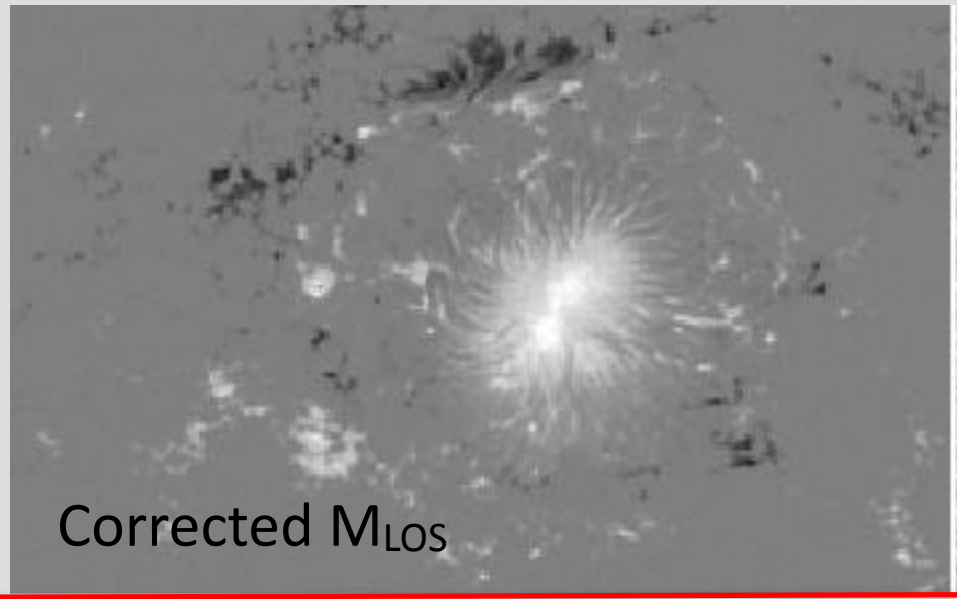
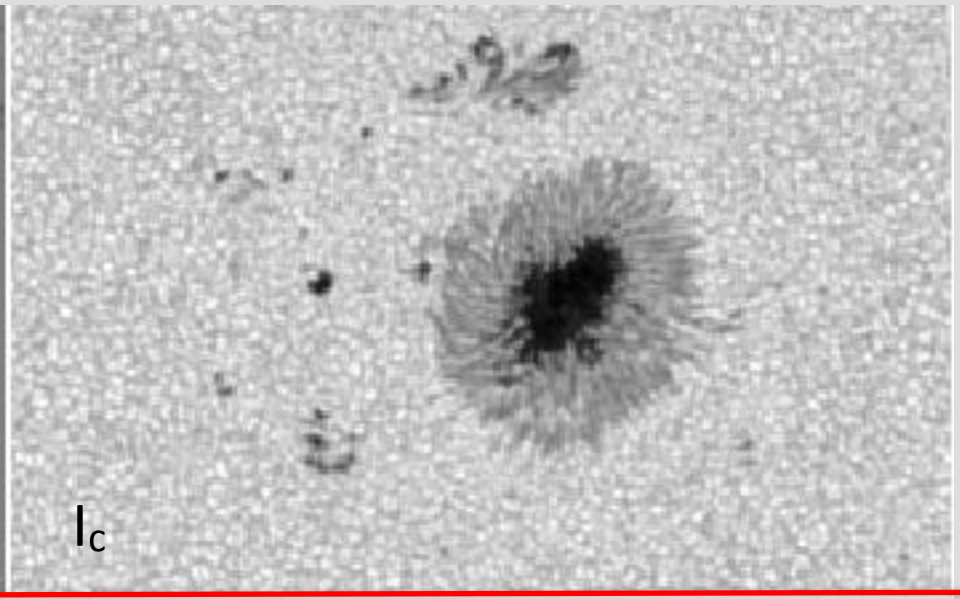
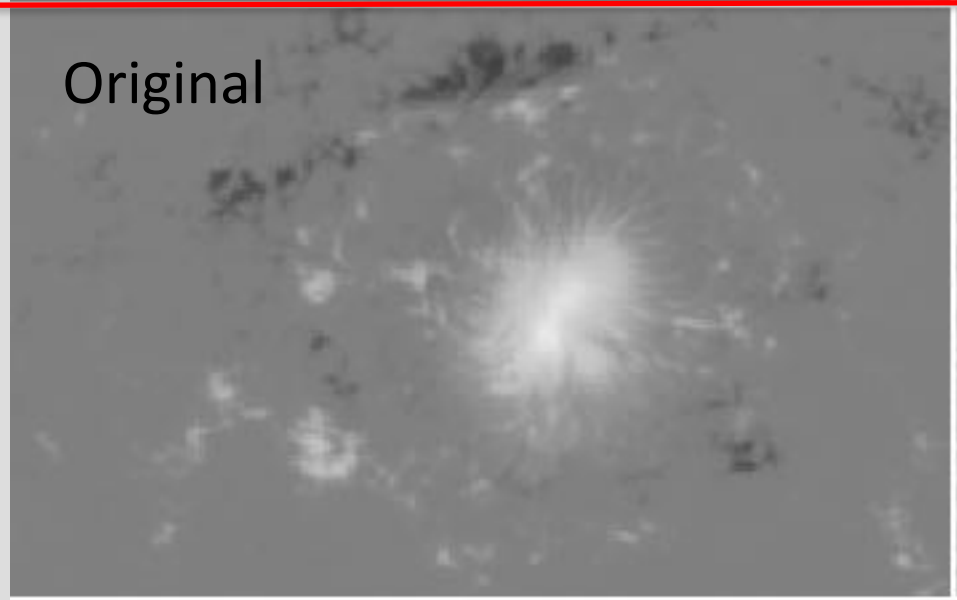
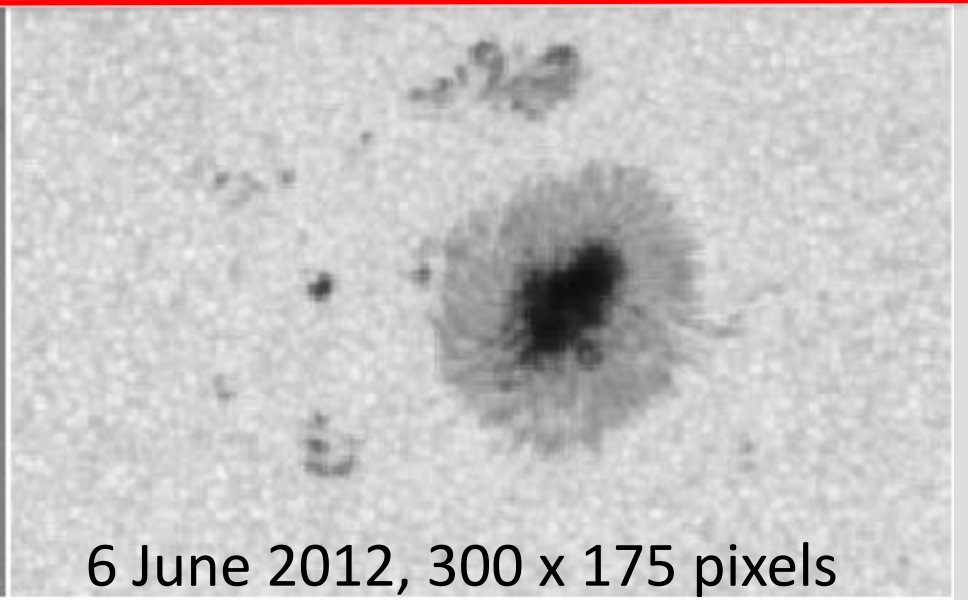
Available: HMI Data Corrected for Stray Light

A. Norton, T. Duvall, J. Schou, M.C.M. Cheung, P.H. Scherrer, K.C. Chu, J. Sommers

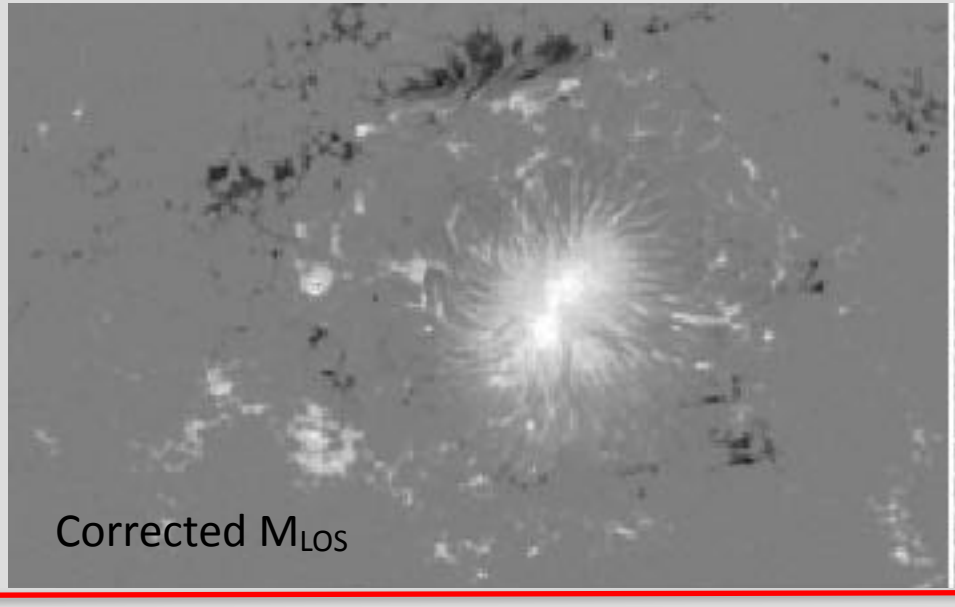


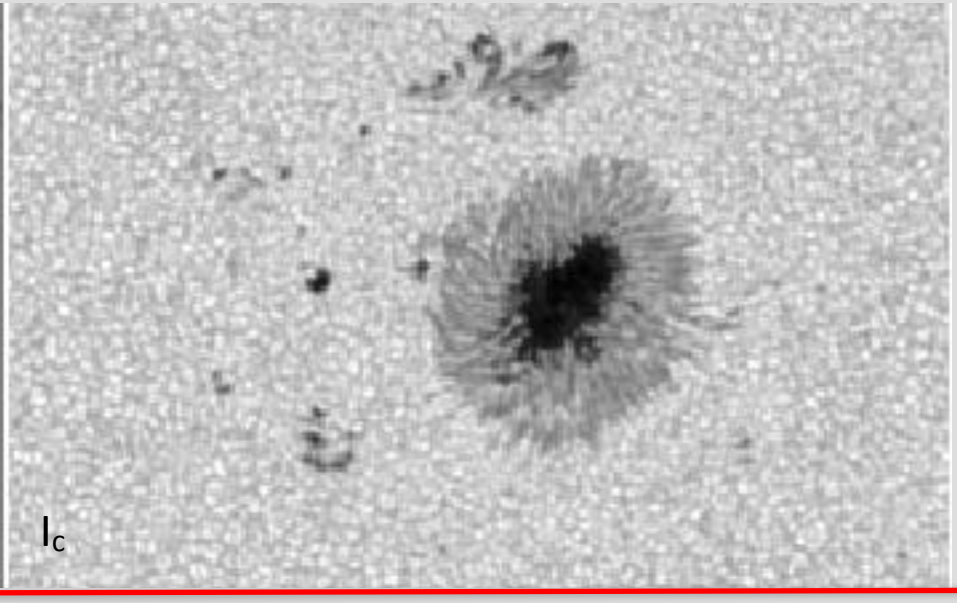






Data with '*_dcon*' or '*_dconS*' in JSOC

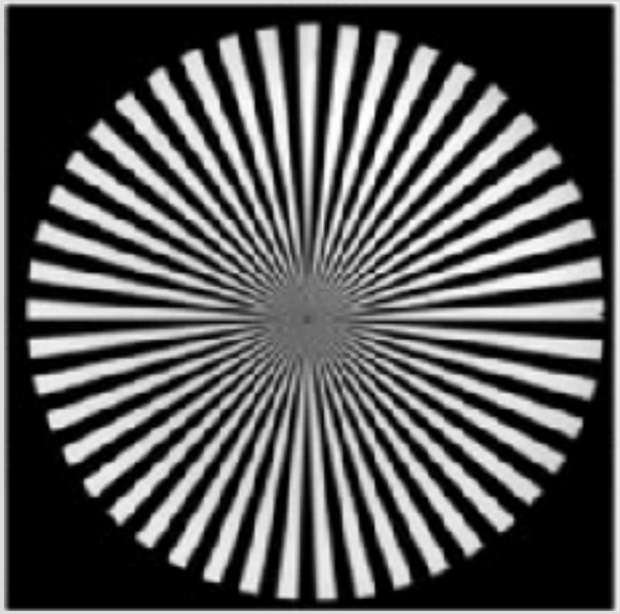


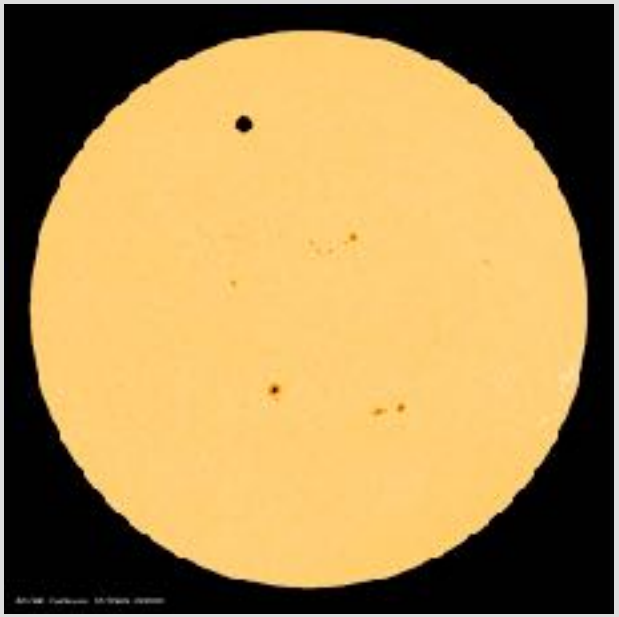


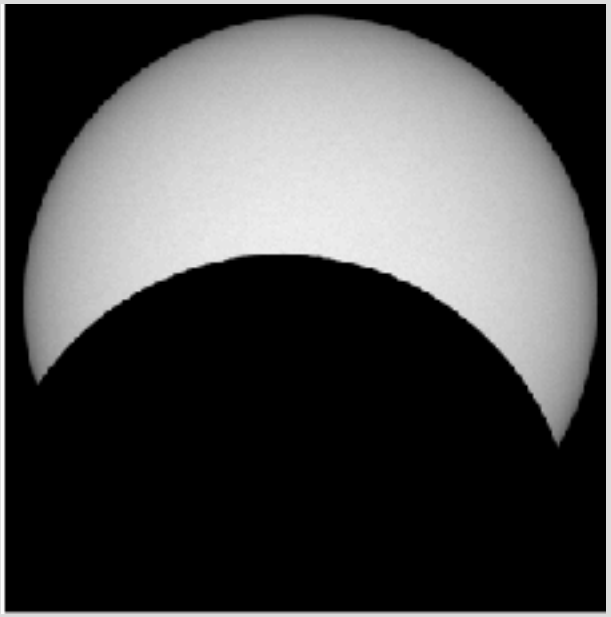
Advantages: Only 3 free parameters in the PSF, produces full-disk data, fast.

Improved B field values in pores and plage,
Better co-alignment with hi-res data (IRIS, CRISP, etc)
Improve Ic and B contrast used for irradiance modeling,
Decrease tracking errors.

Data used for development of PSF







Pre-launch observations

(star target, compare known spatial power spectra with observed)

Venus Transit

(1.8% light level in center of Venus, r_{Venus}~58 pix / 29.5")

Lunar Occultation

(0.34% light level 200 pix/ 100" from Sun or 1% light level 10" off limb)

PSF Development: Mathematical Form

PSF: Airy (Bessel) convolved with Lorentzian (in r, spatial dimension)

$$\mathrm{PSF}_{\mathrm{ideal}}(r) = \left(\frac{2J_1(r')}{r'}\right)^2 \quad \text{where } r' = \frac{\pi P D}{f\lambda} r$$

OTF: Chat function (ideal OTF) × exponential (in frequency space)

$$\mathrm{OTF}(\rho) = \mathrm{OTF}_{\mathrm{ideal}}(\rho)\exp\left(-\pi\rho'\gamma\right),$$

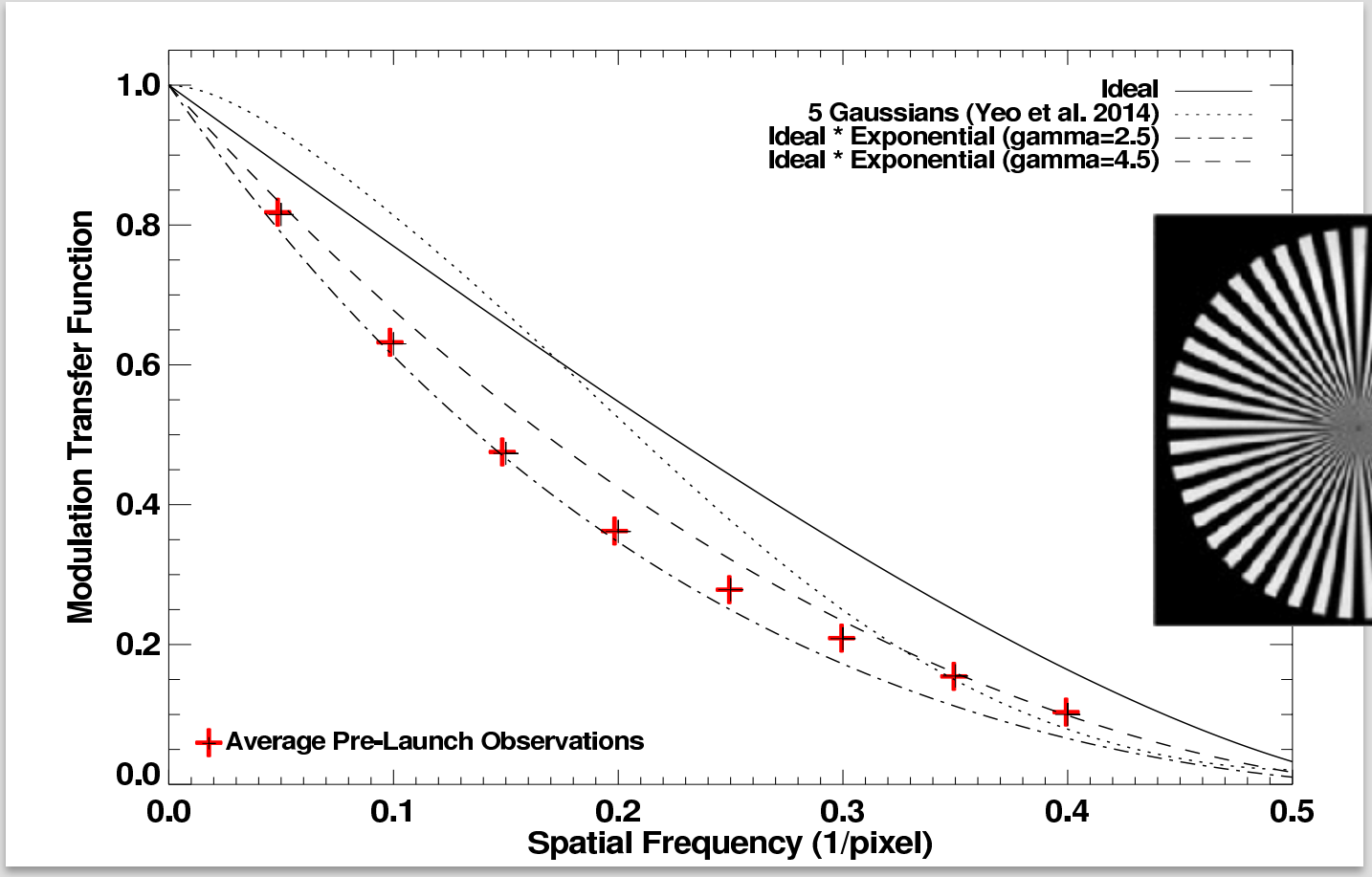
$$\mathrm{PSF}(r) = \mathscr{F}(\mathrm{OTF}) + c\exp\left(\frac{-\pi r}{\xi r_{\max}}\right)$$

Only 3 free parameters.

PSF=point spread function,
OTF=optical transfer function
MTF=|OTF|= modulation transfer function

= free parameters

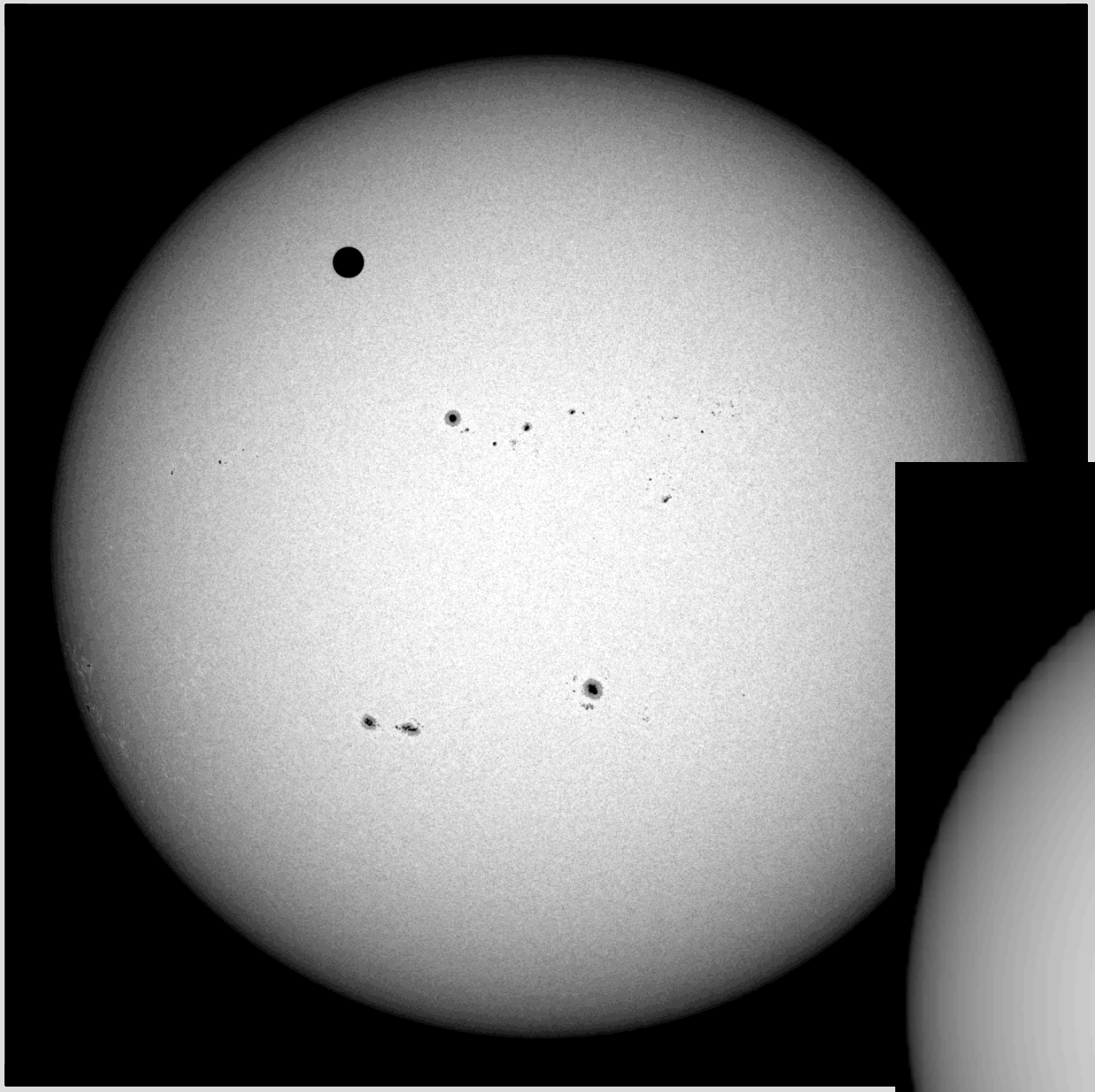
PSF Development: Pre-launch observations



Ideal MTF shown with 2 “guess” MTFs of ideal MTF x simple exponential.

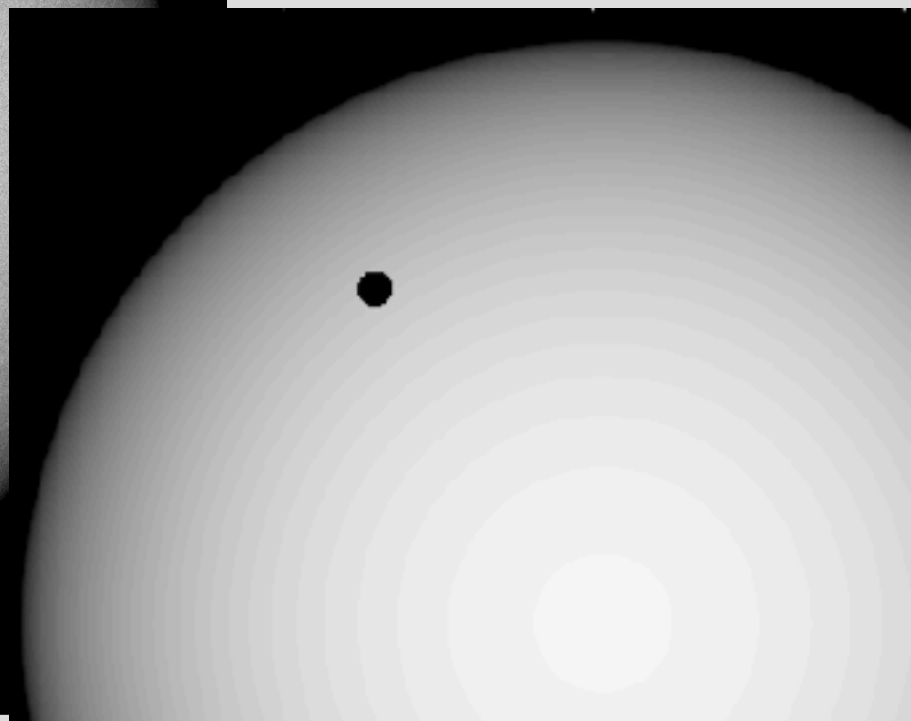
+ are the average of three curves reported from the ground-based testing.

PSF Development: Transit of Venus

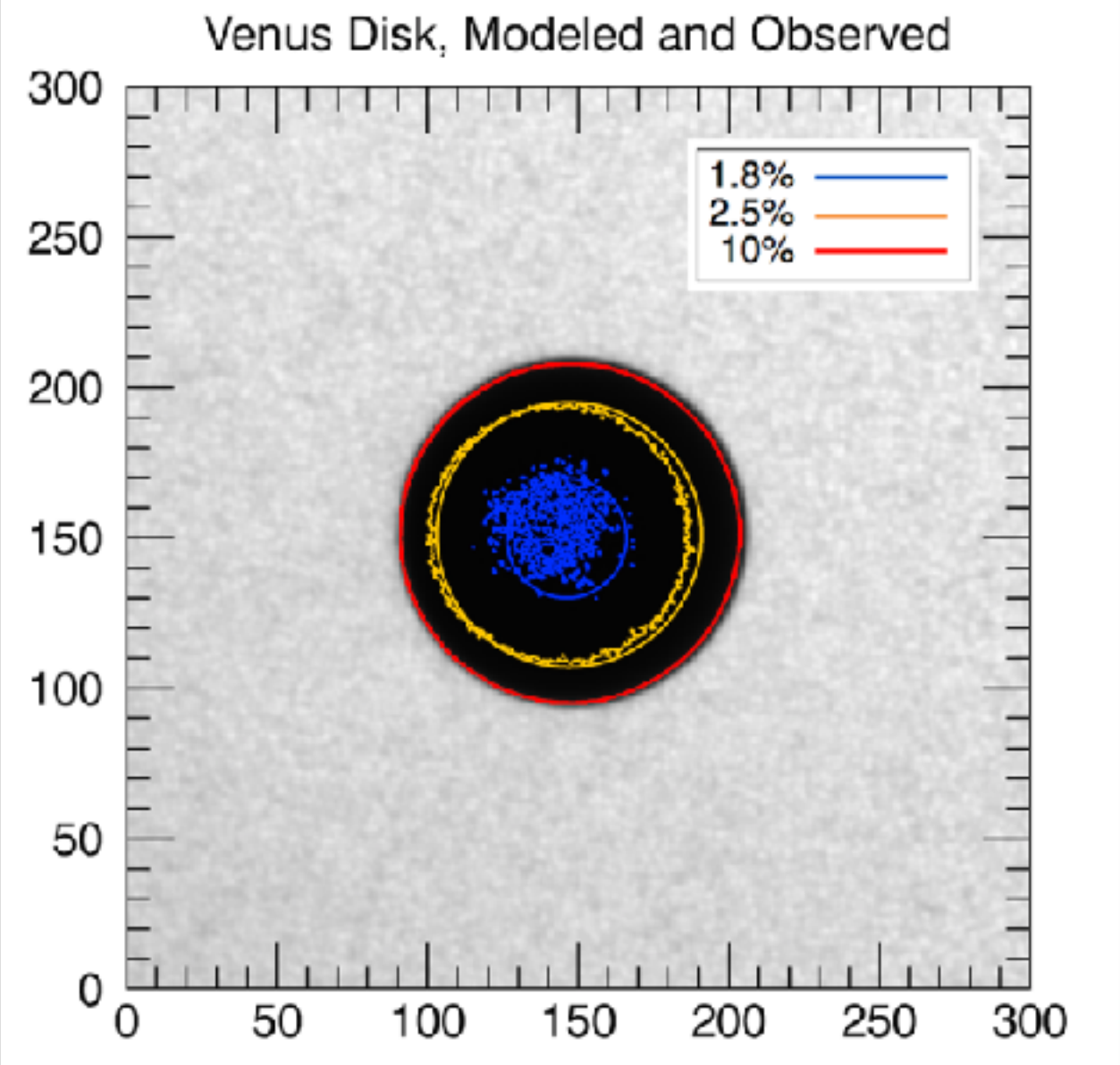


Forward Model

Use a guess PSF.
Convolve with mock solar image with limb-darkening and a disk of Venus filled with zeros.



PSF Development: Transit of Venus

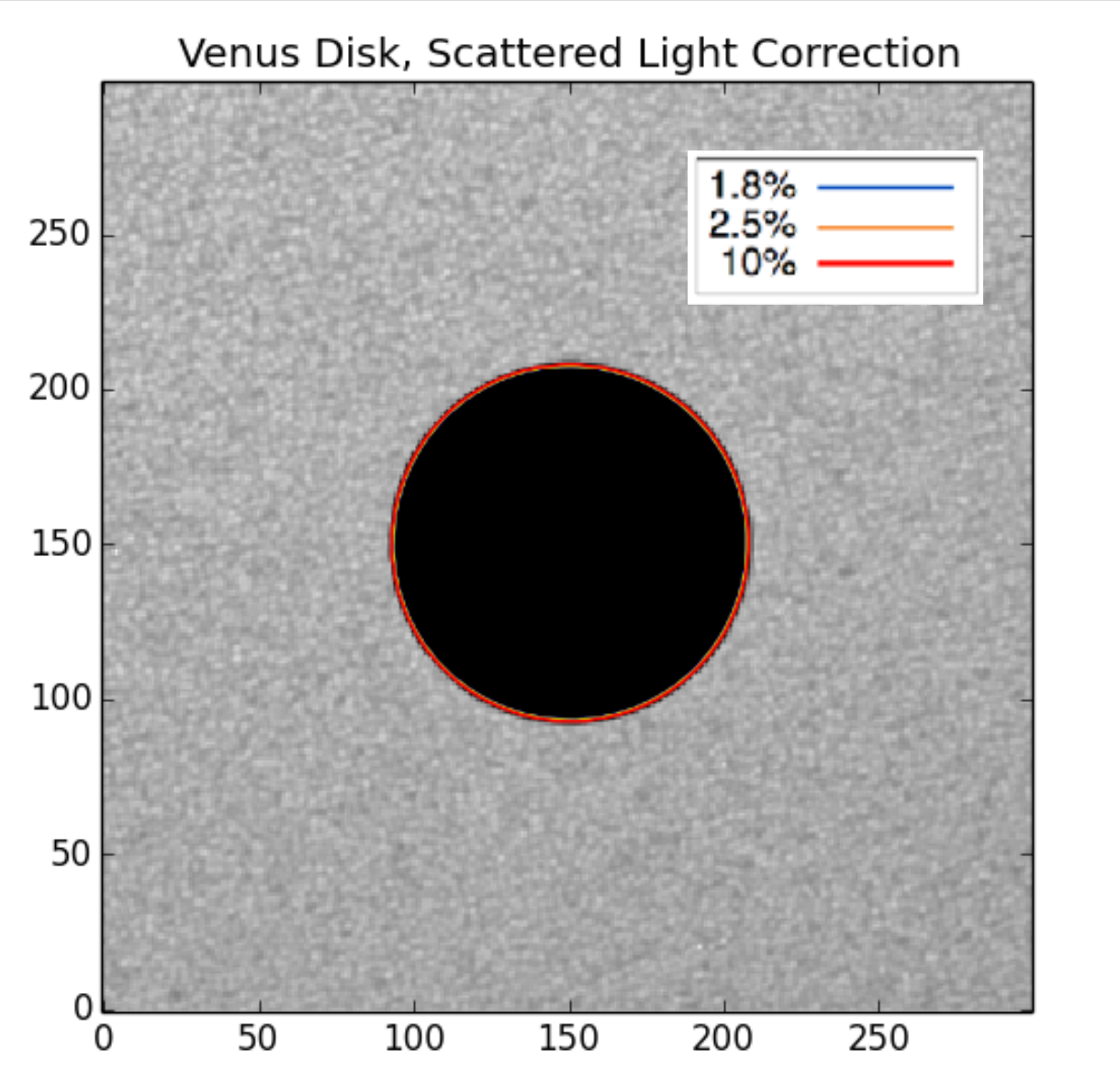


Forward Model

Compare scattered light, both the modeled (straight contours) and observed (squiggly lines), in disk of Venus.

Note azimuthal dependence /asymmetry. We do not include an azimuthal dependency.

PSF Development: Transit of Venus



Deconvolution

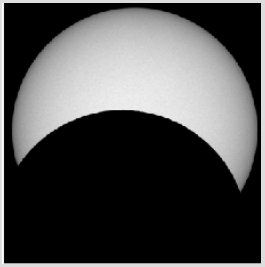
Select parameters of best fit to create full-disk PSF.

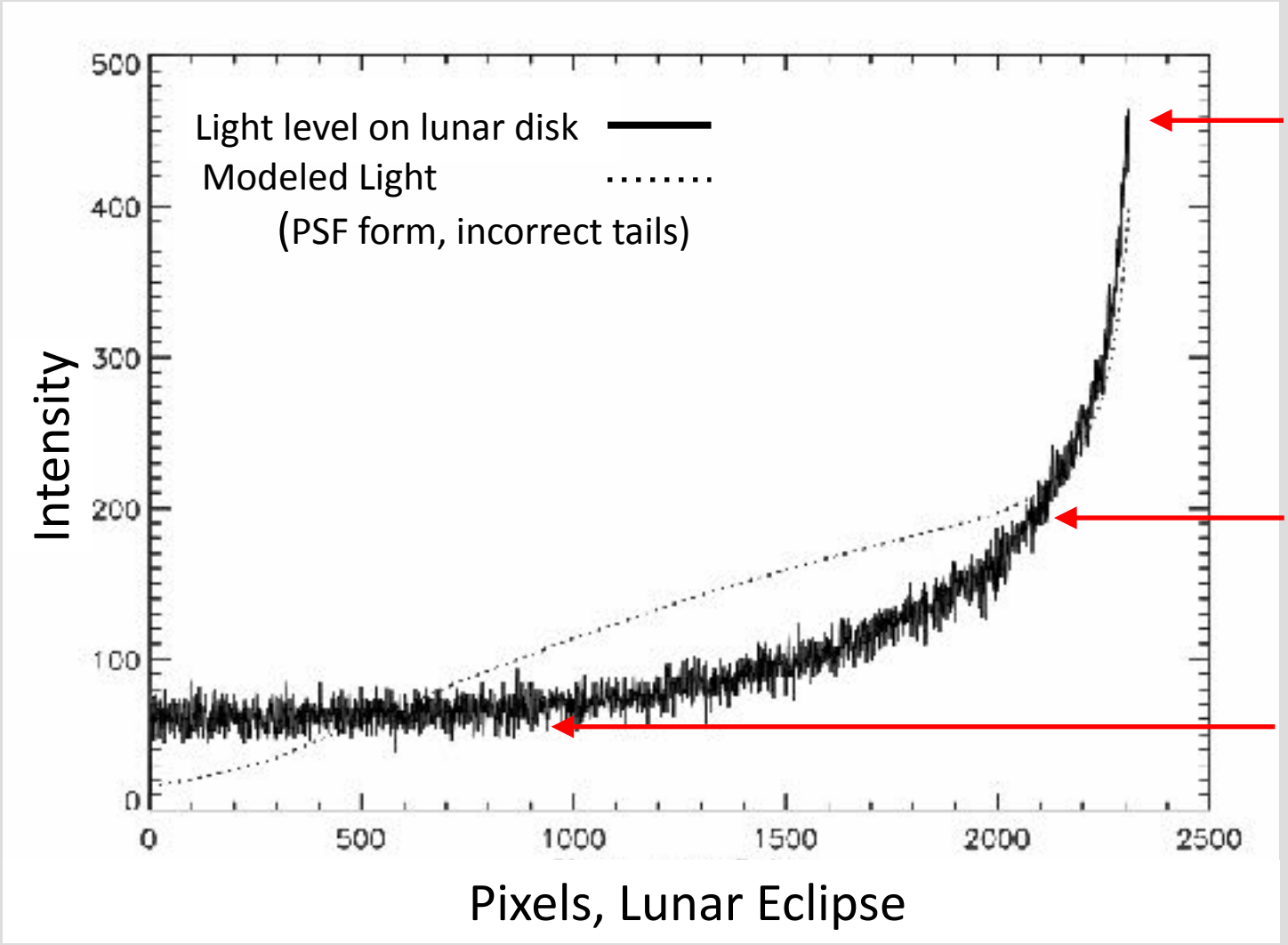
Use Richardson Lucy deconvolution algorithm.

No more stray light.

"Just give him whatever he wants! He's threatening to divide by zero!"

PSF Development: Lunar Occultation





1% light level
10″ off limb

0.3% light level
100″ from limb

0.1% light level
700″ from limb

Far away from the solar limb, light level became a constant.
Venus disk is too small to measure the long-distance scattering.

PSF: Application to Data, Code in JSOC

Table 1. Names of Upgraded Data Products

Original	PSF Corrected
45-second cadence data	
hmi.Ic_45s	hmi.Ic_45s_dcon
hmi.M_45s	hmi.M_45s_dcon
hmi.V_45s	hmi.V_45s_dcon
hmi.Ld_45s	hmi.Ld_45s_dcon
hmi.Lw_45s	hmi.Lw_45s_dcon
720-second cadence data	
hmi.Ic_720s	hmi.Ic_720s_dconS
hmi.M_720s	hmi.M_720s_dconS
hmi.V_720s	hmi.V_720s_dconS
hmi.Lw_720s	hmi.Lw_720s_dconS
hmi.Ld_720s	hmi.Ld_720s_dconS
hmi.B_720s	hmi.B_720s_dconS (multiple segments)
True continuum	(tuned 0.345 Å from line center)
hmi.lev1 [FID=10001]	hmi.cont_dcon

"_dcon"

deconvolution applied to filtergrams taken every 3.75 seconds then combined for 45-second data products

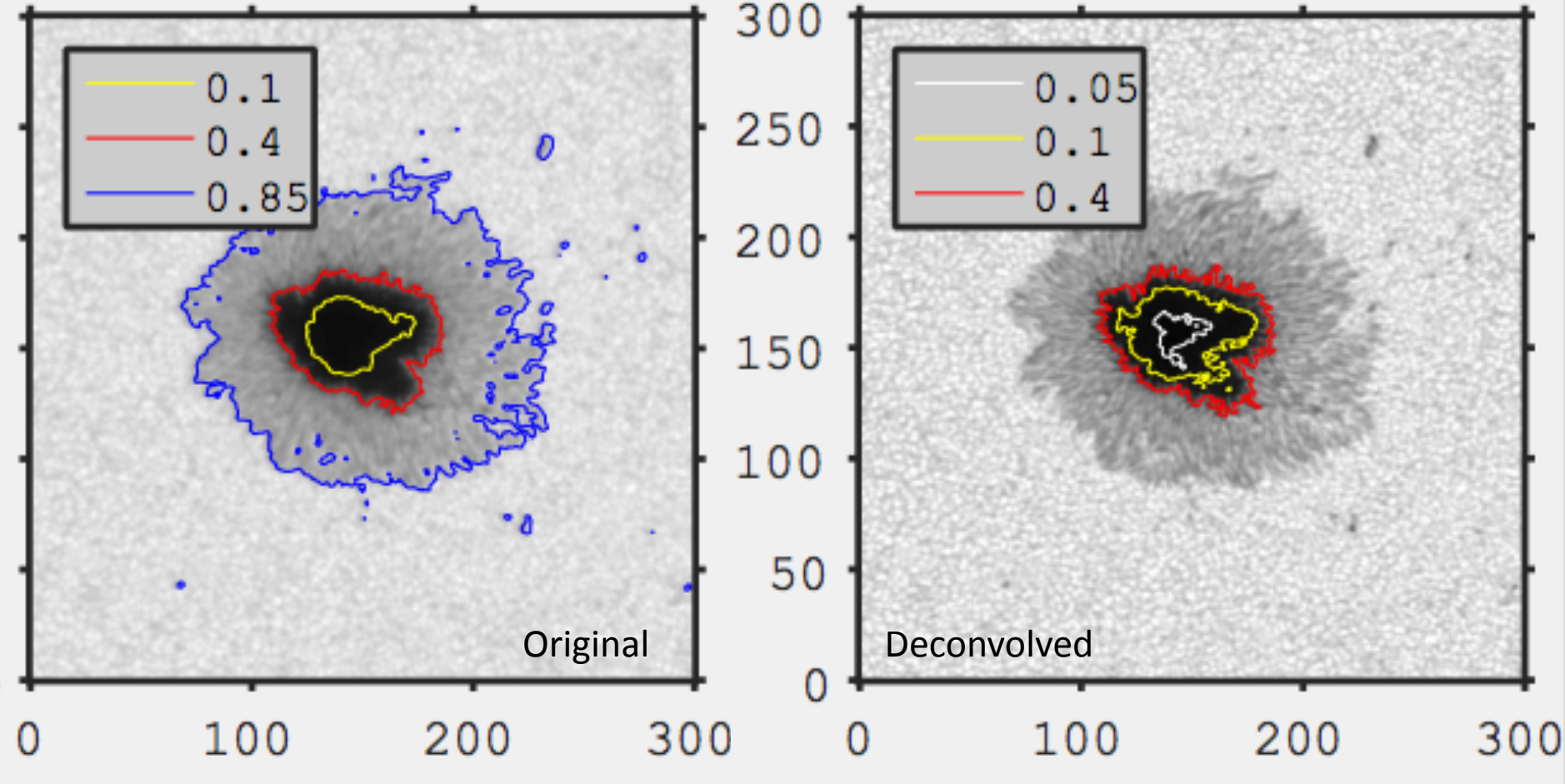
"_dconS"

deconvolution applied to averaged Stokes data then combined / inverted for 720-second data products

Runtime < 1 sec per full disk image

Daily @ 19:00, 19:24

Changes in Science Data: Umbrae



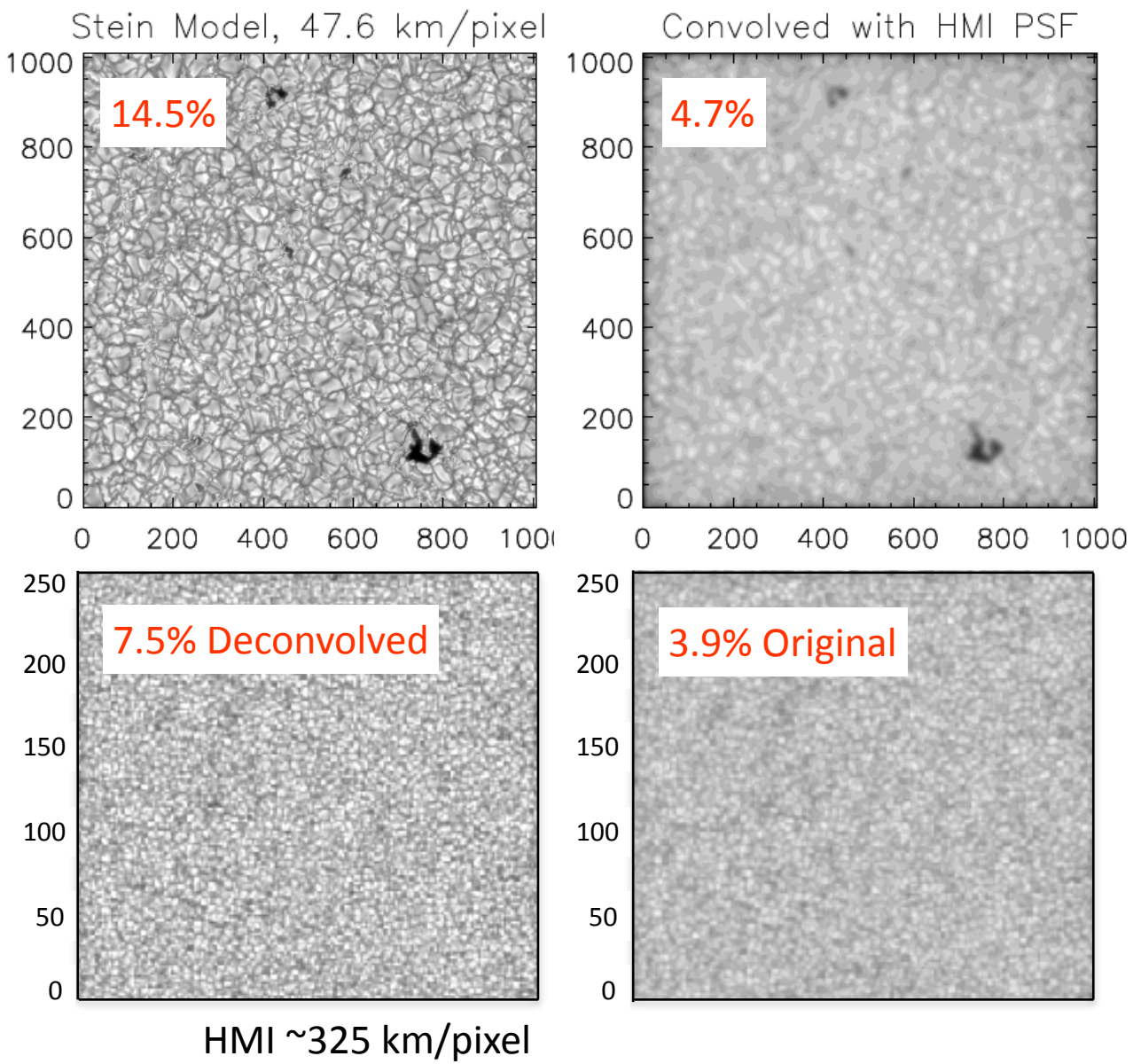
AR 11899 from 2013.11.18

Umbral core I_c(sunspot)/I_c(quiet-Sun) changes from 5.5 to 3.3%

Corresponding to T change of 3370 (original) to 3140 K (corrected).

Expected umbral temp ~2800-3200K (MURAM). How cool do umbrae get?

Changes in Science Data: Granulation

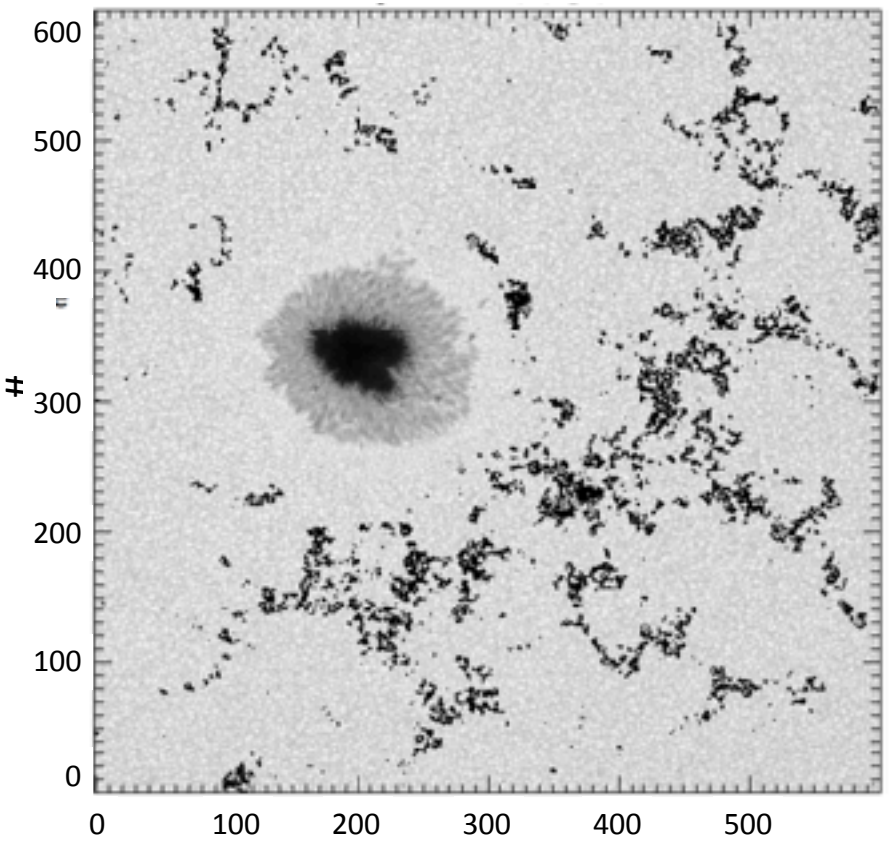


Snapshot of 6173 Fe I
MHD Simulations
1008 x 1008, 47.6 km/pixel

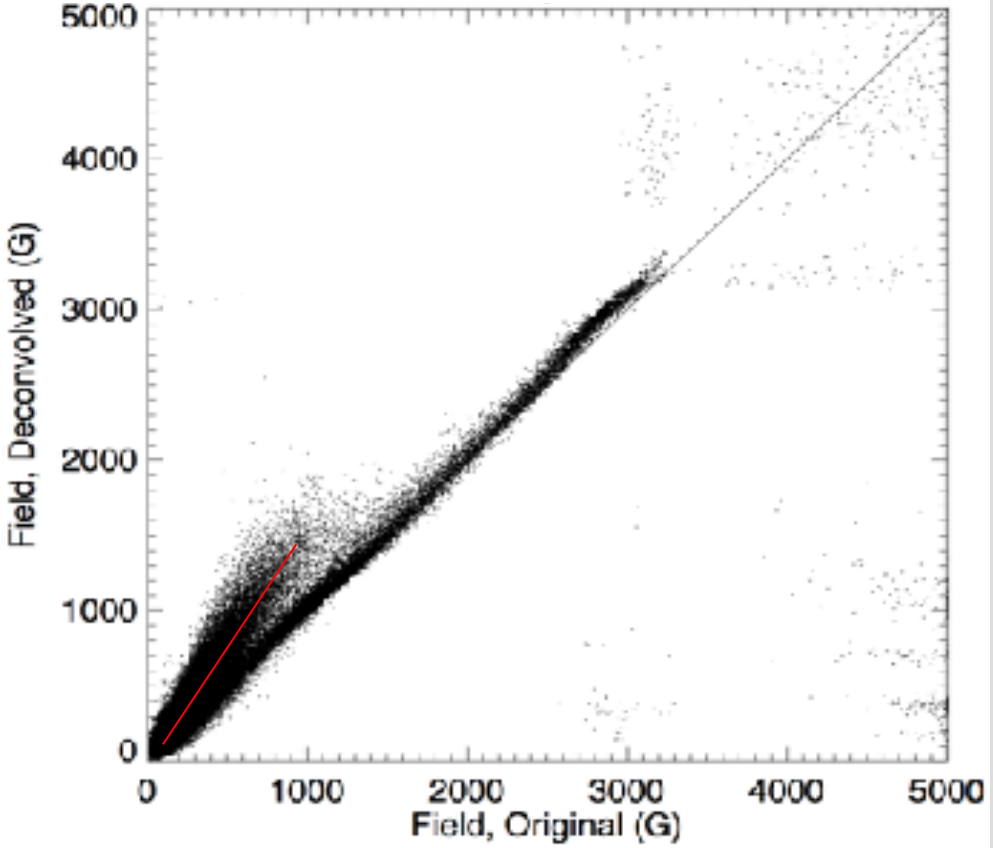
Disk Center HMI Data
Contrast is ~doubled but
varies across the disk
Area shown for HMI
~2X that of simulation

Changes in Science Data: Plage Field

Plage Location in Intensity

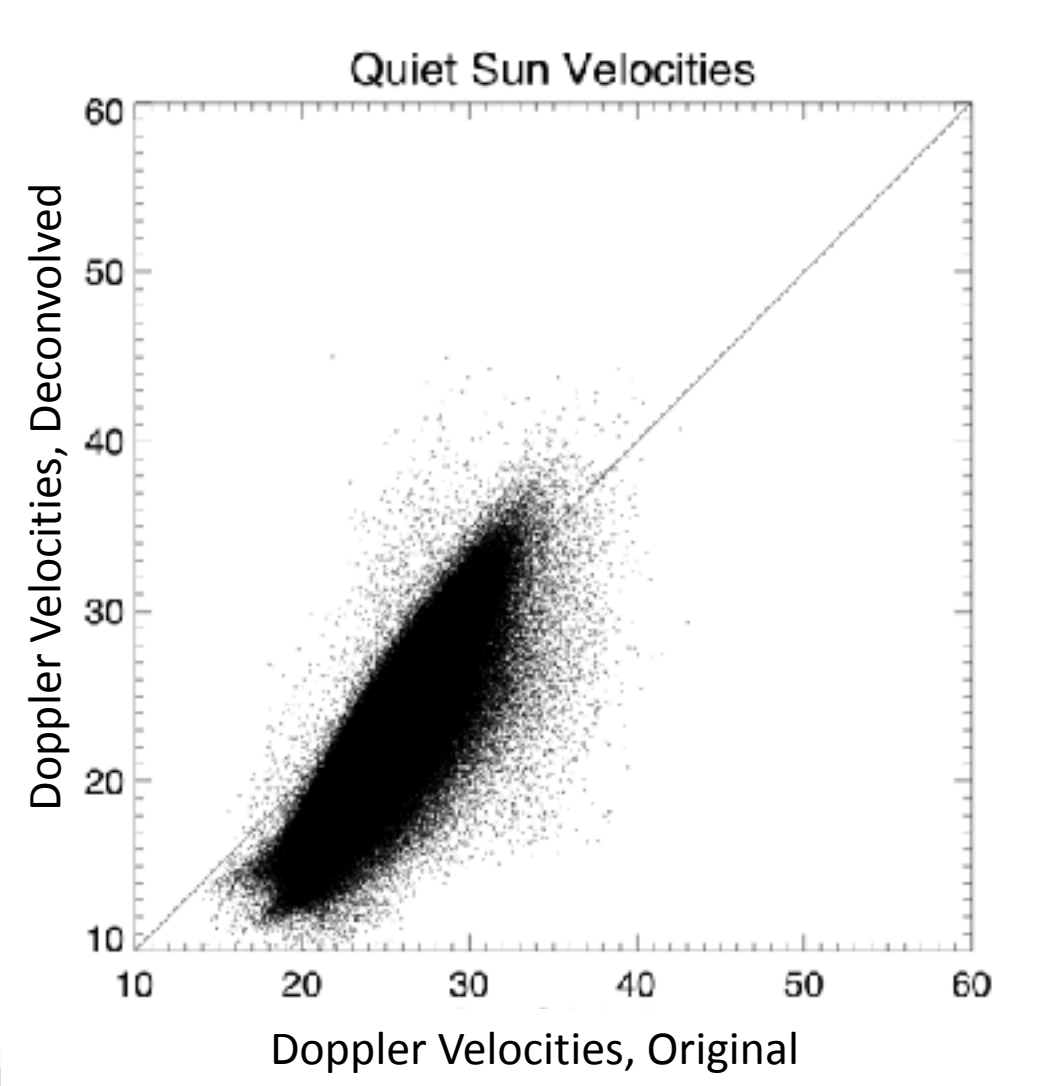


Deconvolved vs Original B Field



AR 11899 from 2013.11.18 Changes in Field strength are ~1.4 x original.

Changes in Science Data: Velocity

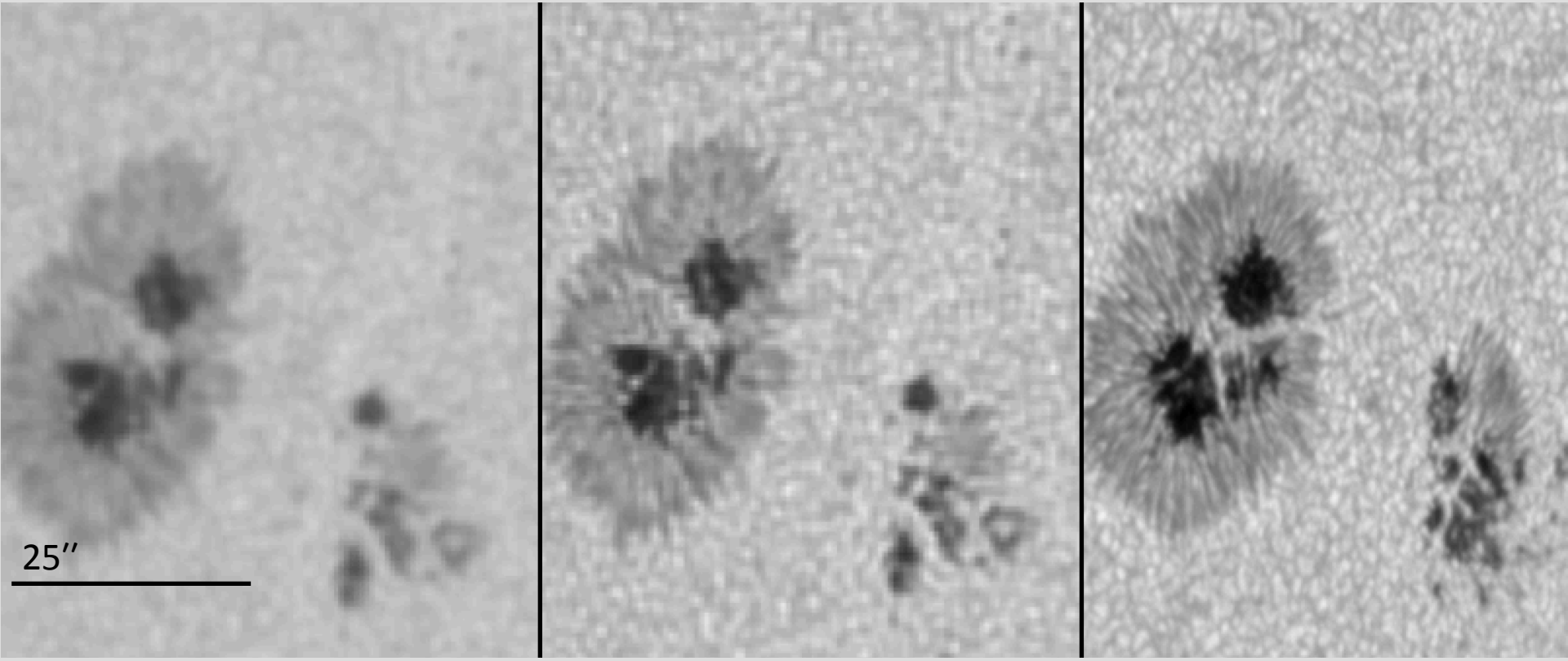


Better resolution of the downflows in granules, i.e. removes some of the convective blue-shift.

Data has positive observed radial velocity offset so no velocities are negative.

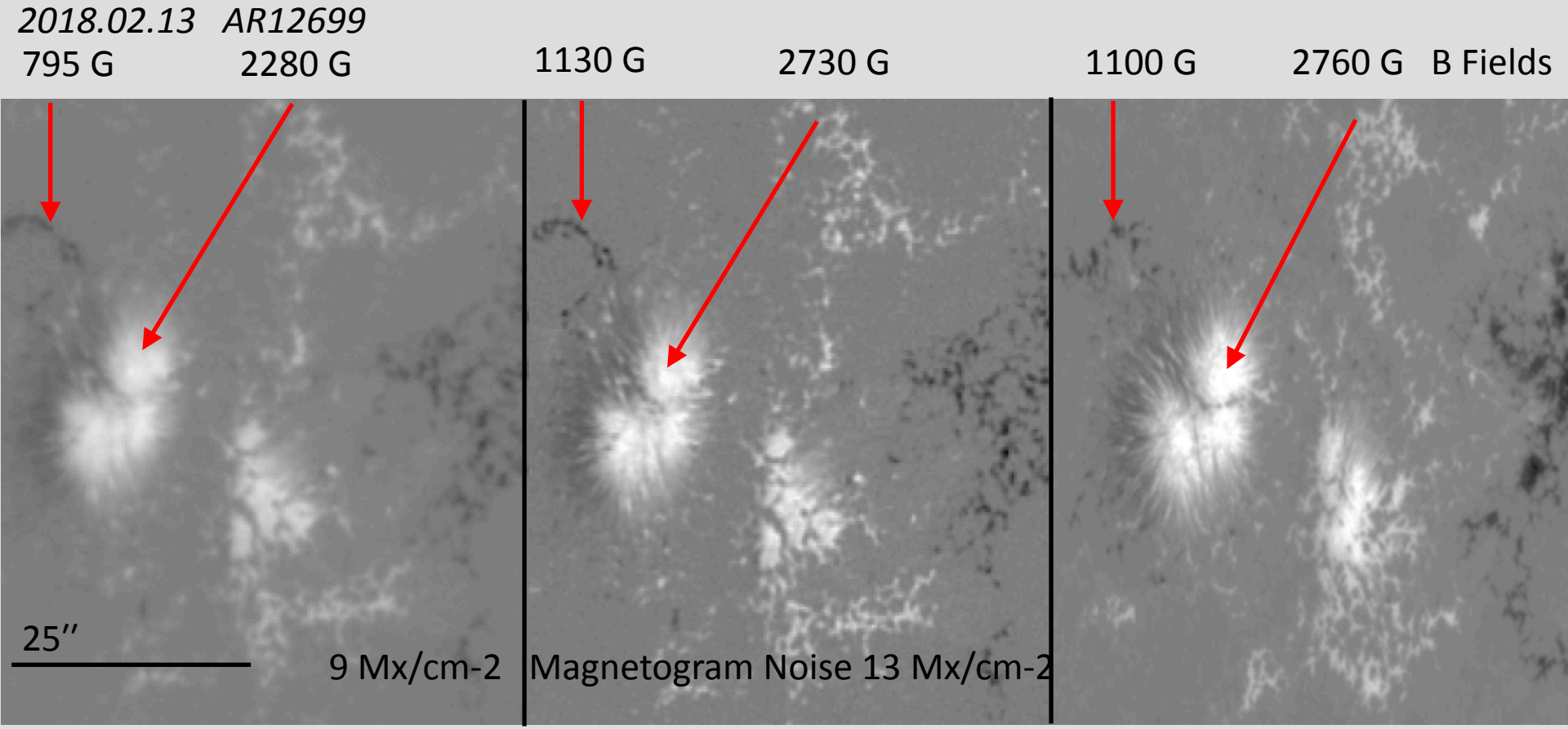
Comparison to Hinode SOT-SP

2018.02.13 AR12699



HMI Ic Original (55'' x 65'') HMI Ic Stray Light Corrected Hinode SOT-SP (different time)

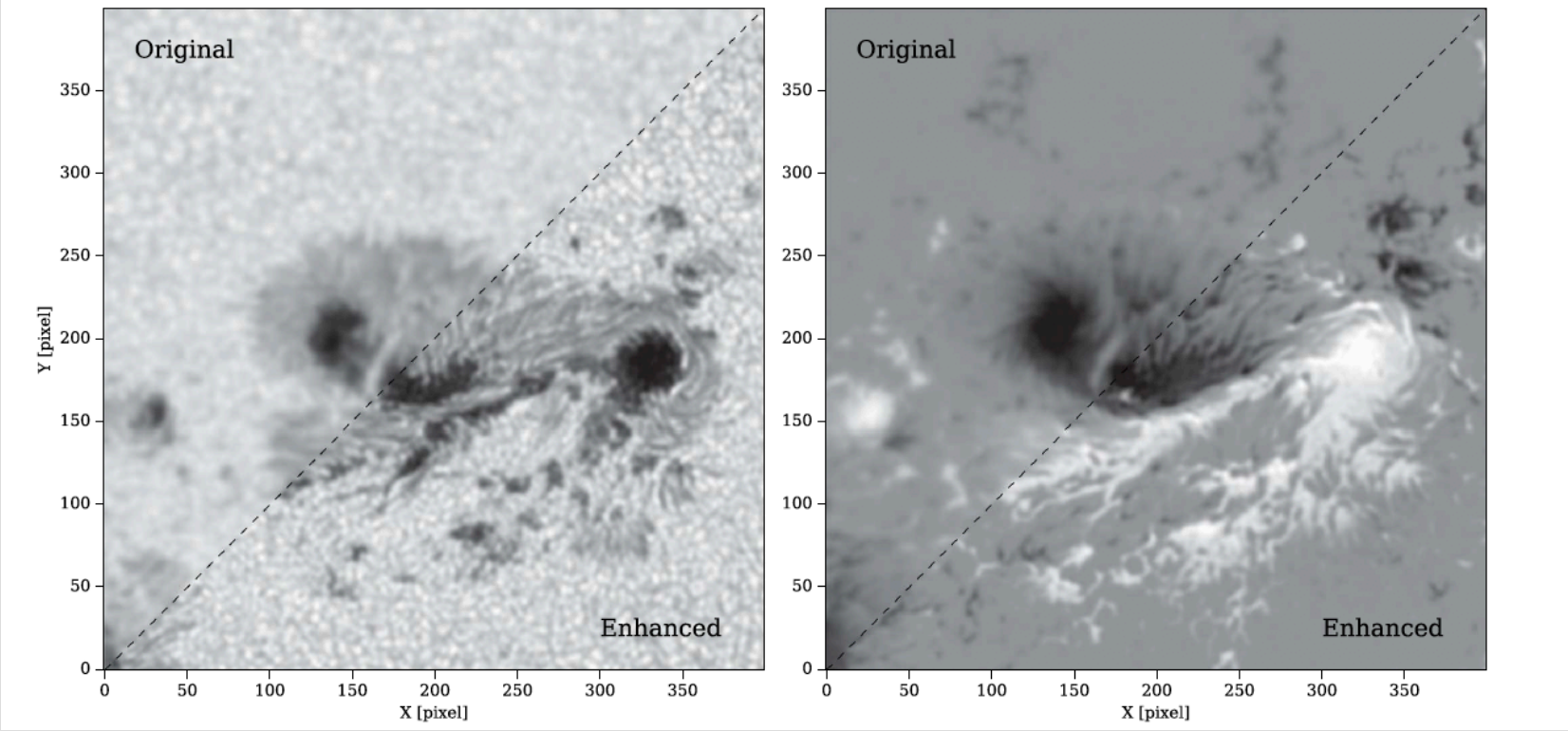
Comparison to Hinode SOT-SP



HMI M Original (55'' x 65'') HMI M Stray Light Corrected Hinode SOT-SP (different time)

Sainz Dalda 2017: HMI vs Hinode SP comparison of AR11084
"*in the umbra & penumbra, the vector magnetic field components... are very similar*",
whereas plage field strengths "*have the most significant differences*".

Re: Diaz Baso & Asensio Ramos (2018) AI Paper



DB & AS super-resolve (2x resolution). We don't.

DB & AS use neural networks trained on simulated data.

We use measured properties of optics & data.

Our corrections achieve the same granulation contrast.

We correct the full disk image (not limited FOV) & vector B data.

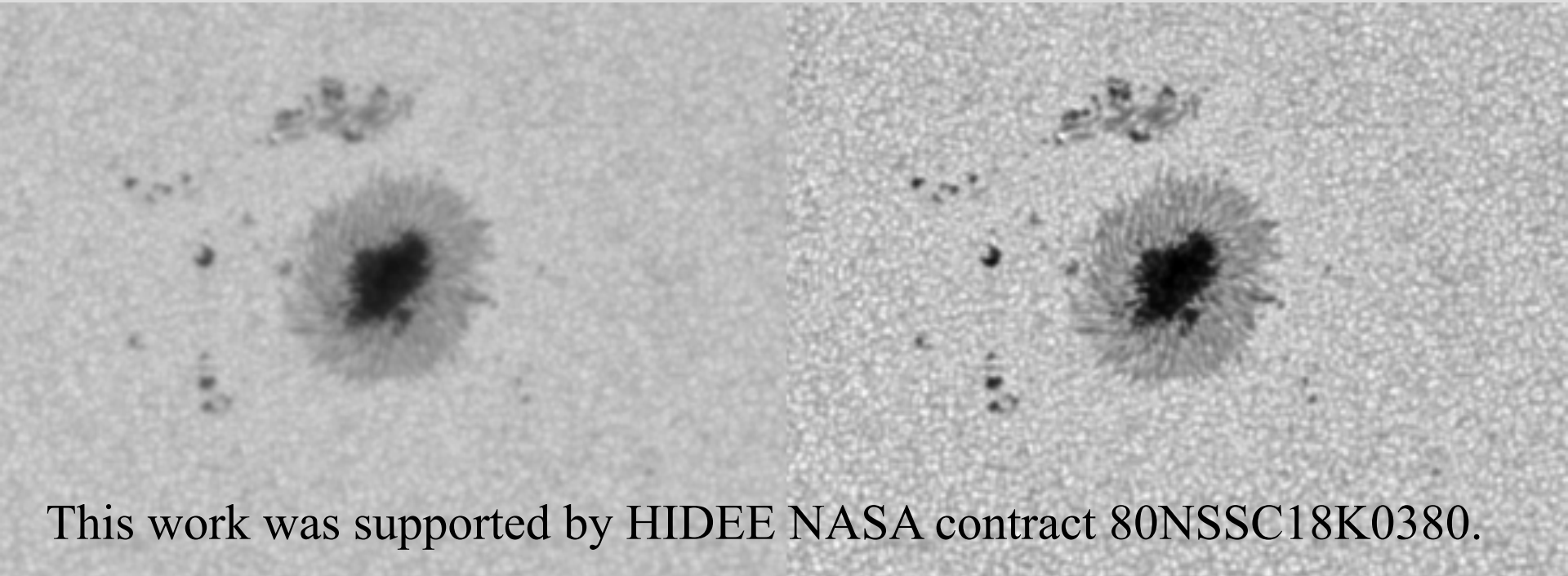
We already provide data *every day* for you.

Available: HMI Data Corrected for Stray Light

Deconvolution changes the data in the following way:

- Ic: Decreases umbral Ic a few% corresponding to ~200 K.
- Ic: Doubles the intensity contrast of granulation.
- B: Increases field strengths in plage.
- B: Increases the # of pixels in umbra with erroneous values.
- Doppler: partially corrects for convective blueshift.

Please ask us for corrected data if it can be useful:



This work was supported by HIDEE NASA contract 80NSSC18K0380.

Extra Slides / Notes

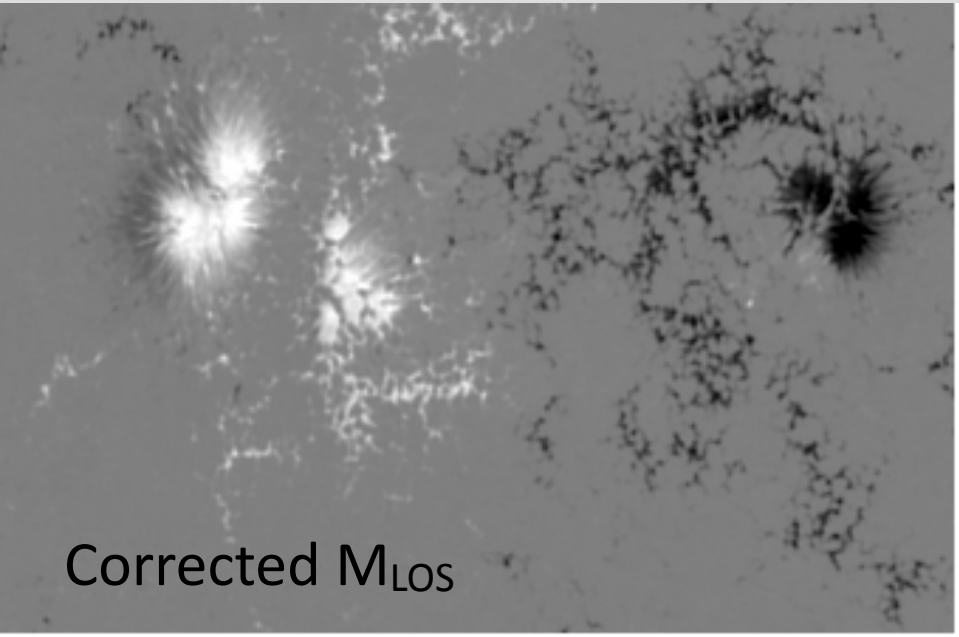
Development of PSF
Application to Data
Changes to Data
Scientific Implications

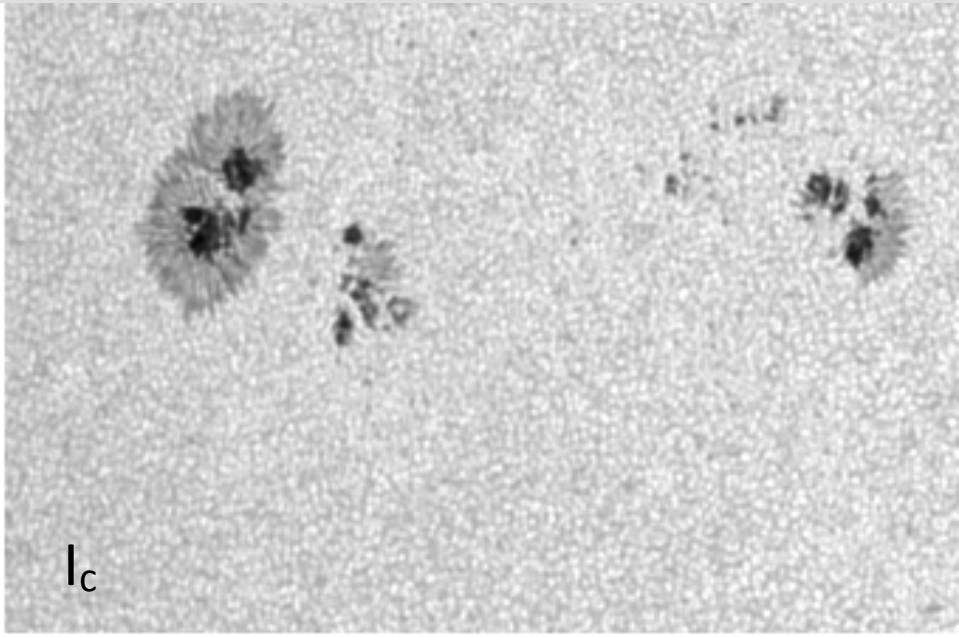
TO DO: Add granulation images and values
cut back on 1 slide in PSF Development
add a slide with direct comparison of Baso Diaz
Implications for research (Criscuoli, Jess, Tracking, Nitta, etc)
Input noise values.

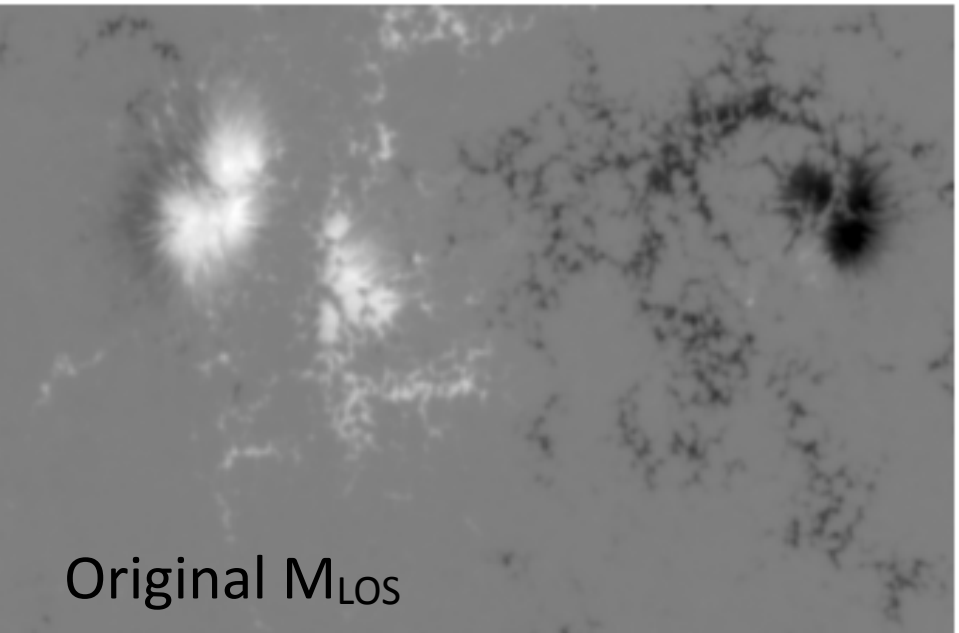
Our method is full disk
Runs fast
In production
Read Yeo
Read Diaz Baso
cite Alberto's paper

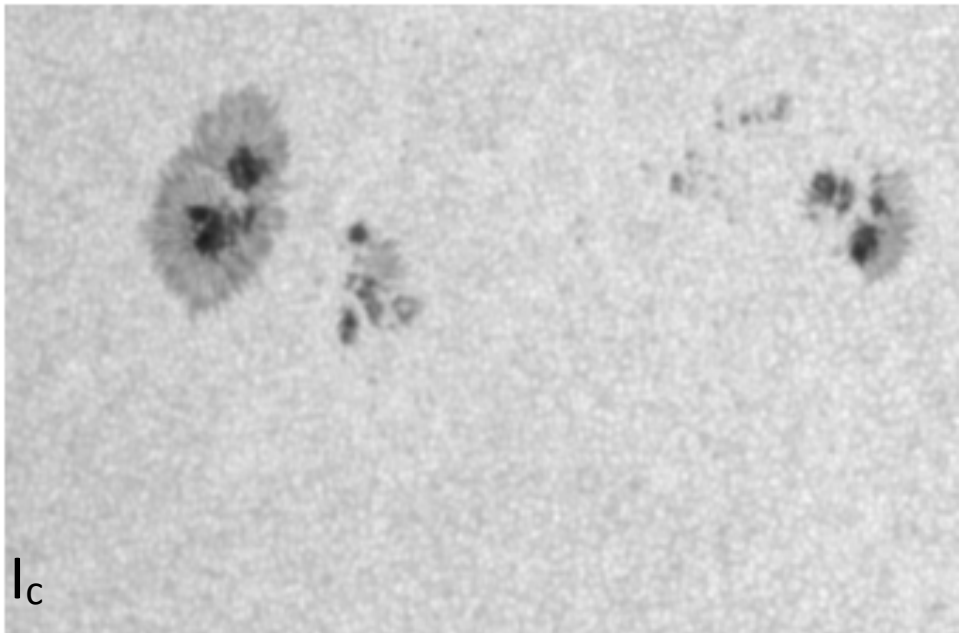
12 & 24 (45 s magneto gram noise)
9 & 13 (720 mag noise)

Spot Check of Values

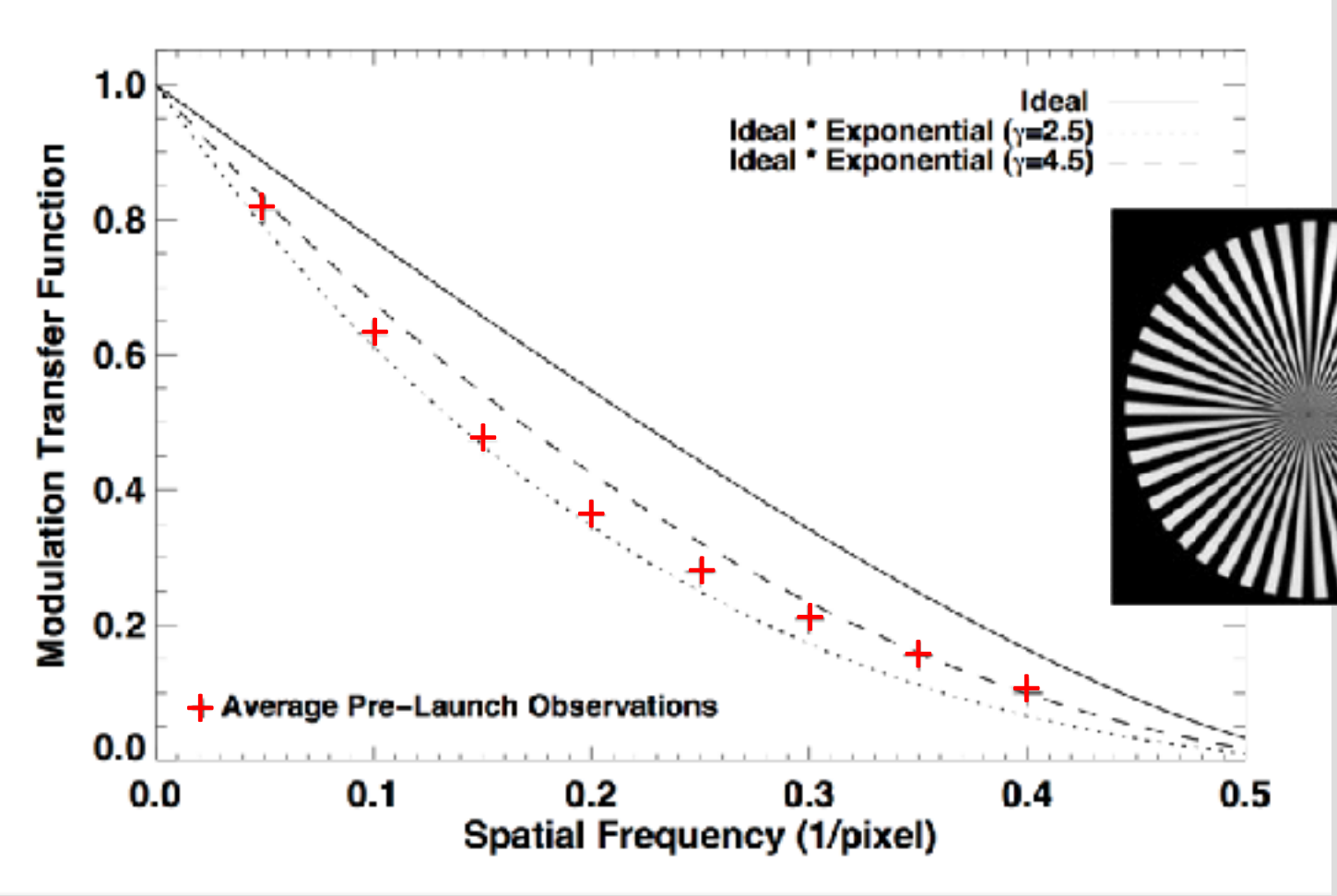








PSF Development: Pre-launch observations



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