Rotational periods and evolutionary models for subgiant stars

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Related Poster: XX

Angular Momentum of Cool Stars:
Collaborators: M. Castro(DFTE), P. Petit(OMP,FR), G. Pace, M. Bazot, (Porto) J. Melendez,(USP) G.P de Melo (UFRJ, Valongo), Jefferson Soares da Costa, Matthieu Castro (CoRoT stars), // B. Chaplin, R. Garcia, S. Manthur (KEPLER stars)

- ✓ Subgiant sample and time series analysis
- ✓ Evolutionary models and rotational periods
- ✓ Results
- ✓ Conclusions

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LETTER TO THE EDITOR

Rotational periods and evolutionary models for subgiant stars observed by CoRoT★,★★

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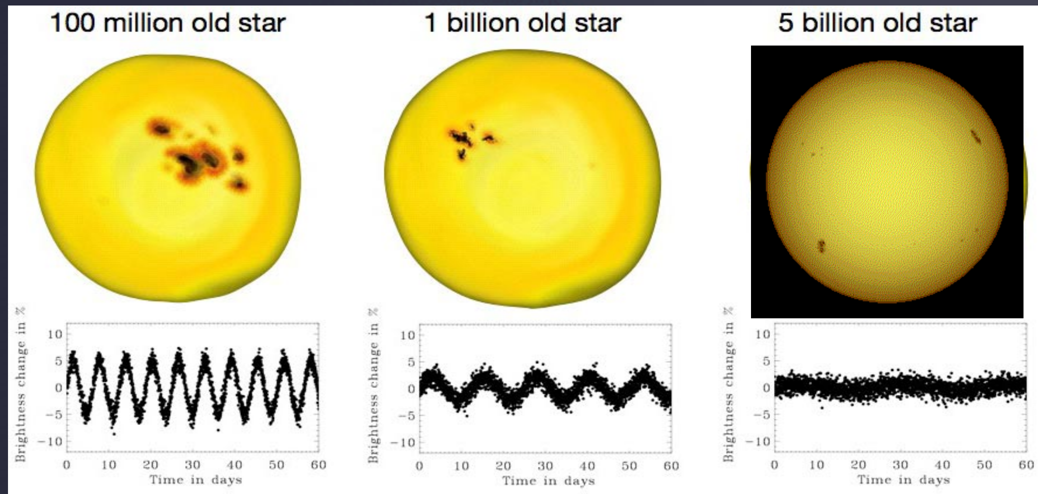
Rotaion

- Fundamental stellar property
- Intimately related
  - generation of magnetic field and magnetic activity
  - Loss of mass
  - Interior structure, mixing, chemical evolution…

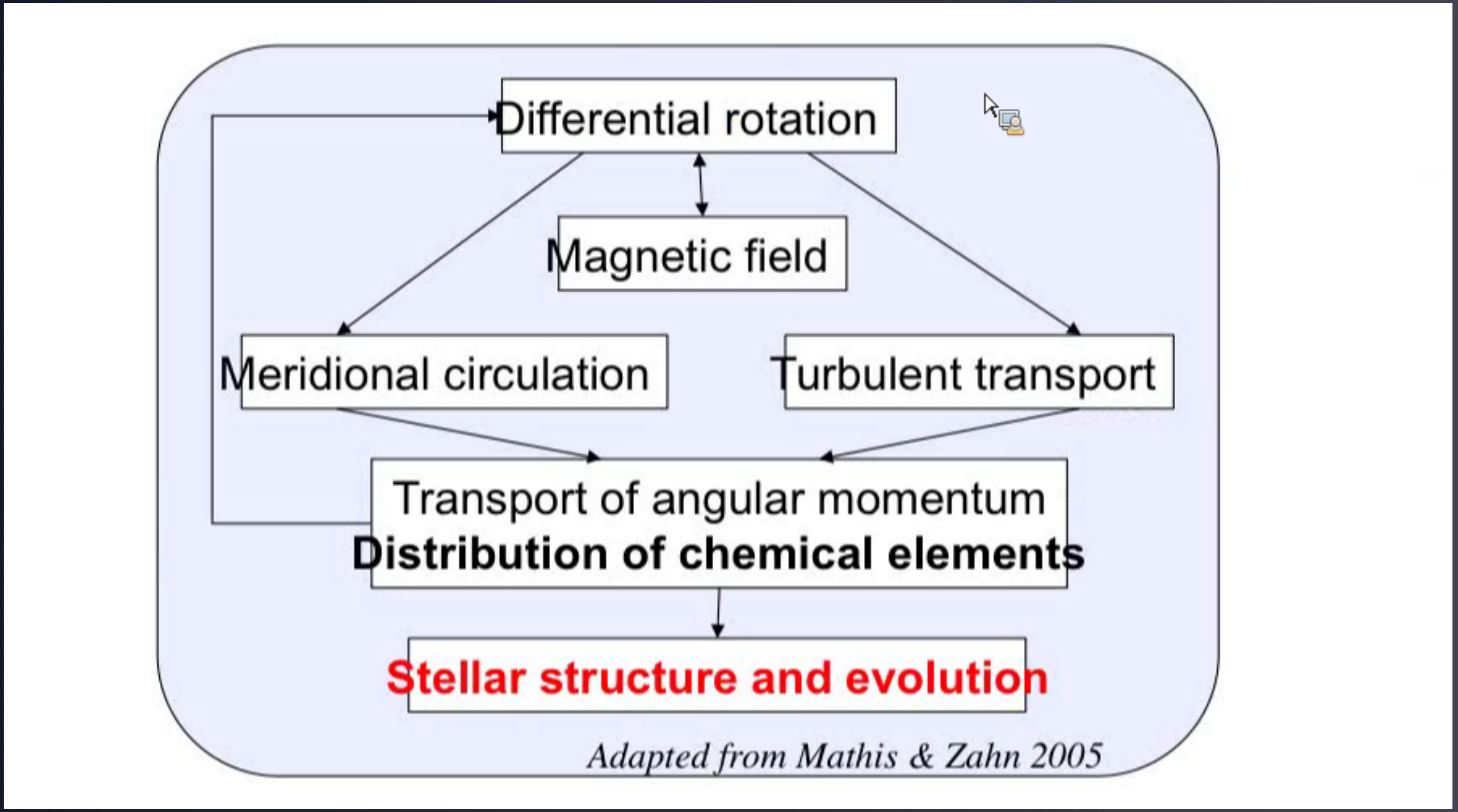
Challenger task

Measuring the spin rates for old stars

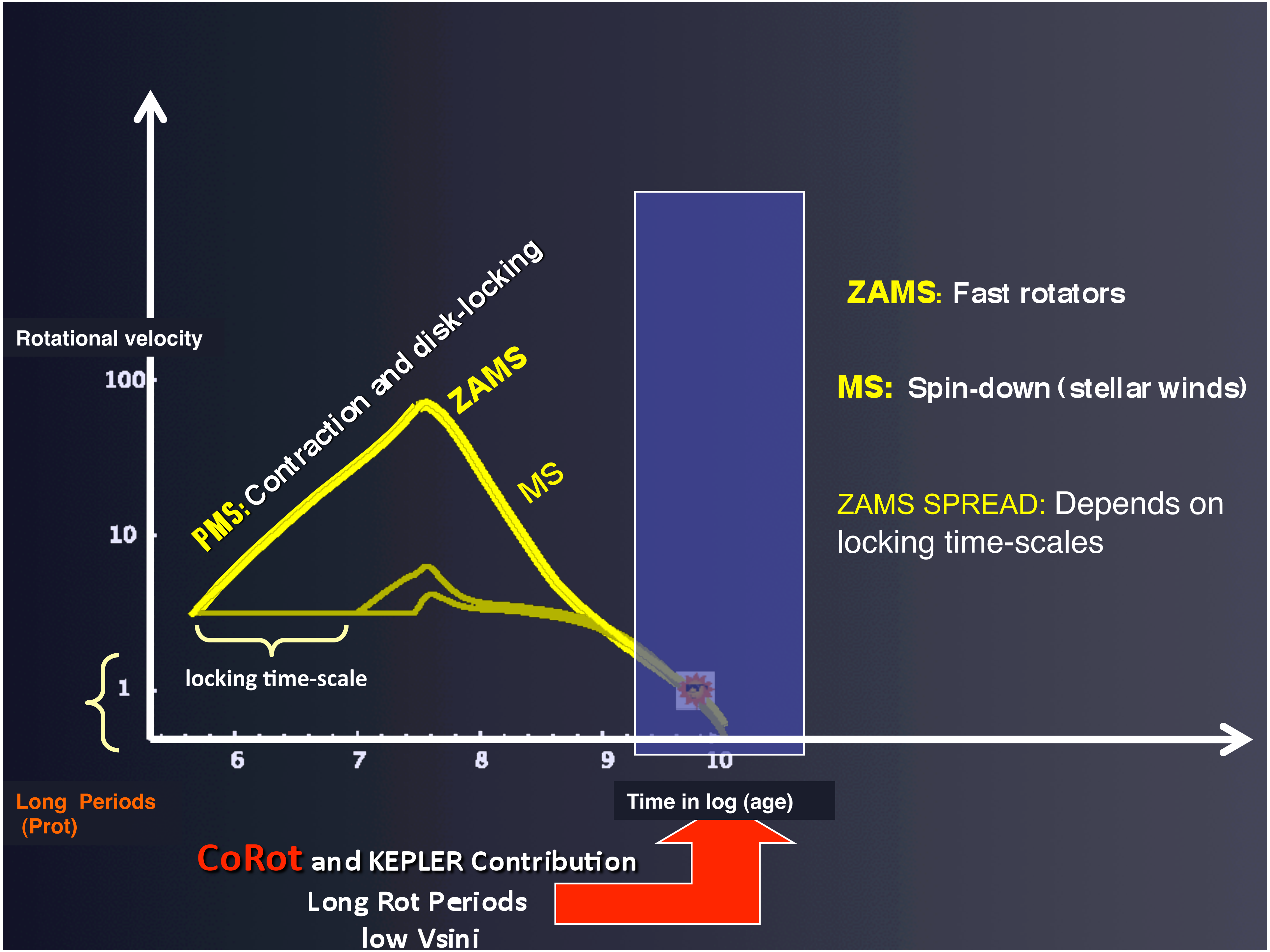


KEPLER / Søren Meibon, ApJL 733 L9. 2011

Rotation and stellar evolution

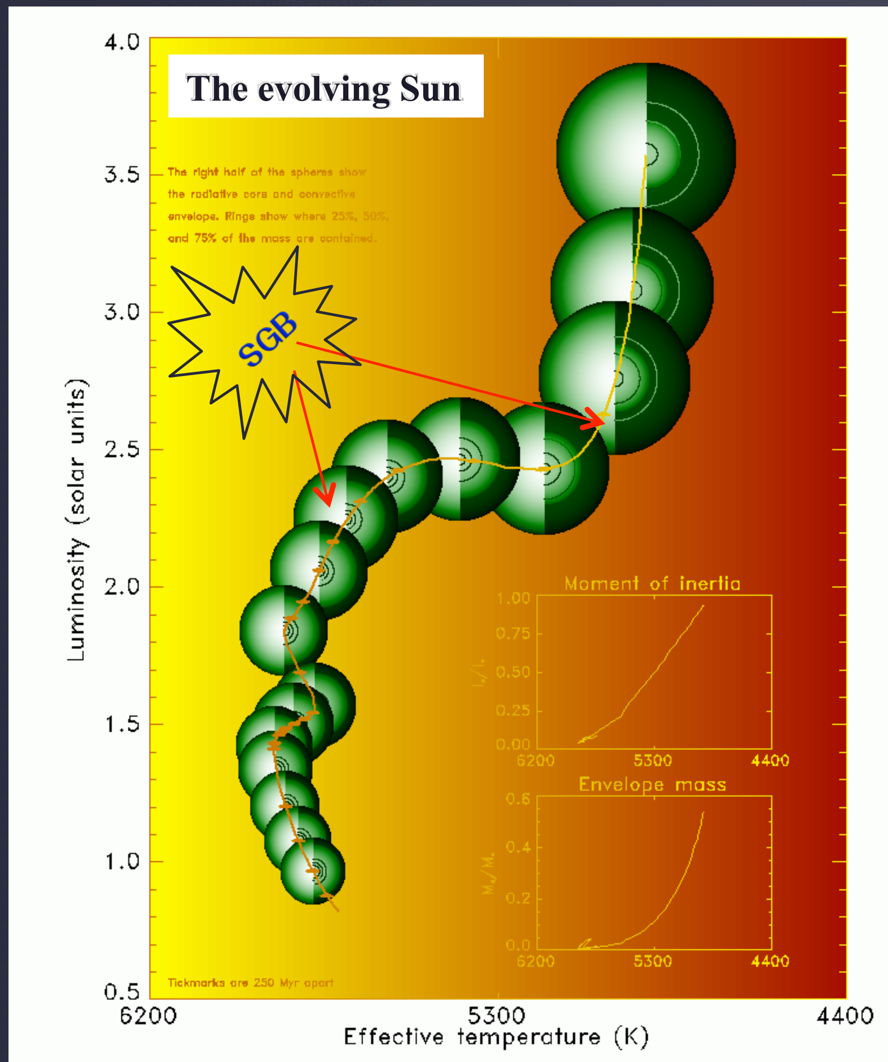


Complex role in our understanding of stellar structure and evolution


Rotational velocity
100
10
1
PMS: Contraction and disk-locking
ZAMS
MS
locking time-scale
6
7
8
9
10
Long Periods
(Prot)
Time in log (age)
ZAMS: Fast rotators
MS: Spin-down (stellar winds)
ZAMS SPREAD: Depends on locking time-scales
CoRot and KEPLER Contribution
Long Rot Periods
low Vsini

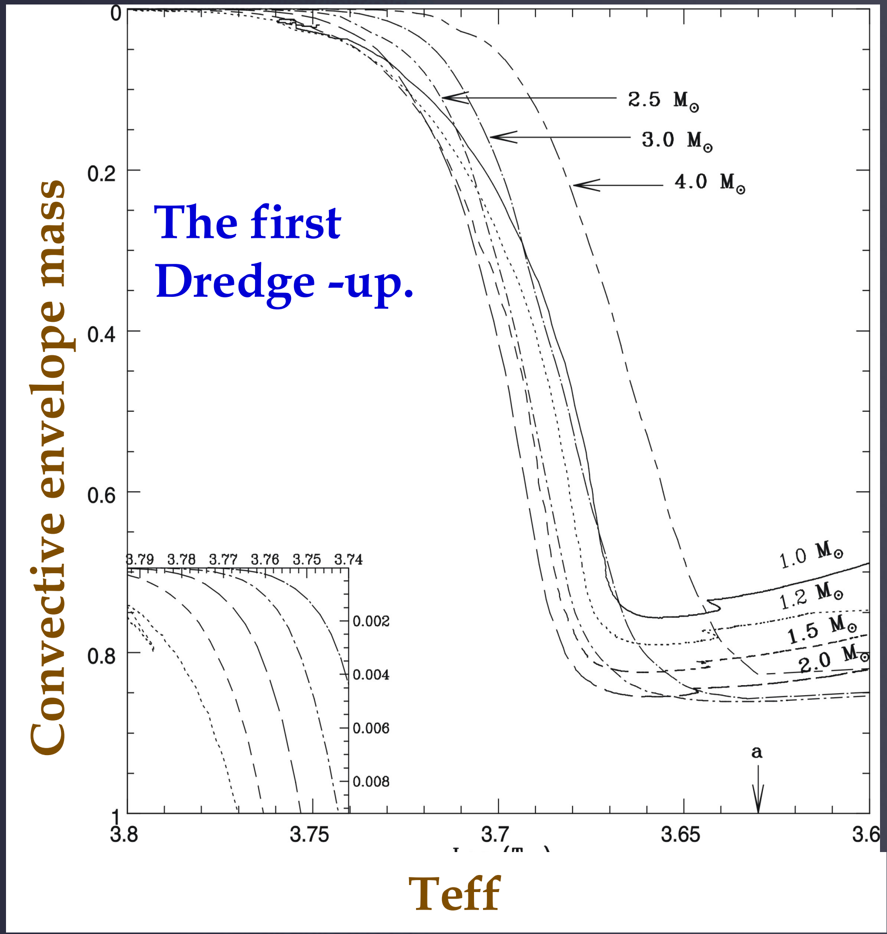
Why subgiants...

- ✓ A known rare class of objects
- ✓ Dating purpose
- ✓ Associated with rotation periods (Prot) -> stellar gyrochronology
- ✓ Small range of masses
- ✓ F-type subgiants are important for studying solar-like oscillations



Why subgiants...

- Subgiant branch: their surface convection zone becomes deeper.
- The matter that resided below the surface convection zone at the MS is then exposed.
- The Prot of subgiant stars could constrain the interior angular momentum distribution and mixing in low-mass stars.



do Nascimento et.al 1999 , do Nascimento et.al 2003 A&A

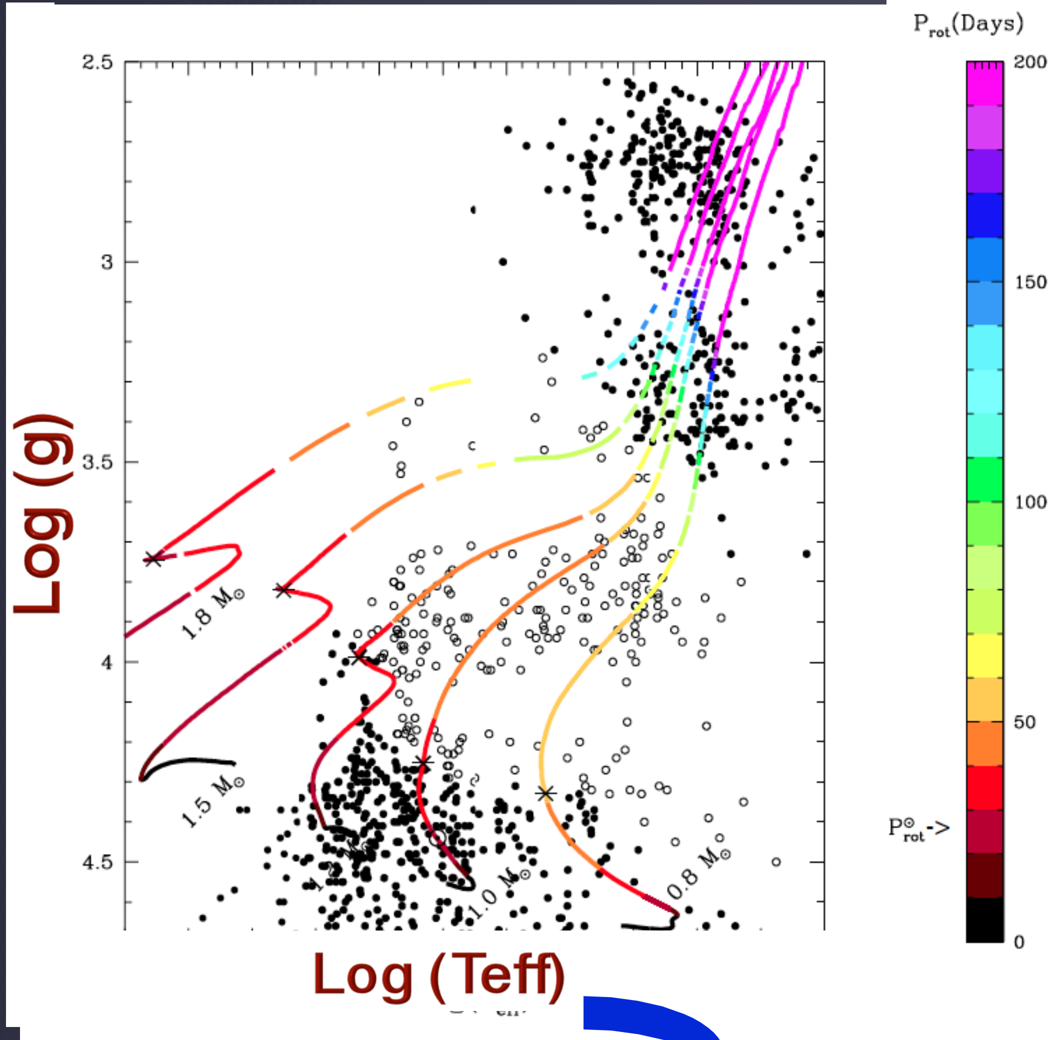
CoRoT Subgiant stars

– 196 subgiants classified as subgiants by Gazzano et al. (2010)

– CoRoT Exo-dat (Deleuil et al. 2006; 2009; Meunier et al. 2007)

– Public data level 2 (N2) delivered by the CoRoT pipeline after nominal corrections (Samadi et al. 2006).

– Teff, logg, [M/H], vsini from Matisse (Recio-Blanco et al. 2006)



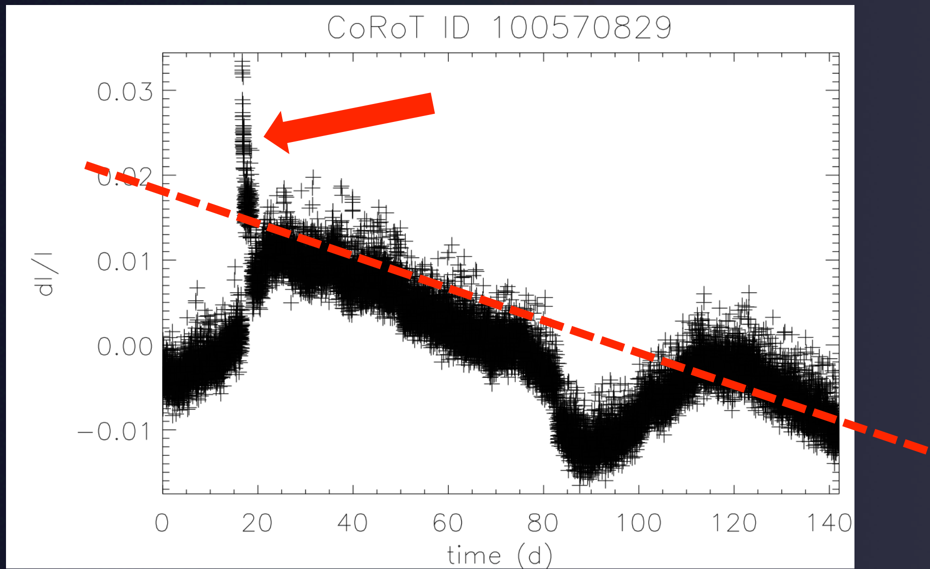
Infrared JHK 2MASS band
c_1, c_2, c_3 e c_4 (Catelan et al. 2011)

$$c_3 \equiv (J-H) - 1.47(H-K)$$

do Nascimento et al. A&A 548, L1 (2012)

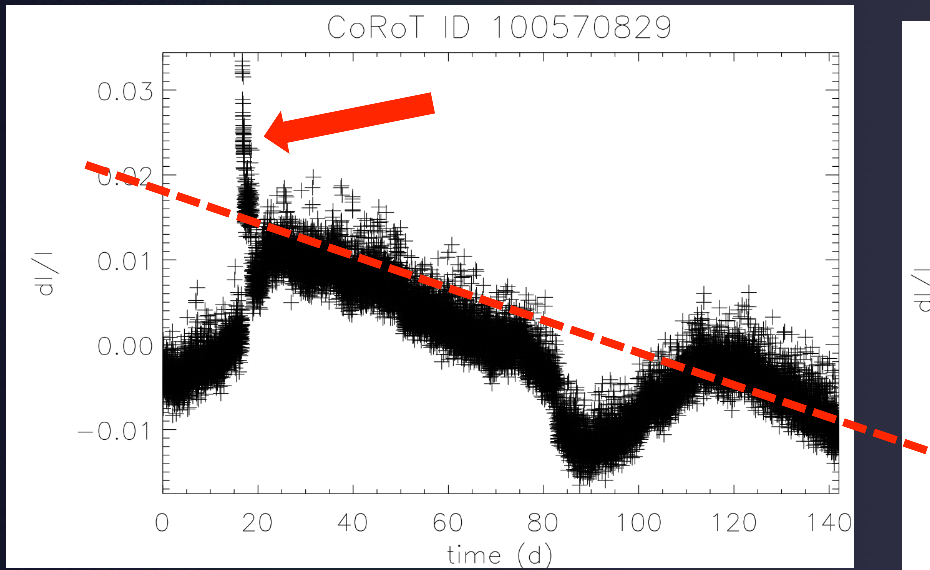
Time series analysis

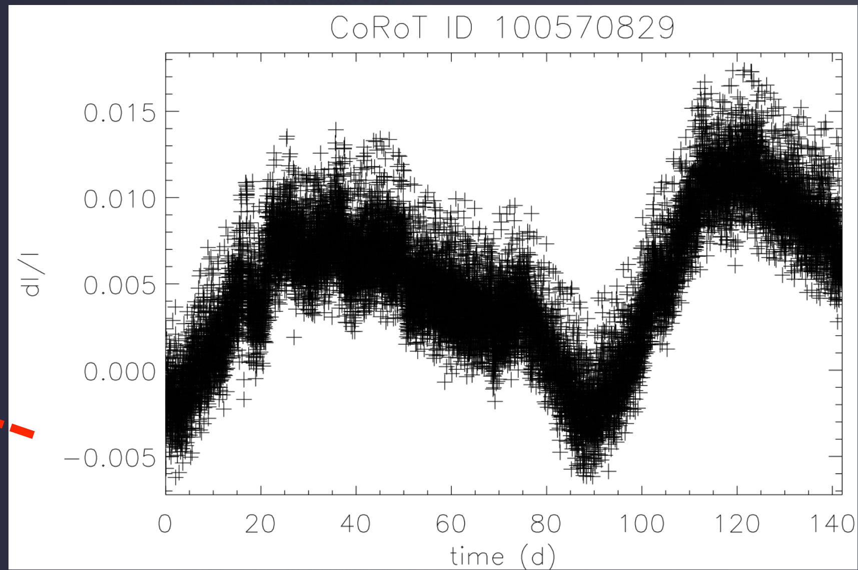
Light Curve correction



CoRoT ID 100570829

CoRoT ID 100570829

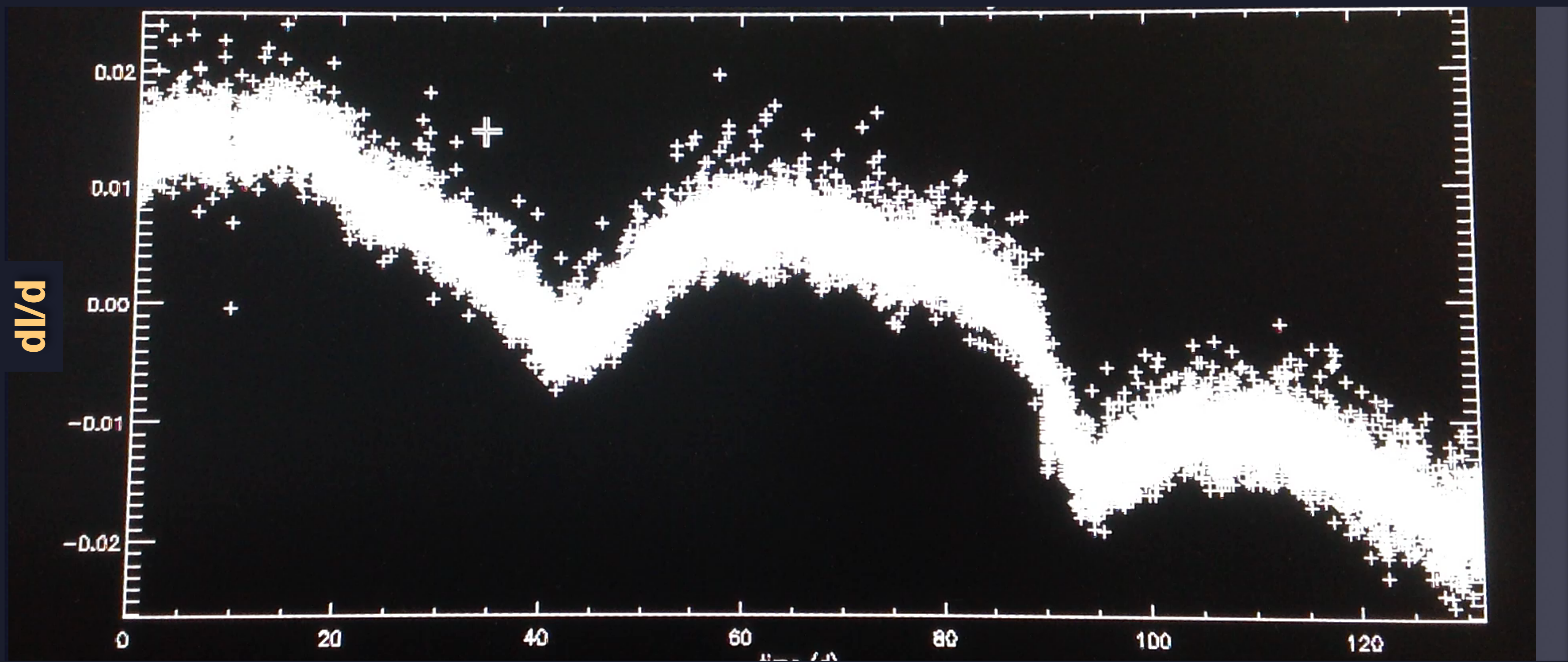




Prot = 84.2 days

DETREND CORRECTION

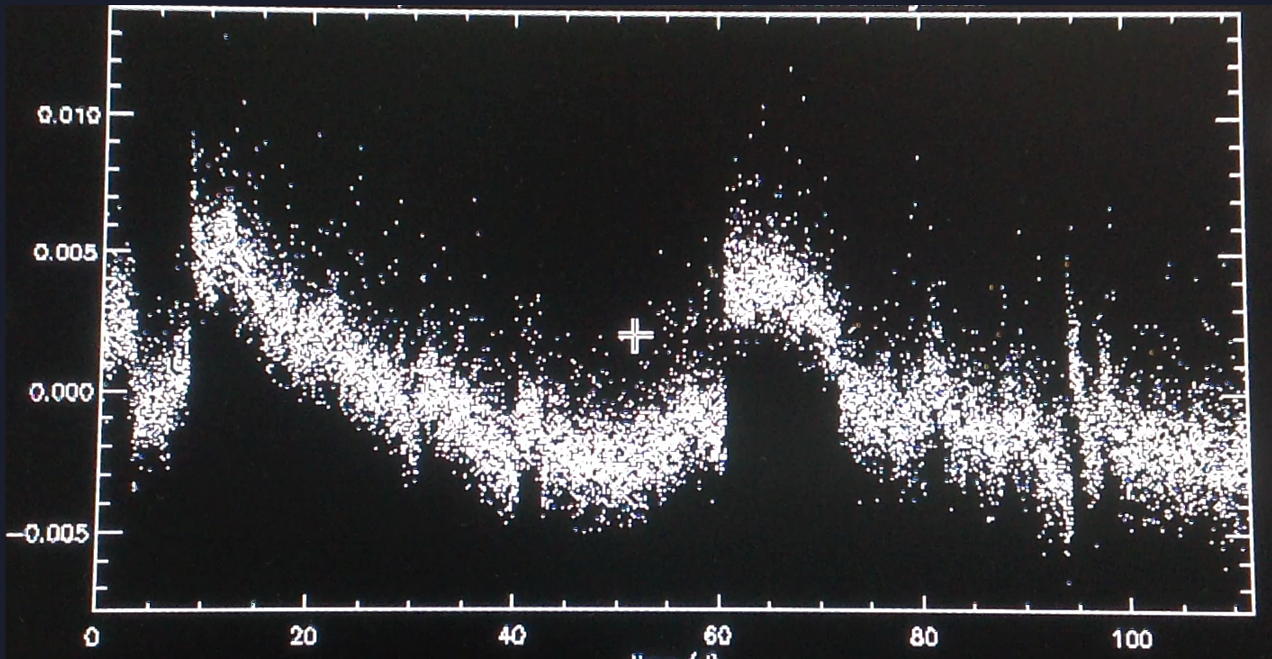
CoRoT ID 0102636100



Time (days)

Discontinuity + DETREND CORRECTION

CoRoT ID 030004247

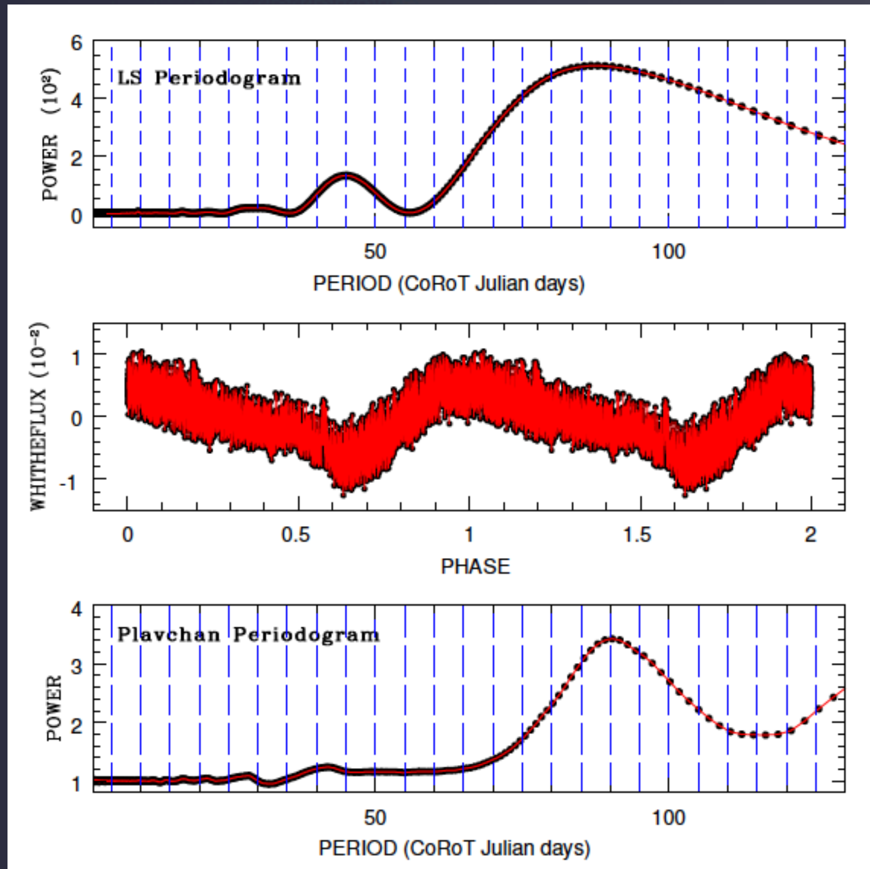


dI/d

Time (days)

Time series analysis

CoRoT ID 0102636100

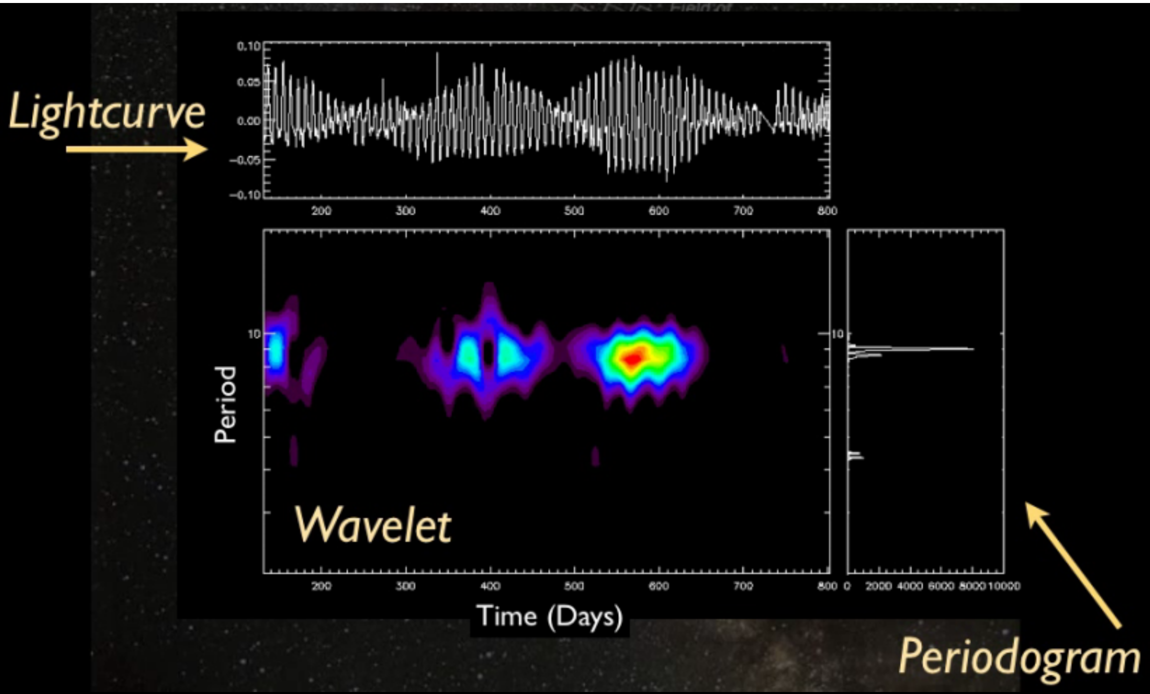


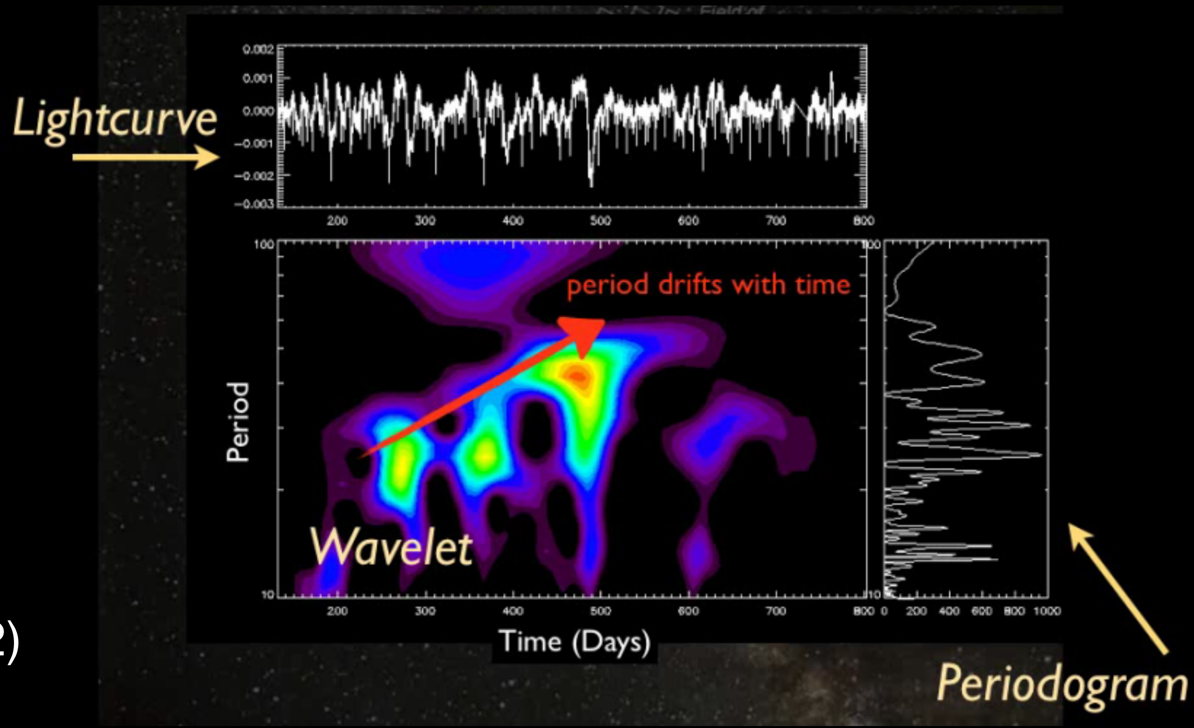
- ✓ Lomb-Scargle
- ✓ Plavchan Periodogram
- ✓ Wavelete
- ✓ Phase Diagram
- ✓ Prot = 74 d

Quality

-FAP (False Alarm Probability) < 10^{-6}

- Prot error   σ Prot = 0,2865 FHWM

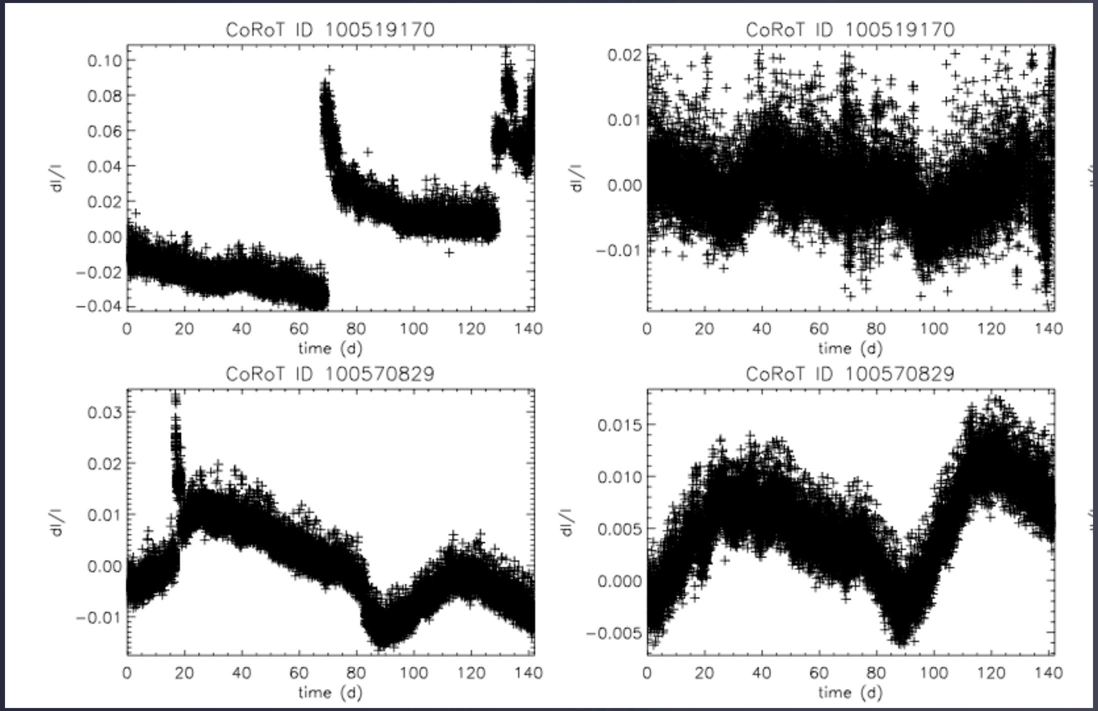




Lucianne Walkowicz (2012)

- Plot of selected light curves **before** and **after** the removal of the discontinuities and / or long-term trends

- The subgiant sample and their rotational periods



CoRoT ID	RA (deg)	Dec (deg)	$(J-H)_{C_3}$ (mag)	P_{rot} (LS) (days)	Error (days)	FAP	*FWHM* (days)	P_{rot} (Plavchan) (days)
100519170	290.743009	1.406339	0.33446	74.3	27.2	$<10^{-6}$	95	73.2
100543054	290.778772	1.326228	0.43519	63.9	10.0	$<10^{-6}$	35	65.6
100570829	290.820823	1.19351	0.31981	84.2	15.8	$<10^{-6}$	55	87.5
100603128	290.869237	1.430996	0.44692	72	10.0	$<10^{-6}$	35	62.9
100686488	290.994464	0.948138	0.44898	66.7	8.6	$<10^{-6}$	30	69.0
100698726	291.015259	1.174825	0.24425	17.1	2.3	$<10^{-6}$	8	16.9

do Nascimento et al. A&A 548, L1 (2012)

Brief description of the physics adopted for the transport of internal angular momentum

- Physics adopted for the transport of internal angular momentum for the present modeling used the same approach as Pinsonneault et al. (1989) after updating the treatment of the instabilities relevant to the transport of angular momentum according to Zahn (1992) and Talon & Zahn (1997).

- Initial conditions: The rotational properties are influenced by the pre-main-sequence phase. Kawaler (1987) determined the initial angular momentum for the Sun as J_0 =1.63×1050 g cm ^{2} s^{-1}.

- Angular momentum loss: Kawaler (1988) described the angular momentum loss for stars with an outer convective envelope as

$$\frac{\mathrm{d}J}{\mathrm{d}t} = -K\Omega^{1+4N/3}\left(\frac{R}{R_\odot}\right)^{2-N}\left(\frac{M}{M_\odot}\right)^{-N/3},$$

with Ω the angular velocity and K a constant that combines scale factors for the wind velocity and magnetic field strength. This is adjusted to give the solar surface rotation velocity at the solar age. N denotes the wind index and is a measure of the magnetic geometry. $N = 3/2$ for the Sun. The mass loss dependence rate is very weak, and we assumed the rate $\dot{M}$ to be $10^{-14}\ M_\odot\ \mathrm{yr}^{-1}$.

The transport of angular momentum is governed by an advection/diffusion equation:

$$\frac{\partial}{\partial t}\left[\rho r^2\Omega\right] = \frac{1}{5r^2}\frac{\partial}{\partial r}\left[\rho r^4\Omega U_r\right] + \frac{1}{r^2}\frac{\partial}{\partial r}\left[\rho\nu_v r^4\frac{\partial\Omega}{\partial r}\right], \quad \text{(A.4)}$$

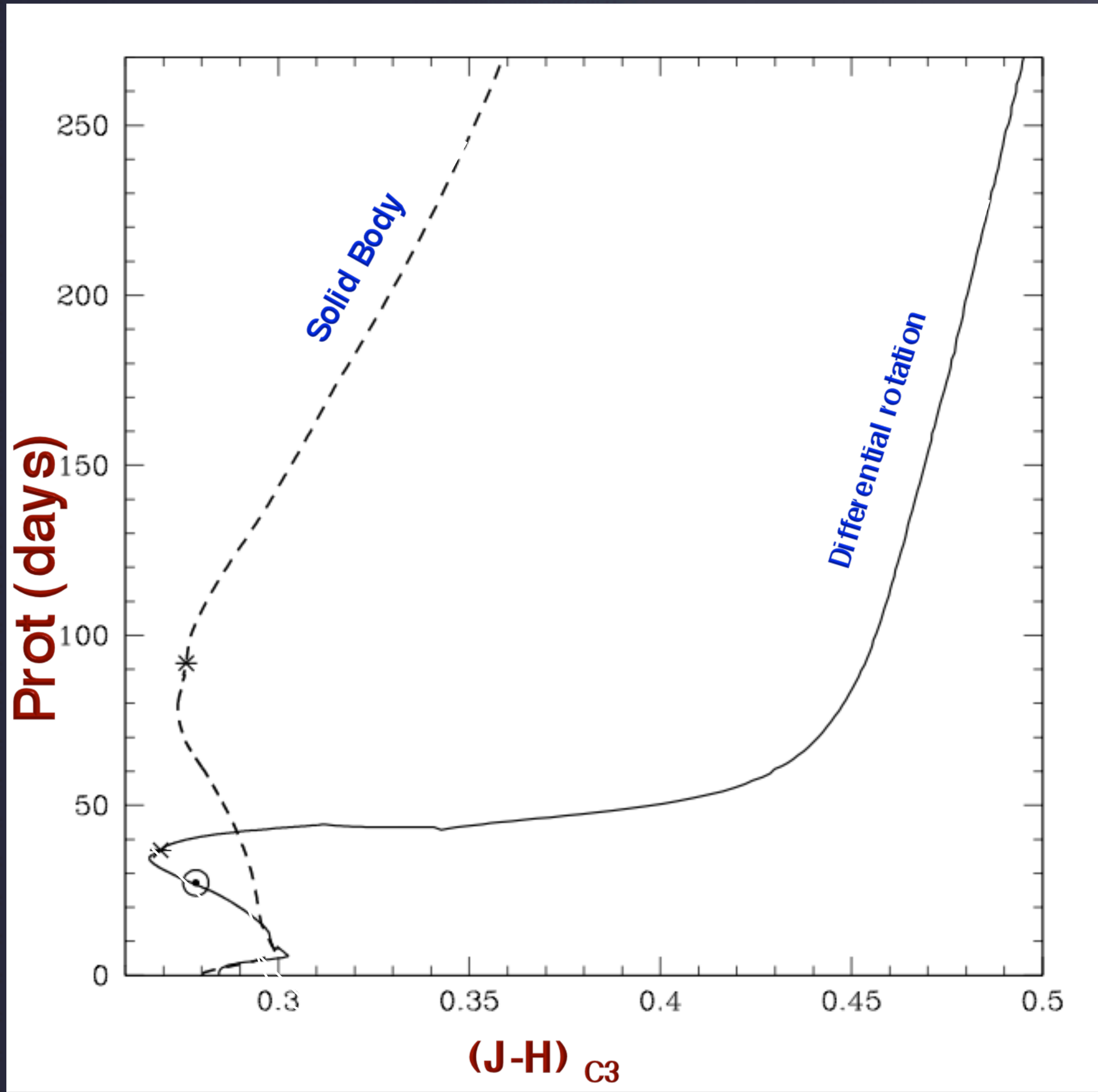
with Ω the angular velocity and ν_v the vertical turbulent viscosity. We use the prescription given by Talon & Zahn (1997):

$$\nu_v = D_v = \frac{8Ri_c}{5}\frac{(r\mathrm{d}\Omega/\mathrm{d}r)^2}{N_T^2/(\kappa + D_h)}, \quad \text{(A.5)}$$

taking into account the homogenizing effect of the horizontal diffusion (D_h) on the restoring force caused by the gradient of molecular weight. $N_T^2 = \frac{g\delta}{H_P}(\nabla_{ad} - \nabla)$ is the Brunt-Väisälä frequency, κ the radiative diffusivity, and $Ri_c \sim 1/4$ is the critical Richardson number (see Talon et al. 1997). The horizontal shear is sustained by the advection of momentum:

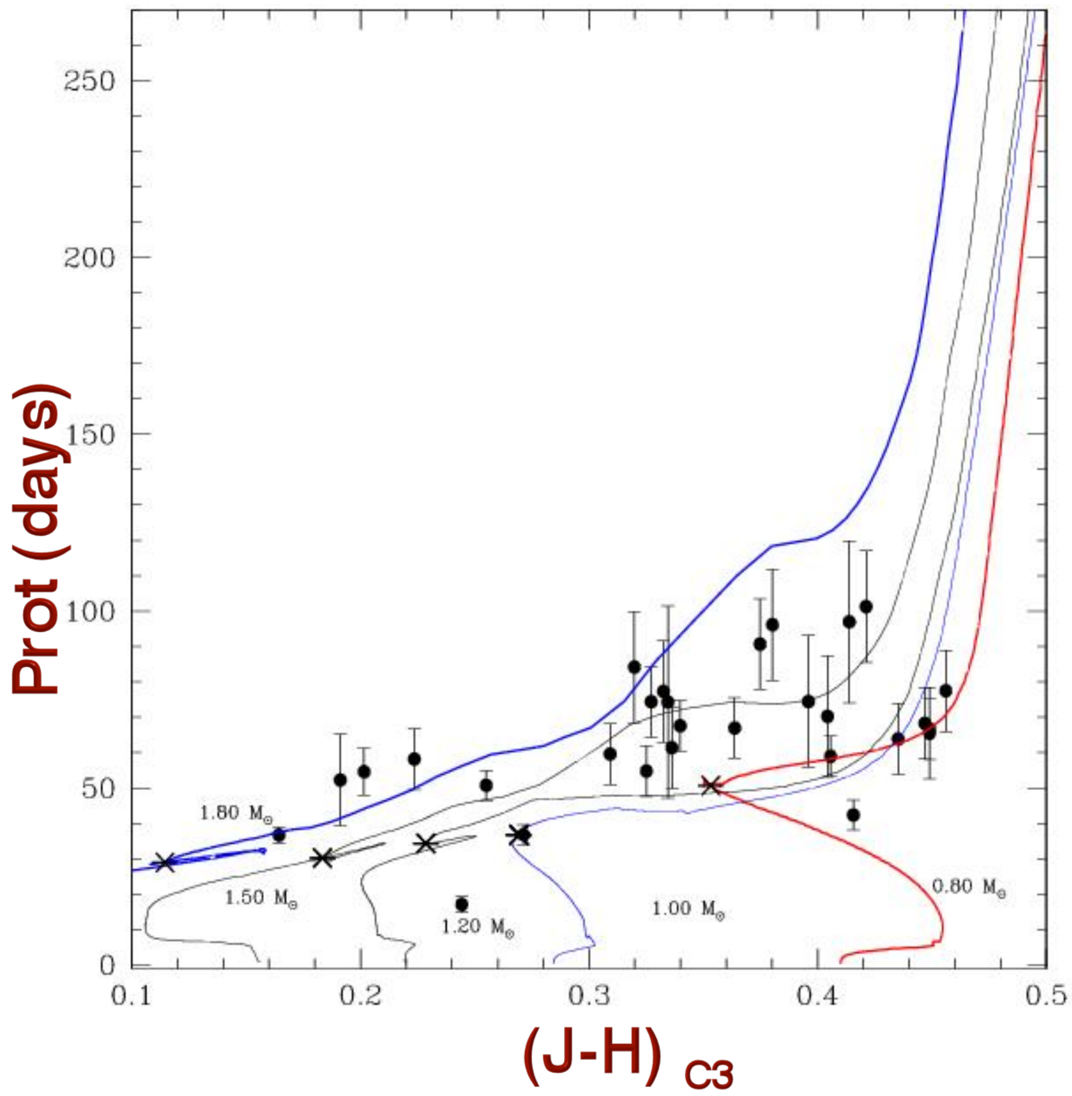
$$D_h = \frac{rU_r}{C_h}\left[\frac{1}{3}\frac{\mathrm{d}\ln\rho r^2 U_r}{\mathrm{d}\ln r} - \frac{1}{2}\frac{\mathrm{d}\ln\rho r^2\Omega}{\mathrm{d}\ln r}\right]. \quad \text{(A.6)}$$

do Nascimento et al. A&A 548, L1 (2012)

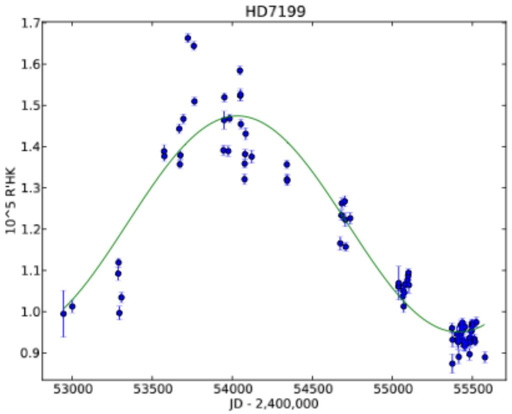


Solid Body
Differential rotation
Prot (days)
(J-H) C3
250
200
150
100
50
0
0.3
0.35
0.4
0.45
0.5

Rotational Periods from CoRoT



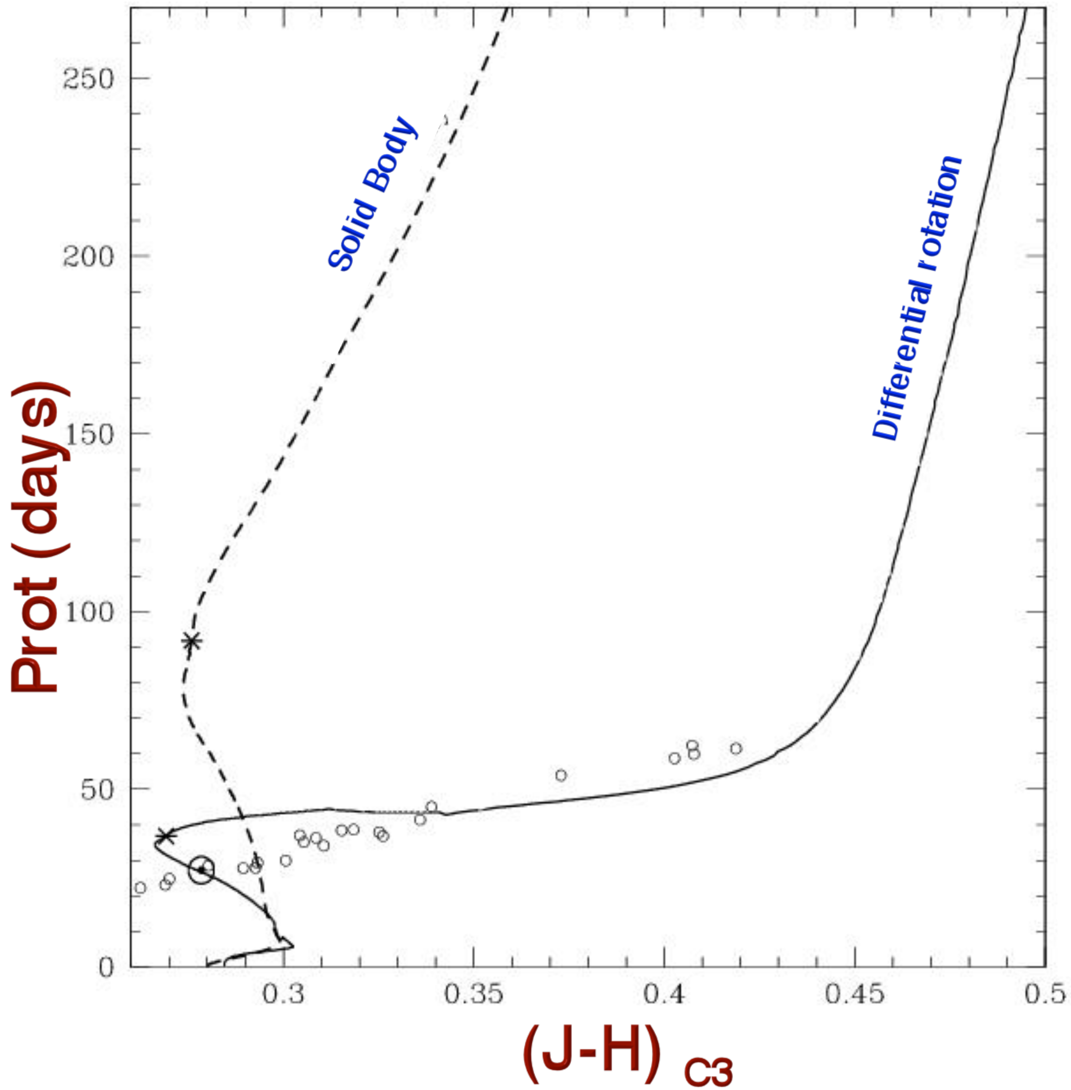
Prot agree well with the range of periods determined from the activity modulation studies of subgiants of 1 Solar mass



high-precision Ca II H&K chromospheric activity measurements

+

Mount Wilson S index



Model Validation: Periods from Lovis et al (2011) !!!

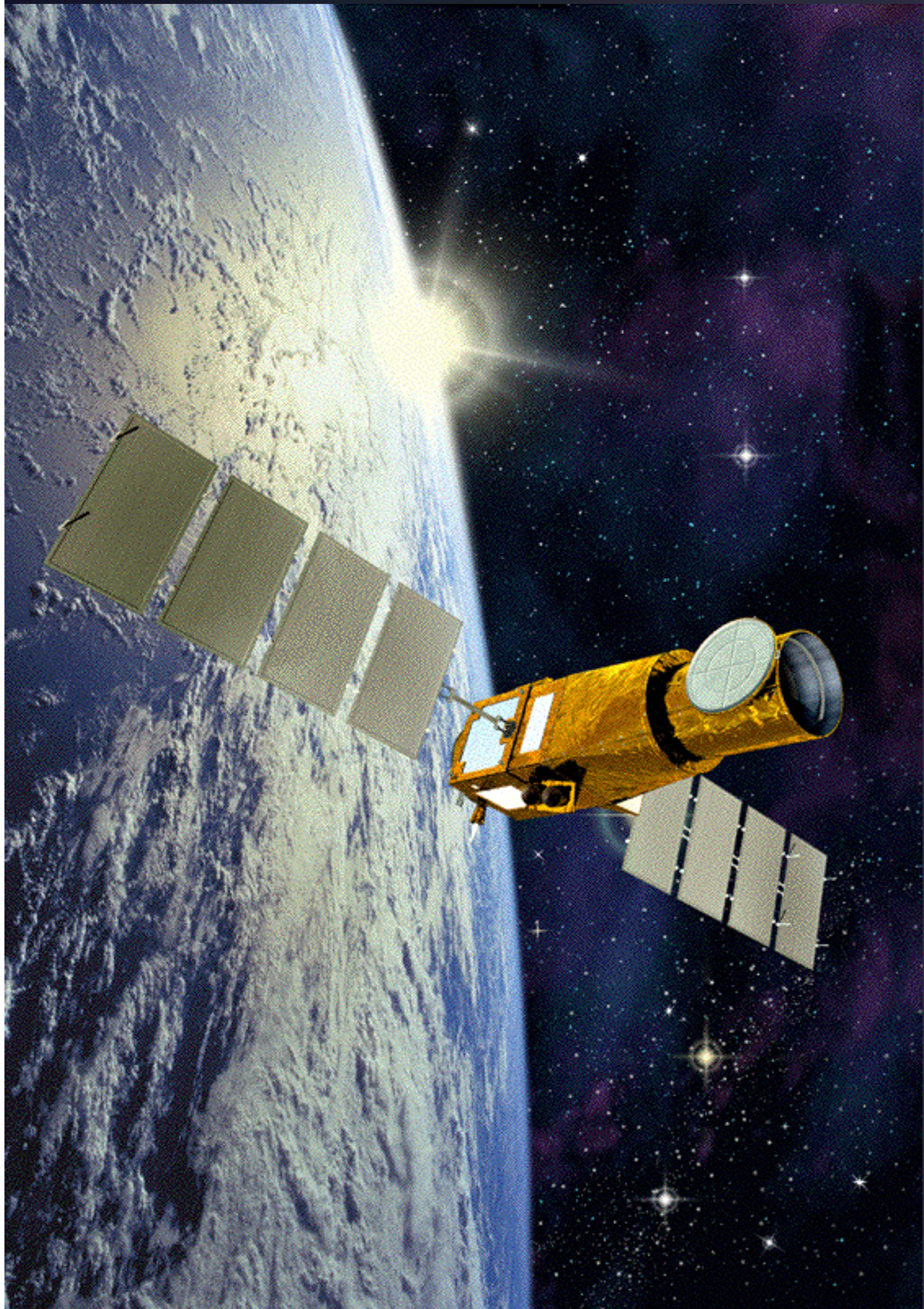
Conclusions

- Prot determined for subgiants observed by CoRoT
- These Prot + evolutionary models helped us to more tightly constrain the angular momentum evolution for evolved stars < = > seismology
- Prot ranging from 30 to 100 d in the range from 0.8 to 1.8 solar masses
- The Prot range for subgiants reinforces the scene of a differential rotation in depth or a fast-core rotating ~~(solid body)~~
- This result also agrees with the findings by Mosser et al. (2012), who observed that rotational splittings and core rotation significantly slows down during the RGB.

Rotation periods for sun-like KEPLER SUBGIANTS: KIC11395018, KIC10920273 (do Nascimento, Garcia, Manthur, Pinsonneault, Chaplin et al. (2013, In preparation)

Things still to do...

- Hints for a dynamo theory in a slowly rotating domain and depth convective zone...
- Mixed models and the core rotation in subgiants
- Better constraint the strong structural evolution in subgiants: core contraction + envelope expansion
- What about the lifetime of spots for subgiants



It is just the beginning for rotation of solar type stars

Thank you!