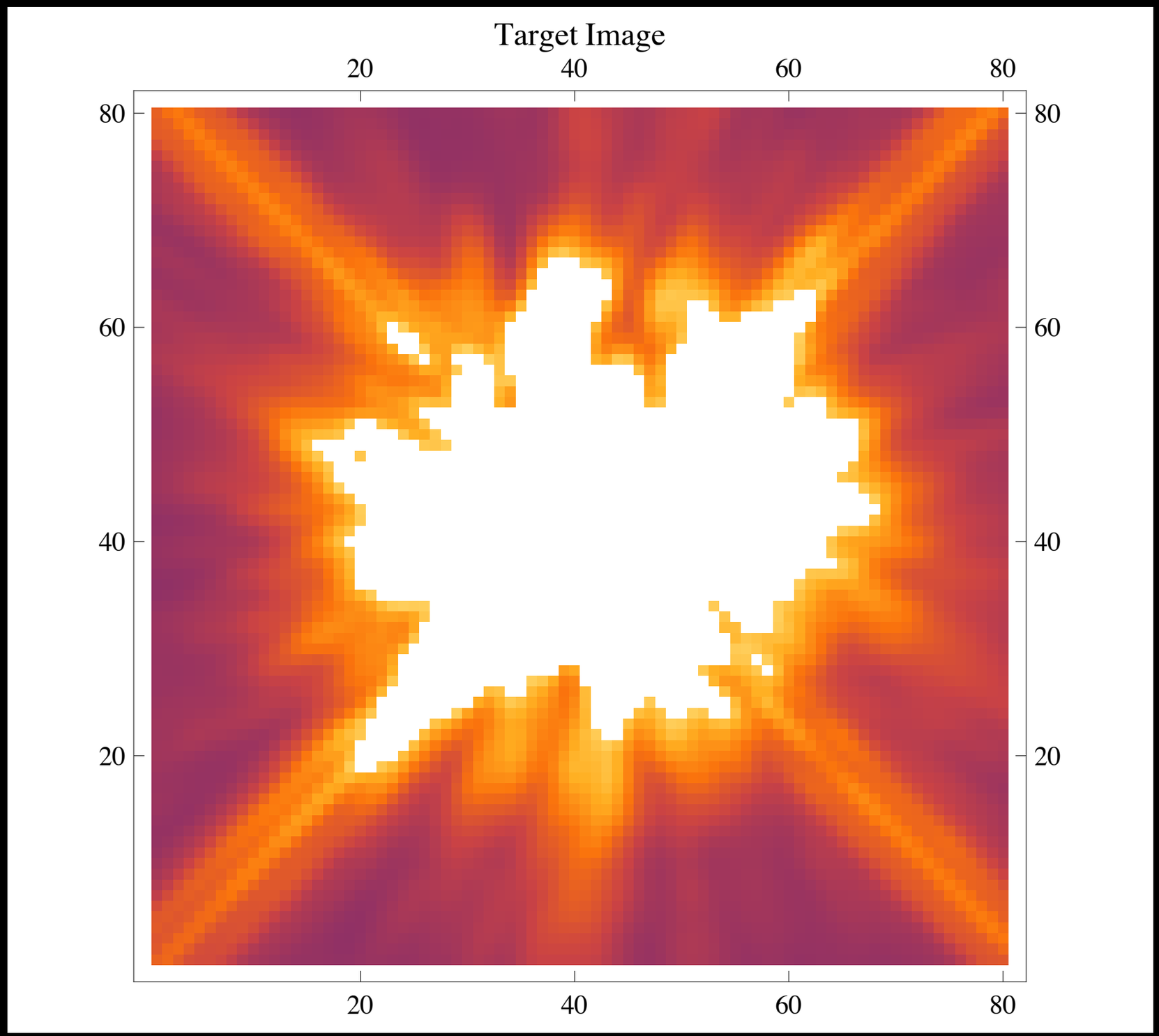
Algorithms for high contrast imaging

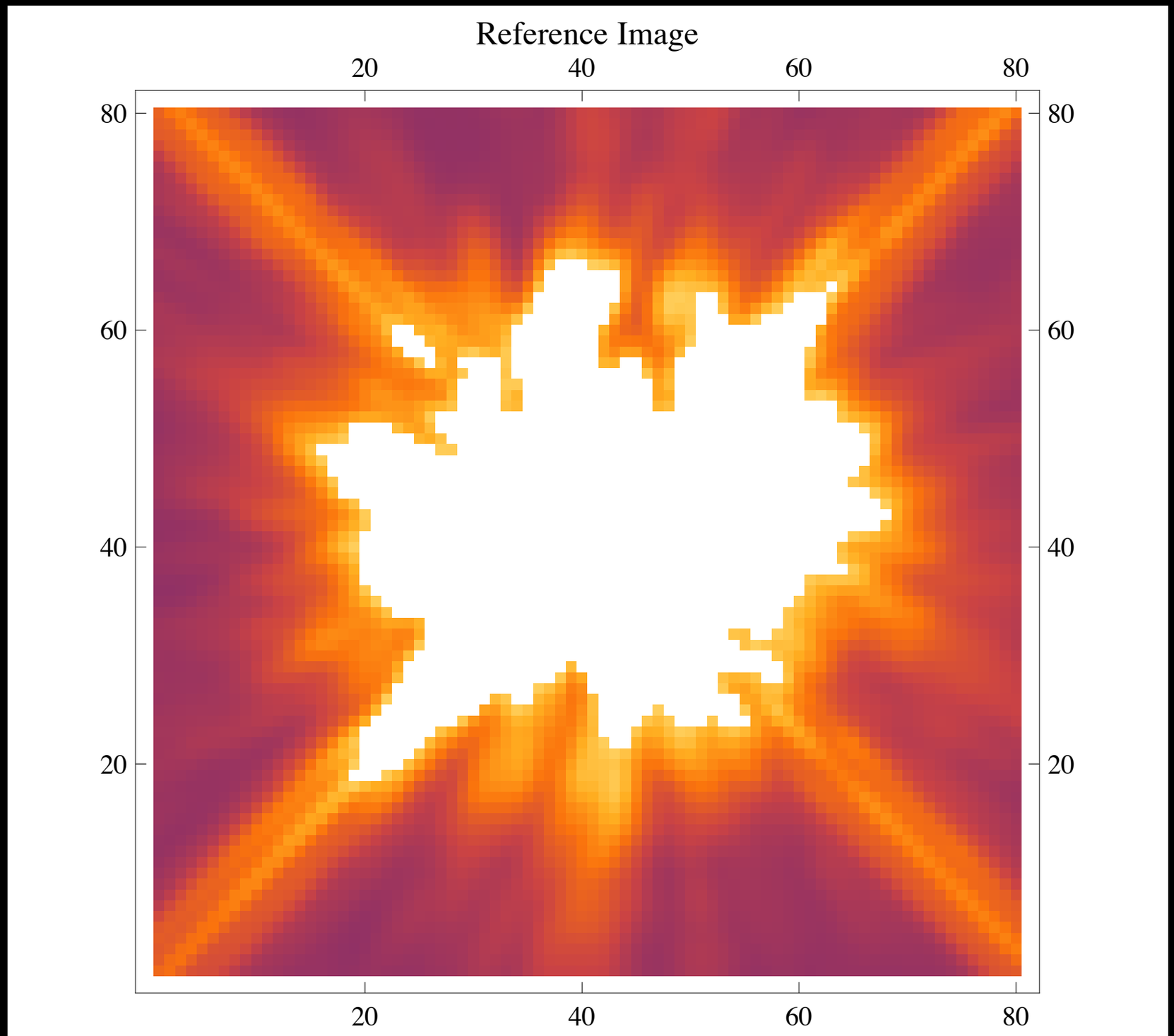
Laurent Pueyo, STScI

04/10/2018

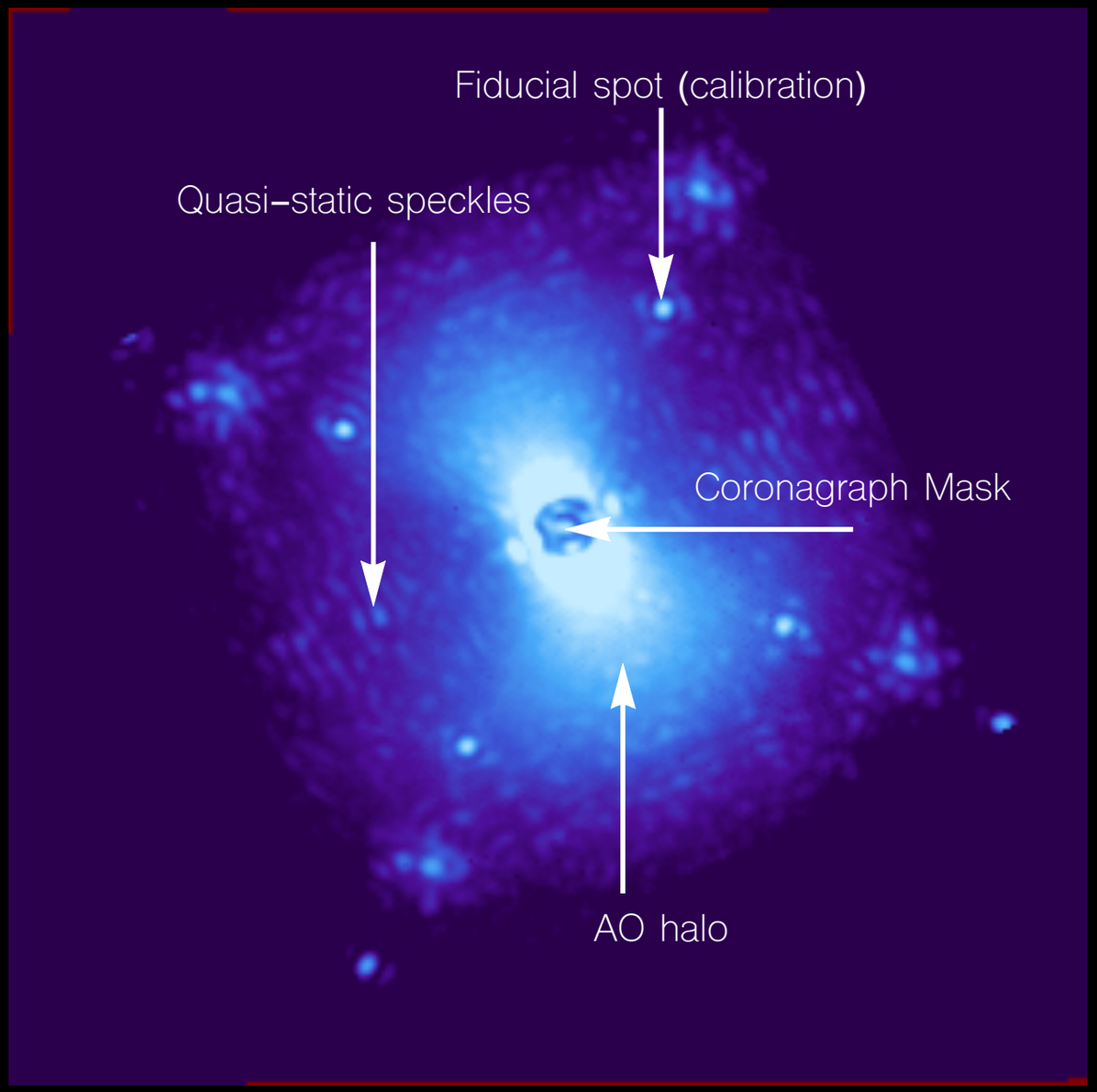
Why do we build libraries of noise realizations?

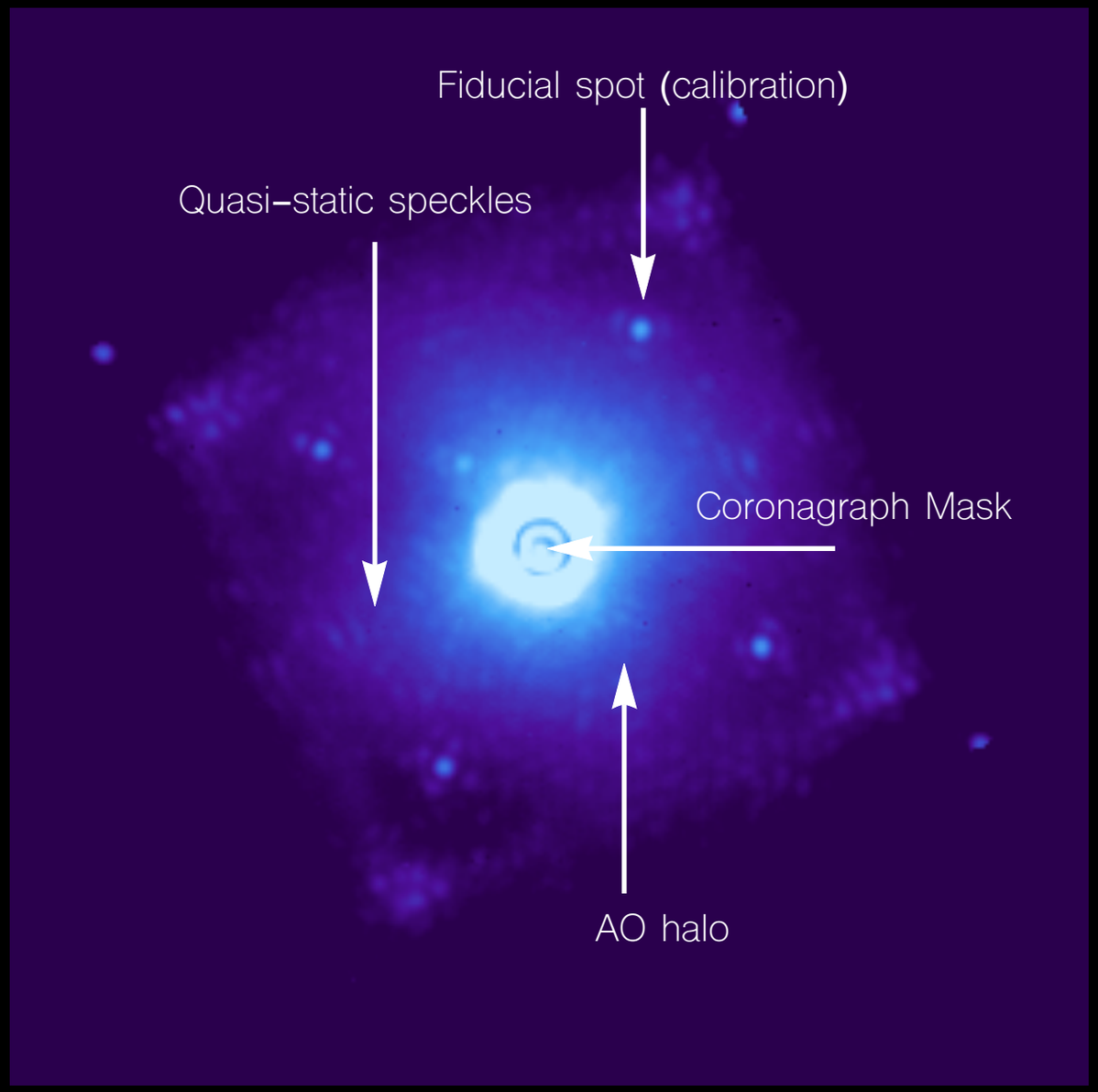


From space: errors in the instrument vary from star to star,

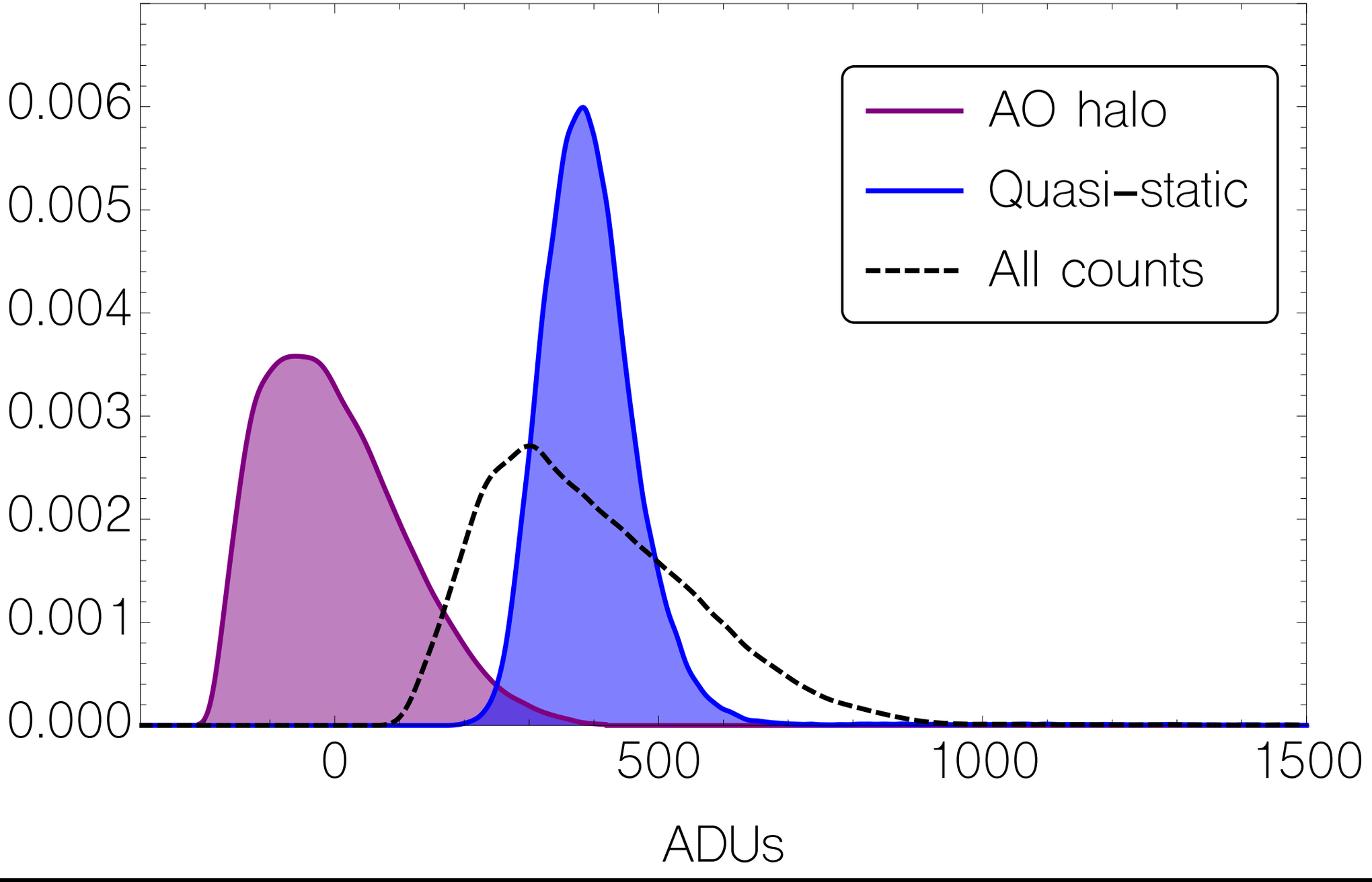


From space: errors in the instrument vary from star to star,

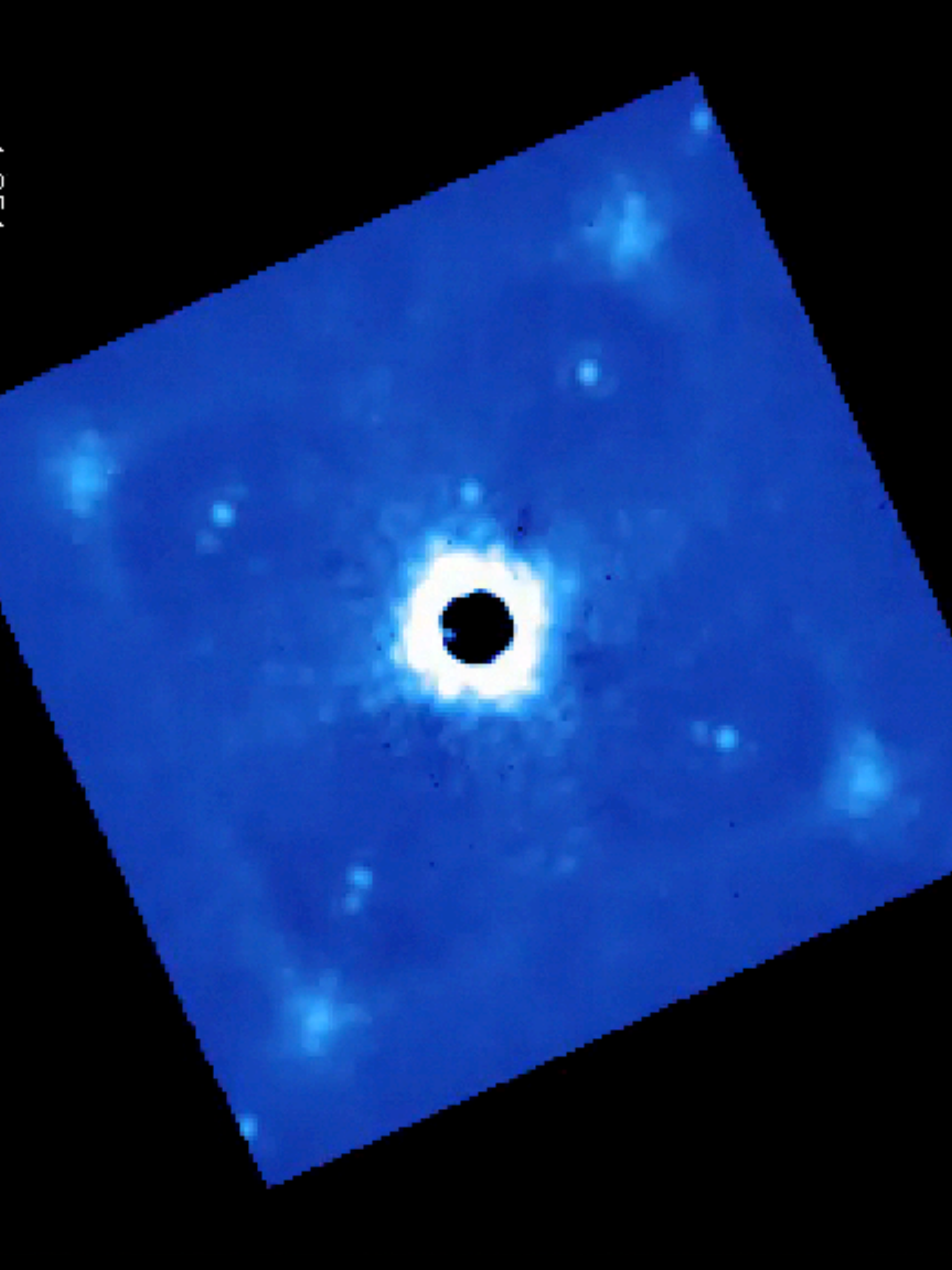


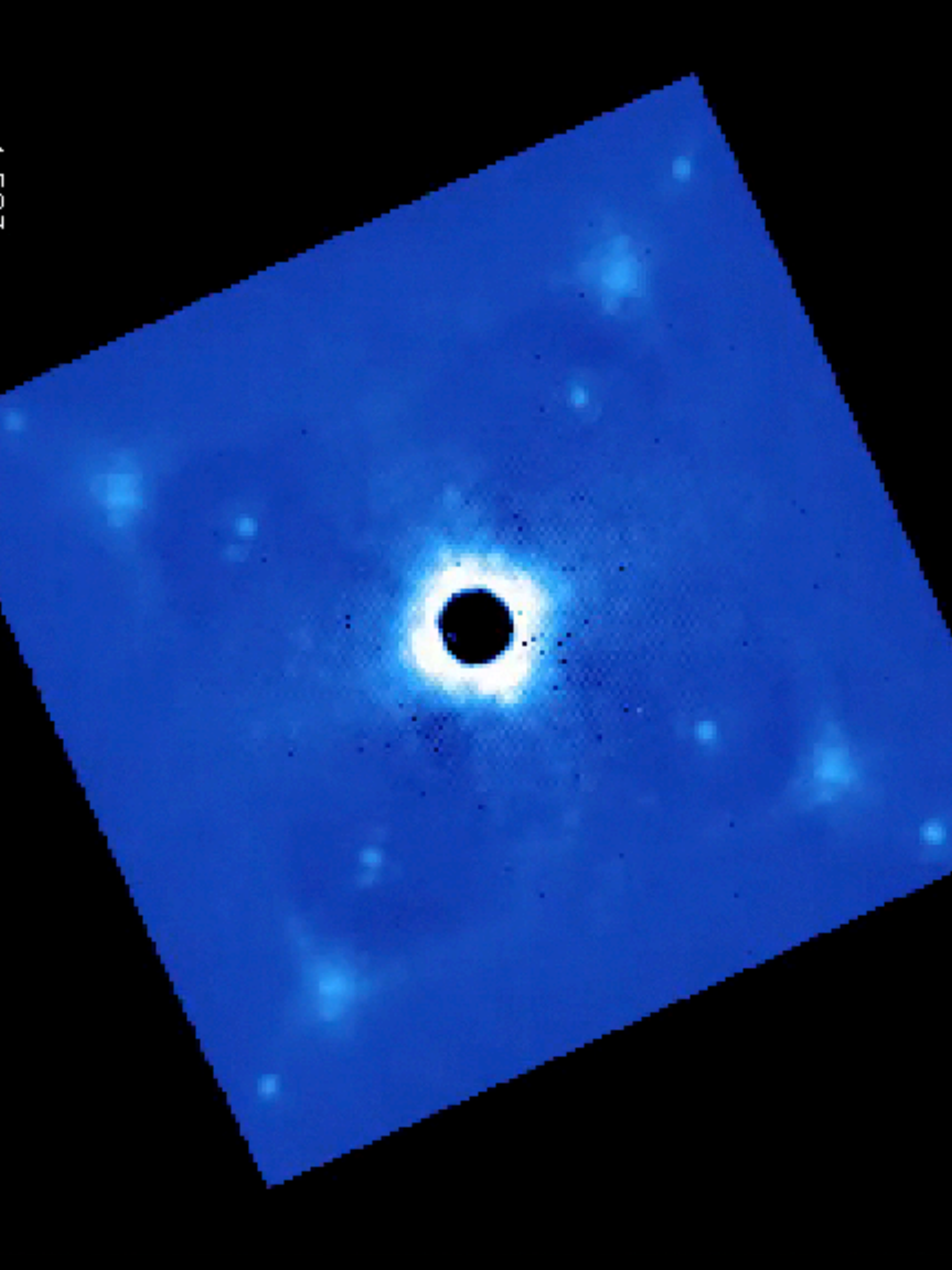


From the ground: AO residuals vary from star to star.

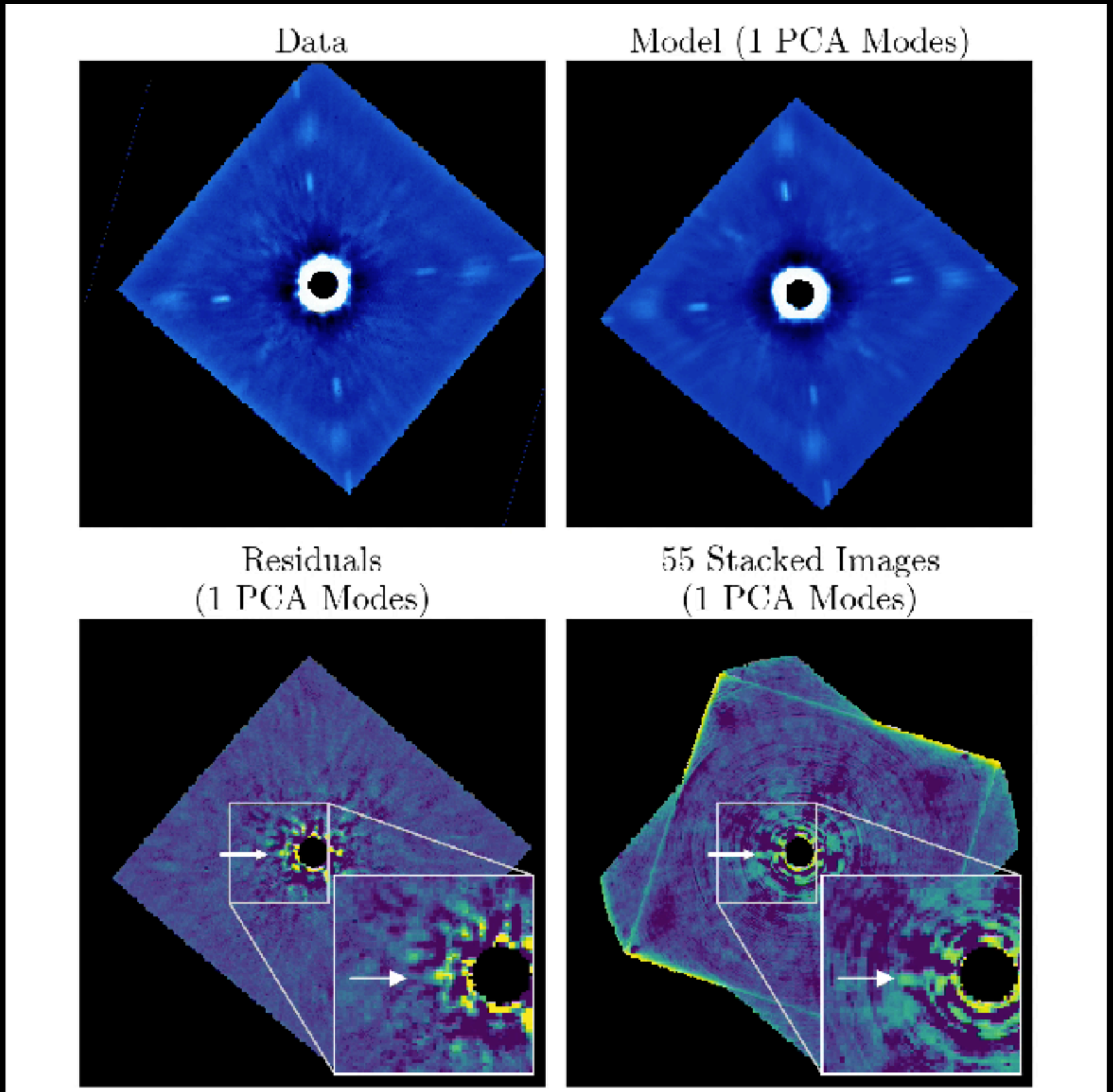


From the ground: there is variance in the cross terms.



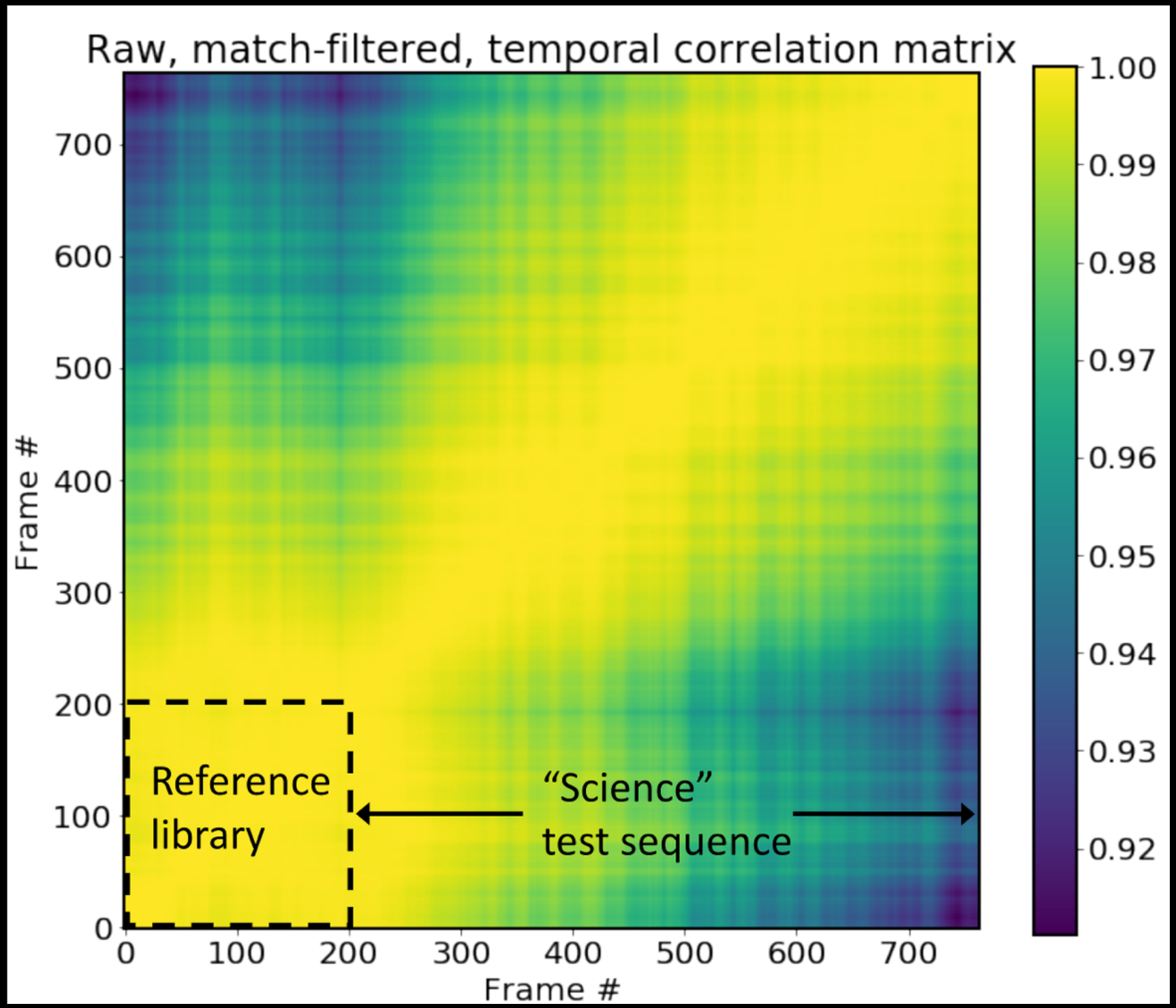


PCA, current “industry standard” for removing noise.

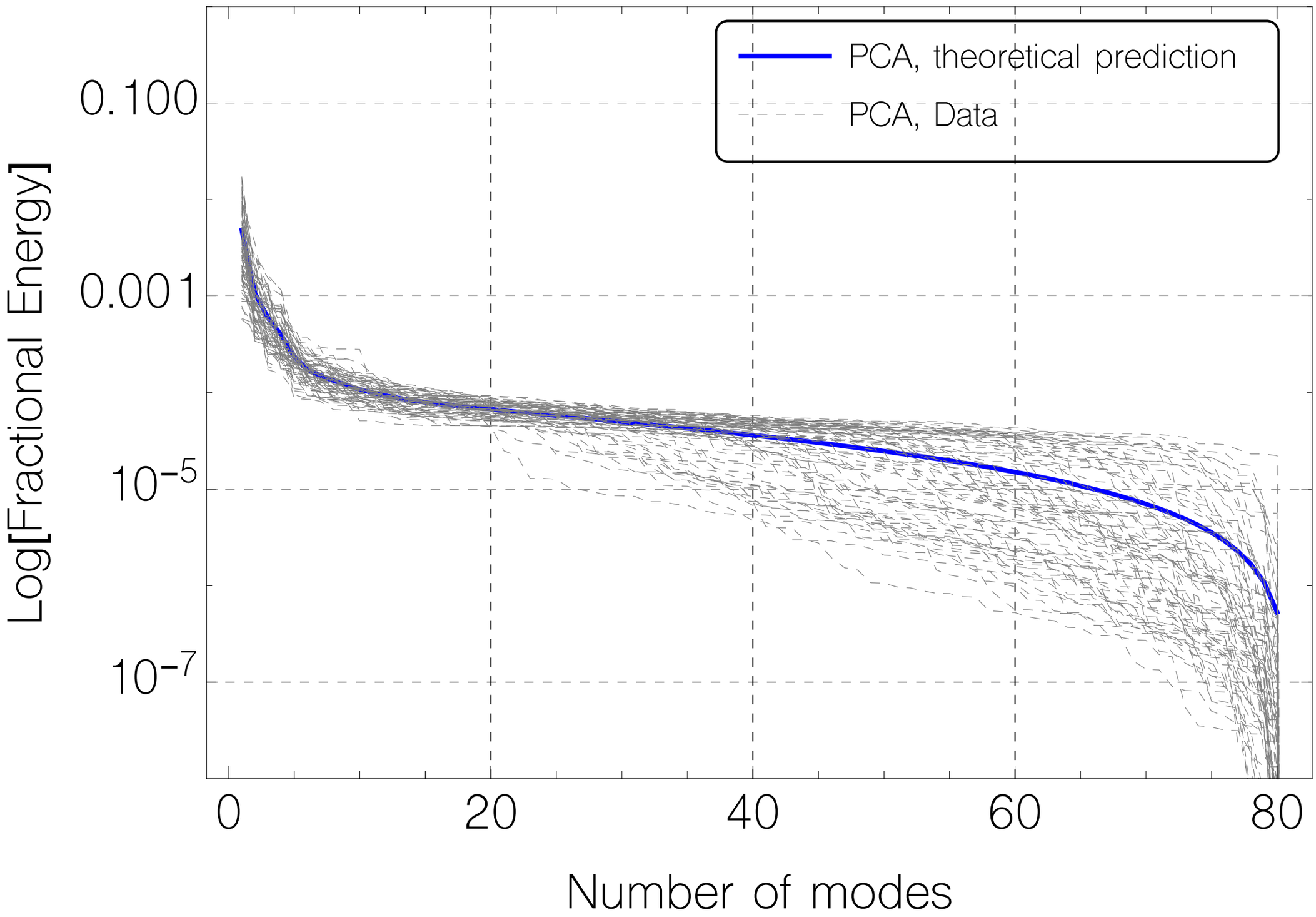


Courtesy of J. Wang

PCA is about noise covariance.

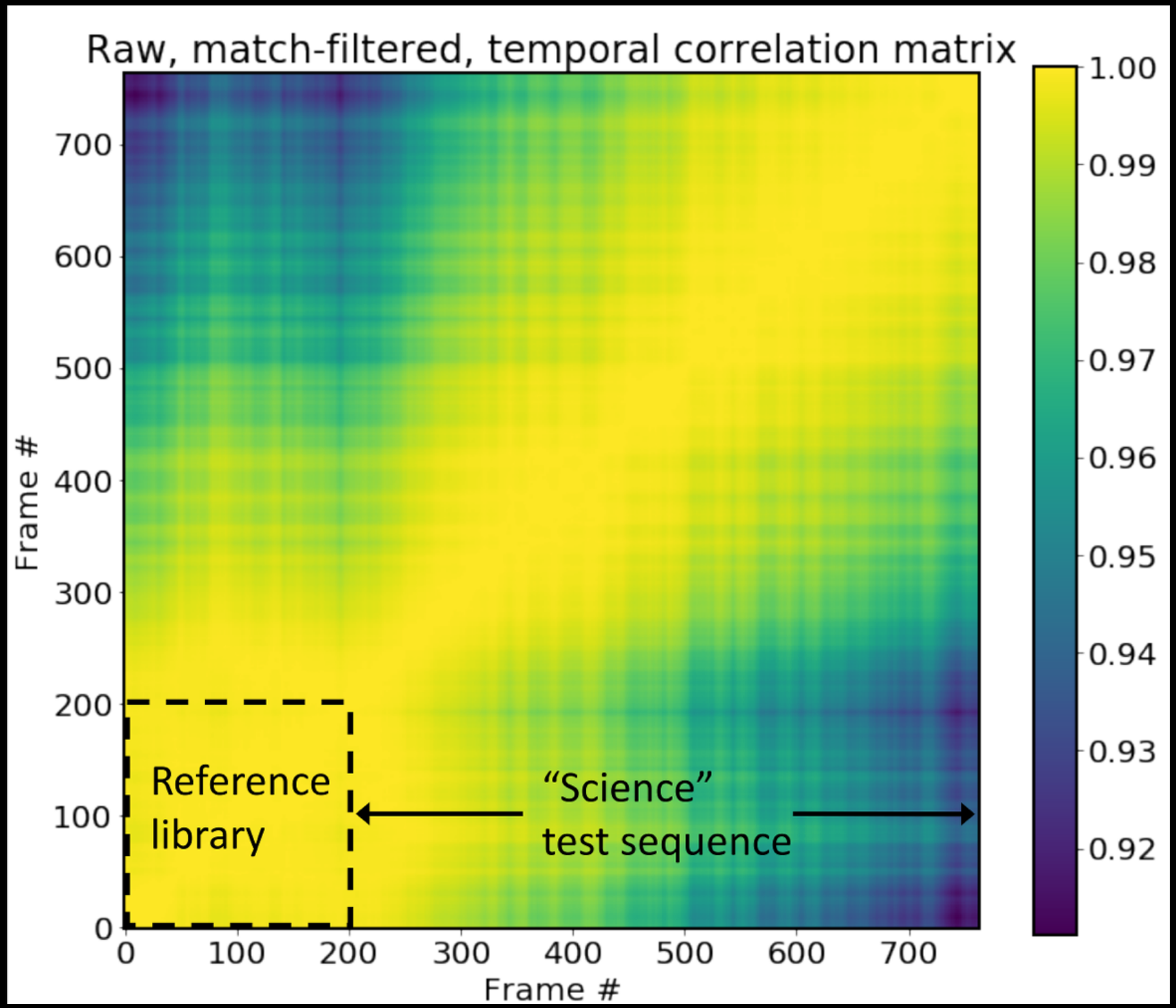


Courtesy of N. Zimmermann



Soummer, Pueyo, Larkin, 2012

PCA is about noise covariance.



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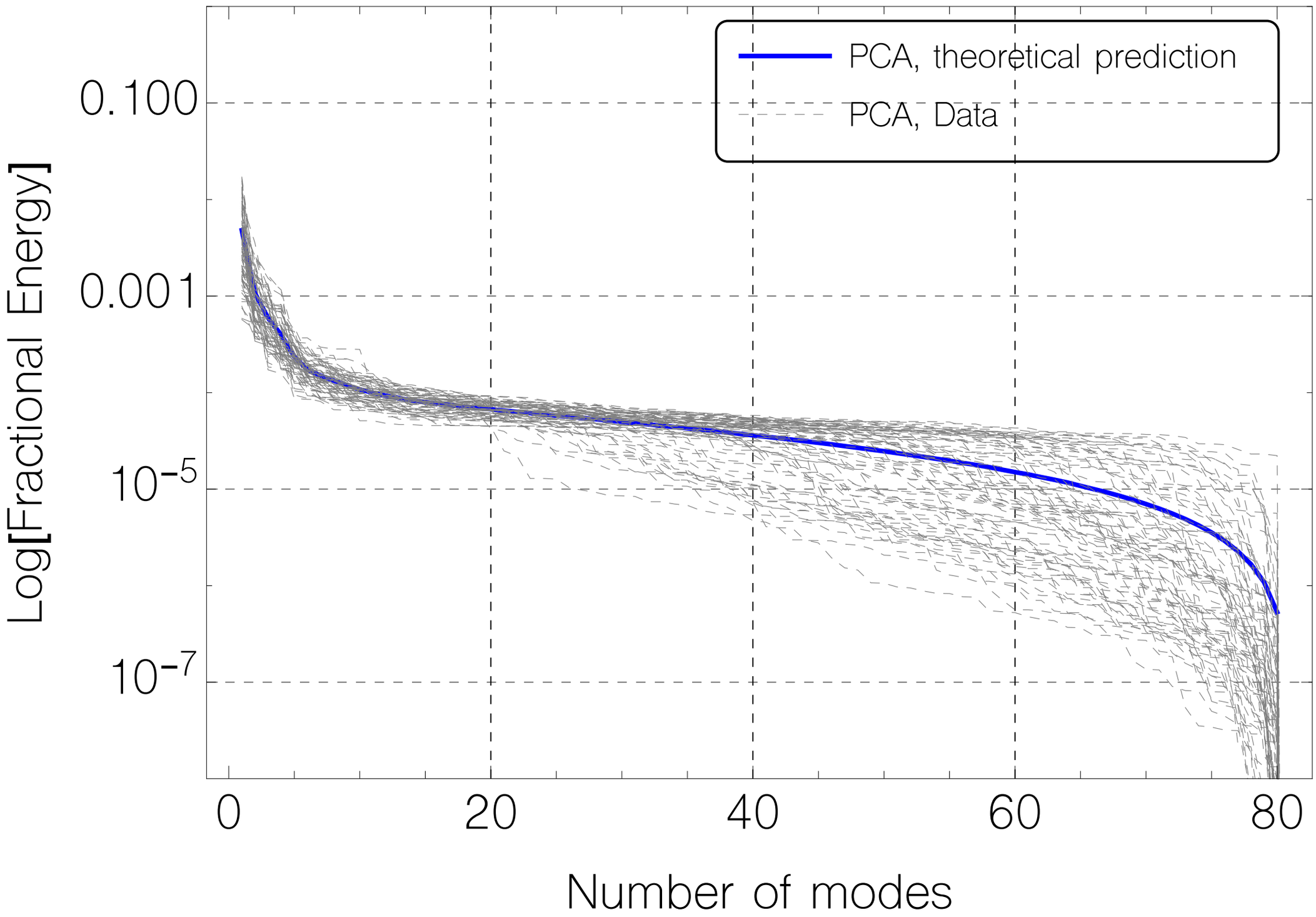
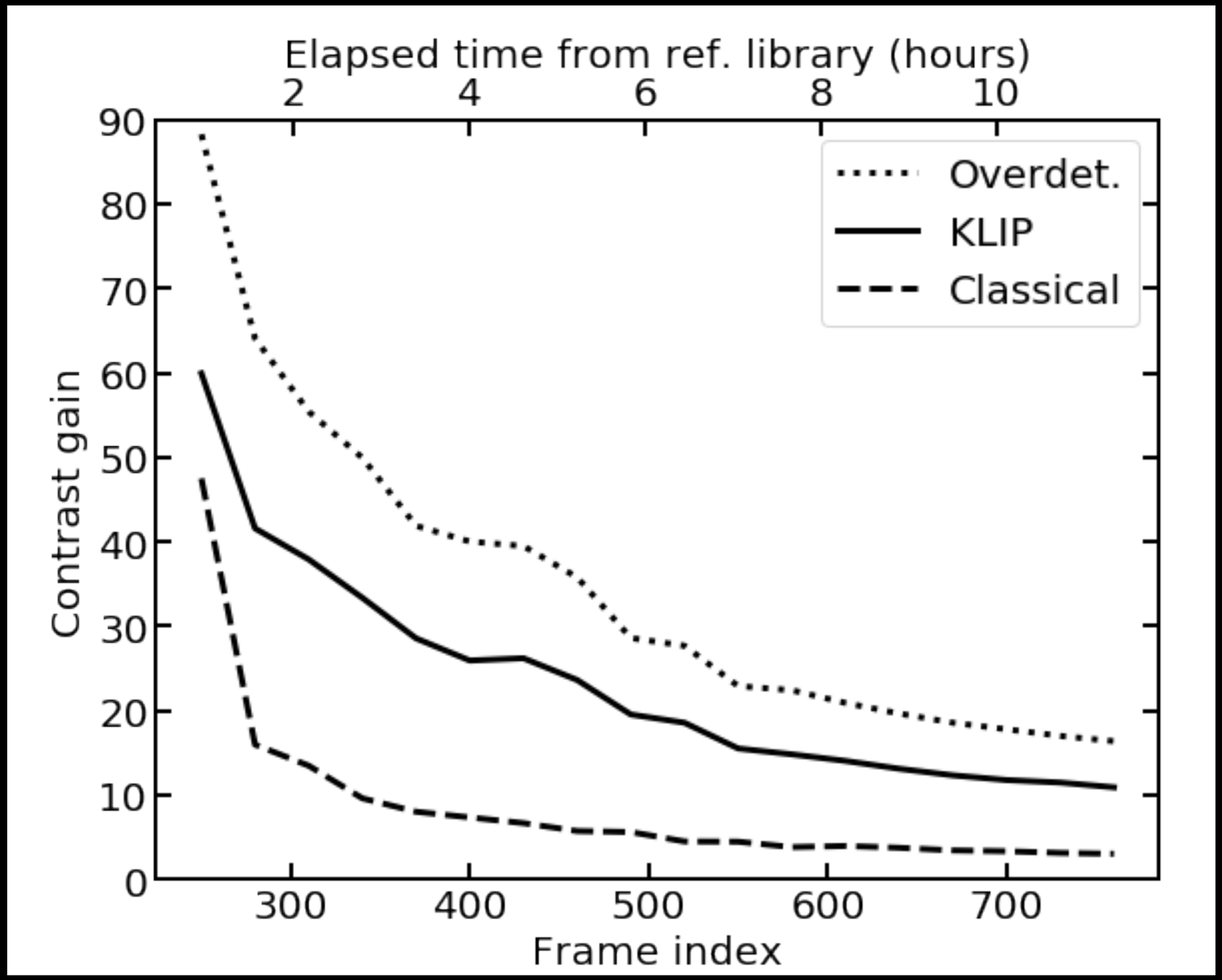


Soummer, Pueyo, Larkin, 2012

PCA performance “predictions”.



Courtesy of N. Zimmermann

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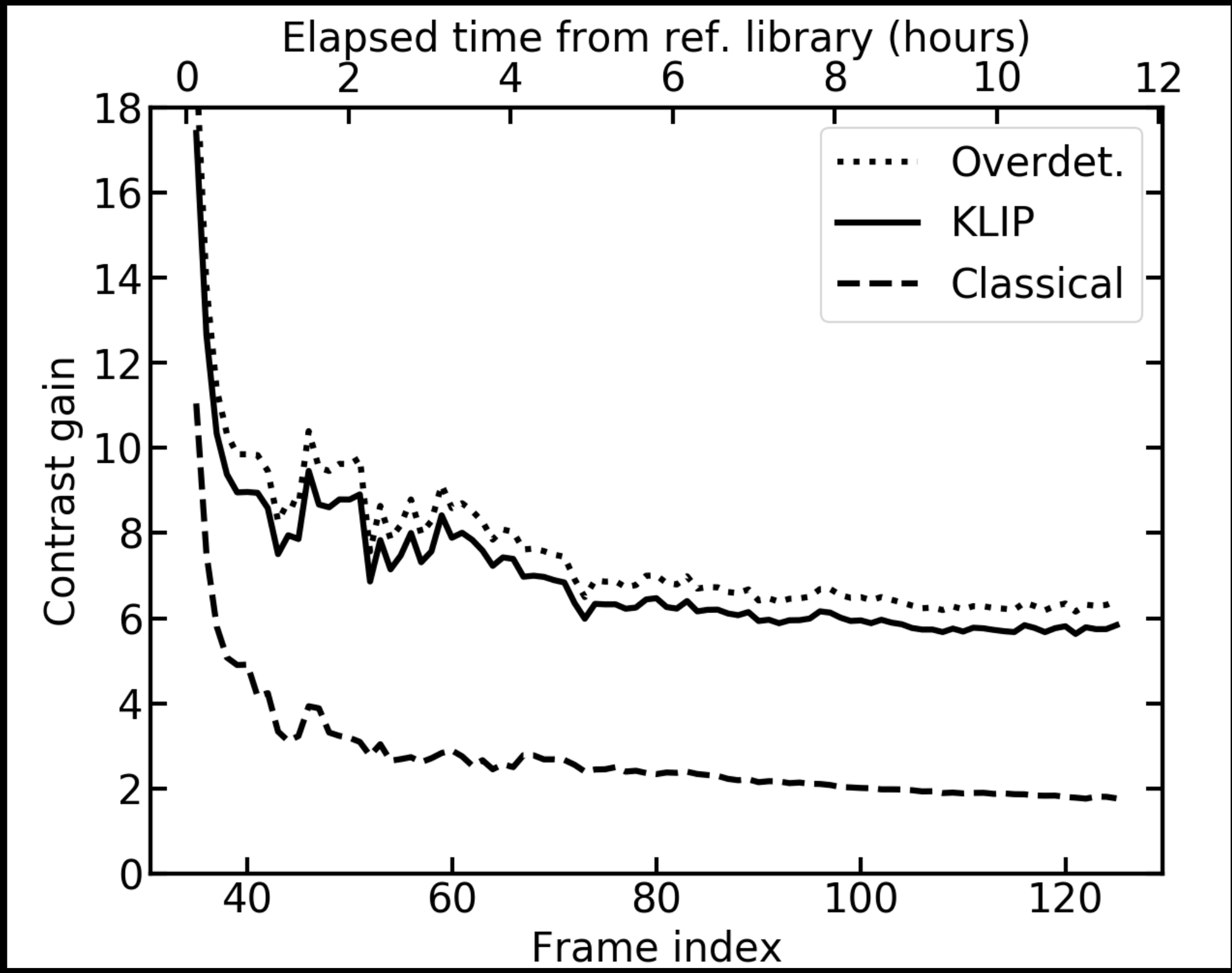


Courtesy of N. Zimmermann

Problem with PCA: kills signal.

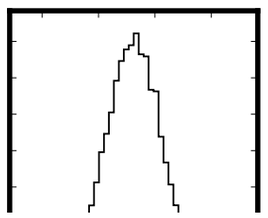
Residual noise.
Flux preserved.

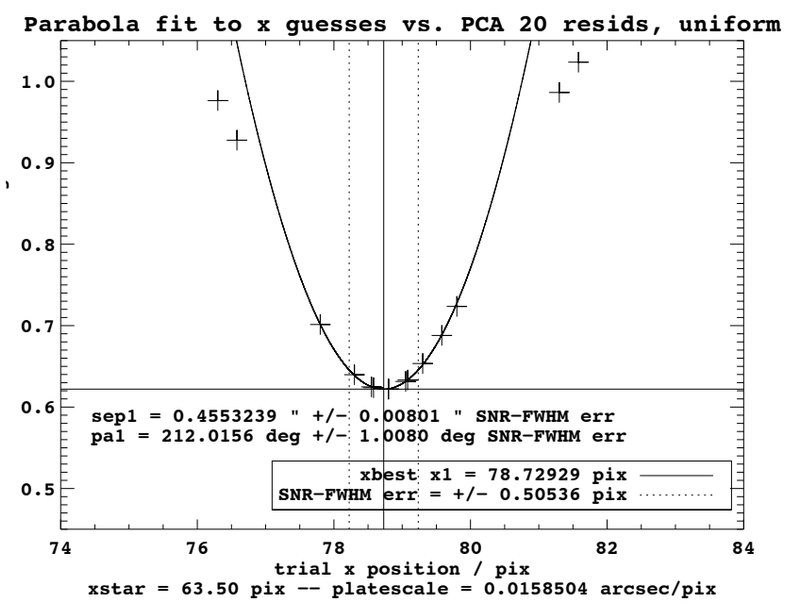
No residual noise.
Flux gone.

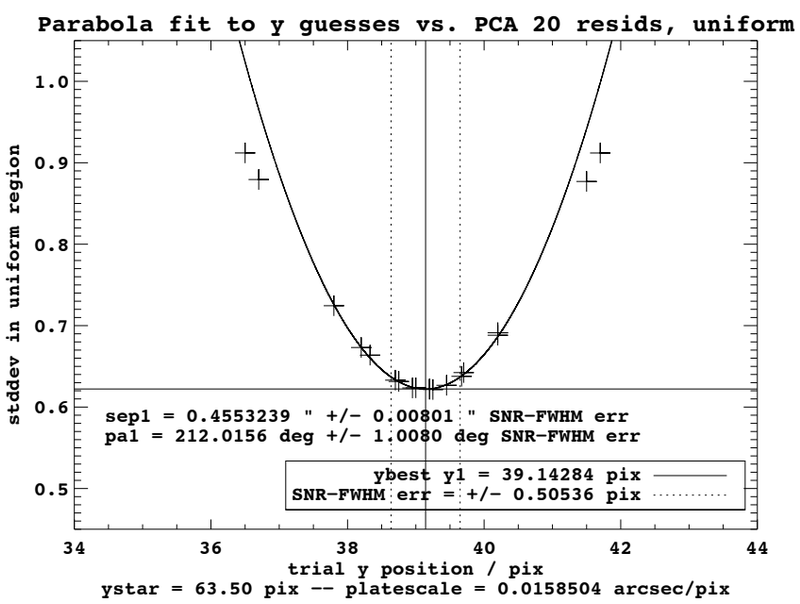
Solution 1:

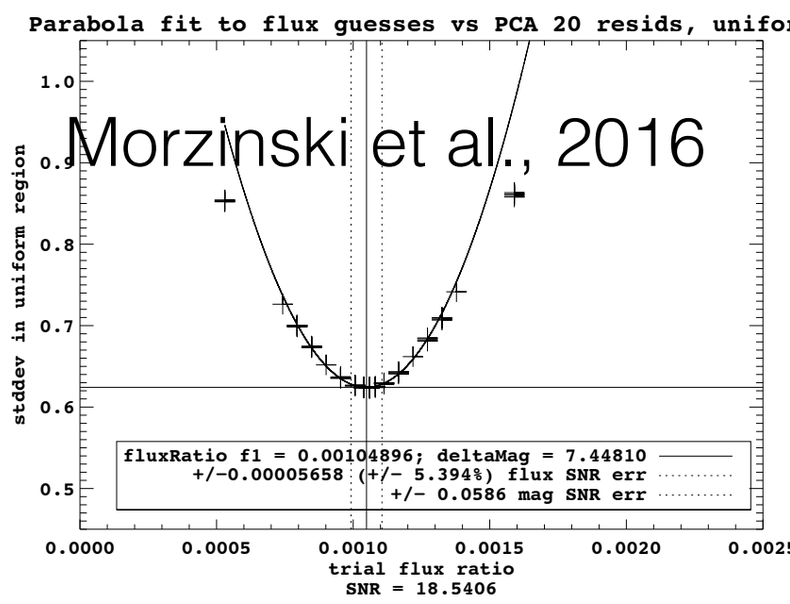
- minimize:

ll PCA(noise + signal - signal_est) ll^2

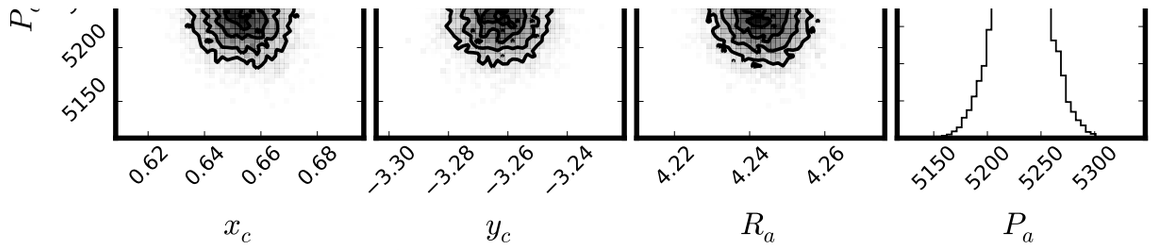








Morzinski et al., 2016



Bottom et al., 2016

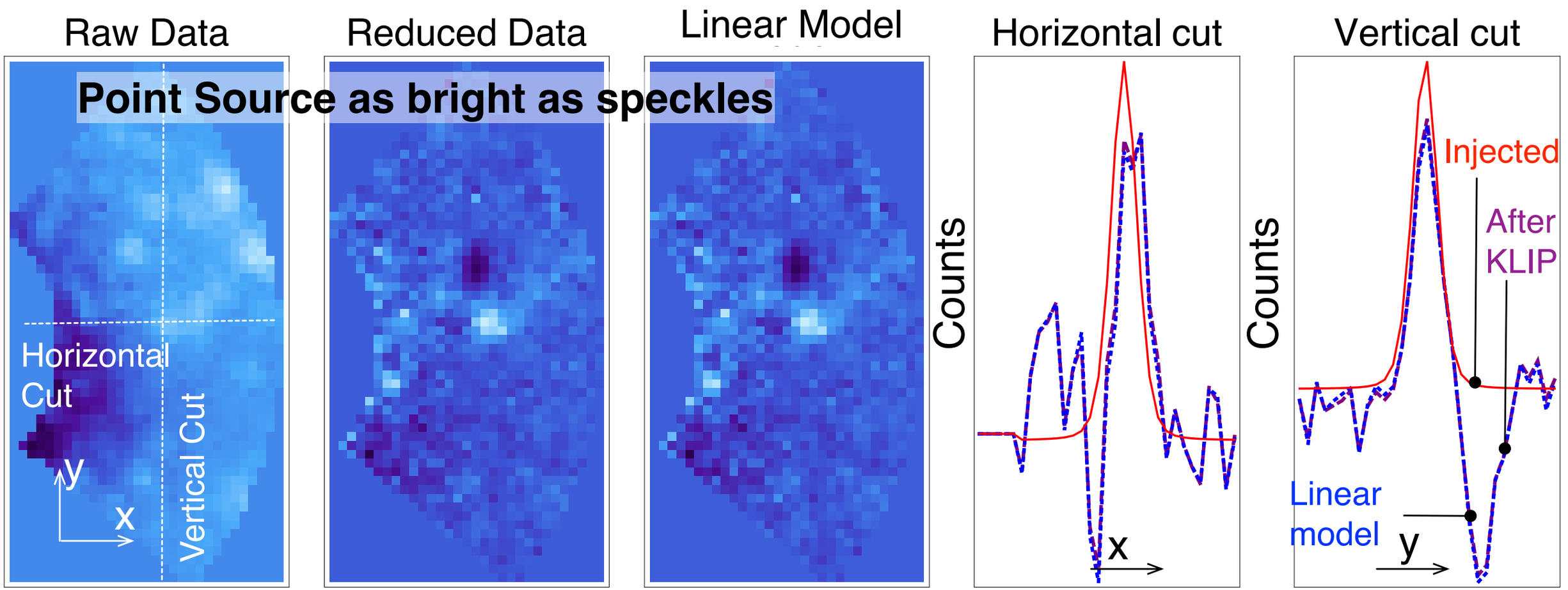
Solution 2:

- figure out that:

PCA(noise + signal) ~= PCA(noise) + signal \delta[PCA(noise)]

- minimize:

|| PCA(noise + signal) - signal_est \delta[PCA(noise)] ||^2



Non aggressive reduction: $\mathbf{N_r = 5}$, $\mathbf{N_\phi = 4}$, $\mathbf{N_{Corr} = 30}$, $\mathbf{K_{Klip} = 30}$, $\mathbf{N_\delta = 0.8}$.

Pueyo, 2016

Solution 2:

- figure out that:

PCA(noise + signal) ~= PCA(noise) + signal \delta[PCA(noise)]

- minimize:

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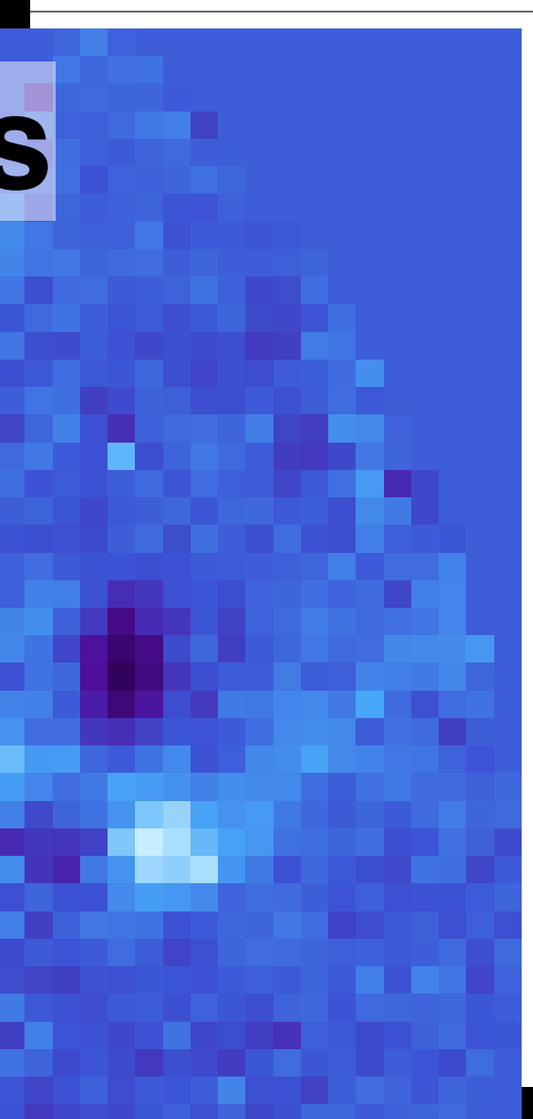
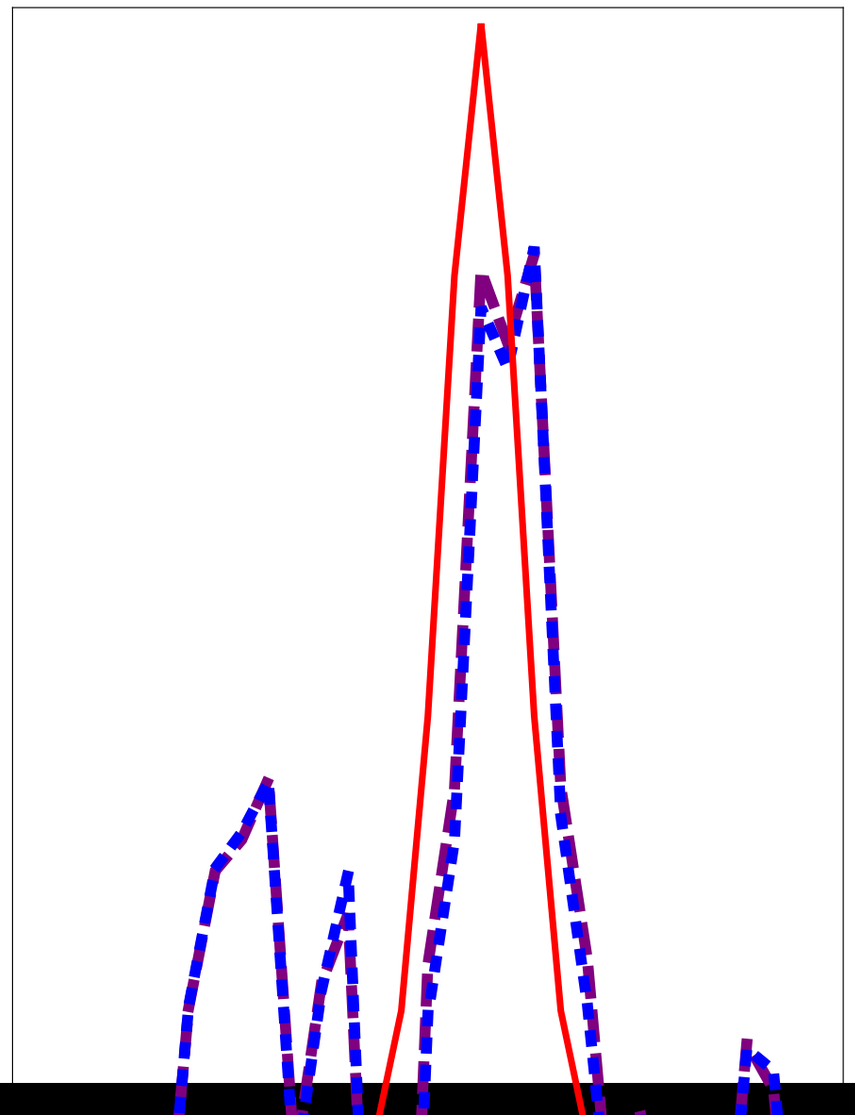
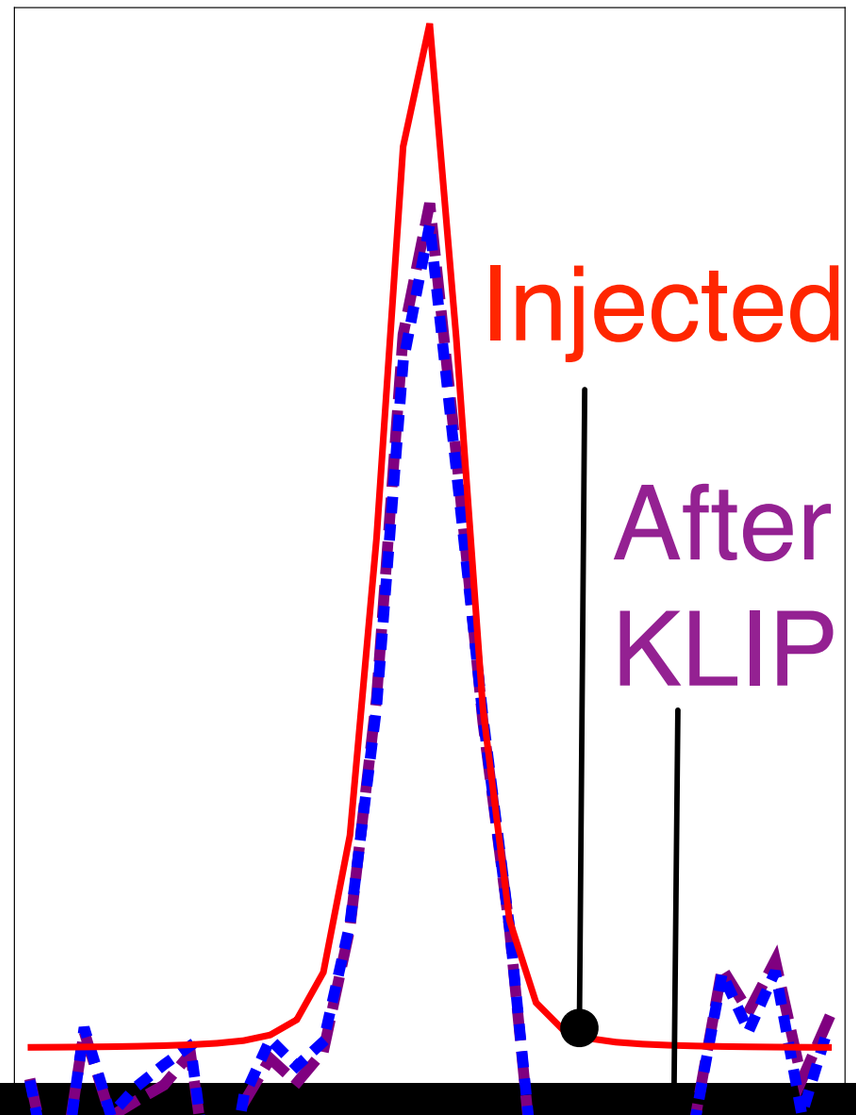
ar Model



Horizontal cut



Vertical cut



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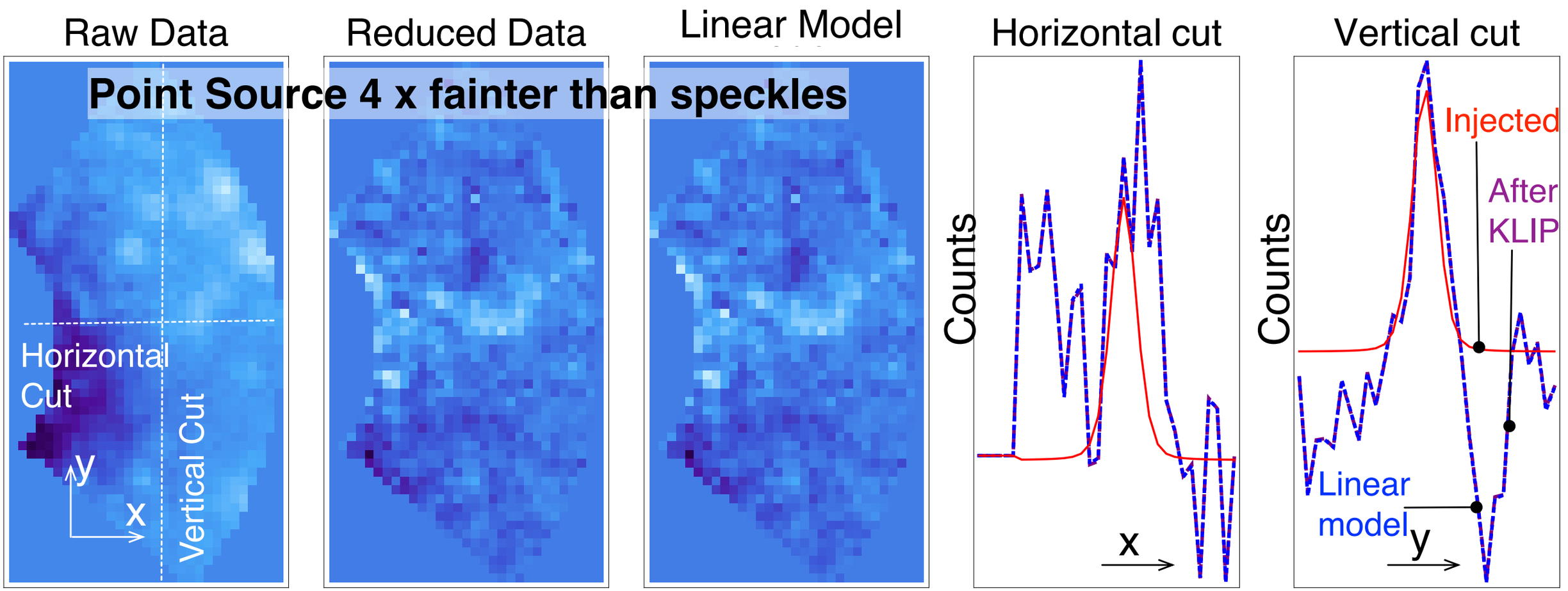


Non aggressive reduction: $\mathbf{N_r = 5},\ \mathbf{N_\phi = 4},\ \mathbf{N_{Corr} = 30},\ \mathbf{K_{Klip} = 30},\ \mathbf{N_\delta = 1}.$

Pueyo, 2016

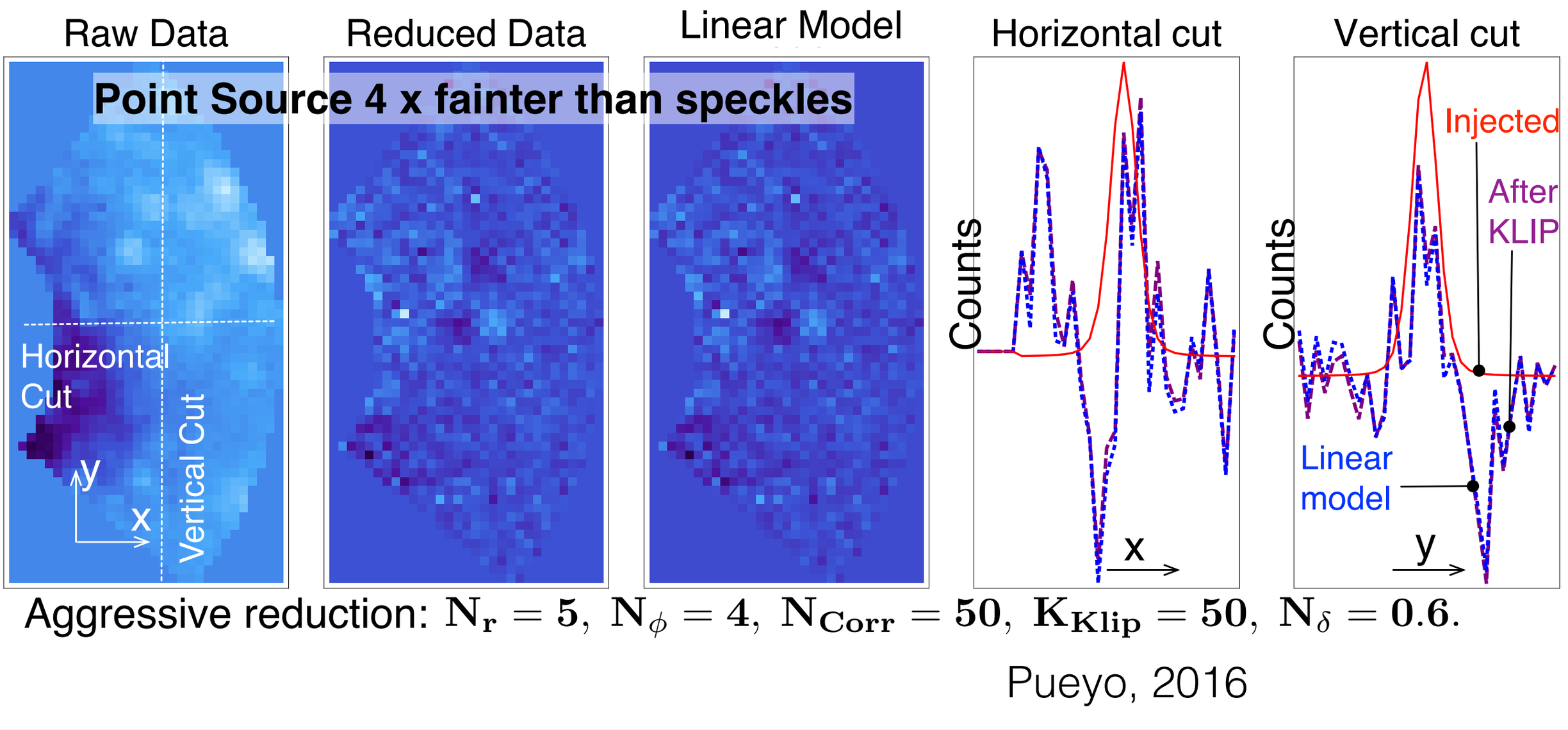
Solution 2:

- figure out that:

PCA(noise + signal) ~= PCA(noise) + signal \delta[PCA(noise)]

- minimize:

|| PCA(noise + signal) - signal_est \delta[PCA(noise)] ||^2



Aggressive reduction: $\mathbf{N_r = 5}$, $\mathbf{N_\phi = 4}$, $\mathbf{N_{Corr} = 50}$, $\mathbf{K_{Klip} = 50}$, $\mathbf{N_\delta = 0.6}$.

Pueyo, 2016

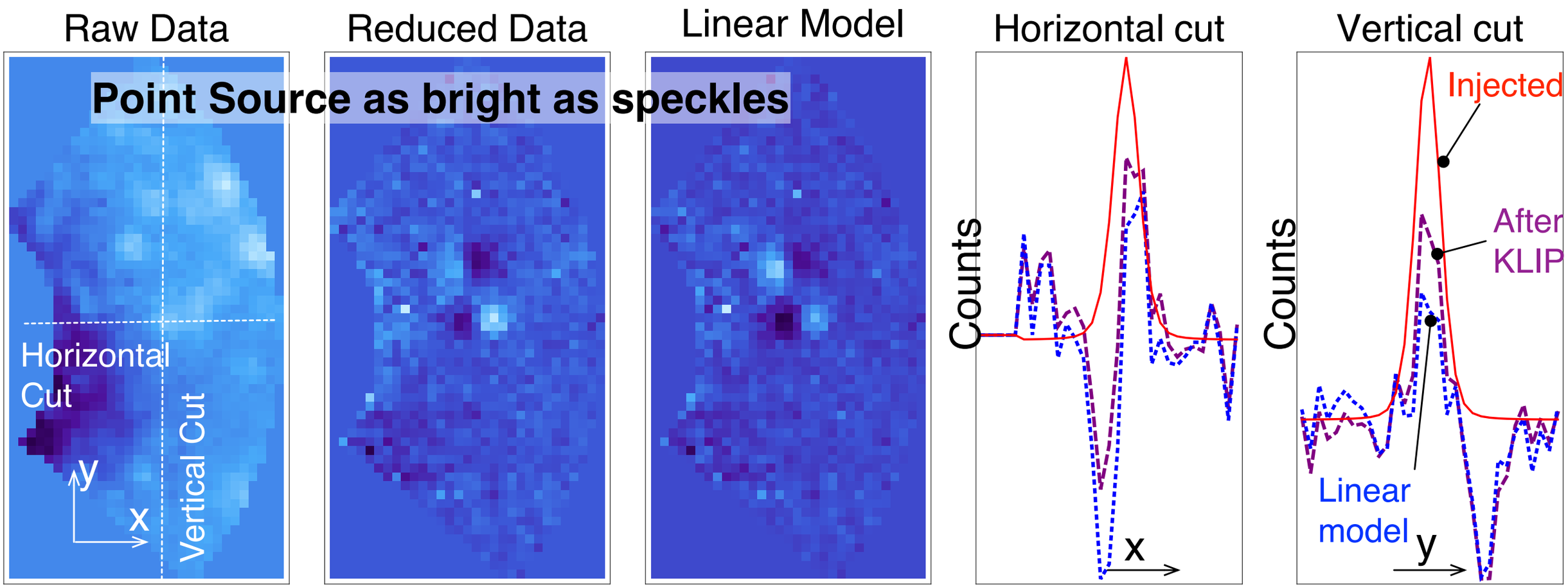
Solution 2:

- figure out that:

PCA(noise + signal) ~= PCA(noise) + signal \delta[PCA(noise)]

- minimize:

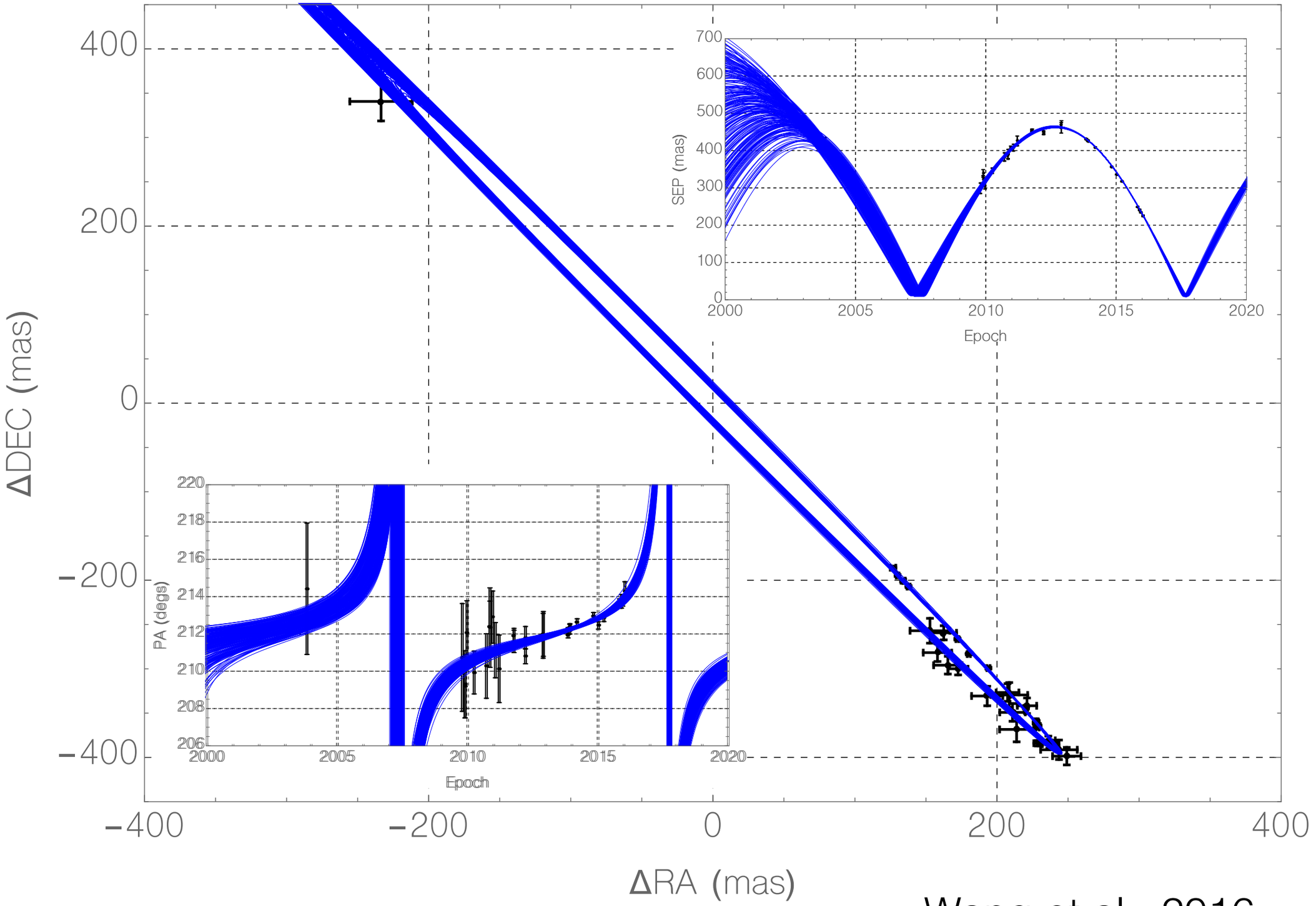
|| PCA(noise + signal) - signal_est \delta[PCA(noise)] ||^2



Aggressive reduction: $\mathbf{N_r = 5}$, $\mathbf{N_\phi = 4}$, $\mathbf{N_{Corr} = 50}$, $\mathbf{K_{Klip} = 50}$, $\mathbf{N_\delta = 0.6}$.

Pueyo, 2016

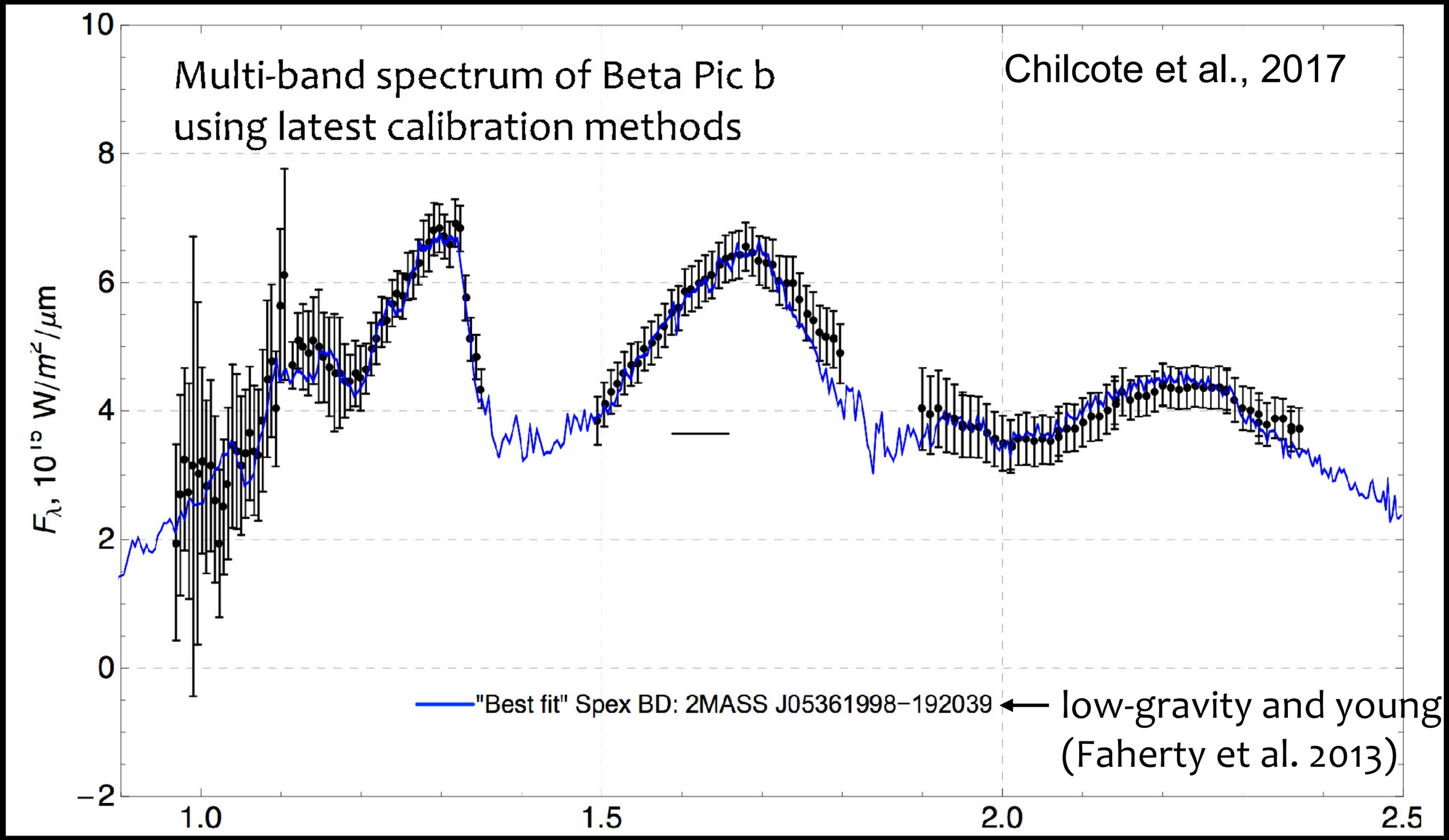
Orbits

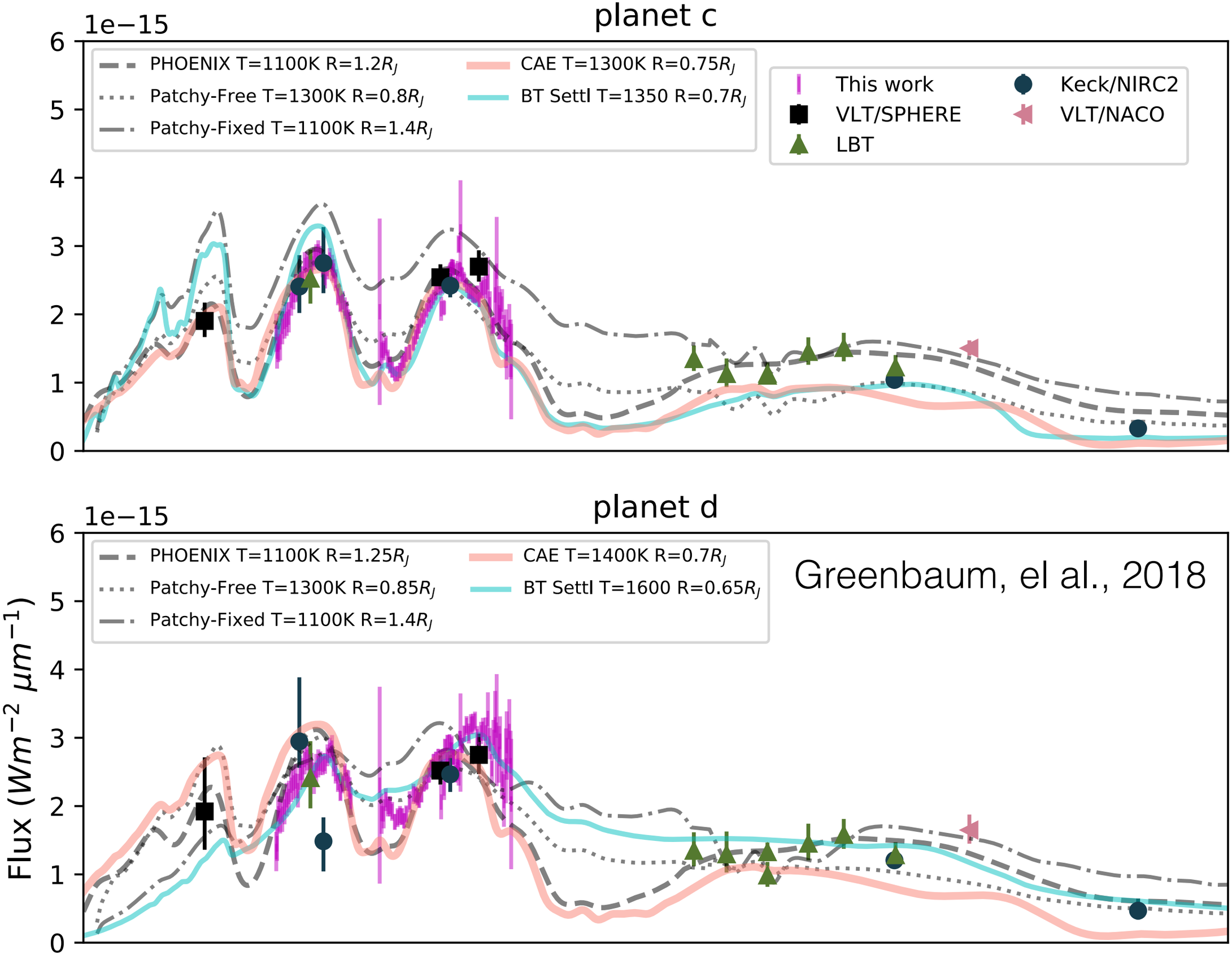


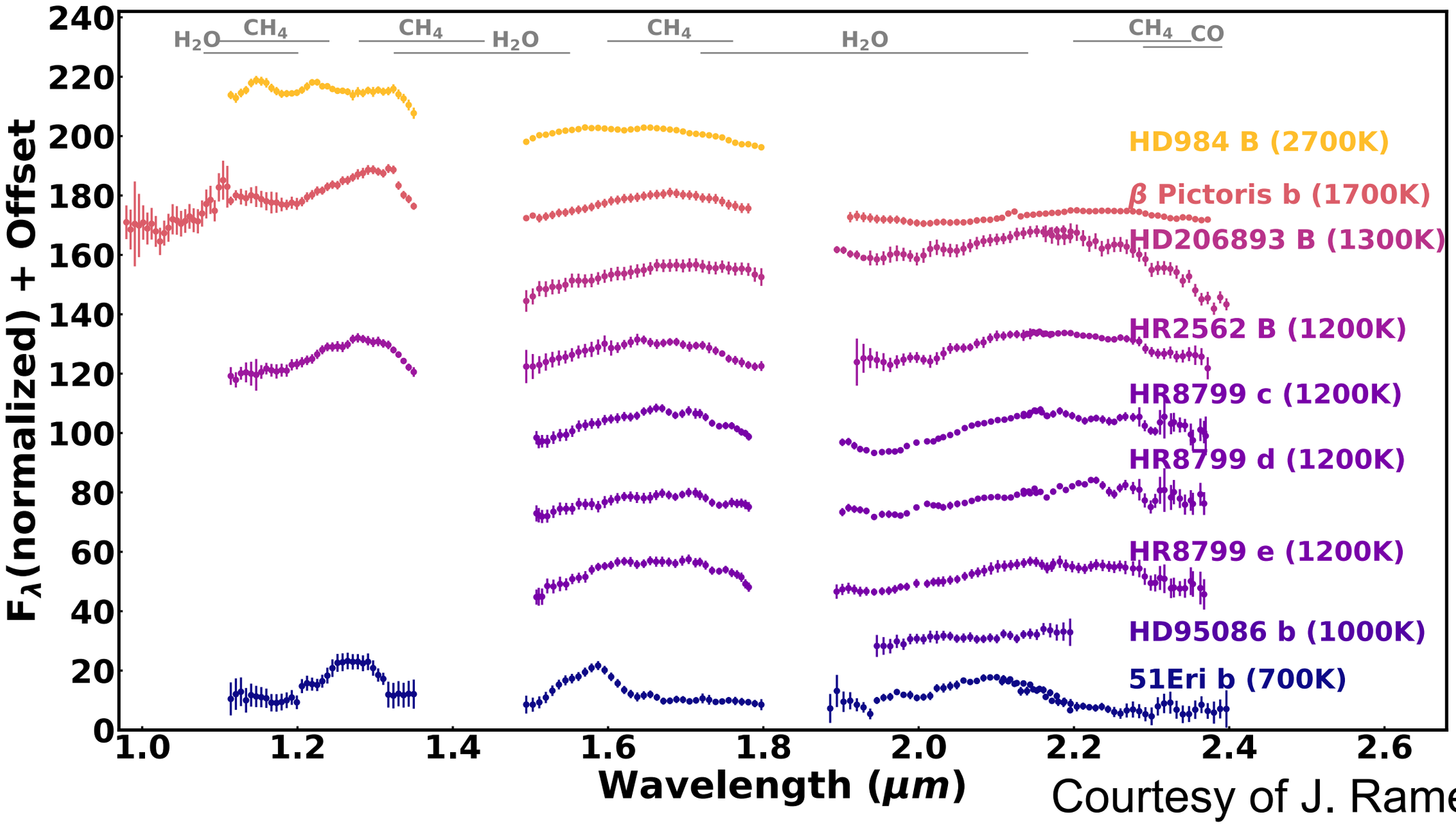
Wang et al., 2016

Spectra

Comparison with field-brown dwarfs.




planet c
1e−15
PHOENIX T=1100K R=1.2R_J
Patchy-Free T=1300K R=0.8R_J
Patchy-Fixed T=1100K R=1.4R_J
CAE T=1300K R=0.75R_J
BT SettI T=1350 R=0.7R_J
This work
VLT/SPHERE
LBT
Keck/NIRC2
VLT/NACO
planet d
1e−15
PHOENIX T=1100K R=1.25R_J
Patchy-Free T=1300K R=0.85R_J
Patchy-Fixed T=1100K R=1.4R_J
CAE T=1400K R=0.7R_J
BT SettI T=1600 R=0.65R_J
Greenbaum, el al., 2018
Flux (Wm^{-2} μm^{-1})



Courtesy of J. Rameau

Better sensitivity?

Ruffio et al., 2017

PDF

0.100

0.010

0.001

10^{-4}

10^{-5}

10^{-6}

FMMF observer

GCC observer

Gaussian PDF

10^{-8}

10^{-5}

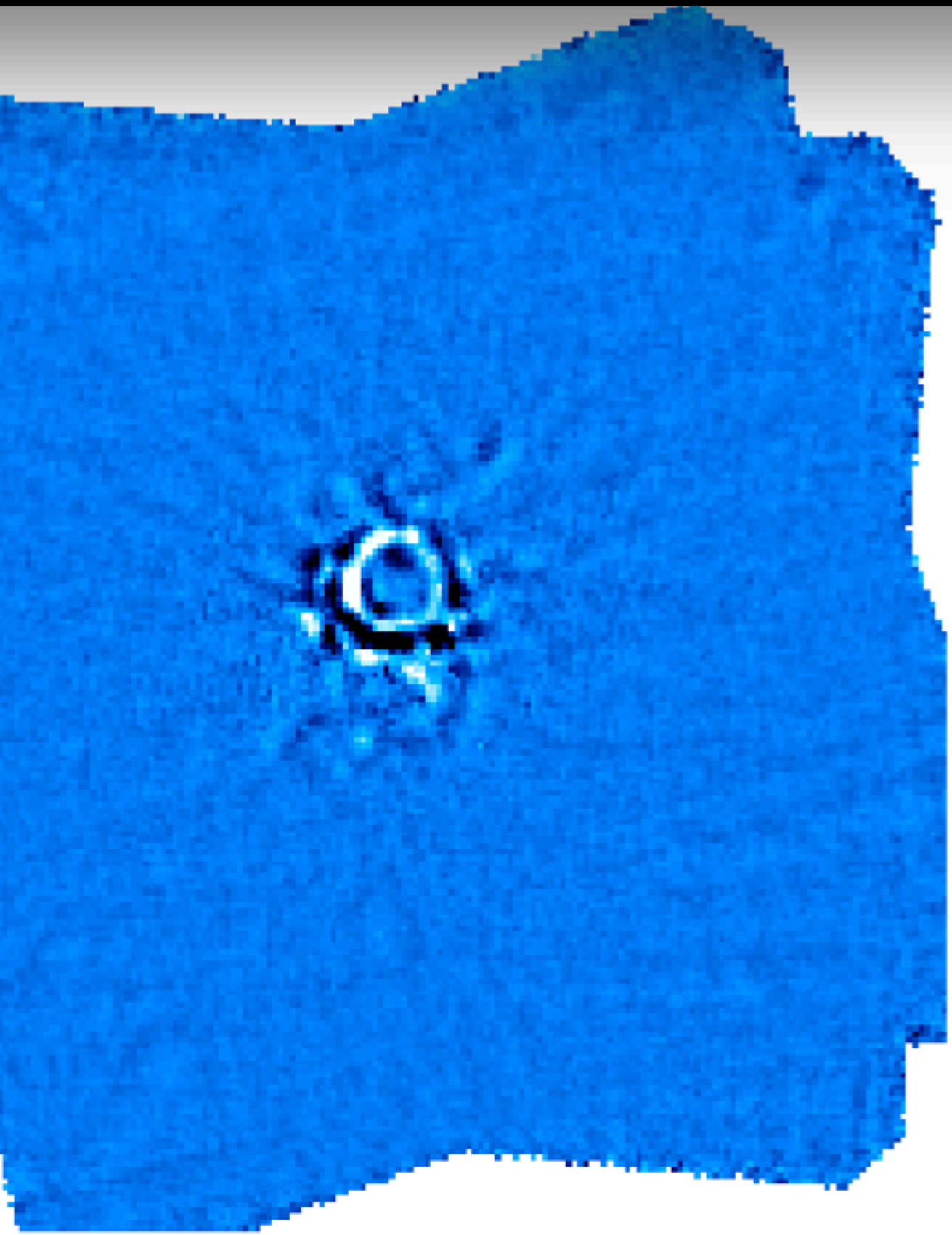
0.01

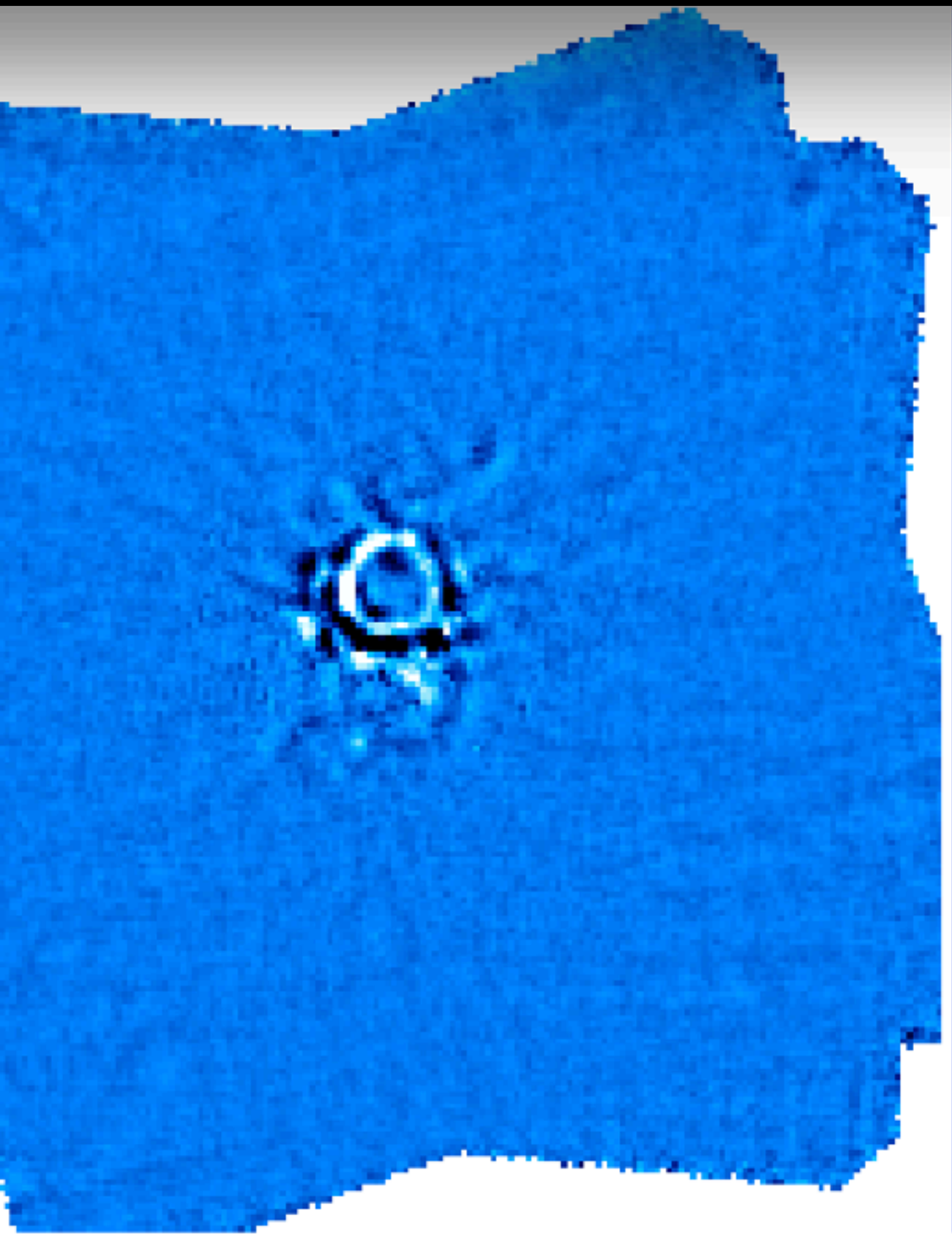
10

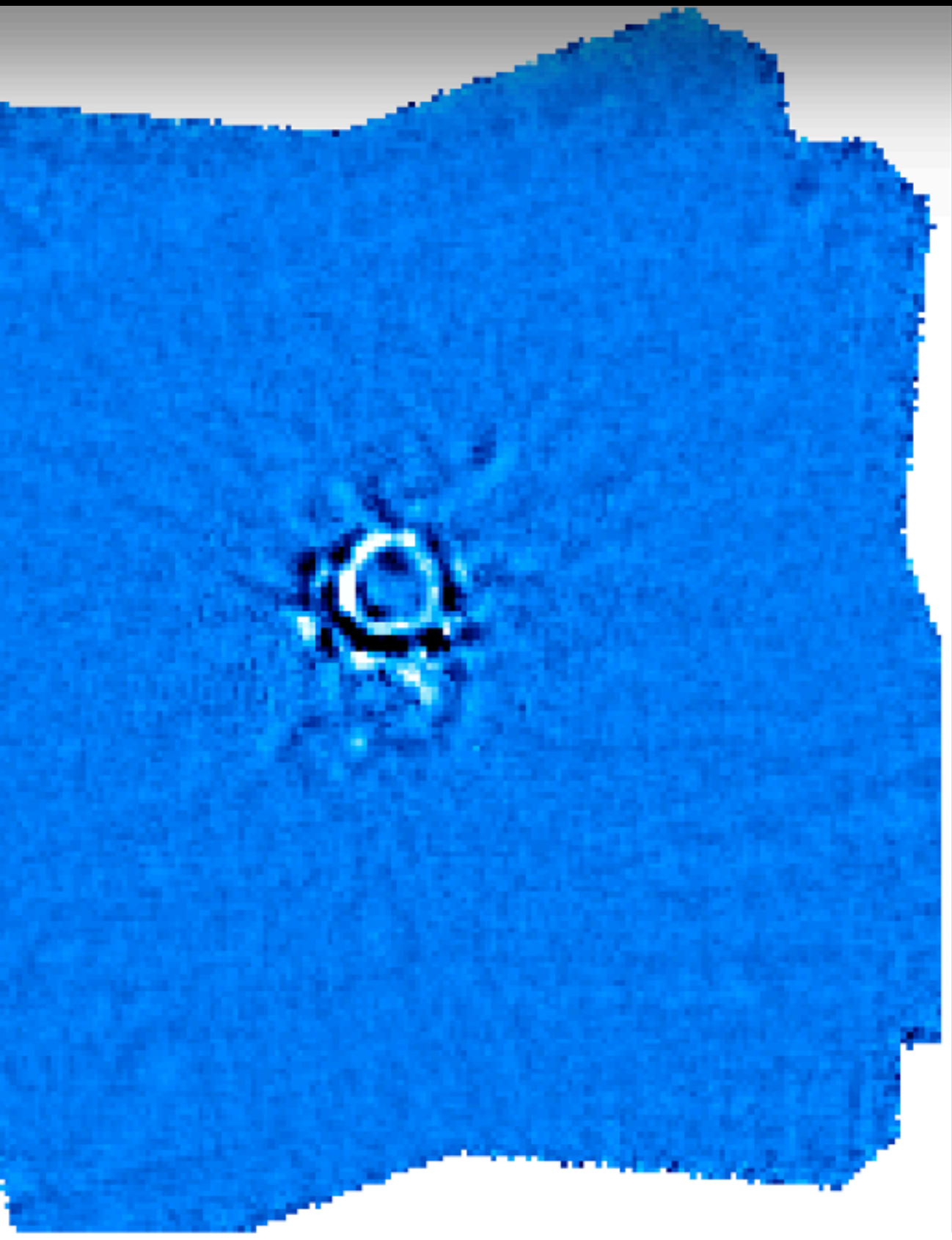
10^{4}

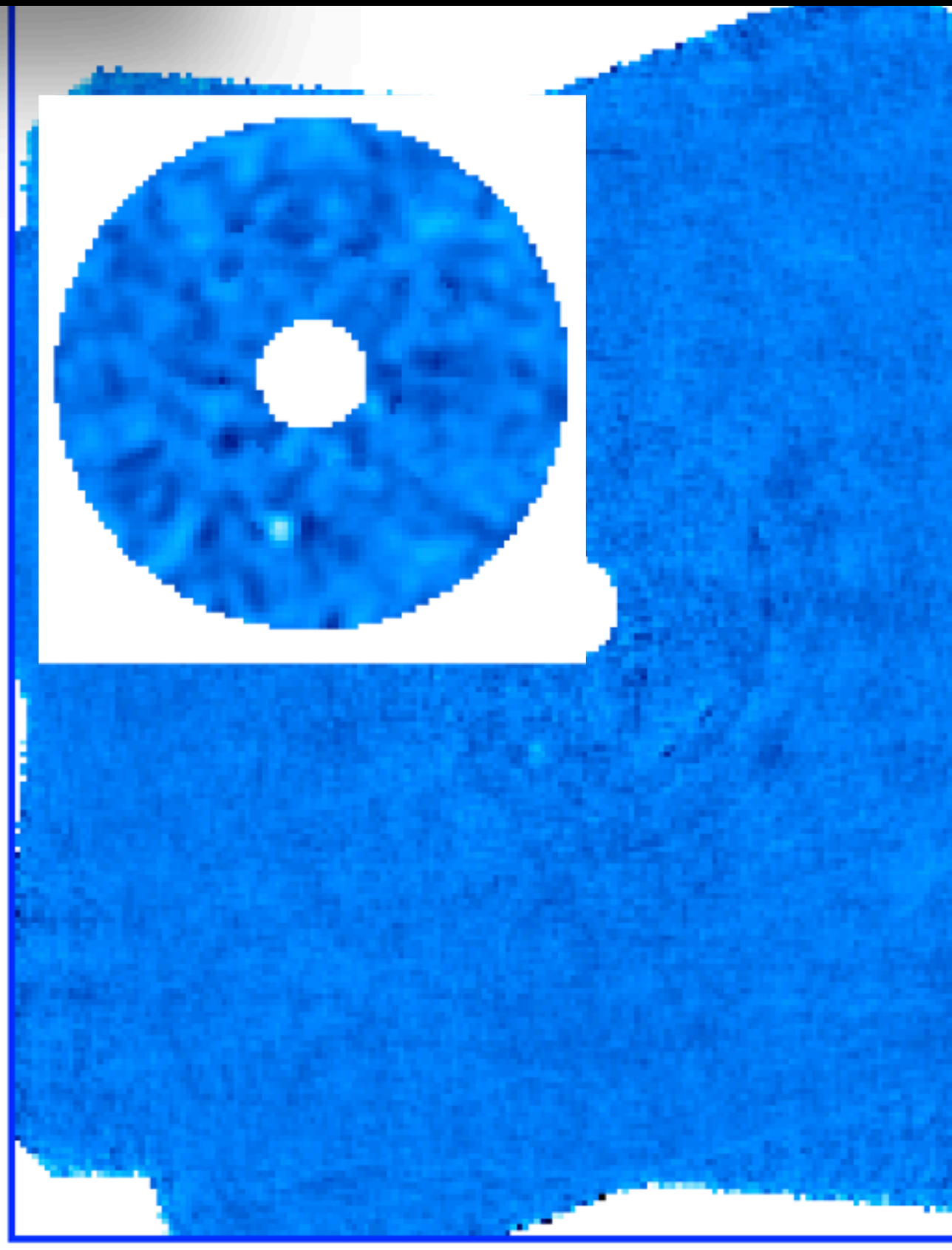
10^{7}

Observed SNR after PCA

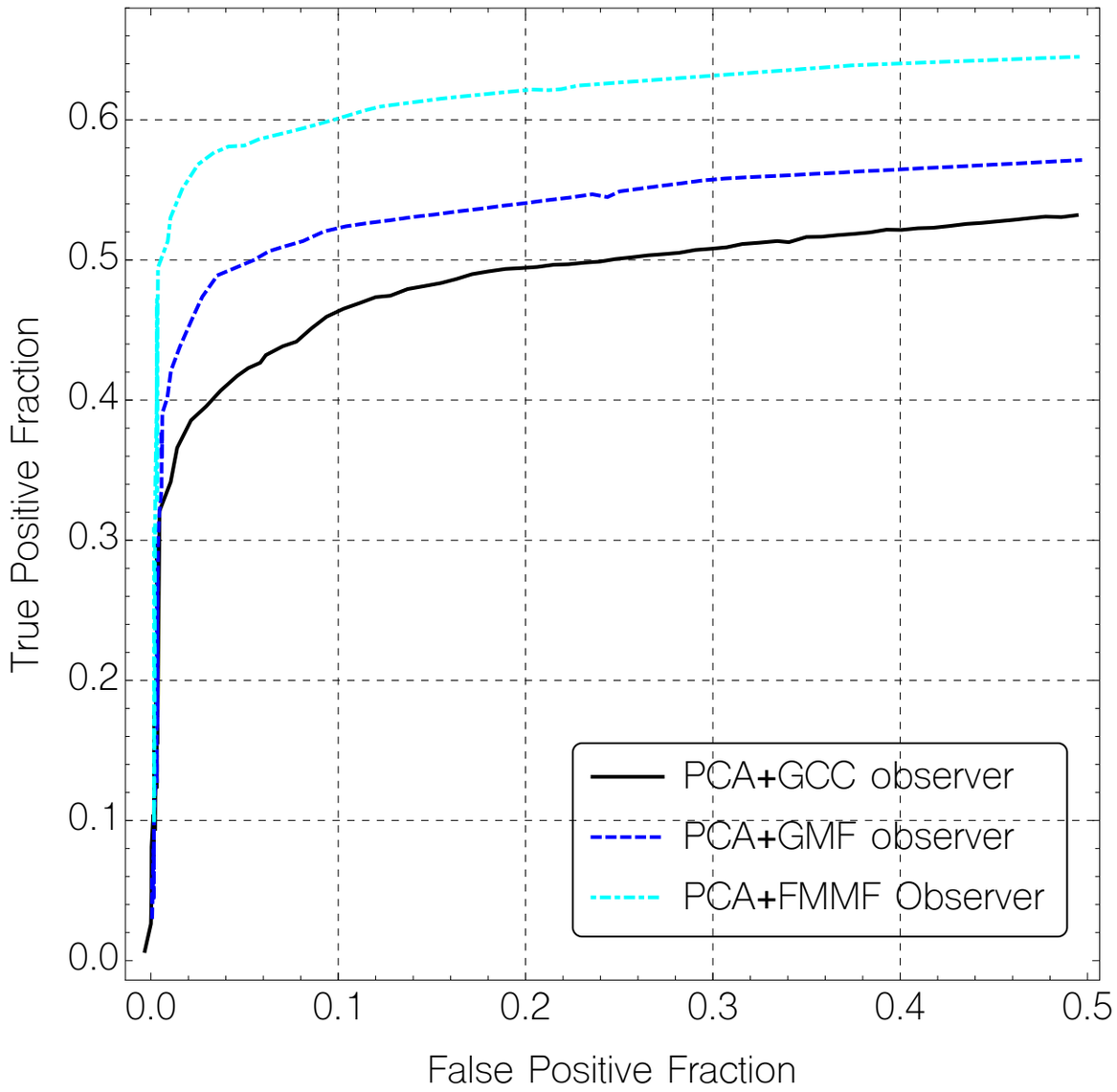


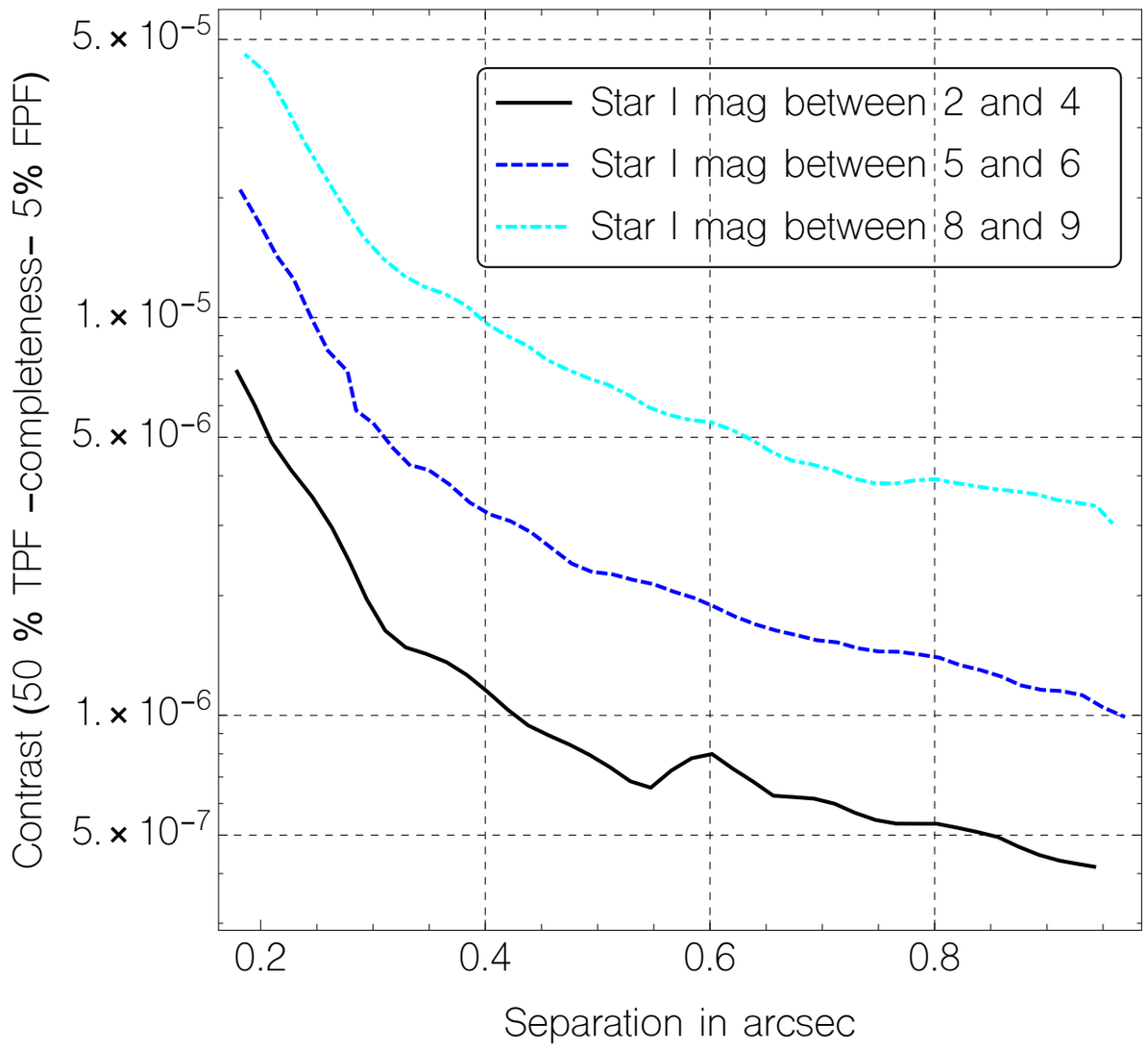






Ruffio et al., 2017





“Inverting the model” might help us squeeze out a few more objects.

Where do we go from there?

- We are more clever about getting the data.
- We change the cost function.
- We change the decision making machine.

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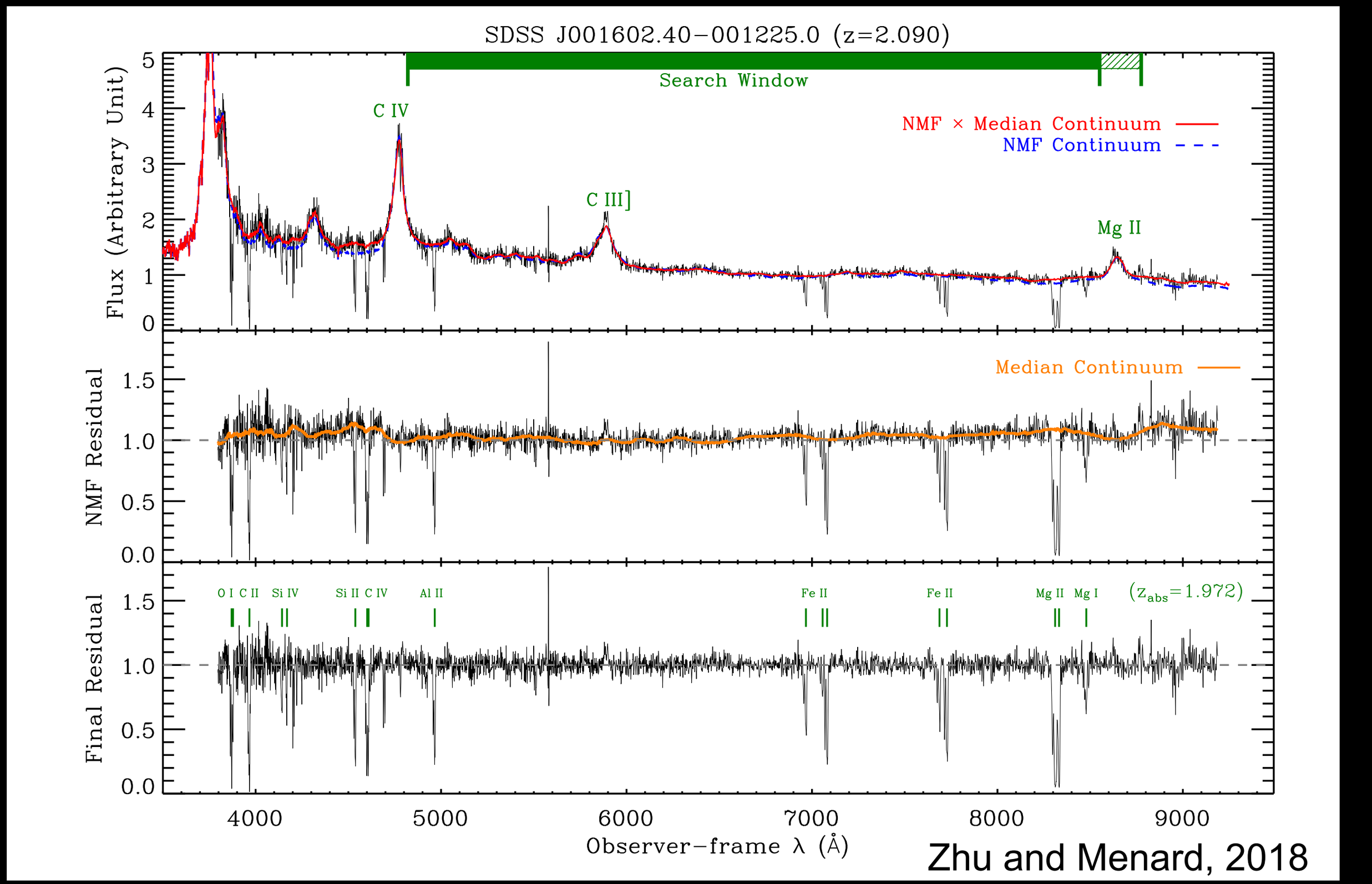
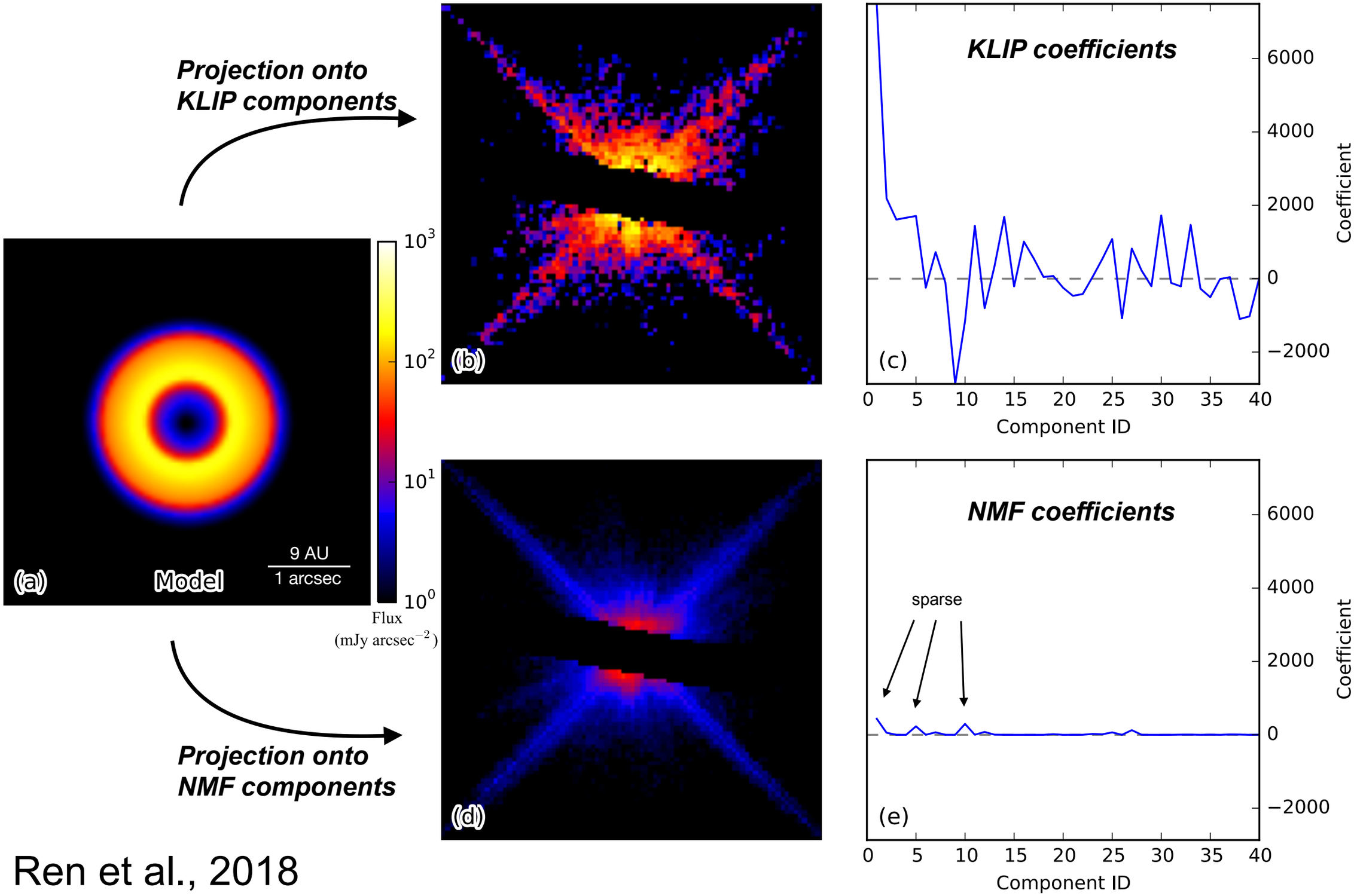
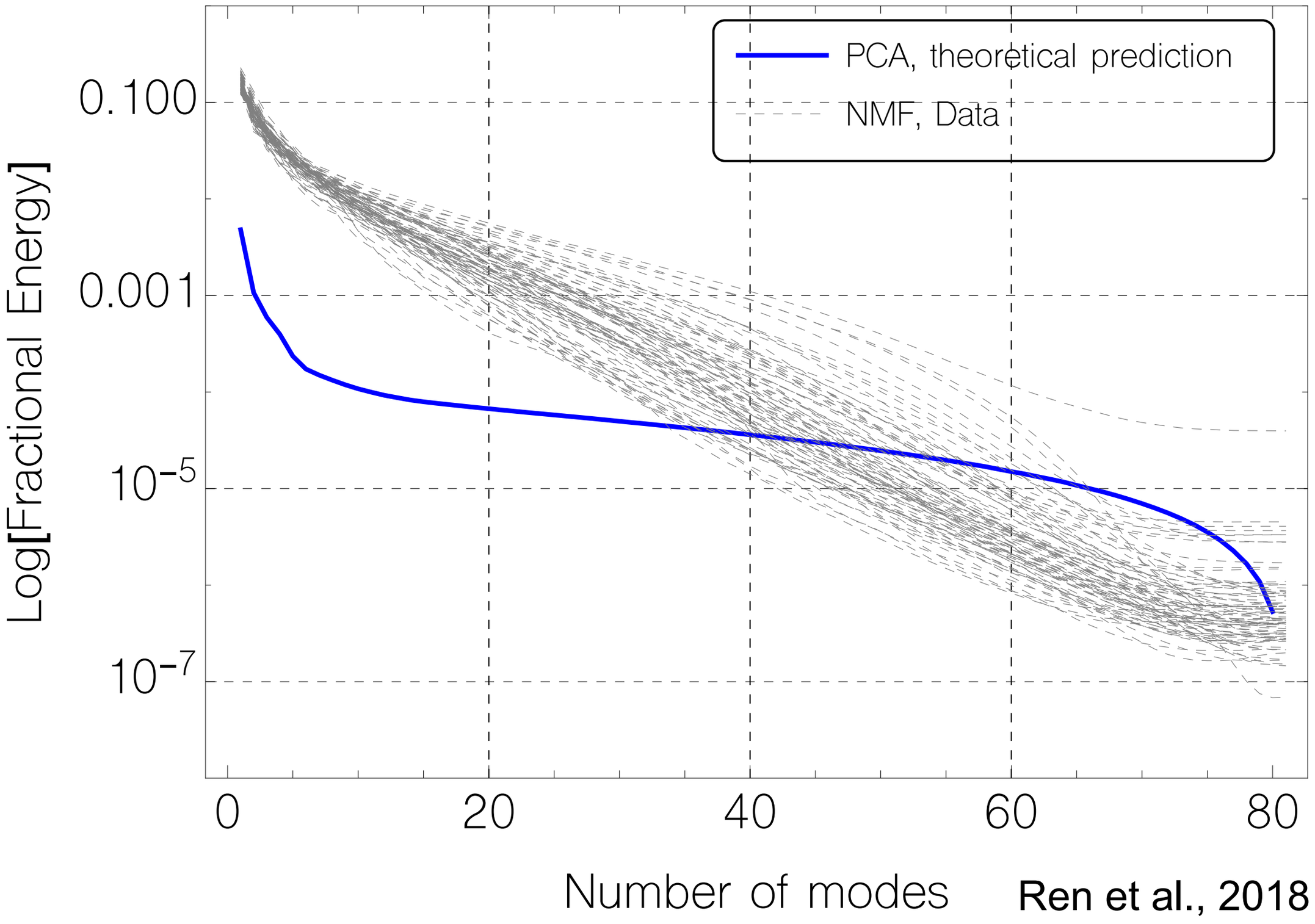


NMF for quasar spectral templates.

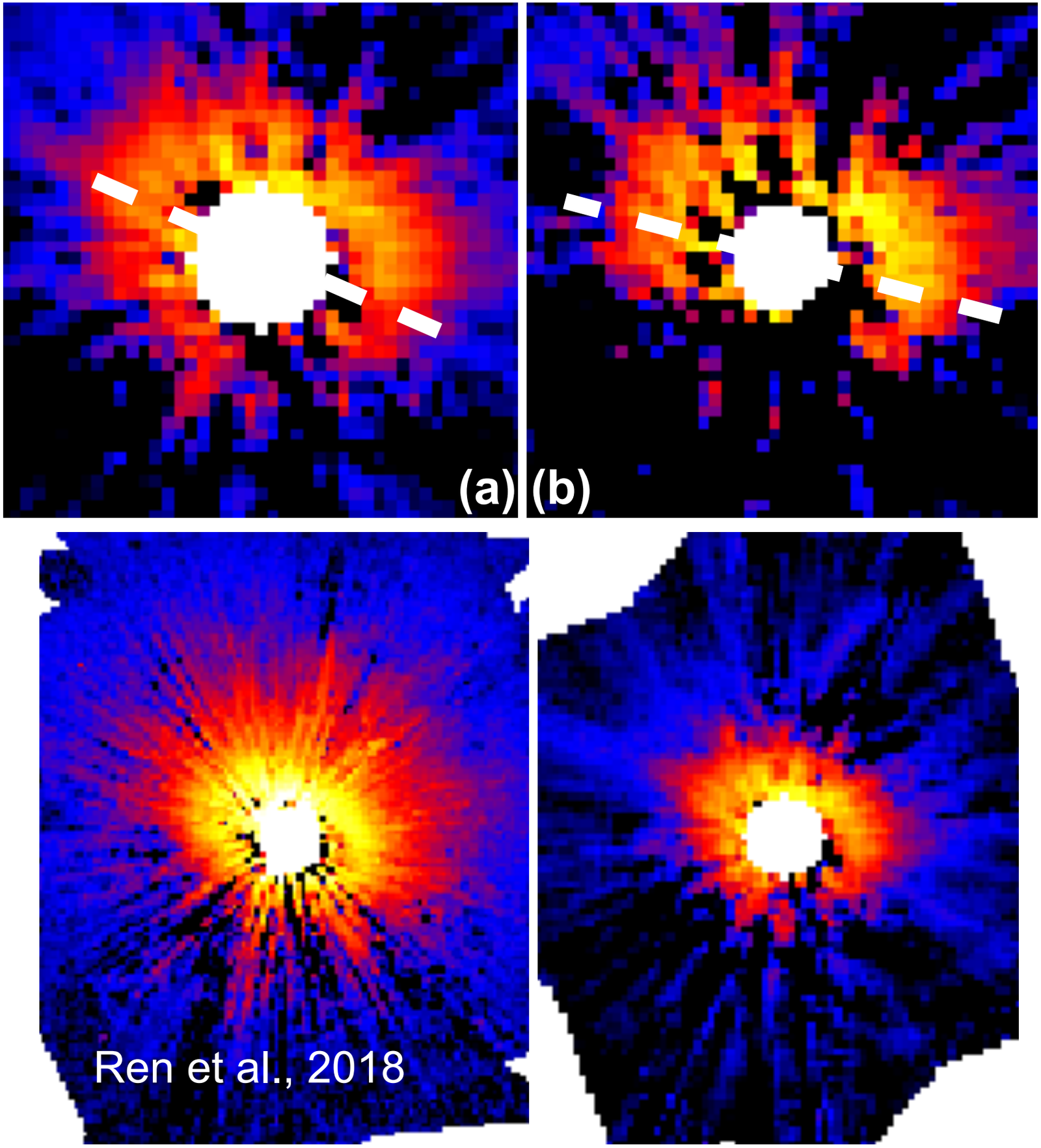


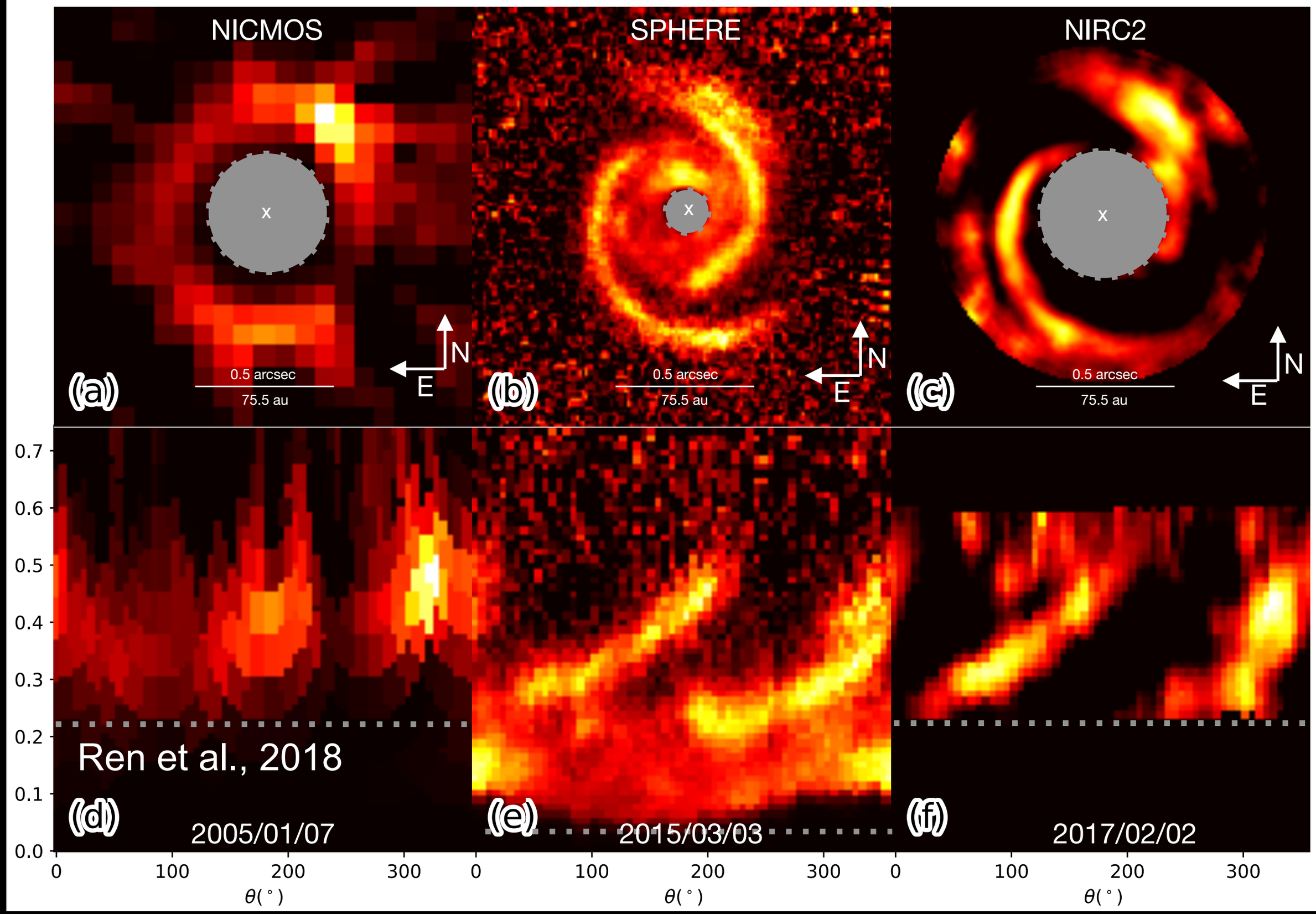
Advantage of using positive coefficients.



Ren et al., 2018

Model
Classical
KLIP
NMF
0°
45°
75°
9 AU
1 arcsec
10^0
10^1
10^2
Flux (mJy arcsec^{-2})
Ren et al., 2018


(a)
(b)
Ren et al., 2018


NICMOS
SPHERE
NIRC2
(a)
(b)
(c)
0.5 arcsec
75.5 au
N
E
Ren et al., 2018
(d)
2005/01/07
(e)
2015/03/03
(f)
2017/02/02
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
100
200
300
θ(°)

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