GRAVITATIONAL LENSING

LECTURE 17

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AA 2016-2017

TODAY'S LECTURE

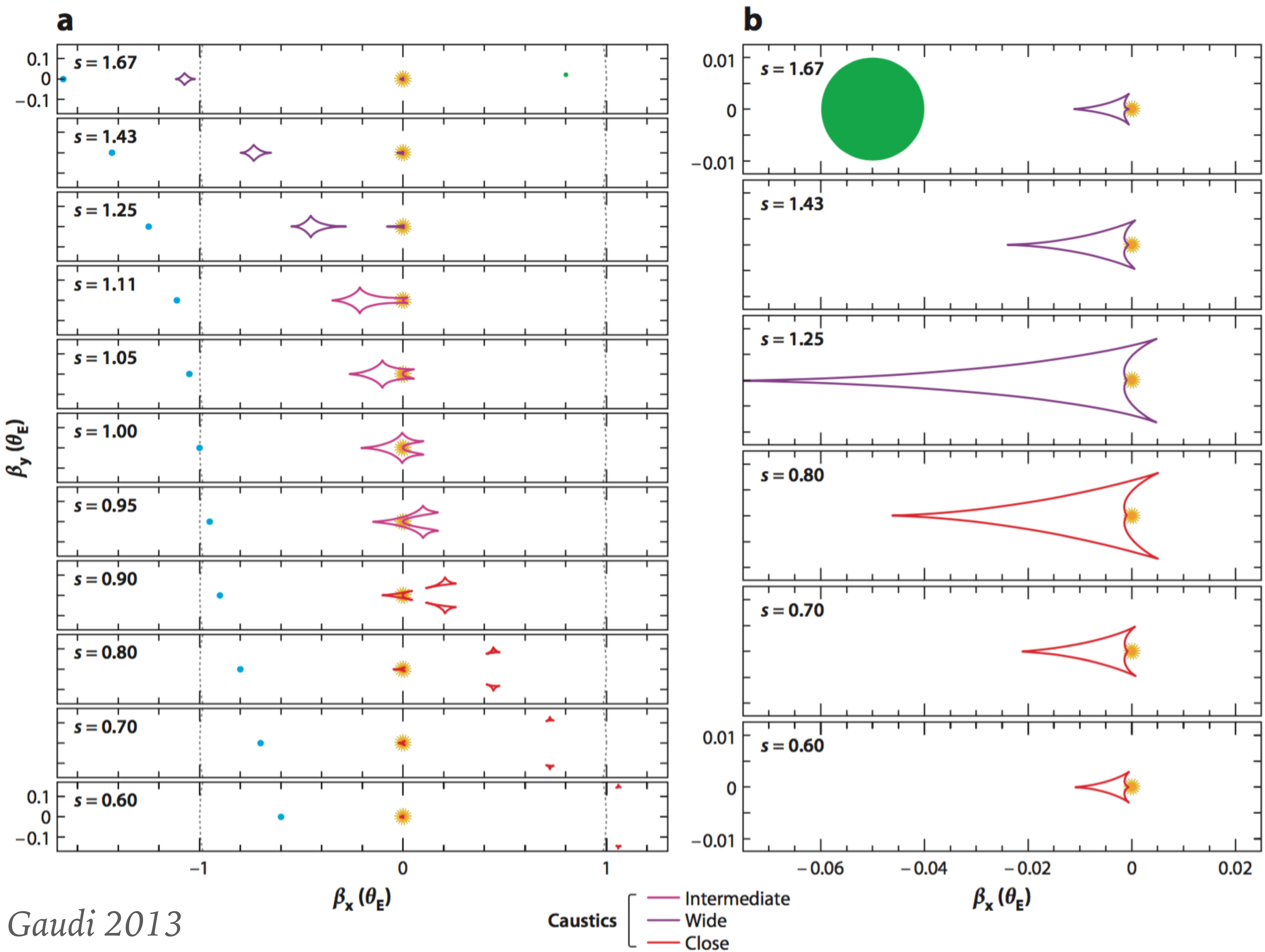
- Lensing by multiple point masses
  - Binary lenses
    - Planetary microlensing

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 $q=0.000003$

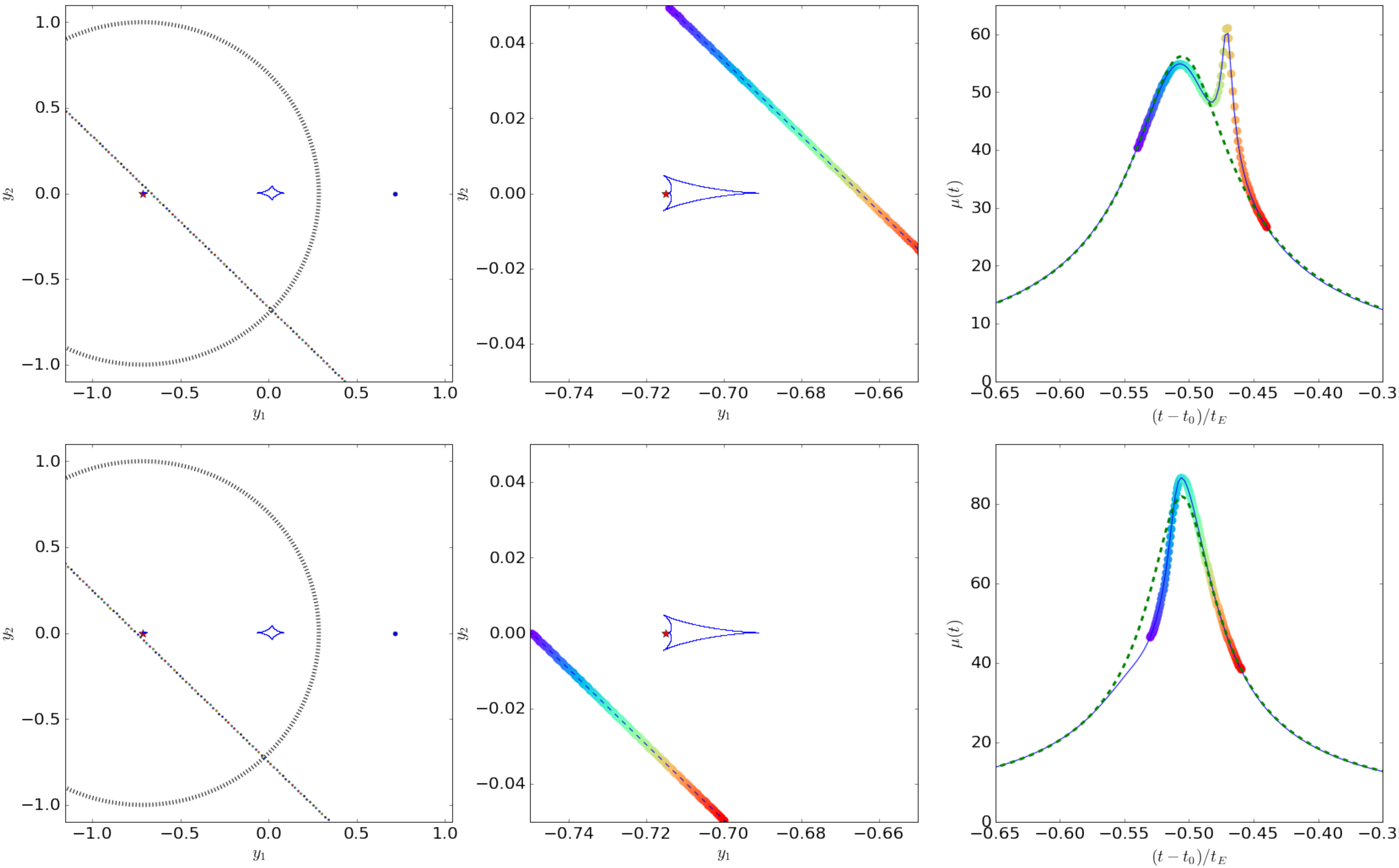
WHAT KIND OF SIGNAL?

- **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…

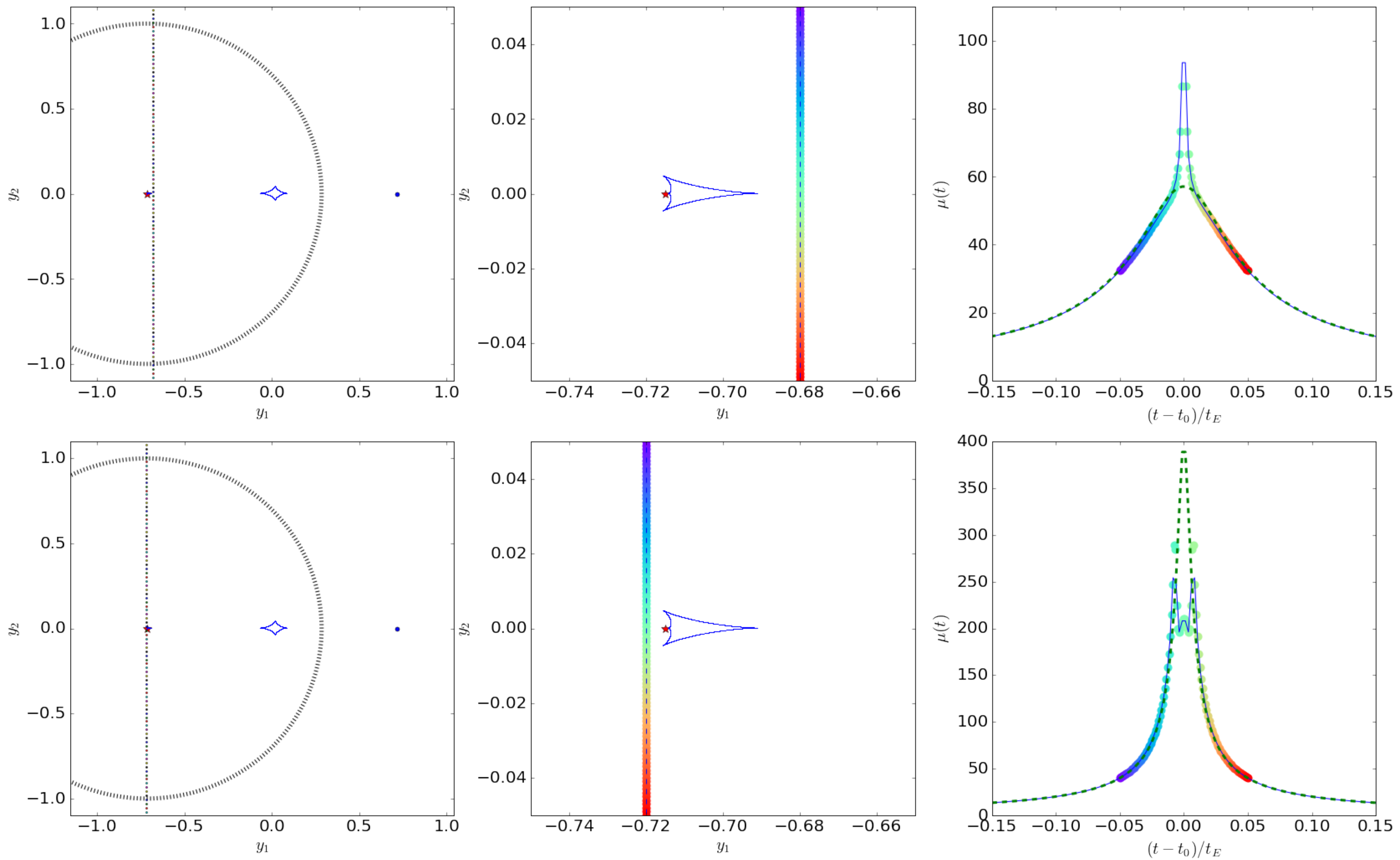

a
b
s = 1.67
s = 1.43
s = 1.25
s = 1.11
s = 1.05
s = 1.00
s = 0.95
s = 0.90
s = 0.80
s = 0.70
s = 0.60
β_y (θ_E)
β_x (θ_E)
Caustics
Intermediate
Wide
Close

Gaudi 2013

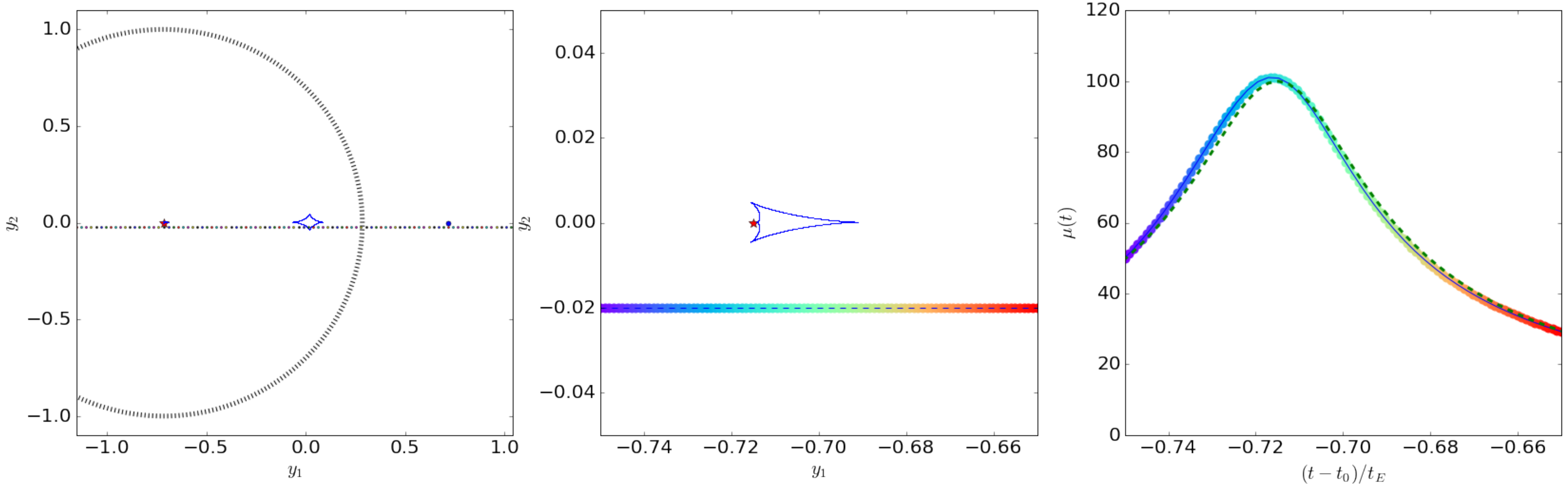
CENTRAL CAUSTIC PERTURBATIONS



CENTRAL CAUSTIC PERTURBATIONS



CENTRAL CAUSTIC PERTURBATIONS

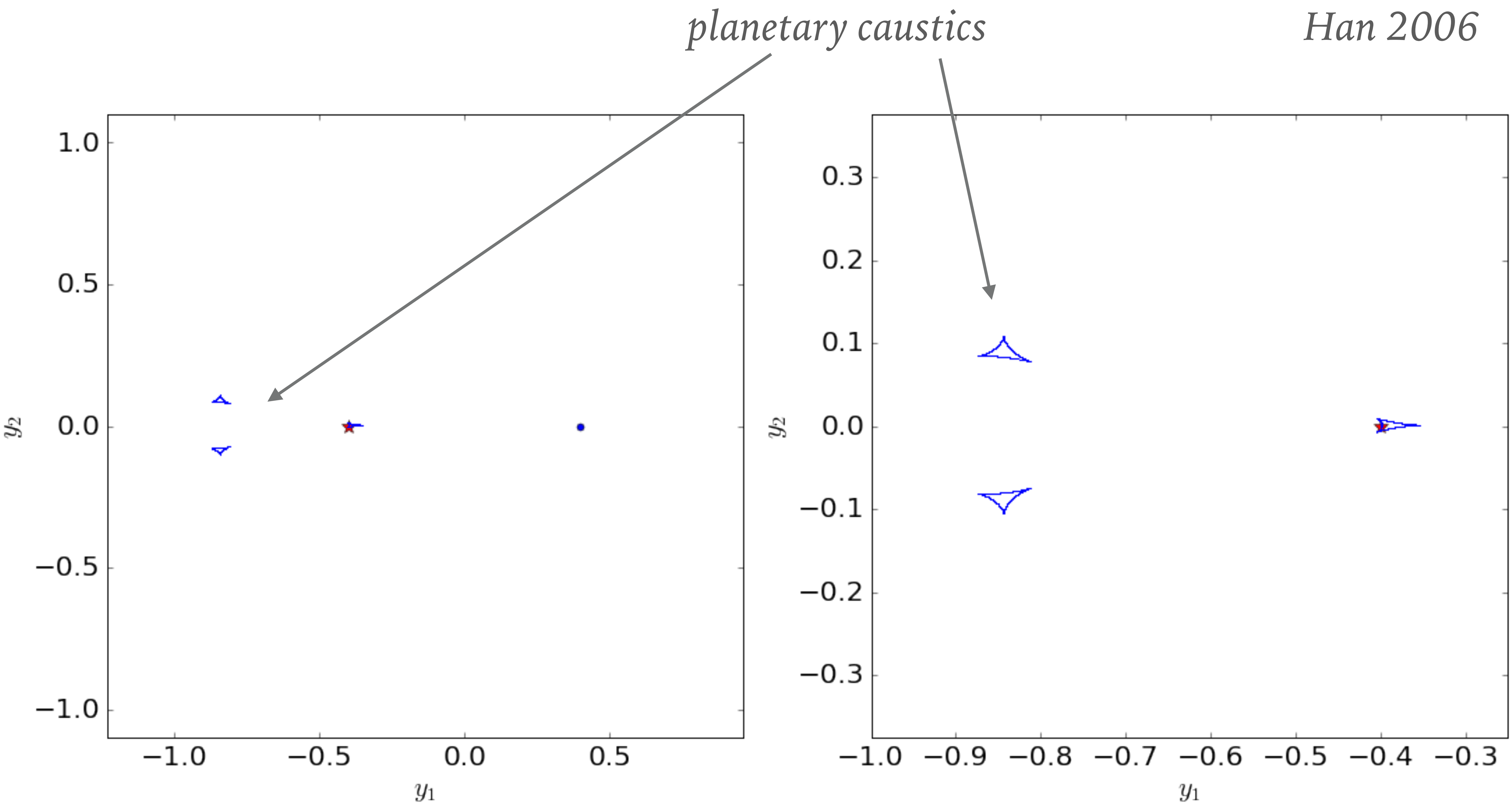


PLANET DETECTION THROUGH CENTRAL CUSP PERTURBATIONS

- 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

Han 2006

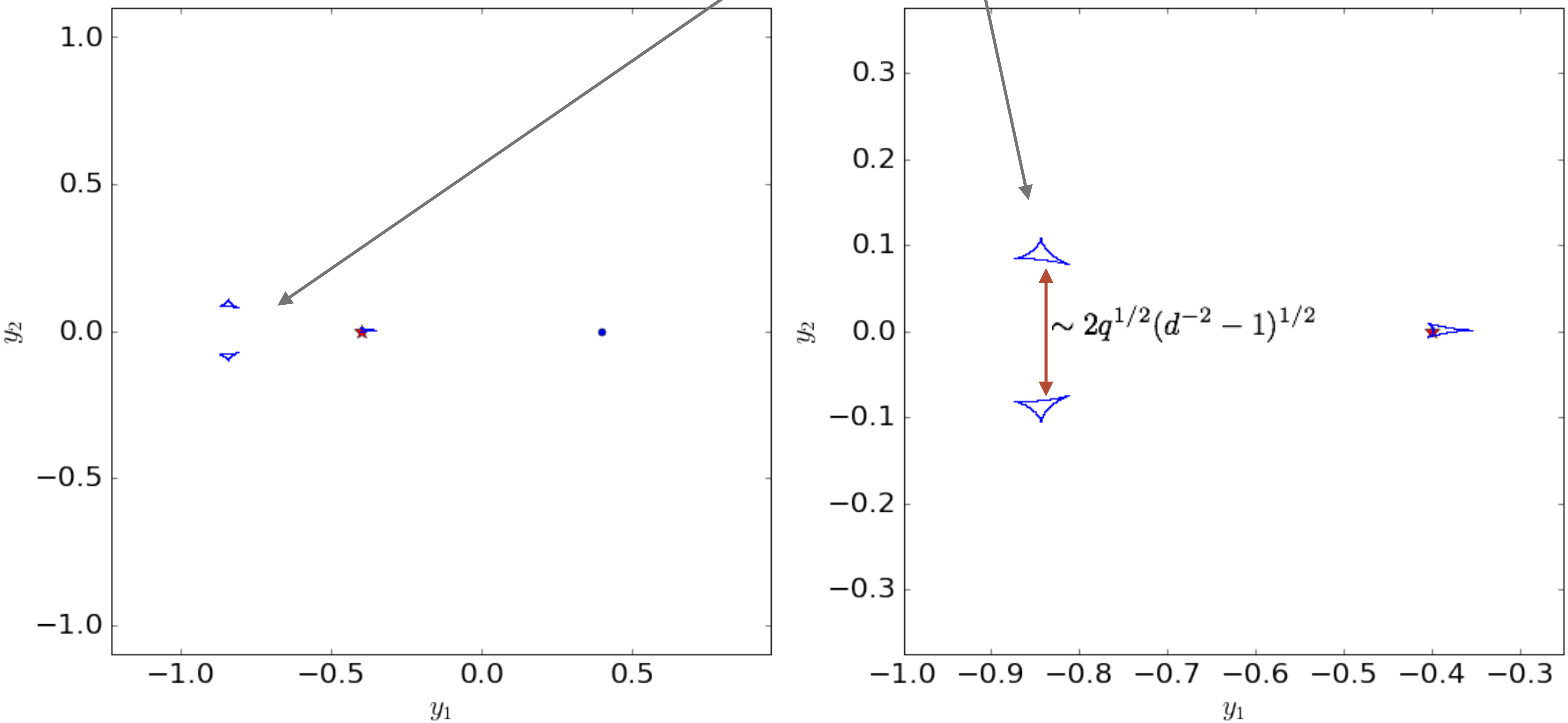


Recommended reading: Han, C., 2006, ApJ, 638, 1080

PLANETARY CAUSTICS IN CLOSE TOPOLOGIES

planetary caustics

Han 2006



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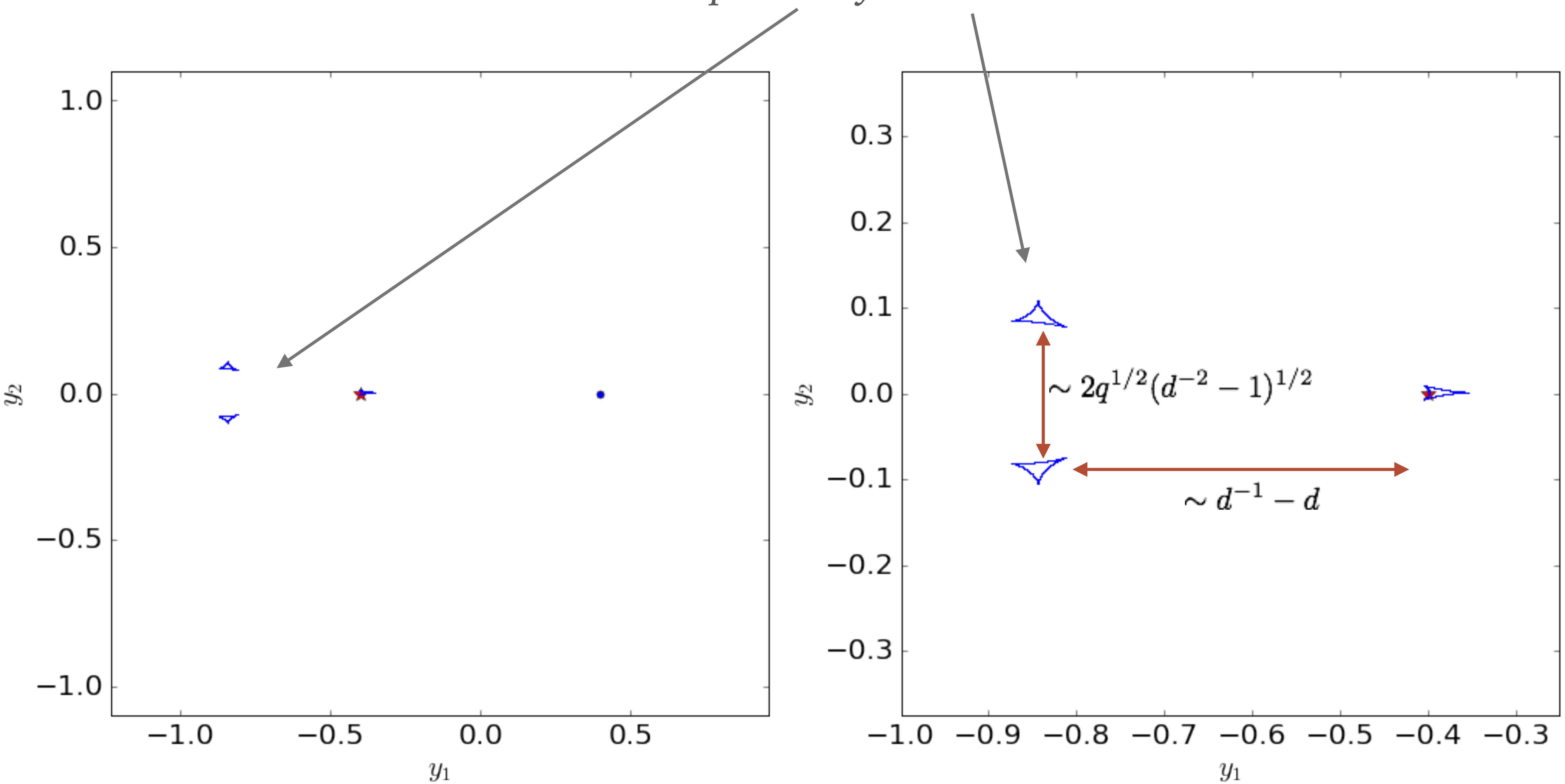
PLANETARY CAUSTICS IN CLOSE TOPOLOGIES

planetary caustics *Han 2006*



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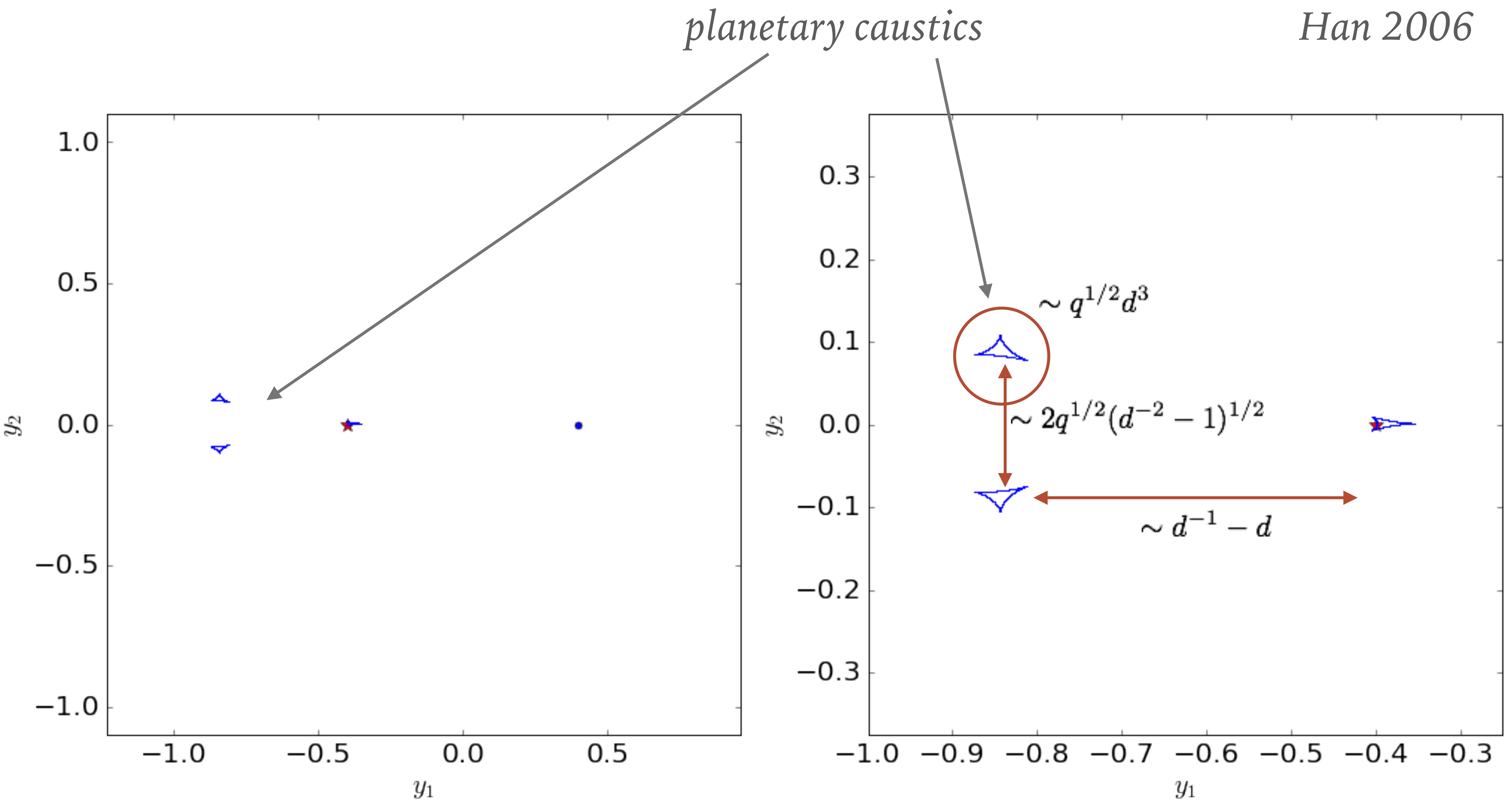

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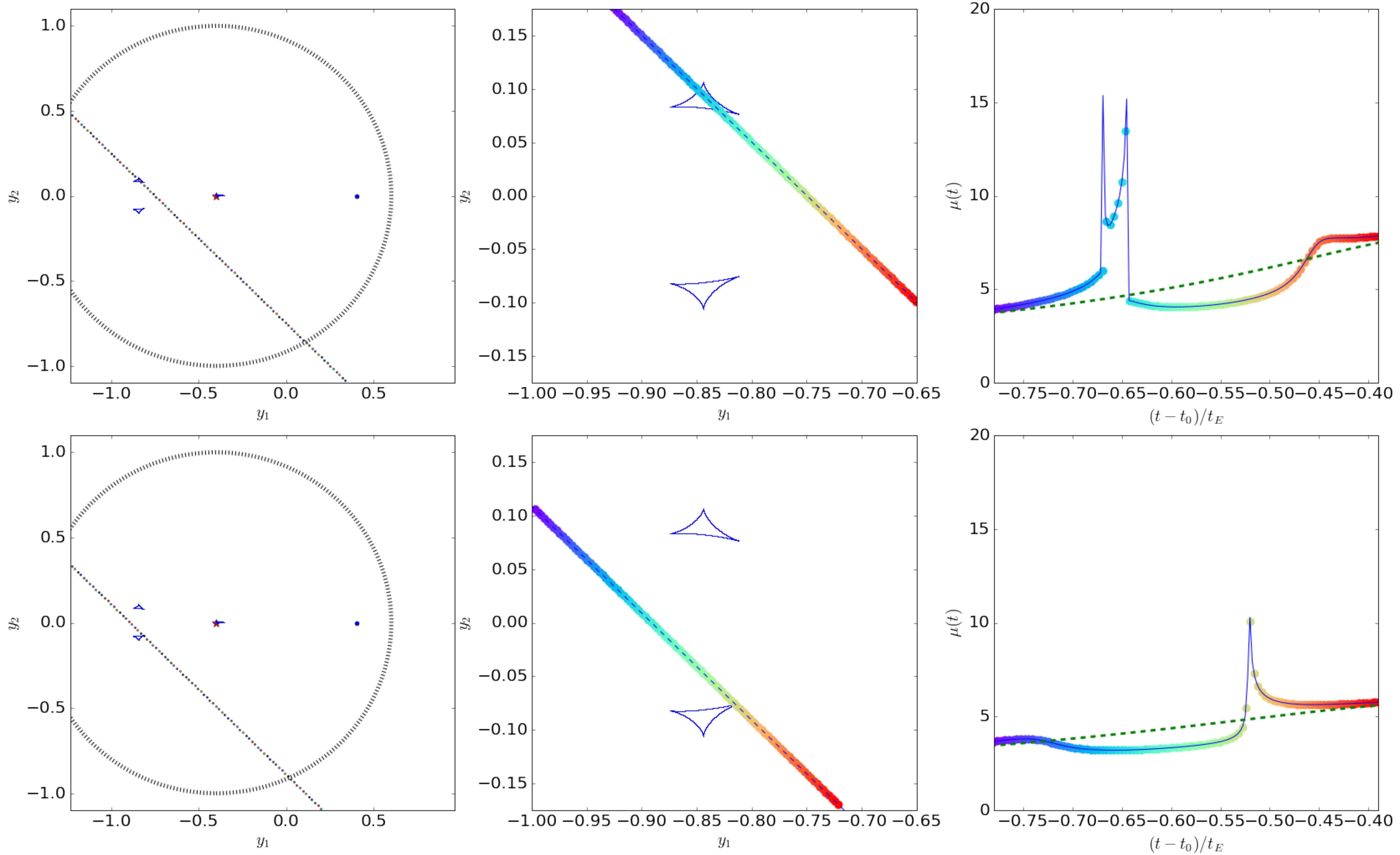

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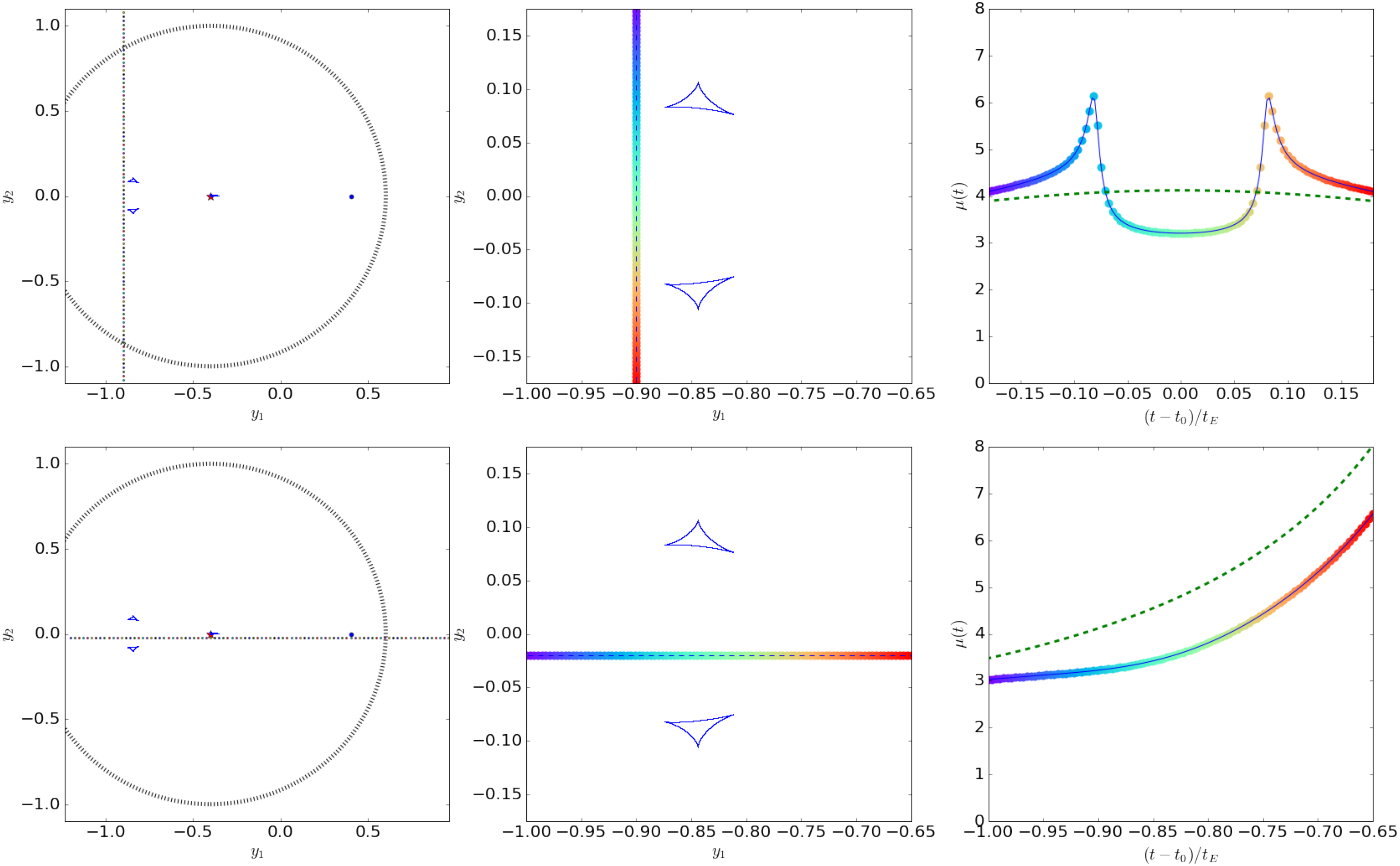
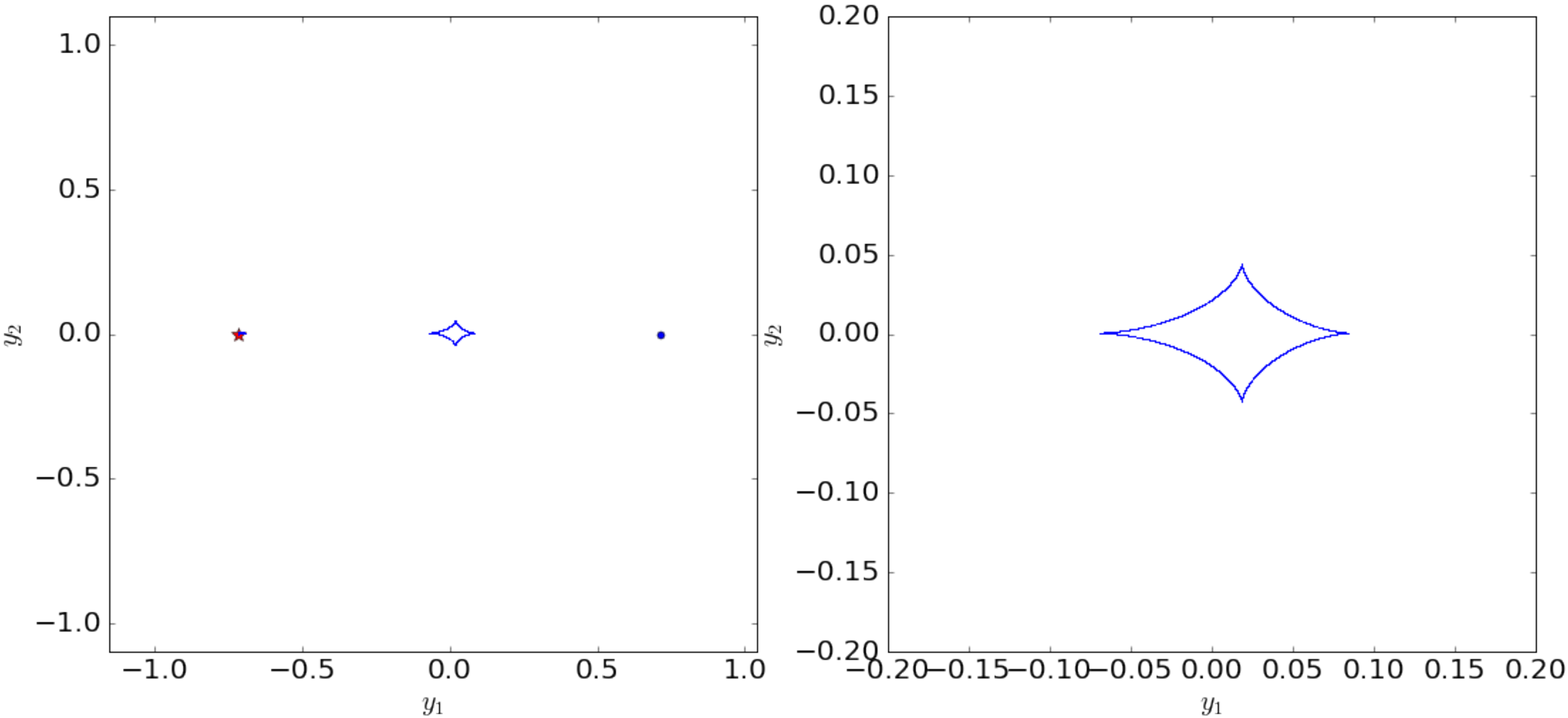


PLANETARY CAUSTICS IN WIDE TOPOLOGIES



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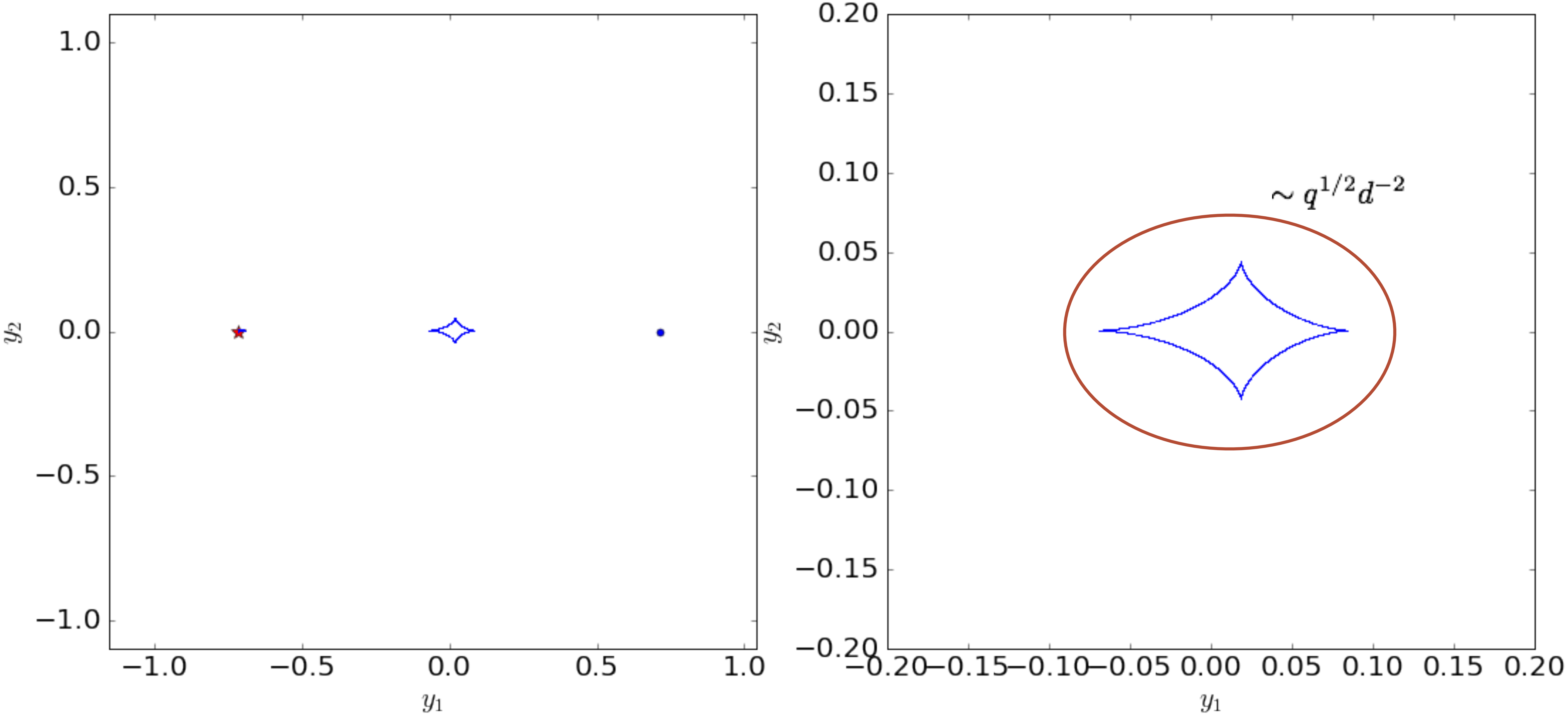

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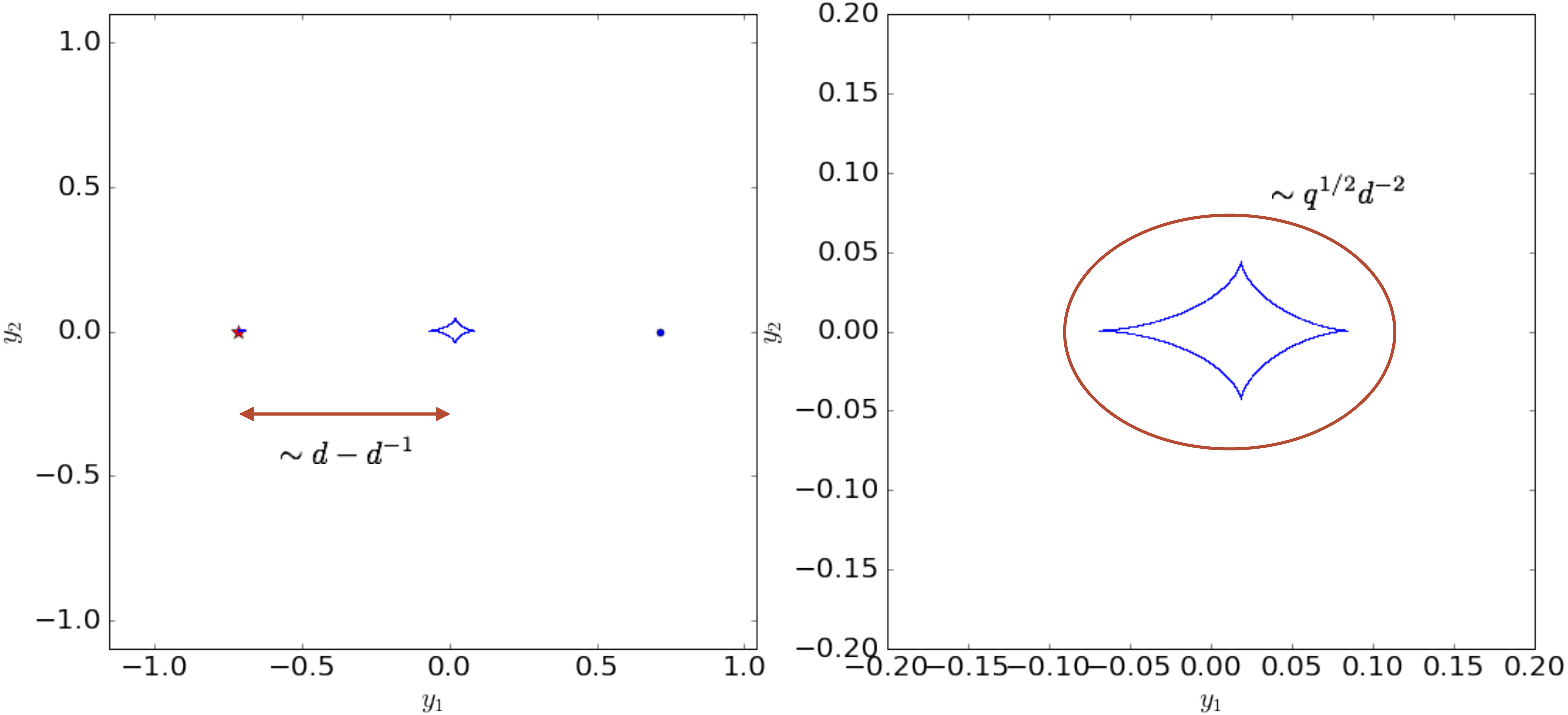

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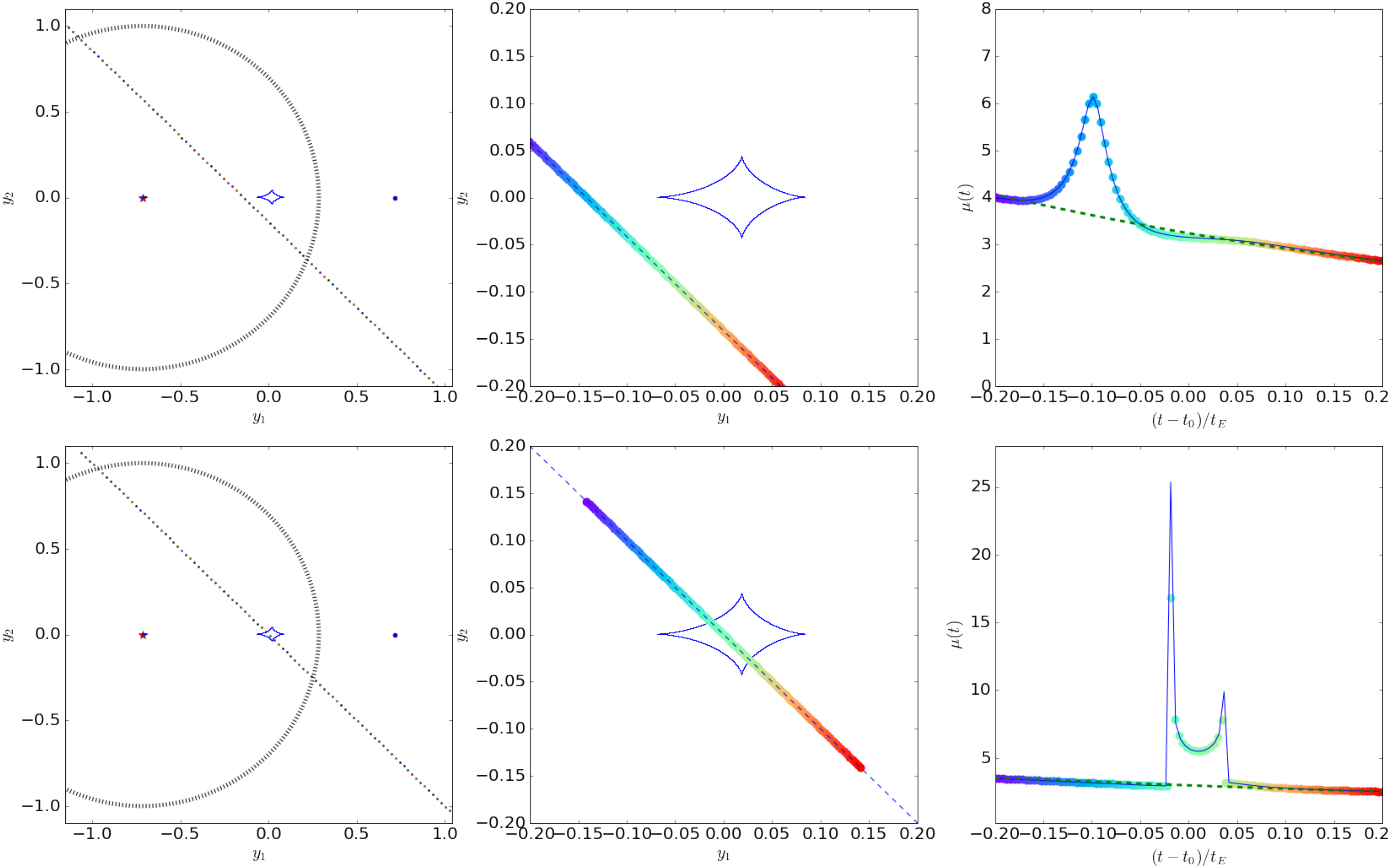

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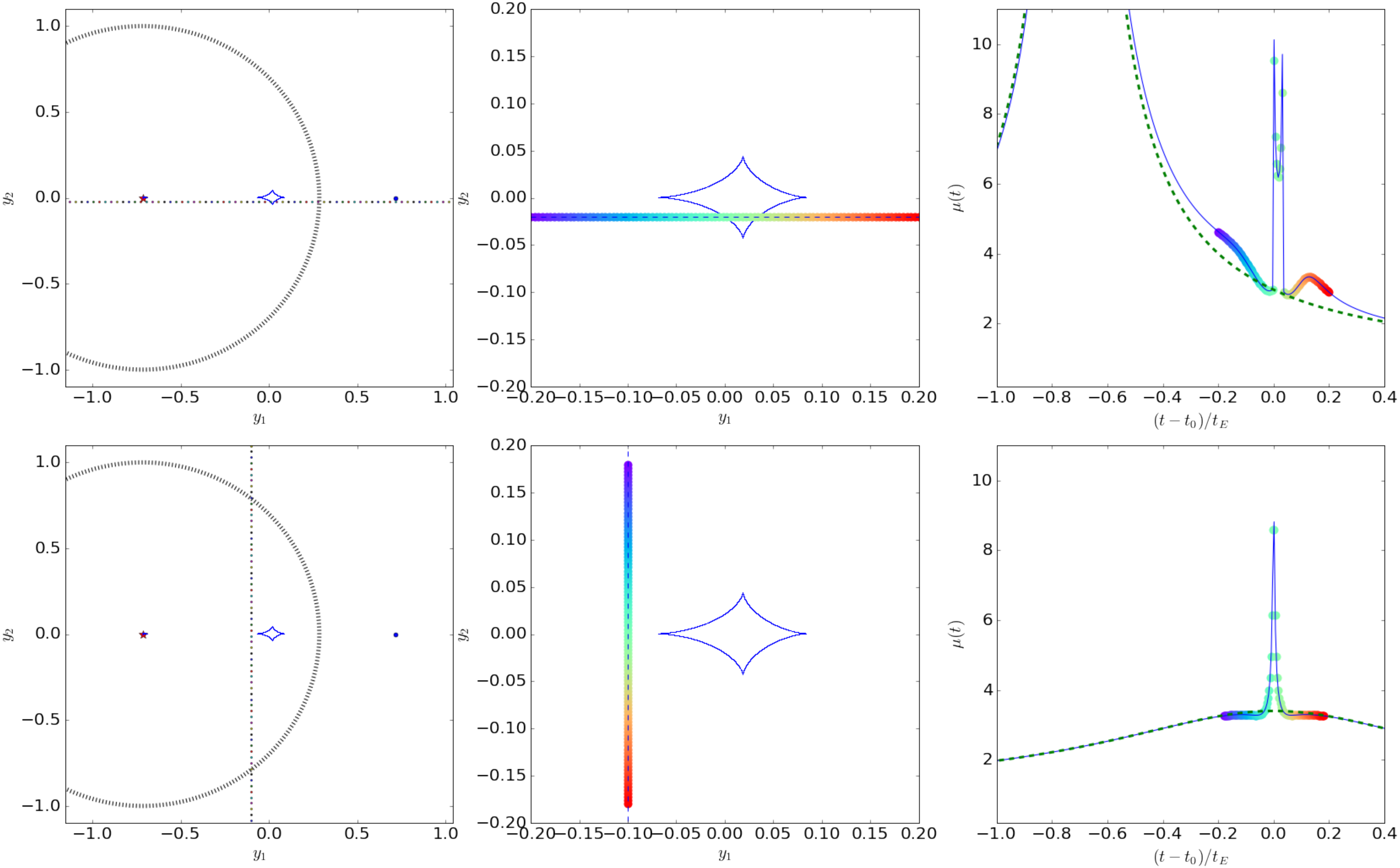

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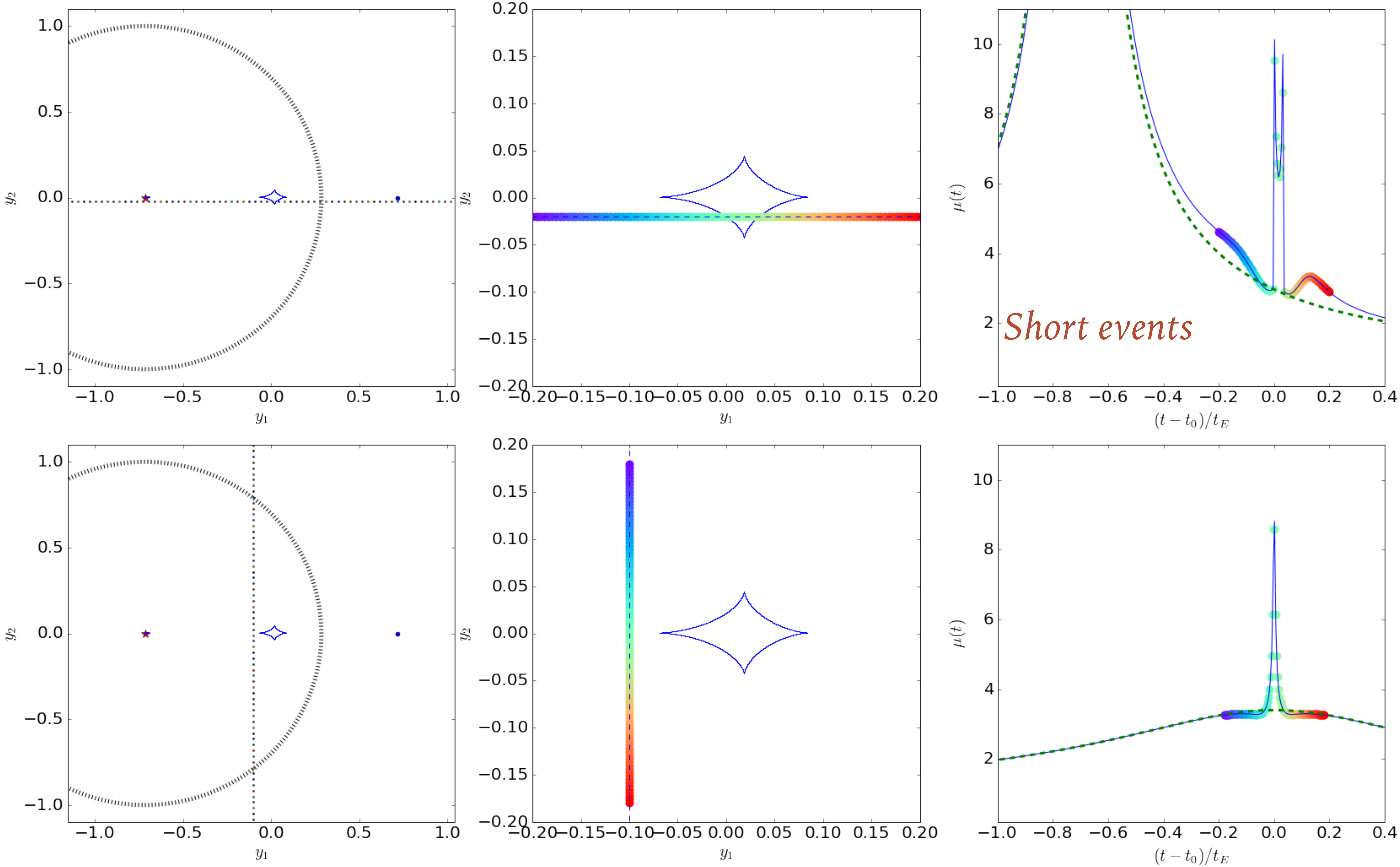

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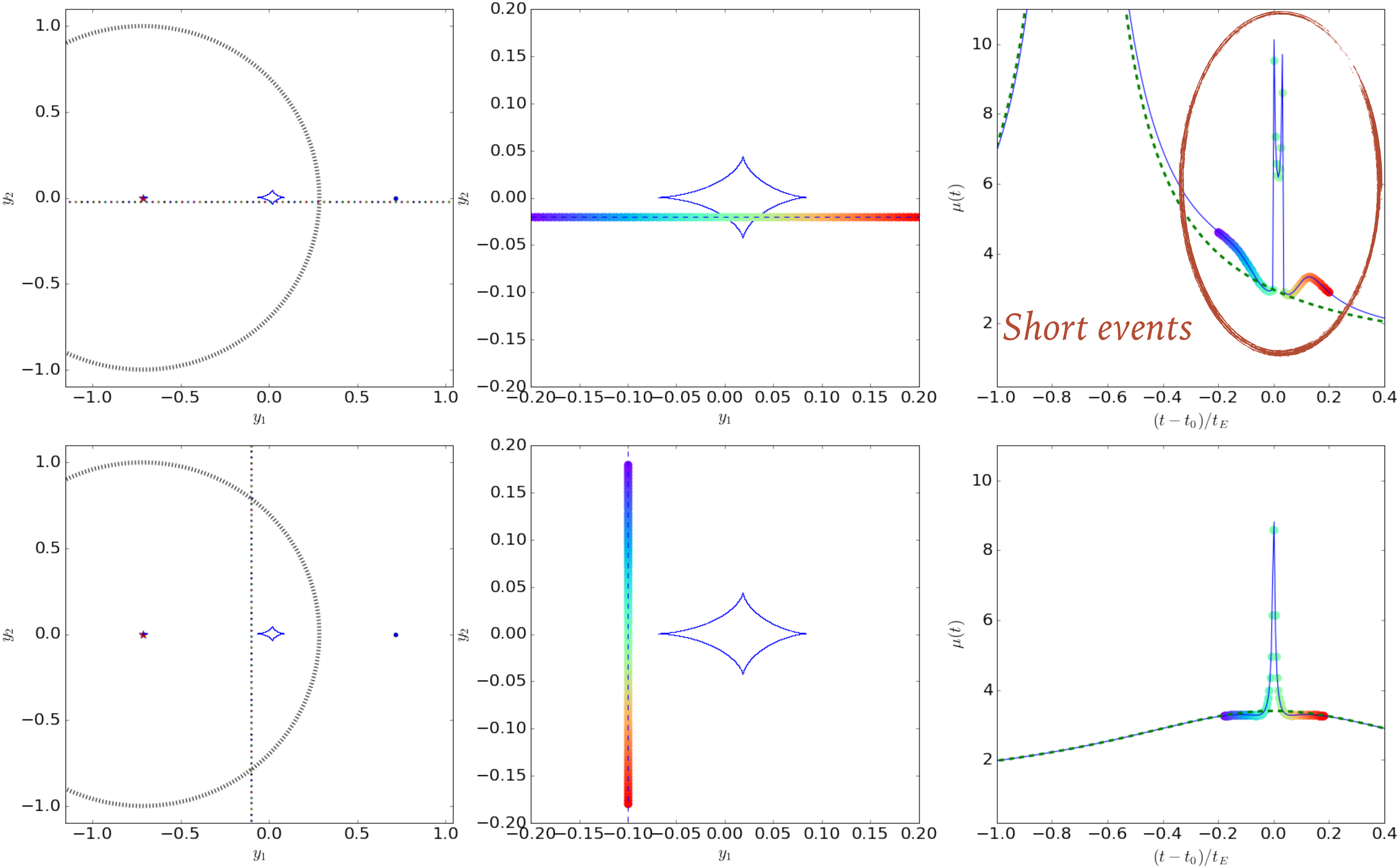
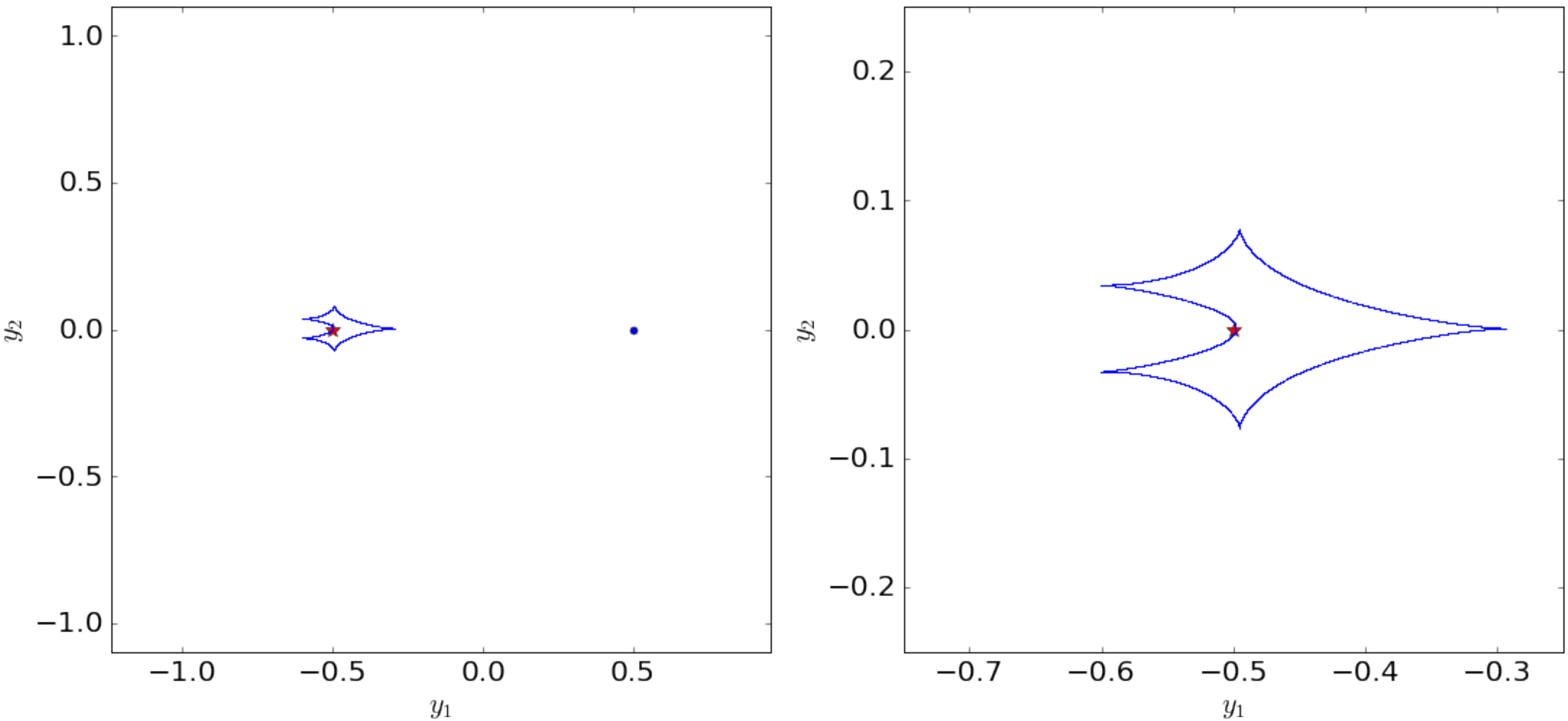


PLANETARY CAUSTICS IN INTERMEDIATE TOPOLOGIES



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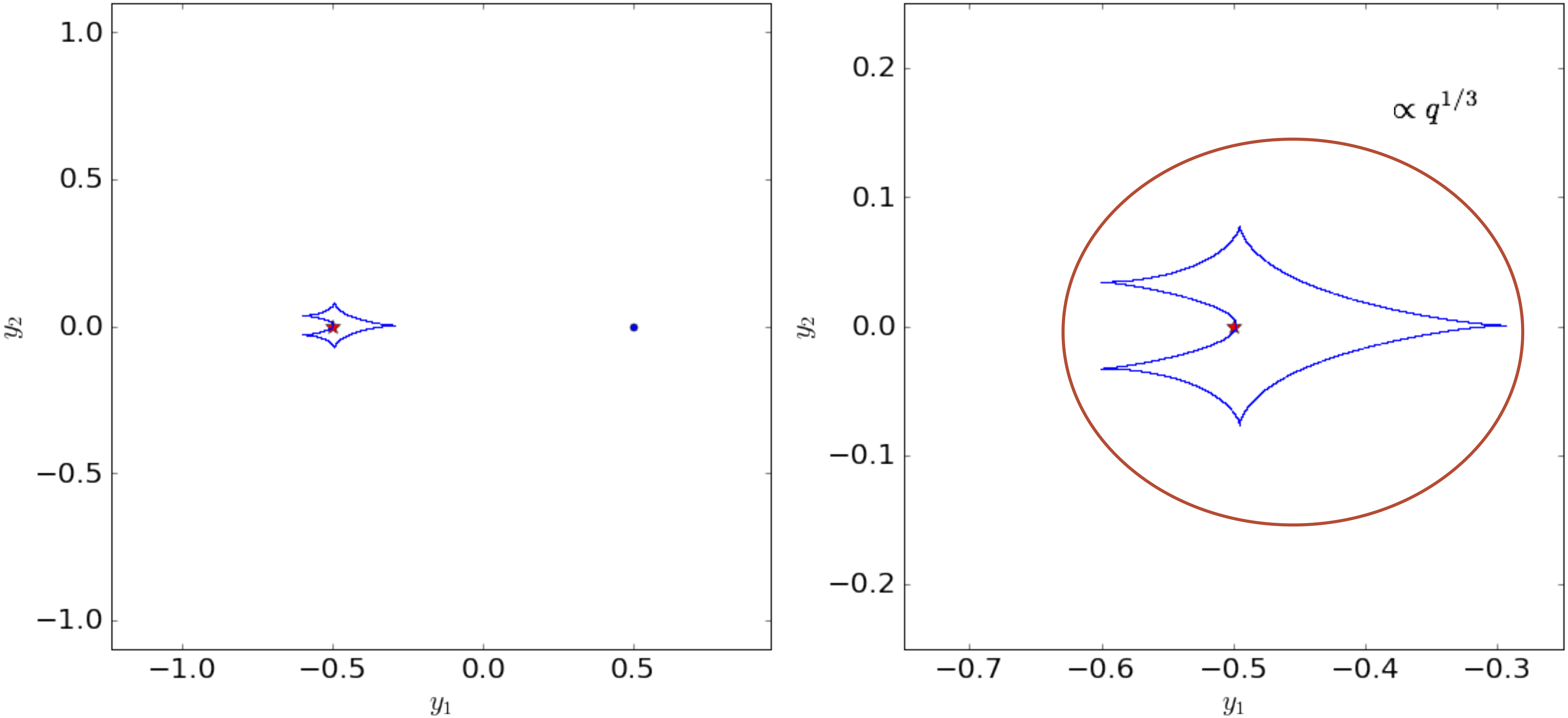

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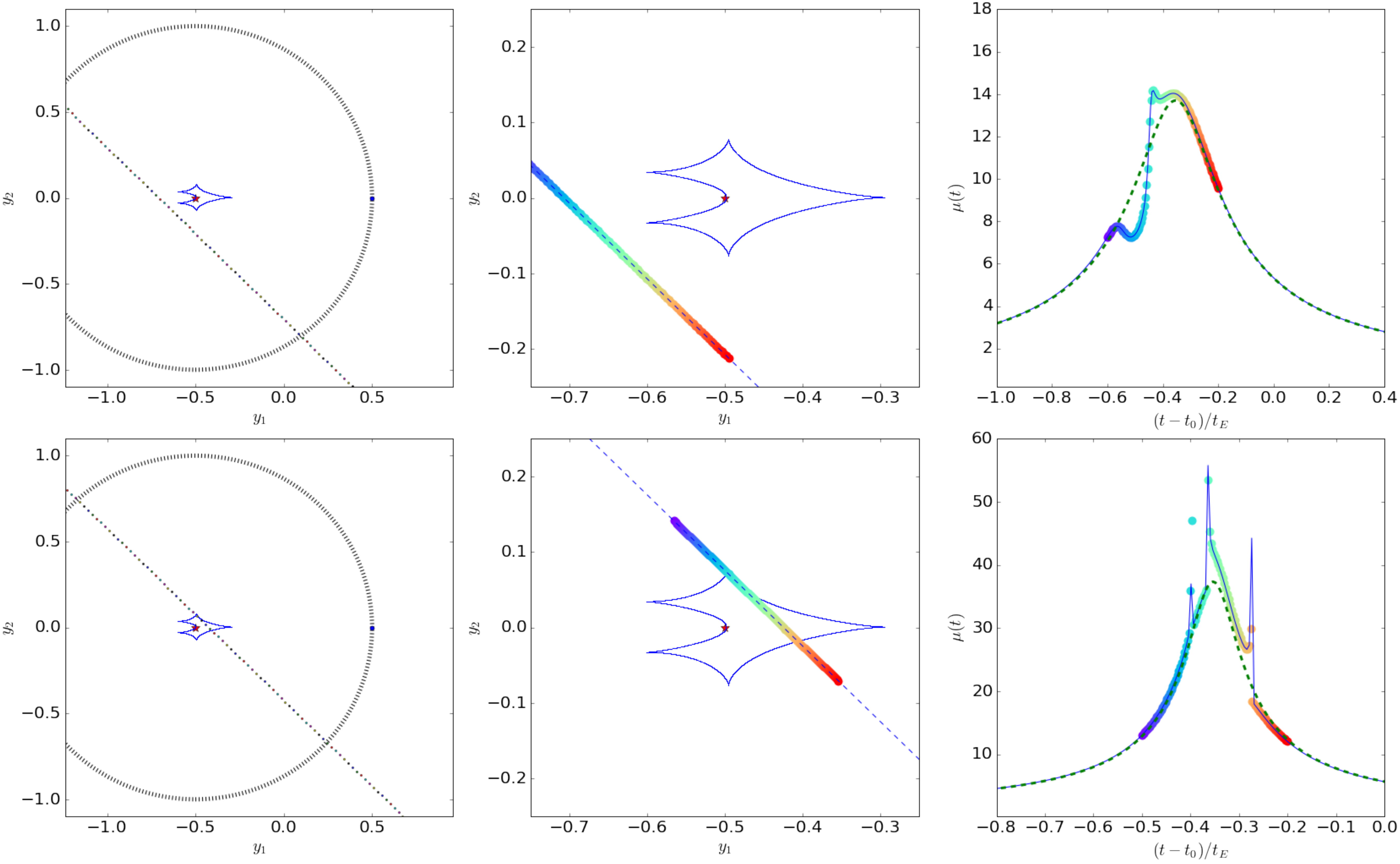

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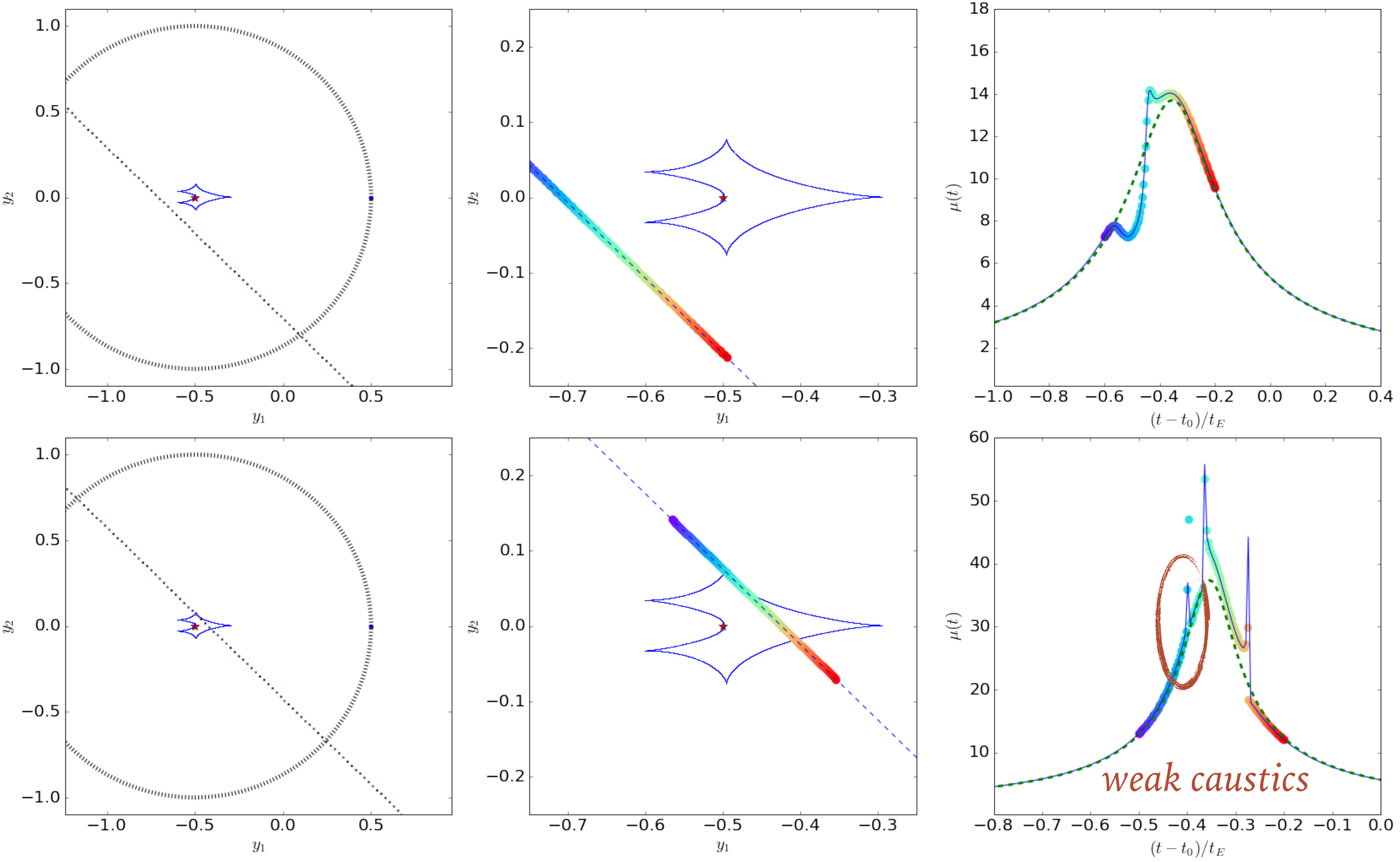

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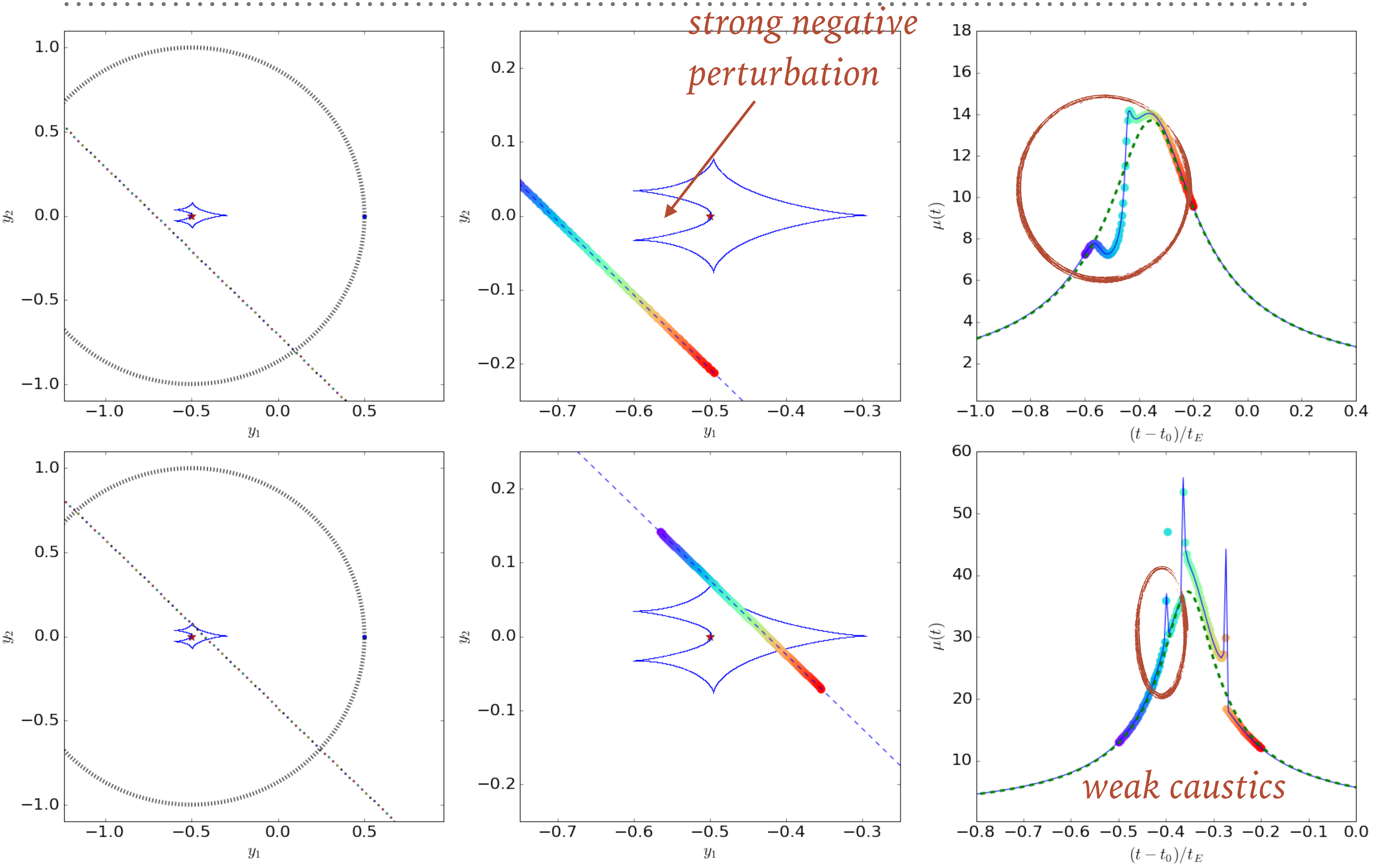

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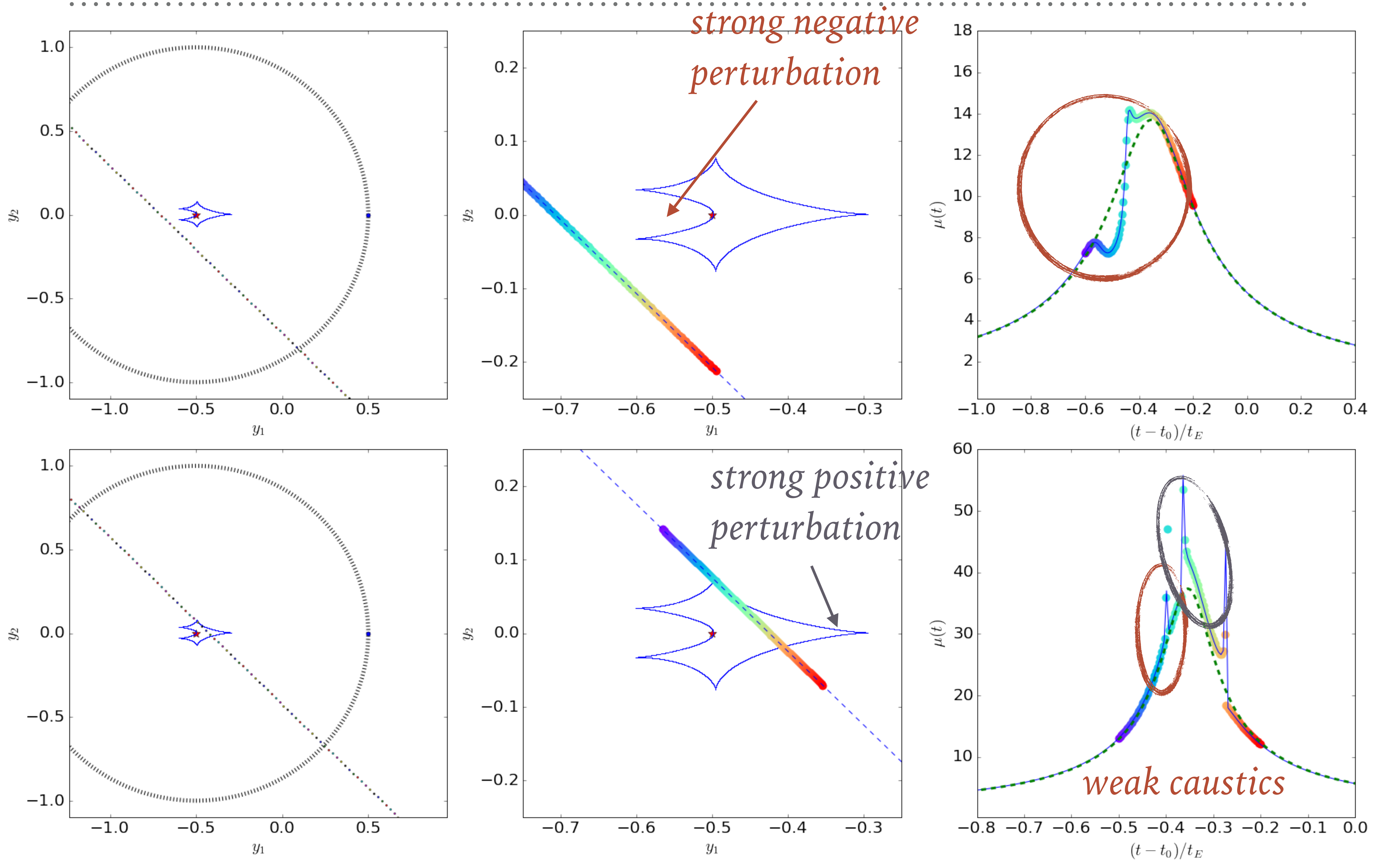


TO SUMMARIZE

- different caustic topologies give rise to different kind of perturbations on the light curves
- planets can be detected in only a few qualitatively different ways:
  - at relatively low magnification of the primary, if the source crosses the planetary caustics from close or wide planets
  - near the peak of the light curve, if the source has a small impact parameter, in both cases of wide and close planets
  - at modest to high-magnification, through the perturbations from the resonant caustic.
  - in the case of free-floating planets, as single, short time-scale events.

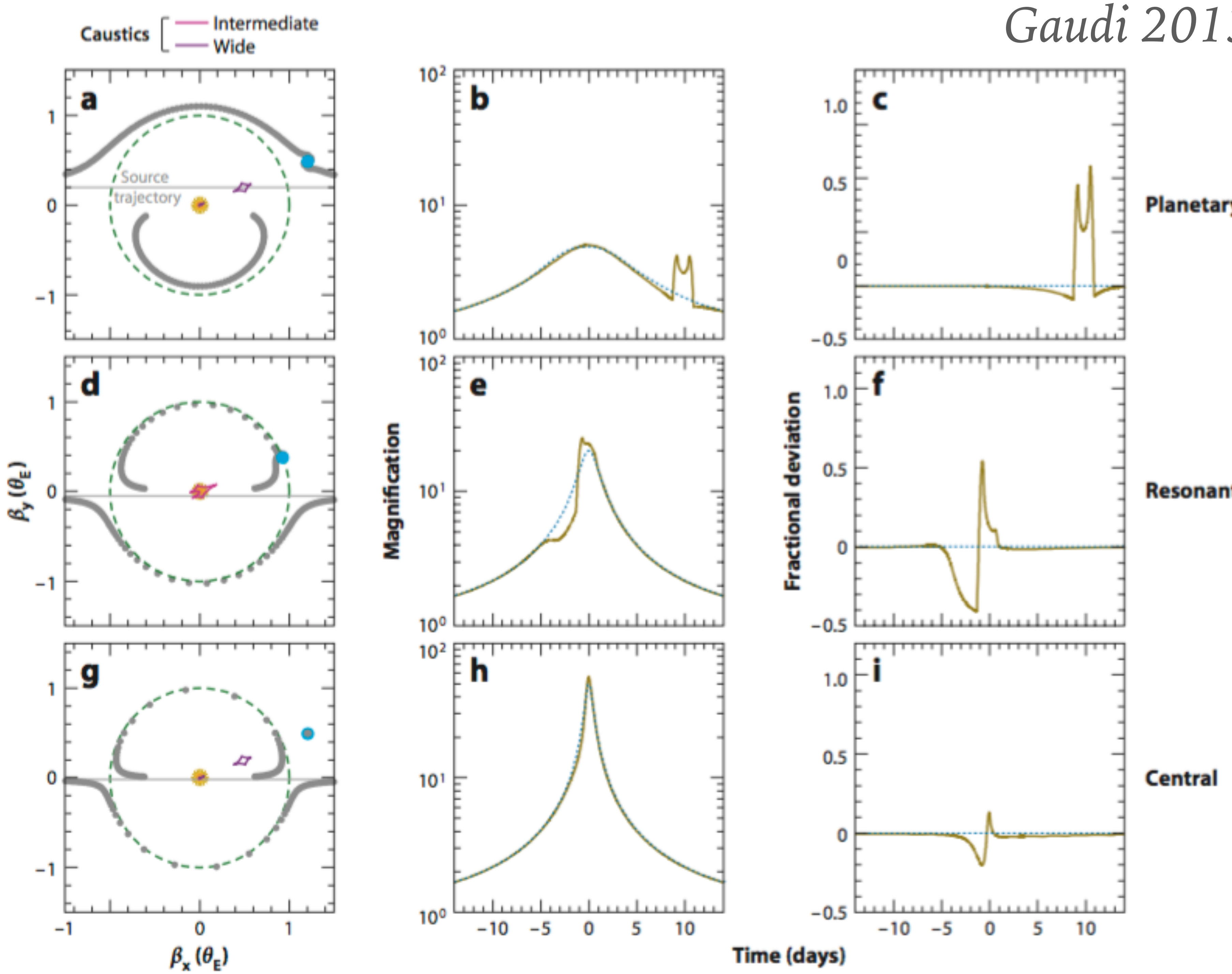
OF COURSE…

- there is also an astrometric perturbation…

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

This tells us that microlensing is sensitive to planets at distances of the order of the star Einstein radius.

Gaudi 2013



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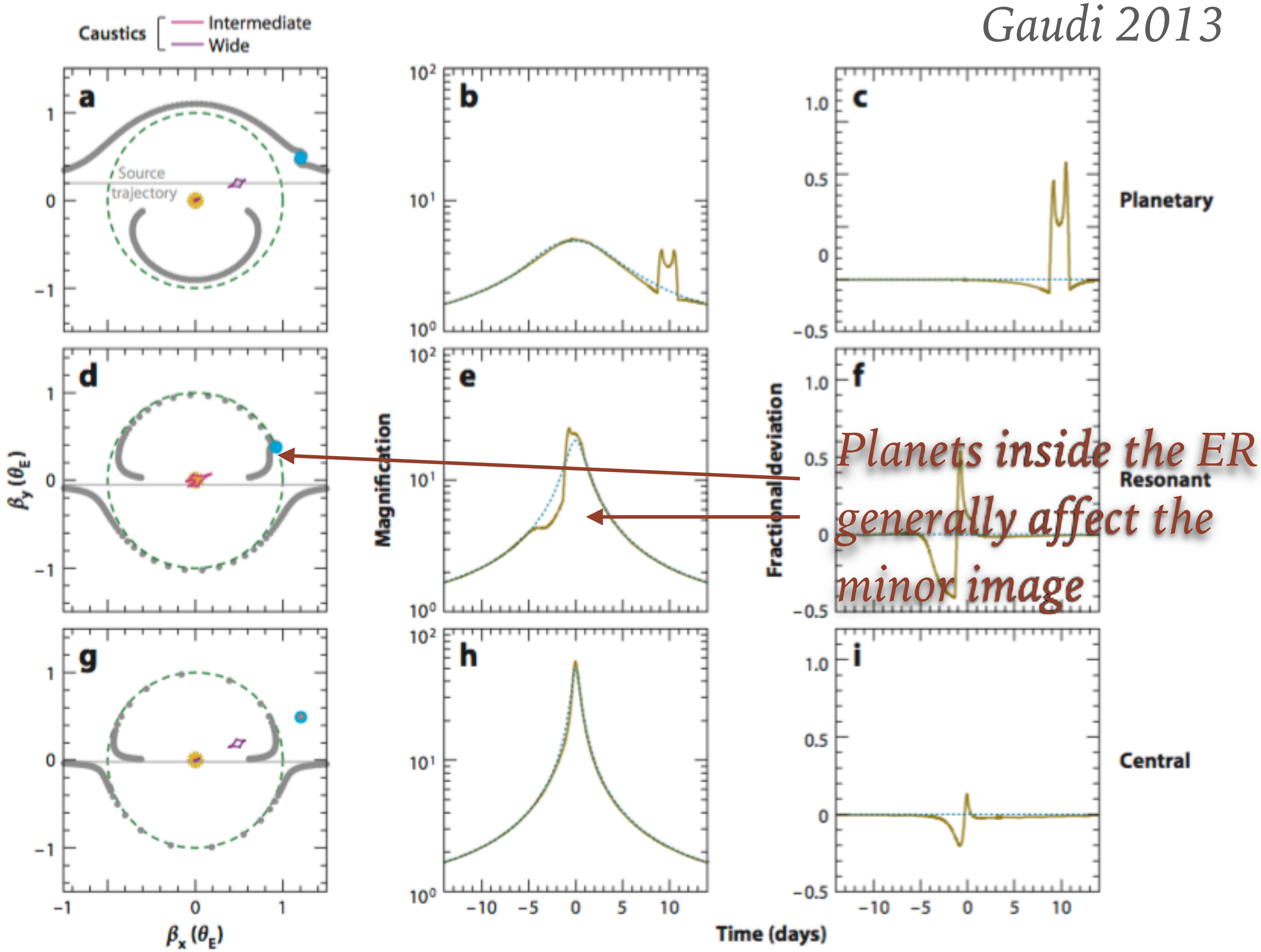

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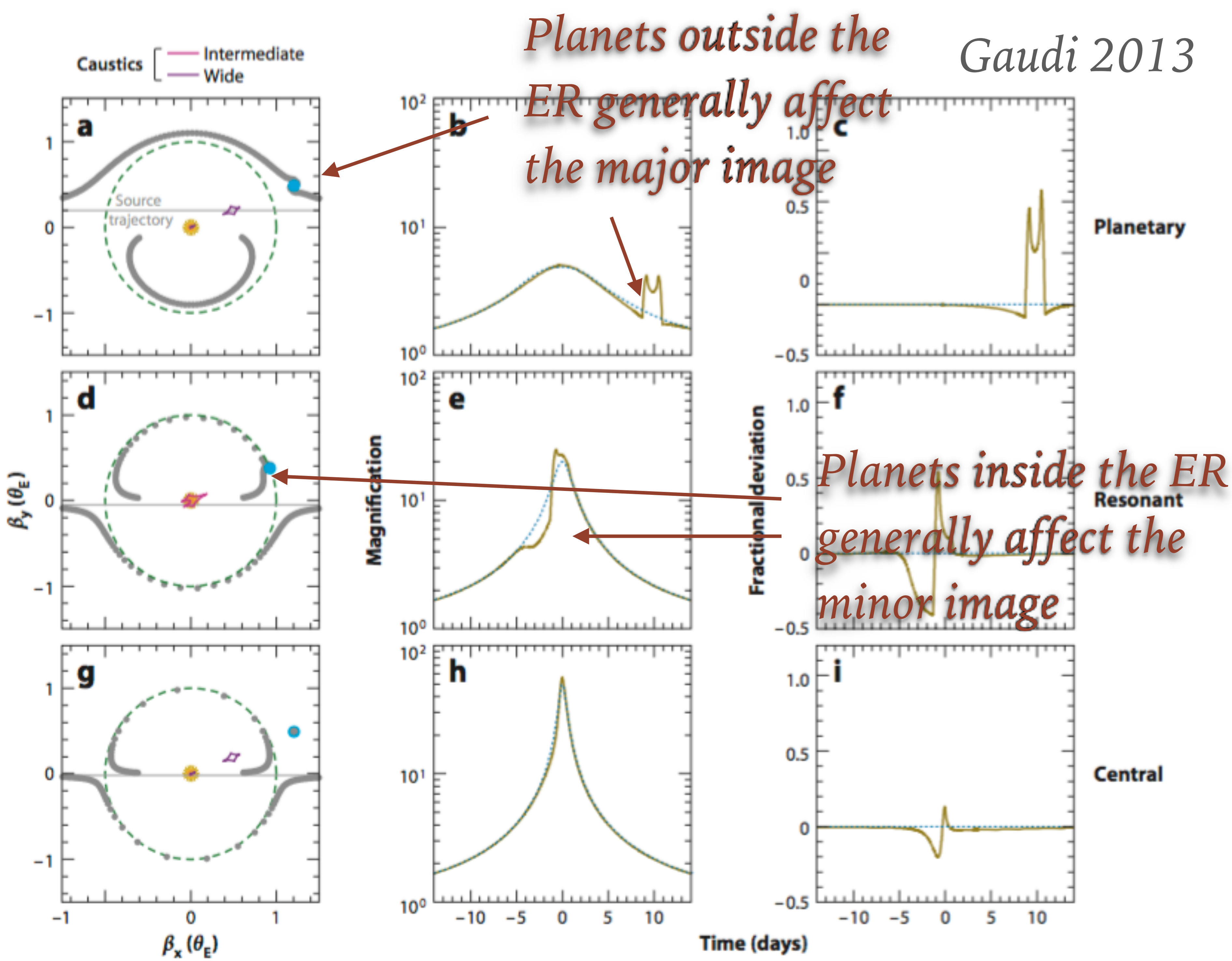

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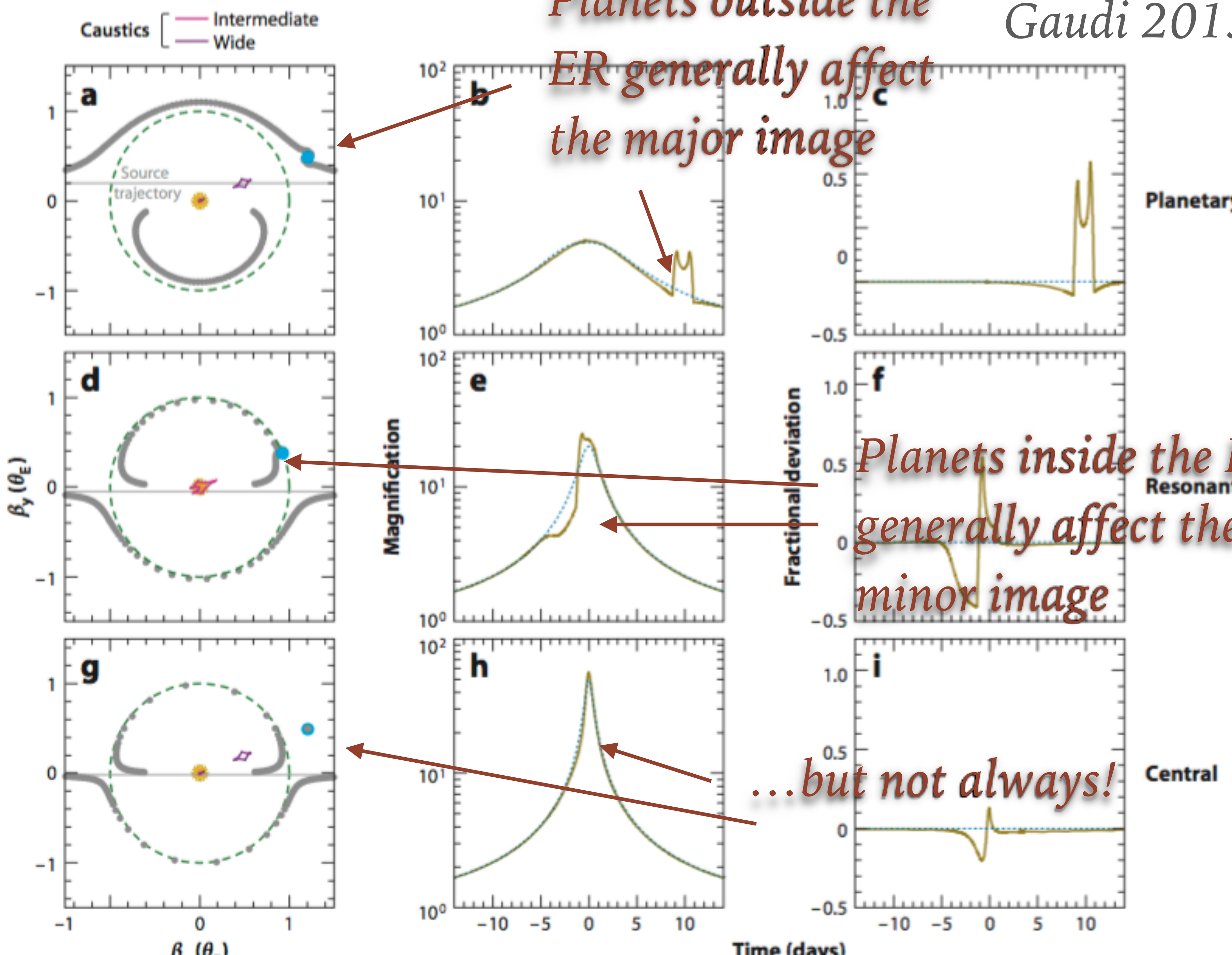
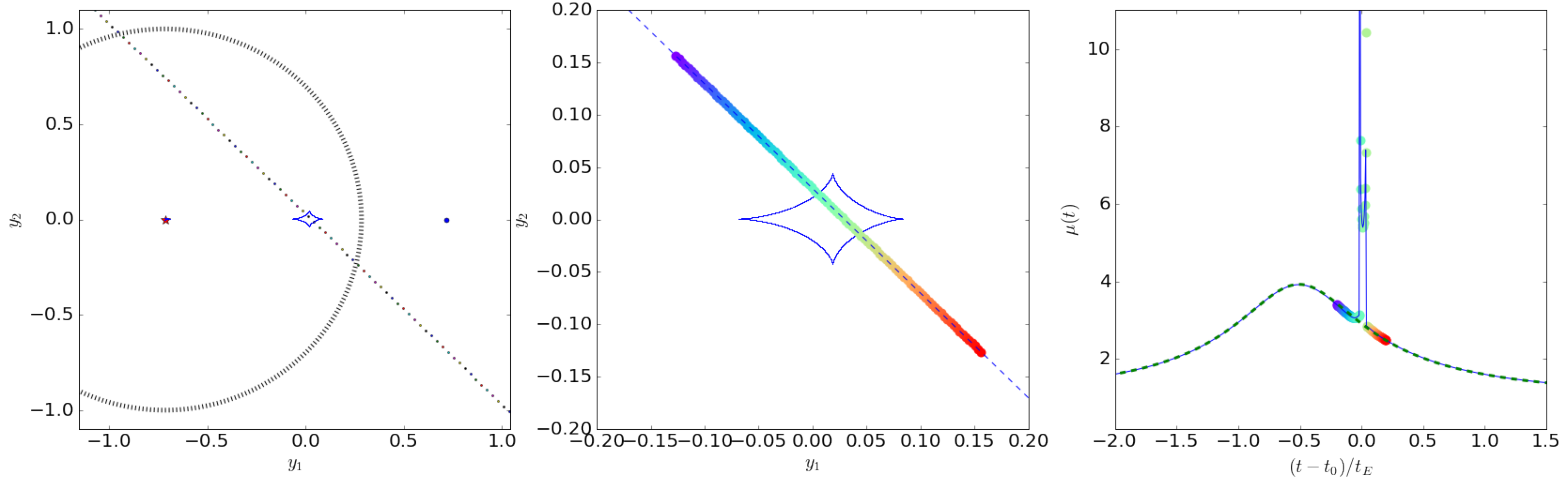


Planets outside the ER generally affect the major image

Planets inside the ER generally affect the minor image

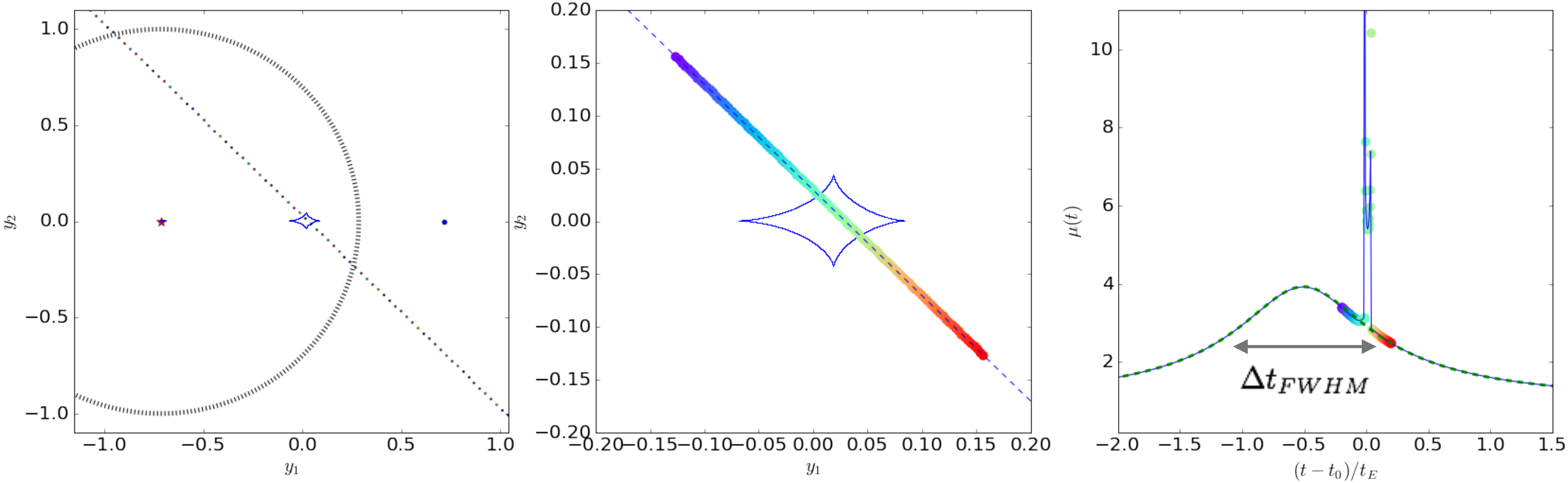
…but not always!

PLANET PROPERTIES "READ OFF" OF THE LIGHT CURVES



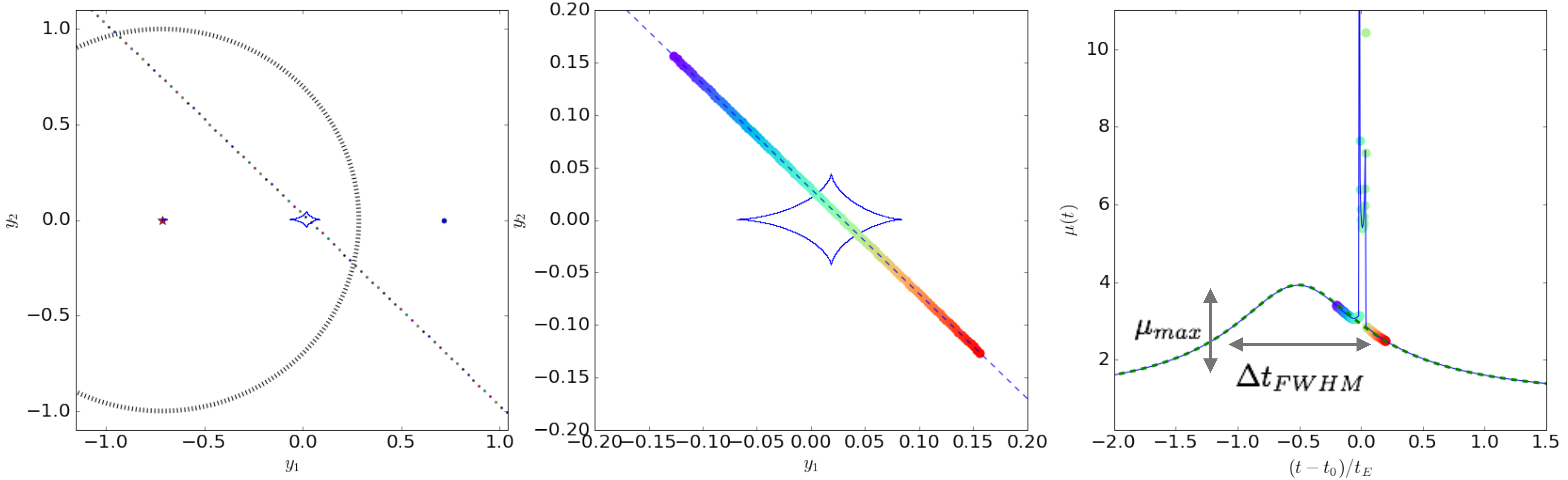
- primary event:
- planetary perturbation:

PLANET PROPERTIES "READ OFF" OF THE LIGHT CURVES



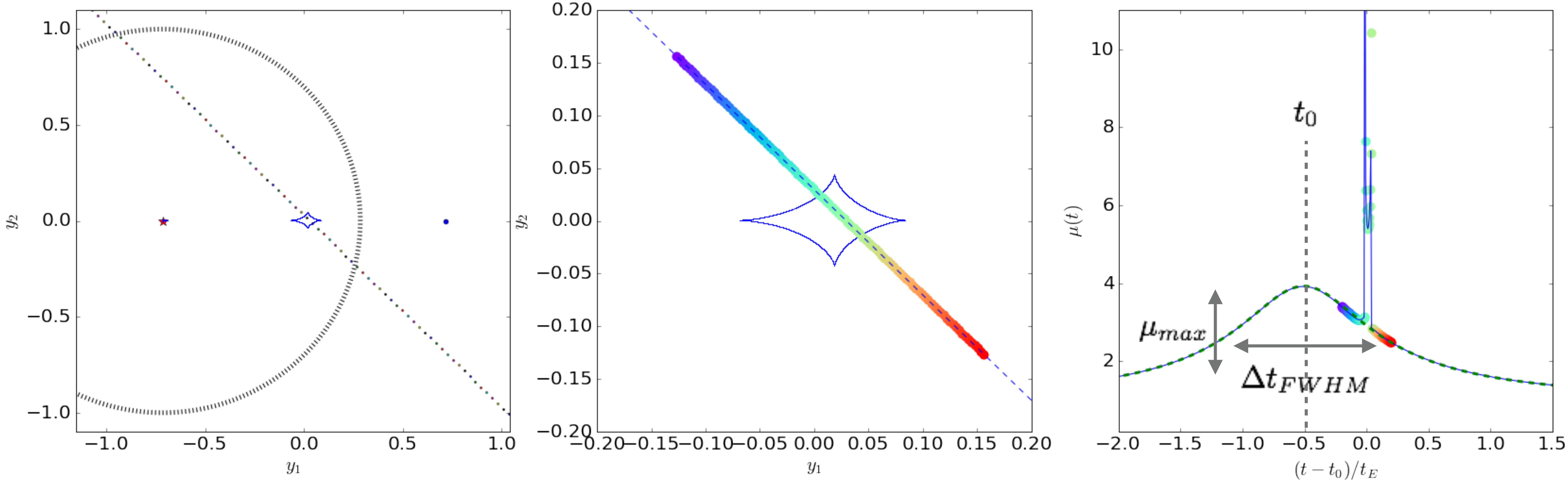
- primary event: Δt_{FWHM}
- planetary perturbation:

PLANET PROPERTIES “READ OFF” OF THE LIGHT CURVES



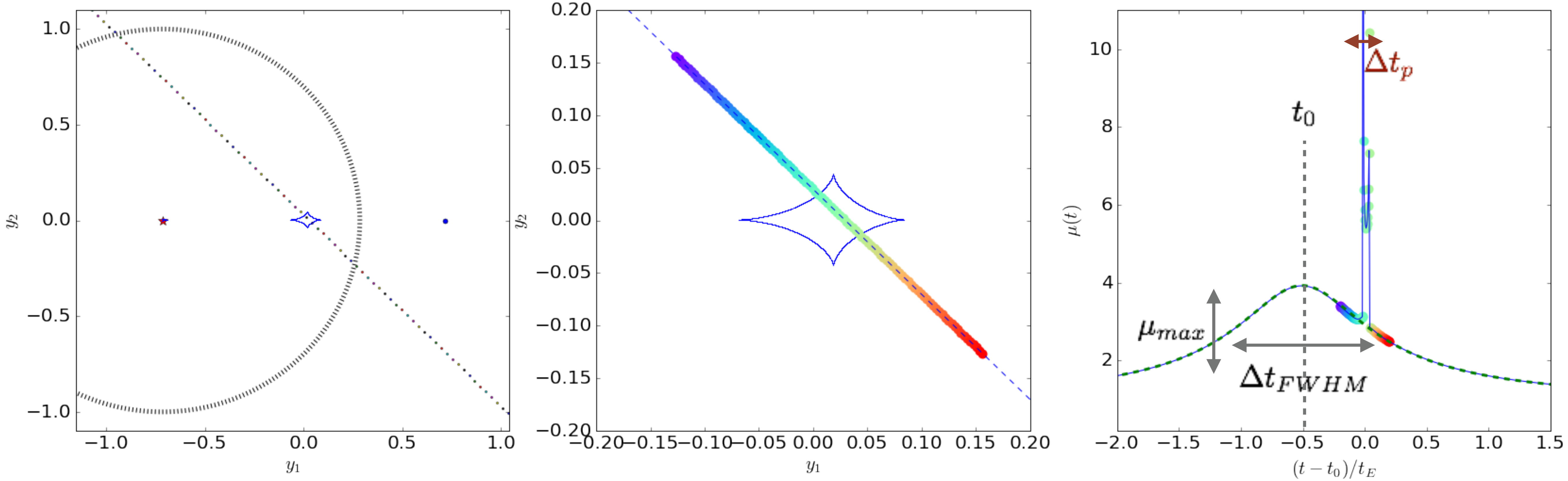
- primary event: Δt_{FWHM} μ_{max}
- planetary perturbation:

PLANET PROPERTIES “READ OFF” OF THE LIGHT CURVES



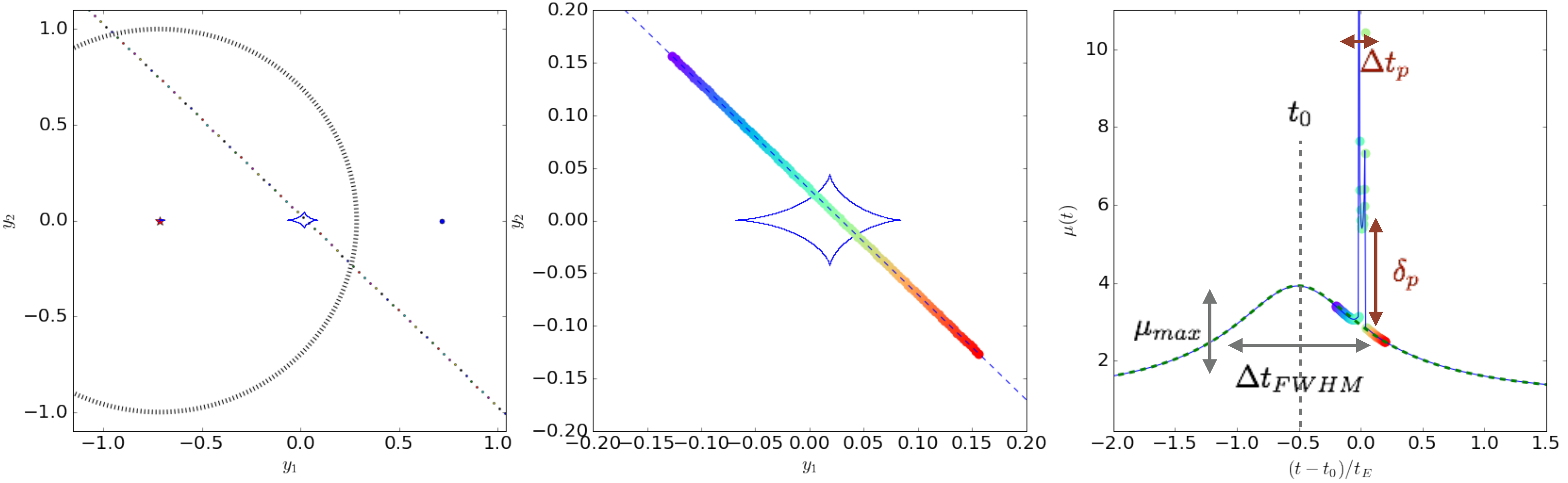
- primary event: Δt_{FWHM} μ_{max} t_0
- planetary perturbation:

PLANET PROPERTIES "READ OFF" OF THE LIGHT CURVES



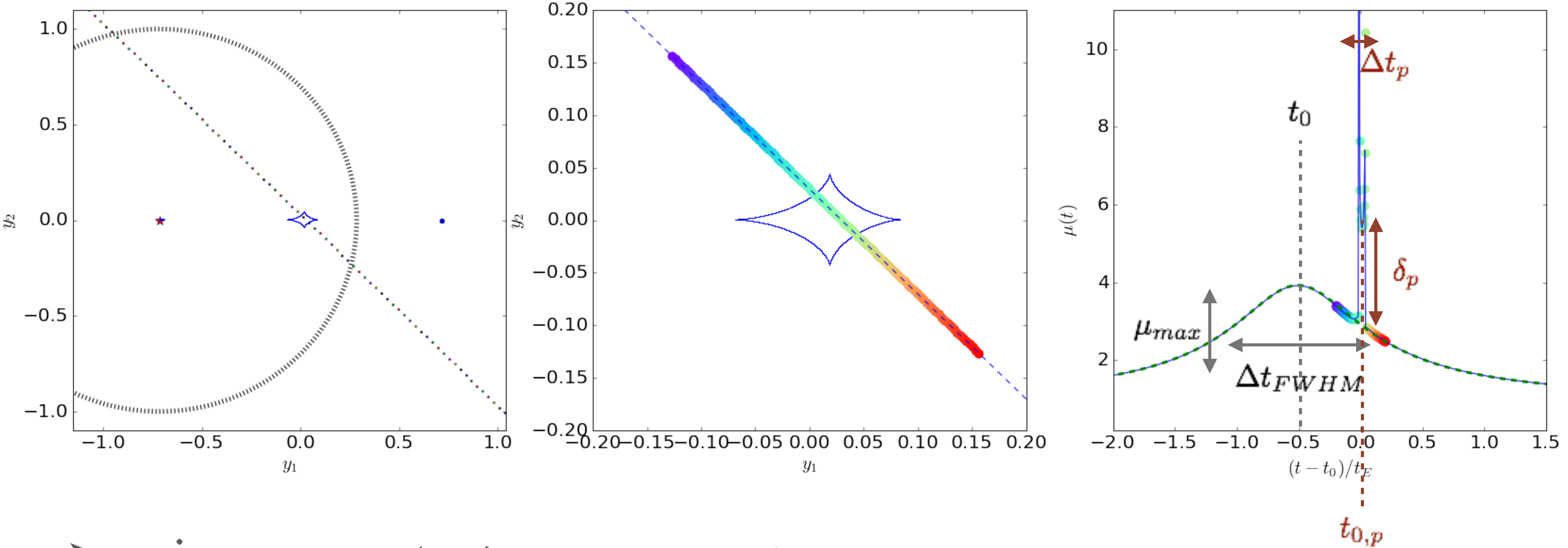
- primary event: Δt_{FWHM} μ_{max} t_0
- planetary perturbation: Δt_p

PLANET PROPERTIES "READ OFF" OF THE LIGHT CURVES



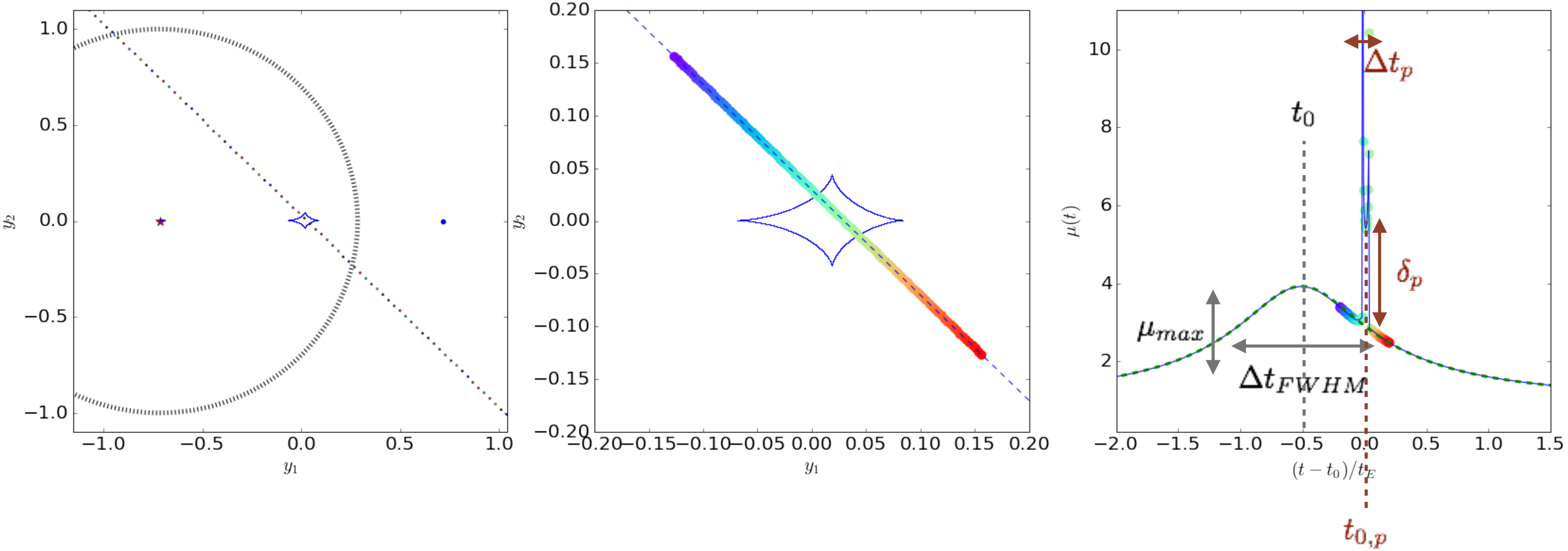
- primary event: Δt_{FWHM} μ_{max} t_0
- planetary perturbation: Δt_p δ_p

PLANET PROPERTIES “READ OFF” OF THE LIGHT CURVES



- primary event: Δt_{FWHM} μ_{max} t_0
- planetary perturbation: Δt_p δ_p $t_{0,p}$

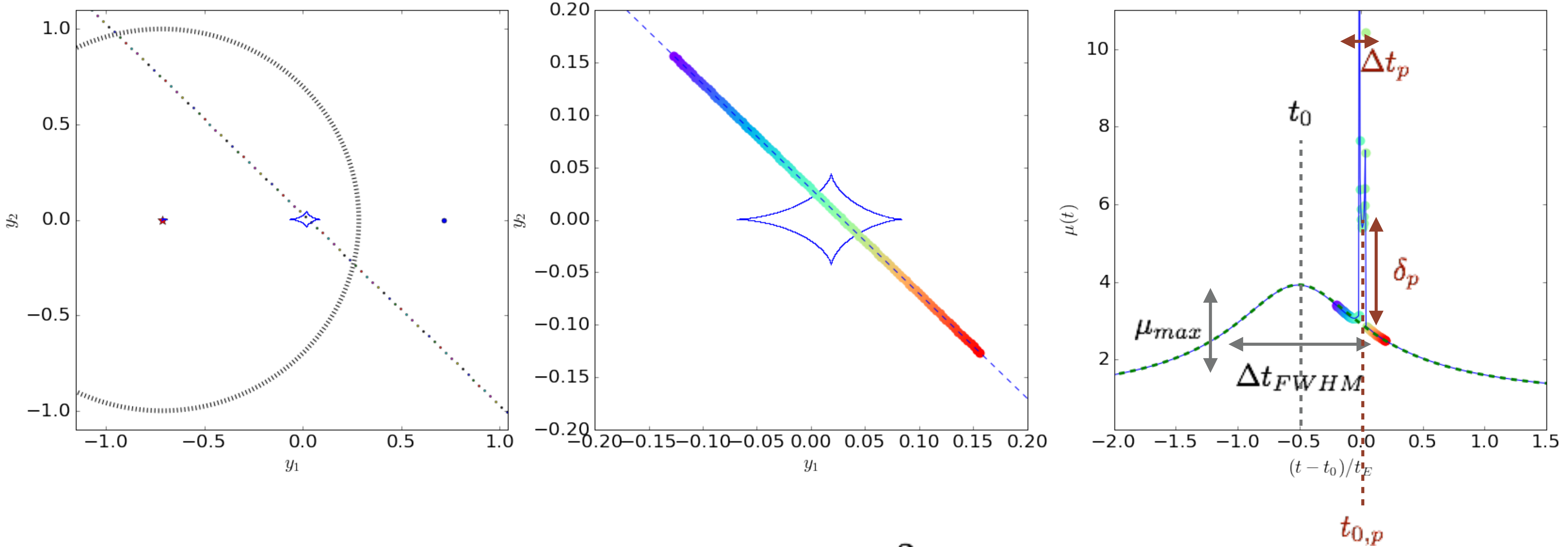
PLANET PROPERTIES "READ OFF" OF THE LIGHT CURVES



$$\Delta t_{FWHM},\ \mu_{max},\ t_0 \ \Rightarrow\ \mu(y) = \frac{y^2+2}{y\sqrt{y^2+4}} \quad y(t) = \sqrt{y_0^2 + \left(\frac{t-t_0}{t_E}\right)^2}$$

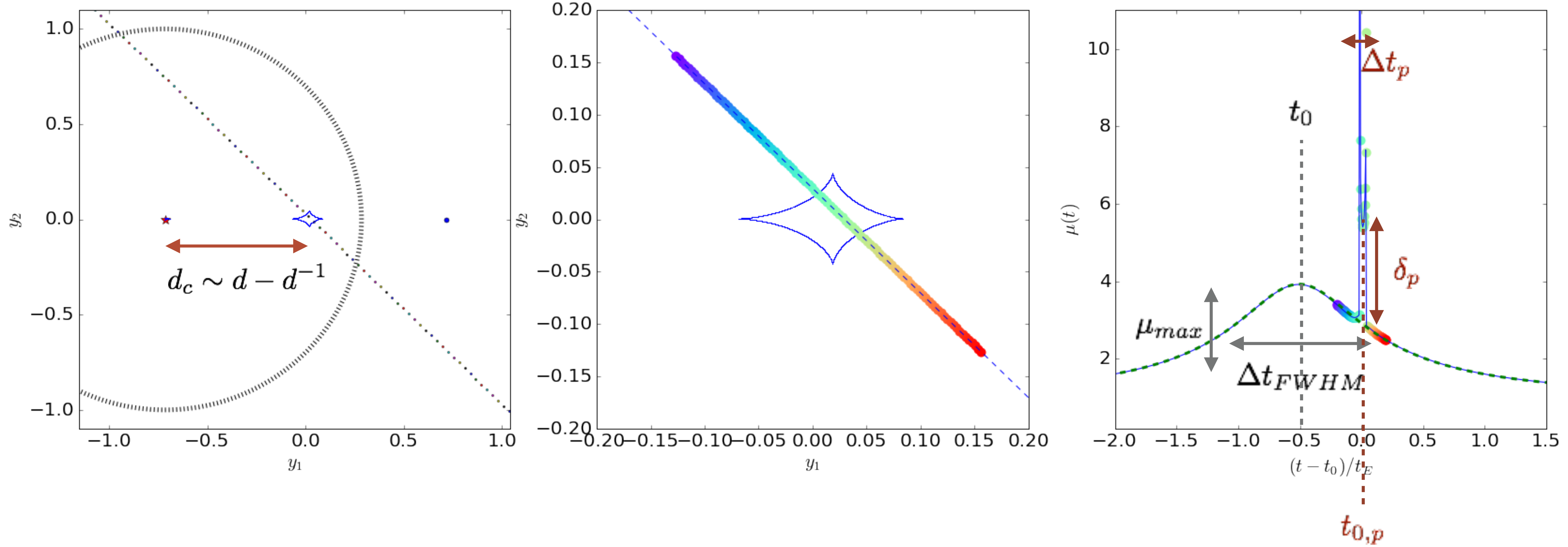
$$\Rightarrow \quad y_0 \quad t_E$$

PLANET PROPERTIES "READ OFF" OF THE LIGHT CURVES



$$\Delta t_p \sim t_{E,p} \;\Rightarrow t_E \Rightarrow \quad q = \left(\frac{t_{E,p}}{t_E}\right)^2$$

PLANET PROPERTIES "READ OFF" OF THE LIGHT CURVES

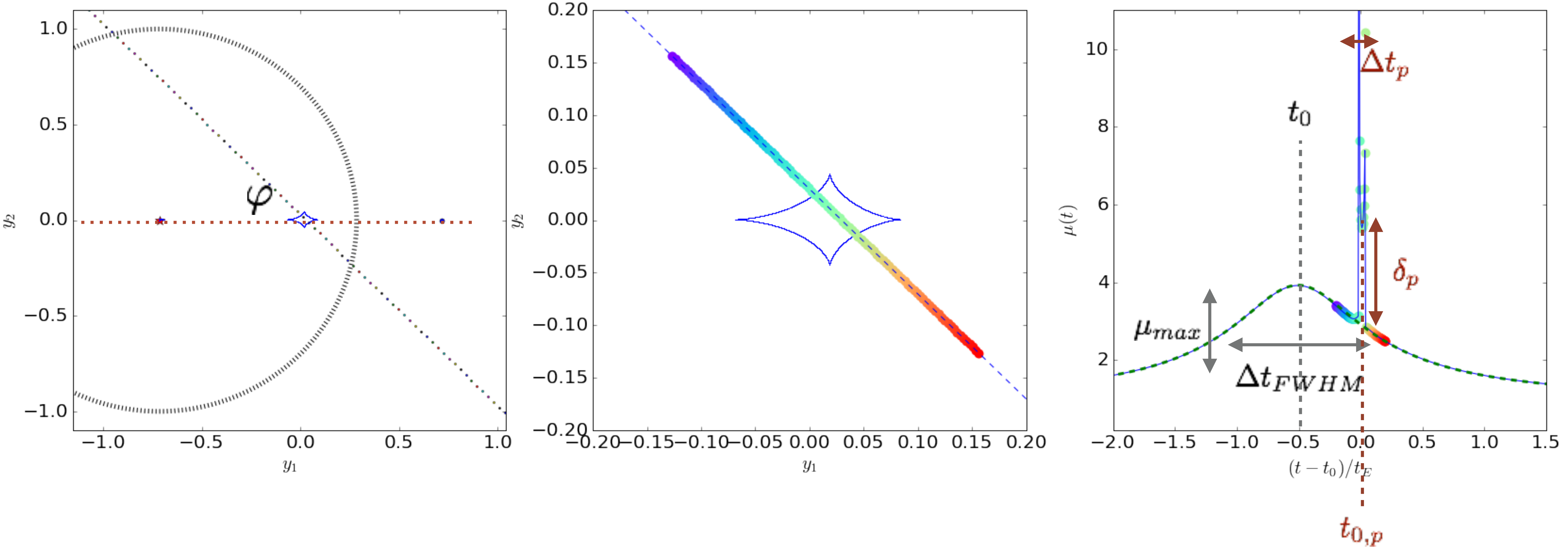


$$\delta_p,\ t_{0,p} \Rightarrow\ y_p = \sqrt{y_0^2 + \left(\frac{t_{0,p} - t_0}{t_E}\right)^2}$$

$$\Rightarrow\ d_c \sim \frac{y_p \pm \sqrt{y_p^2 + 4}}{2} \Rightarrow\ d$$

up to the degeneracy in d

PLANET PROPERTIES "READ OFF" OF THE LIGHT CURVES



$$y_0, y_p \Rightarrow \varphi = \sin^{-1} \frac{y_0}{y_p}$$

ADVANTAGES OF USING MICROLENSING FOR PLANET SEARCHES

- peak sensitivity beyond the snow line
- sensitivity to low-mass planets
- sensitivity to long period and free-floating planets
- sensitivity to a wide range of host stars over a wide range of galactocentric distances
- sensitivity to multiple planets