Early results from Monitor

constraining spin-down on the early main sequence

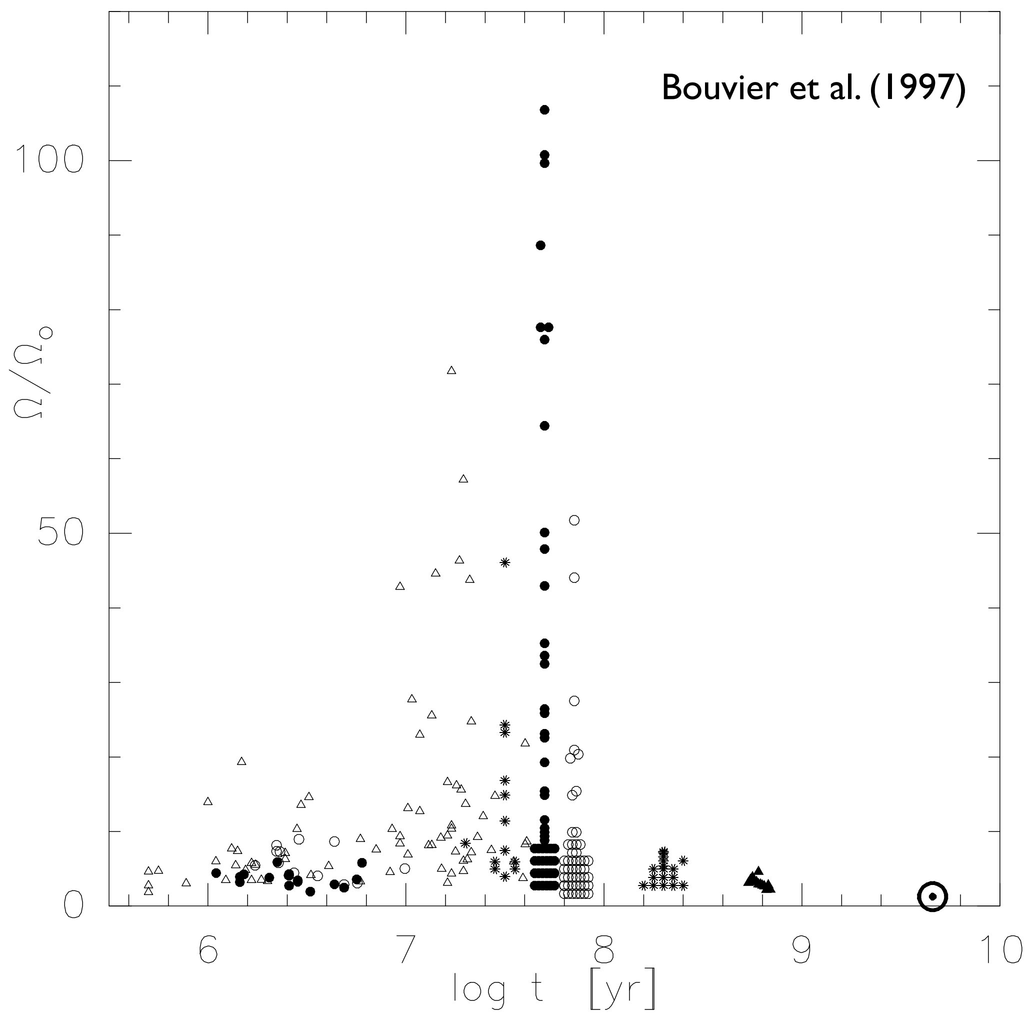
Suzanne Aigrain, Jonathan Irwin, Simon Hodgkin,

Mike Irwin, Jerome Bouvier, Cathie Clarke, Leslie Hebb, Estelle Moraux, & the Monitor Collaboration

Outline

- Angular momentum evolution of young stars
- The Monitor project: data, membership and period detection
- Implications for AM evolution
- Future prospects

Observations of rotation in young stars



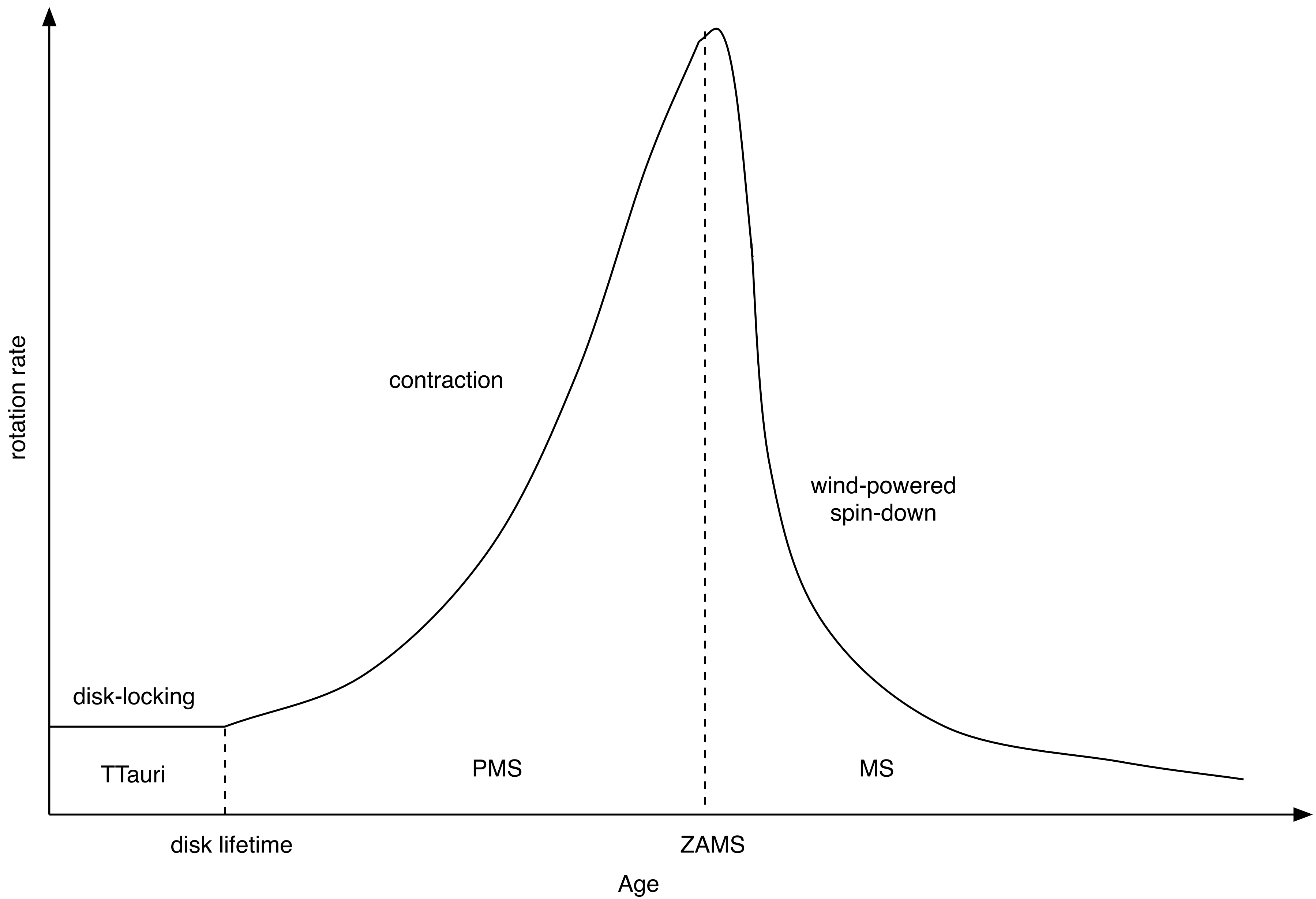
Compilation of rotation rates derived from v sin i for low mass TTauri and post TTauri stars and G-type members of young open clusters

TTauri stars are slower rotators than post-TTauris

The fastest rotators are observed near the ZAMS

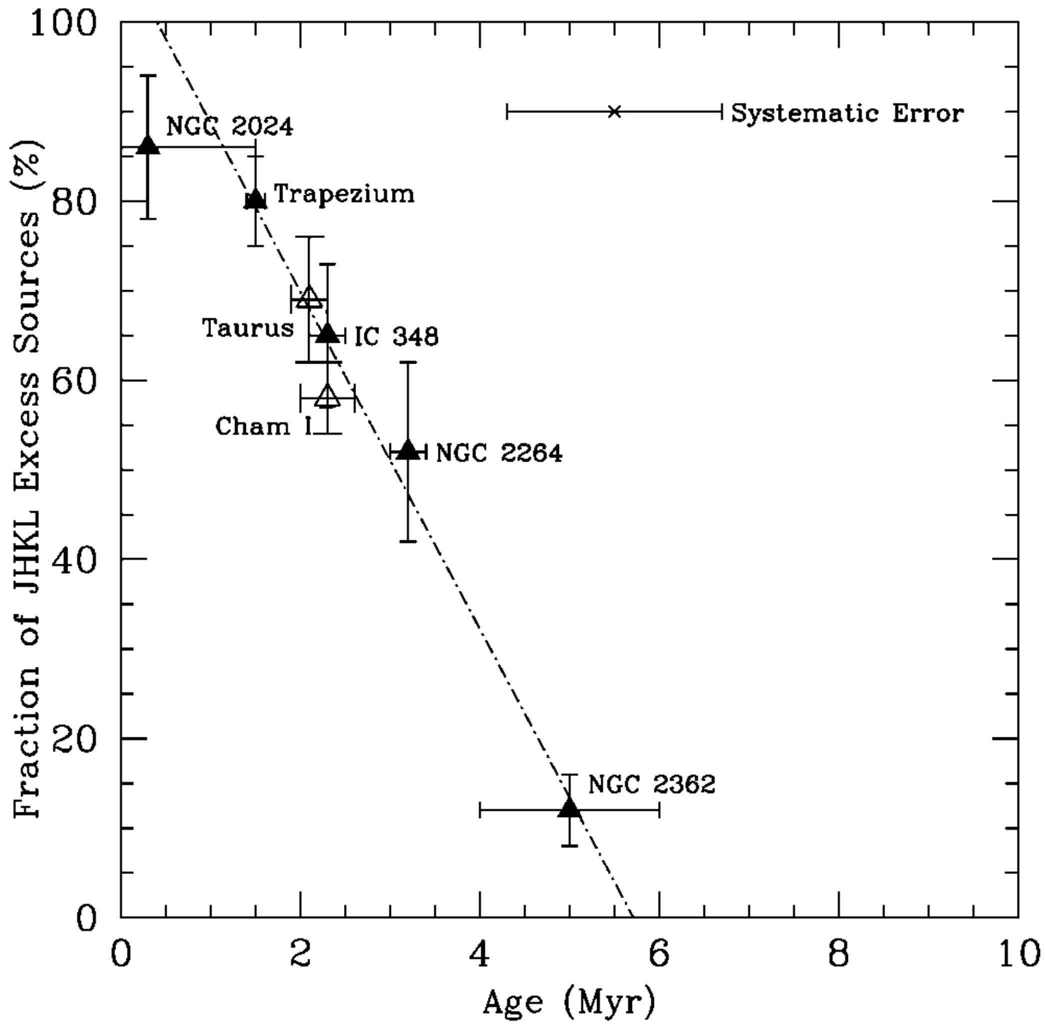
After the ZAMS, all stars quickly converge to a common, low rotation rate

AM evolution - III



Disk locking

First proposed by Königl



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Initial distribution

Disk locking implies distribution of periods of classical T Tauri stars (which have always been locked to their disks) should reproduce initial distribution

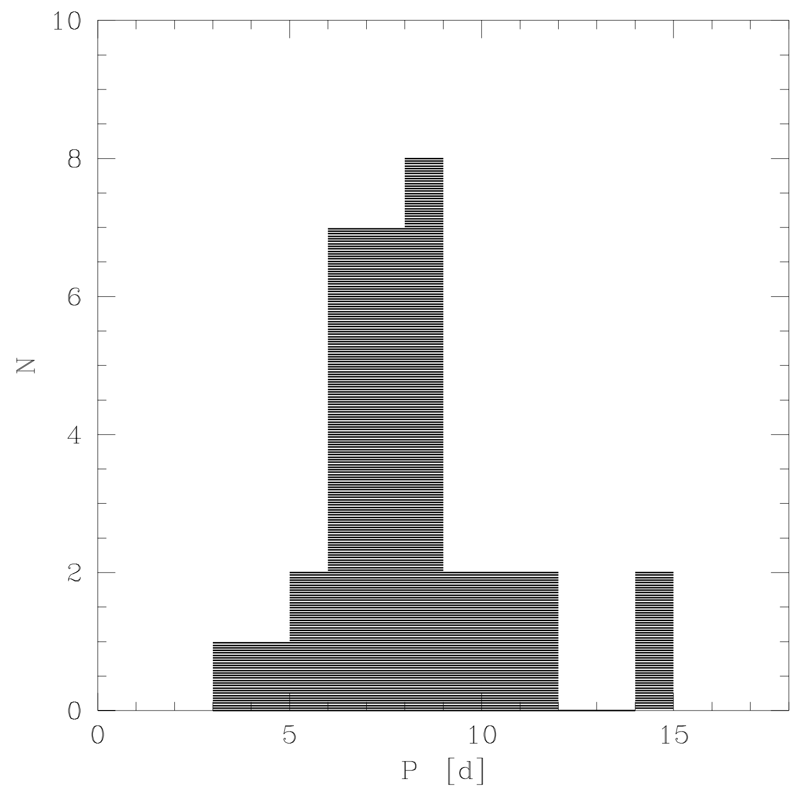
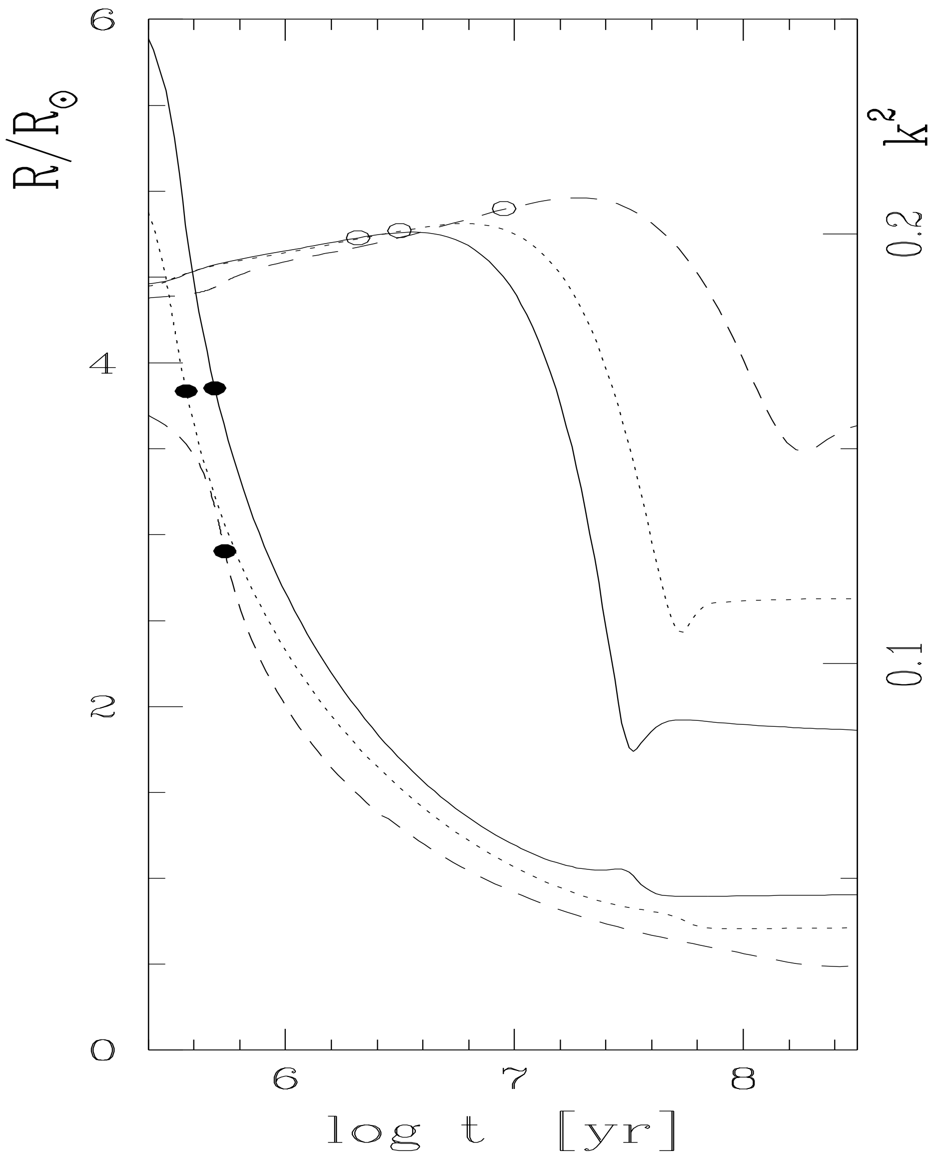


Fig. 2. Histogram of rotational periods of low-mass classical T Tauri stars.

Bouvier et al. (1997)

peak at 6 - 8 d,
but range 4 - 16 d

Contraction



As the star contracts, it must spin up unless it has a way of loosing angular momentum.

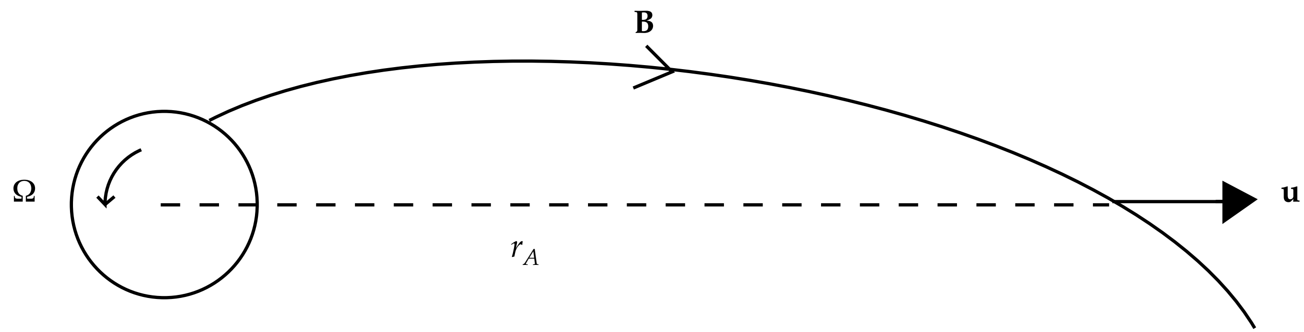
Contraction is the dominant factor in angular momentum evolution on the pre-main sequence once the connection with the disk is broken

Contraction stops once the star reaches the ZAMS (about 100 Myr for solar mass stars)

Bouvier et al. (1997), based on the isochrones of Forestini (1994)

Angular momentum loss through a magnetised wind

First introduced by Weber & Davis (1967) for the solar case



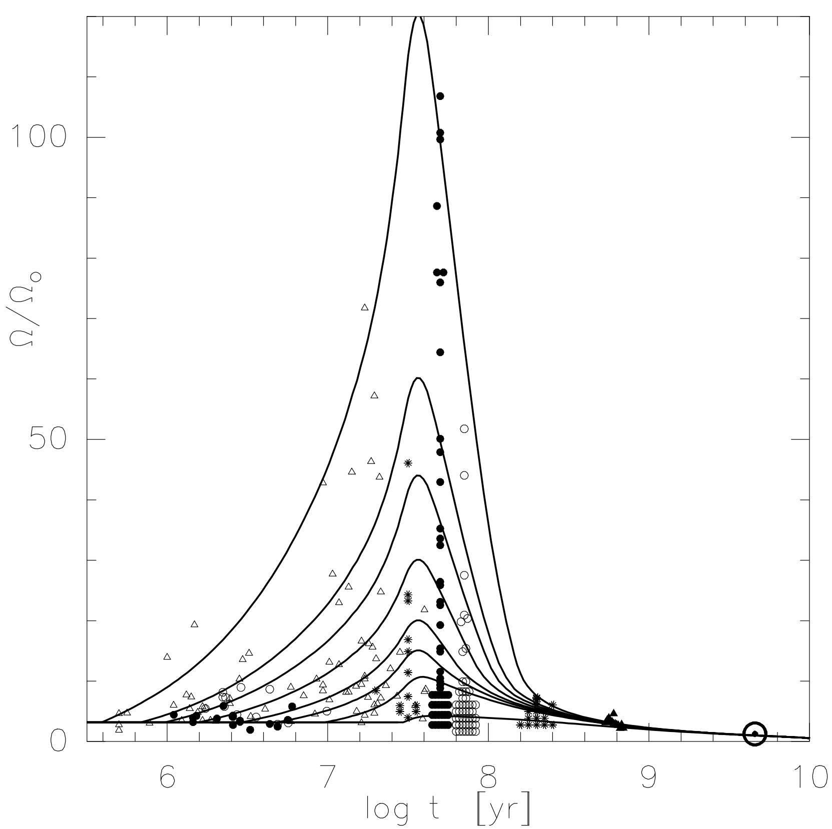
taken from D. Melrose's lecture notes, U. Sydney

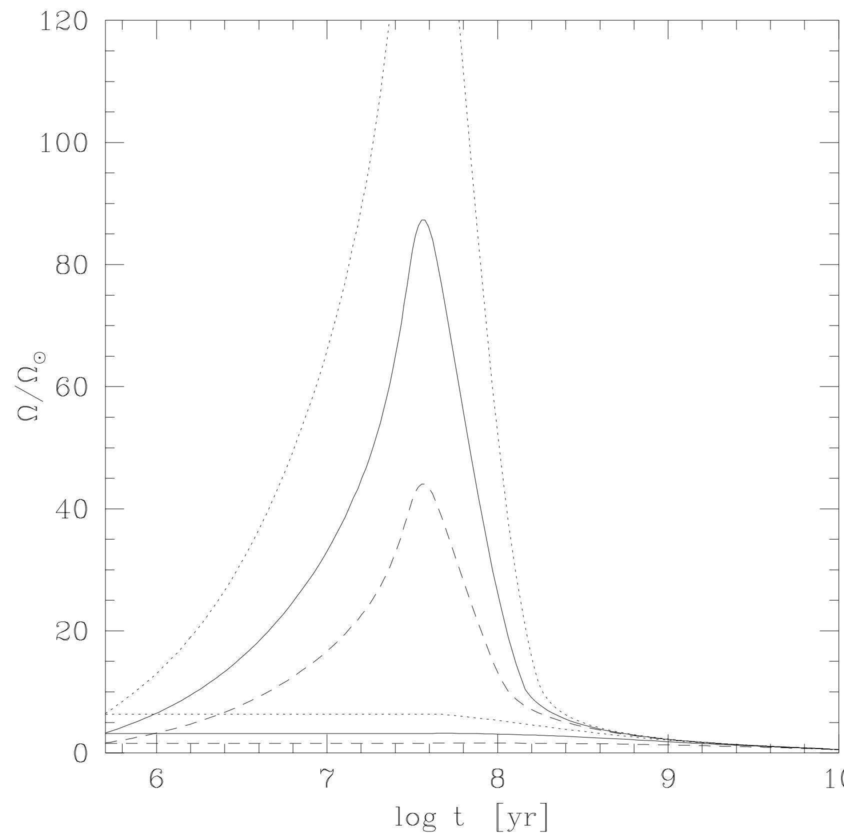
Magnetic field lines connecting to the stellar surface expand beyond the Alfven radius, where the wind speed approximates the escape velocity. The wind must therefore carry away angular momentum.

Observational evidence for Sun-like stars: $P_{rot} \propto t^{1/2}$ (Skumanich 1972).

Effect of disk lifetime and initial rotation rate

Bouvier et al. (1997)

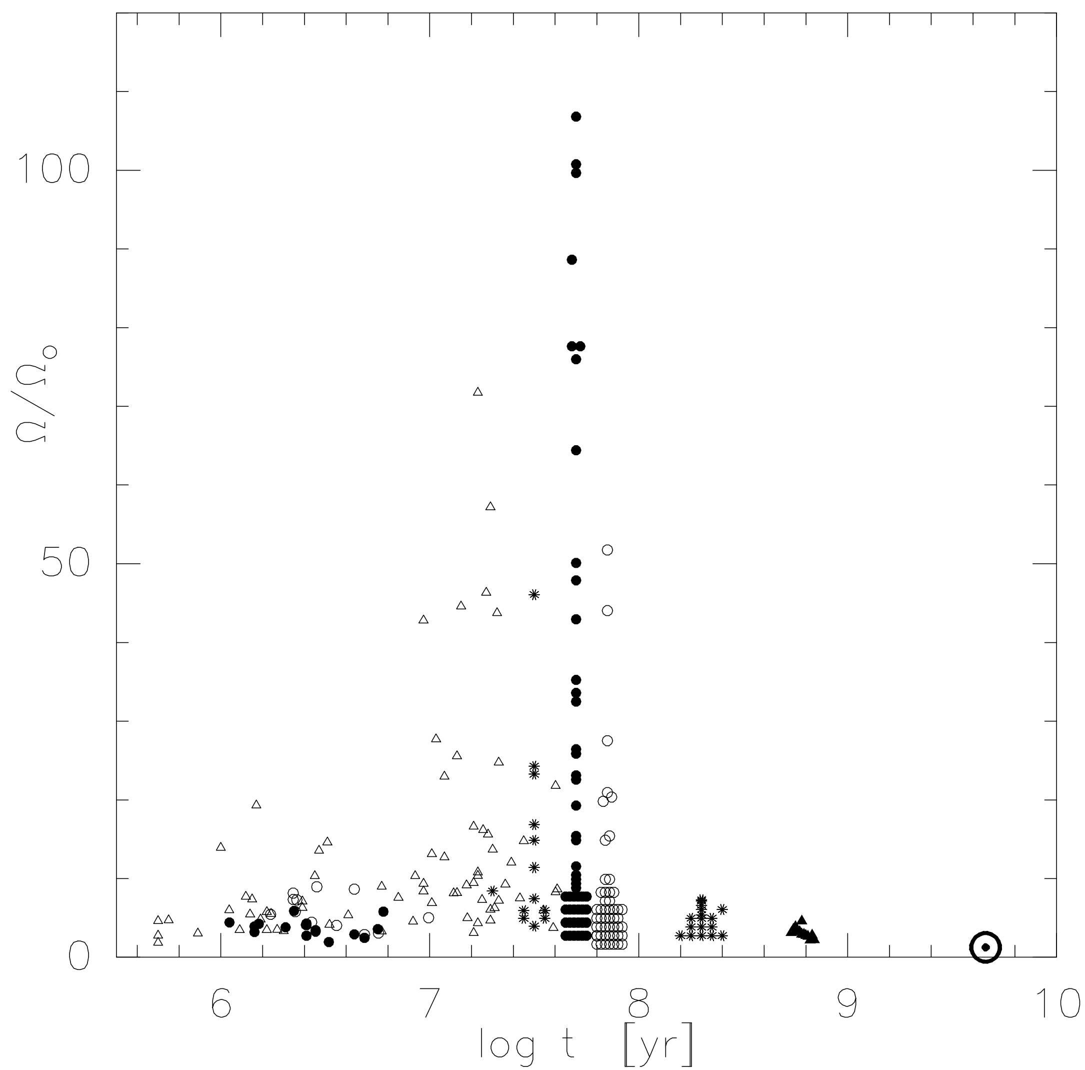




Degeneracy between inital conditions and disk lifetimes persists until several 100 Myr after ZAMS

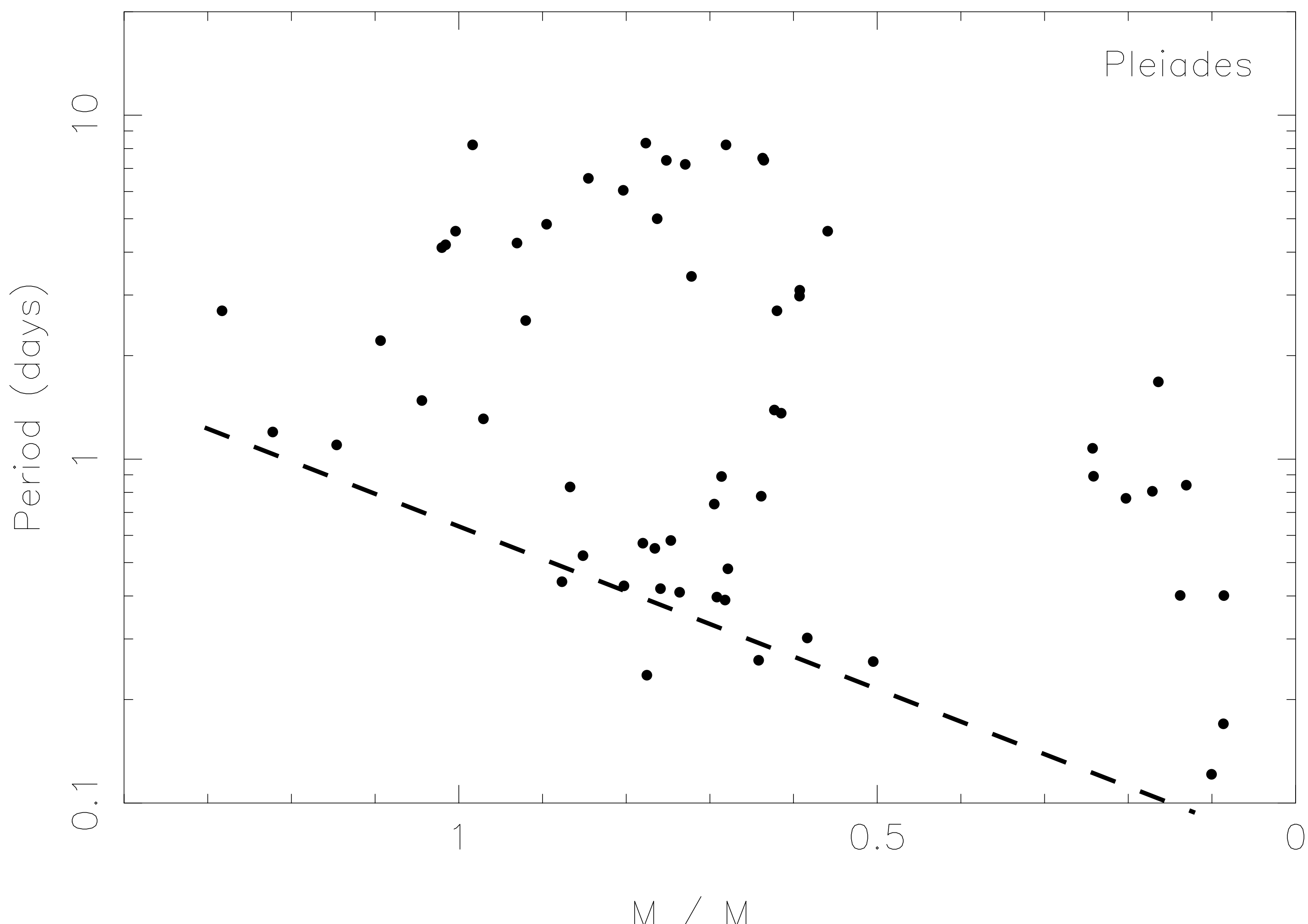
Problems - I

Rapid spin-down on ZAMS



Problems - II

Mass dependence of spin-down rate on ZAMS



Fixes - 1

Solid body wind-breaking with saturation

More sophisticated wind-breaking prescription (Bouvier et al. 1997)

Solid-body $\Omega(r) = \Omega(R_\star)$

Feedback

$$R_\star B \propto \Omega^a$$

Influence of geometry

$$\frac{\mathrm{d}J}{\mathrm{d}t} \propto \left(\frac{r_A}{R_\star}\right)^n$$

Skumanich law recovered for n=1.5 (intermediate between radial and dipolar field), a=1 (linear dynamo)

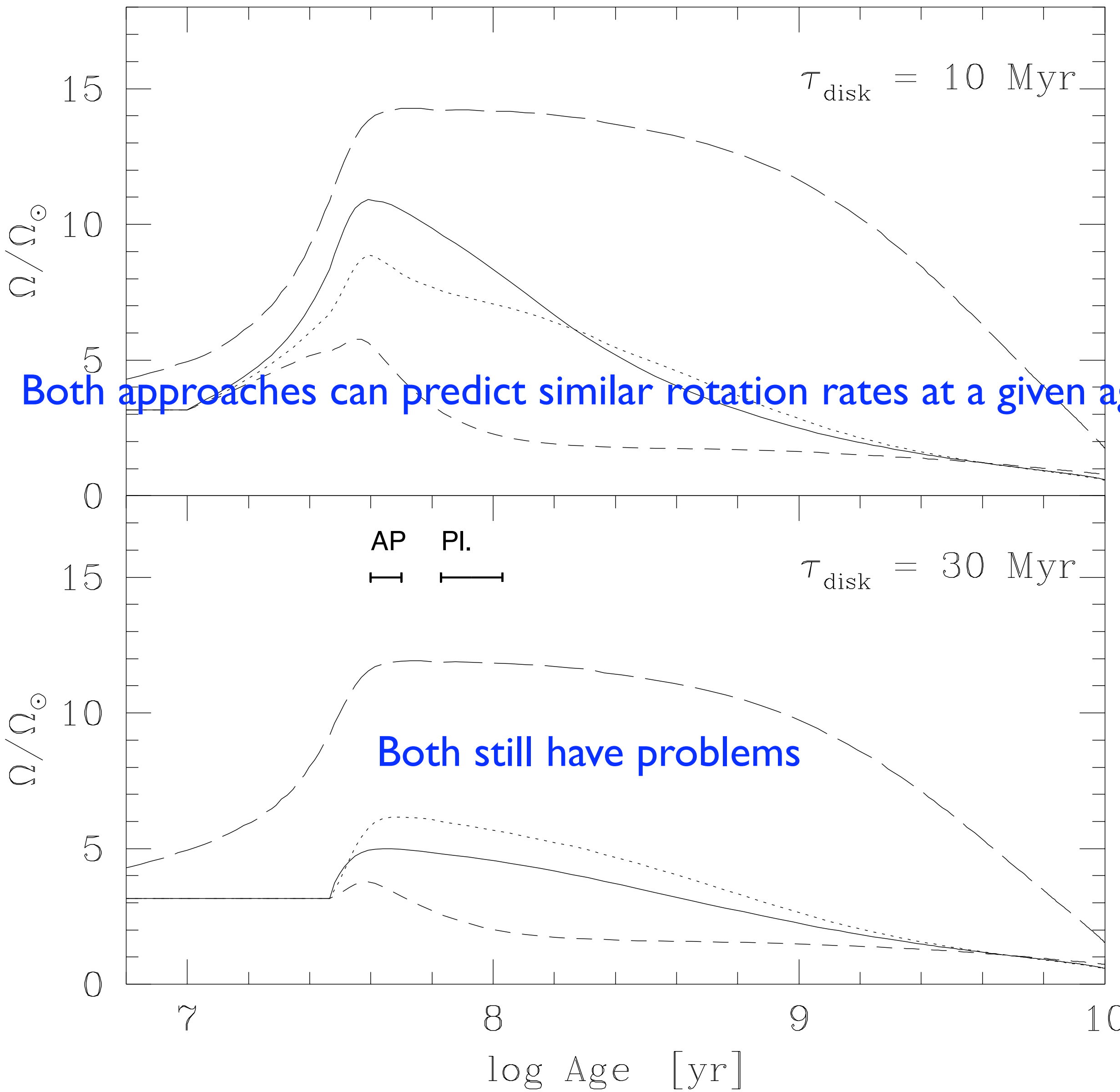
Saturation: becomes less efficient for very fast rotators, with a mass-dependent saturation rate

Fixes - II

Al tar

Cc

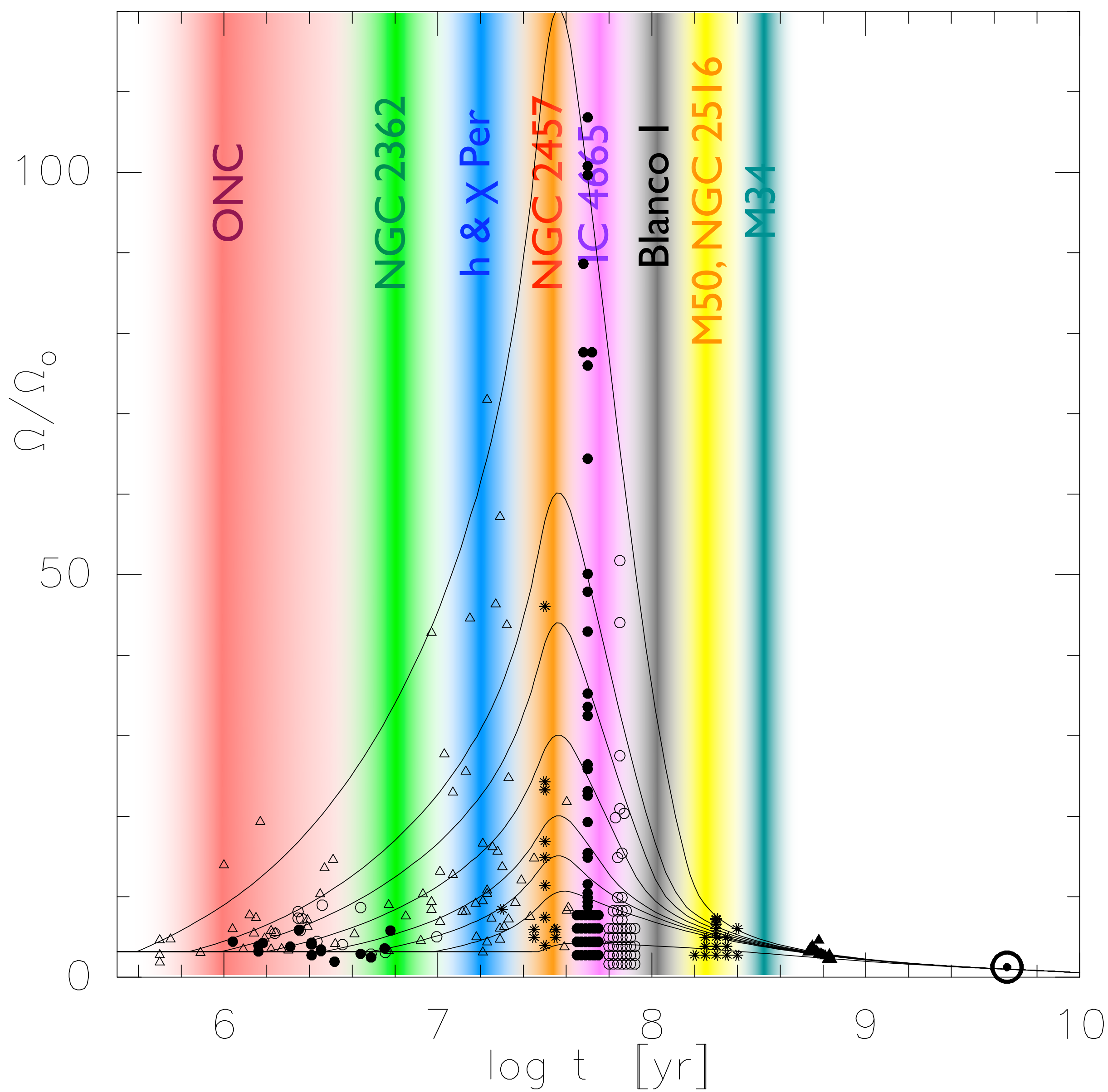
cc



Both approaches can predict similar rotation rates at a given age

Both still have problems

The Monitor project



Monitor target clusters cover the entire evolutionary sequence up to the early MS

In the TTauri phase, examine link between rotation and presence of disks

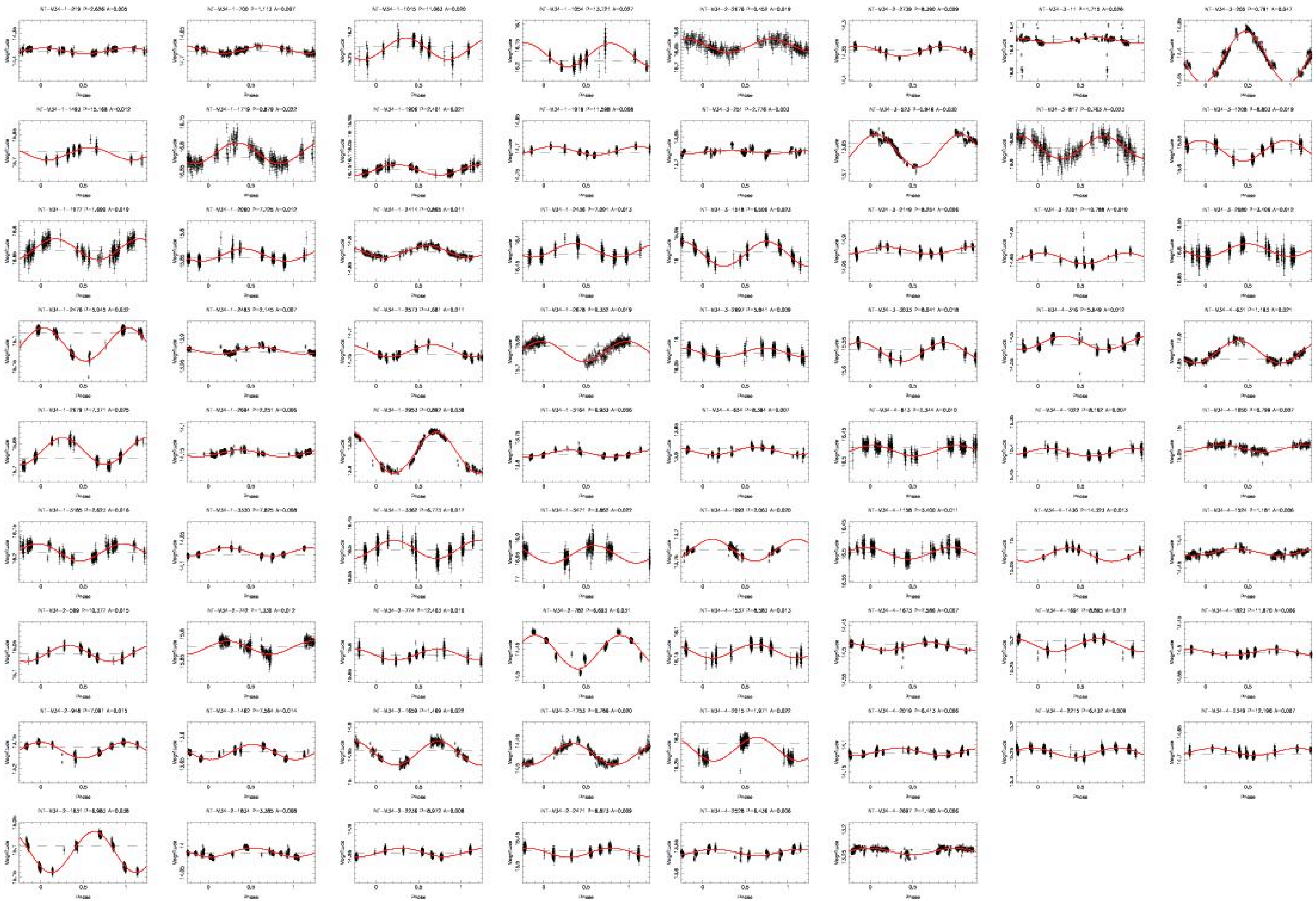
Will also reach down to the BD regime, where the star-disk connection may be altered

Will cover in detail the ZAMS phase, which is crucial for constraining spin-down models

Monitor periods

- Photometric monitoring in I (+V) from 2 - 4m telescopes
- Two types of time sampling:
  - classical scheduling: runs of ~ 10 nights, tightly sampled (3.5 to 8 min), repeated after a few months (up to 1 yr)
  - queue scheduling: blocks of 1-2h, sampling 15min, spread throughout semester
- Automated light curve production using list-driven aperture photometry
  - Photometric precision < 1% over > 4 magnitudes
- Membership selection from deep optical CMDs or previously published data
- Period detection via sine-fitting
  - Completeness and reliability estimated by injecting sinusoids into real, non-variable light curves

Candidate members in M34 with rotation periods



Some cautions

- I am going to show some **very preliminary results**
- M34 has been analysed in detail (Irwin et al. in prep.). For anything else:
  - Don't trust period determinations above 10 days or below 0.3 days
  - Contamination from field variables is expected to be high (except in ONC where we used Hillenbrand 1997 catalogue)

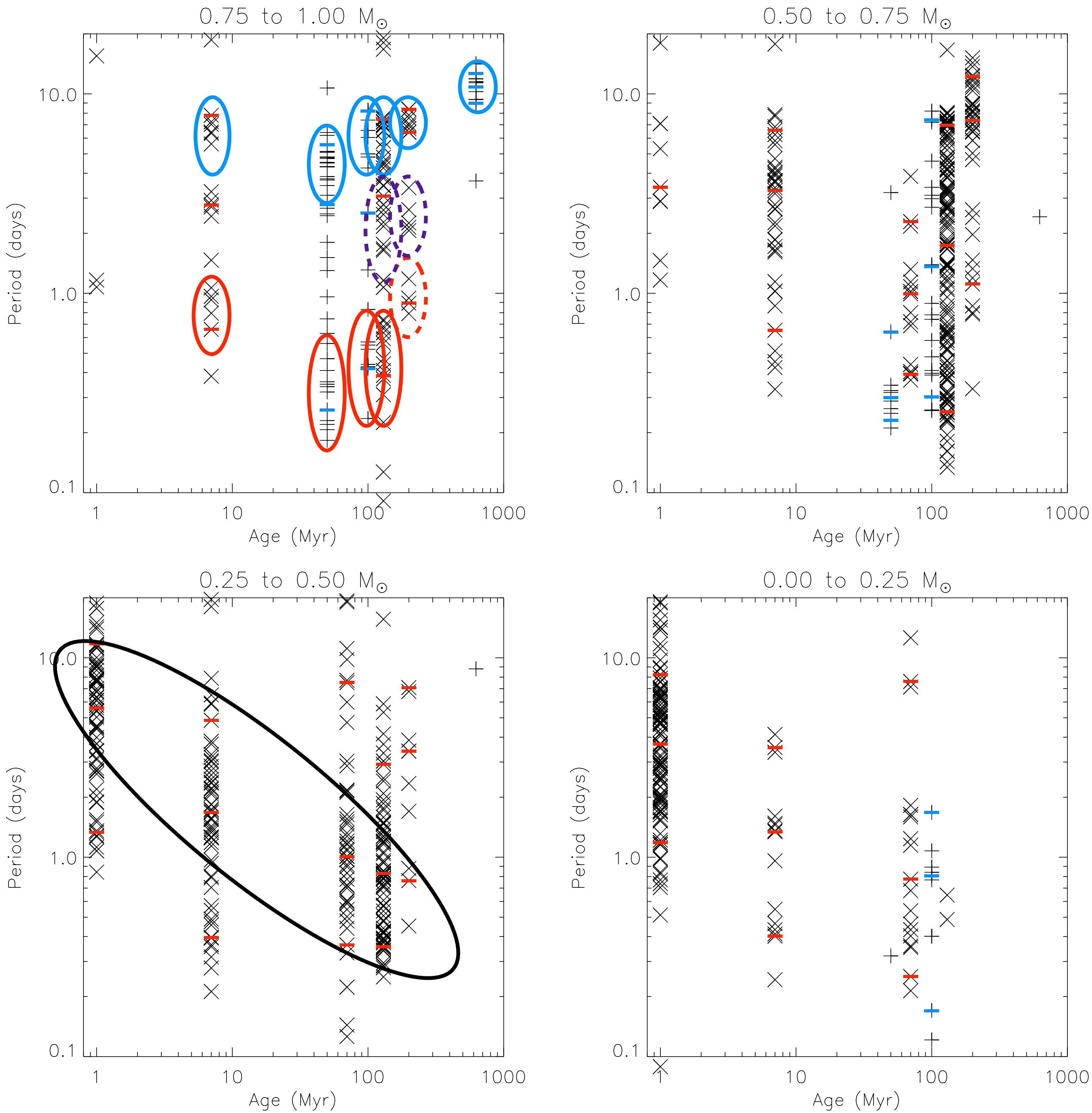
slow rotators

fast rotators

transition objects

only one population at low masses

Consistent with framework of Barnes et al. (2003)



MEDIAN

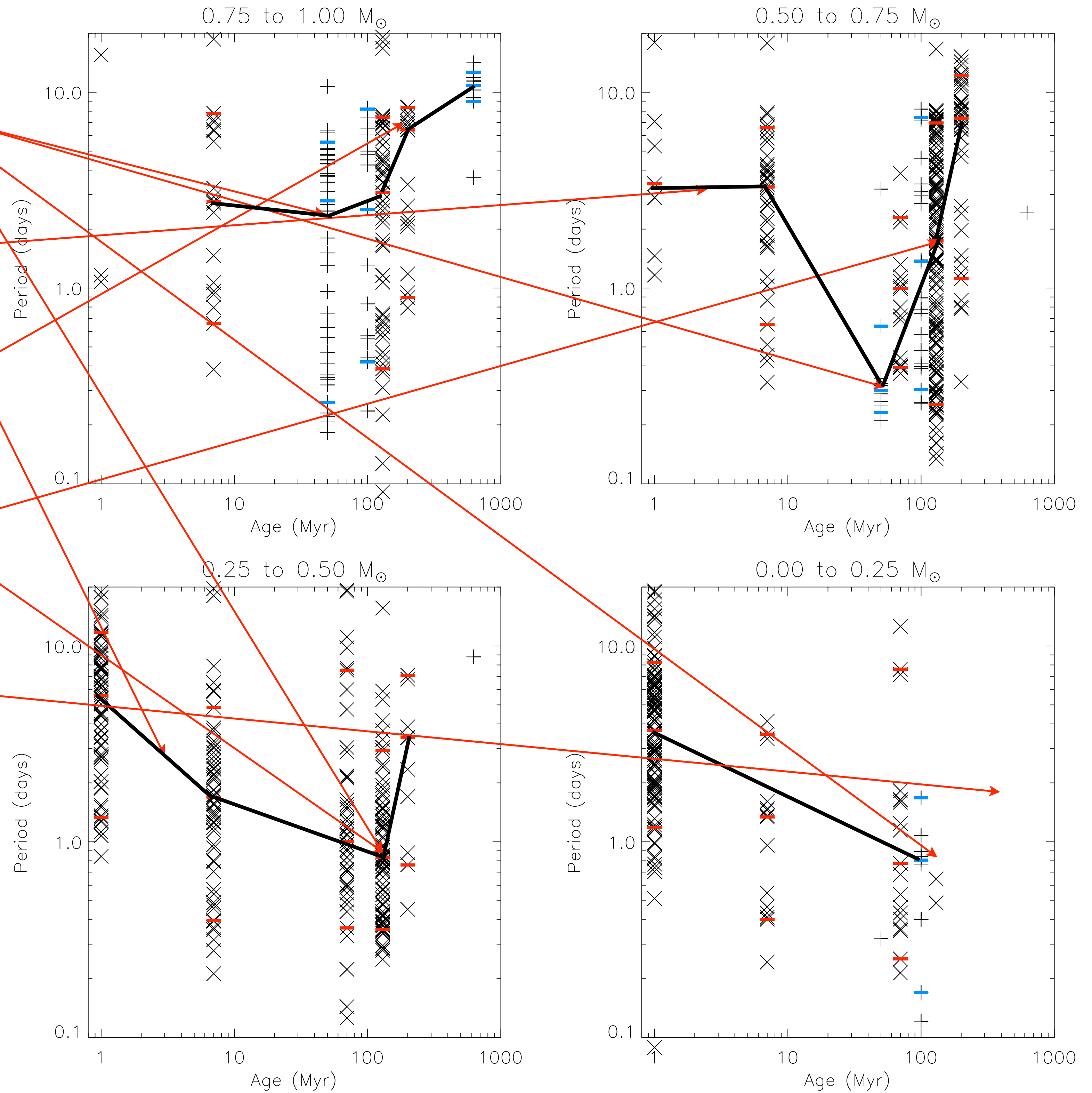
ZAMS age increases with decreasing mass

Disk locking less efficient or less long-lived at lower masses?

Gradual disappearance of fast rotators in highest mass bin

Investigate rate of spin down as function of mass

Really need lower mass objects in post-ZAMS phase



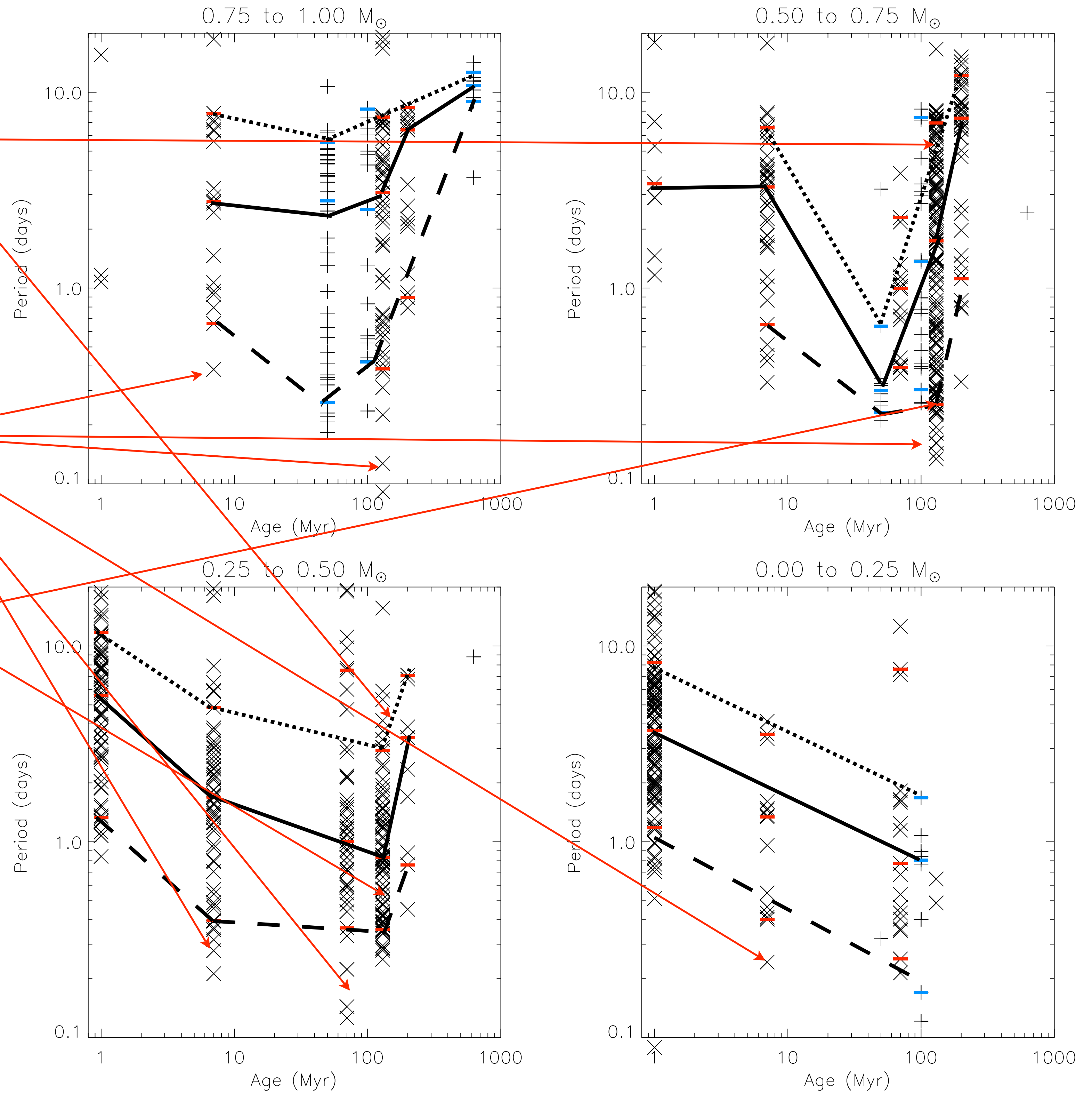
90%ile

Rapid spin-down even for slow rotators on early ZAMS

10%ile

Some objects may be close to break up
(but beware of contamination by W Uma's)

Does the rapid rotator population persist longer after ZAMS at low masses?



Conclusions

- We have determined rotation periods for an unprecedented sample of young stars with known masses & ages, covering:
  - the entire TTauri, PMS and early MS phase
  - solar to brown dwarf masses
- We need to improve membership selection and check the period determinations in some of our clusters but we can already say:
  - the global observed picture fits well with the current paradigm on AM evolution of young stars as described in the introduction
  - evidence of two distinct populations at high masses but only one at low masses
  - ultra-fast rotators?
  - even slow rotators spin down fast on the ZAMS

Future prospects

- Improved membership lists (near IR CMDs, other teams obtaining spectra)
- Additional photometric monitoring data (repeat, other clusters, fainter in M34)
- Spot properties (temperature, area)
- Completeness / reliability corrected period distributions in each mass bin
- Spectroscopic follow-up of stars with periods (better mass and membership, accretion, v sin i, age, binarity)