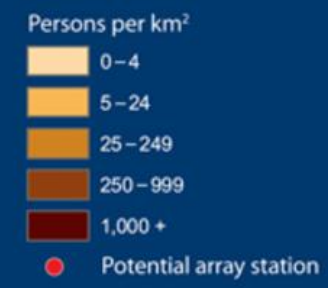
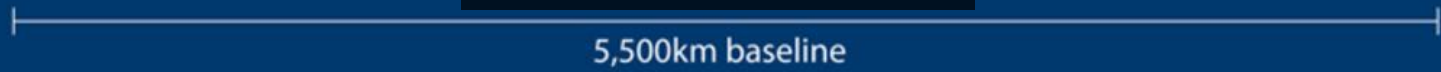


Galactic Astrometry in the SKA era



Nobuyuki Sakai (NAOJ), July 22nd, 2018@Mitaka, WS :
VLBI Science in the SKA era

5,500 km baseline

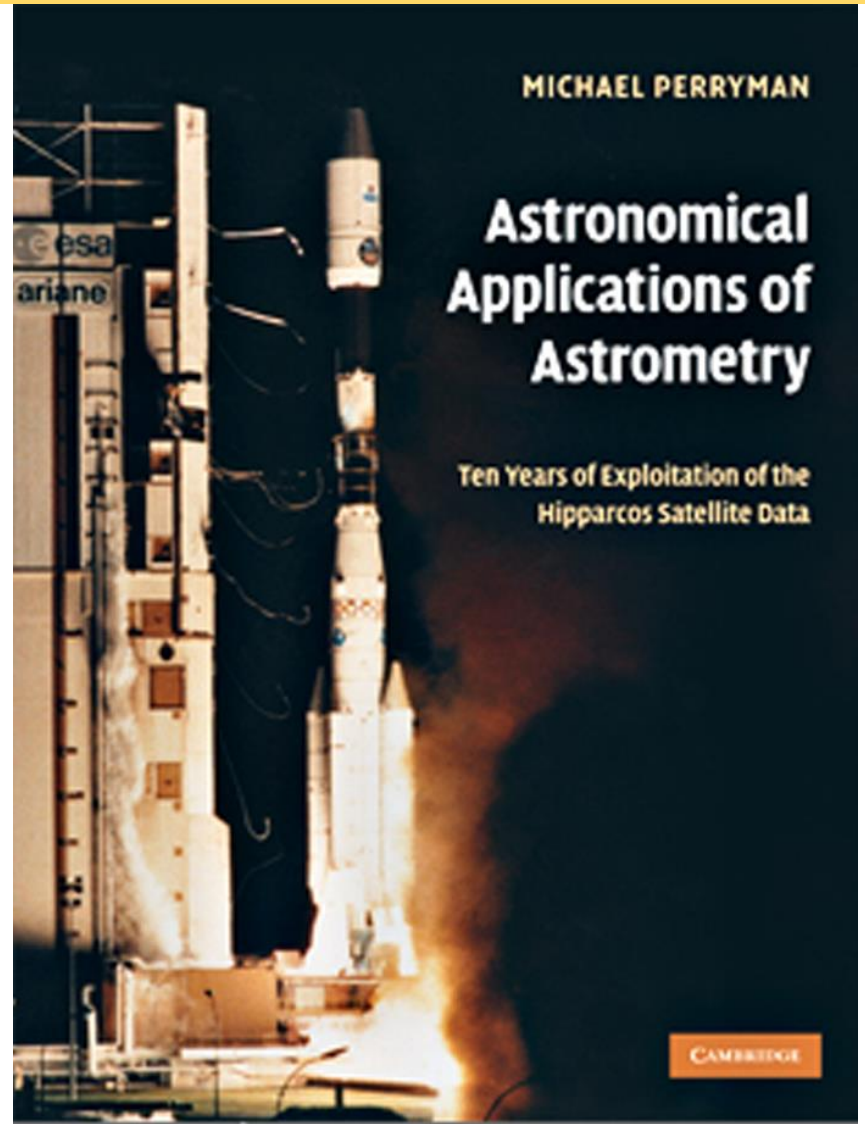


HIPPARCOS results

2/13

-Perryman, M. 2008, Cambridge University Press

- ① The Hipparcos and Tycho catalogs
- ② Derived catalogs and applications
- ③ Double and multiple stars
- ④ Photometry and variability
- ⑤ Luminosity calibration and distance scale
- ⑥ Open clusters, groups and associations
- ⑦ Stellar structure and evolution
- ⑧ Specific stellar types and the ISM
- ⑨ Structure of the Galaxy
- ⑩ Solar System and exoplanets



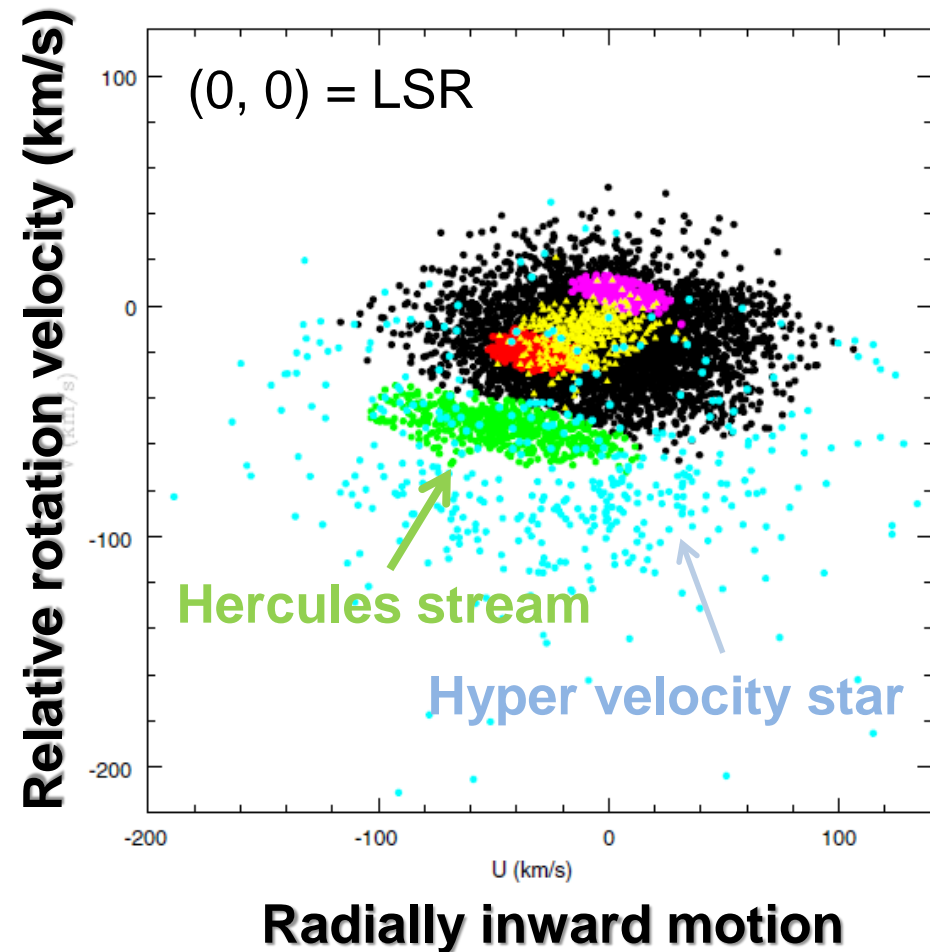
HIPPARCOS result(s) : Hercules stream 3/13

-Perryman, M. 2008, Cambridge University Press

- ① The Hipparcos and Tycho catalogs
- ② Derived catalogs and applications
- ③ Double and multiple stars
- ④ Photometry and variability
- ⑤ Luminosity calibration and distance scale
- ⑥ **Open clusters, groups and associations**
- ⑦ Stellar structure and evolution
- ⑧ Specific stellar types and the ISM
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Origin of the Hercules stream is dynamical resonance of the Galactic bar (Dehnen 2000) ?

Velocity field in the Solar neighborhood



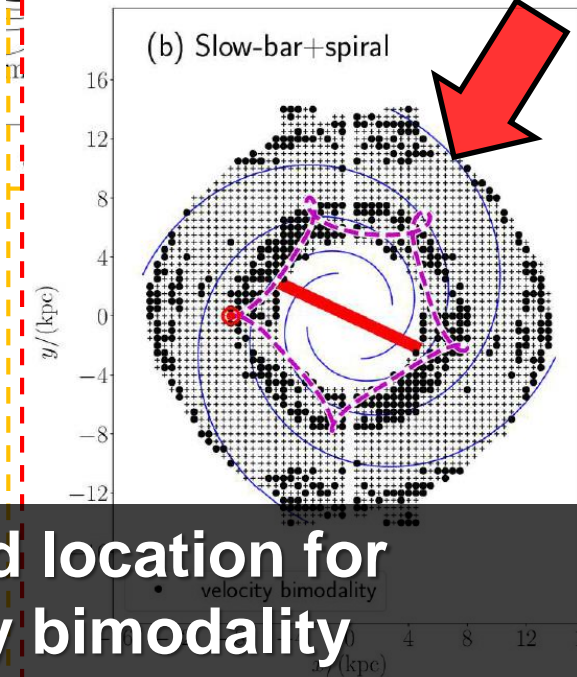
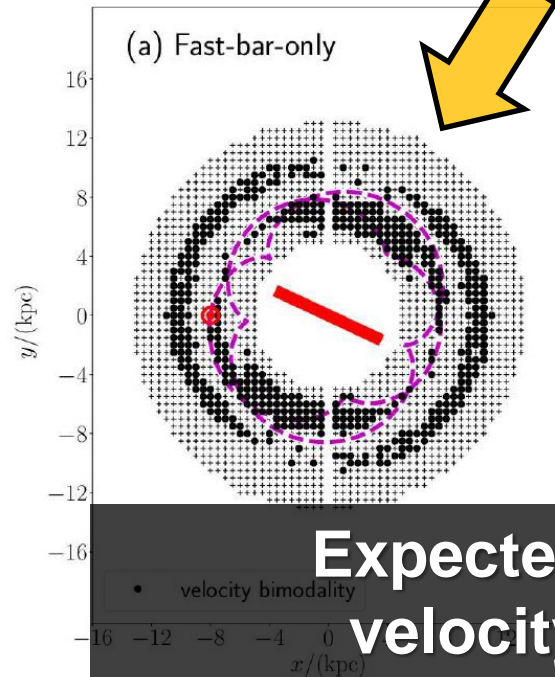
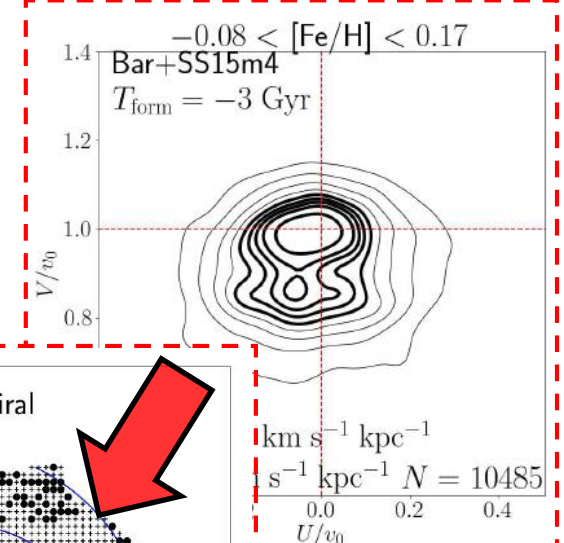
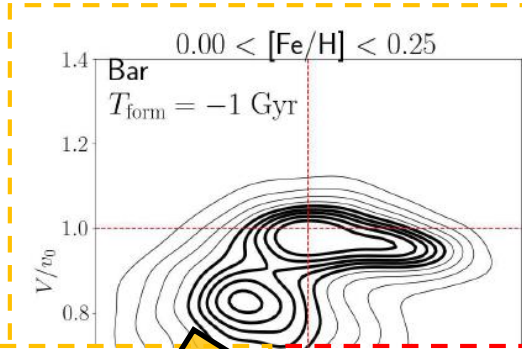
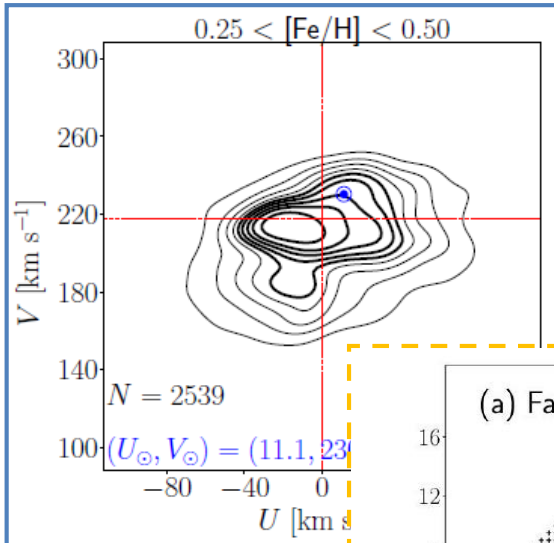
Hercules stream : Hattori+18

Observation

Chemo dynamical 2D test-particle simulation

Bar only

Bar+Spiral



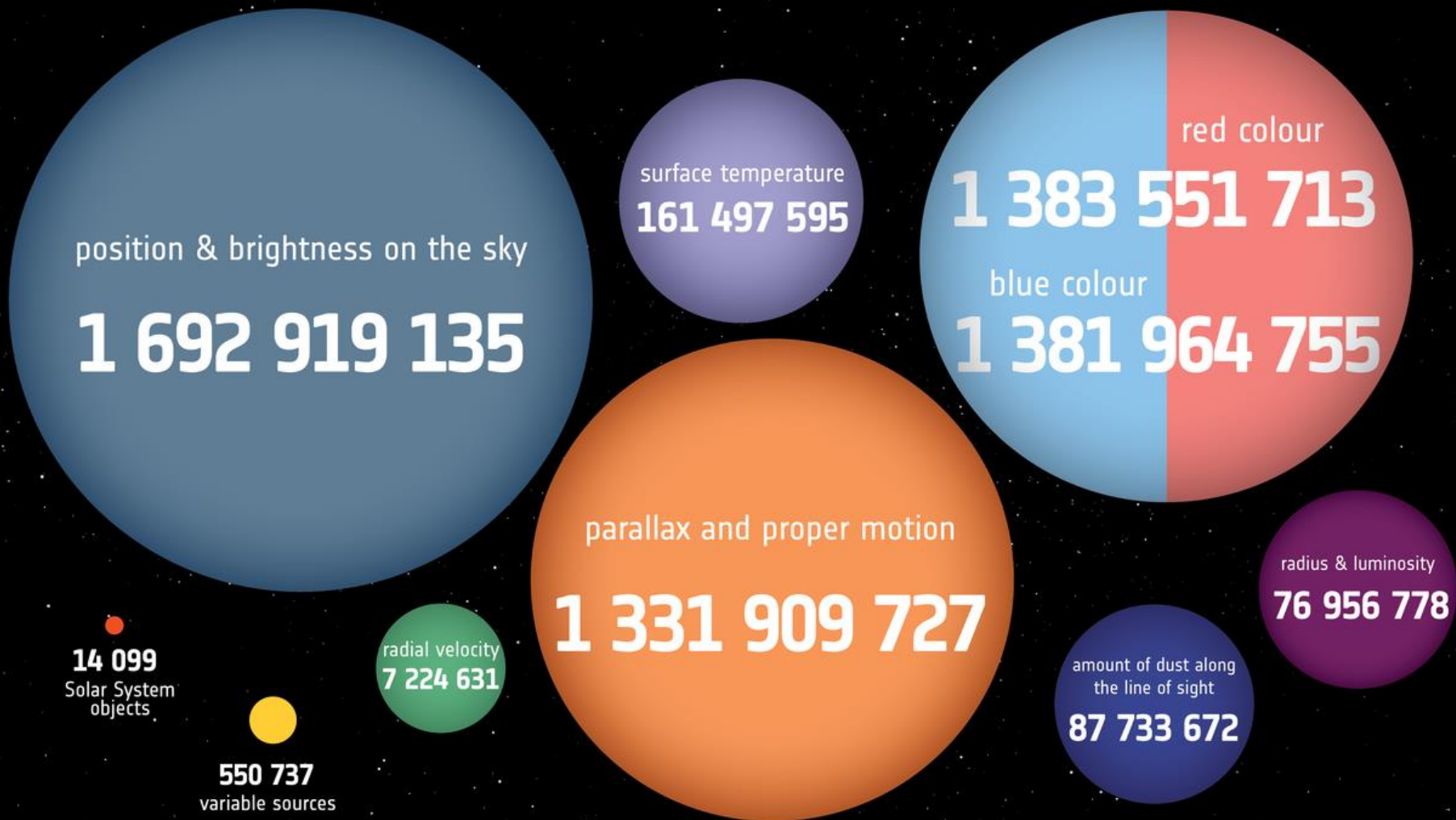
Expected location for velocity bimodality

• velocity bimodality

• velocity bimodality

Gaia sky (DR2)

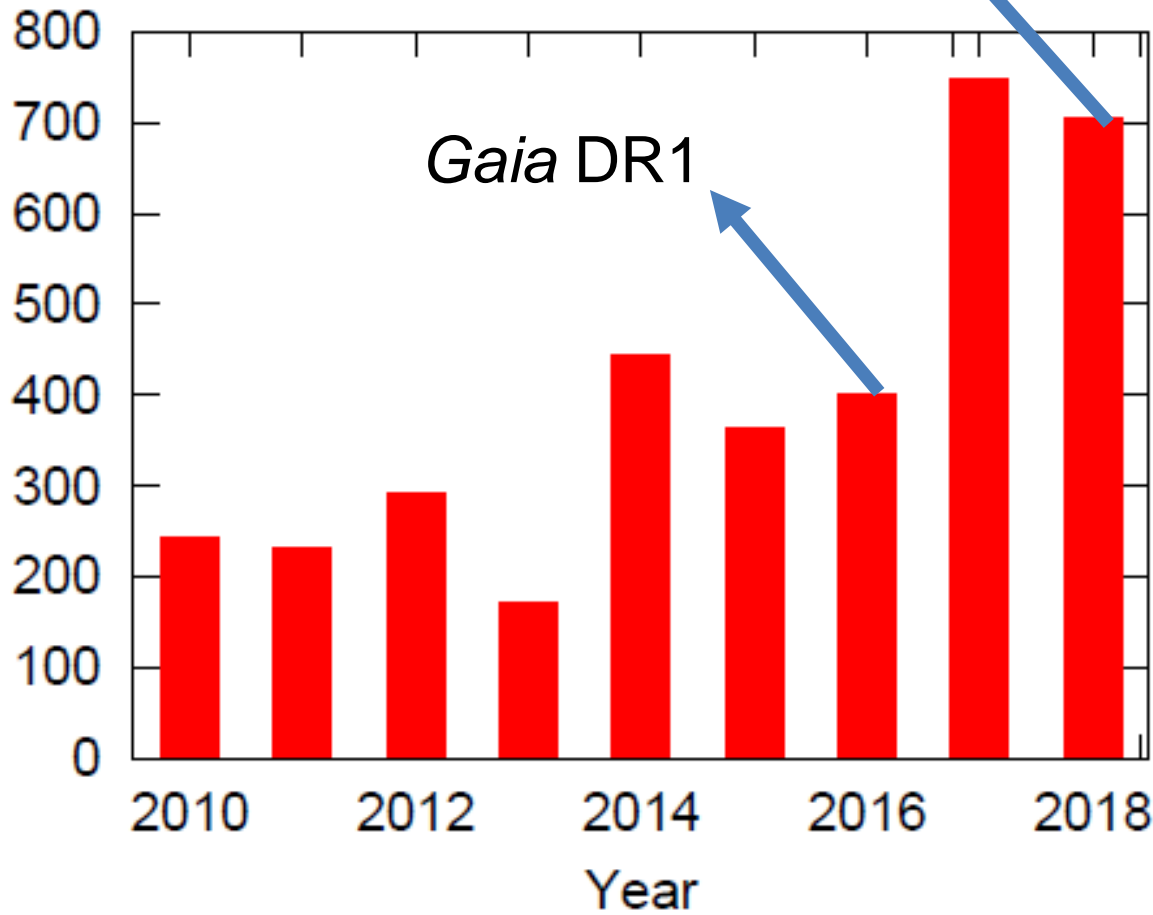
→ HOW MANY STARS WILL THERE BE IN THE SECOND GAIA DATA RELEASE?



Gaia sky (DR2)



of *Gaia* paper (based on ADS)



→ HOW MA

positio

16

#

14 099

Solar System objects

variable sources

colour

713

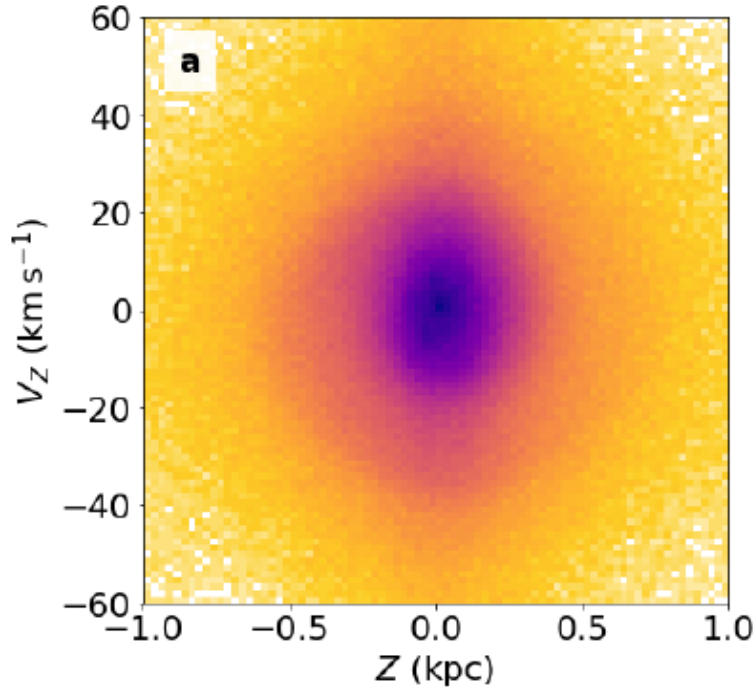
755

radius & luminosity

76 956 778

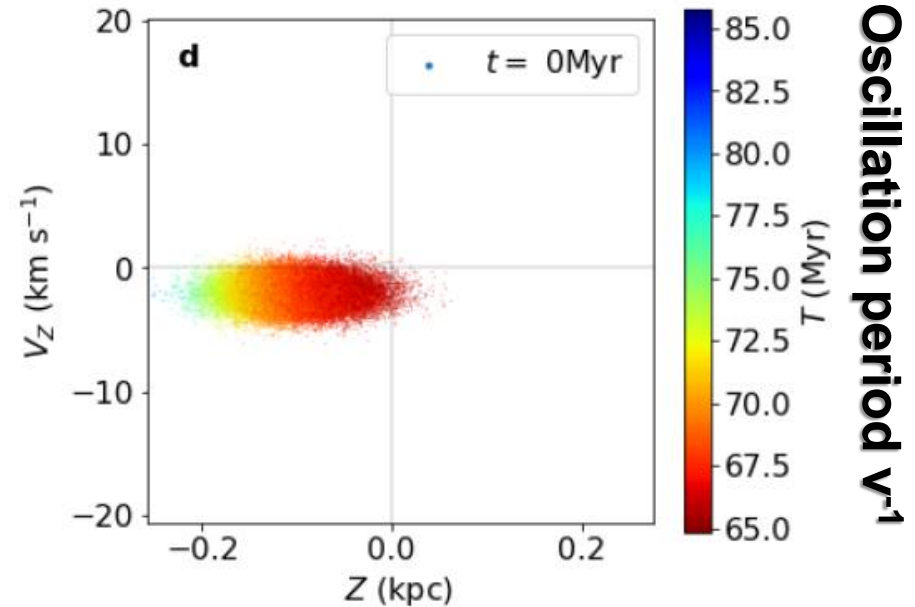
Dynamical non-equilibrium in the MW disk

Distribution of stars



Single Spiral shape → Phase mixing ?

Anharmonic oscillator model

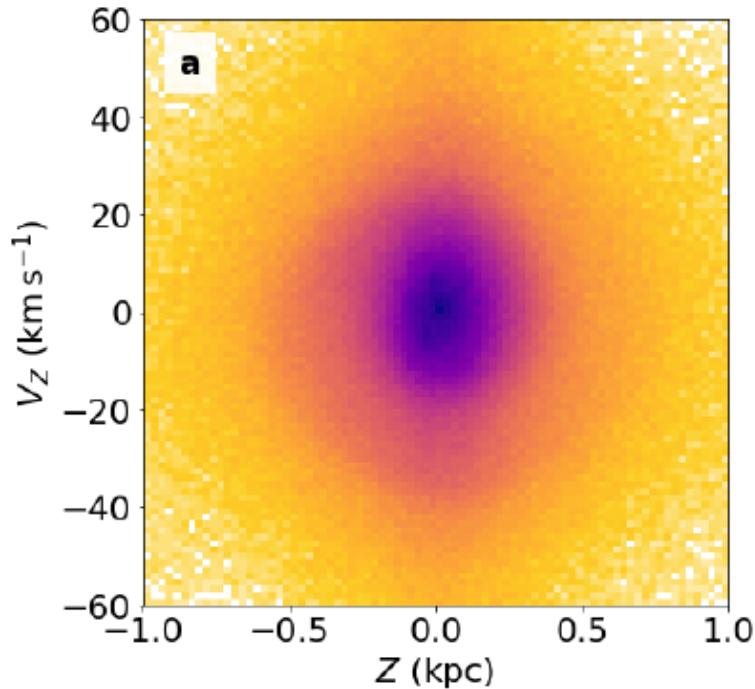


Gravitational potential

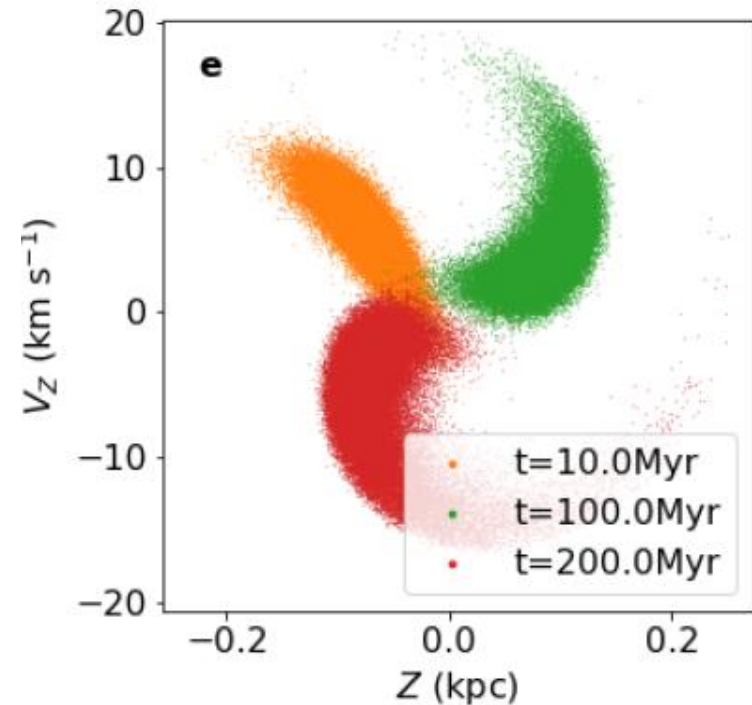
$$\Phi(z) \propto -\alpha_0 + \frac{1}{2} \alpha_1 z^2 - \frac{1}{4} \alpha_2 z^4$$

Dynamical non-equilibrium in the MW disk

Distribution of stars



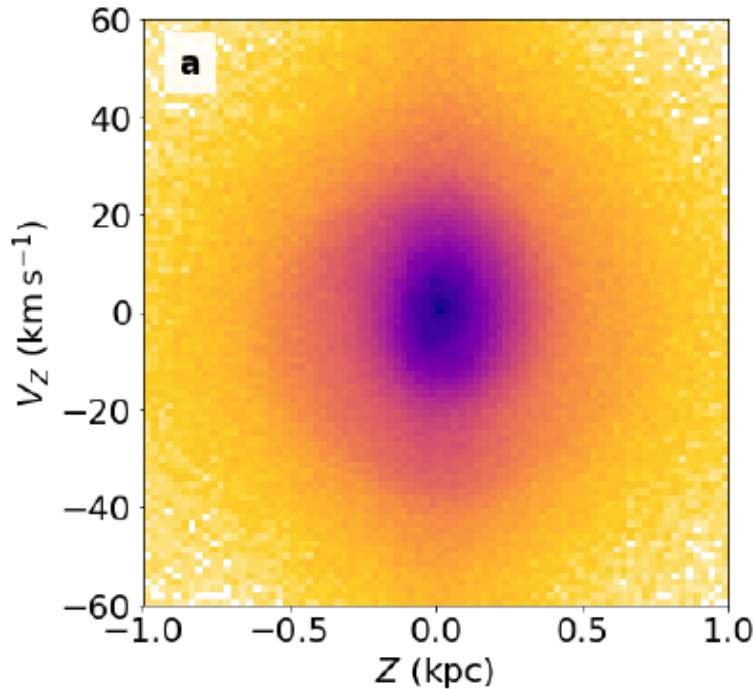
Anharmonic oscillator model



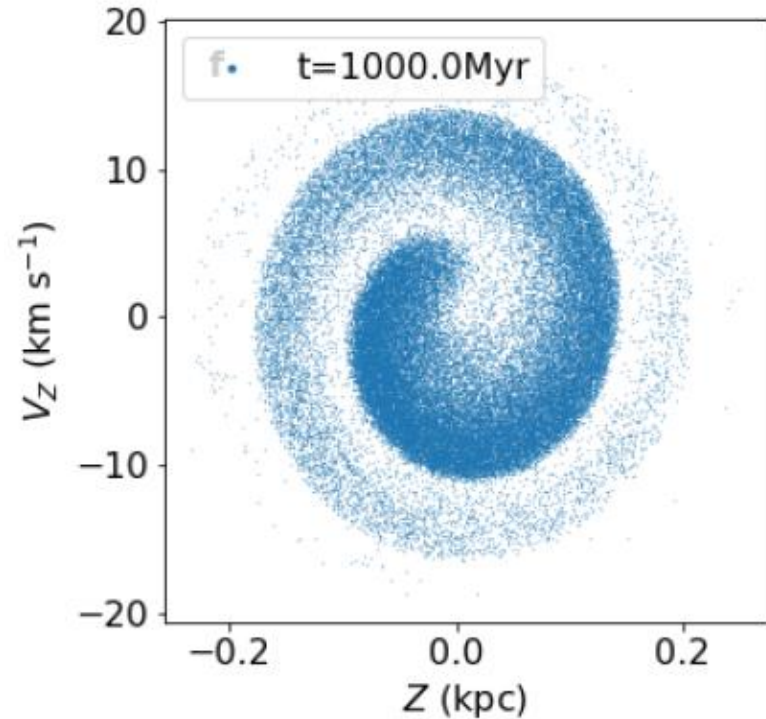
Single Spiral shape → Phase mixing ?

Dynamical non-equilibrium in the MW disk

Distribution of stars



Anharmonic oscillator model



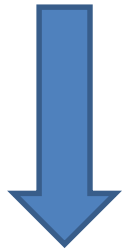
Single Spiral shape → Phase mixing ?

Origin of the phase mixing is the pericentric passage of the Sagittarius dwarf galaxy (~600 Myr ago)?

Mapping the Milky Way

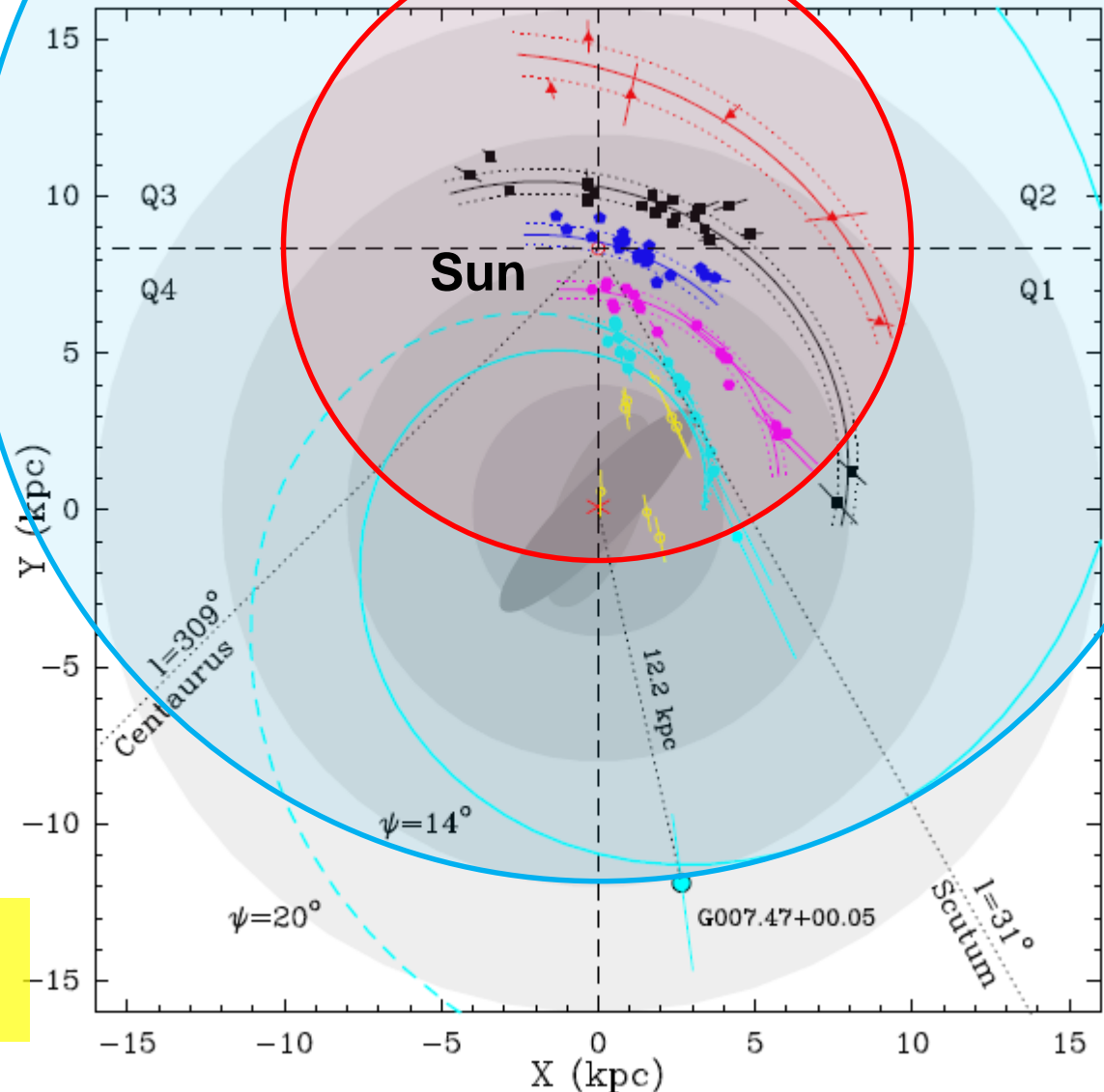
**10 kpc measurements
with VLBI (e.g.
Honma+12; Reid+14)**

- # of spiral arm
- Pitch angle of "
- Kinematics of "

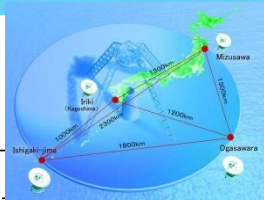


**20 kpc measurement
($d = 20.4 +2.8/-2.2$
kpc)**

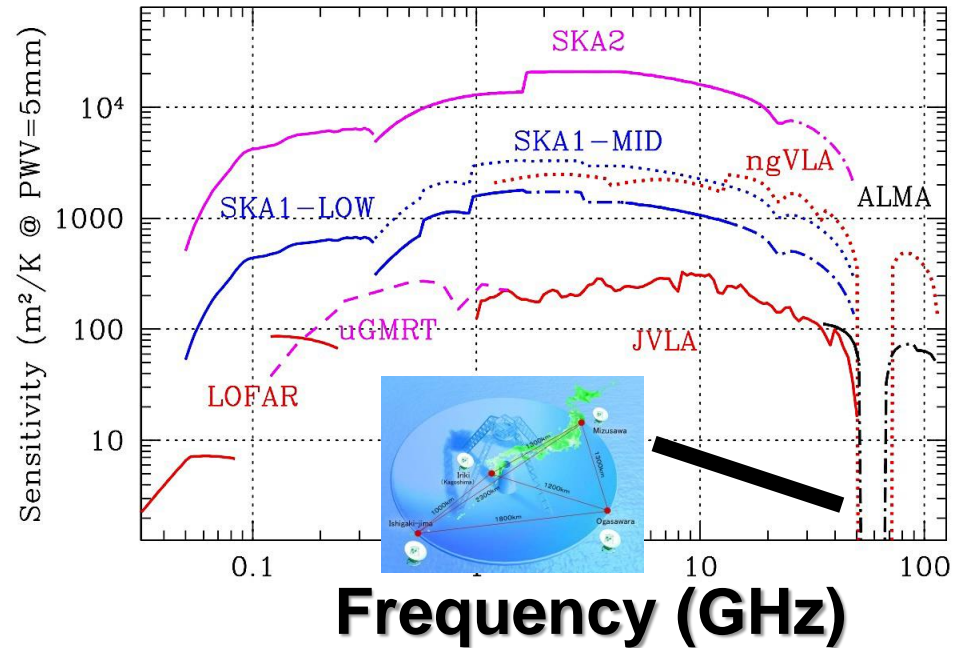
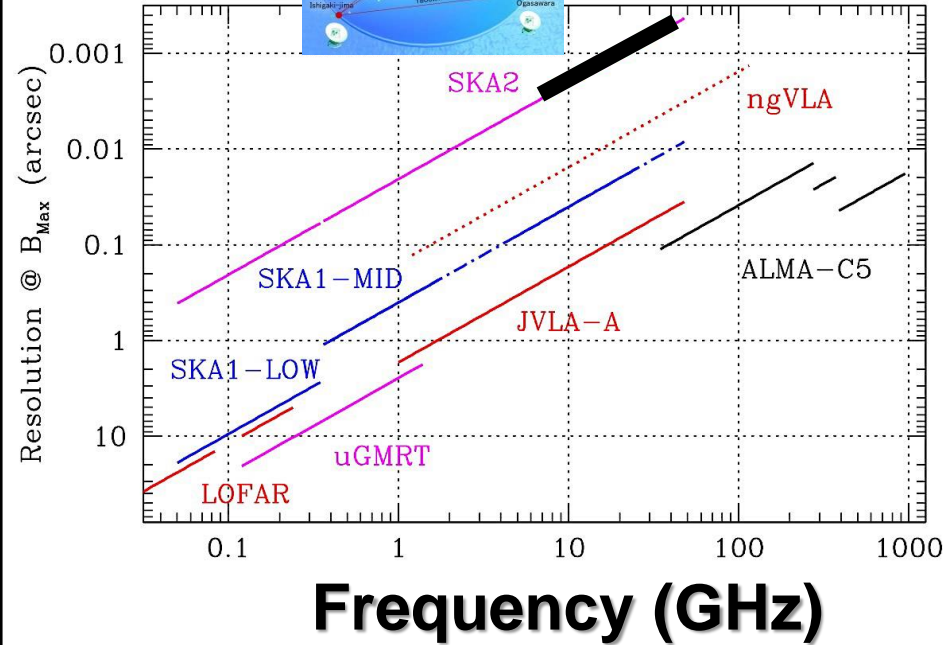
Sanna, et al. 2017,
Science



SKA-VLBI astrometry



VERA



(c) Akahori-san's poster (NAOJ)

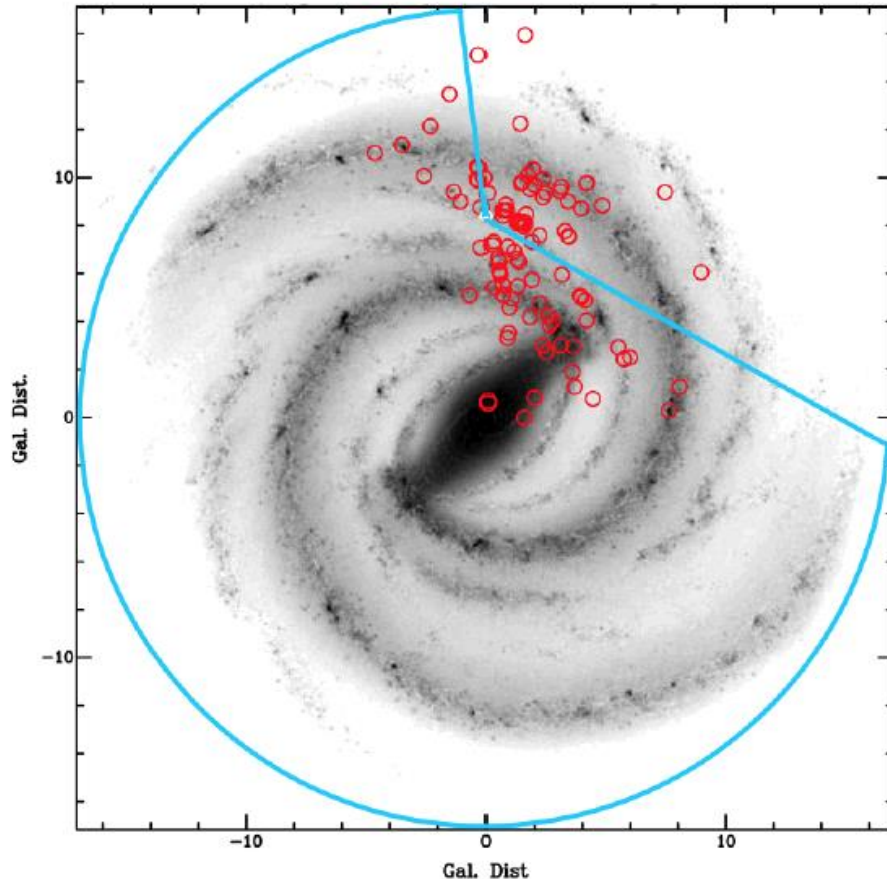
(c) SKA Community Briefing (18th January 2017)

Now (VLBI) **Highest Resolution** **Low sensitivity**

SKA-VLBI **Highest Resolution & Sensitivity**

Maser astrometry : MW structure

SKA-VLBI area



~1,000 CH₃OH masers
ever known

• SKA-1

OH & CH₃OH masers

◎ 20 kpc astrometry **for the latter.**

✕ Ionospheric calibration (e.g.
Reid+17)

• SKA-2

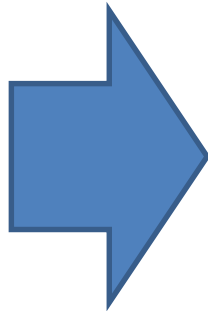
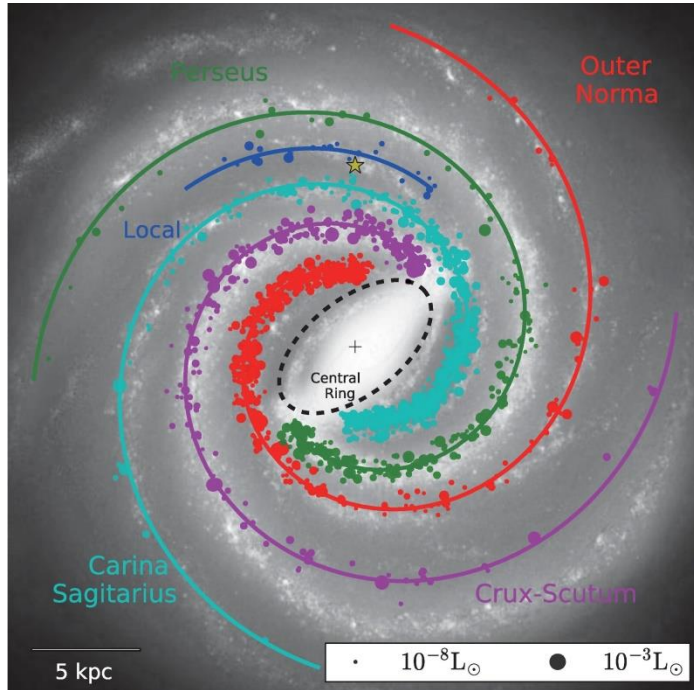
H₂O maser

◎ **> 20 kpc astrometry**

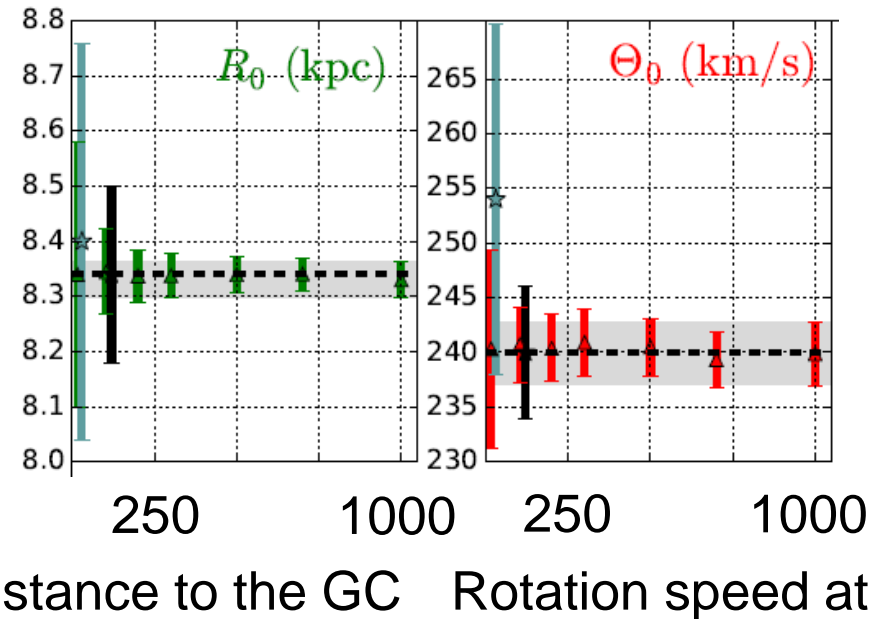
(e.g. Paragi+15)

◎ **Proper motion measurement
toward the Virgo Cluster**

Maser science : MW structure



Galactic fundamental parameters



- Simulated distribution of 6.7GHz maser
 $N = 1300 \pm 60$ (Expected total #)

Background

Winscoat+92 model (disk; bulge; stellar halo; spiral arms; molecular ring)

- Statistical errors decreased with increasing # of source

One of SKA-VLBI targets !

EAVN astrometry in the SKA era

11/13

Astrometric accuracy (Reid & Honma 14)

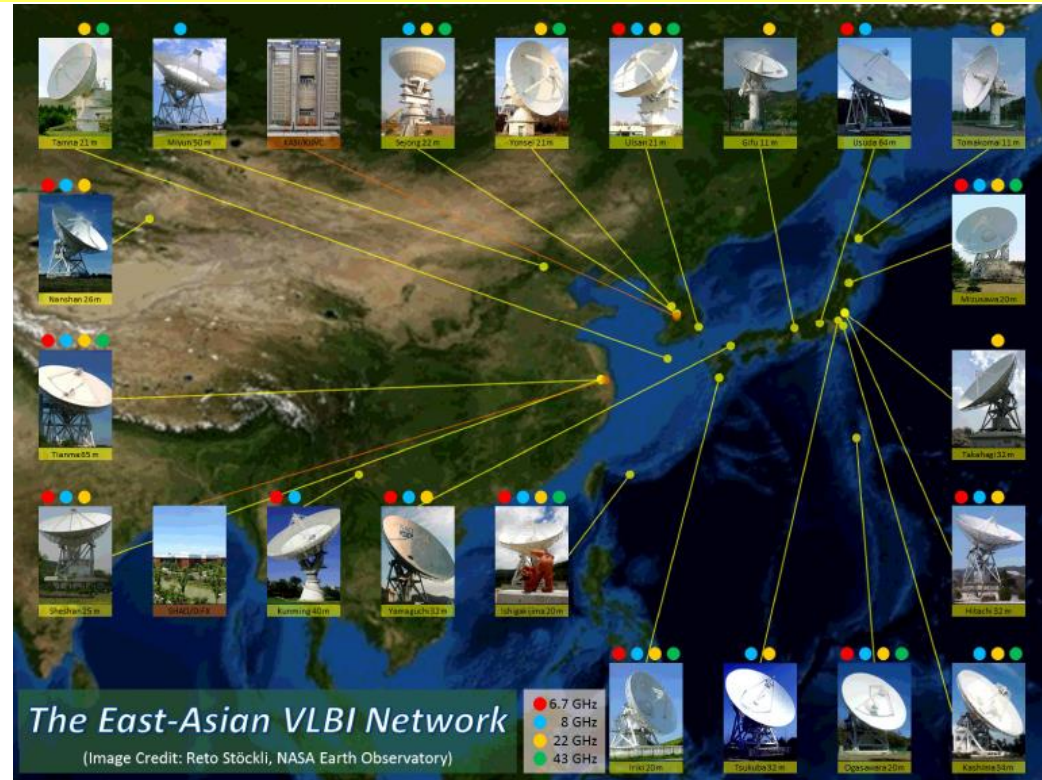
$$\Delta s_{\text{rel}} \approx \overset{\textcircled{1}}{\theta_{\text{sep}}} \frac{c \overset{\textcircled{2}}{\Delta \tau}}{\underset{\textcircled{3}}{|B|}},$$

① Separation angle → High sensitivity array (e.g. SKA-VLBI)

**② Delay residuals → GPS & Mapping function (VERA)
Water Vapor Radiometer?**

③ Baseline length → VERA to KaVA/EAVN

EAVN astrometry in the SKA era

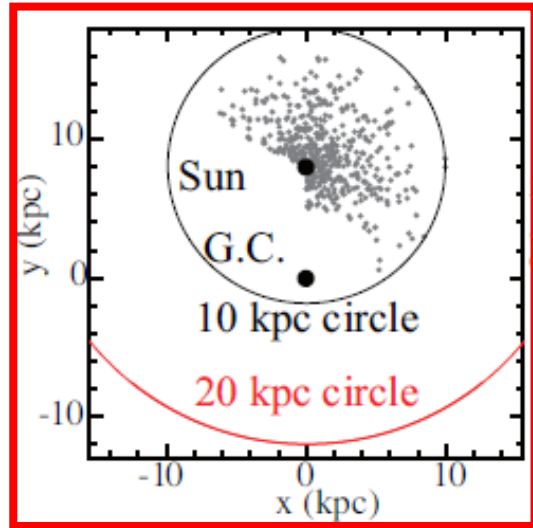


VERA+KVN+Tianma65m+

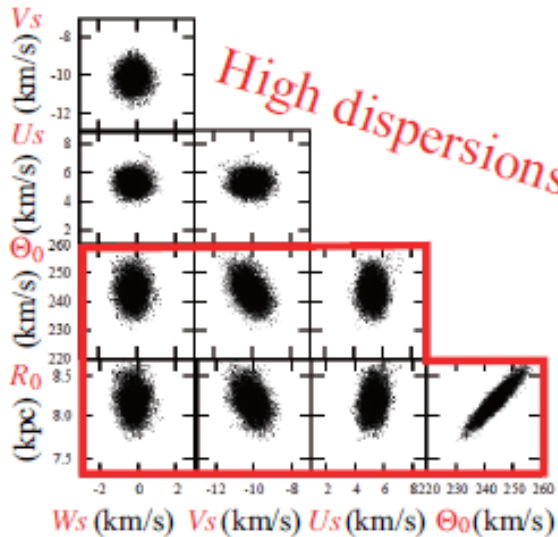
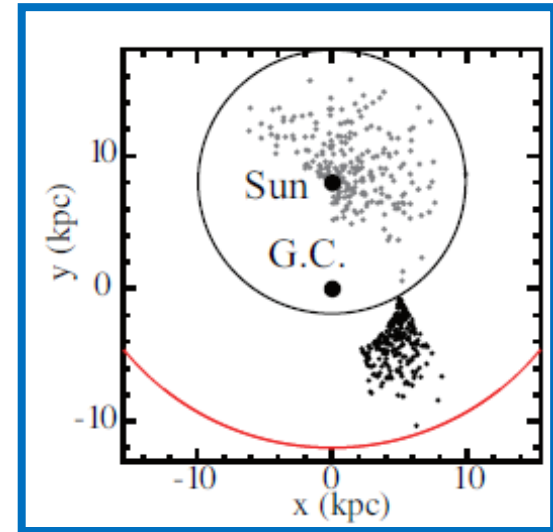
Urumqi26m at $B = 2300 \rightarrow 5000$ km

Simulation with Honma+15 program

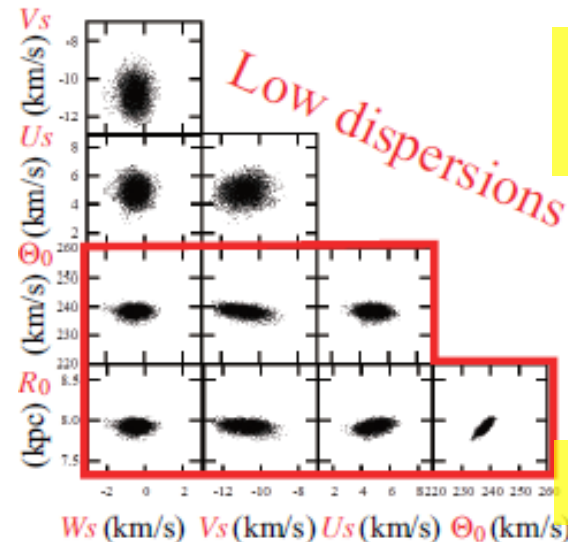
① Data (< 10 kpc) with # = 500



① + Data (> 10 kpc) with # = 500



E.g.
 Input : $R_0 = 8$ kpc
 Output : $R_0 = 8.18 \pm 0.15$

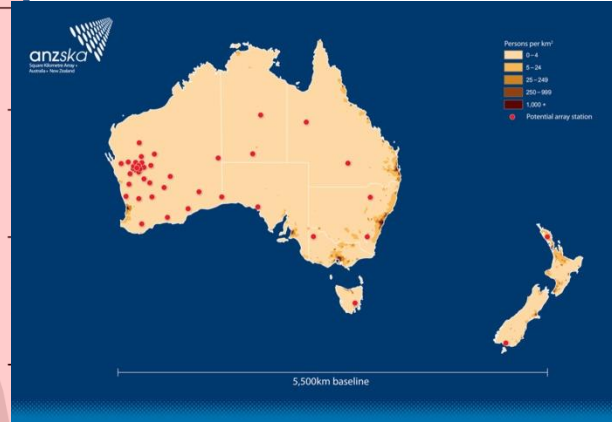
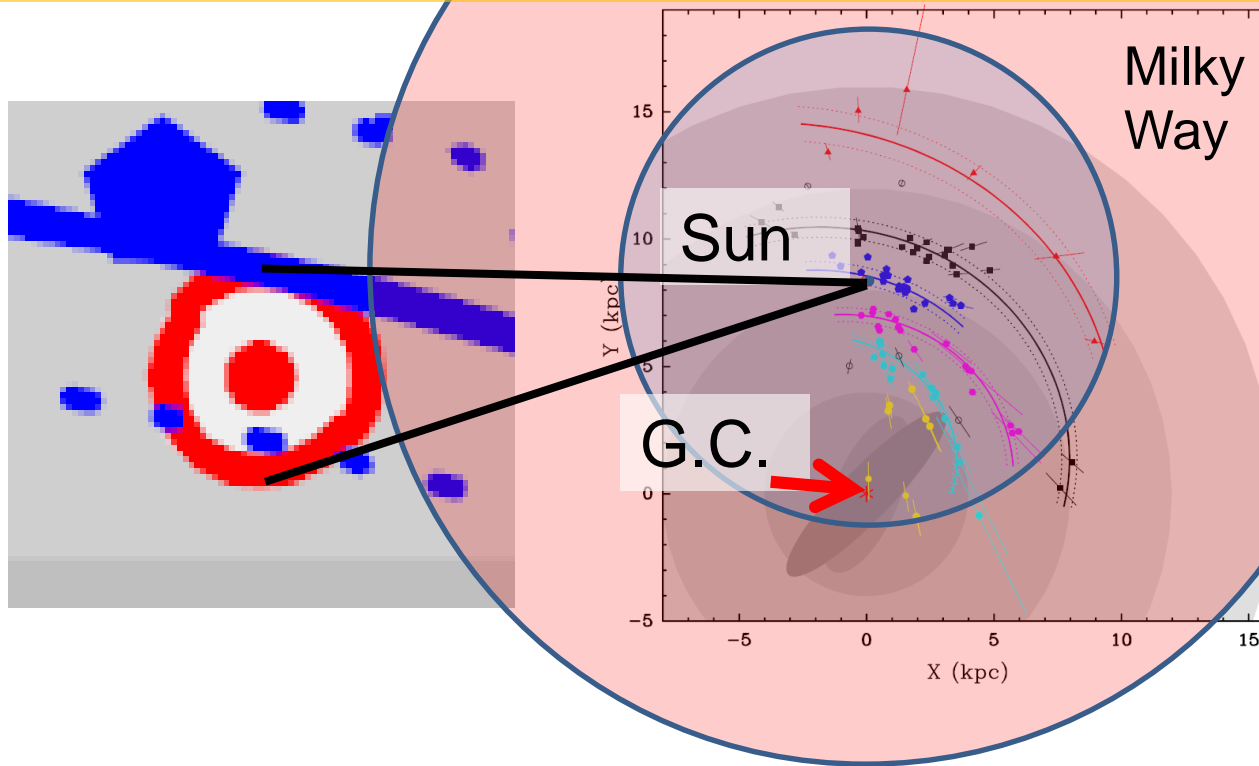


◎ 2% → 0.5% accuracy

Output : $R_0 = 7.92 \pm 0.04$

△ Correlation

Galactic Astrometry in the SKA era



1990-2000s

2000-2020s

2020-2030s

“0.1 kpc” astrometry

“10 kpc” astrometry

“> 20kpc” astrometry