Dynamical modeling of the Galaxy and stellar migration in the disk

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The velocity ellipsoid in the Solar neighbourhood

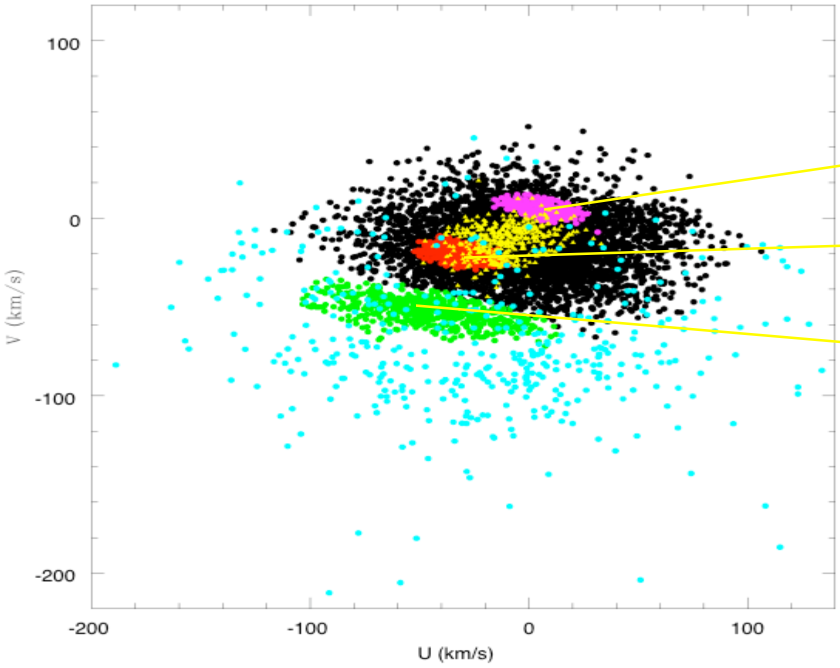
Collisionless Boltzmann Equation: $dF/dt=0$

$F(u,v,w) = (2\pi)^{-3/2} (\sigma_u \sigma_v \sigma_w)^{-1}$
$\exp[-1/2\,(u/\sigma_u)^2 - 1/2\,(v/\sigma_v)^2 - 1/2\,(w/\sigma_w)^2]$

$= F(E_R, E_z)$

Solution of collisionless Boltzmann equation for an axisymmetric potential

Moving Groups



Hipparcos+CORAVEL

- Sirius
- Hyades-Pleiades
- Hercules

Evaporated clusters?

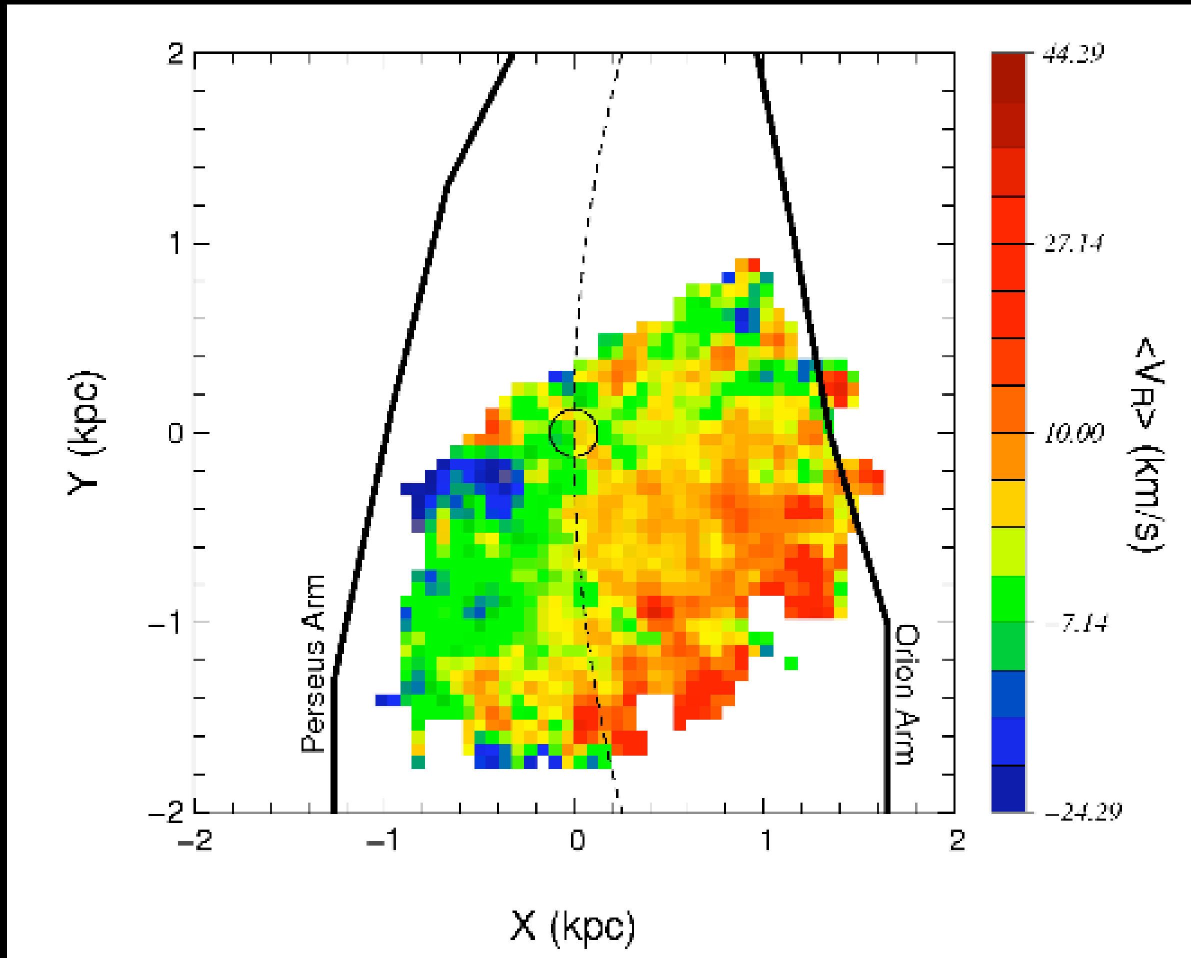
Wide spread of ages, and mass distribution closer to the PDMF than to the IMF (even when taking into account selective evaporation of low-mass stars)

see e.g. Famaey et al. 2005, 2007, 2008

=> Non-axisymmetry of the potential !

Also, if axisymmetric potential, no net radial motion at any radius…

Net outwards motion

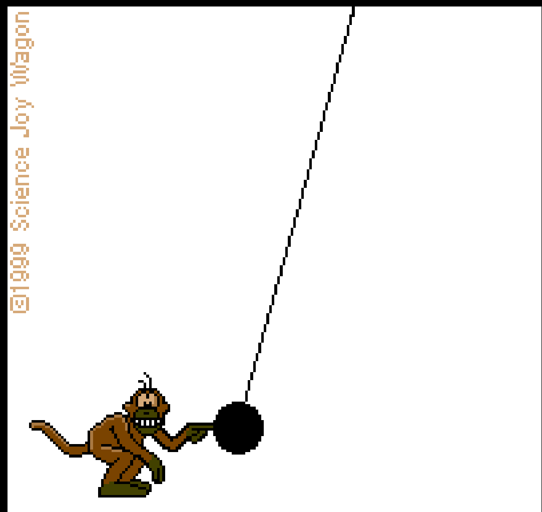


RAVE l.o.s. velocities and UCAC3 proper motions for 213 713 stars

(Siebert et al. 2010 in prep)

Moving groups? Resonances!

- Obvious non-axisymmetric components of the Galactic potential: the bar and the spiral arms
- For each perturber, resonances occur between the rotation frequency $\Omega - \Omega_p$ in the frame of the perturber and the epicyclic frequency κ, meaning that stars are « hit » regularly with the same position w.r.t. the perturber



Lindblad resonances

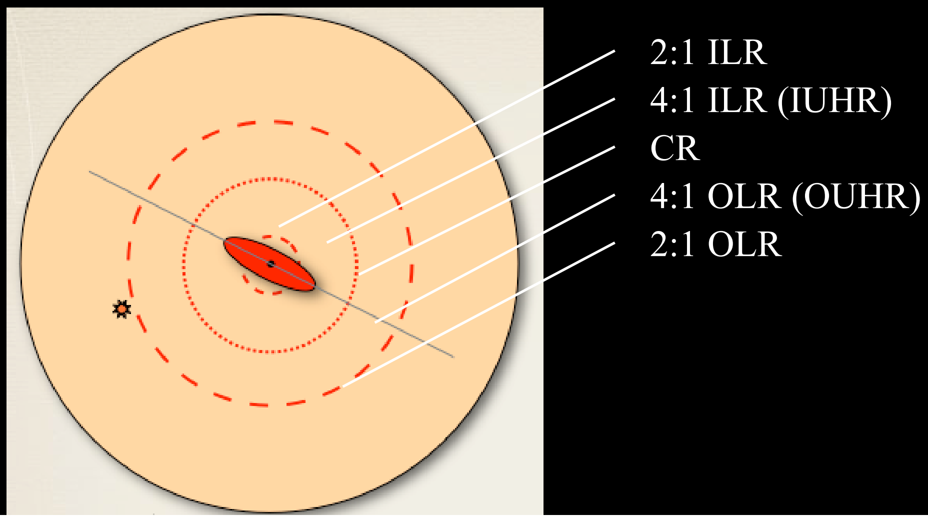
$\Omega(R) - \Omega_p = +- \kappa(R)/m$ <=> m:1 resonance

The m:1 resonances in the case of m-fold symmetry are first order Lindblad resonances

If stars overtake the perturber (+ sign): ILR

If perturber overtakes stars (- sign): OLR

When m=∞ : corotation



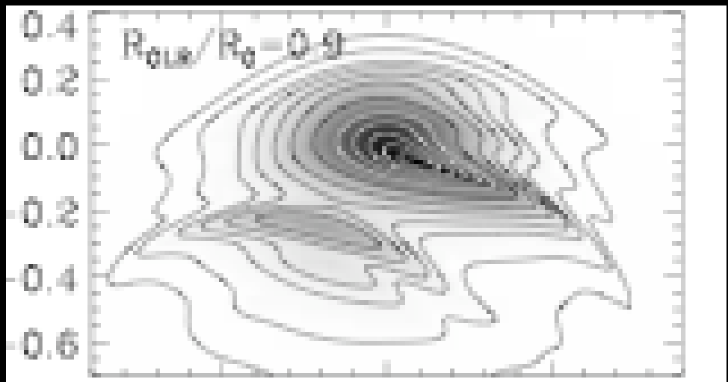
The bar

Radial excursion due to the bar changes sign when crossing the OLR

-> orbits elongated along and perp. to the bar coexist at OLR

-> Hercules stream (along the bar)

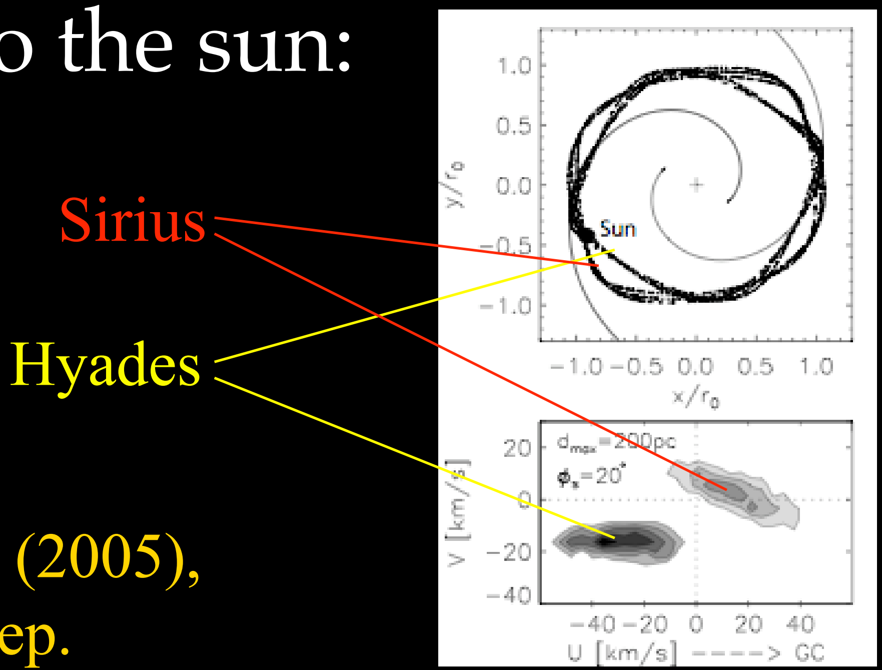
Vauterin & Dejonghe (1997)
Dehnen (2000)



Spiral arms

2 main arms (Centaurus and Perseus) and 2 weaker (Norma and Sagittarius)?

Put the 4:1 ILR (or IUHR) of a 2-armed pattern close to the sun:



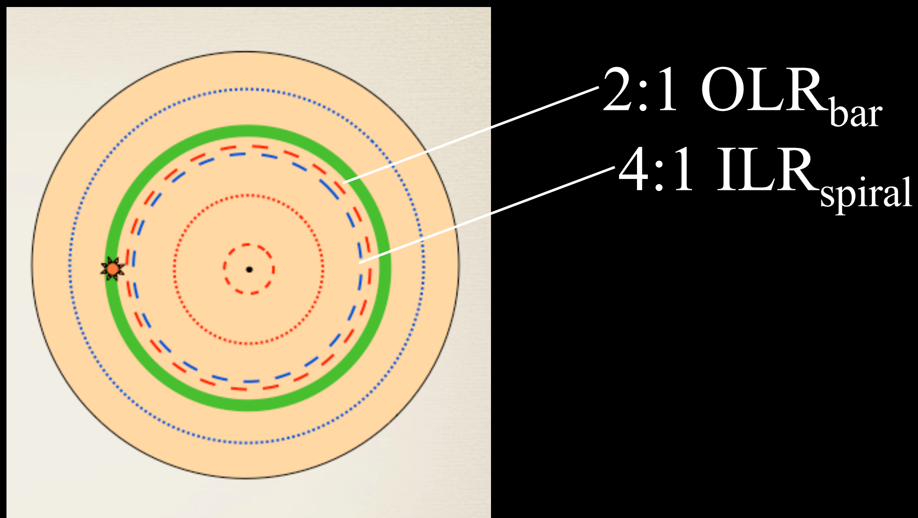
Quillen & Minchev (2005), Pompeia et al. in prep.

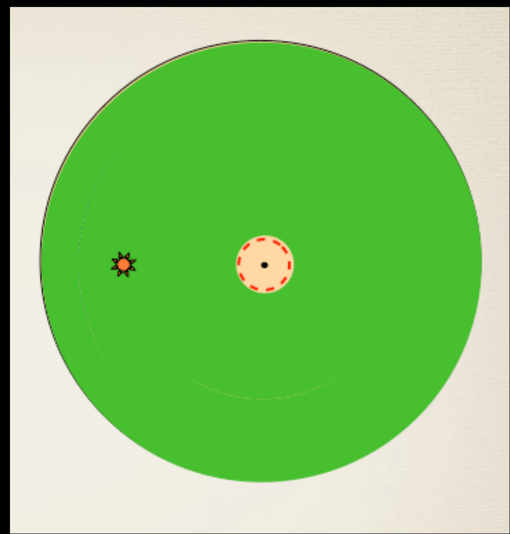
In reality, spiral arms+bar: resonance overlap

Resonance overlap => chaos

(e.g. Chirikov 1960; Walker & Ford 1969; Quillen 2003)

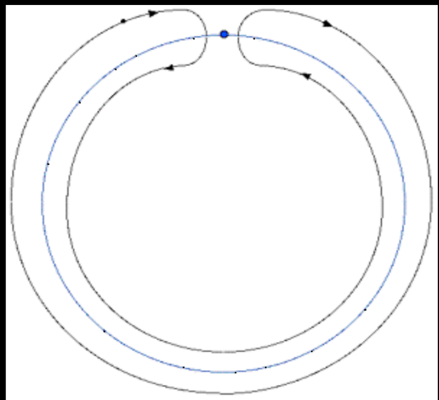
Chaos => migration





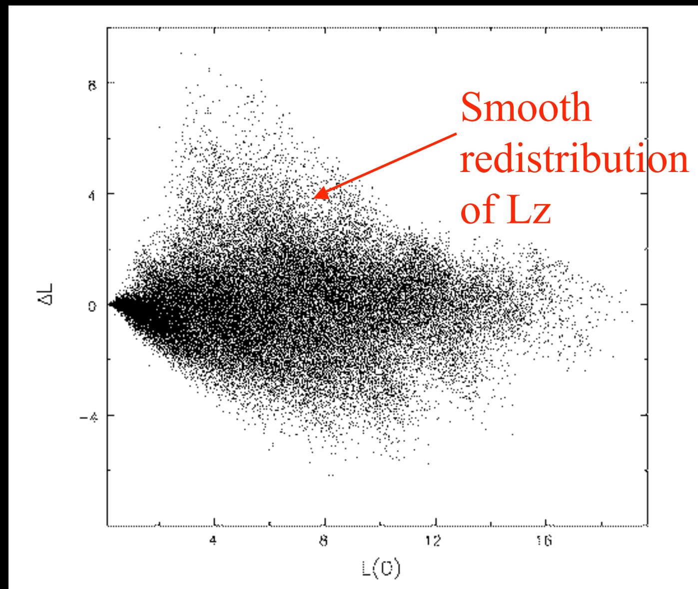
Already known: migration from transient spirals

- Horseshoe orbit:



Stars close to CR overtake the wave, gain Lz, then are being overtaken by the wave, loose Lz

- For transients, the spiral amplitude is large for less than half the period of a complete horseshoe orbit => stars do not return to their original value of Lz=>**migration**
(Sellwood & Binney 2002)



Test-particle simulations

- Exponential disk + halo + bar + quasistatic spiral
- Bar:

$$\Phi_b = A_b(\epsilon_b)\cos[2(\phi - \Omega_b t)] \times \begin{cases} \left(\frac{r_b}{r}\right)^3 & , \; r \geq r_b \\ 2 - \left(\frac{r}{r_b}\right)^3 & , \; r \leq r_b \end{cases}$$

~10^4 km²/s² ~55km/s/kpc ~3.5 kpc

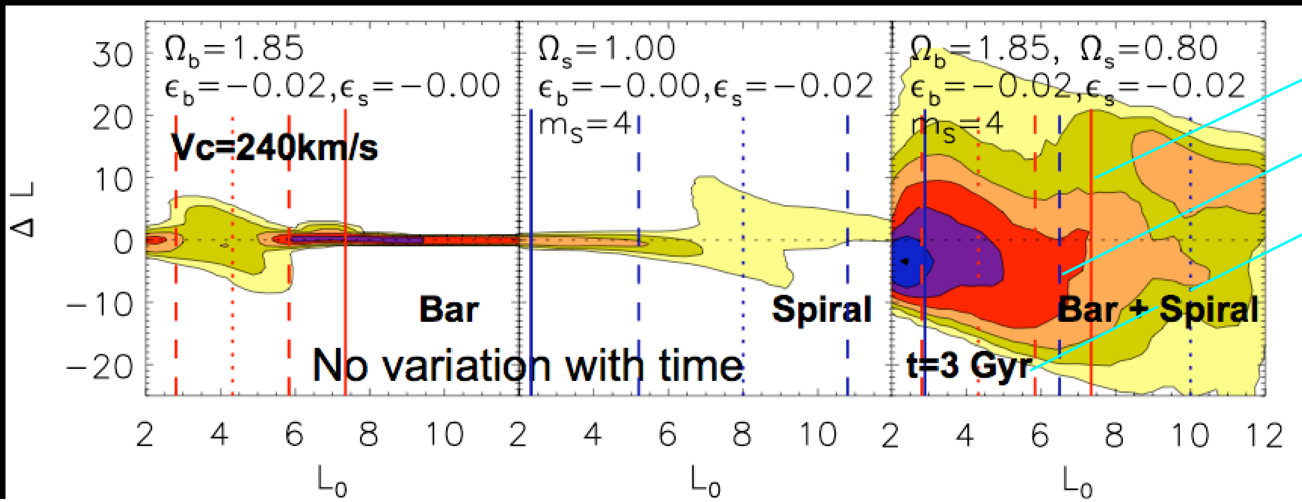
- Spiral:

$$\Phi_s(r, \phi, t) = \epsilon_s \cos[\alpha \ln \frac{r}{r_0} - m(\phi - \Omega_s t)],$$

~5*10^2 km²/s² -8 4 ~20km/s/kpc

Grown in 400 Myrs

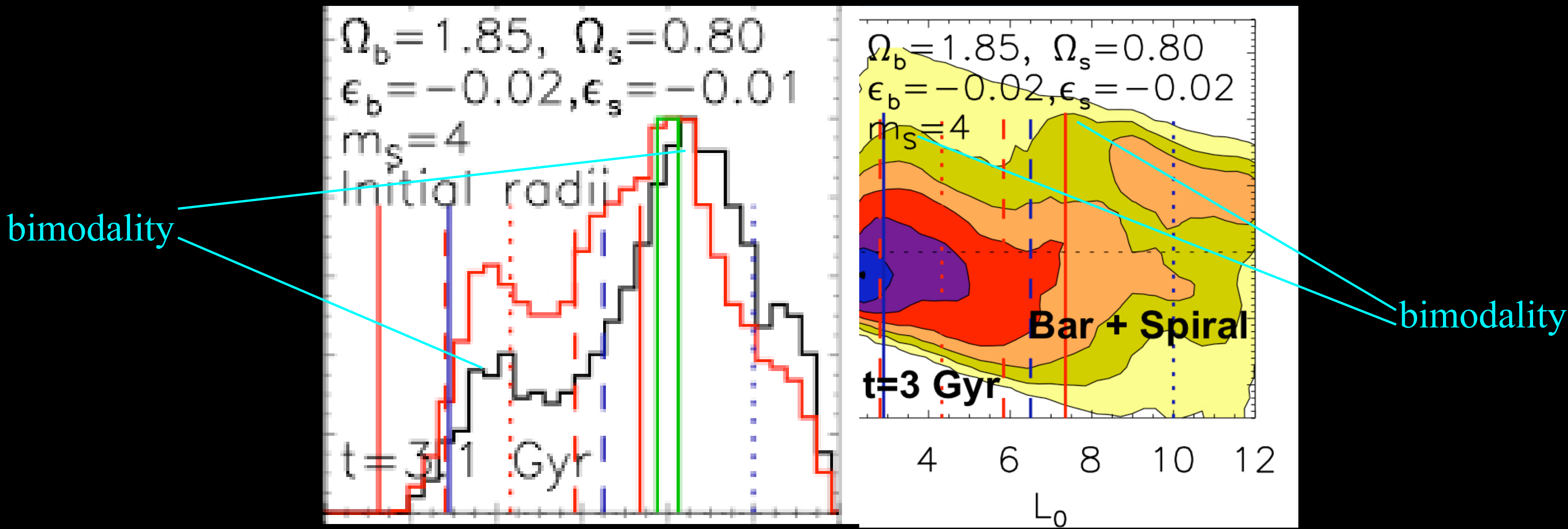
Minchev & Famaey (2010)



2:1 OLR_{bar}
4:1 ILR_{spiral}
4:1 OLR_{bar}

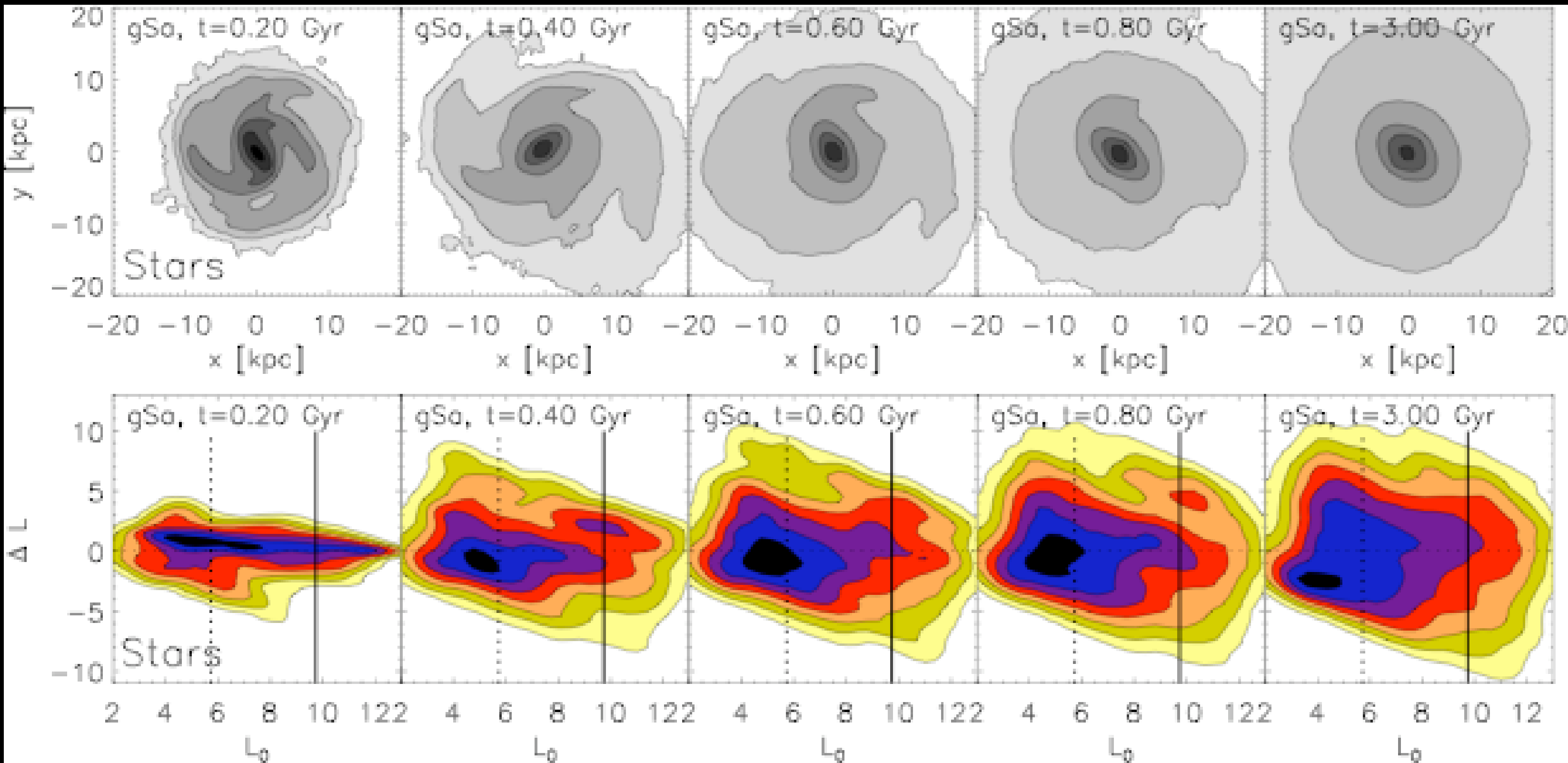
Differences with transient spirals

1/ rapidity of the mechanism (1 to 3 Gyrs)
2/ bimodality in the ΔL vs. L diagram



Self-consistent simulations

Minchev et al. (2010): BOTH mechanisms at work; bimodality found

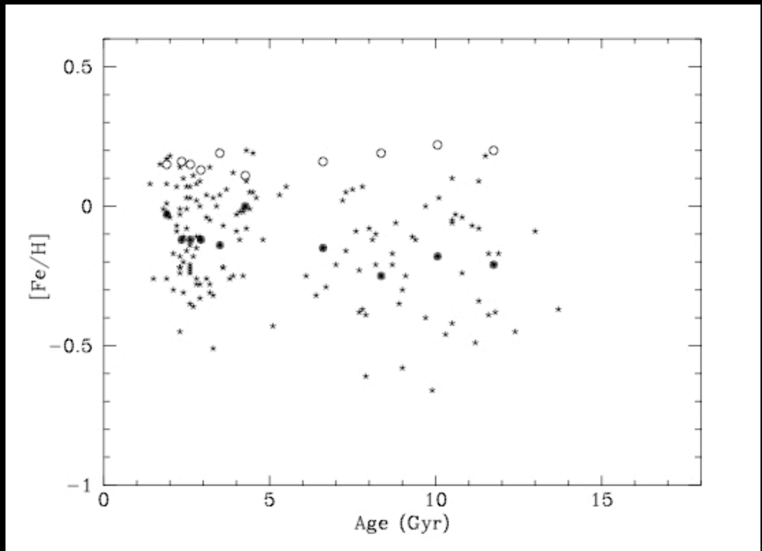


Confirmed by high-resolution (10^7 particles in the disk) N-body simulations

Observational signatures

Known signatures of migration:

- (Non-) Age-metallicity relation in SN



Holmberg et al. (2009):
stars within 40 pc

- Relatively weak metallicity gradients

Observational signatures

Signatures of the resonance overlap mechanism:

- Weaker metallicity gradients in barred galaxies (Zaritsky et al. 1994)
- Extended stellar disks (up to 10 scale-lengths)
- Future signatures with GAIA+ chemical tagging with ground-based spectro

  (HERMES, GYES):

  Measure up to 35 elements, a dissolved cluster will be a point in chemical space. Finding relatively young stars (<2-3 Gyrs) originating in the same open cluster and spread throughout the Galaxy (see e.g. Bland-Hawthorn et al. 2010)