Effects of Wavelength Dependent PSF on Galaxy Shear & Mass Measurement

Physics Ph.D. Prospectus Defense By,

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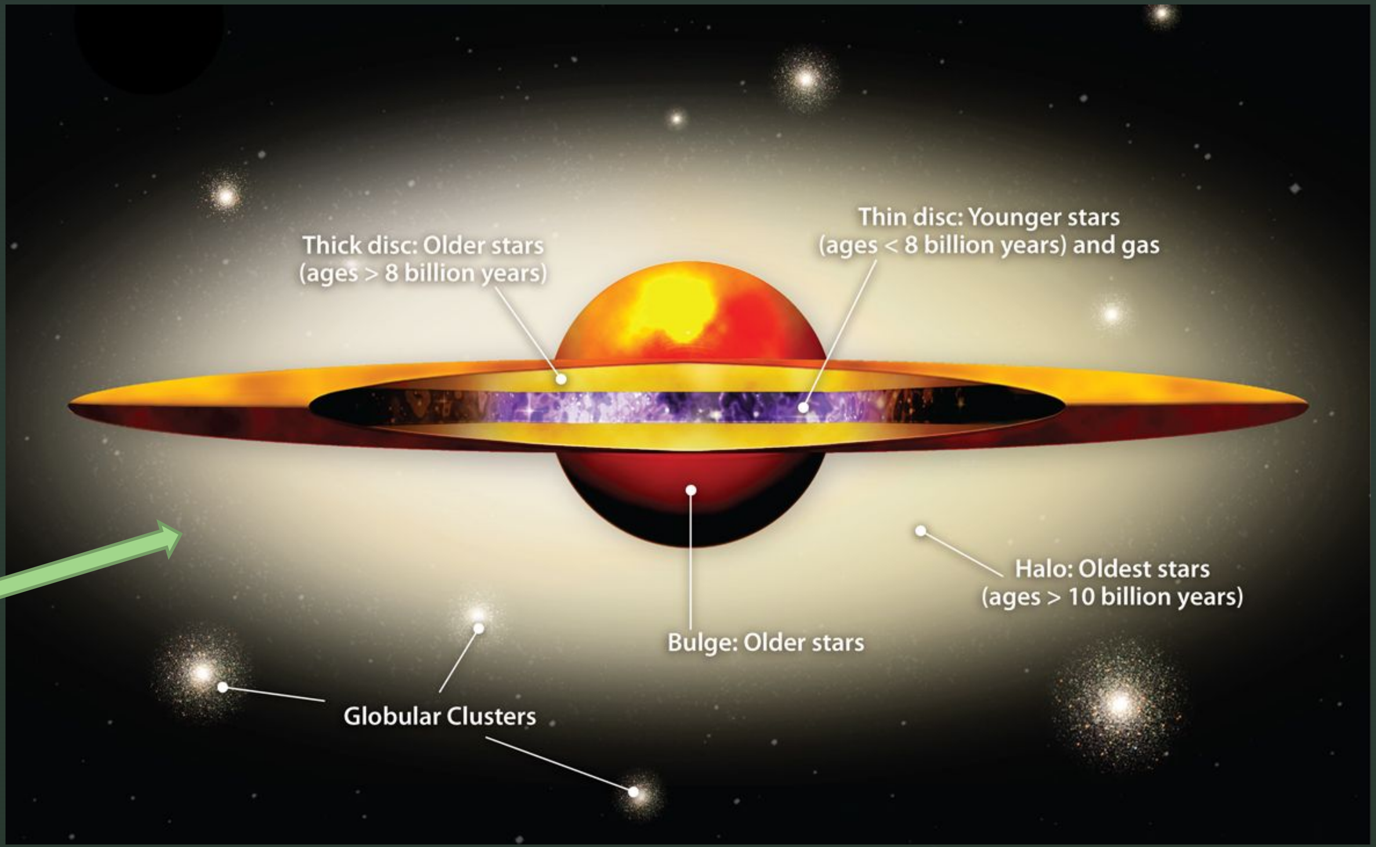
Outline

- Schematic Diagram of Project
- Introduction
- Galaxy Fitting
- PSF Creation
- Galaxy Simulation using **Jedisim**
- Shear Analysis
- Mass Estimation
- Timeline
- References

ACRONYMS

ACS	Advanced Camera for Surveys
CDM	Cold Dark Matter
CMB	Cosmic Microwave Background
DE	Dark Energy
DM	Dark Matter
DMstack	Data Management stack pipeline of LSST
FWHM	Full Width Half Maximum
GR	General Relativity
HST	Hubble Space Telescope
IMCAT	Image and Catalog Manipulation Software
LSS	Large Scale Structure
LSST	Large Synoptic Survey Telescope
PSF	Point Spread Function
SED	Spectral Energy Distribution
UDF	Ultra Deep Field
WFC3	Wide Field Camera 3 of LSST
WFIRST	Wide-Field Infra-red Survey Telescope

Parts of a Galaxy



Dark Matter Halo

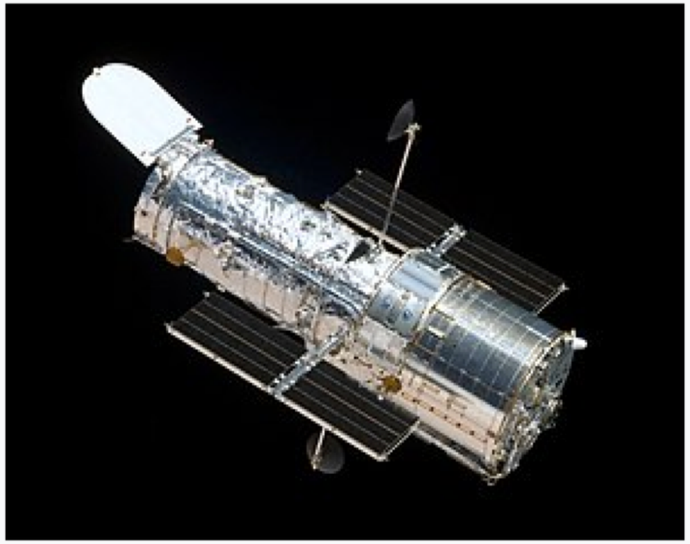
(Source: SolStation.com)

HST & LSST

1. HST (Space Based Telescope)
2. LSST (Ground Based Telescope)

(Source: Wikipedia)

Hubble Space Telescope



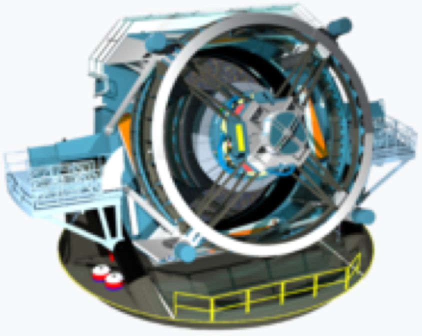
The Hubble Space Telescope as seen from the departing Space Shuttle *Atlantis*, flying Servicing Mission 4 (STS-125), the fifth and final Hubble mission

Mission type	Astronomy
Operator	NASA · ESA · STScI

Main telescope

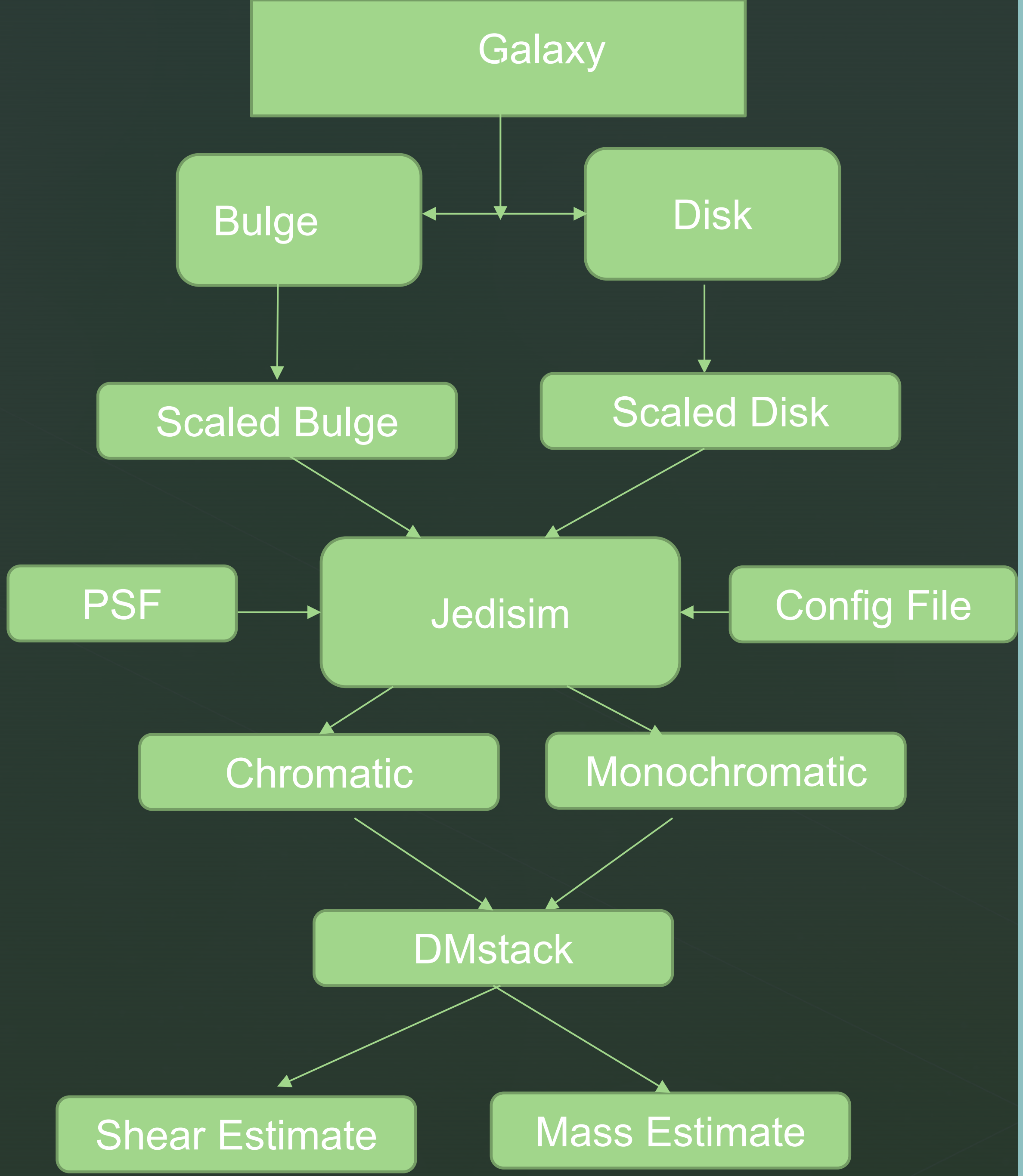
Type	Ritchey–Chrétien reflector
Diameter	2.4 m (7.9 ft)
Focal length	57.6 m (189 ft)
Focal ratio	*f*/24
Collecting area	4.5 m^2 (48 sq ft)[5]
Wavelengths	Near-infrared, visible light, ultraviolet

Large Synoptic Survey Telescope



Rendering of completed LSST

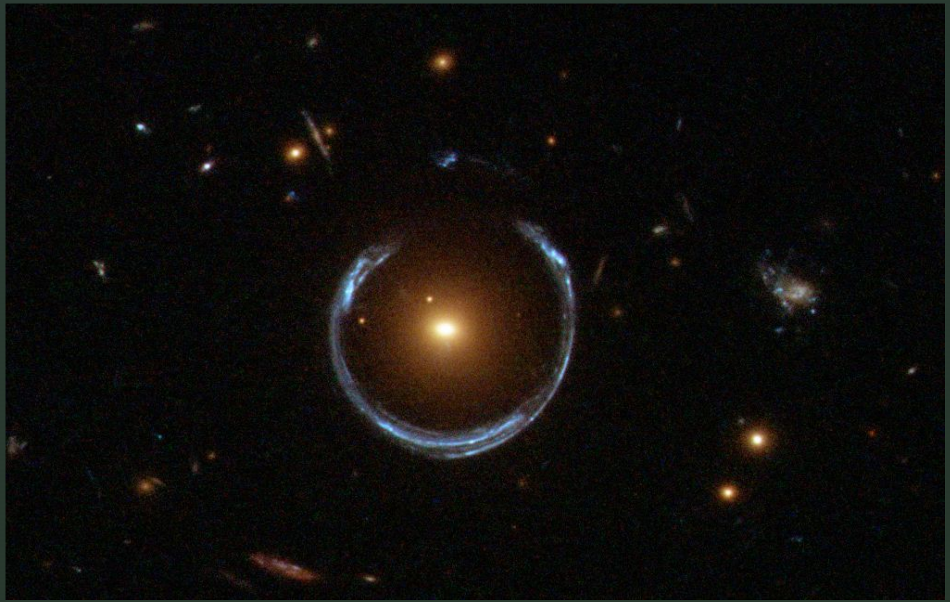
Location(s)	Cerro Pachón, Coquimbo Region, Chile
Coordinates	30°14′40.7″S 70°44′57.9″W[1][3][4]
Altitude	2,663 m (8,737 ft), top of pier[1][5]
Wavelength	320–1060 nm[6]
Built	2014–2019
First light	2019[7]
Telescope style	Three-mirror anastigmat, Paul-Baker / Mersenne-Schmidt wide-angle[8]
Diameter	8.417 m (27.6 ft) physical 8.360 m (27.4 ft) optical 5.116 m (16.8 ft) inner[9][10]
Secondary diameter	3.420 m (1.800 m inner)[9]
Tertiary diameter	5.016 m (1.100 m inner)[9][10]
Angular resolution	0.7″ median seeing limit 0.2″ pixel size[6]
Collecting area	35 square metres (376.7 sq ft)[6]
Focal length	10.31 m (f/1.23) overall 9.9175 m (f/1.186) primary


Galaxy
Bulge
Disk
Scaled Bulge
Scaled Disk
PSF
Jedisim
Config File
Chromatic
Monochromatic
DMstack
Shear Estimate
Mass Estimate


HST UDF Images
(20,000 from 200
galaxies)
(Appear lensed)
SIS Lens
(Cluster,NS,BH,etc)
Observe from Earth
LSST + PSF

Introduction to Gravitational Lensing

- When the light from a distant object is coming to the observer, if there is a massive object near to the line to sight, then the original object appears to be enlarged and distorted (or in some case a circular ring or multiple images of the same objects are seen) which is called Gravitational Lensing.



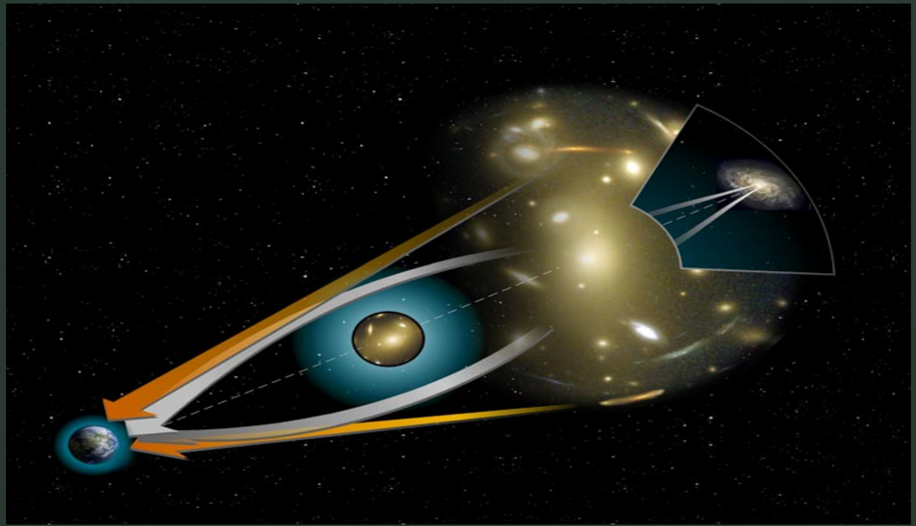
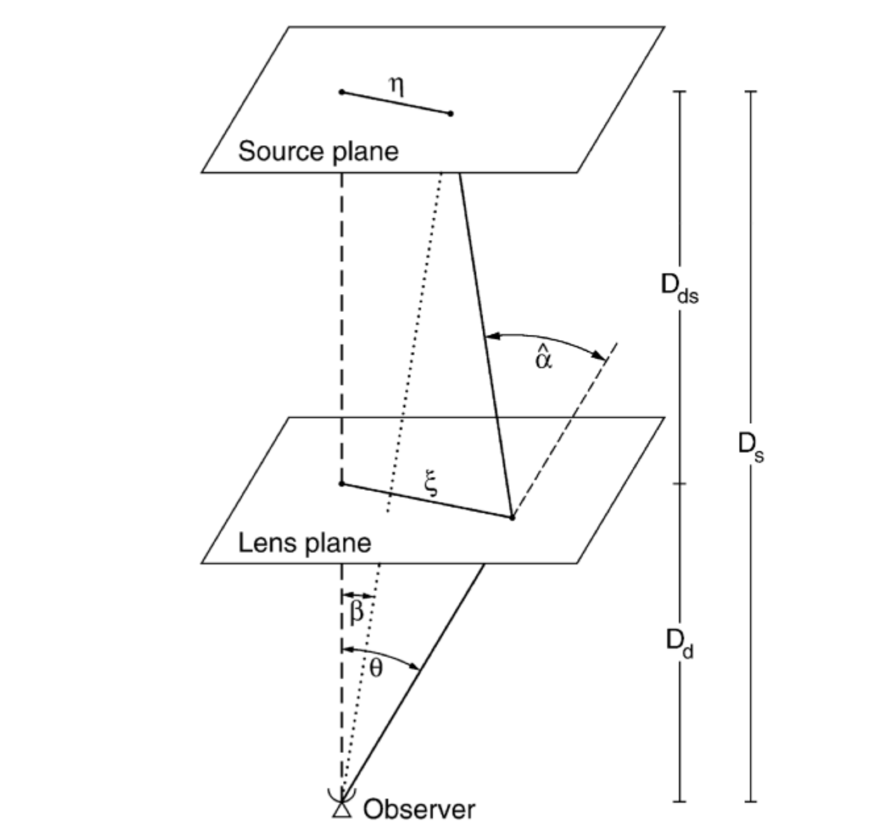


Fig: Left: Einstein Ring around a galaxy and Right: Multiple Images due to lensing (Source: wikipedia)

Lensing Theory



Deflection Angle

$$\hat{\alpha} = \frac{4GM}{c^2 \xi}.$$

Einstein Angle

$$\boxed{\theta_E = \sqrt{\frac{4GM}{c^2}\frac{D_{ds}}{D_s D_d}}} \quad \text{(Einstein Angle).}$$

Lens Equation

$$y = \frac{\boldsymbol{\beta}}{\theta_E} \; ; \; x = \frac{\boldsymbol{\theta}}{\theta_E}$$

$$\mathbf{y} = \mathbf{x} - \frac{\mathbf{x}}{|\mathbf{x}|^2}.$$

Fig: Gravitational Lensing (Source: Schneider and Bartelmann 2001)

Lensing Theory Contd.

Now we can write the observed surface brightness $\boldsymbol{I}(\boldsymbol{\theta})$ in terms of distortion matrix as

$$\boxed{\boldsymbol{I}(\boldsymbol{\theta}) = \boldsymbol{I}^s[\beta_0 + \mathscr{A}(\boldsymbol{\theta})(\theta - \theta_0)]} \quad \text{(Observed Surface Brightness)} \tag{25}$$

In terms of deflection potential ψ *Jacobian matrix* $\mathscr{A}$ can be written as

$$\mathscr{A}(\boldsymbol{\theta}) = \frac{\partial \beta}{\partial \boldsymbol{\theta}} \tag{26}$$

$$= (\delta_{ij} - \frac{\partial^2 \psi(\boldsymbol{\theta})}{\partial \theta_i \partial \theta_j})$$

$$= \begin{pmatrix} 1 - \psi, 11 & -\psi_{,12} \\ -\psi, 21 & 1 - \psi_{,22} \,. \end{pmatrix} \tag{27}$$

From these deflection potential terms, we define shear components

$$\gamma_1 = \frac{1}{2}(\psi_{,11} + \psi_{,22}) \tag{28}$$

$$\gamma_2 = \psi_{,12} \tag{29}$$

Here, the two components tensor γ is called *shear* and is given by

$$\boxed{\gamma \equiv \gamma_1 + i\gamma_2 = |\gamma| e^{2i\phi}} \quad \text{(Shear)} \tag{30}$$

Here, γ_1 and γ_2 are two components of shear as given in equation (28) and ϕ is the phase angle.

$$\mathscr{A}(\boldsymbol{\theta}) = \begin{pmatrix} 1 - \kappa - \gamma_1 & -\gamma_2 \\ -\gamma_2 & 1 - \kappa + \gamma_1 \end{pmatrix}$$

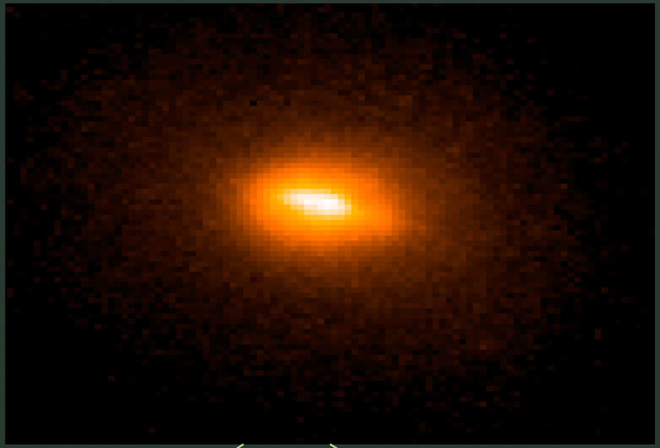
$$\boxed{\kappa = \frac{1}{2}(\psi_{,11} + \psi_{,22})} \quad \text{(Convergence)}$$

$$\boxed{\mu(\boldsymbol{\theta}) \equiv \frac{1}{det|\mathscr{A}|}} \quad \text{(Magnification).}$$

$$\boxed{g(\boldsymbol{\theta}) \equiv \frac{\gamma(\boldsymbol{\theta})}{1 - \kappa(\boldsymbol{\theta})}} \quad \text{(Reduced Shear).}$$

(Source: Schneider and Bartelmann 2001)

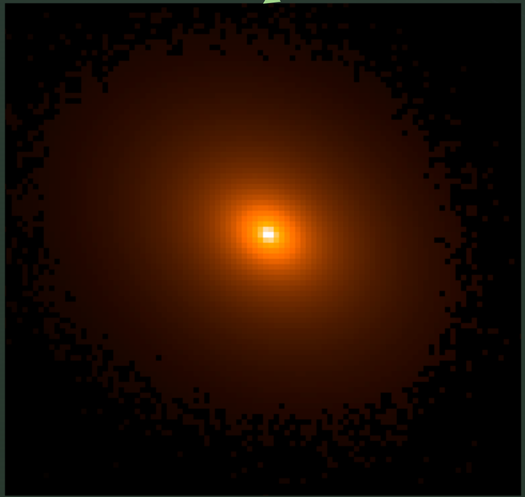
Part 2: Galaxy Fitting (Using Galfit)



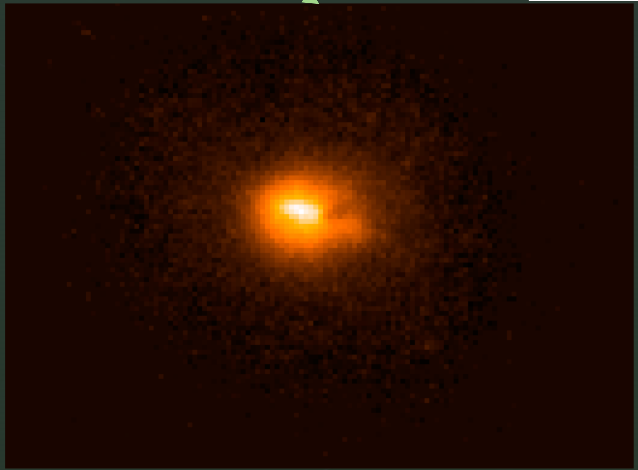
HST F814W Image
(Source: HST)

$$I(R) = I_e e^{-7.669[(R/R_e)^{1/4}-1]}$$

Bulge
(deVaucouleur
Profile)



$$ln\ I(R) = ln\ I_0 - kR$$



Disk
(Exponential
Disk Profile)

Rescaling Ratio of Bulge and Disk From HST to LSST

g0
g1
…
g200

Galfit

b0 d0
b1 d1
…
b200 d200

Bulge to Disk

Ratio Change

sb0 sd0
sb1 s d1
…
sb200 sd200

PSF Creation Using PhoSim

Background →

SED
(21 files) →

Instance
Catalog →

PhoSim

21 normalized
PSFs →

psf0
psf1
…
psf20

3 PSFs →

psfb
psfd
psfm

Equation for Rescaling

$$sb0 = b0 * \left(\frac{F_{b0} + F_{d0}}{F_{b0}.f_{ratb} + F_{d0}.f_{ratd}}\right) * f_{ratb} \quad (1)$$

$$f_{ratd} = \frac{\int_{\lambda_0}^{\lambda_{20}} f_{bz}(\lambda) d\lambda}{\int_{\lambda_{hst0}}^{\lambda_{hst20}} f_{bzcut}(\lambda) d\lambda} \quad (2)$$

$$f_{ratd} = \frac{\int_{\lambda_0}^{\lambda_{20}} f_{dz}(\lambda) d\lambda}{\int_{\lambda_{hst0}}^{\lambda_{hst20}} f_{dzcut}(\lambda) d\lambda} \quad (3)$$

$$(4)$$

$$F_{b0} = \text{Total flux of bulge0} \quad (5)$$

$$F_{d0} = \text{Total flux of disk0} \quad (6)$$

$$For\ LSST\ (z = 1.5) : fbz\ is\ SED\ for\ 3Gyr\ old\ galaxy \quad (7)$$

$$\lambda_0 = 2208\ \lambda_{20} = 2764 \quad (8)$$

$$For\ HST\ (z = 0.2) : fbzcut\ is\ SED\ for\ 12Gyr\ old\ galaxy \quad (9)$$

$$\lambda_{hst0} = 5898\ \lambda_{hst20} = 7990 \quad (10)$$

Creating PSF For Bugle, Disk, and Monochromatic

$$\text{Define :} \tag{1}$$

$$bfr0 = \frac{\int_{\lambda_0}^{\lambda_1} f_{bz}(\lambda) d\lambda}{\int_{\lambda_0}^{\lambda_{20}} f_{bz}(\lambda) d\lambda} \tag{2}$$

$$avg\_rsbd = \frac{\Sigma(F_{sb}/F_{sd})}{n_g} \tag{3}$$

$$avg\_rsbd\_d = \frac{1}{1 + avg\_rsbd} \tag{4}$$

$$avg\_rsbd\_b = \frac{avg\_rsbd}{1 + avg\_rsbd} \tag{5}$$

$$\tag{6}$$

Then,

$$psfb = \frac{p0 * bfr0 + p1 * bfr1 + ... + p20 * bfr20}{bfr0 + bfr1 + ... + bfr20} \tag{7}$$

$$psfd = \frac{p0 * dfr0 + p1 * dfr1 + ... + p20 * dfr20}{dfr0 + dfr1 + ... + dfr20} \tag{8}$$

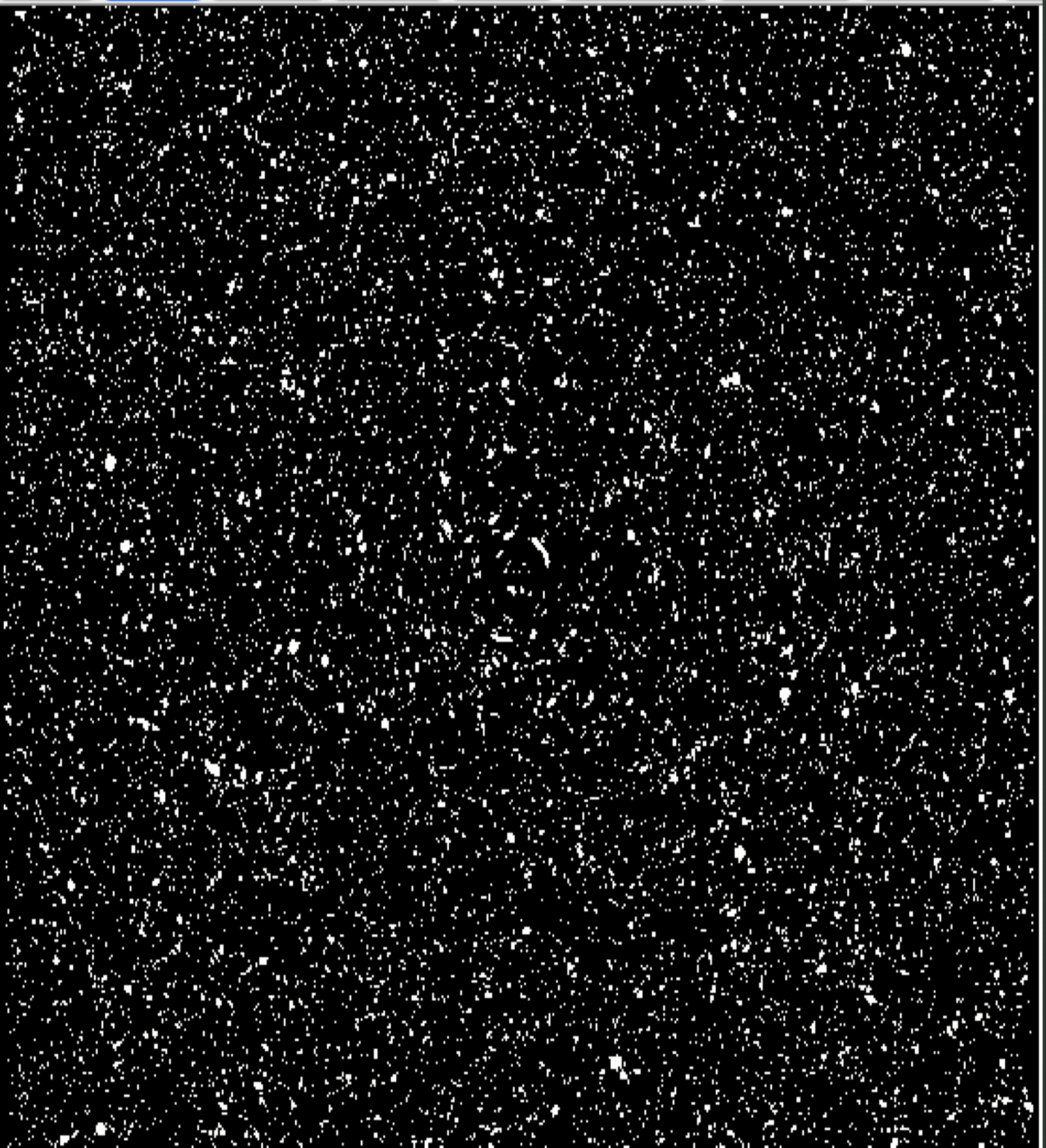
$$psfm = psfb * avg\_rsbd\_b + psfd * avg\_rsbd\_d \tag{9}$$

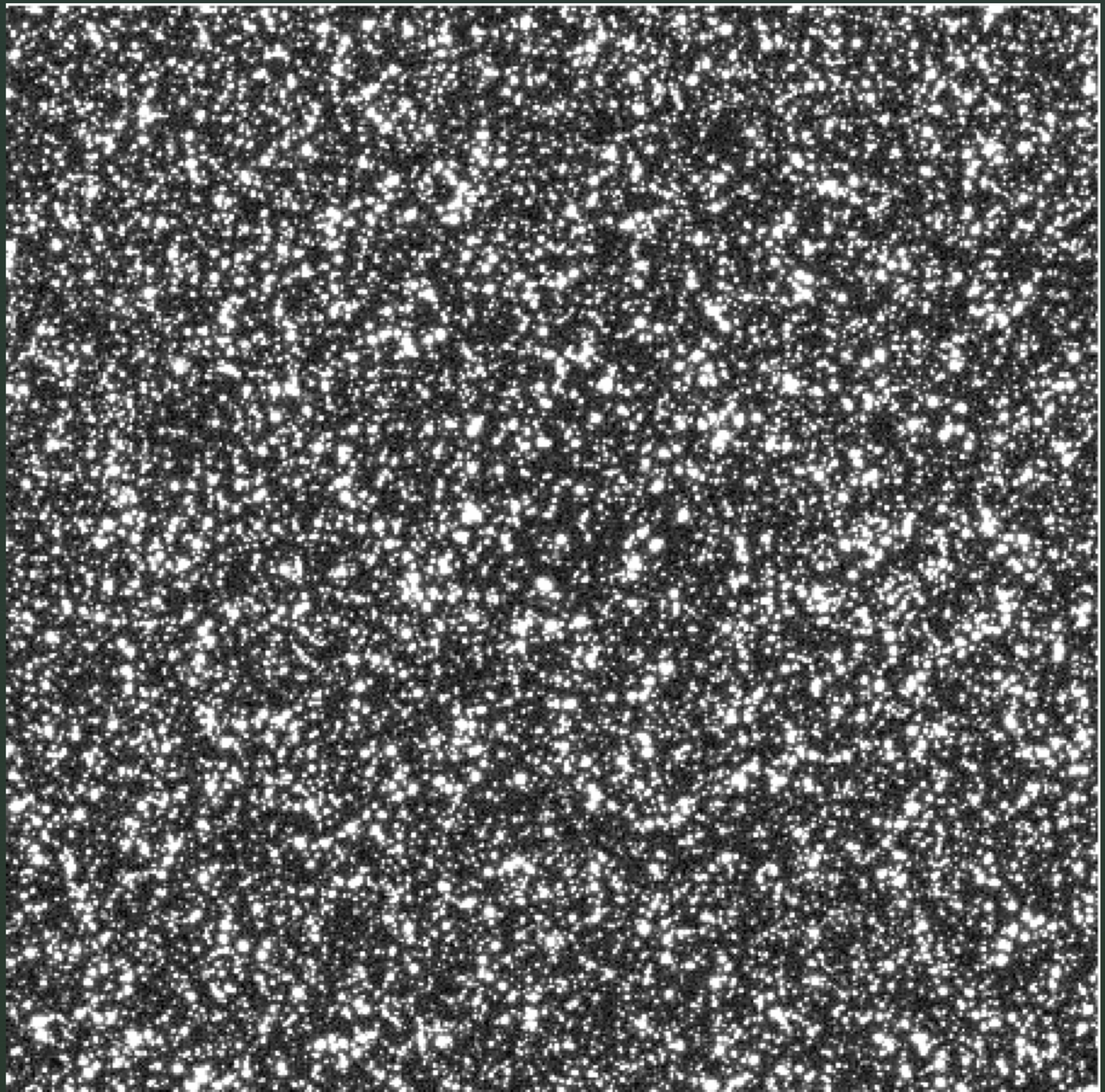
Simulating LSST Images using Jedisim

- Created by Daniel Parker and Dr. Ian Dell Antonio of Brown University (2013).
- Adapted, Modified, and Maintained by Bhishan with help of Dr. Clowe from 2014.[1]
- Takes the HST or CANDELS or Other Surveys Images as input and gives LSST simulated images.
- Jedisim takes in three inputs:
  * Input galaxies (scaled bulge or scaled disk or scaled_bulge_disk).
  * PSF (psfb or psfd or psfm)
  * Physics configuration file (configb or configd or configm)
- Jedisim gives out following outputs:
  * Chromatic Image (lsst)
  * Monochromatic Image (lsst_mono).
  * 90 degree rotated version of chromatic and monochromatic images.

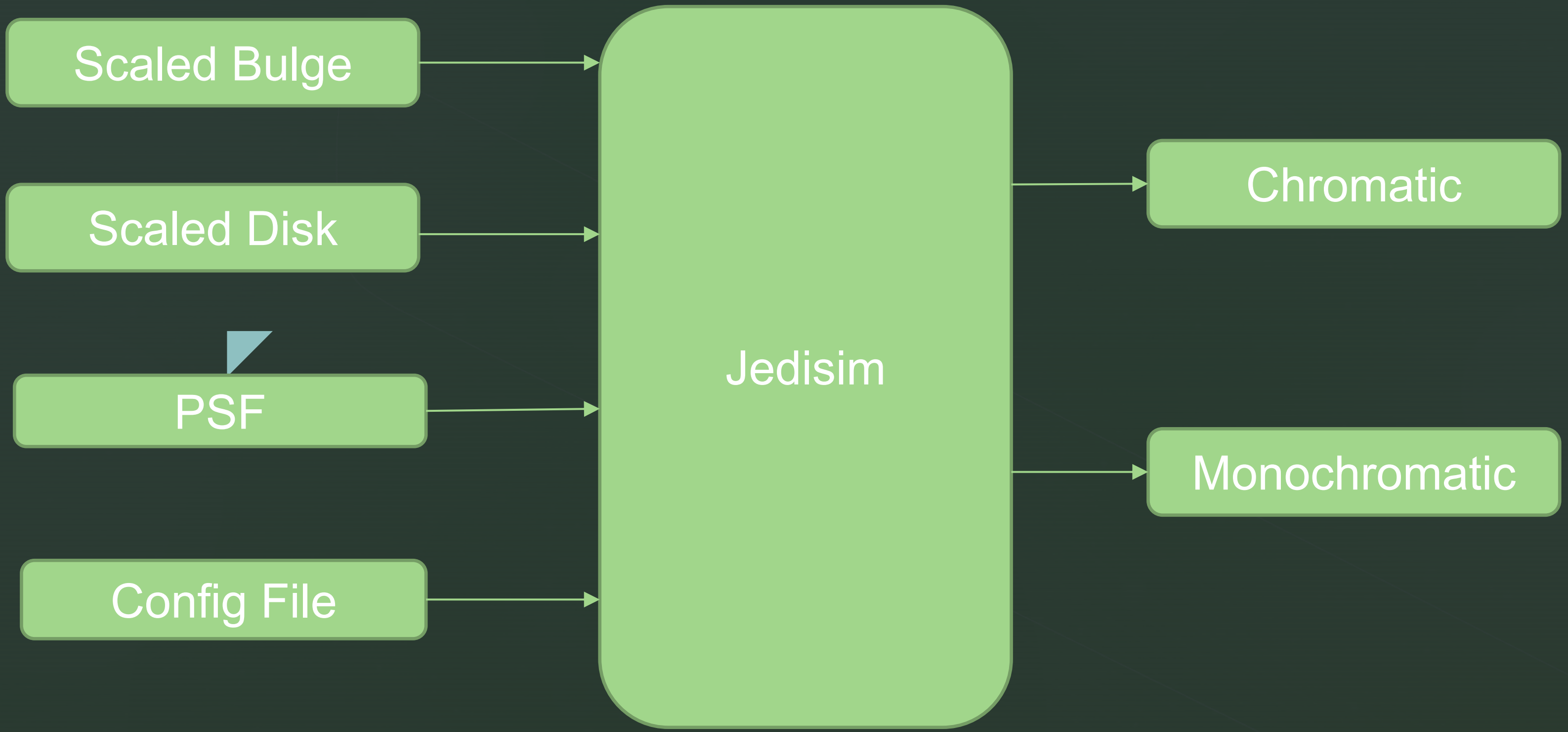
1: https://github.com/bhishanpdl/jedisim

HST and LSST Images





Jedisim Schematic Diagram



Creating Catalog

- Galaxy Parameters
  - Magnitude (Power law, $22 < M < 28$)
  - Radius (r50 radius binned by integer magnitude)
  - Redshift (Constant, also can be changed)
  - Position (601 * 601 pixels)
  - Angle

Create Galaxy Stamps Using Jeditransform

- We have 201 HST ACS UDF F814W Galaxy cutouts.
- The script “Jeditransform.c” will create more images from these.
- Jeditransform reads Position, Angle, Magnitude, Redshift, and Radius from the catalog file and create more stamps.
- Here we generate 20,000 HST galaxy stamps.

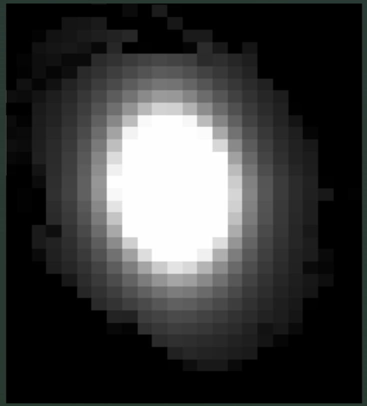
Distort the Stamps Using Gravitational Lens

- Program: Jedidistort
  - lens.txt
  - create lensed
- Mass Profiles
  - Navarrow-Frenk-White (NFW)
  - Singular Isothermal Sphere (SIS)
- Singualr Isothermal Sphere
  - ρ = $\frac{\sigma^2}{2\pi\, G\, r^2}$
  - σ is dispersion velocity

Transform and Distort Image

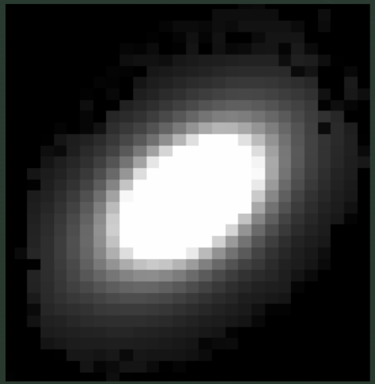
bulge0.fits

Transform



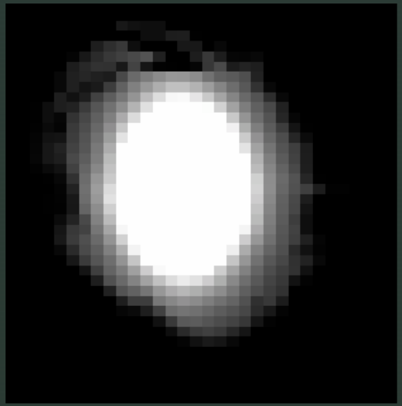
transformed_118.fits

transformed_360.fits

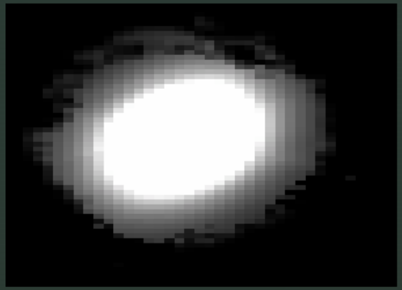


transformed_765.fits

Distort (Lens)



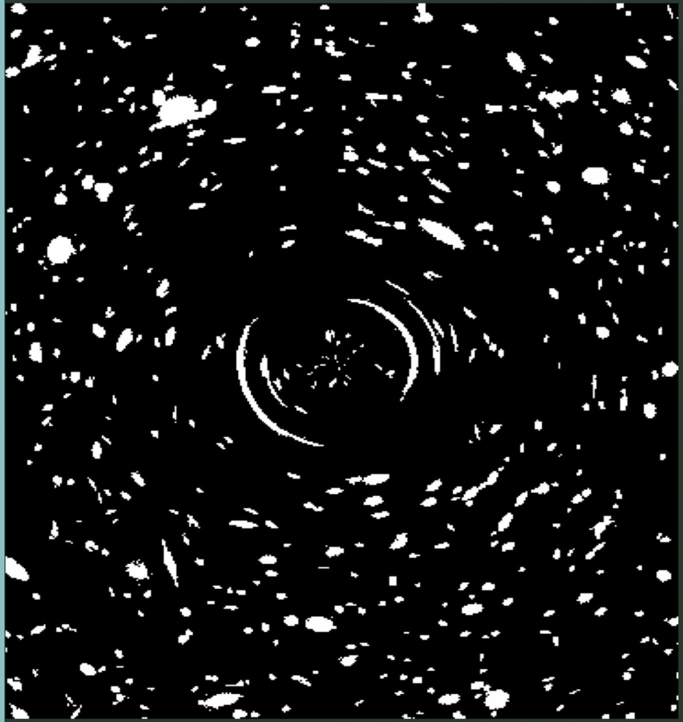
distorted_118.fits

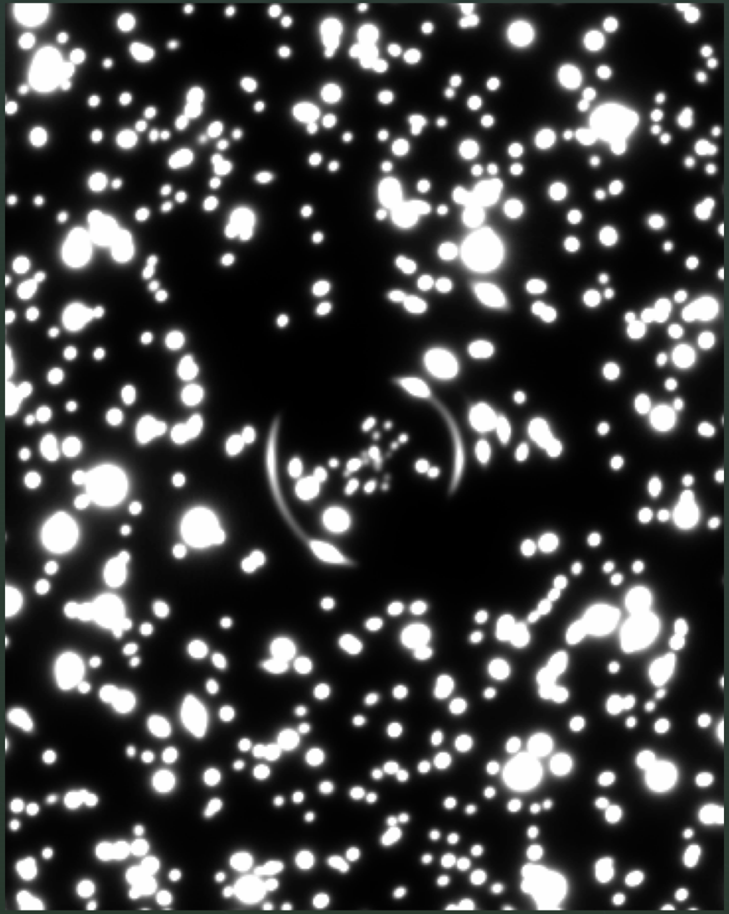


distorted_360.fits

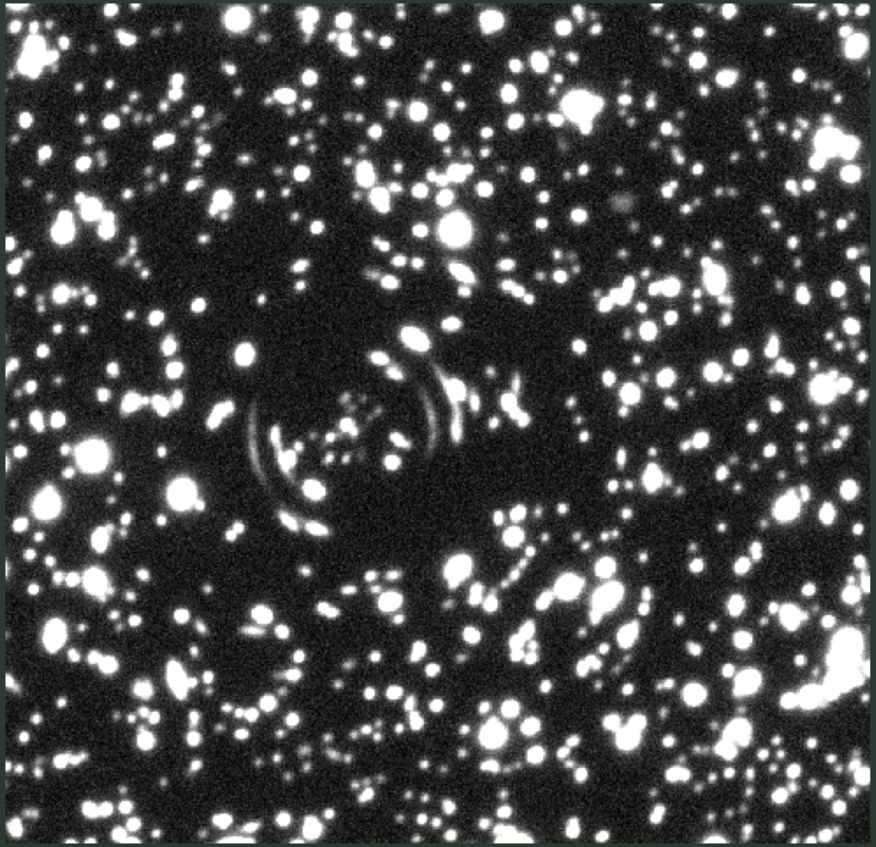
distorted_765.fits

Convolve HST Field with PSF

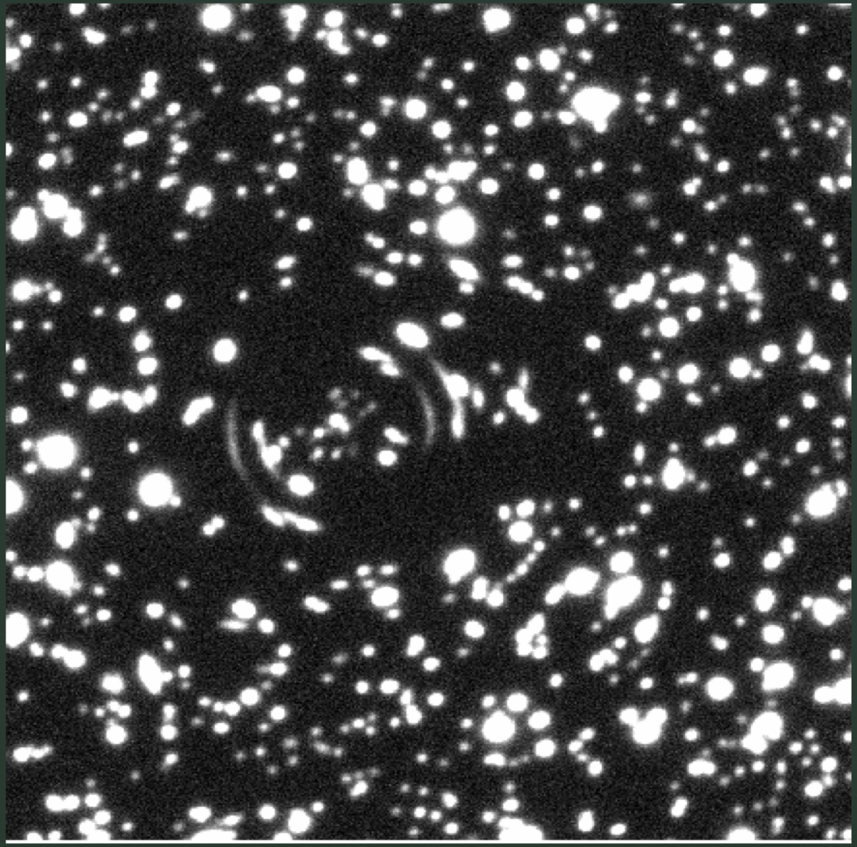




Create Monochromatic and Chromatic Image



lsst.fits (from 20,000 HST Images)



lsst_mono.fits (from 20,000 HST Images)

Shear Analysis on LSST Simulated Images (z=0.7)

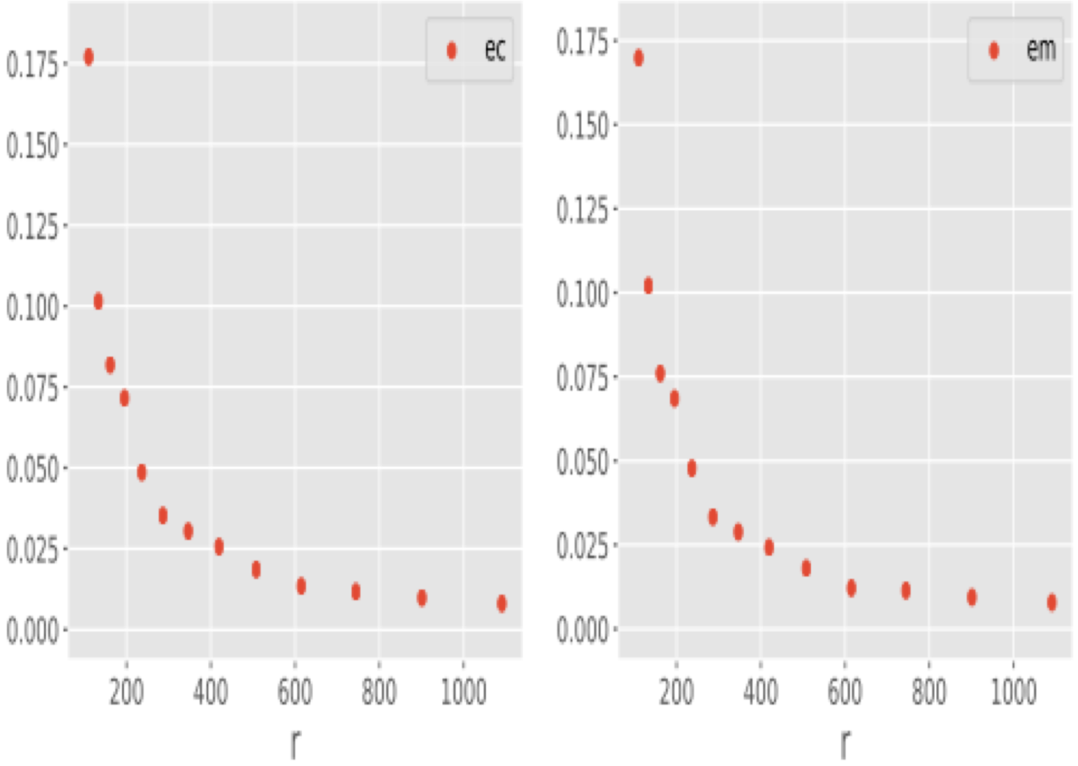


Figure 4: Ellipticites for chromatic and monochromatic files

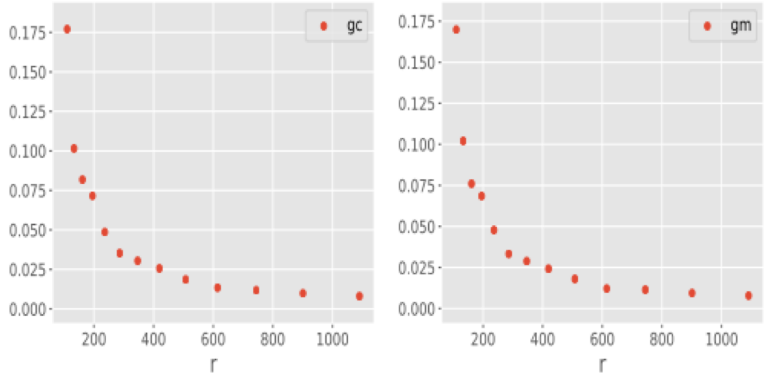


Figure 5: Shears for chromatic and monochromatic files

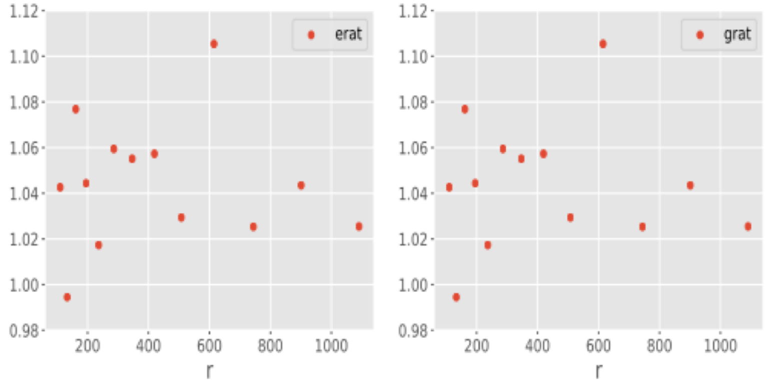


Figure 6: Ellipticites and Shears Ratio (chromatic/monochromatic)

Mass Estimation Using DMstack

- DMstack is LSST Data Management Pipeline
  - obs_file[1]
    - ingest images
    - Process CCD
    - Gives fits table with KSB parameters
  - Clusters[2]
    - Reads fits table in hdf5 format
    - Add photo-z to hdf5 file
    - Estimate mass using cluster_mass script

1. https://github.com/bhishanpdl/DMstack_obsfile_Clusters
2. https://github.com/bhishanpdl/DMstack_obsfile_Clusters/tree/master/run_clusters

Timeline

Table 2: Time-line

Start	Finish	Activity
Aug. 2014	March 2017	Working on galaxy simulating software Jedisim
April 2017	Jan. 2018	Release of Jedisim version 1.0
Sep. 2018	March 2019	Integrating Jedisim with LSST pipelines
March 2019	Aug. 2019	Writing and defending the Ph.D. dissertation

References

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