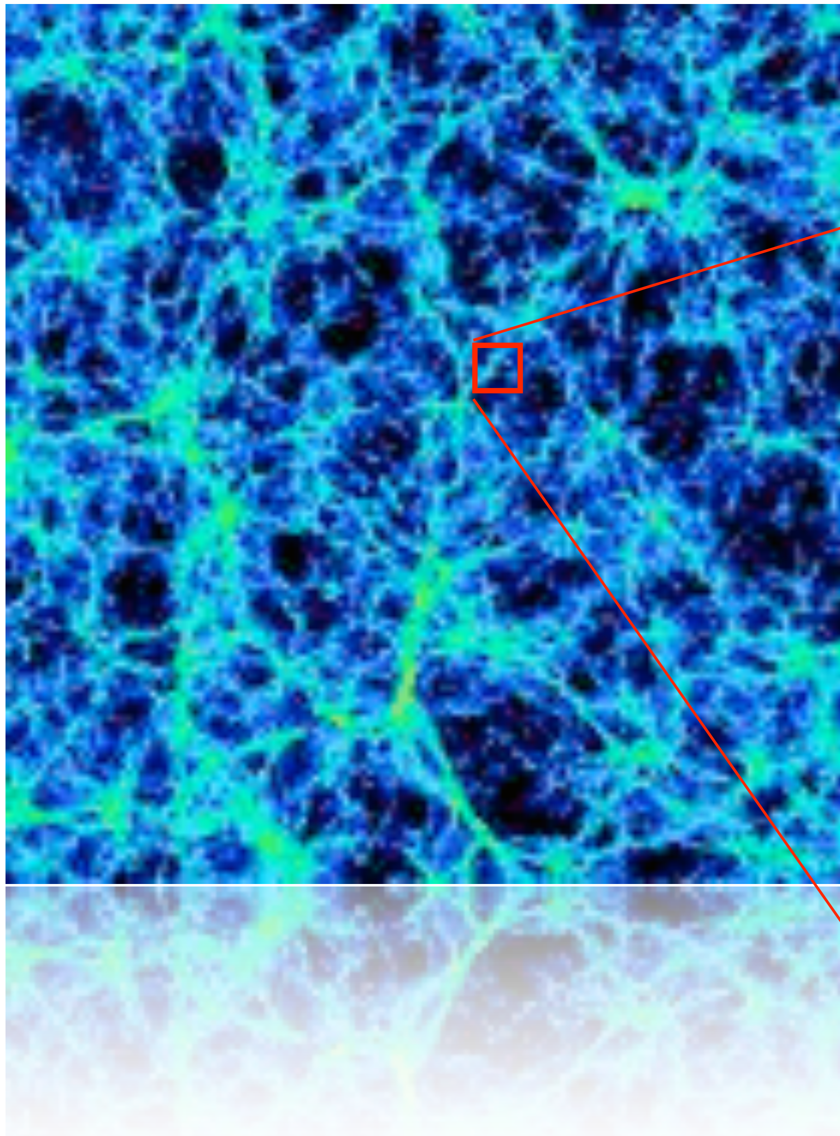
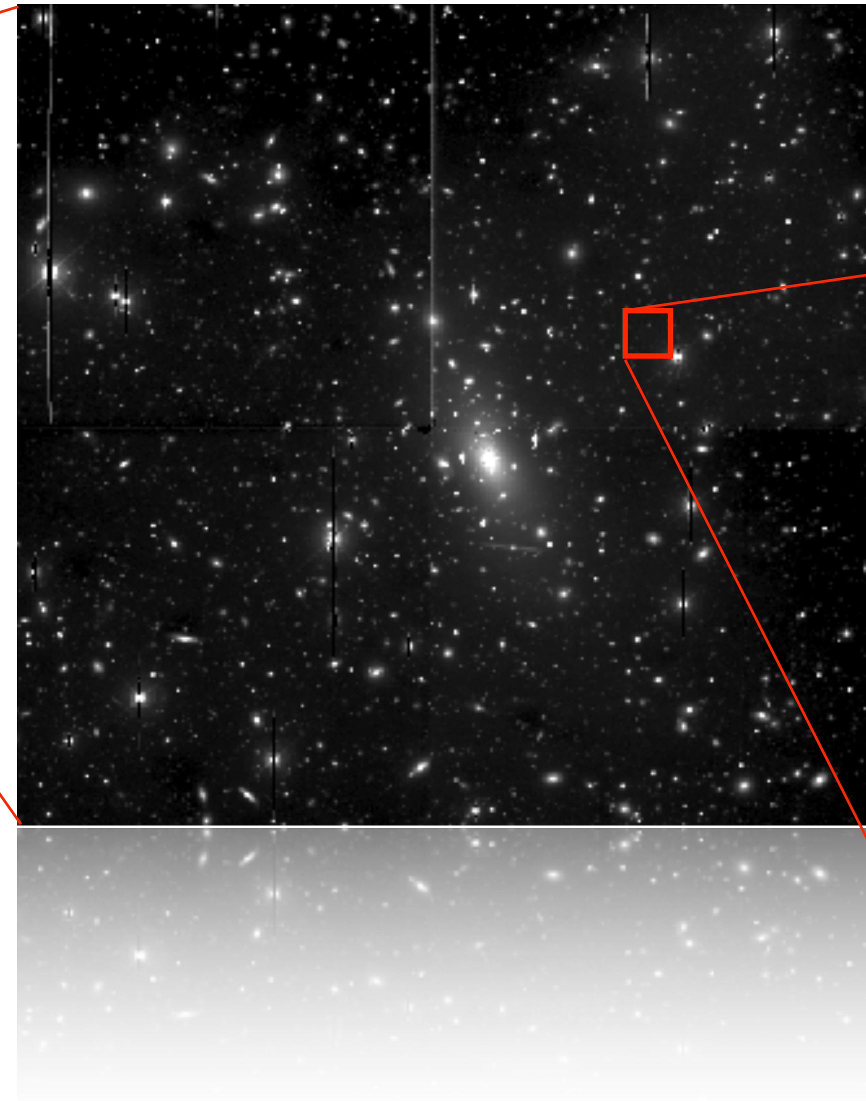
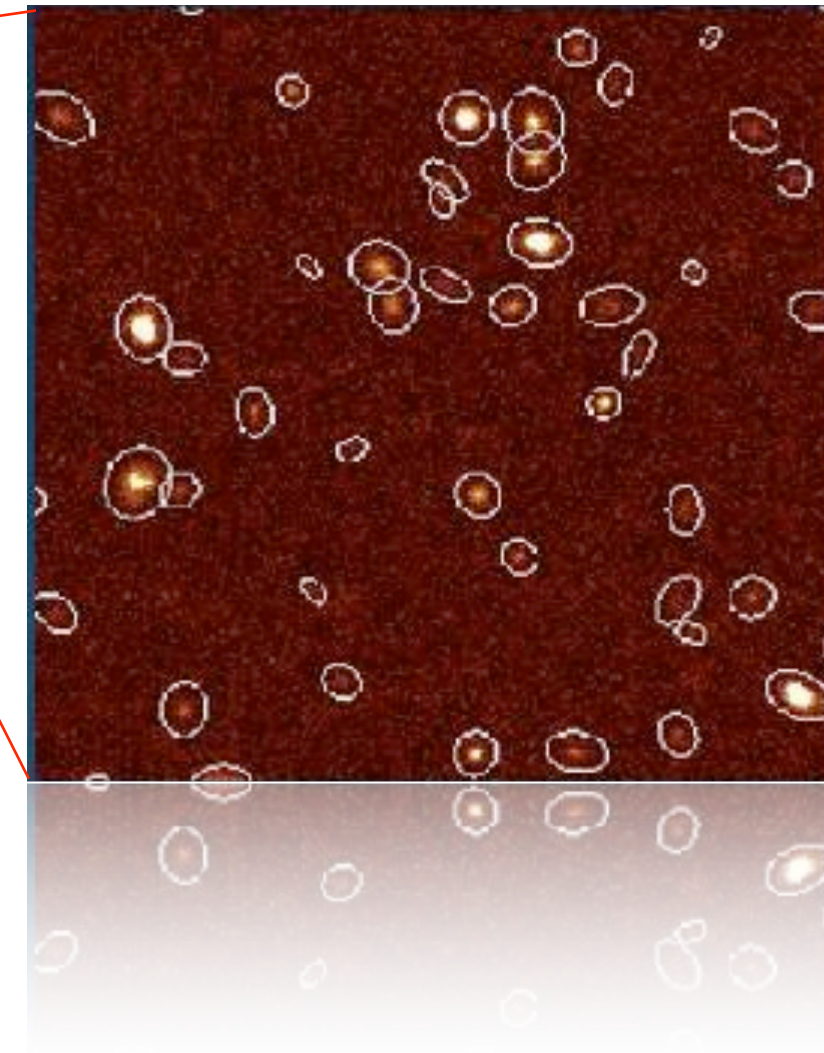
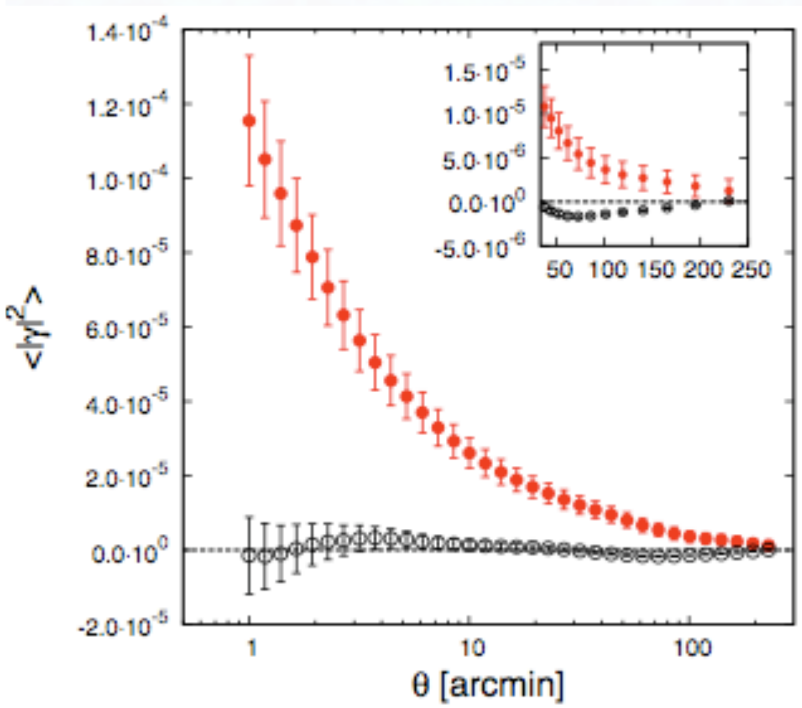
Statistical analyses of the density field

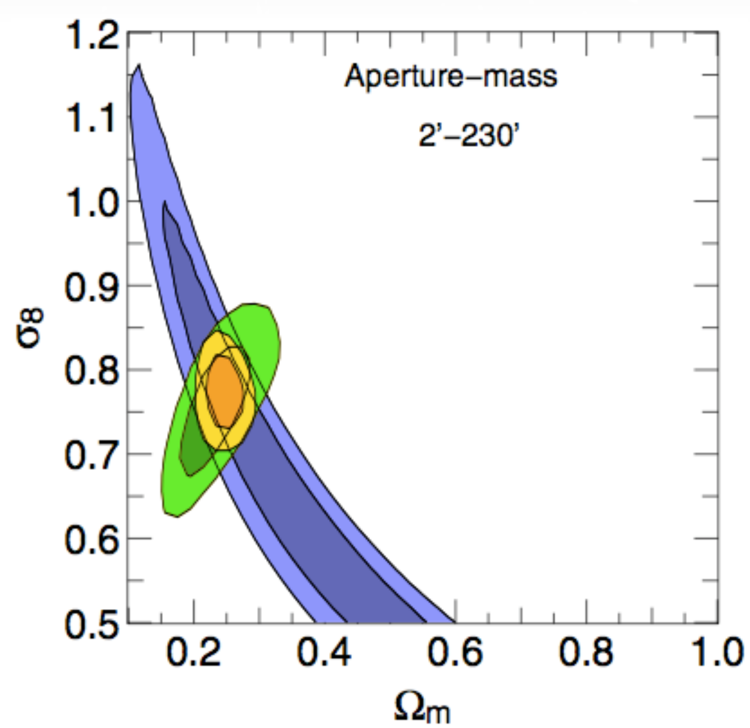








<|γ|²>
θ [arcmin]
1.4·10⁻⁴
1.2·10⁻⁴
1.0·10⁻⁴
8.0·10⁻⁵
6.0·10⁻⁵
4.0·10⁻⁵
2.0·10⁻⁵
0.0·10⁰
-2.0·10⁻⁵
1
10
100
1.5·10⁻⁵
1.0·10⁻⁵
5.0·10⁻⁶
0.0·10⁰
-5.0·10⁻⁶
50 100 150 200 250



Aperture−mass
2'−230'
σ8
Ωm
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.2 0.4 0.6 0.8 1.0

Fu et al, 2008

Correlations & Stacking

$$\langle \delta_g \, X \rangle \qquad\qquad \delta_g = \frac{n_g}{\langle n_g \rangle} - 1$$

$\langle \delta_g \, \delta_g \rangle$	density	$\longrightarrow$	clustering
$\langle \delta_g \, \gamma_t \rangle$	shear	$\longrightarrow$	mass
$\langle \delta_g \, m_{QSO} \rangle$	magnification	$\longrightarrow$	mass
$\langle \delta_g \, C_{QSO} \rangle$	reddening	$\longrightarrow$	dust
$\langle \delta_g \, F_\lambda \rangle$	flux decrement	$\longrightarrow$	gas, metals, ionization

$$\langle \delta_g \, X \rangle$$

X : magnitude, color, ellipticity, flux decrement, etc.

δ : galaxy, LRG, QSO, group, cluster, absorber, etc.

$\langle \delta_g \, \delta_g \rangle$	density	$\longrightarrow$	clustering
$\langle \delta_g \, \gamma_t \rangle$	shear	$\longrightarrow$	mass
$\langle \delta_g \, m_{QSO} \rangle$	magnification	$\longrightarrow$	mass
$\langle \delta_g \, C_{QSO} \rangle$	reddening	$\longrightarrow$	dust
$\langle \delta_g \, F_\lambda \rangle$	flux decrement	$\longrightarrow$	gas, metals, ionization

Density field characterization

$$\delta(\mathbf{x}) = [\rho(\mathbf{x}) - \rho_0]/\rho_0$$

density contrast

$$\delta(\mathbf{x}) = \sum \tilde{\delta}(\mathbf{k}) \exp(i\mathbf{k} \cdot \mathbf{x})$$

Fourier transform

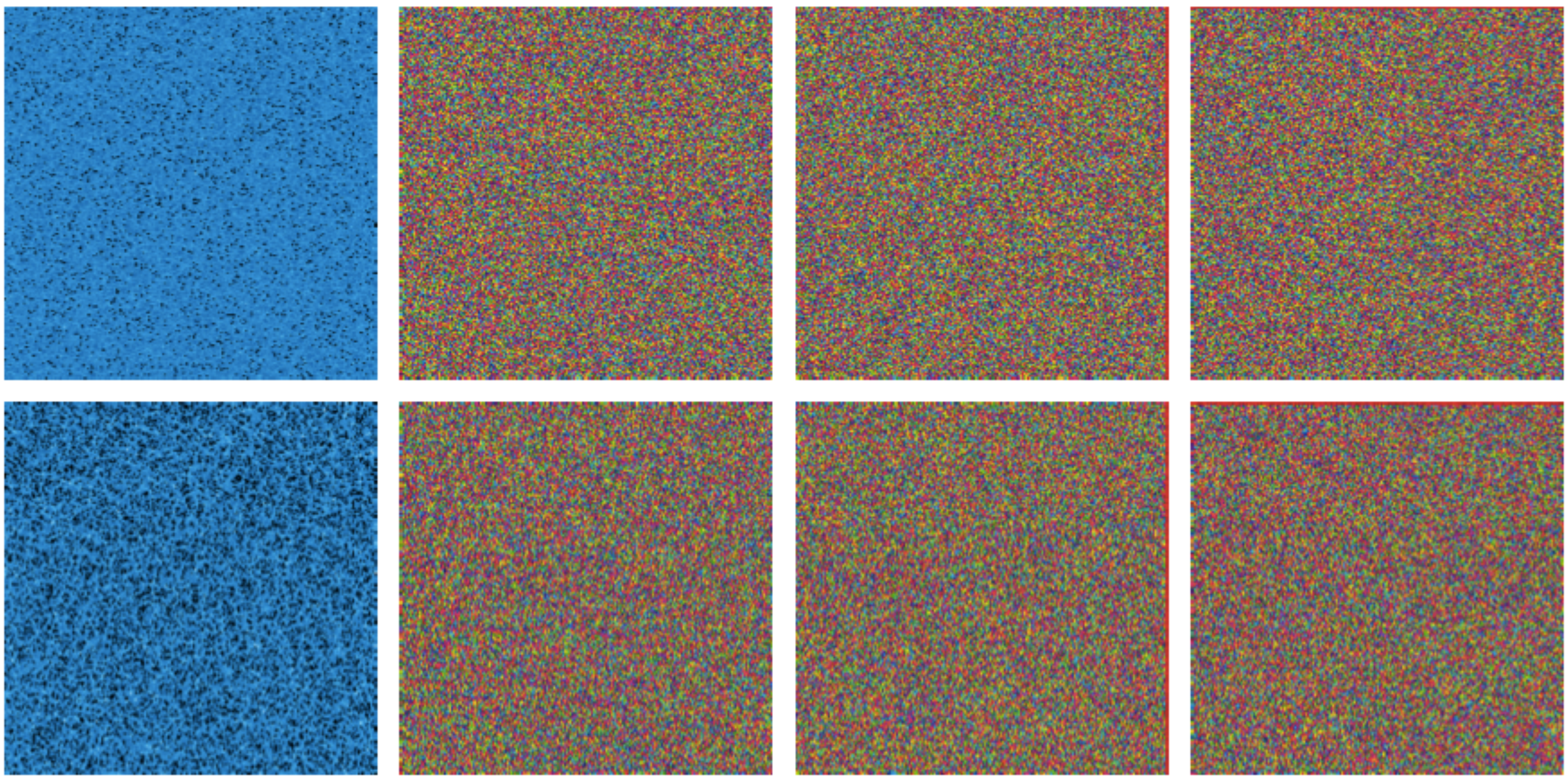
$$\tilde{\delta}(\mathbf{k}) = |\tilde{\delta}(\mathbf{k})| \exp(i\phi_{\mathbf{k}})$$

amplitude/phase decomposition

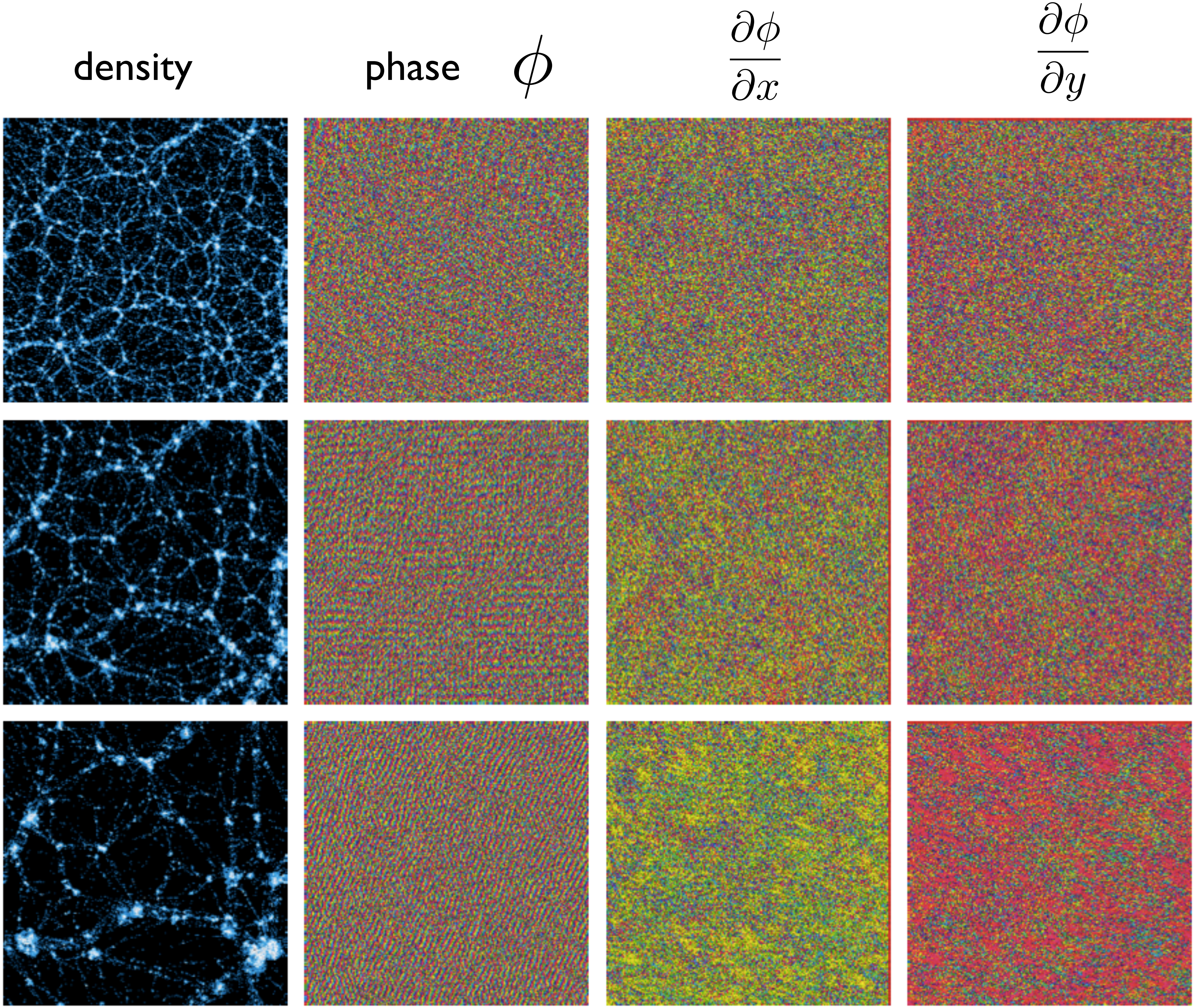
$$P(k) = \langle |\tilde{\delta}(k)|^2 \rangle$$

Power spectrum

density | phase ϕ | $\frac{\partial \phi}{\partial x}$ | $\frac{\partial \phi}{\partial y}$



Coles & Chiang (2000)



Coles & Chiang (2000)

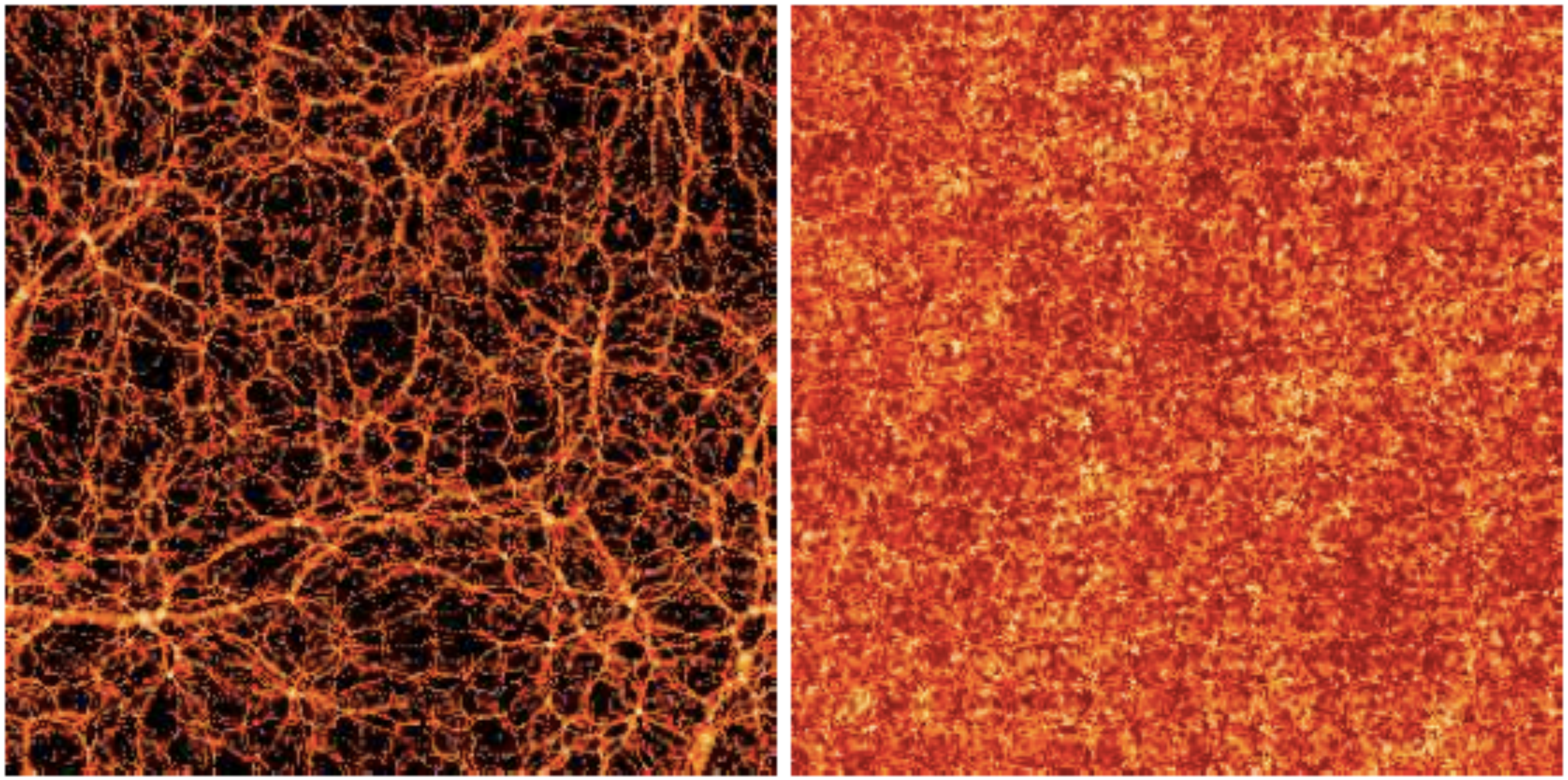
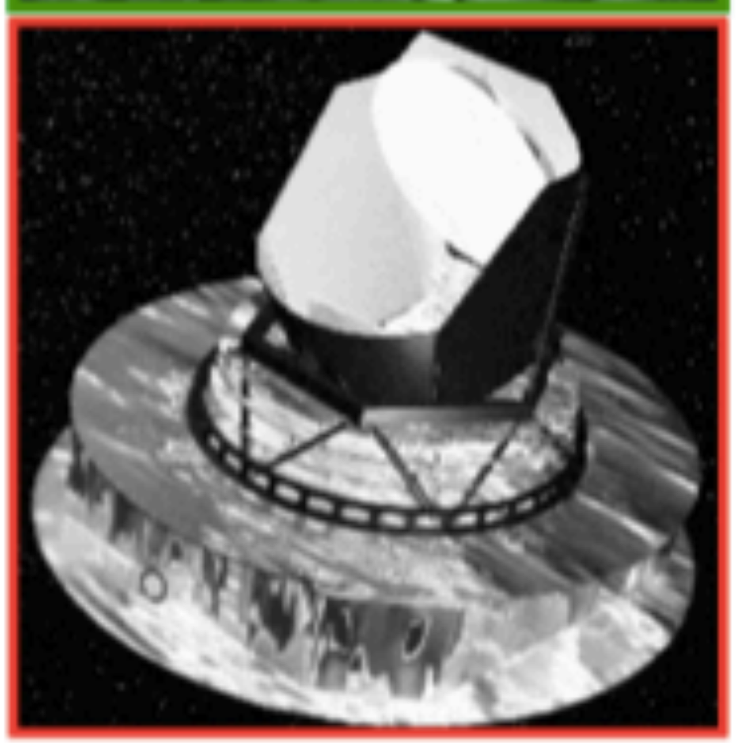


Fig. 1. Numerical simulation of galaxy clustering (left) together with a version generated randomly reshuffling the phases between Fourier modes of the original picture (right).

Coles & Chiang (2001)

$$\delta_{\rm new} = {\rm FT}\left(|\delta_k^{\rm satellite}|\, e^{i\Phi_k^{\rm Max}}\right)$$

Fourier phases

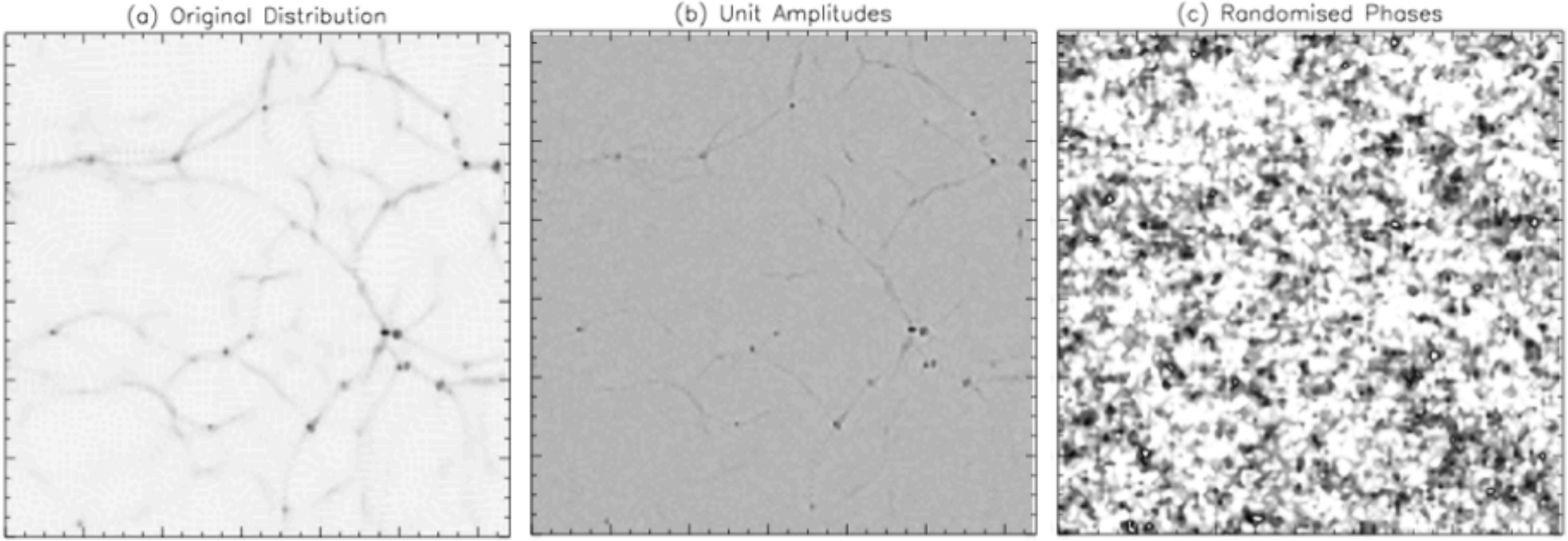


Fourier amplitudes

$P_{new}(k) = P_{satellite}(k)$

Morphology(new) ~ Morphology(Max)

Images from http://www.asiaa.sinica.edu.tw/~lychiang/index/node8.html



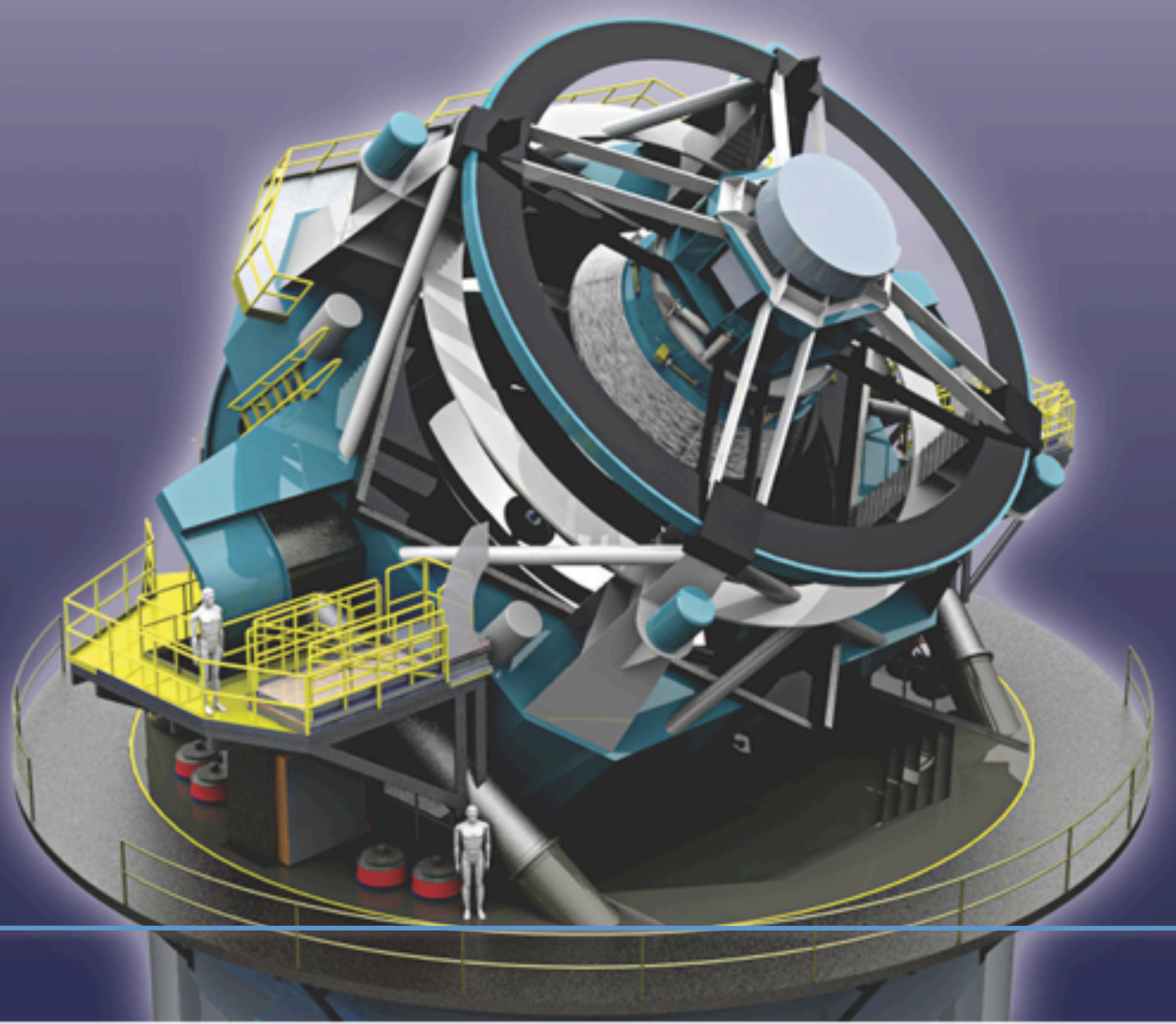
Original image

Reconstructed image:
- same phases
- all amplitudes set to 1

Reconstructed image:
- random phases
- same amplitudes

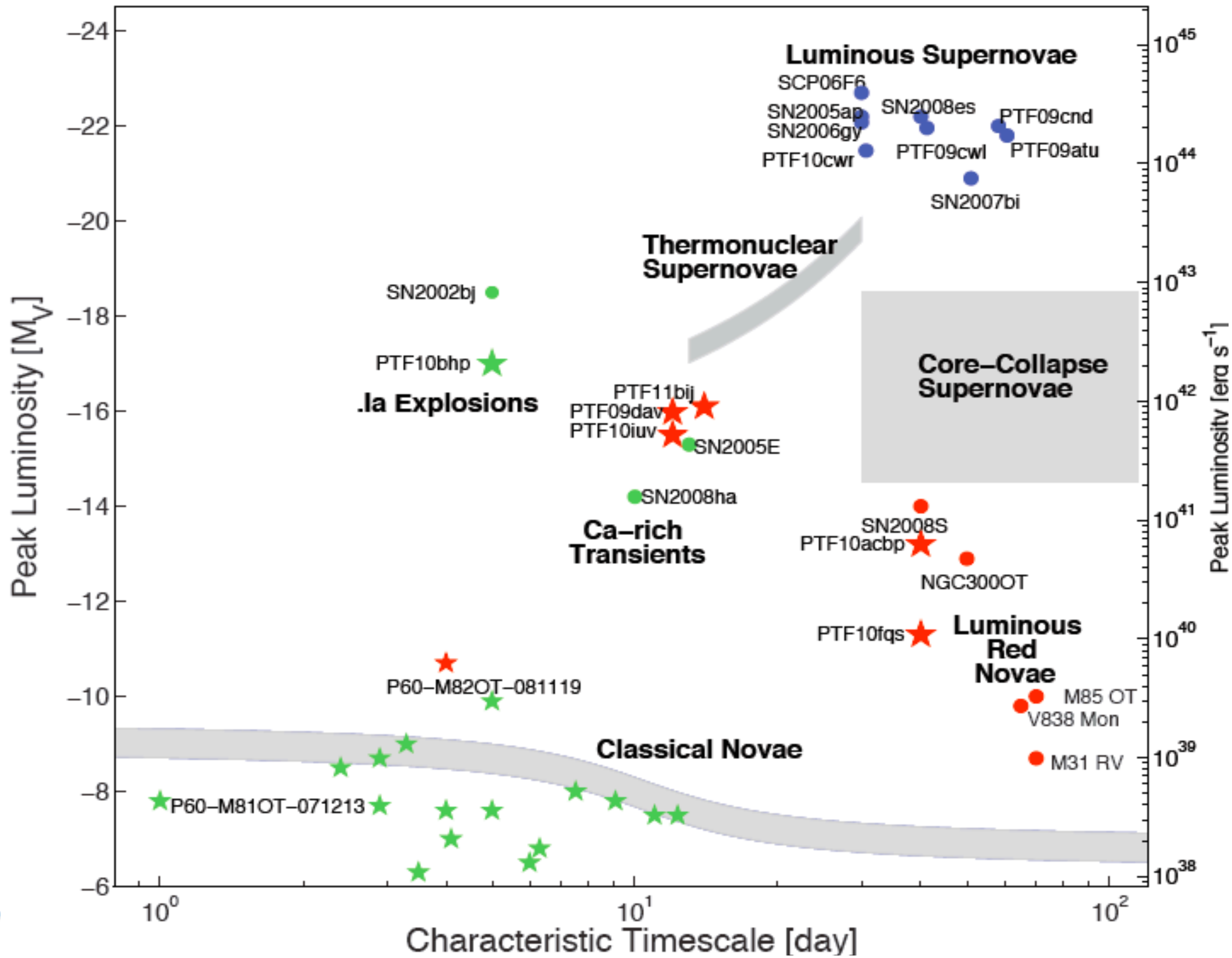
Chiang & Coles (2000)

The Large Synoptic Survey Telescope



Slides from
Michael Strauss
& the LSST collaboration

Level 1 Data Products Overview



LSST: 6.7-m survey telescope on Cerro Pachón in Chilean Andes

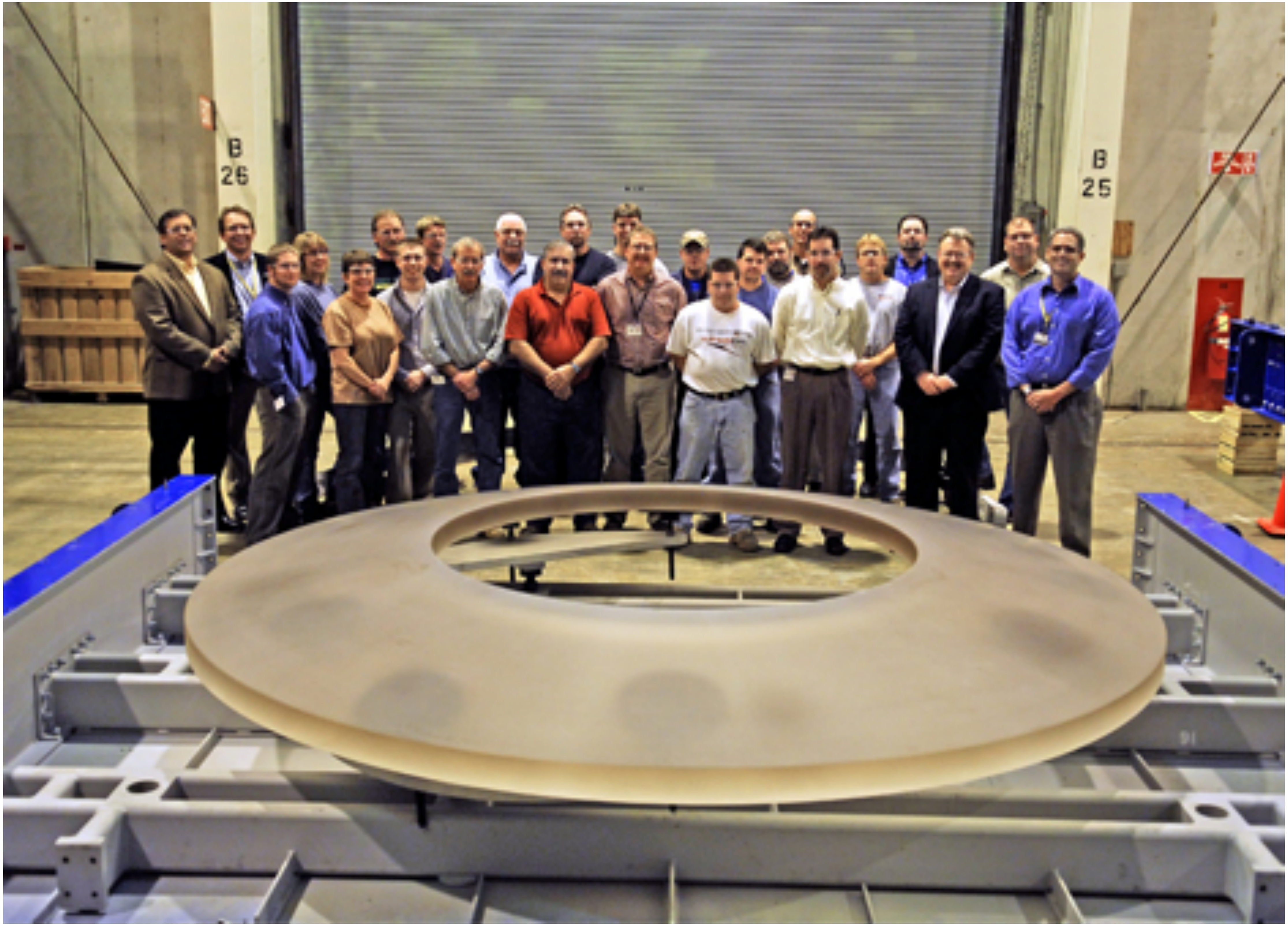
Telescope will be dedicated to imaging survey, and will operate

3-Mirror Design gives 9.6 deg^2 field of view

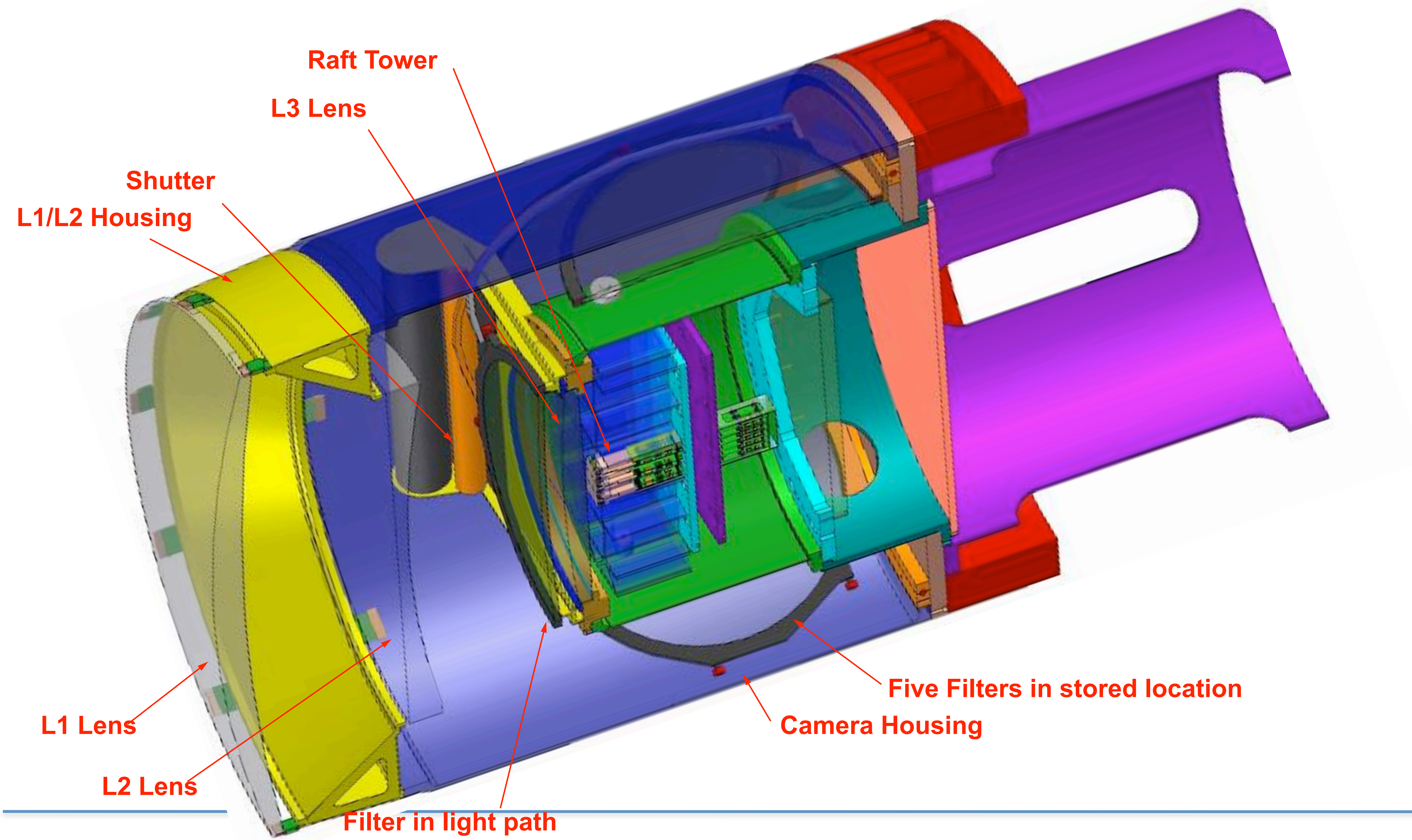
Primary/Tertiary was cast in 2009

Grinding/polishing will be complete next year

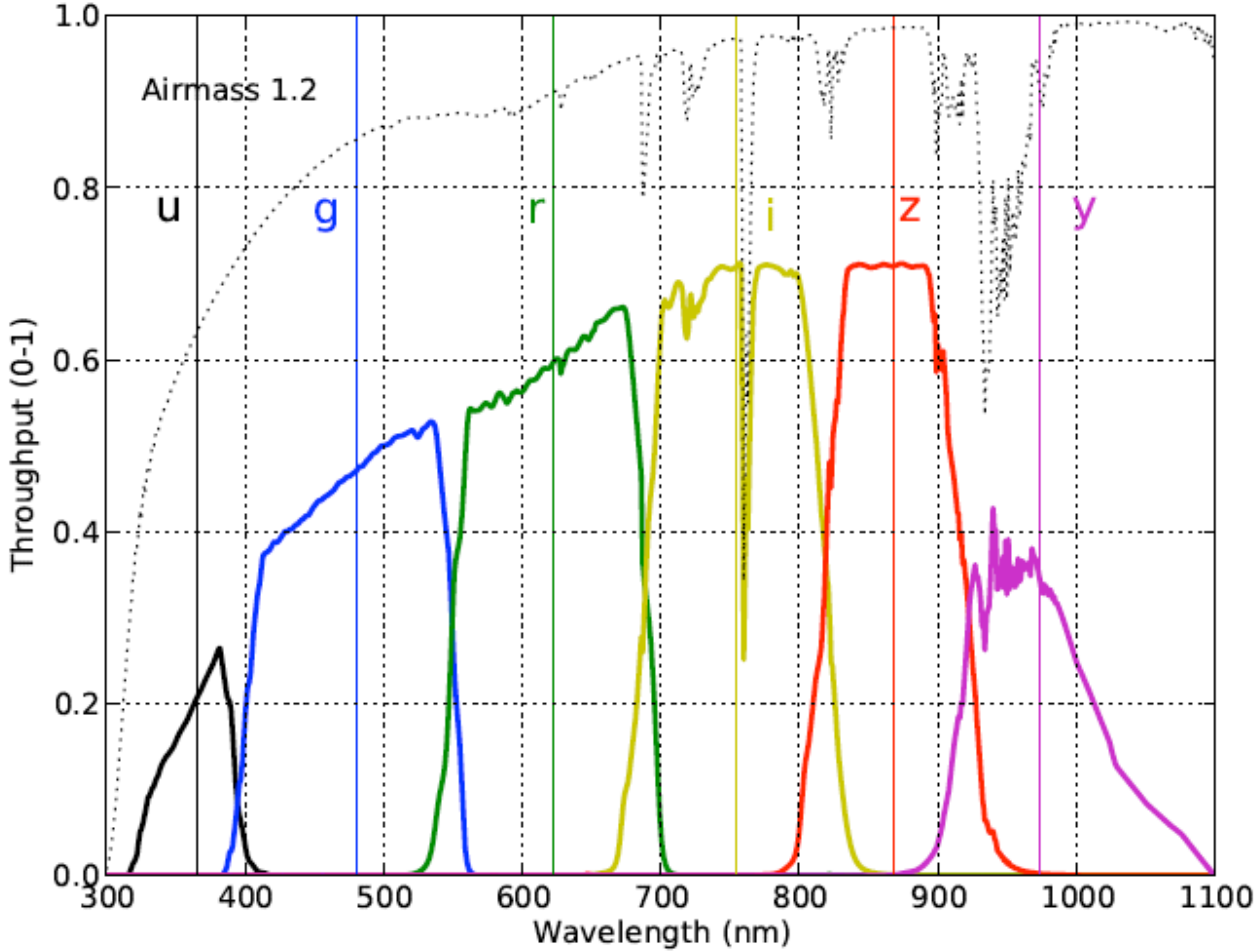
Secondary Mirror is cast, awaiting polishing



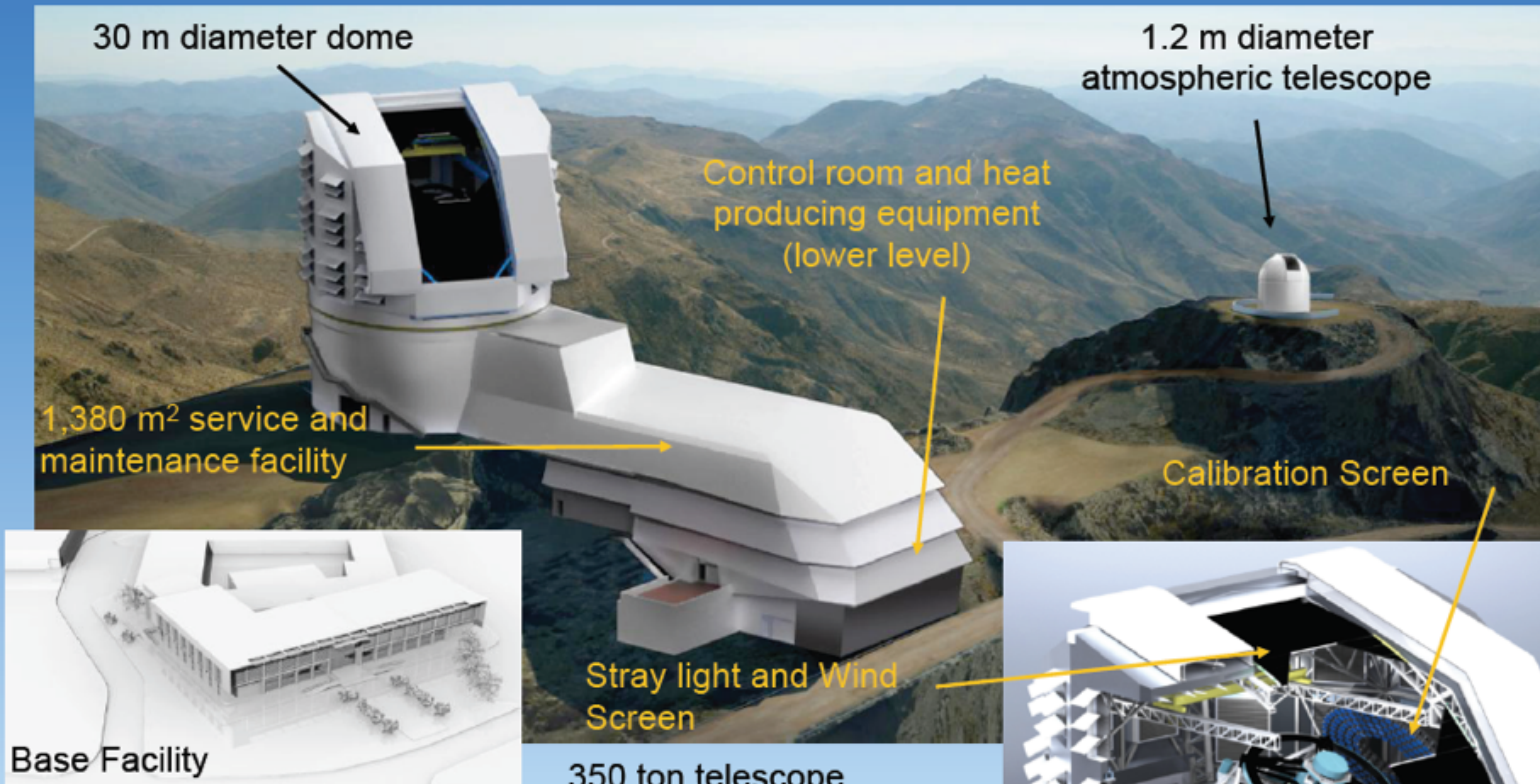
3.2 gigapixel camera. 9.6 deg^2

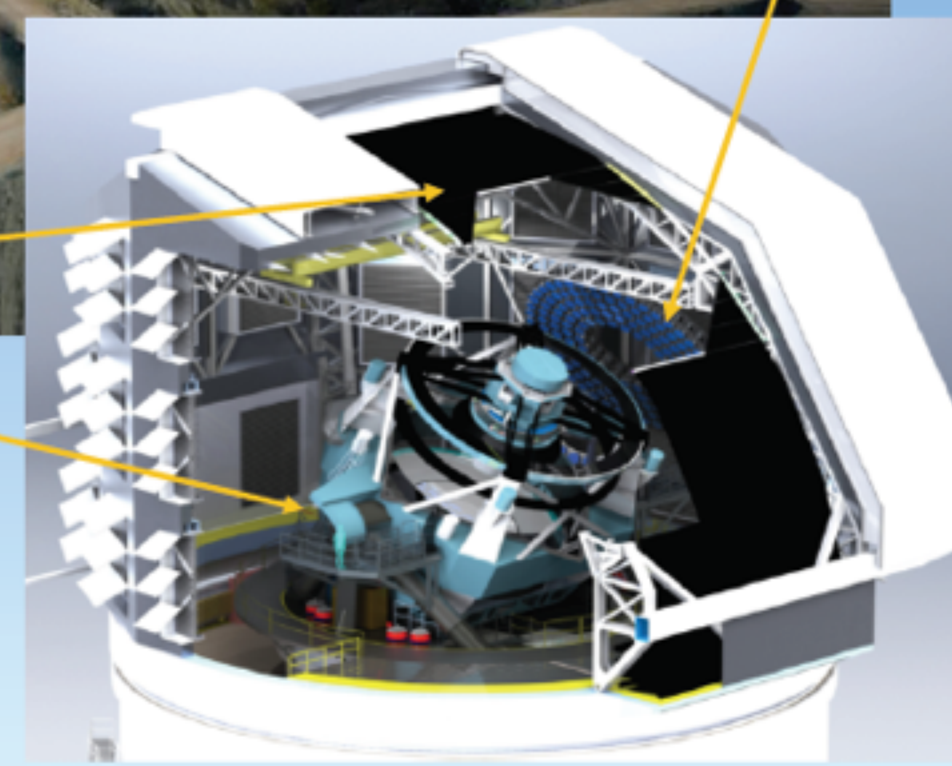


A Filter System similar to SDSS (+ y band)



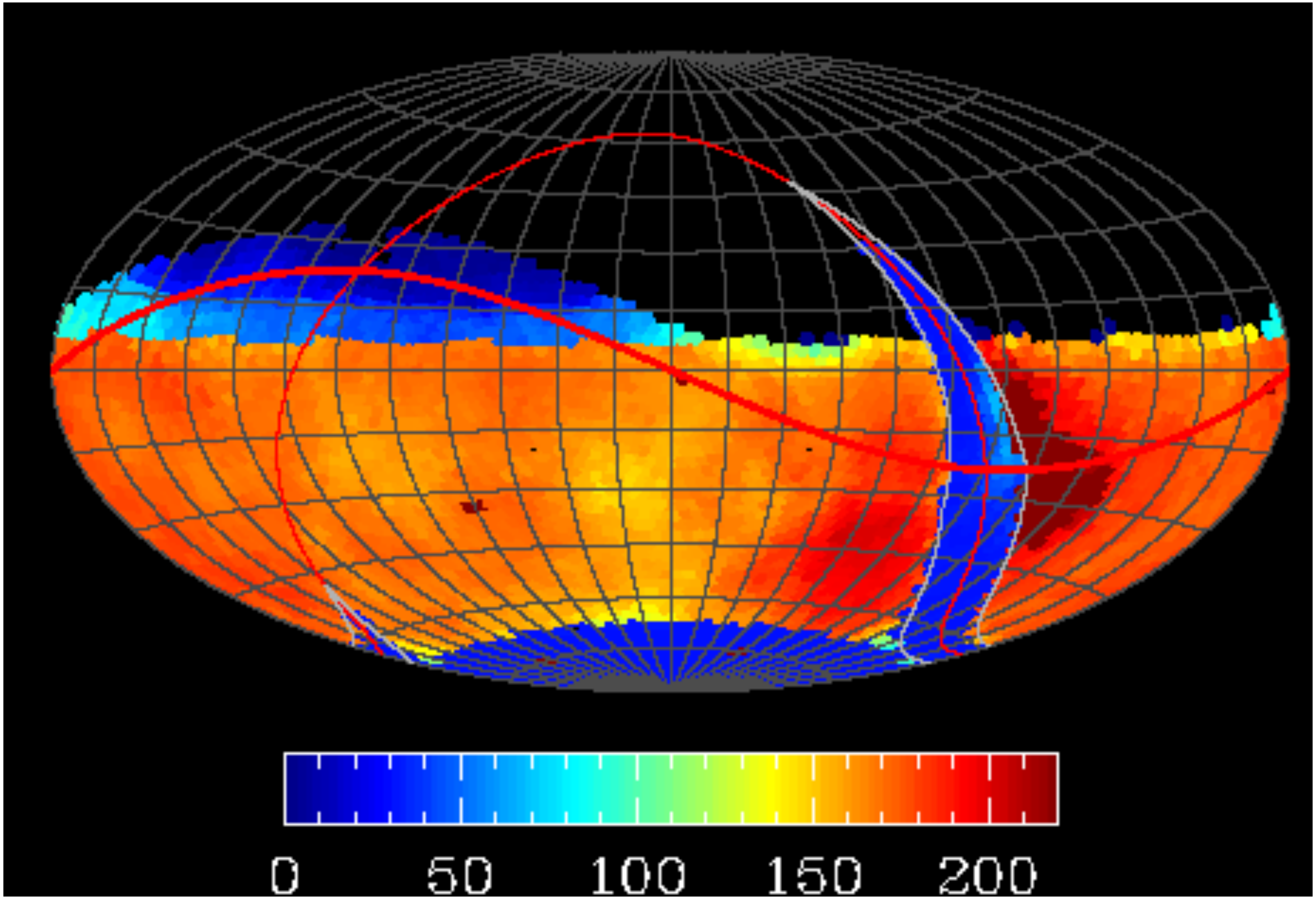
Site has been levelled.





Includes the facilities, and hardware to collect the light, control the survey, calibrate conditions, and support all LSST summit and base operations.

Almost 200 30-sec visits in r across the sky in ten years.



Equatorial coordinates; Based on LSST operations simulations

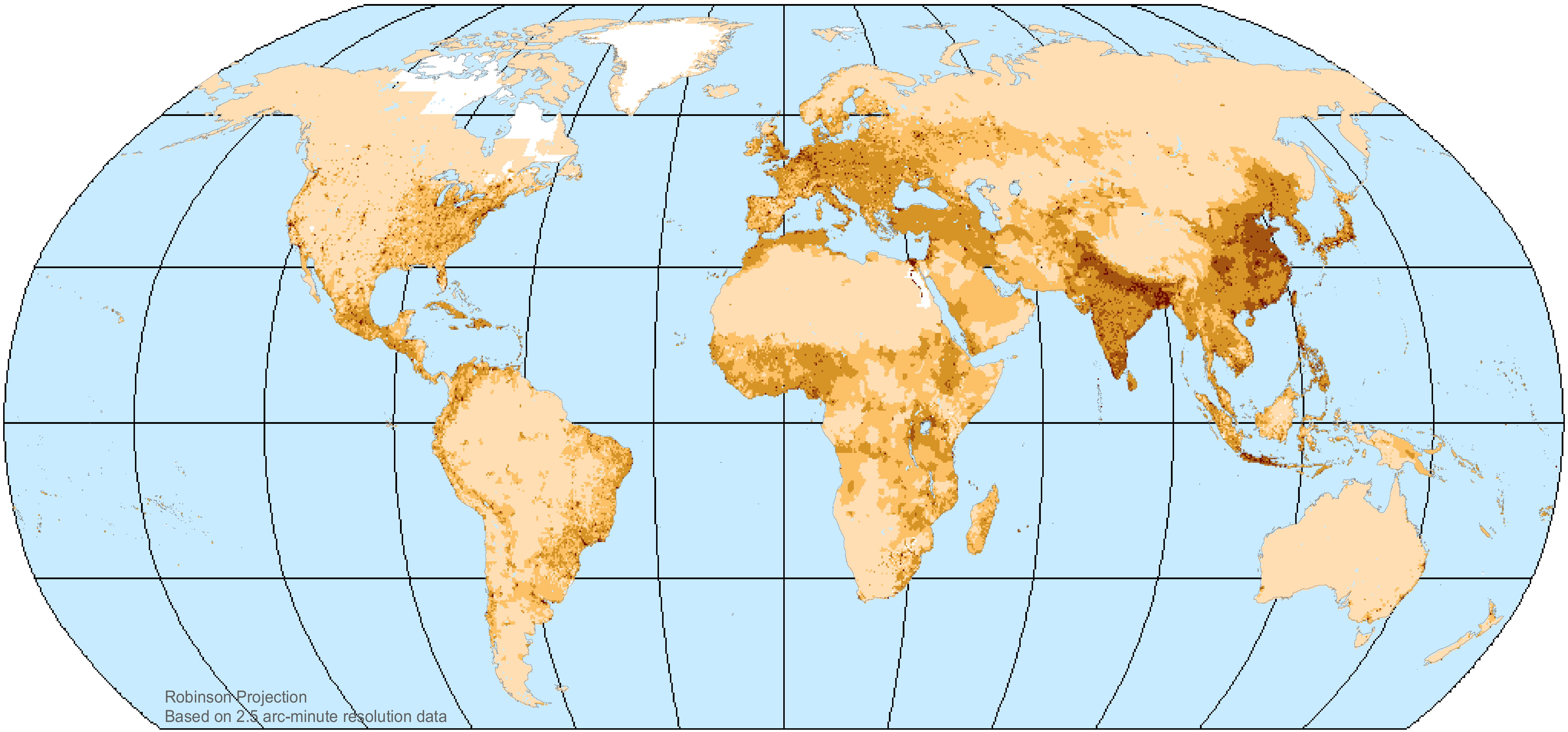
LSST: A dedicated 10-year survey

- Main survey will cover 18,000 deg^2 in Southern Hemisphere, ~1000 pairs of 15-sec exposures across 6 filters.
- 5σ point-source depth after two exposures: 23.9 (u), 25.0 (g), 24.7 (r), **24.0** (i), 23.3 (z), 22.1 (y)
- Depth at end of the survey: 26.3 (u), 27.5 (g), 27.7 (r), **27.0** (i), 26.2 (z), 24.9 (y)
- **32 trillion observations of 38 billion objects**

An introduction
to gravitational lensing

The World: Population Density, 2000

***GPW* [v3]**



Gridded Population of the World

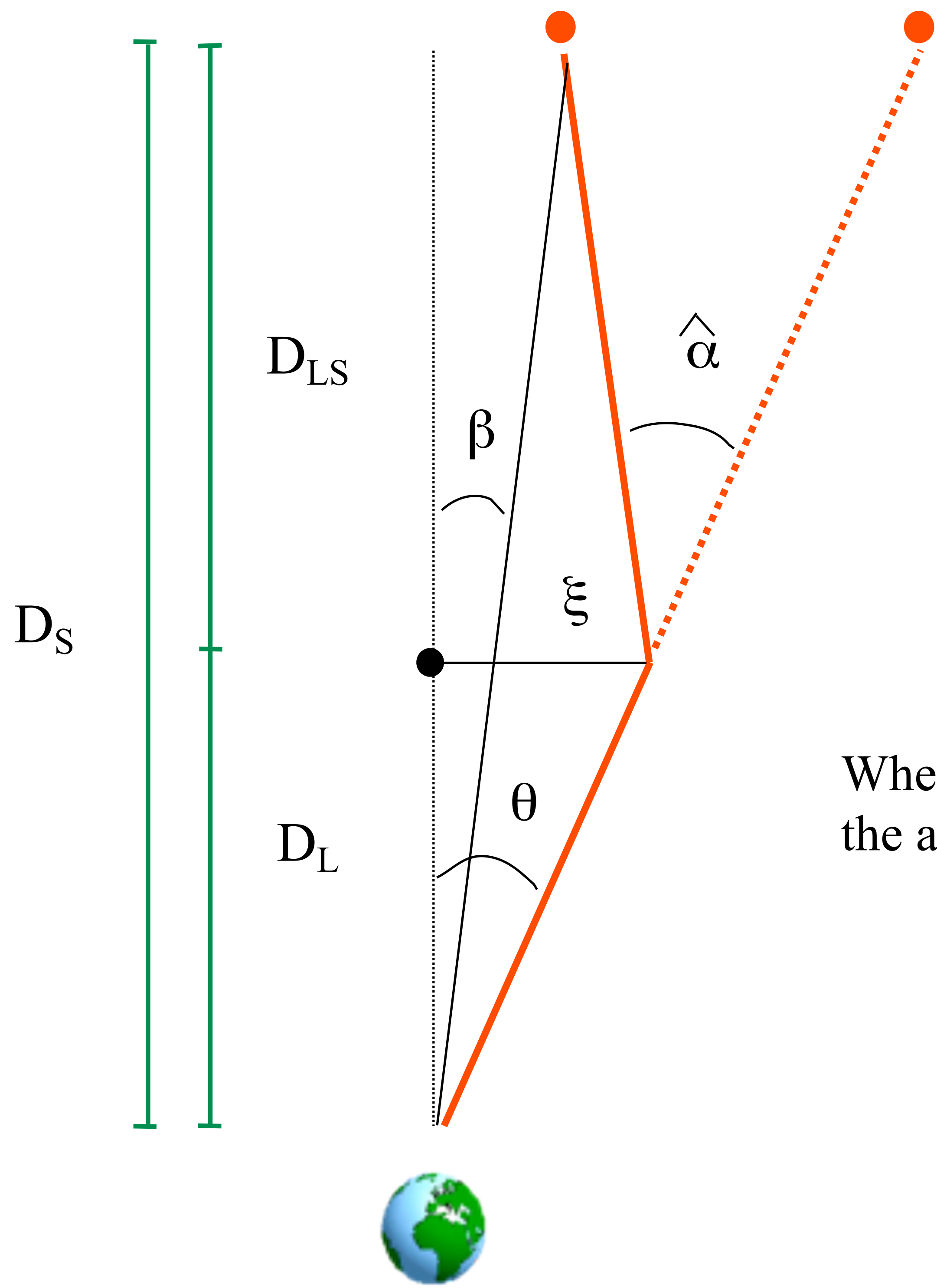
Persons per km^2

- 0
- 1 - 4
- 5 - 24
- 25 - 249
- 250 - 999
- 1,000 +

Source: Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). Gridded Population of the World (GPW), Version 3. Palisades, NY: CIESIN, Columbia University. Available at: http://sedac.ciesin.columbia.edu/gpw.


Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap001127.html
Astronomy Picture of the Day
2000 November 27
http://antwrp.gsfc.nasa.gov/apod/astropix.html

Basics of gravitational lensing



General Relativity => $\hat{\alpha} = 4\,GM / c^2\,\xi$

by defining : $\alpha = \hat{\alpha}\,.\,D_{LS} / D_S$,

we get the lens equation:

$$\theta_{obs} = \beta_{real} + \alpha$$

When the observer, the lens and the source are aligned: $\beta=0$,
the apparent image has a characteristic value: the Einstein radius

$$\theta_E = \left(\frac{4GM}{c^2} \frac{d_{LS}}{d_L d_S} \right)^{1/2}$$

Observables: position change, distortion, magnification

Lensing can probe *M* over 20 orders of magnitude!

Applications of lensing

Lensing induced by:

- **Stars**
- Planets
- Galaxies
- Galaxy clusters
- Large-scale structures

$$\theta_E = \left(\frac{4GM}{c^2}\,\frac{d_{LS}}{d_L d_S}\right)^{1/2}$$

$$\theta_E = \left(\frac{M}{10^{11.9}M_\odot}\right)^{1/2}\left(\frac{d_L d_S/d_{LS}}{Gpc}\right)^{-1/2} arcsec$$

For

- $M \sim 1\ M_{sun}$
- an effective distance of $\sim$ a few kpc,

we find: $\theta_E \sim 10^{-3}$ arcsec

$\longrightarrow$ microlensing

Applications of lensing

Lensing induced by:

- **Stars**
- Planets
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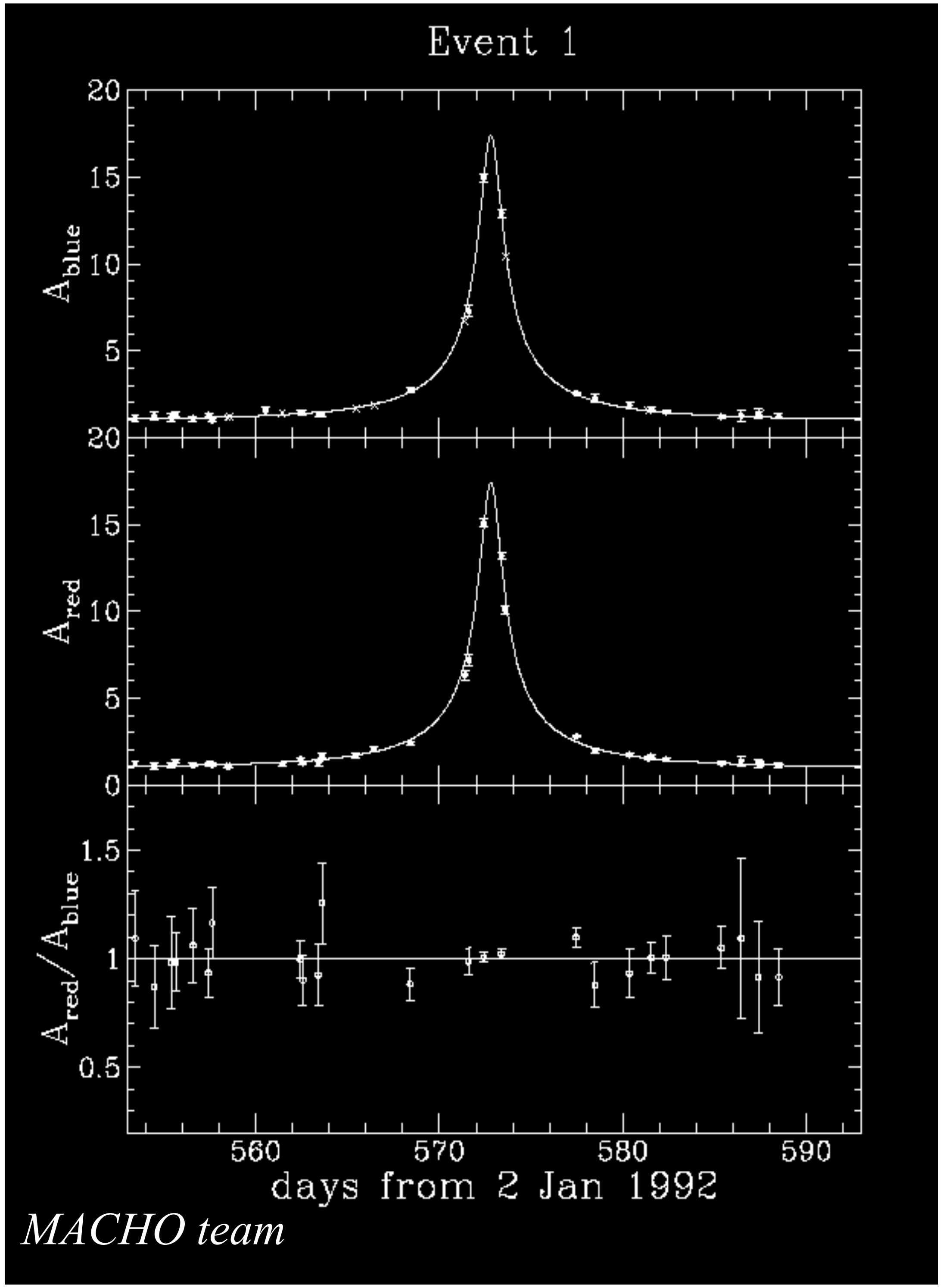
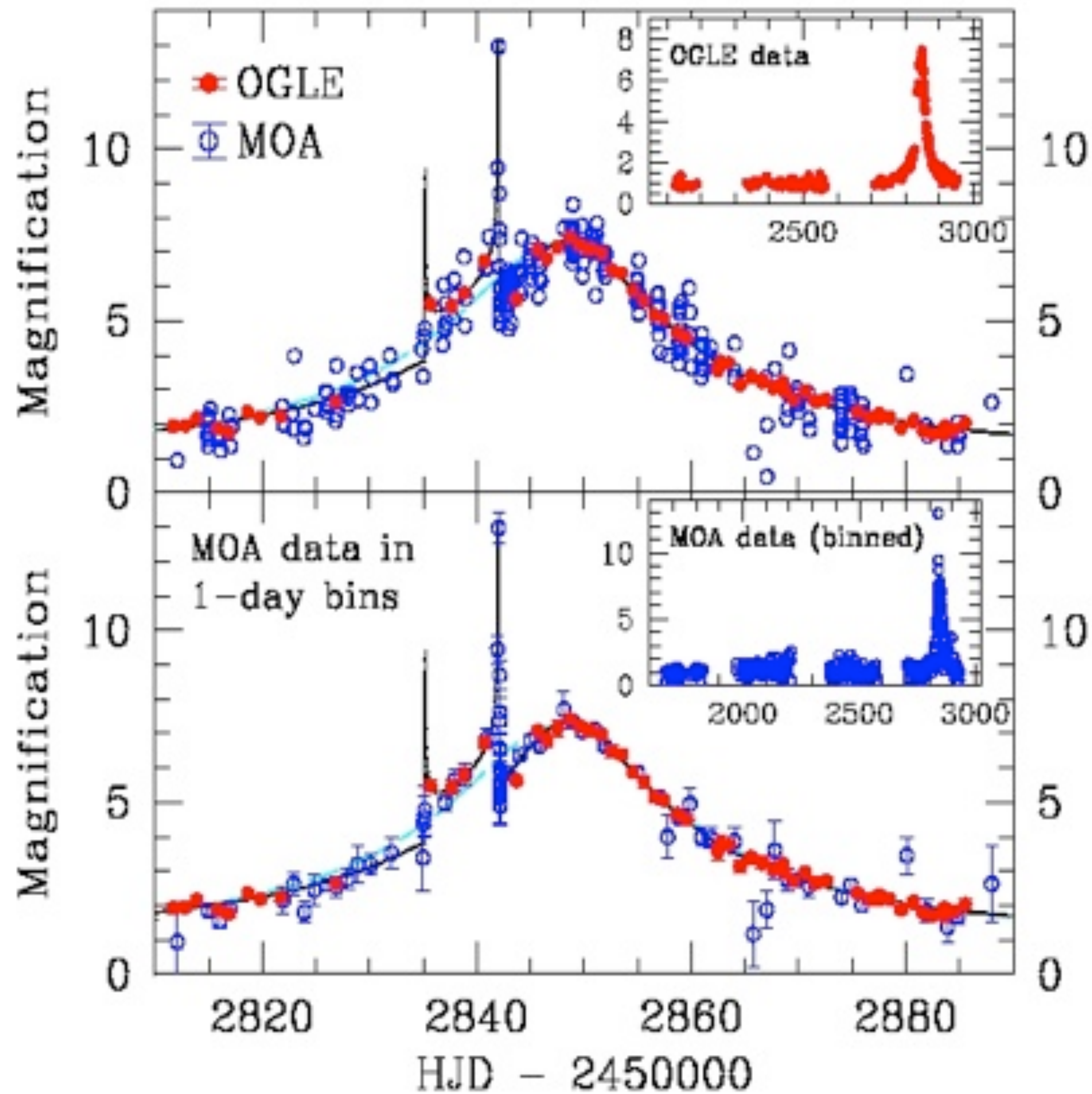


Applications of lensing

Lensing induced by:

- Stars
- **Planets**
- Galaxies
- Galaxy clusters
- Large-scale structures



Applications of lensing

Lensing induced by:

- Stars
- Planets
- **Galaxies**
- Galaxy clusters
- Large-scale structures

$$\theta_E = \left(\frac{M}{10^{11.9} M_\odot}\right)^{1/2} \left(\frac{d_L d_S / d_{LS}}{Gpc}\right)^{-1/2} arcsec$$

For

- $M \sim 10^{12}\ M_{sun}$
- an effective distance of $\sim$ 1 Gpc,

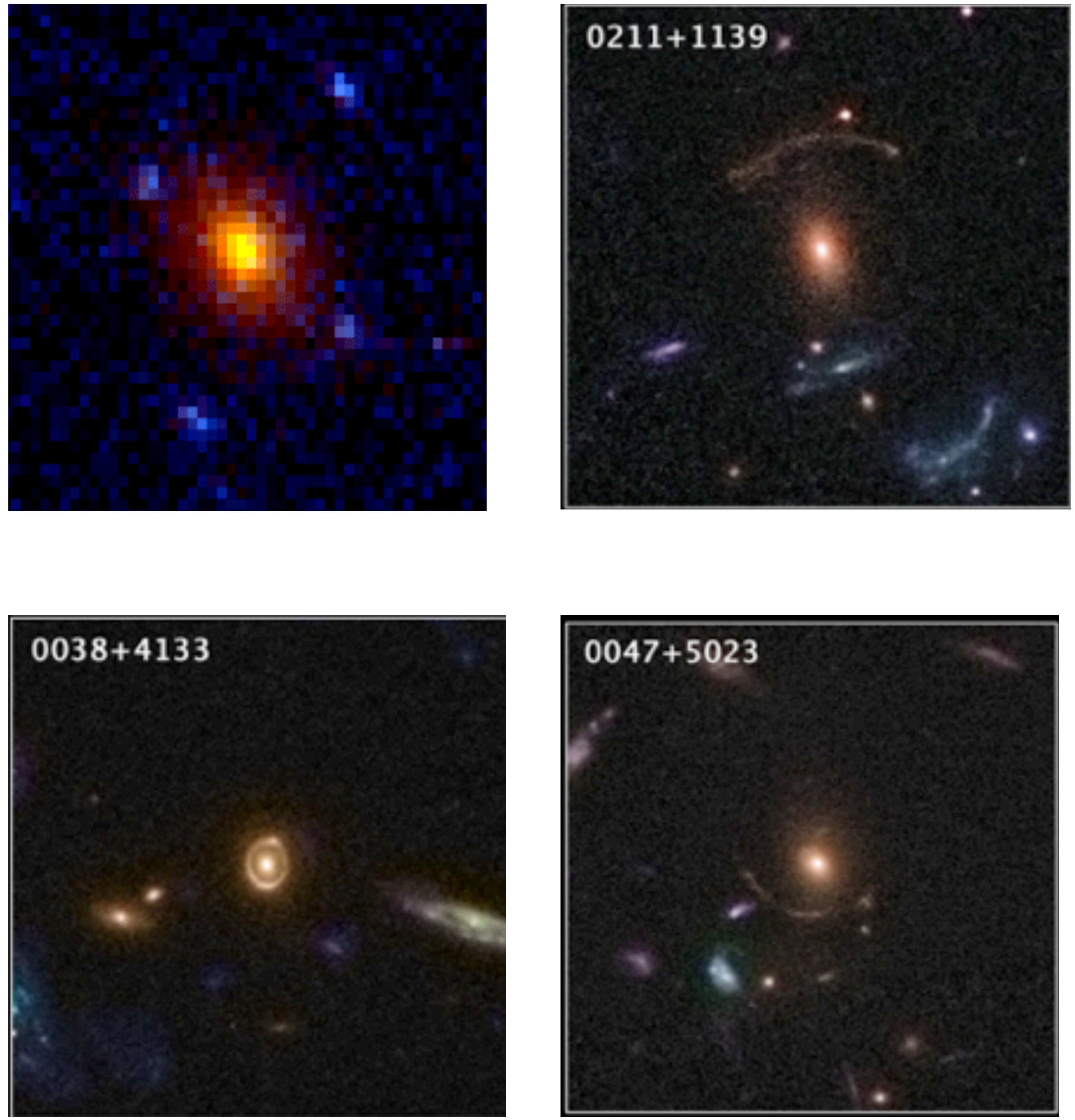
we find: $\theta_E \sim$ a few arcsec

$\longrightarrow$ strong lensing

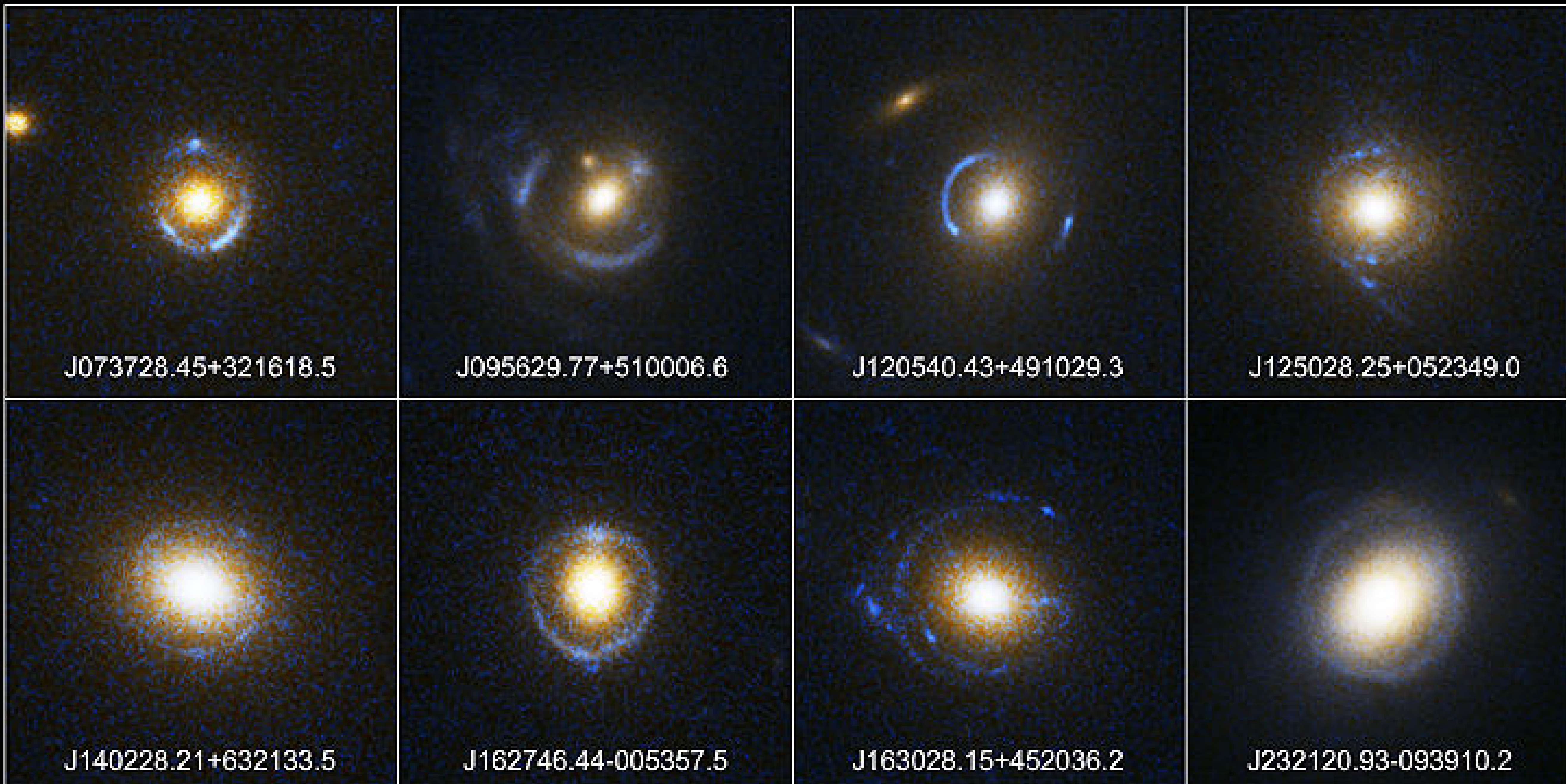
Applications of lensing

Lensing induced by:

- Stars
- Planets
- **Galaxies**
- Galaxy clusters
- Large-scale structures



Strong lensing in the COSMOS survey. Faure et al. (2008)



Einstein Ring Gravitational Lenses

Hubble Space Telescope • Advanced Camera for Surveys

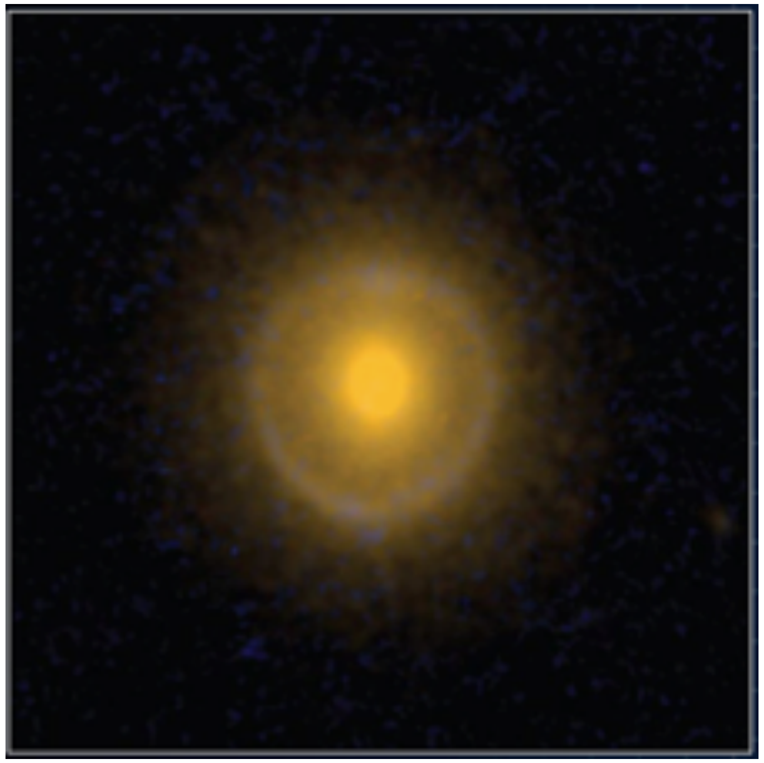
NASA, ESA, A. Bolton (Harvard-Smithsonian CfA), and the SLACS Team

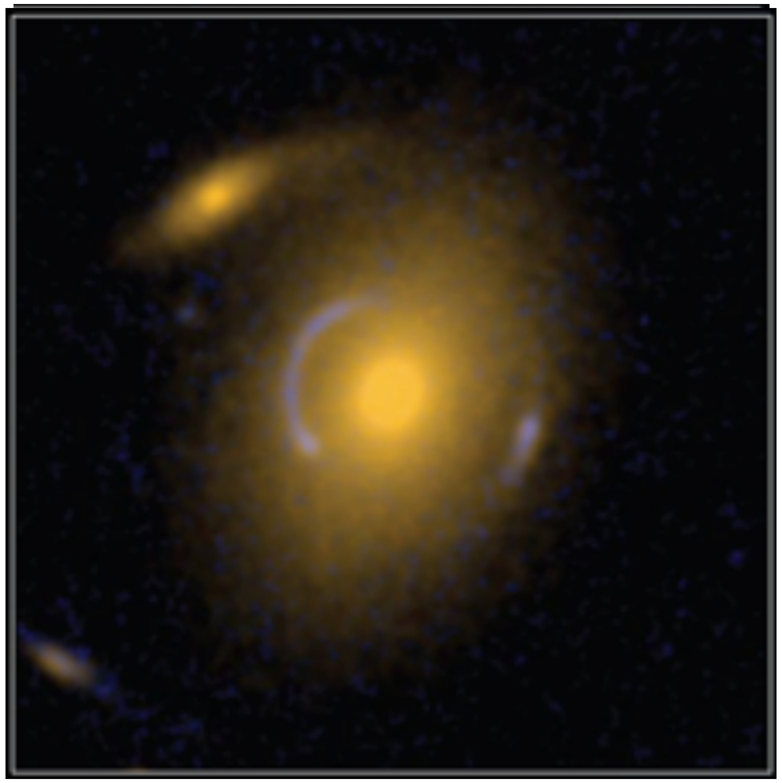
STScI-PRC05-32

Applications of lensing

Lensing induced by:

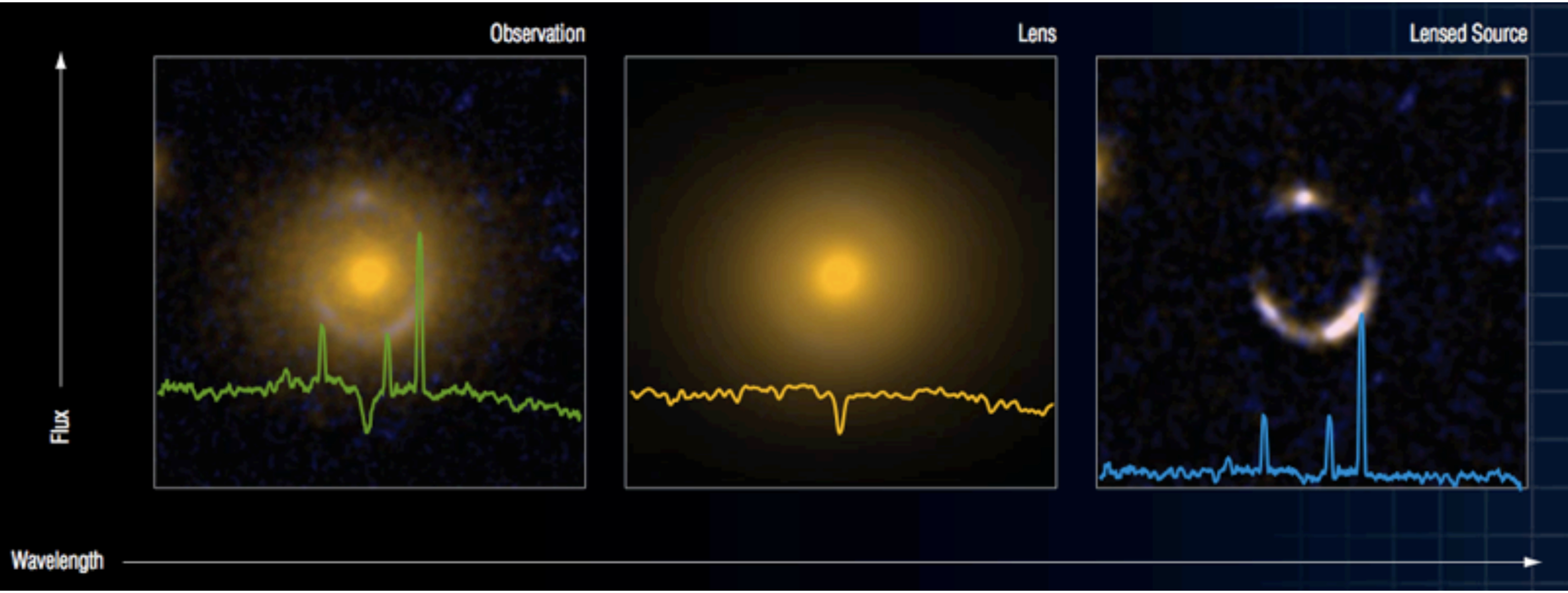
- Stars
- Planets
- **Galaxies**
- Galaxy clusters
- Large-scale structures





The Sloan lens ACS survey
Gavazzi et al. (2008), Bolton et al (2008)

Applications of lensing



The Sloan lens ACS survey
Gavazzi et al. (2008), Bolton et al (2008)

Applications of lensing

Lensing induced by:

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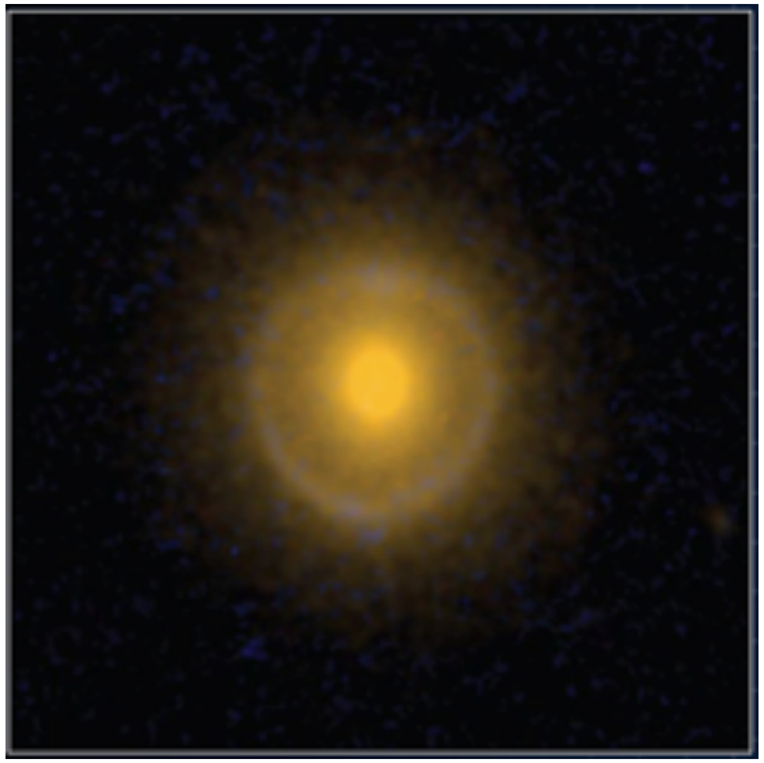
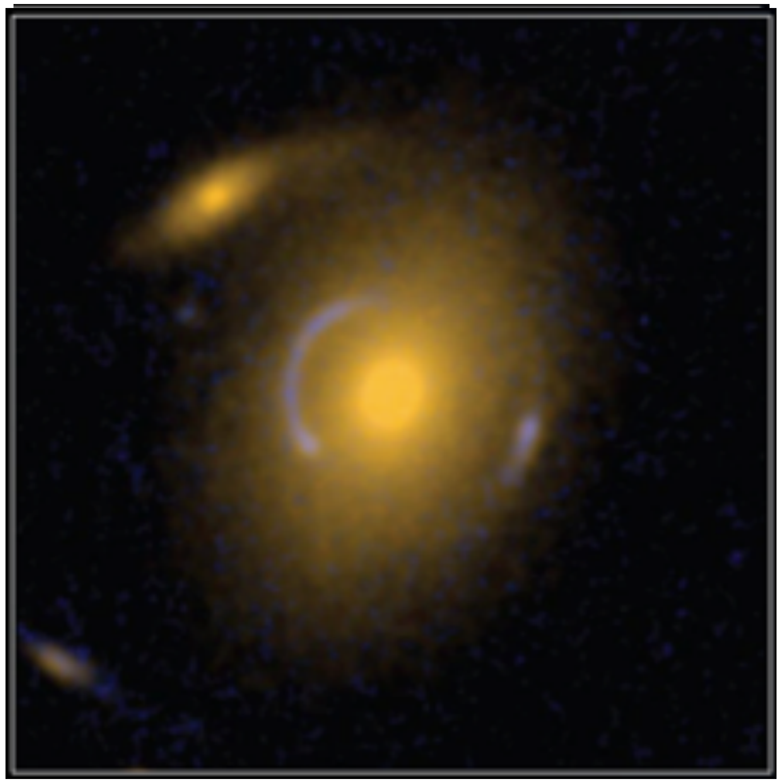
- Planets
- **Galaxies**
- Galaxy clusters
- Large-scale structures





The Sloan lens ACS survey
Gavazzi et al. (2008), Bolton et al (2008)

Applications of lensing

Lensing induced by:

- Stars
- Planets
- Galaxies
- **Galaxy clusters**
- Large-scale structures

$$\theta_E = \left(\frac{M}{10^{11.9} M_\odot}\right)^{1/2} \left(\frac{d_L d_S / d_{LS}}{Gpc}\right)^{-1/2} arcsec$$

For

- $M \sim 10^{15}\ M_{sun}$
- an effective distance of ~ 1 Gpc,

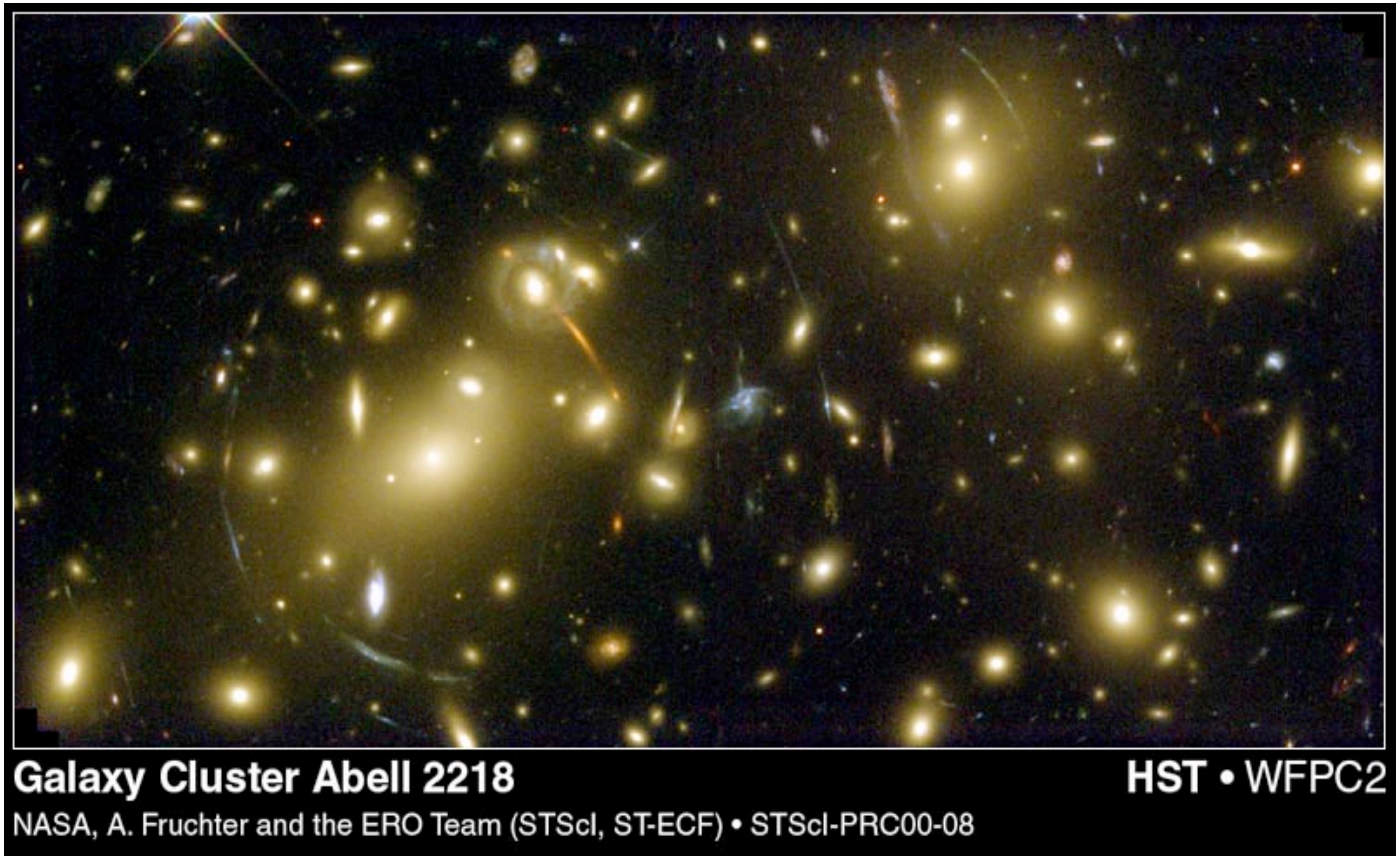
we find: $\theta_E \sim 100$ arcsec

$\longrightarrow$ strong lensing

Applications of lensing

Lensing induced by:

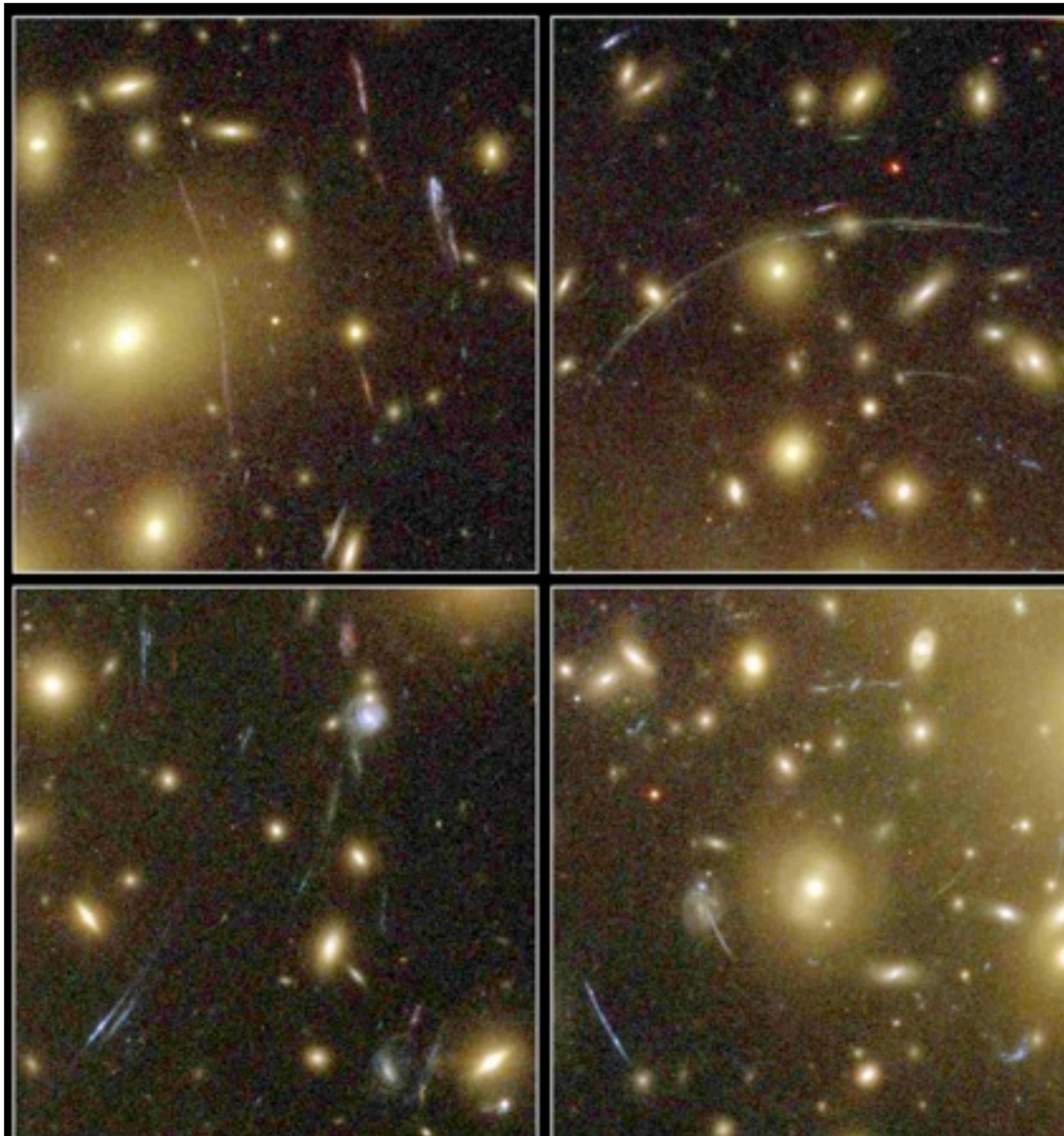
- Stars
- Planets
- Galaxies
- **Galaxy clusters**
- Large-scale structures



Applications of lensing

Lensing induced by:

- Stars
- Planets
- Galaxies
- **Galaxy clusters**
- Large-scale structures

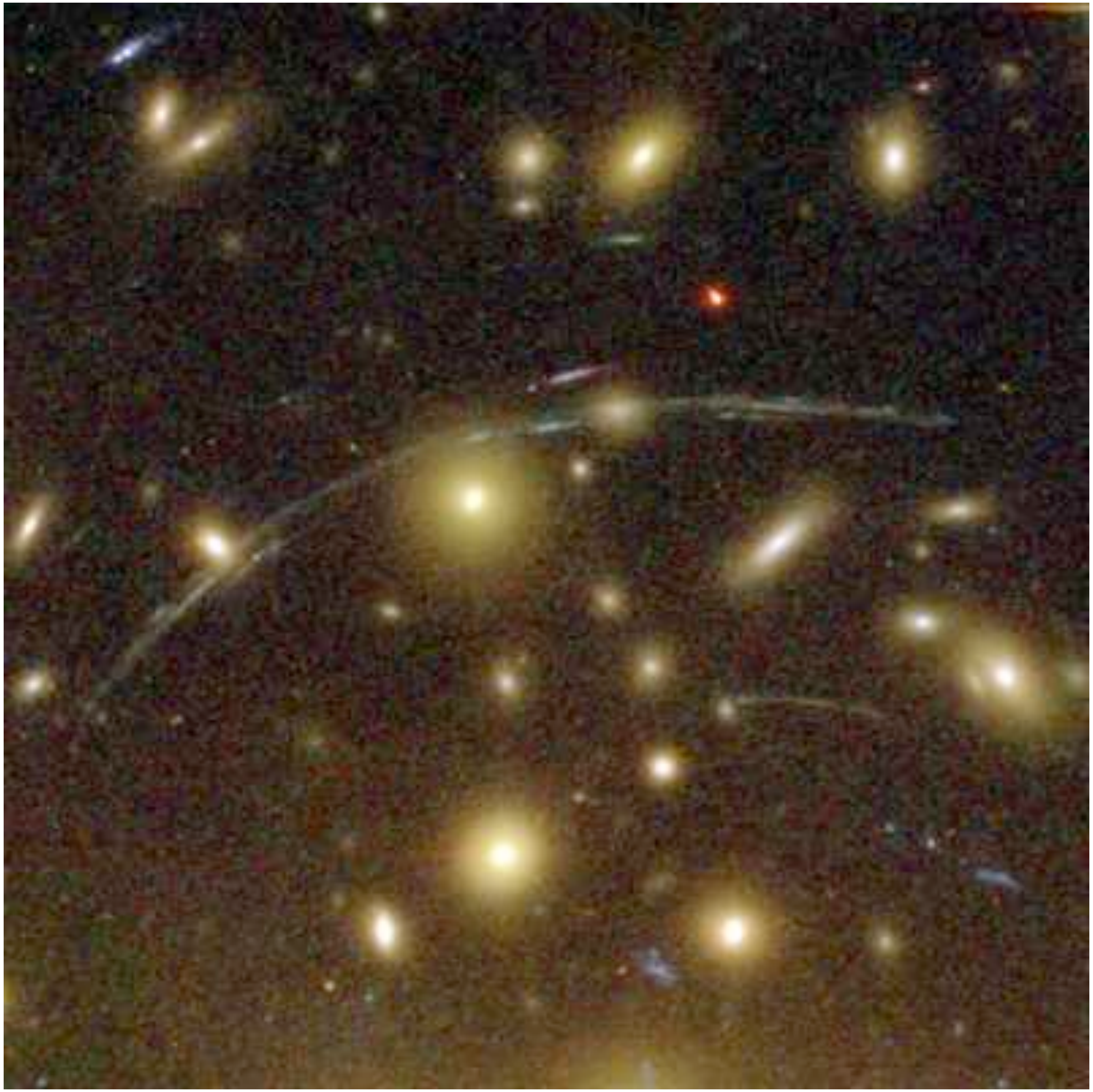


Galaxy Cluster Abell 1689
HST Advanced Camera for Surveys

Applications of lensing

Lensing induced by:

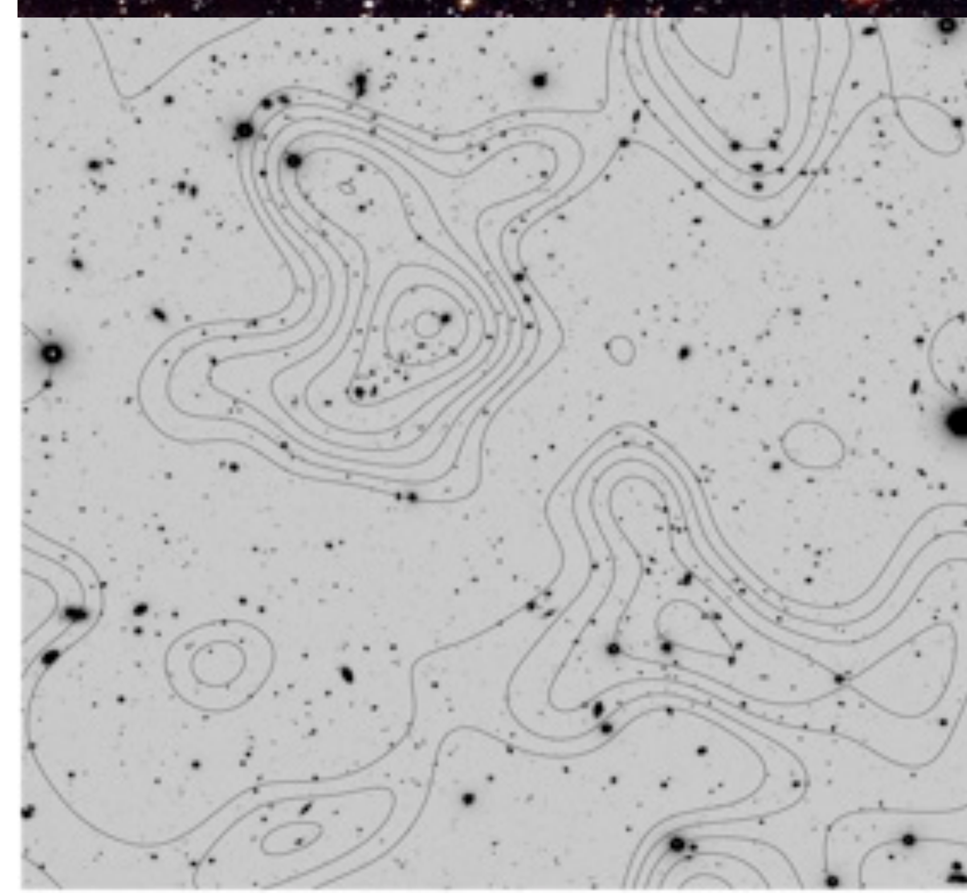
- Stars
- Planets
- Galaxies
- **Galaxy clusters**
- Large-scale structures



Results from lensing

Lensing can be induced by:

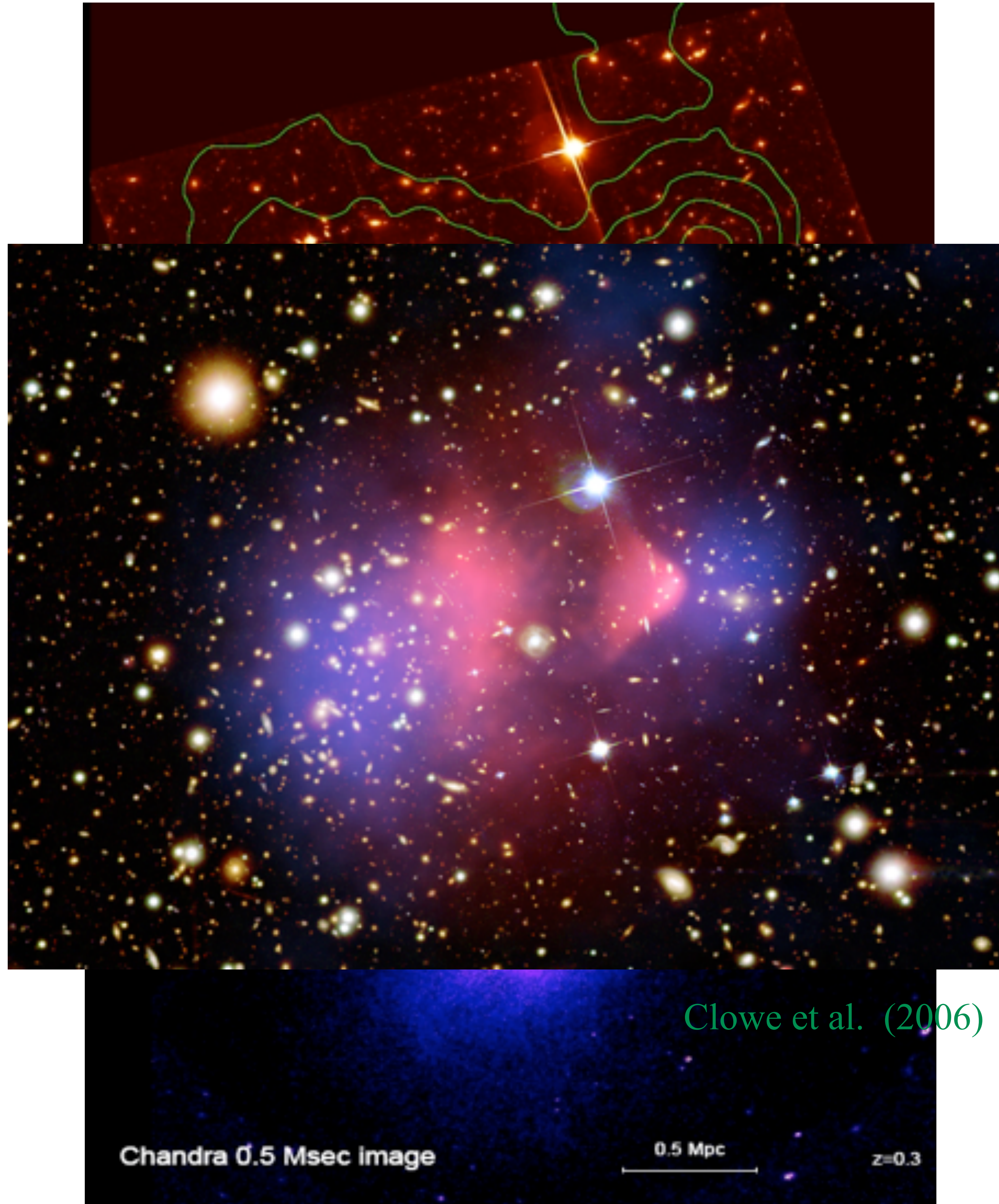
- Stars
- Planets
- Galaxies
- Galaxy clusters
- Large-scale structures



Applications of lensing

Lensing induced by:

- Stars
- Planets
- Galaxies
- **Galaxy clusters**
- Large-scale structures



Clowe et al. (2006)

Applications of lensing

Lensing induced by:

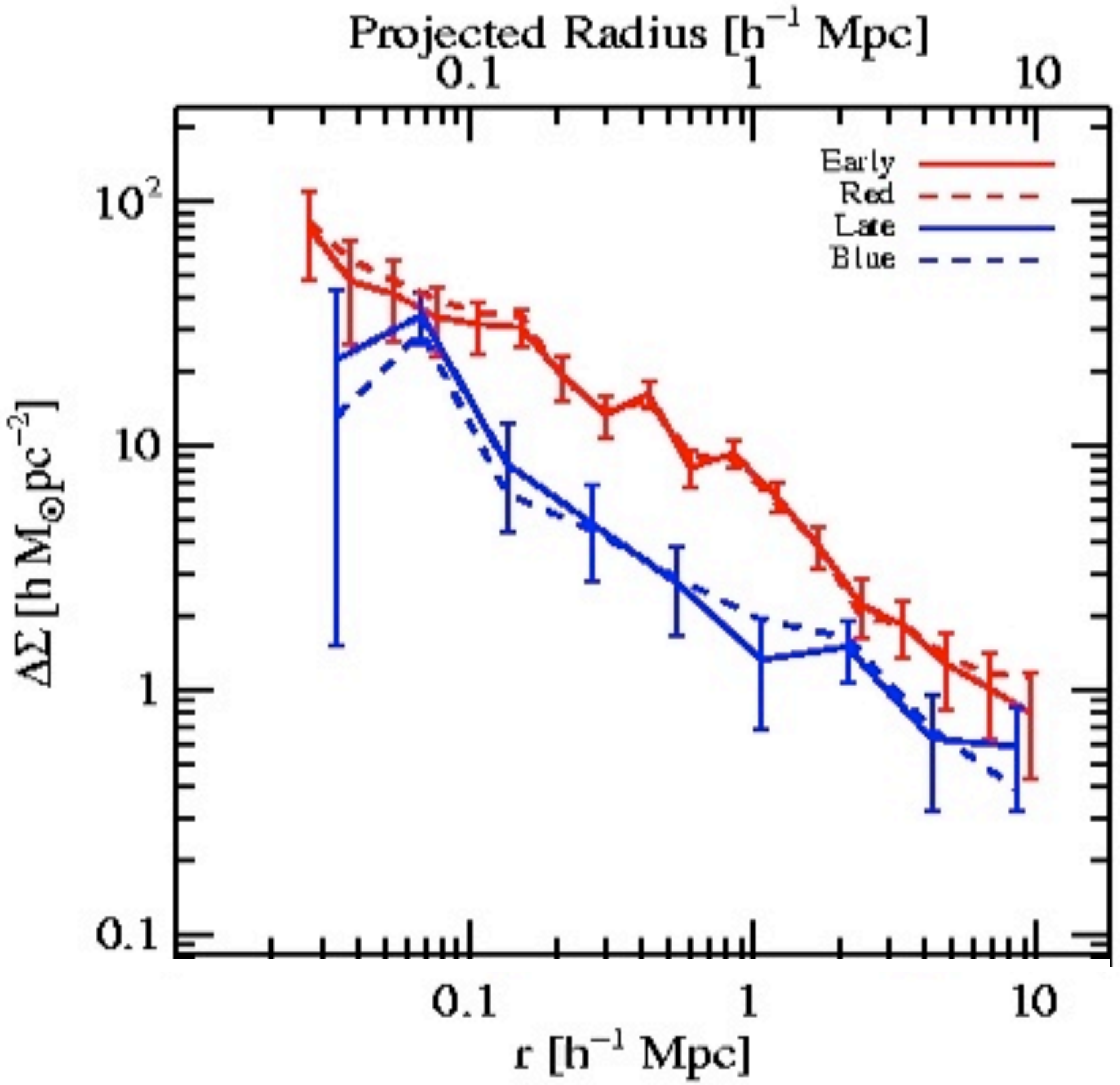
• Stars

• Planets

• **Galaxies**

• Galaxy clusters

• Large-scale structures



Sheldon et al. (2004)
see also Mandelbaum et al. (2004+)

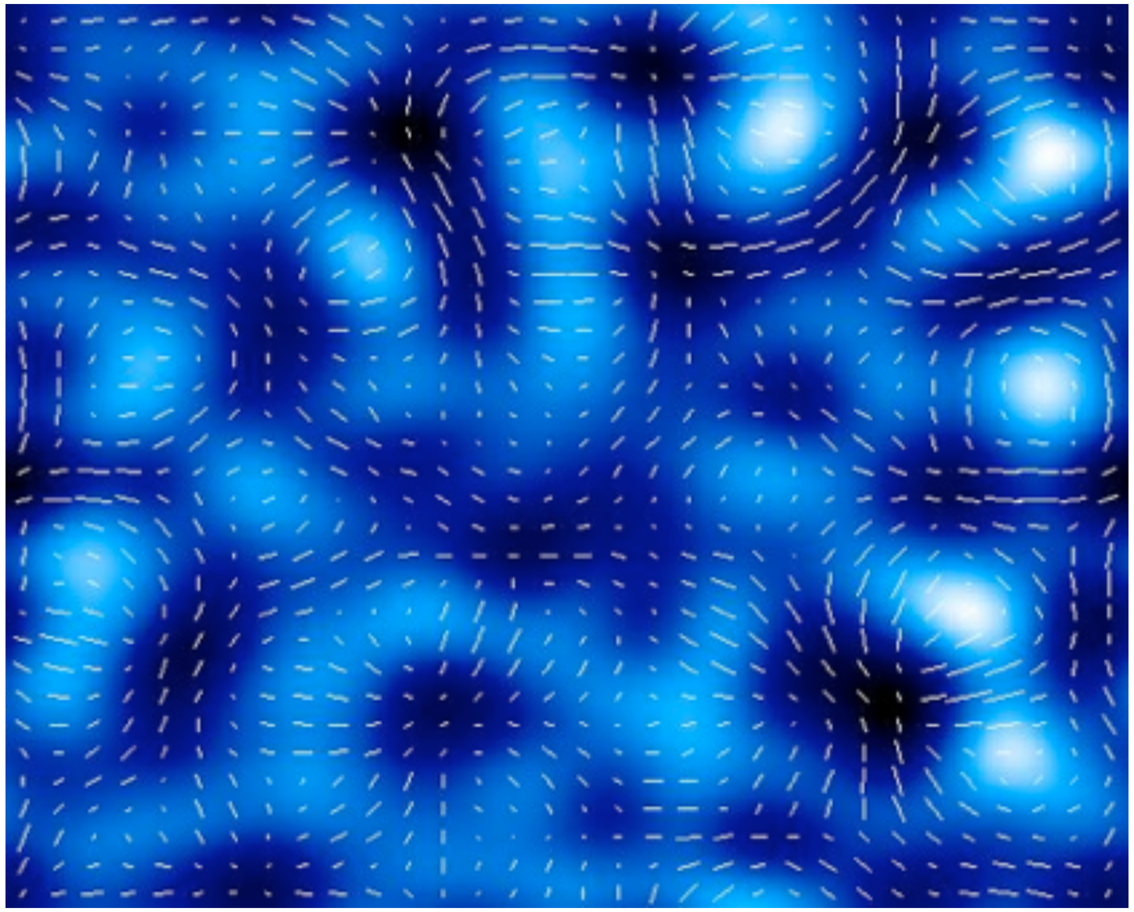
Applications of lensing

Lensing induced by:

- Stars
- Planets
- Galaxies
- Galaxy clusters
- **Large-scale structures**

$$\langle \delta^2 \rangle(\theta)$$

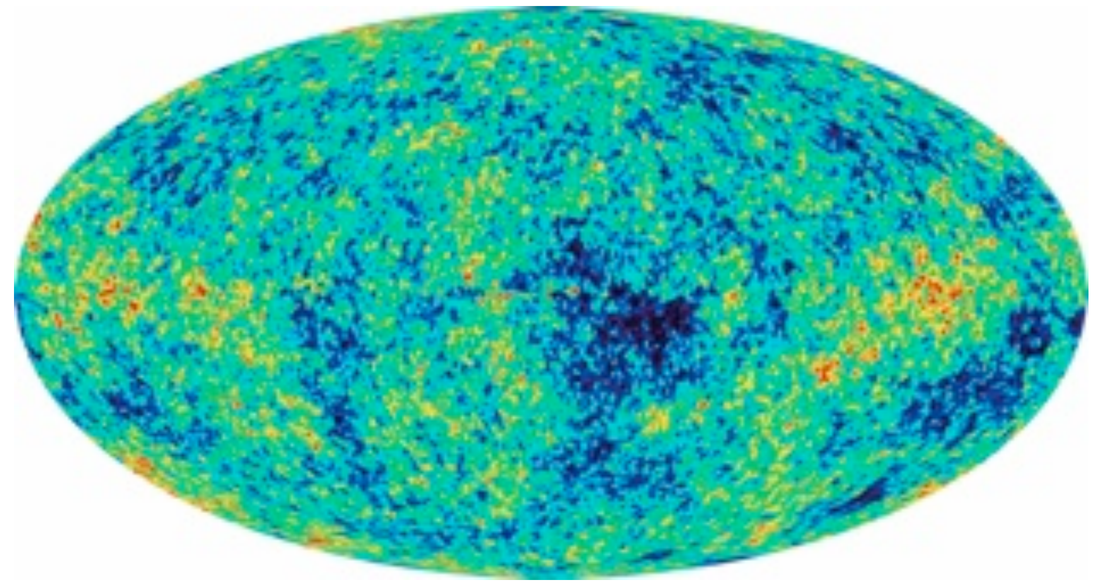
$$\langle |\gamma|^2 \rangle(\theta)$$

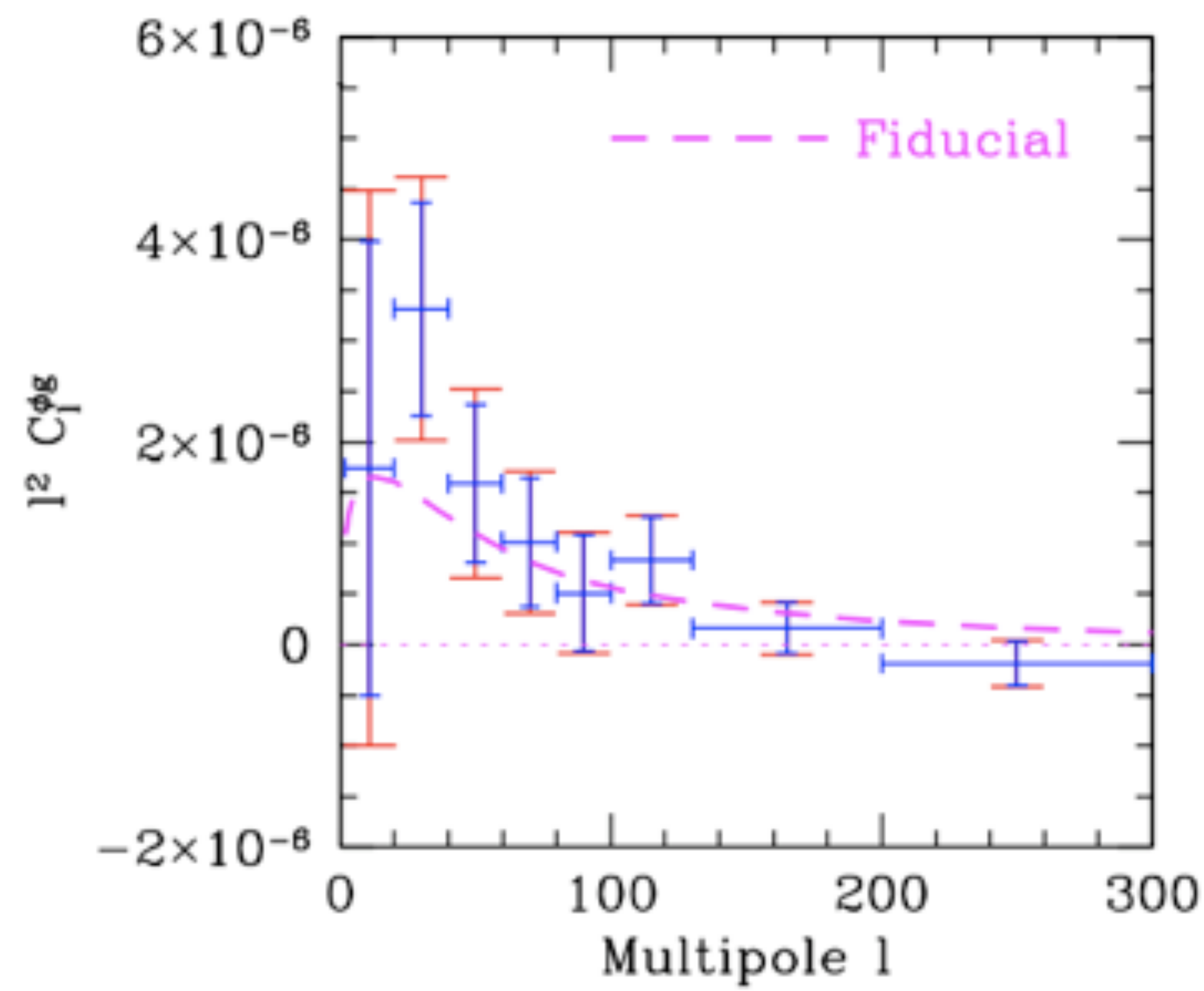


Applications of lensing

Lensing induced by:

- Stars
- Planets
- Galaxies
- Galaxy clusters
- **Large-scale structures**





Lensing of the CMB

Smith, Zahn & Doré (2007)