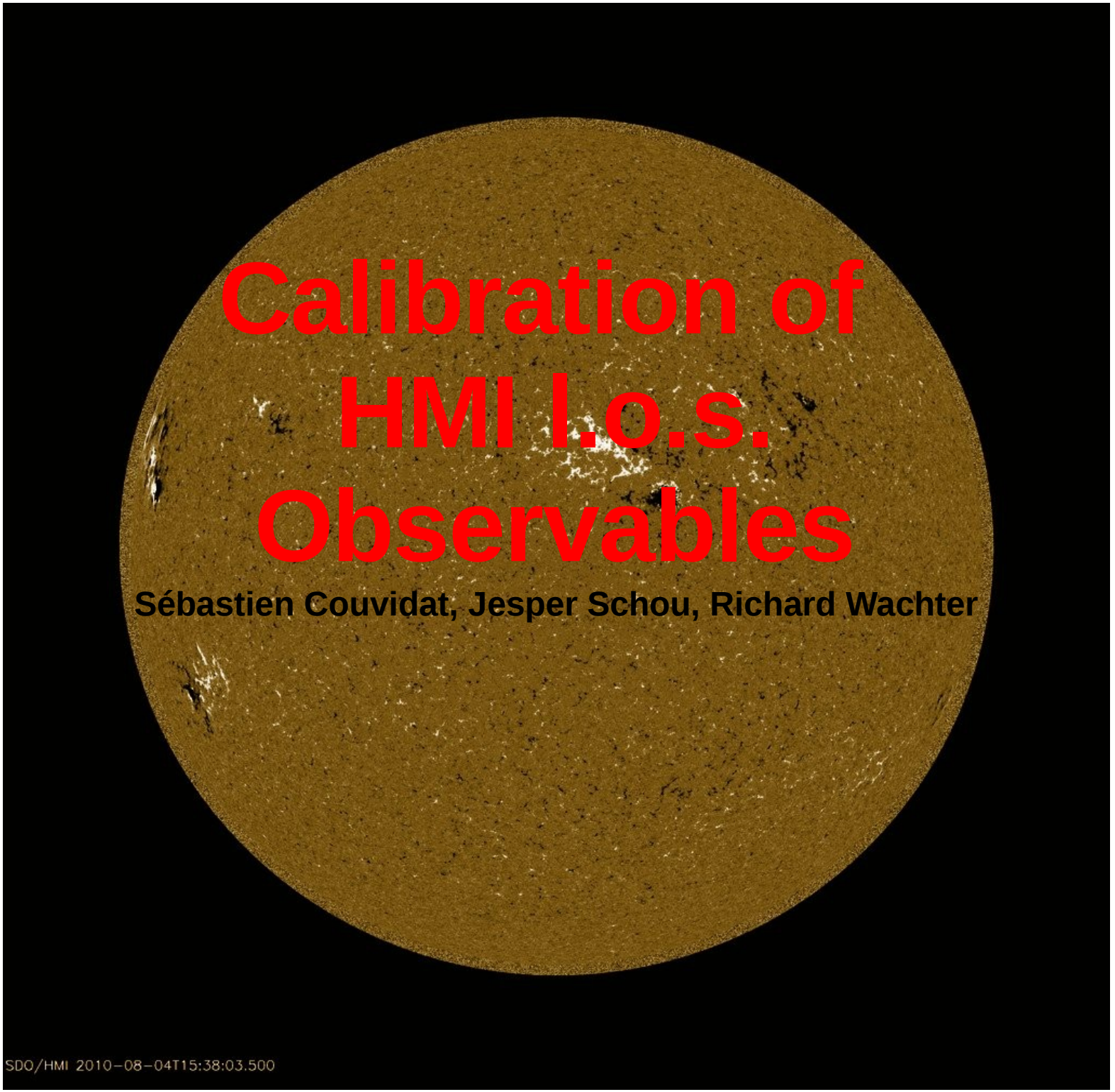
Calibration of HMI l.o.s. Observables
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SDO/HMI 2010-08-04T15:38:03.500

2 observables codes:

- l.o.s. observables (Dopplergram, l.o.s. magnetogram, linedepth, linewidth, continuum intensity)
- 12-min averaged IQUV (I,Q,U, and V images, 12-min Dopplergrams, 12-min l.o.s. magnetograms, 12-min linedepth, 12-min linewidths, 12-min continuum intensity)

both codes take level 1 filtergrams as input (dark subtracted, flat-fielded, normalized by exposure time, limbfit code run on them)

codes use several sub-routines:

-gapfilling (from Jesper and Richard) to correct for bad pixels and cosmic-ray hits
-spatial interpolation (Jesper)
-temporal interpolation (Jesper + Richard) at target time
-de-rotation (Richard)
-un-distortion (Richard+Cristina)
-polarization calibration (Jesper)
-MDI-like algorithm (Sebastien)

NB: I’m not going to talk about polarization calibration (see Jesper)

MDI-like algorithm:

-calculate discrete approximation of 1st and 2nd Fourier coefficients:

$\cos(2.5x2\pi/6)*I_0 + \cos(1.5x2\pi/6)*I_1 + \cos(0.5x2\pi/6)*I_2 + \cos(-0.5x2\pi/6)*I_3 +$
$\cos(-1.5x2\pi/6)*I_4 + \cos(-2.5x2\pi/6)*I_5 = a_1$

$\sin(2.5x2\pi/6)*I_0 + \sin(1.5x2\pi/6)*I_1 + \sin(0.5x2\pi/6)*I_2 + \sin(-0.5x2\pi/6)*I_3 +$
$\sin(-1.5x2\pi/6)*I_4 + \sin(-2.5x2\pi/6)*I_5 = b_1$

similar expressions for a_2 and b_2

-then assuming Fe I line has a Gaussian profile, and that filter transmission profiles are delta functions:

velocity = $K \operatorname{atan}(b_1/a_1)$

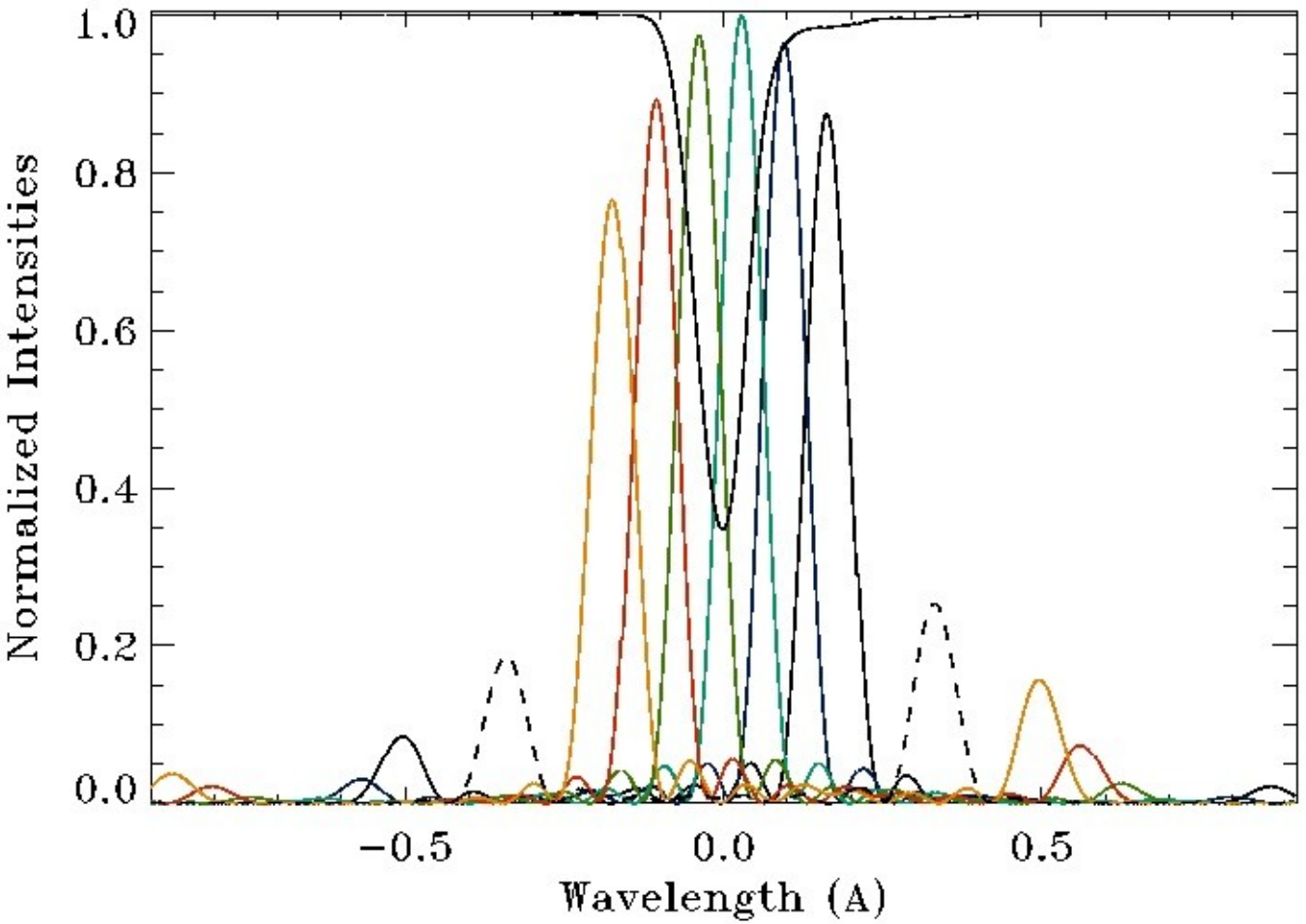
magnetogram = difference of LCP and RCP velocities times a constant

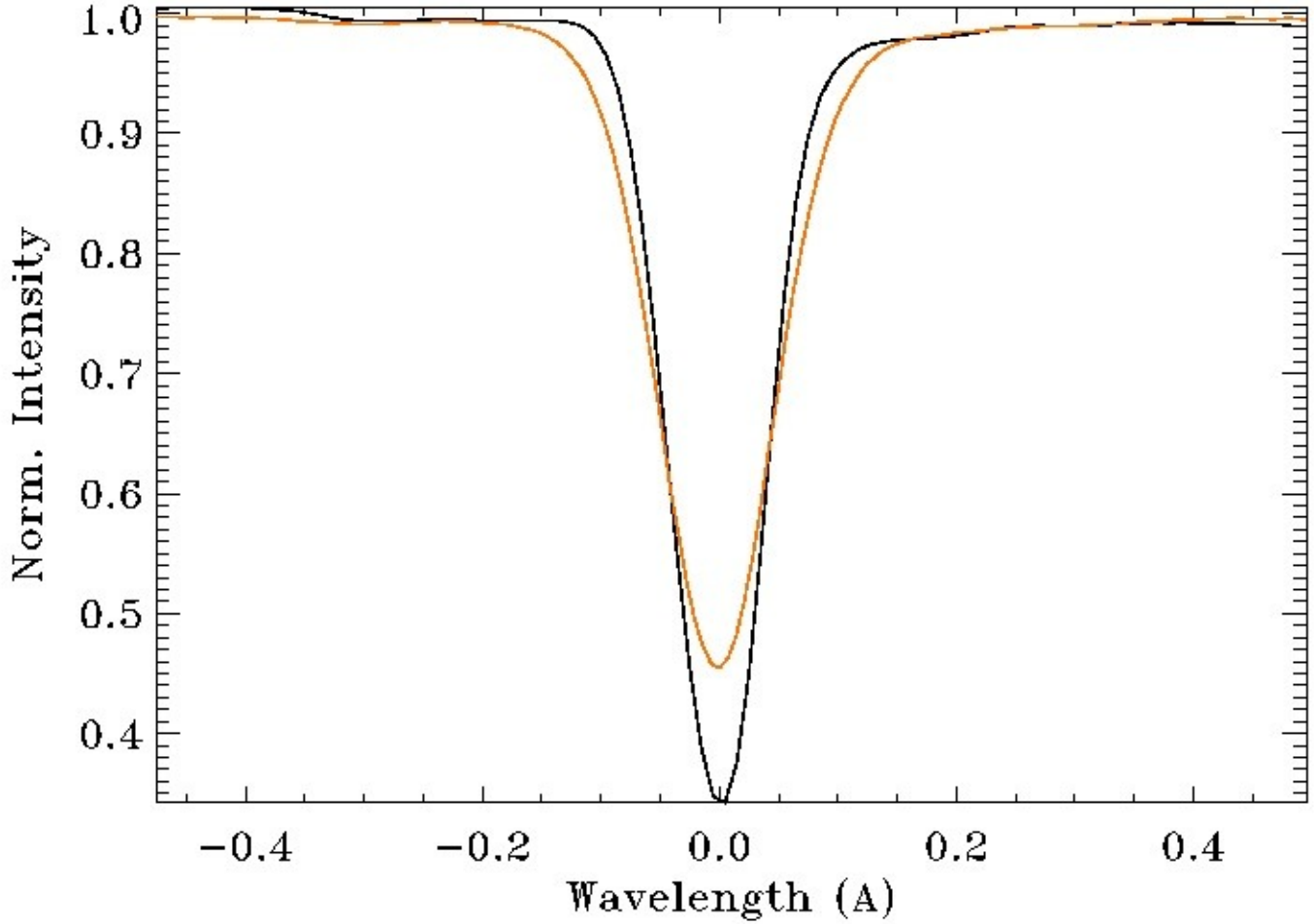
linewidth (σ) = $K_2 \sqrt{\log((a_1^2+b_1^2)/(a_2^2+b_2^2))}$

linedepth = $K_3 / \sigma \, (a_1^2+b_1^2)^{2/3}/(a_2^2+b_2^2)^{1/6}$

-need to correct Doppler velocity with look-up tables (2 look-up tables per pixel)

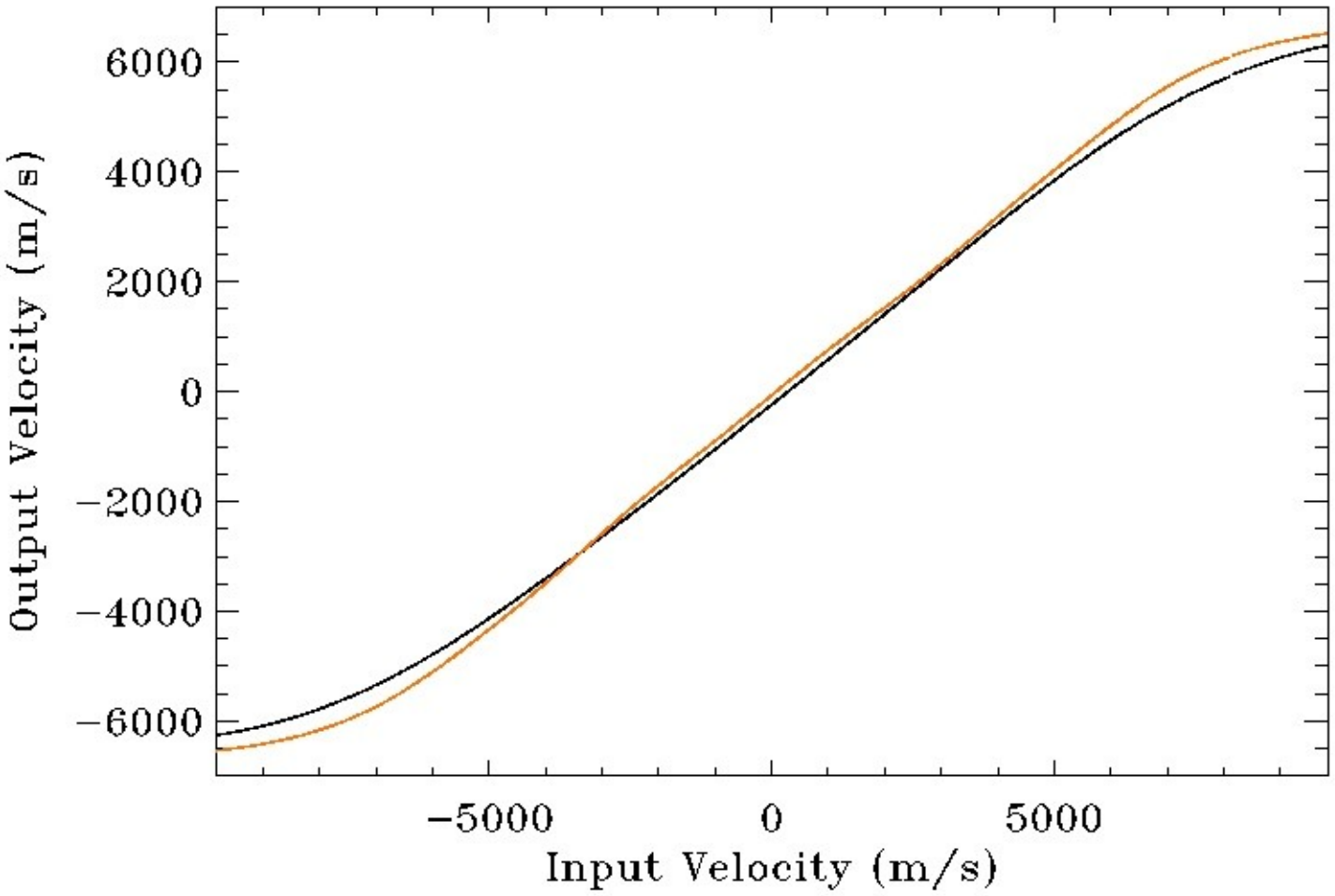
6 HMI-filter transmission profiles derived from ground calibration data and regular calibration sequences taken on-orbit





Fe I lines from the Kitt Peak atlas and Mount Wilson observatory (provided by R. Ulrich)

Example of a look-up table at solar disk center:

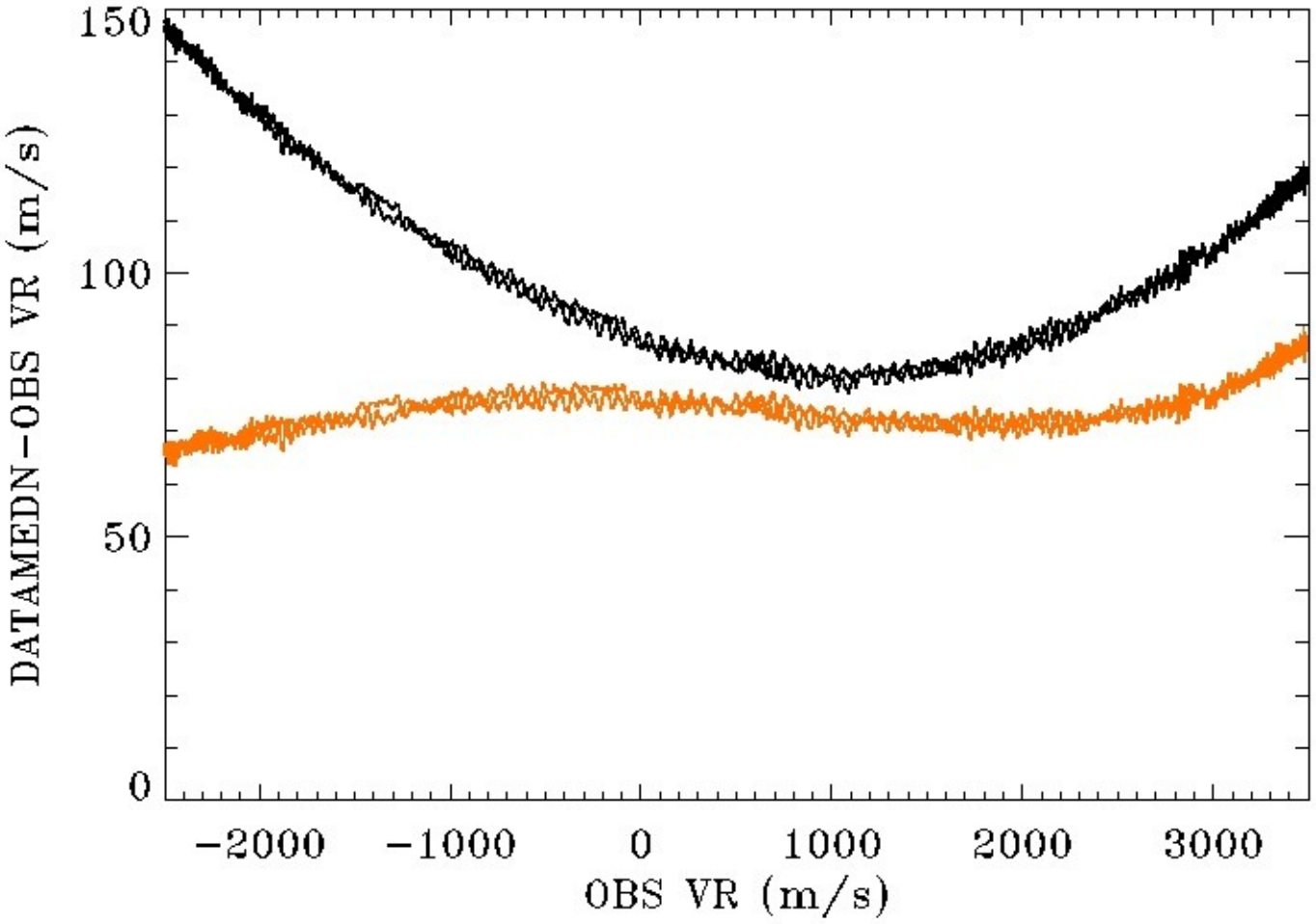


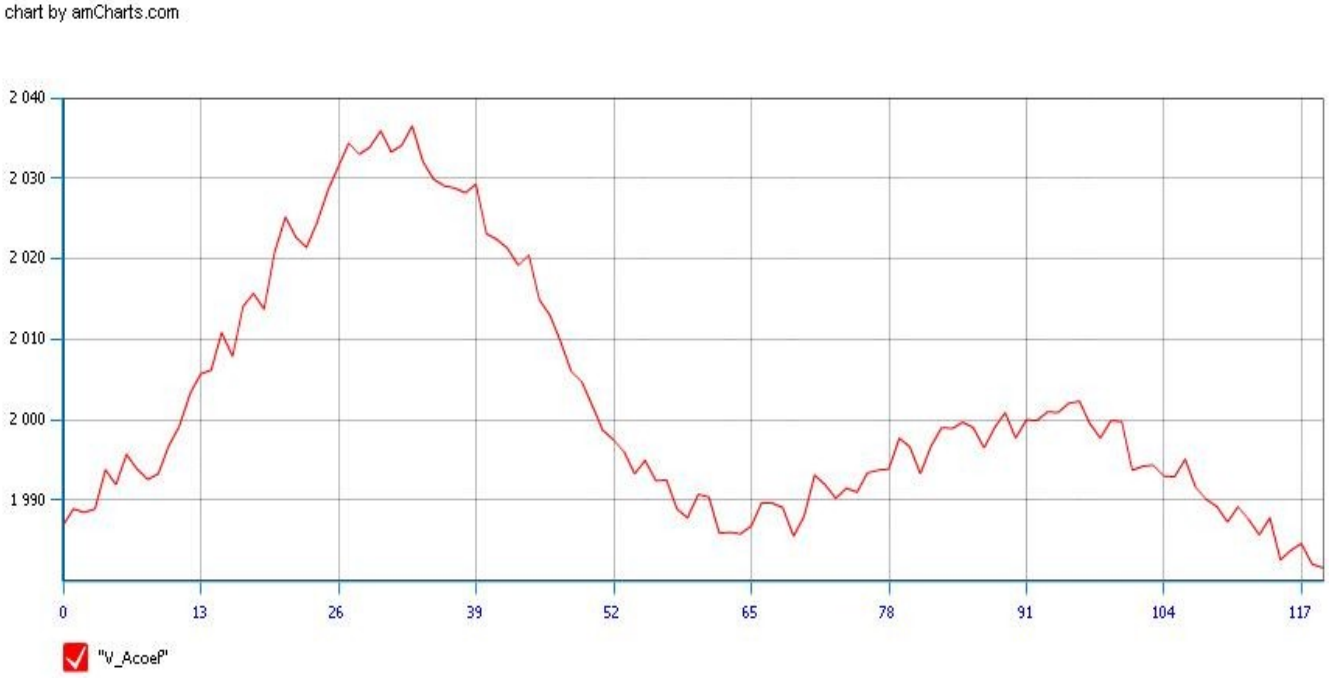
NB: Look-up table for second Fourier coefficient is very sensitive to shape of Fe I line

Calibration Issues

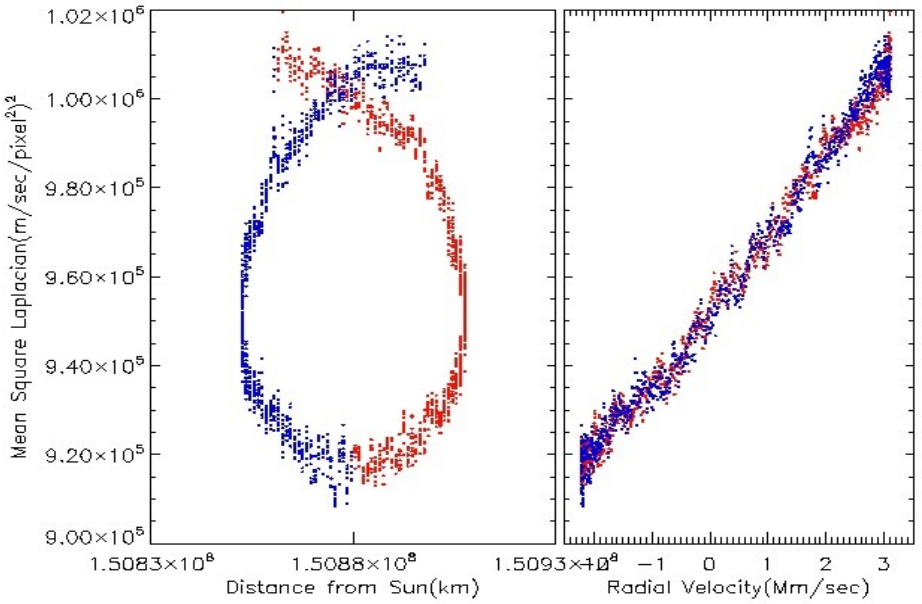
- only 1st Fourier coefficients used, so we lose half the information (and increase noise level by √2) => probably a problem with Fe I line profile used

- daily variation of several quantities, due to dependence on OBS_VR. Seen in median Doppler velocity, equatorial rotation rate (code from Phil), mean square Laplacian (code from Charlie)... might reflect a variation in the differential Doppler sensitivity => problem with Fe I line used and with the filter transmission profiles

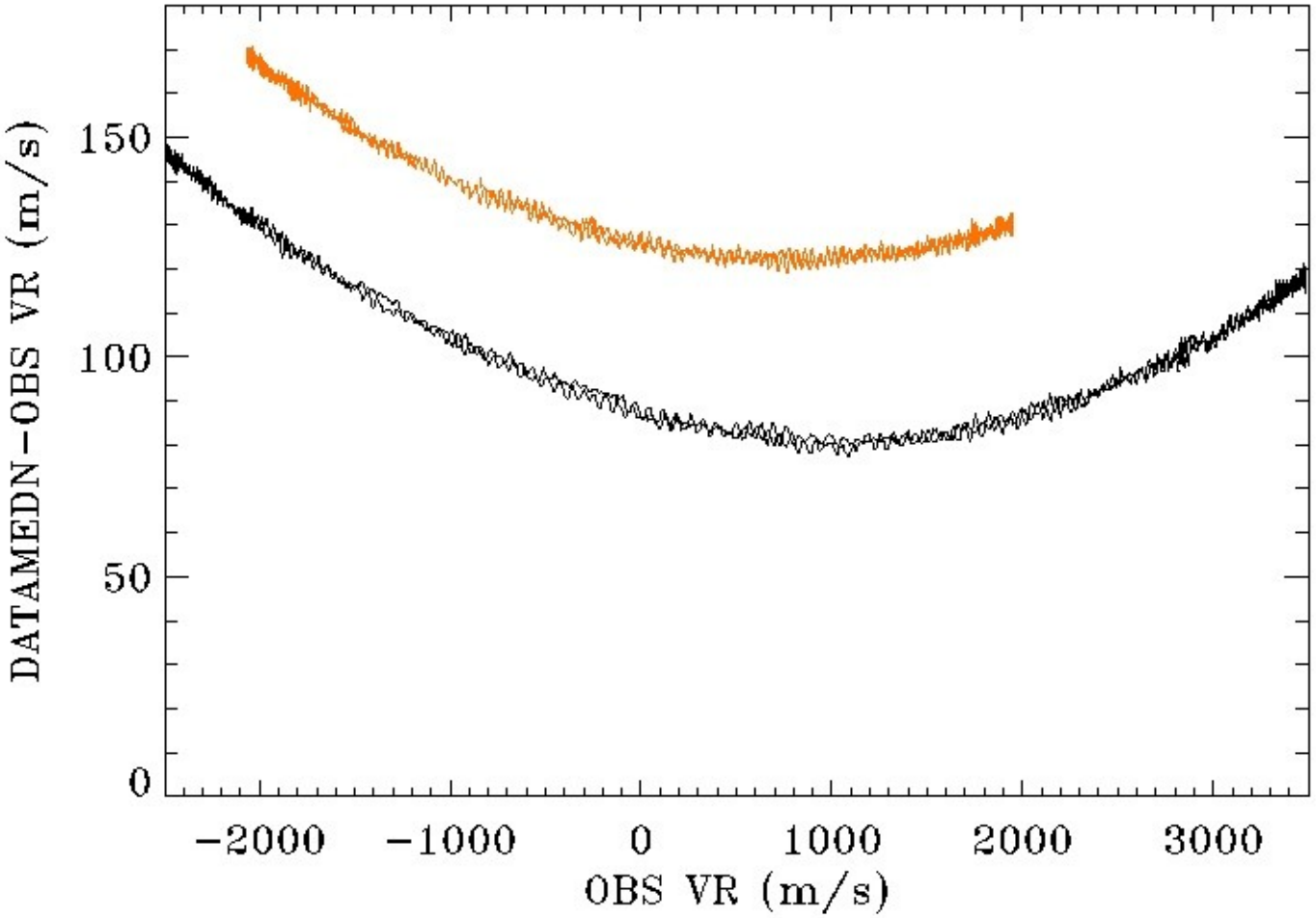




Daily variation in the equatorial rotation velocity (plot from Phil)



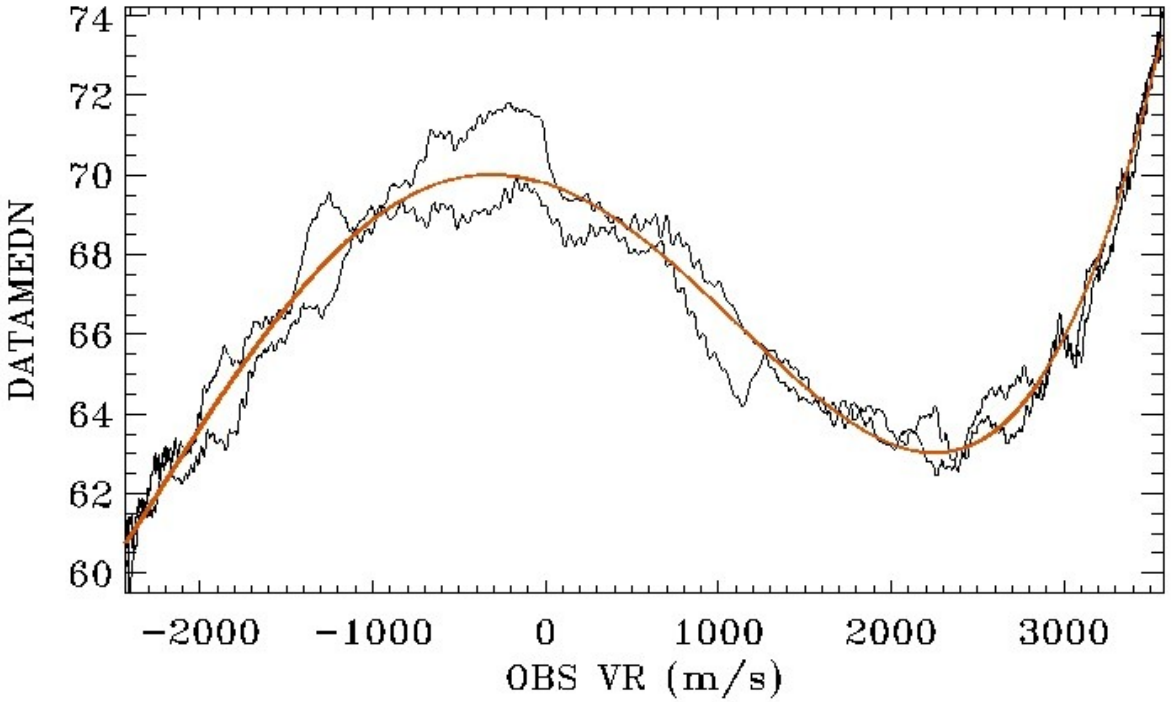
Variation in the mean square Laplacian (from Charles Lindsey)

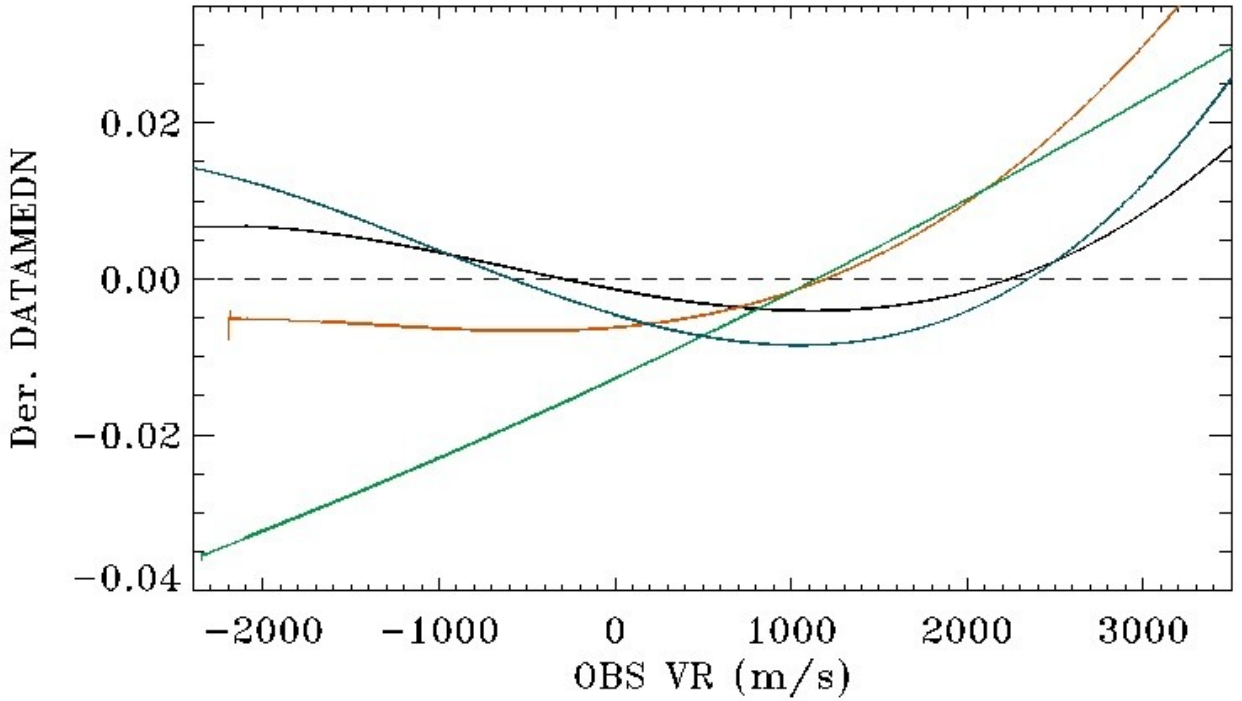


Shift with time due to Michelson drift (black curve= mid-April, red curve=mid-July)

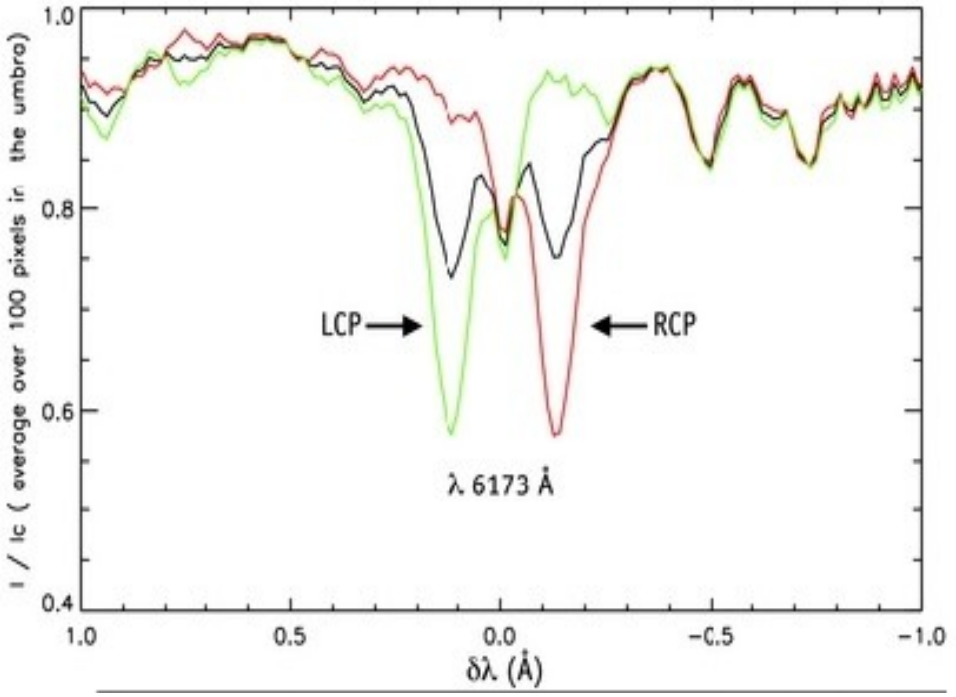
Best calibration as of today (ongoing effort) gives:

Fe I line was modeled as Voigt profile + small Gaussian in the blue wing



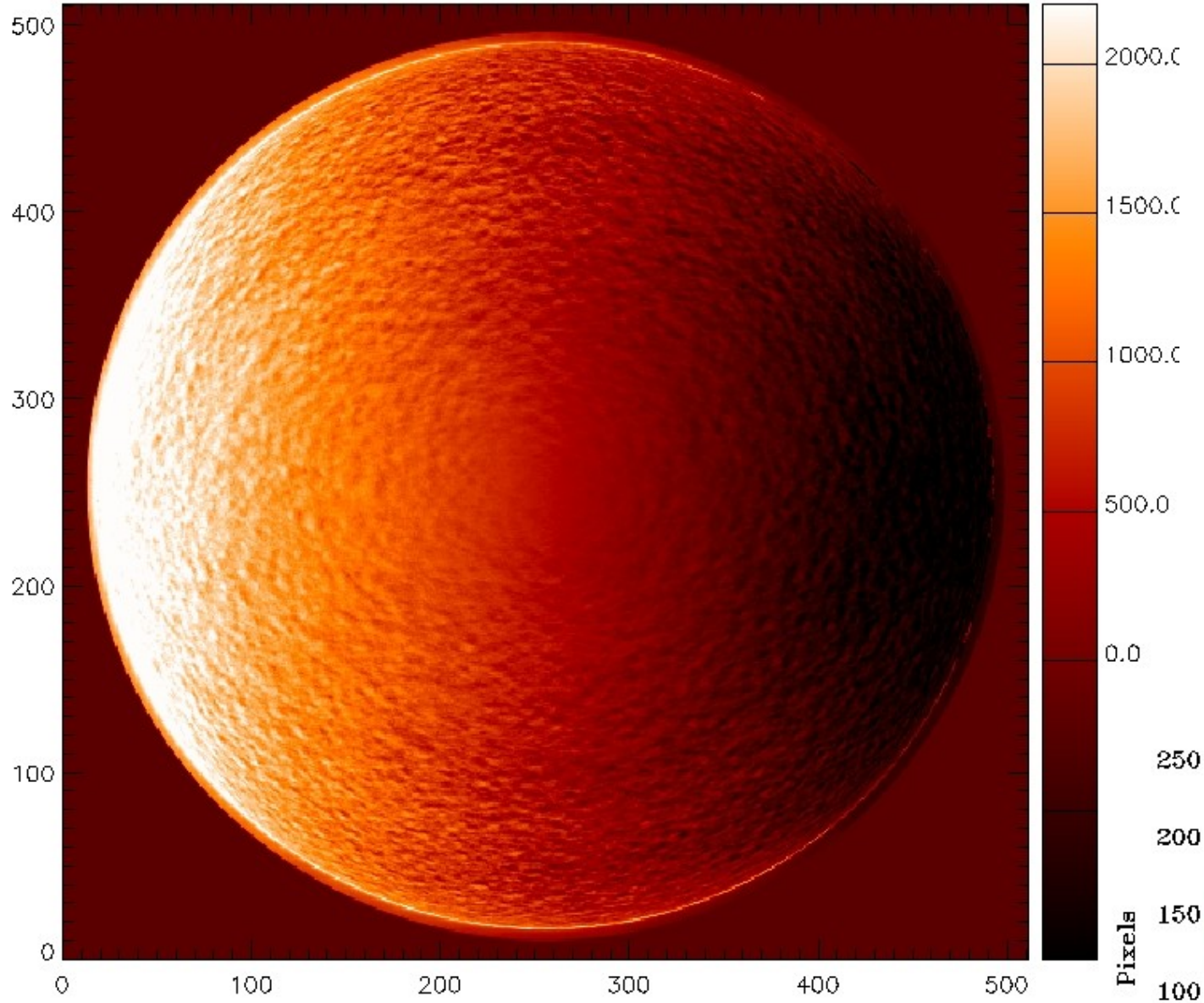


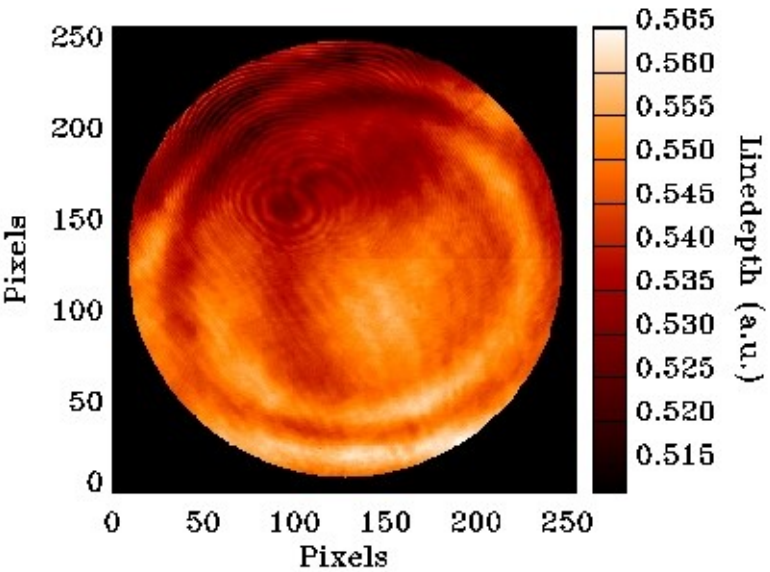
Another issue: solar line profile used for look-up tables is not appropriate in sunspots



Line profile for LCP and RCP polarizations obtained by the Advanced Stokes Polarimeter (ASP) in the umbra of a sunspot (from Norton et al., 2006).

Artifacts from Calmode: fringe pattern of the front window





Main issues in the Dopplergram calibration come from:
-incorrect Fe I line profile
-errors in calibration of the HMI wavelength dependence: overall good, but due to range of orbital velocities of SDO, even an uncertainty at the level of 1-2% creates significant issues in the observables

To Do:

- reduce the daily variation/dependence on OBS_VR by as much as possible
- use a least-squares fit of the Fe I line profile instead of MDI-like algorithm (requires appropriate line profile)
- get rid of the front window interference fringes

To Do ?:

- use just 1 look-up table for a specific co-tuning, or use several and linearly interpolate?