# Finding black holes

## An unconventional multi-messenger route

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*The Chinese University of Hong Kong*

*Supervisors:*
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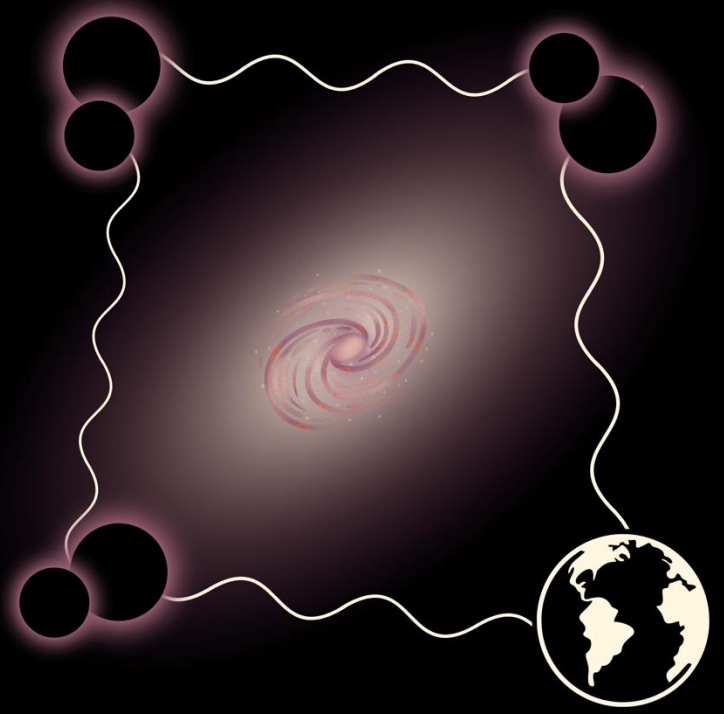
*Dr Justin Janquart*

Royal Society meeting on Multi-messenger Strong Lensing
Manchester, March 2024

# DARK DANCE, BRIGHT HOSTS

- Black holes: easy to hear, hard to see
- No EM counterpart
- Some methods for host identification proposed
- But, if GW is lensed, then EM host must also be lensed
- New proposed avenue…



*Can lensing shine a light on these dark binaries?*

# MOTIVATION

What GW contribute:

- Precise time delays, GR waveform, standard siren…

What EM contributes:

- Detailed lens model, Hubble constant & cosmology…

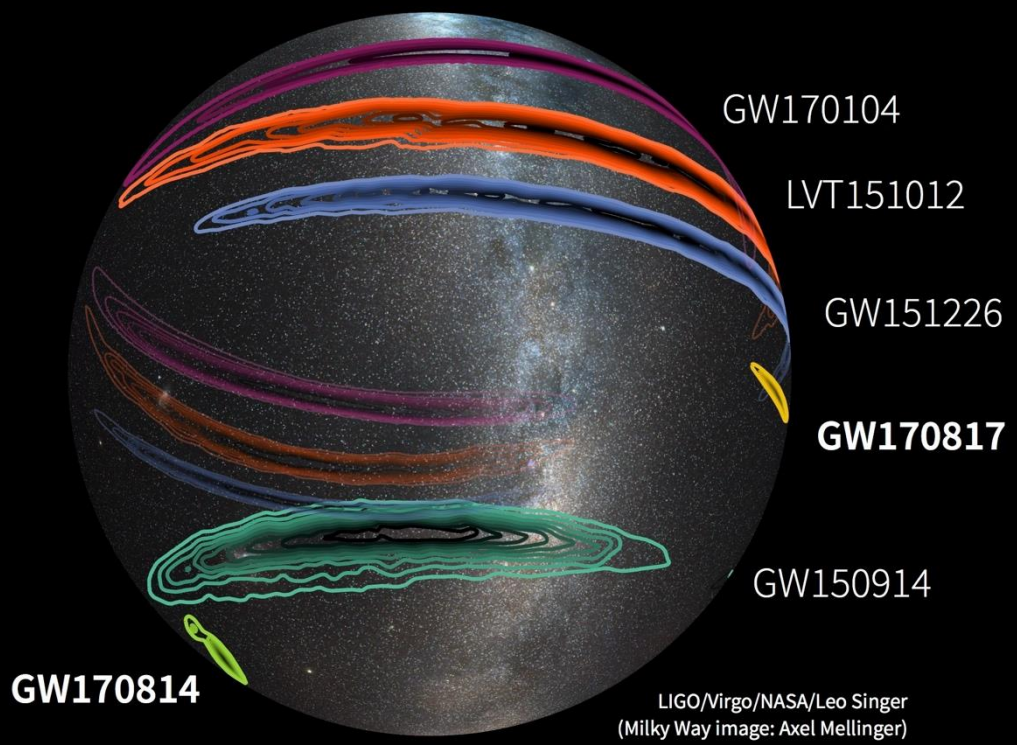
Why this approach?

- Statistical, cosmological methods proposed – no confident host identification
- Host lensing a new avenue?

Forecast? Detection possible in O4/O5… Statistics: ler (Hemanta Phurailatpam)

# ROADMAP TO A BLACK HOLE

Step 1
Needles, haystacks, lensed GW ~ O(100-1000) sq. deg.




Typical LIGO localization skymaps (LVK)

# ROADMAP TO A BLACK HOLE

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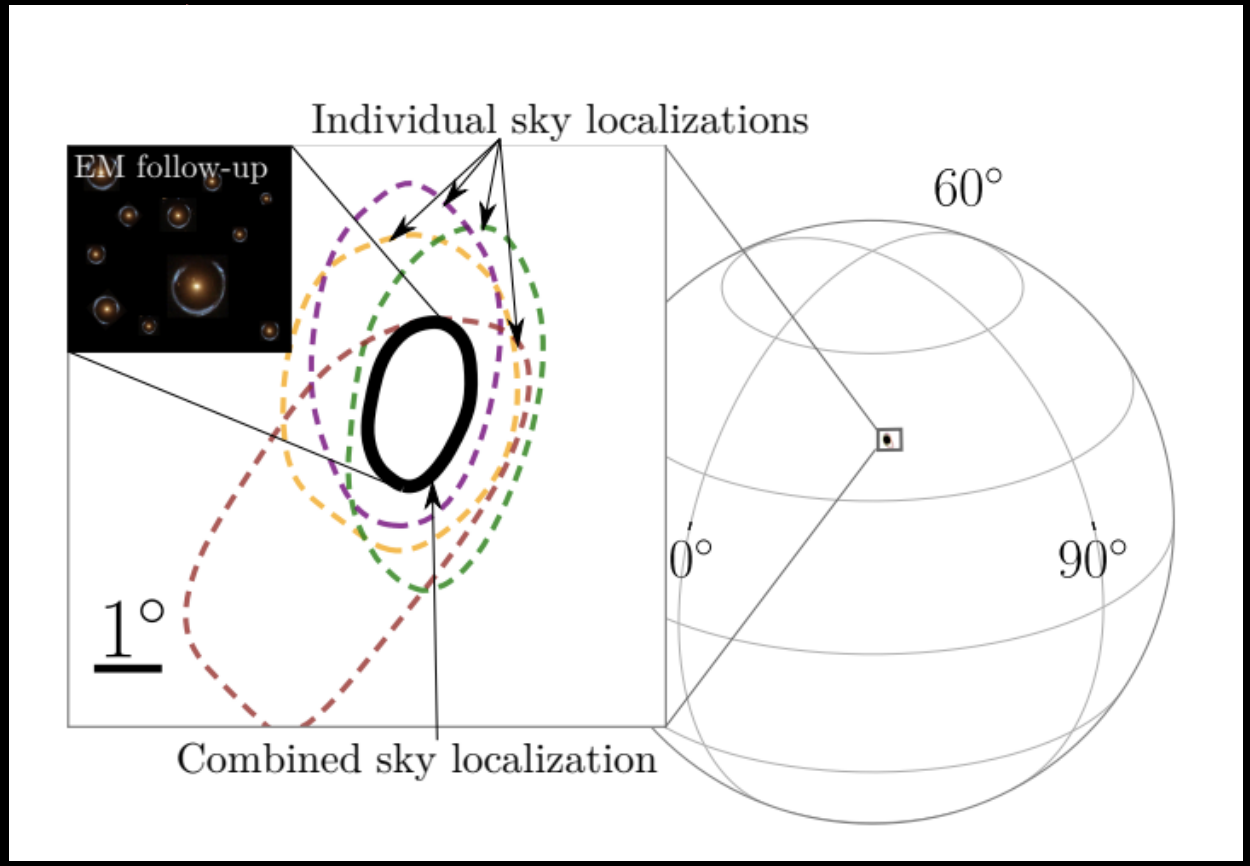
Step 2
Joint analysis sky localization ~ O(10) sq. deg.




Joint sky localization (Hannuksela et al., 2020)

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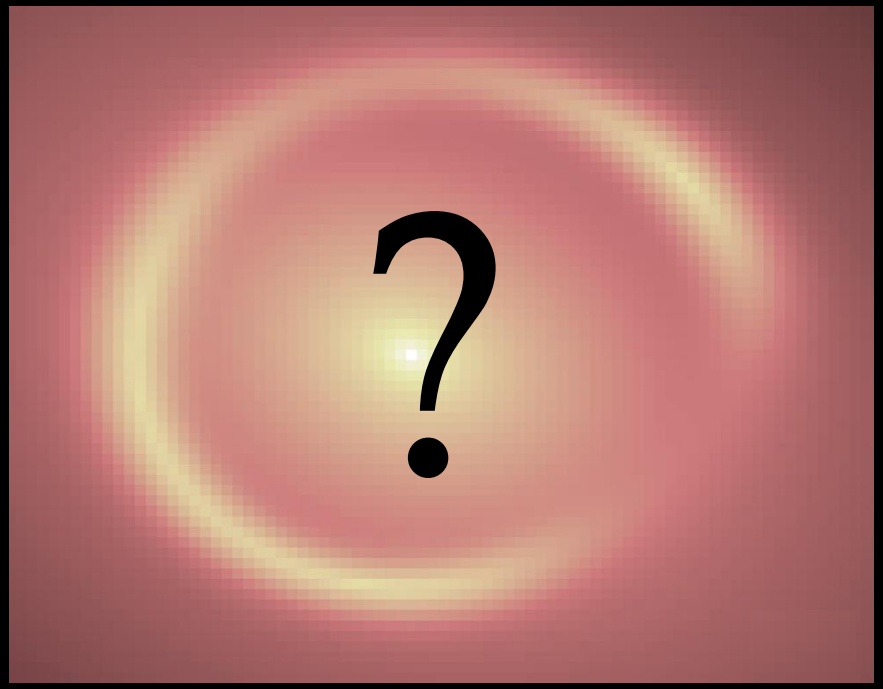
Dark siren lens reconstruction



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Step 4
Searching the sky and identifying the host ~ O(1) arcsec

(HST/NASA)

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Lens reconstruction and time delay modelling

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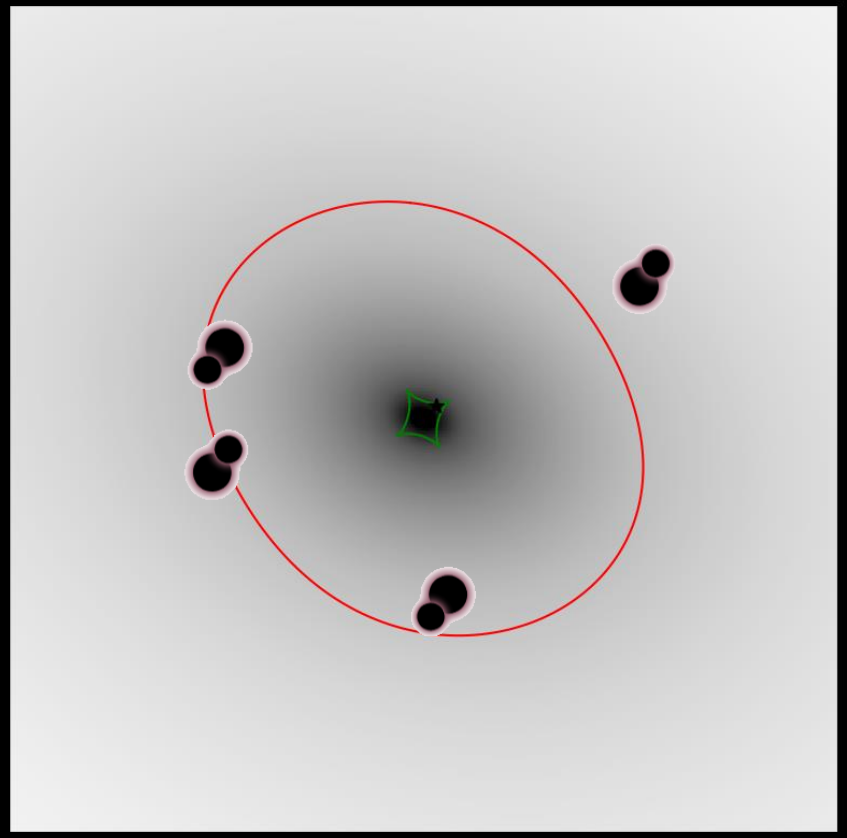
Step 5
Lens reconstruction and time delay modelling

Step 6
Pin-point localization ~ O(<1) arcsec

# DARK SIREN RECONSTRUCTION

- Time delays and effective luminosity distance ratios (i.e. magnifications) obtained from GW
- Poon et al. (*in prep*.): reconstruct some lens parameters, limited by degeneracy
- Scan sky for matching EM lenses
- Wempe et al. (2023): If host observable, host identified 20-50% of the time (Euclid)
- Larger/unique lenses better identified



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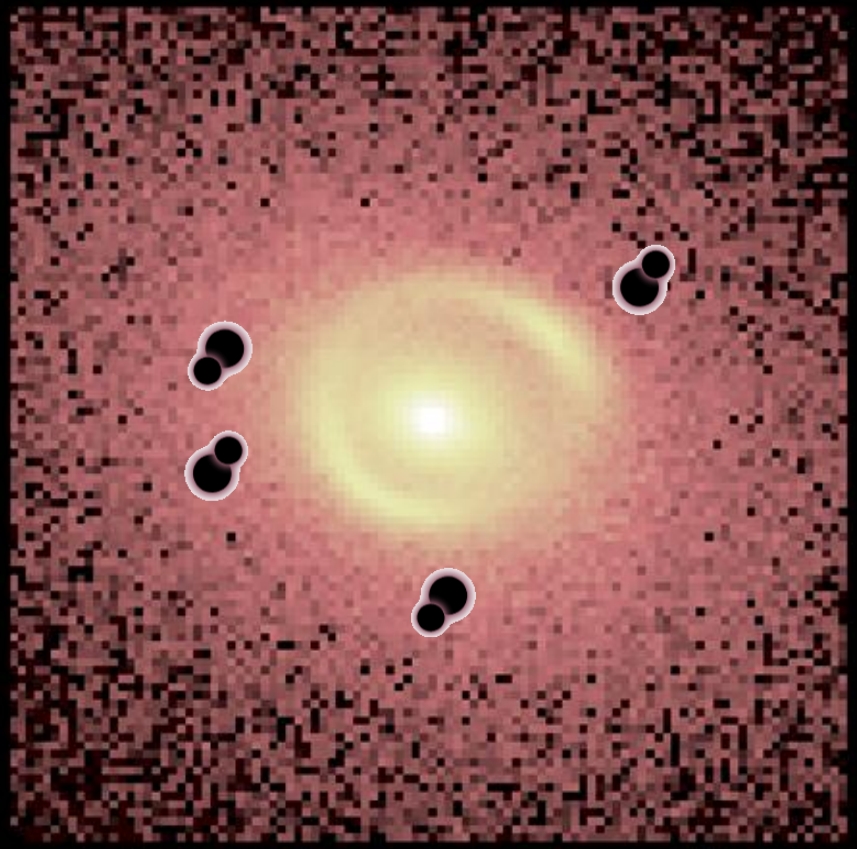

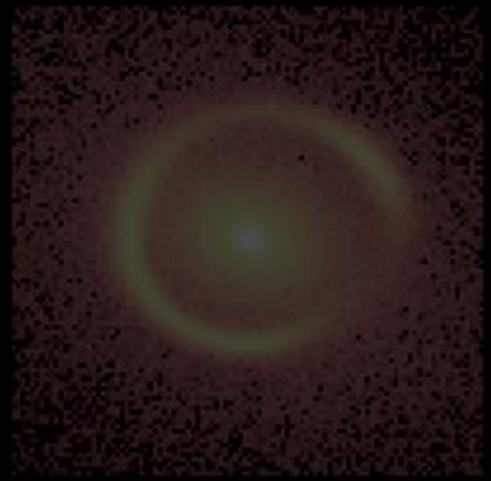

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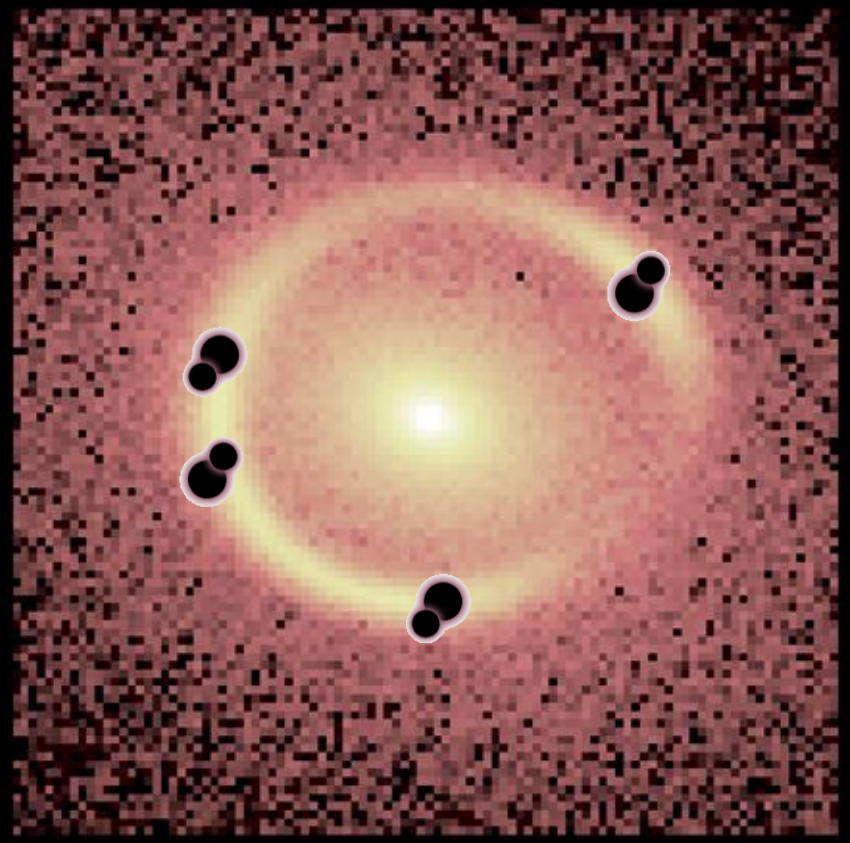
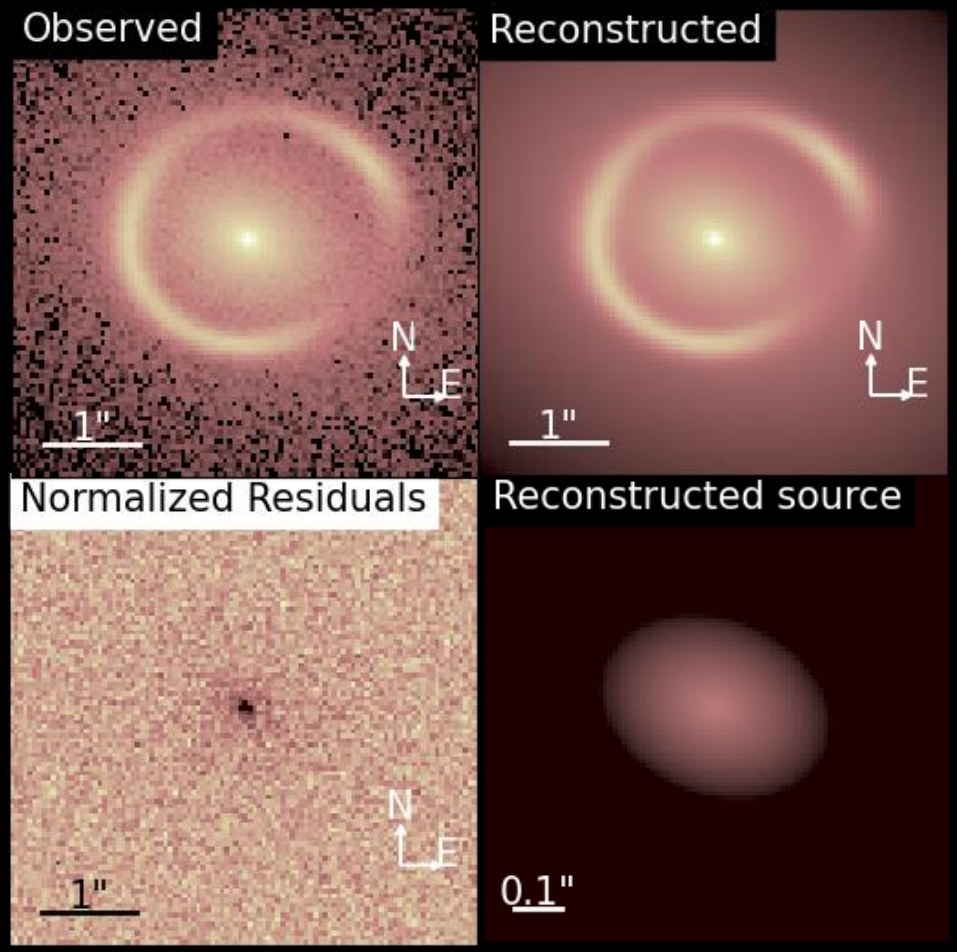


# LENS RECONSTRUCTION

- EPL + Shear
- Location for 4-image GW
- Lensed optical image + lensed GWs observed
- Localization will highly depend on reconstruction
- Relies on image quality
- Complete EM lens reconstruction

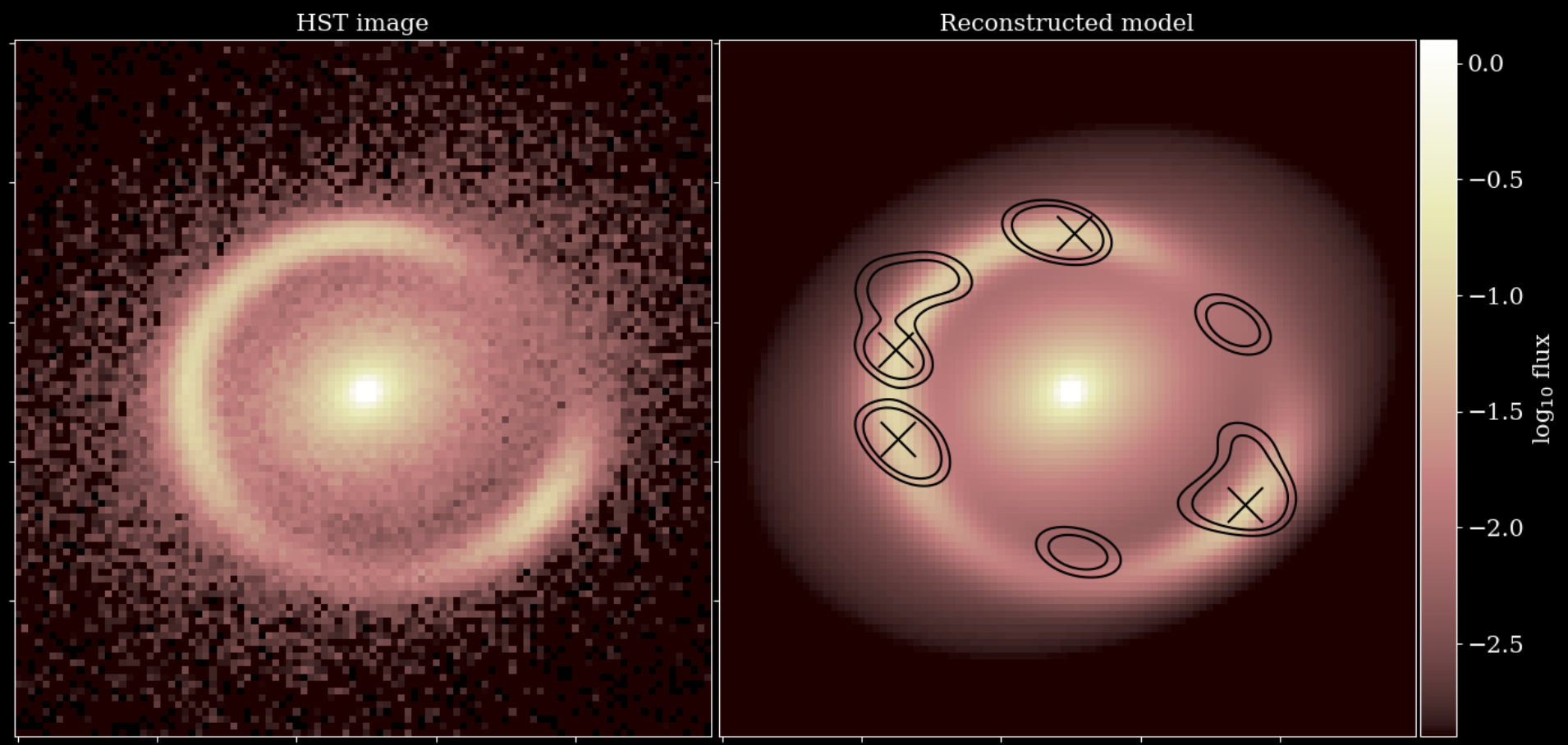


# GOLUM AND TIME DELAYS

- Use GOLUM for ‘reconstruction’ of source parameters
- Retrieves relative time delays to precision of $\mathcal{O}(0.1)$ ms

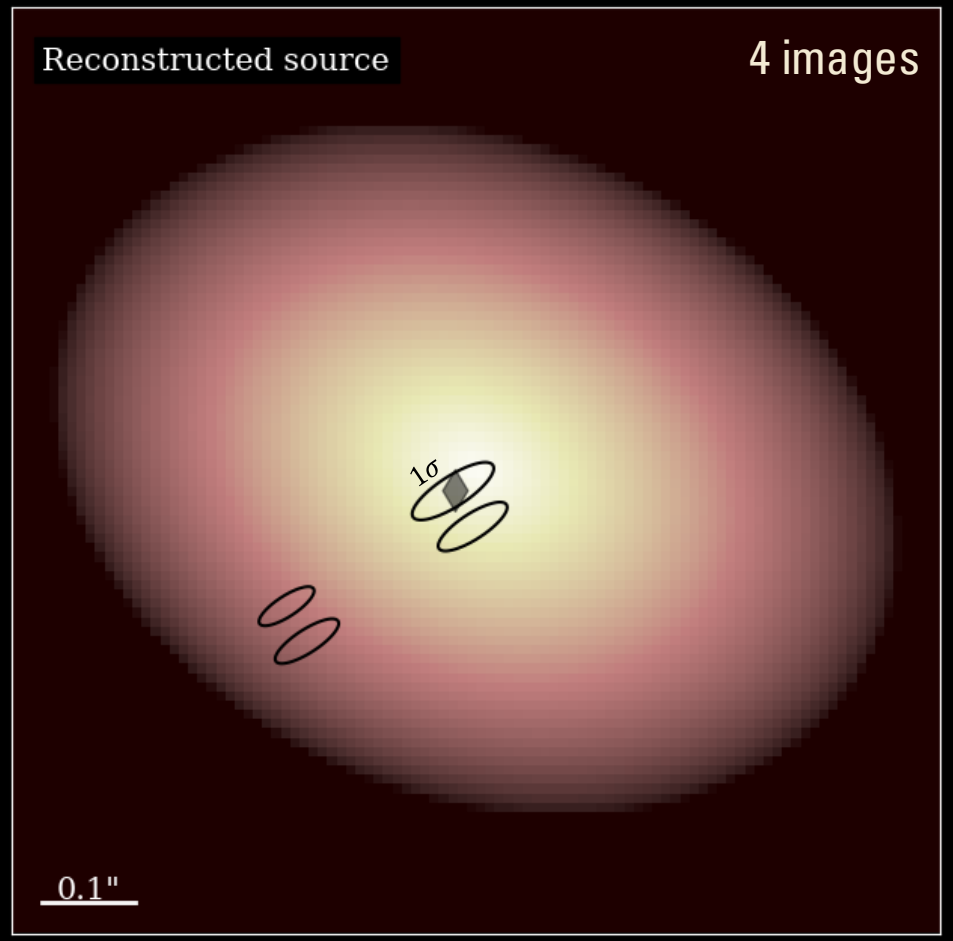
- Sample lens model posteriors, time delay posteriors
- Sample random source plane position
- Calculate log likelihood between relative measured and relative model values
- 4-images: retrieve degenerate positions due to symmetries in lens model

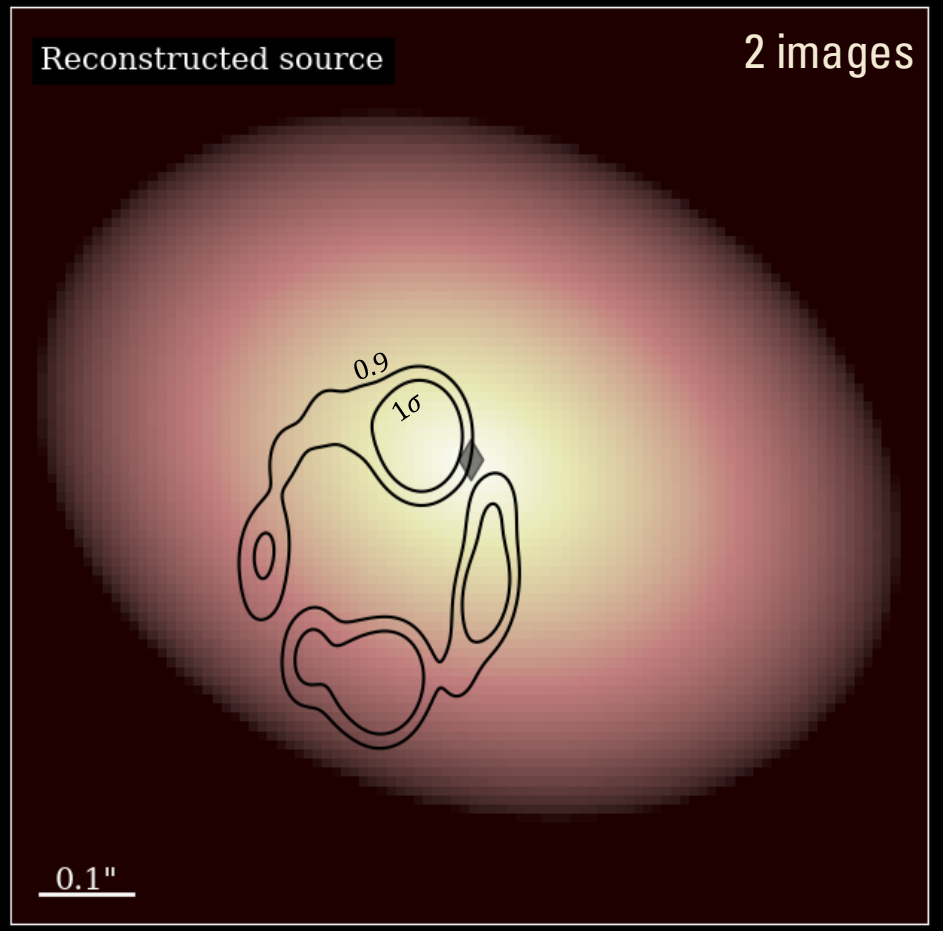
# LOCALIZATION: IMAGE POSITIONS




*representation only

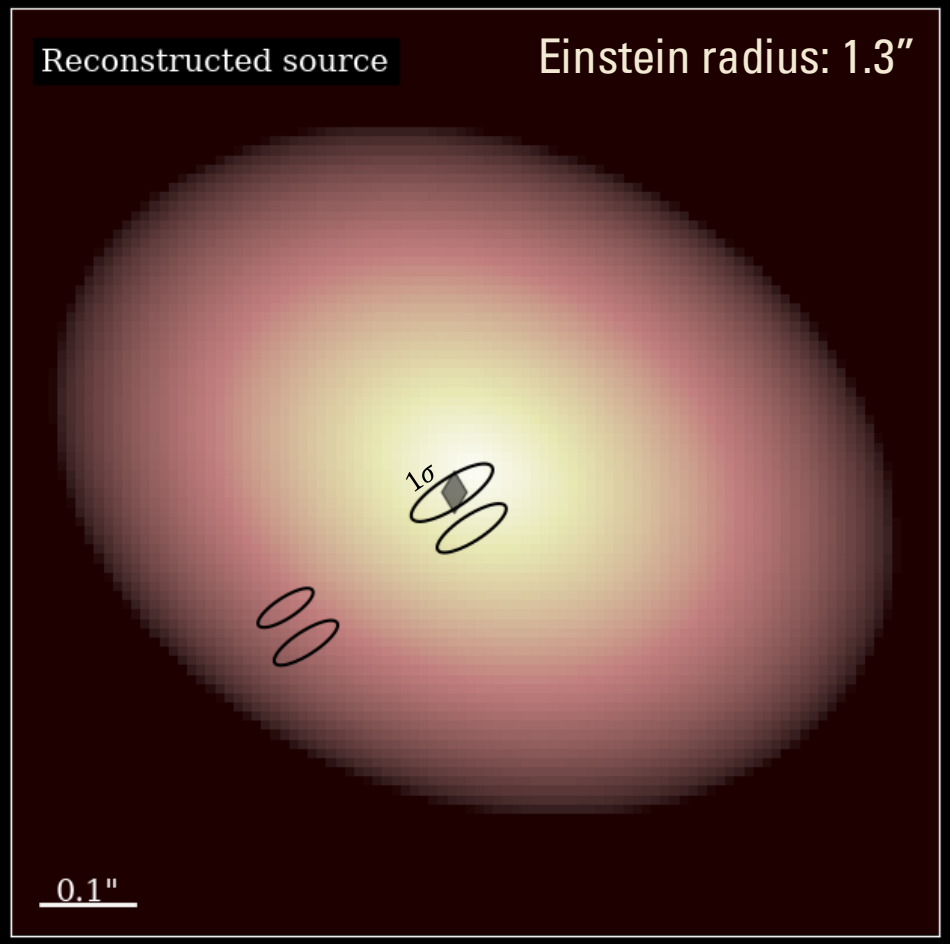
# LOCALIZATION: IMAGE NUMBER

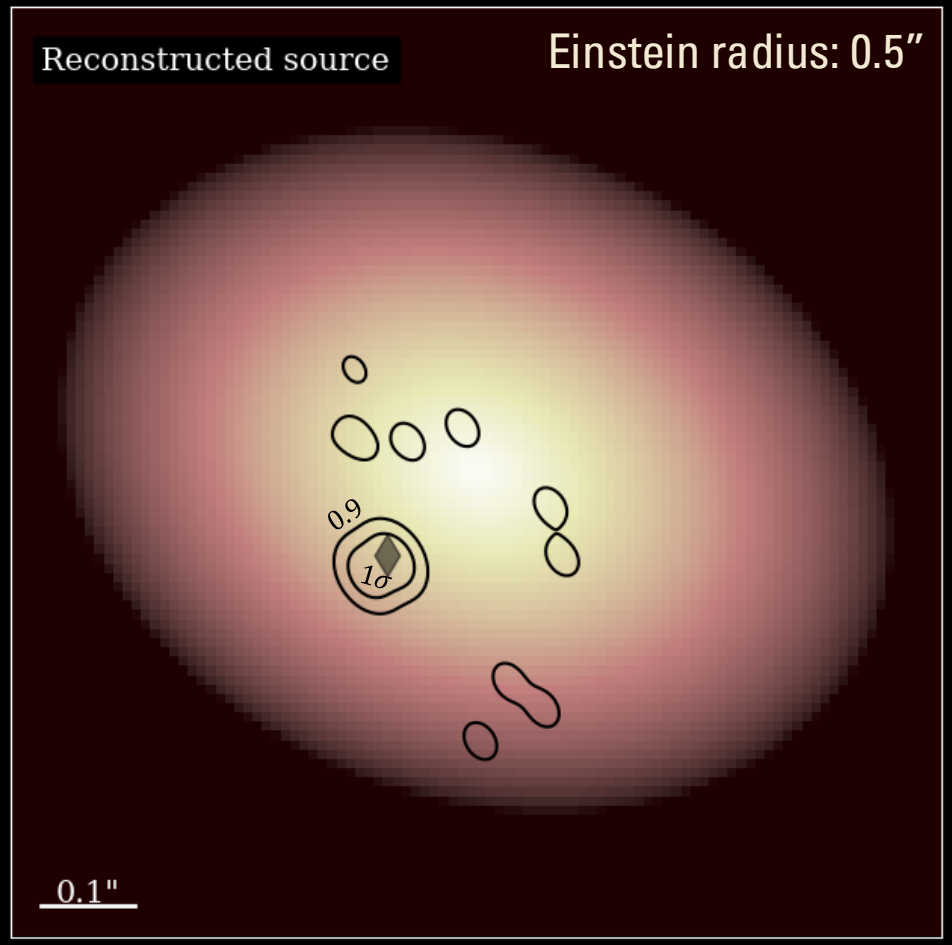



*representation only

# LOCALIZATION: EINSTEIN RADIUS




*representation only

# FUTURE TESTS

- Number of GW images: 2/3/4 images?
- Magnification information?
- Image quality
  - Telescope resolution, source observability, Einstein radius
- How much is localization affected by modelling uncertainties?
- Localization dependence on limitations needs to be quantified

# CONCLUSIONS

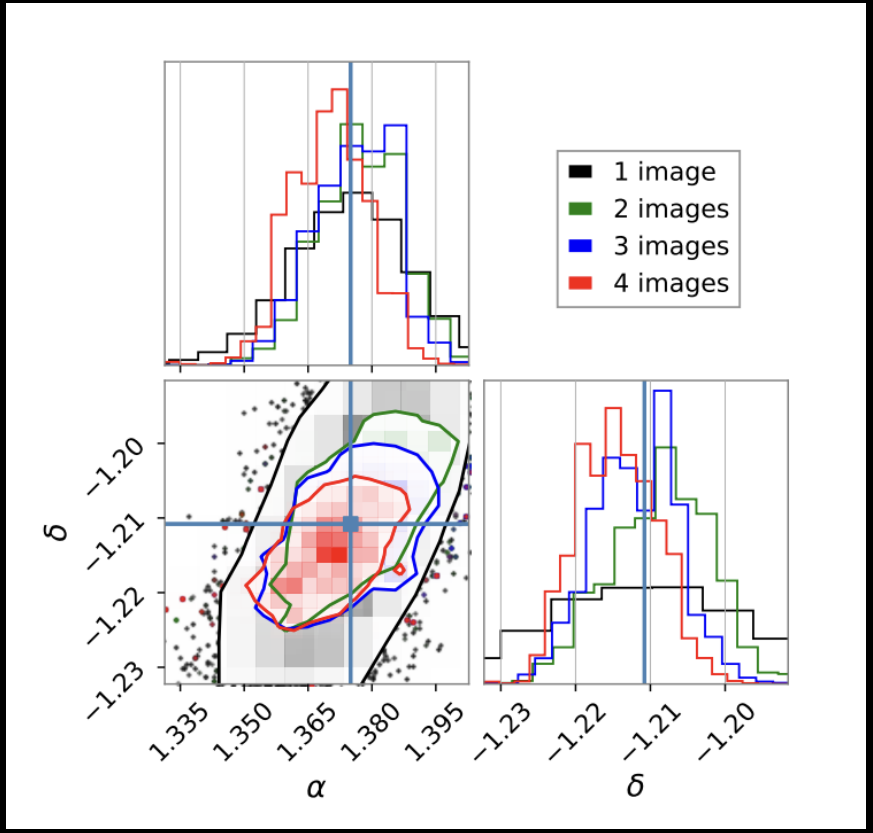
- Sub-arcsec$^2$ degenerate regions
- Aim to quantify precision of the localization and its dependences
- Combining the EM of the host and the BBH GW data, a variety of applications open up
  - Population studies and the links between host and BBH properties
  - Cosmology and Hubble constant
  - Milli- and micro-lensing searches and lens structure

*Lensing of GW and their EM hosts offers a different potential avenue, straying from the traditional approach, towards new multi-messenger science.*

*Thank you!*

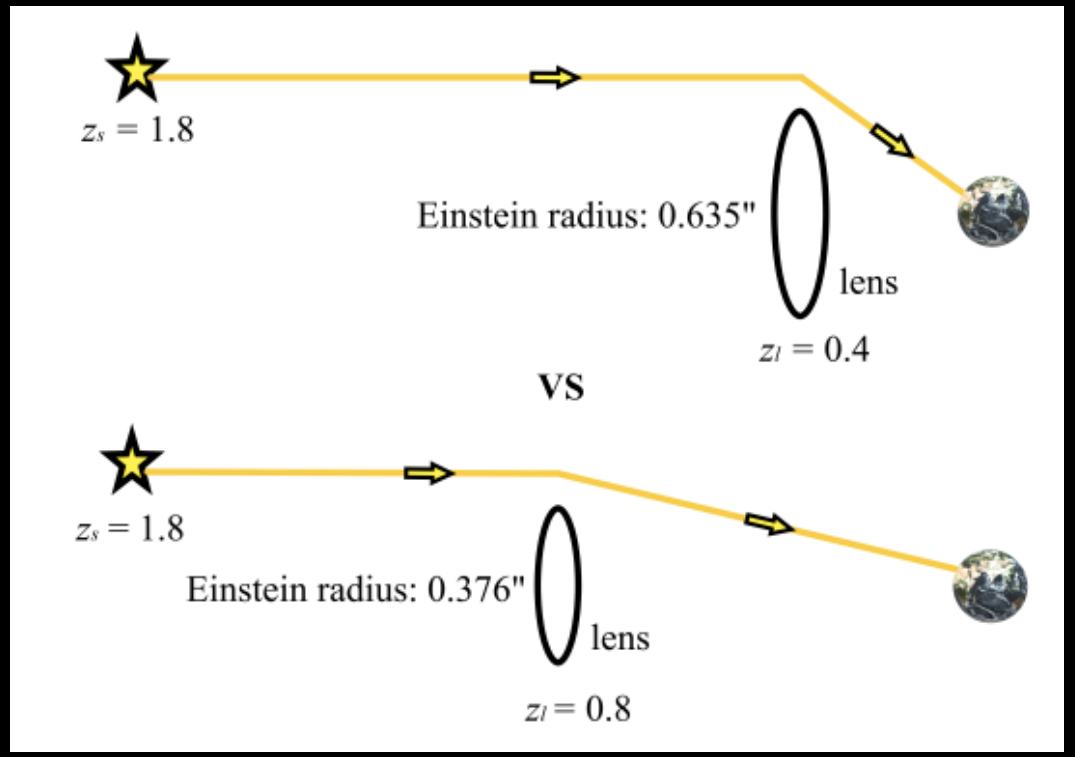
# APPENDIX: JOINT PE

- Sky localization
- Parameters: GW params + $\Delta t_d, \Delta n, \mu_1/\mu_X$



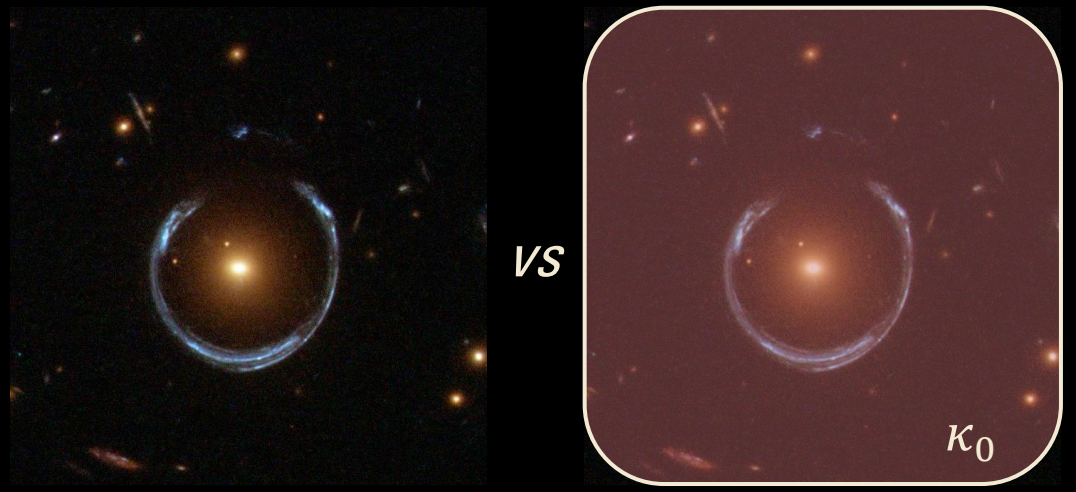
# APPENDIX: DEGENERACIES

## Similarity transformation

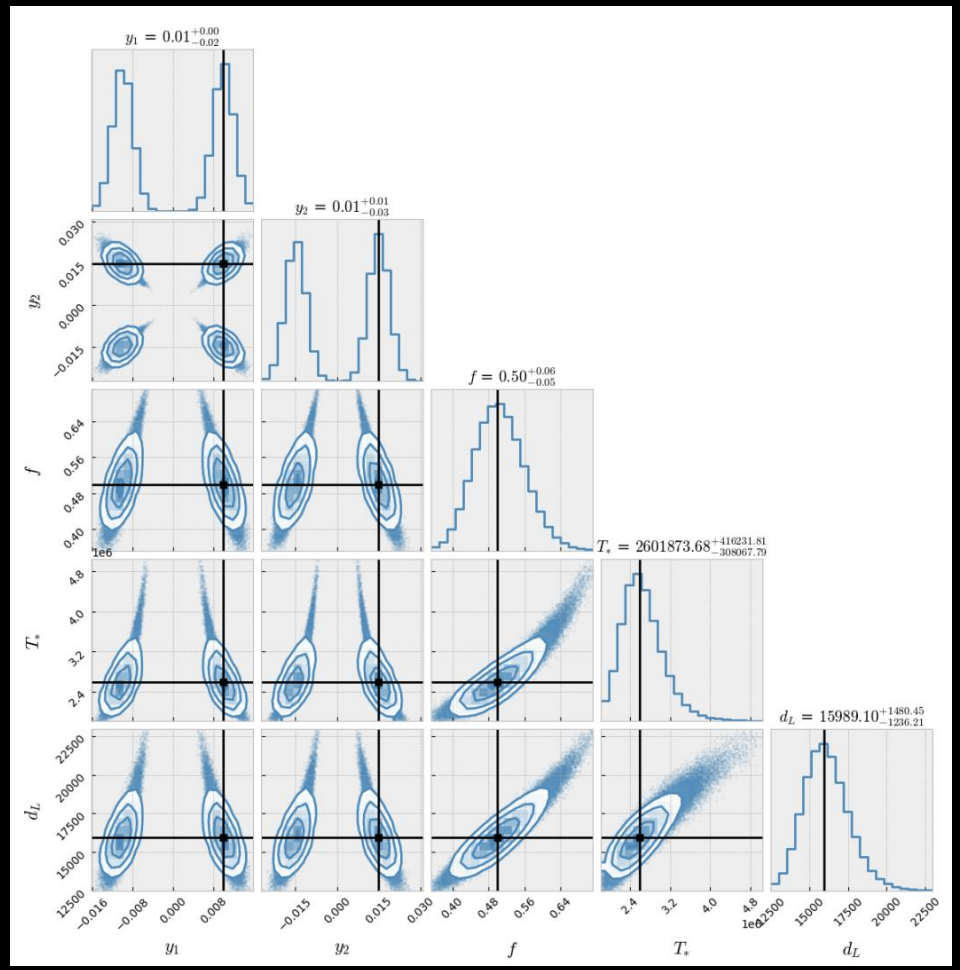


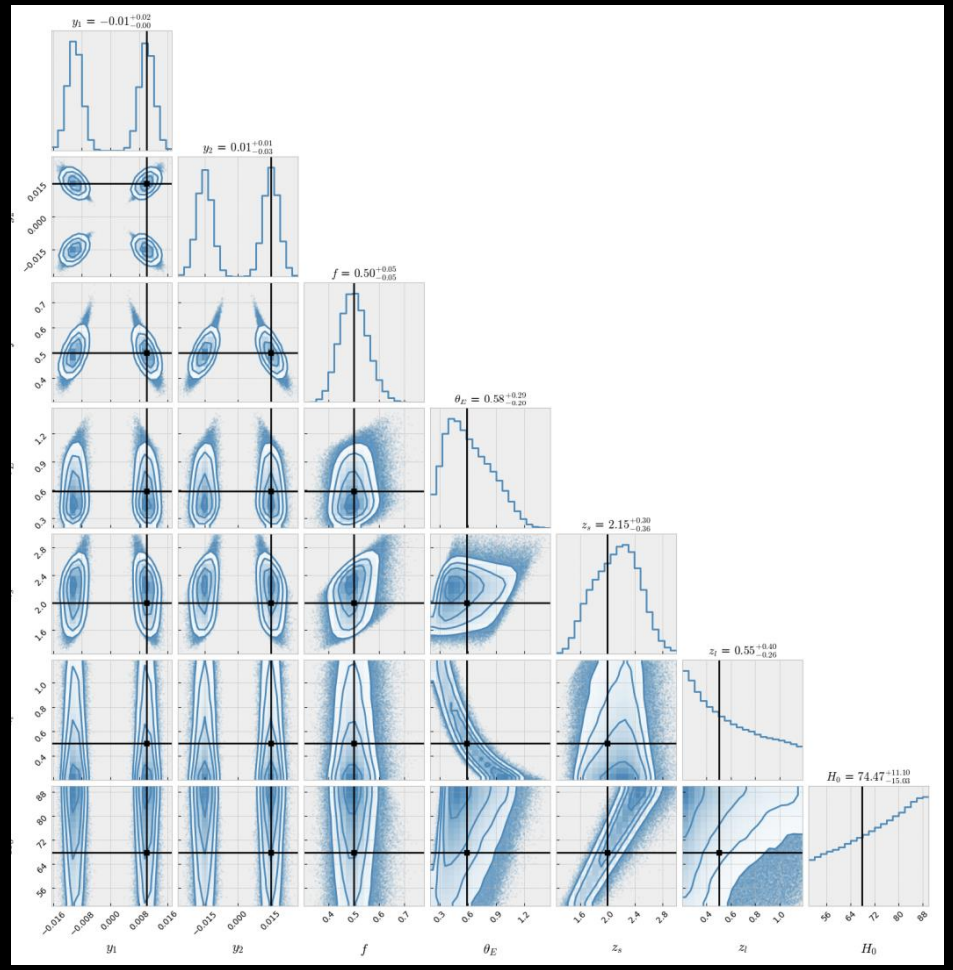

Poon et al. (*in prep*)

## Mass sheet degeneracy



# APPENDIX: DARK SIREN RECONSTRUCTION

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