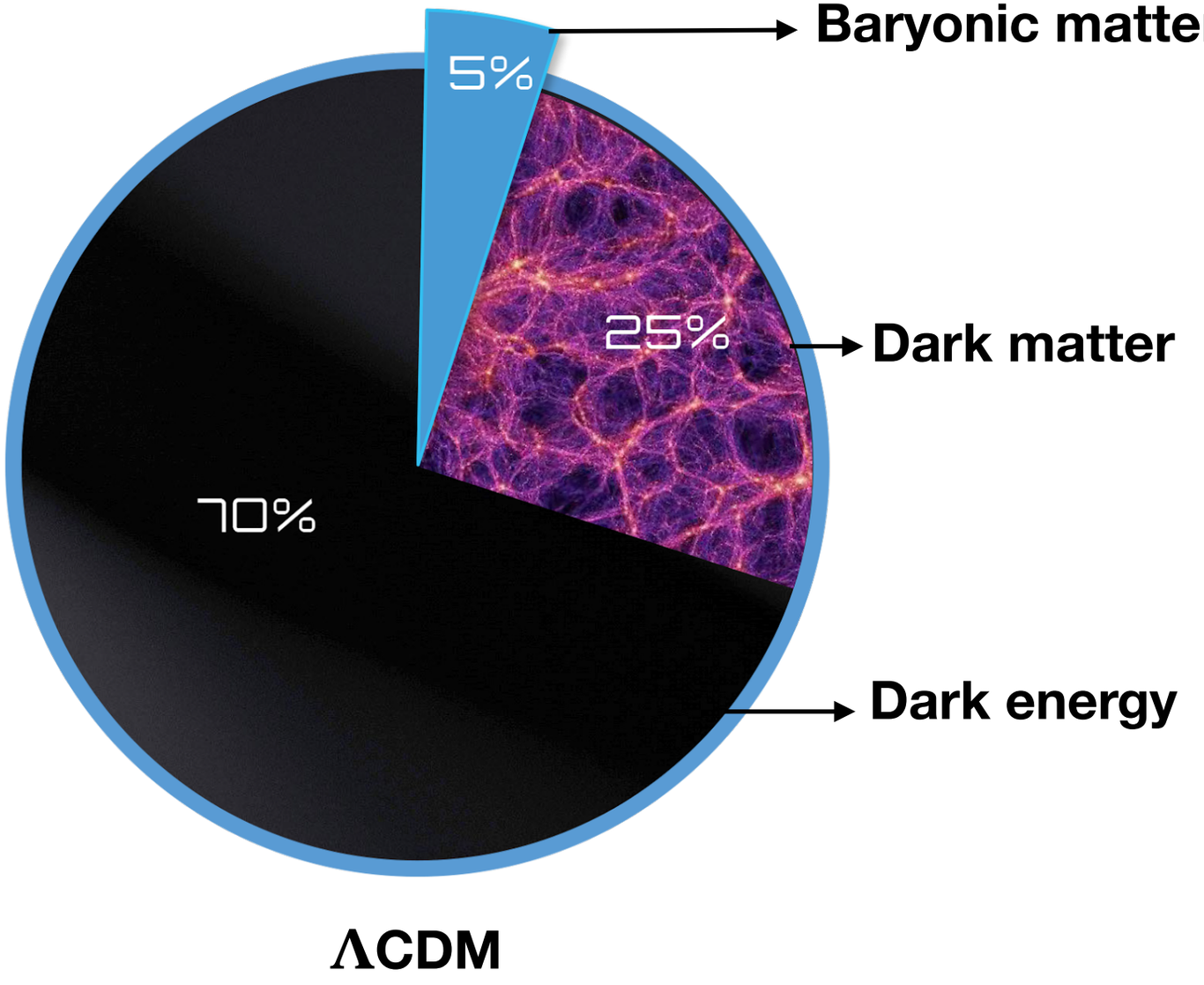
Generative model for shear inference

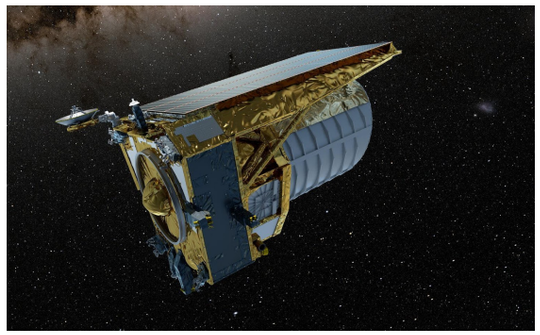
ARGOS-TITAN-TOSCA workshop

CosmoStat

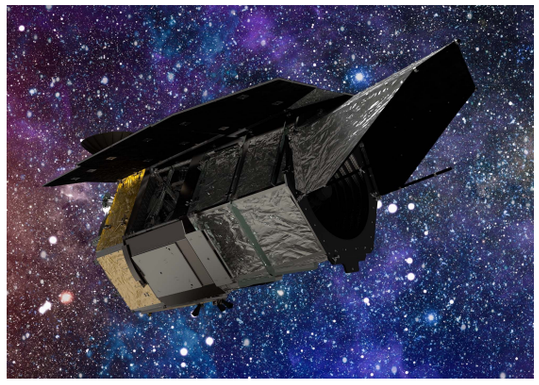
Ezequiel Centofanti

Stage IV surveys & Dark matter





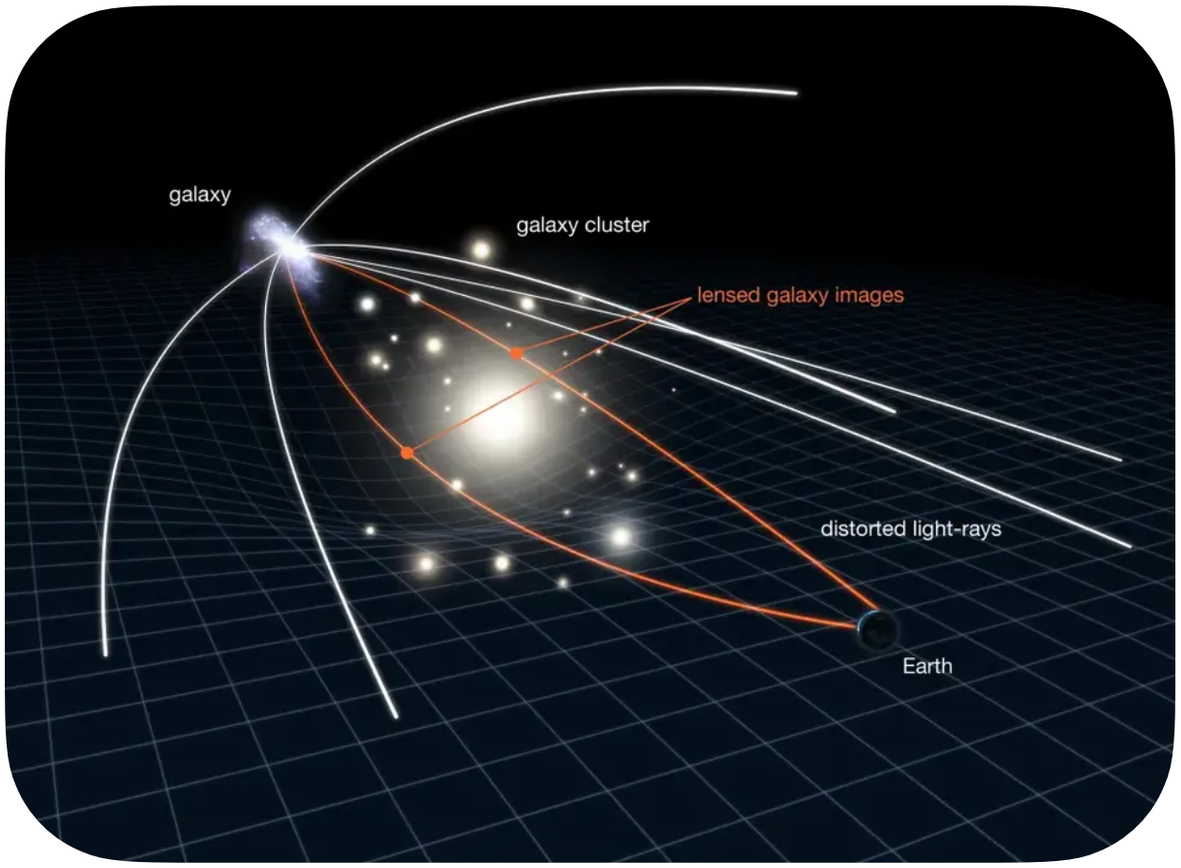
Euclid

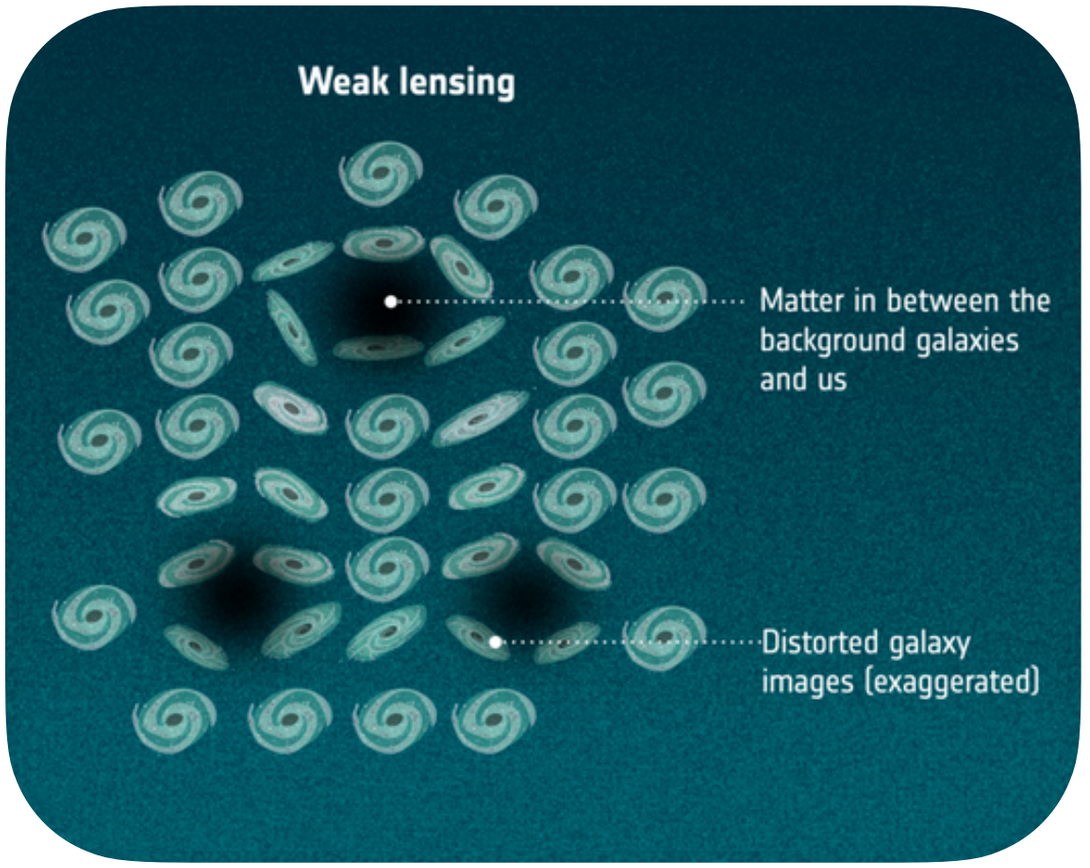


Roman

V. Rubin

Weak gravitational lensing



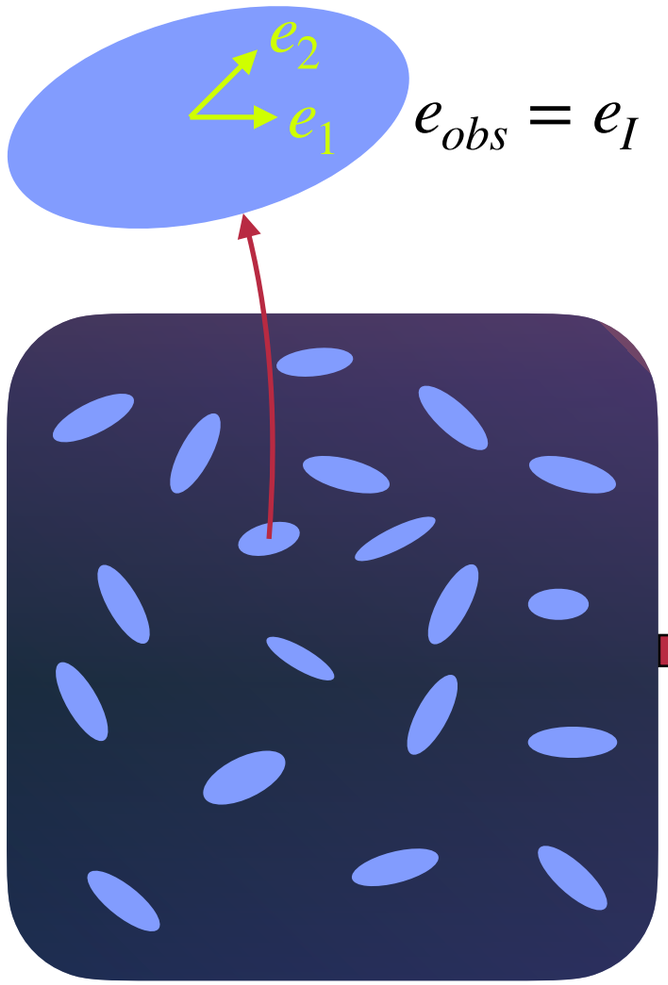


$$A = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

κ Convergence → magnification

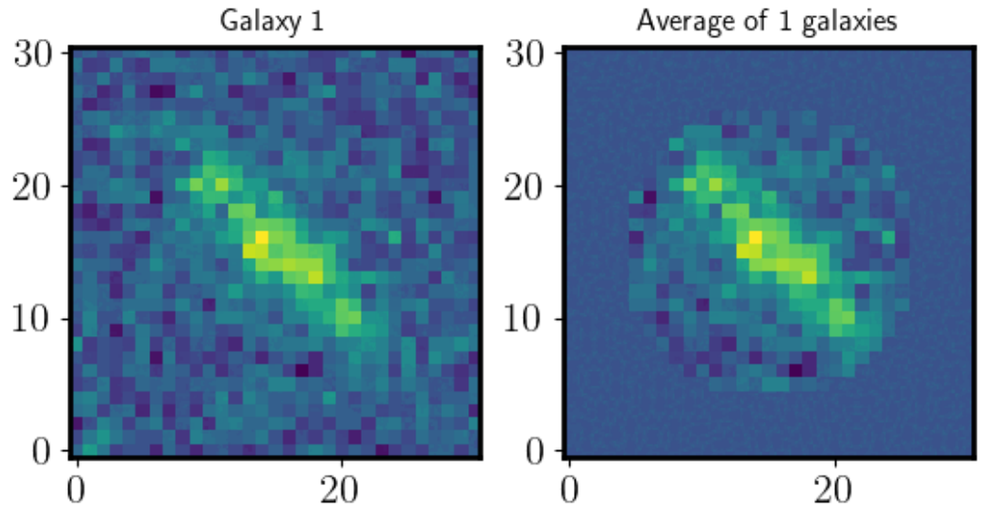
γ Shear → anisotropic stretching

Cosmic shear: γ



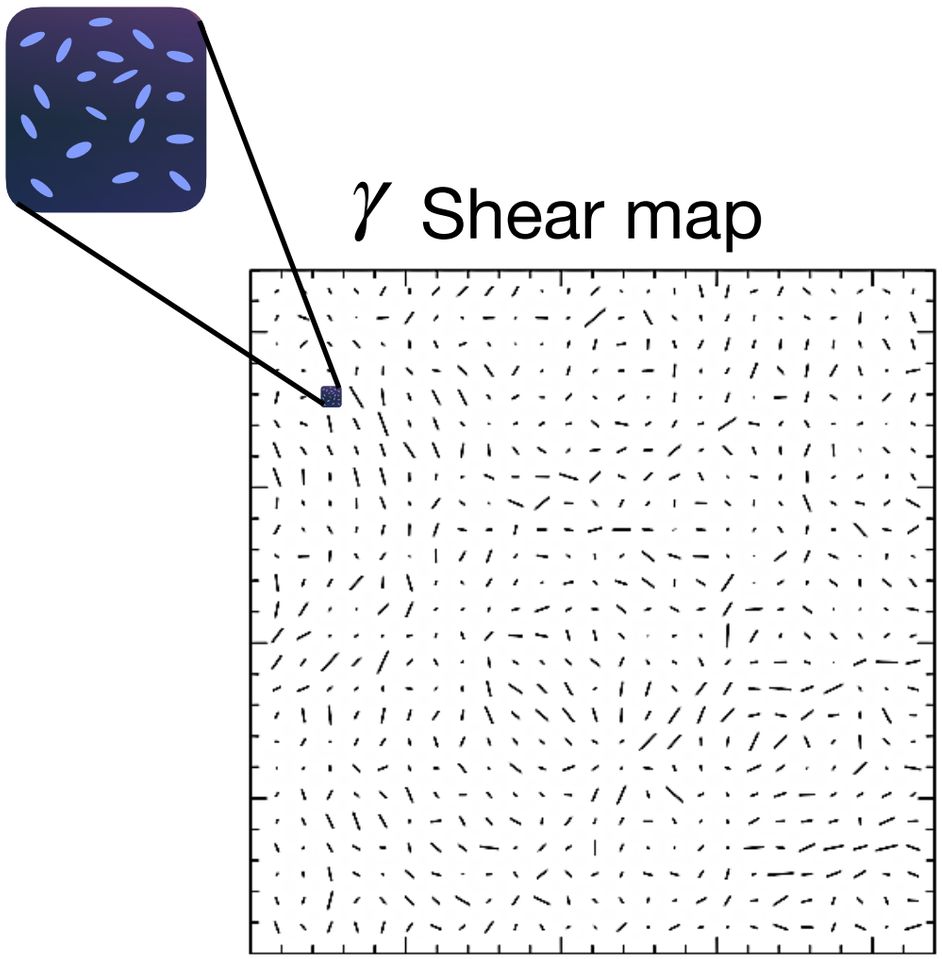
$$e_{obs} = e_I \in \mathbb{C}$$

$$\langle e_{obs} \rangle = 0$$



Credit: Koen Kuijken

Convergence & mass maps

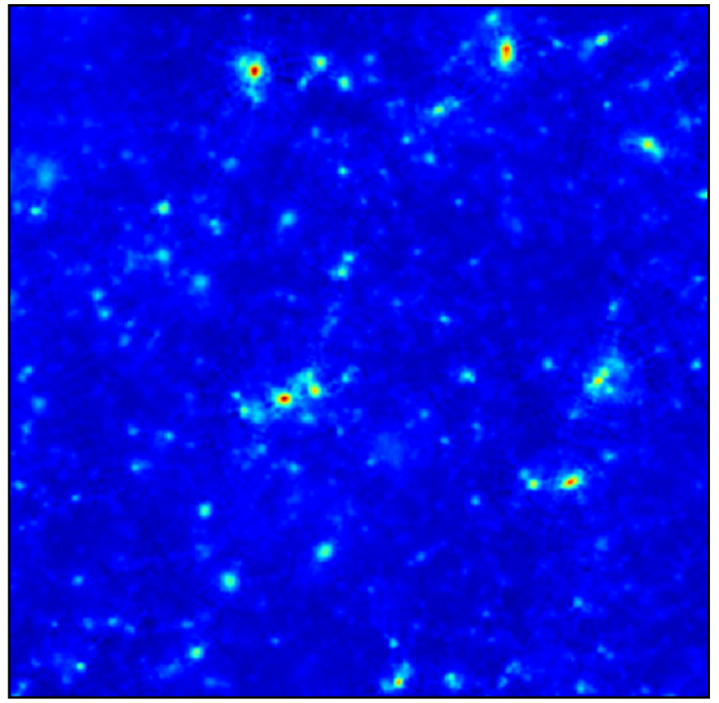


γ Shear map

Kaiser

Squires

κ Convergence map

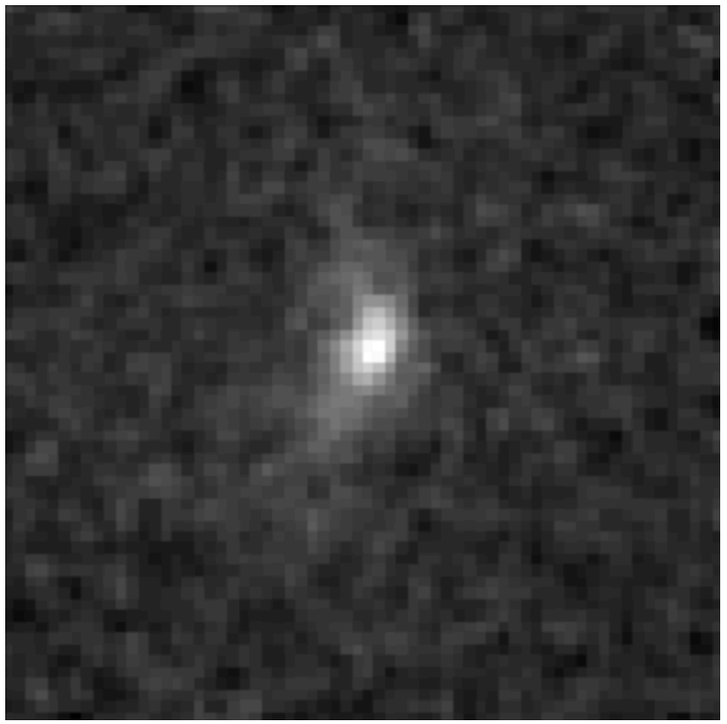


$$\kappa(\theta) = \frac{1}{\pi}\int \mathrm{d}^2\theta'\, \mathscr{D}^*(\theta - \theta')\,\gamma(\theta') + \kappa_0$$

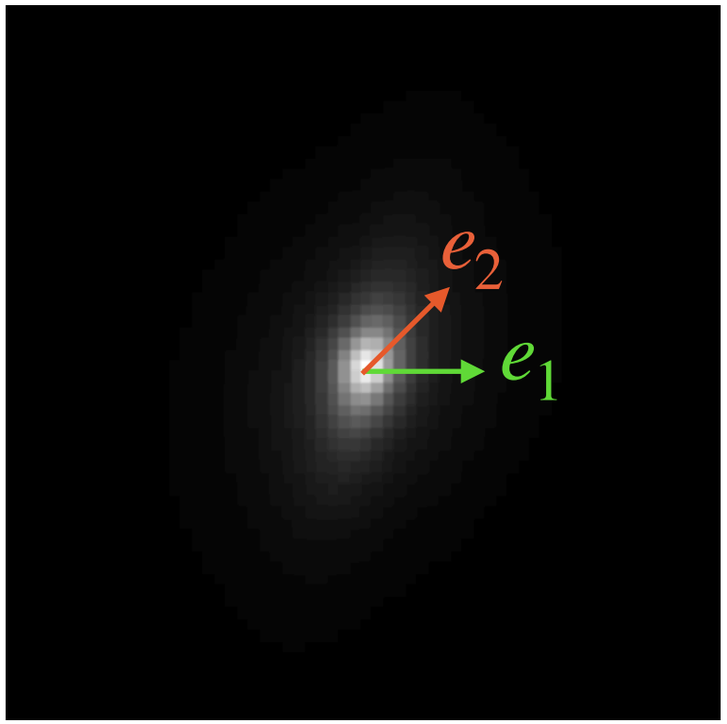
$$\mathscr{D}(\theta) = -1/(\theta_1 - i\theta_2)^2$$

Measuring galaxy shape

Galaxy observation



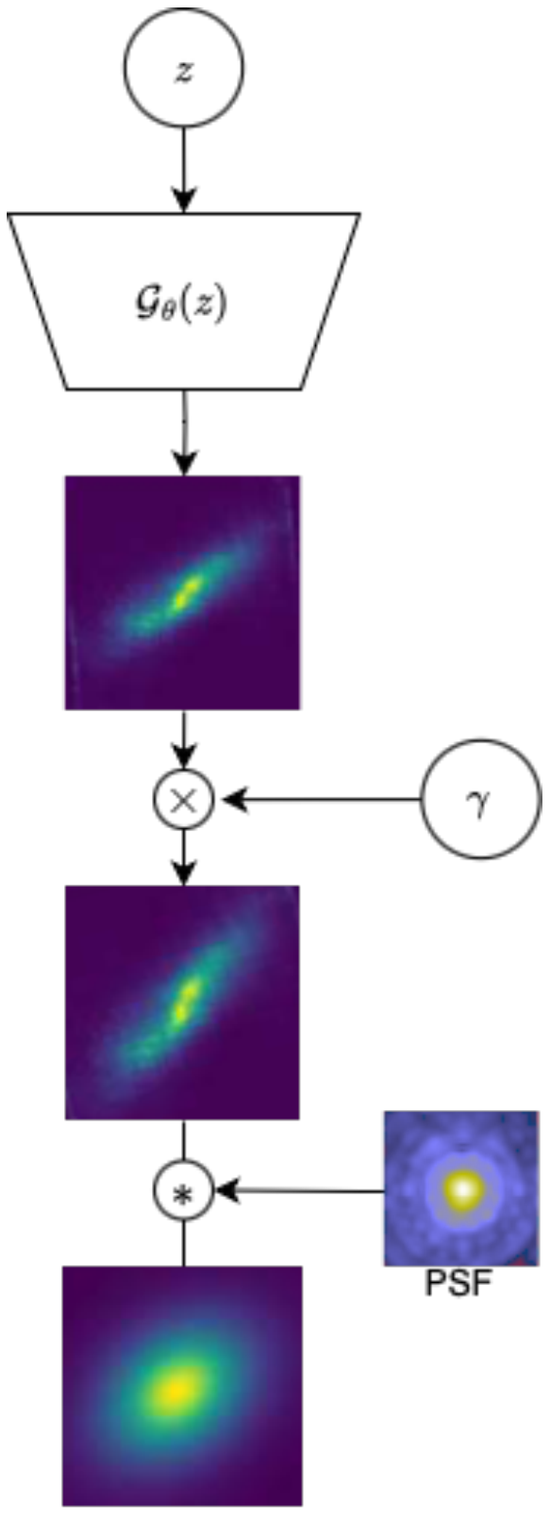
Parametric fit



Moments

$$\left\{ \begin{array}{l} \hat{\mu} \\ \hat{e}_1 \\ \hat{e}_2 \\ \dots \end{array} \right.$$

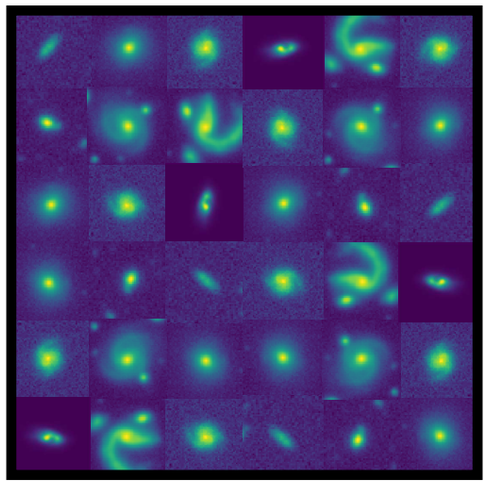
- Need to account for the PSF corrections and **calibration** of the method.
- Parametric modelling doesn't capture complex galaxy **morphologies**.
- **Ellipticity** is not a well-defined quantity for arbitrary galaxies.



B. Remy work [1]

- Pixel level forward model.
- Deep generative model (VAE).
- Optical galaxy observations.
- HMC sampling → shear estimate.

[1] Remy, B., “Generative modeling for weak lensing inverse problems.”

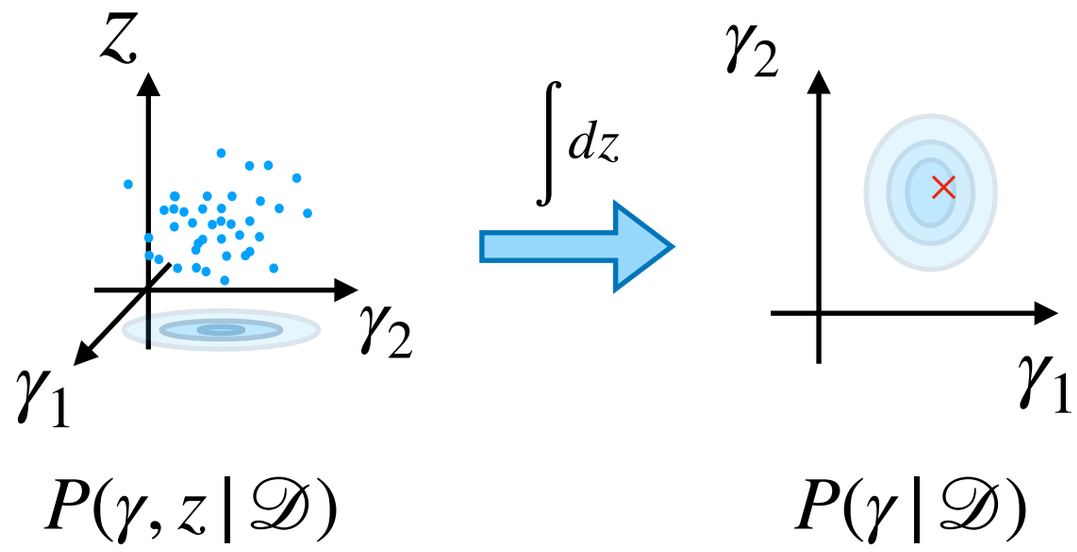


Observed tile

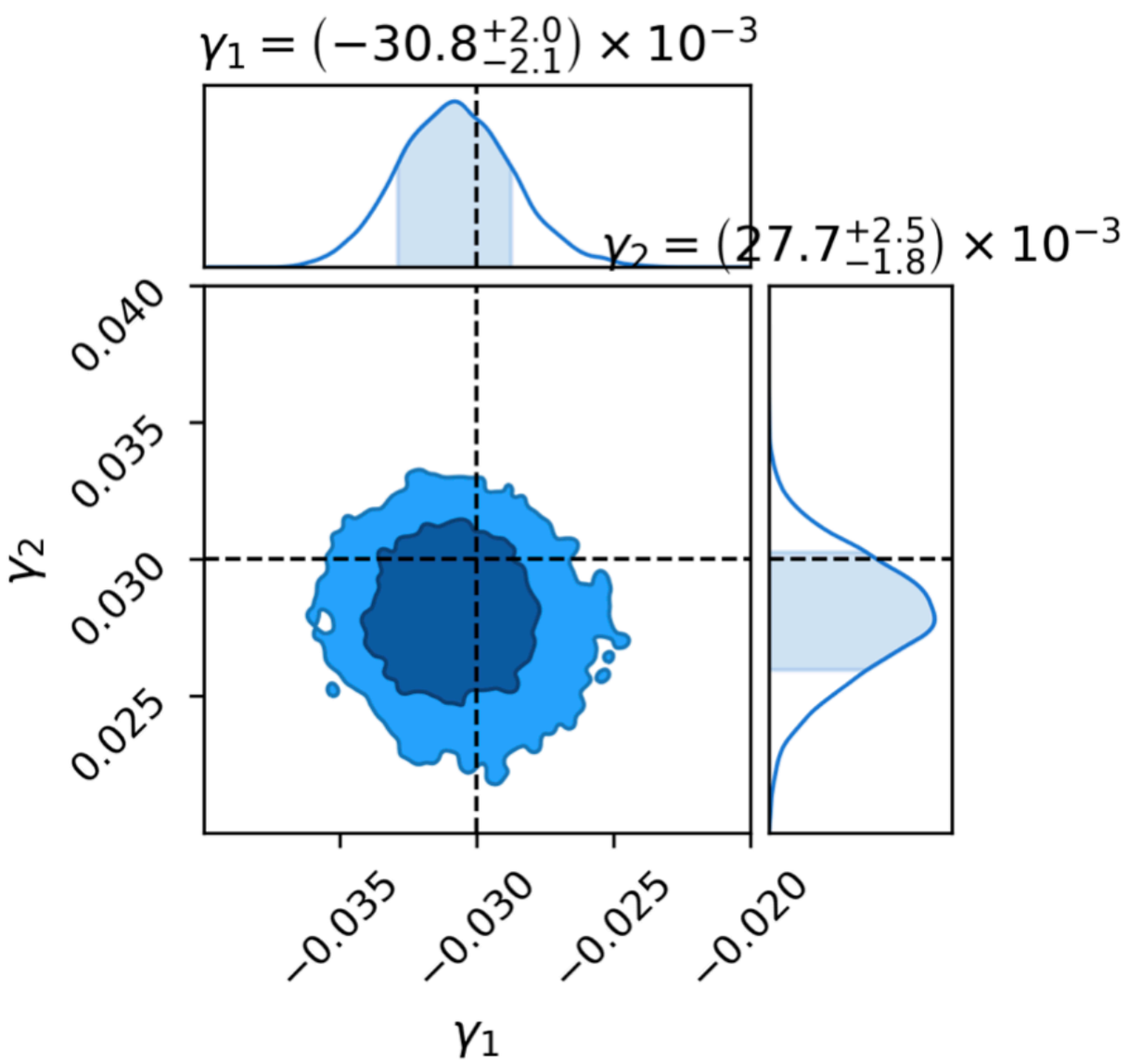
- Common γ
- Dataset: $\mathcal{D}$

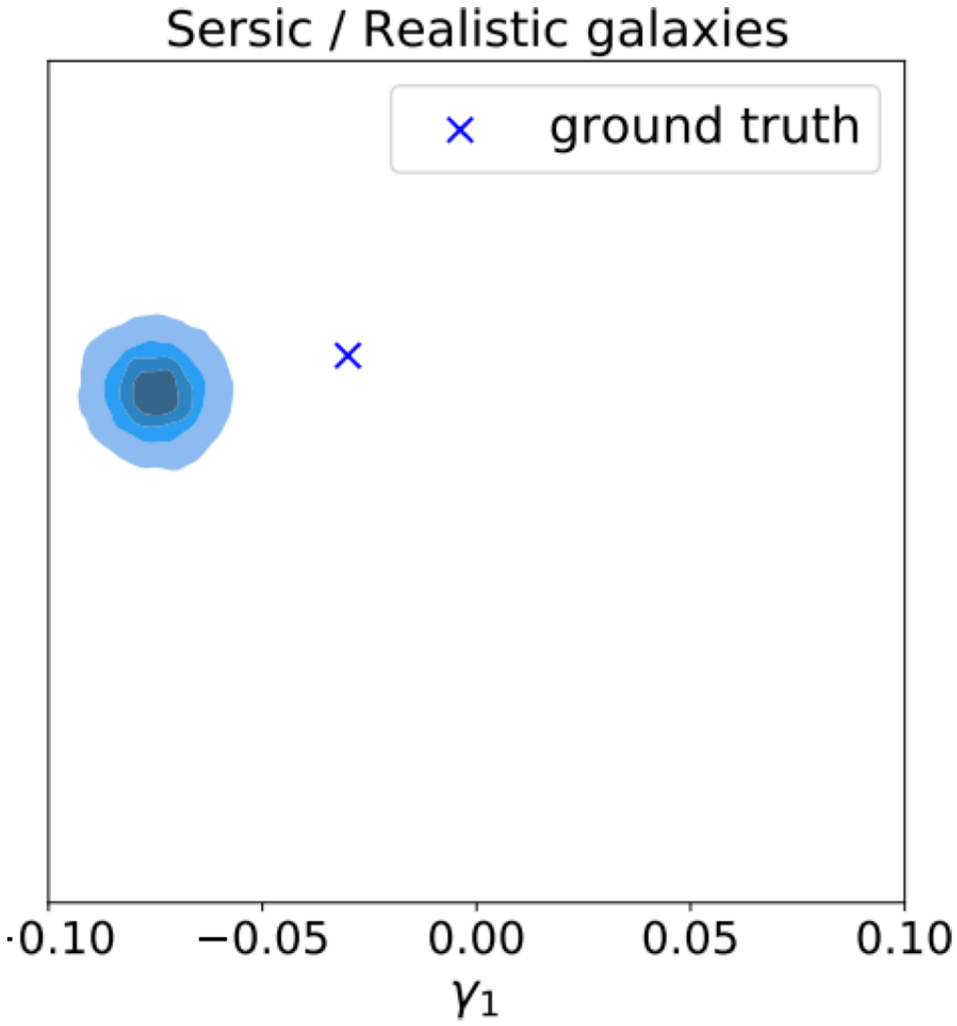
Shear inference - HMC

- Sample (z, γ)
- Generate galaxy $\mathcal{G}(z)$
- Apply shear and PSF
- Evaluate likelihood
- Accept / reject z, γ



B. Remy results





Parametric fit

ARGOS project

ARGOS

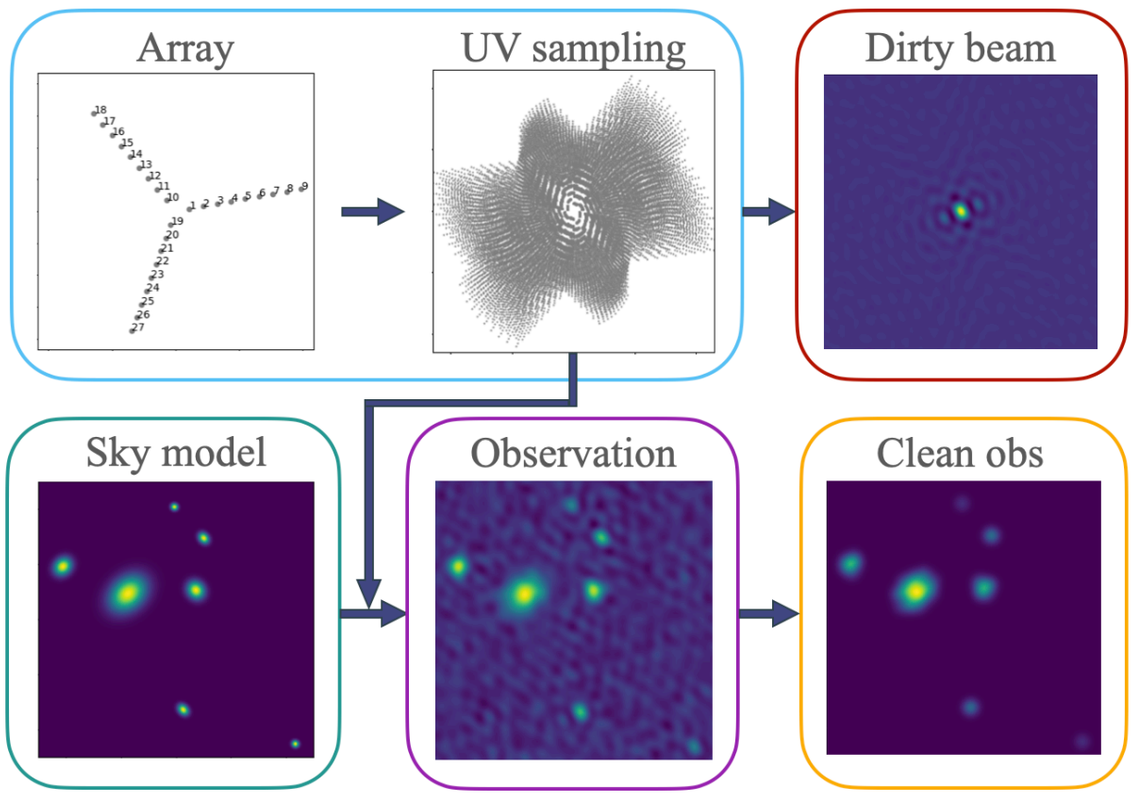
(ARray for Gigahertz ObservationS)

Low-cost, modular and sustainable interferometer.

Planned location: Nida Plateau, Crete 🇬🇷

- ~1000 6m parabolic dishes.
- 1-3 GHz (10 - 30 cm).
- Wide FOV & bandwidth.
- High temporal/angular res.
- European VLBI capability.

Argosim

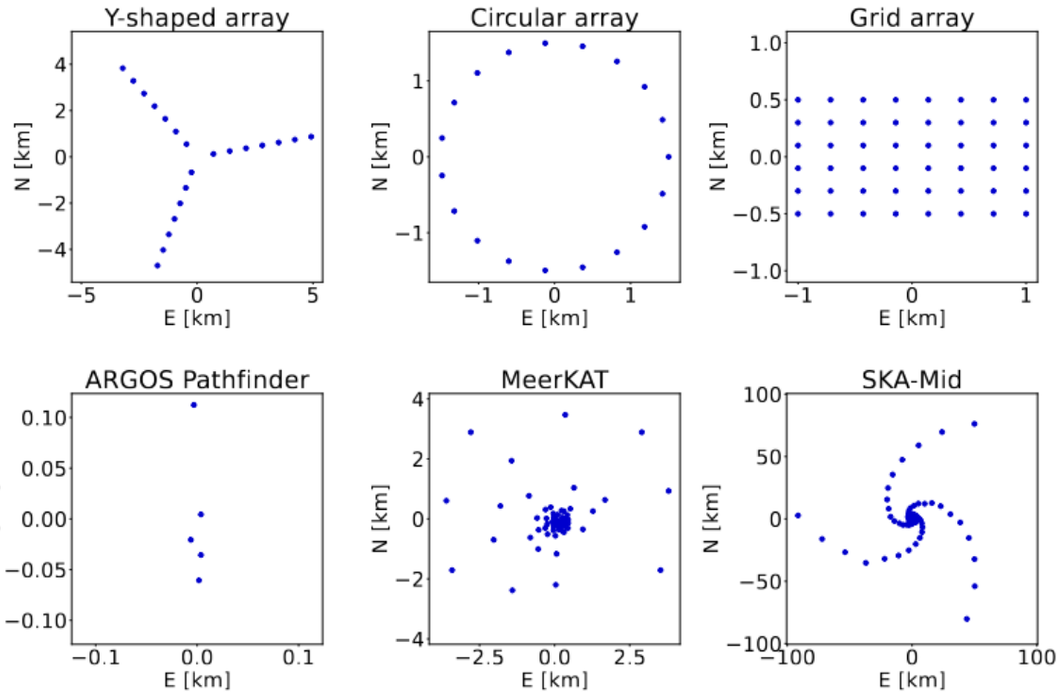


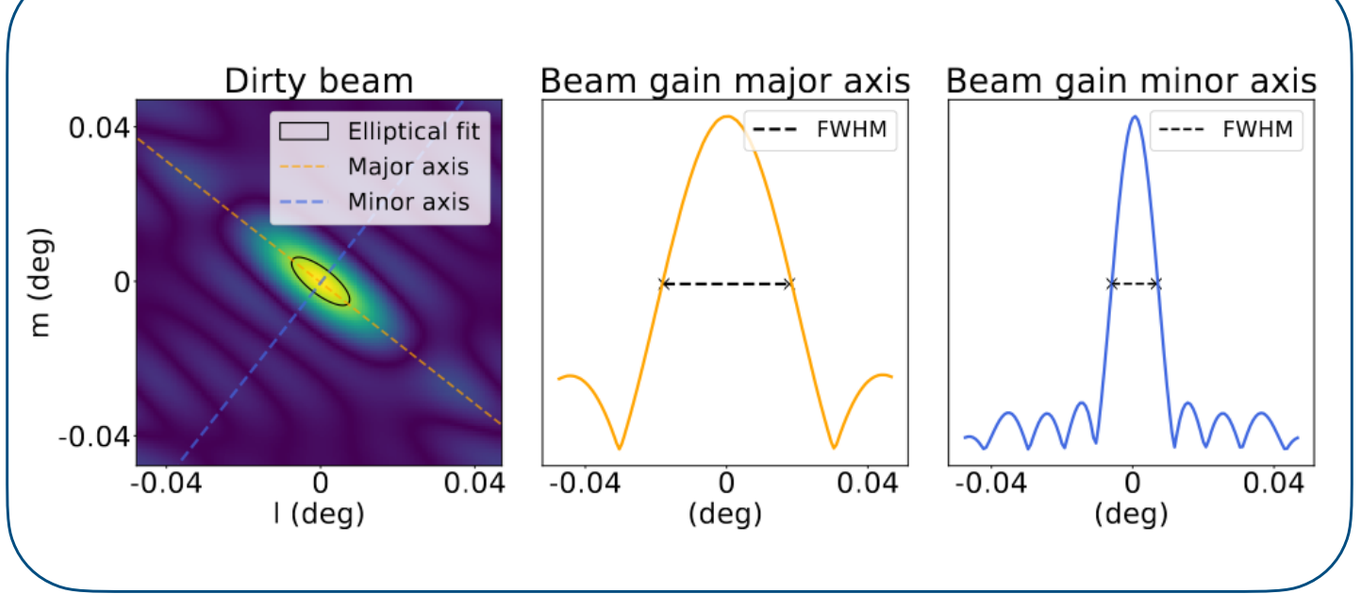
Centofanti et al. in prep
(to be submitted this summer)

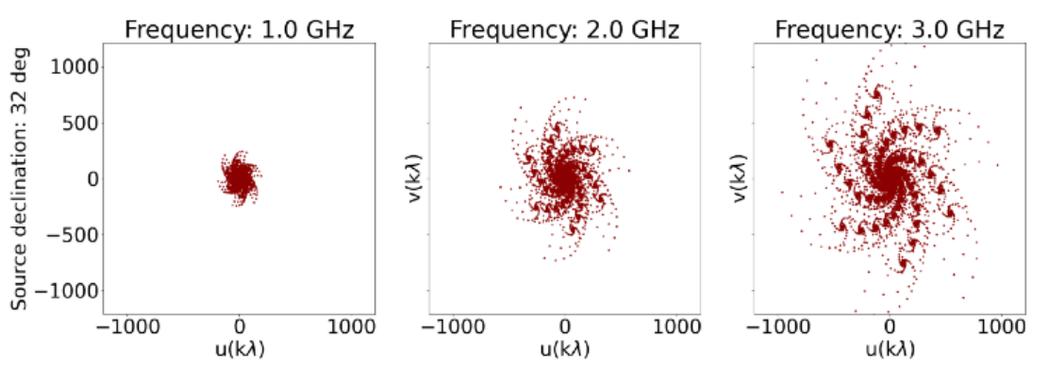
- Radio interferometric sims.
- JAX computational backend.
- Fully open source.
- Available on PyPI.

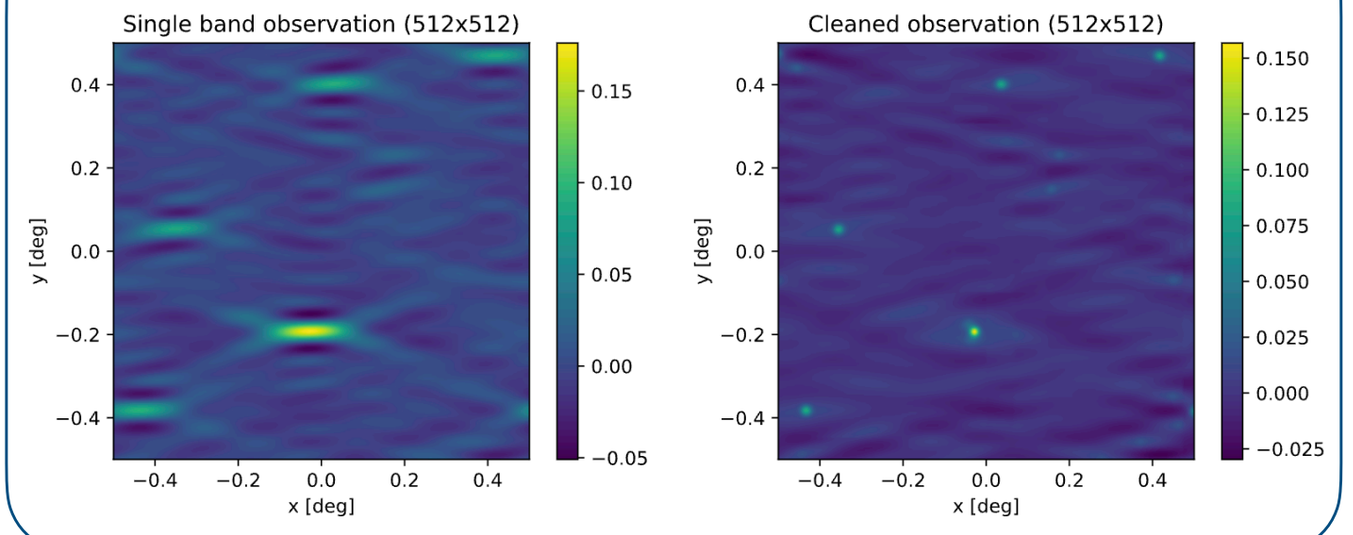
```
$ pip install argosim
```

Argosim examples







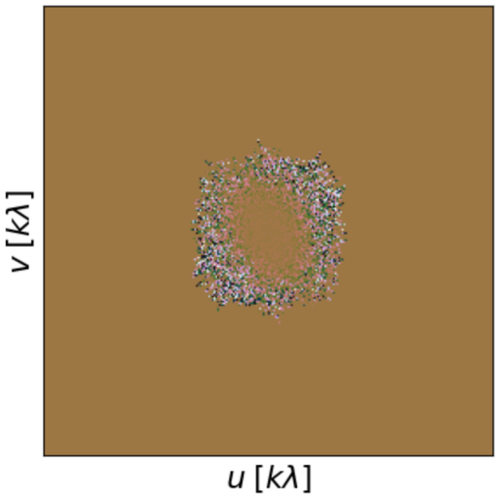


Square Kilometre Array

SKA-mid (graphic representation)

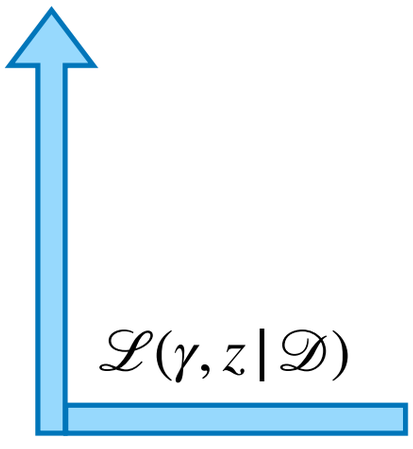
- World’s largest radio telescope.
- Wide sky coverage and depth.
- High sensitivity and resolution.
- Enables radio weak lensing!
- Higher Z, complement optical WL.

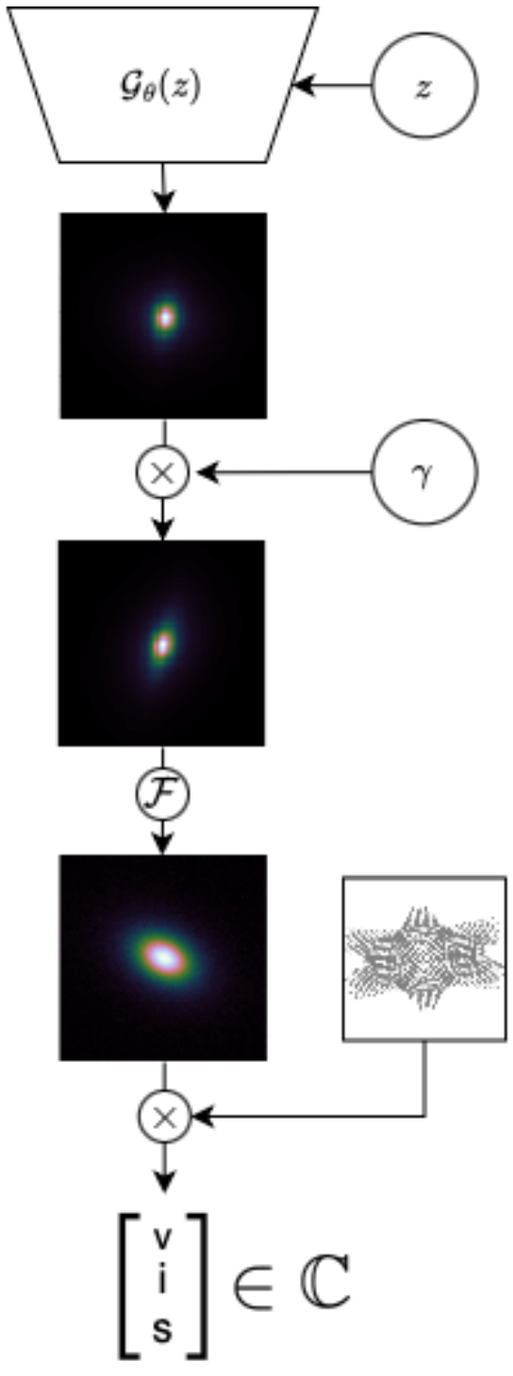
Radio analogue



Observations

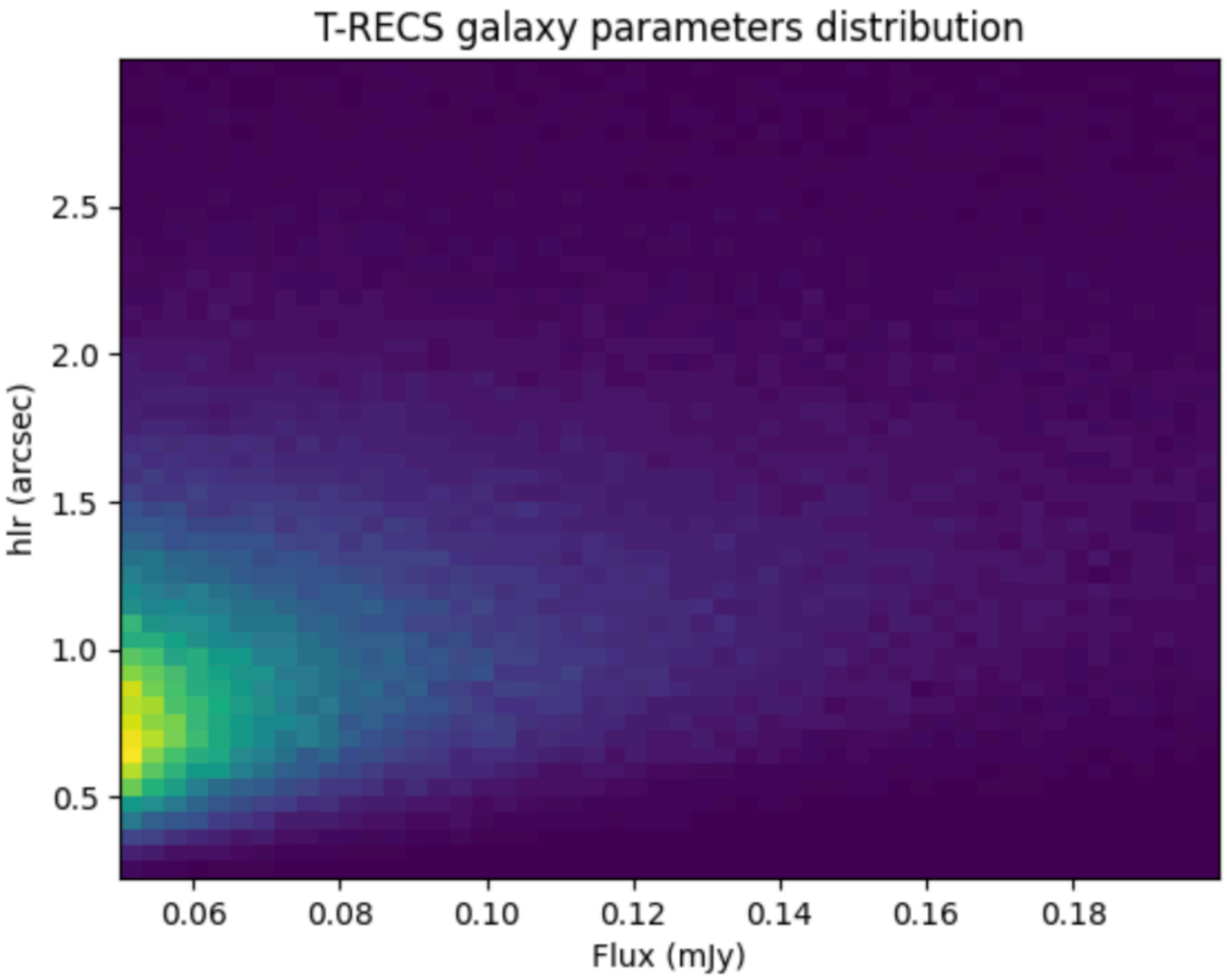
- Common γ
- Visibilities
- Dataset: $\mathcal{D}$

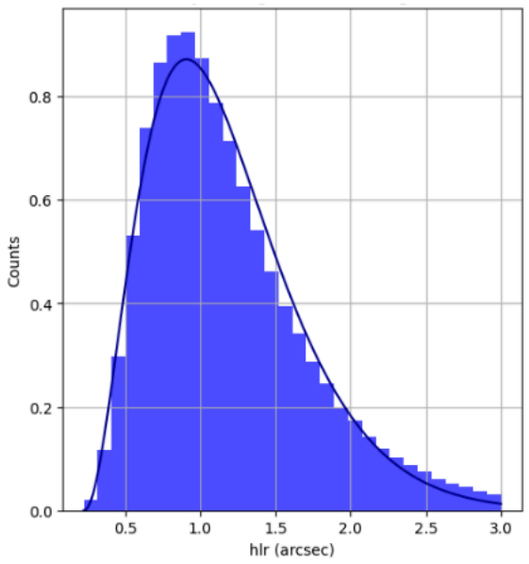


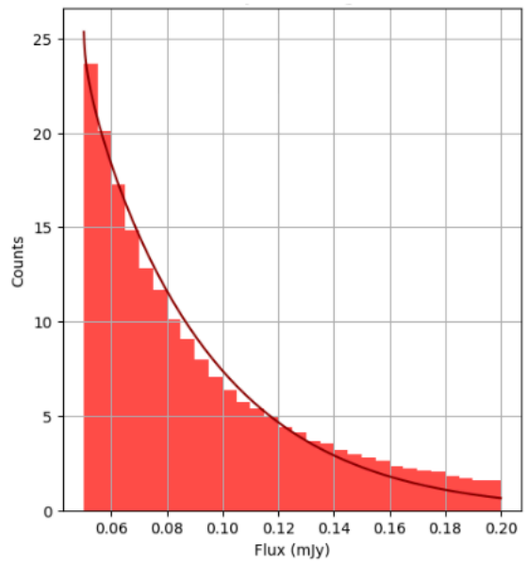


- Different galaxy morphology.
- Data in Fourier domain: visibilities.
- PSF → uv-sampling mask.
- PSF is more complex but known.

Radio Data: T-RECS [2]





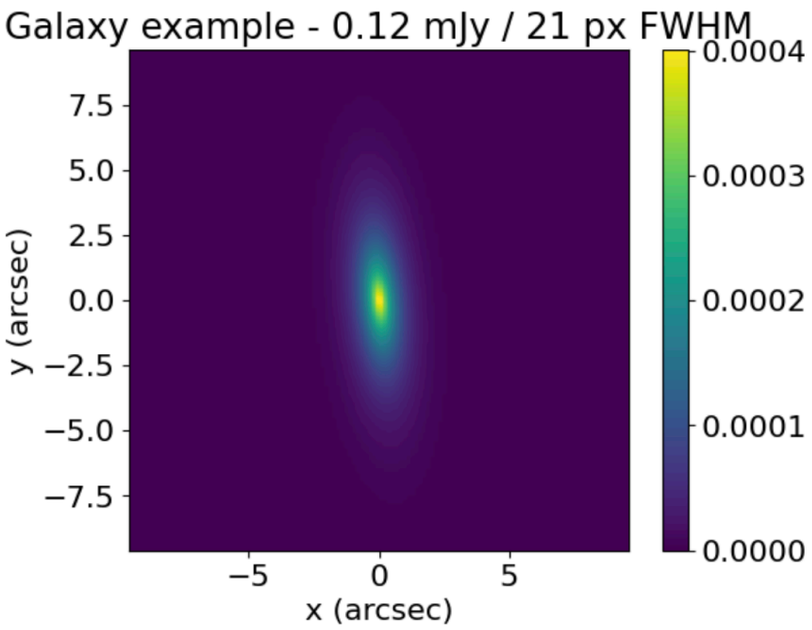


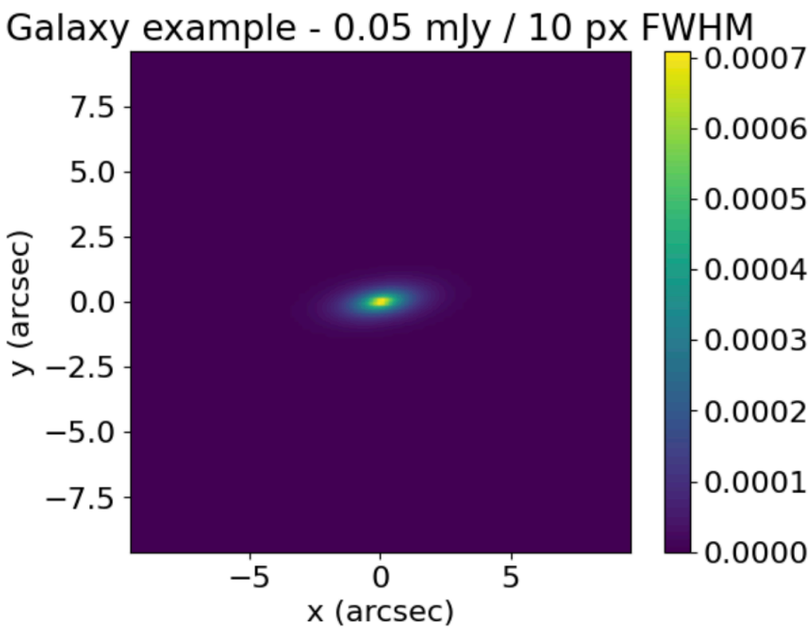
- Faint star-forming radio galaxies.
- Exponential profile:
  - hlr $\in$ (3 - 40) px
  - flux $\in$ (50, 200) μJy

[2] Bonaldi, A., “The Tiered Radio Extragalactic Continuum Simulation (T-RECS)”

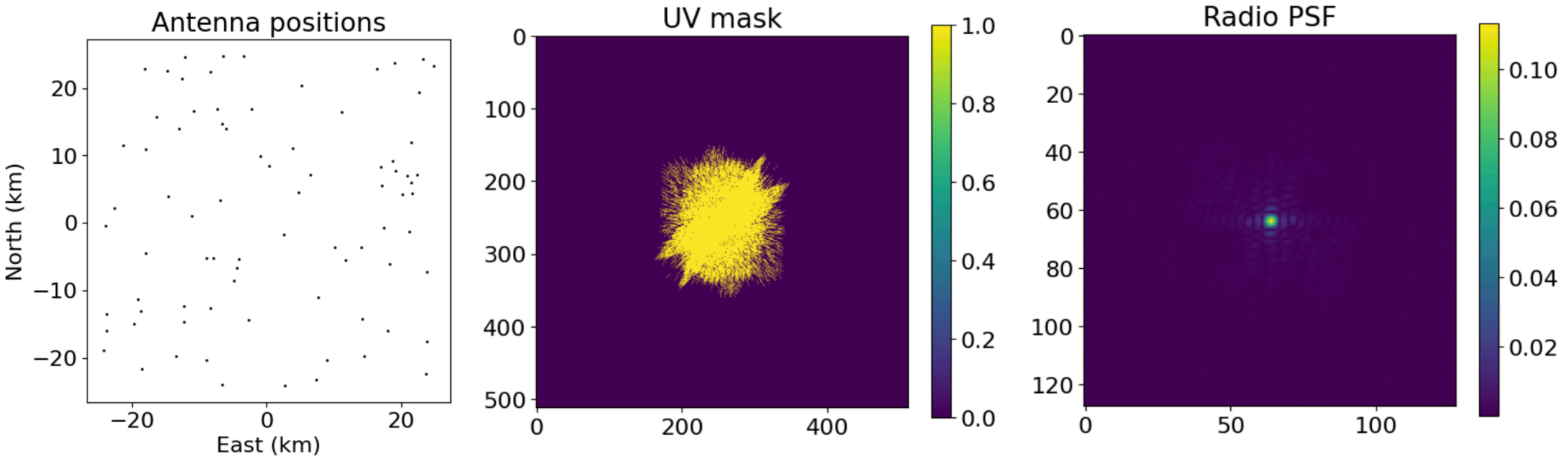
Generator model

- Capture data morphology
- Fast, GPU accelerated.
- Differentiable (HMC).

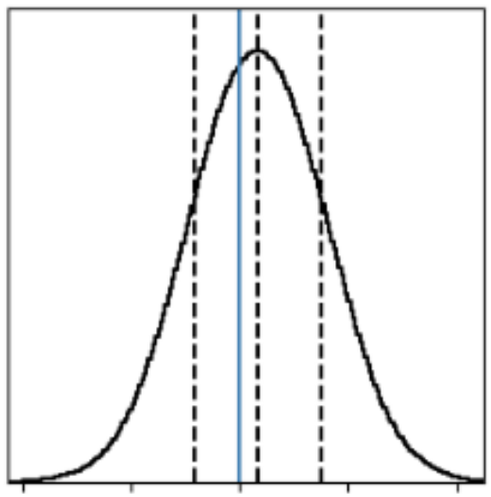


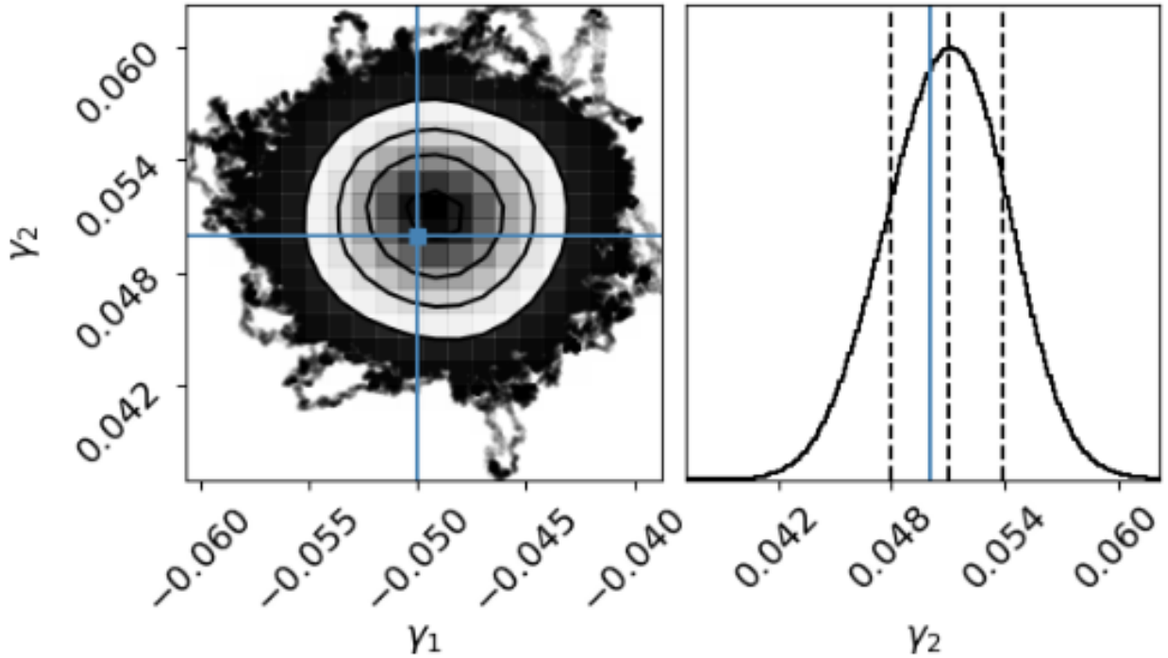


Radio PSF (argosim)



Preliminary Results





- 100 galaxies from TRECS.
- Shear constraints σ = 0.003 (6%).
- Comparable to state-of-the-art.[3,4]
- ~2000 effective shear samples.

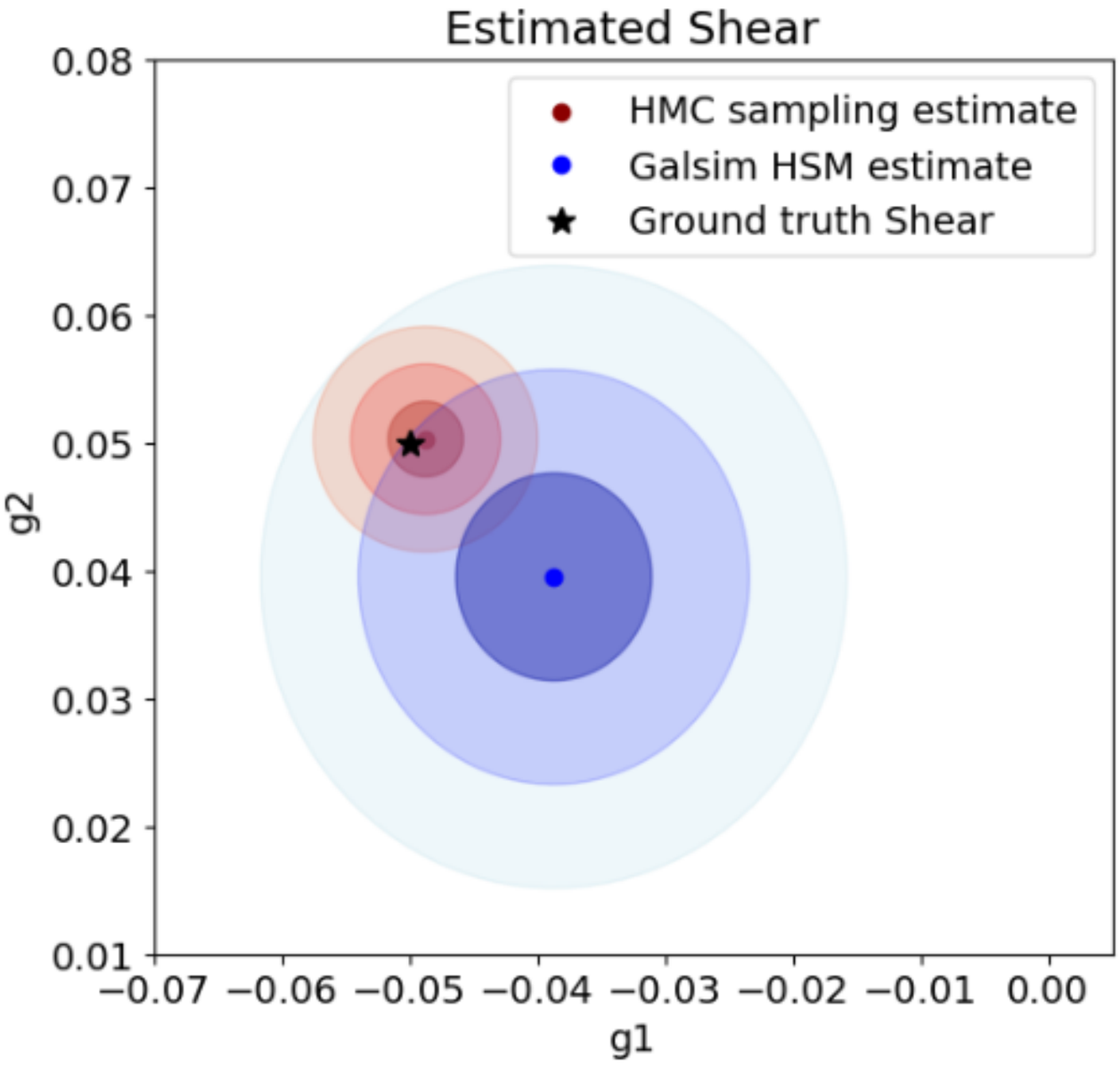
[3] P. Tripathi, “DeepShape: Radio weak-lensing shear measurements using deep learning”
[4] M Rivi, “Radio galaxy shape measurement with Hamiltonian Monte Carlo in the visibility domain”

Galsim HSM

- Moment estimator algorithm.[5]

- Weaker shear constraints.

- Biased by the complex radio PSF.



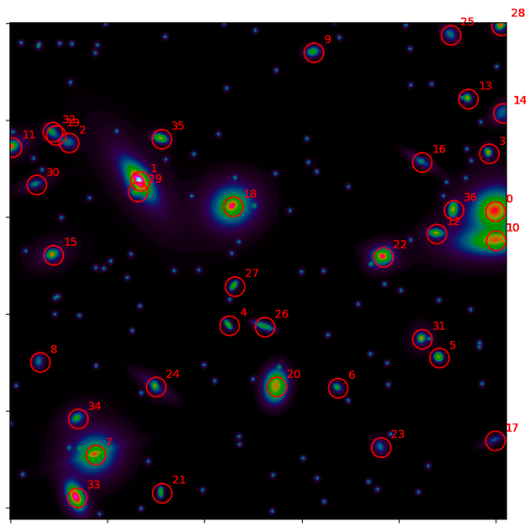
[5] Hirata, C. and Seljak, U., “Shear calibration biases in weak-lensing surveys”

Future work

- Get real radio **data**: complex galaxy morphology.

- Improve the **generative** model: CNN, diffusion, score based.

- Address **selection bias**: fit full field of view.
  - Sample the number of galaxies.
  - Sample the position of galaxies.



Thank you for your attention!

Questions?

...and feedback :)