Bright stars in the Rubin Science Pipelines and other PSF-related fun

Morgan Schmitz (Observatoire Côte d'Azur & Université Côte d'Azur) and the DESC PSF working group

Rubin LSST-France

November 24$^{\text{th}}$, 2021

- Just joined Lagrange (Observatoire Côte d'Azur, Nice) as an assistant professor (maître de conférences)
- Formerly a DM-DRP person (Princeton)
- DESC PSF co-convener since last summer

What a PSF is...

- Images from our telescopes do not appear exactly as they should; they are slightly blurred
- This is due to several different effects: optical effects (distortion); imperfect optics; atmospheric effects; instrument jitter...
- This can be thought of as a convolutional effect:

$$I_{\text{obs}} = I_{\text{real}} * H \tag{1}$$

- H is called the *Point Spread Function* (PSF)

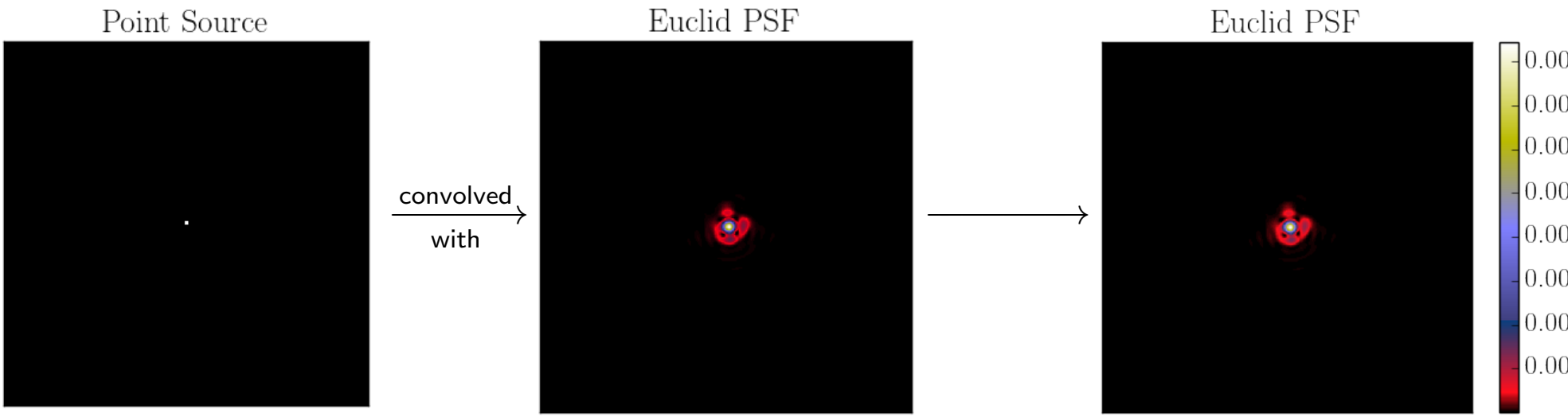
What a PSF is...

... and why you should care

- Many science cases require knowledge of the PSF
- In weak lensing, the main observable is the *shape* of galaxies... which is altered by the PSF!

Point Spread Function

Star



Point Spread Function

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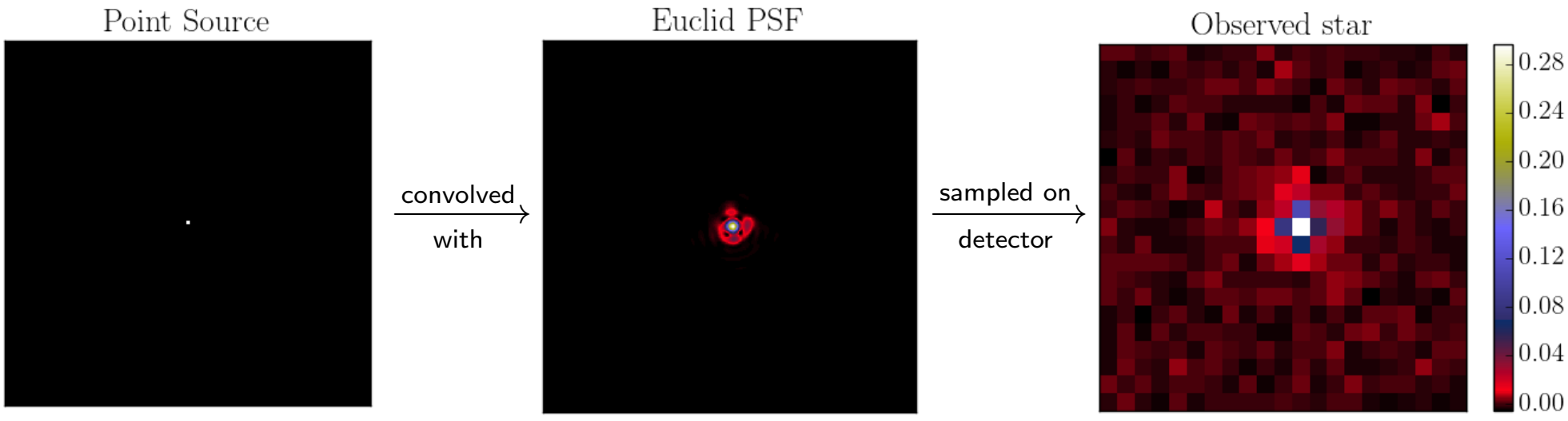

Point Spread Function

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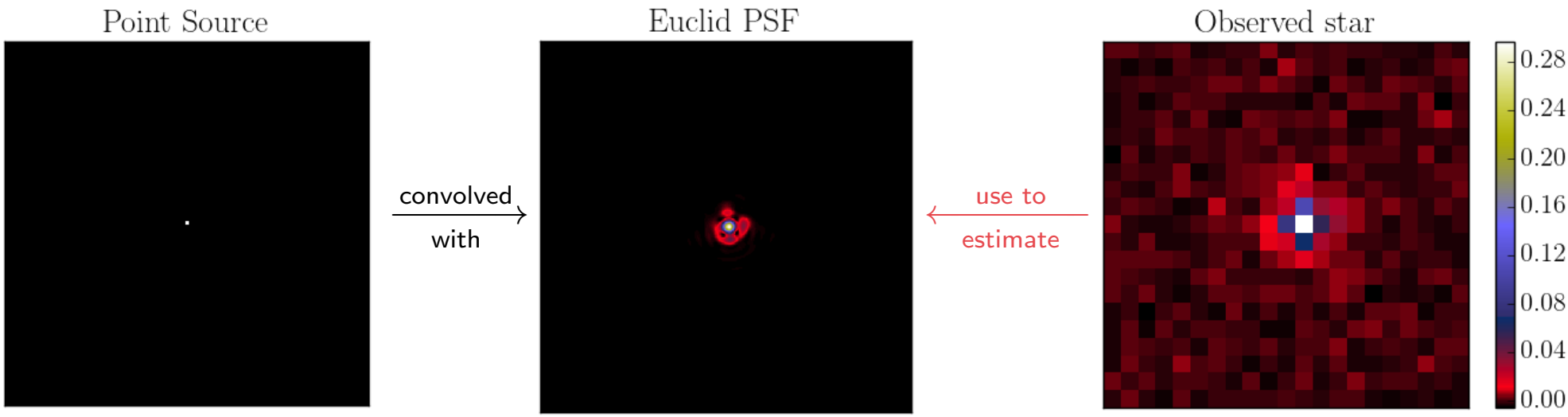


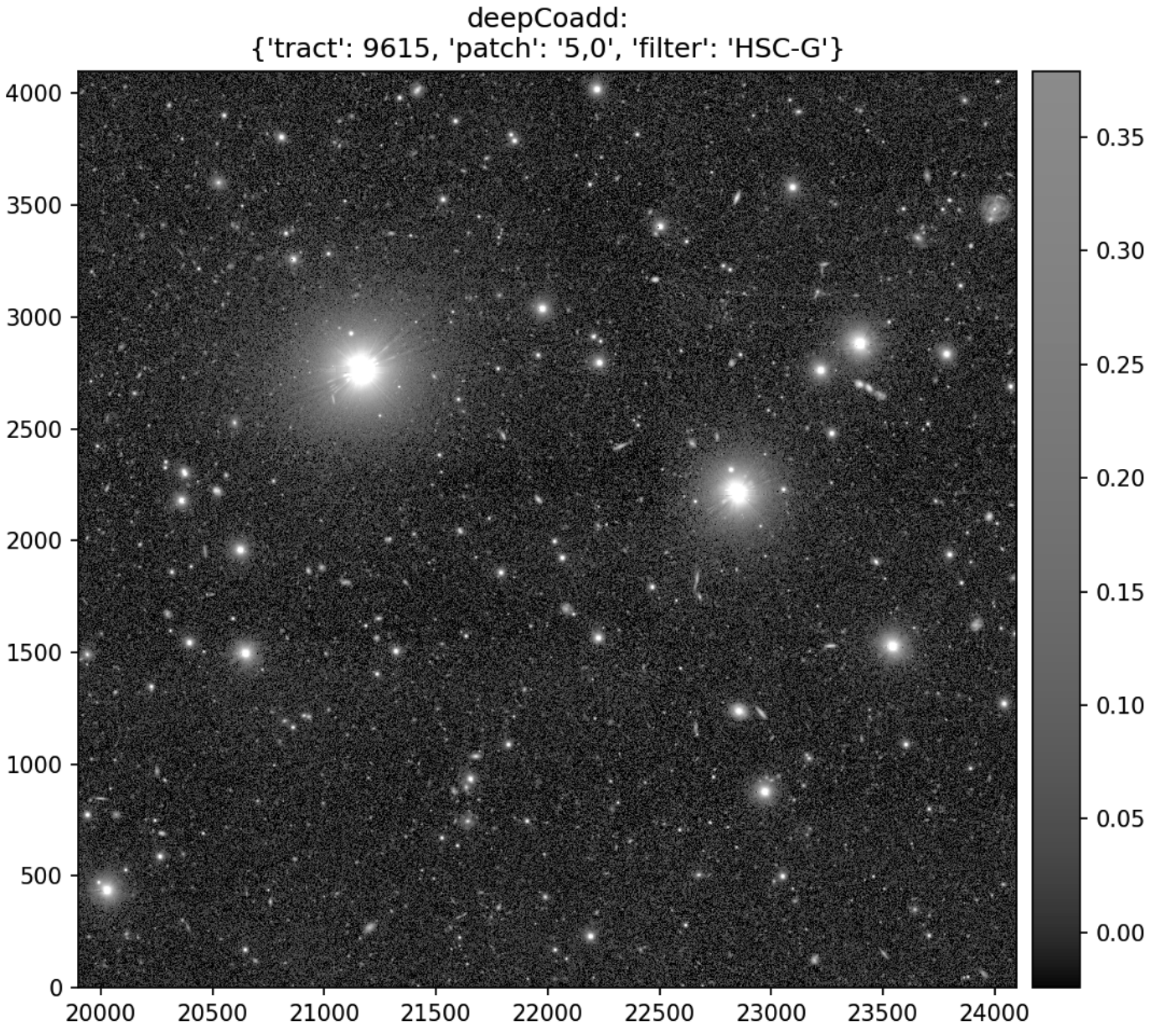
Outline of this talk

- Plans for bright star handling in the Rubin Science Pipelines
- Quick overview of the DESC PSF working group, our current activities, and how they fit within the greater Rubin/LSST

PART I OF II:

Bright stars in the Rubin Science Pipelines

(Very) bright stars in wide-field survey



Bright star halos and extended PSF

- Building an extended PSF model boils down to stacking a large number of very bright stars (Infante-Sainz et al., 2019)...
- ... which still requires solving a *large* number of technical issues:
  - Selecting bright stars
  - Normalizing them
  - Picking valid pixels around each star
  - Measuring extended PSF model quality
- Once the extended PSF model is of sufficient quality, bright stars can be *subtracted* to greatly improve useful survey area
- And make new science cases possible!

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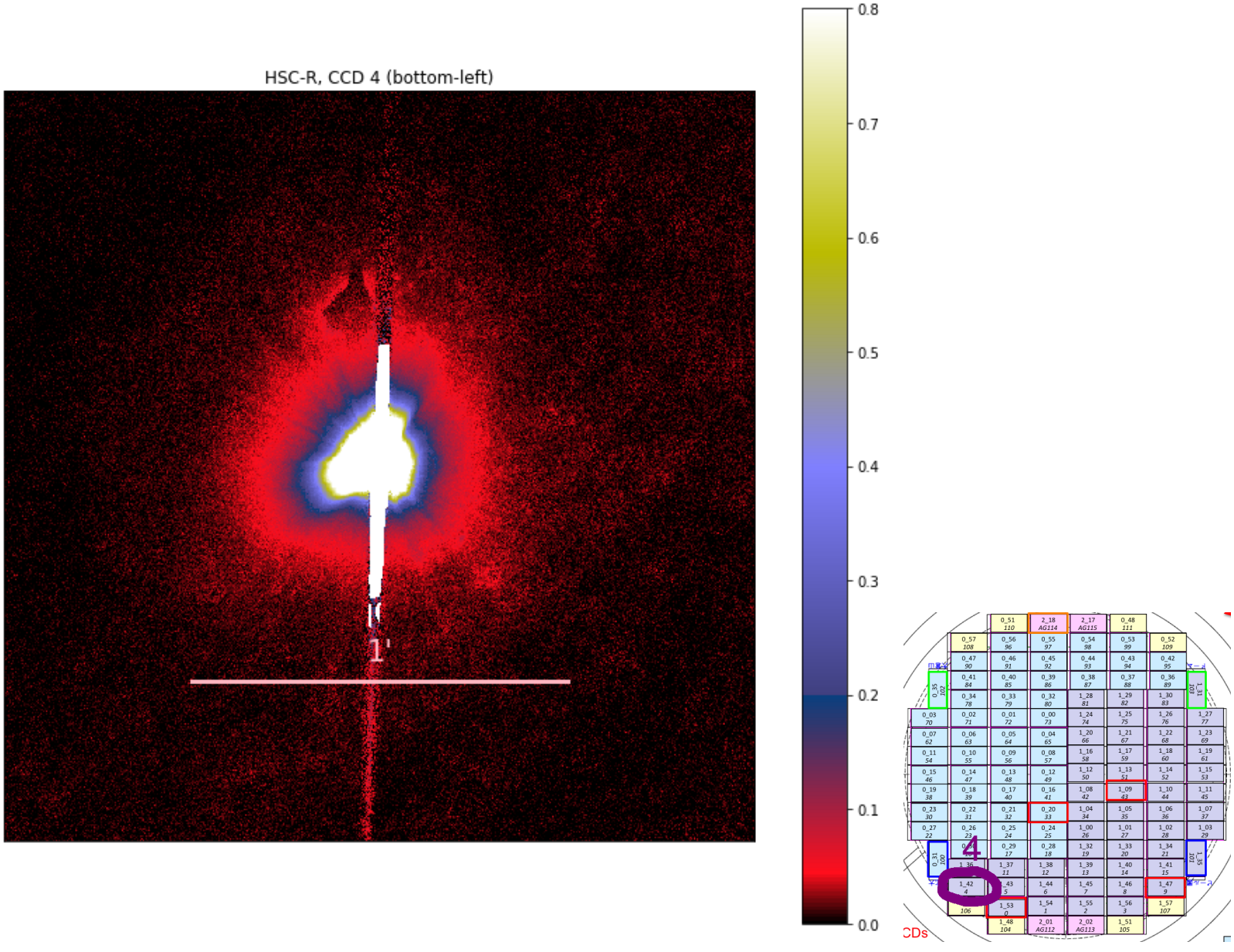
Bright star processing in the Rubin Obs.

- First version of every step in bright star processing (extraction, stacking, subtraction) available in the Science Pipelines (not yet part of regular processing)
- Next steps:
  - Testing at scale on HSC
  - Empirical determination of the main sources of variation in the extended PSF!
  - Example: spatial variations of the HSC extended PSF

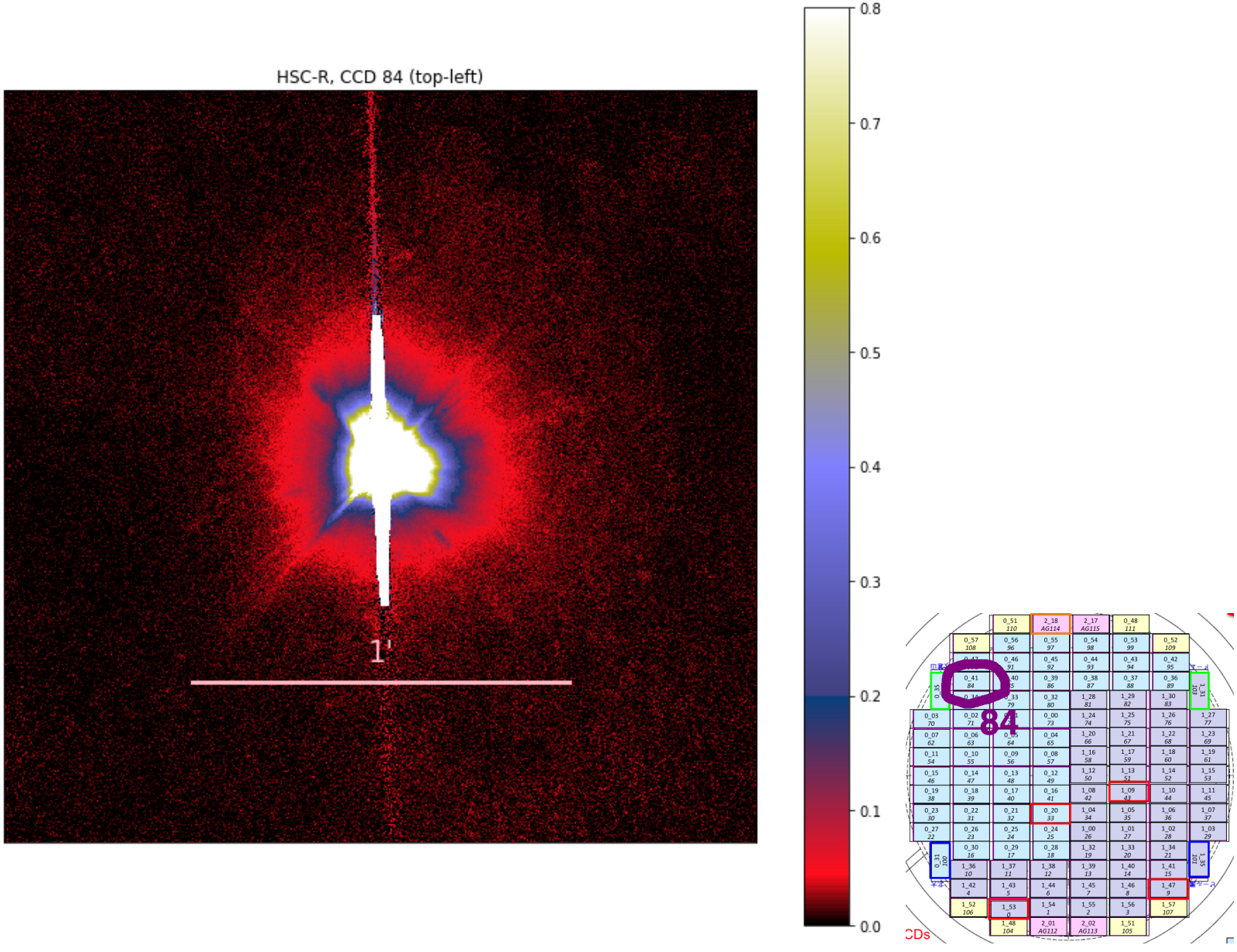
HSC R extended PSF

Per CCD, "bottom-left"



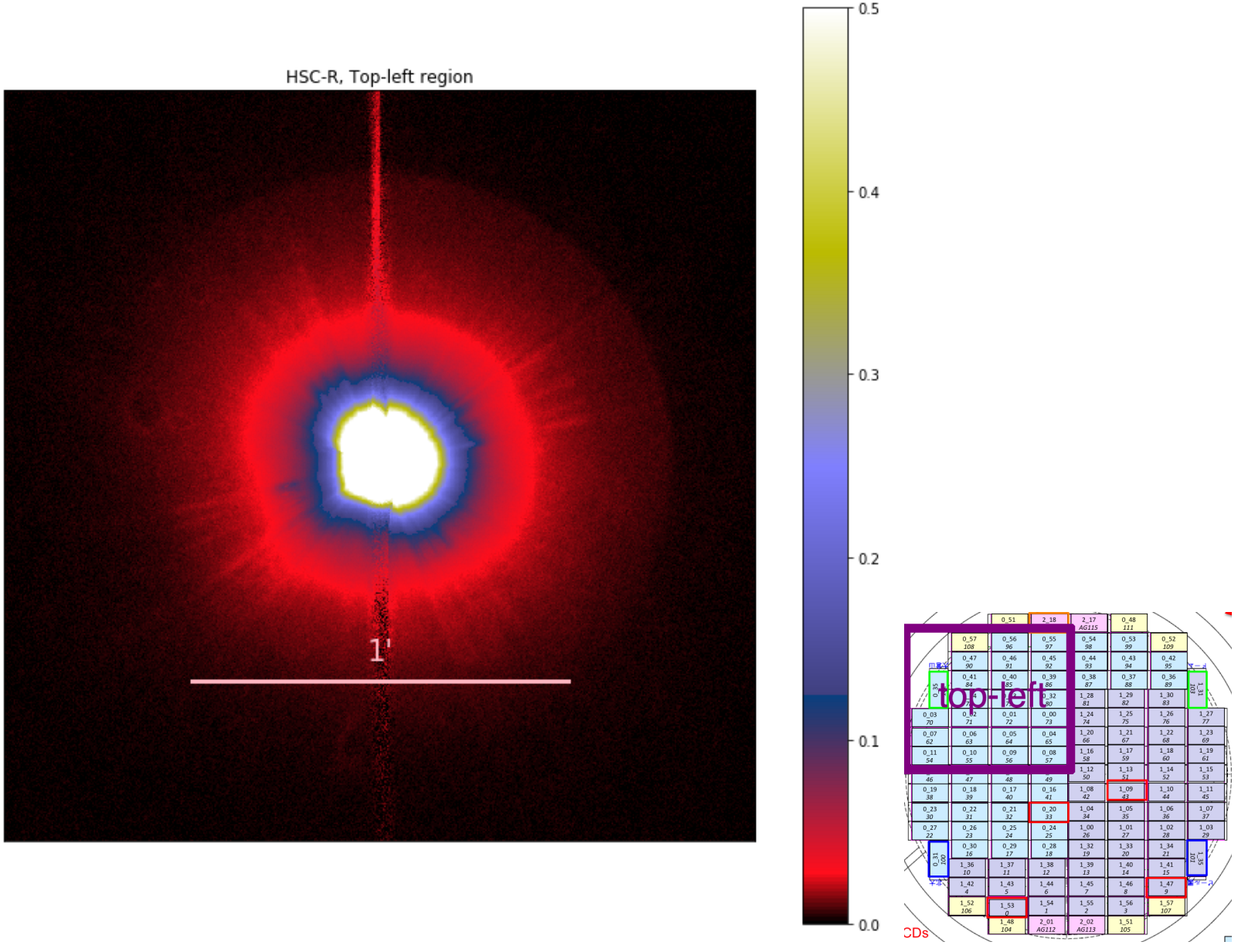
HSC R extended PSF

Per CCD, “top-left”



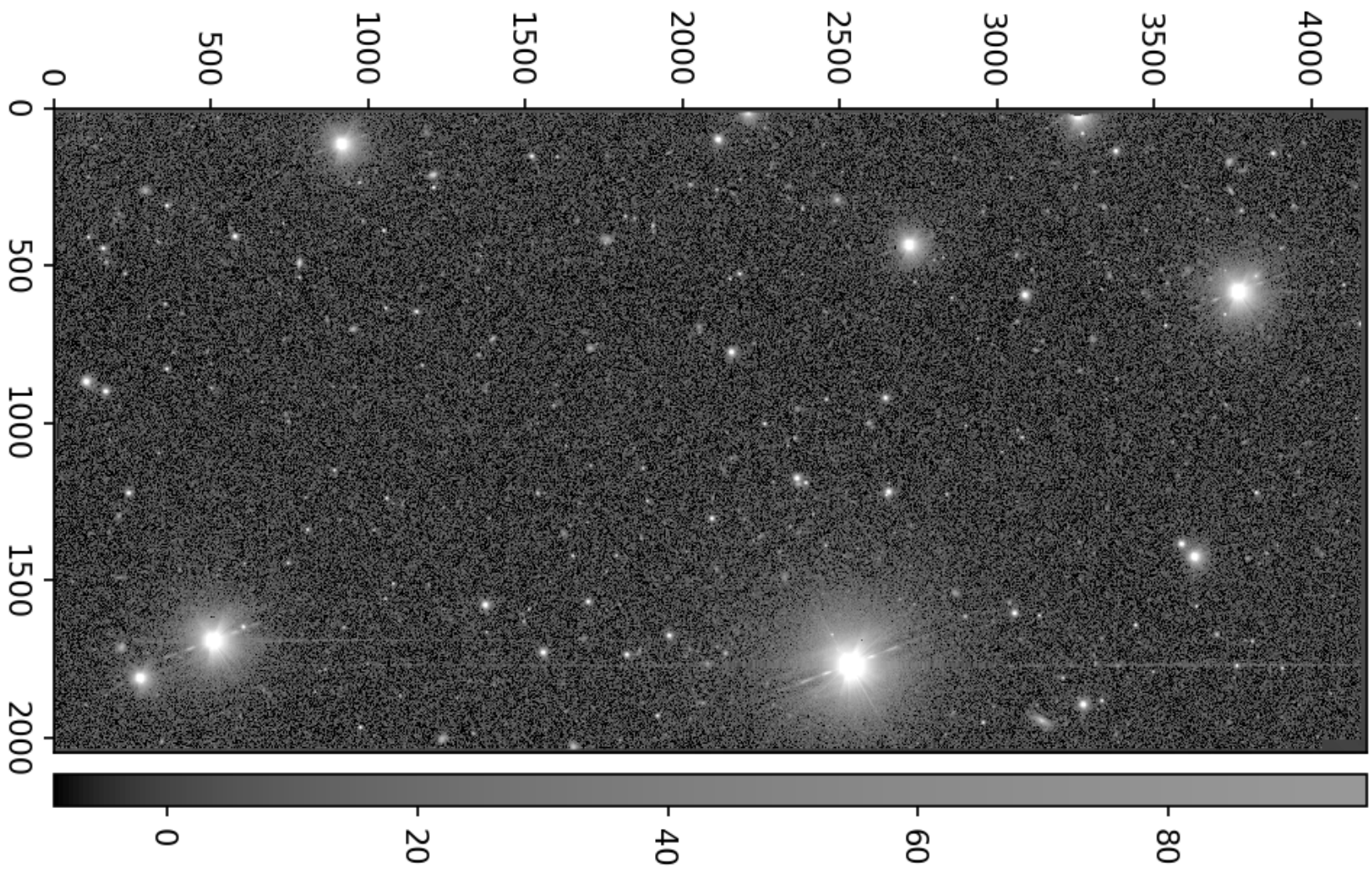
HSC R extended PSF

Per region, “top-left”



Bright star subtraction

"Scattered light exposure" example: HSC G



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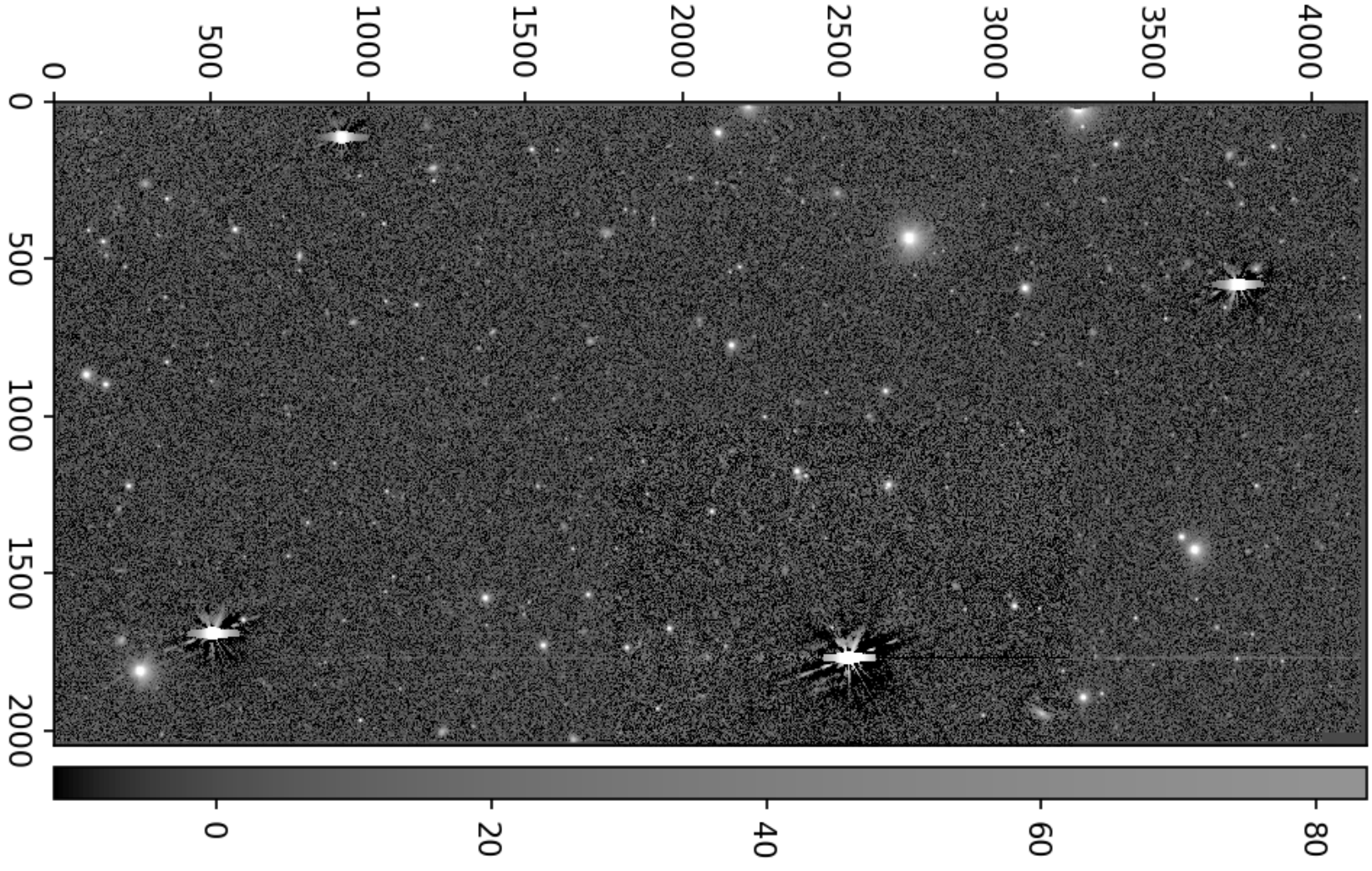

PART II OF II:

The DESC PSF working group

PSF modelling for Rubin Obs. data

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PSF modelling for Rubin Obs. data

Results on HSC data

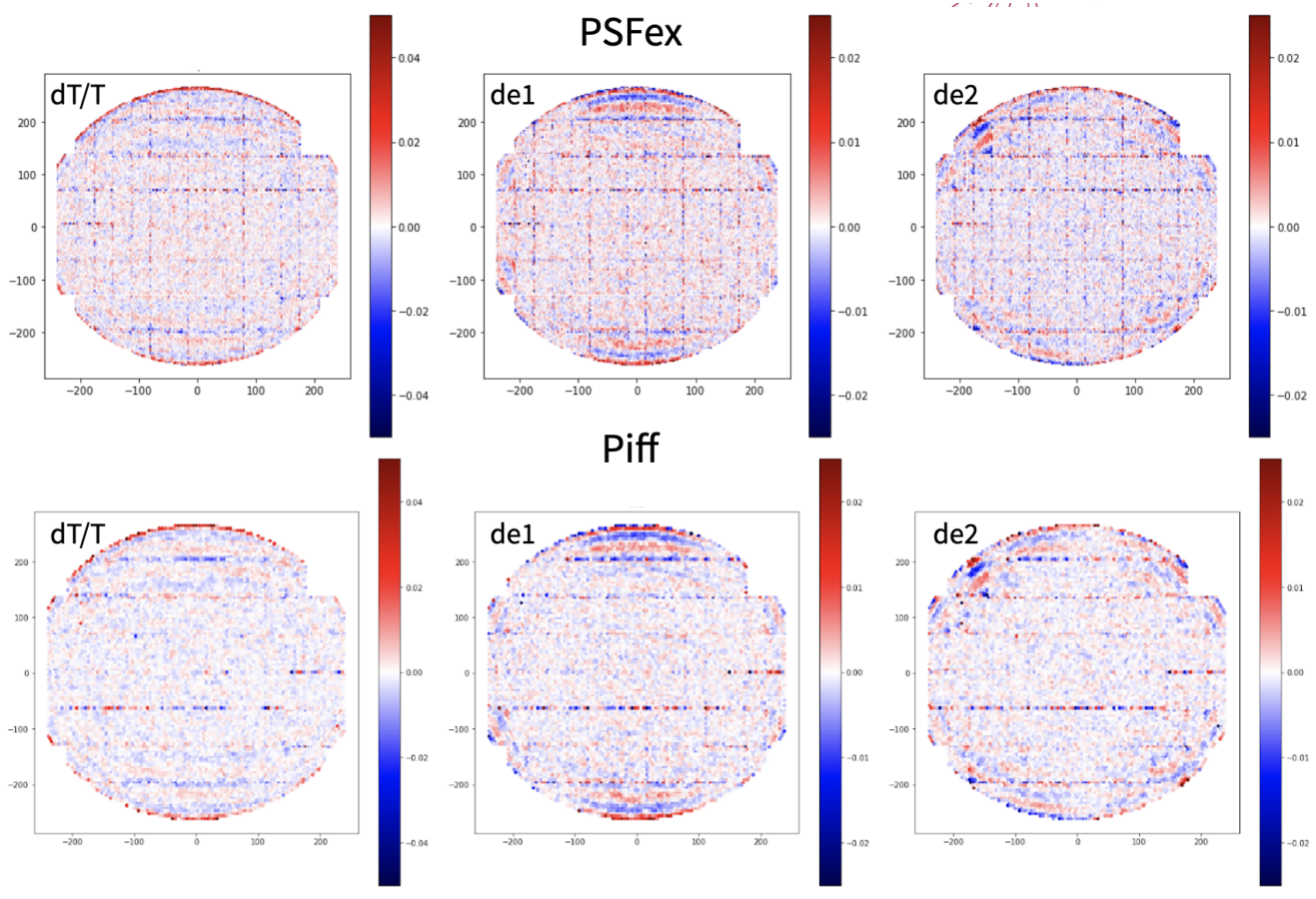


Figure credit: J. Meyers

PSF error propagation

Paulin-Henriksson formalism

- Paulin-Henriksson et al., 2008 give analytical expression for impact of PSF errors on measured galaxy shapes:

$$\hat{e}_i = e_i \left(1 + \frac{\delta(R^2_{\rm PSF})}{R^2_{\rm gal}}\right) - \left(\frac{R^2_{\rm PSF}}{R^2_{\rm gal}} \delta e_i^{\rm PSF} + \frac{\delta(R^2_{\rm PSF})}{R^2_{\rm gal}} e_i^{\rm PSF}\right) \tag{2}$$

- Where $\delta(R^2_{\rm PSF}), \delta e_i^{\rm PSF}$ are the error in size and ellipticity of the PSF model: 2nd order quantities
- Prelude (Schmitz et al., 2020): does this formalism hold for Euclid?

PSF error propagation

Results

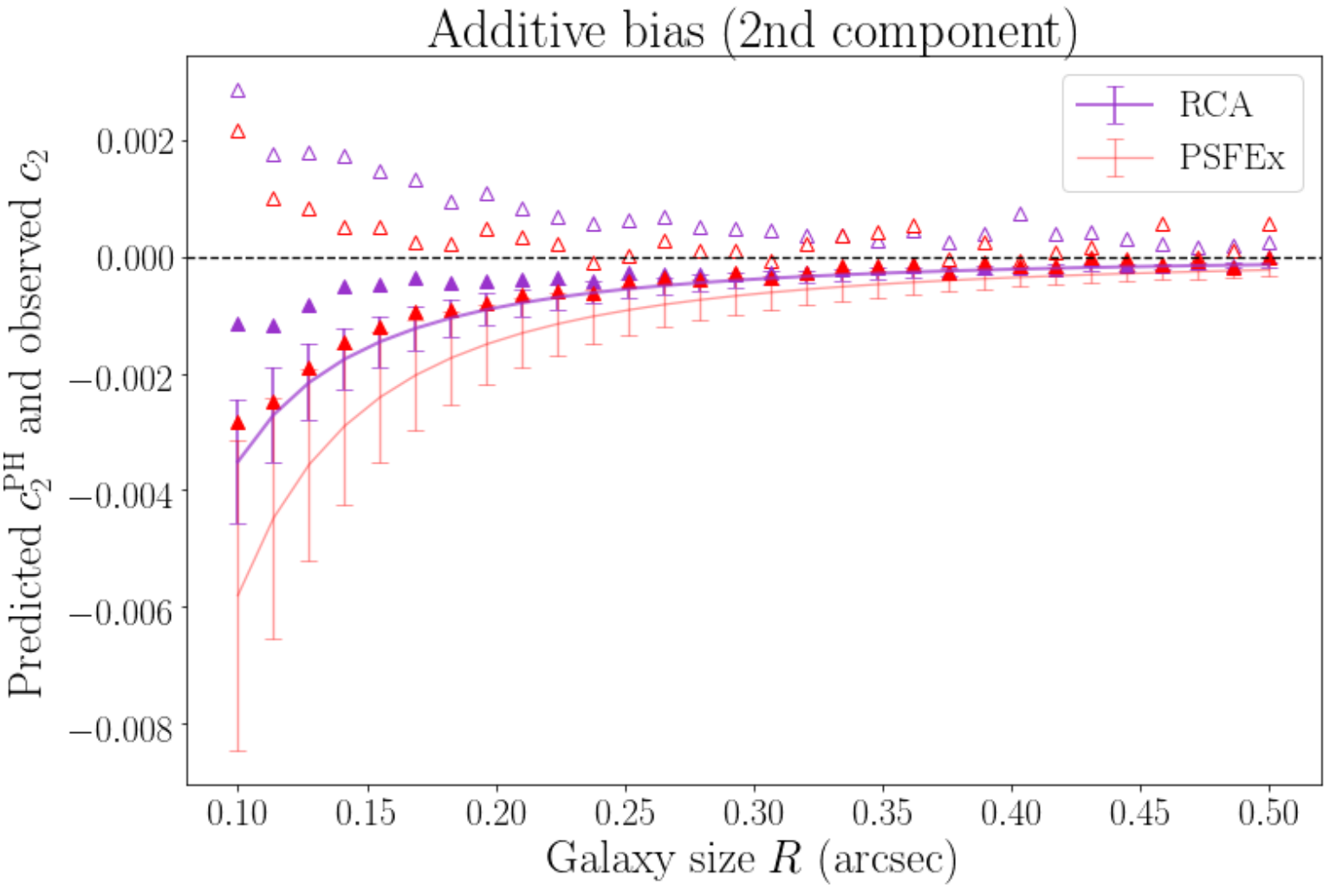
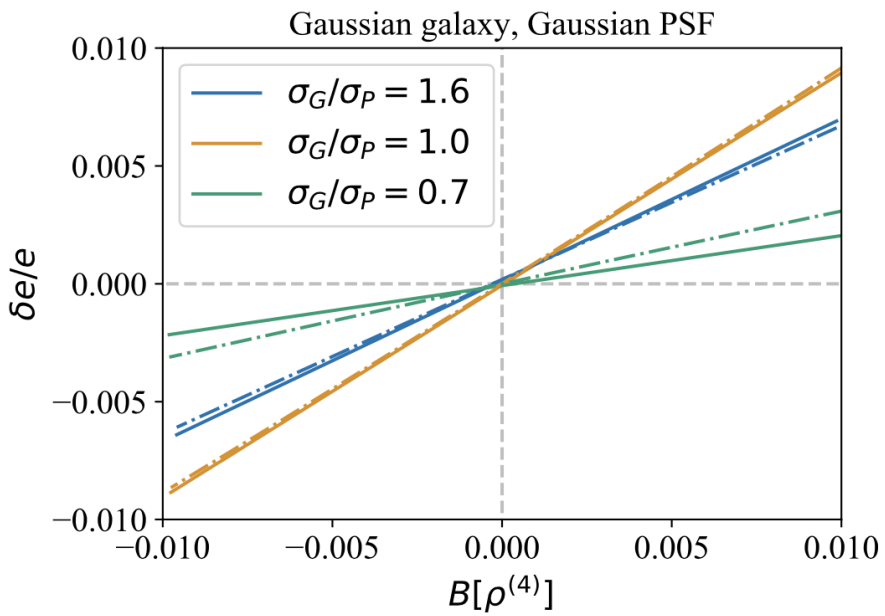


Figure: Euclid PSFs

PSF error propagation

Tests on ground-based surveys

- Zhang & Mandelbaum, 2021:
  - Use radial kurtosis as example higher-order moment quantity
  - Study induced multiplicative shear bias
  - Redshift-dependent
  - ∼0.05% induced shear bias for HSC
  - Probably okay for Stage III surveys; won't be for Y10 LSST analysis



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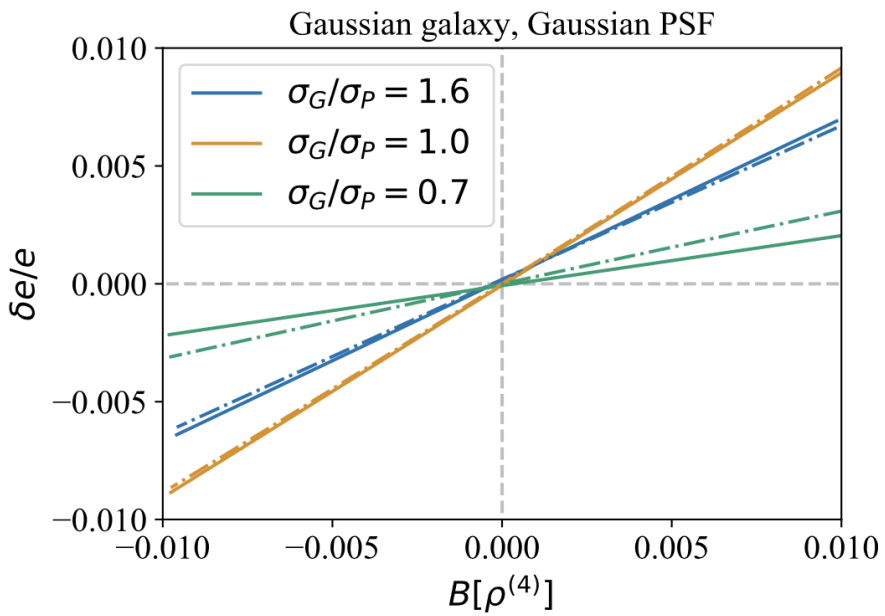

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PSF error propagation

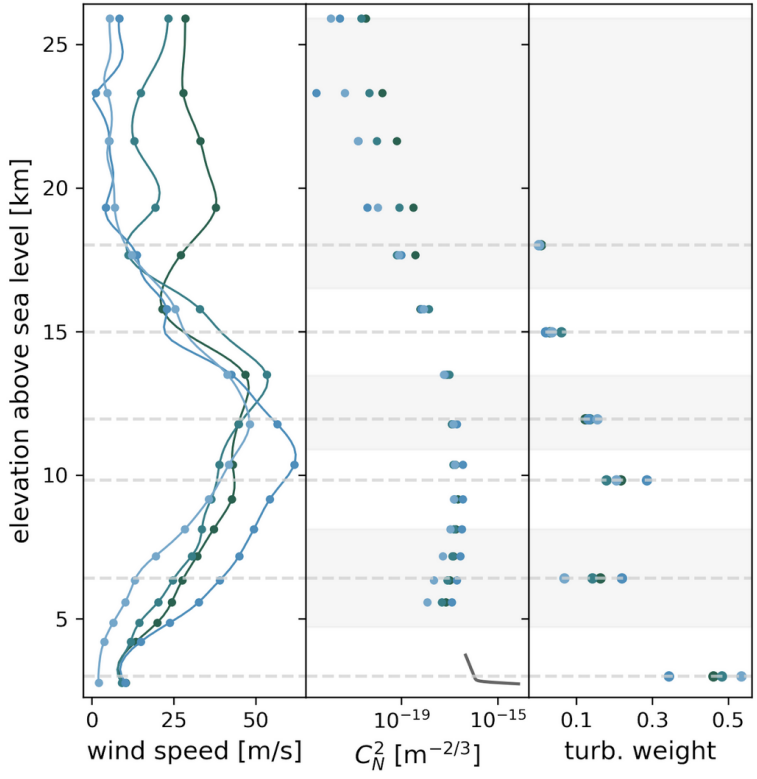
Next steps (project lead: **T. Zhang**, CMU)

- Quantify the impact of each higher-order moment separately
- Propagate it to cosmology
- Try analytical predictions?
- Come up with requirements

PSF weather station

Predicting atmospheric parameters (project lead: **C.-A. Hébert**, Stanford)

- Software package to generate realistic atmospheric parameters for PSF simulation
- Relies on variety of inputs: global weather forecast, telemetry from observatory, different models (numerical and empirical)
- Can be used to generate realistic PSFs for various studies (e.g. astrometric residuals, impact of correlated atmospheric parameters on cosmology)



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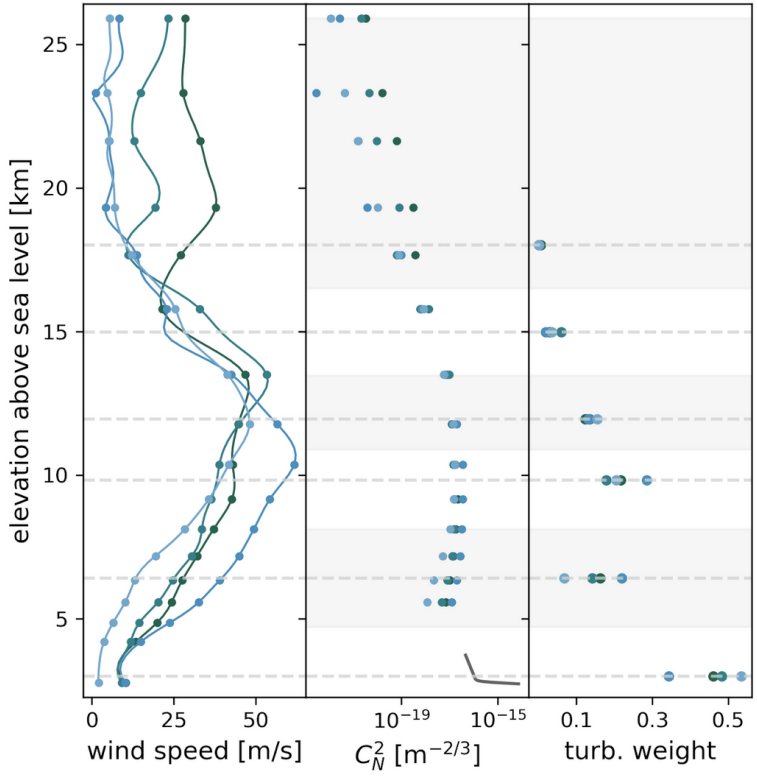

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Other PSF WG activities

- Studying time variation of atmospheric parameters (C.-A. Hébert)
- LOI submitted for PSF characterization during commissioning (M. Jarvis)
- Dormant PSFxSupernovae project on chromatic effects?!

Come say hi!

- #desc-psf on Slack (LSSTC)
- Confluence page
- Telecon every other Thursday, 5pm Paris time
- Or hit me or Arun Kannawadi up anytime!

Thank you!

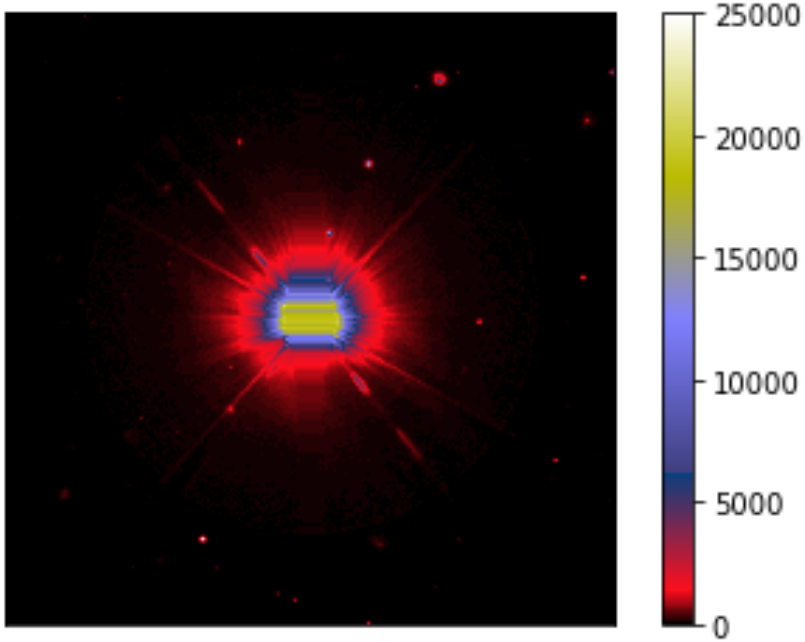
APPENDIX

Annular flux

- Stacking step will require normalizing each star in the same way, but center of each object is saturated and potentially affected by ghosts

  → cannot use circular aperture flux measurements

- Compute *AnnularApertureFlux*, far enough away from center:



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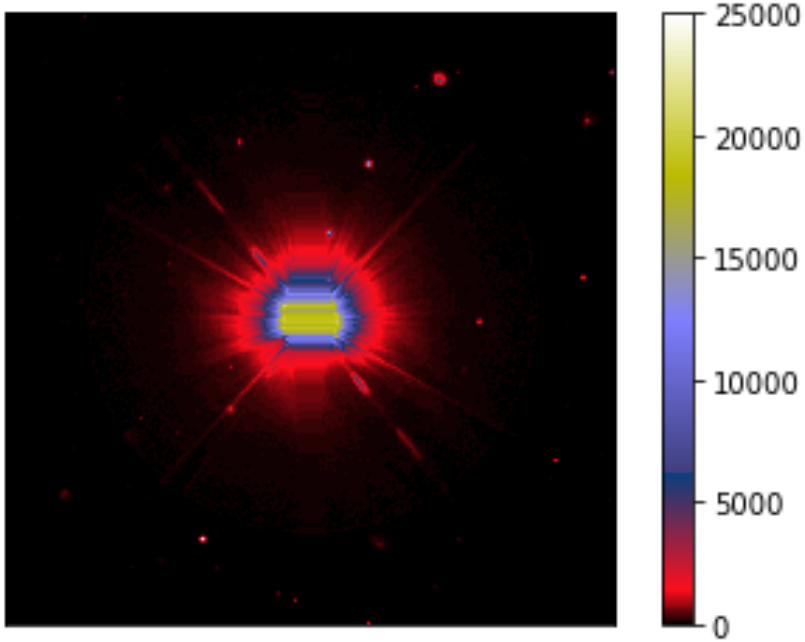

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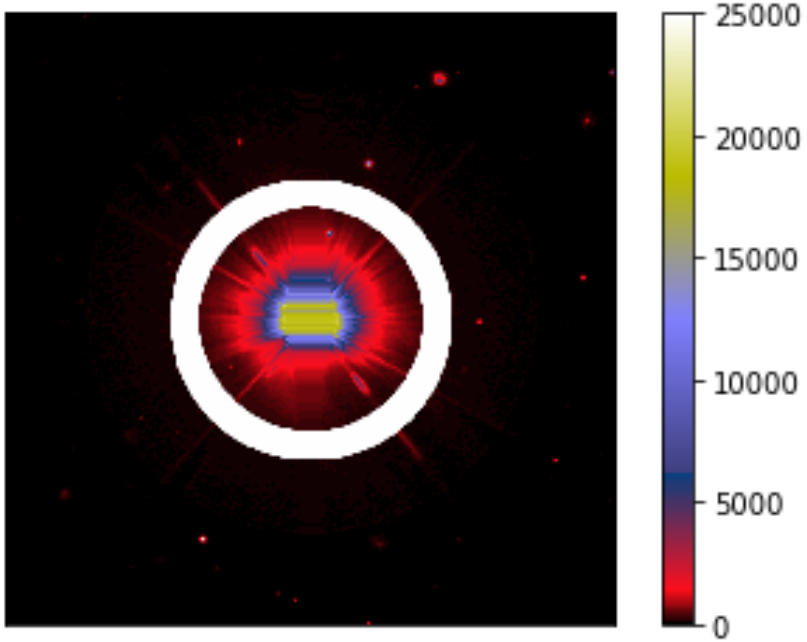
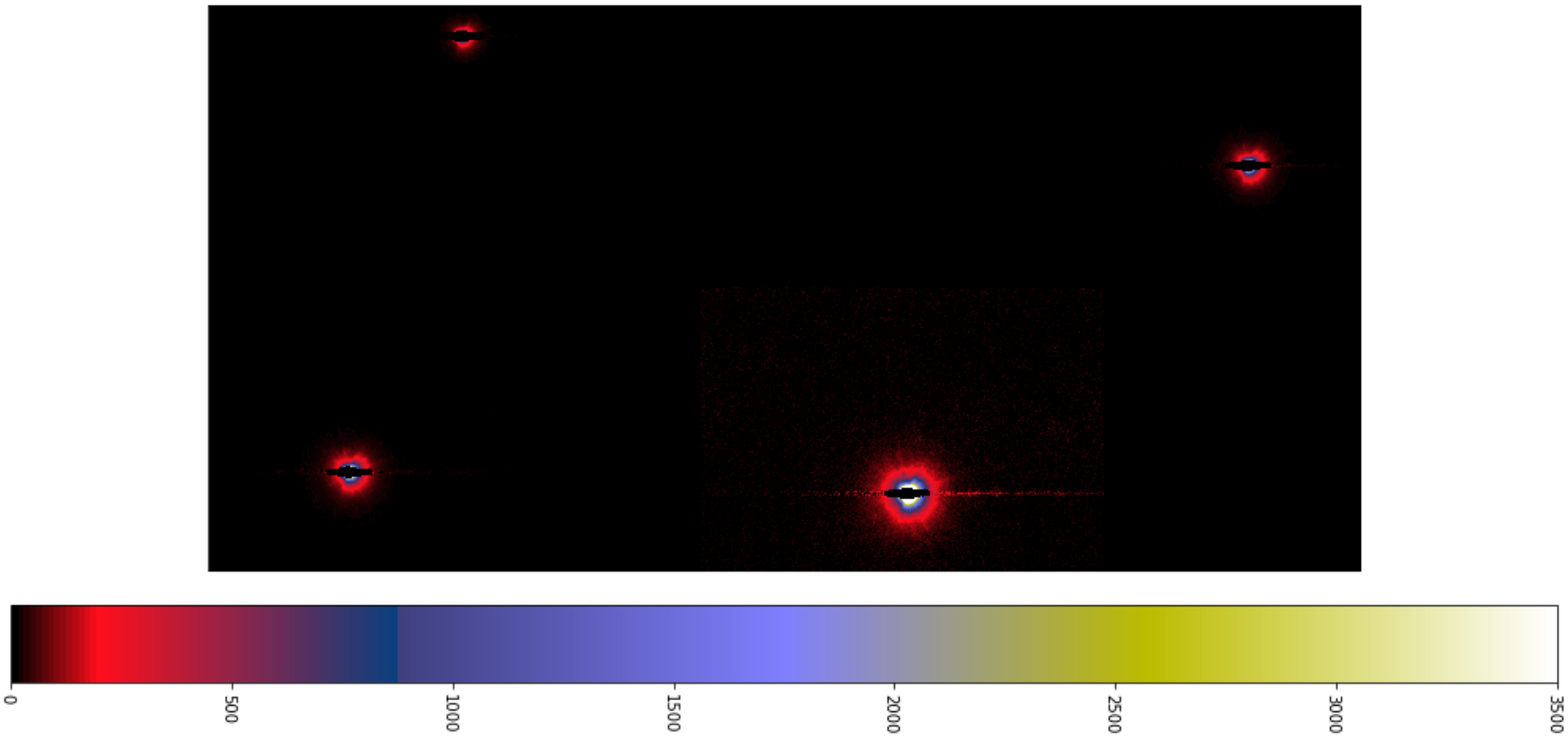


Bright star subtraction

“Scattered light exposure” example: HSC G



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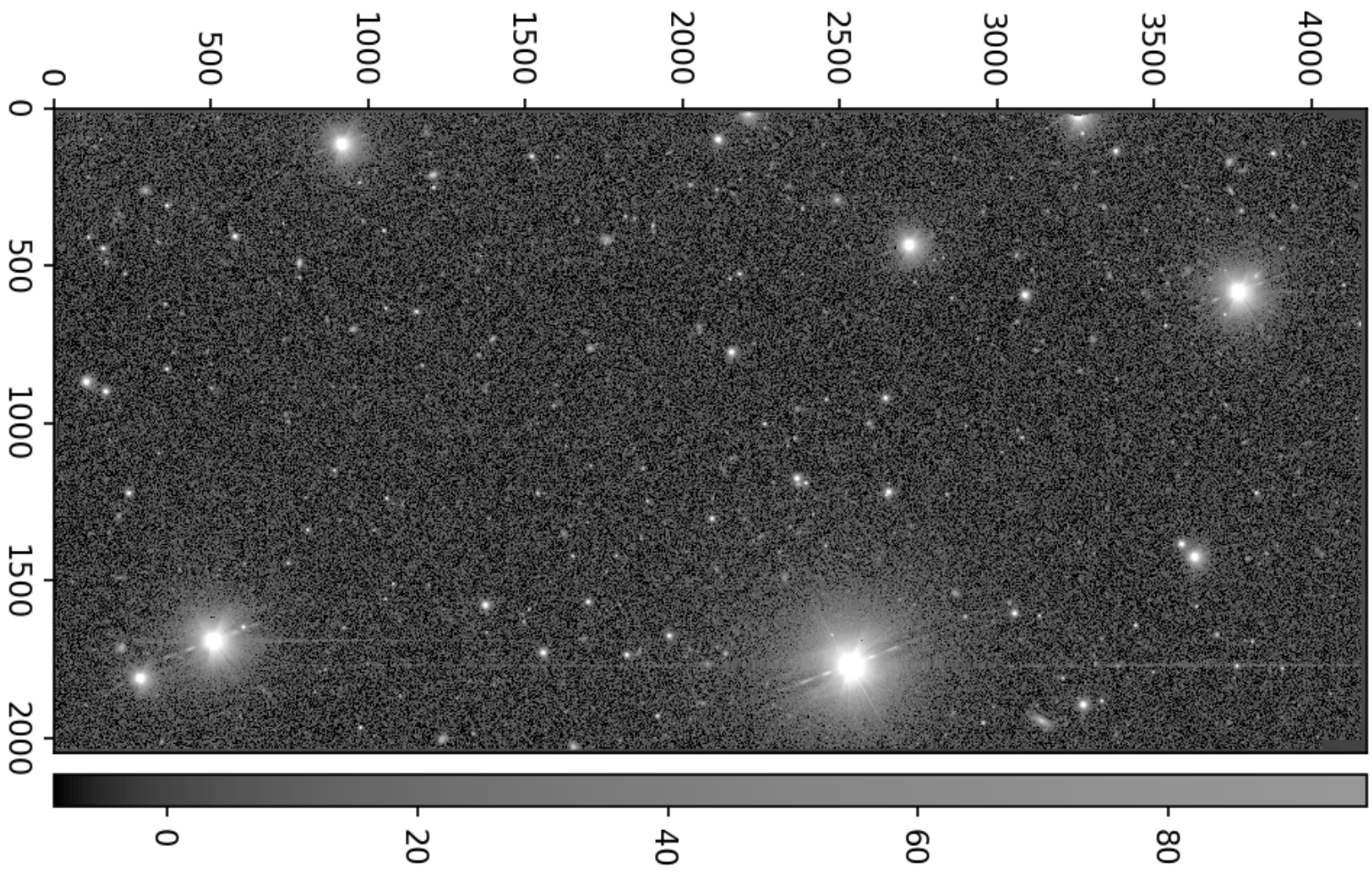

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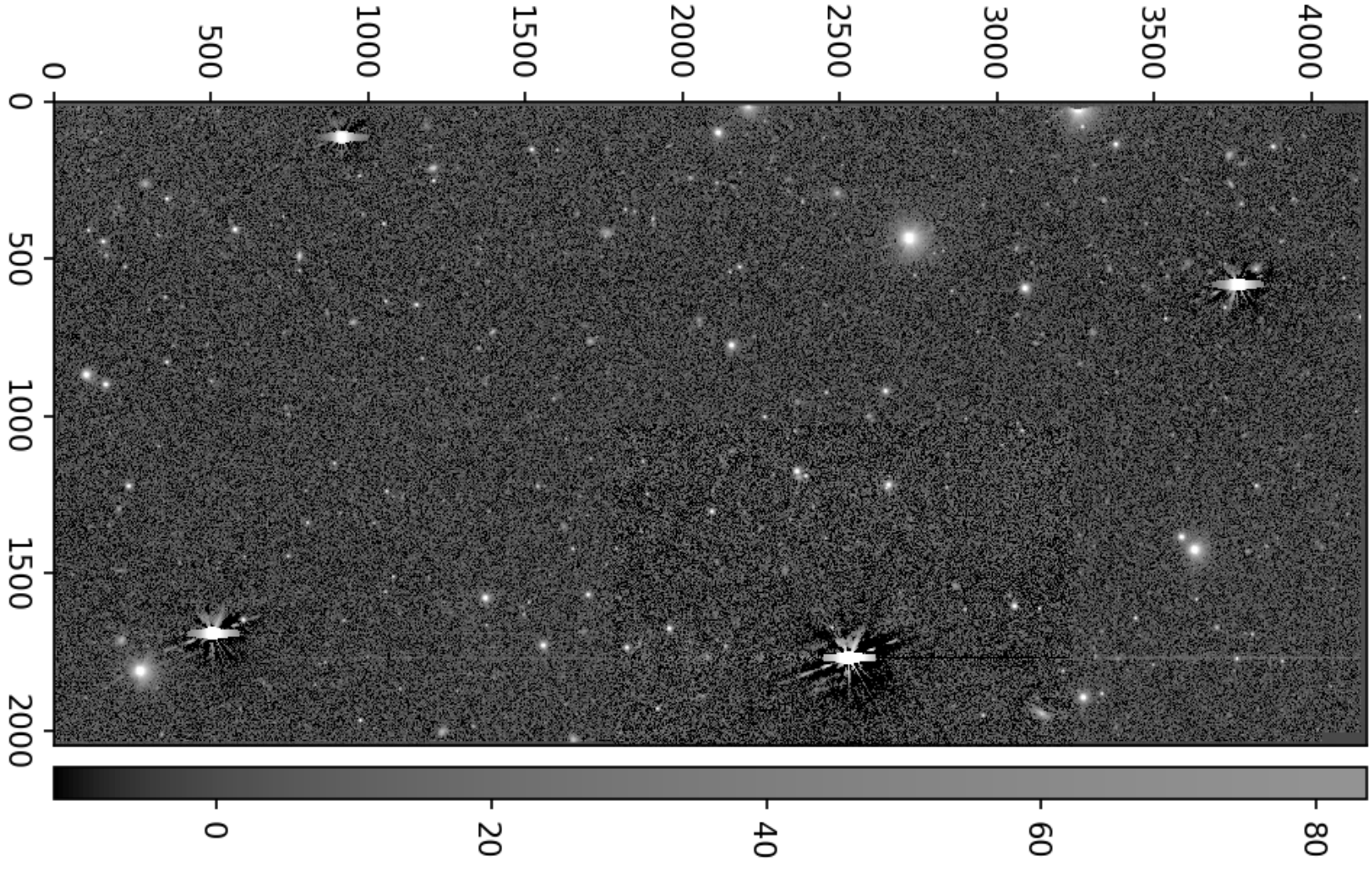
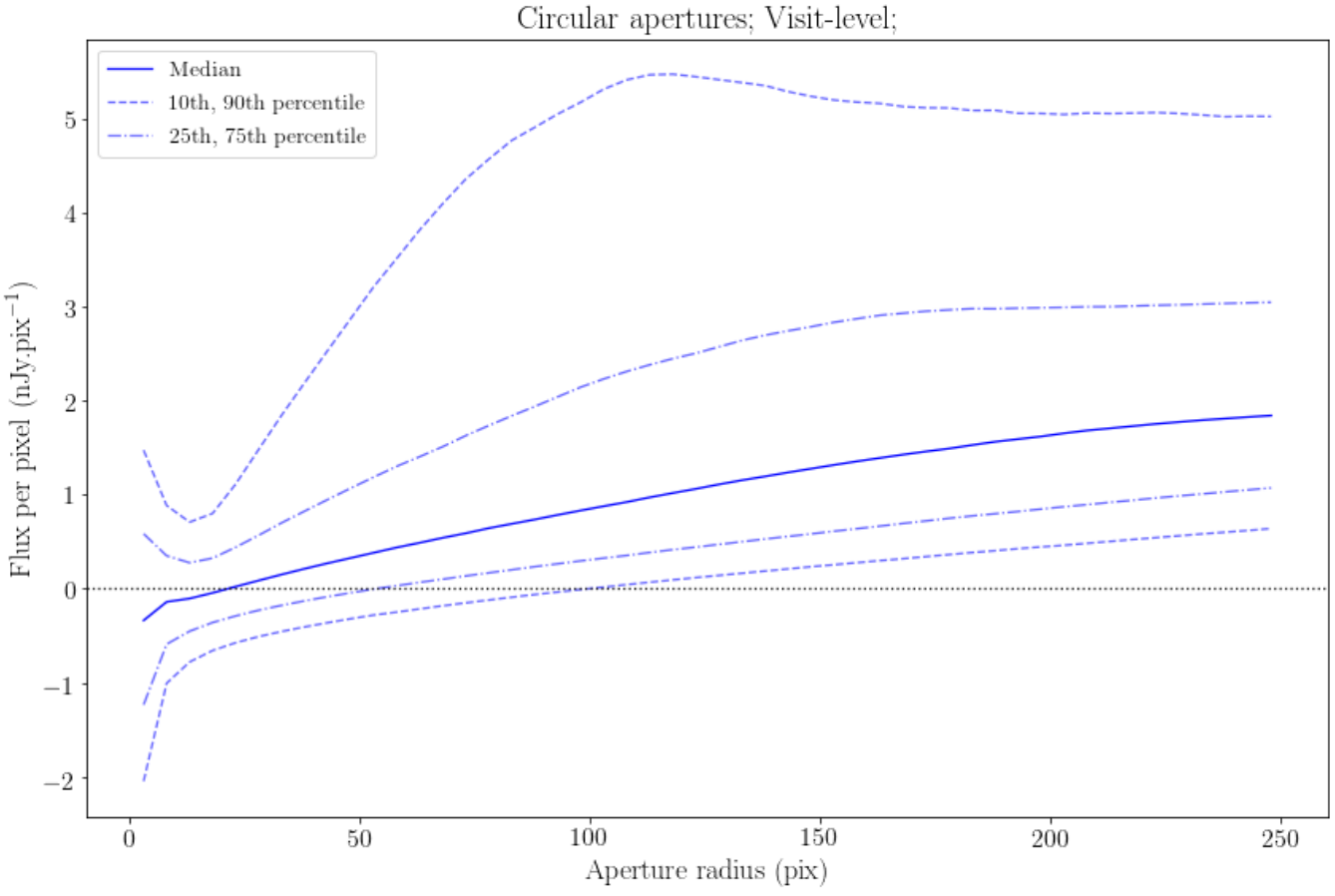


How to compare bright star models

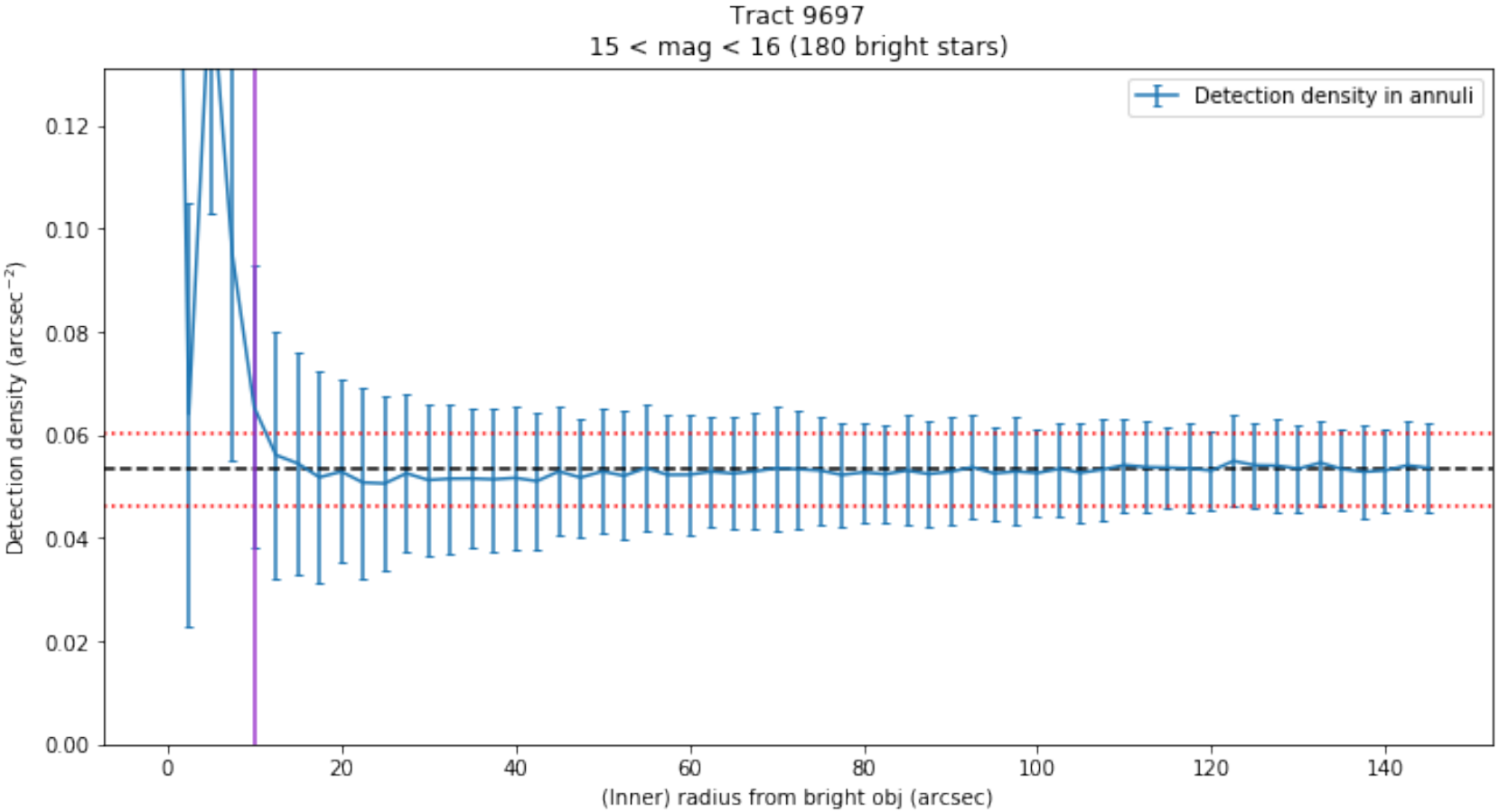
The Yuanyuan plot



- Can boil down to a scalar value by looking at slope of median

How to compare bright star models

The masquerade plot



- Can boil down to a single $\mathrm{magBin} \mapsto \mathrm{masquerade}(\mathrm{magnitudeBin})$ relationship (or a single scalar for chosen reference magnitude bin, or scalars from a parametrization)

PSF error propagation

Testing the validity of P-H formalism

$$\hat{e}_i = e_i \left(1 + \frac{\delta(R^2_{\rm PSF})}{R^2_{\rm gal}}\right) - \left(\frac{R^2_{\rm PSF}}{R^2_{\rm gal}}\delta e_i^{\rm PSF} + \frac{\delta(R^2_{\rm PSF})}{R^2_{\rm gal}} e_i^{\rm PSF}\right)$$

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  - Perform image simulations with both stars and galaxies
  - Run PSF estimation *and* galaxy shape measurement with estimated PSF
  - Compute predicted bias $m^{\rm PH}, c_i^{\rm PH}$ and contribution of PSF errors to observed shear bias m_i, c_i

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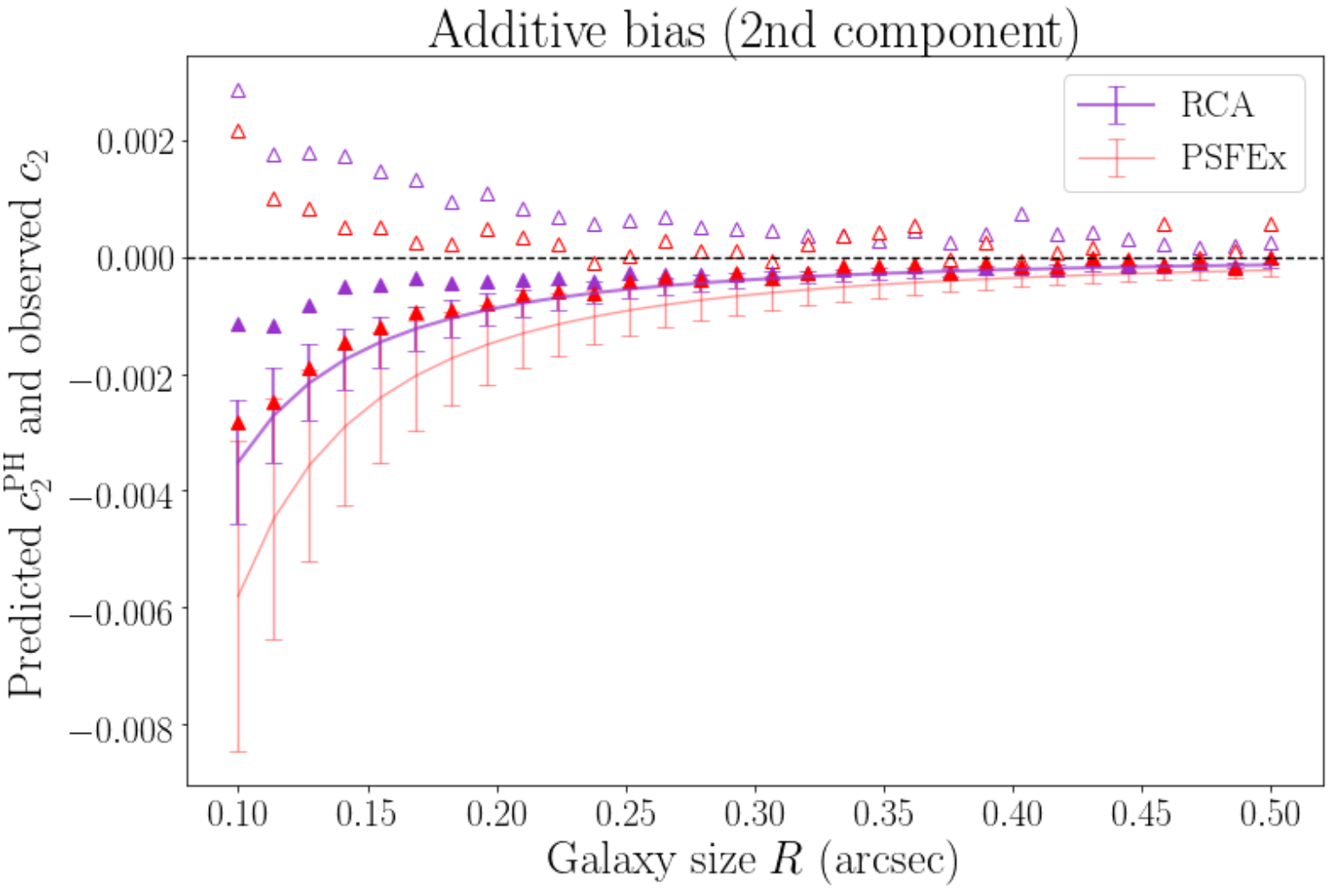

Figure: Euclid PSFs

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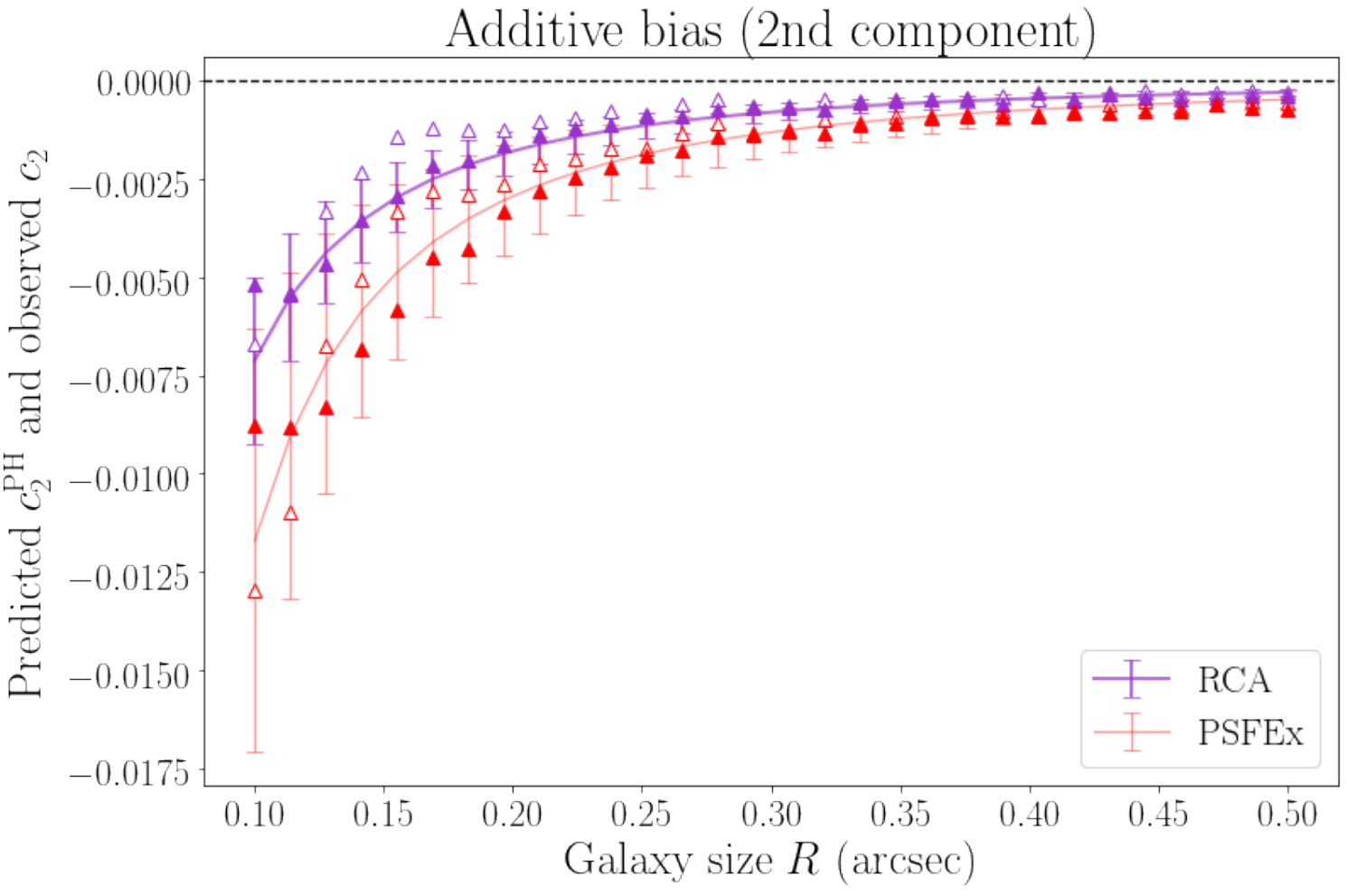

Figure: Gaussian PSFs

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