Influence of Straylight Correction on Measurements of Doppler Velocity

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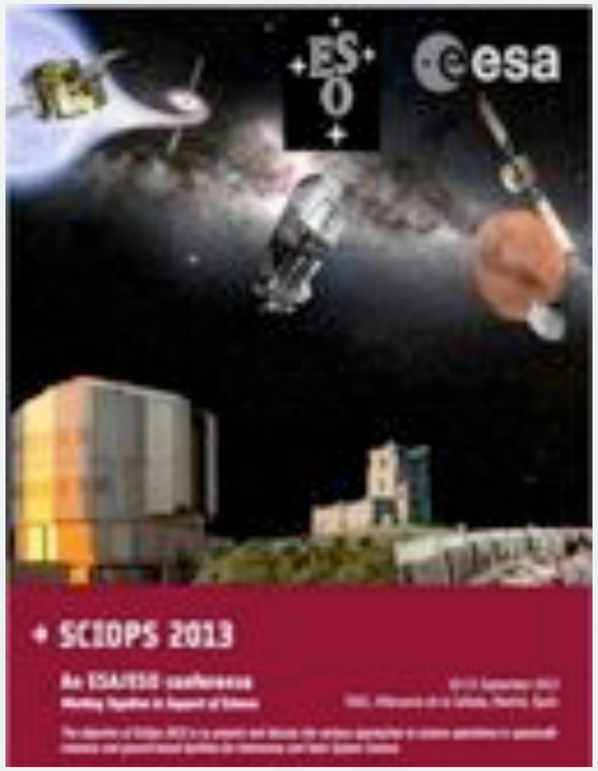

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Straylight

Definition:

Distortions along the optical path cause the photons emitted by a point source to be spread on the detector. Mathematically, this phenomenon can be described by a point spread function (PSF).

Wedemeyer-Böhm (2008)

Straylight

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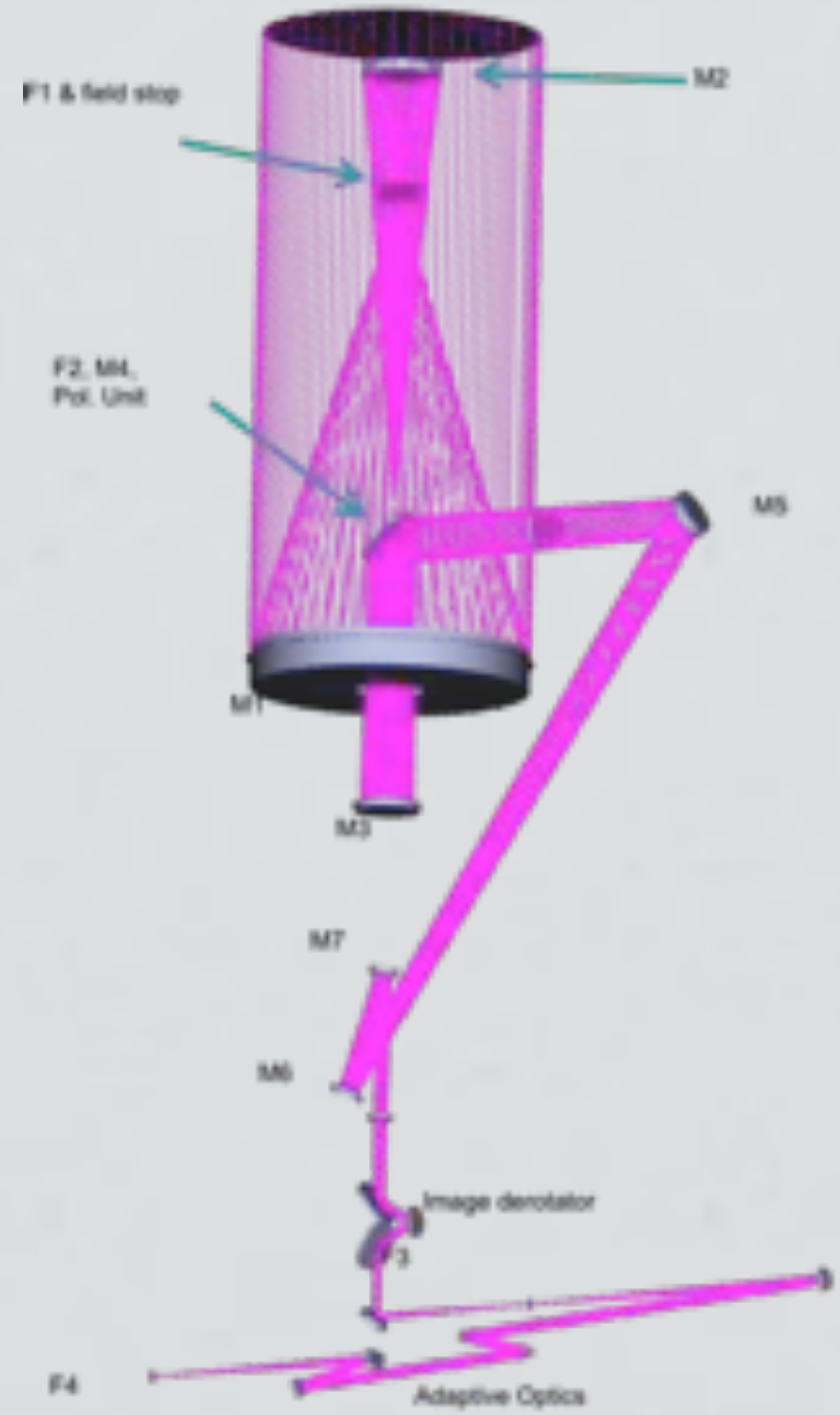
Wedemeyer-Böhm (2008)

Consequence:

Image quality is degraded leading to a decrease in granular contrast when compared to MHD simulation.

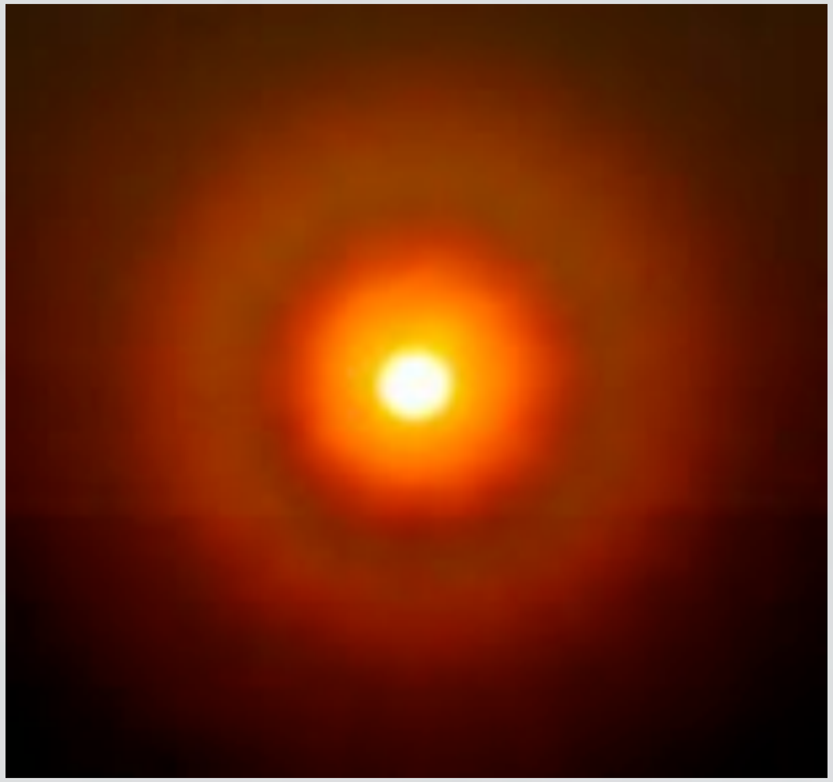
Sources of Straylight

* The optical elements of the telescope
    * Micro-roughness of mirror
    * Obstacles within the optical train e.g. spider
    * Dust
    * PSF can be measured



Soltau et al. (2012)

Sources of Straylight

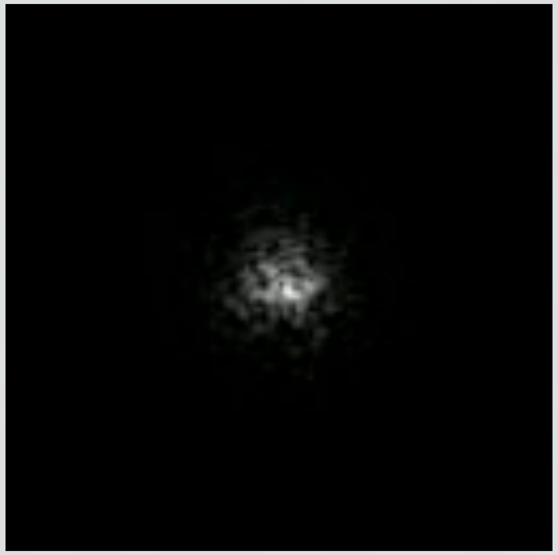


Wikipedia (2013)

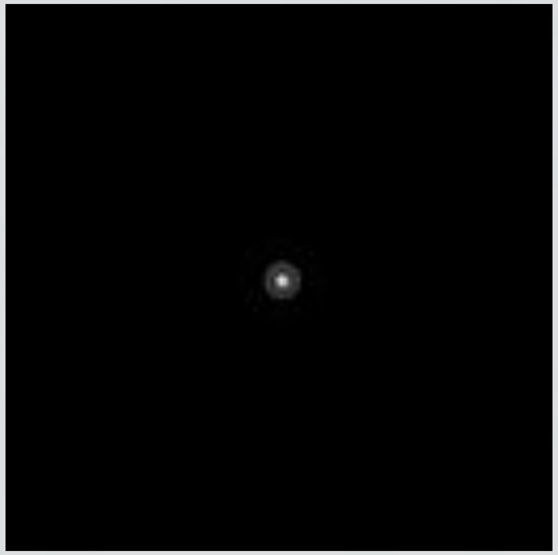
* Atmospheric scattering
  * Aureole
  * Diffraction and refraction processes on dust, aerosols or water vapor
  * Slow temporal variation (h)
  * Influence on far wings of the PSF

Sources of Straylight

- Atmospheric turbulence (‘seeing‘)
  - Blurring of image
  - Change of atmospheric index of refraction
  - Fast temporal variation (50ms)
  - Influence on central peak of PSF



Pickering 1 (very poor)



Pickering 10 (Excelent)

Correction for Straylight

- Build telescope with high Strehl ratio
  - Use high quality optical components
  - Use small number of mirrors, lenses etc.
- Avoid earth atmosphere altogether (spacecraft)
- Use adaptive optics to suppress seeing effects
- Use a posteriori image restoration techniques (PD, Speckle, MOMFBD)
- Deconvolve image with an assumed PSF (Gauss, Lorentz, (various) combinations of the latter, etc.)

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A Simple Example

* Straylight is simulated using a mixing parameter $0 \le \beta \le 0.5$. Matrix multiplication yields the observed profiles.

blue shifted observed profile

blue shifted true profile

$$\begin{pmatrix} i_{\mathrm{b,o}}(\lambda) \\ i_{\mathrm{r,o}}(\lambda) \end{pmatrix} = \begin{pmatrix} 1-\beta & \beta \\ \beta & 1-\beta \end{pmatrix} \begin{pmatrix} i_{\mathrm{b,t}}(\lambda) \\ i_{\mathrm{r,t}}(\lambda) \end{pmatrix} =: m(\beta) \cdot \begin{pmatrix} i_{\mathrm{b,t}}(\lambda) \\ i_{\mathrm{r,t}}(\lambda) \end{pmatrix}$$

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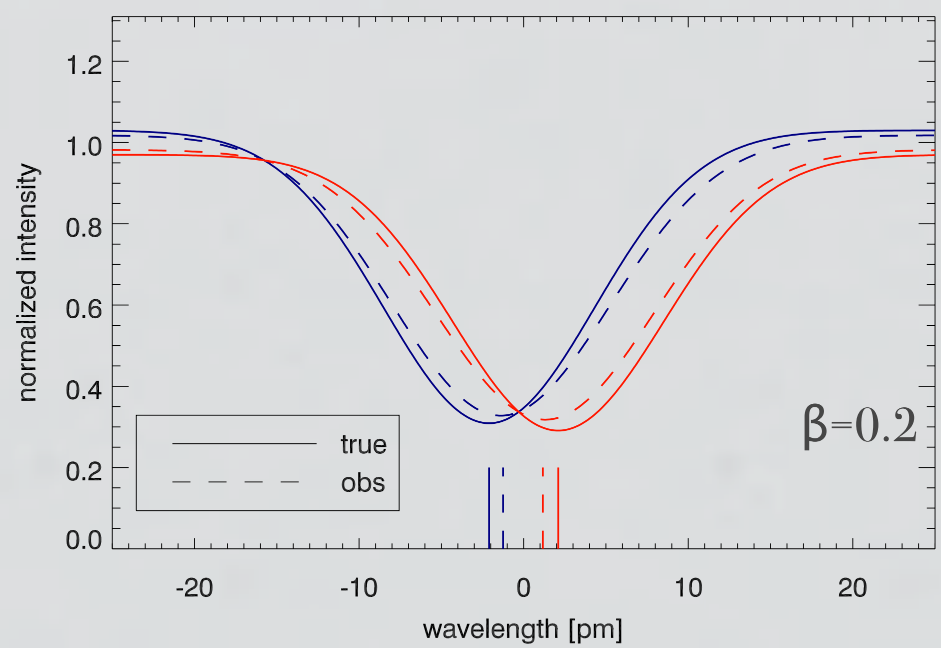

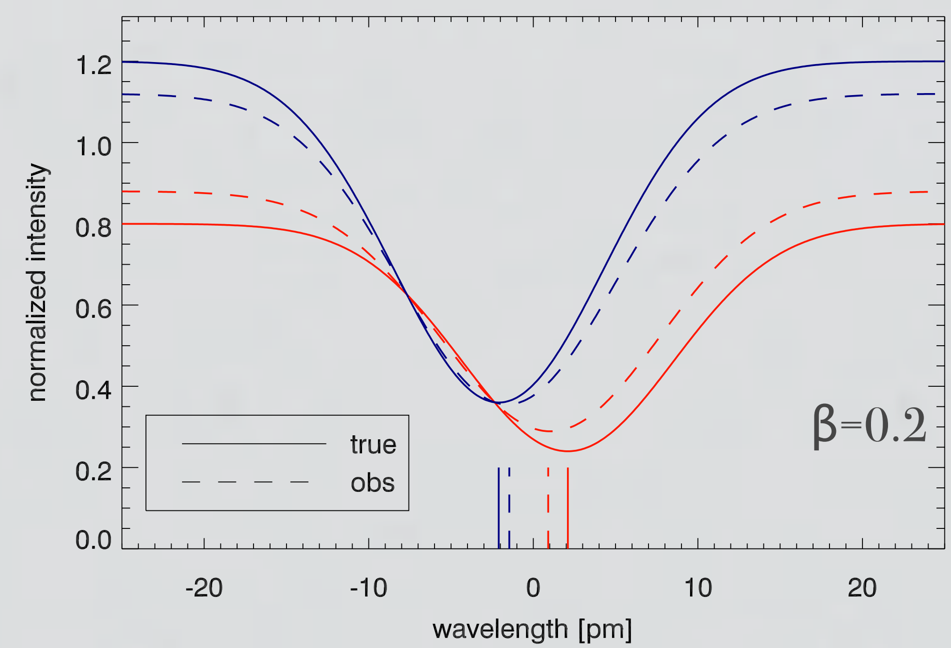

Schlichenmaier & Franz (2013)

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red shifted observed profile — red shifted true profile

- To correct for straylight, the inverse of $m(\beta)$ has to be determined. Since β is unknown, it has to be approximated $\tilde{\beta} \approx \beta$.

blue shifted corrected profile — blue shifted observed profile

$$\begin{pmatrix} i_{\mathrm{b,c}}(\lambda) \\ i_{\mathrm{r,c}}(\lambda) \end{pmatrix} = m^{-1}(\tilde{\beta}) \cdot \begin{pmatrix} i_{\mathrm{b,o}}(\lambda) \\ i_{\mathrm{r,o}}(\lambda) \end{pmatrix}$$

red shifted corrected profile — red shifted observed profile

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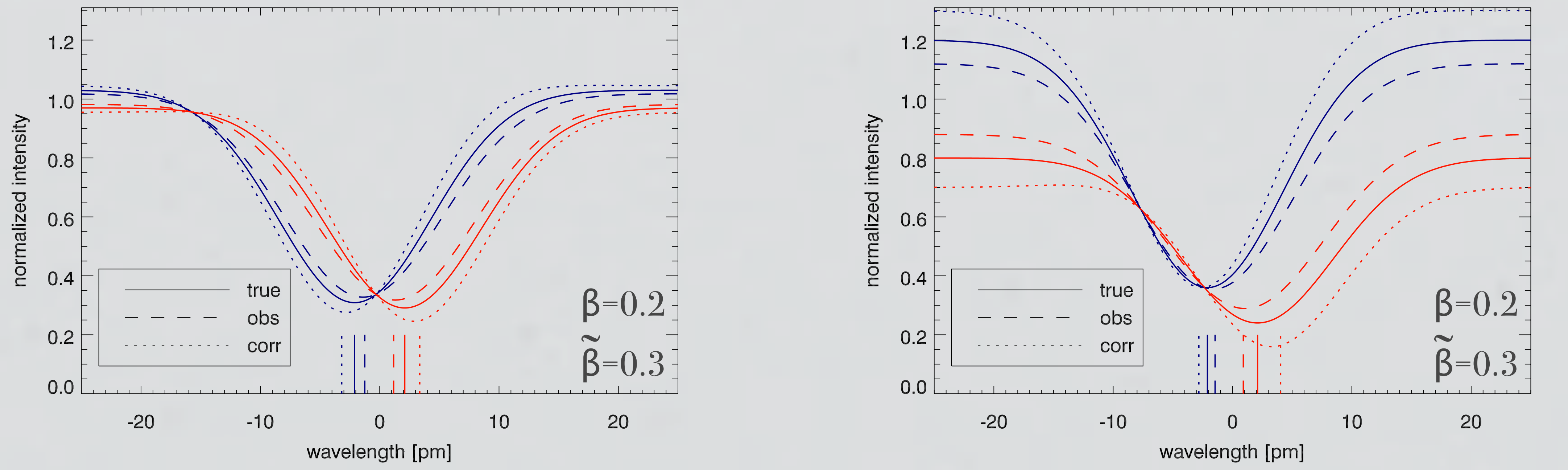


Schlichenmaier & Franz (2013)

A Realistic Example

- The effect of straylight in an observed image i_o as described by a parameter $0 \leq \alpha \leq 1$ and function s with $\int s(x, y)\,\mathrm{d}x\mathrm{d}y = 1$.

true image

$$i_\mathrm{o}(x, y) = [(1 - \alpha) \cdot \delta + \alpha \cdot s] * i_\mathrm{t}(x, y)$$

observed image — stray light parameter — stray light function

- Assume s to be a single Gaussian with FWHM of 2.35σ.

$$s = g(\sigma) = \frac{2\sigma}{\pi} \exp[-(x^2 + y^2)/(2\sigma^2)]$$

A Realistic Example

- Defining $p(\alpha,\sigma) := (1-\alpha)\delta + \alpha g(\sigma)$ one can write

$$i_\mathrm{o} = p(\alpha,\sigma) * i_t$$

- The deconvolution is a division in Fourier space

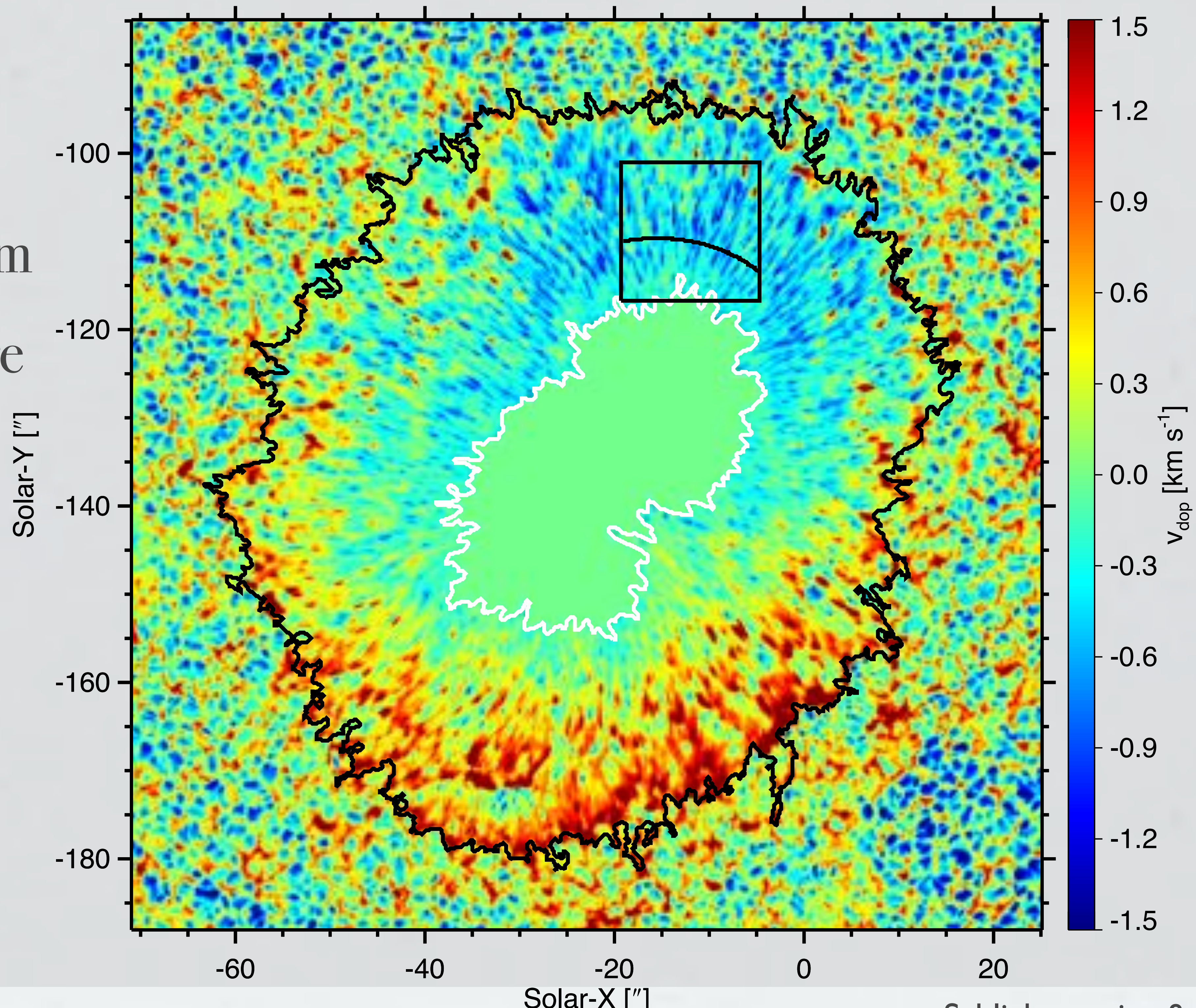
$$I_\mathrm{t} = I_\mathrm{o}/P(\alpha,\sigma)$$

- Transforming I_t back into real space yields the straylight corrected image i_t.

A Realistic Example

Hinode SP
@
Fe I 630.15nm

Original Image



Schlichenmaier & Franz (2013)

A Realistic Example

Hinode SP
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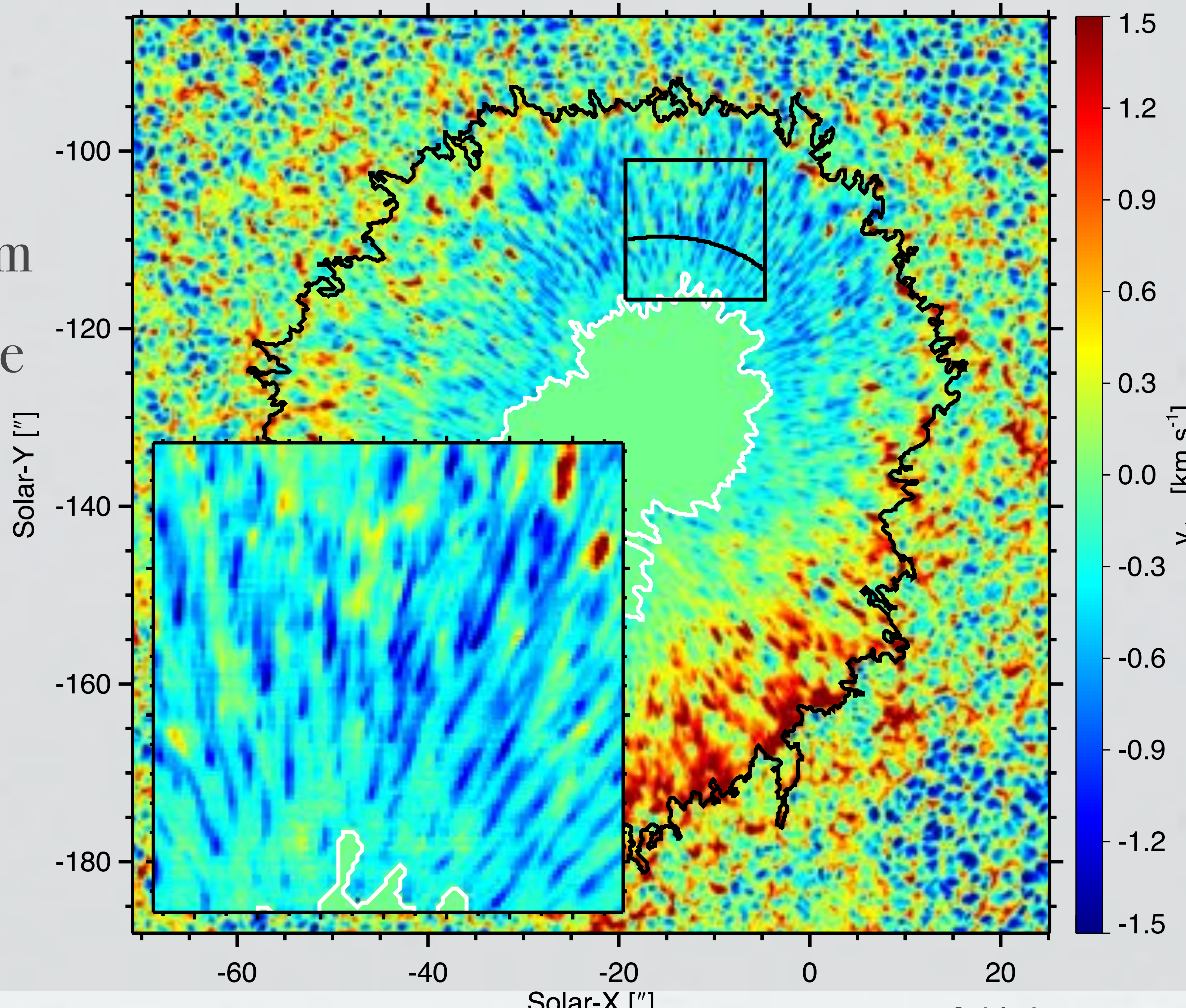
Fe I 630.15nm

Original Image

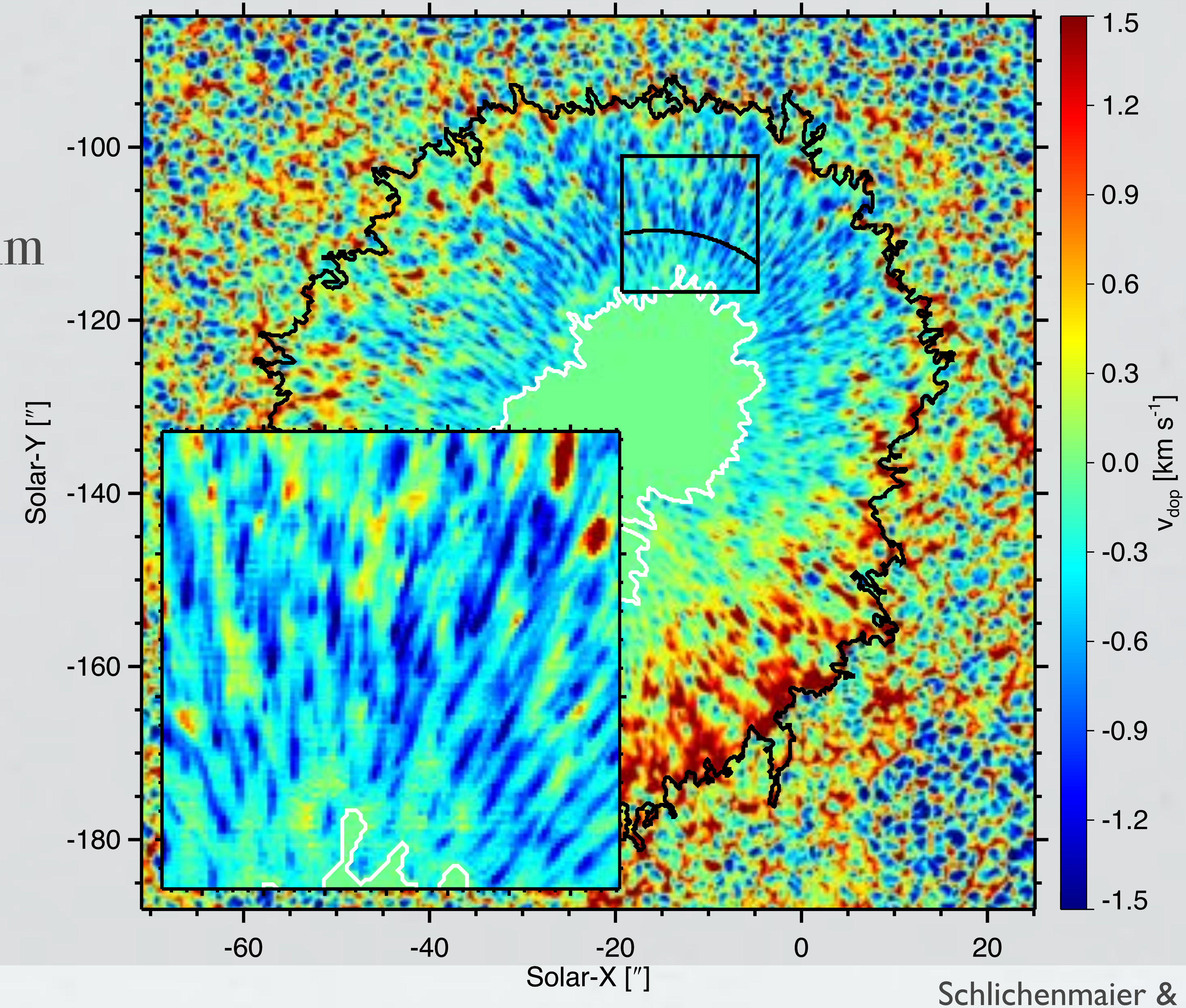


Schlichenmaier & Franz (2013)

A Realistic Example

Hinode SP
@
Fe I 630.15nm

$\alpha = 0.2$
$\sigma = 2''$

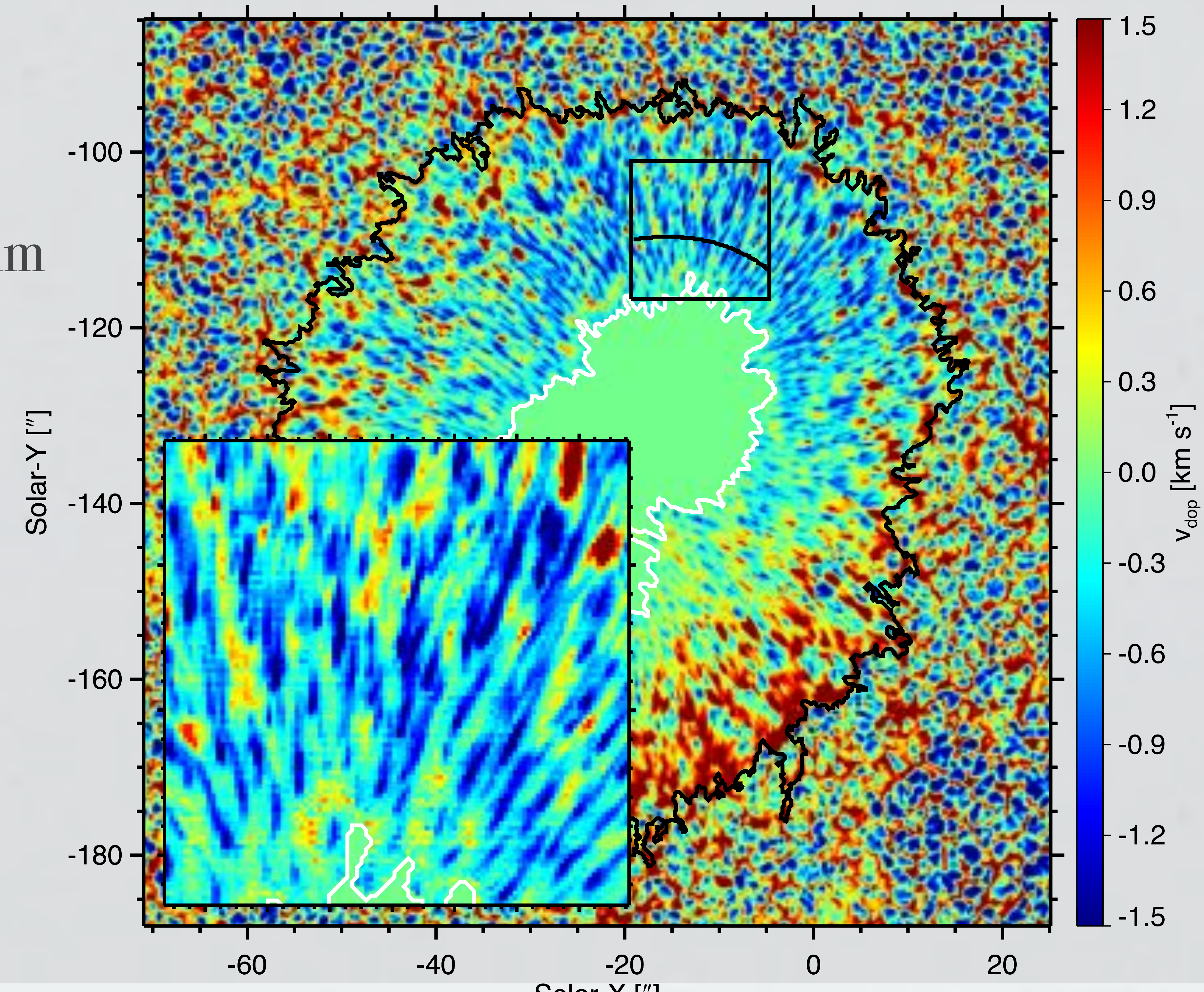


Schlichenmaier & Franz (2013)

A Realistic Example

Hinode SP
@
Fe I 630.15nm

$\alpha = 0.4$
$\sigma = 2''$

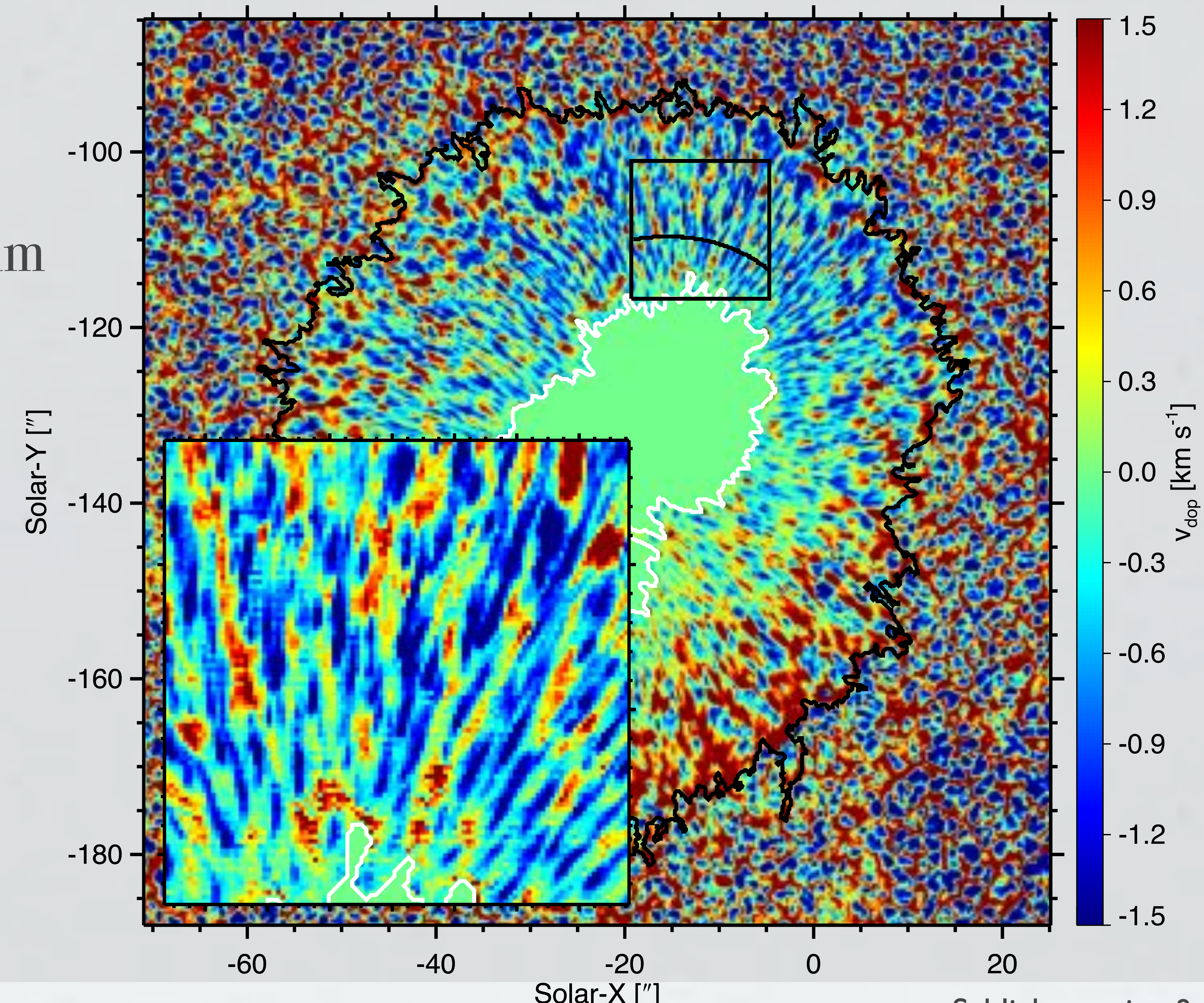


Schlichenmaier & Franz (2013)

A Realistic Example

Hinode SP
@
Fe I 630.15nm

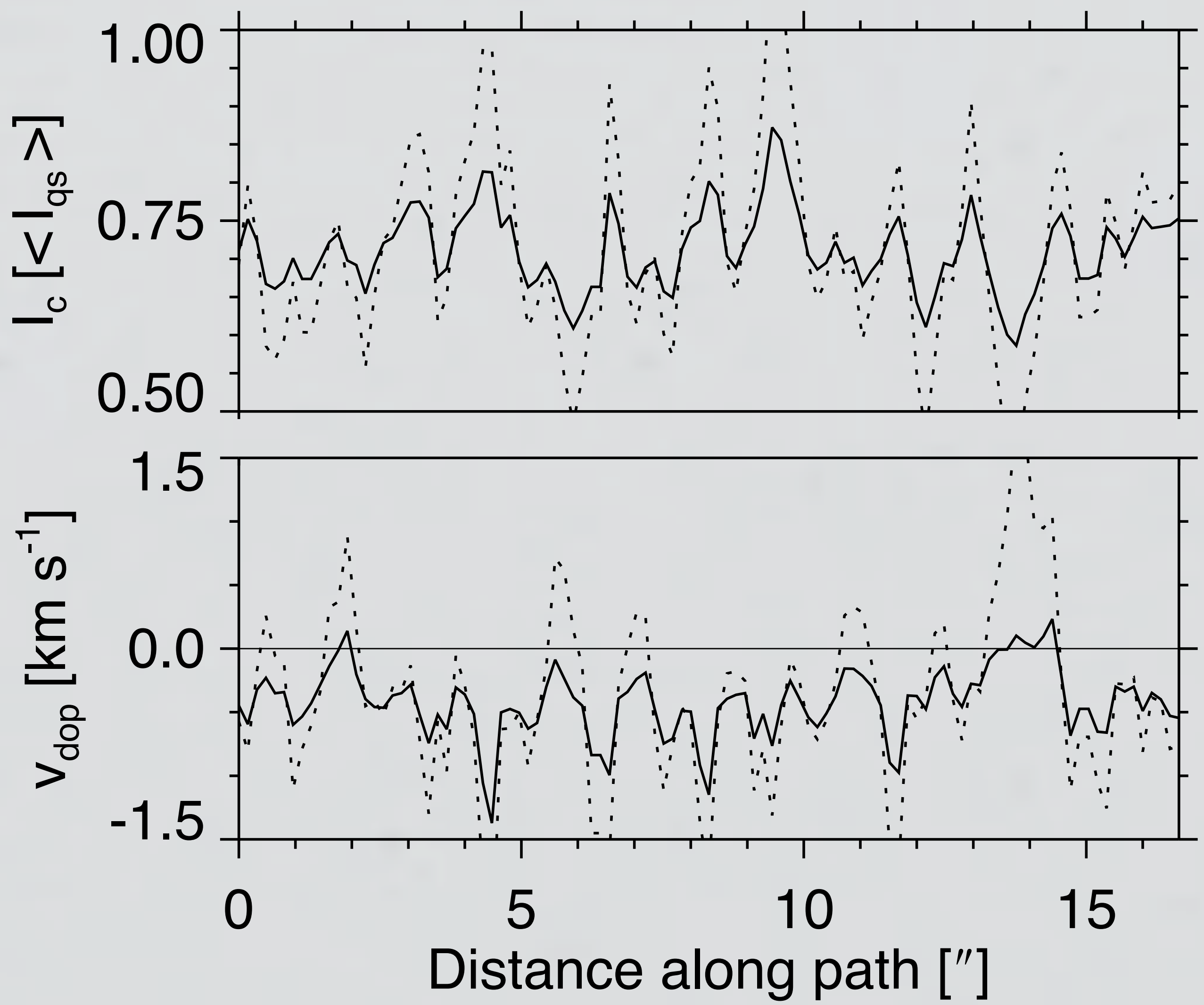
α = 0.6
σ = 2"



Schlichenmaier & Franz (2013)

A Realistic Example

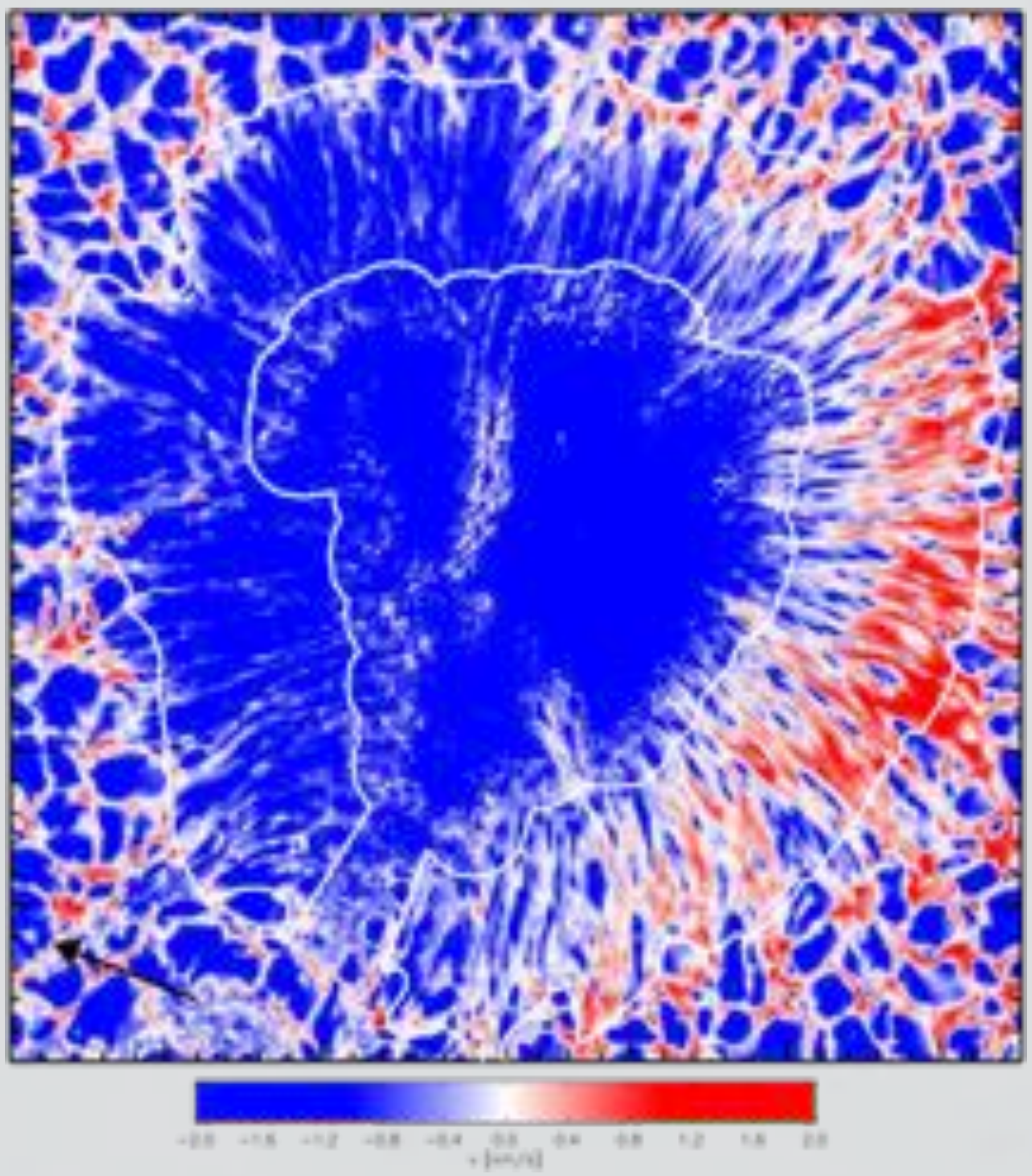
- Intensity and line shift along the indicated path before (solid) and after (dotted) deconvolution with $\alpha = 0.6$ & $\sigma = 2$“.



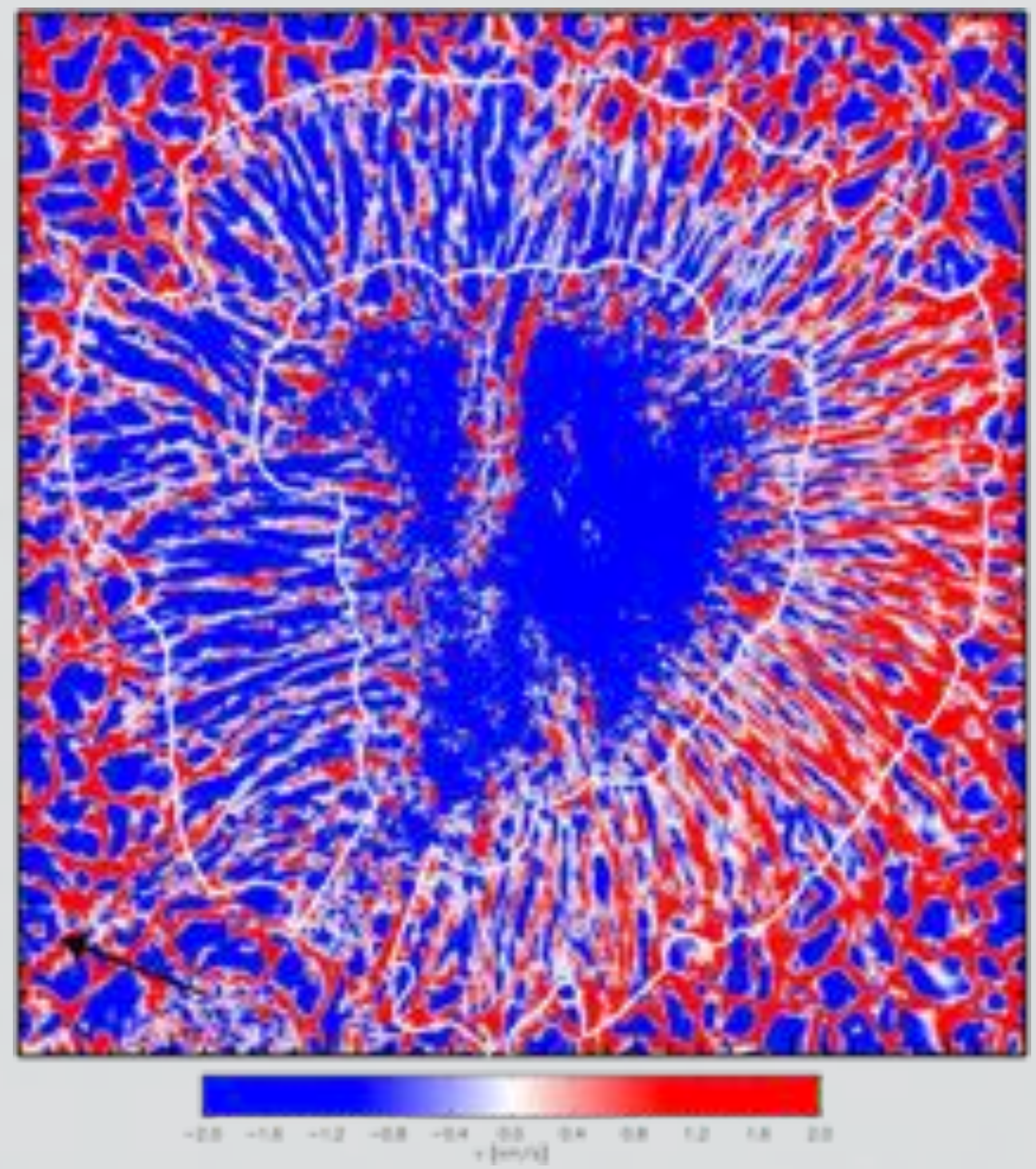
Schlichenmaier & Franz (2013)

A Realistic Example

SST CRISP @ C I 538 nm



$\alpha = 0.58$ $\sigma = 1.2$“



Scharmer et. al (2011)

Results

- Deconvolution yields an image with higher contrast, i.e. an increase of the peak-to-peak values in intensity.
- Additionally the peak-to-peak values in line shift (Doppler velocity) increase and sometimes change their direction.
- Elongated patches of redshifts become more and more prominent with increasing α. They tend to lie in regions of dark penumbral filaments.
- Straylight correction preserves the mean intensity in each image, but introduces a mean redshift.

Conclusion

- Deconvolution yields an image with higher contrast in intensity but also in Doppler velocity.
- Be careful. Unless you know exactly how much straylight is present in your data and how it varies spatially, a correction can yield unwanted or even false results.
- Reference is crucial (are MHD simulations reliable enough?)
- A reliable assessment of the straylight properties of each telescope would be necessary.


Thank you for your attention

References

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