Constraints on the mass of microlenses from HST astrometric measurements

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Constraints from astrometry

- Introduction to astrometric microlensing- Jessica Lu’s talk
- Stellar-mass BH produce astrometric signals of the order of 1 mas
- Efforts to constrain potential lens BH masses from the ground (Lu et al. 2016) and from space (Sahu et al., Kains et al. 2016, 2017 in prep.)
- How far down the mass spectrum can we get using HST?

HST astrometric precision

- The HST ACS/ UVIS pixel scales are 50 and 40 mas, respectively
- Stars down to *V*~21 can have their position measured with a precision of <1% of a pixel, i.e. ~0.4-0.5 mas per measurement
- We should be able to detect astrometric signals from some regular star-star microlensing with lenses down to ~0.3 $M_{\odot}$
- Use astrometric measurements to measure and/ or place limits on the size of the Einstein ring radius θ_E

Measuring masses of isolated objects

$t_E = \theta_E / v_{\mathrm{ang}}$

$$\theta_{\mathrm{E}} = \sqrt{\frac{4GM}{c^2}\pi_{\mathrm{LS}}} \longrightarrow M = \frac{\theta_{\mathrm{E}}^2\, c^2}{4G\pi_{\mathrm{LS}}}$$

$$\pi_{\mathrm{LS}} = \left(\frac{1}{D_L} - \frac{1}{D_S}\right)$$

- Lens mass is a function of Einstein ring radius θ_E and lens-source parallax π_{LS}
- If we can constrain both θ_E from astrometry and π_{LS} from photometry, we can combine them to constrain the lens mass

HST observing program

- We monitored ~1.8 million stars with ACS and UVIS over the course of 3 years (2011-2014, PI: Sahu), down to V~27 at a cadence of ~2 weeks
- We also observed the same footprint using VIMOS at the VLT with a higher cadence (3-4 days) to constrain parallax

Survey events in our observations

- HST footprint contains 20 OGLE + 1 MOA events
- Of these, 5 were too short to be caught by our observations, 2 were too bright, 5 were too early/ late in the season
- This results in 9 events with HST astrometry and photometry

Reduction

- We measured both photometry and astrometry for all HST stars using the *KS2* pipeline (Anderson & King 2006)
- For VIMOS images, we used DanDIA (e.g. Bramich et al. 2008) to obtain time-series for all stars
- The result is 46 HST epochs, and 823 for VIMOS observations

Reduction

- For HST data, we applied local corrections for 2D variations across images, and the mid-year change in orientation of the telescope
- Did this for each event by selecting nearby reference stars of similar magnitude, within a radius of 150 pixels

OGLE-2013-BLG-0804

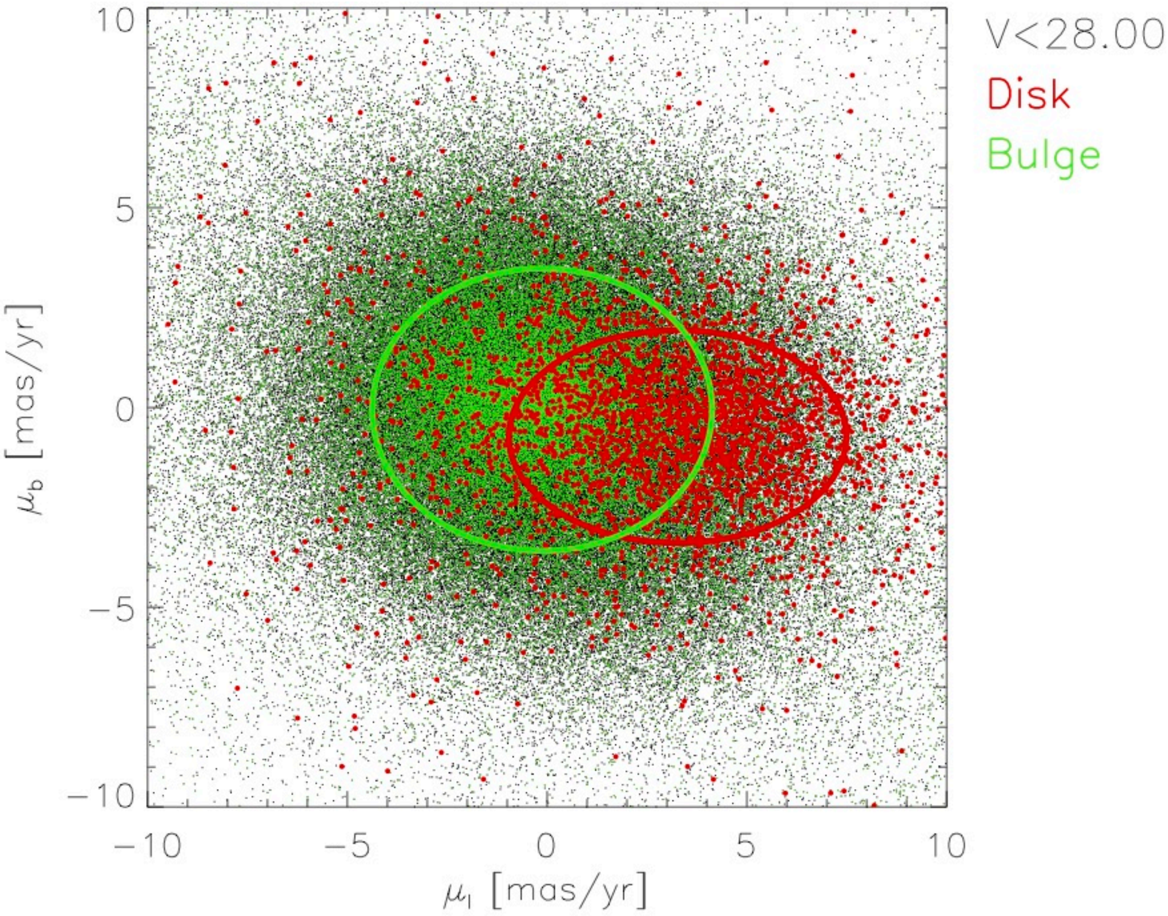
- Detected by OGLE EWS (Udalski+ 2003) in April 2013
- This V~20 event is within our ACS footprint, and peaked halfway through 2013, with a timescale of ~42 days
- Should be an ideal target for our observations

Modelling procedure

- Fit PSPL + parallax parameters (e.g. Dominik 1998, Gould+ 2004) and check whether it is well constrained and detected at a statistically significant level
- Use the posterior distributions on the parameters as priors for the astrometric microlensing model
- Use proper motion measurements to constrain the source-lens relative inclination

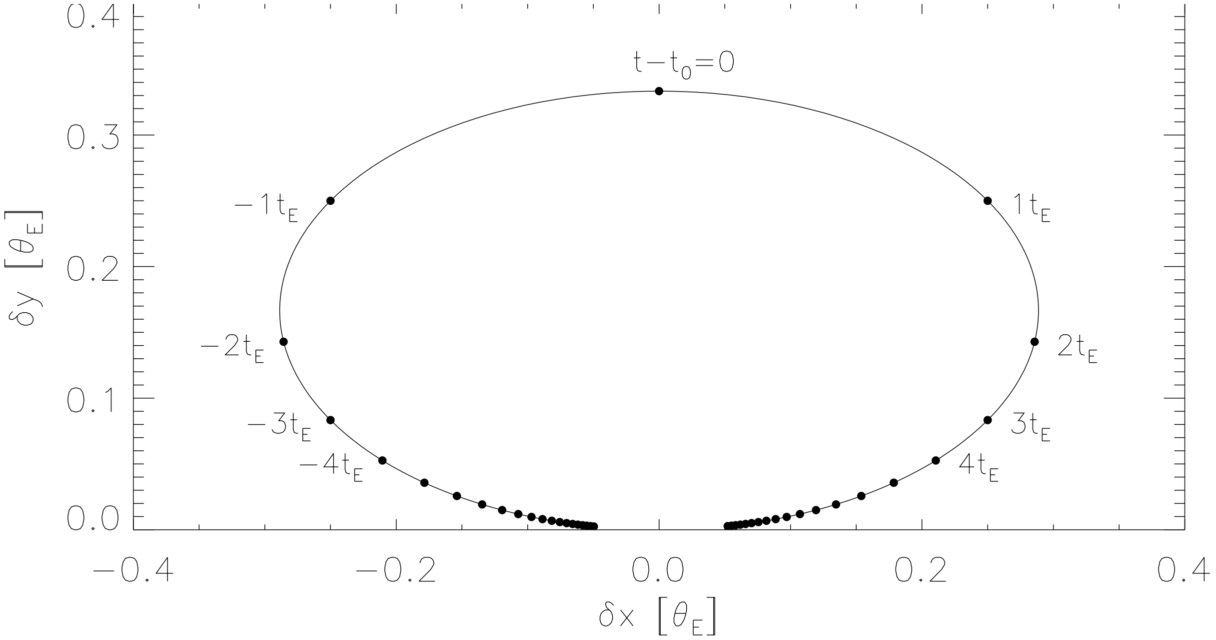
Proper motion

- We know the proper motion components of the source
- We know the locus of Disk stars in μ_l, μ_b and dispersion
- Assuming the lens is a Disk star, we can work out the relative angle α, and its error bar (mostly from lens pm uncertainty)
- For OGLE-2013-BLG-0804, we find α = 1.43 ± 0.82 rad

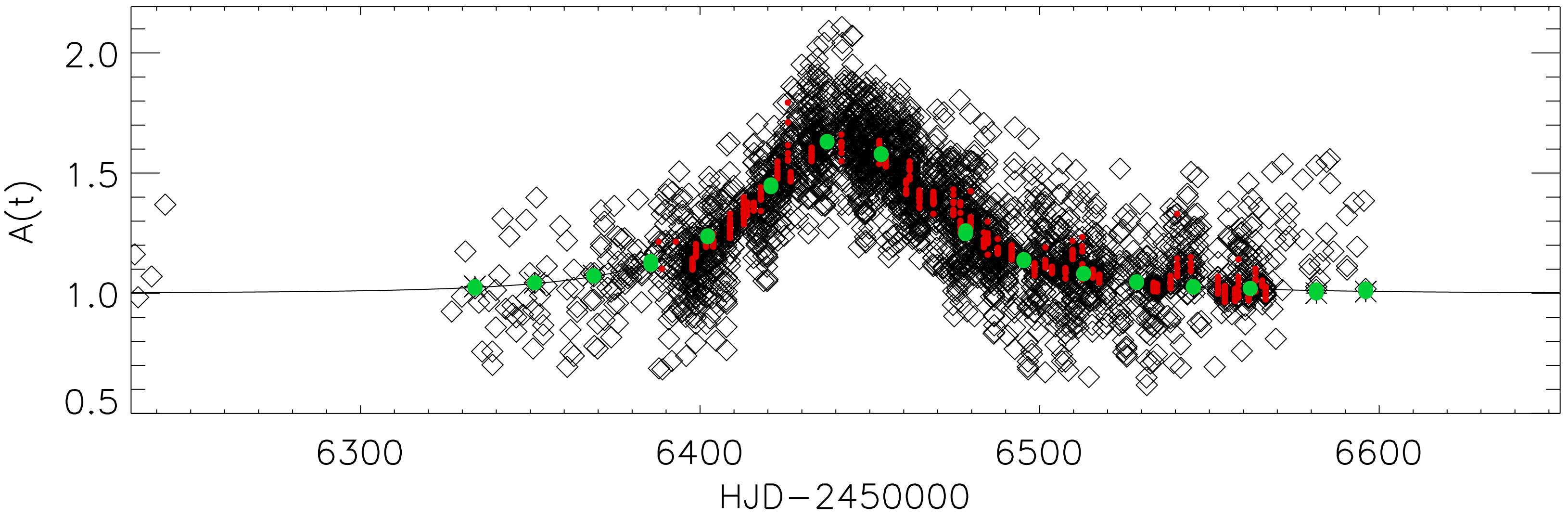


Astrometric microlensing model

- Subtract the mean proper motion of the source to keep only the elliptical motion caused by lensing (e.g. Dominik & Sahu 2000)
- Fit the residual astrometric motion with an elliptical trajectory with t_0, t_E, u_0, α, θ_E, x_0, y_0 (e.g. Kains+ 2016)
- The size of the ellipse scales with θ_E

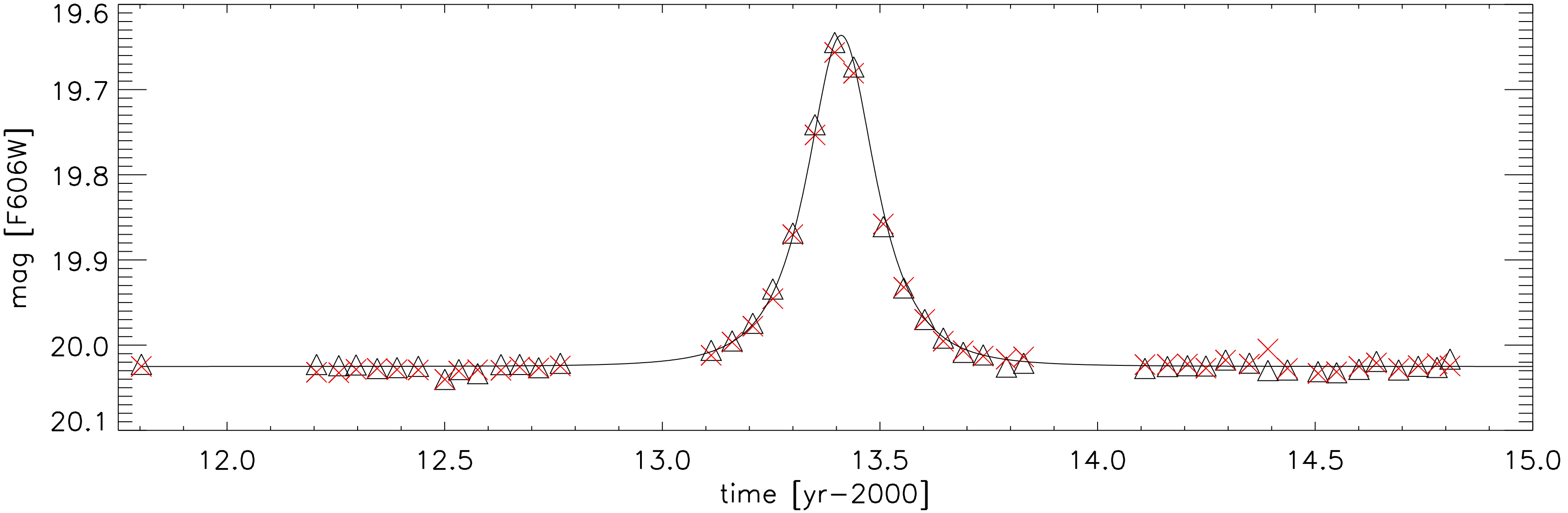


OGLE-2013-BLG-0804 – PSPL+parallax

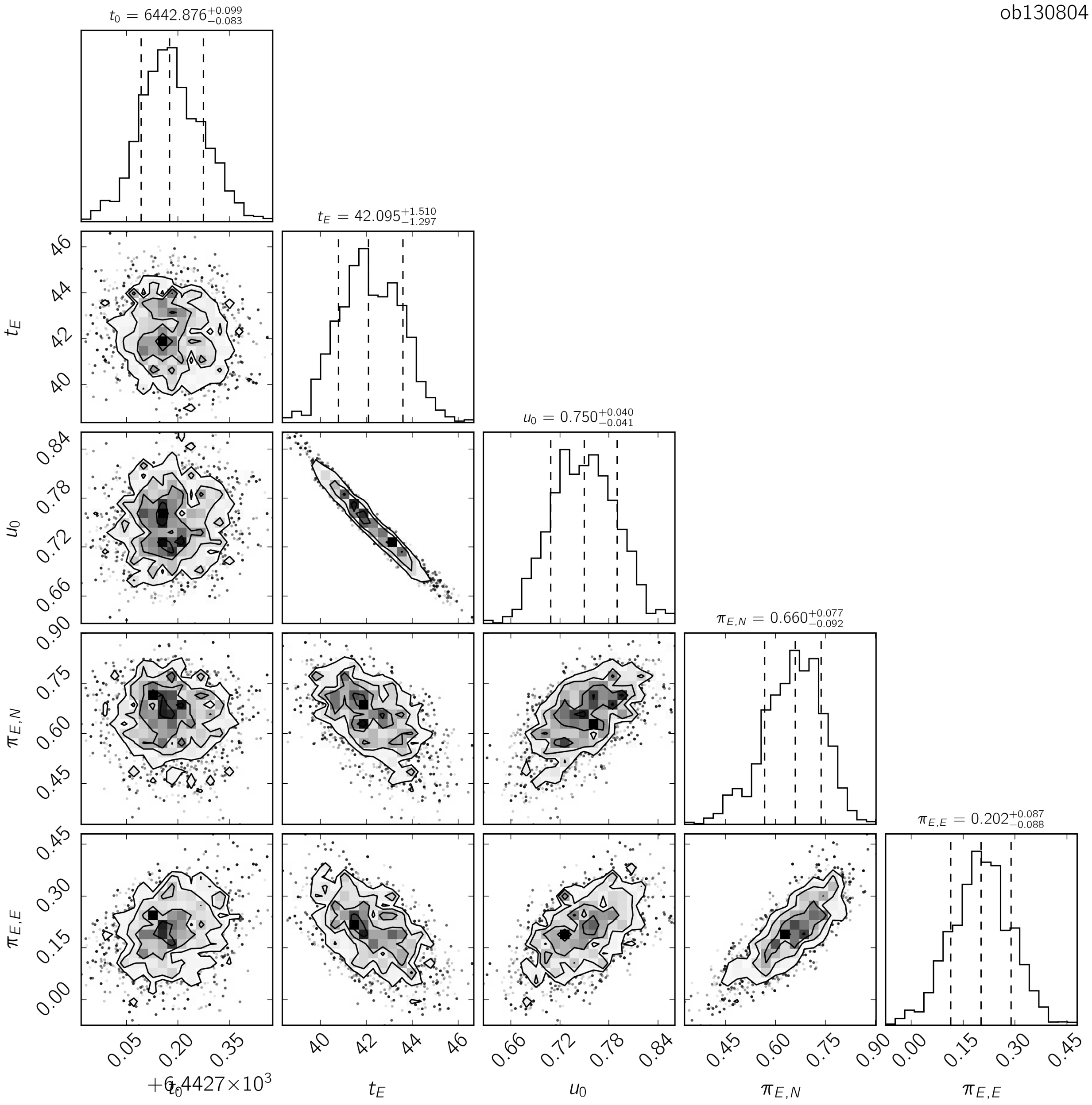


OGLE−2013−BLG−0804

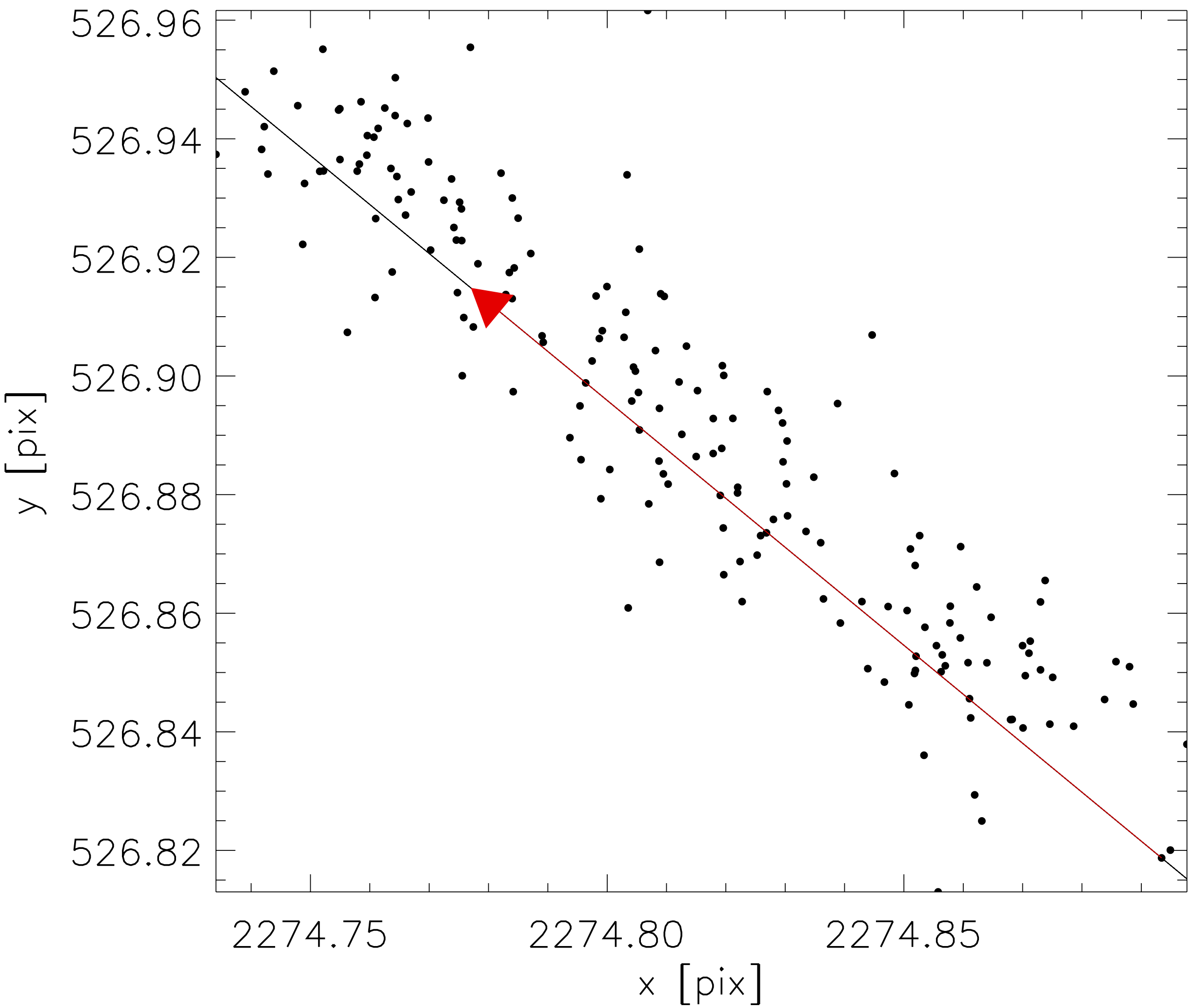
$t_0=6442.877\pm0.076$ $t_E=42.08\pm1.16$, $u_0=0.719\pm0.054$, $M=0.06\pm0.06\ M_\odot$



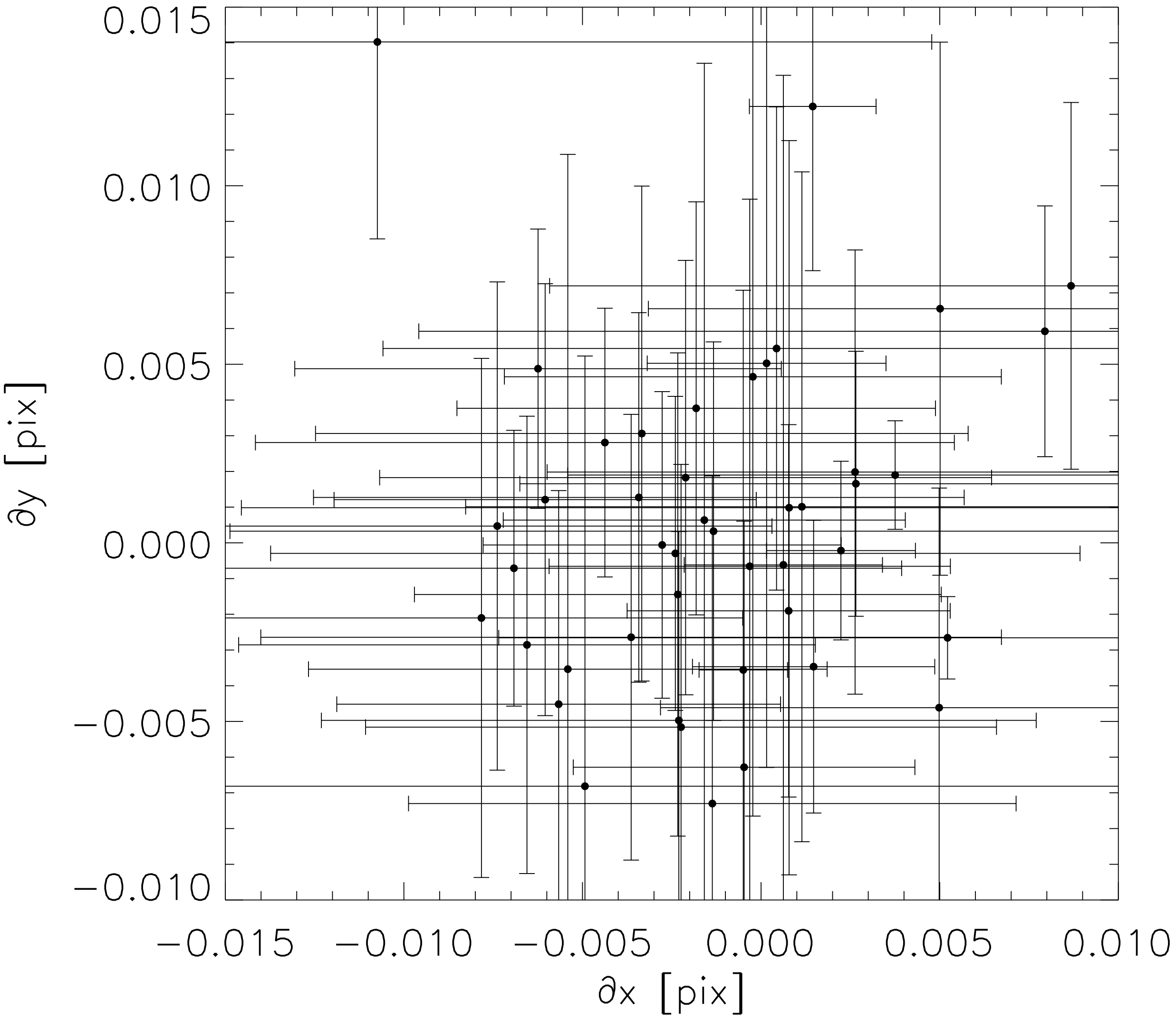
OGLE-2013-BLG-0804 – PSPL+parallax



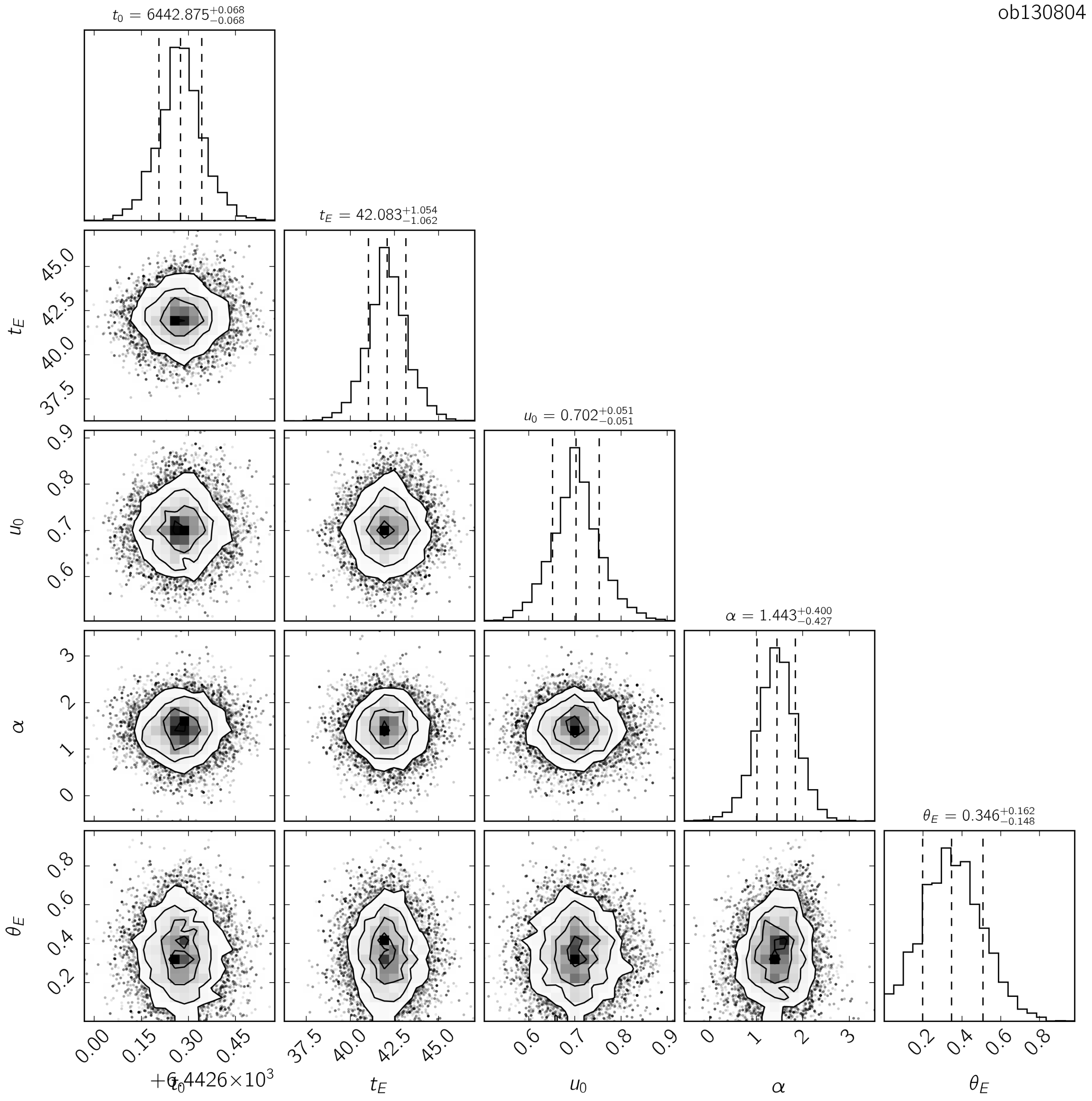
Astrometric data with PM (3 years)



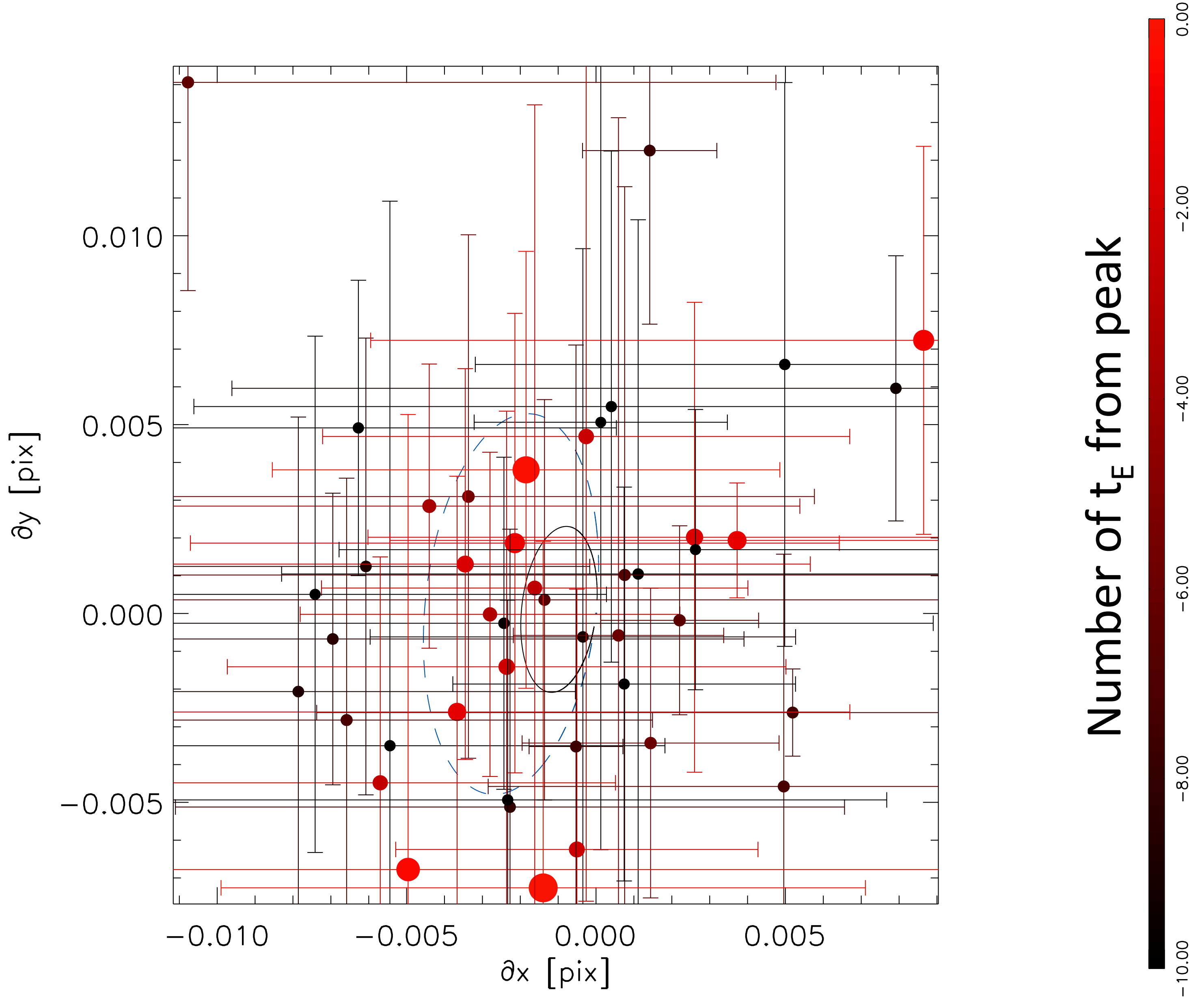
Astrometric data with PM subtracted



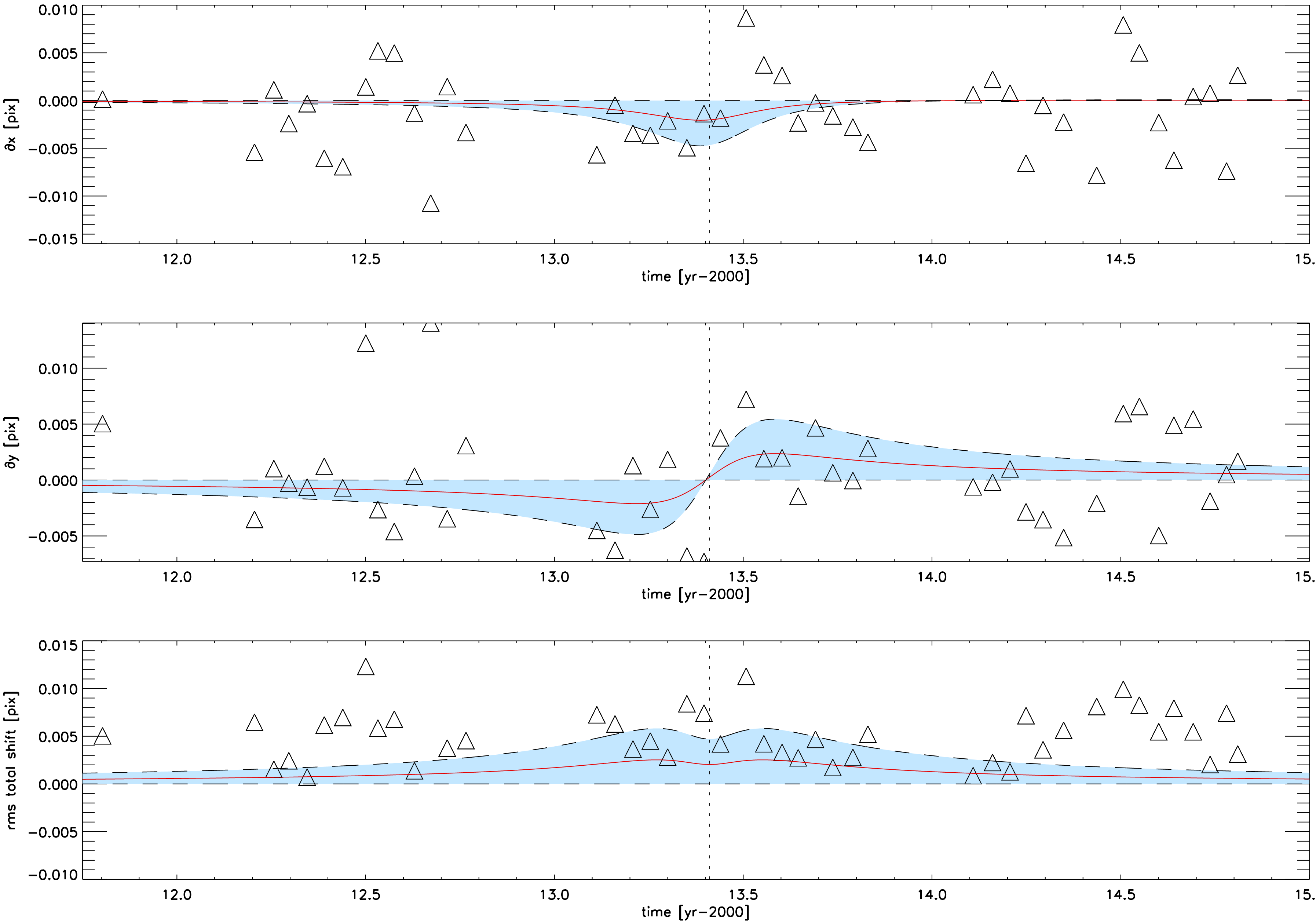
Astrometric fit



Astrometric model - 2D



Astrometric model – 1D



Mass constraints

- Astrometric fit has θ_E= 0.35±0.16 mas, α_{LS}=1.44±0.43 (compared to 1.43 from pm)
- Best-fit parallax is π_{LS}= 0.69±0.08, giving a lens distance of 2.7±0.3 kpc, assuming a source at 8.0±0.3 kpc (Yelda+ 2011)
- This yields a 3-σ upper limit for the lens mass of 0.36 $M_\odot$
- But parallax detection is not good enough

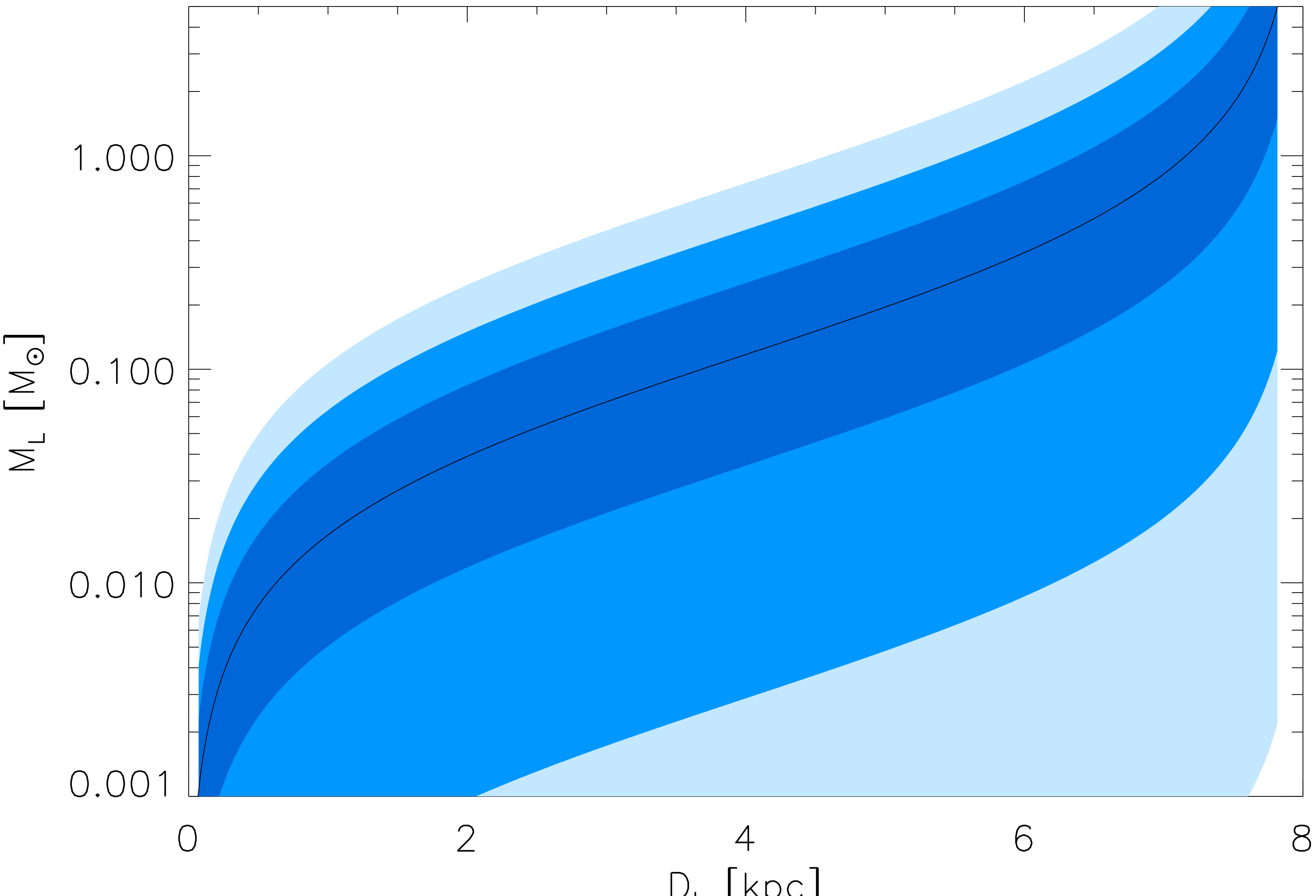
Summary

- Working on 4 more OGLE events in our ACS footprint + a few UVIS (Kains et al. 2017, in prep.)
- No clear astrometric microlensing signal detected yet, but good mass limits
- Working on scaling up/ automating this modelling for many fainter events not detected by surveys
- Demonstrates use of this technique for future routine mass measurements using astrometry- especially for BH and exoplanet demographics with WFIRST

Without parallax

(shaded blue = 1, 2, 3 σ)

(and without Galactic model etc.)



ACS CMD