LSST sensor effect in constraining the cosmological parameters

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We are studying about LSST sensors.
LSST is a new telescope being developed,
and one of the goal of the project is to constrain the cosmological parameters strongly.
Recent studies about cosmology suggests existence of dark energy.
There are many unknown properties in dark energy.
The project is going to determine by precise observation.

Cosmology : What is Cosmology?

Cosmology is study of the Universe. Age, energy components, density and variation, accelerate or decelerate expansion, development of structure and so on. –

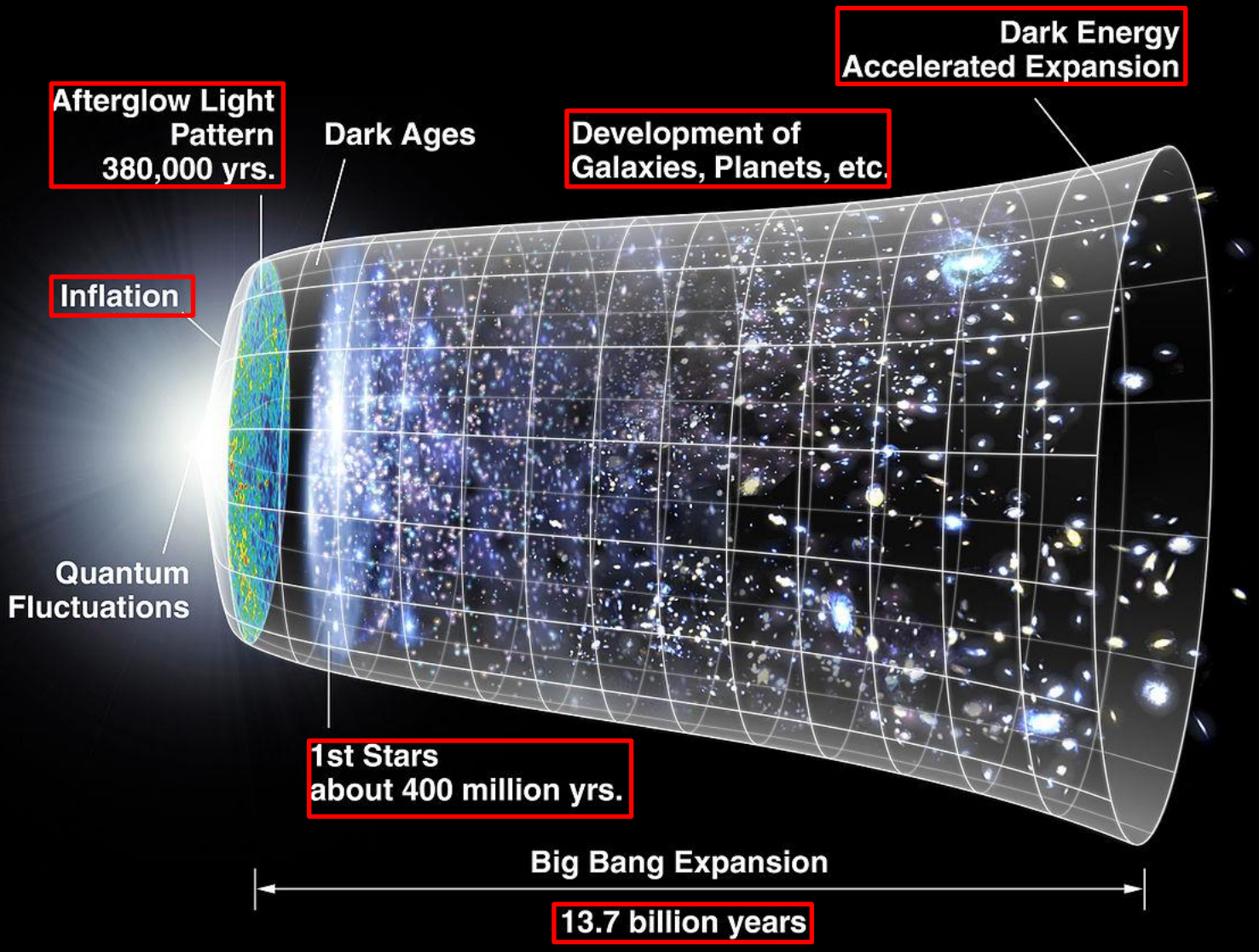


Illustration NASA/WMAP Science team

Cosmology : Cosmological parameters

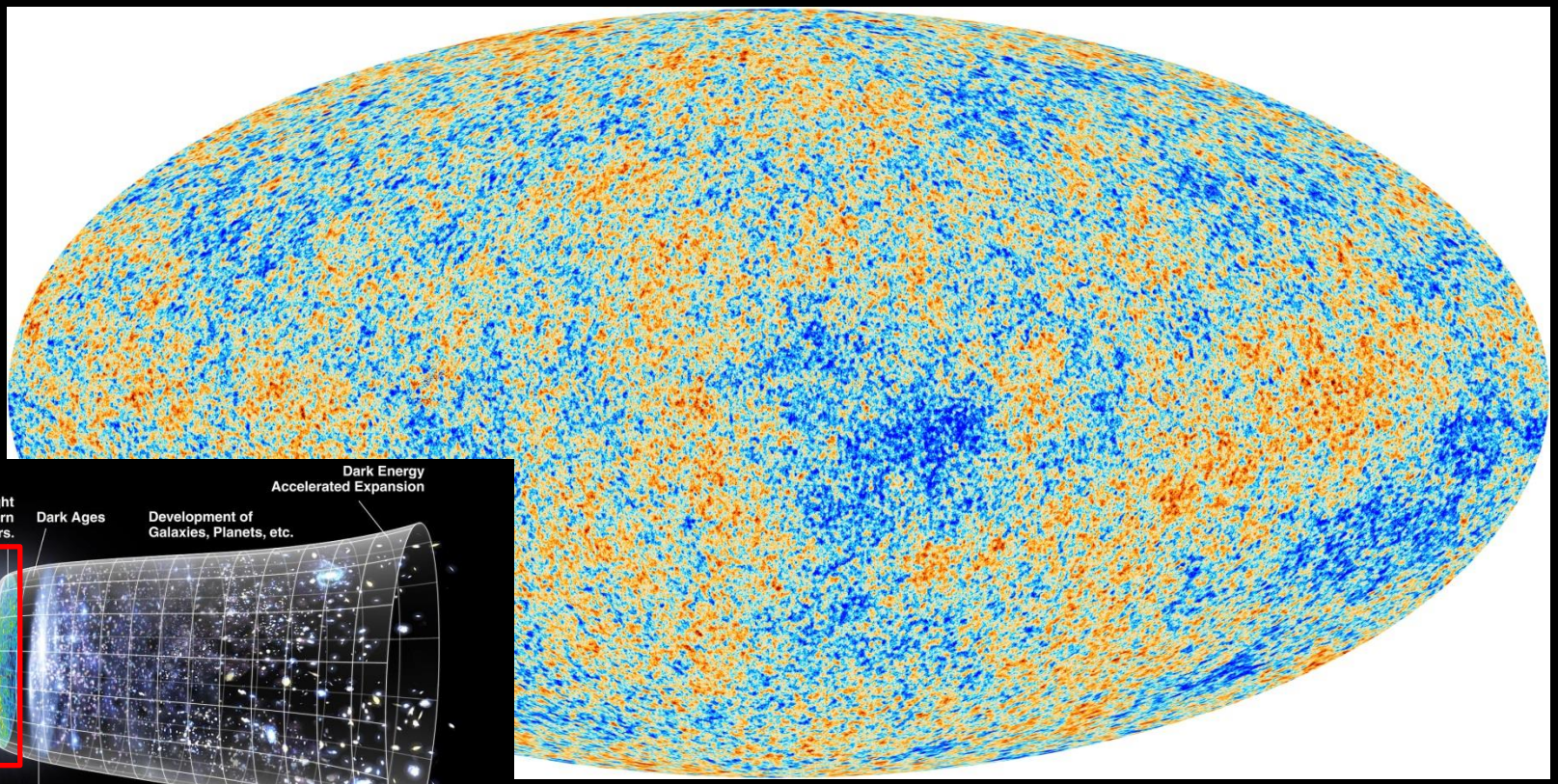
The behaviour of the Universe is parameterized by the cosmological parameters, because the parameters determined the initial condition of the universe.
The main parameters are

Ω_{tot}	Density parameter of total energy
w	Equation of state of dark energy
Ω_{Λ}	Density parameter of dark energy
Ω_{b}	Density parameter of baryon
Ω_{m}	Density parameter of matter
σ_8	Fluctuation amplitude of matter
h	Hubble parameter(expansion rate of the universe), and so on……

The parameters are constrained by measuring statistics of the Universe.

Cosmology : Constraining methods

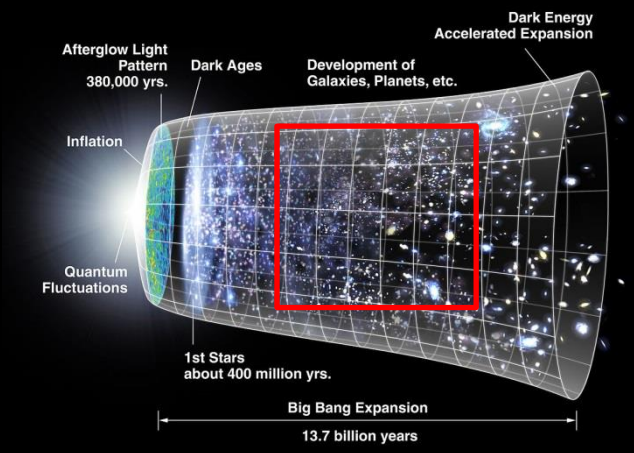
One of the method is measuring The Cosmic Microwave Background(CMB).
CMB is the thermal radiation with temperature variation
at decoupling time in the early Universe.
CMB has information of variation of mass and photons
which are determined by the initial condition.
So we can constrain the parameters from the statistics of CMB.

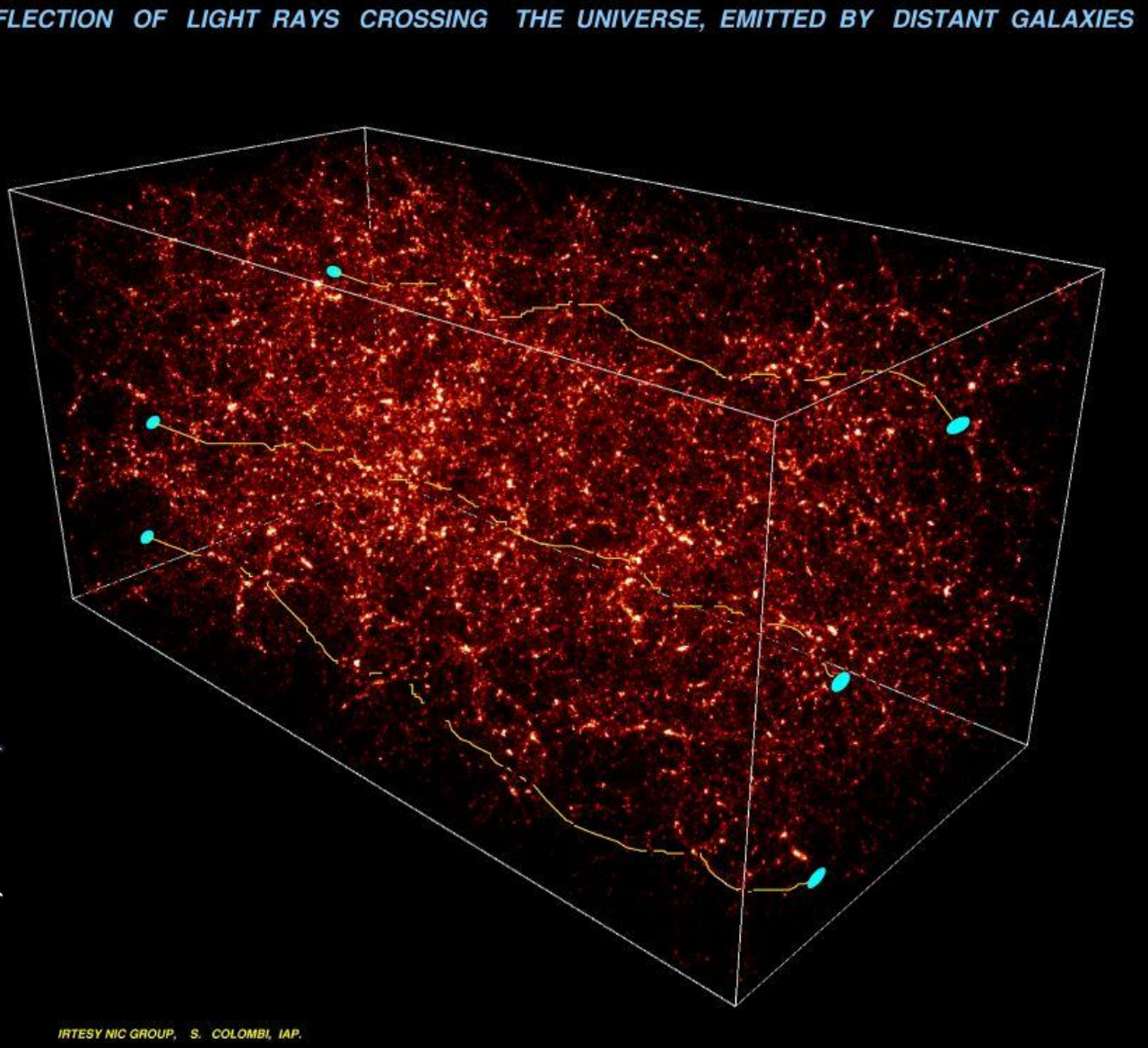


www.cosmos.esa.int/web/planck

Cosmology : Constraining methods

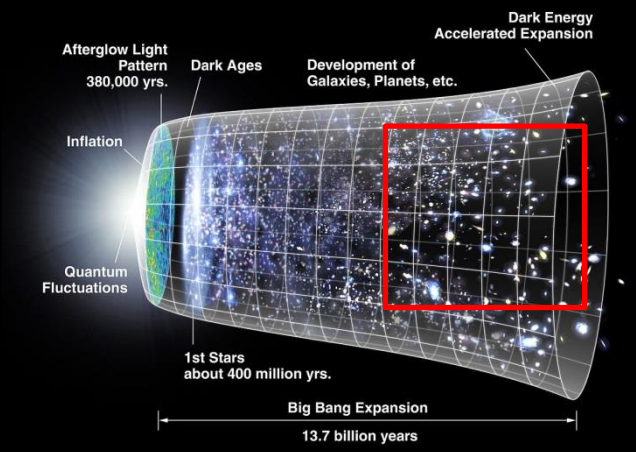
Other one is measuring statistics of The Large Scale Structure(LSS).
LSS is a matter structure larger than galaxy clusters,
the mass distribution of the LSS has developed from the initial condition.
So we can constrain the parameters from the statistics of LSS.

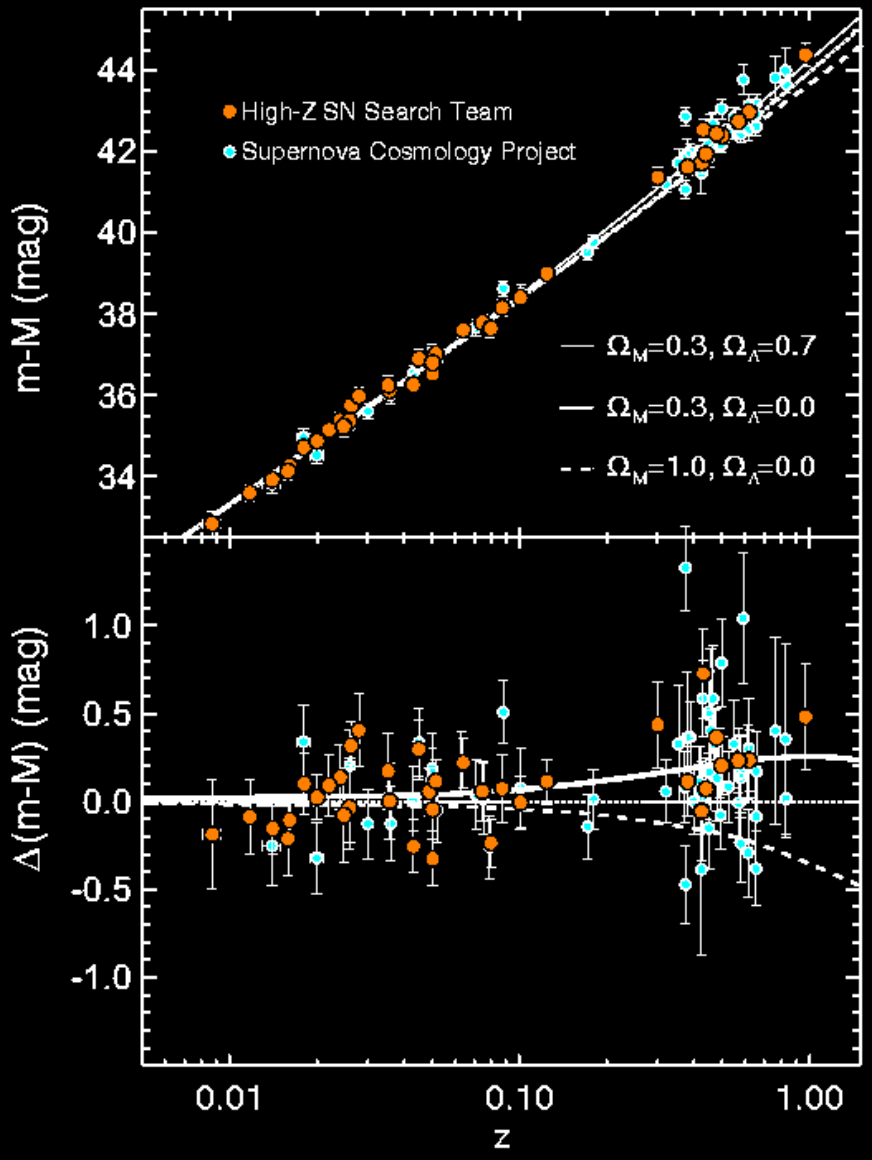




Cosmology : Constraining methods

Other one is measuring apparent magnitude and distance of Type 1a Supernova.
Type 1a Supernova has known absolute magnitude, so we can measure expansion of the universe between the Supernova and us from the absolute magnitude and apparent magnitude.





Cosmology : Constrains

The results of many observations, the cosmological parameters were constrained.
One of the recent results is from PLANCK CMB observation.

	Planck	
Parameter	Best fit	68% limits
Ω_Λ	0.6825	0.686 ± 0.020
Ω_m	0.3175	0.314 ± 0.020
σ_8	0.8344	0.834 ± 0.027
z_{re}	11.35	$11.4^{+4.0}_{-2.8}$
H_0	67.11	67.4 ± 1.4

Planck Collaborators 2014

But the equation of state of dark energy is not constrained strongly from CMB,
Because CMB is information of the early universe,
and, in that time, dark energy density is very smaller than matter.
So combination with other methods is used
for constraining the equation of state.

Cosmology : What is dark energy?

The results says 70% of energy in the universe is dark energy,
it comes from having found the accelerate expansion of the universe.
But the usual energies such as matter and photons decelerate expansion of the Universe.
So some energies which accelerate the Universe are needed.
But it is predicted such energies have negative pressure.

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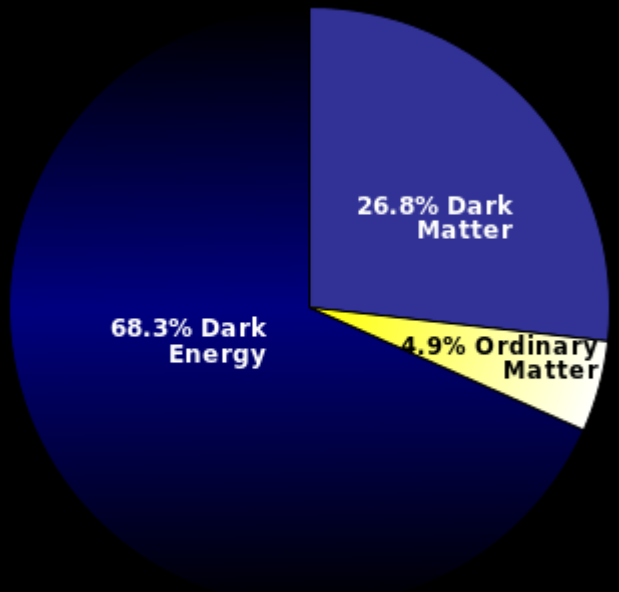
One of the candidate is called ”dark energy”.

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2}(\rho + 3p)$$



Weak Lensing : Weak gravitational lensing

One of method to constrain the cosmological parameters is measuring the statistics of the Large scale structure by weak lensing shear analysis. LSST project uses this method. Weak gravitational lensing distorts images due to mass fluctuations. So the distortion has information of mass and we can obtain mass information from the distortions.

M. Bartelmann, P. Schneider / Physics Reports 340 (2001) 291–472

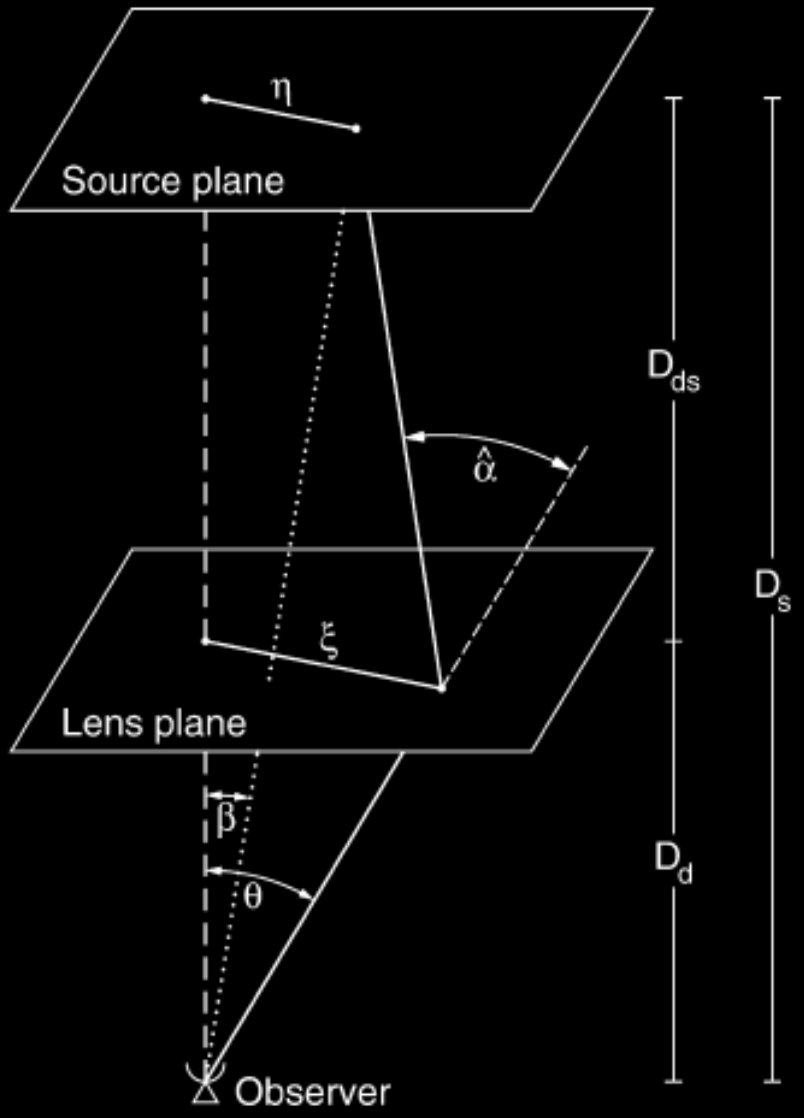
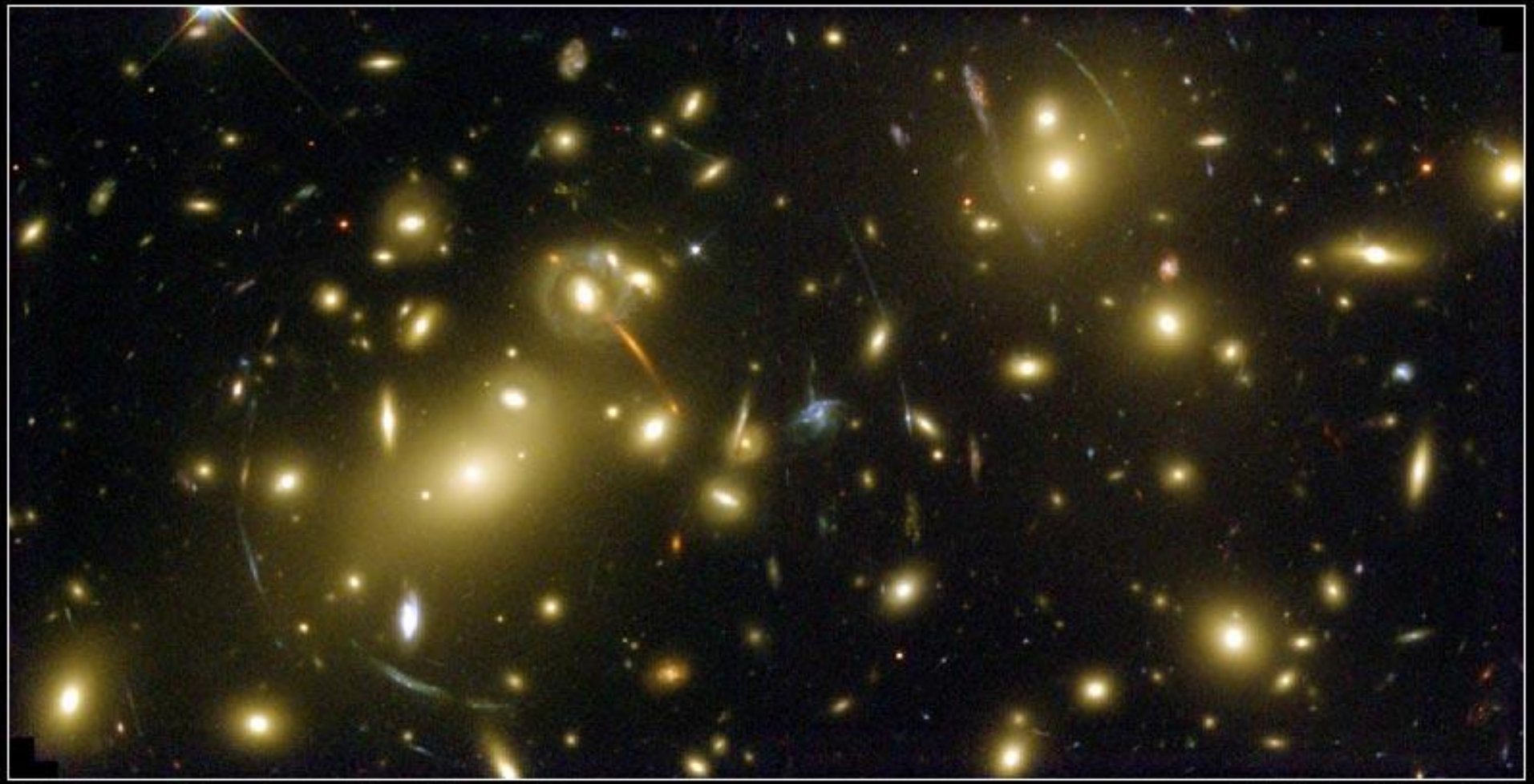


Fig. 11. Sketch of a typical gravitational lens system.

Weak Lensing : Weak lensing by galaxy clusters

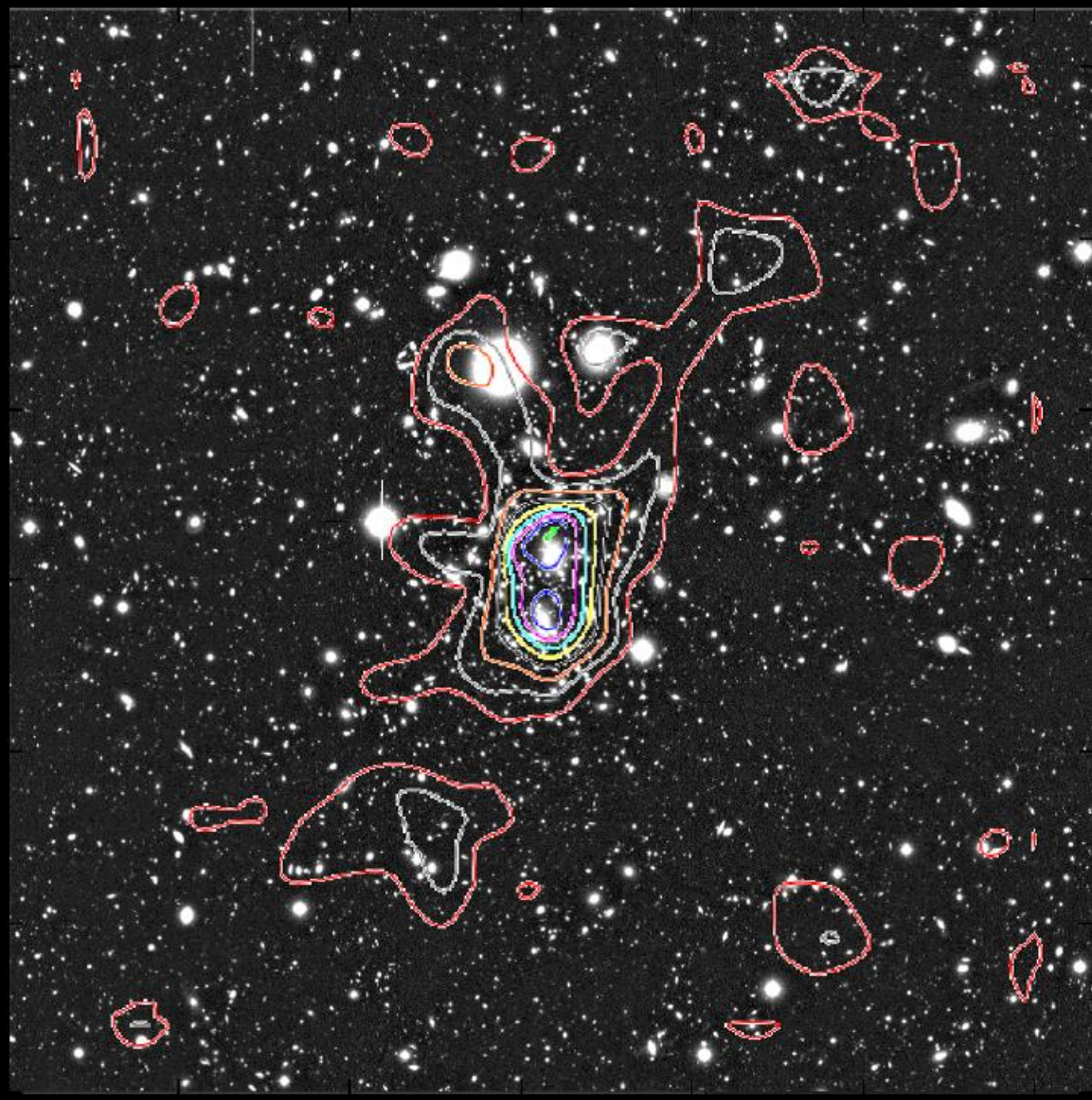
Abell 2218 galaxy cluster distorts background images. –



Weak Lensing : Weak lensing by galaxy clusters

Reconstructed mass distribution of Abell 1689 by weak lensing shear analysis.

We can find mass peaks at center of the galaxy clusters.



$\Delta\kappa = 0.1$

S/N is 9.034

Okura and Futamase 2012

Weak Lensing : The cosmic shear

The large scale structure also makes lensing effect.

This means we can obtain the statistic of the large scale structure from the weak leaning shear of the large scale structure, it is called as ”the cosmic shear”.

There are many projects to constrain the cosmological parameters by measuring the cosmic shear

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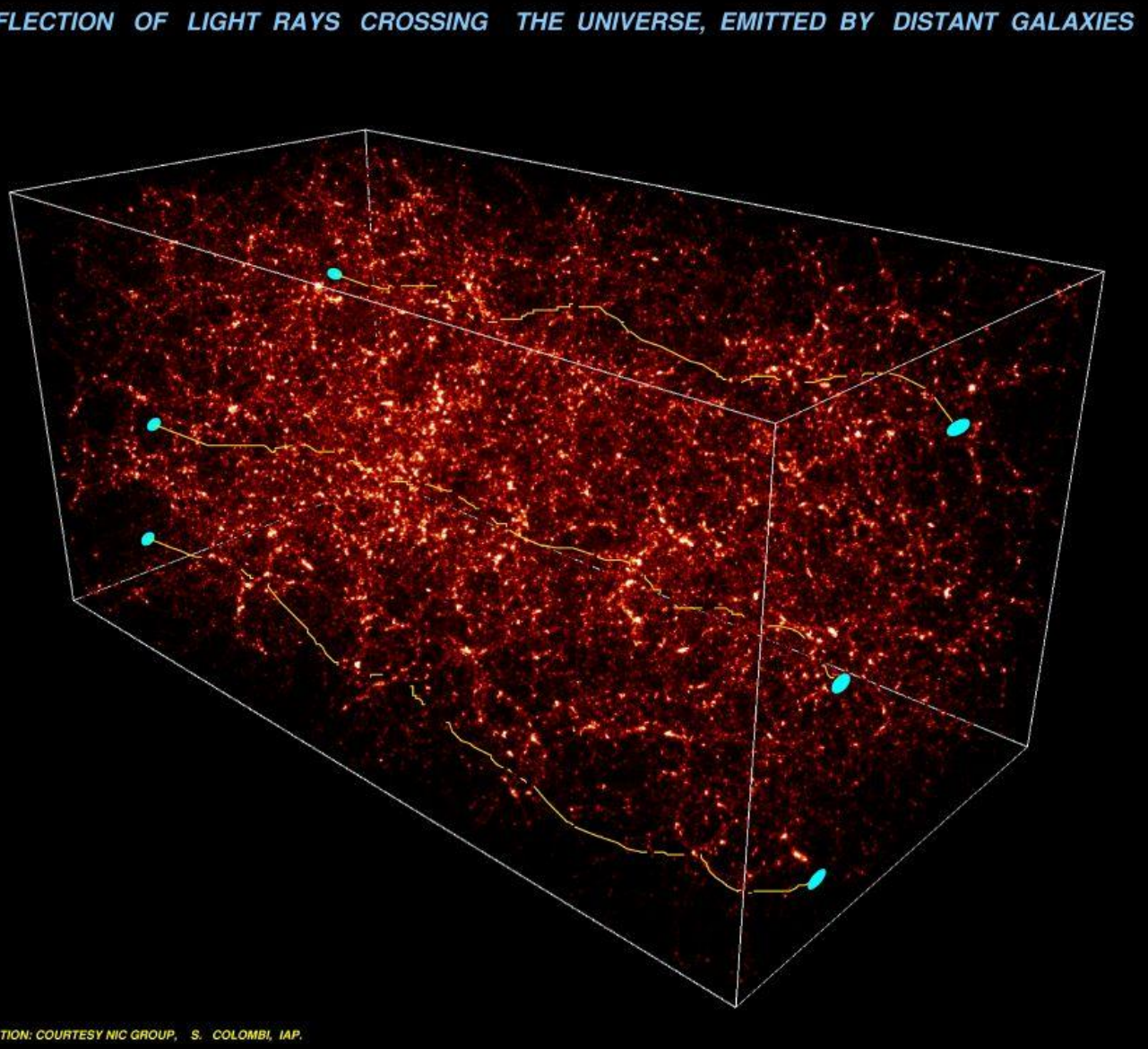


Weak Lensing : Observation survey projects

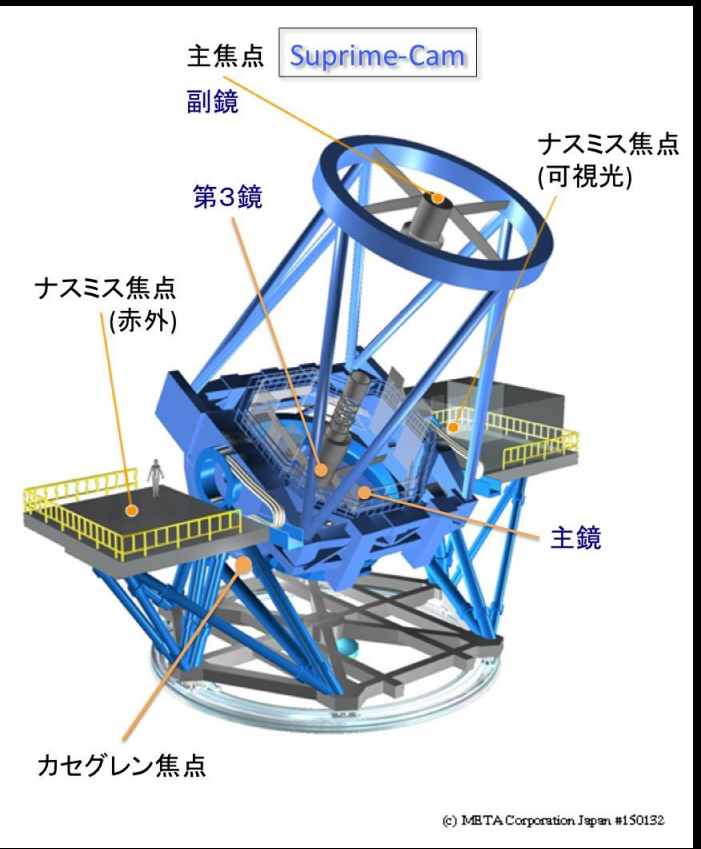
- Hyper suprime-cam(HSC)-

HSC is a new camera made in NAOJ for Subaru telescope. -

This camera has wide field of view about 1.8deg^2 with more than 100 CCDs.

HSC can observe about 9 full moons region at one time. -

For constraining the cosmological parameters, HSC project plans to observe 1400deg^2 and 100million of objects, and it already started.

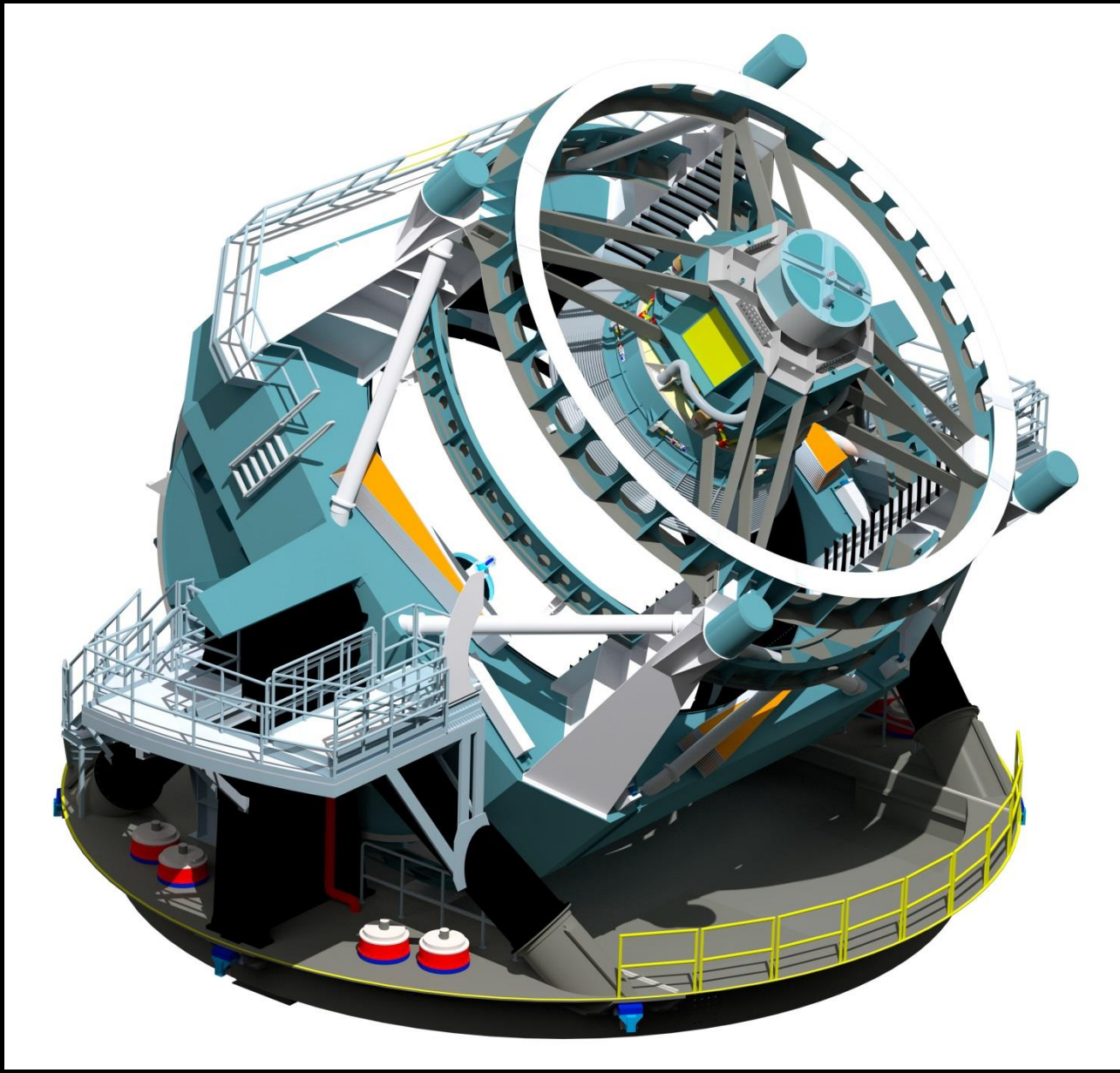


www.naoj.org/Projects/HSC

Weak Lensing : Observation survey projects

-Large Synoptic Survey Telescope(LSST)-

LSST is a new telescope being developed now, and will have about 10deg^2 field of view. and there is a plan to observe 20000deg^2 and billions of objects for constraining cosmological parameters strongly.



www.lsst.org/lsst

Weak Lensing : Required Precisions for lensing analysis

The cosmic shear is very weak, so we need to analyze the cosmic shear with high precision.
The observation project with HSC plans to reduce the statistic error under 1% in constraining the cosmological parameters,
so this project requires weak lensing analysis method to reduce systematic error under 1%.
The observation plan with LSST requires under 0.1%.

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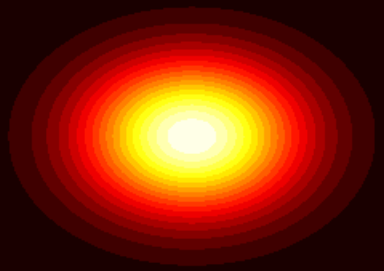
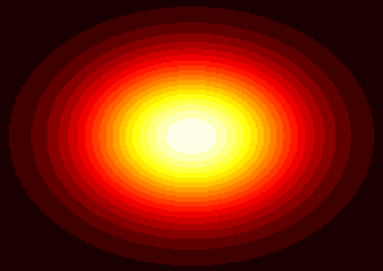
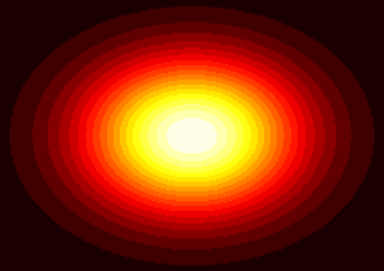
So we need to consider any small effects which makes systematic error.



HSC requires to distinguish them

Ellipticity = 0.310



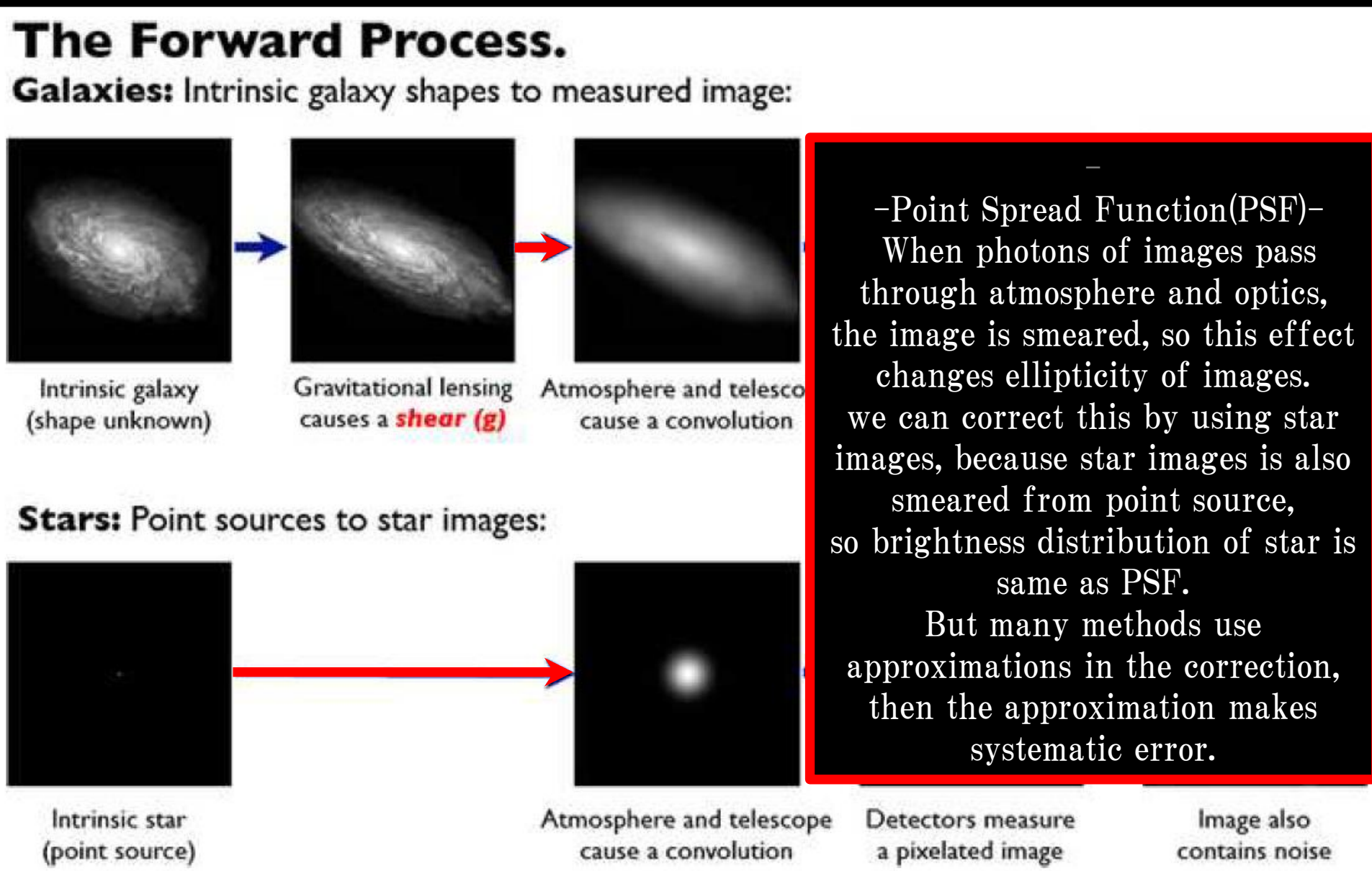


LSST requires to distinguish them

Ellipticity = 0.301

Ellipticity = 0.300

Weak Lensing : systematic errors in weak lensing analysis

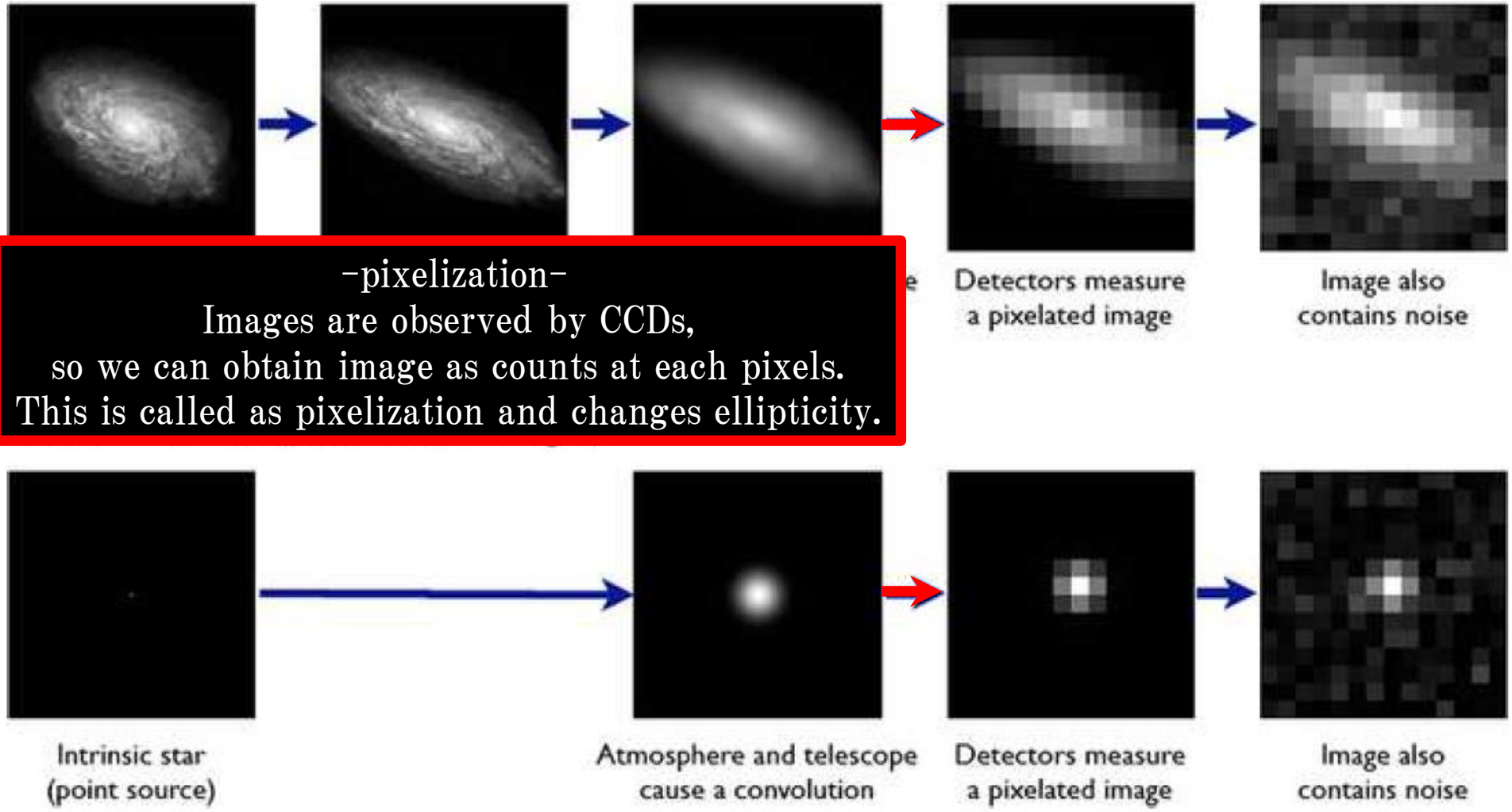


-Point Spread Function(PSF)-
When photons of images pass through atmosphere and optics, the image is smeared, so this effect changes ellipticity of images.
we can correct this by using star images, because star images is also smeared from point source, so brightness distribution of star is same as PSF.
But many methods use approximations in the correction, then the approximation makes systematic error.

Weak Lensing : systematic errors in weak lensing analysis

The Forward Process.

Galaxies: Intrinsic galaxy shapes to measured image:



-pixelization-
Images are observed by CCDs,
so we can obtain image as counts at each pixels.
This is called as pixelization and changes ellipticity.

Weak Lensing : systematic errors in weak lensing analysis

The Forward Process.

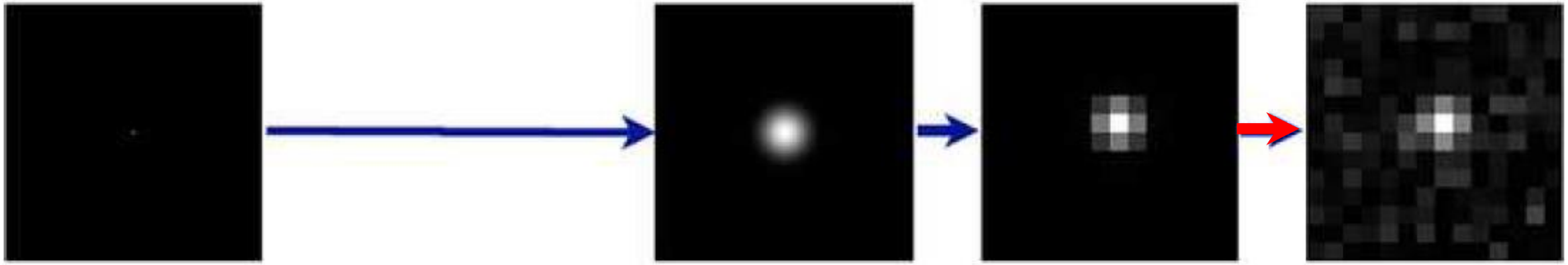
Galaxies: Intrinsic galaxy shapes to measured image:

Intrinsic galaxy (shape unknown)

Image also contains noise

-pixel noise-
Pixel noise is Poisson noise of sky count.
It disturbs us to measure image correctly.

Stars: Point sources to star images:



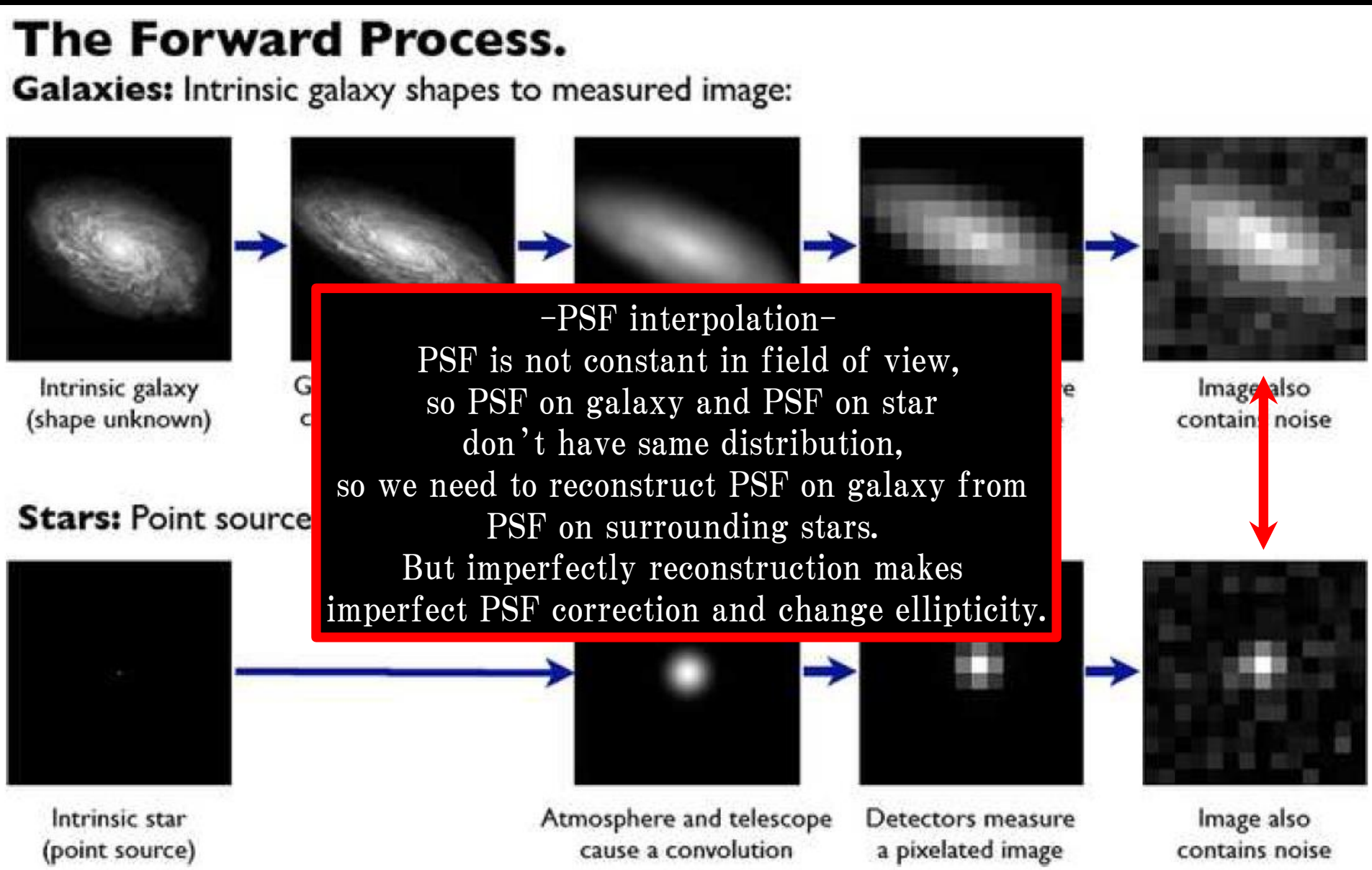
Intrinsic star (point source)

Atmosphere and telescope cause a convolution

Detectors measure a pixelated image

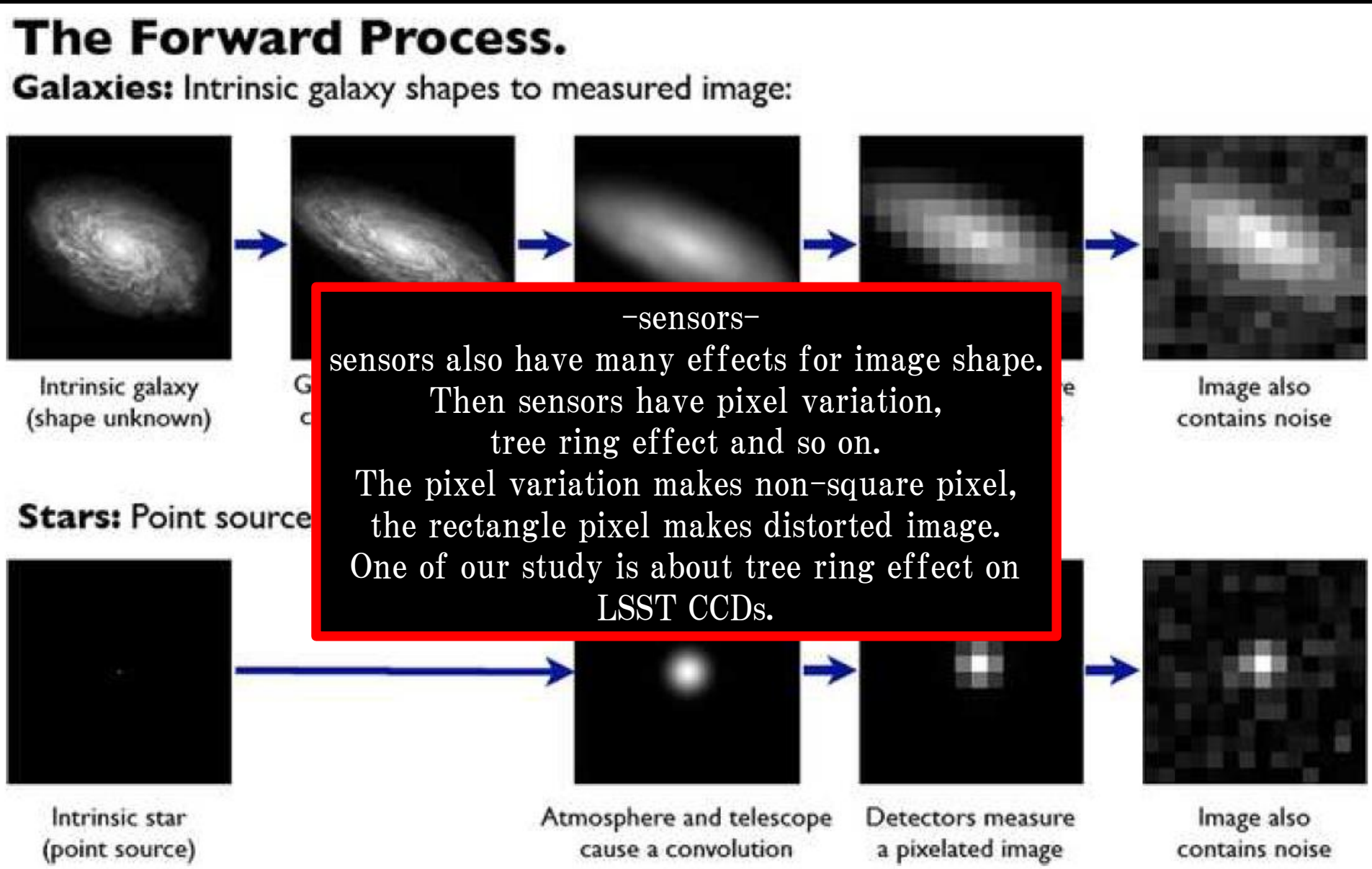
Image also contains noise

Weak Lensing : systematic errors in weak lensing analysis



-PSF interpolation-
PSF is not constant in field of view,
so PSF on galaxy and PSF on star
don't have same distribution,
so we need to reconstruct PSF on galaxy from
PSF on surrounding stars.
But imperfectly reconstruction makes
imperfect PSF correction and change ellipticity.

Weak Lensing : systematic errors in weak lensing analysis

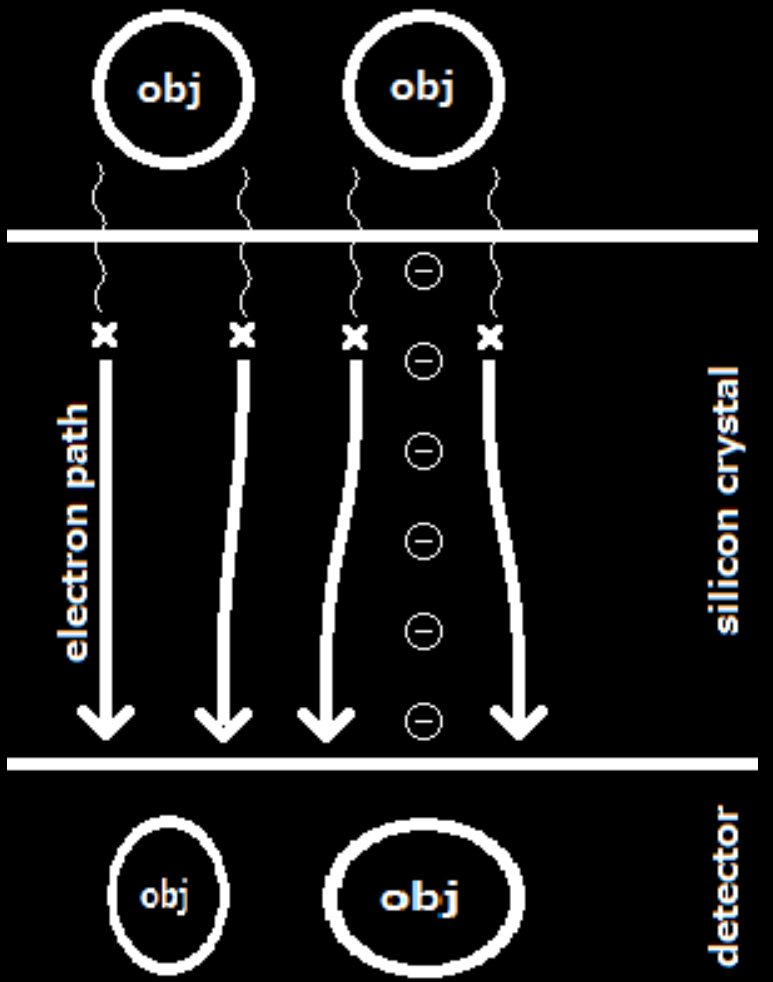


-sensors-
sensors also have many effects for image shape.
Then sensors have pixel variation,
tree ring effect and so on.
The pixel variation makes non-square pixel,
the rectangle pixel makes distorted image.
One of our study is about tree ring effect on
LSST CCDs.

Tree Ring : Tree Ring Effect

CCDs have a silicon crystal layer which changes photon to electron.
The silicon crystal is grown from melted silicon, and impurity variations in the crystal can make cylindrically symmetric patterns like tree ring which makes additional electric field and bends the electron path.
Then it makes dark and bright region in flat image and displaces and distorts image.

Therefore this effect makes error in weak lensing analysis and in constraining the cosmological parameters.

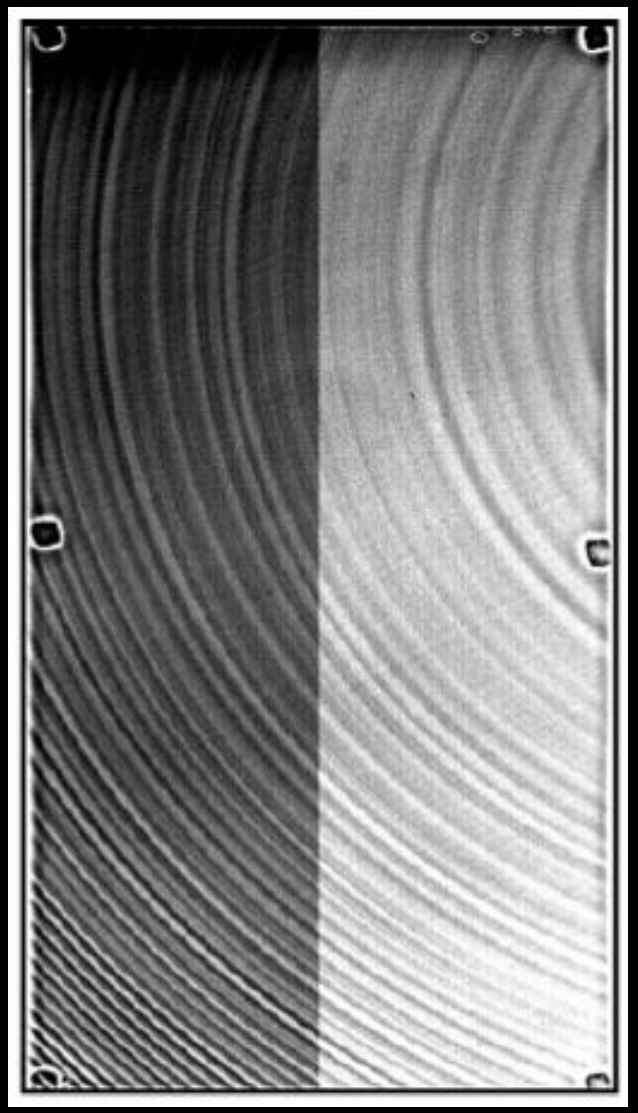


Bending electron path

Tree Ring : Flux Modulation

Dome flat is flat image projected on dome screen,
this is used to check CCD sensitivity.

We can see concentric patterns,
these are from concentric impurity.
The typical scale of the flux modulation is about
0.5% on DES CCD.

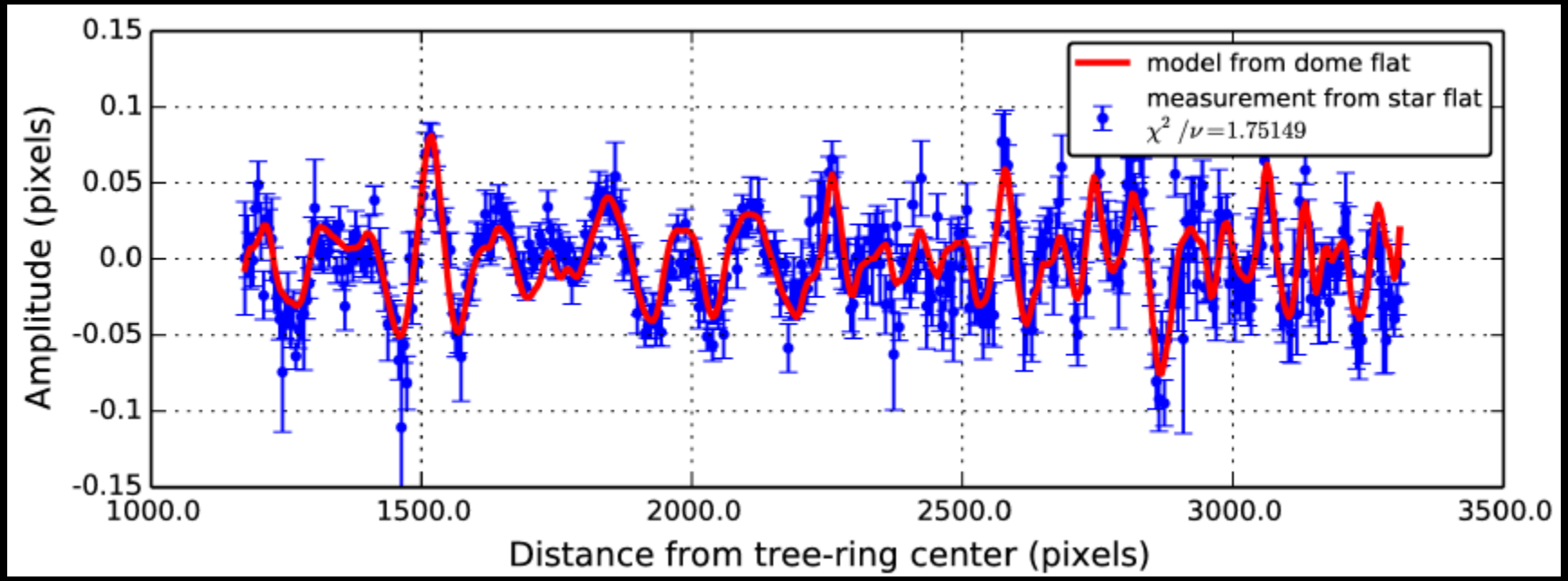


Dome flat image of DES CCD
(Andres Plazas et al., 2014)

Tree Ring : Displacement

Displacement can be measured by astrometry.
– Typical scale of the displacements is 0.1 pixel, so it is hard to be measured,
but it is easy to measure the flux modulation of dome flat.
So Plazas made a formula which estimates the displacement from the flux modulation.–

$$d(r) = -\frac{1}{r}\int_0^r dr' r' f(r')$$



The measured displacement and predicted displacement from flat image
(Andres Plazas et al., 2014)

Tree Ring : Spurious Shear

Tree ring effect makes distortion, so it makes systematic error in weak lensing shear analysis(Spurious shear).
So we need to consider how the tree ring makes error in shear measurement.

We can calculate distortion from displacement easily,
if displacement is concentric.

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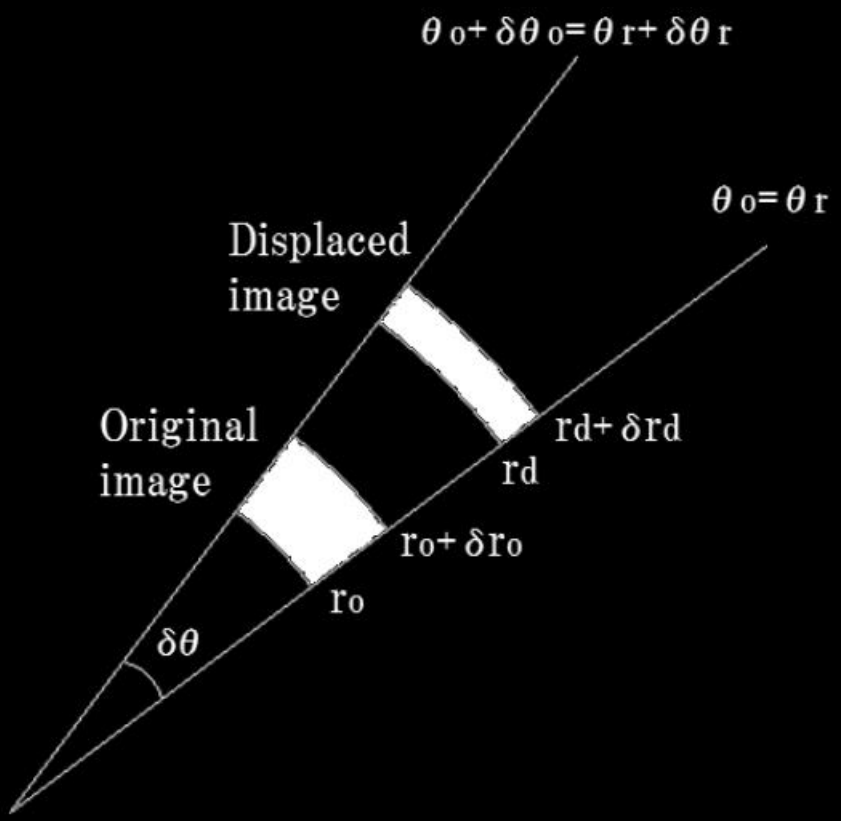
These are described by derivative of displacement and half of flux modulation.
Therefore we can estimated spurious shear by measuring flux modulation of flat image.



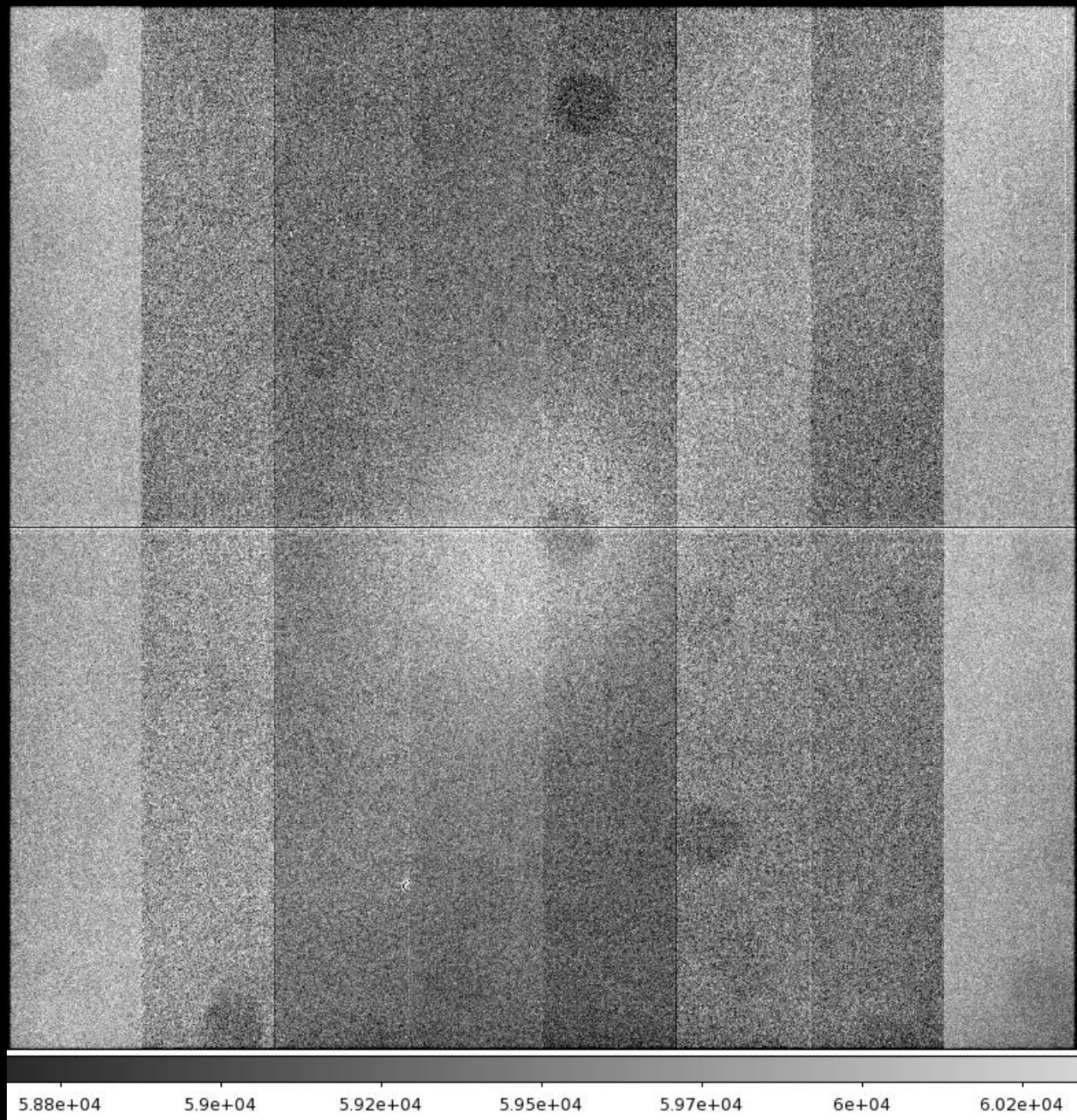
$$\kappa^{TR}(r) \equiv \frac{1}{2}\left(\frac{\partial d(r)}{\partial r} + \frac{d(r)}{r}\right) = -\frac{1}{2}f(r)$$

$$\gamma^{TR}_{rad}(r) \equiv \frac{1}{2}\left(\frac{\partial d(r)}{\partial r} - \frac{d(r)}{r}\right) = -\frac{1}{2}\left(f(r) - 2\frac{d(r)}{r}\right) \approx -\frac{1}{2}f(r)$$

Tree Ring : The Tree Ring on LSST CCD

Flat image of LSST test CCD.
This flat has 0.4% STD
but we can not find any
concentric patterns.

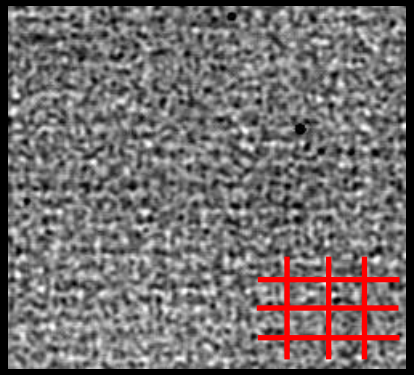
So we need many correction
for precise measurement.



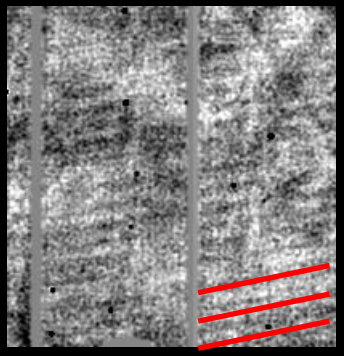
Tree Ring : Masking and Normalization

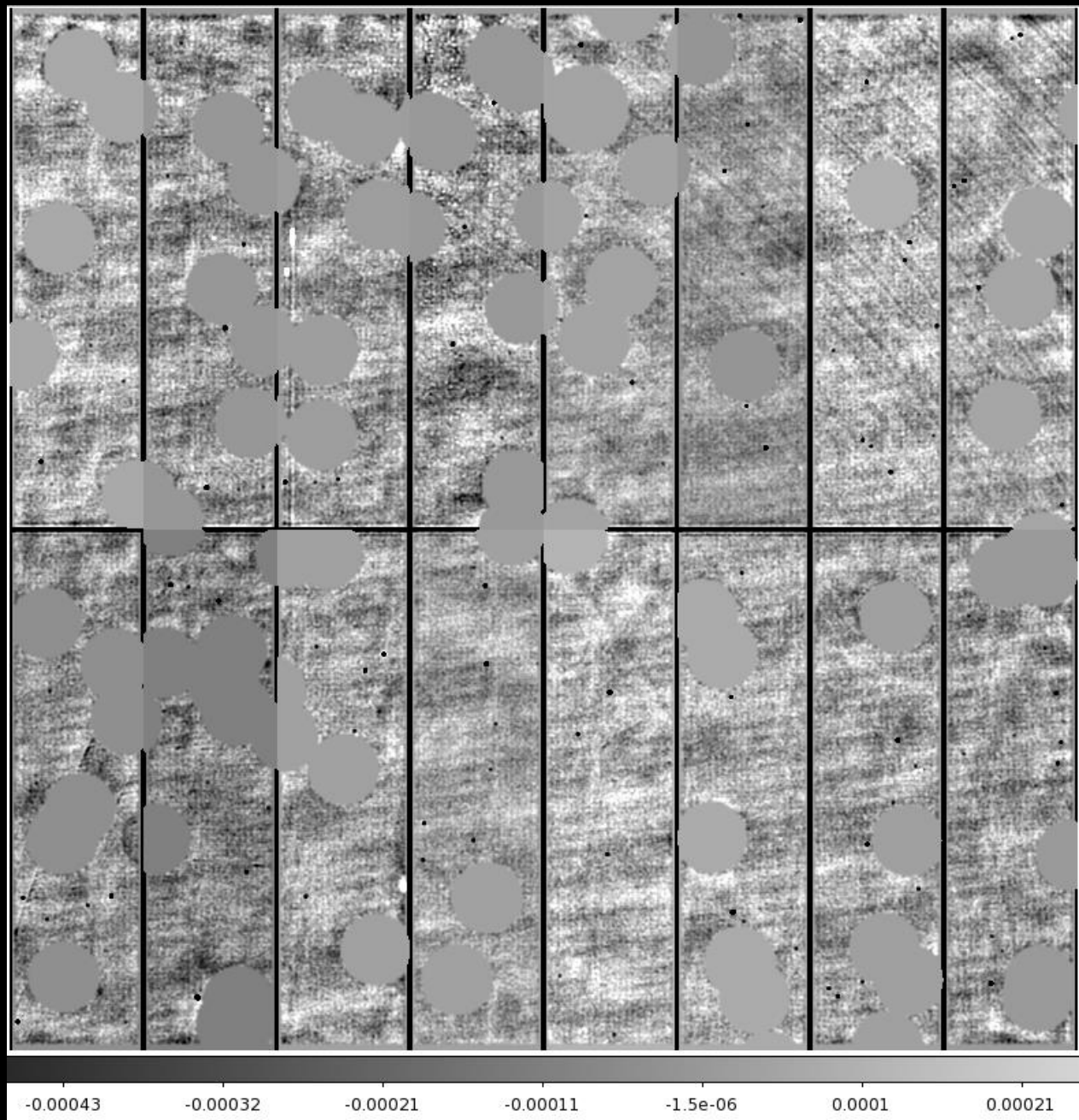
– – We can find tree ring from smoothed image. But there are some other patterns.

Grid pattern
(Pixel size variance)



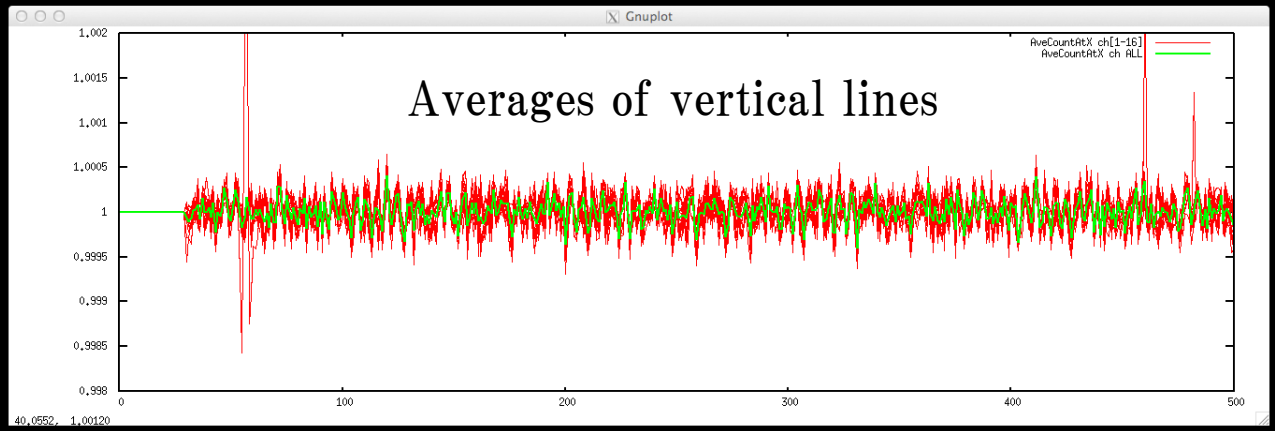
Sloped pattern

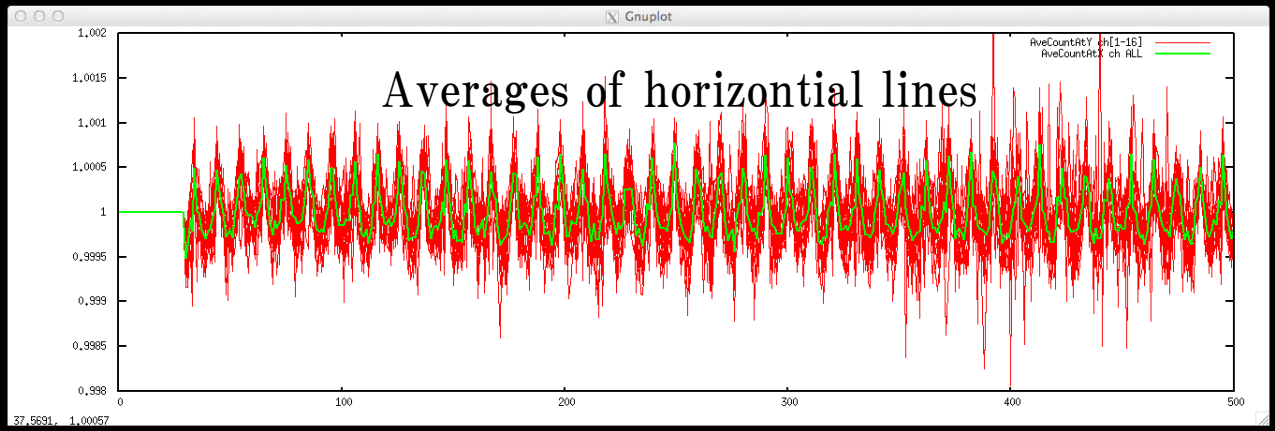


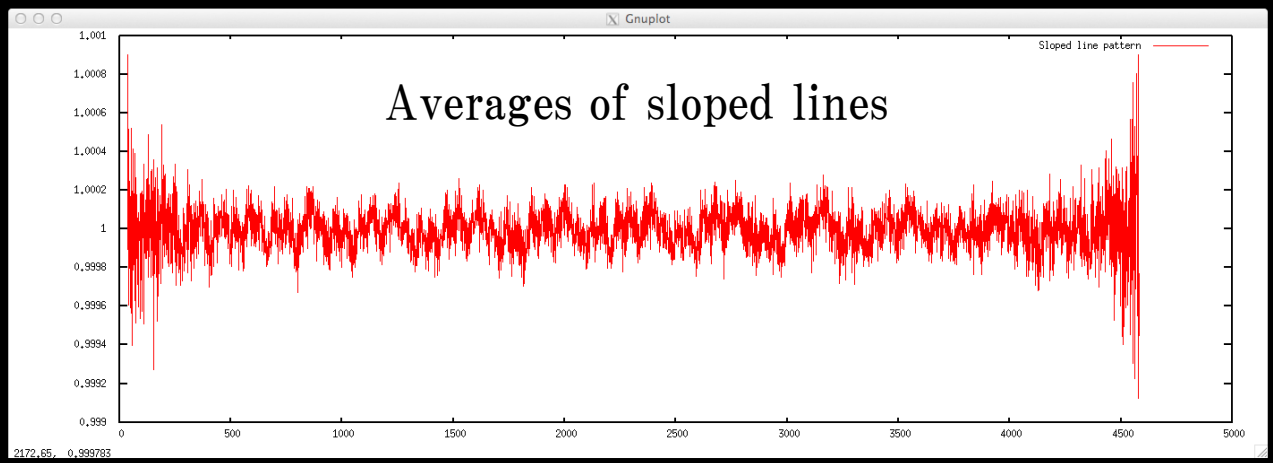


Tree Ring : Correcting other patterns

These patterns are corrected by dividing by average of horizontal, vertical and sloped lines.
But there was large scale modulation,
and it was eliminated in Fourier space.

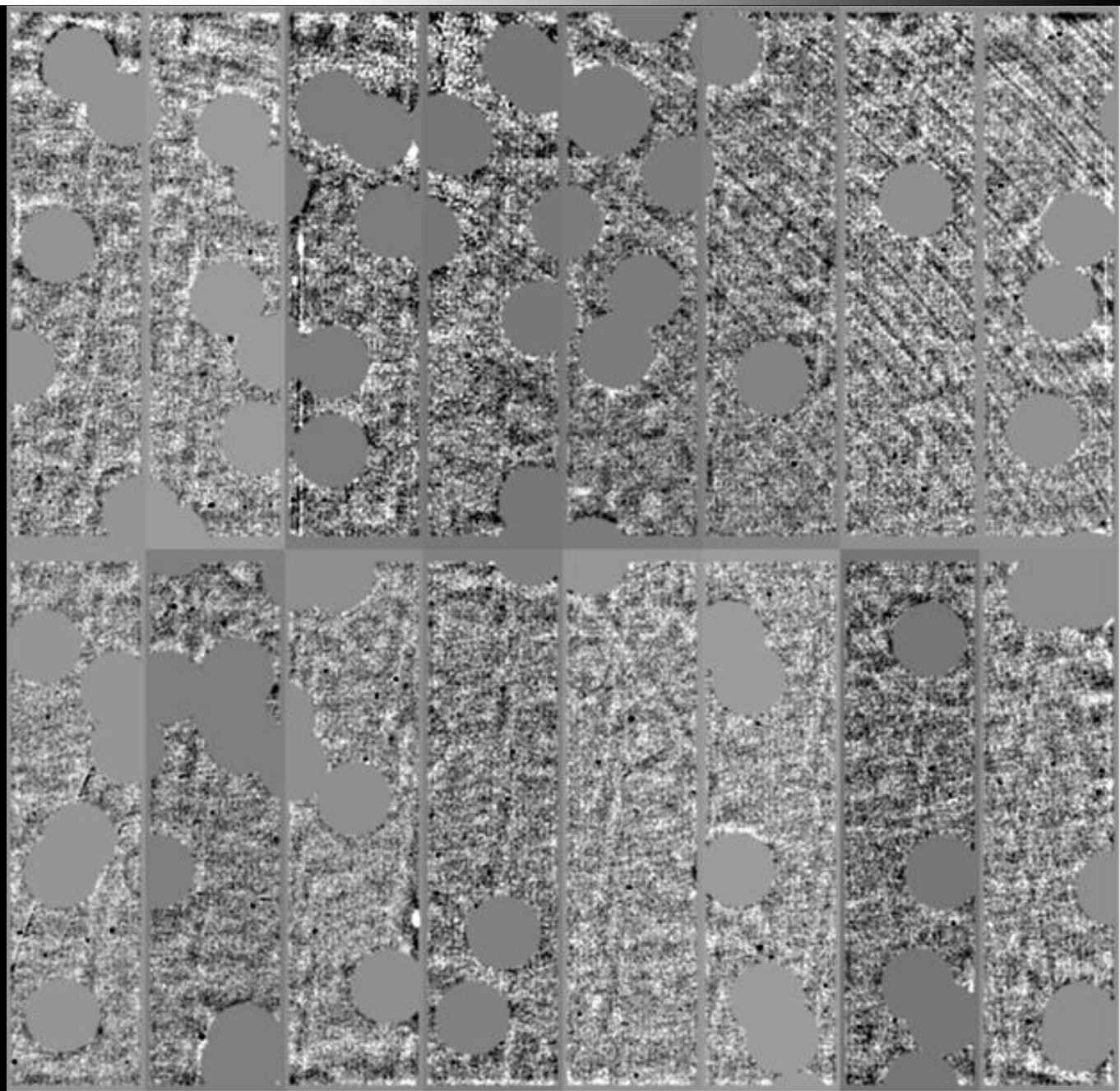






Tree Ring : LSST CCD Flat Image after All Correction

We can see the tree ring pattern more clearly.



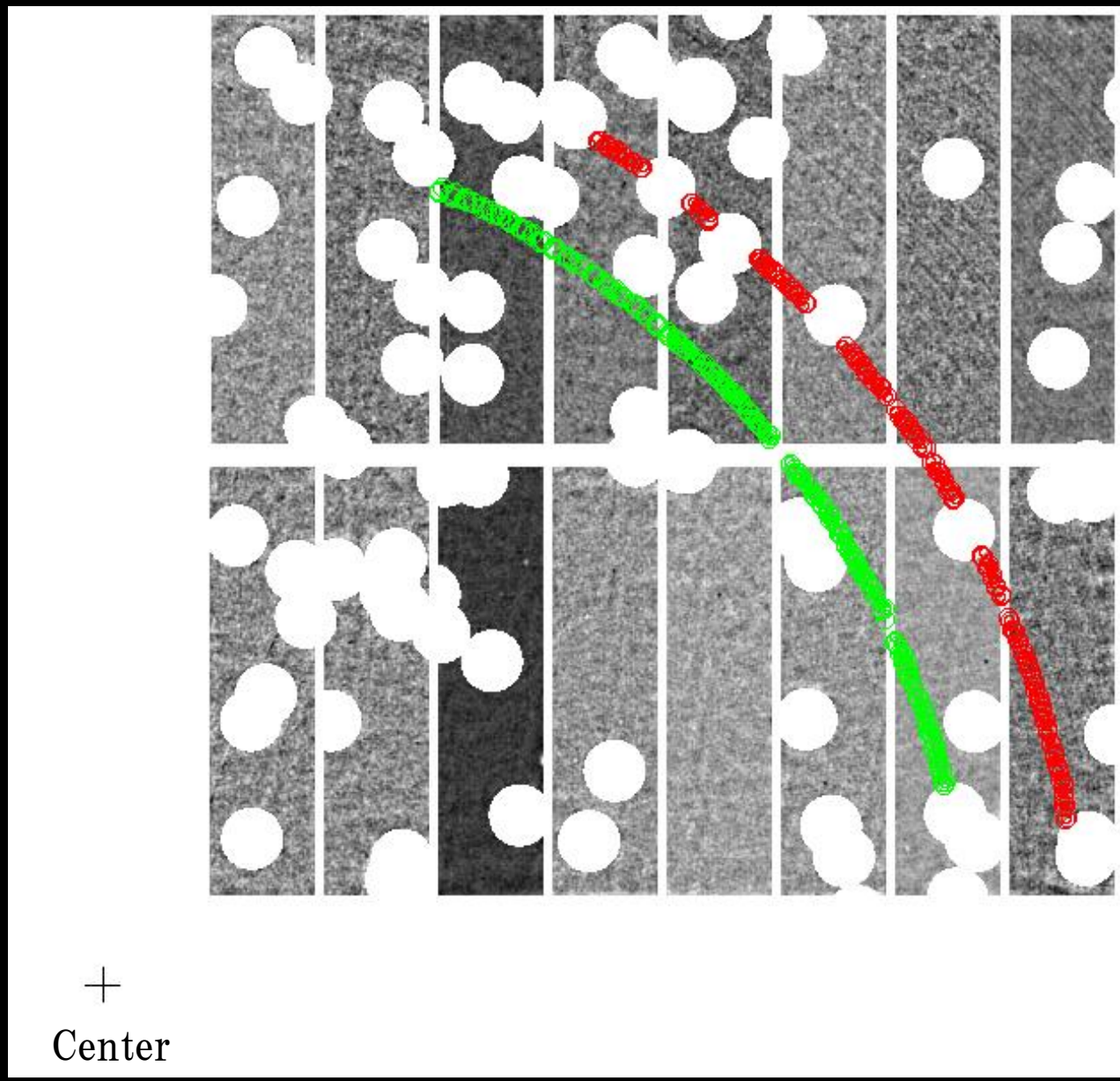
Tree Ring : Determining Tree Ring Center

Next step is determining tree ring center.

Tree ring center is defined as making maximum peaks when averaging tree ring pattern over angle.

The position can be determined by fitting treeing line as circle.

We found it near the corner.
Center : [4575, -375]

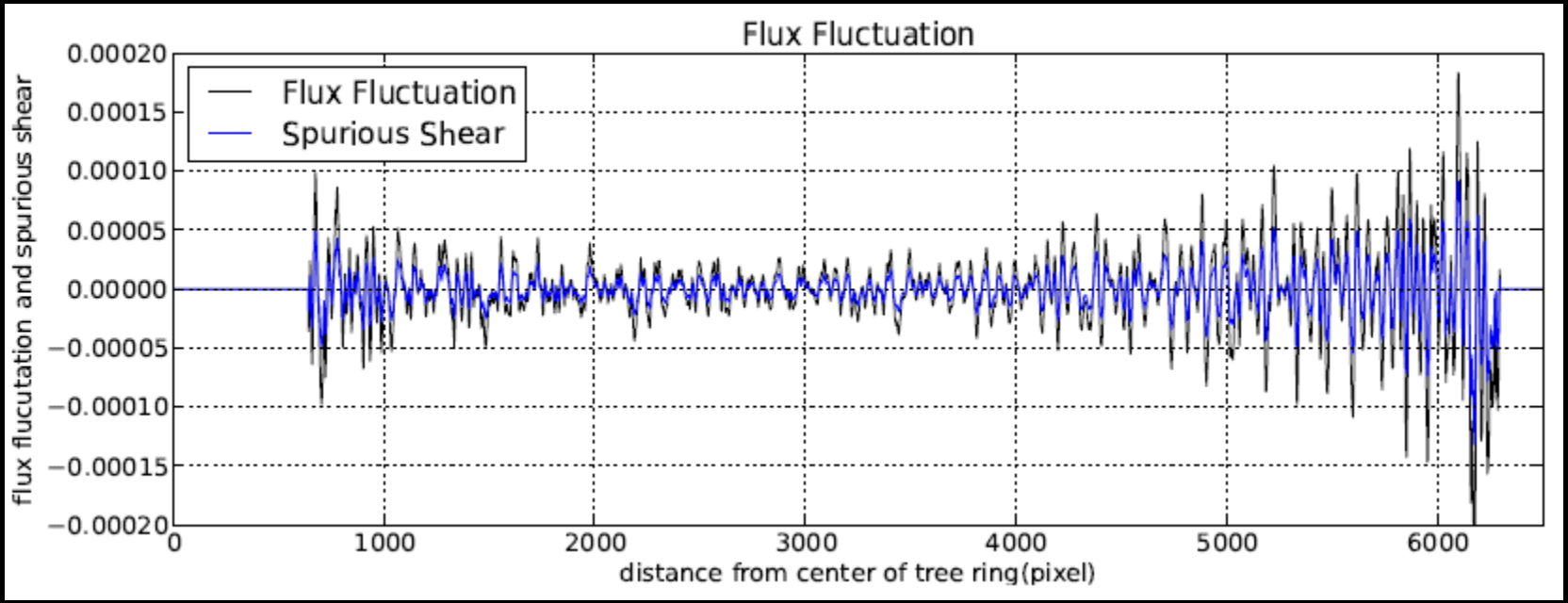


Tree Ring : Tree Ring profile

Tree ring profile by averaging the pattern over angle(black line).

The typical scale of the tree ring is 0.01%

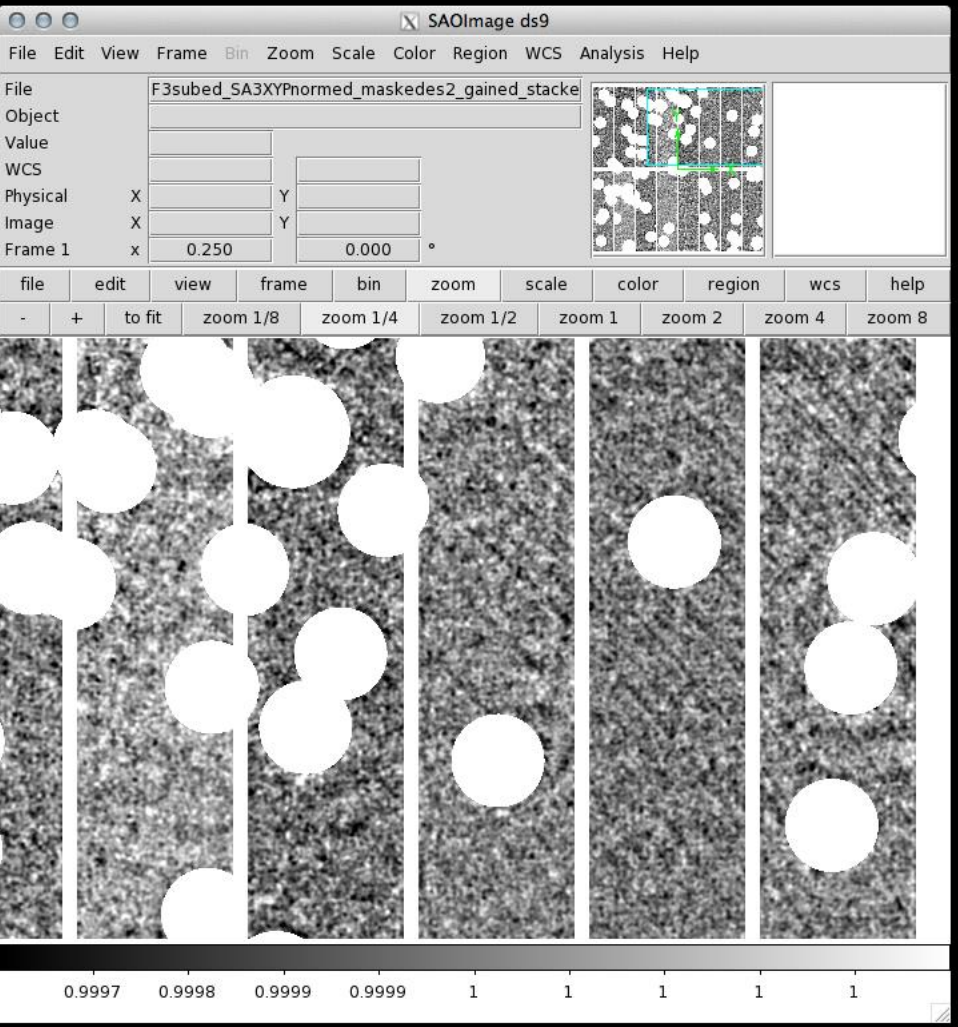
This profile is smoothed to reduce noise,
because non smoothed image has many fake peaks from noise.
The smoothing scale is smaller than the width of tree ring peaks,
so it does not reduce the amplitude of the peaks so much.



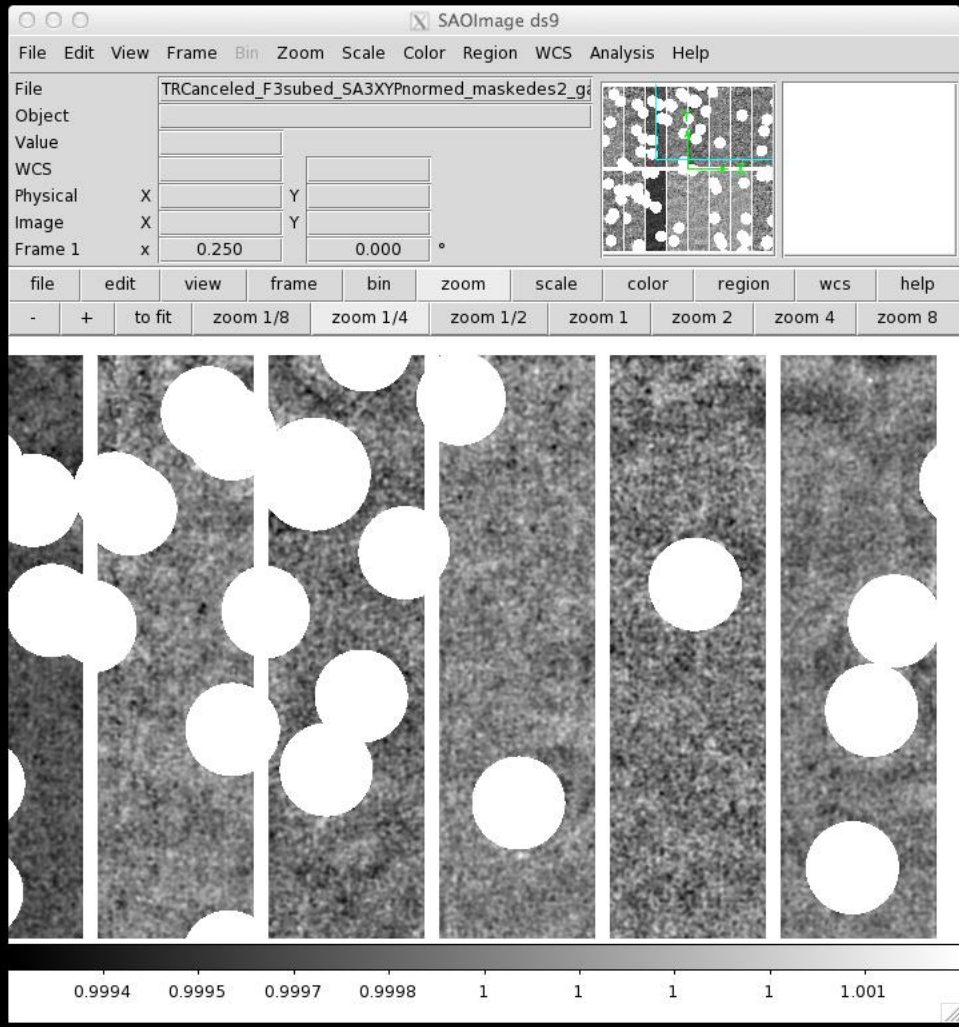
Flux modulation by the tree ring effect(Black line)

Tree Ring : Cancelation

Tree ring cancelation is for checking the profile comes form really tree ring patterns.
The method is dividing tree ring image by measured Tree ring profile.
Almost tree ring lines are canceled.



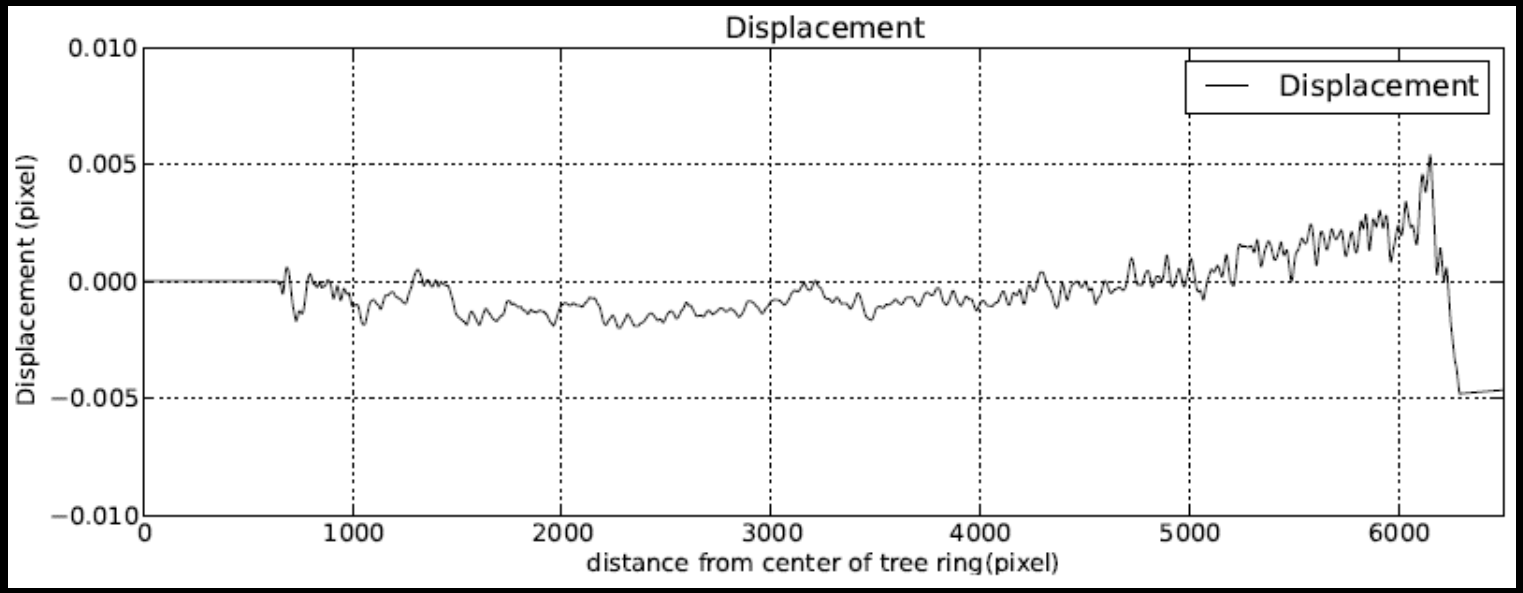
Before Cancelation (Smoothed image)



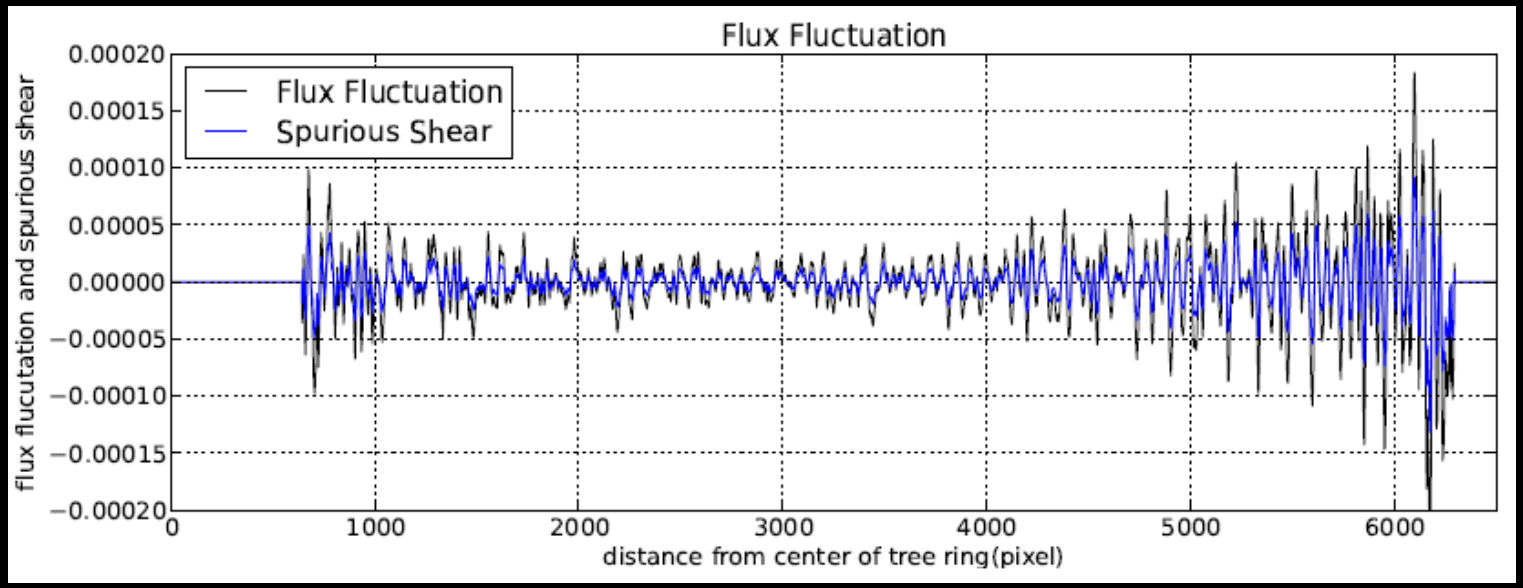
After Cancelation (Smoothed image)

Tree Ring : Displacement and Spurious Shear

Displacement estimated from the flux modulation, the typical scale is 0.001 pixel.

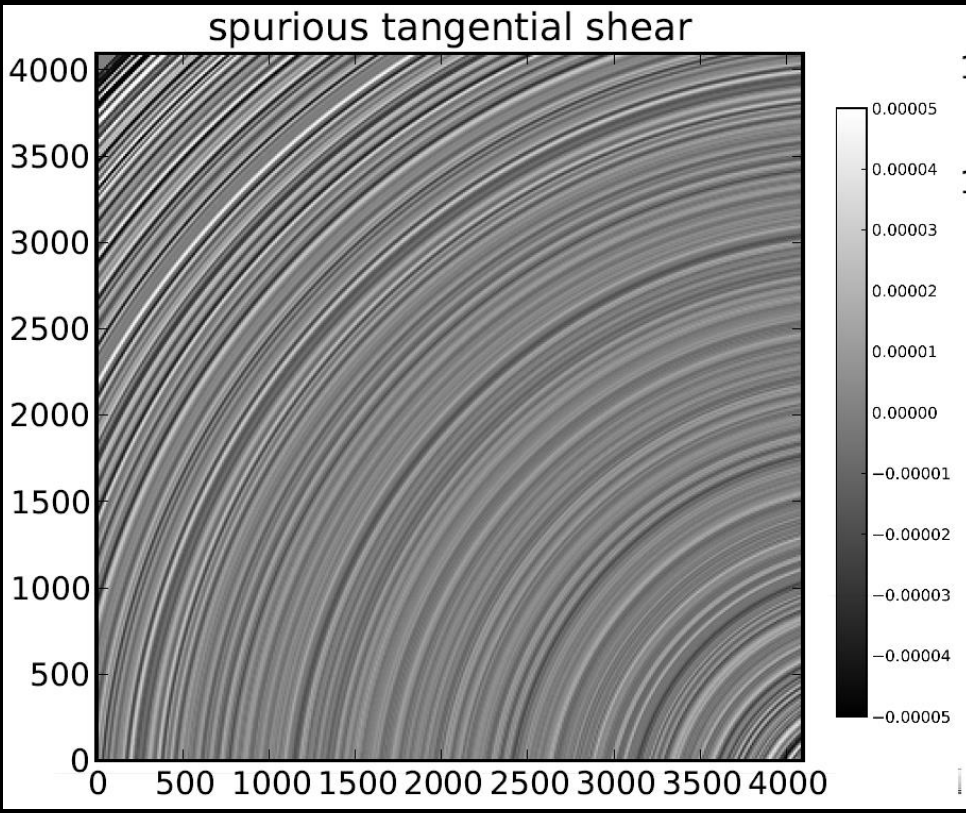


spurious shear estimated from the flux modulation, the typical scale is 0.05%

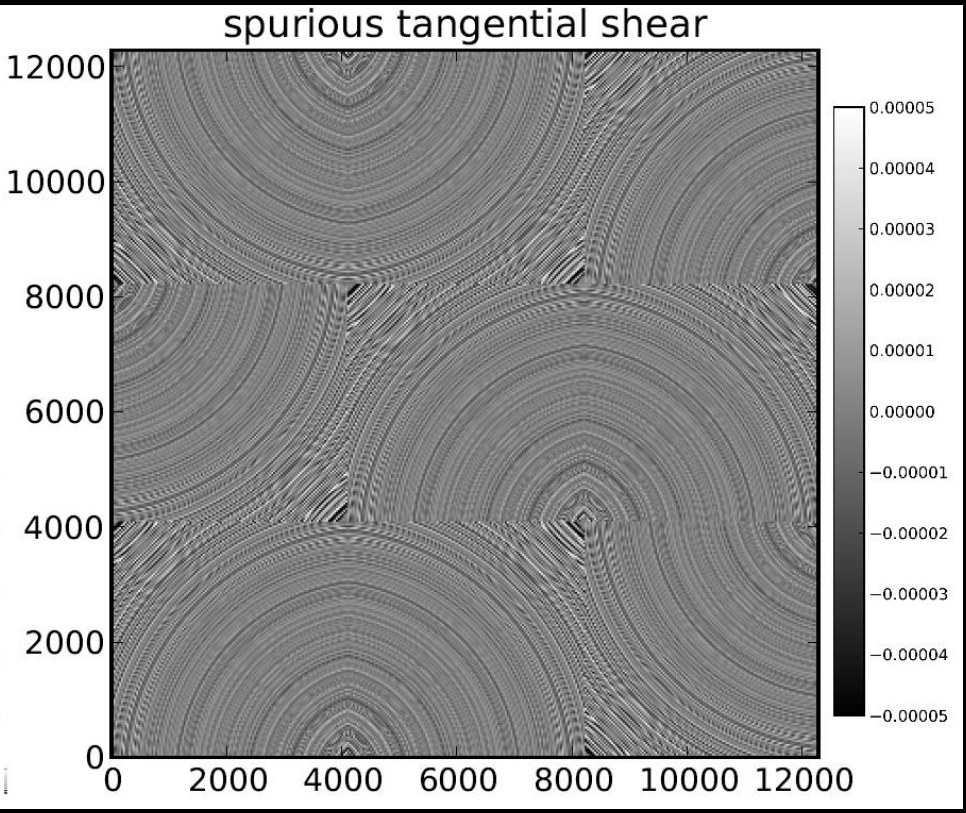


Tree Ring : Spurious shear in LSST focal plane

Spurious shear calculated on one CCD and on one raft, one raft has 9CCDs.
Because we have only one CCD for test,
so we assumed all CCDs have same profile but different orientation.
Then focal plane pf LSST has 21 rafts.



Calculated spurious shear in one CCD



Calculated spurious shear in one raft

Tree Ring : 2point shear correlation on LSST focal plane

2-point cosmic shear correlation is statistic value of the large scale structure,
so we can constrain the cosmological parameters from correlation of the cosmic shear.
Typical scale of cosmic shear correlation is about 10^-5 to 10^-6.

But tree ring effect also makes correlation,
so the correlation makes systematic error in constraining the cosmological parameters.

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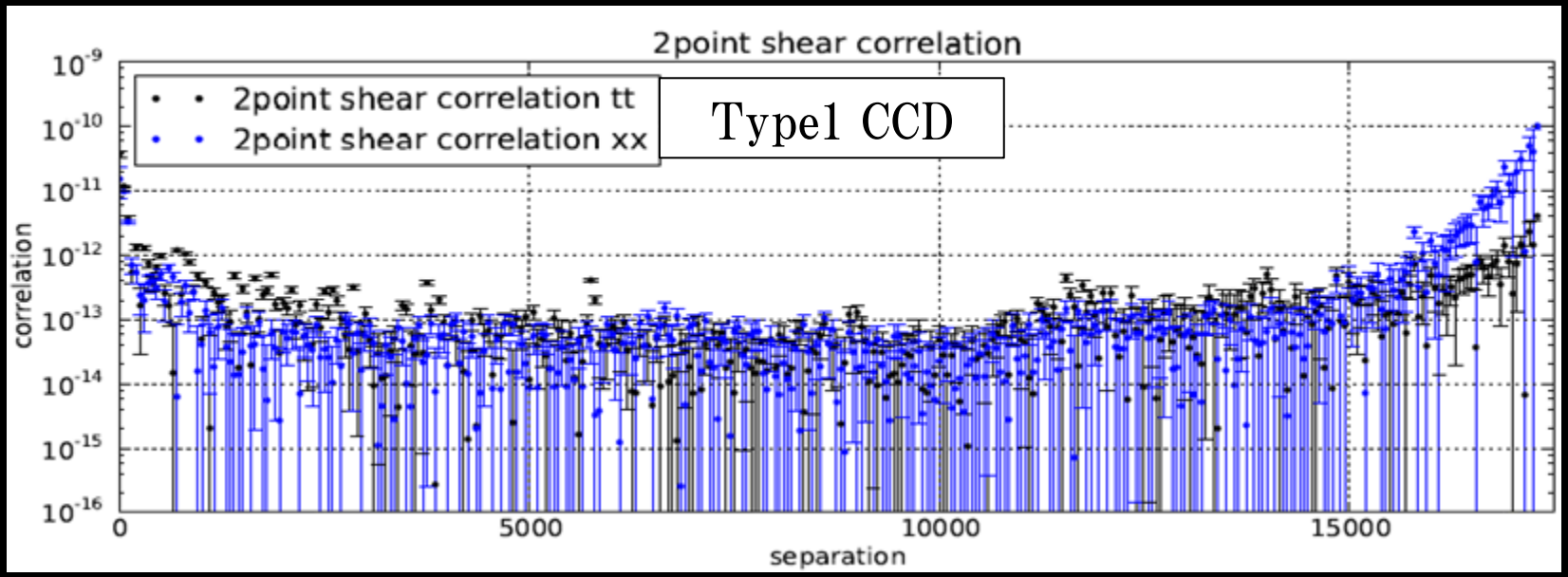
Typical scale of correlation from tree ring is about 10^-12,
so this effect is very small.



Conclusion and Future Works

- Conclusion -

We measured the tree ring pattern on LSST CCDs.
The typical scale of spurious shear from the tree ring pattern is about 0.005%
(this amplitude is 50times smaller than for existing large survey telescope)
and 2 point shear correlation is about 10^-12,
so it may be small enough to neglect in measuring cosmic shear with LSST.

- Future Works -

We found other effects which change shapes, e.g. the pixel size variation.
The typical scale is about 0.1%, so it is 10 times larger than the tree ring effects.
So studying their effects in measuring cosmic shear is future work.