SONG – what have we learned ?

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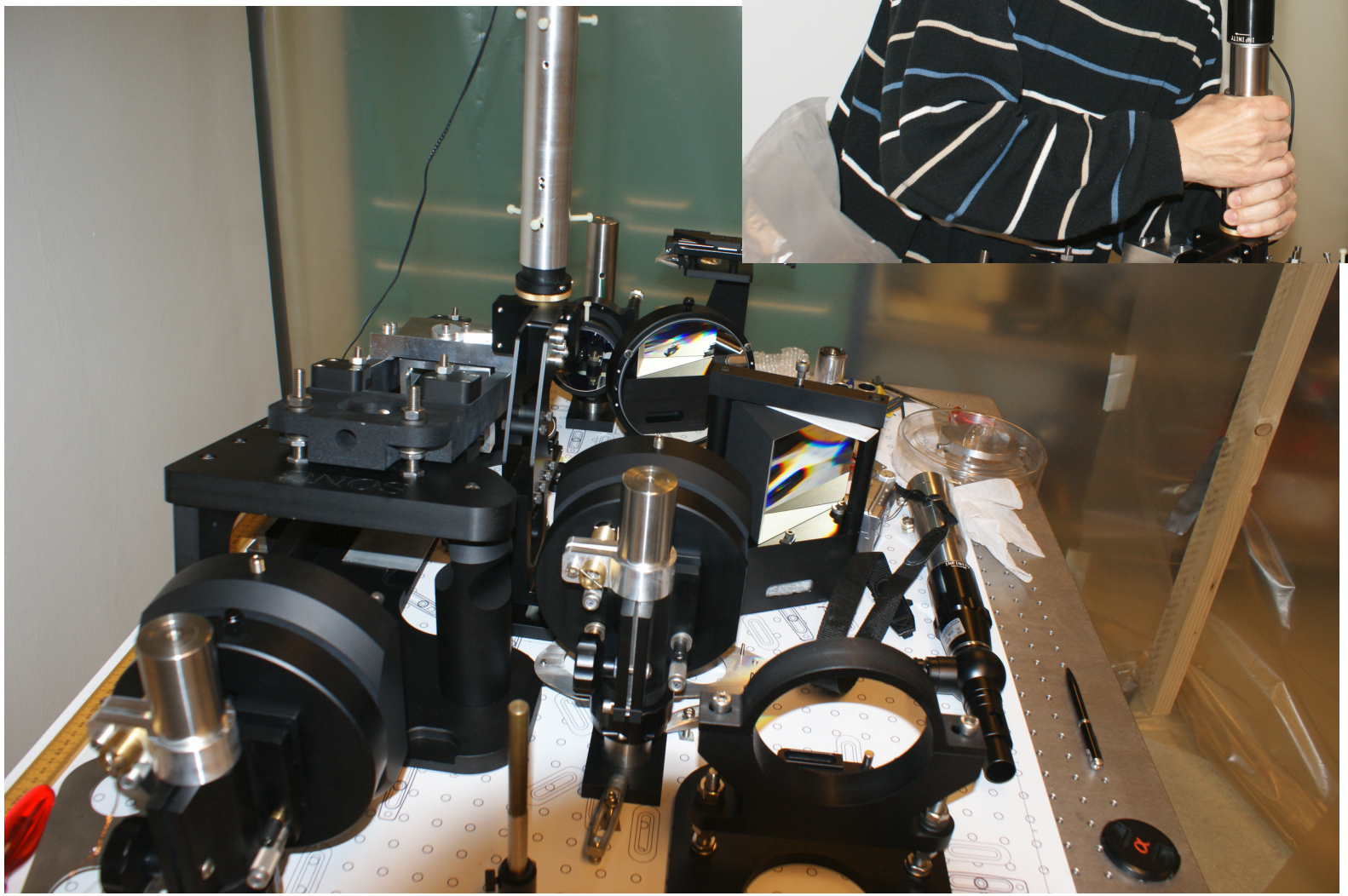
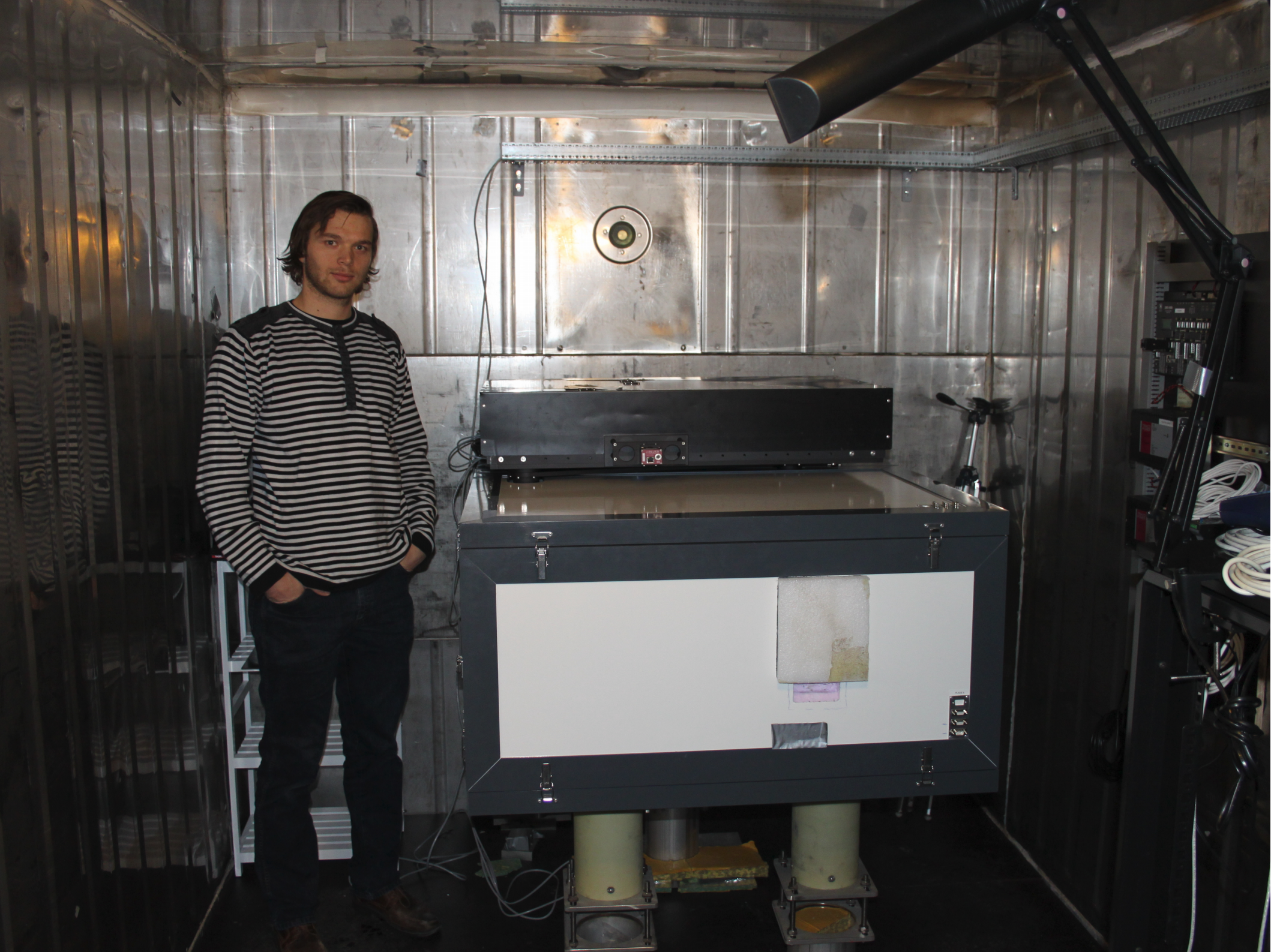




Basic features of the SONG spectrograph:

- Wavelength coverage: 440 – 680nm
- 51 orders, full coverage below 530nm, 2048 pixels per order
- Resolution: 60-120.000 (2 pixel sampling at max resolution)
- Temperature stabilized to ~0.1C on short
- 0.5C stability on long time scales
- CCD readout time 2.8s
- Two available iodine cells
- ThAr calibration
- *Not* fiber-fed

One pixel corresponds to ~1km/s (depending on wavelength)

Guide limit: V ~ 9.5 (after upgrade in 2016)

Radial velocity precision

$$\sigma_{RV} = Const \times (S/N)^{-1} \times R^{-3/2} \times \Delta\lambda^{-3/2} \times (vsini) \times f(T_{eff})$$

$f(T_{eff})$: factor depending on stellar line density

$f(T_{eff}) \approx 1$ for solar type star

$f(T_{eff}) \approx 3$ for A-type star

$f(T_{eff}) \approx 0.5$ for M-type star

Equation from talk by Artie Hatzes

Capabilities:

Strengths:

- slowly rotating stars, SGB, RGB ..., short period planets
- the Sun
- fast reaction

Weaknesses:

- fast rotating stars
- main-sequence solar-like oscillators
- 1-year problem
- single-site
- 1m diameter!
- Close ~few arcsecond separation binaries.

The SONG data-flow:

- *Afternoon:* calibrations (bias, flat, ThAr, flat+Iodine)

- *Nighttime:* Observations (Sun > 6deg. below horizon)

- *Morning:*

SONGwriter: (developed by Jens Jessen-Hansen)

- processing of calibration frames
- extraction of spectra

iSONG

- extraction of iodine velocities

SONGwriter – extracting the spectra

C++ code from Ritter et al. (2014, *PASP*, **126**, 170)

Formalism developed by Piskunov & Valenti (2002, *A&A*, **385**, 1095)

Set up for fully automated processing of the raw SONG spectra

Output:

- optimal extracted spectrum (~3min. per spectrum)
- simple summation of the spectrum (~2s per spectrum)
- blaze function
- ThAr calibration from nearest in time **before** science spectrum
- ThAr calibration from nearest in time **after** science spetrum

iSONG - “sad songs say so much”

iSONG calculates velocities based on the algorithms introduced by Butler et al. (1996):

Doppler shift Convolution

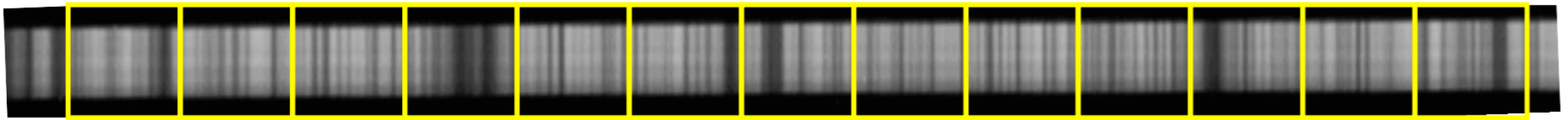
$$I_{obs}(\lambda) = k\,T_{I2}(\lambda)\,I_S(\lambda + \Delta\lambda) \otimes IP$$

Observed stellar spectrum

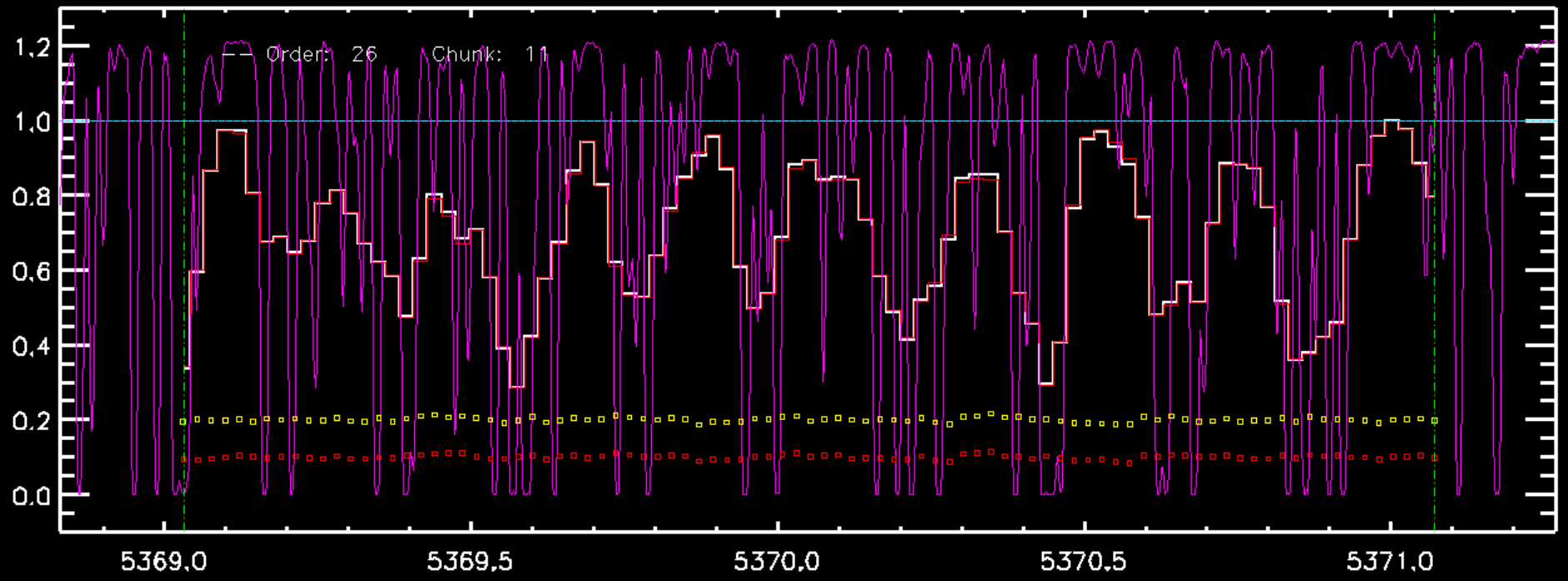
Iodine absorption spectrum

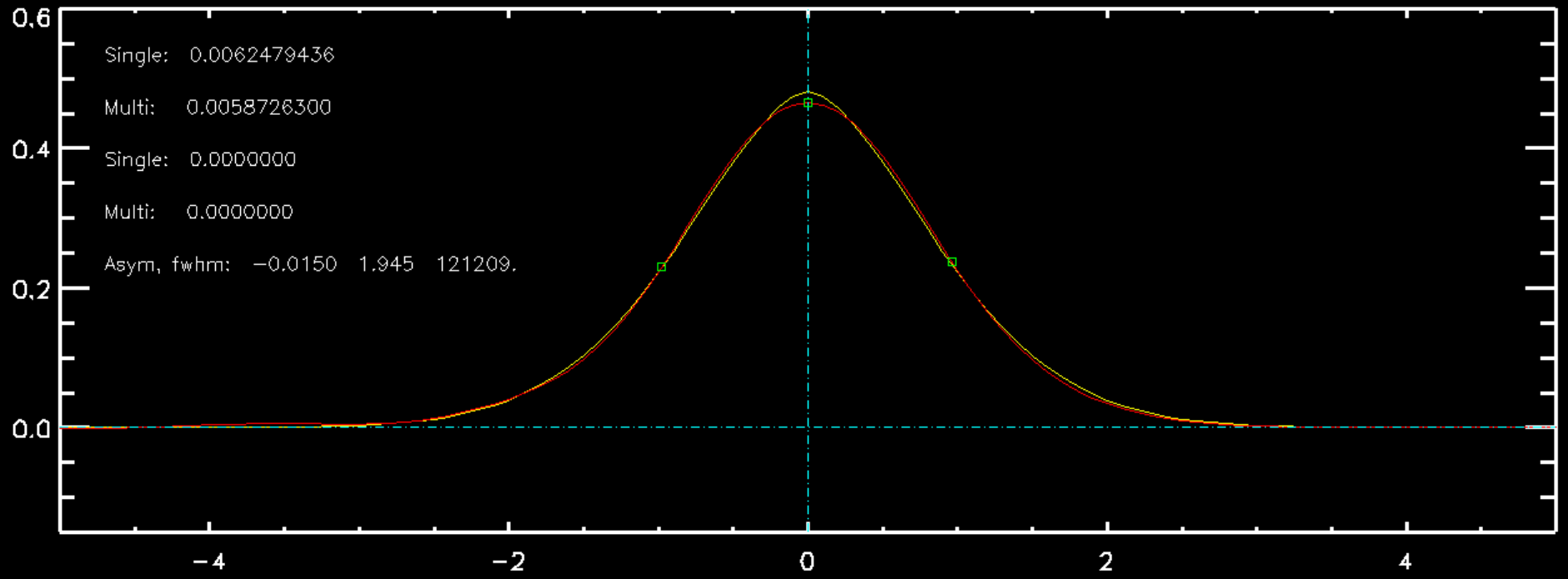
Intrinsic stellar spectrum

Instrument profile

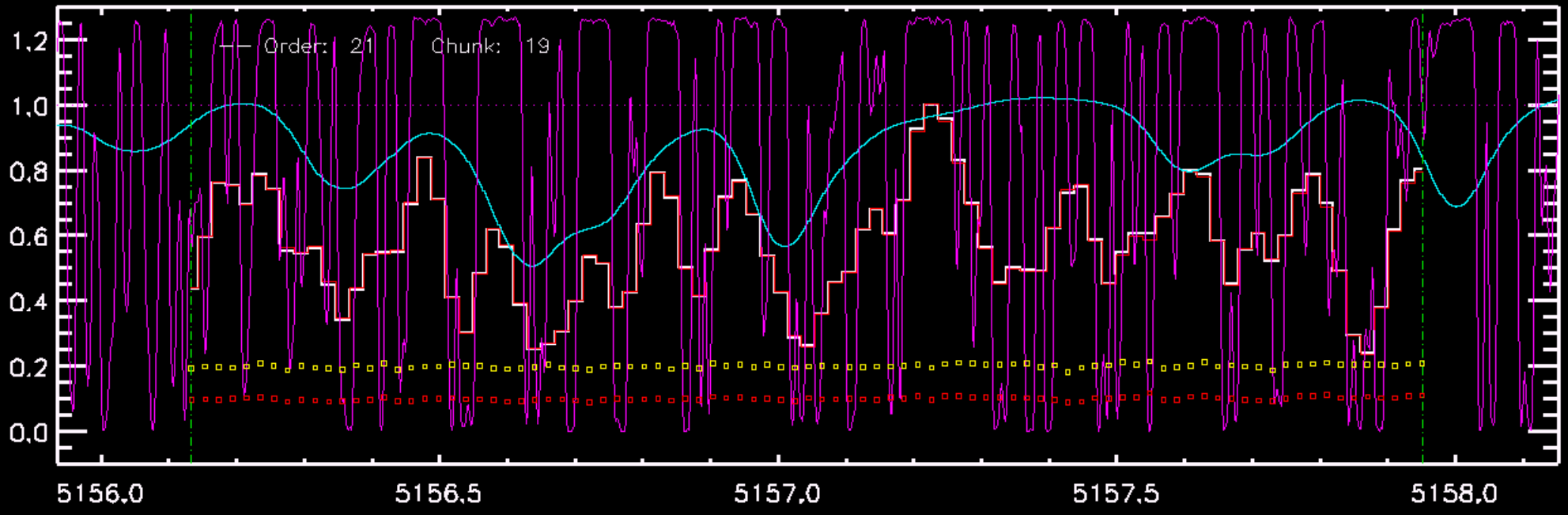


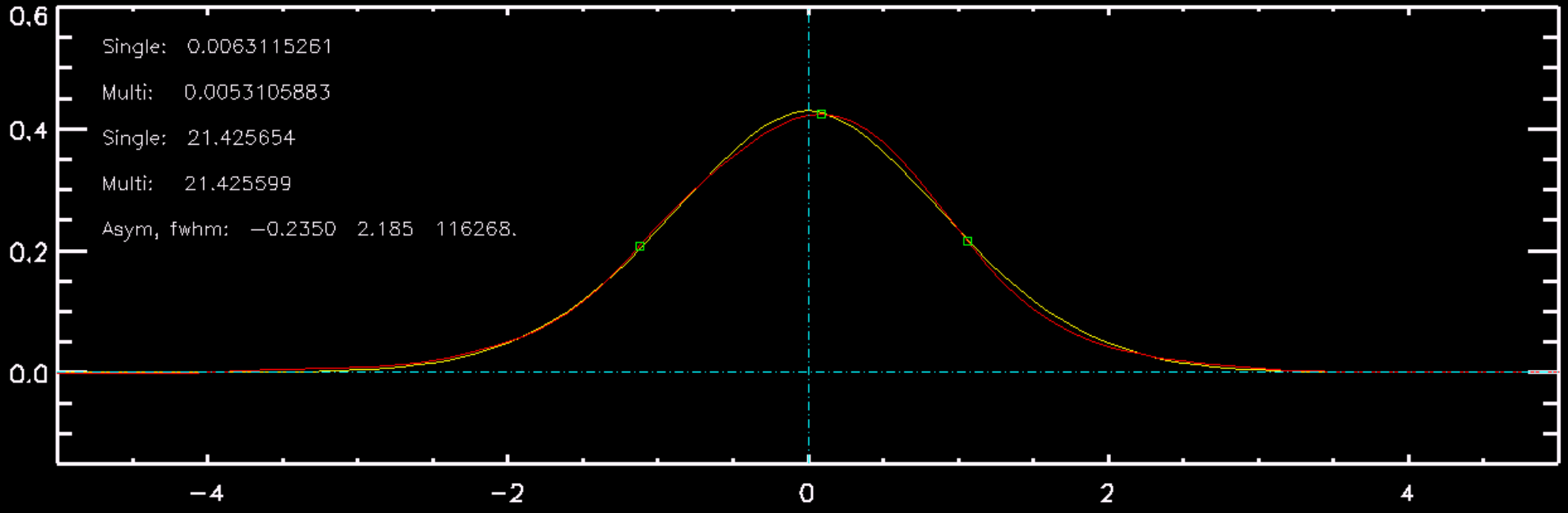
Iodine flat field



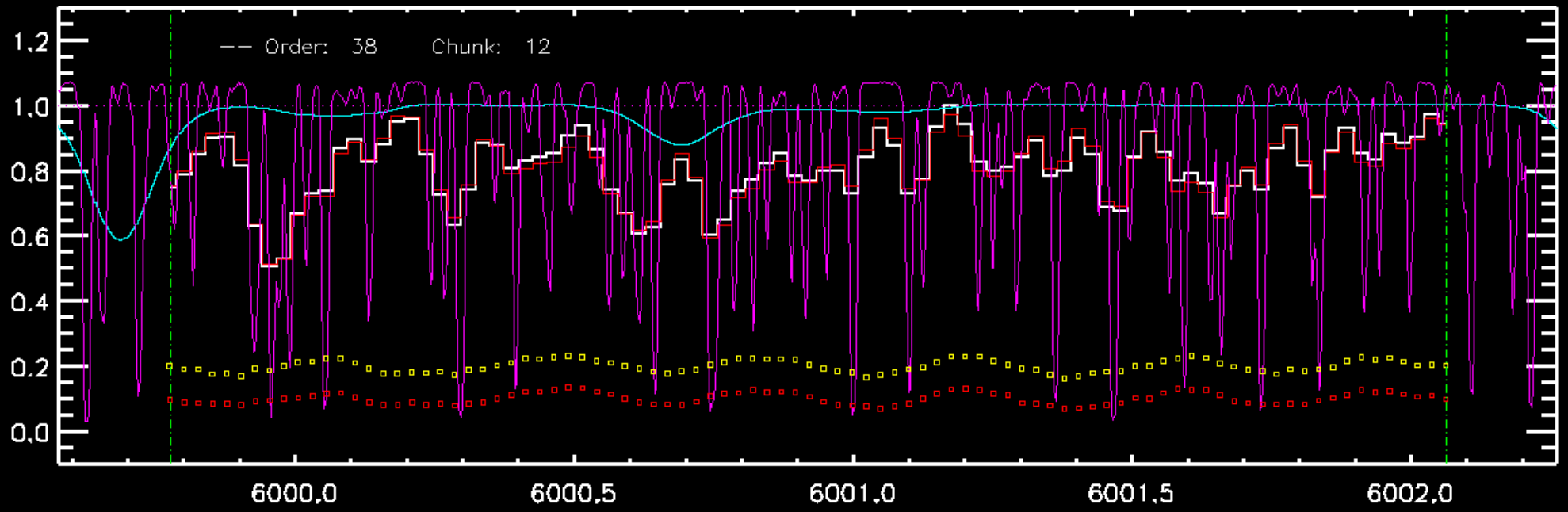


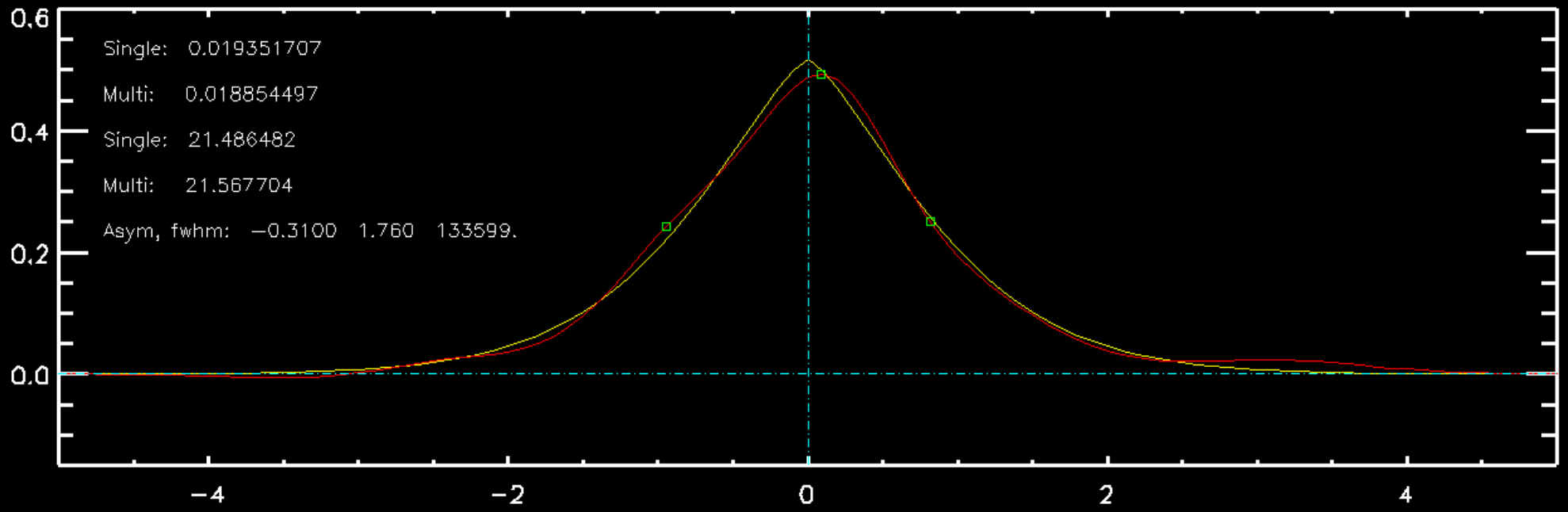
Arcturus + Iodine



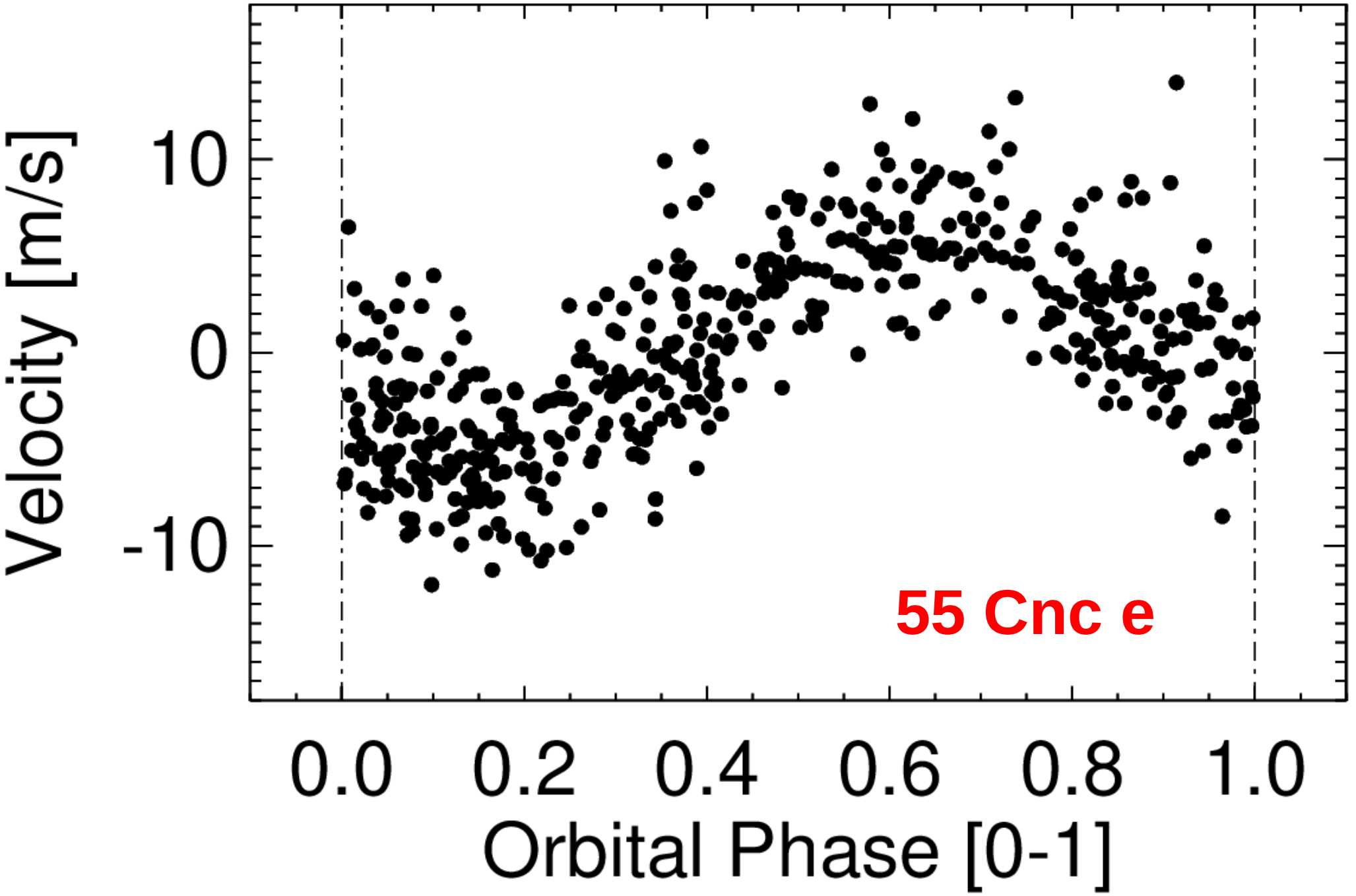


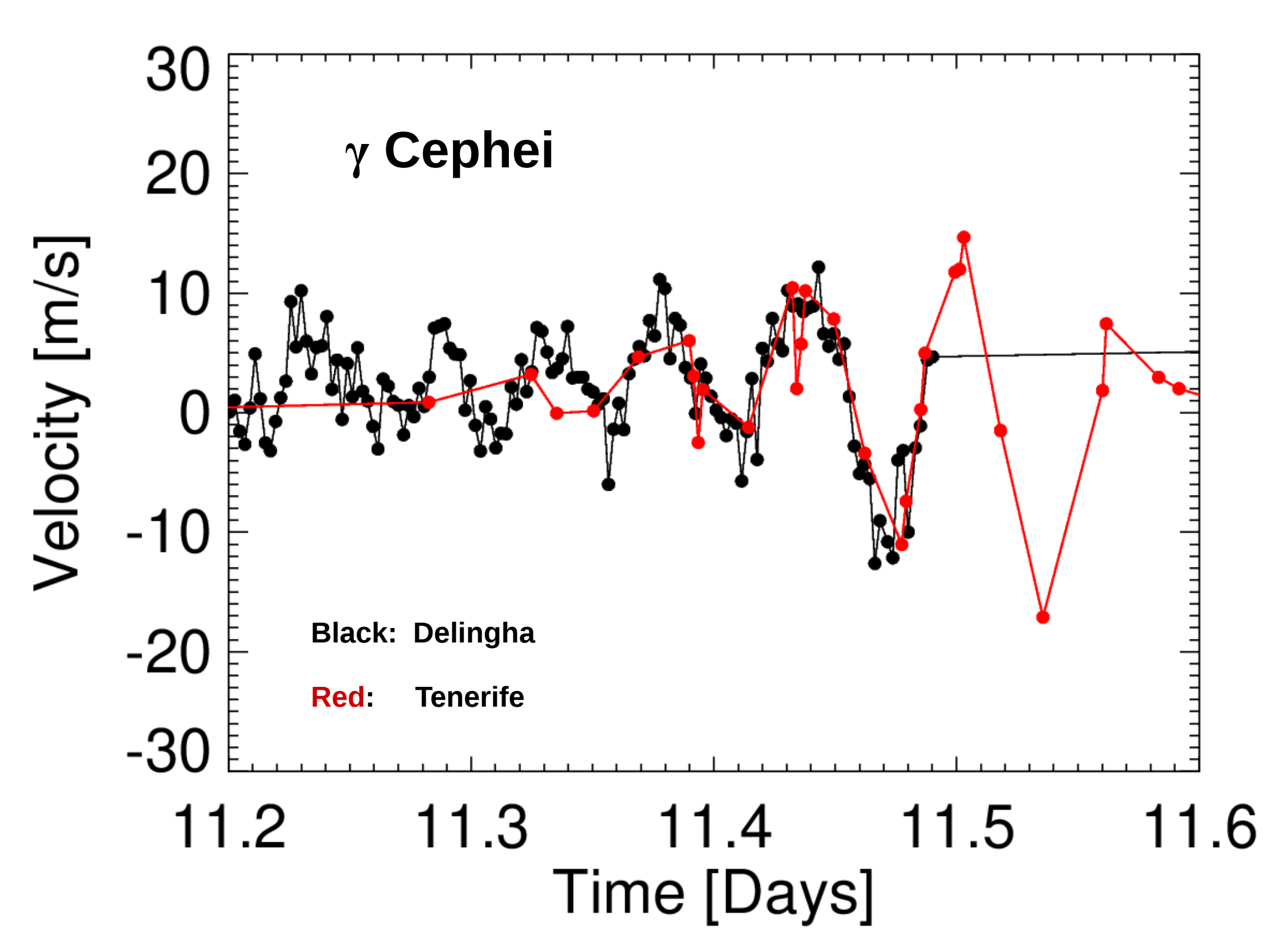
Arcturus + Iodine + fringing



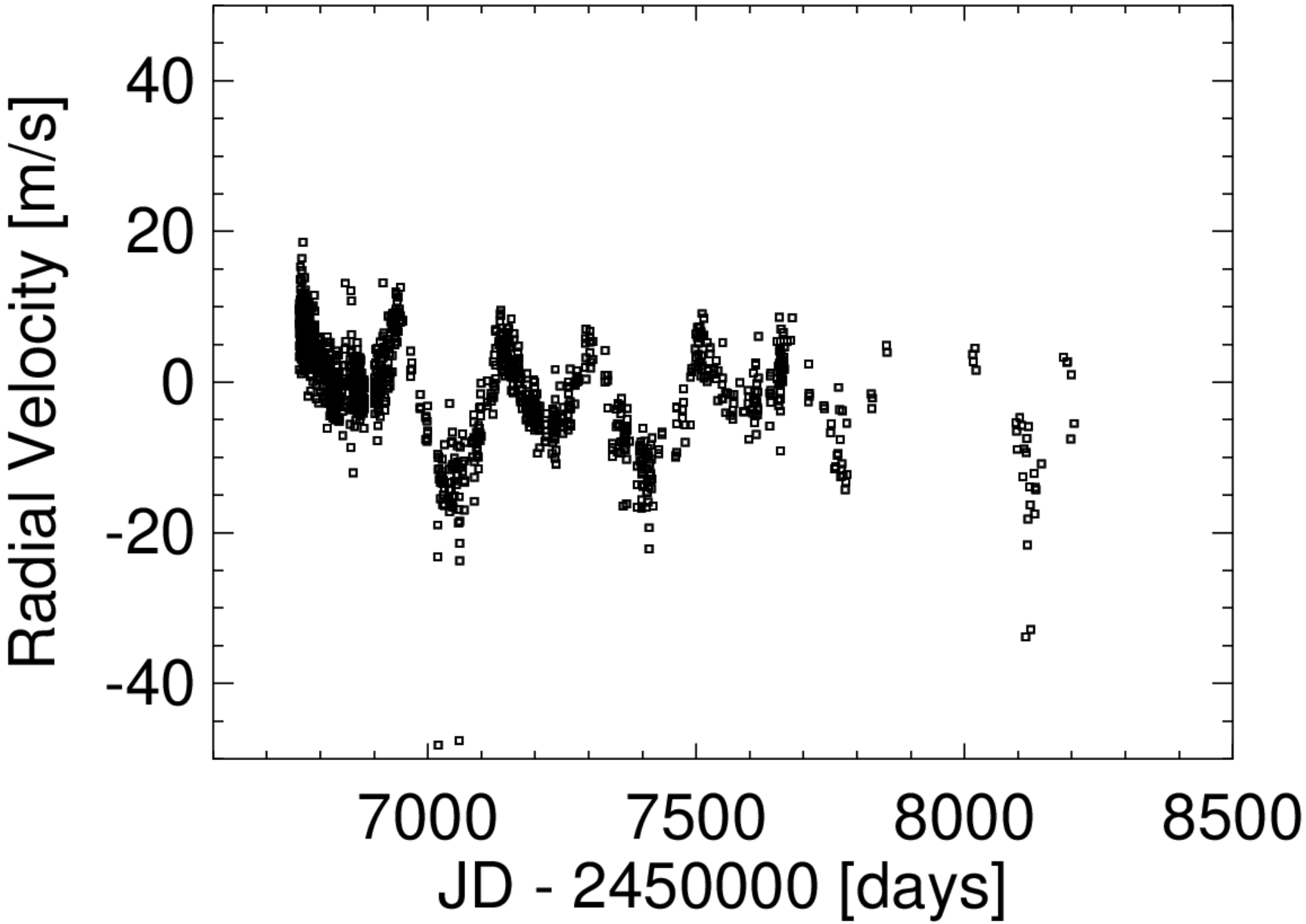


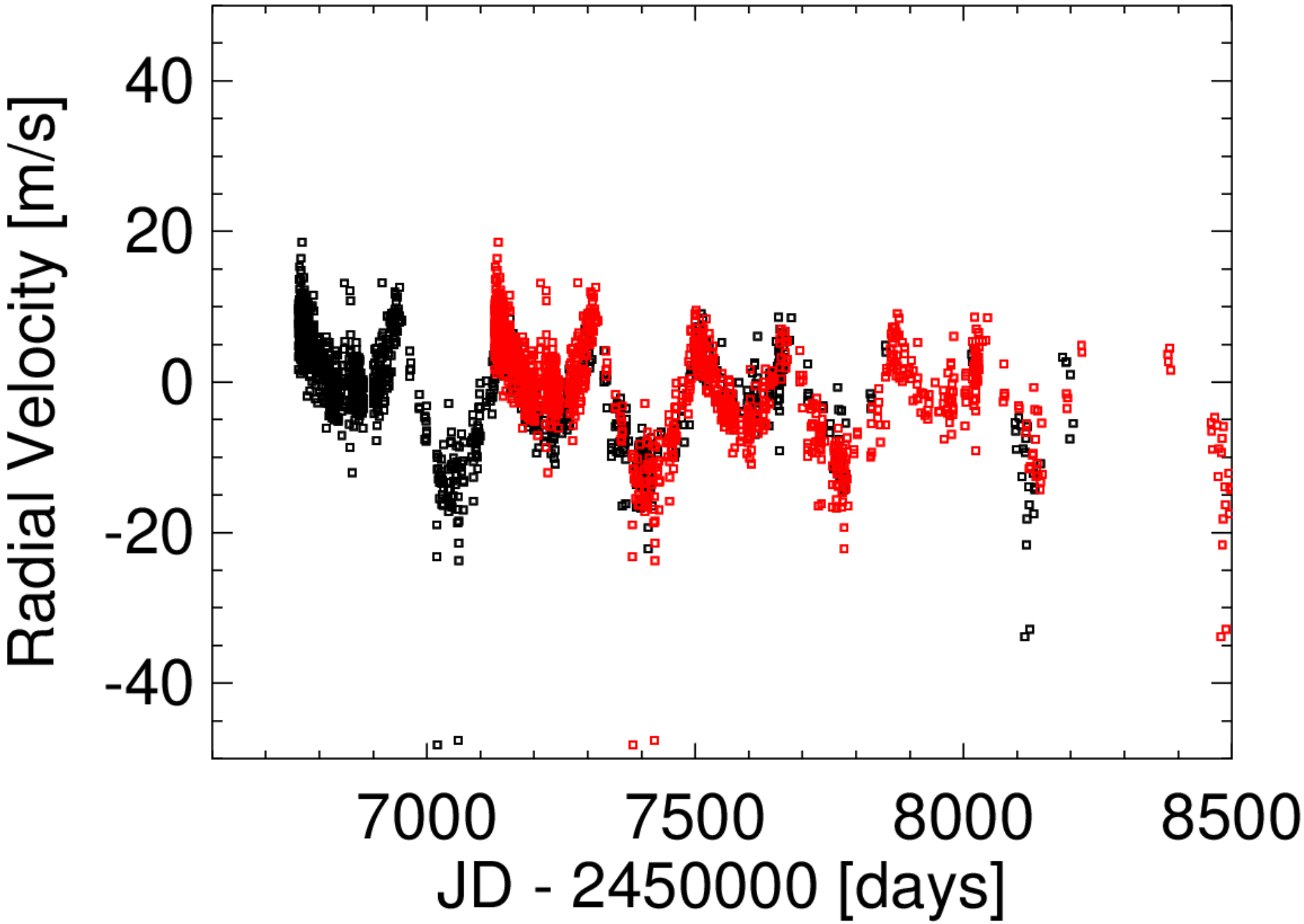
Short term precision is really good….

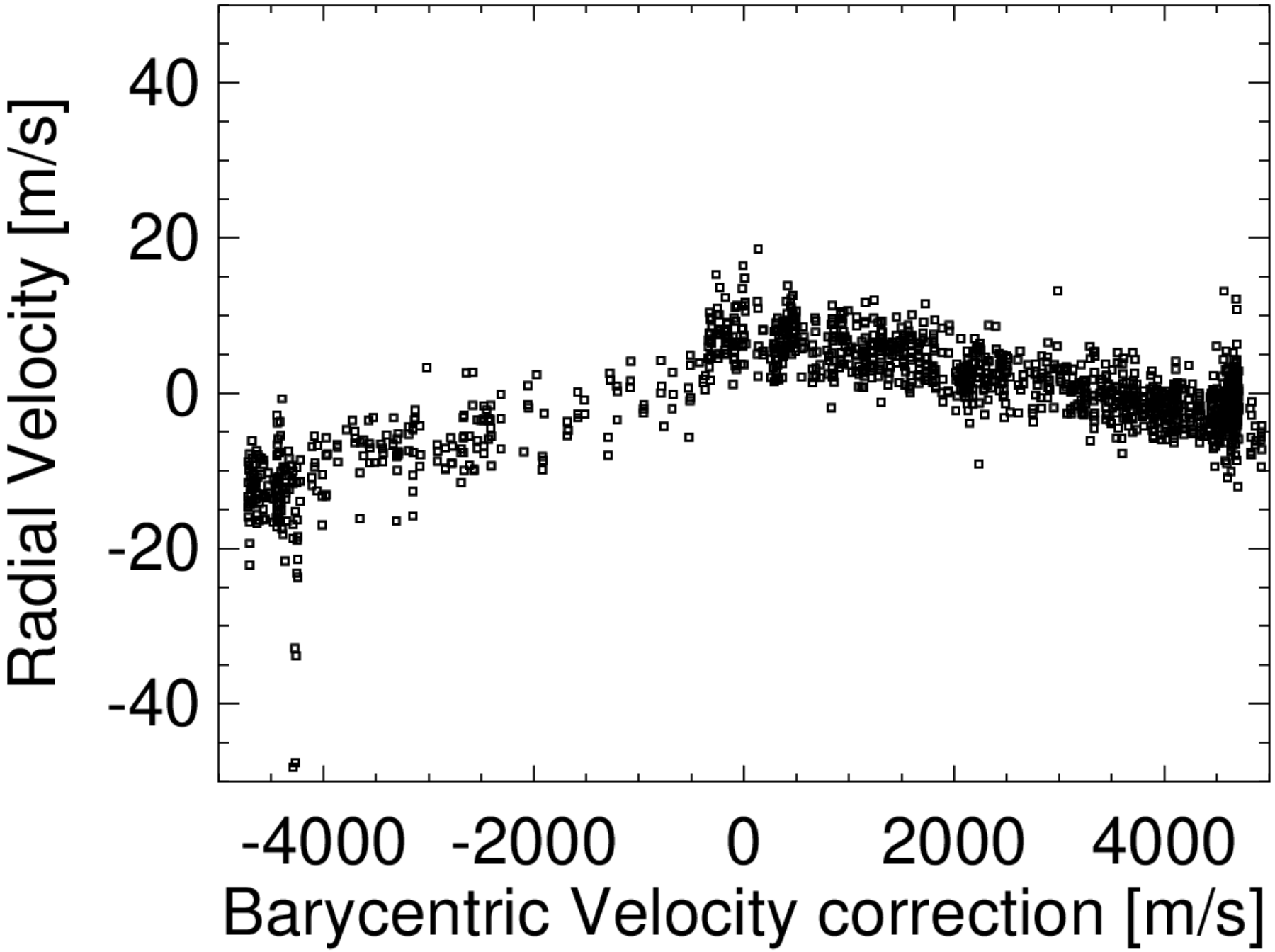


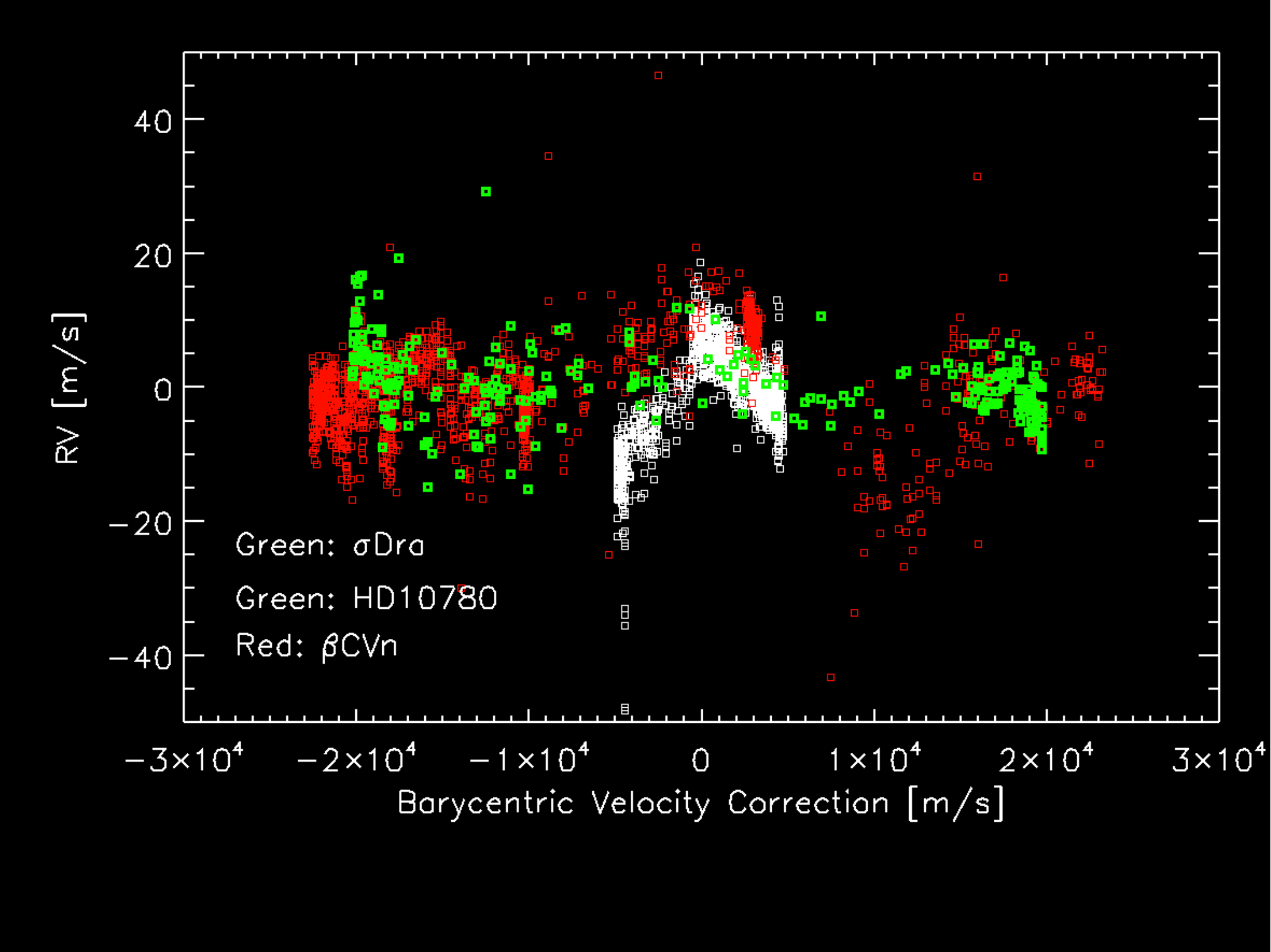

γ Cephei
Black: Delingha
Red: Tenerife
Velocity [m/s]
Time [Days]
30
20
10
0
-10
-20
-30
11.2
11.3
11.4
11.5
11.6

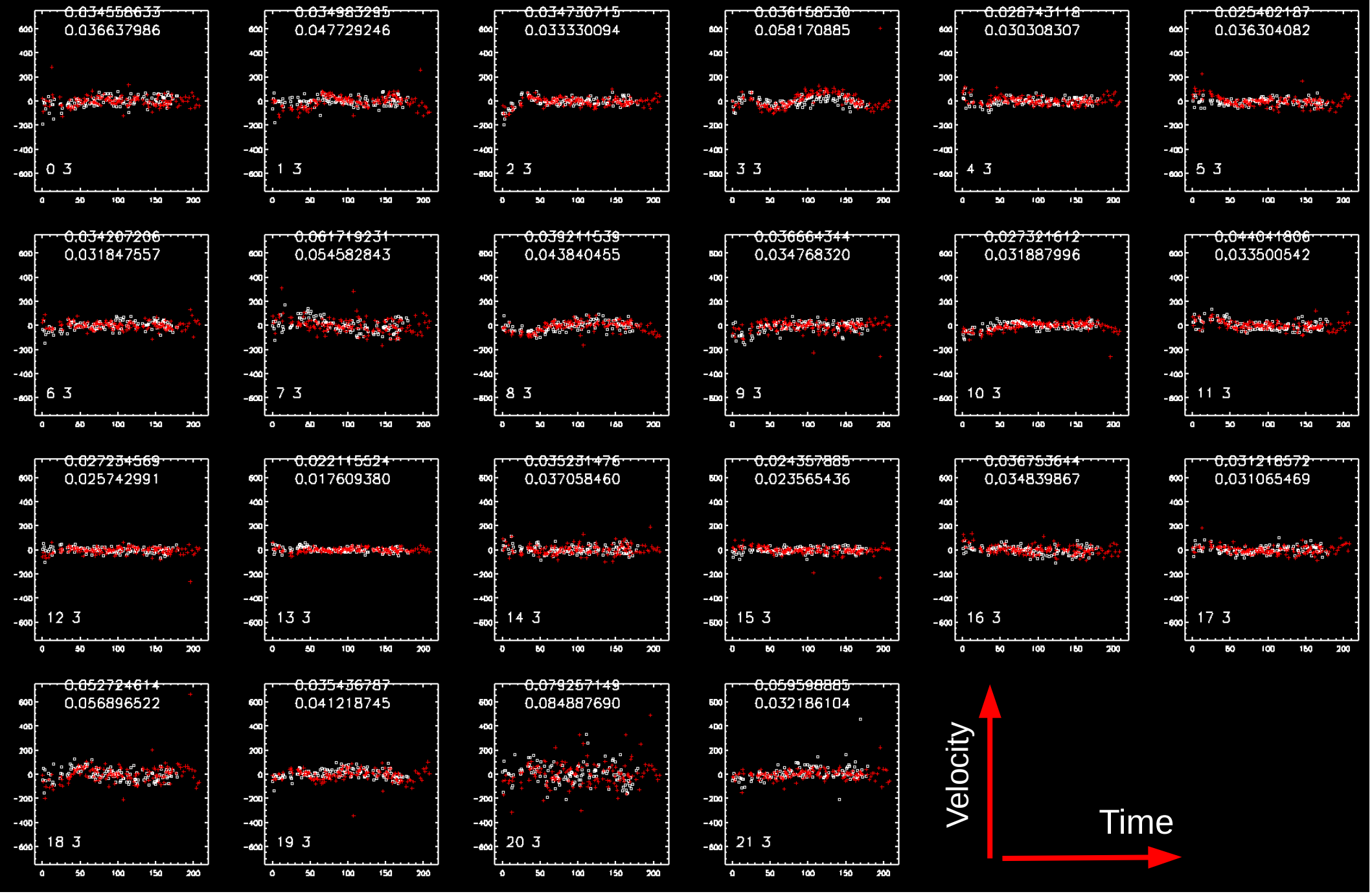
But…….. now the “sad **song**s say so much” bit….


Radial Velocity [m/s]
40
20
0
-20
-40
7000
7500
8000
8500
JD - 2450000 [days]


Radial Velocity [m/s]
40
20
0
-20
-40
7000
7500
8000
8500
JD - 2450000 [days]


Radial Velocity [m/s]
40
20
0
-20
-40
-4000
-2000
0
2000
4000
Barycentric Velocity correction [m/s]


40
20
0
−20
−40
RV [m/s]
Green: σDra
Green: HD10780
Red: βCVn
−3×10^4
−2×10^4
−1×10^4
0
1×10^4
2×10^4
3×10^4
Barycentric Velocity Correction [m/s]


0.034558633
0.036637986
0 3
0.034983295
0.047729246
1 3
0.034730715
0.033330094
2 3
0.036158530
0.058170885
3 3
0.028743118
0.030308307
4 3
0.025402187
0.036304082
5 3
0.034207206
0.031847557
6 3
0.061719231
0.054582843
7 3
0.039211539
0.043840455
8 3
0.036664344
0.034768320
9 3
0.027321612
0.031887996
10 3
0.044041806
0.033500542
11 3
0.027234569
0.025742991
12 3
0.022115524
0.017609380
13 3
0.035231476
0.037058460
14 3
0.024357885
0.023565436
15 3
0.036753644
0.034839867
16 3
0.031218572
0.031065469
17 3
0.052724614
0.056896522
18 3
0.035436787
0.041218745
19 3
0.079257149
0.084887690
20 3
0.059598885
0.032186104
21 3
Velocity
Time

The 1-year problem is independent of:

- iodine cell is used (3 different)
- reduction code (two independent codes)
- its not an erroneous barycentric correction

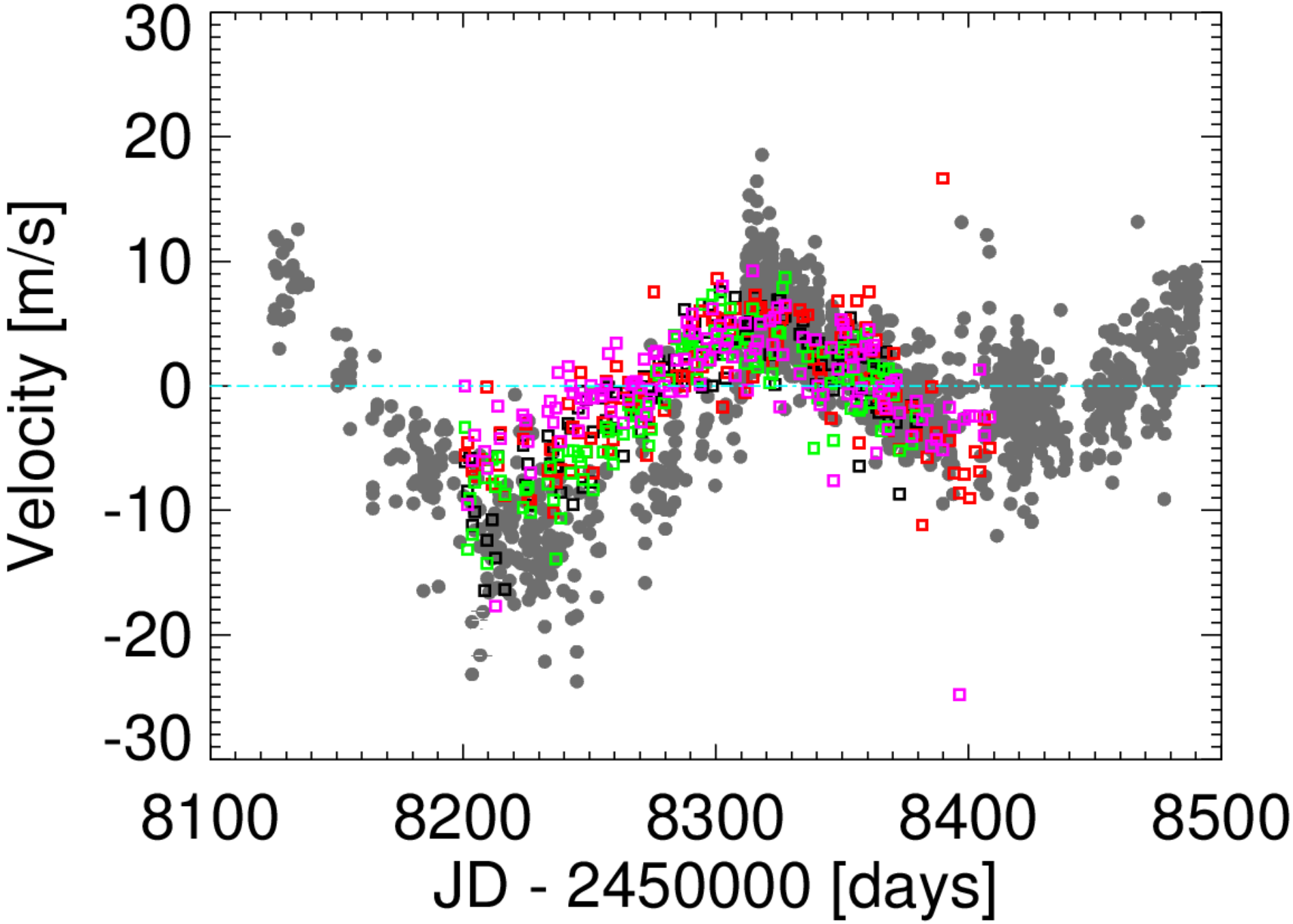
March 2018: CCD rotated by 90 deg.

The problem persists (lower amplitude?)

Will know for sure in ~5 months.

Favorite candidate: the CCD ….

- but its not due to non-linearity
- perhaps Charge-Transfer Inefficiency


30
20
10
0
-10
-20
-30
Velocity [m/s]
8100
8200
8300
8400
8500
JD - 2450000 [days]

ThAr based velocities

- the spectrograph does not use an optical fiber

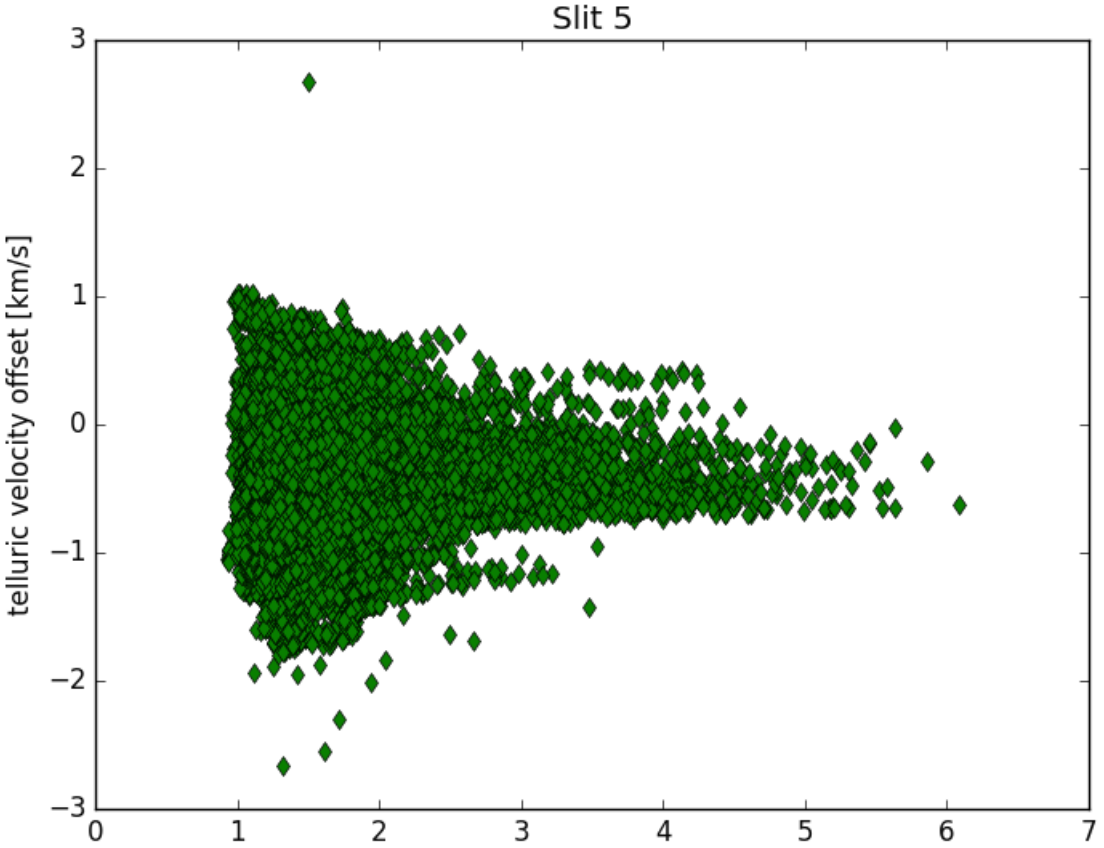
→ star moves on the slit → imperfect ‘scrambling’

- Changes in pressure/temperature changes wavelength

- ThAr precision is (much) lower than for iodine, and depends heavily on how narrow the slit we use is.

- Special measures must be taken for getting ~100m/s long-term (use telluric lines).

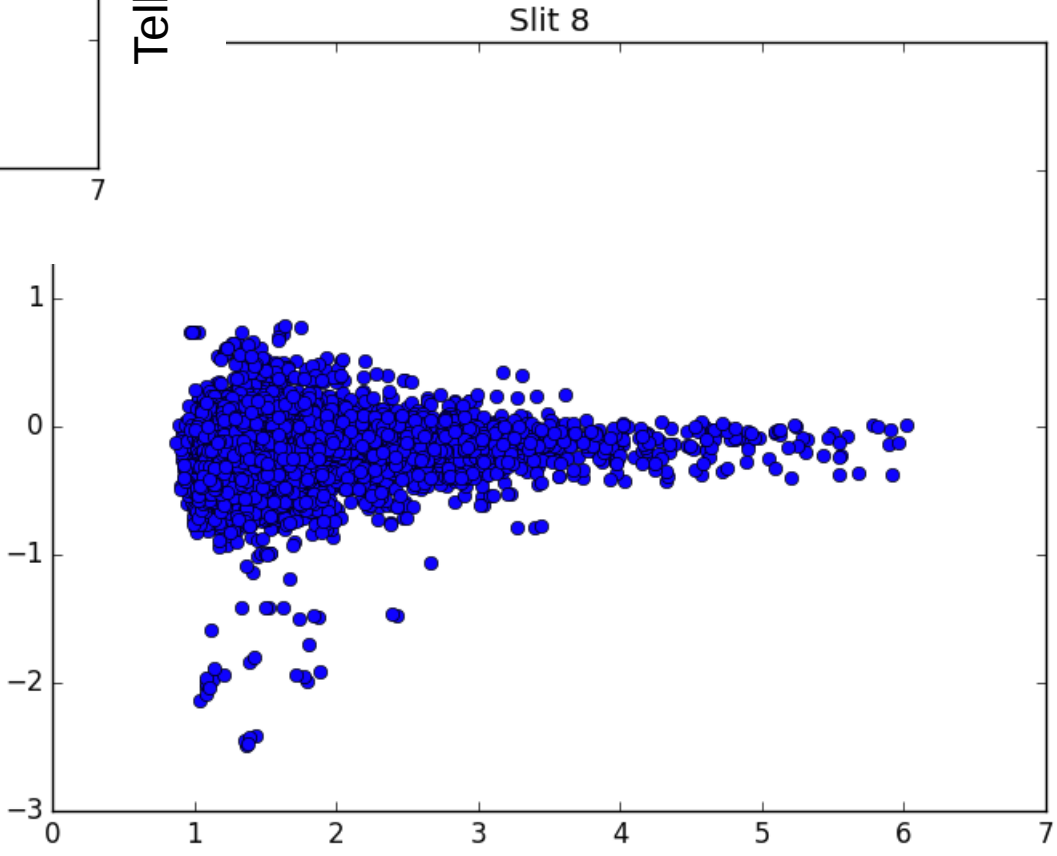
- we still have A LOT to learn about optimizing the ThAr data.

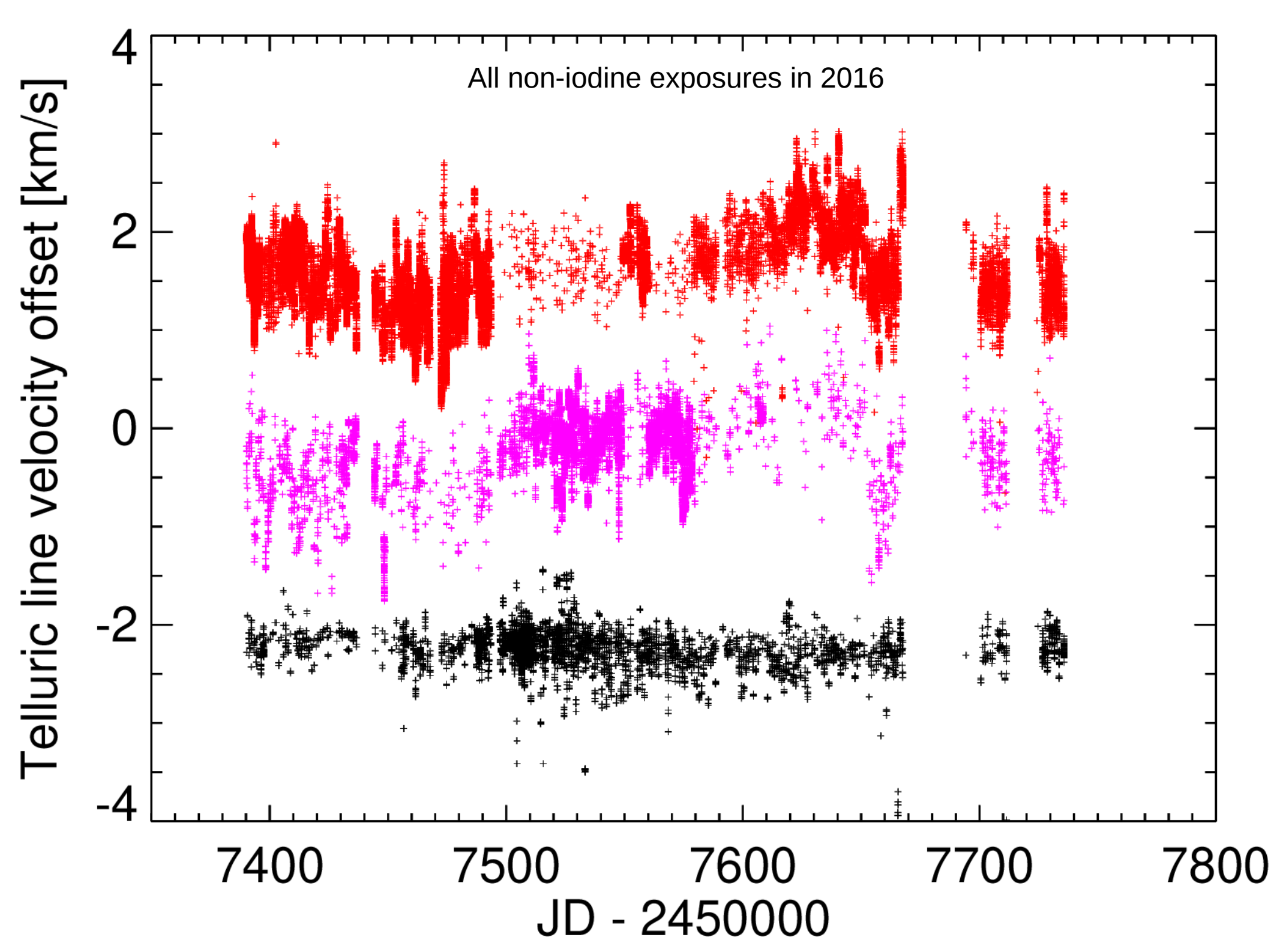


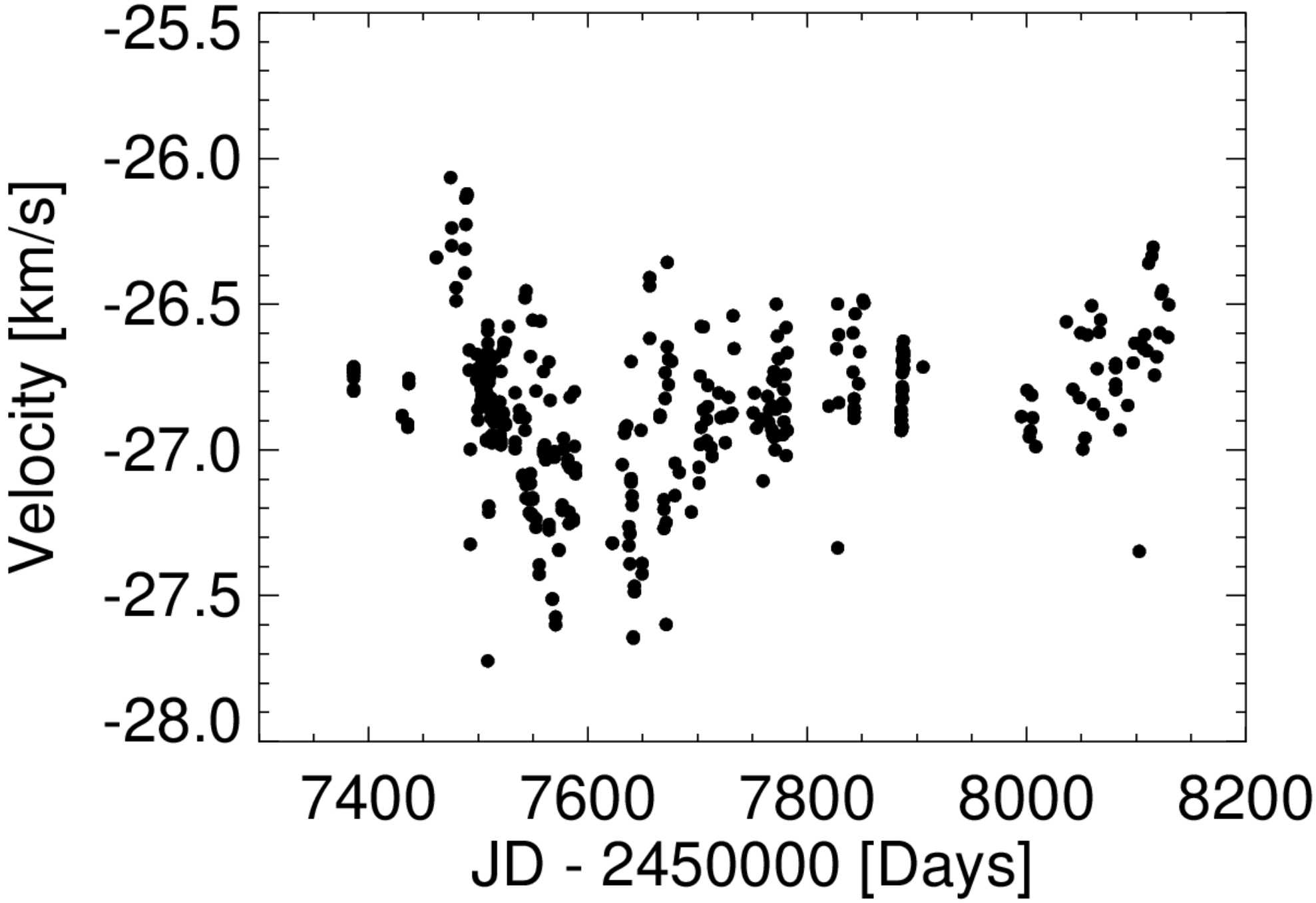
Telluric velocity offset [km/s]

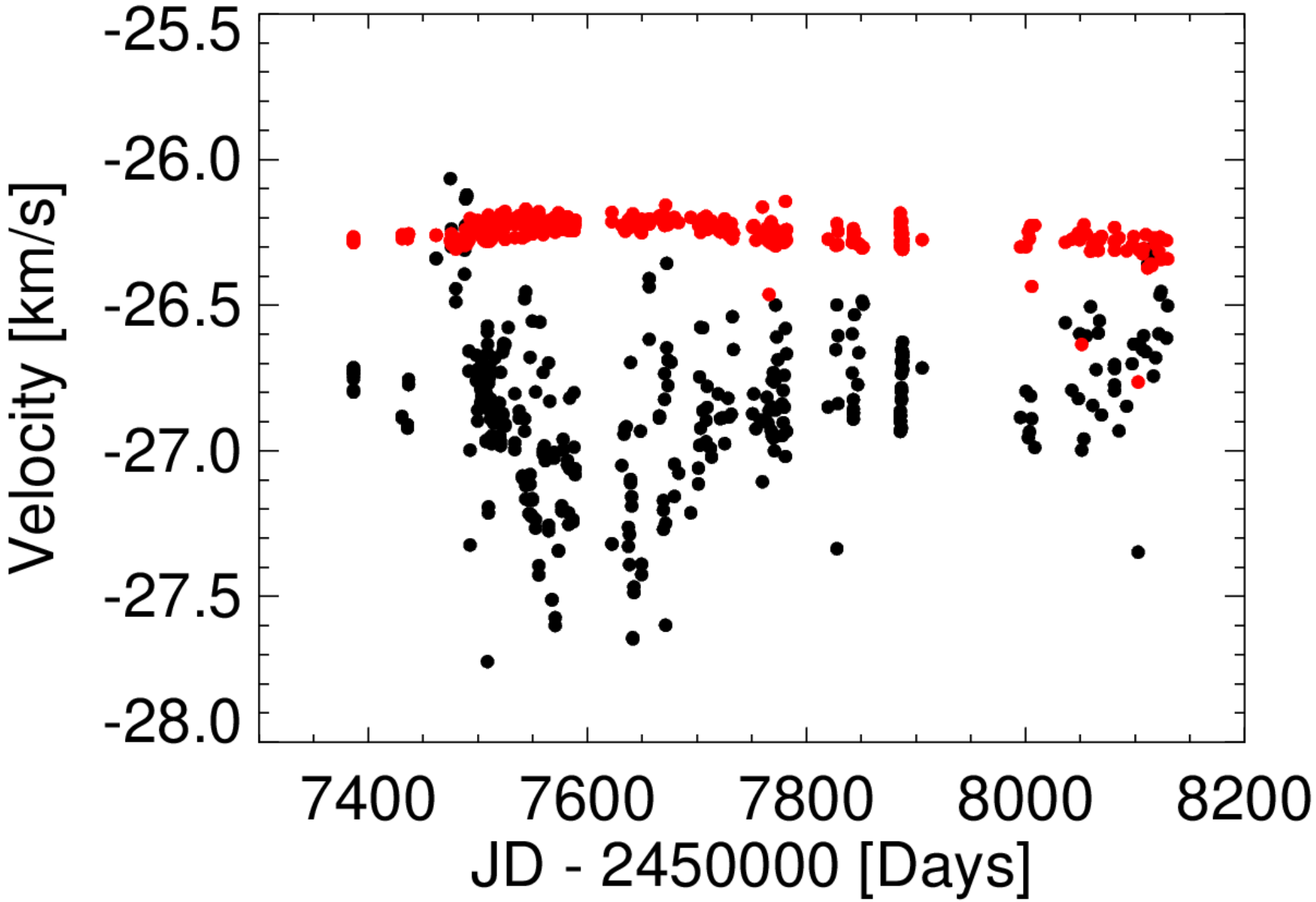
Cross-order width

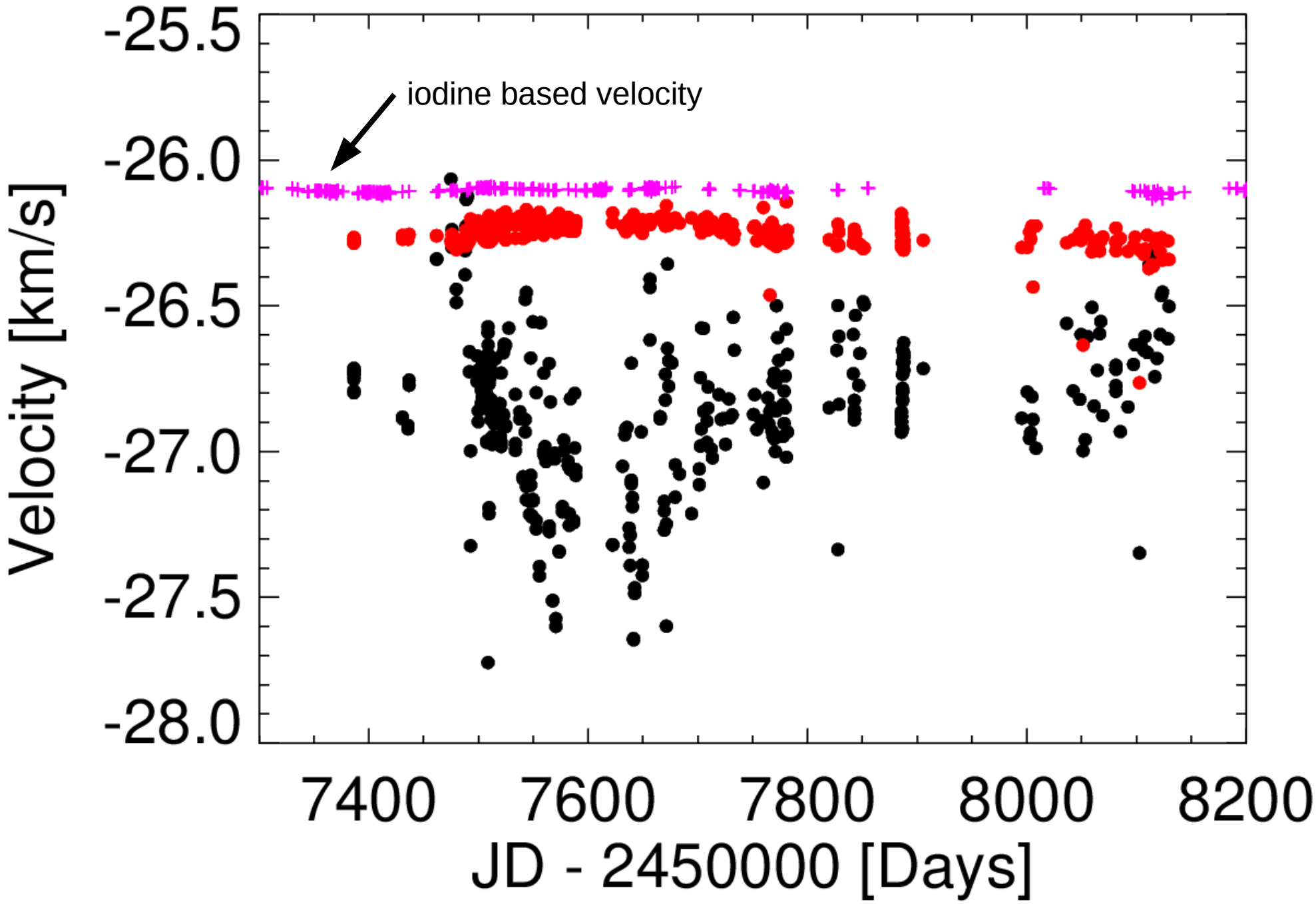
[FWHM / 2.35]




All non-iodine exposures in 2016
Telluric line velocity offset [km/s]
4
2
0
-2
-4
7400
7500
7600
7700
7800
JD - 2450000


-25.5
-26.0
-26.5
-27.0
-27.5
-28.0
Velocity [km/s]
7400
7600
7800
8000
8200
JD - 2450000 [Days]


-25.5
-26.0
-26.5
-27.0
-27.5
-28.0
Velocity [km/s]
7400
7600
7800
8000
8200
JD - 2450000 [Days]


iodine based velocity
-25.5
-26.0
-26.5
-27.0
-27.5
-28.0
Velocity [km/s]
7400
7600
7800
8000
8200
JD - 2450000 [Days]

What's next for the SONG spectrograph ?

- find (and solve !) the '1-year-problem'
- fiber feed with fixed resolution for better ThAr stability
- upgrade with Fabry-Perot etalon ?
- new detector (4K x 4K)
- improve blue throughput with new Coudé mirrors

…. and then we go down under

SONG South


Mt Kent Observatory,
University of Southern...

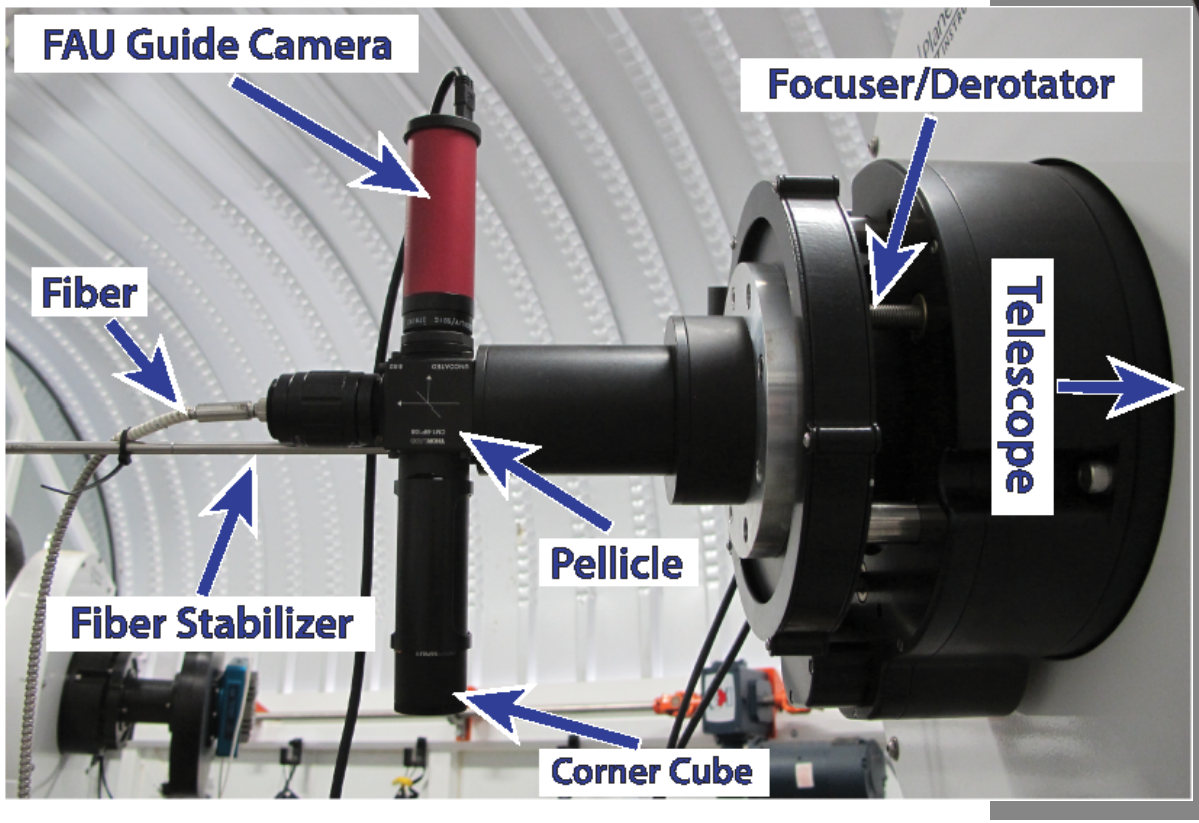
11.2 hours difference

Telescopes

0.7m PlaneWave teleskope

3 telescopes feed one

spectrograph via octagonal fibers



Work in the lab. starts after this meeting.

All major components ordered or in-house.