Progress on a Noise Amplitude Band-Rejection Filter for Spatial Heterodyne Spectroscopy

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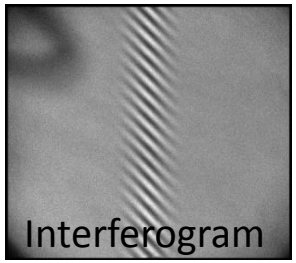
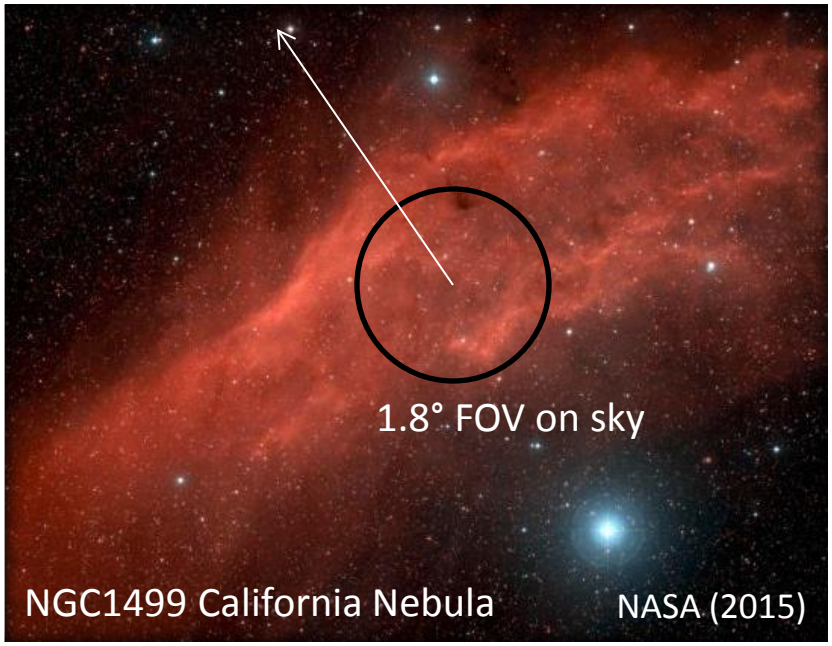
FW-SHS Interferogram



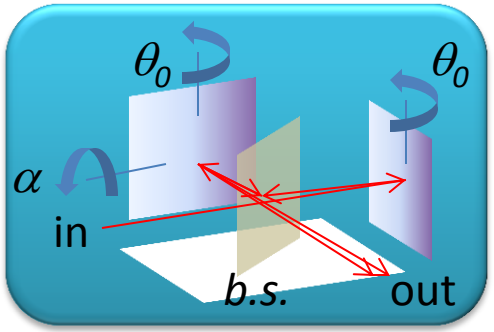
$$I(x,y)_{modulated} = \int A(x,y,\sigma)\, B(\sigma) \cos[2\pi(\sigma'\, 4\, tan(\theta_0)\, x + \sigma\alpha\, y)]d\sigma$$

σ_0, Littrow wavenumber
$\sigma' = (\sigma - \sigma_0)$, heterodyned wavenumber
A, line-shape envelope

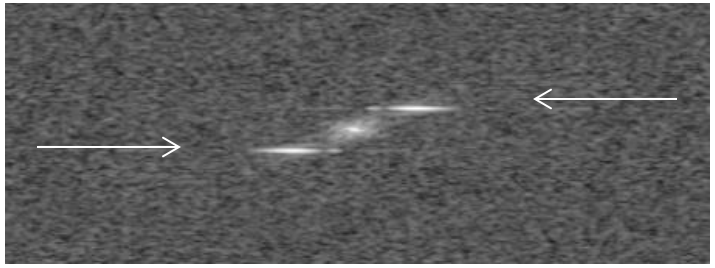
B, spectral density
θ_0, Gratings selected Littrow angle
α, Grating selected cross-tilt angle



Grating cross-tilt α rotates fringes, removes $\sigma \pm\sigma_0$ ambiguity (aliasing)

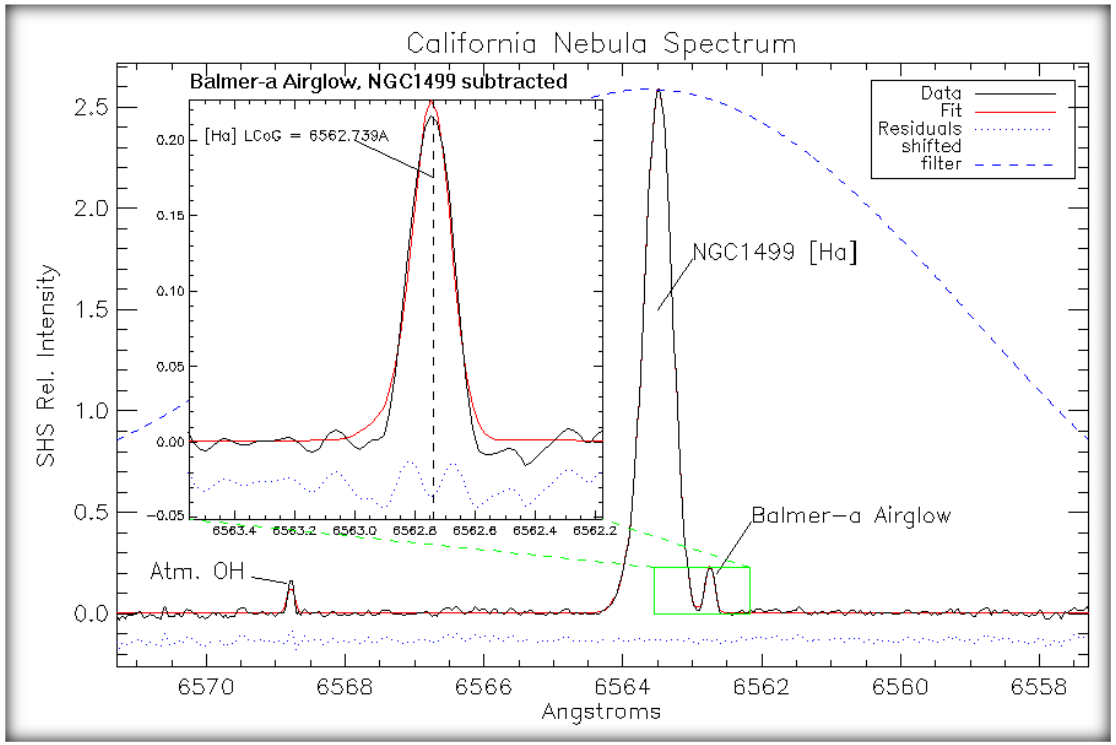


FW-SHS |A| Spectrum



Observation 02/22/14

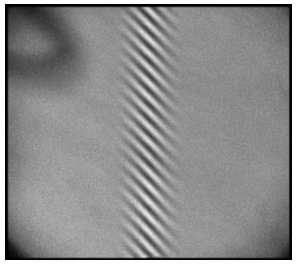
- **UTC time: 01:00**
- **Exposure length: 120 s**
- **VLSR: + 35 km/s**
- **Zenith distance: 14.3°**
- **Shadow altitude: 330 km**



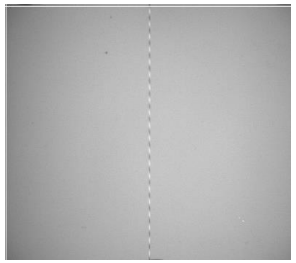
In addition to large Galactic Hα emission, the FW-SHS sees both Geocoronal Hα and mesopause OH airglow

Doppler-shift sensitivity, **100m/s**
Spectral Baseline, **~14 A** (640km/s)

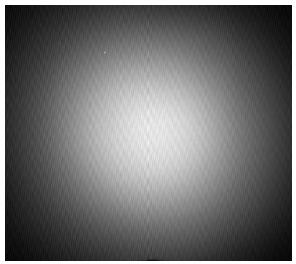
Motivation



Night sky



Continuum (WL)



Thorium Argon Lamp

- Night sky and calibration lamps illuminate our interferometric setup a bit differently
- Flat-fielding (FF) using lamps is challenging, and day sky is not always available

Goal

- Develop a Numerical Filter Correction
- Remove spurious interferogram artifacts, and artificially flat-field
- Compare to traditional Flat Field methods

Noise Amplitude Band-Rejection

- Isolate signal region in 2D FT
- Set noise amplitude threshold

- Remove signal above threshold
  (KEEP ALL THE NOISE)

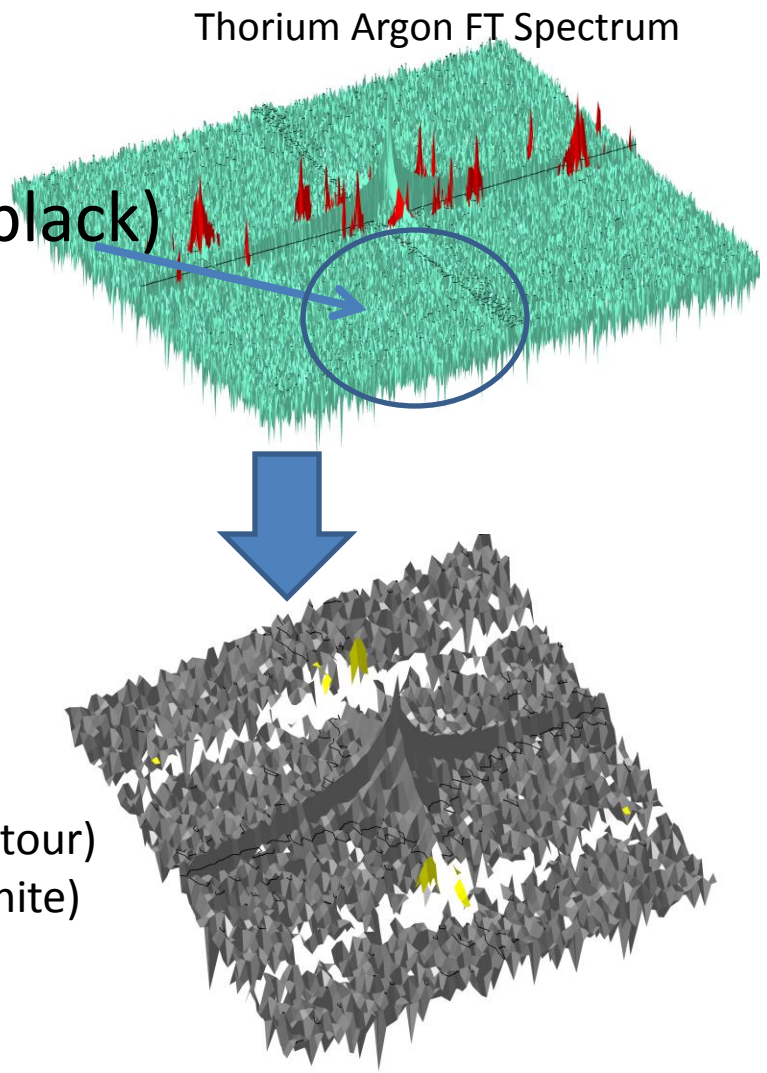
- Inverse transform the noise
- Subtract noise from original interferogram
- Forward transform to get cleaned spectrum

Noise Amplitude Band-Rejection

- Isolate signal region (Red peaks)
- Set noise amplitude threshold (black)

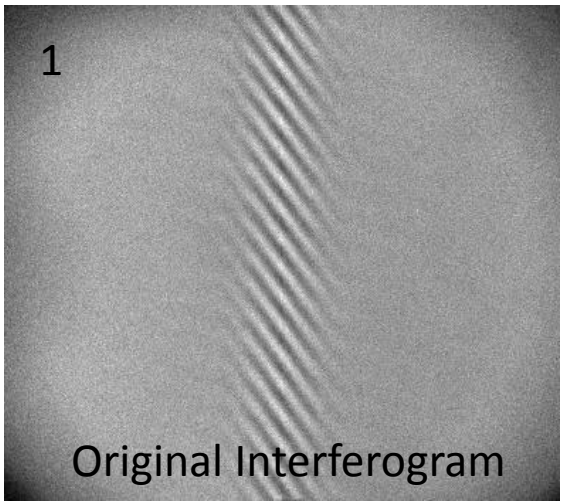
- Remove <u>signal</u> above threshold

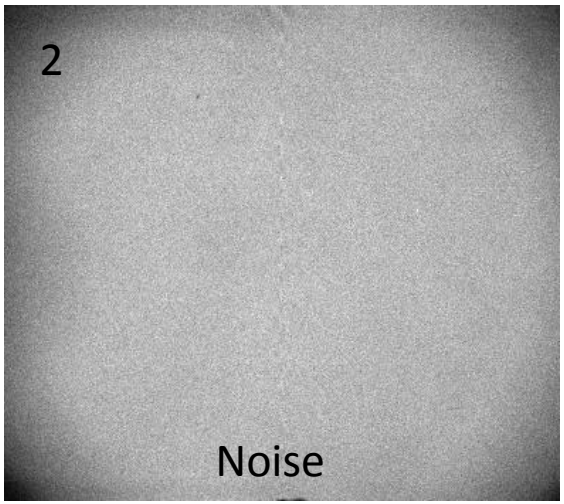
  (KEEP THE NOISE)

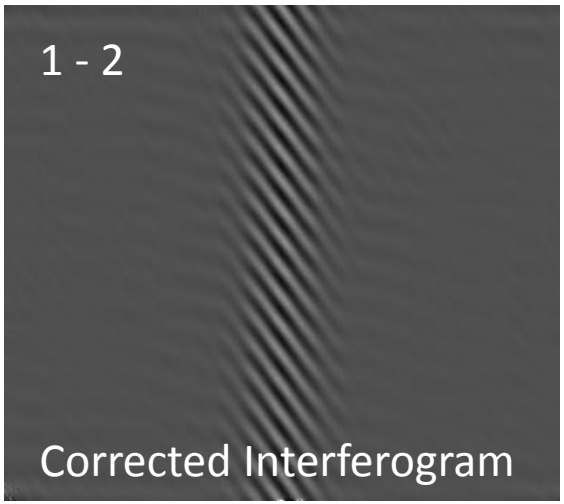


Fourier transform surface near zero spatial frequency: noise (gray) amplitude (black contour) used to isolate & remove emission signal (white) locally in FT domain. Yellow peaks indicate position of removed signal

Noise Amplitude Band-Rejection

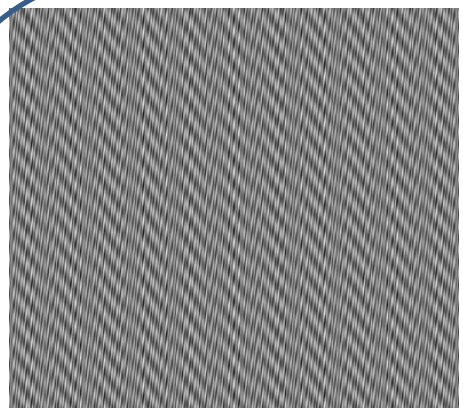




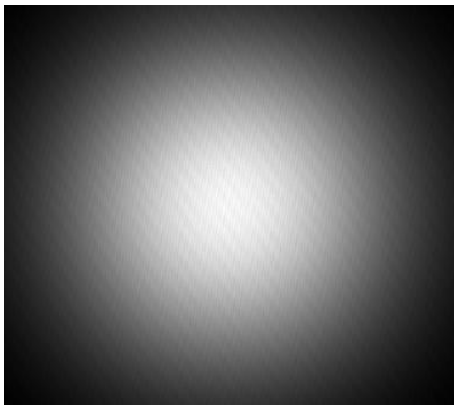


- Inverse transform the noise
- Subtract noise from original interferogram
- Forward transform to get cleaned spectrum

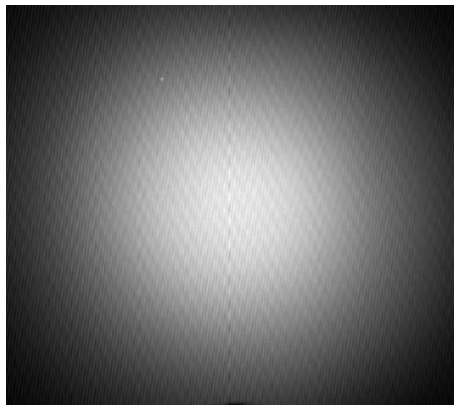
Thorium Argon: Model, REAL



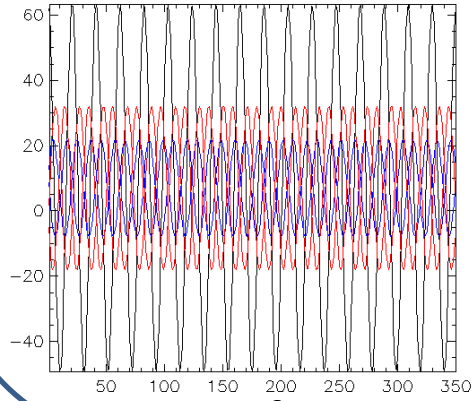
Clean Model

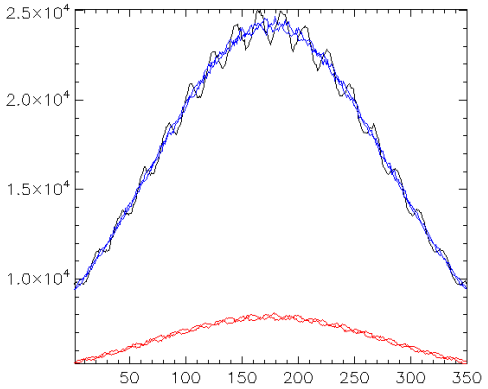


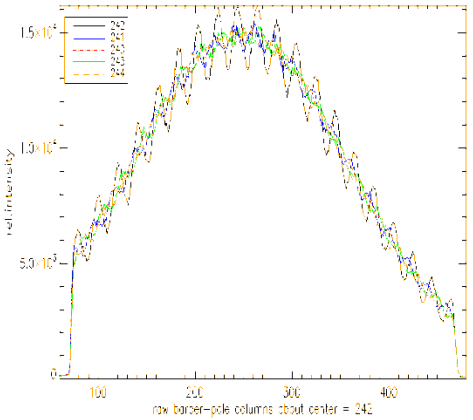
Degraded Model
+ Warping function
+ 3x random bias noise
+ heavy DC offset



... Very similar to real ThAr IFG

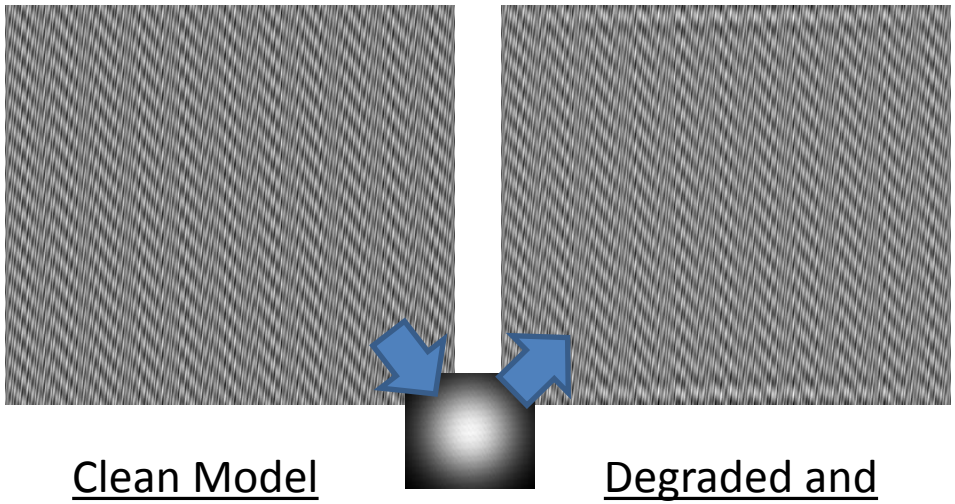






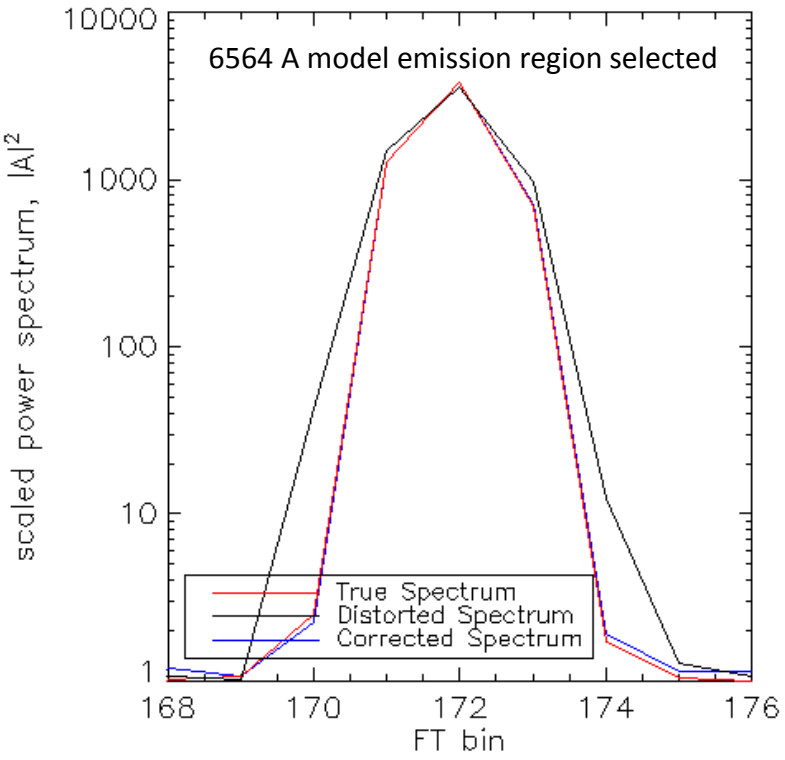
IFG fringe traces for comparison

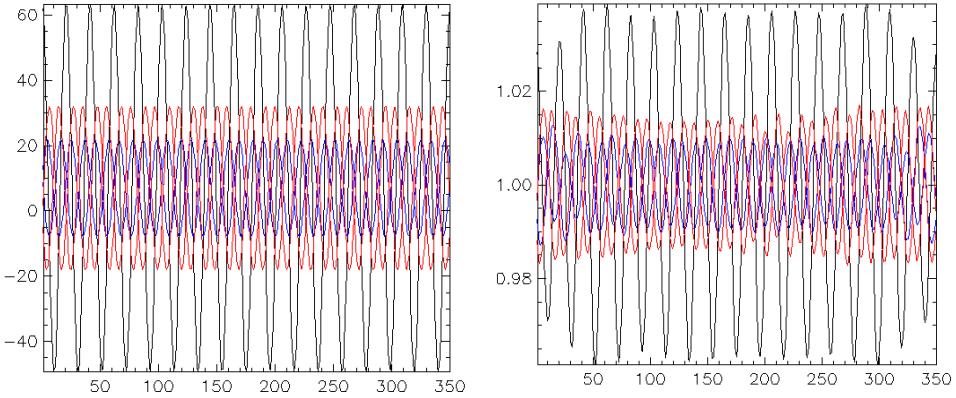
Model Thorium Argon Correction



Clean Model

Degraded and Noise Amp. Filter Corrected Model

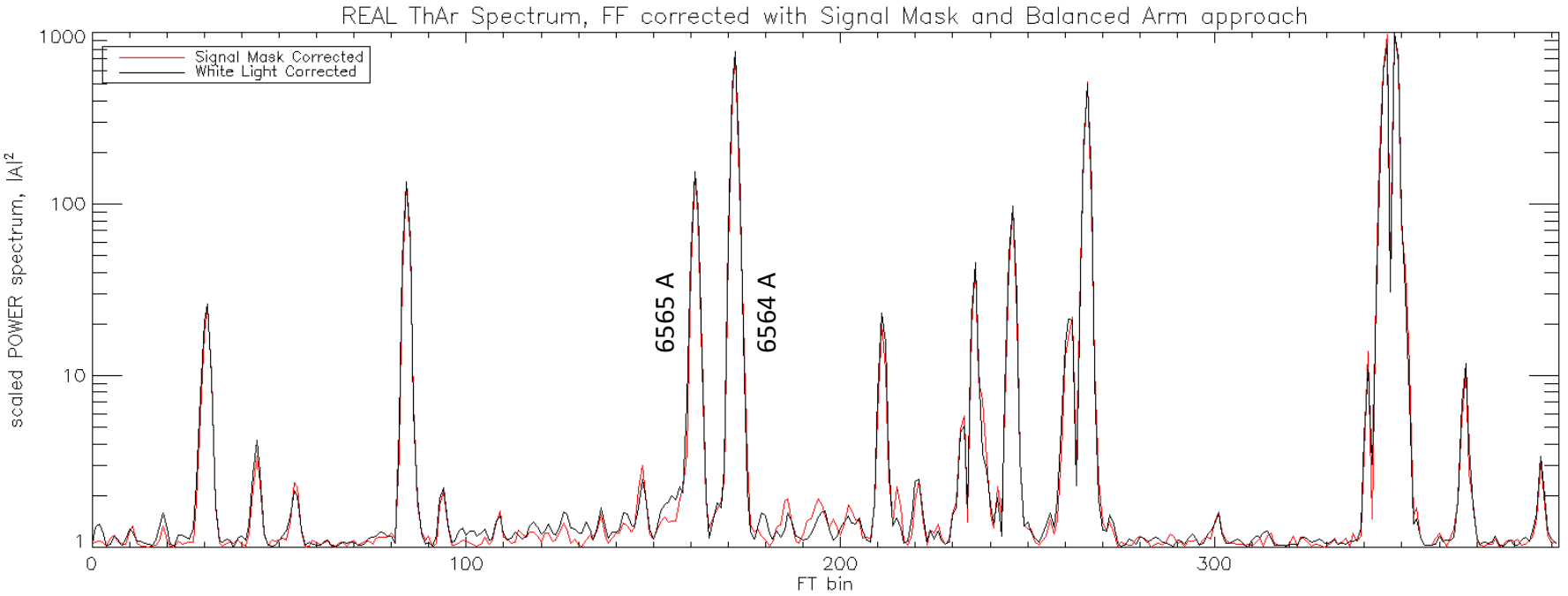




IFG fringe traces for comparison

Modulation efficiency is slightly affected in the recovered fringes, and the corrected Fourier transformed line shape very nearly reproduces the clean model line shape across four decades of power.

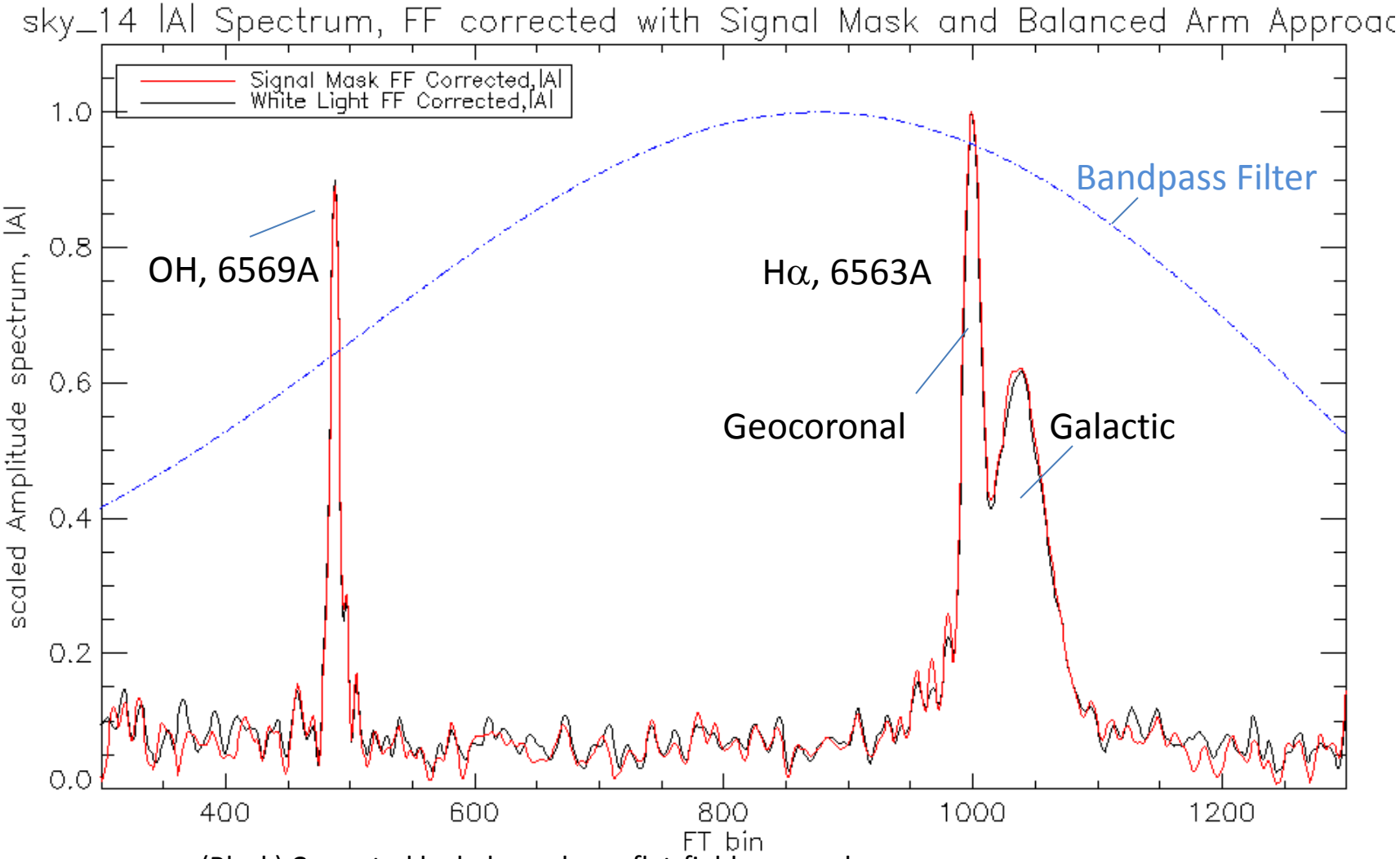
Real Thorium Argon FF Corrections



(Black) Corrected by balanced arm flat-field approach
(Red) Corrected using Noise Amplitude Band-Rejection approach

Spectral resolution is ***slightly*** increased, as model correction results suggested
(Red is narrower than black)

Real Night Sky FF Corrections



(Black) Corrected by balanced arm flat-field approach
(Red) Corrected using Noise Amplitude Band-Rejection approach

Ok... arguably not much better....

Conclusions: FT artwork in progress...

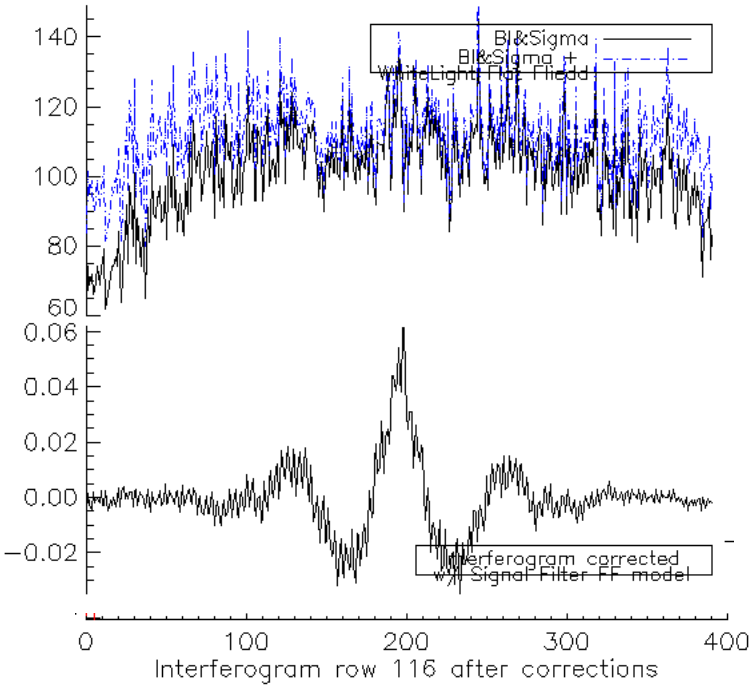
Artificial “flat-field” achieved numerically (no calibration lamps)

Removes: DC-term contamination, cable shadows, speckle noise

Slightly improves unresolved emission line-profile accuracy

For resolved emission, no apparent difference between these two FF correction approaches (WL-Balanced Arm, vs Noise Amp. Filter)

Night Sky Interferogram Row Cuts



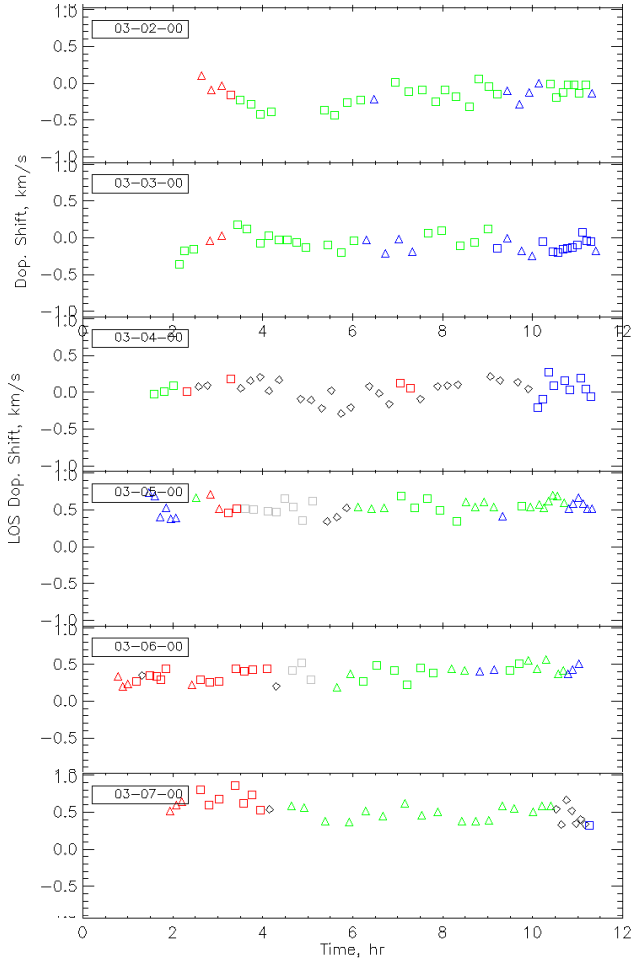
Black: Original interferogram row

Blue: Traditional Flat-field corrected, using “balanced-arm approach” with White Light continuum source

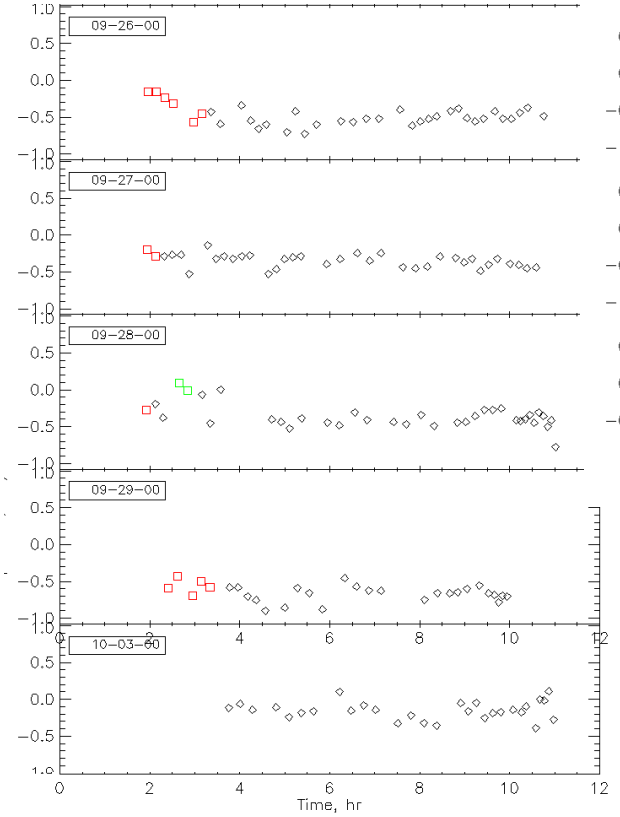
Black: Noise Amplitude Filter corrected

LOS Doppler-shifts in the Geocorona by Fabry Perot

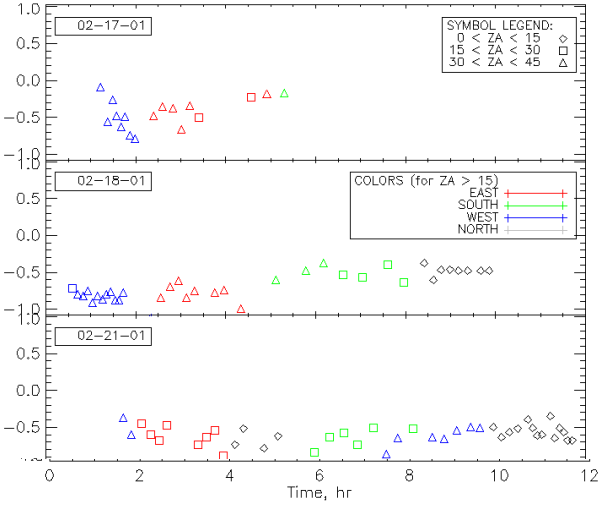
March, 2000

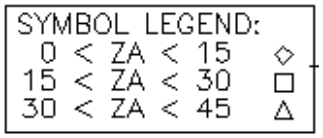


Late Sept, 2000



Feb, 2001



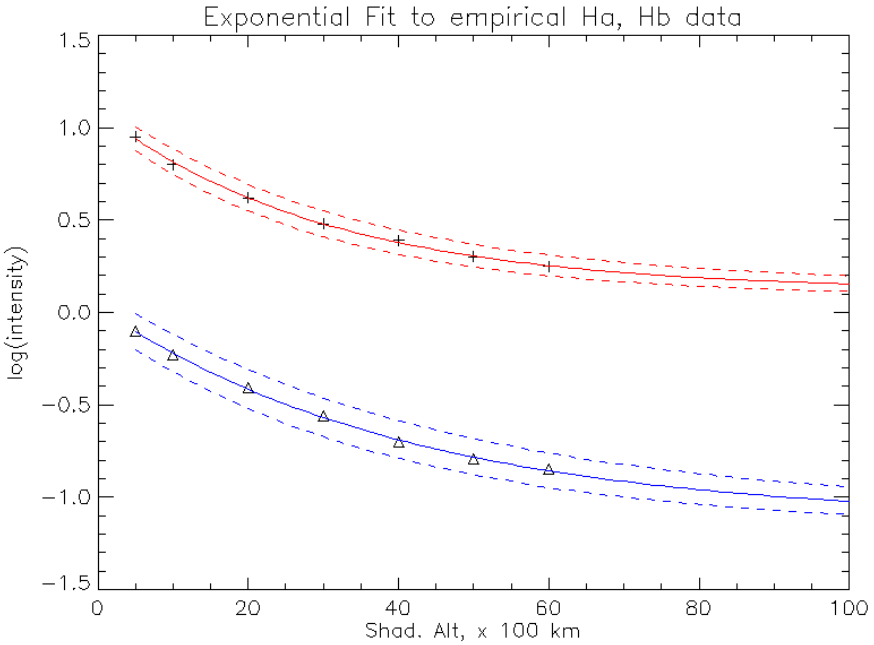


Preliminary results...

Night variations on order of 300 m/s

Possible seasonal variations as well?

Geocoronal Cascade Excitation Constraints From Hα & Hβ



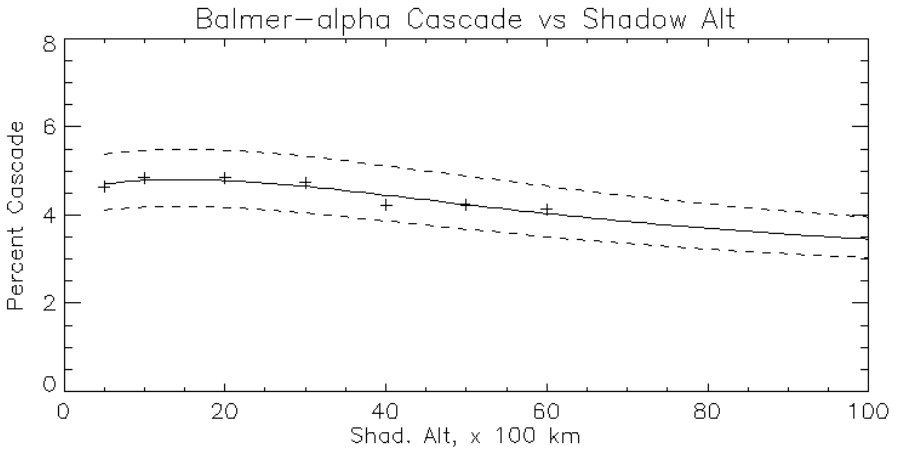
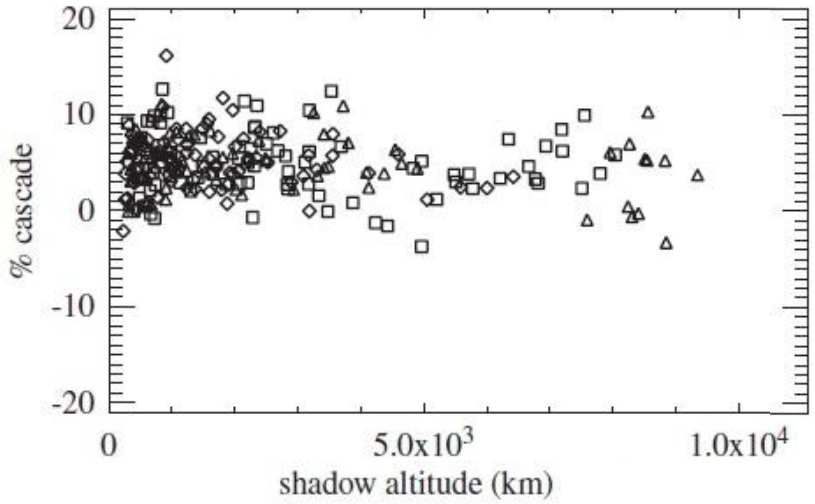


Figure 1:
Average WHAM observations of Hα & Hβ intensity, log(R) vs shadow altitude, (km). Over plotted are the (solid) exponential fits and (dashed) 1σ fit parameter error bands

Figure 2:
Hβ/Hα derived cascade function (see Roesler, 2014), and associated 1σ fit parameter error bands. Over plotted (plus symbols) are the unique values from the seven intensity ratios in Fig. 1 used for determination.



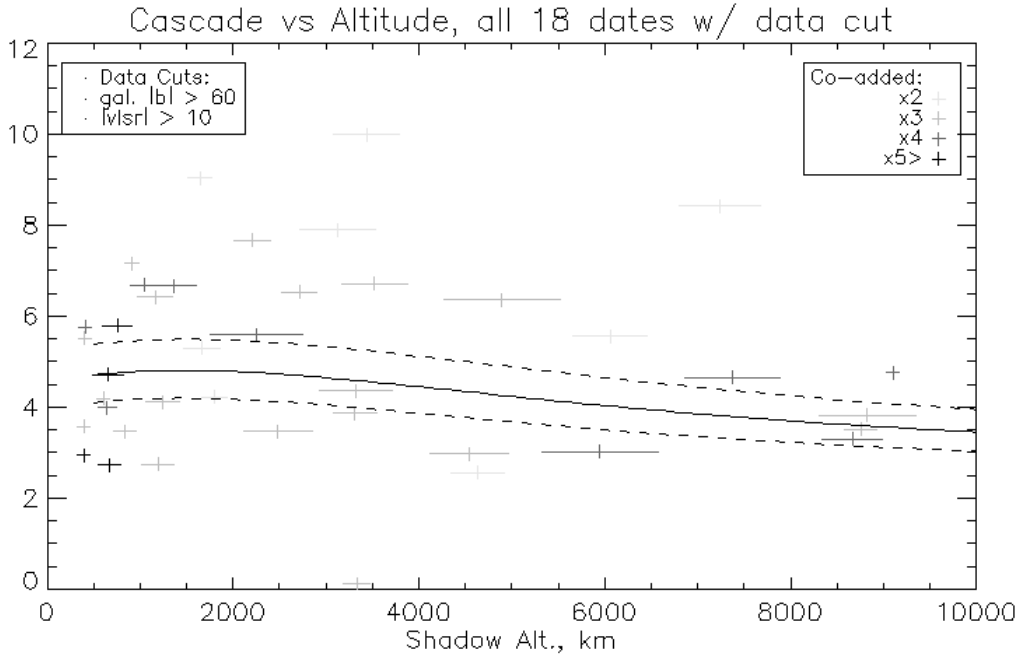


Figure 1:
Cascade contribution vs shadow altitude, as determined from individual FP geocoronal Hα line profile observations [Mierkiewicz at al., 2006]. Only observations towards regions of low galactic Hα background are plotted.

Figure 2:
(plus symbols) Cascade contribution, as determined from co-added and refit FP geocoronal Hα line profile observations (shown in Fig. 1). Darker colors indicate higher SNR by co-addition. Width indicates range of shadow altitudes co-added. Over plotted is the predicted cascade behavior (& error) as determined by WHAM Hα and Hβ observations