Galactic structure revealed with VERA and dark matter

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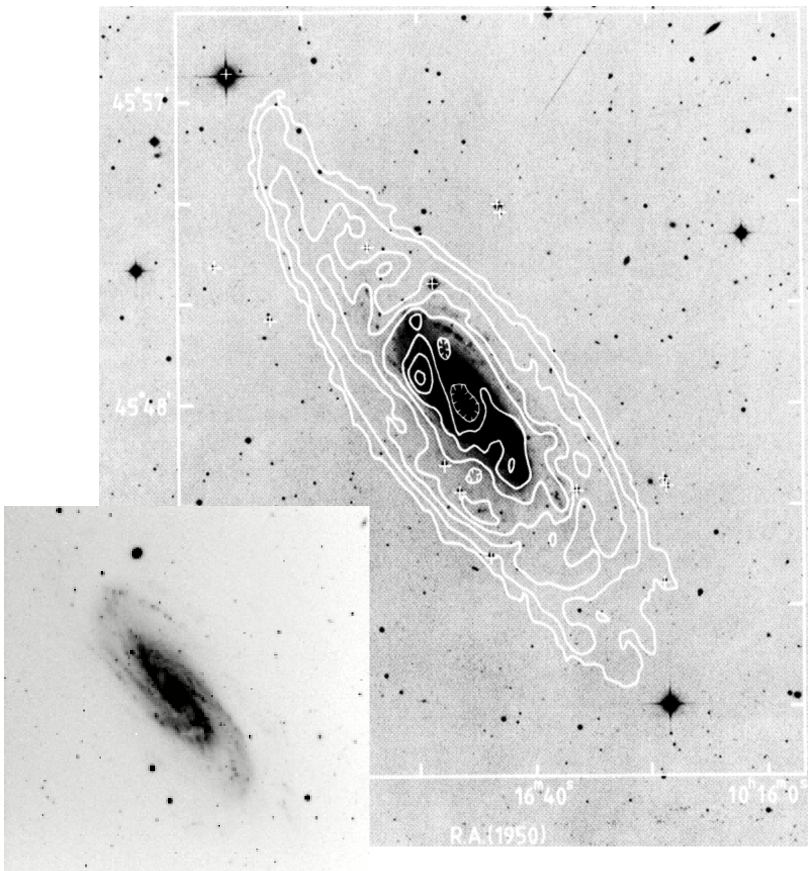
Contents

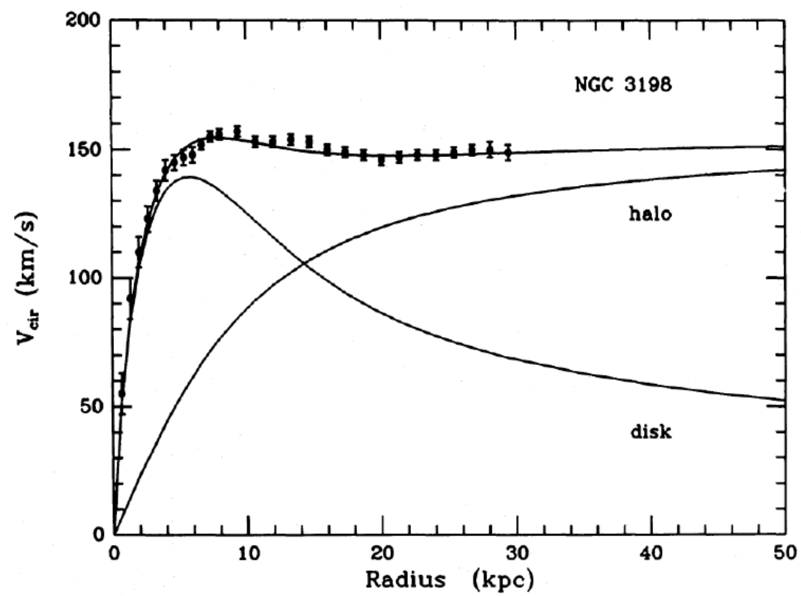
- Introduction to VERA: Galaxy scale astrometry
- most-updated results from VERA
- implication for Dark Matter search

Galactic Rotation and DM

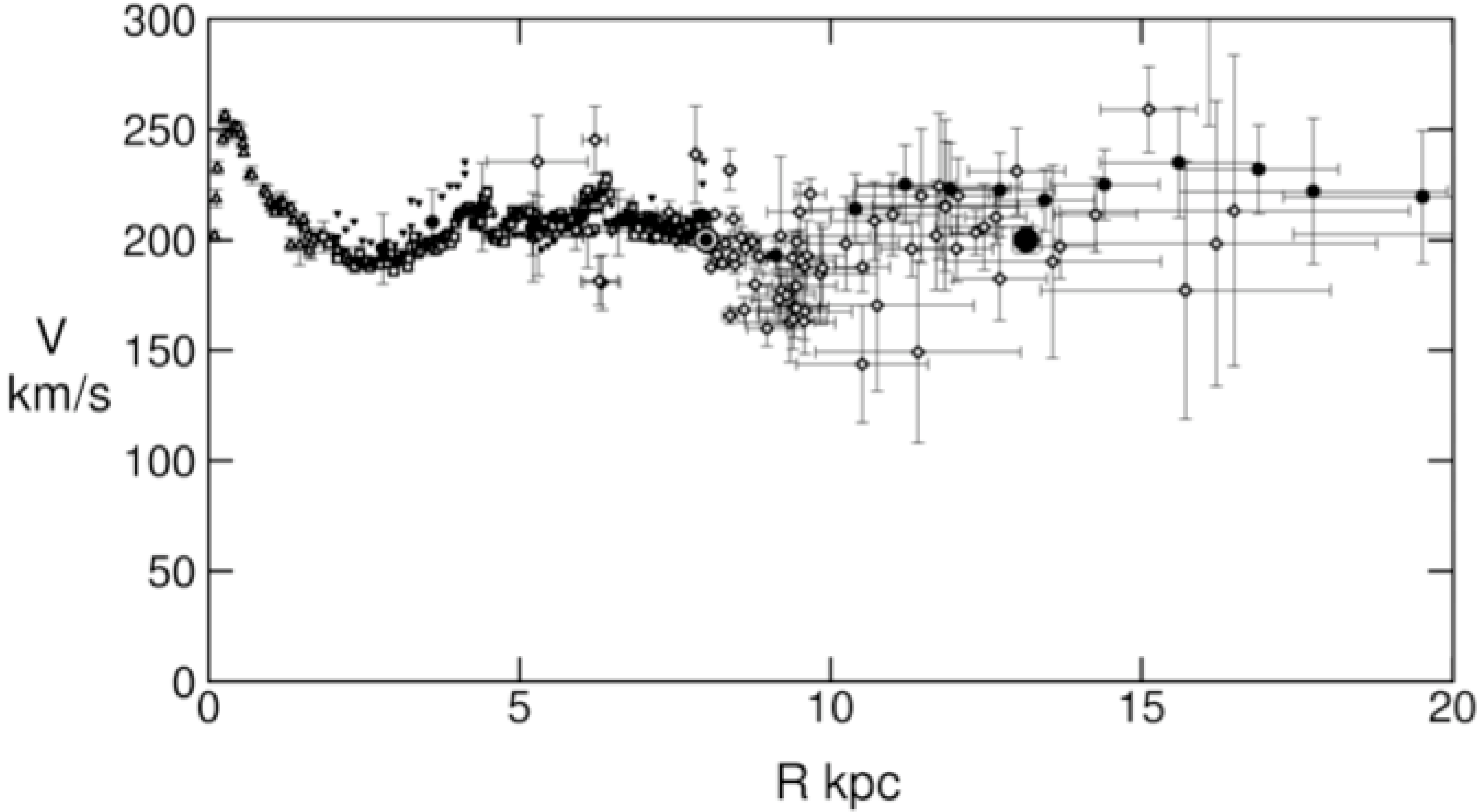
- Measurement of Galaxy rotation is important for determining where and how much DM is



Rotation curve for NGC3198
van Albada+(1985)

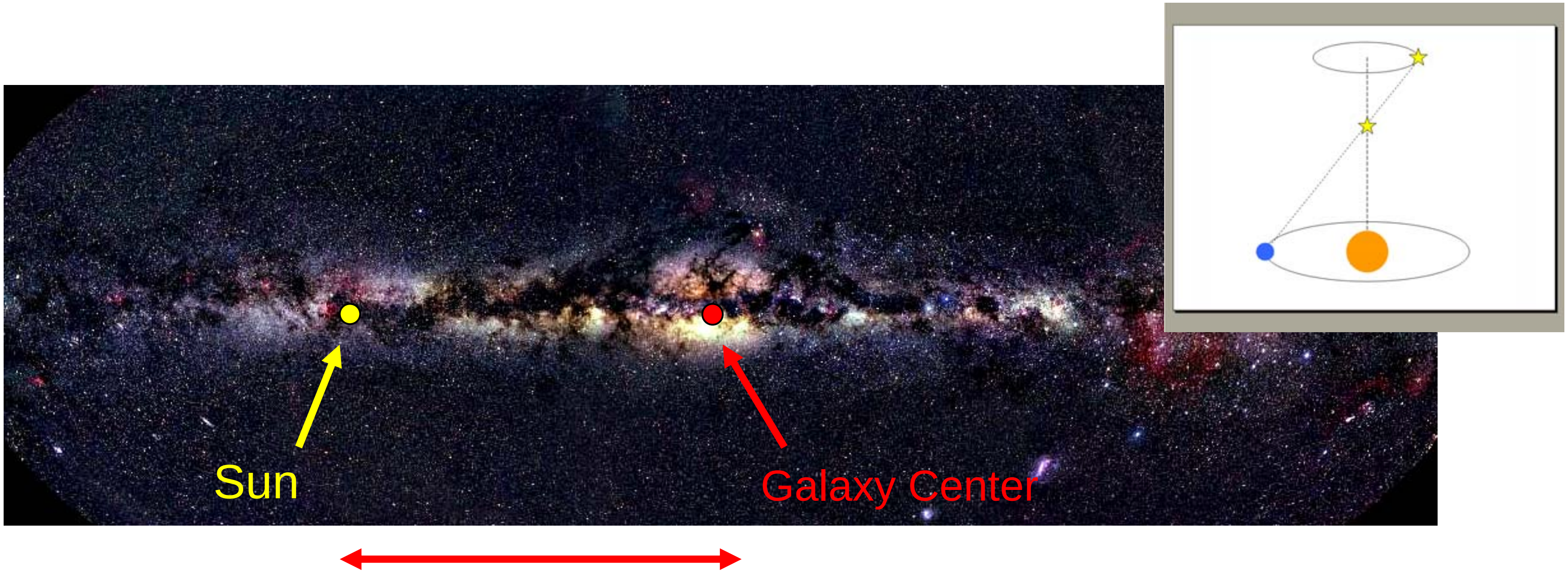


Rotation curve of the Galaxy



Based on (rather uncertain) estimates of distances.
RC shape is still uncertain, and also strongly dependent on
Adopted values of Galactic constants (R0, Θ0 etc.)

Galaxy-scale maser astrometry



Parallax

Galaxy's center D= **8 kpc**

$\pi =$ **125 μ as**

Galaxy scale astrometry requires 10 μ as accuracy

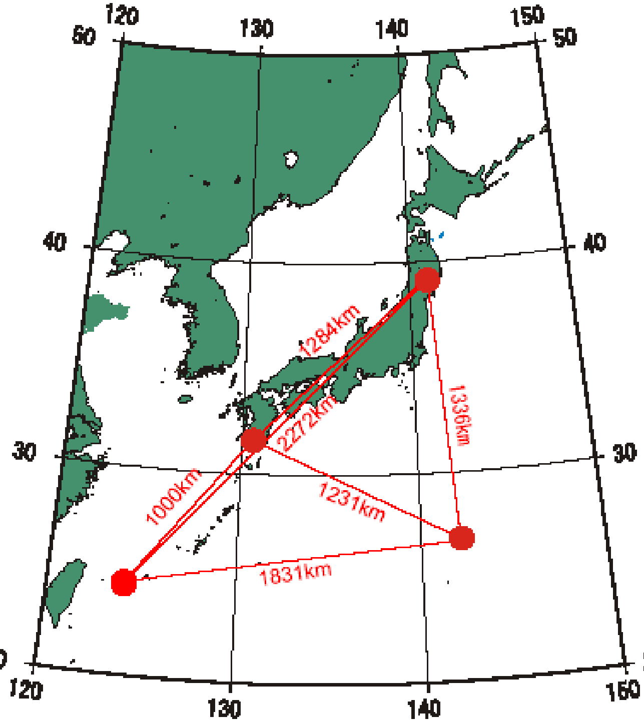
Galaxy scale astrometry = frontier in 21st century

(c.f., astrometric missions like GAIA, JASMINE)

VERA : VLBI Exploration of Radio Astrometry

Construction completed in 2002

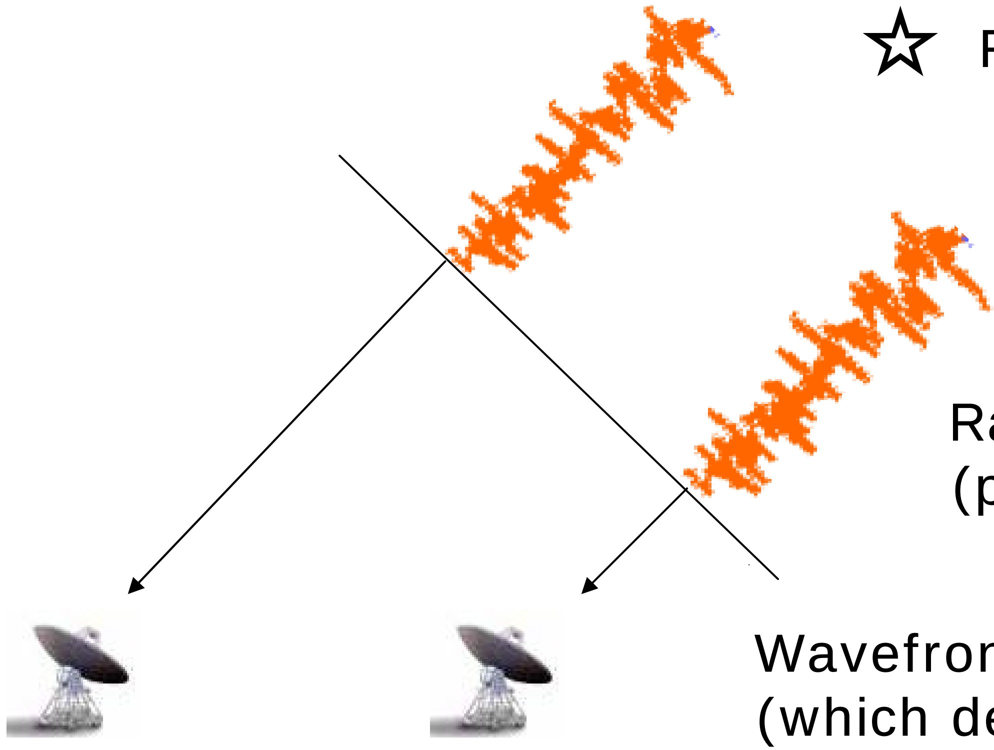
Regular observations from 2004



Target sources : Galactic masers (H2O@22GHz, SiO@43GHz & CH3OH@6.7GHz)

New aspect: dual-beam for phase-referencing

What does an interferometer measure ?

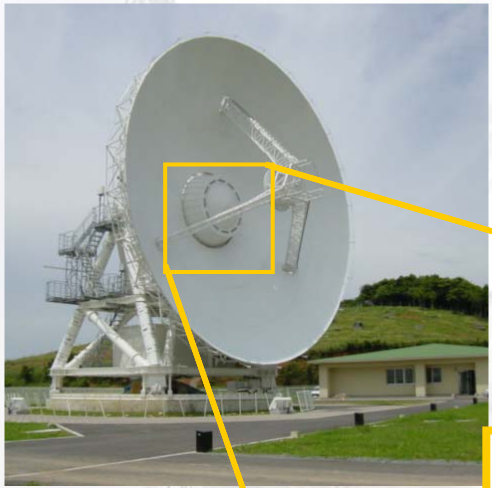


By comparing the voltage patters recorded at each station, time delay can be measured

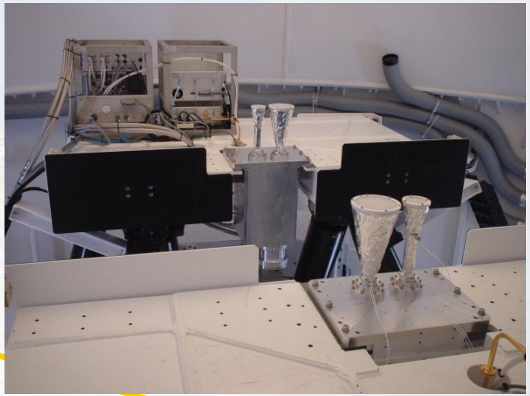
→ *accurate source position can be measured*

Dual-beam receiving system

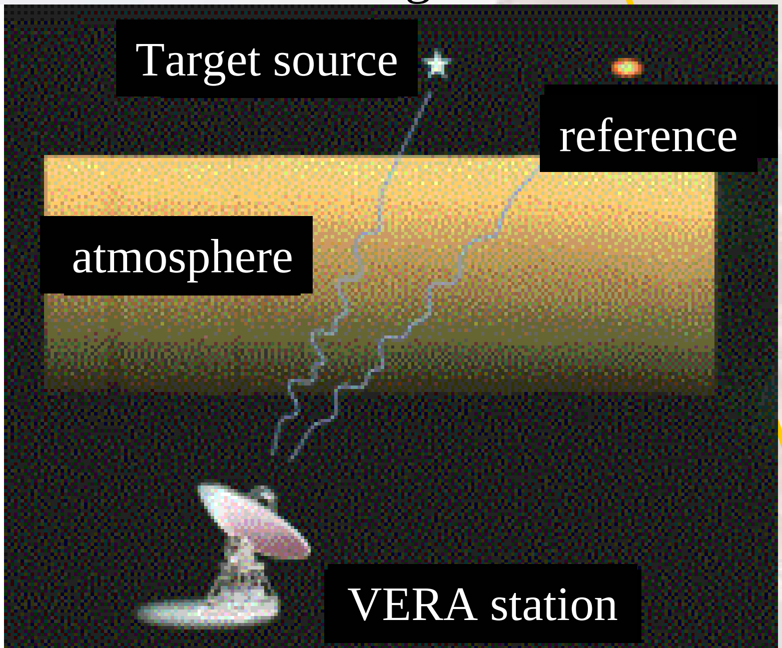
telescope



dual-beam receivers



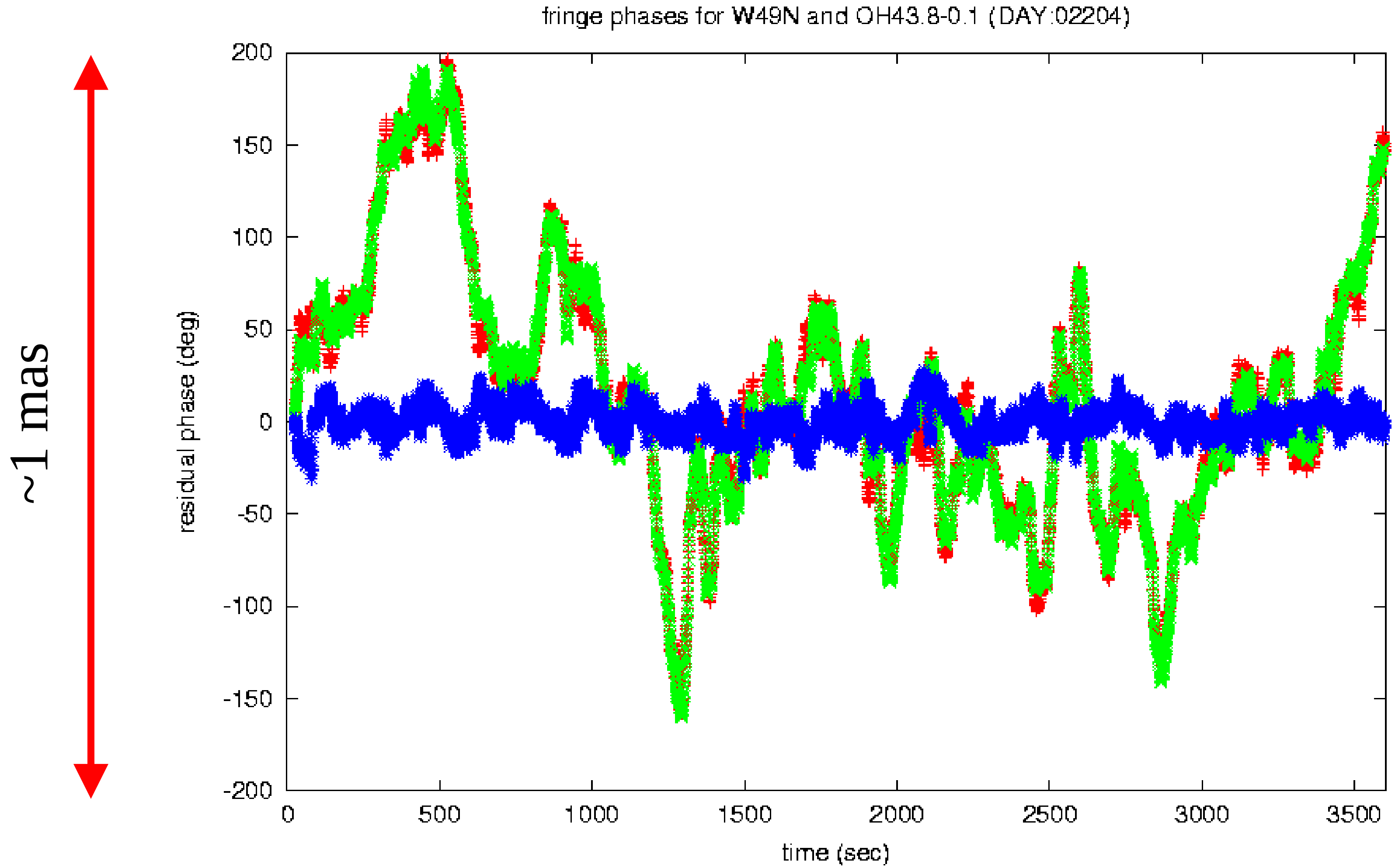
Phase-referencing



Dual-beam
platform
(2.2 deg max)

Dual-beam phase compensation

W49N and OH43.8-0.1 again (on 23/Jul/2002)

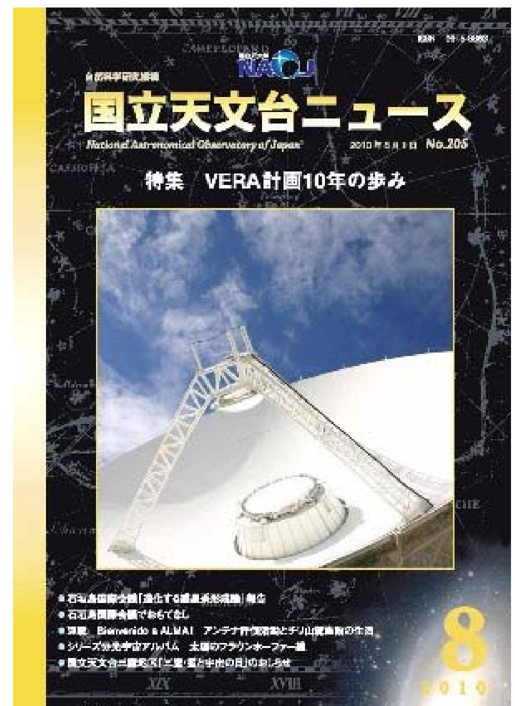


Phase residual : ~8 degree in RMS

Brief history

2000	Budget approval, construction
2001	Completion of 3 stations
2002	Completion of full array
2003	Start of test VLBI observations
2007	First parallax published
2008	PASJ special issue
2011	PASJ special issue
2012	28 parallaxes published

NAOJ NEWS
Aug 2010
“10 yr of VERA”



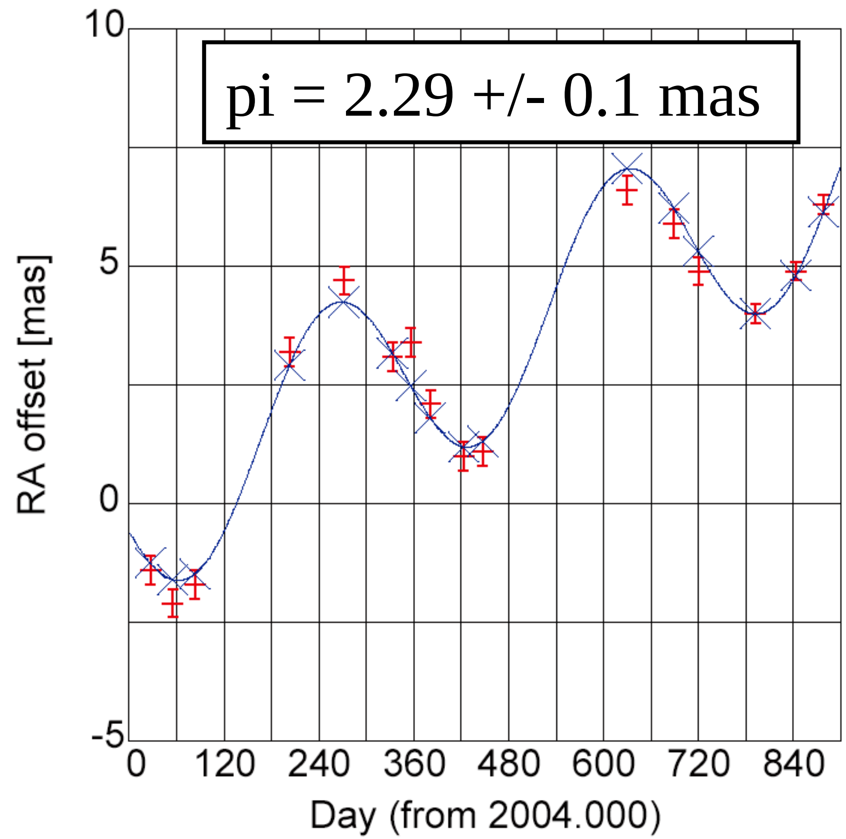
Distance to Orion KL

Astrometry of H2O masers in Orion KL

Orion nebula with Subaru

Hirota et al. (2007)

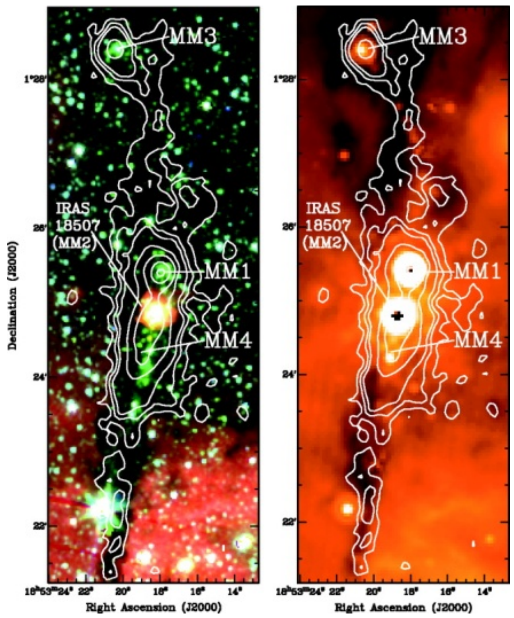
D = 437 +/- 19 pc

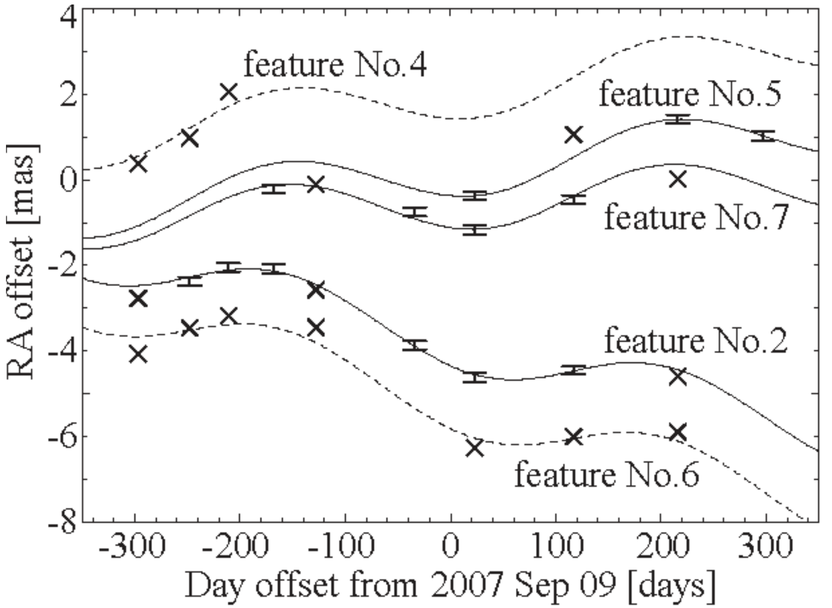


Distance and motions can be obtained

Most recent results

- 10 papers in PASJ special issue in 2001
- Case for G034.43+0.24 kpc (Kurayama et al. 2011)

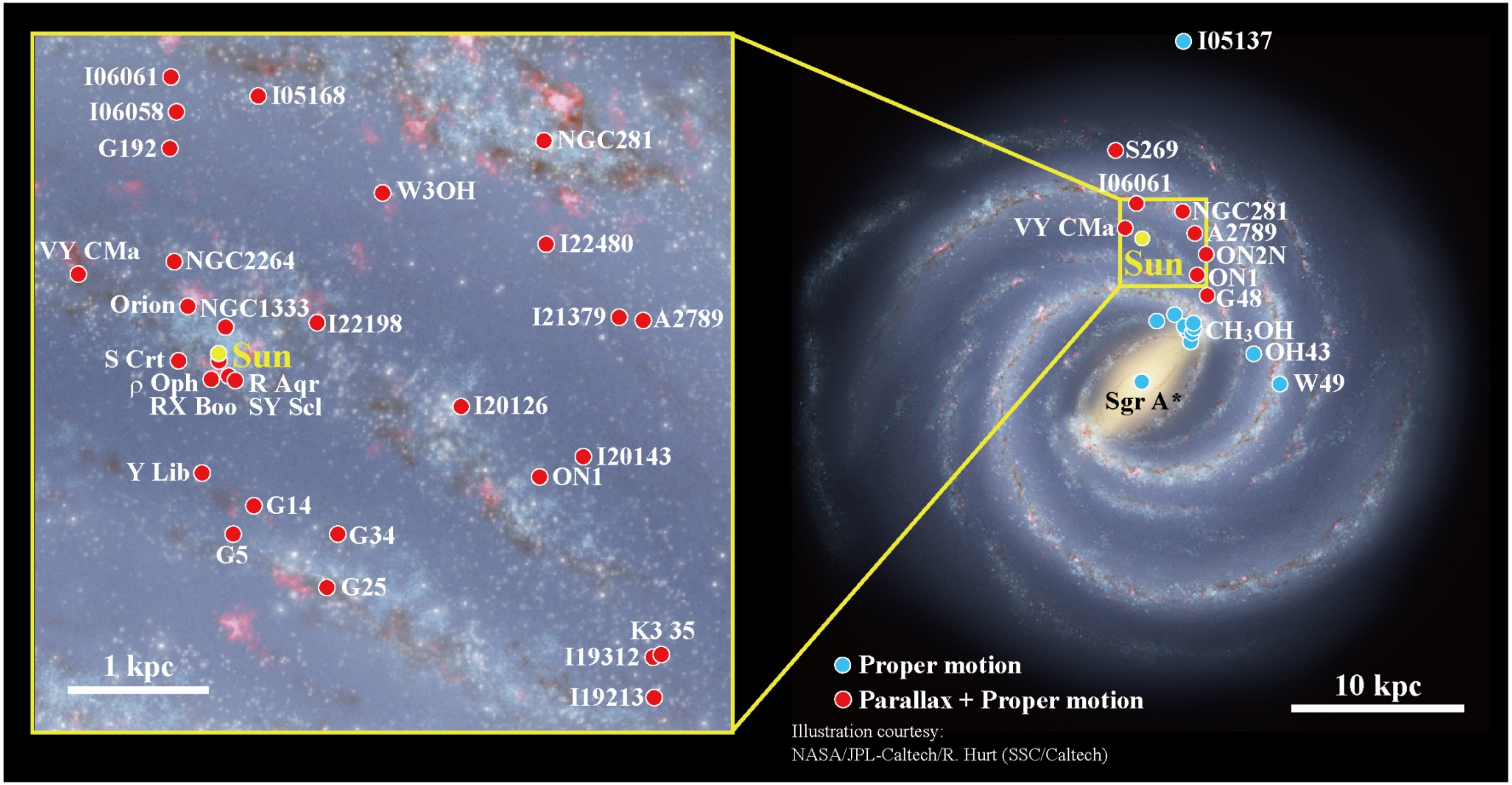




- Parallax : 0.643+/-0.049 mas
- Distance : $1.56^{+0.12}_{-0.11}$ kpc

Current status of VERA's astrometry

- More than 120 sources have been observed
- Parallaxes are obtained for more than 30 sources



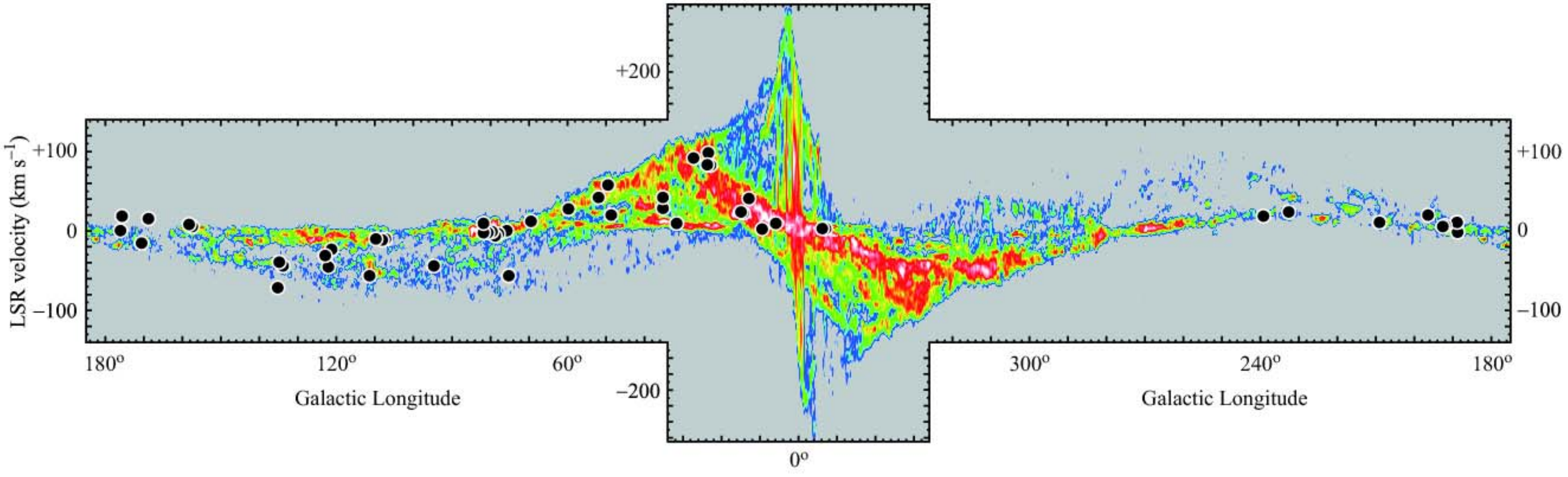
Galactic structure determination

- 52 SFRs from VERA/VLBA/EVN
- Galactic parameters to be determined

  R0, Ω0(=Θ0/R0), α(RC index)

  mean peculiar motion of SFR (U, V, W)_src

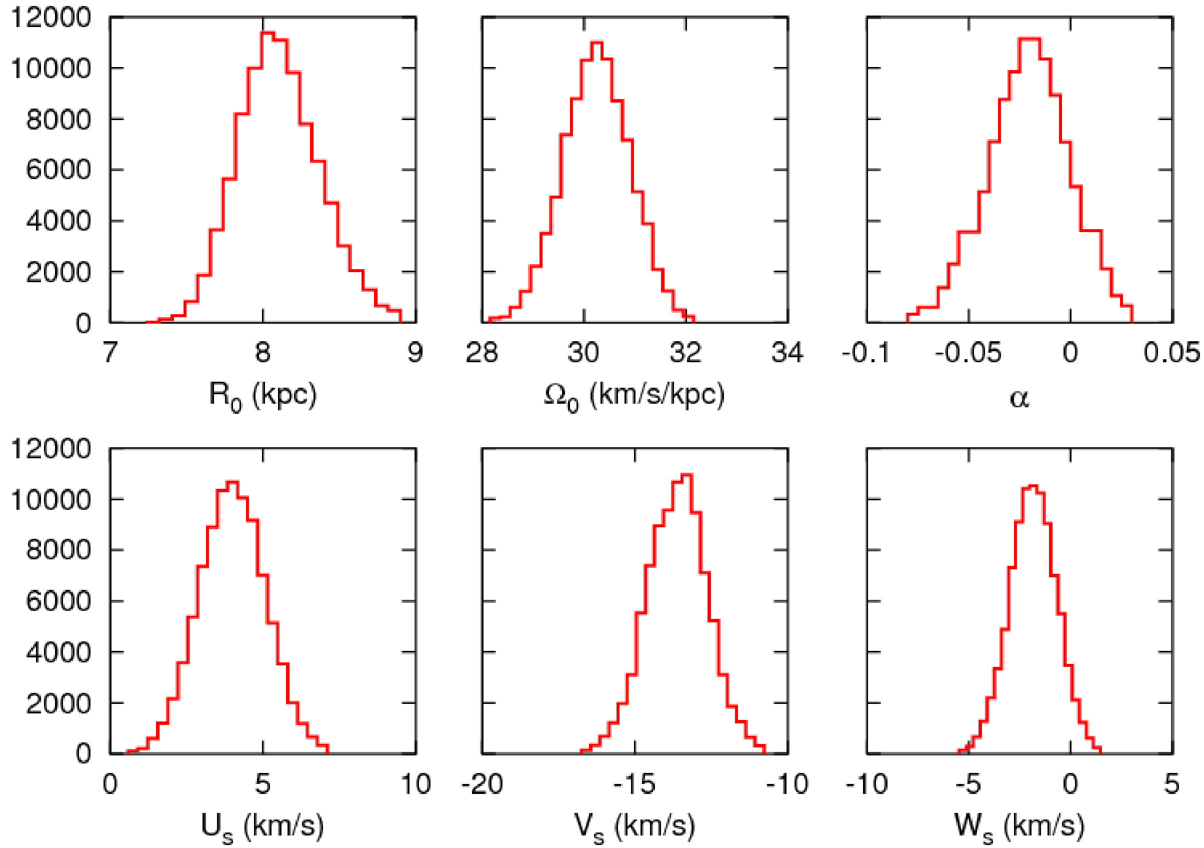
- Estimates based on MCMC (Markov Chain Monte Carlo)



Method : Markov Chain Monte Carlo

- Random walk in Galactic parameter spaces
- Markov Chain with Metropolis algorithm
- 10^5 runs, with initial 10% discarded as “burn-in”

Example of MCMC results



Galactic parameter determination

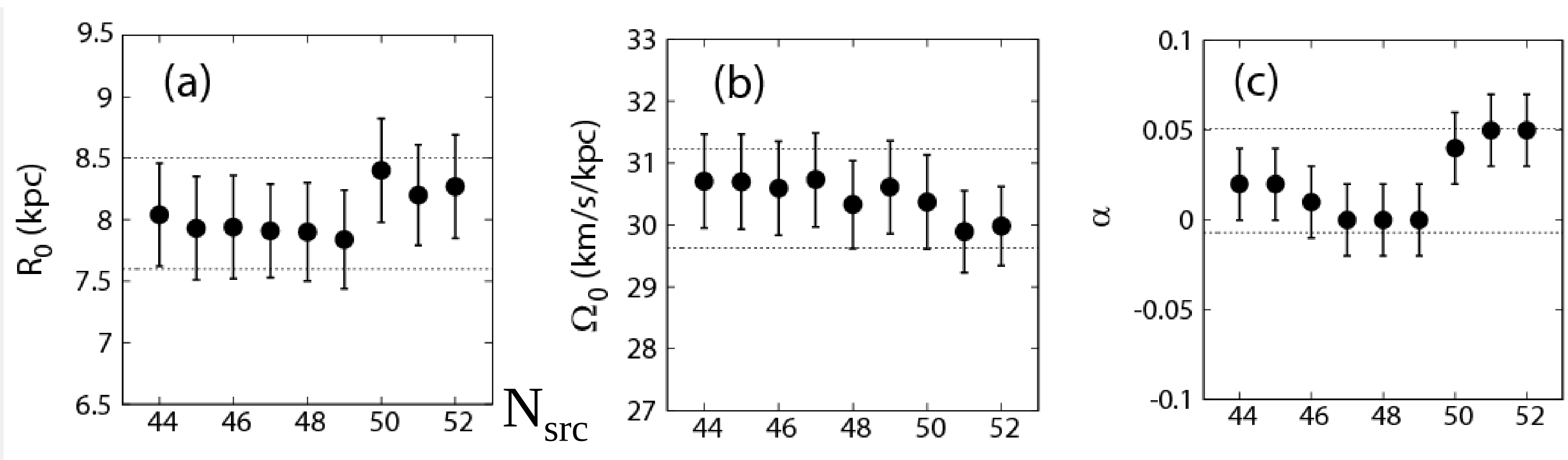
- Fundamental Galactic parameters (Honma et al. in prep.)

  R_0 = 8.05+/-0.45 kpc

  $\Omega_0 = (\Theta_0/R_0)$=30.4+/-0.8 km/s/kpc ($\Theta_0$ ~ 240 km/s)

  (for V_sun=5.2 km/s)

  α = 0.022 +/- 0.029 (nearly flat rotation curve)

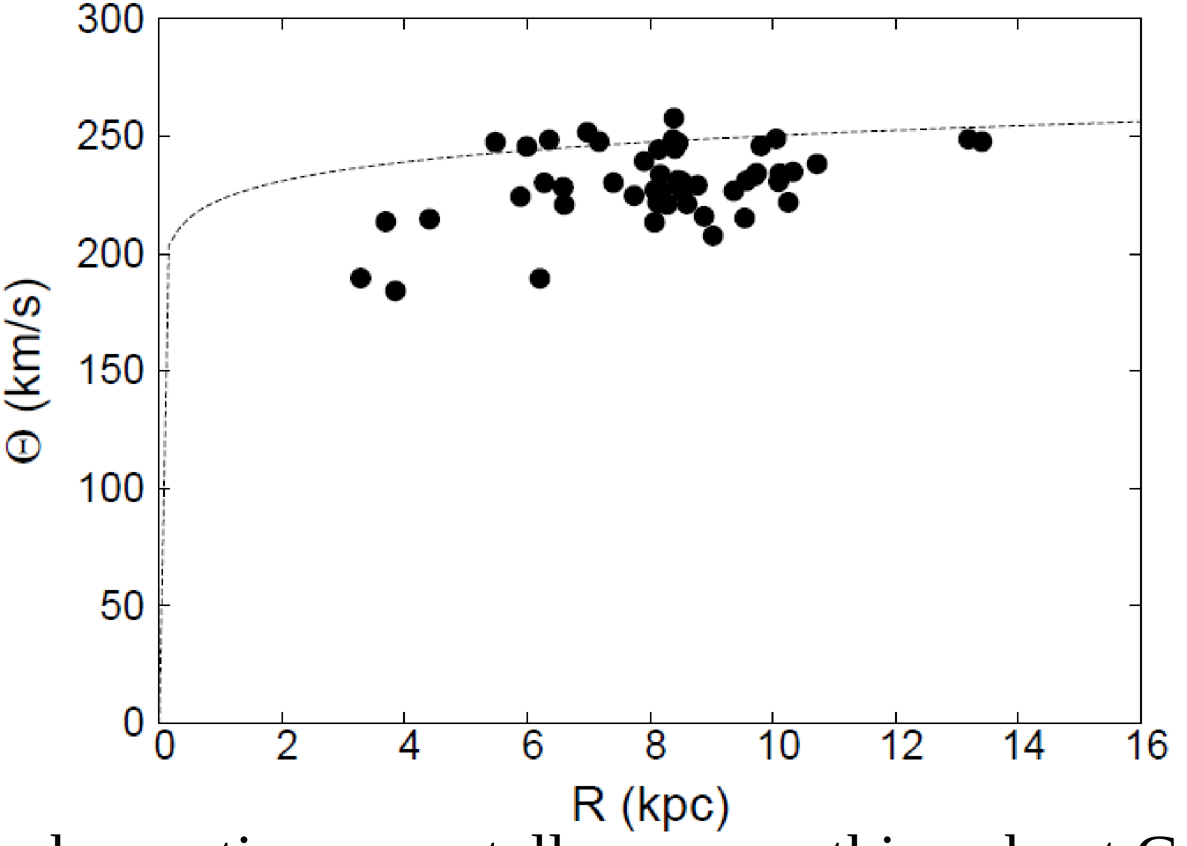


Results with eliminating possible “outliers”

Rotation curve

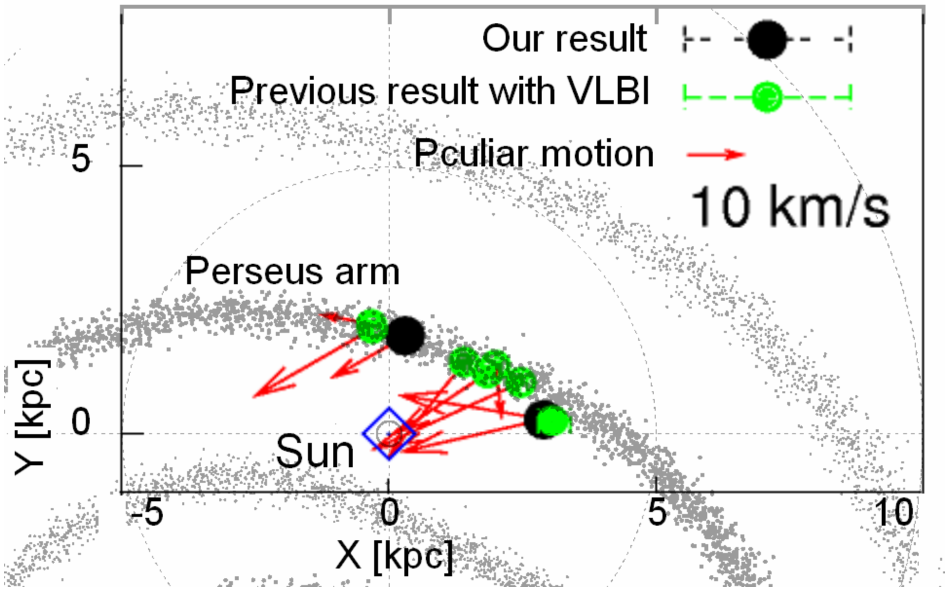
- Rotation curve obtained from maser 3D motions

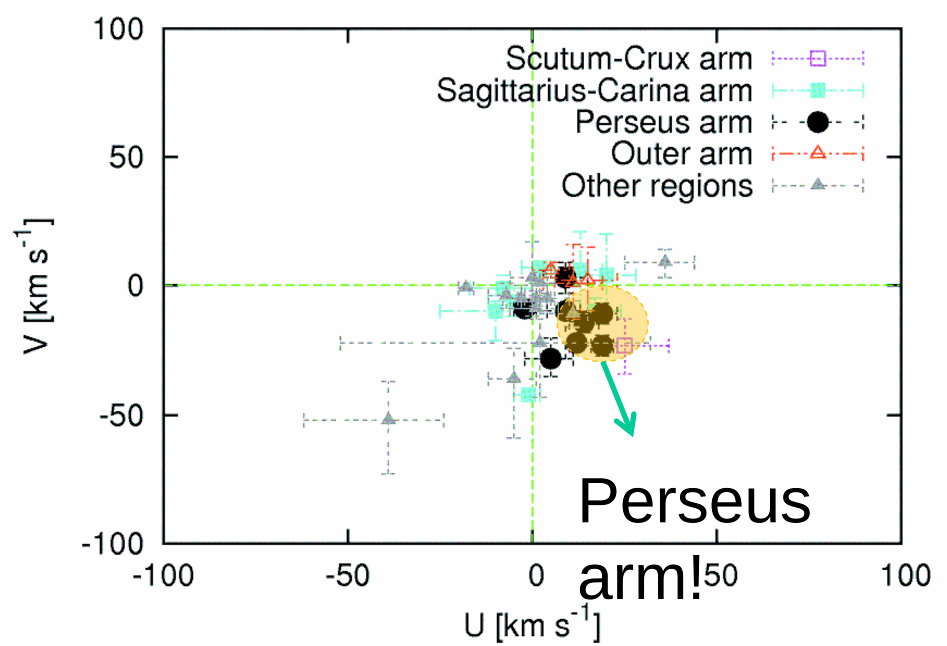
Basically consistent with flat rotation between 4 to 13 kpc
SFR rotation lag of ~ 15 km/s (in case of V_sun = 5 km/s)



Maser observations now tell you something about Galaxy

Outer rotation curve and Perseus arm peculiar motions



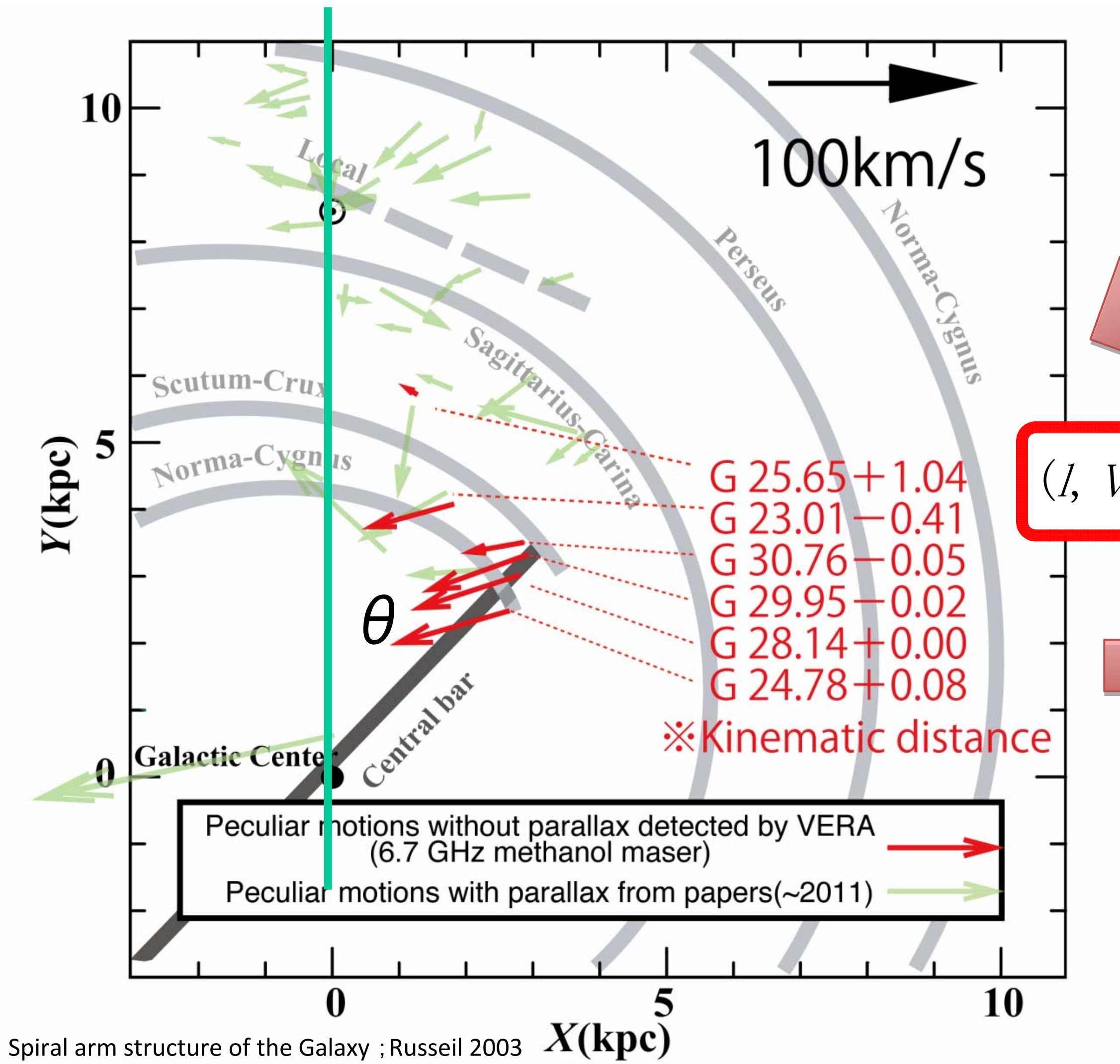


Our parallax measurements place IRAS 05168 and 21379 in the Perseus arm with peculiar motions.

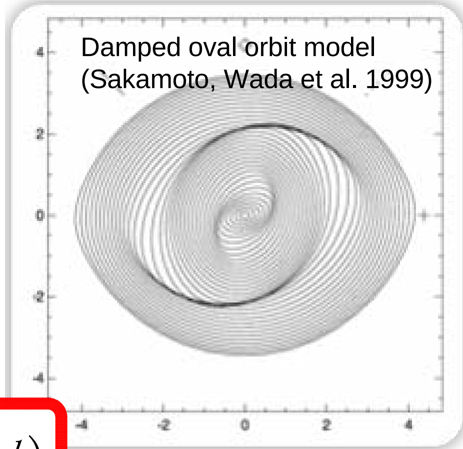
Sources in the Perseus arm are systematically moving toward Galactic Center with slower Galactic rotation.

6.7 GHz methanol maser motions and Galactic bar

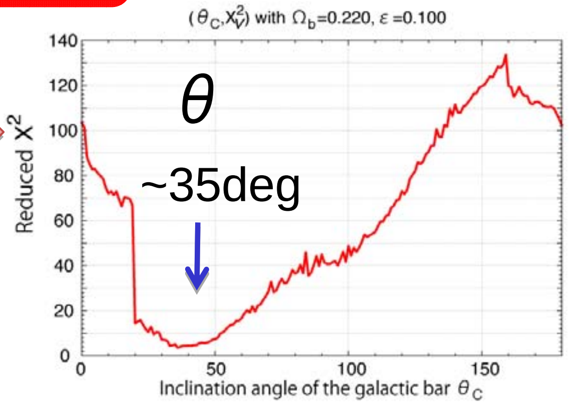
Non-circular motions by Galactic bar



Spiral arm structure of the Galaxy ; Russeil 2003



$(l,\ V_{LSR},\ \mu_l \cos b)$



Matsumoto's PhD thesis
(Mar. 2011)

Implications for DM study

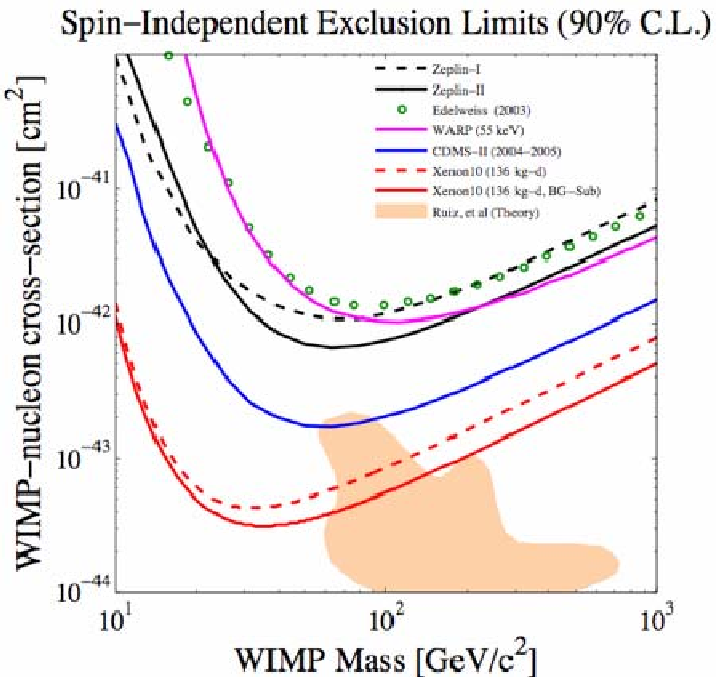
- Galactic rotation is a very important parameter for DM experiments

  mass density ∼ V^ 2

  mass flux ∼ ρ V ∼ V^3

  Precise measurement of Galactic rotation is very important

Xmass detector



Xenon results

DM density (Global approach)

- Global determination of DM density at the Sun
- Higher velocity (Θ0 ~ 240 km/s) means more DM
- With maximum disk (M~ 6x10^10 M_sun, h~ 3kpc), local DM density is as high as

$\sim$0.014 M_{sun} pc^{-3}

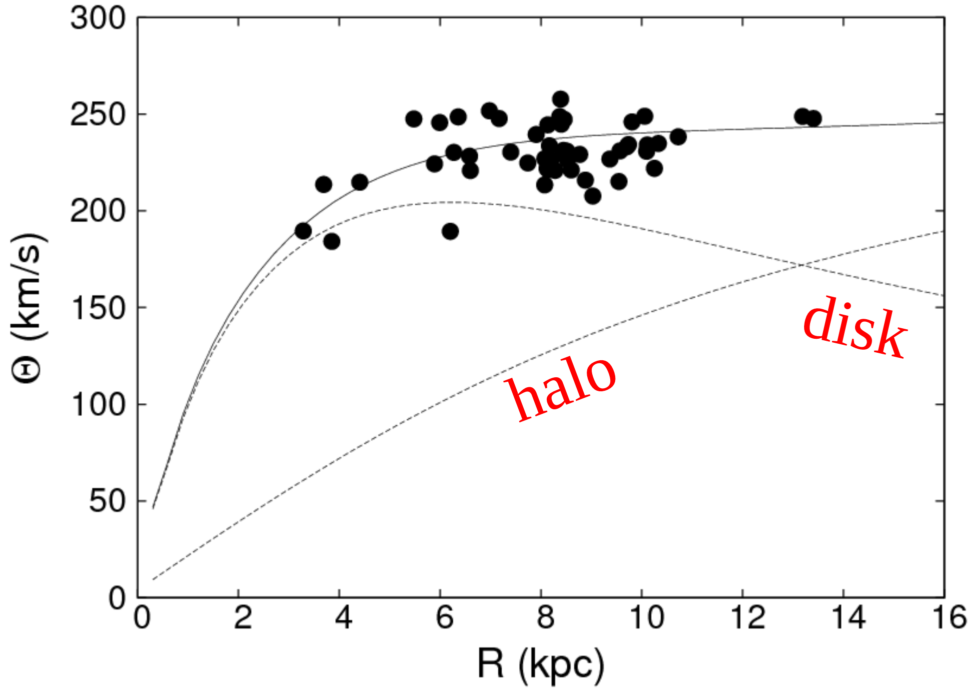
($\sim$0.5 Gev / cc)

but solution is not unique

(disk mass & scale,

halo shape etc. are still

highly uncertain)



We definitely need more observations !

Concluding remarks

- VERA (and VLBA) has been regularly conducting kpc-scale astrometry for Galactic maser sources.

- VLBI astrometry of masers provides a unique tool for studying the structure of the Milky Way Galaxy as well as dark matter distribution.

- Current best estimate of Θ_0 ~ 240 km/s would raise the expected local DM density and DM flux as well.

  In future, we will observe 300 sources and determine R_0 and Θ_0 at ~1 % level.