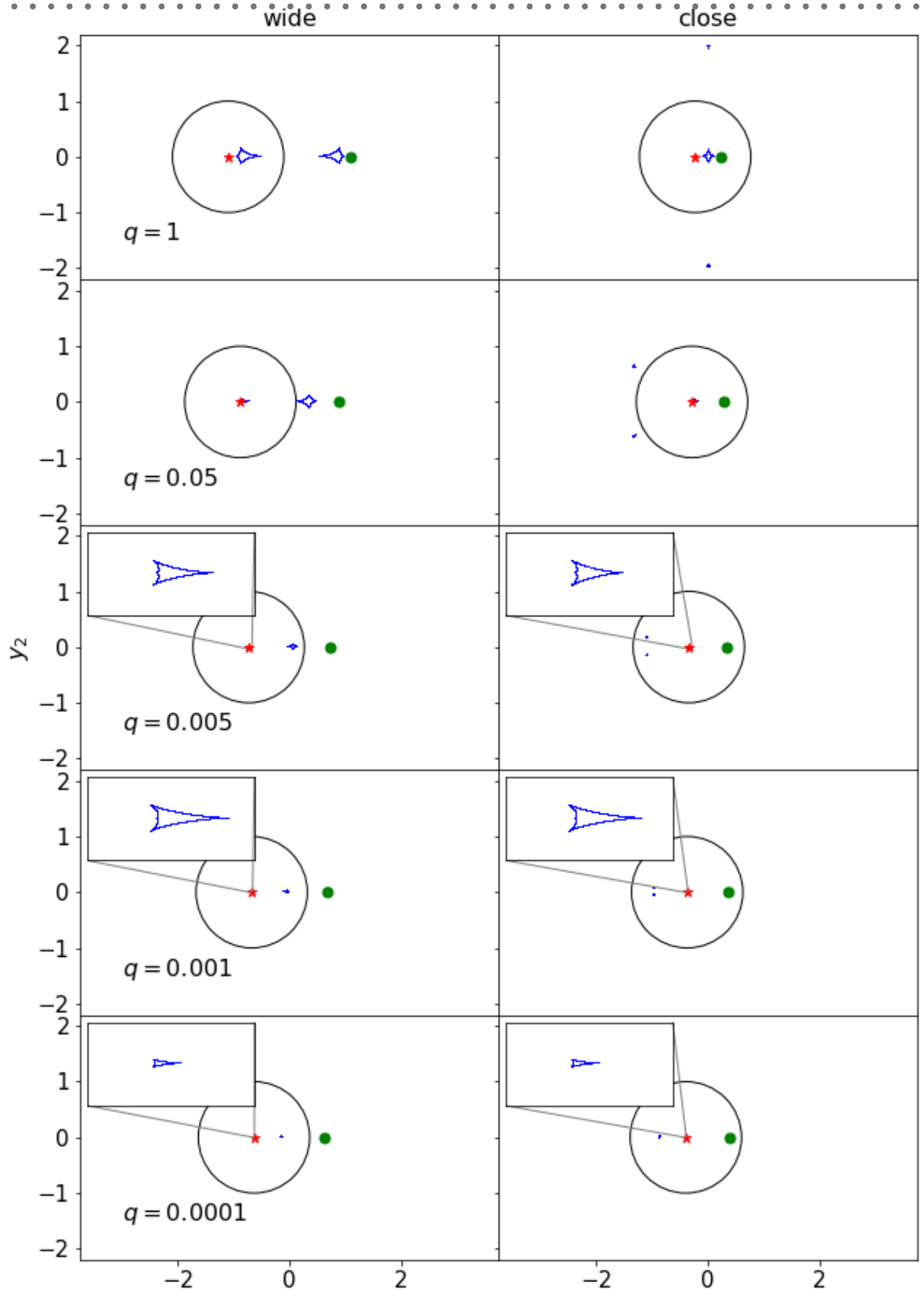
GRAVITATIONAL LENSING

14 – PLANET MICROLENSING (II)

Massimo Meneghetti
AA 2019-2020

PERTURBATIONS OF THE CENTRAL CAUSTIC (WIDE/CLOSE SYSTEMS)

- As q decreases, we see that one caustic shrinks and approaches the primary lens (i.e. the star)
- This is what we call the ***"central caustic"*** in wide and close systems
- Four cusps and four folds
- One cusp is elongated towards the planet
- Three cusps on the back
- **Different from point-like caustic of a point lens!**



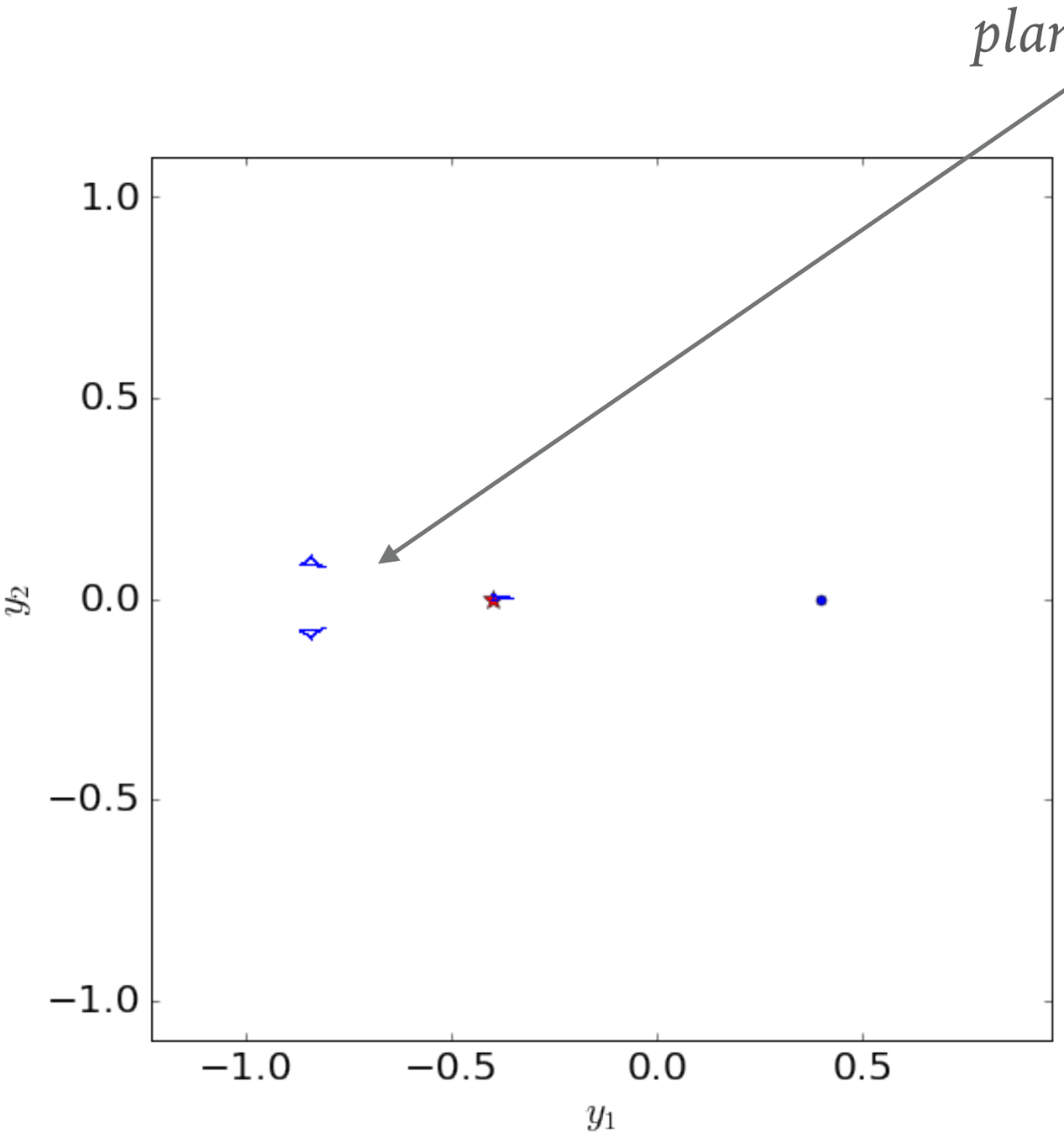
PLANET DETECTION THROUGH CENTRAL CAUSTICS PERTURBATIONS

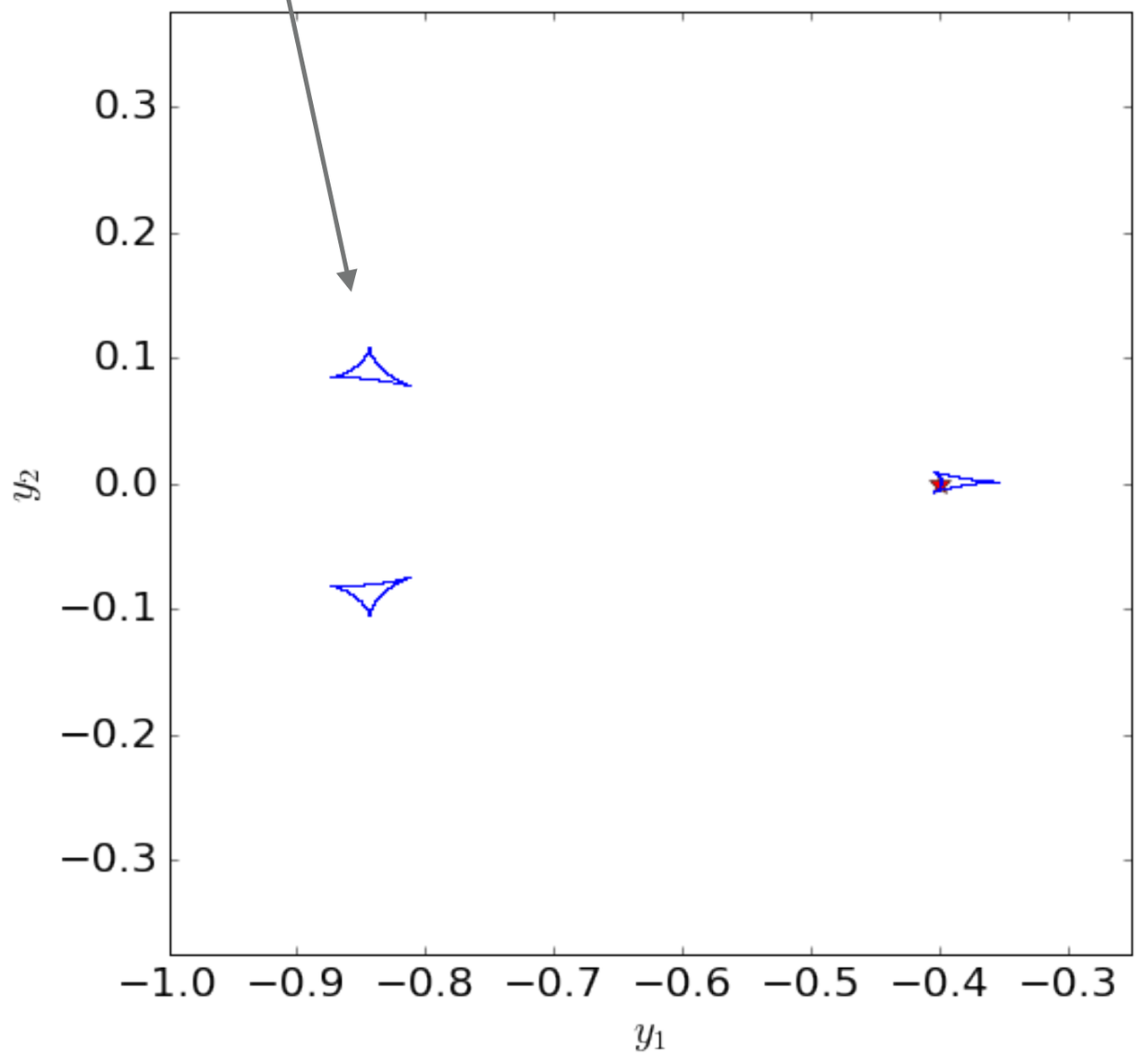
- Only possible in the case of high magnification events (sources passing very close to the host stars)
- For this reason, they are rare events
- Advantages:
  - near the peak of the event
  - can sometimes be predicted in advance
  - high magnification makes possible to follow-up the events using small telescopes
  - more accurate photometry
- Disadvantages:
  - degeneracy wide-close topologies

PLANETARY CAUSTICS IN CLOSE TOPOLOGIES

planetary caustics

Han 2006



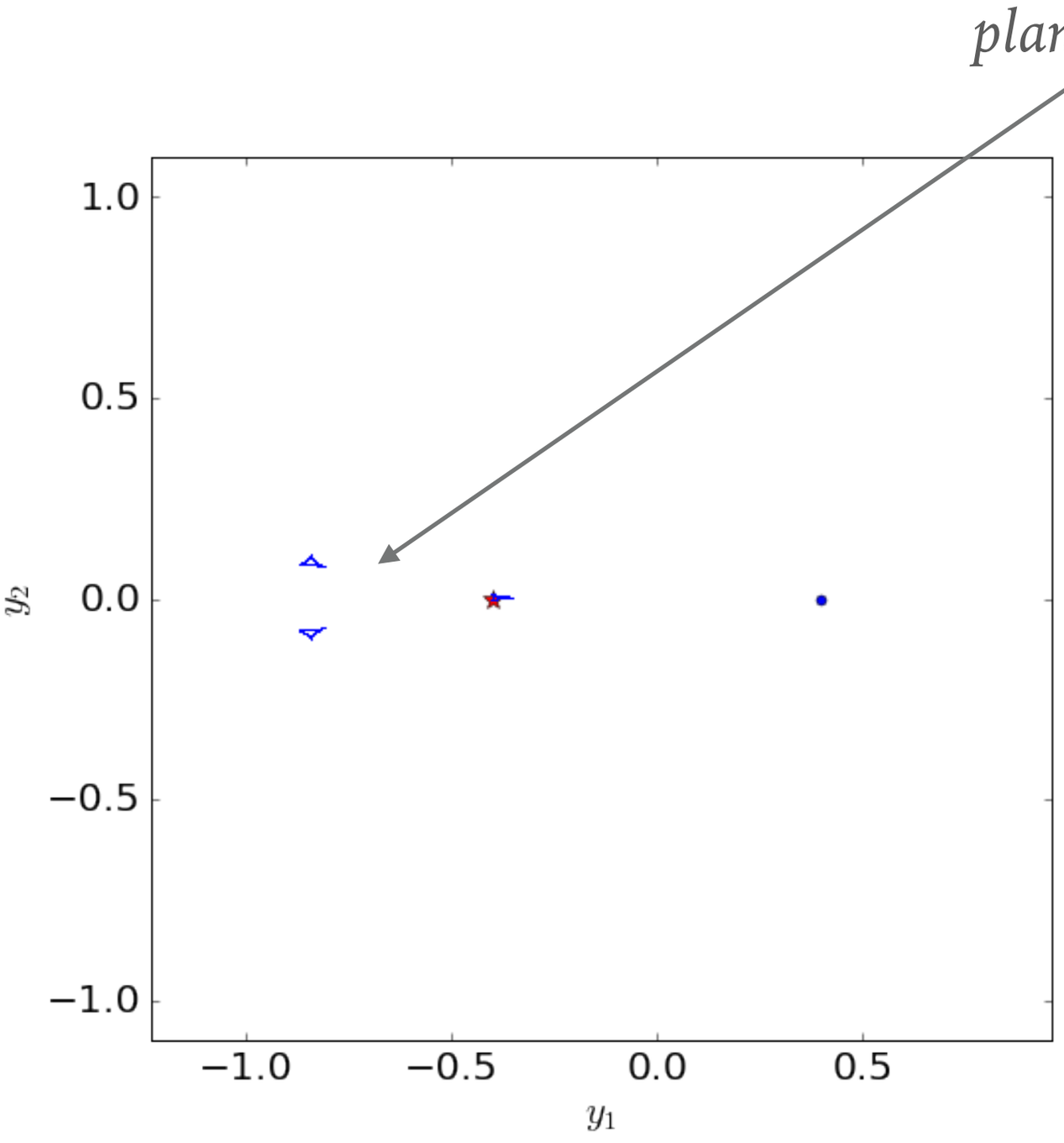


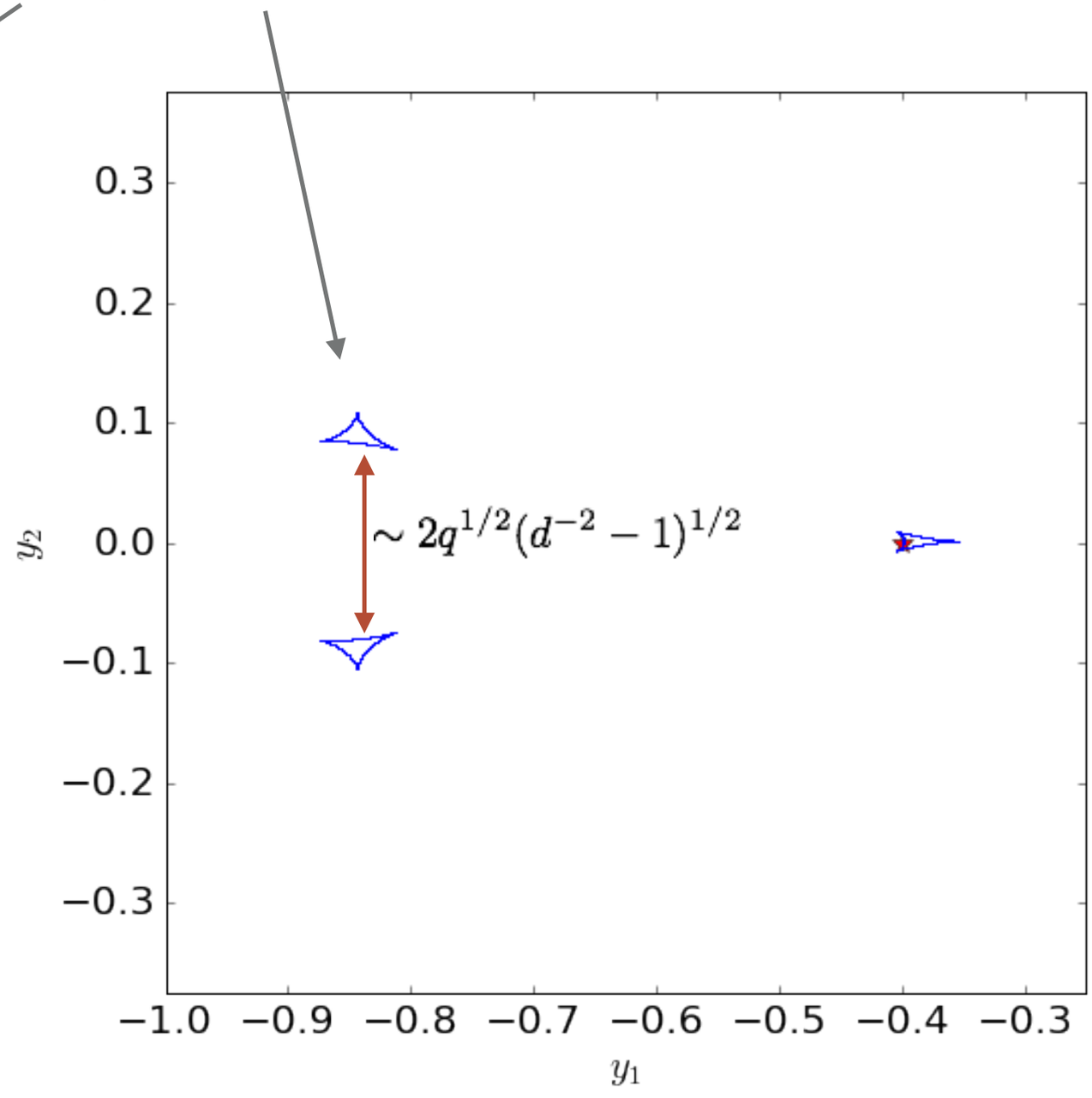
Recommended reading: Han, C., 2006, ApJ, 638, 1080

PLANETARY CAUSTICS IN CLOSE TOPOLOGIES

planetary caustics

Han 2006



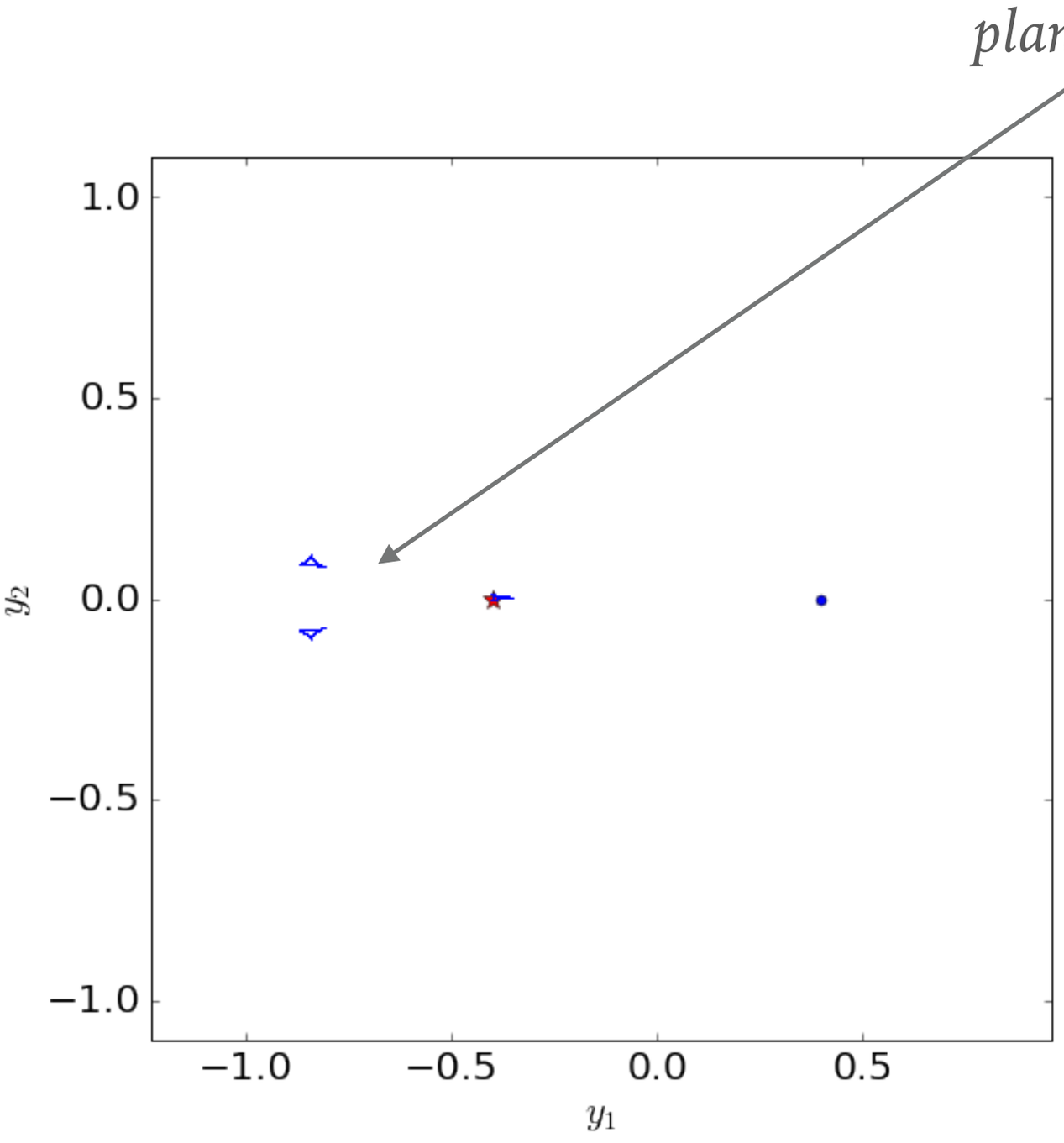


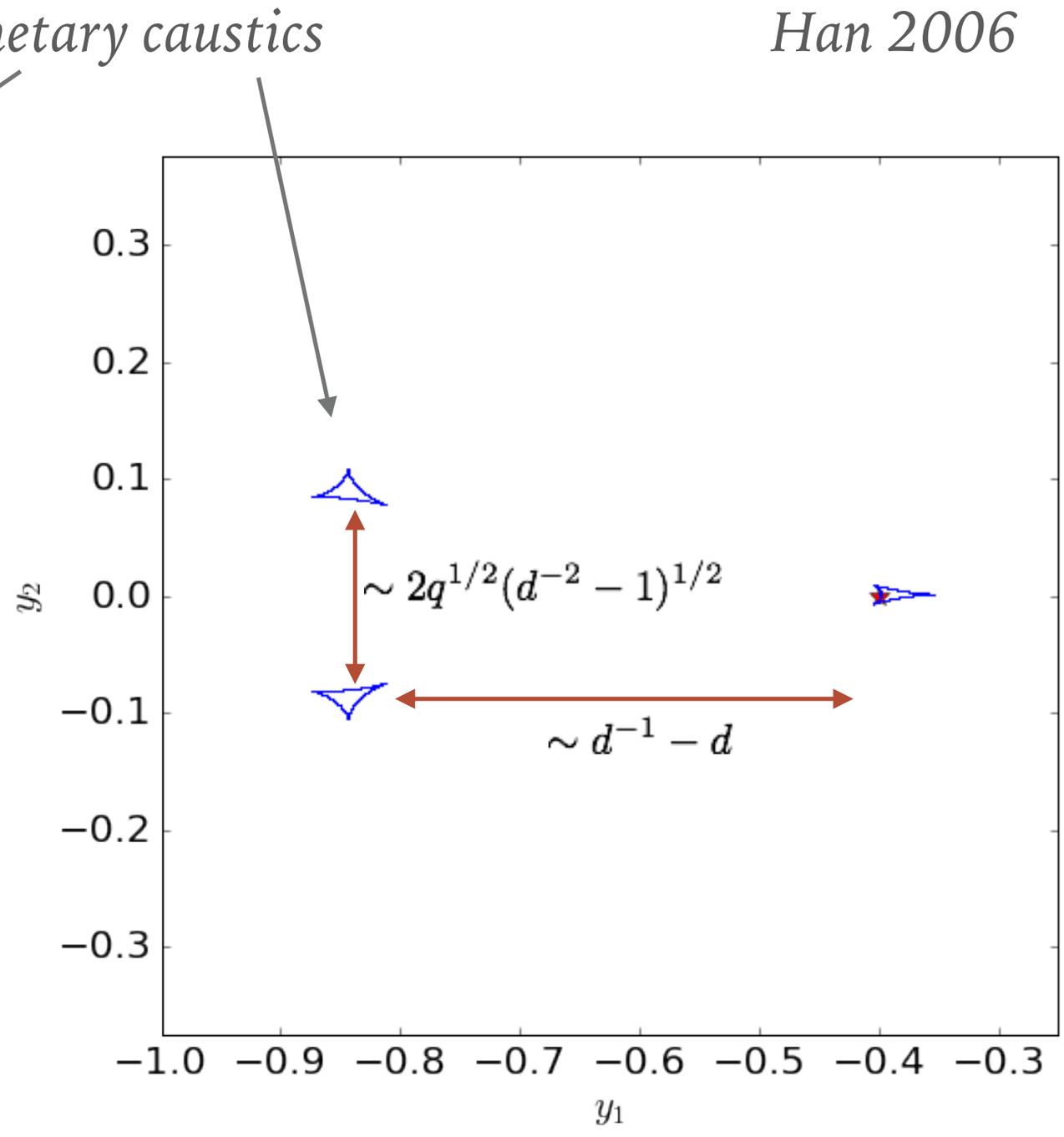
Recommended reading: Han, C., 2006, ApJ, 638, 1080

PLANETARY CAUSTICS IN CLOSE TOPOLOGIES

planetary caustics

Han 2006



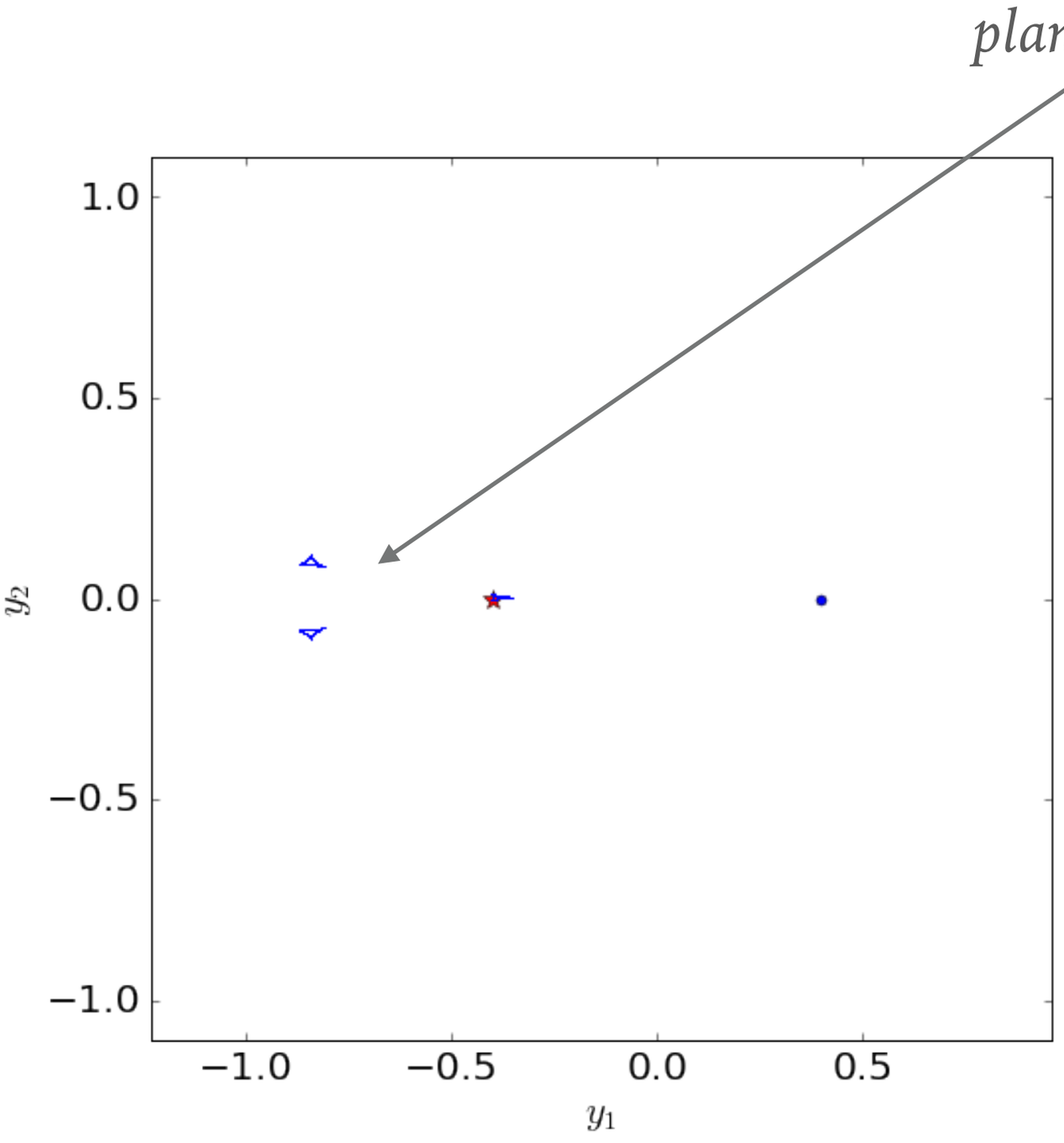


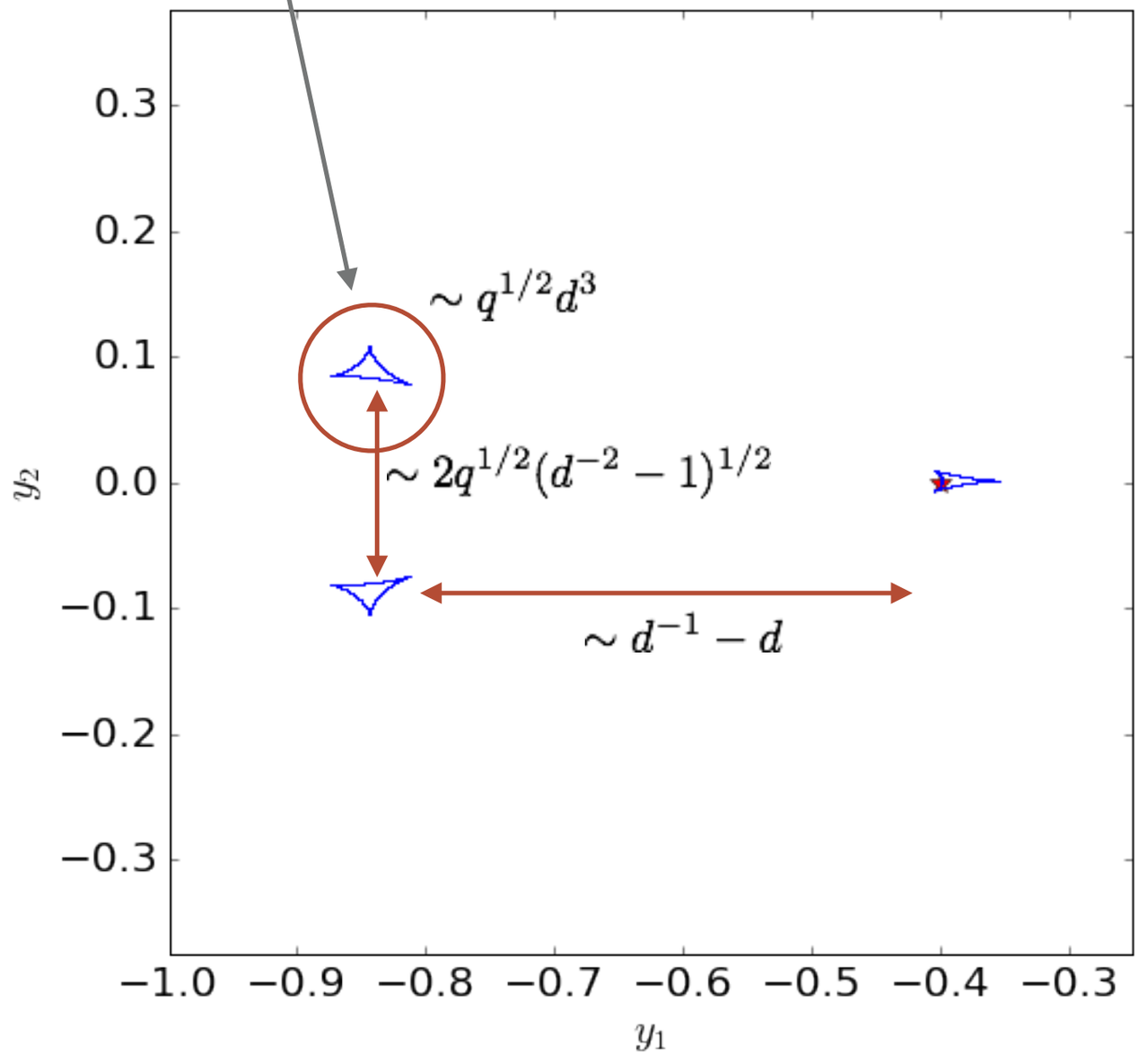
Recommended reading: Han, C., 2006, ApJ, 638, 1080

PLANETARY CAUSTICS IN CLOSE TOPOLOGIES

planetary caustics

Han 2006

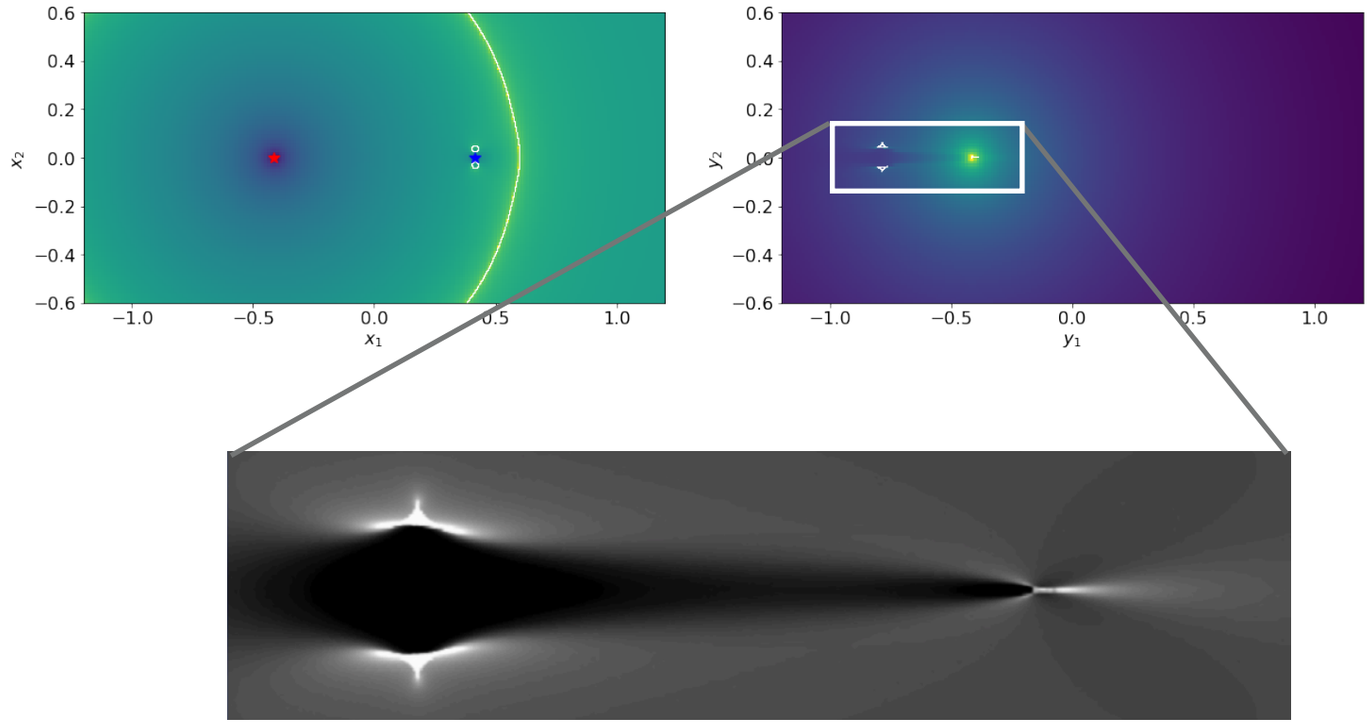




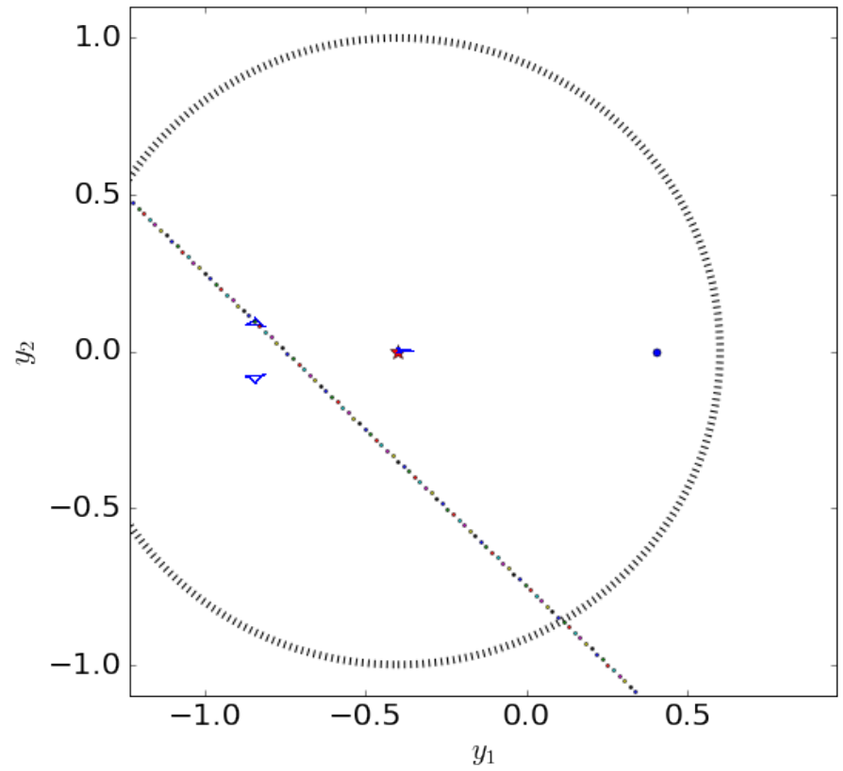
Recommended reading: Han, C., 2006, ApJ, 638, 1080

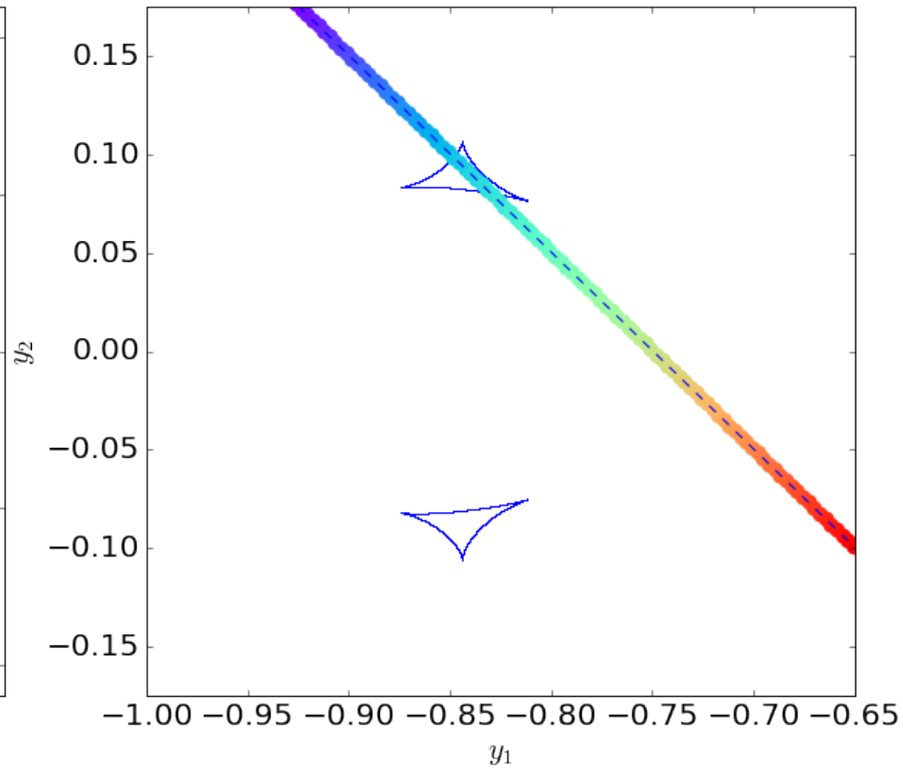
WHAT KIND OF SIGNATURES?

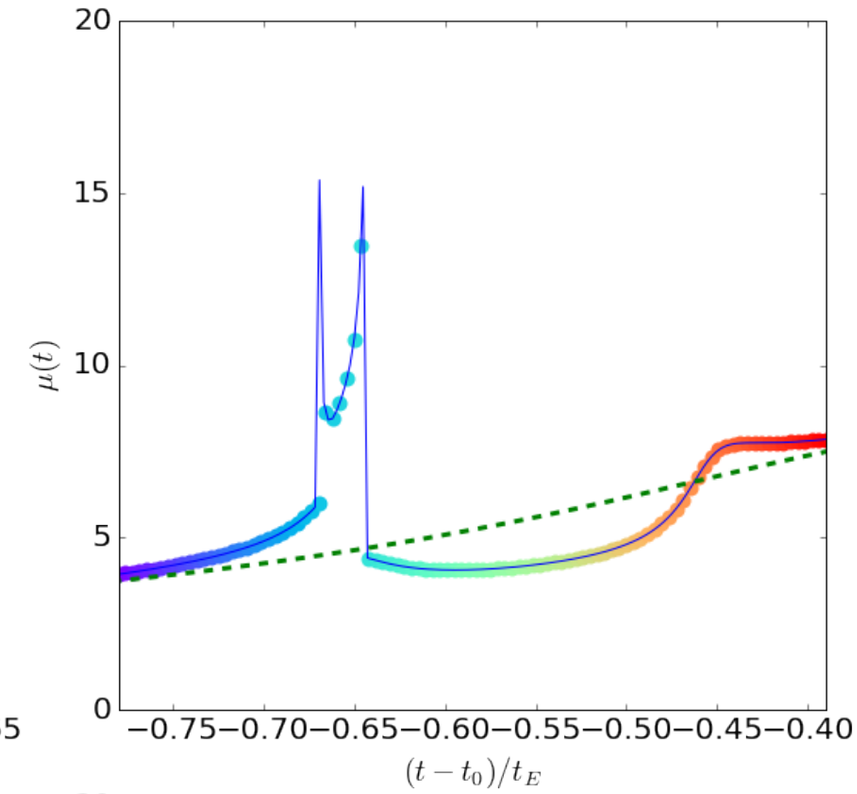
- Caustics have three cusps: magnification near the cusps
- They also have three folds: sudden magnification jumps
- Strong demagnification in between the planetary caustics

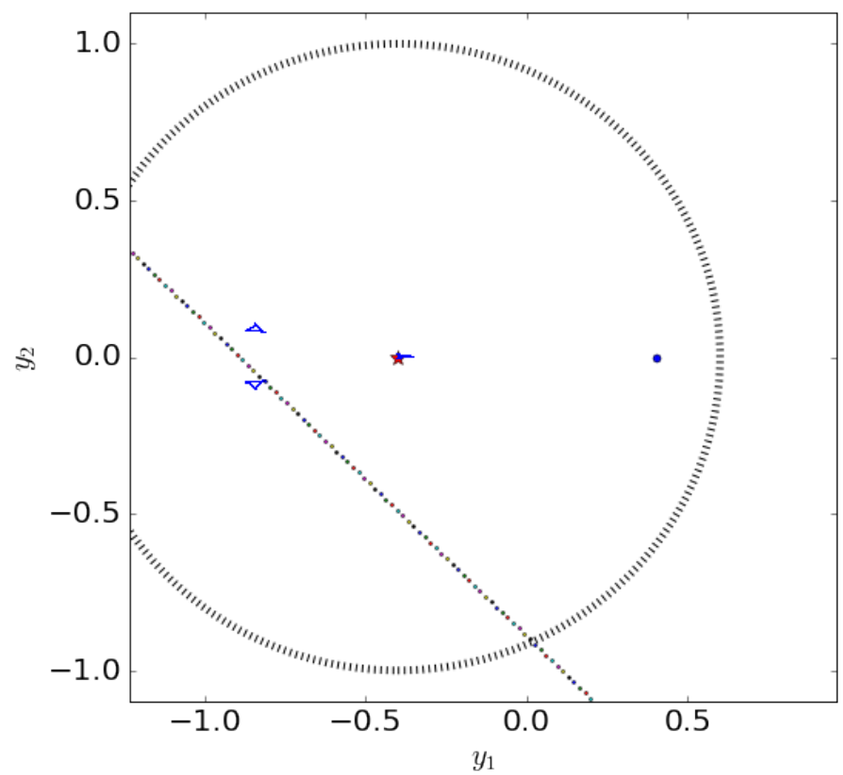


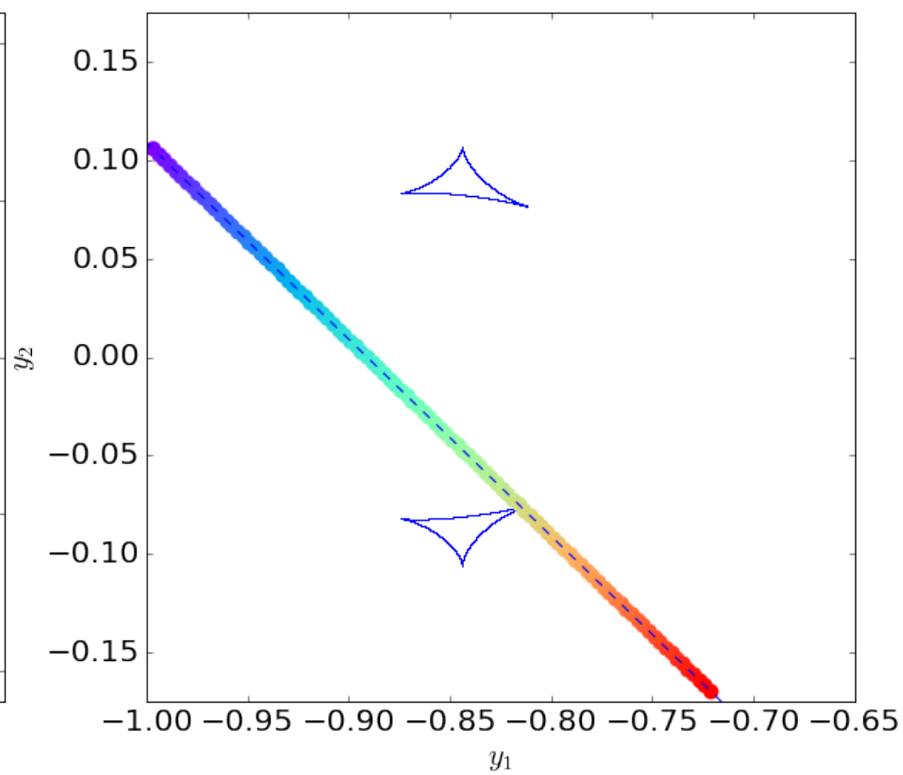
PLANETARY CAUSTICS PERTURBATIONS IN CLOSE TOPOLOGIES

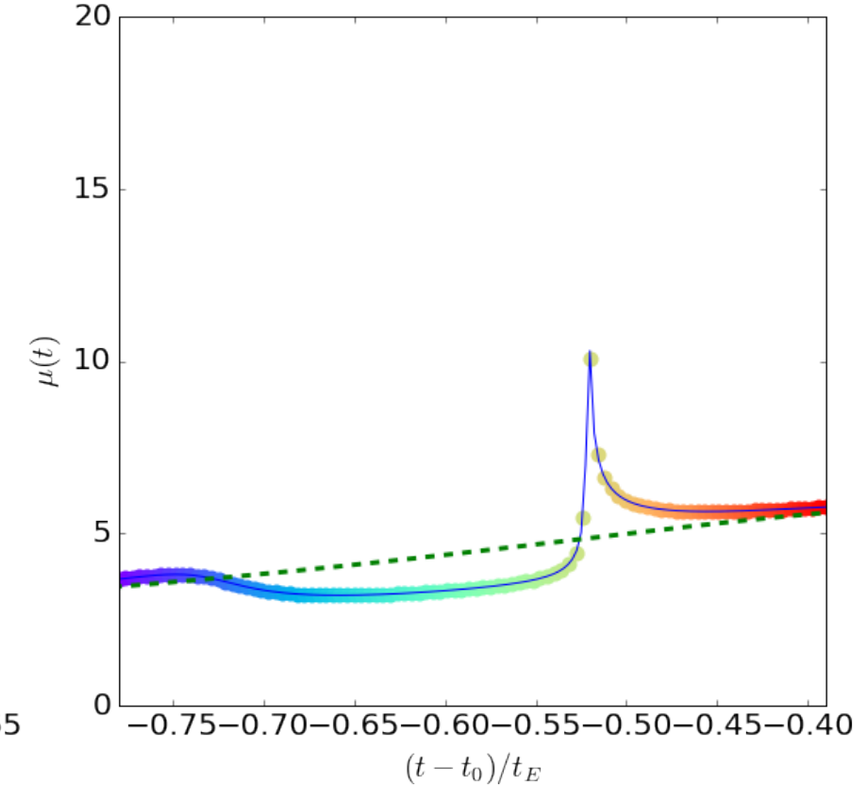




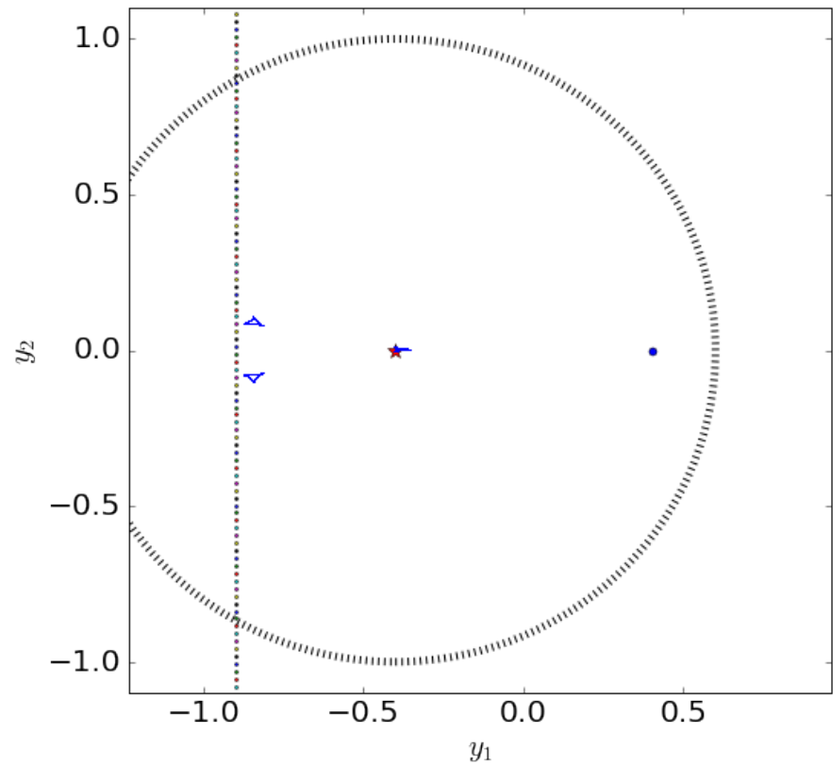


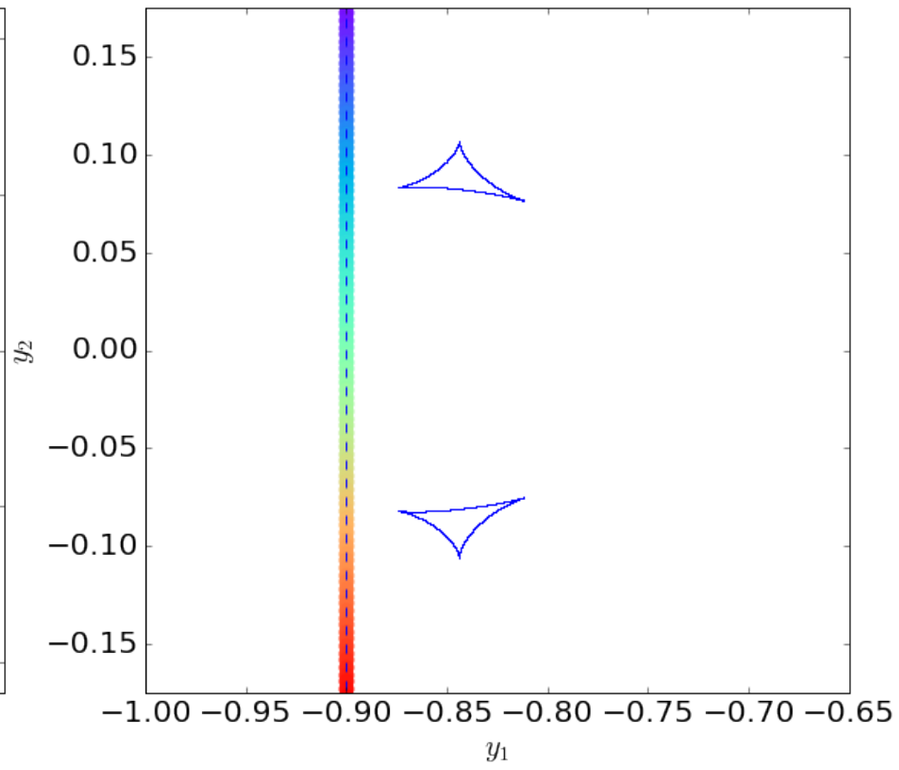


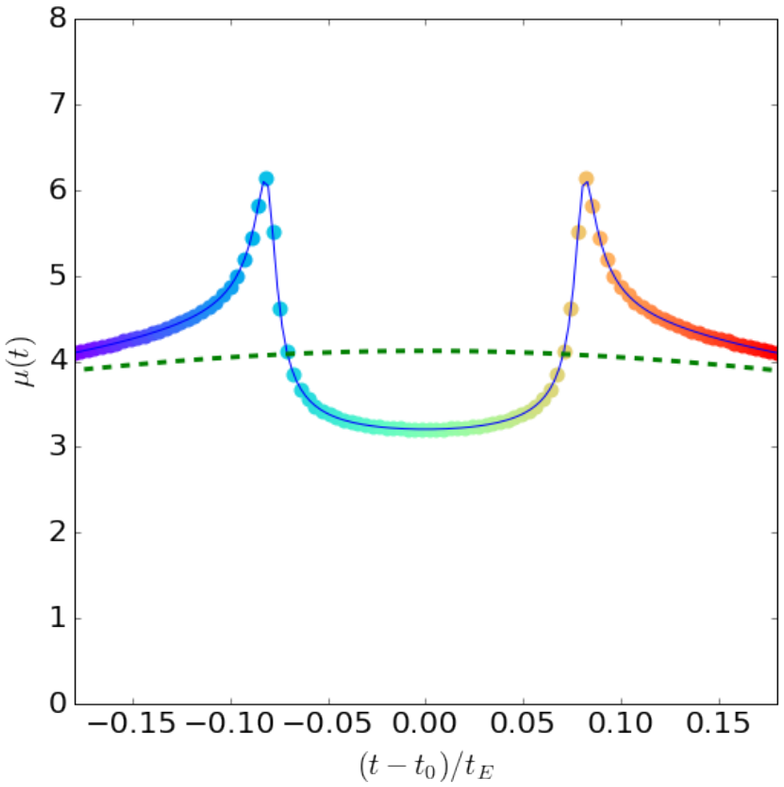


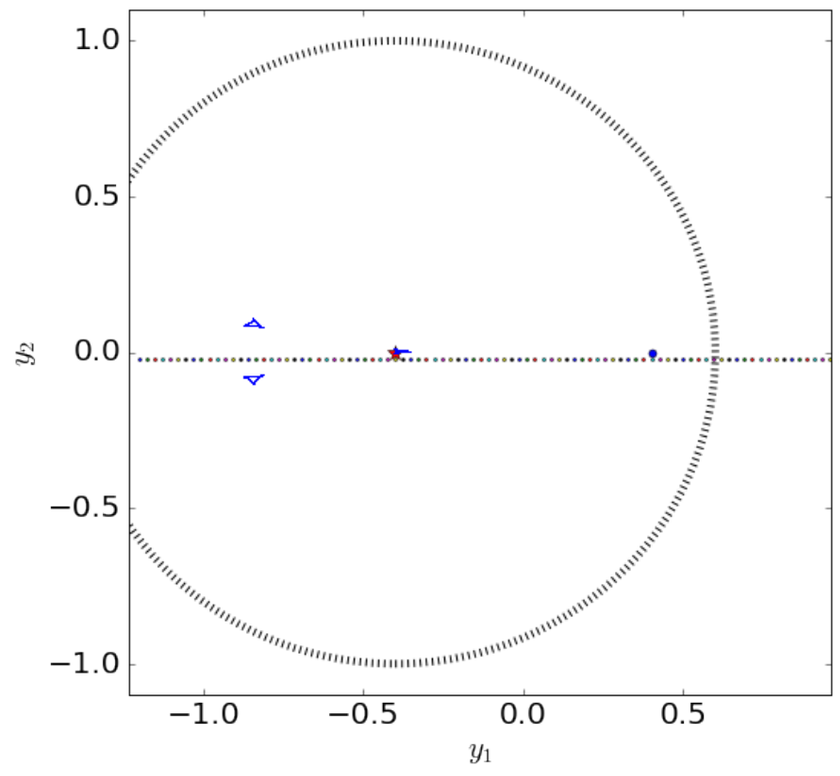


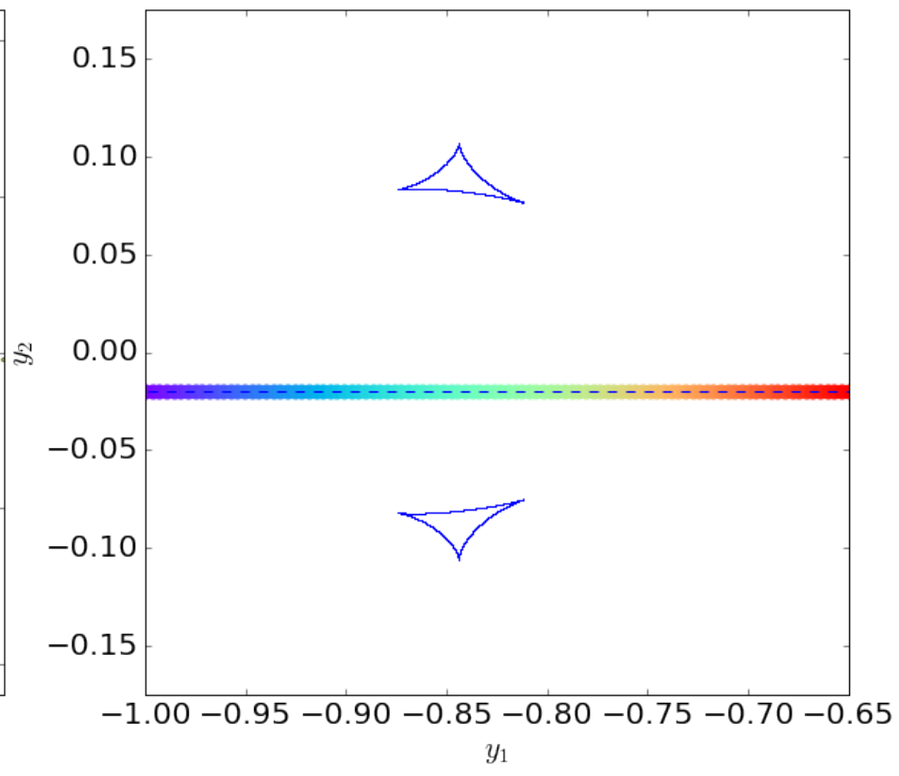
PLANETARY CAUSTICS PERTURBATIONS IN CLOSE TOPOLOGIES

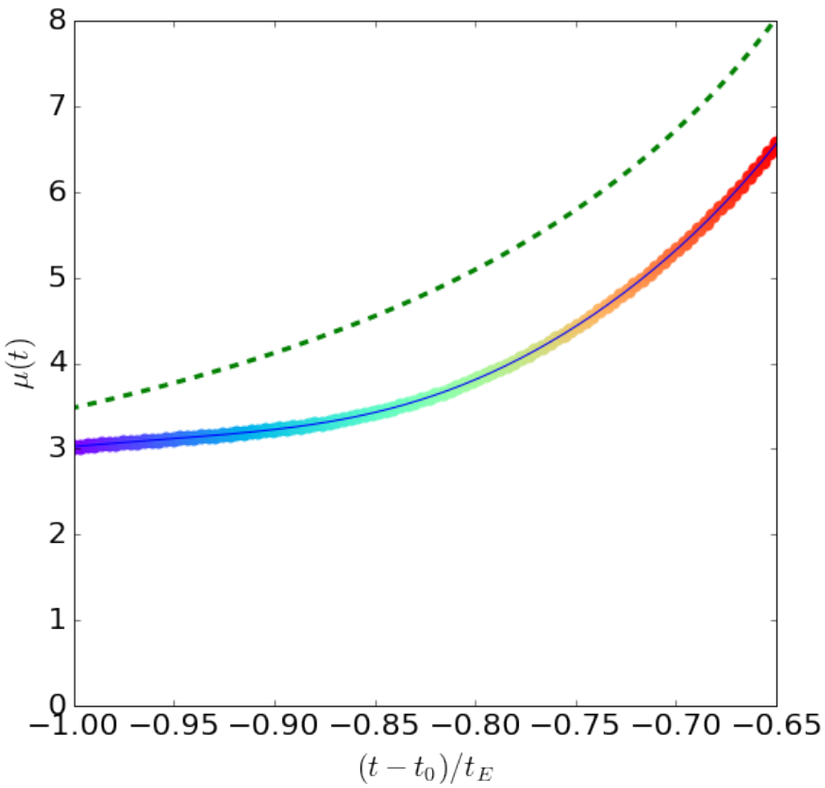




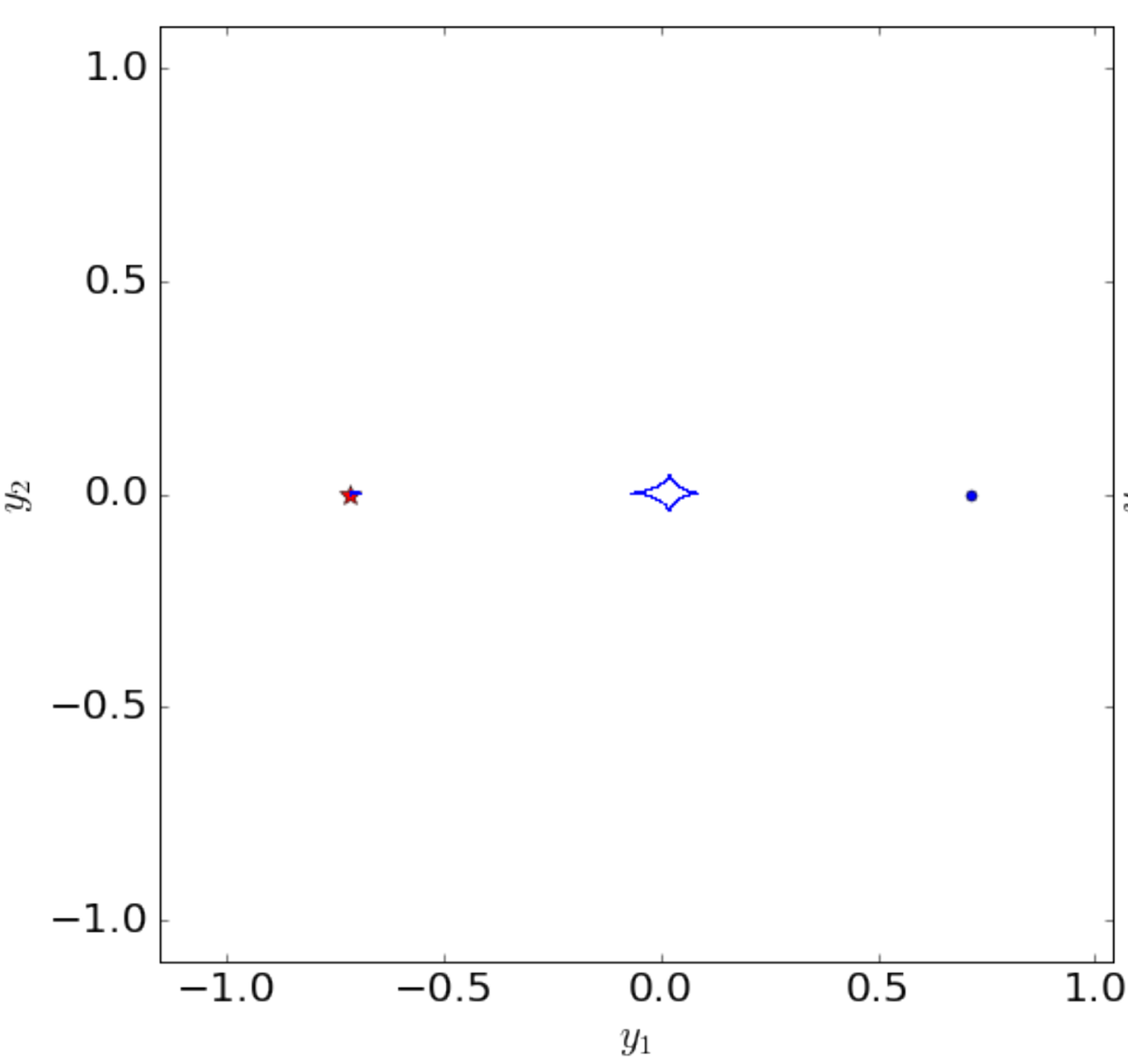


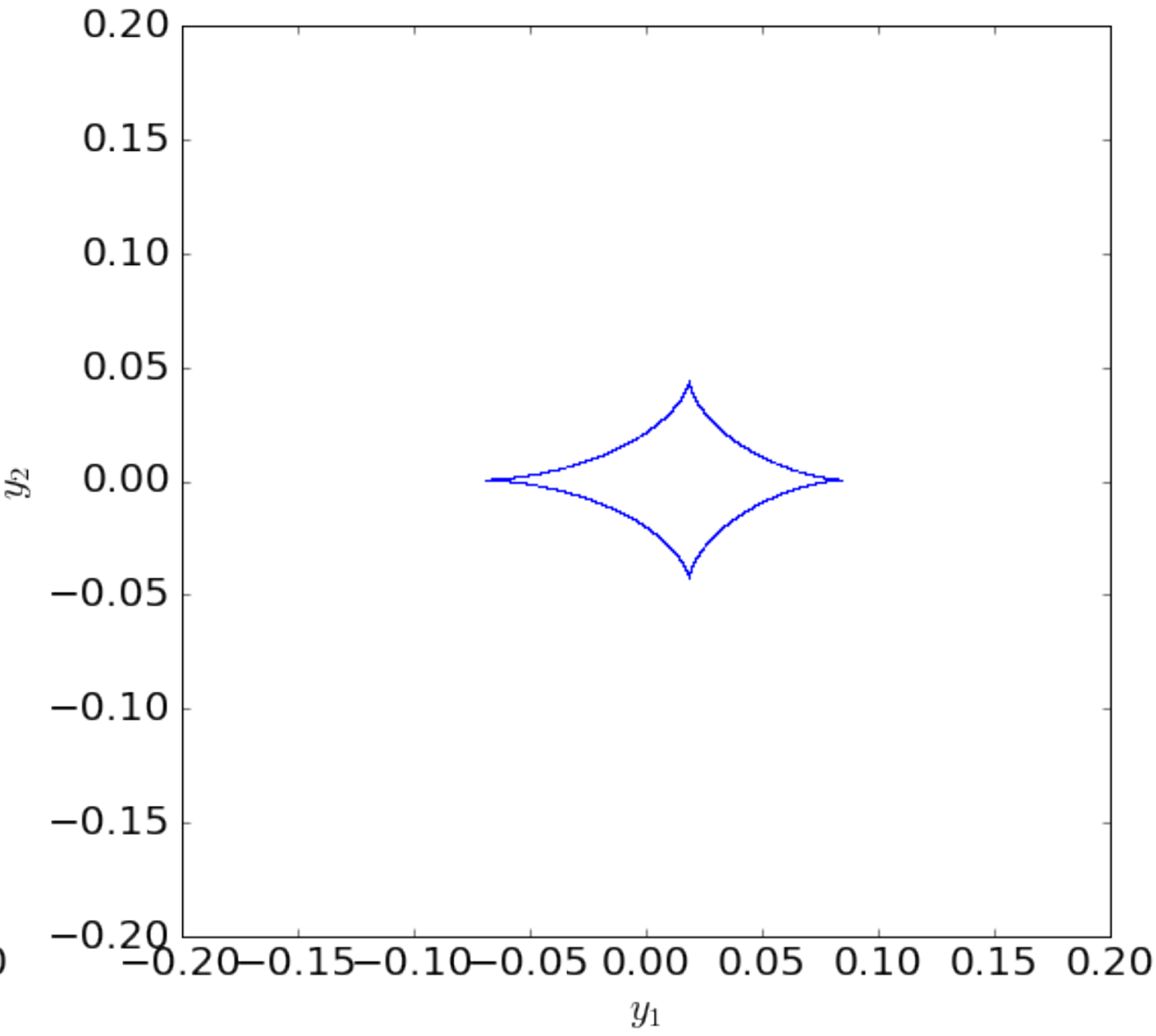




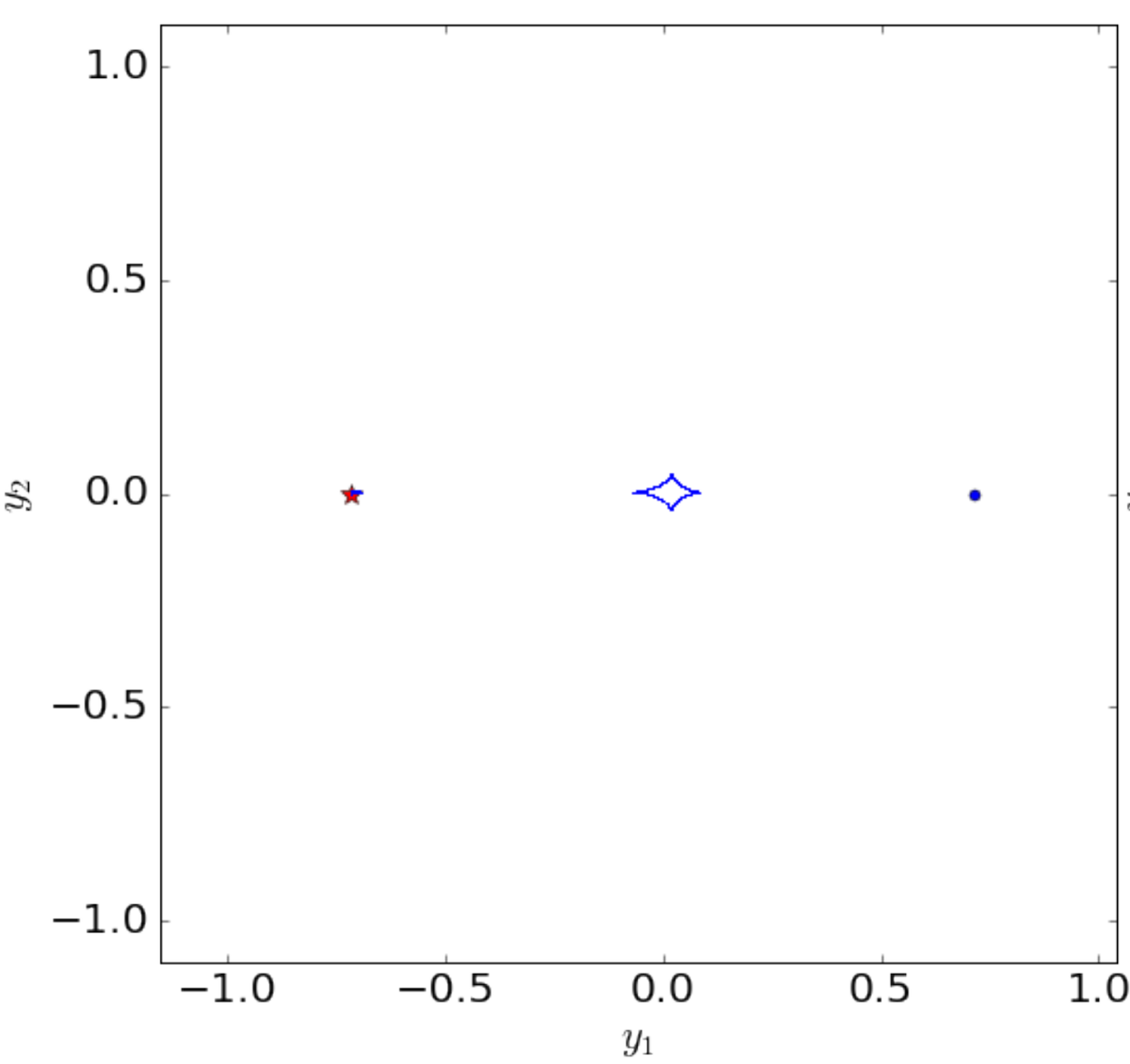


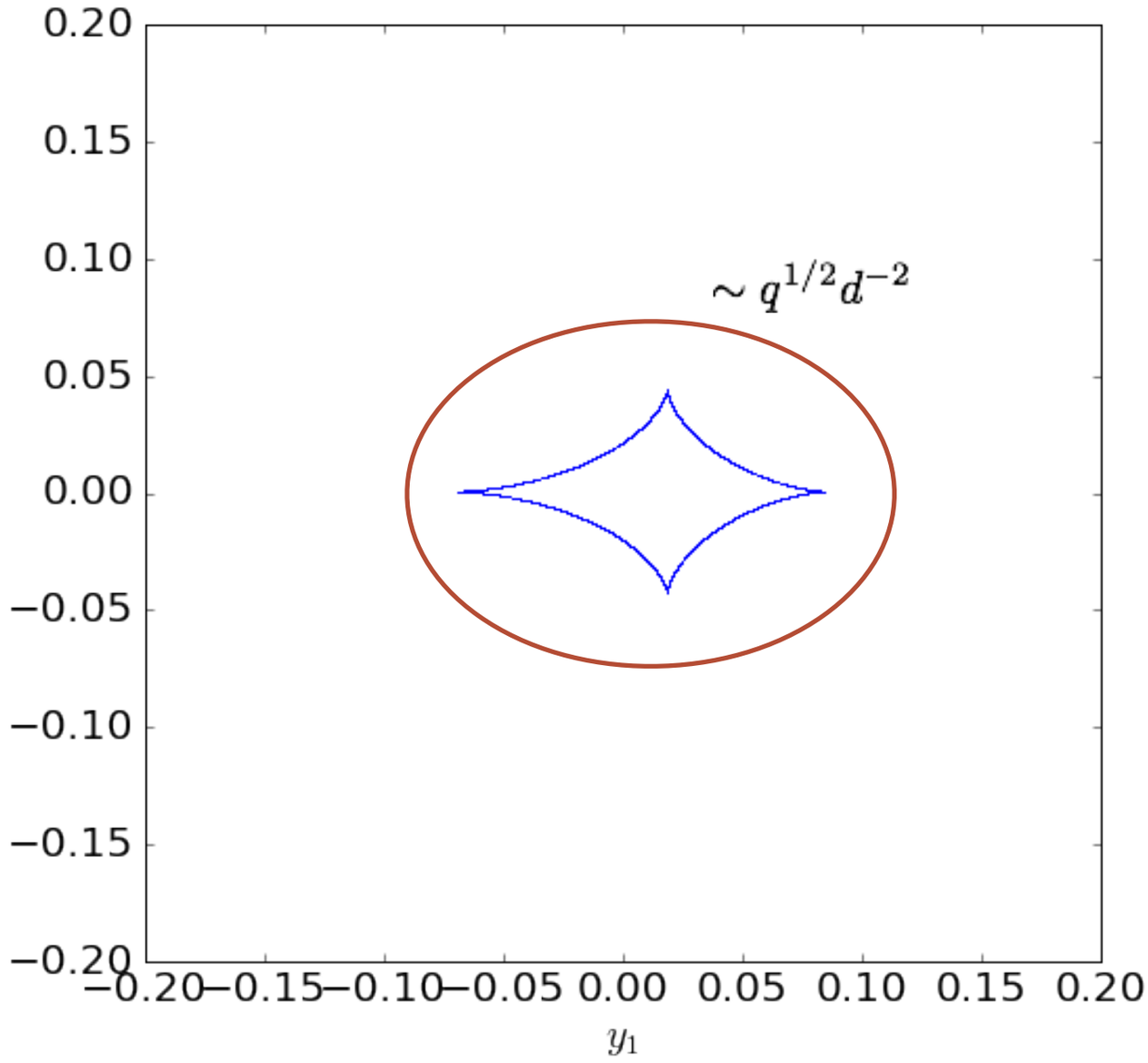
PLANETARY CAUSTICS IN WIDE TOPOLOGIES



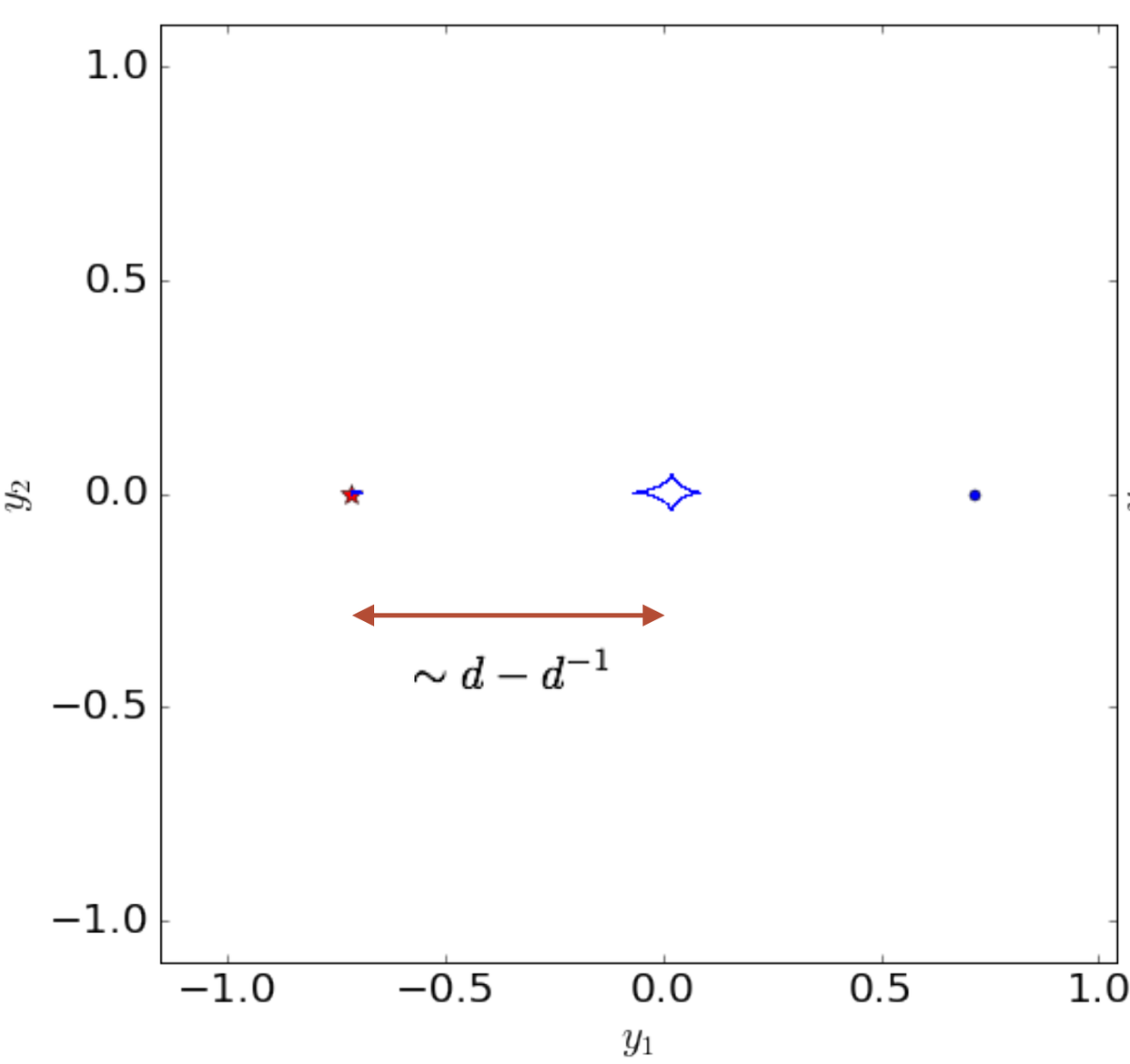


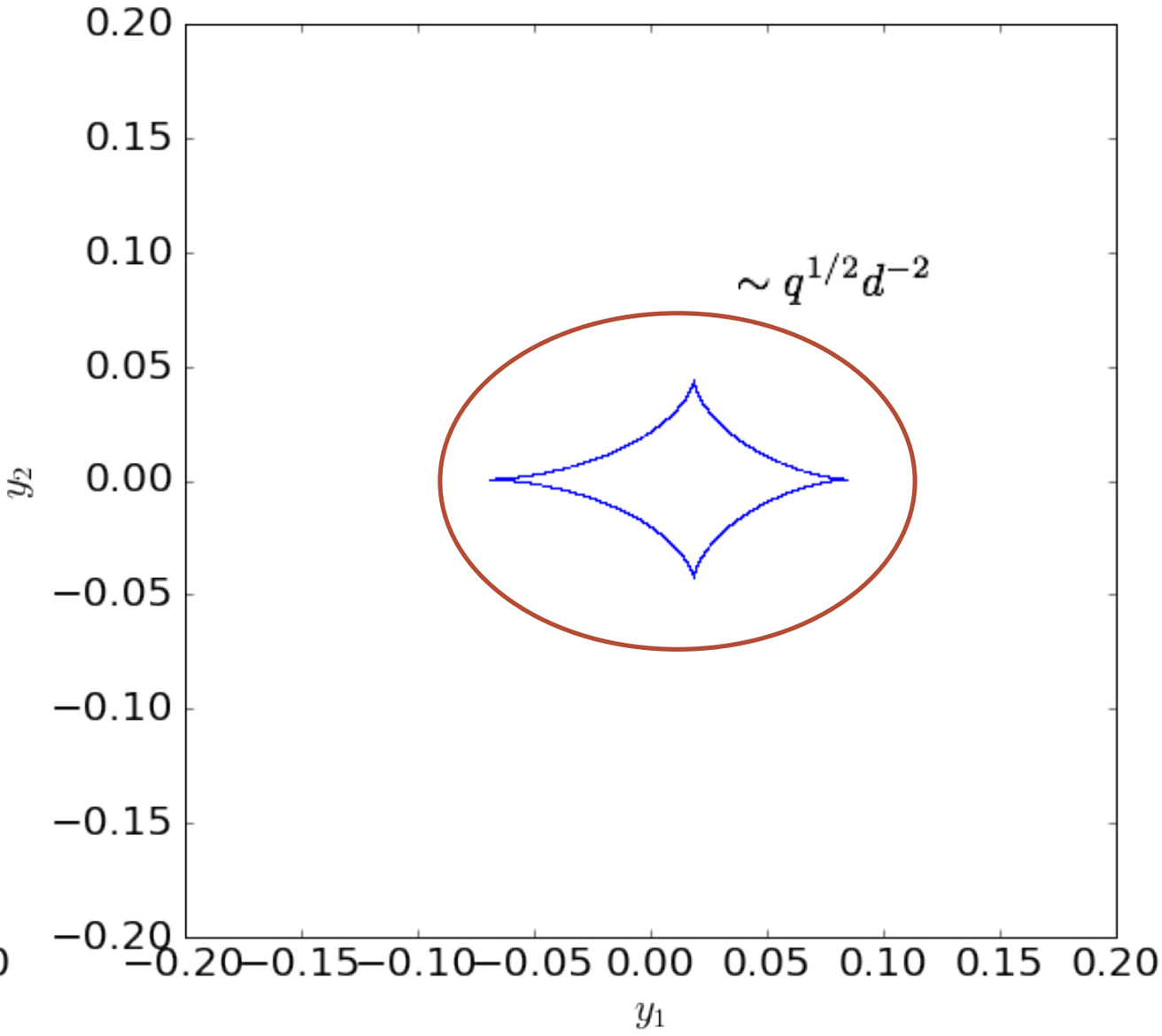
PLANETARY CAUSTICS IN WIDE TOPOLOGIES





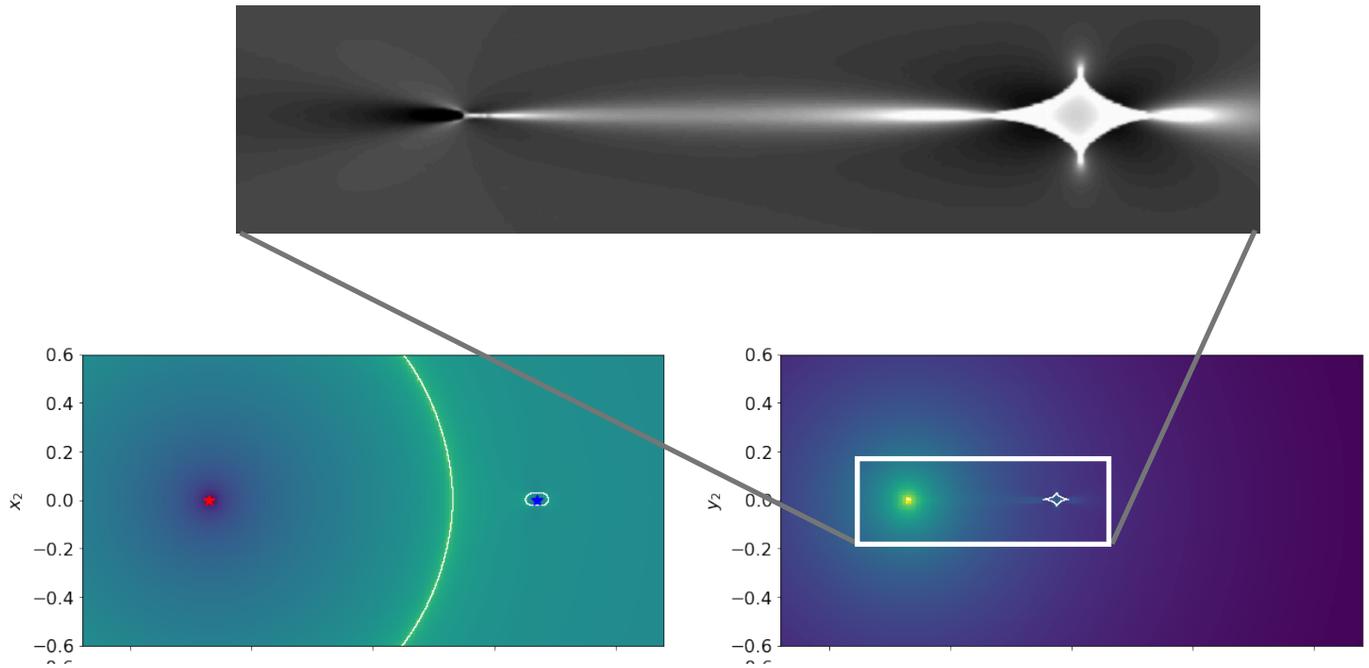
PLANETARY CAUSTICS IN WIDE TOPOLOGIES



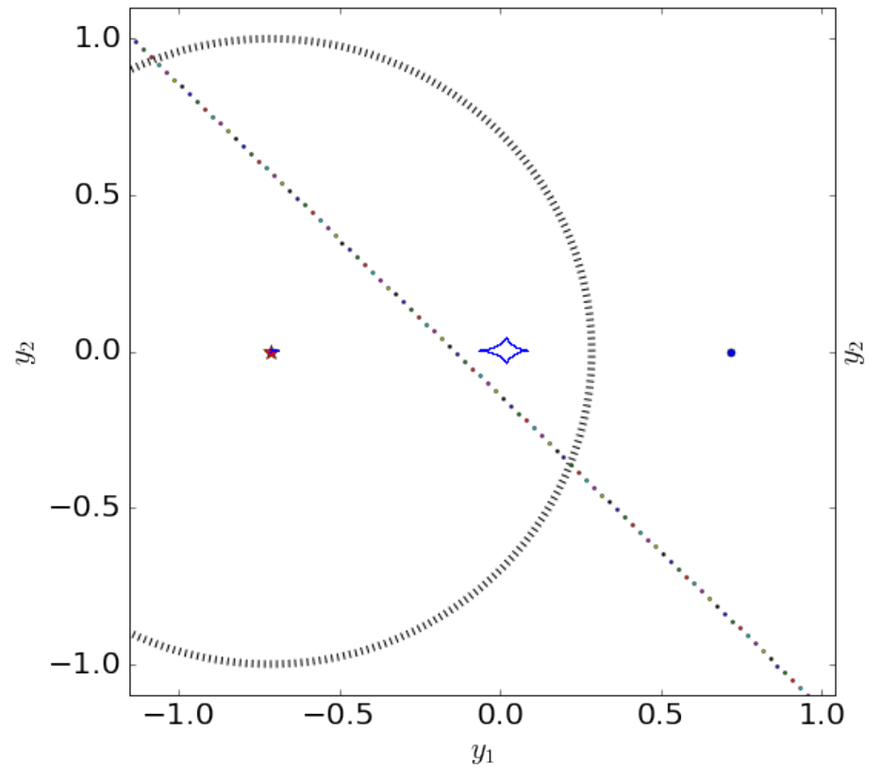


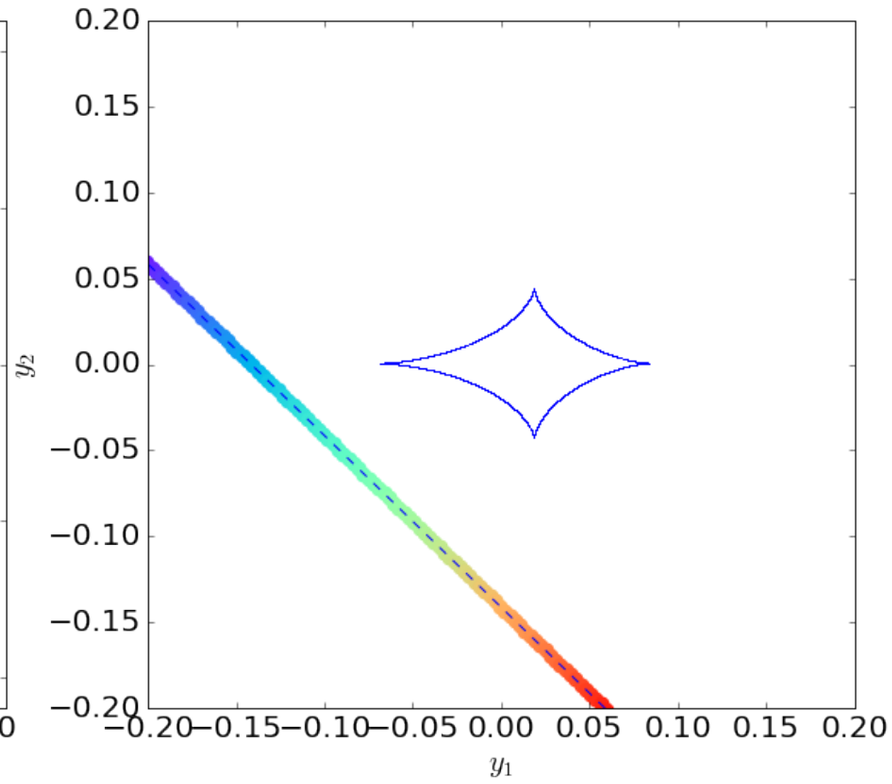
WHAT KIND OF SIGNATURES?

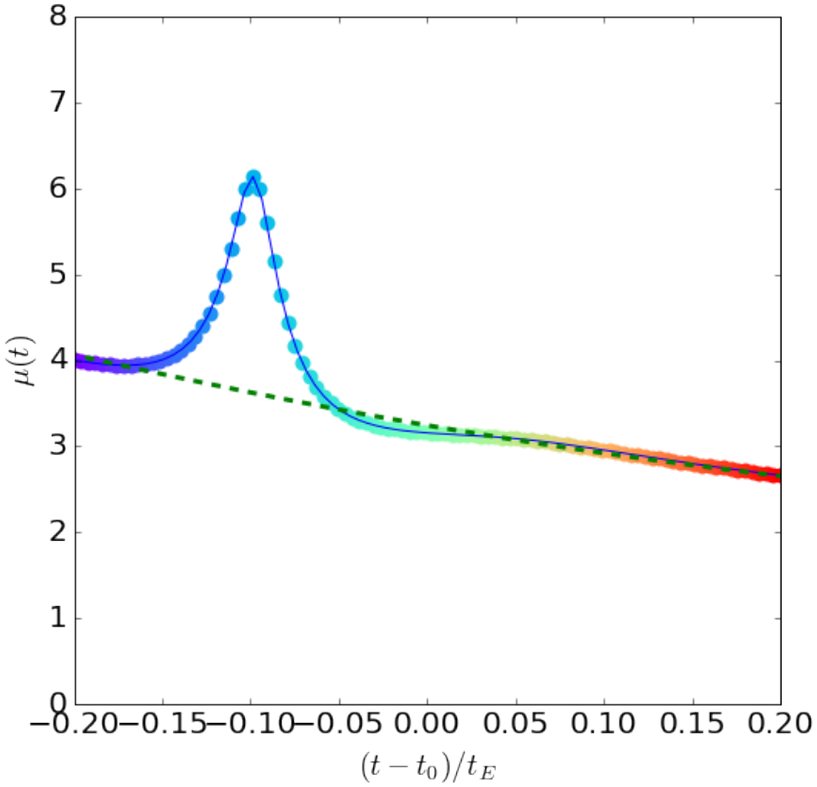
- Four cusps, four folds
- Strong magnification near the cusps
- Sudden magnification jumps when crossing the folds
- De-magnification on the outer parts of the folds
- Mild magnification inside the caustic

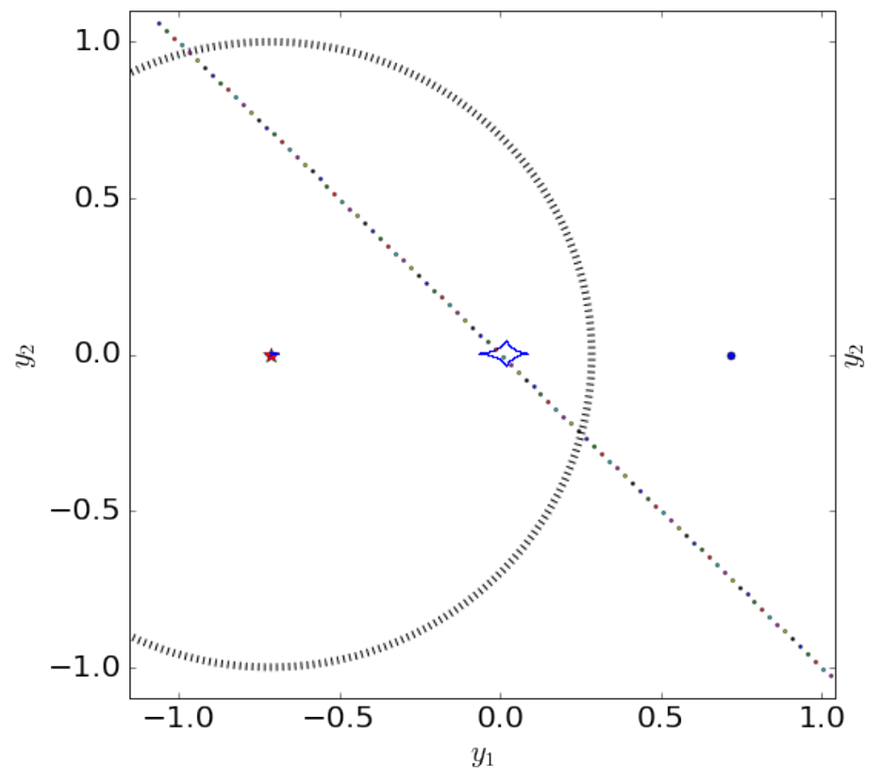


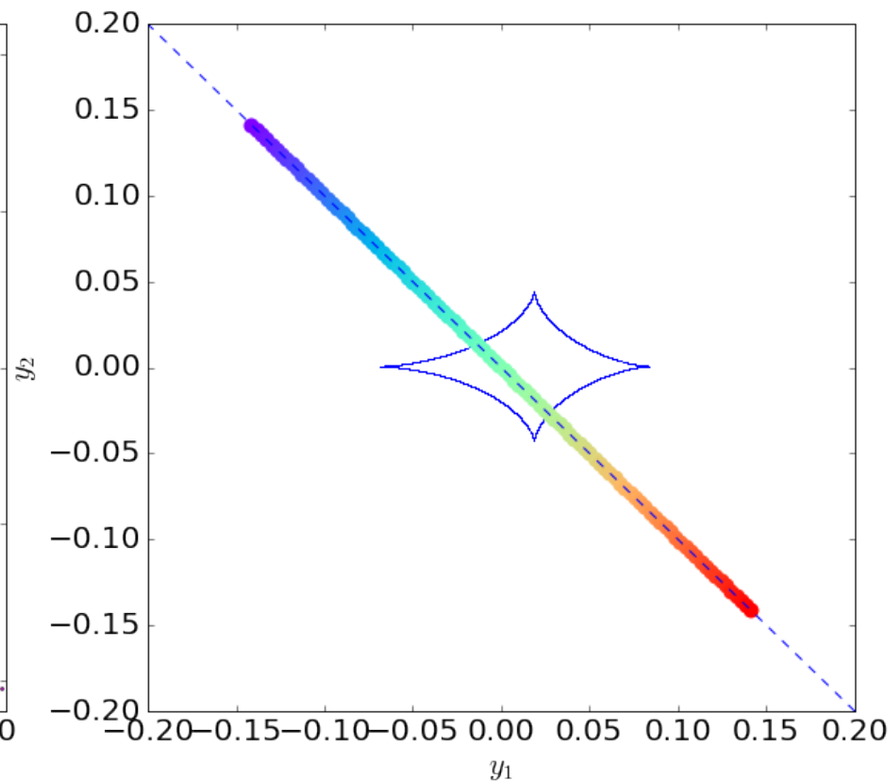
PLANETARY CAUSTICS PERTURBATIONS IN WIDE TOPOLOGIES

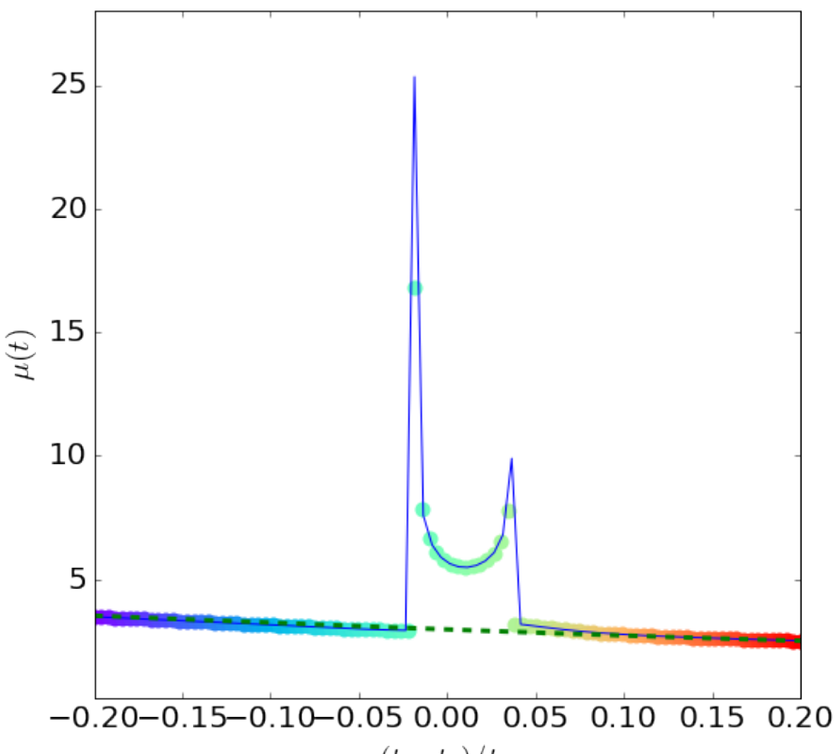




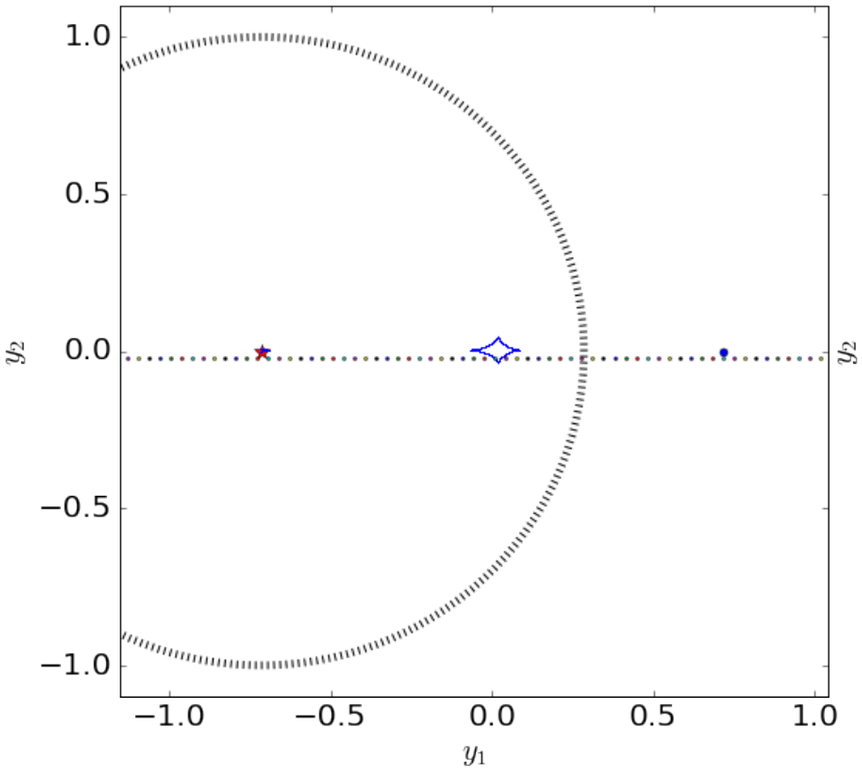


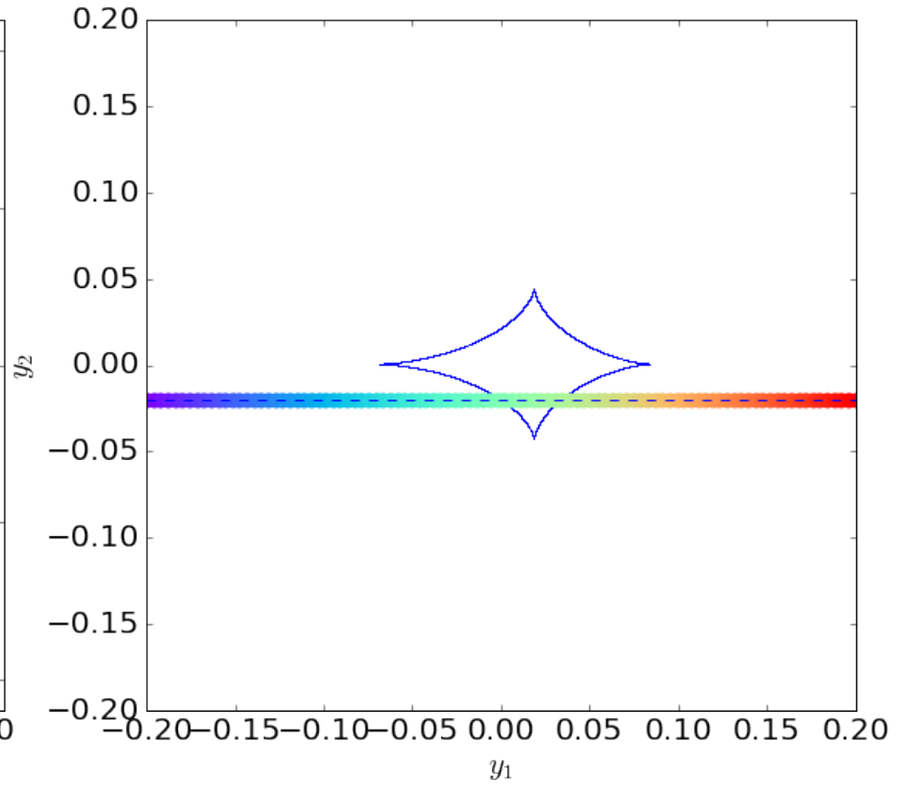


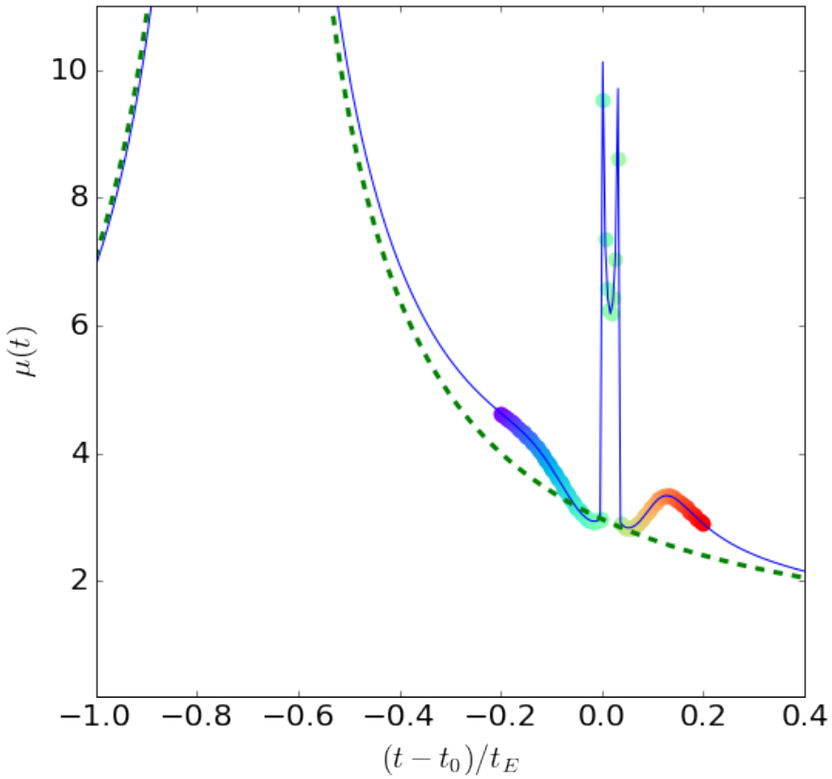


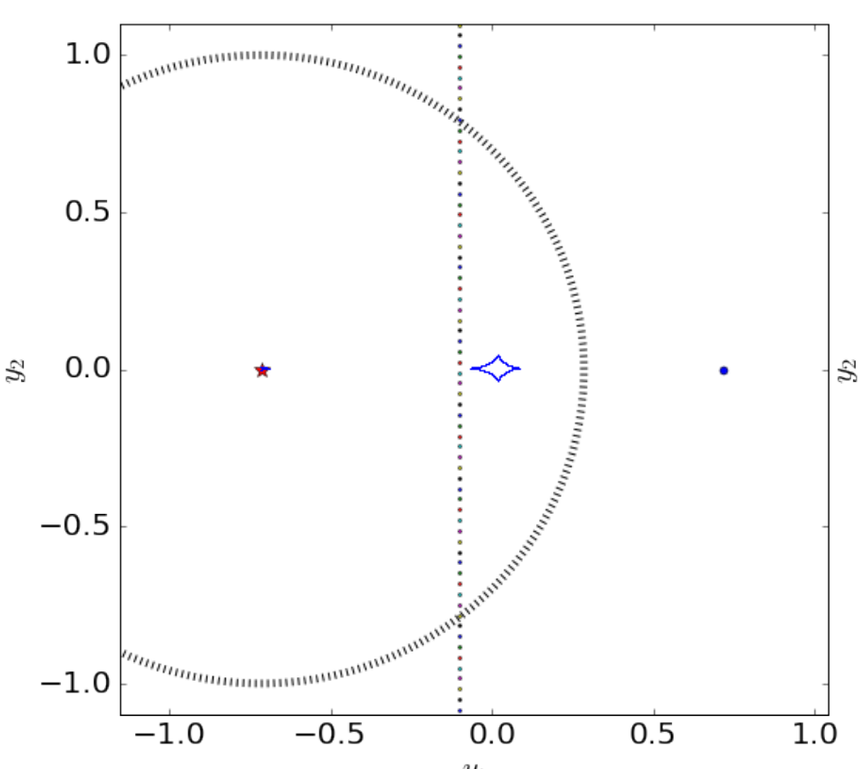


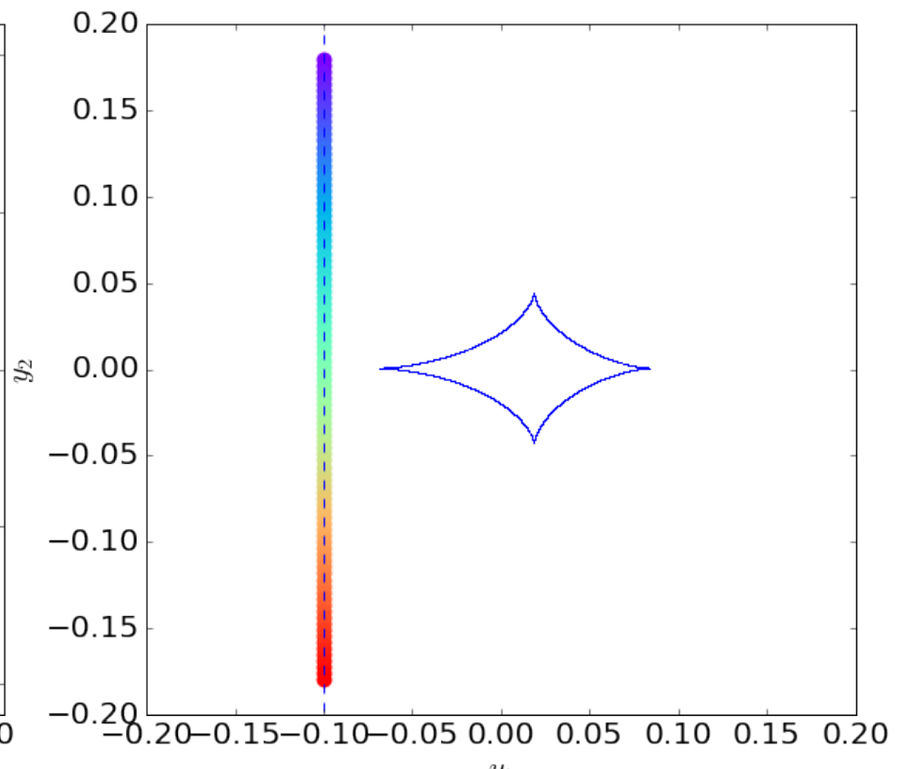
PLANETARY CAUSTICS PERTURBATIONS IN WIDE TOPOLOGIES

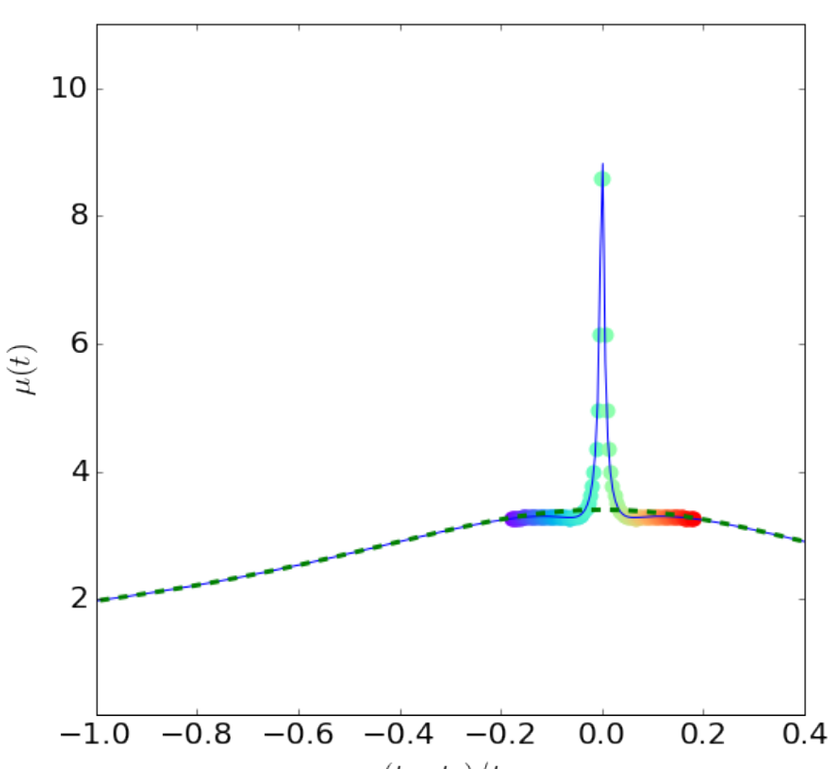




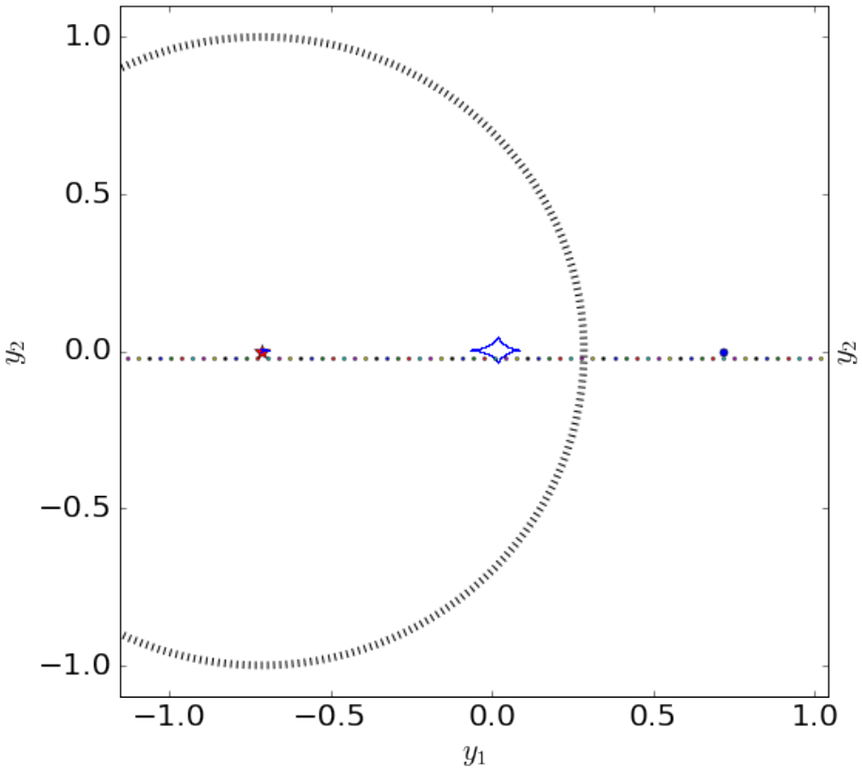


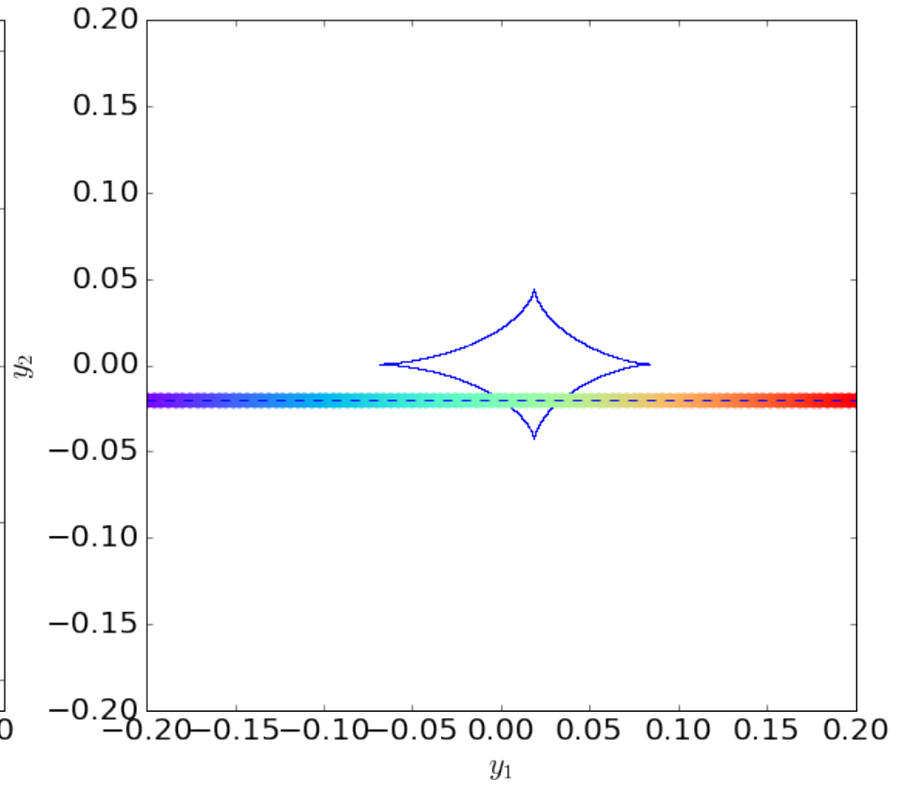


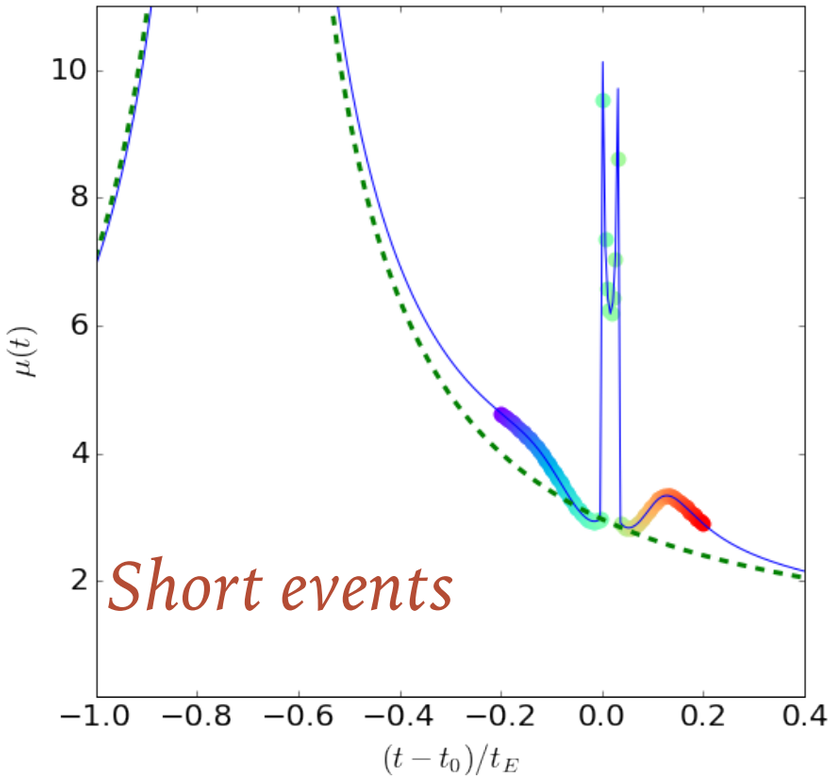


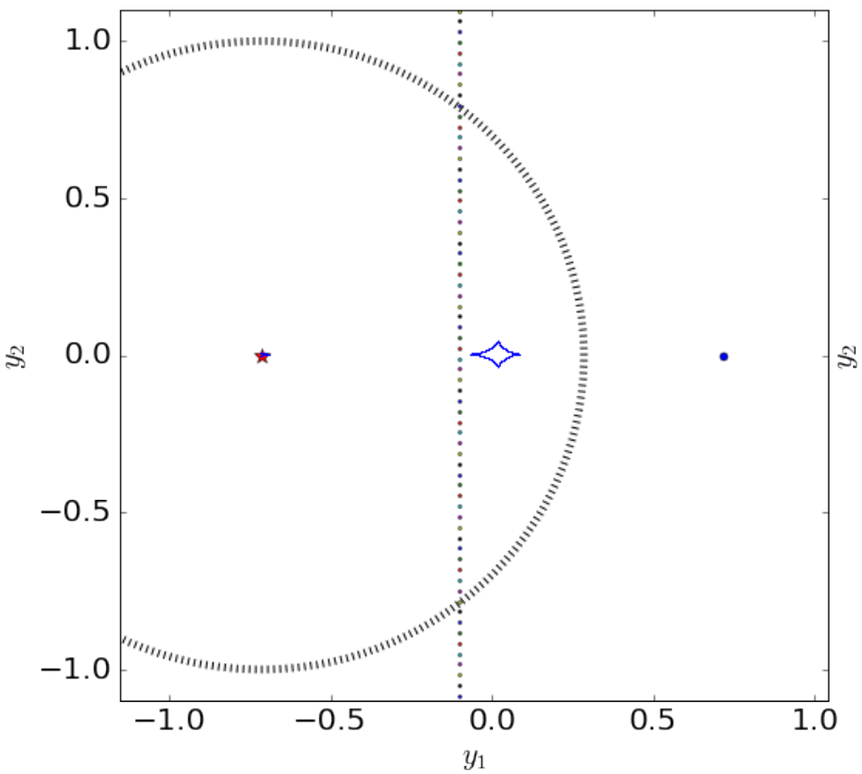


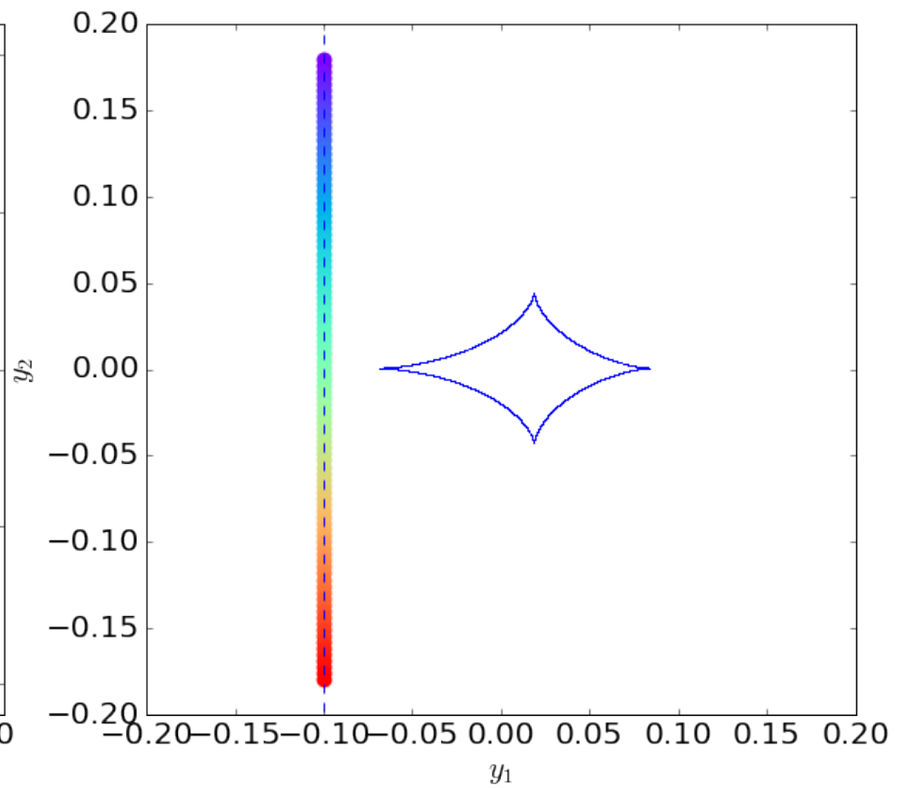
PLANETARY CAUSTICS PERTURBATIONS IN WIDE TOPOLOGIES

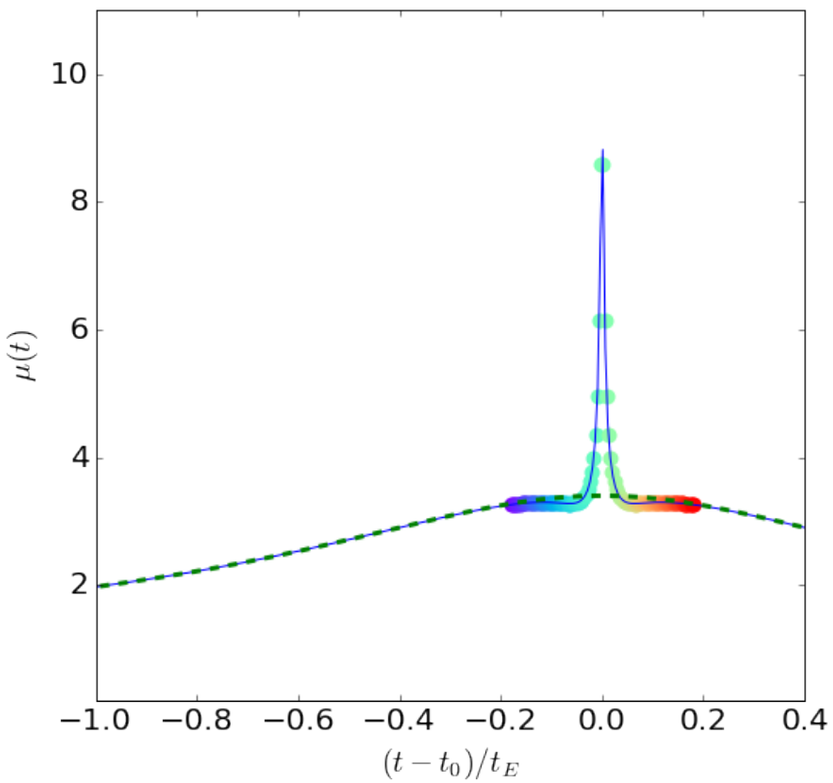




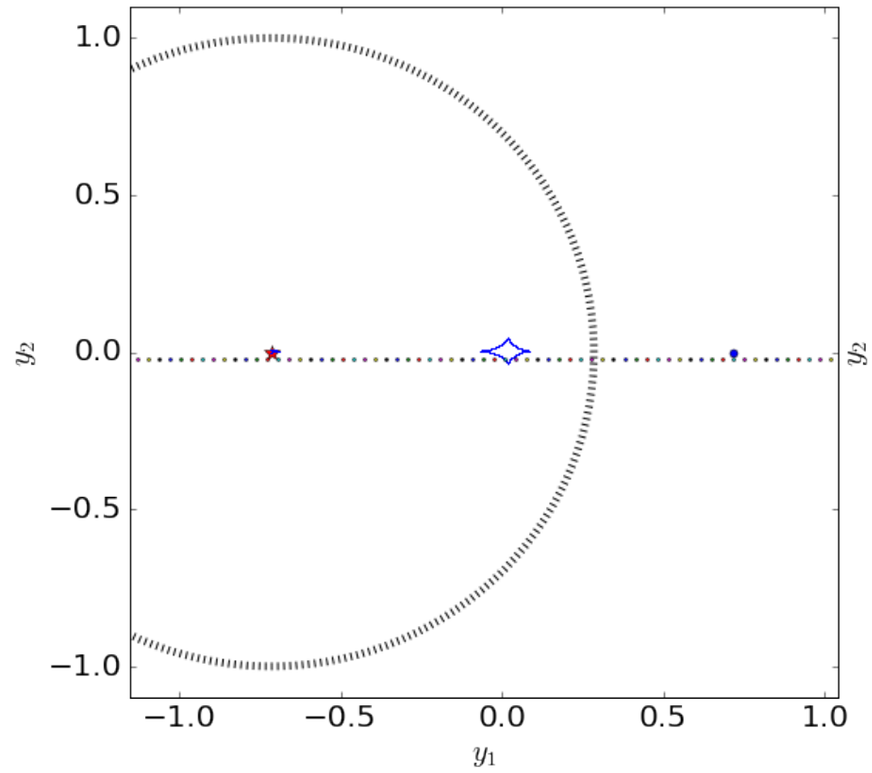


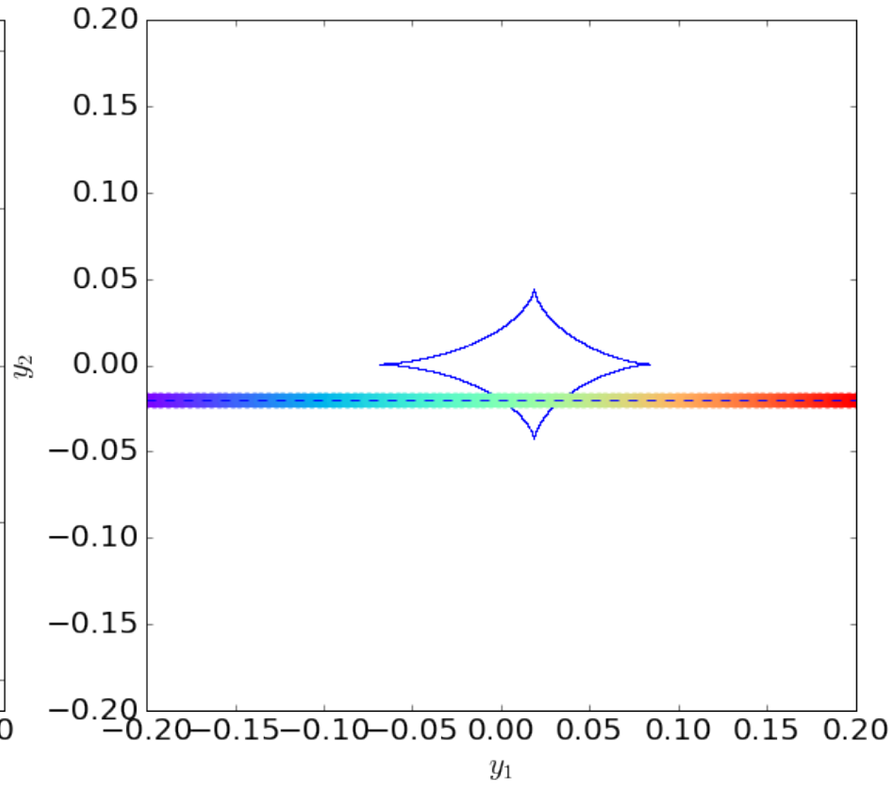


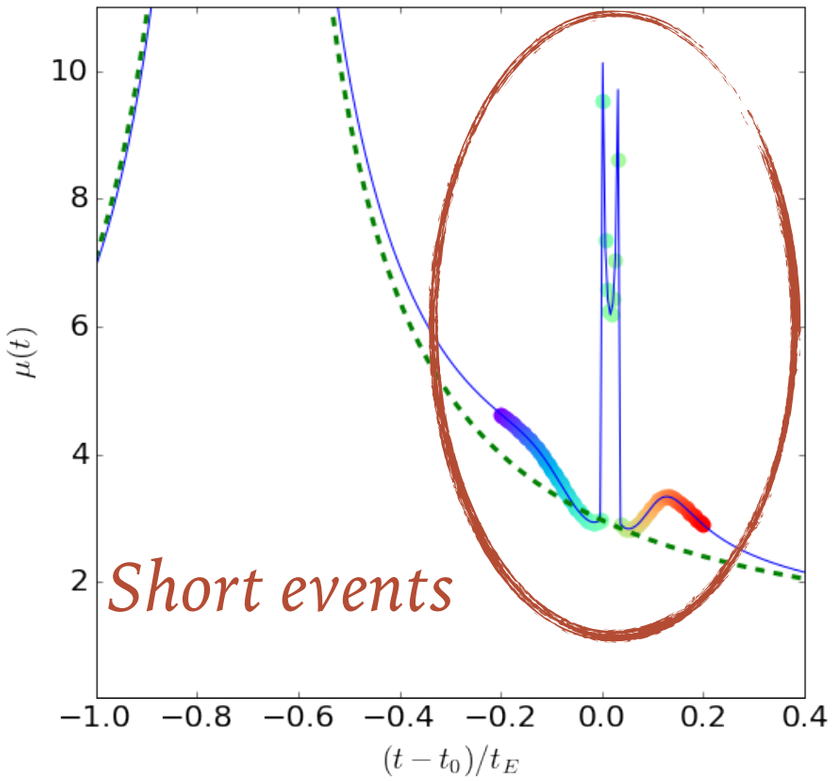


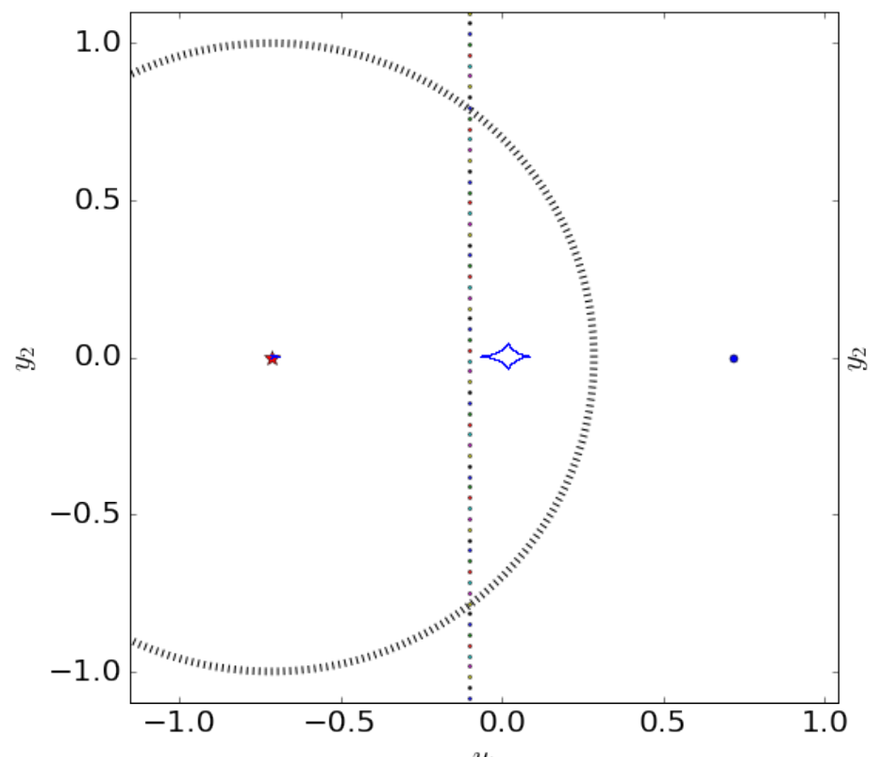


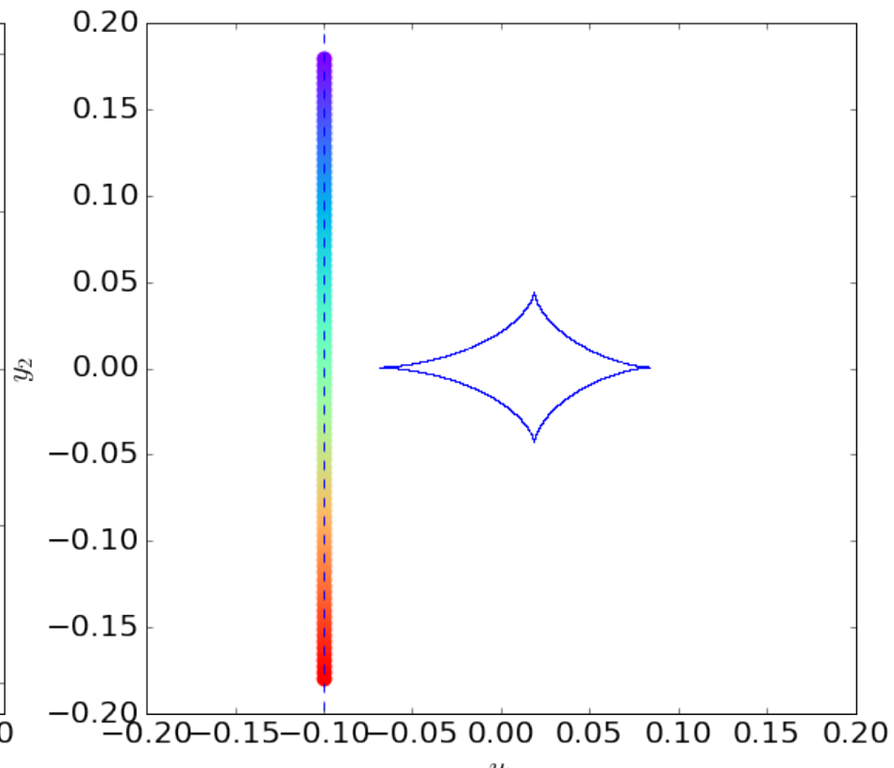
PLANETARY CAUSTICS PERTURBATIONS IN WIDE TOPOLOGIES

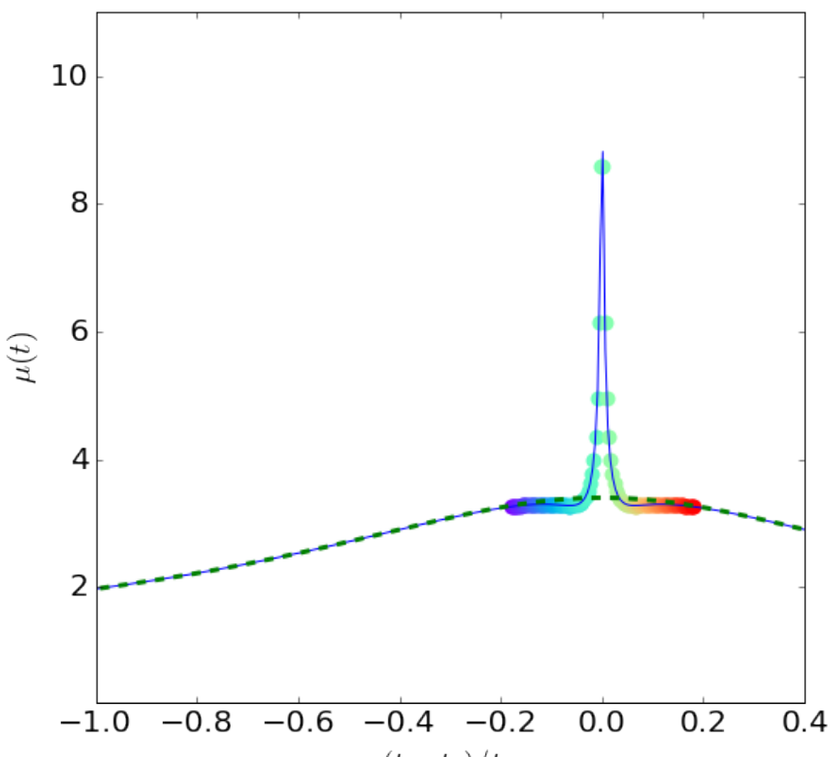








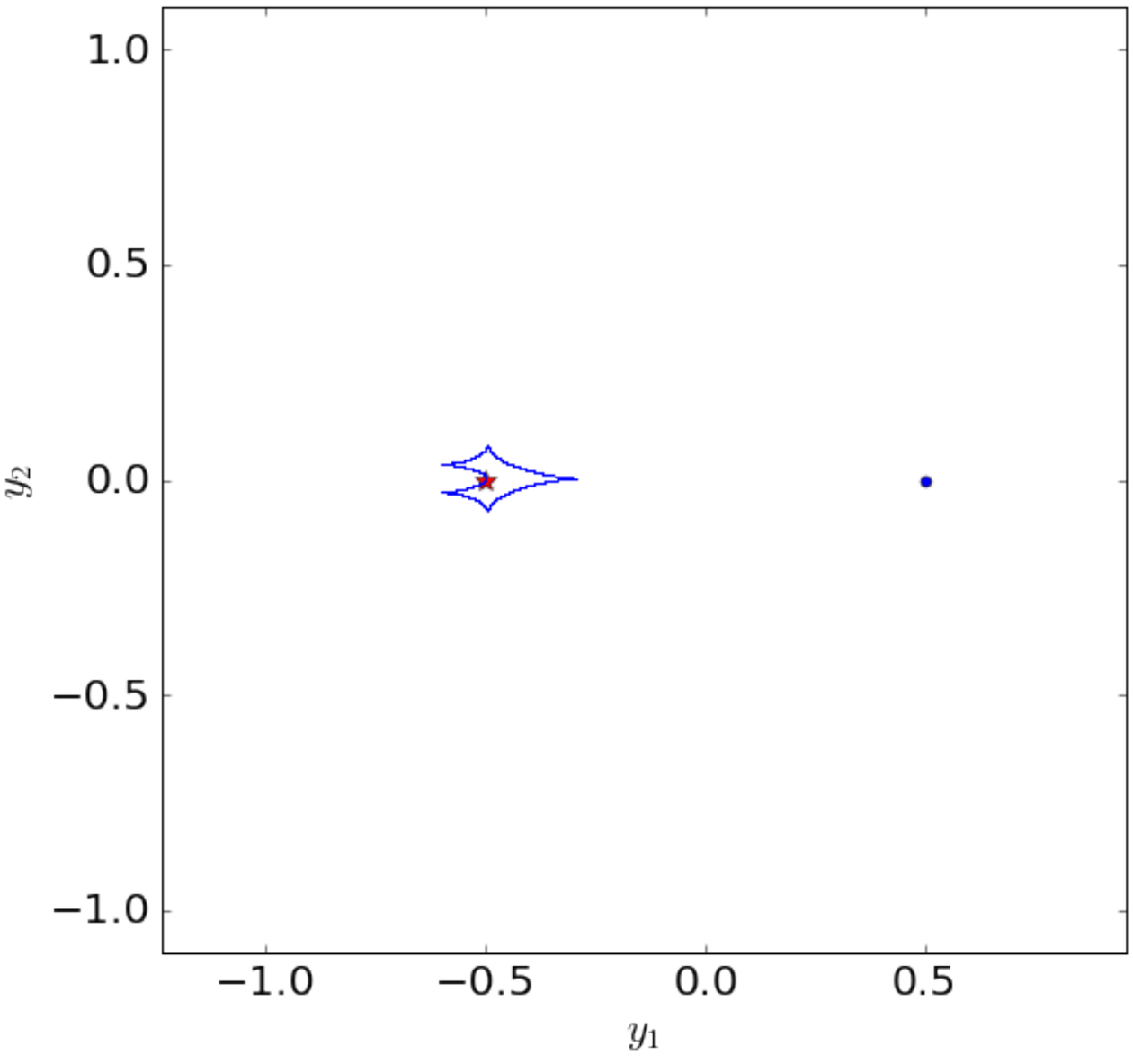


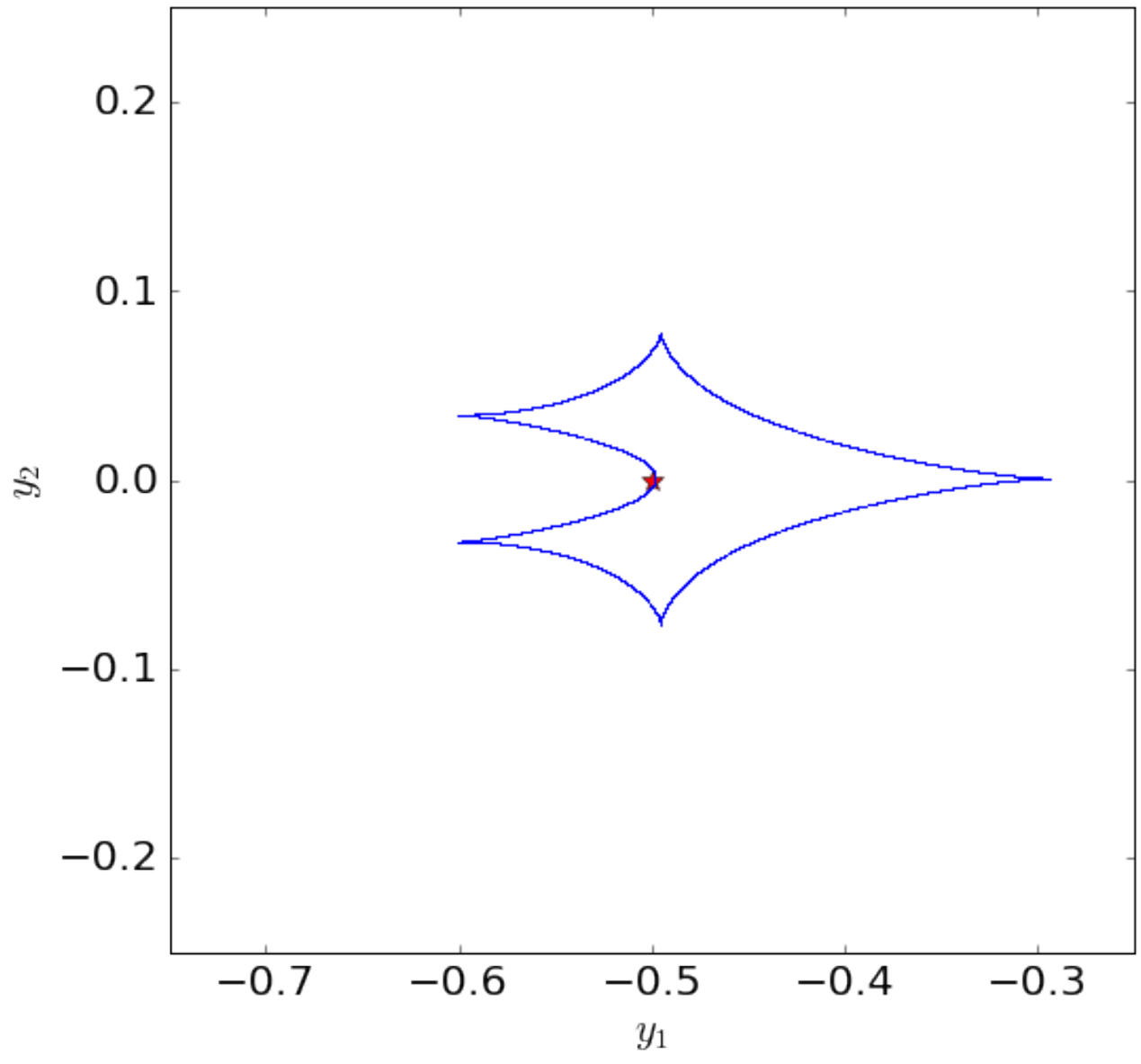


PLANET DETECTION THROUGH PLANETARY CAUSTICS PERTURBATIONS

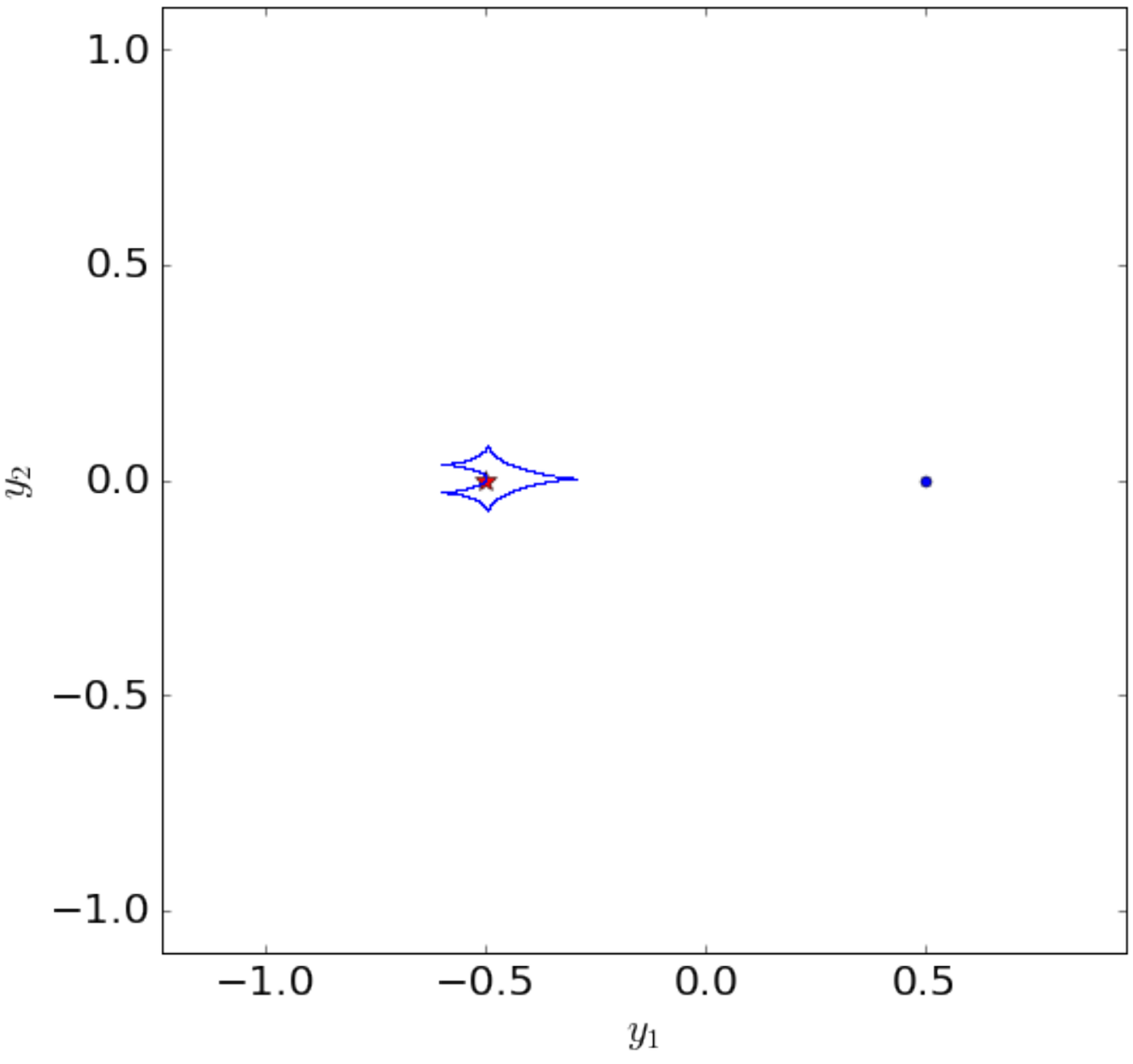
- Typically in low-to-mid magnification regimes, as the source passes at relatively large distance from the primary lens
- Short!
- More frequent
- Less predictable

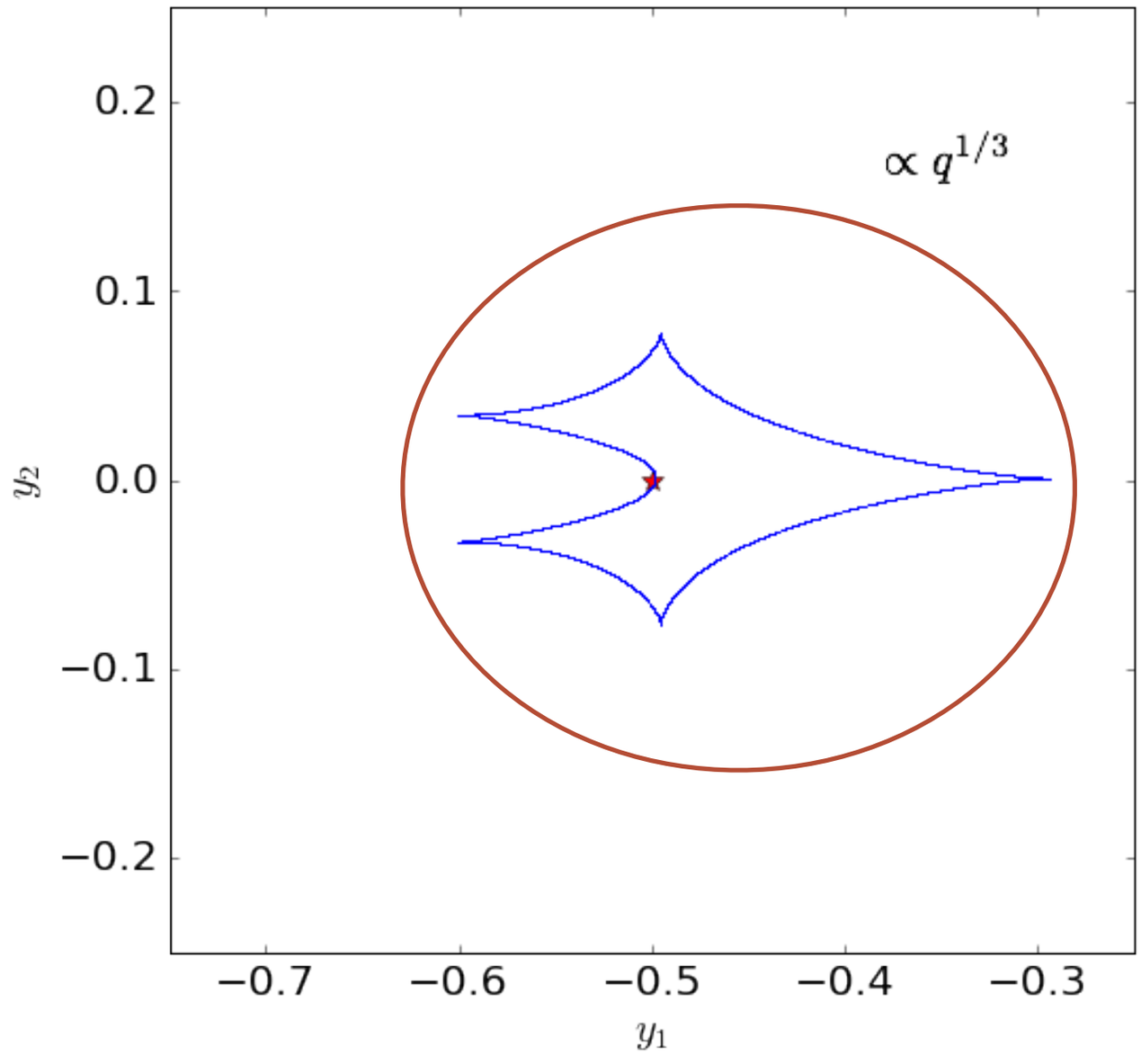
PLANETARY CAUSTICS IN INTERMEDIATE TOPOLOGIES





PLANETARY CAUSTICS IN INTERMEDIATE TOPOLOGIES





INTERMEDIATE OR RESONANT CAUSTICS

In order to have a resonant caustic the distance between the binary components must be

$$d_{IC} < d < d_{WI}$$

where $d_{WI} = (m_1^{1/3} + m_2^{1/3})^{3/2}$ $d_{IC} = (m_1^{1/3} + m_2^{1/3})^{-3/4}$

These two relations can be written in a different form:

$d_{WI} = m_2^{1/2}(1 + q^{1/3})^{3/2}$ $d_{IC} = m_2^{-1/4}(1 + q^{1/3})^{-3/4}$

Note that d is the distance between the two lenses in units of θ_E *(i.e. the equivalent Einstein radius)*

INTERMEDIATE OR RESONANT CAUSTICS

We can work out the following relations:

$$\theta_E = \sqrt{\frac{4GM_{tot}}{c^2}\frac{D_{LS}}{D_L D_S}} = \sqrt{\frac{M_{tot}}{M_2}}\sqrt{\frac{4GM_2}{c^2}\frac{D_{LS}}{D_L D_S}} = \frac{\theta_{E,2}}{\sqrt{m_2}}$$

$$d'_{WI} = d_{WI}\frac{\theta_E}{\theta_{E,2}} = \frac{d_{WI}}{m_2^{1/2}} = (1+q^{1/3})^{3/2}$$

In the limit where $q \ll 1 \Rightarrow M_{tot} \sim M_2;\ m_2 \sim 1$

$$d'_{WI} \sim d_{WI} \sim \left(1+\frac{3}{2}q^{1/3}\right)$$

Similarly:

$$d'_{IC} \sim d_{IC} \sim \left(1-\frac{3}{4}q^{1/3}\right)$$

INTERMEDIATE OR RESONANT CAUSTICS

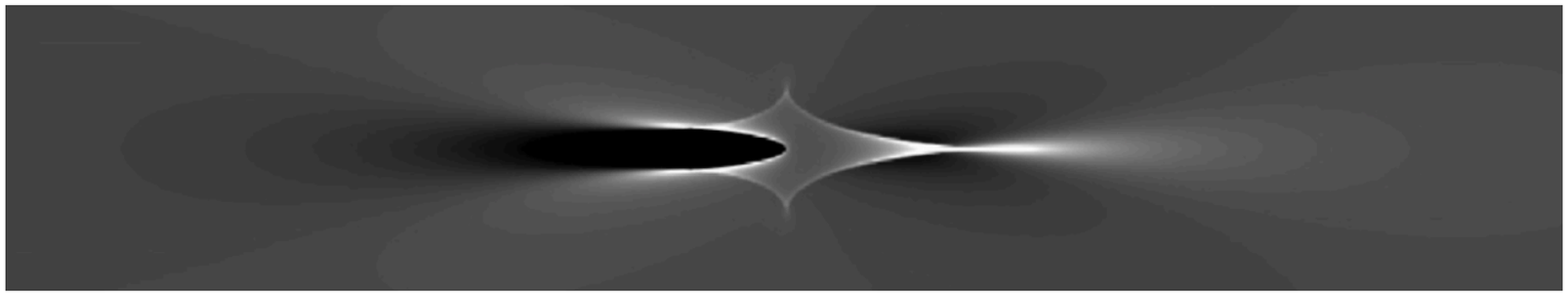
Therefore, in the case of star-planet pairs, resonant caustics exist within a very narrow range of distances around the Einstein radius of the star:

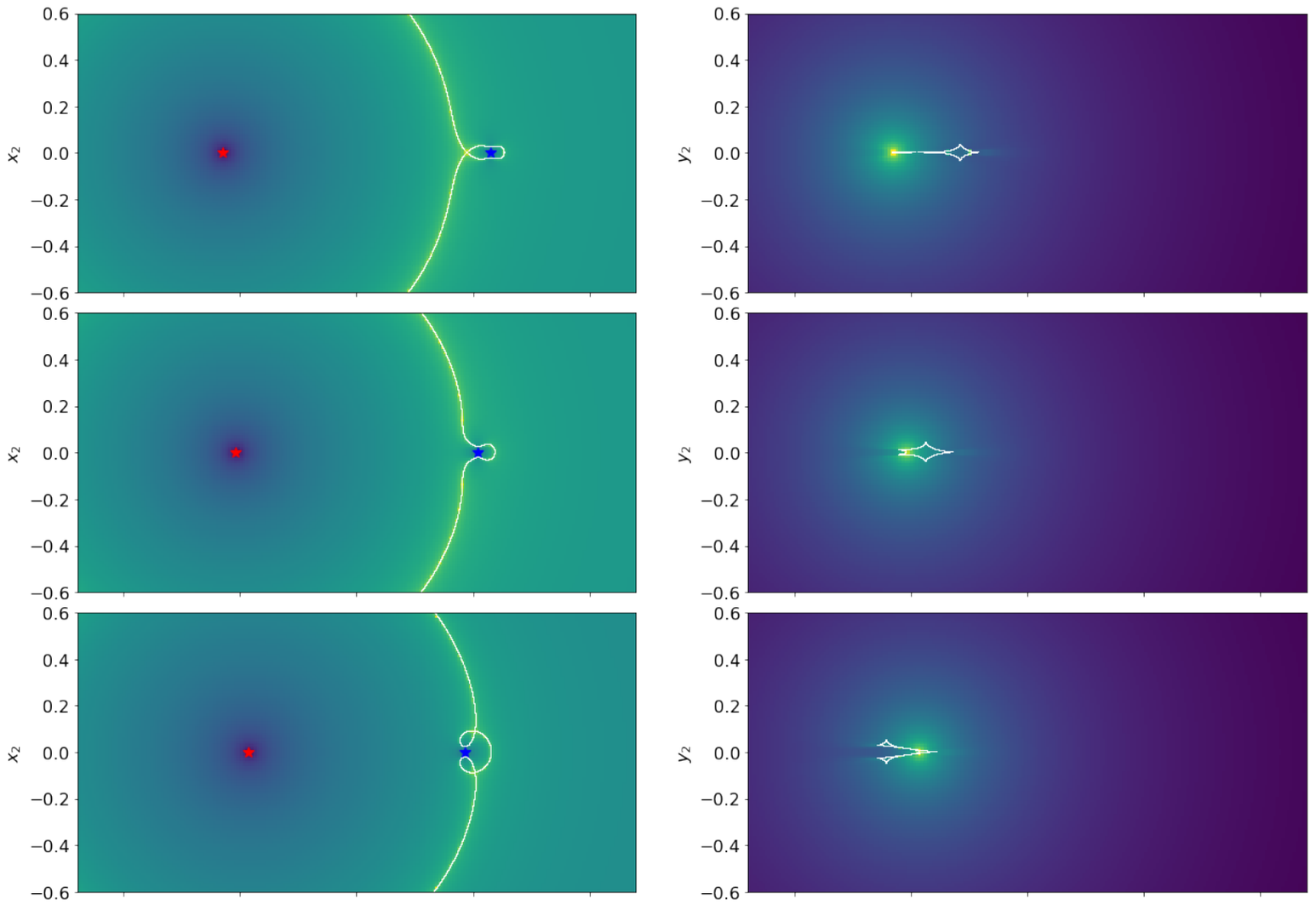
$$d'_{WI} \sim d_{WI} \sim \left(1 + \frac{3}{2} q^{1/3}\right) \qquad d'_{IC} \sim d_{IC} \sim \left(1 - \frac{3}{4} q^{1/3}\right)$$

$$d_{WI} - d_{IC} \sim \frac{9}{4} q^{1/3}$$

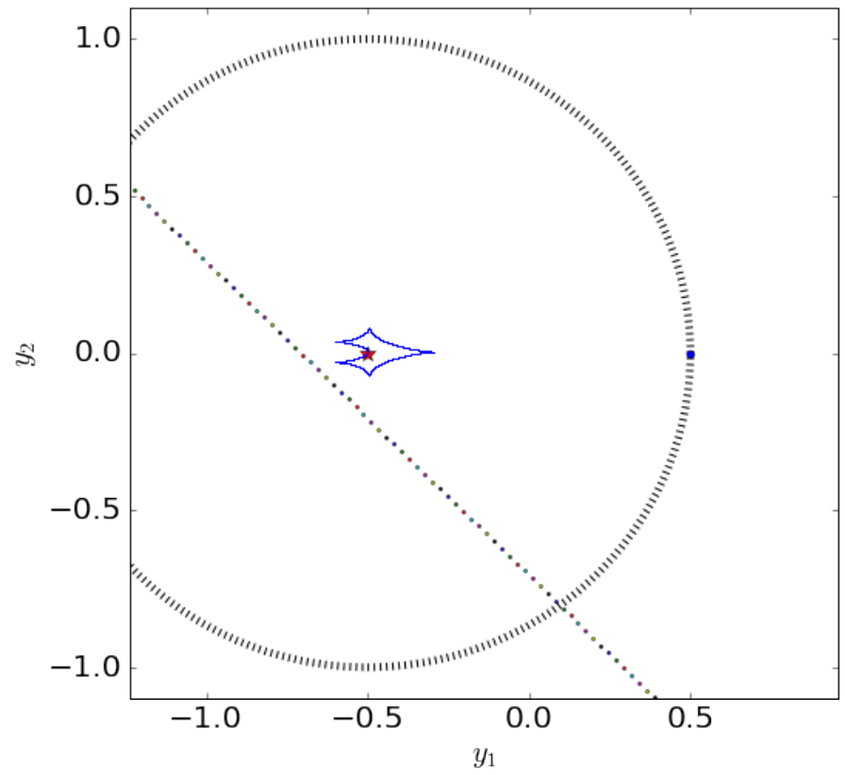
WHAT KIND OF SIGNATURES?

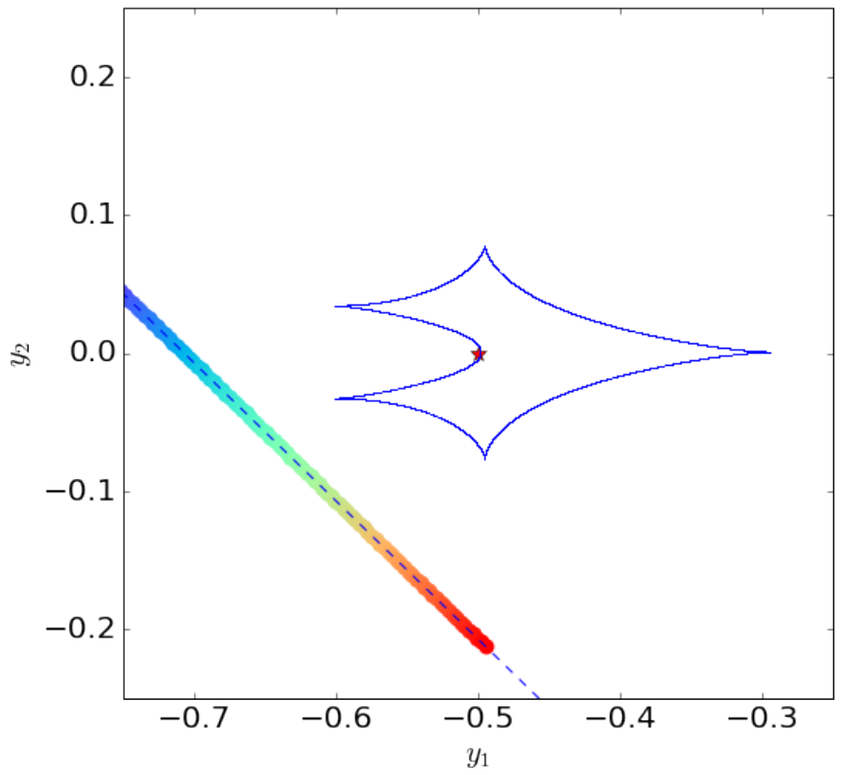
- 6 cusps, 6 folds
- Weak and strong cusps
- Extended
- De-magnification on the back of the caustic
- Examples:

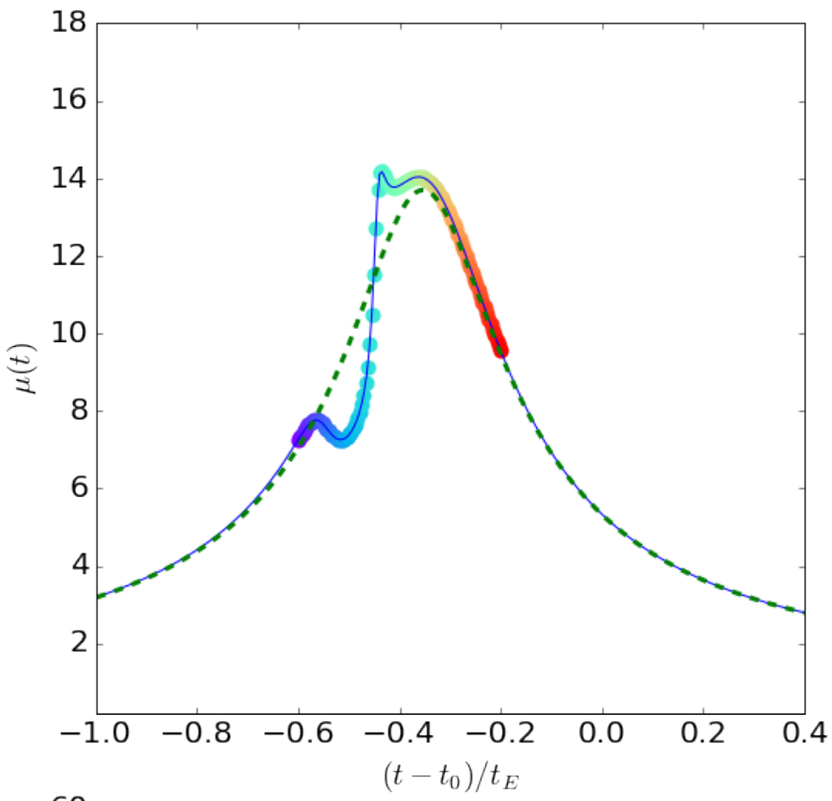


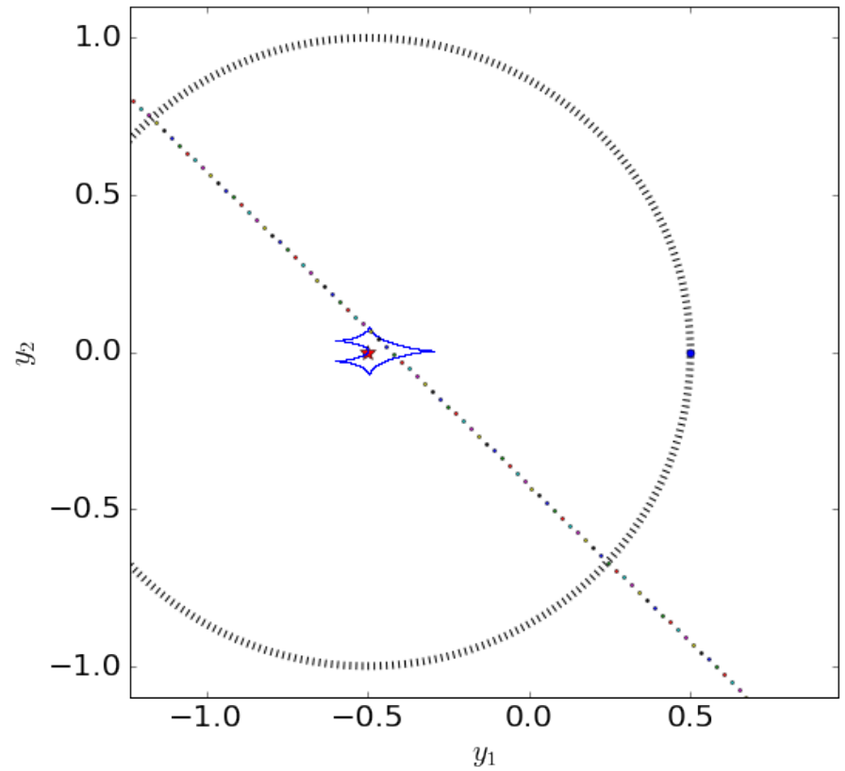


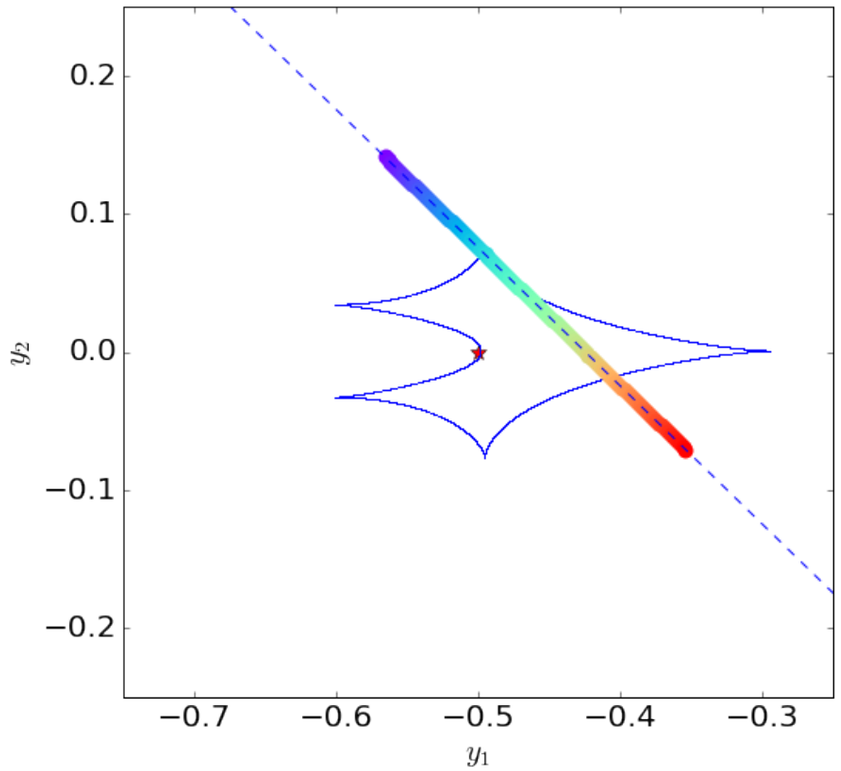
PLANETARY CAUSTICS PERTURBATIONS IN INTERMEDIATE TOPOLOGIES

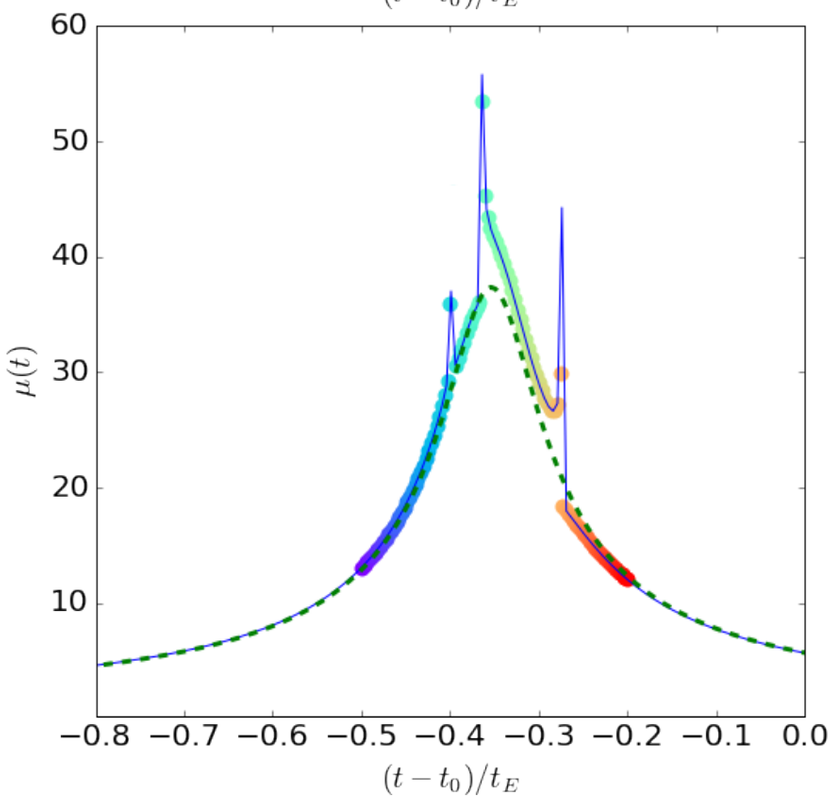




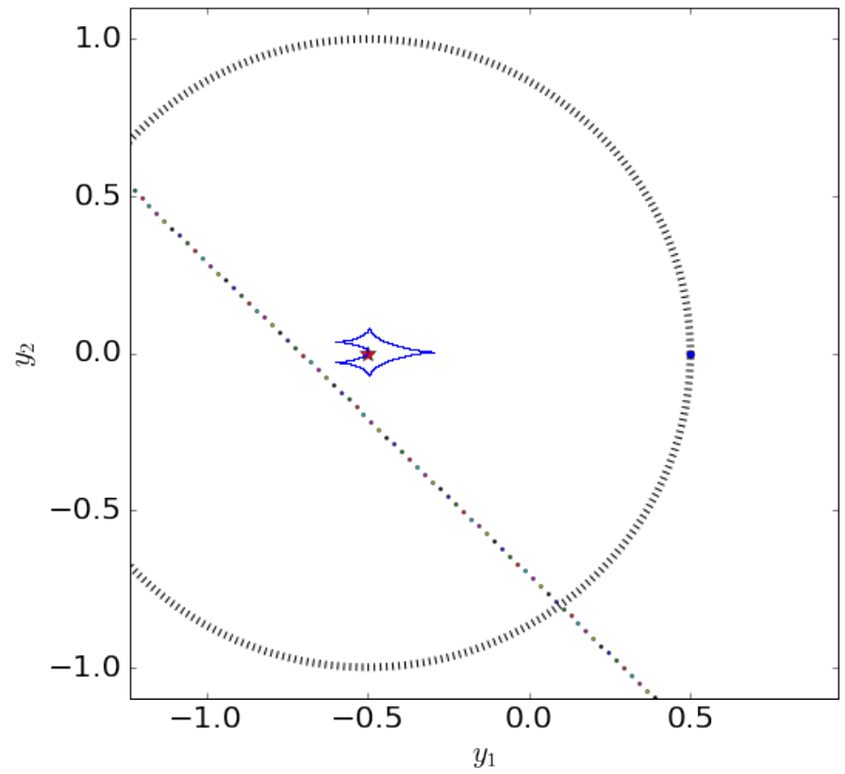


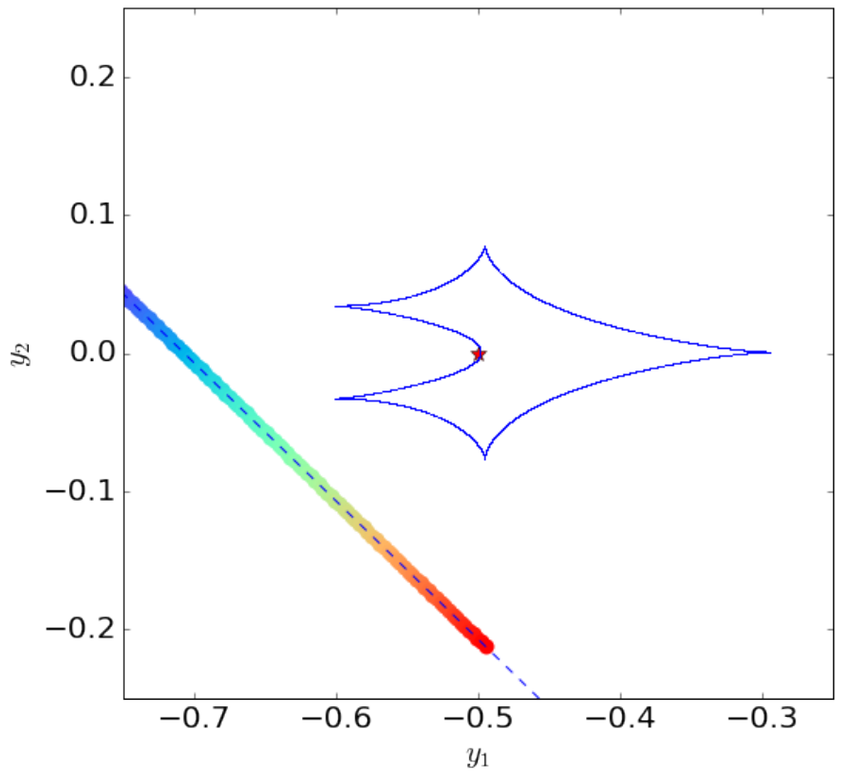


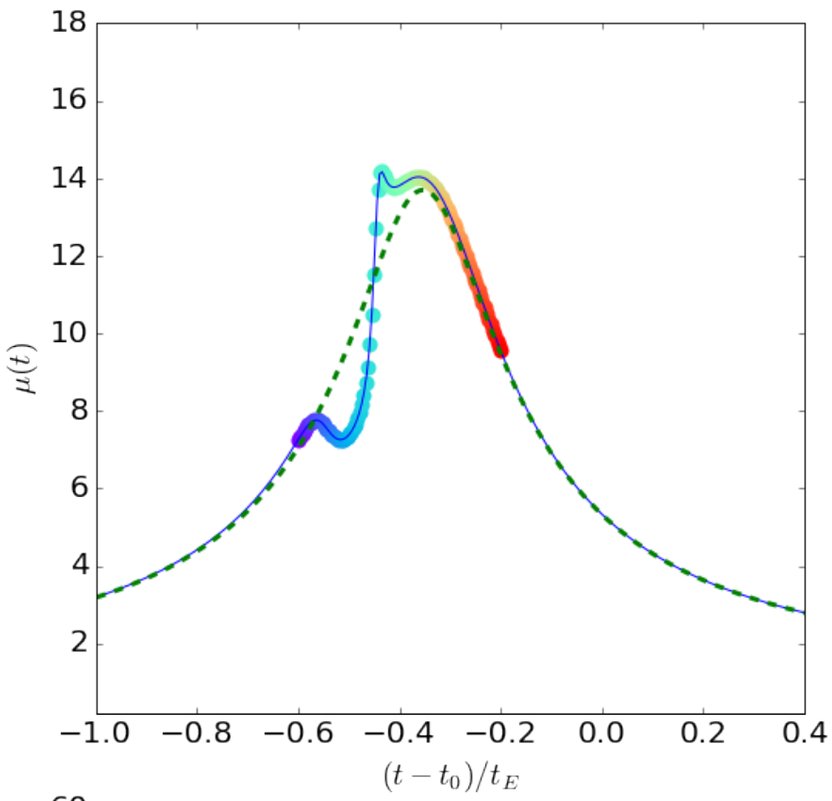


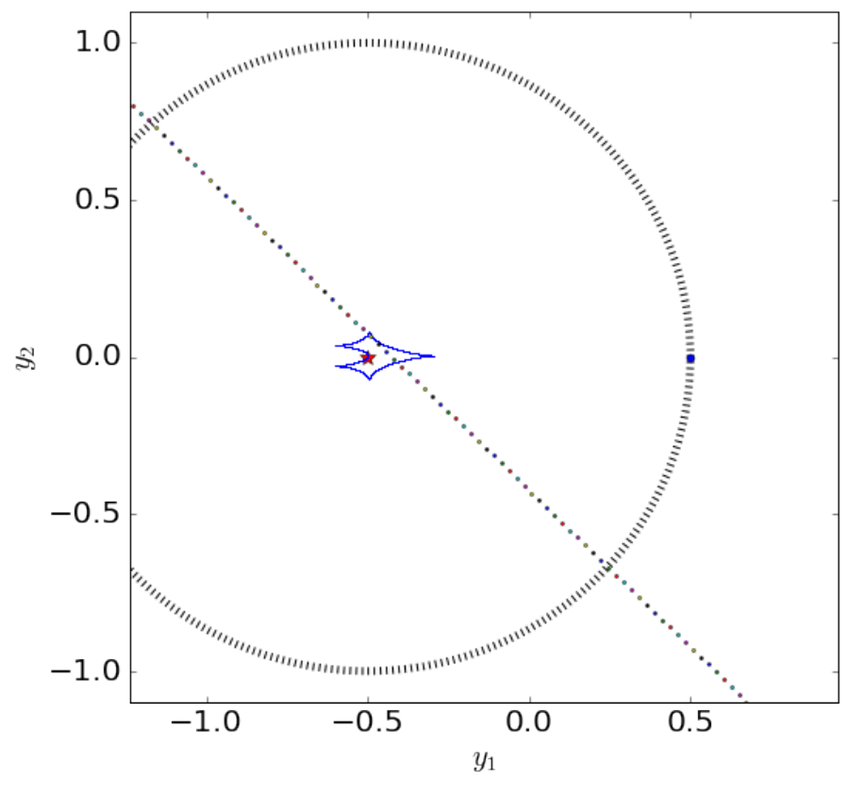


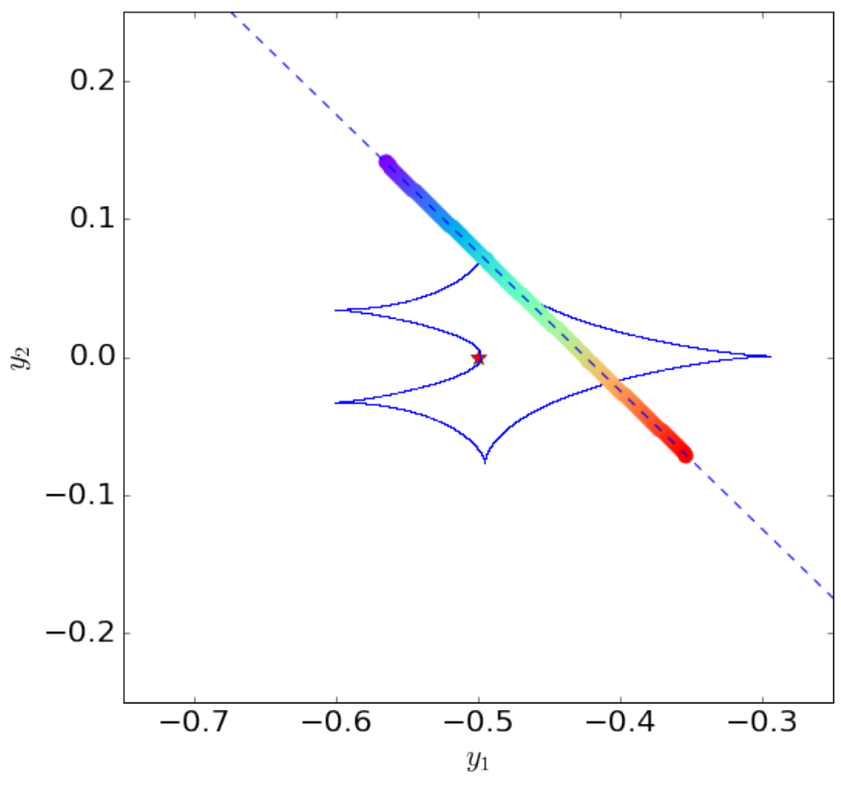
PLANETARY CAUSTICS PERTURBATIONS IN INTERMEDIATE TOPOLOGIES

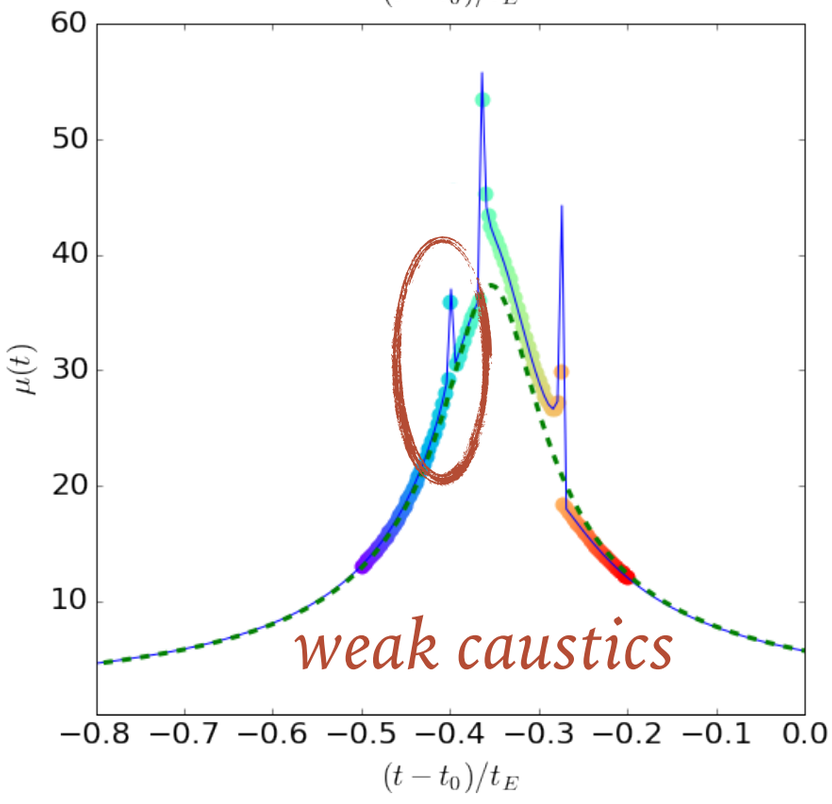




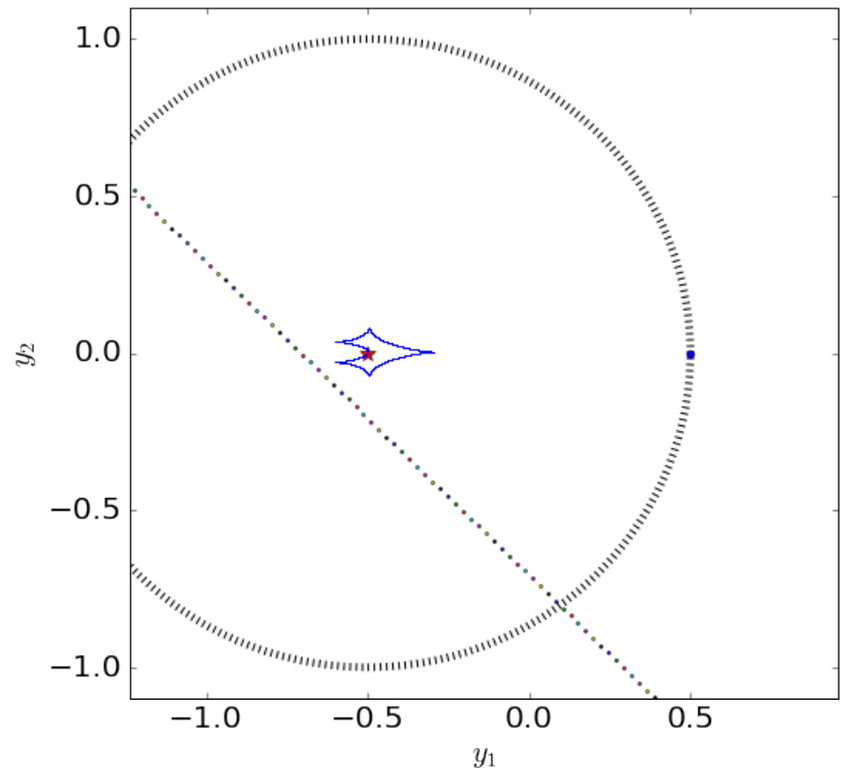


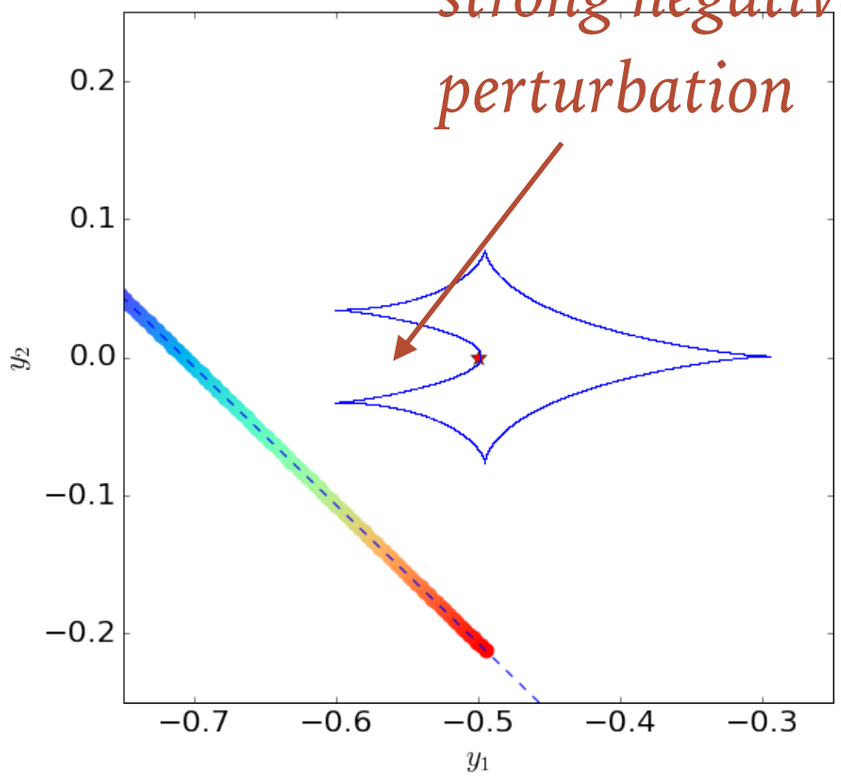


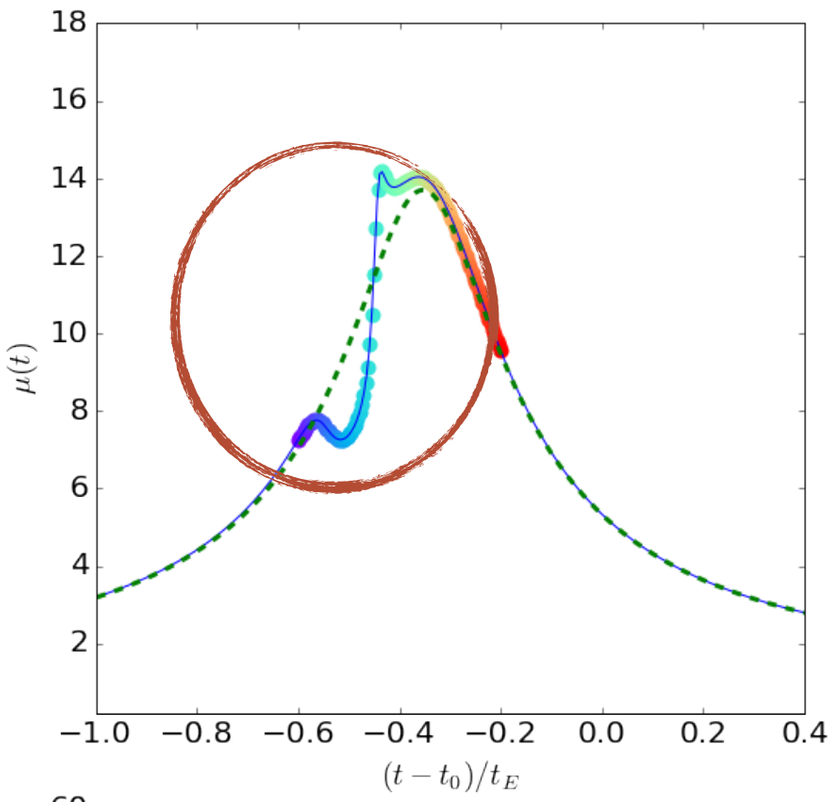


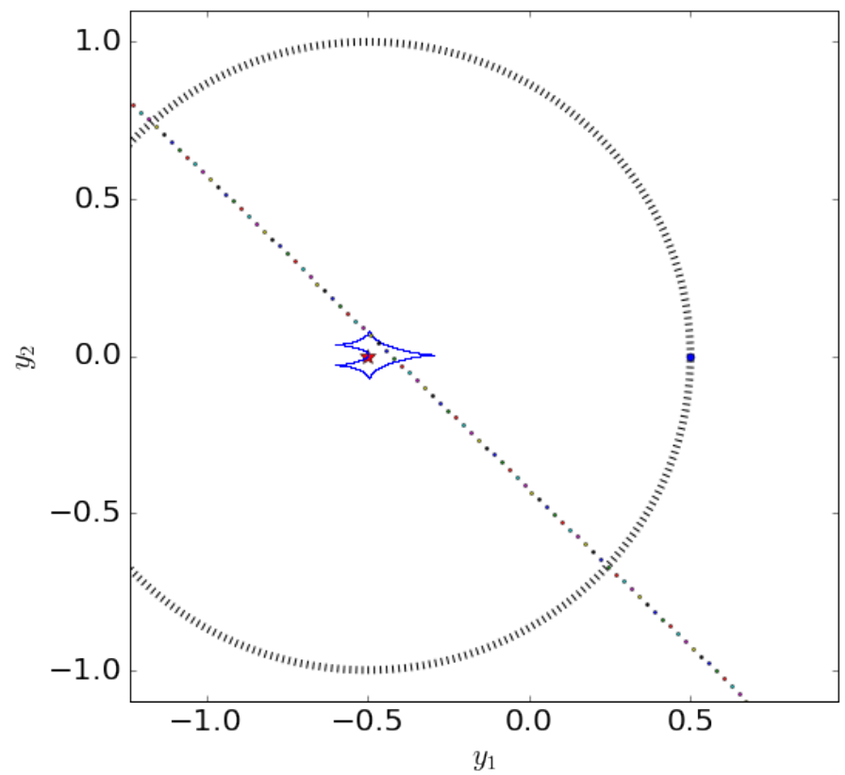


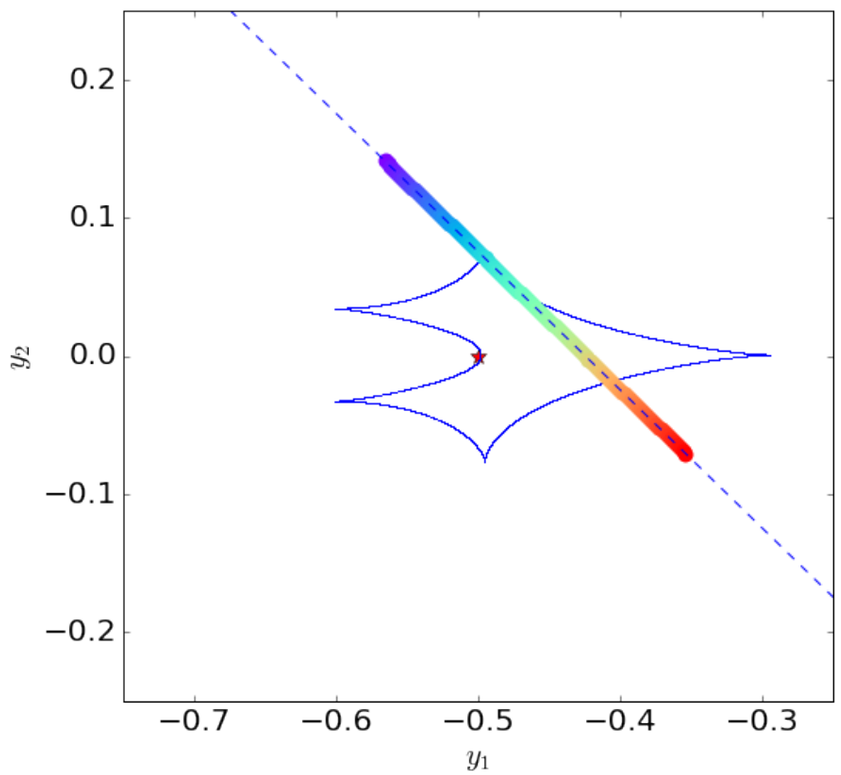
PLANETARY CAUSTICS PERTURBATIONS IN INTERMEDIATE TOPOLOGIES

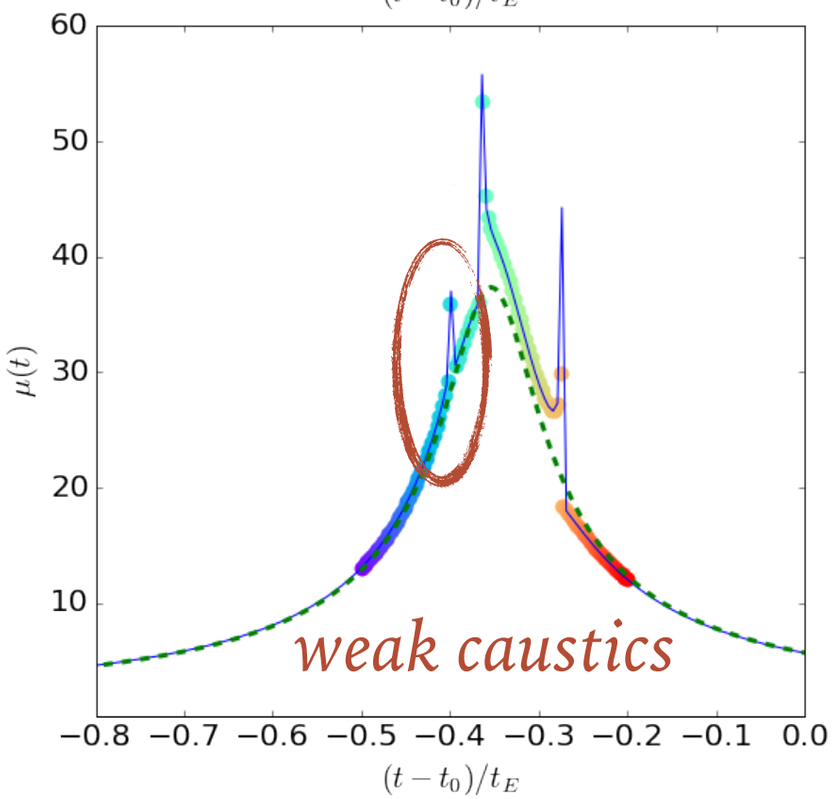




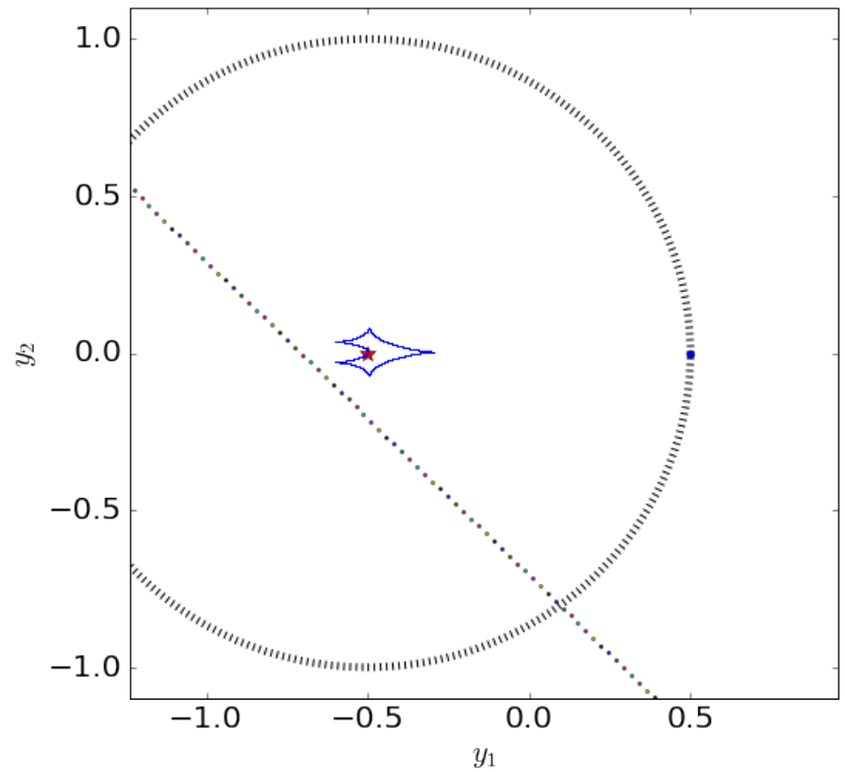


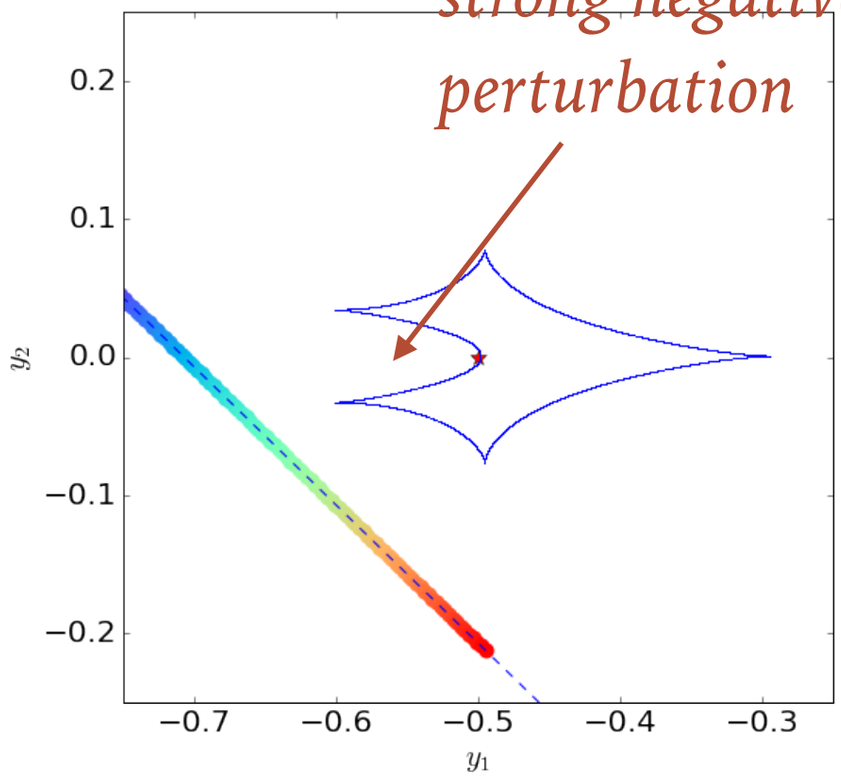


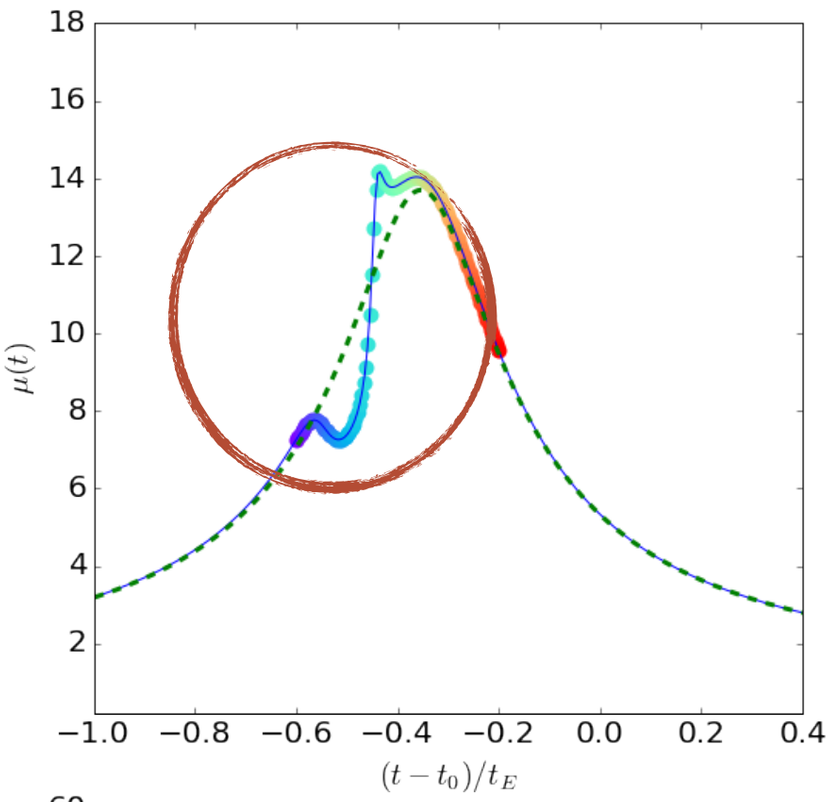


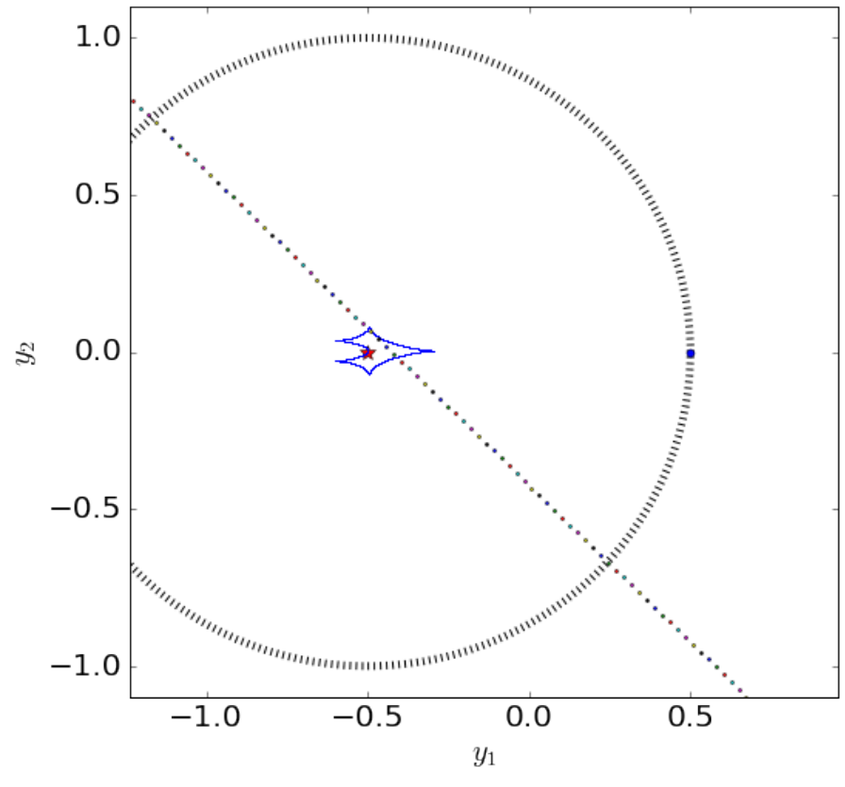


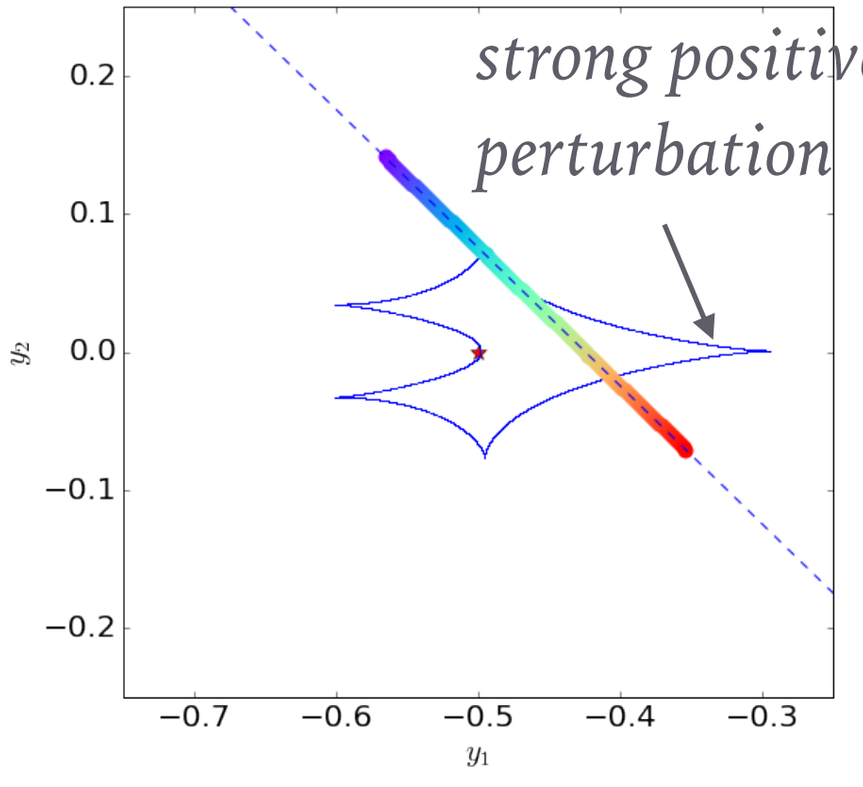
PLANETARY CAUSTICS PERTURBATIONS IN INTERMEDIATE TOPOLOGIES

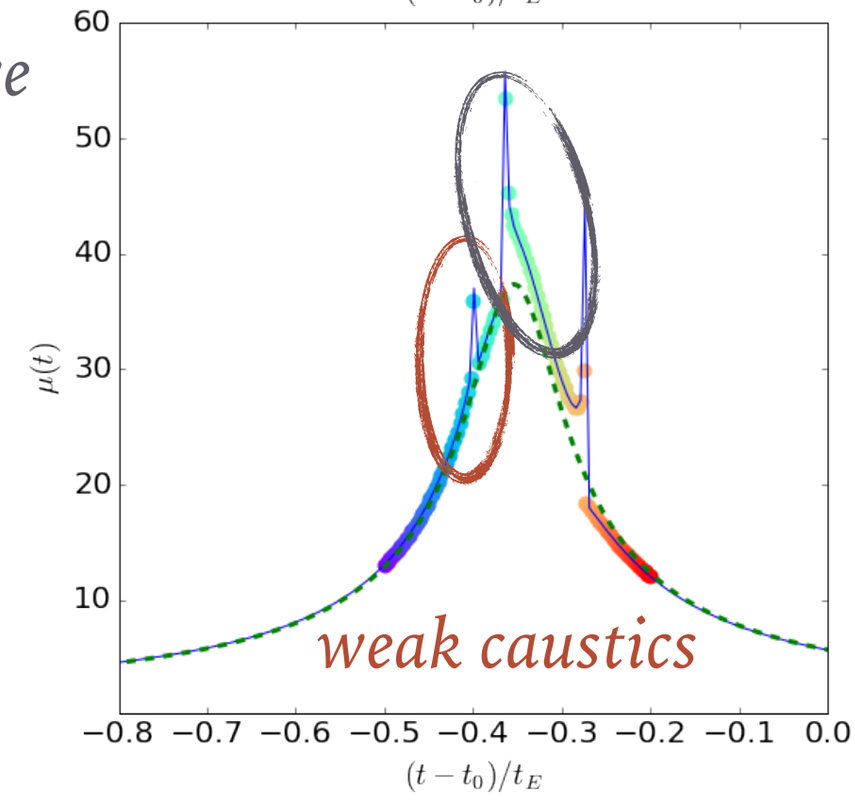






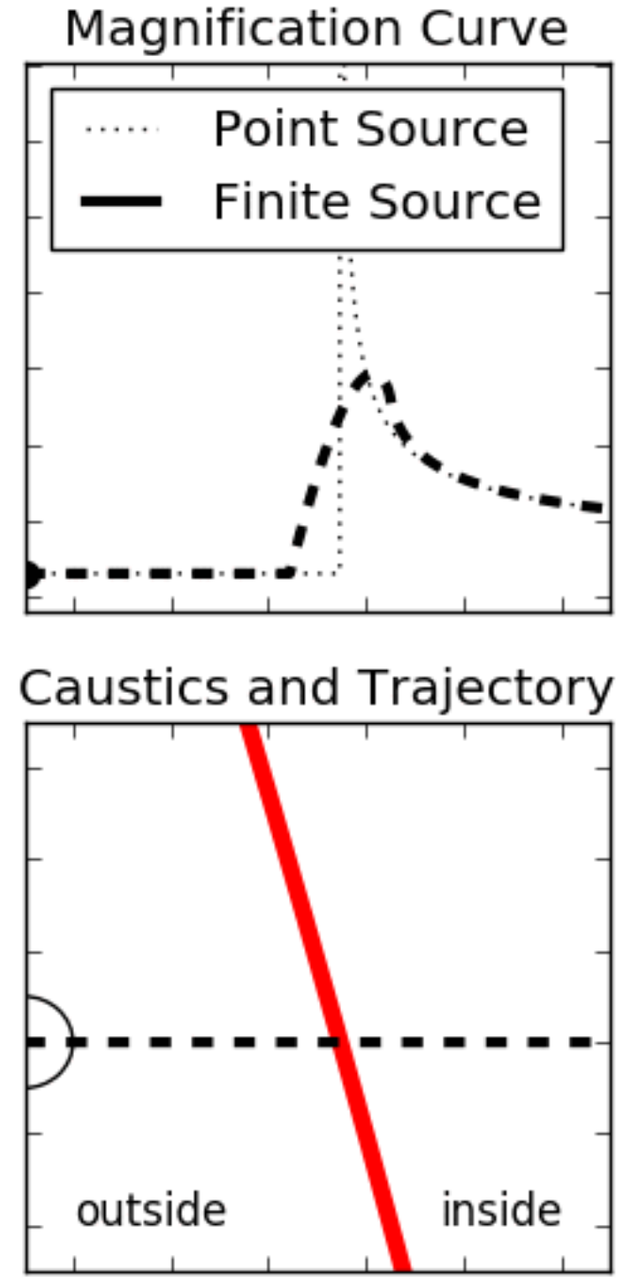






PLANET DETECTION THROUGH RESONANT CAUSTIC PERTURBATIONS

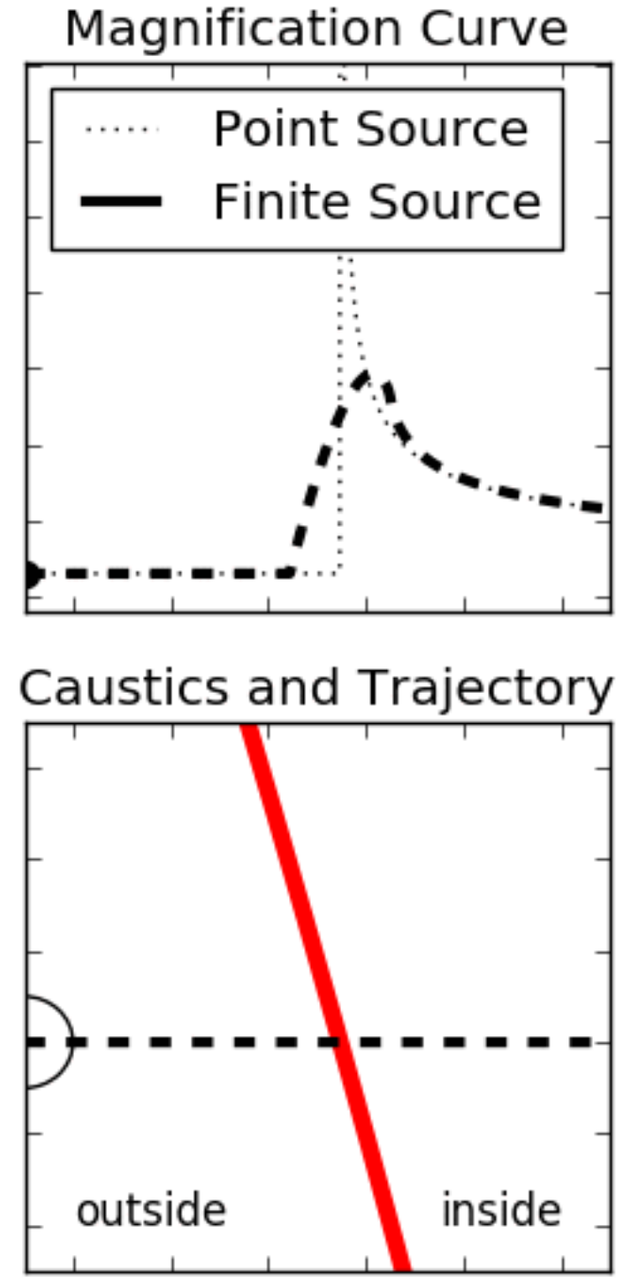
- Typically in intermediate-to-high magnification regimes, as the source passes close the primary lens
- Weak caustics: sharp peaks that can be washed out by finite source effects
- Long events
- Sensitive to orbital motions



Credit: J. Yee

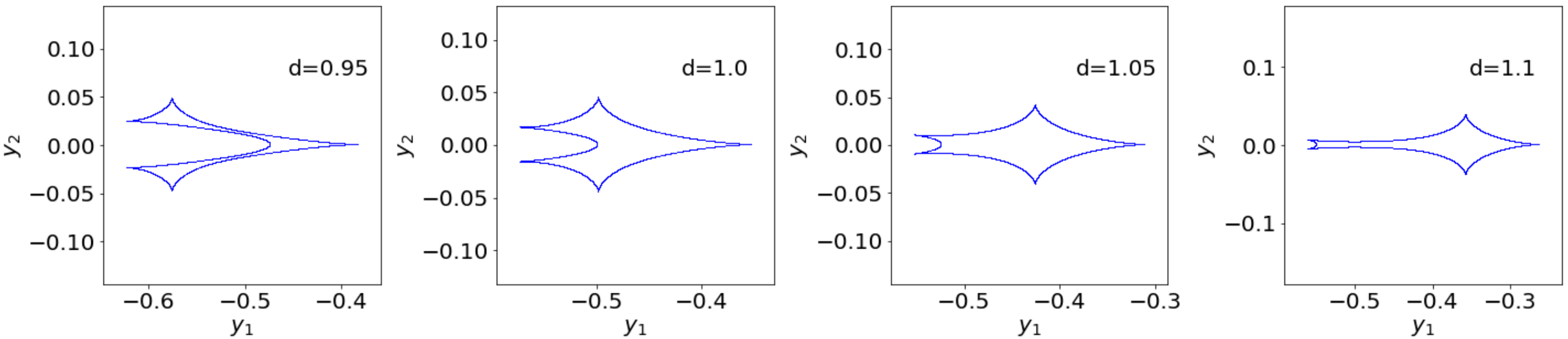
PLANET DETECTION THROUGH RESONANT CAUSTIC PERTURBATIONS

- Typically in intermediate-to-high magnification regimes, as the source passes close the primary lens
- Weak caustics: sharp peaks that can be washed out by finite source effects
- Long events
- Sensitive to orbital motions



Credit: J. Yee

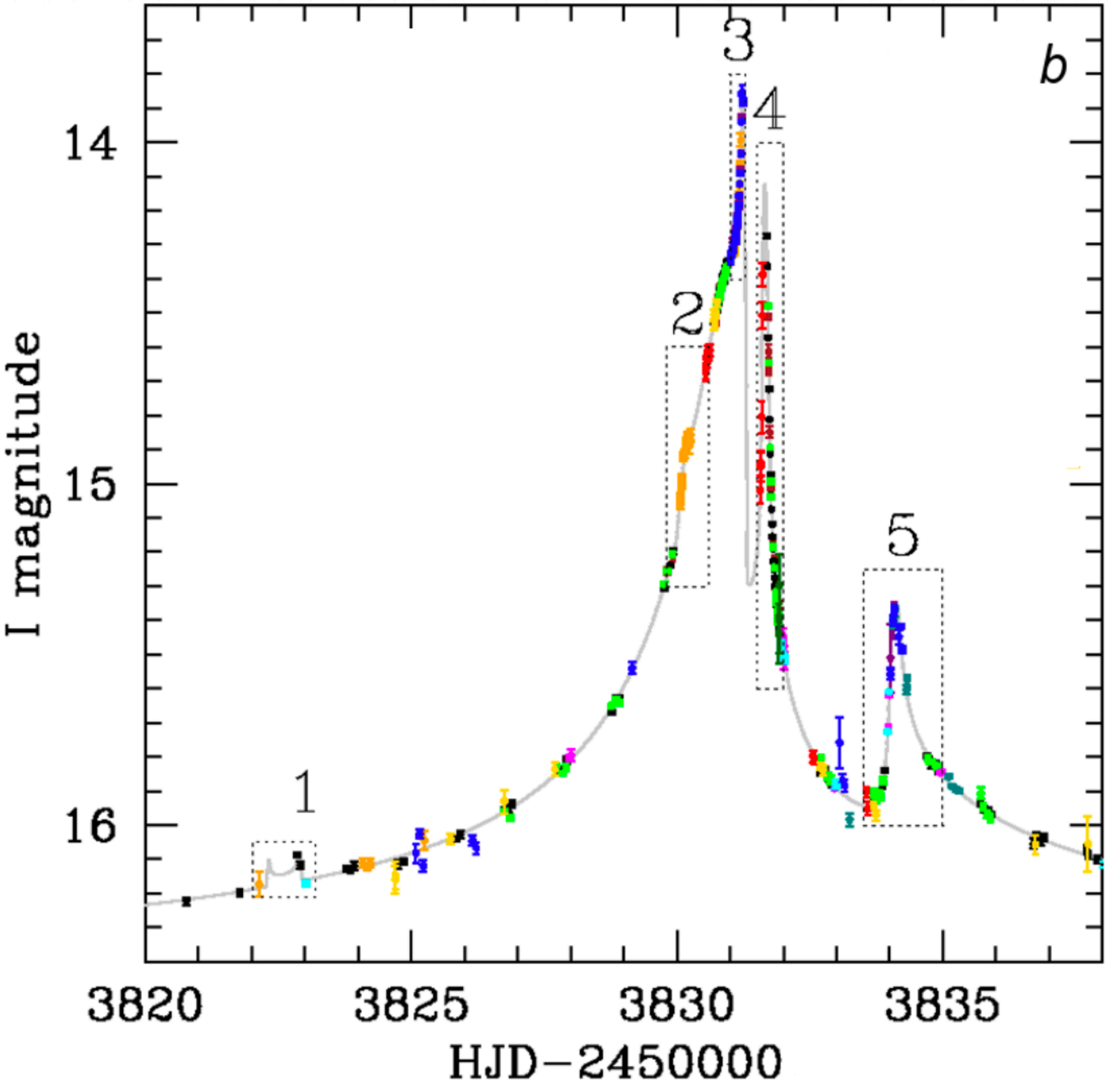
RESONANT CAUSTIC DEPENDENCE ON d



The shape of the resonant caustic changes dramatically if d varies.

Since events are long, it happens that, on the timescale of the event the distance between the star and the planet change due to the planet orbital motion.

Consequently, the structure of the caustic changes. This effect can be modelled.



OGLE-2006-BLG-109

Several deviations from standard microlensing LC.

Features are typical of a resonant caustic perturbation.

MULTIPLE PLANETS AND EVOLVING CAUSTIC