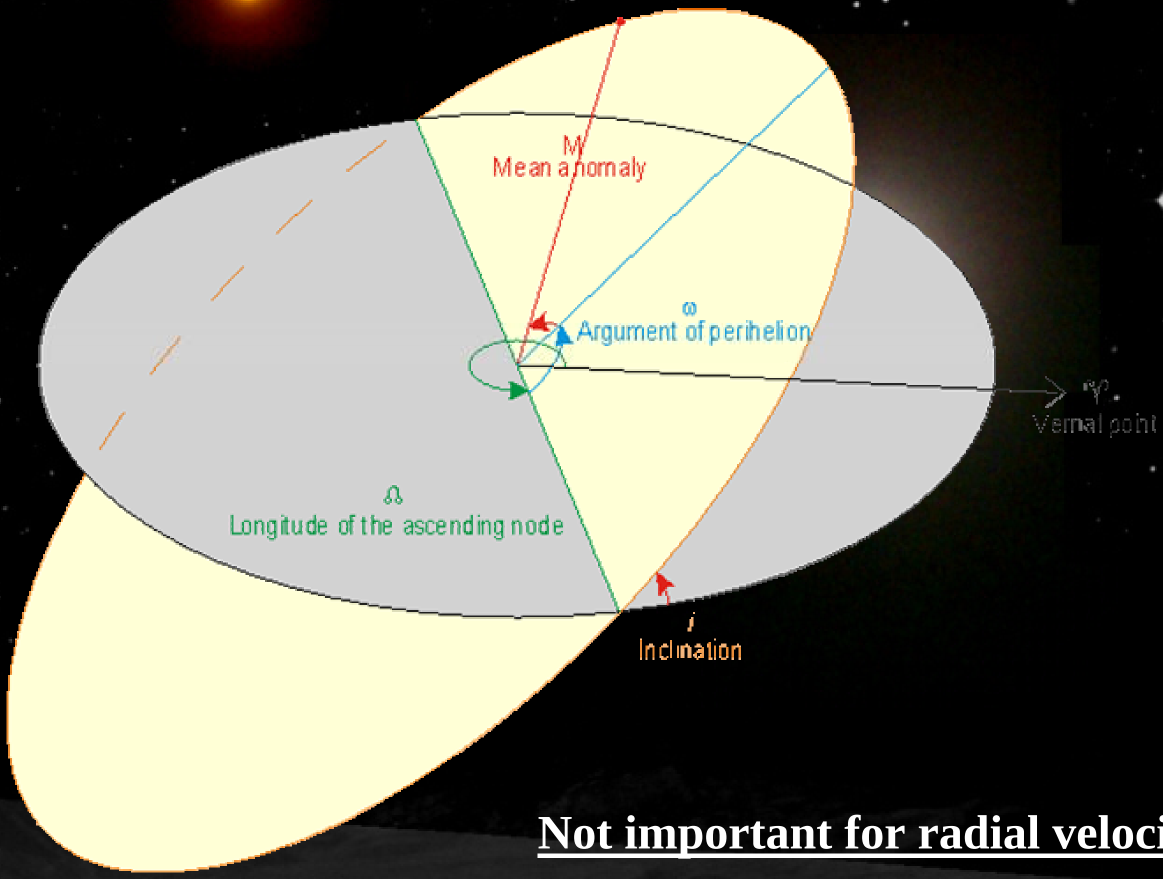
HOW TO FIND EXTRASOLAR PLANETS?

by starring at the monitor

Keplerian Orbits



Important for radial velocities

- P: period of orbit
- ω: orientation of periastron
- e: eccentricity
- M or T: mean or true anomaly
- K: velocity amplitude

Not important for radial velocities

Ω: angle between Vernal equinox and angle of ascending node direction (orientation of orbit in sky)

i: orbital inclination (unknown and cannot be determined

Keplerian Orbits

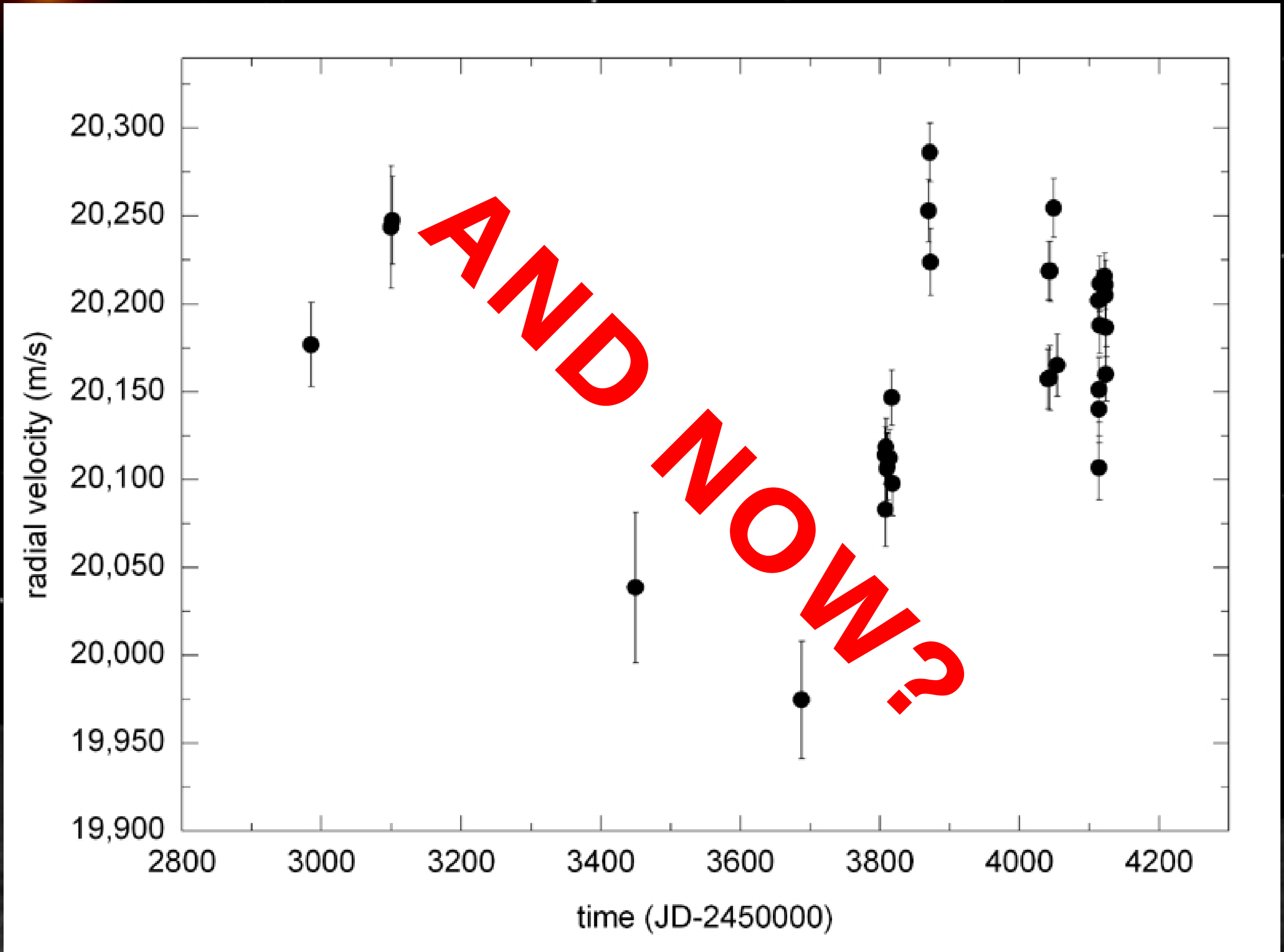
$$v_r(t) = \gamma_0 + K \cdot \left[\cos\left(\omega + T(t)\right) + e\cos\omega\right]$$

$$\tan\frac{T(t)}{2} = \sqrt{\frac{1+e}{1-e}}\tan\frac{E(t)}{2}$$

Kepler's equation

$$M(t) = E(t) - e\sin E(t)$$

Radial Velocity Data



Radial Velocity Data

- reality is not so easy like a plate capacitor
- 5 parameters per planet
- perturbations due to stellar activity
  (spots, circumstellar disk, pulsation, ...)
- bad sampling rate (time coverage)
  because you didn‘t get observing time, it was cloudy, ...

Period Estimation – Scargle Periodogram

$$P_x(\omega) = \frac{1}{2}\left\{ \frac{\left[\sum_j^{N_0} X(t_j)\cos\omega(t_j-\tau)\right]^2}{\sum_j^{N_0}\cos^2\omega(t_j-\tau)} + \frac{\left[\sum_j^{N_0} X(t_j)\sin\omega(t_j-\tau)\right]^2}{\sum_j^{N_0}\sin^2\omega(t_j-\tau)} \right\}$$

$$\tan(2\omega\tau) = \sum_j^{N_0}\sin 2\omega t_j \Big/ \sum_j^{N_0}\sin 2\omega t_j$$

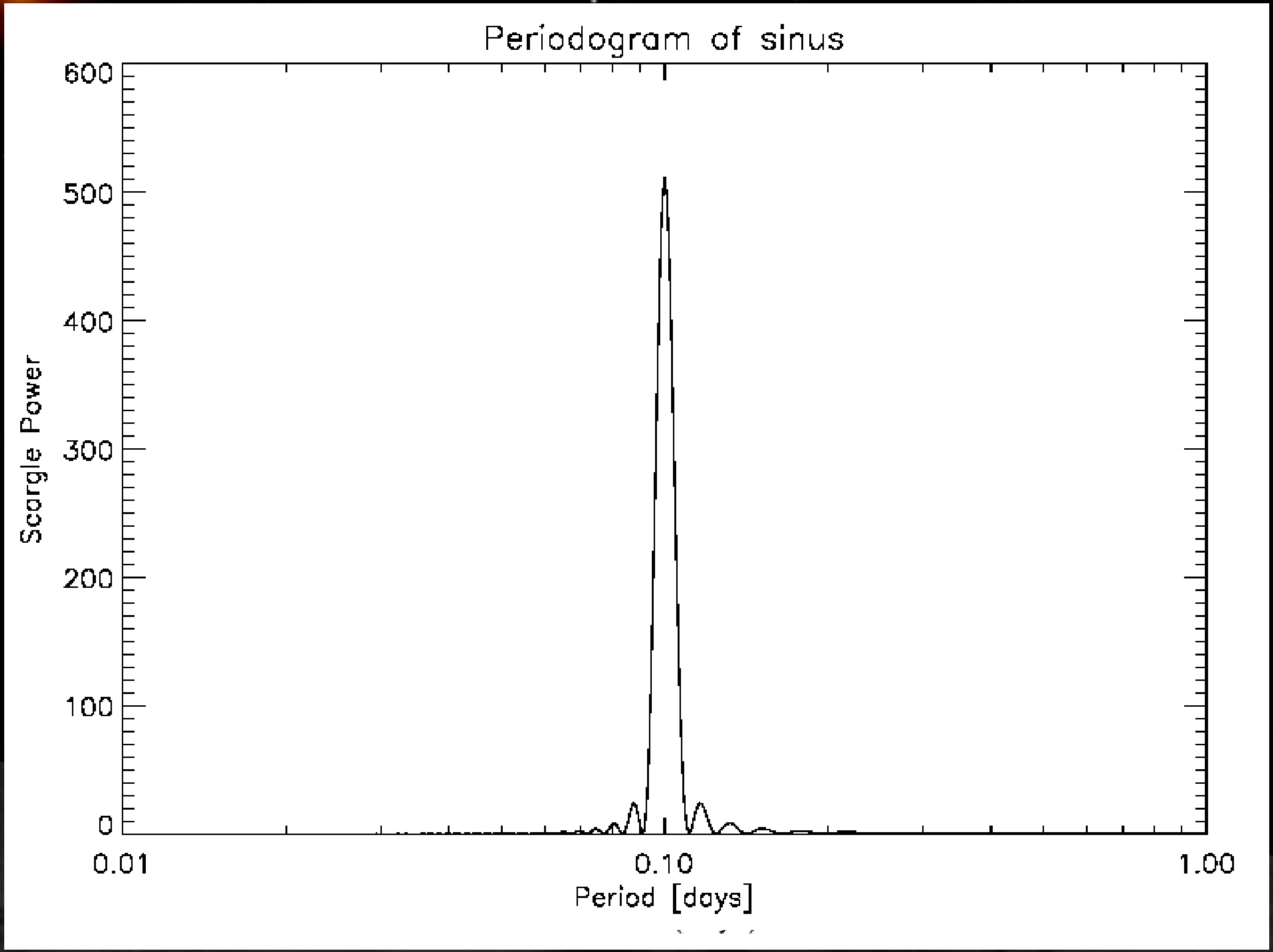
(Scargle 1982)

Power is a measure of the statistical significance of that frequency (period):

False alarm probability ≈ 1 – $(1–e^{-P})^N$ = probability that noise can create the signal

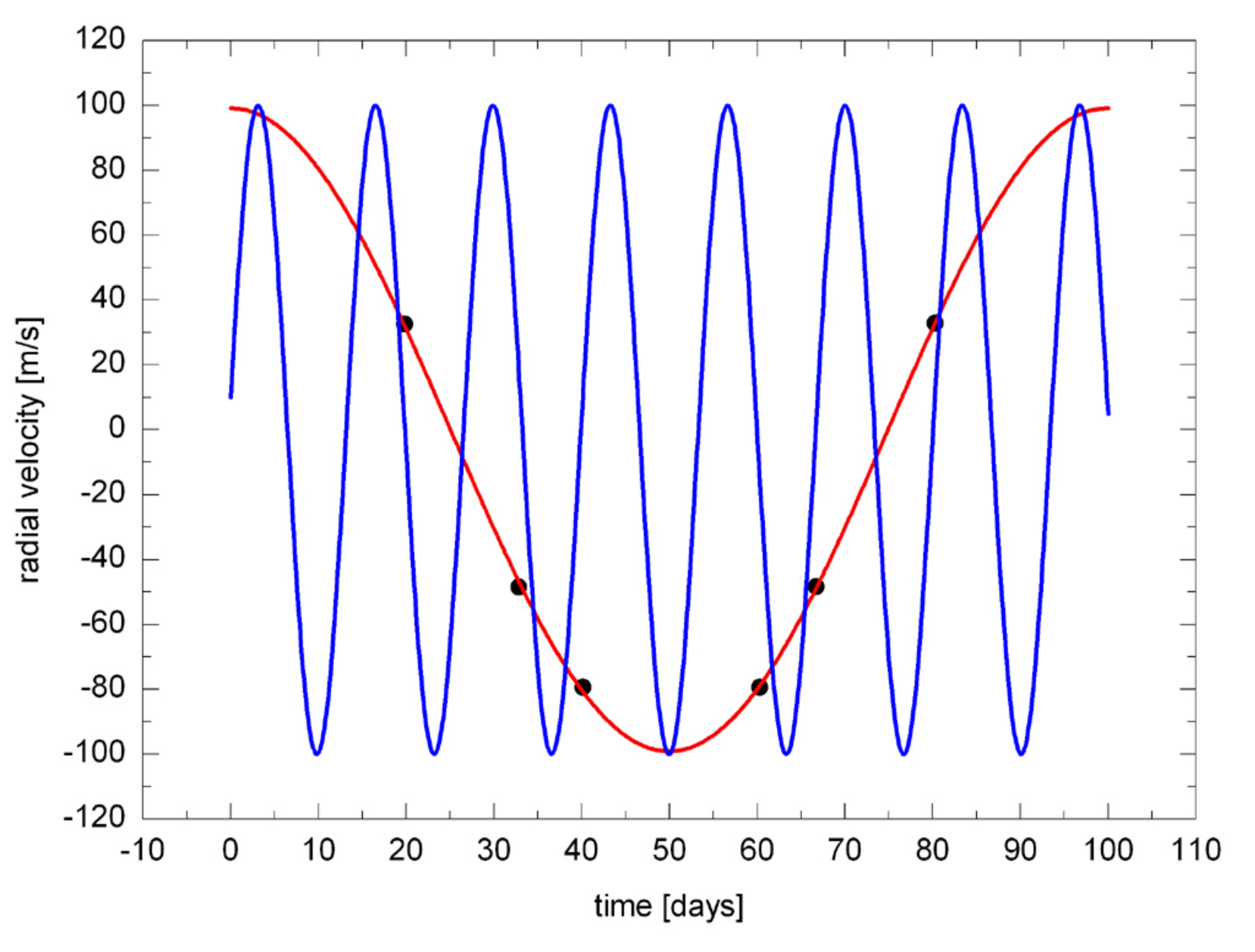
N = number of indepedent frequencies ≈ number of data points

Example I



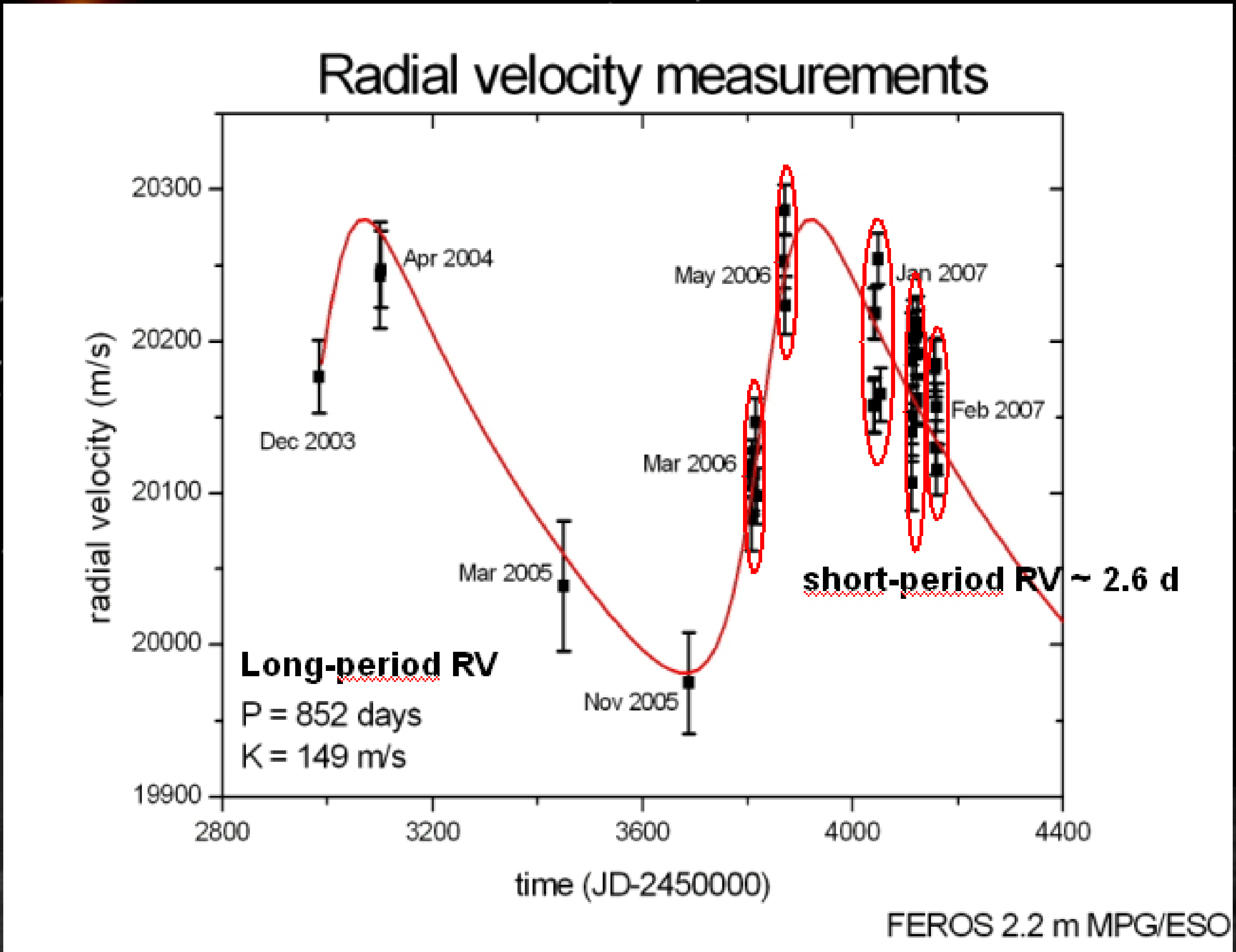
Periodogram of sinus
600
500
400
300
200
100
0
Scargle Power
0.01
0.10
1.00
Period [days]

Example II



120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
radial velocity [m/s]
-10
0
10
20
30
40
50
60
70
80
90
100
110
time [days]

Real Data



Radial velocity measurements
radial velocity (m/s)
20300
20200
20100
20000
19900
2800
3200
3600
4000
4400
time (JD-2450000)
Dec 2003
Apr 2004
Mar 2005
Nov 2005
Mar 2006
May 2006
Jan 2007
Feb 2007
short-period RV ~ 2.6 d
Long-period RV
P = 852 days
K = 149 m/s
FEROS 2.2 m MPG/ESO

Bisector

Starspots

- Magnetic activity on the stellar chromosphere.
- Produce variation in the shape of spectral line.
- Can cause rotational modulation that mimicks the signature of a planet.

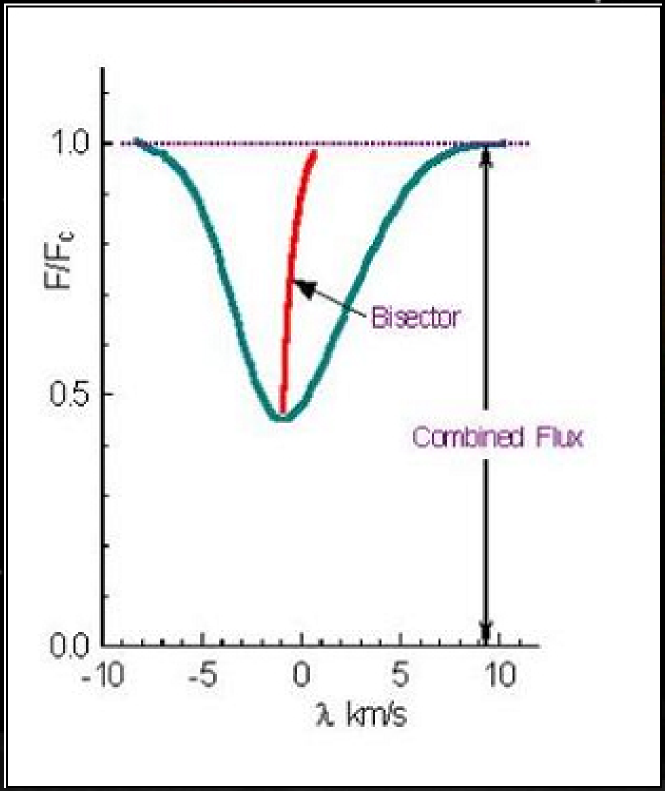
But,

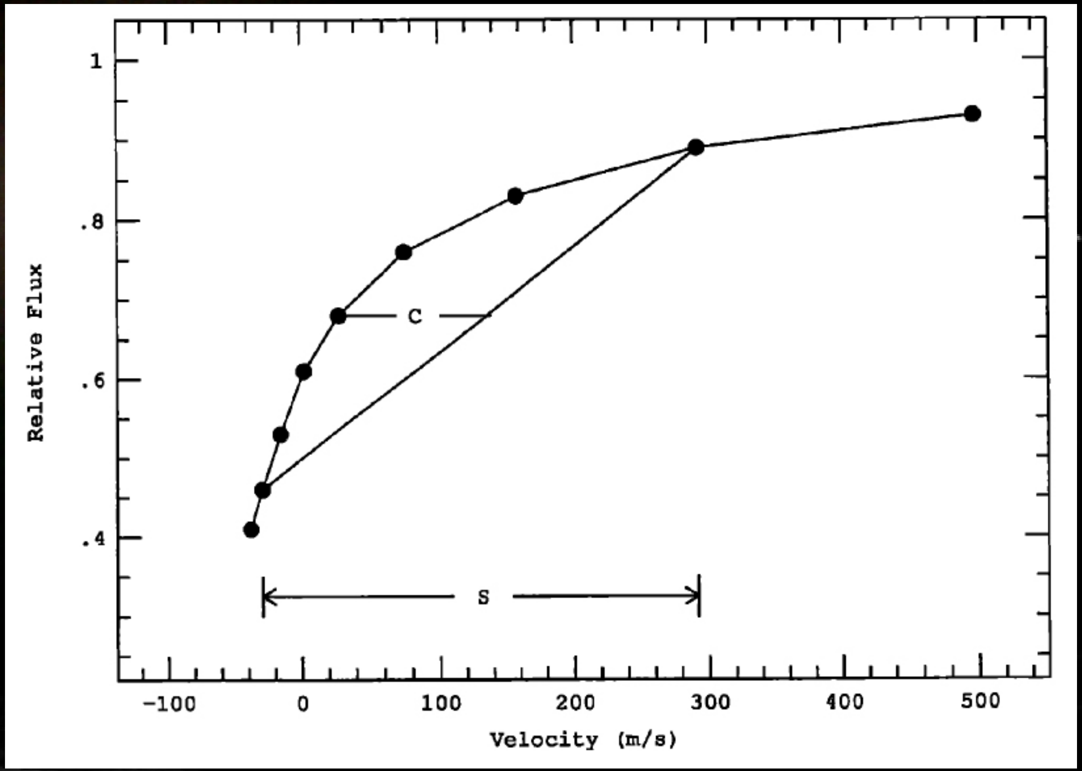
- Their size changes → RV amplitude changes.
- Typical stellar rotational period: P_{rot} ~ 2-8 days

(photometric survey, Lamm 2004)

Bisector

Stellar activity indicator: line profile asymmetry



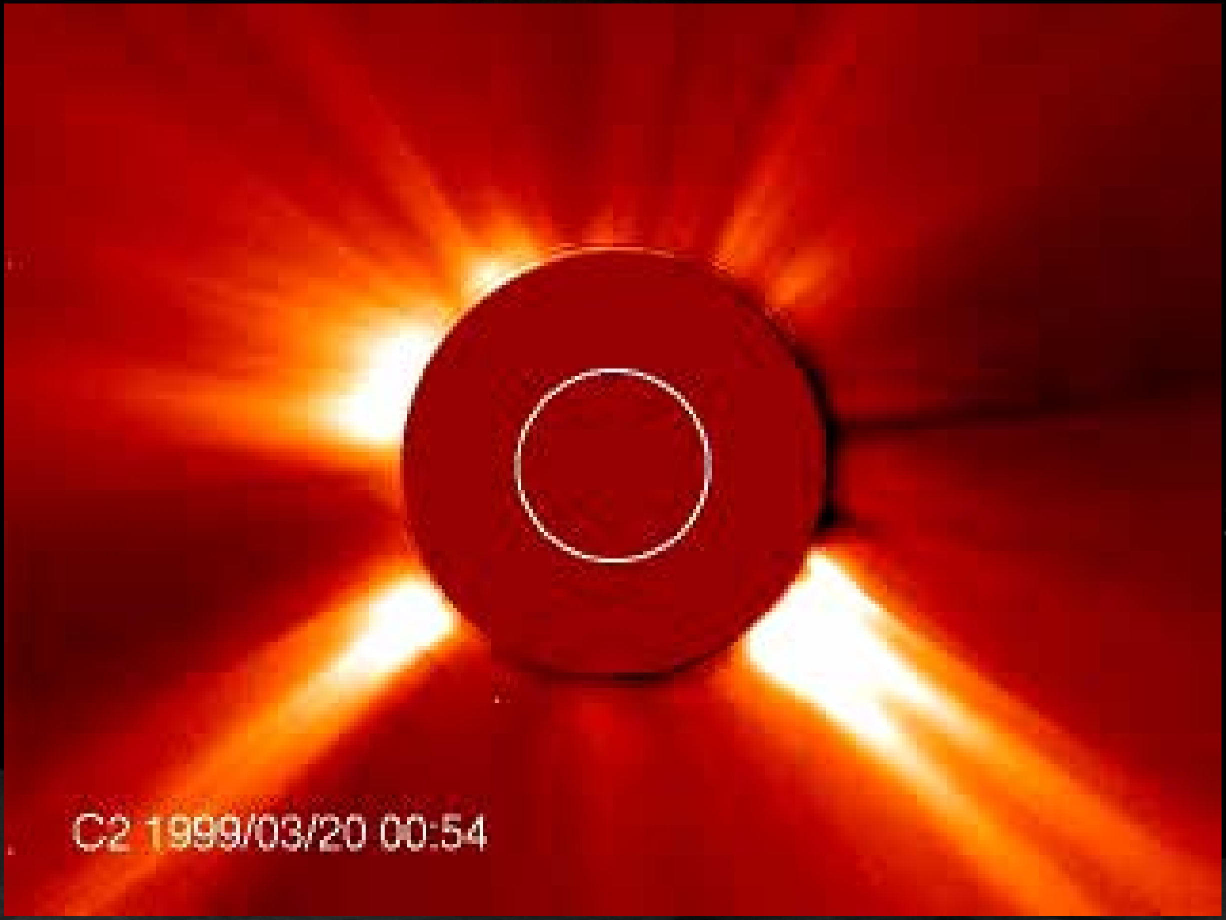


Bisector shape (Gray 1982)

Bisector velocity span (Hatzes 1996)

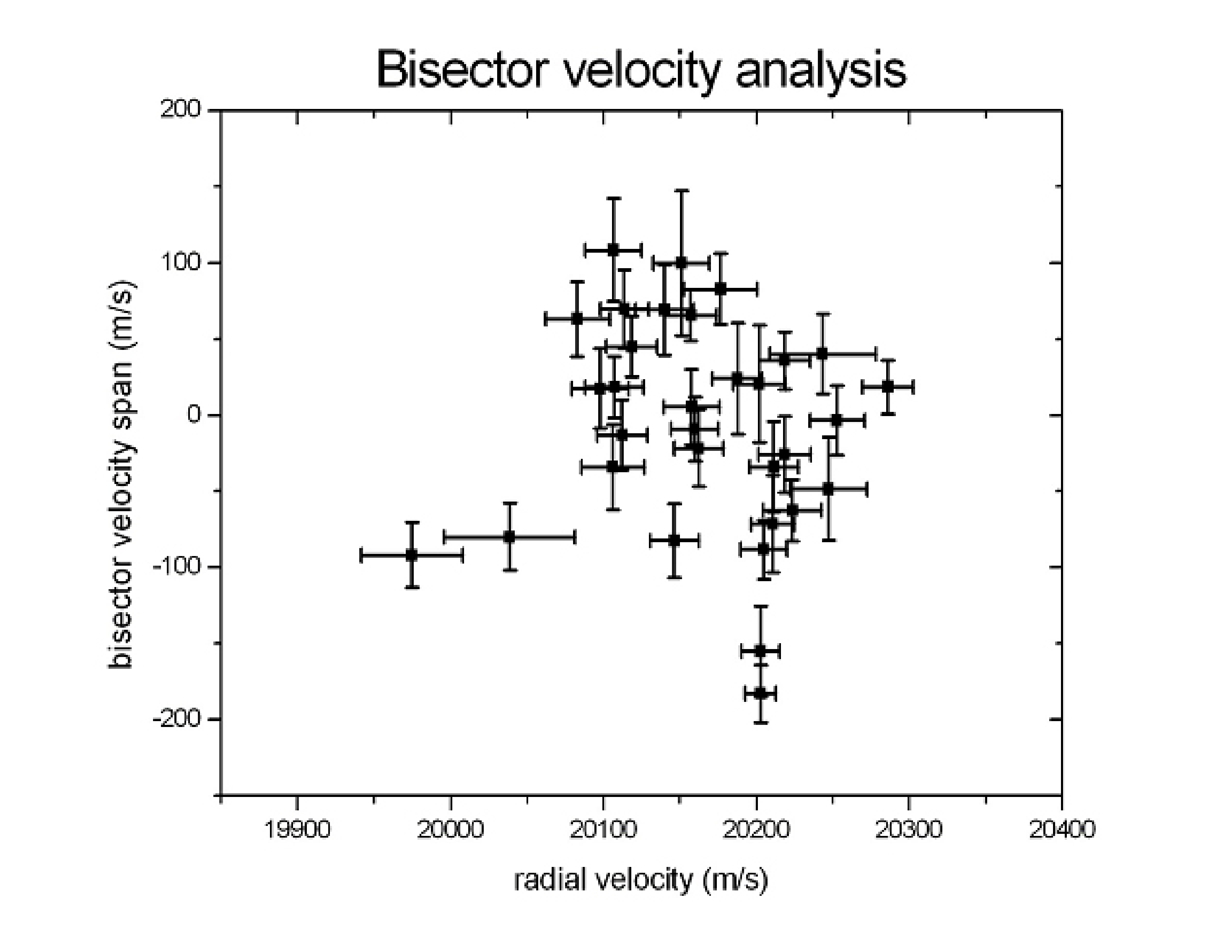
Application: e.g. Queloz et al. (2001), Setiawan et al. (2005, 2006)

Stellar Activity



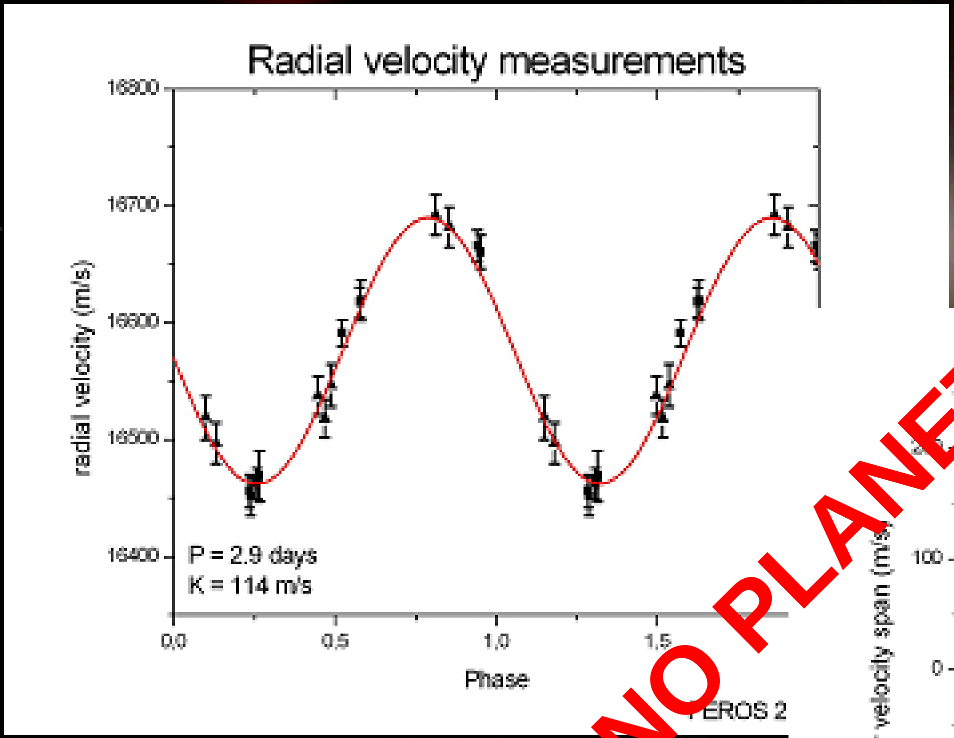
(SOHO)

Real Data

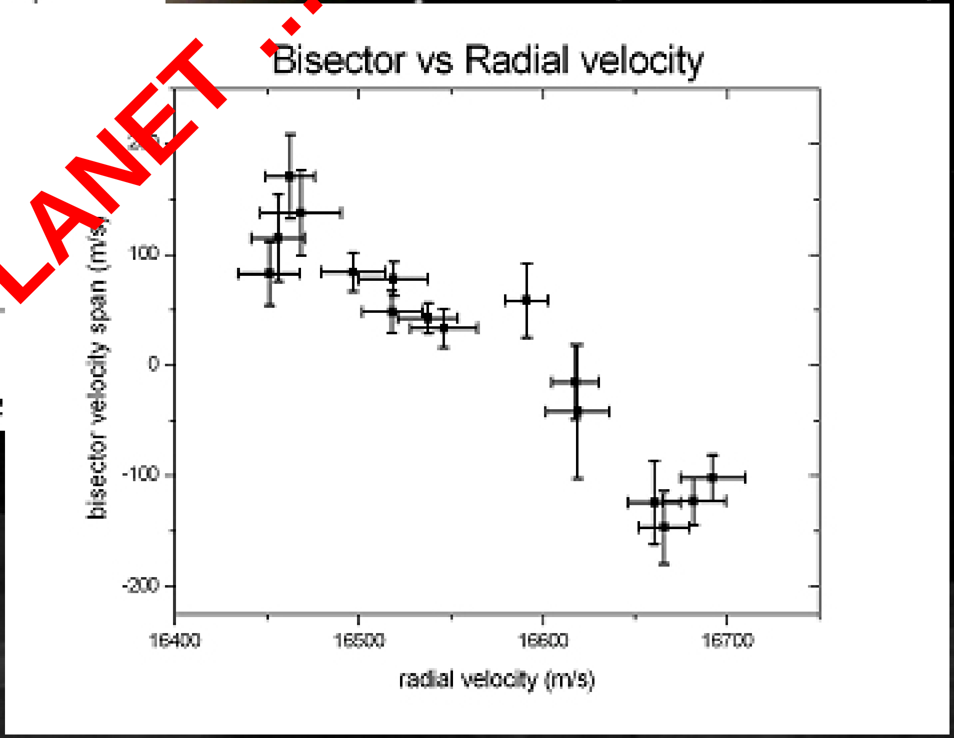


Bisector velocity analysis
bisector velocity span (m/s)
200
100
0
-100
-200
19900
20000
20100
20200
20300
20400
radial velocity (m/s)

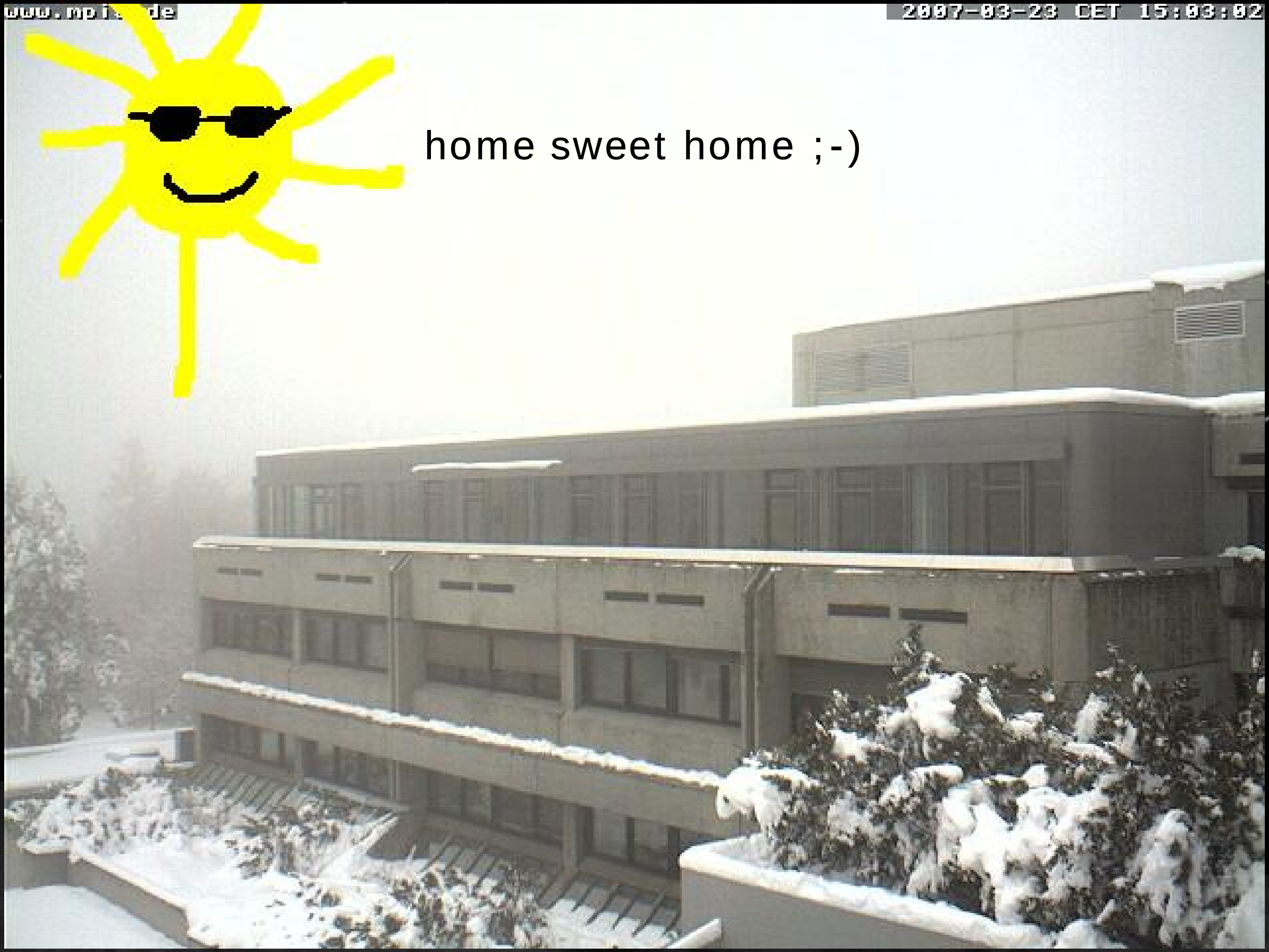
Stellar activity with periodic RV variation
Period ~ 2.9 days
Semi amplitude = 114 m/s



NO PLANET .....



Correlation between line shape variation and radial velocity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home sweet home ;-)