Gravitational Lensing from Cosmic Shear to Microlensing

OATS
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Outline:

Very Short Introduction to Gravitational Lensing -

Weak lensing -

simulating weak lensing

Strong Lensing -

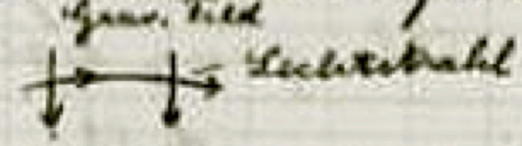
simulating strong lensing

Zürich 14. X. 13.

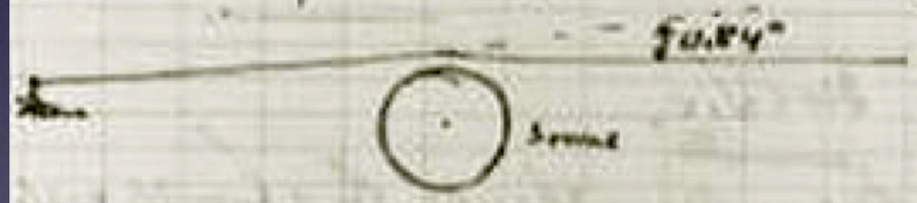
Aus

Hoch geehrter Herr Kollege!

Eine einfache theoretische Überlegung macht die Annahme plausibel, dass Lichtstrahlen in einem Gravitationsfelde eine Deviation erfahren.



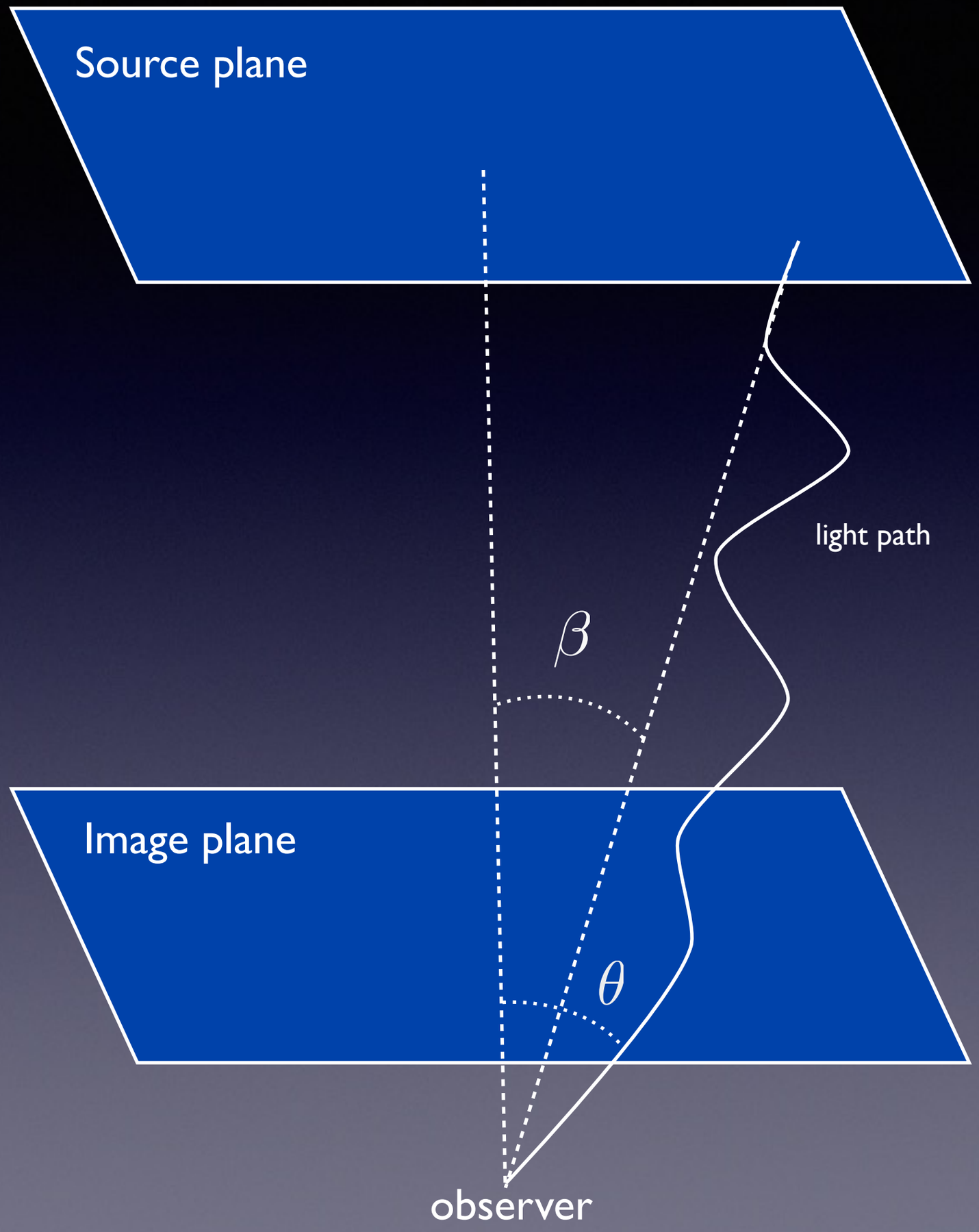
Am Sonnenrande müsste diese Ablenkung 0,84" betragen und wie $\frac{1}{R}$ abnehmen (R = Entfernung vom Sonnen-Mittelpunkt)



Es wäre deshalb von grösstem Interesse, bis zu wie grossen Sonnennähe helle Fixsterne bei Anwendung der stärksten Vergrösserungen bei Tage (ohne Sonnenfinsternis) gesehen werden können.

Lensing Equation

$$\vec{\beta} = \vec{\theta} - \vec{\alpha}(\vec{\theta})$$

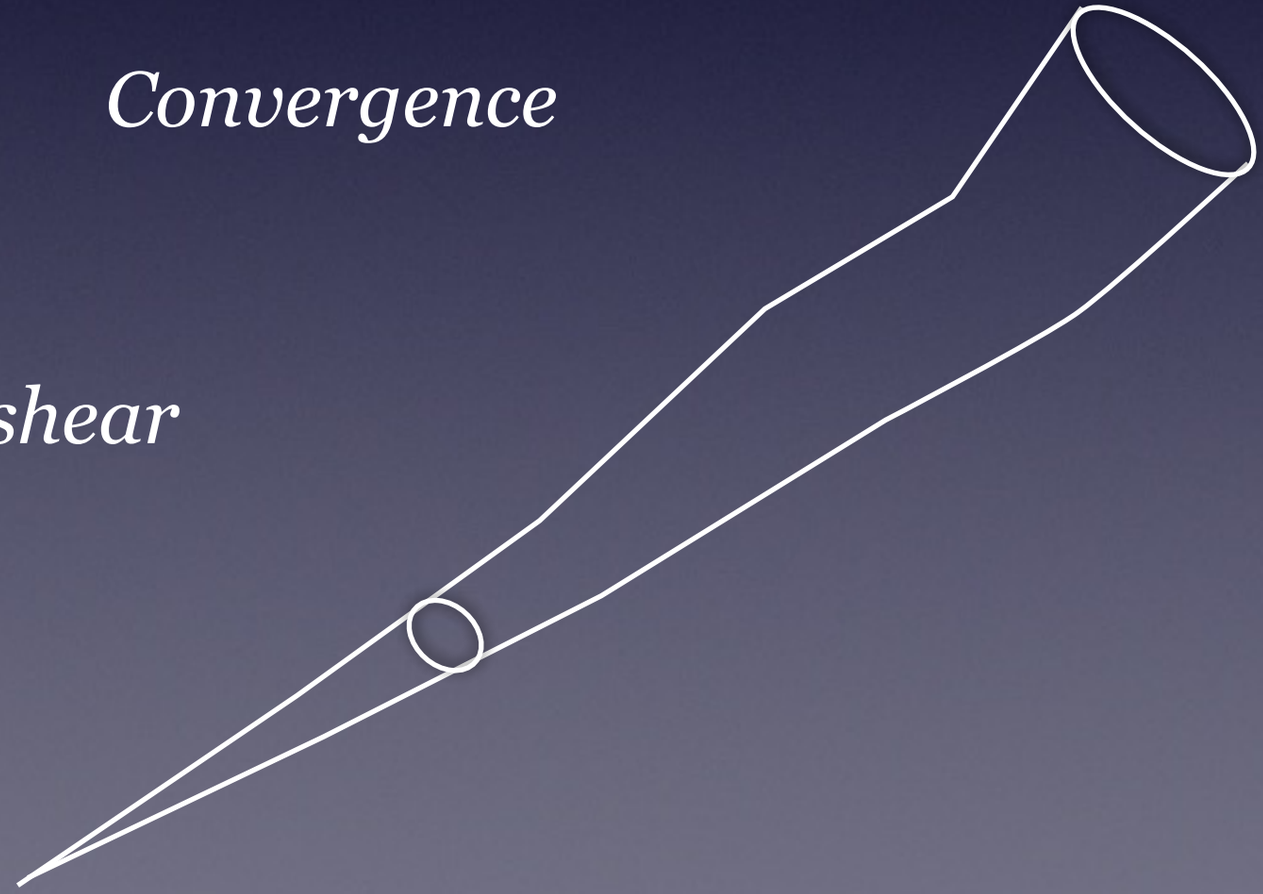


$$\vec{\beta} = \vec{\theta} - \vec{\alpha}(\vec{\theta})$$

$$\frac{\partial \vec{\beta}}{\partial \vec{\theta}} = \mathbf{A} = \begin{pmatrix} 1 - \kappa - \gamma_1 & \gamma_2 \\ \gamma_2 & 1 - \kappa + \gamma_1 \end{pmatrix}$$

$\kappa \equiv 1 - \frac{1}{2}\mathrm{tr}\mathbf{A}$ *Convergence*

$\{\gamma_1, \gamma_2\}$ *shear*



Propagation of a light ray

$$\frac{d^2 x_\perp}{d\lambda^2} = -2\nabla_\perp \phi_N$$

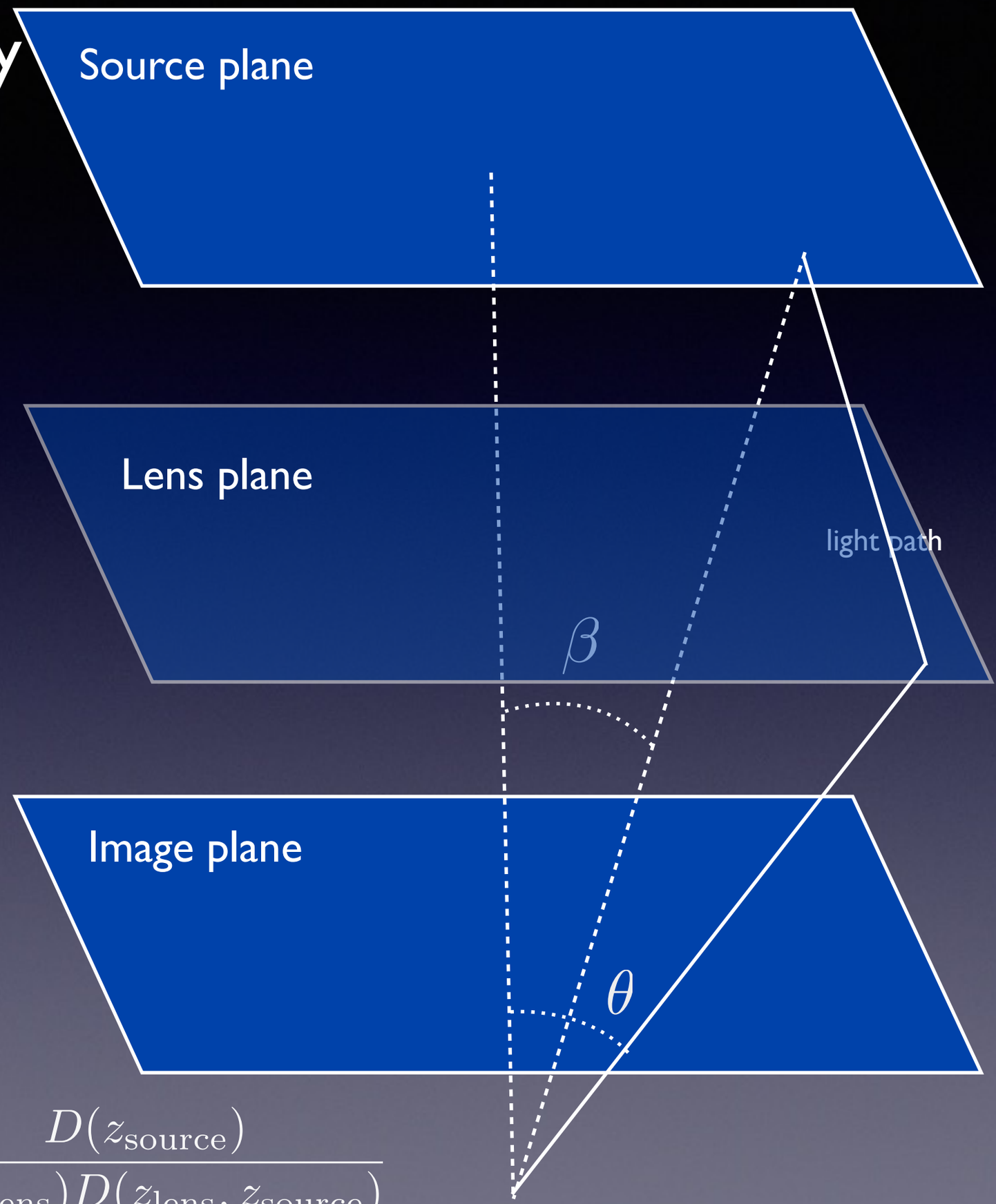
Single Lens Plane

$$\vec{\alpha} = \nabla\phi$$

$$\nabla^2\phi = 2\kappa$$

$$\kappa(\theta) = \frac{\Sigma(\theta)}{\Sigma_{\rm crit}}$$

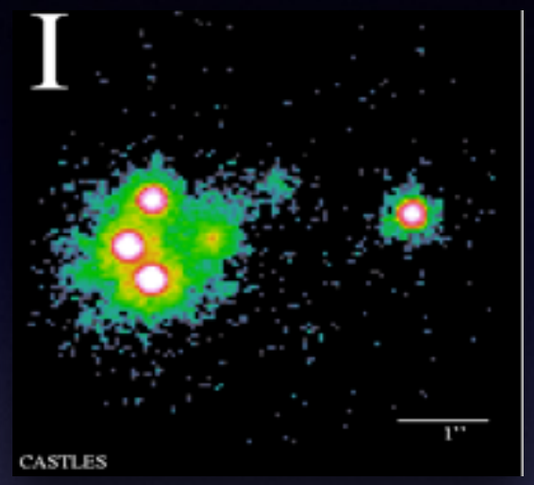
$$= \frac{\text{surface density}}{\text{critical density}}$$



$$\Sigma_{\rm crit}(z_{\rm lens}, z_{\rm source}) = \frac{c^2}{4\pi G}\frac{D(z_{\rm source})}{D(z_{\rm lens})D(z_{\rm lens}, z_{\rm source})}$$

$\kappa\ ,\ \gamma\ \gtrsim\ 1$ *Strong Lensing*

Multiple Images



Highly Distorted Images

$\kappa, \gamma << 1$

Weak Lensing

1) Deflection (and shear) field is a potential field even for multiple planes

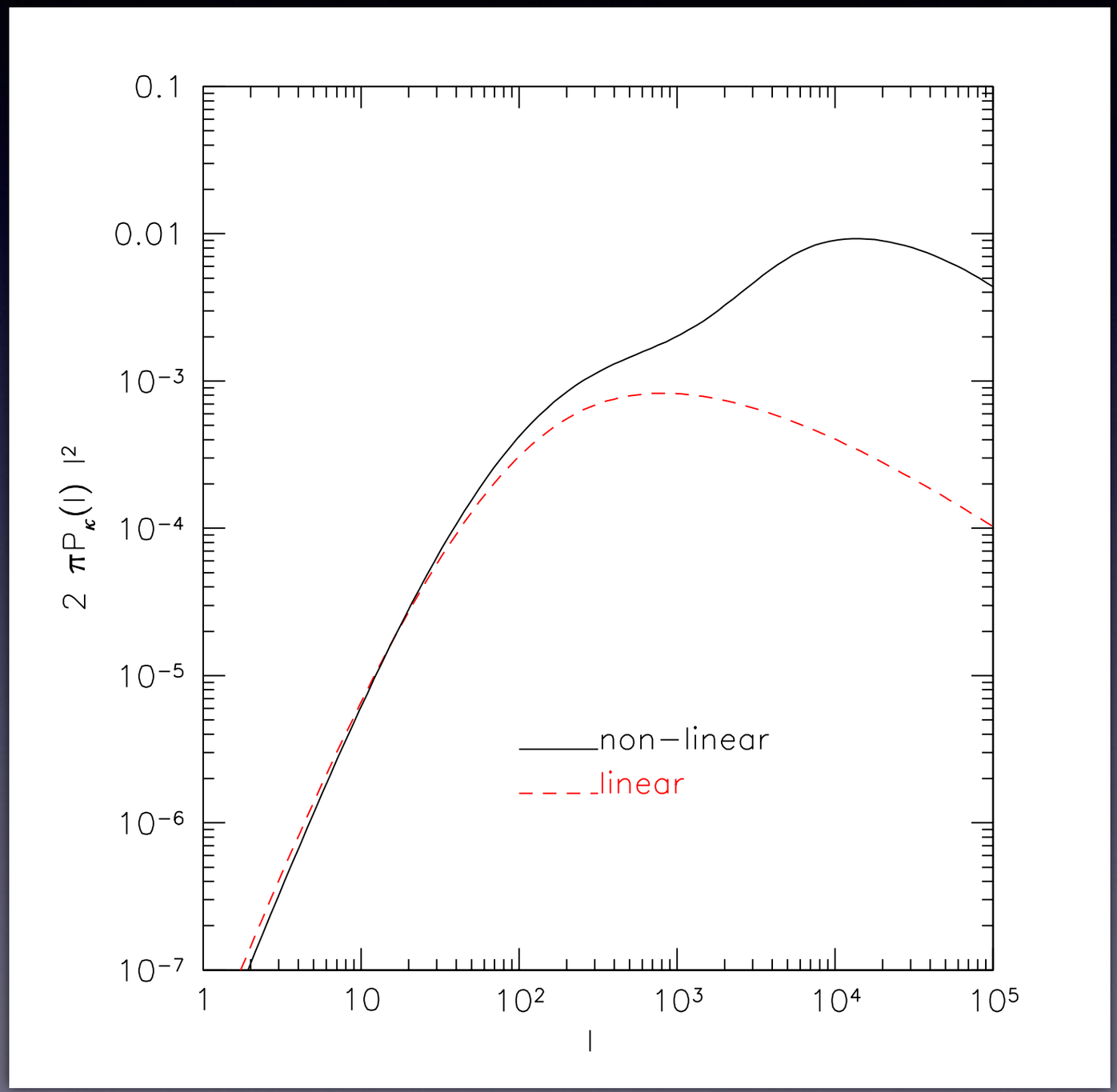
2) The ellipticity of a galaxy is an unbiased estimator of the shear

$$\vec{\alpha} = \nabla\phi$$
$$\nabla^2\phi = 2\kappa$$
$$\mathbf{D}\phi = \boldsymbol{\gamma}$$

$$\boldsymbol{\epsilon} = \boldsymbol{\epsilon}_{\mathrm{intrinsic}} + \boldsymbol{\gamma}$$
$$\langle\boldsymbol{\epsilon}\rangle_{\mathrm{orientation}} = \boldsymbol{\gamma}$$
$$\nabla^2\mathbf{D}^{-1}\langle\boldsymbol{\epsilon}\rangle = 2\kappa$$

Cosmic Shear

Convergence Power Spectrum

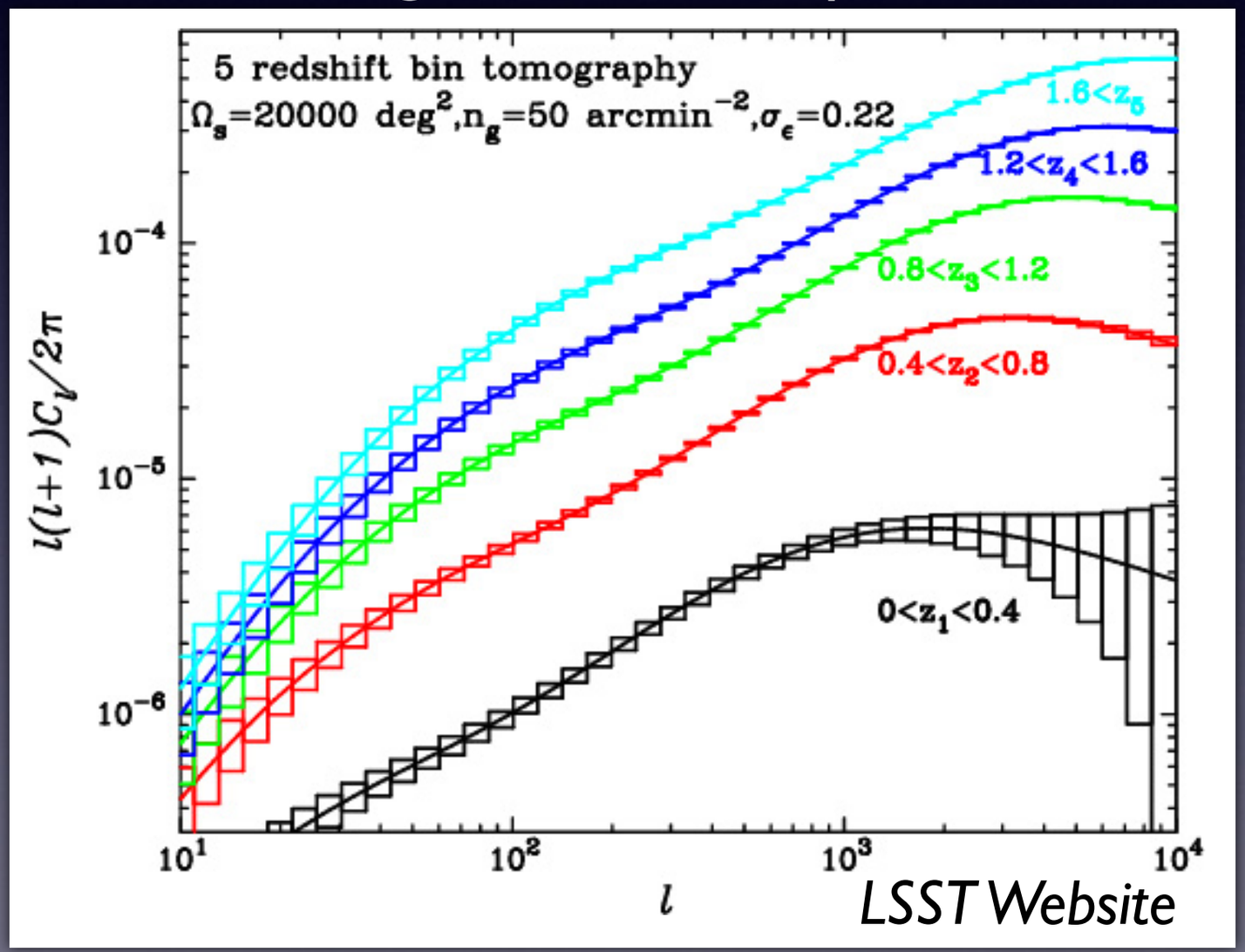


Non-linear structure is clearly important

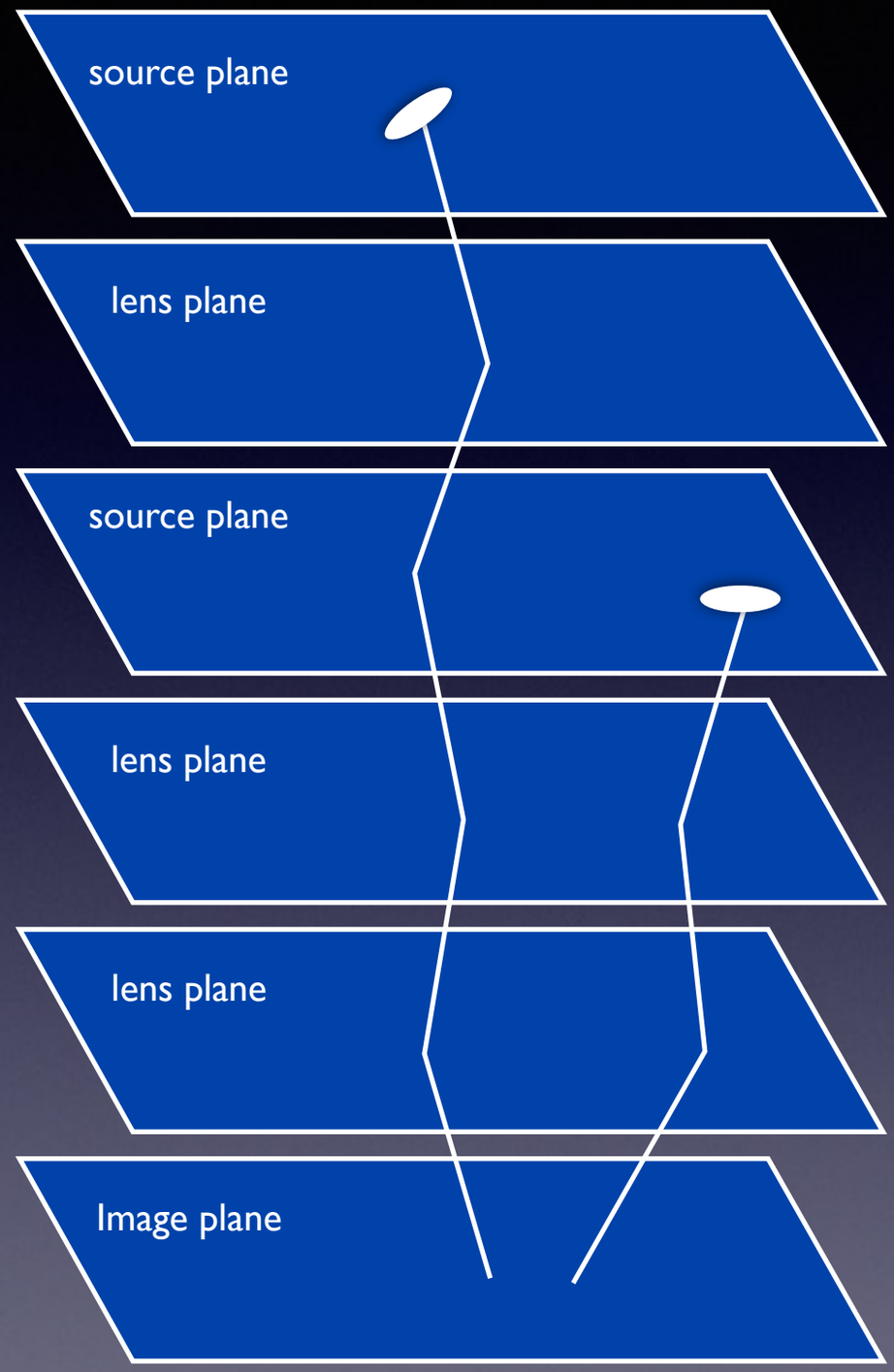
Cosmic Shear

Tomographic lensing

Convergence Power Spectrum



LSST Website



lensing simulation with *GLAMER*

calculating deflection angle

analytic model or from particles:

tree code deflection solver
modified algorithm to handle halos efficiently

adaptive smoothing for Nbody/hydro particles

multiple lens planes:
3d along light paths

lens model

single analytic lens
multiple analytic halos
Nbody/SPH particles
point masses (stars)
pixelized mass map

the grid of rays

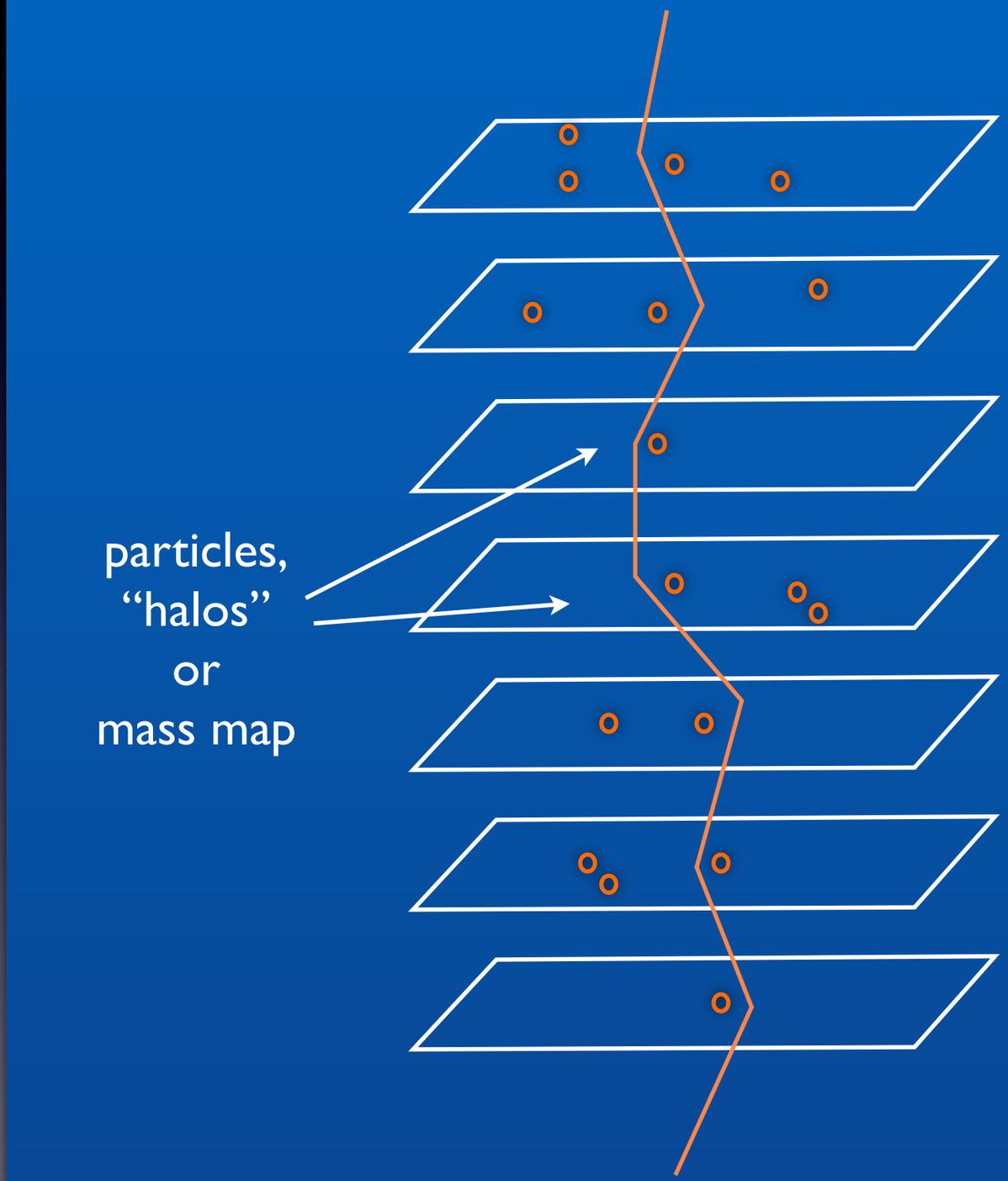
adaptive grid refinement

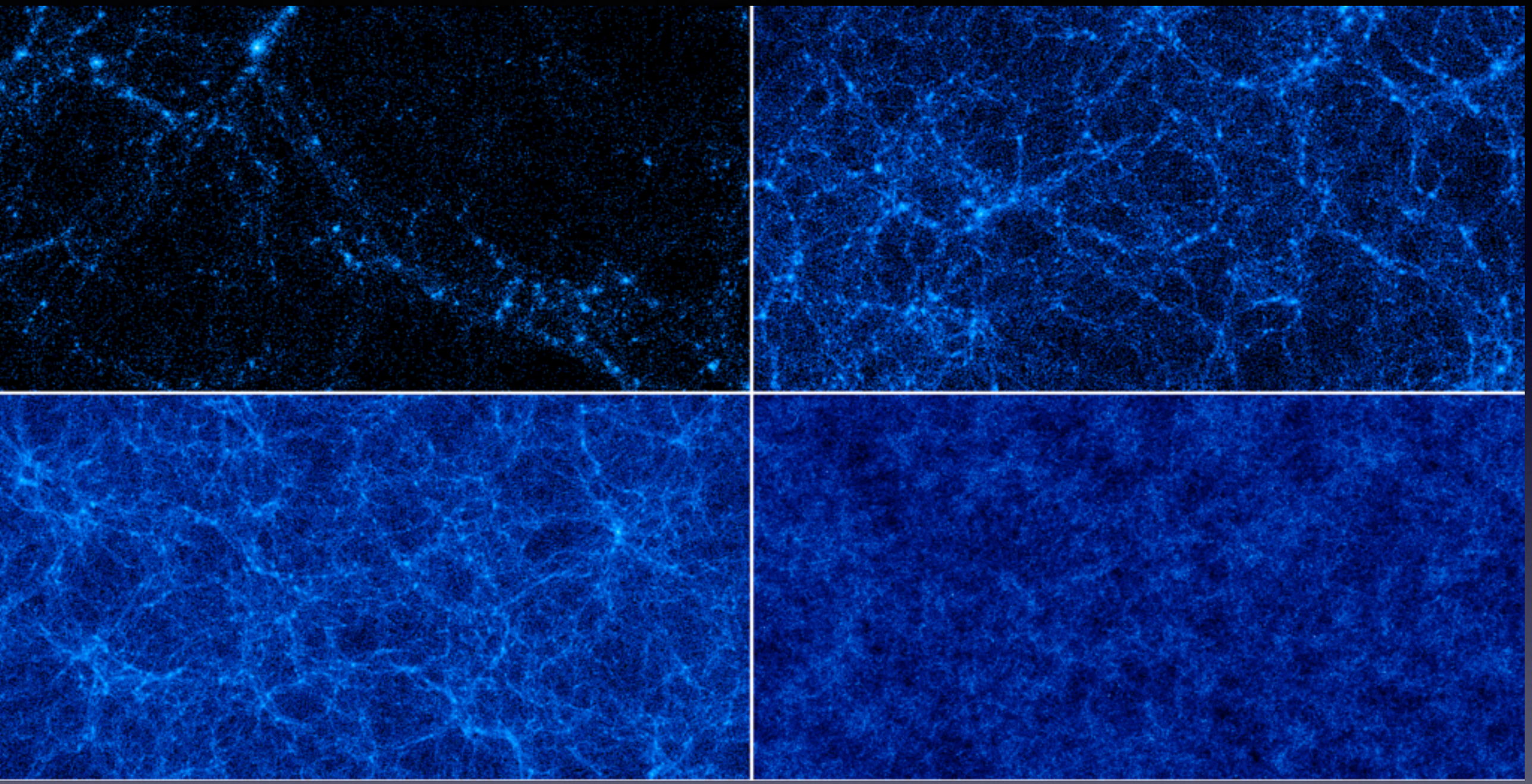
full image reconstruction or just shear and convergence

source model

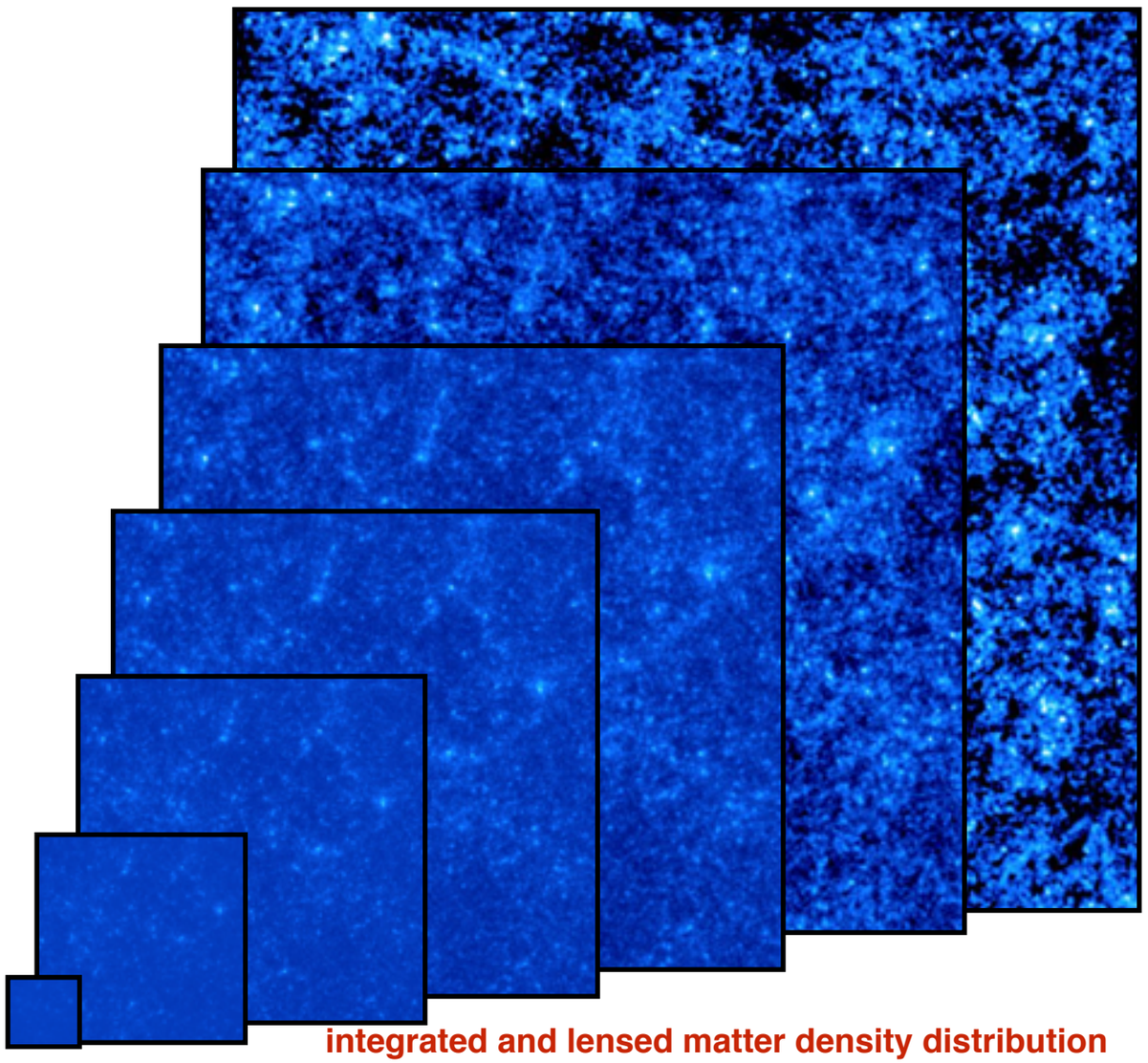
analytic model for surface brightness
and
direct pixelized images

multi-plane lensing

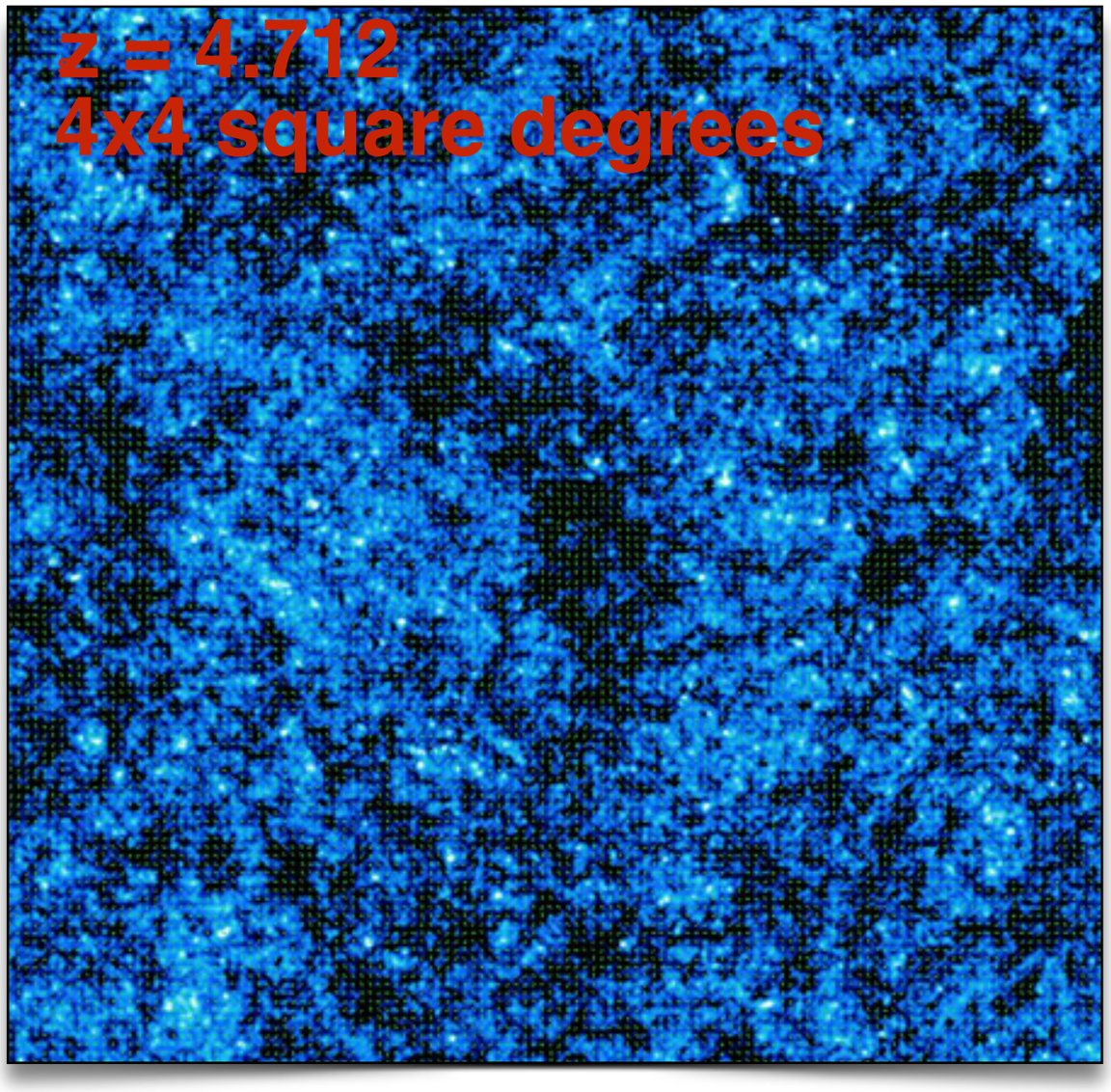




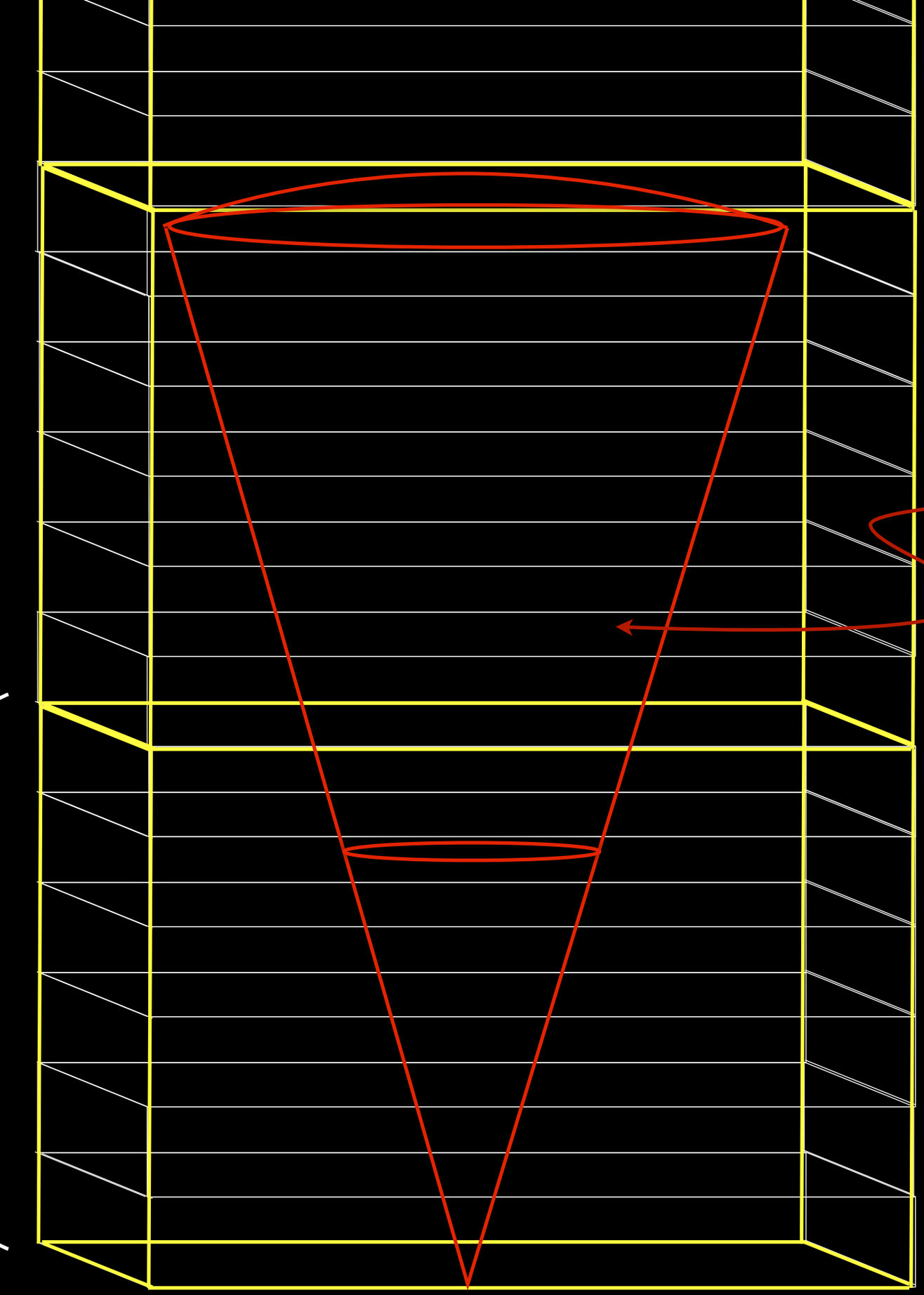
Building up the cone from the MultiDark simulation



integrated and lensed matter density distribution



constructing light-cones

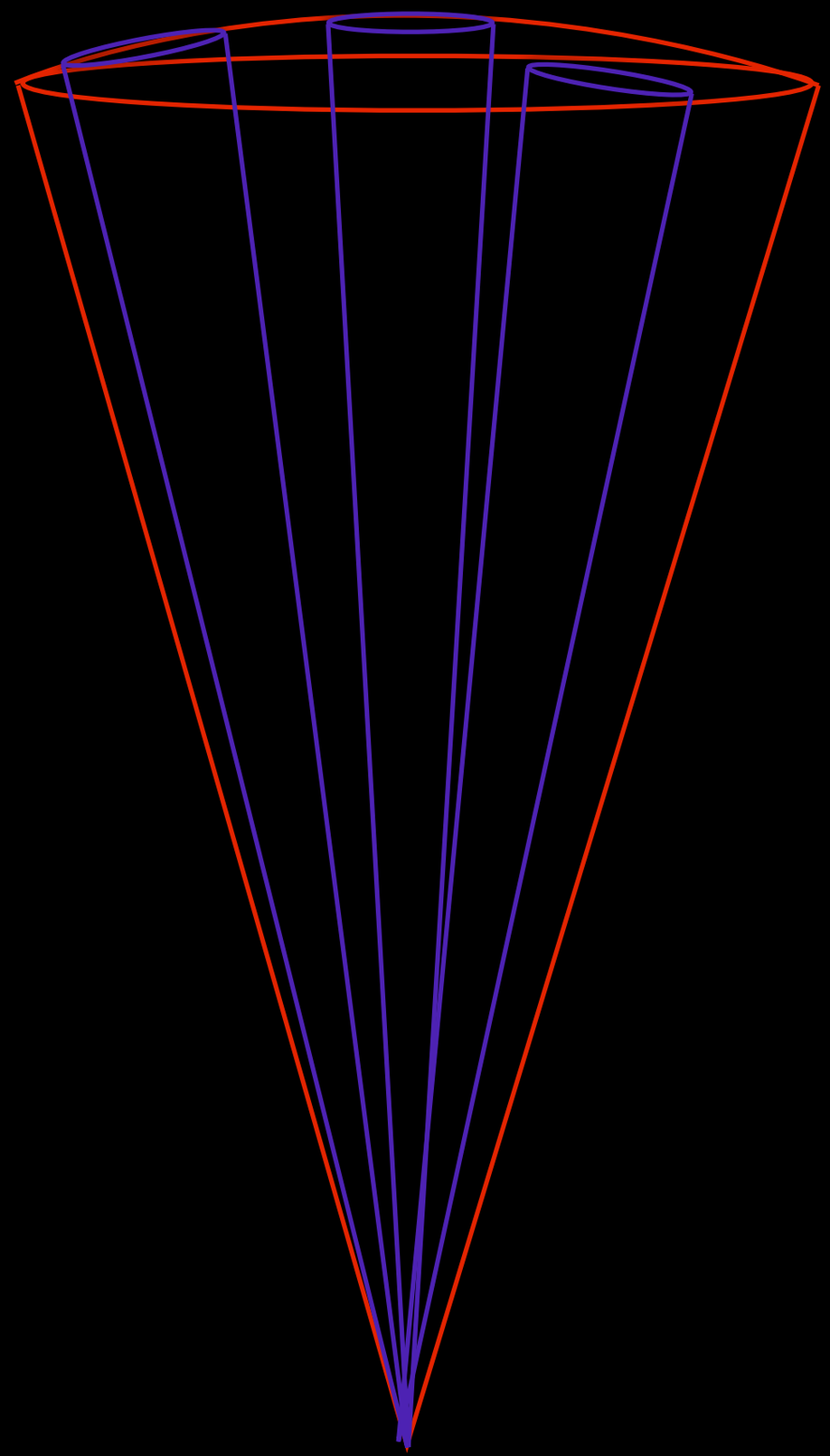


light-cone

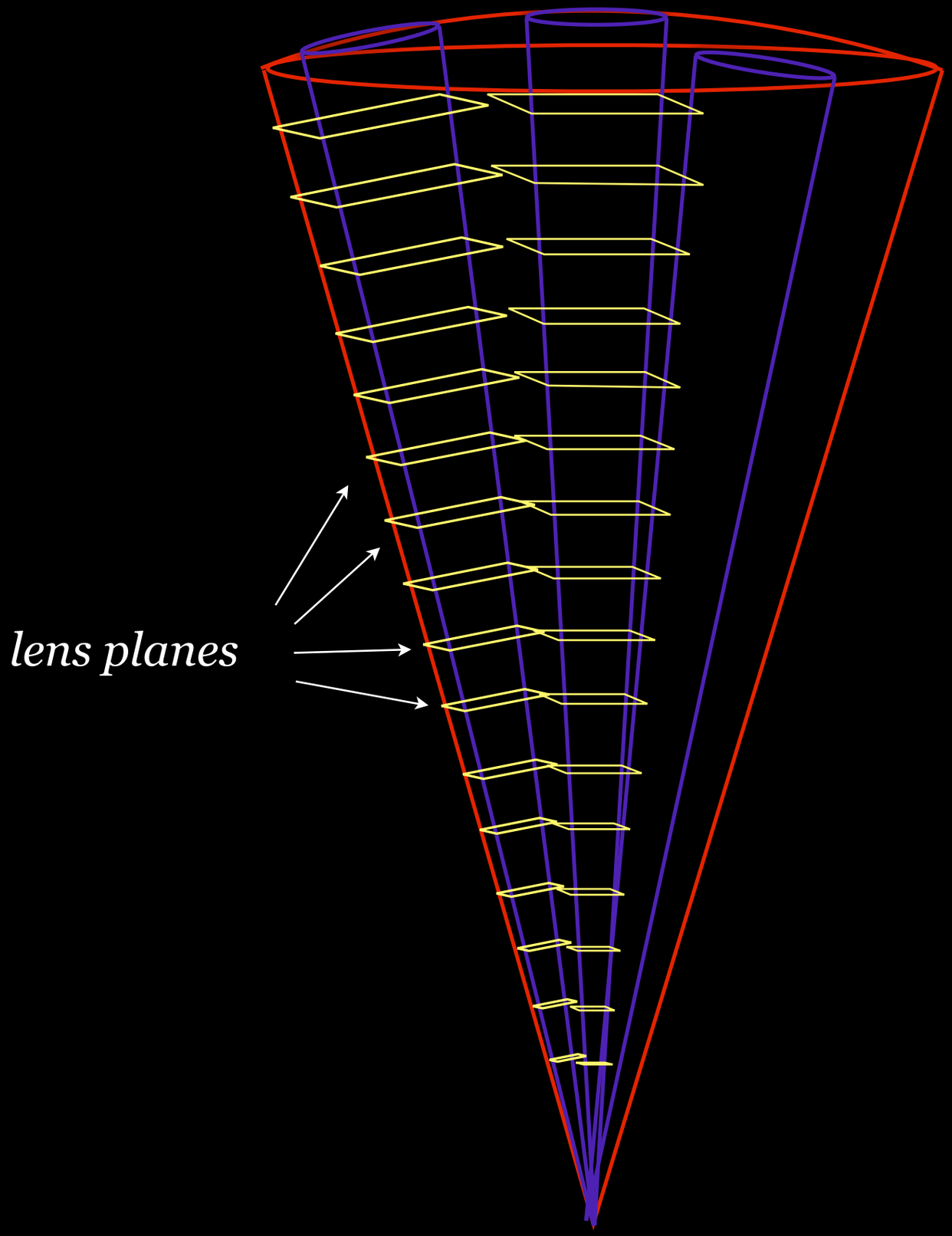
simulation box

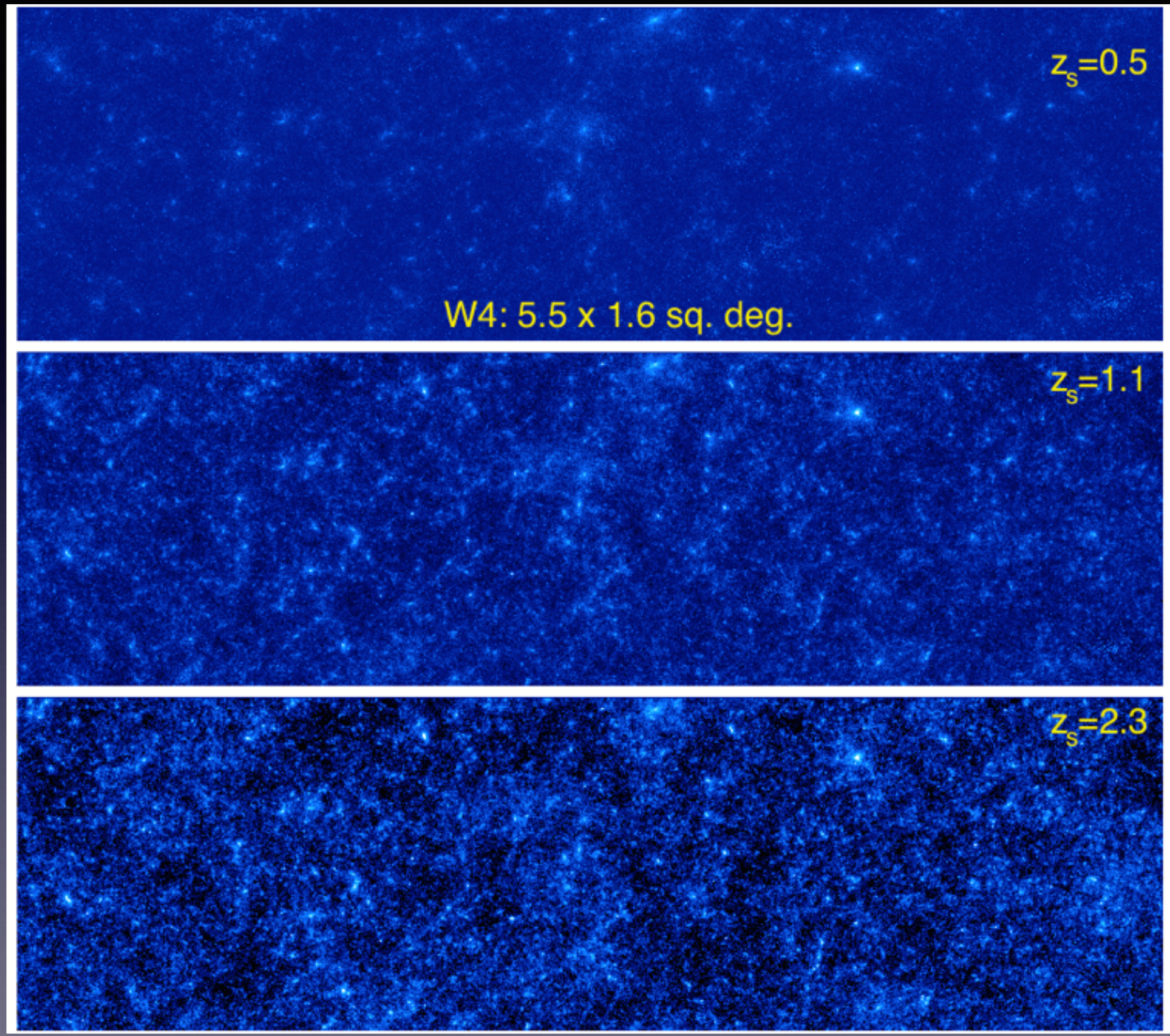
simulation snapshots

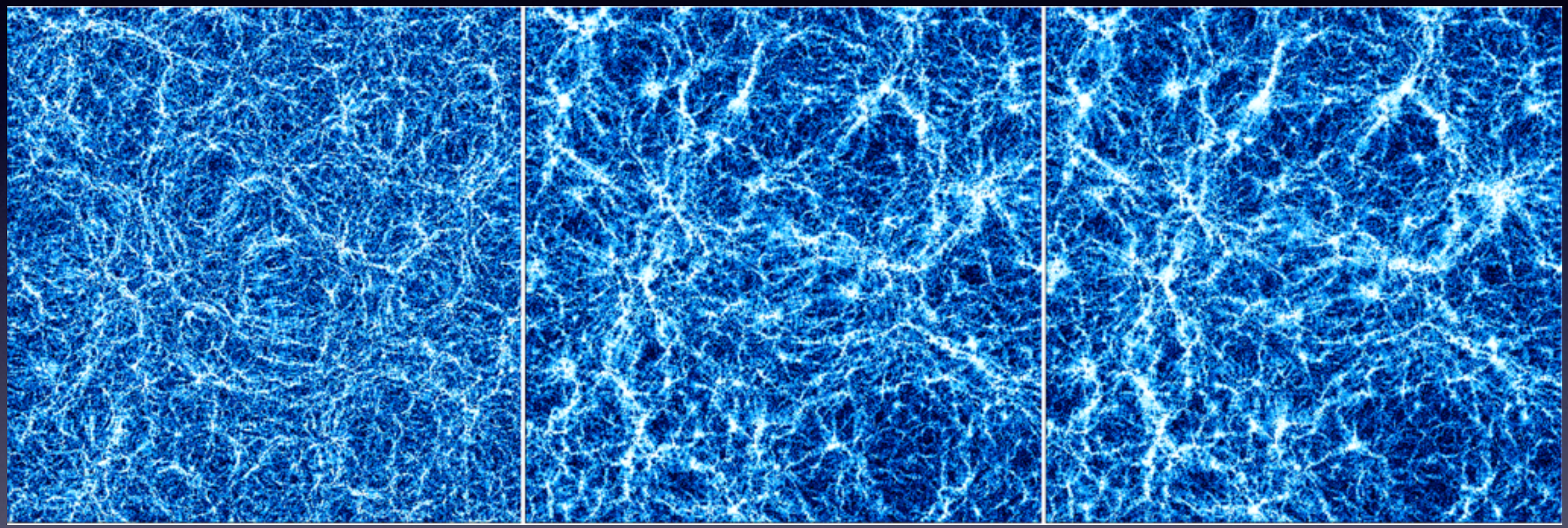
constructing light-cones

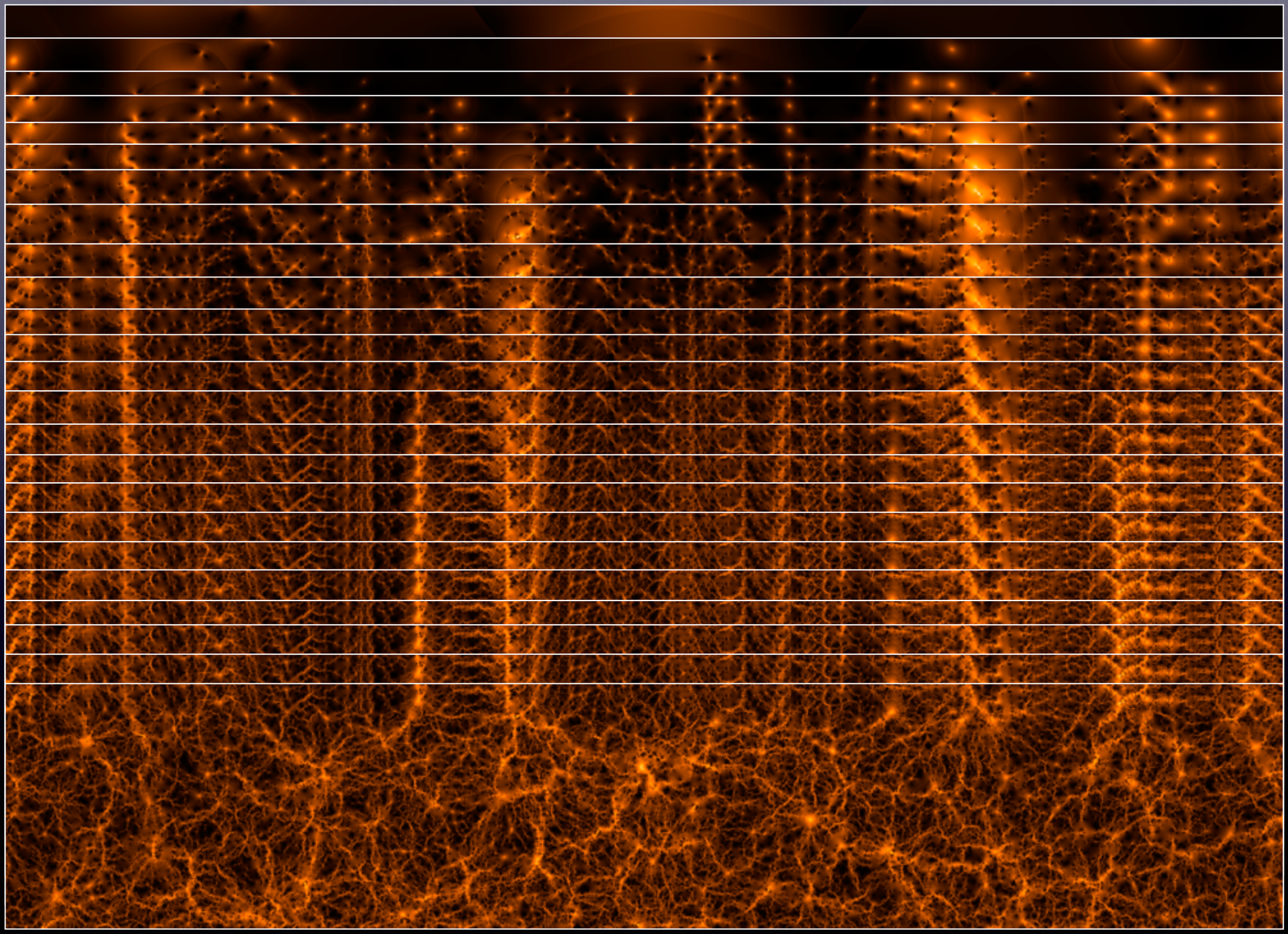


constructing light-cones

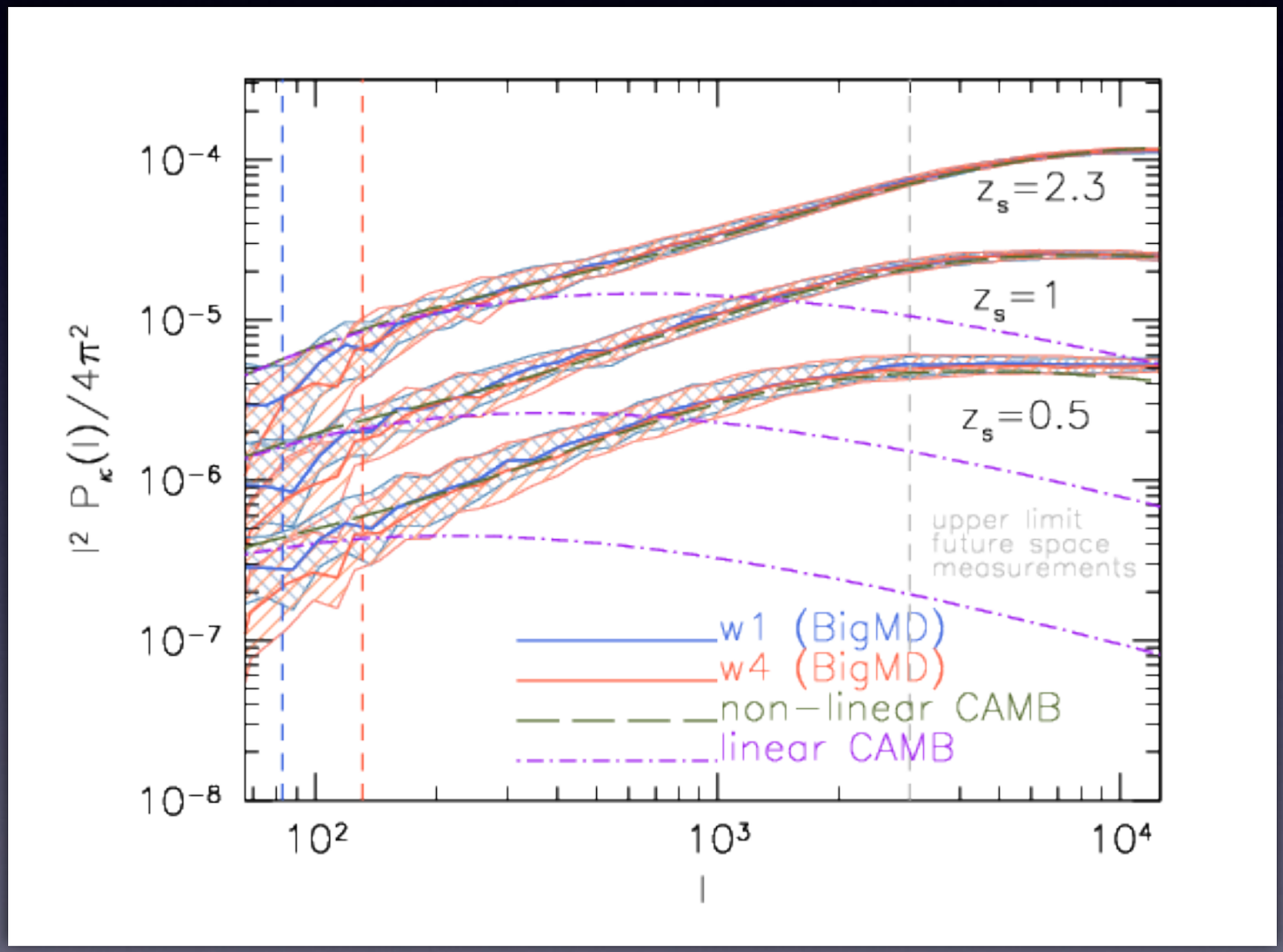



z_s=0.5
W4: 5.5 x 1.6 sq. deg.
z_s=1.1
z_s=2.3



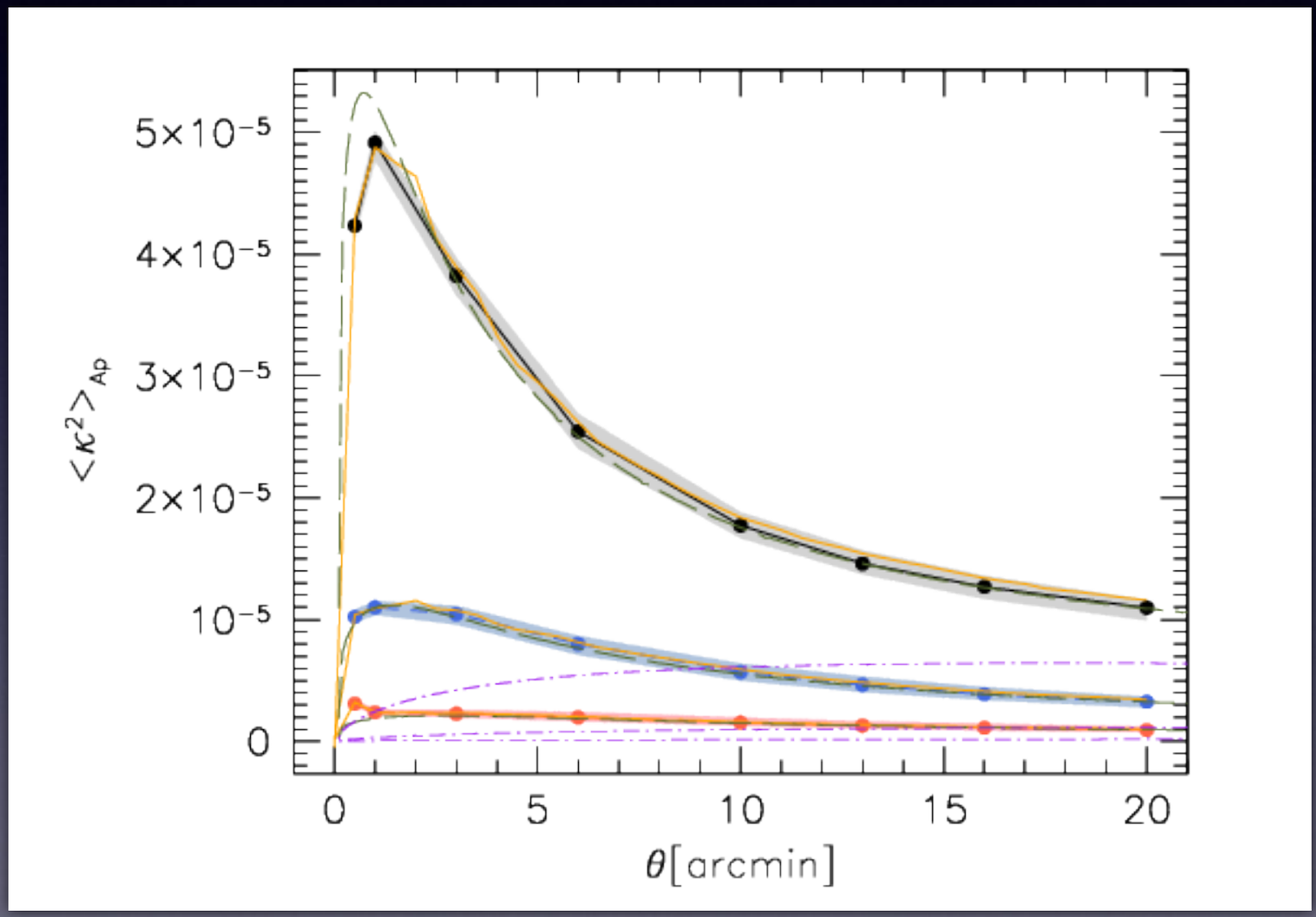


Convergence Power Spectrum



Giocoli, Jullo, Metcalf et al

Variance of the Compensated Aperture Filter

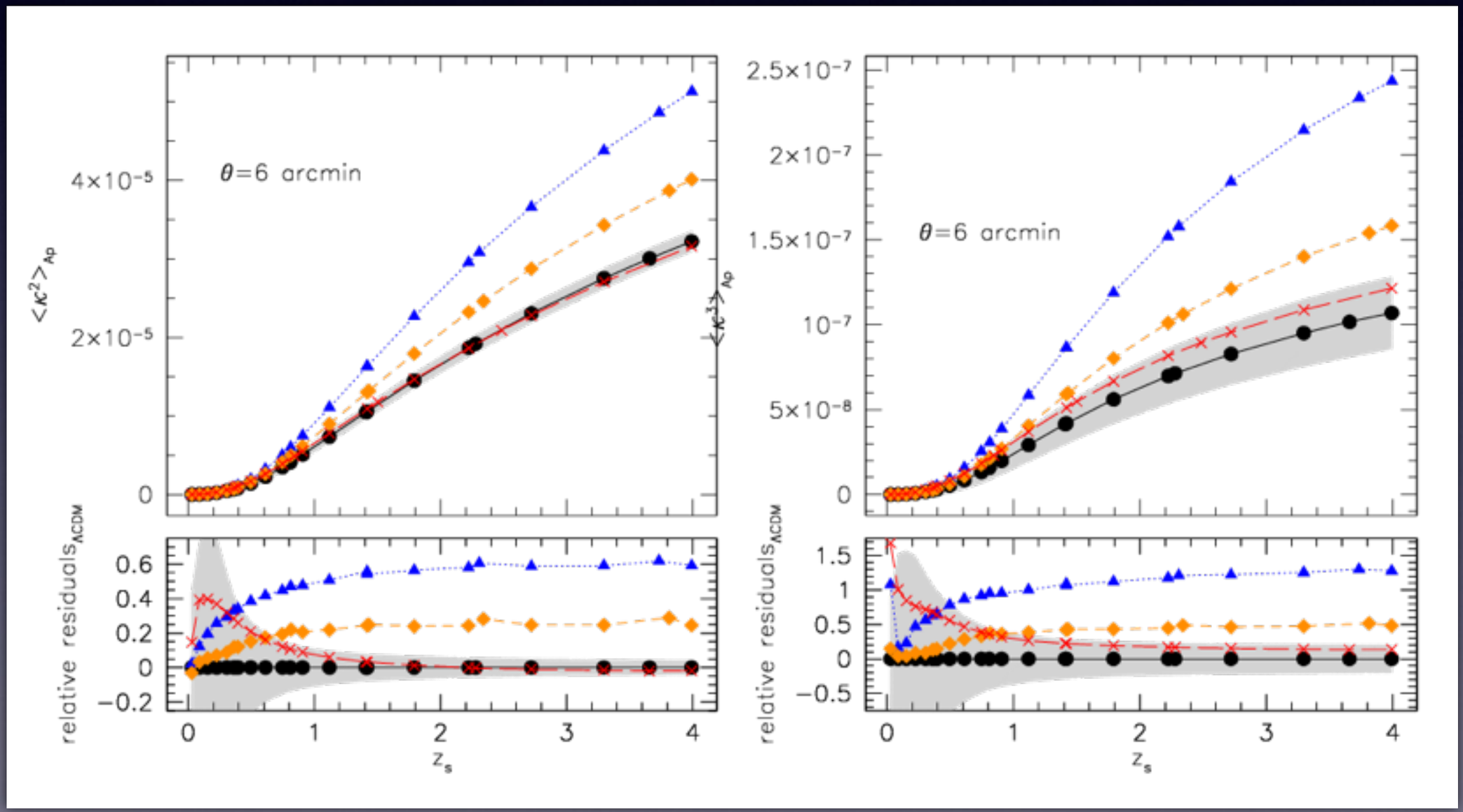


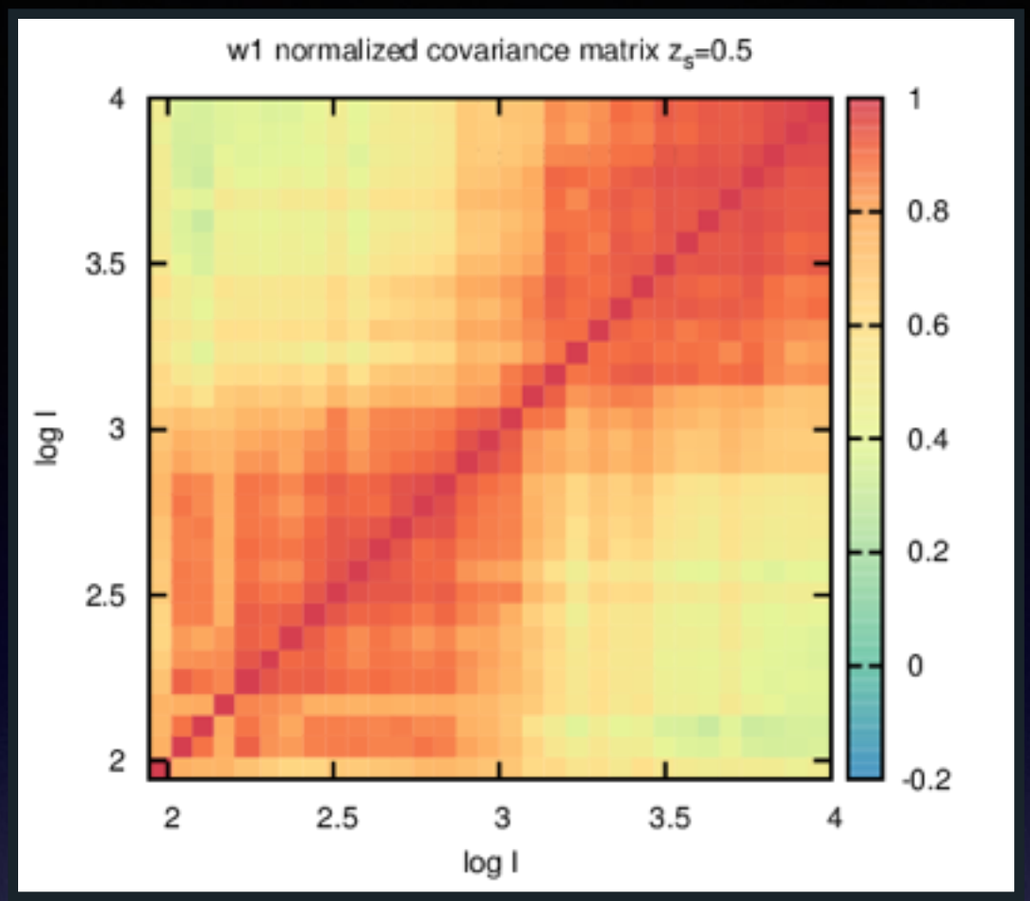
Giocoli, Jullo, Metcalf et al

Lensing with the CoDECS simulation

Baldi, M. 2012
Giocoli, et al. in prep.

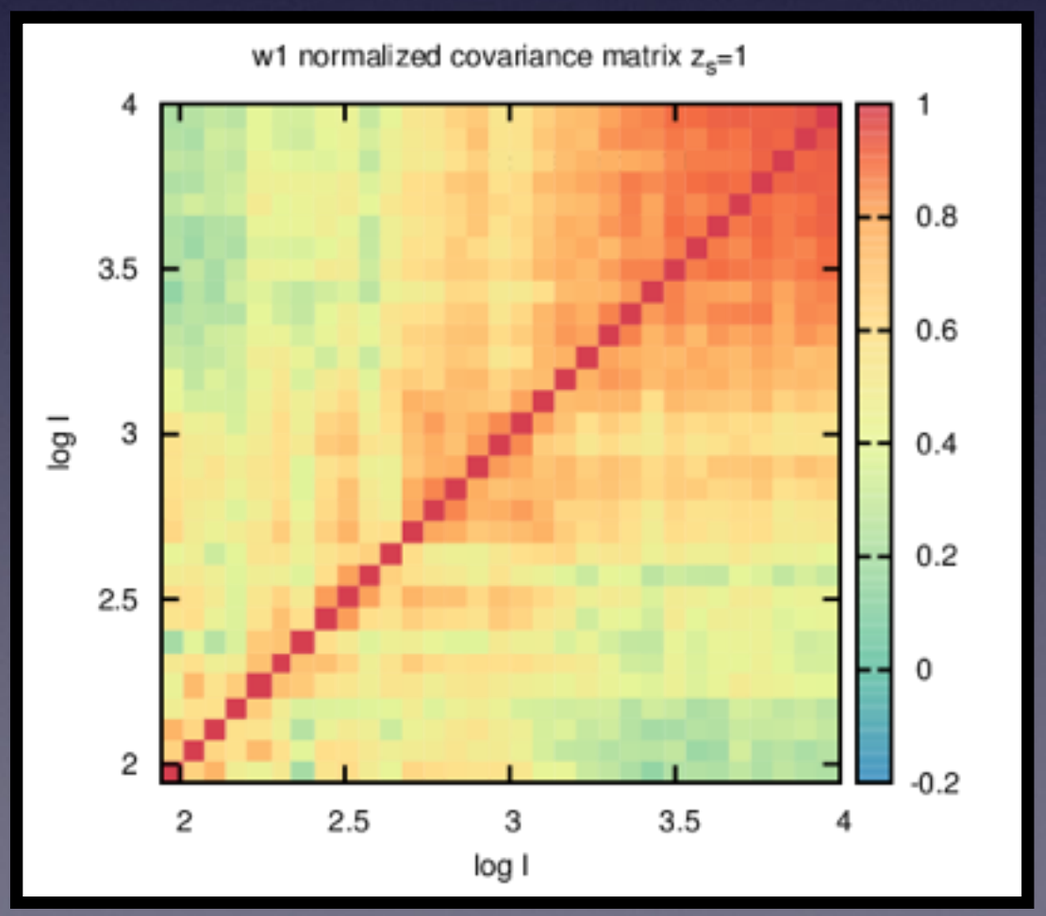
Coupled Dark Energy Models

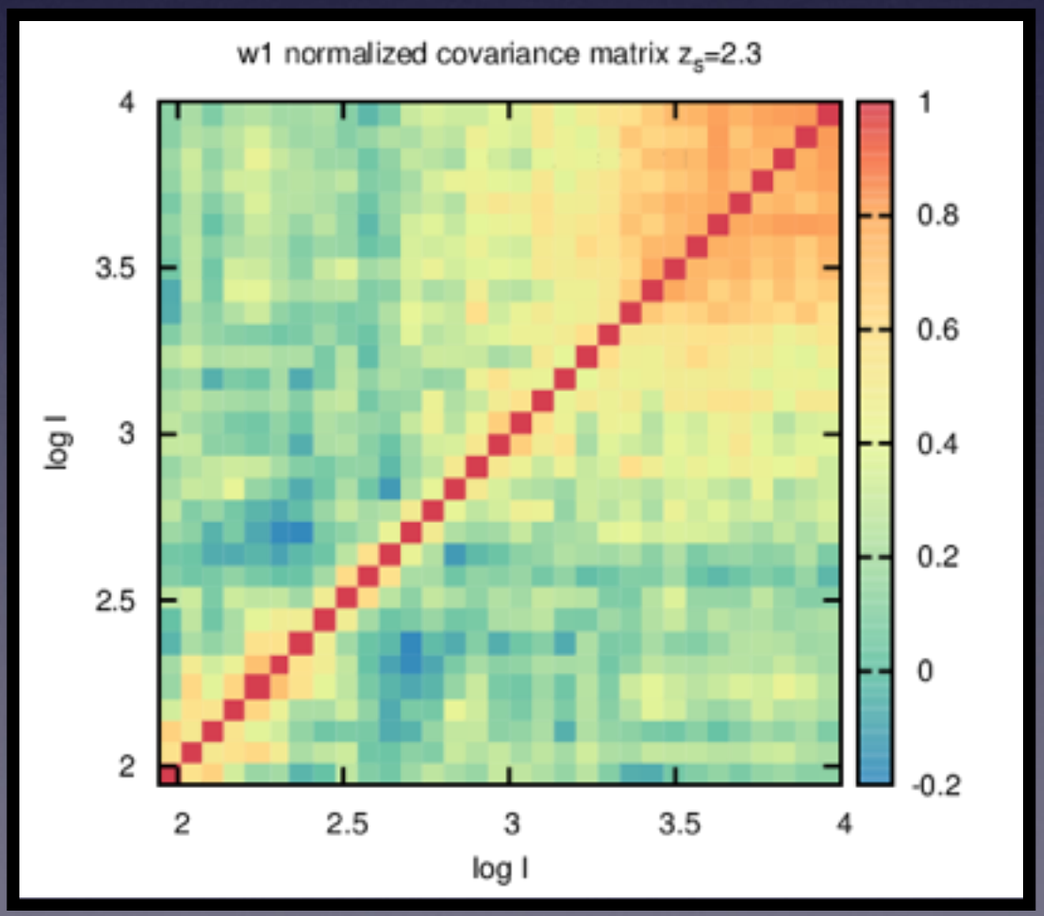




correlation matrix for P(k)

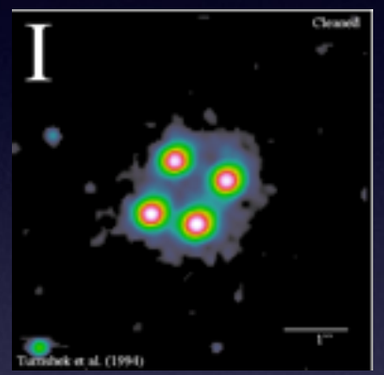
$$M(l,l') = \langle [P(l) - \bar{P}(l)][P(l') - \bar{P}(l')] \rangle$$

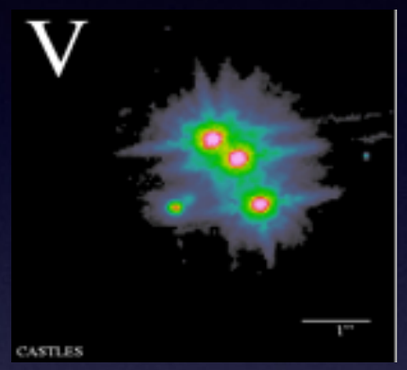


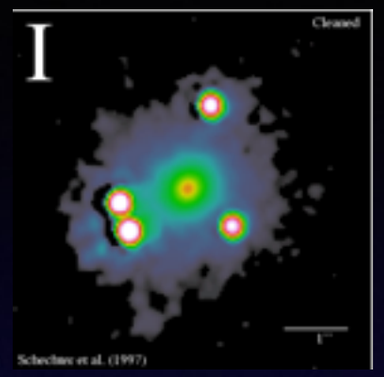


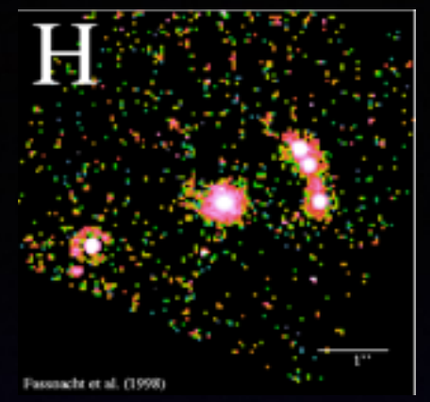
Galaxy Scale Strong Lenses

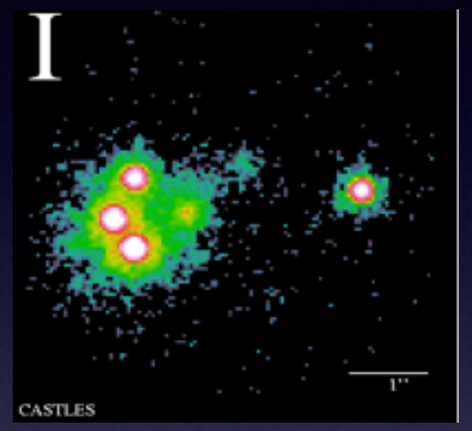
Galaxy - QSO Lenses



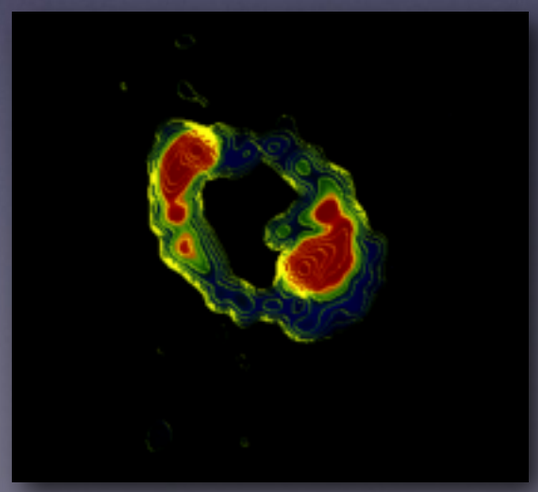


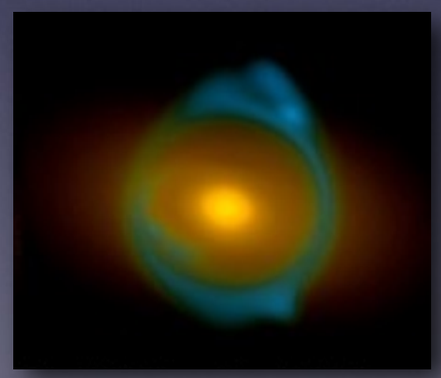


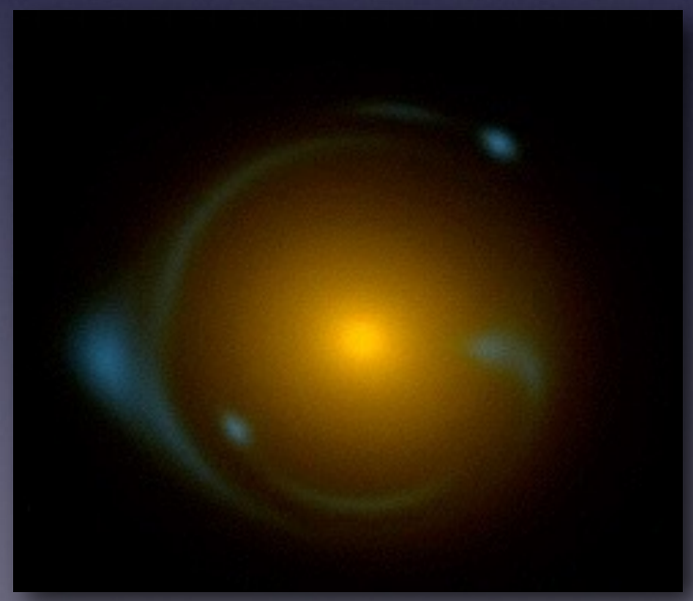




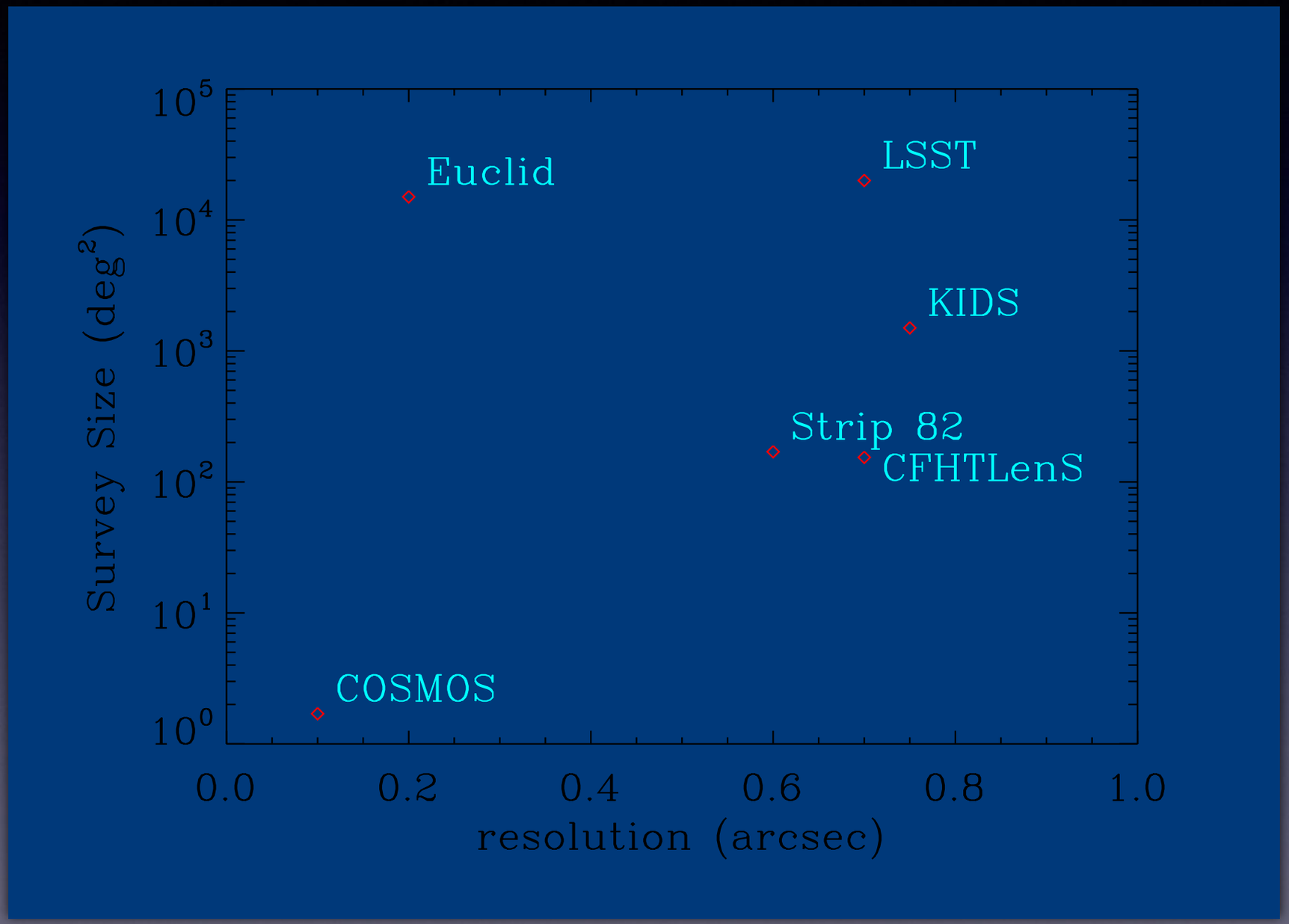
Galaxy - Galaxy Lenses



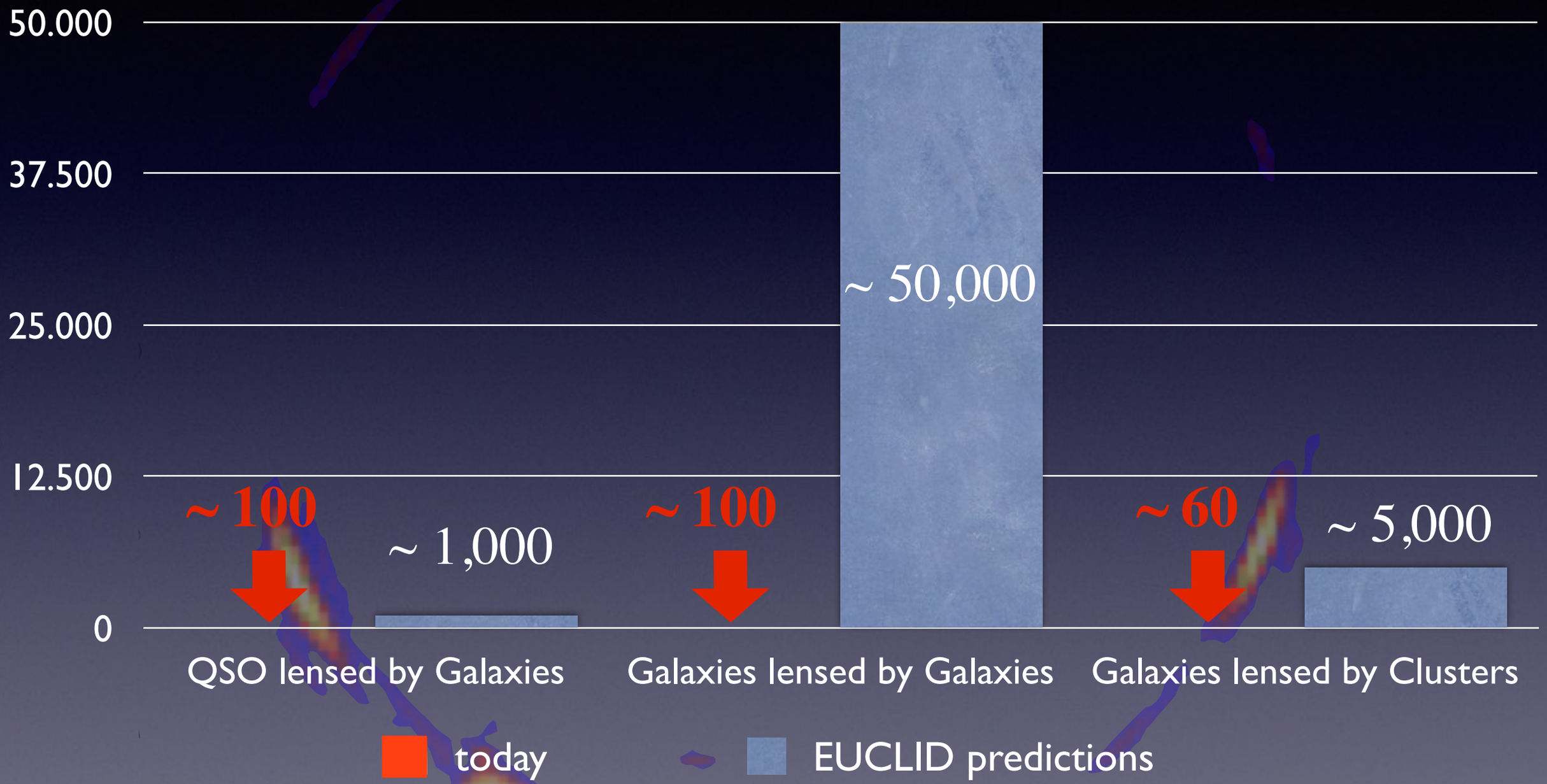




Imaging Surveys



Expected Number of Strong Gravitational Lenses



Future Data Sets : KIDS, DES, Pan-Starrs, LSST, EUCLID

lensing simulation with *GLAMER*

calculating deflection angle

analytic model or from particles:

tree code deflection solver
modified algorithm to handle halos efficiently

adaptive smoothing for Nbody/hydro particles

multiple lens planes:
3d along light paths

lens model

single analytic lens
multiple analytic halos
Nbody/SPH particles
point masses (stars)
pixelized mass map

the grid of rays

adaptive grid refinement

full image reconstruction or just shear and convergence

source model

analytic model for surface brightness
and
direct pixelized images

Source Plane

Image Plane

$$\vec{\alpha}\left(\vec{x}\right),\ \kappa\left(\vec{x}\right),\ \vec{\gamma}\left(\vec{x}\right)$$

$$\phi(\vec{x}), \varrho(\vec{x})$$

$$\vec{y} = \vec{x} - \vec{\alpha}\left(\vec{x}\right)$$

Source Plane

Image Plane

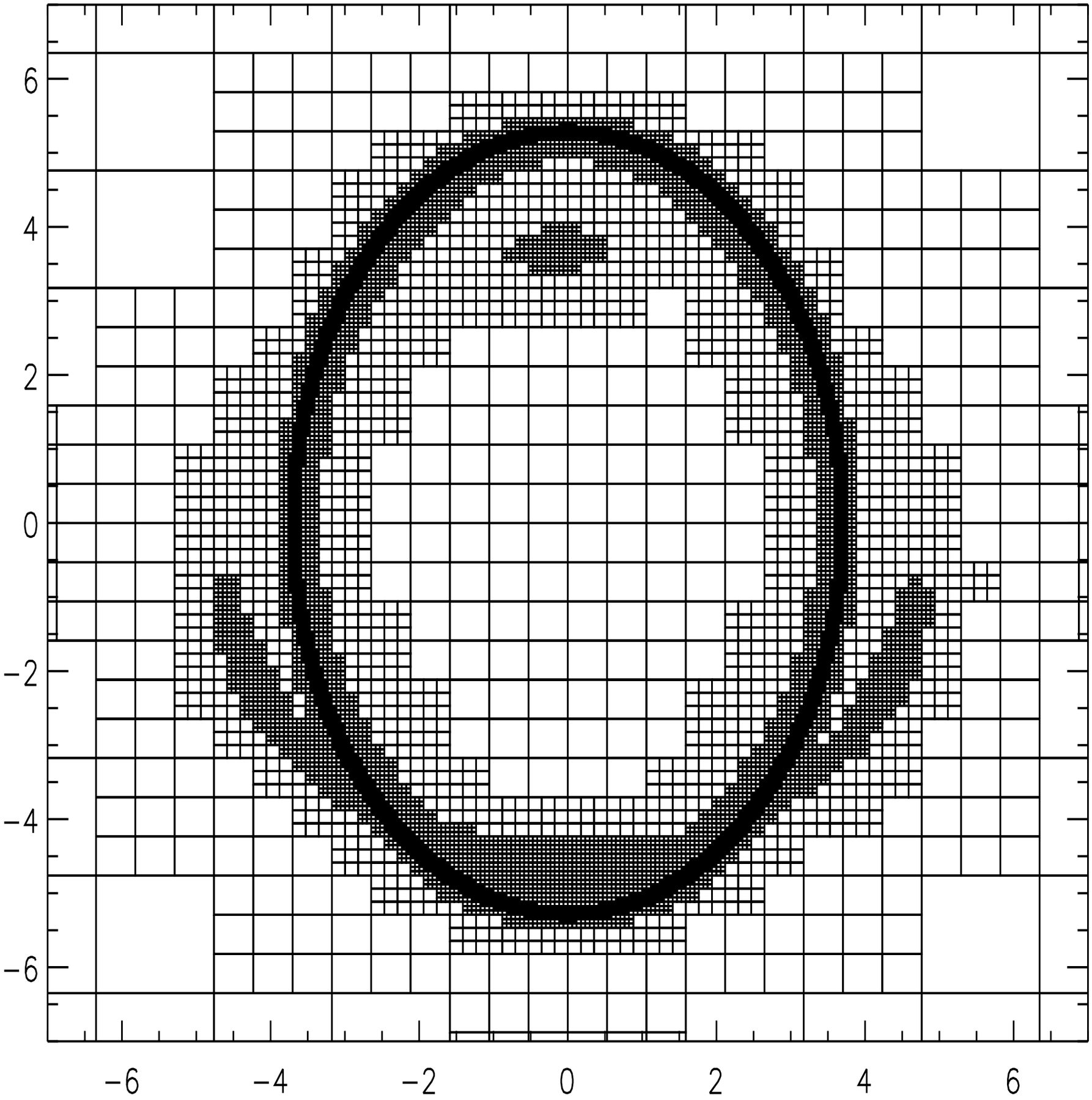
source

images

Source Plane

Image Plane

source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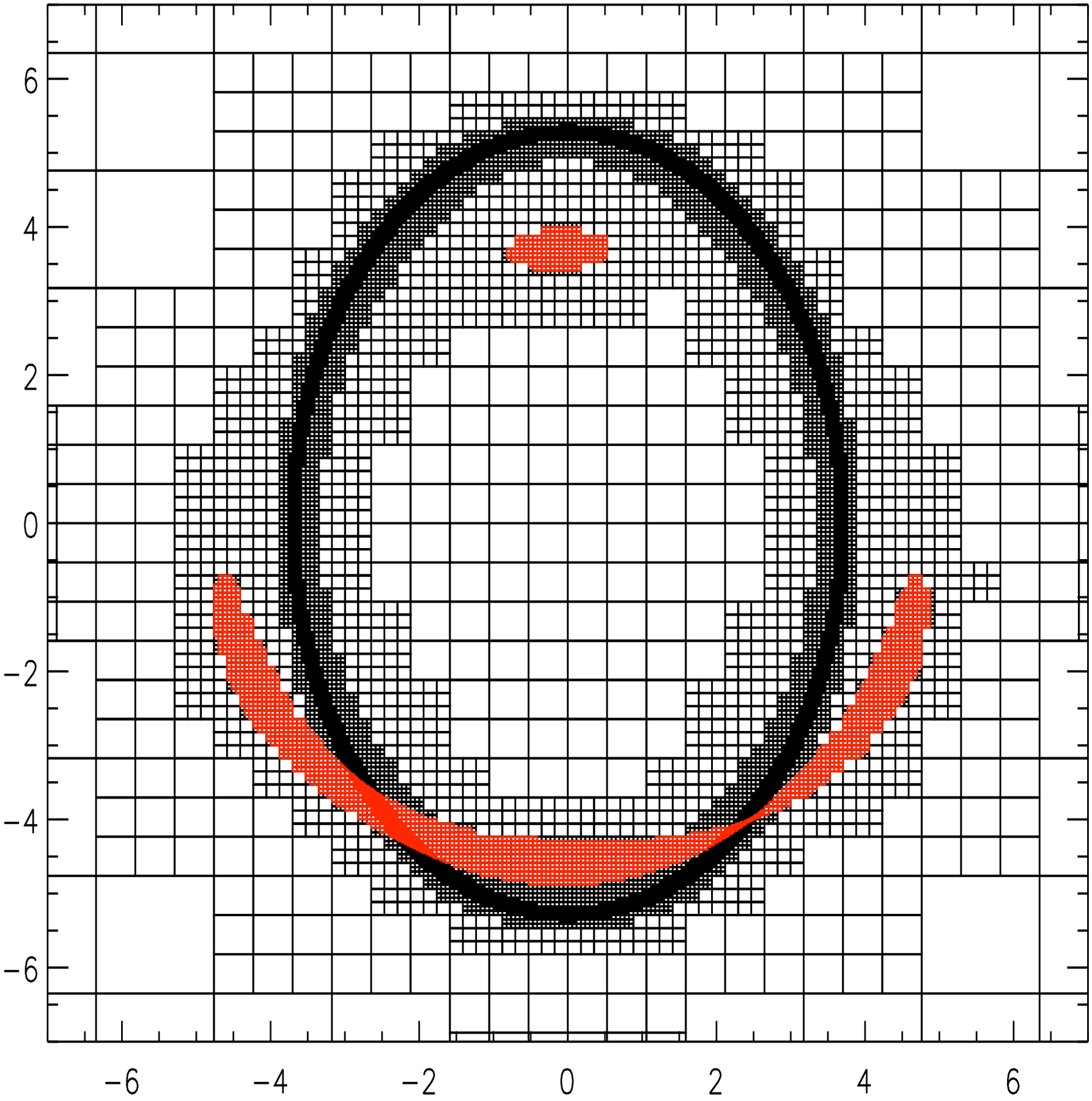
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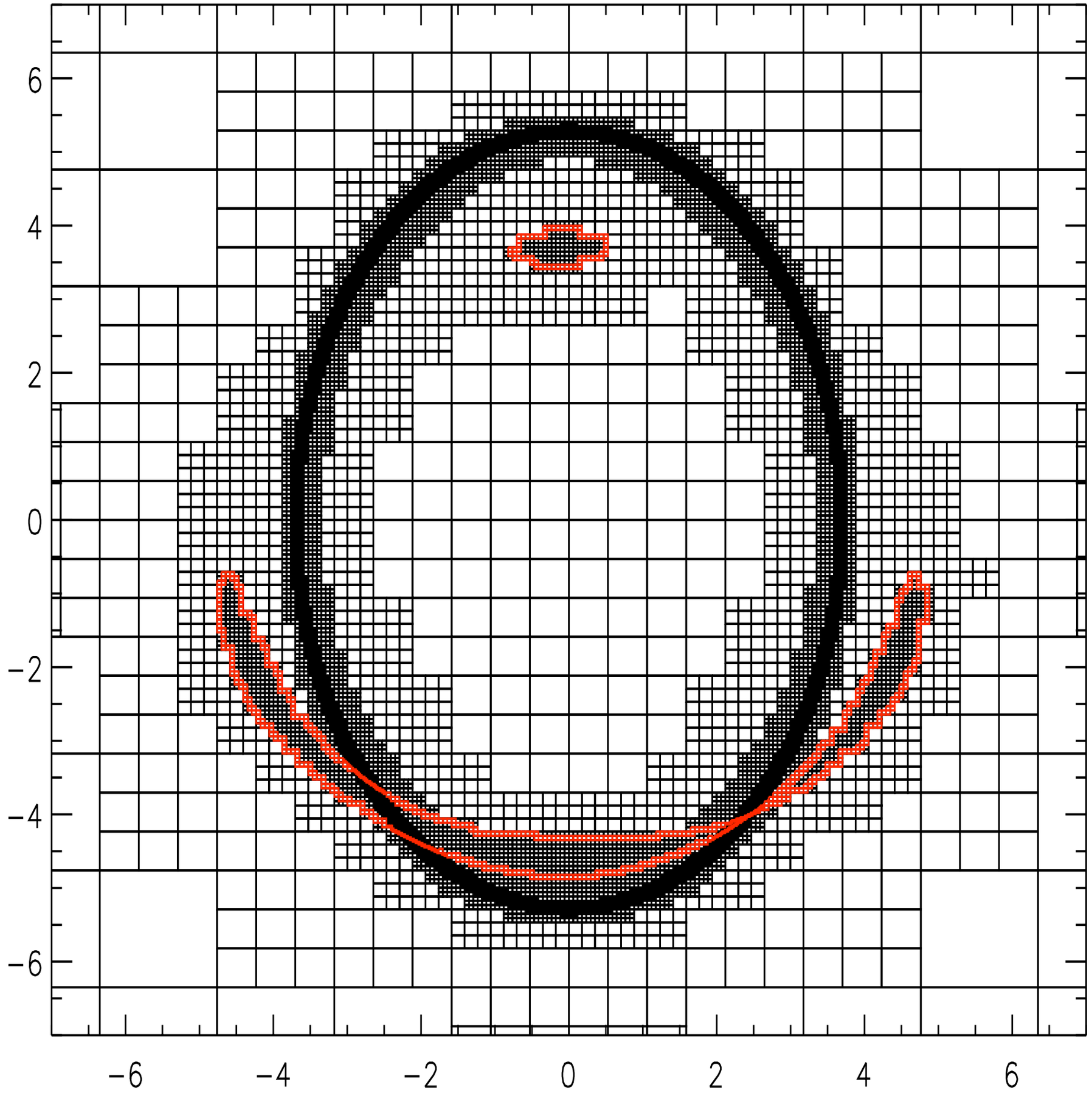
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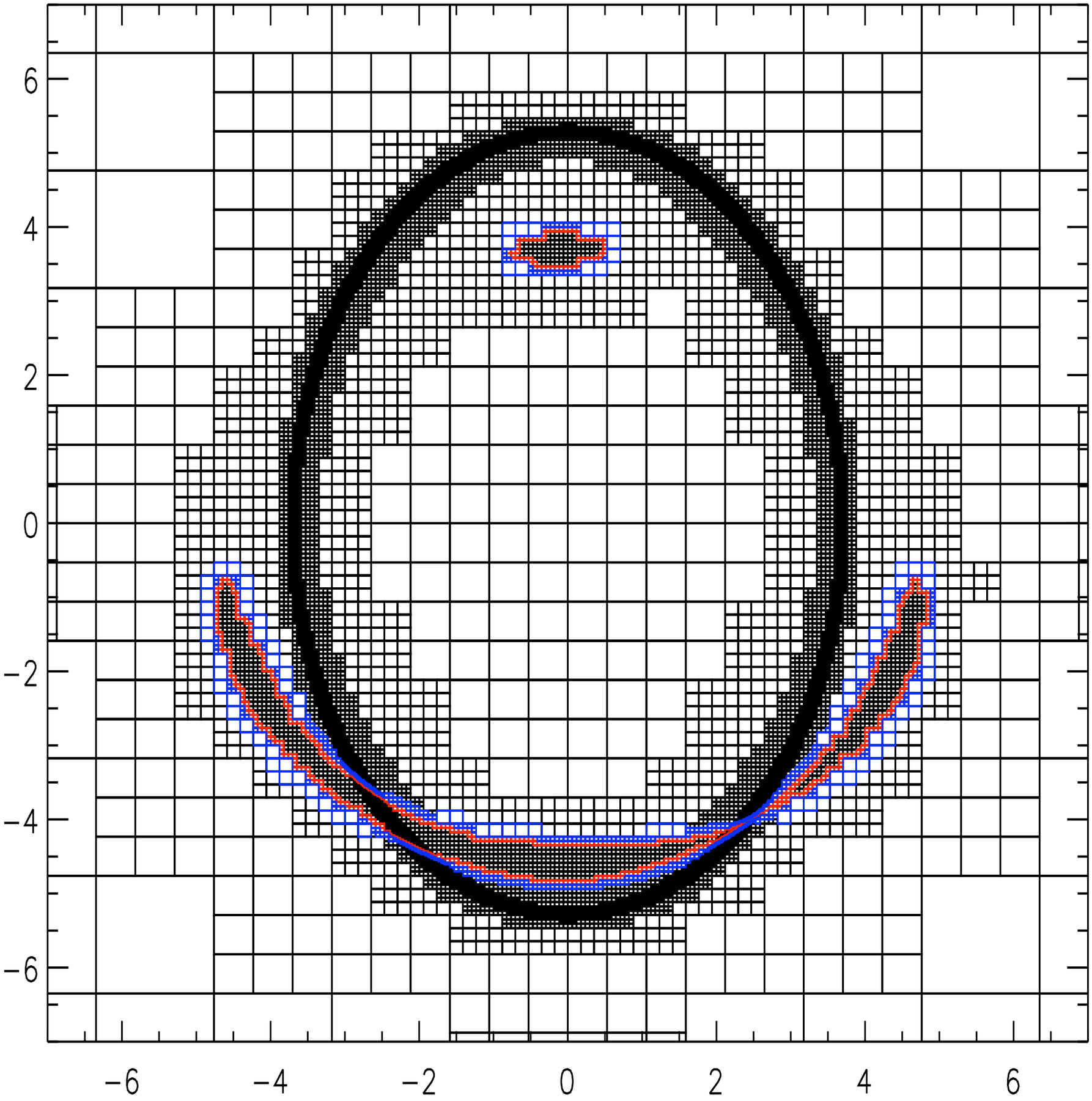
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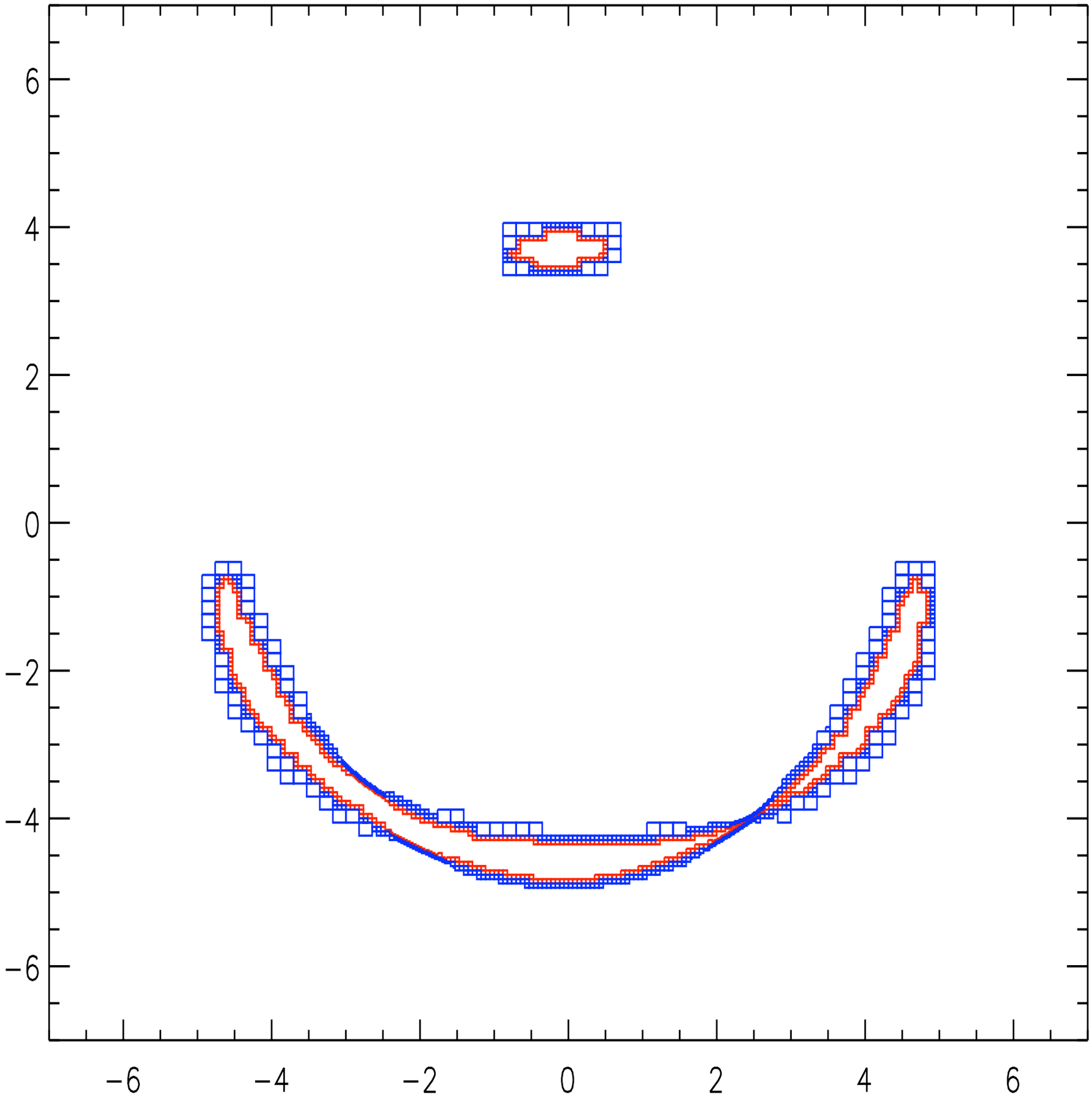
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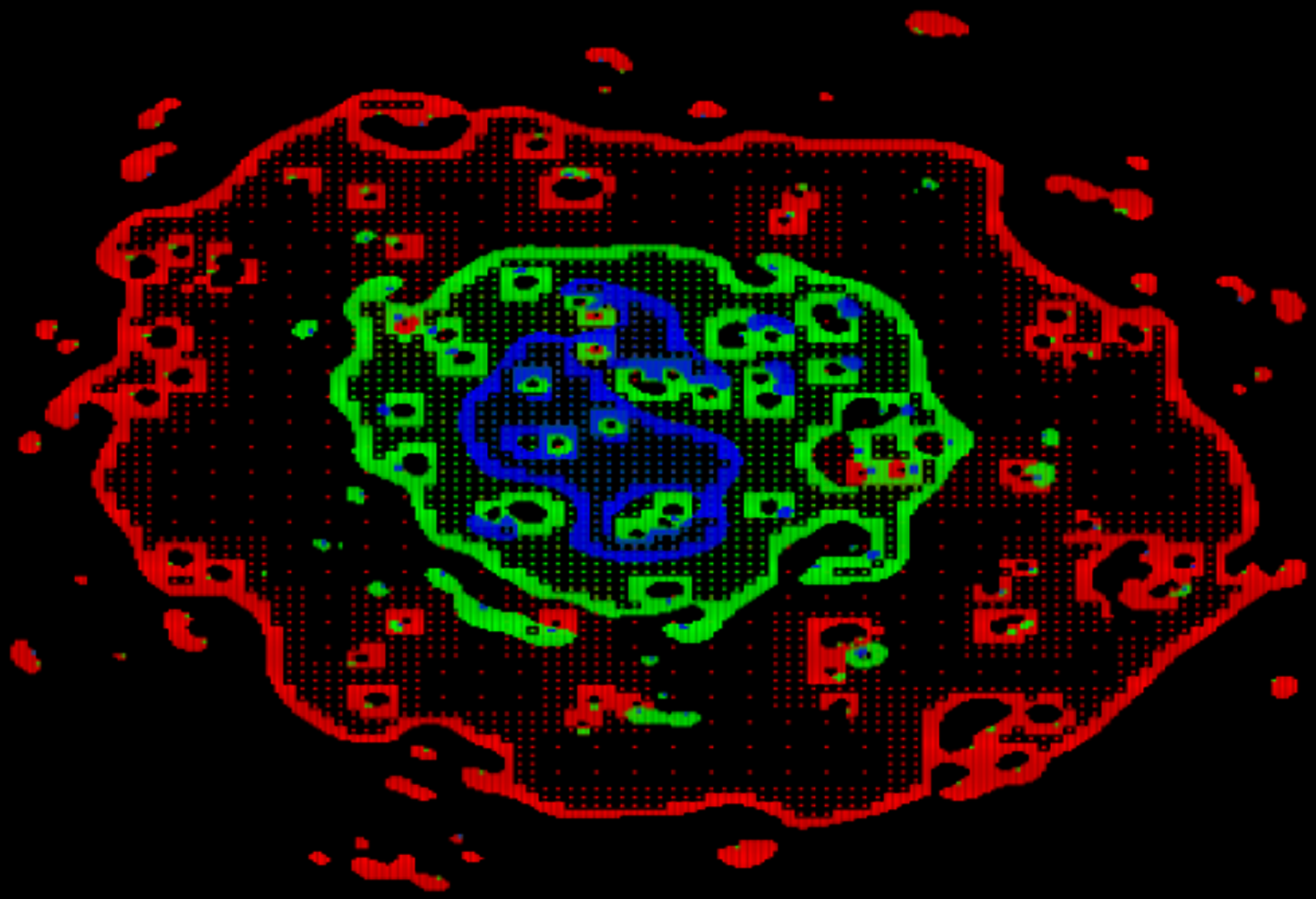
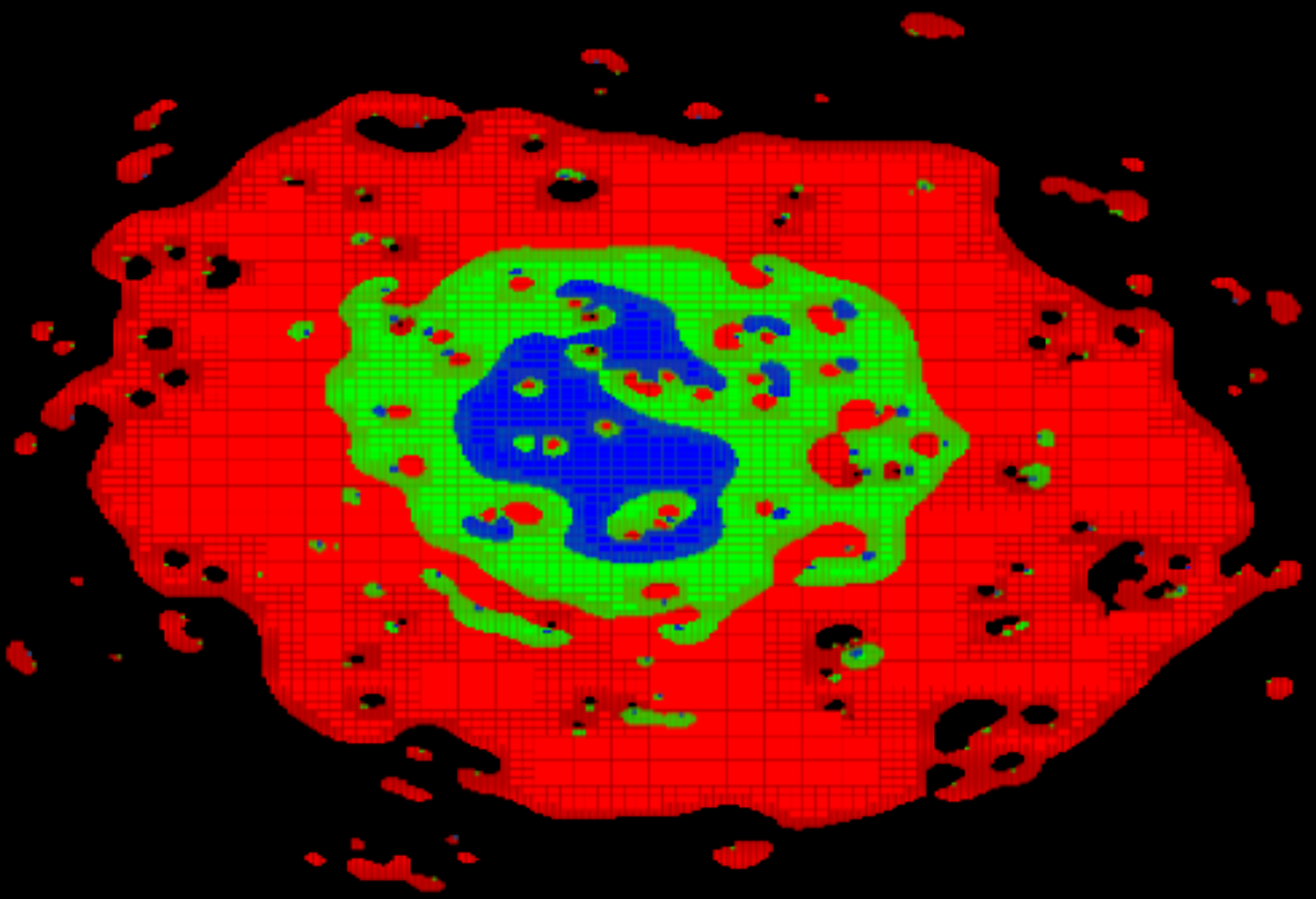
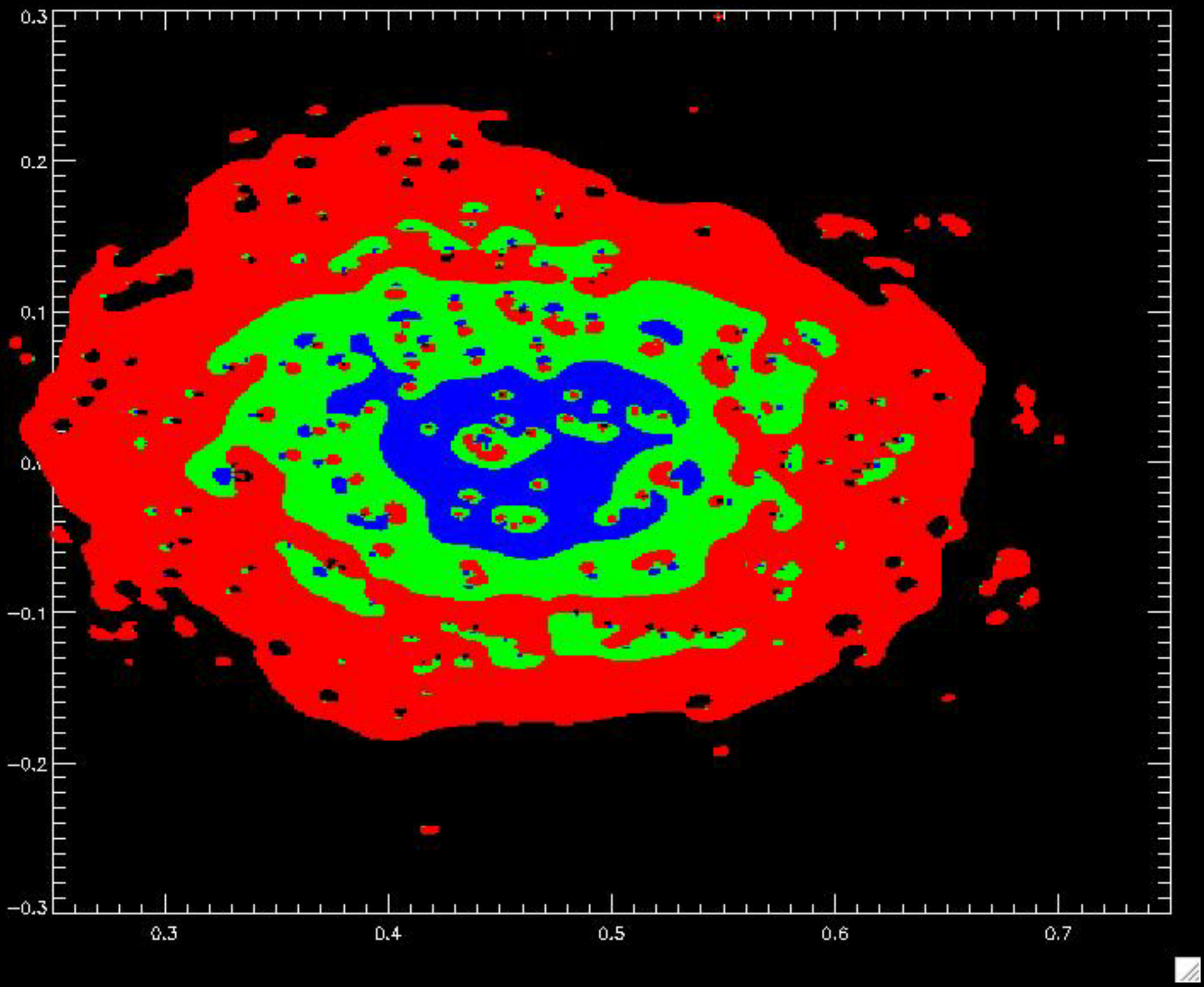
QSO Microlensing



QSO Microlensing



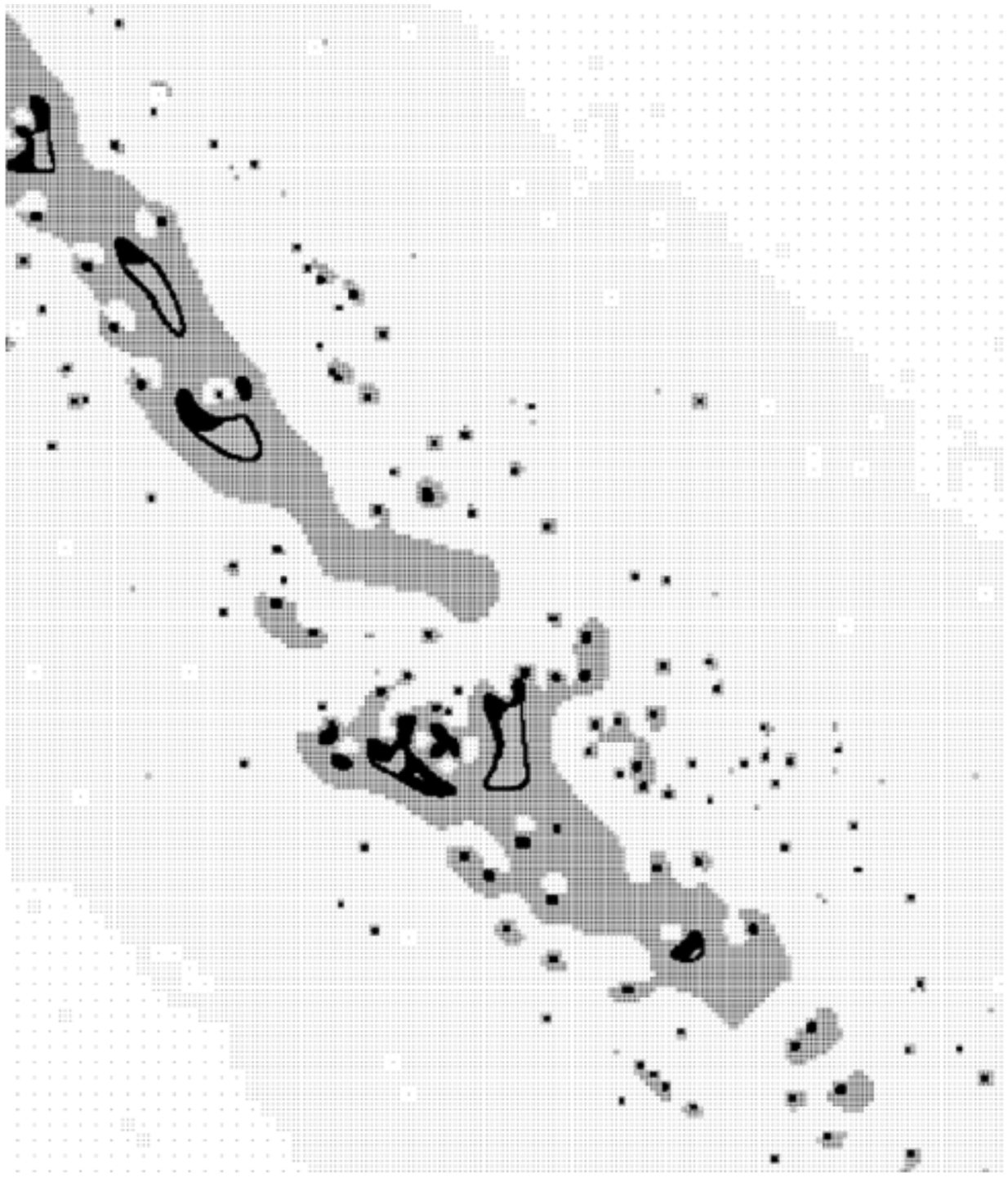
QSO Microlensing



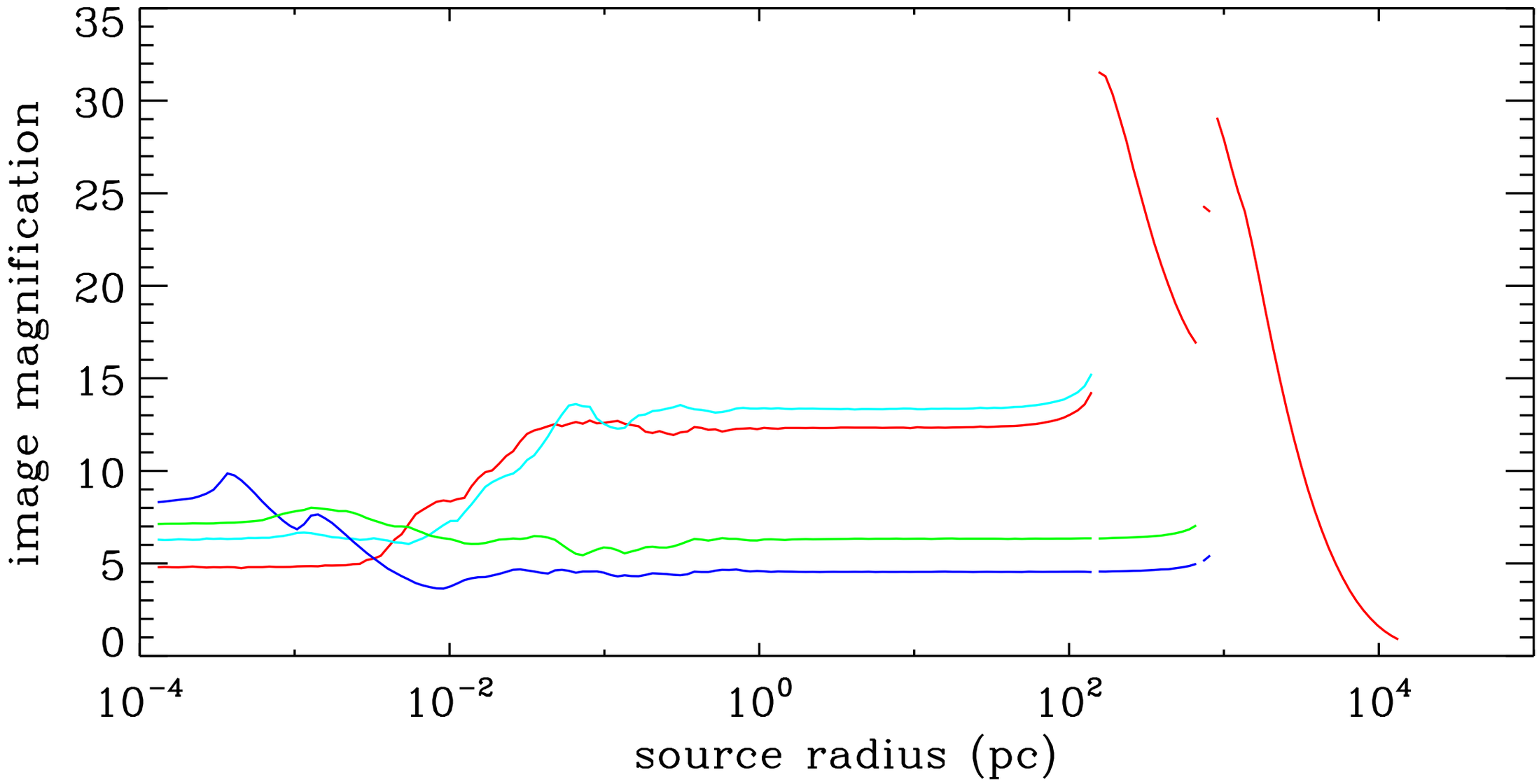
Microlensing Example

Images

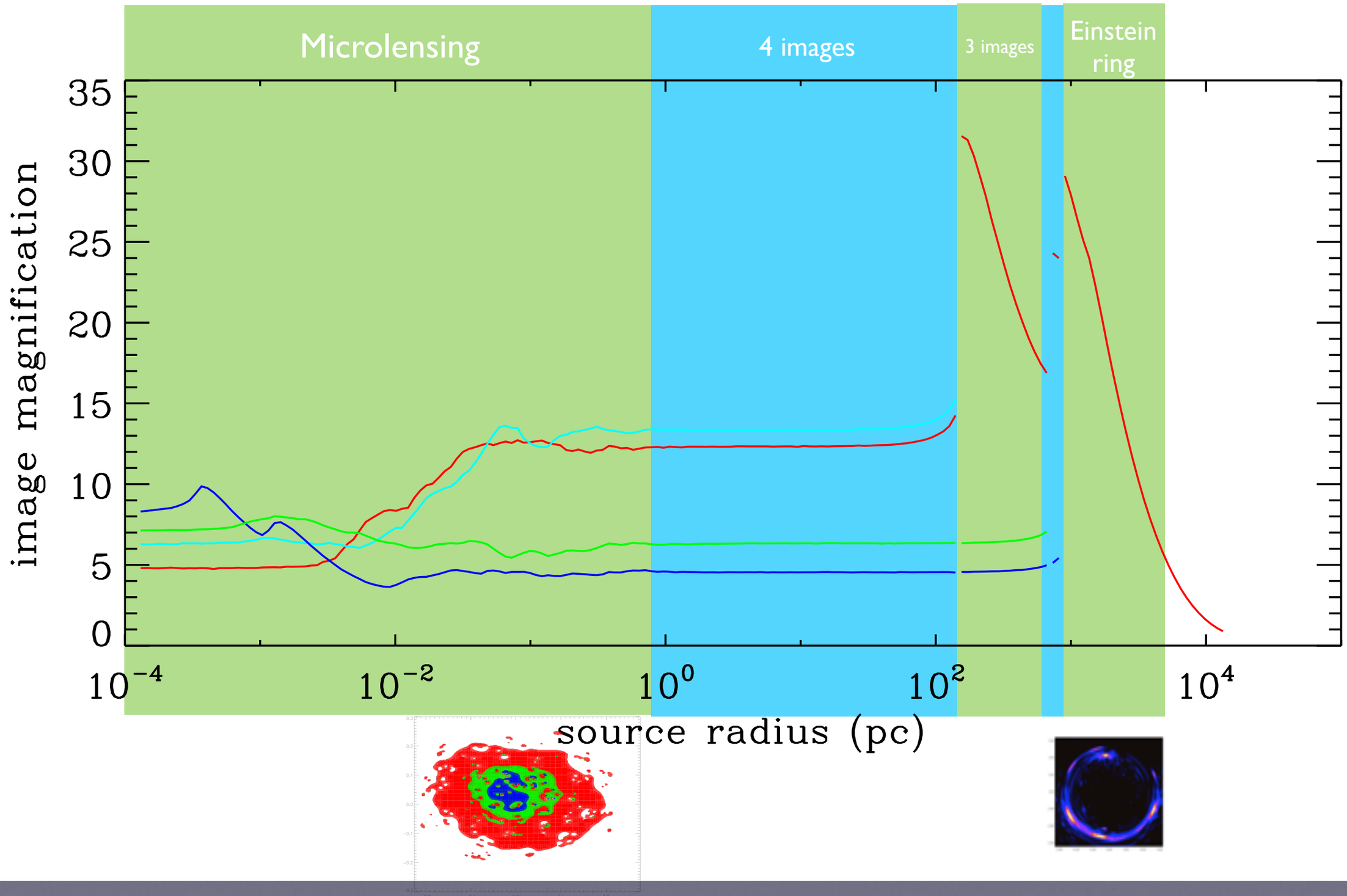
Adapted grid



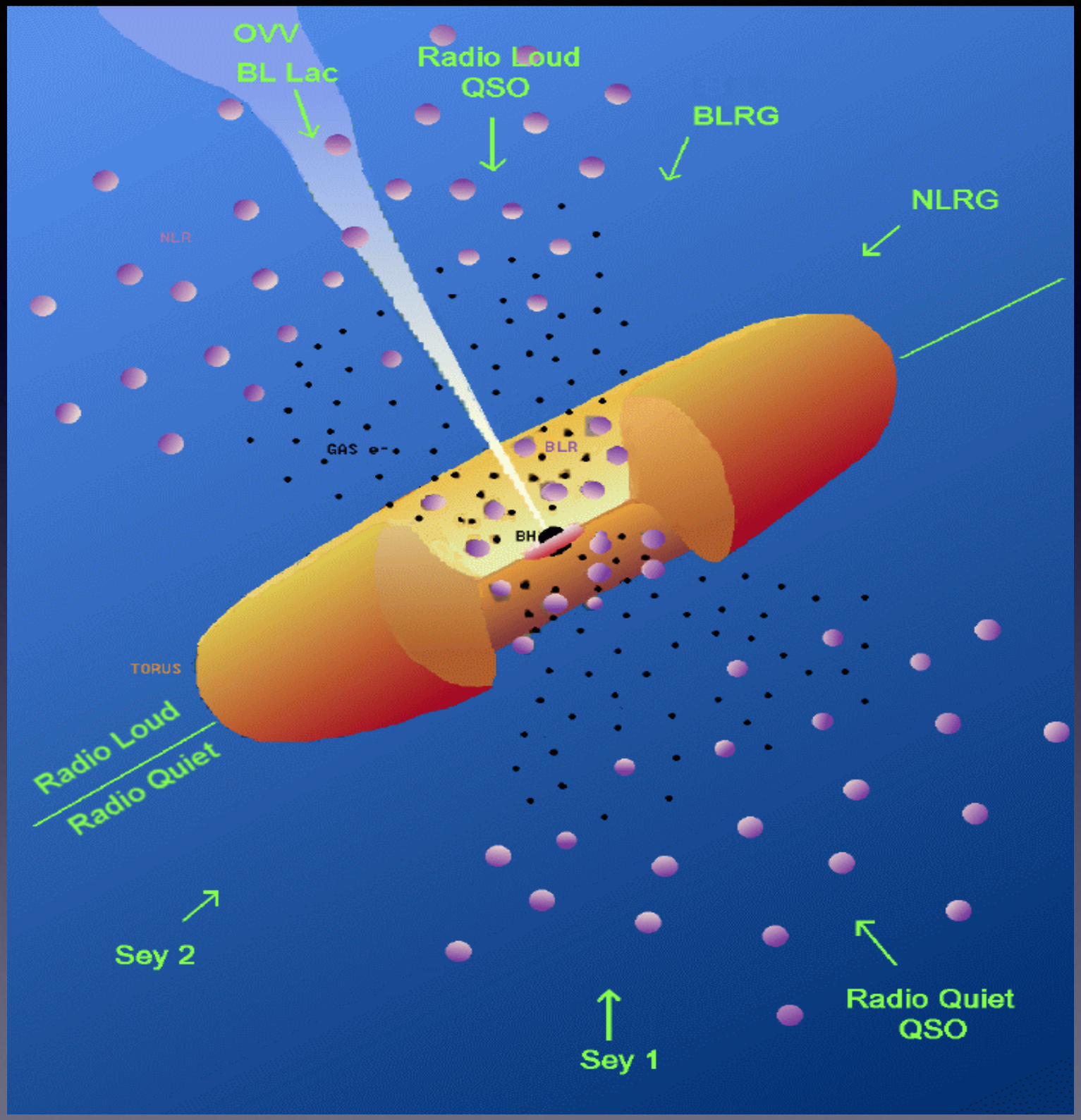
Gravitational Lensing on all Scales



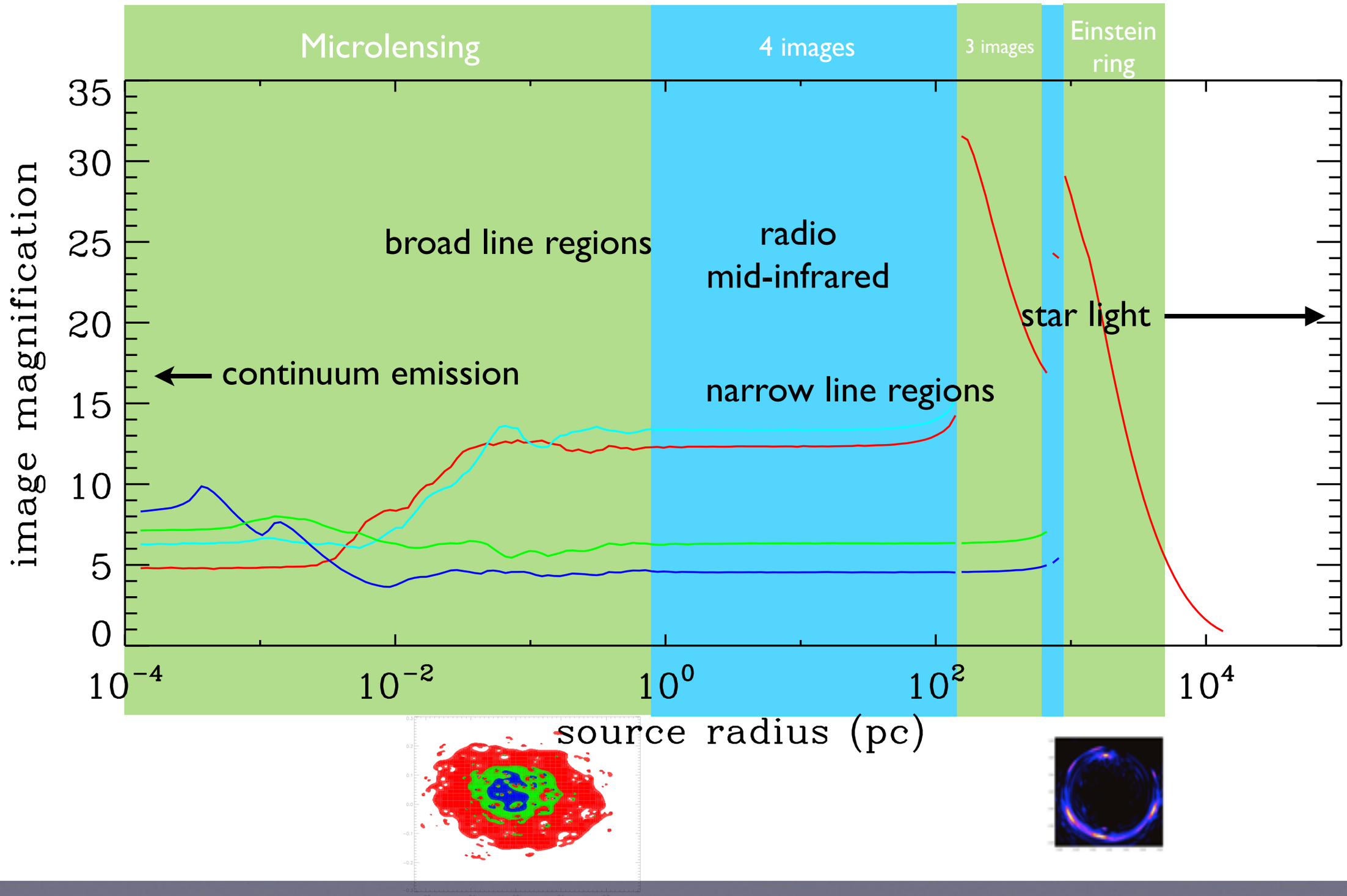
Gravitational Lensing on all Scales



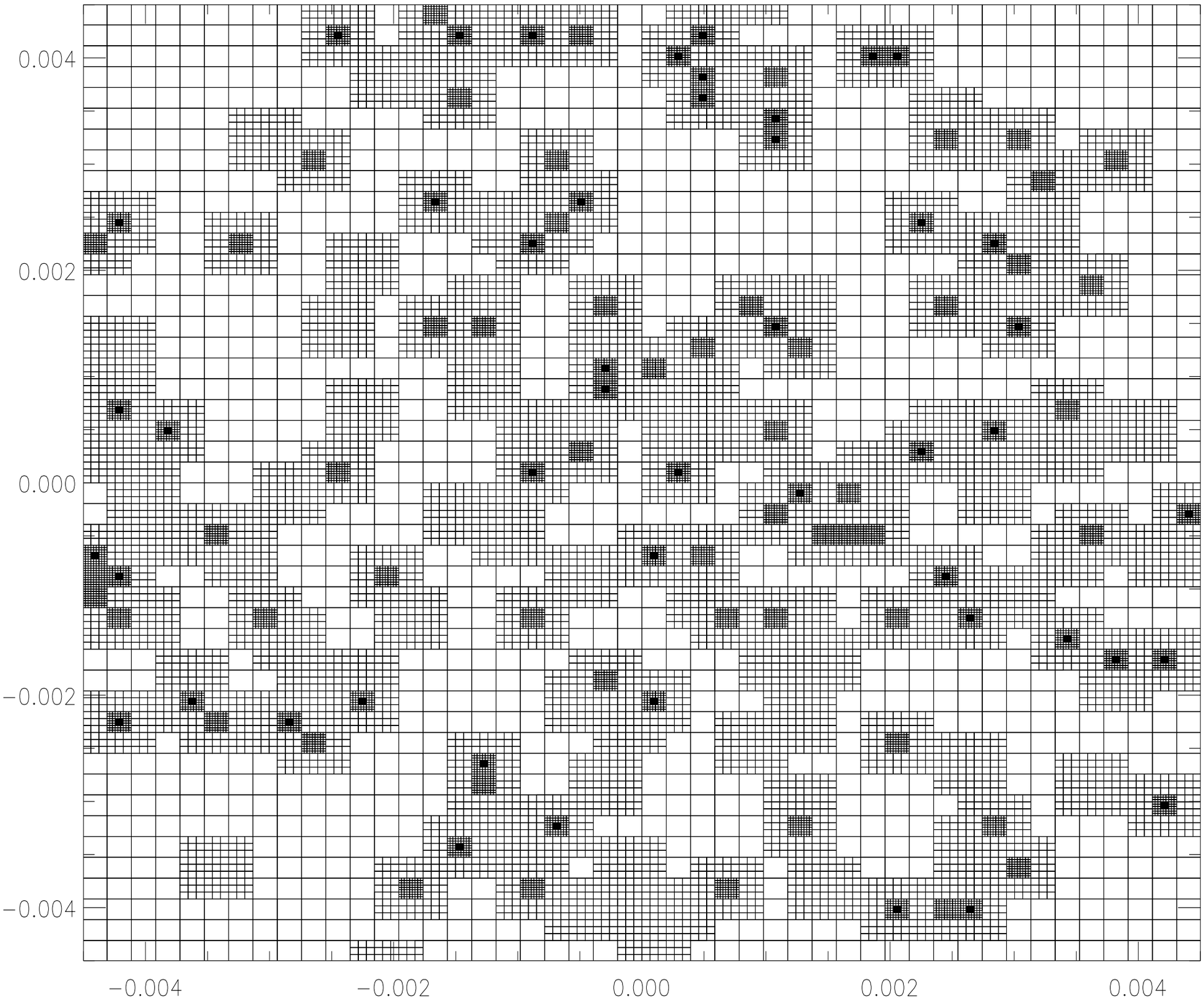
Anatomy of an active galactic nuclei and QSOs

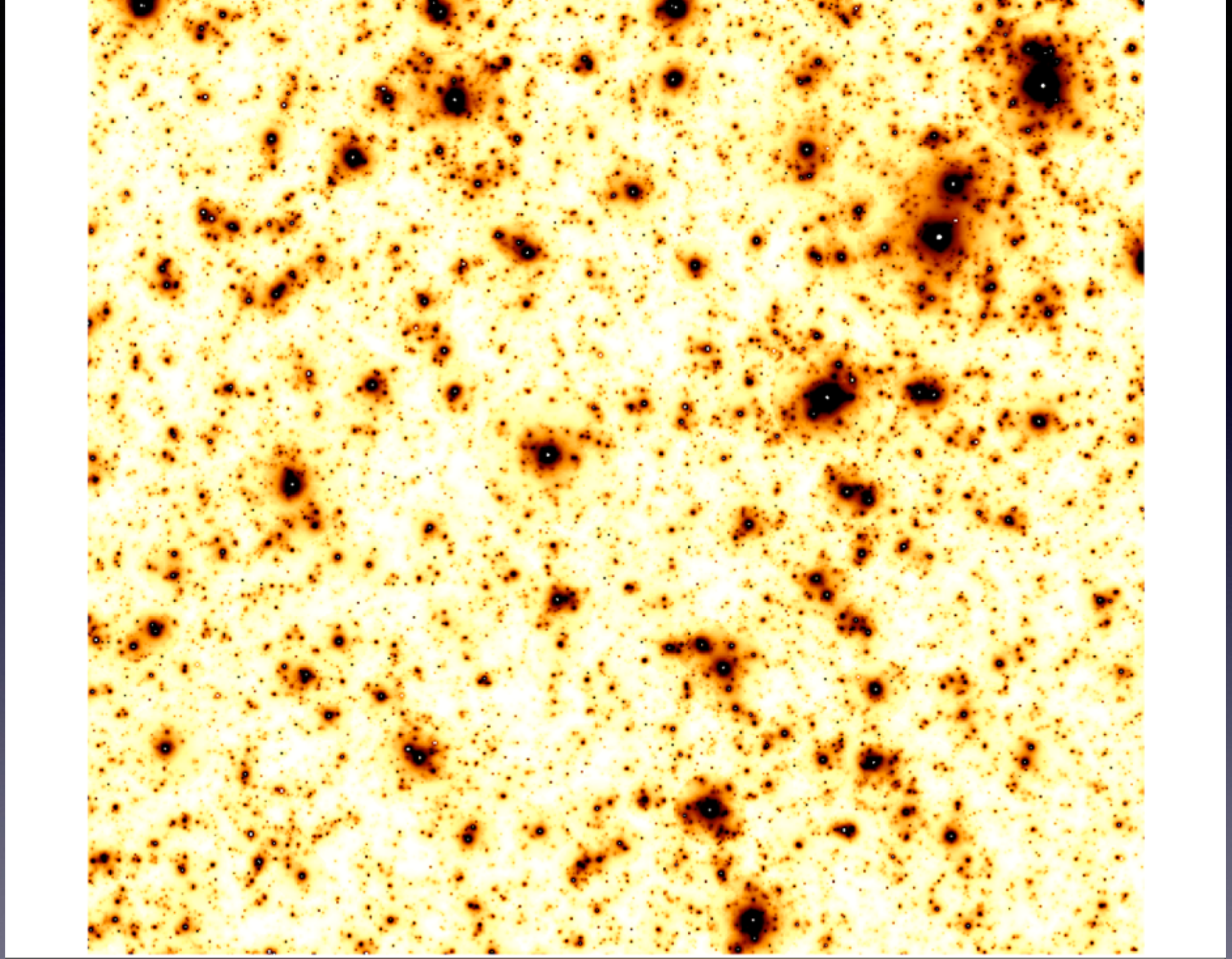


Gravitational Lensing on all Scales



Adaptive Grid Refinement




0.56
0.62
0.68
0.74
0.8
0.86
0.92
0.98
1

lensing simulation with *GLAMER*

calculating deflection angle

analytic model or from particles:

tree code deflection solver
modified algorithm to handle halos efficiently

adaptive smoothing for Nbody/hydro particles

multiple lens planes:
3d along light paths

lens model

single analytic lens
multiple analytic halos
Nbody/SPH particles
point masses (stars)
pixelized mass map

the grid of rays

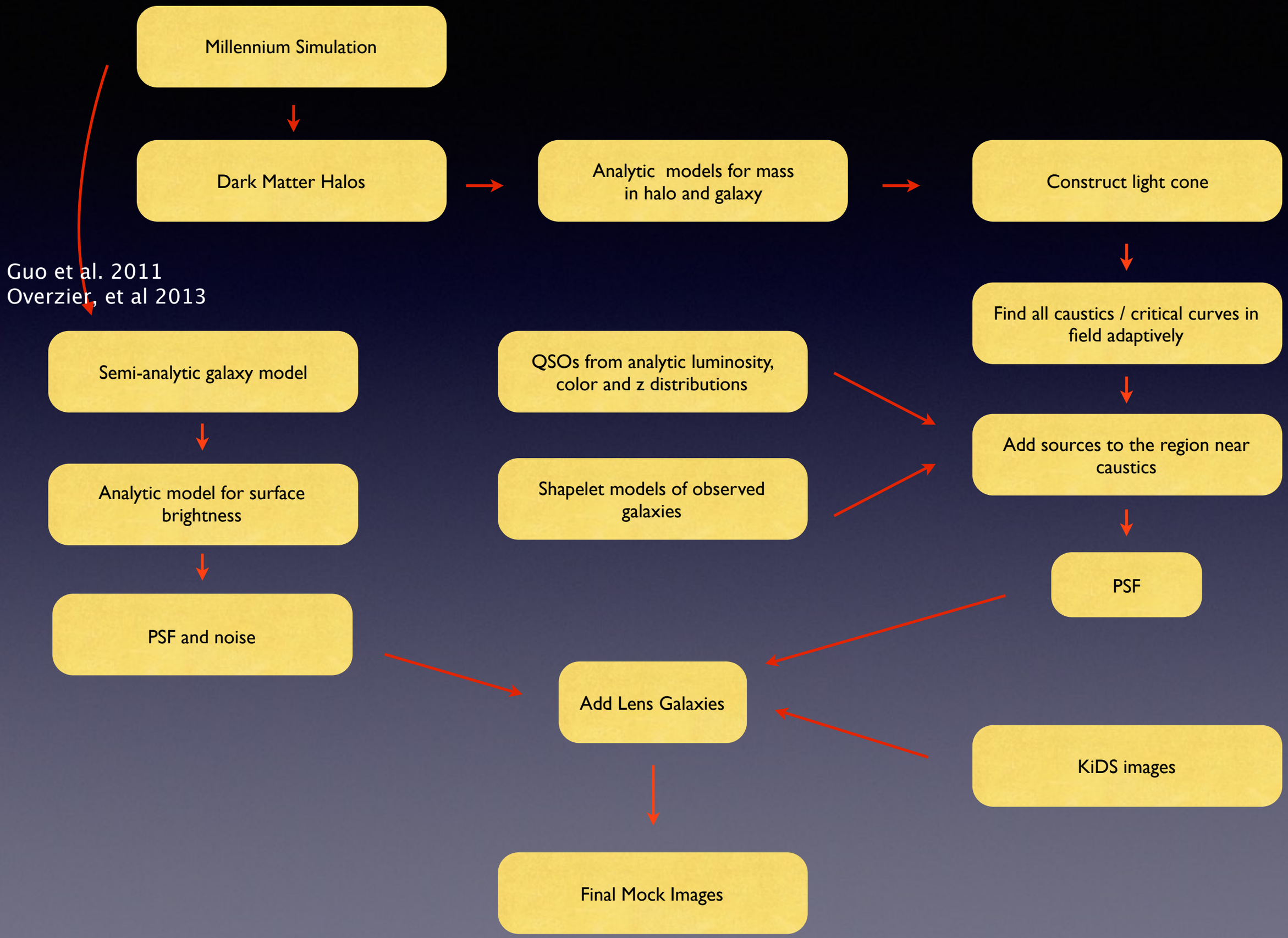
adaptive grid refinement

full image reconstruction or just shear and convergence

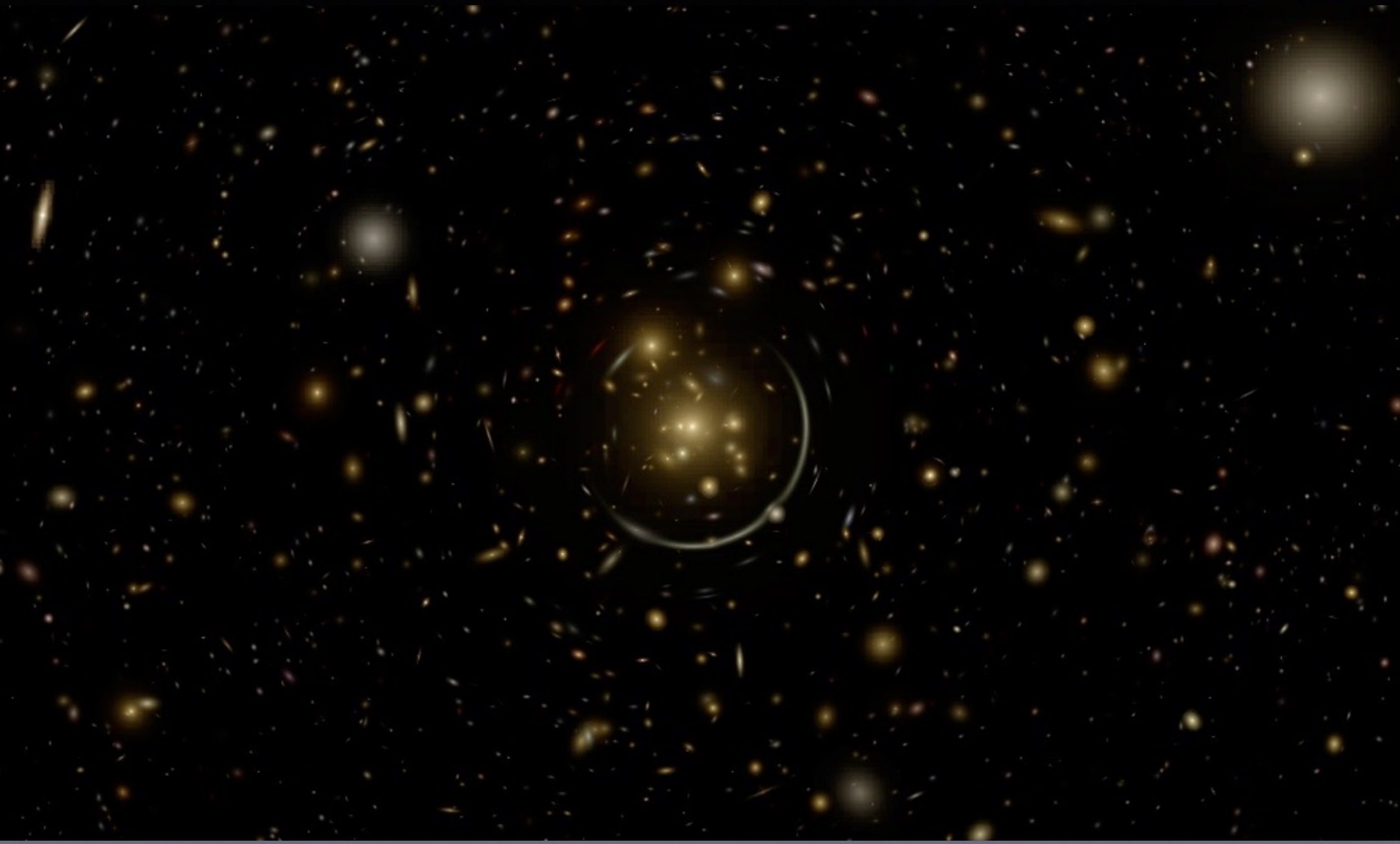
source model

analytic model for surface brightness
and
direct pixelized images

Making of Mock Images

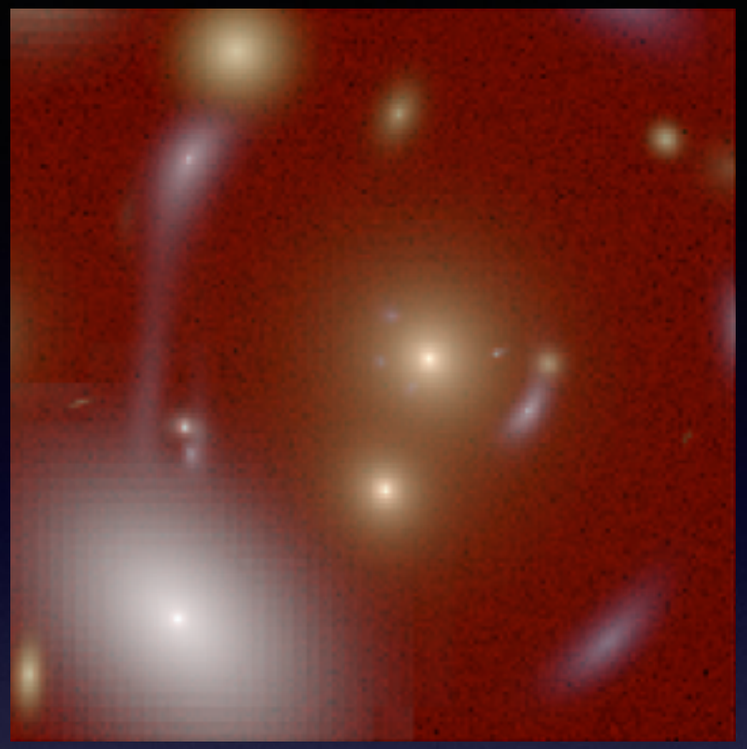


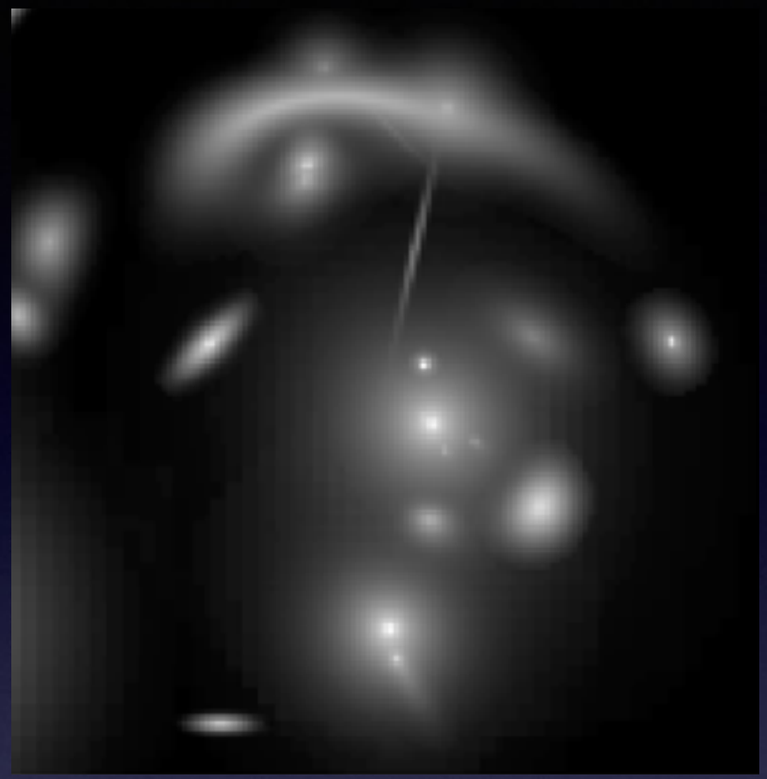
Field Lensing Simulations

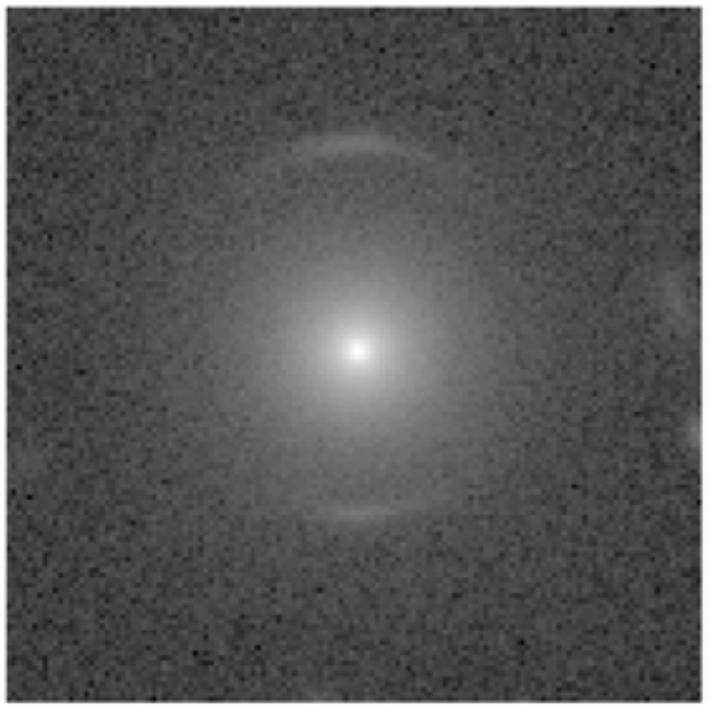


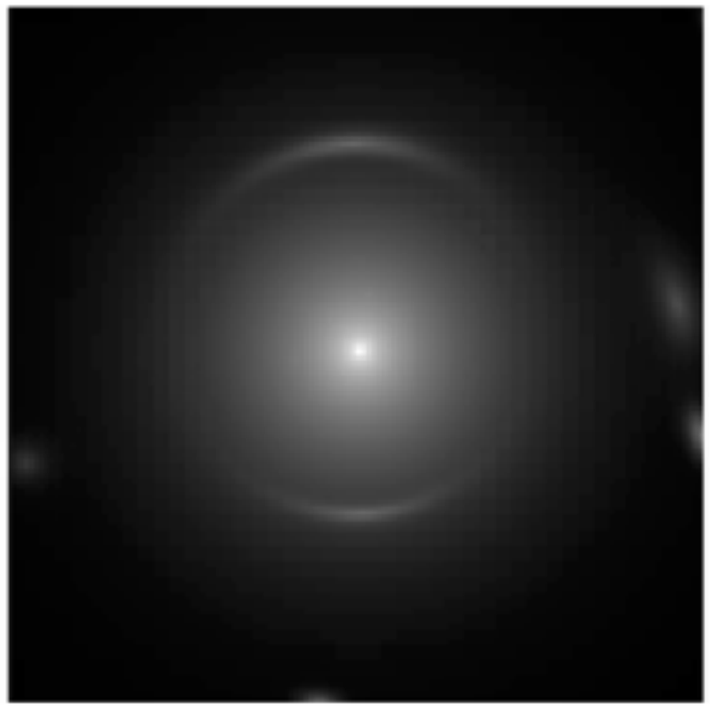
Field Lensing Simulations

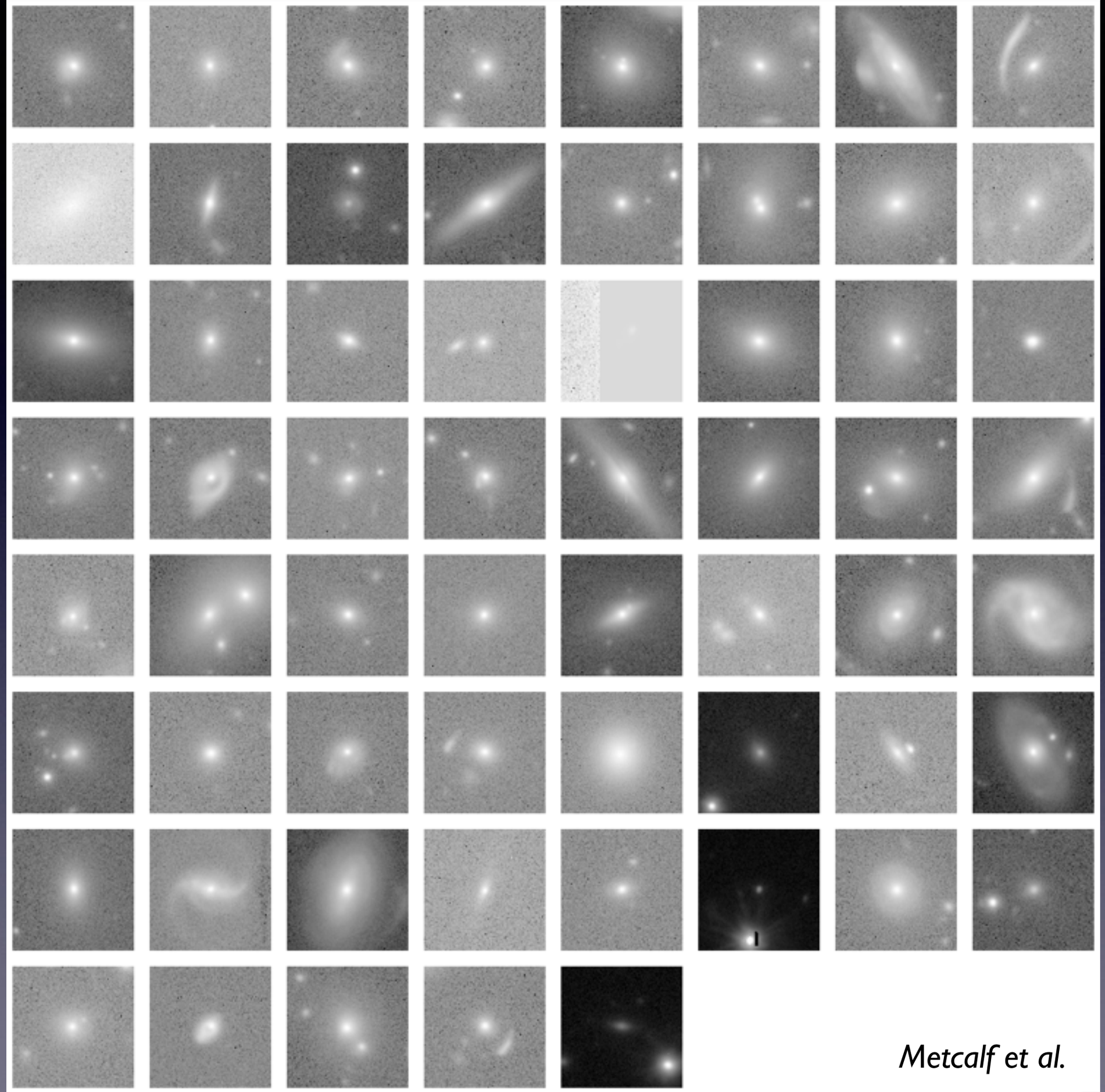
Field Lensing Simulations







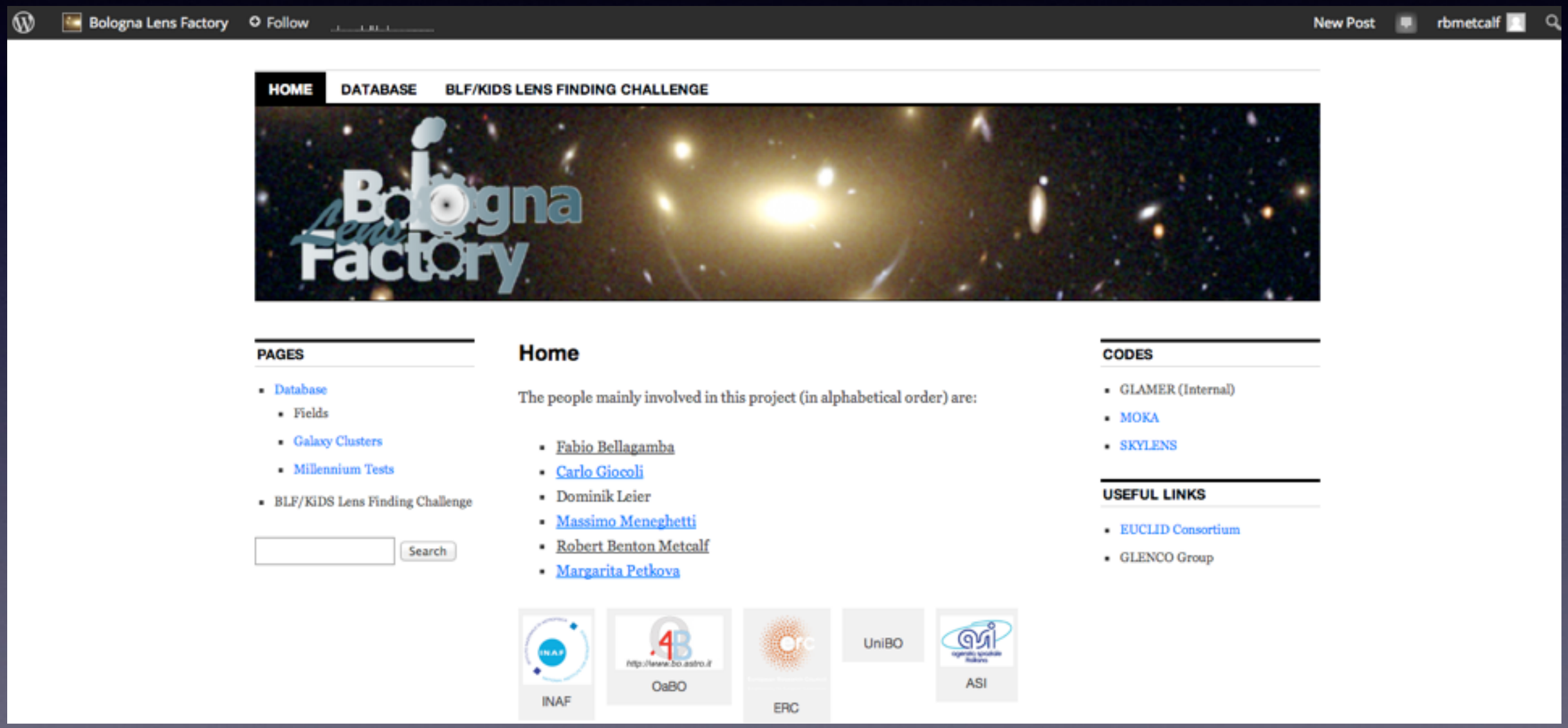




Metcalf et al.

The Bologna Lens Factory

Bologna Lens Factory / KiDS *Lens Finding Challenge*



http://bolognalensfactory.wordpress.com

Gravitational Microscope

Detection of small-scale dark objects in galaxy-galaxy and galaxy-quasar lenses

Lens Modeling of Clusters & Galaxies

Measuring the distribution of mass and its relation to observed galaxies

Predicting the magnification so they can be used as gravitational telescopes

Doing cosmology with galaxy cluster lensing

Lensing of the 21 cm sky

A new method for measuring weak gravitational lensing that will be available for future radio telescopes such as SKA.

Weak Lensing Simulations

Studying systematic effects that will influence cosmological constraints using weak lensing surveys.

Studying the influence of baryons and small scale halo structure on weak lensing

Testing alternative gravity theories

Quasar Microlensing

Measuring the dark matter content of distant galaxies using microlensing statistics