

arXiv:1411.5398

# Strong-Gravitational-Lens Hunter in Imaging Surveys

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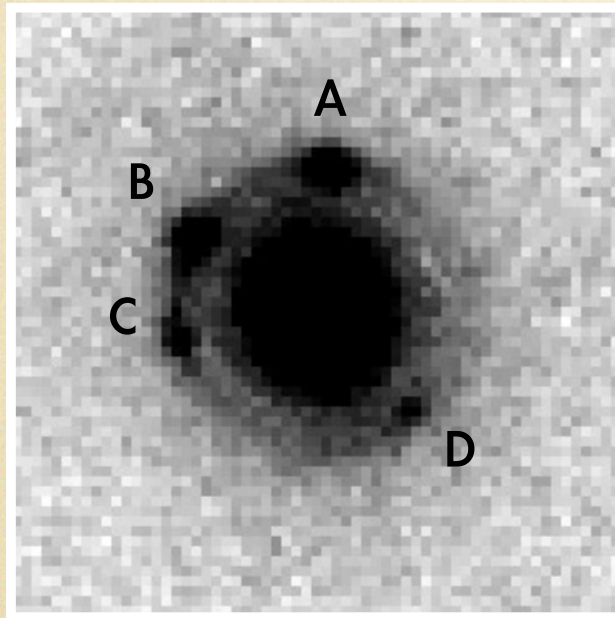
In collaboration with

Sherry Suyu (ASIAA), Tzihong Chiueh (NTU),  
Anupreeta More (Kavli IPMU), Phil Marshall (KIPAC),  
Jean Coupon (U. Geneva), Masamune Oguri (U. Tokyo),  
Paul Price (Princeton University)

Galaxies and Cosmology in Light of Strong Lensing  
2014 Nov. 21 @ Kavli IPMU



# Motivation



## Cosmology

probe dark energy through  
time delays of lenses

## Galaxy evolution

study galaxy structure by  
disentangling dark matter  
and baryons

## Black holes

co-evolution of supermassive  
black holes and spheroids

Currently there are only a handful of **4-image (quad)** lensed quasars

➡ expect to have thousands of lenses in current/upcoming survey.

e.g. ~600 lensed quasars (~80 quads) in Hyper Suprime-Cam (HSC) survey  
[Oguri & Marshall 2010]



HSC survey  
(Hyper Suprime-Cam)



Typical Apparent  
Diameter of the  
Moon (0.5 degrees)



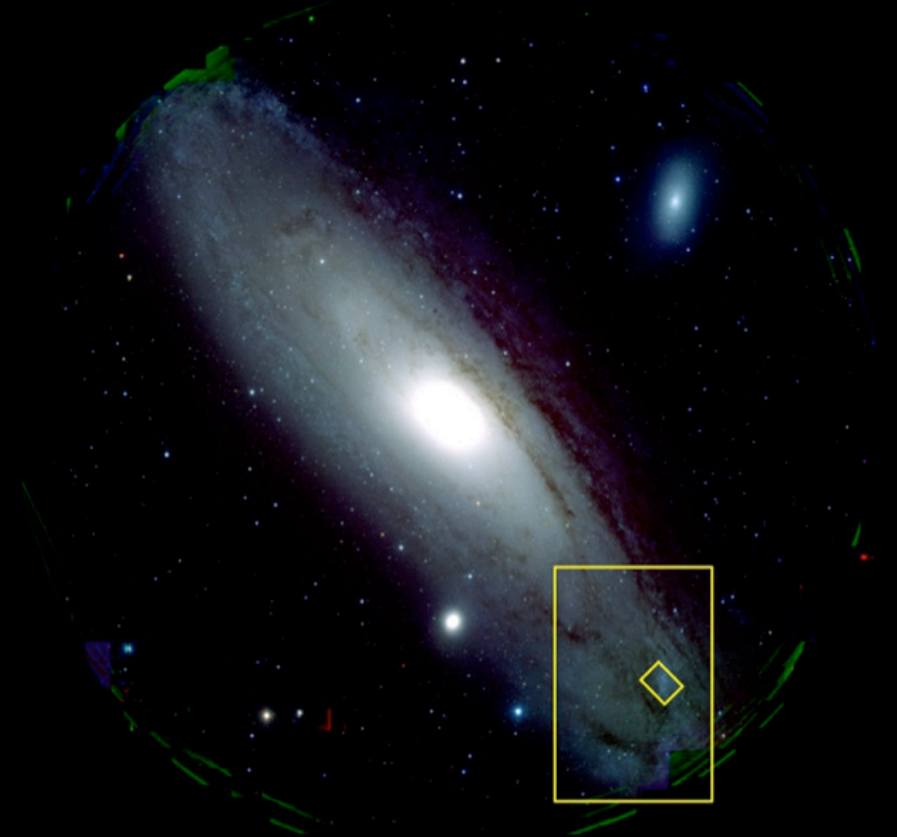
**Suprime-Cam**

First Light Release  
January 1999



**Suprime-Cam**

Image Release  
September 2001

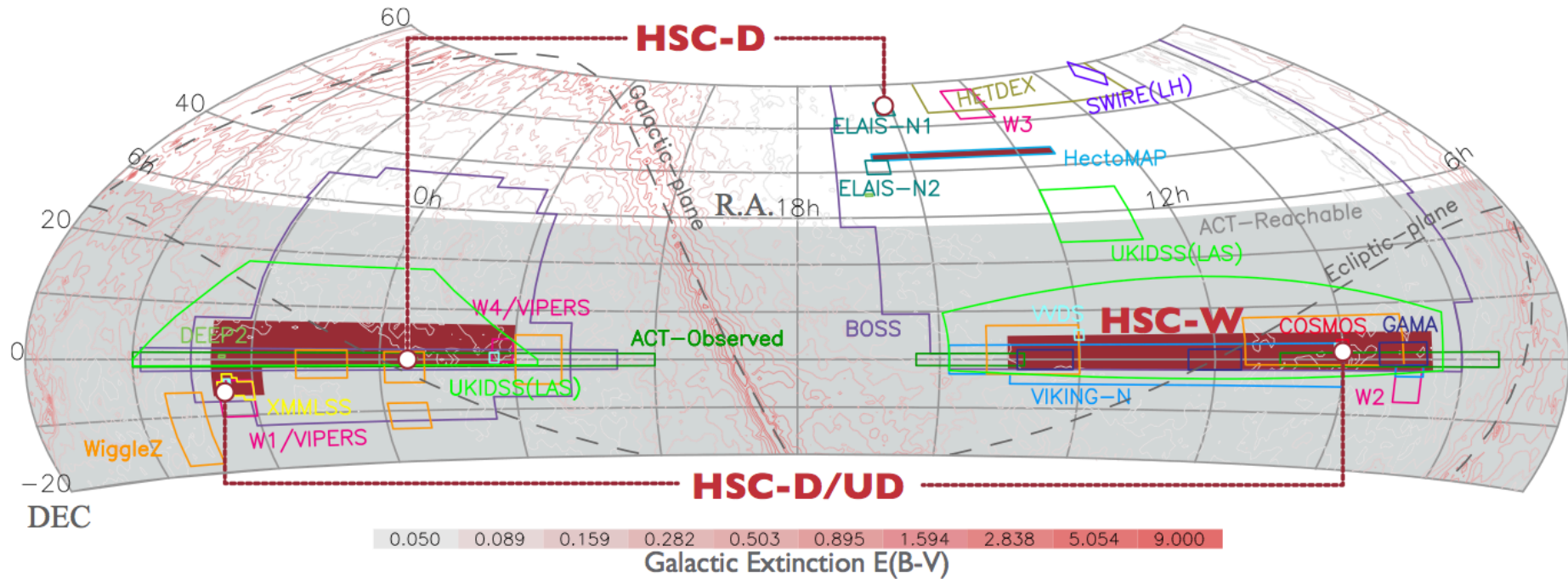


**Hyper Suprime-Cam**

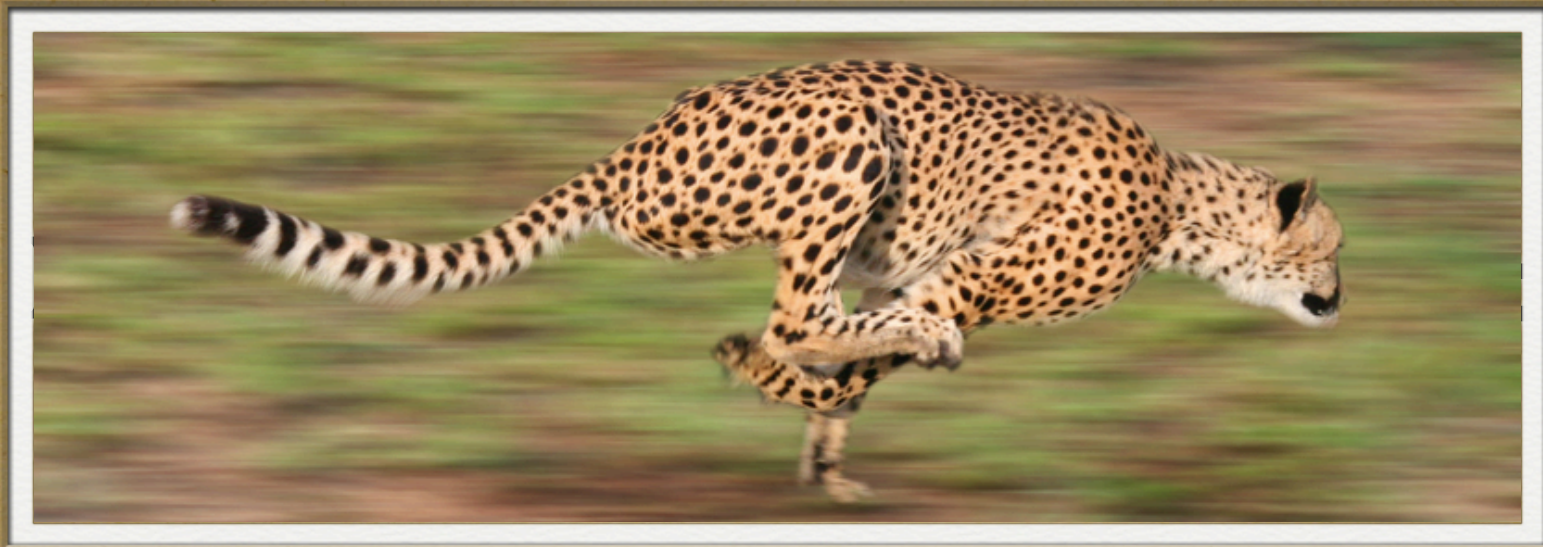
Image Release  
July 2013



# HSC Survey



Wide	1400 deg <sup>2</sup>	grizy	r~26
Deep	27 deg <sup>2</sup>	grizy+3NB	r~27
Ultra-Deep	3.5 deg <sup>2</sup>	grizy+3NB	r~28



# 重力和影像探奧號

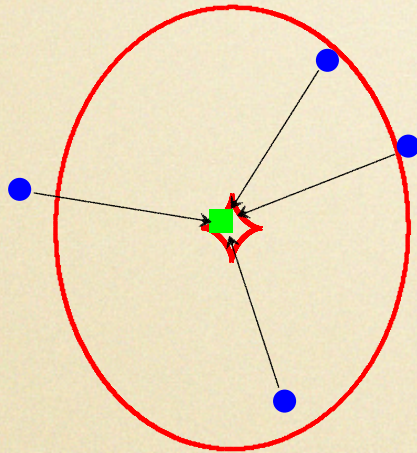
Chung-li He In-hsiang Tan Ao Hao

# CHITAH



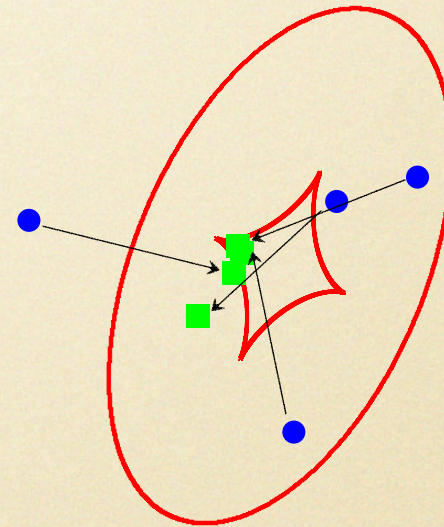
# Modeling the image configuration

small  $\chi^2$



probably a lens

large  $\chi^2$



probably NOT a lens



# Modeling the image configuration

Singular Isothermal Ellipsoid (SIE)  
for foreground lens galaxy

Surface mass density:

$$\kappa(x, y) = \frac{1}{2} \frac{r_{\text{ein}}}{\sqrt{x^2 + y^2} / q^2}$$

$r_{\text{ein}}$ : einstein radius

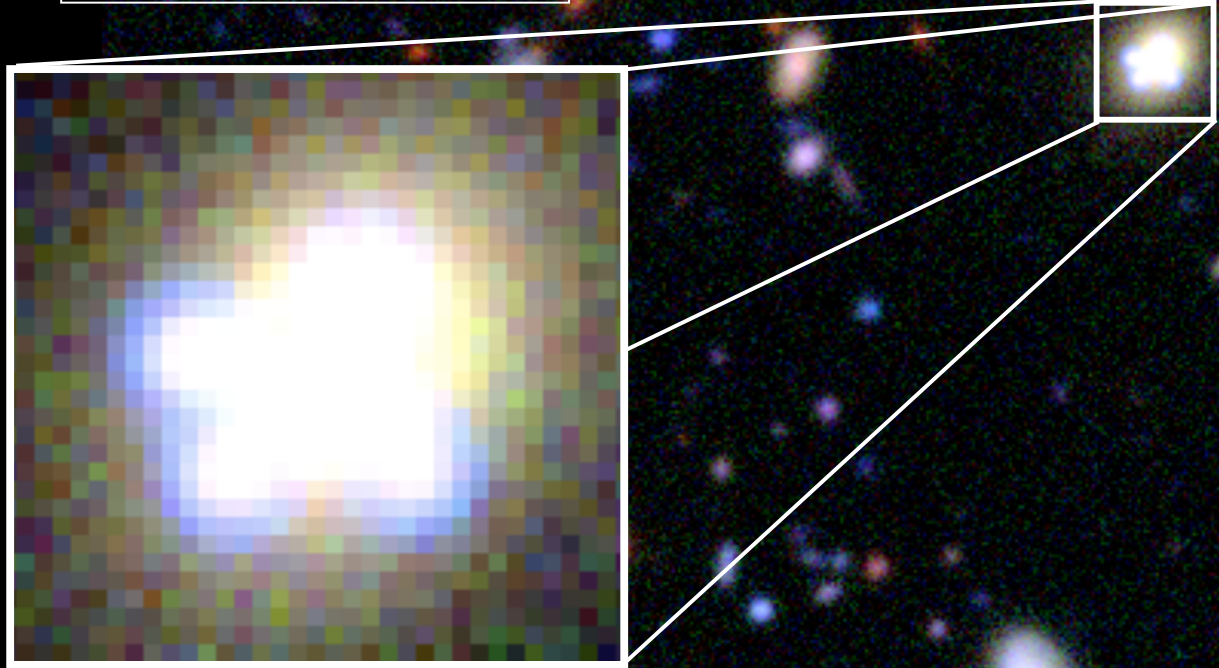
$q$ : projected axis ratio

PA: position angle of the lens

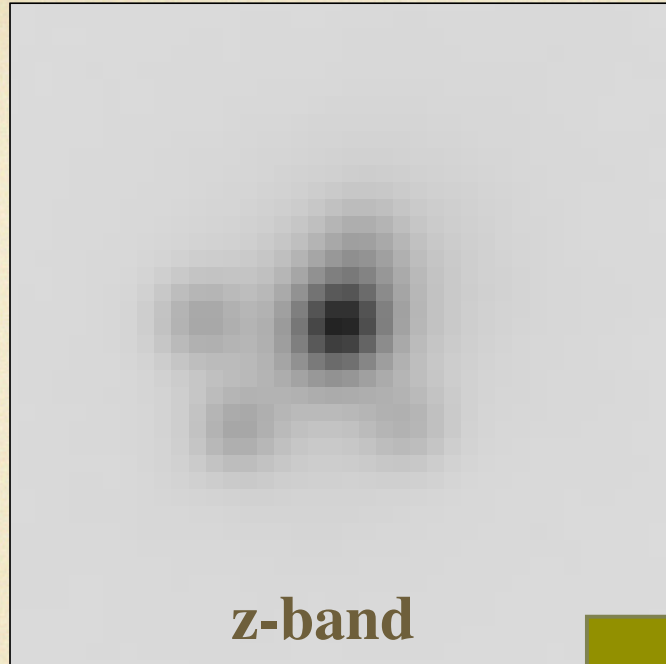
$(x_{\text{lens}}, y_{\text{lens}})$



simulated CFHTLS lens  
from Space Warps  
(Anupreeta More)



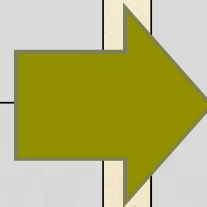




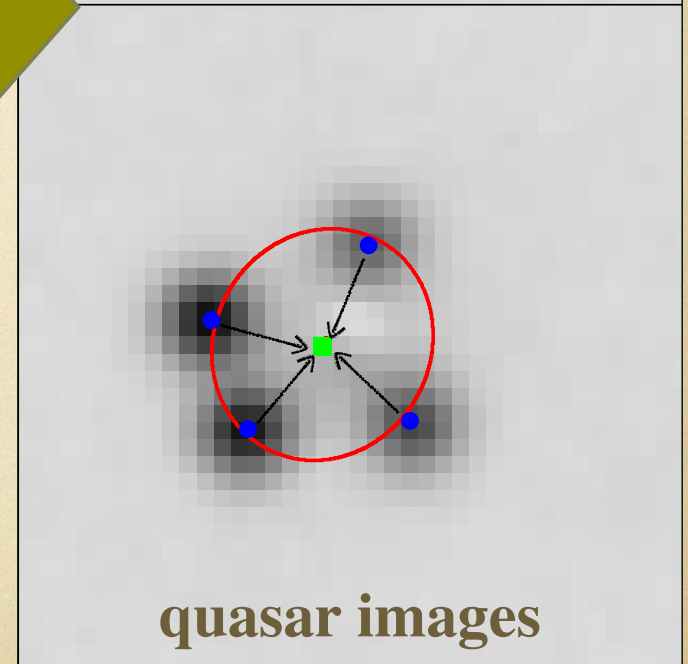
z-band



lens galaxy



g-band



quasar images

• **SIE profile:**

$r_{\text{ein}}$ : einstein radius

$q$ : axis ratio

PA: orientation

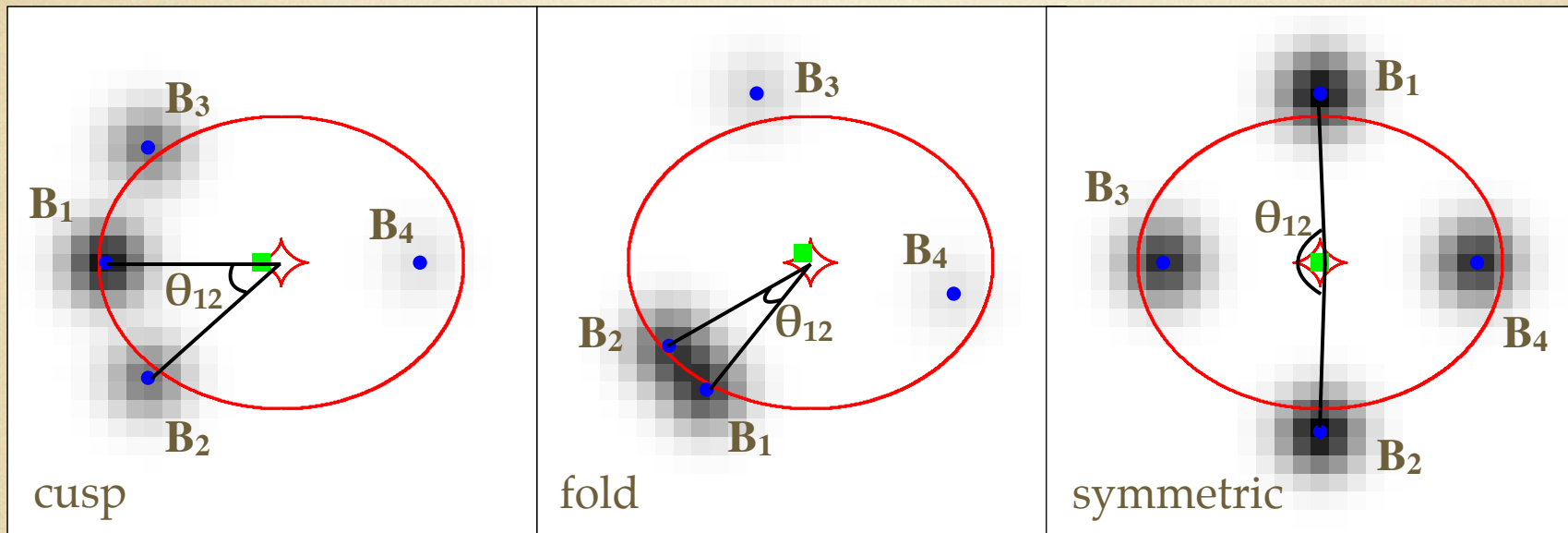
$(x_{\text{lens}}, y_{\text{lens}})$

**5 parameters**

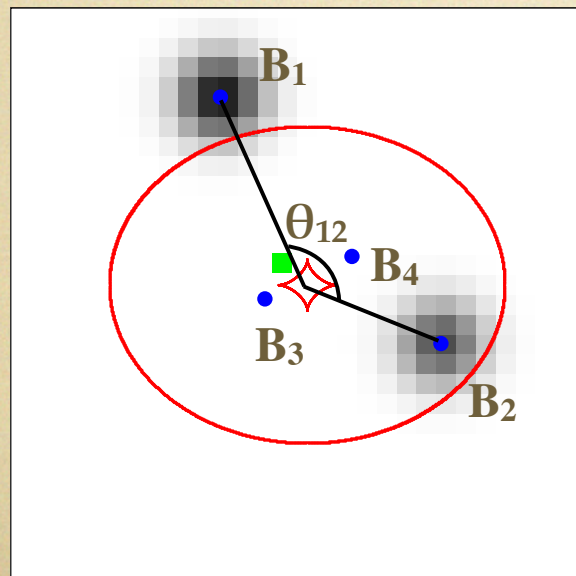
• **lens light centroid  
as prior for mass  
centroid**



## 4-image (quad)



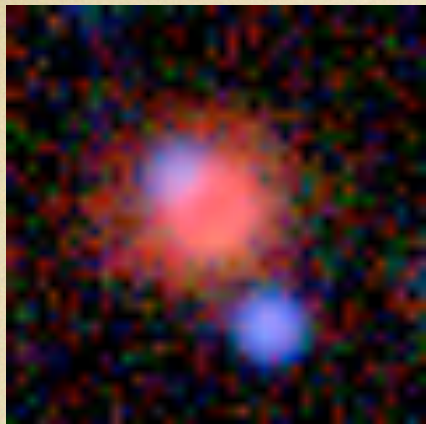
## 2-image (double)



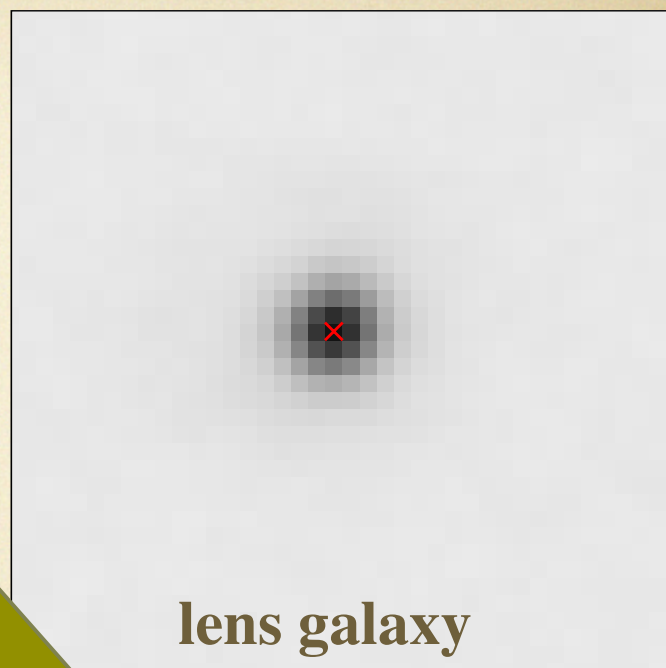
Selection rule for doubles:

$$B_4 / B_1 < 0.2 \Rightarrow \theta_{12} > 120^\circ$$

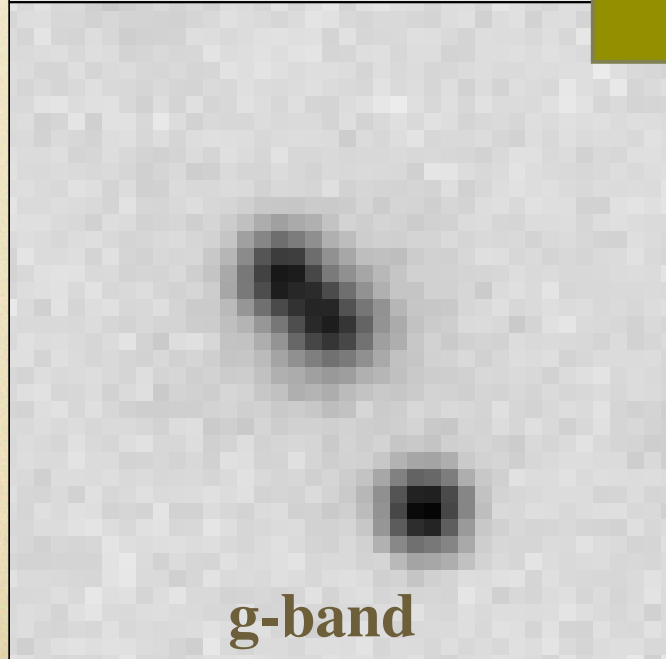
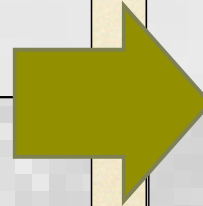




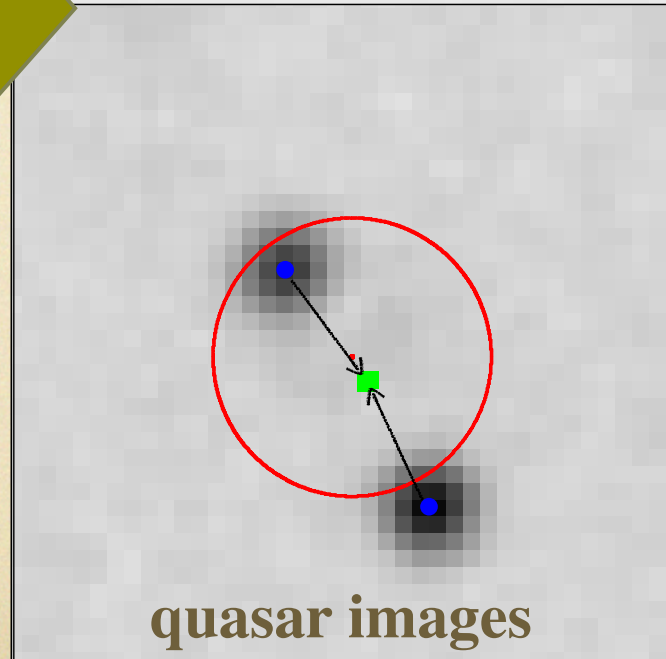
z-band



lens galaxy



g-band



quasar images

• SIS profile:  
 $r_{\text{ein}}$ : einstein radius  
( $X_{\text{lens}}, Y_{\text{lens}}$ )  
**3 parameters**


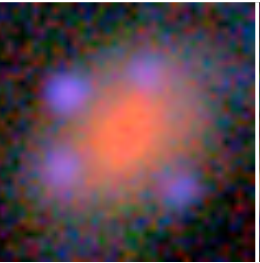

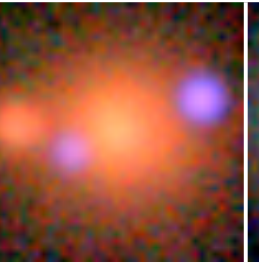
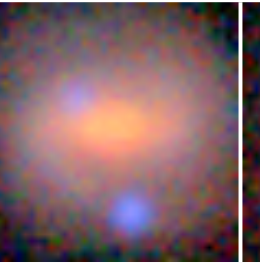
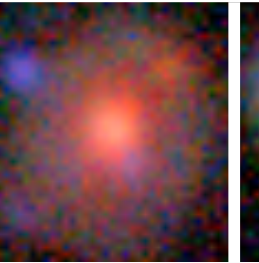
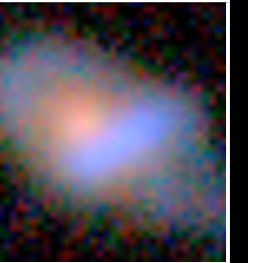
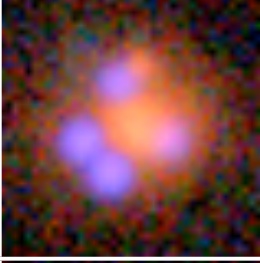


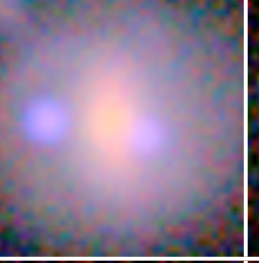
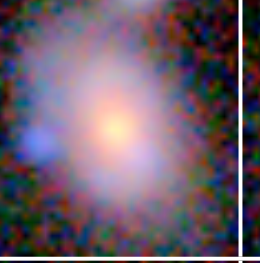
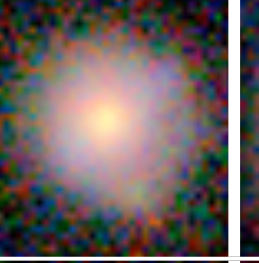
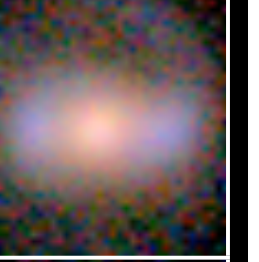
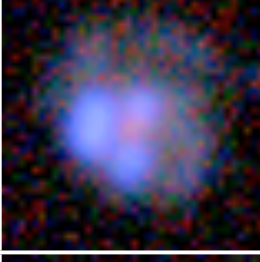

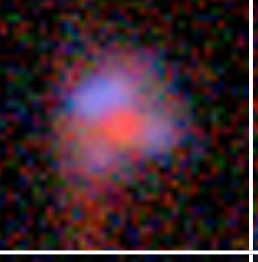
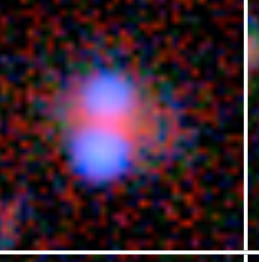
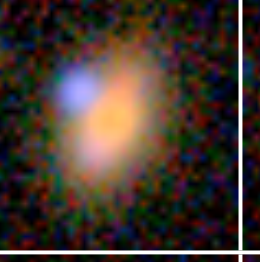
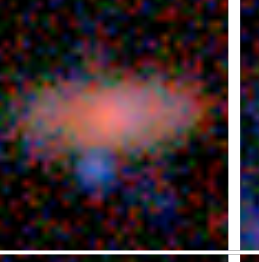
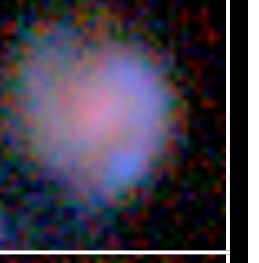
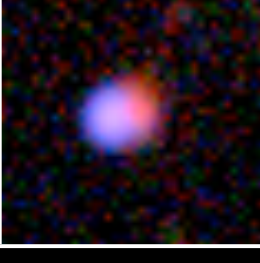

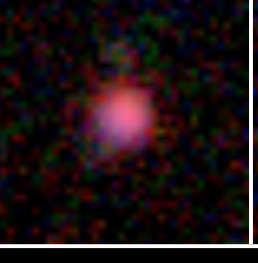
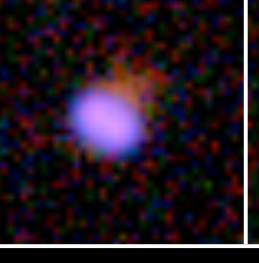
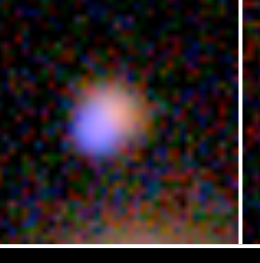
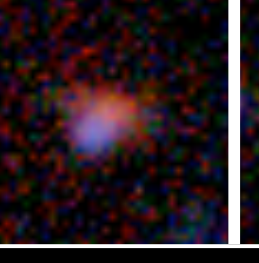
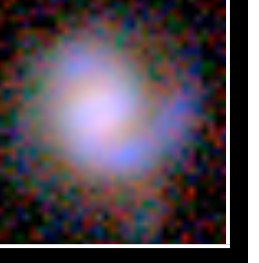
• lens light centroid  
as prior for mass  
centroid



# Procedure Overview

- Separate Lens and Images
- Estimate Lens center and Image positions
- Classify potential quads and doubles
- Fit SIE / SIS model to quads / doubles



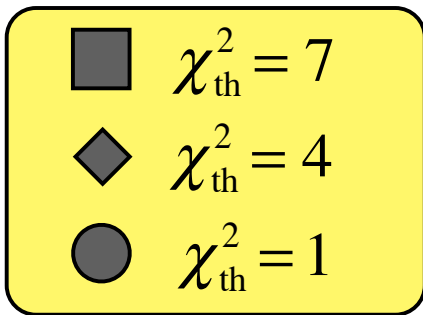
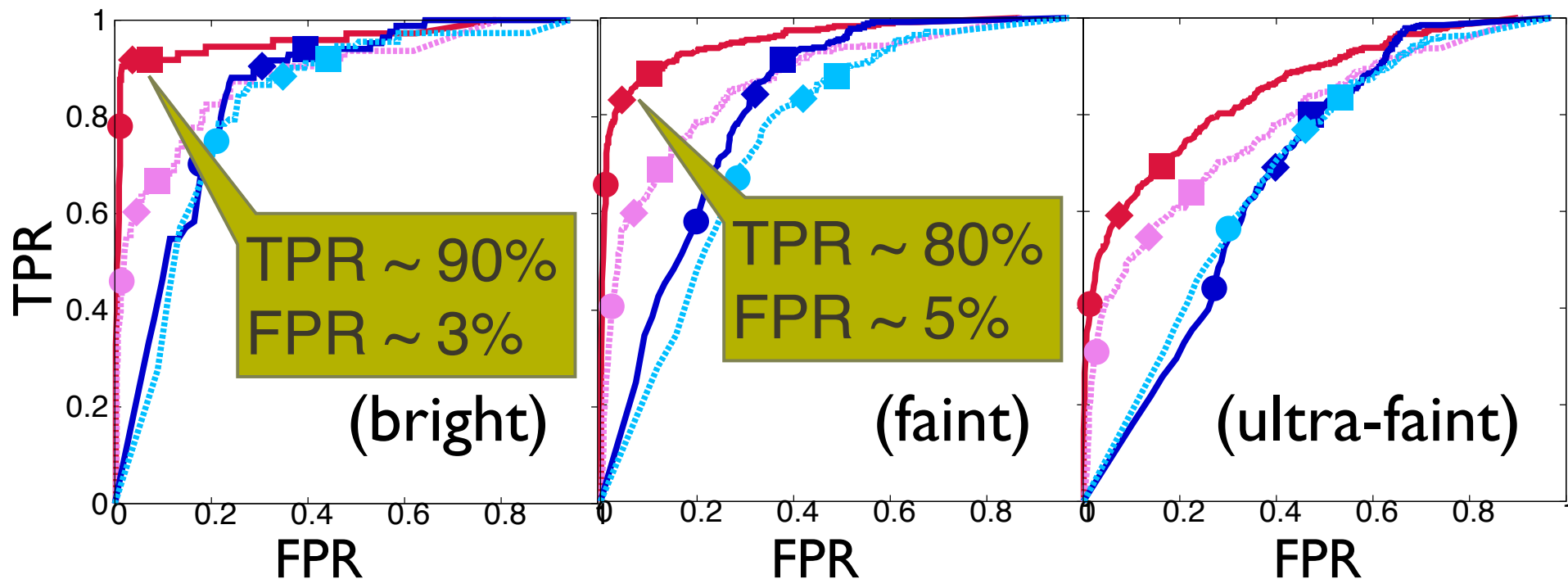
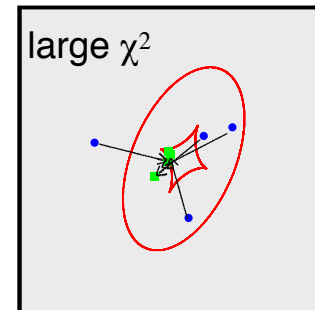
	<b>quad</b>			<b>double</b>			<b>dud</b>
	bright	faint	ultra-faint	bright	faint	ultra-faint	
<b>large sep.</b> ( $r_{\text{ein}} > 1.1''$ )							
							
<b>small sep.</b> ( $r_{\text{ein}} < 1.1''$ )							
							



# TPR vs FPR

true-positive rate

false-positive rate

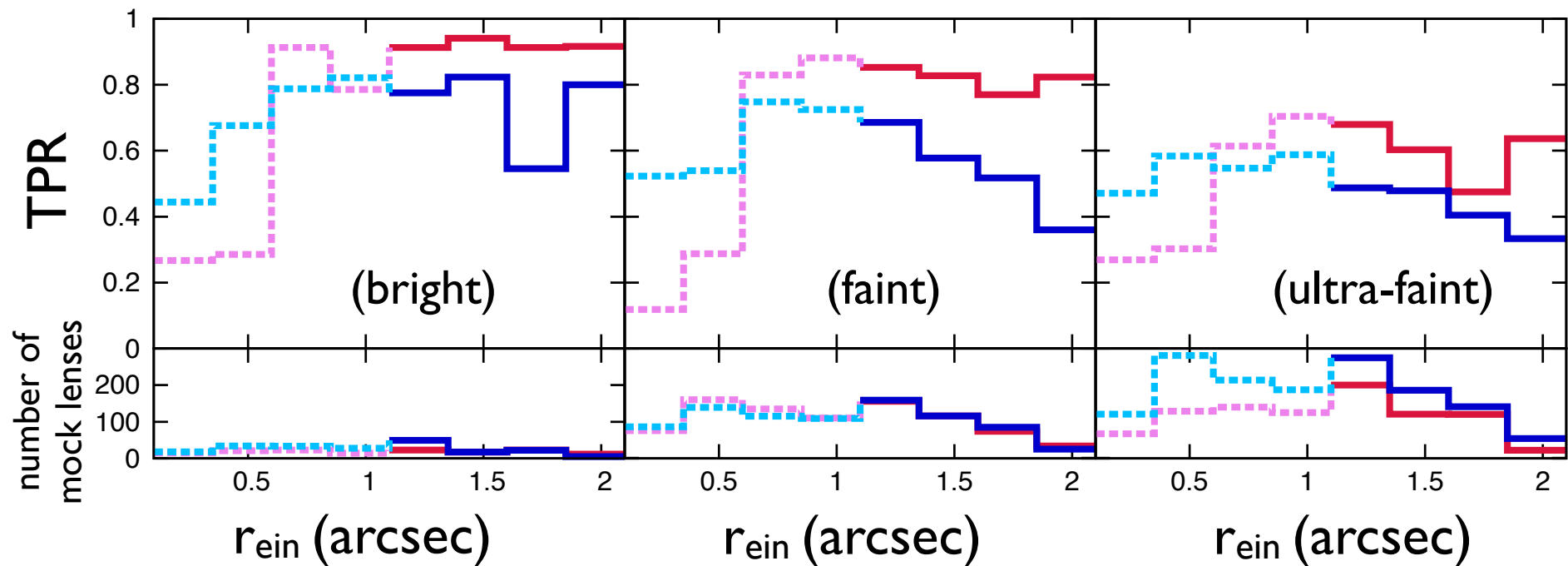


**quads** large sep.  
small sep.

**doubles** large sep.  
small sep.



# TPR vs $r_{\text{ein}}$

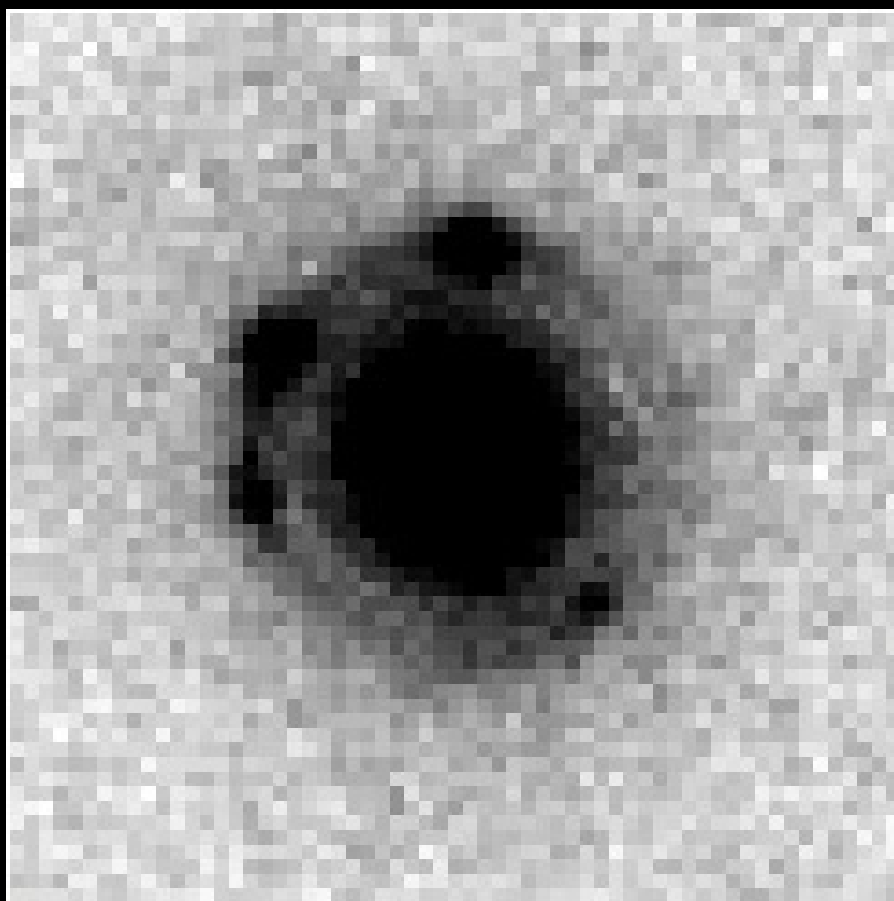


**quads** large sep.  
small sep.  
 $\chi_{\text{th}}^2 = 4$

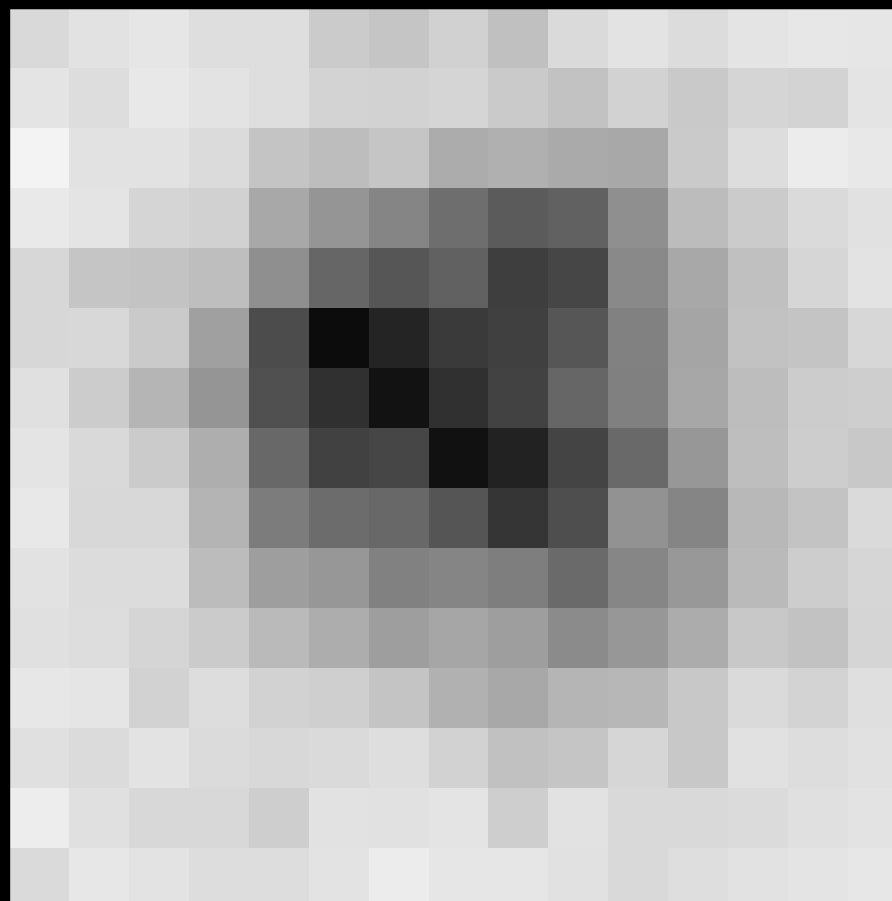
**doubles** large sep.  
small sep.  
 $\chi_{\text{th}}^2 = 1$



# COSMOS 5921+0638



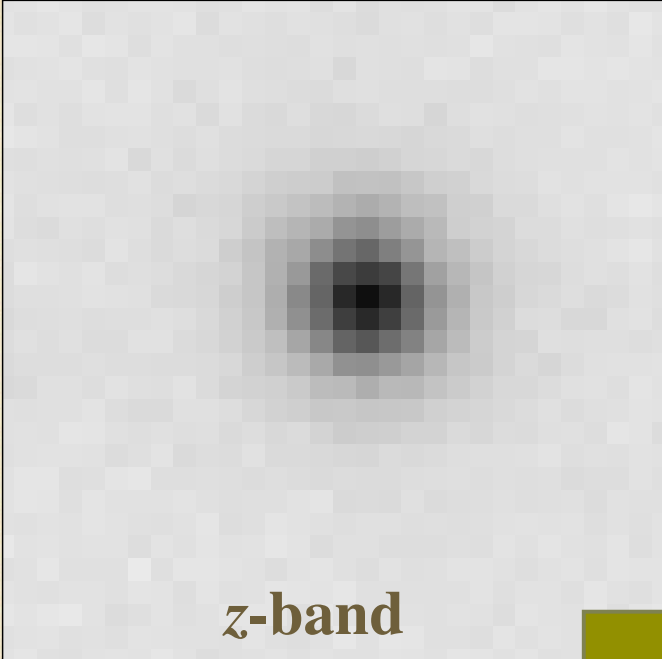
HST ACS F814W



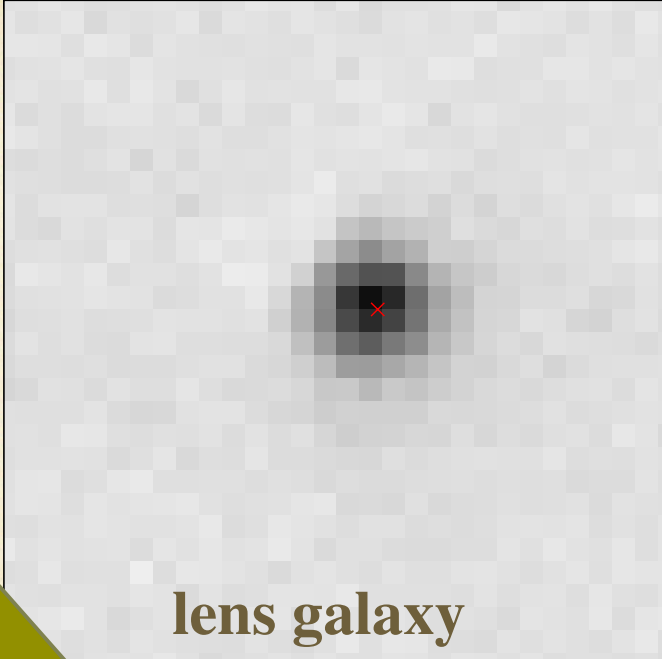
Subaru Suprime-Cam *B* band

(Anguita et al. 2009)

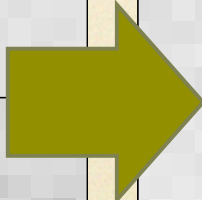




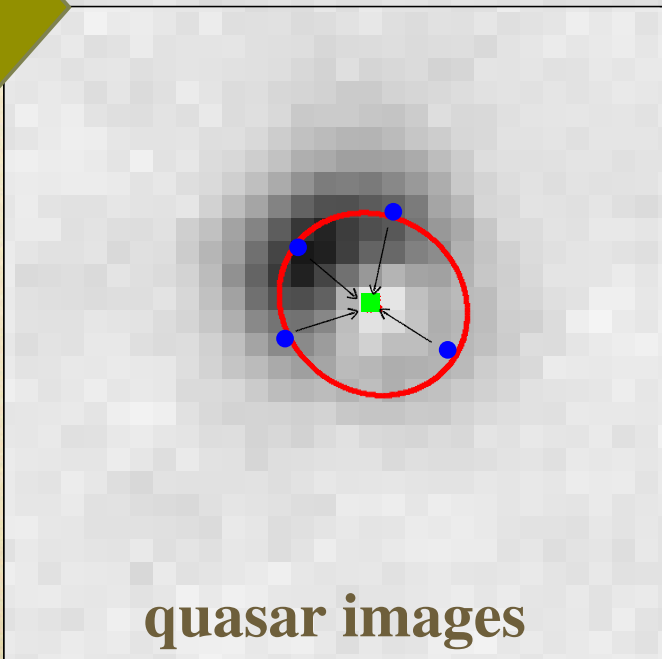
*z*-band



lens galaxy



*B*-band



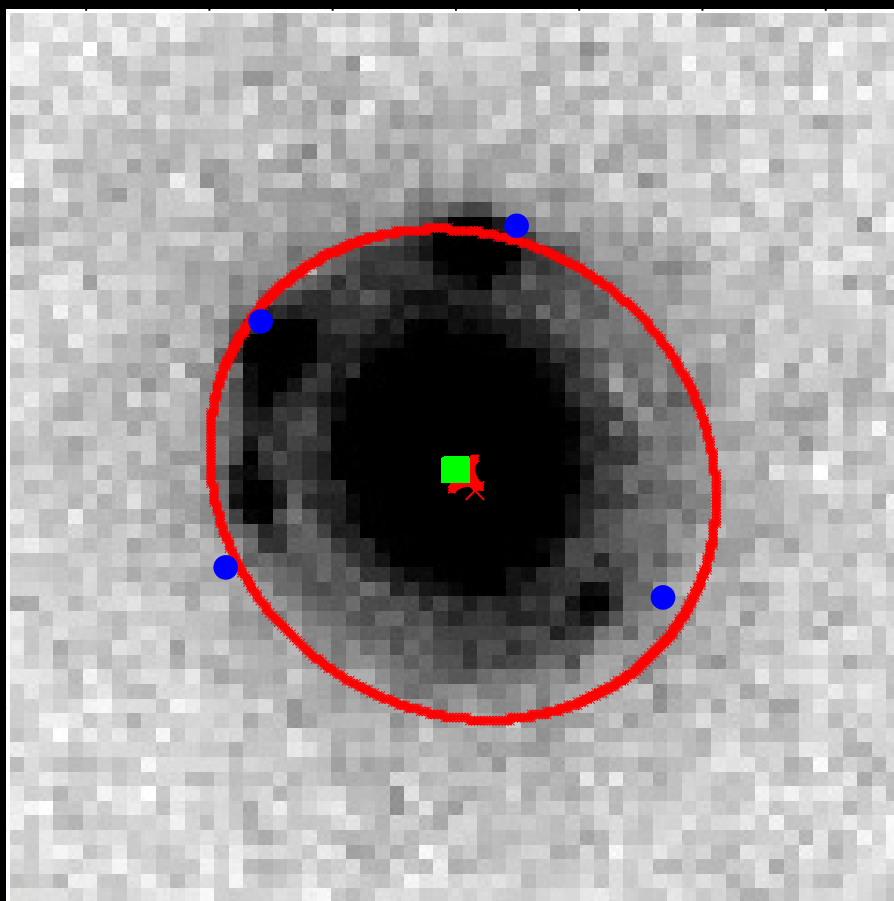
quasar images

• **SIE profile:**  
 $r_{\text{ein}}$ : einstein radius  
 $q$ : axis ratio  
PA: orientation  
( $x_{\text{lens}}, y_{\text{lens}}$ )  
**5 parameters**

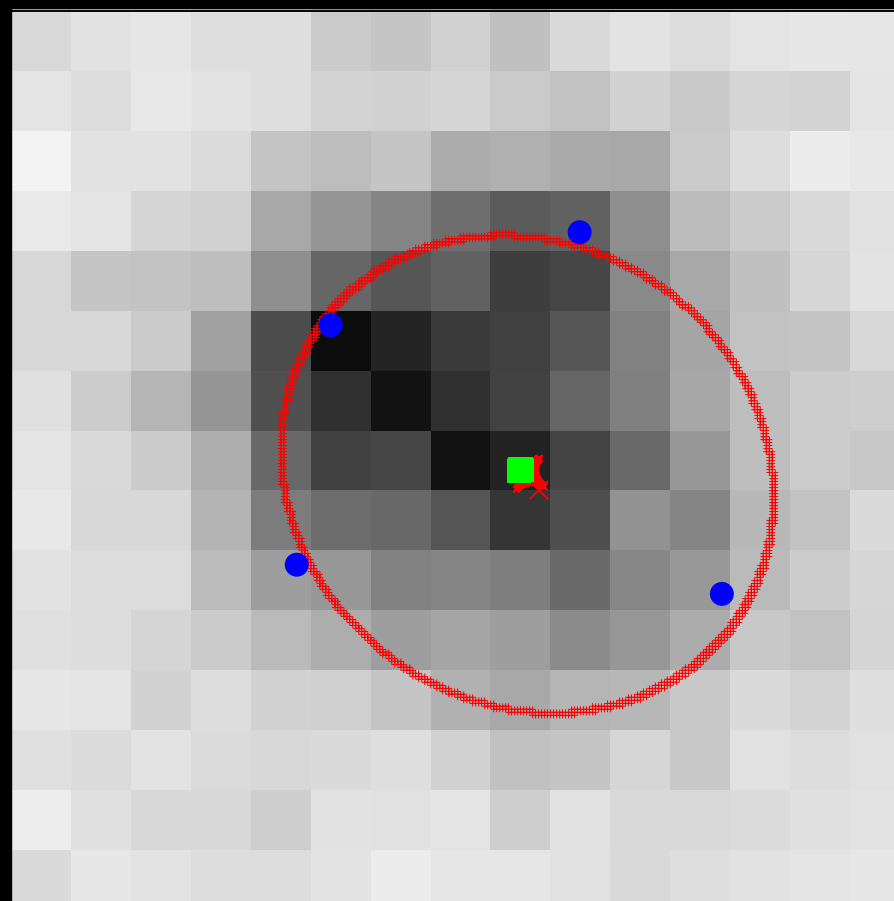
• **lens light centroid**  
as prior for mass  
centroid



# COSMOS 5921+0638



HST ACS F814W



Subaru Suprime-Cam *B* band

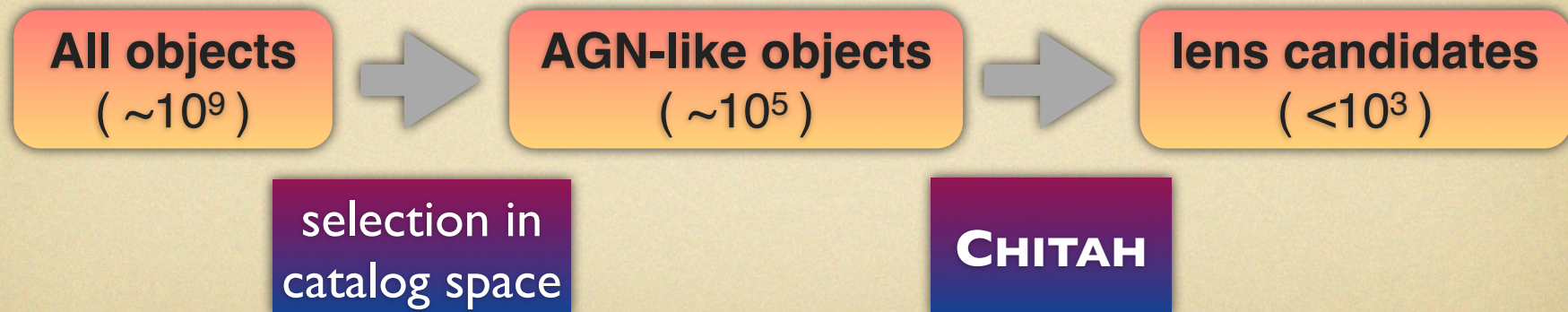


# Future Work

- **Search for new lenses in surveys:**
  1. HSC data / CFHTLS data / DES data
  2. CPU version → GPU version

efficiency ~ 5 sec/object

- **Candidate selection for CHITAH:**  
(unfeasible to run CHITAH on all objects)





Thanks