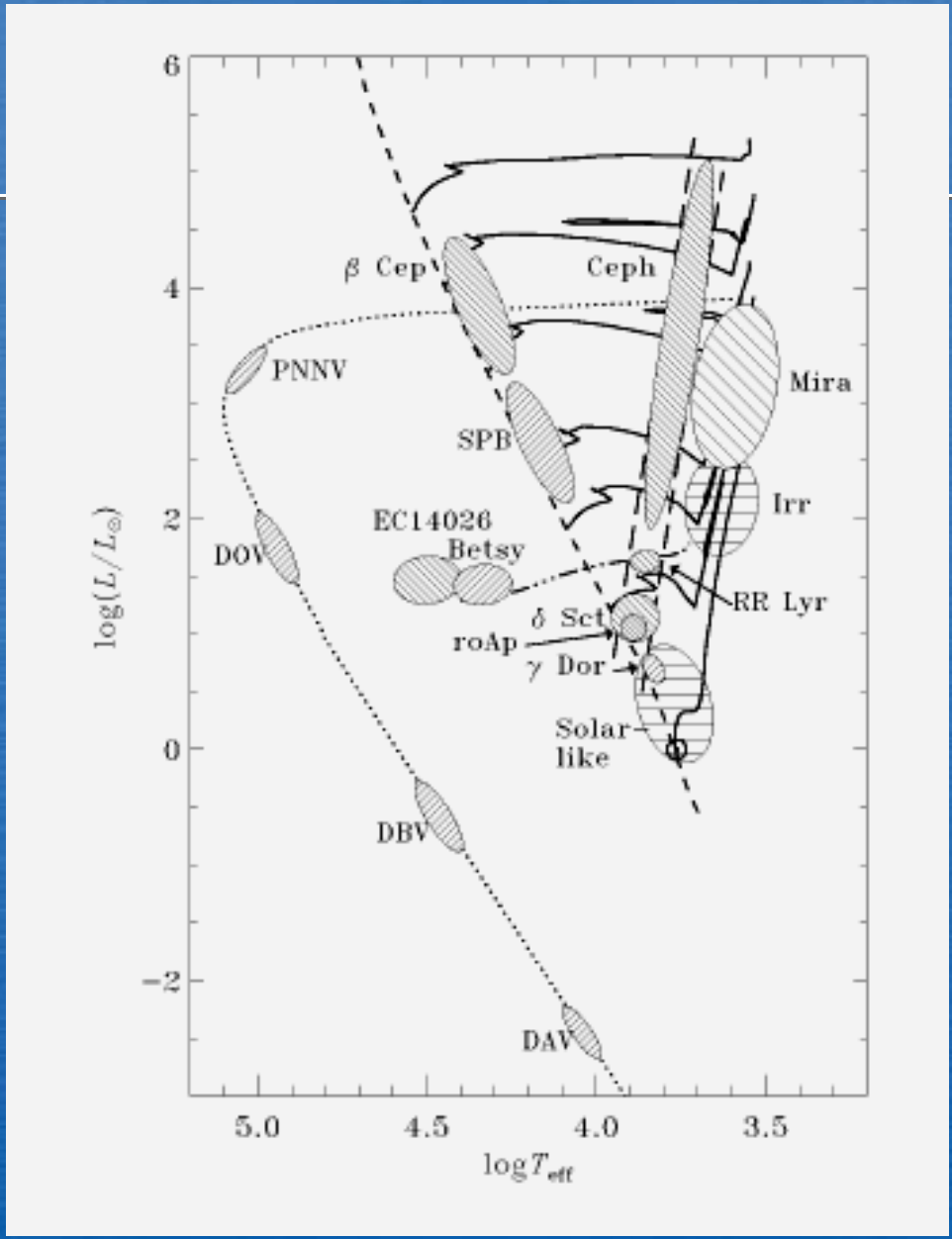
高精度視線速度観測
―恒星振動への応用―

安藤裕康

20１１年１２月28日

恒星の振動現象


β Cep
Ceph
PNNV
Mira
SPB
Irr
EC14026
Betsy
DOV
RR Lyr
δ Sct
roAp
γ Dor
Solar
like
DBV
DAV
6
4
2
0
−2
5.0
4.5
4.0
3.5
log(L/L⊙)
log T_eff

観測手法

太陽の視線速度観測

Brookes, Isaak, van der Raay (1978 MN)
start in 1975　at Tenerife

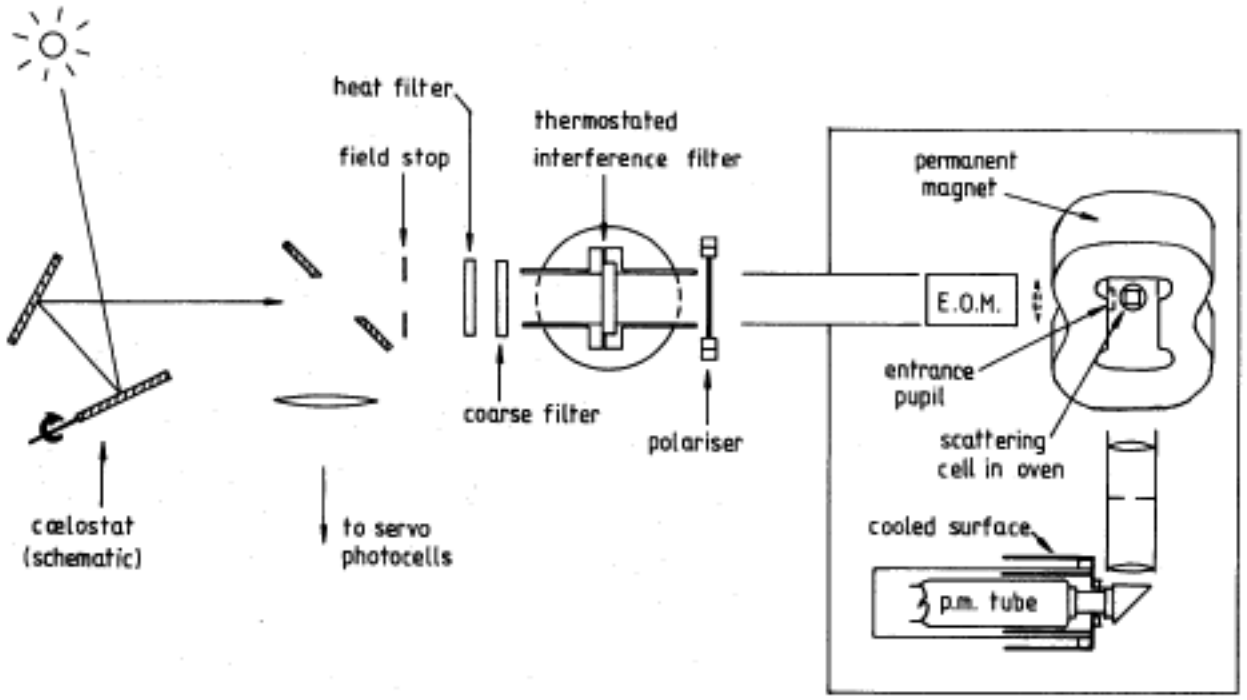
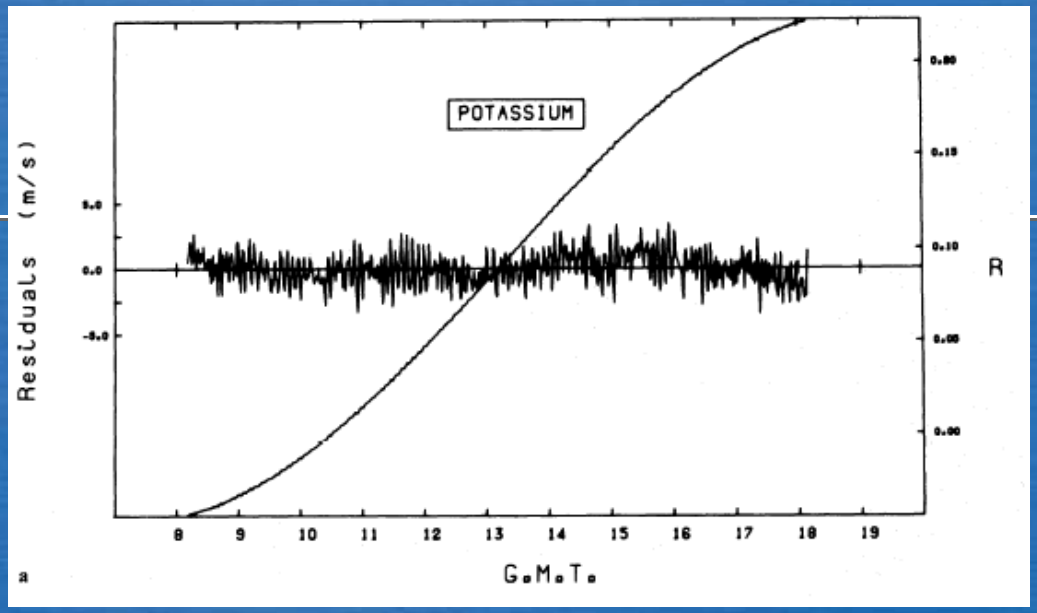


Figure 3. The coelostat and spectrometer optics.



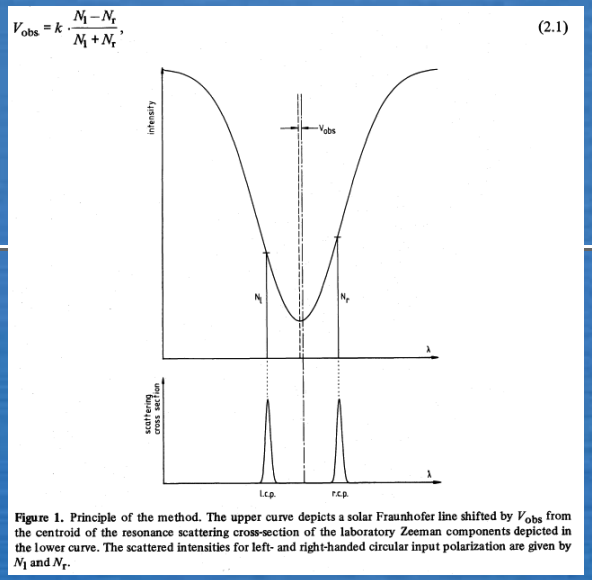


Figure 1. Principle of the method. The upper curve depicts a solar Fraunhofer line shifted by V_{obs} from the centroid of the resonance scattering cross-section of the laboratory Zeeman components depicted in the lower curve. The scattered intensities for left- and right-handed circular input polarization are given by N_l and N_r.

Radial velocity measurement of the Sun

恒星の相対視線速度は一般に大きい

–> 恒星の観測には同じ方法は使えない

星の高精度視線速度観測の試み

1. Optical Resonance Spectrometer

   Fossat et al., (1982)

   3.5m ESO Telescope（αCen A)

   3.6m CFH 望遠鏡（αCMi)

2. Telluric O_2 absorption line
   Smith (1982, 83) at
   MacDonald

3. Absorption gas cell (HF)
   Campbell & Walker（1 9 79） at CFHT
   more than 10 years negative results(1988)

4. Cross correlation with spectrum mask
Baranne(1979) at Haute-Provence
Mayor (1991 start, 1995 extra-solar planet)

5. I_2 gas absorption cell
Marcy & Butler (1991)
spectrum synthesis with use of star and I_2 template
confirm Mayor's discovery

高精度視線速度観測の現状

1. HARPS (comparison lines, Mask correlation)
   at ESO 3.8m
   less than 1m/s (30~50 cm/s)
   (strict environmental control)

2. I2 gas cell (spectrum synthesis)
   over the globe
   cheap and convenient
   more than 1m/s

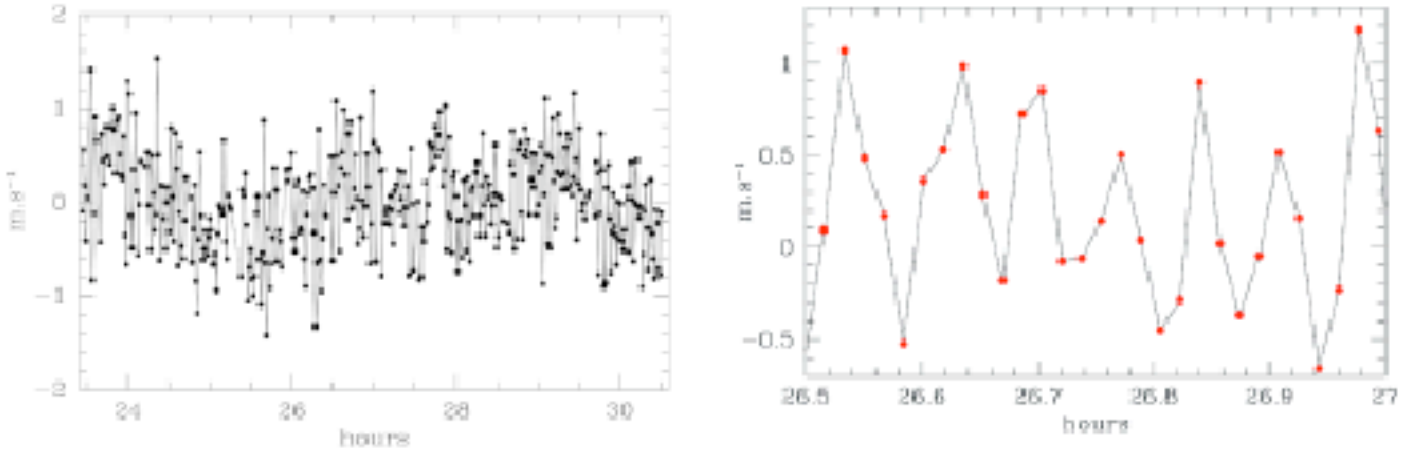


Figure 4: a) Series of 7 hours and 420 exposures on α Centauri B proving the extraordinary short-term precision of HARPS. b) Zoom of figure a) to illustrate the presence of a periodic signal produced by the stellar pulsation.

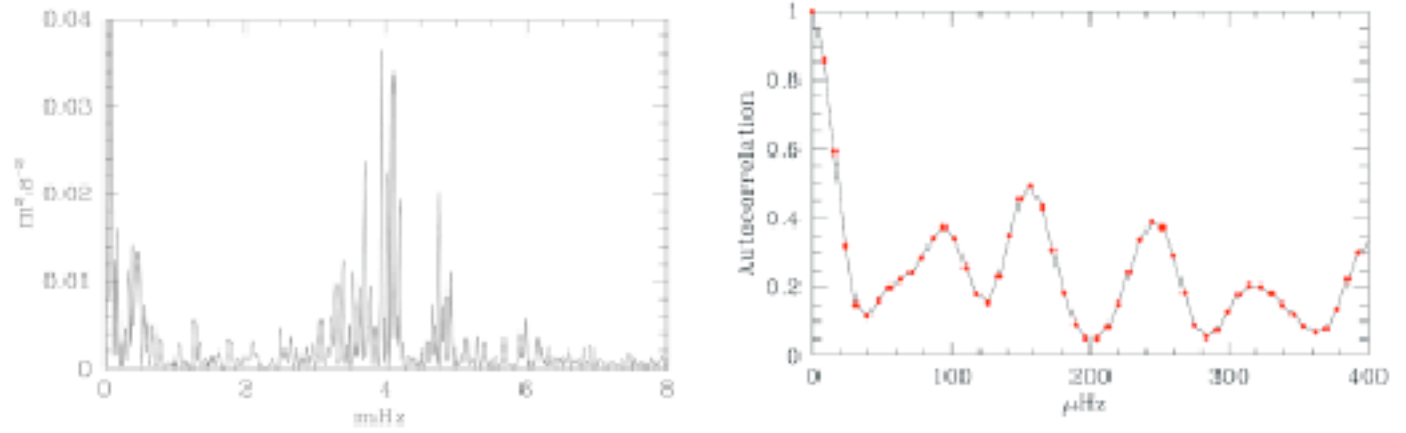


Figure 5: a) Power spectrum of α Cen B. The acoustic modes corresponding to the 4-minutes oscillation are clearly identified and emerge well above the noise. b) Autocorrelation of the power spectrum of α Centauri B.

岡山のＨＩＤＥＳエシェル分光器の登場（２０００）

ヨウ素セルの導入（竹田、神戸）

1997: Start development of HIDES (Izumiura et. al)
1998: Preliminary development of I2 cell (Takeda, Miyazaki, Wada)
1999: I2 cell development（Kambe, Sato,Takeda）
Test observation start on HIDES
2000: I2 cell installation on HDS (Kambe)
HIDES open-use to the community
exoplanet search program prepared by Sato
2001: Monitoring start by Sato（50 samples）
2002: achievement of accuracy 5m/s
2003: Discovery of exoplanet in HD 104985

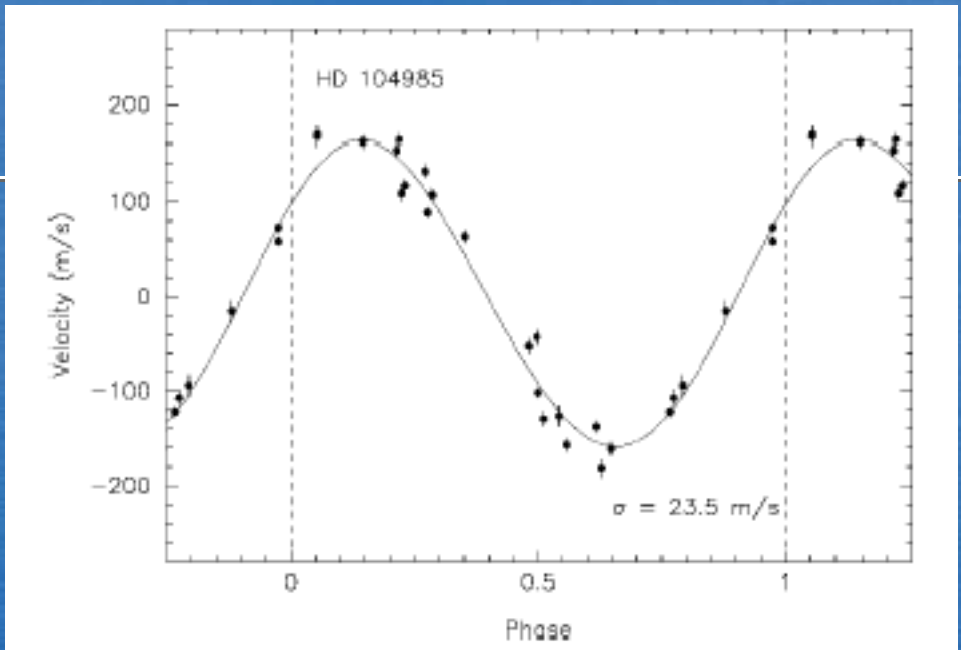
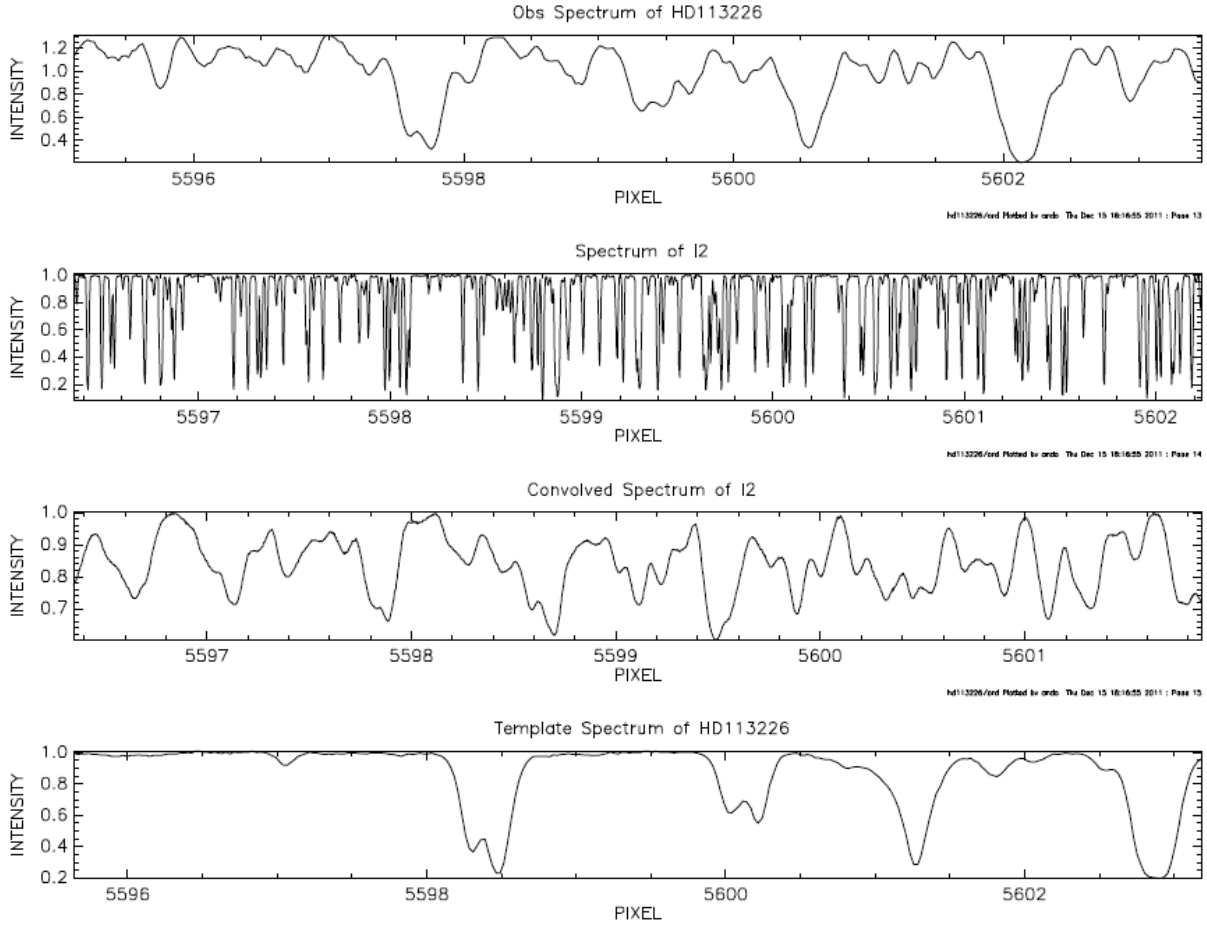


FIG. 2.—Phased radial velocities of HD 104985. The Keplerian orbital fit is shown by the solid line.

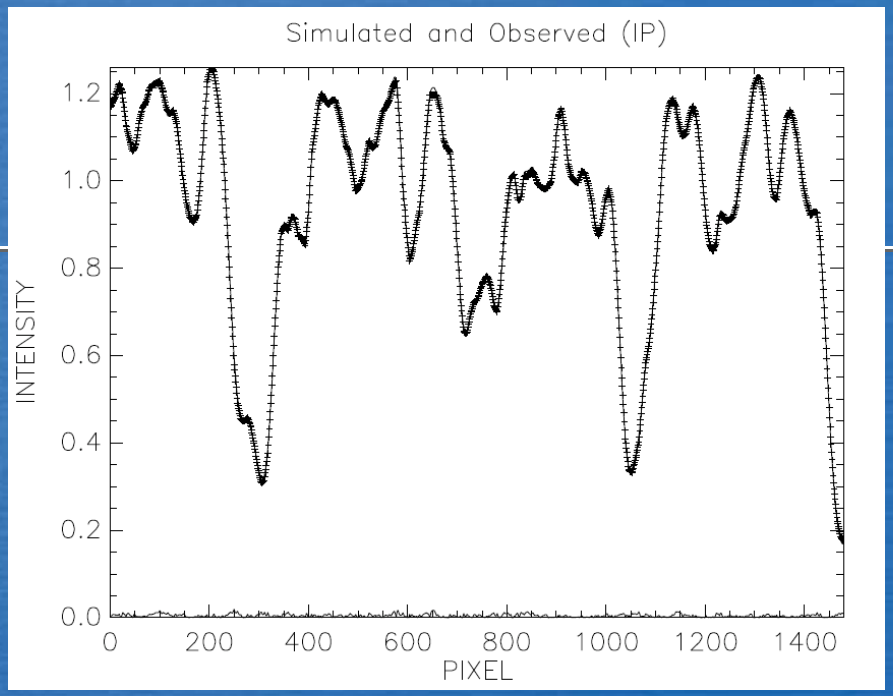
Radial velocity



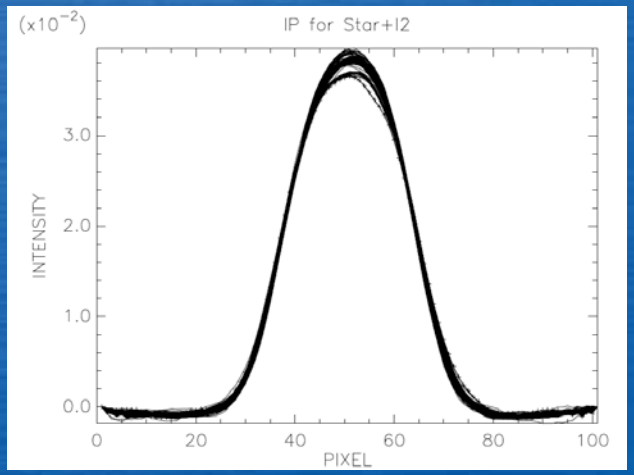
Observed spectrum

I_2 template

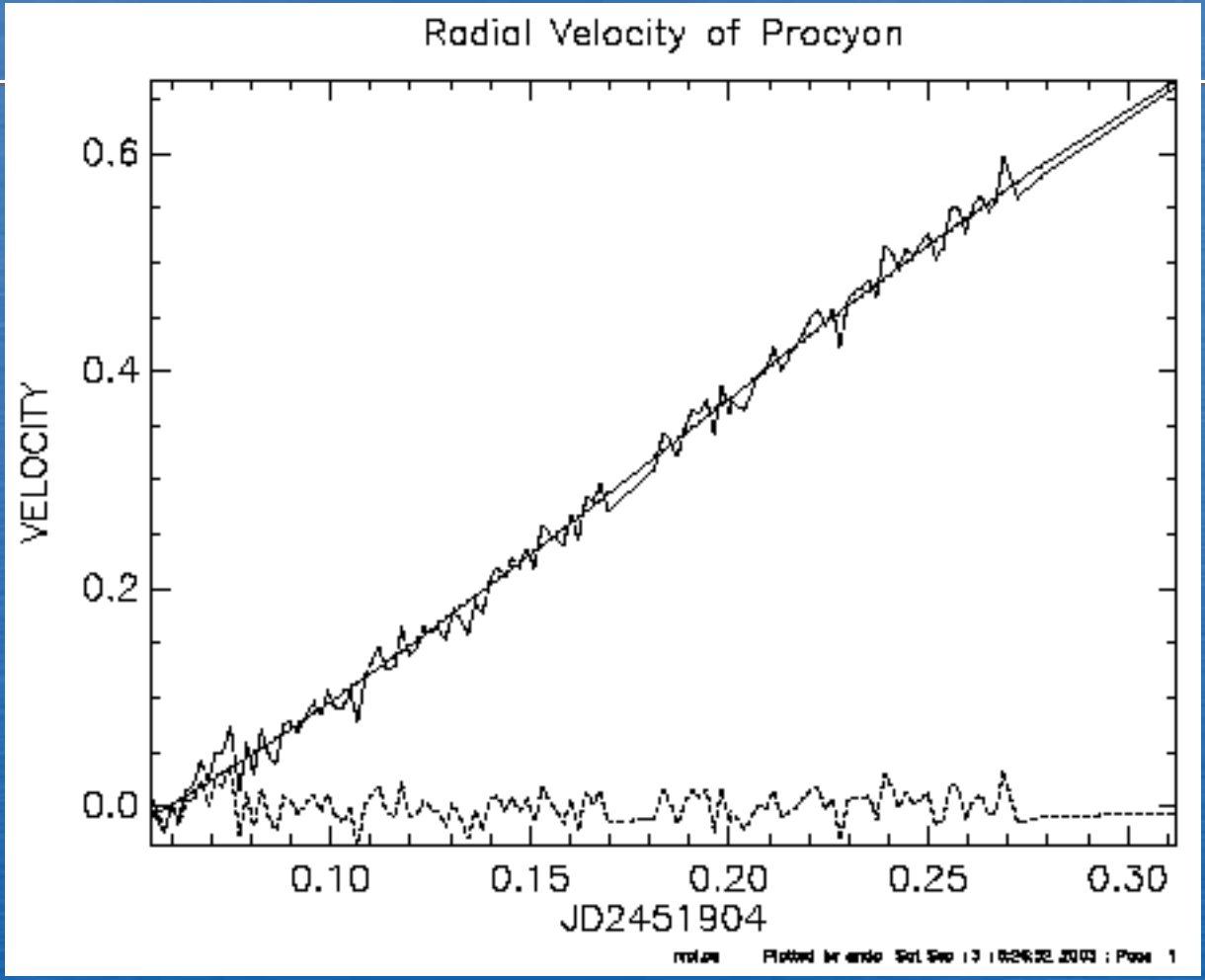
Sta template



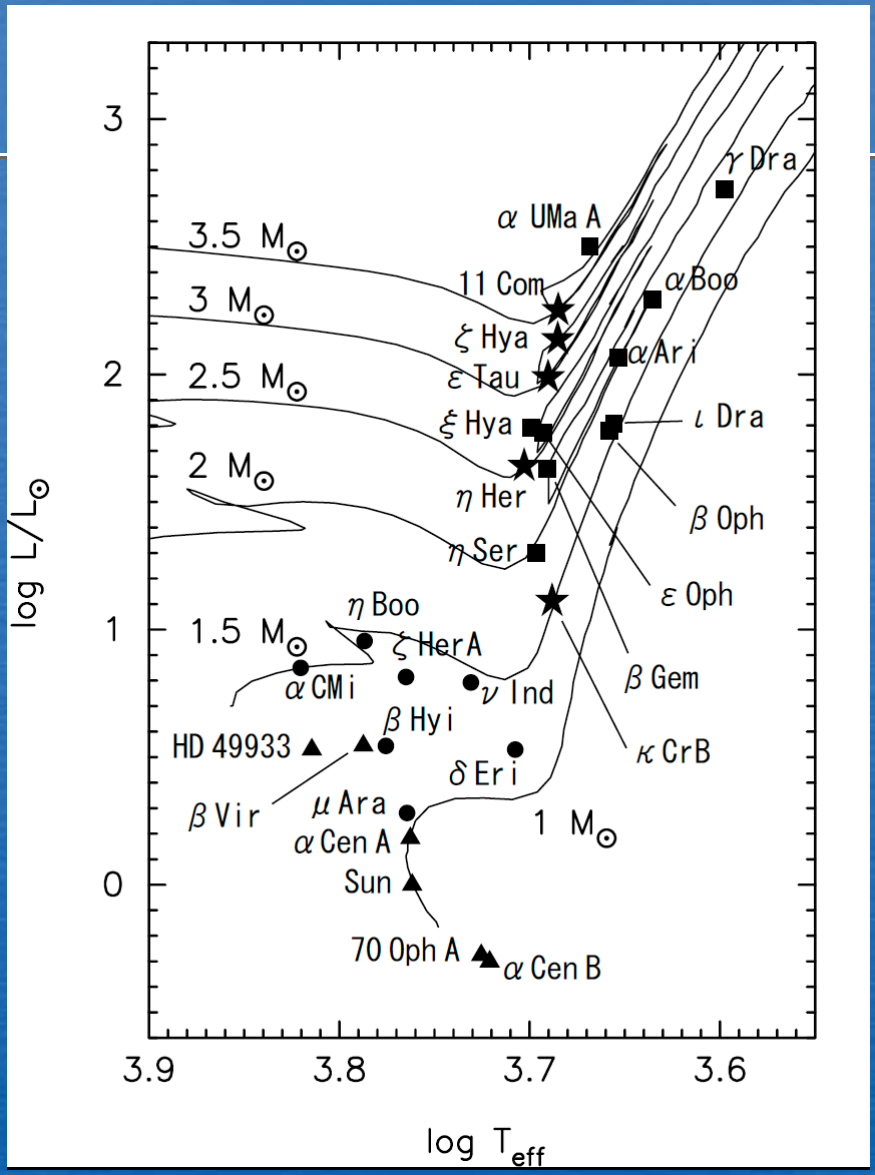
Observed &
Synthetic spectra



Instrumental profile


Radial Velocity of Procyon
VELOCITY
0.6
0.4
0.2
0.0
0.10
0.15
0.20
0.25
0.30
JD2451904

HIDESによる巨星、準巨星の高精度視線速度観測



Stellar parameters for Observational objects（G-type giants）

Table 2. Stellar parameters

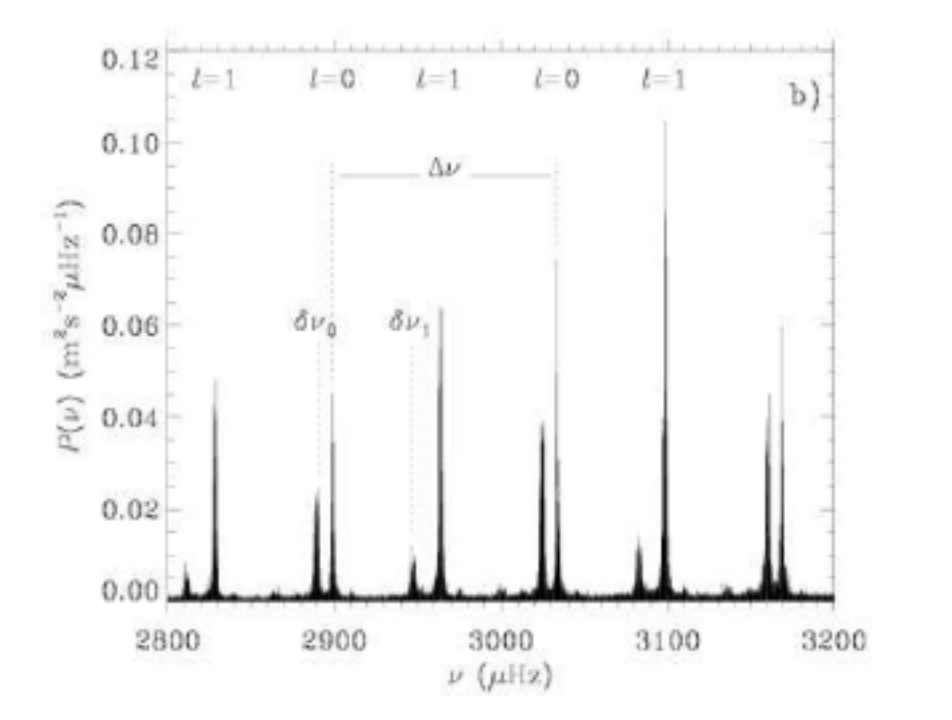
Star	Te	$\log g$	$L/L_{\odot}$	$R/R^{*}_{\odot}$	Ref.
11 Com	4742	2.31	172	19.5	1
ζ Hya	4844	2.48**	132	17.9	3
ϵ Tau	4901	2.64	97	13.7	2
η Her	5045	2.79	50	9.2	3

* Radii are calculated from Hipparcos parallaxes and interferometrically determined apparent diameters (see the text) except for 11Com.

** modified from Takeda, et al. (2008). See the text for the details.

1: Sato et al. (2008), 2: Sato et al. (2007), 3: Takeda, et al. (2008)

Characteristics of oscillations



even odd

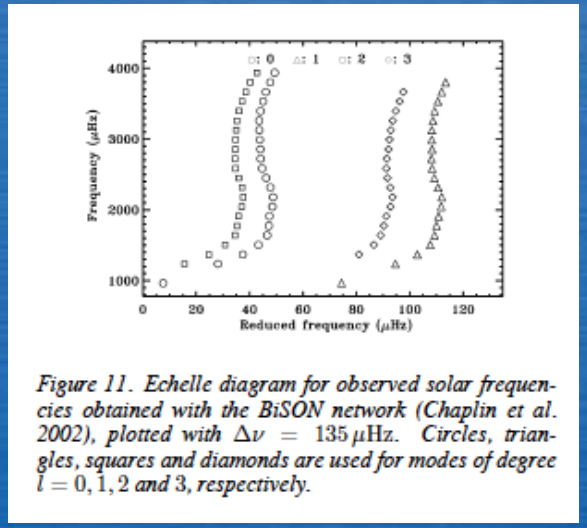
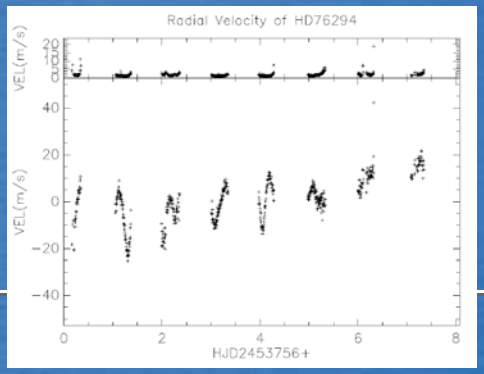
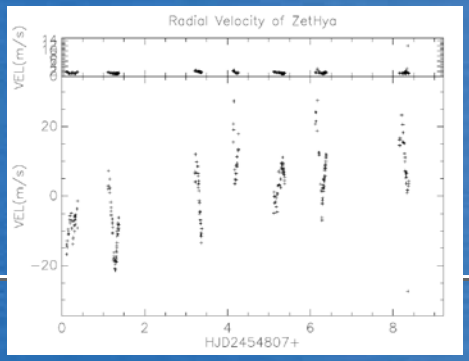


Figure 11. Echelle diagram for observed solar frequencies obtained with the BiSON network (Chaplin et al. 2002), plotted with $\Delta\nu = 135\,\mu$Hz. Circles, triangles, squares and diamonds are used for modes of degree $l = 0, 1, 2$ and 3, respectively.

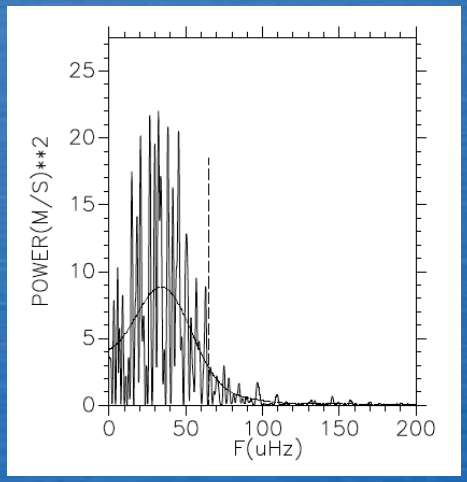
$$\nu_{nl} = \Delta\nu_0 \left(n + \frac{l}{2} + \epsilon \right) - l(l+1)D_0$$

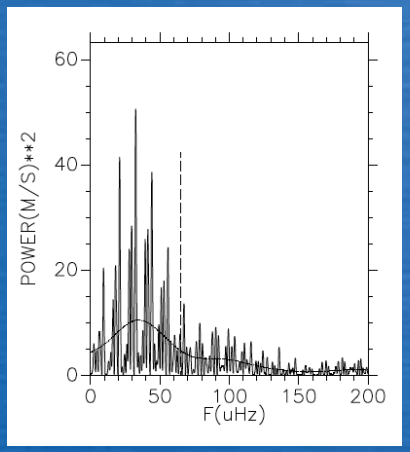
Echelle diagram for frequency
Solar 5 min. oscillations

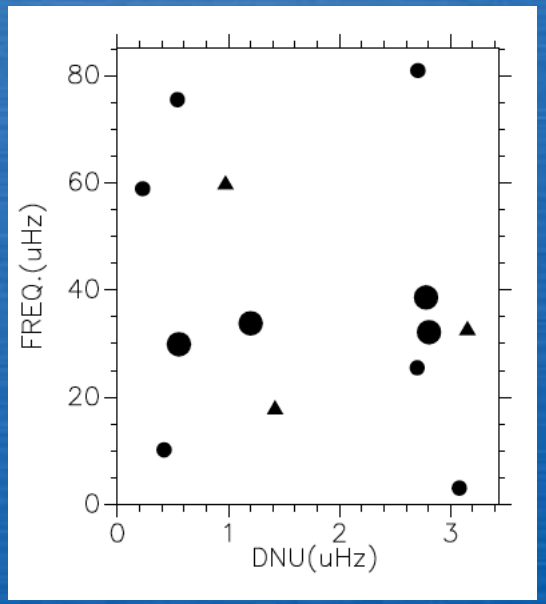

Radial Velocity of HD76294
VEL(m/s)
HJD2453756+


Radial Velocity of ZetHya
VEL(m/s)
HJD2454807+

ζ Hya

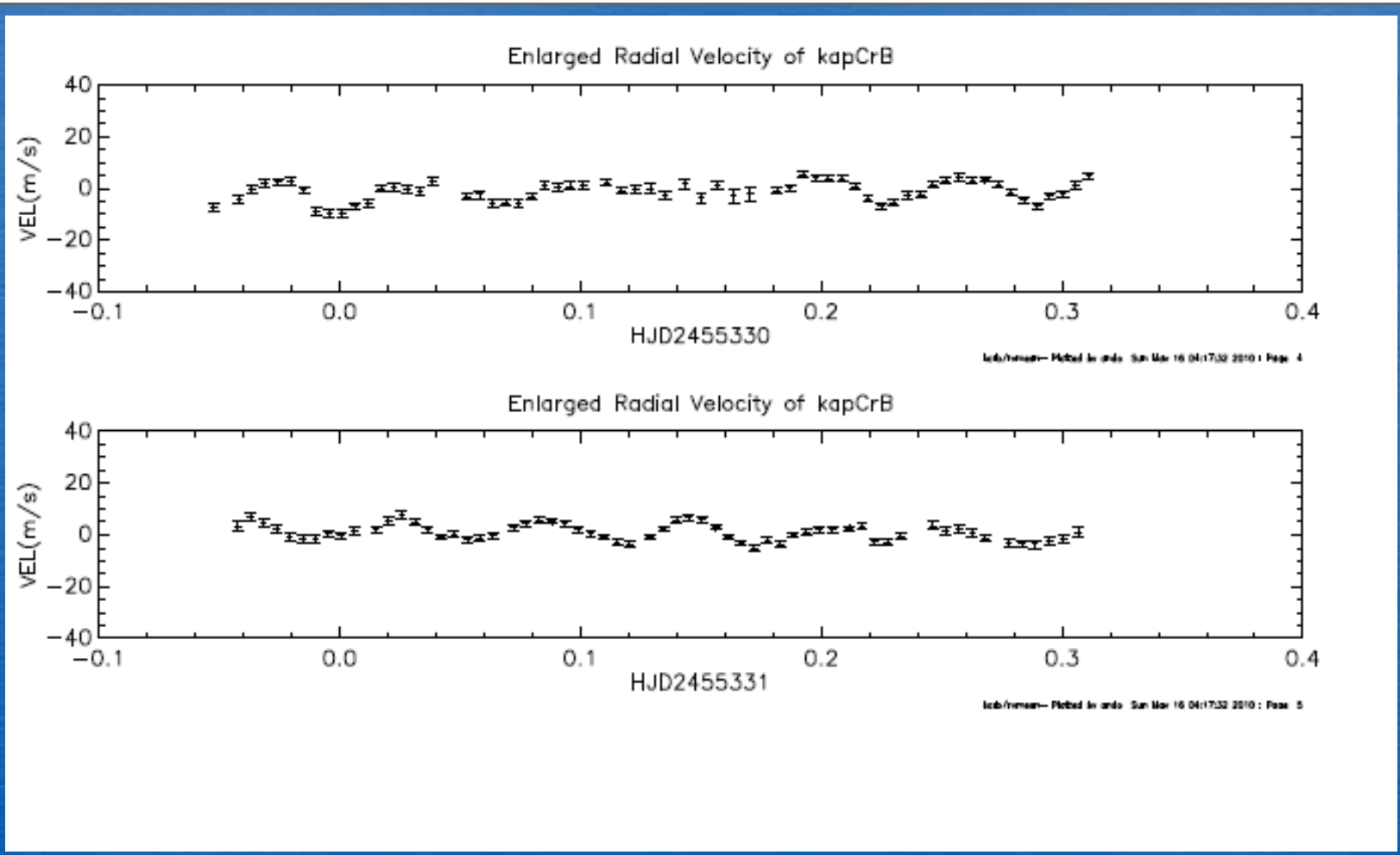

POWER(M/S)**2
F(uHz)


POWER(M/S)**2
F(uHz)

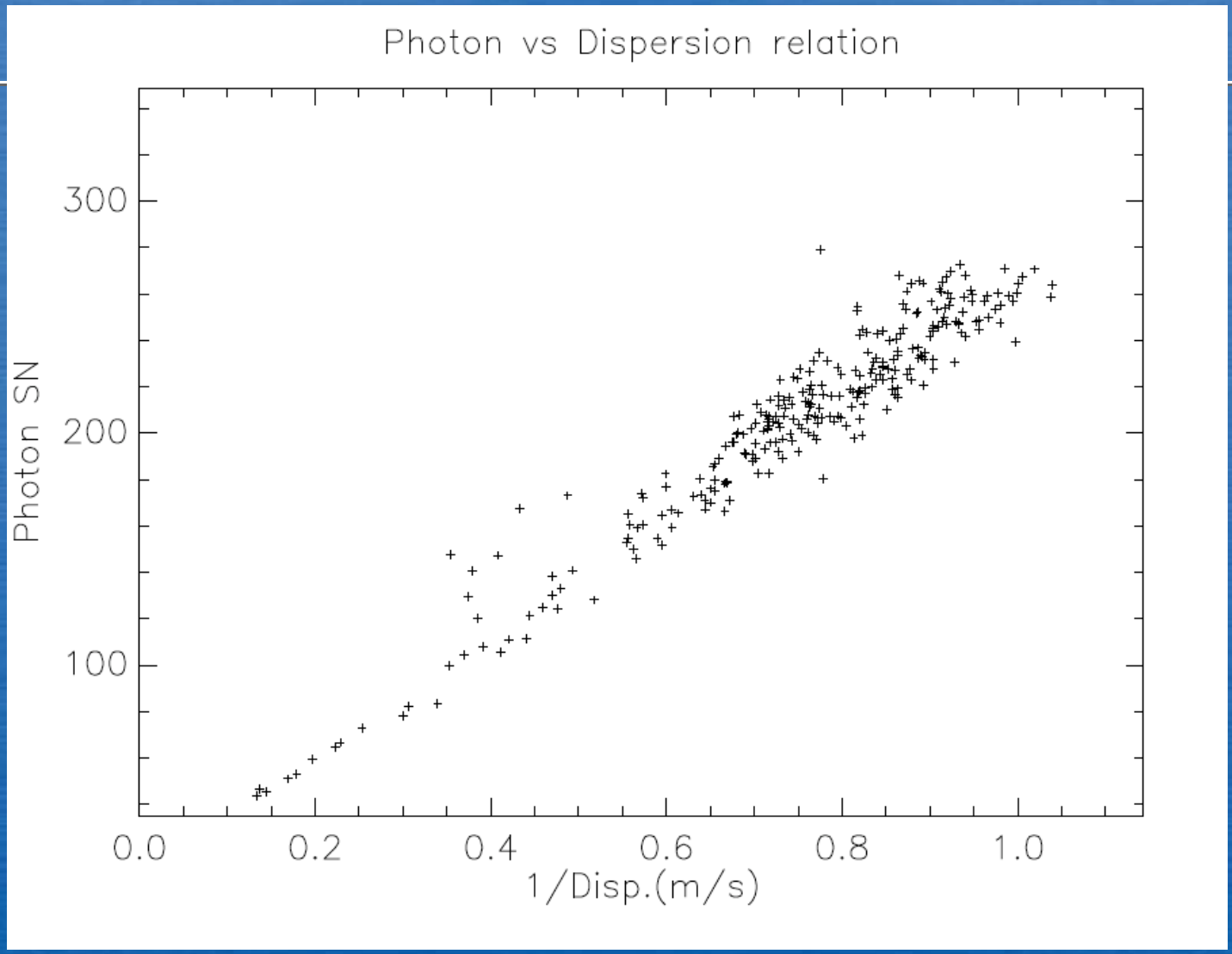

FREQ.(uHz)
DNU(uHz)

ζ Hya

K CrB


Enlarged Radial Velocity of kapCrB
VEL(m/s)
40
20
0
−20
−40
−0.1
0.0
0.1
0.2
0.3
0.4
HJD2455330
Enlarged Radial Velocity of kapCrB
VEL(m/s)
40
20
0
−20
−40
−0.1
0.0
0.1
0.2
0.3
0.4
HJD2455331

視線速度精度の現状


Photon vs Dispersion relation
Photon SN
300
200
100
0.0
0.2
0.4
0.6
0.8
1.0
1/Disp.(m/s)

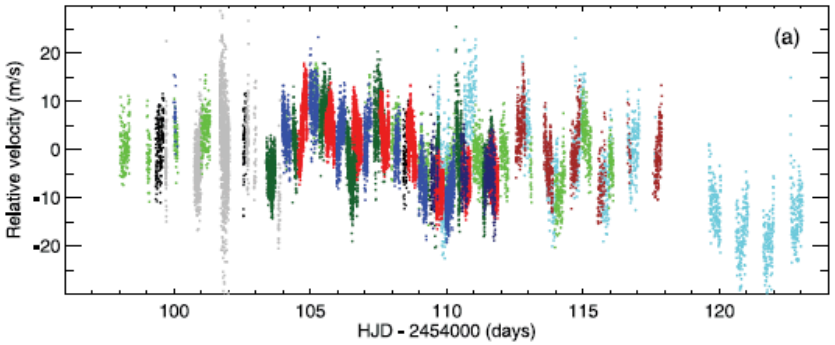
まとめ

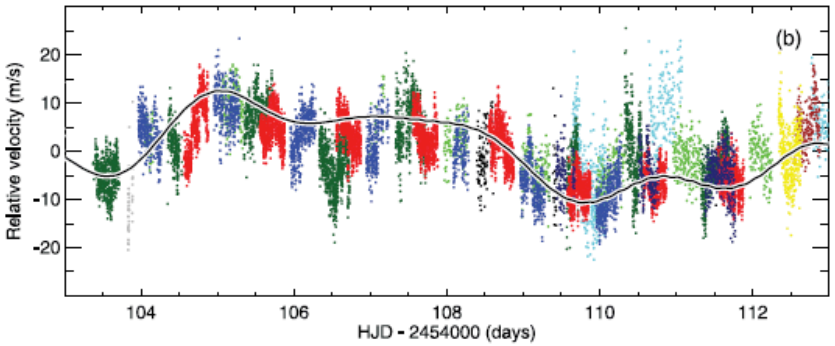
Digital detector + rapid computing
でしかなしえない仕事

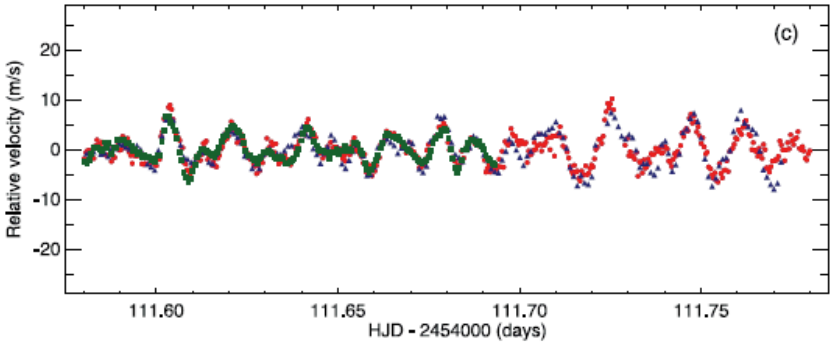
Kepler 衛星の時代
　視線速度観測は生き残れるか

ex.　地上連続観測 (Multi-site observation)
　　Procyon campaign observation in 2006-07

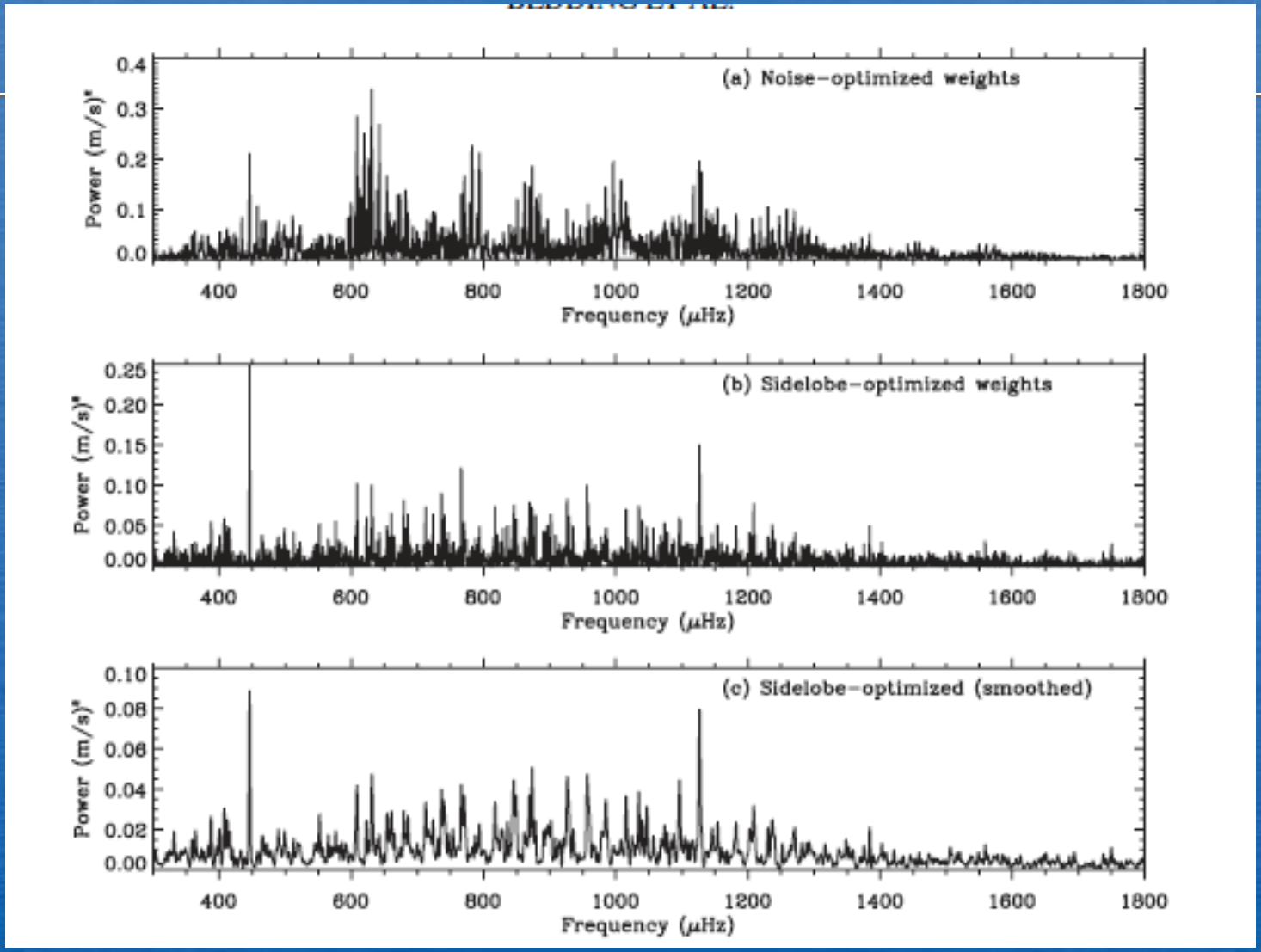
Procyon Campaign observation in 2006-07







Procyon Campaign observation in 2007-08



Echelle diagram of period