The angular momentum evolution of low mass young stars : observations

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Outline

- What do observations tell us about J evolution during the PMS ?
- Is PMS braking linked to the accretion process ?
- Modeling J evolution : where do we stand ?

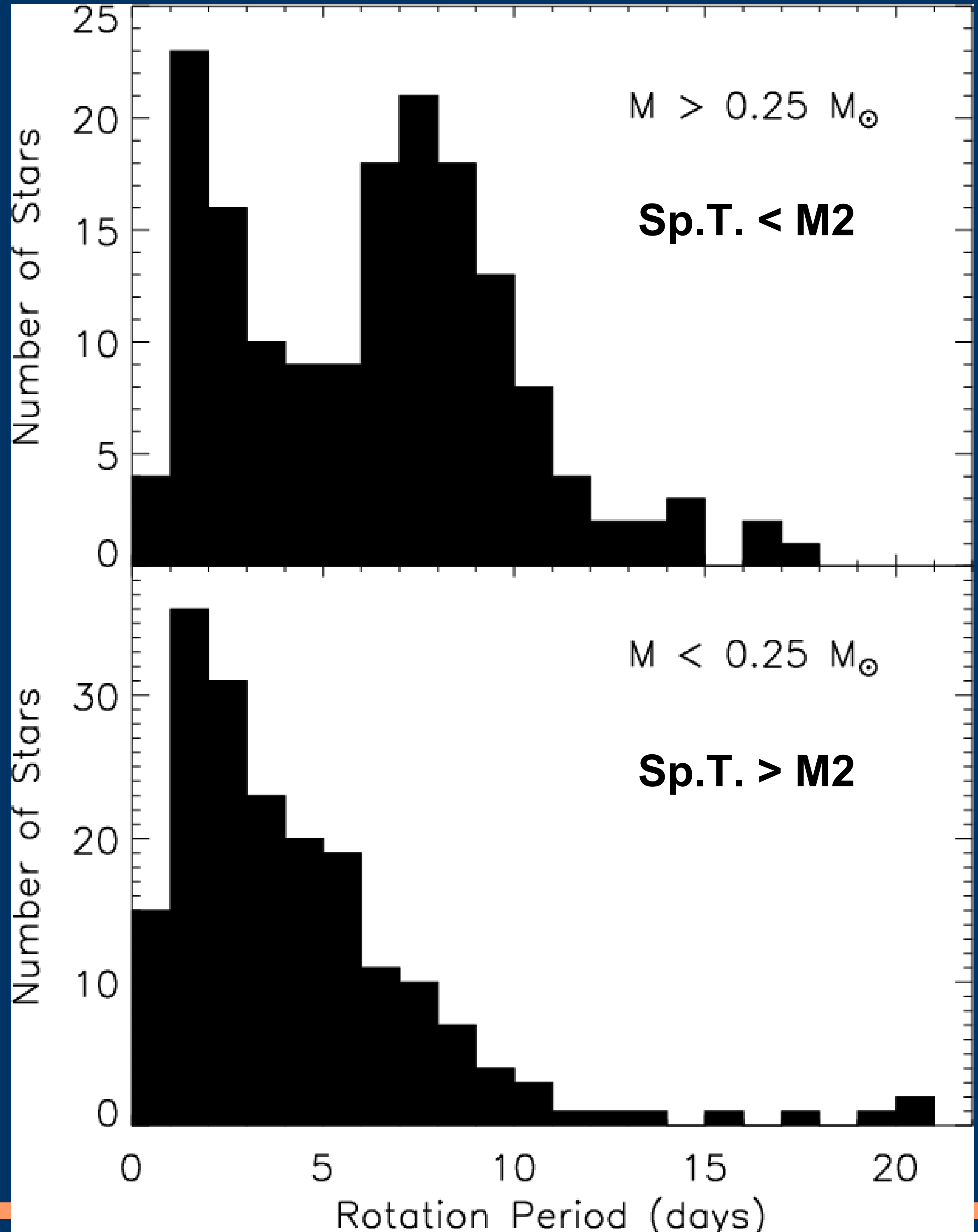
I. What do observations tell us about J evolution during the PMS ?

ONC rotation period distribution (~1 Myr)

Herbst et al. 2002

Strongly mass dependent

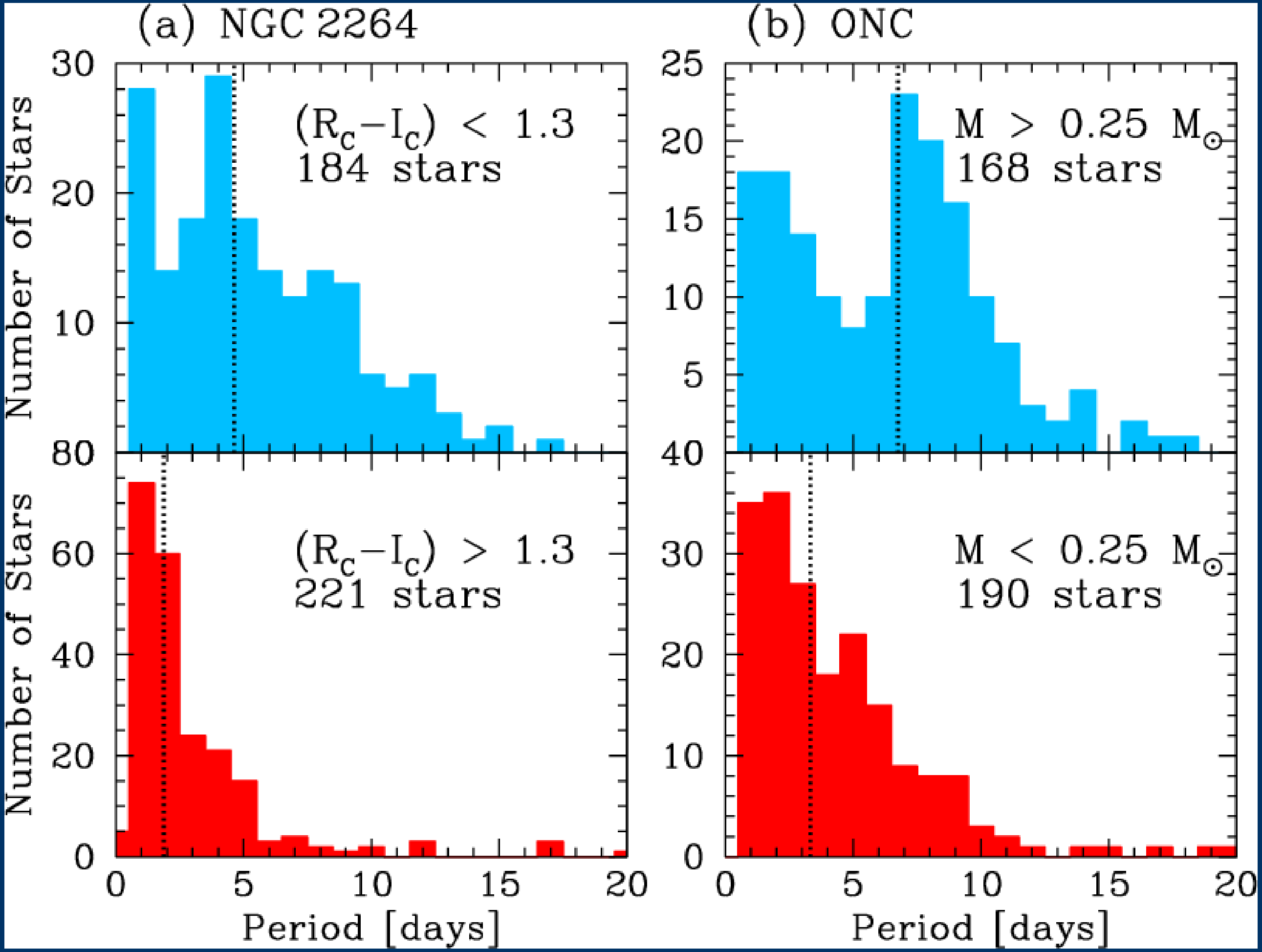
- Bimodal distribution for low-mass stars
- Peaked + tail distribution for very low mass stars which rotate faster on average

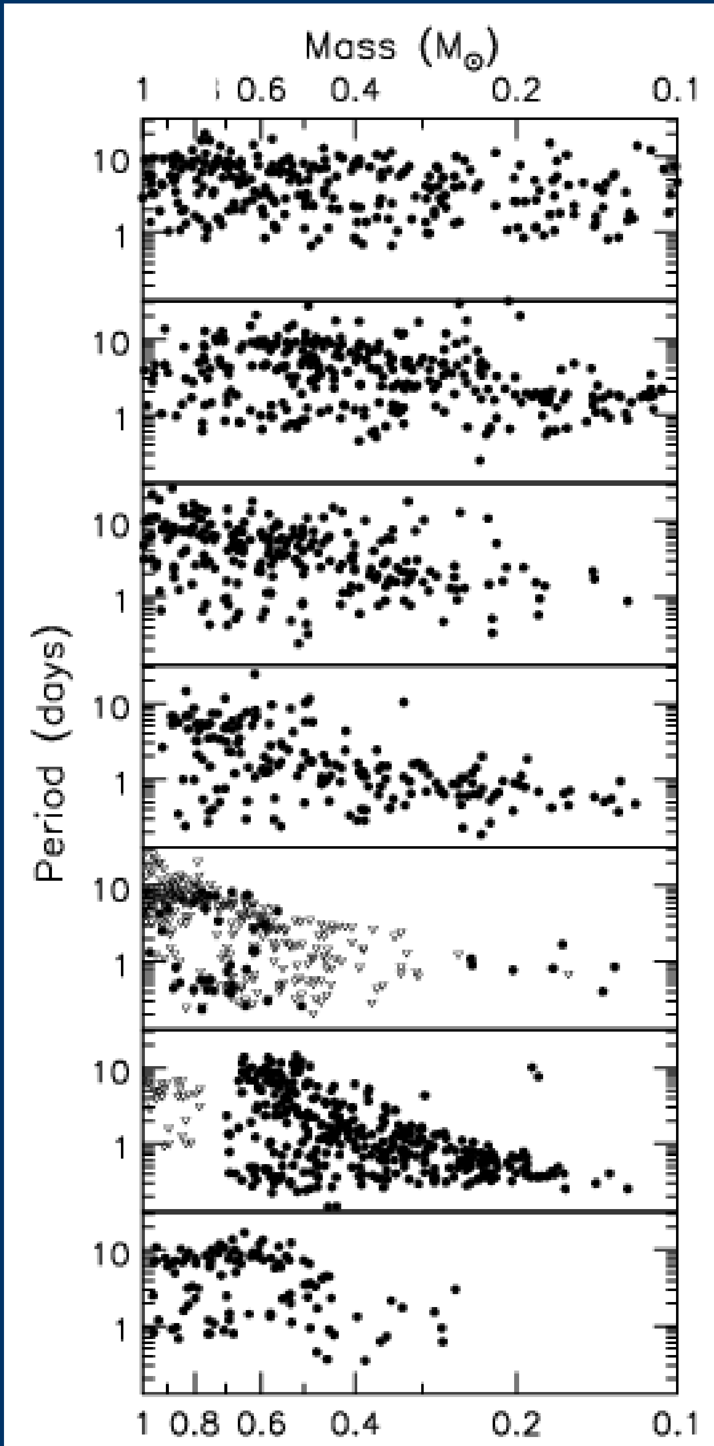


NGC 2264 rotation period distribution (~2 Myr)

Lamm et al. 2005

Similar shape as in ONC but median period spun up by ~ 1.5 on a timescale of ~1 Myr





ONC
1 Myr
(Herbst et al. 2002)

NGC 2264
2 Myr
(Lamm et al. 2005)

NGC 2362
5 Myr

NGC 2547
40 Myr

Pleiades
100 Myr
(compilation)

NGC2516
150 Myr

M34
200 Myr

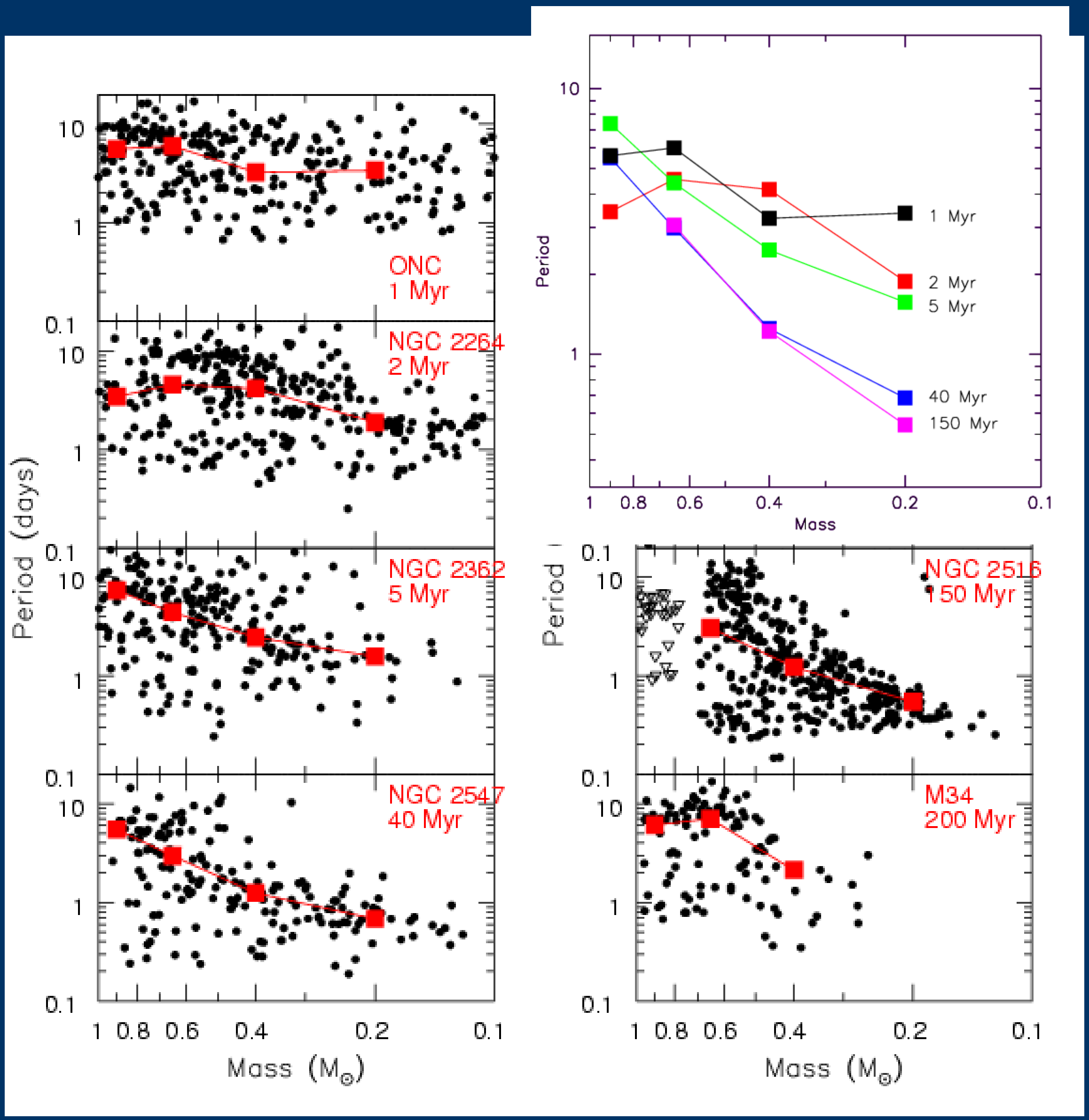
Monitor

Irwin et al. 2006, 2007
Hodgkin et al. 2007
Aigrain et al. 2007

Rotation period measurements for hundreds of stars in the mass range 0.1-1.0Mo in PMS and ZAMS clusters in the age range 1-200 Myr

Provides unique constraints on PMS and early ZAMS angular momentum evolution

Global evolution : median period <P>



<u>Initially</u> (ONC, 1 Myr) :

<P> ~ 3 days 0.1-0.5Mo

<P> ~ 6 days 0.5-1.0Mo

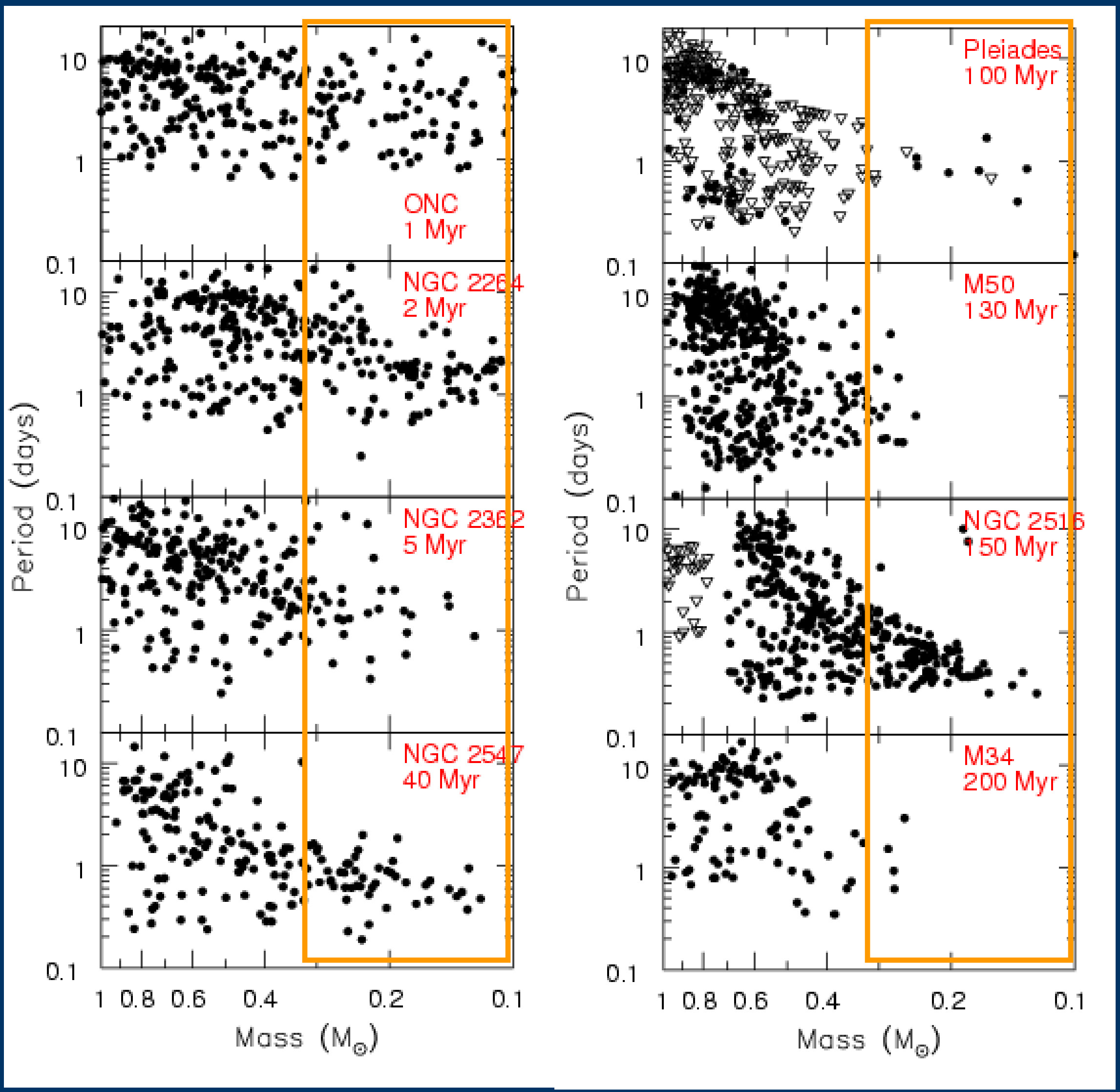
<u>PMS evolution</u> (1 to 40 Myr):

<P> decreases at all masses

More spin up at lower masses

but <P> is not very meaningful…

The very low mass stars (≤ 0.3M$_\odot$)



Initial distribution (~1 Myr) peaks at short periods (~2d) with a tail of slower rotators (up to ~10d)

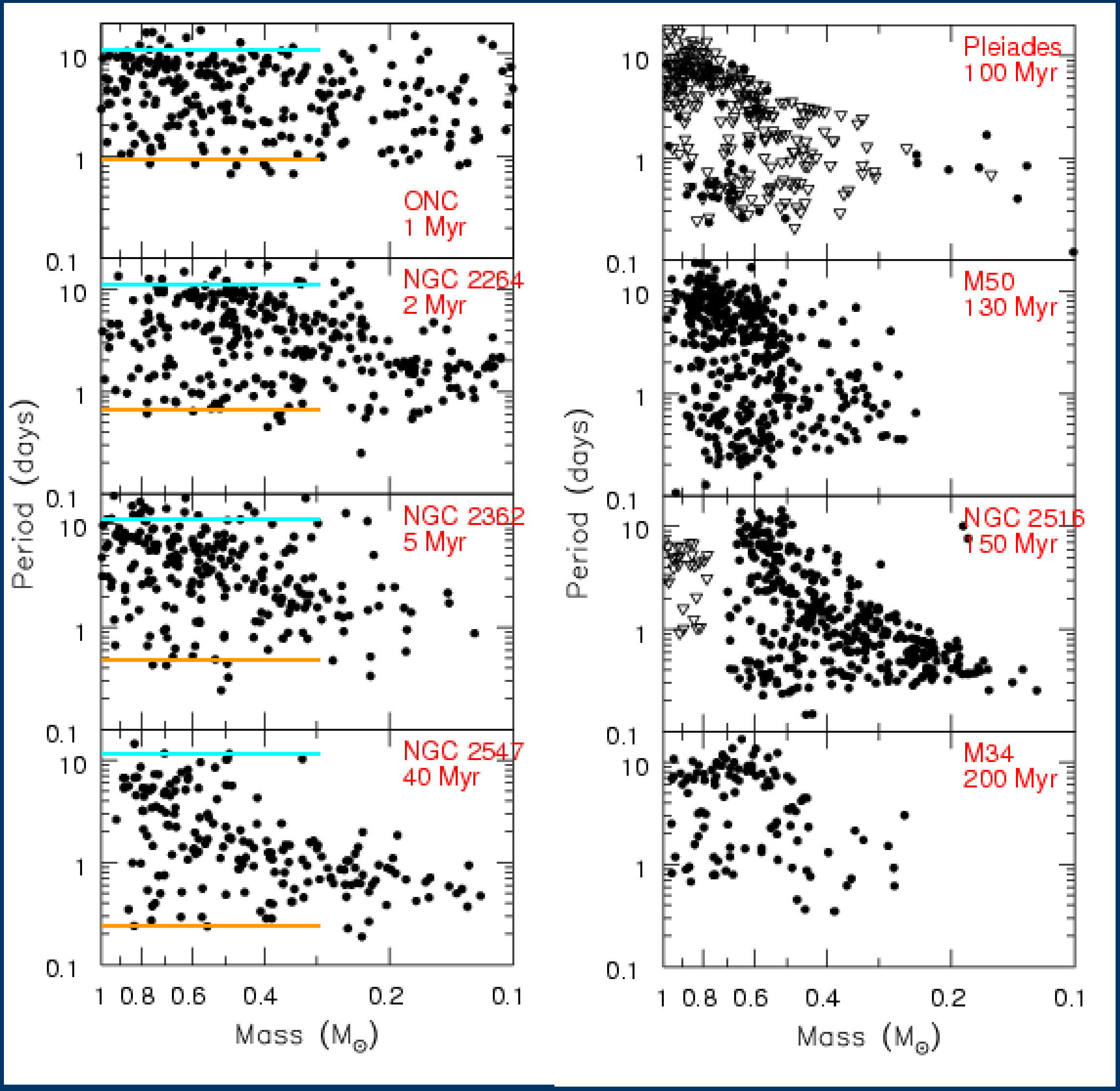
Then, continuous spin up during PMS evolution :

- Slow rotators are quickly spun up (~Myr)
- Fast rotators still accelerate

No evidence for efficient PMS braking for VLM stars

(N.B. : Pmin~0.2d ≡ 0.5 break-up)

The low mass stars ($0.3 \leq M_o \leq 1.0$)



Initial distribution (~1 Myr) is bimodal with peaks at ~2d and ~8d

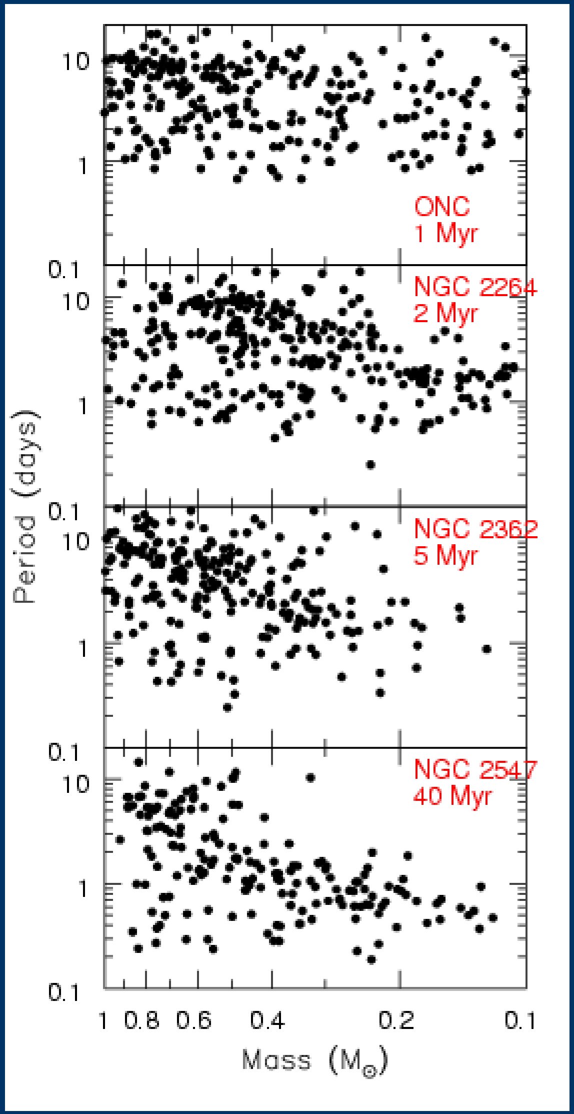
Slow rotators : a fraction of stars remain slowly rotating (P~8-10d) for at least 5 Myr

Fast rotators : spin up from ~0.9d to ~0.2d over a timescale of 40 Myr

Strong PMS braking for a fraction of low mass stars, free spin up for others ($J \sim J_o$).

Angular momentum evolution

Period



Specific angular momentum

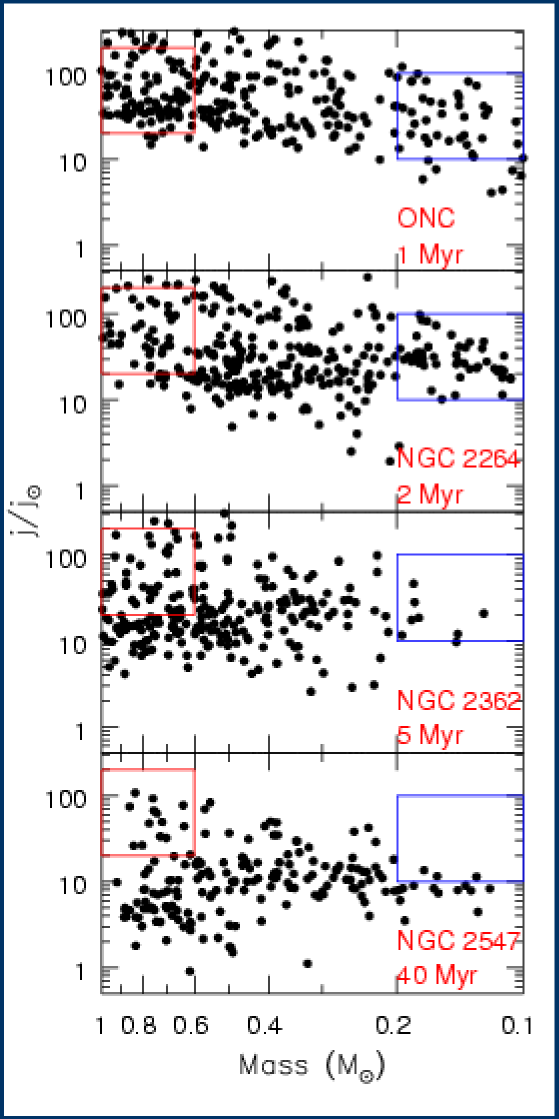
$j \approx R^2/P_*$

j is reduced by a factor of ~3 on average in VLM stars over a timescale of 40 Myr

(instead of ~10 in low mass stars)

Strongly mass dependent

Angular momentum



I. Summary

Low mass stars

(0.3-1.0 M_o)

Strong PMS braking for a fraction of low mass stars, free spin up for others ($J \sim J_o$).

Braking timescale ≥ 5 Myr

Very low mass stars

(0.1-0.3 M_o)

Relatively inefficient PMS braking for VLM stars

II. Is PMS braking linked to the accretion process ?

An accretion-related braking process ?

Search for a correlation between
rotation and accretion diagnostics :
slower rotation expected for accretors

Which accretion diagnostics ?

Near IR excess (JHK) : ambiguous

- passive vs active disks
- NIR variability

UV excess :

- few measurements
- uncertain extinction

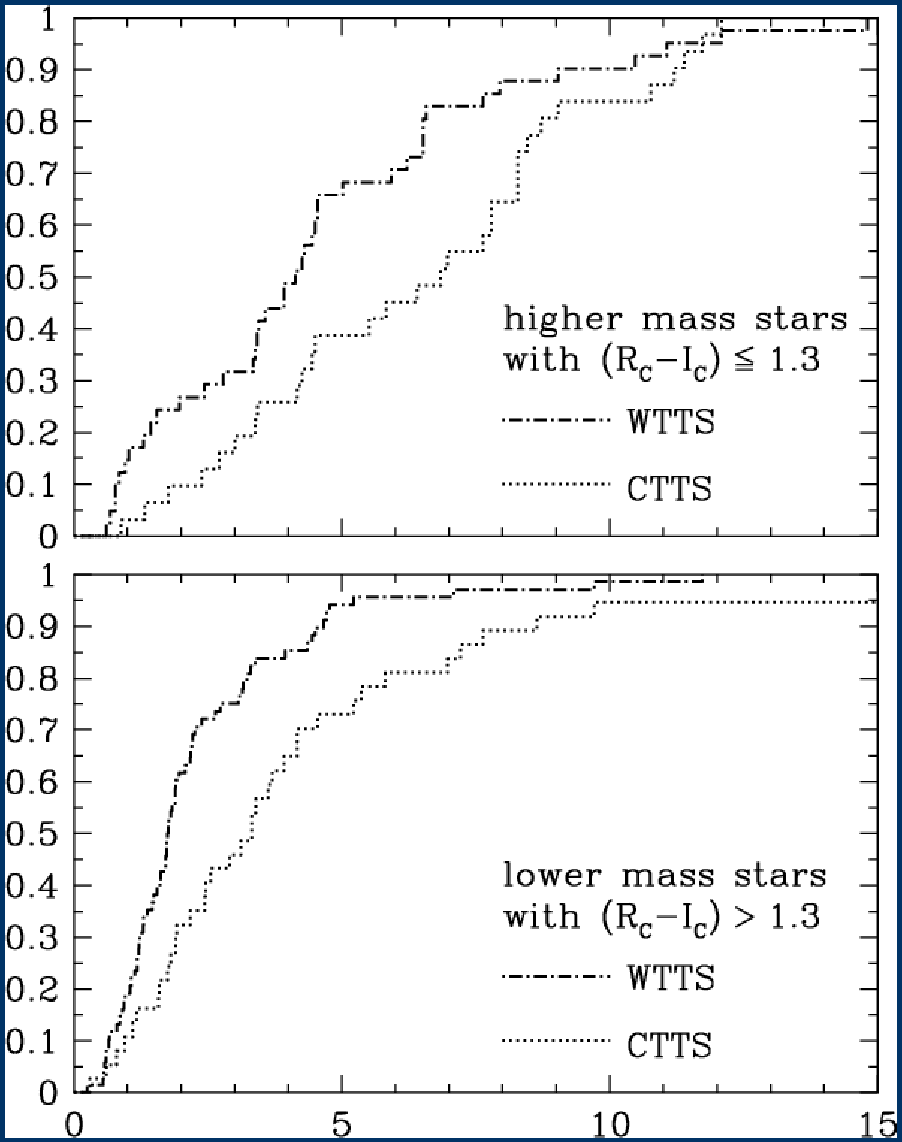
Hα emission : 10% width ≥ 250 km/s

- need hires spectroscopy
- strong nebular emission (ONC)

Mid-IR excess :

- Spitzer
- passive / active disks ?

Rotation – accretion correlation ?



Period (d)

YES !

NGC 2264 (Lamm et al. 2005)

Accretion diagnostics :
photometric EW(Hα)

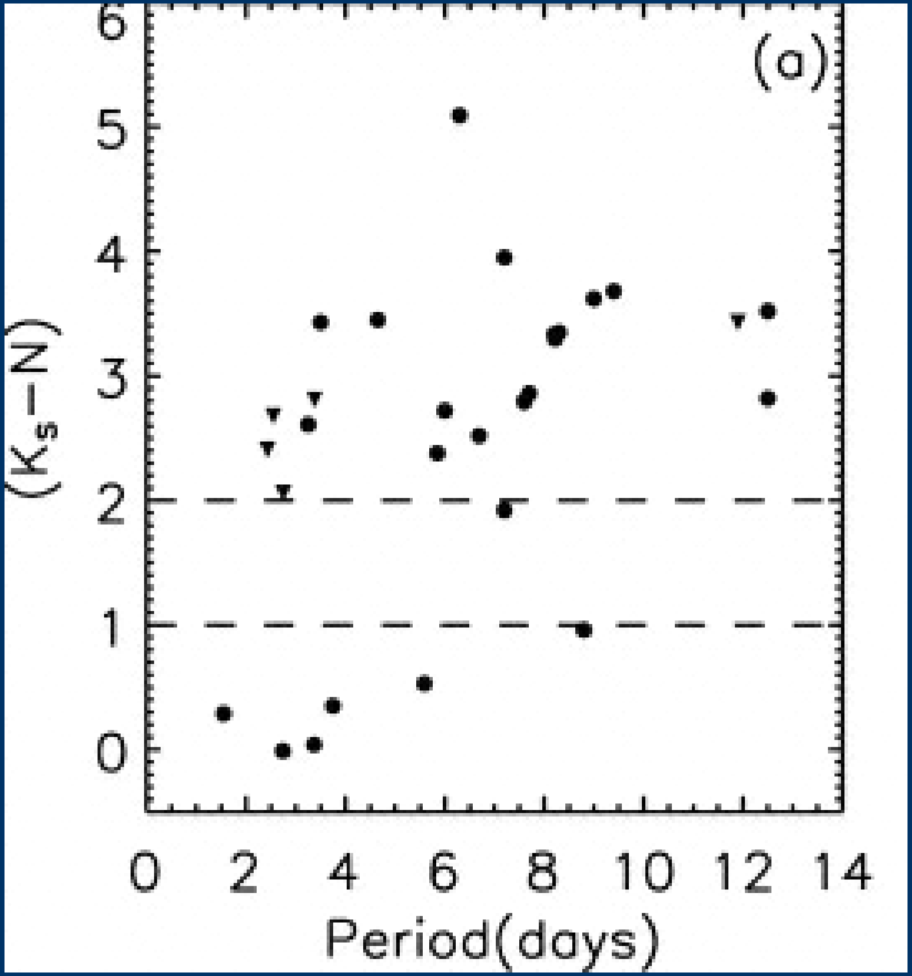
CTTS EW(Hα) ≥ 10 A

WTTS EW(Hα) < 10 A

CTTS rotate more slowly than WTTS on average

Rotation – accretion correlation ?

YES !



Taurus (Kundurthy et al. 2006)

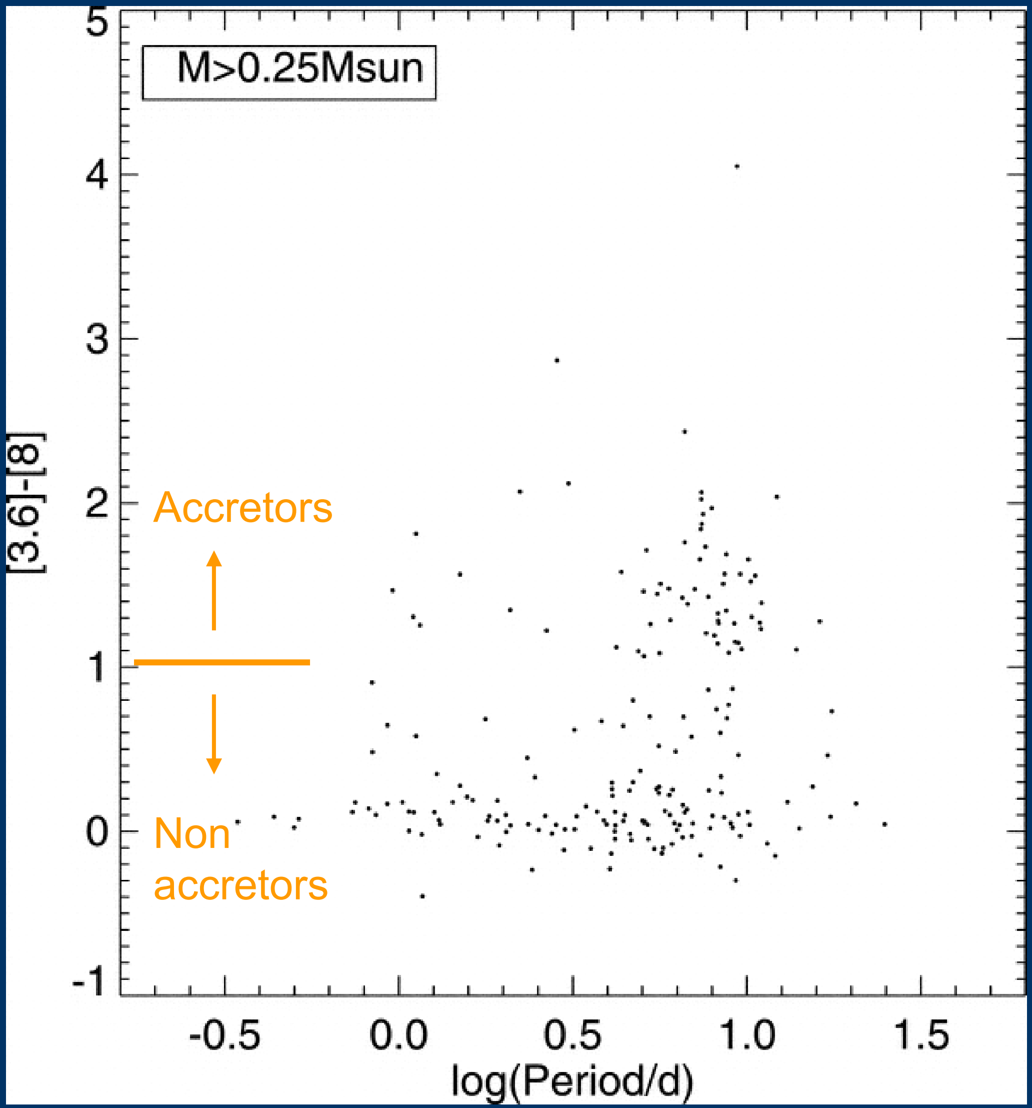
Accretion diagnostics :
mid-IR excess

Disk : (K-N) ≥ 2 mag

No disk : (K-N) < 2 mag

Stars with optically thick disks rotate more slowly than diskless stars on average

Rotation – accretion correlation ?



YES !

Orion region (Rebull et al. 2006)

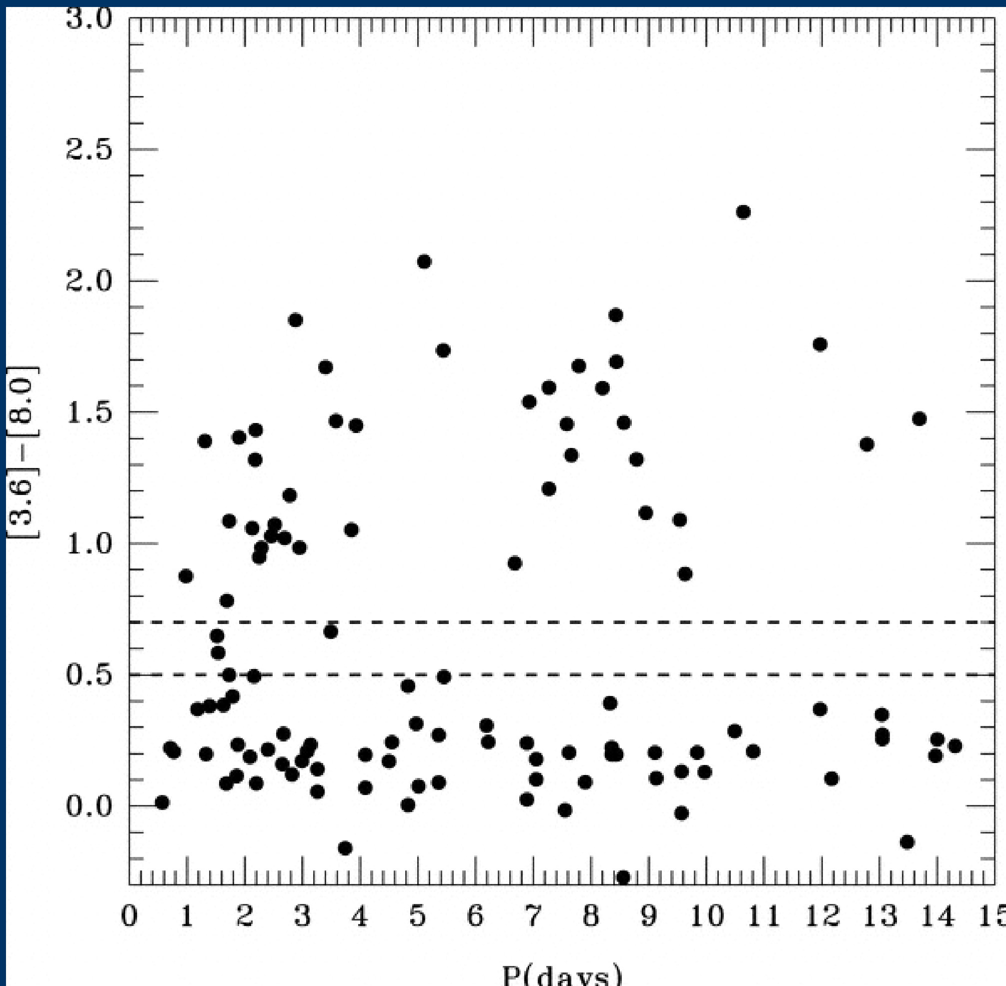
Accretion diagnostics :
mid-IR excess (Spitzer)

Accretors : [3.6]-[8] ≥ 1 mag

Non accretors : [3.6]-[8] < 1 mag

Accretors rotate more slowly than non accretors on average

Rotation – accretion correlation ?



NO !

IC 348 (Cieza & Baliber 2006)

Accretion diagnostics :
mid-IR excess (Spitzer)

Accretors : [3.6]-[8] ≥ 1 mag

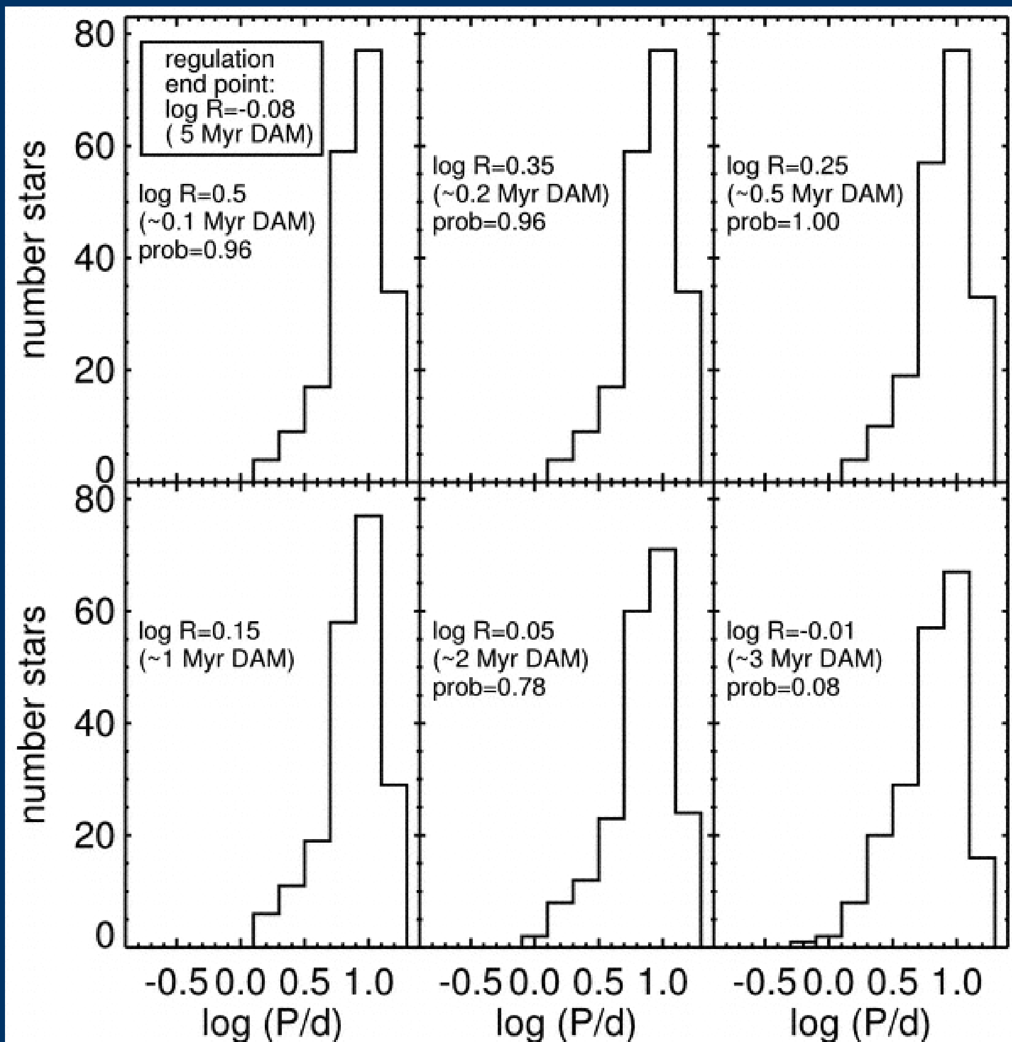
Non accretors : [3.6]-[8] < 1 mag

Statistically similar period distributions for excess and non excess stars

N.B. : 0.1-1.0 M_o

Do conflicting results exclude disk braking ?

How conspicuous should the rotation-accretion correlation be ?



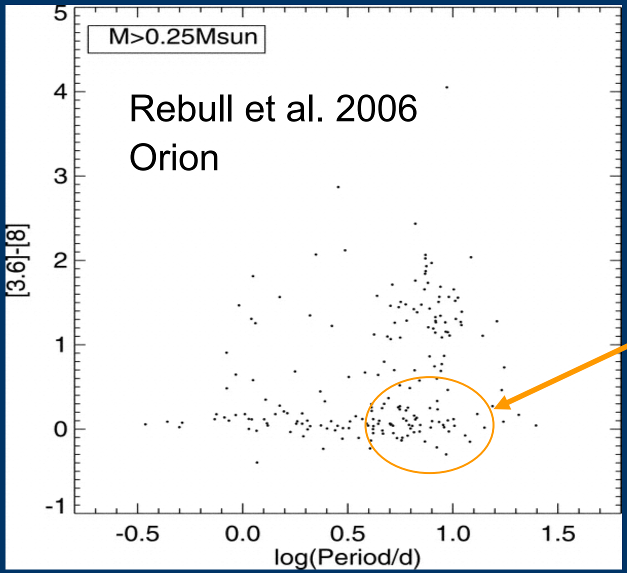
Monte Carlo simulations (Rebull et al. 2004)

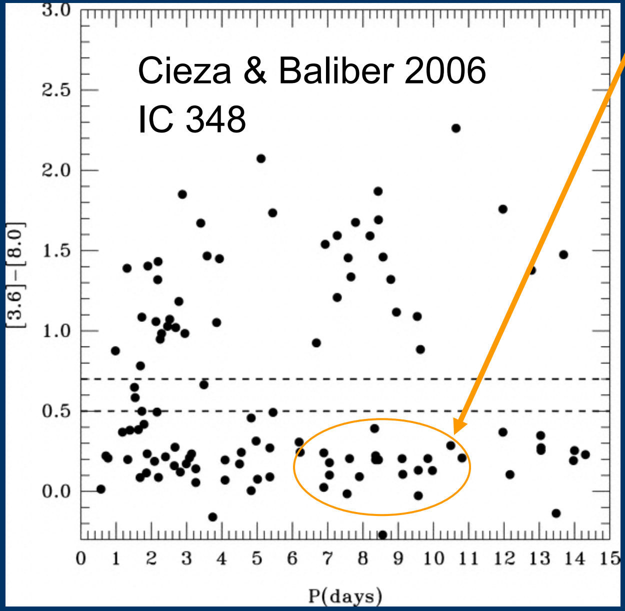
Synthetic sample of stars released from their disk linearly with time between the birth line and 5 Myr

The period distribution of regulated and released stars cannot be distinguished statistically unless N ≥ 400 per mass bin !

(even with a perfect knowledge of accretors / non accretors)

Lack of rotation-accretion correlation would not disprove accretion-related PMS braking.





Still…

A significant fraction of slowly rotating stars are diskless !

Recently released from their disks ?

Unlikely : disk dissipation timescale ~ 0.1 Myr

What are these ? Accreting stars with large inner disk holes ? Search for spectroscopic diagnostics of accretion…

II. Summary

- Conflicting evidence for/against accretion-rotation correlations from current samples
- Does not disprove accretion-related PMS braking (needs better statistics & better characterized samples)
- Still, a significant fraction of (apparently) non accreting stars have low rotation rates. Does not fit well into the disk-locking paradigm.

III. Modeling J evolution : where do we stand ?

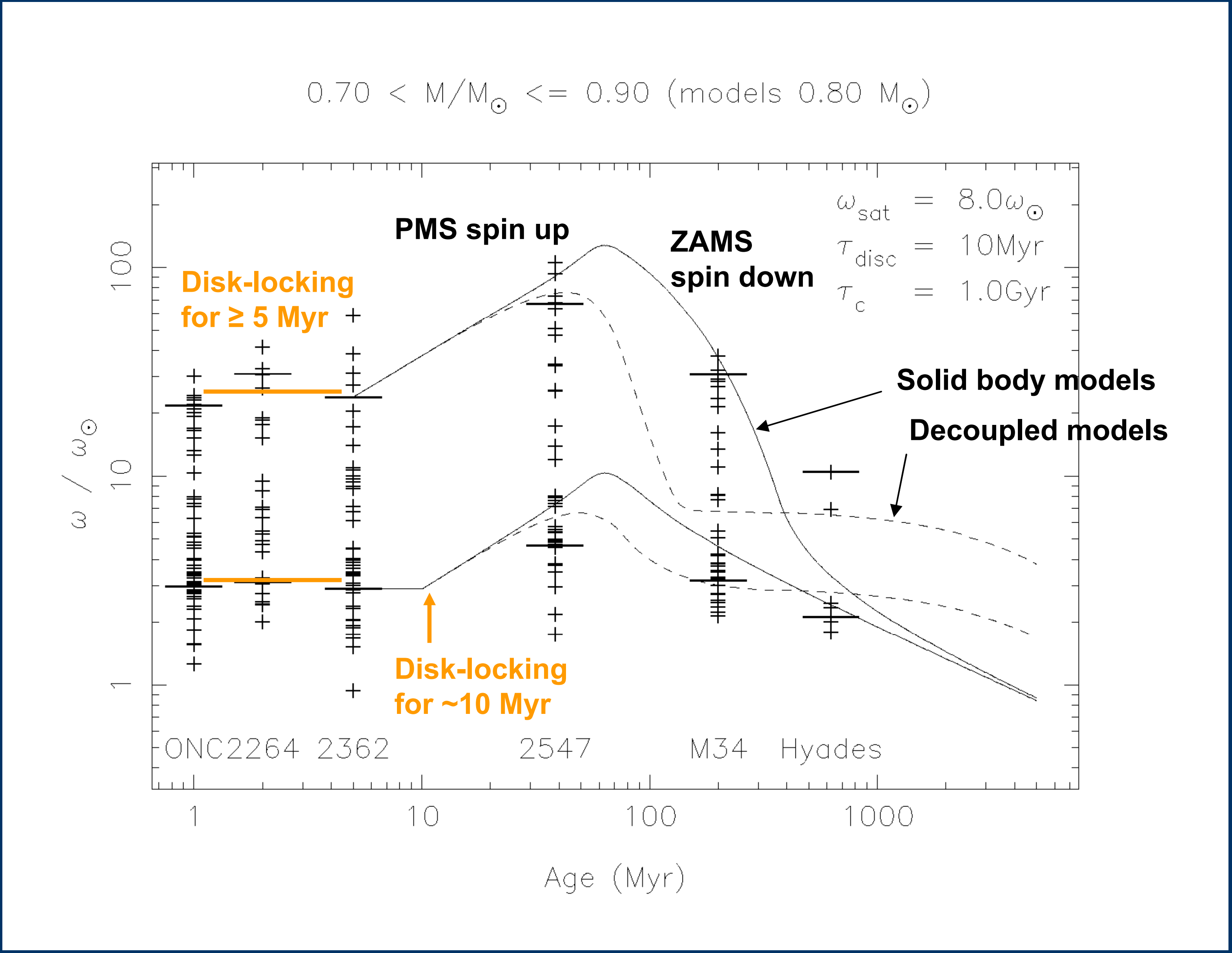
J evolution models : assumptions

- H0 : Stars accreting from their disk evolve at constant angular velocity (« disk-locking » hypothesis)
- H1 : When the disk dissipates, they start to freely spin up as they contract towards the ZAMS
- H2 : A magnetized wind brake the stars on the ZAMS

Little progress in the last 10 years !

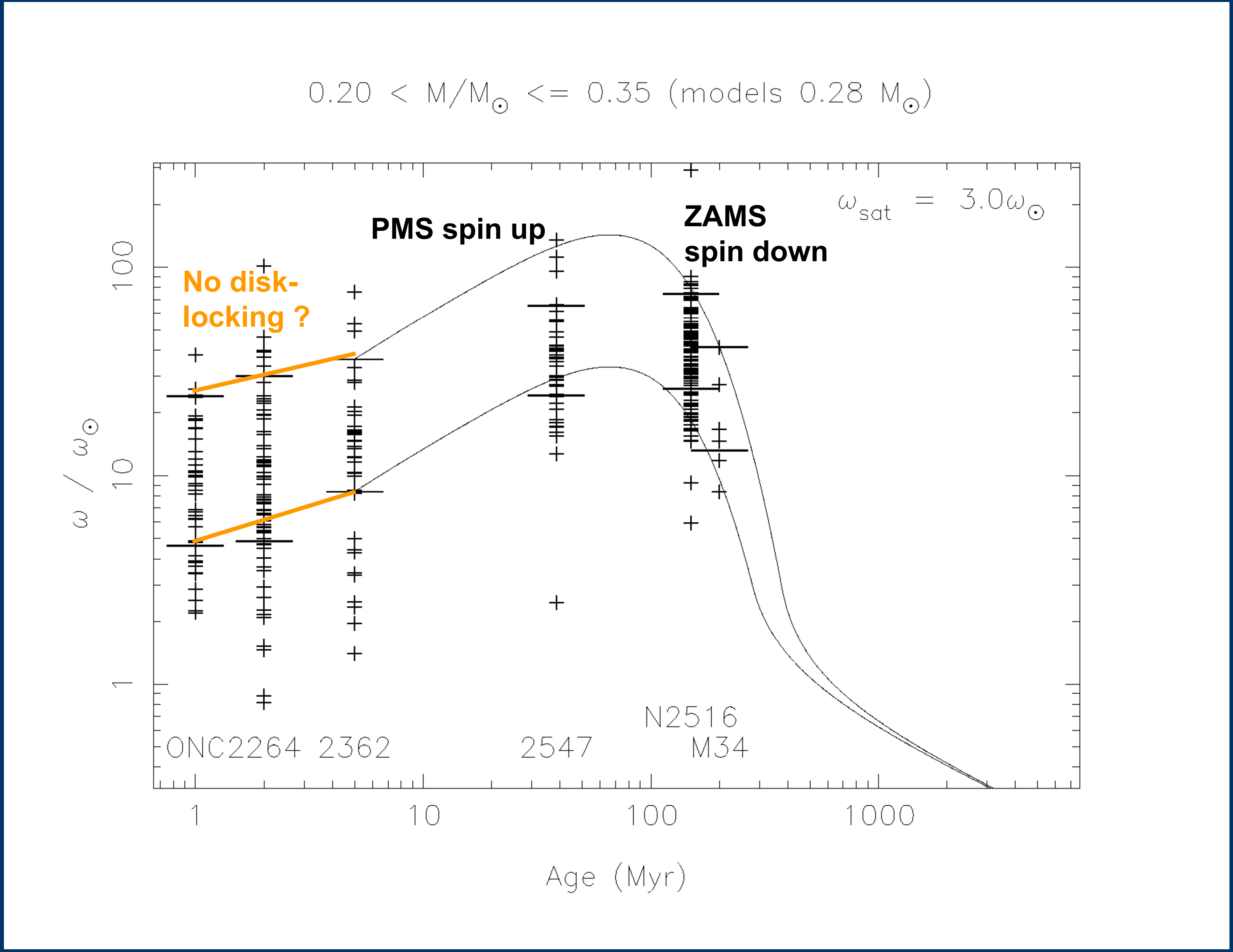
0.8 M_o models

(Irwin et al., in prep.)



0.3 M_o models

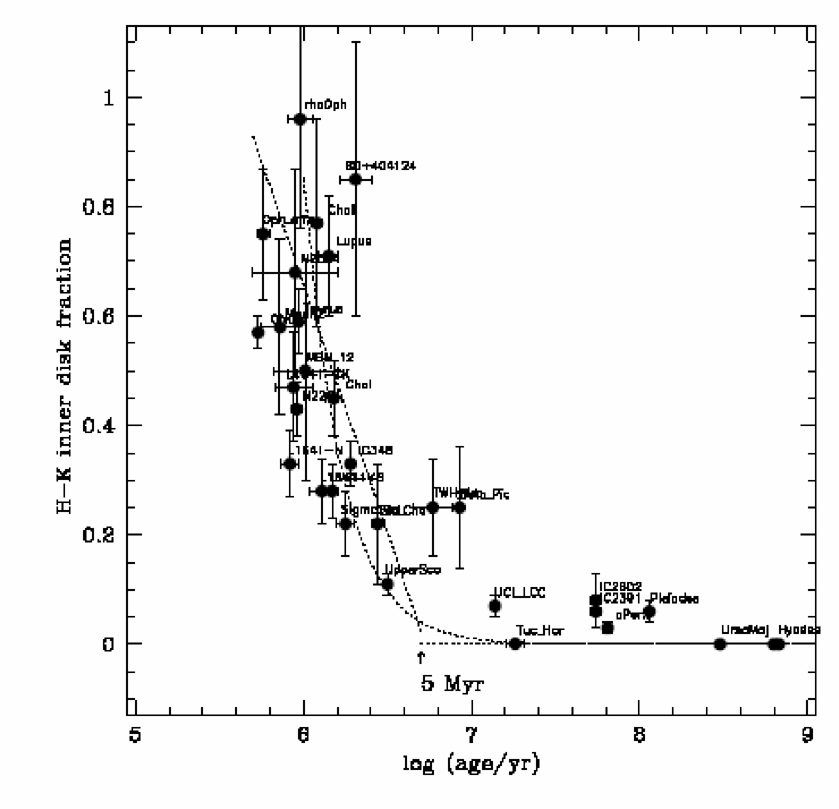
(Irwin et al., in prep.)



<u>Accretion</u> disk lifetimes ?

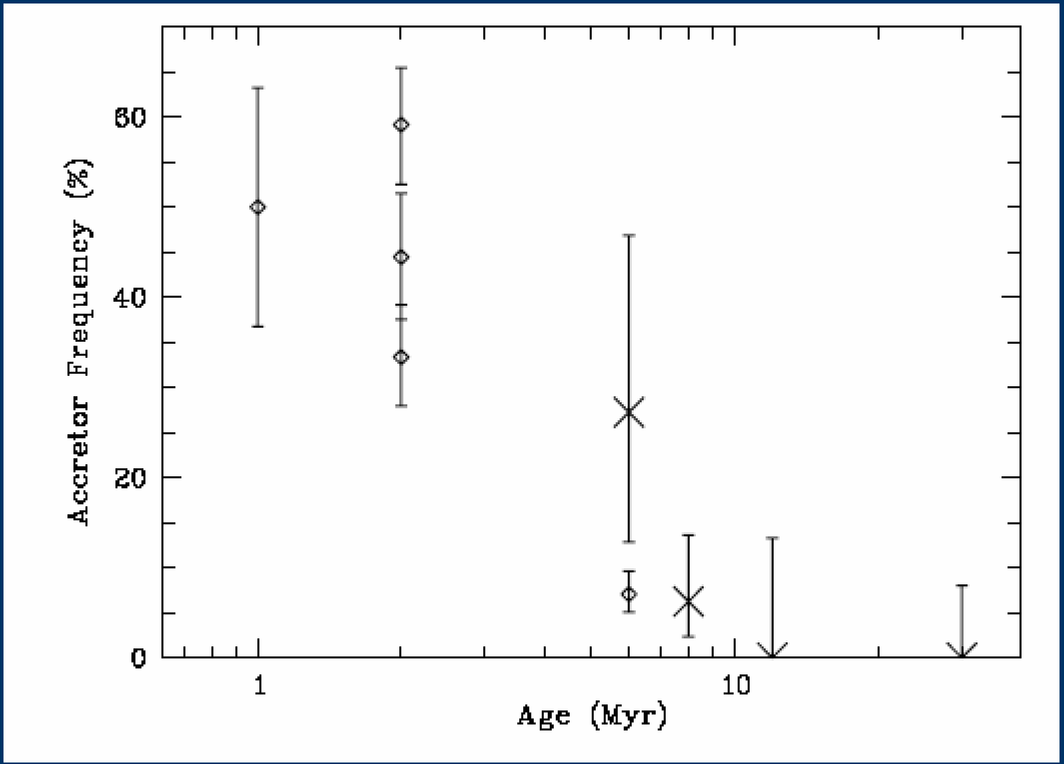
- J evolution models suggest accretion disk lifetimes ≥ 5 Myr for a significant fraction of low mass stars, and up to 10 Myr

H-K excess : inner disks



Hillenbrand 2005

Hα 10% width : accretors



Jayawardhana et al. 2006

Conclusions

- Compelling evidence for (mass-dependent) PMS braking over a timescale ≥ 5 Myr

  Observations need to bridge the gap between 5 and 40 Myr

- Evidence for accretion-related PMS braking.

  X-winds ? Disk-locking ? Accretion-driven stellar winds ?
  Need predictions that can be tested observationally !

- J evolution models : need for a physical description of PMS braking instead of empirical assumptions/parametrized laws

  (+ idem for core-envelope decoupling, solar-type winds)

- Slowly rotating diskless stars : « a pebble in the shoe » ?

(is PMS braking a continuous or sporadic process ? e.g. FUOri eruptions?)