Stars with a stable magnetic field: from pre-main sequence to compact remnants
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Differential rotation in magnetic chemically peculiar stars

The reasoning and motivation of the project of rotationally unstable Kepler mCPs census

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Rotation of main sequence stars

Main sequence - an inhomogeneous group of stars burning its H in their cores - the most striking differences can be found between the stars of upper and lower MS.

Lower main sequence stars display **solar-type activity** powered by the dissipation of local magnetic fields generated by interplay of **convective motion** in subphotosperic layers and long known **differential latitudinal rotation** (DLR).

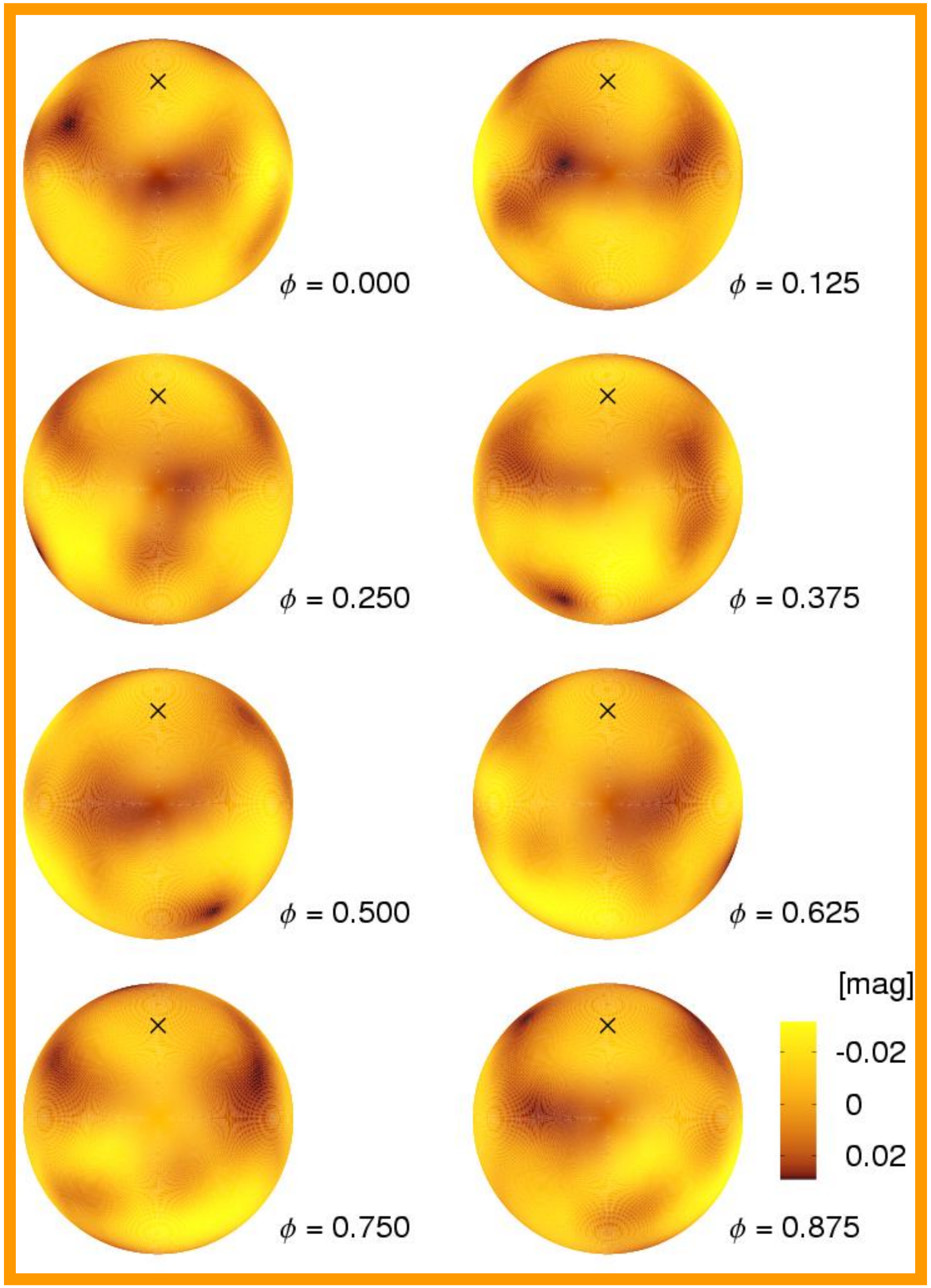
- Characteristics of DLR can be derived traditionally by tracking of solar-type spots (now also by astro/helioseismology).

Unfortunately, we have only a poor information about the rotational periods of individual **upper main sequence stars** because of a lack of common solar-type star rotation tracers as spots, flares, active regions.

- Balona et al. recently argued that they can find in Kepler data some signs of the stellar activity and differential rotation also in A-type stars. However, their findings are controversial in so much that they are not generally accepted.

Fortunately, there are **magnetic chemically peculiar stars of upper MS** (mCPs) with stable **photometric** and **spectroscopic spots** and **strong magnetic fields** that can be utilized to very precise rotation period analysis and a solution of the crucial question whether **hot MS stars rotate differentially or not**.

V901 Orionis - photometric spots



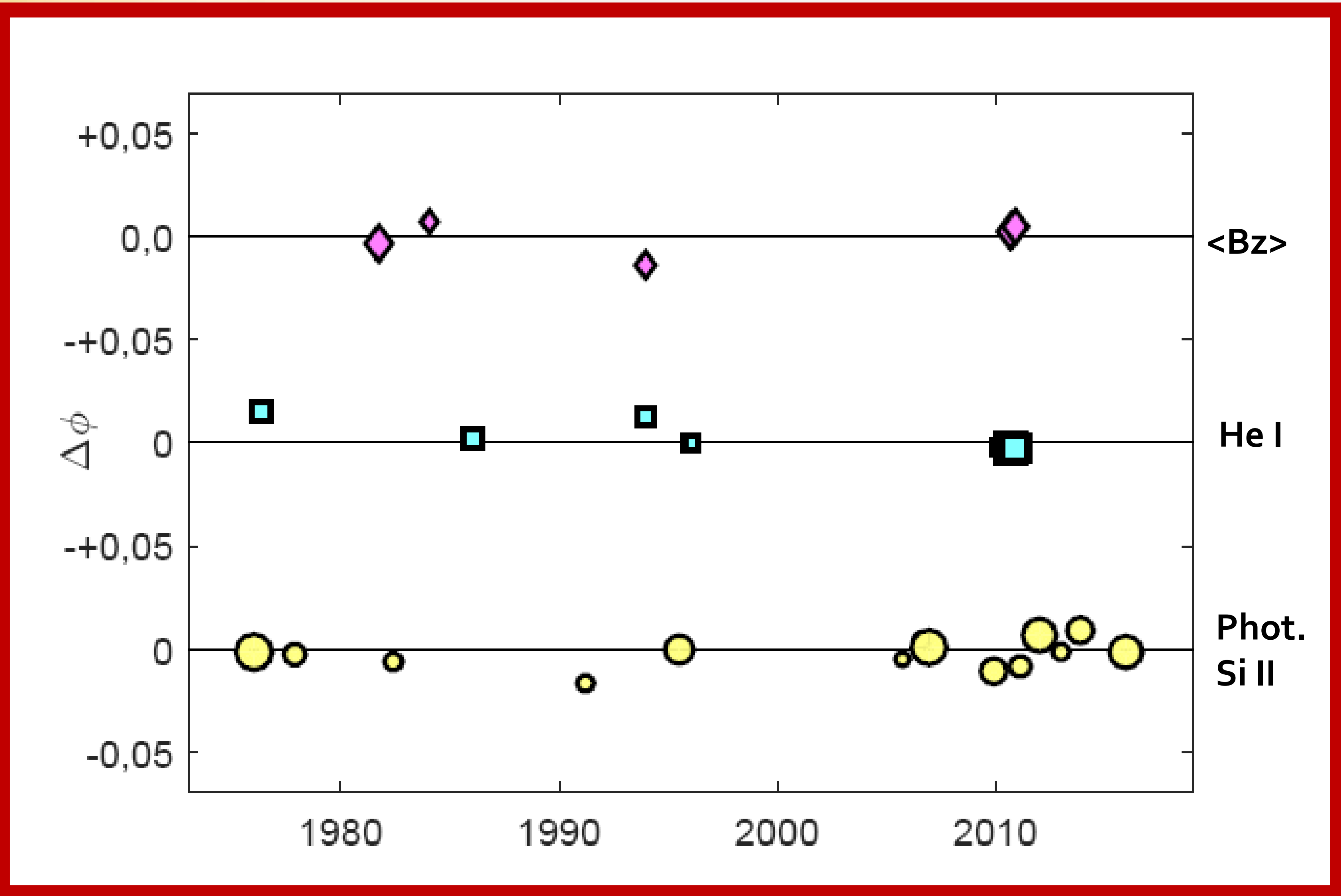
On the variability and physics of magnetic CP stars

Most of **mCP**s exhibit strictly periodic light, magnetic, radio, and spectral variations which can be fully explained by the **model of a rigidly rotating MS star** with persistent surface structures and stable magnetic field frozen into the surface of the star.

The phases curves of various rotation tracers (light curves, sp. line intensities, or <Bz>) share information about rotation of region with generally **different latitude**.

- So, it enable us not only to determine the rotational period but also to test the presence of latitudinal differential rotation. See e.g. the mutual phase shifts in V901 Ori (Mikulášek, 2016).

V901 Orionis = HD 37 776



On the variability and physics of magnetic CP stars

- The found strict equality of periods derived from phase curves related to the different tracer supports the concept of **solidly rotating mCP stars without any latitudinal differential rotation**.

Fastening of the outer parts of the star is due to a global magnetic field intervening not only the stellar body but also and its close environment. MF plays its decisive role only in rarified parts of the star – in the magnetosphere, photospheric, and subphotospheric layers where the density of MF energy prevails the density of thermal motion.

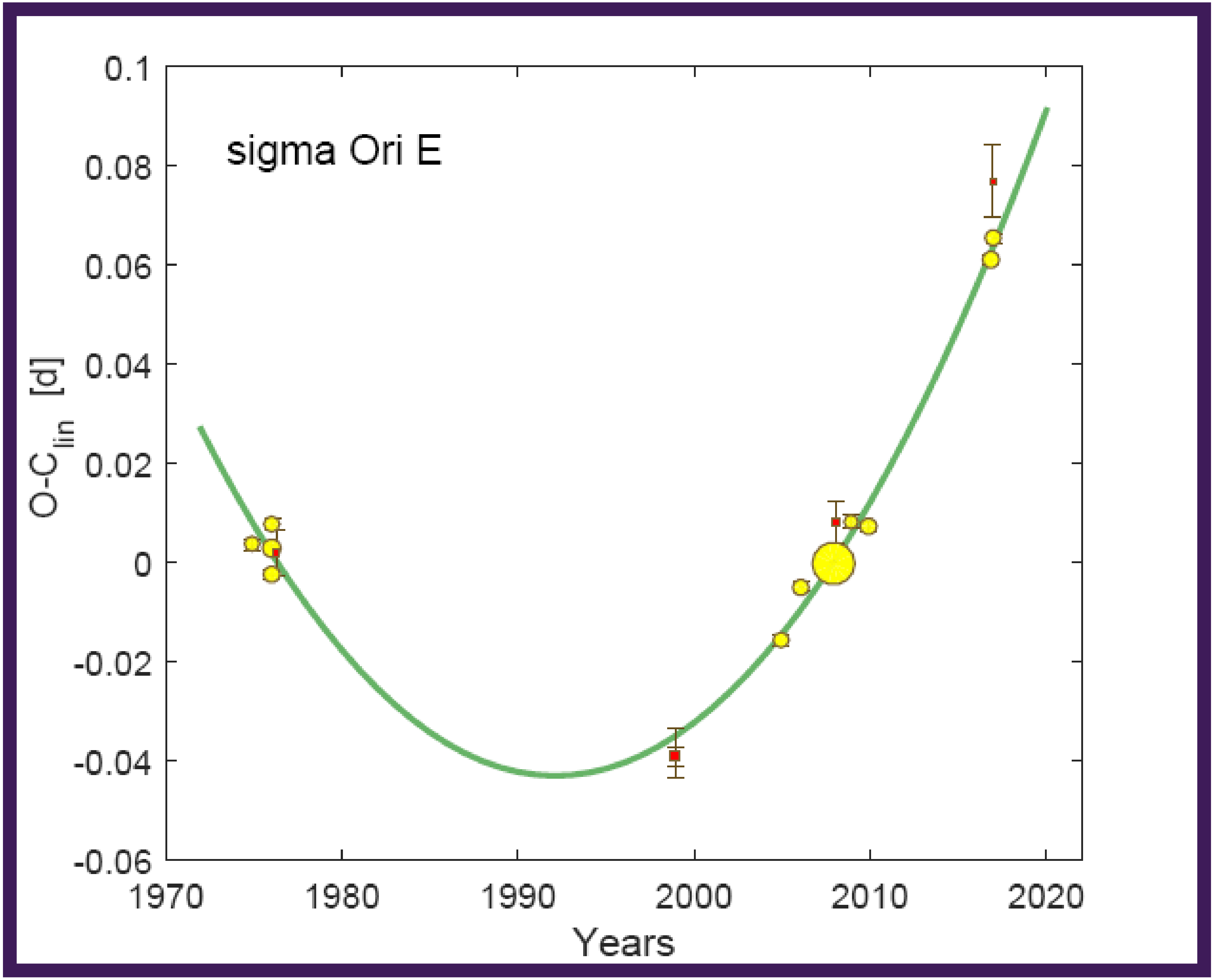
- Assuming B ~ 2 kG, at optical depth $\tau = 1$, $T \sim 10^4$ K, density $\rho = 10^{-6}$ kg m^{-3}, pressure $P = 6\times10^{-4}$ atm = 60 Pa; density of kinetic energy of the thermal motion: 90 J m^{-3}, while energy density of MF, $\eta_B = \frac{1}{2} B^2/\mu_o \sim 16\,000$ J m^{-3}.
- Equalizing of both energy densities arrives at $\tau \sim 100$. There one can put a bottom of stellar skin dominated by a magnetic field. Its mass is roughly $2\times10^{-9}\ M_{\odot}$.

Such light shell can glide on the inner part of the star and exhibit another rotational period than the rest of the star. Now we need only a negligible transport of the angular momentum through the stellar wind escaping from the magnetosphere that can brake the rotation of the visible part of a mCP star.

mCP stars with variable rotational periods

Using the method, developed by Mikulášek et al. (2008,2016), we analyzed archival data from several hundreds of mCP stars, with the aim to monitor the possible variations in their rotation. We found that the periods of almost all of mCPs are pretty constant. However, we also revealed that periods of variations of several of them are continuously changing.

These odd mCP stars differ in almost all respects; the reasons for their period variability may also be different.



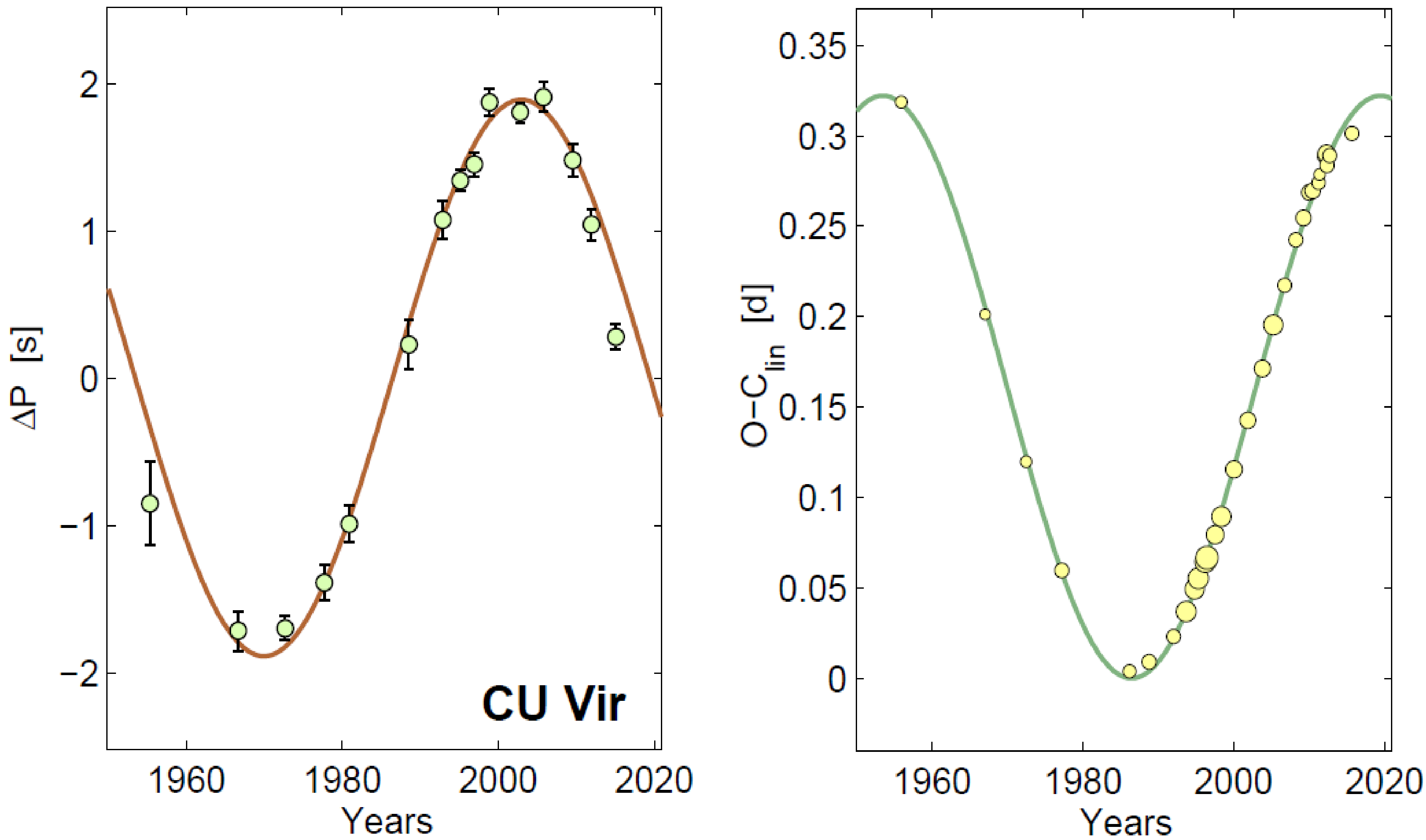
sigma Ori E
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
O-C$_{lin}$ [d]
1970
1980
1990
2000
2010
2020
Years

mCP stars with variable rotational periods

Using the method, developed by Mikulášek et al. (2008,2016), we analyzed archival data from several hundreds of mCP stars, with the aim to monitor the possible variations in their rotation. We found that the rotational periods of the most of them are pretty constant. However, we also revealed that periods of four of them are continuously changing.

These odd mCP stars differ in many respects; the reasons for their period variability may also be different.

- **Magnetic braking** through to the angular momentum loss caused by the wind escaping from the extended magnetosphere can apparently be effective only in very specific cases mCP/Be hybrids as **σ Ori E** (Townsend et al. 2010; Mikulášek, 2016).


ΔP [s]
2
1
0
−1
−2
1960
1980
2000
2020
Years
CU Vir
O−C$_{lin}$ [d]
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1960
1980
2000
2020
Years

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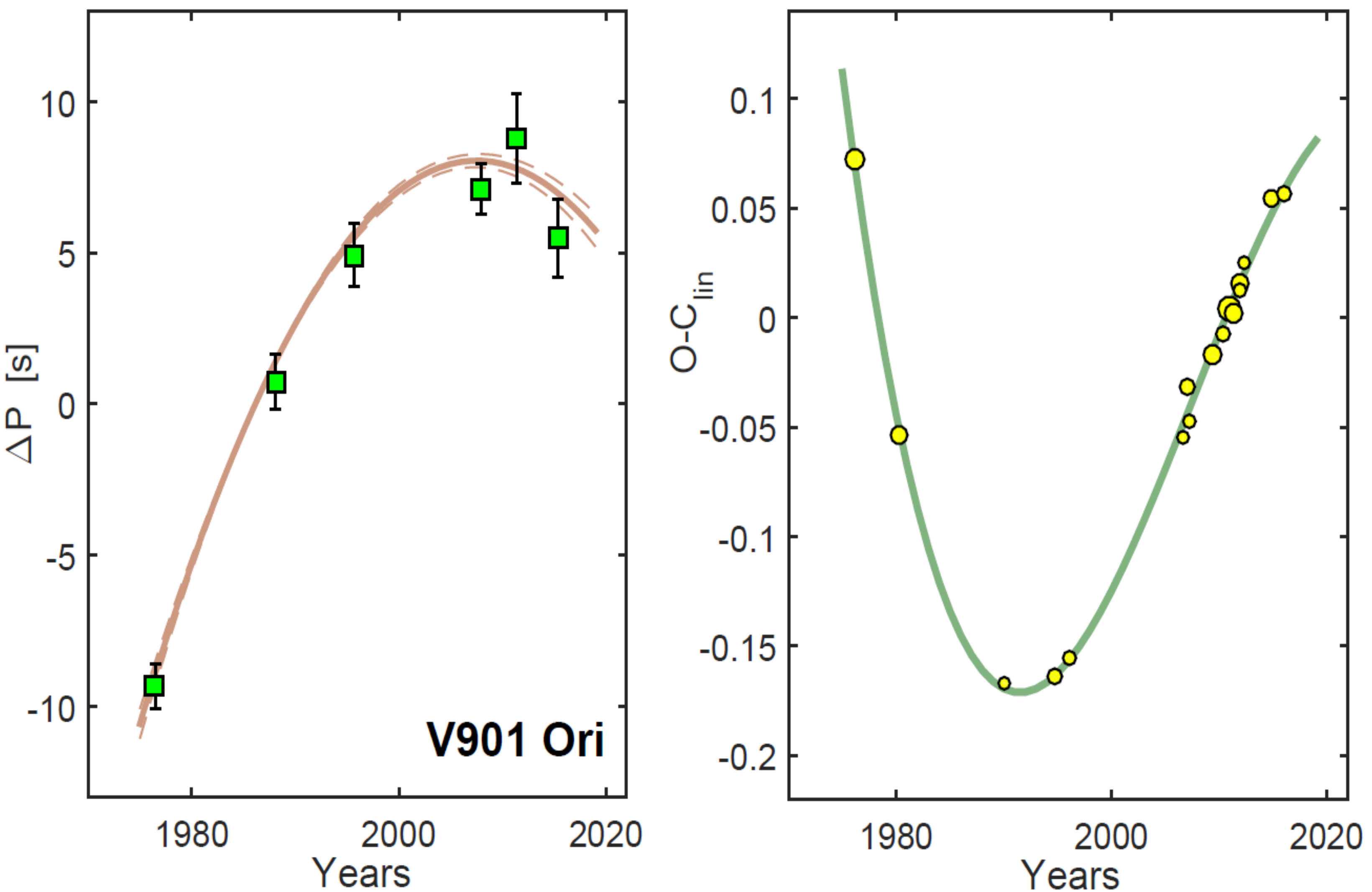
- The period oscillations of at least of **CU Vir** can be interpreted as a consequence of **torsional waves** that may disseminate in magnetic rotating stars (Krtička et al., 2016).



V901 Ori
ΔP [s]
Years
O-C$_{lin}$
Years
10
5
0
-5
-10
1980
2000
2020
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2

mCP stars with variable rotational periods

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- Period changes in a hot **V901 Ori** may be caused by AM loss through the stellar wind escaping from its extended magnetosphere, modulated by the gradual reconfiguration of its complex magnetic field firmly connected with the surface.

Unfortunately, we do not know up to now the real incidence of mCP stars varying their rotational periods. In the sample of 39 Kepler mCPs, we have found no one so far, but research proceeds…

Speculations on internal differential rotation

While the surface latitudinal differential rotation has been observationally proven for the Sun and some sun-like stars, the knowledge of internal rotation in main sequence stars remains vague up to now. In principle, we could obtain the relevant information by the analysis of astroseismological observations. Unfortunately, the interpretation of them is far from to be unambiguous.

The most of the specialist think that the **radiative regions** rotate as a **solid body** while in **convective zones or cores** the **differential rotation** develops.

- Because of outer parts of **mCP stars** are dominated by the global magnetic field and **envelopes** covering the convective cores are radiative, we do not expect any latitudinal differential rotation. Nevertheless, some differences in the angular velocities of the envelope and "**solid shell**" fastened by a magnetic field may exist, because the shell is braked by stellar wind escaping from the magnetosphere.
- The separation of those regions is not perfect – the elastic connection between them provides internal magnetic field. So we can expect either almost **firm interconnection** between them (σ Ori E) or freer one, allowing some **cyclic oscillations** (CU Vir). The possible changes in the intensity of the dynamical interaction with the environment may **modulate** the oscillations, as well (V901 Ori).