(Some) future plans for GalSim

Josh Meyers

- galsim.ChromaticRealGalaxy
- galsim.PhaseScreenPSF

The LSST PSF is chromatic

- Atmosphere
  - Differential chromatic refraction
  - Chromatic seeing
- Optics (diffraction/refraction)
- Sensors (absorption length)

- Primary concern for weak lensing is difference between PSF star SED and gal SED.

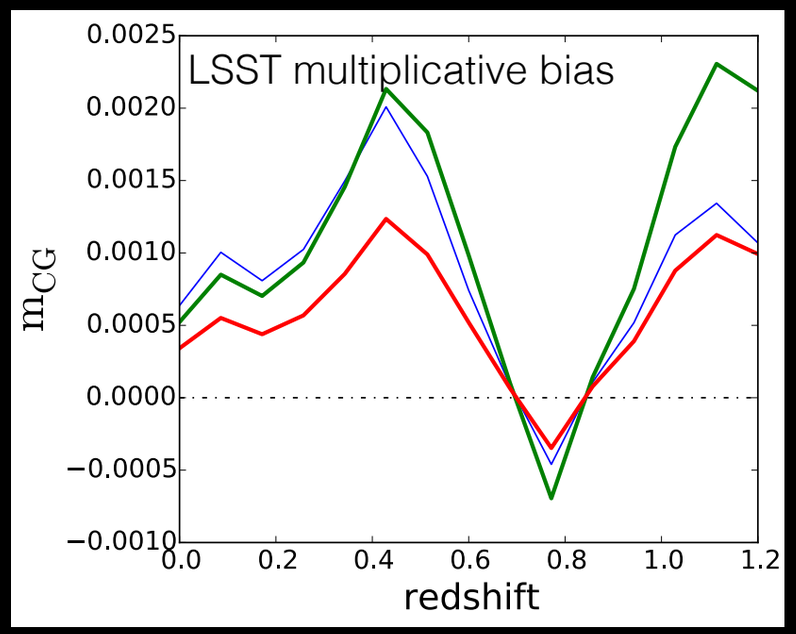
Color gradients

- SED varies with position in real galaxies; so does the PSF.
- Definitely a problem for Euclid (Voigt++12, Semboloni++13)
- Bias due to color gradient scales like

$$\frac{\mathrm{dPSF}}{\mathrm{d}\lambda} \times (\text{filter width})^2 \times \frac{\text{PSF area}}{\text{gal area}}$$

- LSST/Euclid ~ (0.3) x $(0.4)^2$ x 3^2 ~ 0.4
- At least this bad in actual simulations (S. Kamath)
- However, real galaxies are not bulge+disk! Especially at high redshift.


NGC 2442



Kamath++ in prep.

galsim.RealGalaxy

- Use HST images to model realistic galaxies.

Observed image HST PSF galaxy

$$I(\vec{x}) = \Pi(\vec{x}) * f(\vec{x})$$

galsim.RealGalaxy

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Observed image HST PSF galaxy

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- Deconvolve HST PSF. Apply affine transformation (e.g., shear, dilate, rotate). Convolve by desired (larger) PSF.

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$$\tilde{I}(\vec{k}) = \tilde{\Pi}(\vec{k})\tilde{f}(\vec{k}) \xrightarrow{\text{deconvolve}} \tilde{f}(\vec{k}) = \frac{\tilde{I}(\vec{k})}{\tilde{\Pi}(\vec{k})}$$

galsim.RealGalaxy

- Use HST images to model realistic galaxies.

Observed image, HST PSF, galaxy

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$$\xrightarrow{\text{transform}} \tilde{f}'(\vec{k}) = \tilde{f}(A\vec{k})$$

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- Use HST images to model realistic galaxies.

Observed image ↘ HST PSF ↓ galaxy ↙

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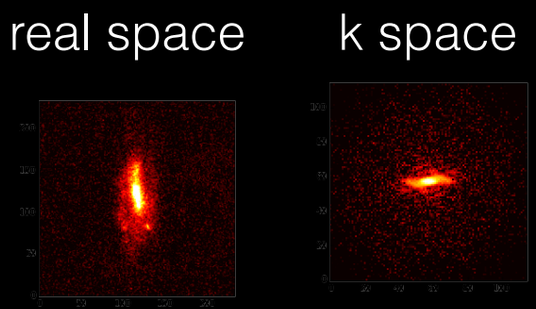

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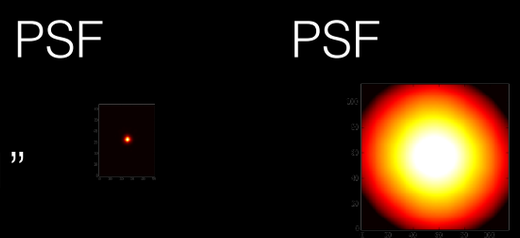

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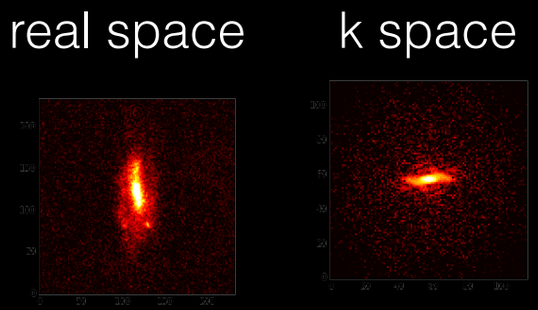

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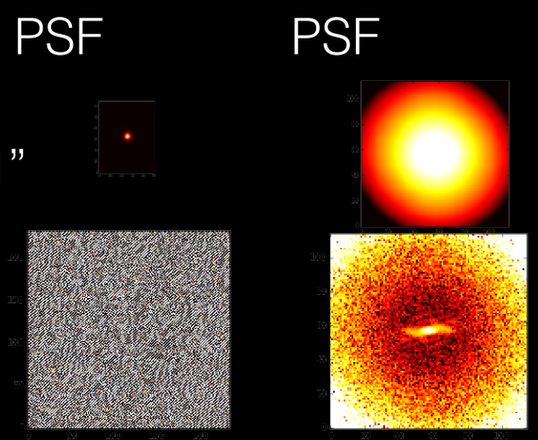

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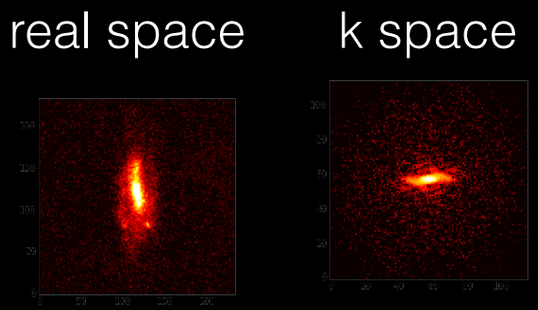

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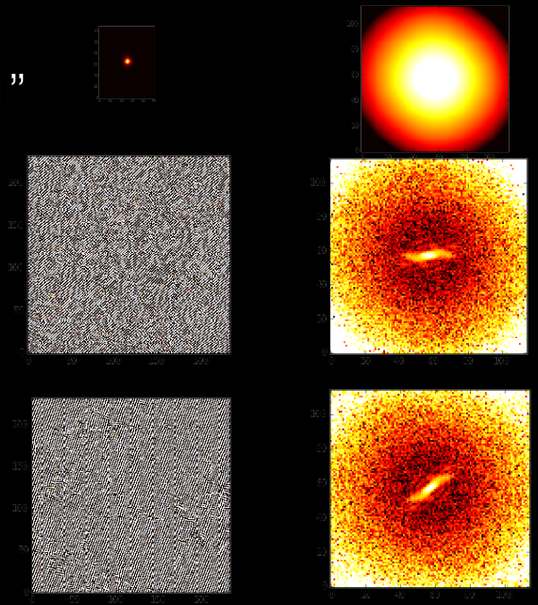

galsim.RealGalaxy

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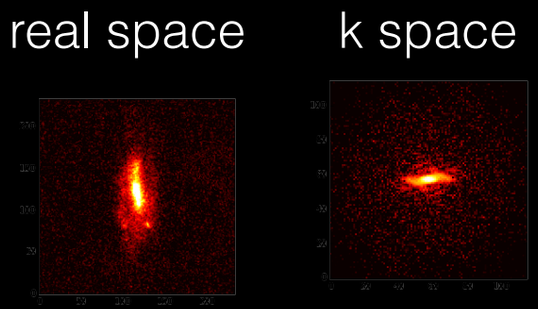

- Deconvolve HST PSF. Apply affine transformation (e.g., shear, dilate, rotate). Convolve by desired (larger) PSF.

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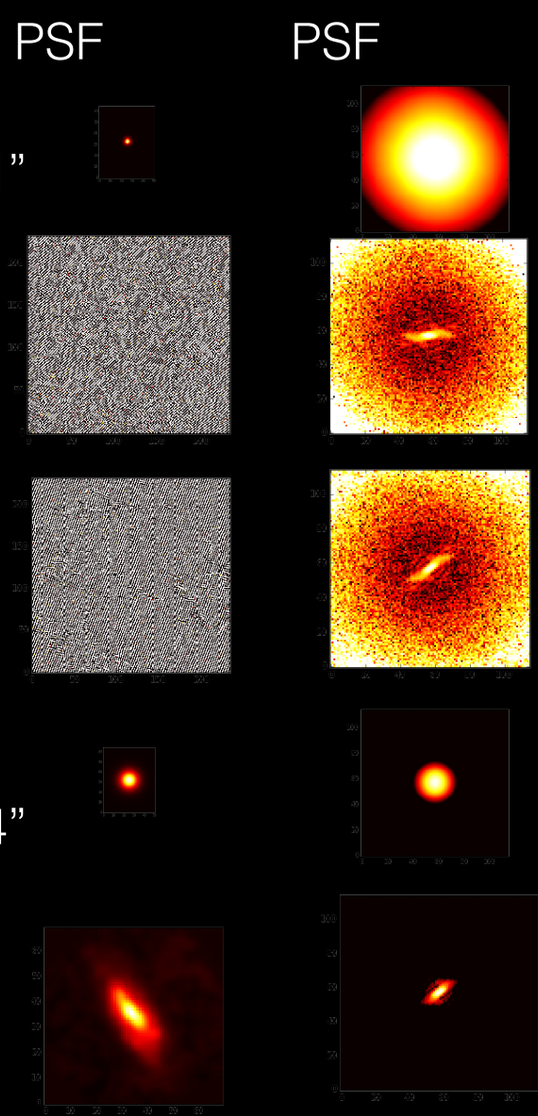


galsim.RealChromaticGalaxy

- Use multi-band HST images to model realistic galaxies with color-gradients.

Images

Filters

HST PSF

galaxy

$$I_i(\vec{x}) = \int T_i(\lambda) \left[\Pi(\vec{x}, \lambda) * f(\vec{x}, \lambda)\right] \mathrm{d}\lambda$$

filter index

galsim.RealChromaticGalaxy

- Use multi-band HST images to model realistic galaxies with color-gradients.

Images → $I_i(\vec{x})$ = ∫ Filters → $T_i(\lambda)$ [HST PSF → $\Pi(\vec{x}, \lambda)$ ∗ galaxy → $f(\vec{x}, \lambda)$] $\mathrm{d}\lambda$

filter index → i

- Assert that galaxy is sum of separable profiles with particular SEDs; solve for spatial components.

$$f(\vec{x}, \lambda) = \sum_j S_j(\lambda) a_j(\vec{x})$$

SED index → j; $S_j(\lambda)$: SEDs; $a_j(\vec{x})$: spatial terms

RealChromaticGalaxy

- Again, go to Fourier space:

Ansatz ⟶ $$\tilde{I}_i(\vec{k}) = \int T_i(\lambda)\tilde{\Pi}(\vec{k},\lambda)\sum_j S_j(\lambda)\tilde{a}_j(\vec{k})\,\mathrm{d}\lambda$$

Rearrange ⟶ $$= \sum_j \left[\int T_i(\lambda)S_j(\lambda)\tilde{\Pi}(\vec{k},\lambda)\,\mathrm{d}\lambda\right]\tilde{a}_j(\vec{k})$$

Relabel ⟶ $$= \sum_j \tilde{\Pi}^{\mathrm{eff}}_{ij}(\vec{k})\tilde{a}_j(\vec{k})$$

j

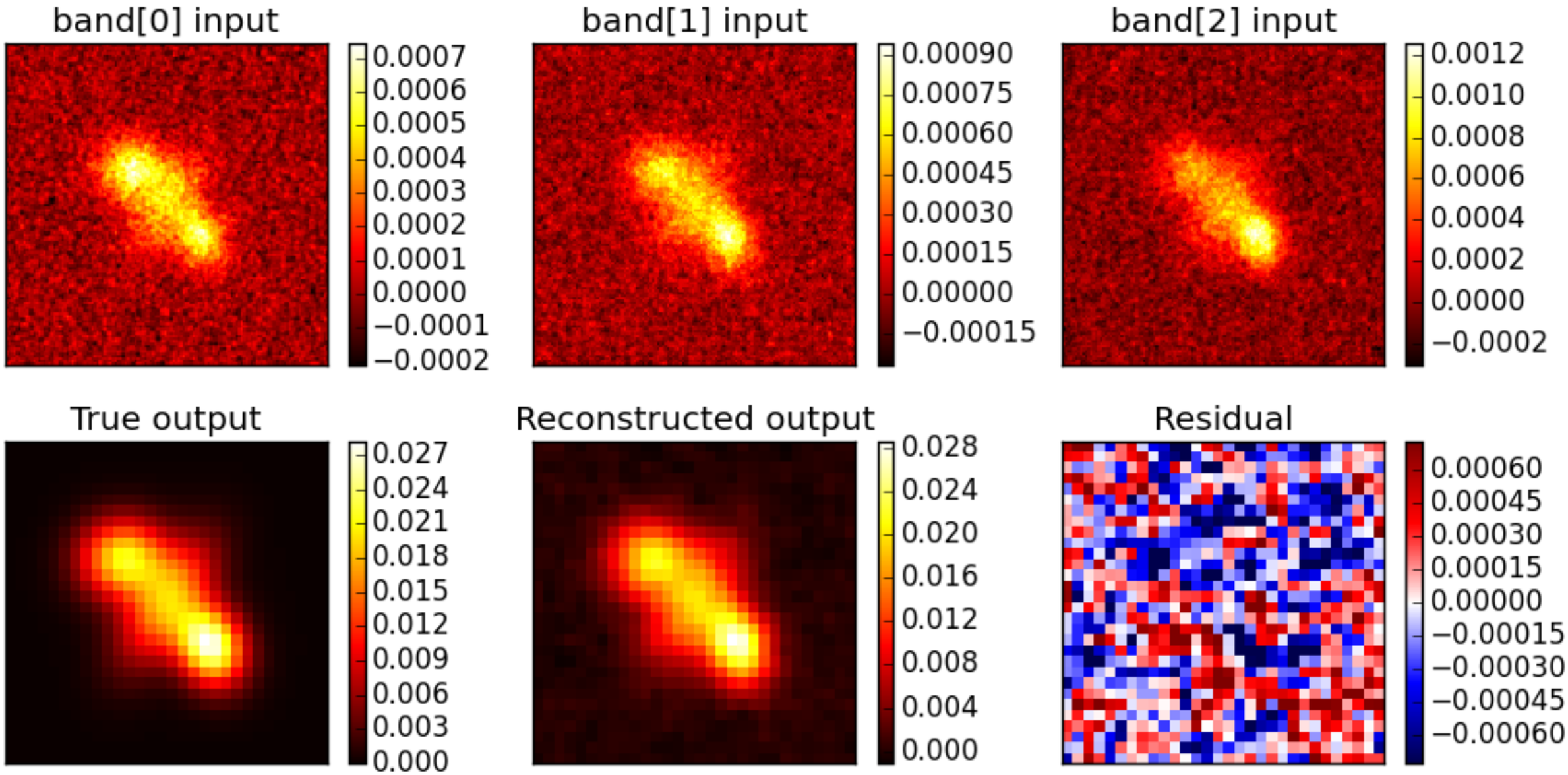
Solving for these.

Effective PSF of jth SED through the ith filter.

- Left with a matrix equation for each k-mode. So solve it!
- Can also do this properly accounting for correlated noise in each image: see https://github.com/GalSim-developers/GalSim/blob/%23640/devel/modules/CGNotes.pdf for details

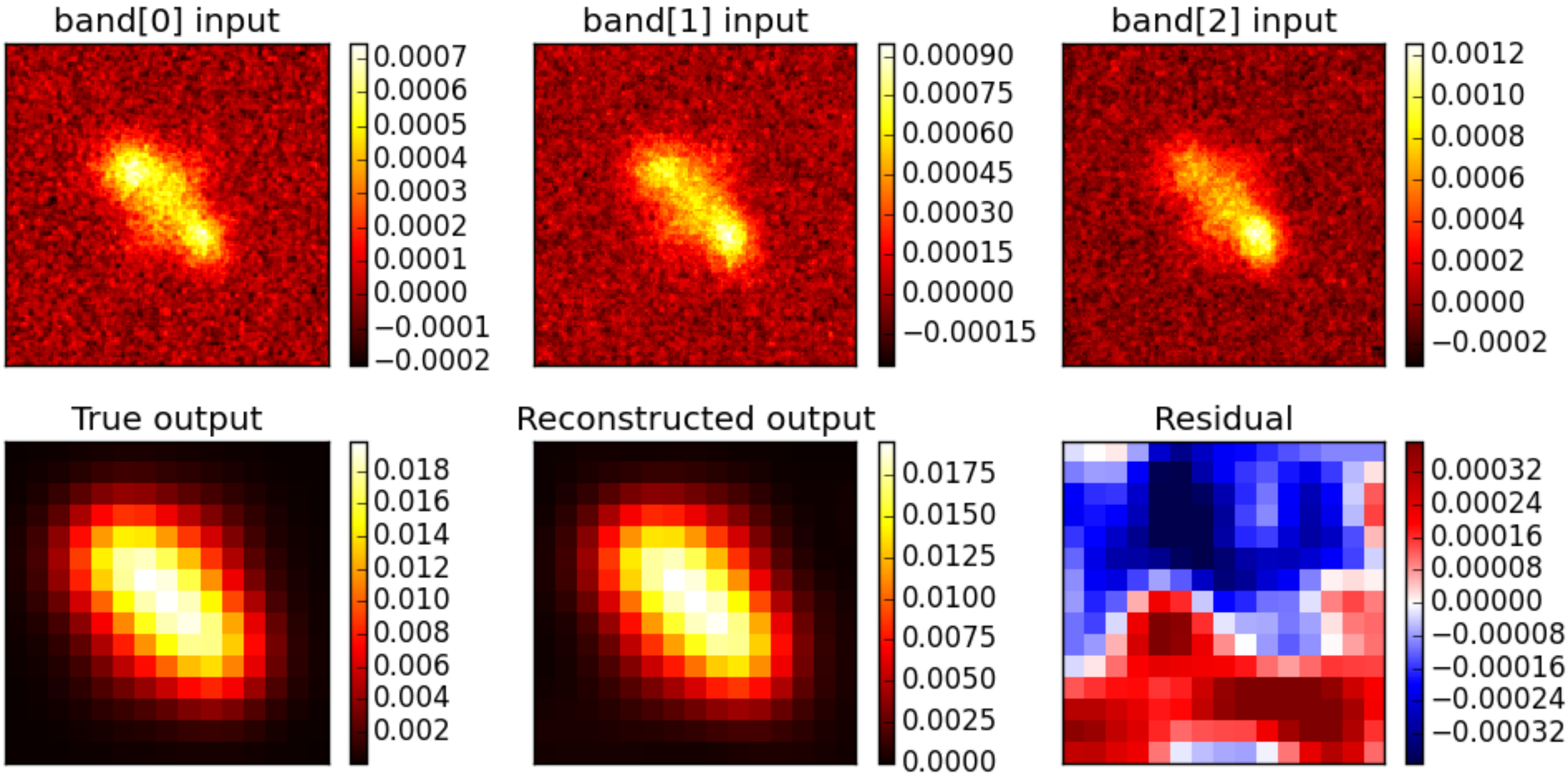
(Toy) example

- r-, i-, z-like input filters, Euclid-like output filter, PSF, and pixels.



(Toy) example

- r-, i-, z-like input filters, out-of-phase output filter and LSST-like PSF, pixel scale.

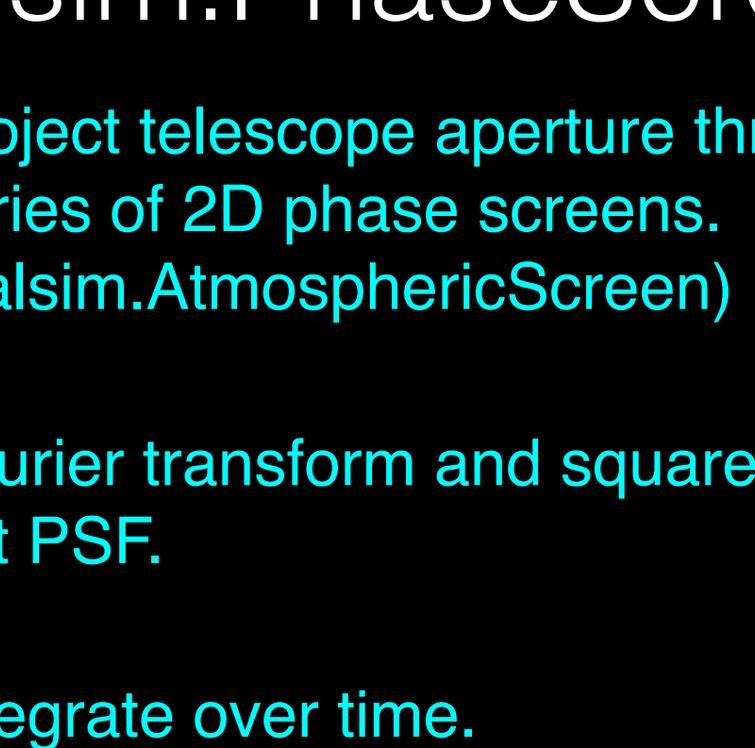


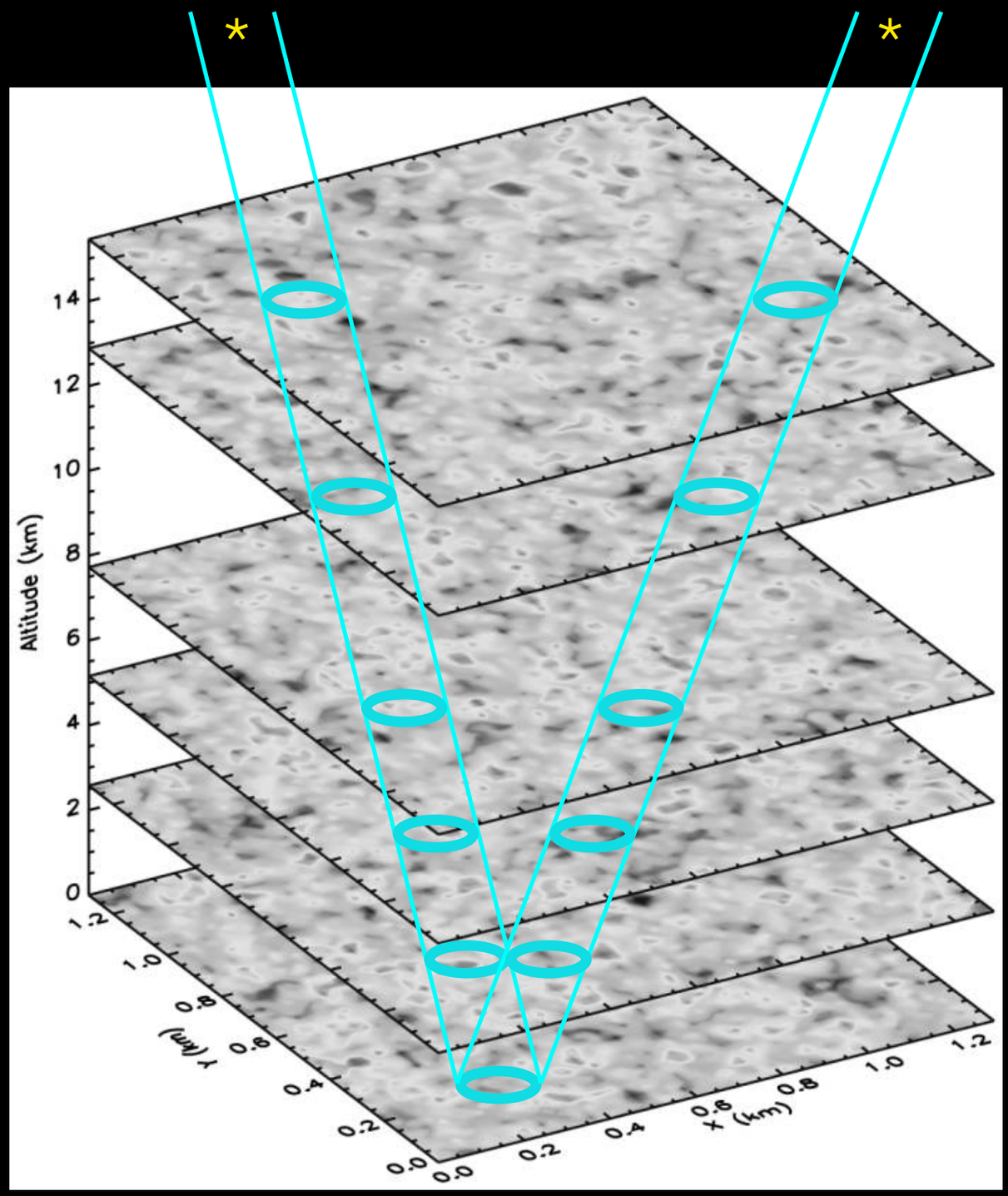
Next steps

- AEGIS catalog of ~29000 galaxies in V- and I-band.
  - Sowmya Kamath currently processing these (continuing work done by Bradley Emi, Jason Rhodes, Andres Plazas, and Rachel Mandelbaum.)
- CANDELS - similar area/depth to AEGIS, but 5-8 filters.
- HST Frontier Fields (parallels) - smaller but deeper, ~7 filters.
- (Chromatic)RealGalaxies from hydro sims (Issue #669)
- Tests: assess the importance of asserted SED mismatch.

galsim.PhaseScreenPSF

- Project telescope aperture through series of 2D phase screens. (galsim.AtmosphericScreen)
- Fourier transform and square to get PSF.
- Integrate over time. (galsim.PhaseScreenPSF)

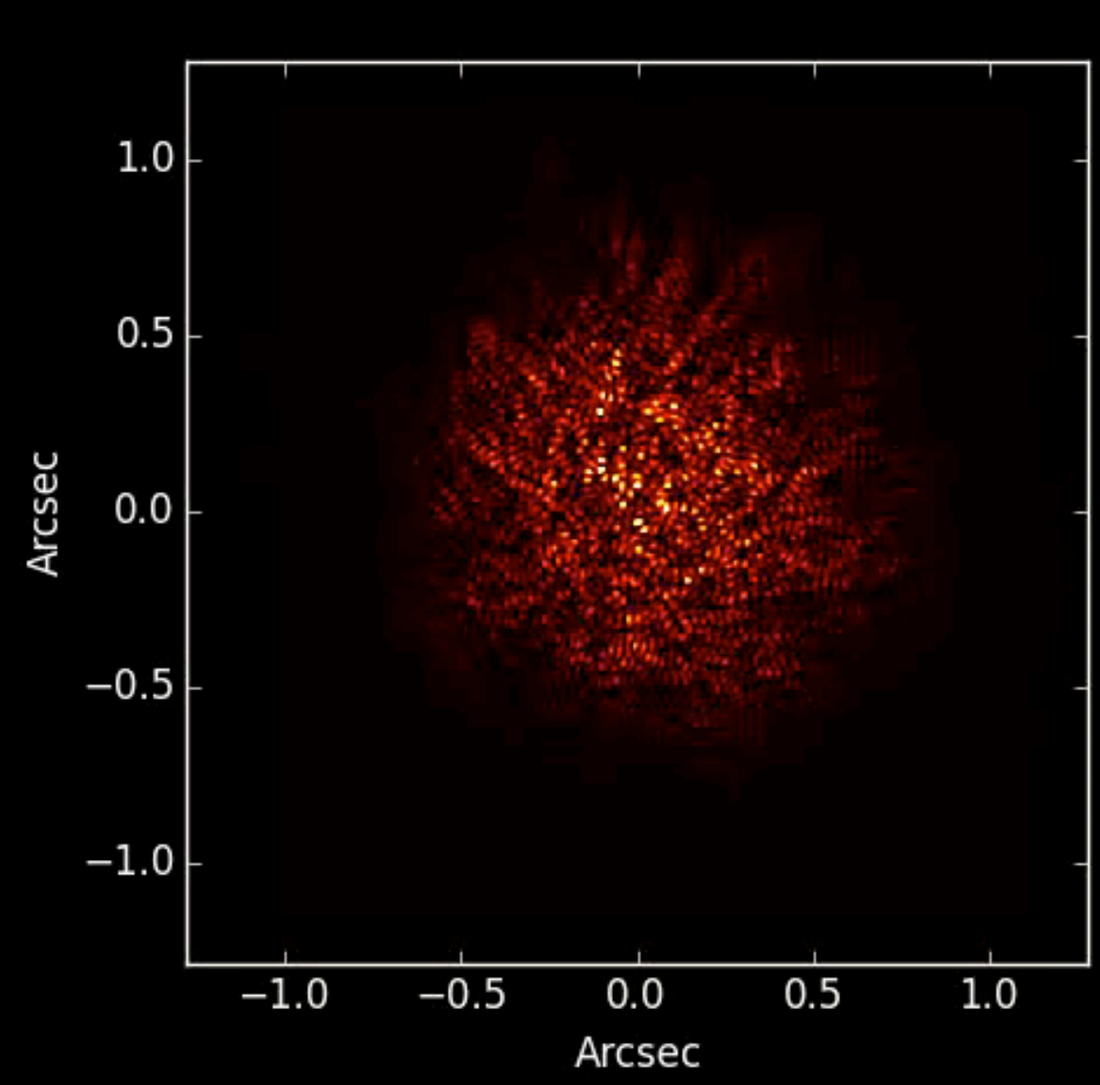


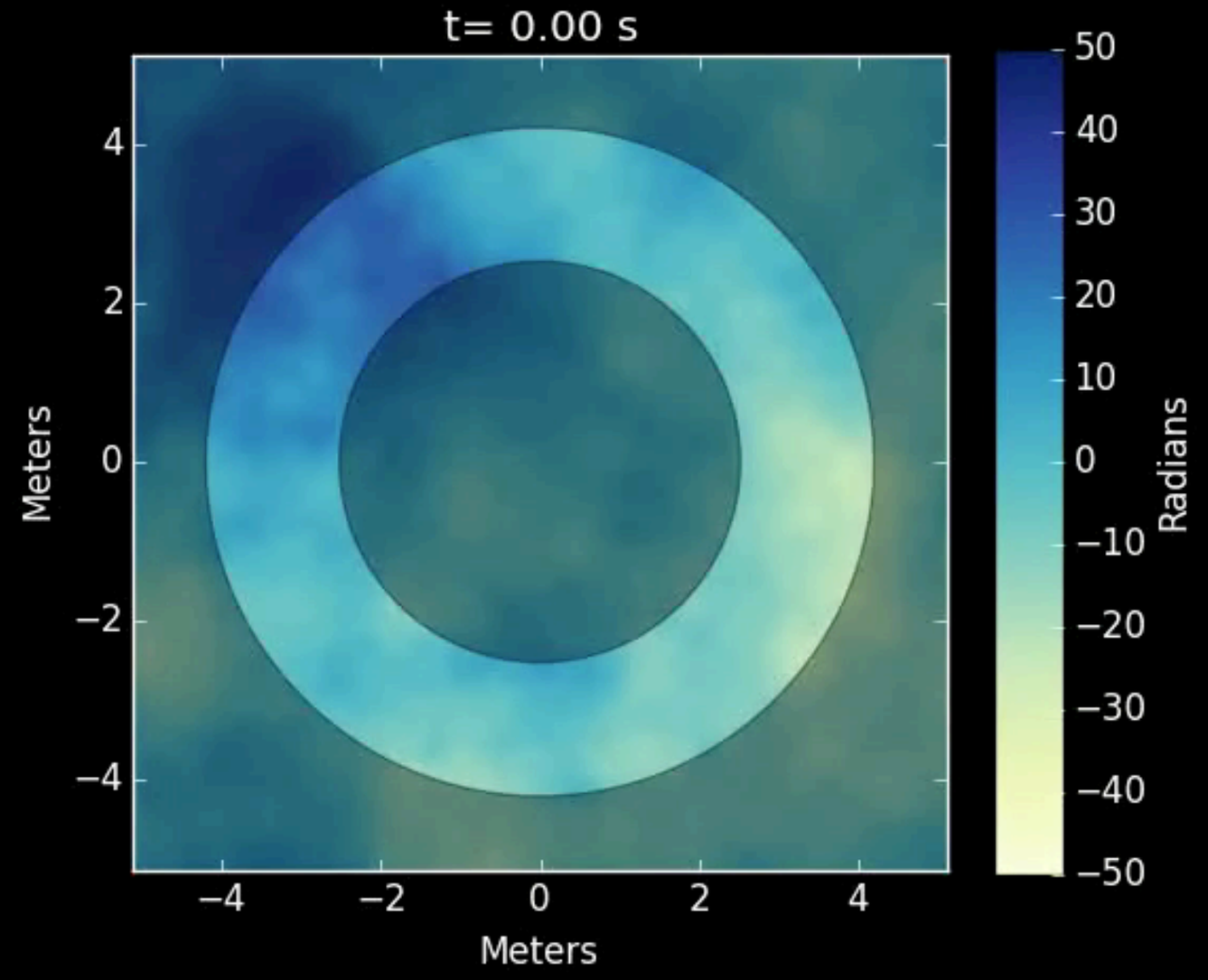


Jee+Tyson11

Instantaneous PSF

$$I(x,y) \propto \left| \mathcal{F}\left[P(u,v) \exp\left(\frac{-2\pi i}{\lambda} W(u,v) \right) \right] \right|^2$$

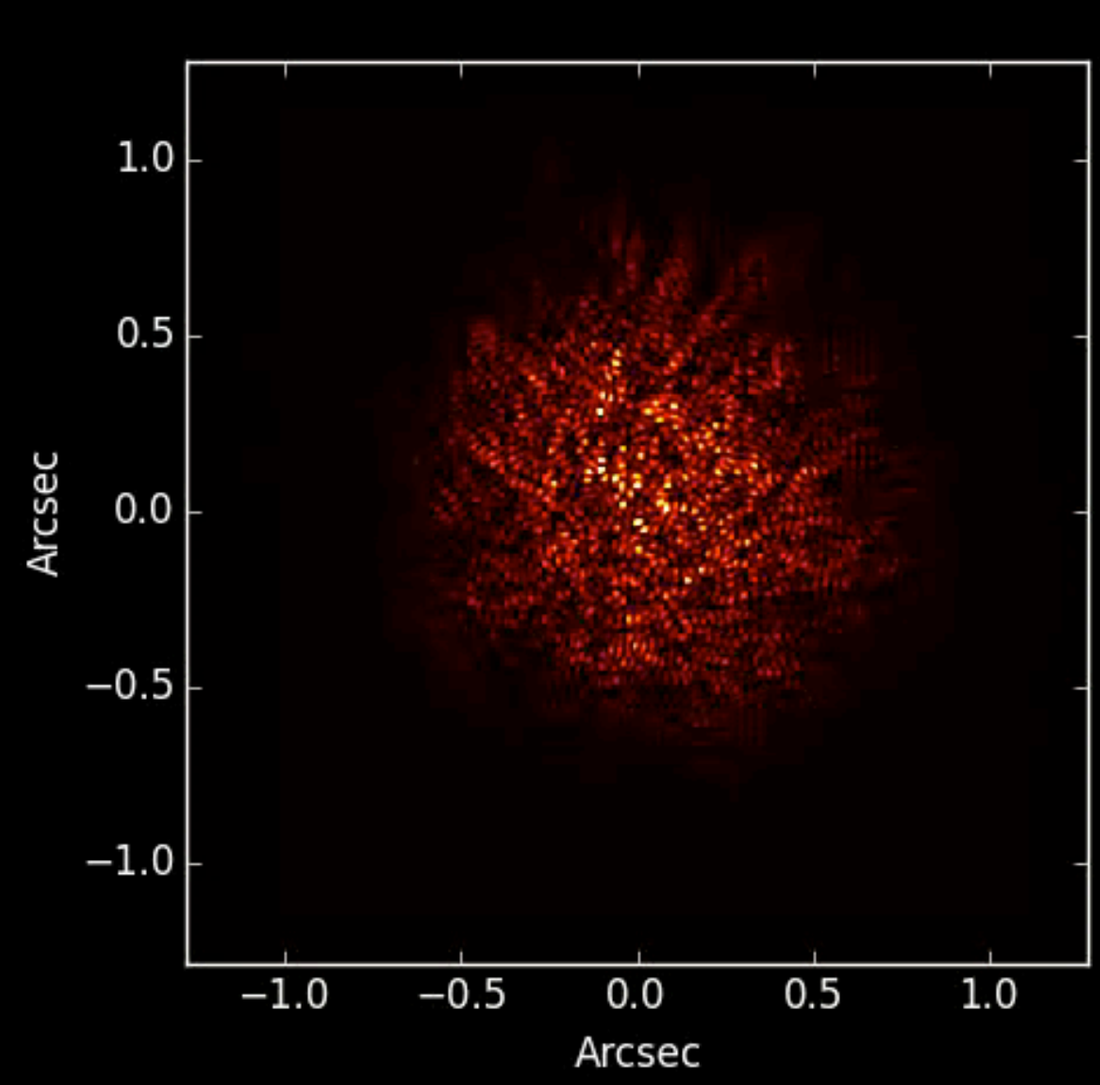


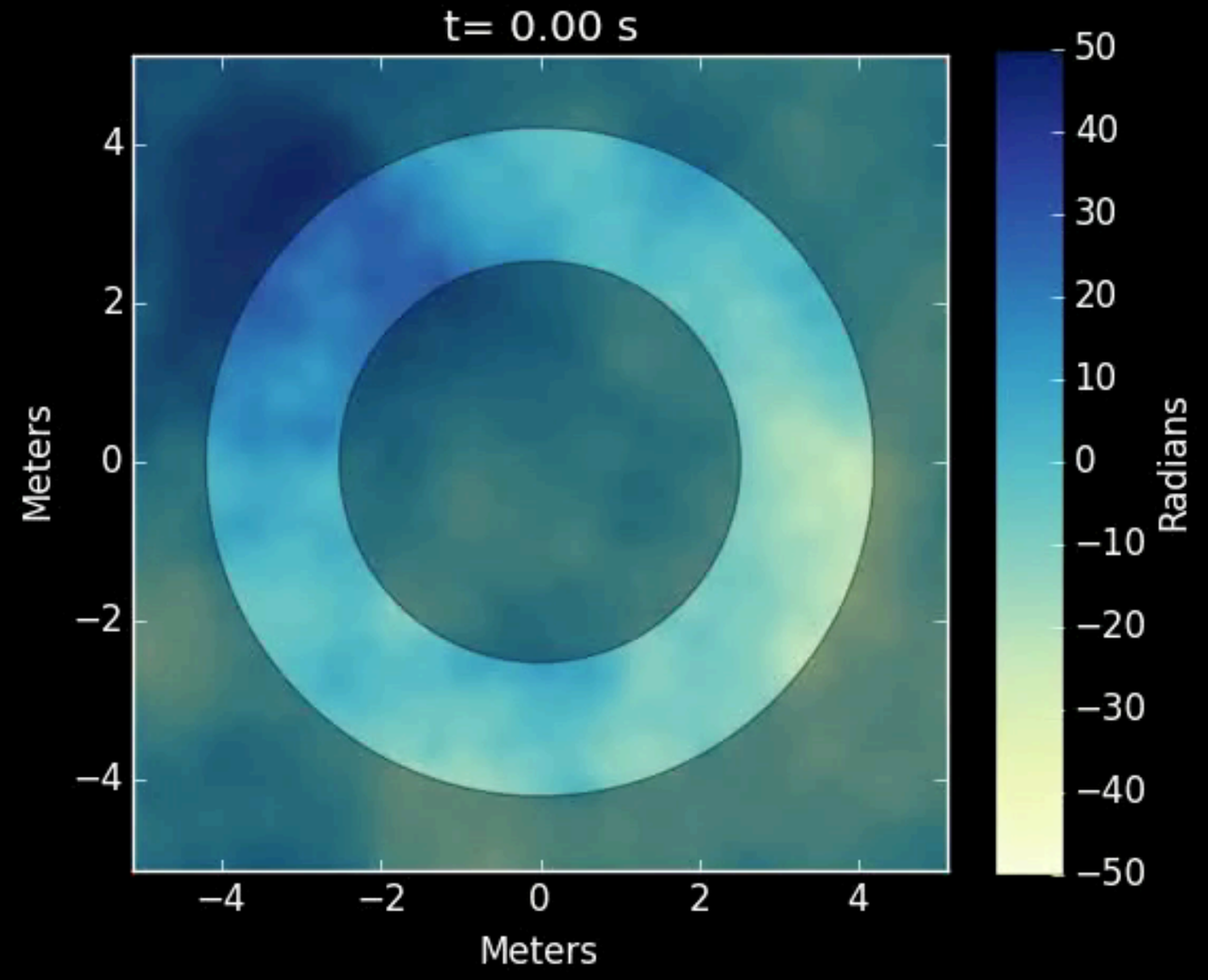


https://youtu.be/kwxKvWAxOb0

Cumulative PSF

$$I(x,y) \propto \left| \mathcal{F}\left[P(u,v) \exp\left(\frac{-2\pi i}{\lambda} W(u,v) \right) \right] \right|^2$$





https://youtu.be/1IN3Ub4lESA

Interface

```
aper = galsim.Aperture(diam=8.4, obscuration=0.6, nstruts=4, strut_thick=0.02)

screen1 = galsim.AtmosphericScreen(screen_size=100.0, screen_scale=0.1, altitude=1.,
                                   time_step=0.03, r0_500=0.15, L0=25.0, vx=1.2, vy=2.3)

screen10 = galsim.AtmosphericScreen(screen_size=100.0, screen_scale=0.1, altitude=10.,
                                    time_step=0.03, r0_500=0.3, L0=25.0, vx=-12.0, vy=-1.)

#                    Z1   Z2   Z3   Z4   Z5   Z6   Z7 and so on...
aberrations = [0.0, 0.0, 0.0, 0.0, 0.1, 0.2, 0.3, 0.4]

optics = galsim.OpticalScreen(aberrations=aberrations, lam_0=500.0)
```

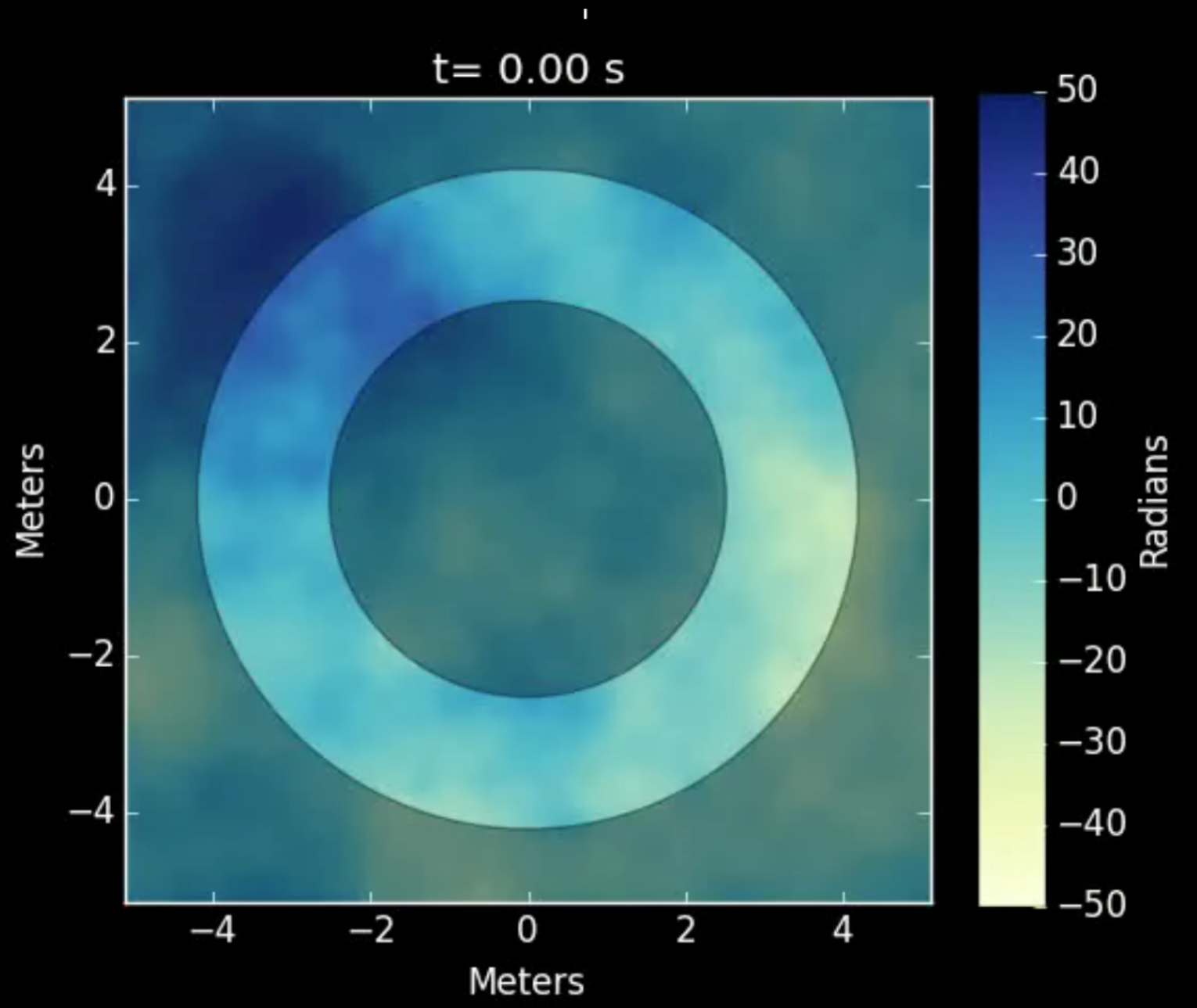
```
screens = galsim.PhaseScreenList([screen1, screen10, optics])

wavefront = screens.wavefront(aper, theta_x=0.1*galsim.degrees, theta_y=0.2*galsim.degrees)

# Get 5x5 array of PSFs
thx = thy = numpy.linspace(-0.5, 0.5, 5)
thx, thy = numpy.meshgrid(thx, thy)

PSFs = screens.makePSF(lam=625., aper=aper, exptime=30.0,
                       theta_x=thx*galsim.degrees, theta_y=thy*galsim.degrees)
```

Speed and Accuracy

- Both under assessment
  - especially accuracy
    - especially PSF correlations

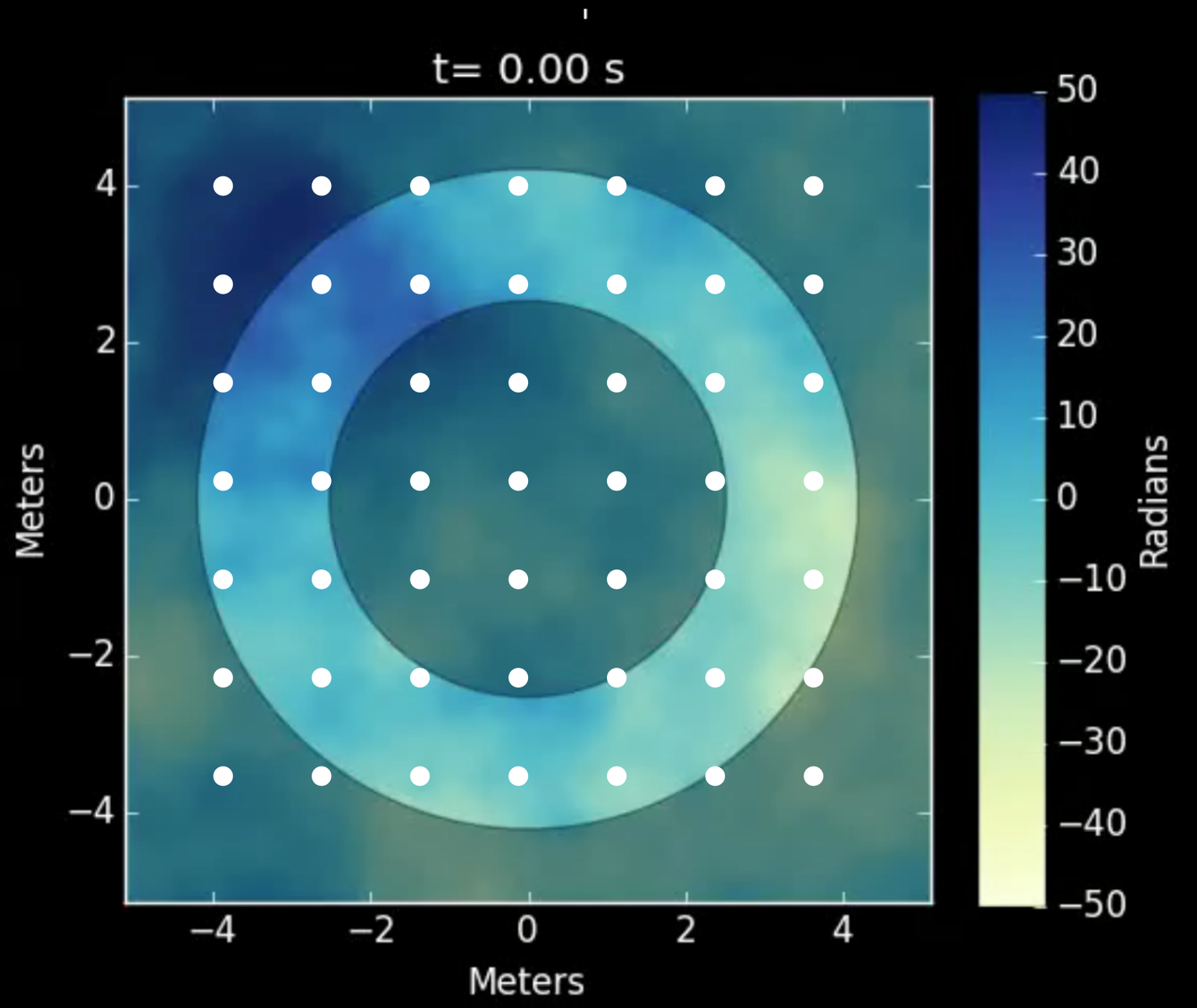
- Speed for 6-layer atmosphere with default settings:
  - 2.5h per 30s monochromatic PSF.
- Cautiously optimistic potential speed:
  - ~minute per monochromatic PSF.

Knobs


t= 0.00 s
Meters
Meters
Radians
4
2
0
−2
−4
−4
−2
0
2
4
50
40
30
20
10
0
−10
−20
−30
−40
−50

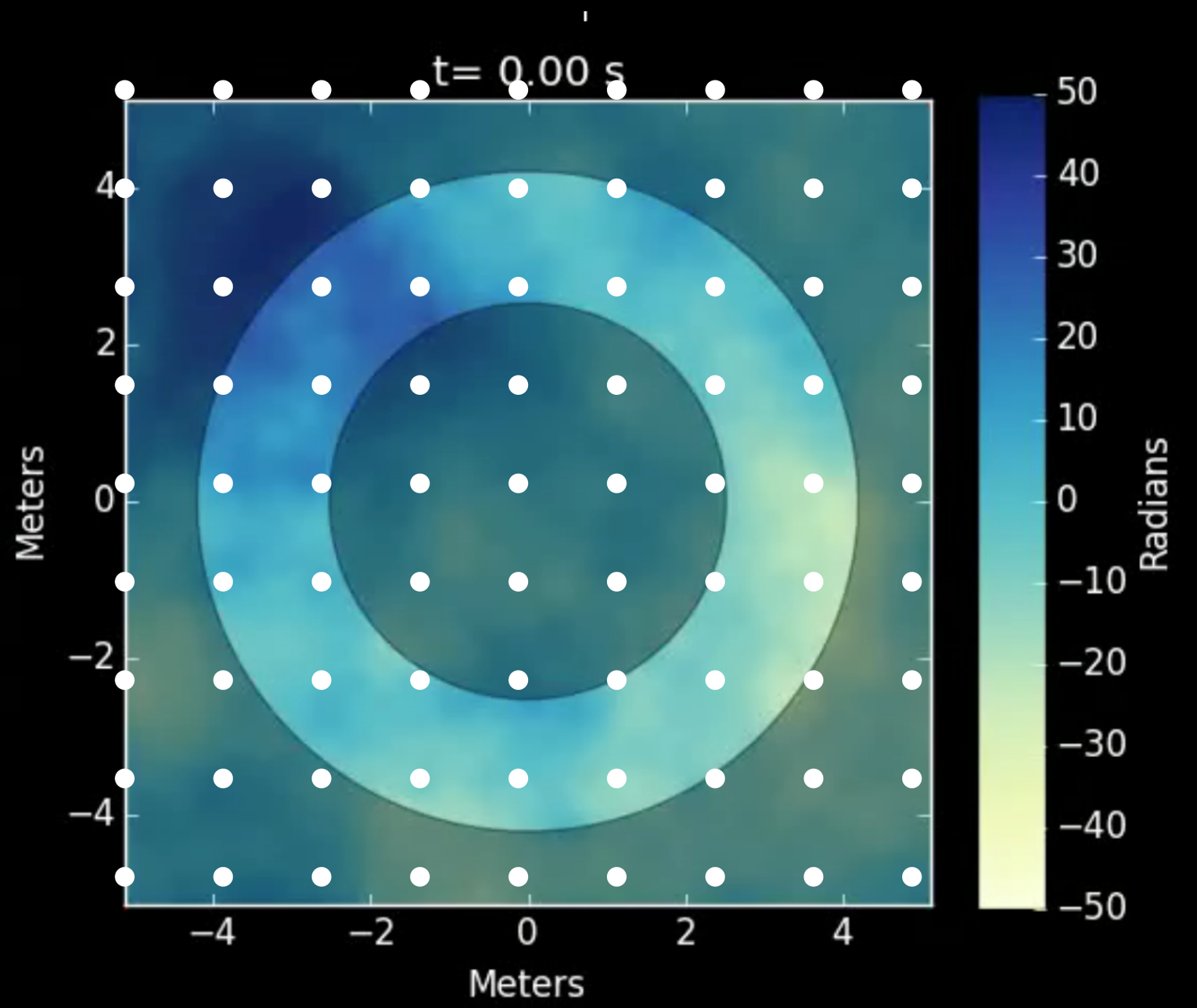
Knobs

- Pupil sampling



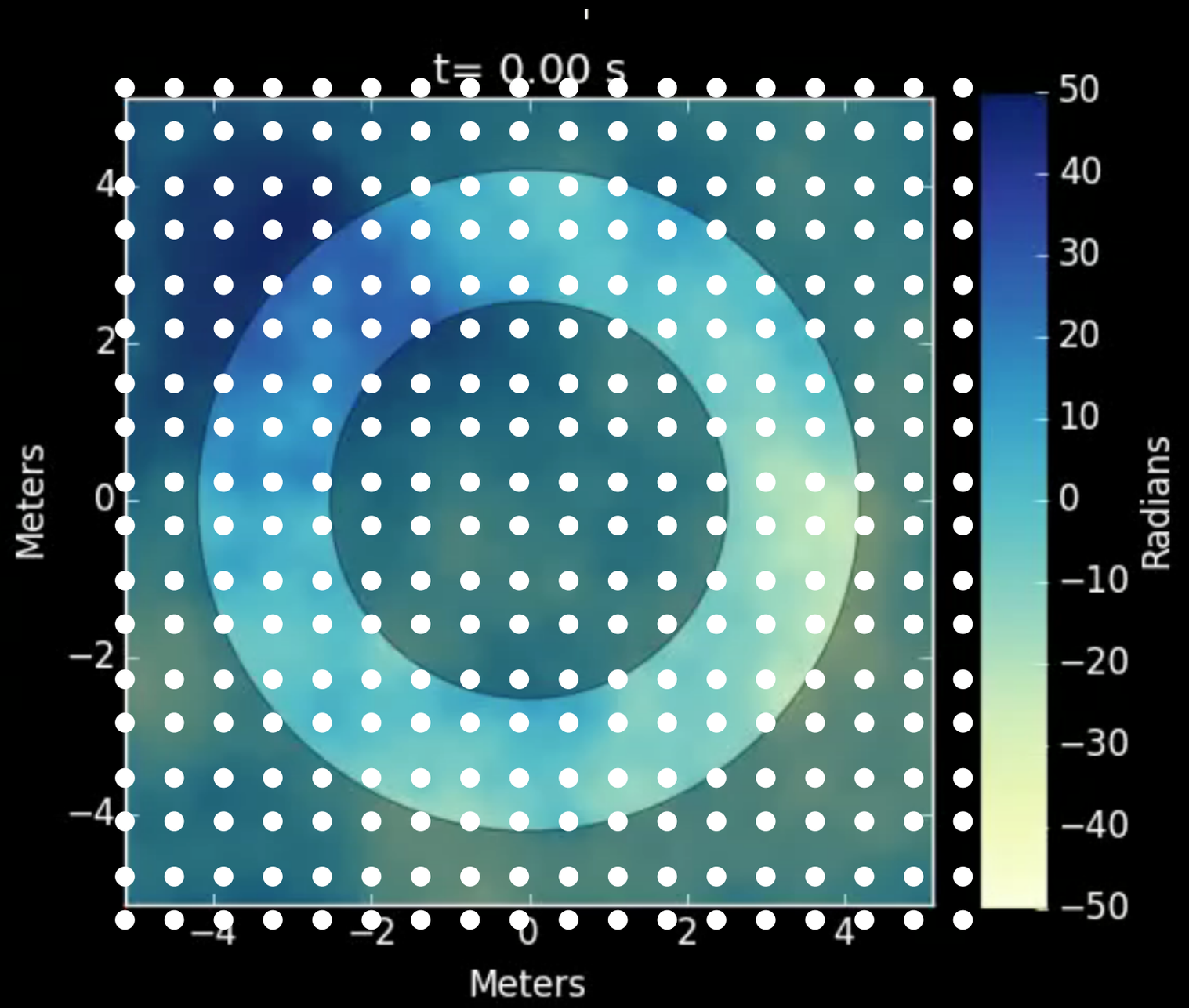
Knobs

- Pupil sampling
  - zero-padding



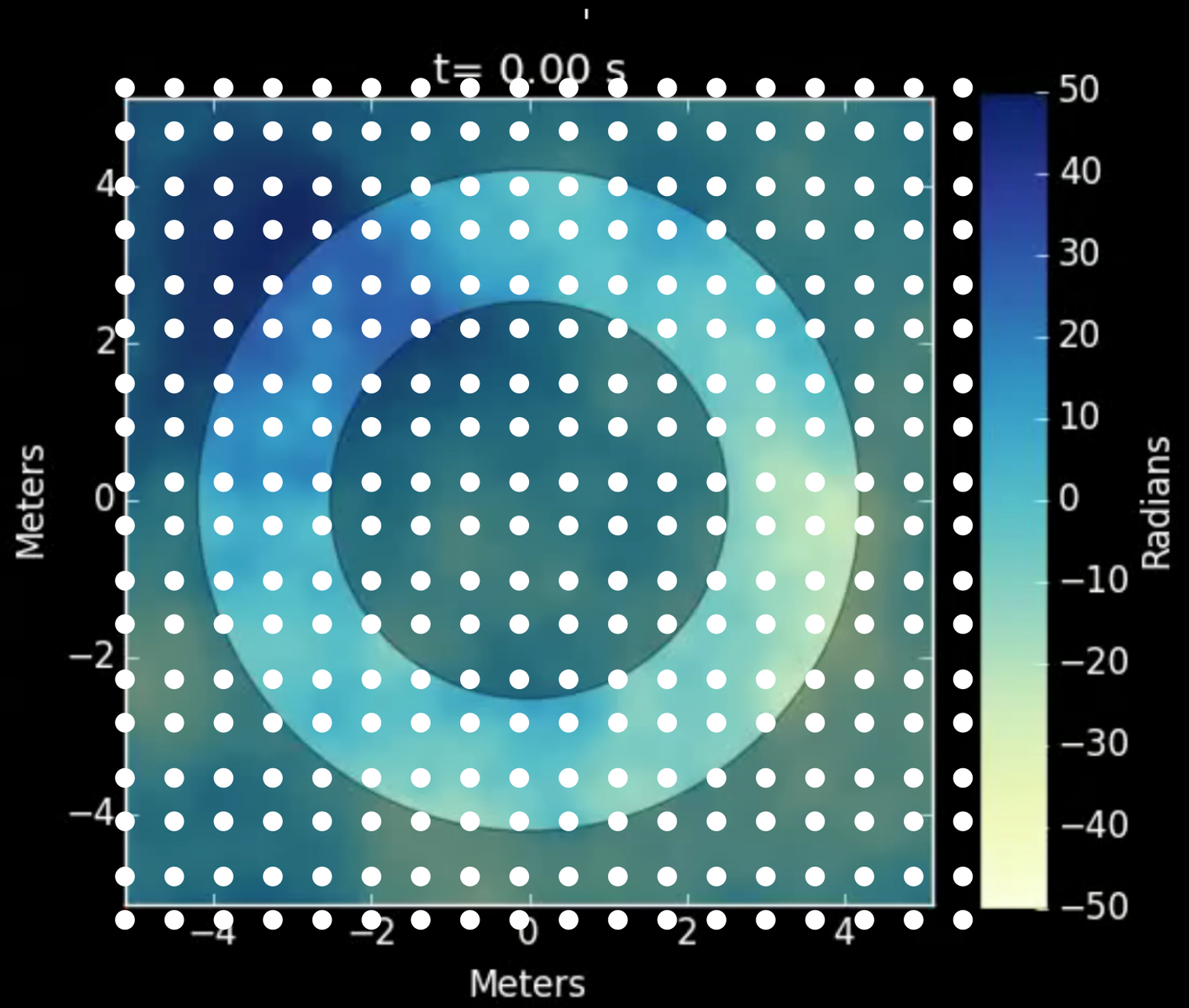
Knobs

- Pupil sampling
  - zero-padding
  - sampling frequency



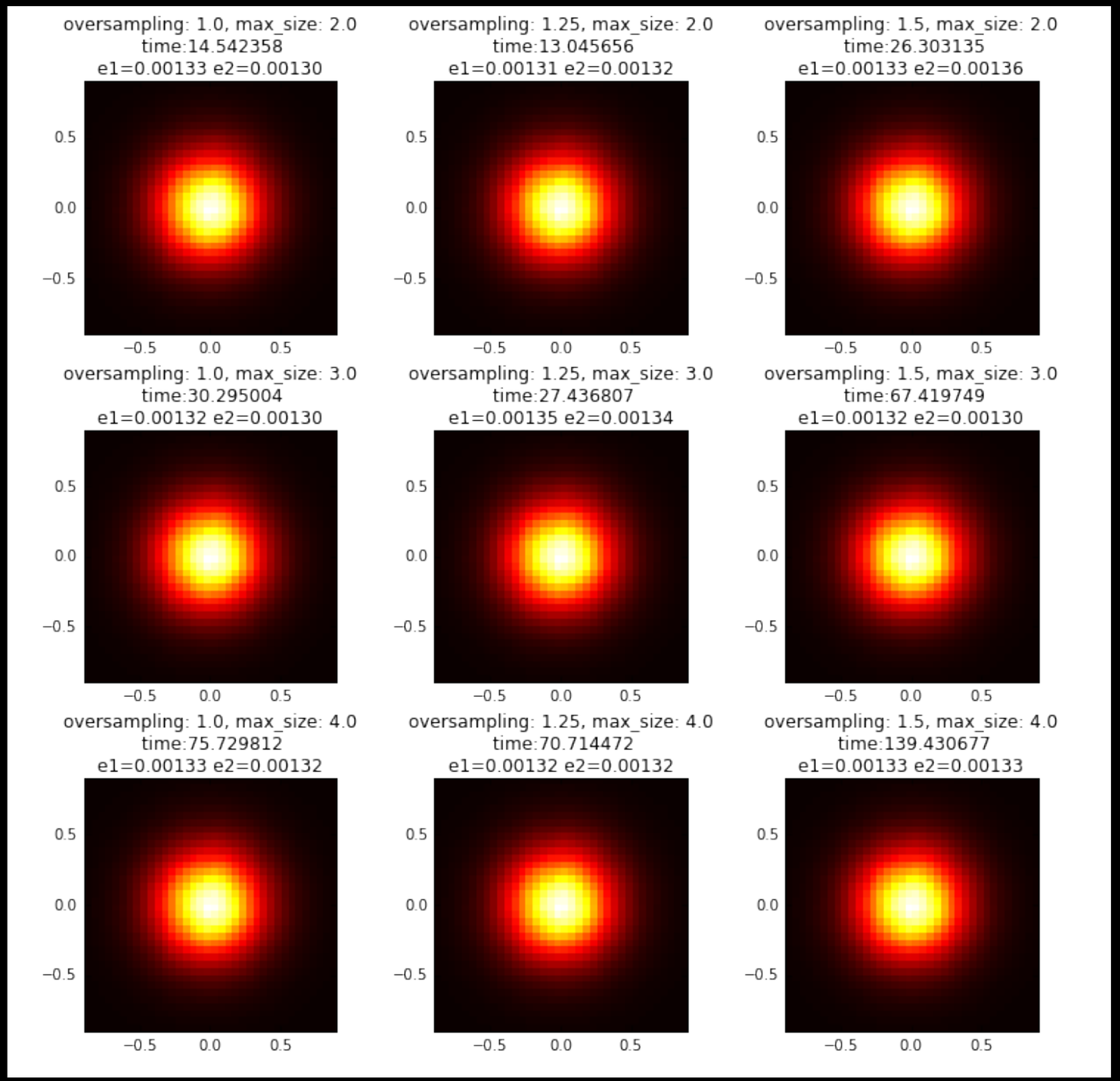
Knobs

- Pupil sampling
  - zero-padding
  - sampling frequency
- Time step interval



Direct comparison of sampling settings

max_size ~ stepK

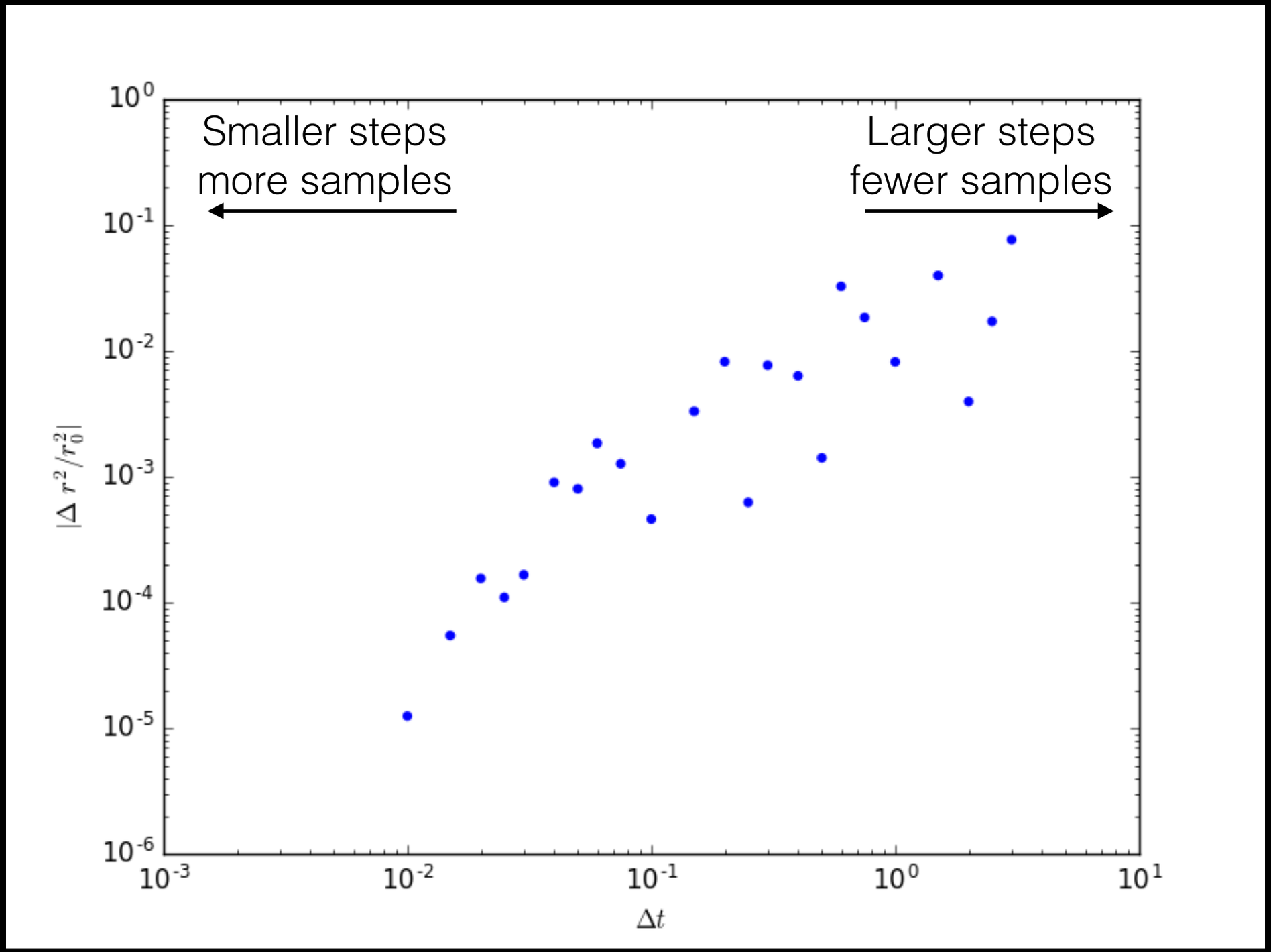


Oversampling ~ maxK

Time step

- Default (5 ms) follows Jee+Tyson (2011)
  - Roughly half the ratio of the Fried parameter (0.16 m) to the maximum wind speed (20 m/s).
  - (I think) this is mostly important for getting PSF correlations right.

Single 30 s PSFs with different temporal samplings to PSF with default sampling



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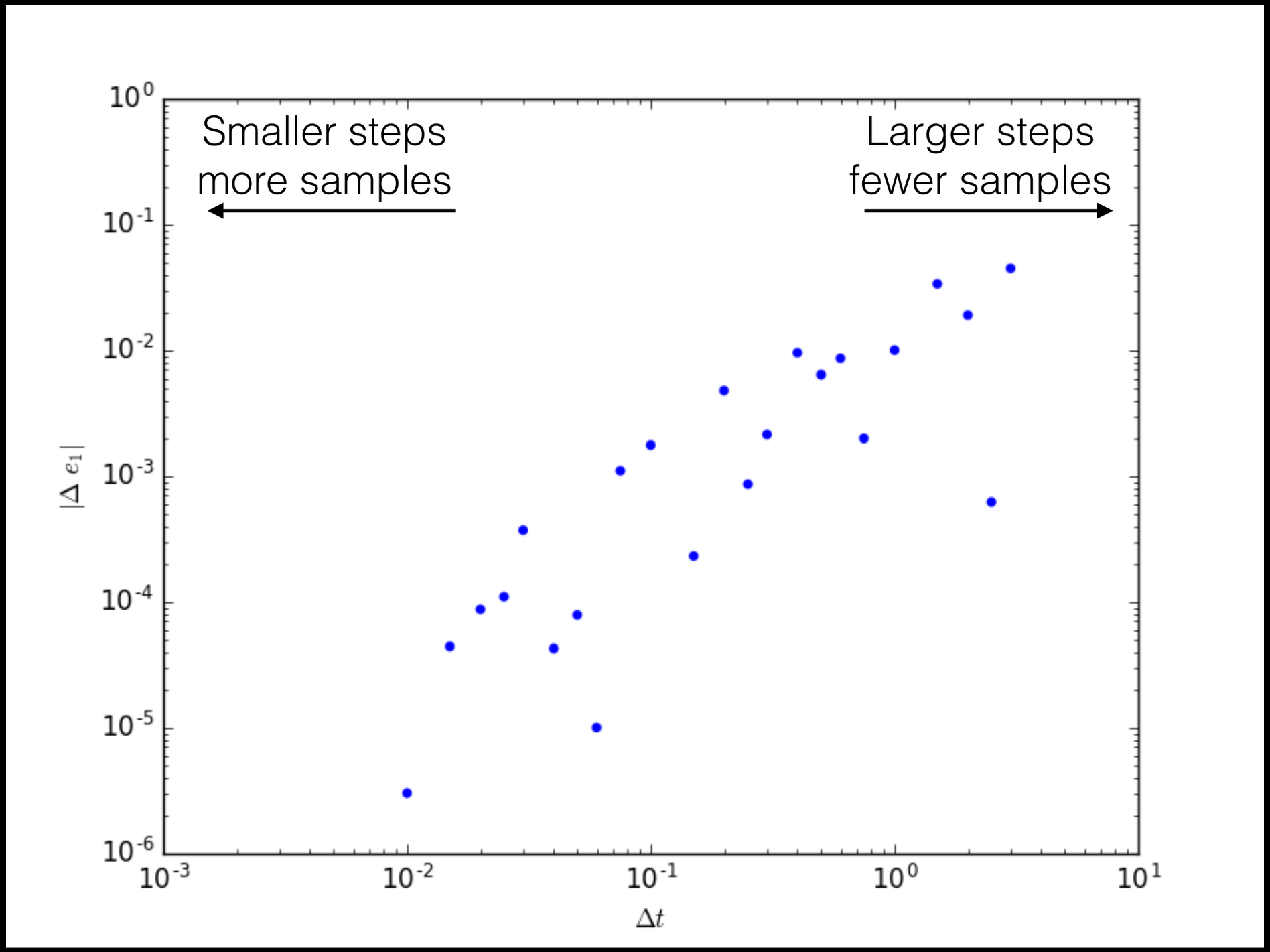
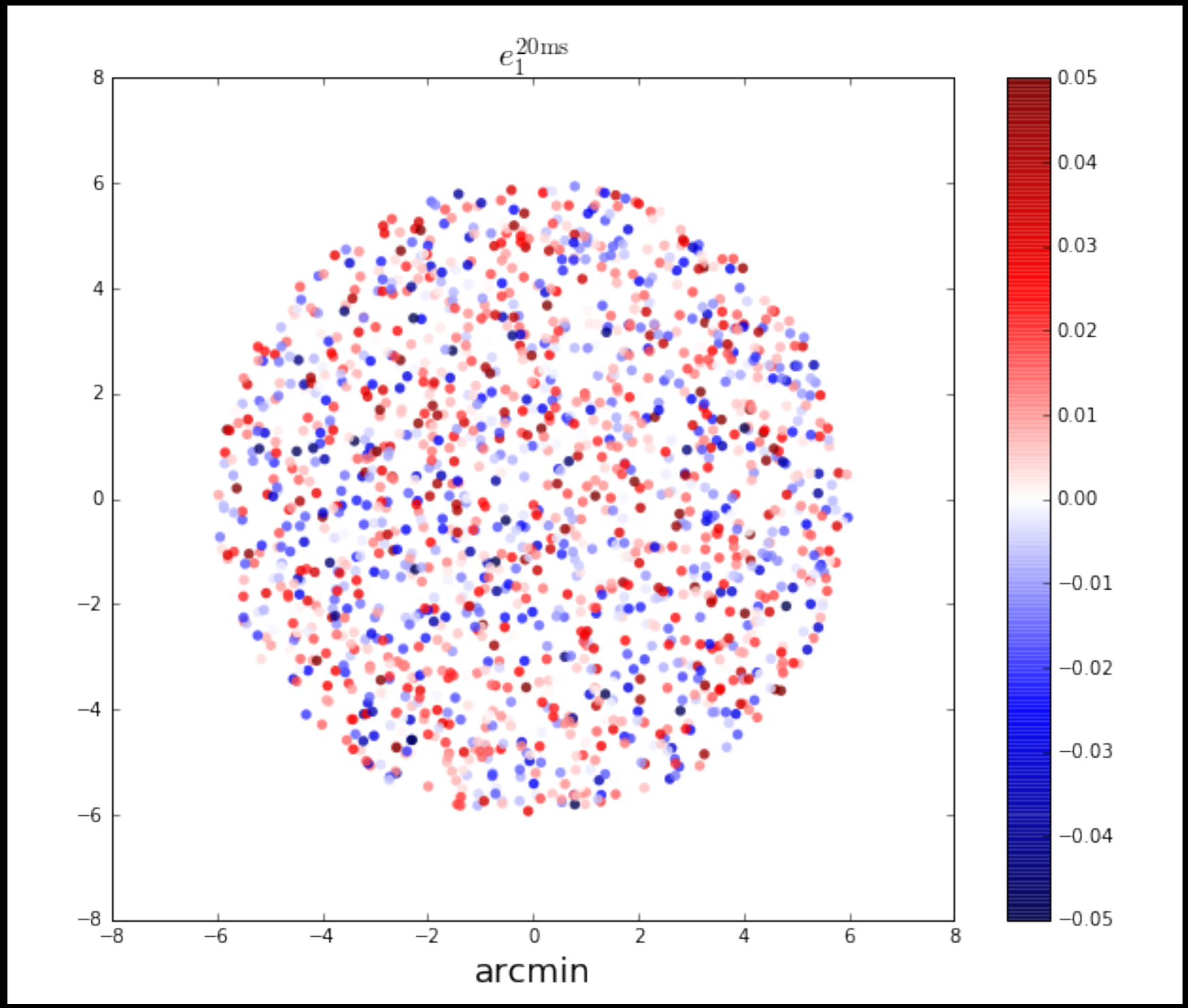


PSFs across the field of view



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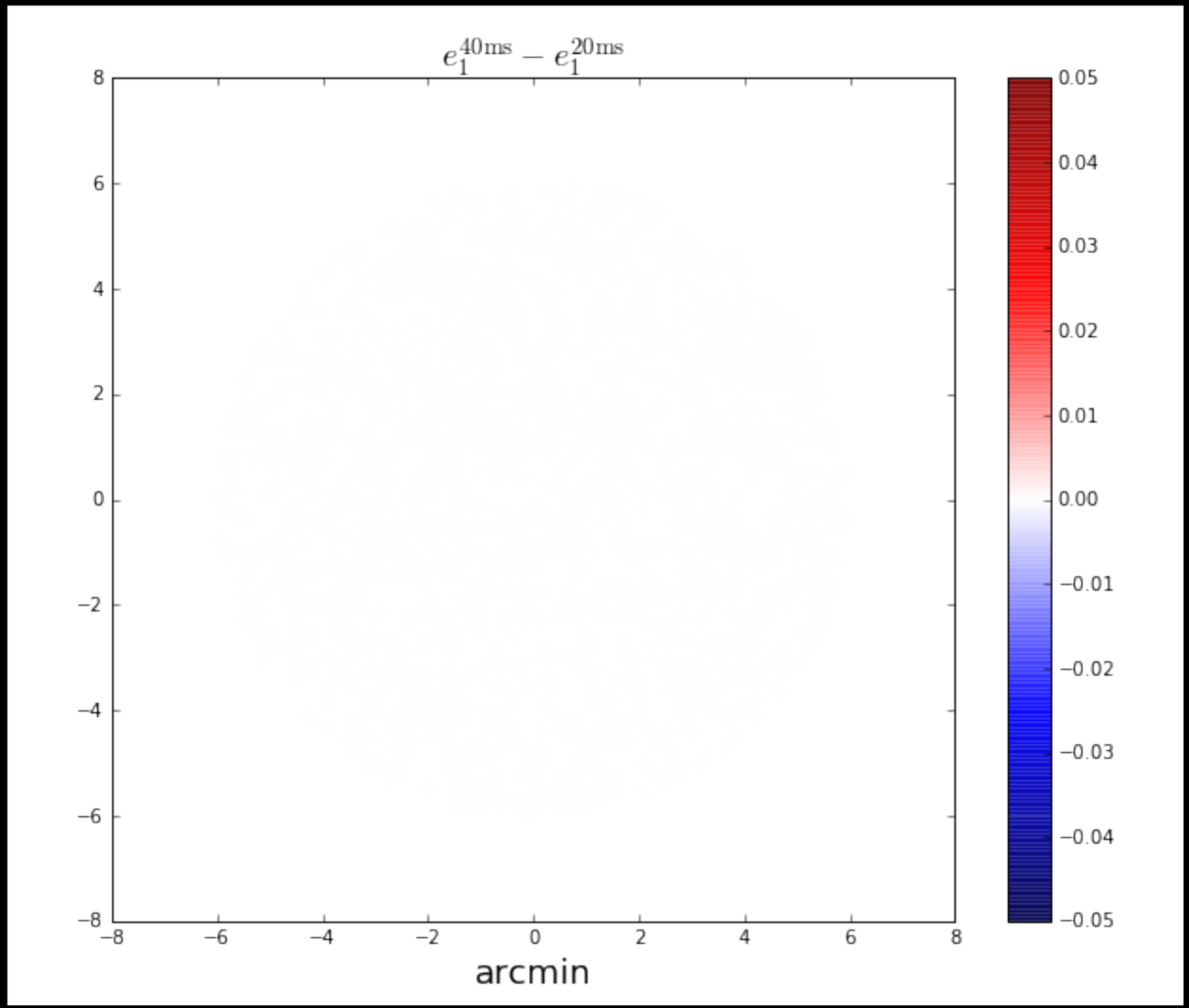

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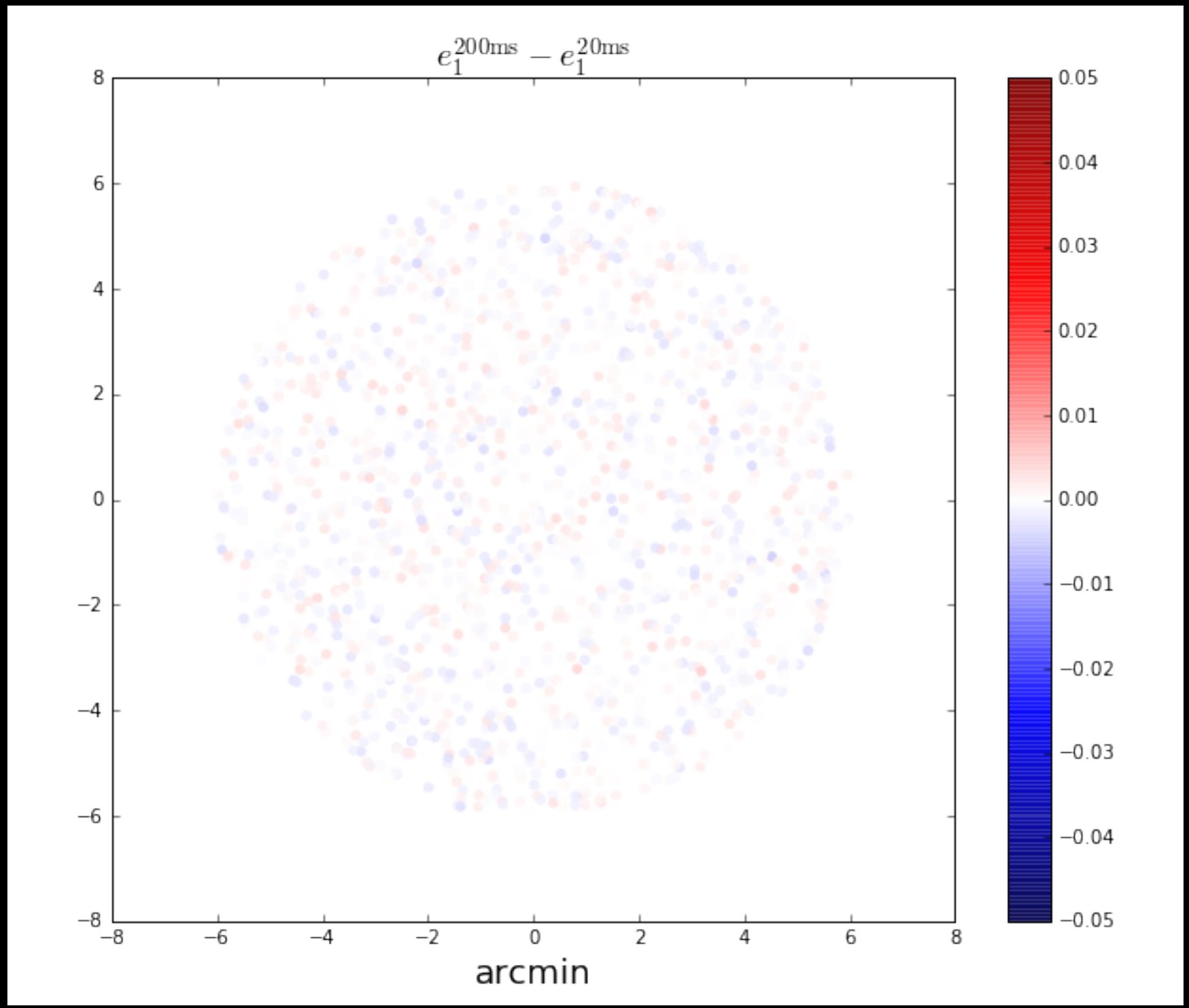

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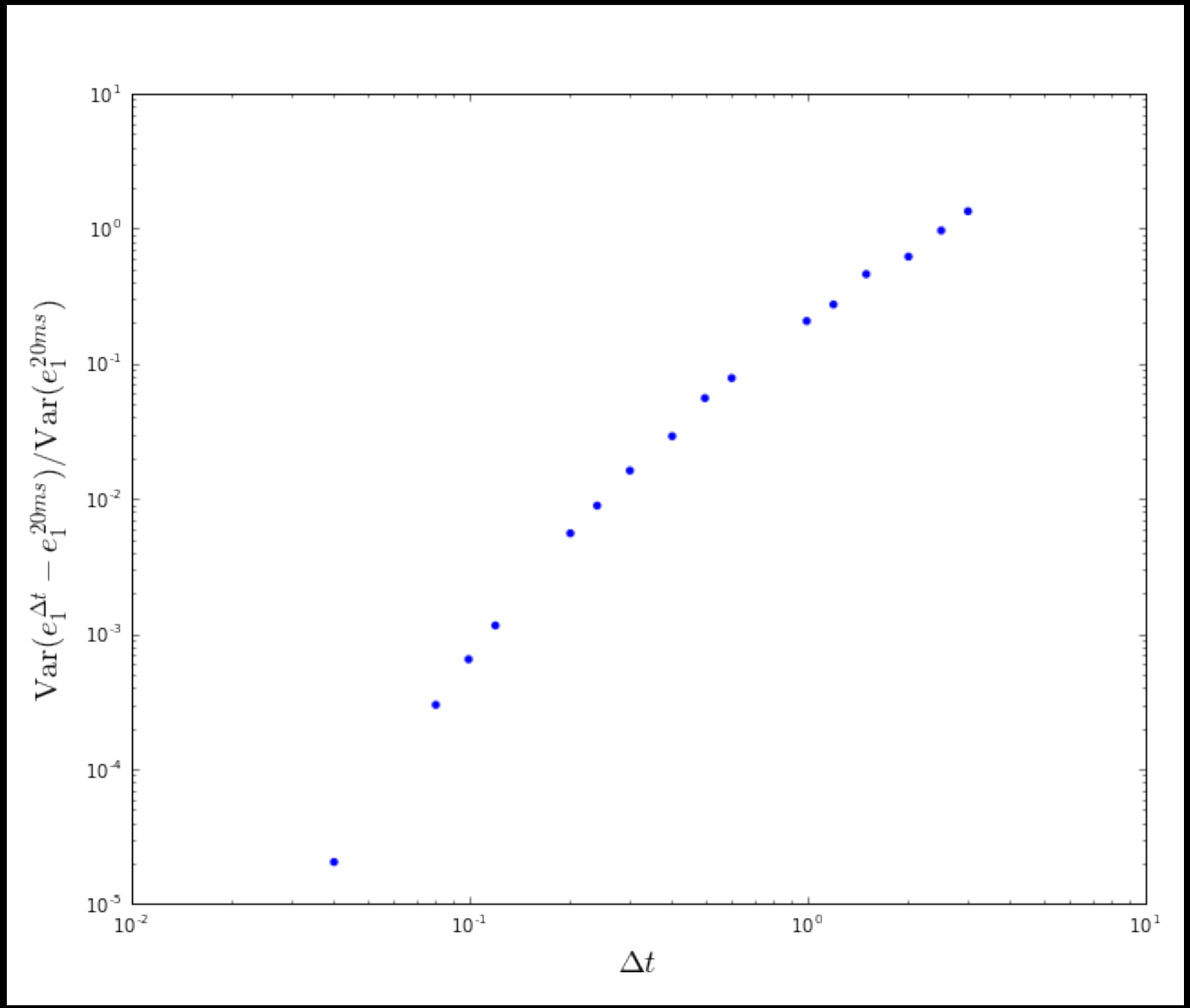

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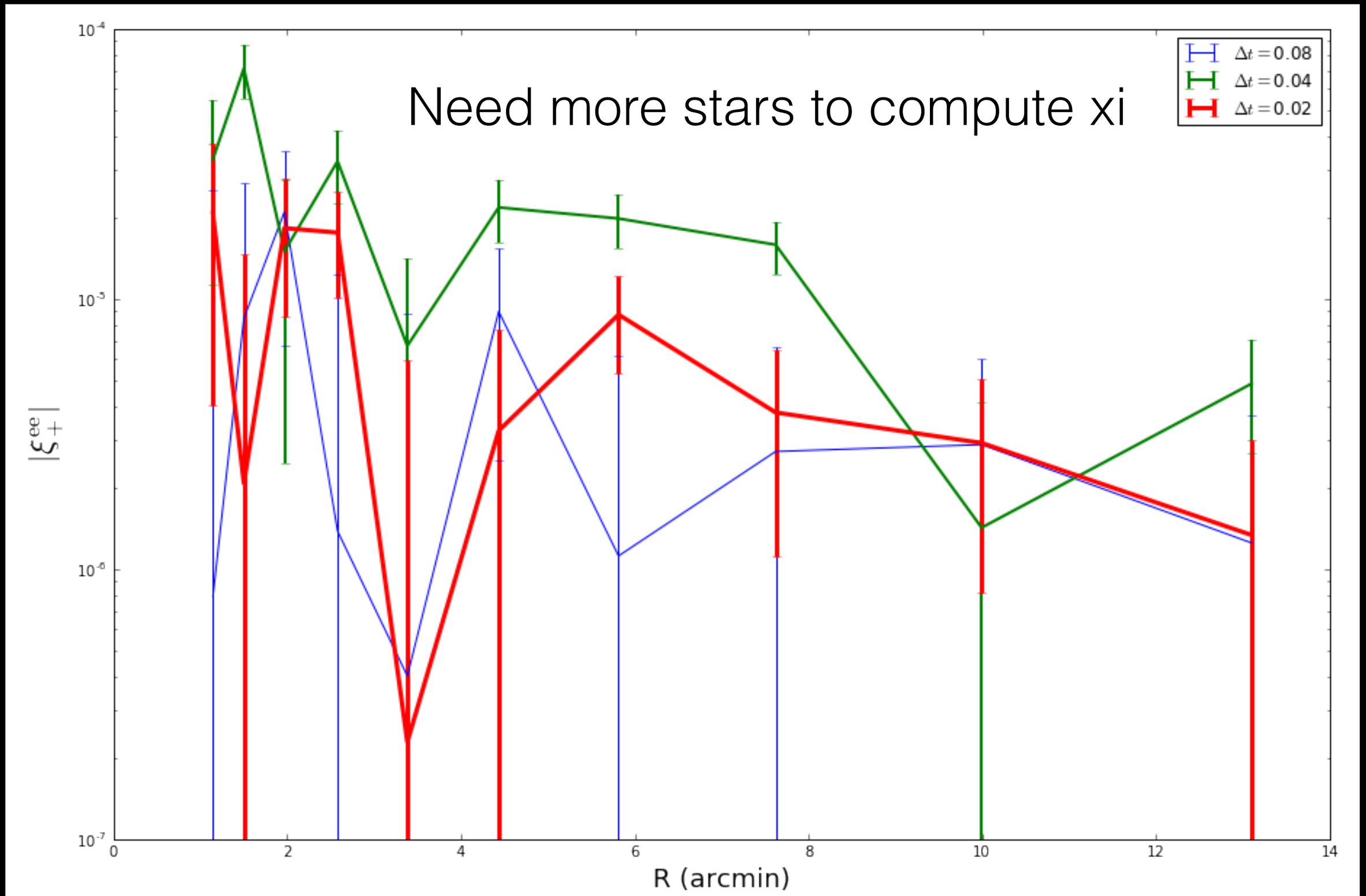


Questions.

- Appropriate atmospheric screen parameters? Number of layers?
- What are requirements for “realism?”
- What are requirements for “realistic level of complexity?”

Backup slides

Conclusions & todo

- Cautiously optimistic that can reduce running time of single monochromatic atmospheric PSF from ~few hours to ~few minutes while maintaining a “realistic level of complexity.”

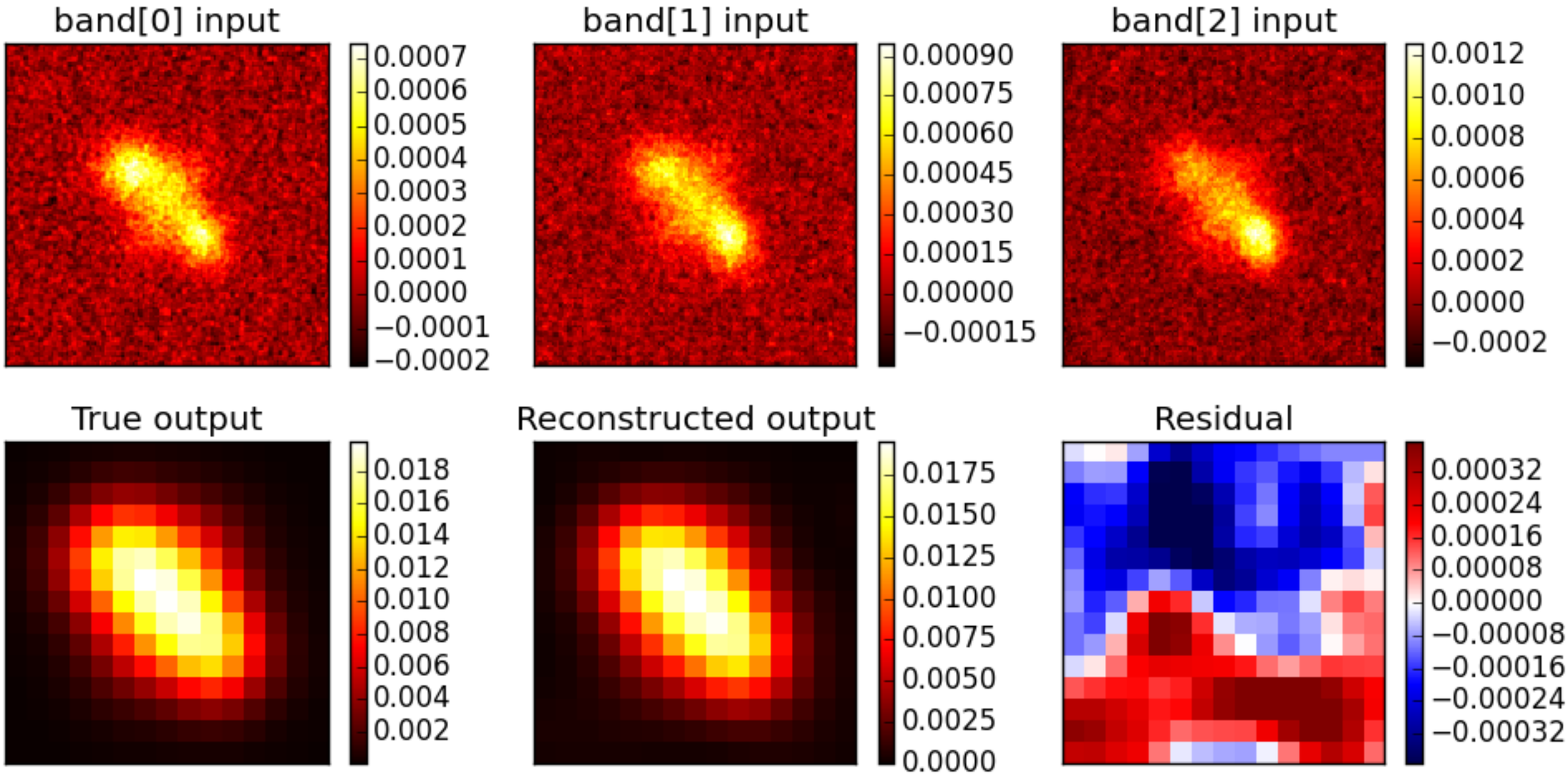
- Exact level of realism is tricky.

    - In particular, need to verify that atmospheric PSF correlation function is “realistic.”

    - What are are the requirements?

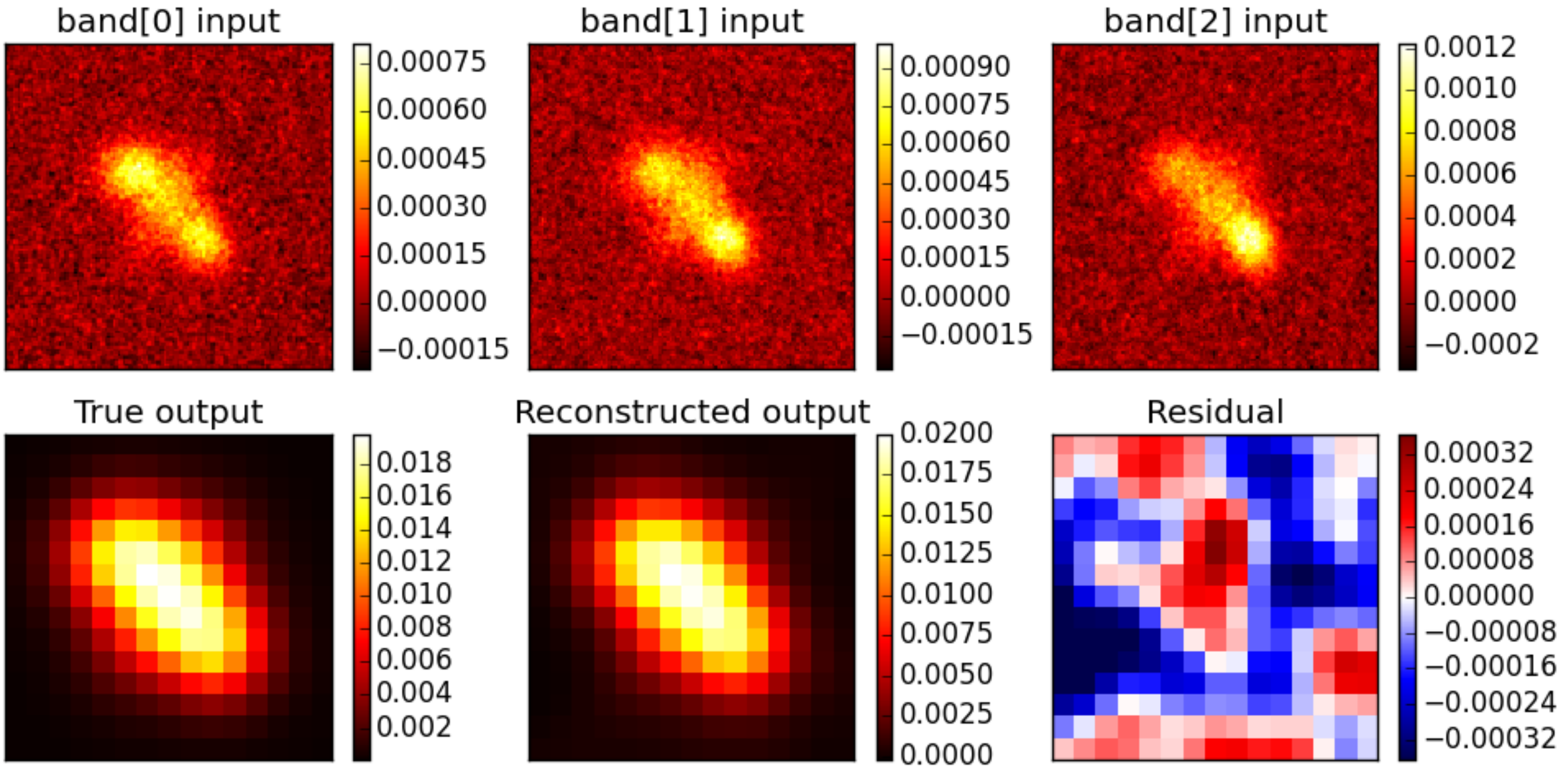
(Toy) example

- r-, i-, z-like input filters, out-of-phase output filter and LSST-like PSF, pixel scale.



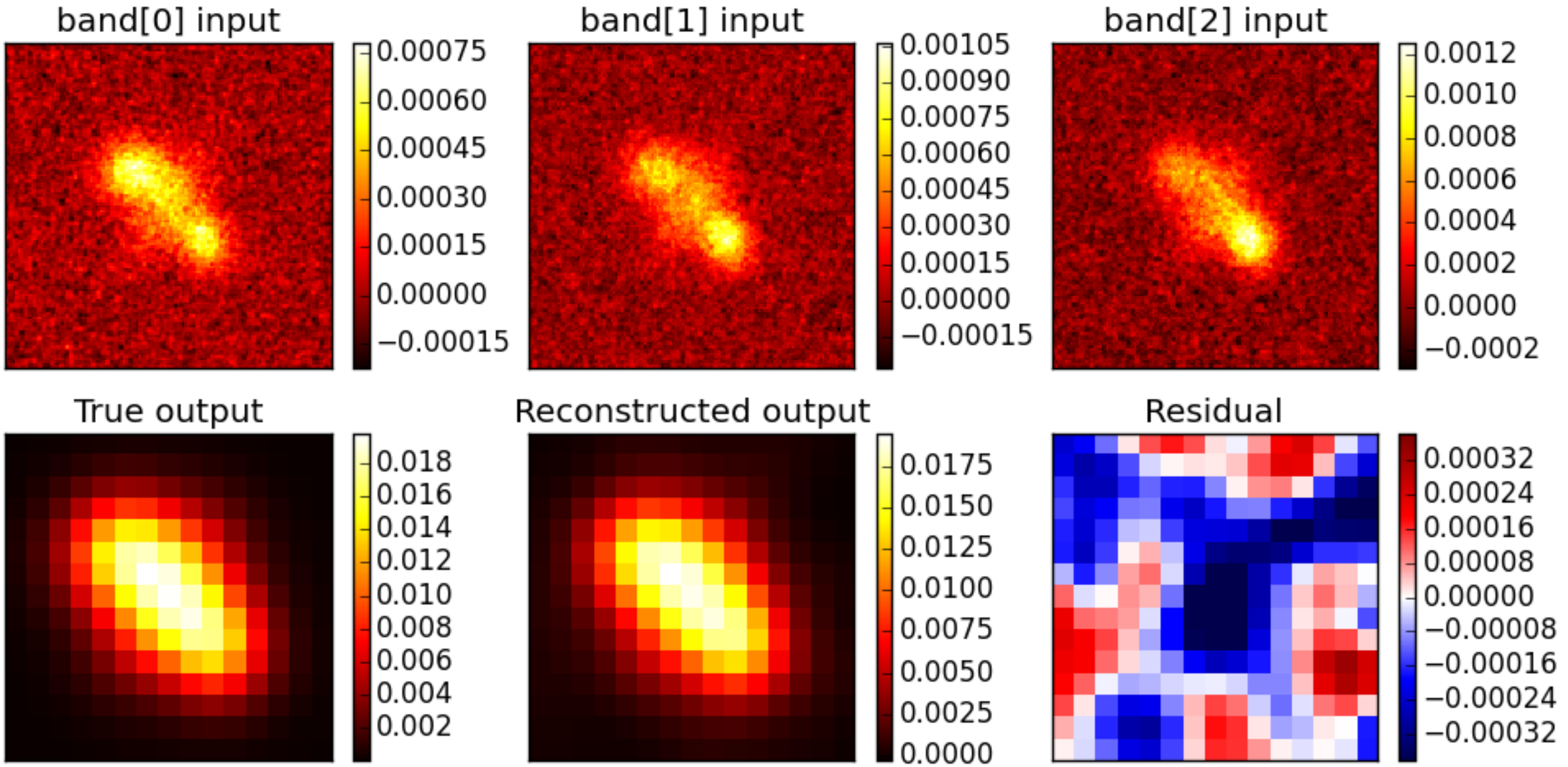
(Toy) example

- r-, i-, z-like input filters, out-of-phase output filter and LSST-like PSF, pixel scale. Different random seed.



(Toy) example

- r-, i-, z-like input filters, out-of-phase output filter and LSST-like PSF, pixel scale. Yet another different random seed.



Planes of interest and relations required for FFTs

$$P(u,v)\exp\left(\frac{-2\pi i}{\lambda}W(u,v)\right)$$

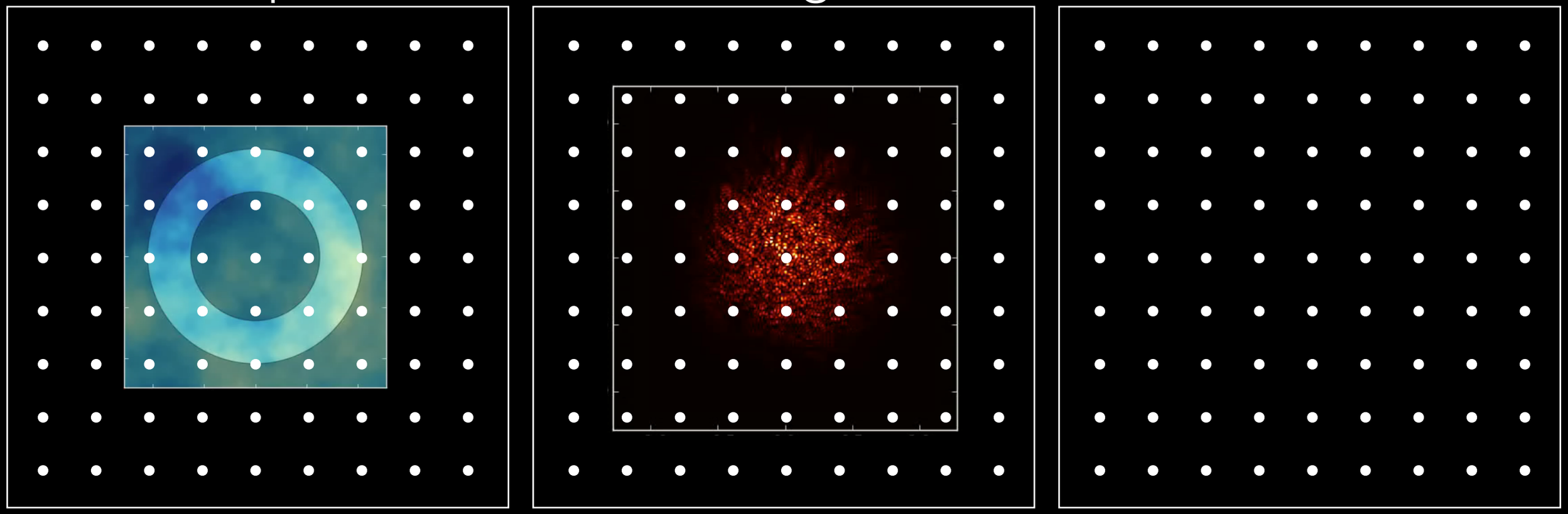
$$\left|\mathcal{F}\left[P(u,v)\exp\left(\frac{-2\pi i}{\lambda}W(u,v)\right)\right]\right|^2$$

$$\mathcal{F}^{-1}\left\{\left|\mathcal{F}\left[P(u,v)\exp\left(\frac{-2\pi i}{\lambda}W(u,v)\right)\right]\right|^2\right\}$$

Pupil

Image

Fourier



$\leftrightarrow \Delta L$

L

$\leftrightarrow \Delta\theta$

θ

$\leftrightarrow$ stepK

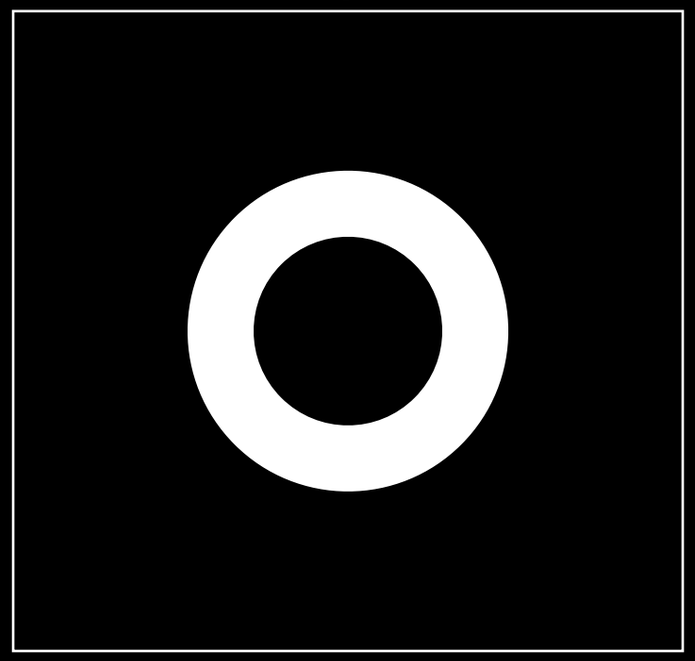
$2 \times \text{maxK}$

$$L = \frac{\lambda}{\Delta\theta} = \frac{\lambda \cdot \text{maxK}}{\pi}$$

$$\Delta L = \frac{\lambda}{\theta} = \frac{\lambda \cdot \text{stepK}}{2\pi}$$

Obscured Airy

Pupil

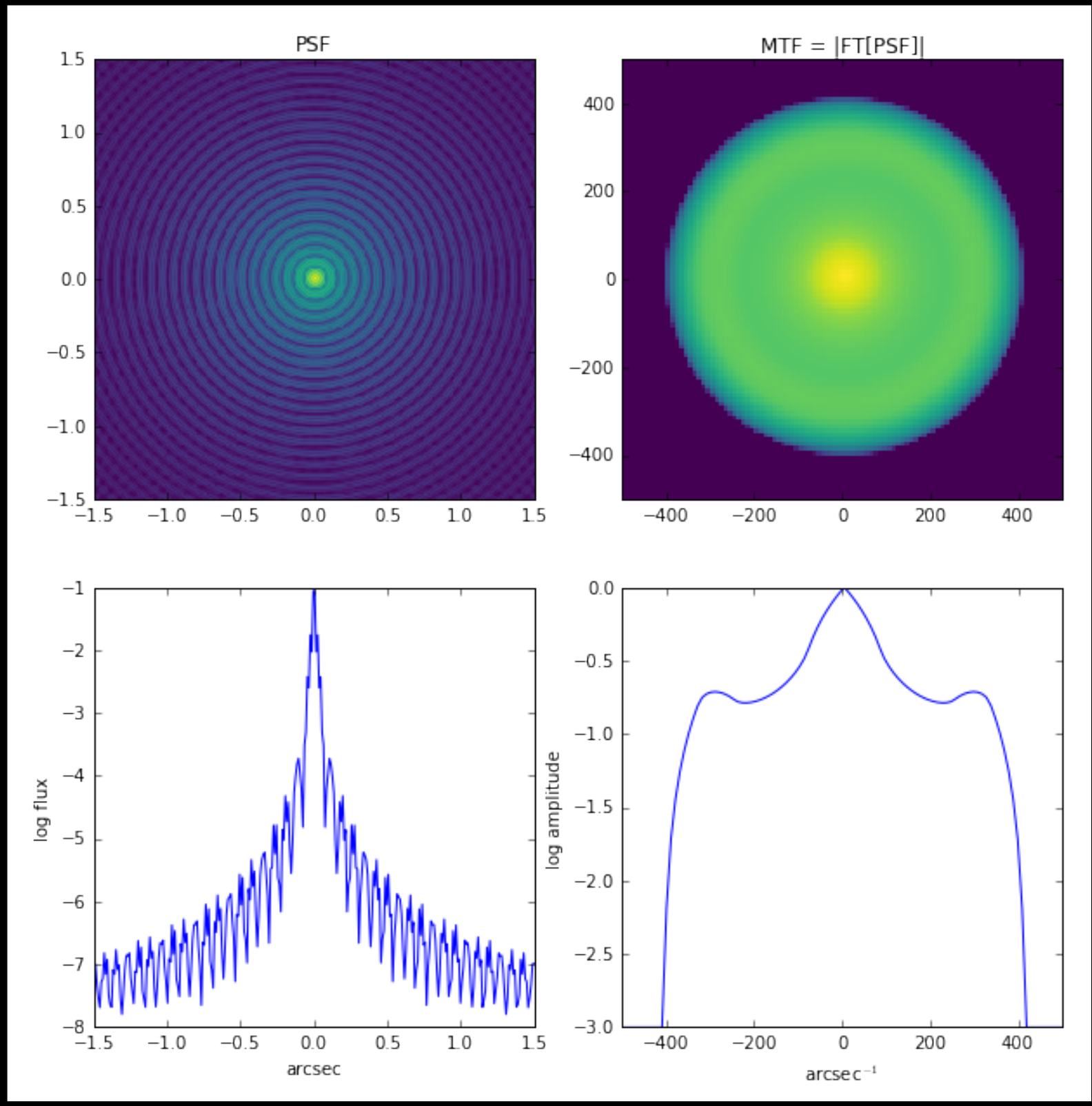


need large maxK

compact PSF

can use large stepK

maxK/stepK ~ 200



Kolmogorov

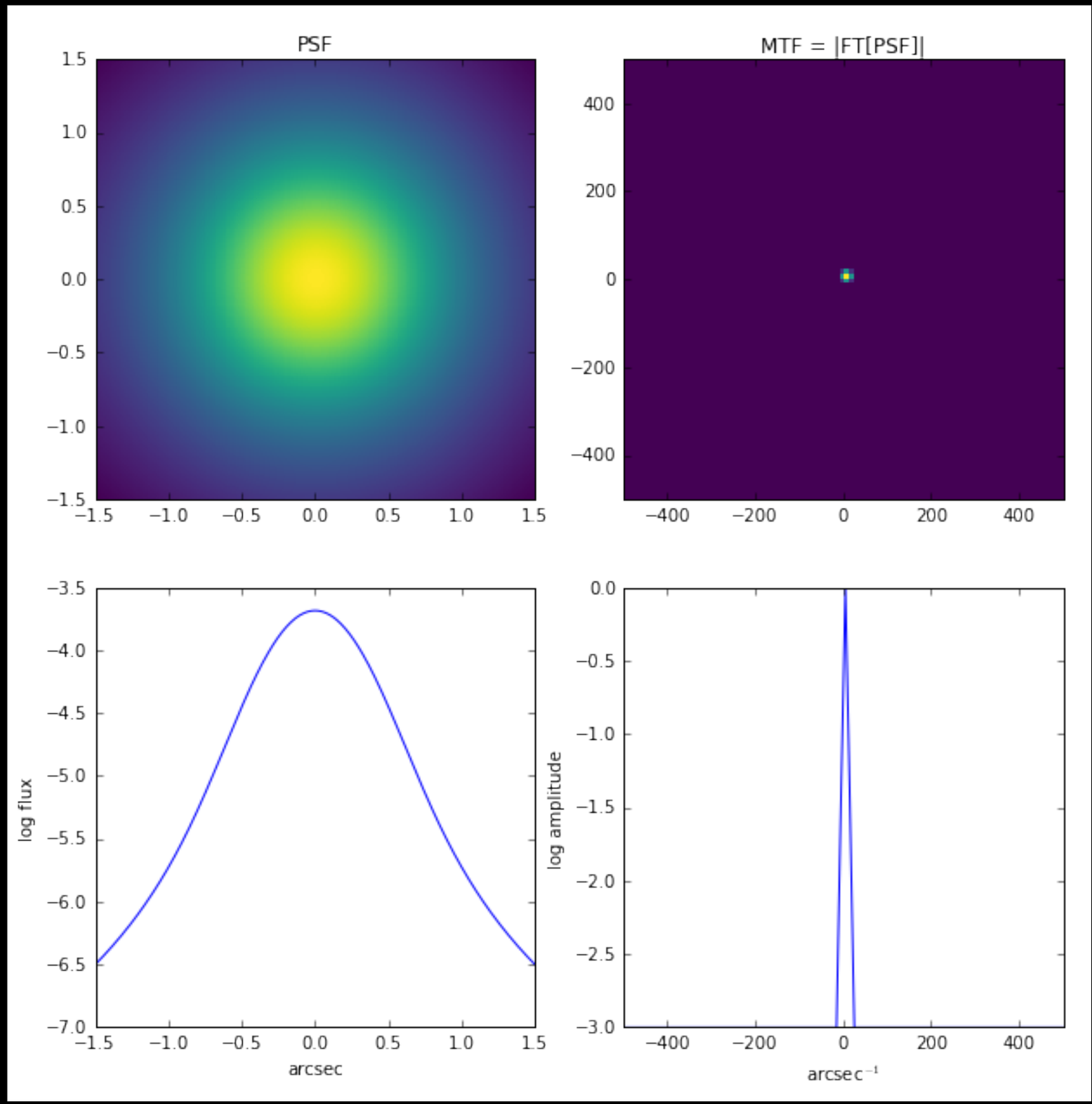
No pupil

can use small maxK

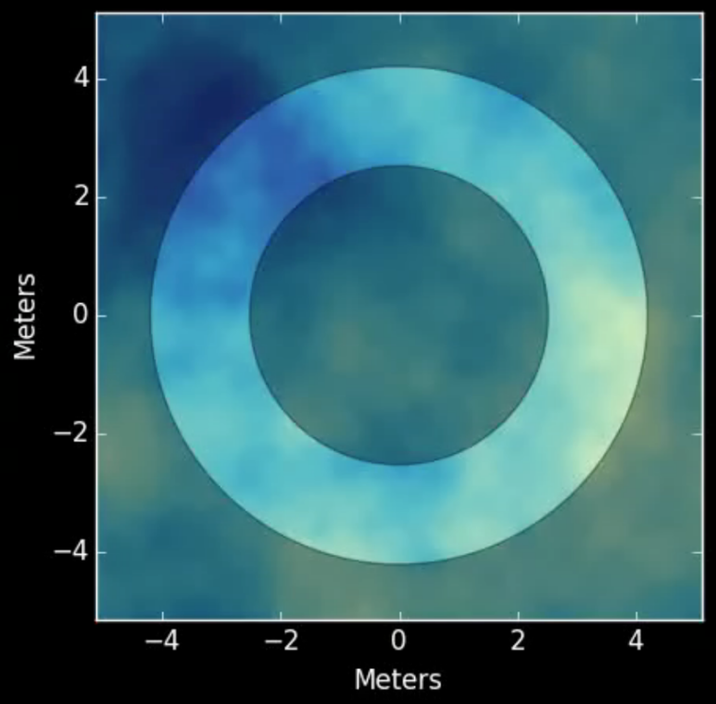
wide PSF

need small stepK

maxK/stepK ~ 25

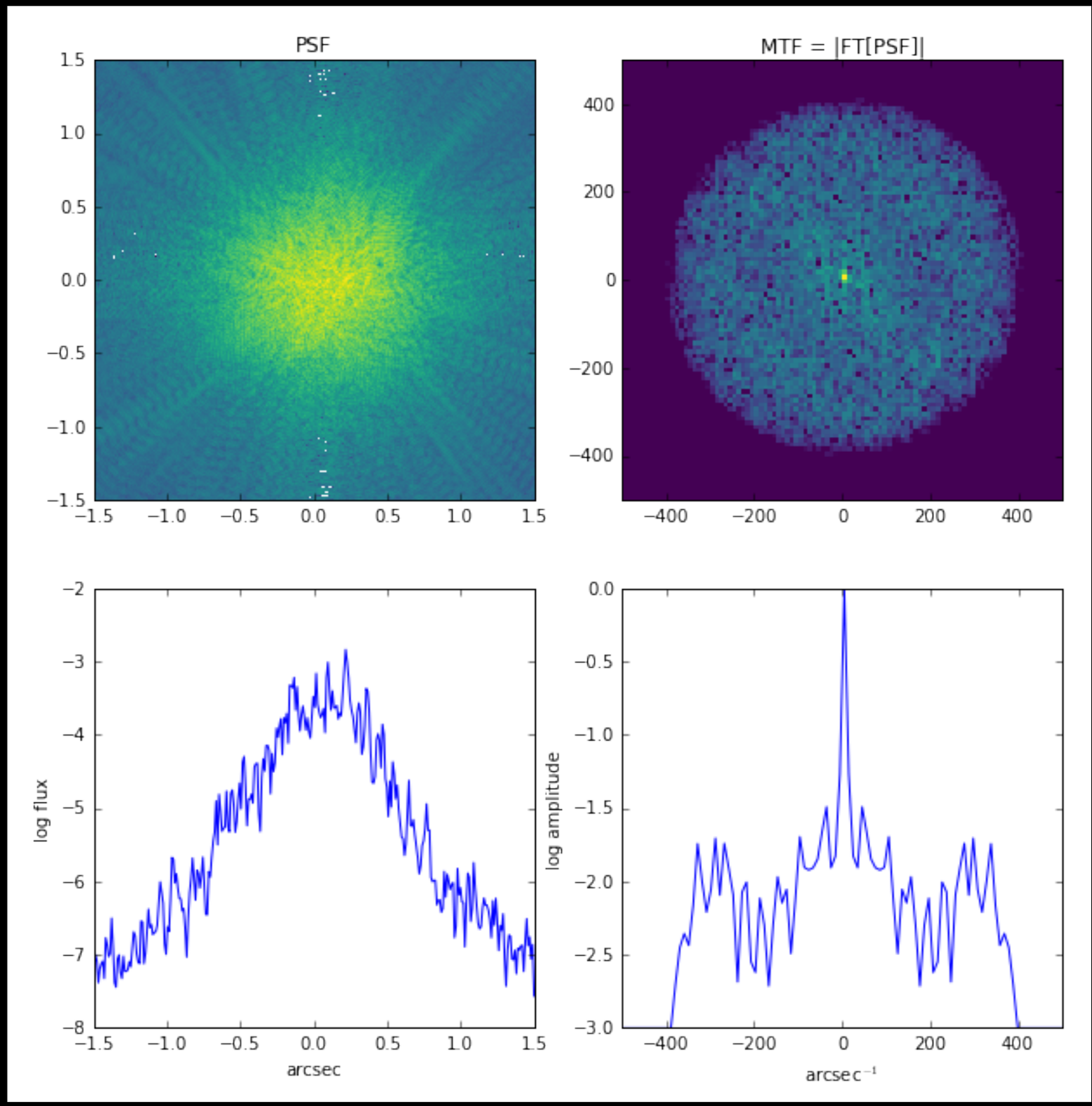


Instantaneous Atmospheric



requires large maxK
wide PSF
need small stepK

GalSim assumed
maxK/stepK ~800
could have
used ~200 (!)

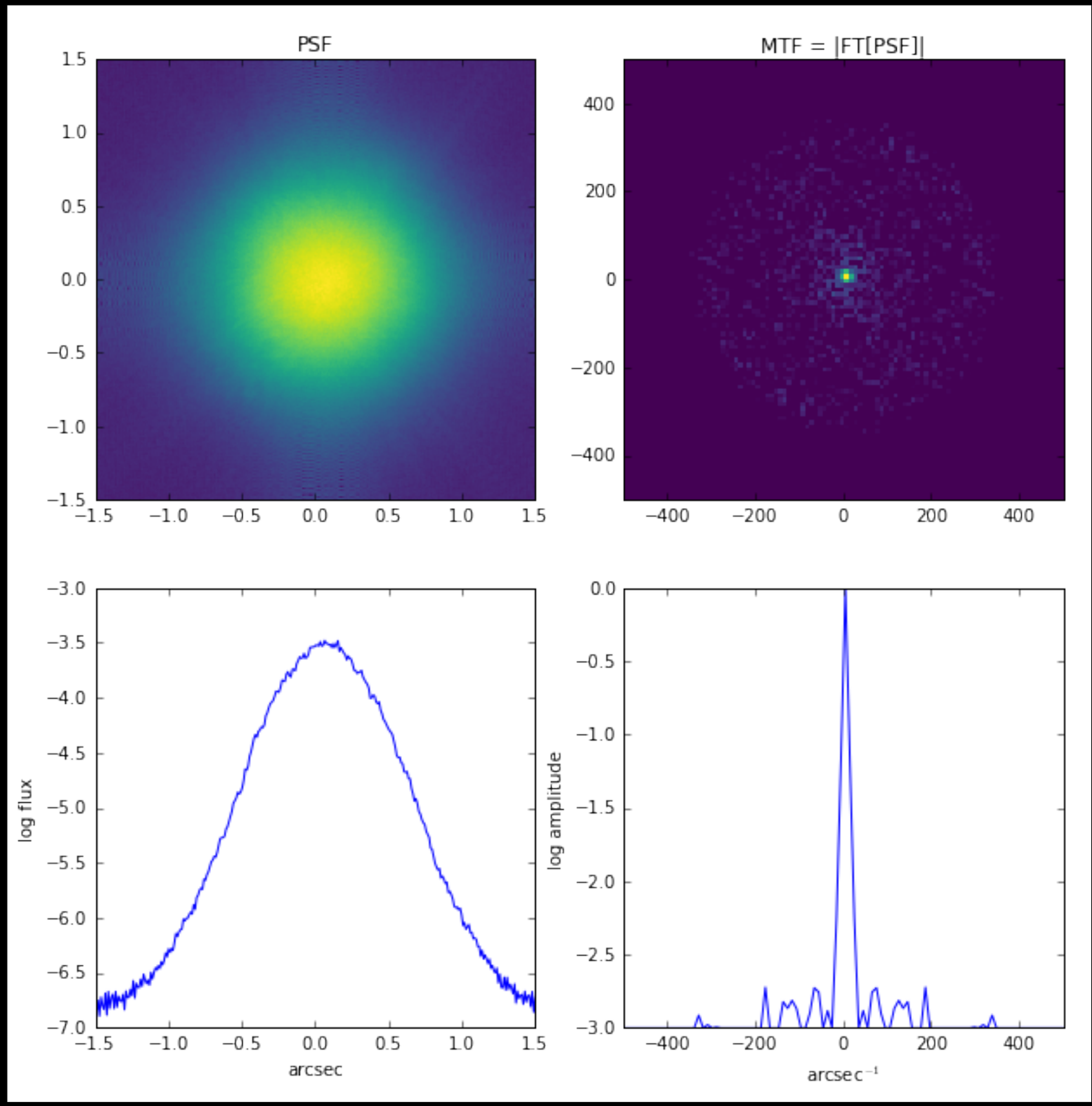


3 seconds cumulative atmospheric

No single equivalent pupil

OTF = autocorrelation of pupil (MTF = |OTF|)

even though cumulative OTF is compact, need whole aperture to compute needed correlations.

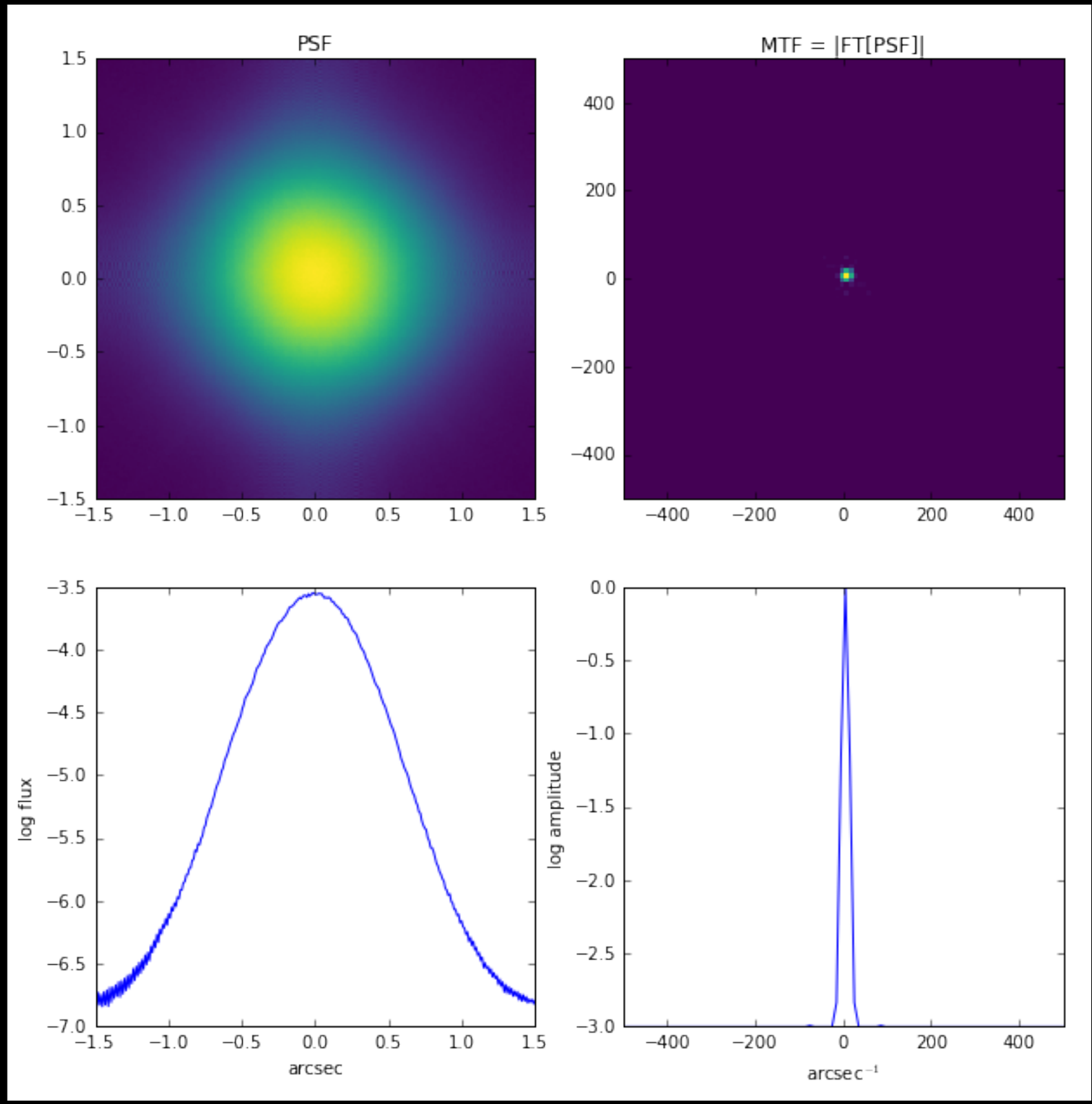


30 seconds cumulative atmospheric

Now similar to Kolmogorov

maxK/stepK ~ 25

Large k modes disappear. No need for oversampling.



Sampling

- Expected atmospheric PSFs would require the worst attributes of Airy (large maxK) and Kolmogorov (small stepK).

- Simulated atmospheric PSF appears to be more compact than Kolmogorov, so possibly don’t need quite as small of stepK as is currently being employed.

- Needs more study.

More Timing

```
[josh@Trogdor ~/sandbox/speed_accuracy]$ python speed.py --oversampling 1.0 --pad_factor 1.0 --max_size 1e6 --exptime 30.0
Making atmosphere
Done making atmosphere
(1536, 1536)
|>------------------------------------------------------------------|  19 /6.0k (  0.32%) ETA 51m39s
```

Restrict output size to 5 arcsec

```
[josh@Trogdor ~/sandbox/speed_accuracy]$ python speed.py --oversampling 1.0 --pad_factor 1.0 --max_size 5 --exptime 30.0
Making atmosphere
Done making atmosphere
(768, 768)
|=>----------------------------------------------------------------|  85 /6.0k (  1.42%) ETA 10m42s
```

Restrict output size to 2 arcsec

```
[josh@Trogdor ~/sandbox/speed_accuracy]$ python speed.py --oversampling 1.0 --pad_factor 1.0 --max_size 2 --exptime 30.0
Making atmosphere
Done making atmosphere
(384, 384)
|===>--------------------------------------------------------------| 263 /6.0k (  4.38%) ETA  1m56s
```