Weak Gravitational Lensing

Take a closer and wider look of our universe

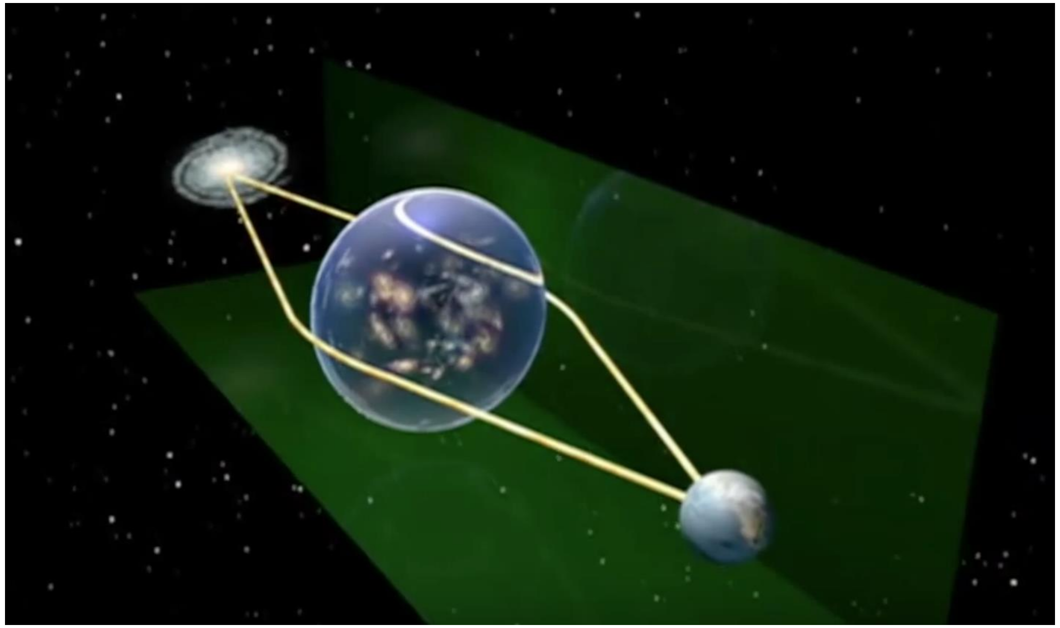
Vera Wu Hiu Sze

Overview

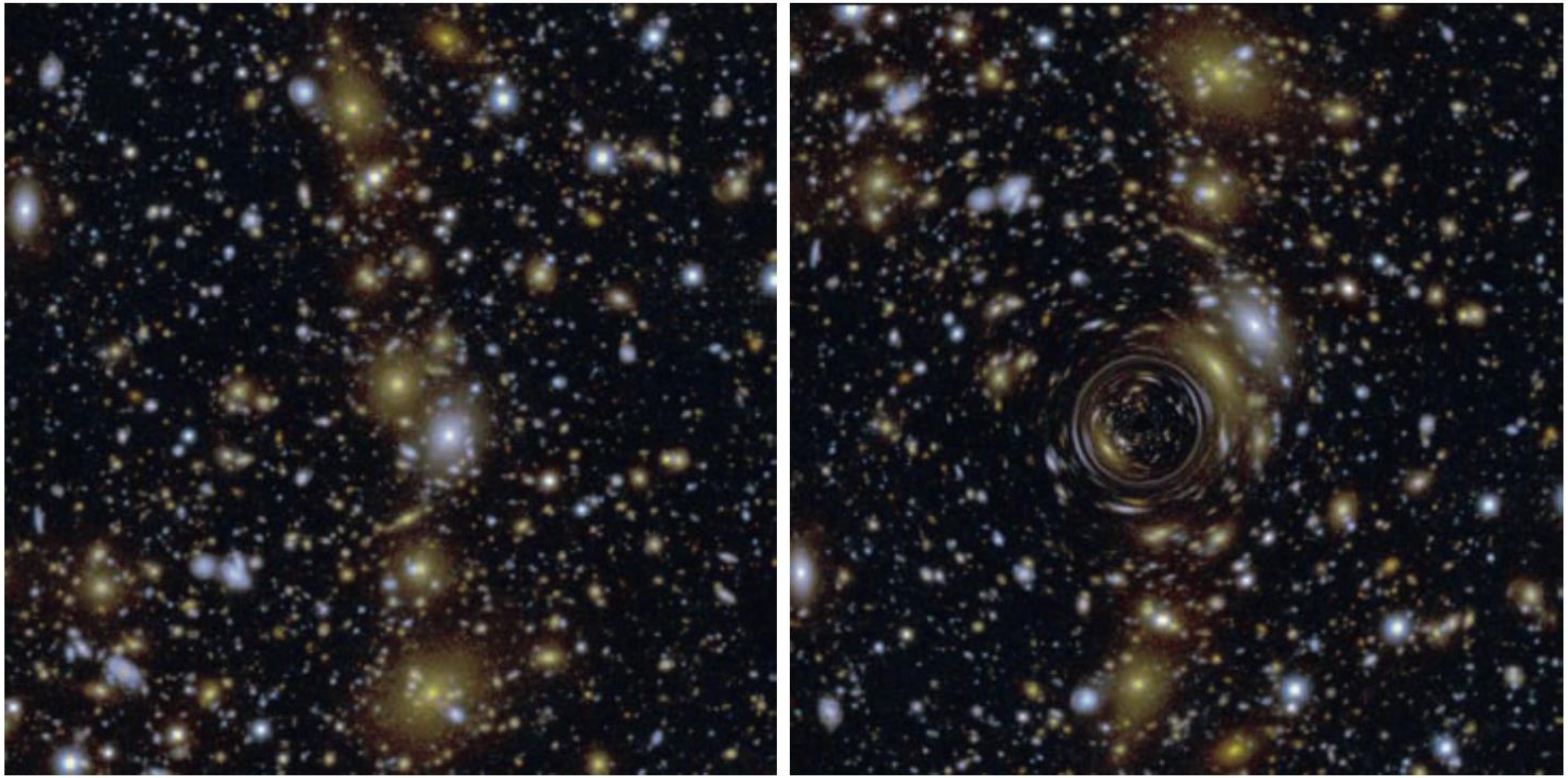
- Theory and Background (Weak Gravitational Lensing)
- Methods (LSST pipeline)
- Result (Mass Distribution)
- Conclusion

Theory and Background

- What is weak lensing?
- Theoretical proposal of weak lensing measurement.
- Advantage of the method.
- Possible sources of error.



Artist interpretation of Gravitational Lensing [1]



- Simulation of the effect of gravitational lensing. Left is weak gravitational lensing, right is strong gravitational lensing. “Real sources are not in a plane, but this does not dramatically affect the appearance.” Image by David Wittman [2]

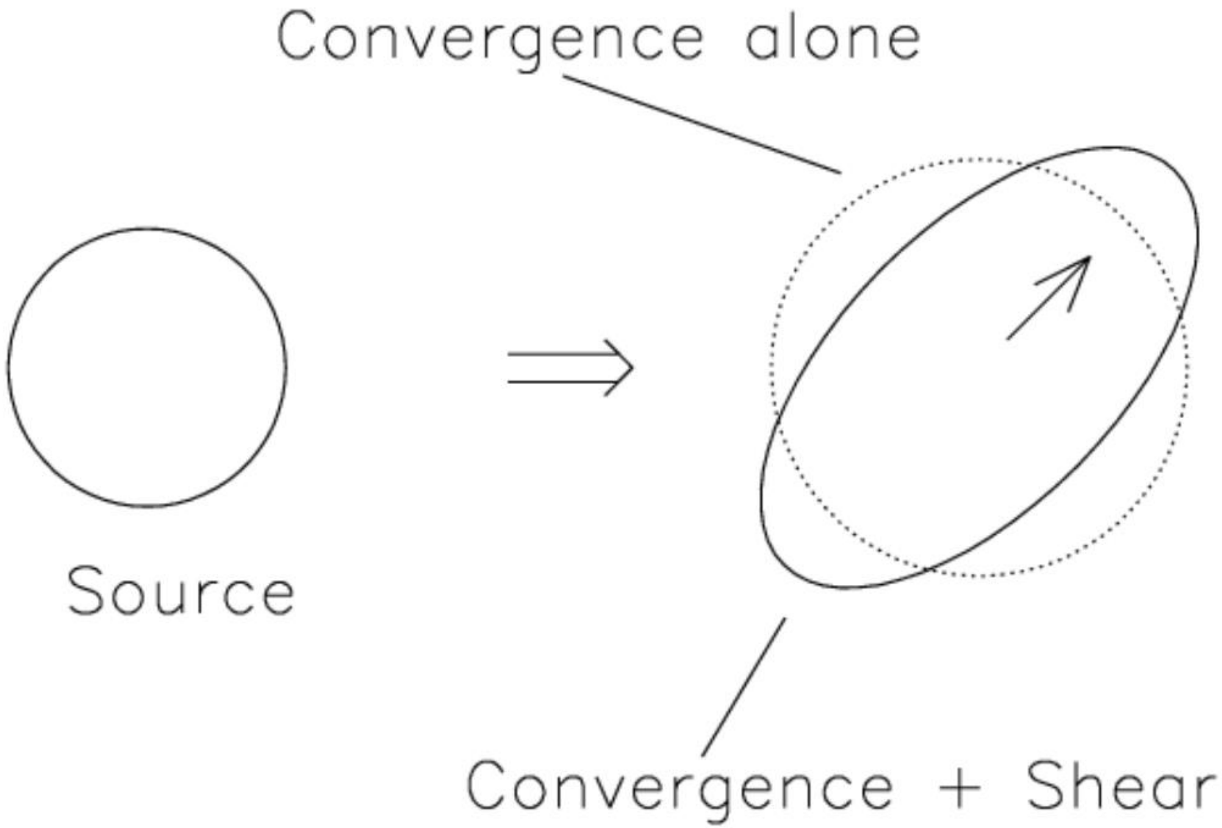
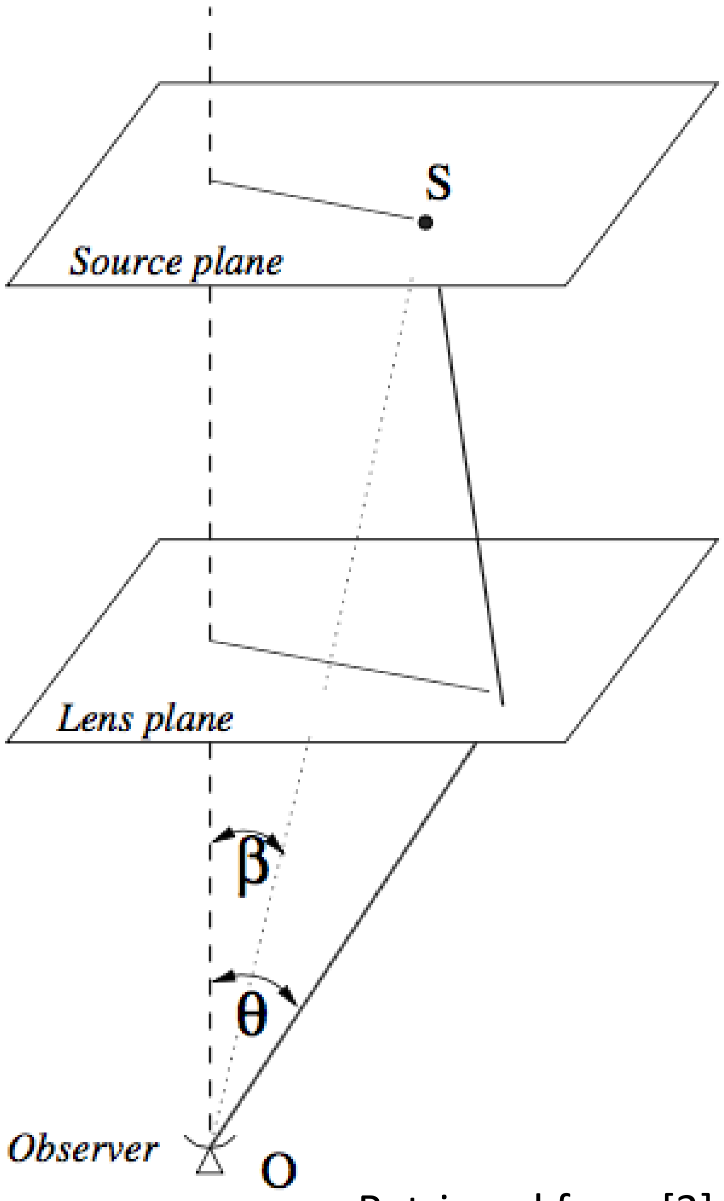


Figure 2.2: Distortion effects due to convergence and shear on a circular source (Figure from Narayan & Bartelmann, 1995). [3]



Retrieved from [3]

$$\kappa(r) = \frac{\Sigma(r)}{\Sigma_{crit}} \quad , \qquad \sum_{crit} = \frac{c^2}{4\pi G} \frac{D_L D_S}{D_{LS}}$$

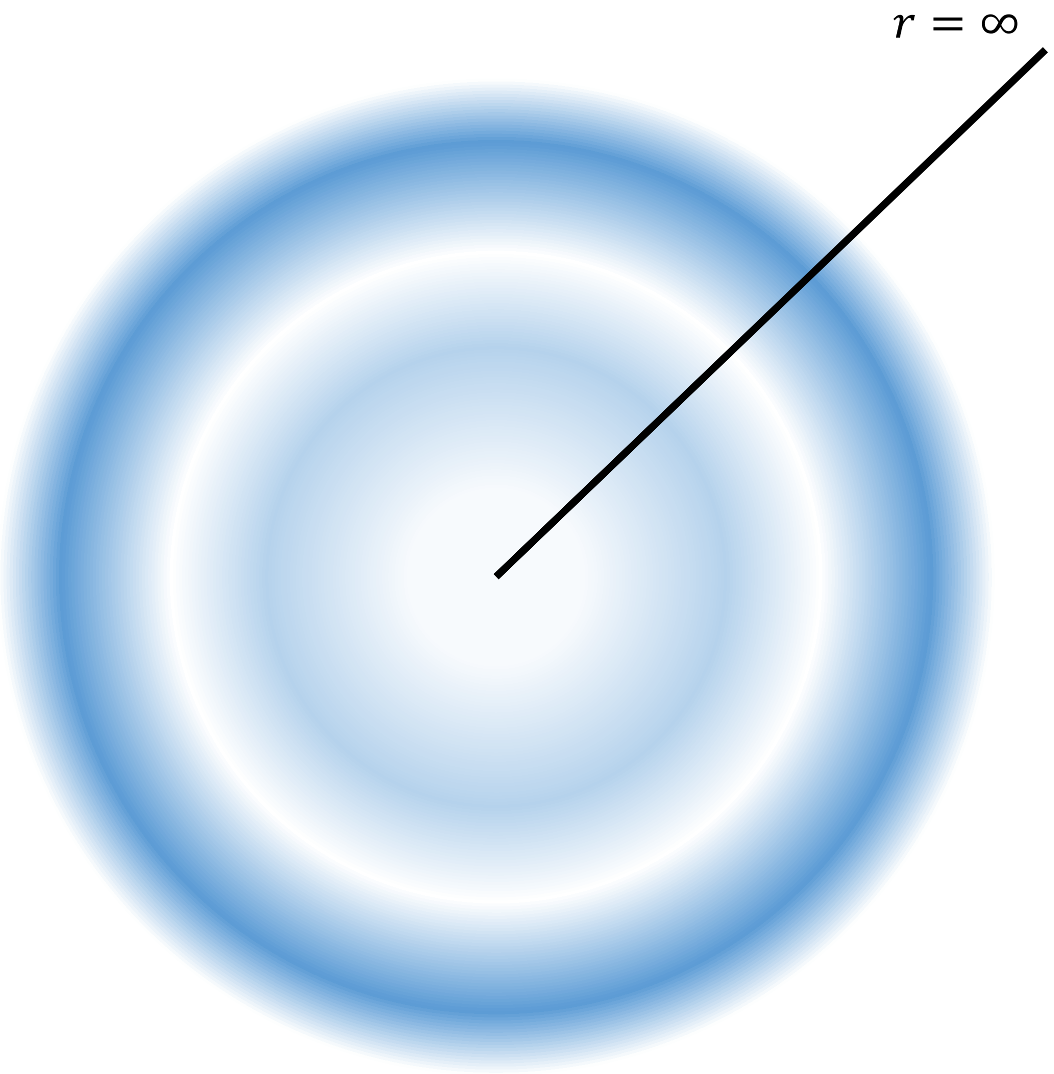
In weak gravitational lensing regime:

$$\langle e_t \rangle = \left\langle \frac{\gamma_t}{1-\kappa} \right\rangle \approx \langle \gamma_t \rangle \text{ , when } \kappa \ll 1$$

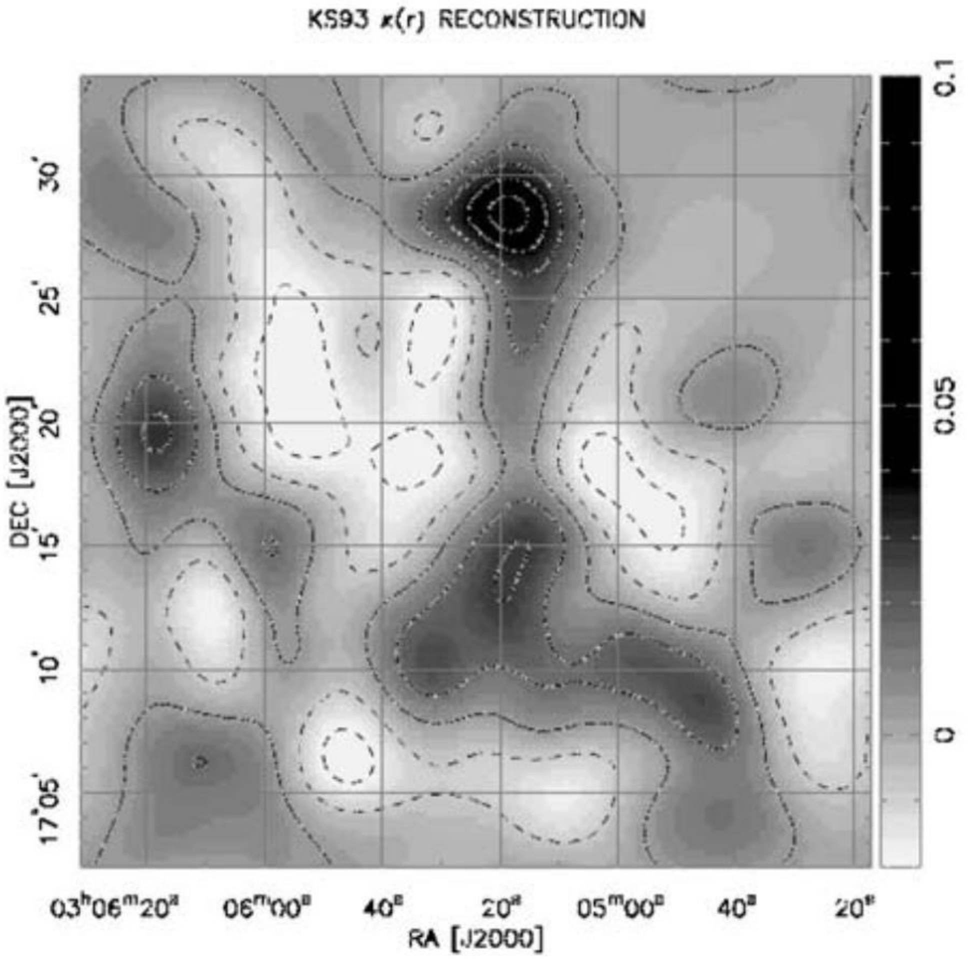
under the assumption that the background is randomly oriented.

Radial Densitometry:

$$\bar{\kappa}(< r_1) - \bar{\kappa}(r_1 < r < r_2) = \frac{2}{1 - \frac{r_1^2}{r_2^2}} \int_{r_1}^{r_2} \frac{\langle \gamma_t(r) \rangle}{1 - \kappa(r)} \, d \ln r$$



conceptual picture of
1D convergence reconstruction



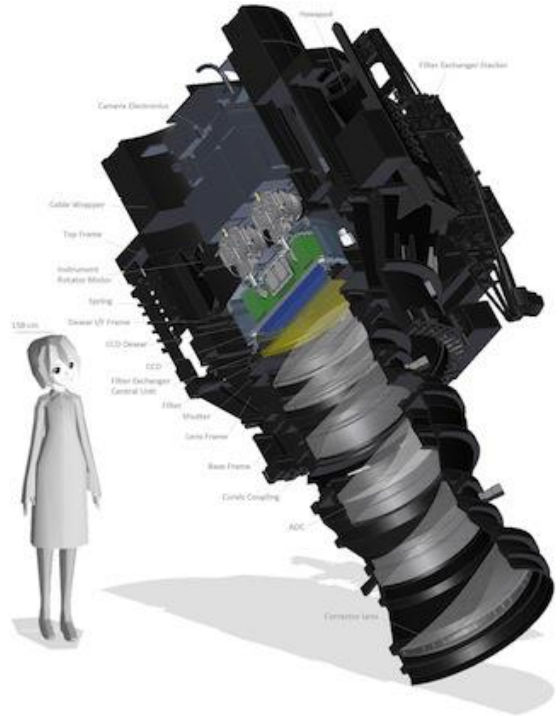
2D convergence reconstruction [2]

Possible sources of error

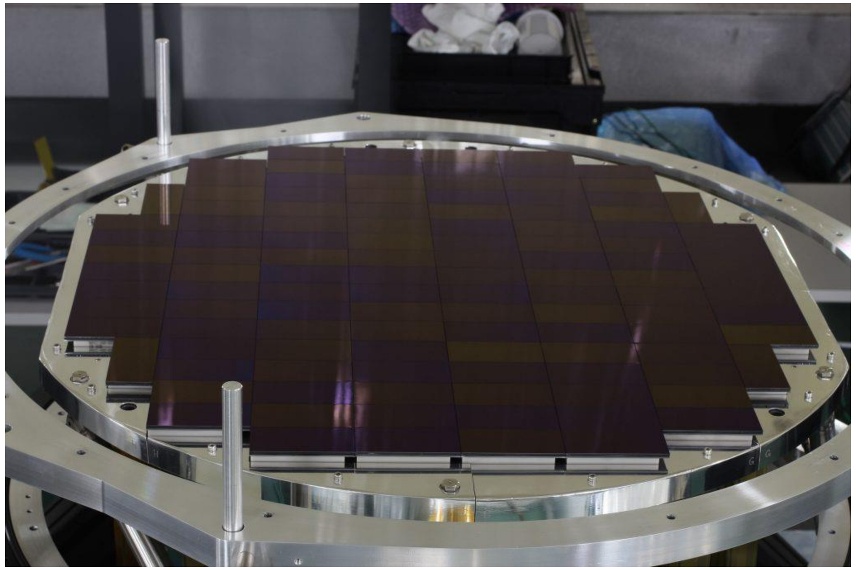
- Shape noise
- Intrinsic Alignment
- PSF anisotropy
- Atmosphere turbulence
- ……

Imaging – Subaru Telescope w/ Hyper Suprime-Cam

Subaru Telescope
Effective diameter: 8.2 m
Focal length: 15 m



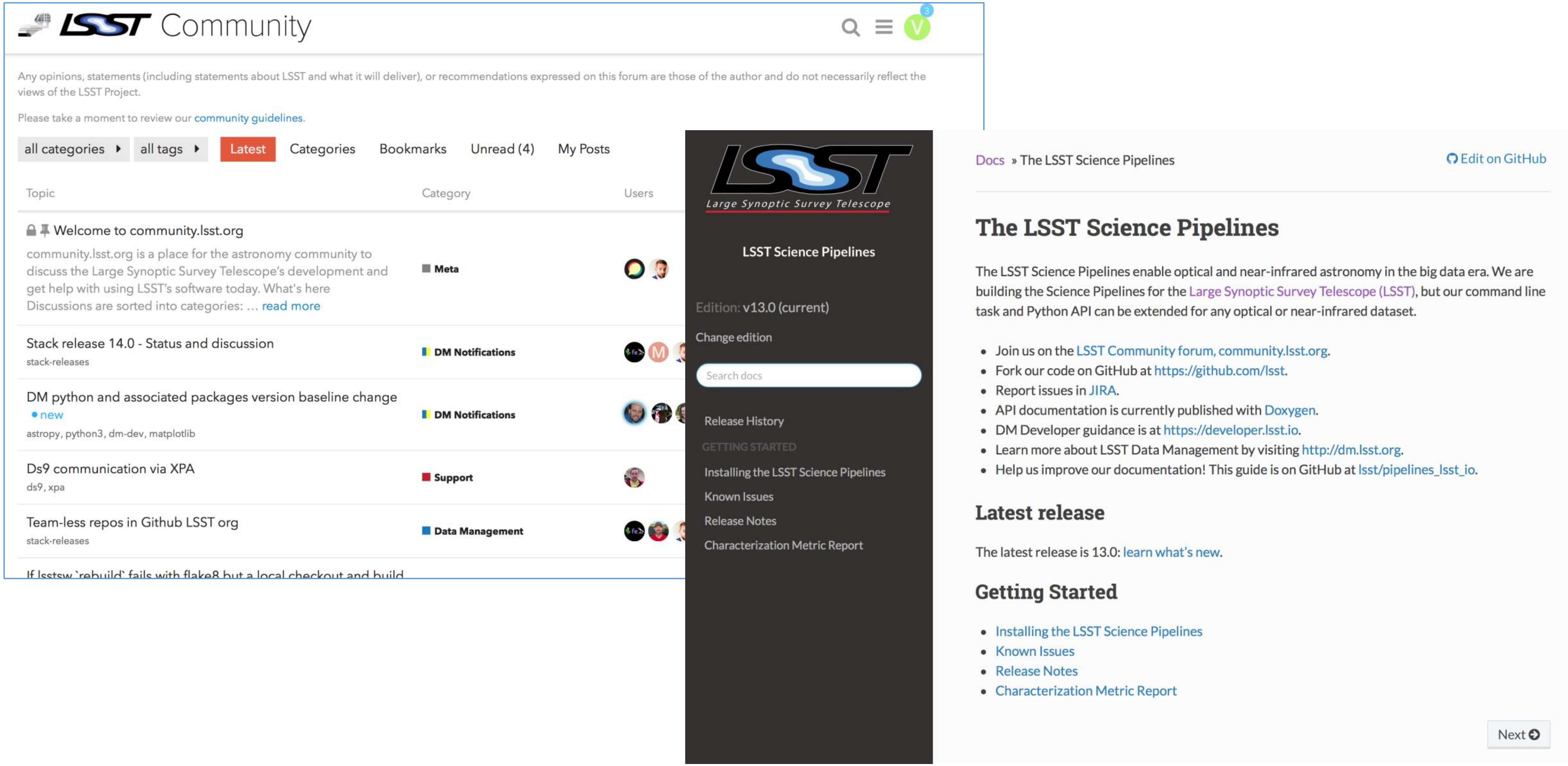
Hyper Suprime-Cam (HSC) model

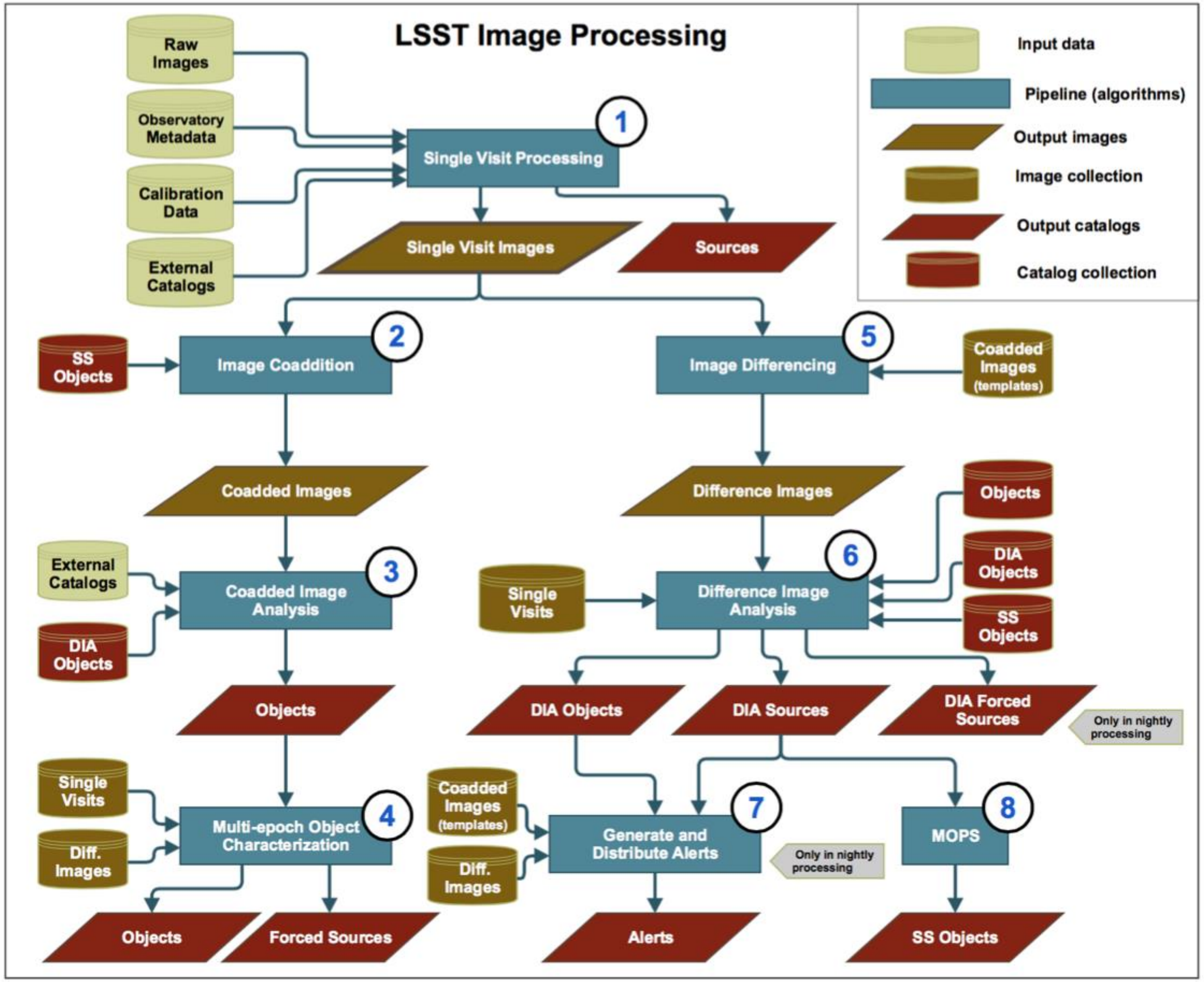


Sensor: 116 2kx4k CCDs
Diameter: 60 cm
Resolution: 870 Megapixels

Combine the sensor & the telescope
FOV: 1.8 deg^2

Methods (LSST pipeline)





LSST image processing flow chart [4]

Pipeline

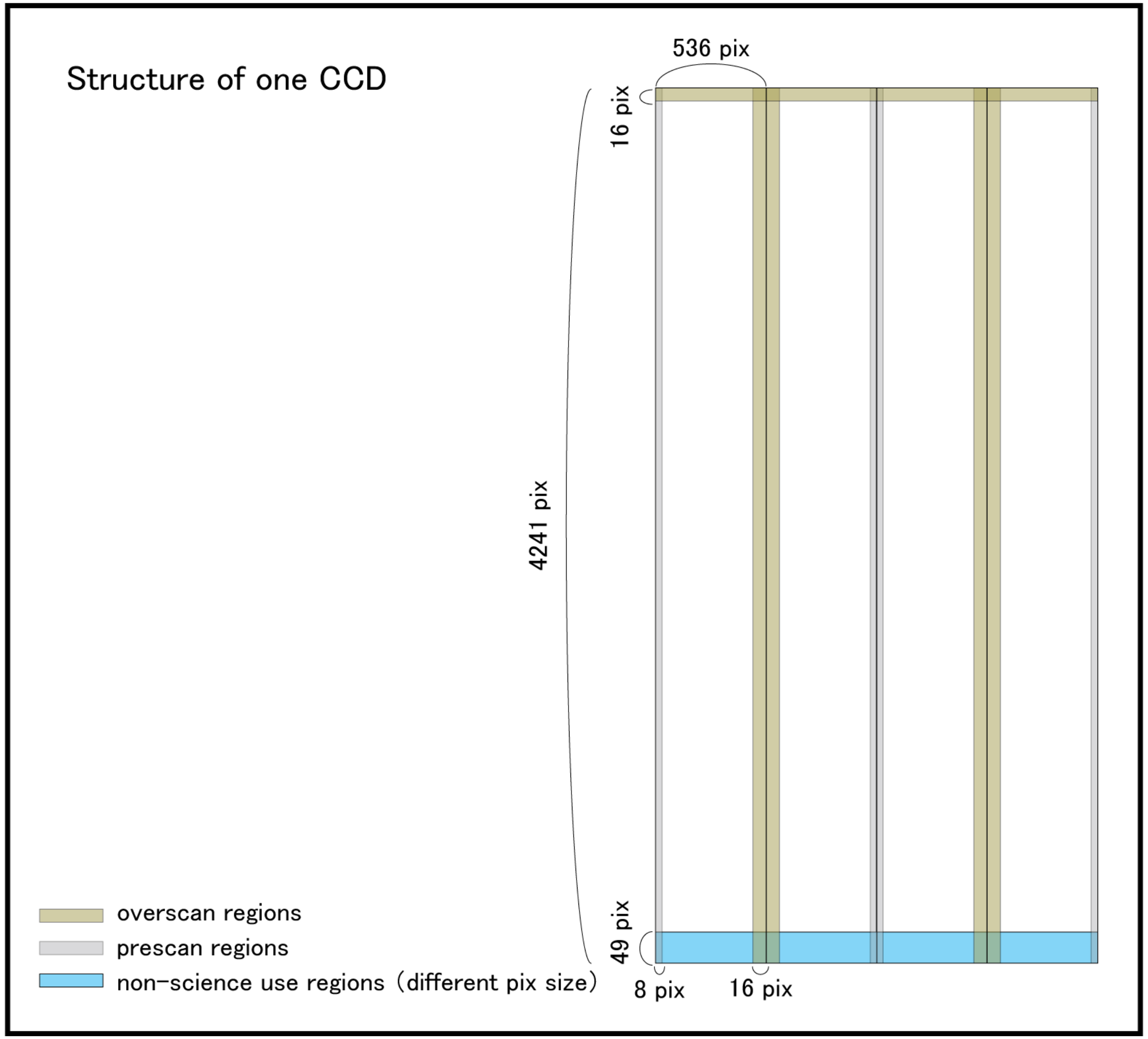
1. Making Calibration Frames (Bias, Dark, Flat Frame)
2. Reduction for each image for one filter
3. Mosaicing
4. Stacking
5. Multiband Analysis

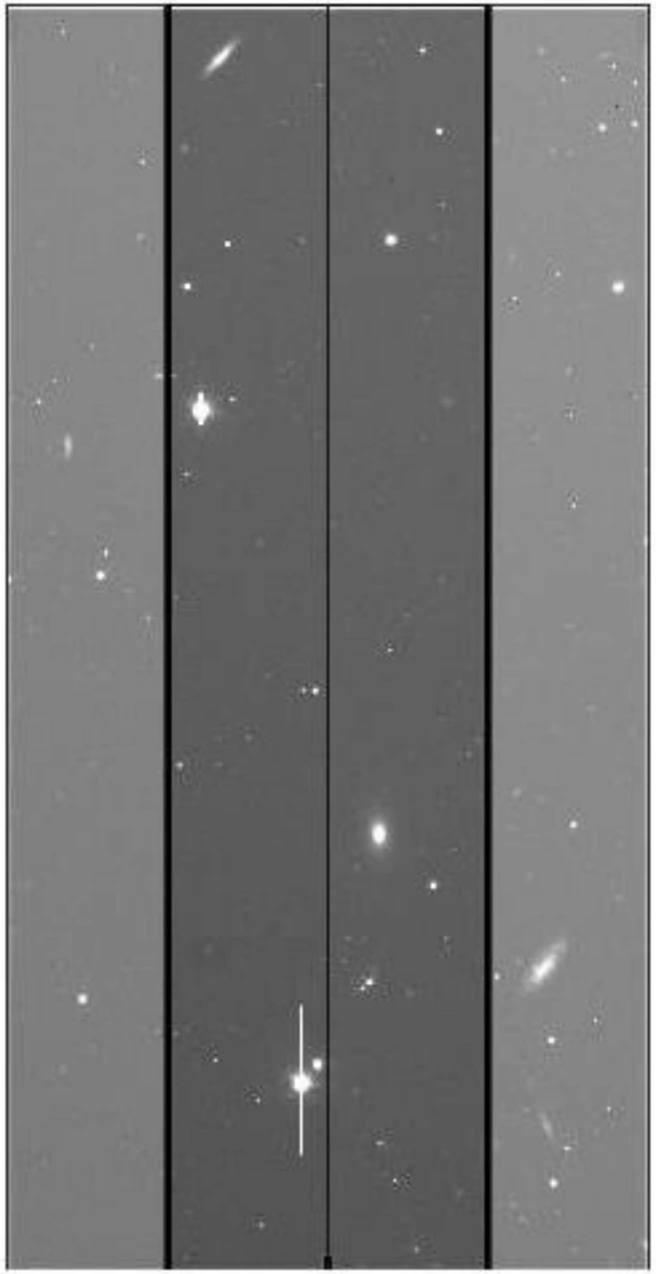
OUTPUT catalog

Calibration Frames

- Dark Frame: Measuring thermal noise for each sensor
- Bias Frame: Measuring the response of sensors
- Flat Frame: Calibrating the even dispersion of light by lens (telescope)

Raw Data

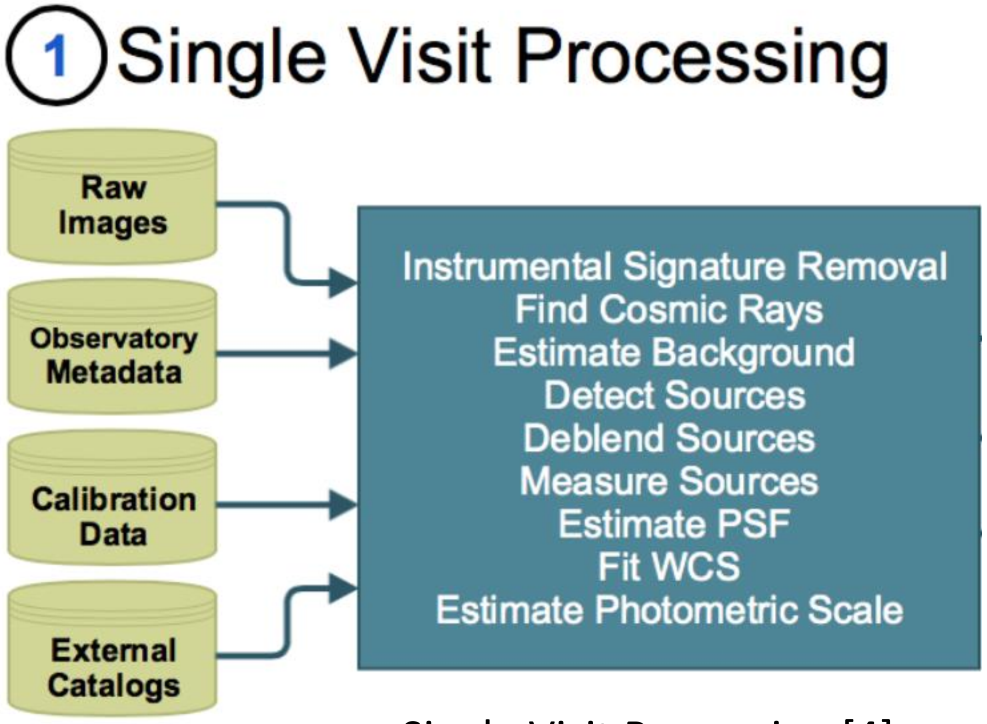




One of the CCD raw image of A85.

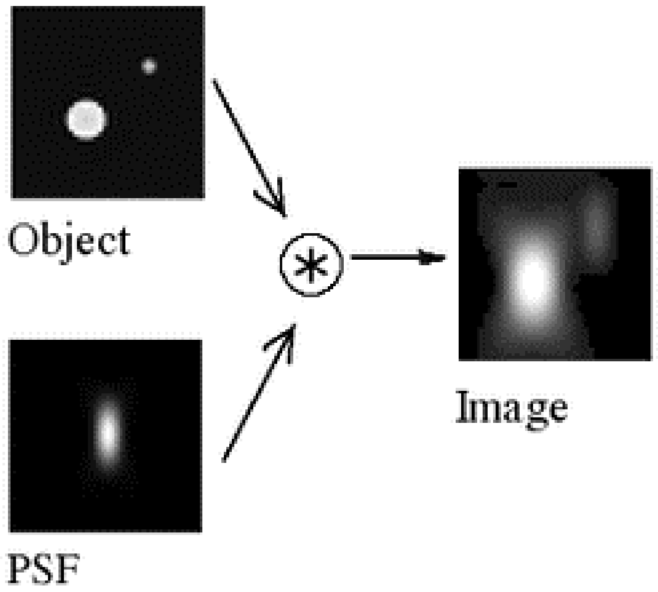
All raw data retrieved from SMOKA.

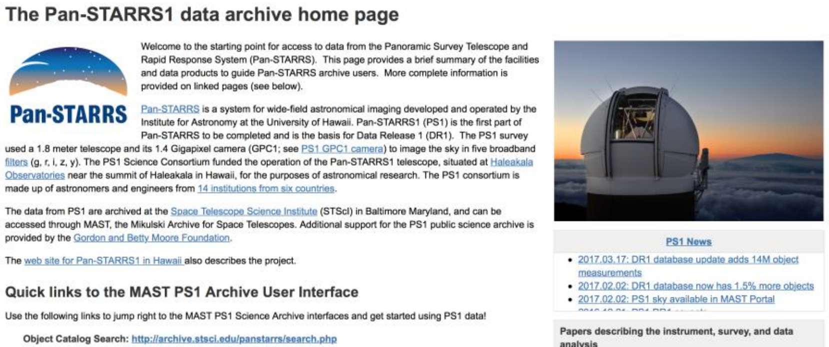
Reduction for each image for one filter



Single Visit Processing [4]

conceptual PSF [5]





The Pan-STARRS1 data archive home page

Welcome to the starting point for access to data from the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). This page provides a brief summary of the facilities and data products to guide Pan-STARRS archive users. More complete information is provided on linked pages (see below).

Pan-STARRS is a system for wide-field astronomical imaging developed and operated by the Institute for Astronomy at the University of Hawaii. Pan-STARRS1 (PS1) is the first part of Pan-STARRS to be completed and is the basis for Data Release 1 (DR1). The PS1 survey used a 1.8 meter telescope and its 1.4 Gigapixel camera (GPC1; see PS1 GPC1 camera) to image the sky in five broadband filters (g, r, i, z, y). The PS1 Science Consortium funded the operation of the Pan-STARRS1 telescope, situated at Haleakala Observatories near the summit of Haleakala in Hawaii, for the purposes of astronomical research. The PS1 consortium is made up of astronomers and engineers from 14 institutions from six countries.

The data from PS1 are archived at the Space Telescope Science Institute (STScI) in Baltimore Maryland, and can be accessed through MAST, the Mikulski Archive for Space Telescopes. Additional support for the PS1 public science archive is provided by the Gordon and Betty Moore Foundation.

The web site for Pan-STARRS1 in Hawaii also describes the project.

Quick links to the MAST PS1 Archive User Interface

Use the following links to jump right to the MAST PS1 Science Archive interfaces and get started using PS1 data!

Object Catalog Search: http://archive.stsci.edu/panstarrs/search.php

PS1 News

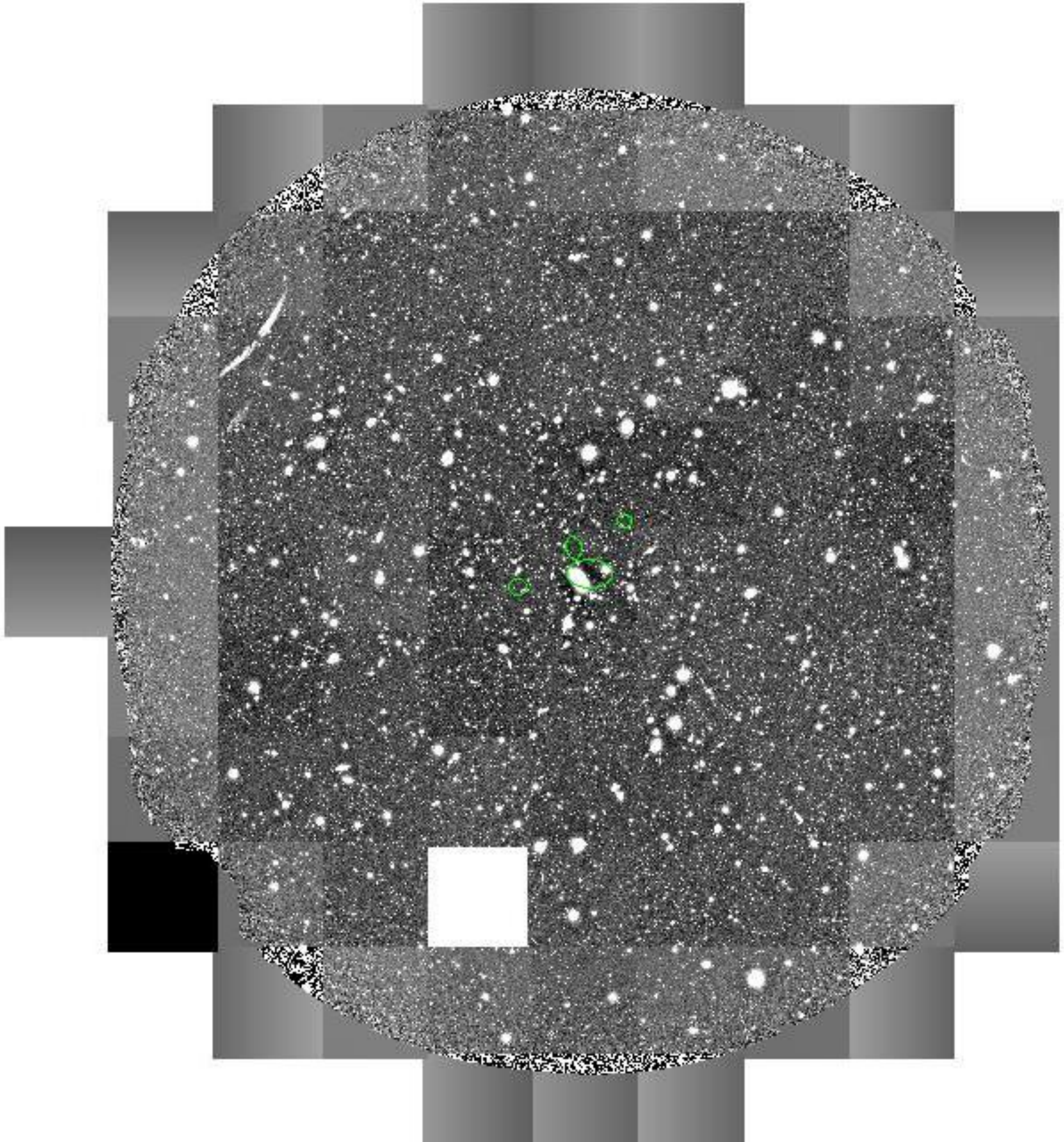
- 2017.03.17: DR1 database update adds 14M object measurements
- 2017.02.02: DR1 database now has 1.5% more objects
- 2017.02.02: PS1 sky available in MAST Portal

Papers describing the instrument, survey, and data analysis

Mosaicing

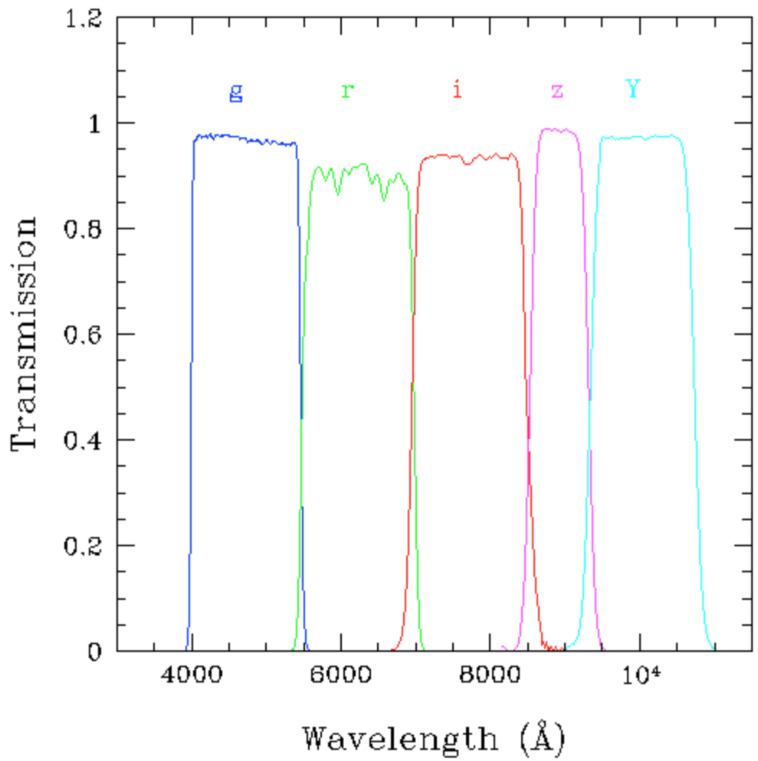
0,0	1,0	2,0	…	13,0
0,1	1,1	…	…	13,1
⋮	⋮			⋮
⋮	⋮			⋮
0,13	1,13	…	…	13,13

Stacking



Multiband Analysis

- Final calibration between different broad-band filters (g, r, i, z, Y)



Catalog

- output a catalog with measurements

id: unique ID
coord_ra: position in ra/dec
coord_dec: position in ra/dec
parent: unique ID of parent source
calib_detected: Source was detected as an icSource
calib_psfCandidate: Flag set if the source was a candidate for PSF determination, as determined by the star selector.
calib_psfUsed: Flag set if the source was actually used for PSF determination, as determined by the
calib_psfReserved: Flag set if the source was selected as a PSF candidate, but was reserved from the PSF fitting.
deblend_nChild: Number of children this object has (defaults to 0)
deblend_deblendedAsPsf: Deblender thought this source looked like a PSF
deblend_psfCenter_x: If deblended-as-psf, the PSF centroid
deblend_psfCenter_y: If deblended-as-psf, the PSF centroid
deblend_psfFlux: If deblended-as-psf, the PSF flux
deblend_tooManyPeaks: Source had too many peaks; only the brightest were included
deblend_parentTooBig: Parent footprint covered too many pixels
deblend_masked: Parent footprint was predominantly masked
deblend_skipped: Deblender skipped this source
deblend_rampedTemplate: This source was near an image edge and the deblender used "ramp" edge-handling.
deblend_patchedTemplate: This source was near an image edge and the deblender used "patched" edge-handling.
deblend_hasStrayFlux: This source was assigned some stray flux
base_GaussianCentroid_x: centroid from Gaussian Centroid algorithm
base_GaussianCentroid_y: centroid from Gaussian Centroid algorithm
base_NaiveCentroid_x: centroid from Naive Centroid algorithm
base_NaiveCentroid_y: centroid from Naive Centroid algorithm
base_SdssCentroid_x: centroid from Sdss Centroid algorithm
base_SdssCentroid_y: centroid from Sdss Centroid algorithm
base_SdssCentroid_xSigma: 1-sigma uncertainty on x position
base_SdssCentroid_ySigma: 1-sigma uncertainty on y position
base_SdssShape_xx: elliptical Gaussian adaptive moments
base_SdssShape_yy: elliptical Gaussian adaptive moments
base_SdssShape_xy: elliptical Gaussian adaptive moments
base_SdssShape_xxSigma: 1-sigma uncertainty on xx moment
base_SdssShape_yySigma: 1-sigma uncertainty on yy moment
base_SdssShape_xySigma: 1-sigma uncertainty on xy moment
base_SdssShape_x: elliptical Gaussian adaptive moments
base_SdssShape_y: elliptical Gaussian adaptive moments
base_SdssShape_flux: elliptical Gaussian adaptive moments base_SdssShape_fluxSigma: 1-sigma flux uncertainty base_SdssShape_psf_xx:

- fiat tools by Deep Lens Survey
- fiatfilter

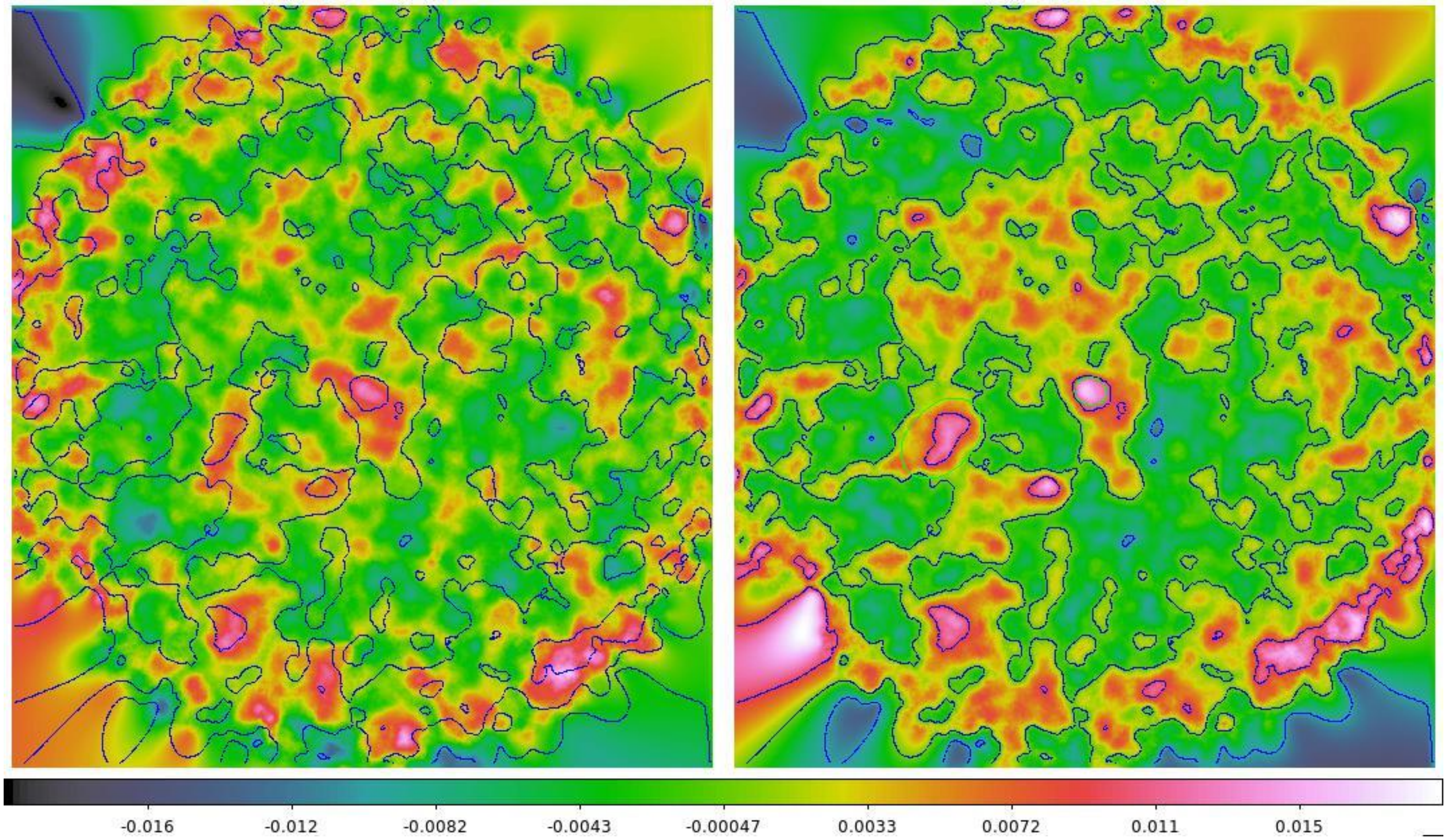
ext_shapeHSM_HsmShapeRegauss_e1)**2+(ext_shapeHSM_HsmShapeRegauss_e2)**2<1.5 && deblend_nChild==0 && ext_shapeHSM_HsmShapeRegauss_flag==0 && base_CircularApertureFlux_12_0_flag==0 && base_SdssShape_xx+base_SdssShape_yy<200 && base_SdssShape_xx>1 && base_SdssShape_yy>1 && calib_psfUsed==0 && base_PixelFlags_flag_interpolatedCenter==0 && base_CircularApertureFlux_12_0_flux>14 && base_CircularApertureFlux_12_0_flux<300000

- fiatmap

Results!

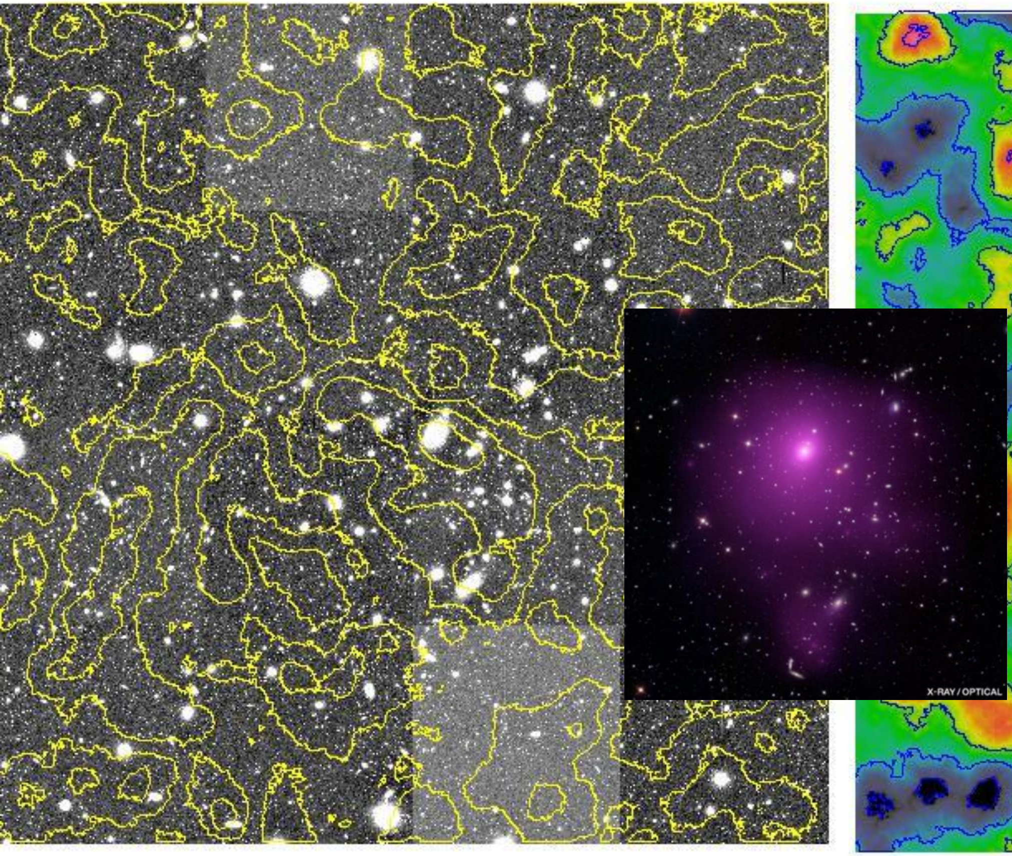
Name	Redshift[]	Diameter (arcmin)[6]
Abell 85	0.055061	2
Abell 2199	0.03051	182
Abell 119	0.0442	69

A85G A85I

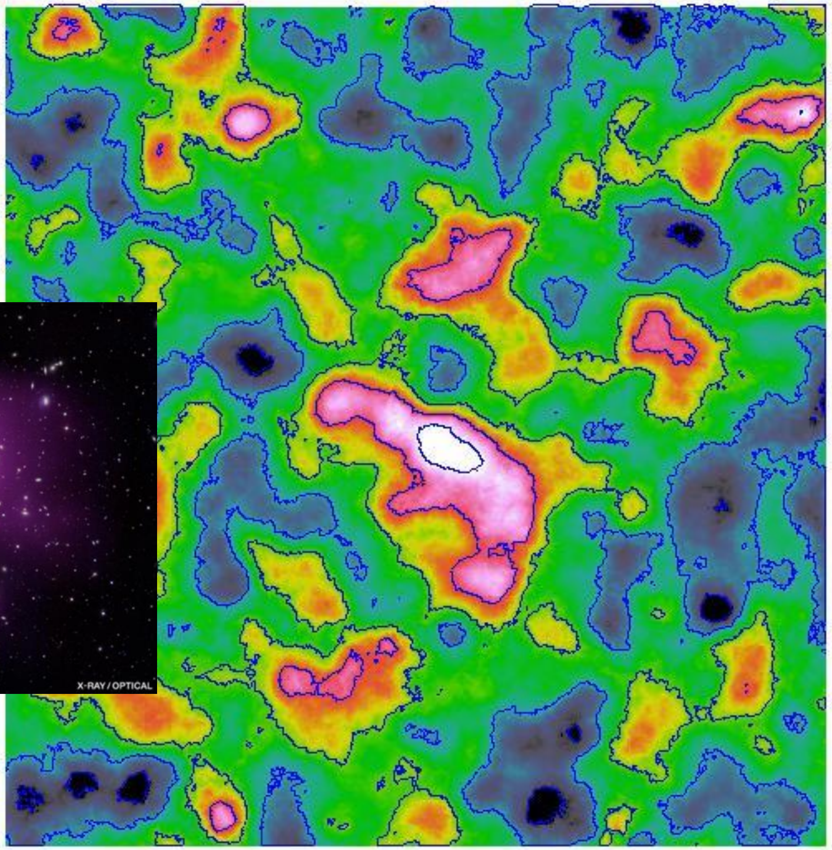


A85

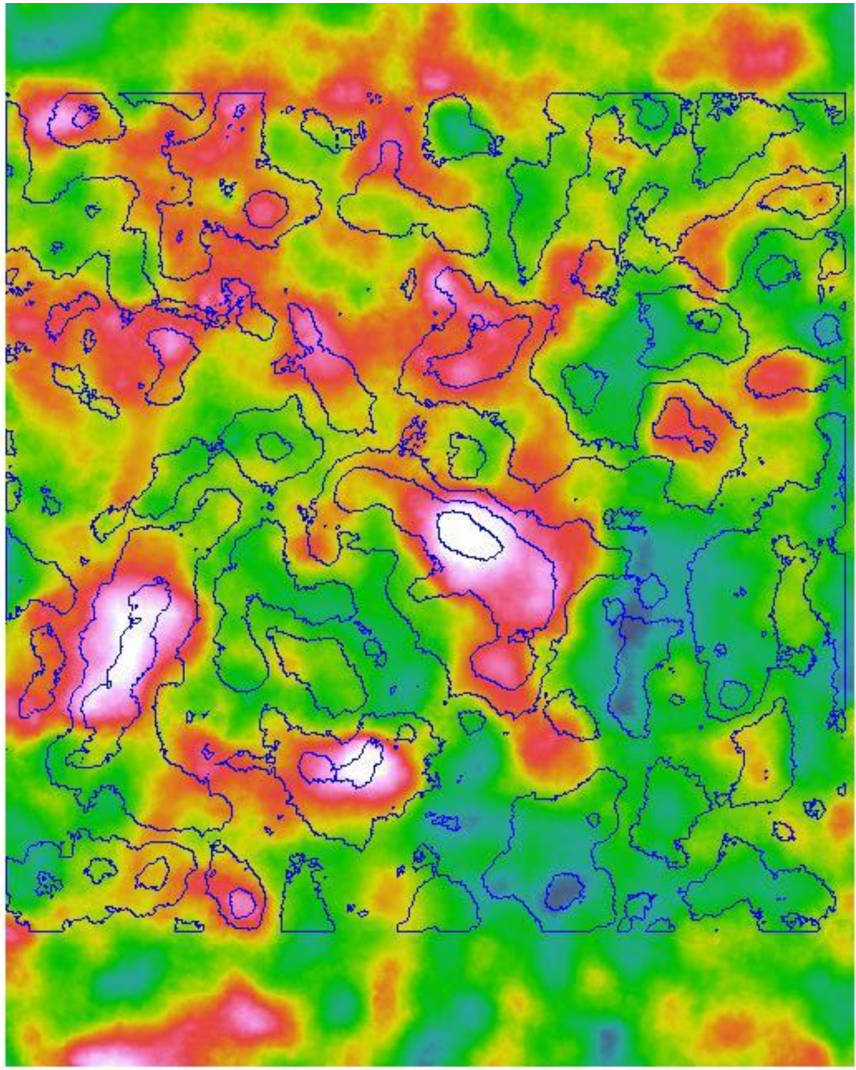
Optical Image

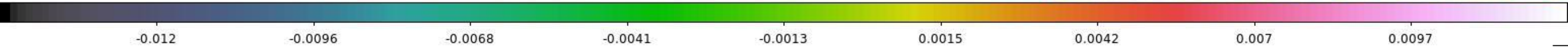


I-filter mass map

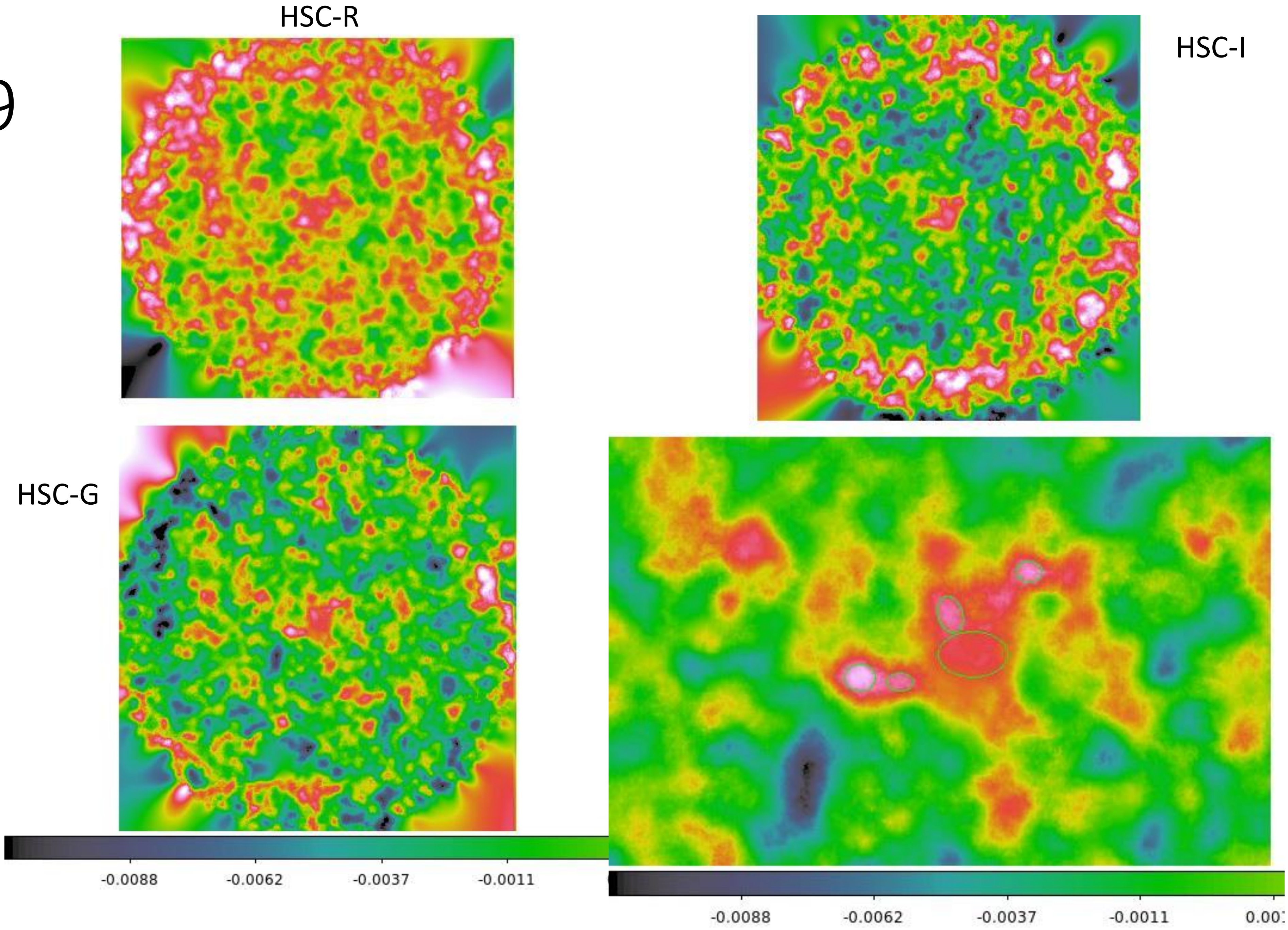


G-filter mass map





A2199


HSC-R
HSC-I
HSC-G
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-0.0037
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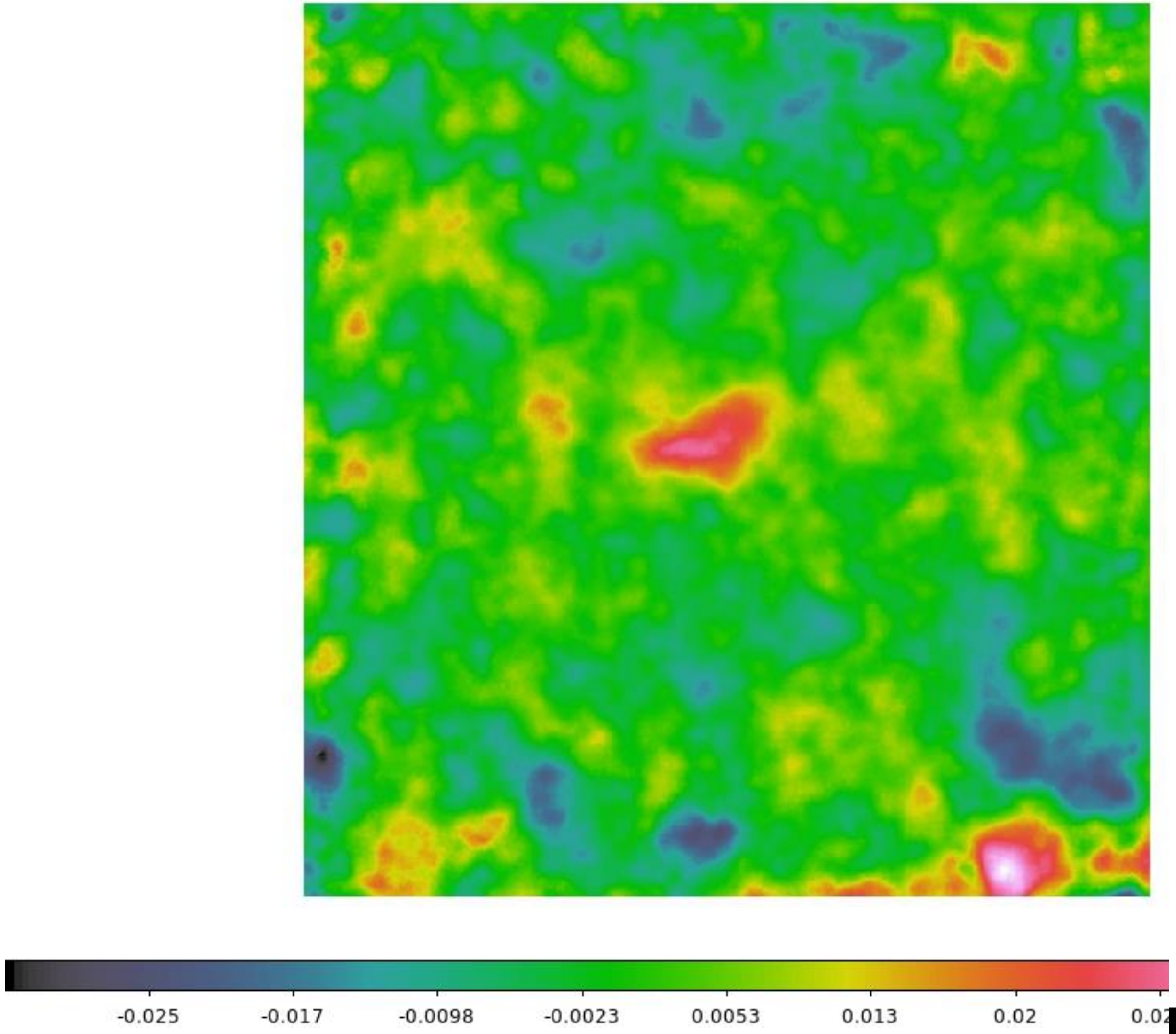
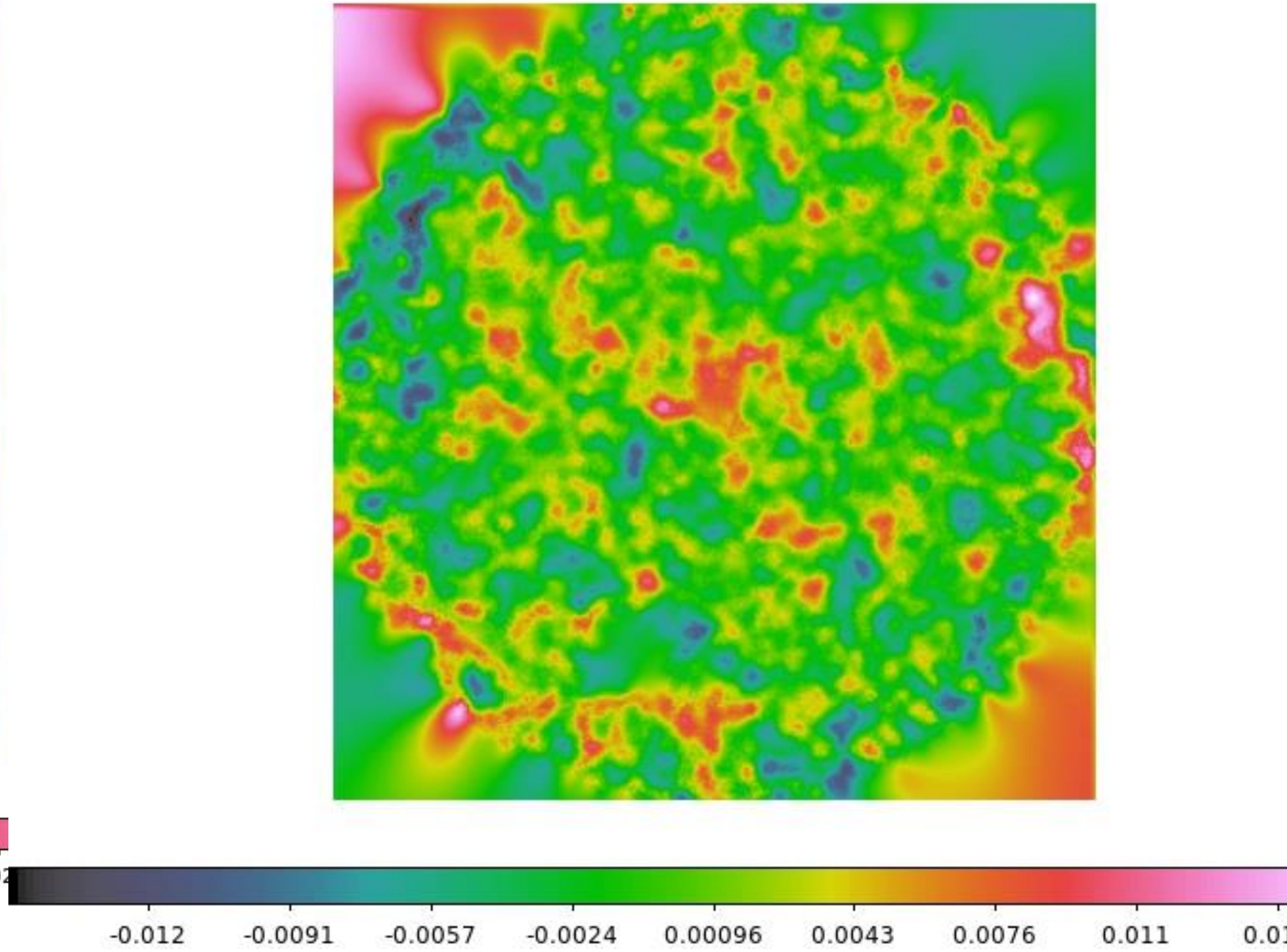
-0.0088
-0.0062
-0.0037
-0.0011
0.00

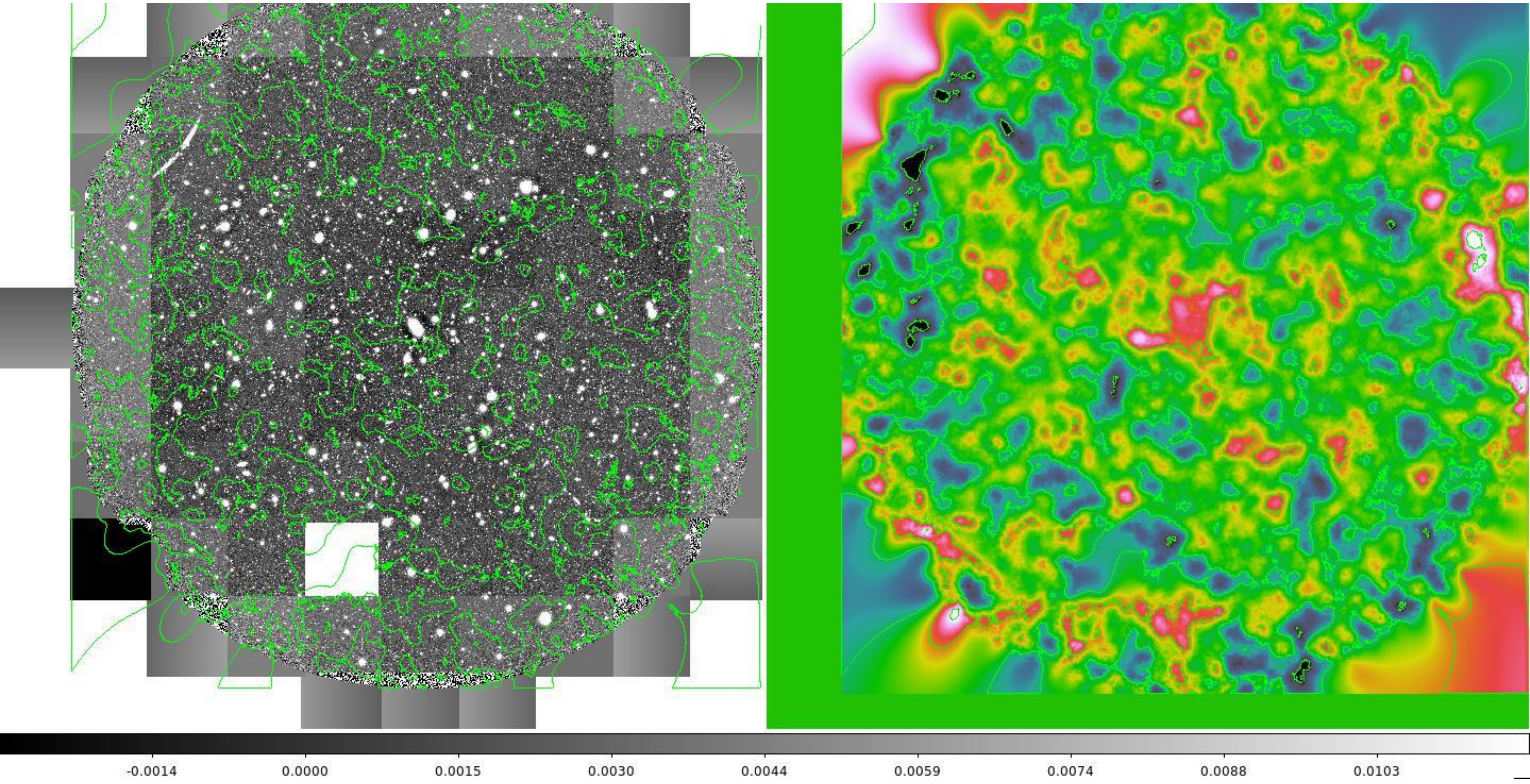
A2199



CFHT-I

HSC-G




-0.0014
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0.0103

Q & A

Acknowledgement

Professor Dell'Antonio, Brown University

Brown University

The Chinese University of Hong Kong, Wu Yee Sun College

The Chinese University of Hong Kong, Physics Department

The Chinese University of Hong Kong

Reference

[1] The Dark Matter Mystery: Gravitational Lensing

https://www.youtube.com/watch?v=7xKFrdzhM2Y

[2] Gravitational Lenisng: An Astrophysical Tool. Springer (2002).

[3] Massimo Meneghetti. Introduction to Gravitational Lensing: Lecture scripts.

[4] Large Synoptic Survey Telescope (LSST) Data Products Definition Document. (2017).

[5] https://en.wikipedia.org/wiki/Point_spread_function

[6] http://ned.ipac.caltech.edu/