Prediction and Confirmation of the Microlens parallax effect based on Space-based observation: OGLE-2016-BLG-0168

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Microlens Parallax

$$\mathbf{M_L} = \theta_E \: / \: \kappa \, \pi_E$$
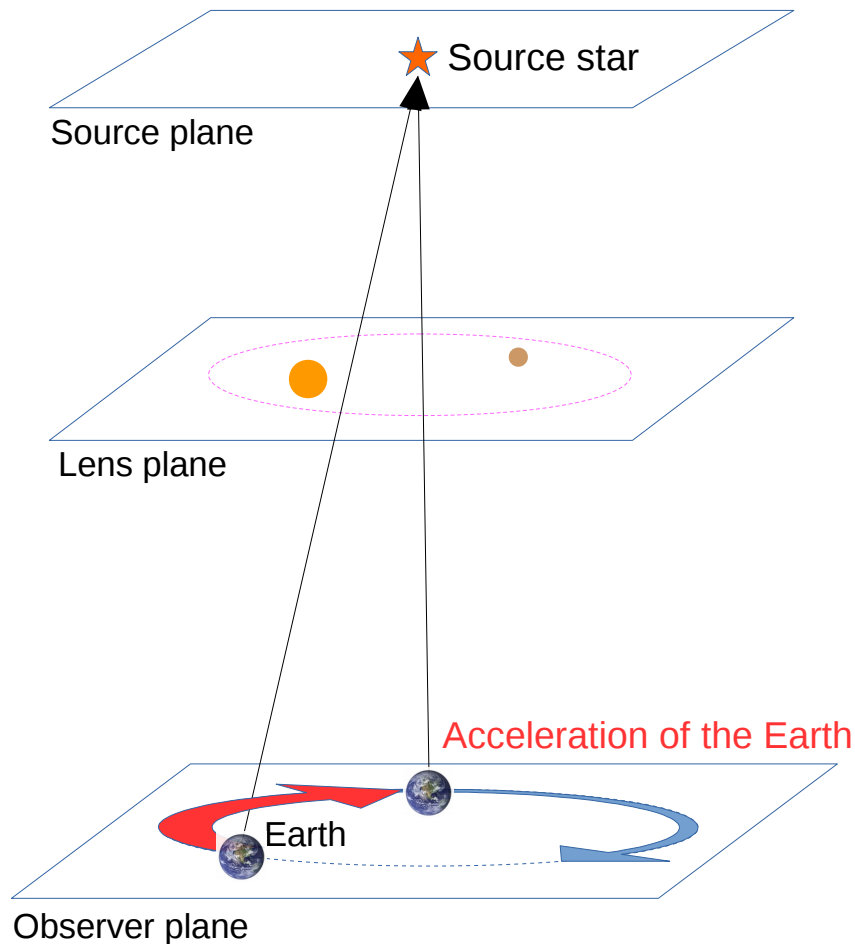
where $\kappa = $ constant

Microlens Parallax

Essential information to characterize the lens system

$$M_L = \theta_E \,/\, \kappa \pi_E$$

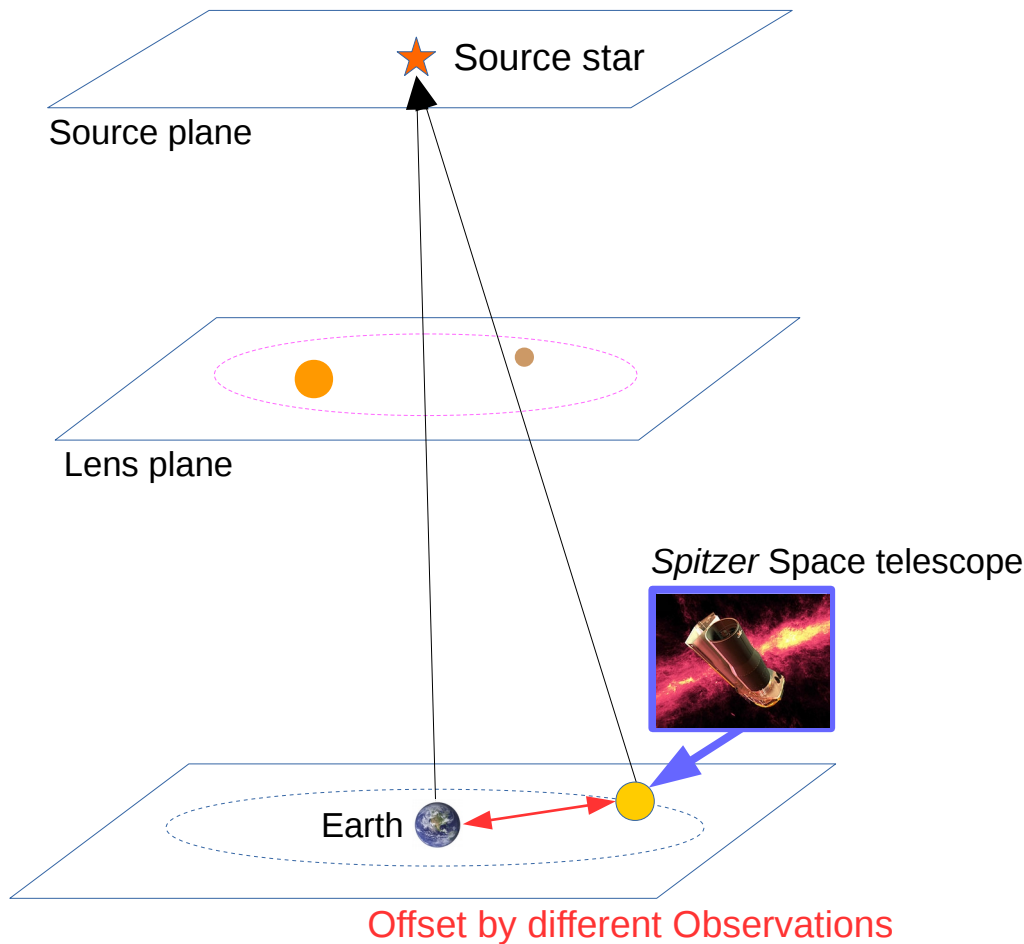Fundamental scale of microlensing : angular Einstein ring radius

$$\text{where} \quad \kappa = \text{constant}$$

Annual Microlens Parallax

Source plane

Source star

Lens plane

Observer plane

Acceleration of the Earth

Earth

- Caused by acceleration of the Earth motion
  - Dependency of event timescale
- Ground-based observation ONLY
  - Degeneracy in lens-parallax and lens-orbital motion
 - Systematics in observations

Satellite Microlens Parallax

Source plane

Source star

Lens plane

Spitzer Space telescope

Earth

Offset by different Observations

- Caused by offset of effectively separated observations
  - Possible to be routinely detected
  - Possible to resolve the degeneracy (Han et al. 2016)

- Space observations provide
  - ➜ Chance to check microlens parallax
 - ➜ Chance to resolve the degeneracy

OGLE-2016-BLG-0168
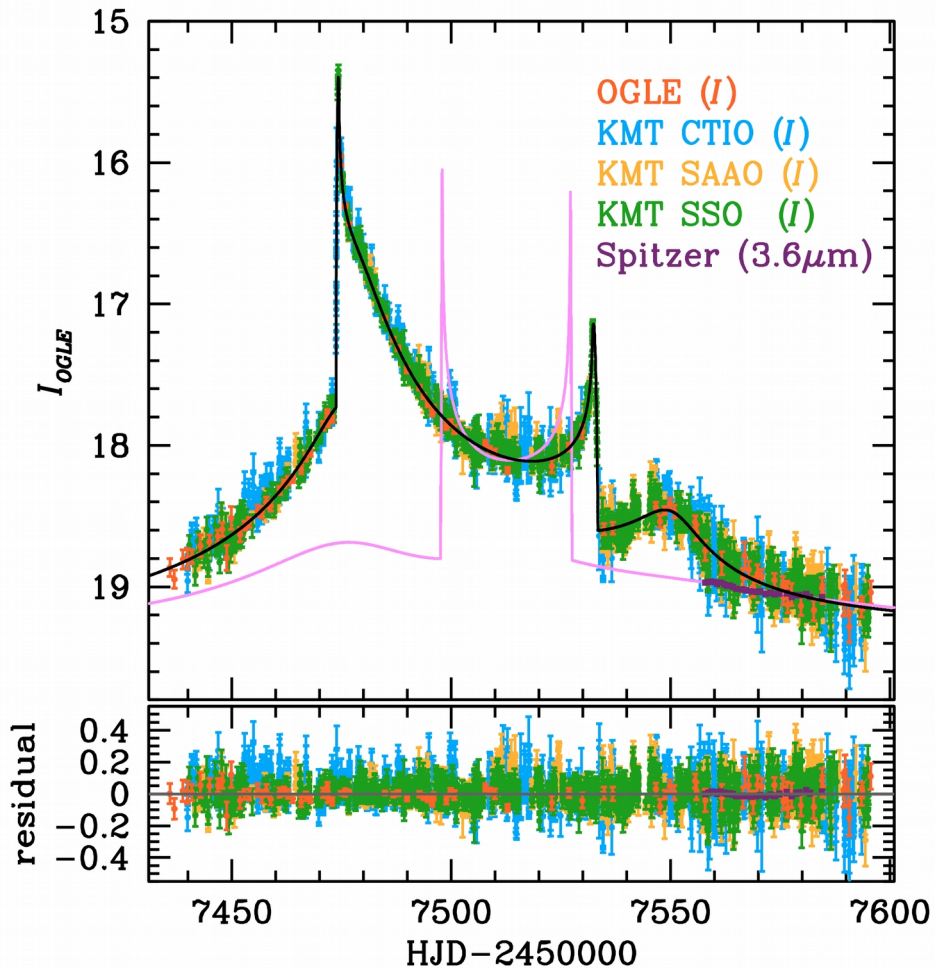
- Perfect test bed to validate the microlens parallax

- Detected both microlens parallax and lens-orbital effects

- Exist degenerated solutions

- *Spitzer* observed

- Fragmentary *Spitzer* observed lightcurve
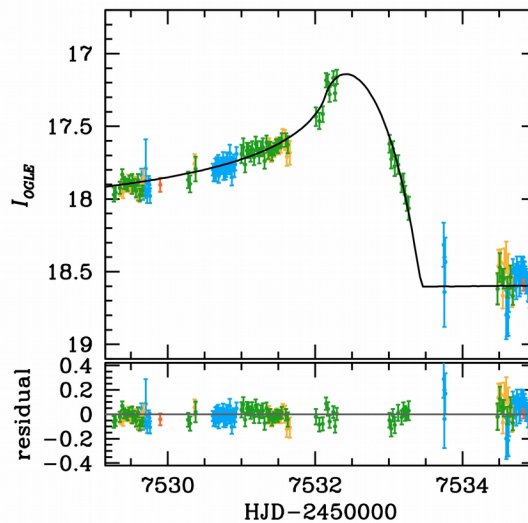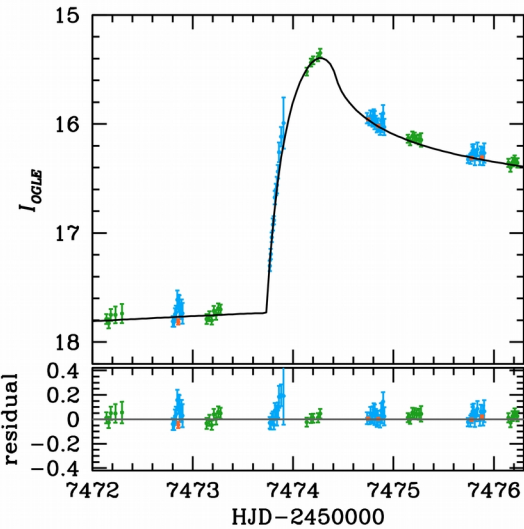
OGLE-2016-BLG-0168
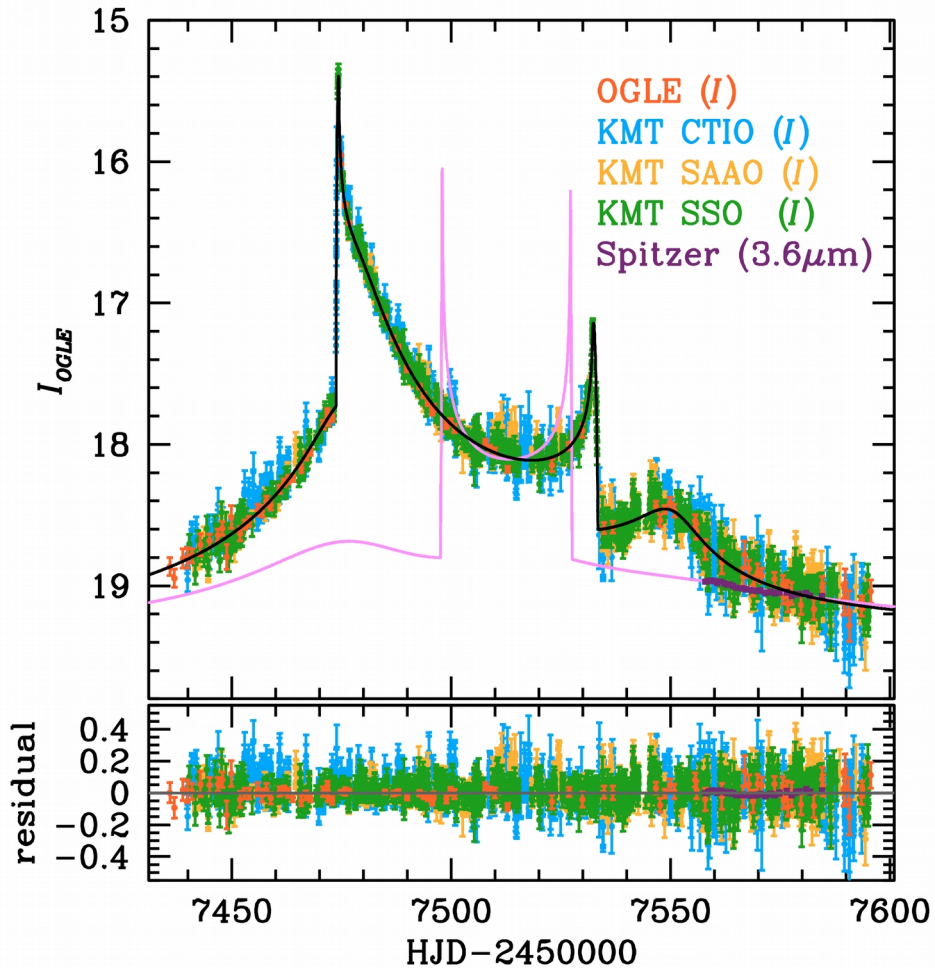
- Well covered caustic features by KMTNet
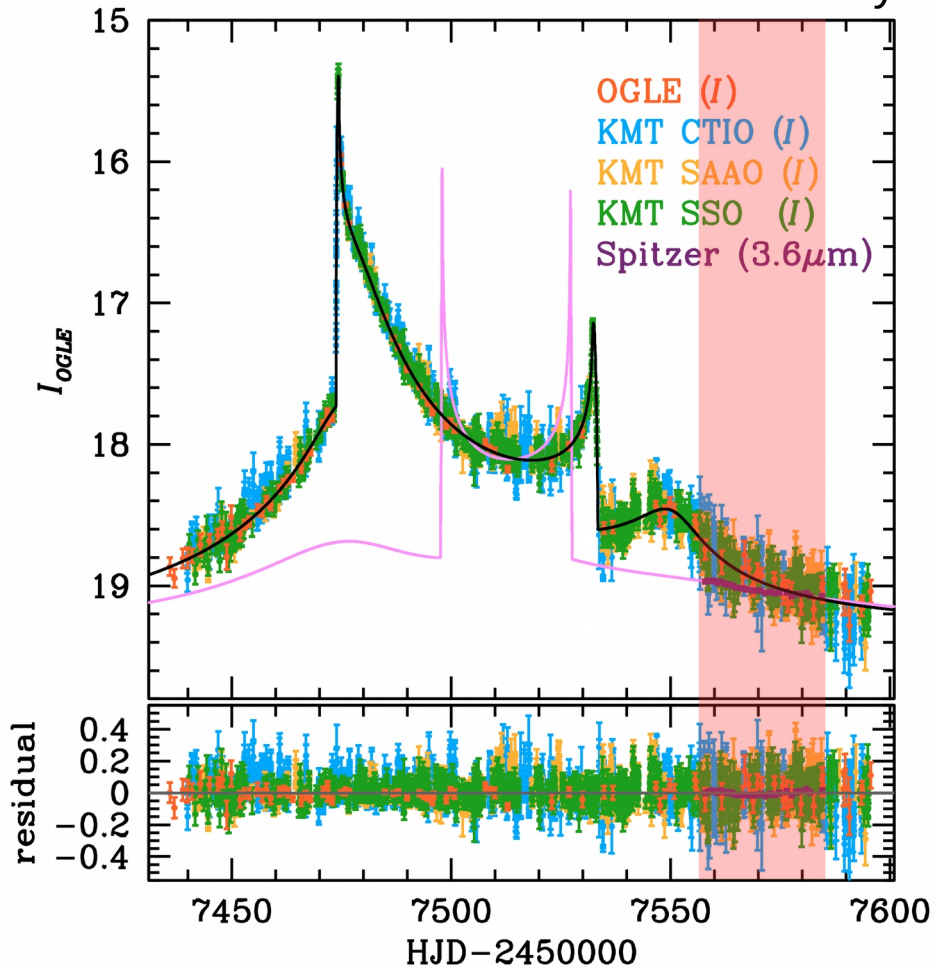- Clearly detect the finite source effect
- Fragmentary Spitzer observation
- Microlens parallax effect signal is detected
- Lens-orbital effect signal is detected
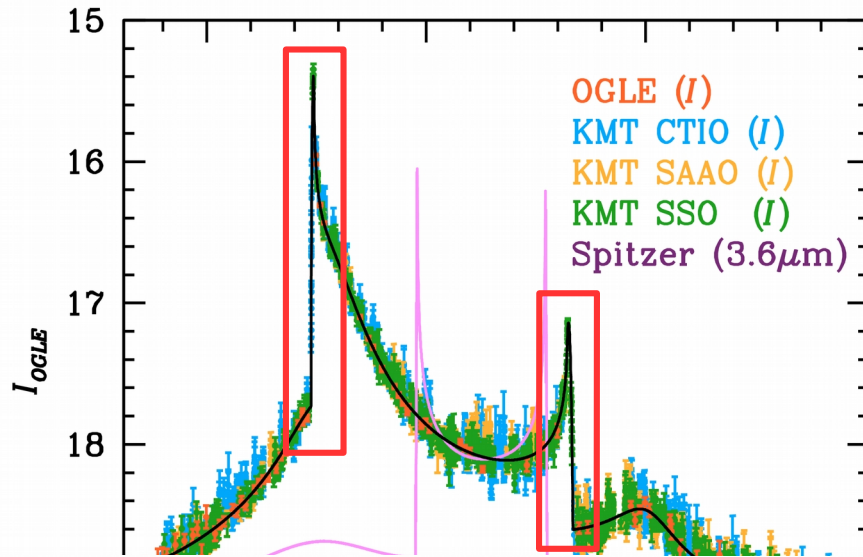
OGLE-2016-BLG-0168

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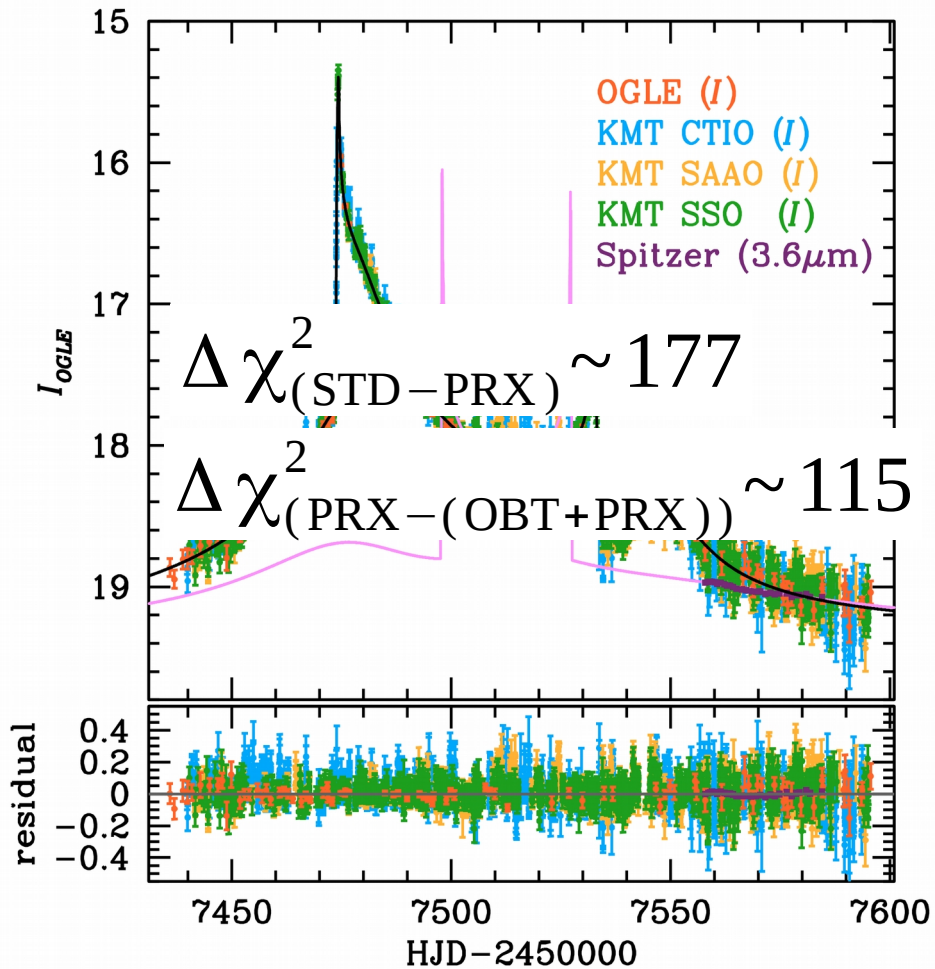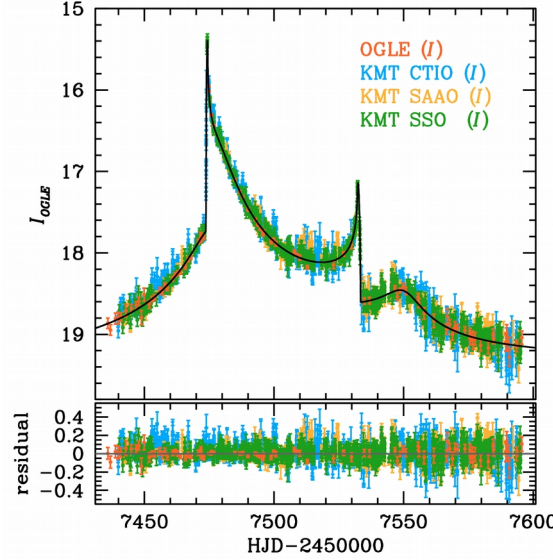- ns-orbital effect signal is ected

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2016 June 18 ~ July 14

- Well covered caustic features by KMTNet
- Clearly detect the finite source effect
- Fragmentary Spitzer observation
- Microlens parallax effect signal is detected
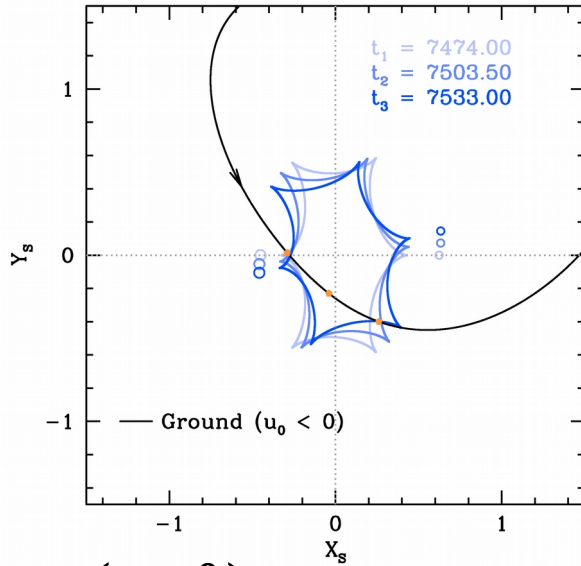- Lens-orbital effect signal is detected

OGLE-2016-BLG-0168

- Well covered caustic features by KMTNet

- Clearly detect the finite source effect

- Fragmentary Spitzer observation

- Microlens parallax effect signal is detected

- Lens-orbital effect signal is detected

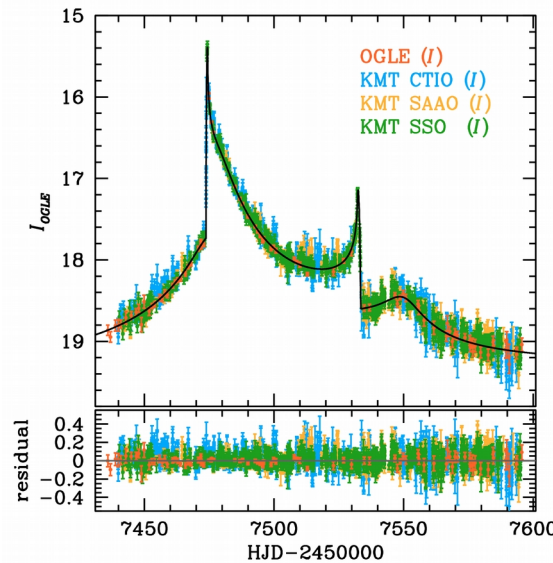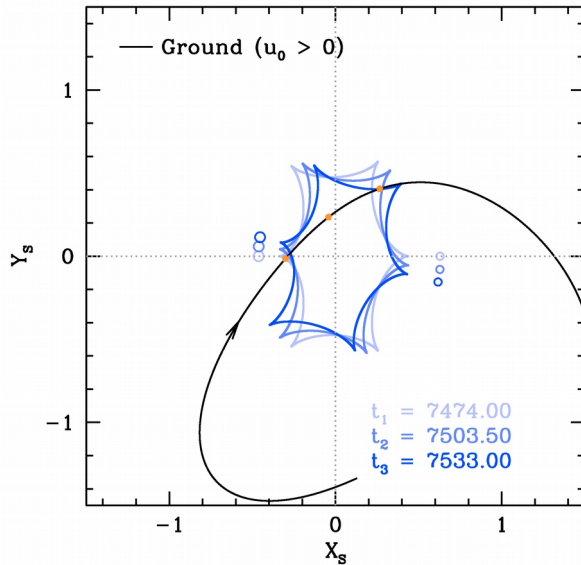# Prediction and Confirm

($u_0 < 0$) case

$t_1 = 7474.00$
$t_2 = 7503.50$
$t_3 = 7533.00$

— Ground ($u_0 < 0$)

OGLE (I)
KMT CTIO (I)
KMT SAAO (I)
KMT SSO (I)

$\pi_{E,N(u_0<0)} = 0.382 \pm 0.022$

$\pi_{E,E(u_0<0)} = 0.057 \pm 0.011$

$ds/dt_{(u_0<0)} = 0.287 \pm 0.120 \ yr^{-1}$

$d\alpha/dt_{(u_0<0)} = -1.437 \pm 0.138 \ yr^{-1}$

($u_0 > 0$) case

— Ground ($u_0 > 0$)

$t_1 = 7474.00$
$t_2 = 7503.50$
$t_3 = 7533.00$

OGLE (I)
KMT CTIO (I)
KMT SAAO (I)
KMT SSO (I)

$\pi_{E,N(u_0>0)} = -0.475 \pm 0.025$

$\pi_{E,E(u_0>0)} = -0.026 \pm 0.011$

$ds/dt_{(u_0>0)} = 0.090 \pm 0.067 \ yr^{-1}$

$d\alpha/dt_{(u_0>0)} = 1.574 \pm 0.121 \ yr^{-1}$

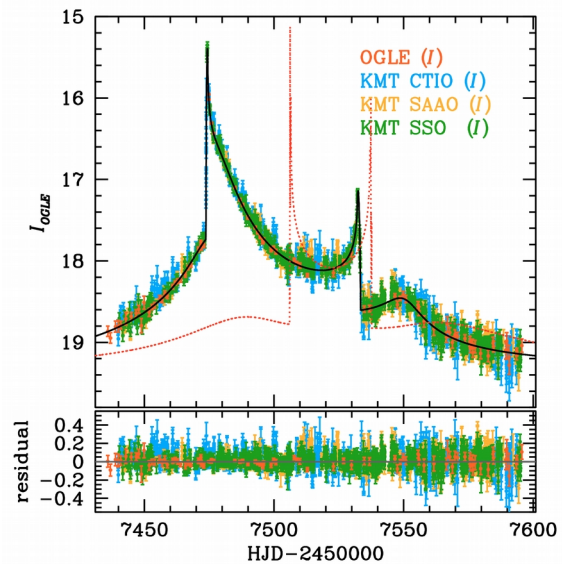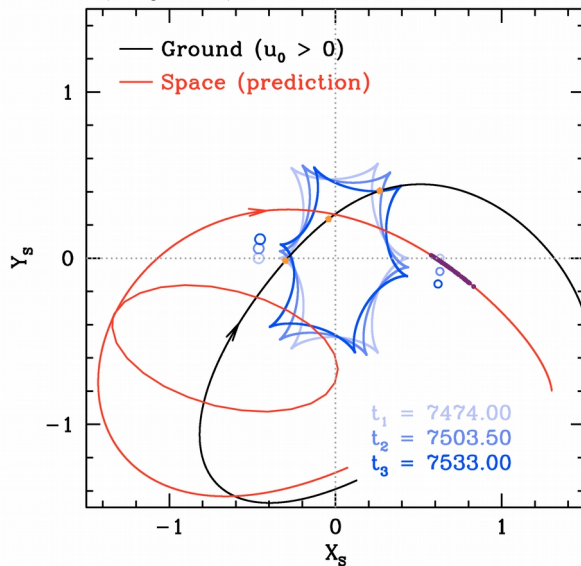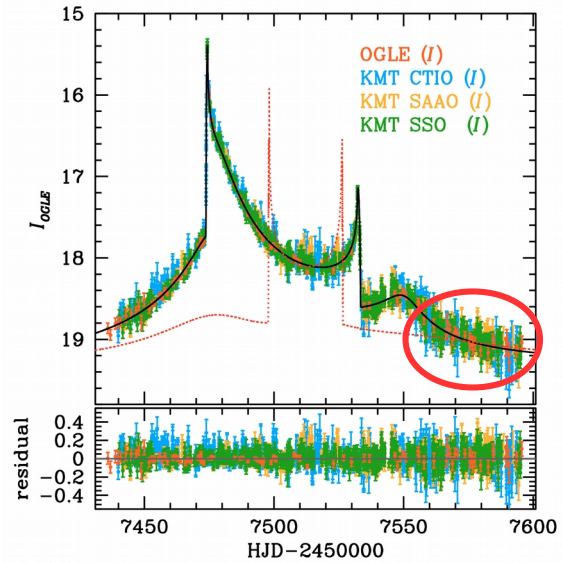# Prediction and Confirm
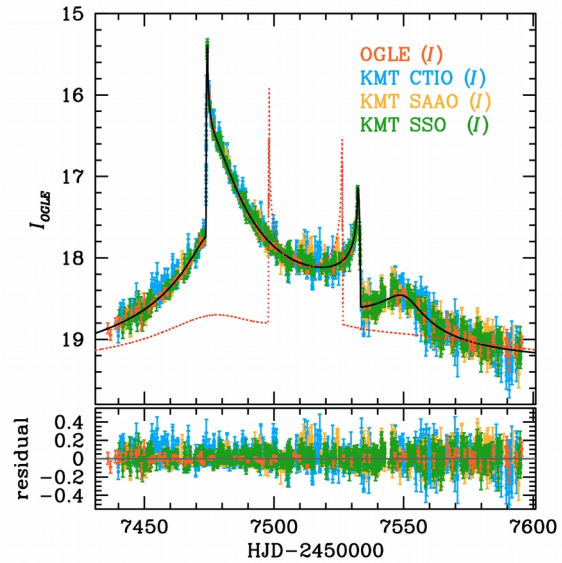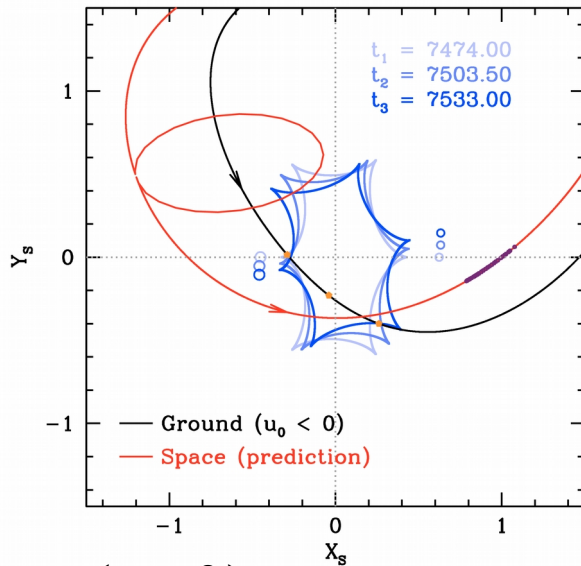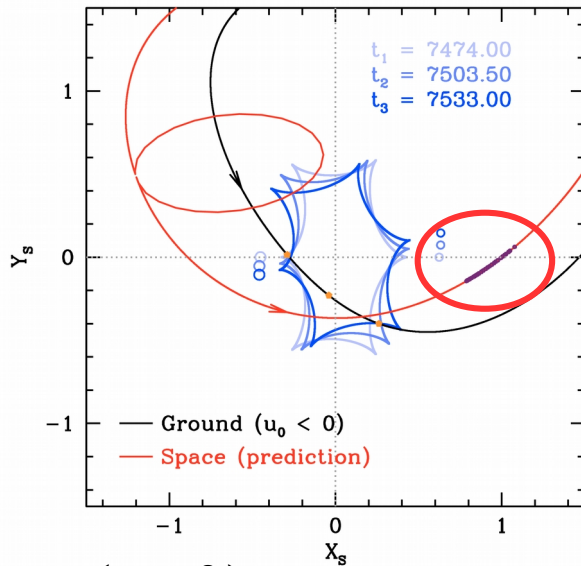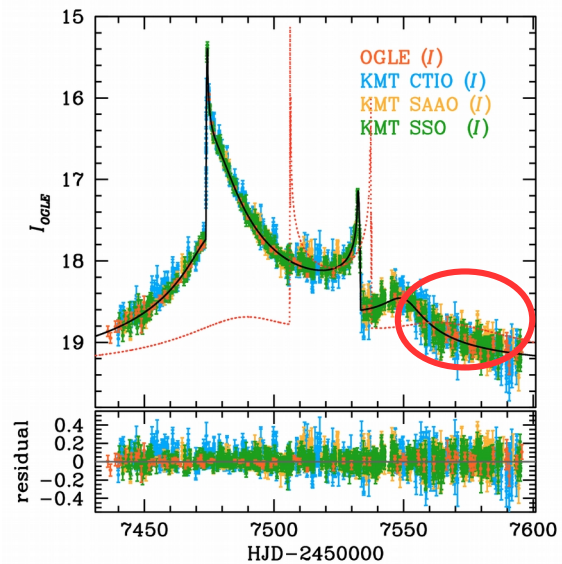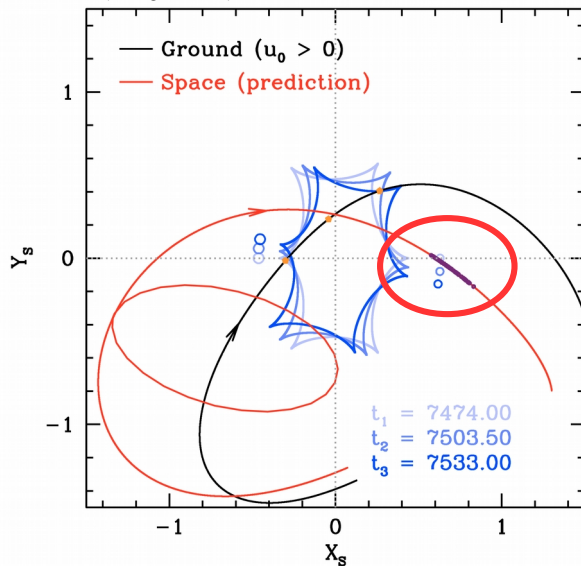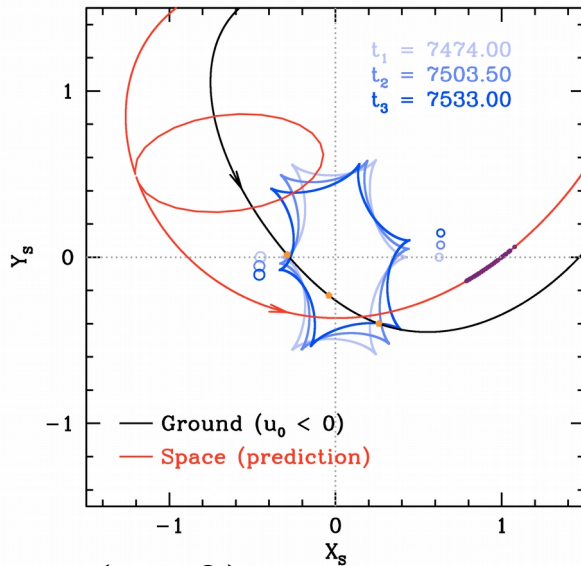

Predict Spitzer Lightcurve from Ground-based models

Prediction and Confirm

$(u_0 < 0)$ case

$(u_0 > 0)$ case

Predict Spitzer Lightcurve
from Ground-based models

Prediction and Confirm

$(u_0 < 0)$ case

$t_1 = 7474.00$
$t_2 = 7503.50$
$t_3 = 7533.00$

— Ground ($u_0 < 0$)
— Space (prediction)

Y_S / X_S

$(-,-)$ case

$t_1 = 7474.00$
$t_2 = 7503.50$
$t_3 = 7533.00$

— Ground ($u_0 < 0$)
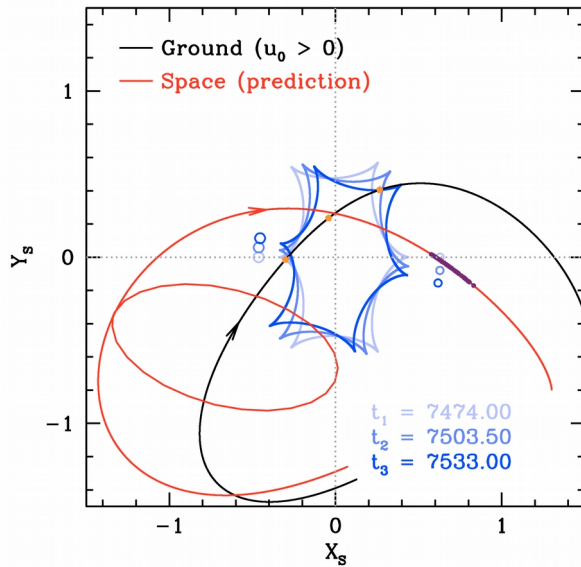— Space: $(-,-)$ case
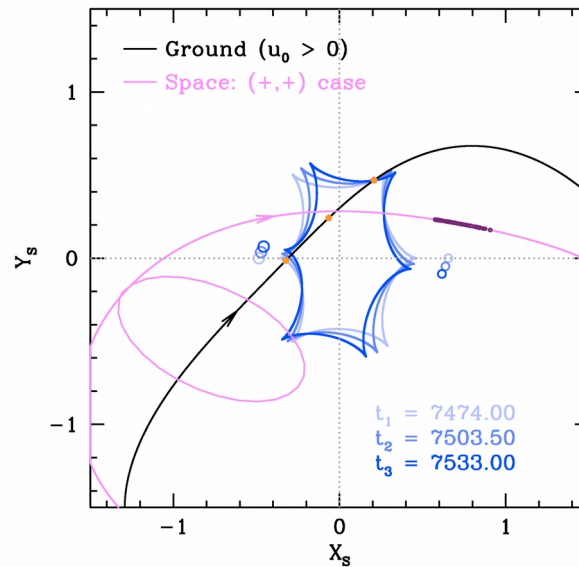
Y_S / X_S
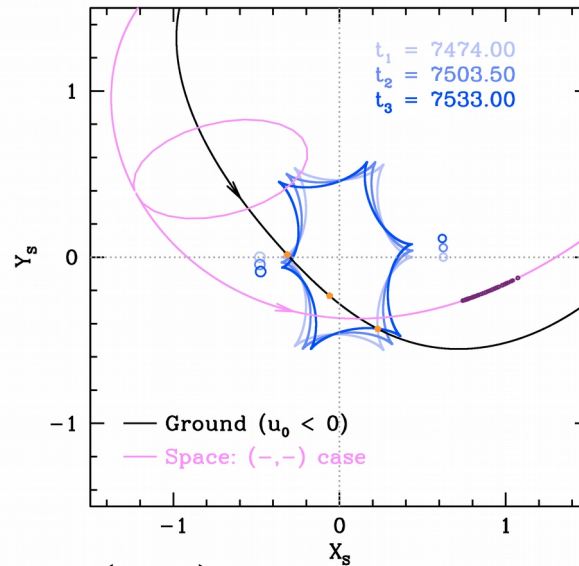
$$\pi_{E,N(-,-)} = 0.360 \pm 0.027$$

$$\pi_{E,E(-,-)} = 0.047 \pm 0.009$$

$$ds/dt_{(-,-)} = 0.050 \pm 0.094 \ yr^{-1}$$

$$d\alpha/dt_{(-,-)} = -1.133 \pm 0.125 \ yr^{-1}$$

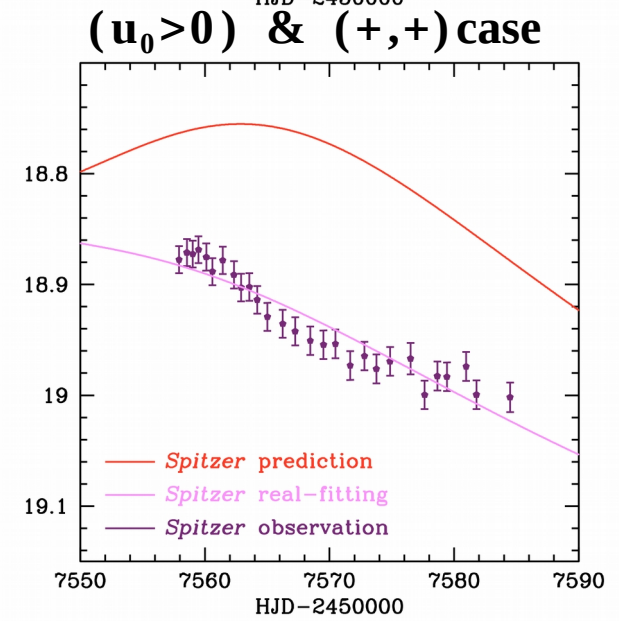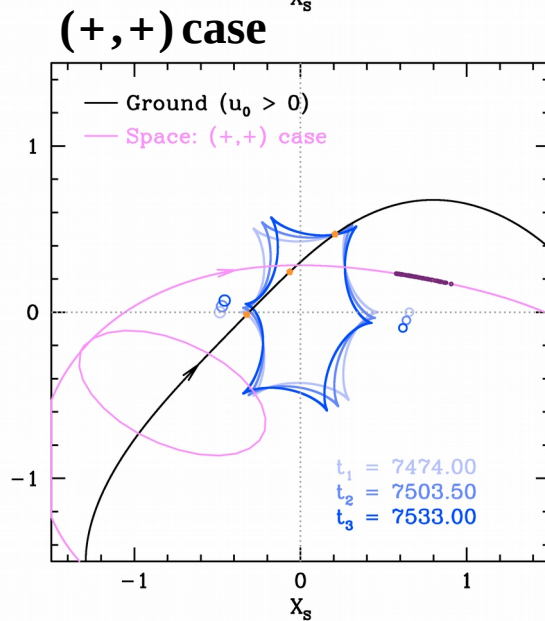**$(u_0 > 0)$ case**

— Ground ($u_0 > 0$)
— Space (prediction)

$t_1 = 7474.00$
$t_2 = 7503.50$
$t_3 = 7533.00$

Y_S / X_S

$(+,+)$ case

— Ground ($u_0 > 0$)
— Space: $(+,+)$ case

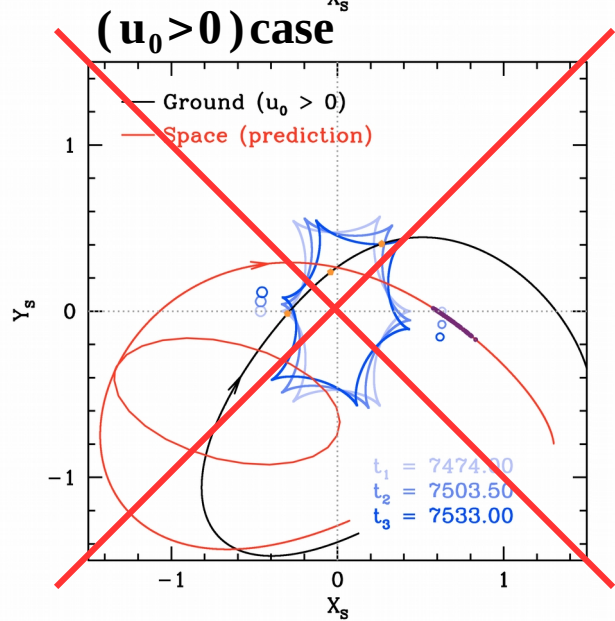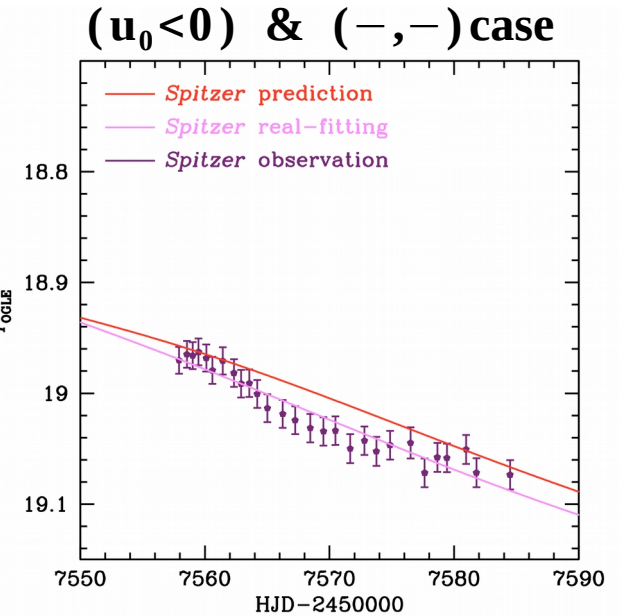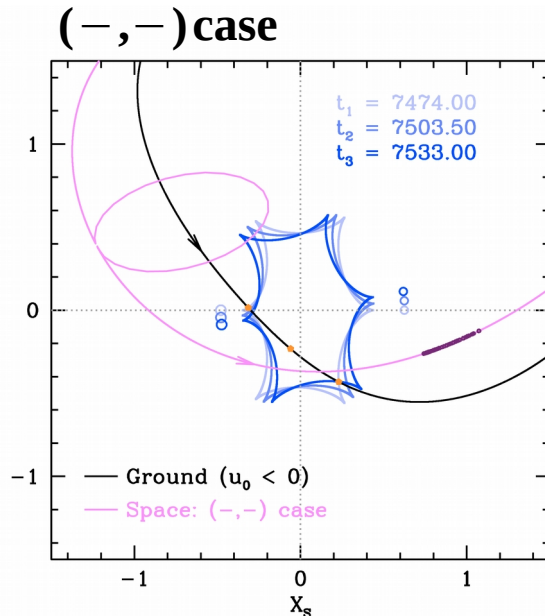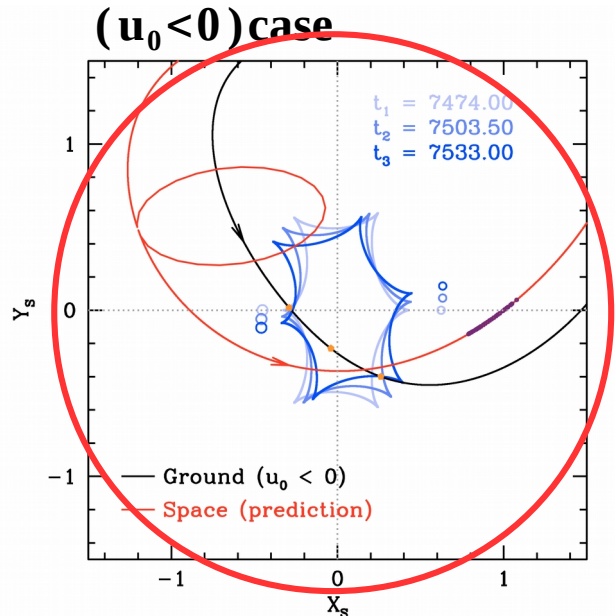$t_1 = 7474.00$
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$t_3 = 7533.00$

Y_S / X_S

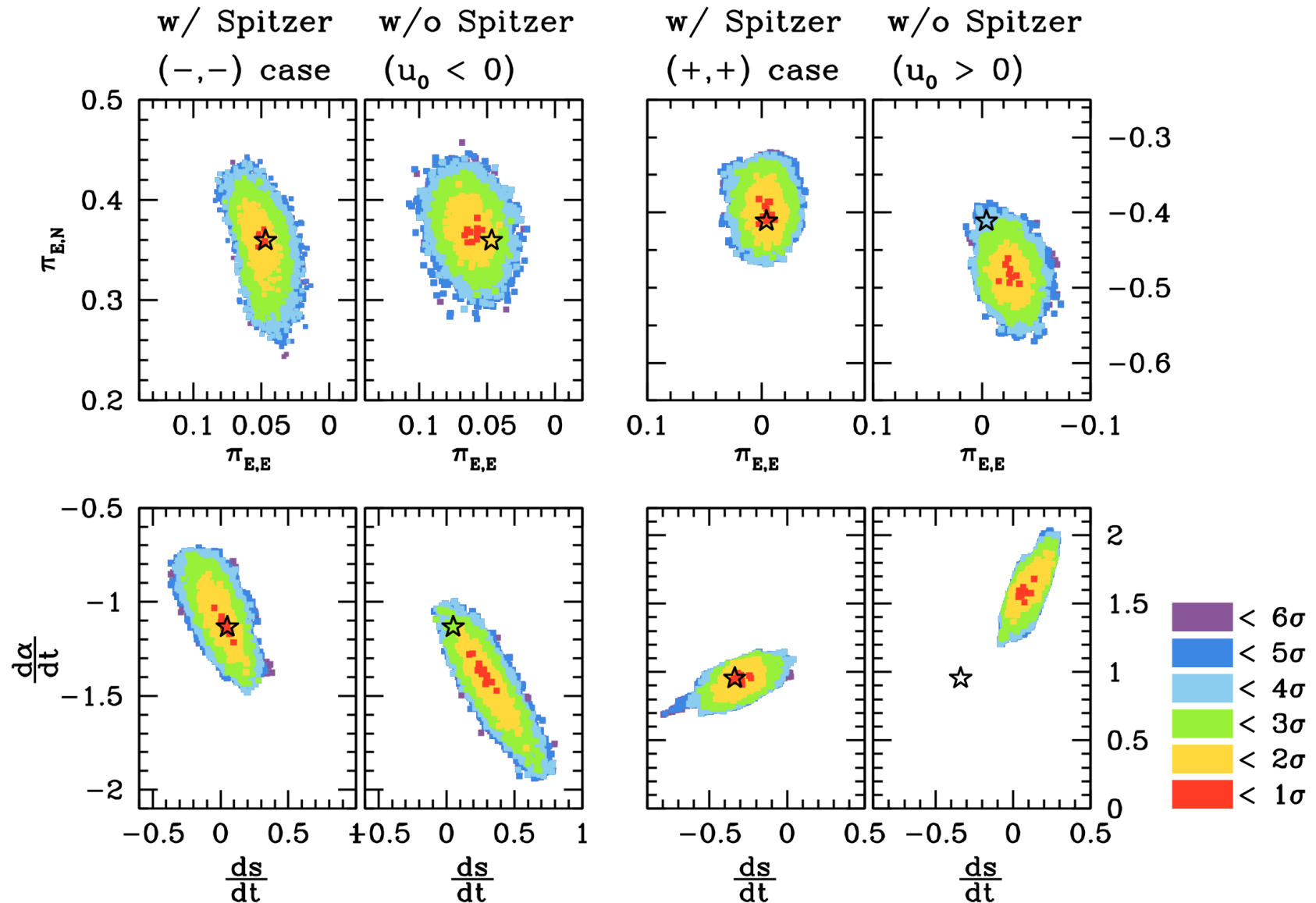$$\pi_{E,N(+,+)} = -0.411 \pm 0.023$$

$$\pi_{E,E(+,+)} = -0.004 \pm 0.010$$

$$ds/dt_{(+,+)} = -0.337 \pm 0.093 \ yr^{-1}$$
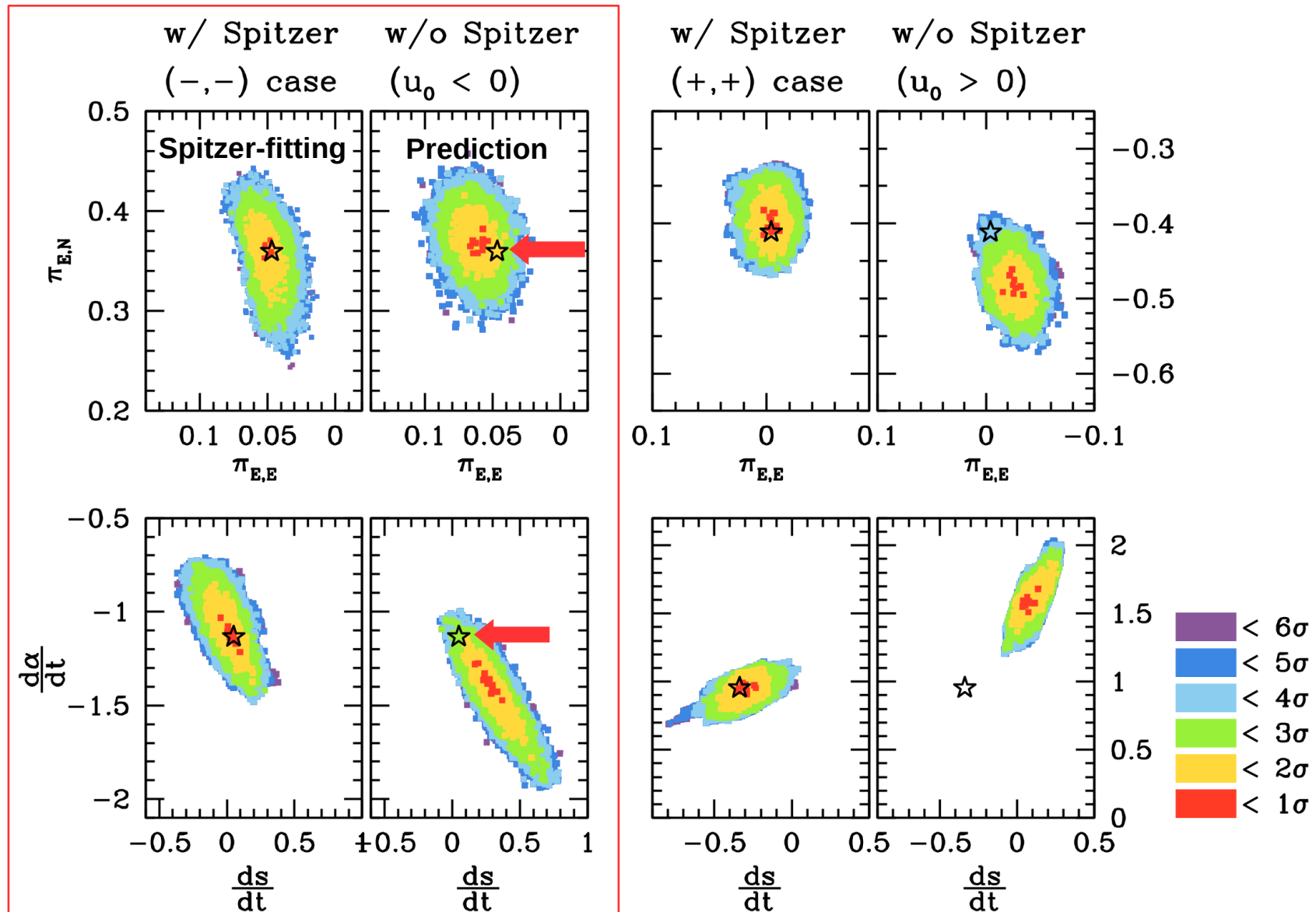
$$d\alpha/dt_{(+,+)} = 0.954 \pm 0.070 \ yr^{-1}$$
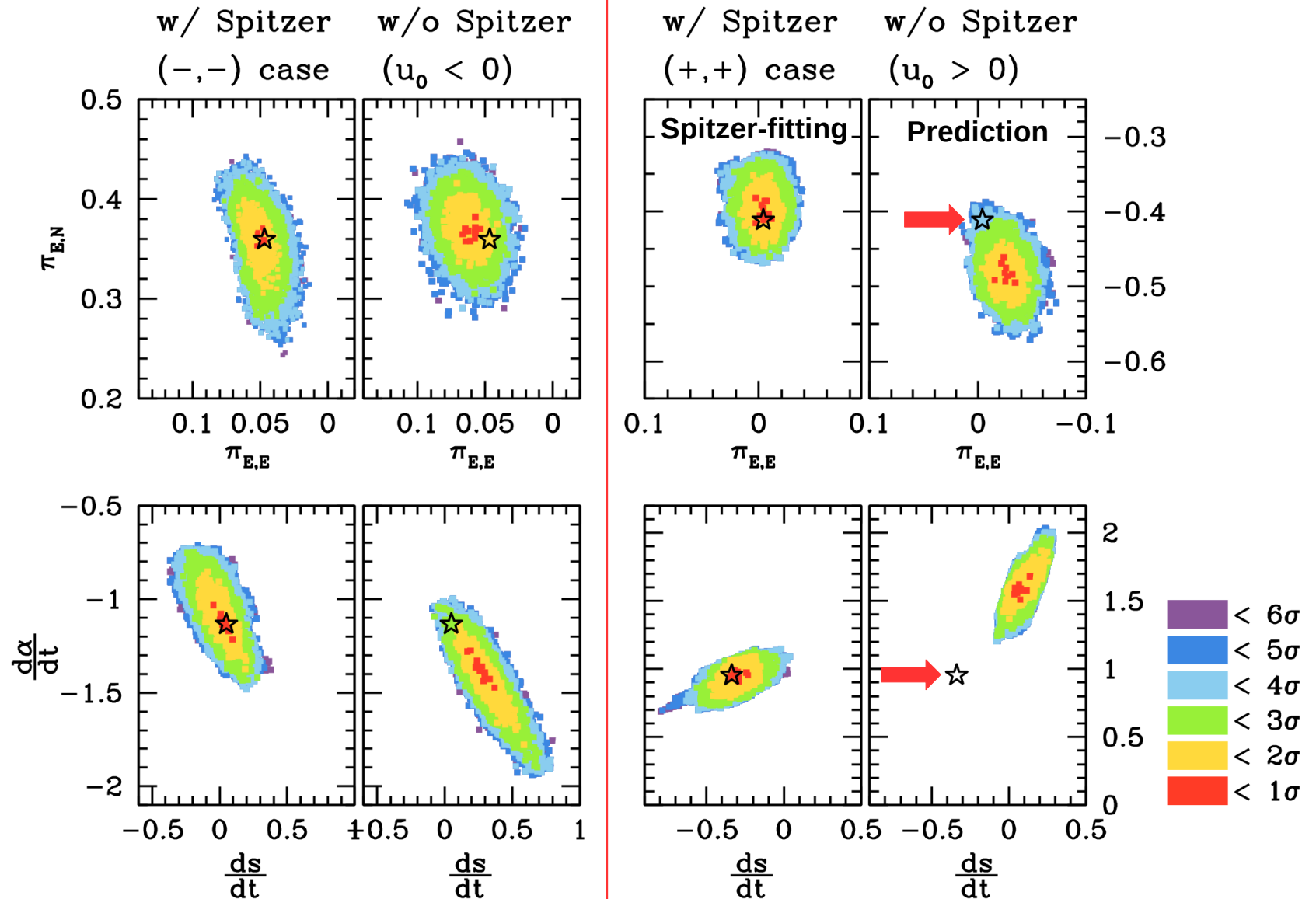
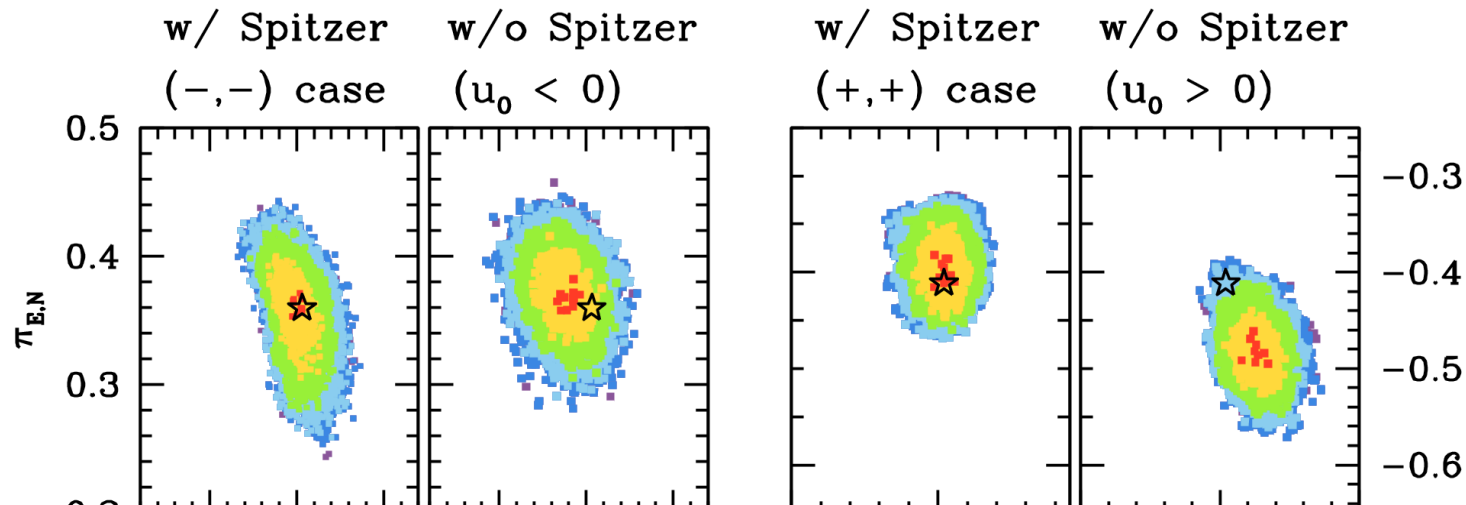# Prediction and Confirm

Validation of the microlens parallax

Validation of the microlens parallax

Validation of the microlens parallax

Validation of the microlens parallax

| | w/ Spitzer $(-,-)$ case | w/o Spitzer $(u_0 < 0)$ | w/ Spitzer $(+,+)$ case | w/o Spitzer $(u_0 > 0)$ |

For (u0 < 0) & (−,−) case,
the parameters are well-matched within 3σ level
➡ Confirmed the annual microlens parallax by using *Spitzer*

$< 6\sigma$
$< 5\sigma$
$< 4\sigma$
$< 3\sigma$
$< 2\sigma$
$< 1\sigma$
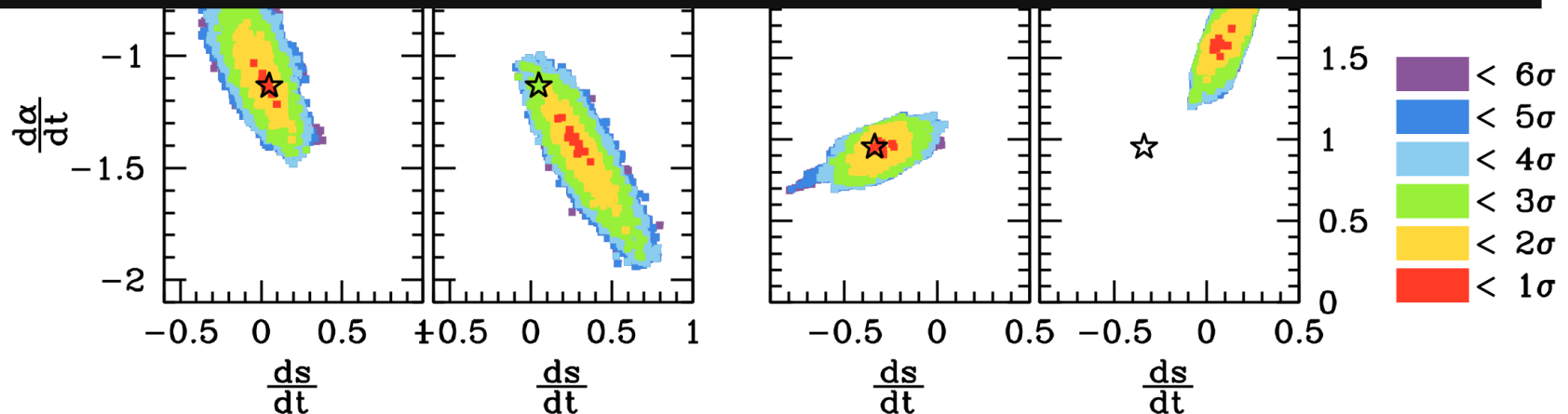
Conclusion & Summary

- By using the space observation (*Spitzer*),

- Even though *Spitzer* lightcurve is fragmentary,

- It is possible to extract reliable microlens parallax information

- It is possible to resolve degeneracy in parallax