Deconvolution of IFU Data: Kinematics Restoration

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The 8th Survey Science Group Workshop @High 1

Haeun Chung (KIAS/SNU) and Changbom Park (KIAS)

Introduction: When IFU meets PSF

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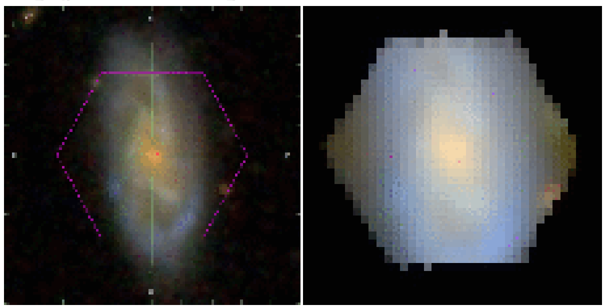
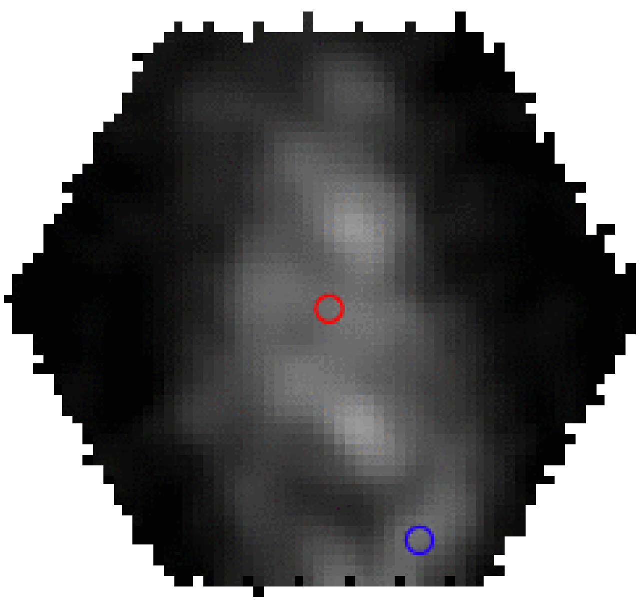
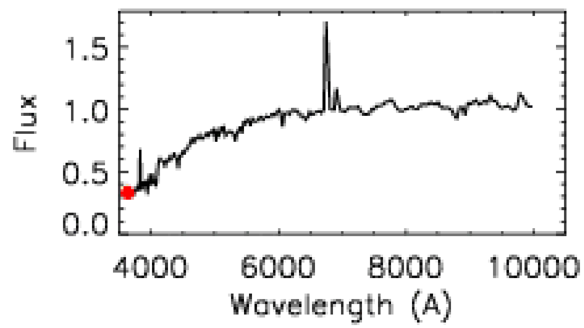
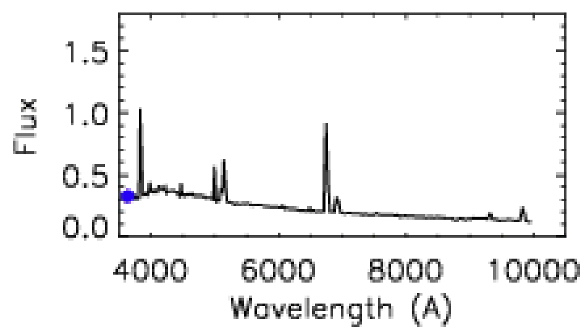
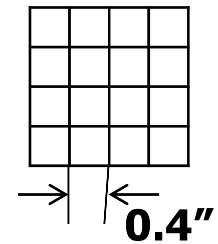




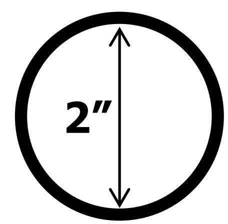




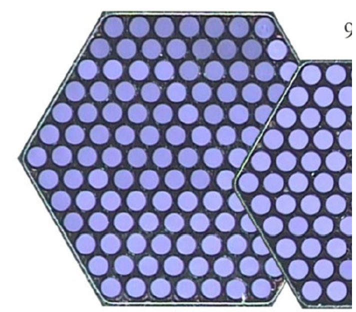
SDSS Camera Pixel Size



MaNGA Fiber Size



127-Fiber IFU

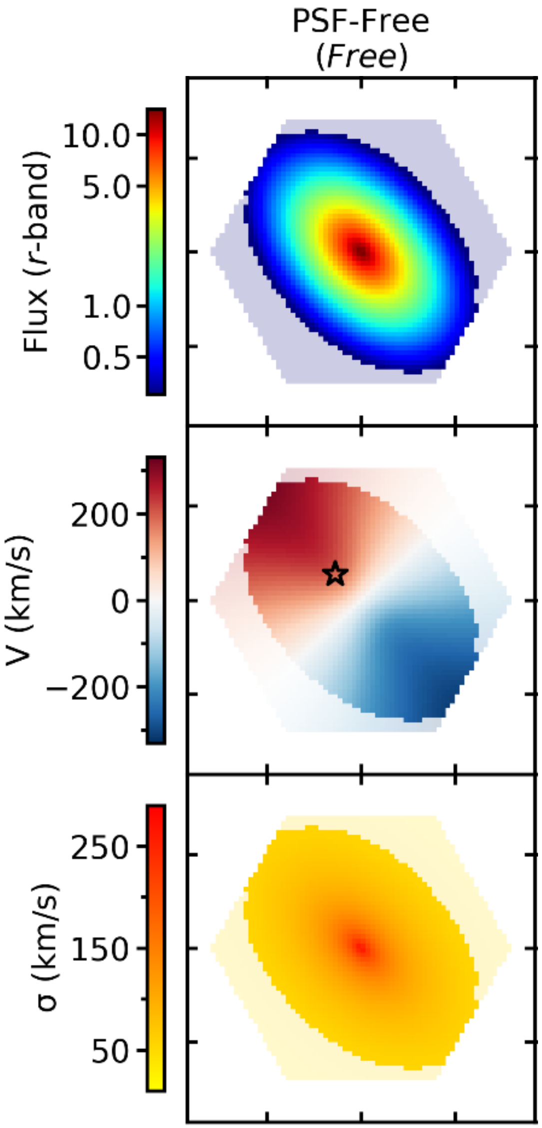


Bundy+15

+ Seeing (~1.5″)

-> MaNGA PSF (~2.6″ FWHM)

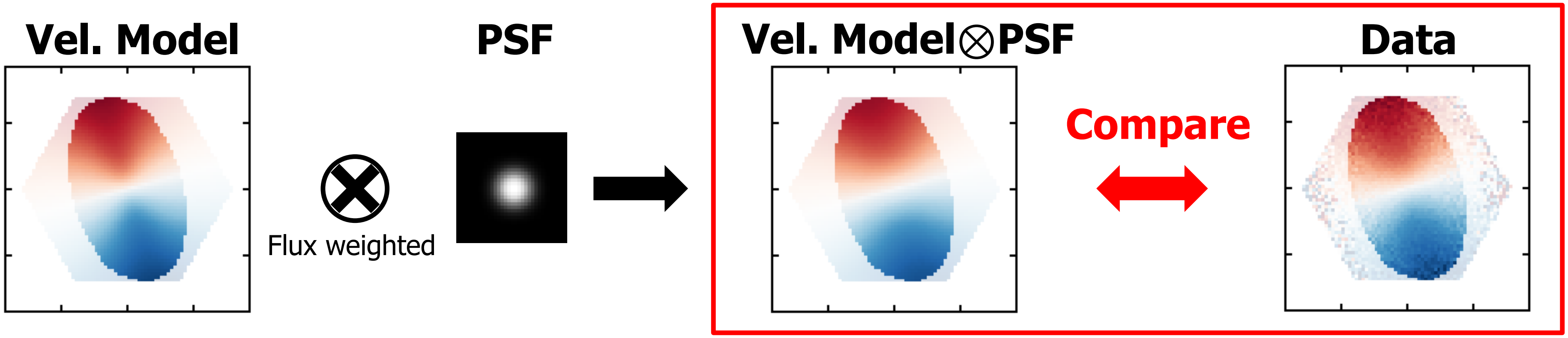
Introduction: When IFU meets PSF



Introduction: When IFU meets PSF

Q. How to mitigate the PSF effect?

- One possible way of mitigating PSF is using forward modeling.



- Flux weighted convolution is an approximation
- PSF need to be considered repeatedly for each model

Our answer: Deconvolution

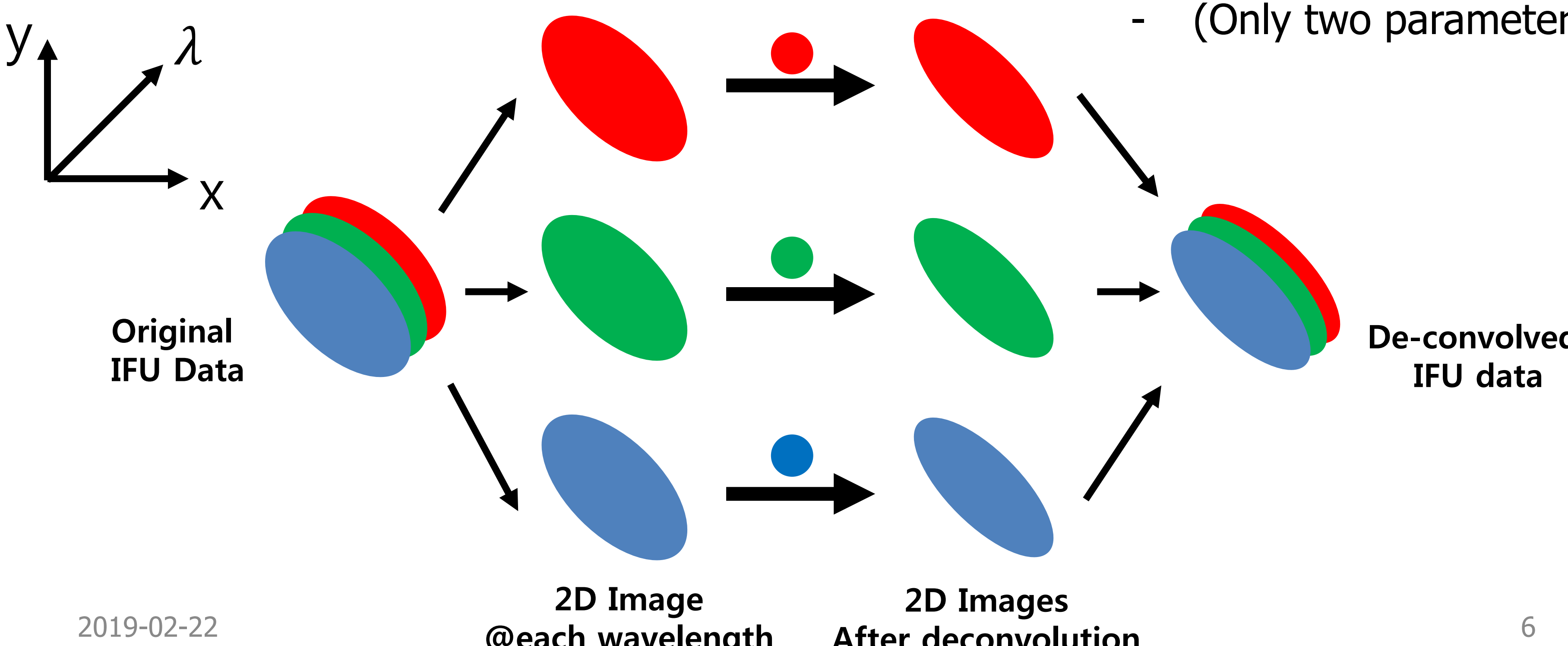
Method: Deconvolution

- **The convolution process can be reversed with a known PSF.**
- In the field of **signal/image processing** many deconvolution algorithms have been developed.
- Few attempts on astronomical IFU data (3D cube) (Bourguignon+11, Soulez+11, Bongard+11, Villeneuve+14).
  - Not fully demonstrate the application on the restoration of the kinematics
  - Or only in limited fashion with weak performance
- Noise amplification

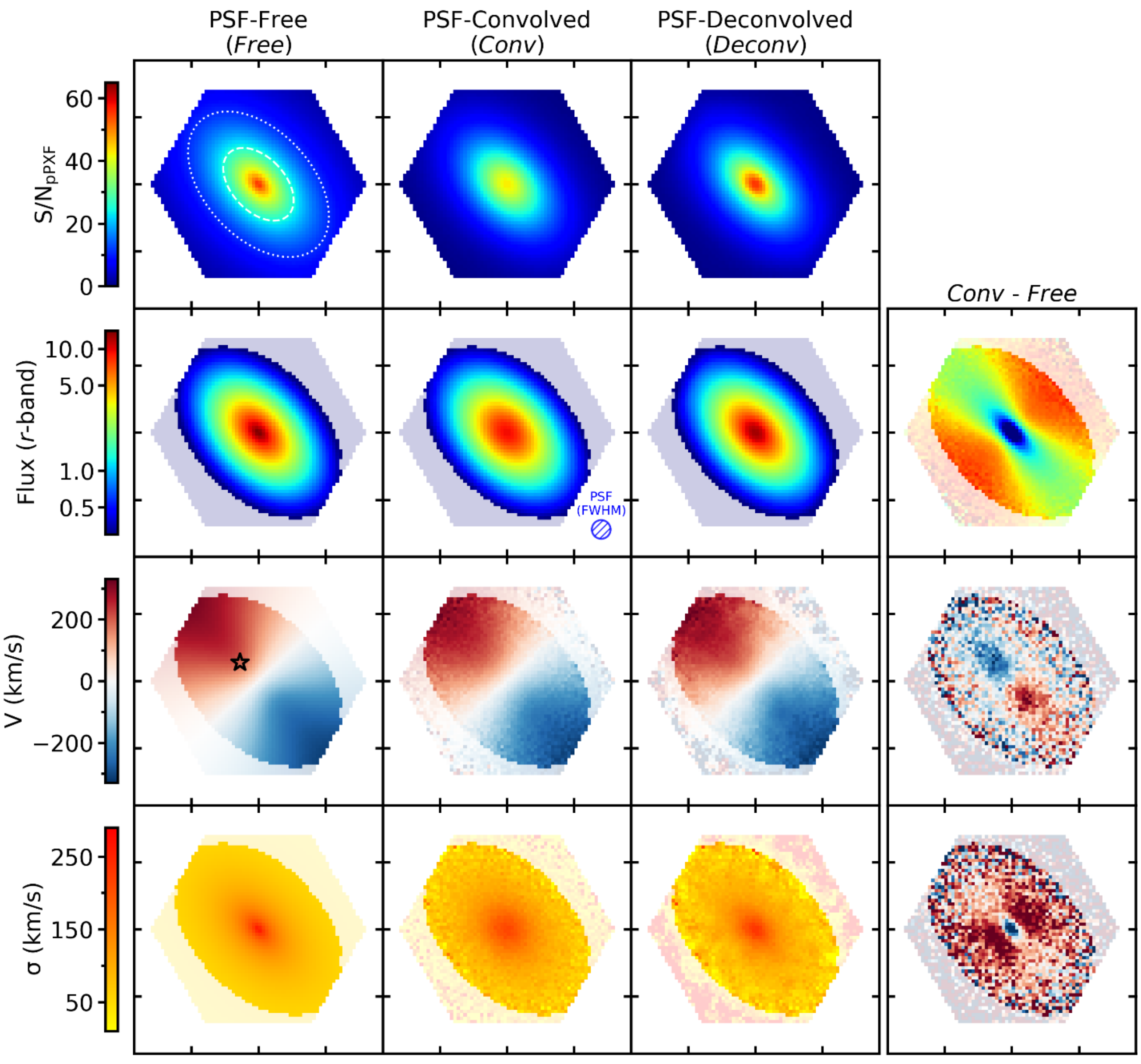
Method: Deconvolution

- Lucy-Richardson algorithm (Richardson 1972, Lucy 1974)
- Iterative process (Shepp and Vardi 1982)
- $u^{(t+1)} = u^{(t)} \cdot \left(\frac{d}{u^{(t)} \otimes p} \otimes p\right)$, $\otimes$: $Convolution$

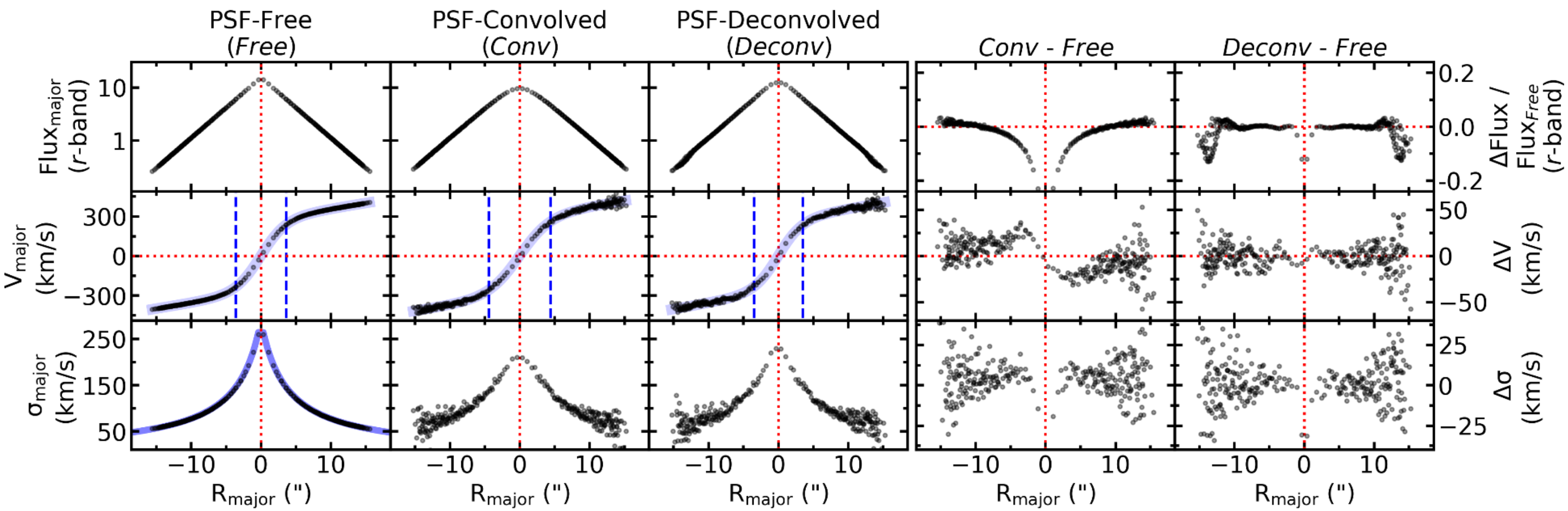
- Number of iteration
- Size of PSF FWHM
- (Only two parameters)



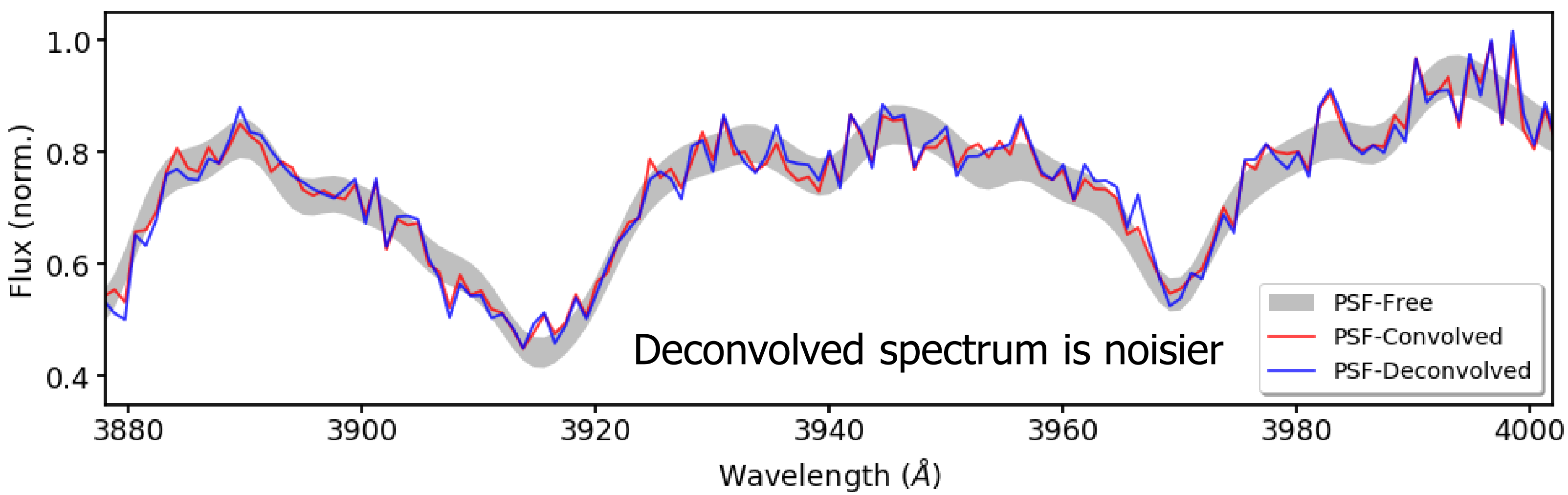
Result: Deconvolution



Result: Deconvolution



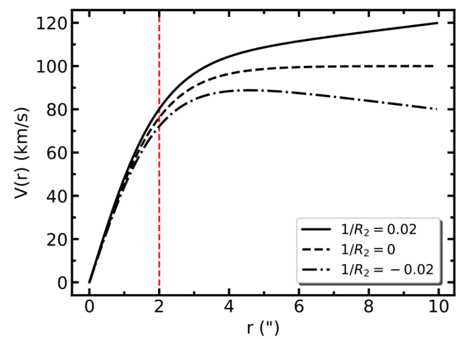
- **Spectrum where V_{Conv}-V_{Free}=-20km/s**



Result: Deconvolution

- Verify method with various mock IFU data (>100,000 mock IFU data)
  - IFU size & field of view
  - Sersic index & effective radius & Geometry
  - S/N @1Re
  - Kinematics (velocity / velocity dispersion)
  - PSF FWHM
- Rotation curve model

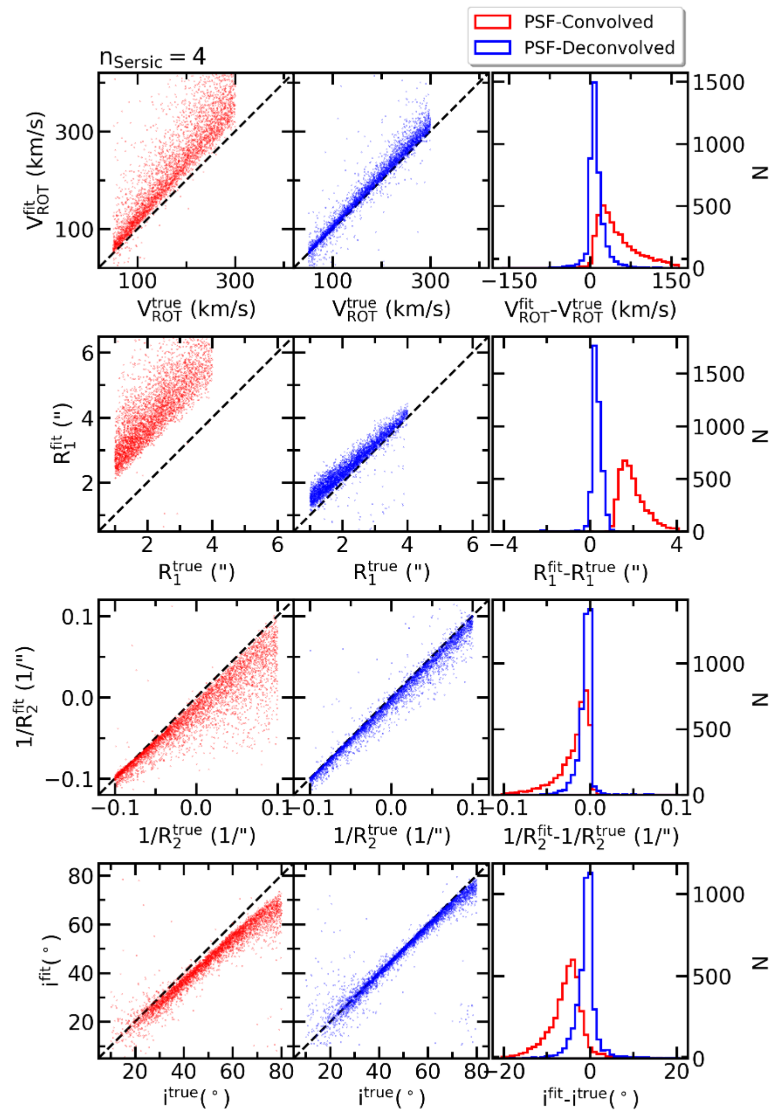
$$V(r) = V_{\rm ROT}\ (\tanh(\frac{r}{R_1}) + \frac{r}{R_2})$$



- Velocity dispersion model

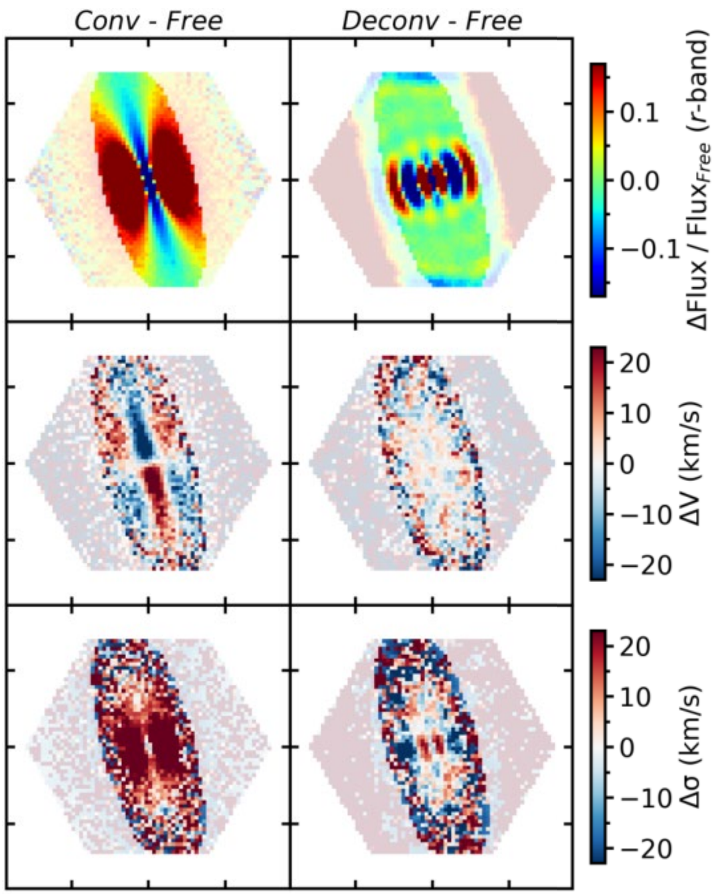
$$\sigma_r = \sigma_0/(r + R_1)$$

- Number of iteration: Checked (N_{iter}=20).
- Sensitivity on FWHM: Checked (±10% fine).



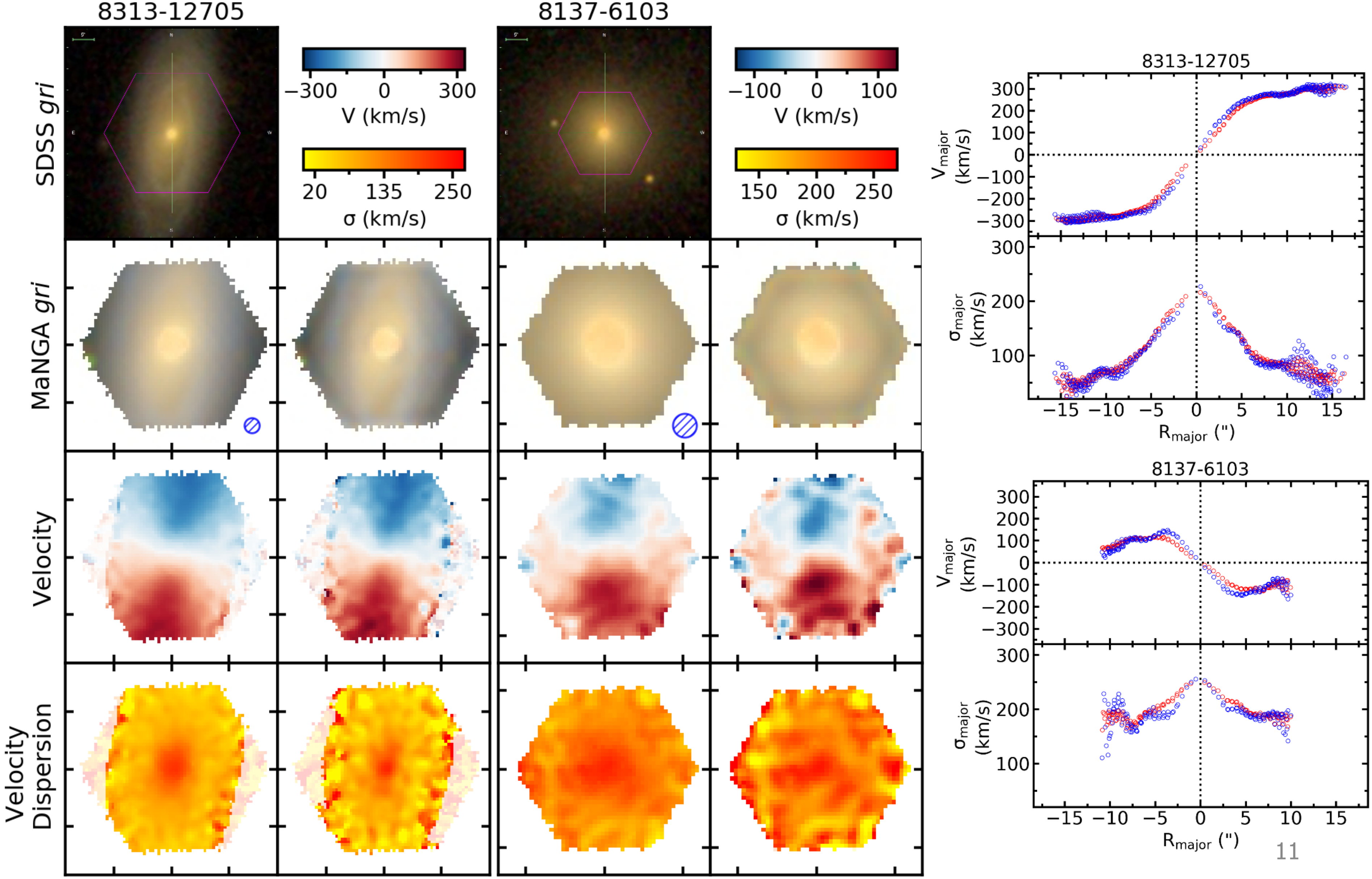
Limitation

- Deconvolution is not a magic wand:
  - Noise remains.
  - Moderate S/N (> 10/spectral resolution element/spaxel @1R_e)
  - Works efficiently when relative PSF size w.r.t. object is small. ($\mathrm{PSF}_{\mathrm{FWHM}}/R_e$ <0.5)
  - Dependency on inclination.
  - Dependency on light distribution.
  - Edge effect presents.
  - Artificial structure presents.



- Still quite effective to beat our enemy (PSF!!).

Application: MaNGA Data

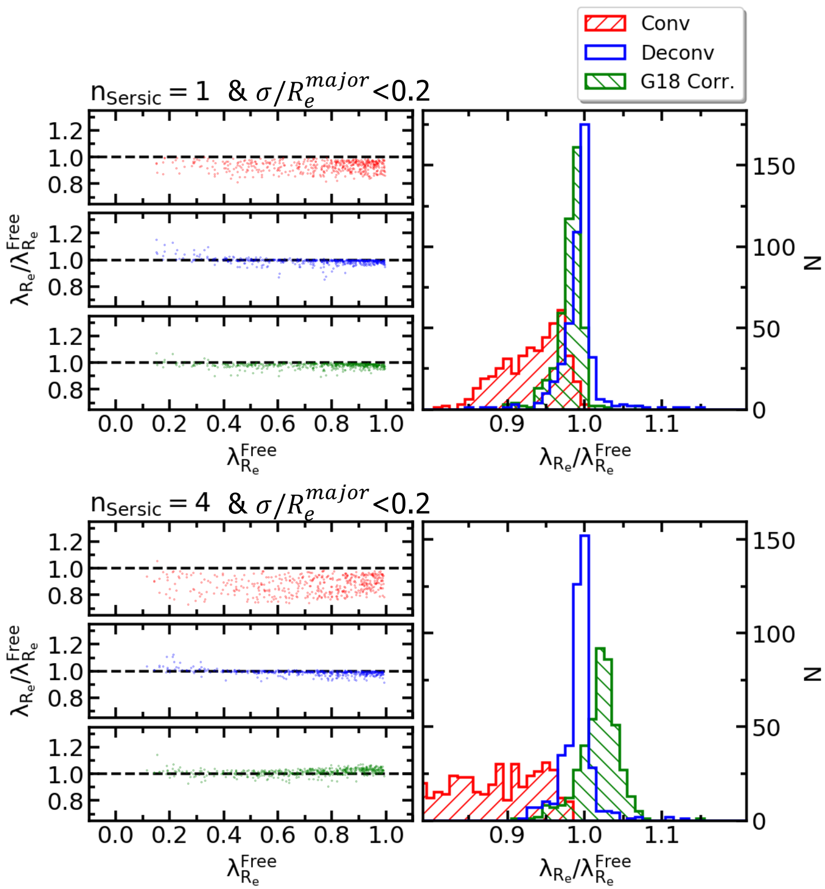


Application: λ_R

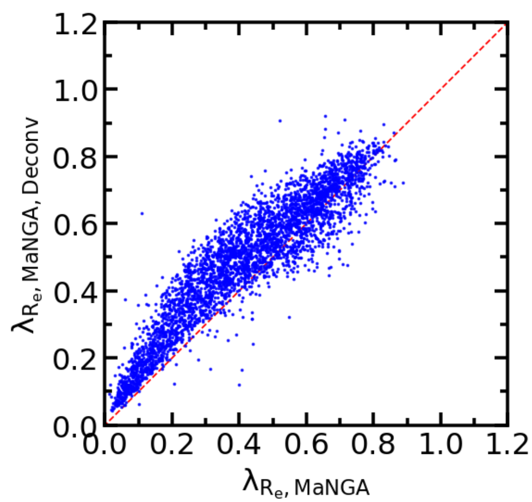
- λ_R: a proxy of the spin parameter λ.

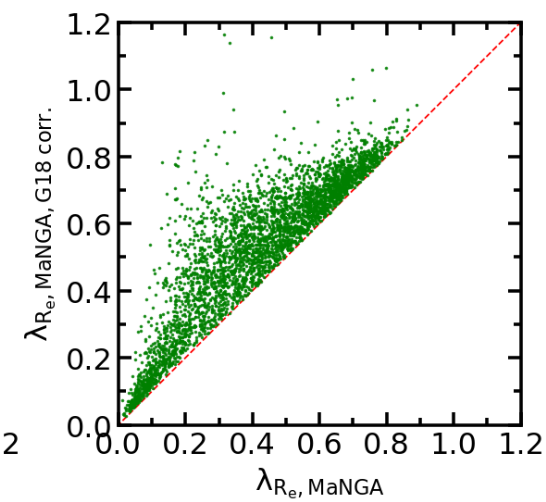
$$\lambda_R \equiv \frac{\langle R|V|\rangle}{\langle R\sqrt{V^2+\sigma^2}\rangle} = \frac{\Sigma_{i=1}^{N} F_i R_i |V_i|}{\Sigma_{i=1}^{N} F_i R_i \sqrt{V_i^2+\sigma_i^2}}$$

(Emsellem+07)



- Graham+18 derives λ_R correction function (depends on n_{Sersic} and σ/R_e^{major}) by using forward modeling.
  - Sometimes it over-corrects the λ_R value.
  - Model-dependent correction.
- Deconvolution can be a solution for this.





Future Applications

- Other current & future IFU data (MUSE, CALIFA, SAMI, DOTIFS…)
- Stellar/gas - kinematic/dynamical modeling
- Spectral indices distribution
- Stellar population distribution

Summary

- We applied Lucy-Richardson deconvolution algorithm to an IFU data.
- Deconvolution is working efficiently, with only two parameters ($N_{iter.}$, PSF_{FWHM})
- Experiments on the large number of mock IFU data show that the deconvolution is working and it can be used to recover the true velocity and velocity distribution.
- Application on actual IFU data (SDSS-IV MaNGA) is presented.
- Deconvolution can effectively correct the λ_R value.