The effect of the MW bar and spiral arms in action-angle coordinates

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Dynamical models

Model of the Galaxy and of each of its components (stellar populations, gas, dark matter) through DF-potential pair
=> fundamental Galactic parameters enter the model (V_0,V_{sun},$R_{d,}$…)

Collsionless Boltzmann Equation for the DF:

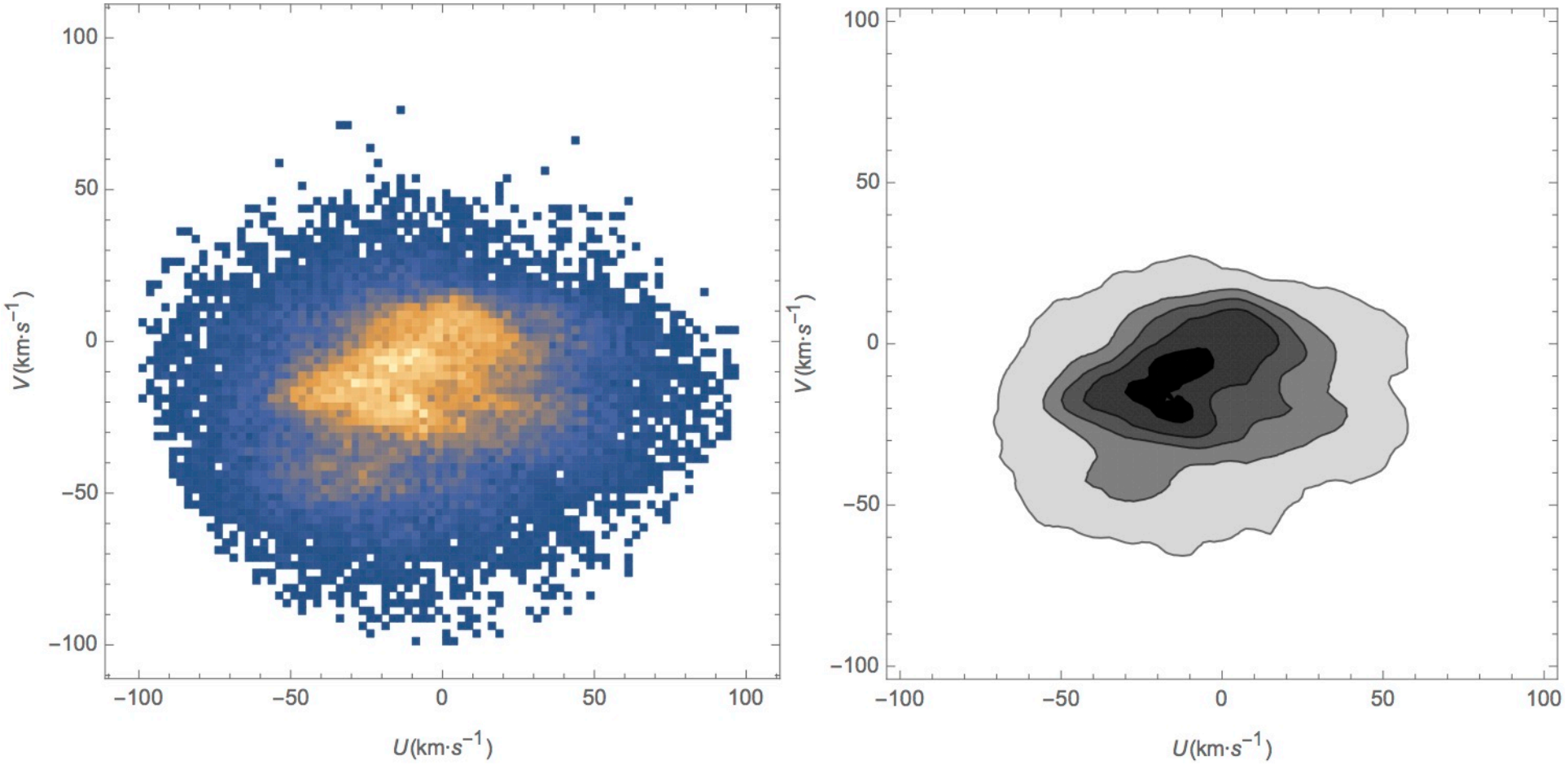
$df/dt = 0$

Moments of f (integrate over velocity space) give observables

If in axisymmetry and equilibrium :

$f = f(\mathbf{J})$ useful because **J** adiabatic invariants

The Galaxy is not axisymmetric



Gaia DR1 (σ_π/π <0.1) + RAVE DR5

Non-axisymmetric modelling

- For the thin disk, we use the epicyclic approximation:

$$J_R = E_R/\kappa,\ J_\Phi = L_z,\ J_z = E_z/\nu$$

- Start from a parametrized axisymmetric DF f_0 , for instance:

$$f_0(J_R, J_\phi, J_z) = \frac{\gamma\tilde{\Sigma}_0 \exp(-R_g/h_R)}{4\,(2\pi)^{3/2}\,\tilde{\sigma}_R^2\tilde{\sigma}_z z_0} \exp\left(-\frac{J_R\kappa}{\tilde{\sigma}_R^2} - \frac{J_z\nu}{\tilde{\sigma}_z^2}\right)$$

- Then fit also the non-axisymmetric potential parameters to get the best possible $f_0 + \varepsilon f_1$ fit :

$$\Phi_1(\boldsymbol{J}, \boldsymbol{\theta}, t) = \mathrm{Re}\left\{\mathcal{G}(t)\sum_{\boldsymbol{n}} c_{\boldsymbol{n}}(\boldsymbol{J})\mathrm{e}^{\mathrm{i}\boldsymbol{n}\cdot\boldsymbol{\theta}}\right\}$$

$$\mathcal{G}(t) = g(t)h(t)$$

Non-axisymmetric modelling

Linearized CBE: $\dfrac{\mathrm{d}f_1}{\mathrm{d}t} + [f_0, \Phi_1] = 0$

$$\frac{\mathrm{d}f_1}{\mathrm{d}t} = \frac{\partial f_0}{\partial \mathbf{J}} . \frac{\partial \Phi_1}{\partial \boldsymbol{\theta}}$$

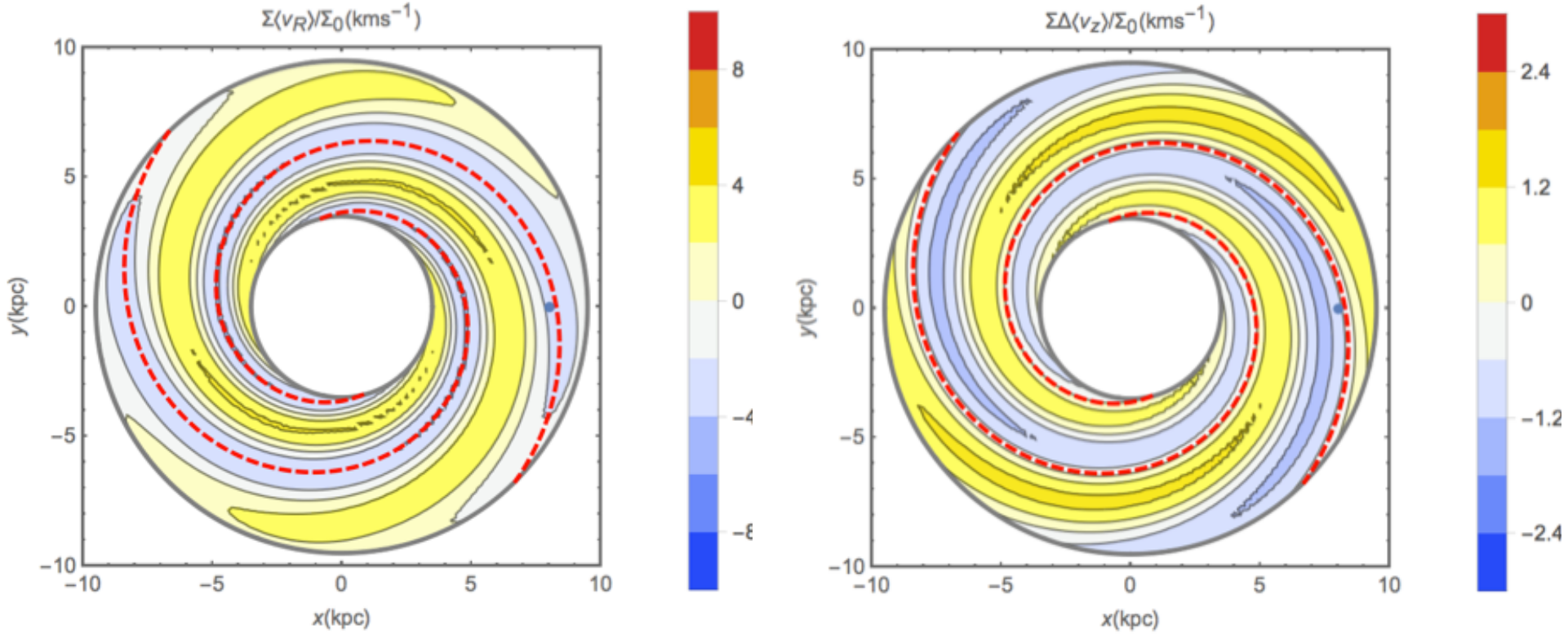
$$\Rightarrow \quad f_1(\boldsymbol{J}, \boldsymbol{\theta}, t) = \mathrm{Re}\left\{ \frac{\partial f_0}{\partial \boldsymbol{J}}(\boldsymbol{J}) \cdot \sum_{\boldsymbol{n}} \boldsymbol{n} c_{\boldsymbol{n}}(\boldsymbol{J}) \frac{h(t) \mathrm{e}^{i\boldsymbol{n}\cdot\boldsymbol{\theta}}}{\boldsymbol{n}\cdot\boldsymbol{\omega} + \omega_p} \right\}$$

Assumption: we are currently in plateau of max amplitude

Take BT08 MW potential for Φ_0, Schwarzschild DF for f_0, 3D log spiral with local amplitude of 60% of backgd for $\varepsilon\Phi 1$, compute DF moments

First order moments for log spirals

Monari, Famaey & Siebert (2016)



Breathing mode with $\Delta\langle v_z\rangle \sim 1$ km/s (up to 3 km/s when coupled w bar)

Could be larger for transient spirals? (work in progress)

Recover bar and spiral parameters

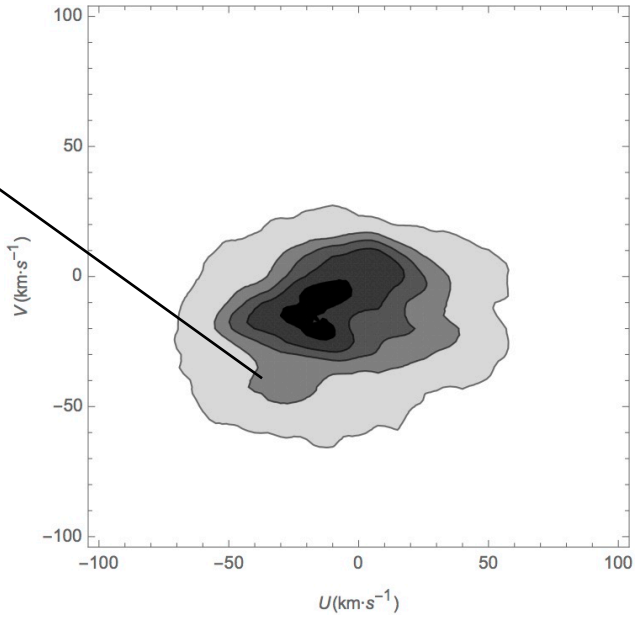
- Pattern speed of the bar?
- 3D density of RC stars + gas kinematics

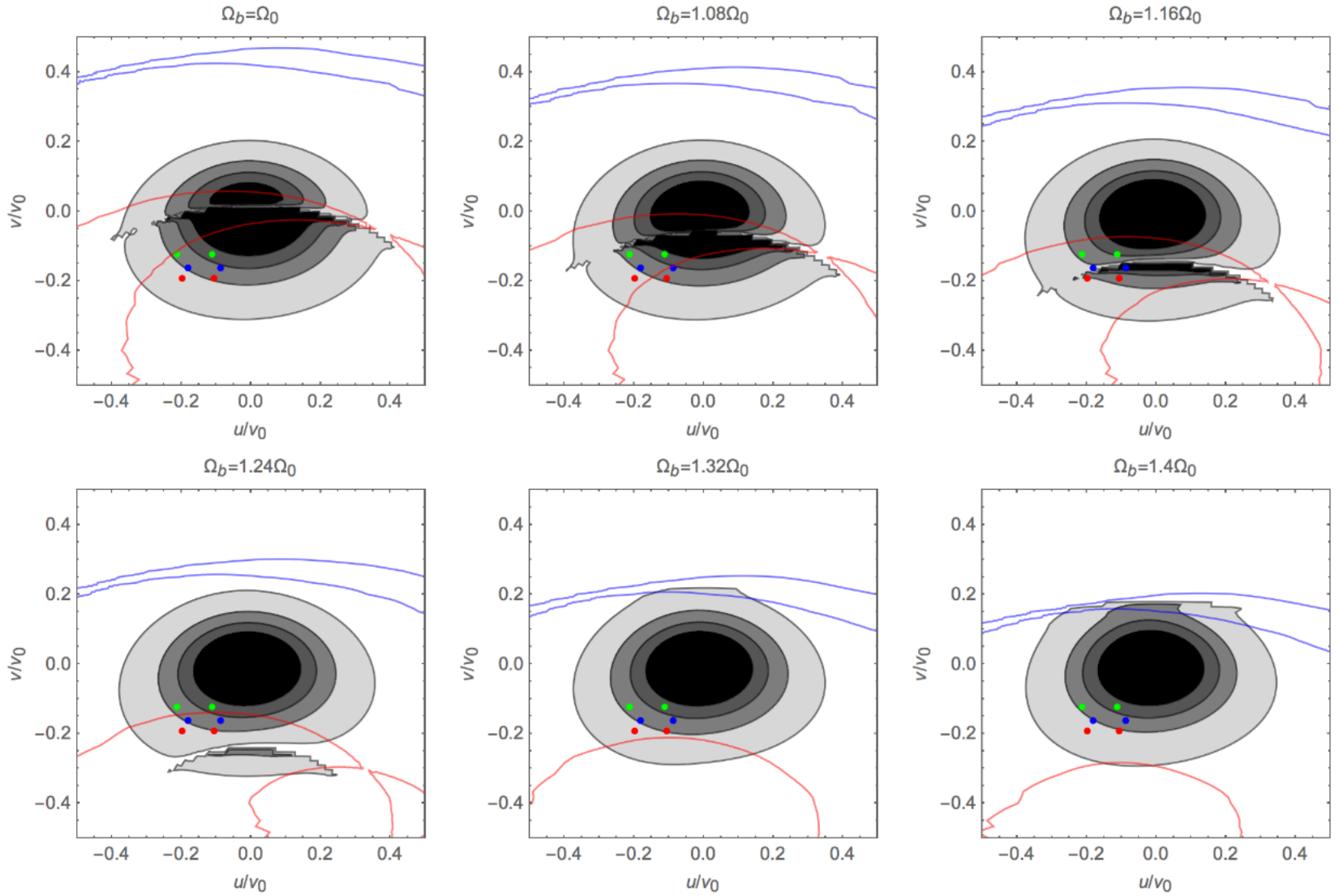
$\Rightarrow$ long extension of the bar reaching R~5 kpc

$\Rightarrow \Omega_0 < \Omega_b < 1.45\ \Omega_0$

(Portail, Wegg, Li, Gerhard et al.)

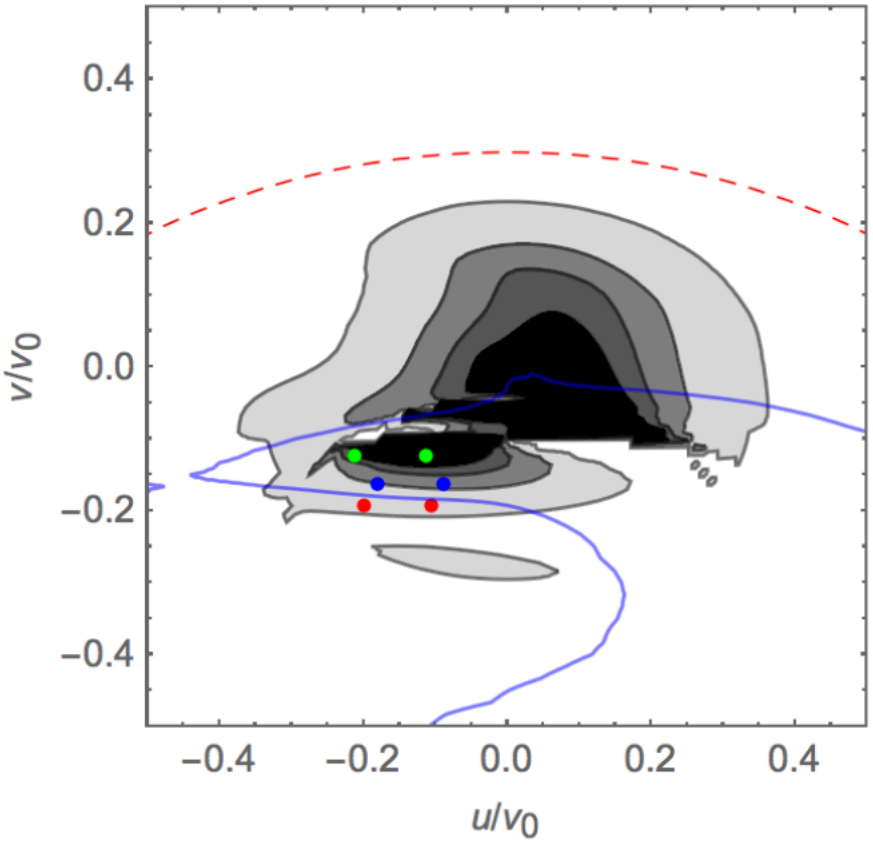
- Hercules stream?

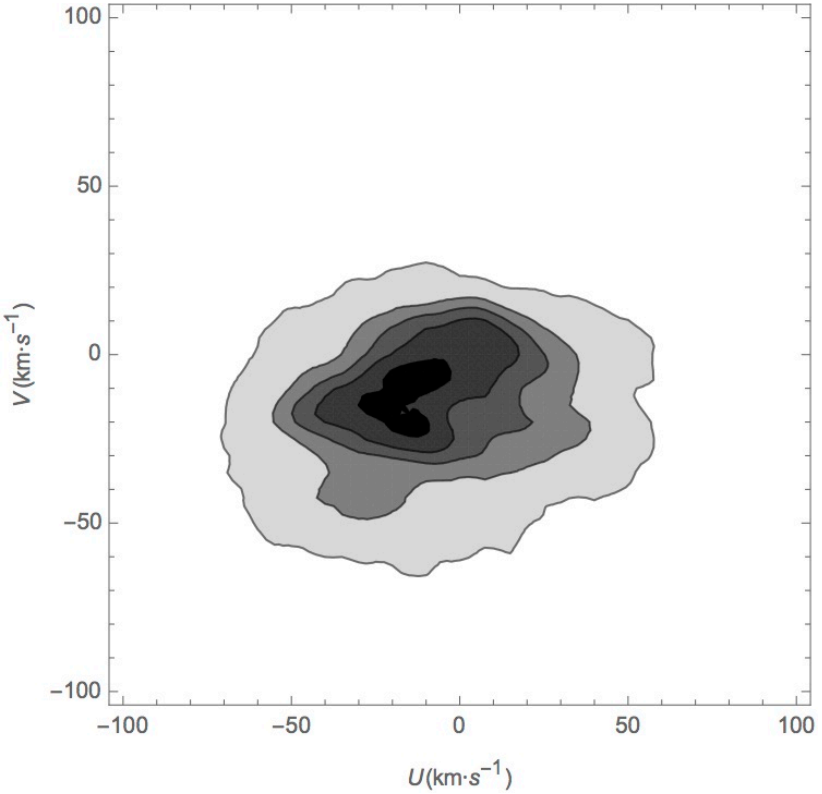




Quadrupole, ratio of bar/axisym radial force at the Sun = 1%, $\varphi_b = 25°$

Not a fit…





$\Omega_b = 1.9\ \Omega_0$
+ m=2 spiral with $\Omega_s = 0.7\ \Omega_0$

Monari et al. 2016
arXiv:1609.02557

Bar pattern speed in accordance with all the old results from Dehnen, Minchev, Bovy, etc. + N-body simulations of Quillen et al (2011)

Conclusions

- Include the effect of the bar and spirals in the DF in action-angle coordinates => will be able to directly fit the DF and pot. parameters to observations
- Spirals produce non-zero mean vertical motions (breathing modes), more important when coupled with bar or when spirals are strongly transient

- **No alternative to a fast bar ($\Omega_b > 1.8\ \Omega_0$) found to explain shape of local velocity space. Has to be $>1.3\ \Omega_0$ to avoid signature of bar corotation**
- Antoja et al. (2014) based on RAVE between ~0.9 and ~1.1 R0 => Hercules consistent with bar's OLR