CFHT data for K2C9 and modelling binary events

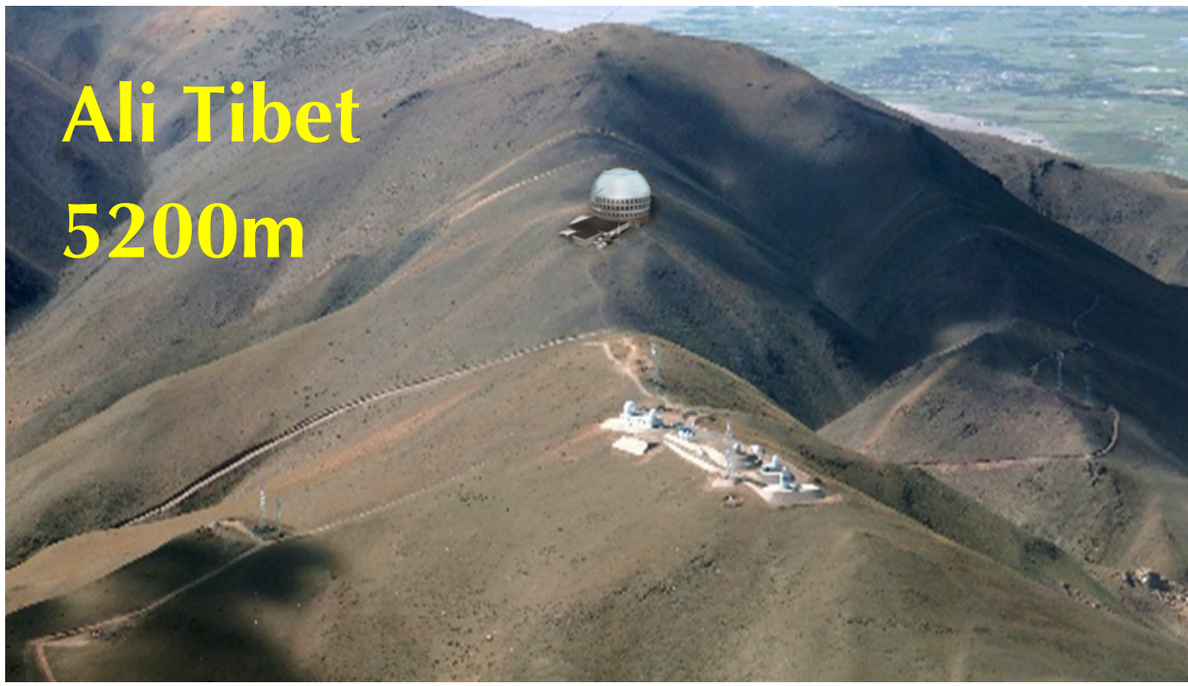
Shude Mao
Tsinghua/NAOC

Collaborators:

Weichen Zang (Zhejiang University)
Tiansu Wang (Tsinghua University)
Matthew Penny, Wei Zhu (OSU)
Pascal Fouque (CFHT), Subo Dong (KIAA)

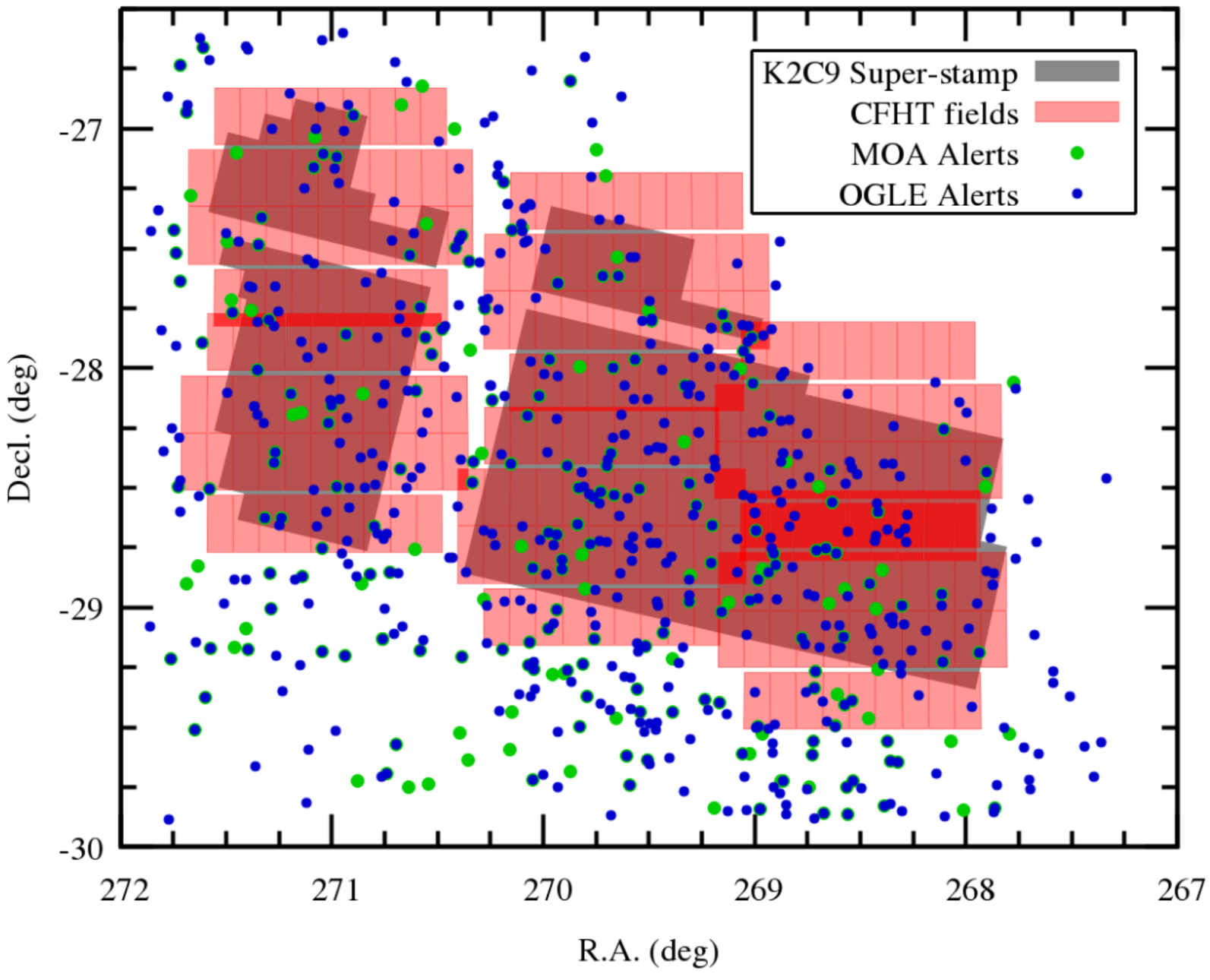
1. Motivations

- **Theory predicts fewer free-floating planets than Sumi et al.** (Ma, Mao et al. 2016; Mroz's talk)
- **Measure the population empirically (e.g. with K2C9)**
  - Applied for CFHT time (SM+ Penny, Zhu, Fouque, Dong)
- **Strenthening microlensing efforts**
  - Joined RoboNET through LCO
  - two 1m telescopes being built in Tibet
  - build up observational expertise



Currently: 460 hours
Future: ~2500 hours

2. CFHT observations overview for K2C9



- Single (~150)
- Binary (>10)
- Planetary (>2)
- Short-t_E (<2.5d, ~5)

Map of CFHT field and K2C9 field

CFHT data overview

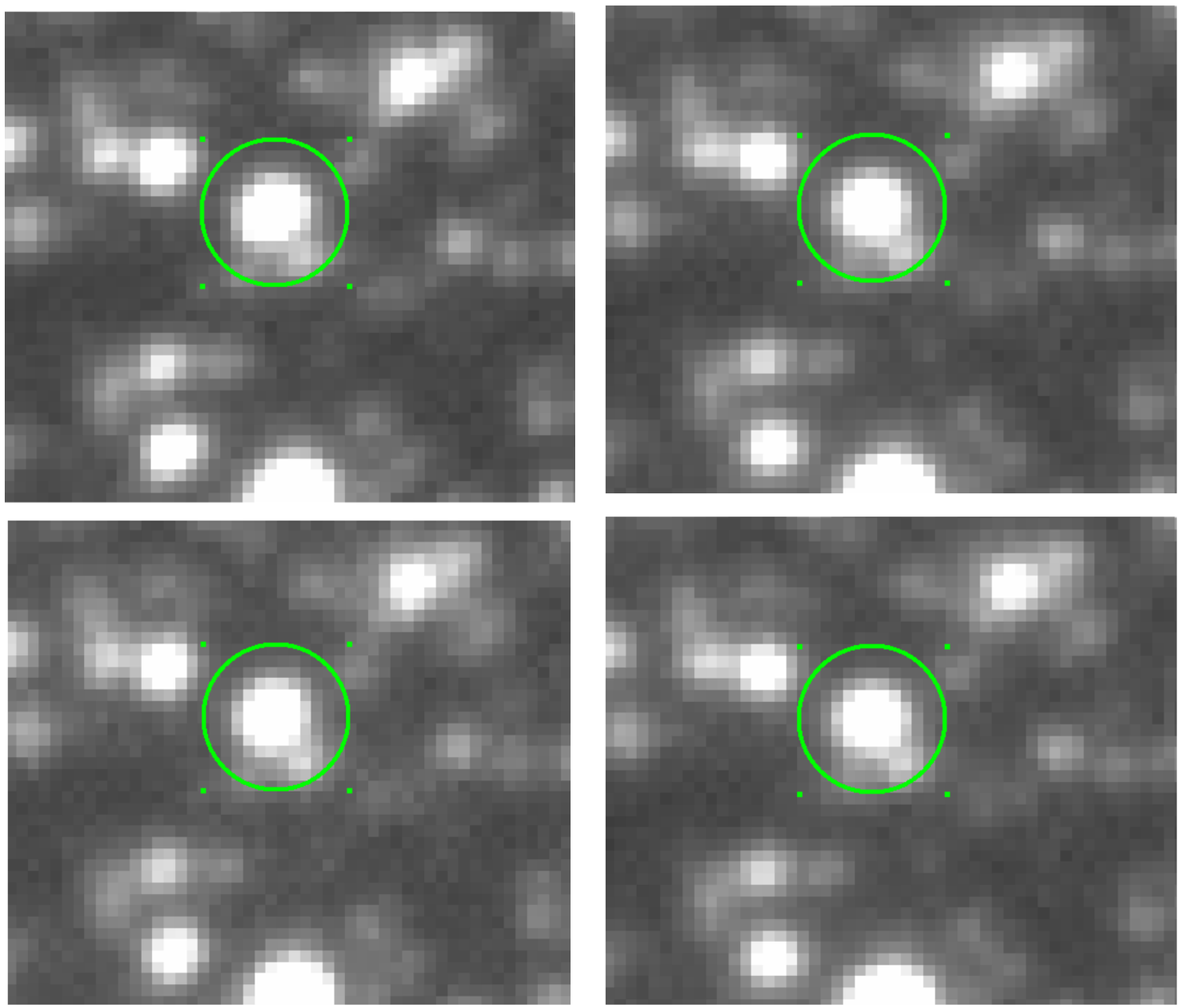
Dates (HJD-2450000)

7485 -7493	7509 - 7522	7538 - 7548	7565 -7576

Filters	g	r	i
Exposure time(s)	60	20	20
Median seeing (arcsec)	1.1	0.8	0.8
Airmass	<2		
Cadence	Each band twice per night		

- We use a difference image analysis pipeline provided by Matthew Penny modified by Weichen Zang
- Based on Alard's ISIS package

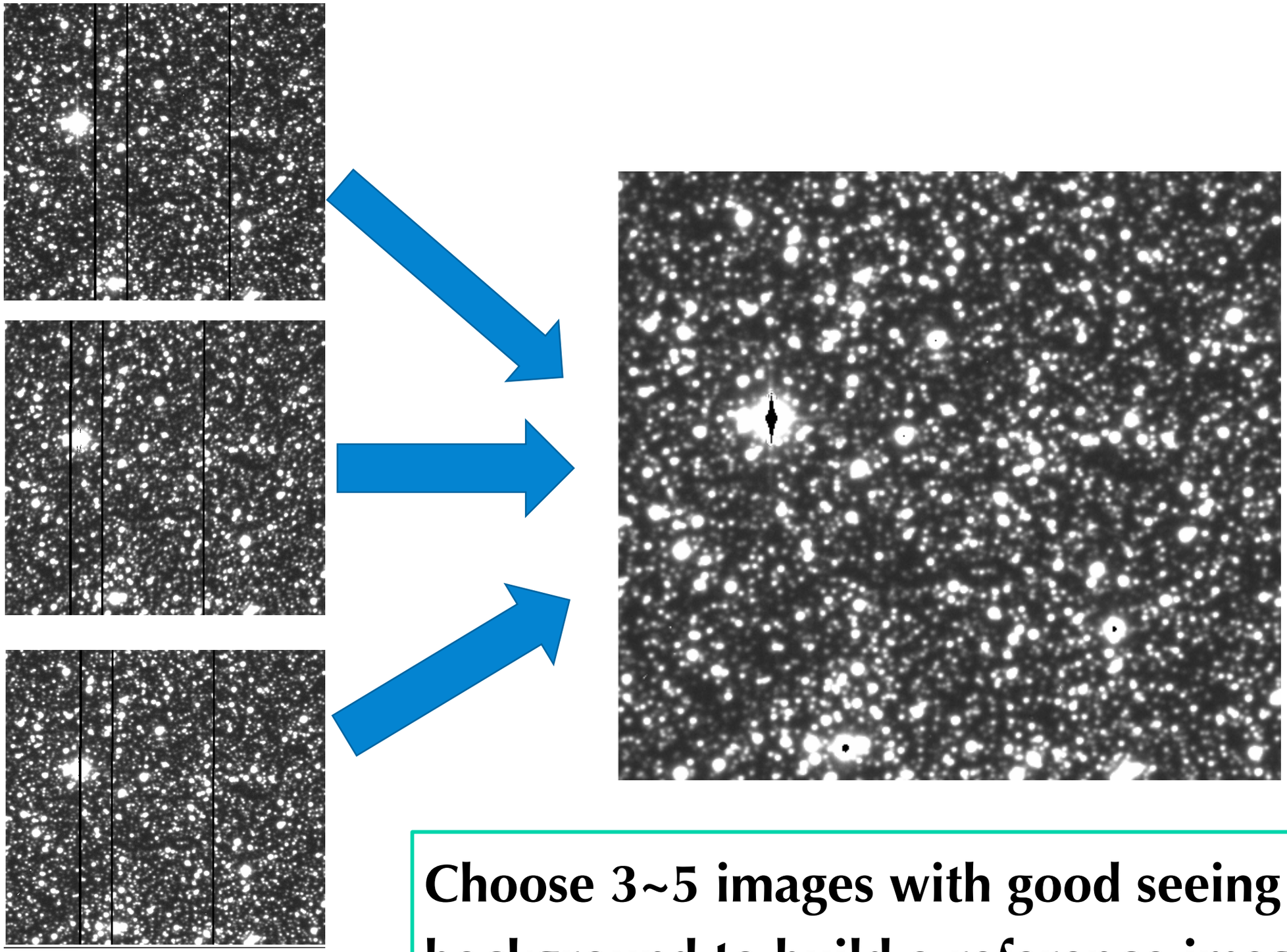
CFHT data reduction: Images Matching



4 epochs

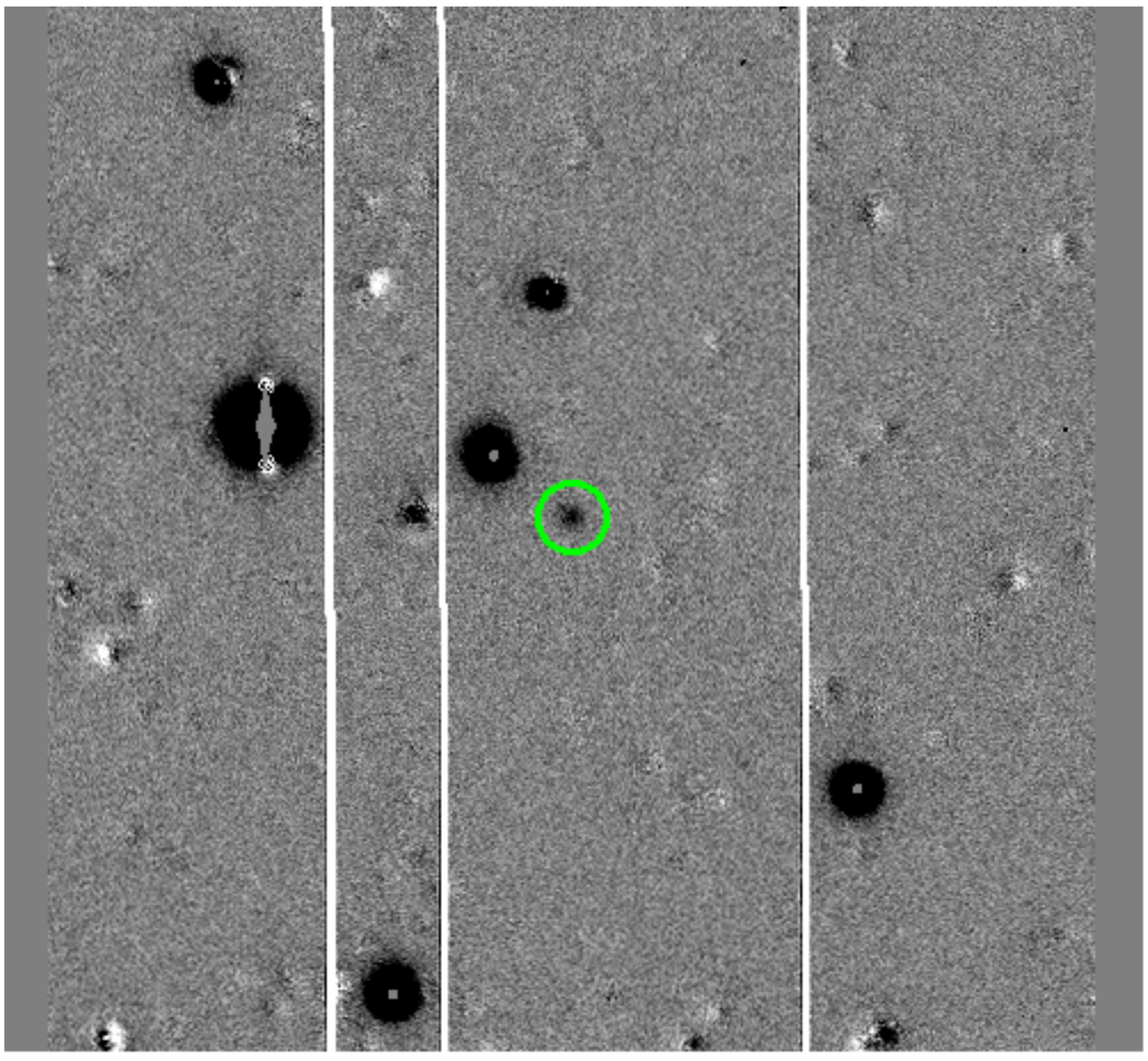
- **Alignment is better than < 1 pixel (0.18″)**

Building a reference image



Choose 3~5 images with good seeing and low sky background to build a reference image

Image subtraction and photometry

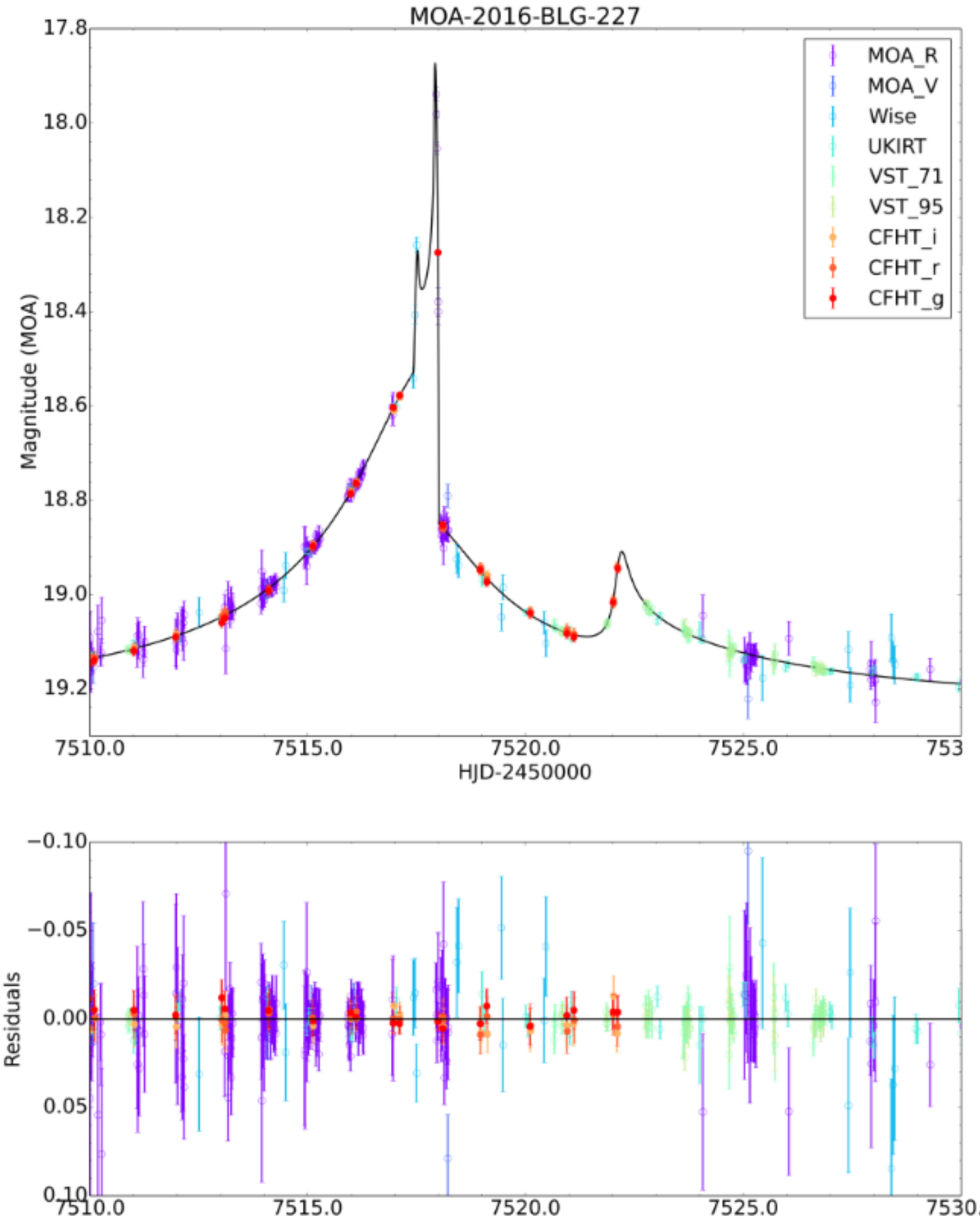


- **Perform image subtraction using ISIS**
- **Perform photometry around the target identified from OGLE or MOA.**
- **Output both aperture and PSF photometry**

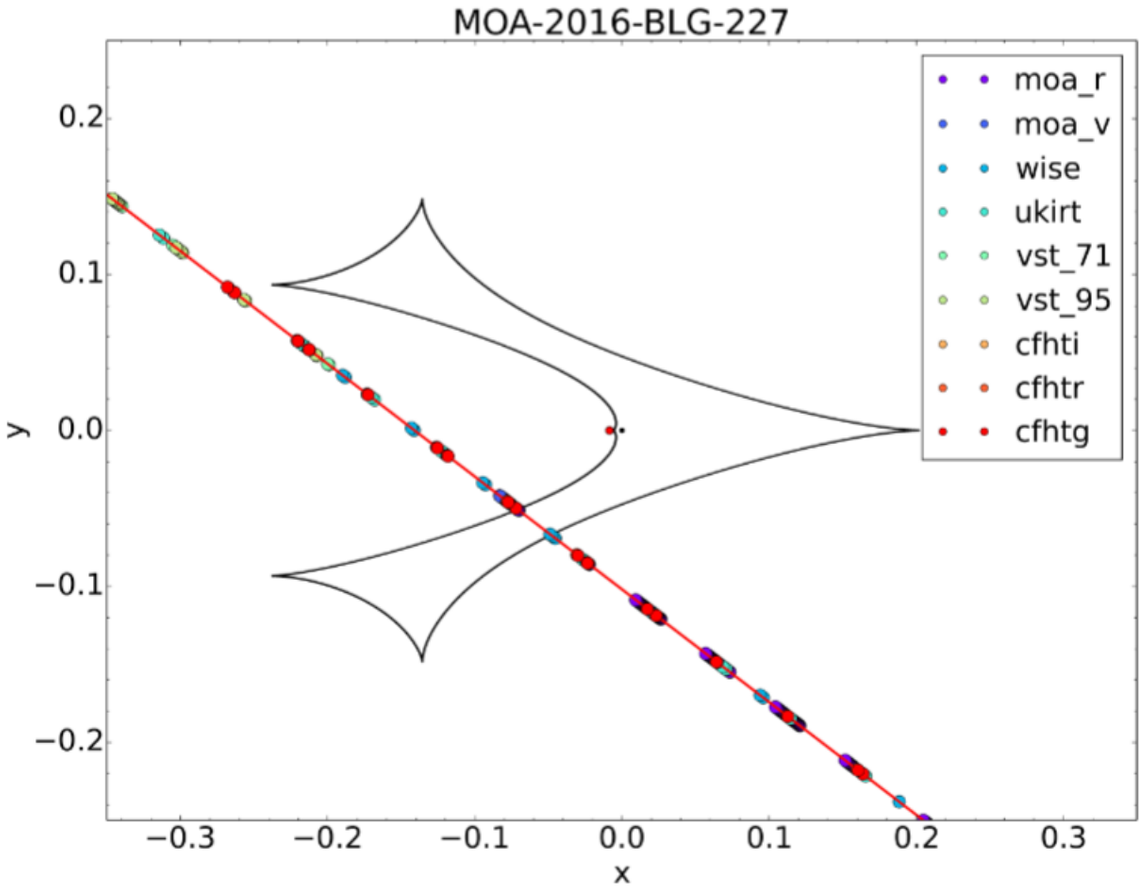
Many (~170) interesting events in the CFHT field

Event Name	Comment	Event Name	Comment
OB160241/MB16132	Planetary event	**OB160611**	Short time scale
MB16227	Planetary event	**OB161268**	Short time scale
OB160613	Planetary? Triple lens?	OB161231/MB16368	Short time scale
OB161190/MB16383	Planetary?	OB161236/MB16360	Short time scale
OB160722/MB16181	Planetary?	**OB161206**	Very High magnification
OB160562	Binary	MB16296	Very High magnification
OB160676/MB16215	Binary	OB160919	Very High magnification
OB160674	Binary	OB161050	Very high magnification

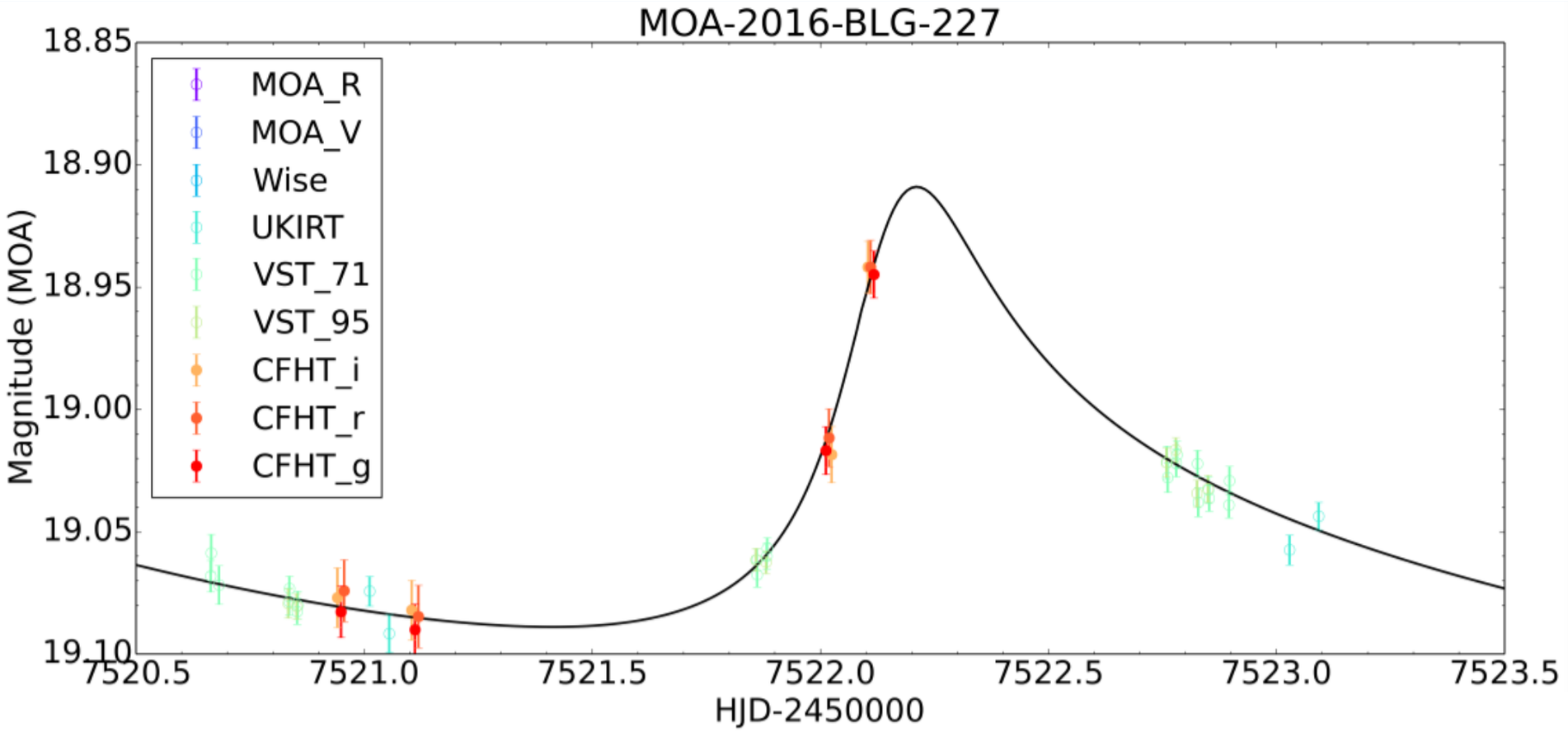
Planetary event MOA-2016-BLG-227



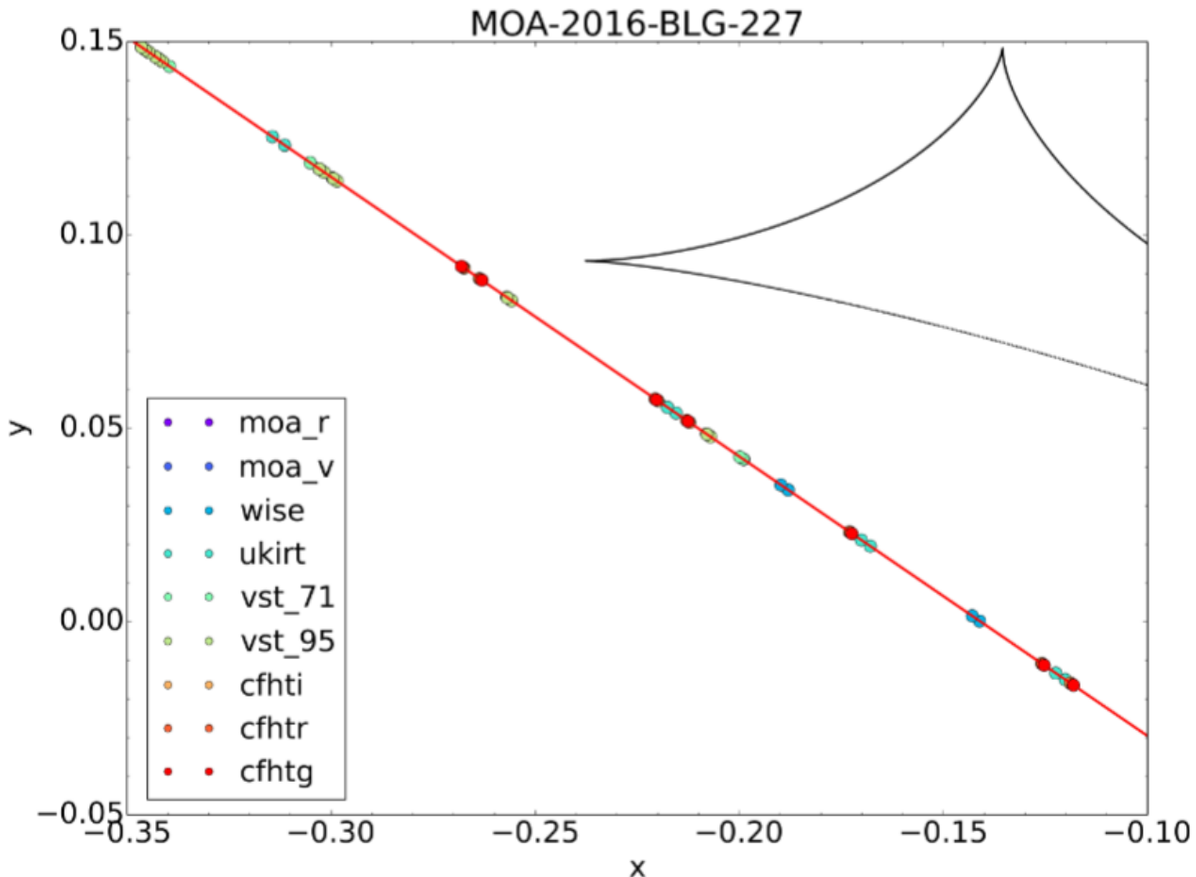
Talk by Naoki Koshimoto



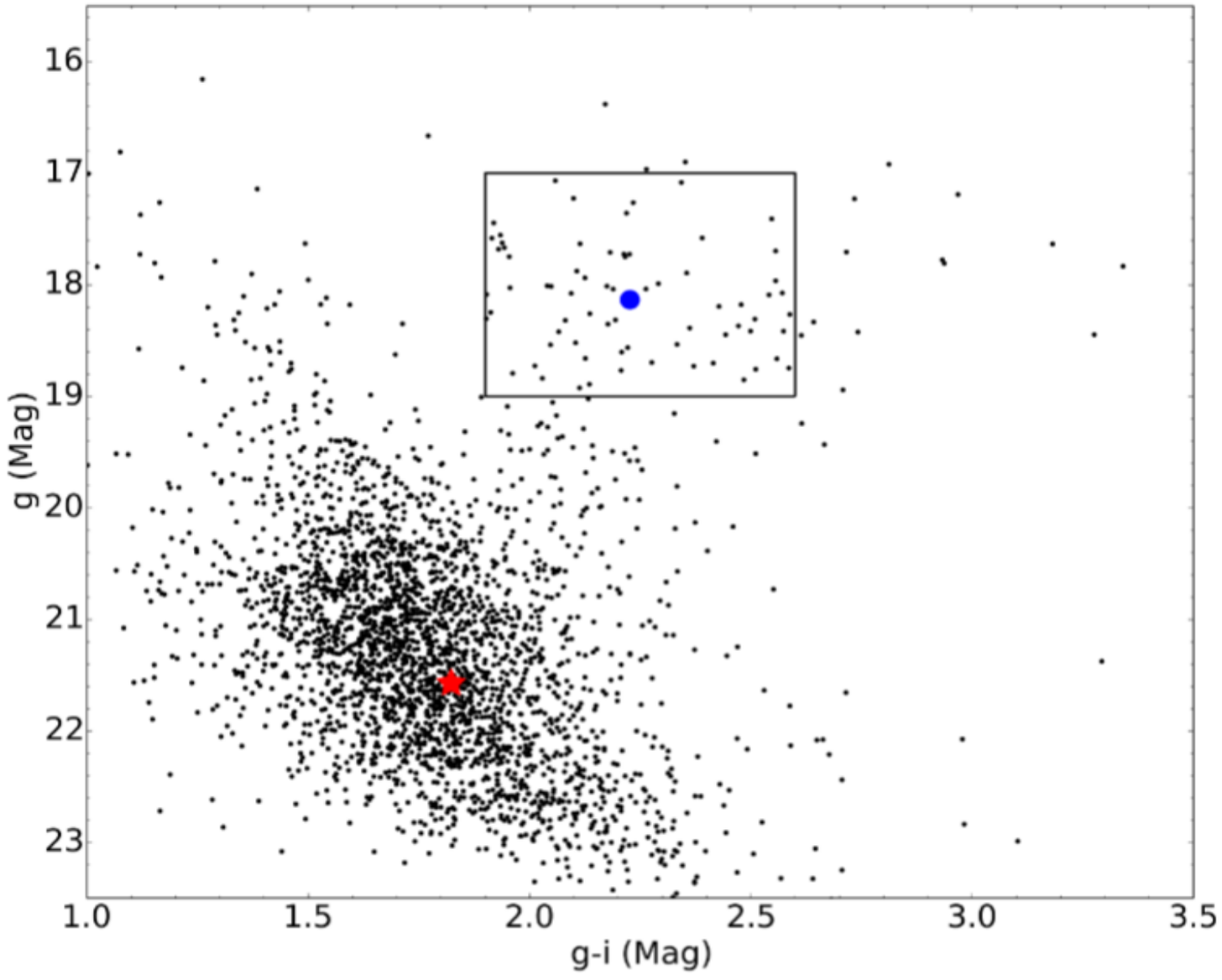
Modelling planetary event MOA-2016-BLG-227



- **Around cusp approach, CFHT data is unique**
- **valuable for constraining parallax and/or orbital motions**

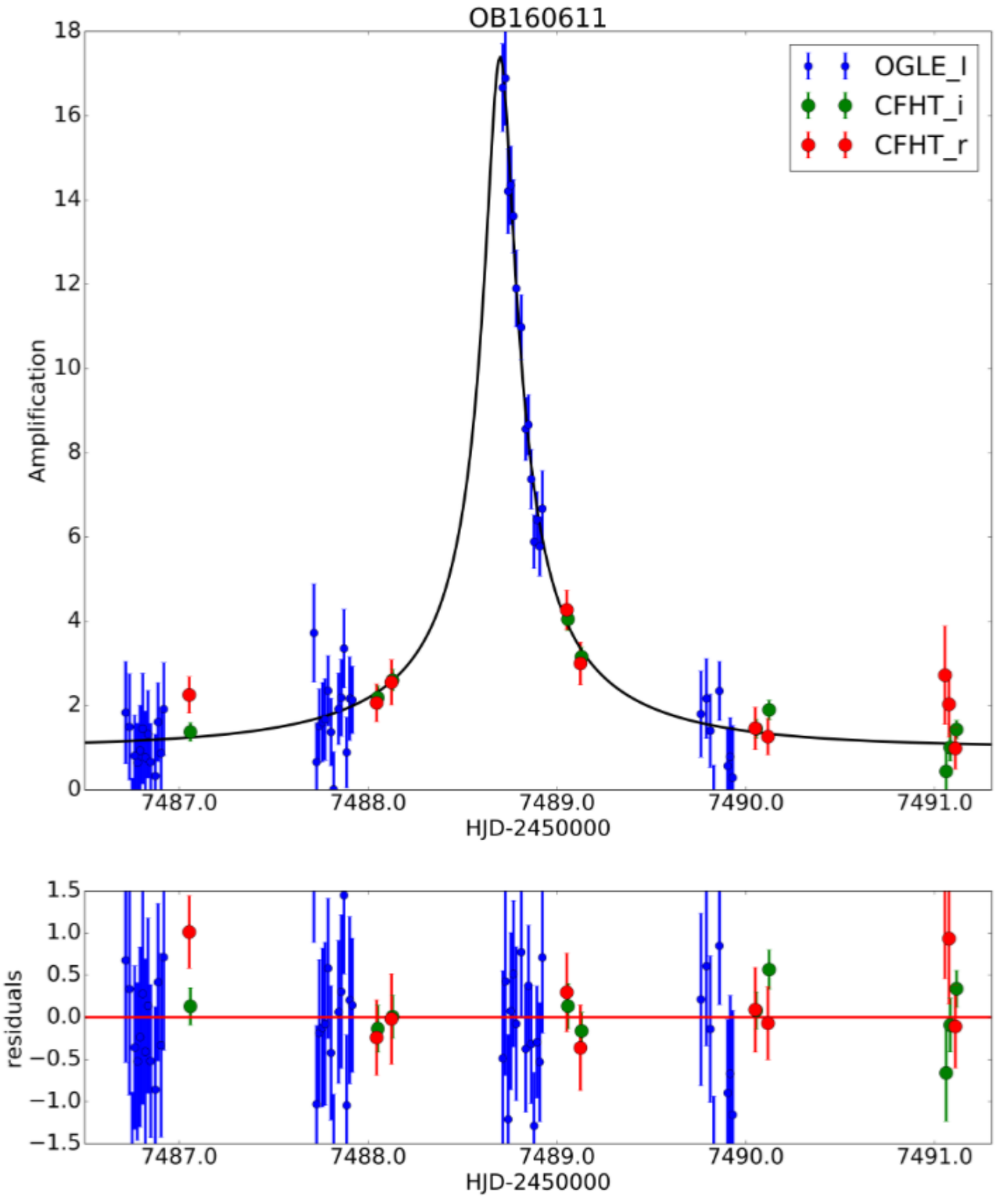


Color-magnitude diagrams



- **With CFHT CMD data, we find the angular source radius to be about 0.8 0.1 micro-arcseconds**
- **Consistent with Naoki Koshimoto's estimate of about 0.67 0.02**
- **Our data can be combined with datasets to shed light on its nature**

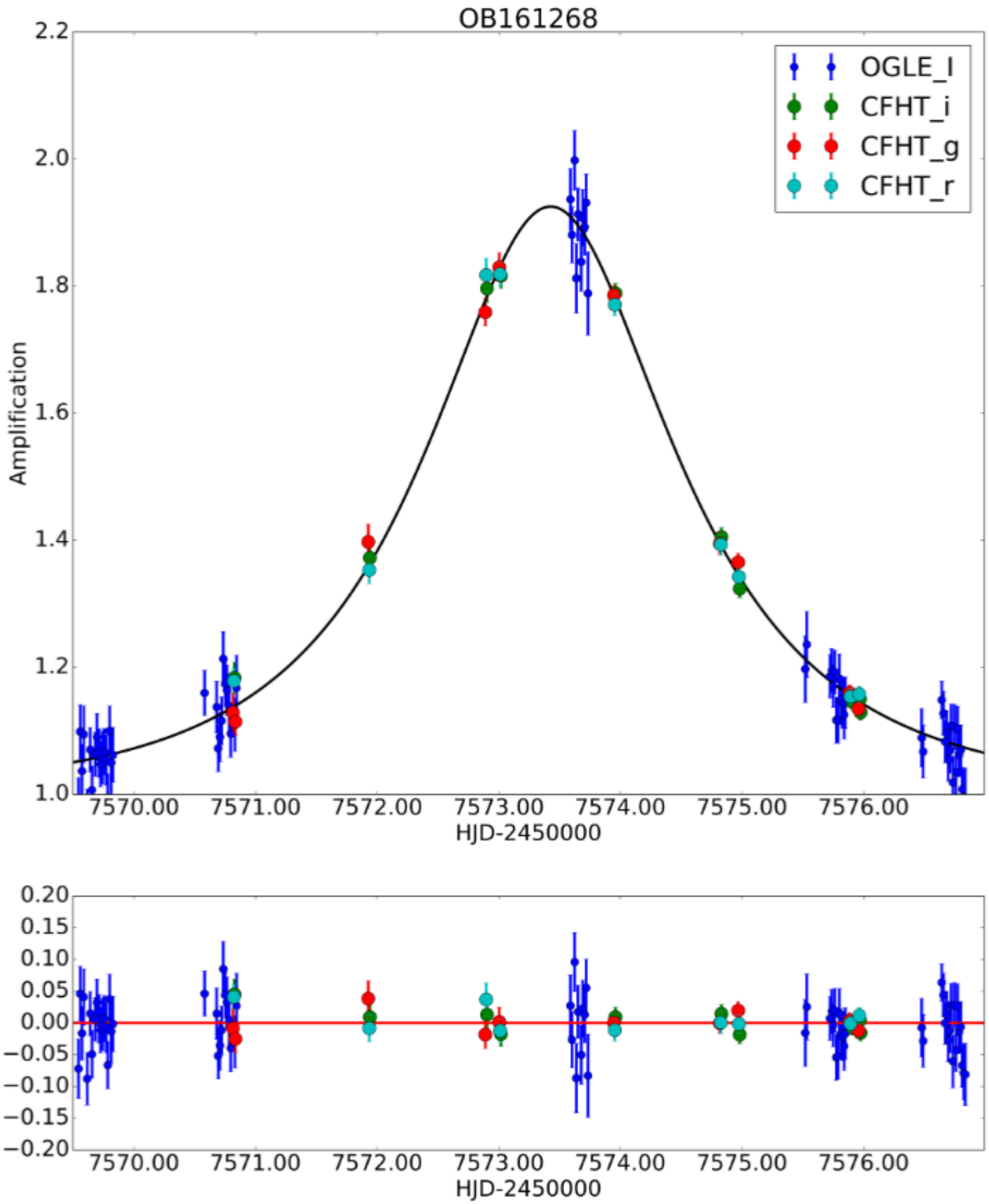
Short timescale event: OGLE-2016-BLG-0611



- t_E = 1.22 ± 0.55 day
- u_0 = 0.067 ± 0.041
- t_0 = 7488.700 ± 0.019

- However, K2 data is from 7500 to 7570
- K2C9 missed the peak of this event

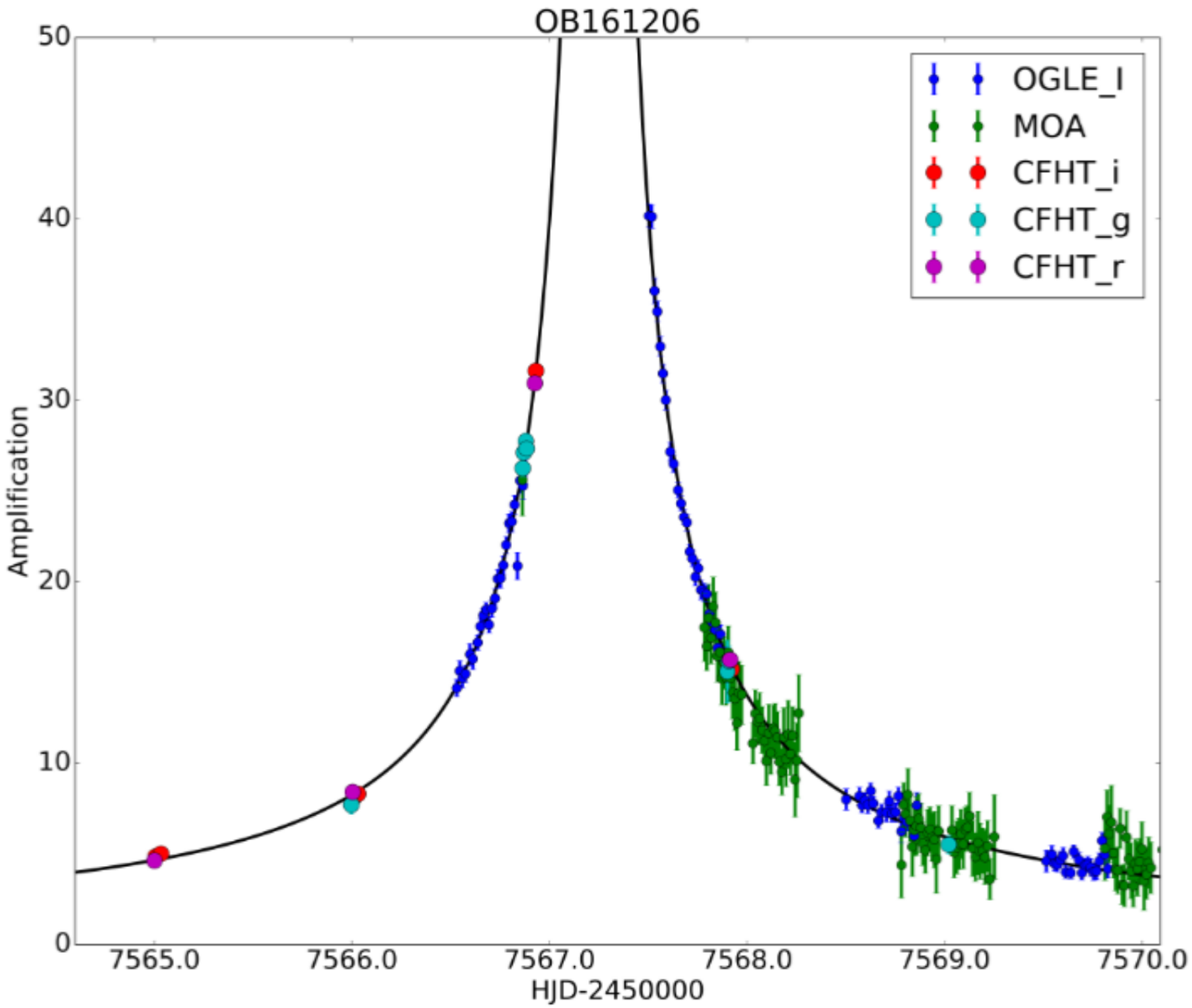
OGLE-2016-BLG-1268

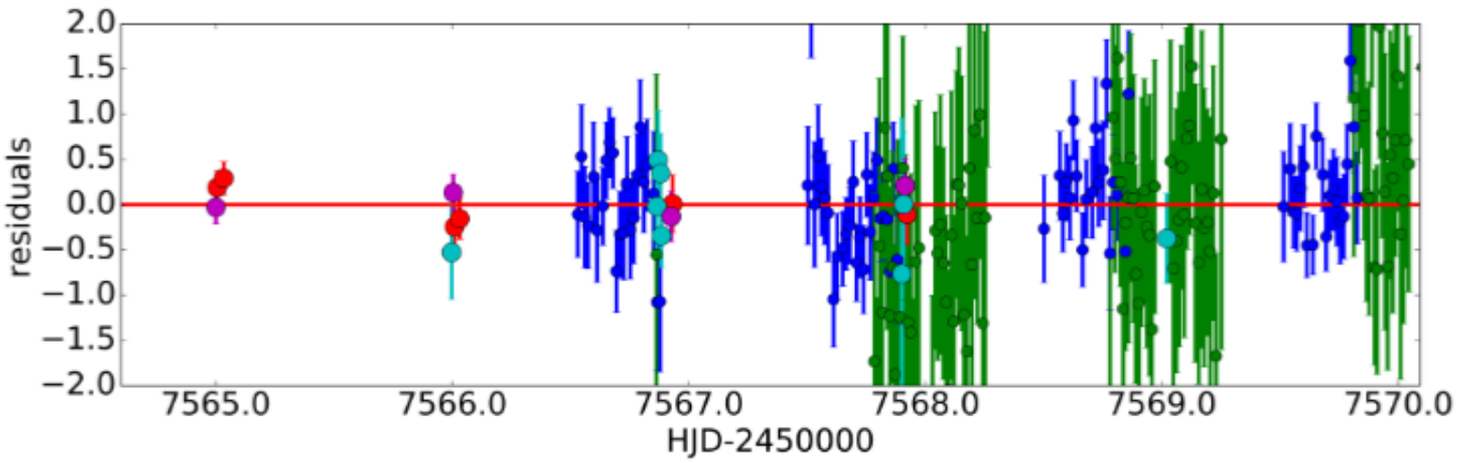


- t_E = 1.91± 0.06 day
- u_0 = 0.58 ± 0.02
- t_0 = 7573.428 ± 0.011

- Has K2 data

High magnification event: OGLE-2016-BLG-1206

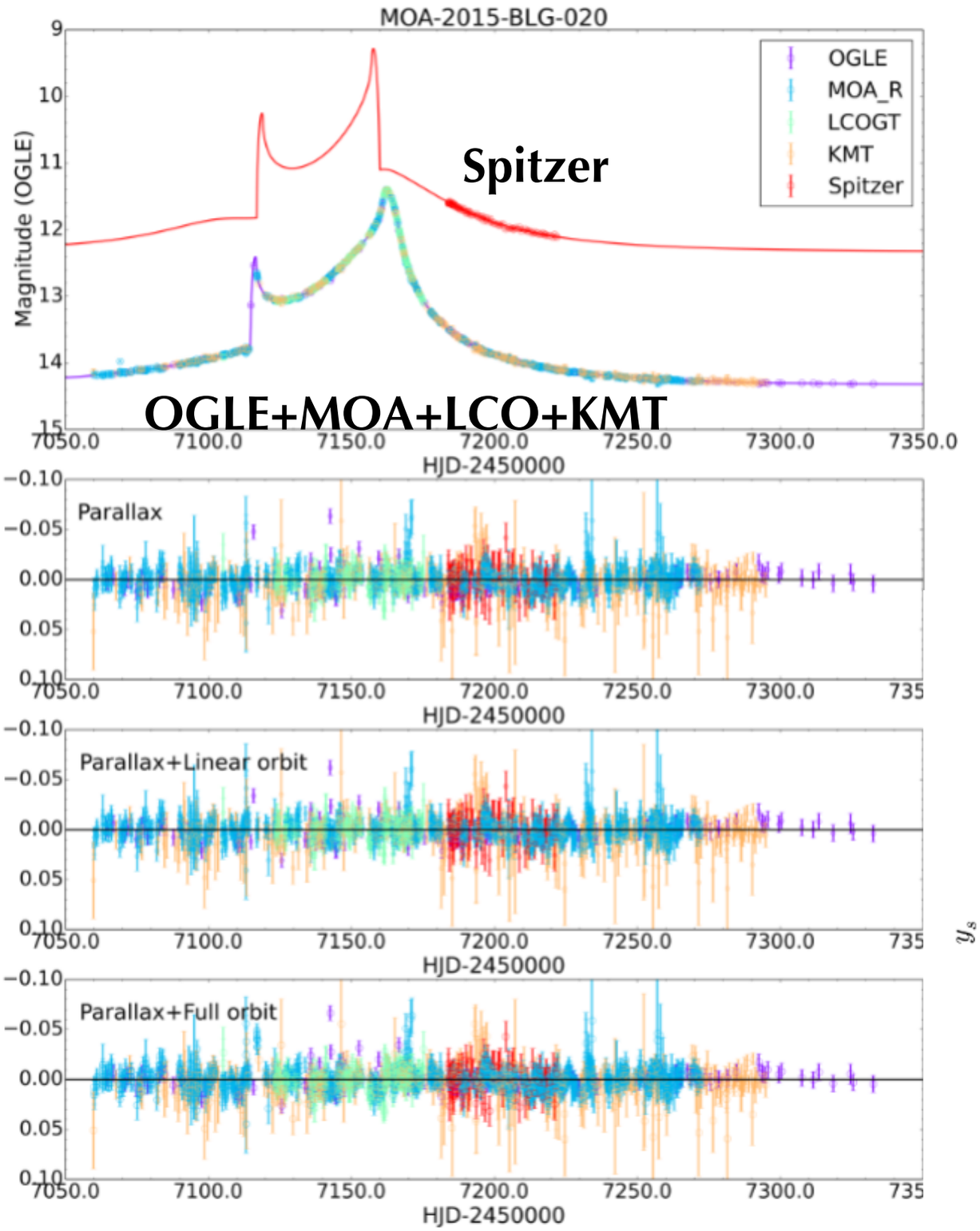




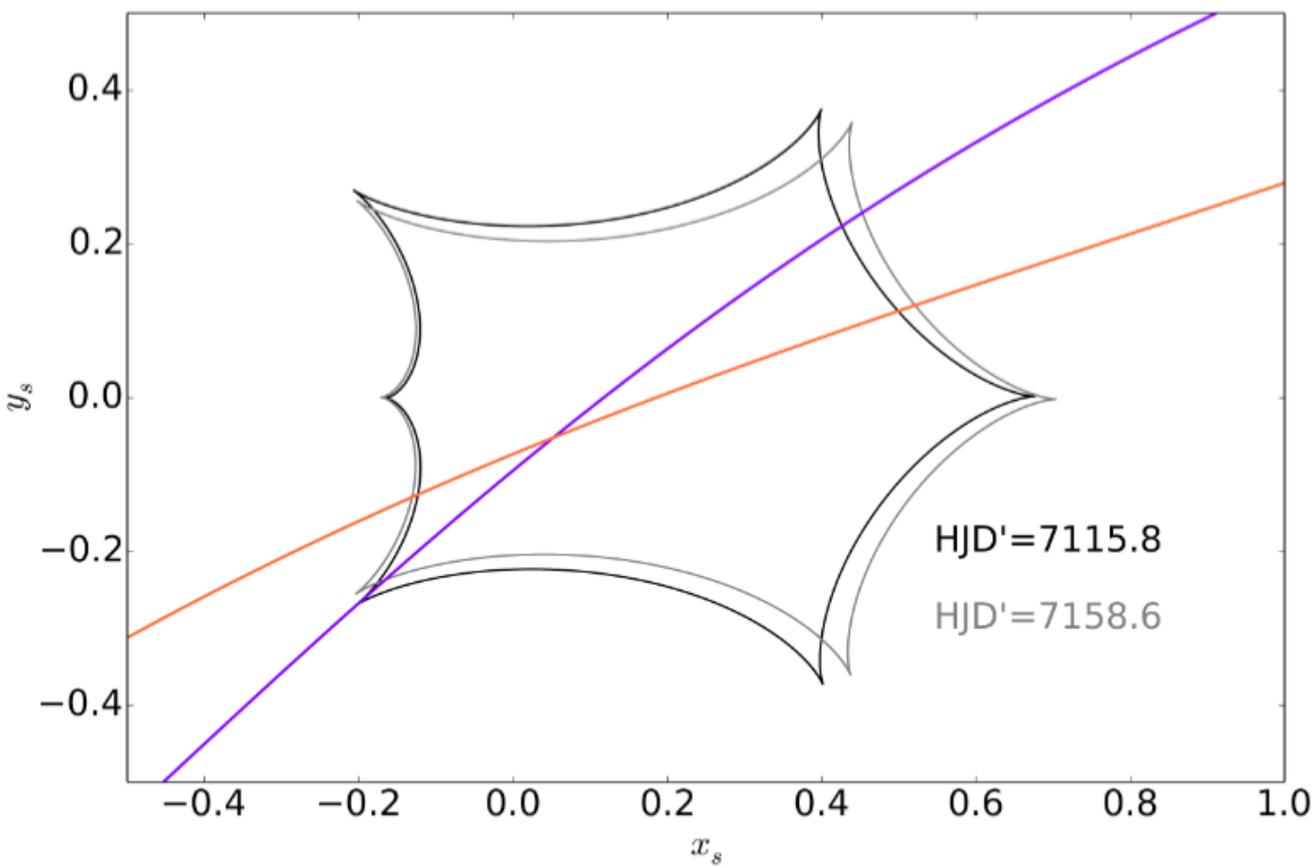
- t_E = 10.56± 0.70 day
- u_0 = 0.005 ± 0.002
- t_0 = 7567.251 ± 0.001

- Has K2 data
- Additional data to estimate lens mass?

3. Modelling binary event MOA-2015-BLG-020

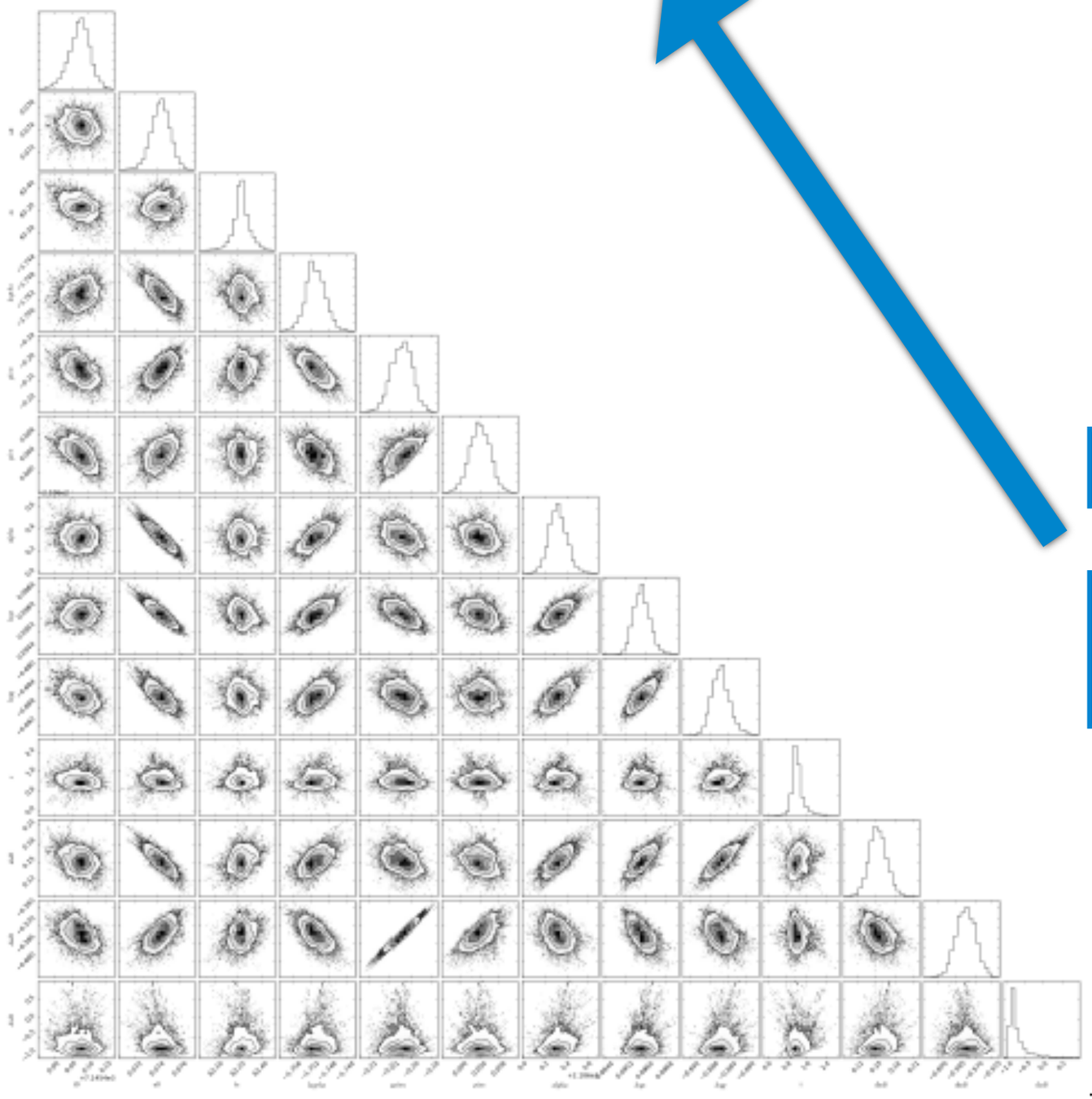


- Use a grid search to find the best initial guesses
- Then run MCMC to identify the best-fit parameters
- parallax from ground-based data confirmed by Spitzer



Markov Chain Monte Carlo simulations

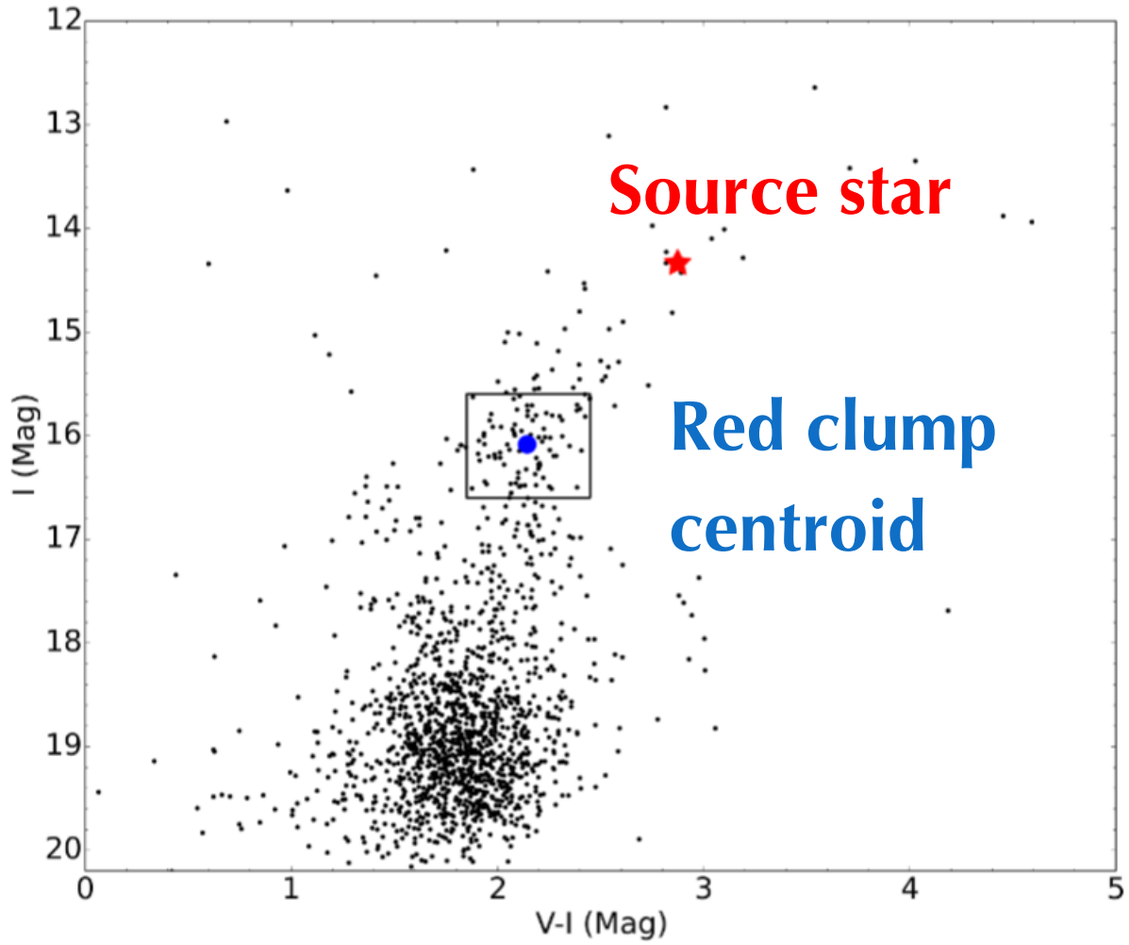
Good constraints on parallax and source size ρ



Code from Wei Zhu

Parameters	Full Orbit	Linear Orbit	Parallax Only
χ^2/dof	3982.2 / 4028	4000.8 / 4028	4222.4 / 4028
log s_0	0.0960±0.0003	0.0963±0.0003	0.0940±0.0002
log q	-0.686±0.002	-0.683±0.002	-0.703±0.001
u_0	0.0733±0.0009	0.0715±0.0008	0.0798±0.0004
t_0	7145.49±0.03	7145.46±0.03	7145.72±0.03
t_E	63.38±0.06	63.55±0.06	62.94±0.06
log ρ	-1.749±0.002	-1.744±0.002	-1.757±0.002
α	219.01±0.07	219.14±0.08	218.27±0.05
$\pi_{E,N}$	-0.207±0.004	-0.223±0.005	-0.220±0.006
$\pi_{E,E}$	0.001±0.002	-0.006±0.002	0.003±0.002
$\frac{ds}{dt}$	0.172±0.015	0.217±0.017	
$\frac{d\alpha}{dt}$	-0.581±0.007	-1.197±0.038	
z	1.41±0.32		
$\frac{dz}{dt}$	-0.48±0.40		
V-I	2.874±0.003	2.874±0.003	2.867±0.003

Modelling binary event MOA-2015-BLG-020



Angular source size and θ_E

Physical Parameters	
$M_1(M_\odot)$	0.679±0.044
$M_2(M_\odot)$	0.140±0.009
Distance to lens (kpc)	2.43±0.13
Projected separation (AU)	3.03±0.23
Geocentric proper motion (mas yr^{-1})	5.95±0.18

Two low-mass stars located in the Galactic disk

Summary

- CFHT Data reduction of the K2C9 field is nearly complete (Zang et al. 2017)
  - data quality is usually high
  - we will publically release the data (including light curve and CMD)
- We modelled the binary event MOA-2016-BLG-020
  - a low-mass binary in the disk (Wang et al. 2017)

Welcome to visit or join us at Tsinghua

- **One of the most prestigious universities in China**
- **Recruiting 10-15 new professors in the next 4 years**