Test of the density-wave theory based on VLBI astrometry results

Sakai et al. 2015

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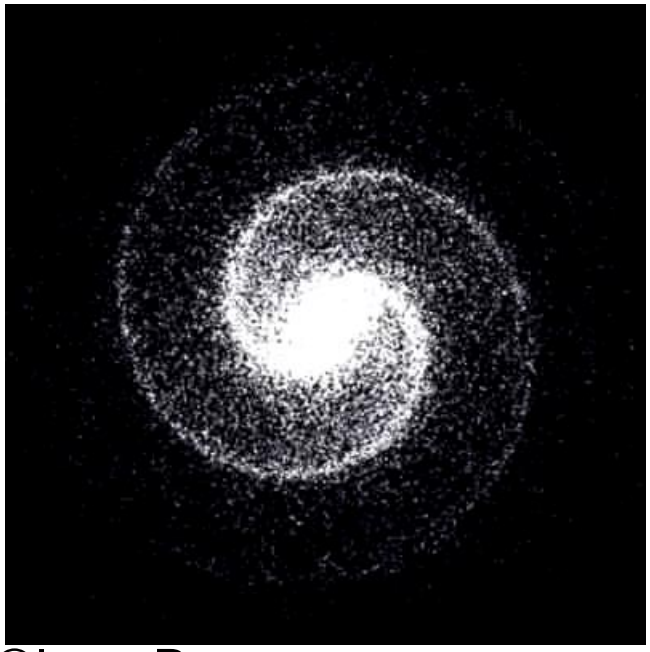
Context : Theory

Density wave theory
(Lin & Shu 1964)



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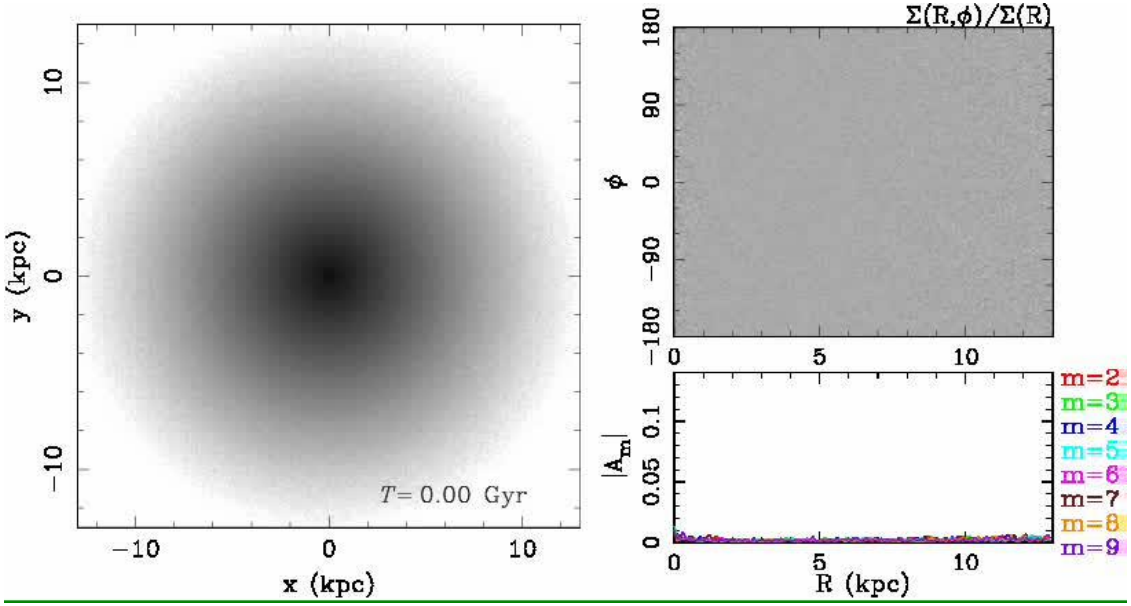
Recurrent transient spiral
(e.g., Miller+1970; many papers)



Fujii et al. 2011:N-body simulation

- Spiral arm is the most prominent structure in a disk galaxy.
- However, the nature, origin and evolution are still unknown.

Context：1−D observation

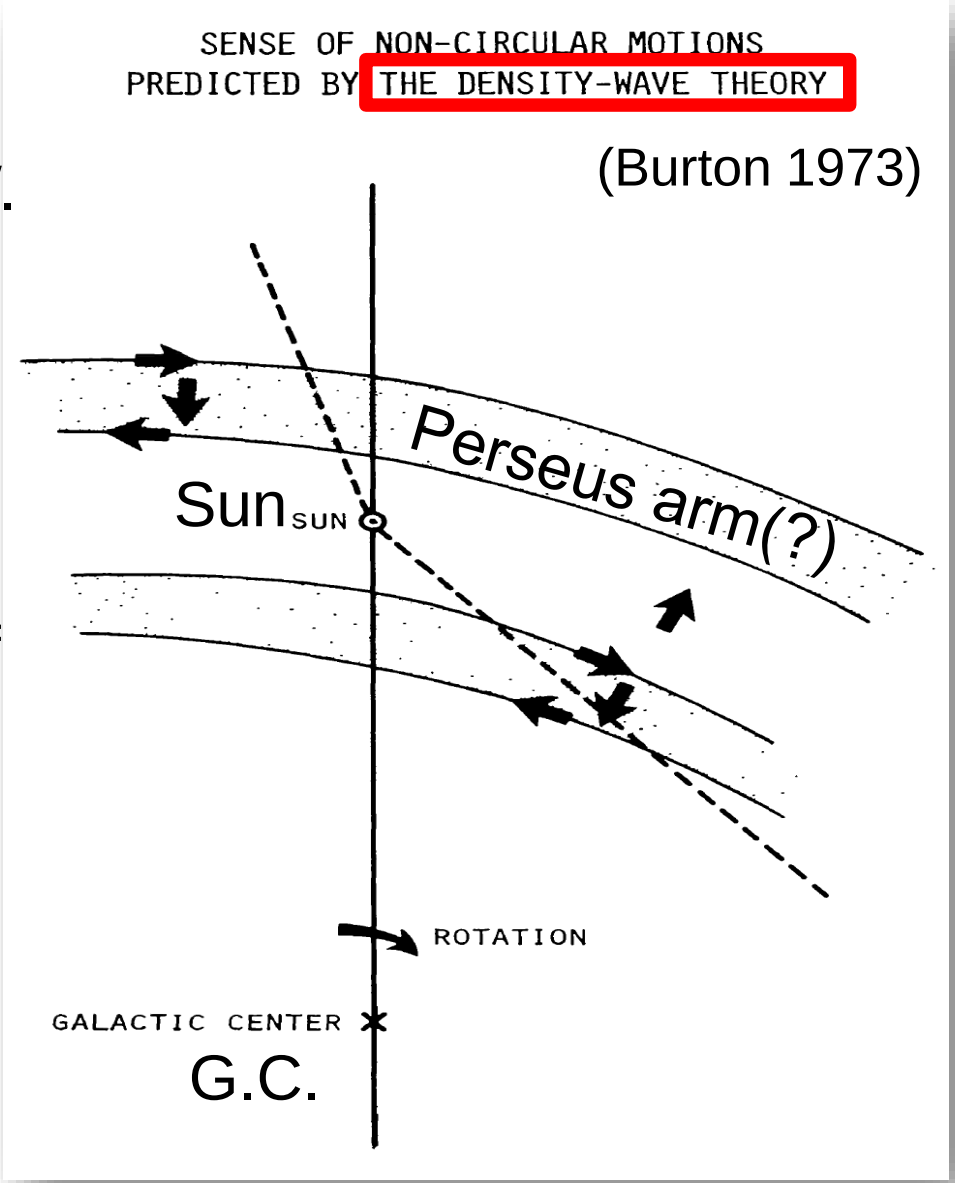
(Burton 1973)

●Distribution of line-of-sight velocity is **asymmetry** in the MW.

→ **Effect of spiral arm ?**

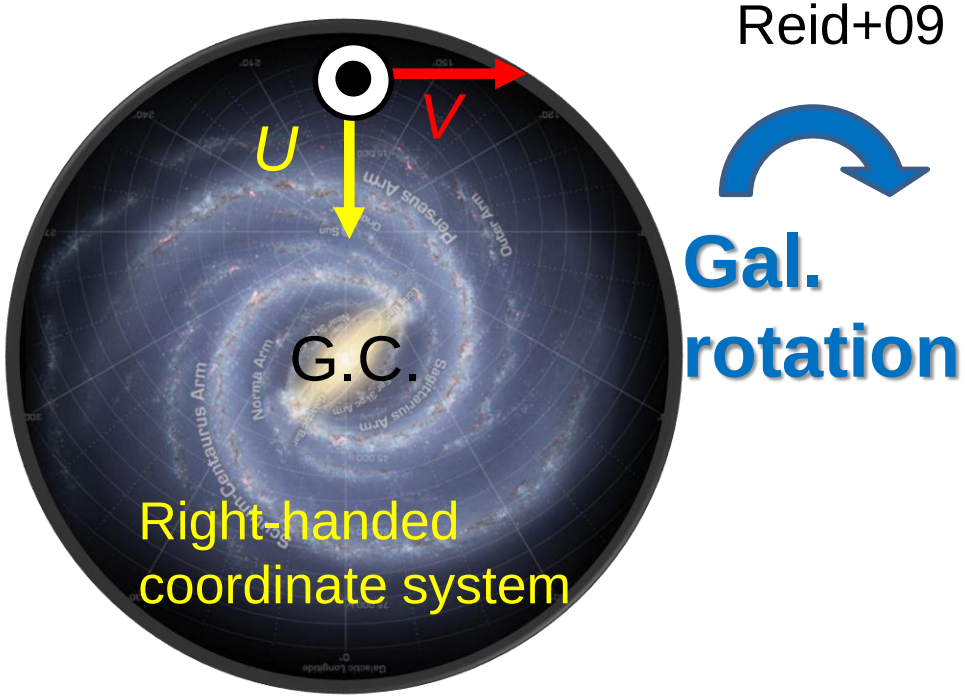
●The observed velocity field might be explained by a gravitational perturbation (i.e., **spiral arm**) in the context of **the density-wave theory.**

Systematic non-circular motion might be explained by the density-wave theory !

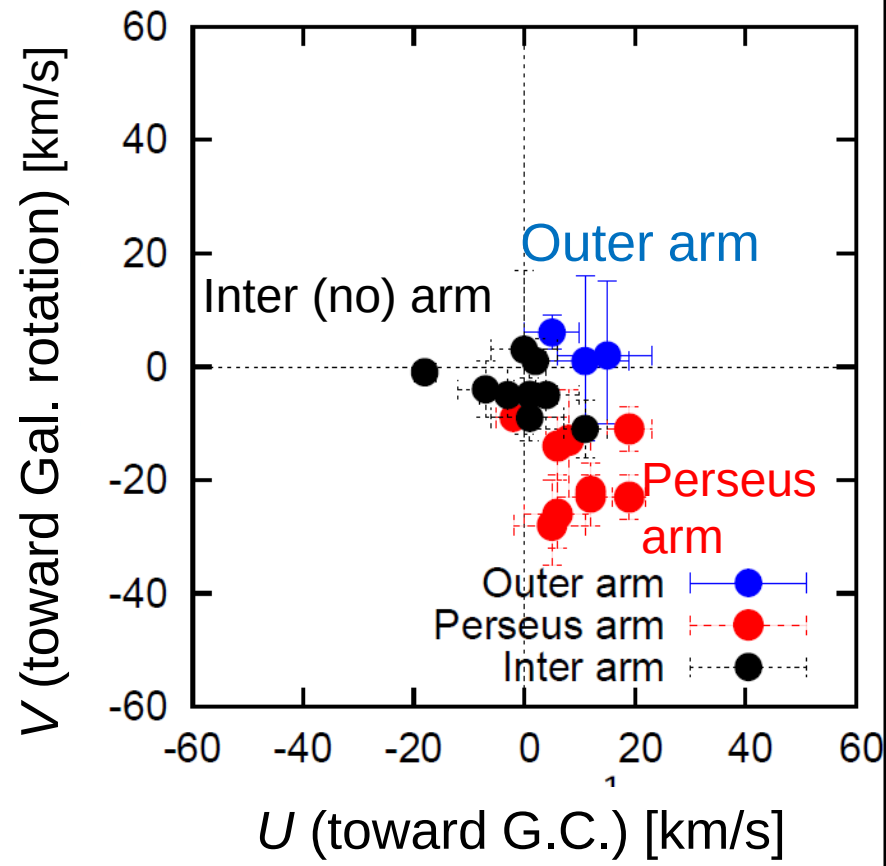


Context : 3-D observation

3D non-circular motion (*U, V, W*) in Reid+09



Flat rotation assumed.



Averaged non-circular motions with 8 sources in the Perseus arm

(*U*_mean, *V*_mean) = (9.8+/-2.6, −17.8+/-2.5) km/s in Sakai et al. (2012)

→Systematic inward motion and slower Gal. rotation

Context : 3-D observation

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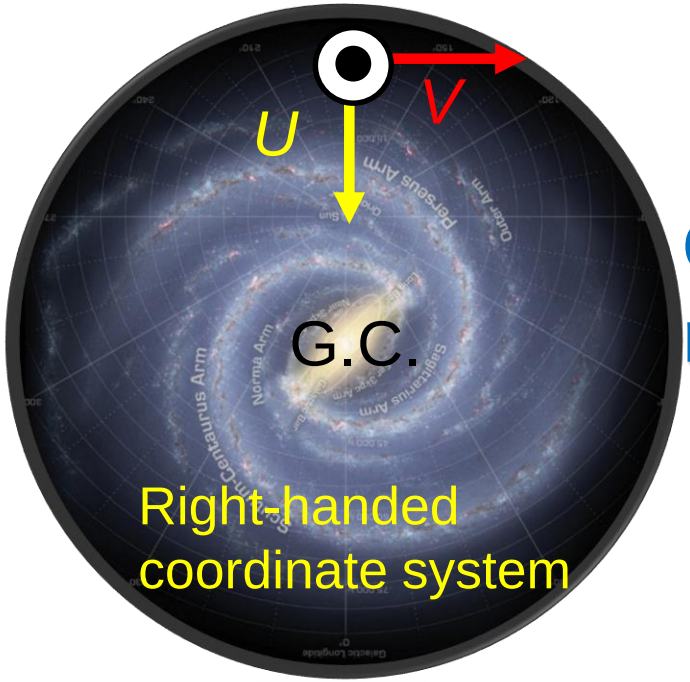
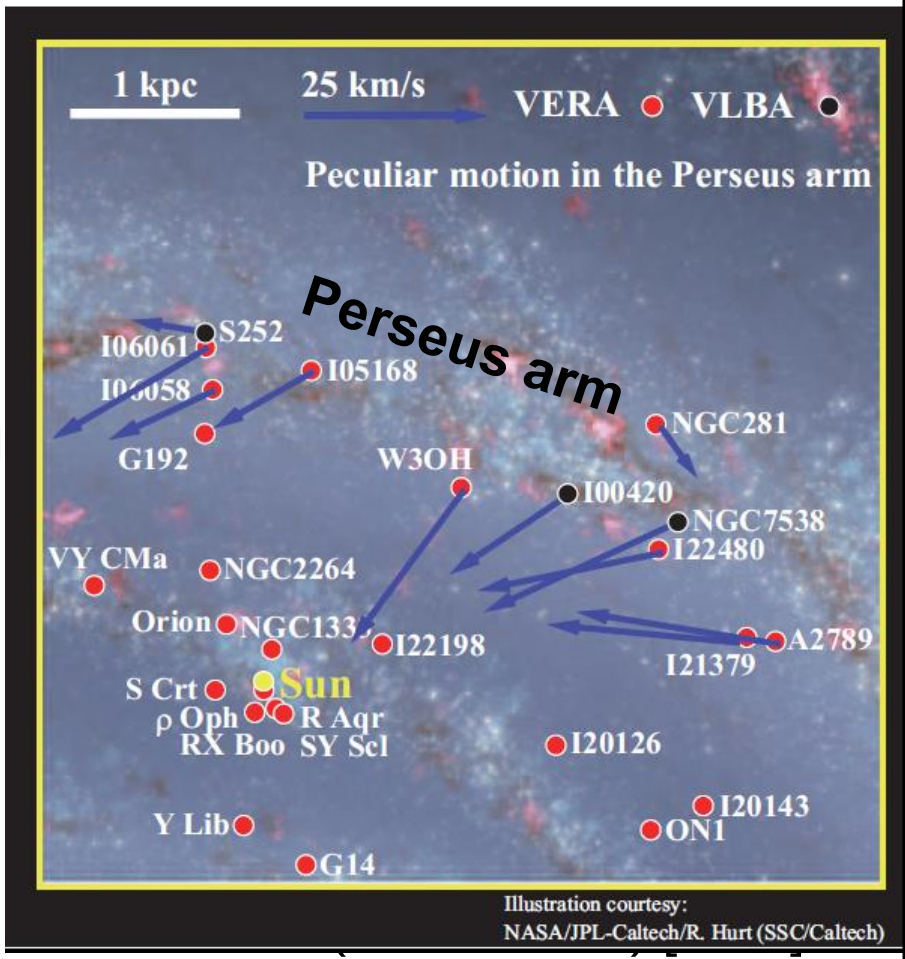


Gal. rotation



Choi et al. (2014) found the same tendency **with 25 sources** !

Averaged non-circular motions with 8 sources in the Perseus arm
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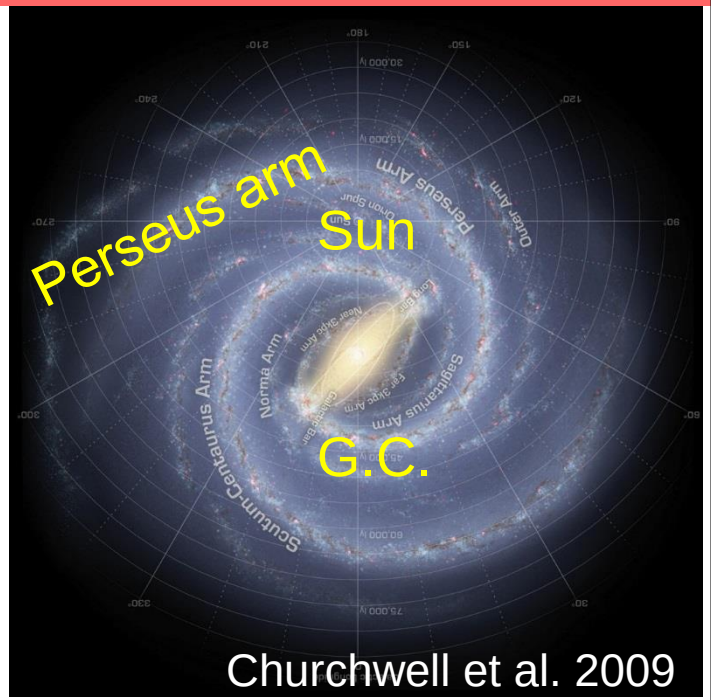
Goals of this research

①We compare astrometry (3D) results for **the Perseus arm** with an analytic gas dynamics model for testing the density-wave theory.

②Using the results, we make a suggestion toward an **incoming astrometry** (e.g., Gaia).



Churchwell et al. 2009

Ultimate Goal

・We understand the nature, origin and evolution of the spiral arm especially for the Milky Way Galaxy.

The least squares fit

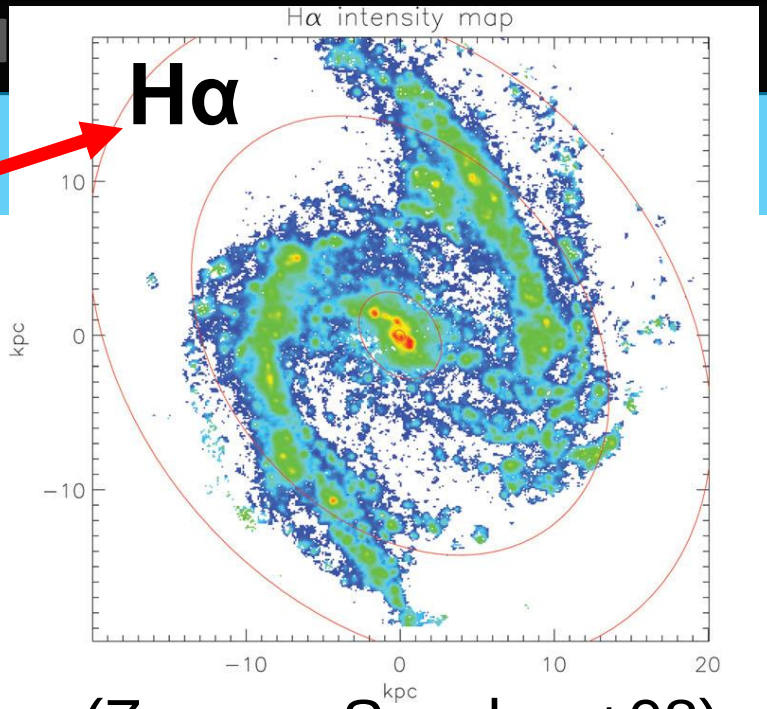
Observables

(U, V) for 27 sources in the Perseus arm

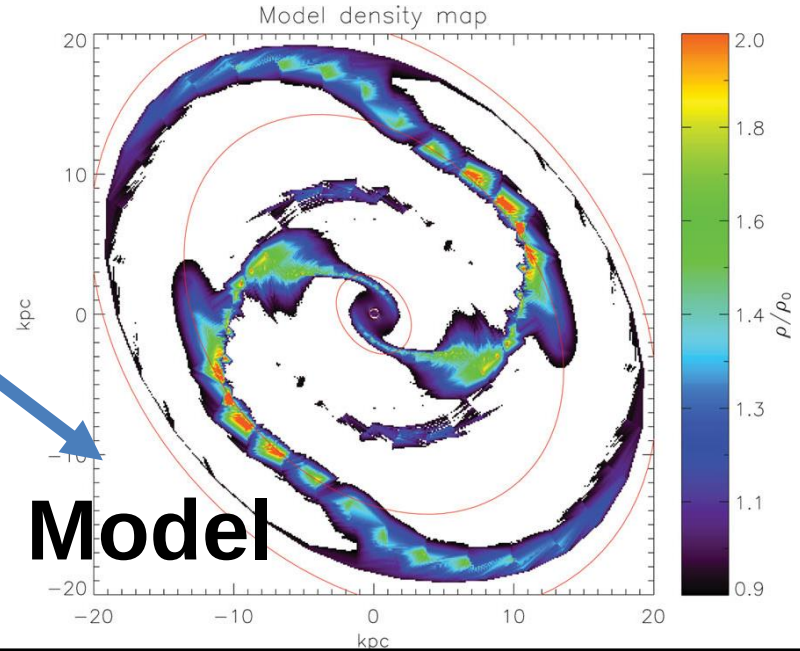
χ^2_ν was minimized.

Spiral model (density wave)

- Pinol-Ferrer+12 & 14 (analytic)
- Equations of motion with gas friction term were solved using the linear approximation.



(Zanmer Sanchez+08)

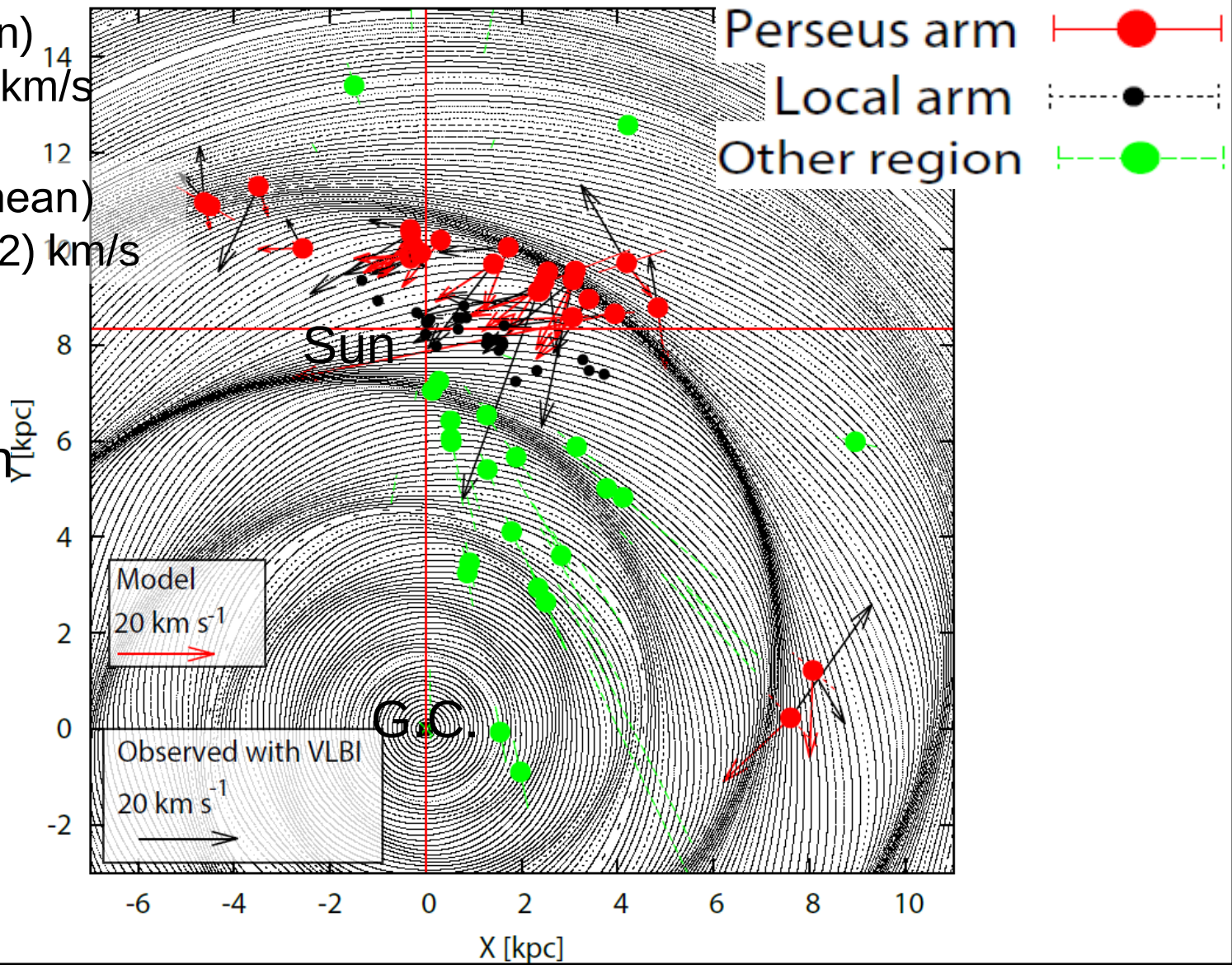


Results

(U_mean, V_mean)
= (8+/-3, −9+/-2) km/s

(ΔU_mean, ΔV_mean)
= (−2+/-2, −2+/-2) km/s

Gas distribution model



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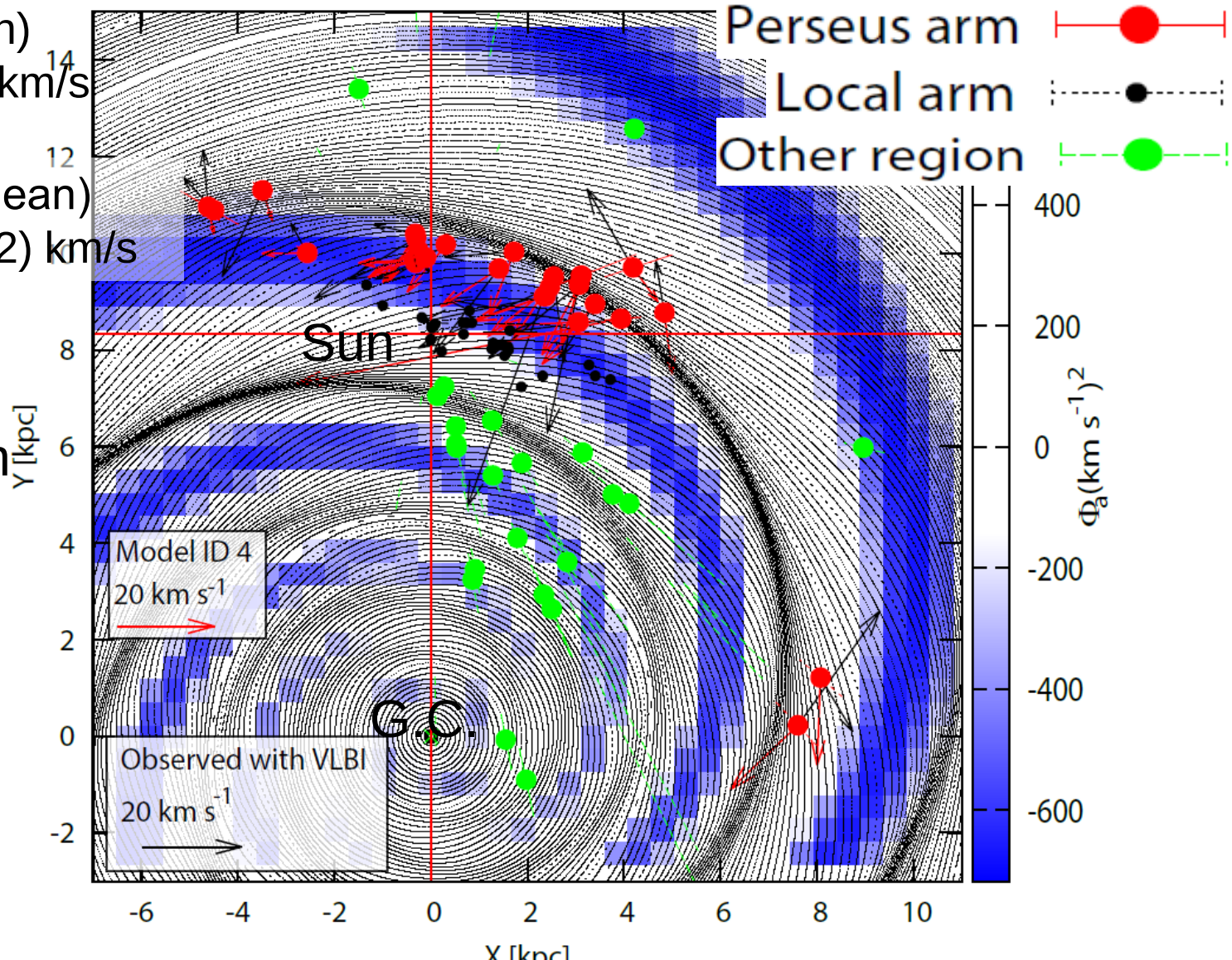
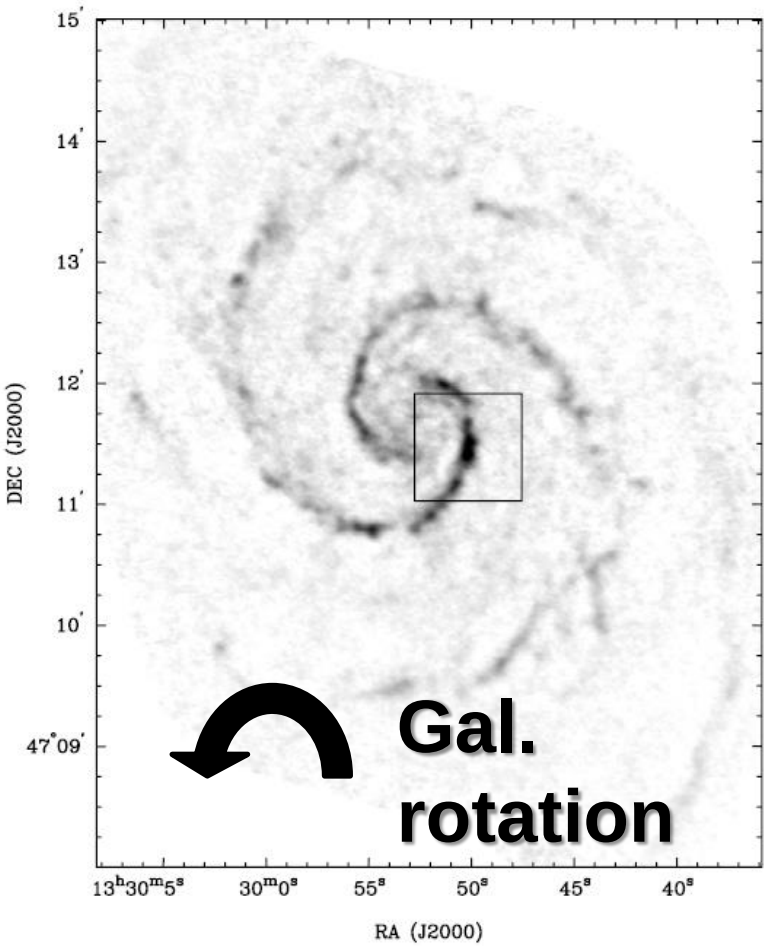
Gas distribution model

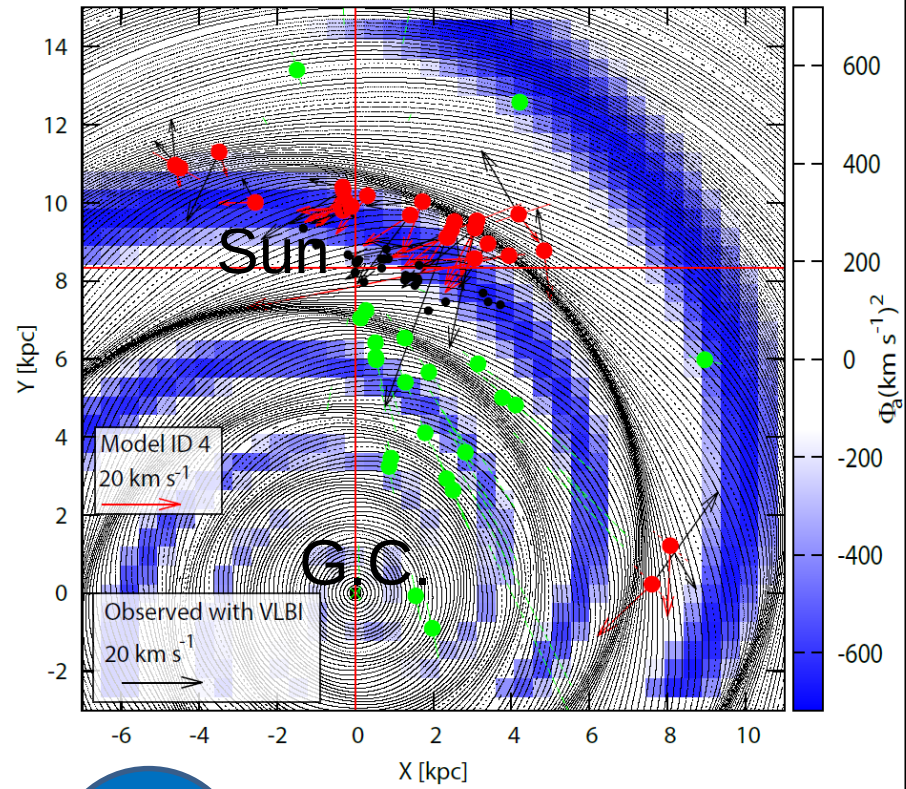
Spiral potential model



M51 vs. The model of the Milky Way



^{12}CO intensity map (Koda+09)

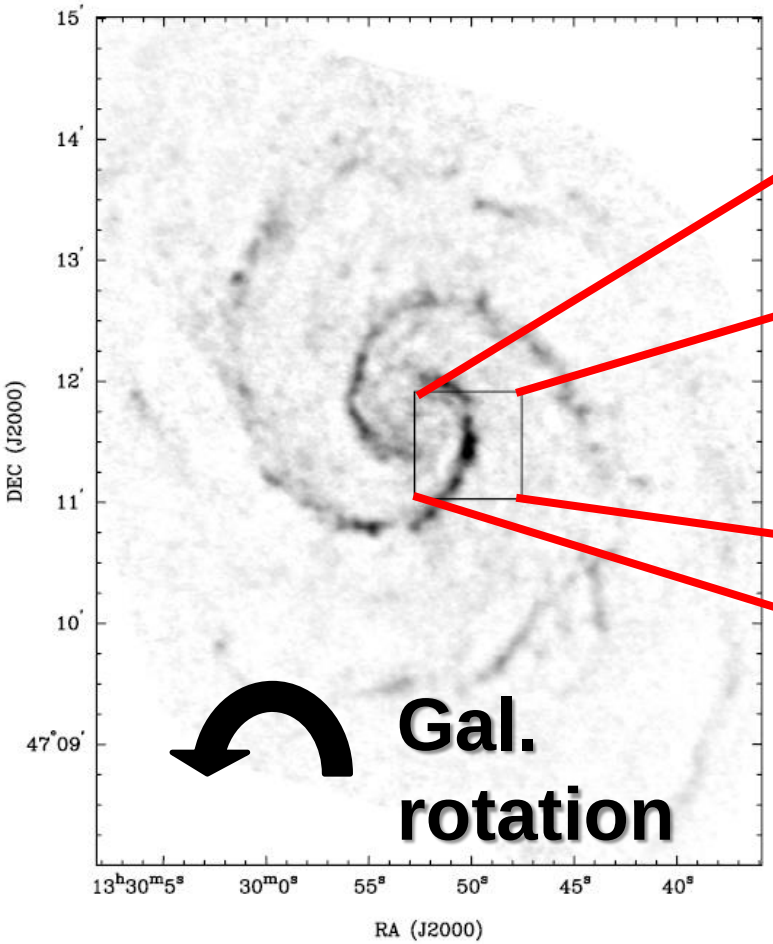


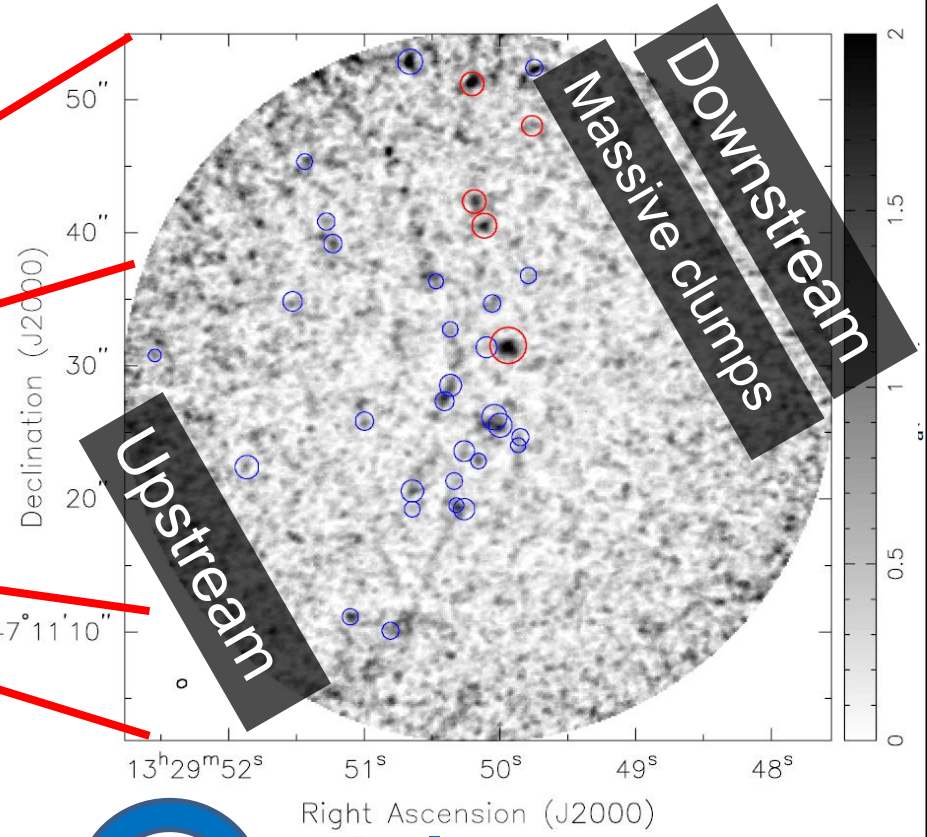
Gal. rotation

Egusa+10

The model of the Milky Way (Sakai et al. 2015)

M51 vs. The model of the Milky Way





Gal. rotation

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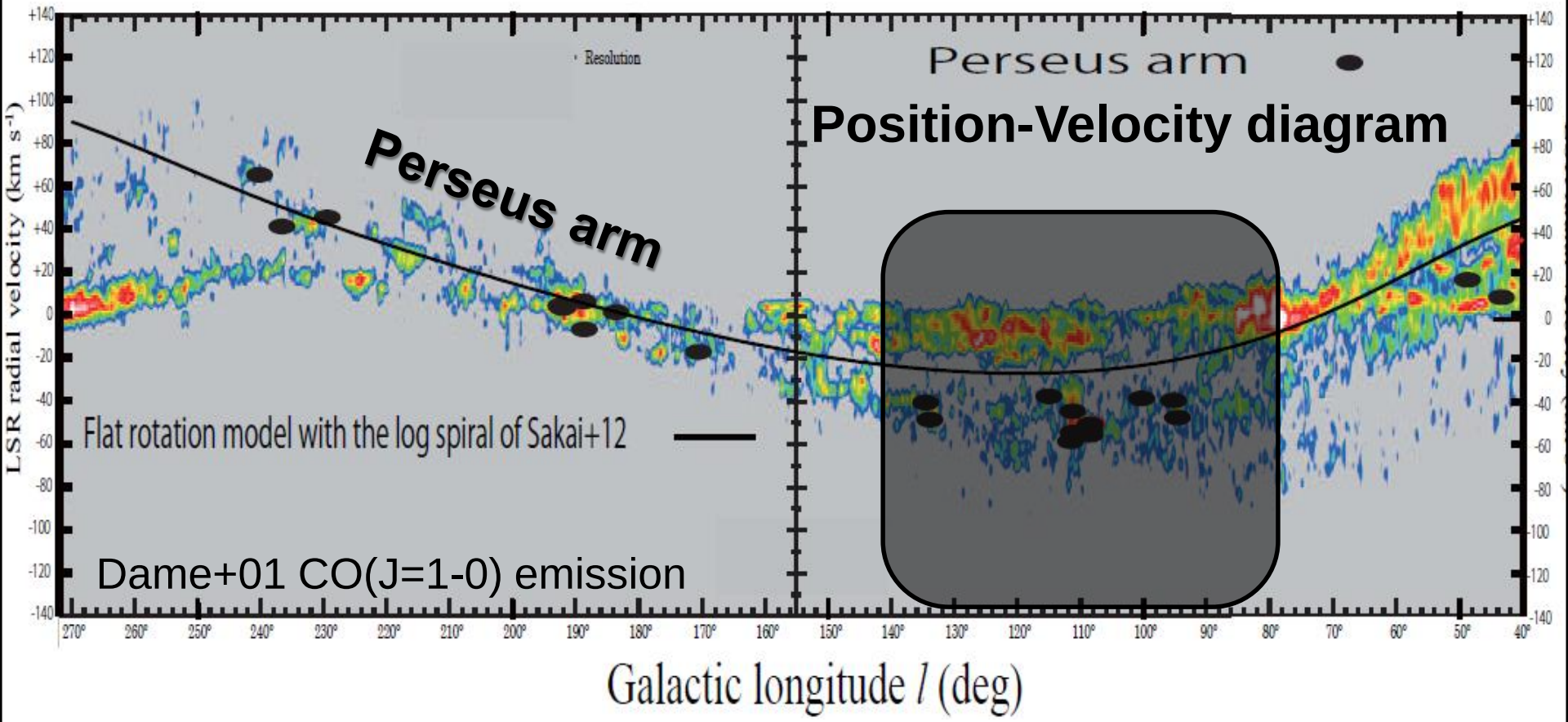
^{12}CO intensity map (Koda+09)

Massive clumps were traced by bright HII regions.

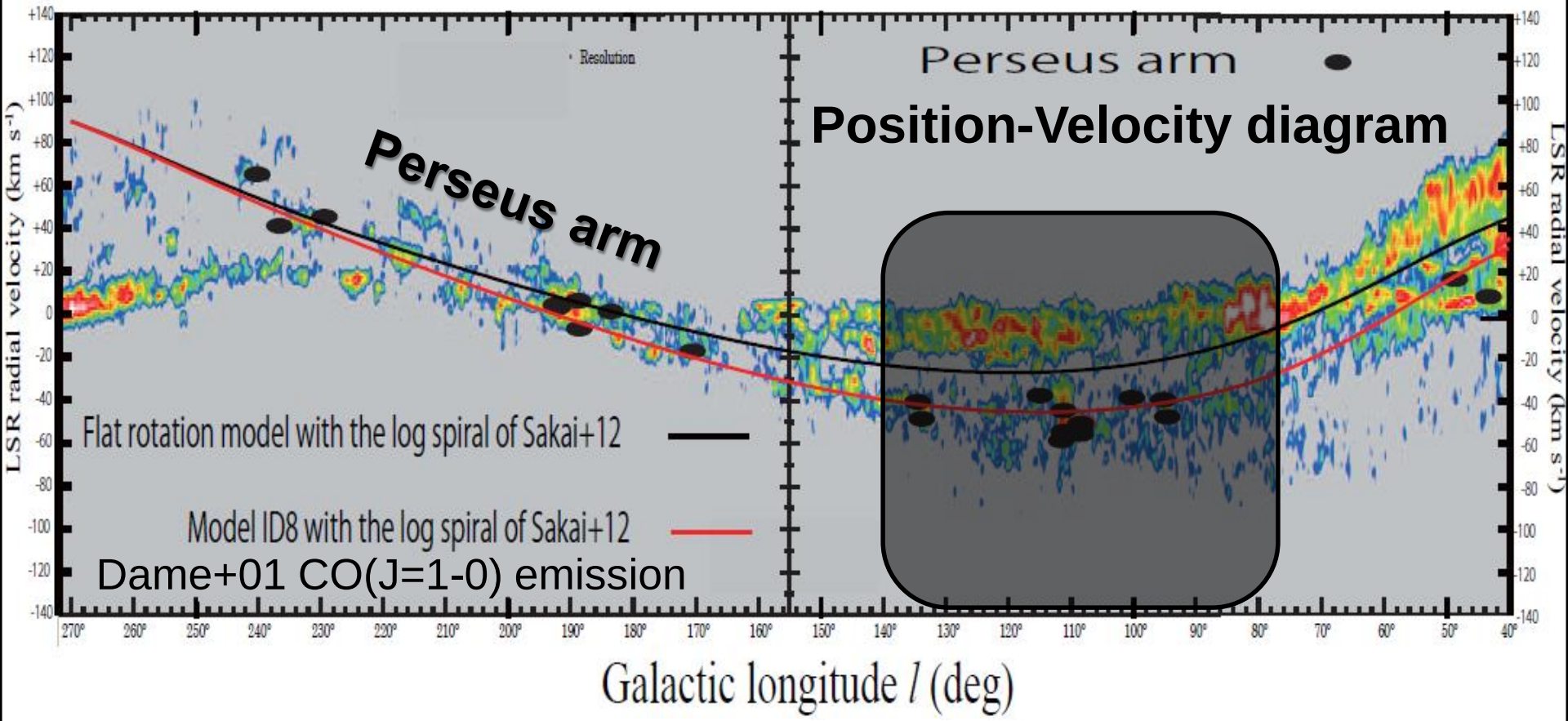
Revised kinematic distance



・Shadow region : **| D_kin / D_π | = 1.45 +/- 0.35**

-----> Impact on astrophysics, e.g., **Luminosity ∝ D^2**

Revised kinematic distance



・Shadow region : **| D_kin / D_π | = 1.45 +/- 0.35**

-----> Impact on astrophysics, e.g., **Luminosity ∝ D^2**

・Shadow region : **| D_revis-kin / D_π | = 1.03 +/- 0.20**

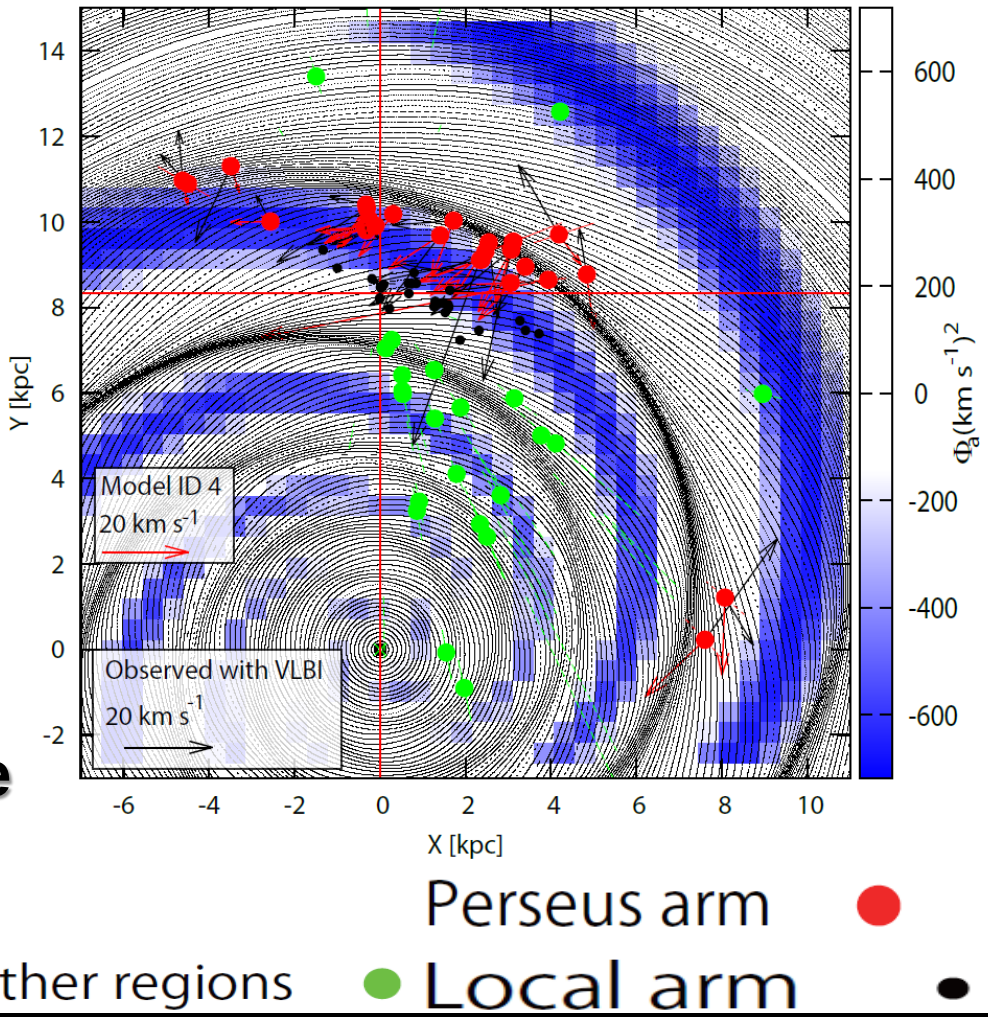
Conclusion

・We tested the density-wave theory using VLBI astrometry results. Then, we found

①A dense gas region at the downstream of the spiral potential (model)
------> Identical to M51 (Egusa+2011)

②Revised kinematic distance

③Gas (VLBI) + Stellar (Gaia) astrometry



VLBI astrometry vs. The model of the Milky Way