AN EHT SCATTERING FRAMEWORK IN JULIA

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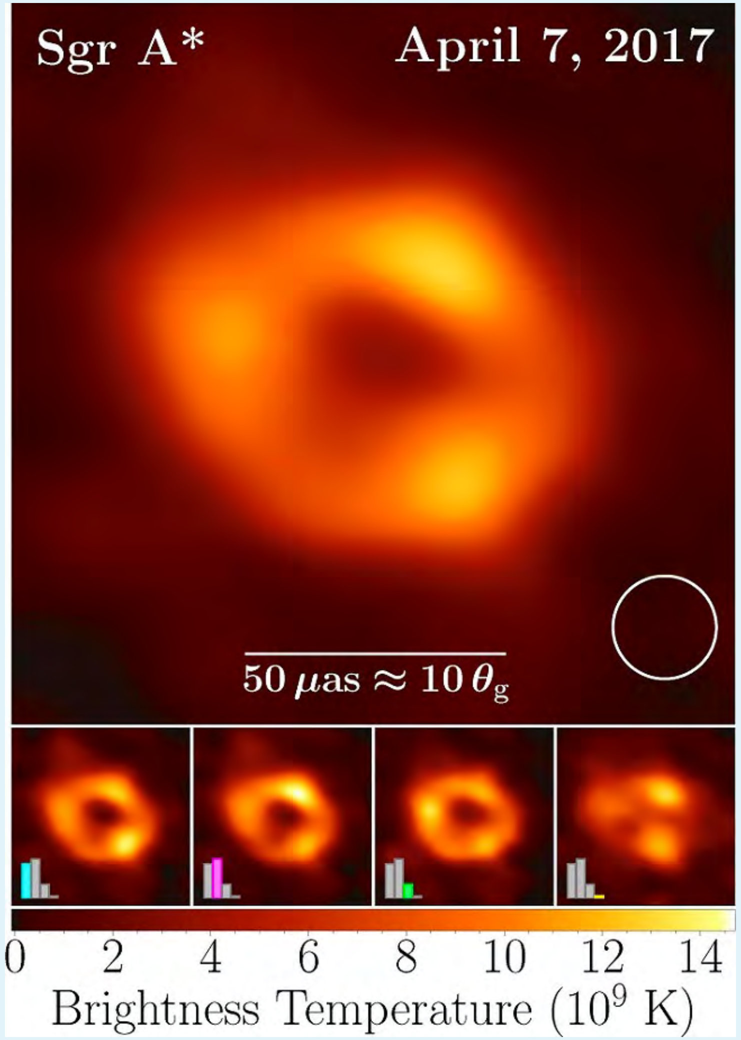
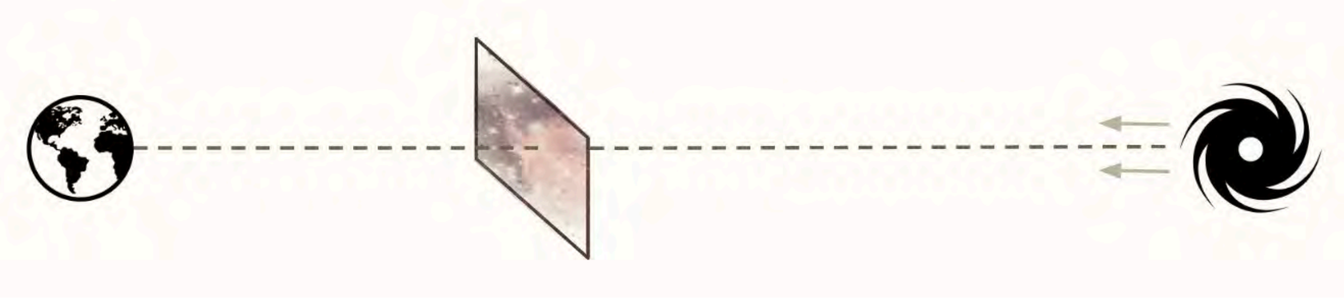
INTRODUCTION

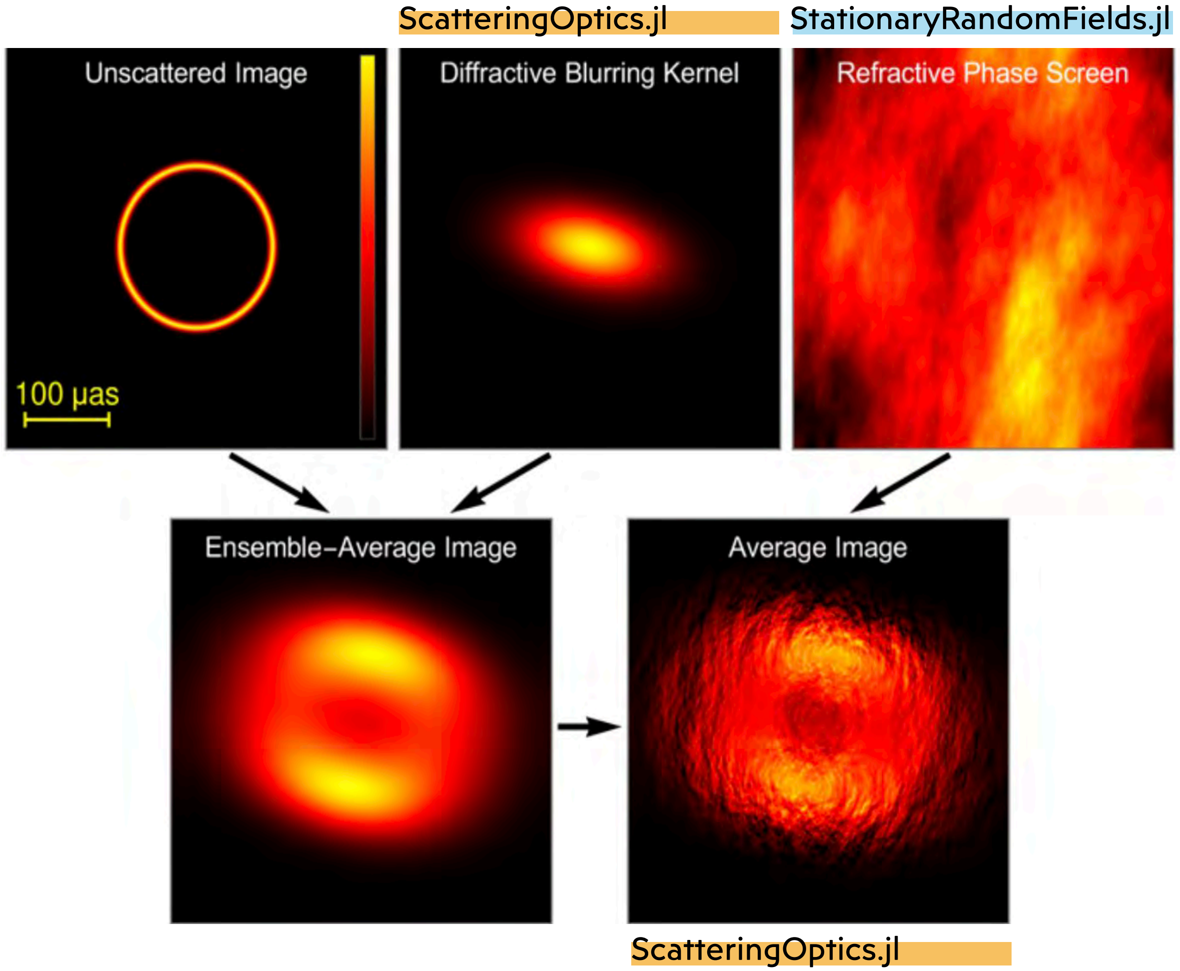




- Event Horizon Telescope uses Very Long Baseline Interferometry to image M87* and Sgr A* black holes
- Sgr A* imaging faces unique scattering mitigation challenges due to ISM presence
- Milky Way spiral arm acts as a scattering screen between Earth and source

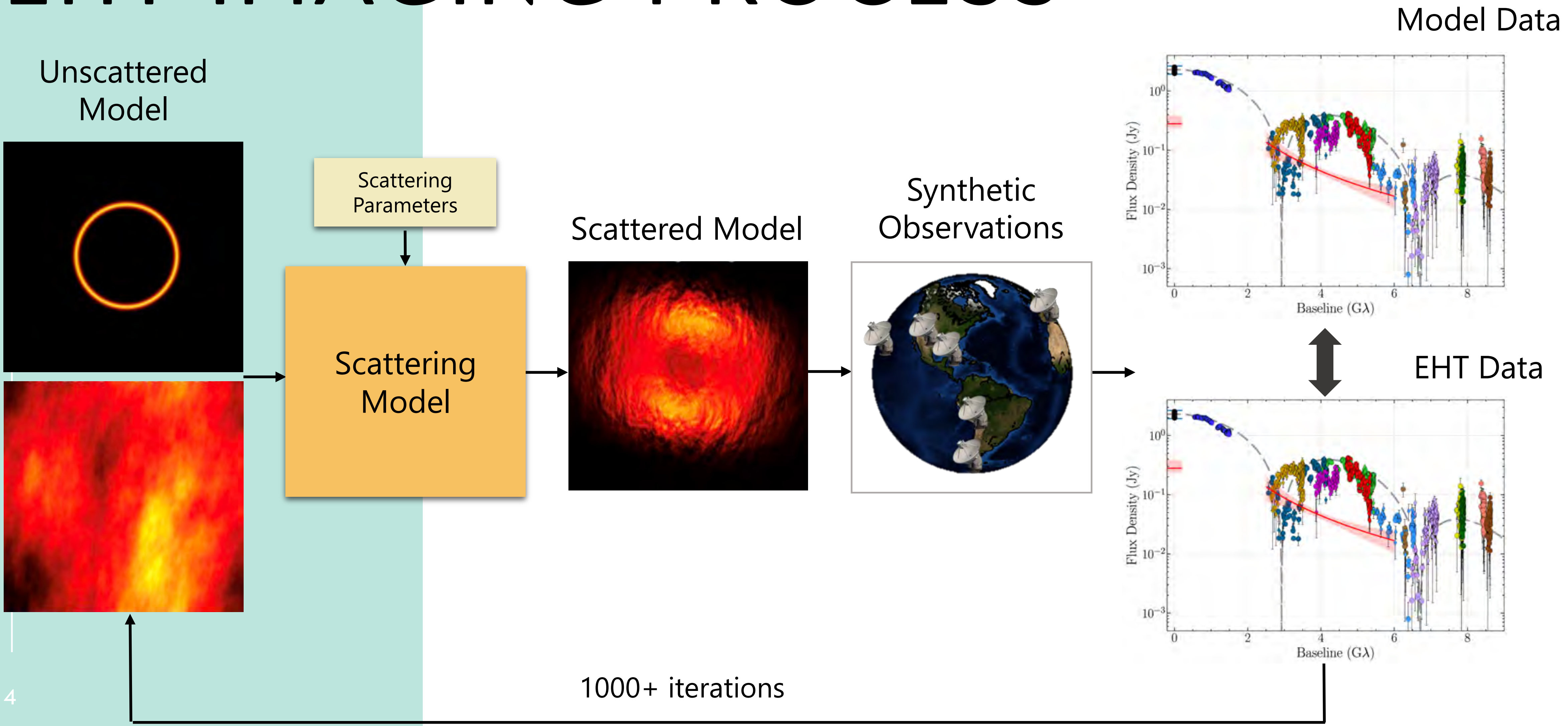
ISM SCATTERING

- Diffractive scattering:
  - from small-scale irregularities
  - short timescales
- Refractive scattering:
  - large scale
  - time scale >> observation
  - introduces refractive substructures



$$
\begin{aligned}
I_{\mathrm{a}}(\boldsymbol{r}) &\approx I_{\mathrm{ea}}\left(\boldsymbol{r} + r_{\mathrm{F}}^{2}\nabla\phi_{\mathrm{r}}(\boldsymbol{r})\right) \\
&\approx I_{\mathrm{ea}}(\boldsymbol{r}) + r_{\mathrm{F}}^{2}\left[\nabla\phi_{\mathrm{r}}(\boldsymbol{r})\right]\cdot\left[\nabla I_{\mathrm{ea}}(\boldsymbol{r})\right] \\
&= I_{\mathrm{src}}(\boldsymbol{r}) * G(\boldsymbol{r}) + r_{\mathrm{F}}^{2}\left[\nabla\phi_{\mathrm{r}}(\boldsymbol{r})\right]\cdot\left[\nabla\left(I_{\mathrm{src}}(\boldsymbol{r}) * G(\boldsymbol{r})\right)\right].
\end{aligned} \tag{2}
$$

EHT IMAGING PROCESS

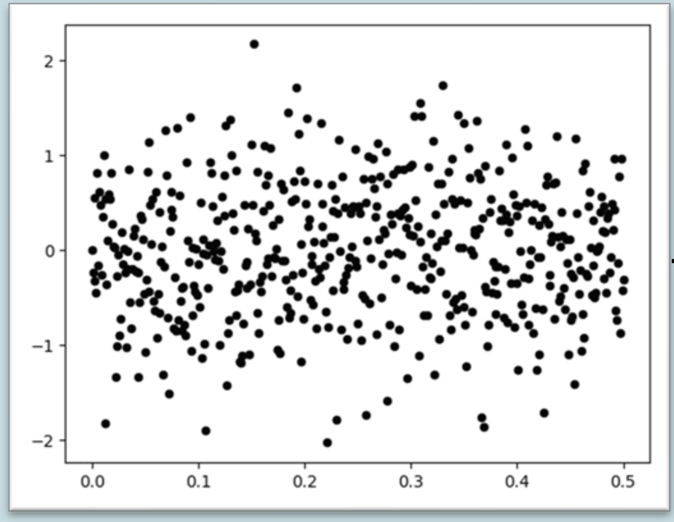


STATIONARY RANDOM FIELDS

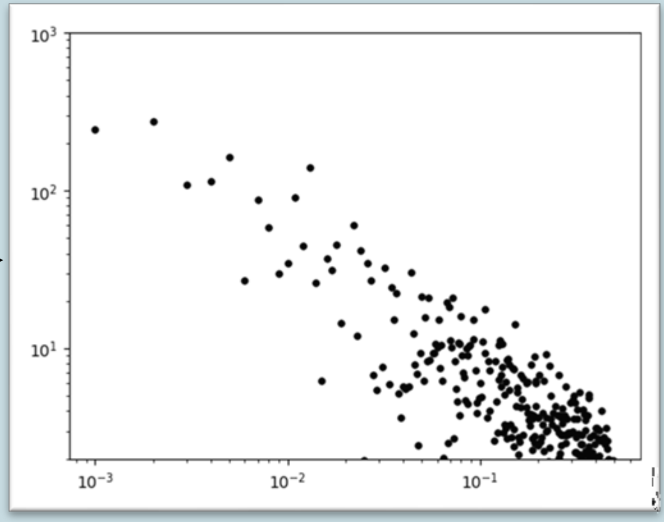
StationaryRandomFields.jl Public

GENERATING SIGNAL NOISE

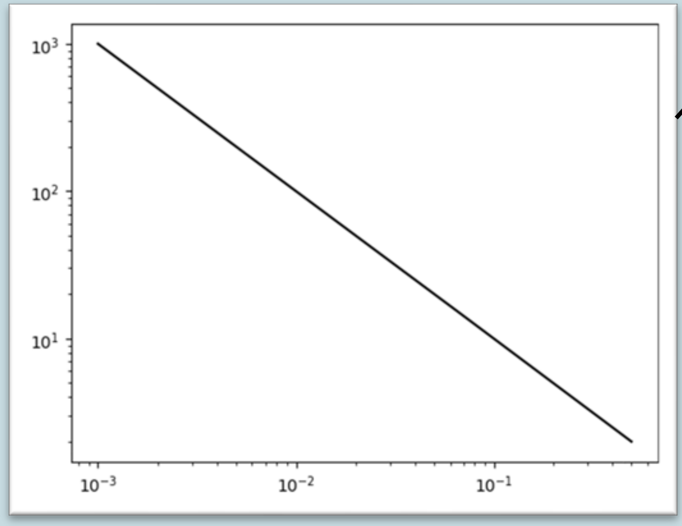
Fourier Space Gaussian Noise



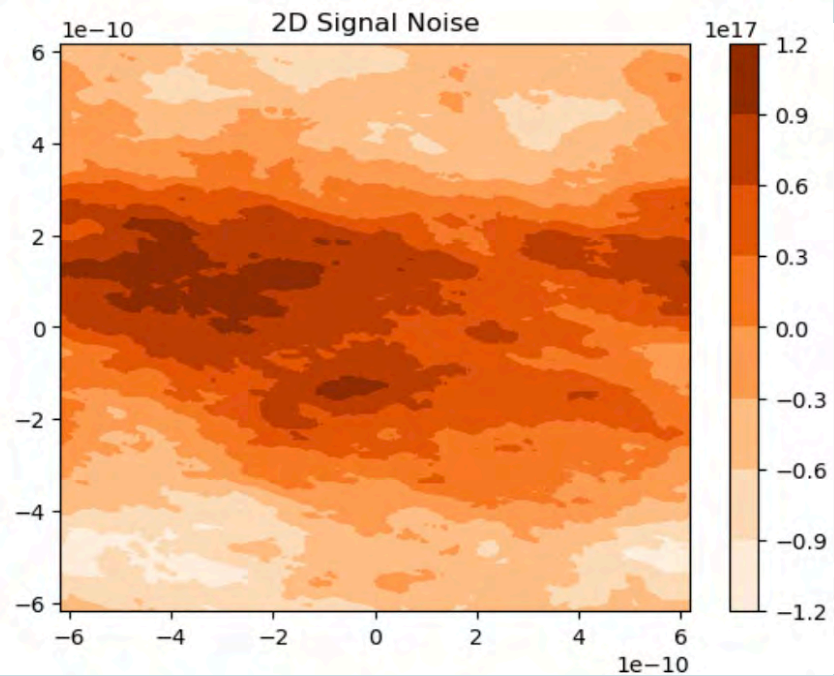
Power Scaled Fourier Noise



Inverse Fourier Transform to signal space



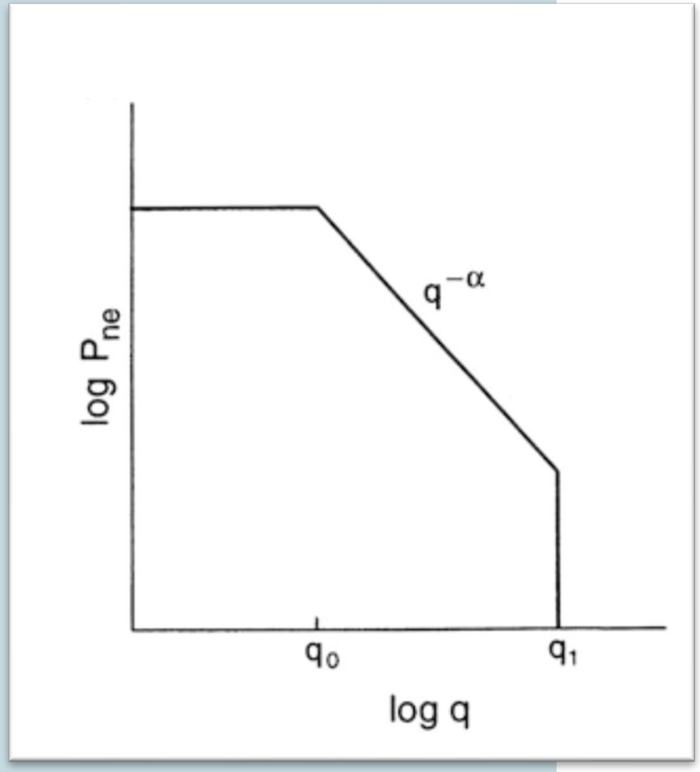
Fourier Space Power Law Spectrum



Correlated signal noise!

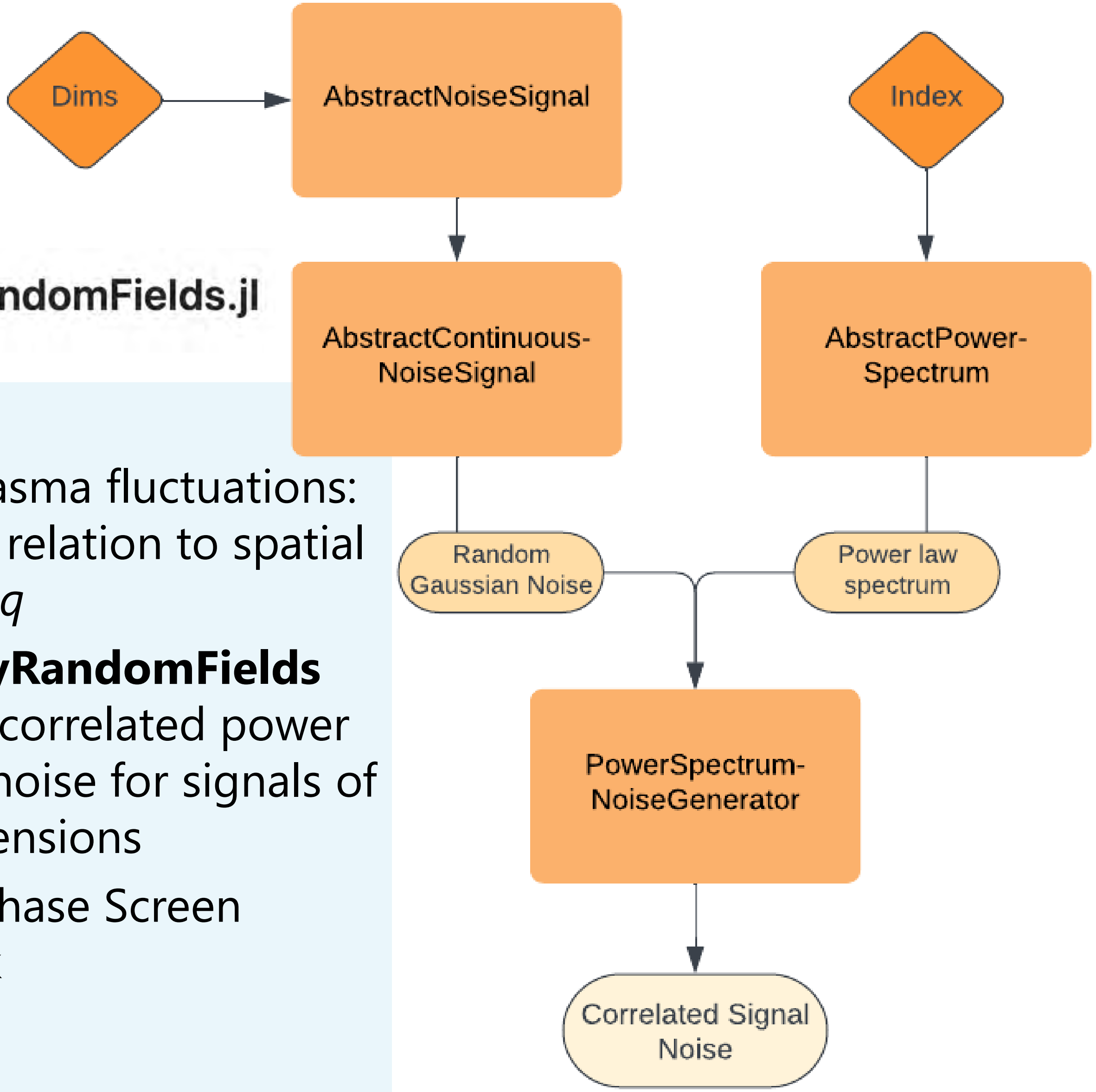
REFRACTIVE PHASE SCREEN

Fourier Space Power **Law** Fluctuations



StationaryRandomFields.jl

- Ionized plasma fluctuations: power law relation to spatial frequency *q*
- **StationaryRandomFields** generates correlated power spectrum noise for signals of given dimensions
- Provides Phase Screen framework



SCATTERING OPTICS

DIFFRACTIVE KERNEL

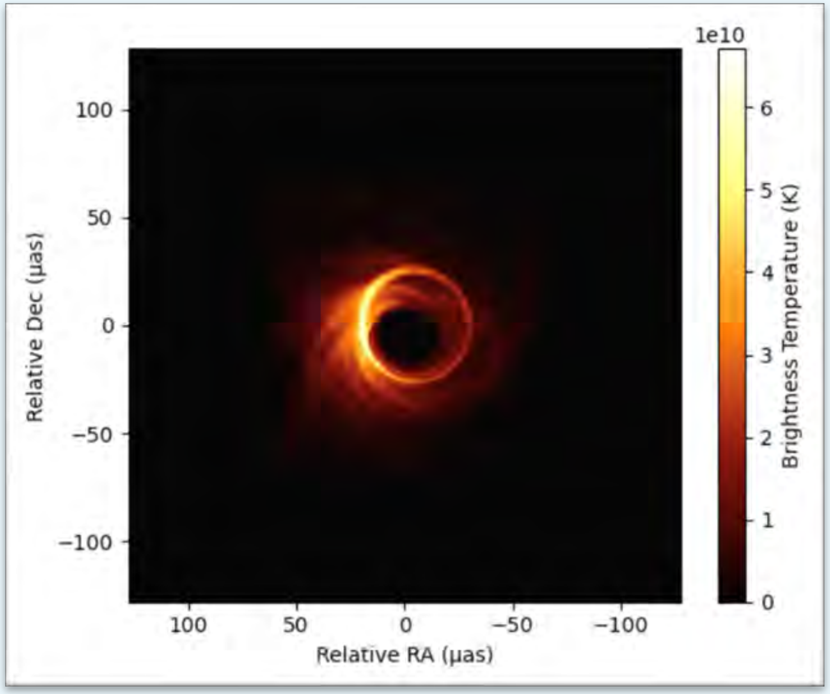
Ensemble Average Image: diffractively scattered source image

Phase Structure Function

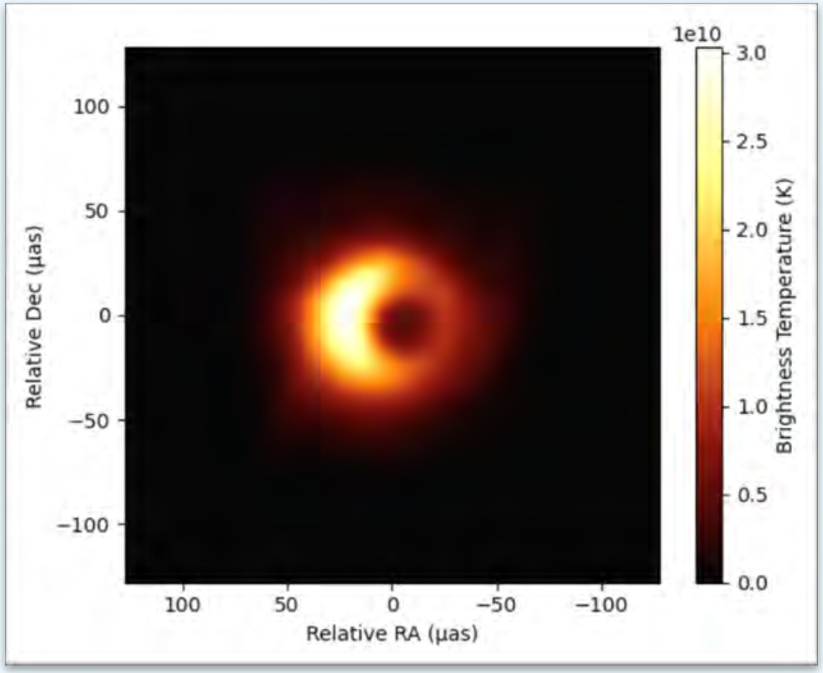
$$I_{ea} = I_{src} * I_{kernel}$$

$$V_{ea}(\vec{b}) = V_{src}(\vec{b}) \exp\left[-\frac{1}{2} D_\phi\left(\frac{\vec{b}}{1+M}\right)\right]$$

$$D_\phi(r,\phi) = \left[\frac{D_{maj}(r)+D_{min}(r)}{2}\right] + \left[\frac{D_{maj}(r)-D_{min}(r)}{2}\right]\cos[2(\phi-\phi_0)]\ .(35)$$



Source Image



Ensemble Average Image

PHASE STRUCTURE FUNCTION: A CLOSER LOOK!

so many equations.

$$D_{\min}(r) = \frac{\mathcal{C}(1-\zeta_0)}{2} B_{\min} \Big(\ldots$$
$$\Big\{ \Big[1 + \Big(\frac{2}{\alpha B_{\min}} \Big) \ldots$$

$$D_{\phi}(\vec{r}) = \int_0^{2\pi} \frac{dD_{\phi}(\vec{r})}{dz} P(\phi_z) d\phi_z \, .$$

$$\frac{dD_{\phi}(\vec{r})}{dz} = \frac{\lambda^2 Q_z}{2\pi^2} \int (q r_{\mathrm{in}})^{-(\alpha+2)} \exp(-q^2 r_{\mathrm{in}}^2) \left[1 - \cos(\vec{q}\cdot\vec{r}) \right] \delta(\phi_q - \phi_z) d^2 q$$
$$= \frac{\lambda^2 Q_z}{2\pi^2 r_{\mathrm{in}}^2} \int_0^{\infty} q'^{-(\alpha+1)} \exp(-q'^2) \left[1 - \cos\left(q' \frac{r}{r_{\mathrm{in}}} \cos(\phi - \phi_z) \right) \right] dq'$$
$$= \frac{4\mathcal{C}}{\alpha} \left[M\left(-\frac{\alpha}{2}, \frac{1}{2}, -\frac{r^2}{4 r_{\mathrm{in}}^2} \cos^2(\phi - \phi_z) \right) - 1 \right], \quad (13)$$

$$D_{\mathrm{maj}}(r) = \frac{\mathcal{C}(1+\zeta_0)}{2} B_{\mathrm{maj}} \Big(\ldots$$
$$\Big\{ \Big[1 + \Big(\frac{2}{\alpha B_{\mathrm{maj}}} \Big)^{2} \ldots$$

$$\ldots \; {}_1\tilde{F}_2 \left(\frac{1+\alpha}{2}; \frac{1}{2}, 1+\frac{\alpha}{2}; \frac{k_{\zeta,1}^2}{4} \right) . \quad (38)$$

$$\ldots \; {}_0\tilde{F}_1 \left(1+\frac{\alpha}{2}, \frac{k_{\zeta,1}^2}{4} \right) .$$

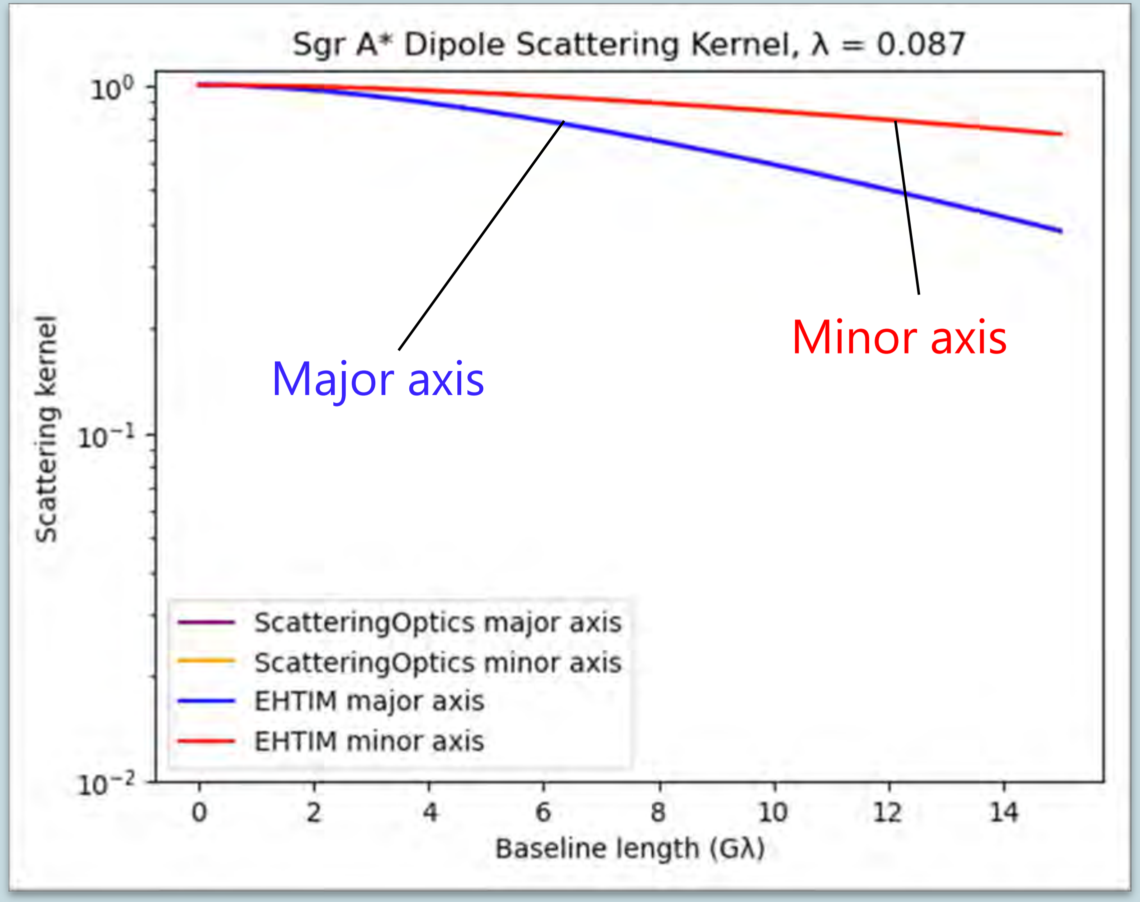
$$\ldots \frac{r_{\mathrm{in}}}{\lambda_0} \Big)^4 . \qquad \mathcal{C} \equiv \frac{\lambda^2 Q_z \Gamma\left(1-\frac{\alpha}{2}\right)}{8\pi^2 r_{\mathrm{in}}^2} .$$

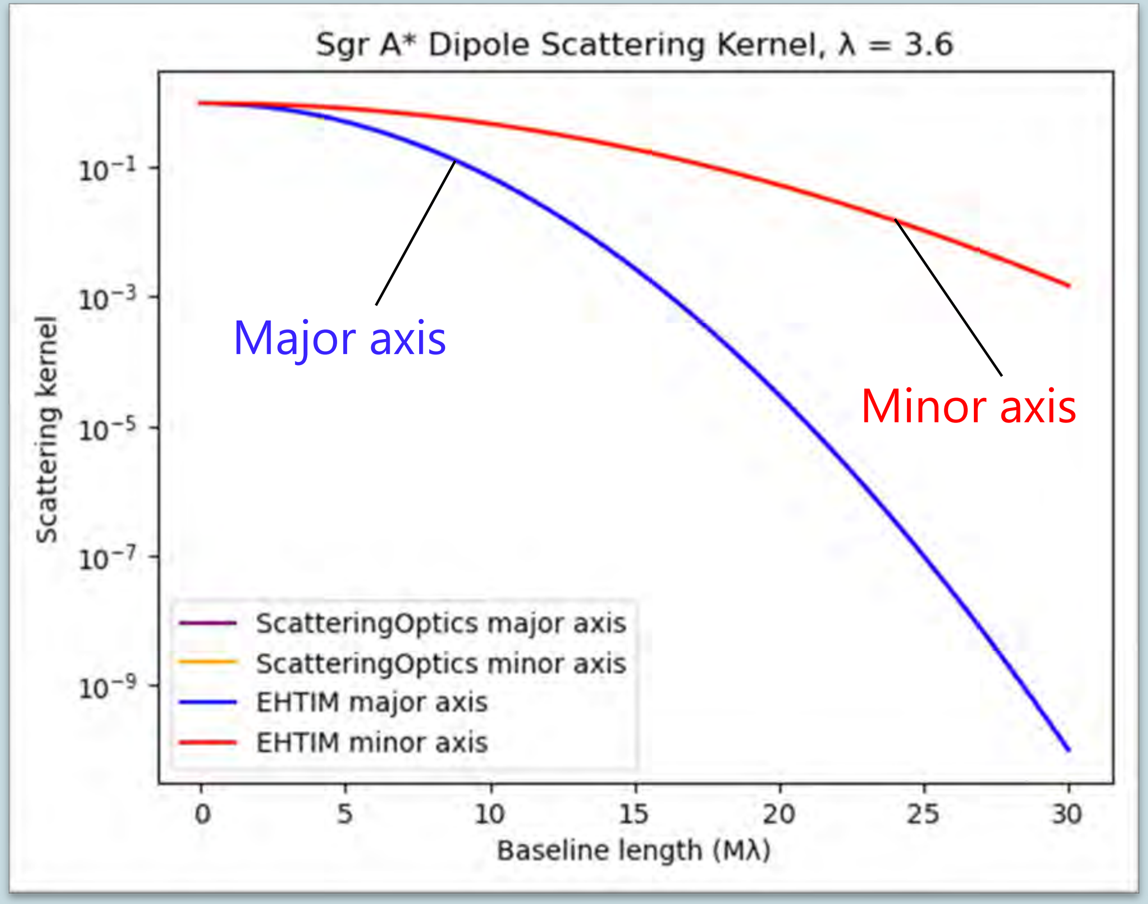
$$\ldots 2 = \frac{{}_2F_1\left(\frac{\alpha+2}{2}, \frac{1}{2}, 2, -k_{\zeta,2}\right)}{{}_2F_1\left(\frac{\alpha+2}{2}, \frac{3}{2}, 2, -k_{\zeta,2}\right)}$$

CONSISTENT RESULTS

Fractional errors on the order of 10^{-6} and 10^{-7}

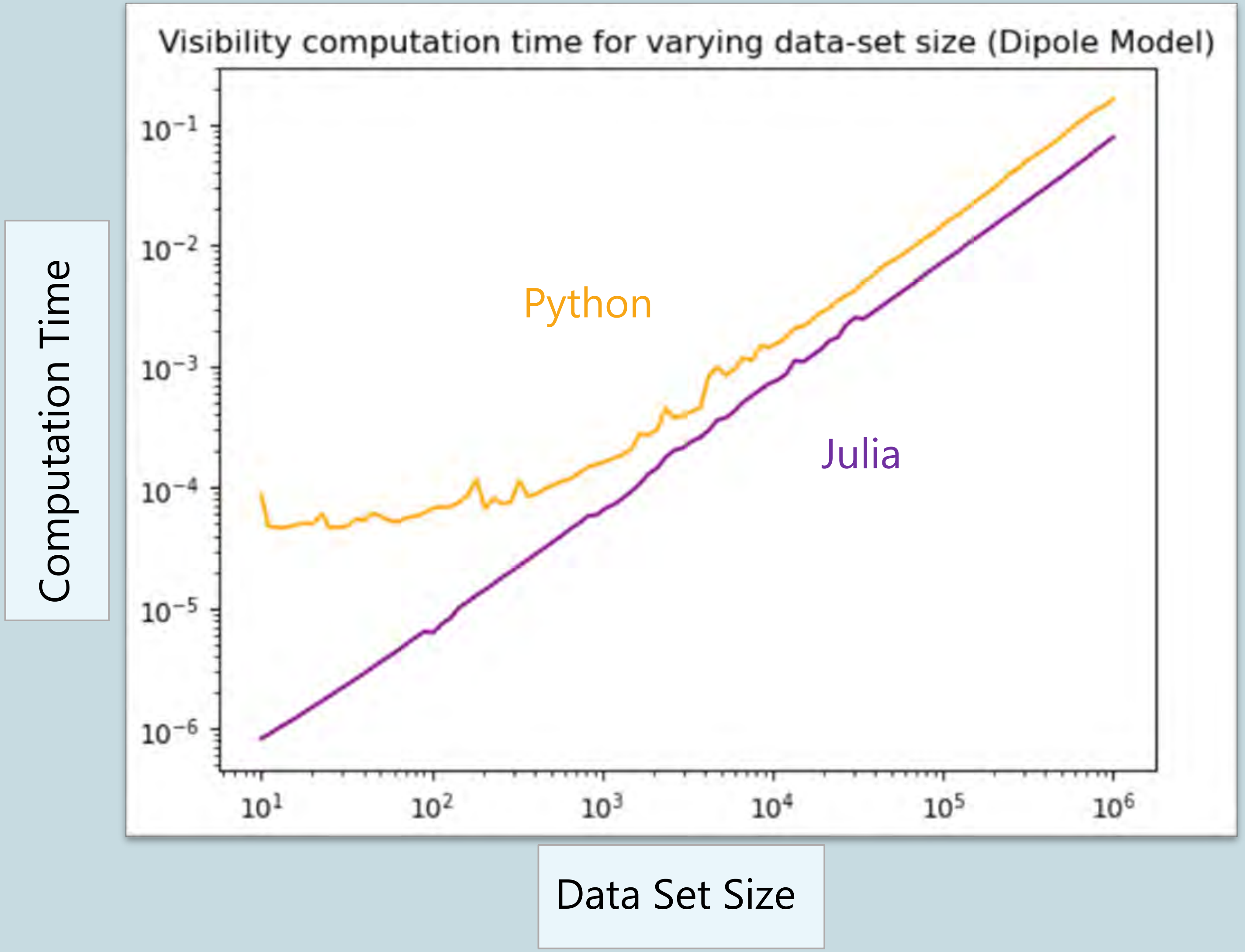
Scattering Kernel in Fourier space





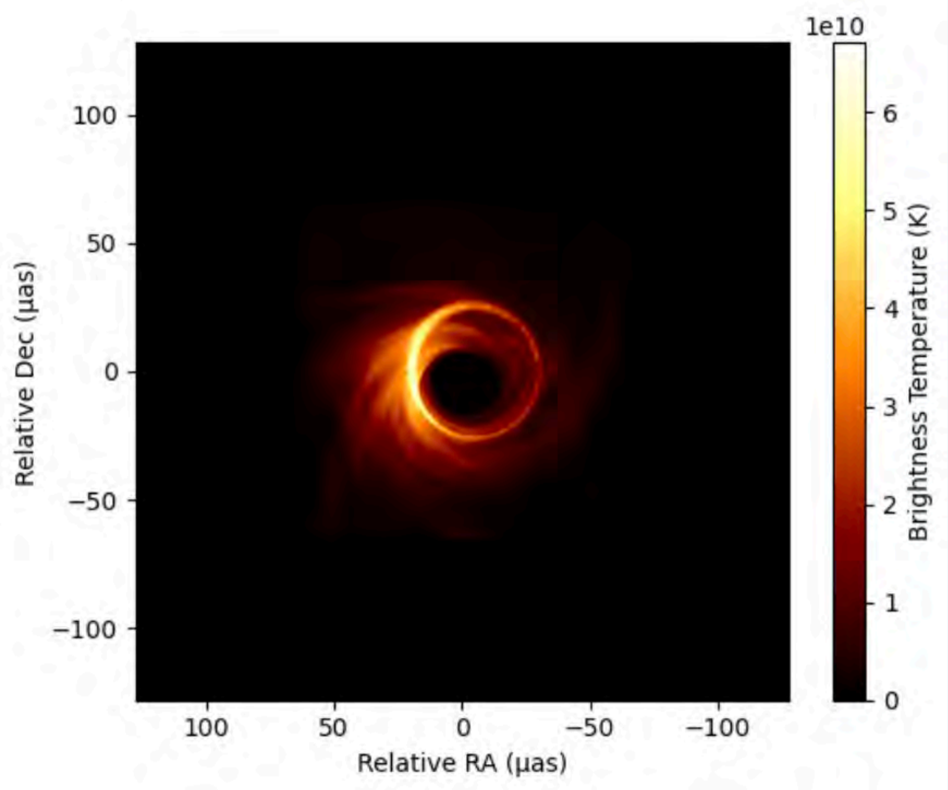
KERNEL TIME IMPROVEMENTS

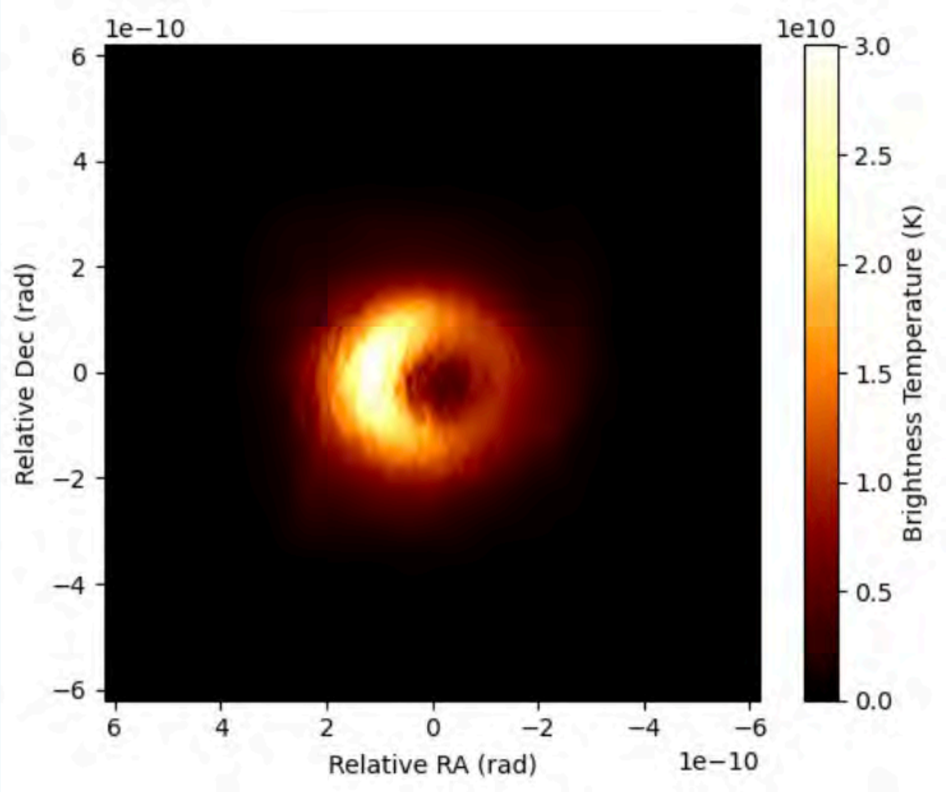
- Kernels load 100x faster
- Visibilities compute faster for all models



FINAL PRODUCT

- Scatters image 10x faster than Python counterpart





QUESTIONS?

Thank you to my mentors: Kazu Akiyama, Dongjin Kim, and Vincent Fish for their guidance and support; to Paul Tiede for sharing his Julia expertise; Nancy, Phil, and Diane for all the work they put in to make this program great; and thank you to the entire Haystack community for being so supportive and welcoming!