

First Mid-Infrared Characterization of the Galactic Center WR Star Population

Zachary Ireland

Supervisors: Sebastiano von Fellenberg, Bart Ripperda



UNIVERSITY OF
TORONTO

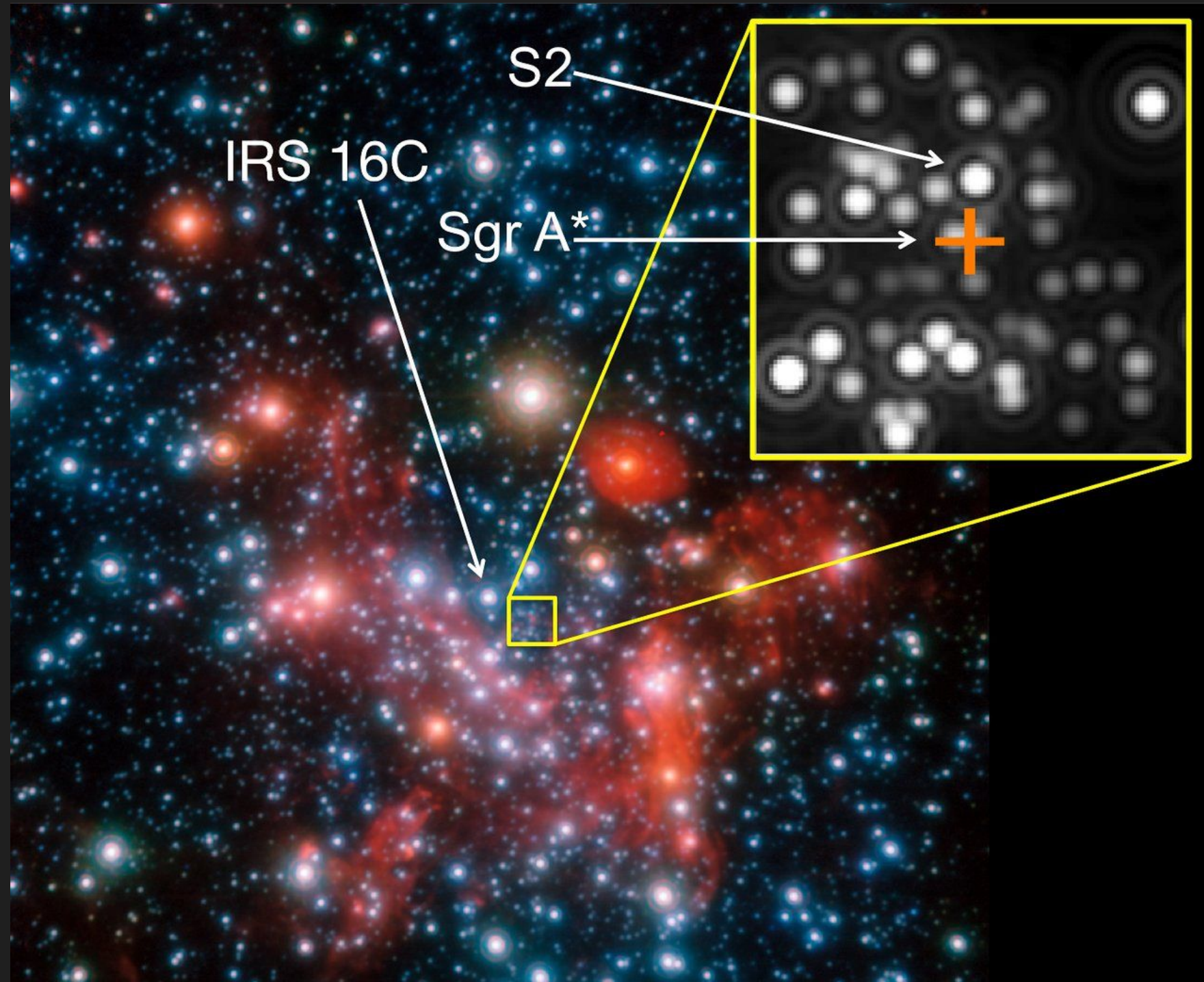


CITA
ICAT

Canadian Institute for
Theoretical Astrophysics

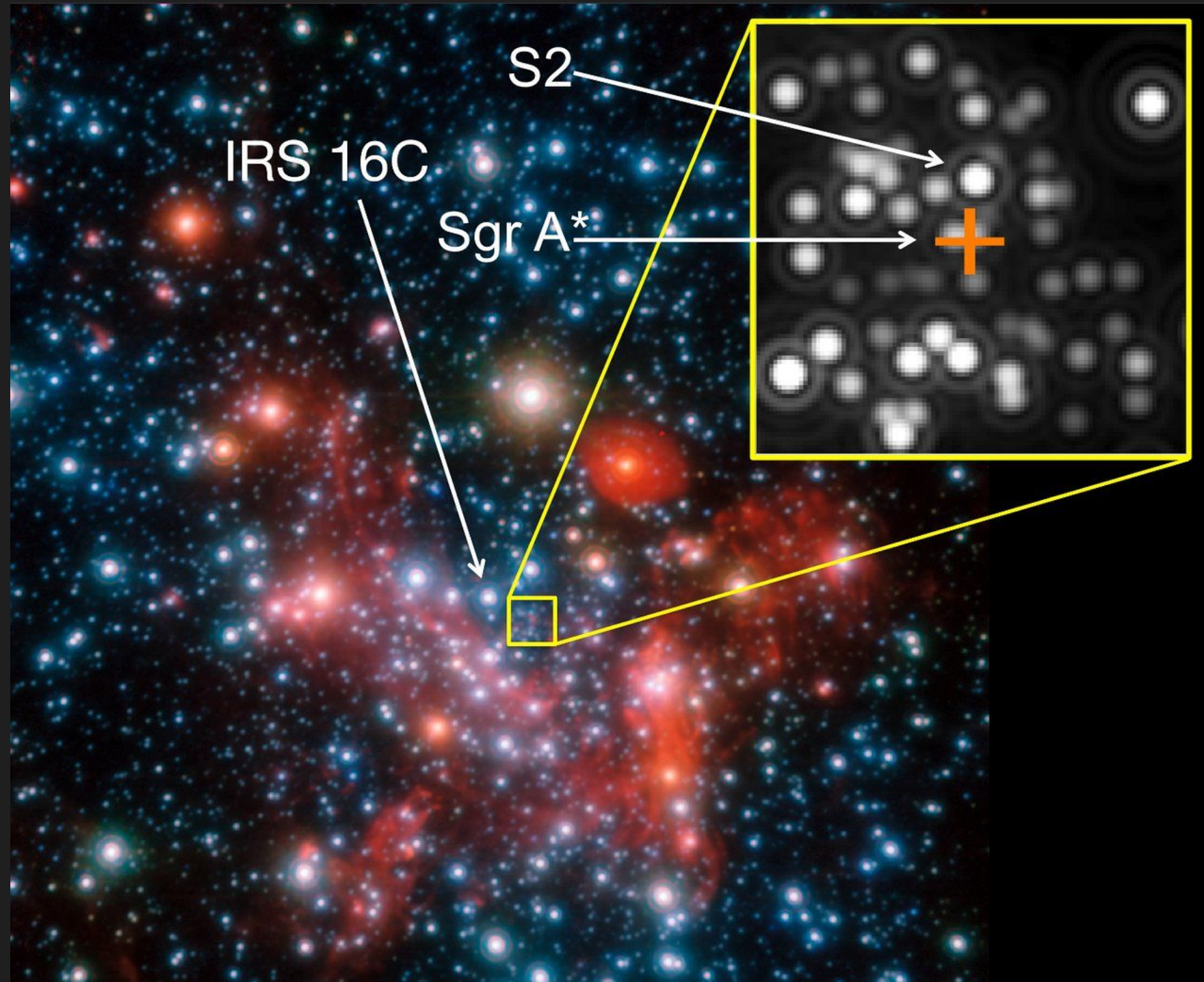
L'institut Canadien
d'astrophysique théorique

What is the Galactic Center



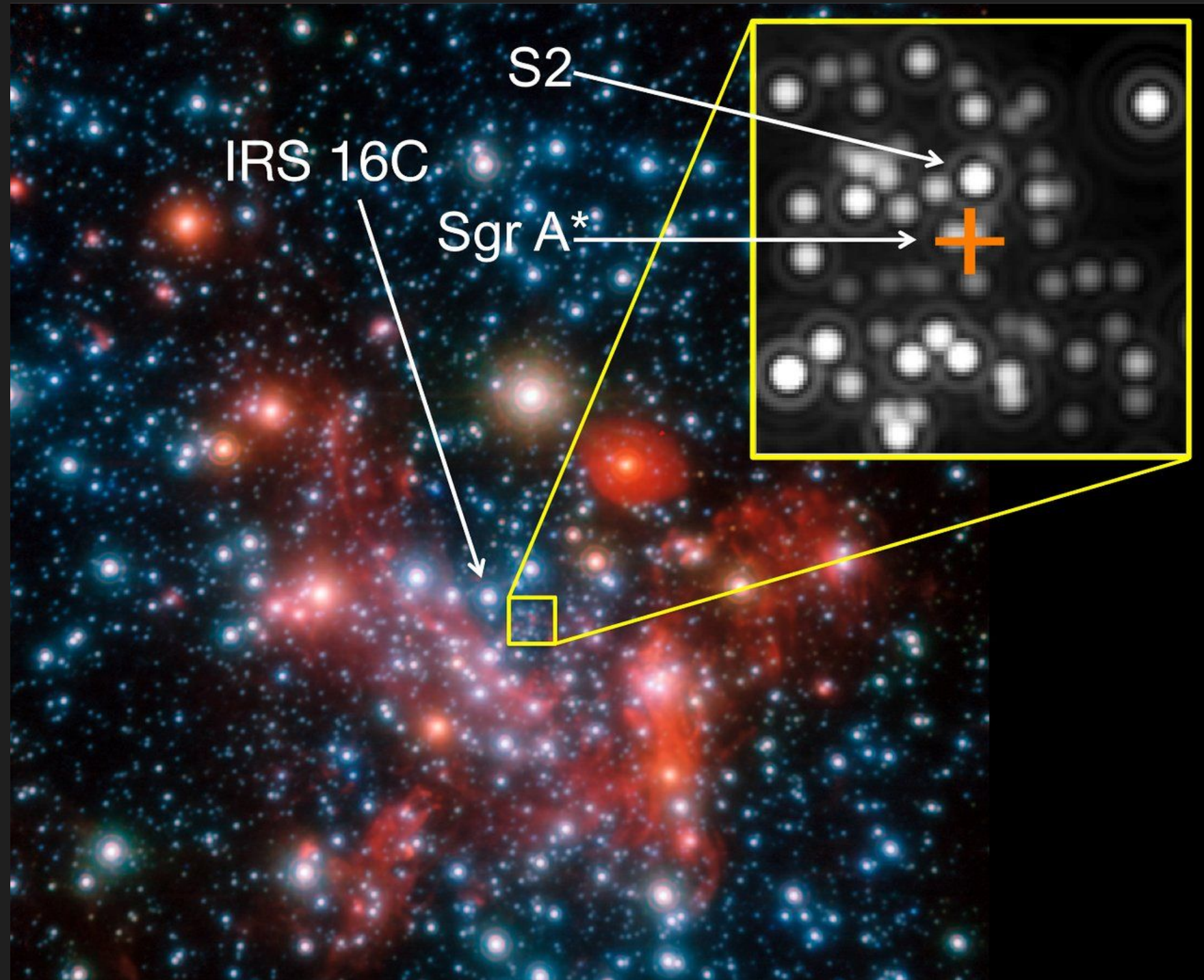
Gillessen et al. (2008)

What is the Galactic Center



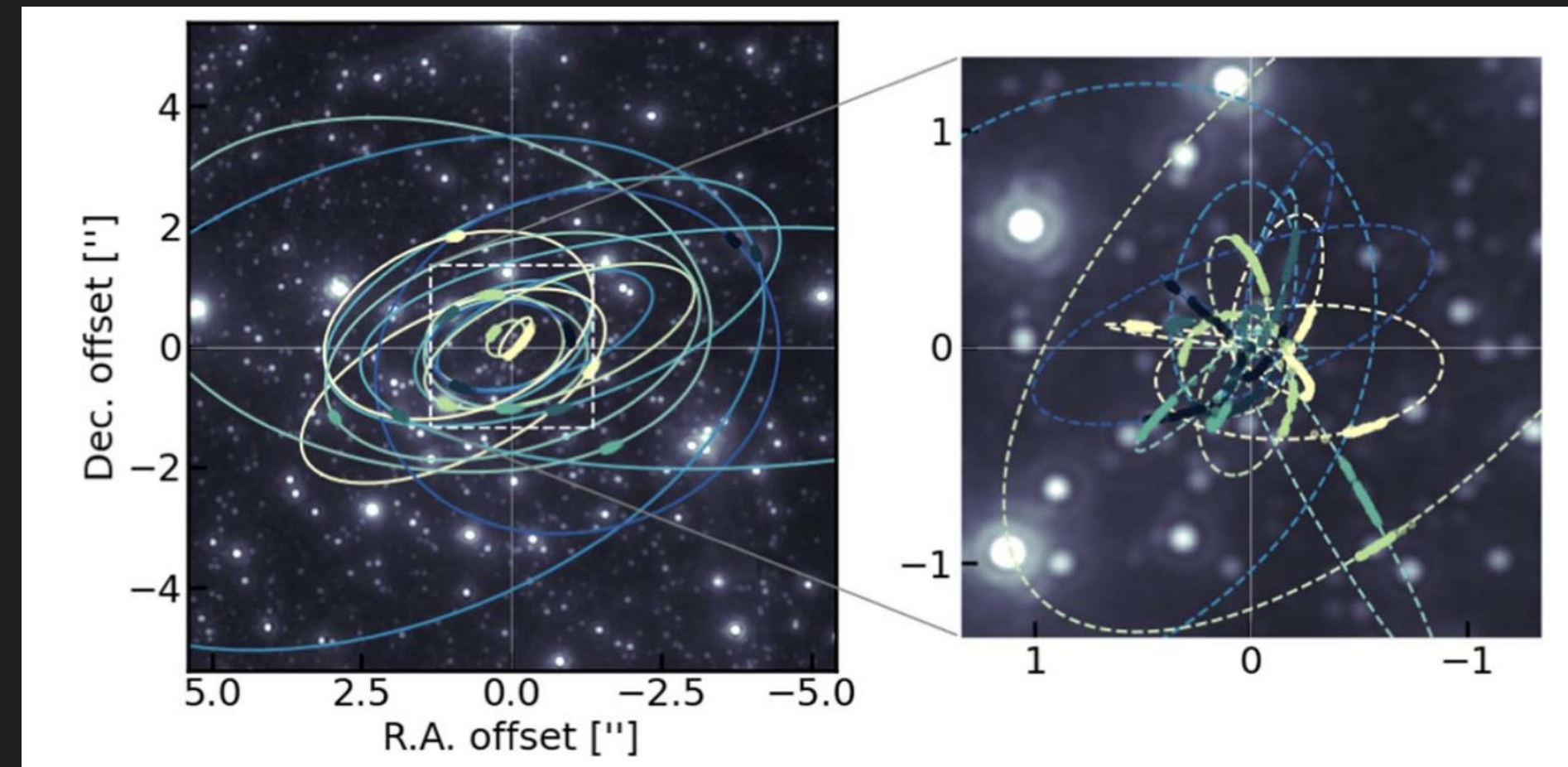
$$d \sim 8 \text{ kpc} \sim 2.6 \times 10^4 \text{ ly}$$

What is the Galactic Center



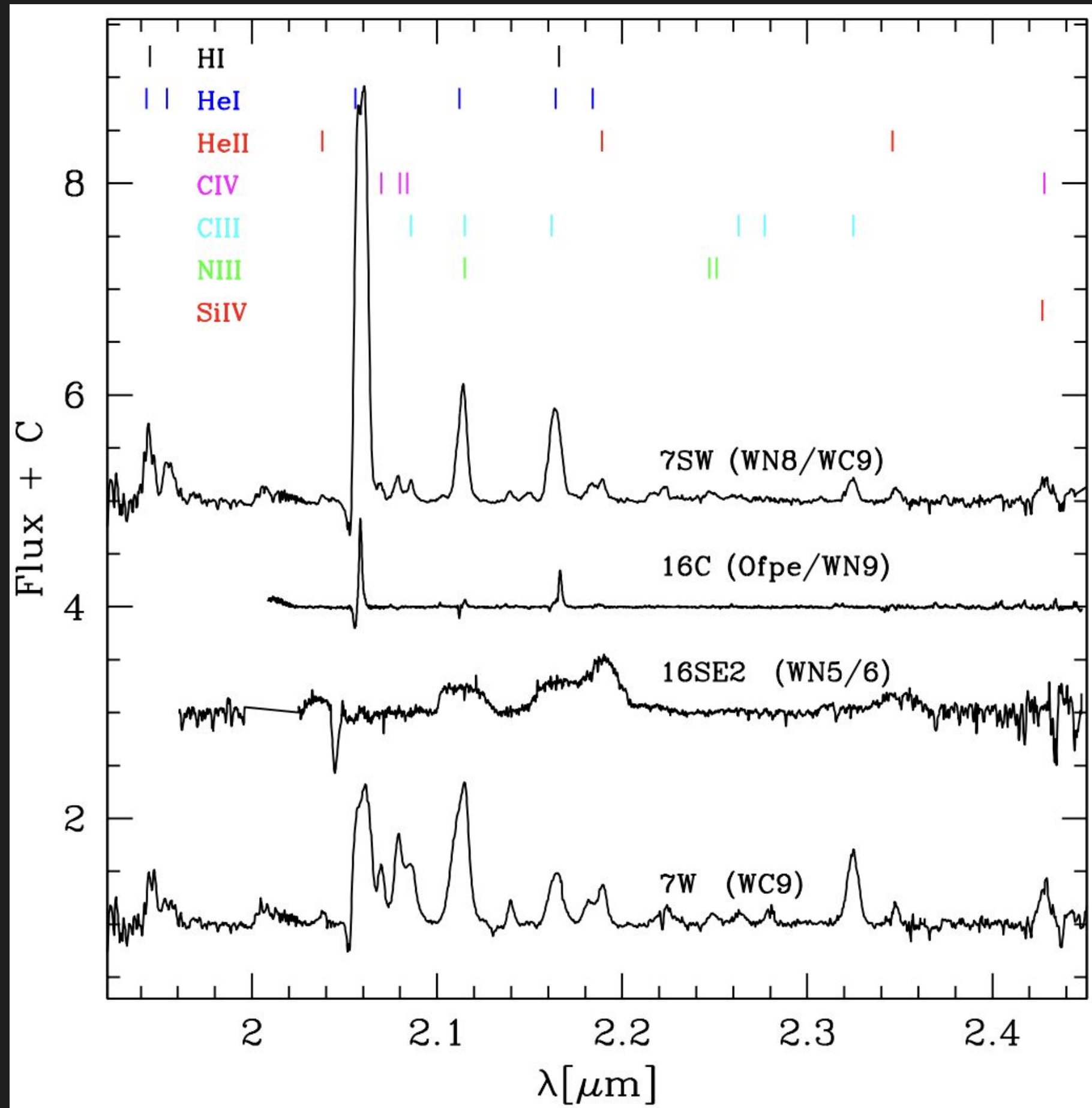
Gillessen et al. (2008)

$$d \sim 8 \text{ kpc} \sim 2.6 \times 10^4 \text{ ly}$$

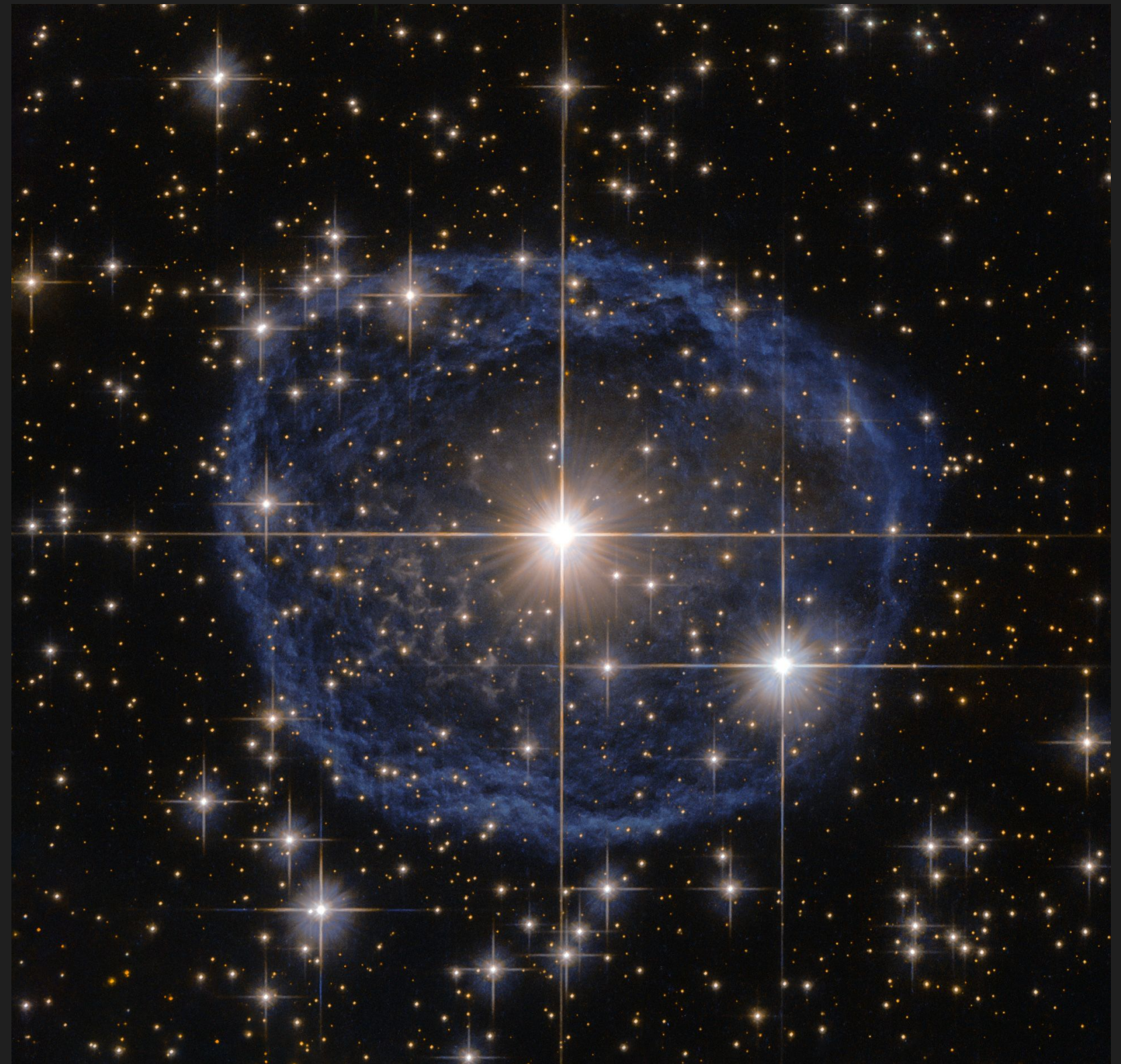
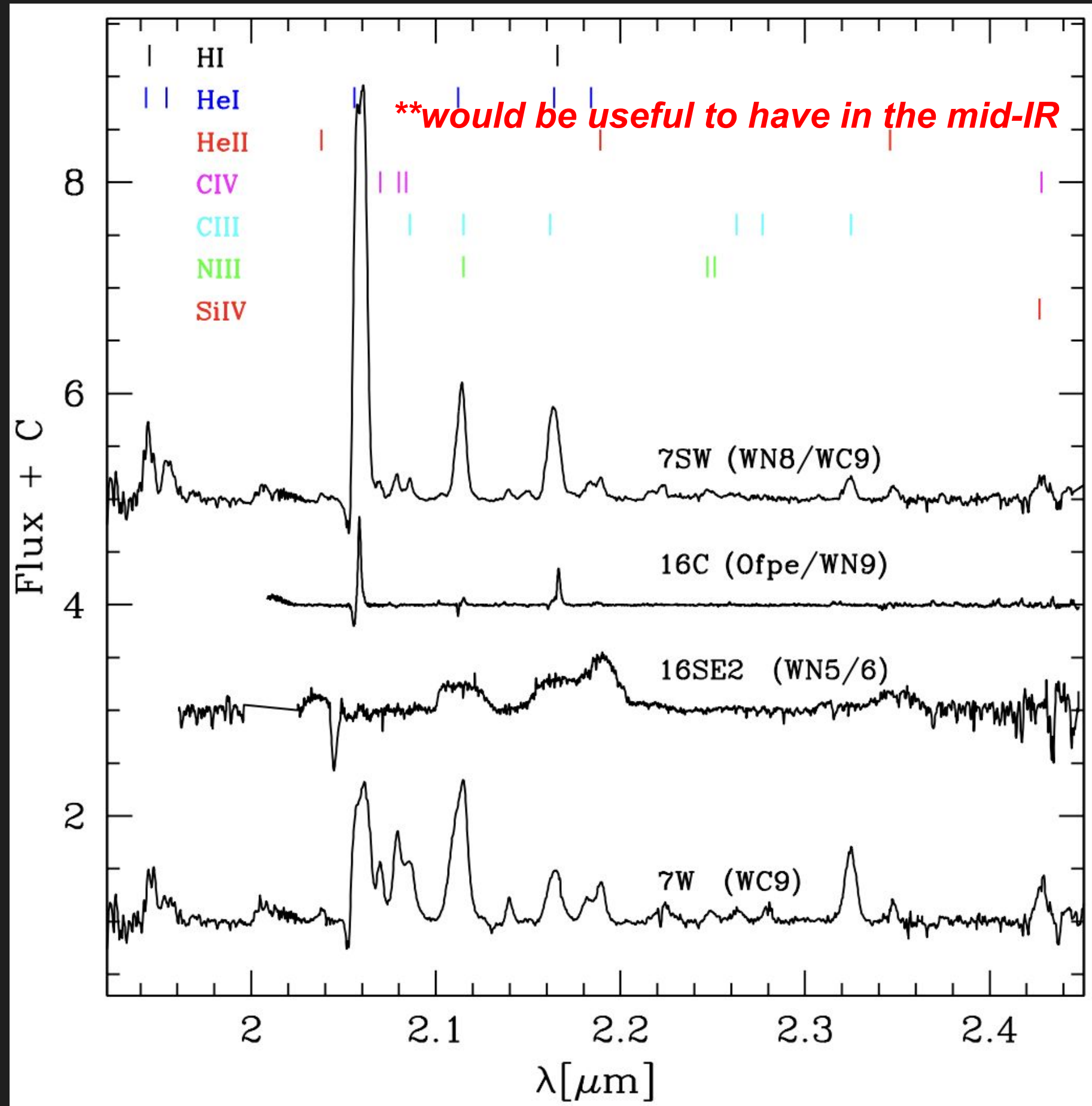


Fellenberg et al. (2022)

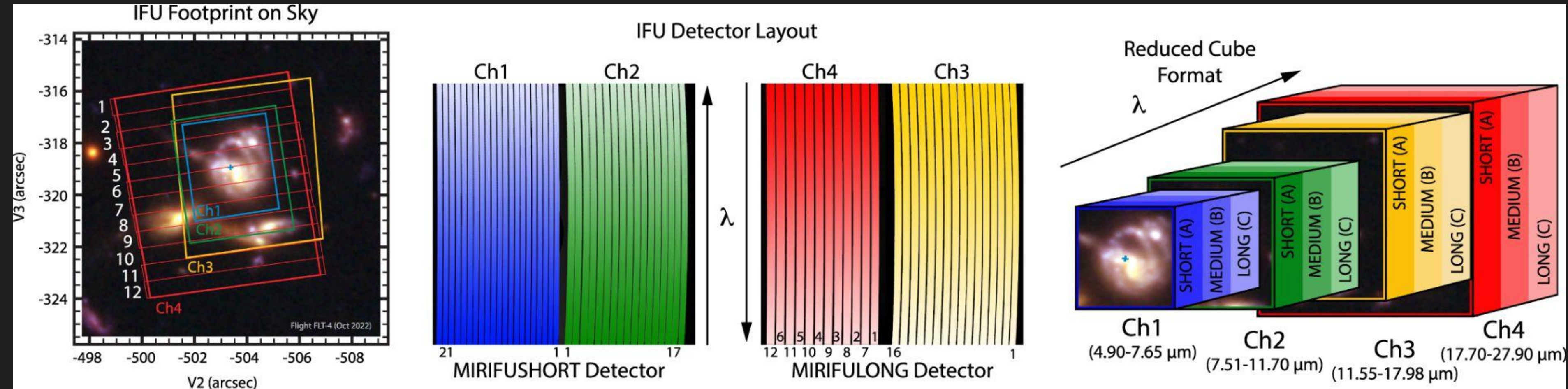
Motivation



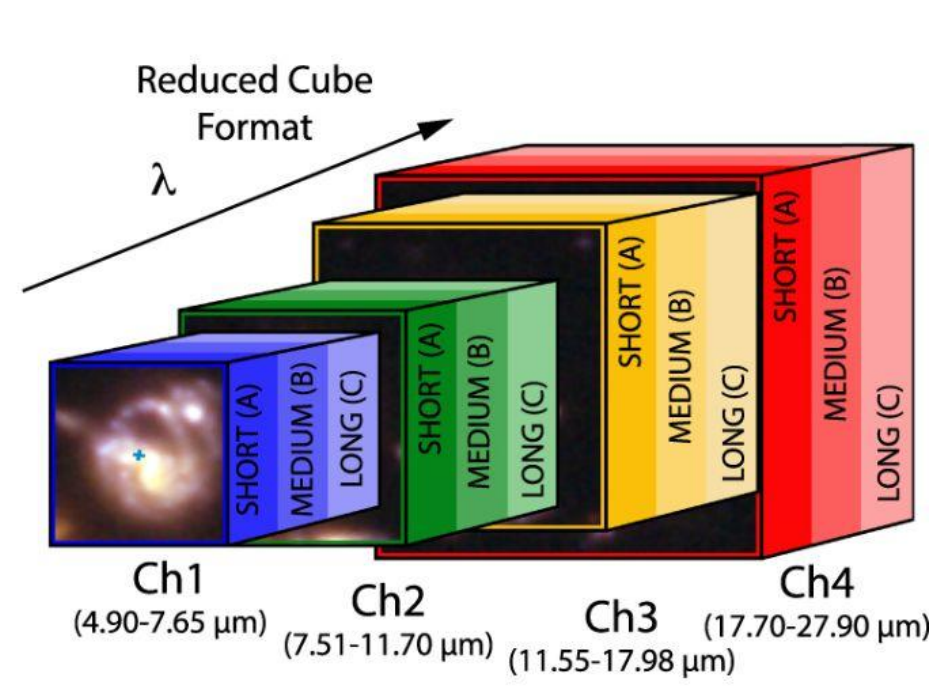
Motivation



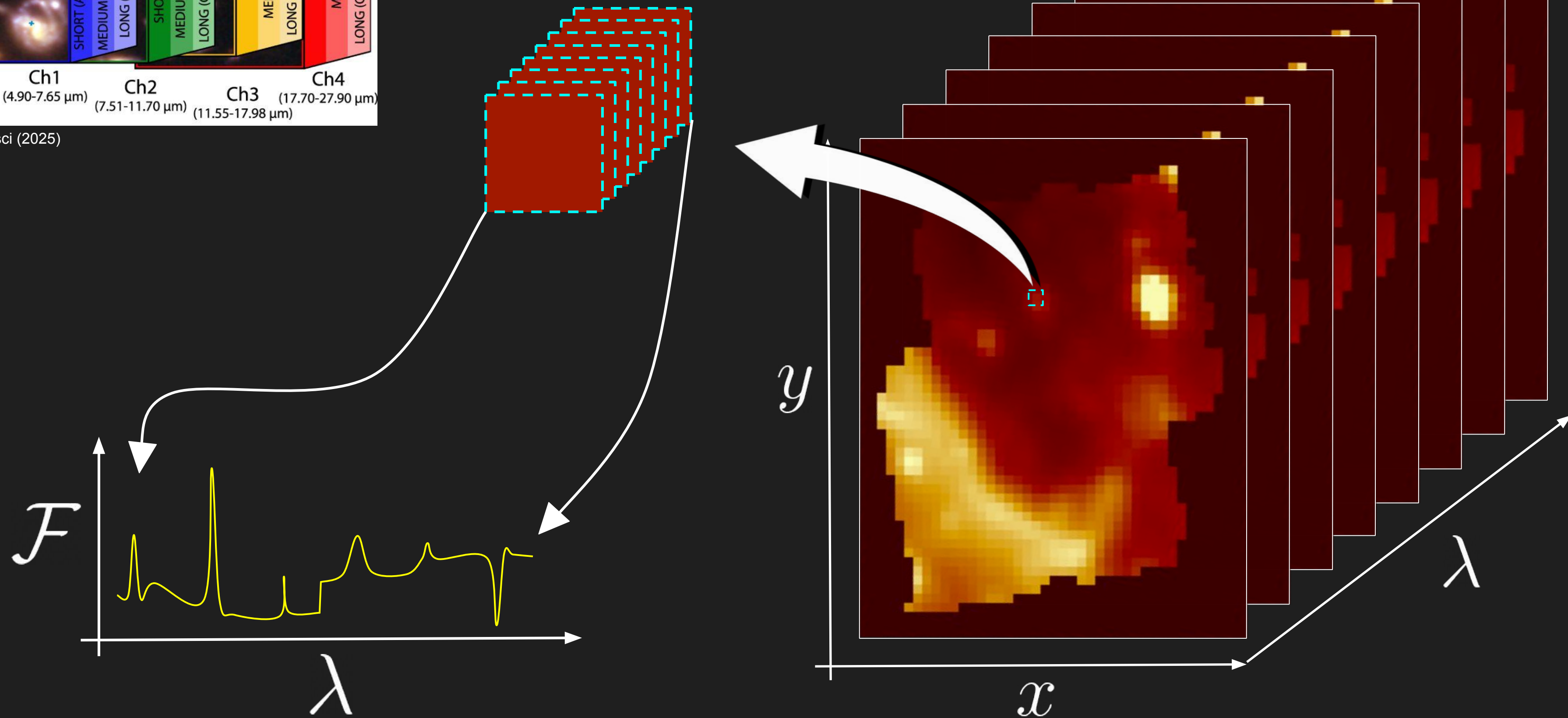
JWST/MIRI-MRS IFU

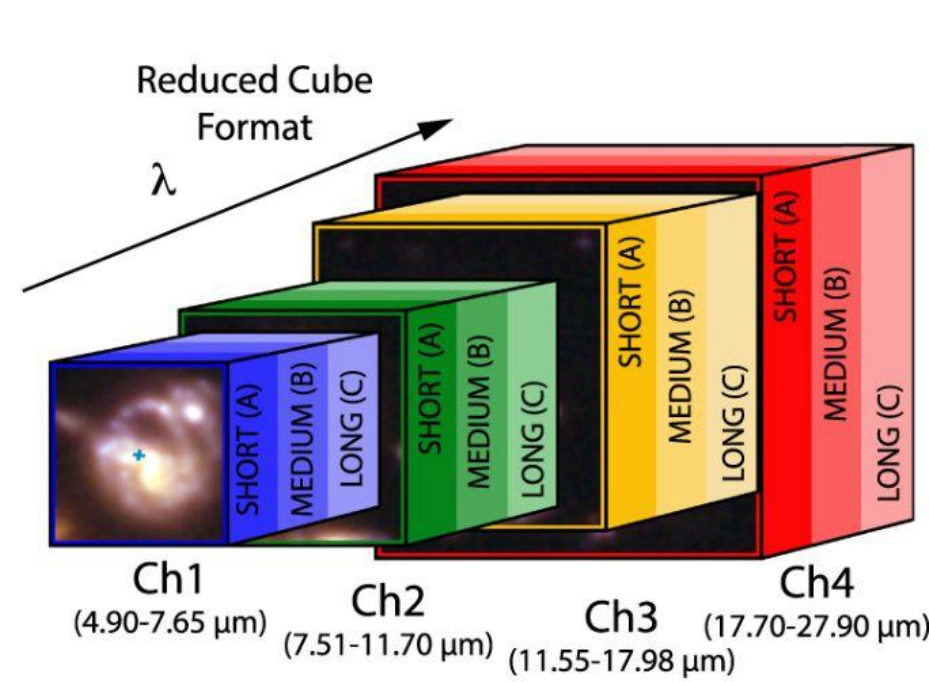


Stsci (2025)

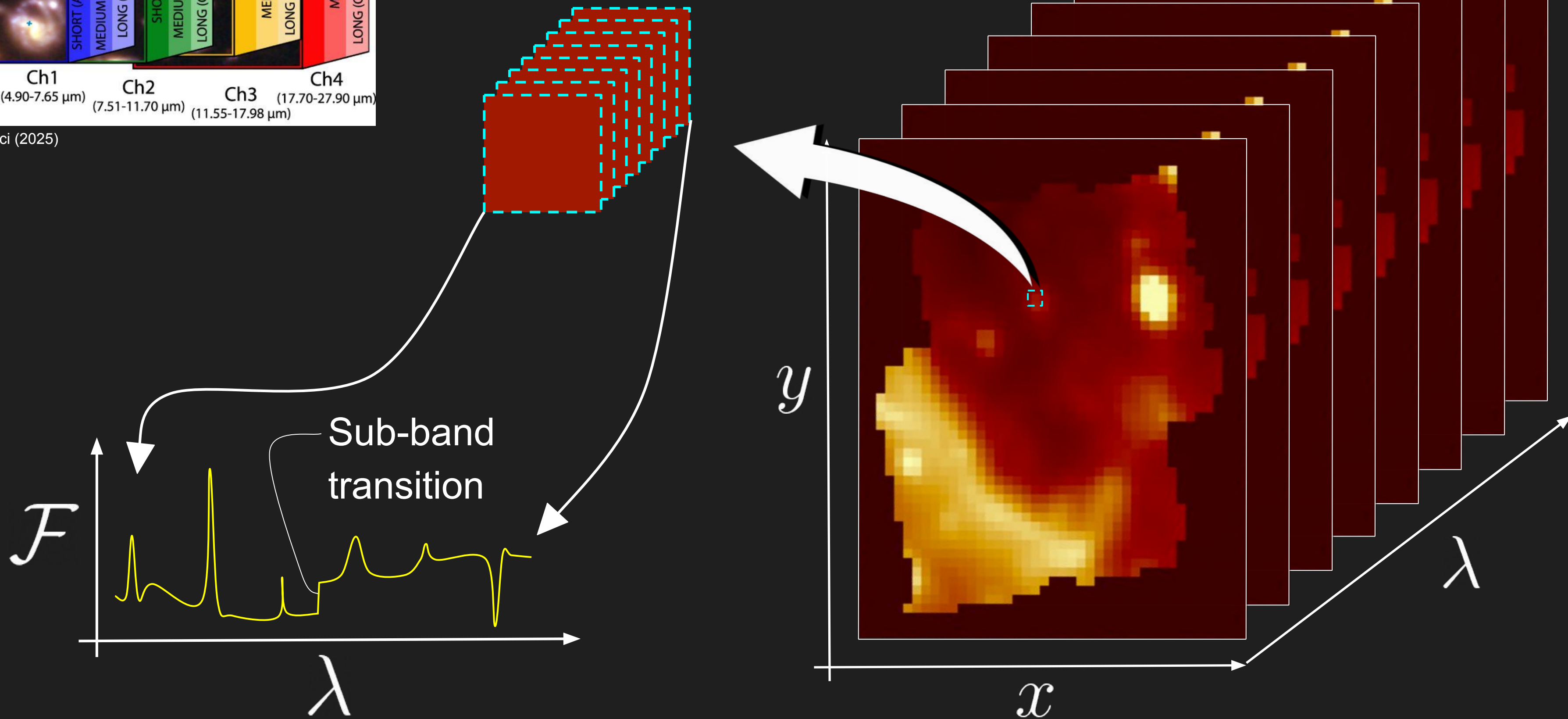


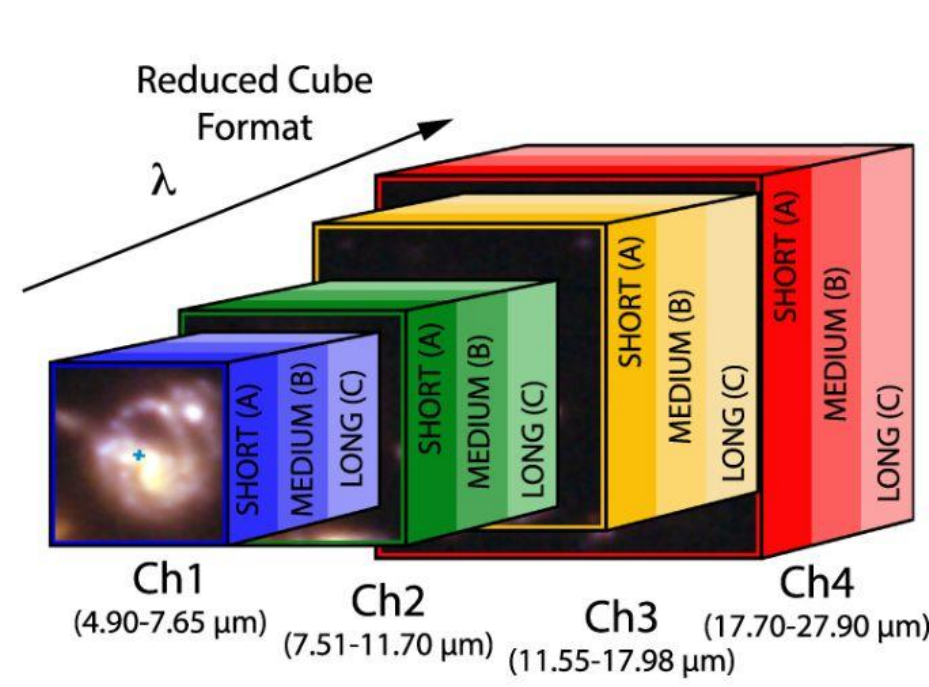
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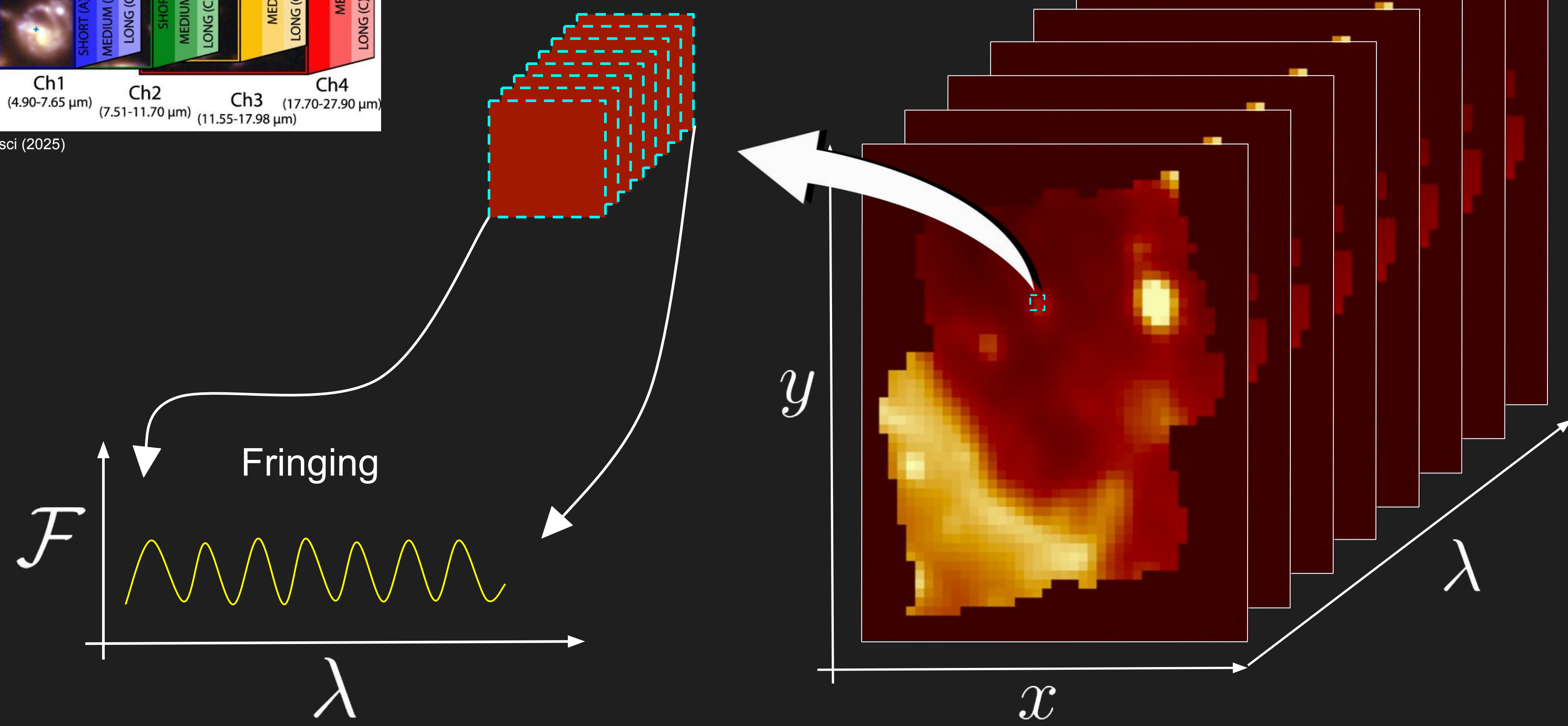


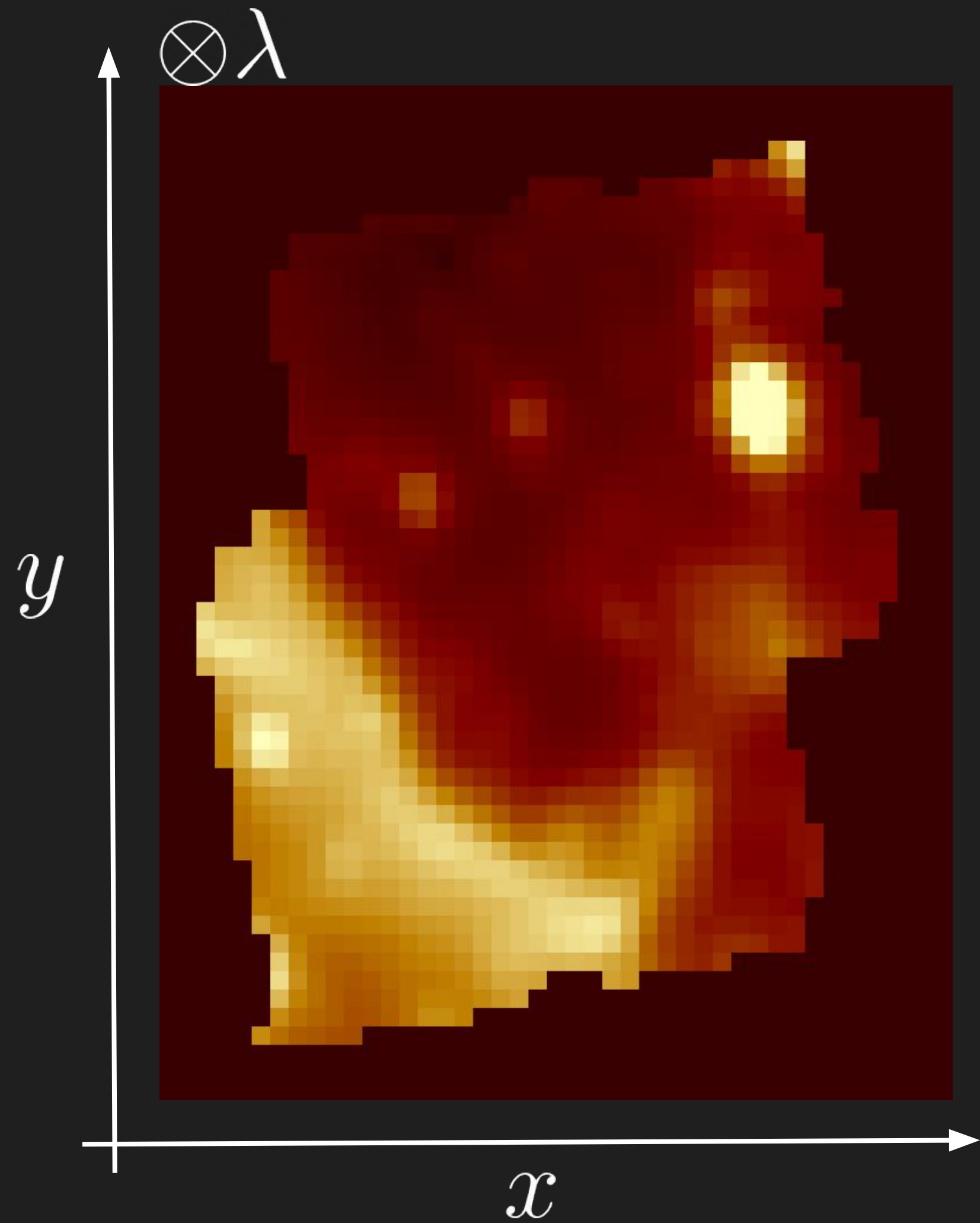
Stsci (2025)



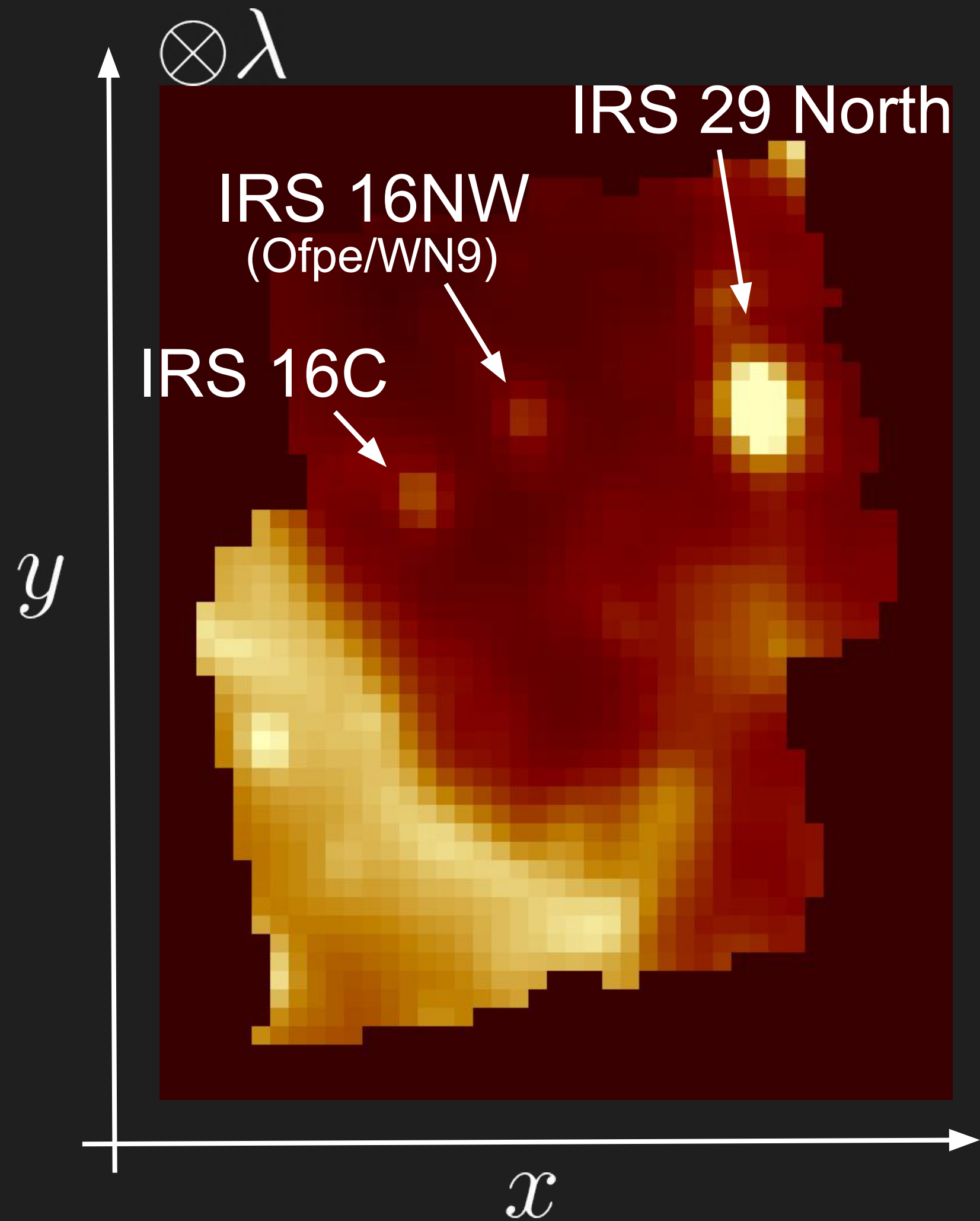


Stsci (2025)



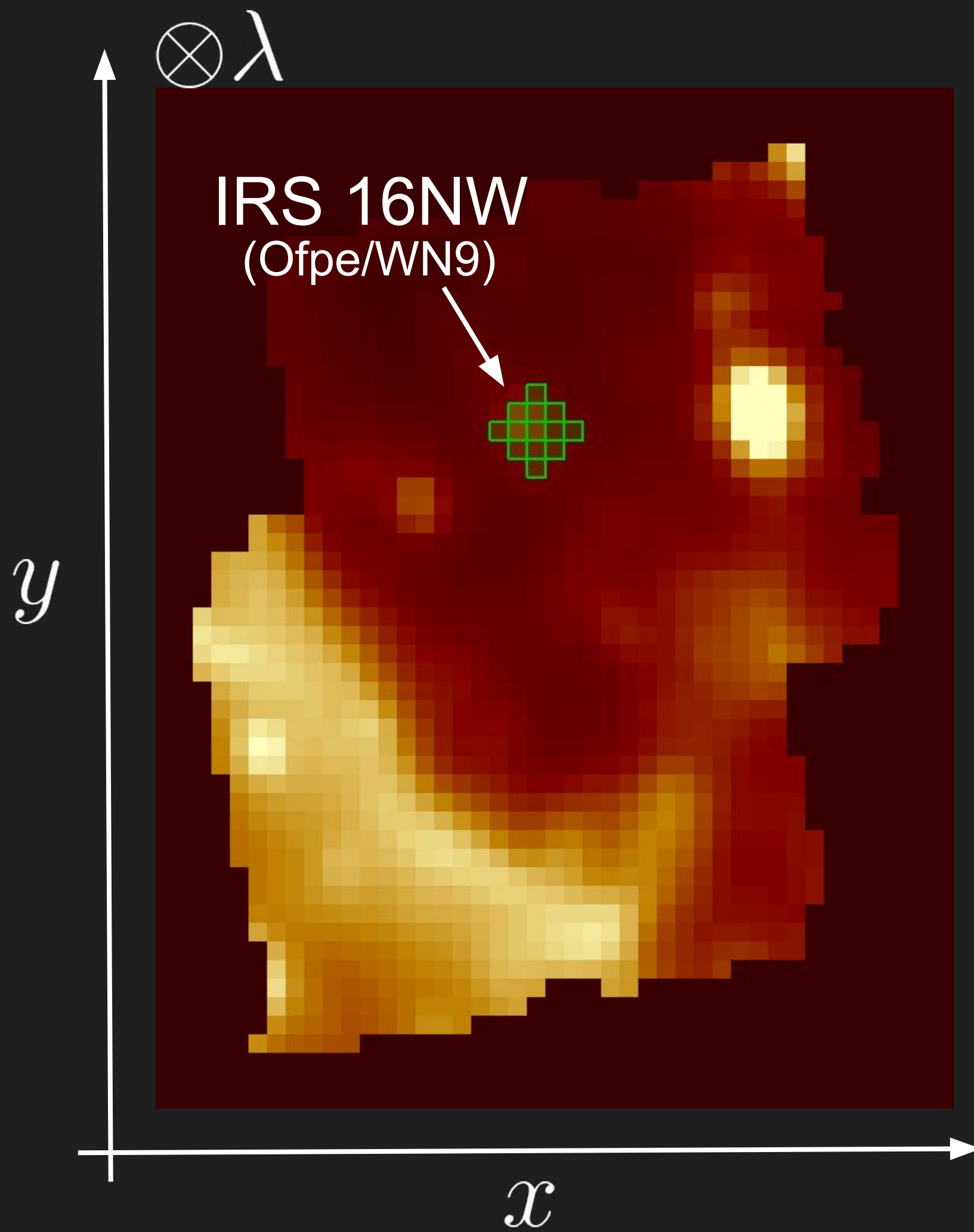


Spectrum extraction
(Channel 1 brightness-continuum map)



Spectrum extraction

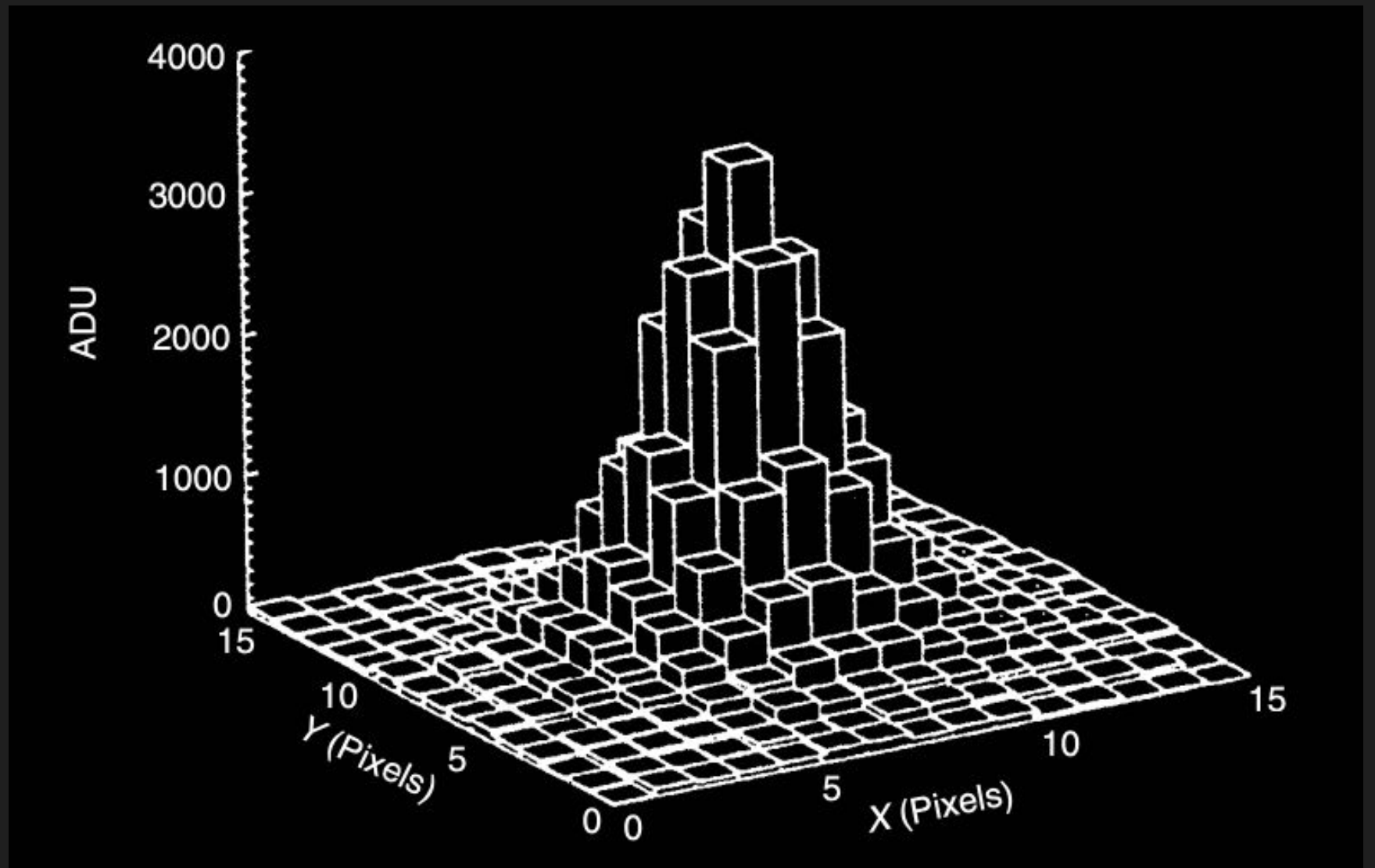
(Channel 1 brightness-continuum map)



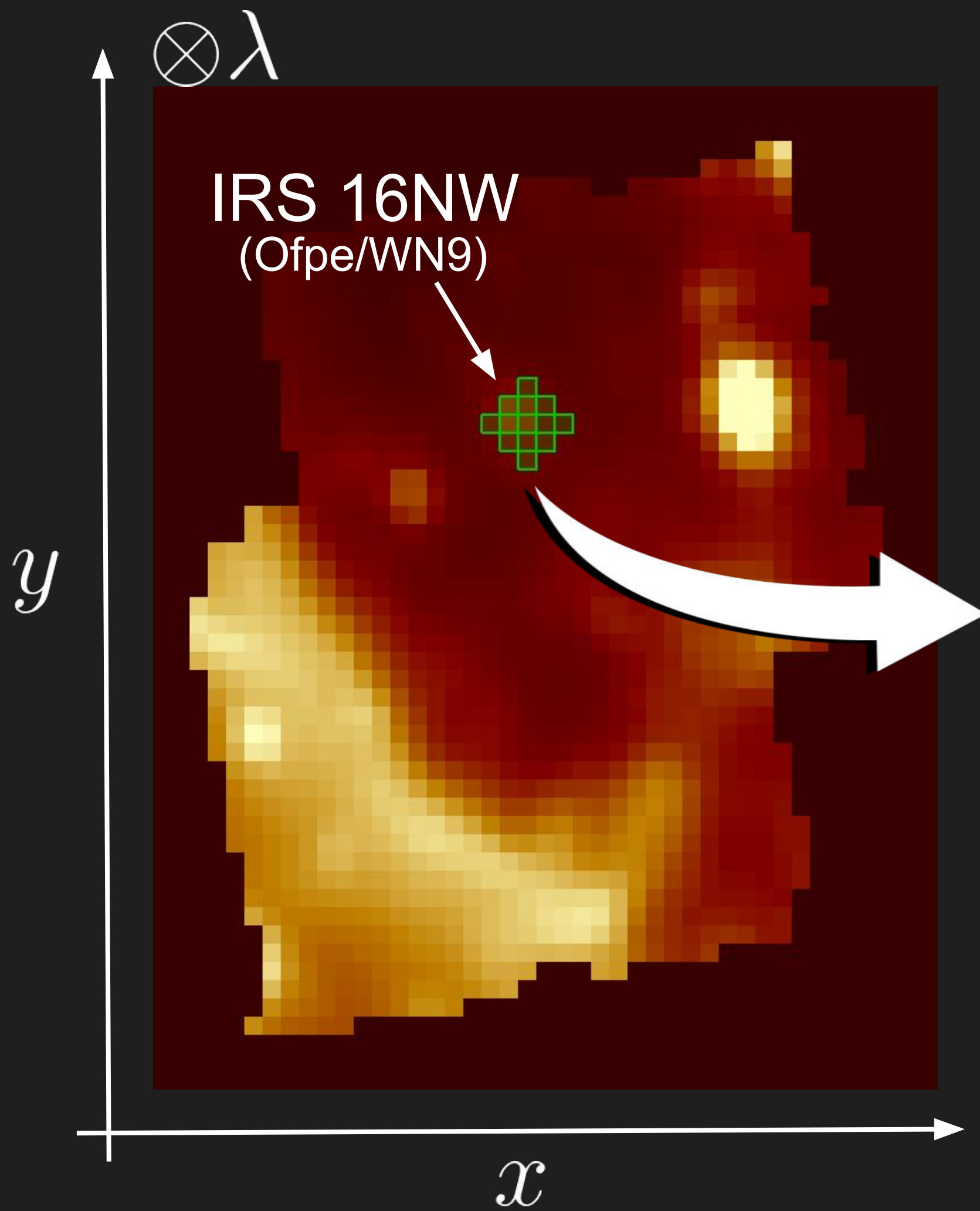
Spectrum extraction

(Channel 1 brightness-continuum map)

- 13 spaxel aperture, \mathcal{S}_{13} , to avoid undersampling of the PSF



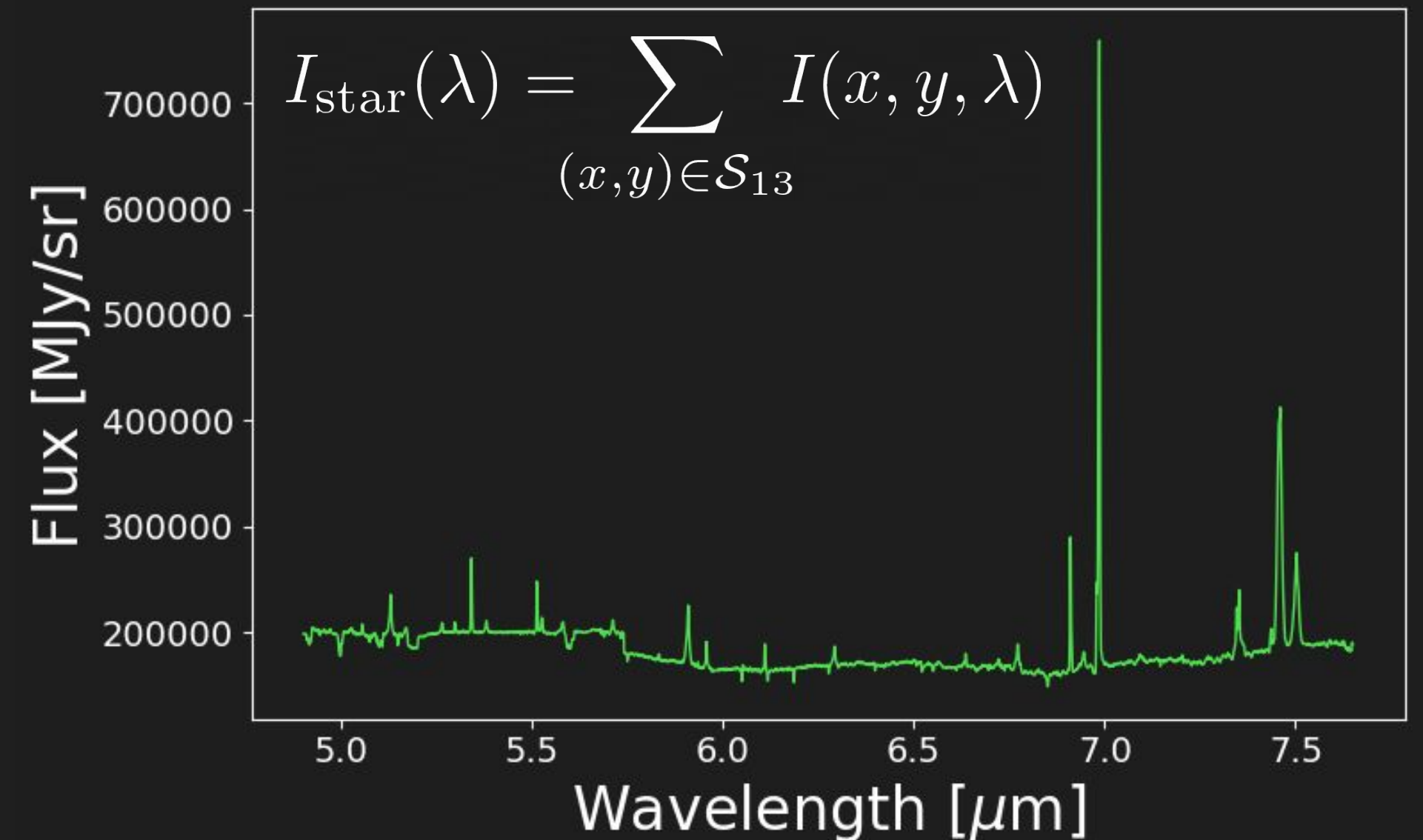
Howell (2006)



Spectrum extraction

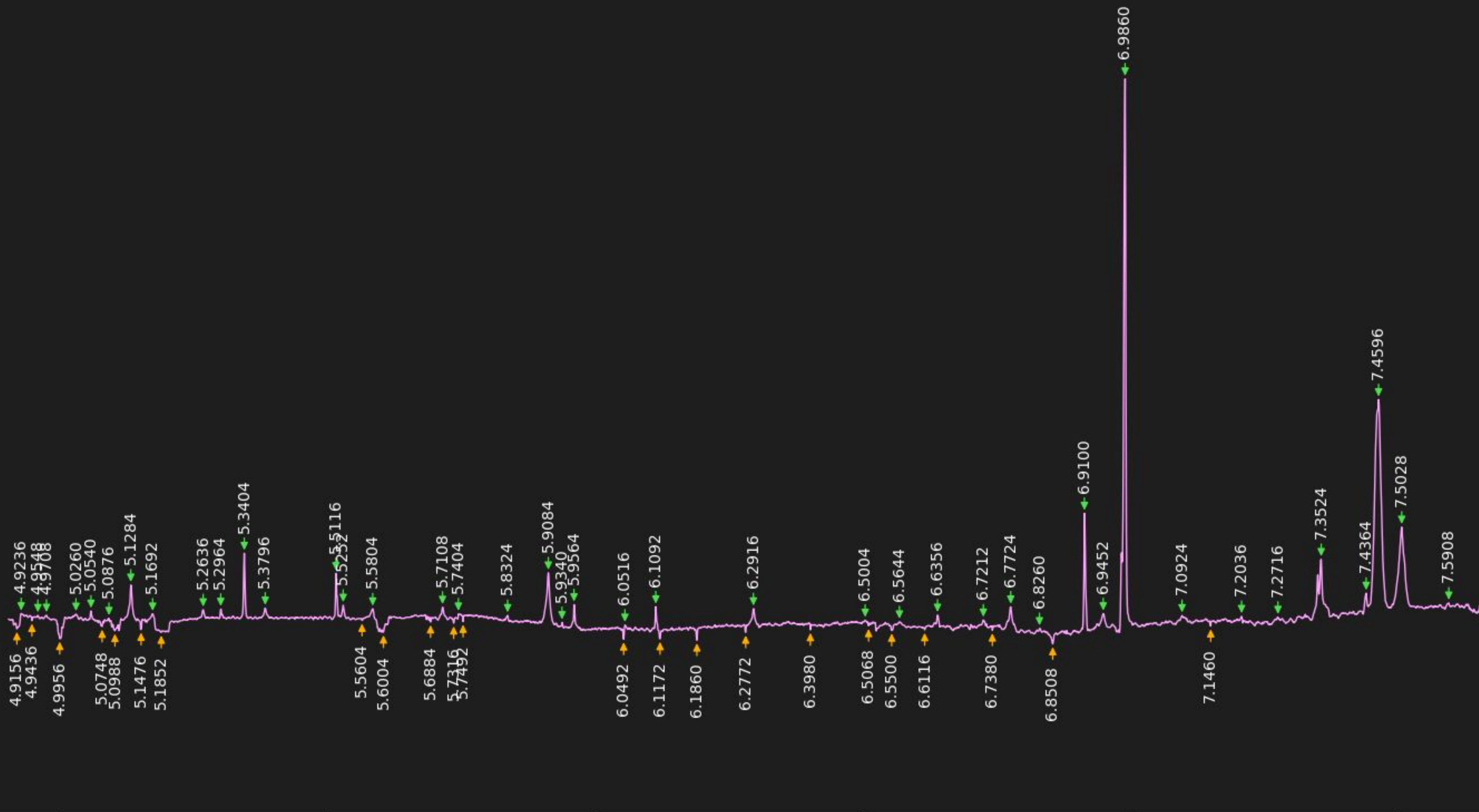
(Channel 1 brightness-continuum map)

- 13 spaxel aperture, \mathcal{S}_{13} , to avoid undersampling of the PSF

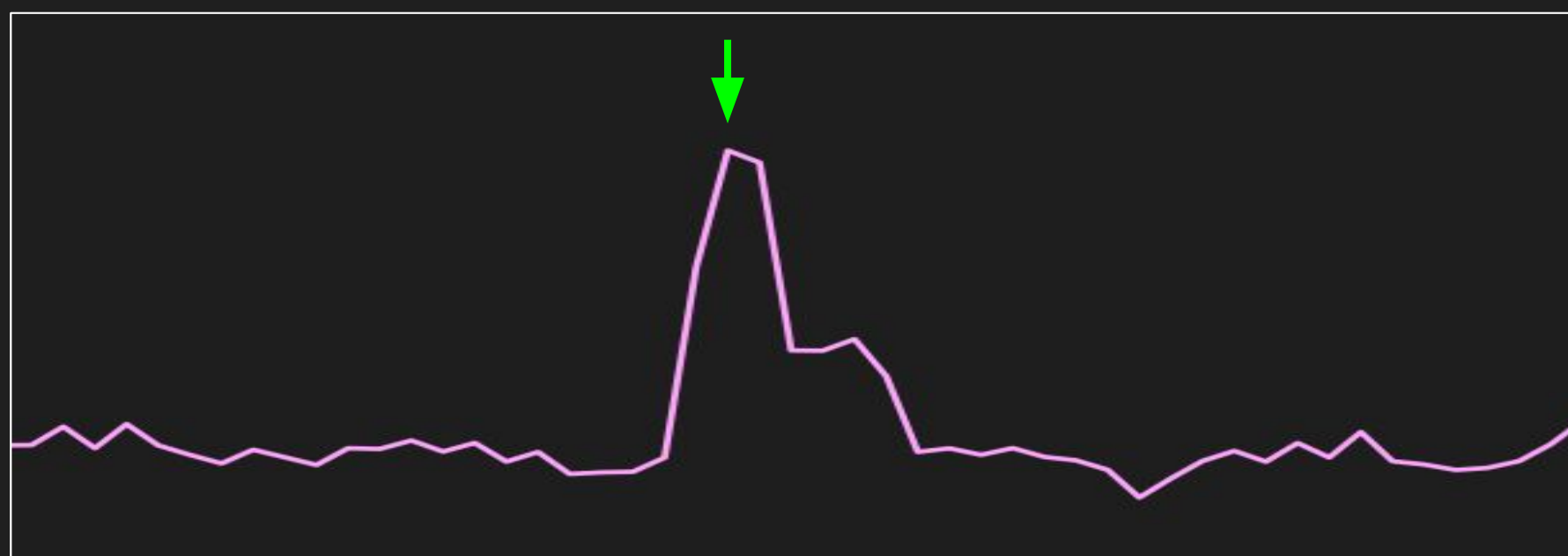
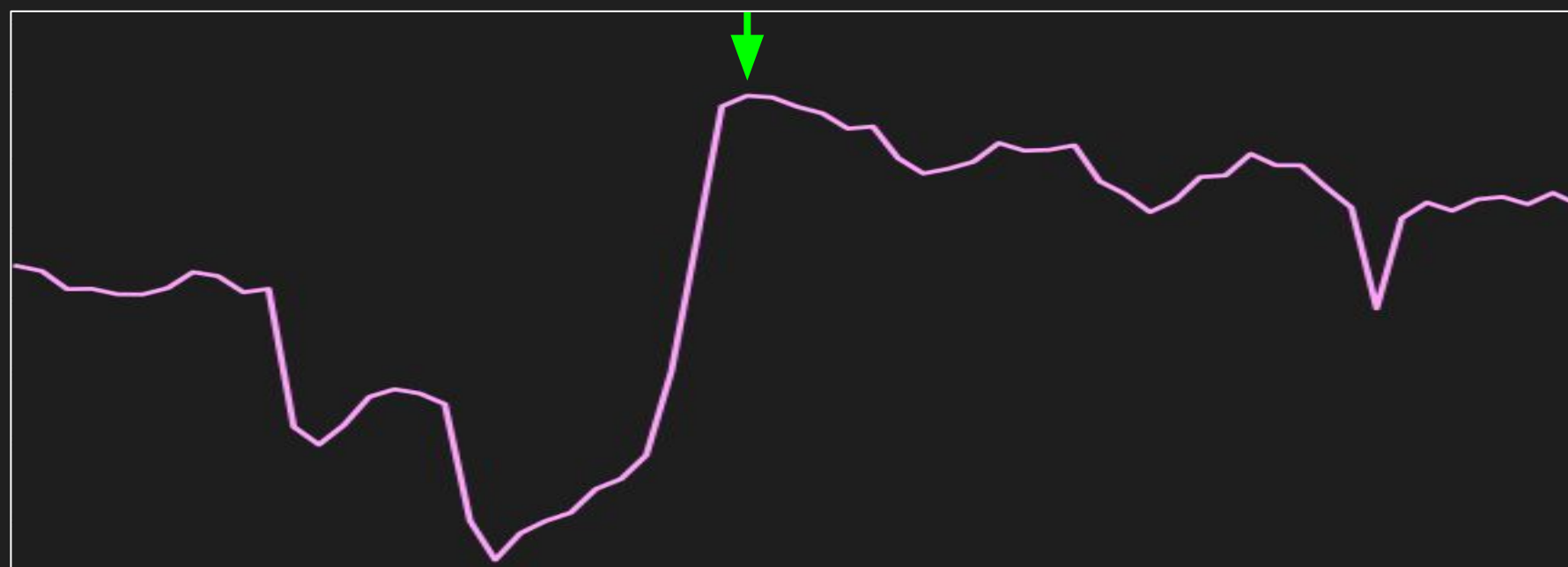
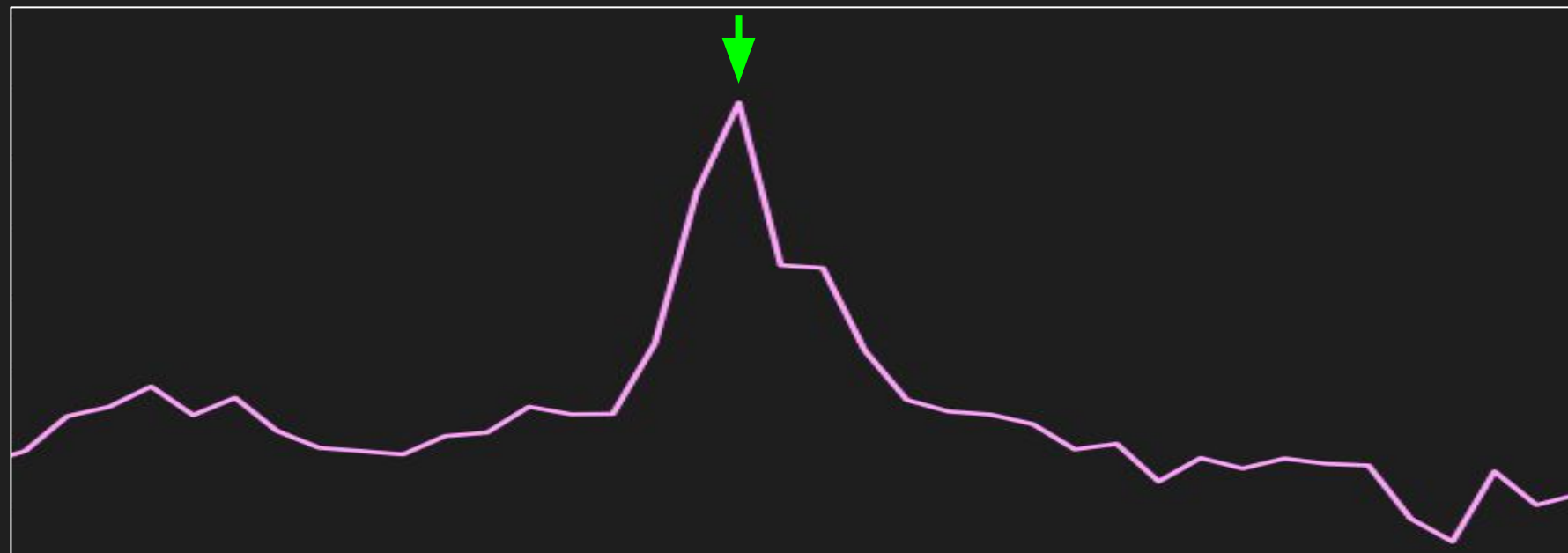


Flux [MJy/sr]

80000
60000
40000
20000
0

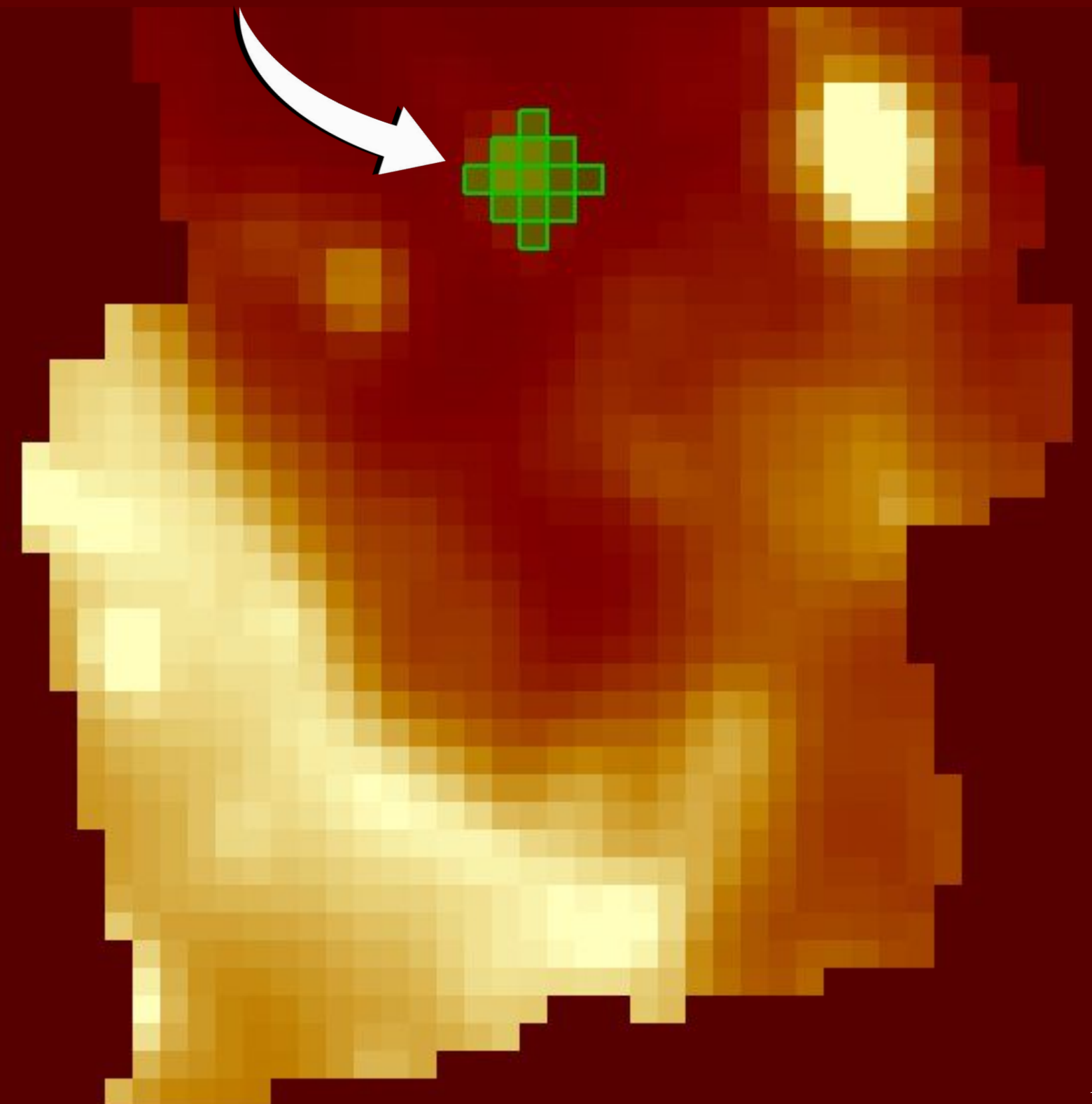


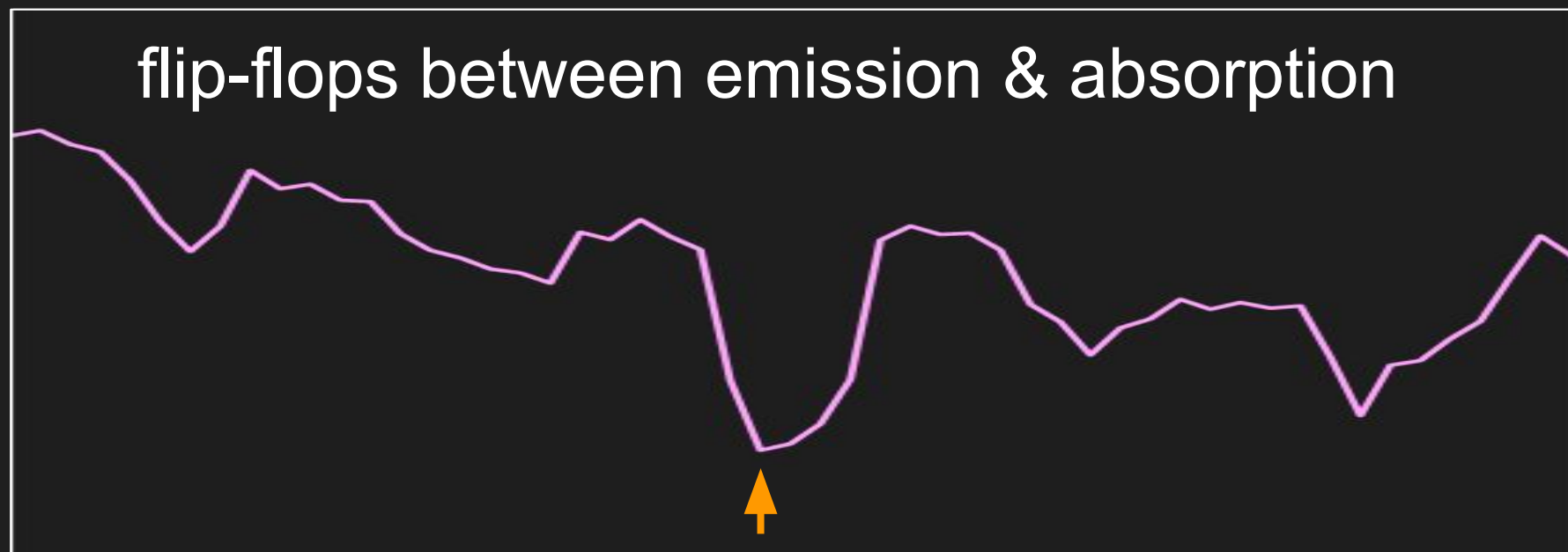
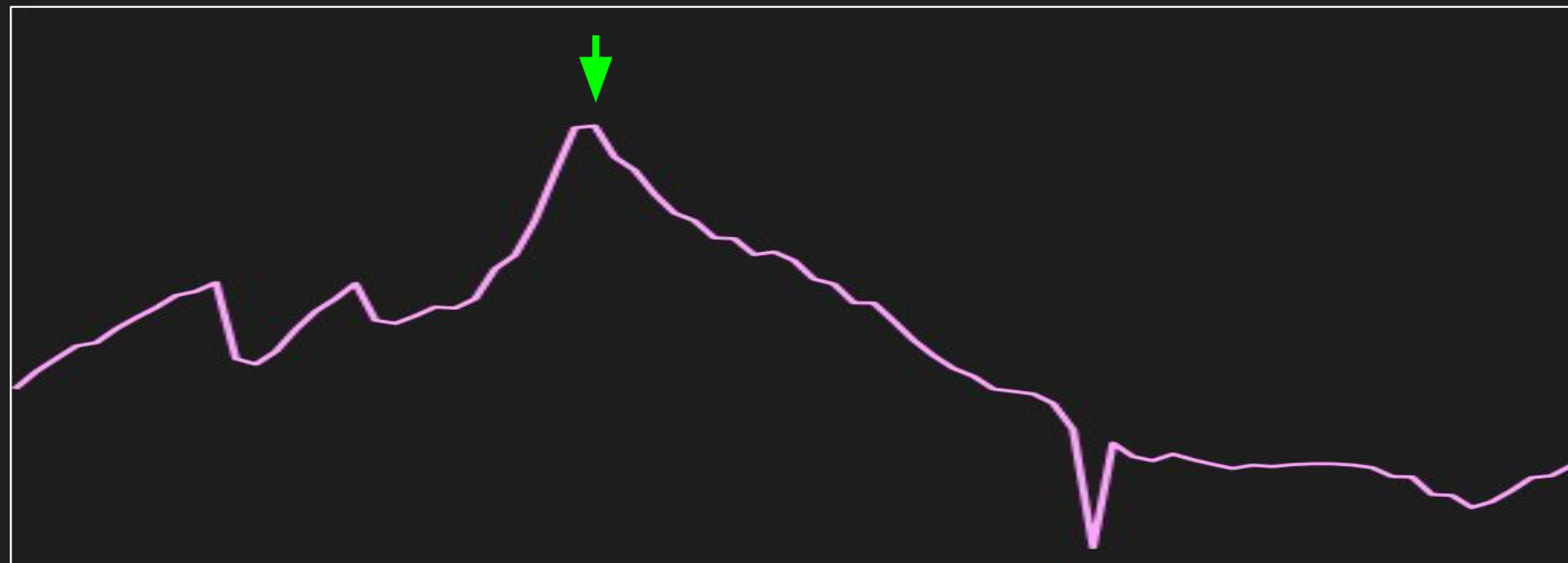
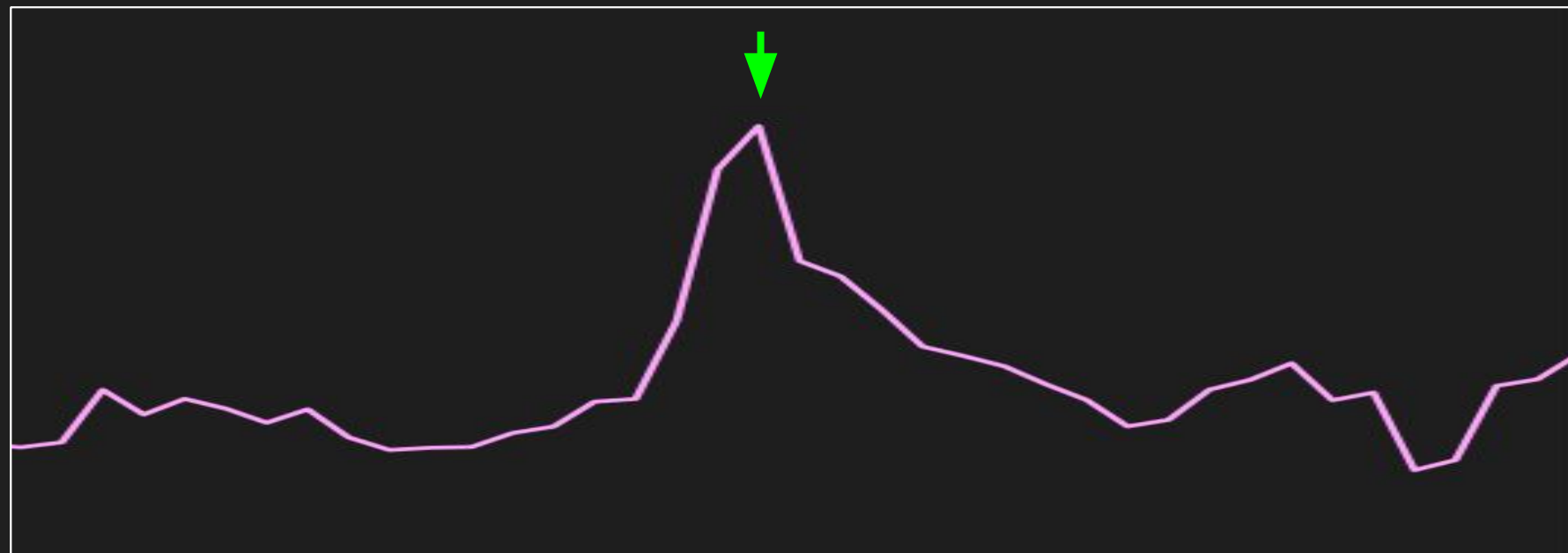
Wavelength [μm]



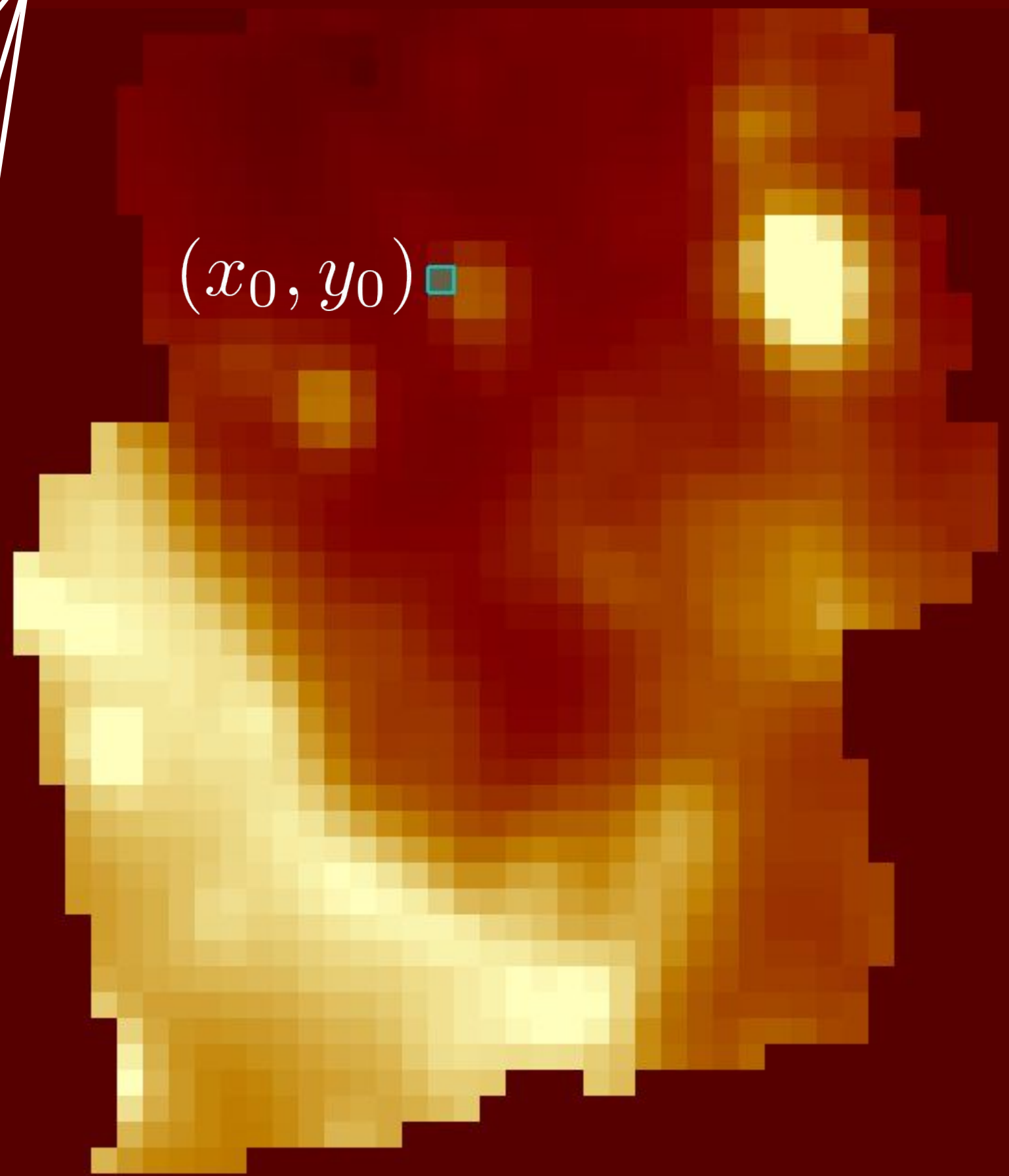
$$I_{\text{star}}(\lambda) = \sum_{(x,y) \in \mathcal{S}_{13}} I(x,y,\lambda)$$

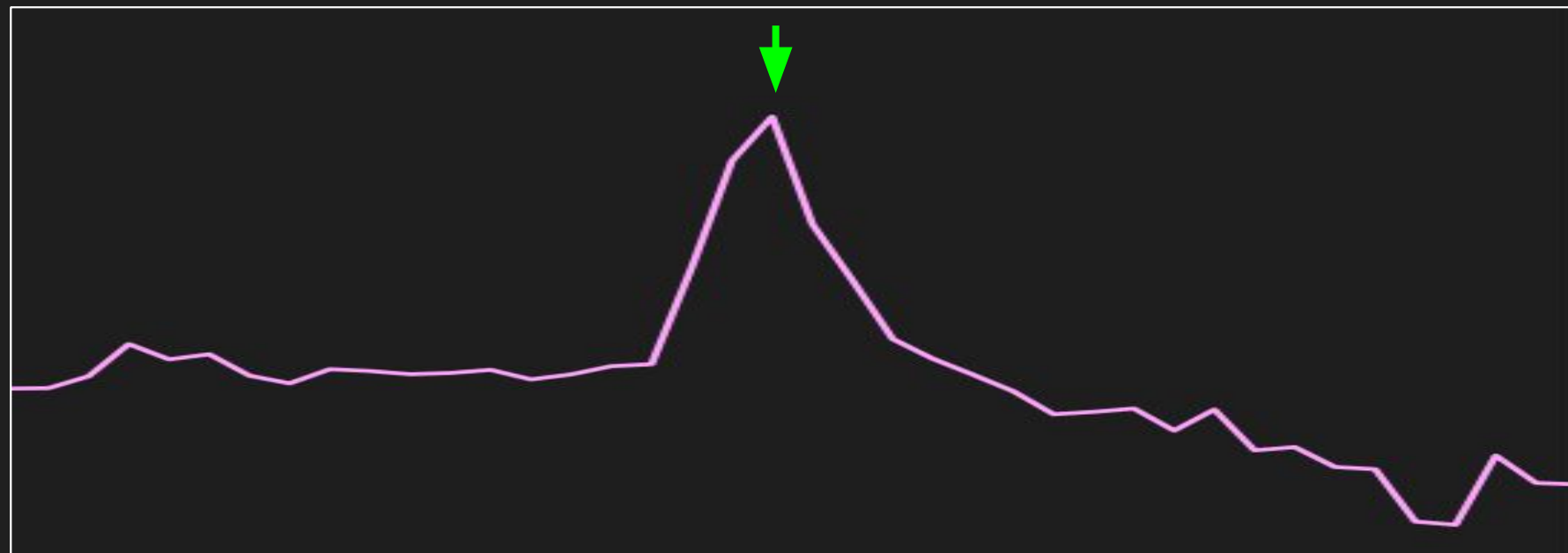
(summed over aperture)





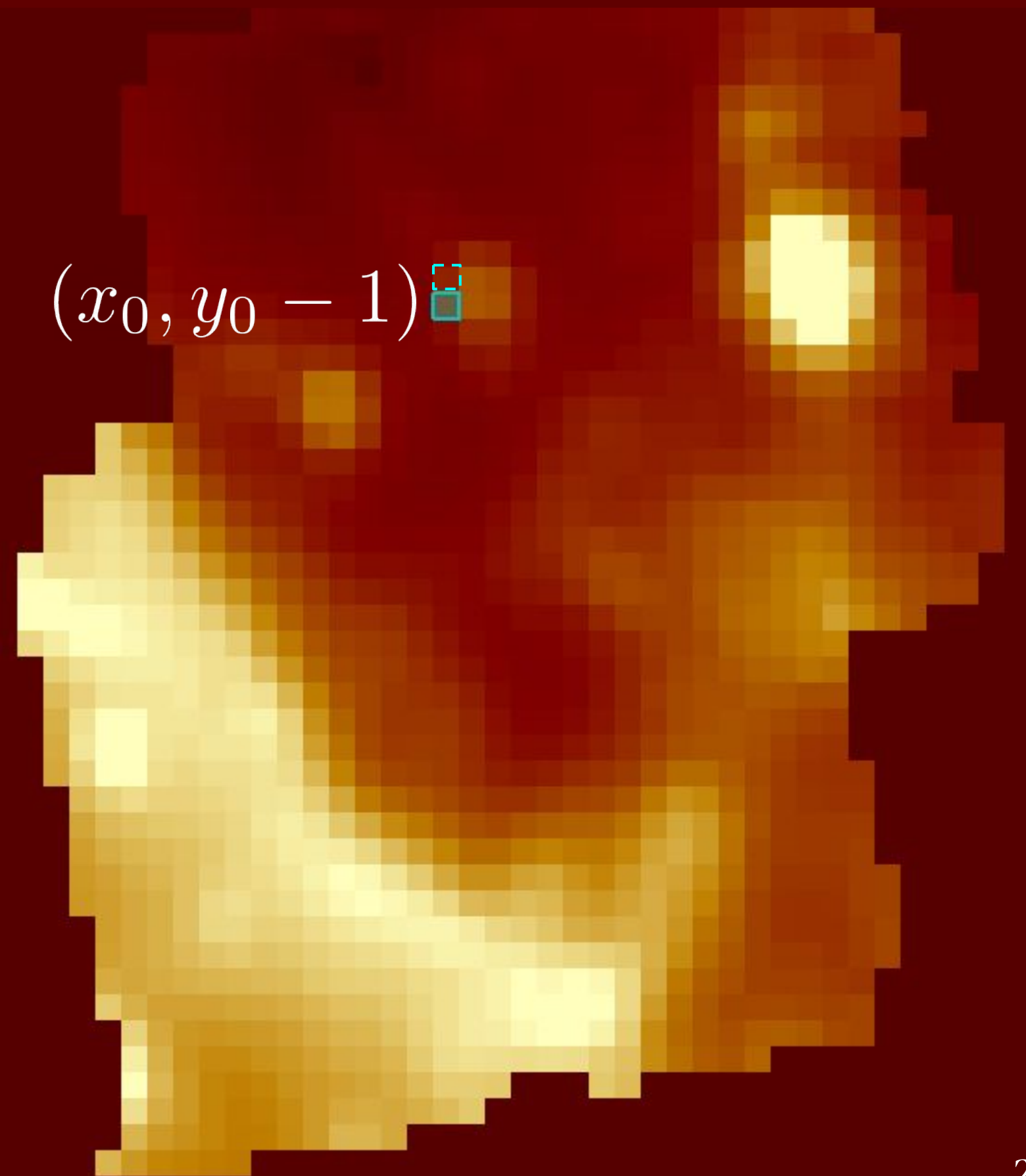
$$I(\lambda) = I(x_0, y_0, \lambda)$$

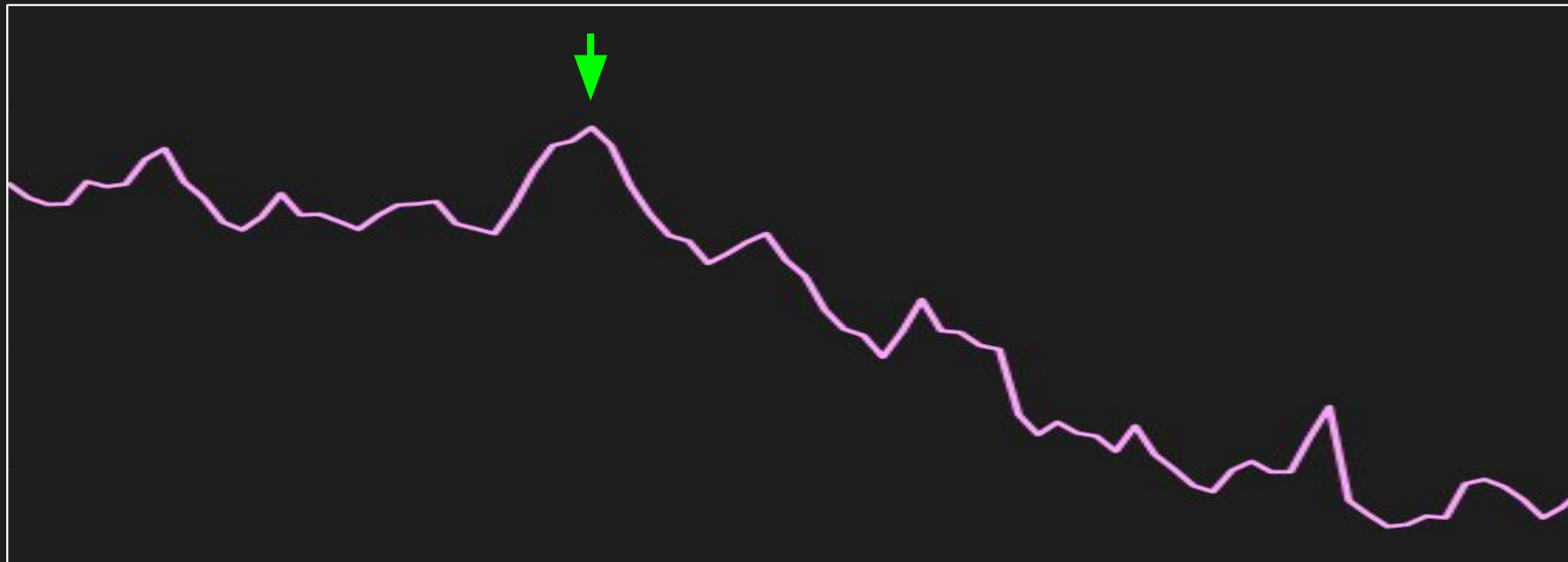
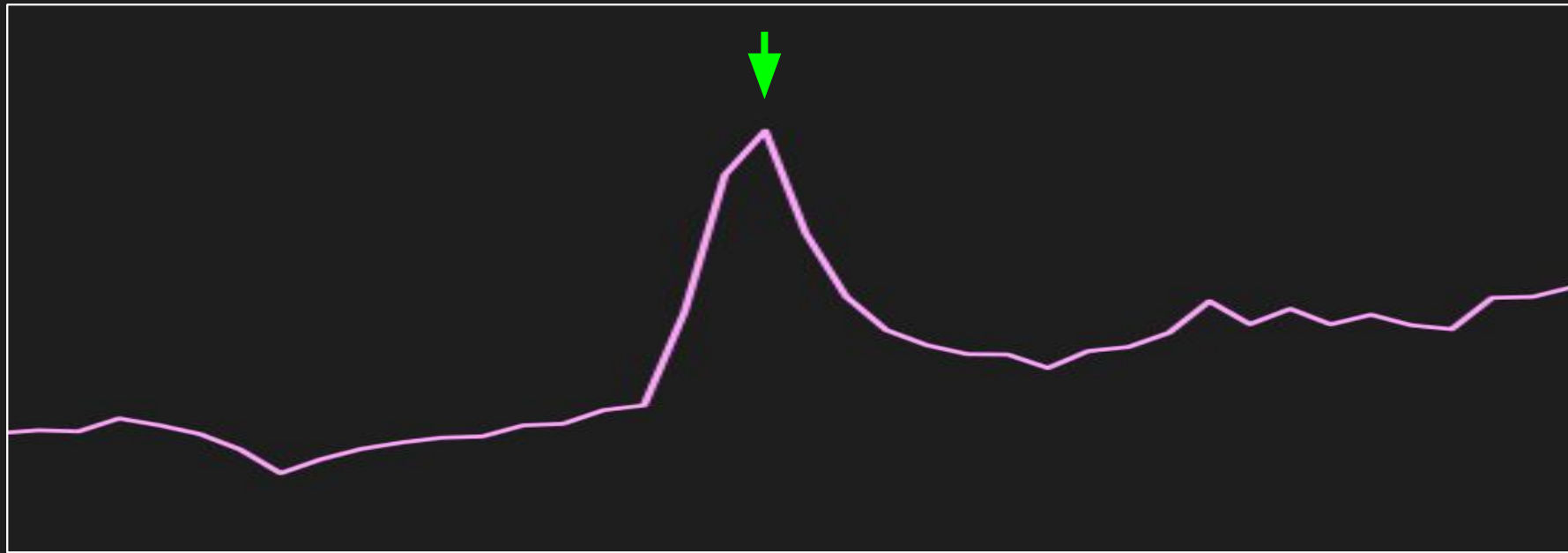




$$I(\lambda) = I(x_0, y_0 - 1, \lambda)$$

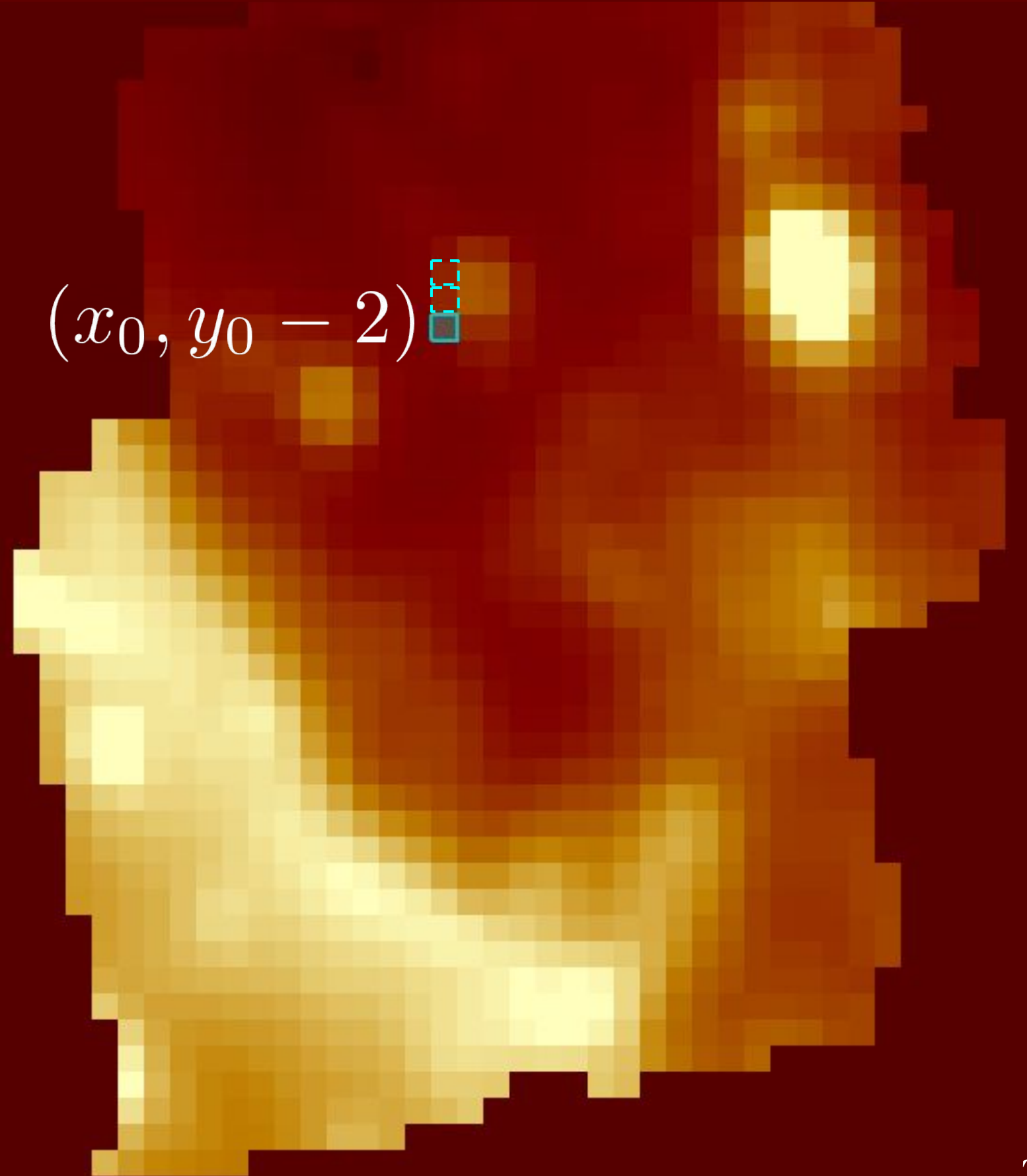
$(x_0, y_0 - 1)$

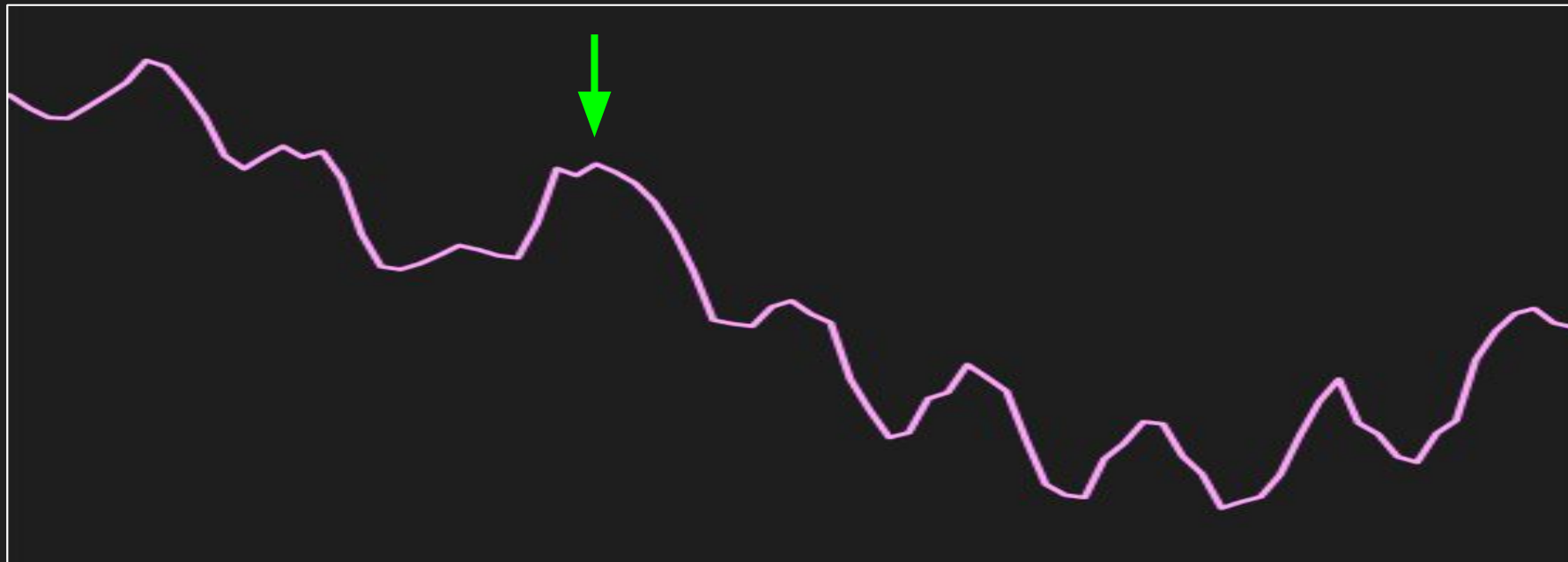
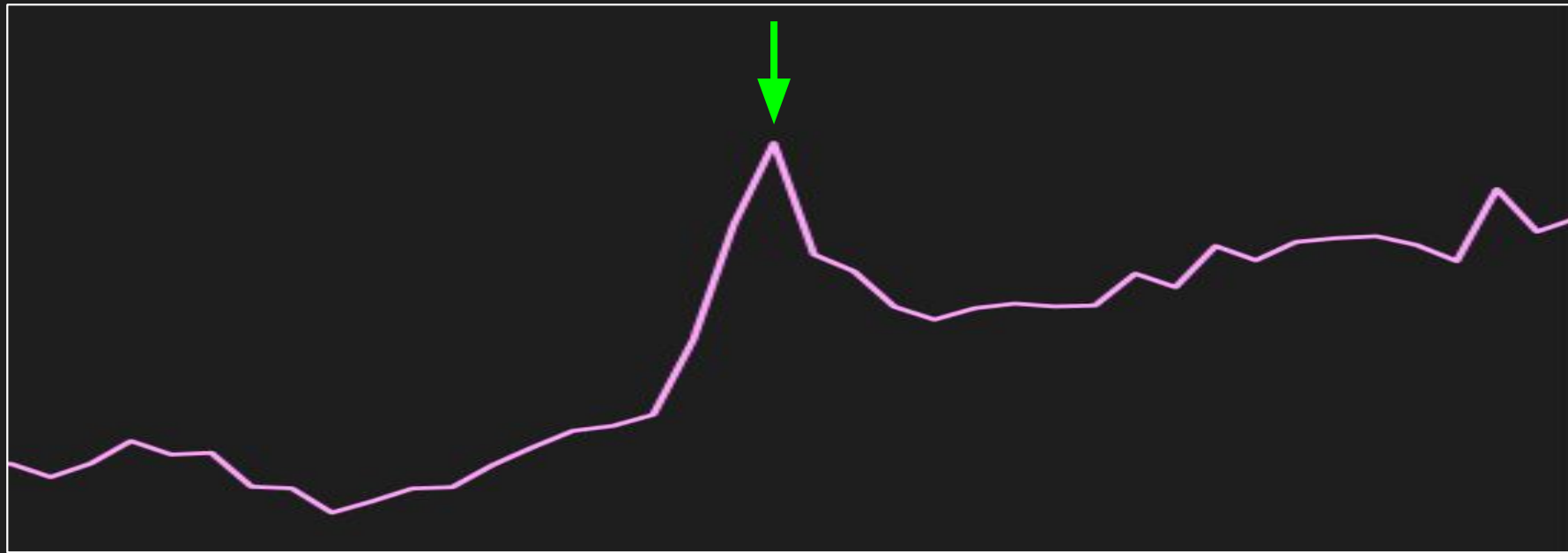




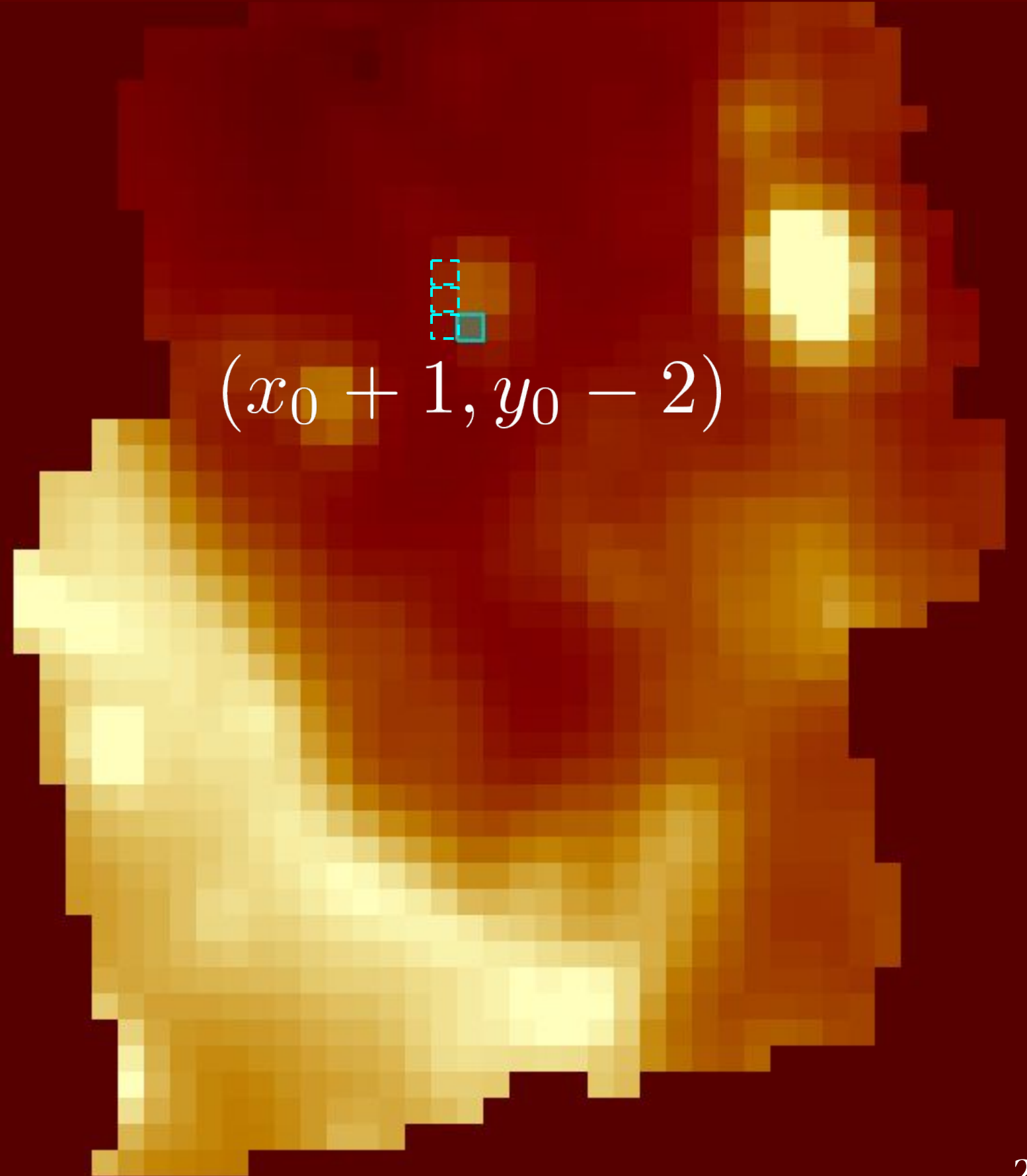
$$I(\lambda) = I(x_0, y_0 - 2, \lambda)$$

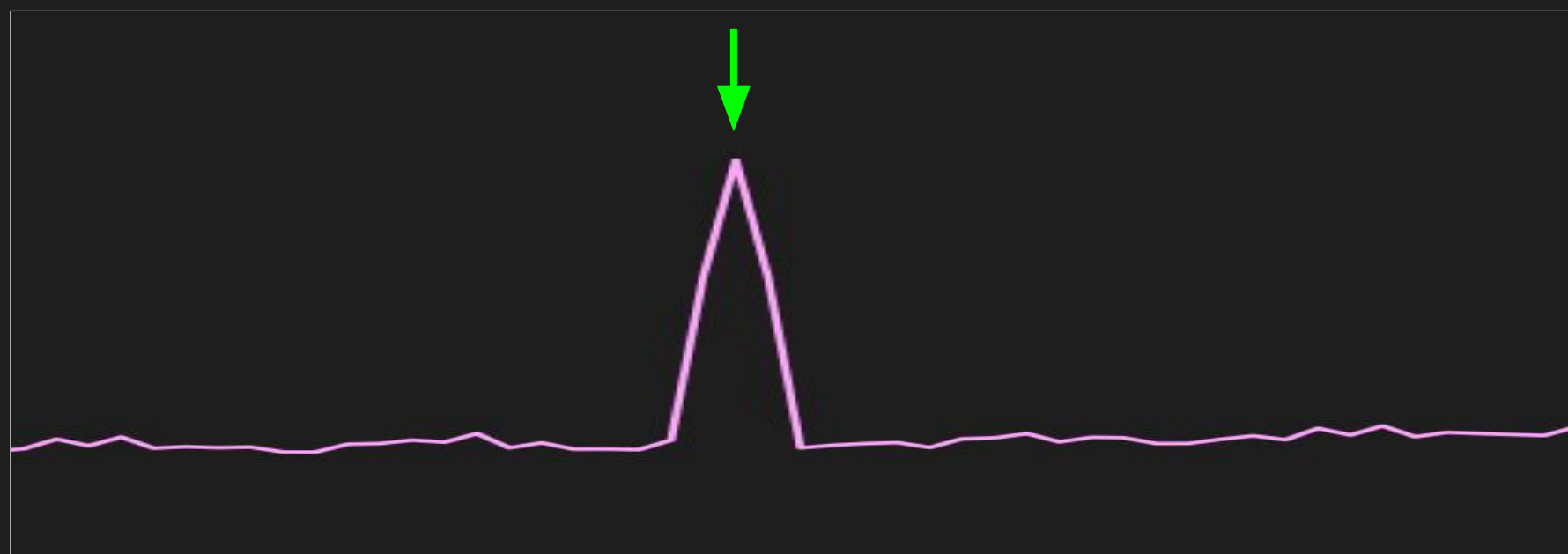
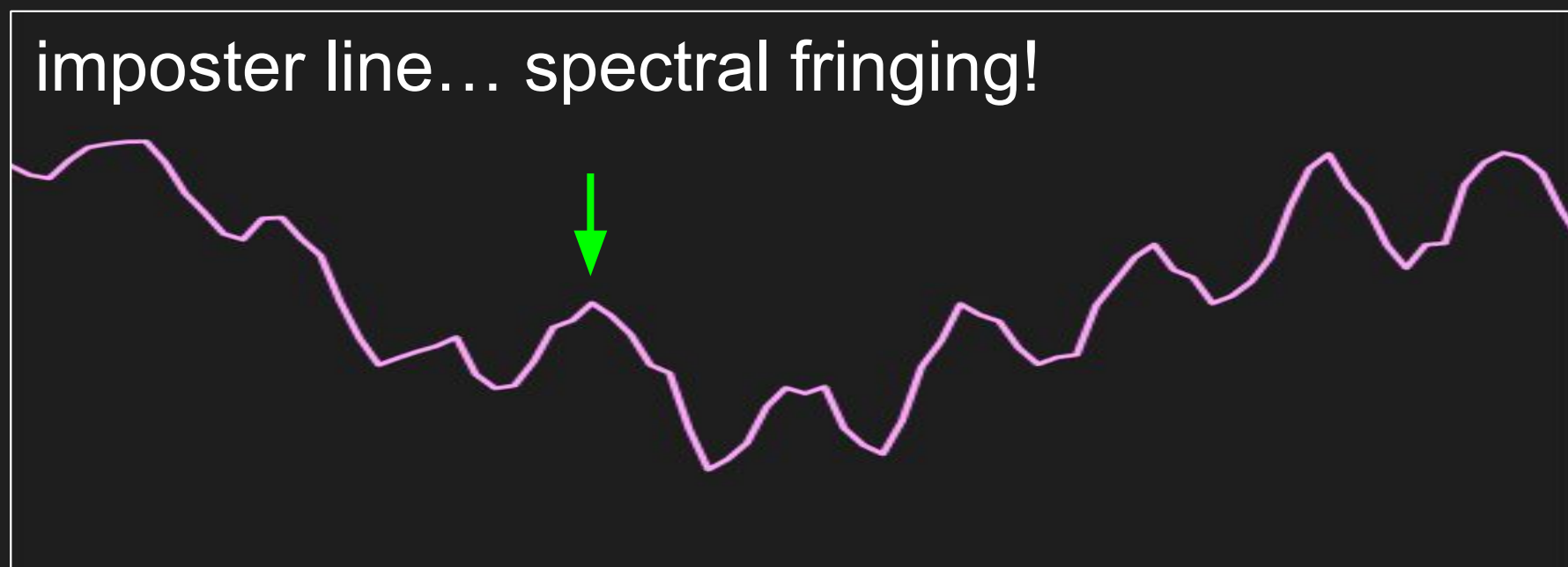
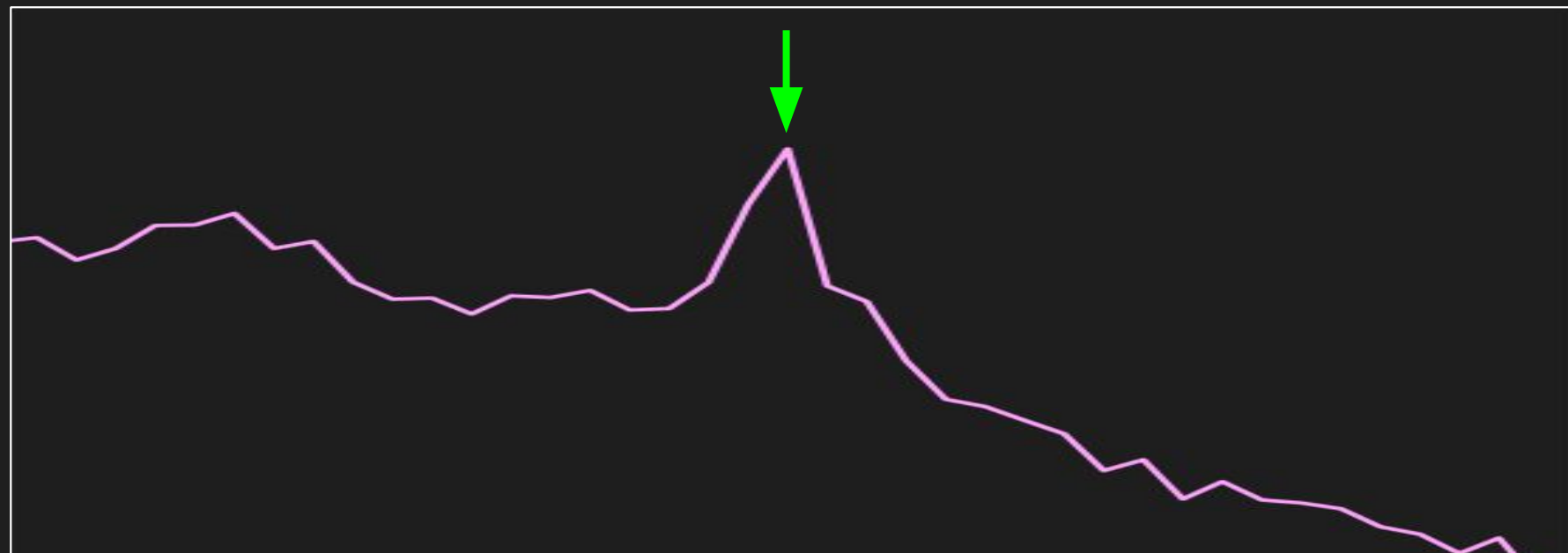
$(x_0, y_0 - 2)$



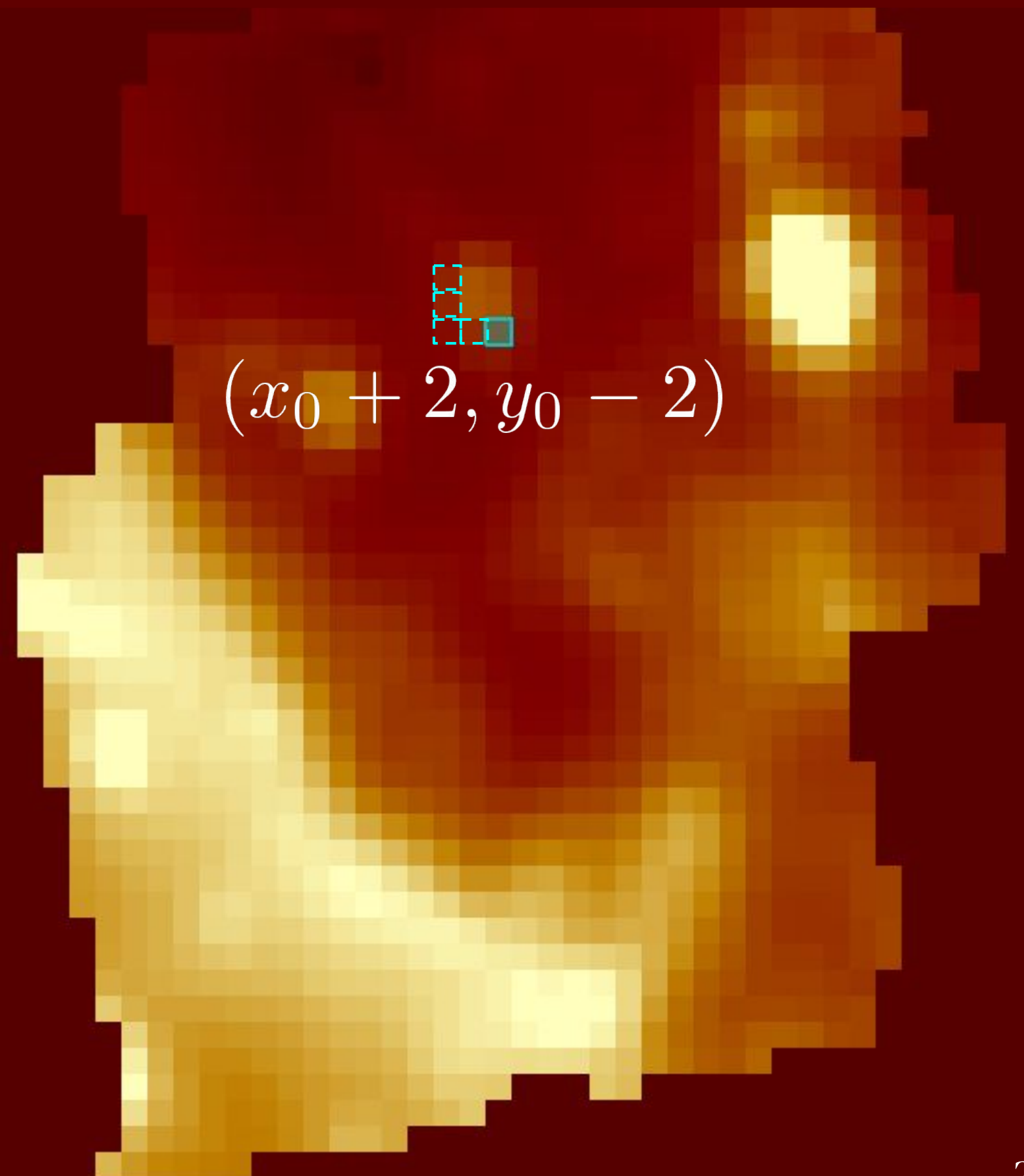


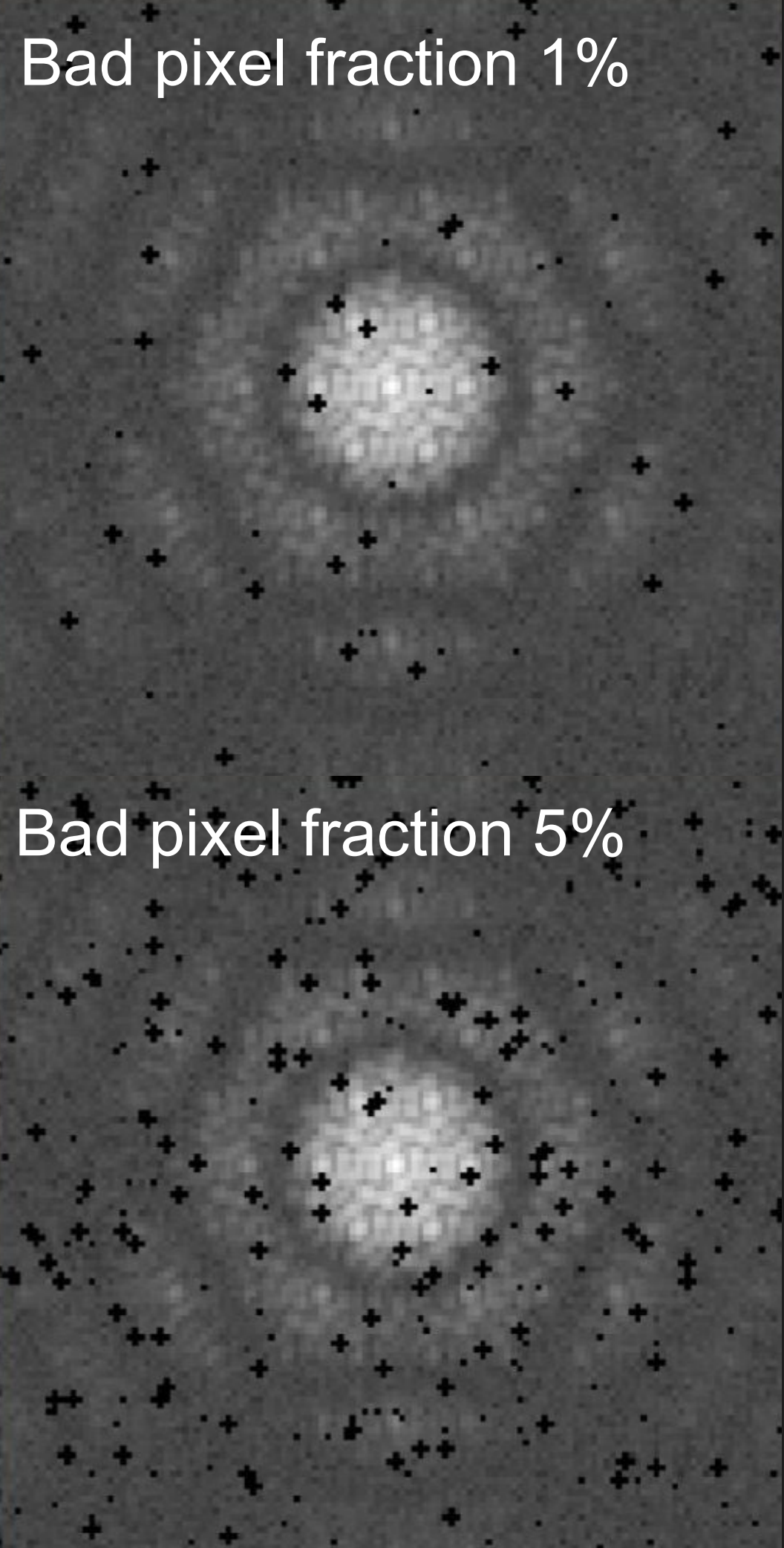
$$I(\lambda) = I(x_0 + 1, y_0 - 2, \lambda)$$



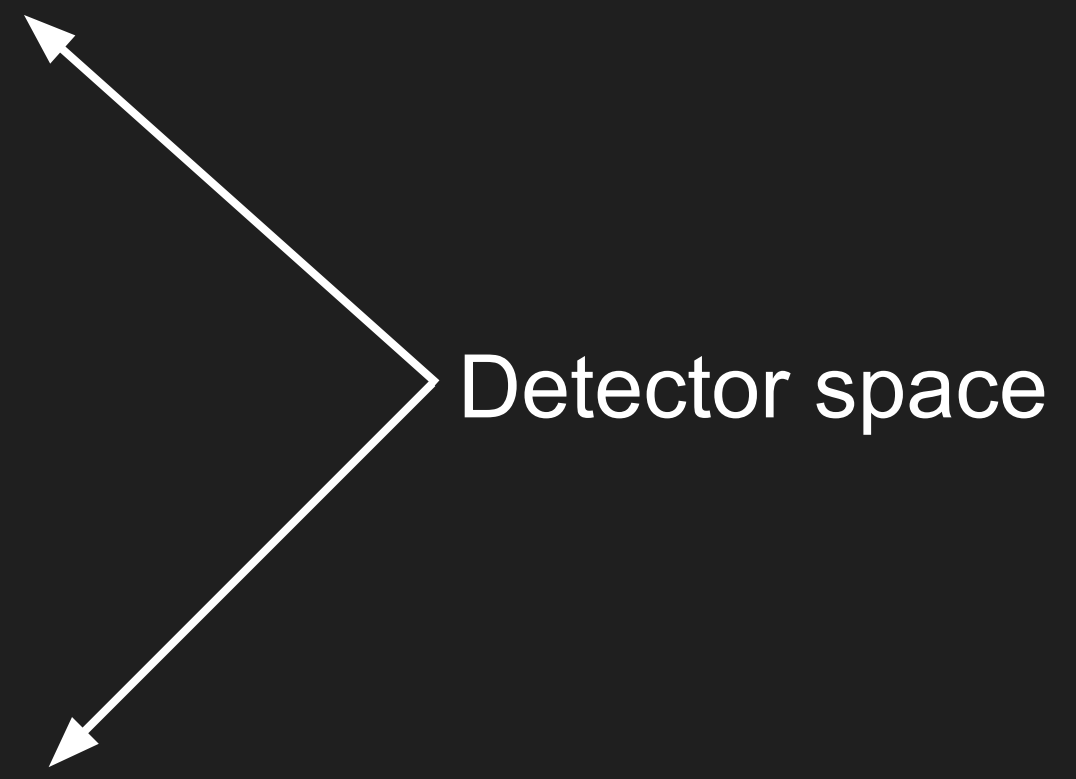


$$I(\lambda) = I(x_0 + 2, y_0 - 2, \lambda)$$





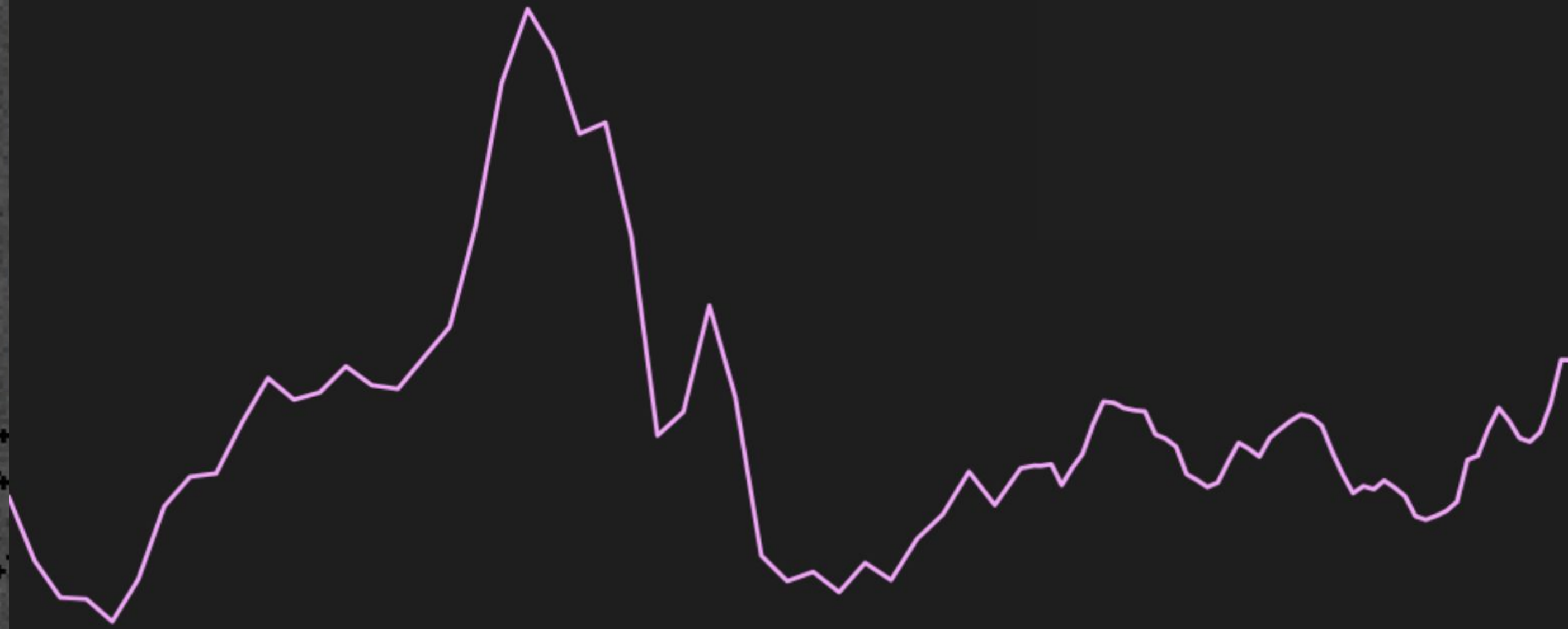
Further discrimination of peak-detected 'lines'?



Bad pixel fraction 1%

Bad pixel fraction 5%

Further discrimination of peak-detected 'lines'?

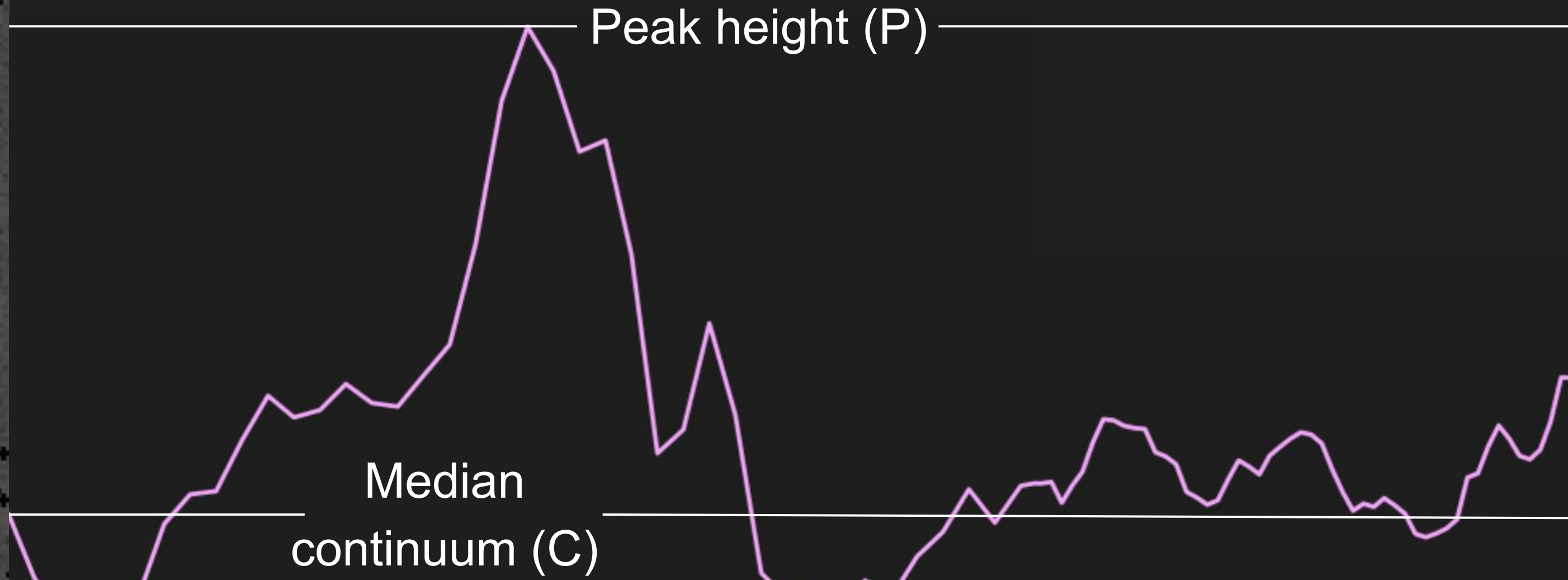


Suspicious line or flux data?

Bad pixel fraction 1%

Bad pixel fraction 5%

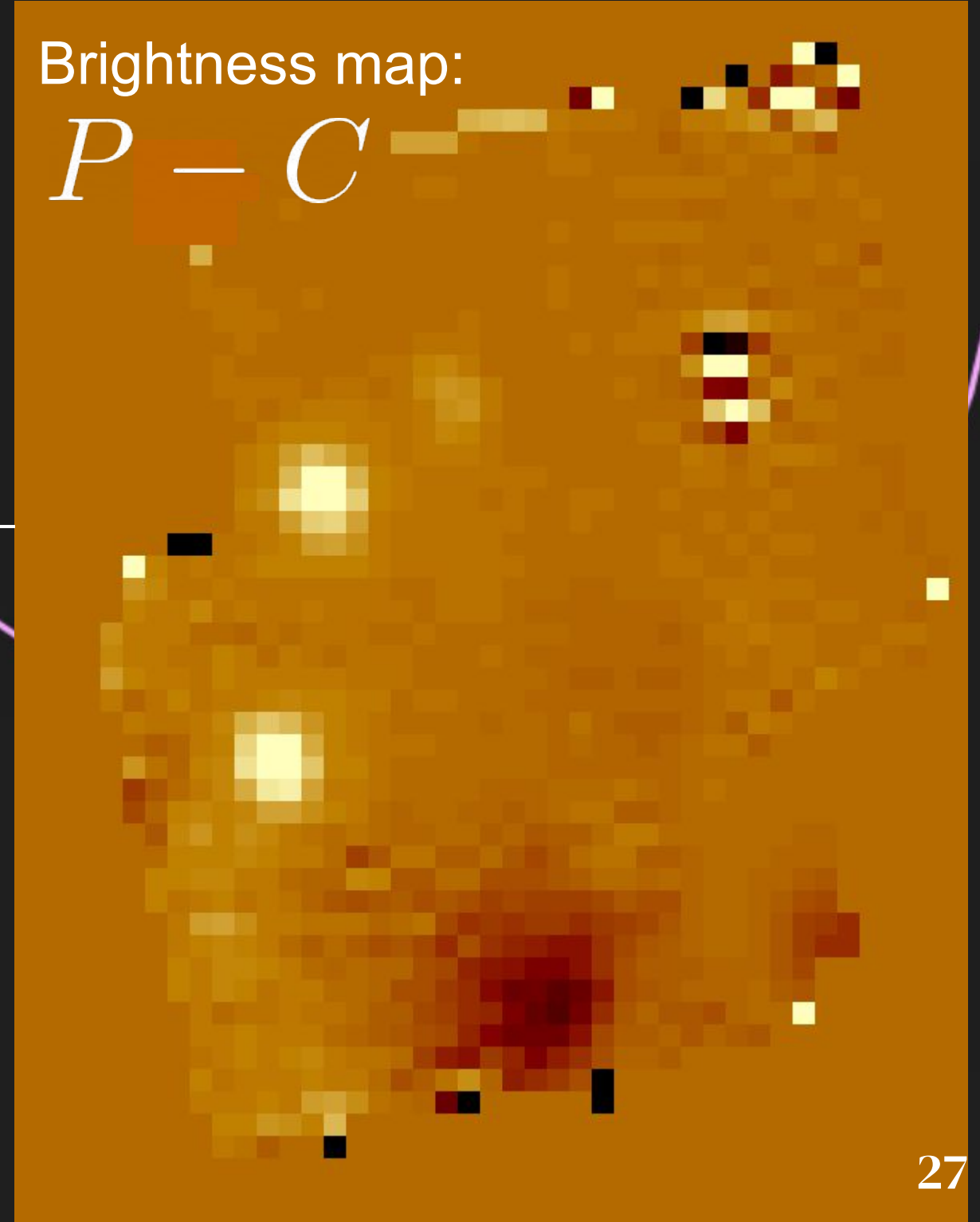
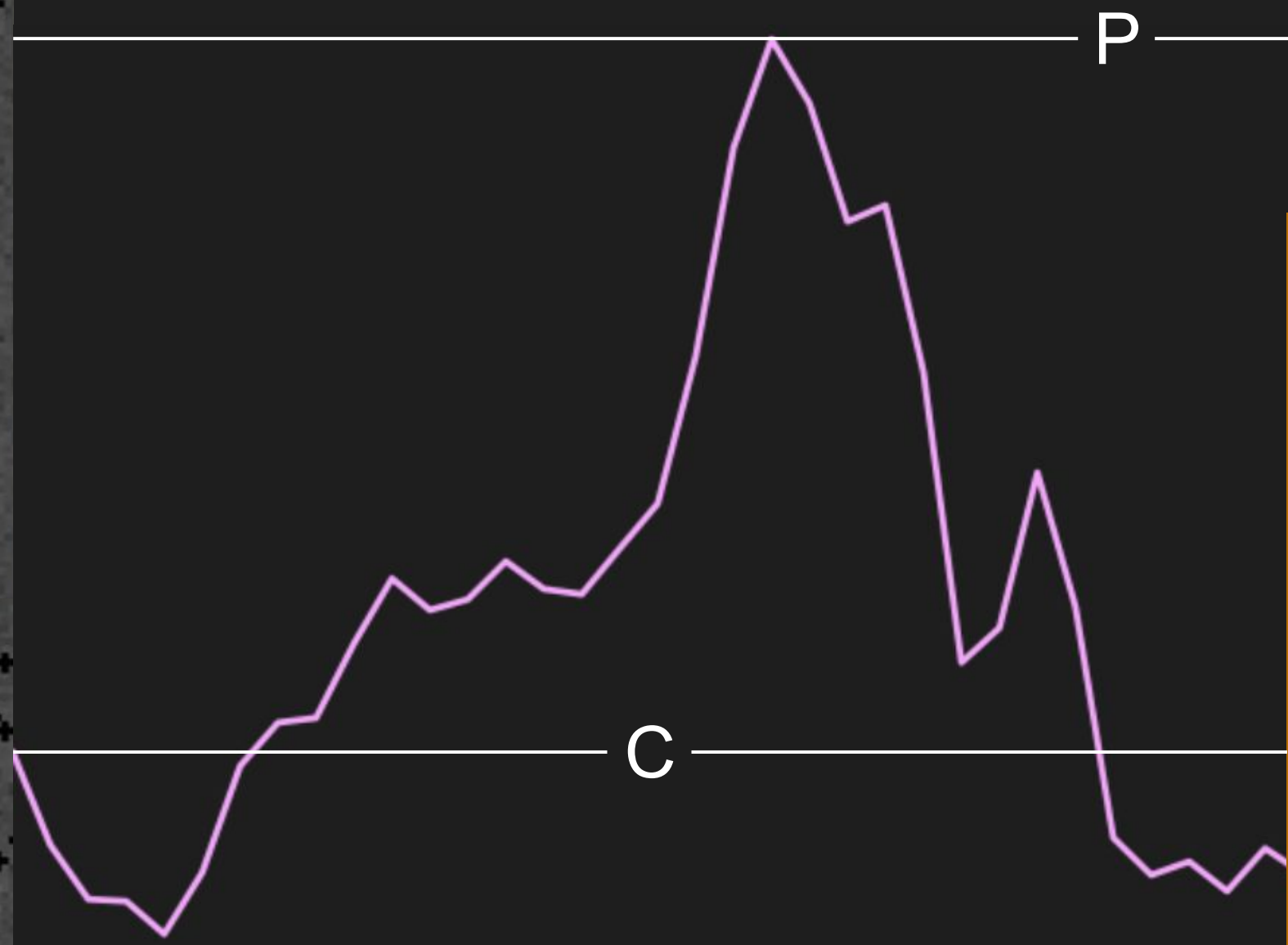
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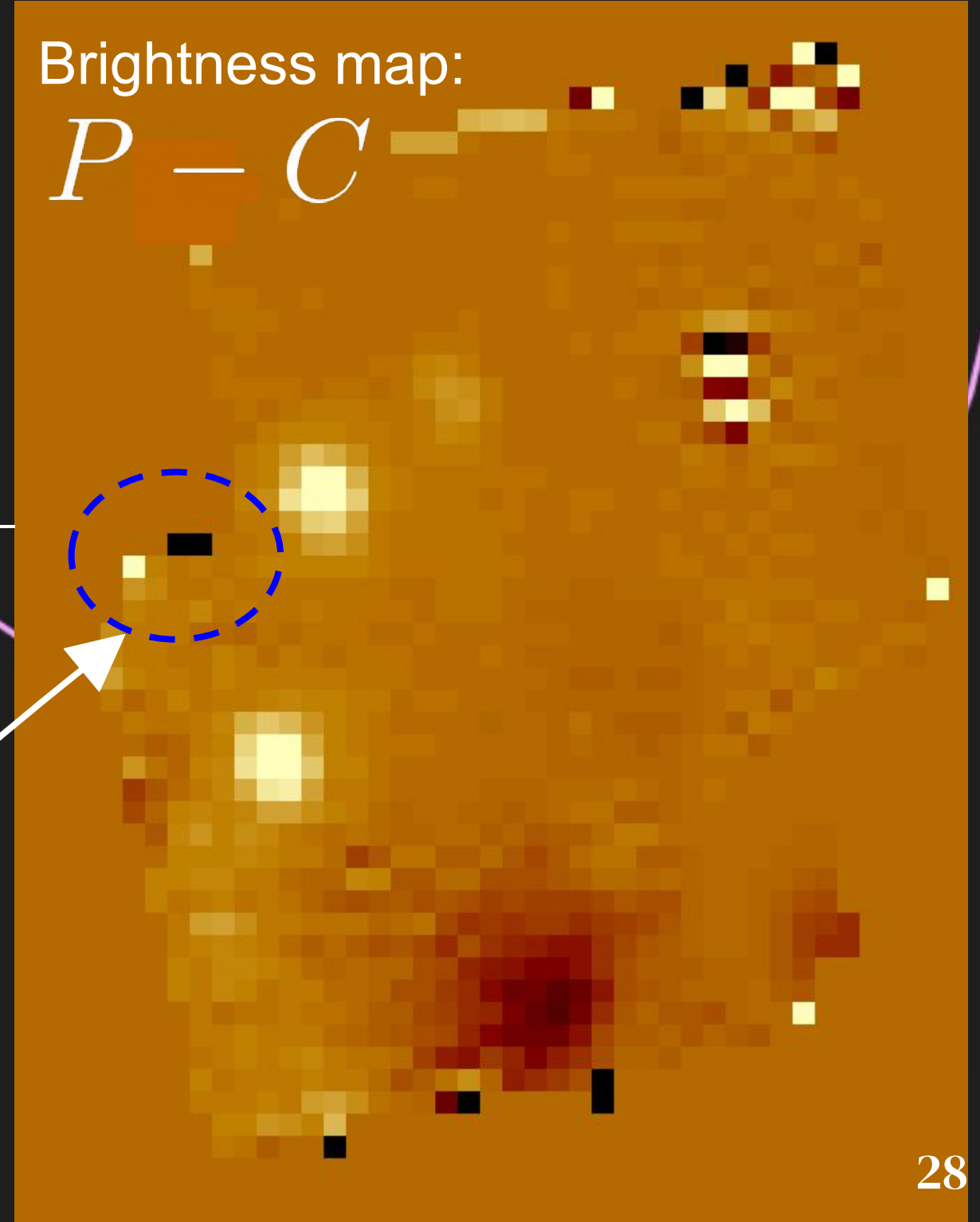
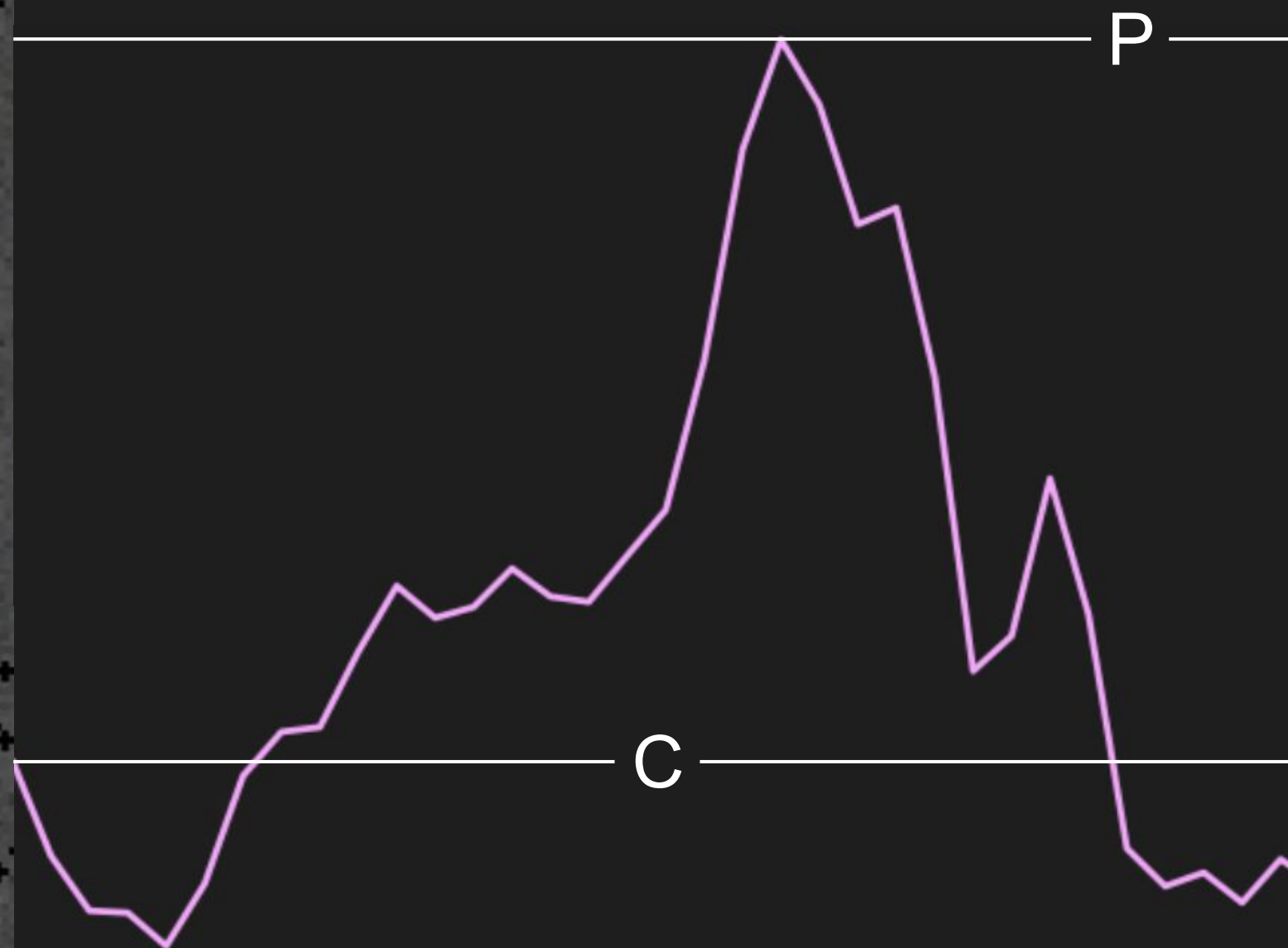


Pull a line-map!

Bad pixel fraction 1%

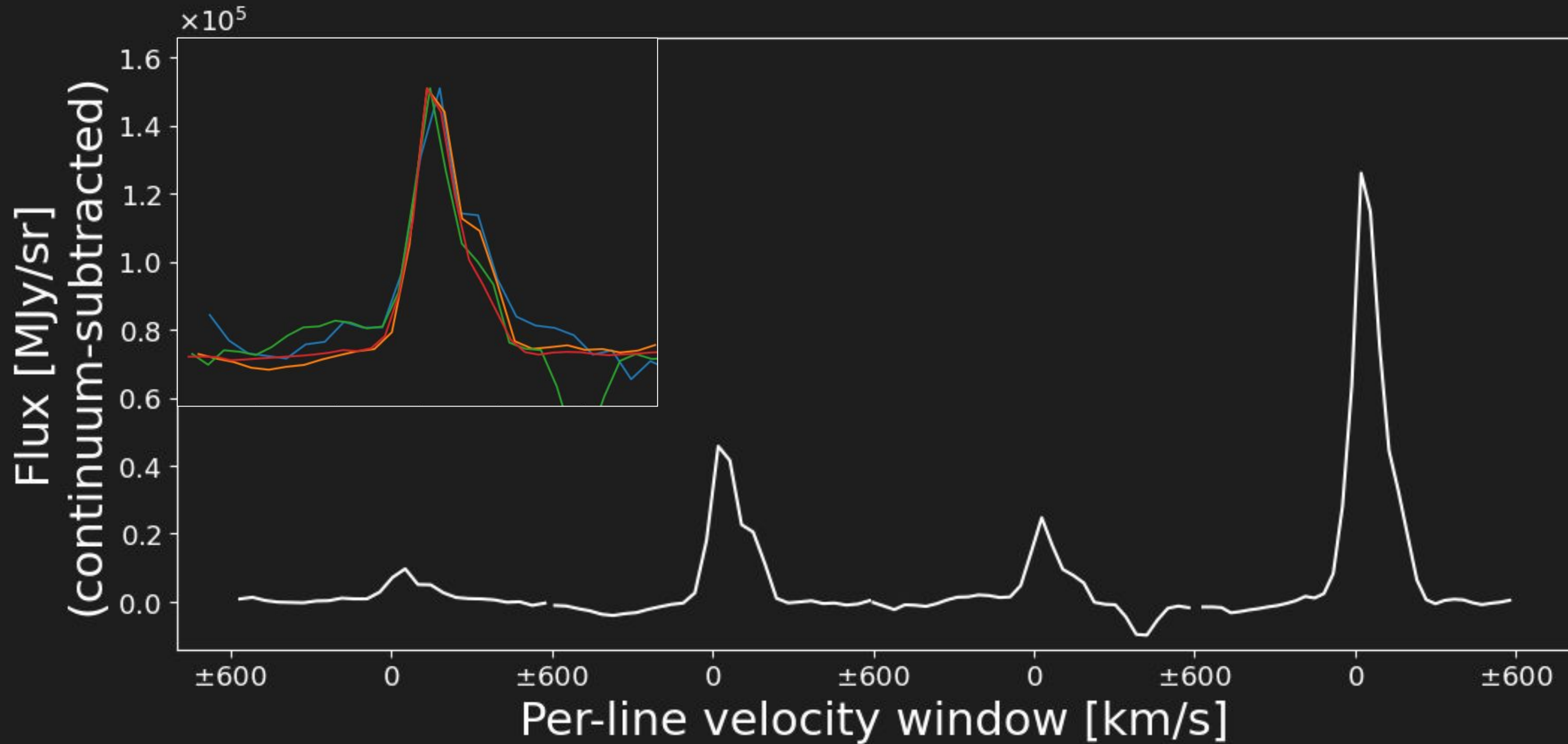
Further discrimination of peak-detected 'lines'?

Bad pixel fraction 5%

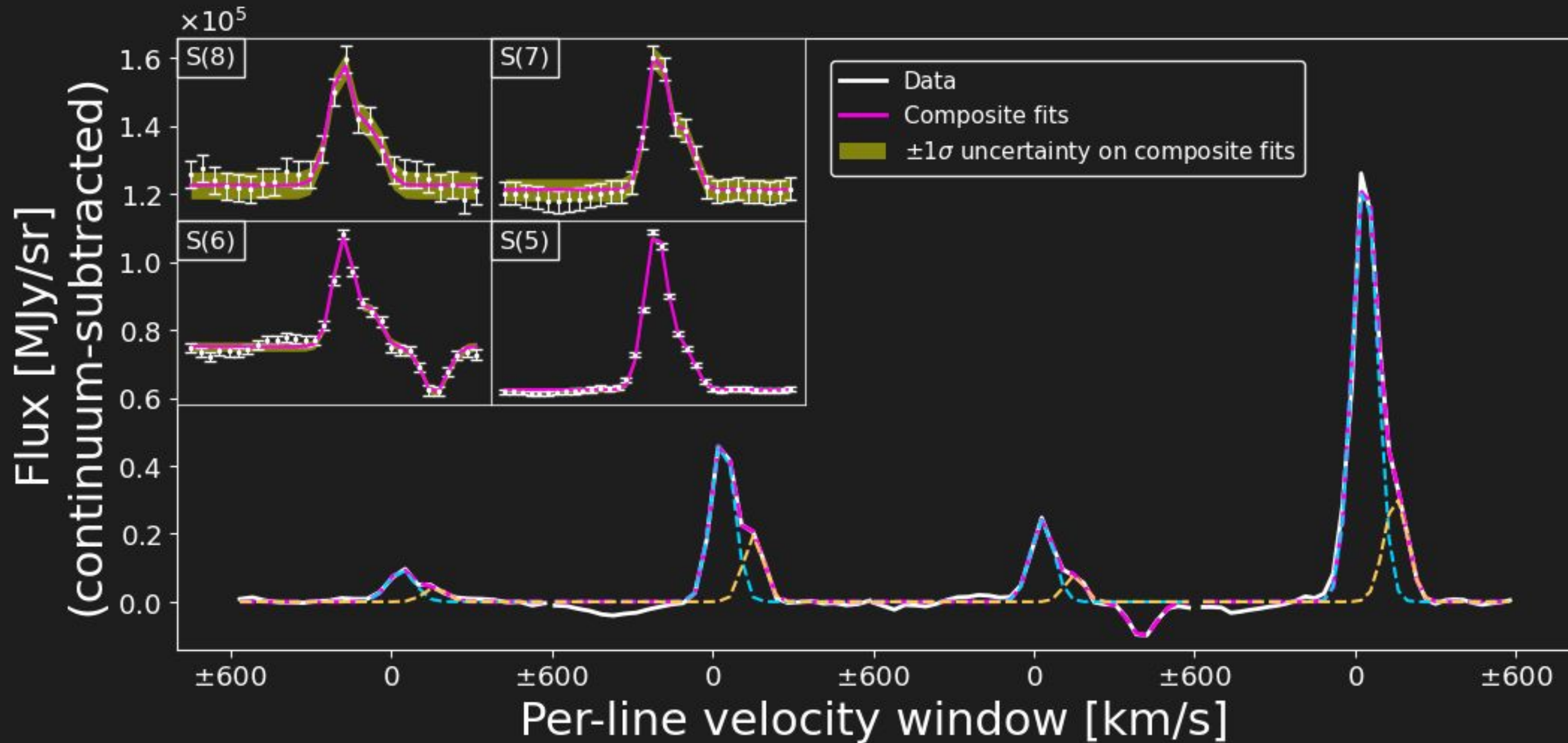


Ensure bad spaxels aren't responsible for the 'line'

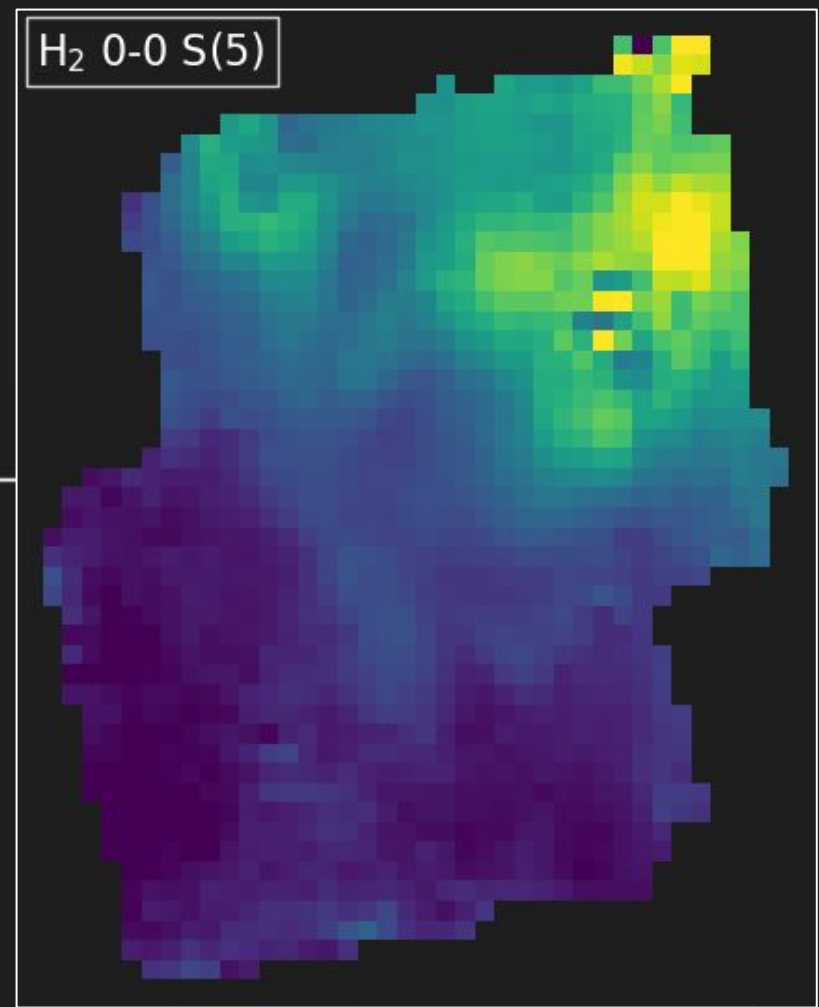
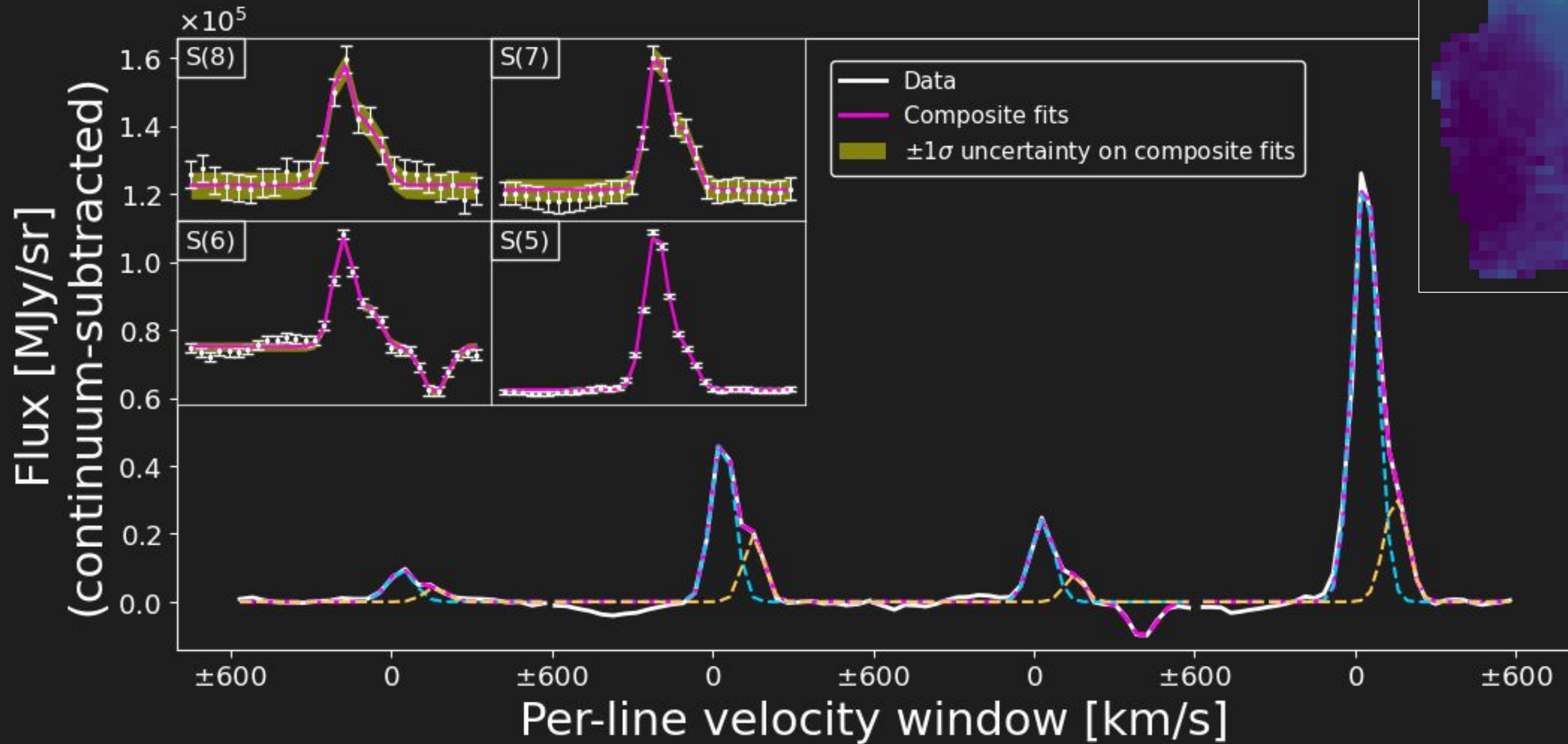
Confirmed real? Great! Fit time



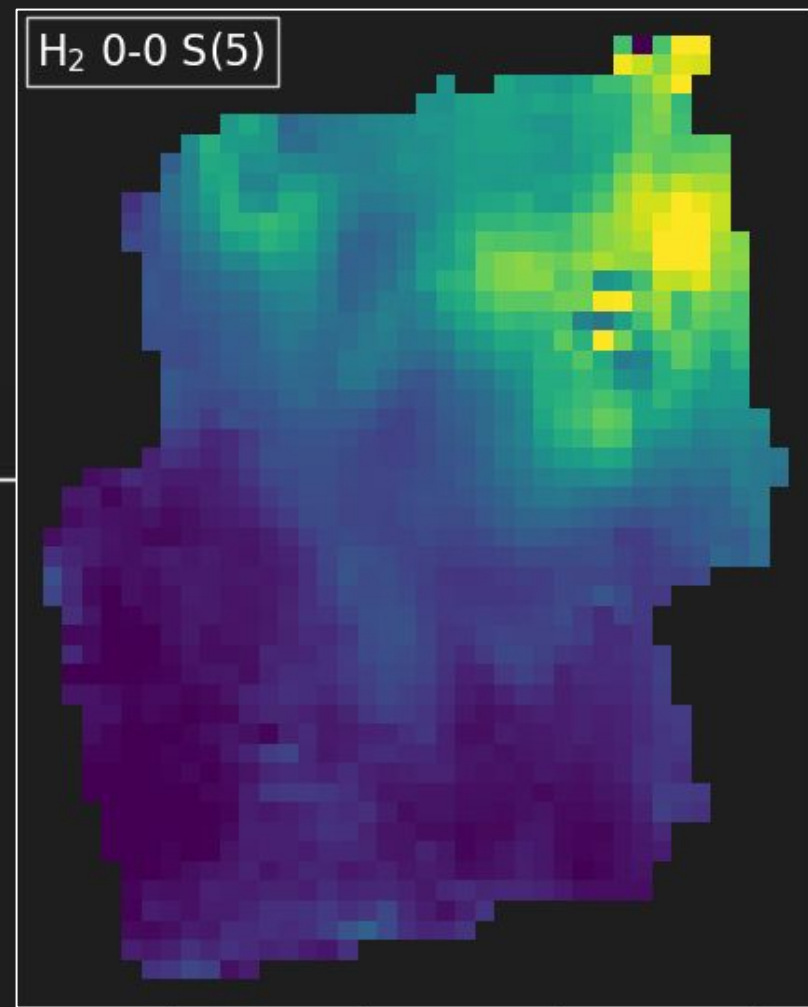
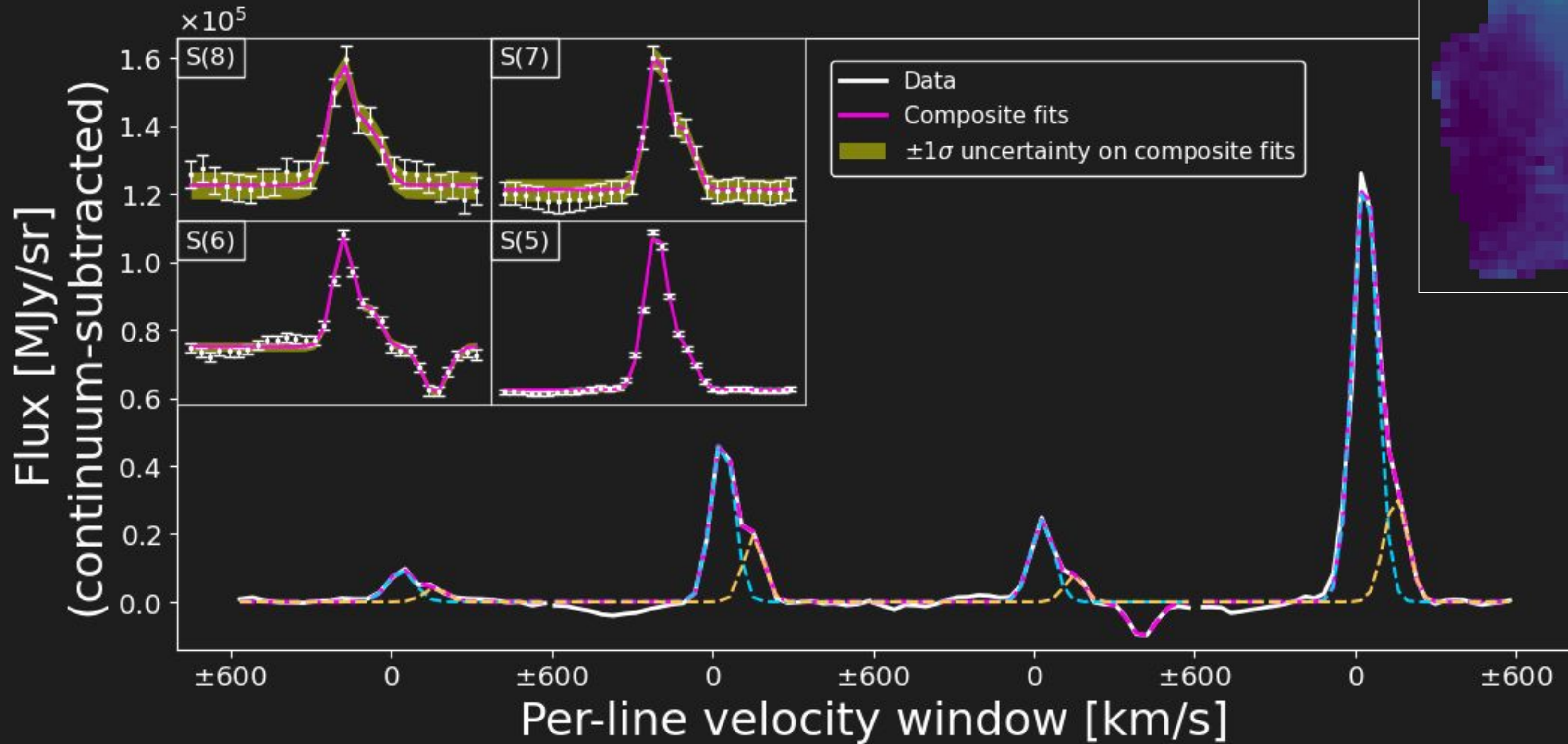
- Consistent (μ, σ) across lines



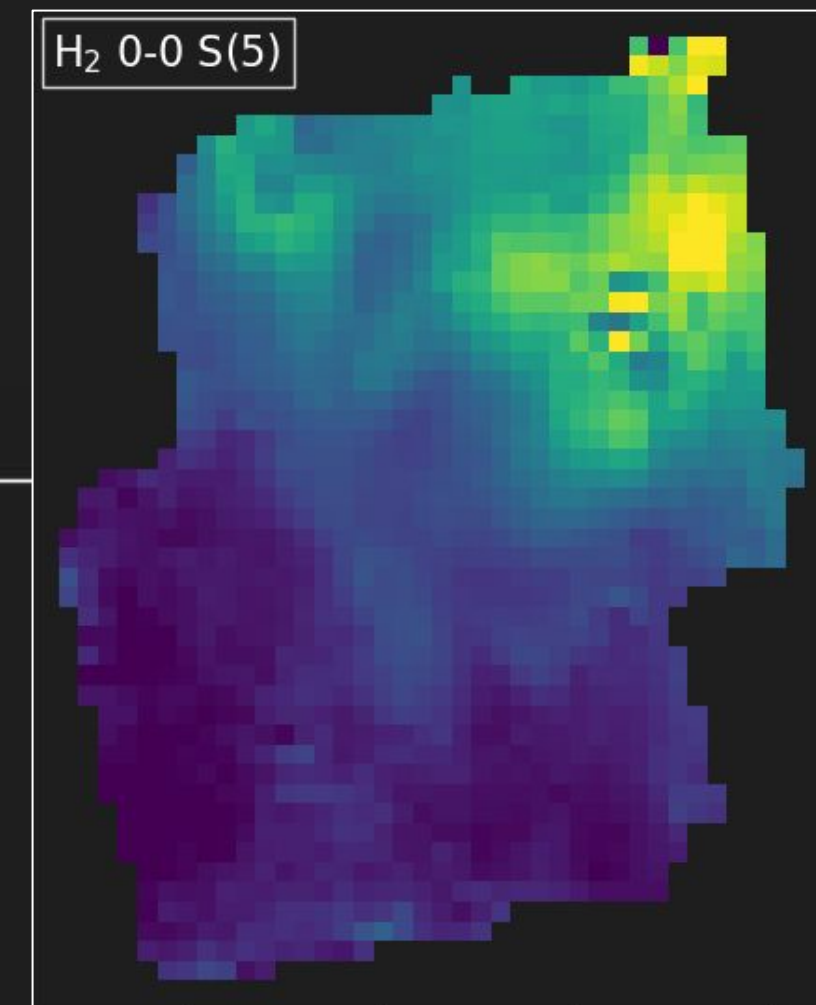
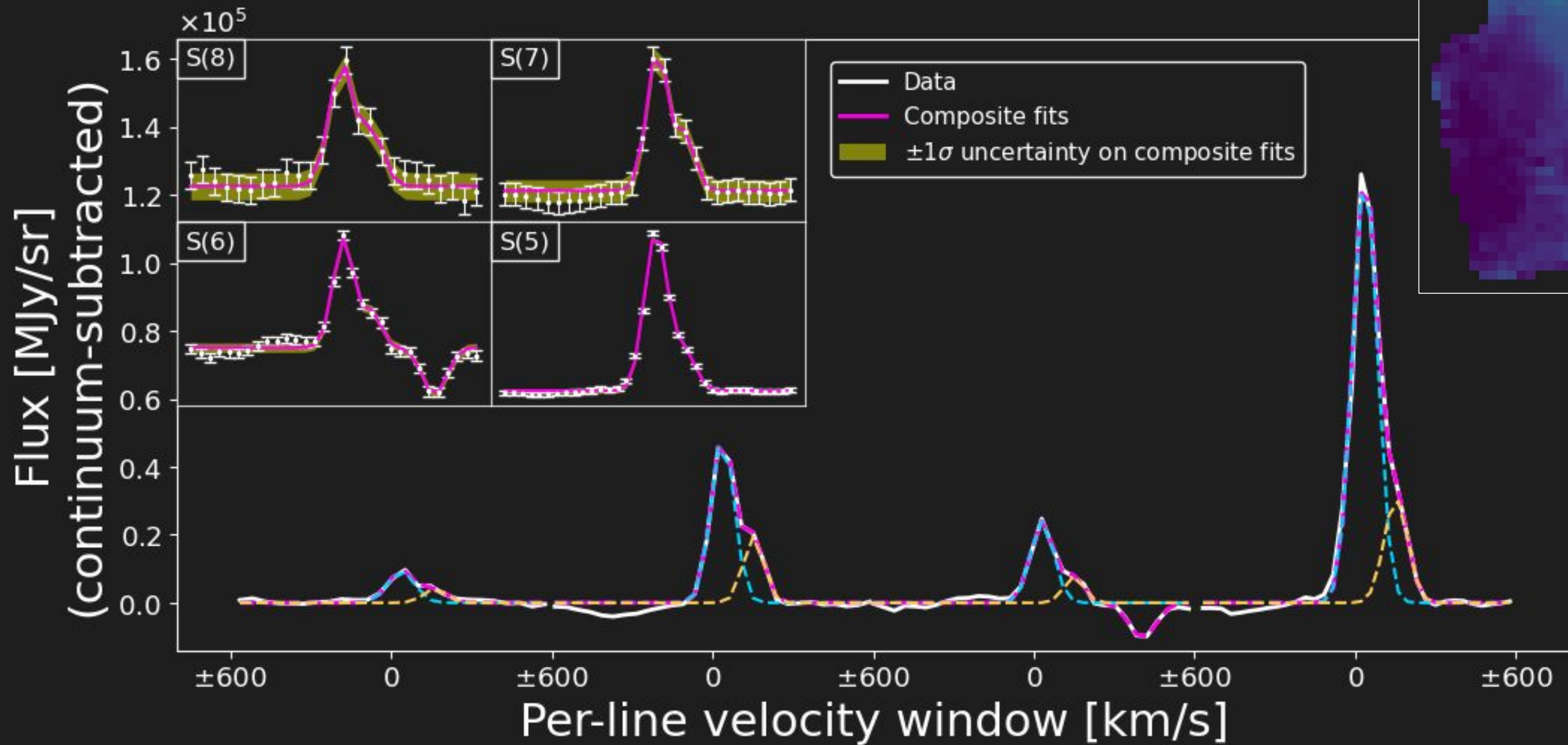
- Consistent (μ, σ) across lines



$$|\Delta v_{\text{LOS}}| = \left| c \frac{\left(\frac{\lambda_{\text{obs}}}{\lambda_{\text{rest}}}\right)^2 - 1}{\left(\frac{\lambda_{\text{obs}}}{\lambda_{\text{rest}}}\right)^2 + 1} \right| \leq 1000 \text{ km/s}$$

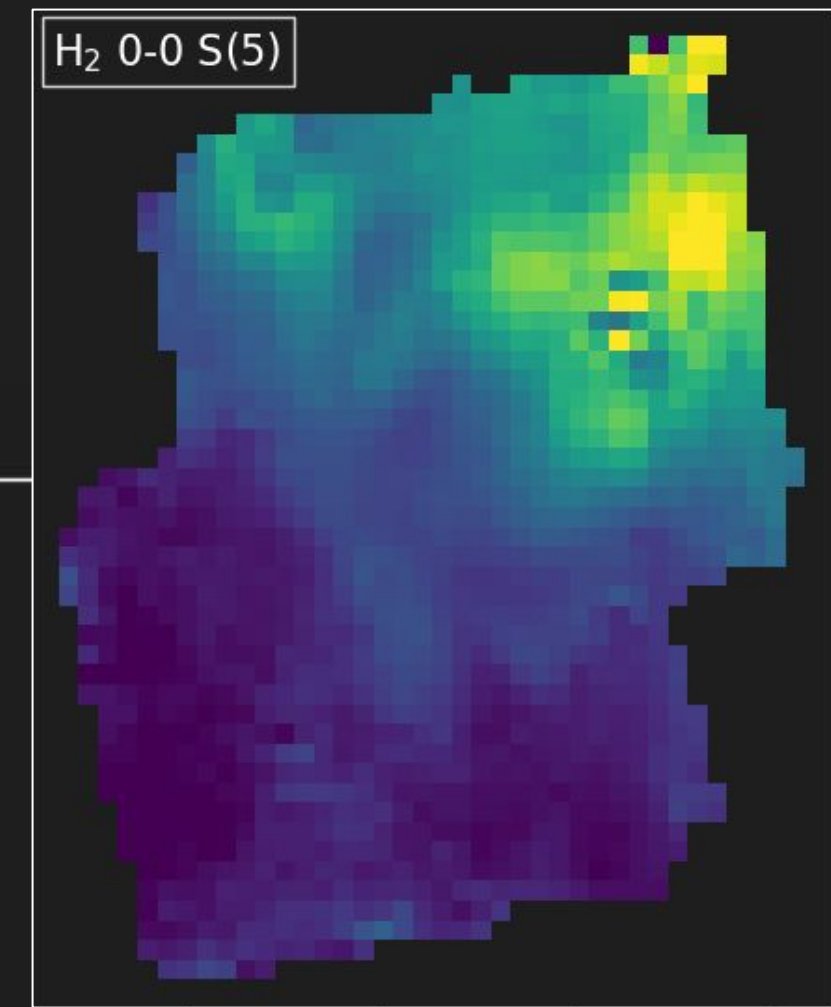
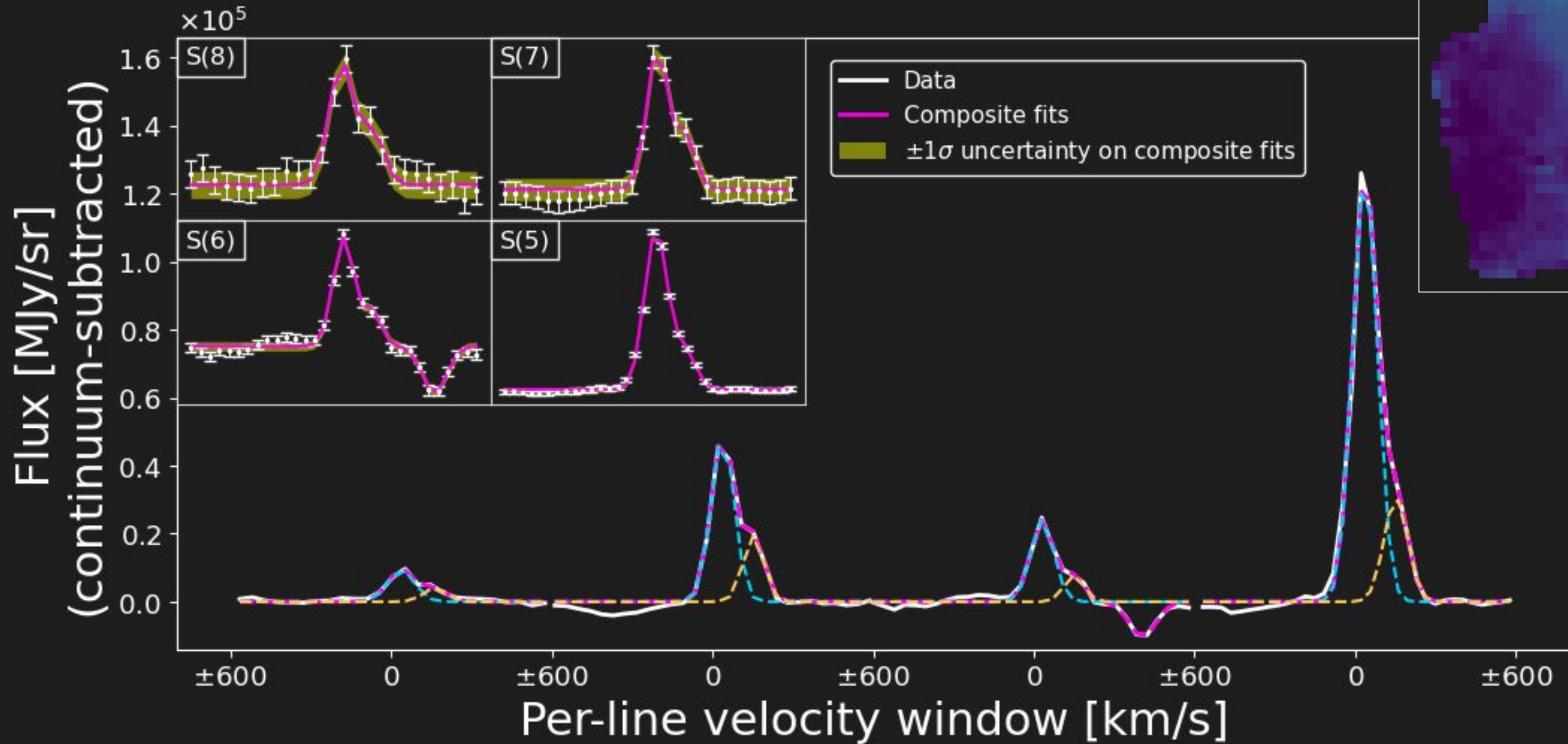


H_2 0-0 S(J), $J = 5, \dots, 8$

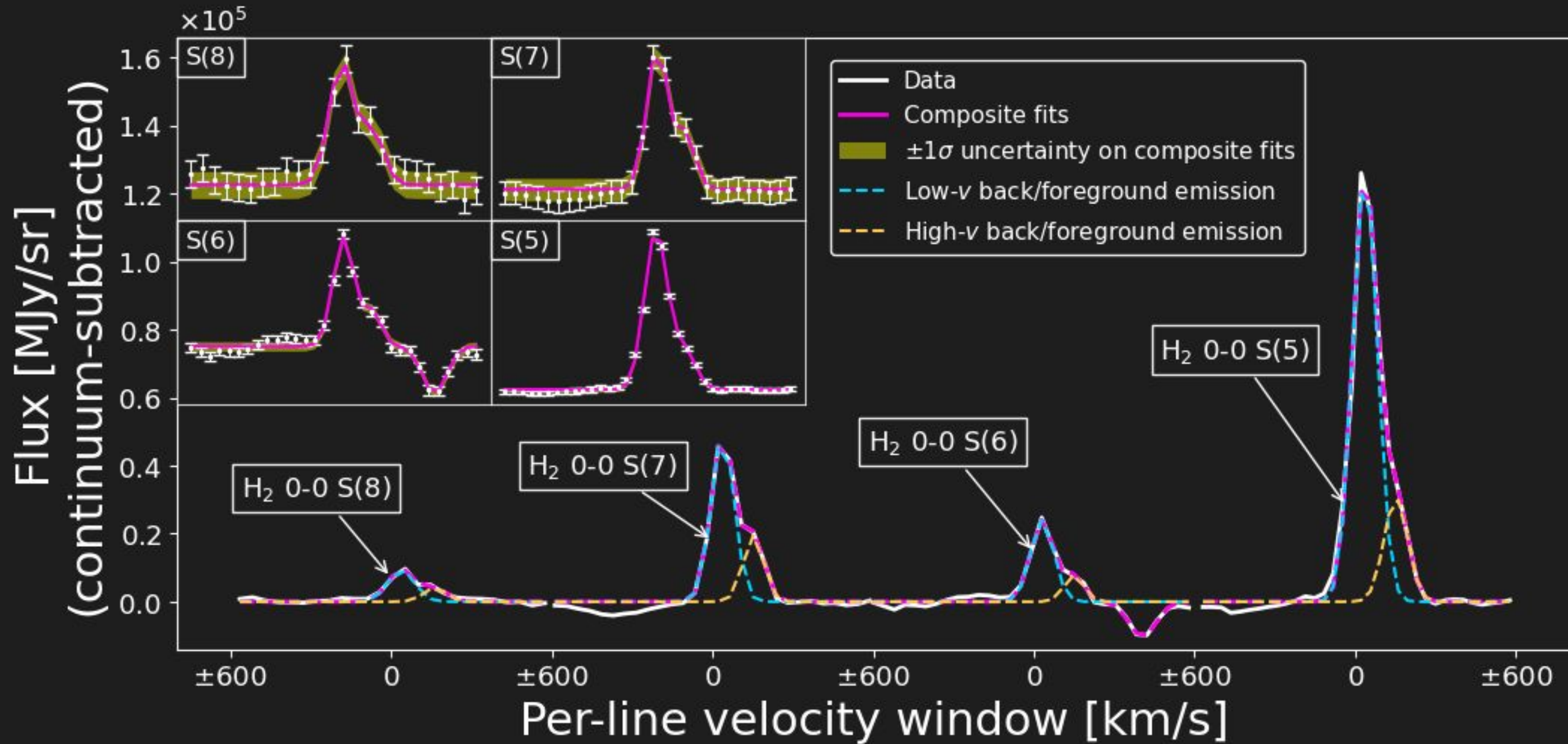


H_2 0-0 S(J), $J = 5, \dots, 8$

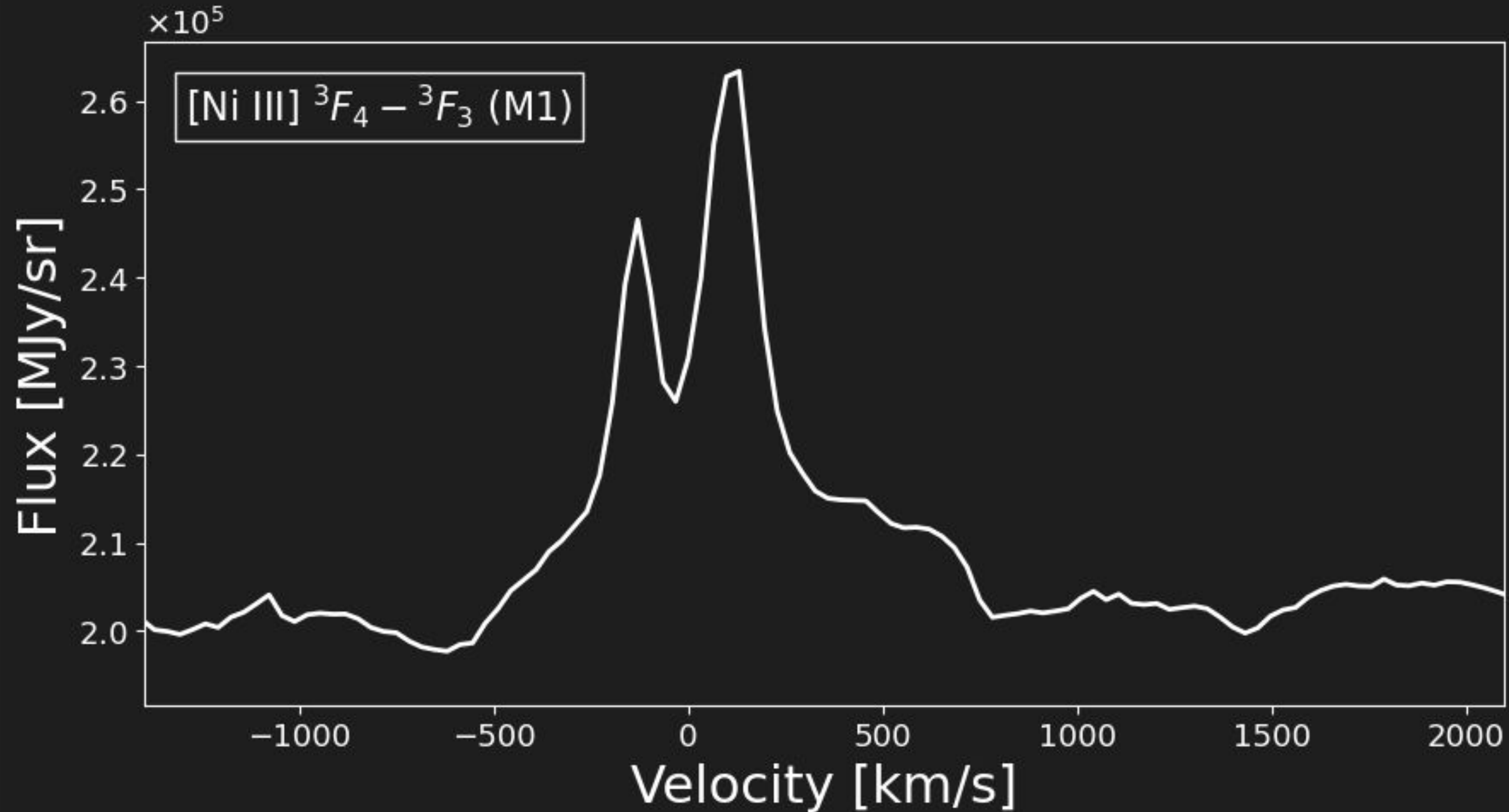
$S(5) > S(7) > S(6) > S(8)$



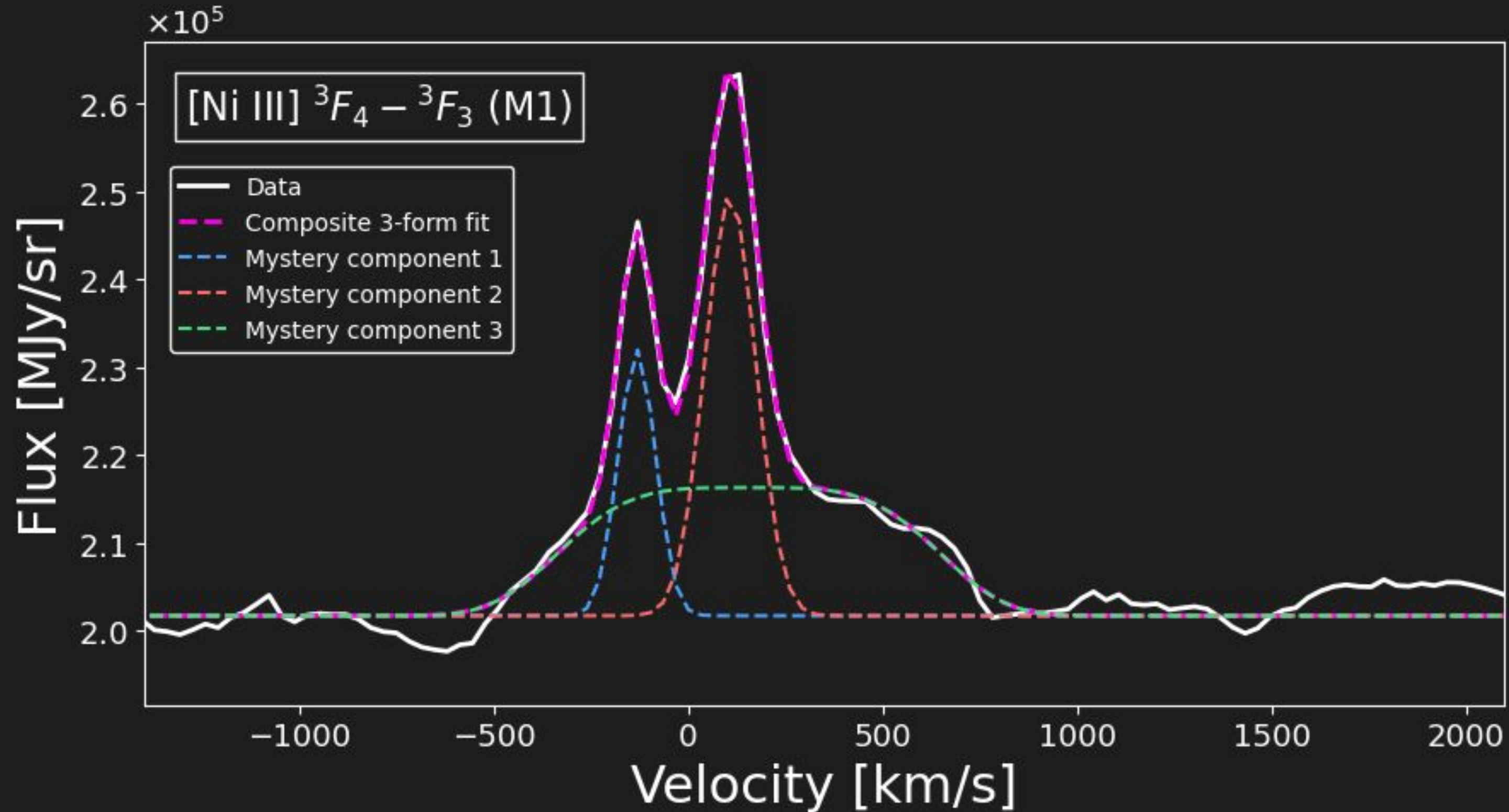
- Plausible IDs!



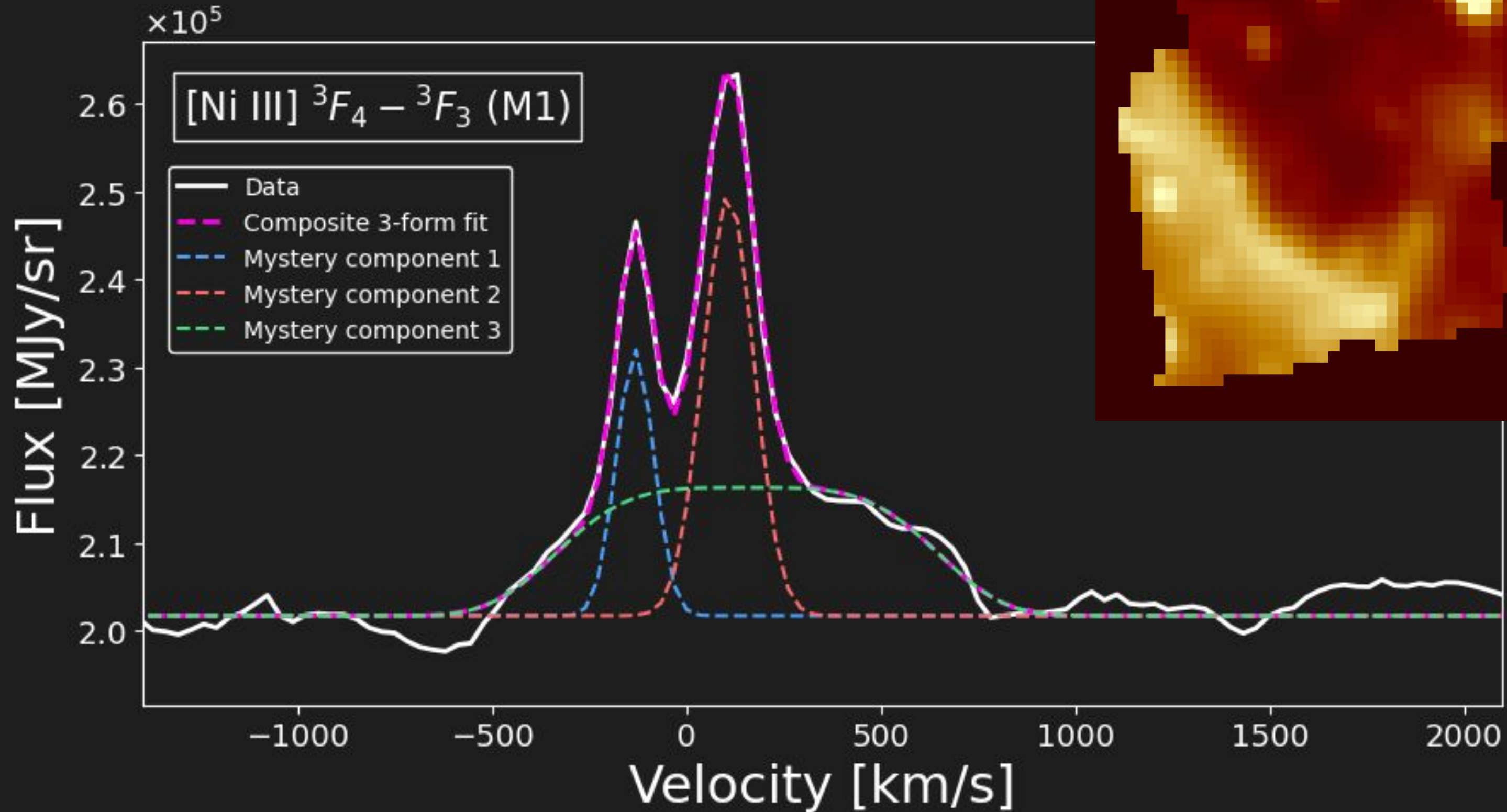
What about stellar correspondence?

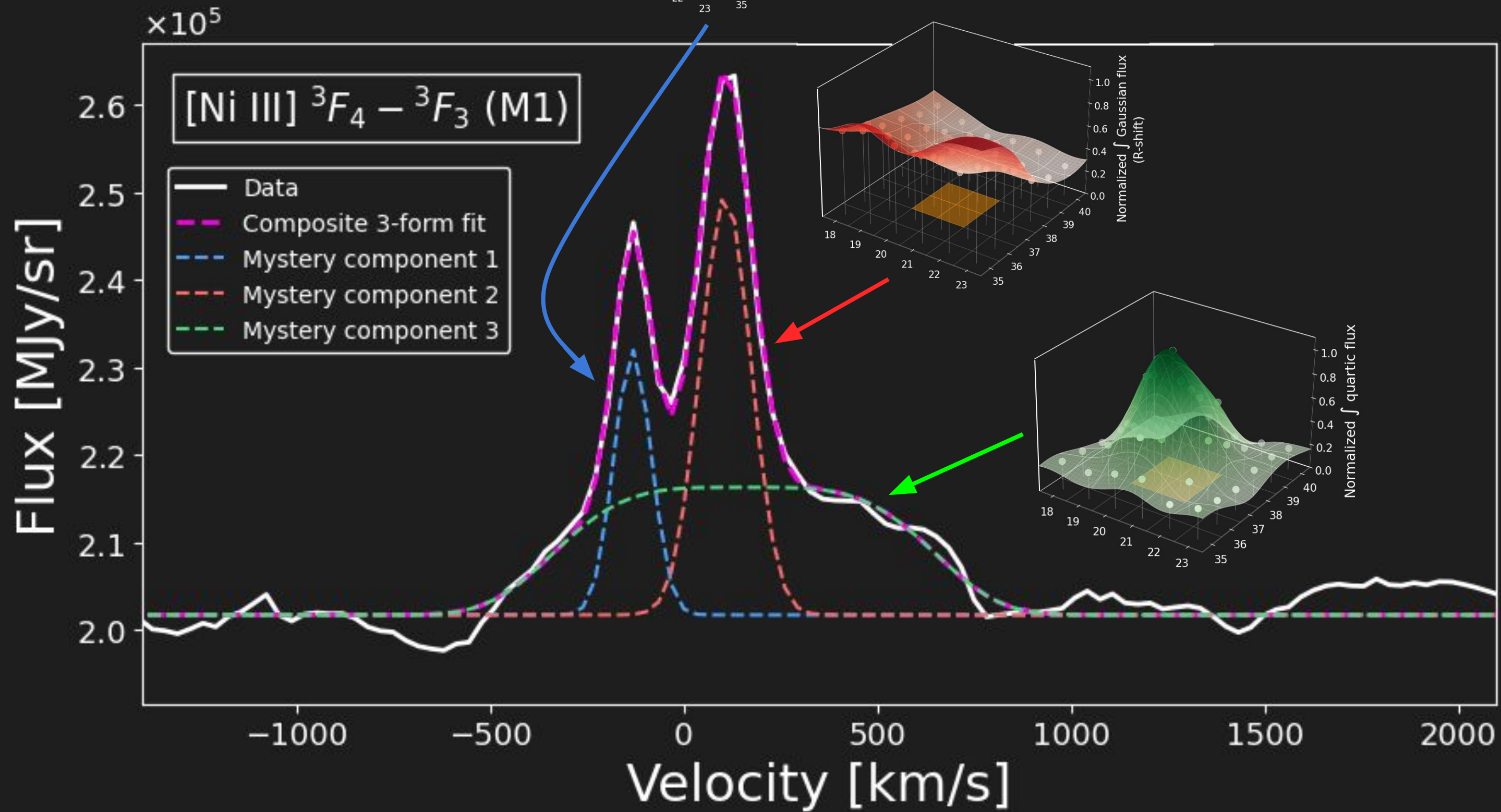


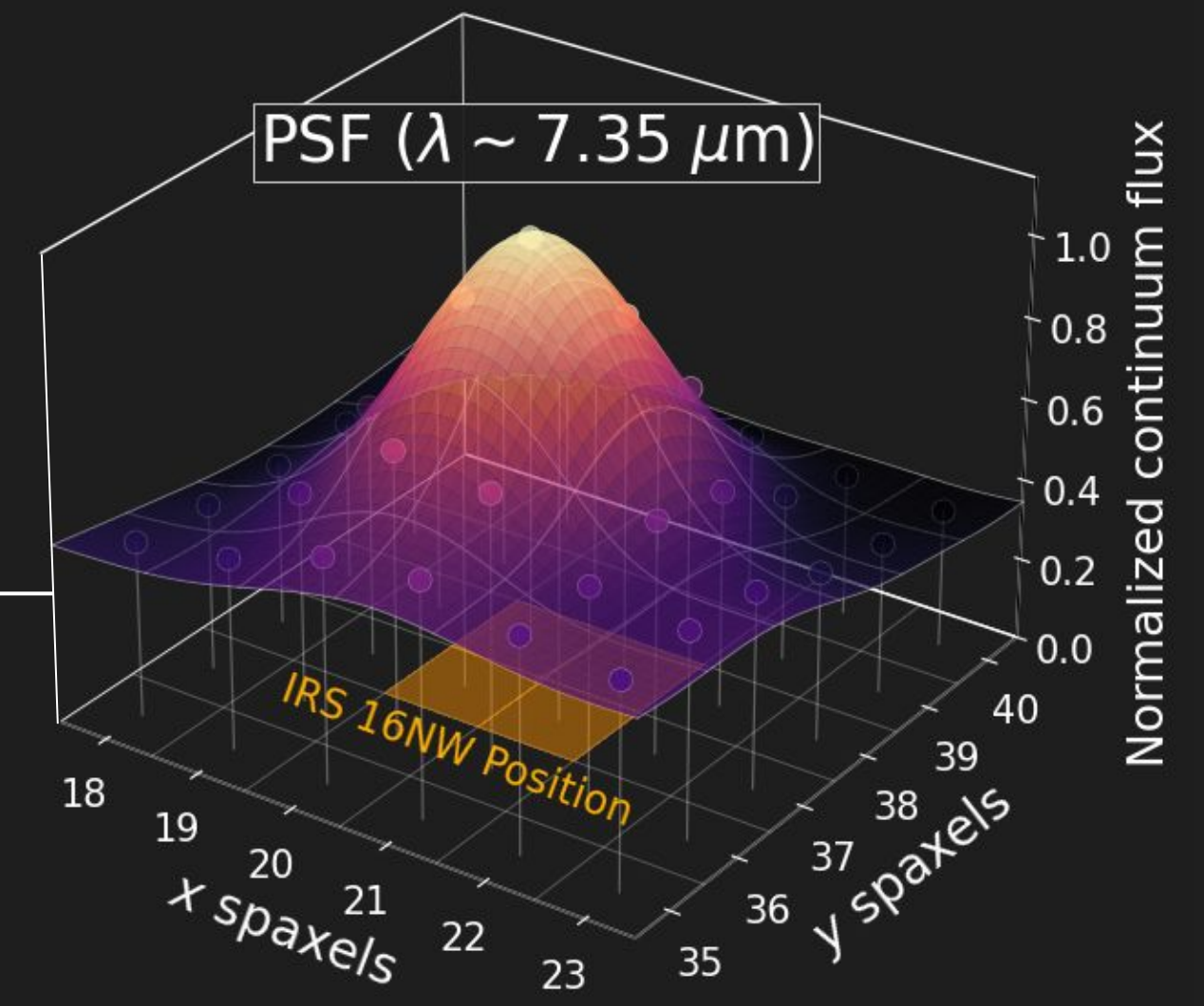
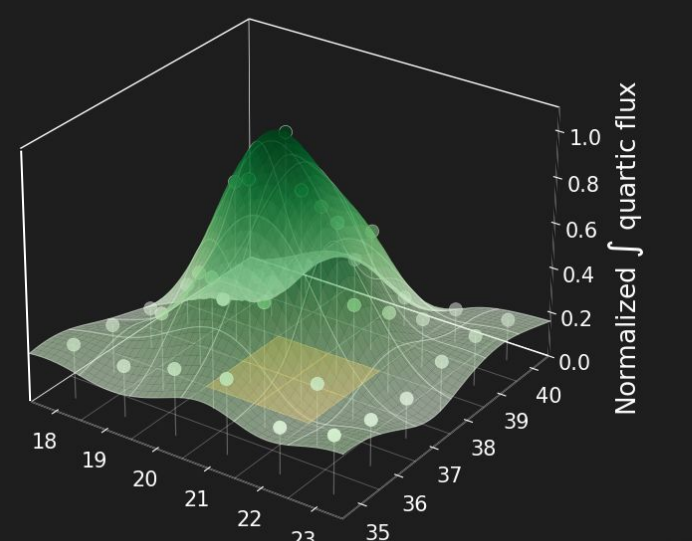
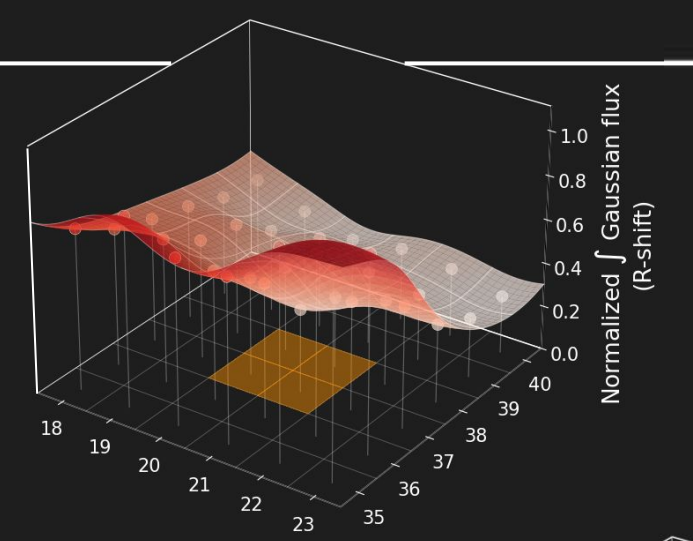
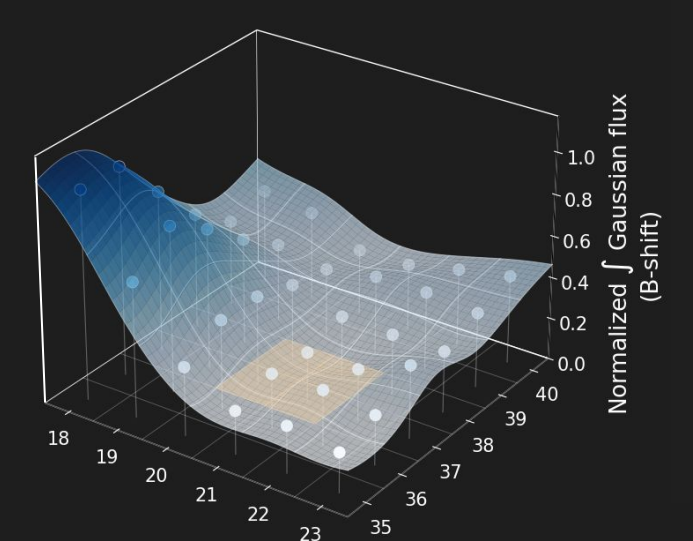
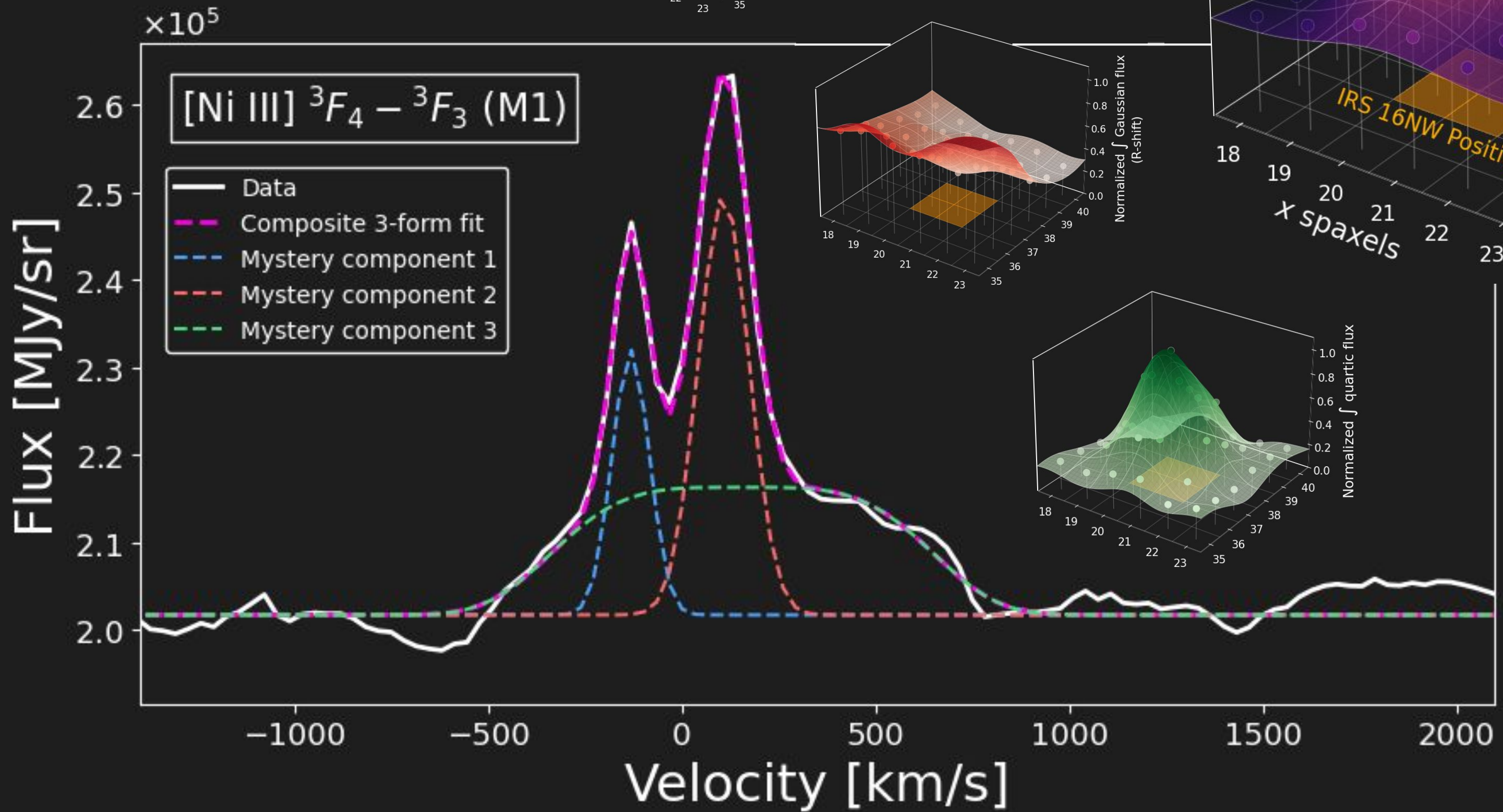
What about stellar correspondence?



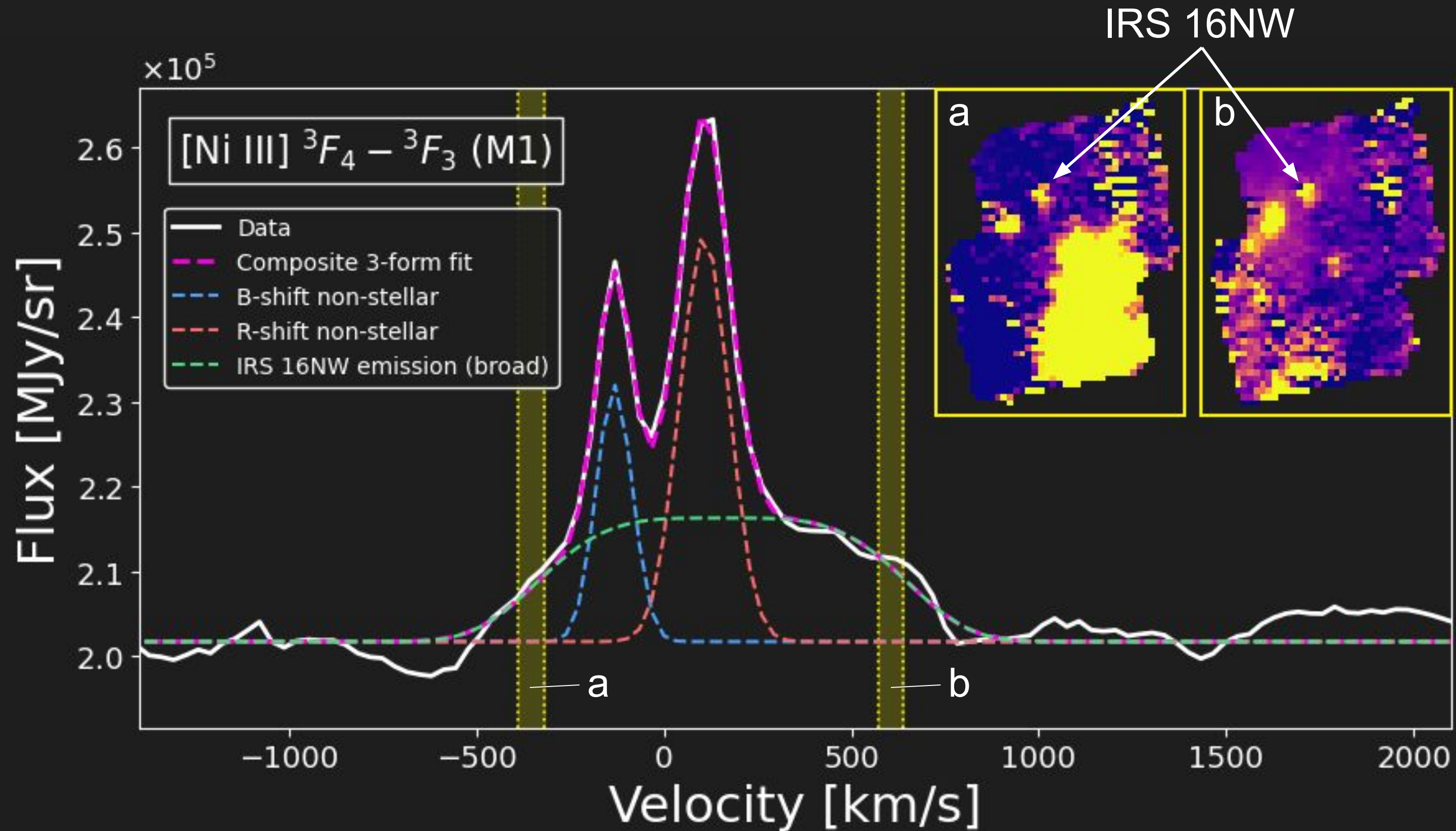
What about stellar correspondence?



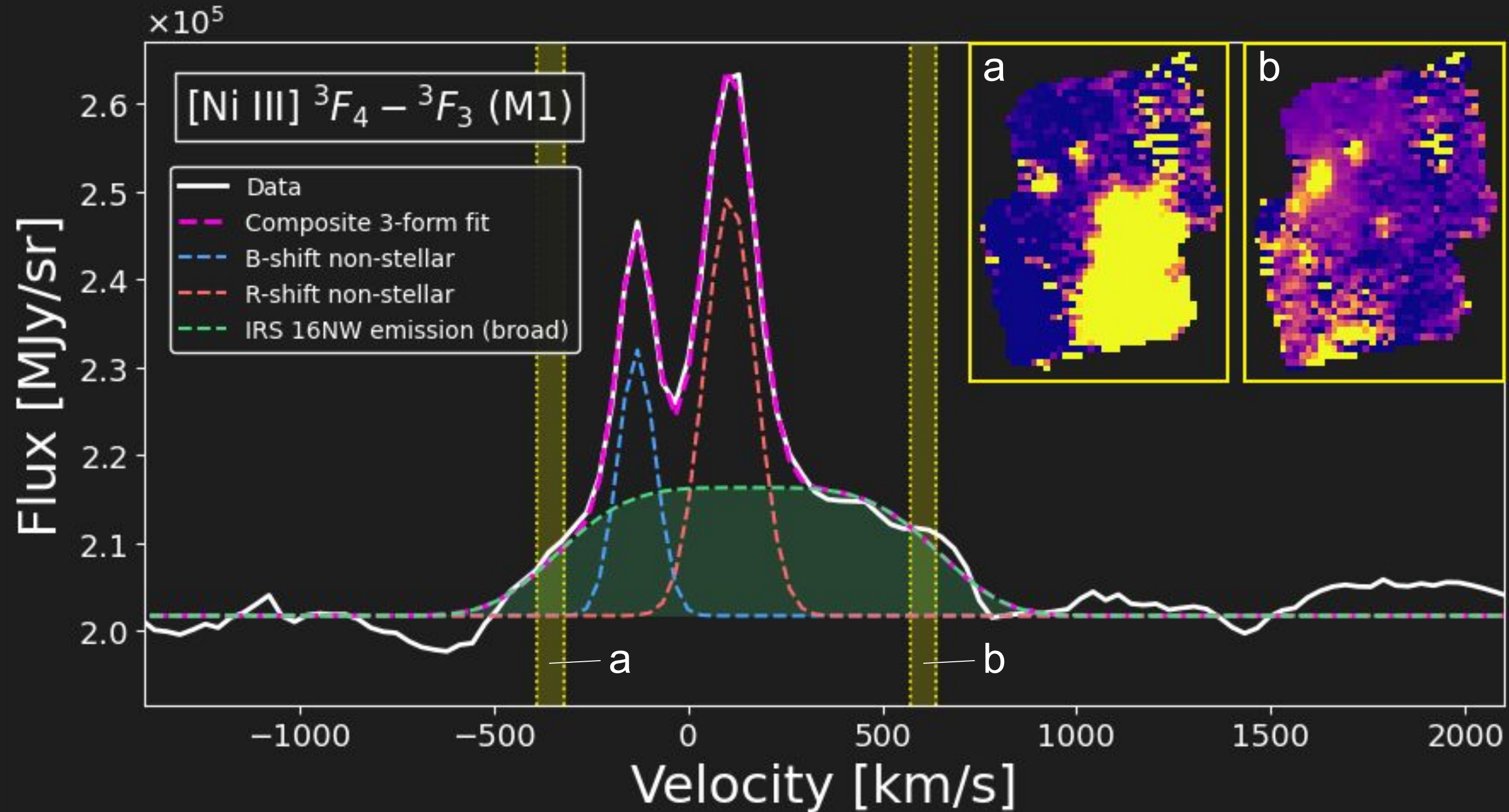




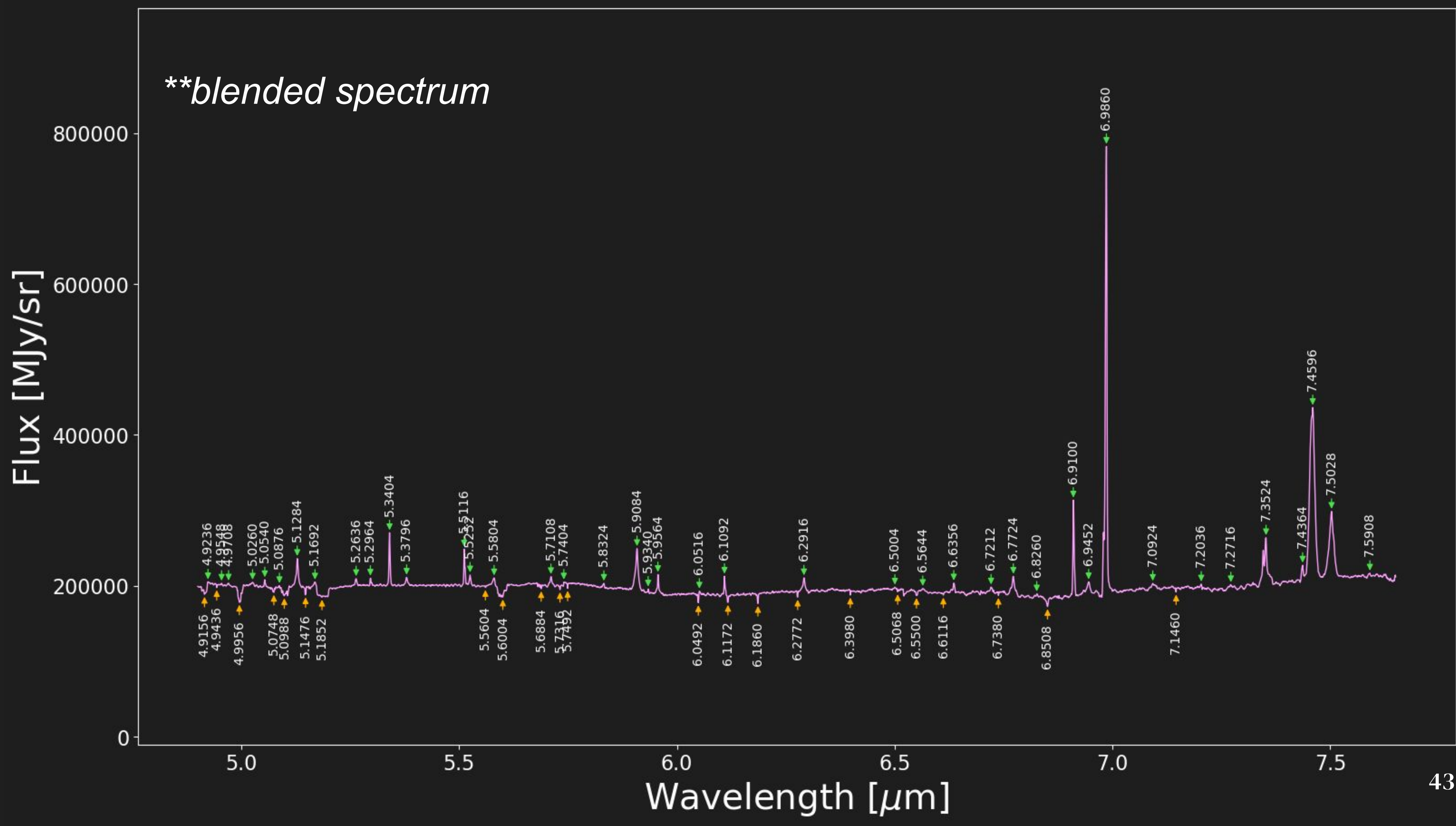
What about stellar correspondence?



Broad is stellar! (shaded)



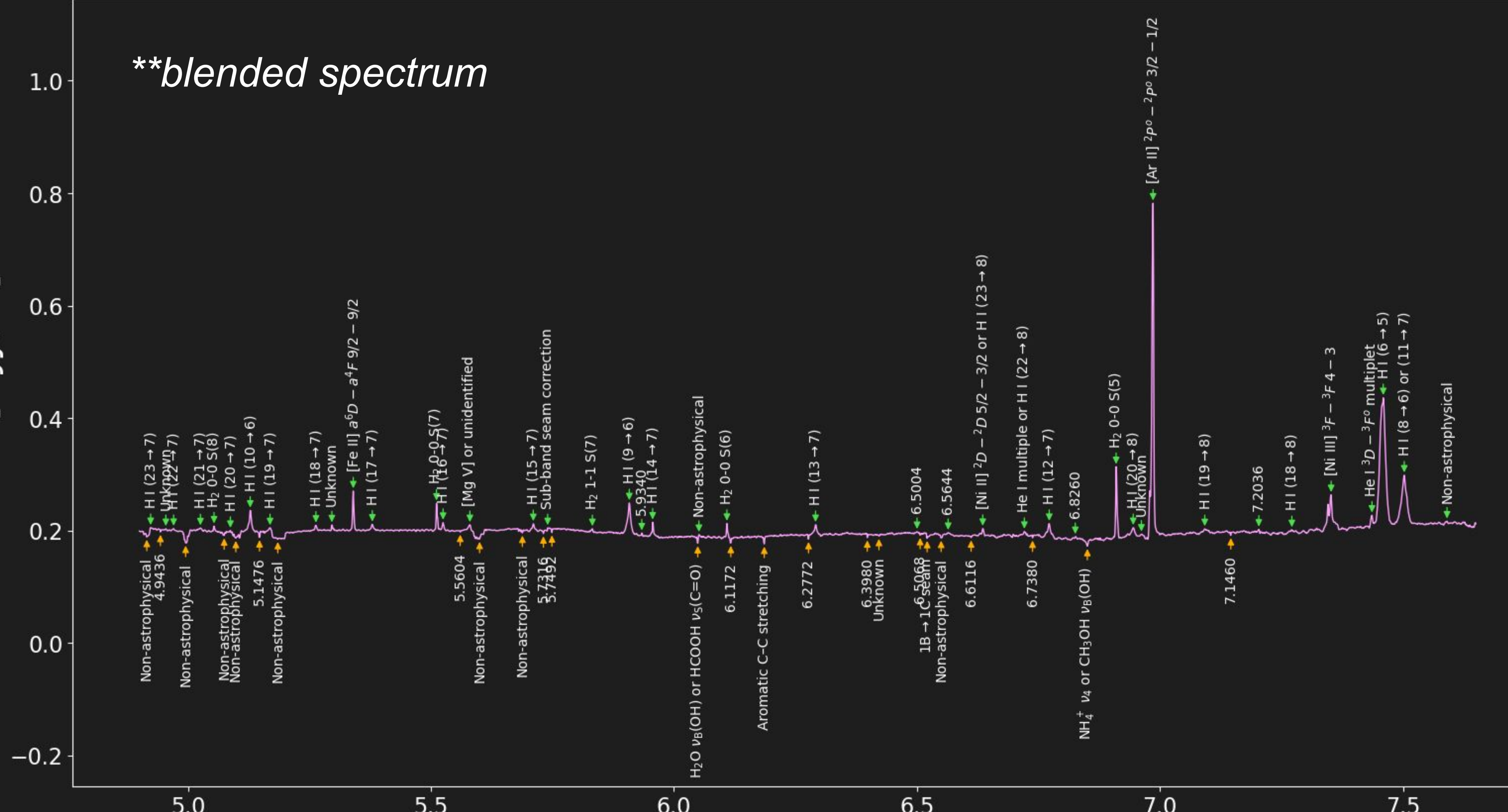
****blended spectrum**

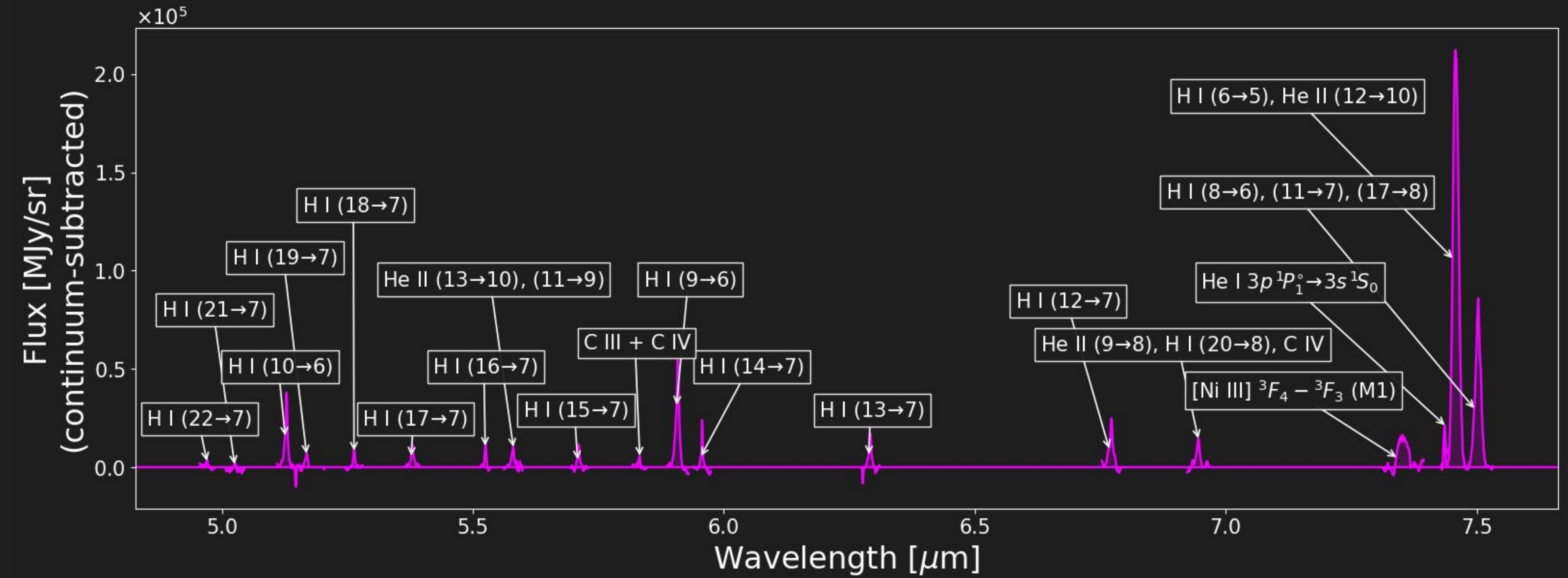


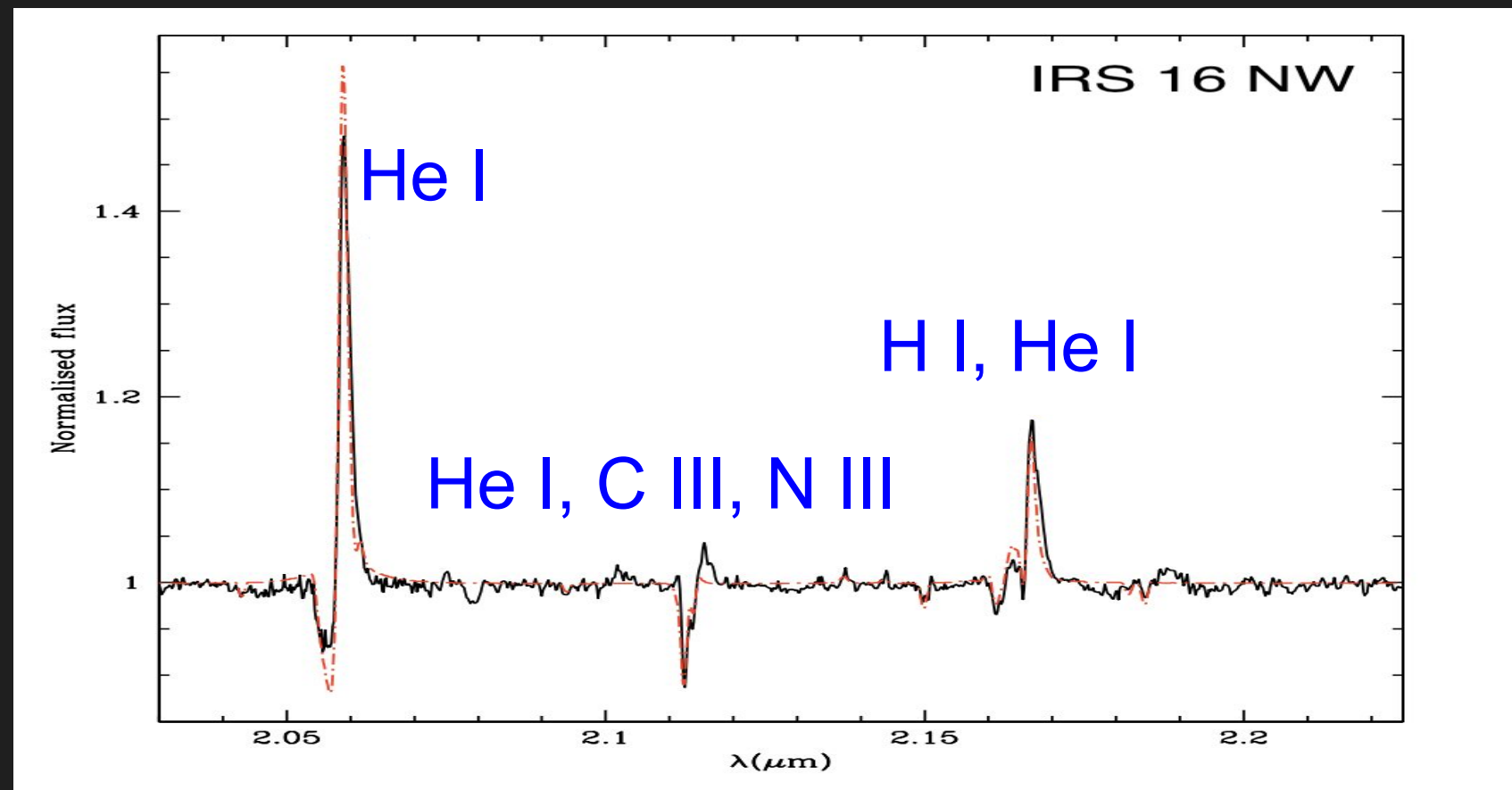
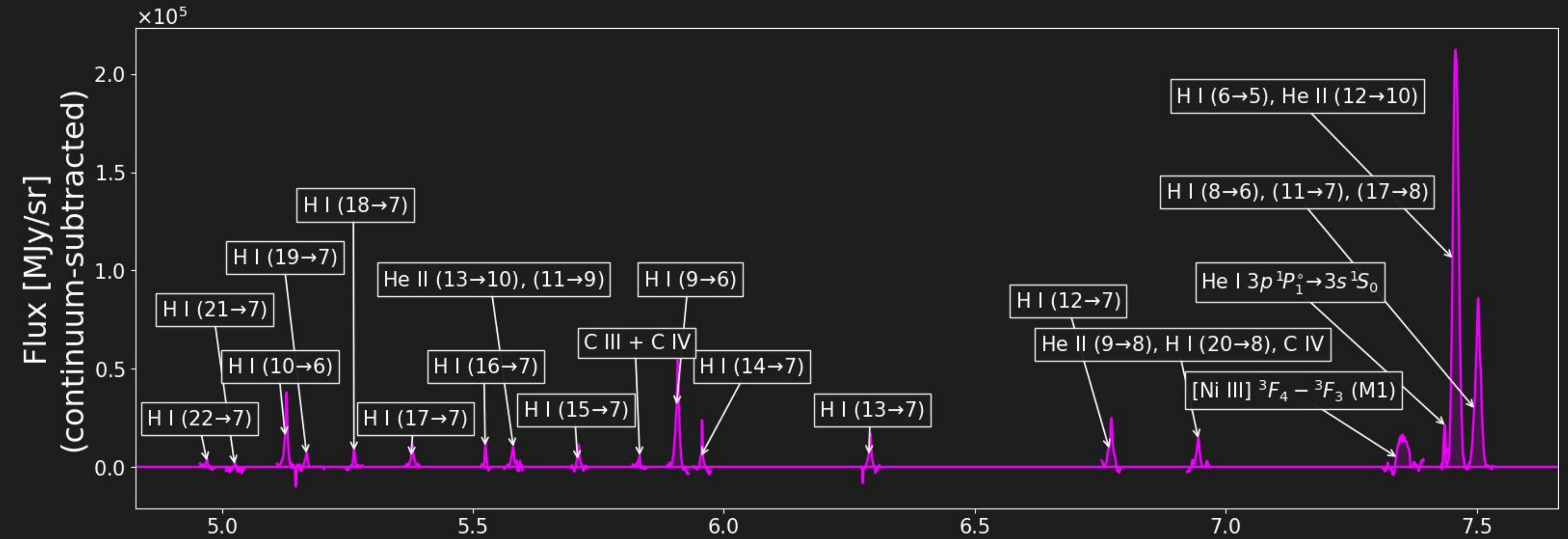
Flux [MJy/sr]

1e6

****blended spectrum**

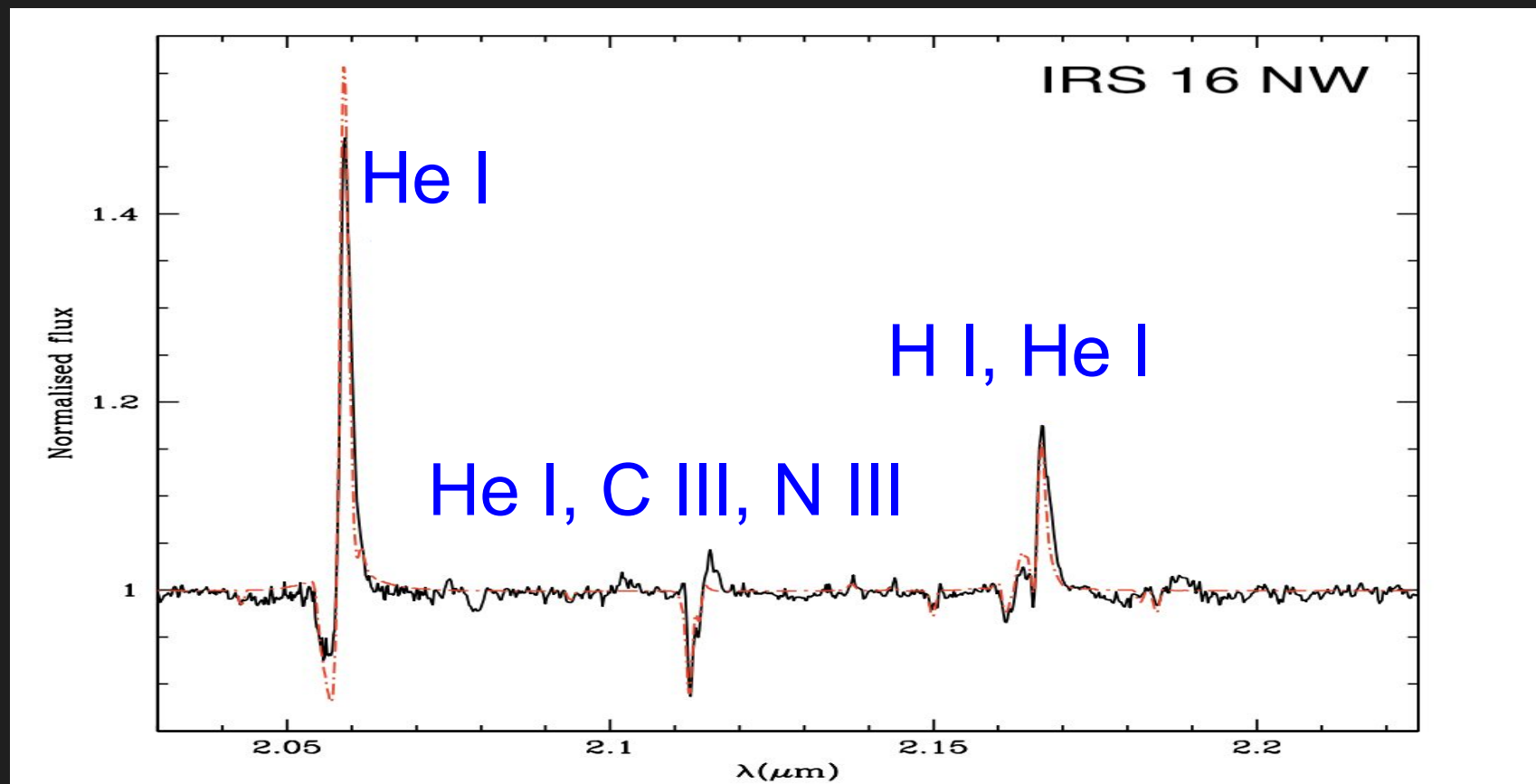
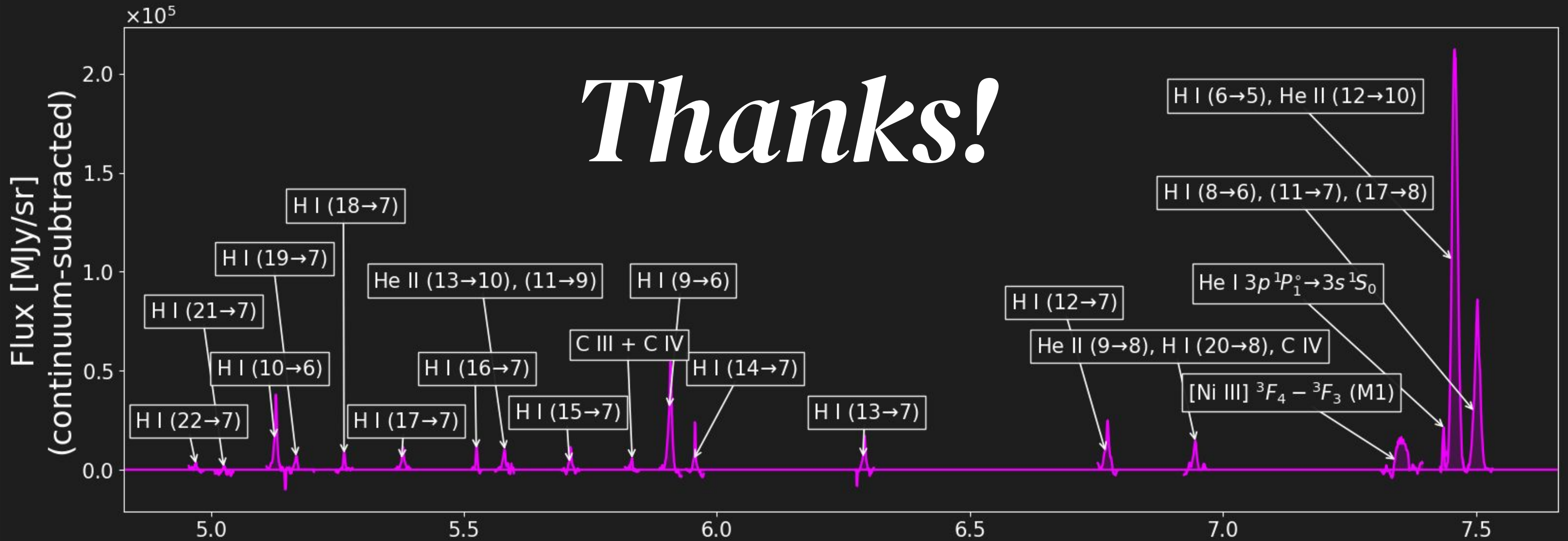






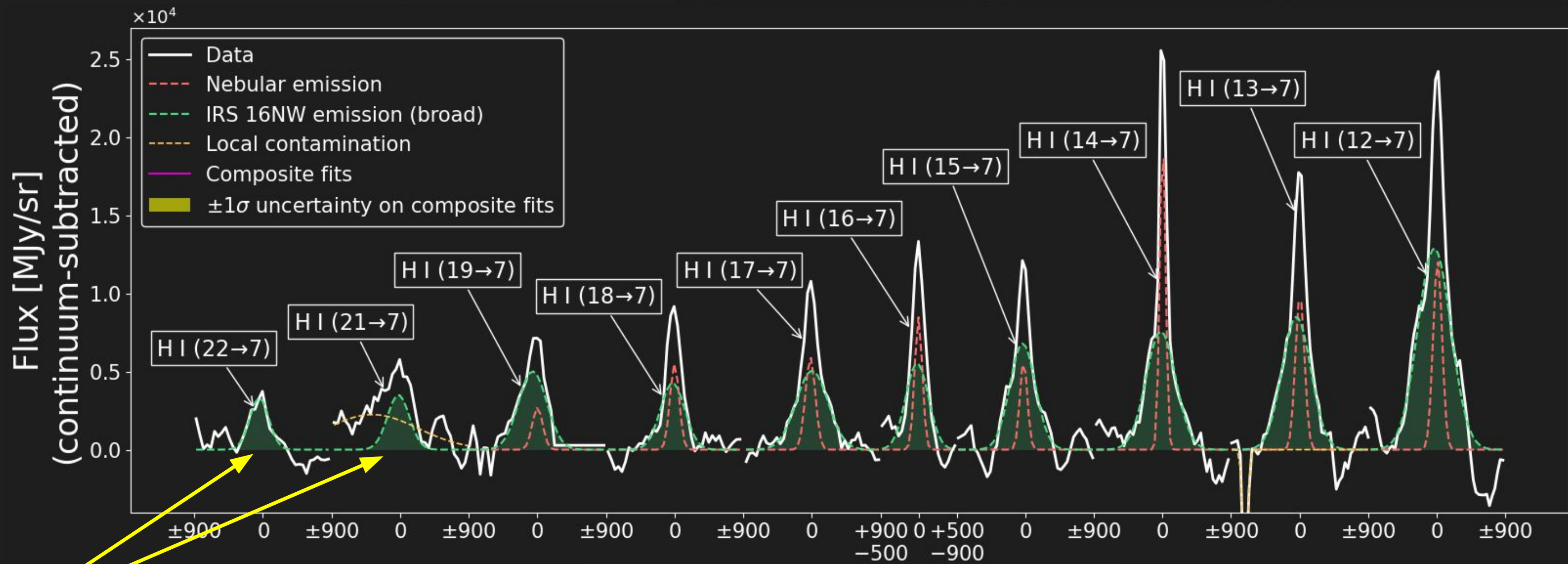
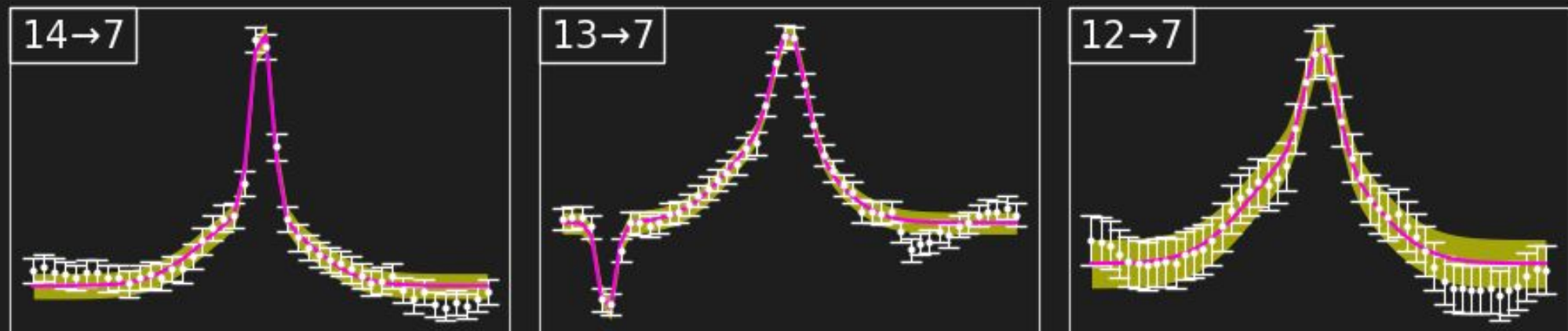
- *near-IR spectrum of IRS 16 NW, as measured by Martins et al. (2007)*

Thanks!



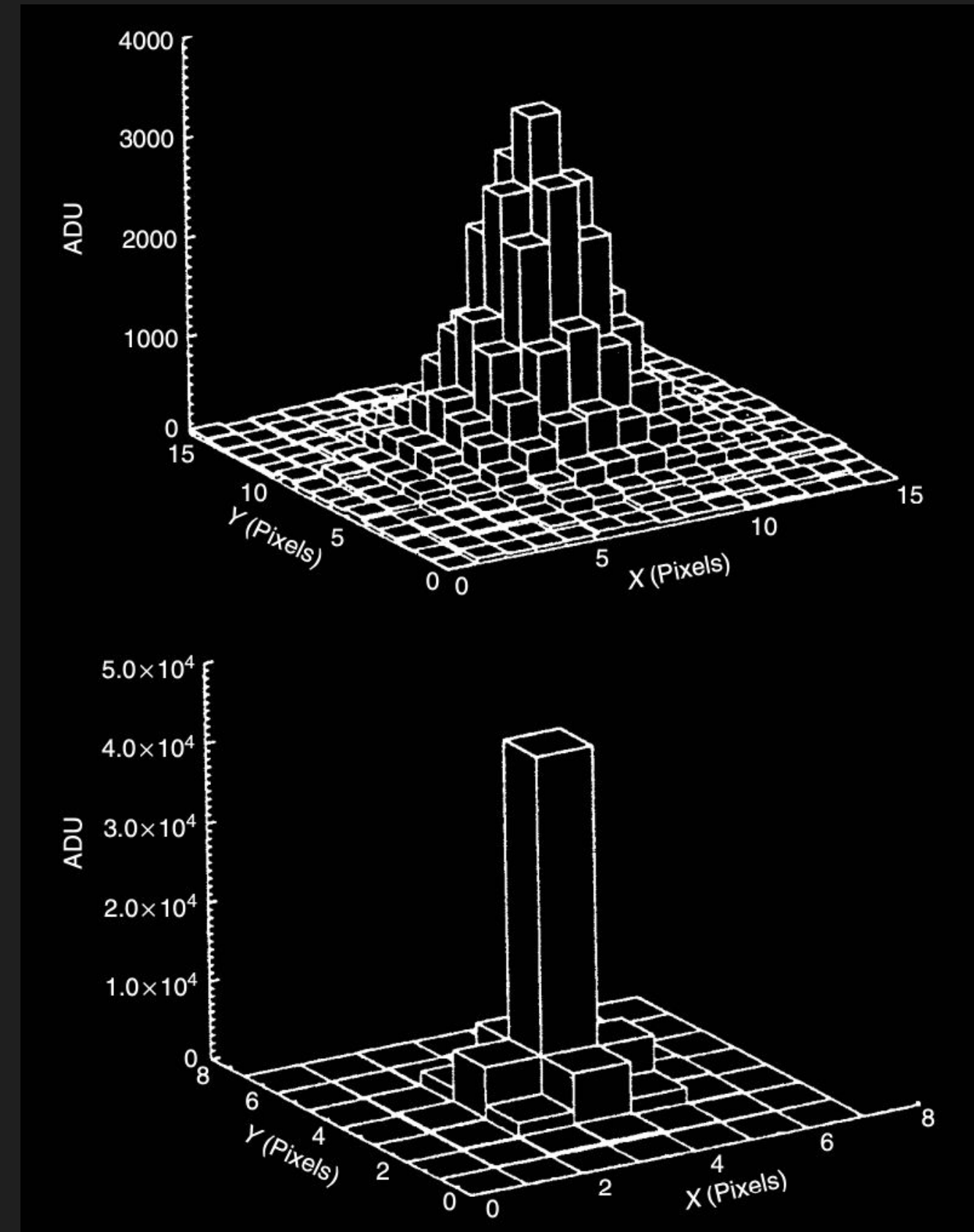
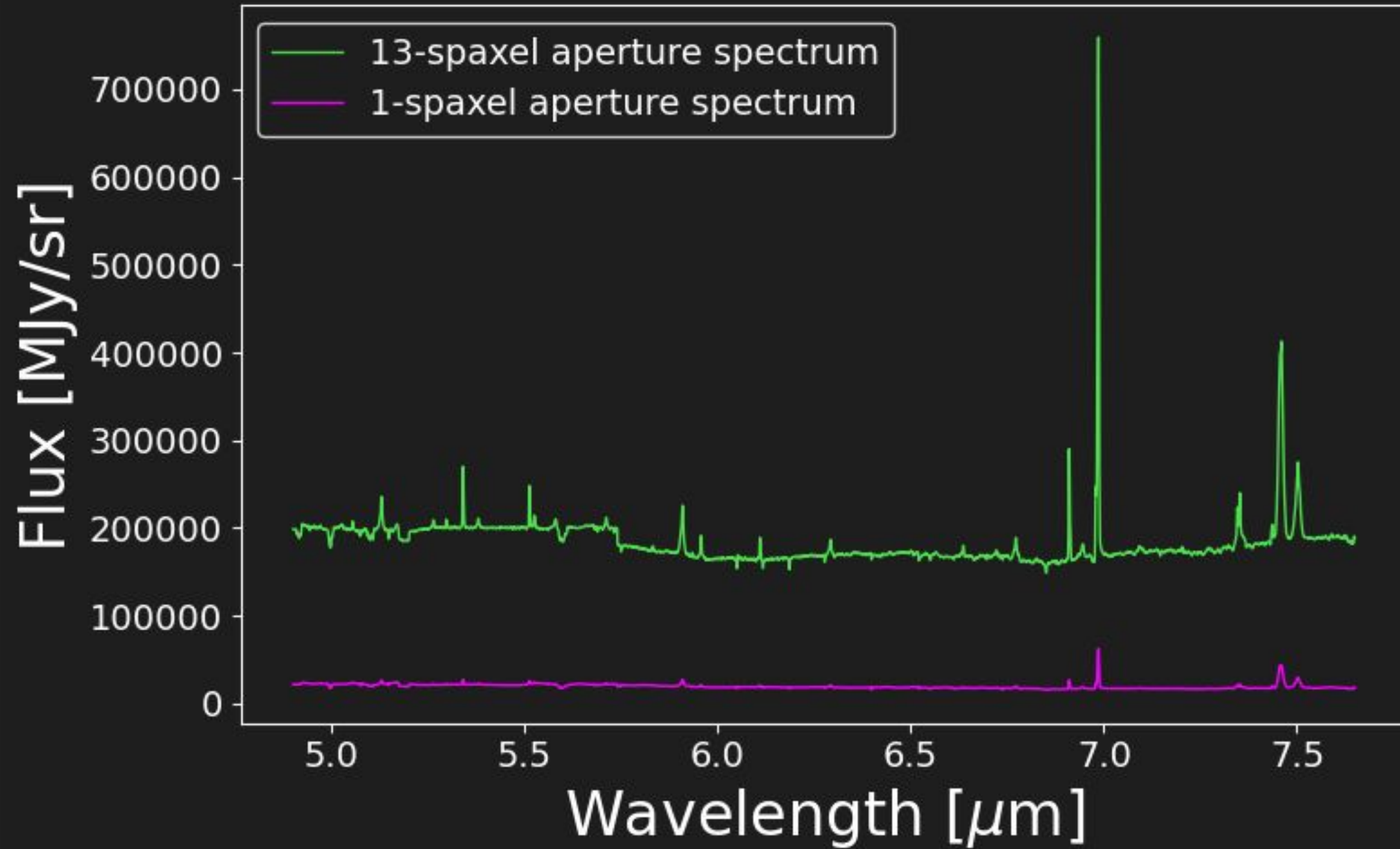
- *near-IR spectrum of IRS 16 NW, as measured by Martins et al. (2007)*

$$\underbrace{(v_{\text{LOS}}, \sigma)}_{\text{IRS 16 NW}} = \left(\sum_i \tilde{w}_i \mu_b^i, \sum_i \tilde{w}_i \sigma_b^i \right)$$

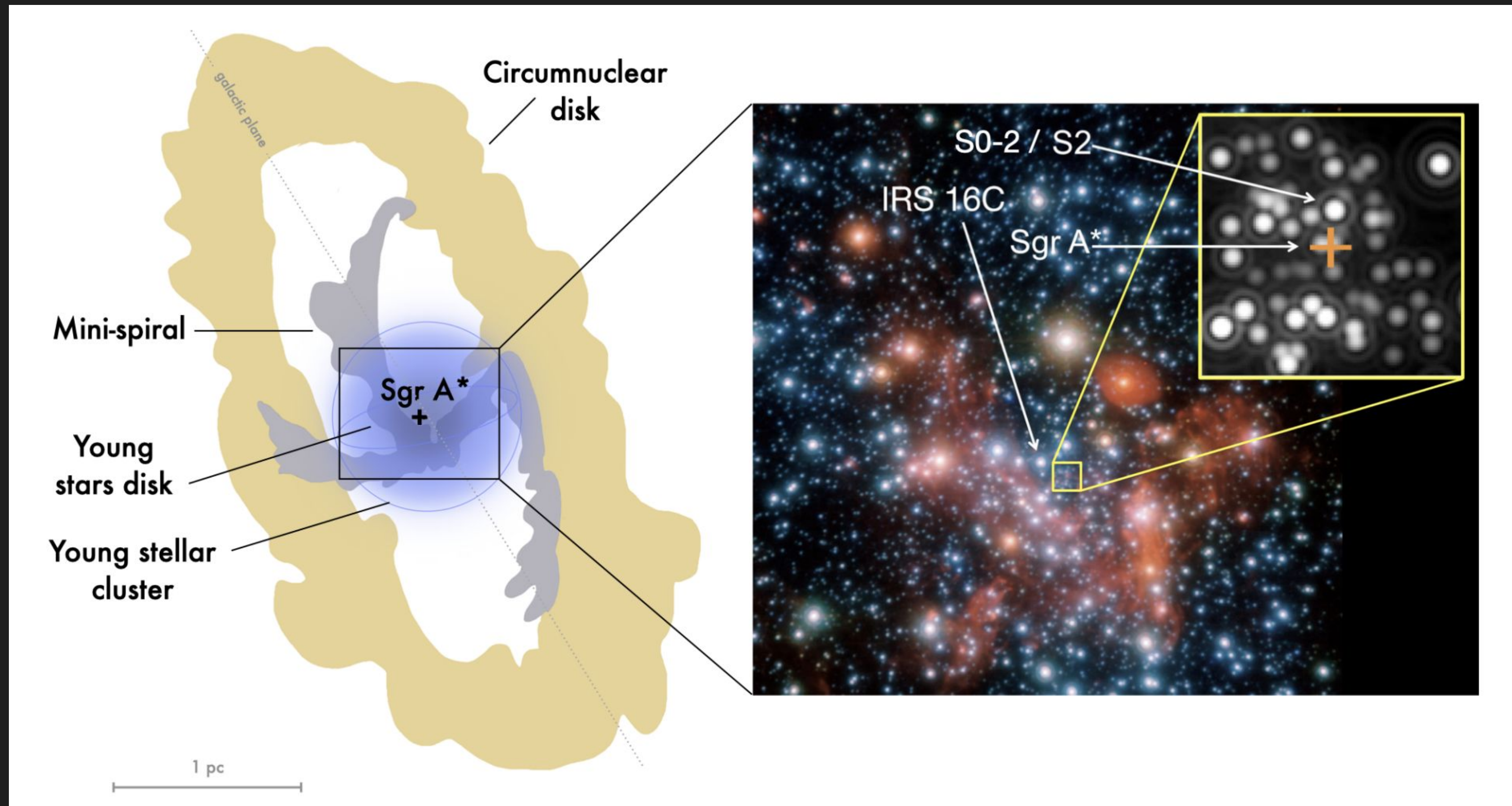


● Recombination rate generally increases with decreasing n (ignoring extinction)

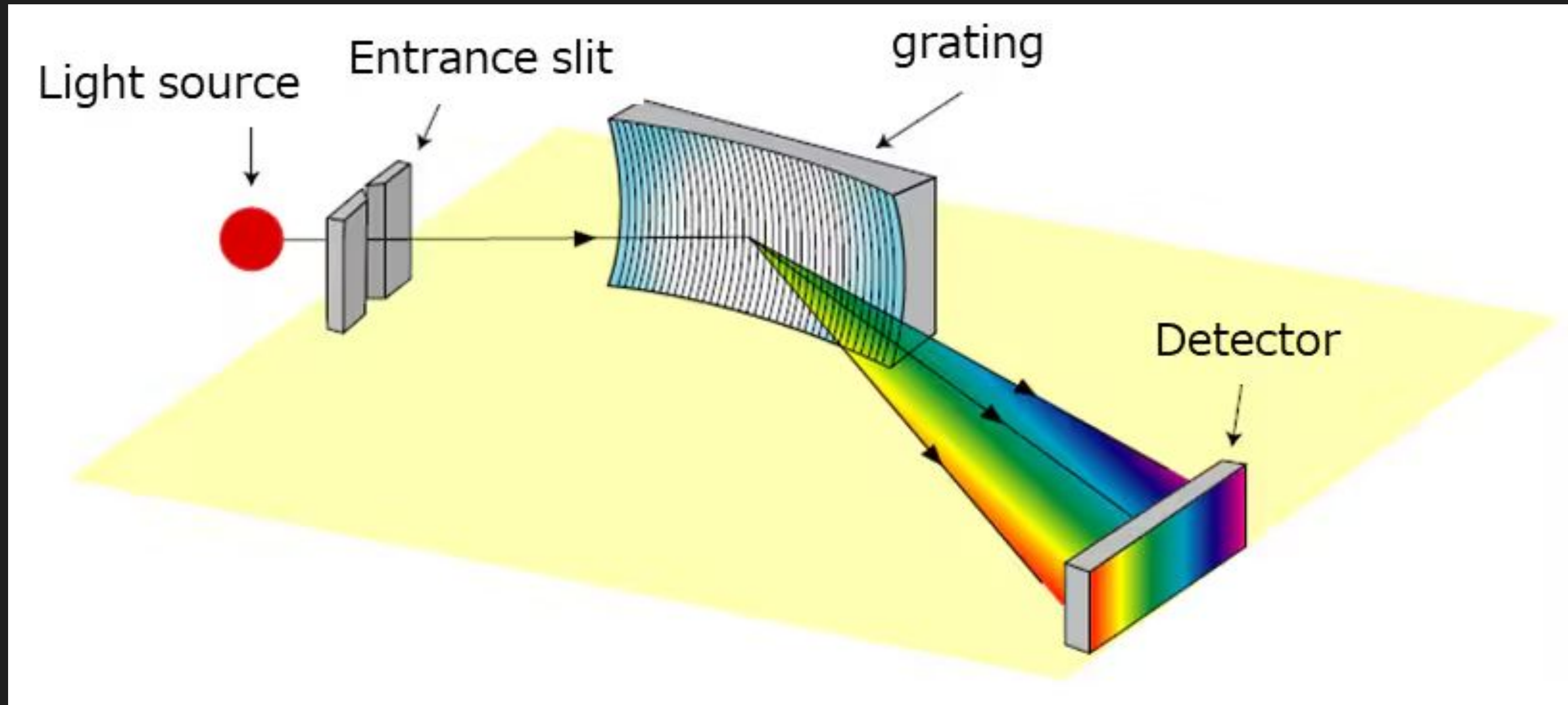
Bonus slide



Bonus slide

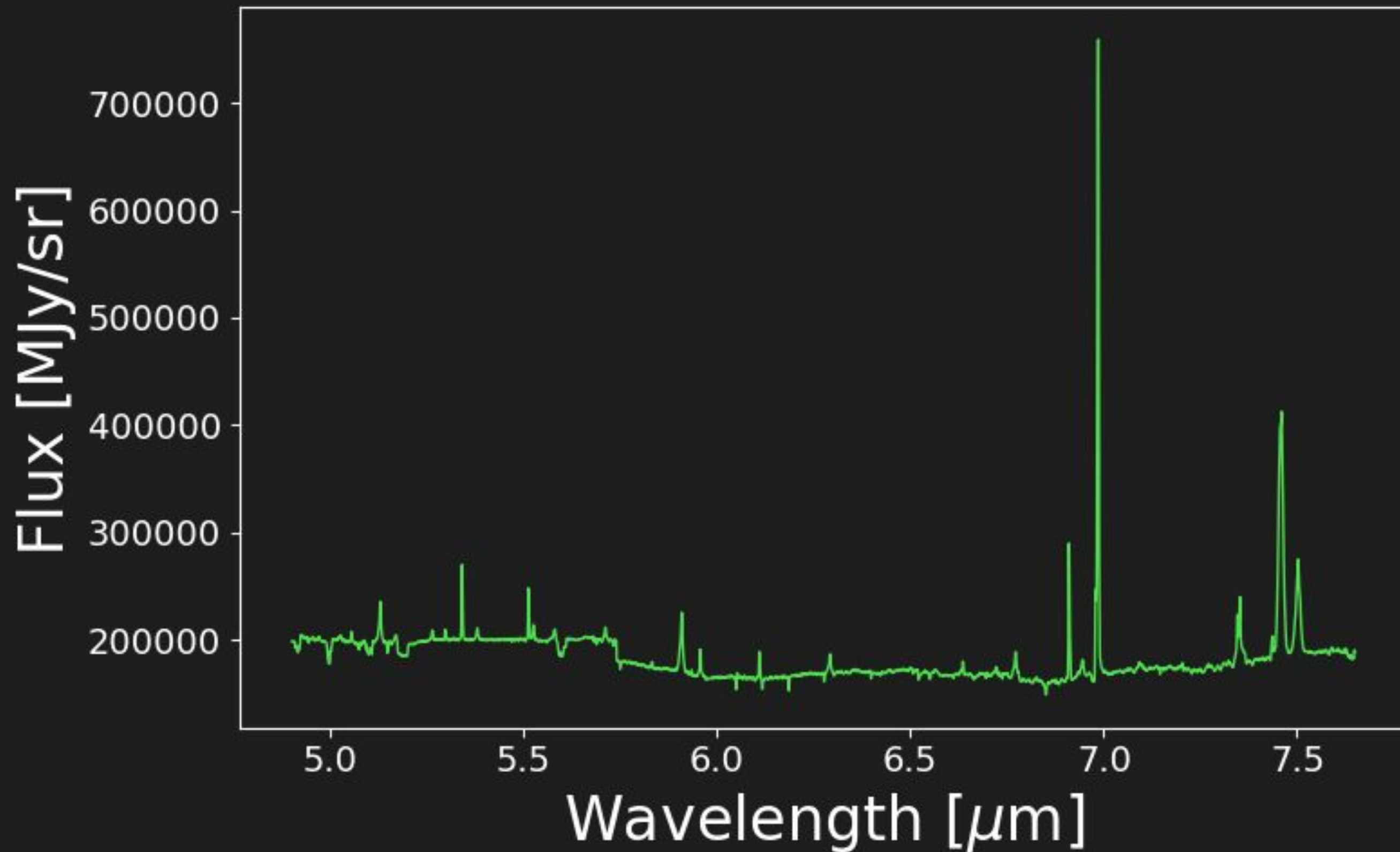


Bonus slide

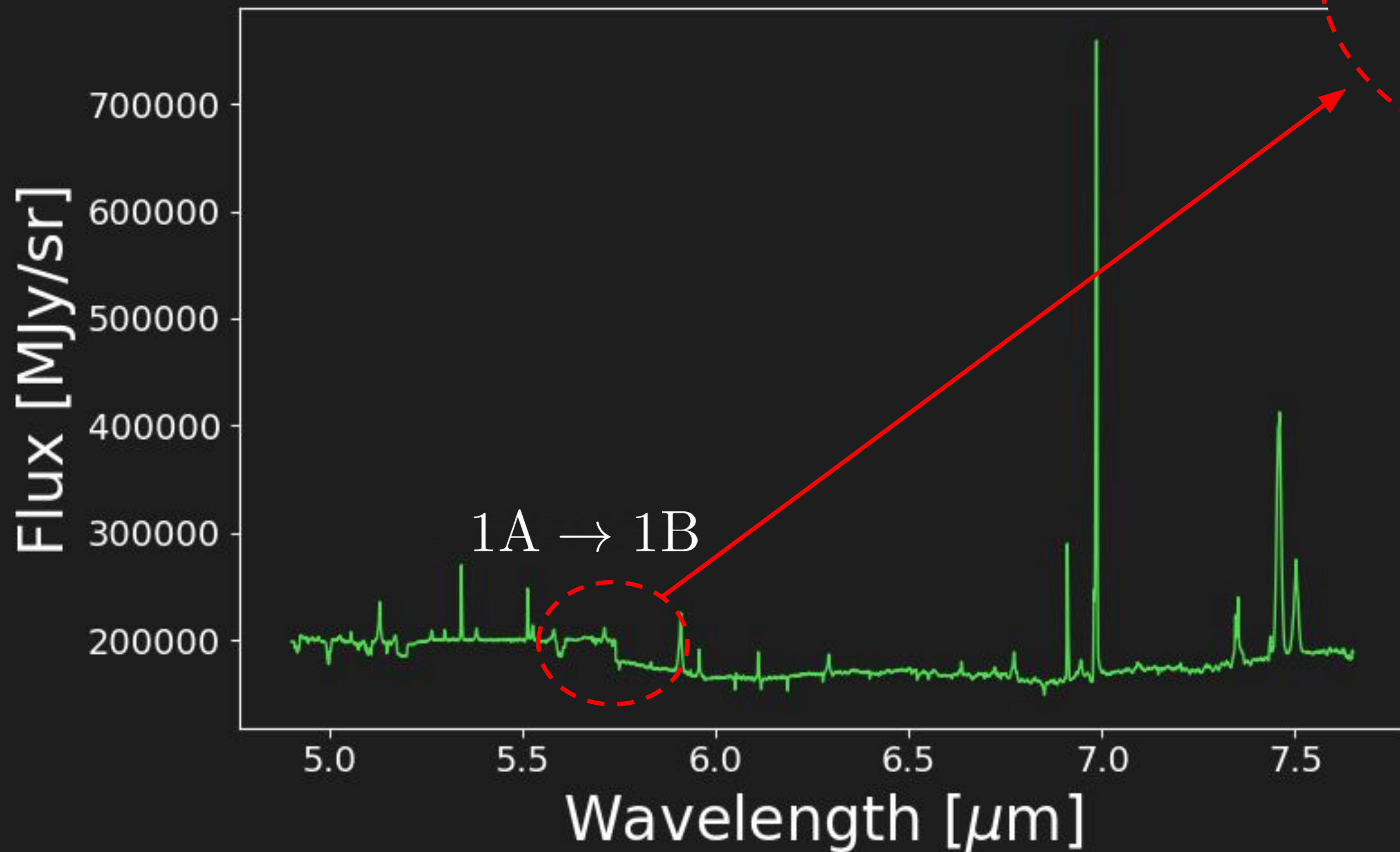


Shimadzu (n.d.)

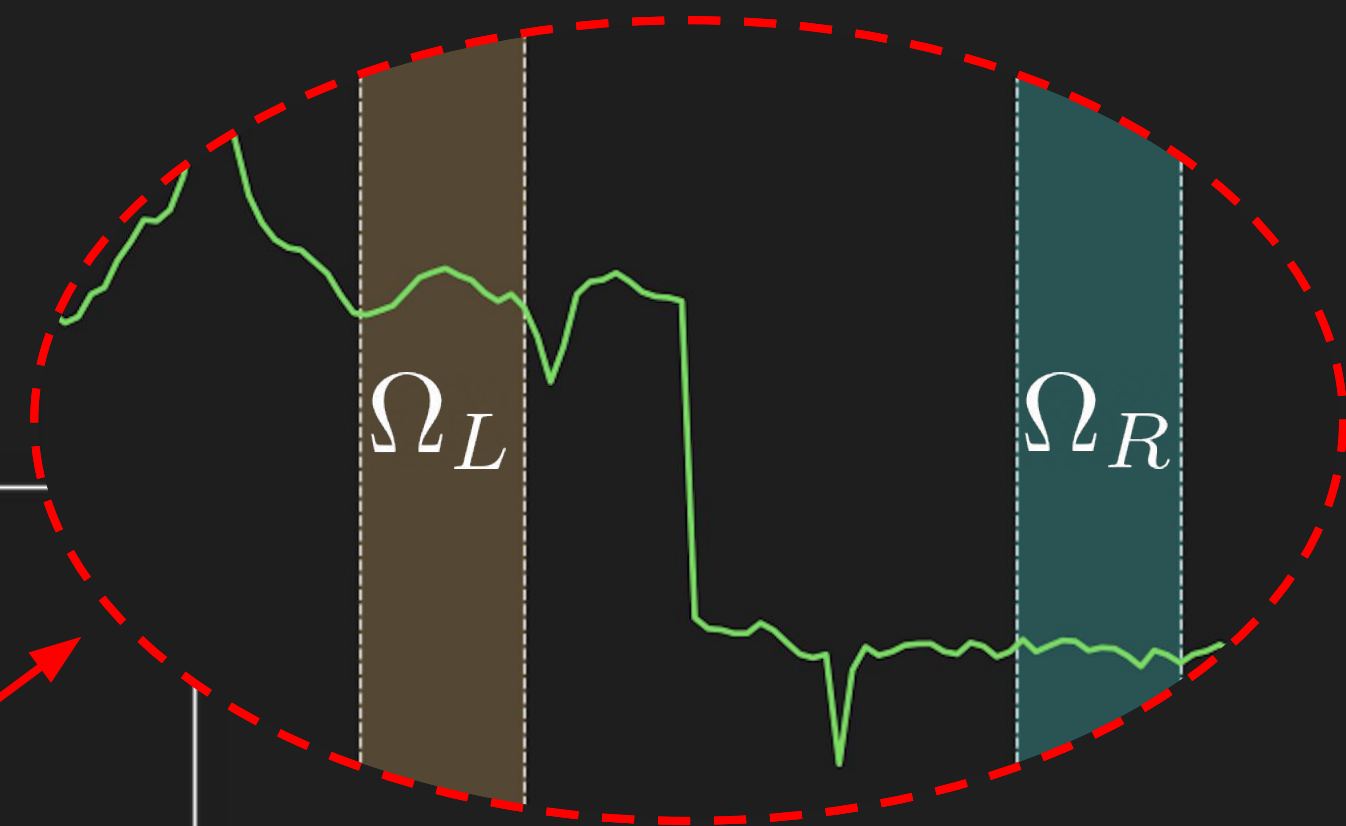
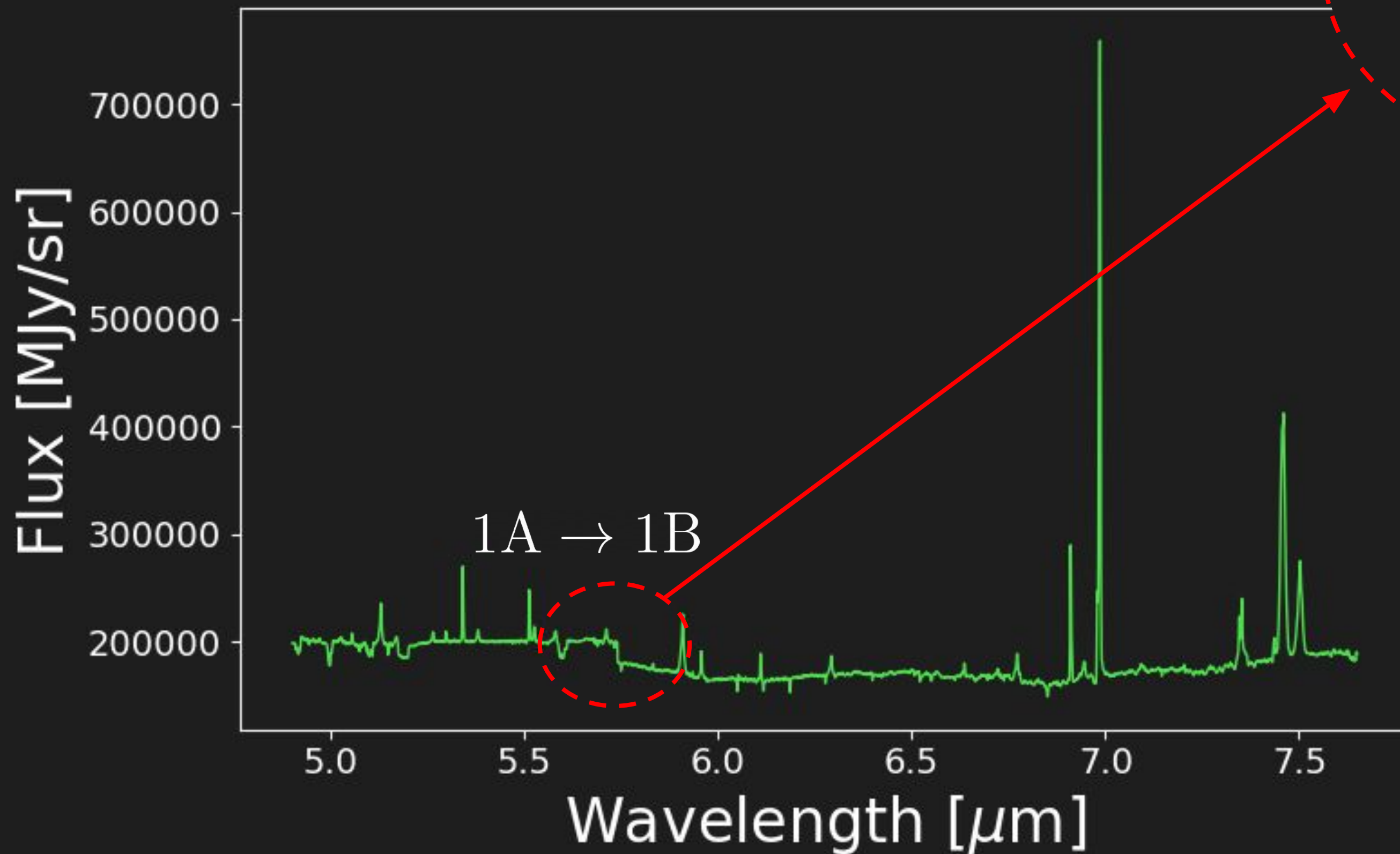
$$I_{\text{star}}(\lambda) = \sum_{(x,y) \in \mathcal{S}_{13}} I(x,y,\lambda)$$



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- (windows Ω_L and Ω_R shrunk for visualization)
- perform additive offsets to remediate seams

$$I_{\text{star}}(\lambda) = \sum_{(x,y) \in \mathcal{S}_{13}} I(x,y,\lambda)$$

