Rotational evolution of young stars through Monte Carlo simulations

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Introduction

- Rotational properties of a set of young stars (from 1 Myr to 12 Myr)
  - how do they depend on **co-existence** of **disk** and **diskless** stars?
  - how the **disk lifetime** influences them?
  - how do we explain some observational properties like the **bimodal period distribution**, the **period – mass relation** or the **evolution of specific angular momentum**?

- We investigated these questions in a "controlled environment" ➔Monte Carlo simulations

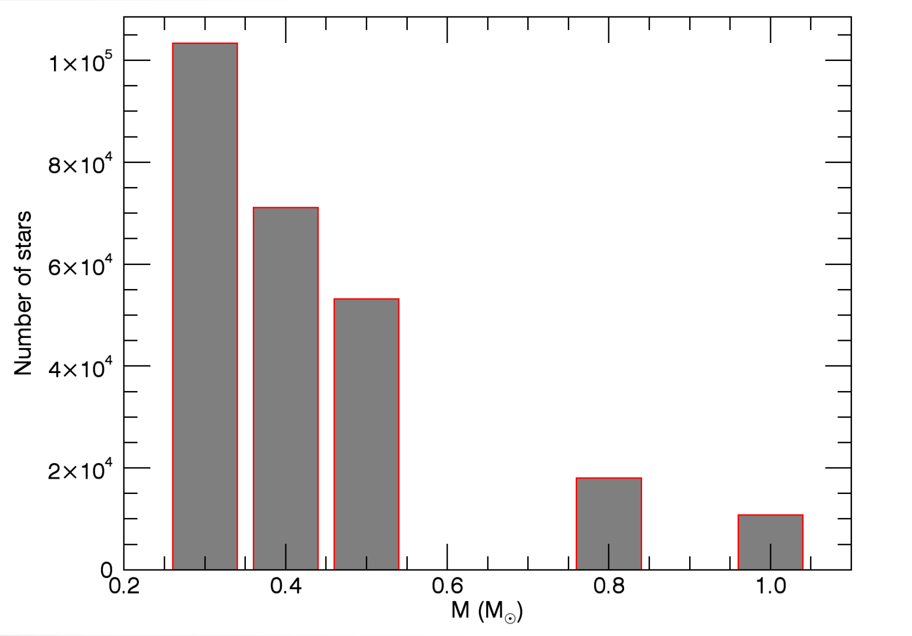
- We considered two models:

    - **M1**: the **same initial setup** for both **disk** and **diskless** stars

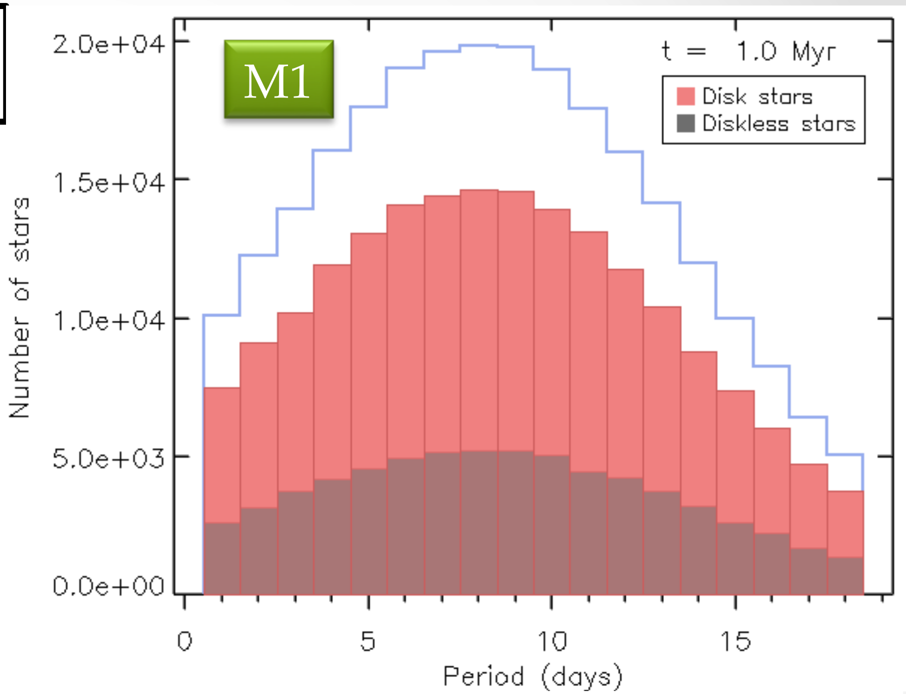
    - **M2**: **different initial period distributions** for **disk** and **diskless** stars

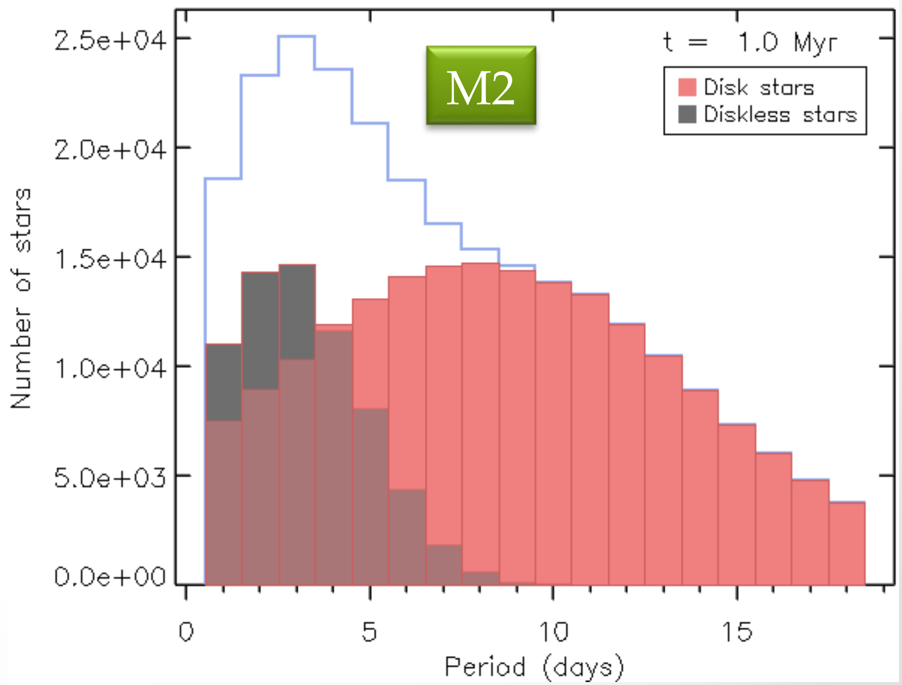
Numerical setup

- 280,000 stars in 5 mass bins
- The number of stars in each mass bin taken from the canonical IMF by Kroupa et al. (2013)



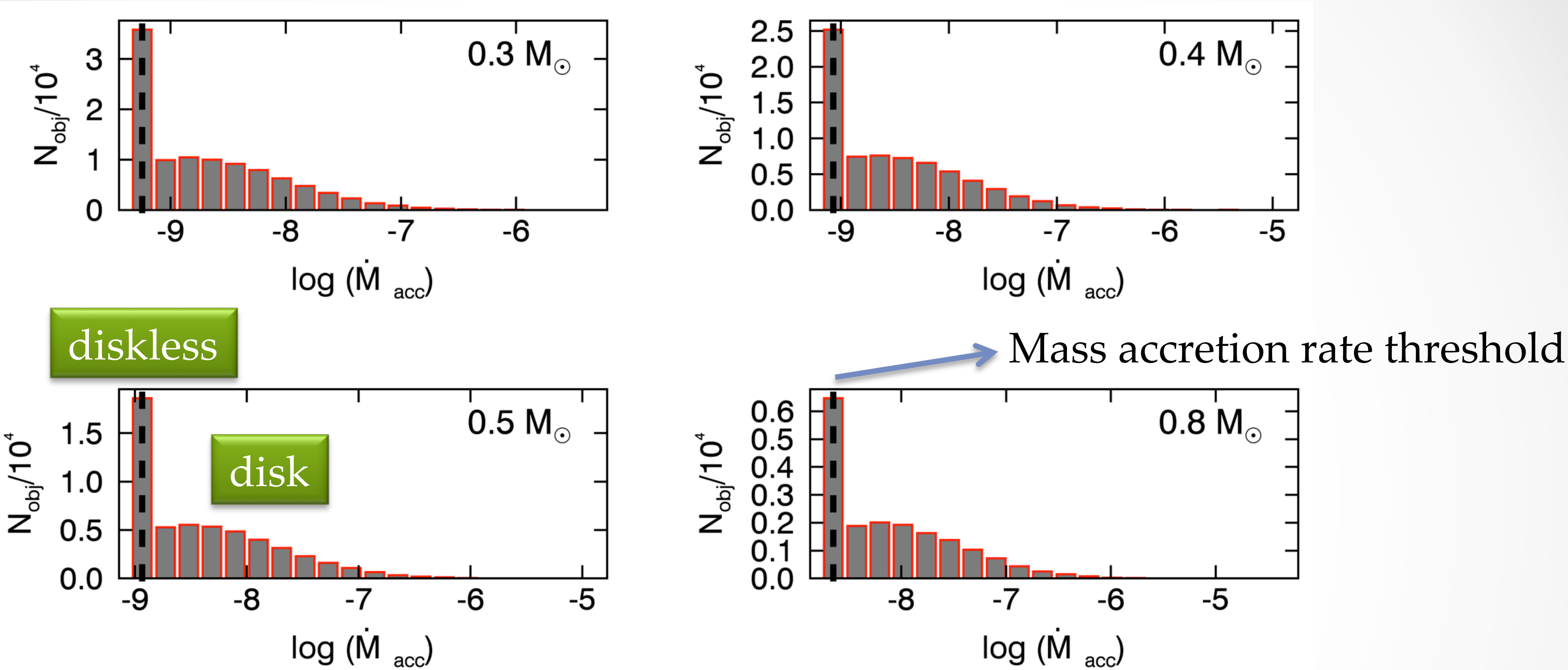
Five mass values: 0.3, 0.4, 0.5, 0.8 and 1.0 $M_\odot$

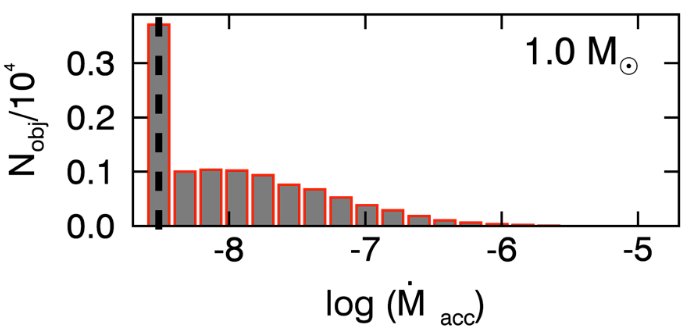




- ESTEC/ESA 2015 meeting

Initial mass accretion rate





Log – normal distributions:

$$\left\langle \dot{M}_{acc,i} \right\rangle = 10^{-8} M_{*}^{1.4} \; M_{\odot} \; yr^{-1}$$

$$\sigma_{\log \dot{M}_{acc}} = 0.8$$

- The mass accretion rate is evolved following the equation:

$$\dot{M}_{acc}(t, M_*) = \dot{M}_{acc}(0, M_*)\, t^{-1.5}$$

- Rotational evolution of each object:

Disk star:

$$\omega(t+\Delta t) = \omega(t)$$ constant

$$j(t+\Delta t) = j(t)\frac{I(t+\Delta t)}{I(t)}$$ decrease

From polytropic models j α $t^{-0.67}$

Diskless star:

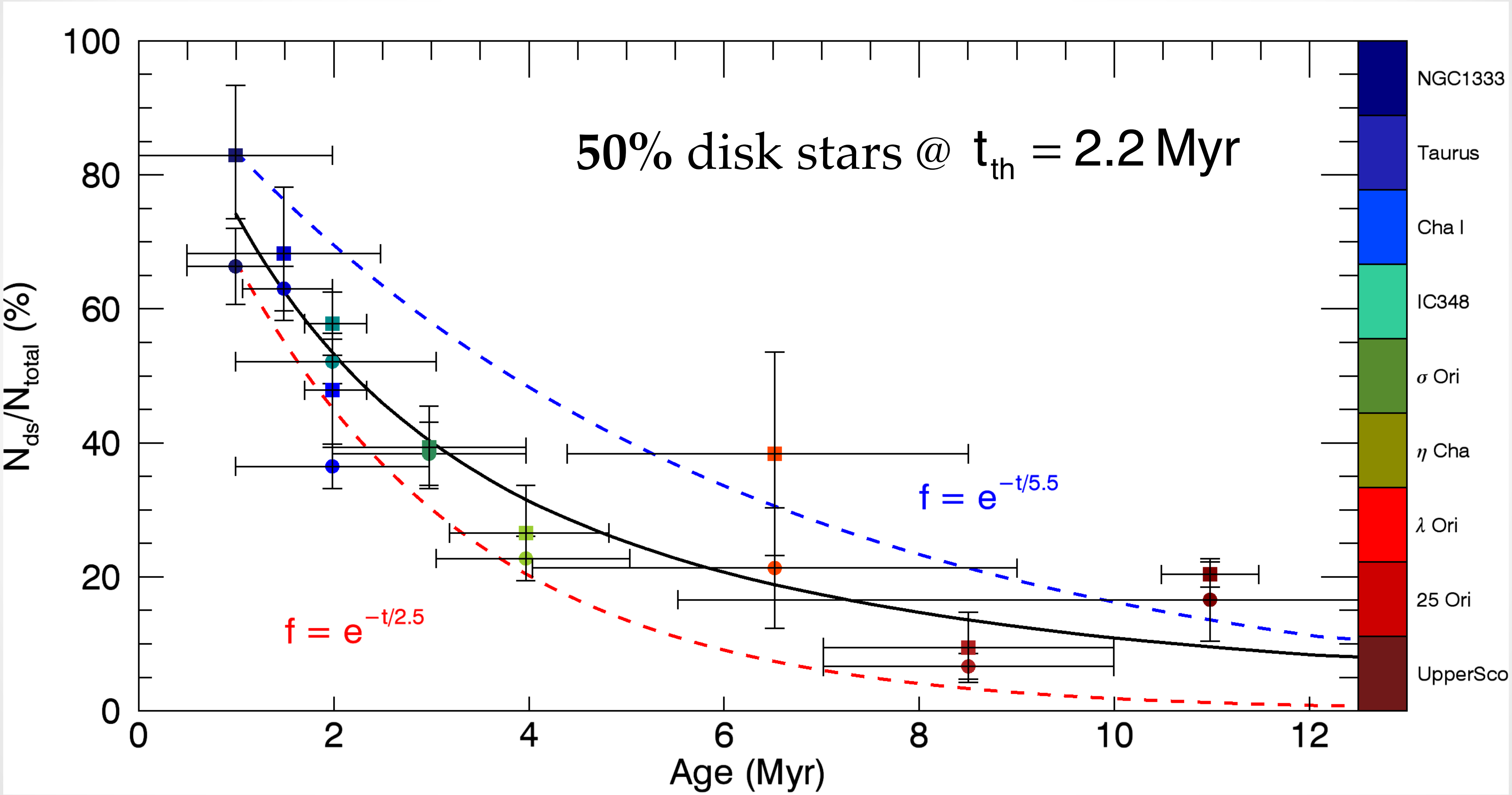
$$j(t+\Delta t) = j(t)$$ constant

$$\omega(t+\Delta t) = \omega(t)\frac{I(t)}{I(t+\Delta t)}$$ increase

Moments of inertia taken from Baraffe et al. (1998)'s models

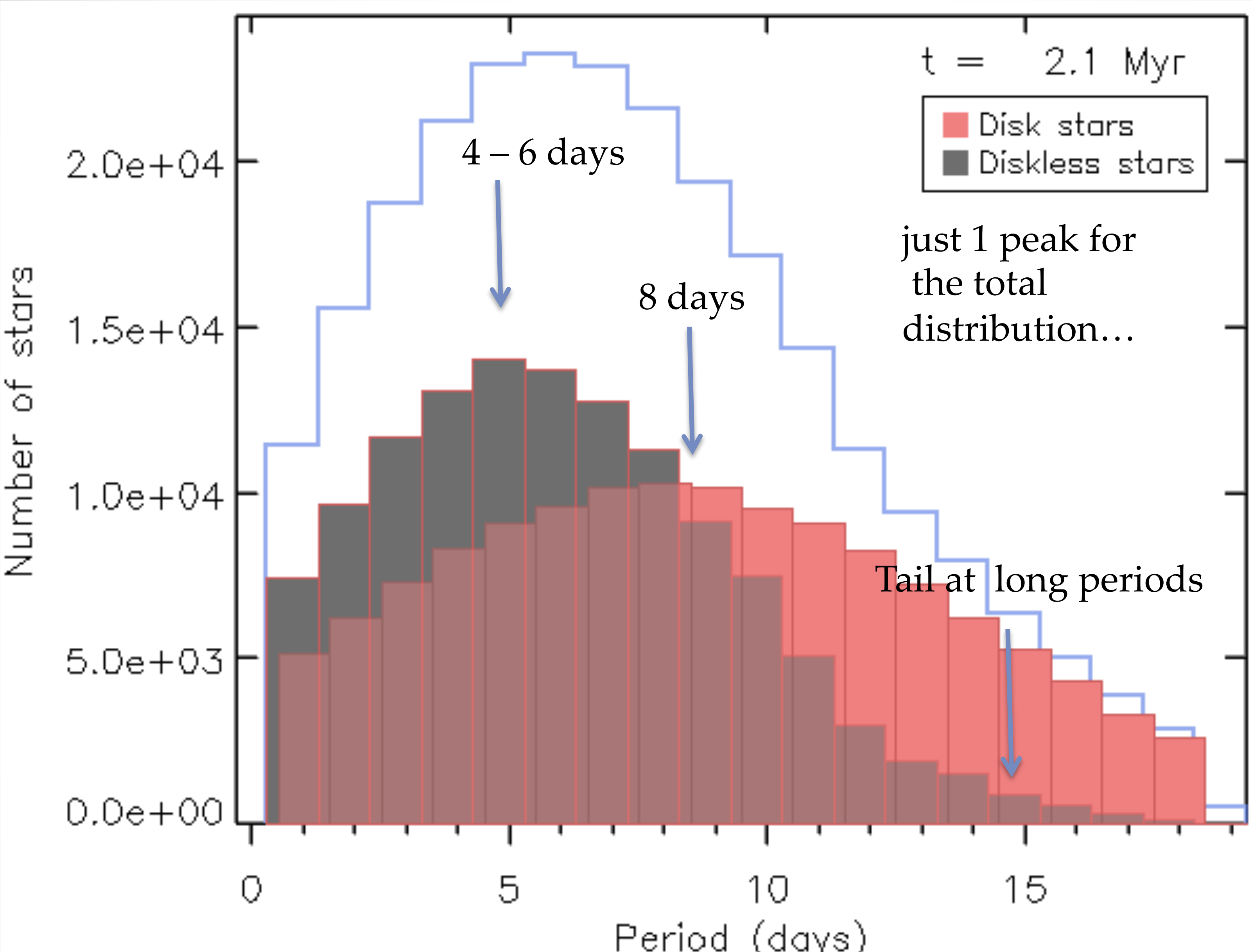
Results

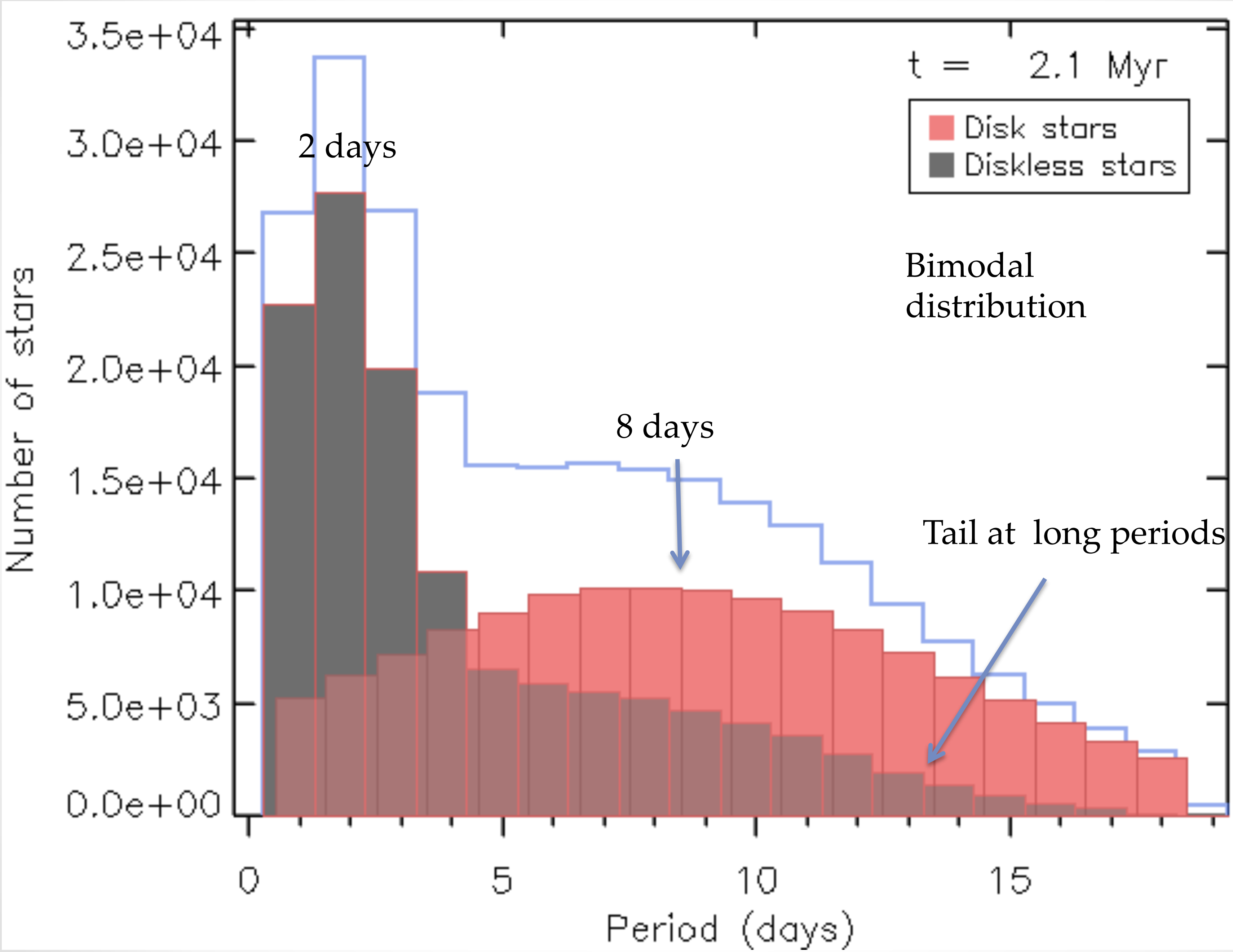
Disk fraction



Ribas et al. (2014, circles), Hernández et al. (2007) and Hernández et al. (2008, squares)

- Period distributions

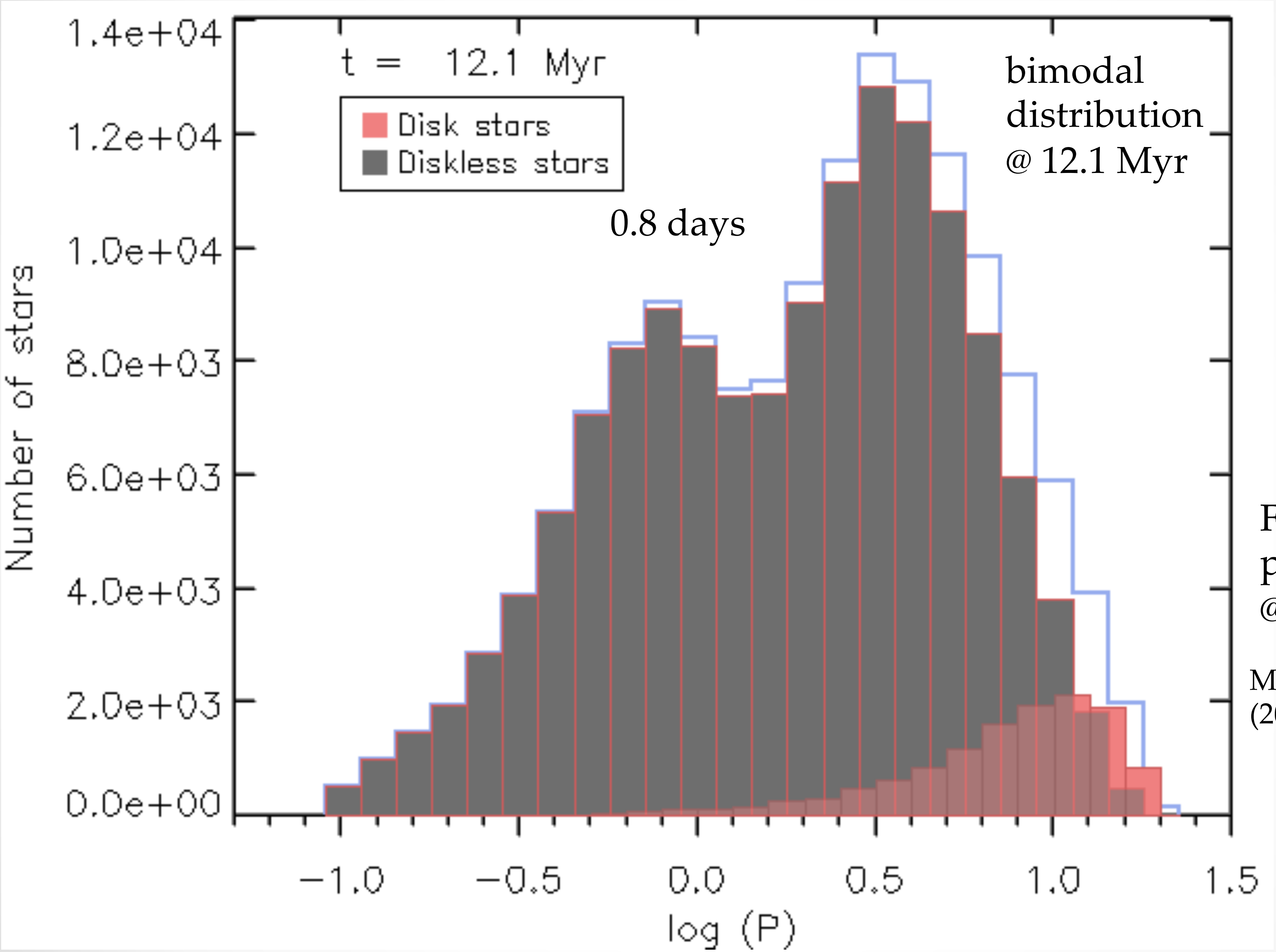




3.5e+04
3.0e+04
2.5e+04
2.0e+04
1.5e+04
1.0e+04
5.0e+03
0.0e+00
Number of stars
0
5
10
15
Period (days)
t = 2.1 Myr
Disk stars
Diskless stars
2 days
8 days
Bimodal distribution
Tail at long periods

M2

3-4 days

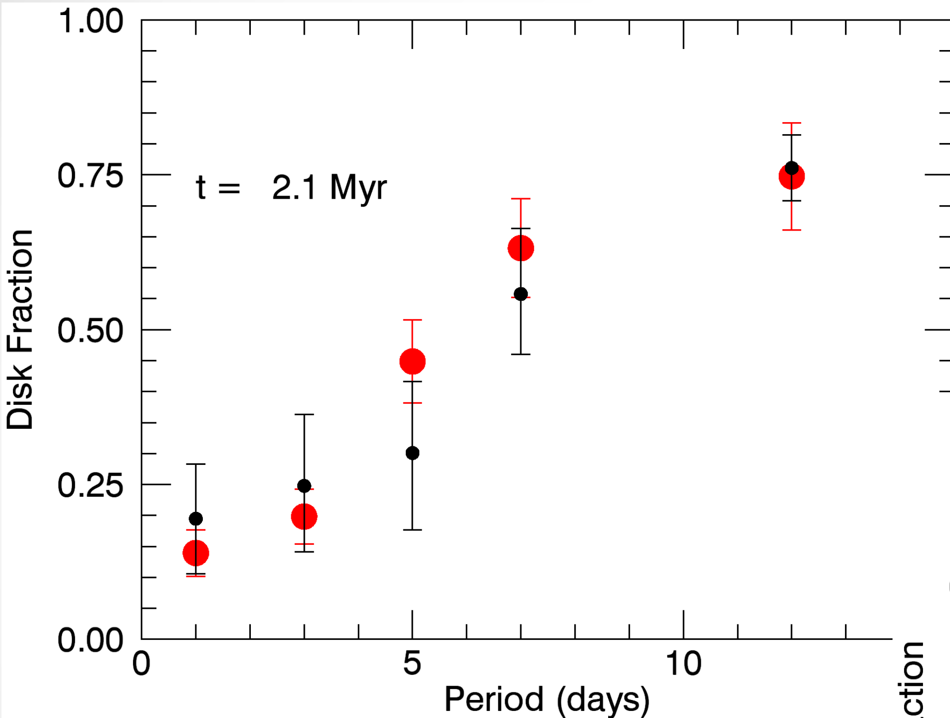


M2

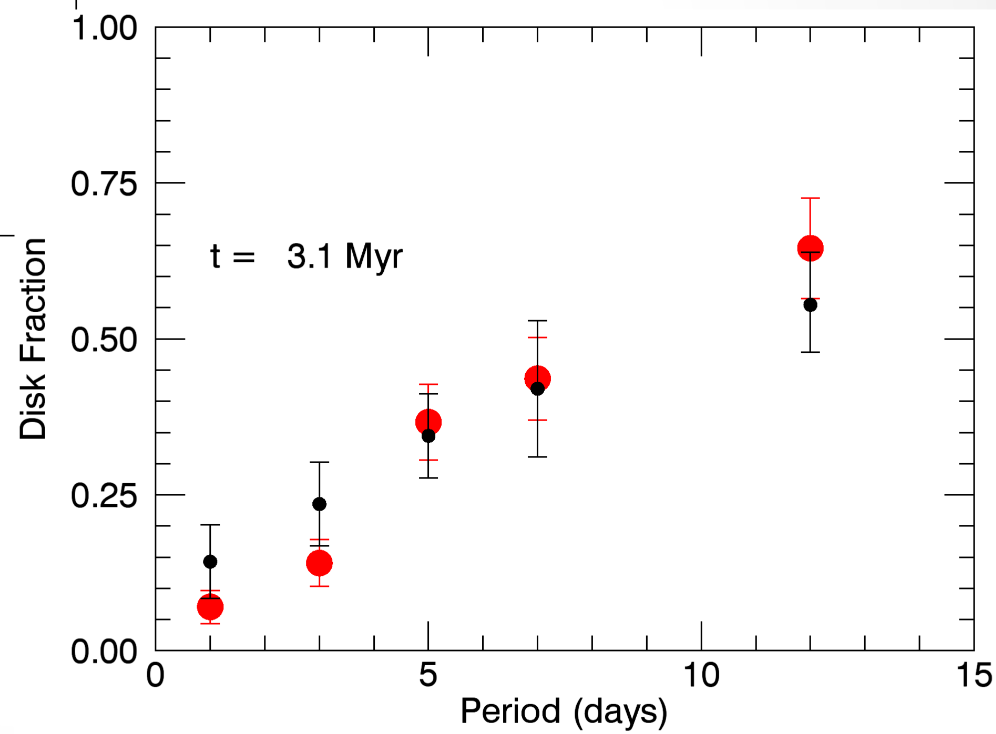
For hPer, long period peak @ higher P

Moraux et al. (2013)

- Another way to see that in average disk stars rotate slowly than diskless stars

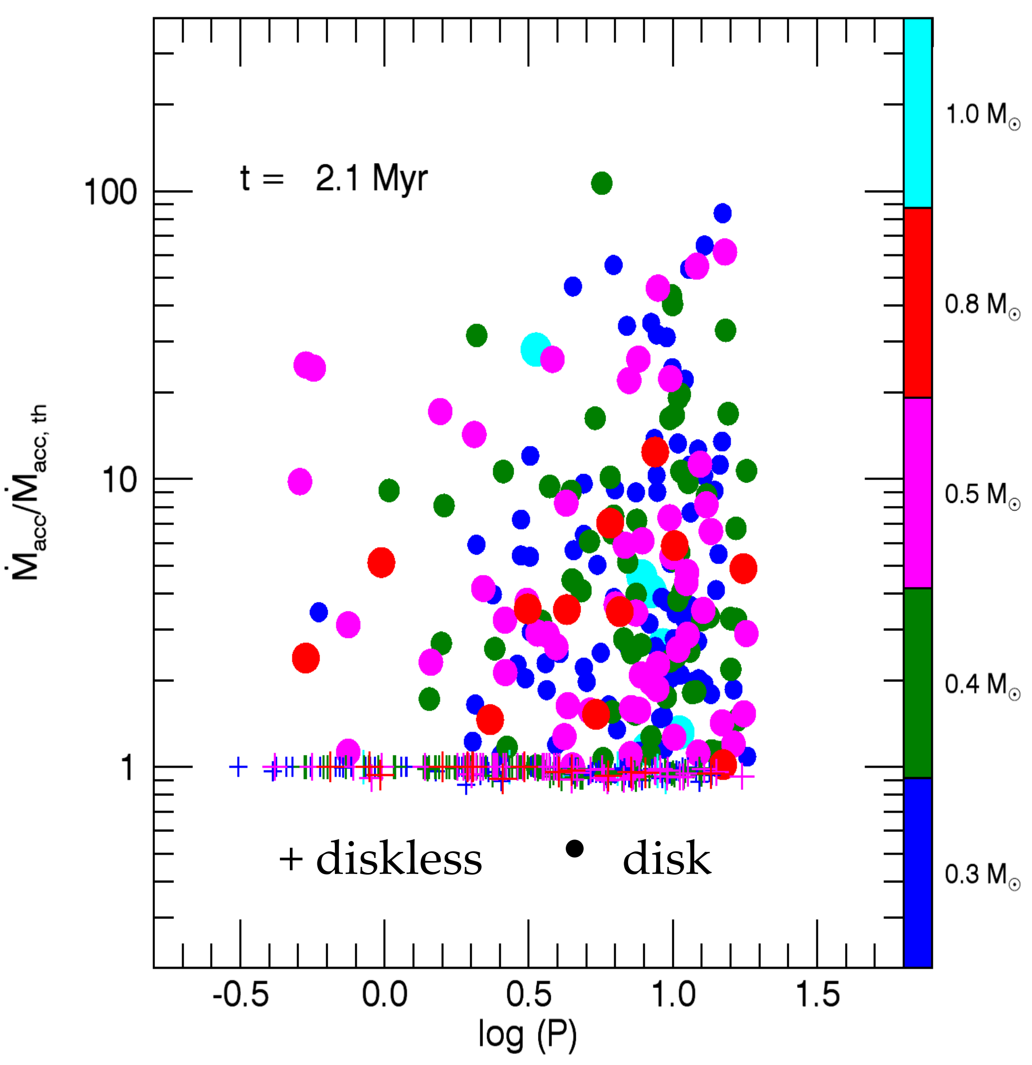


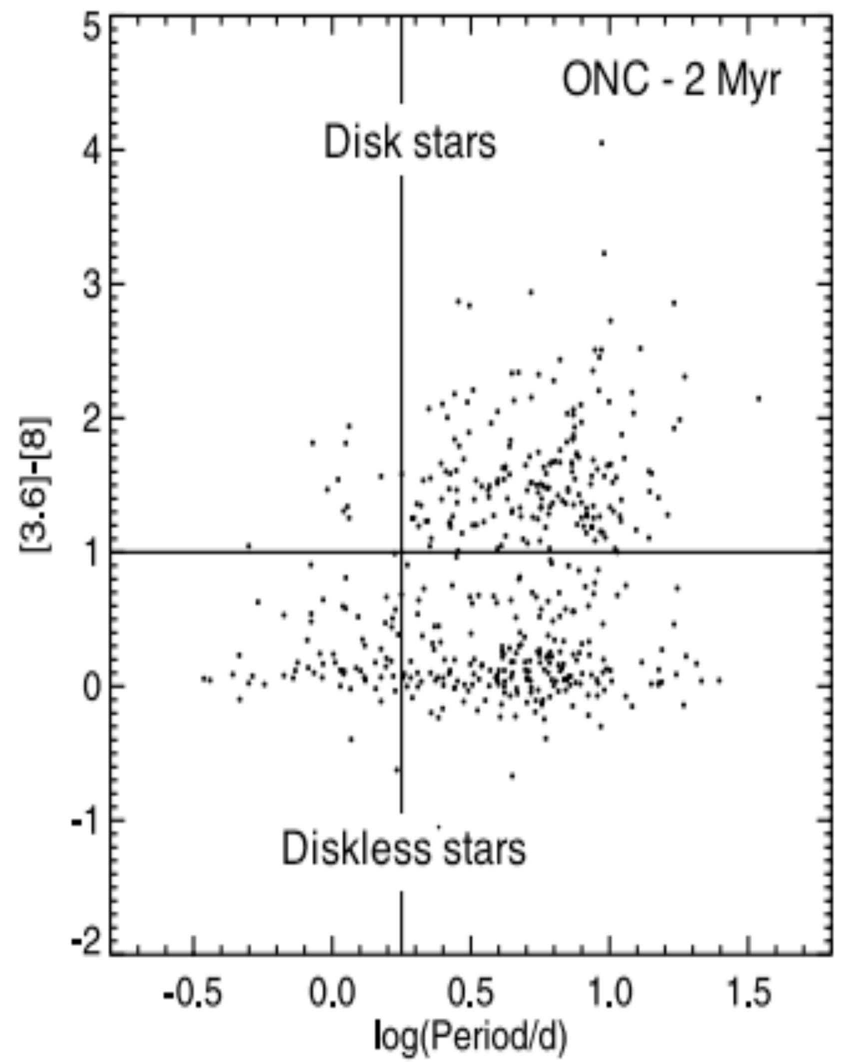
M2



black dots: data from Cieza & Baliber (2007) for ONC and NGC 2264

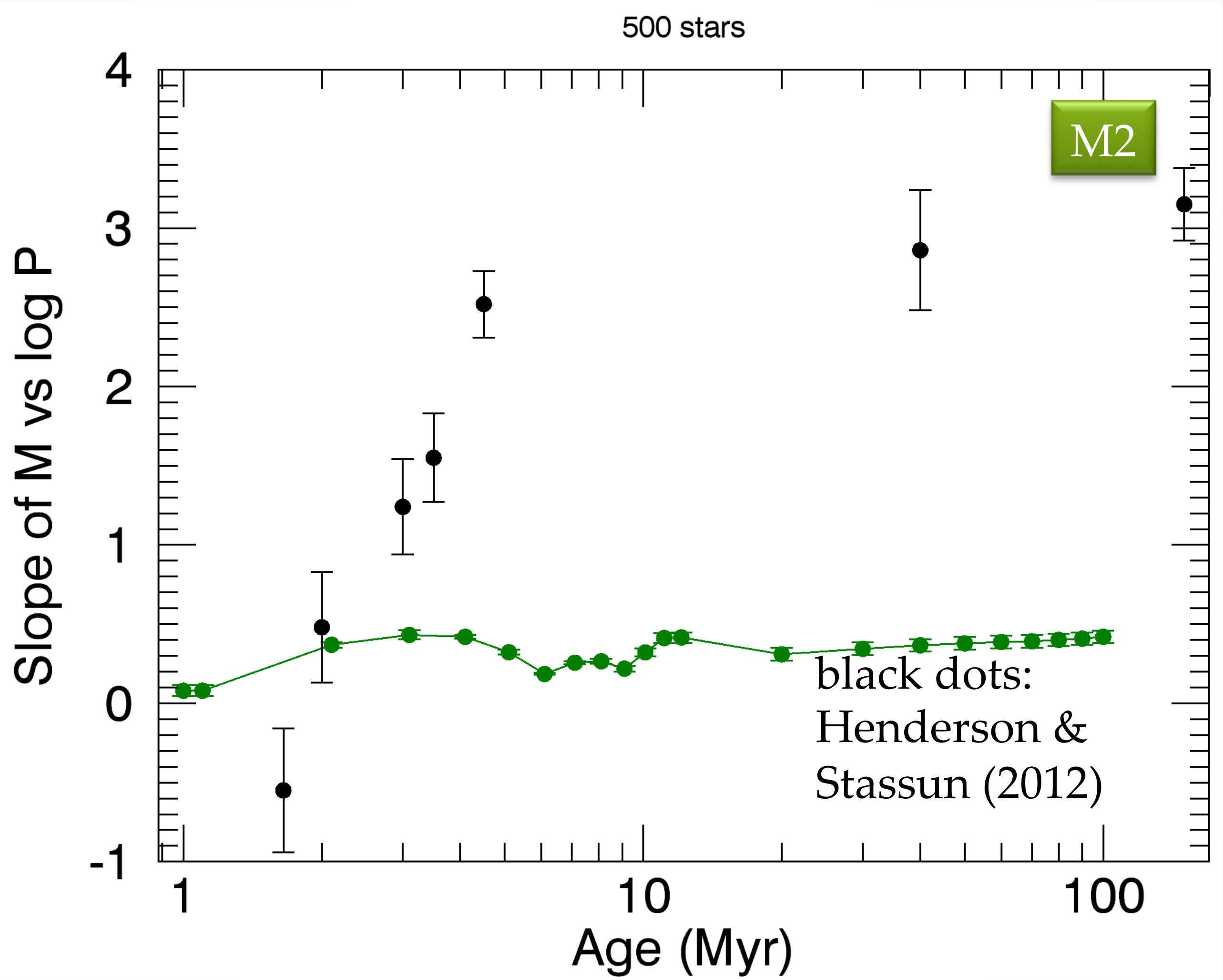
Mass accretion rate





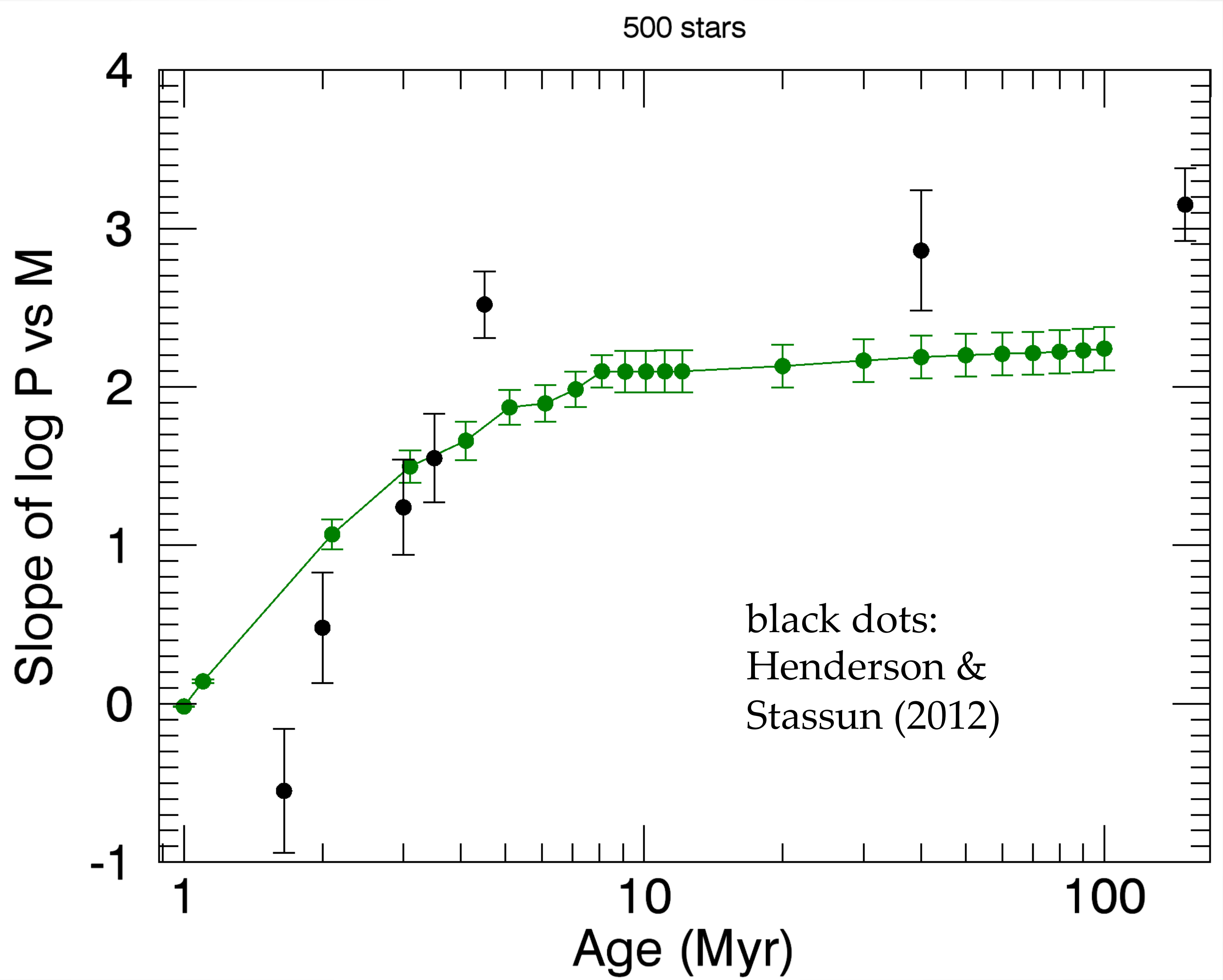
Rebull et al. (2006)

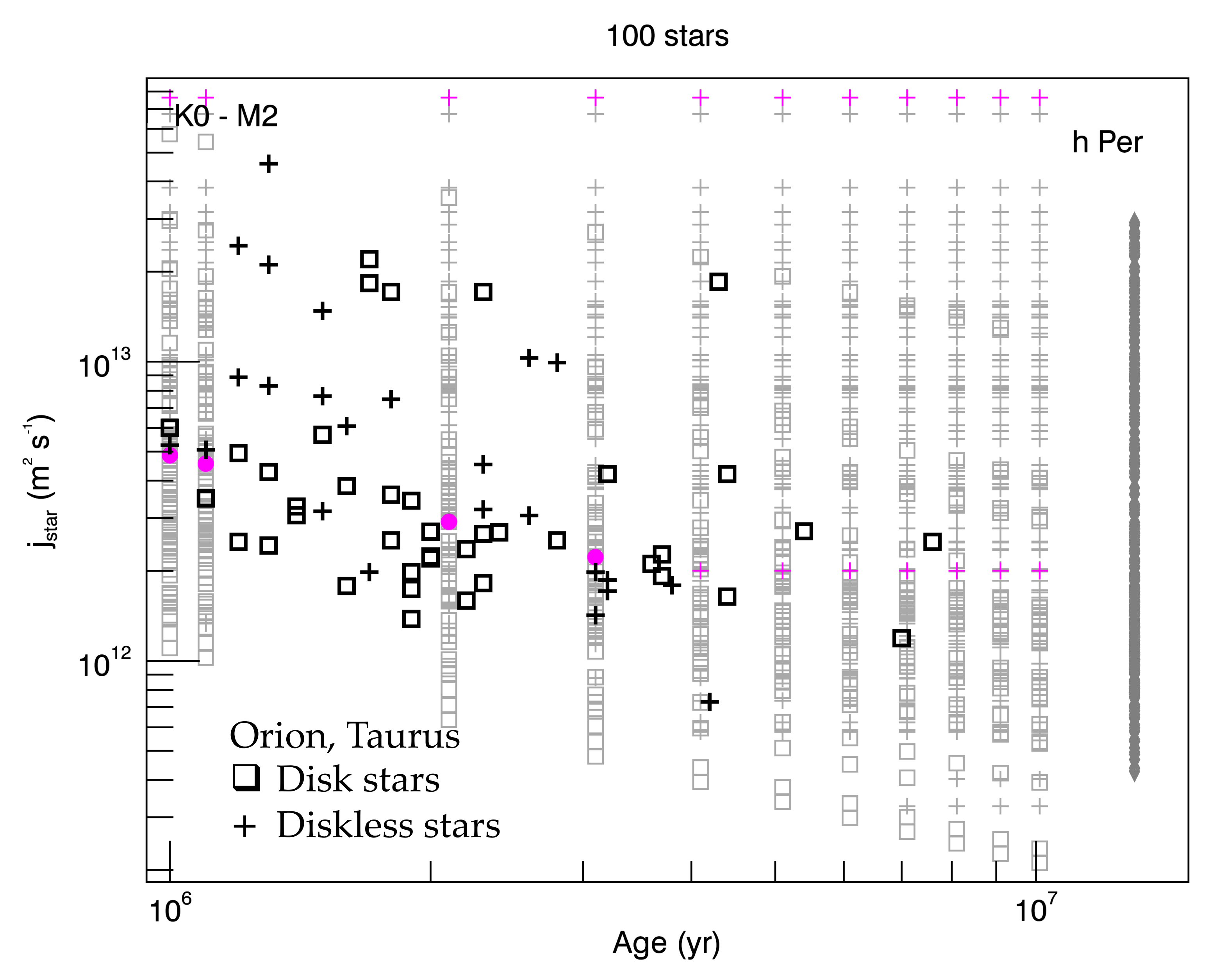
- Check for the period - mass dependency:



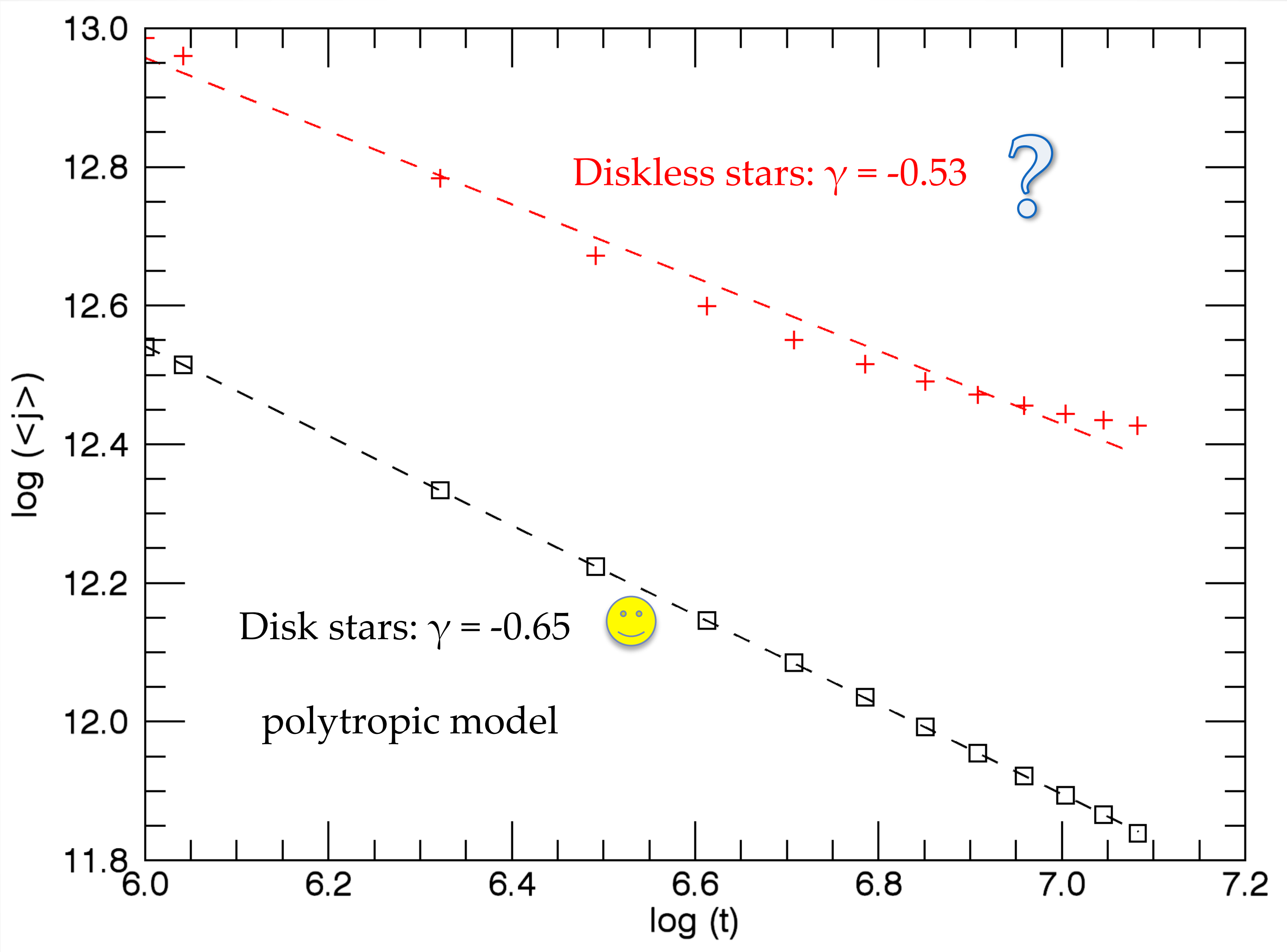
No correlation between mass and period.

- but with no disk-locking for 0.3 $M_\odot$ stars…




100 stars
K0 - M2
h Per
10^{13}
10^{12}
j_{star} (m^2 s^{-1})
Orion, Taurus
Disk stars
Diskless stars
10^6
10^7
Age (yr)

- Time dependency of median j:



- It’s a combination of constant evolution of individual angular momentum

+

- sequential release from disk over a wide range of disk lifetimes, from about 1 to 10 Myr.

Conclusions

- We were able to reproduce:
  - binomial period distributions if initial P is bimodal
  - diskless stars rotate faster in average than disk stars
  - fast rotators among disk stars
  - slow rotators among diskless stars
  - For a sample of diskless stars, the angular momentum evolution is not constant BUT this is because disk lifetime is not the same for all stars

- But no period – mass relation, unless no disk-locking for 0.3 $M_{\odot}$.