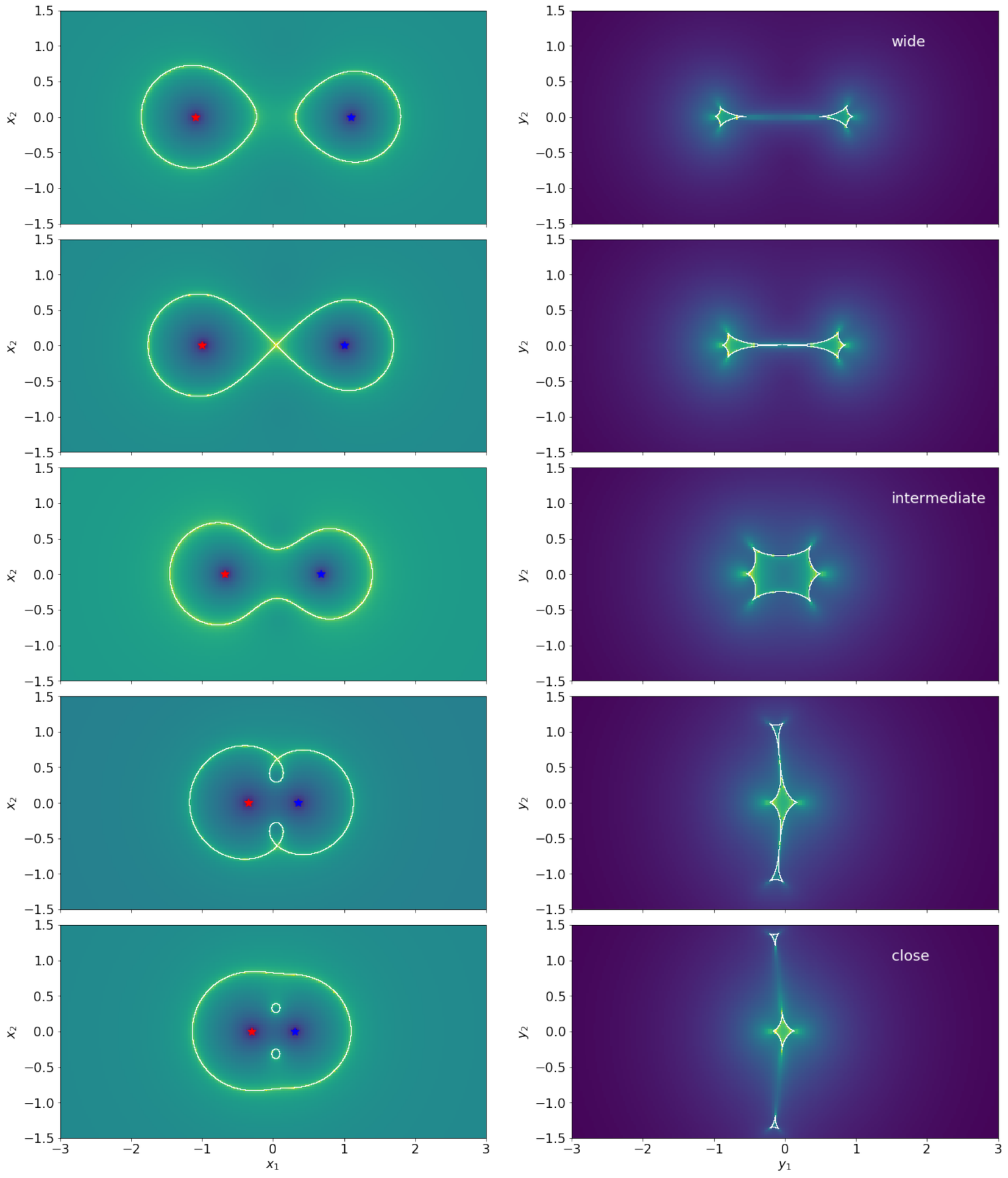
GRAVITATIONAL LENSING

15 – BINARY LENSES

Massimo Meneghetti
AA 2018-2019


wide
intermediate
close
x_1
x_2
y_1
y_2

PLANETARY MICROLENSING

- Let us consider the system consisting of an host star and a planet orbiting around it.
- This is an example of **binary** lens
- The host star is of course much heavier than the planet!
  - example: for a Jupiter-like planet q=0.001 (solar mass star)
  - example: for a Earth-like planet q=0.000003

WHAT KIND OF SIGNAL?

- **The light curve is that of the star…**
- The planet produces only a small perturbation to the magnification pattern, localized in a small region around the caustics
- Must cross one of these perturbed regions in order for the planet to be detected.
- The shape of the perturbation is determined by the caustic configuration…

a

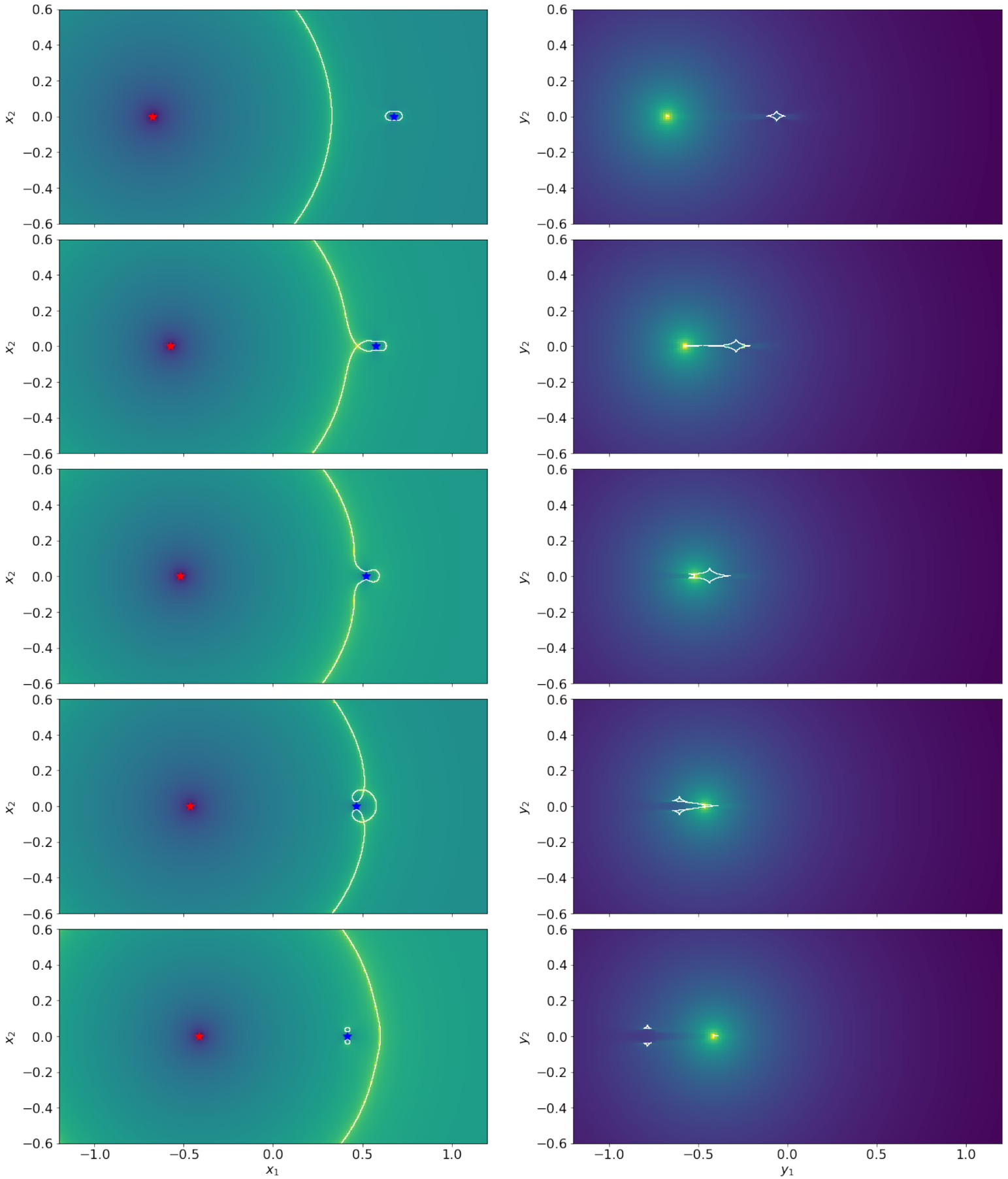
b

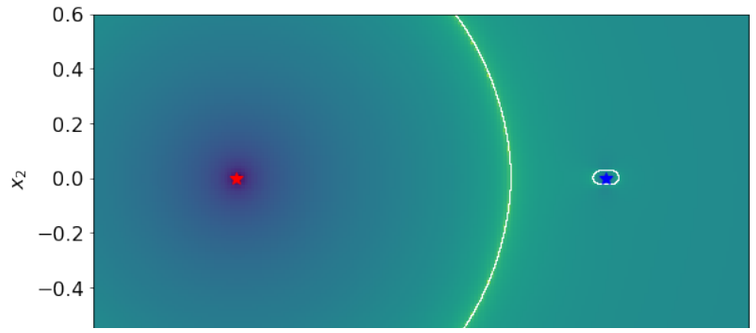
β_y (θ_E)

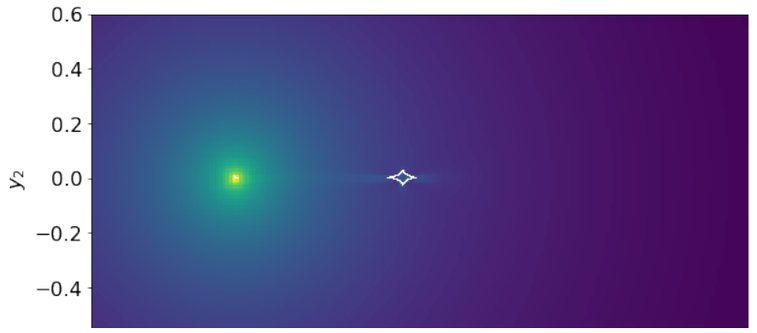
β_x (θ_E)

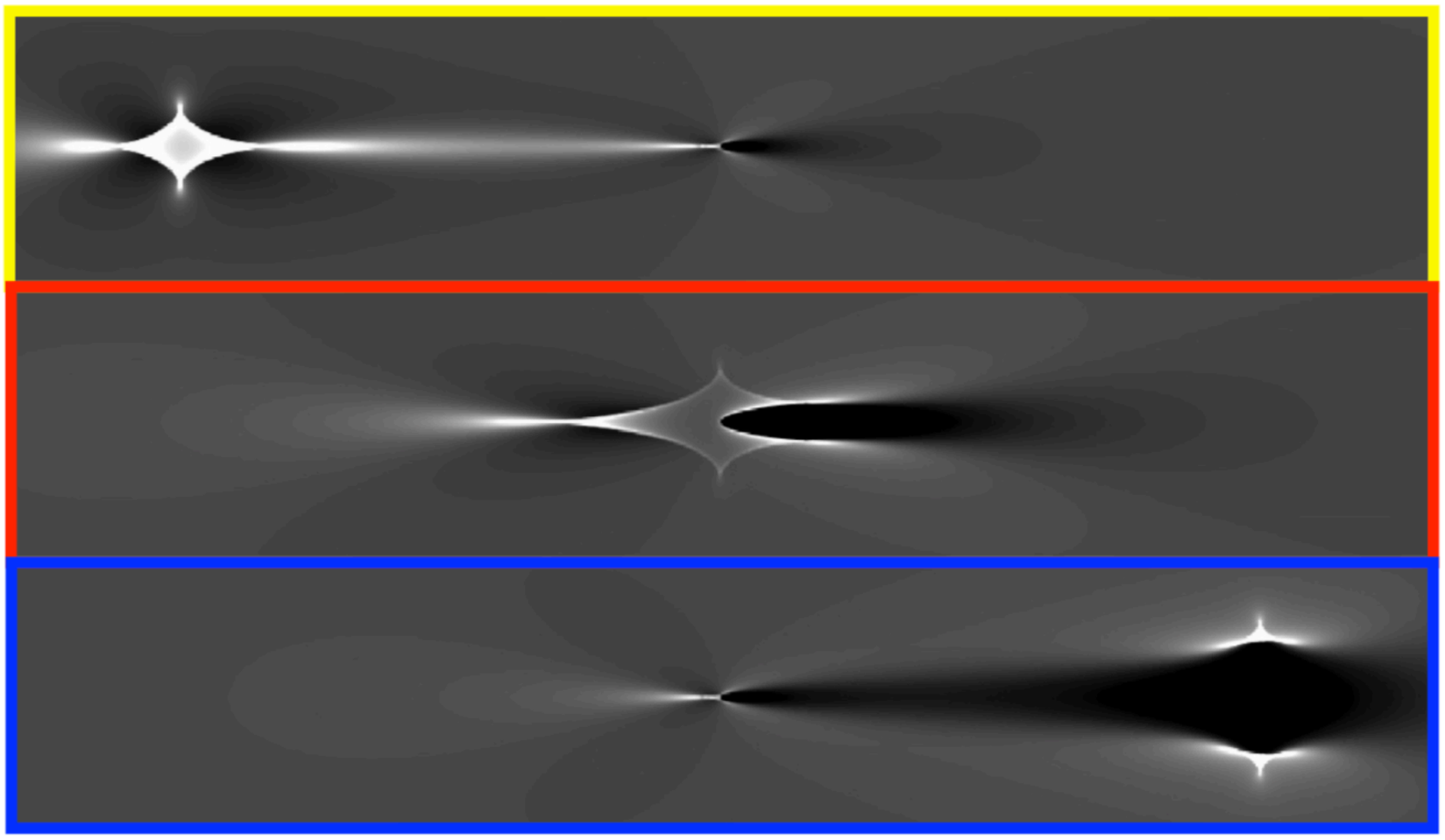
Caustics: Intermediate, Wide, Close

Gaudi 2013


0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
x_2
y_2
−1.0
−0.5
0.0
0.5
1.0
x_1
y_1



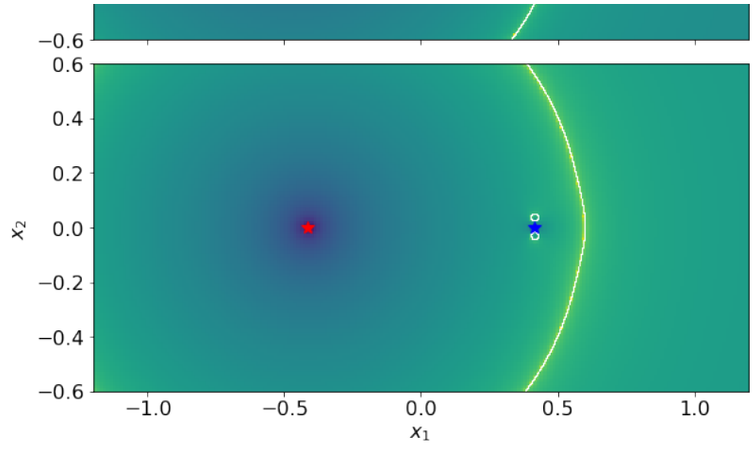


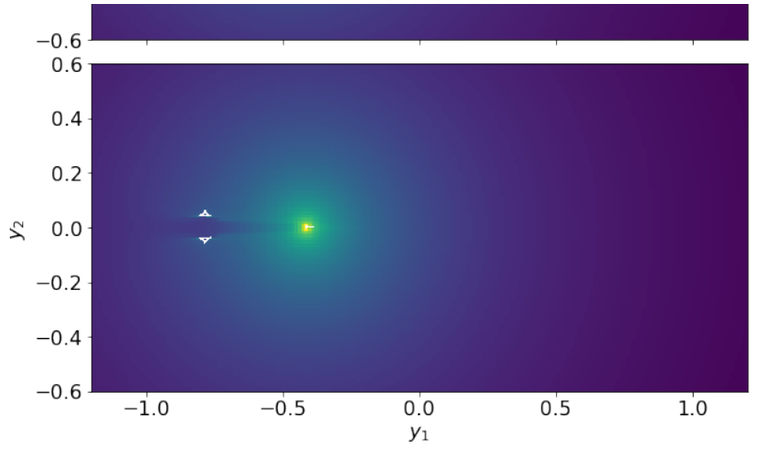


Wide

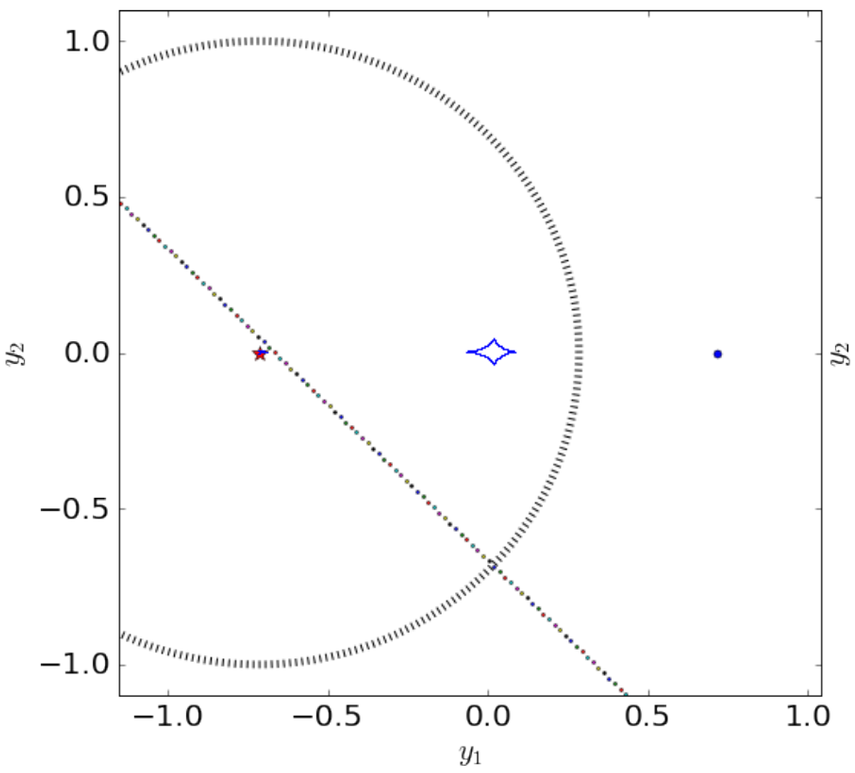
Intermediate/
Resonant

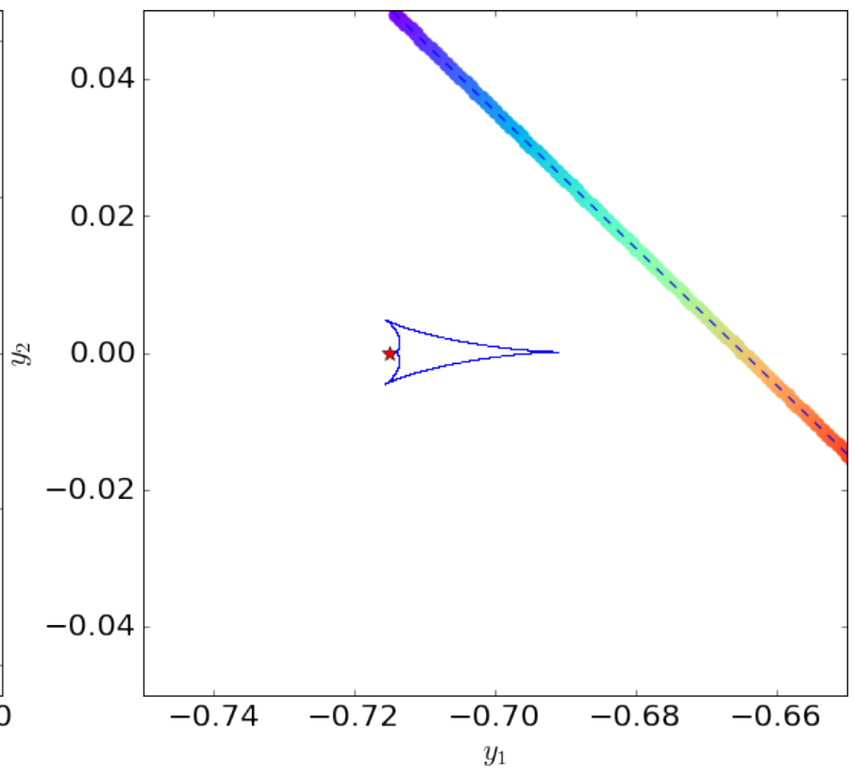
Close

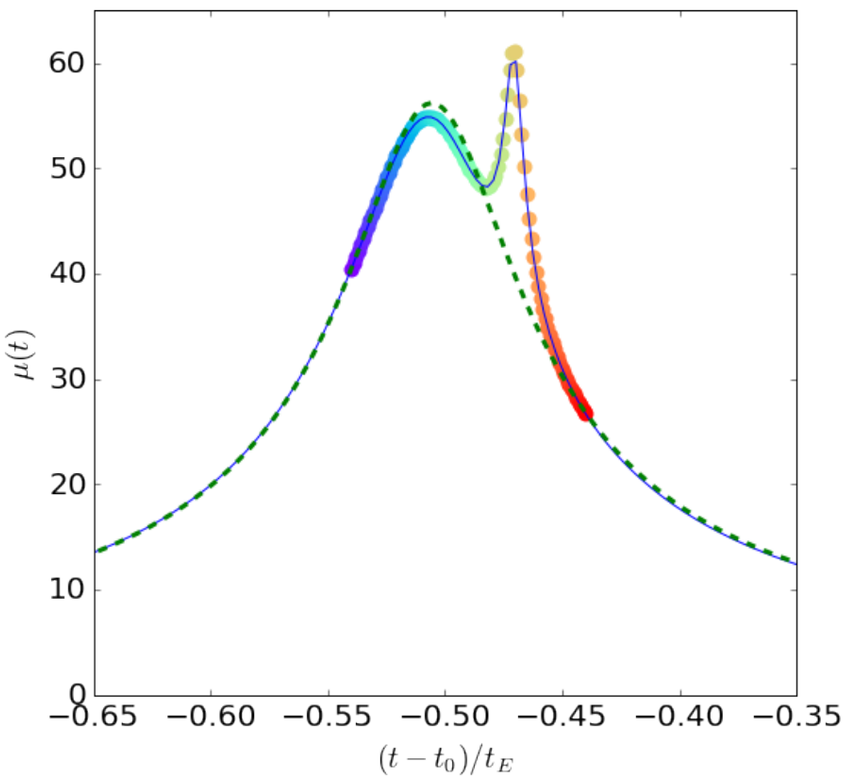


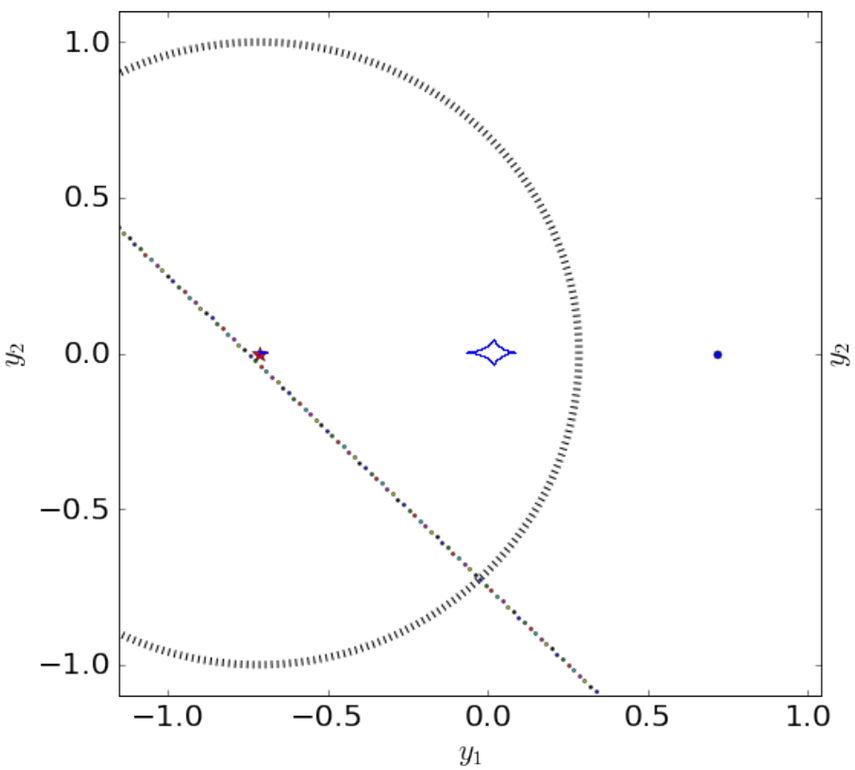


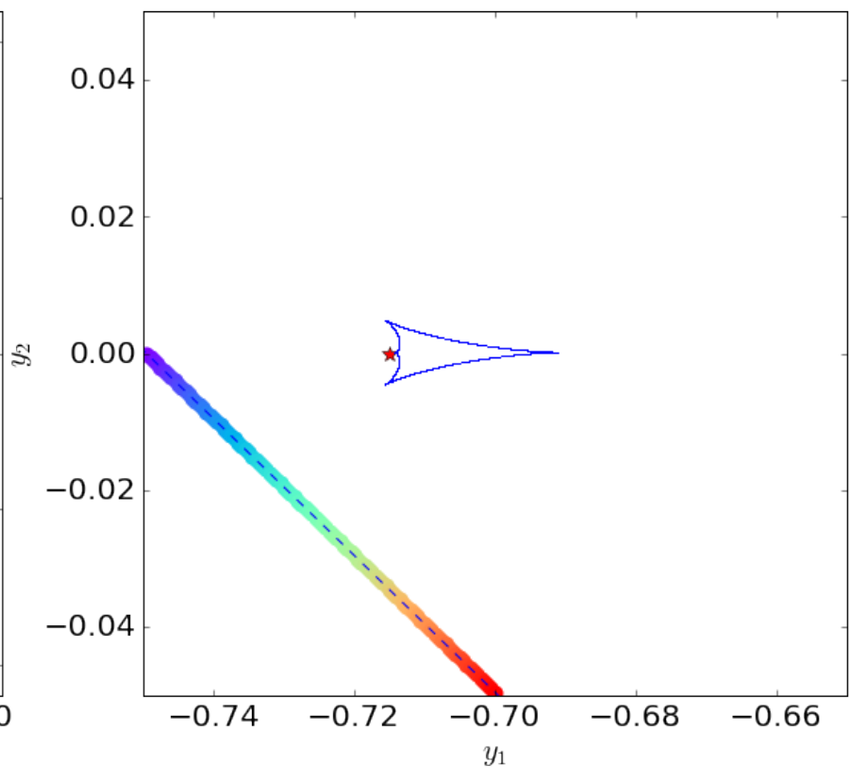
CENTRAL CAUSTIC PERTURBATIONS

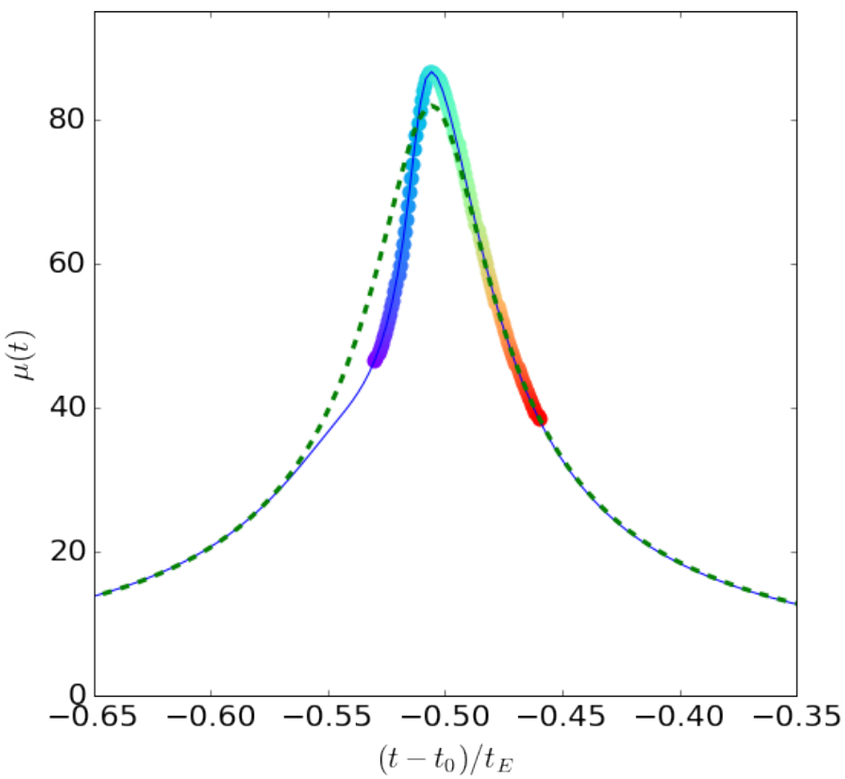












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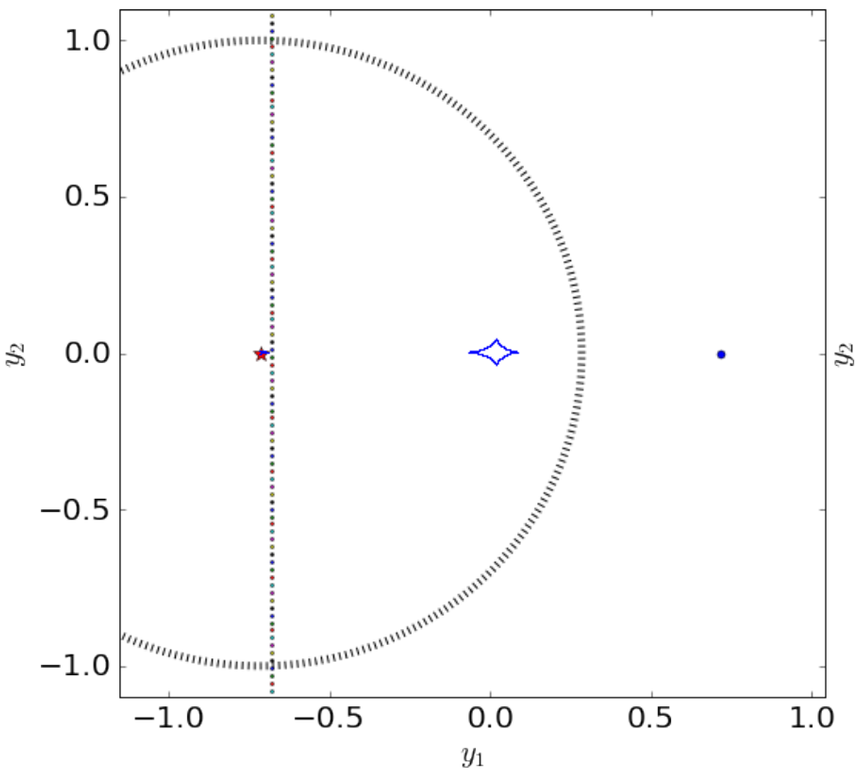

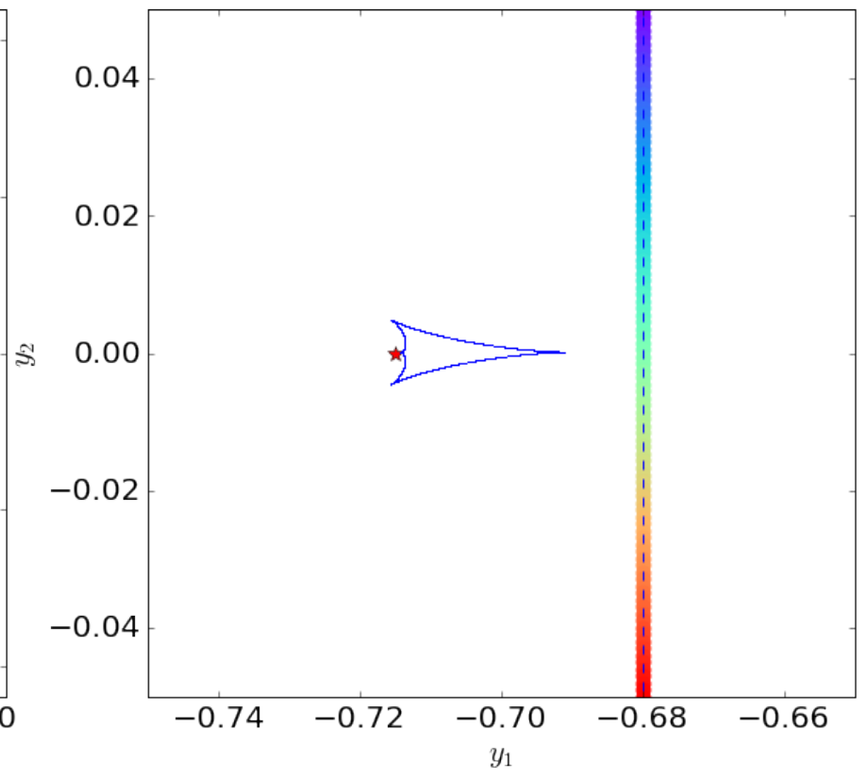

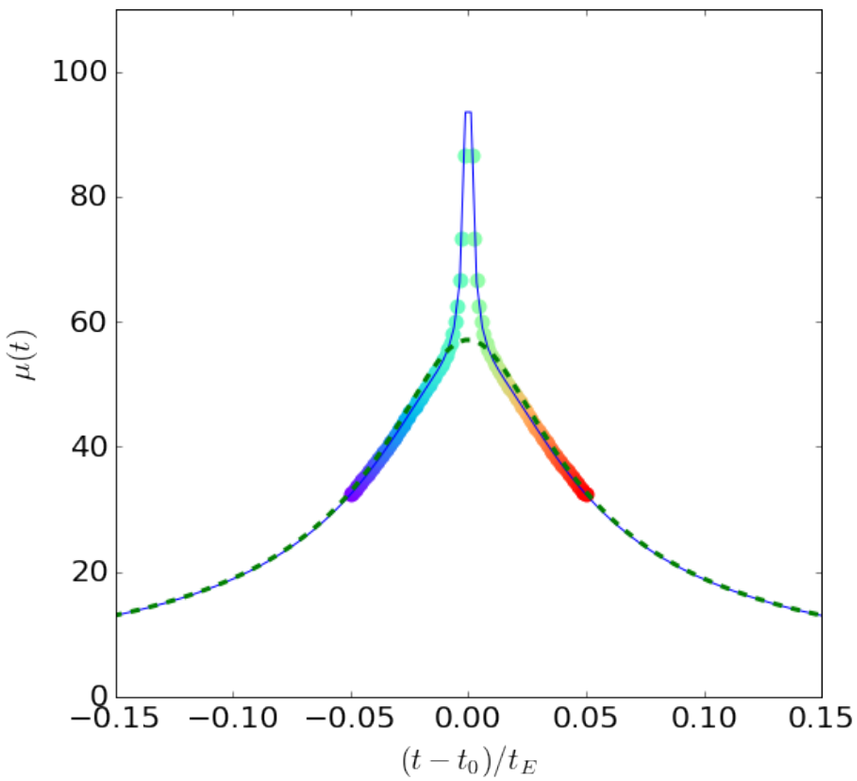

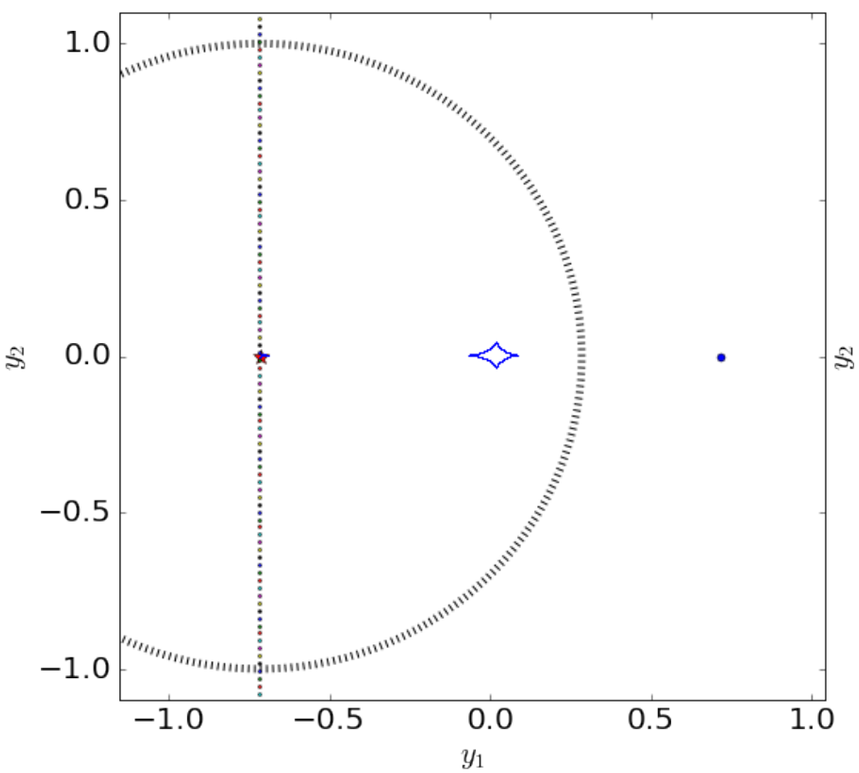

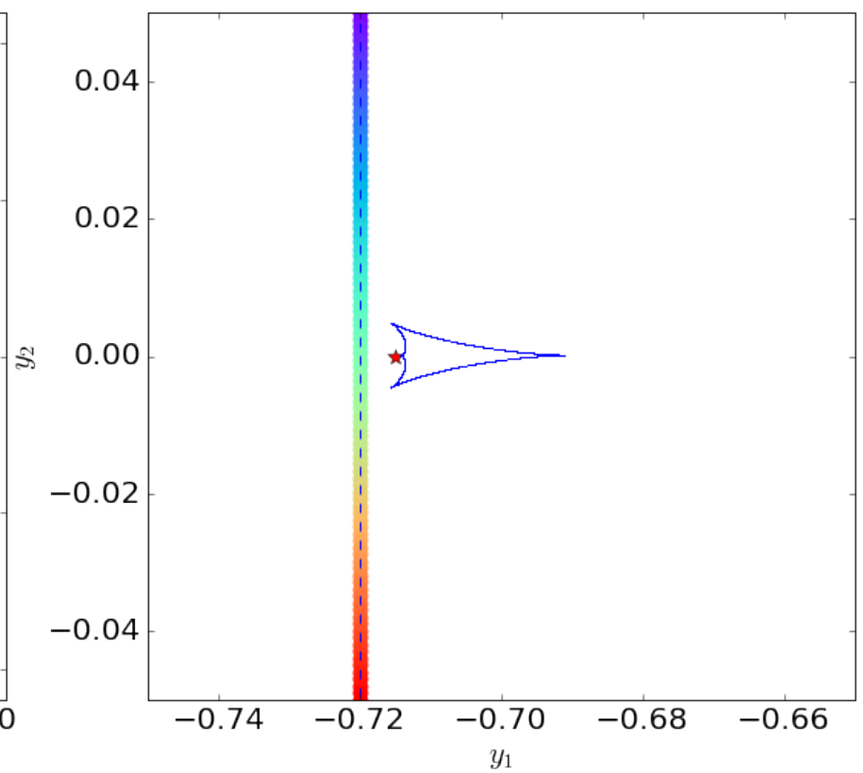

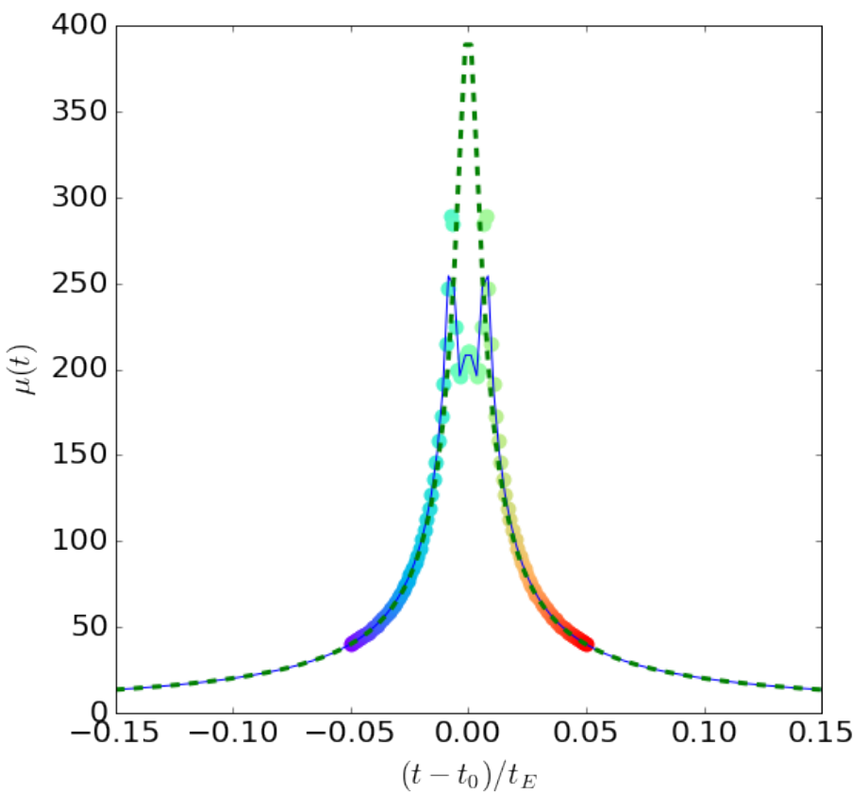

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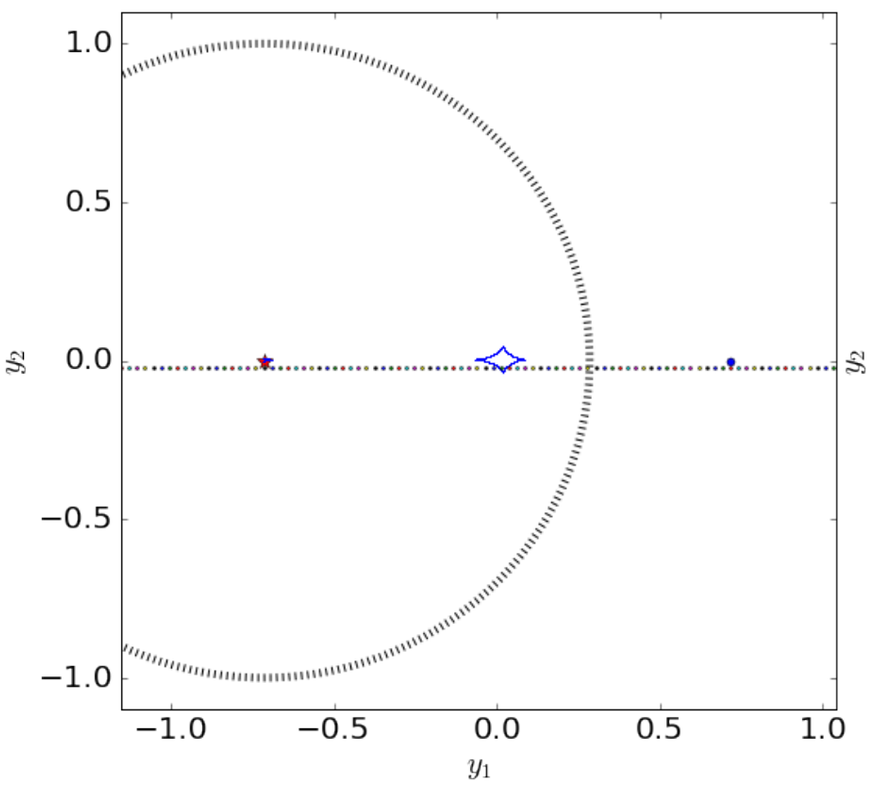
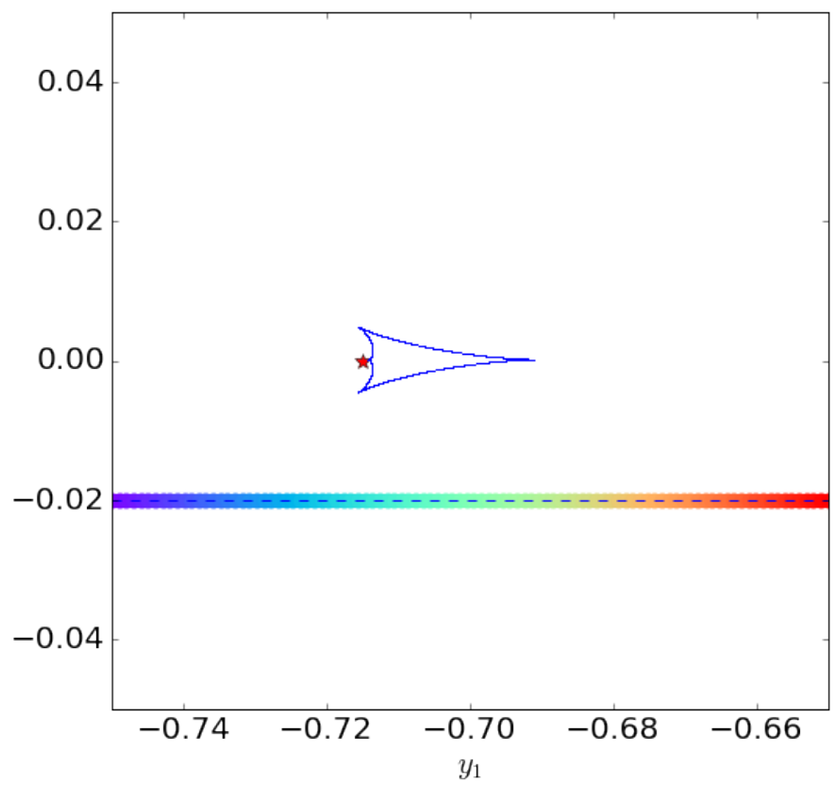
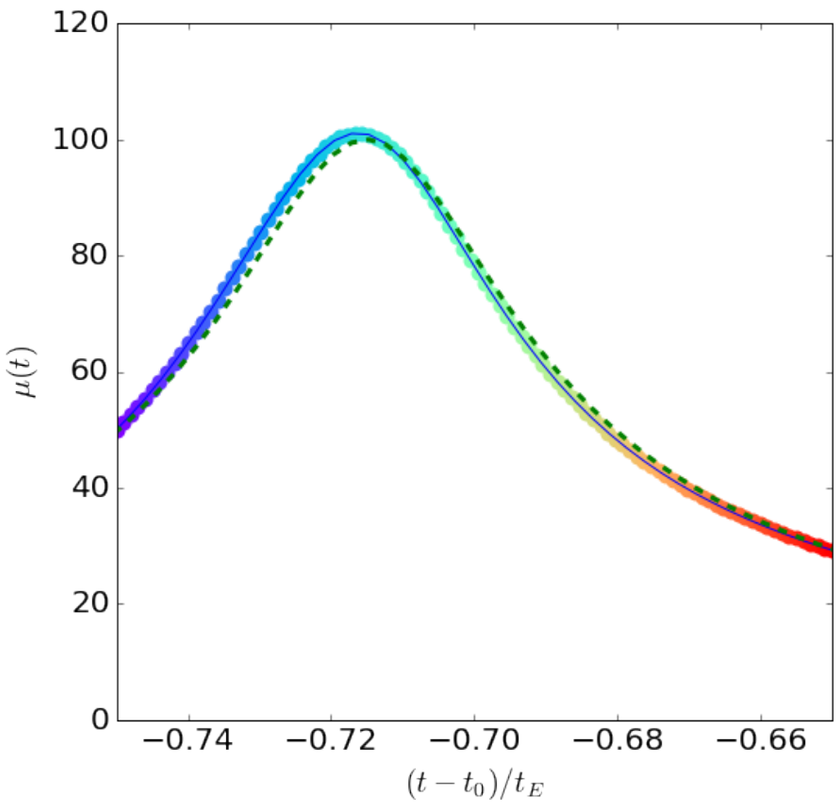






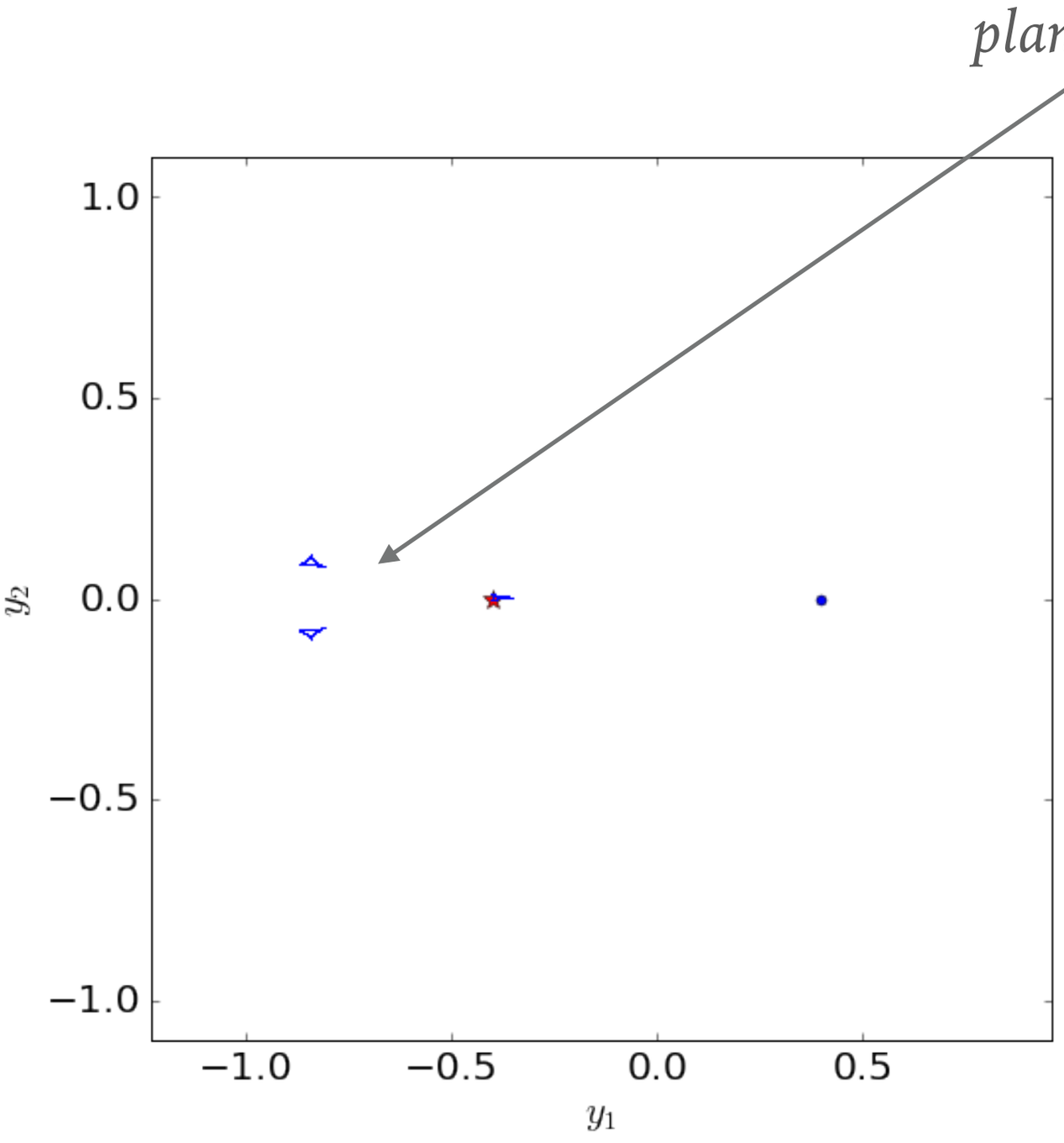
PLANET DETECTION THROUGH CENTRAL CUSP PERTURBATIONS

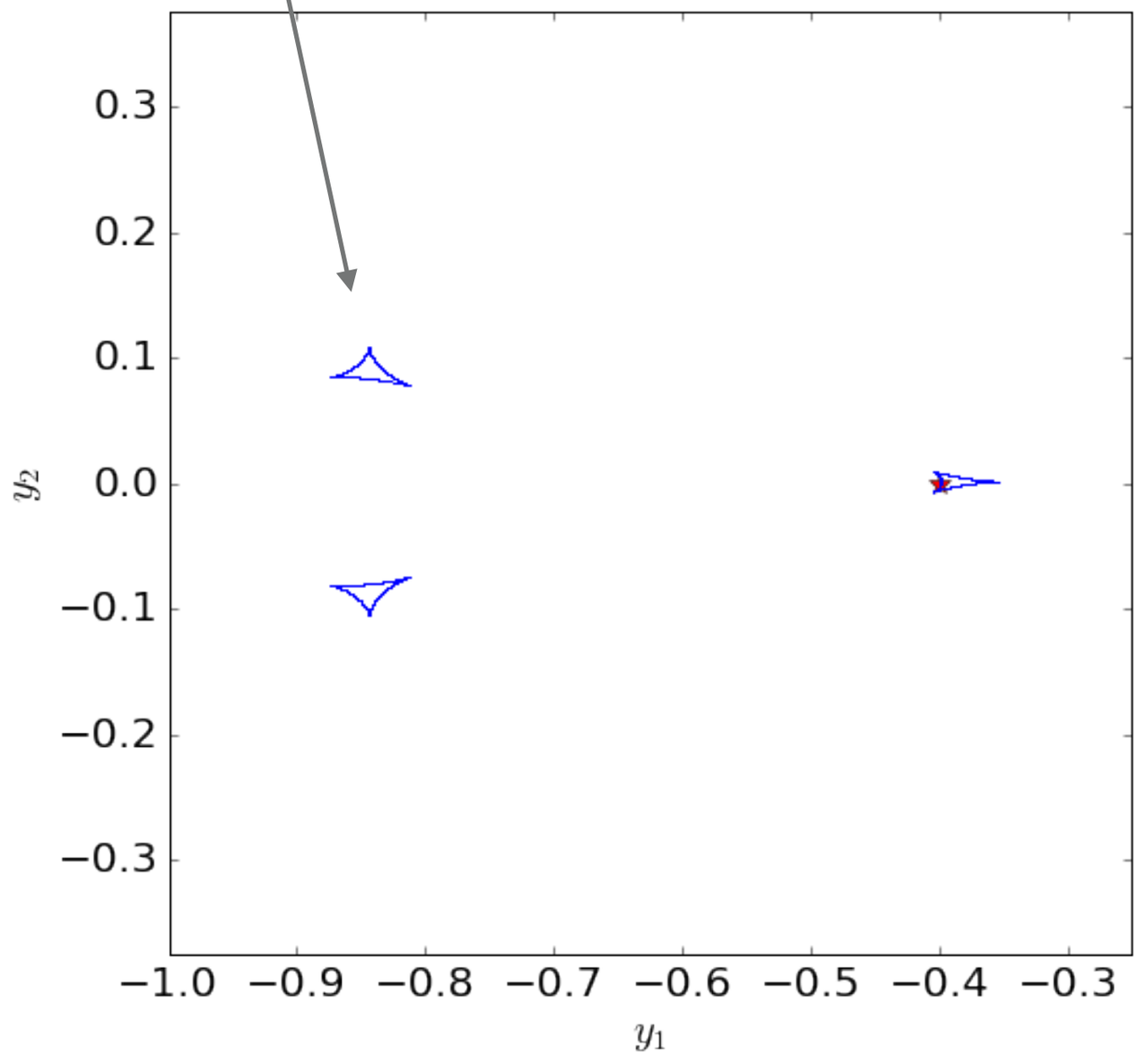
- Only possible in the case of high magnification events (sources passing very close to the host stars)
- For this reason, they are rare events
- Advantages:
  - near the peak of the event
  - can sometimes be predicted in advance
  - high magnification makes possible to follow-up the events using small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

PLANETARY CAUSTICS IN CLOSE TOPOLOGIES

planetary caustics

Han 2006





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

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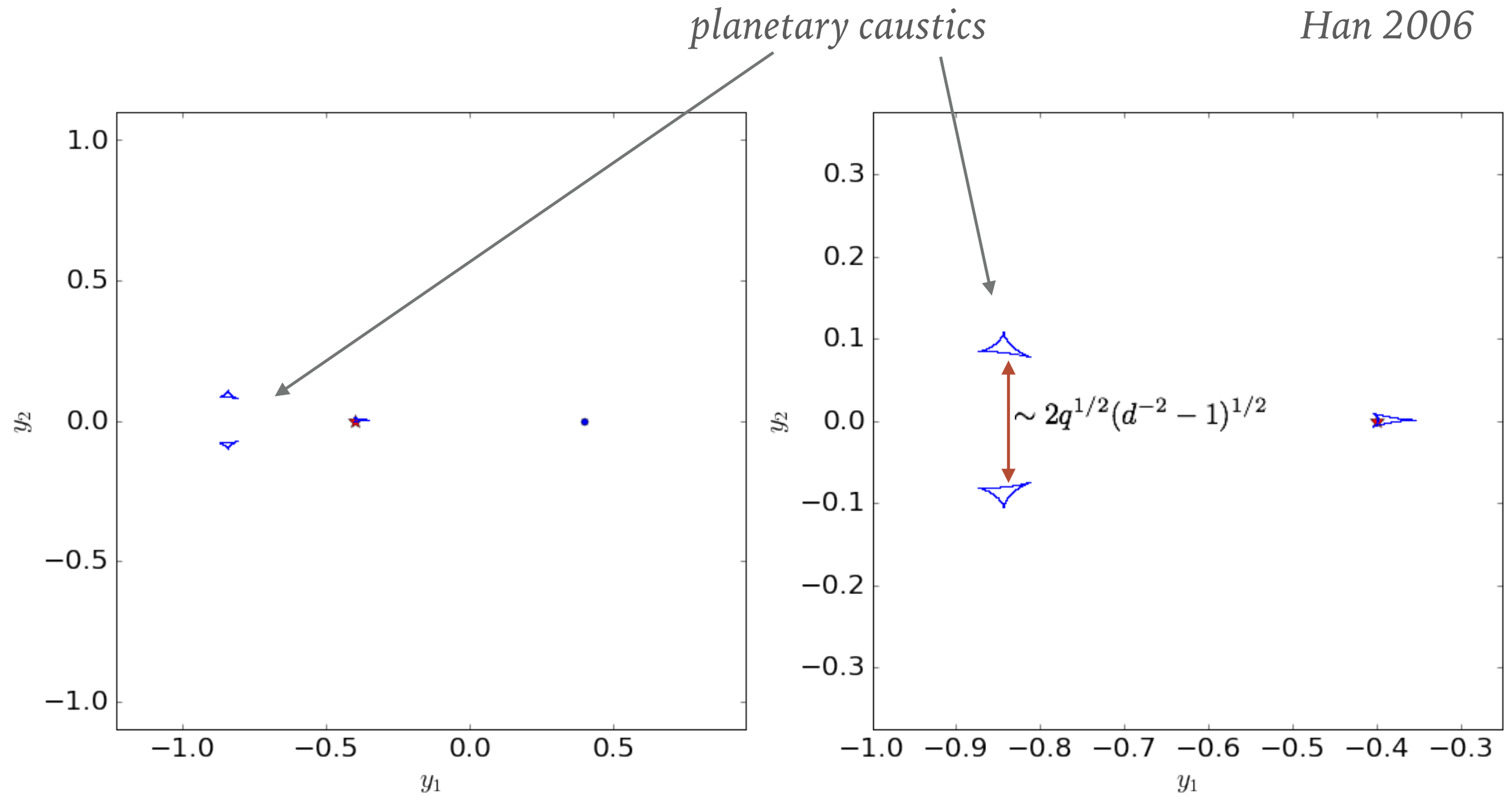

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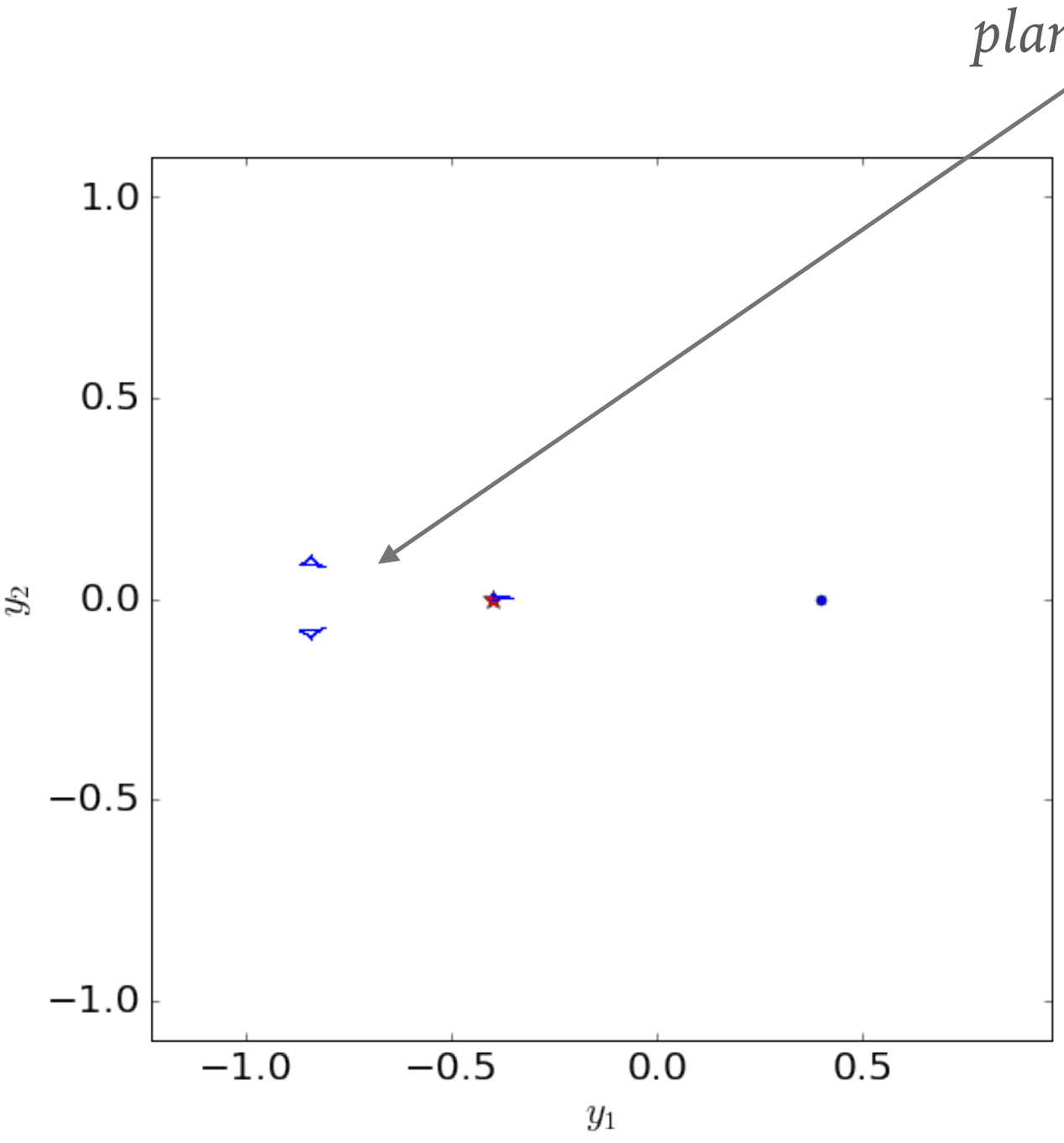

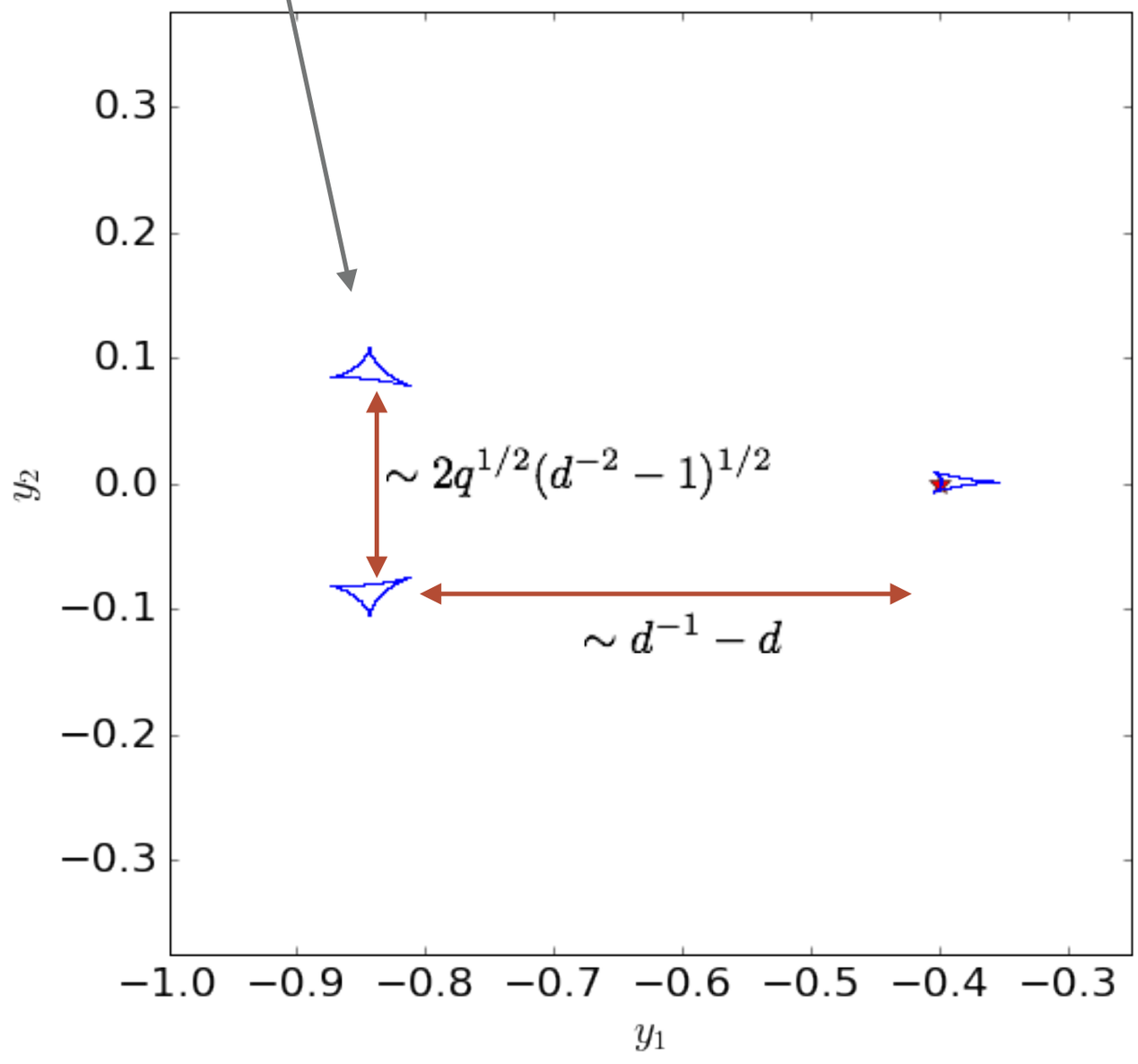

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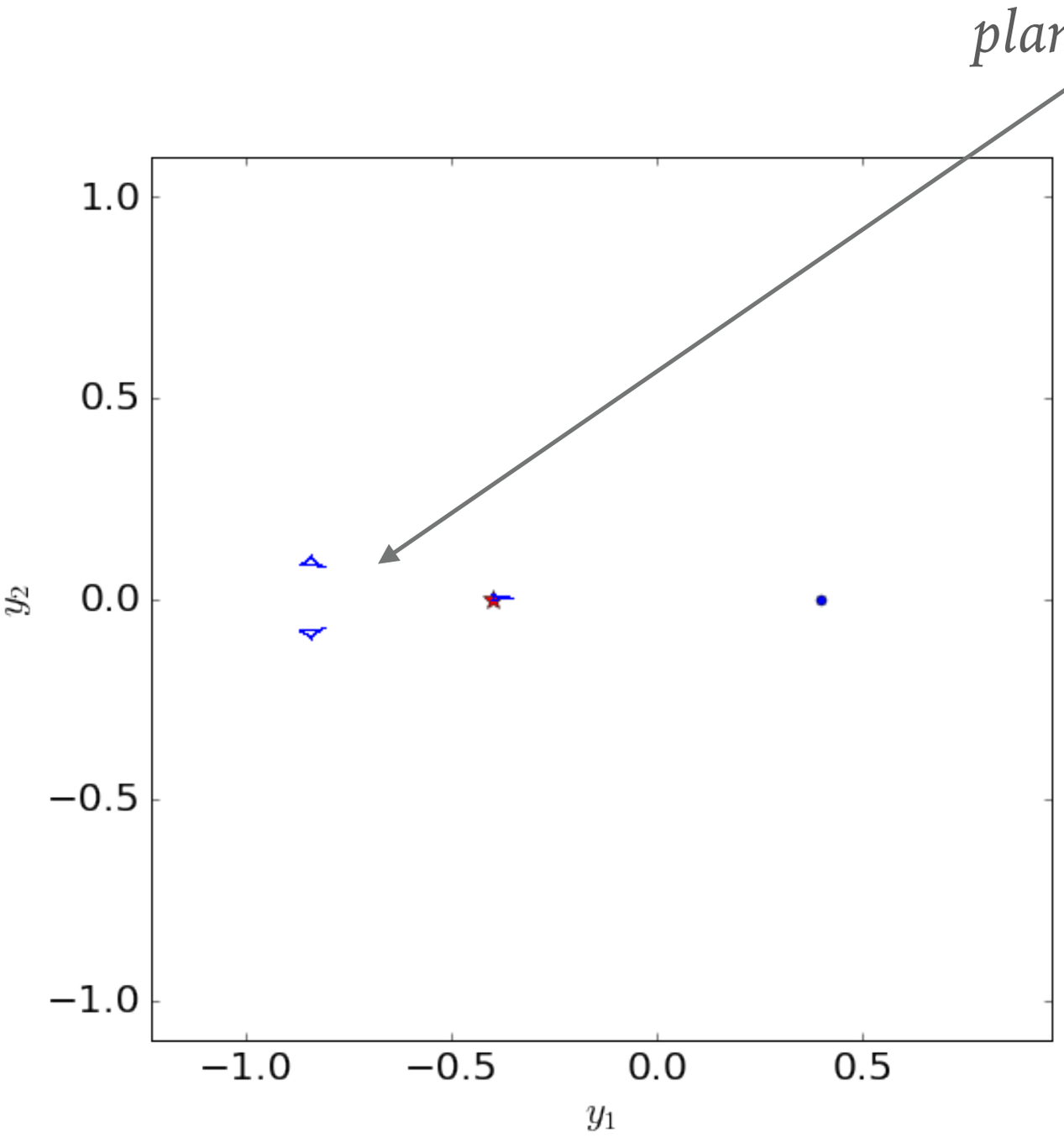

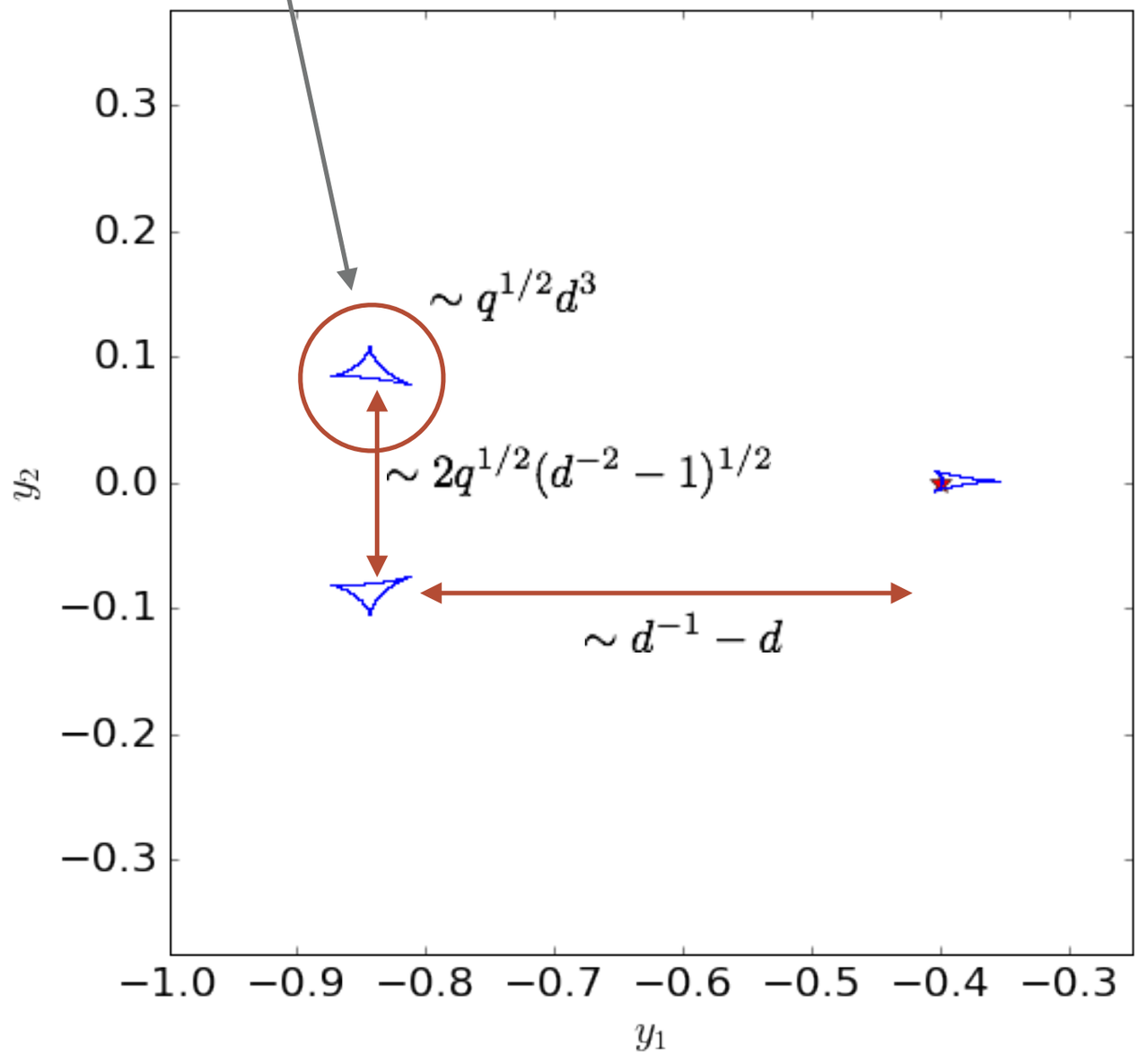

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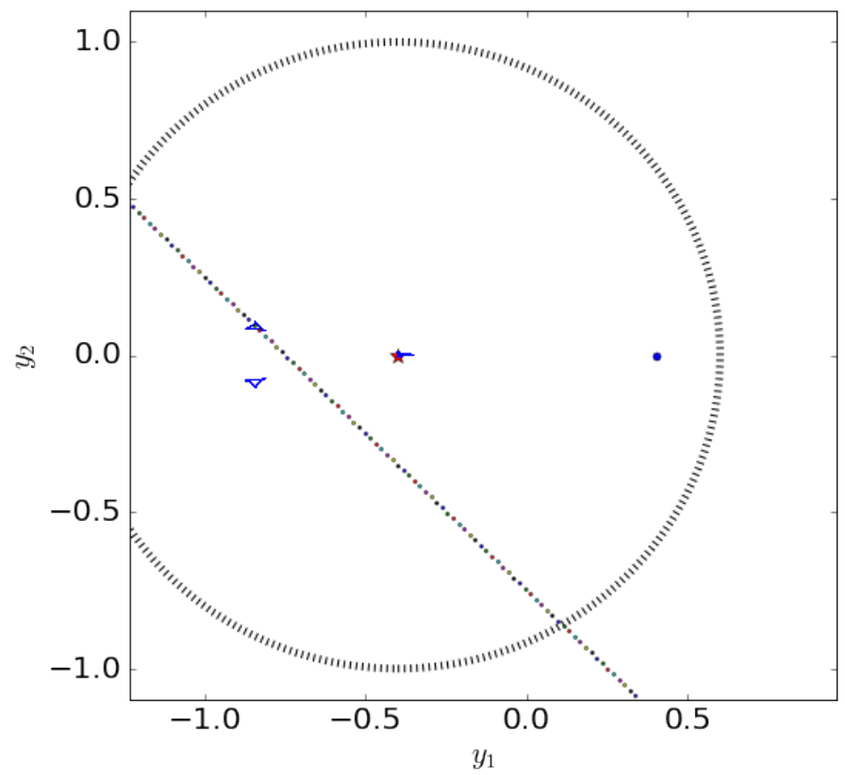

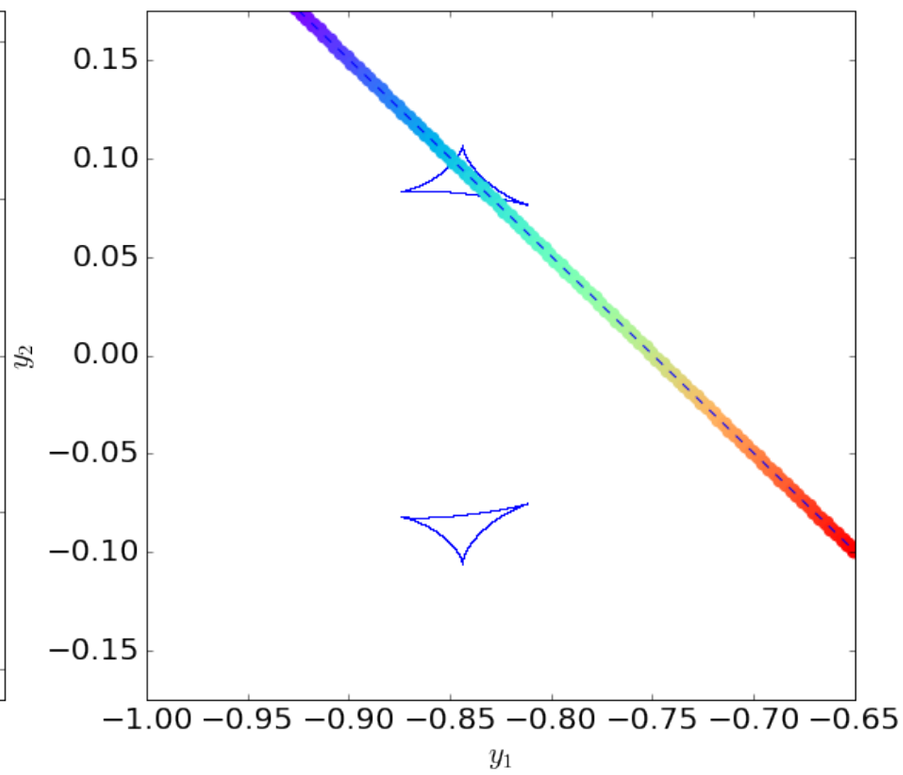

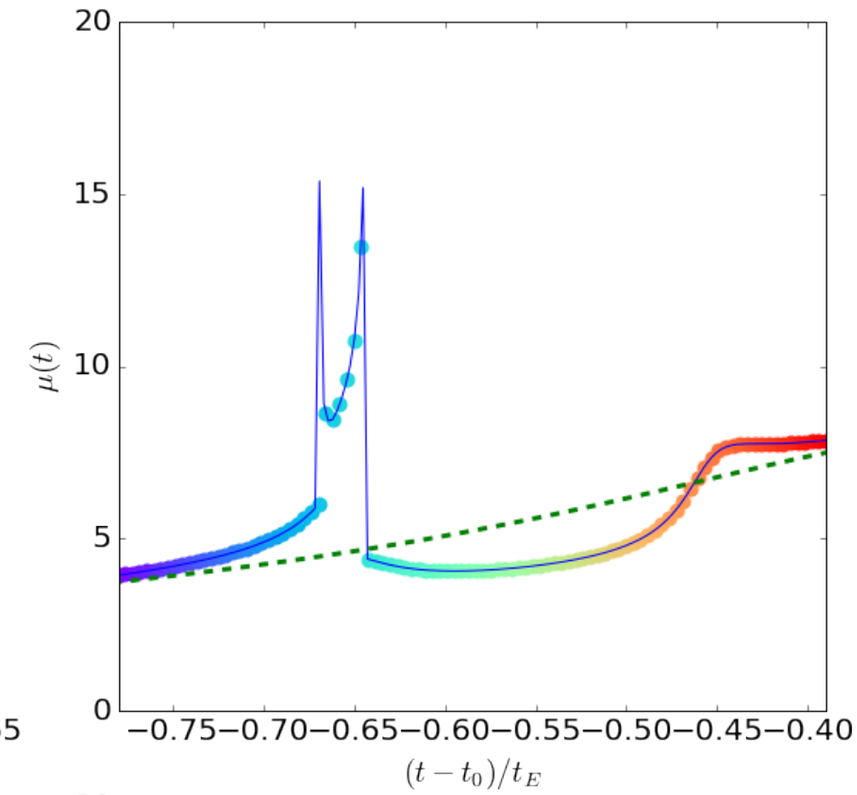

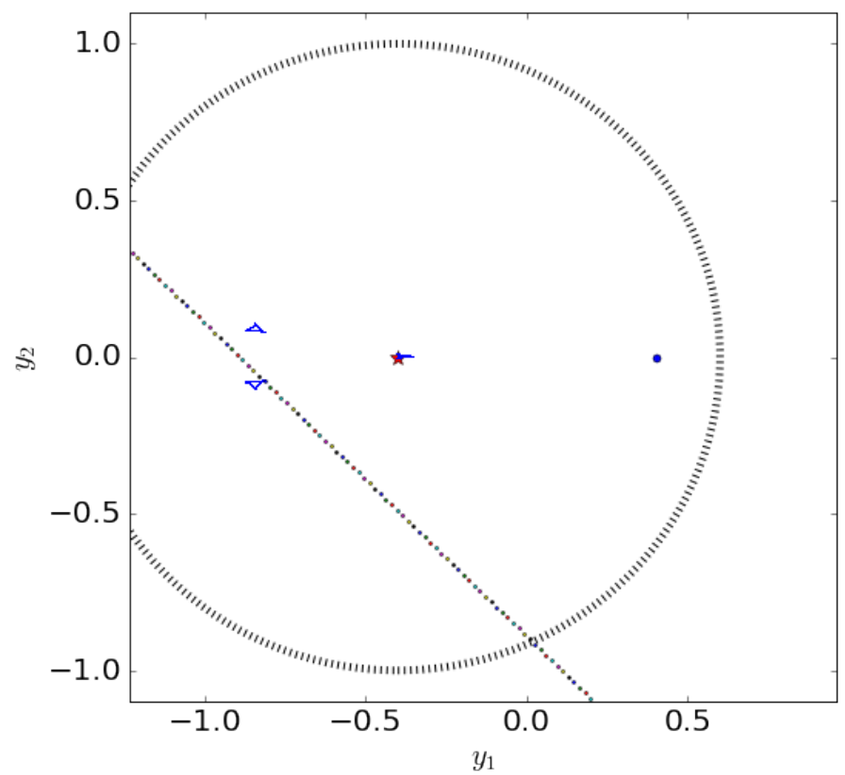

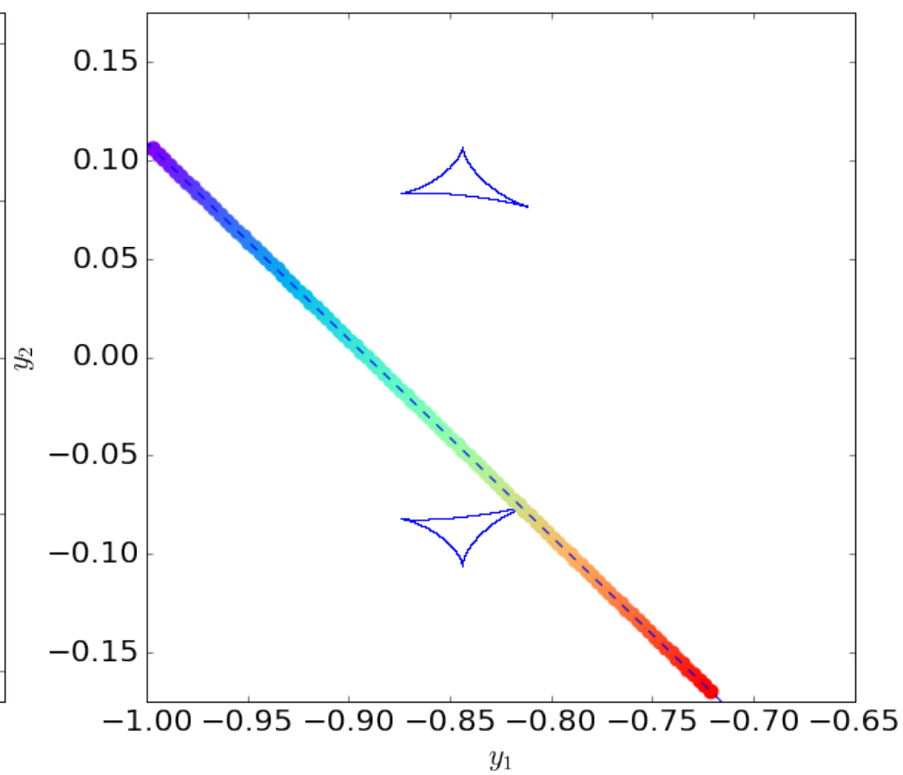

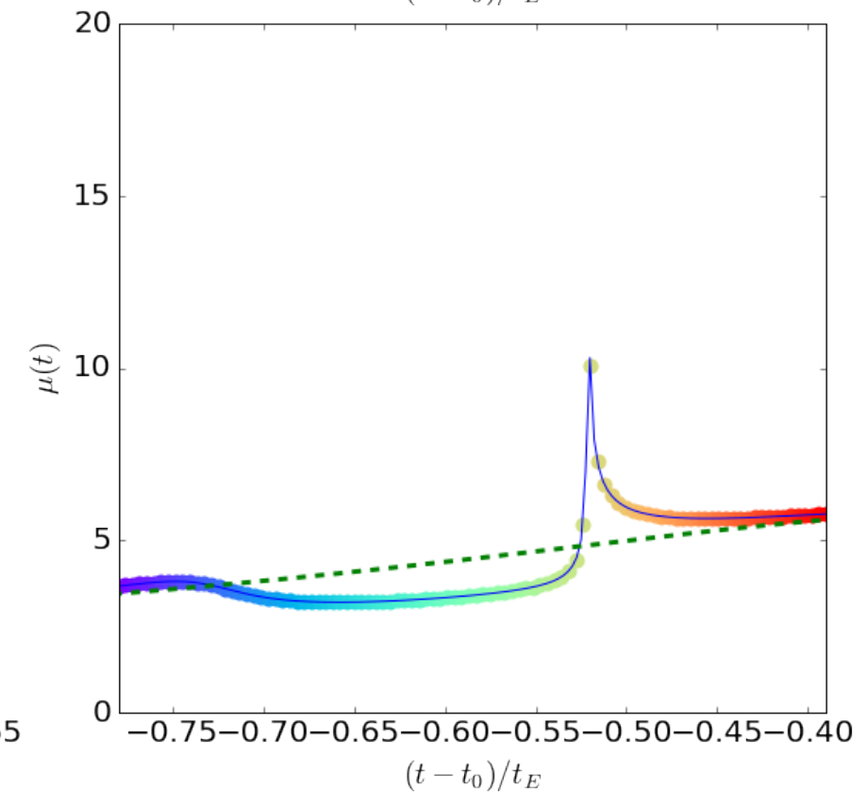

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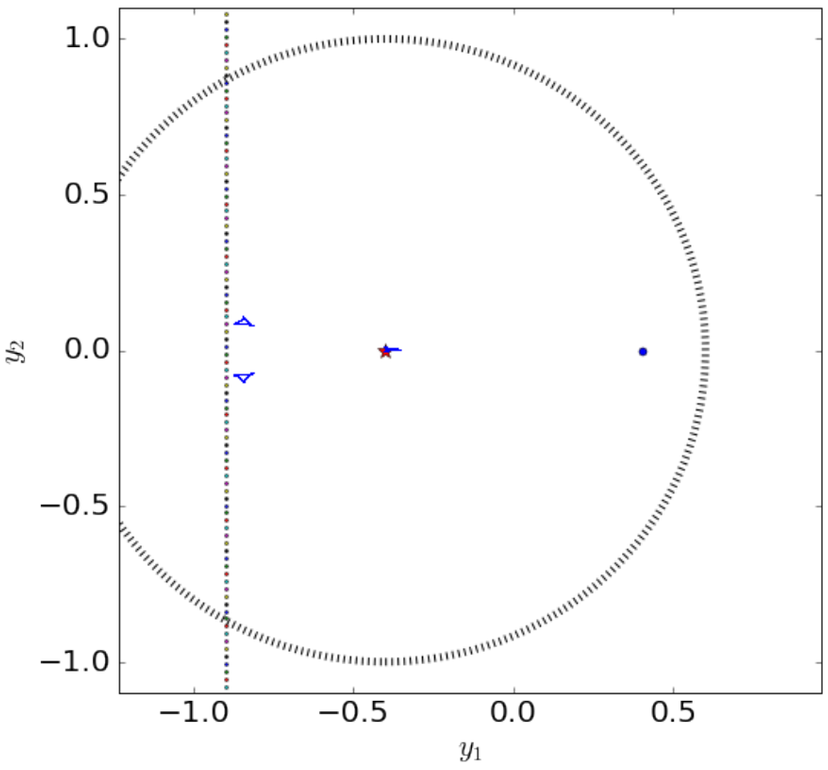
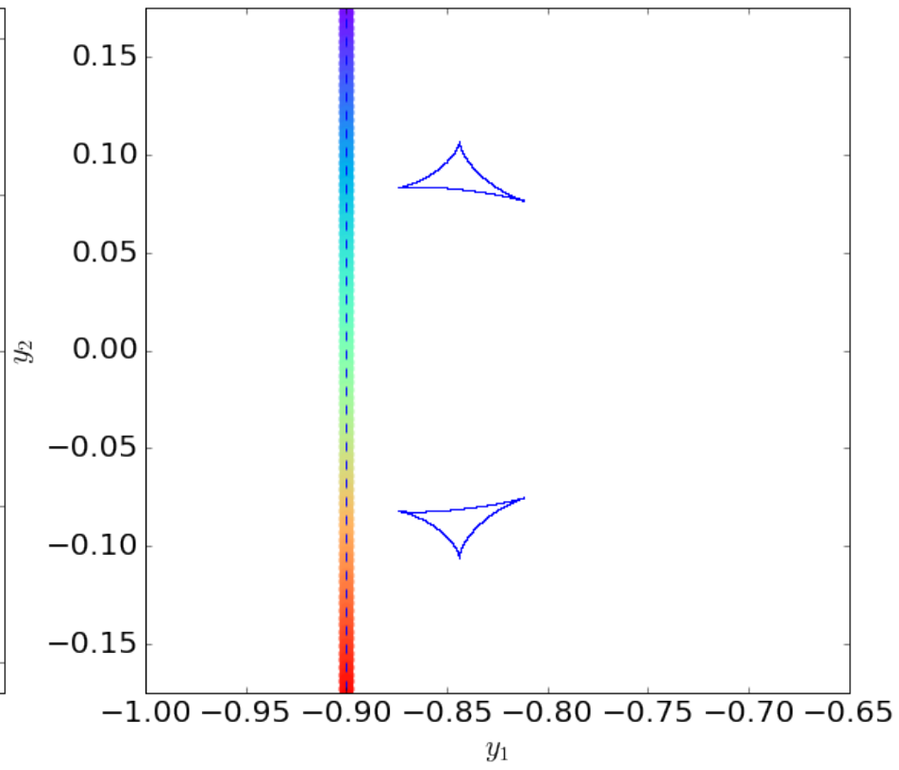
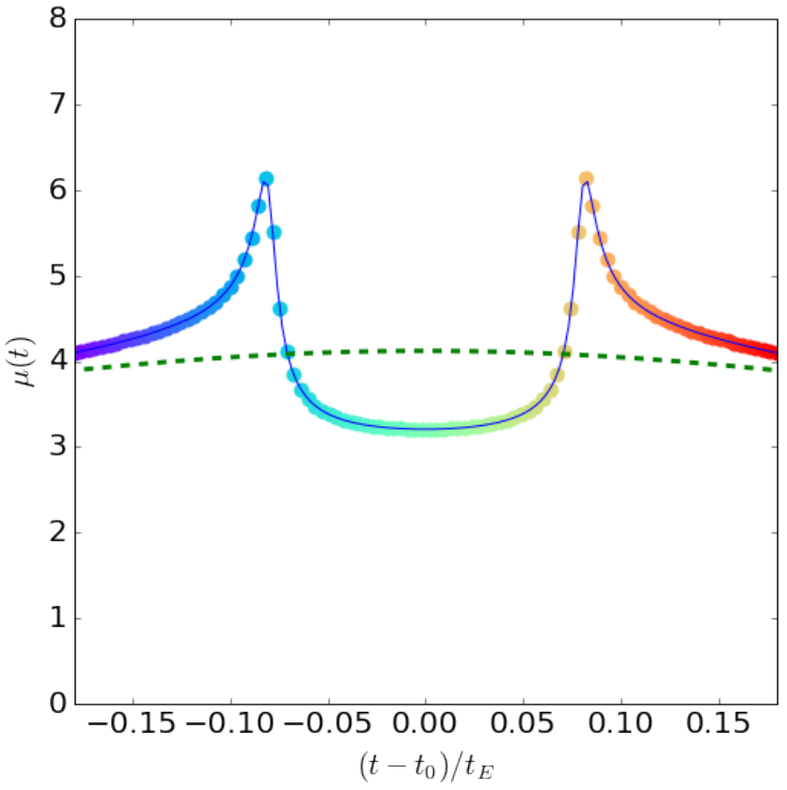
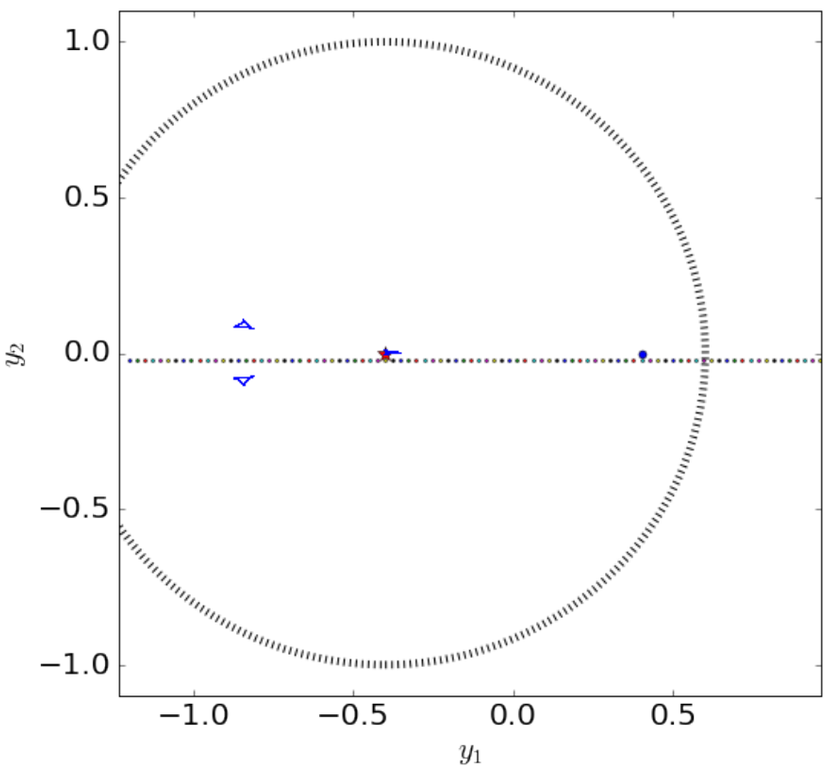
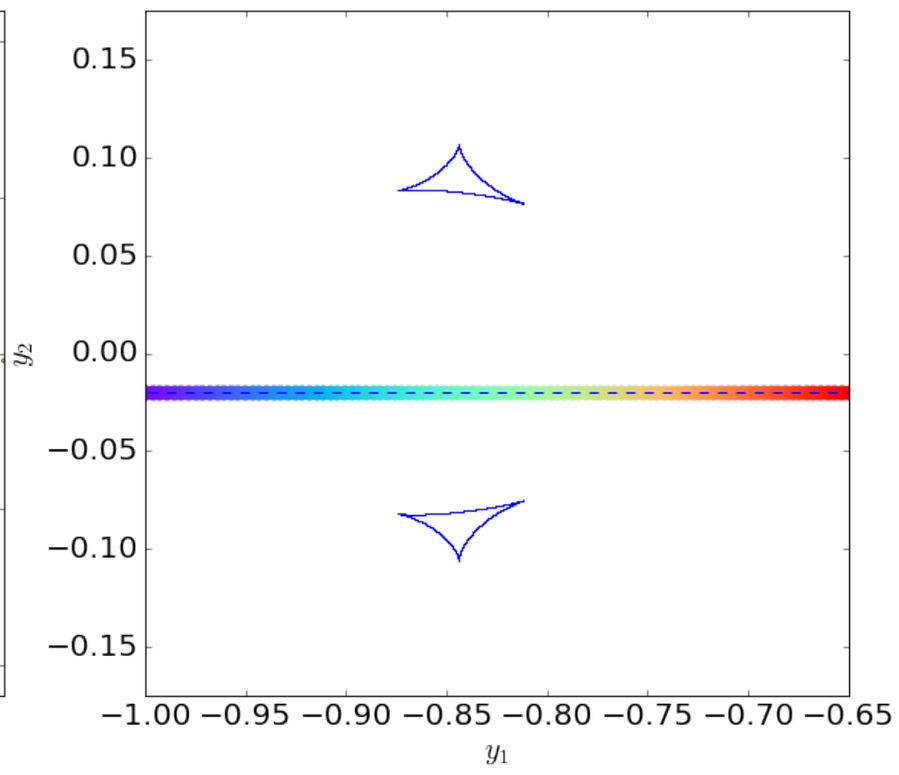
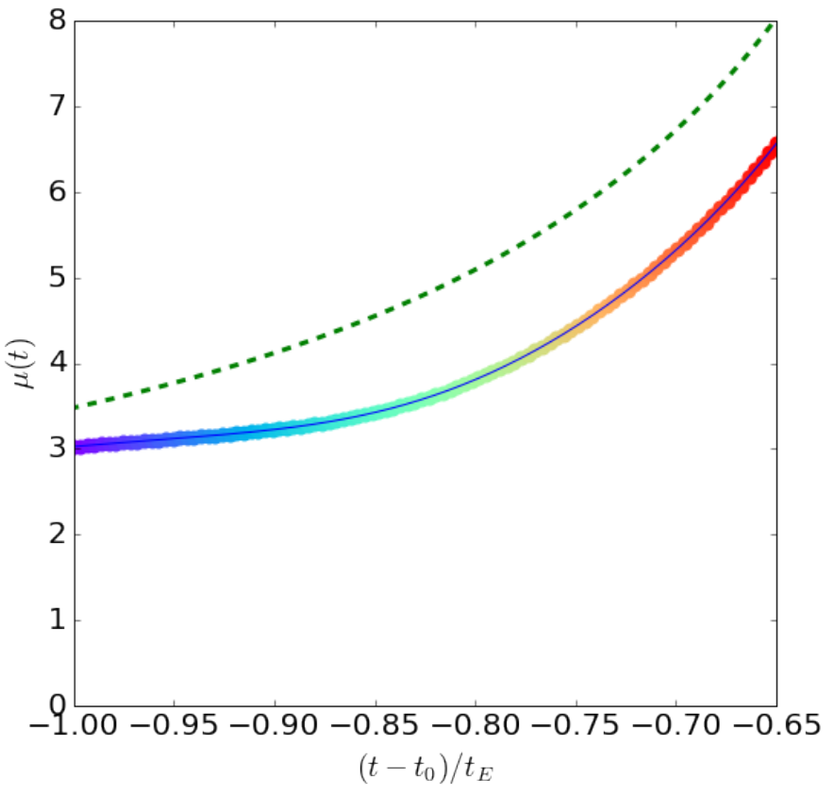




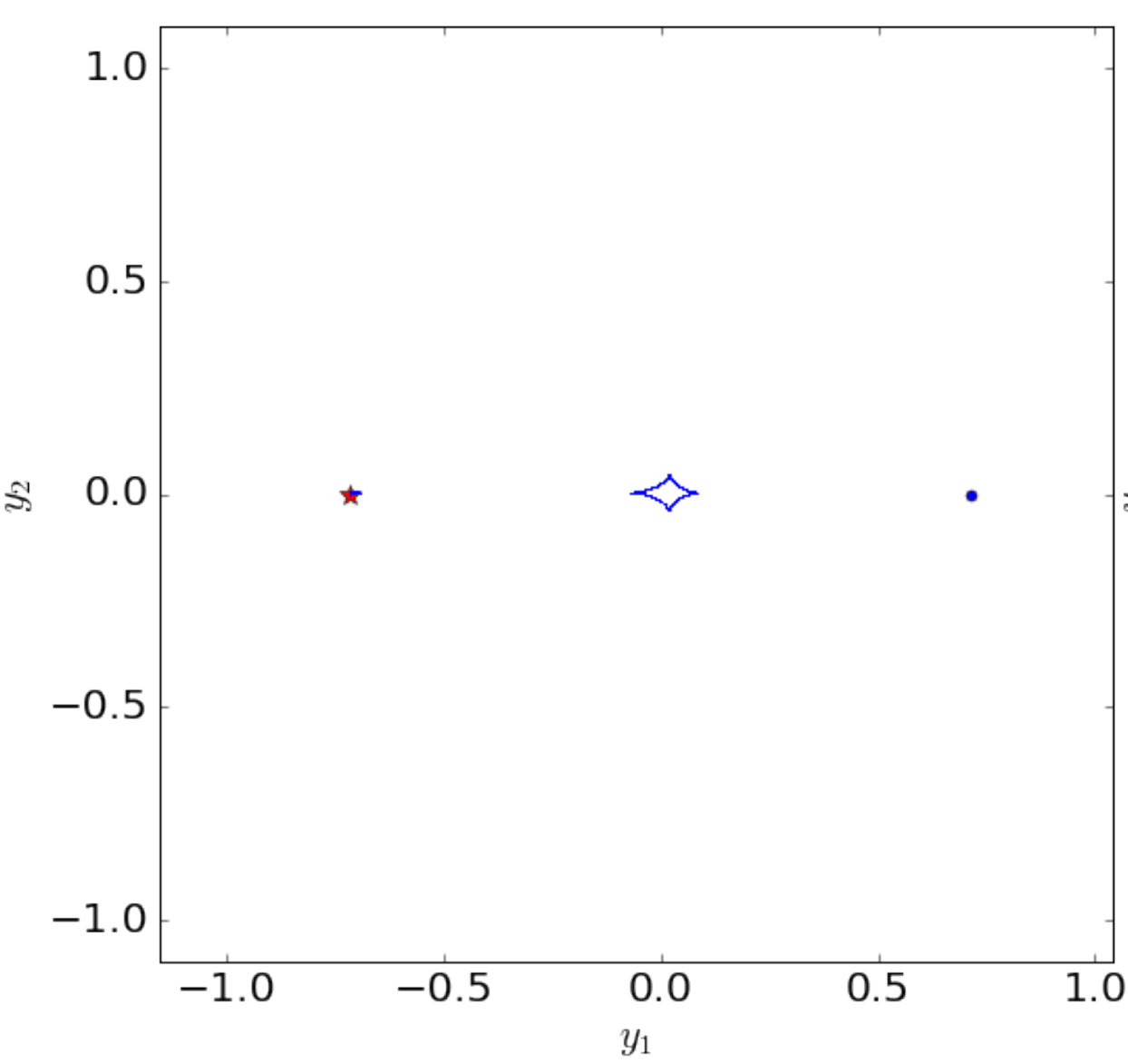


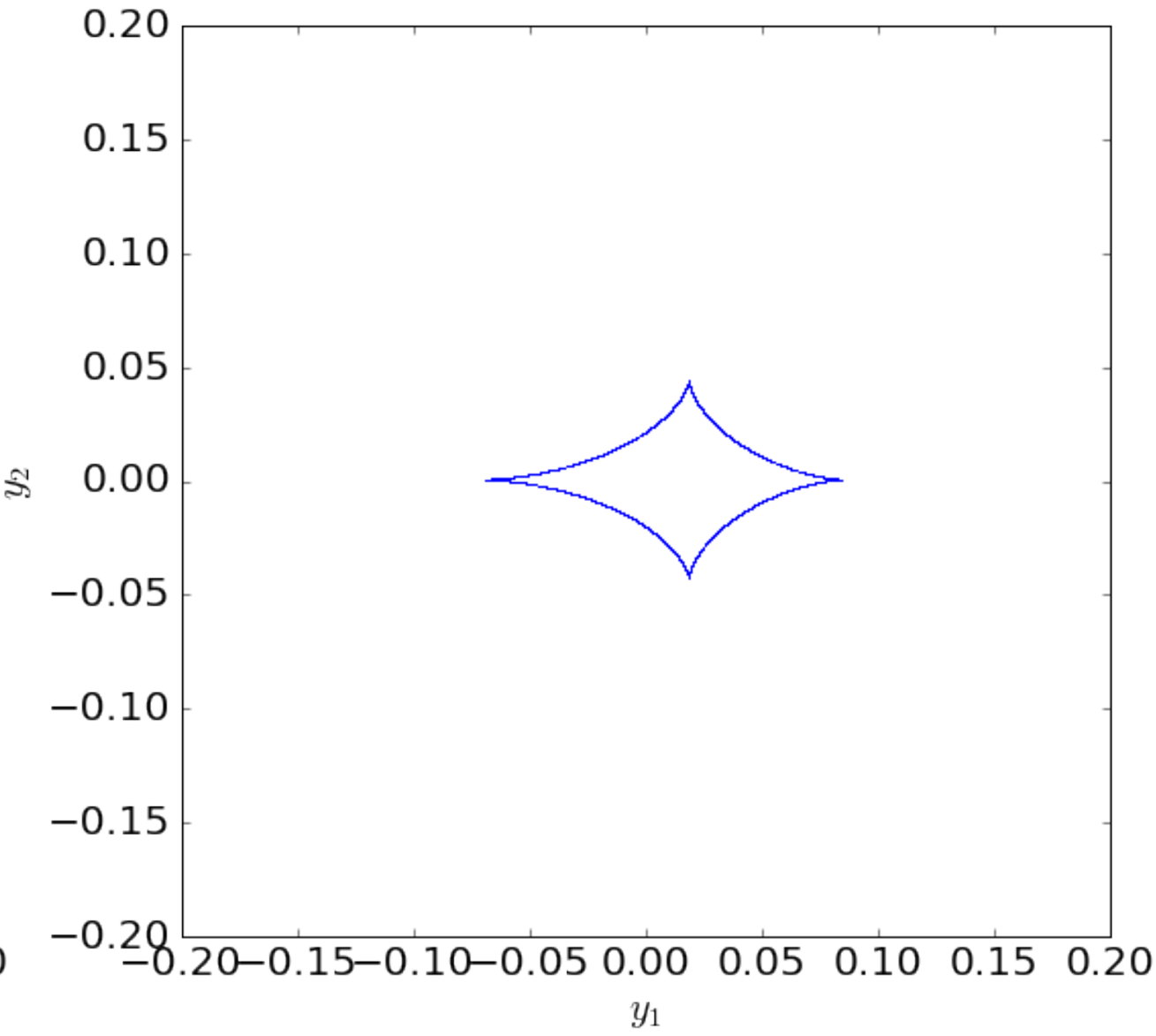






PLANETARY CAUSTICS IN WIDE TOPOLOGIES





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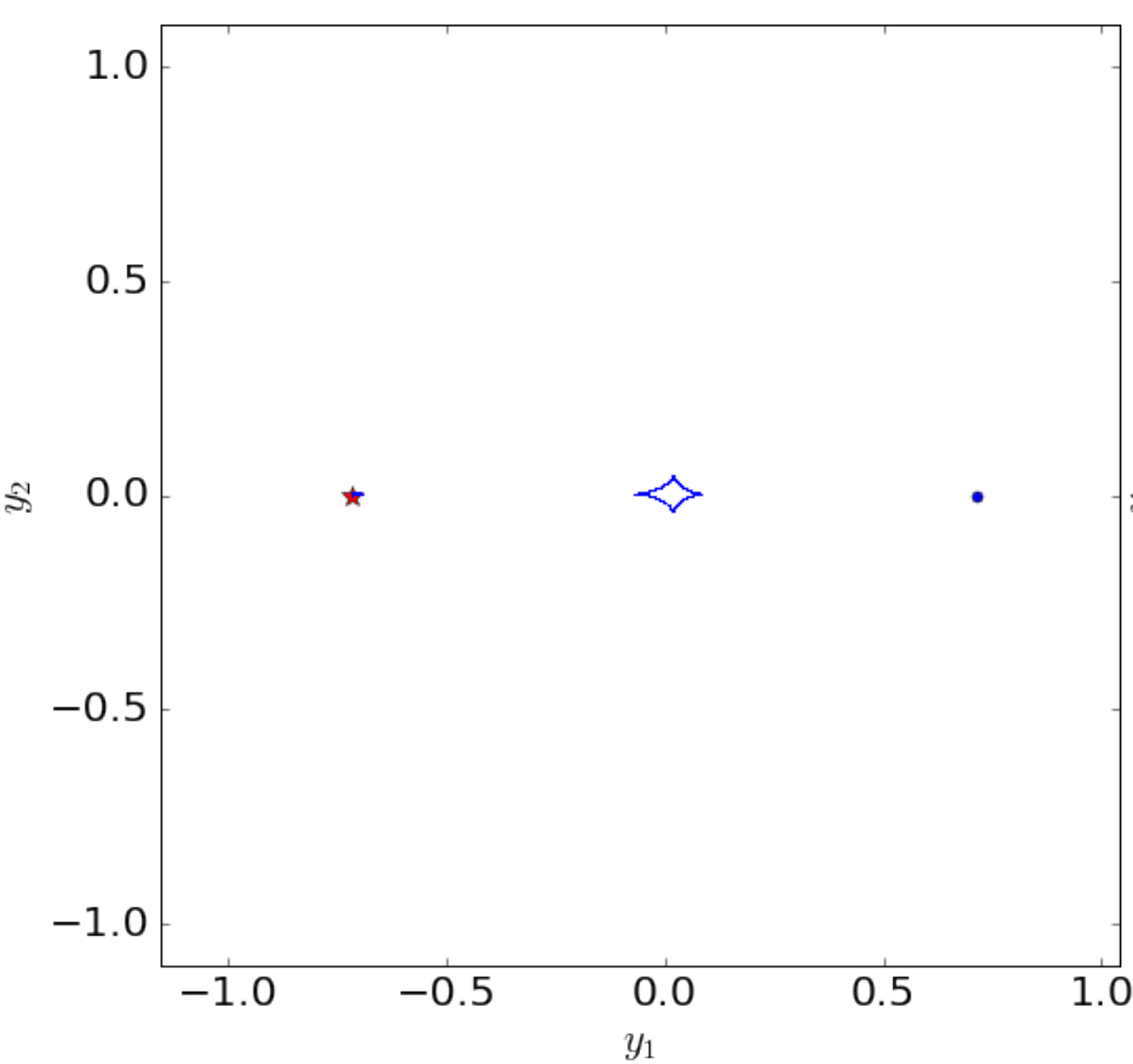

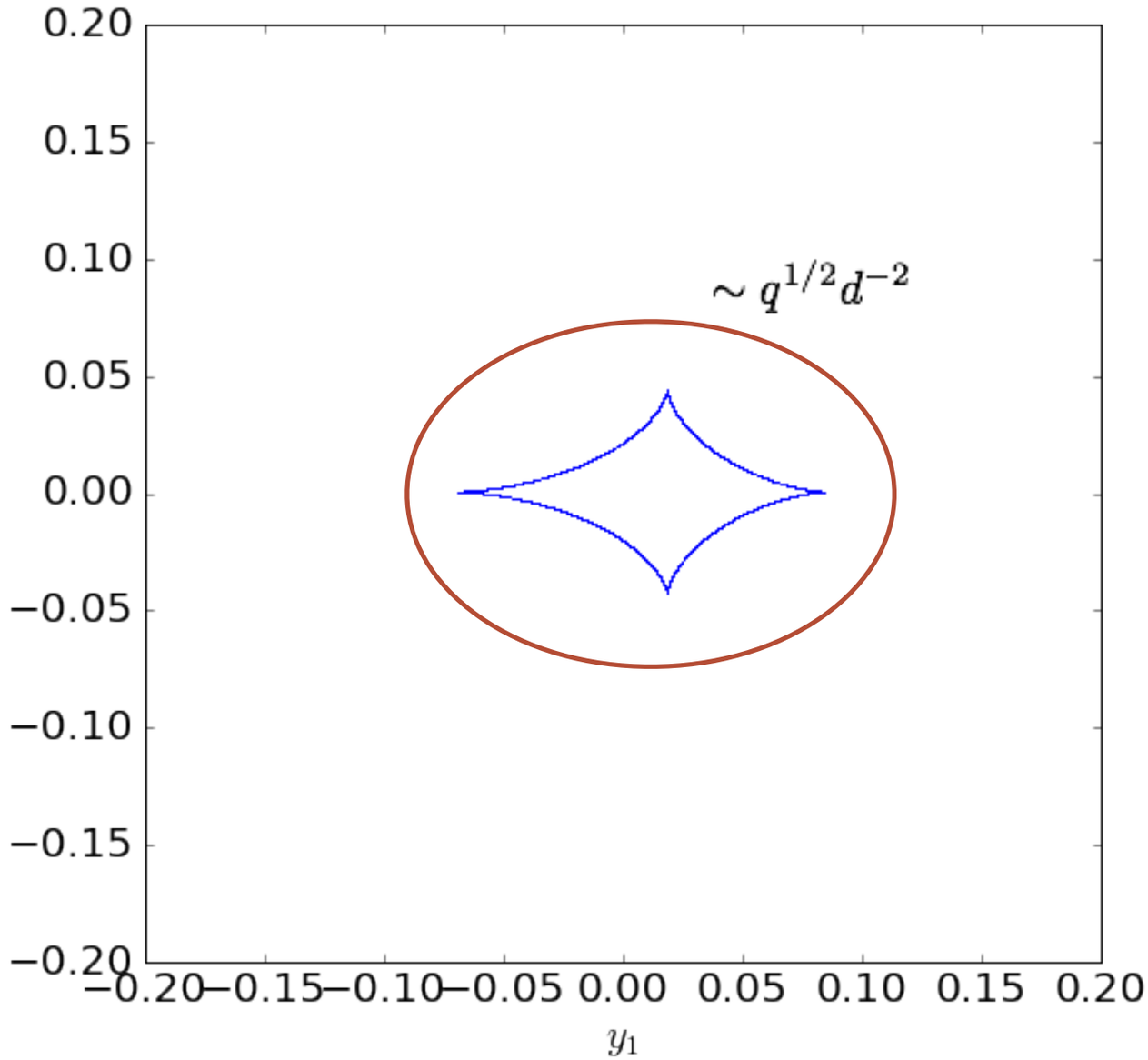

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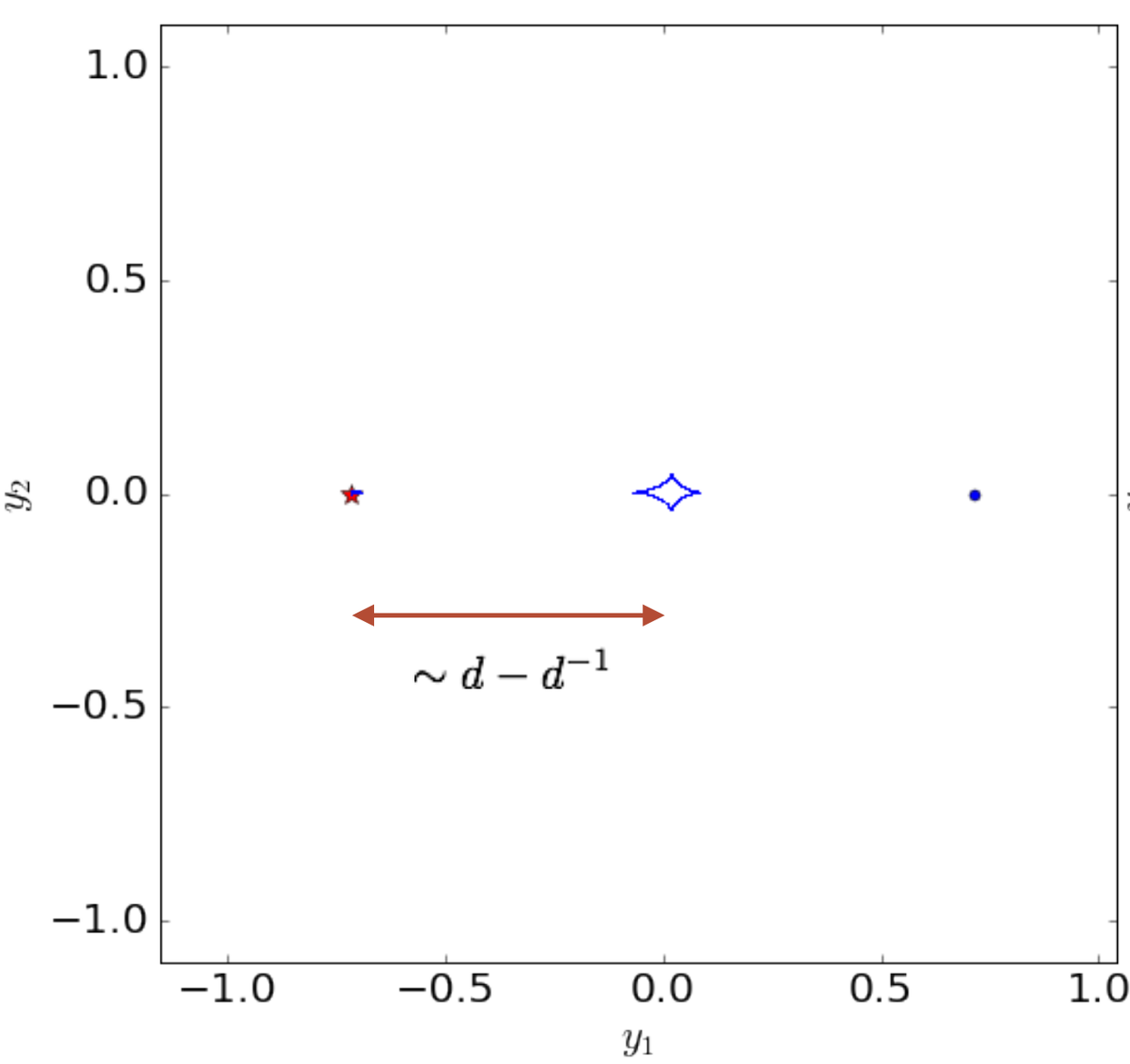

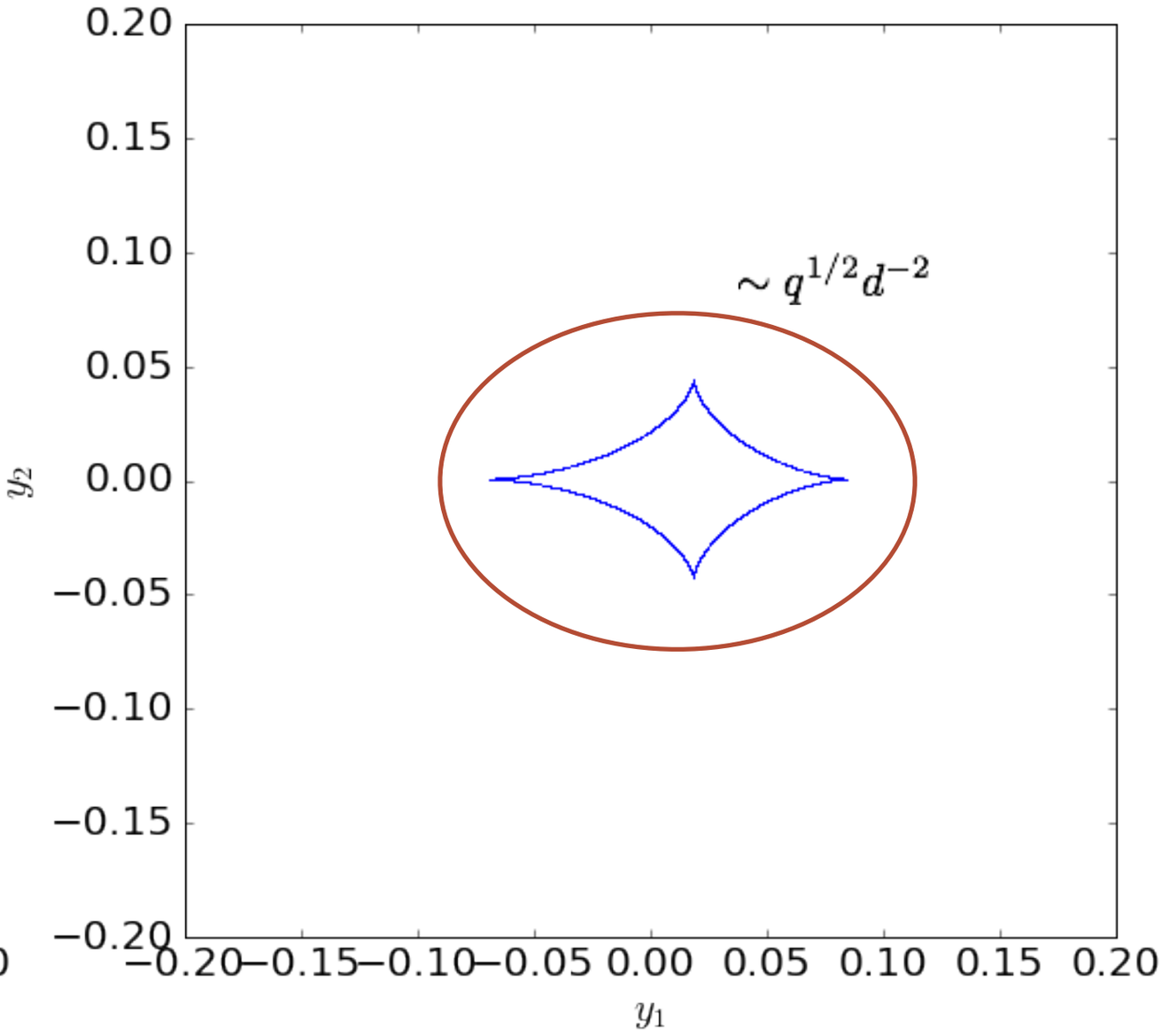

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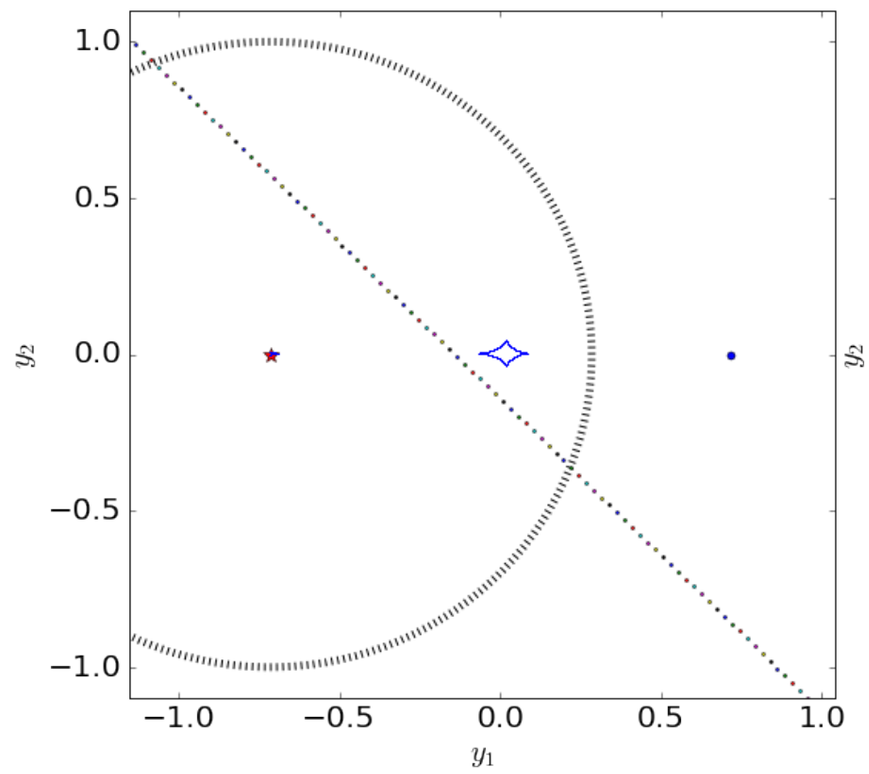

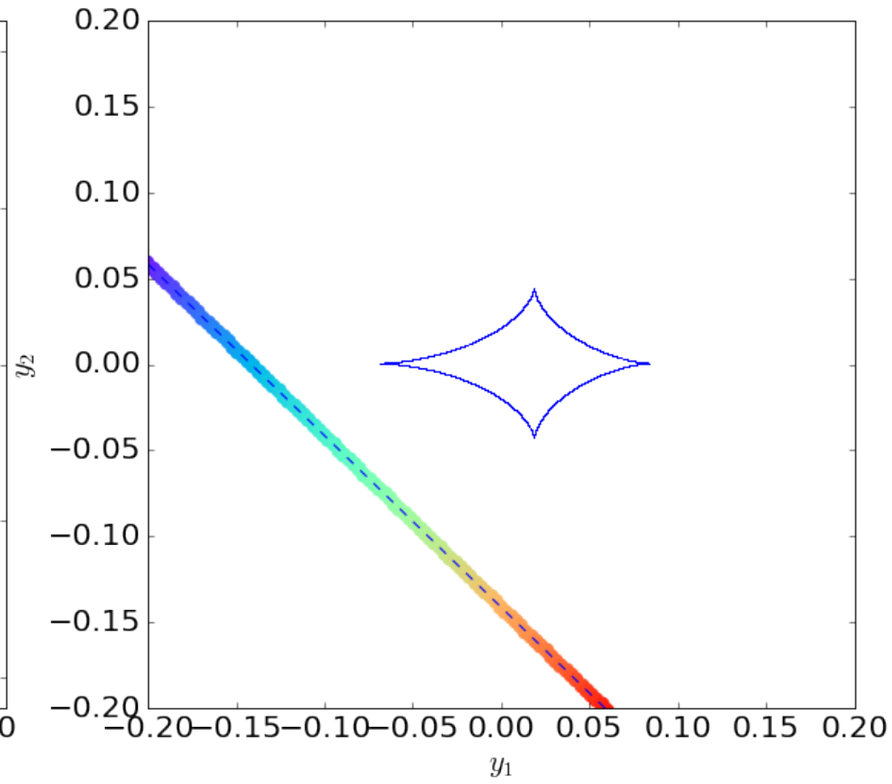

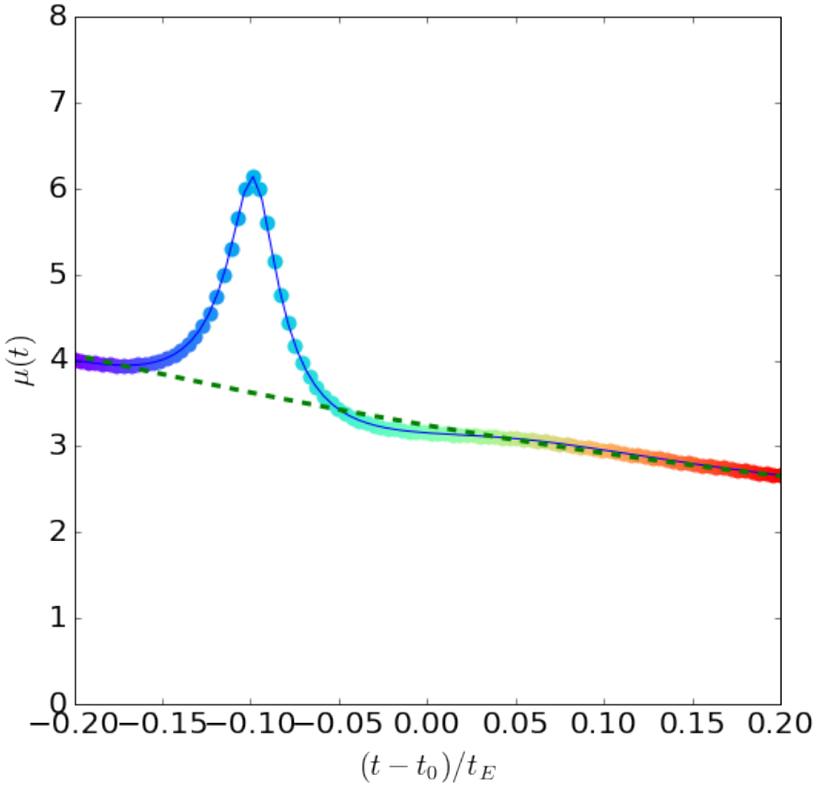

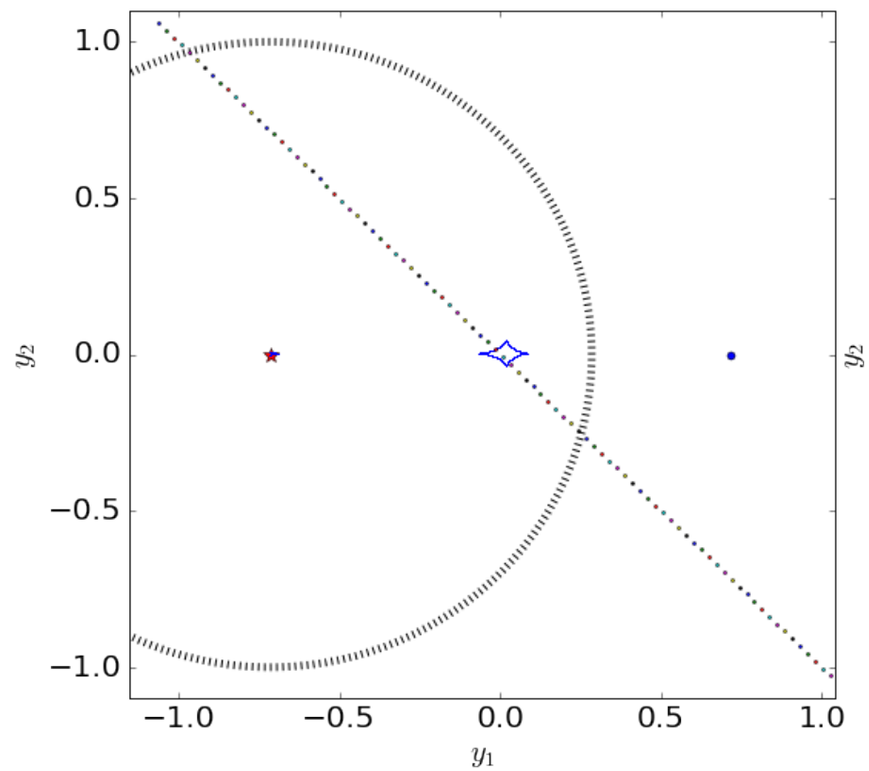

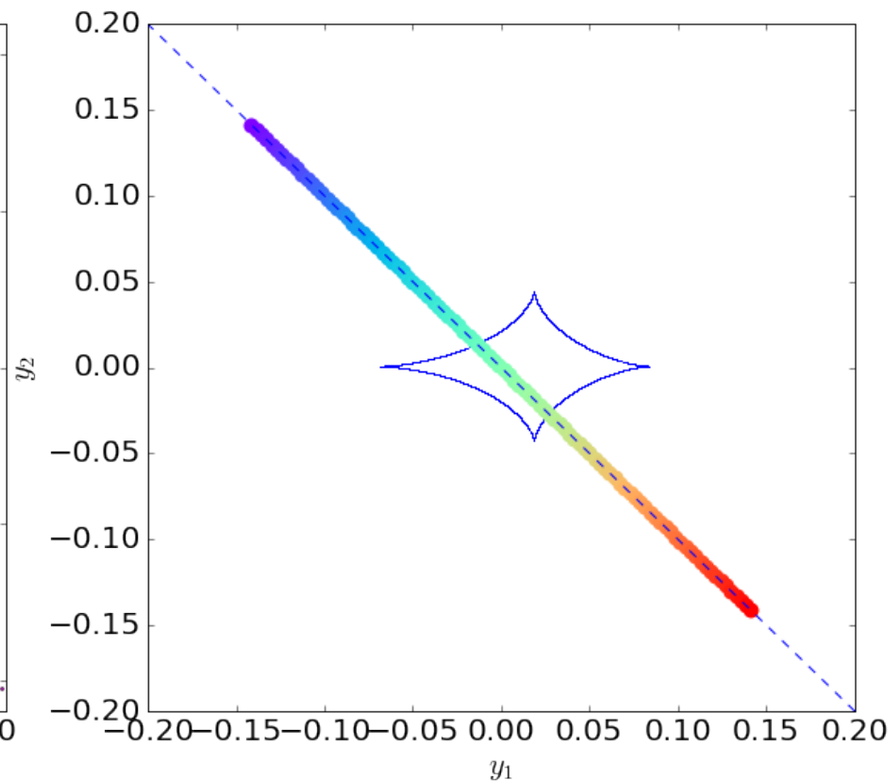

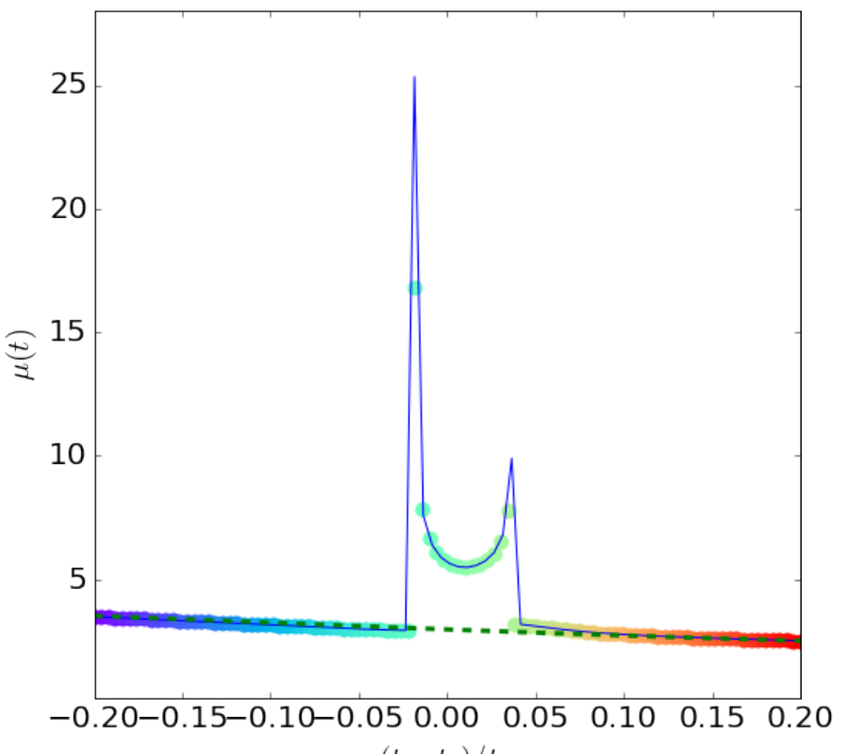

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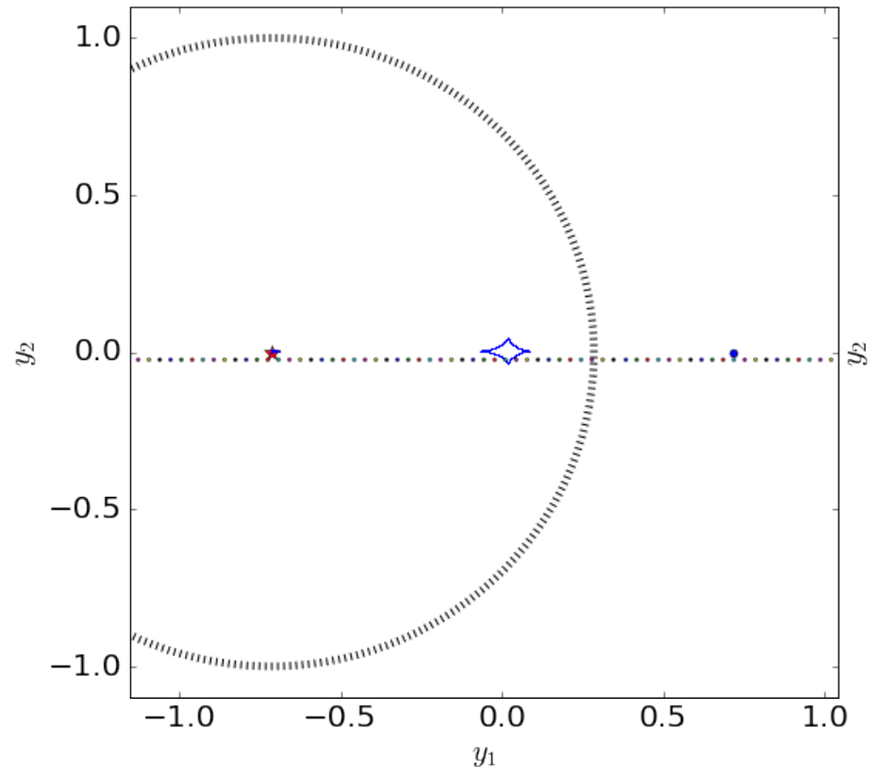
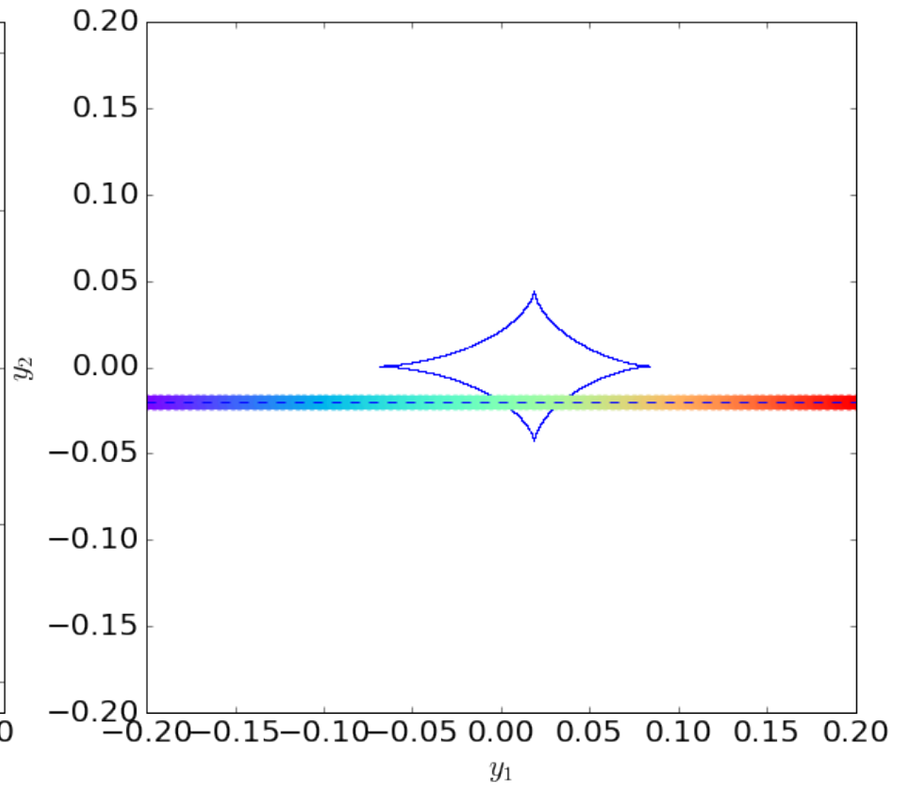
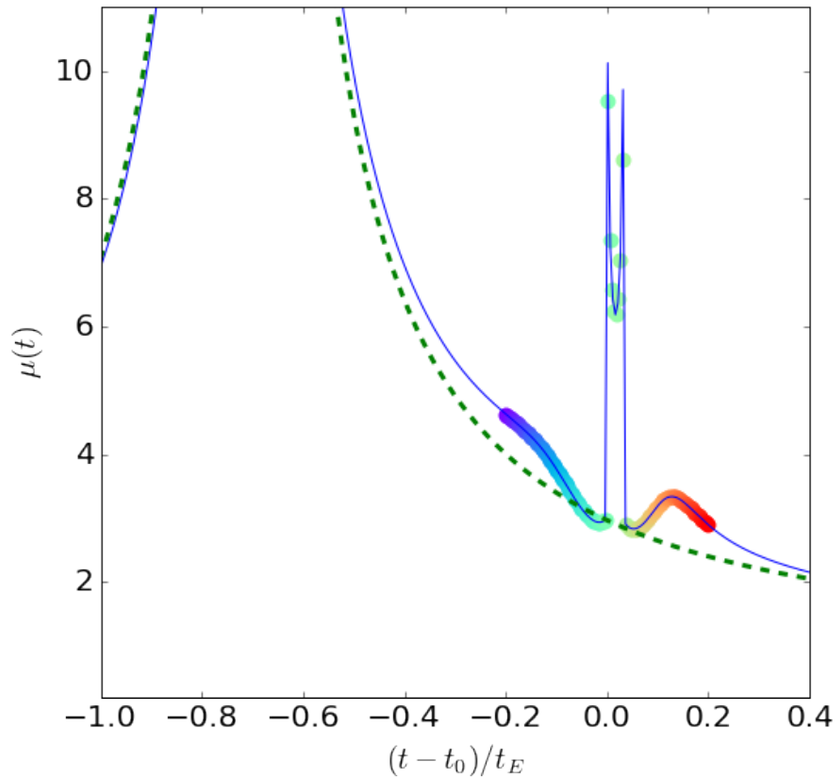
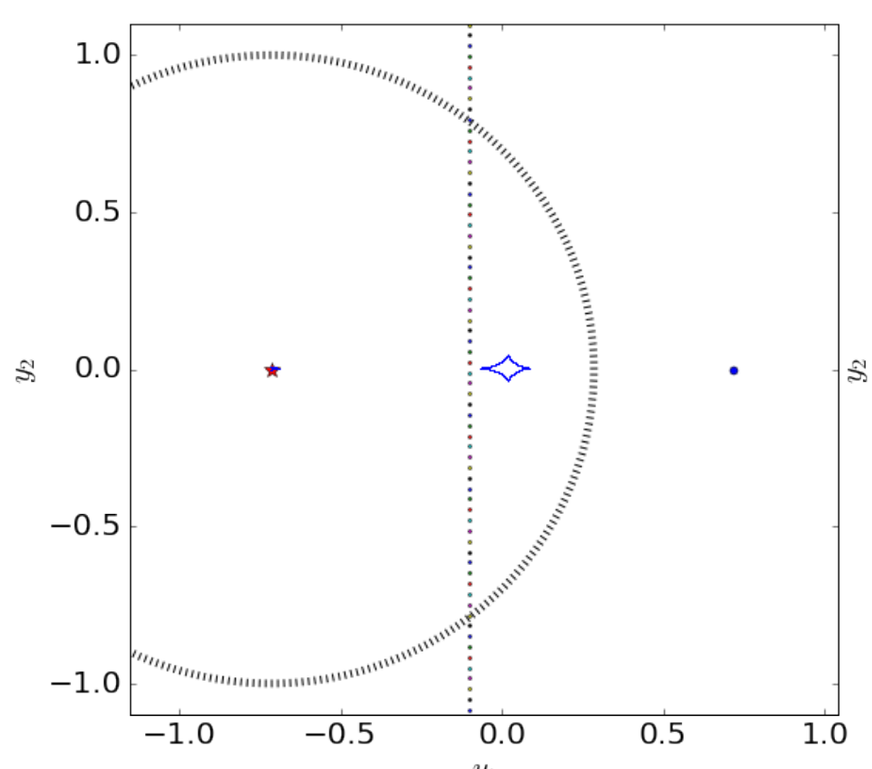
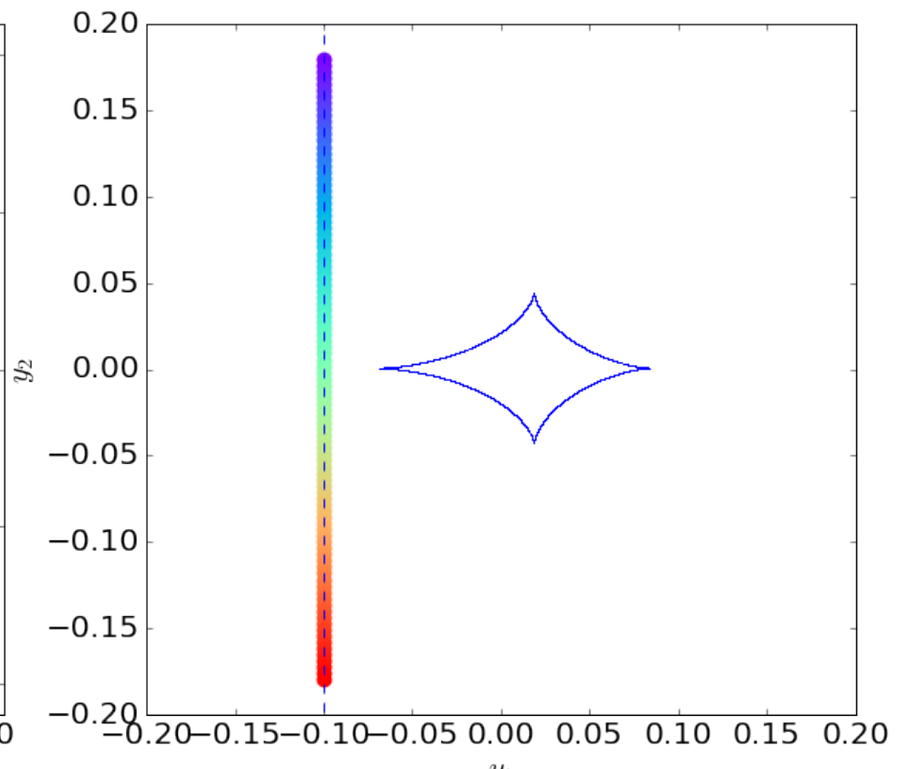
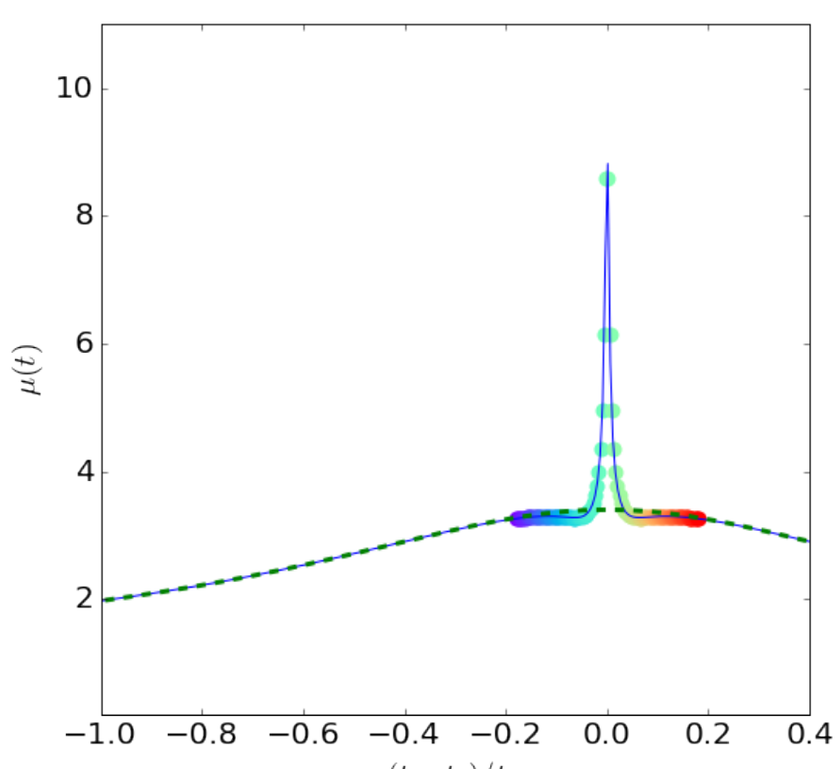




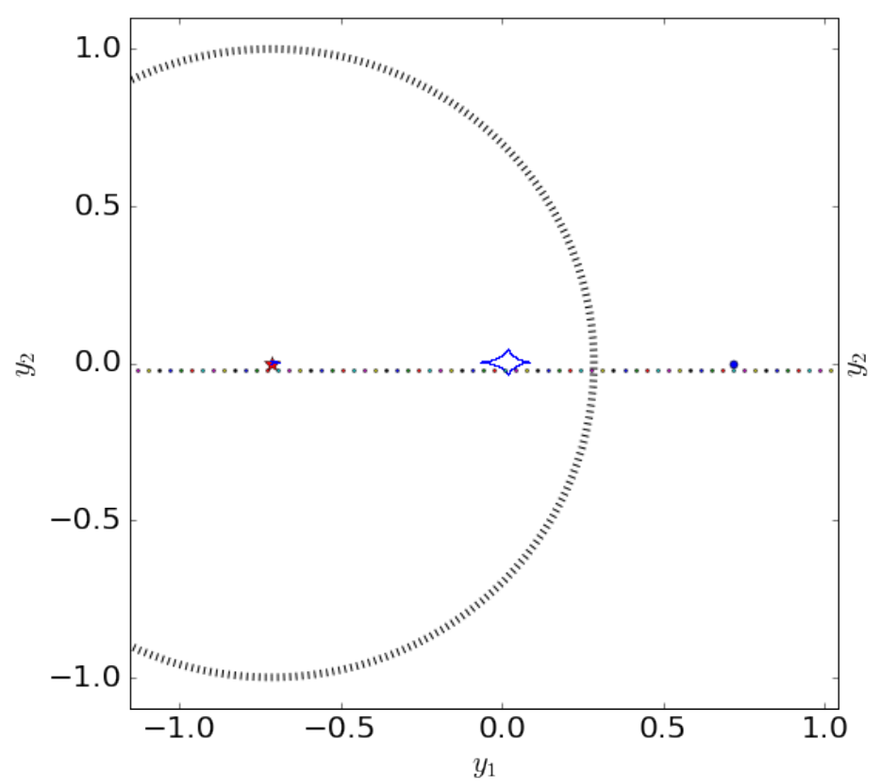


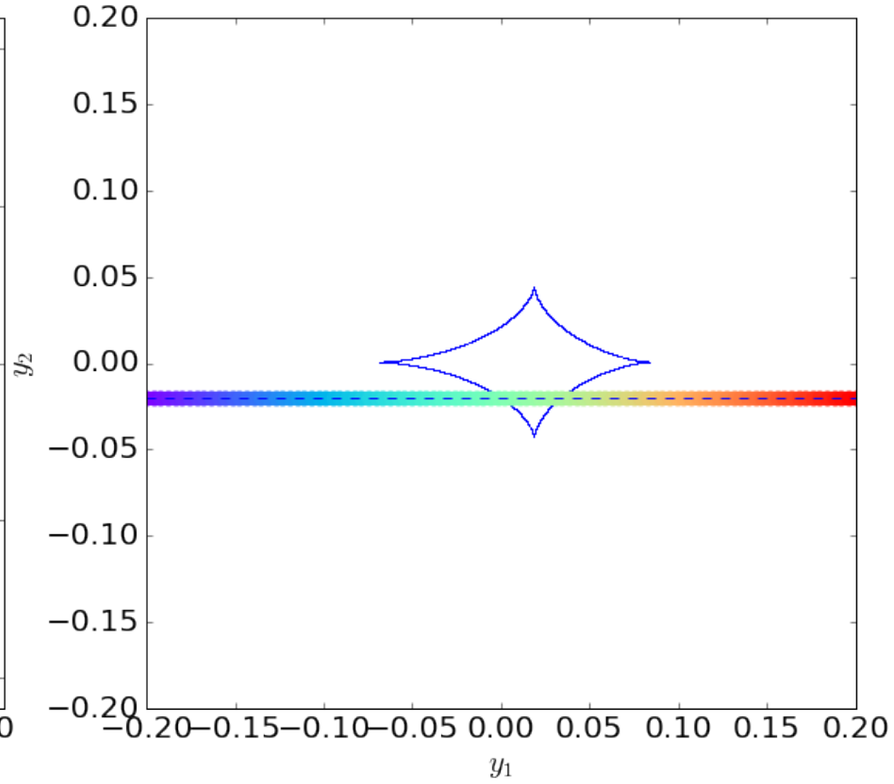


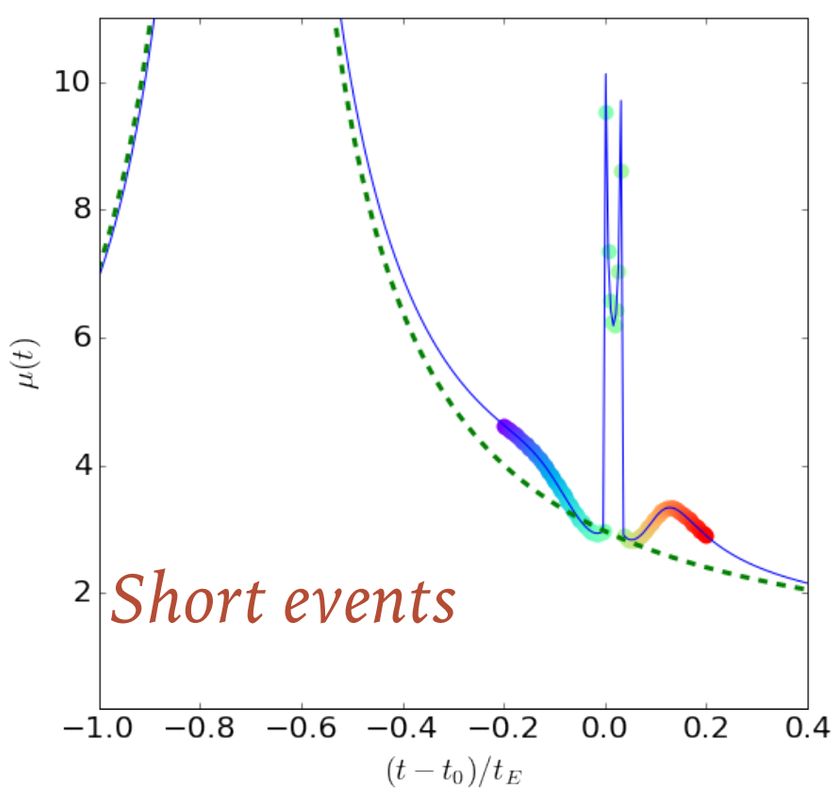


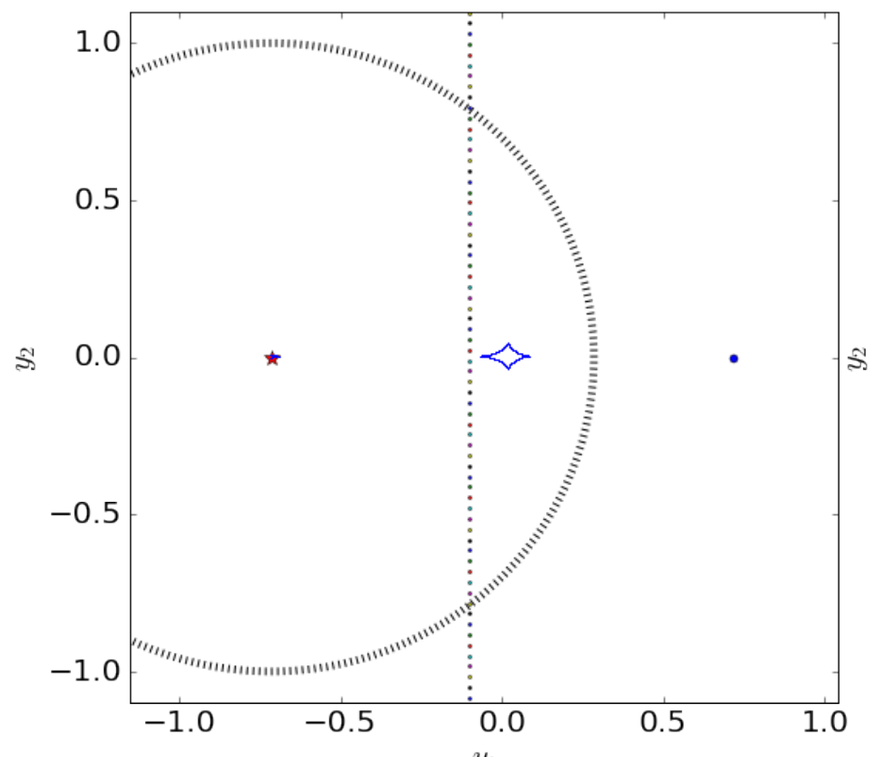


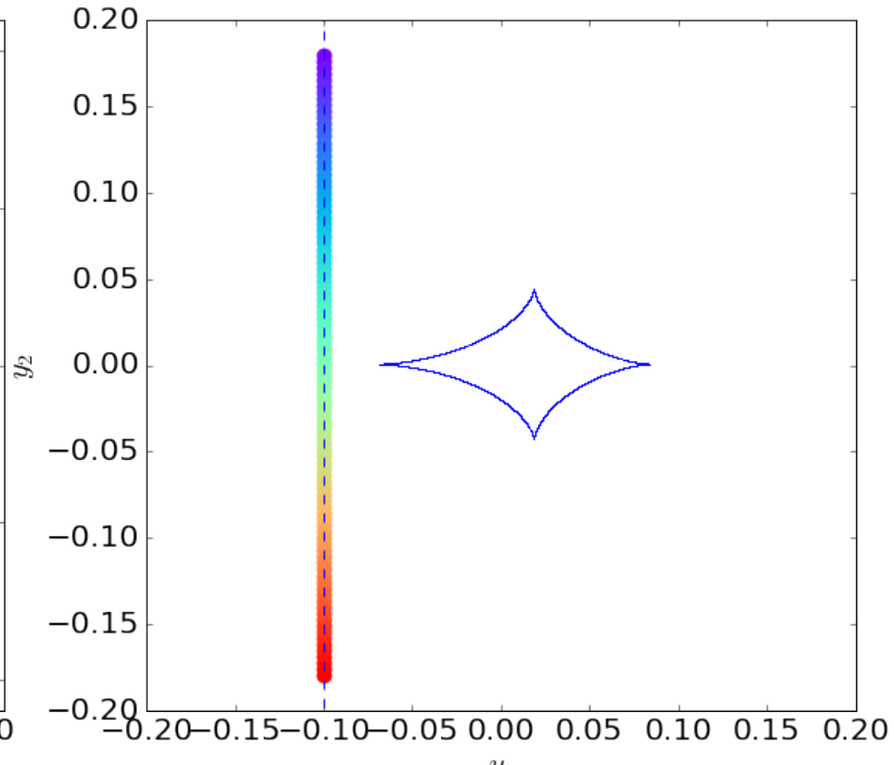
PLANETARY CAUSTICS PERTURBATIONS IN WIDE TOPOLOGIES

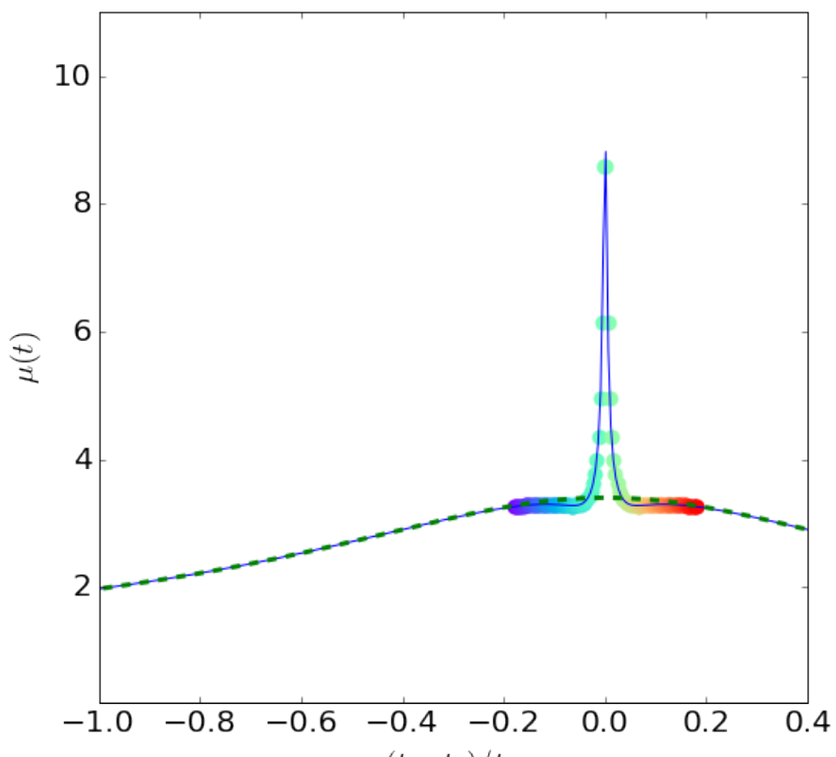




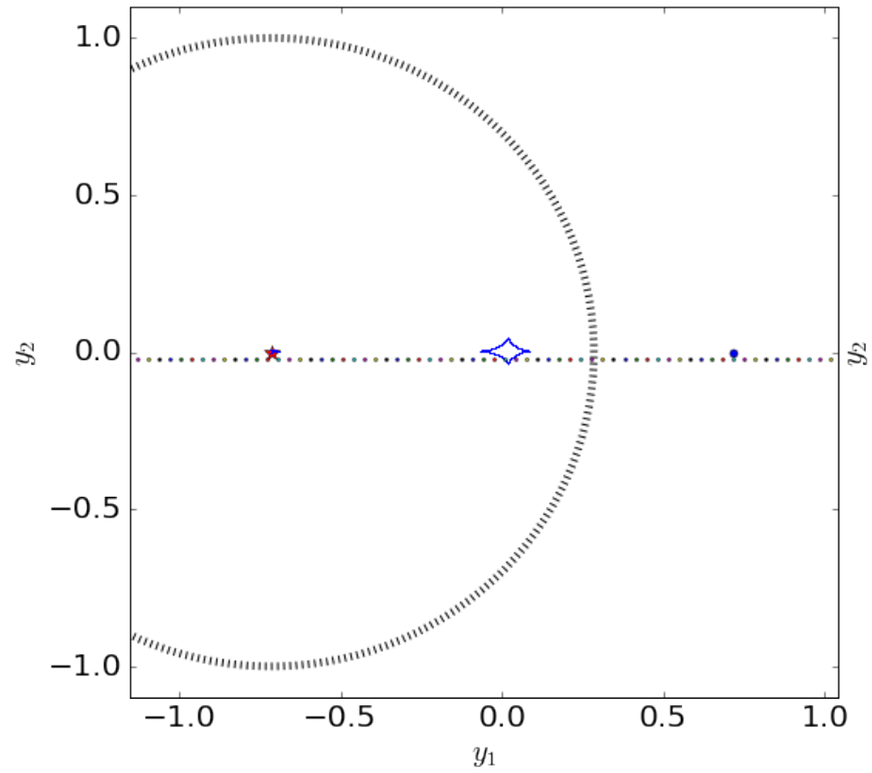


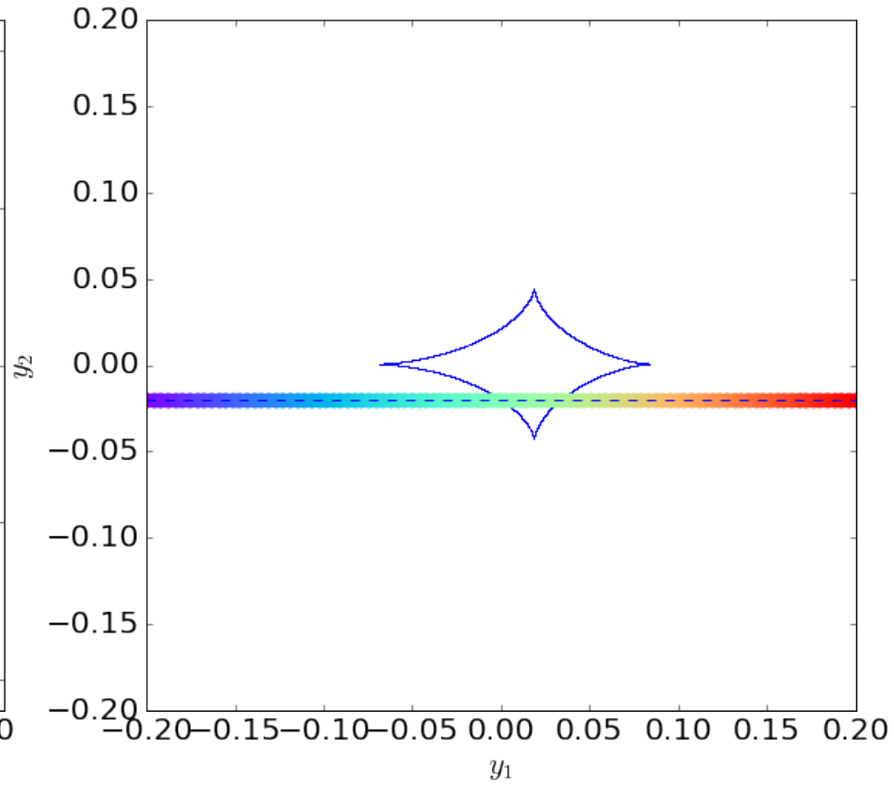


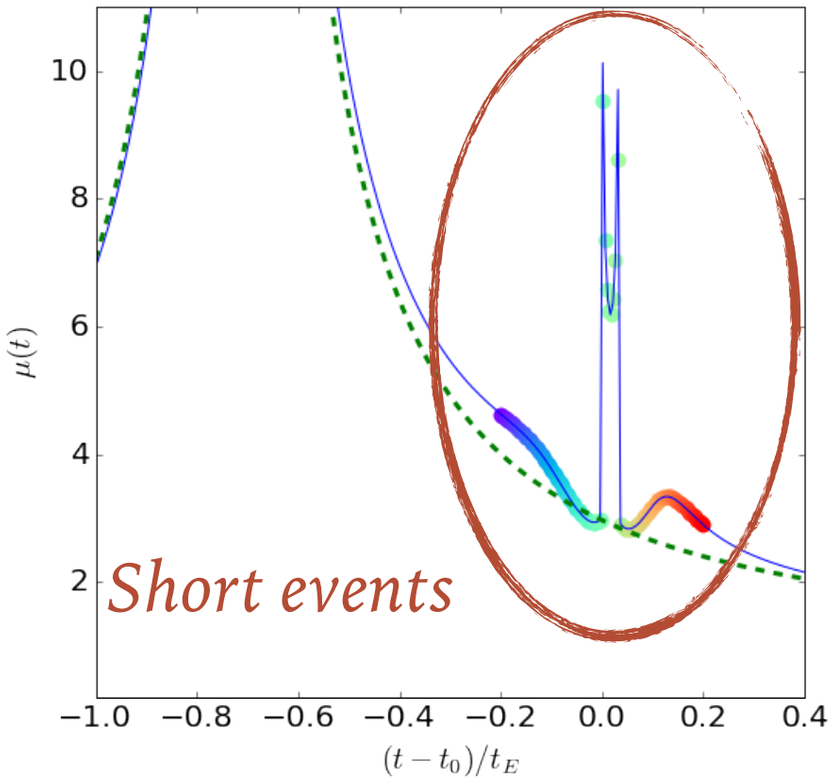


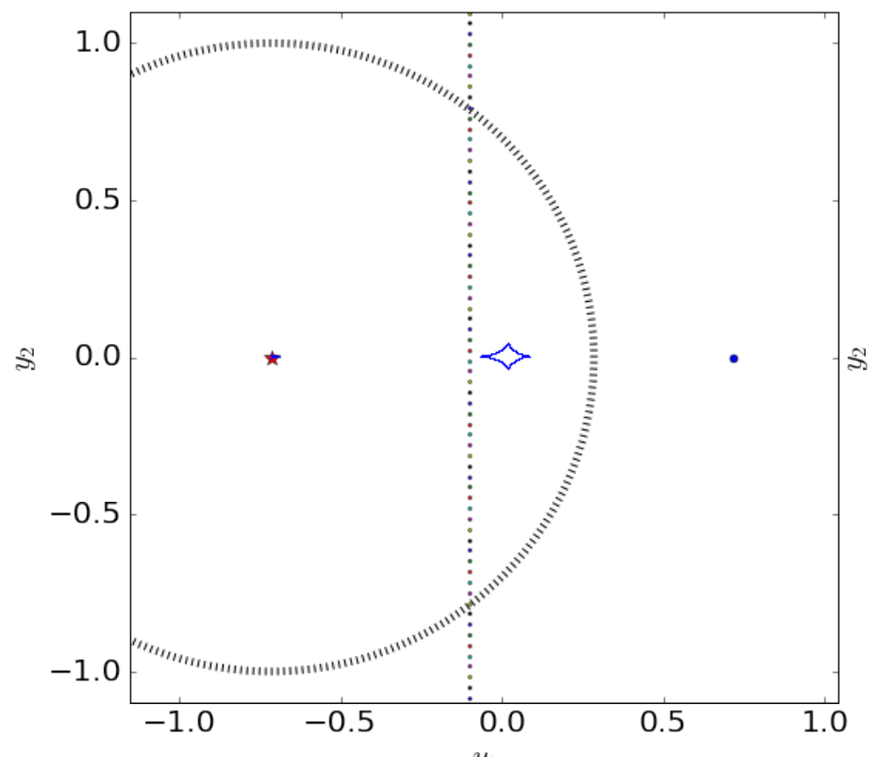


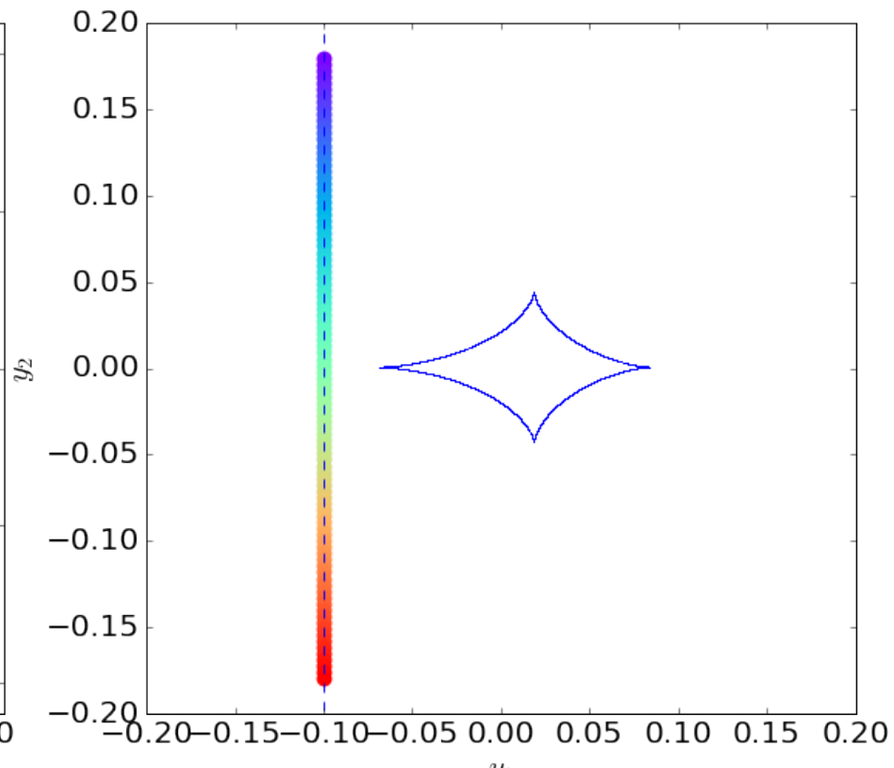
PLANETARY CAUSTICS PERTURBATIONS IN WIDE TOPOLOGIES

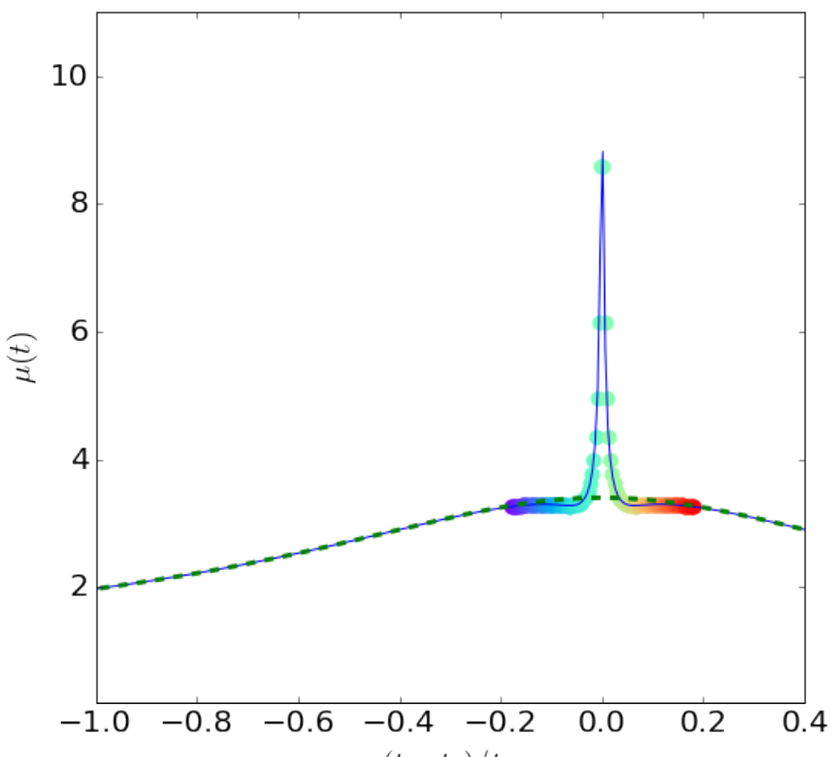




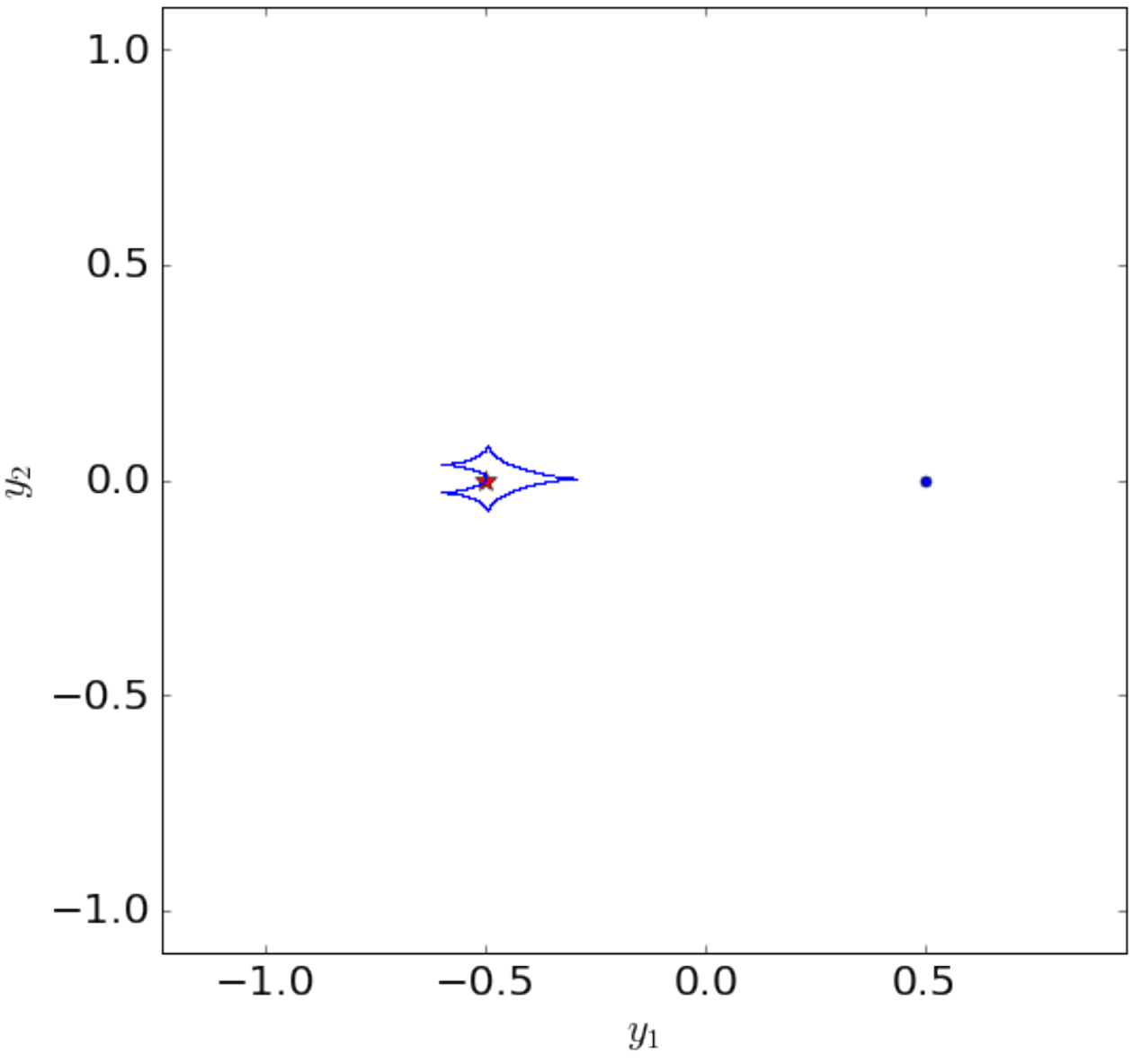


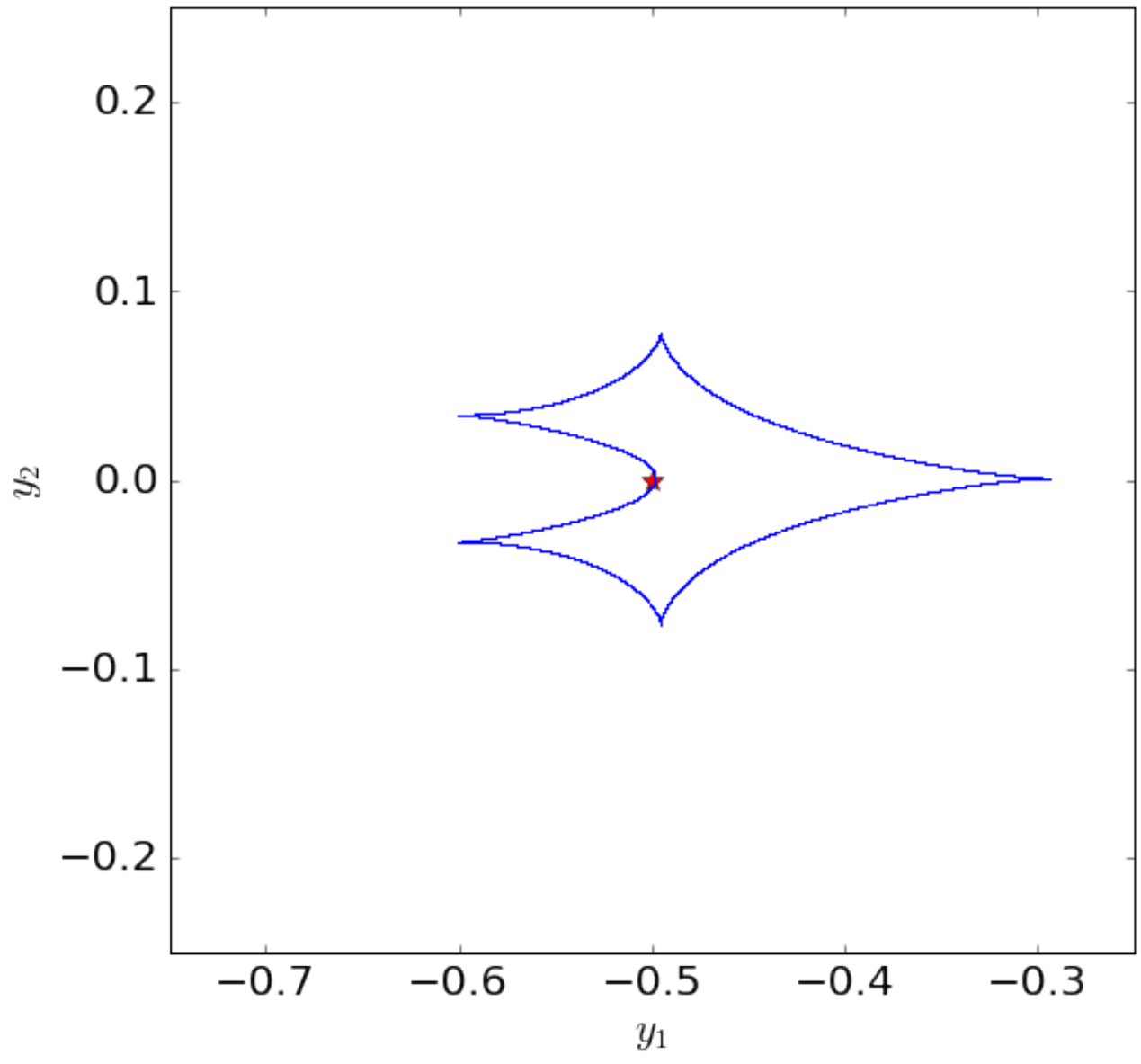




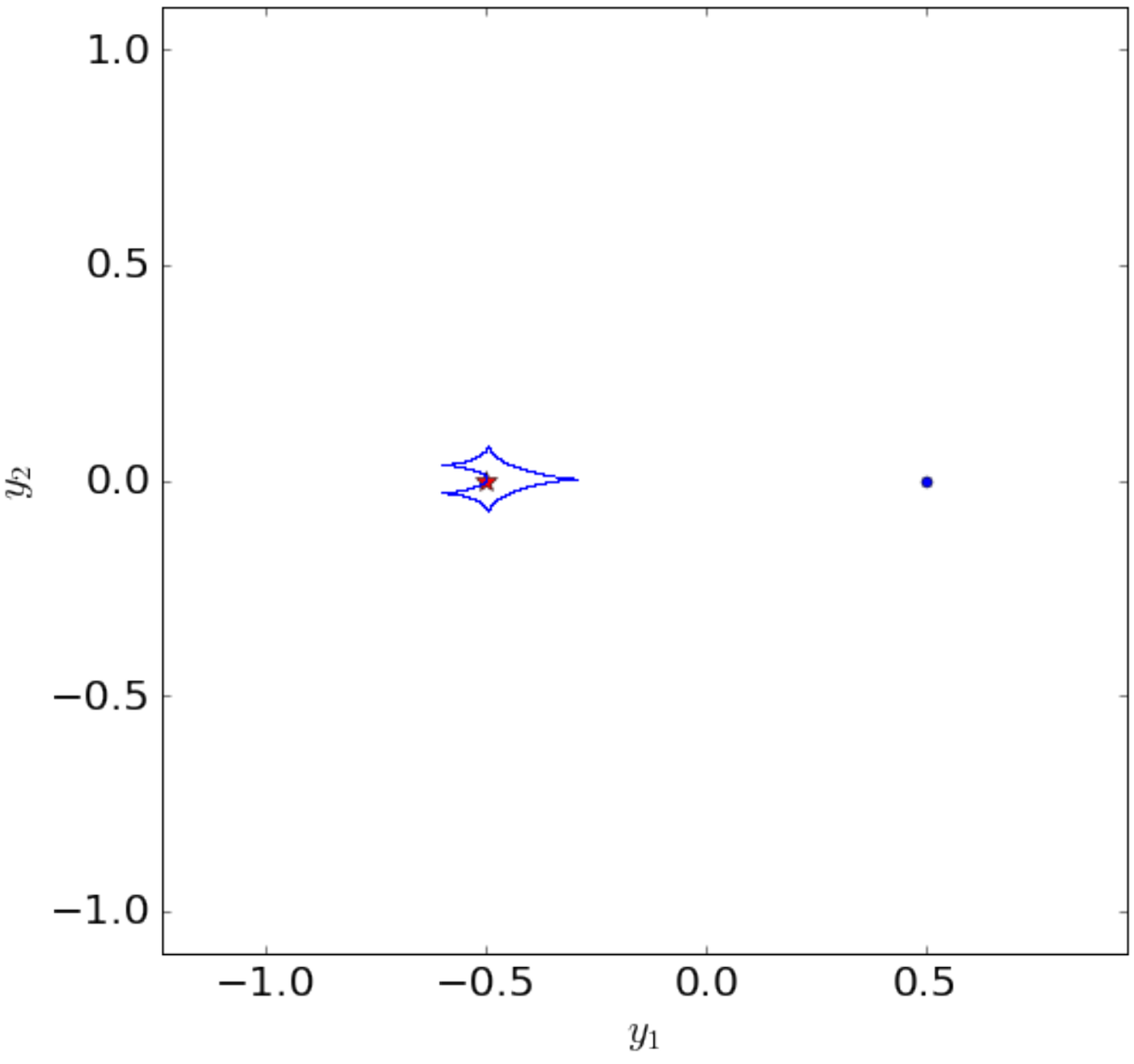


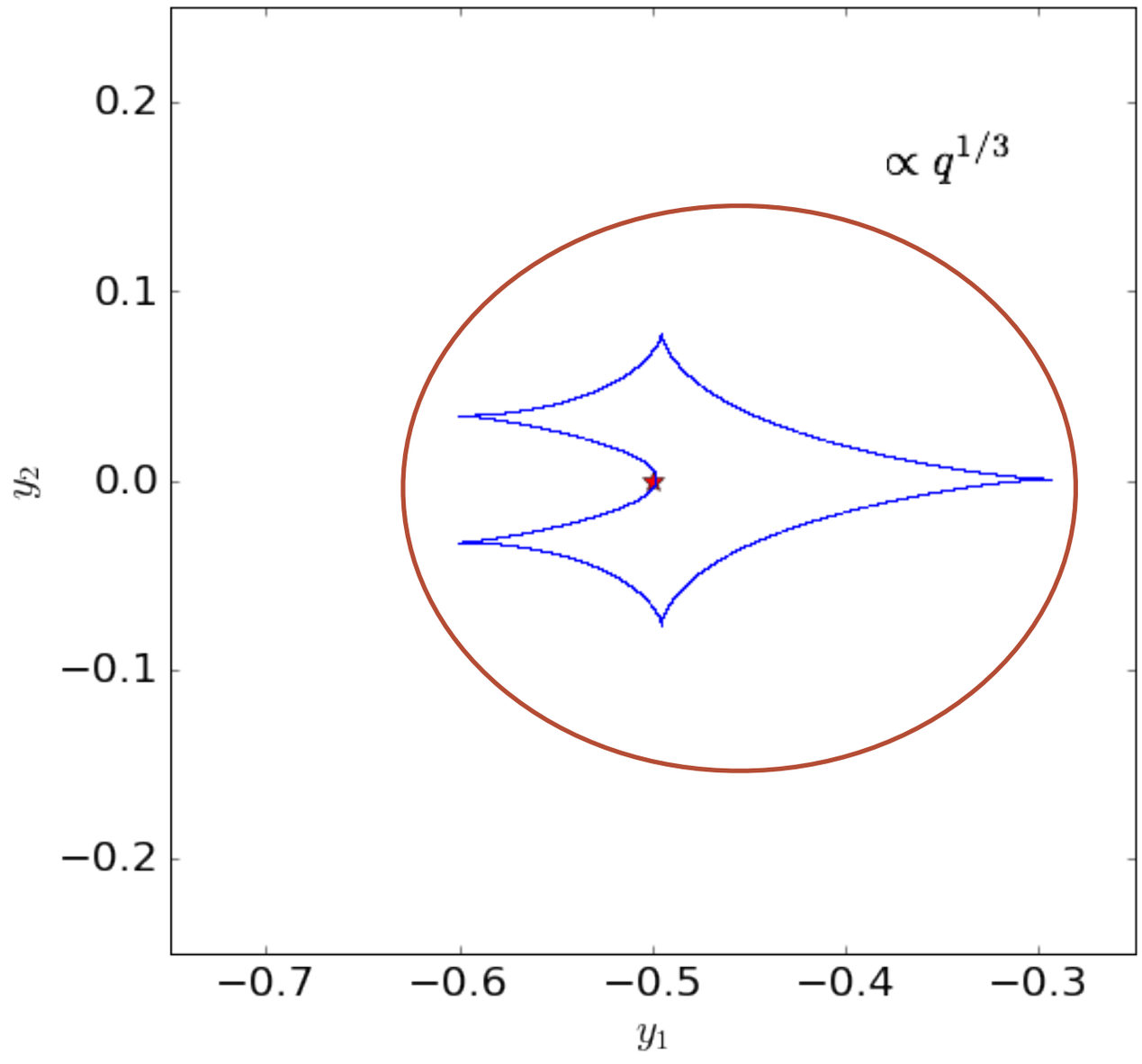
PLANETARY CAUSTICS IN INTERMEDIATE TOPOLOGIES



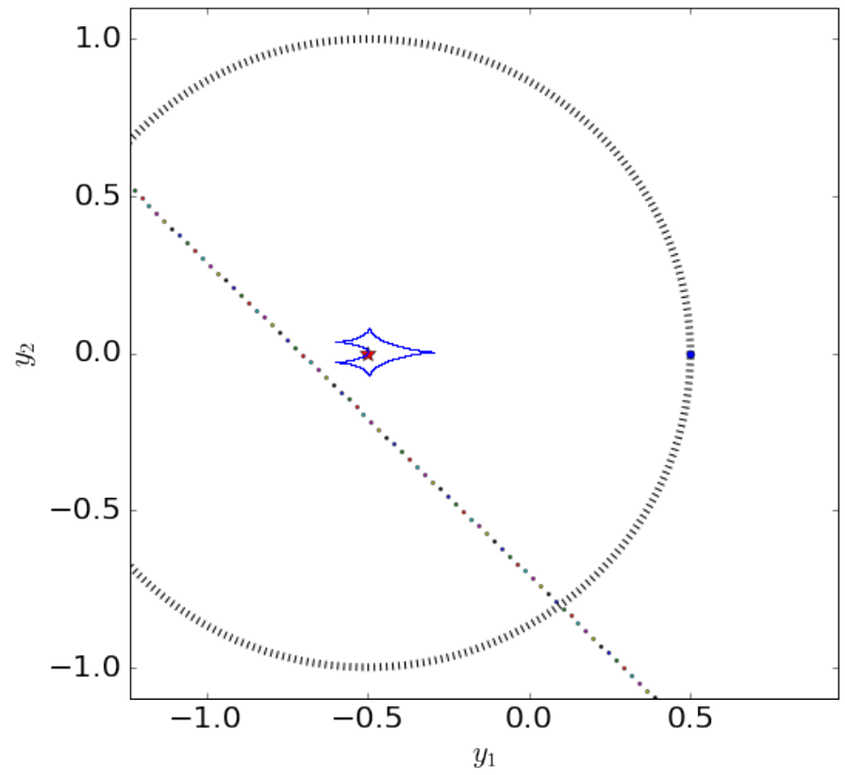


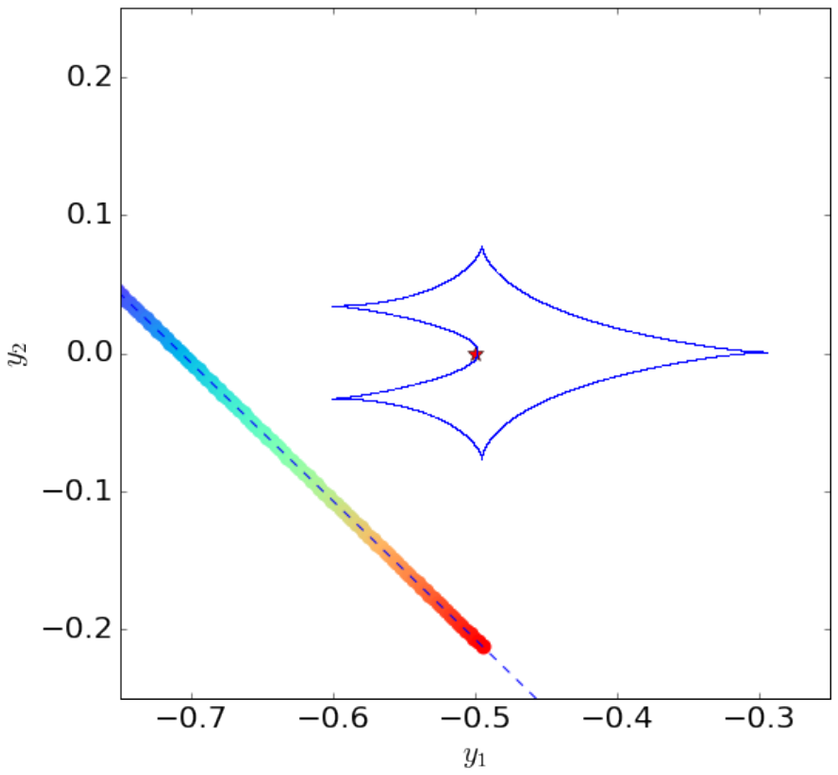
PLANETARY CAUSTICS IN INTERMEDIATE TOPOLOGIES

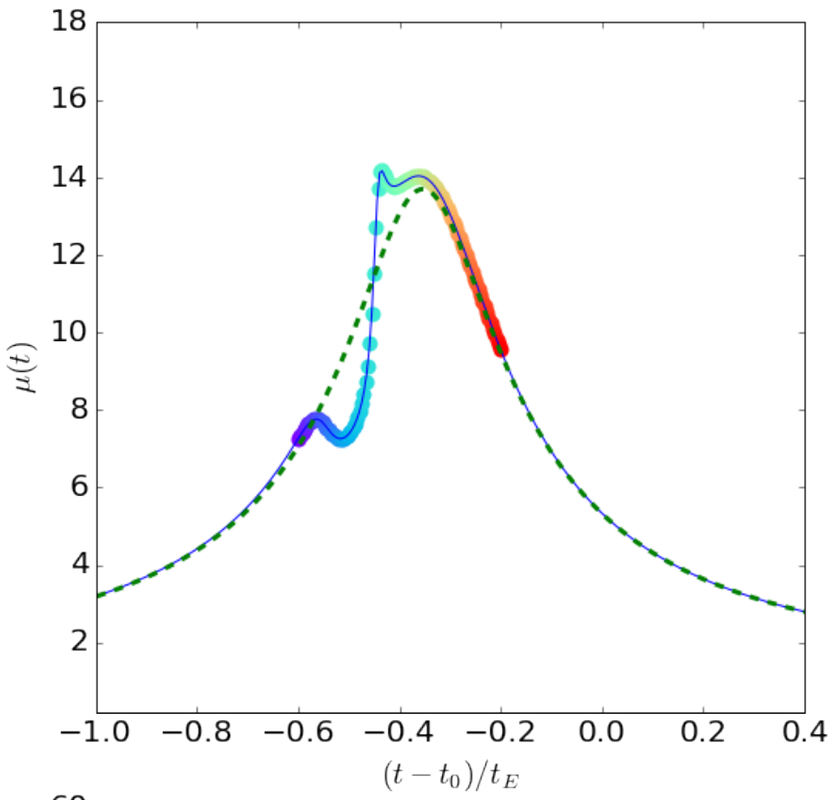


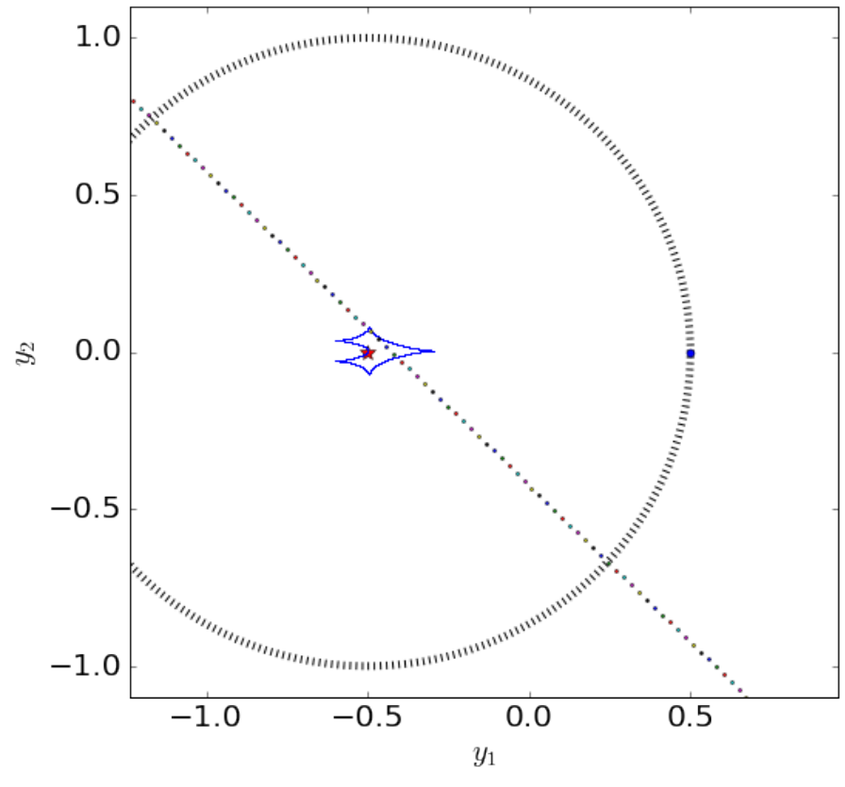


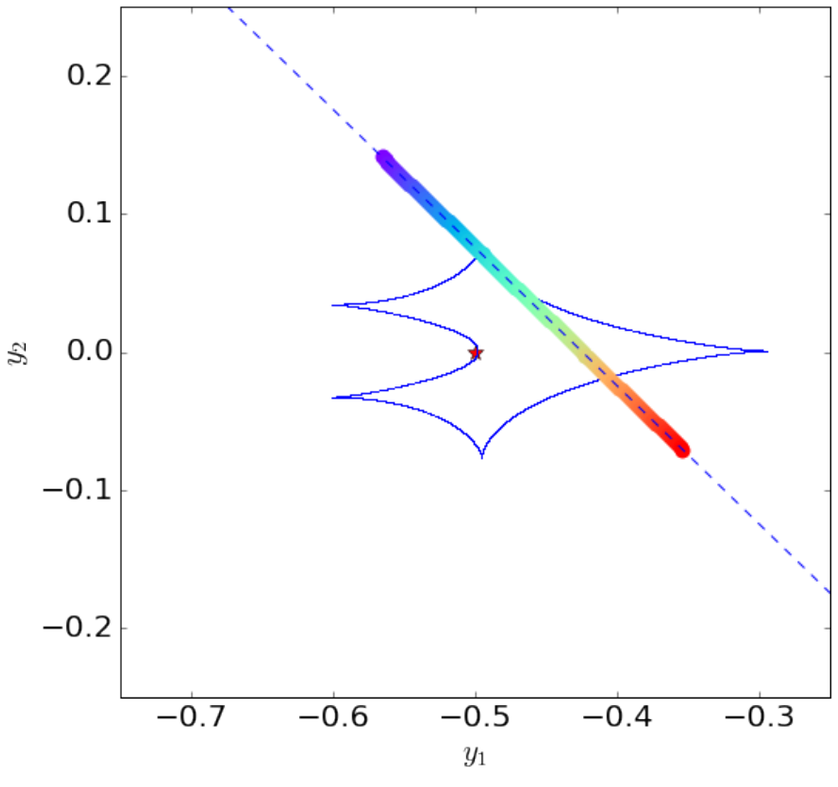
PLANETARY CAUSTICS PERTURBATIONS IN INTERMEDIATE TOPOLOGIES

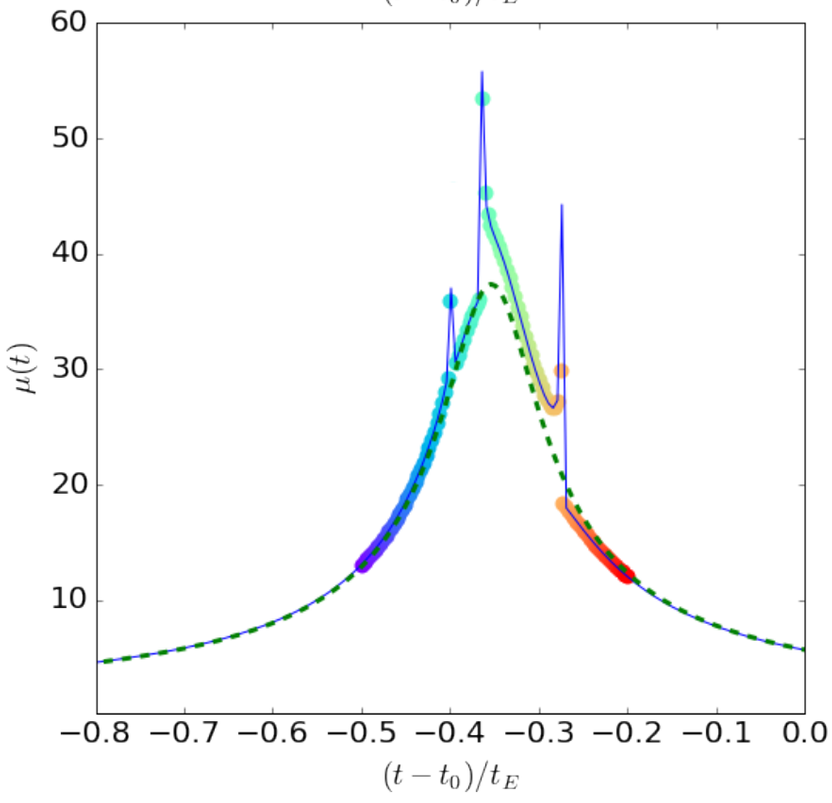




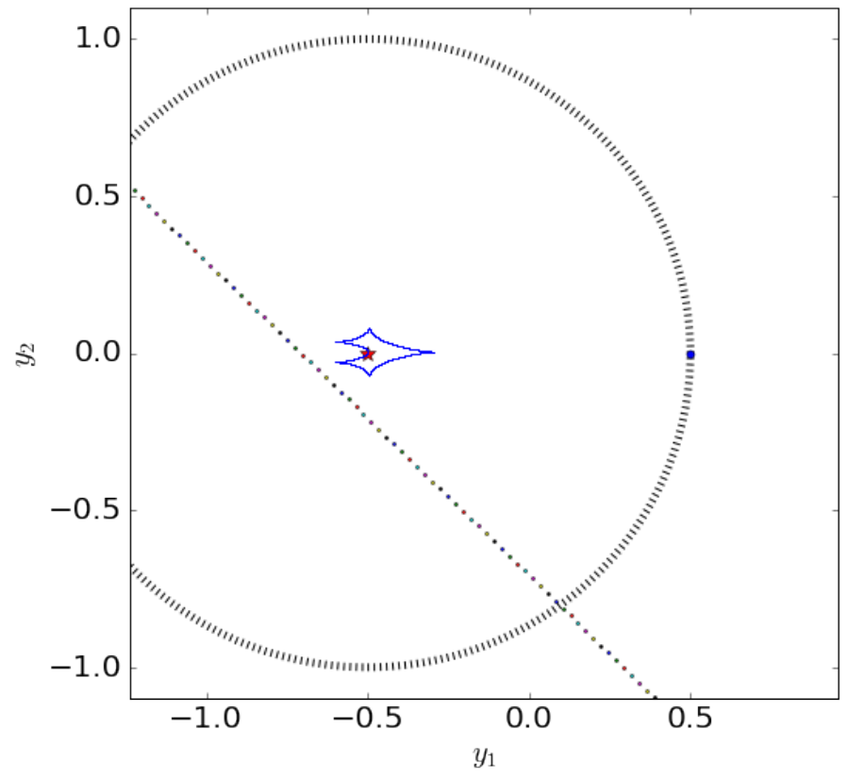


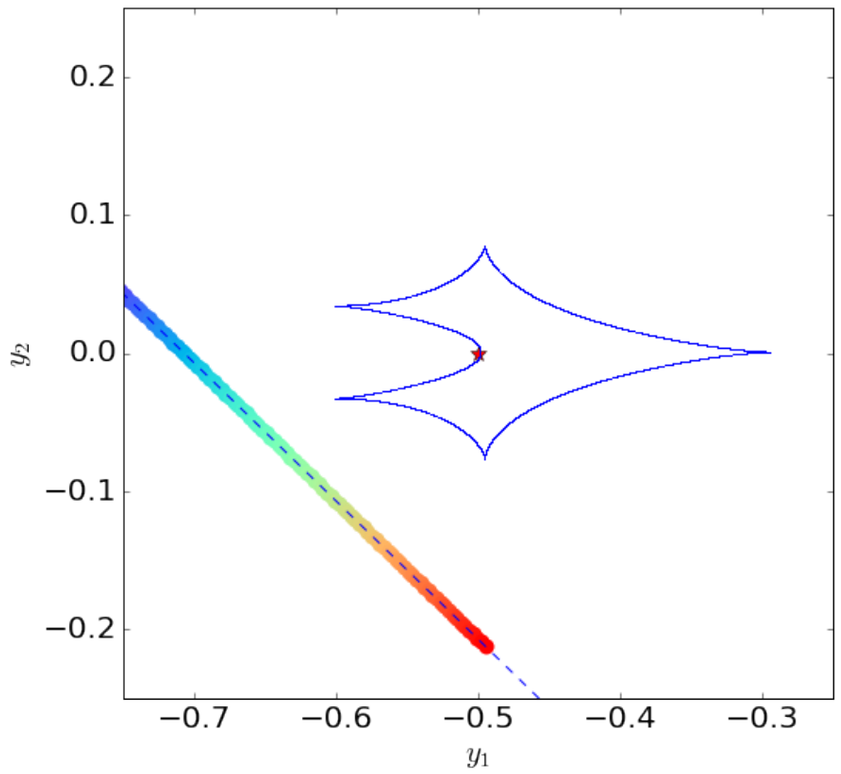


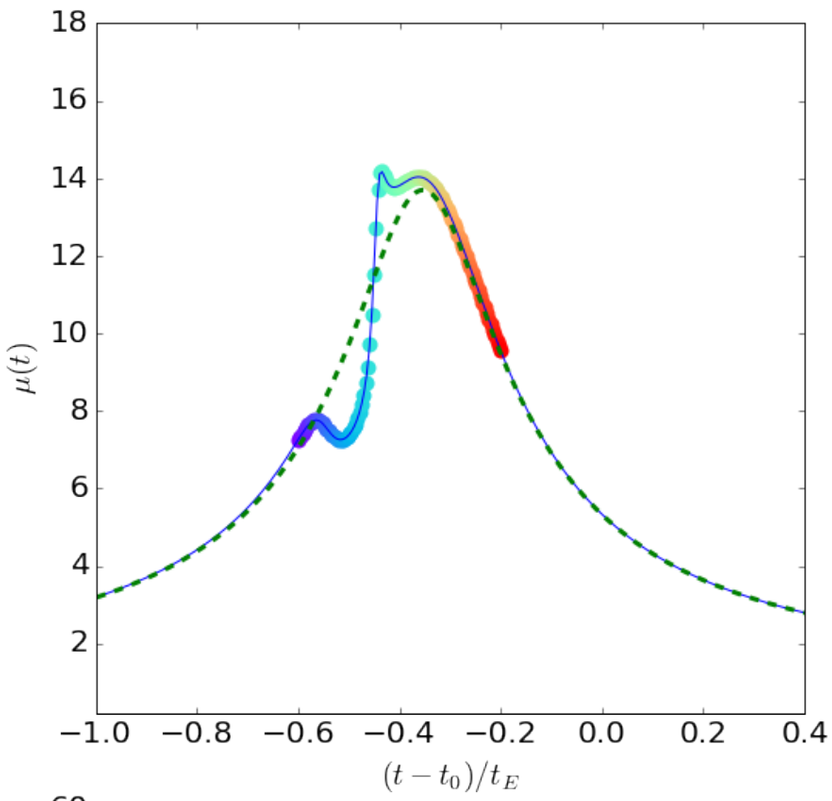


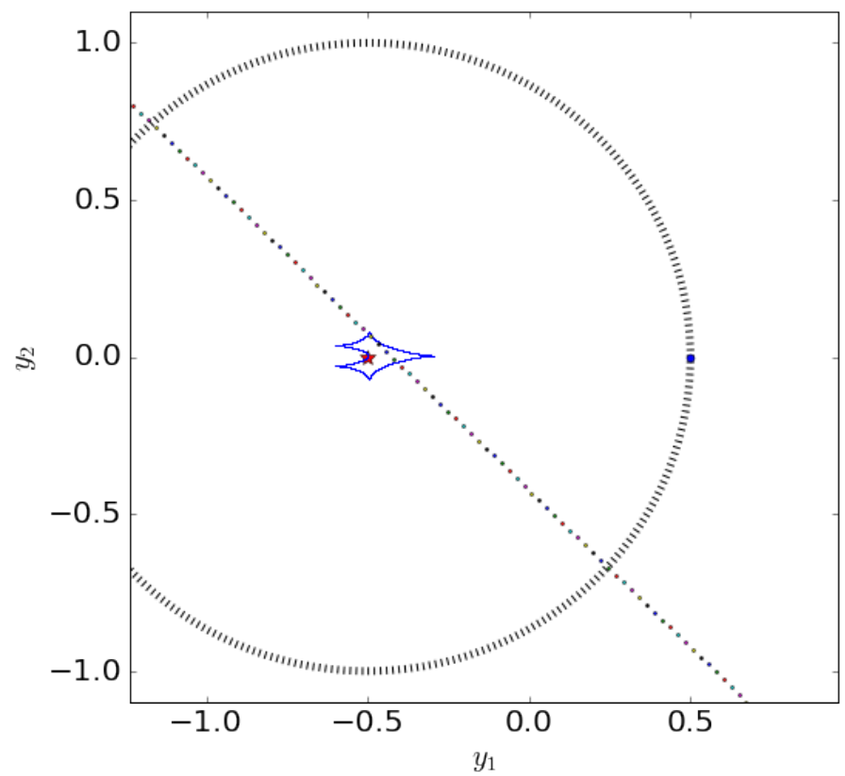


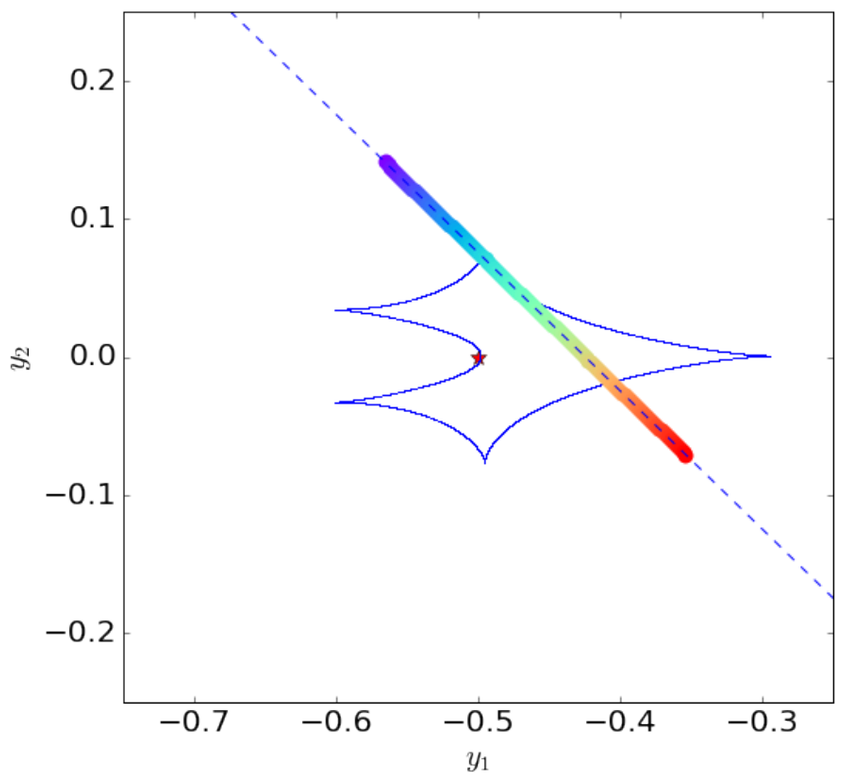
PLANETARY CAUSTICS PERTURBATIONS IN INTERMEDIATE TOPOLOGIES

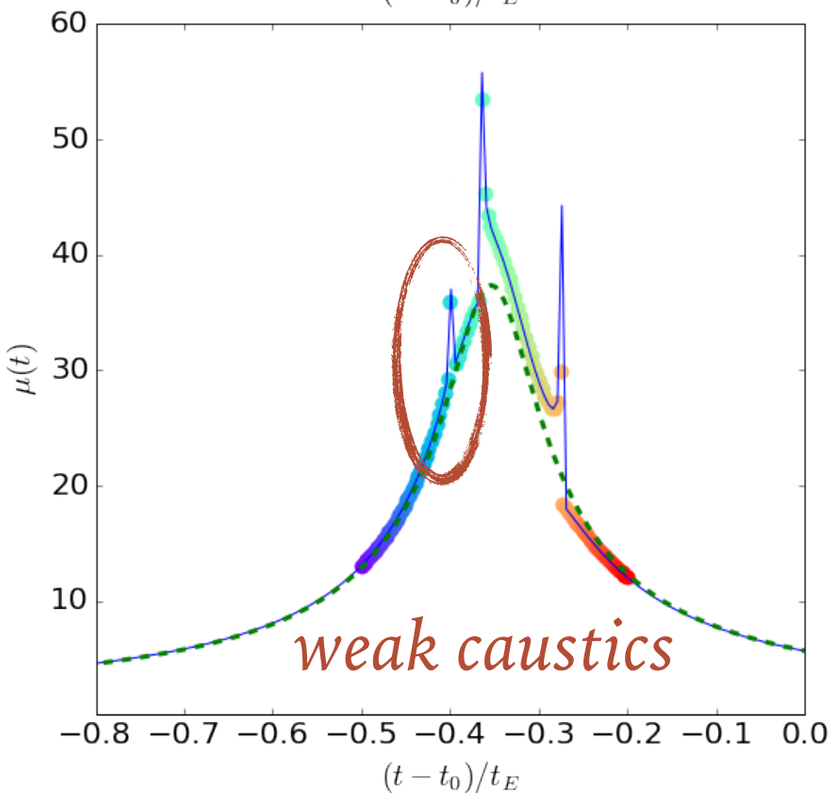




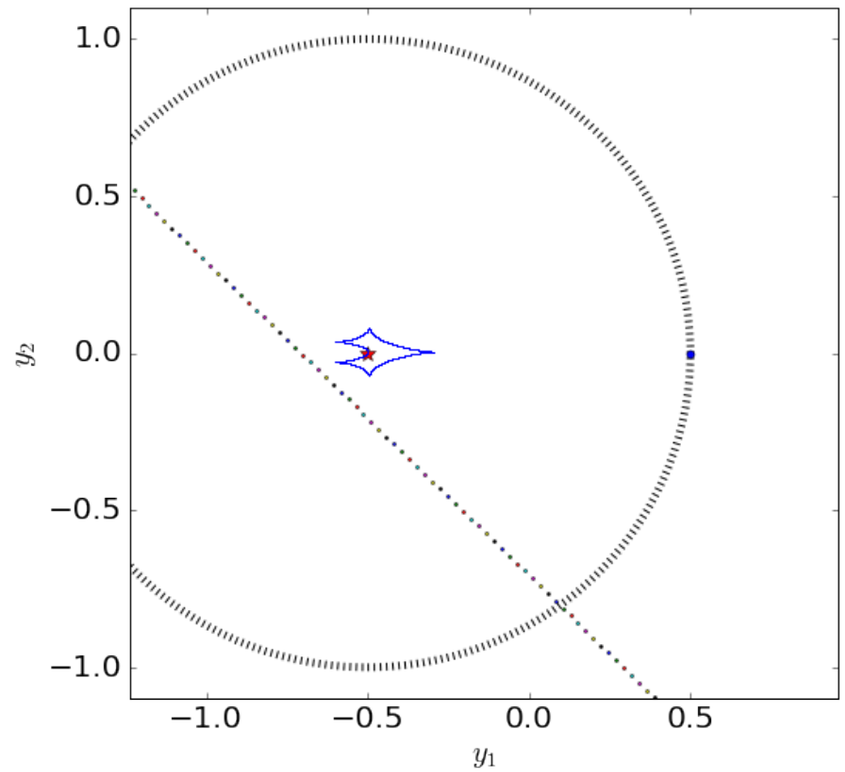


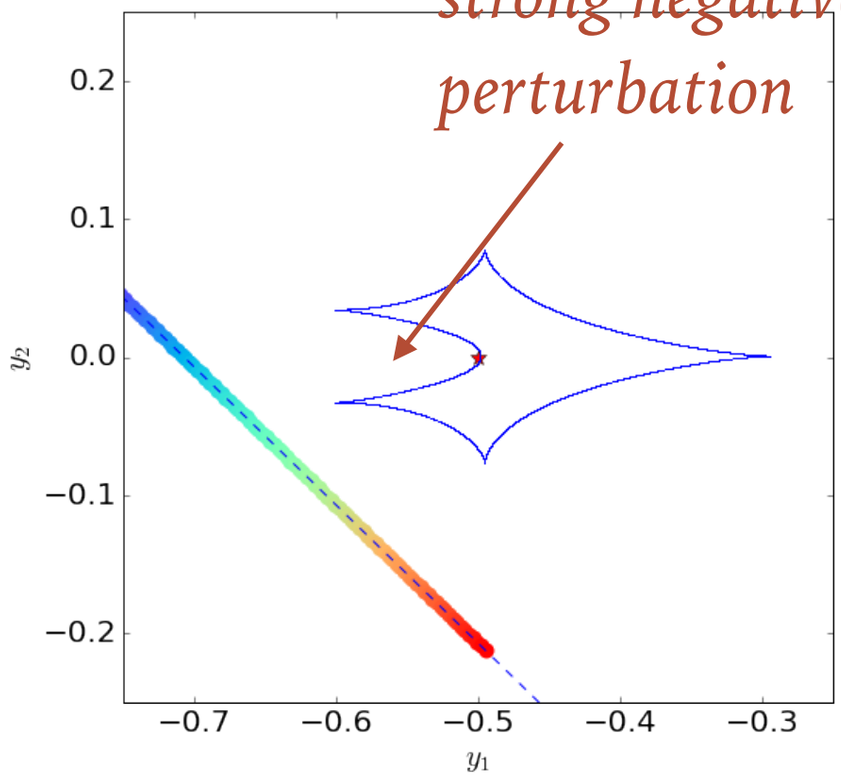


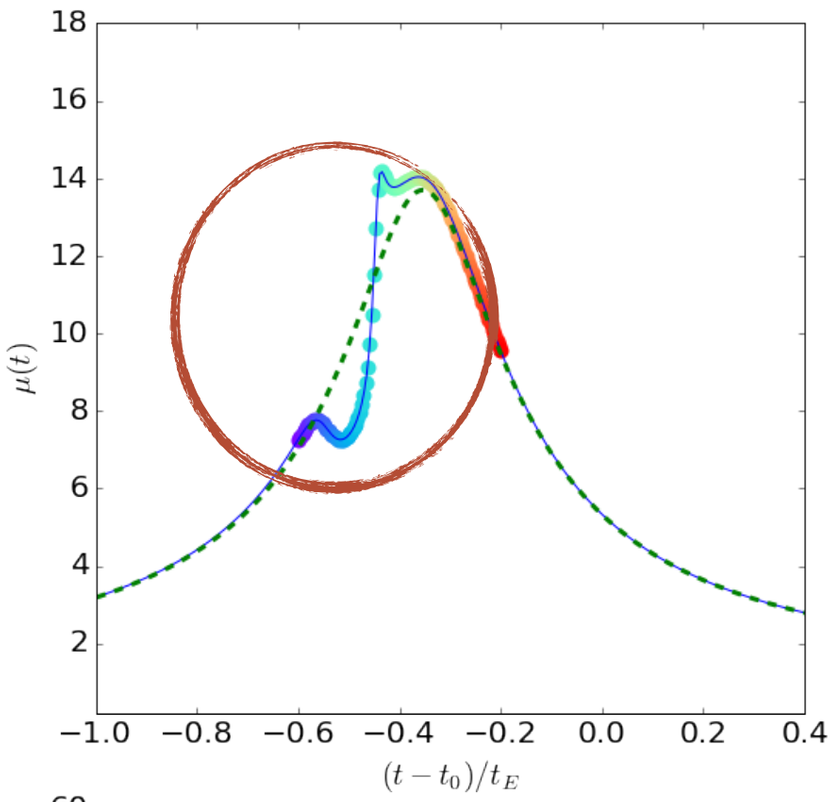


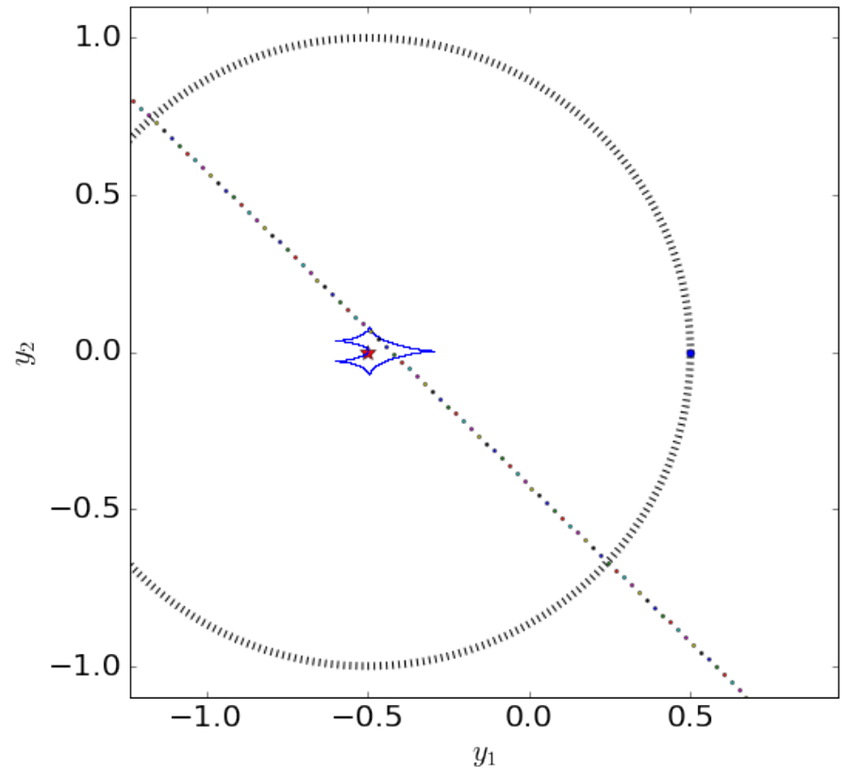


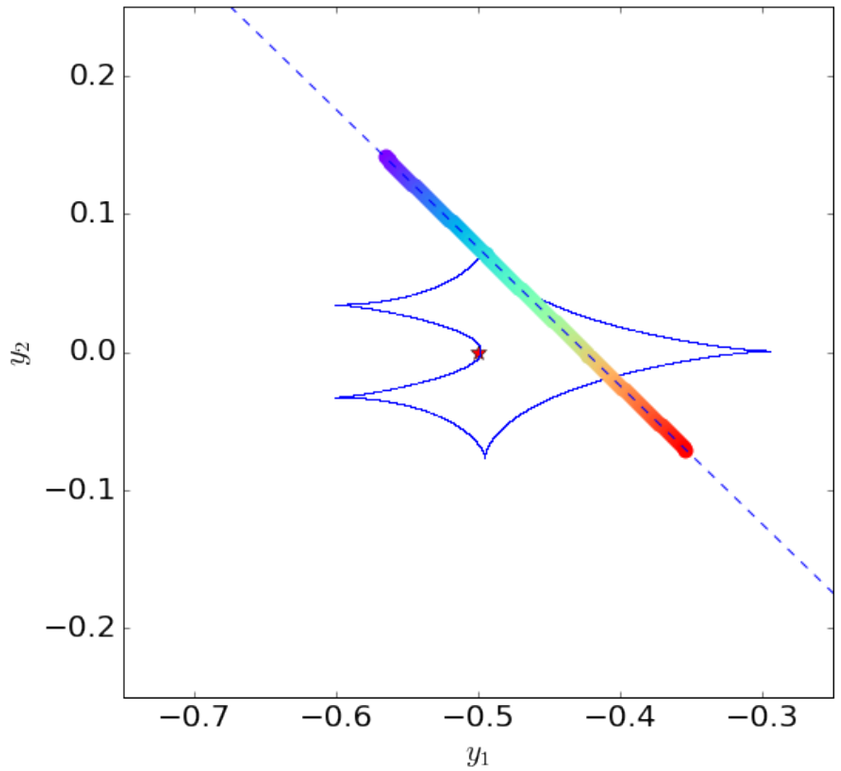
PLANETARY CAUSTICS PERTURBATIONS IN INTERMEDIATE TOPOLOGIES

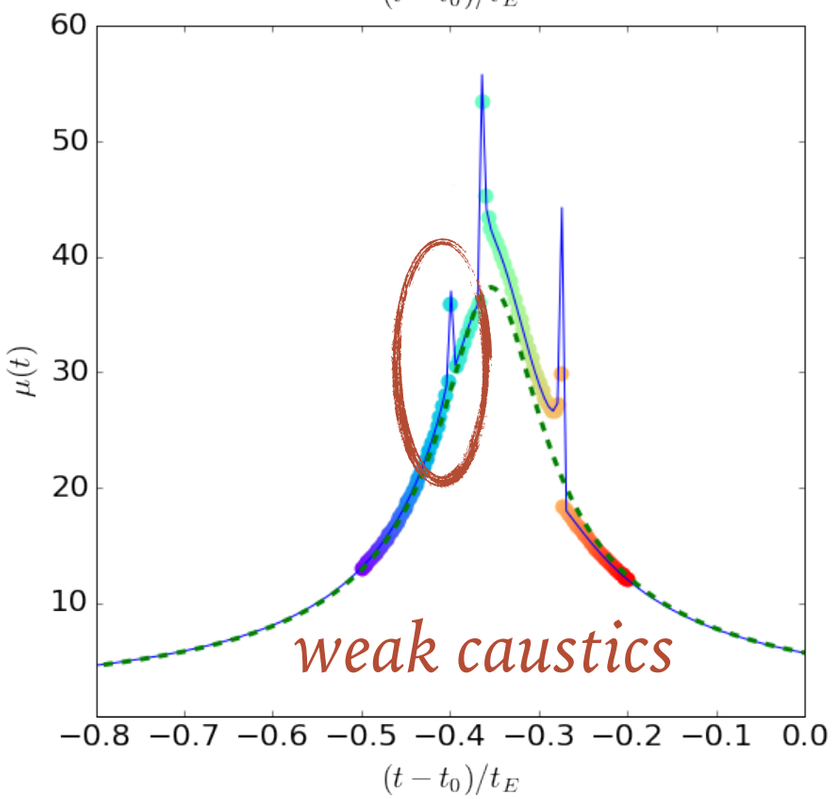




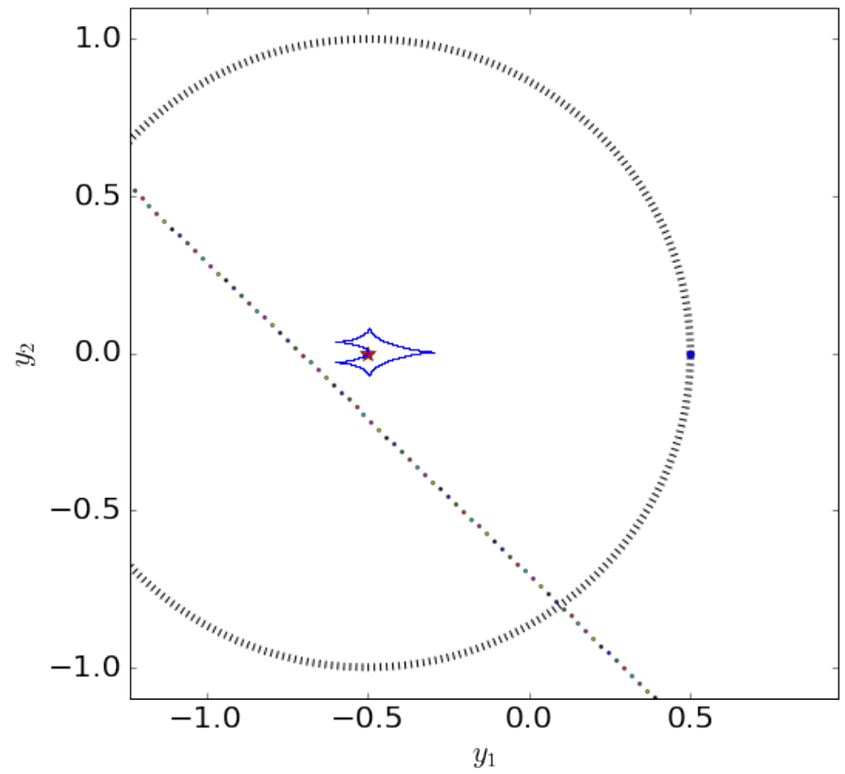


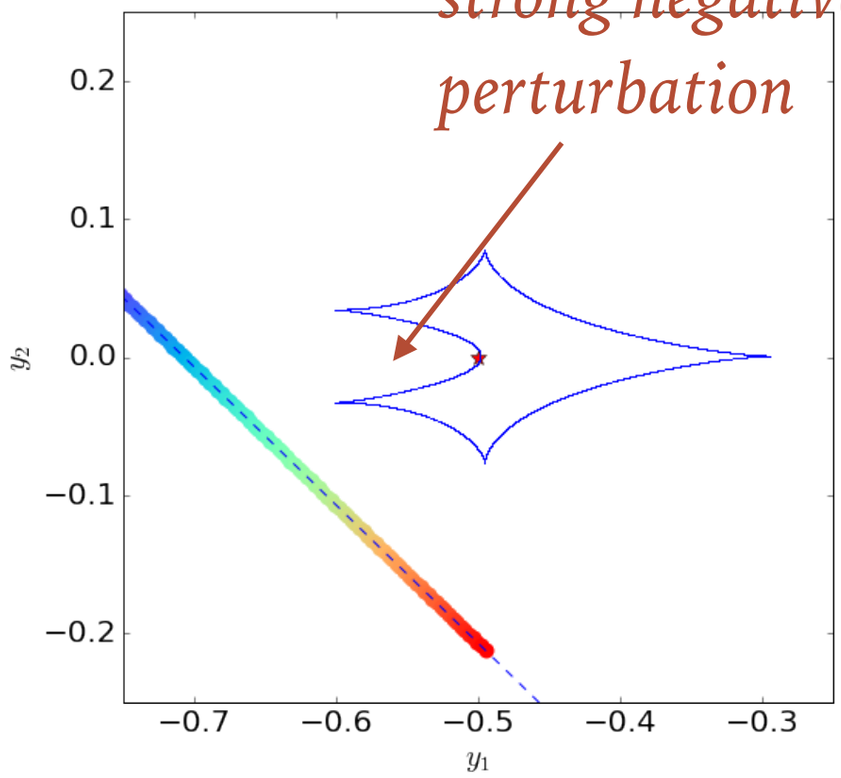


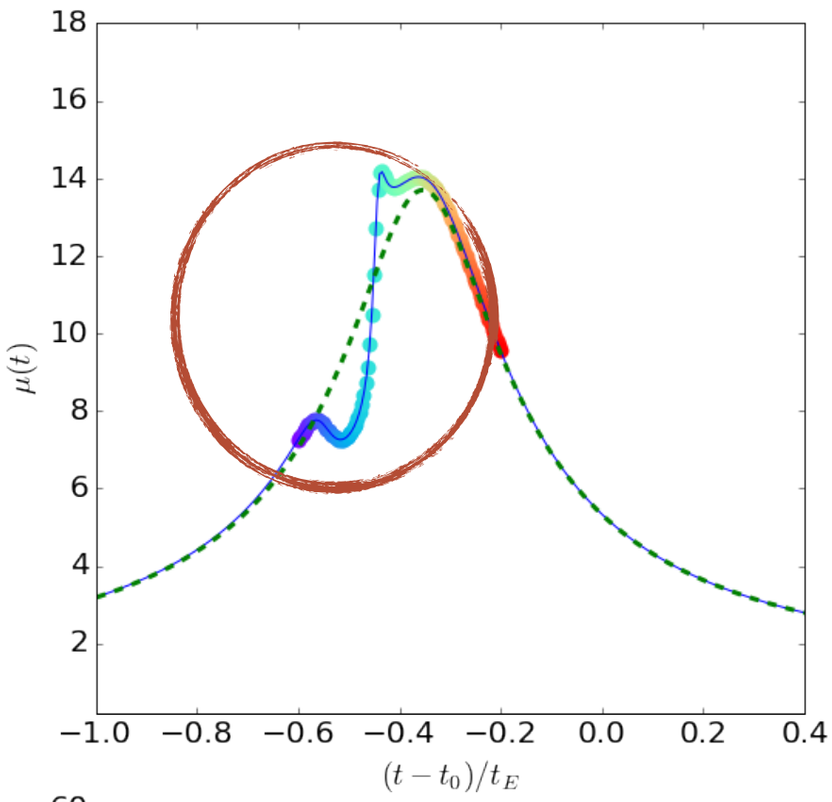


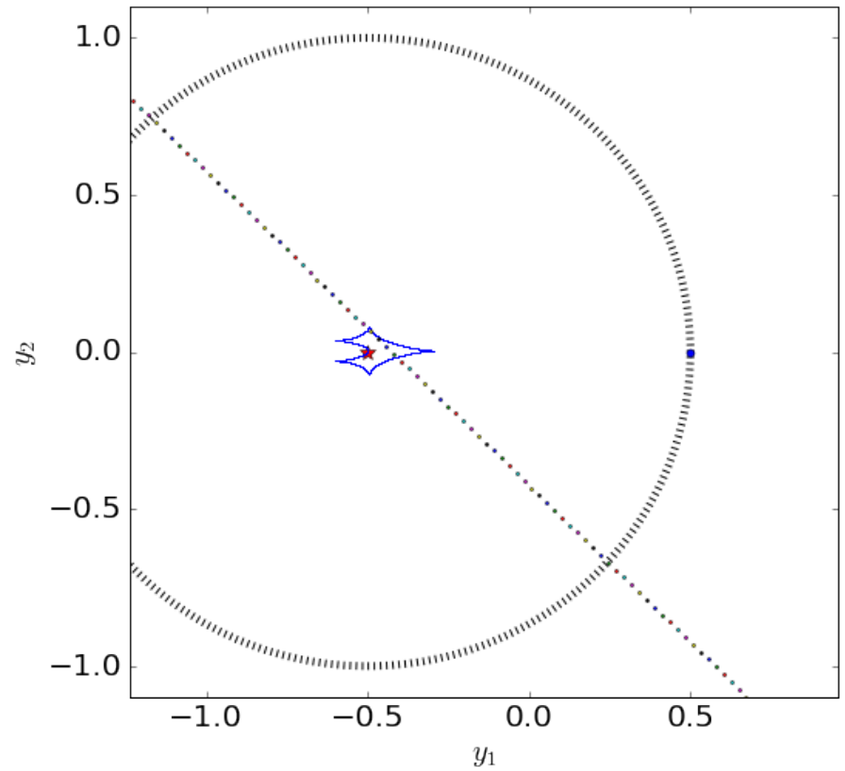


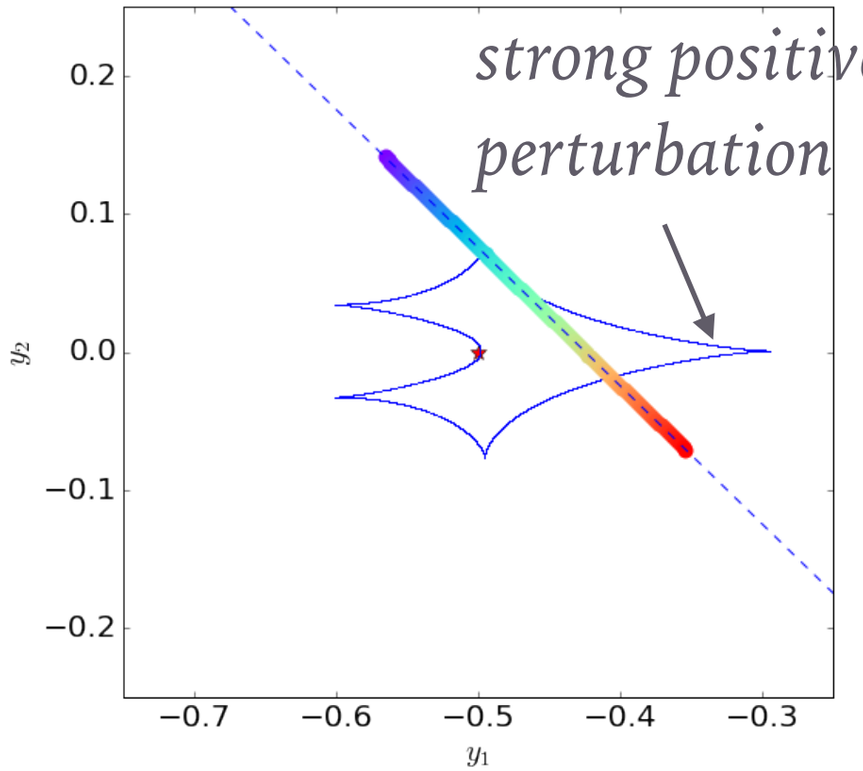
PLANETARY CAUSTICS PERTURBATIONS IN INTERMEDIATE TOPOLOGIES

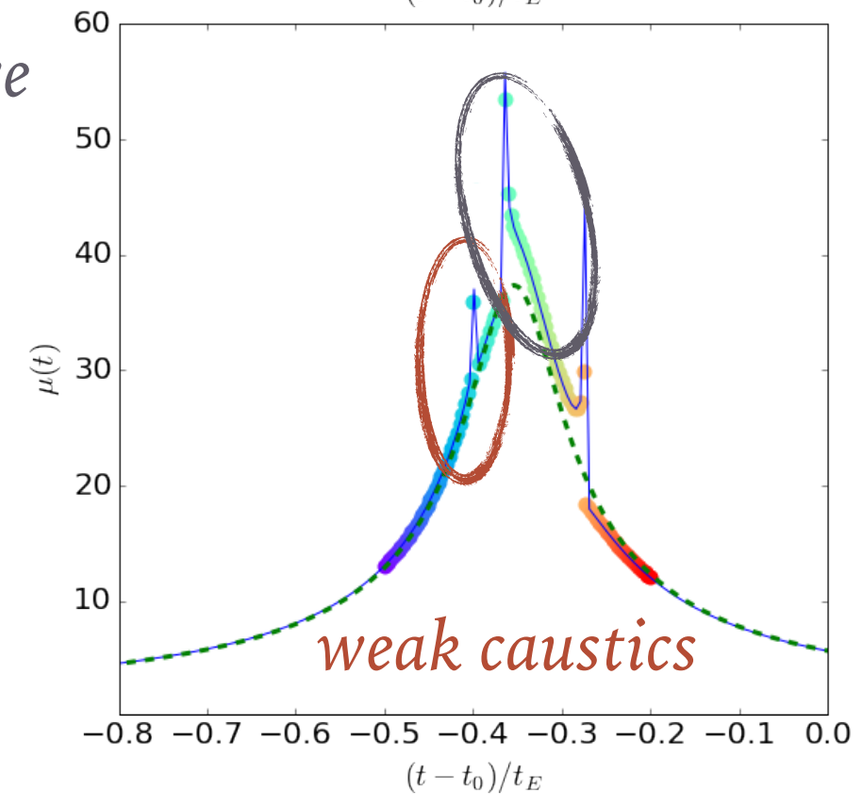






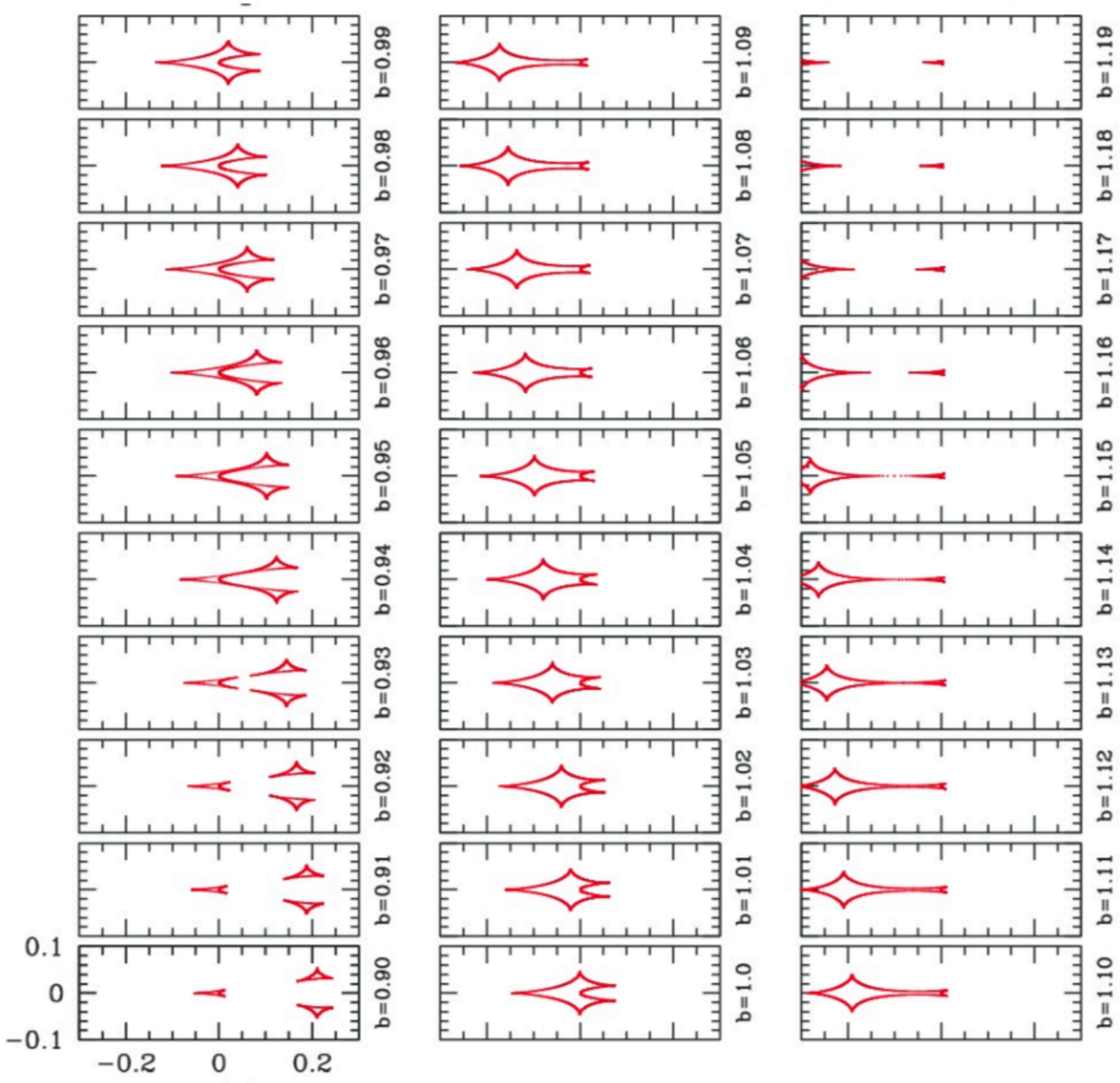






SHAPE OF THE RESONANT CAUSTIC VS D

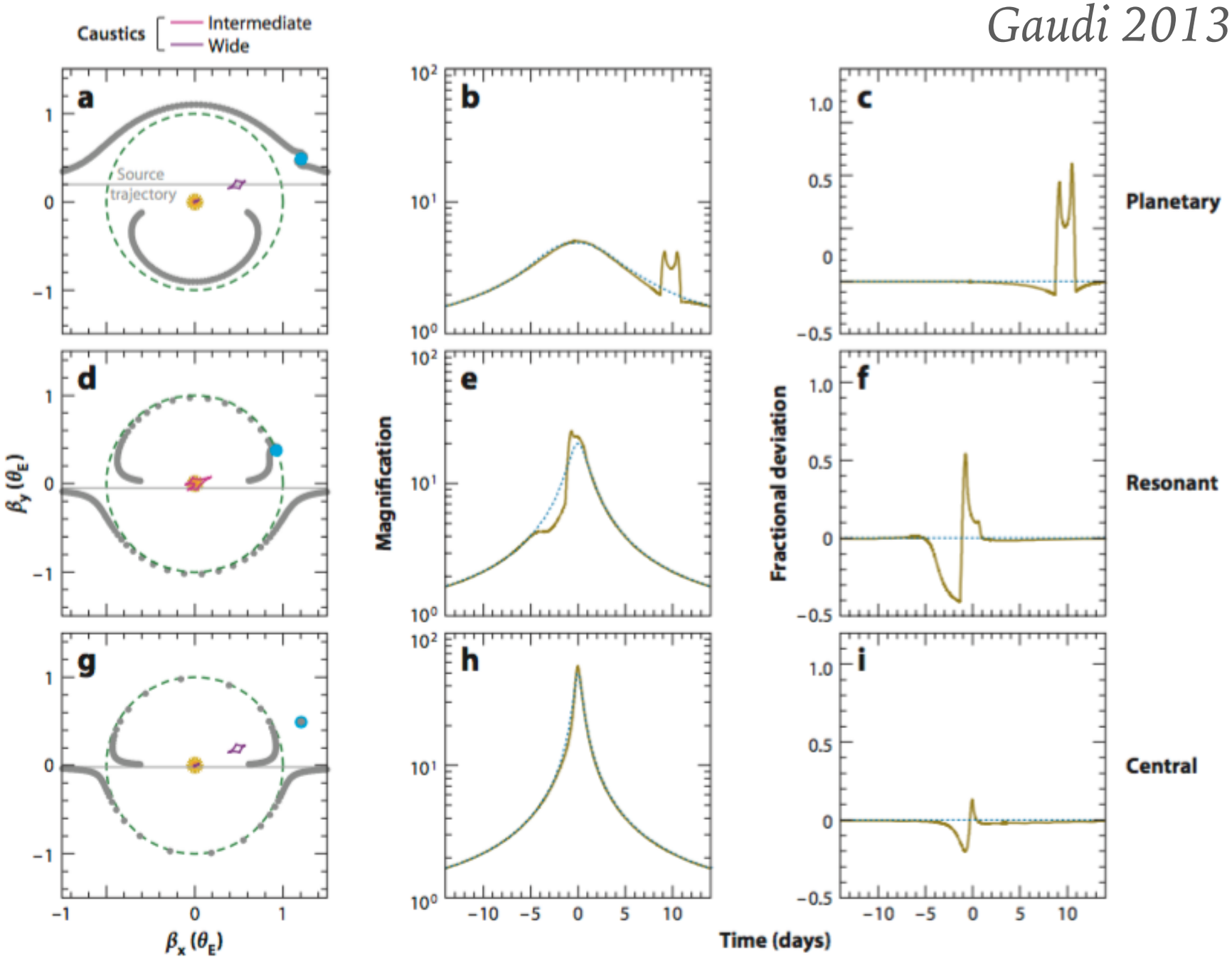
$$q = 0.001,\ s = 0.90 - 1.19,\ \Delta s = 0.29$$



A COMPLEMENTARY VIEW

Gaudi 2013

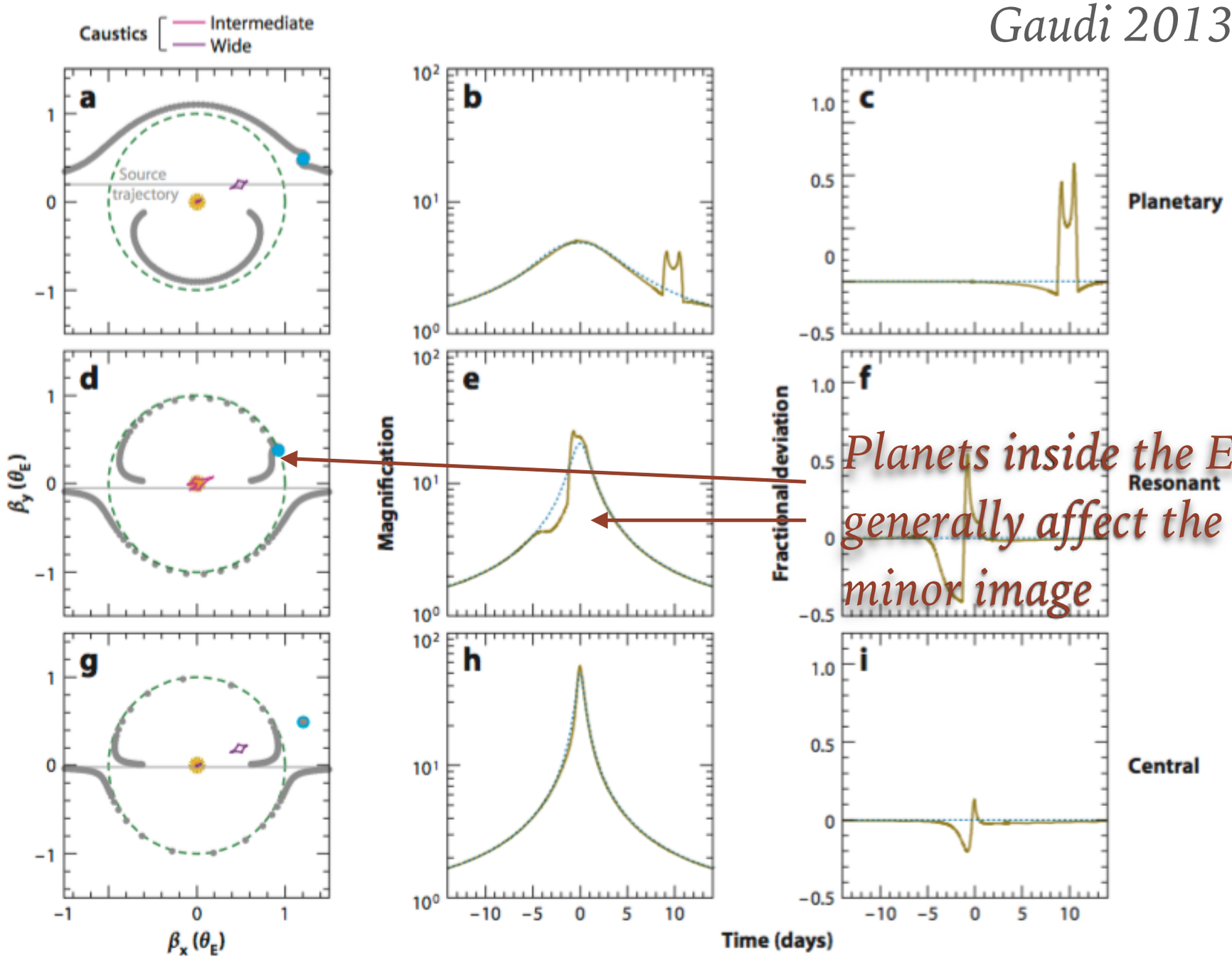
The planet can be detected when it perturbs one of the two images of the source!



A COMPLEMENTARY VIEW

Gaudi 2013

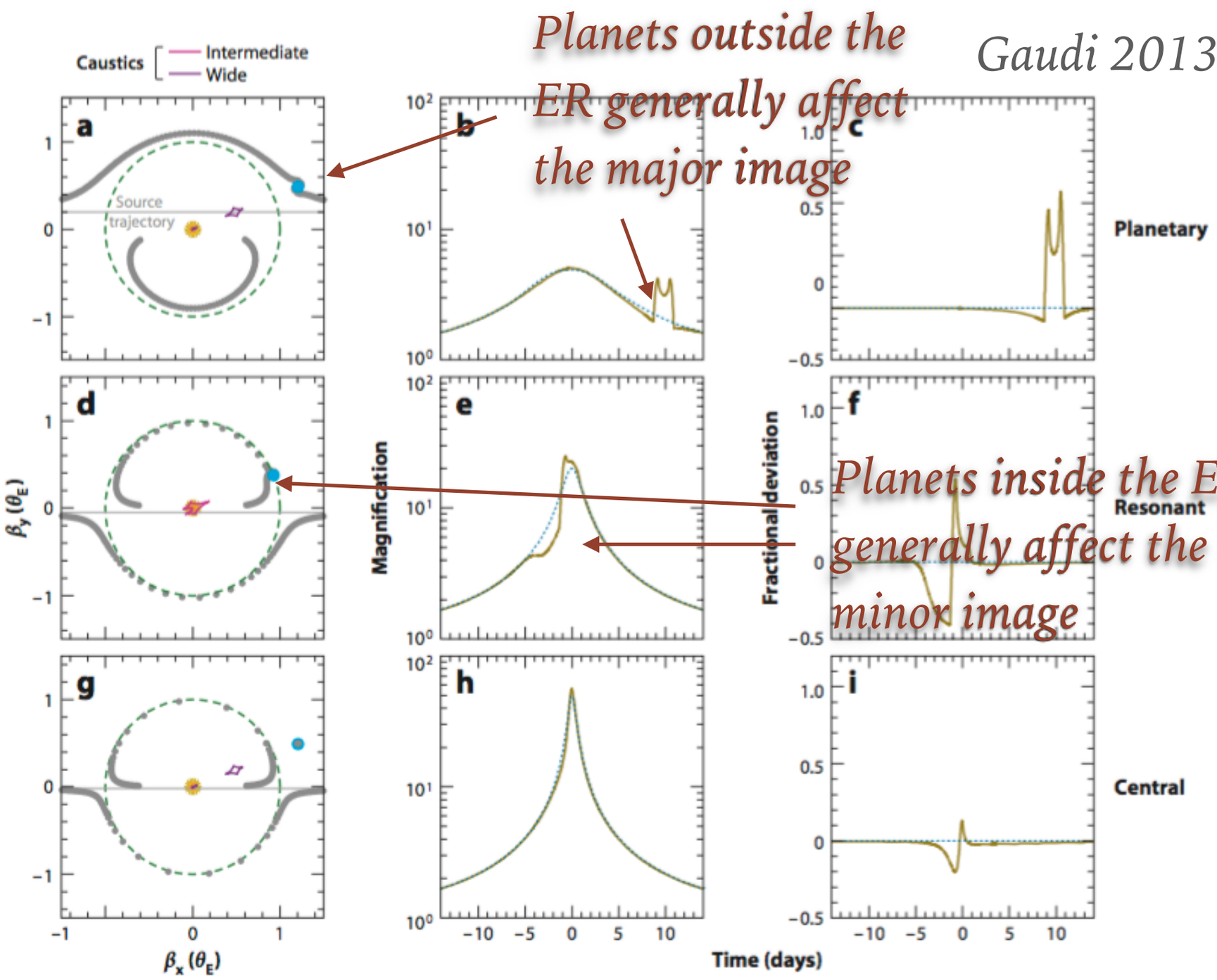
The planet can be detected when it perturbs one of the two images of the source!



Planets inside the ER generally affect the minor image

A COMPLEMENTARY VIEW

The planet can be detected when it perturbs one of the two images of the source!



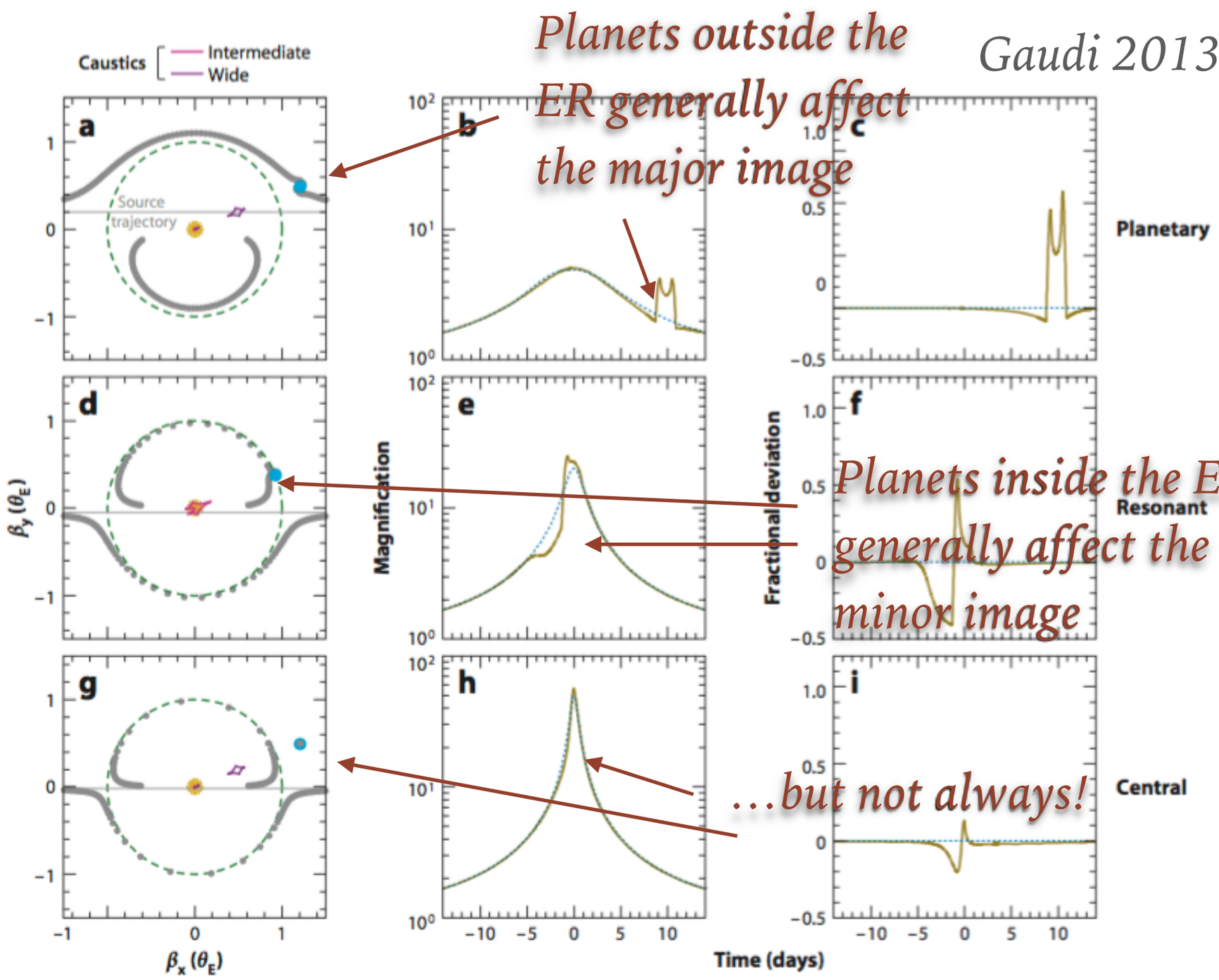
Planets outside the ER generally affect the major image

Planets inside the ER generally affect the minor image

Gaudi 2013

A COMPLEMENTARY VIEW

The planet can be detected when it perturbs one of the two images of the source!



Planets outside the ER generally affect the major image

Gaudi 2013

Planets inside the ER generally affect the minor image

…but not always!

INTERPRETING THE LIGHT CURVES

If we notice a planetary caustic perturbation, it means that the planet is located at the position of one of the images:

$$x_{\pm} = d$$

Consequently the caustic which is being crossed has a position which can be derived from the lens equation (which is satisfied by the images)

$$y_c = |d - d^{-1}|$$