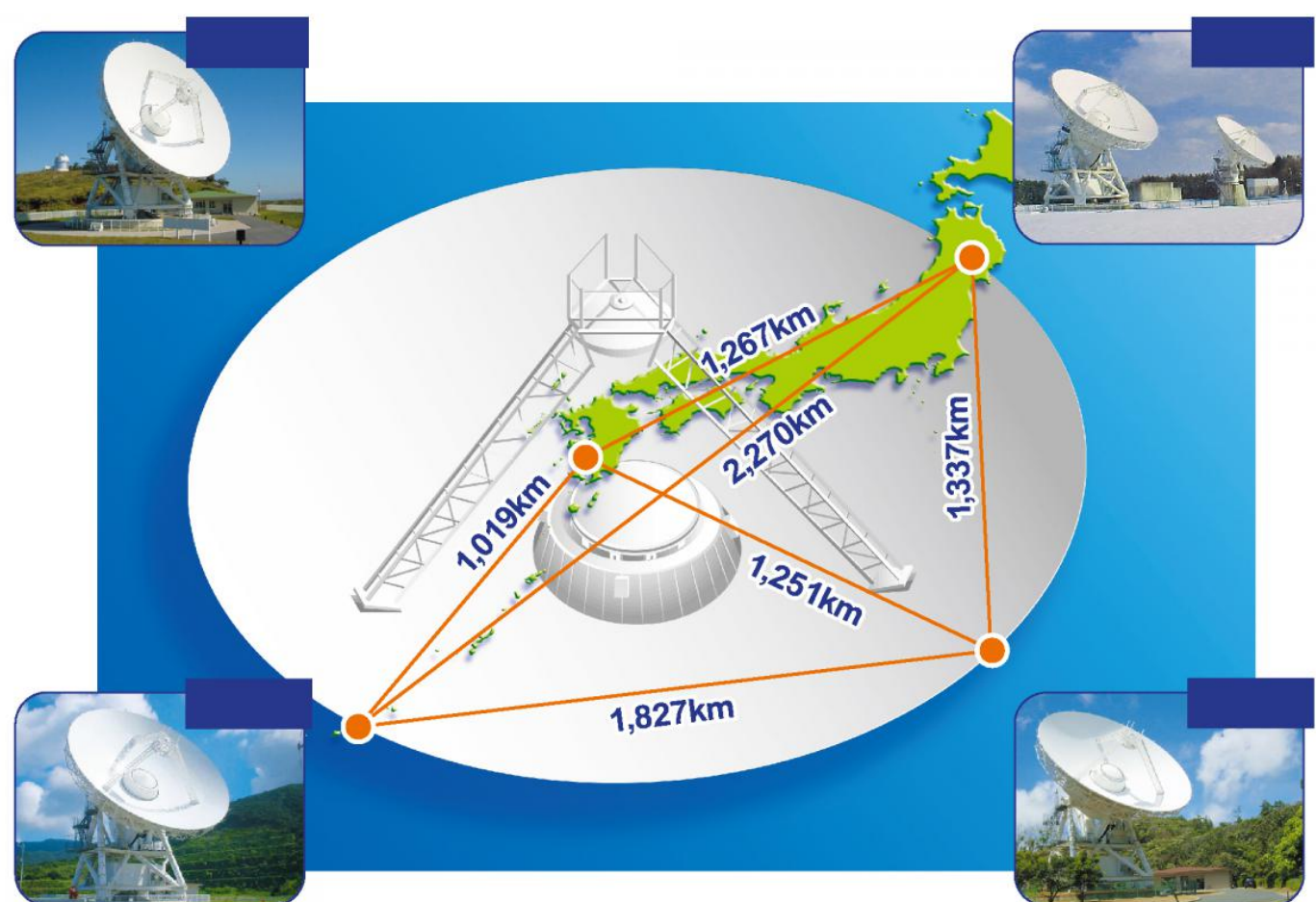
- The orbit is **closed**.
- Orbital velocities at each position of the orbit is constant (80 km/s).
- Position of Sgr A* is displaced from dynamical center of the orbit.



2. Open orbit model (Krujissen et al. 2015)

- The orbit is **open**.
 - Orbital velocities are different by position angle.
 - Star formation in CMZ are triggered by tidal shear and compression.
- 3D velocities and parallax measurement by VLBI are essential to reveal the real dynamical nature in CMZ.

Observations



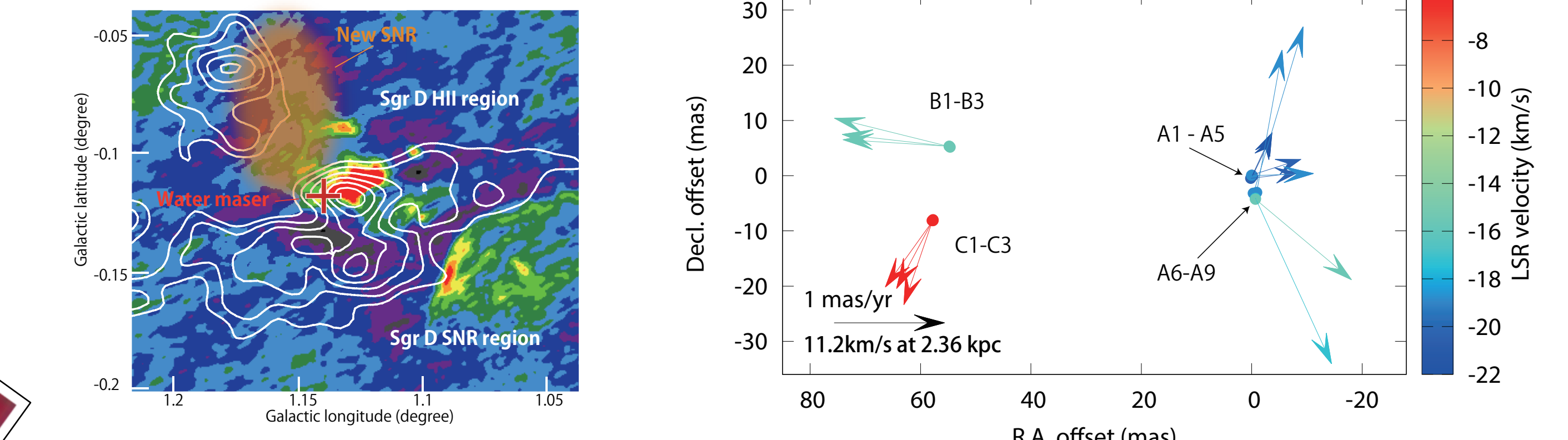
Array : VERA
Target line : 22 GHz water maser
Mode : 2-beam
Longest baseline : 2,300 km (Mizusawa-Ishigaki)
Phase-reference source : J1745-2820 (~30 mJy)

VERA array(Mizusawa, Iriki, Ogasawara, and Ishigaki)

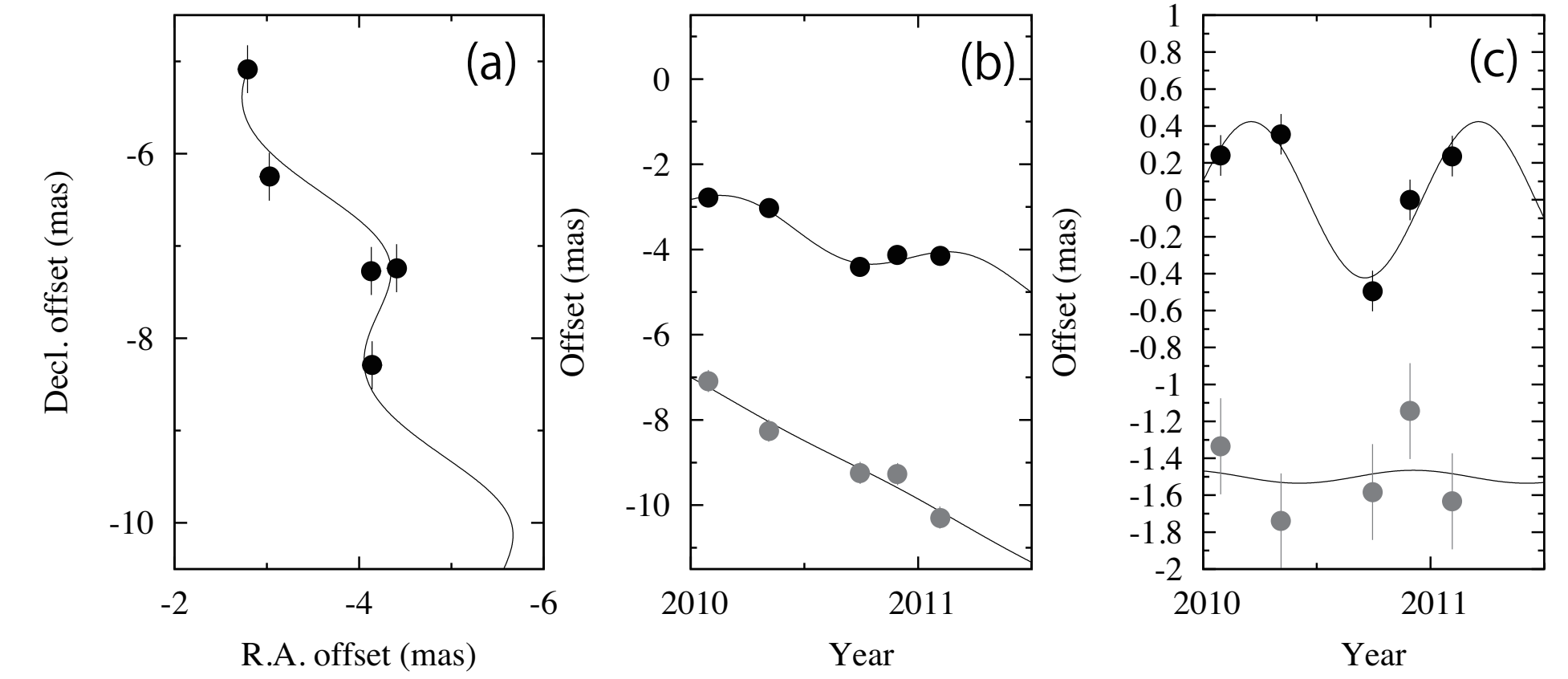
Target sources	l(Galactic longitude)	b(Galactic latitude)	Vlsr	Obs. epochs
Sgr D HI region	1.14°	-0.13°	-19 km/s	9 epochs(2008-2011)
Sgr B2	0.67°	-0.04°	+60 km/s	11 epochs(2014-2017)
G000.16-00.44	0.17°	-0.45°	+10 km/s	7 epochs (2016-2017)
G359.94-00.14	-0.06°	-0.14°	-35 km/s	9 epochs (2014-2016)
G0.21-0-0	-0.21°	0.00°	+47 km/s	5 epochs (2017- continuing)

Results

Sgr D HII region

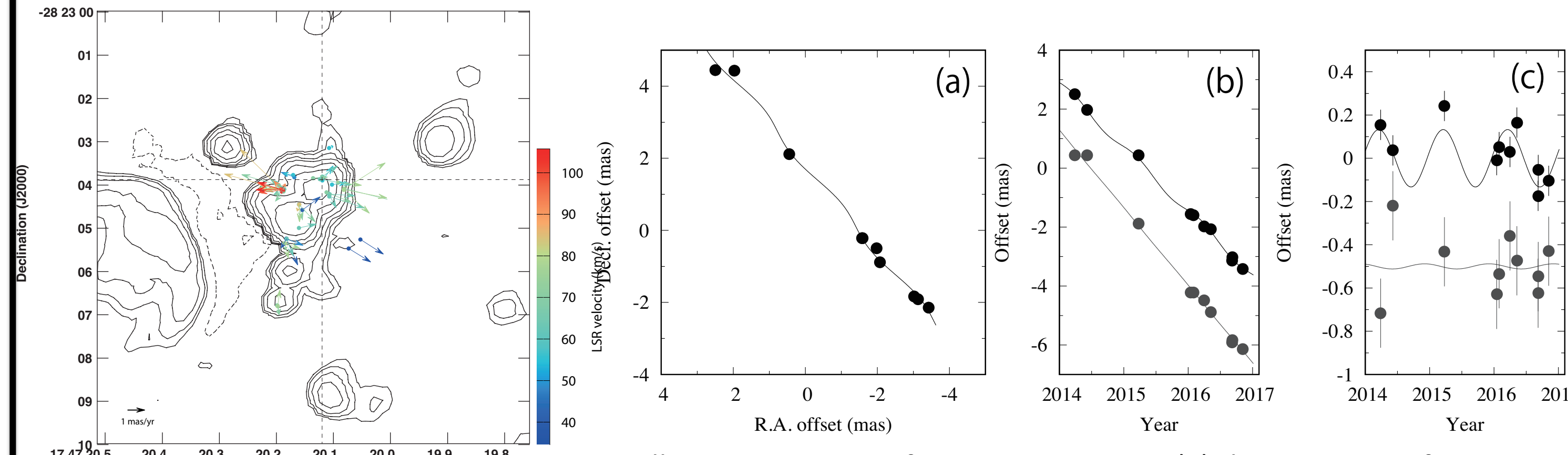


6 cm radio continuum image with CS (J=1-0) contour. Water maser distribution and Red cross represents the position of 22 GHz water maser. Internal motion of water maser spots in Sgr D



Parallax measurement for Sgr D HII region. (a) the positions of masers for each epoch on the sky plane. (b) R.A. and Dec. position as a function of year. (c) Parallax fitting.

Sgr B2



Parallax measurement for Sgr B2M region. (a) the positions of masers for each epoch on the sky plane. (b) R.A. and Dec. position as a function of year. (c) Parallax fitting.

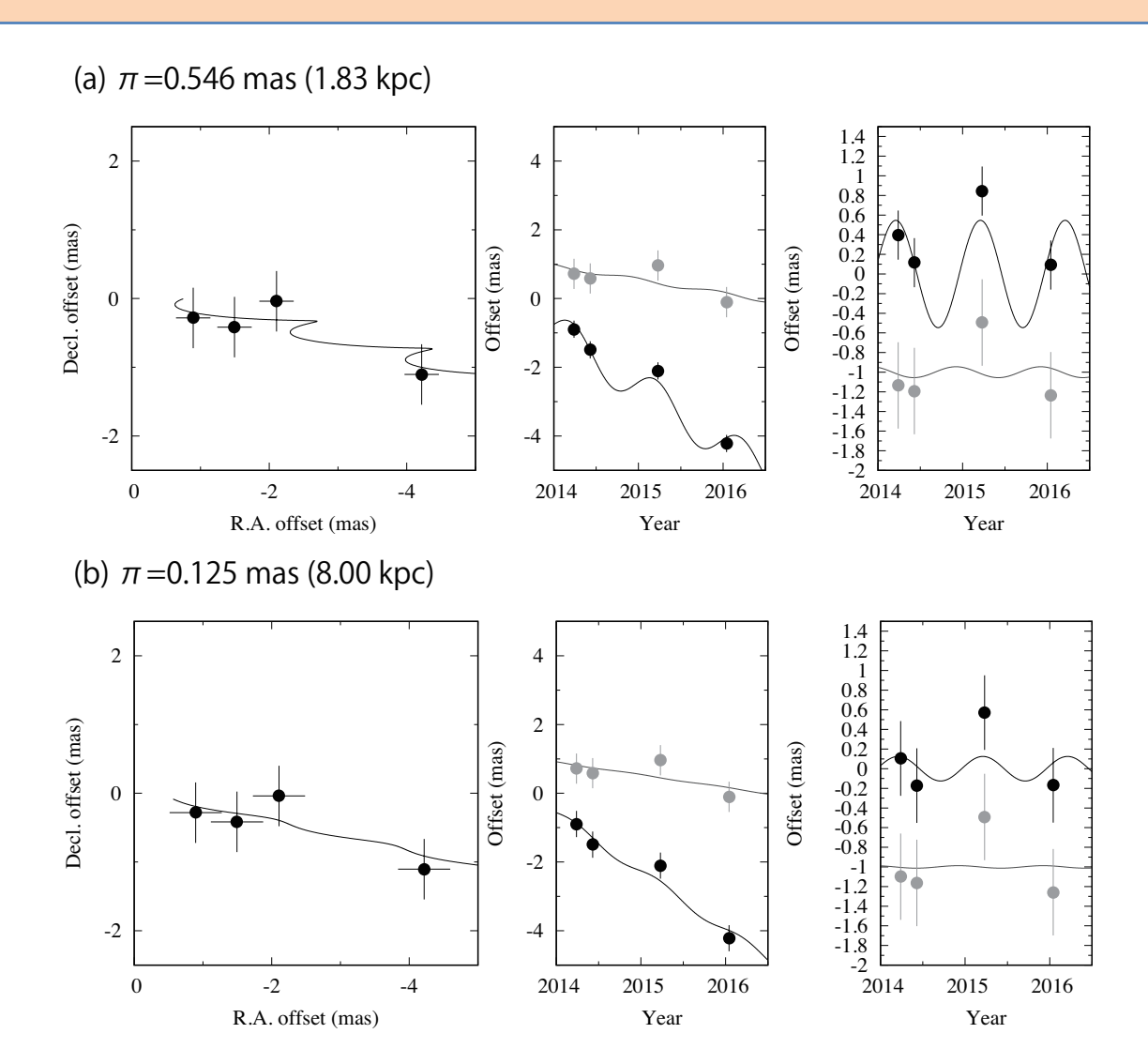
Parallax fitting for Sgr B2(M)

	Fitted value	Error
Parallax	0.133 mas	0.038 mas
Distance	7.52 kpc	+3.01/-1.67 kpc
RA motion	-2.17 mas/yr	0.03 mas/yr
Dec motion	-2.63 mas/yr	0.06 mas/yr

- Fitted values are consistent with VLBA result within errors (Reid et al. 2009).
- Proper motions relative to Sgr A* on the Galactic coordinate is $(\mu_{lgc}, \mu_{bgc}) = (2.569, -0.202)$ mas/yr.
- This is corresponding to 102 km/s at the distance of 8.3 kpc.
- Proper motions and orbital velocity for Sgr B2 is prefer closed orbit model prediction.

Other sources

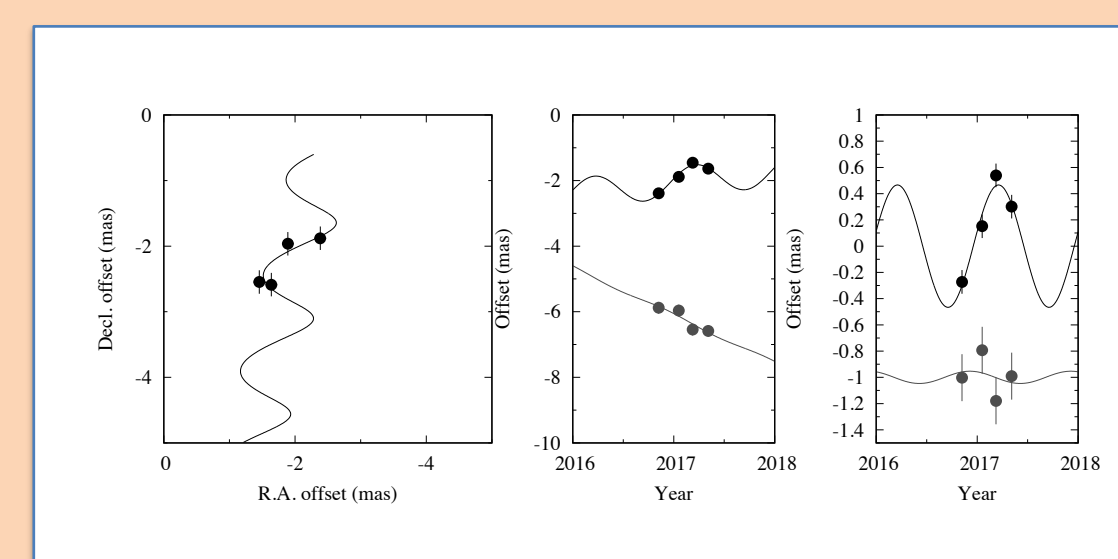
G359.94-00.14



- Large variability of maser flux
 - Not enough for parallax fitting
 - Proper motions relative to Sgr A*
- if we adopt the distance of Galactic center (8kpc)
 $(\mu_{lgc}, \mu_{bgc}) = (5.18 \pm 0.38, 1.45 \pm 0.40)$ mas/yr

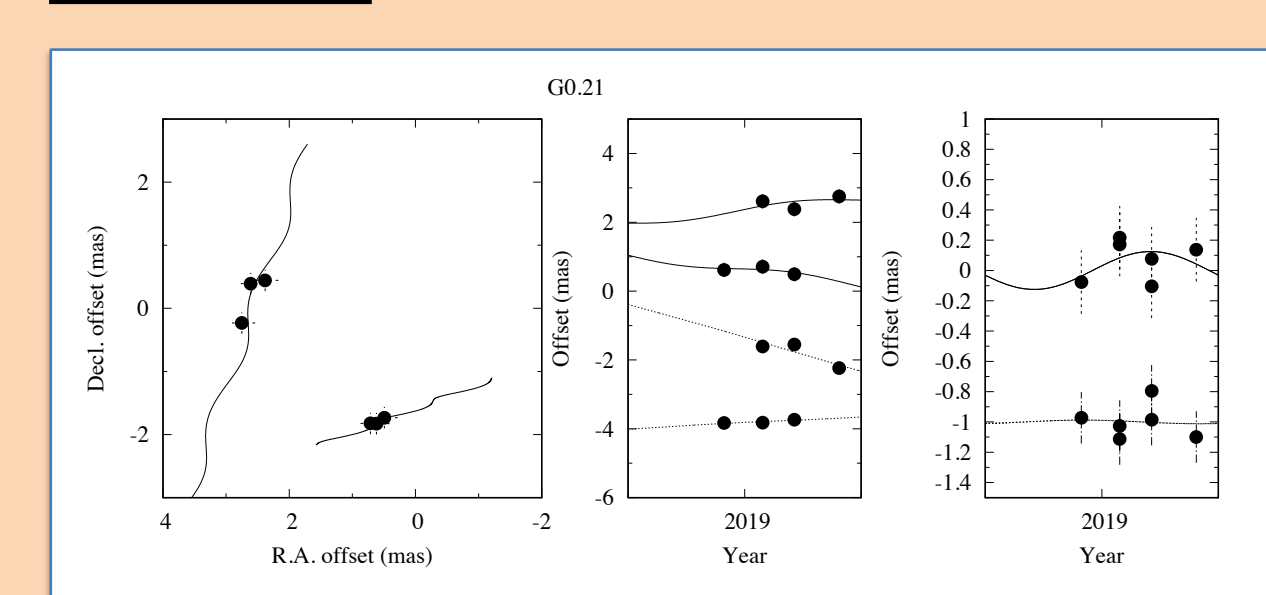
This proper motions value is consistent with proper motion prediction by Krujissen et al. (2015) at 20 km/s cloud in CMZ

G000.16-00.44



- Projected position is displaced from CMZ disk
 - Parallax measurement suggests **foreground source**
- Parallax = 0.645 ± 0.074 mas
Corresponds to 1.55(+0.20/-0.16) kpc

G0.21-0-0

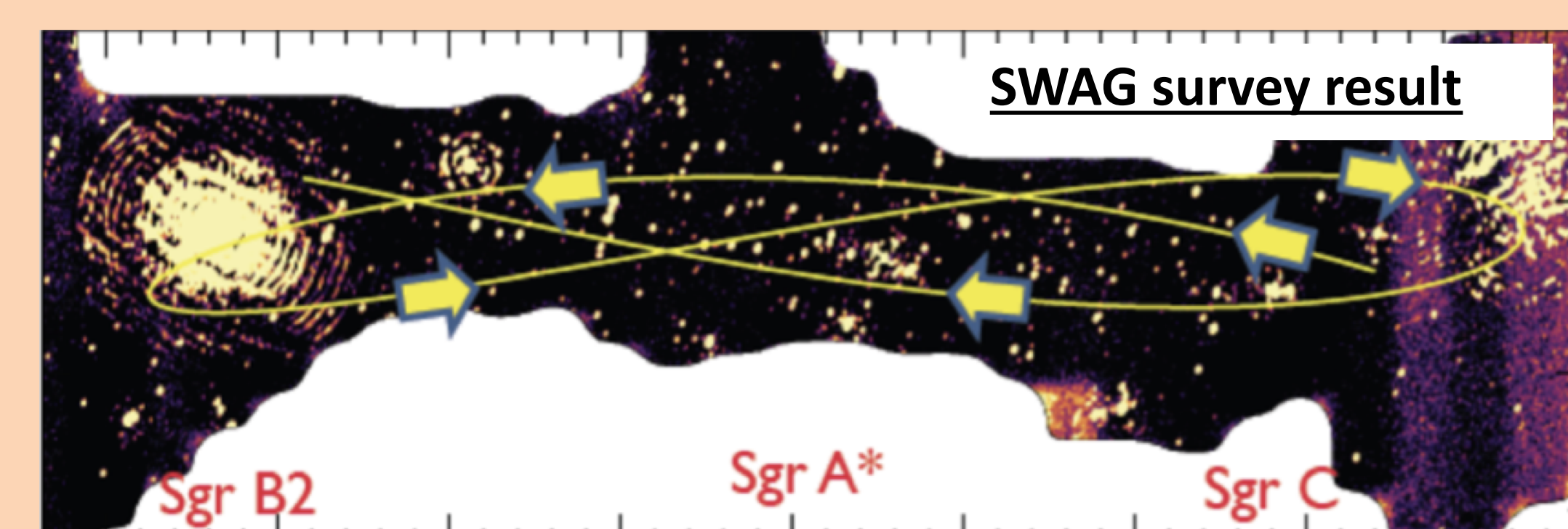


- Preliminary results
- Observations not finished
 - Current data implies > 5kpc distance

Future prospects

EAVN (East Asia VLBI Network) will be able to detect more weak maser sources and weak phase-referencing sources.
- It leads the number of sources which we can measure proper motions increase.

Current detection limits for astrometry are
1 Jy for maser sources
30 – 40 mJy for phase reference QSO
According to SWAG water maser survey,
If the limit of sensitivity down to 0.1 Jy,
the number of source increase by an order.



EAVN arrays

Water maser distribution
> 10 Lsun
SWAG survey
Ott et al. (2018)