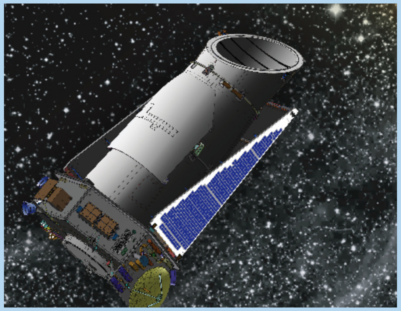
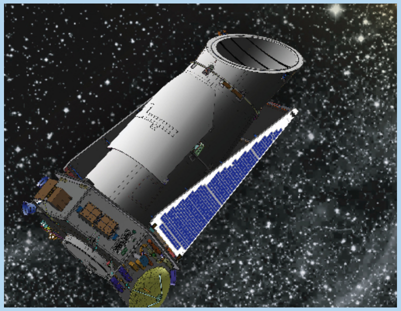


RRs/Delta Scuti Pulsators: Effects of Stellar Rotation and Cycles on Amplitudes and Frequencies

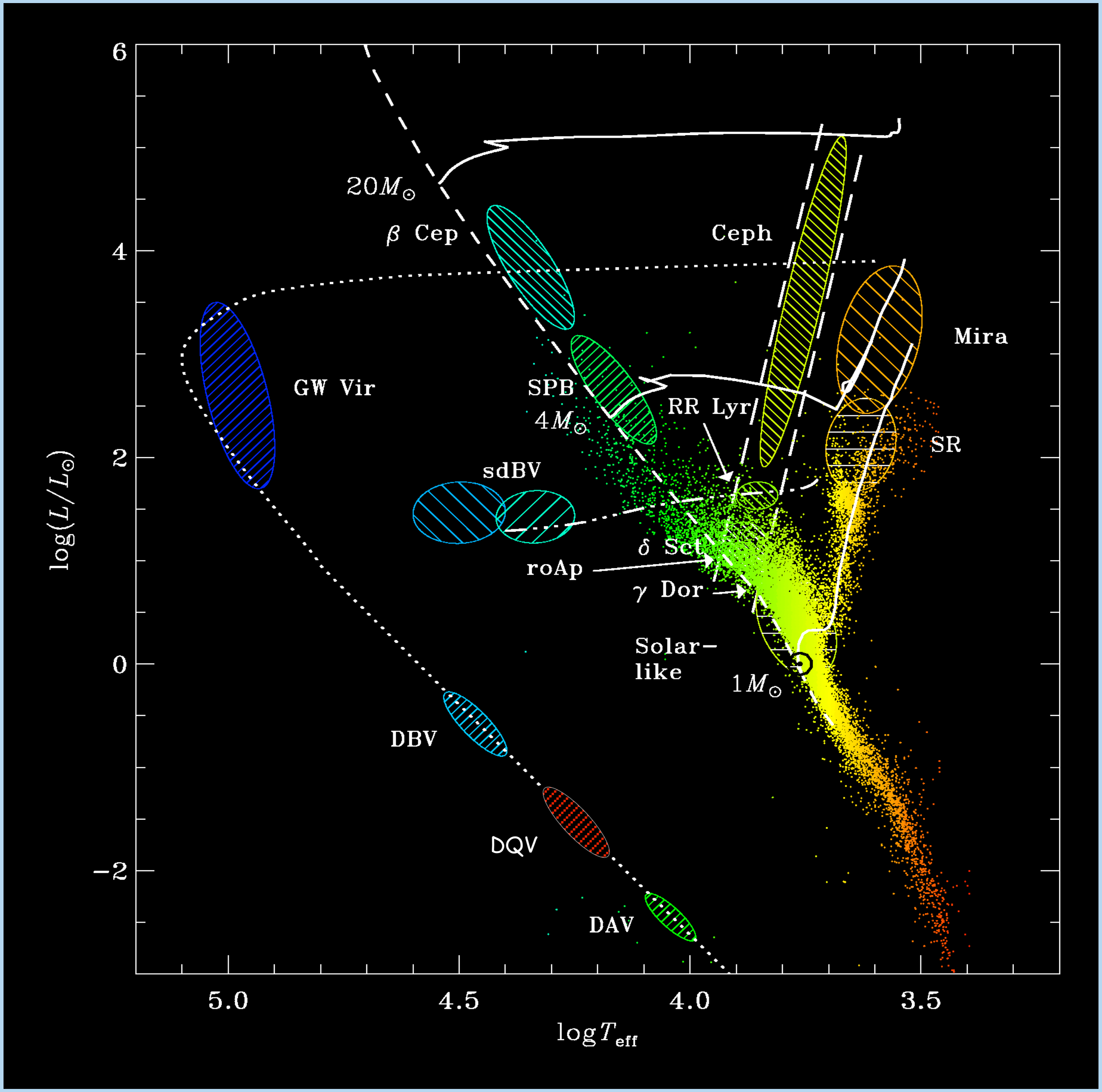
Michel Breger

Department of Astronomy, University of Texas at Austin
and
Department of Astronomy, University of Vienna, Austria

Outline



1. Introduction
2. Effects of stellar rotation
   - Rotational velocity and mode selection/amplitudes
   - Change during a rotation
3. Stellar cycles and nonradial pulsation



6
4
2
0
−2
log(L/L⊙)
5.0
4.5
4.0
3.5
log Teff
20M⊙
β Cep
Ceph
Mira
GW Vir
SPB
4M⊙
RR Lyr
SR
sdBV
δ Sct
roAp
γ Dor
Solar–
like
1M⊙
DBV
DQV
DAV

1. Introduction

A VARIABLE STAR WITH AN EXTREMELY SHORT PERIOD*

During 1966 an extensive program was started in an effort to establish the variability of F stars for a large sample of bright stars. Of particular interest was the possibility of finding new examples of variables of the δ Scuti and ρ Puppis type. Very few of these stars are known because their light variation is in the range of only several hundredths of a magnitude. Of the over seventy stars tested for variability so far, HR 8494 (= HD 211336, F0 IV) has the shortest period of all the δ Scuti stars known at present.

The light variability of HR 8494 was discovered on September 4, 1966, with a photoelectric photometer attached to the 24-inch reflector at the Lick Observatory. The observing technique and precautions taken to test stars for variability will be described in a later paper. It is estimated that all light variations in excess of 0.010 mag. with periods ranging from 30 min to 5 hours should be detected this way. Further observations covering four successive cycles were taken on September 9. The two comparison stars used are listed in Table 1 together with new *UBV* measurements of these stars. During the last $1\frac{1}{2}$ cycles, only HR 8472 was used as a comparison star and observations were extended to the blue color.

TABLE 1

Comparison Stars

Star	Spectral Type	V	B−V	U−B
HR 8613	A7 IV	4 65	+0 24	+0 11
HR 8472	F8 V	5 25	+0 50$_5$	+0 05

The probable error per *single* observation derived from observations of comparison stars on September 9 is better than 0.001 mag. HR 8494 varies with a period of about 61 min and has a variable amplitude of less than 0.03 mag. (Table 2). The observations are shown in Figure 1 in which Δm is in the sense m(HR 8494) − m(HR 8472).

* *Contributions from the Lick Observatory*, No. 222.

Because of the shortness of the period, the presence of a beat period, and the relatively poor photometric quality of the first night, the observed maxima of the two nights cannot be combined to define a unique period. From the September 9 data alone, the following elements are derived:

$$\text{Heliocentric J.D. of maximum: } 2439378.789\ (\pm 0.002) + (0^{d}042 \pm 0.003)\ n.$$

TABLE 2

Successive Light Amplitudes of HR 8494

Cycle	Δm_v	Δm_b
1	0 021	
2	026	
3	022	
4 .	0 020	0 025

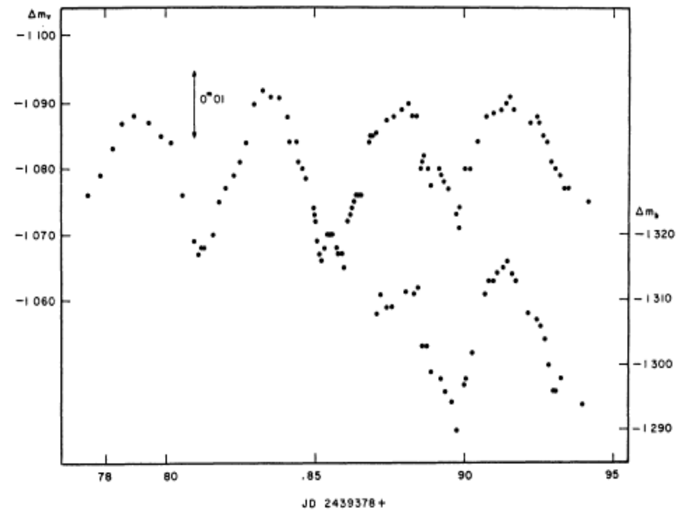


Fig. 1.—Light variation of HR 8494 with a period of 61 min

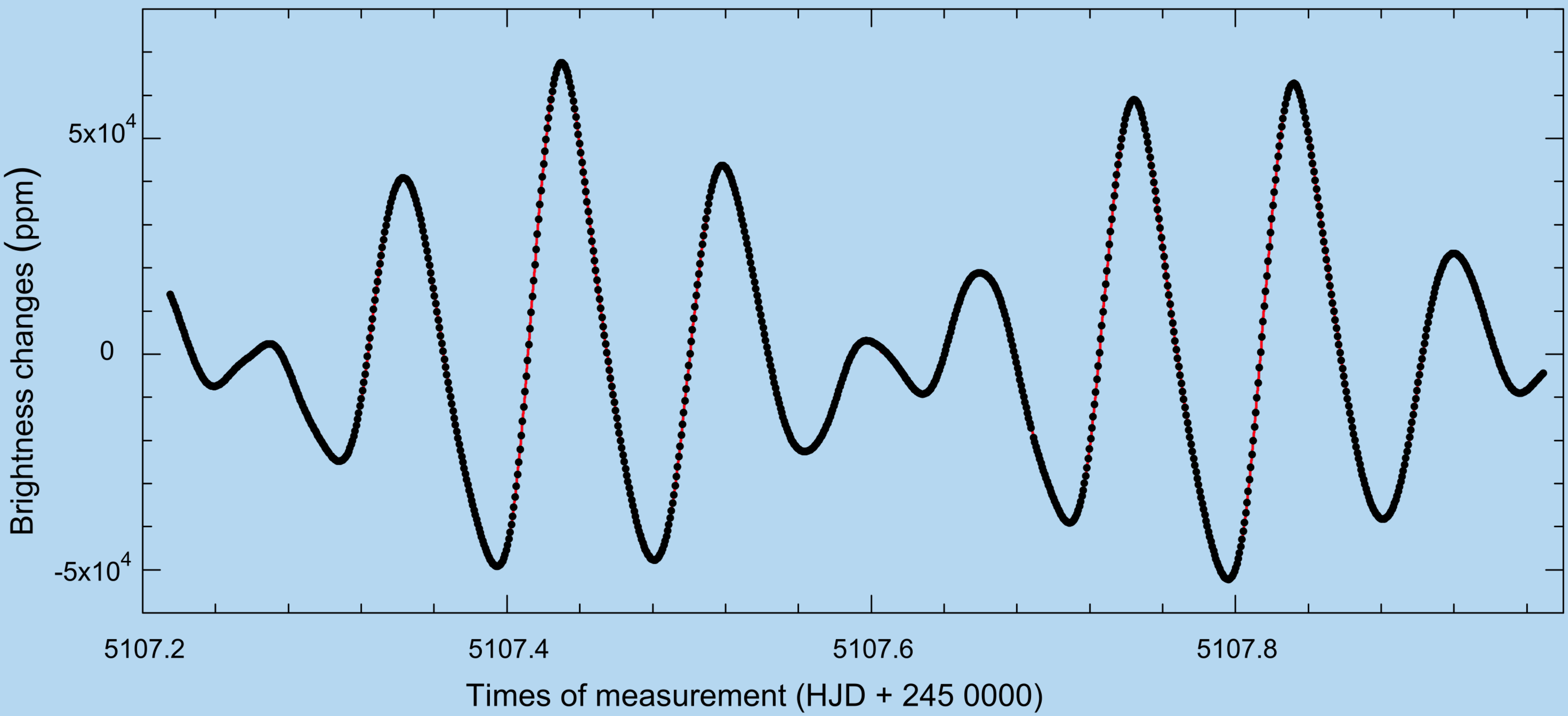
This is the shortest period for a variable star known to the author. The short period and extremely small light amplitude make the detection of variables like HR 8494 very difficult.

It is a pleasure to thank Dr. G. W. Preston for stimulating discussions.

M. Breger

October 7, 1966
Lick Observatory
University of California
Mount Hamilton, California

Kepler satellite: KIC 9700322



2. Effects of stellar rotation
    - Rotational velocity and mode selection/amplitudes

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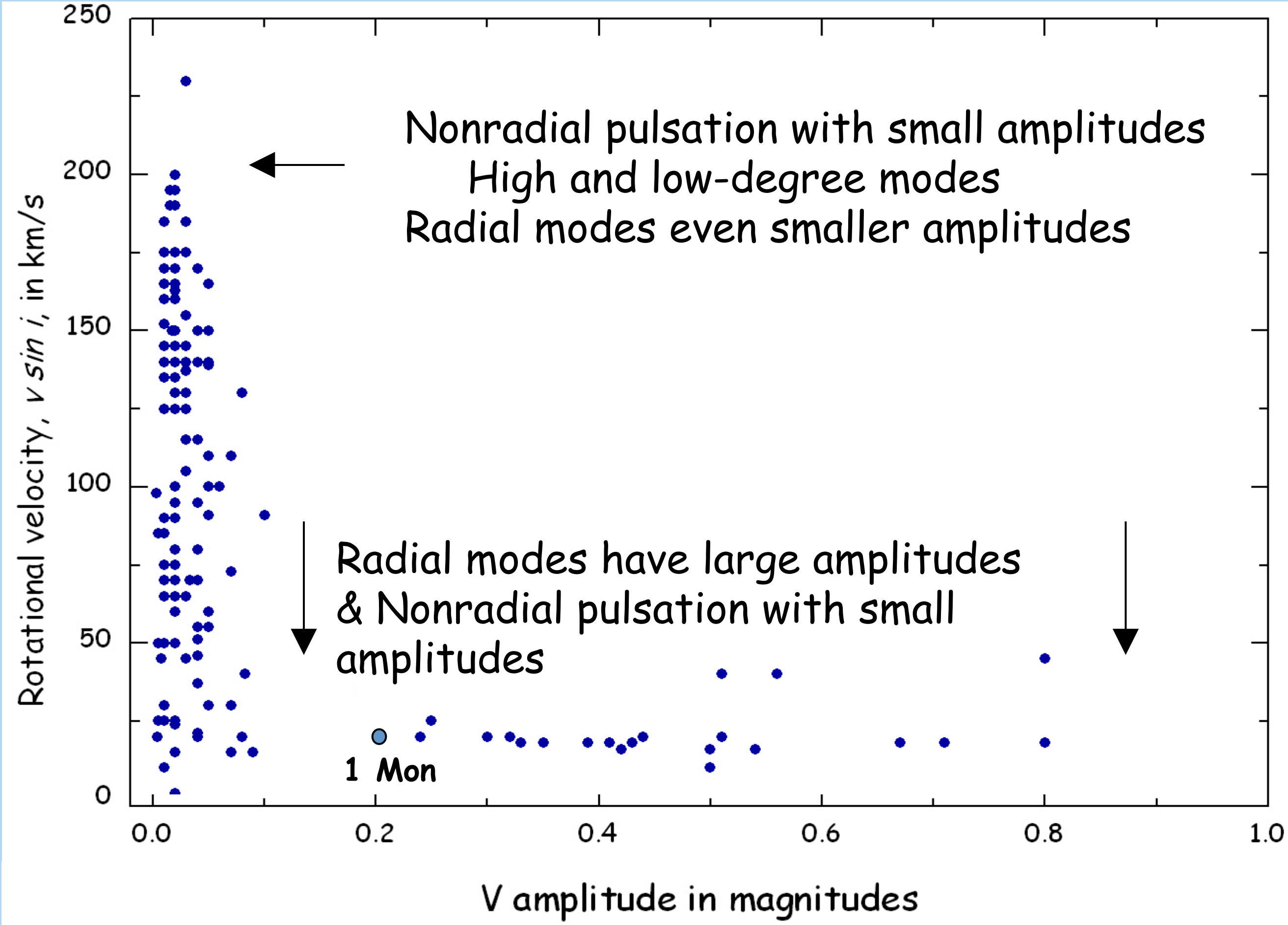

Effects of stellar rotation: Changes during rotation

Effects of stellar rotation: Changes during rotation

Kepler Delta Scuti star KIC 9700322:

76 frequencies with amplitudes from 14 to 29500 ppm

Hobby-Eberle Telescope (HET) spectrum:

T_{eff} = 6700 ± 100 K, log g = 3.7 ± 0.1

v sin i = 19 ± 1 km/s, solar abundances

Reference: Breger, Balona, Lenz, Hollek et al., 2010arXiv1012.4373B & MNRAS, in press

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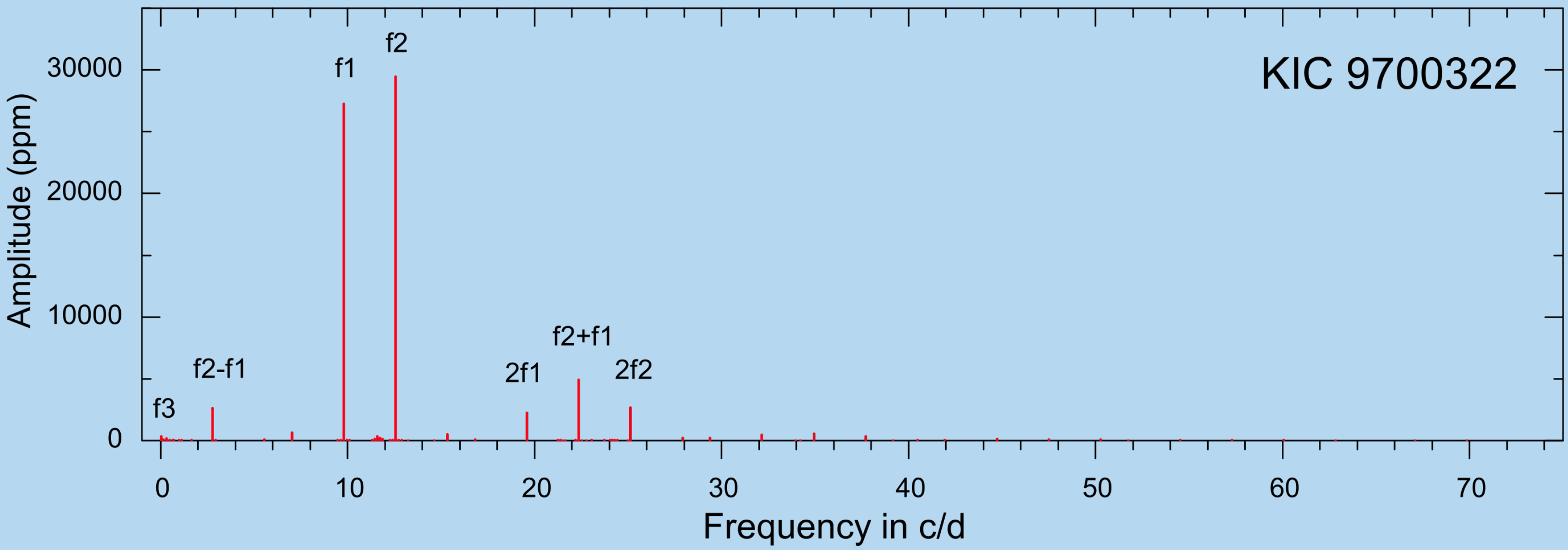
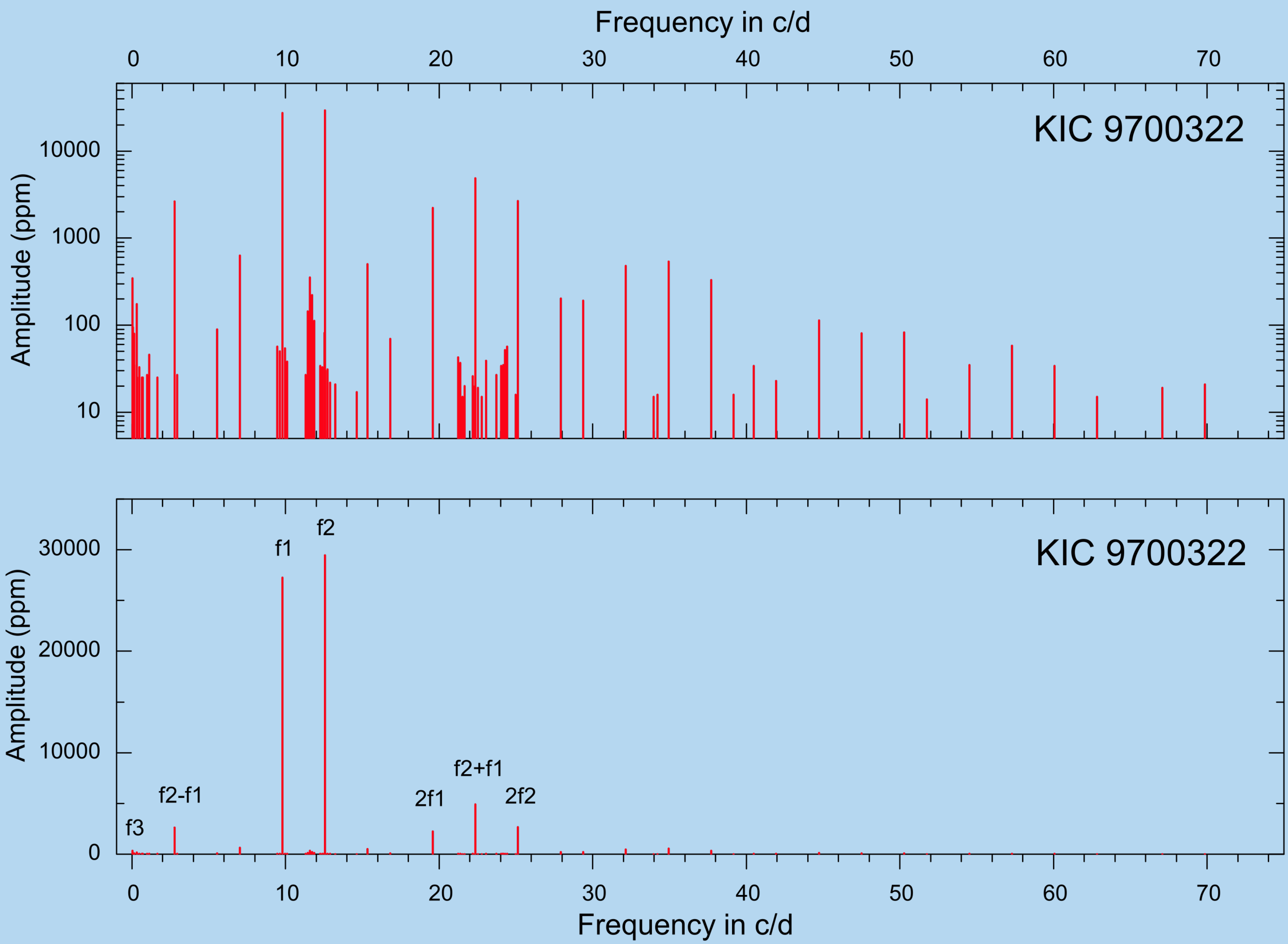
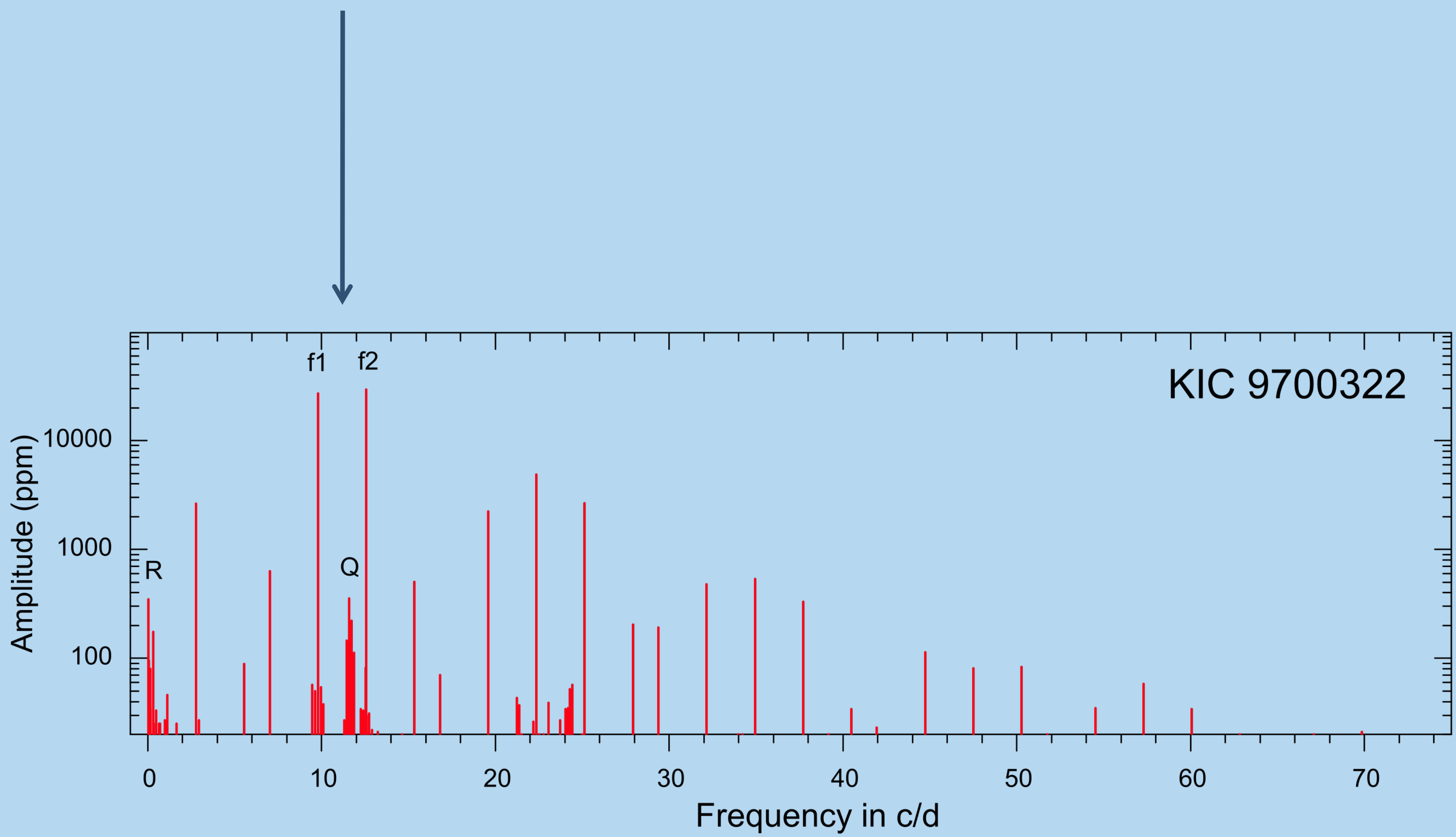



Frequency in c/d
KIC 9700322
Amplitude (ppm)
10000
1000
100
10
0
10
20
30
40
50
60
70
KIC 9700322
Amplitude (ppm)
30000
20000
10000
0
f1
f2
f3
f2-f1
2f1
f2+f1
2f2
Frequency in c/d

Star has simple patterns

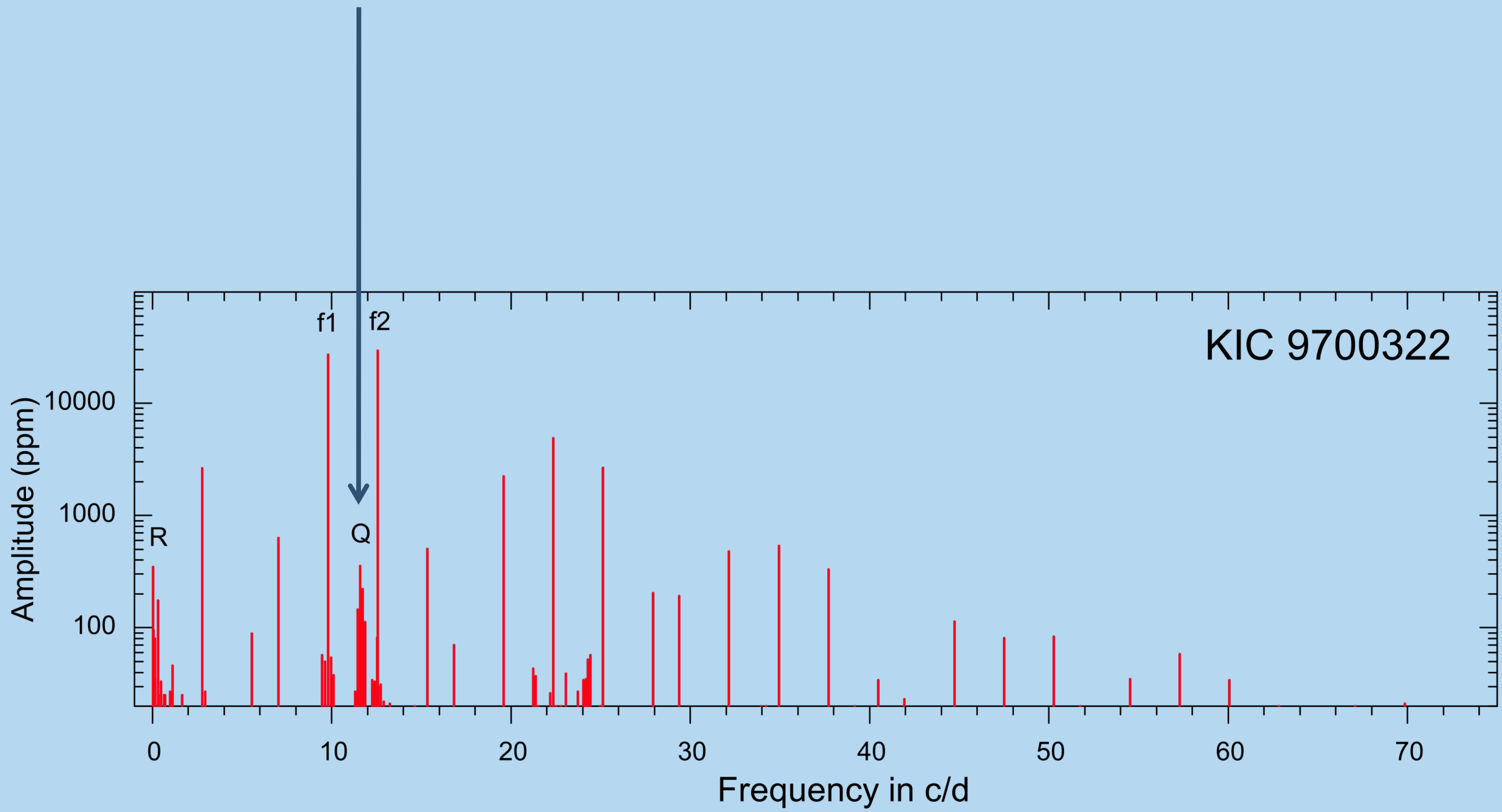
(a) 2 radial modes f1 and f2, (F + 1H)



Star has simple patterns

(a) 2 radial modes f1 and f2, (F + 1H)

(b) ℓ = 2 quintuplet (named Q)

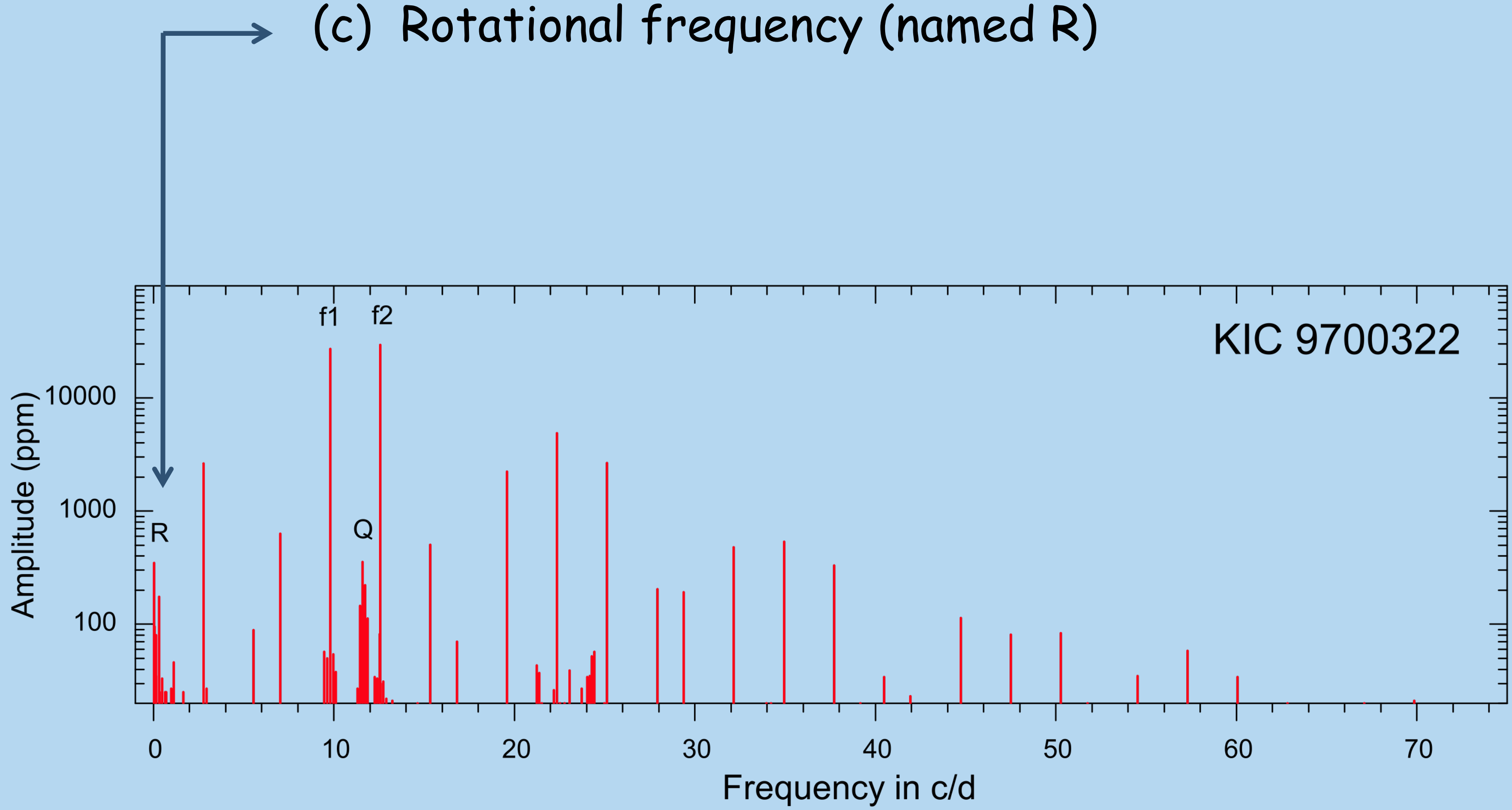


Star has simple patterns

(a) 2 radial modes f1 and f2, (F + 1H)

(b) ℓ = 2 quintuplet (named Q)

(c) Rotational frequency (named R)



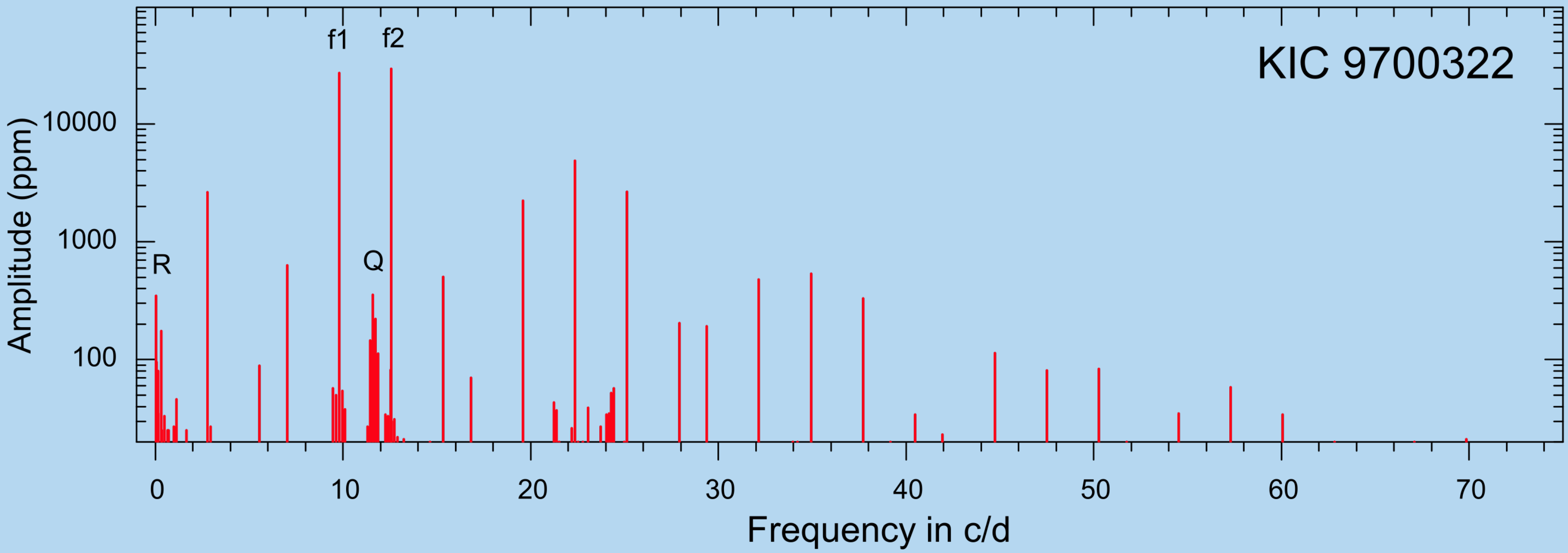
Star has simple patterns

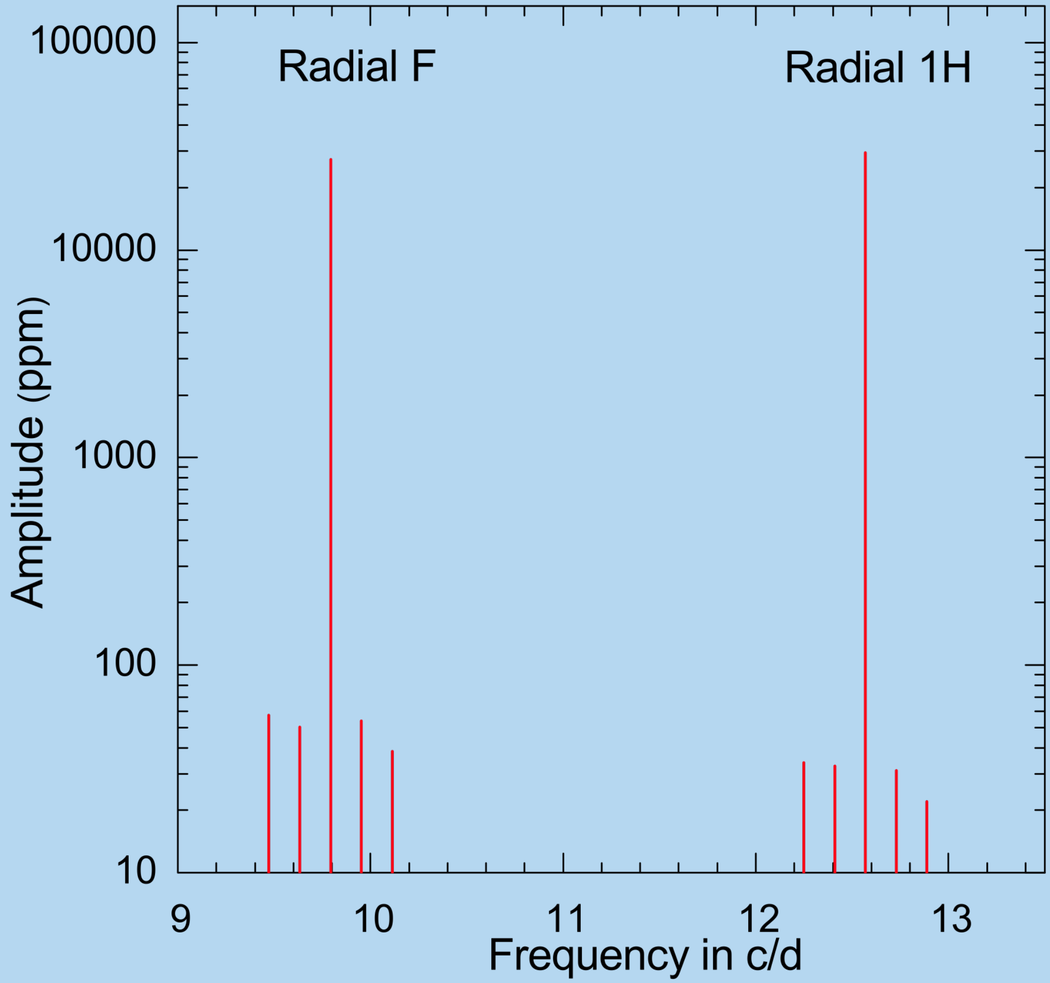
(a) 2 radial modes f1 and f2, (F + 1H)

(b) ℓ = 2 quintuplet (named Q)

(c) Rotational frequency (named R) at 0.160 c/d

(d) Combination frequencies of above
(almost all others!)





Modes show sidelobes with amplitudes smaller by a factor of 500

Absolutely equidistant spacings of

0.1597 ± 0.0002 c/d

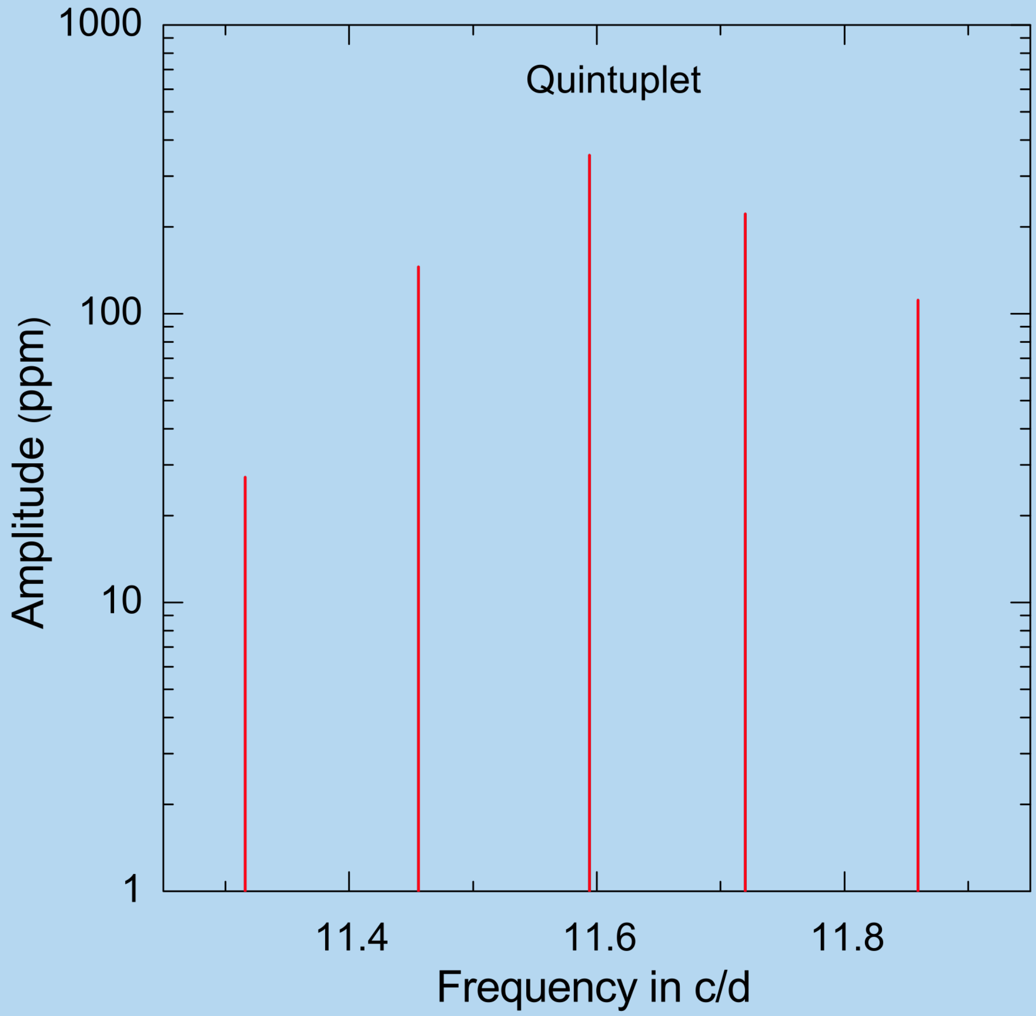
(which also shows up as a peak in the power spectrum)

Too exact for $\ell = 2$ quintuplets

Pattern also shows up in the combination frequencies

→ Amplitude modulation

ℓ = 2 quintuplet



Average spacing = 0.134 c/d

Rotational splitting:

$\sigma_m = \sigma_o - (1 - C_1)\, m\, \Omega$,

Ledoux constant is 0.164 (pulsation model)

Predicts rotation Ω = 0.160 c/d

Perfect agreement.

Evidence for 0.160 c/d peak being the rotational frequency:

* v sin i = 19 ± 1 km/s (measured)
  v = 23 ± 1 km/s (calculated from 0.160 c/d)
* ℓ = 2 quintuplet spacings predict 0.160 c/d rotation
* sidelobes of both radial modes have exact spacing of 0.160 c/d

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Implications:

* Surface of this normal-looking star is not symmetric
  Brightness changes by 0.16% during rotation
* Amplitudes of radial modes change by 0.2% of their value during rotation

3. Stellar cycles and nonradial pulsation

Amplitude and period variability are common

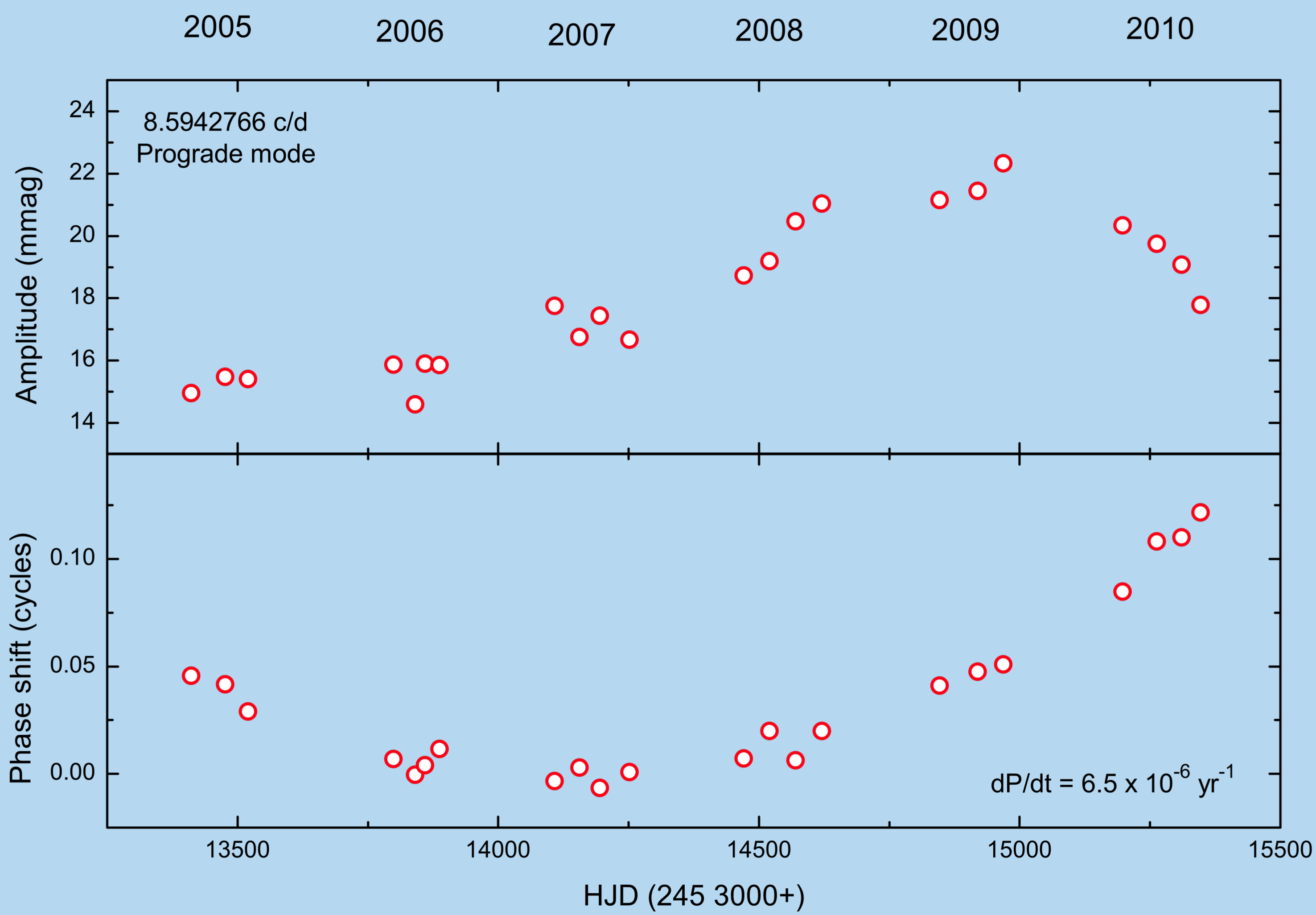
Program: Pick nonradial pulsators, since modes with different (ℓ, m) values probe different parts of the star

4 CVn: Teff = 6900K, log g = 3.4, v sin i = 120 km/s

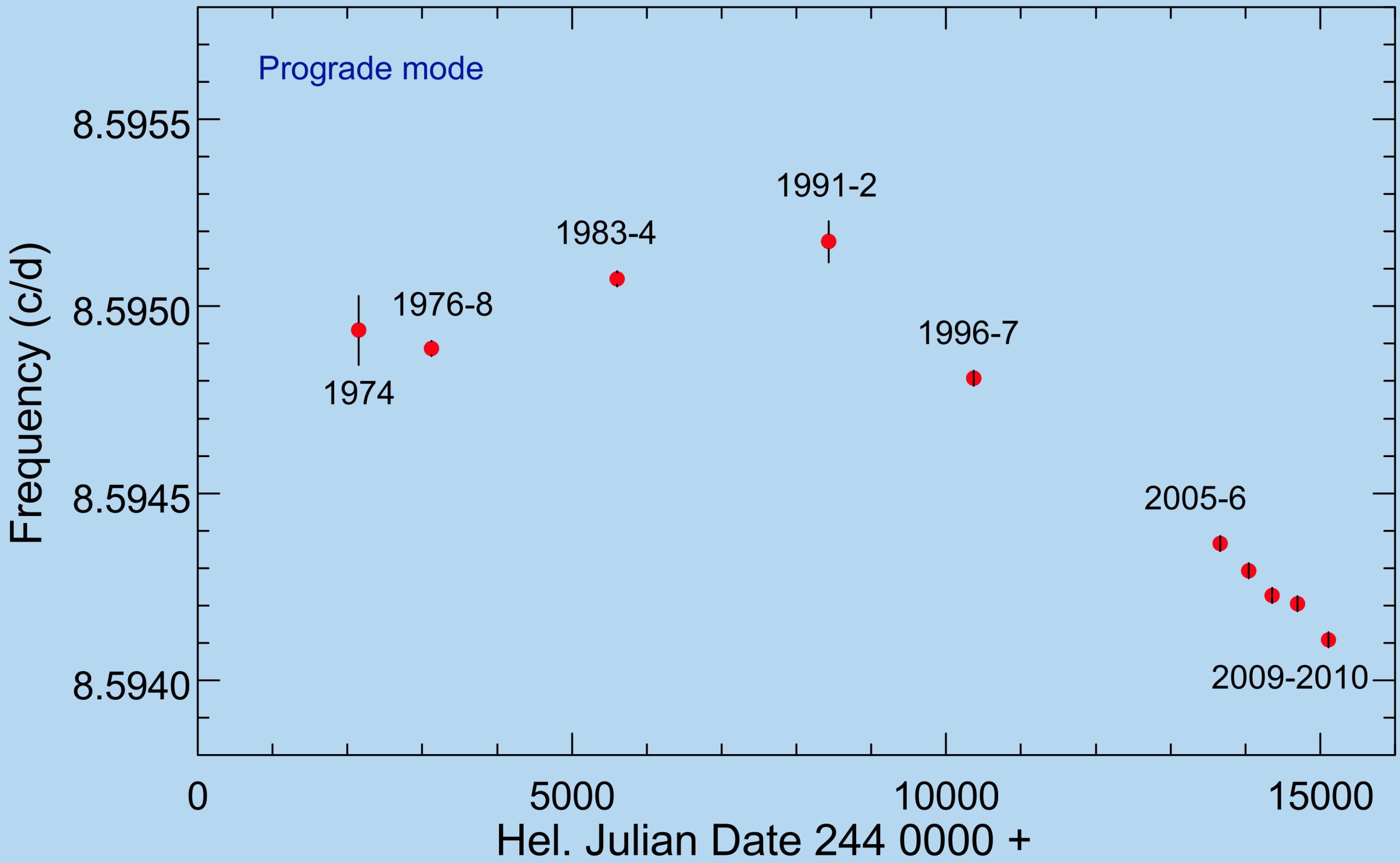
650+ nights on 4 CVn with 75-cm APT + intl. campaigns

- two colors allow determination of ℓ values
- couple with high-dispersion spectroscopy for mode identification
- compare changes in individual pulsation modes

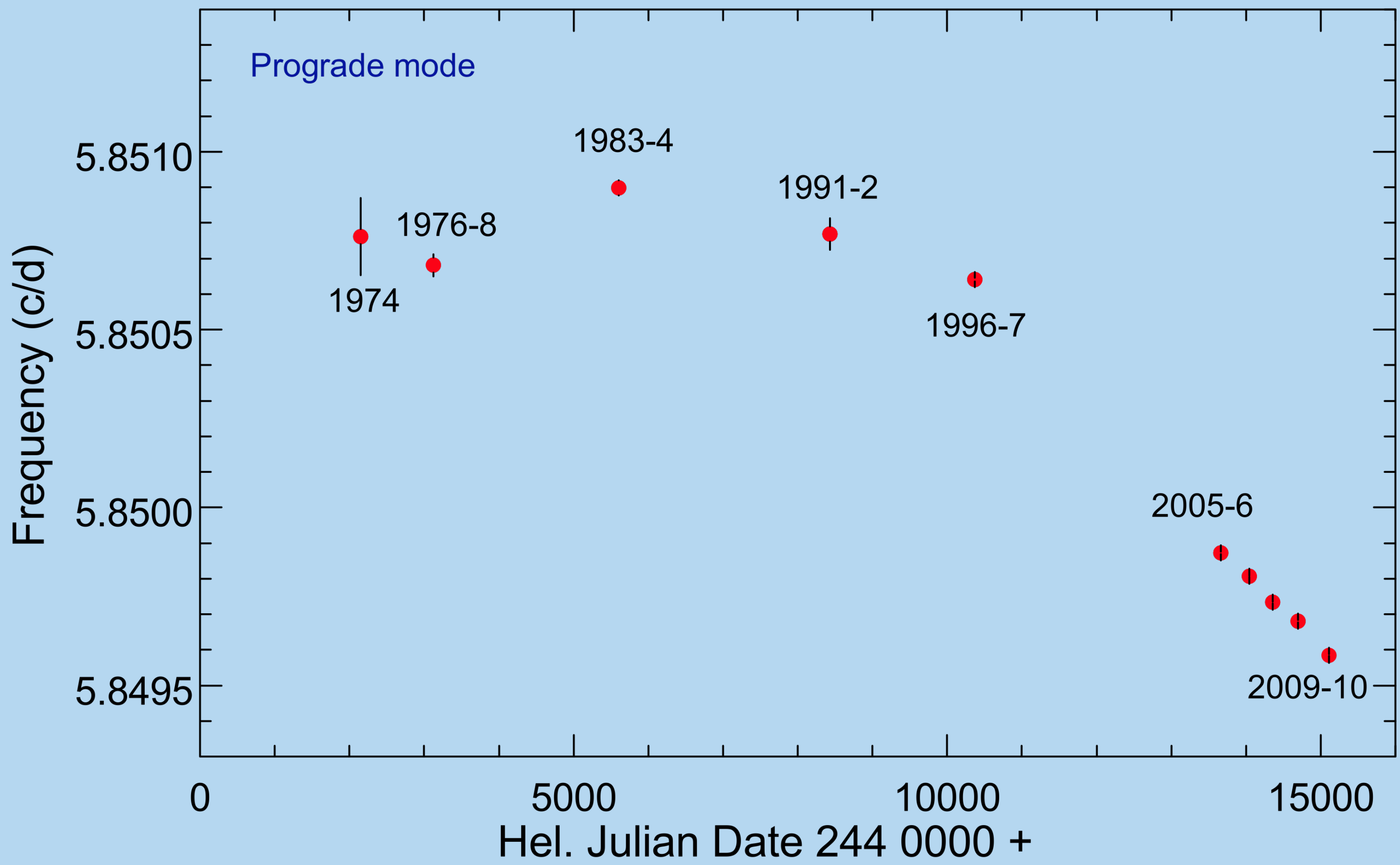
4 CVn: Prograde mode at 8.59 c/d



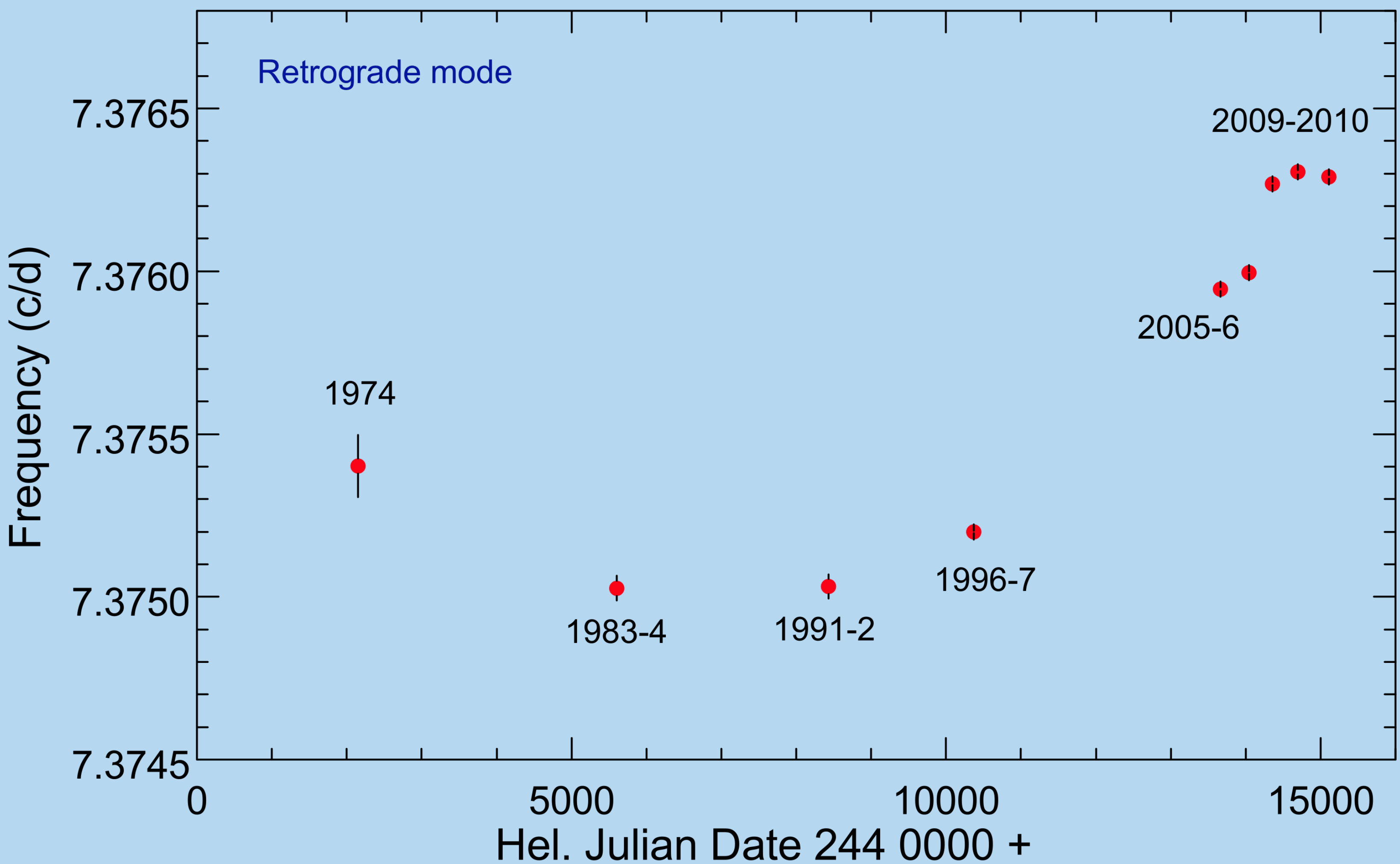
4 CVn: Prograde mode at 8.59 c/d



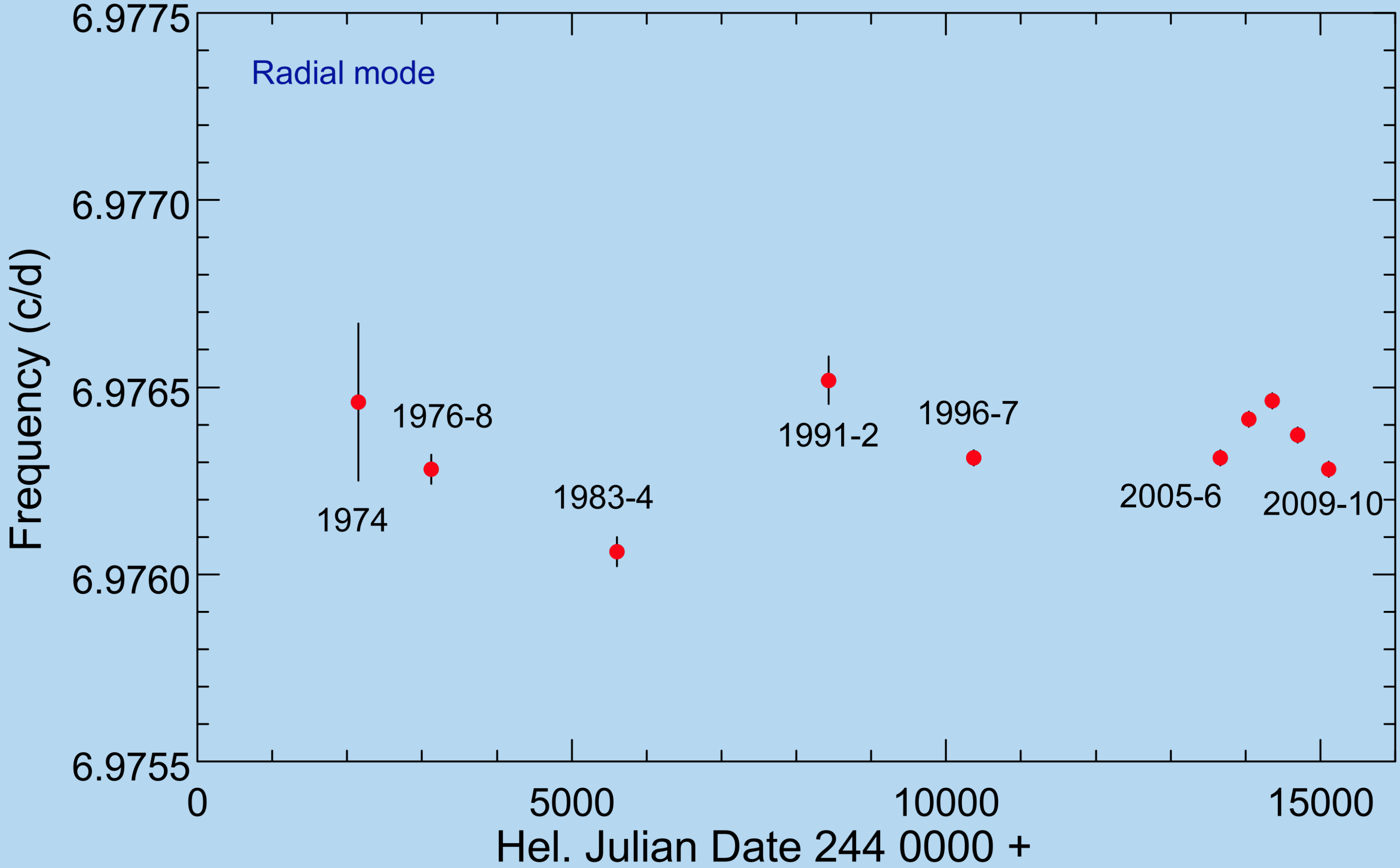
4 CVn: Prograde mode at 5.85 c/d



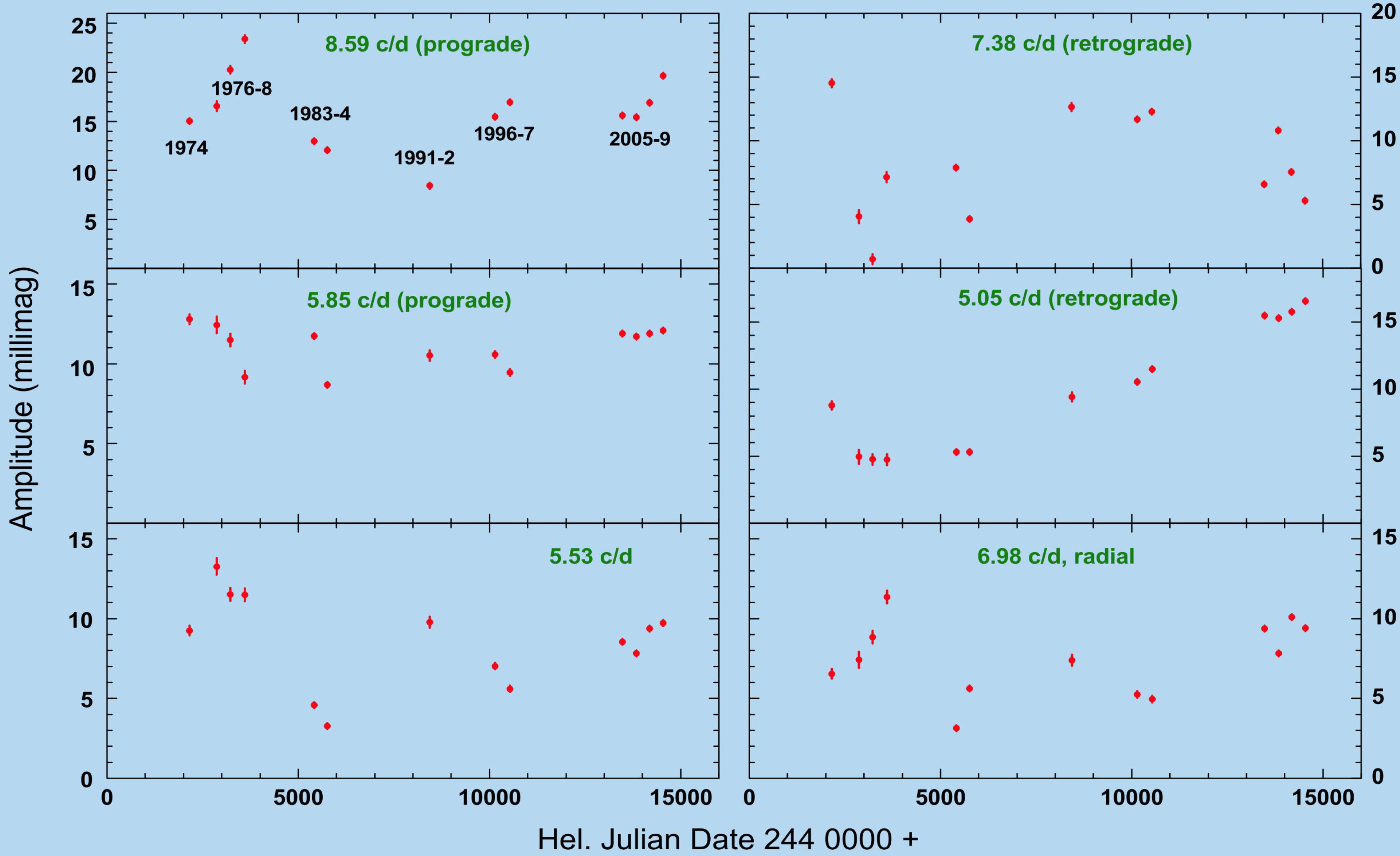
4 CVn: Retrograde mode at 7.38 c/d



Delta Scuti star 4 CVn: Radial mode at 6.98 c/d



Amplitude and period changes do not correlate.
Amplitude changes are not random, but show no patterns.



Variations suggest the presence of stellar cycles with time-scales of years and decades

Amplitude variations are not in sync with period variations

In 4 CVn the considerable amplitude variations make no sense

In 44 Tau, the modulations of the $\ell = 1$ modes are similar

Period variations in 4 CVn

Radial modes nearly constant (as in 44 Tau)

Nonradial $\ell = 1$ mode very variable:

1992 – 2007: (1/P) dP/dt =~ ± 10^{-5} yr^{-1}

Sign of dP/dt depends on whether mode is prograde or retrograde.

Simultaneous sign reversal near 1990, for both +ve and –ve changes

dP/dt variations of different modes are in phase

The dP/dt dependence on m suggests a rotation effect.

Rotational splitting: $\sigma_m = \sigma_o - (1 - C_1)\, m\, \Omega$,

Ω changes. Why?

* Stellar radius changes (up to 1 part in 10^{-5})
* Differential rotation changes (stellar latitude and depth)
* Stellar structure changes

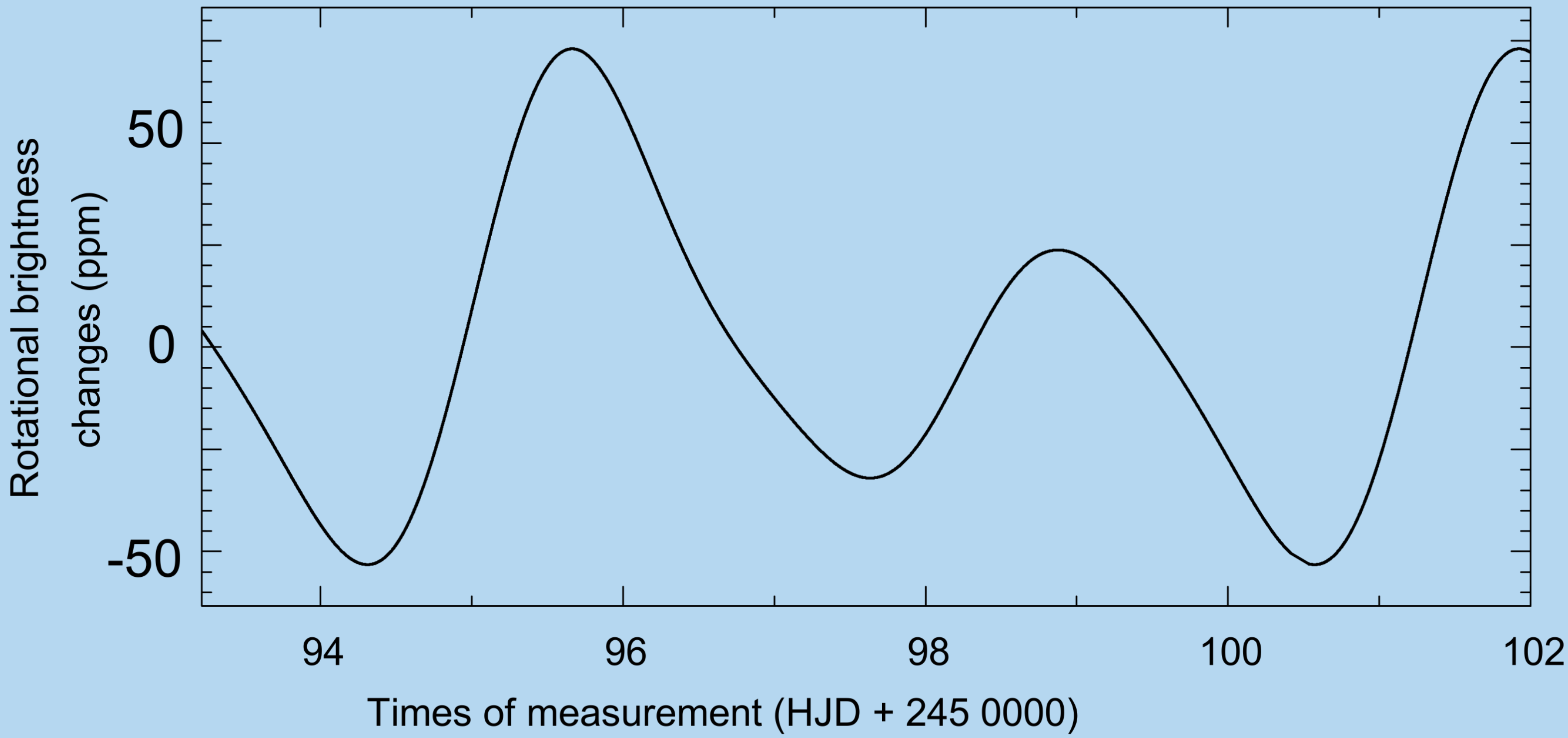
Other pulsators show this effect too, *e.g.*, other RRS stars, Sun, DAV White Dwarf (unpublished, McDonald Observatory), sdB stars

Conclusion

KIC 9700322 (and other ‘normal’ Kepler stars) show a small Change of light output as well as pulsational amplitudes during rotation.

There exist stellar cycles even among main-sequence and giant stars hotter than the Sun. Blazhko Effect is everywhere.

KIC 9700322 – rotational modulation



roAp star Alpha Vir similar rotation and rotn lite curve, rotl. modulation is millimag, not 50 ppm

Some reasons for amplitude and period variability

Magnetic/convective interaction with radial pulsation (Stothers 2006)

Periodic build up and destruction of magn. field via interaction with turbulent convection

Details why amplitudes change missing (see Kovacs 2009)

Resonances between modes

e.g., nonradial resonant rotator/pulsator model (NRRP)

Modulation side lobes are asymmetric, too many variable modes?

AI CVn (later) may not fit

Magnetic oblique rotator/pulsator model

Modulation side lobes are unequal, need fields, ok for roAp stars

Pulsational damping upon leaving the instability strip (Dall et al. 2003)
No, unless they always weave in and out

Evolutionary
Too fast for Delta Scuti, Beta Cephei, White Dwarf stars etc.

Beating between very close frequencies
Not general, partial yes due to mode-trapping in Delta Scuti stars

Precession of the pulsation axis to the line of sight (Balona 1985)
Three axes: orbital, rotation, pulsation
Cannot explain radial mode variability, may fit some stars (Spica)

"It seems … that the inspiration for new types of models should come from the observational side."
(G. Kovacs, 'The Blazhko Effect', arXiv:0908.4536v1, 2009)