Spiral structure in v space

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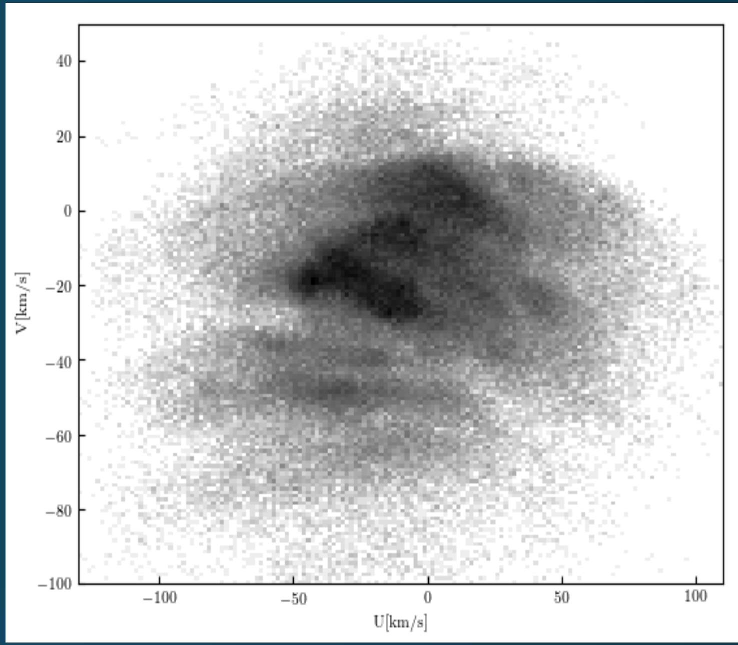
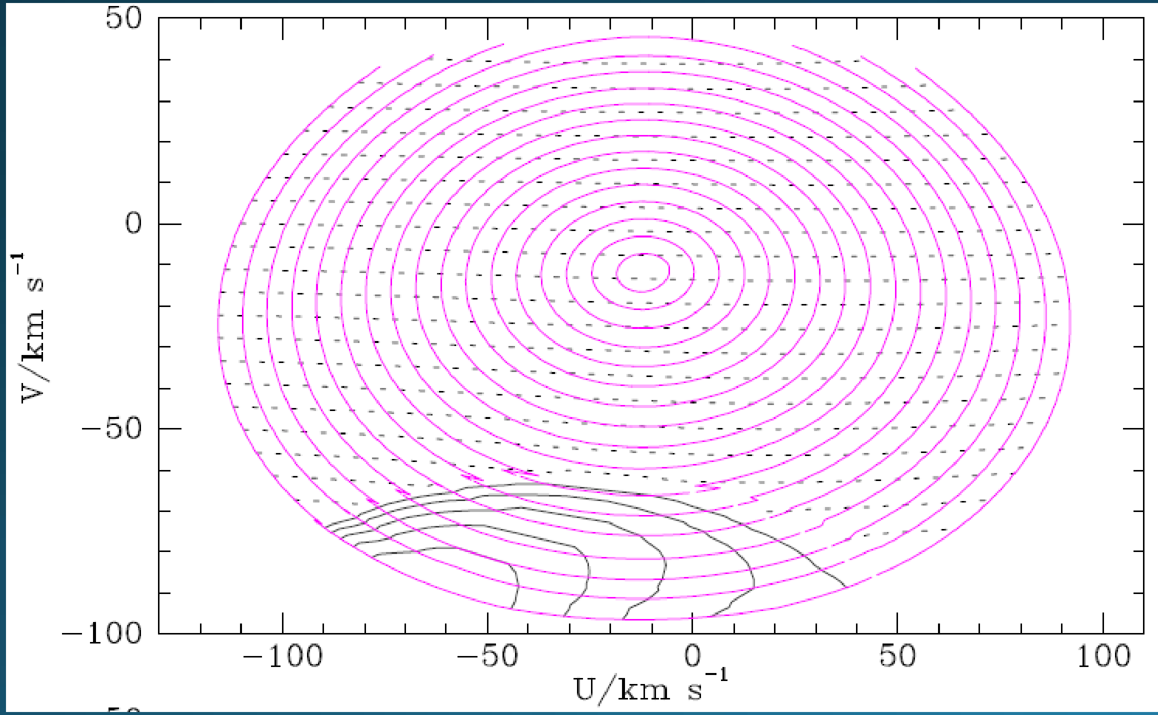
Outline

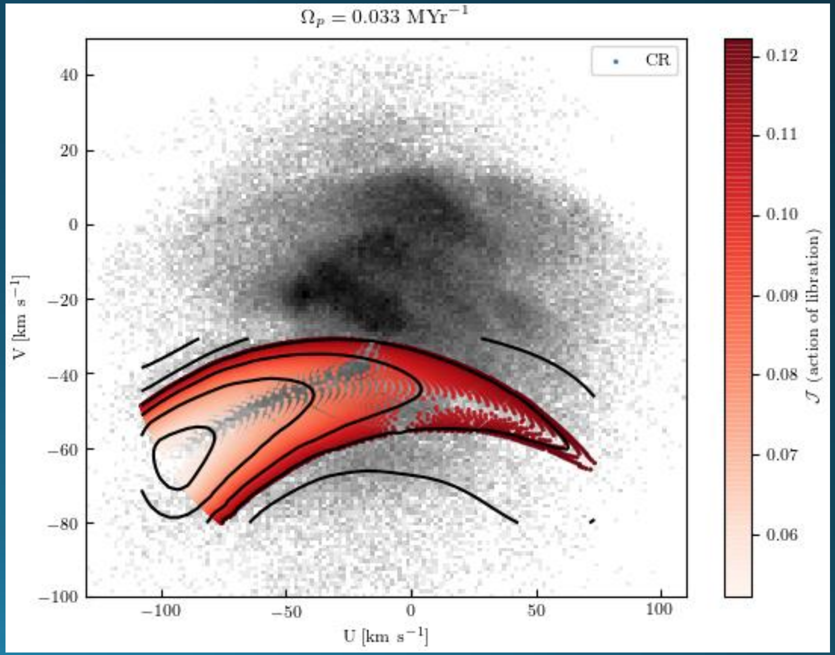
- Gaia phenomenology: bar & no-bar
- Impact of a steady spiral
- Dynamics of spirals
- Revisiting the shearing sheet

V space structure Gaia DR2

- RVS sample with s from Schoenrich + (2018)
- Non-axisymmetric tori by Tom Galligan

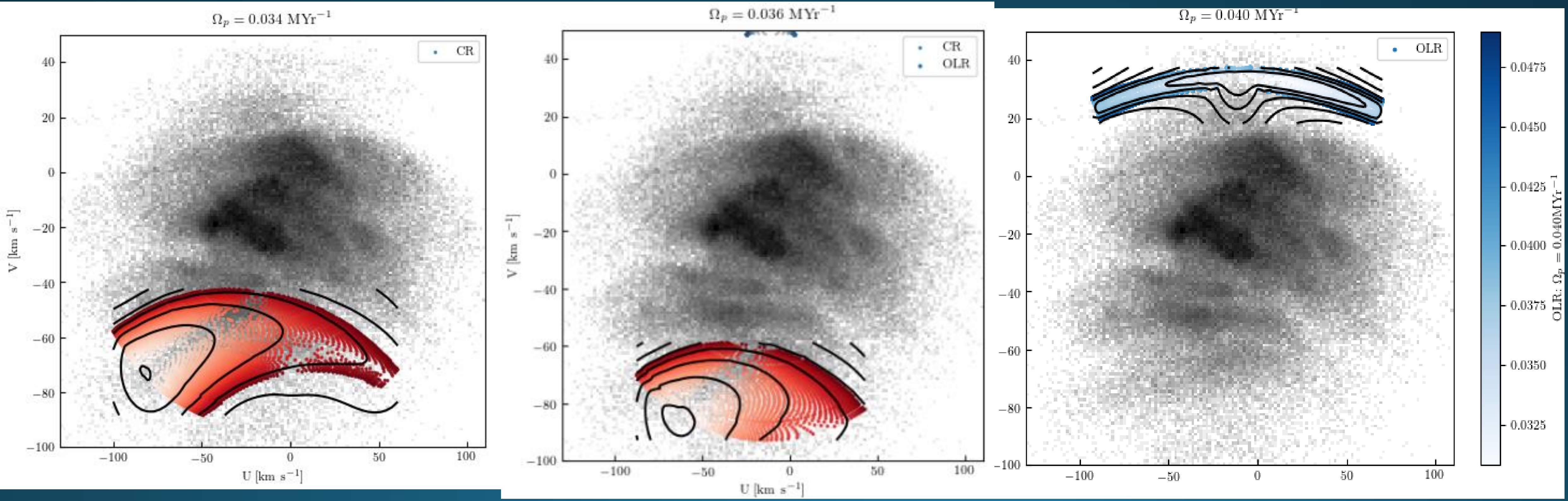




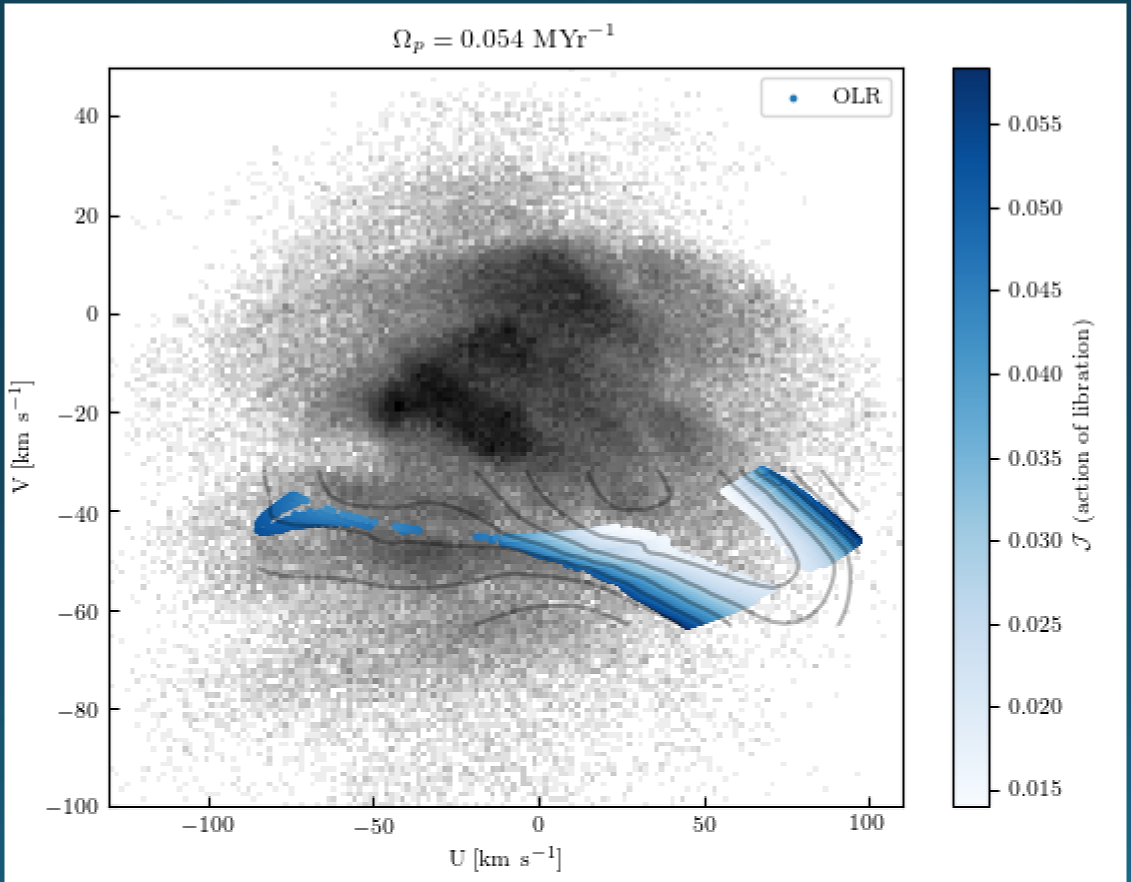


CR or OLR?

- Axisymm background McMillan (2017) Φ(R,z)
- Need to explore bar strength, etc

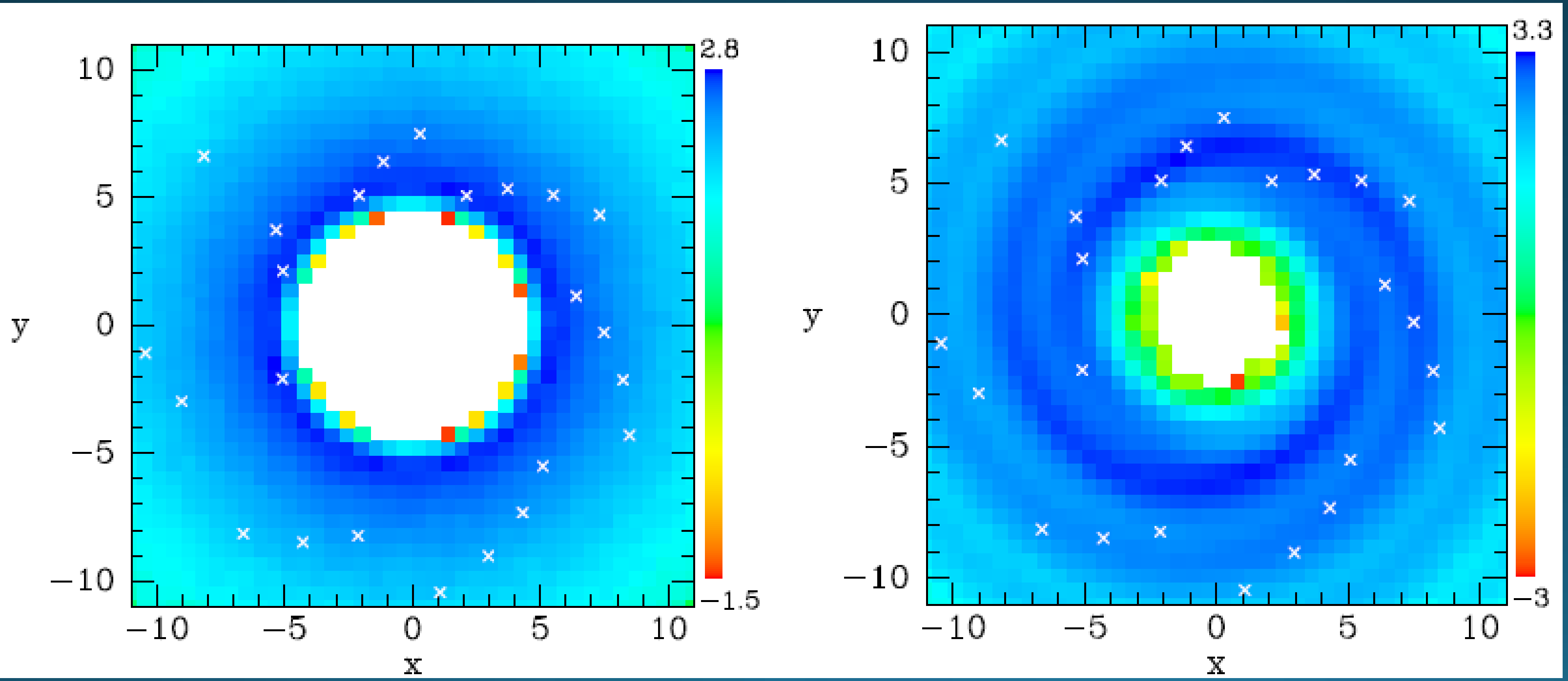


Dehnen (1999) value



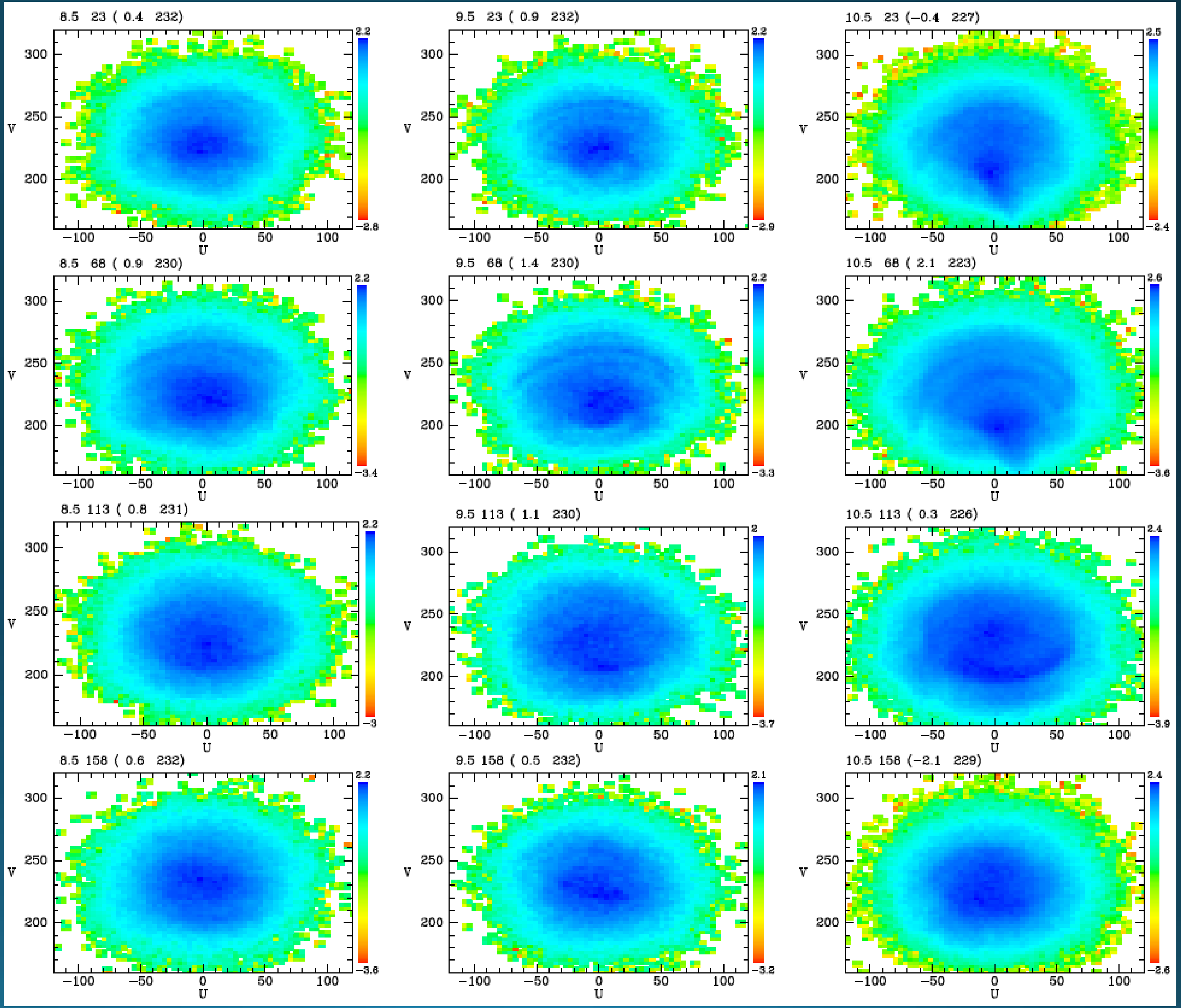
What would a spiral potential do?

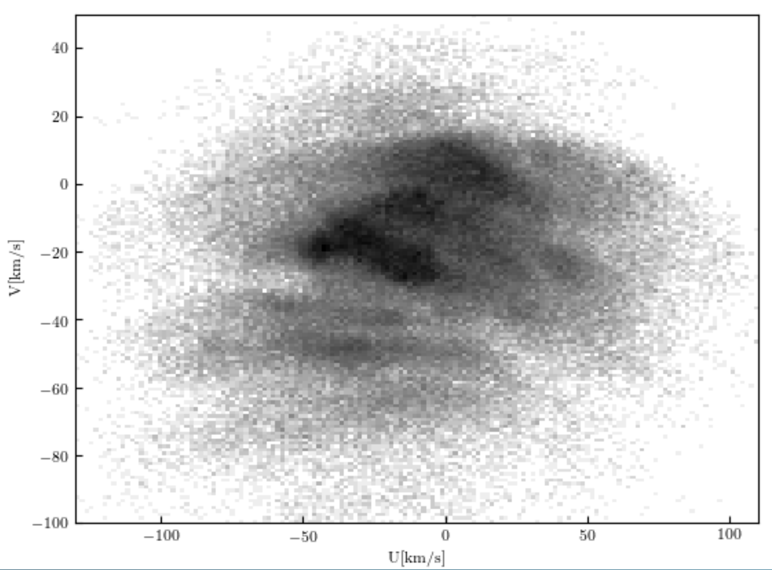
- A million particles in $\Phi(r,\phi) = v_c^2 \log(r + r_c)\left[1 + S\cos(k_r r + 2\phi)\right]$
- Pattern speed ~30 km/s/kpc



Model UV planes

- Each column fixed R = 8.5 9.5 & 10.5 kpc
- Each row fixed phase wrt spiral





- Promising...
- But is this really the way to go?
- Justified by existence of LSK dispersion reln?

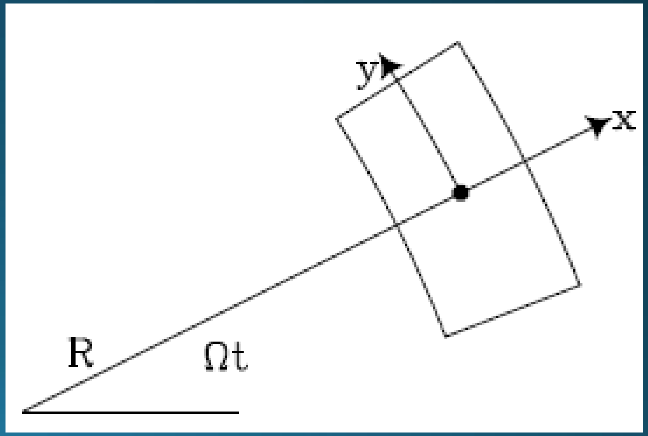
Our understanding of spiral structure assembled from

- Nbody simulations
- Matrix mechanics
- Interpreted in terms of waves
  - LSK dispersion reln (Lin & Shu 1964, Kalnajs 1963)
  - Shearing sheet (Goldreich & Lynden Bell 1965, Julian & Toomre 1966)

Julian & Toomre 1966

- Excluded from *Galactic Dynamics* on grounds of complexity
- Recently reworked with stuff from Toomre 1969 & 1981
- The setting
  - (x,y) plane with $v_y=-2Ax$ (closed orbits, $J_r=0$)
- Perturbed $\Sigma \sim \exp(ik.x)$ with $k_x=2Atk_y$
- General (epicyclic) orbits

$$x = \overline{x} + X \cos\theta_r$$
$$v_y + 2Ax = v_\phi = 2BX \cos\theta_r$$



Julian & Toomre

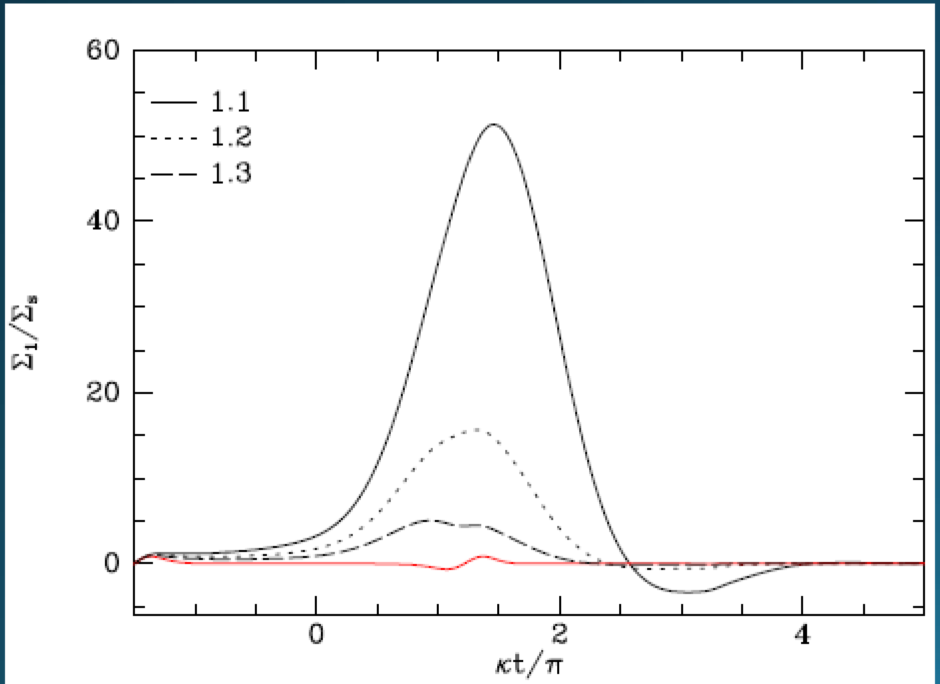
- CBE -> $$f_1(\mathbf{x},\mathbf{v},t) = \int_{t_i}^{t} \mathrm{d}t \, \frac{\partial \Phi_1}{\partial \mathbf{x}} \cdot \frac{\partial f_0}{\partial \mathbf{p}} \text{ along unperturbed orbit}$$
- Ansatz $$\Phi_1 = \Phi_{\rm ext} + \Phi_{\rm self} = \widetilde{\Phi}(t) \exp(i\mathbf{k}. \cdot \mathbf{x})$$ $$\Rightarrow \Sigma_1 = \widetilde{\Sigma}_1(t) \exp(i\mathbf{k} \cdot \mathbf{x})$$
- After integrating over v assuming bi-axial Maxwellian f_o

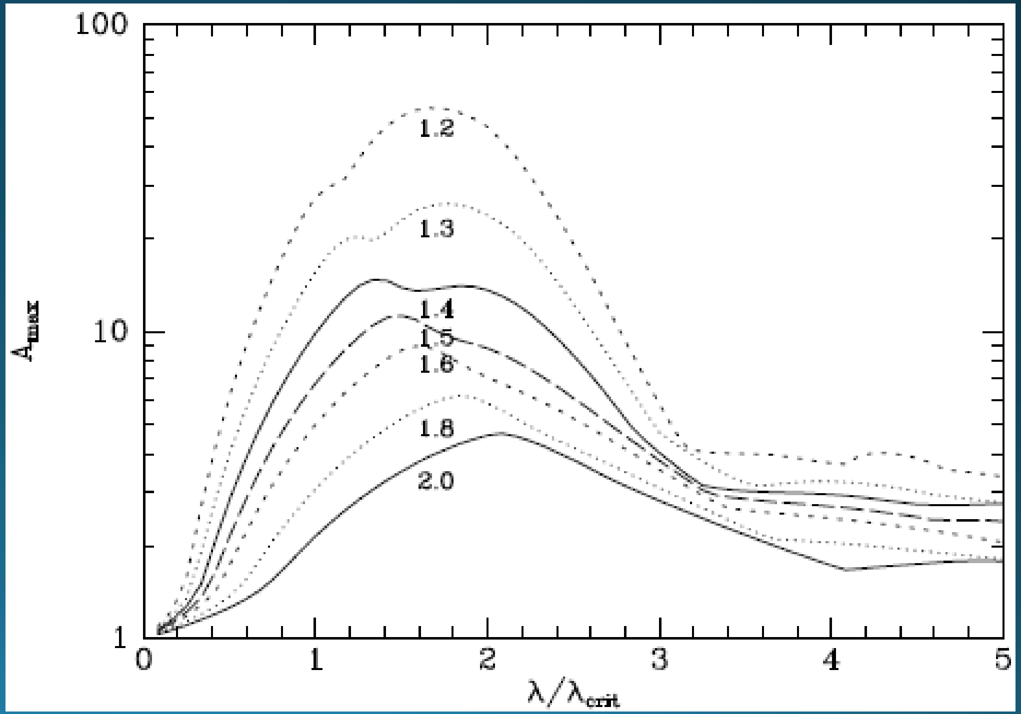
$$\widetilde{\Sigma}_1(t) = \int_0^t \kappa \mathrm{d}t' \, K(t,t') \left[\widetilde{\Sigma}_{\rm ext}(t') + \widetilde{\Sigma}_1(t') \right]$$

- $K(t,t';Q,k_y/k_{crit})$
- Easily solved numerically

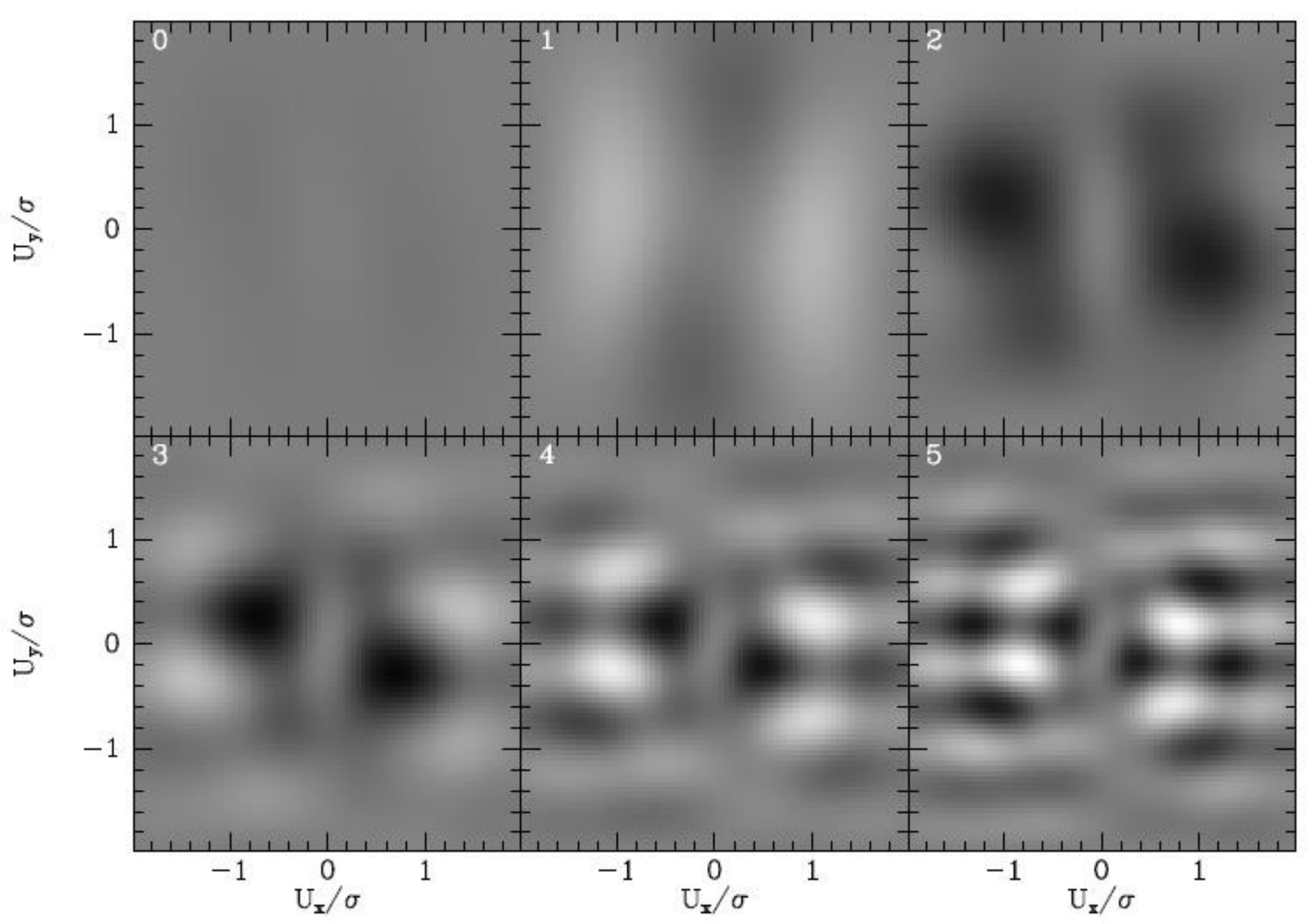
Basic application: impulse

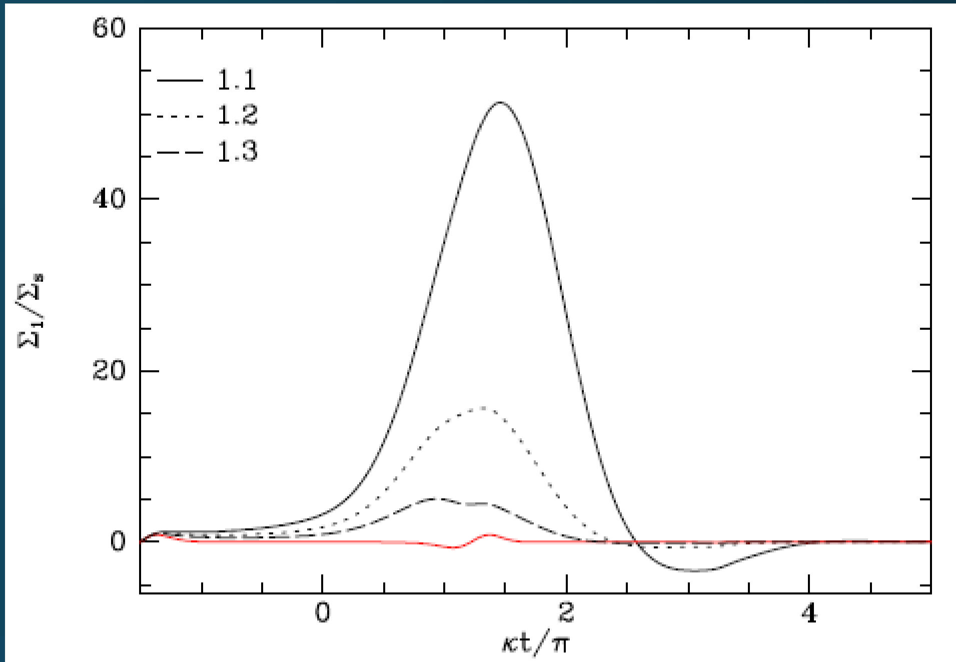
- Assume $\widetilde{\Sigma}_{\rm ext}(t) = \frac{\Sigma_{\rm s}}{\kappa}\delta(t - t_{\rm i})$
- Response is transient & Q sensitive
- Self-gravity v. important: Q=1.4 -> Amp ~ 14

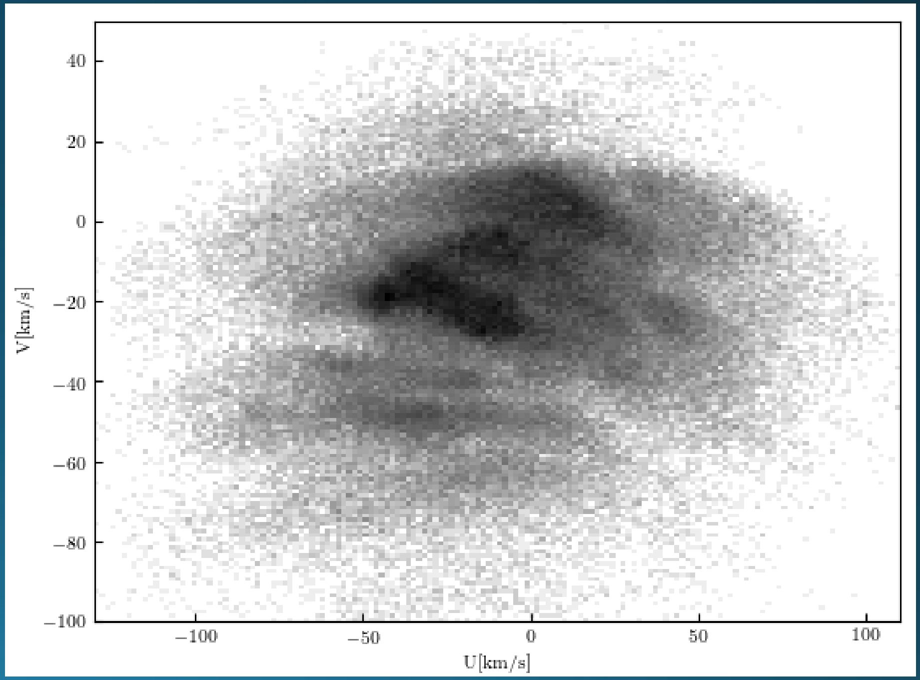




The afterlife





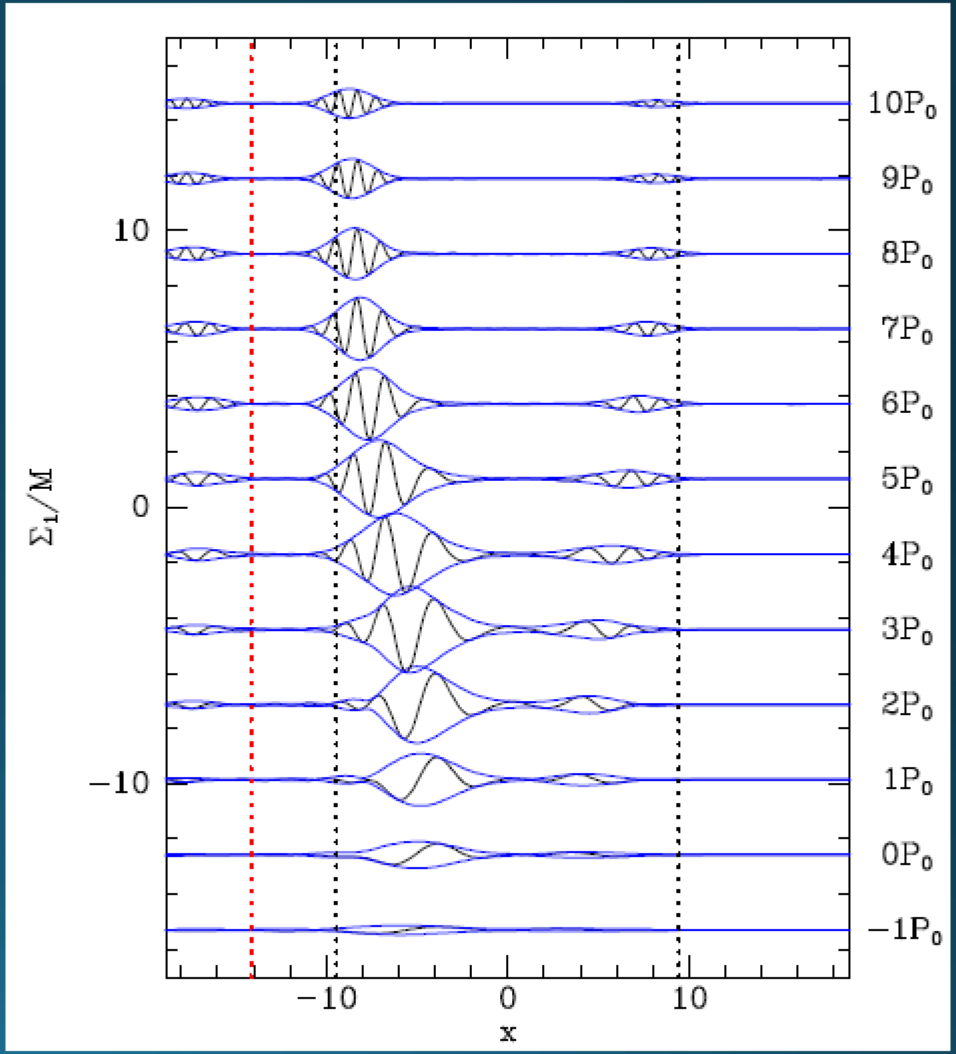


Wavepackets

- Stimulate with

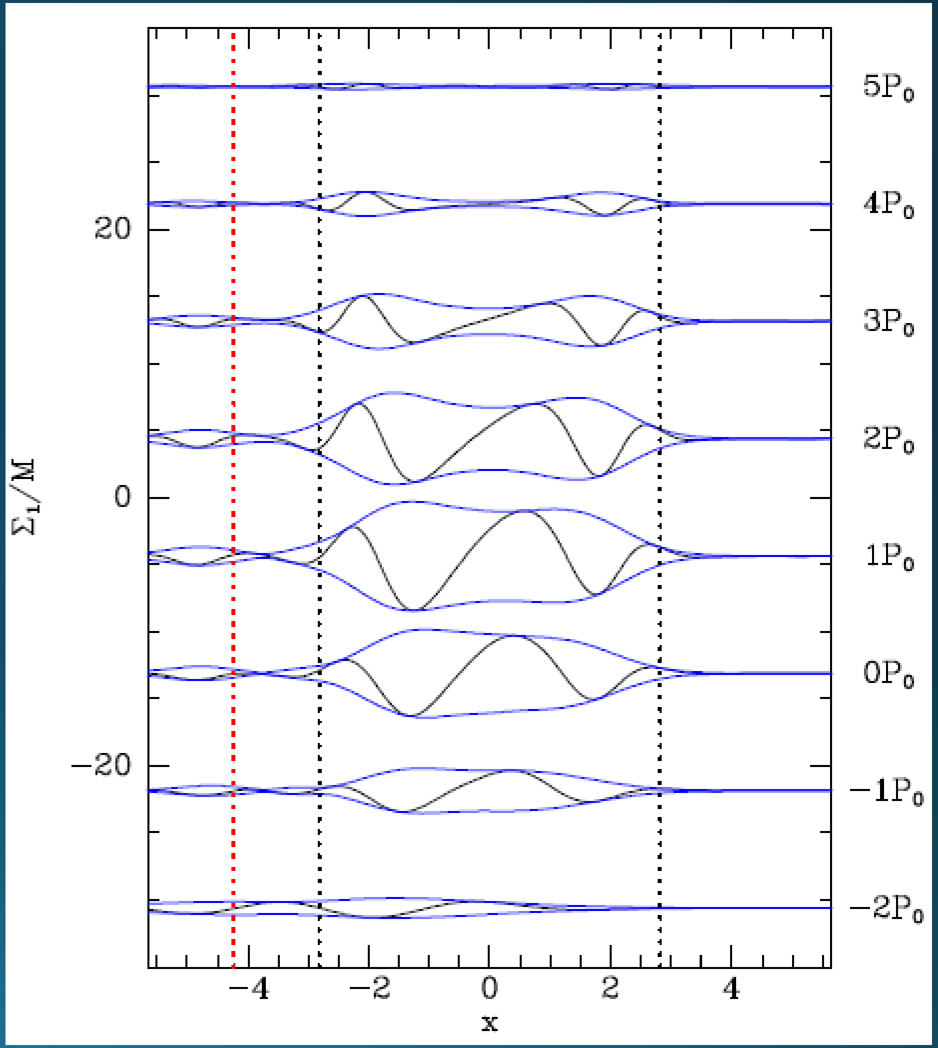
$$\Sigma_e(\mathrm{x}, t) = \frac{M}{\sqrt{2\pi}\Delta} \exp\left(\frac{(x - x_i)^2}{2\Delta^2}\right) \cos(k_i y) e^{-t^2/t_0^2}$$

- With k_y=0.15 k_{crit} packets appear & move to LRs and decay there



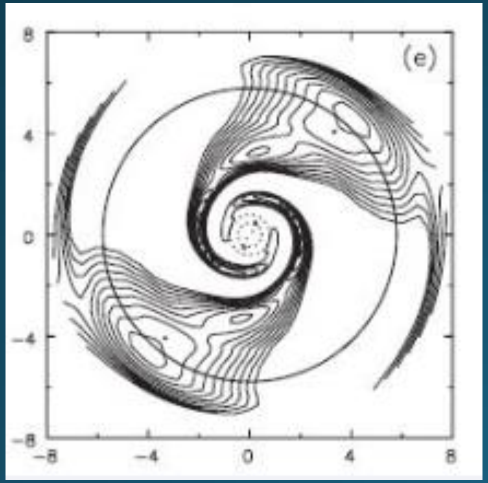
But for $k_y = k_{crit}/2$

- With shorter λ waves fill whole region between LRs
- Response larger
- Essentially decay in situ

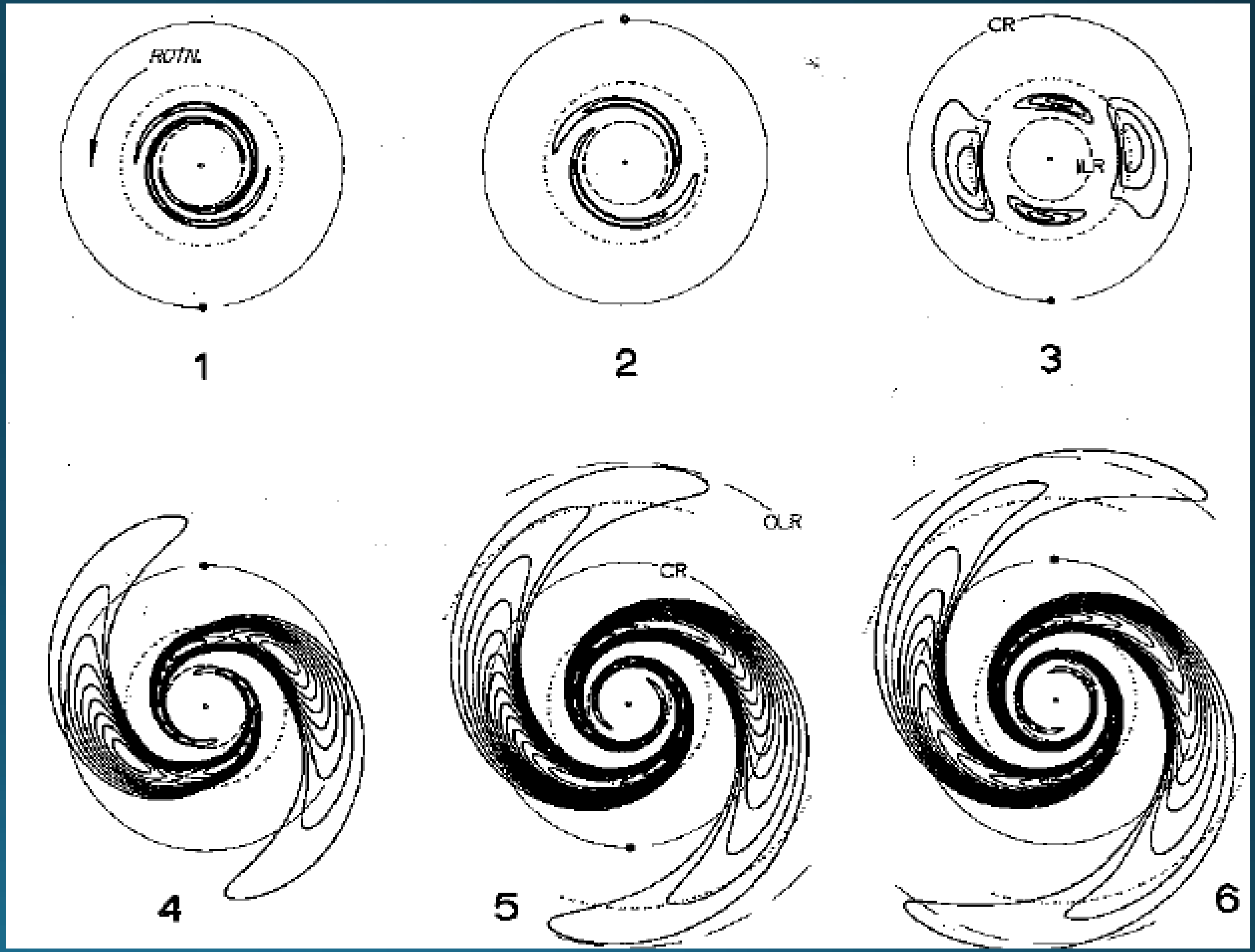


Comparison LSK theory

- LSK dispersion reln predicts exclusion zone around CR
- Zone widens with Q-1
- Clearly inconsistent with
  - Toomre wavepackets
  - Matrix mechanics
  - N-body simulations



Sellwood & Carlberg 2014



Toomre/Zang 1981

Resolution

- L&S start from assumption that $k(x,\omega)$
- But J&T show that k depends on t: spirals wind up
- Far from CR, L&S get by because packet moves away from CR so x dependence -> t dependence
- But near CR L&S can't hack it & declare waves impossible

Take home messages

- Spirals do wind up
- Perturbation lives in v space long after it's vanished from x space
- For realistic Q self gravity is v. important
- You can stimulate the disc how you want, but it will generate its own Φ_1 : a winding spiral
- The bang you get from your buck depends on how close your stimulus keeps to the disc's response
- J&T eqn allows modes only in axisymmetric limit
- It allows us to compute (U,V) plane