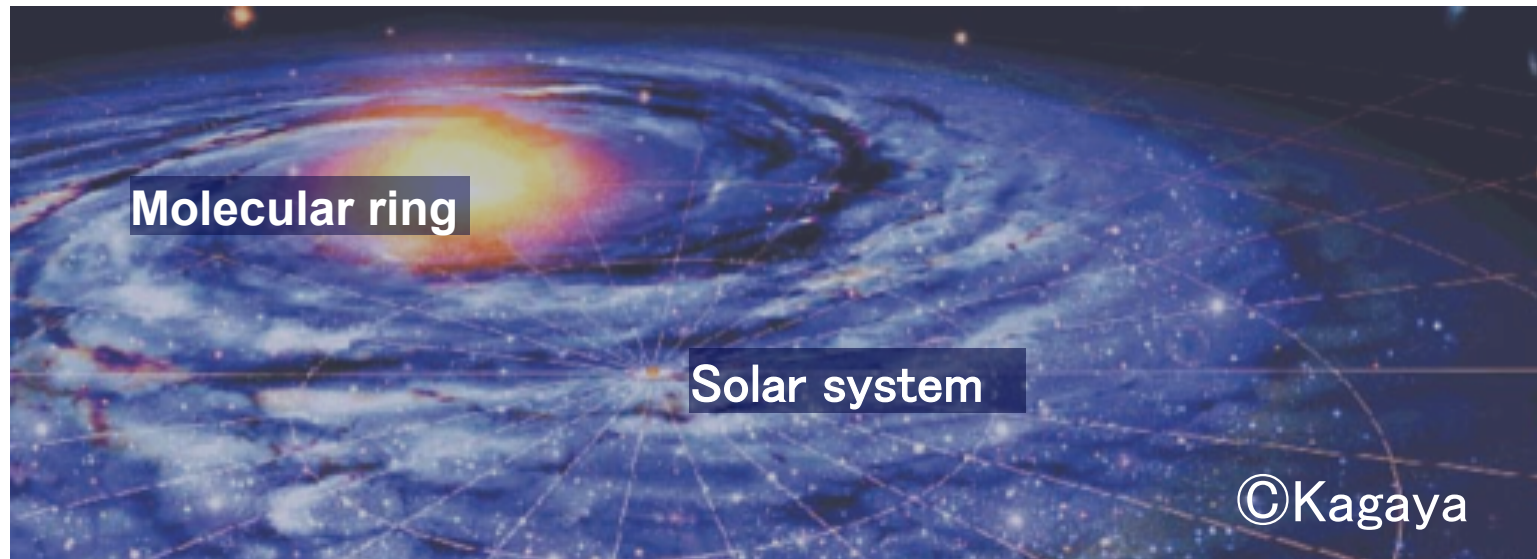# Investigation of 3D Galactic Gas Dynamics with 6.7 GHz Methanol Masers Sources

Naoko MATSUMOTO
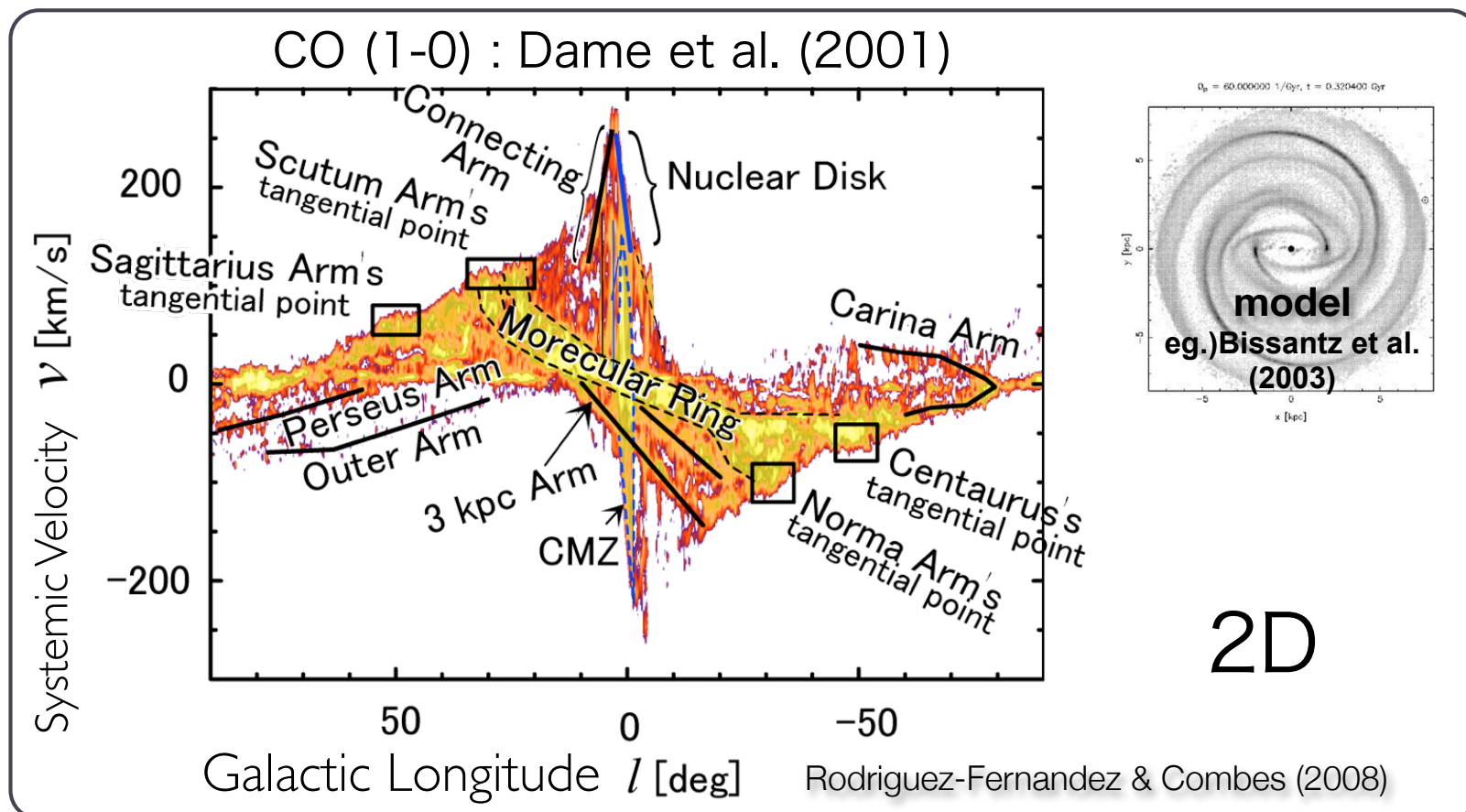(JSPS PD; Mizusawa VLBI observatory, NAOJ)

Collaborators:
    Mareki HONMA (NAOJ) and other VERA/JVN members

Contents

- Purpose

- Introduction, Method

  - About 6.7 GHz methanol maser

  - Recent activity of EAVN

  - Recent result of VERA observations of 6.7 GHz methanol masers

- Results and discussion

- Expectation about SKA

Purpose

- Establish an existence of the galactic bar structure from **3D** gas kinematics.

  →Investigate 3D peculiar motions around the galactic bar.

  →Estimation of the galactic bar parameter.

CO (1-0) : Dame et al. (2001)

Connecting Arm

Scutum Arm's tangential point

Nuclear Disk

Sagittarius Arm's tangential point

Carina Arm

Perseus Arm

Morecular Ring

Outer Arm

3 kpc Arm

CMZ

Centaurus's tangential point

Norma Arm's tangential point

Systemic Velocity v [km/s]

Galactic Longitude l [deg]

model
eg.)Bissantz et al. (2003)

2D

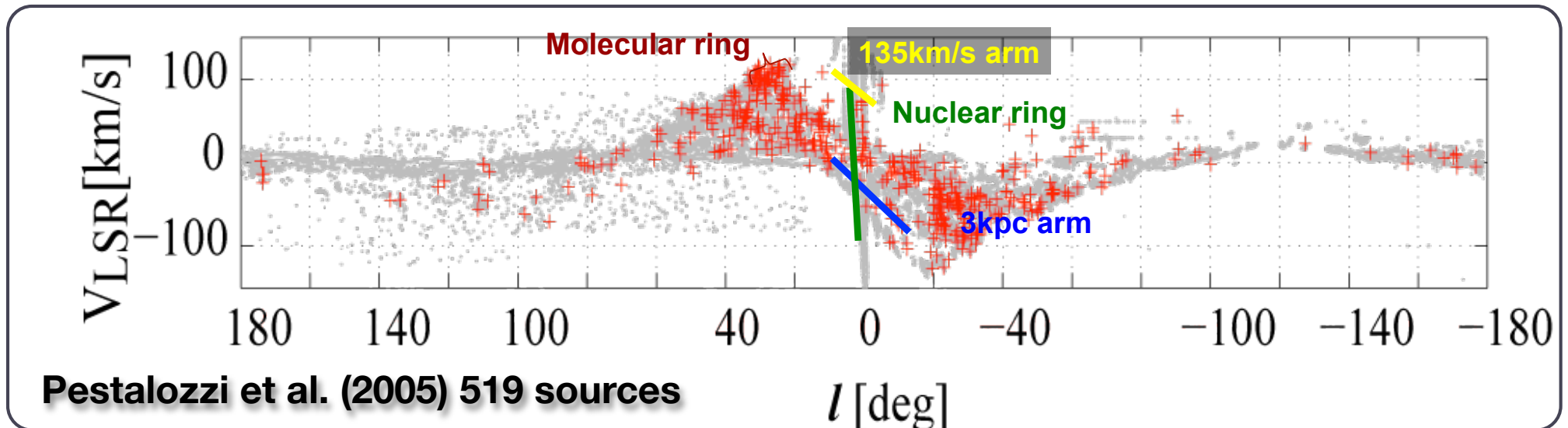Rodriguez-Fernandez & Combes (2008)

Method

- VLBI astrometric observation is good way to detect accurate/absolute gas motions using maser sources.

➡6.7 GHz methanol maser sources

About 6.7 GHz methanol maser

Pestalozzi et al. (2005) 519 sources

- The 5_1–6_0 A^+ transition of methanol maser is the second-strongest line next to 22 GHz H_2O maser.

- Only associate with massive star forming regions (Xu et al. 2009)
- Small internal proper-motion ~3km/s→negligible small to the galactic motion
- Stable spatial distribution, Long lifetime (a few years~decades)

Systems:
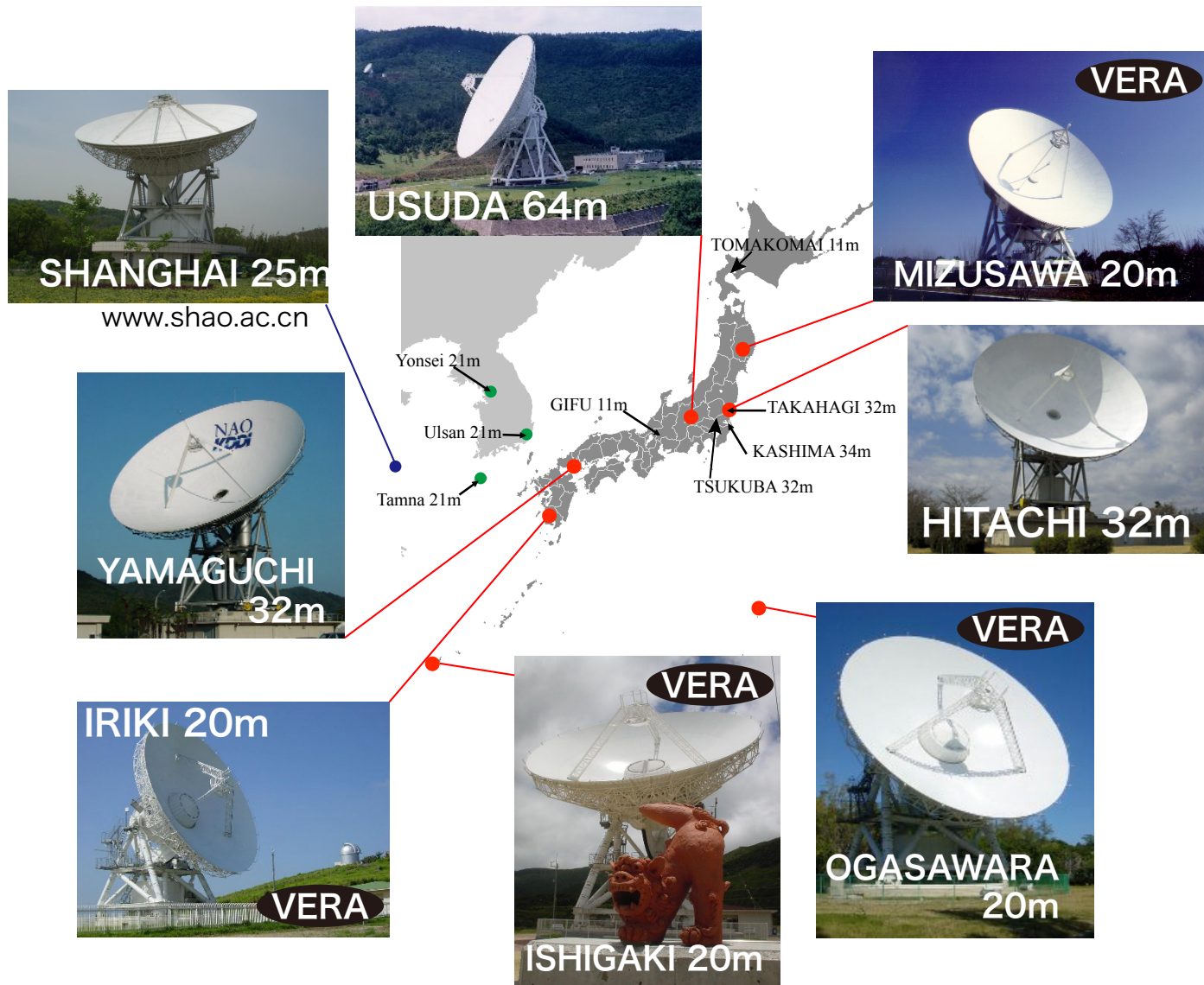# Current 6.7 GHz observation in VERA/JVN/EAVN

USUDA 64m

SHANGHAI 25m

www.shao.ac.cn

YAMAGUCHI 32m

VERA

MIZUSAWA 20m

TOMAKOMAI 11m

HITACHI 32m

Yonsei 21m

GIFU 11m

TAKAHAGI 32m

Ulsan 21m

KASHIMA 34m

TSUKUBA 32m

Tamna 21m

IRIKI 20m

VERA

ISHIGAKI 20m

VERA

OGASAWARA 20m

VERA

Photo: 6.7 GHz observation available

Just for information...

VLBI imaging survey of the 6.7GHz methanol maser with the EAVN
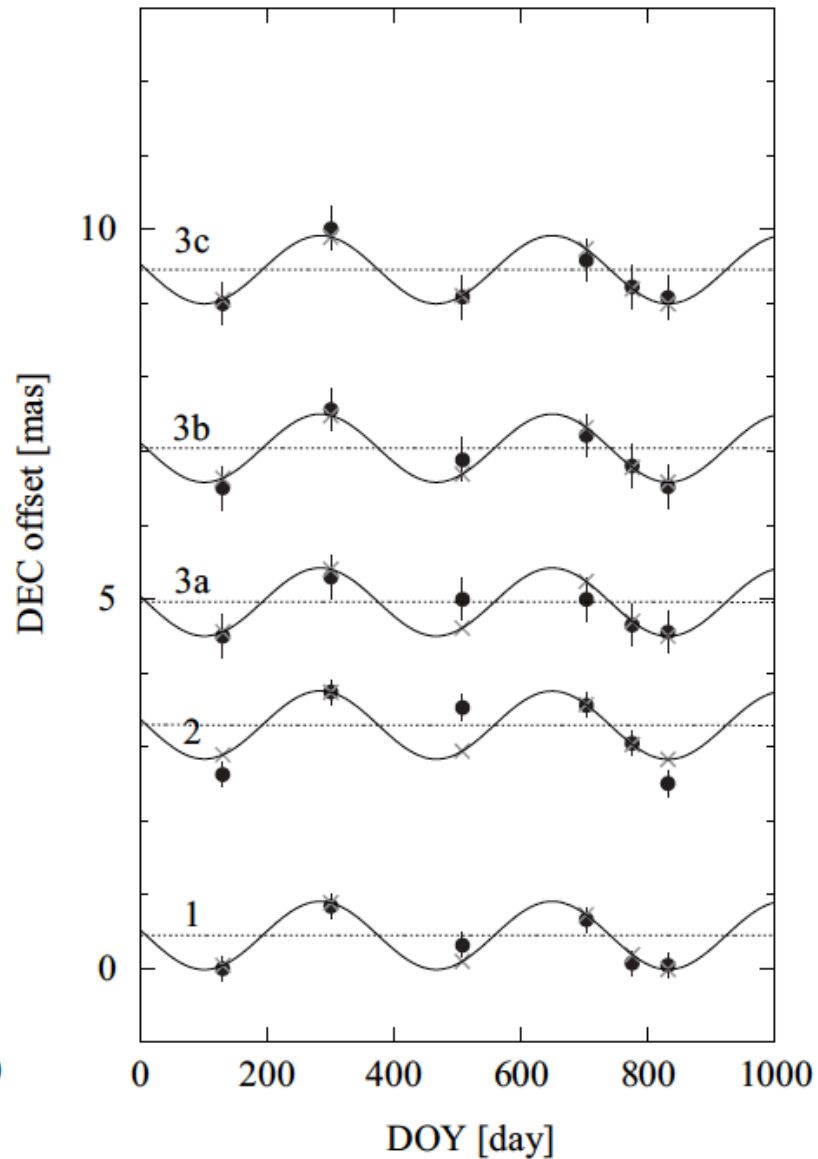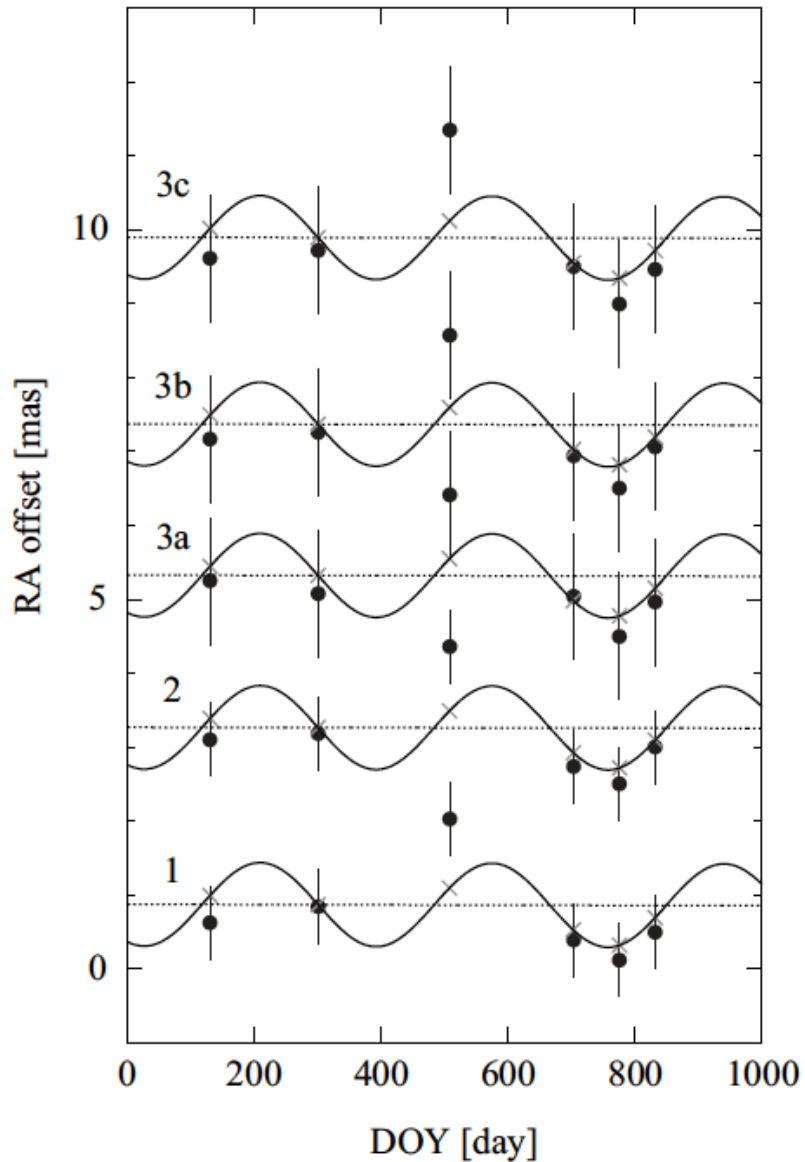
Sugiyama (Yamaguchi Uni.), Hachisuka (SHAO) et al.

➢ VLBI obs. with the East Asian VLBI Network

   ➢ Yamaguchi, Hitachi, VERA x4, + Shanghai

➢ New VLBI images for 22 sources in Aug. 2010

➢ Classified into five categories for spatial morphology
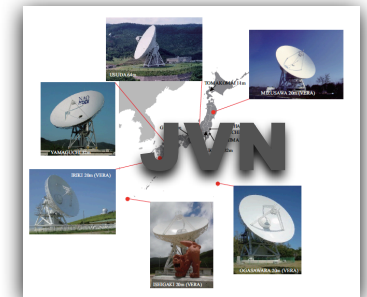
➢ Continuing to make catalog for PROPER MOTIONS
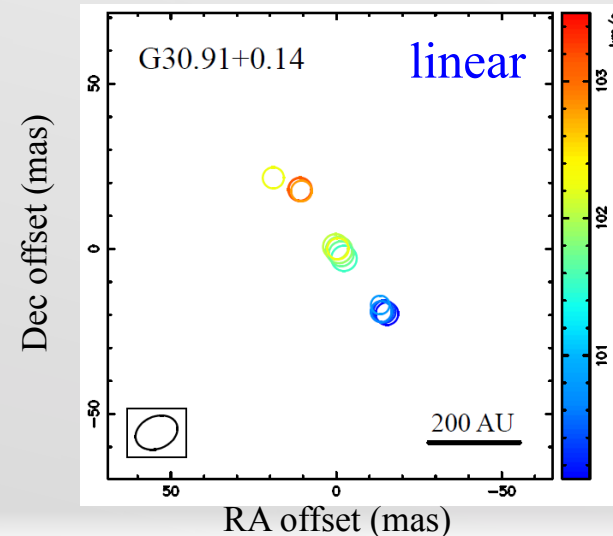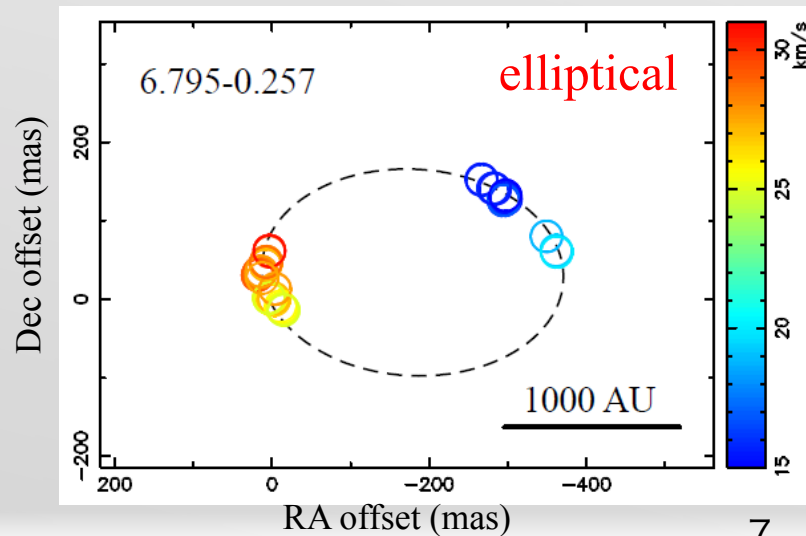
A recent result of JVN/VERA with 6.7 GHz methanol maser:
Astrometry for W3(OH)

Matsumoto et al.
(2011)
in press

▸ $\pi = \mathbf{0.598 \pm 0.067}$ mas, D $= \mathbf{1.67}^{+0.21}_{-0.17}$ kpc (err: **11%**)

Observations
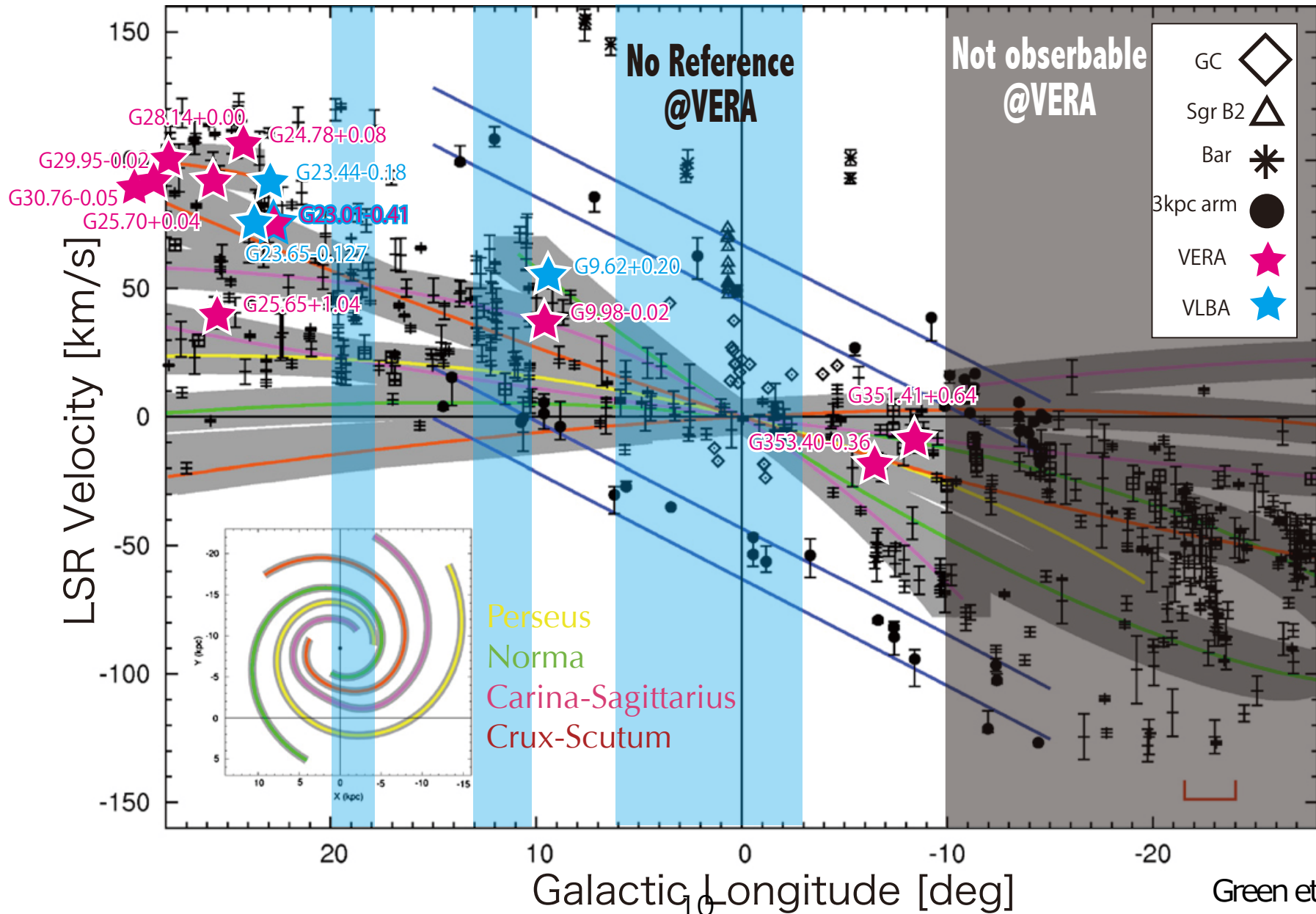
- Catalog: Pestalozzi et al. (2005)
- Four criteria for source selection:

  - Galactic longitude of |l|<40deg

  - Flux in the catalog above 15 Jy

  - Kinematic distance within 5 kpc from the GC

  - Having reference sources within 4 deg(➜Actually 2.4-3.6deg)

- Observations with VERA

  - Nov. 2009~May 2011 (Every few months)
  - Phase referencing (4min cycle switching)
  - DIR2000 Recording (8MHz 512ch x 1IF, 16MHz 32ch x 14IF)
  - θ_{beam}~3x6°-4x9°

Observed	Selected
75	10
masers	masers

Observations

Green et al. (2011)

Astrometry of 6.7 GHz methanol masers around the galactic bar
Results

Adapt	Source name	Vlsr[km/s]	$\mu_l\cos b$ [mas/yr] ↓Velocity width	μ_b [mas/yr] ↓Fitting error
	G9.98-0.02	42.0(8)	-7.99 (2 point fit)	-5.76 (2 point fit)
	G23.01-0.41	75.0(15)	-4.33 (0.42)	-0.30 (0.18)
◎	G24.78+0.08	113.5(9)	-6.13 (0.45)	-0.42 (0.08)
◎	G25.65+1.04	41.9(6)	-2.10 (0.54)	-2.18 (0.05)
	G25.70+0.04	95.3(12)	-4.81 (2 point fit)	3.32 (2 point fit)
◎	G28.14+0.00	101.0(13)	-6.04 (0.25)	-0.12 (0.05)
◎	G29.95-0.02	95.5(37)	-5.76 (0.59)	-0.11 (0.11)
◎	G30.76-0.05	91.0(7)	-5.17 (0.79)	0.01 (0.22)
	G351.41+0.64	-10(5)	---------	---------
	G353.40-0.36	-20.2(4)	---------	---------
Referred from another papers				
◎	G23.01-0.41	81.5(15)	-4.45 (0.28)	Brunthaler+09
◎	G23.44-0.18	97.6(6)	-4.54 (0.11)	Brunthaler+09
◎	G23.65-0.127	83.0(10)	-3.24 (0.04)	Bartkiewicz+08

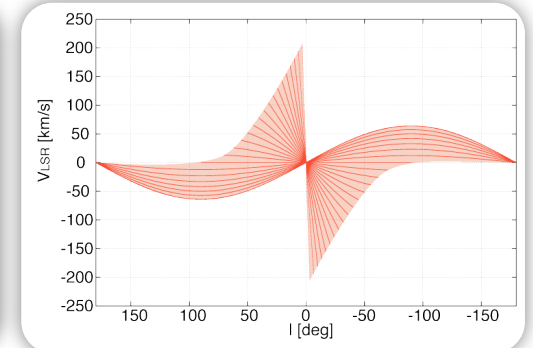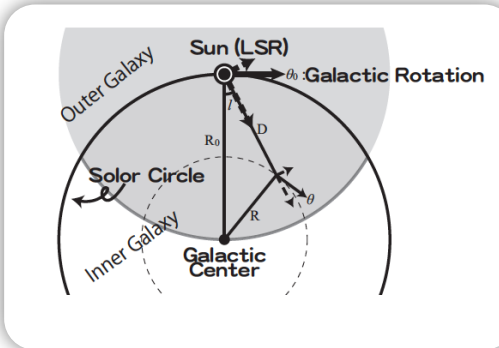We successfully obtained accurate absolute motions for 6 sources.

↓

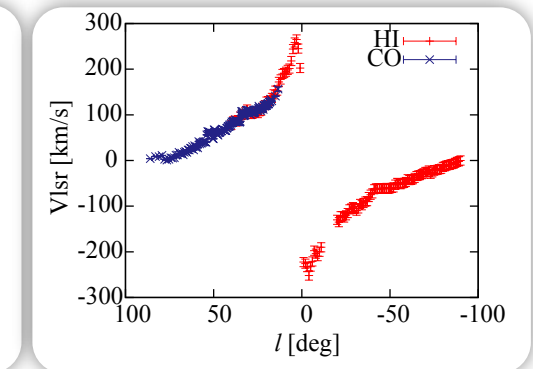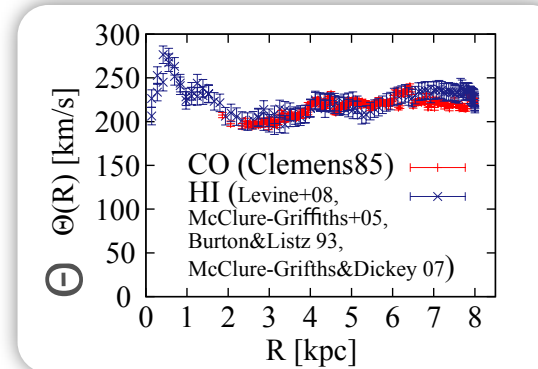Finally we used
(l, Vlsr, $\mu l\cos b$)

for 8 sources (◎).

Discussion

1)Flat Circular Rotational Model
- $\Theta_0 \equiv 220$ km/s, $R_0 \equiv 8.0$ kpc

2)Non-Flat Circular Rotation Model
- HI/CO terminal velocities
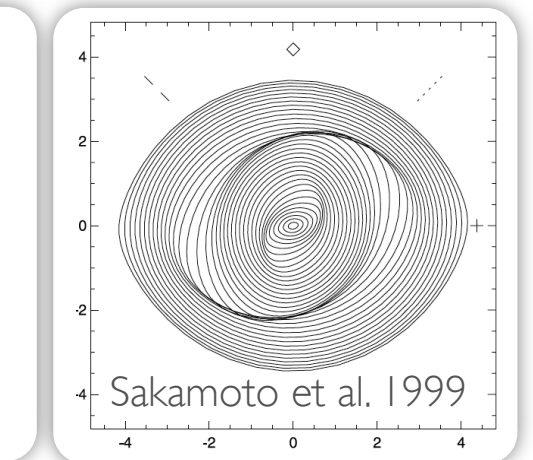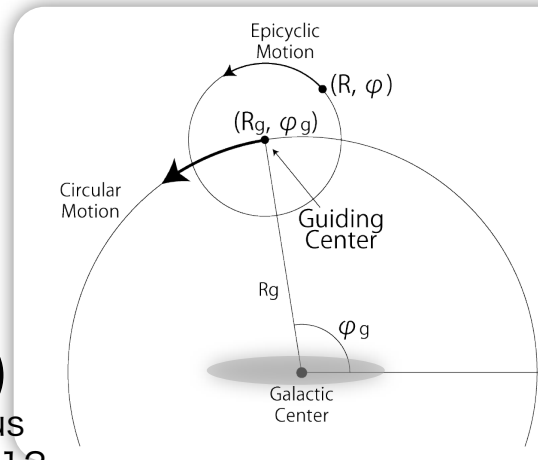

3)Damped Oval Orbit Model
- Sakamoto et al. (1999), Wada (1994)
- Gas orbit with a weak bar potential
- Linear equation
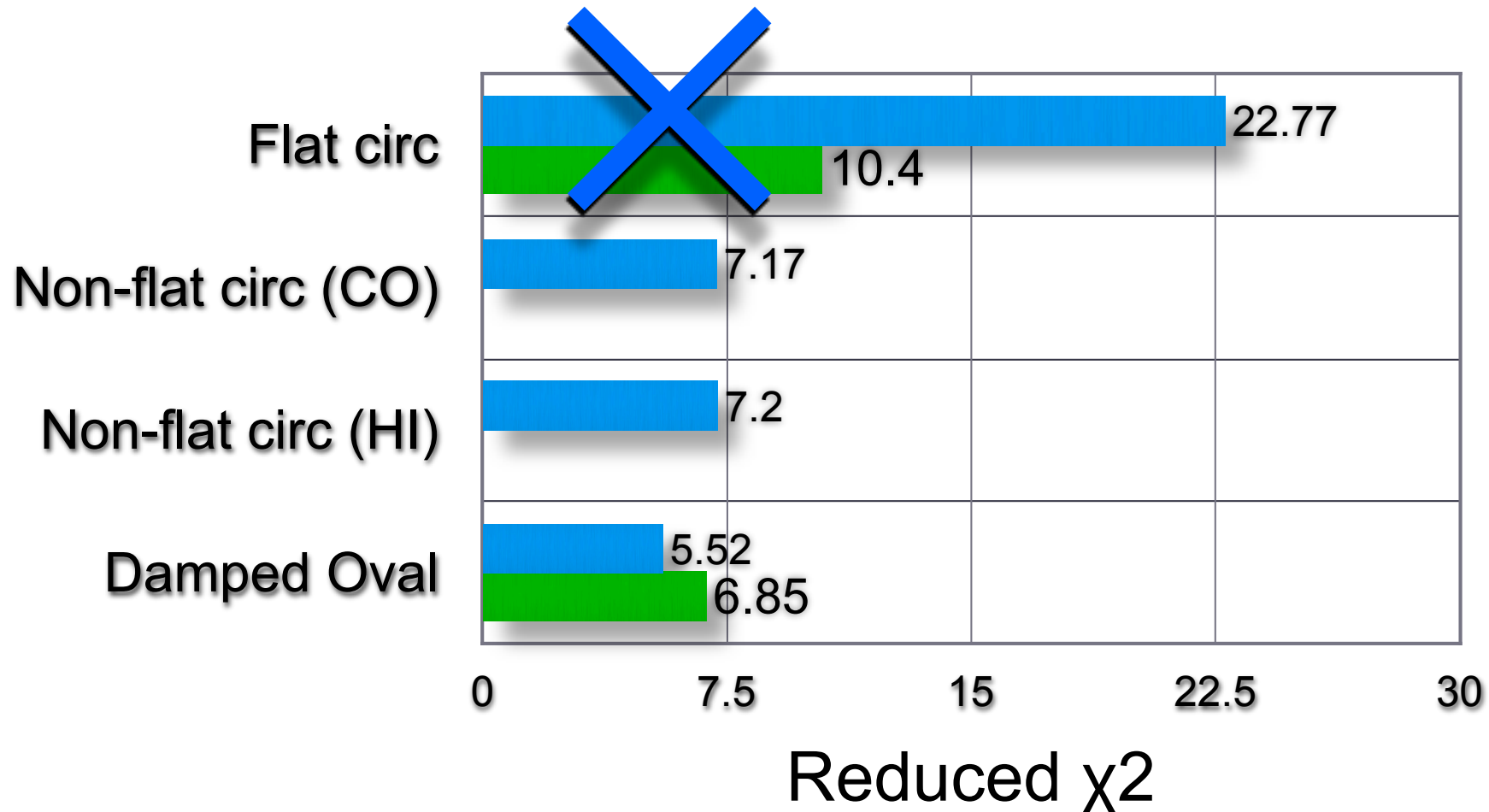- Free parameter : Ω_b, ε, θ, (Λ) viscous

(43.5 km/s/kpc, 0.1, 50deg)12

Discussion

Reduced χ2

■ **(l, Vlsr, μlcosb) of VLBI data**
■ **(l, Vlsr) of HI gas**

Non-flat circular &Damped oval orbit models are acceptance.

13

Conclusion

- The non-flat rotation model and the damped oval orbit model are better to explain the adopted VLBI data sets (3D) and terminal velocity of HI.

- VLBI data with the damped oval orbit model show a bar parameter about inclination angle of the bar.

  $\rightarrow\theta$~50°(This value is consistent with previous works about the galactic bar structure.)

- **With 3-D data, we could suggest the presence of the bar for the first time.**

- In the future, we have to get more data sample belong to wider range of galactic longitude.

Expectation about SKA

High sensitivity, High resolution array and the Southern Hemisphere

- High sensitivity is good to get large number of sources.

- Dense (u, v)-coverage allow efficient observations to a large number of sources.

- Good (u, v)-coverage to sources around Galactic Center.

- Maximum spatial resolution is enough to detect absolute proper motions.

＊Maser flux：median 6-10Jy@spiral arm (Green+11)

　→Resolved out effect could make above flux weaker.

＊Current number of 6.7 GHz methanol masers：>1,000 sources

＊Especially for -28°<l<+28°：~550 sources

　(Green+09,11: MMB Catalogue, 3σ=0.7Jy)

Conclusion

- Methanol maser source is the most powerful target to investigate the bar effects on the galactic disk.

- Proper motions are able to be detected with current VLBI array (and also SKA) with high accuracy.

- However, we need much more data to investigate the bar effect statistically.

- SKA will be powerful tool to observe 6.7 GHz methanol maser sources around the bar.

Thank you for your attention!