Characterization of the low-mass companion around HD 142527 with VLT/SINFONI

Valentin Christiaens

Supervisors: Simon Casassus - Olivier Absil

Collaborators: C. Gomez, **R. Ramirez**, S. Kimeswenger, **J. Girard**, O. Wertz, **A. Zurlo**, S. Lacour, **Z. Wahhaj**

ESO workshop: Resolving planet formation in the era of ALMA and extreme AO

16-20 May 2016

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and non-extreme

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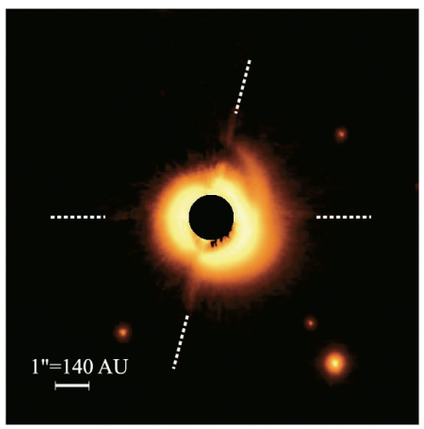
HD 142527

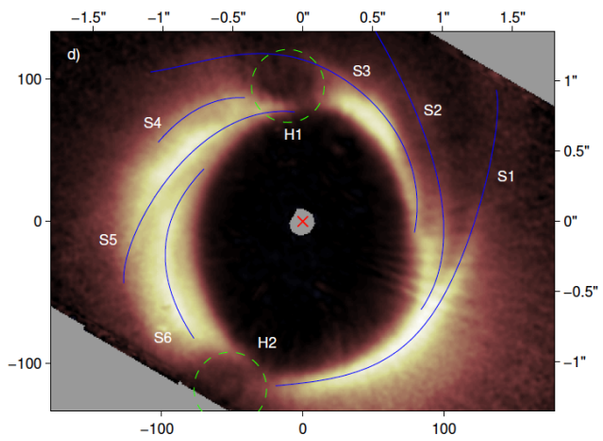
Herbig Fe star, 145pc, 1-6Myr old, ~2 M_{Sun}

um-dust

- **Spiral arms**
- **Large gap**
- **Shadows**



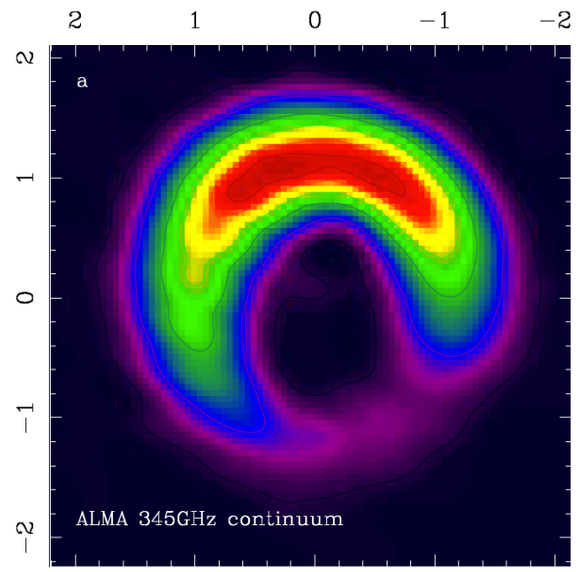
Fukagawa+06



Avenhaus+14

mm-dust

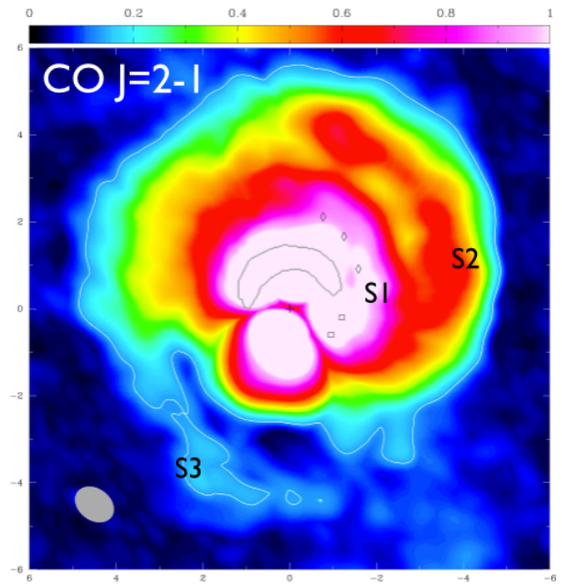
- **Dust trap**
- **Large gap**



Casassus+13

gas

Large-scale spiral arms



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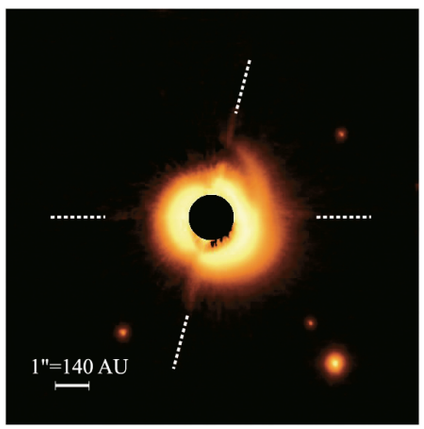

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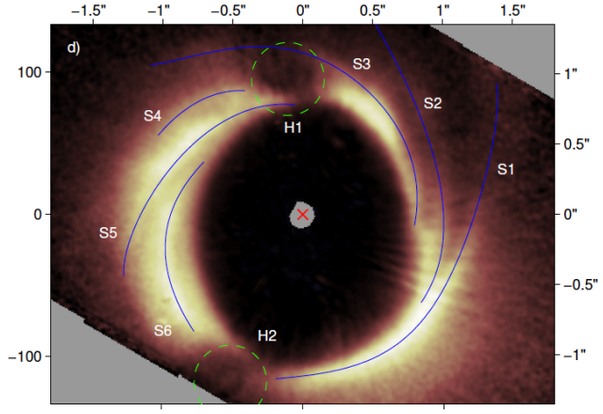

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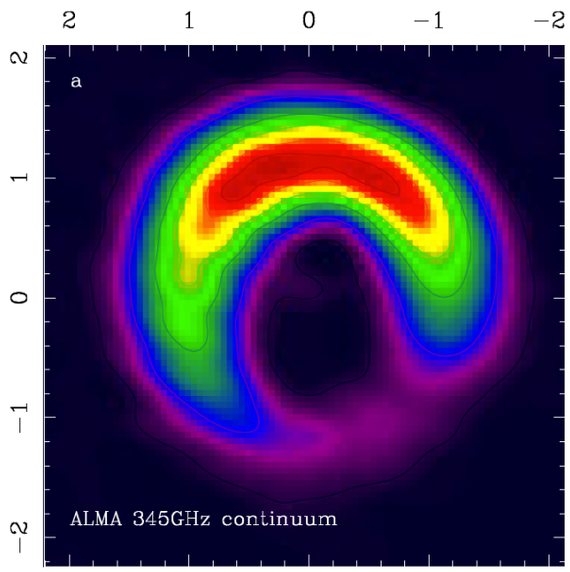

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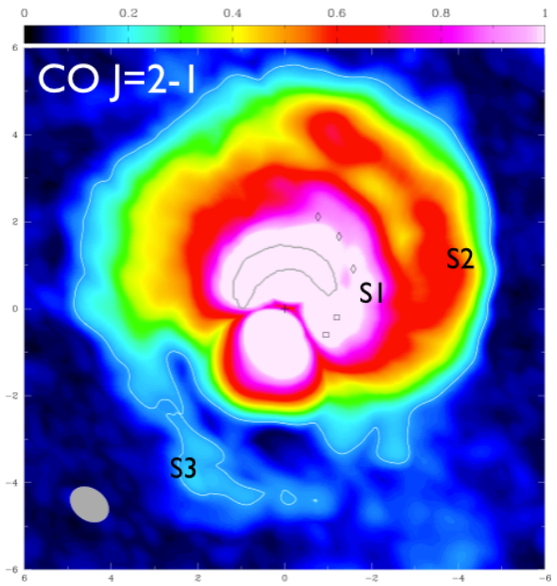
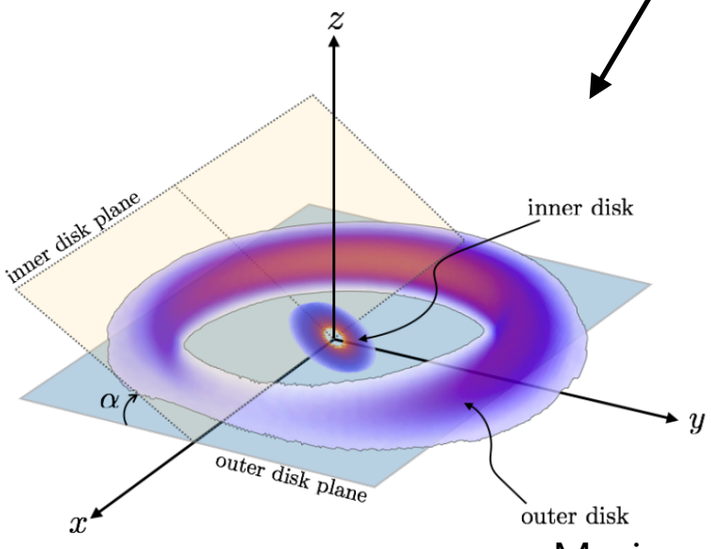


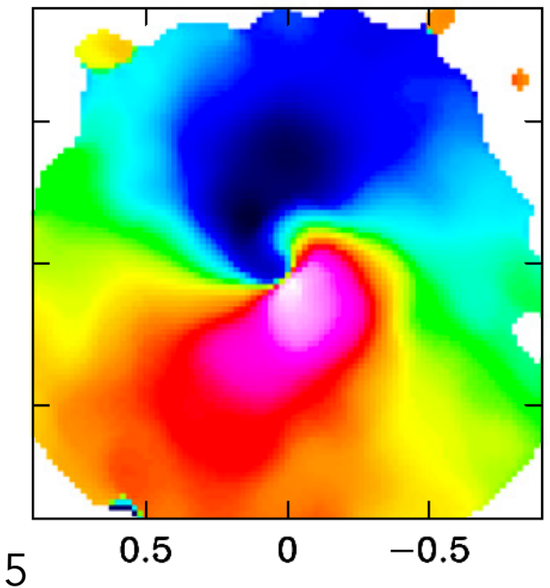
Christiaens+ 14

Inclined inner disk



Marino+ 15

Non-keplerian motion



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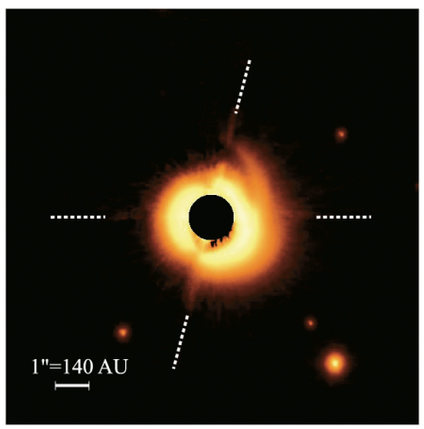

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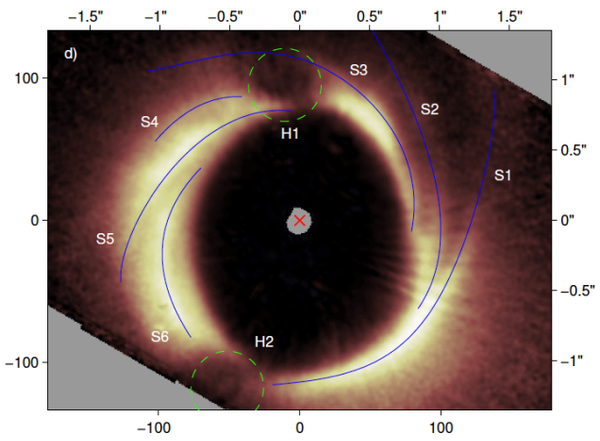

Avenhaus+14

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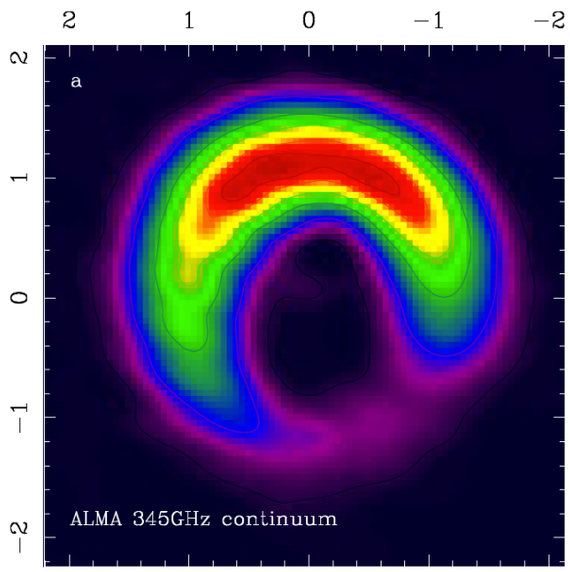

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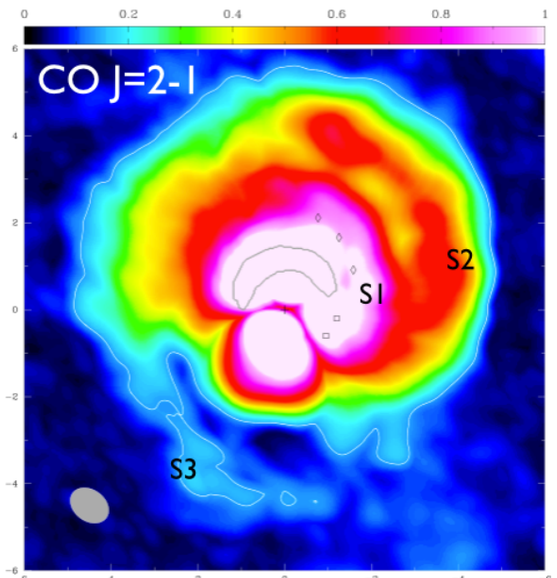
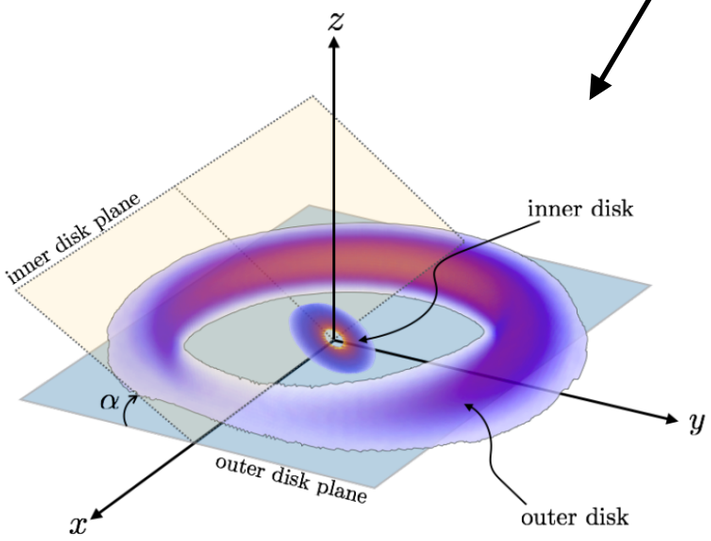


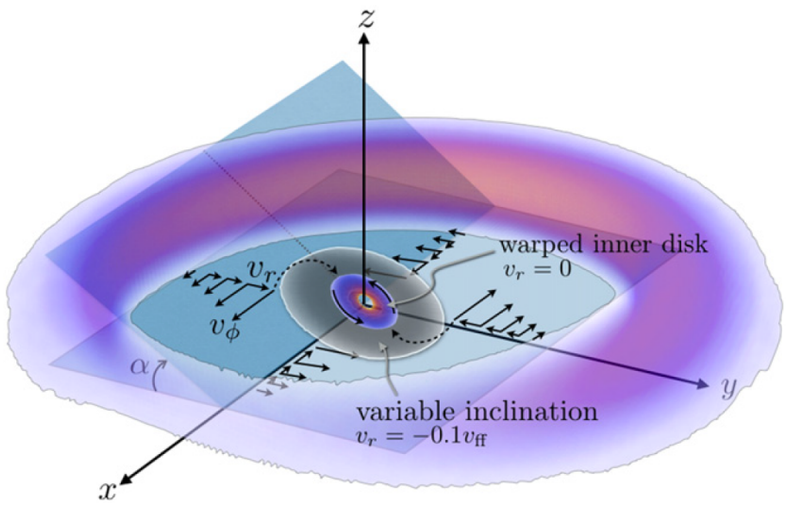
Christiaens+ 14

Inclined inner disk

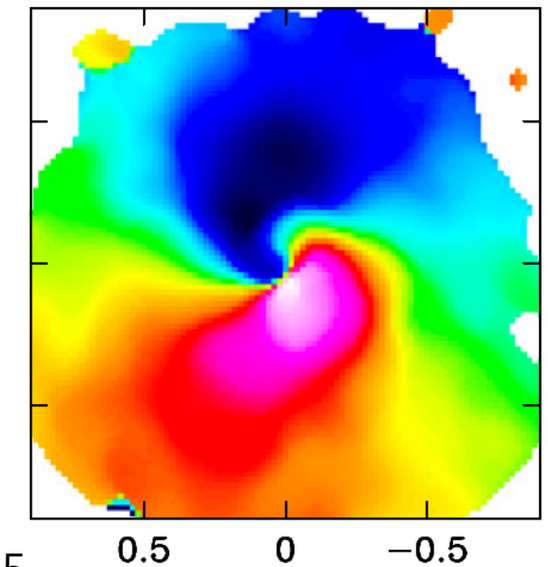


Marino+ 15

Warp



Non-keplerian motion

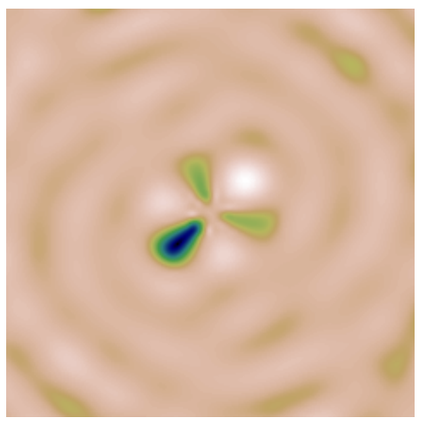


Casassus+ 15

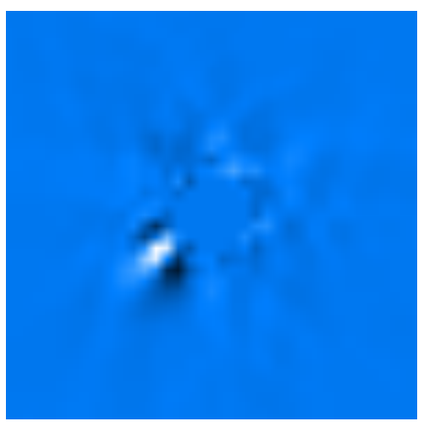
HD 142527 B

Detection/confirmation of companion B at ~80mas (12au)

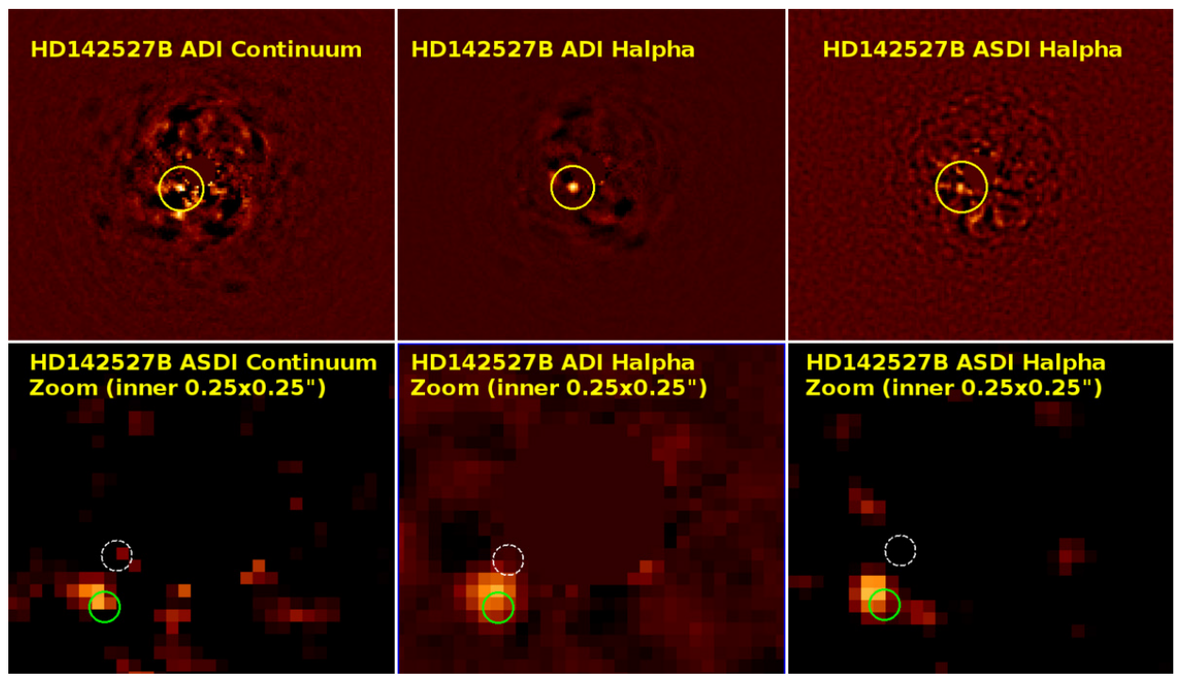
Biller+12

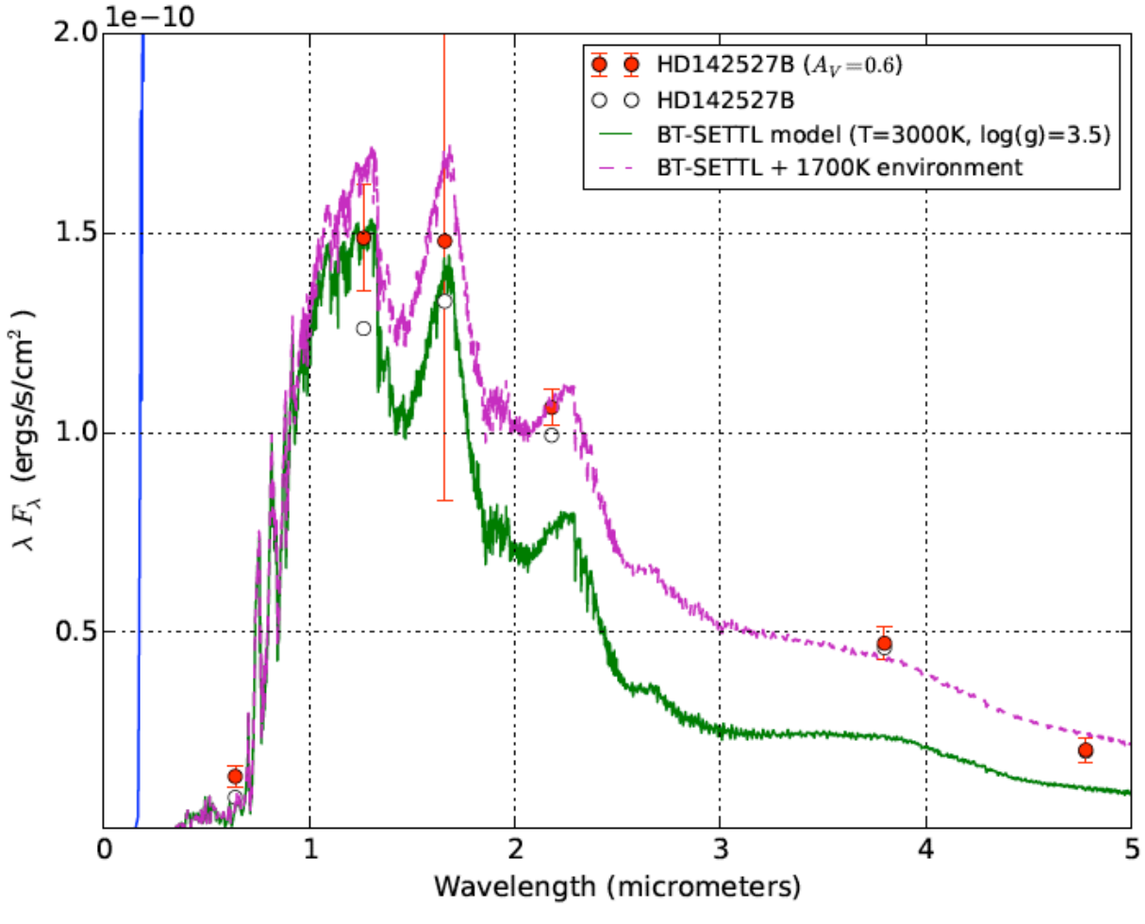


Rodigas+14

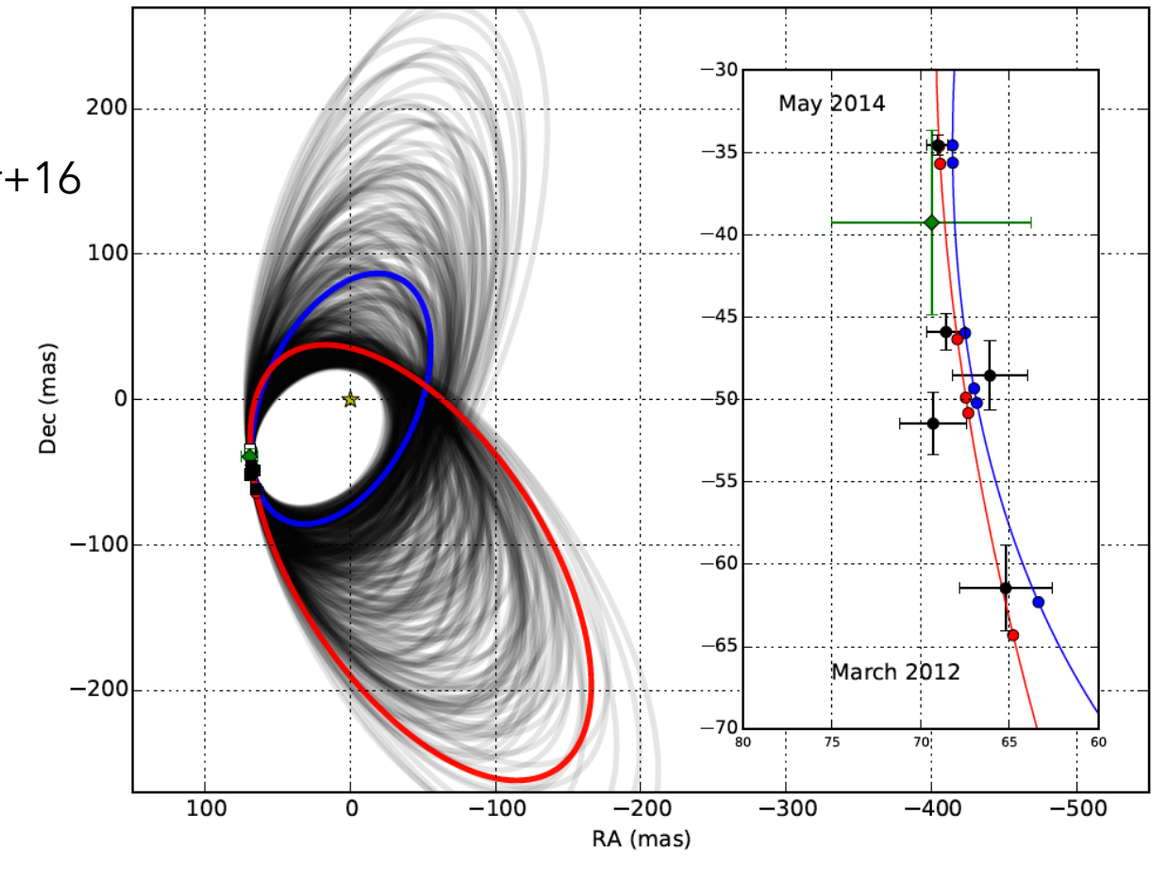


Close+14



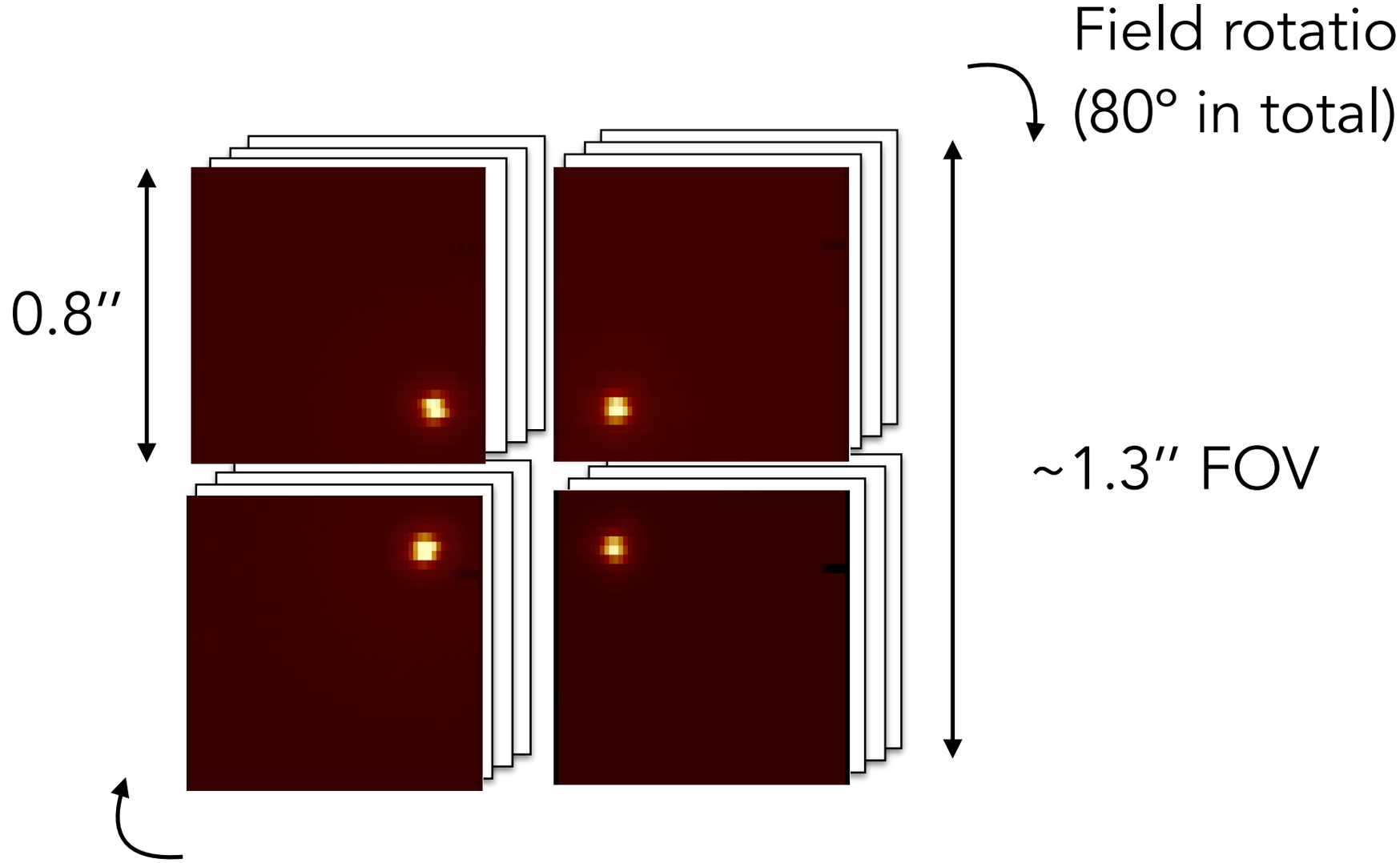


Lacour+16



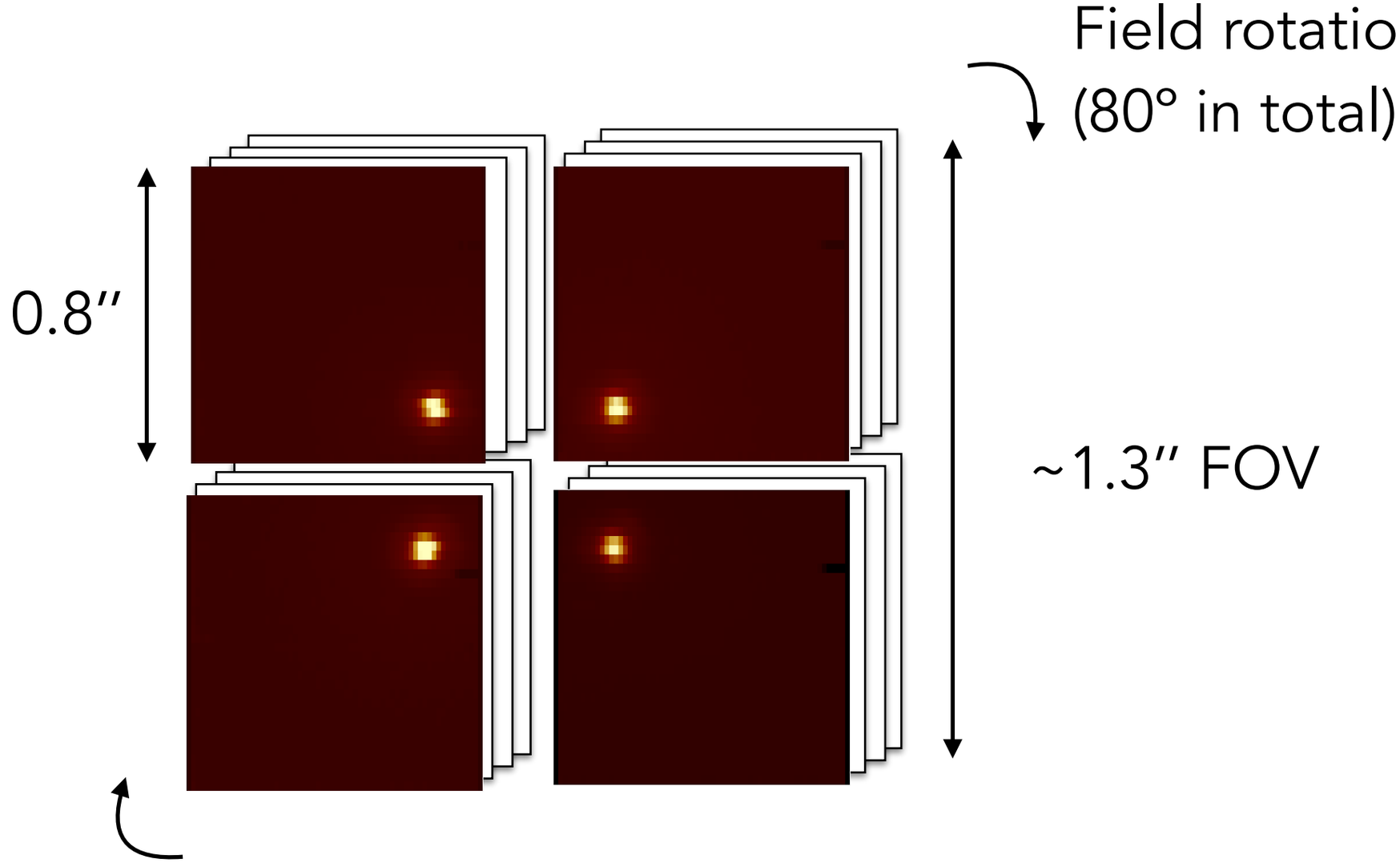
Dataset

Initial goal: finding forming planets in the gap
Instrument: VLT/SINFONI (H+K) Integral field spectrograph
Data: 40 spectral cubes of 1992 channels
Observation strategy: pupil tracking + 4 points dithering
Post-processing algorithms: ADI+SDI, ADI in each spectral channel



Dataset

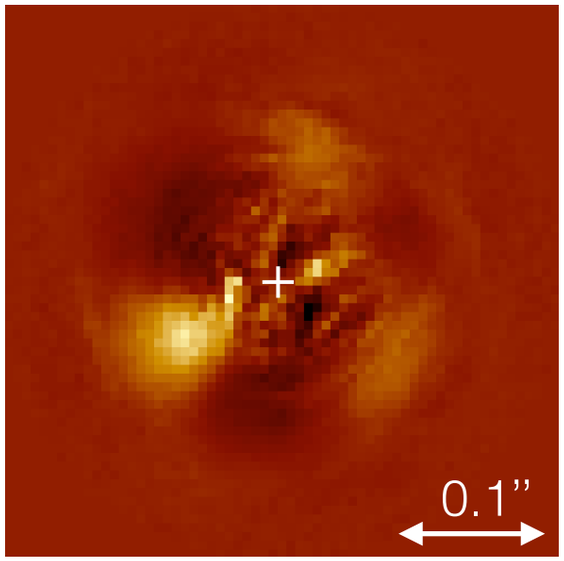
Initial goal: finding forming planets in the gap
Instrument: VLT/SINFONI (H+K) Integral field spectrograph
Data: 40 spectral cubes of 1992 channels (photometric conditions)
Observation strategy: pupil tracking + 4 points dithering
Post-processing algorithms: ~~ADI+SDI,~~ ADI in each spectral channel

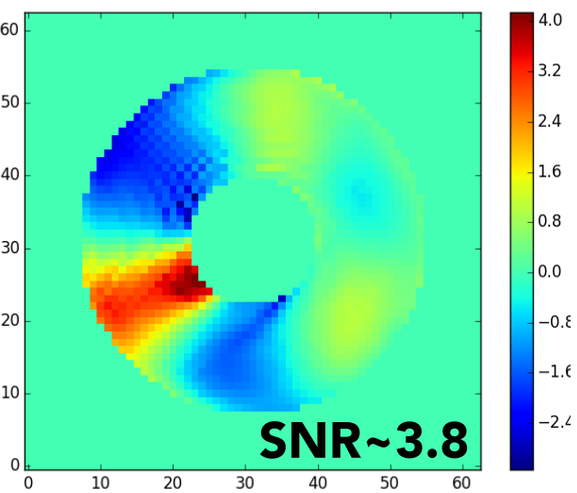


Re-detection of HD 142527 B

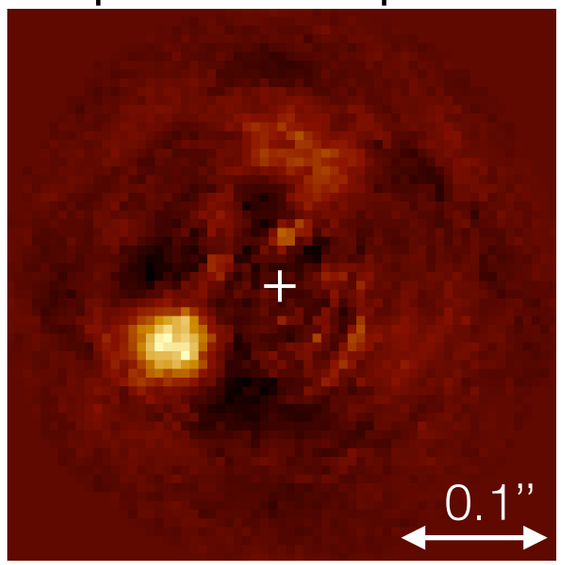
Example for the Br-g line (2.166um) channel:

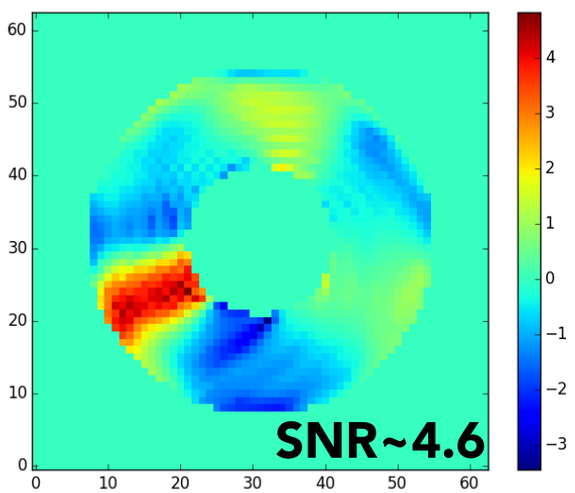
classical-adi



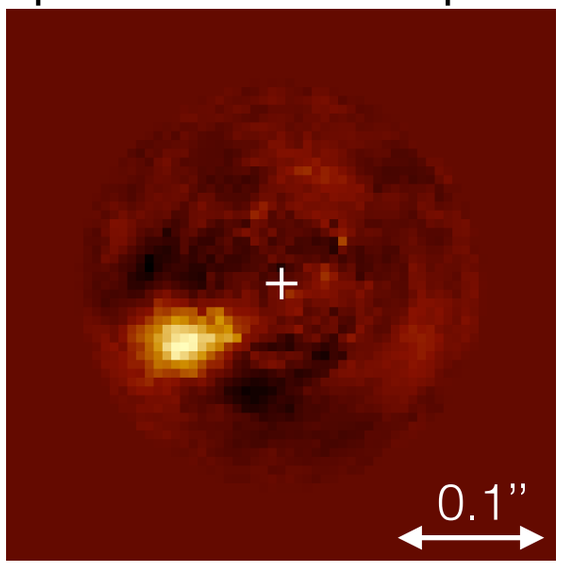


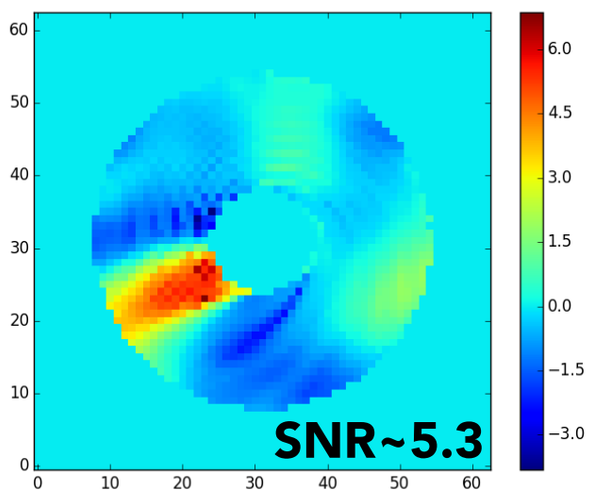
pca-full (6pc)



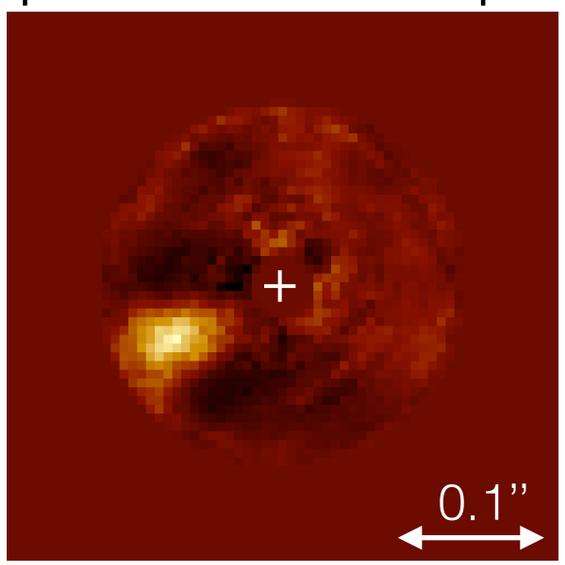


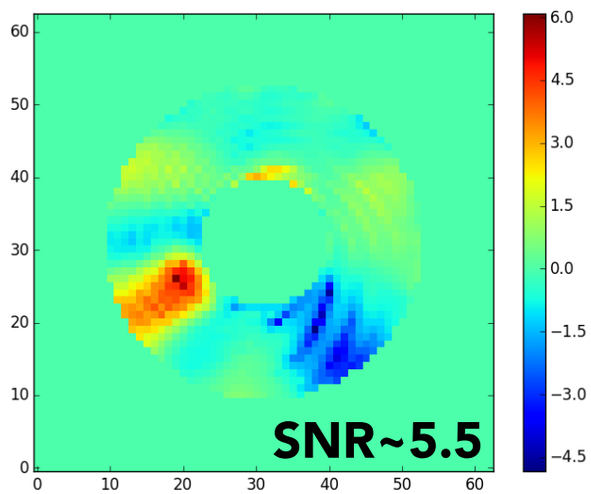
pca-annuli (10pc)





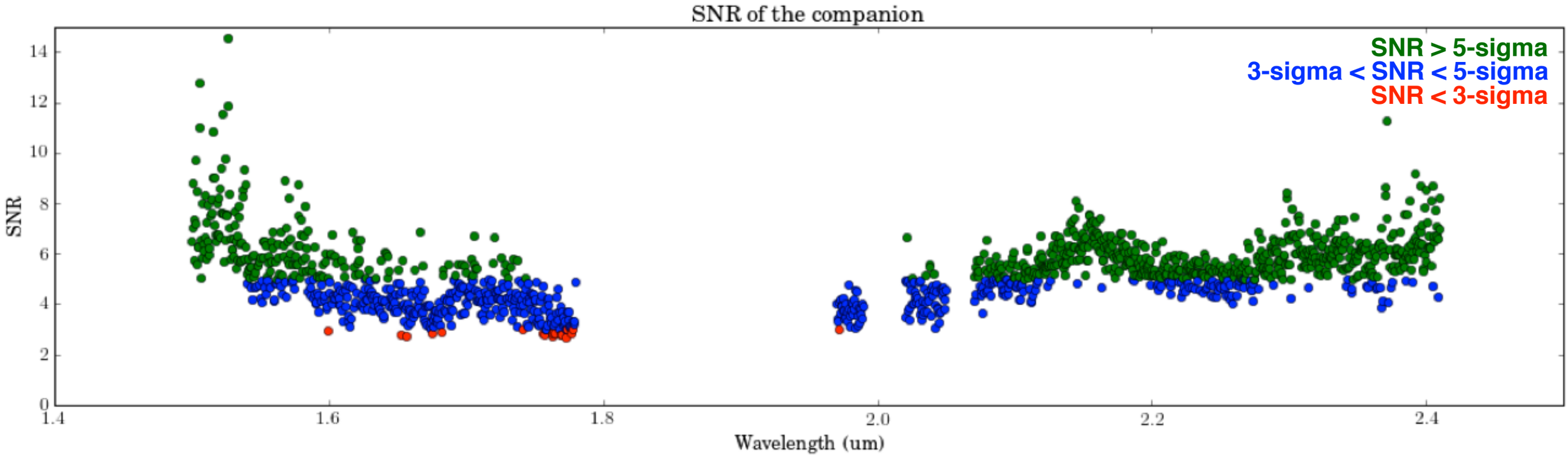
pca-annulus (13pc)





Re-detection of HD 142527 B

For all spectral channels:

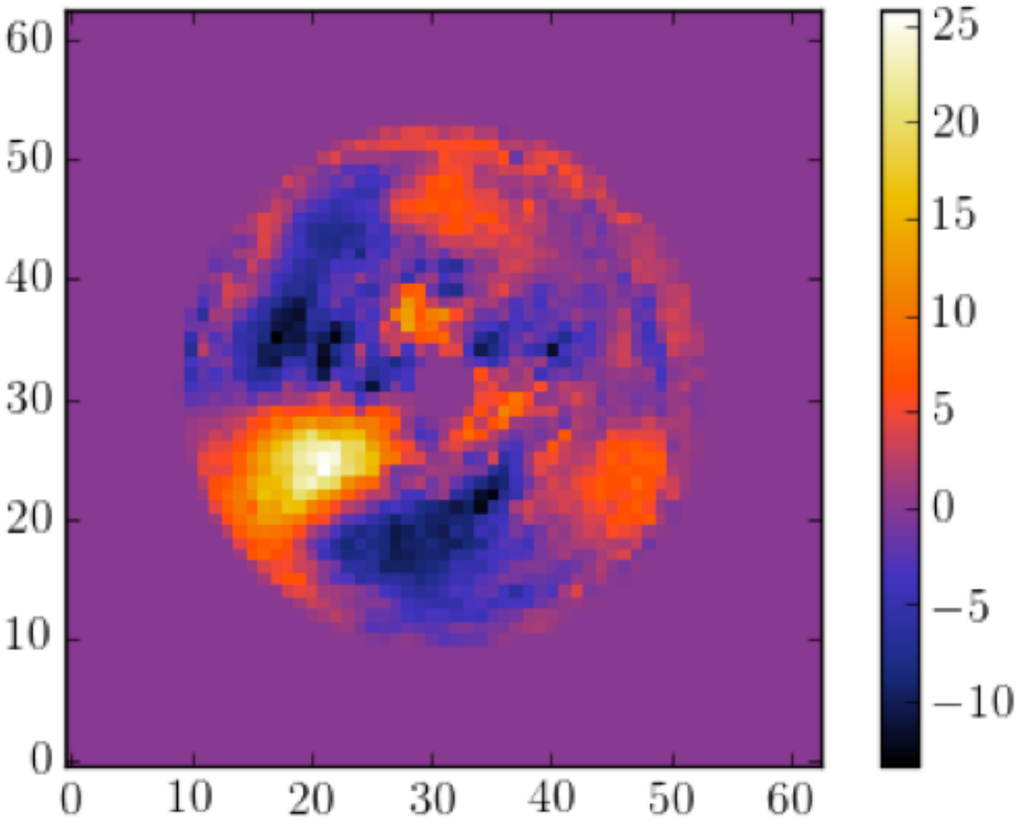


The detection of the companion is > 3-sigma in all but 20 channels

NEGFC technique (Marois+10, Lagrange+10, Wertz+16)

- Inject **negative** fake companions with slightly different *r*, *PA* and *-f* in the original cubes
- PCA-ADI
- Optimal parameters minimize residual flux or stddev in post-processed image
- Optimization with a simplex algorithm

PCA-processed image on original cube



PCA-processed image after injection of an optimal negative fake companion

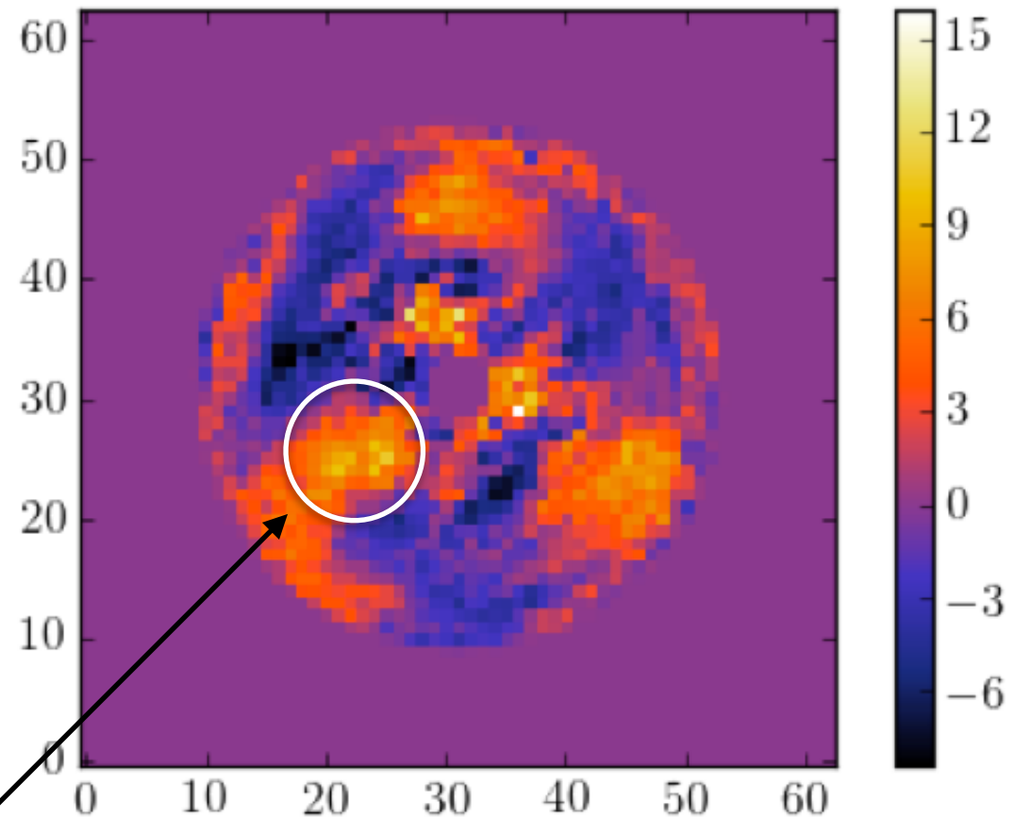
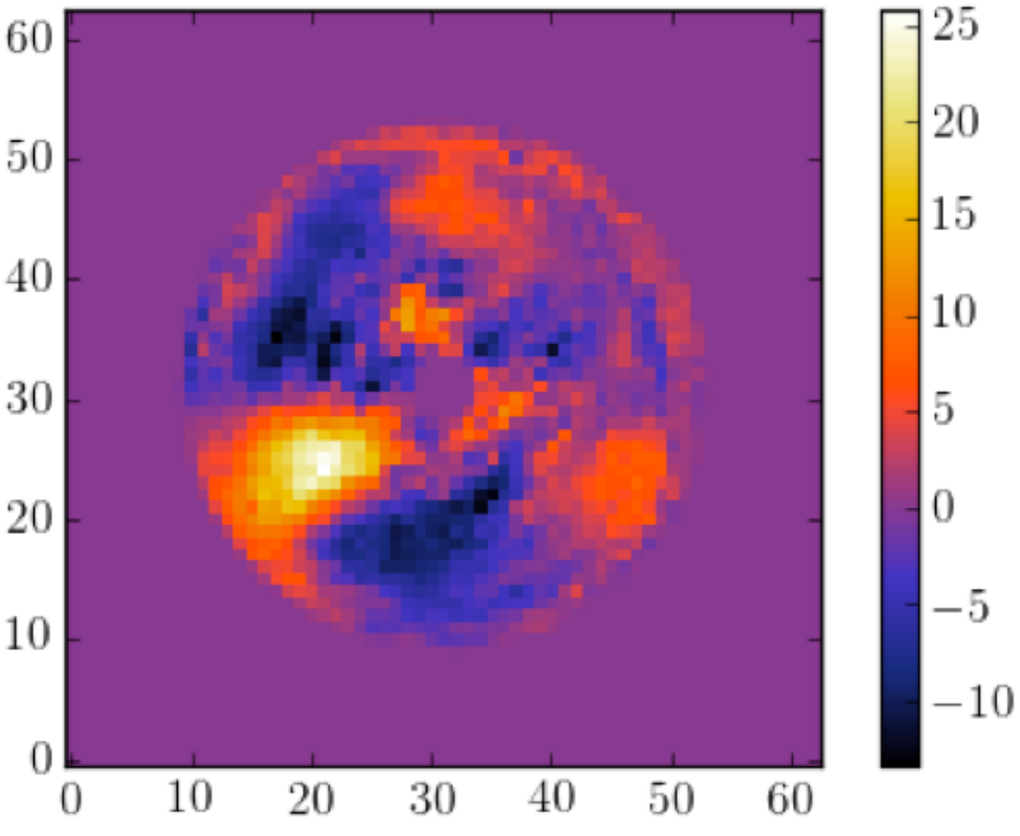


figure of merit: minimize either residual flux or stddev in this area

NEGFC technique (Marois+10, Lagrange+10, Wertz+16)

- Inject **negative** fake companions with slightly different *r*, *PA* and *f* in the original cubes
- PCA-ADI
- Optimal parameters minimize residual ~~flux or~~ **stddev** in post-processed image
- Optimization with a downward simplex algorithm

PCA-processed image on original cube



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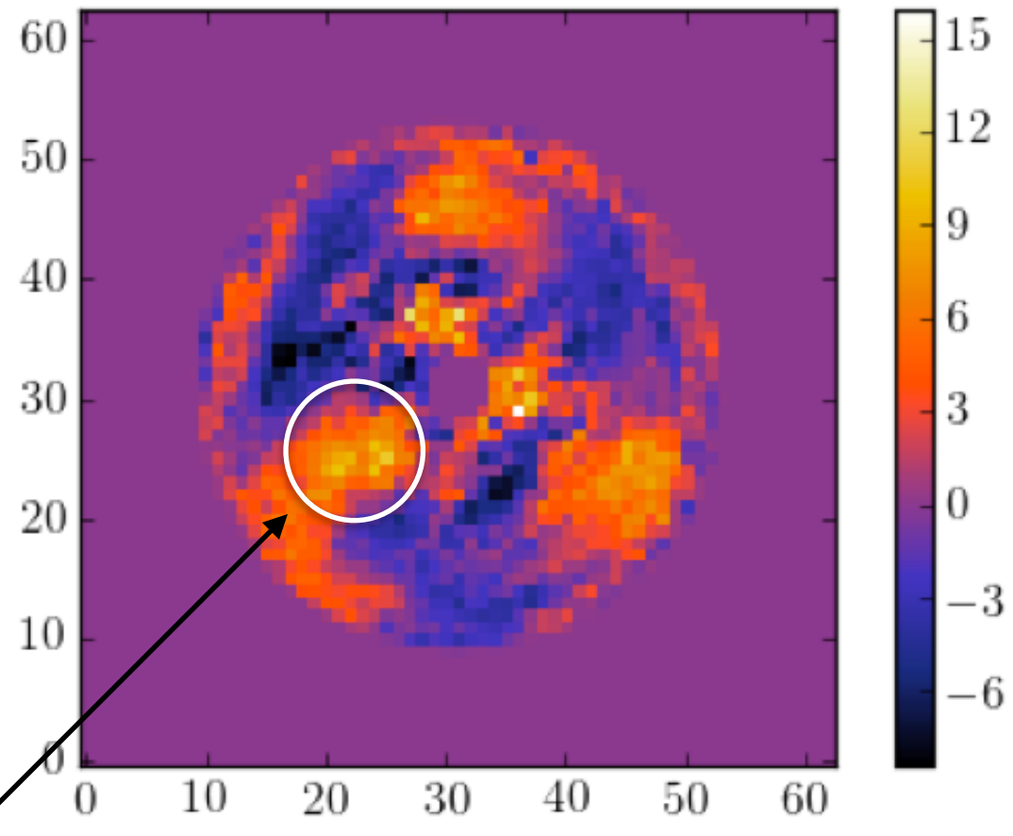
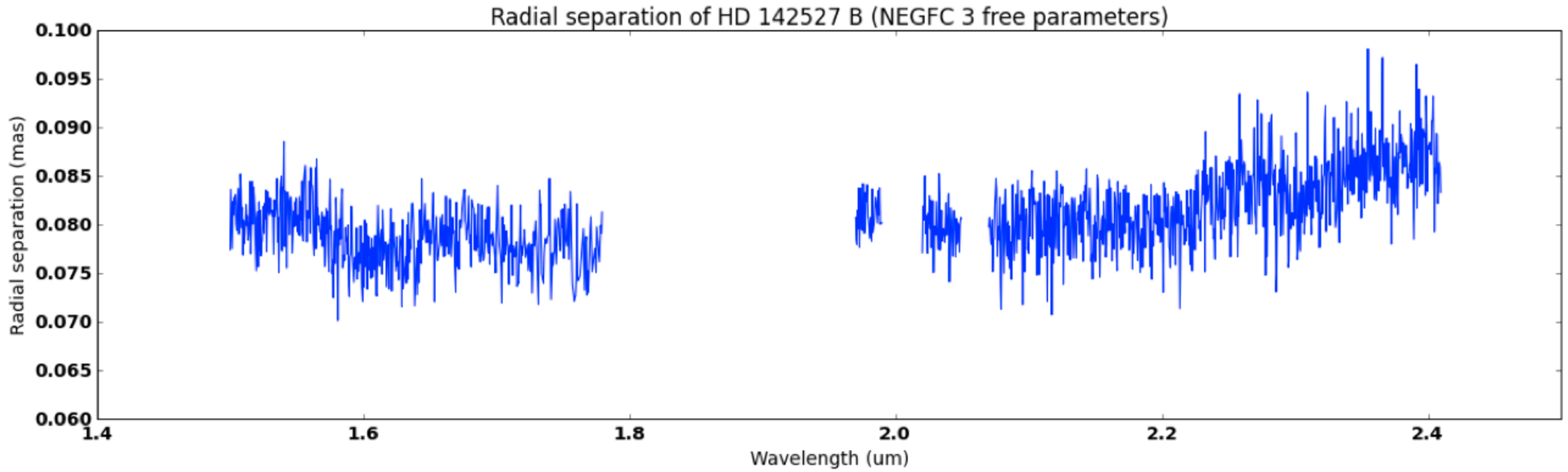


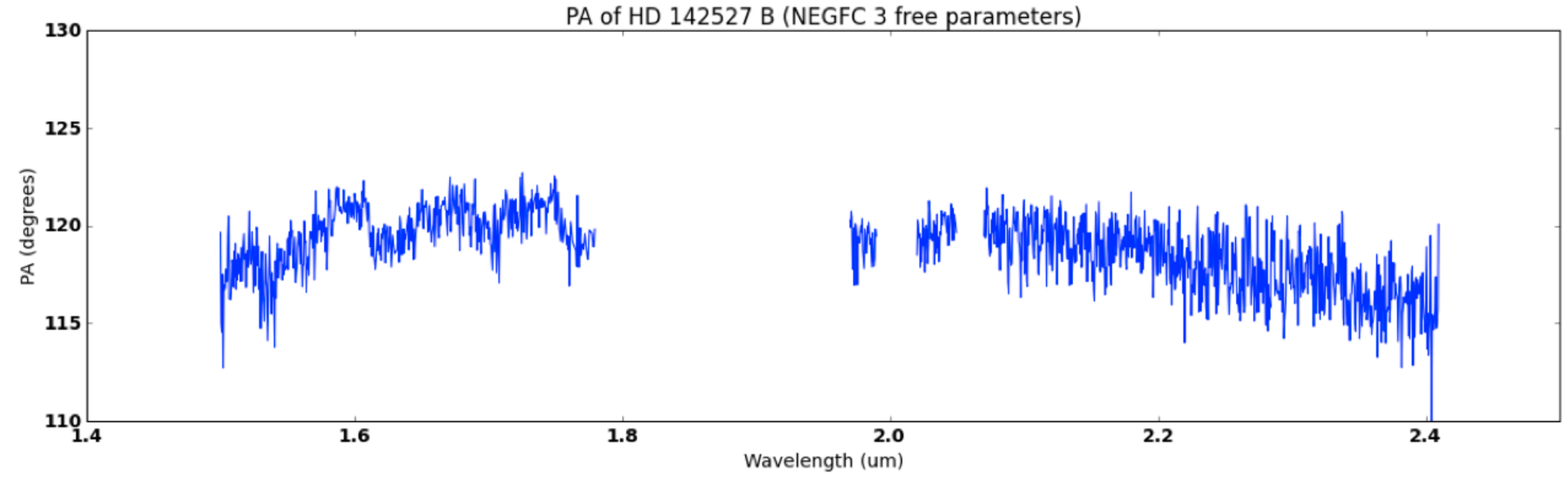
figure of merit: minimize ~~either residual flux or~~ **stddev** in this area

Position and contrast of HD 142527 B

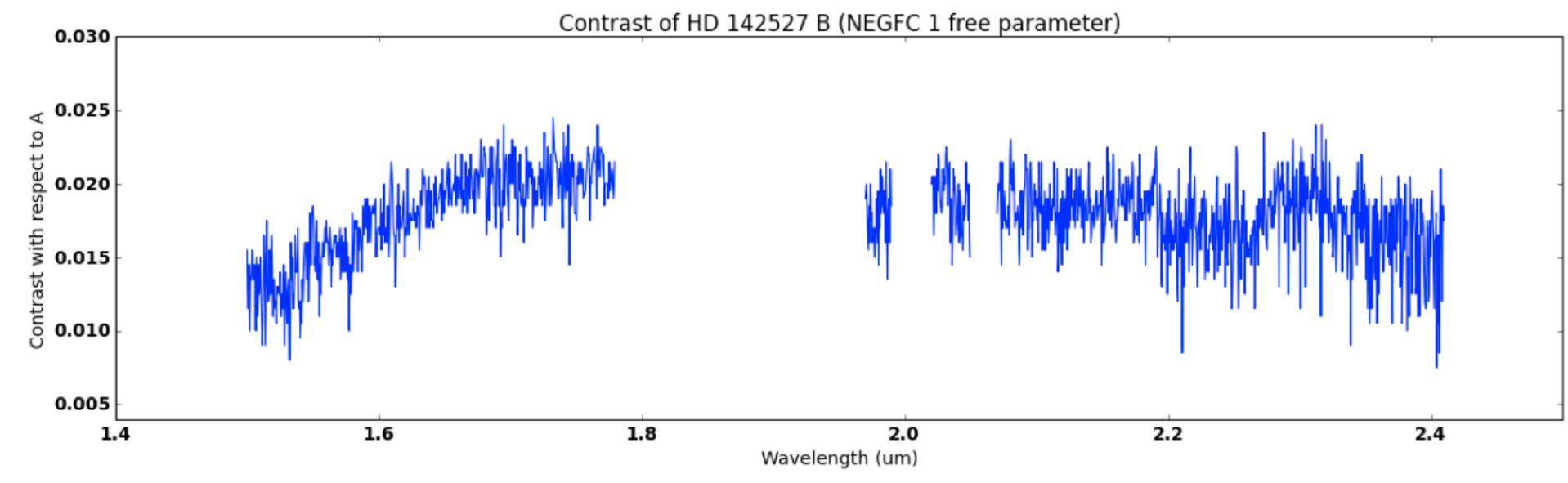


median: 80.4 mas
stat. error: 4.1 mas

in agreement with previous detections



median: 119.1°
stat. error: 1.8°

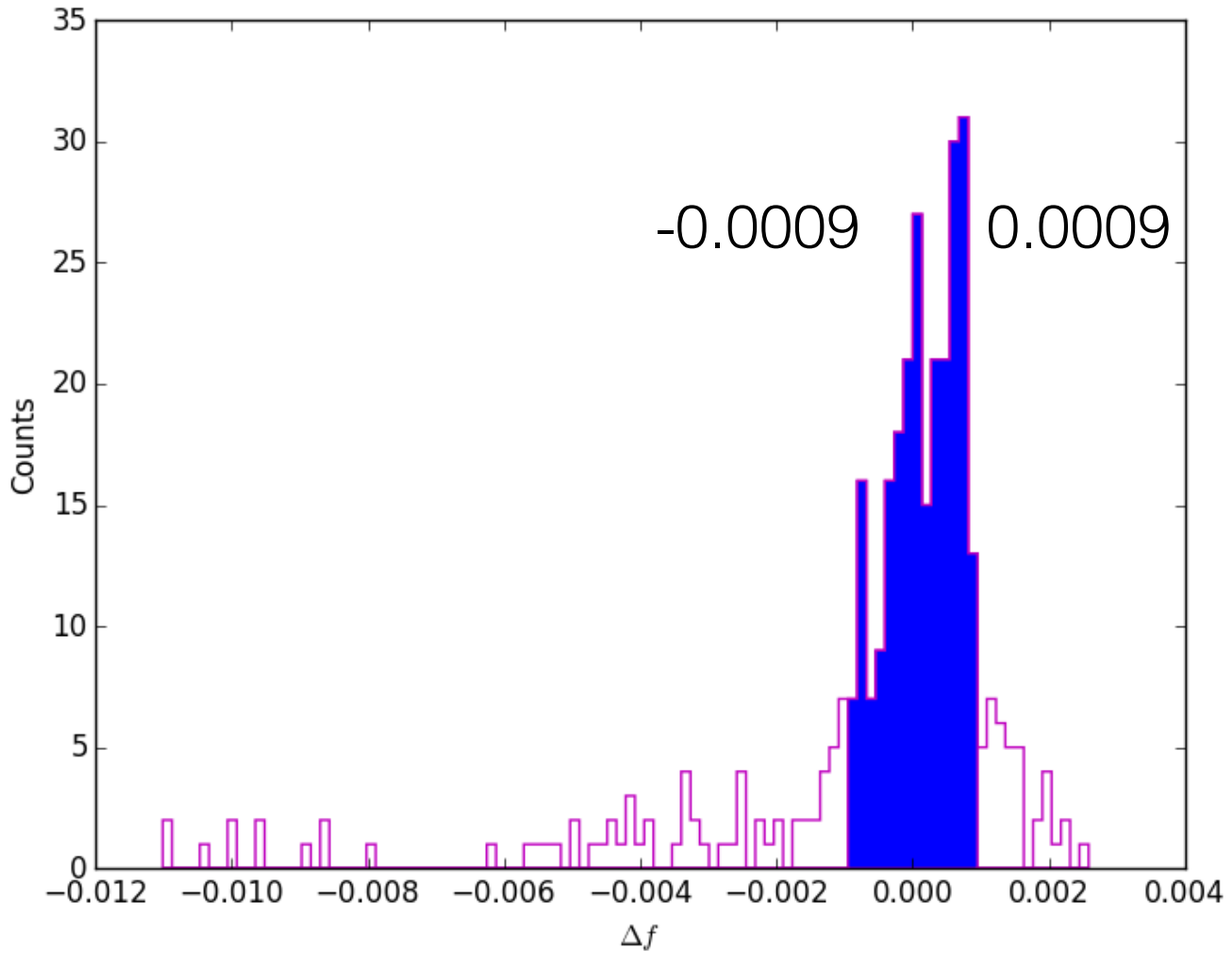


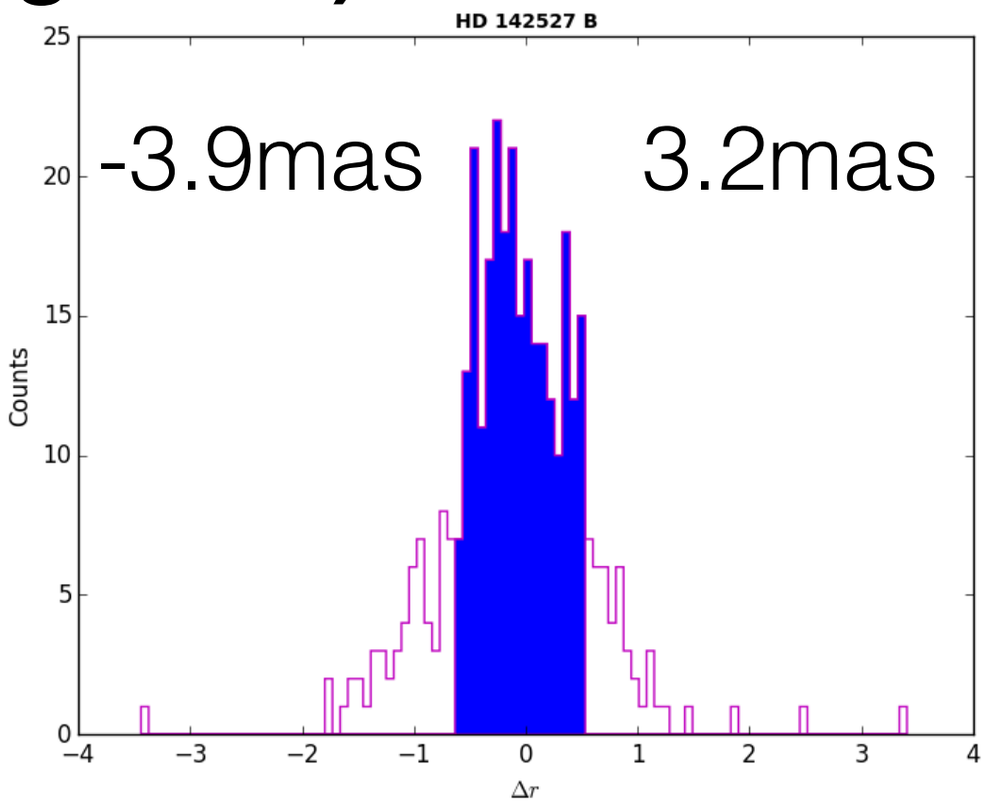
=> contrast varies between 1/100 to 1/50

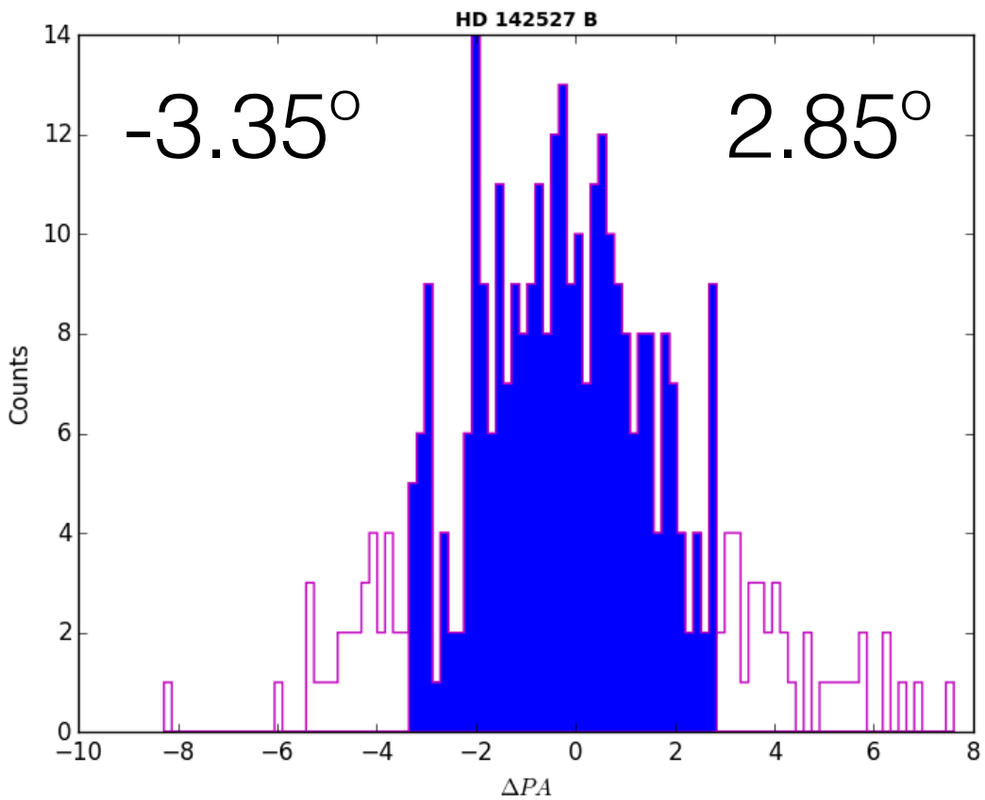
Uncertainties estimates due to residual speckle noise

In one channel (Br-gamma)

- Remove the companion from original frames
- Inject 360 **positive** fake companions on a same annulus as the companion, at its estimated flux
- Use NEGFC to determine (fake) companion parameters
- Measure the deviations with known injection parameters (*r*, *PA* and *contrast*)

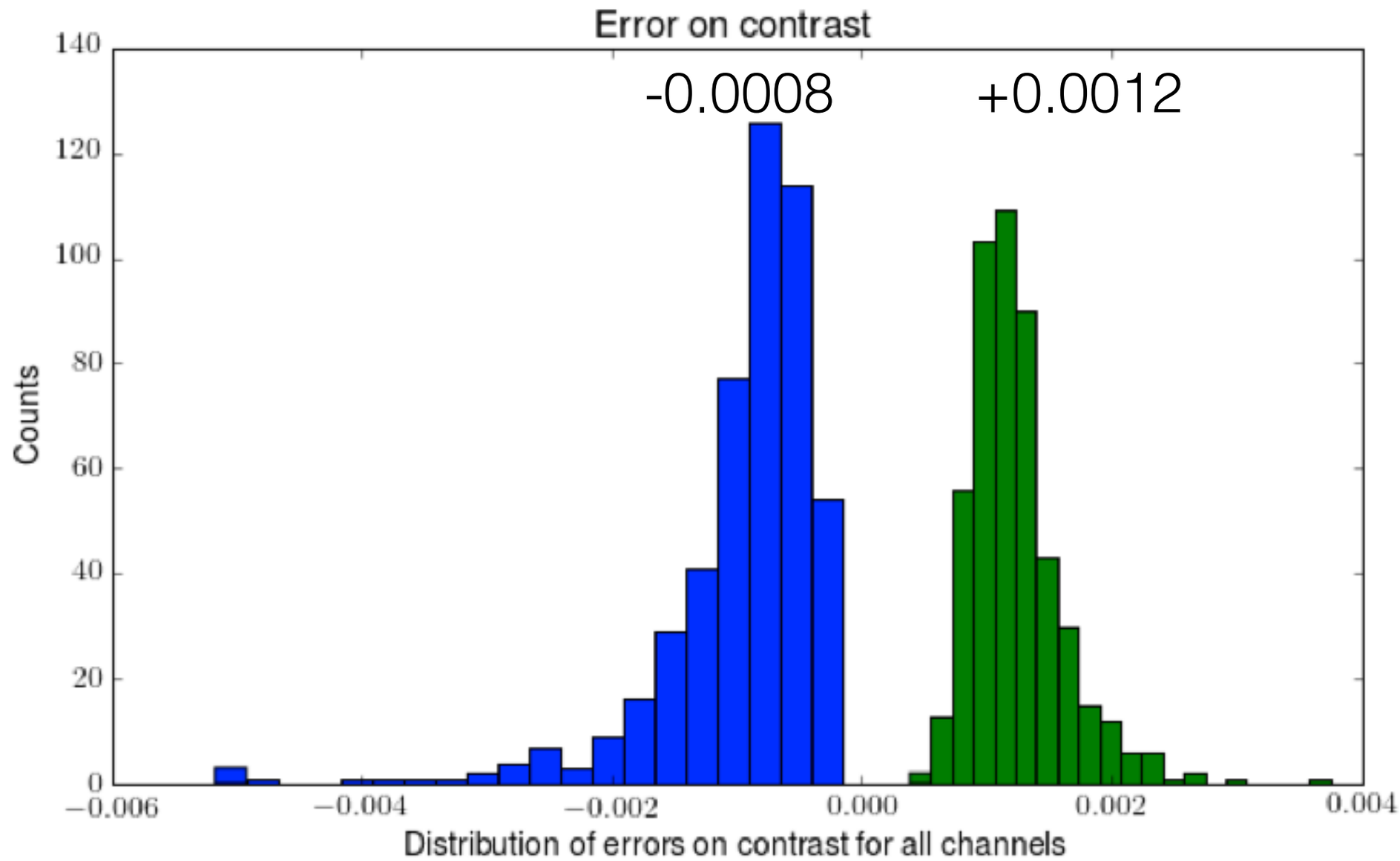






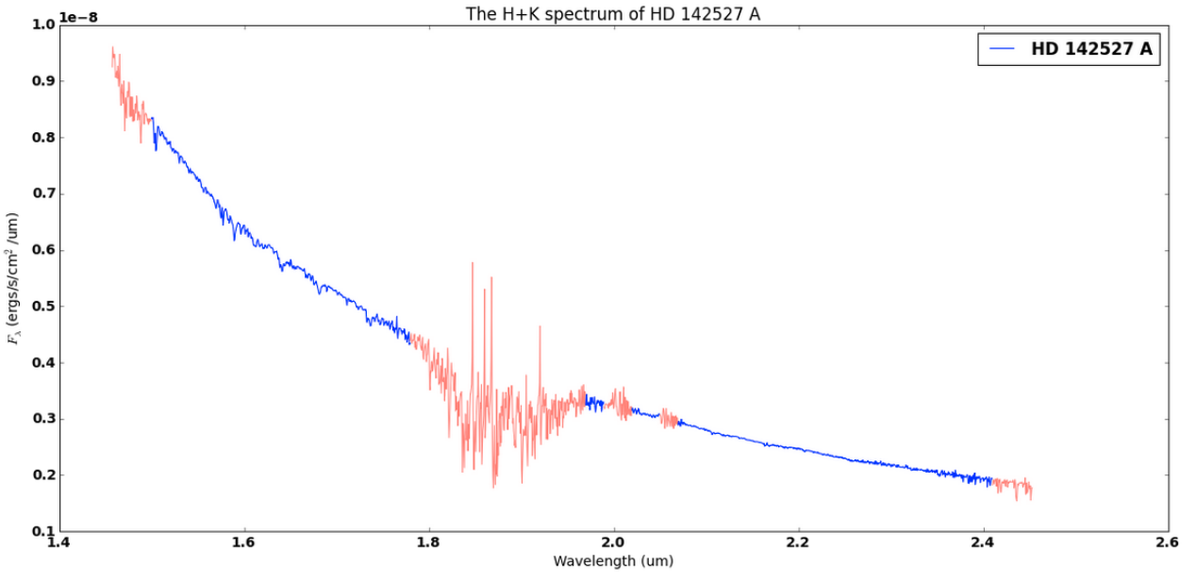
Uncertainties estimates due to residual speckle noise

Across all channels (preliminary)

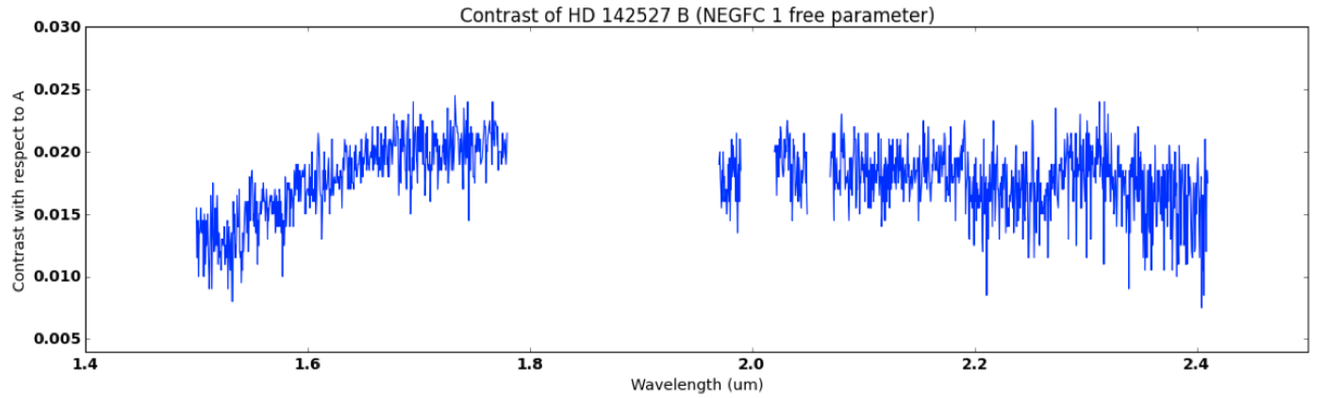


=> 5-10% rel. uncertainty on the contrast across the spectrum

Spectrum of HD 142527 B



X



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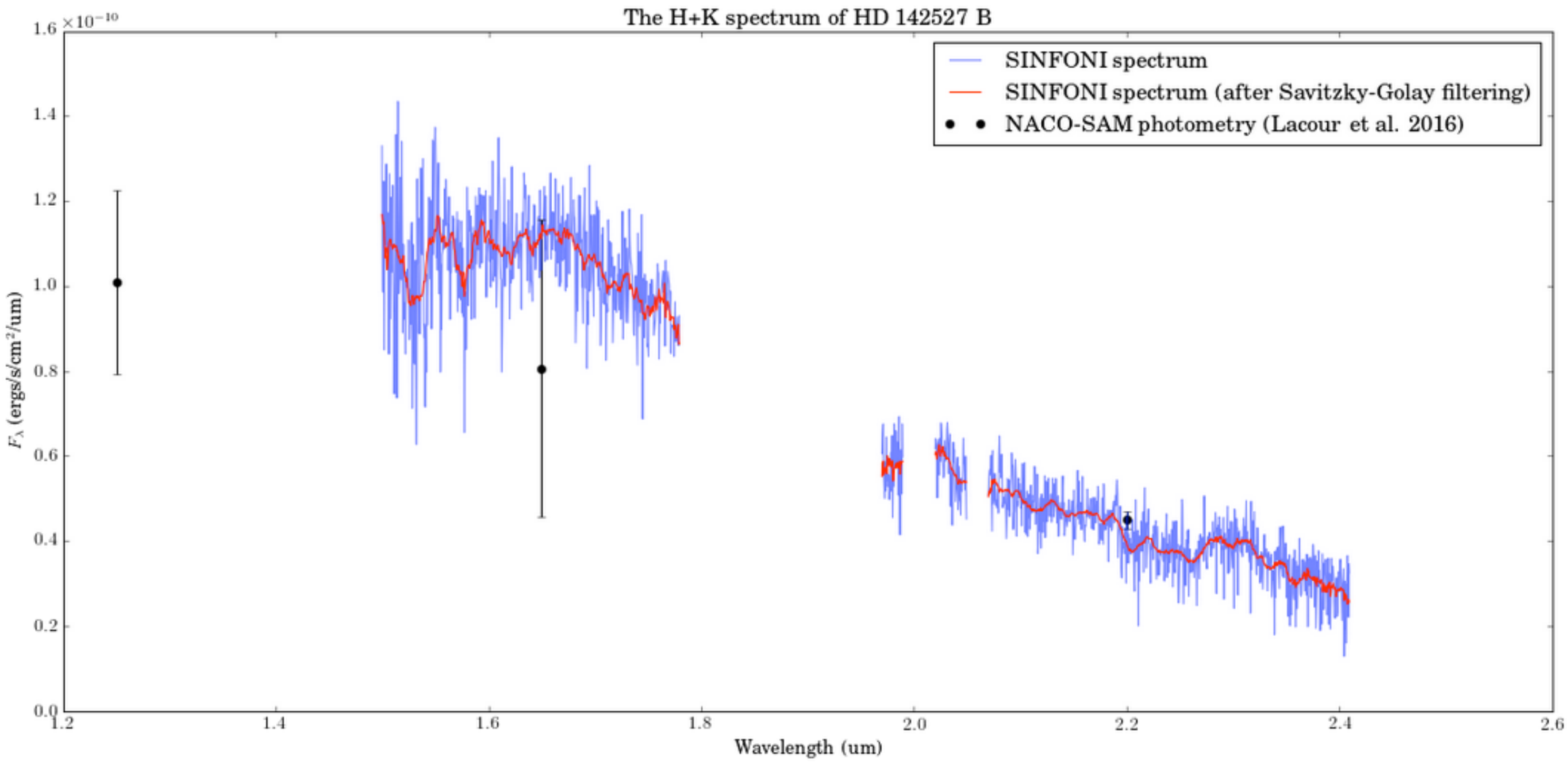
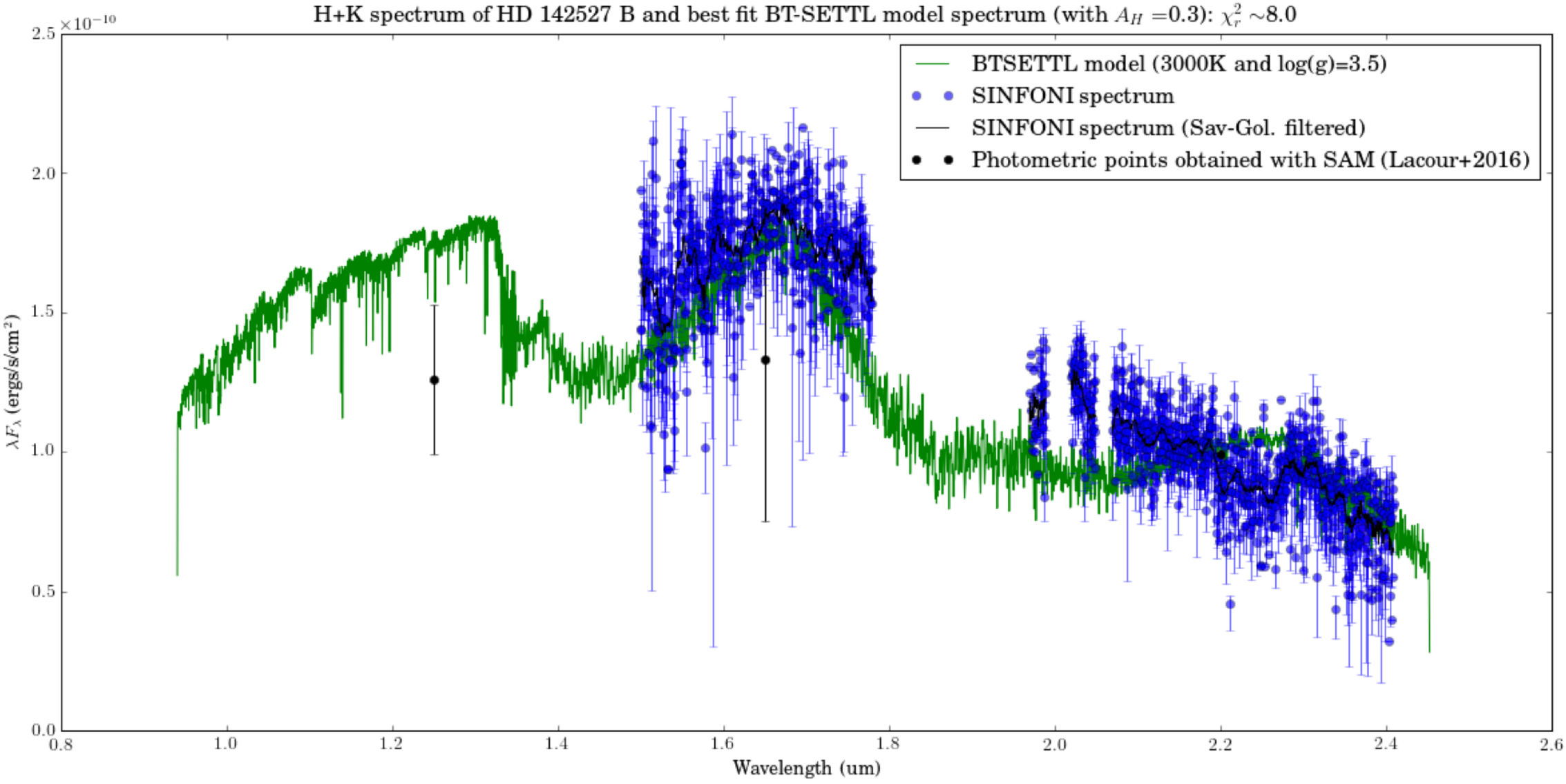
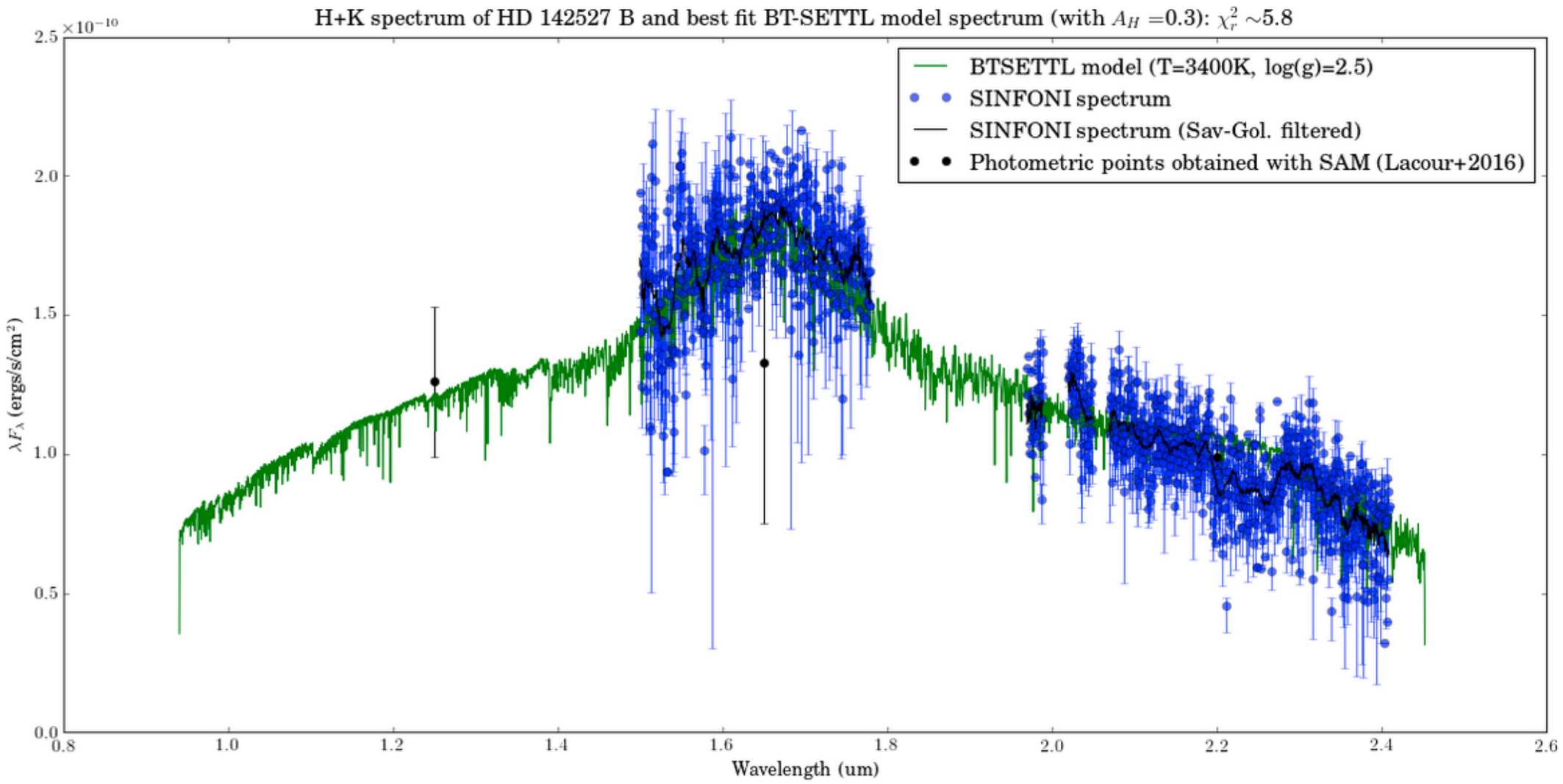


Interpretation of the spectrum of B



- not a very good fit
- the fit gets worse when injecting a 1700K circum-secondary component

Interpretation of the spectrum of B



Best fit parameters for the BT-SETTL model:

$$\begin{cases} T_B = 3400 \pm 50\mathrm{K} \\ \log(g) = 2.5 \pm 1.0 \\ R_B = 1.1 \pm 0.02 R_\odot \\ A_H = 0.3 \pm 0.05 \end{cases}$$

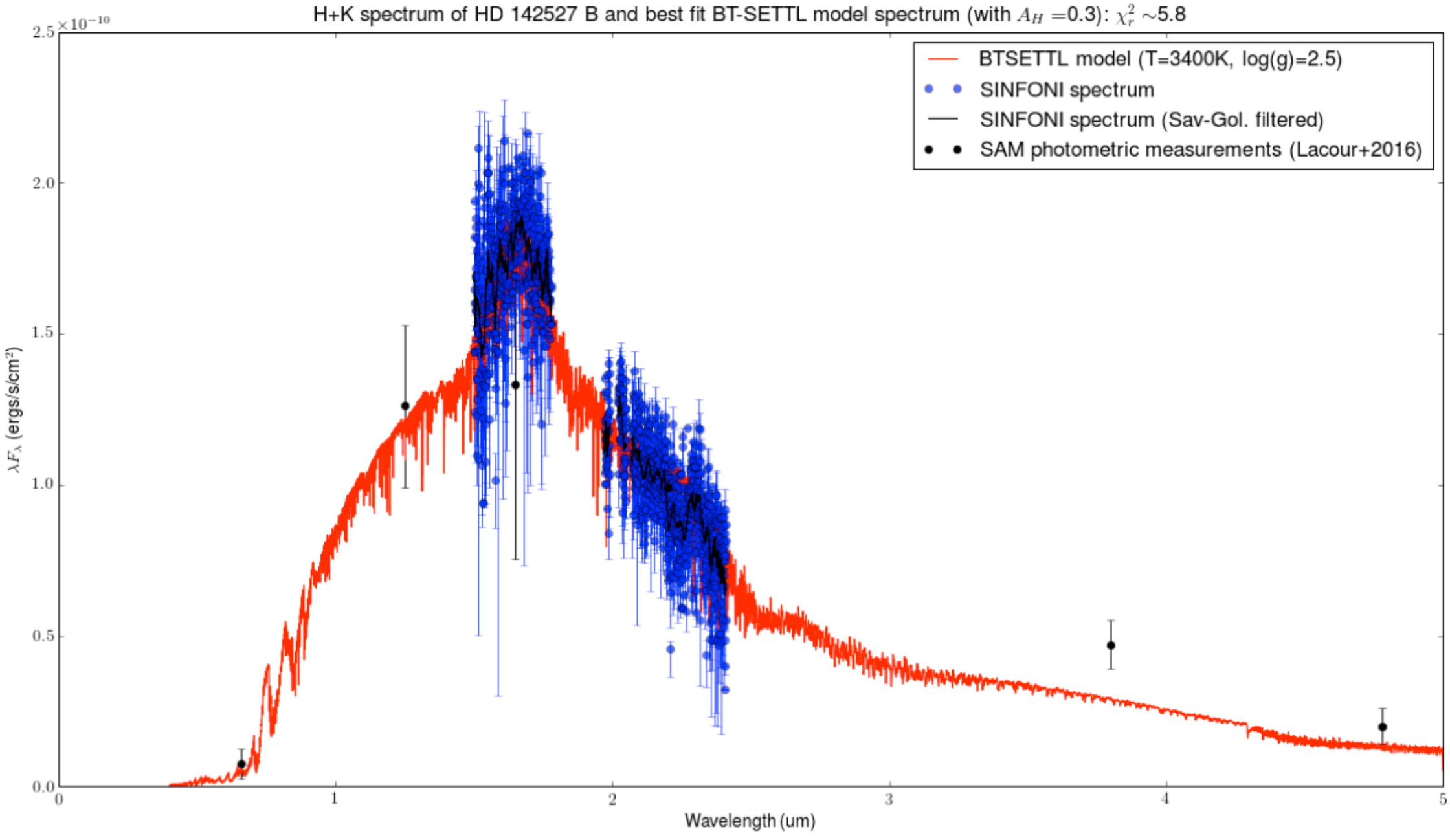
Using L. Siess on-line stellar parameter tool (based on PMS tracks)

$$\Rightarrow \quad \begin{cases} M_B \sim 0.3 M_\odot \\ R_B \sim 1.1 R_\odot \\ \text{Age} \sim 3.6 \text{ Myr old} \end{cases}$$

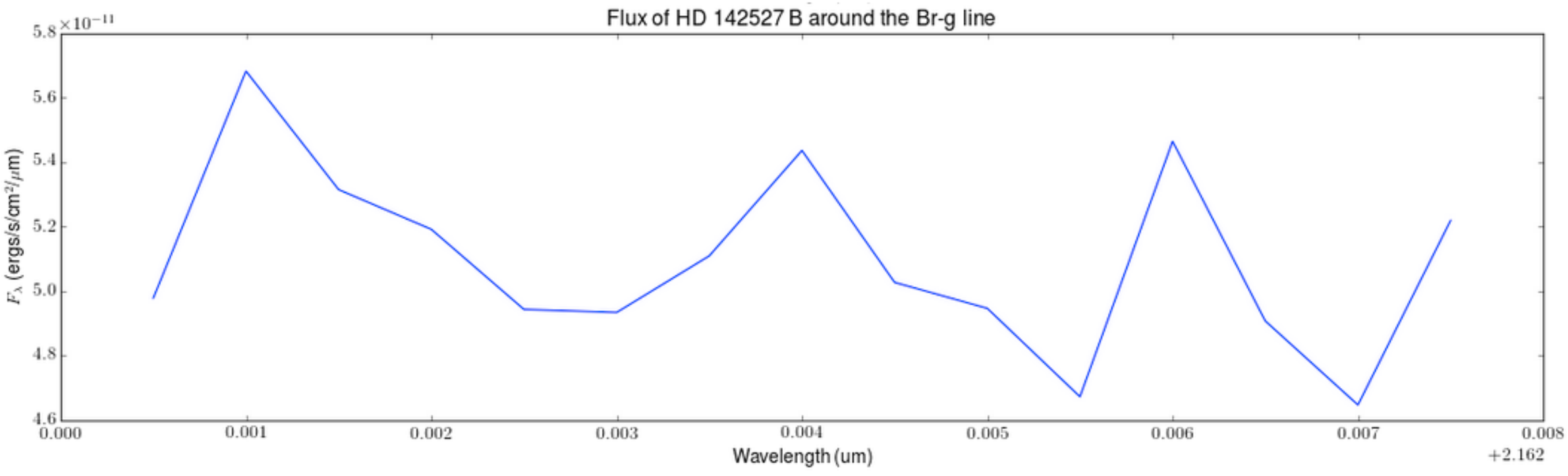
Conclusions

- VLT/SINFONI combined with ADI allows to extract the spectrum of faint low-mass companions
- We obtained the first medium-resolution spectrum of a low-mass companion at less than 0.1” from the central star
- The biases due to residual speckle noise were estimated with the injection of fake companions
- The spectrum of HD 142527 B is well modeled by a 3400K object with log(g)=2.5 => **M ~ 0.3 M_Sun => q ~ 0.15**

Appendix: the whole spectrum of HD 142527 B



Appendix: Br-g line of the companion



Non-significant detection:

$$\log(L_{\rm acc}/L_\odot) = 0.9 \times (\log L({\rm Br}_\gamma)/L_\odot) + 4) - 0.7 \longrightarrow L_{acc} \lesssim 2.5\% L_\odot$$

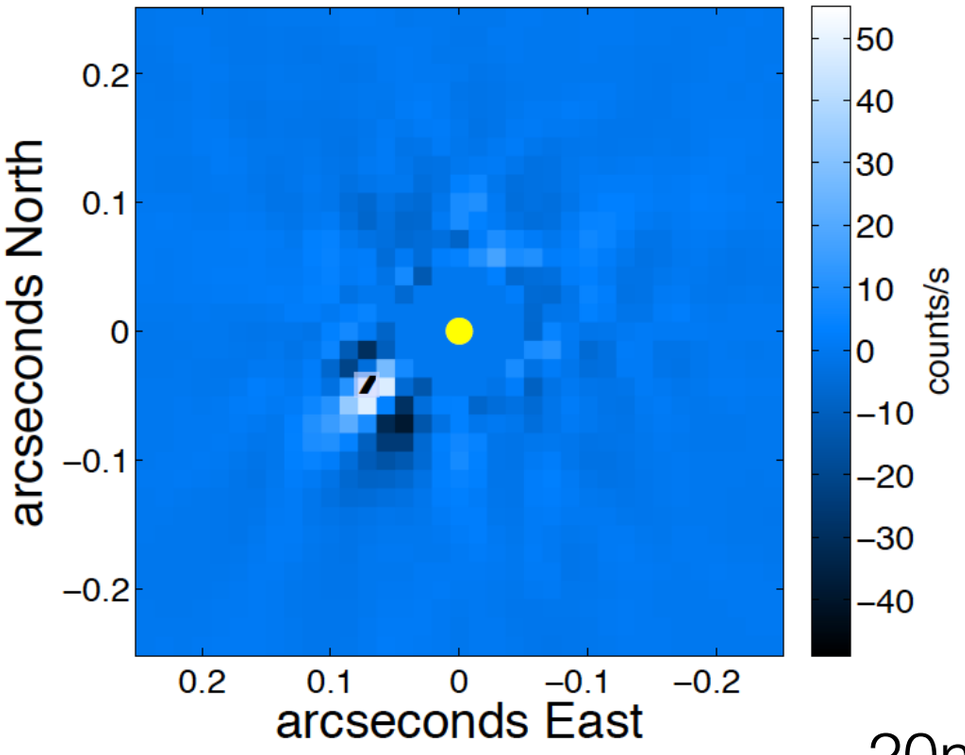
Consistent with the H-alpha detection: $L_{acc} \sim 1.3\% L_\odot$ (Close et al. 2014)

Mass accretion rate: $\dot{M}_B \sim 2 \times 10^{-9} M_\odot {\rm yr}^{-1}$

$\dot{M}_B \sim 0.01 \dot{M}_A$

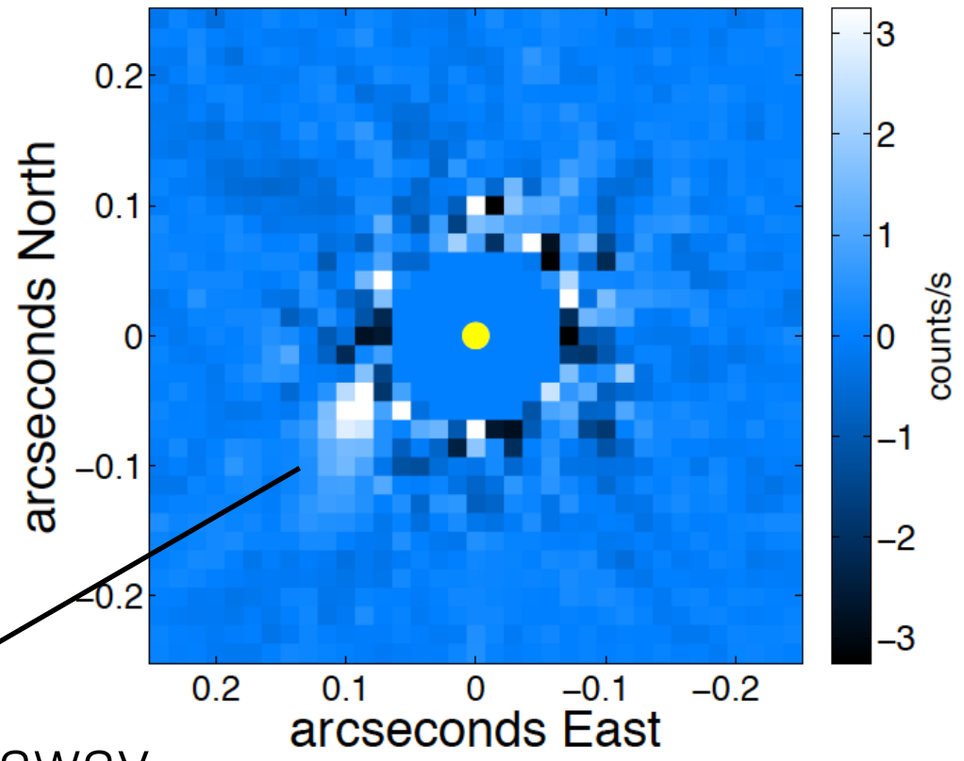
Appendix: extended emission

Full intensity image (Y-band)



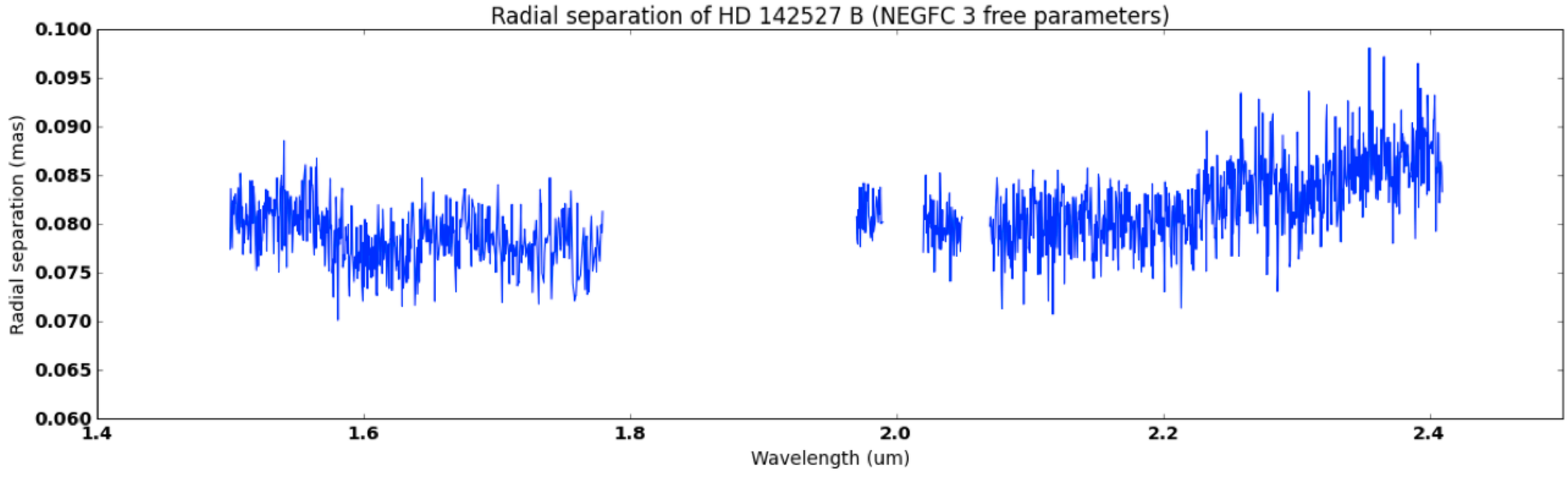
Rodigas et al. 2014

Polarized image (Y-band)



~20mas further away

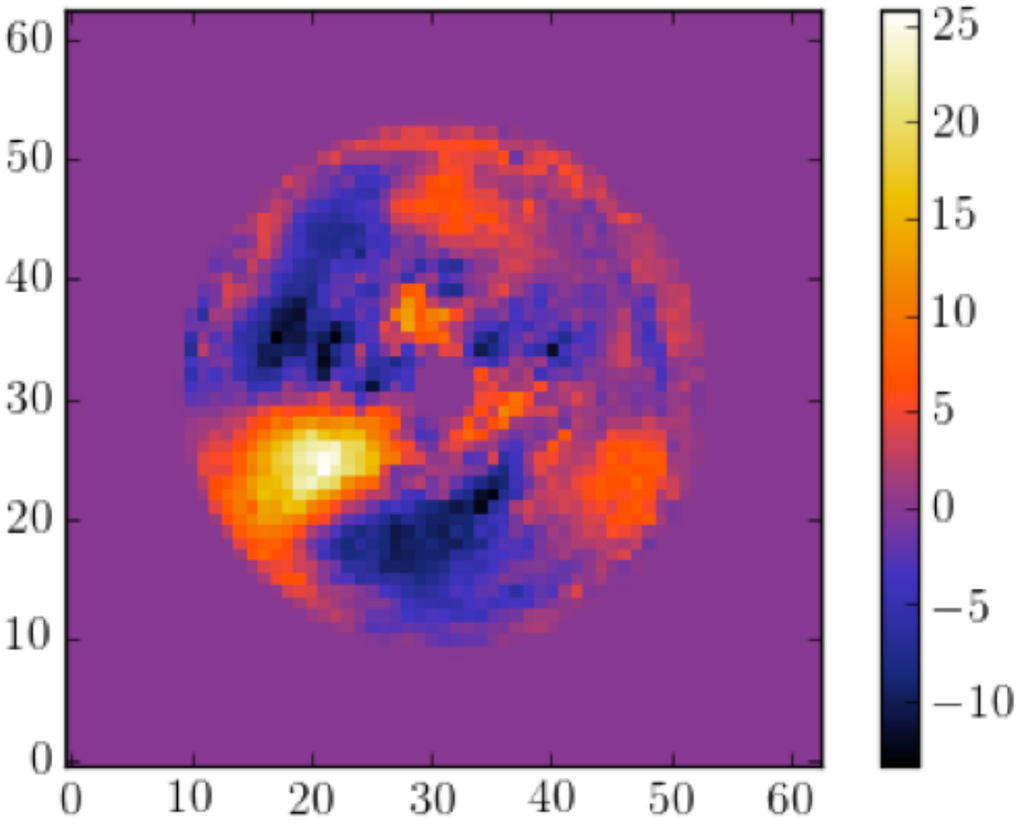
Rodigas et al. 2014



NEGFC technique (Marois+10, Lagrange+10, Wertz+16)

- Inject **negative** fake companions with slightly different *r*, *PA* and *f* in the original cubes
- PCA-ADI
- Optimal parameters minimize residual flux or stddev in PCA-processed image
- Optimization with a downward simplex algorithm

PCA-processed image on original cube



PCA-processed image after injection of an optimal negative fake companion

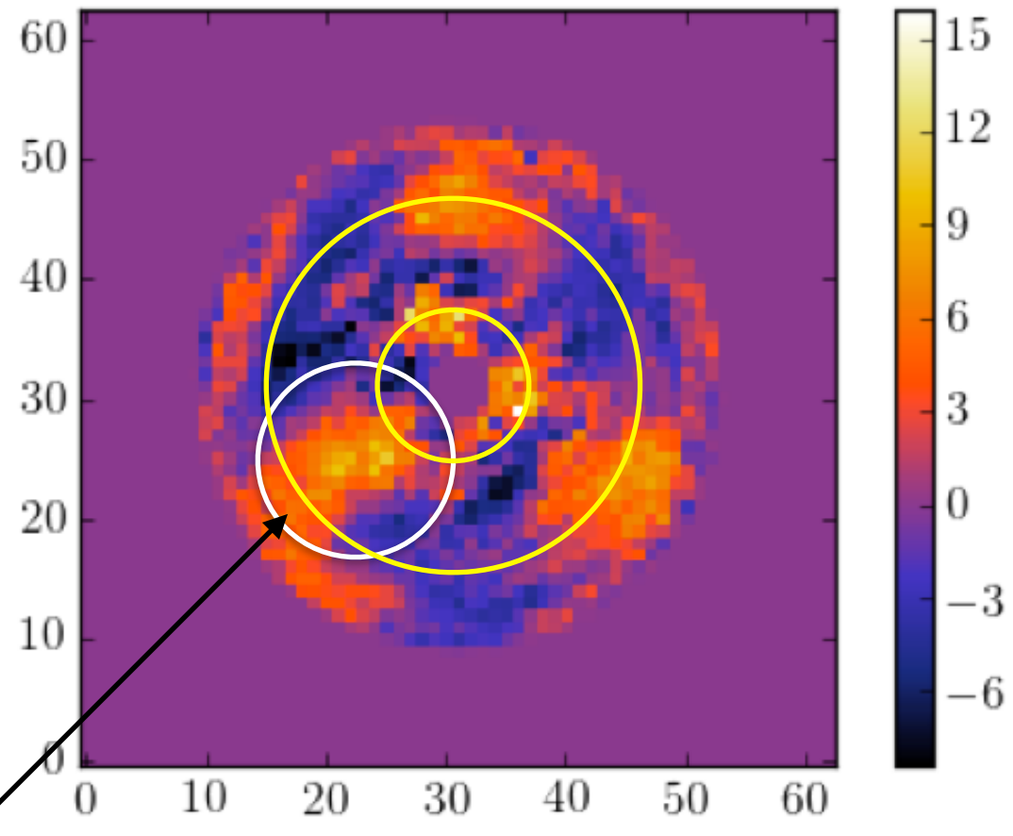
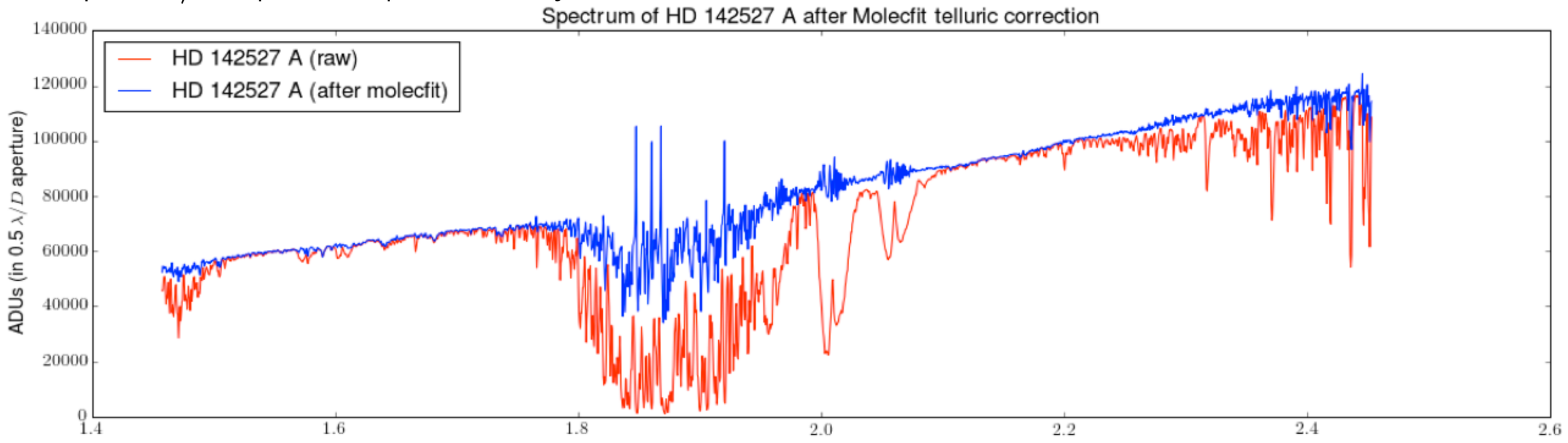


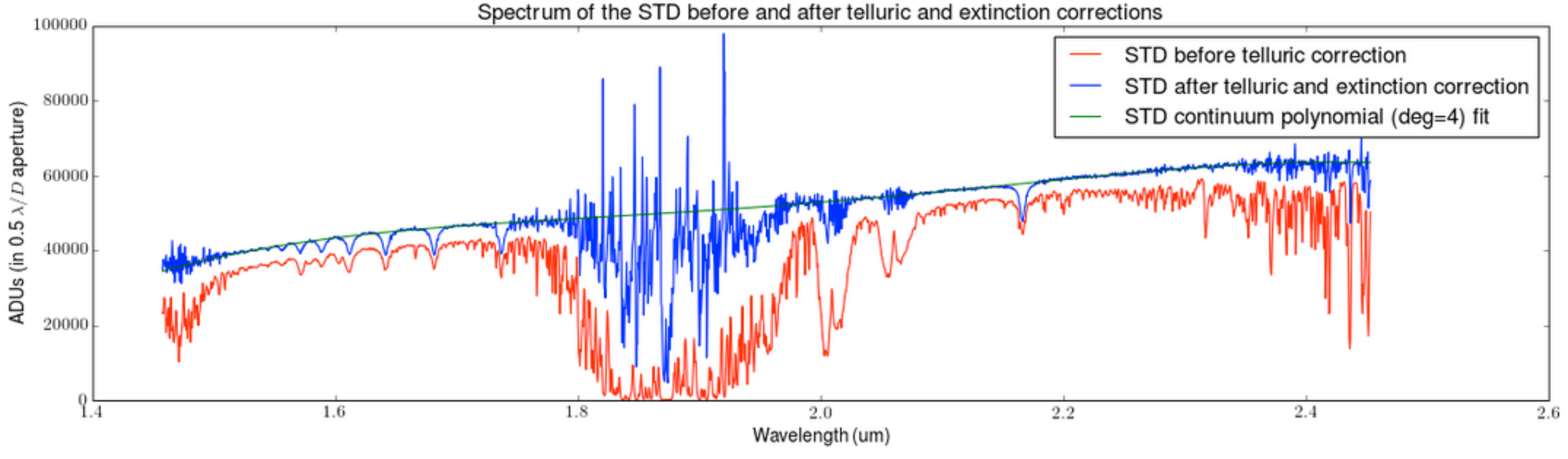
figure of merit: minimize either residual flux or stddev in this area

Appendix: Calibration of HD 142527 A spectrum

Simple $1\lambda/D$ aperture photometry measurement centered on the star in each channel

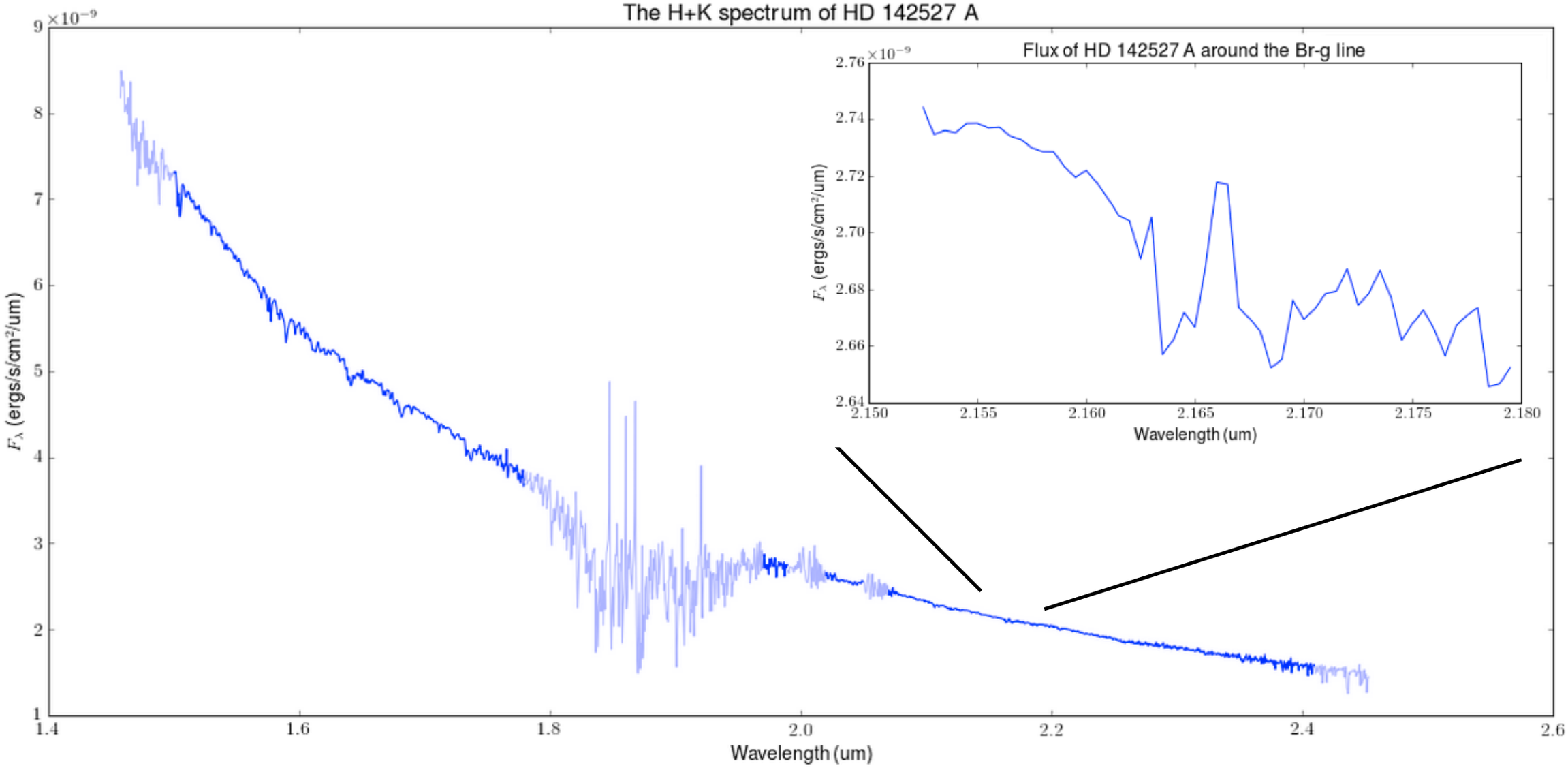


We use the B8V STD to correct for the instrumental response;
a B8V star should have a 12300K BB continuum shape

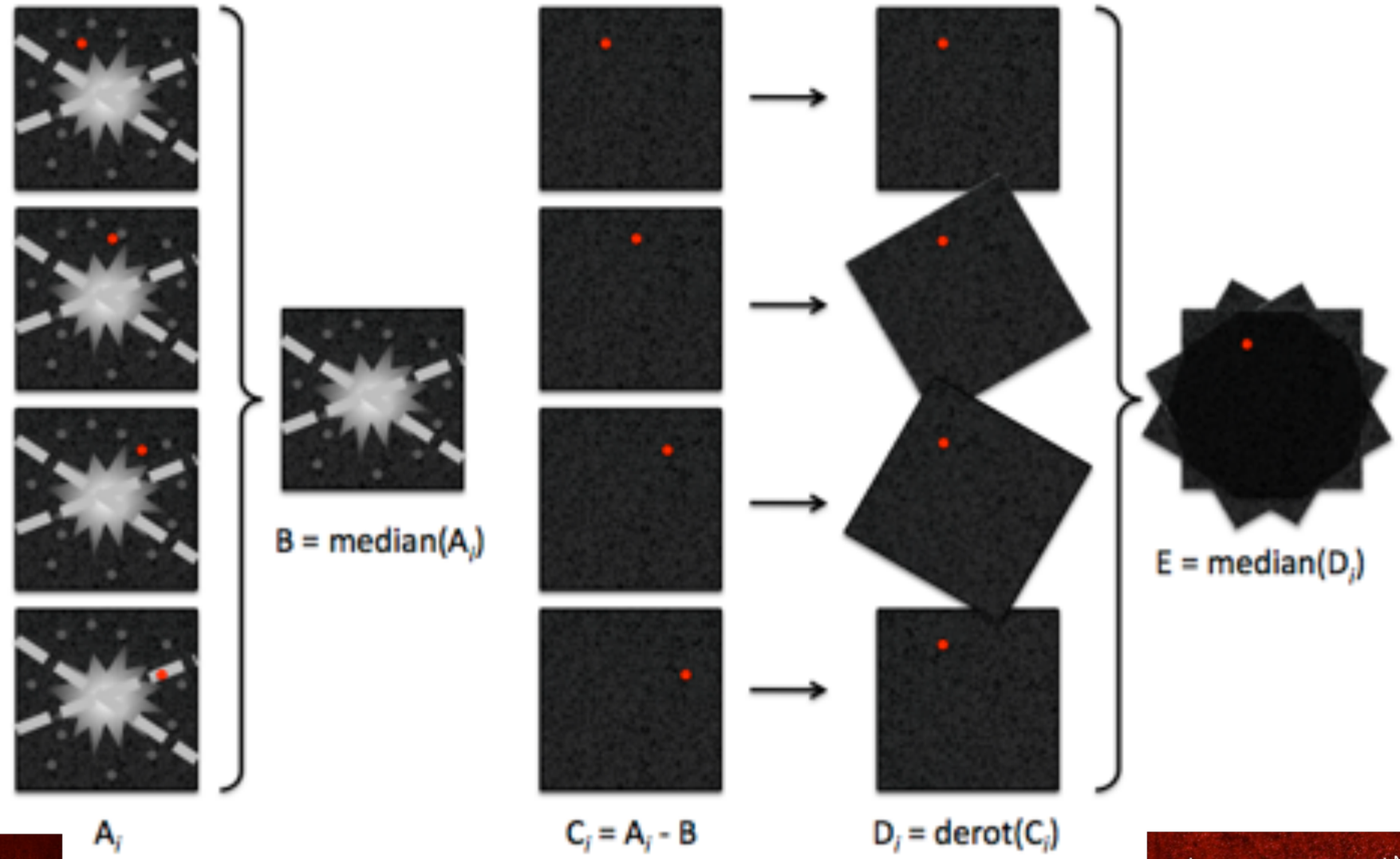


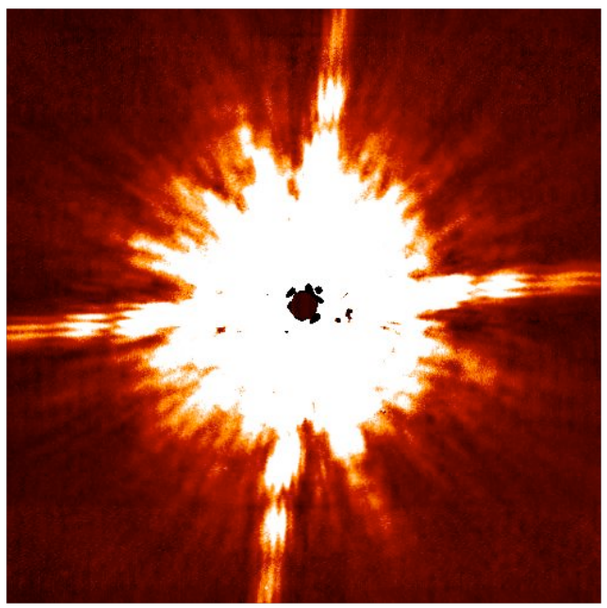
Appendix: Spectrum of HD 142527 A

- $1\lambda/D$ aperture photometry centered on the star in each channel => raw spectrum
- Use of Molecfit to correct it from telluric lines
- Use of the STD star to correct it for the instrumental response
- The spectrum is less reliable in low atmospheric transmission wavelength ranges (light red)

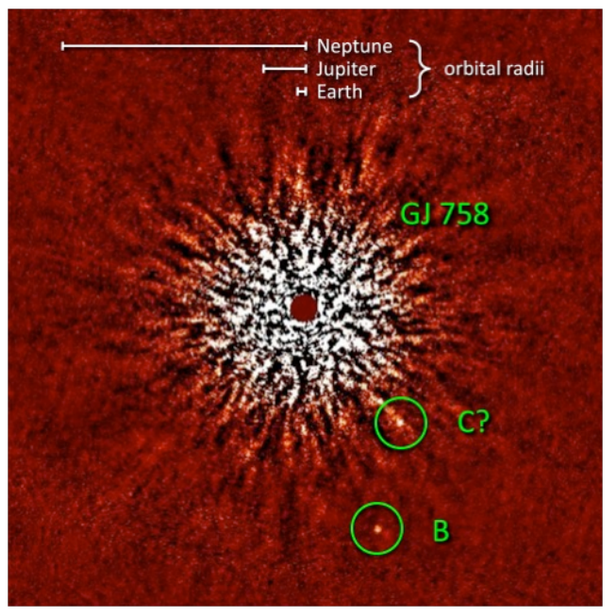


Appendix: Angular Differential Imaging (ADI)

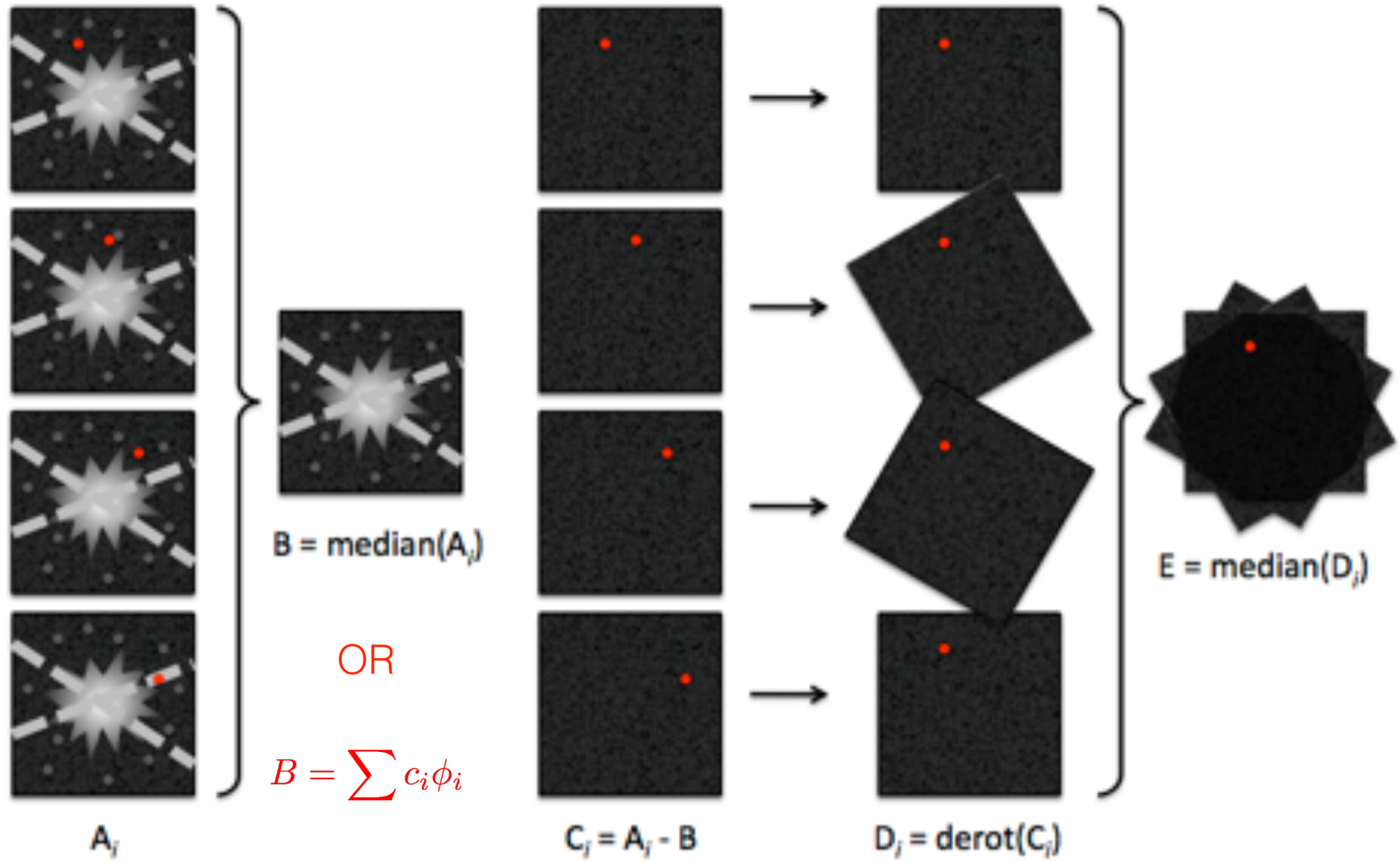




credit: C. Thalmann



Appendix: ADI with Principal Component Analysis



credit: C. Thalmann

where

$\{\phi_1, \phi_2, ...\phi_N\}$ is an orthogonal basis constructed from Principal Component Analysis applied to our data frames A_i (e.g. using Singular Value Decomposition)

$\{c_1, c_2, ...c_N\}$ are scalar coefficients