On the path to SPIRou:

first results from the CoolSnap observing program

CoolSnap team

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Goals

- identify visual and spectroscopic binaries
- investigate relationship between magnetic activity, chromospheric activity, stellar structure, rotation and age for M2-M5 V stars
- measure spectroscopic indices to estimate Teff and [Fe/H]
- measure v sin i and deduce Prot to estimate age
- measure kinematics to separate different populations

Allocated time on Espadons

- 3 components: Brazil, Canada, France
- allocated 14B-16A: 95h, 75% validated
- 14B: 28h val / 34h (B07: B1, C27: C3, F13: C1)
- 15A: 14h val / 18.8h (B02: B2, F04: C1)
- 15B: 18h val / 28.1h (B07: A1, C21: A4, F13: S2)
- 16A: 10.8h val / 13.8h (F25: C2)

Sample definition

- Lépine et al. (2011) sample of 8000 M dwarfs with proper motion > 40 mas/yr and dec > -30°
- Merit function combining H flux and predicted RV semi-amplitude for a 3 Earth mass planet in the HZ
- K>0.75 m/s and sorted according to MF: cut at 0.4 (H=7, K=1) gives 150 objects
- 25% of M stars in SIC
- remove stars already observed when high S/N polarimetric observations with Espadons or Narval exist
- remove known close binaries and known active stars (X and UV)

Observed sample

- 85 stars, 189 spectra at SNR>100: all but 4 at two different epochs

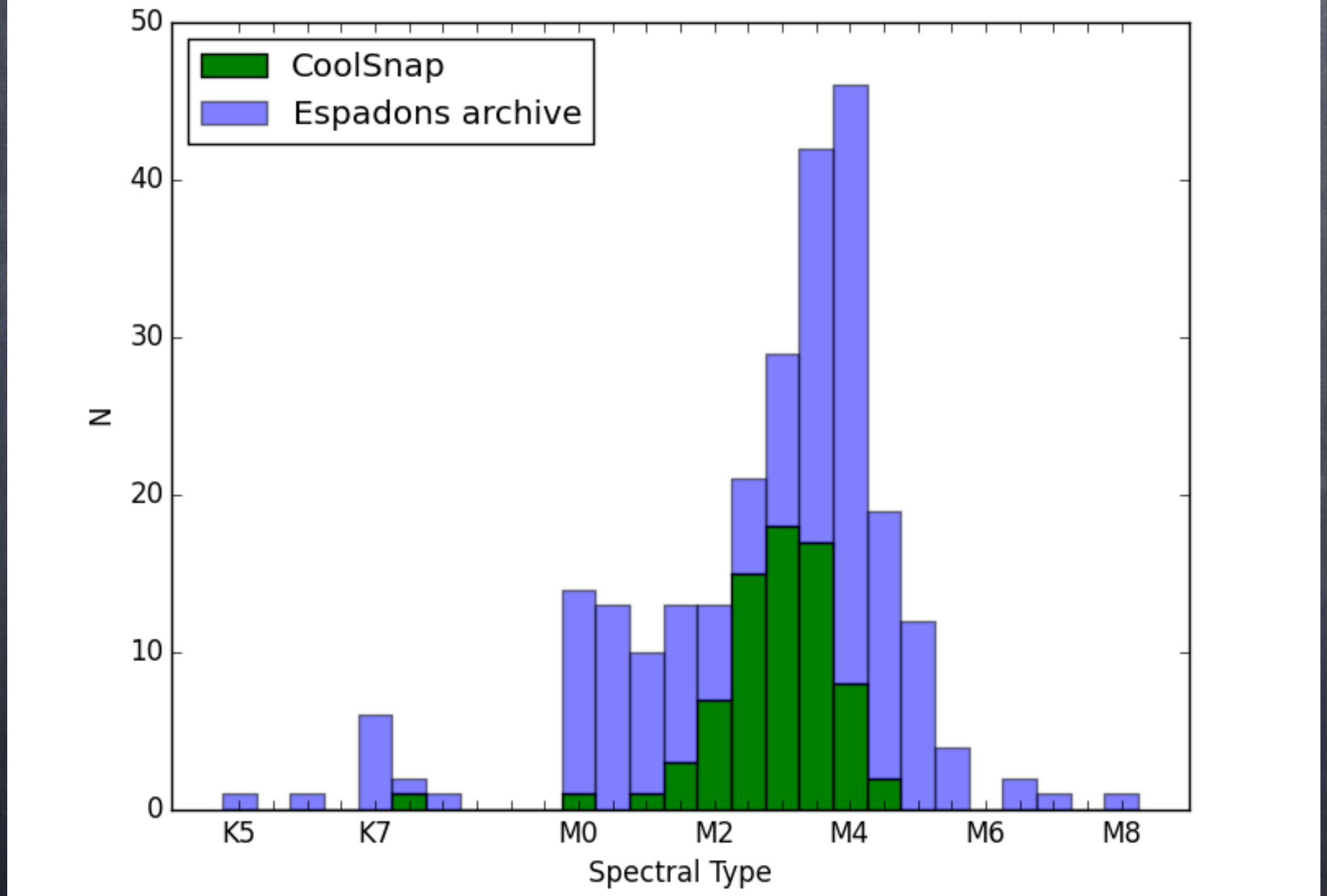
- LSD analysis with M2 mask

- 49 detections in Stokes V (including marginal): 34 are variable, 36 non-detections

- some discarded: 1 not dwarf (wrong PM), 1 wrong V (selected on V-J), 1 SB1, 5 SB2

Espadons archive

- All public M stars observed by Espadons in the Lépine et al. (2011) sample: 255 stars
- Remove binaries: 223 stars
- 56 stars with suitable observations (polarimetry, SNR>100), 746 spectra


CoolSnap
Espadons archive
N
50
40
30
20
10
0
K5
K7
M0
M2
M4
M6
M8
Spectral Type

Determination of Teff and [Fe/H] (1)

- Method of Neves et al.: measure EW of spectral features and calibrate temperature and metallicity vs adopted values

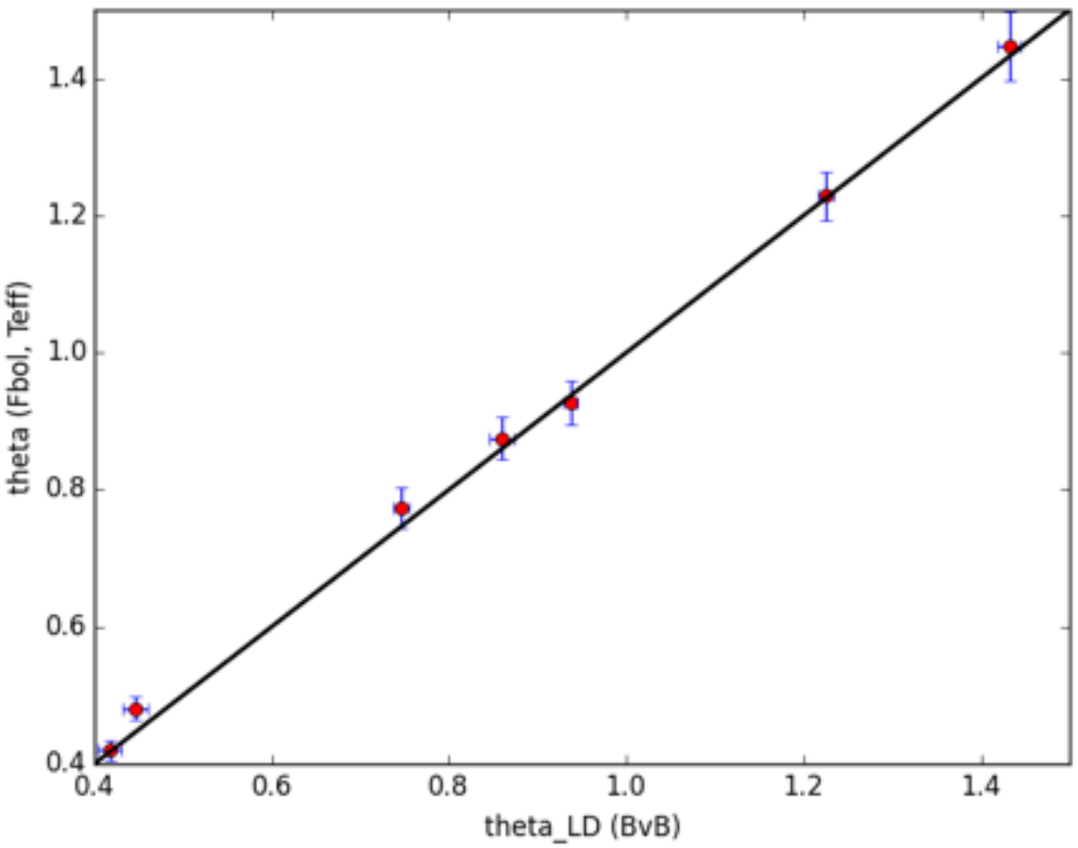
- Raphaël Delage's internship under Claire Moutou's supervision

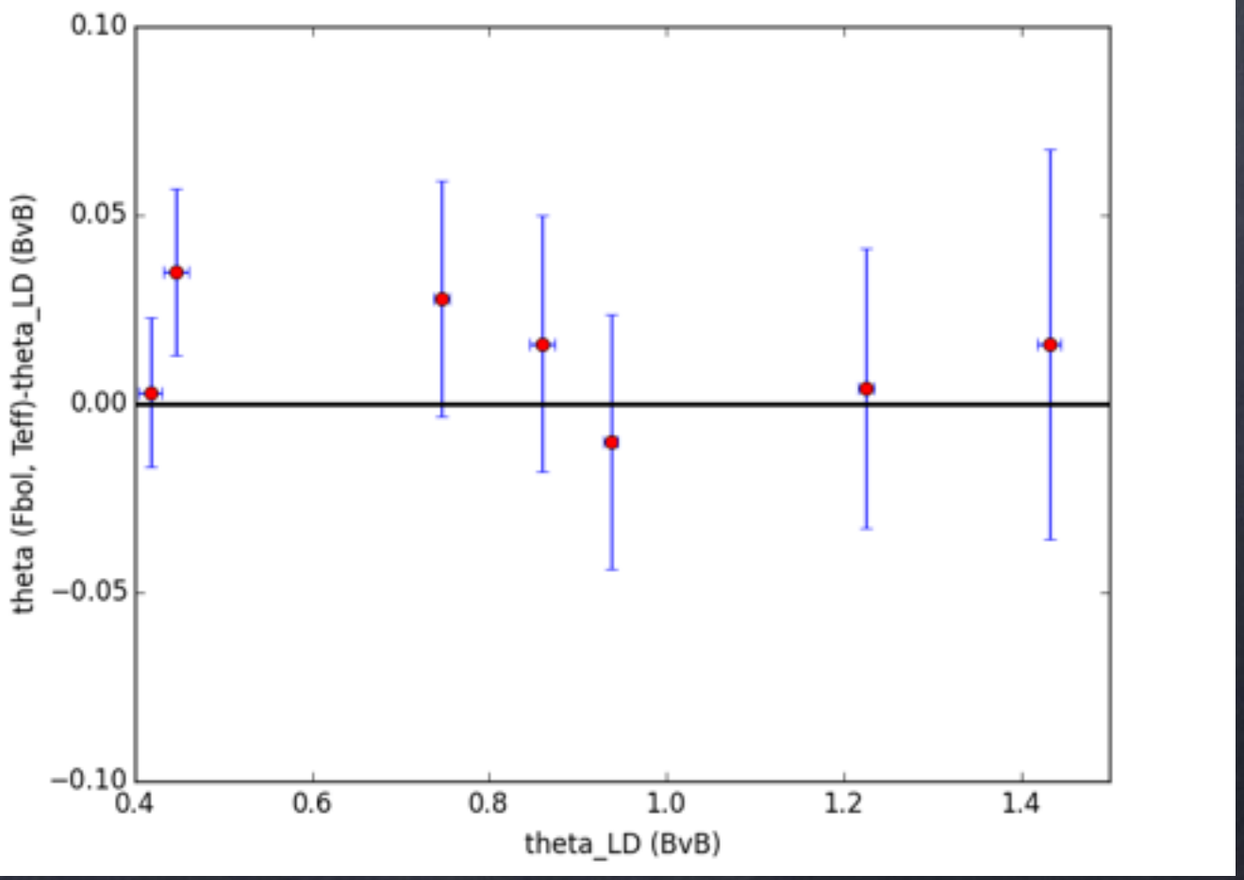
- Compare results to "reliable" values, but who is reliable?

- Original Neves et al. calibration predicts too low Teff

Determination of Teff and [Fe/H] (2)

- Neves et al. calibration of Teff based on Casagrande et al. (2008)
- Compute a new calibration based on Mann et al. (2015)
- Teff and [Fe/H] now OK, but less calibrators
- check with predicted angular diameter vs LBOI
- Compute Teff and [Fe/H] for stars in the Espadons archive with a merit function > 0.4: but most are active stars with Ha in emission, for which Teff and [Fe/H] cannot be reliably measured with Neves' technique: only 11 additional stars


theta (Fbol, Teff)
theta_LD (BvB)
0.4
0.6
0.8
1.0
1.2
1.4


theta (Fbol, Teff)-theta_LD (BvB)
theta_LD (BvB)
0.10
0.05
0.00
−0.05
−0.10
0.4
0.6
0.8
1.0
1.2
1.4

Stellar activity

- Halpha EW and S_HK index measure chromospheric activity

- Stokes V measures effective magnetic polarization

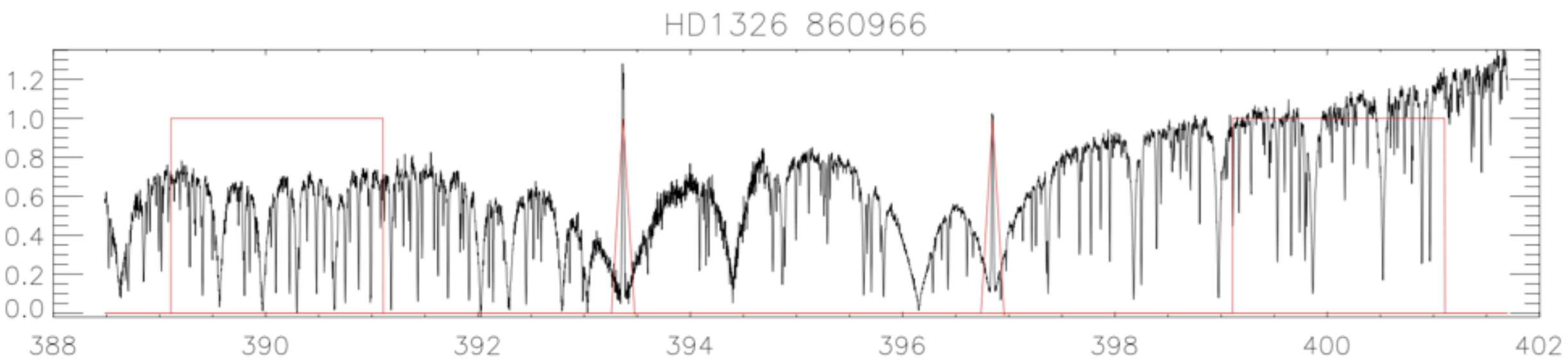
- diagnostics differ: importance of spectropolarimetric observations

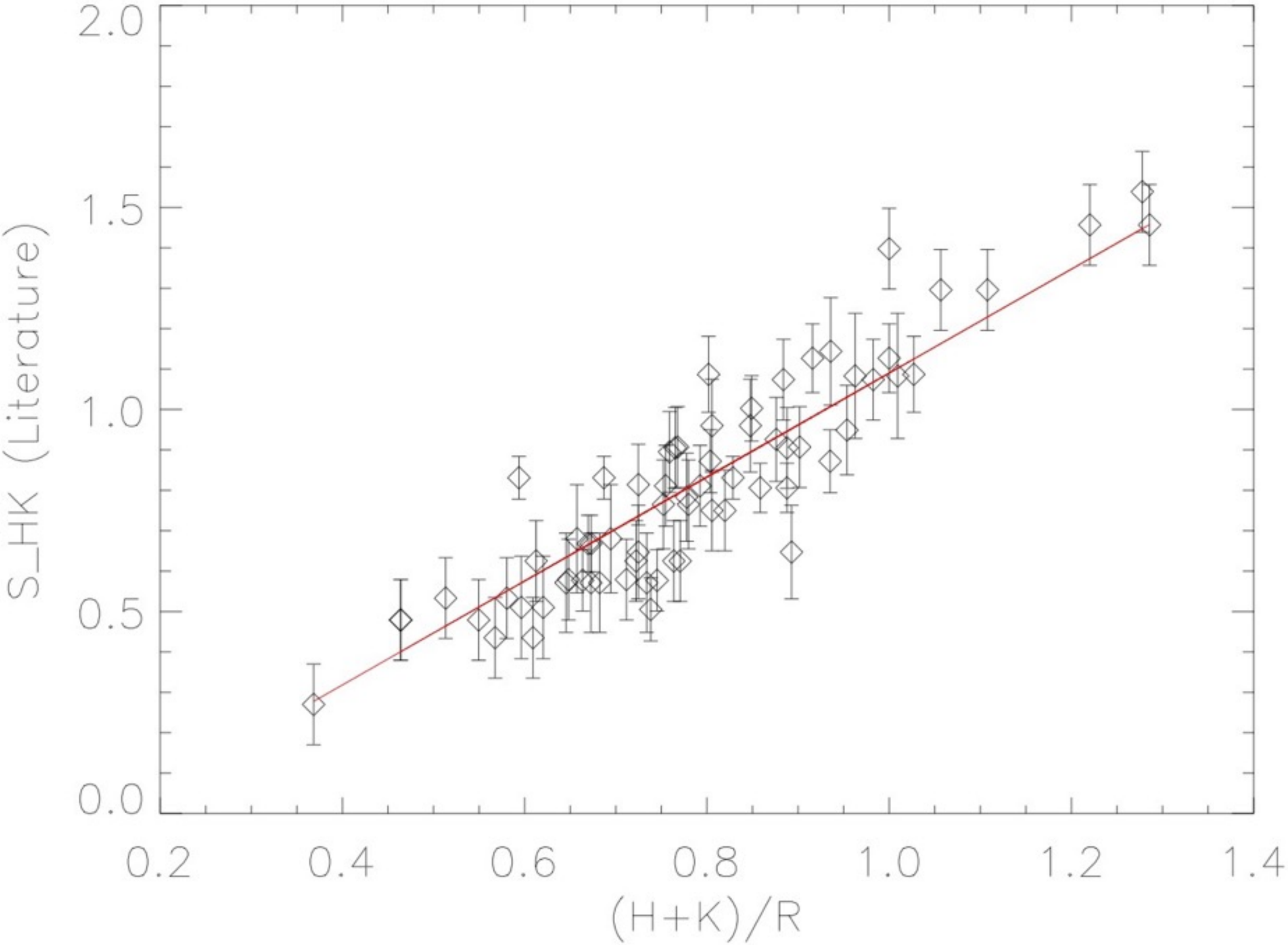
- measure Ca II H&K, Na I, Ca II triplet and compare to Halpha

S_HK

- V K H R measured for all CoolSnap targets and Espadons archive, but SNR is low in the blue
- Compute S_HK from (H+K)/R
- Calibrate with S_HK from Astudillo-Defru+ 2016 (error bars represent dispersion of measurements) or Isaacson & Fischer 2010 (single measurement)

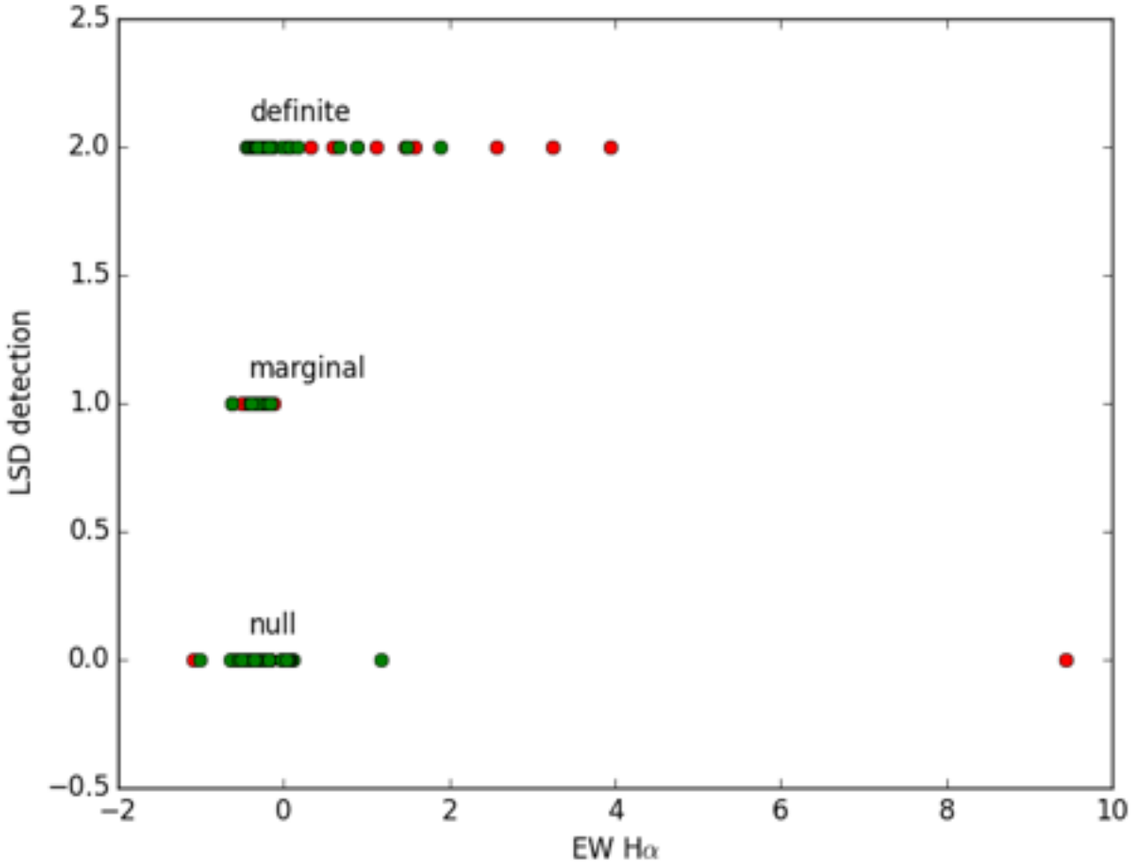
Definition of V K H R

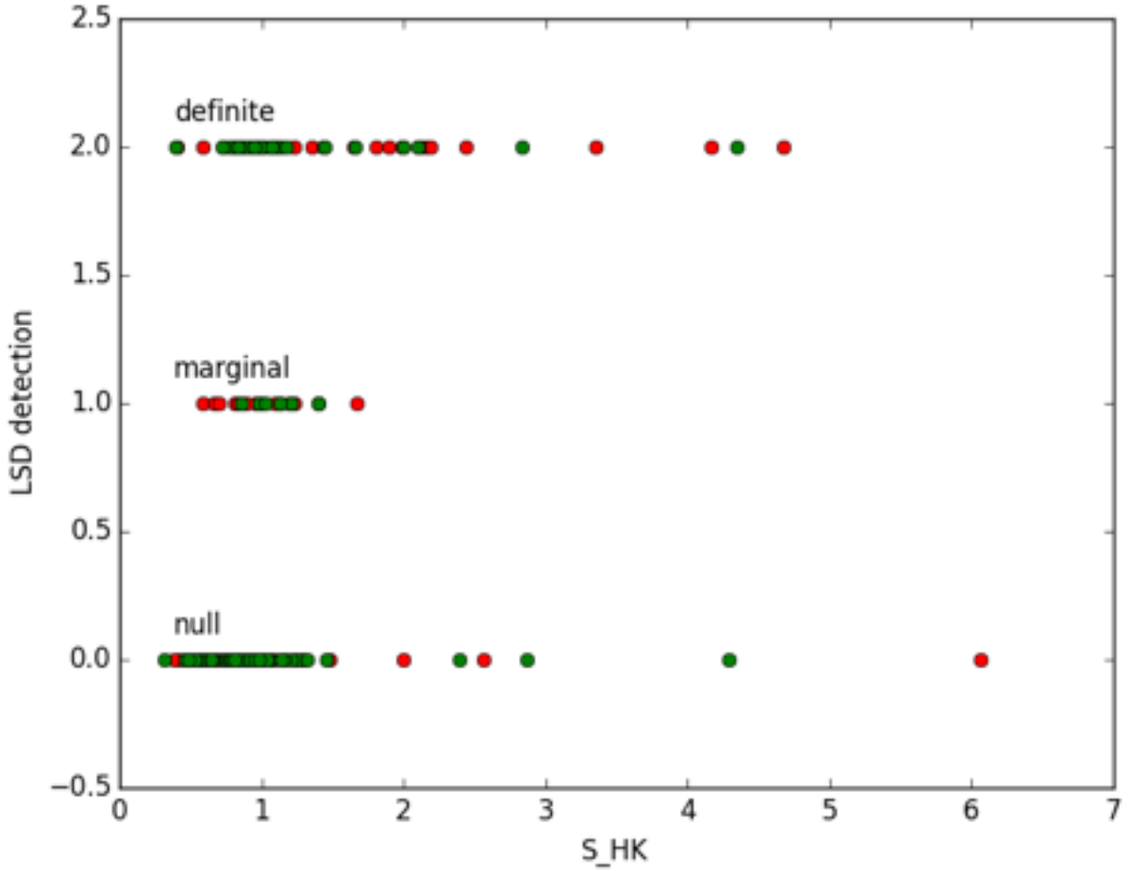


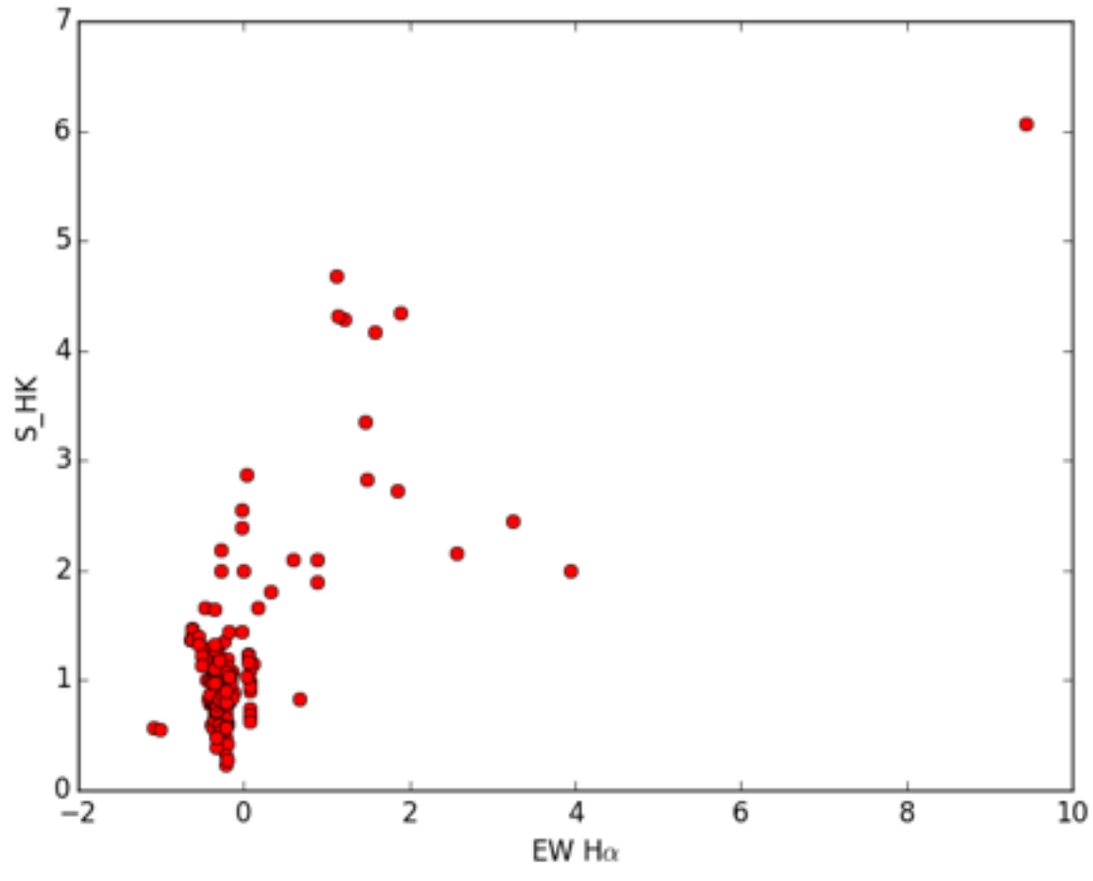

2.0
1.5
1.0
0.5
0.0
S_HK (Literature)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
(H+K)/R

S_HK and Halpha

- Halpha EW measured for all CoolSnap targets
  - some correlation between S_HK and Halpha
  - no clear correlation between LSD detection and either Halpha or S_HK

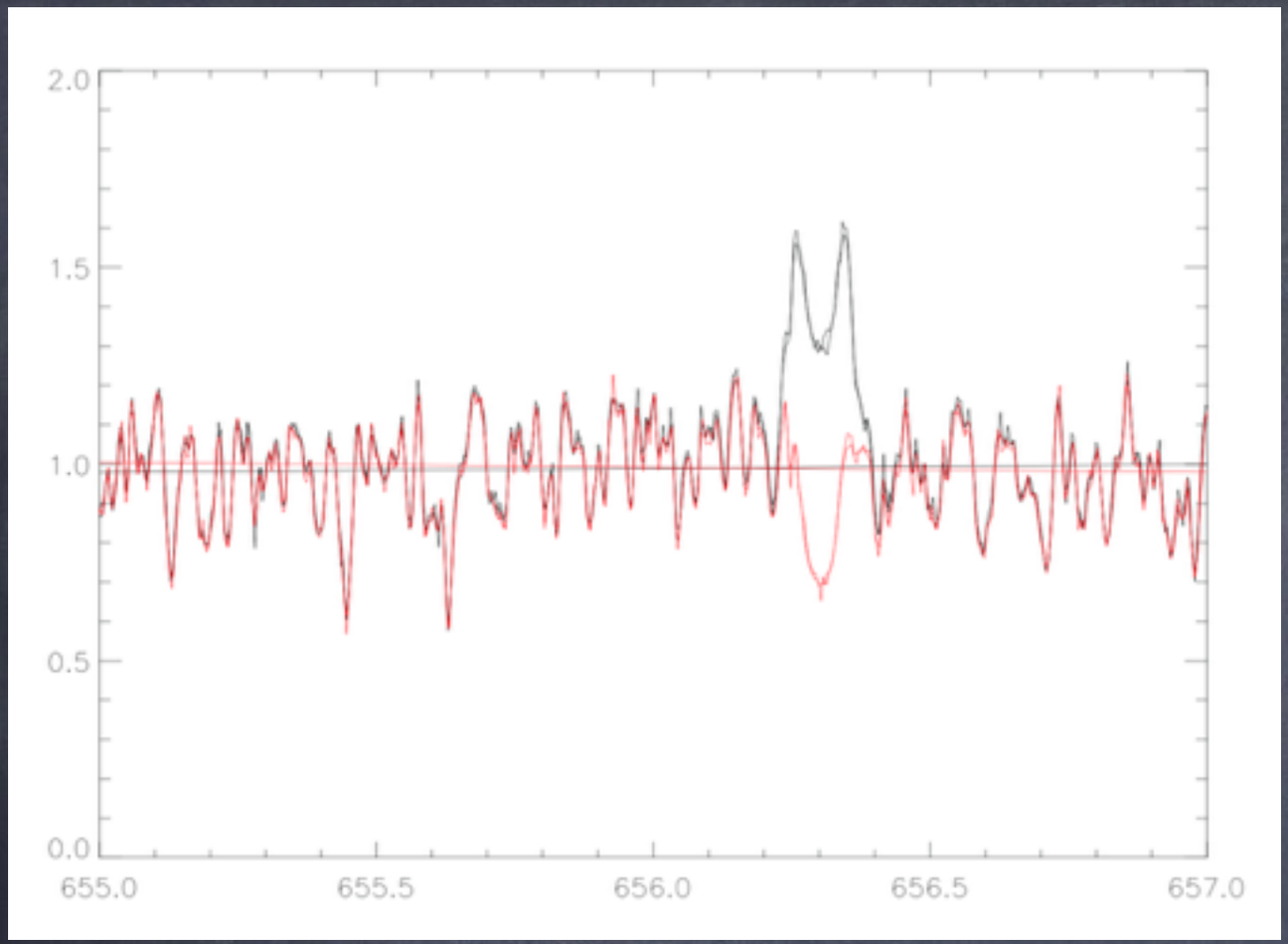

definite
marginal
null
LSD detection
EW Hα

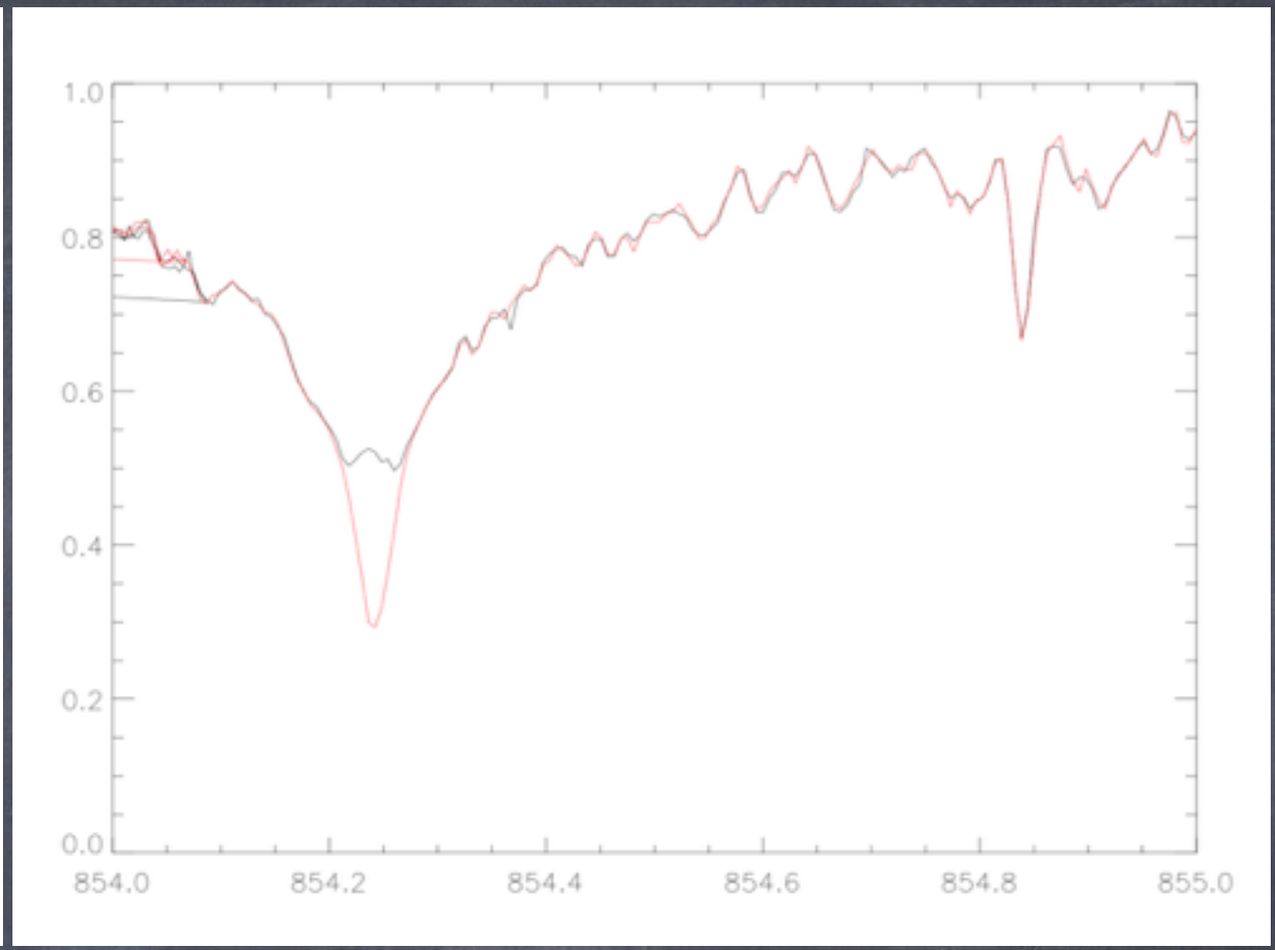

definite
marginal
null
LSD detection
S_HK

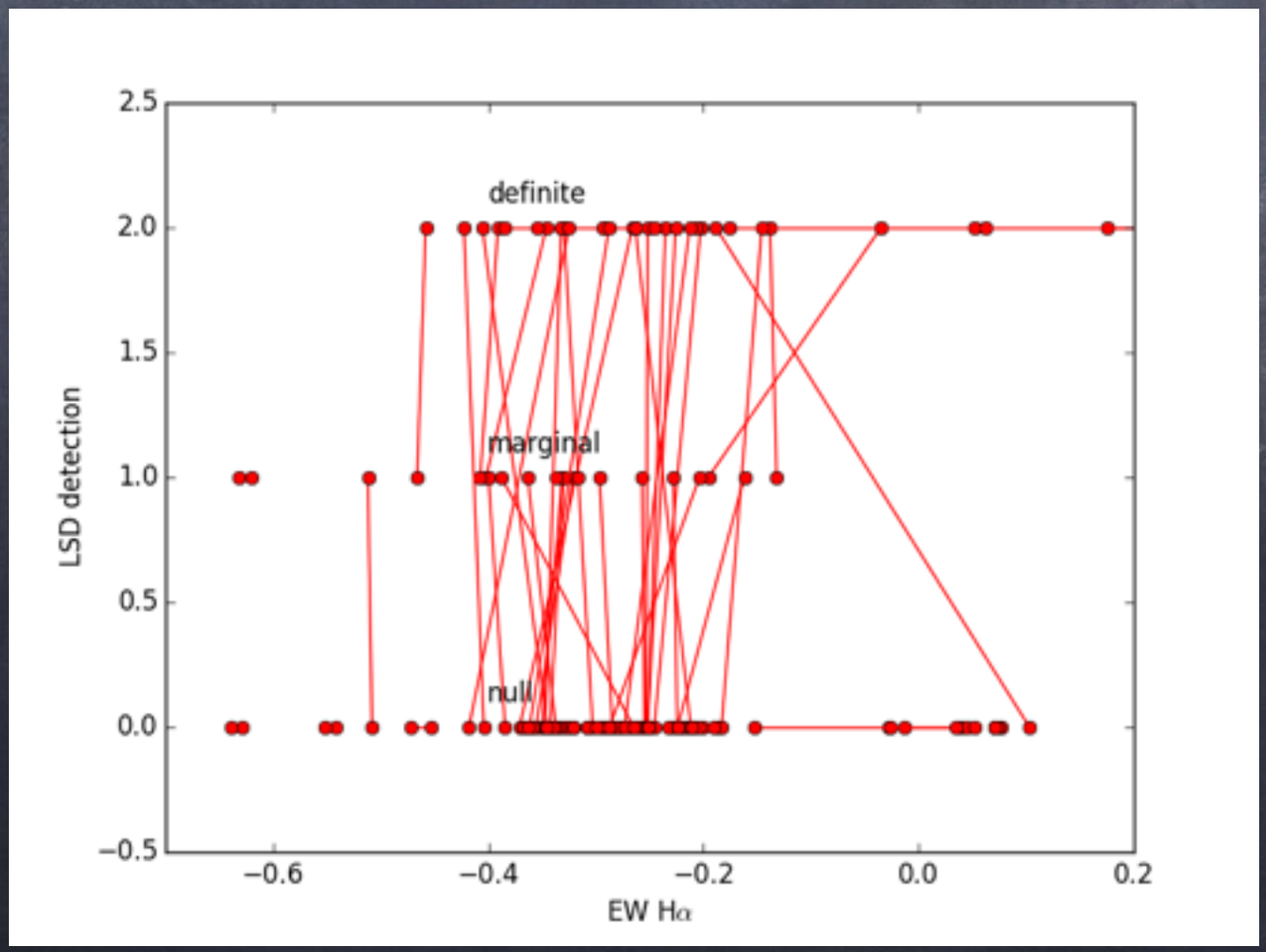

S_HK
EW Hα

Variability

- Halpha may significantly vary between spectra of the same star
- LSD detection may vary too: null, marginal, definite


2.0
1.5
1.0
0.5
0.0
655.0
655.5
656.0
656.5
657.0


1.0
0.8
0.6
0.4
0.2
0.0
854.0
854.2
854.4
854.6
854.8
855.0

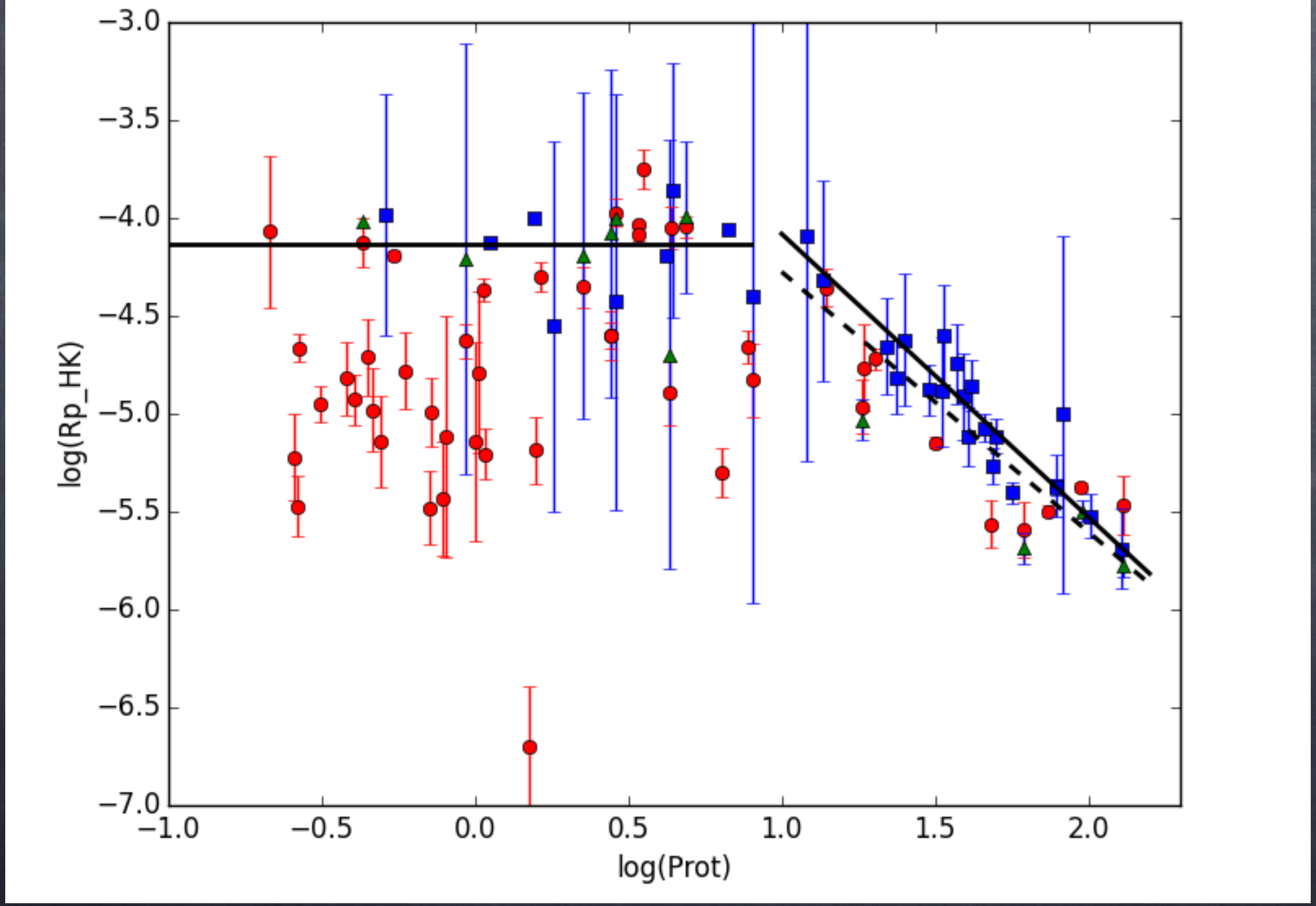

definite
marginal
null
LSD detection
EW Hα
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−0.6
−0.4
−0.2
0.0
0.2

Log (R'_HK) and Prot

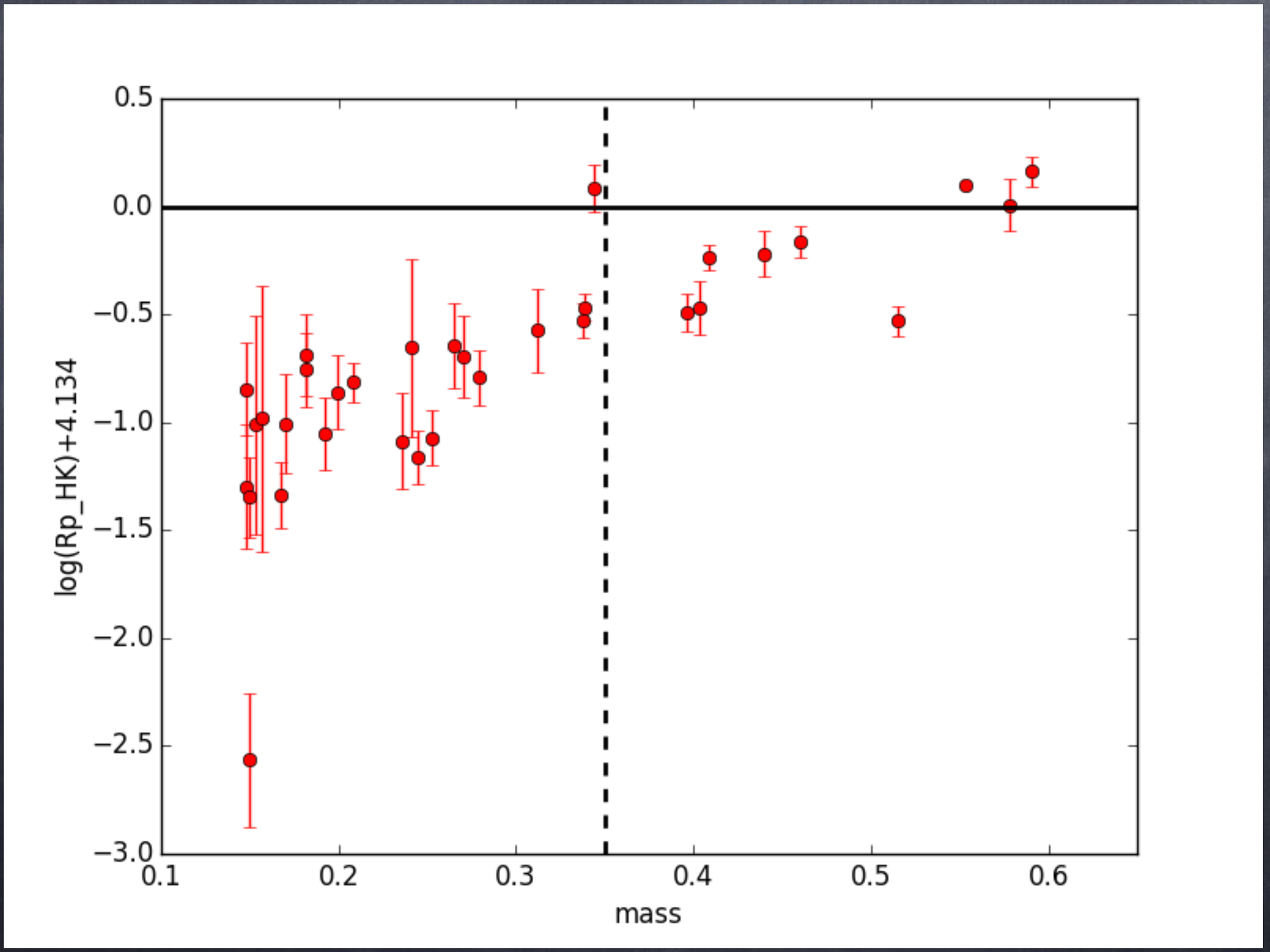
- Use calibration of R'_HK and Rphot from Astudillo-Defrut 2016

- Compare our R'_HK for stars with photometric Prot to relations from AD +2016 and Suarez Mascareno+2015

- New population with short periods but small log(R'_HK)

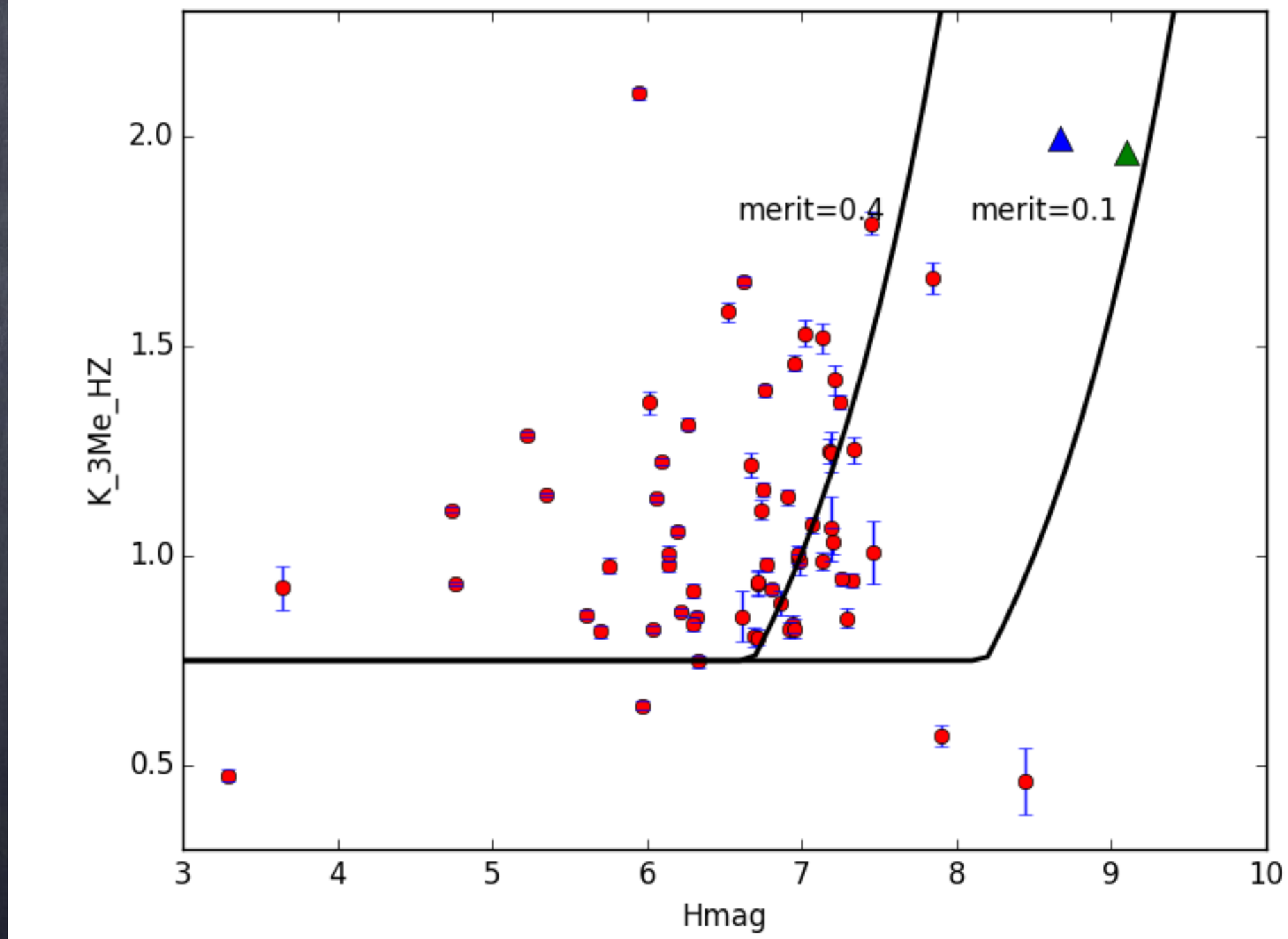

−3.0
−3.5
−4.0
−4.5
−5.0
−5.5
−6.0
−6.5
−7.0
log(Rp_HK)
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
log(Prot)

Rapid rotators (Prot < 10d)



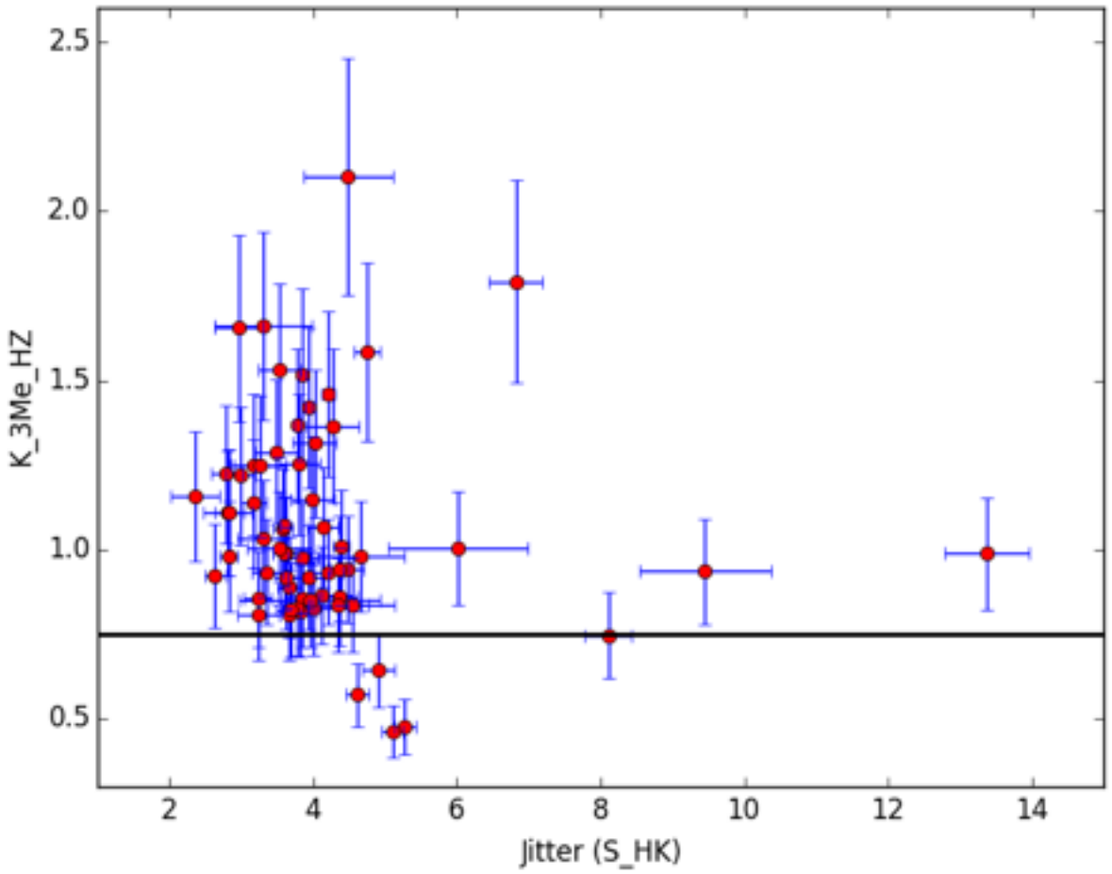
Predicted RV semi-amplitude (1)

- Original metric based on estimated radius and temperature derived from spectral type
- Fbol well-measured from photometry and spectrum, or estimated from bolometric correction
- Fbol and Teff give angular diameter, and parallax gives radius

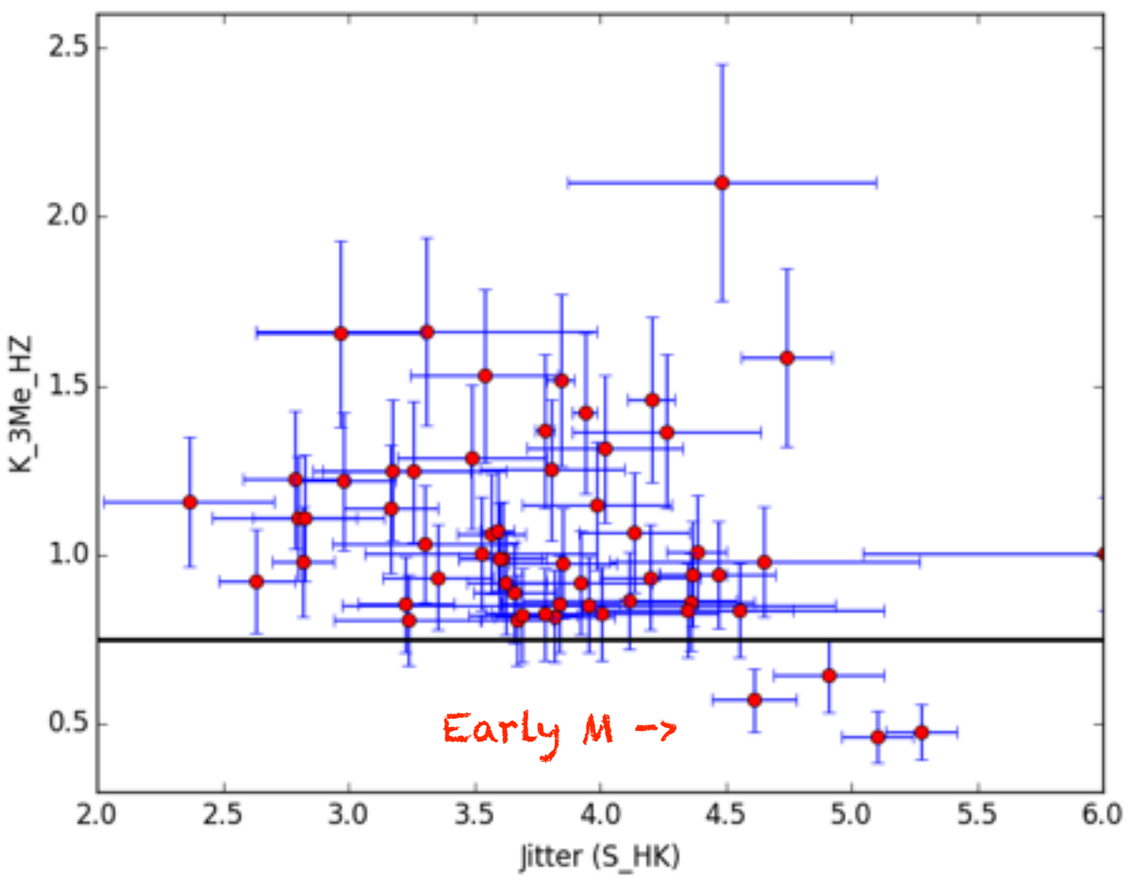

merit=0.4
merit=0.1
2.0
1.5
1.0
0.5
K_3Me_HZ
3
4
5
6
7
8
9
10
Hmag

Predicted RV semi-amplitude (2)

- Small incertitude from measured stellar parameters: K varies as Mstar-1/2, Teff-1, R-1/2 or Mstar-1, Fbol-1/4, parallax+1/2
- But systematic uncertainties: circular orbit, sin i=1, albedo=0.4, uniform energy redistribution, T(HZ)=250K, Mplanet=3 Mearth
- Fit Kopparapu's models to simple law gives a conservative HZ at 300K (inner 350, outer 250)
- Use Isaacson & Fischer formula to predict jitter from S_HK
- Compare computed K_3Me to expected jitter

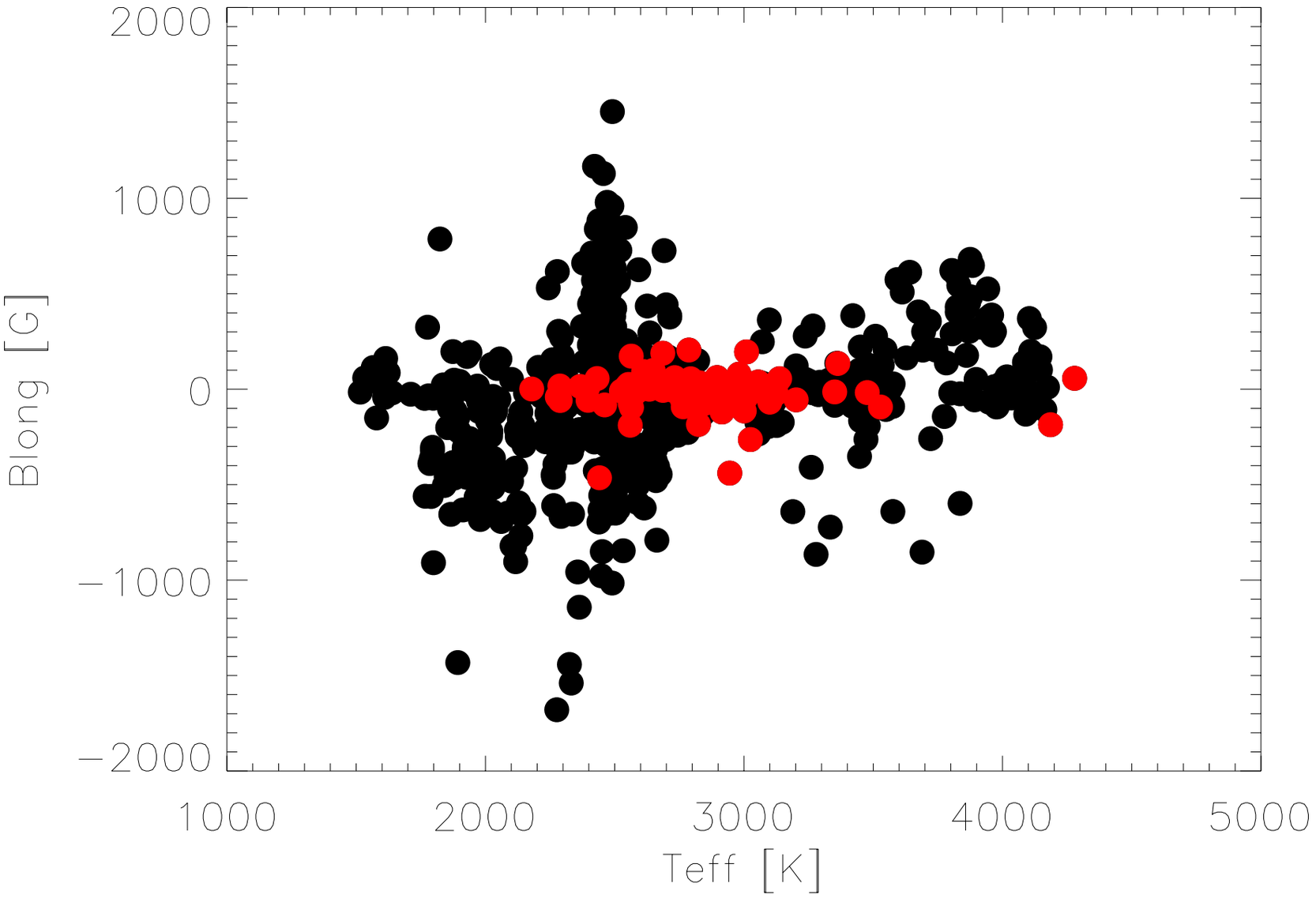


Reduction of jitter
in the NIR and correction
using polarimetric information



Future

- Two follow-up programs:
- Elodie Hebrard will get more epochs for a few stars with 2 detections
- Extend the sample to later M dwarfs: Mearth focused on d<33 pc, R<0.33 Rsun (M4-M8): fainter and more active (?), but larger RV amplitude: good targets for SPIRou if not active
- Inclusion in SPIRou WP1.1: "input catalog coordination"


2000
1000
0
−1000
−2000
Blong [G]
1000
2000
3000
4000
5000
Teff [K]