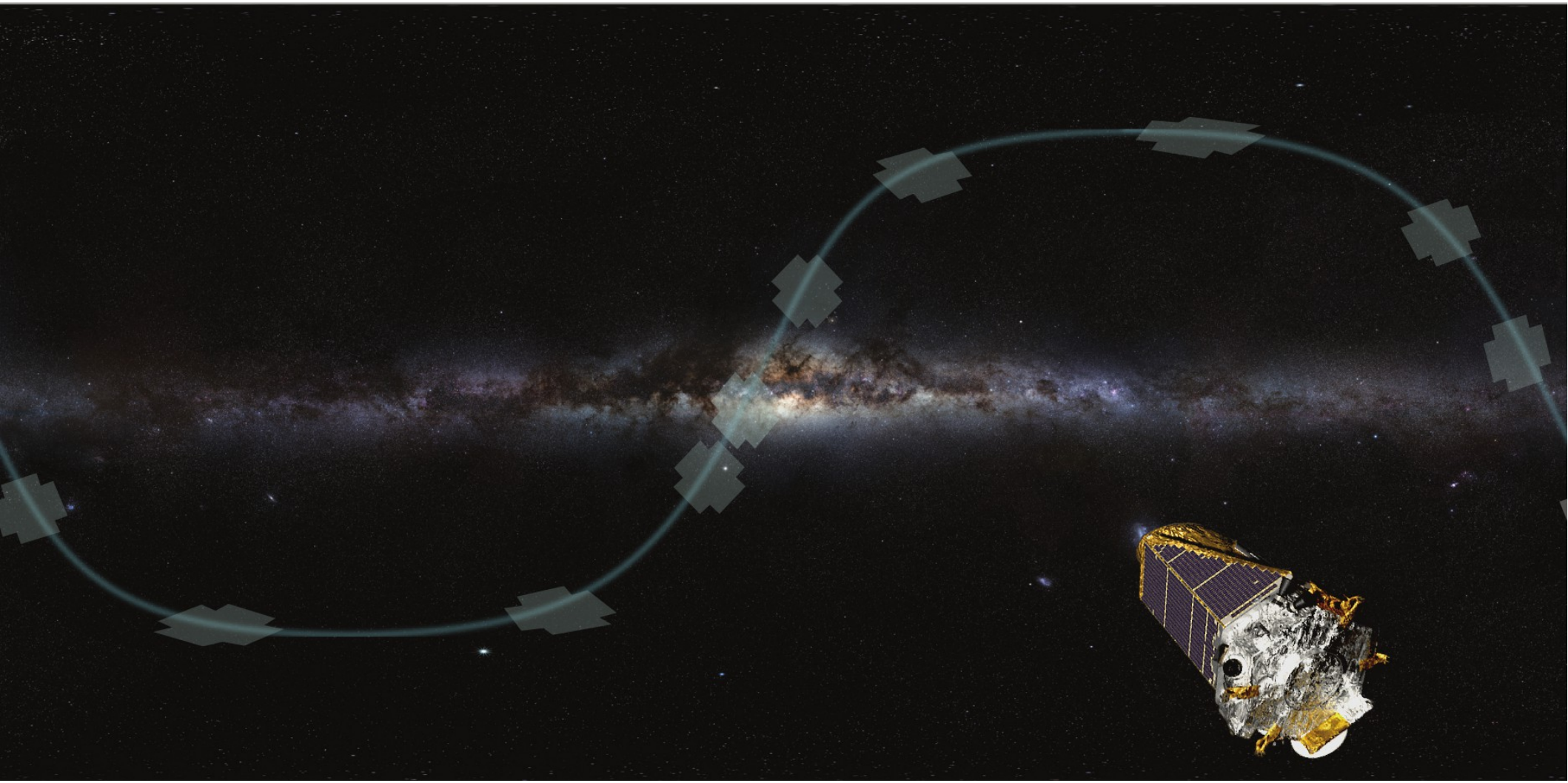
K2 Microlensing Workshop

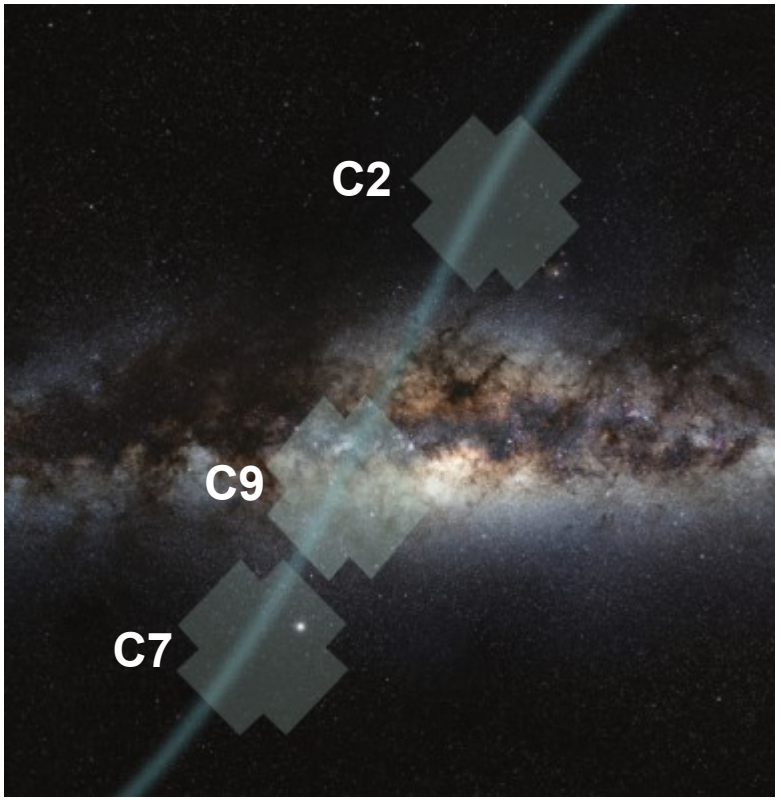
Held 7-8 May 2015, SETI Institute, CA



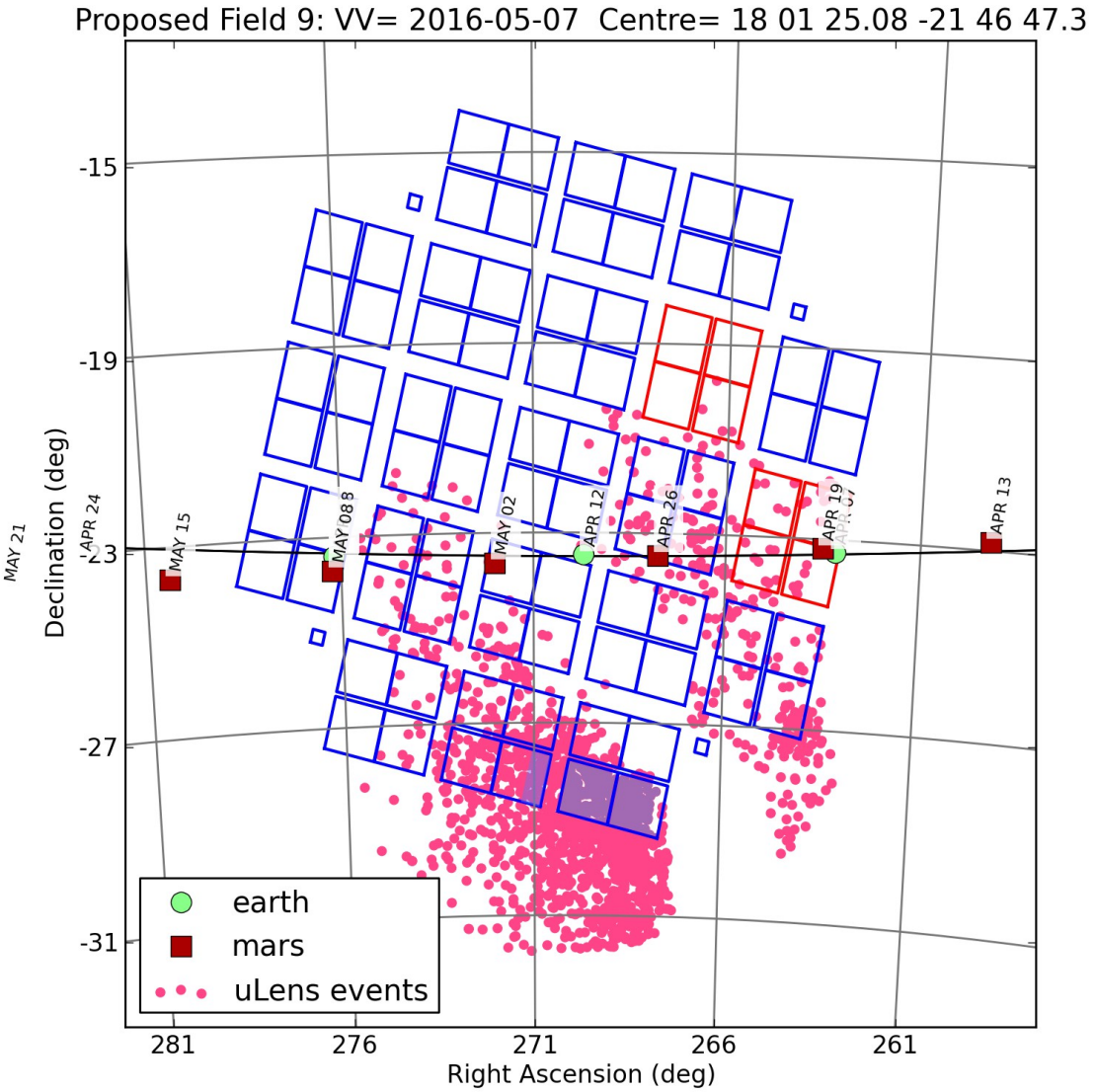
Rachel Street

LCOGT.net

K2 Mission

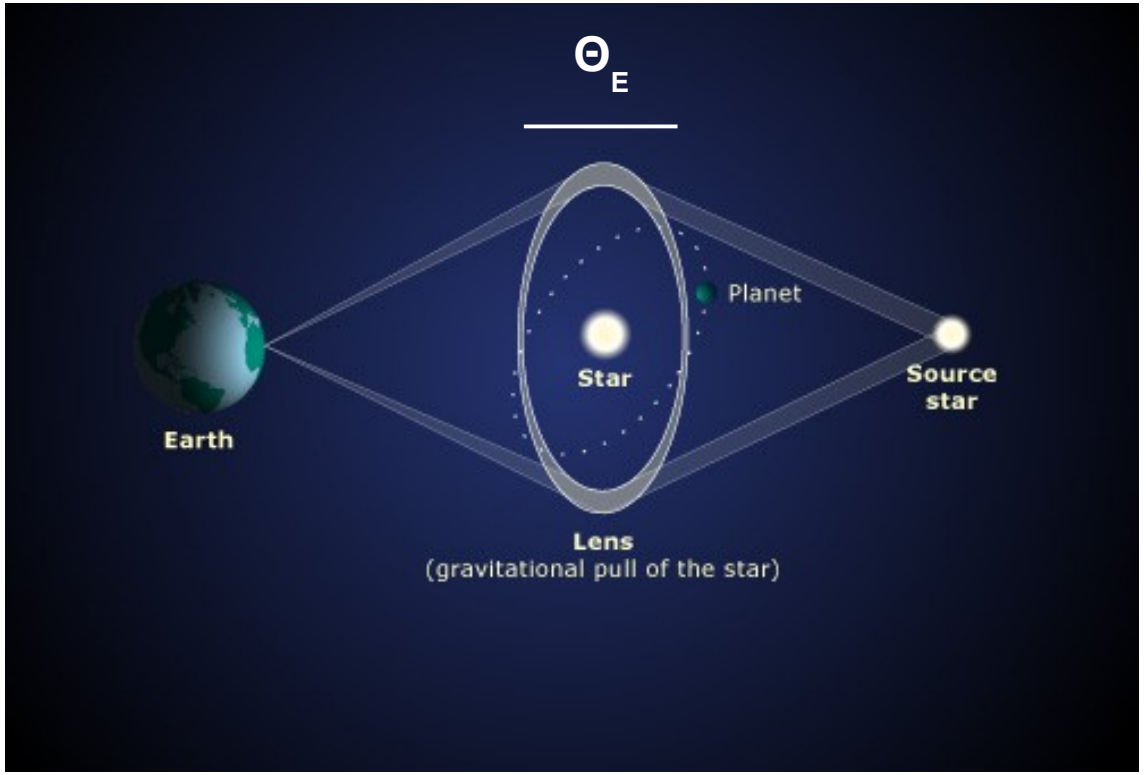


Campaign 9 overlaps region of highest microlensing rate



Expect ~85-100 events
(not including short-tE events)
Zhu: Including ~20 binary events (planets, brown dwarfs, compact objects)

Measuring Lensing Objects



We want to measure the mass...

Ang. Einstein radius

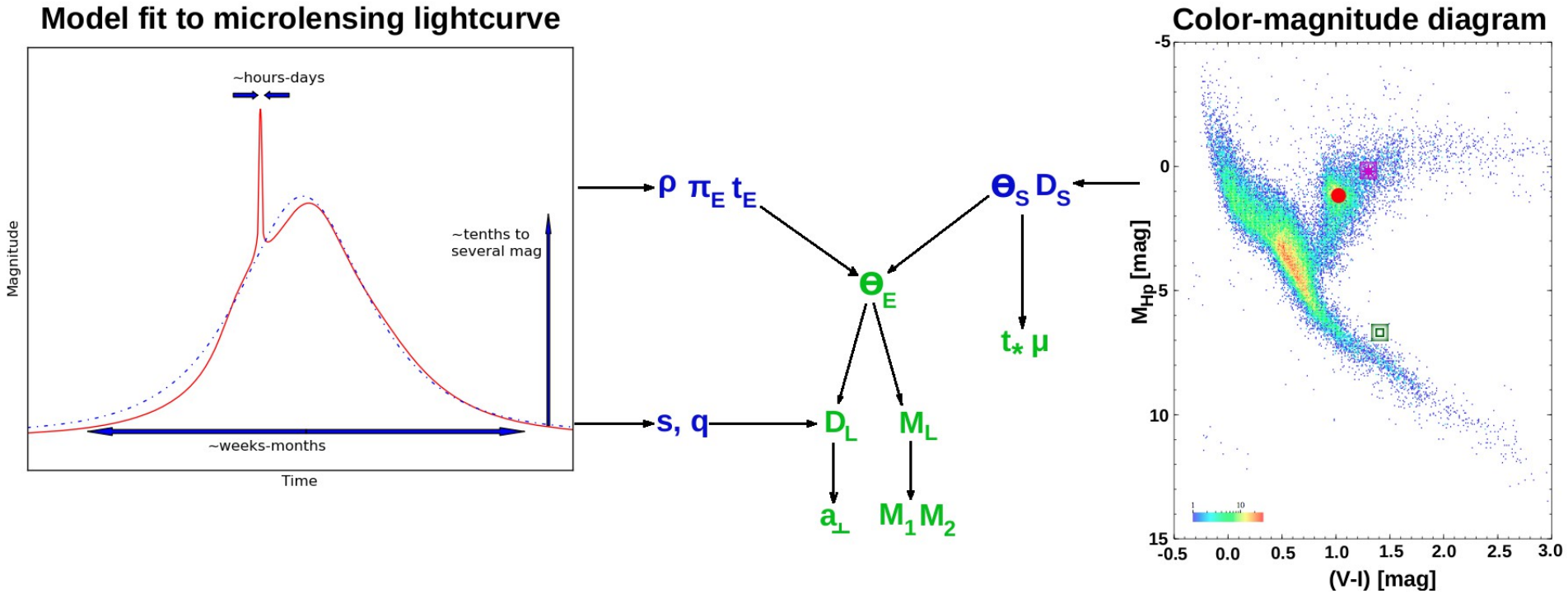
$$M_{Lens} = \frac{c^2\, AU}{4G}\,\frac{\Theta_E}{\pi_E}$$

Parallax

Ang. Source size

$$\rho = \frac{\Theta_S}{\Theta_E} = \frac{t_S}{t_E}$$

Measuring Lensing Objects

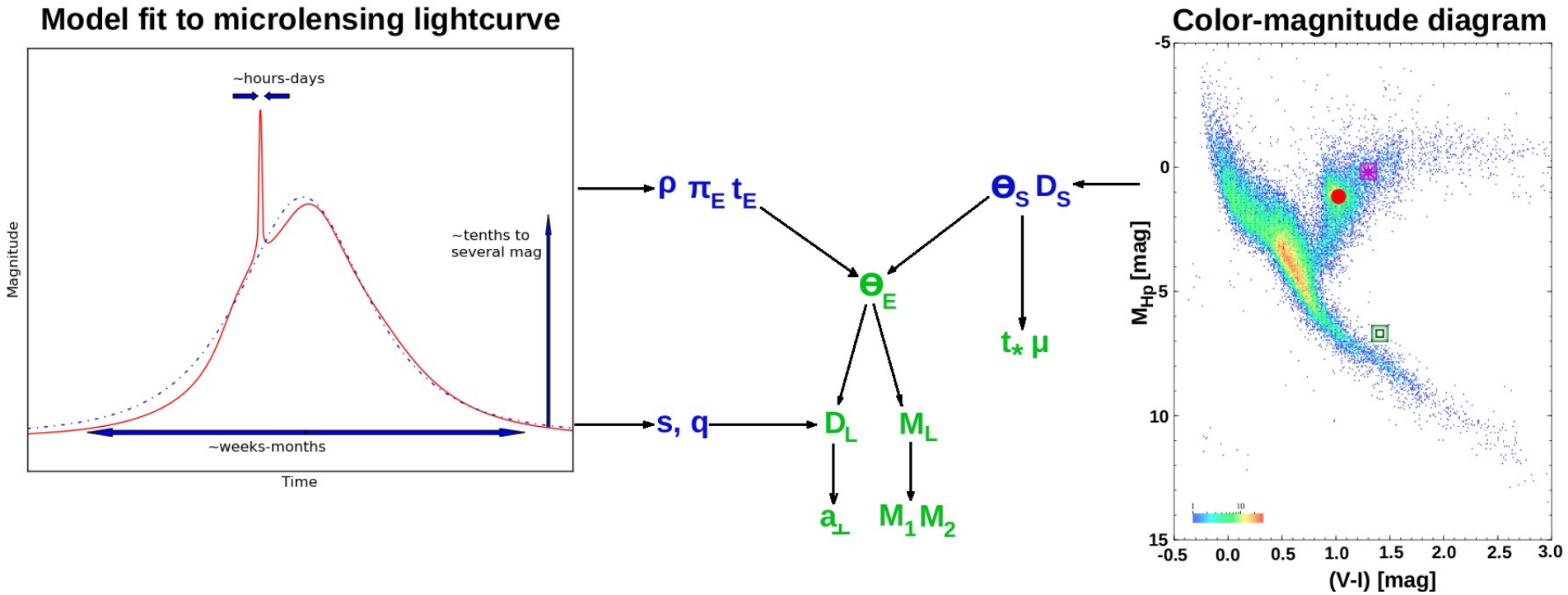


To measure M_{Lens}, we need to measure:

- the parallax, π_E
- the angular source size, Θ_E

Measuring Lensing Objects – Source Size

Determine spectral type, infer radius from stellar models
Measure abs. mag relative to Red Clump, infer distance → Angular source size, Θ_E

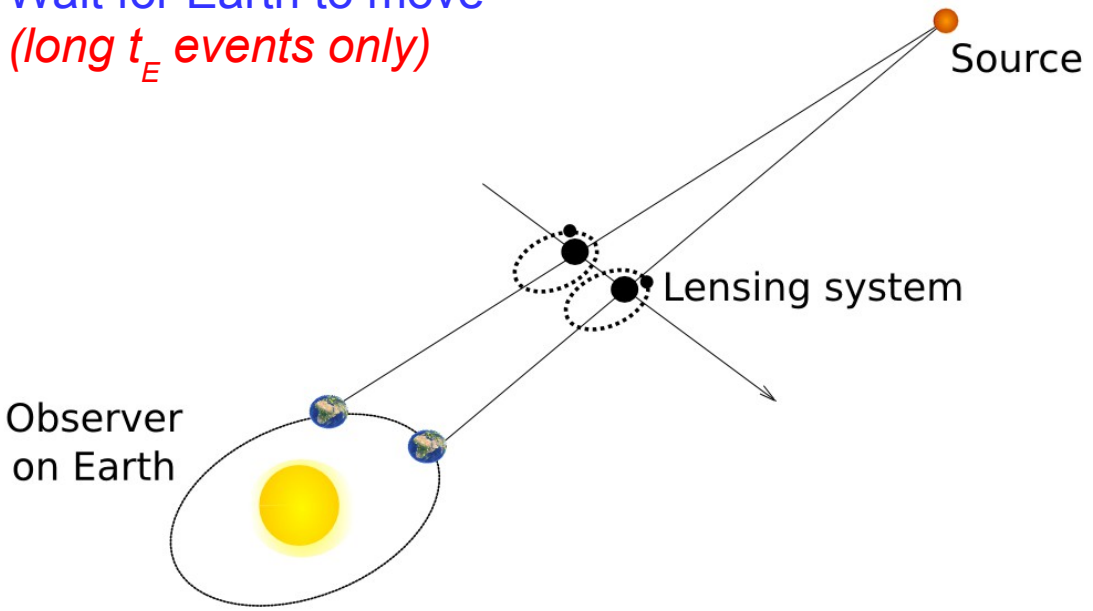


→ *Require multi-color photometry during and after (before) event to deblend source*

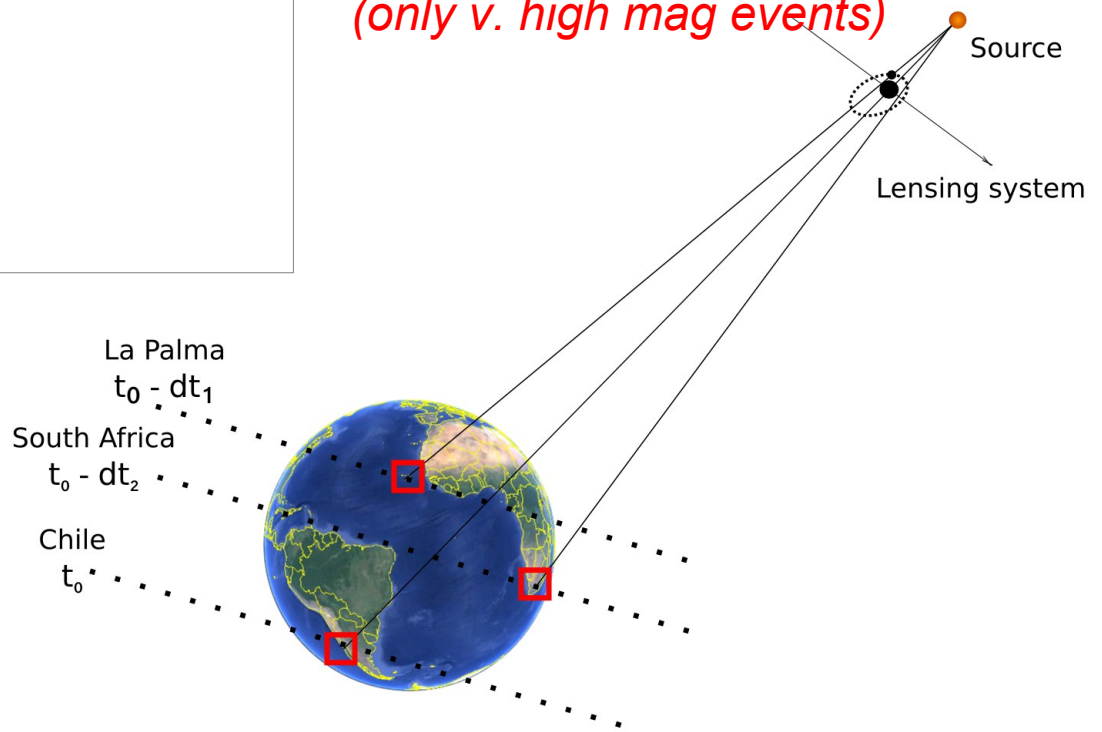
Measuring Lensing Objects - Parallax

Ground-based observations only

Wait for Earth to move
(long t_E events only)

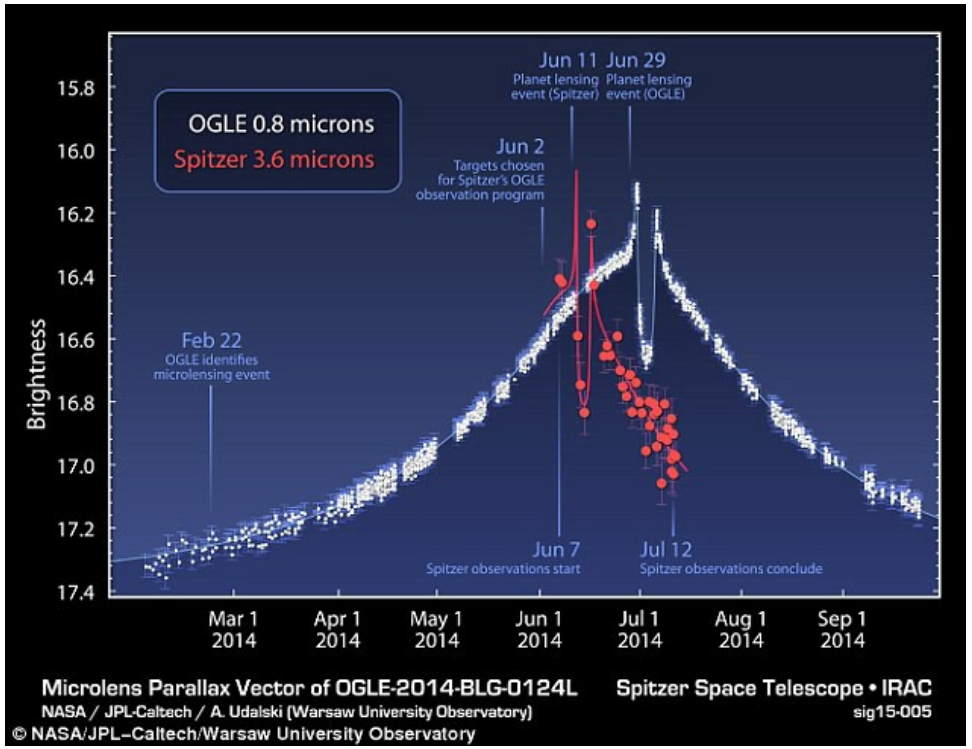


Simultaneous observations
(only v. high mag events)

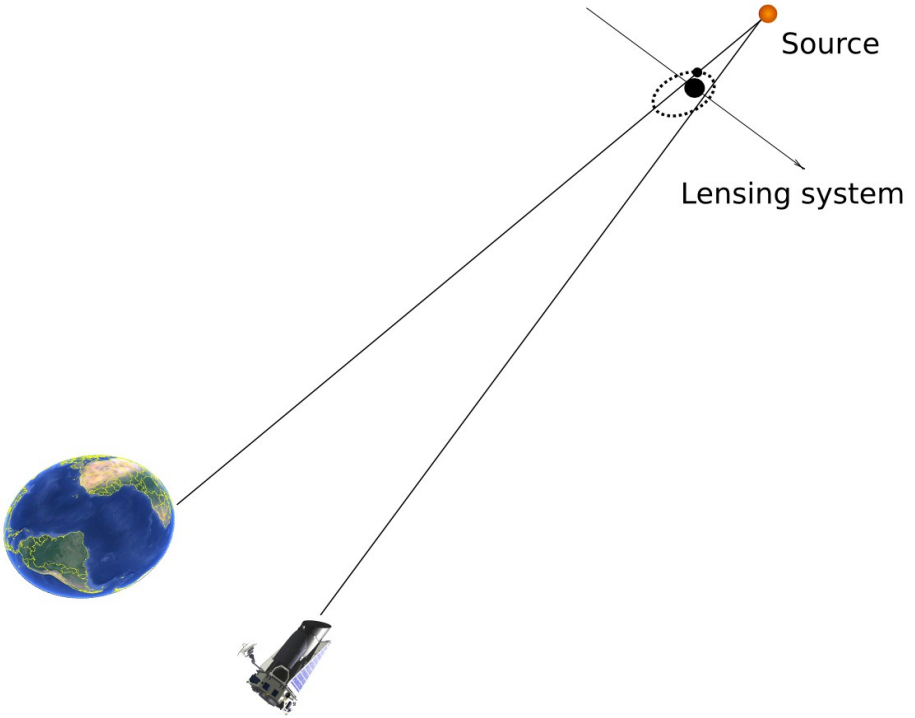


Measuring Lensing Objects - Parallax

Space + ground-based observations



Udalski et al. 2014



→ Measure parallax for almost all events

K2 Sensitive to Free-floating/wide-separation planets

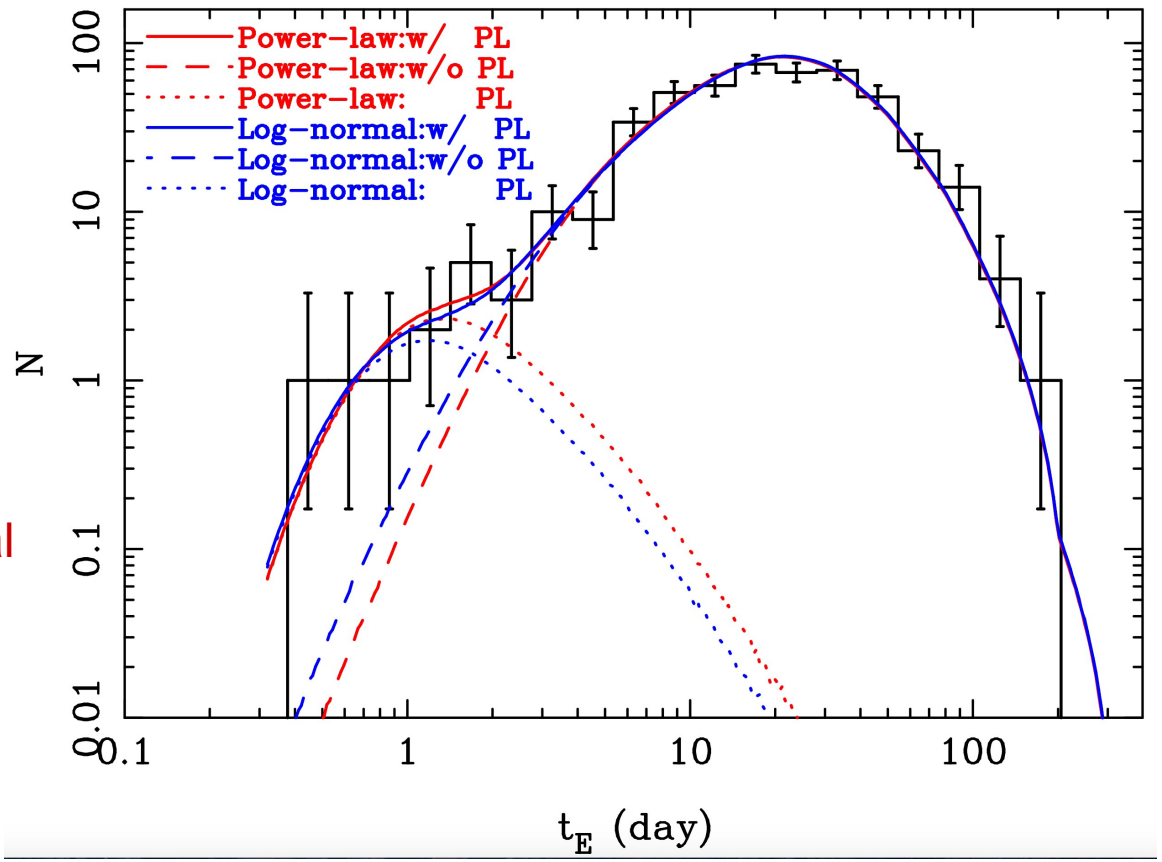
Unique wide-field, continuous-stare space-based survey facility
Mass distribution may give clues to formation/evolution

Penny:

- Expect ~40 FFP events
- Measure parallax for ~30
- Derive masses for ~3

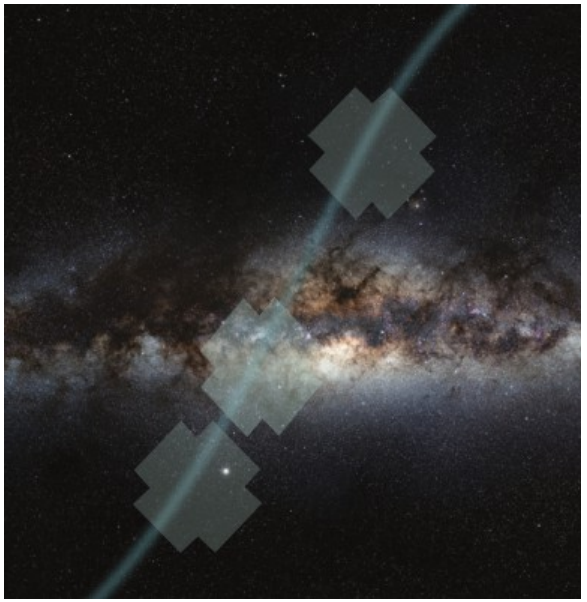
→ Need photometry for whole K2/C9 field at least several times per night from space+ground

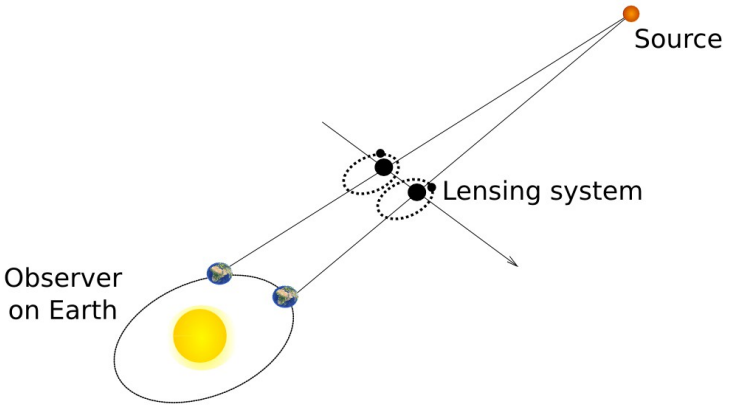
From Sumi et al. 2011: ~1.9 FFP per star



K2 Campaign 9

A unique opportunity to measure the mass and distances of *almost all* lenses





Need simultaneous observations from Earth:

→ Enabled by pointing K2 in the +VV direction

Short mid-campaign break for uplink (allows larger, ~3.8sq.deg. area to be surveyed)

Management of Campaign

- GO proposals will NOT be for targets – superstamp region pre-determined
- Propose for membership of K2 Microlensing Science Team
  5-10 people who will guide program for *benefit of community*
- Step 1 proposals submitted, Step 2 due July 1
- ~$500K total funds to be made available
- Selection planned for October 2015
- Hoping to host K2 meeting along side K2 Sci Con in November 2015

K2 Microlensing Workshop

Goals of Microlensing ScienceTeam:

- Maximise the science return of Campaign 9 for whole community
- Develop capability and grow the microlensing community, particularly in the US

Identified major work areas (but not limited to):

- Ground-based observing campaign
- K2 crowded field photometry
- Field selection
- Data archiving and access

Gaudi:
*"Watershed in microlensing coming...
need to position the US community with expertise"*

Ground-based Observing Campaign - Current surveys

OGLE

Las Campanas, Chile
1.3m telescope
0.26”/pixel
1.4 sq.deg FOV

MOA

Mt. John, NZ
1.8m telescope
0.57”/pixel
2.18 sq.deg FOV

KMT*Net*

Las Campanas, Chile,
SAAO, South Africa
Siding Spring, Australia
1.6m telescopes
0.36”/pixels
16 sq.deg FOV

- All optical (V, I)
- None US-based
- Will monitor K2/C9 field
- No motivation to share data

Ground-based Observing Campaign – Proposed Surveys

DECam on 4m Bianco @ CTIO

- ✔ Pixel scale 0.2626 - 0.2637 arcsec/pixel (edge - center)
- ✔ Field of view 2.2 square degree (c.f. K2/C9 superstamp ~3.8 sq. deg)
- ✔ Excellent field visibility
- ✔ ugrizY and VR filters available
- ✔ Data will be made public

Problem:
~76d campaign
Very limited time available
through normal channels

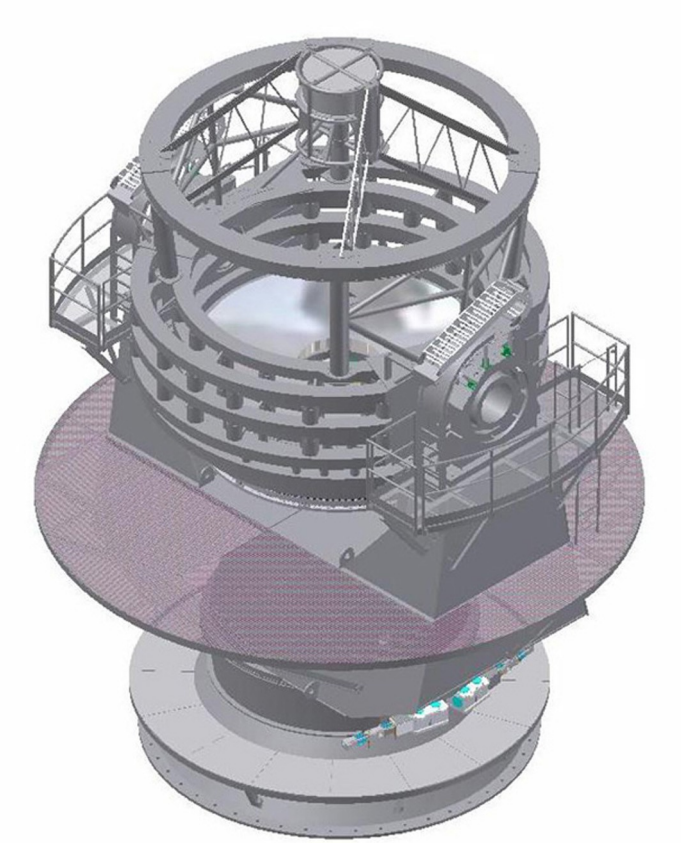
Need community support!

Data useful for other science too

Ground-based Observing Campaign – Proposed Surveys

Invited collaborators from VVV survey

Kerins: Tiles b306 and b307 cover K2/C9 field



<u>VISTA 4m Survey Telescope</u>

- ✔ 4m ESO-run telescope at Cerro Paranal, Chile
- ✔ Pixel scale 0.34 arcsec/pixel
- ✔ Field of view 1.65 square degree (c.f. K2/C9 superstamp ~3.8 sq. deg)
- ✔ Excellent field visibility
- ✔ ZYJHKs filters available

Ground-based Observing Campaign – Proposed Surveys

Howell: exploring options to use NASA time for K2/C9

Problem:
2016 status unknown

UKIRT

- ✔ 3.8m telescope at Mauna Kea, Hawai'i
- ✔ Pixel scale 0.4 arcsec/pixel
- ✔ Field of view 0.75sq.deg in 4 pointings (c.f. K2/C9 superstamp ~3.8 sq. deg)
- ✔ Excellent field visibility
- ✔ ZYJHK filters available

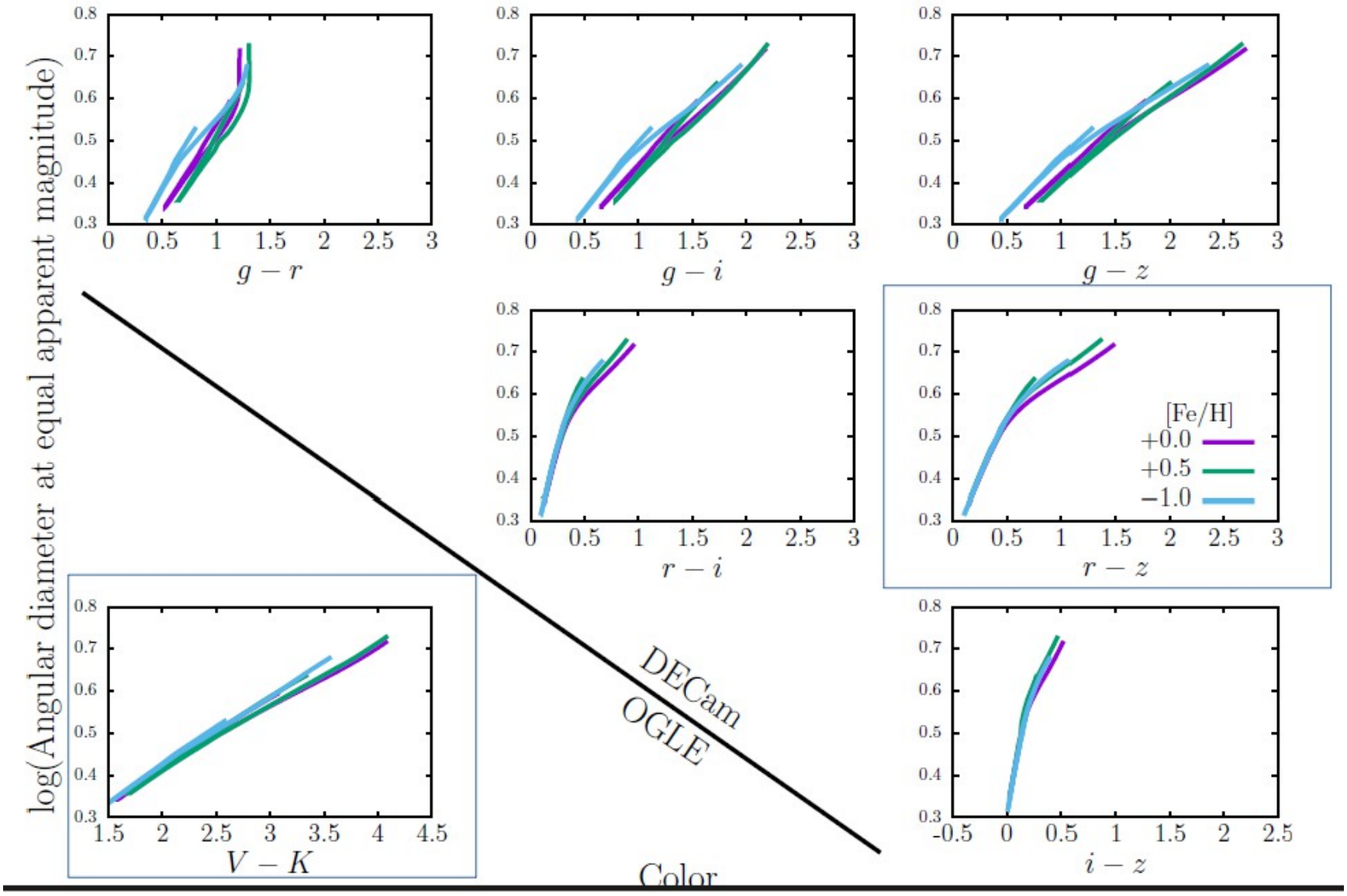
Ground-based Observing Campaign – Alternative Facilities

- Subaru-HyperSuprimeCam
- VLT Survey Telescope
- Pan-Starrs
- CFHT-MEGACAM
- SkyMapper
- Magellan-Clay-(MEGACAM or IMACS f/2)

Photo by Hideaki Fujiwara - Subaru Telescope, NAOJ

Ground-Based Observing Campaign - The need for NIR

Depend on stellar radius/color relations, but know nothing about the age of the star, leading to uncertainty.



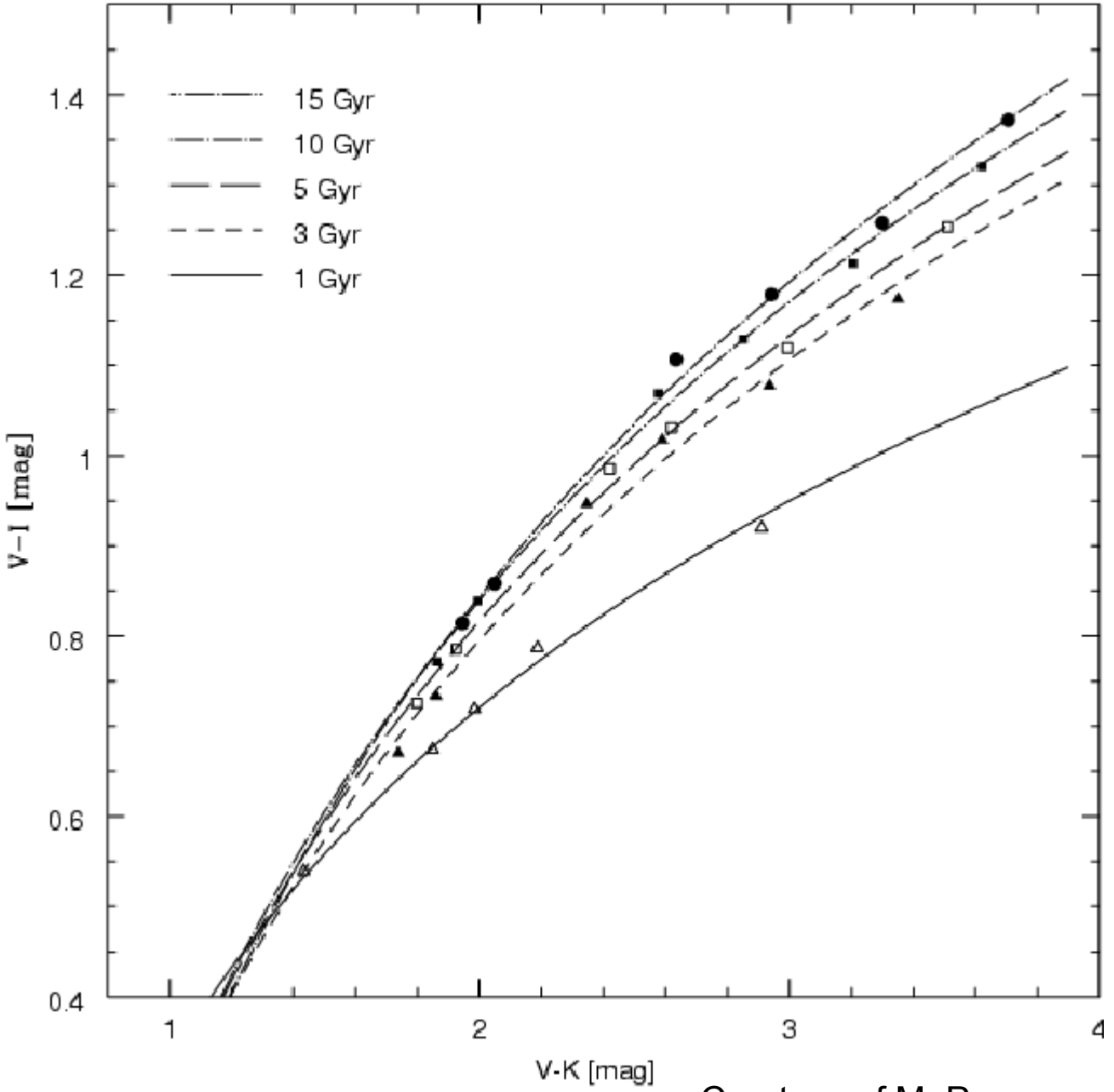
Courtesy of M. Penny

Ground-Based Observing Campaign - The need for NIR

Depend on stellar radius/color relations, but know nothing about the age of the star

→ NIR photometry delivers more accurate measurements

→ Need 2+ datapoints per tile per night for ~76d



Courtesy of M. Penny

Ground-Based Observing Campaign - The need for NIR

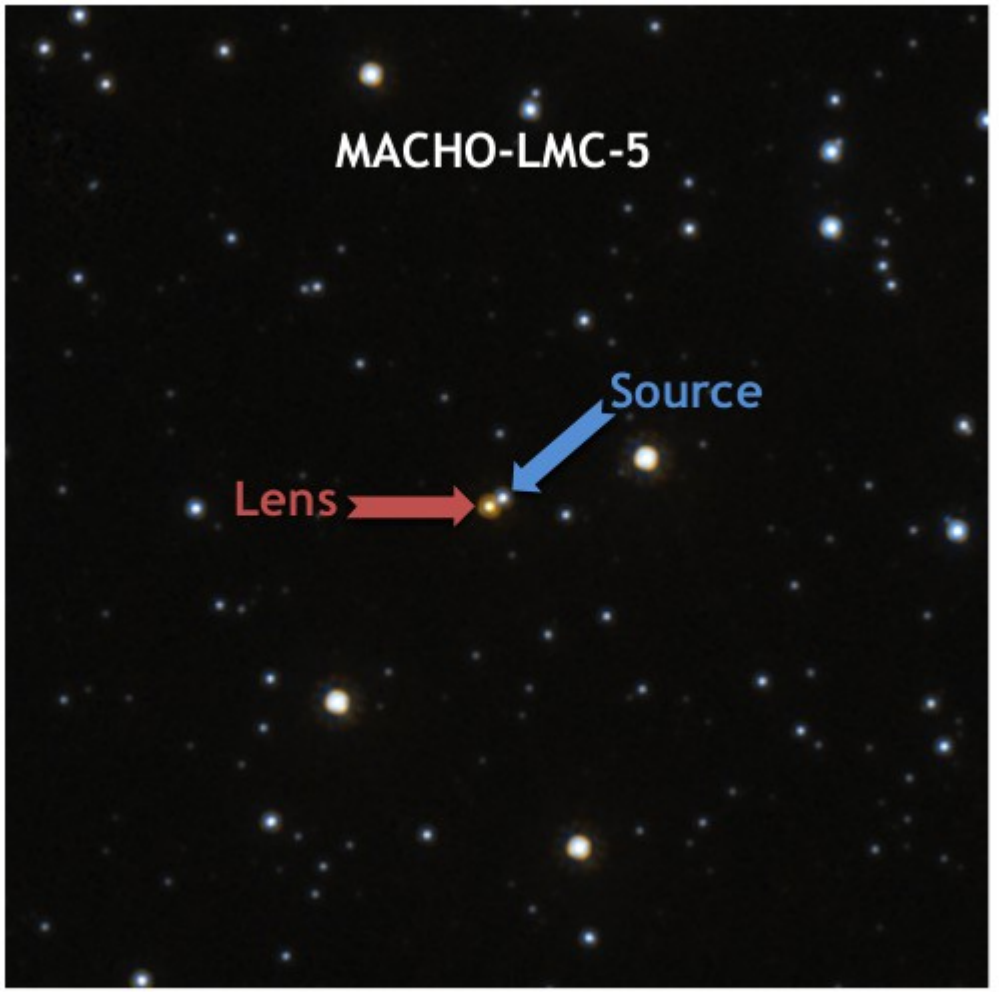
Henderson: Hi-res NIR during and post event
→ Distinguish light from the lens by PSF elongation
→ The only way to distinguish free-floating planets from widely-separated ones, by probing for dynamical companions

Measured from lightcurve

$$\Theta_E = \mu_{rel} t_E$$

Measure: Relative proper motion (source/lens)

Derive,
→ **determine M_{Lens}**



Credit: NASA, ESA, A. Drake, K. Cook

Field Selection

Poleski: Optimize K2/C9 pixel selection based on OGLE data

To measure parallax → maximize N_{Events}

To detect free-floating planets → maximize N_{Stars}

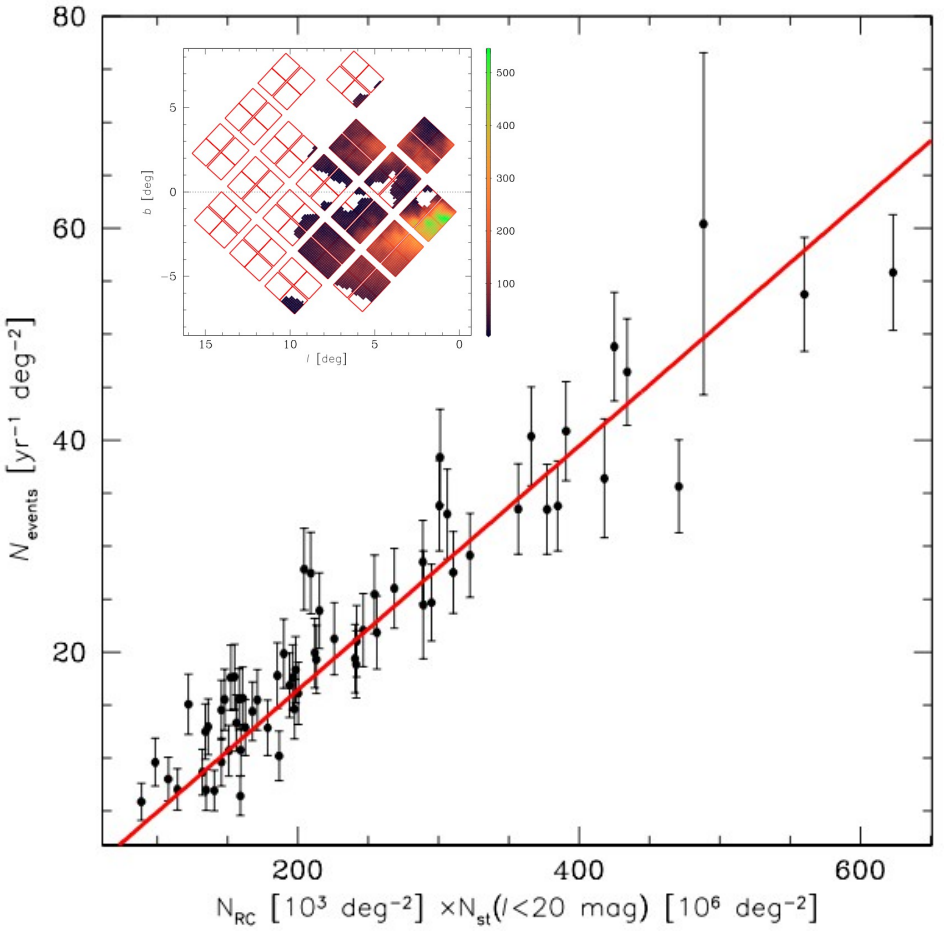
$$N_{Events\,/\,field} \propto N_{RedClumpStars}\, N_{Stars}$$

- Optimization effects the event yield by ~20%.
- High yield of variables: 1 per 50 K2 pixels

→ multiband photometry and hi-res imaging

Gaudi: Select field to include disk-Bulge events + Bulge-Bulge events

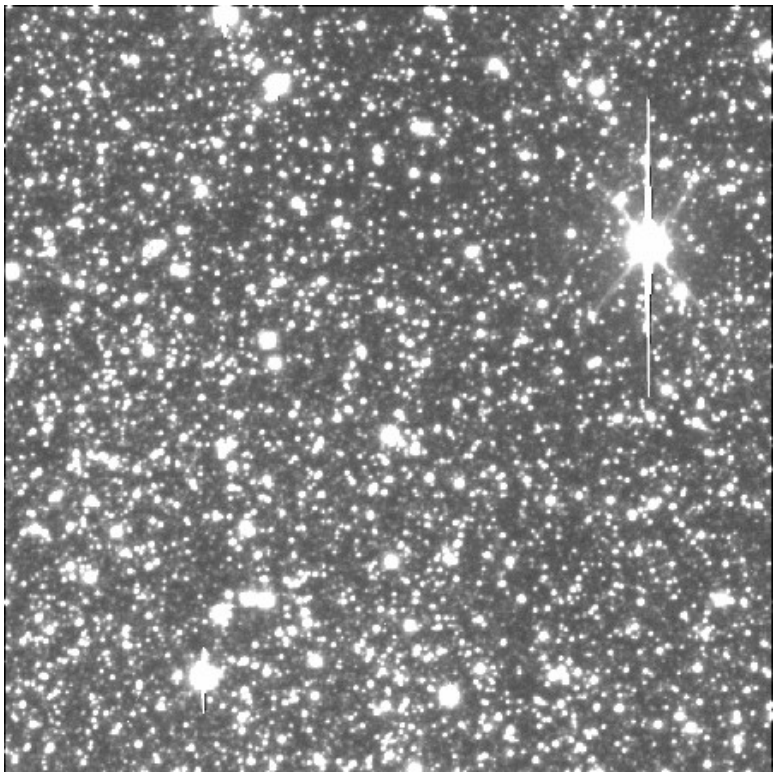
→ pathfinder for WFIRST field selection



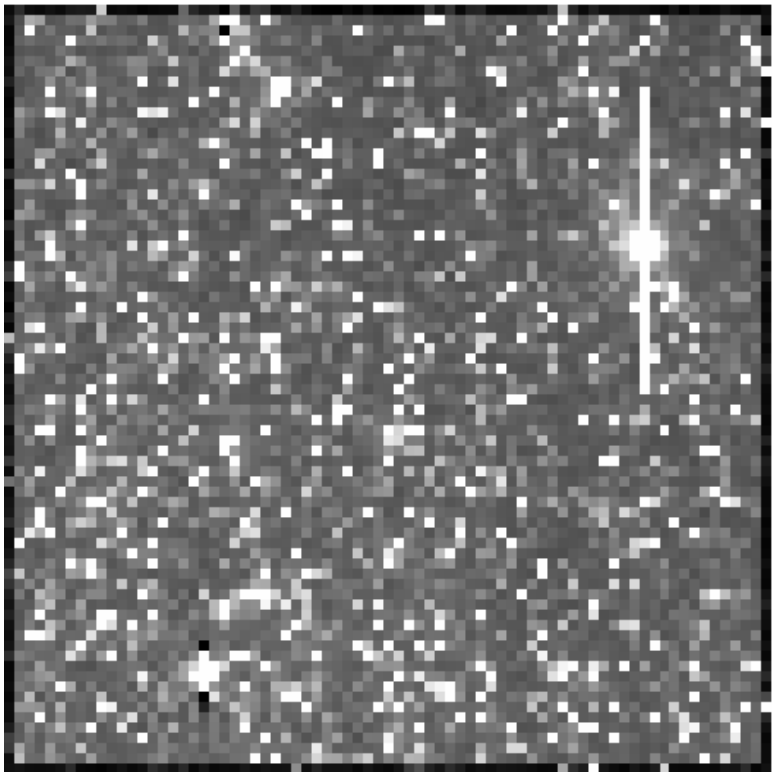
K2 Crowded Field Photometry

Need 1% photometry

Existing pipelines likely to struggle



5x5' image of OGLE-2014-BLG-1186
LCOGT-Chile 1m, 0.387”/pixel



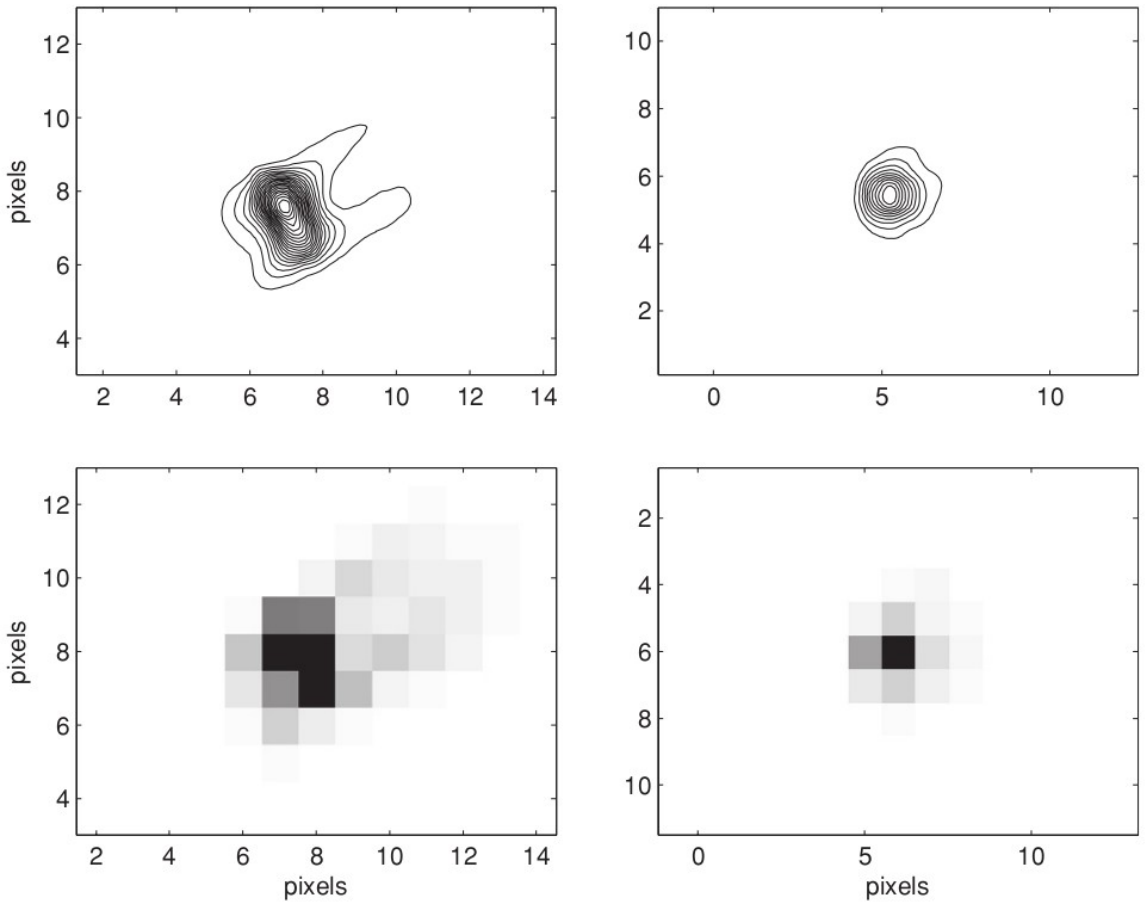
Same image, resampled to K2
pixel scale 3.98”/pixel

K2 Crowded Field Photometry

Need 1% photometry
Kepler PRF variable across focal plane

Adding complexity:
→ Solar-pressure induced drift & 6hr cycle of thruster pointing corrections

→ (heavily blended) lensed source may change brightness rapidly rel. to drift



Near edge

Near center

K2 Crowded Field Photometry

Community already exploring multiple approaches
[Penny, Street, Bennett, Beaulieu]

- DIA analysis
- Detrending
  → 1st order: variation due to pointing
  → 2nd order: variation due to blended lensed star moving across pixel of variable sensitivity
- Forward-modeling based on high-resolution ground-based data
- Modeling of K2 PSF as a function of temperature, time and position on CCD based on existing K2 data

Data Archiving

- K2 data public
- K2/C9 GO strongly encourages teams to make public their data products
- Akeson/Ciardi: Support from NASA Exoplanet Database
- Community feedback:
  → would like OGLE-III catalog data in archive with extraction/analysis tools
  → extract source (blend) positions and associate with K2 objects
  → Color-mag diagram analysis

Microlensing Community

- Clear a community-wide effort is required

- US-based community is small but strong links with teams worldwide
  → want to expand US community ahead of WFIRST
  → want to benefit from expertise overseas

- General agreement to form working groups to tackle tasks
  Coordinators: Rachel Street / Matthew Penny

- First steps:
  Mailing list: k2-microlensing@lcogt.net
  Wiki for sharing & discussion of results

- Ongoing discussions regarding GO proposals and large-scale ground-based follow-up programs

- Proposing to host K2 Microlensing Science Team meeting & session at K2SciCon in Santa Barbara in Nov 2015

Summary

- K2/C9 is a unique opportunity!
  → will measure and characterize a large sample of lenses
  → sensitive to free-floating planet events

- ***Only*** chance to measure masses for free-floating Jovian planets
  (WFIRST-AFTA may measure terrestrial planets)

- Selection biases well understood → population analysis

- Science return ***impossible without*** simultaneous ground-based coverage
  → no current US-based survey
  → Need optical, NIR survey

- Crowded field photometry challenging with K2...but not impossible.
  Analysis is underway.

- Coordinating community-wide response to this opportunity