

Lensing Galaxies in the CFHT Legacy Survey

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**University of
Zurich**^{UZH}

Motivation

- Strong lensing analyzes wide field surveys
 - Robots are not very good at finding and modelling lenses
 - Human intervention is needed!
- ⇒ SpaceWarps citizen science project
(50'000 volunteers; 11 mio classifications; 51 candidates)

SpaceWarps Results and Outlook

- CHFT Legacy Survey: 150 deg^2

- 59 candidates found (29 promising)¹

⇒ ≈ 1 lens every few deg^2

- DES, Pan-STARRS (now); LSST, Euclid, ... (2020ies)

- more area, better resolution, deeper images

⇒ 10'000 lenses over 10 years (\approx one per hour)

¹[A. More et al; arXiv:1504.05587]

Outlook

A lot of computational- and manpower needed

Detecting lenses:

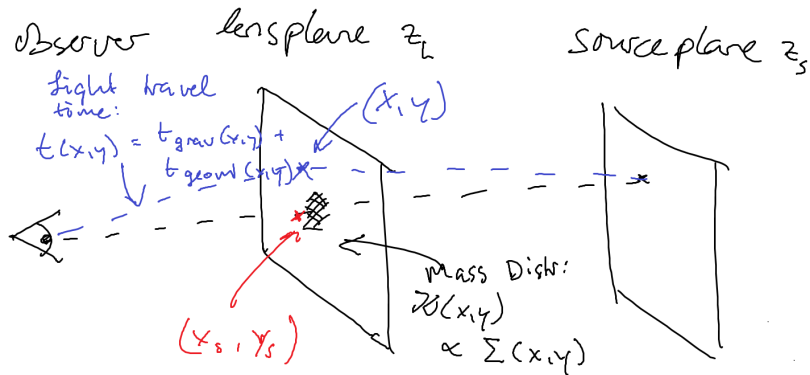
- Robots making progress (RingFinder; ArcFinder)
in combination with
- Future SpaceWarps runs

Post processing?

- Robots not there (yet?)
- ⇒ Citizen science: SpaghettiLens

Theory

Setup



Fermat's Principle

Fermat's Principle²

Rays of light traverse the path of stationary optical length with respect to variations of the path.

Fermat's Principle

Time t for path X :

$$t[X] = \frac{1}{c} \int_{t_1}^{t_2} n(\vec{x}(t)) \sqrt{1 + \left(\frac{d\vec{x}(t')}{dt'} \right)^2} dt'$$

Path X where t stationary.

²Ghatak, Ajoy (2009), Optics

Light Travel Time

Light travel time

$$t(x, y) = t_{\text{geom}} + t_{\text{grav}} \quad (1)$$

$$t_{\text{geom}} \propto (x - x_s)^2 + (y - y_s)^2 \quad (2)$$

$$t_{\text{grav}} = \langle t_{\text{grav}}(x_o, y_o) \rangle + (1 + z_L) \frac{2G}{c^3} M(x_{\bullet}, y_{\bullet}) \quad (3)$$

$$A_t = A_{\text{geom}} + A_{\text{grav}} \quad (4)$$

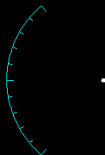
$$A_{\text{geom}} = \frac{1}{2} (x^2 + y^2) \quad (5)$$

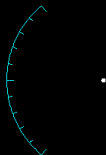
$$\nabla^2 A_{\text{grav}}(x, y) = -2\kappa(x, y) \quad (6)$$

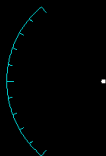
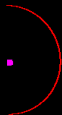
$$A = \frac{cD_L}{(1+z_L)^2} \frac{D_{LS}}{D_S} \times t \quad (7)$$

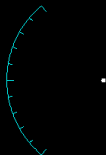
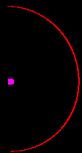
$$\kappa(x, y) = \frac{4\pi G}{c^2} \frac{D_L}{1+z_L} \frac{D_{LS}}{D_S} \times \Sigma(x, y) \quad (8)$$

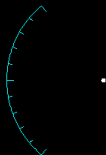
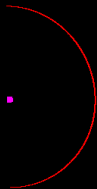
Alternative explanation

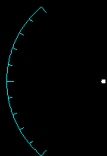
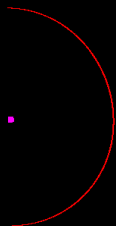


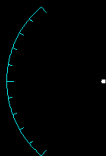
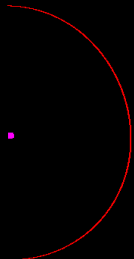


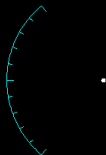
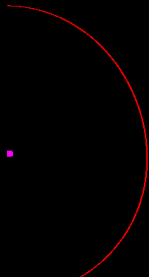


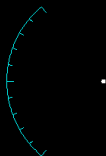
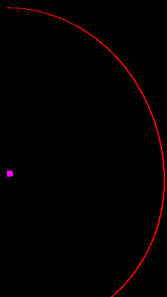


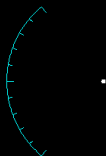
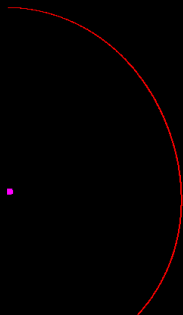


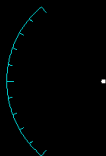
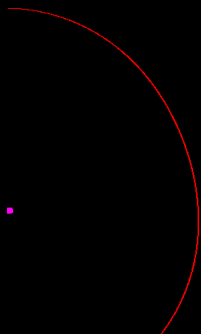


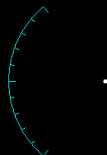
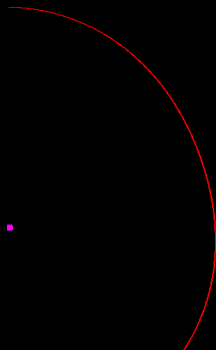


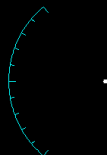
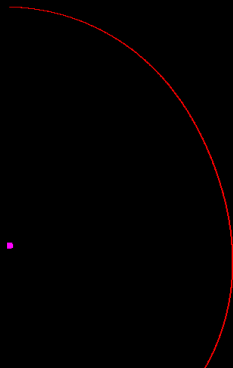


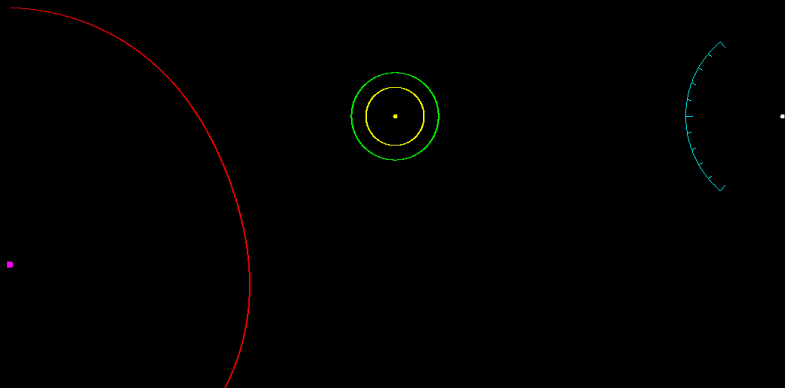


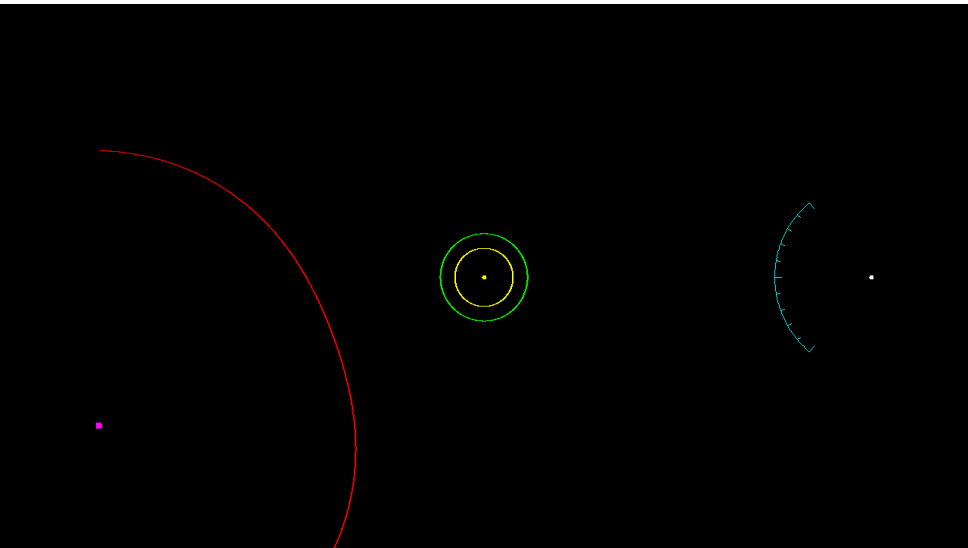


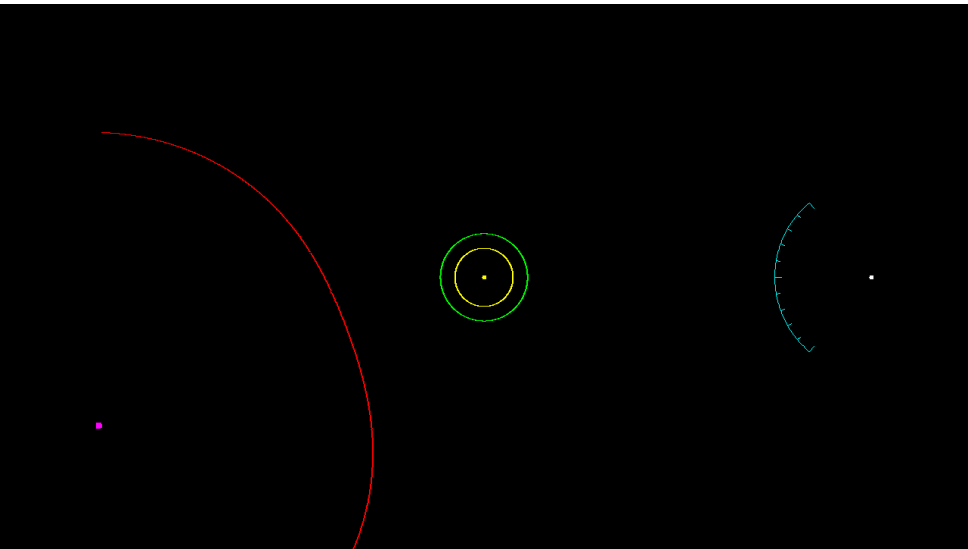


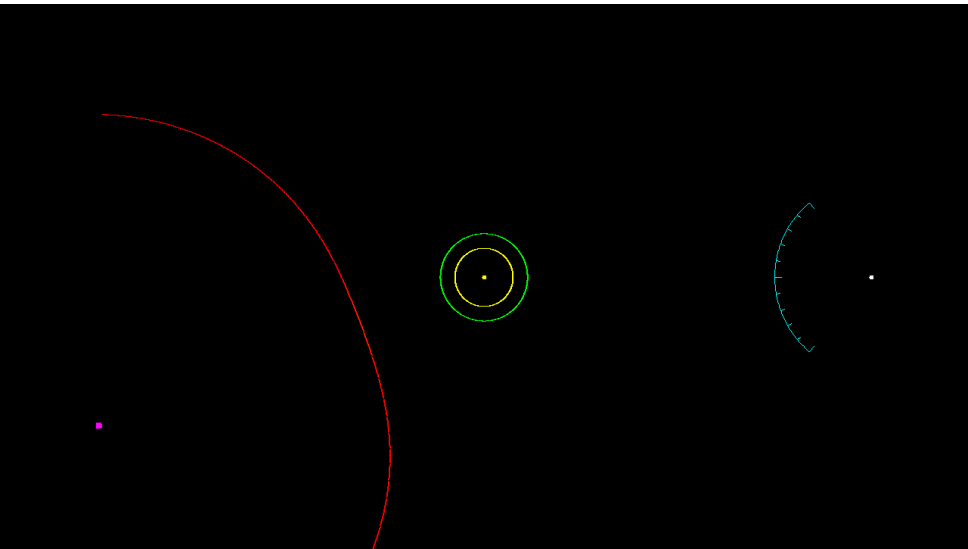


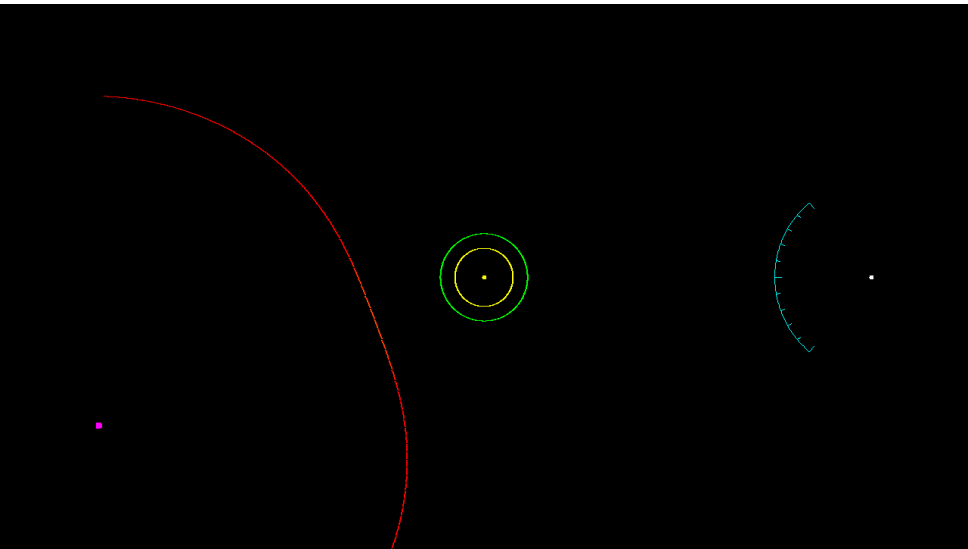


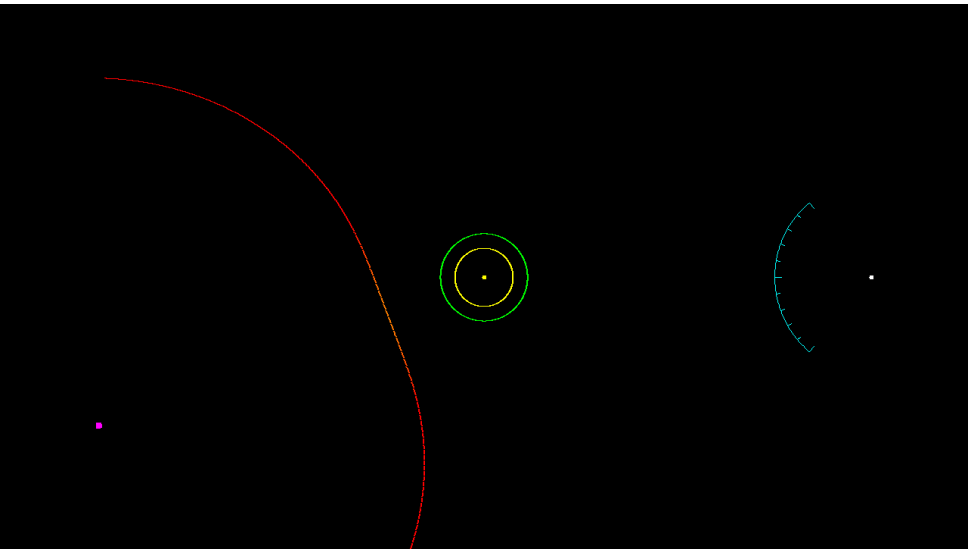


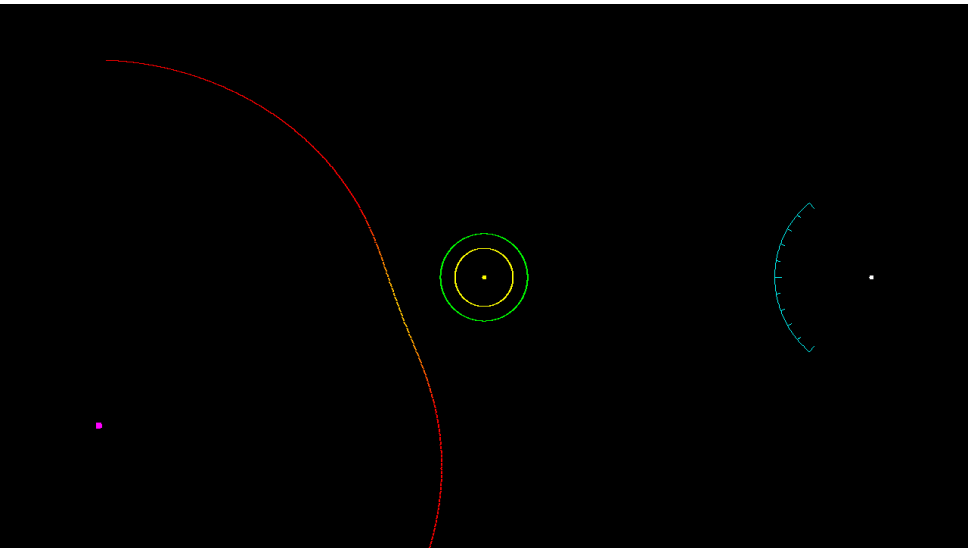


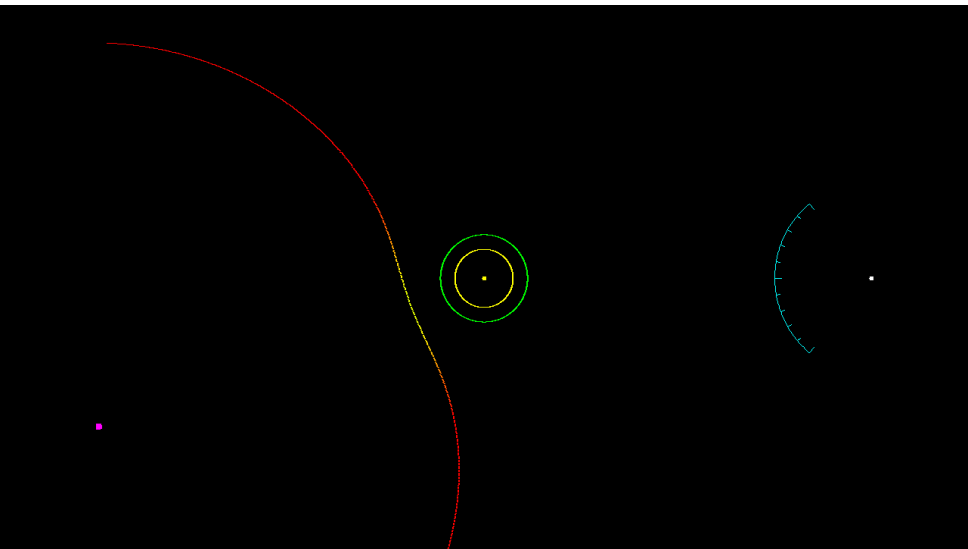


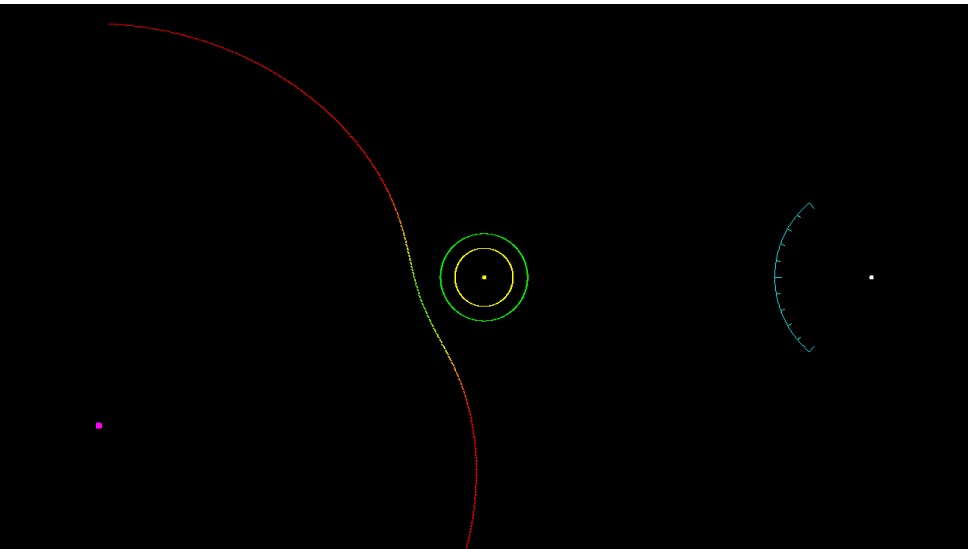


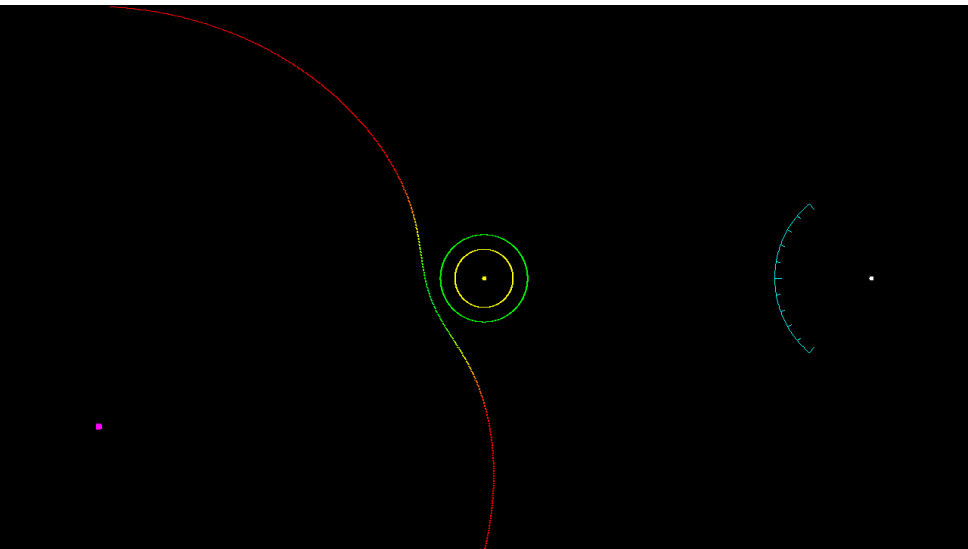


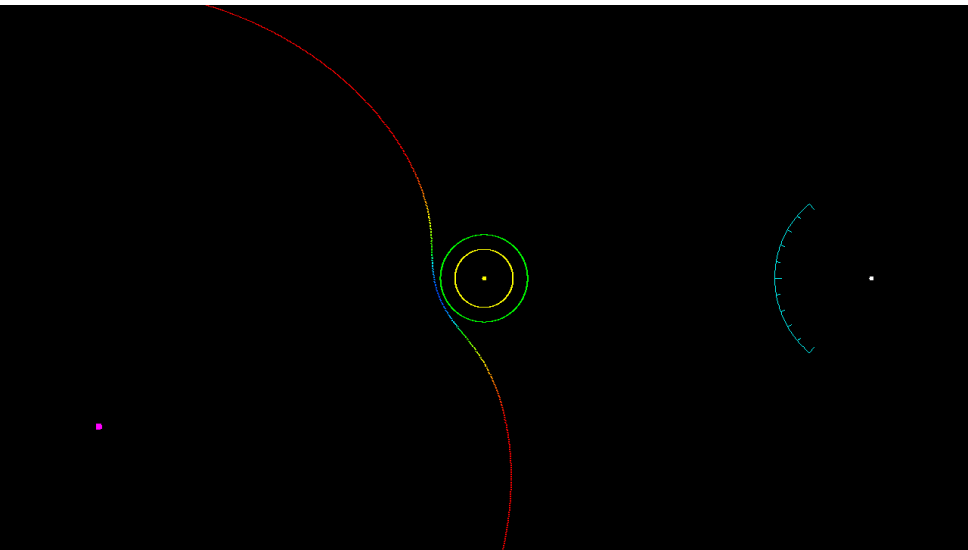


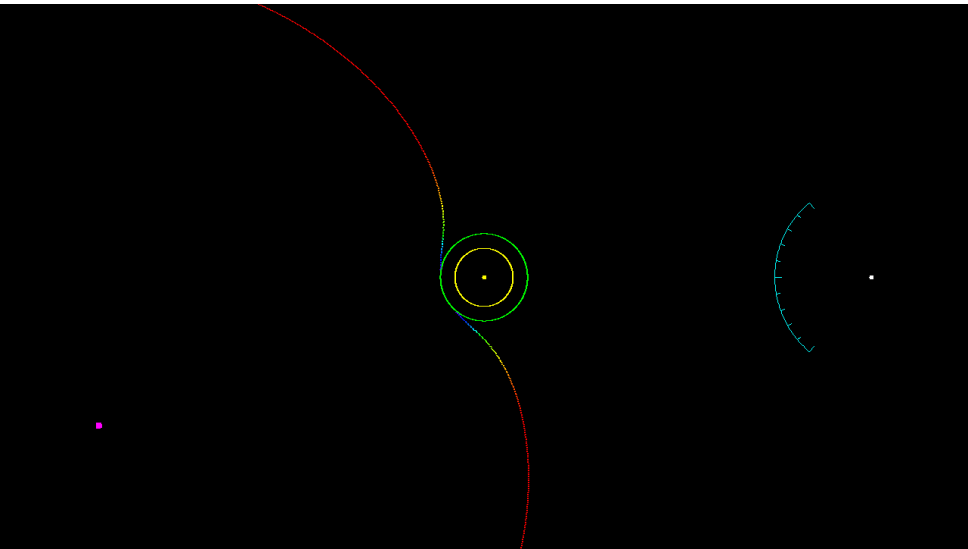


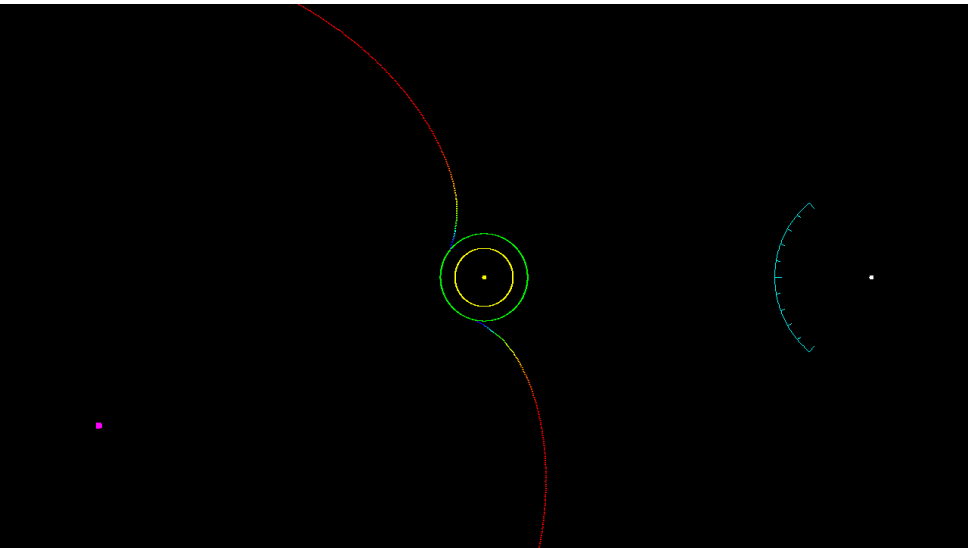


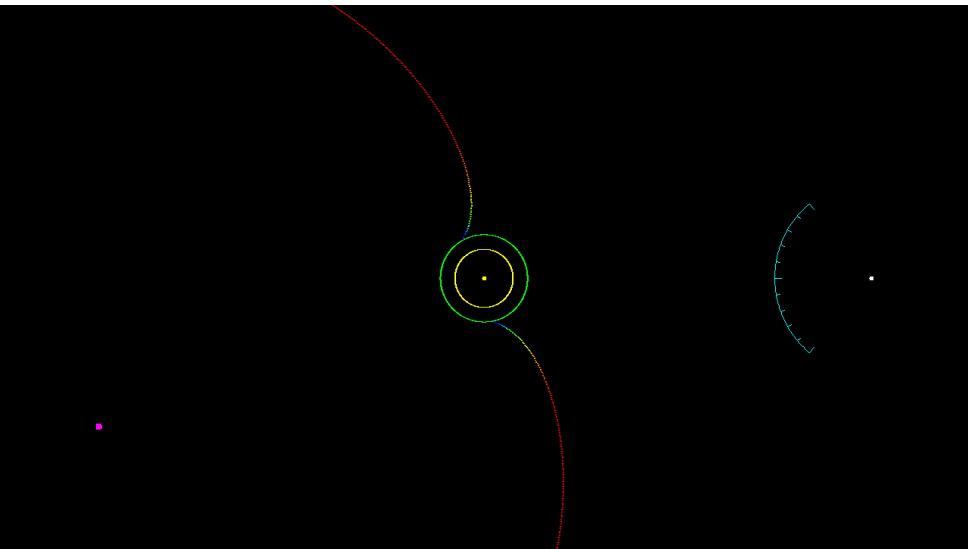


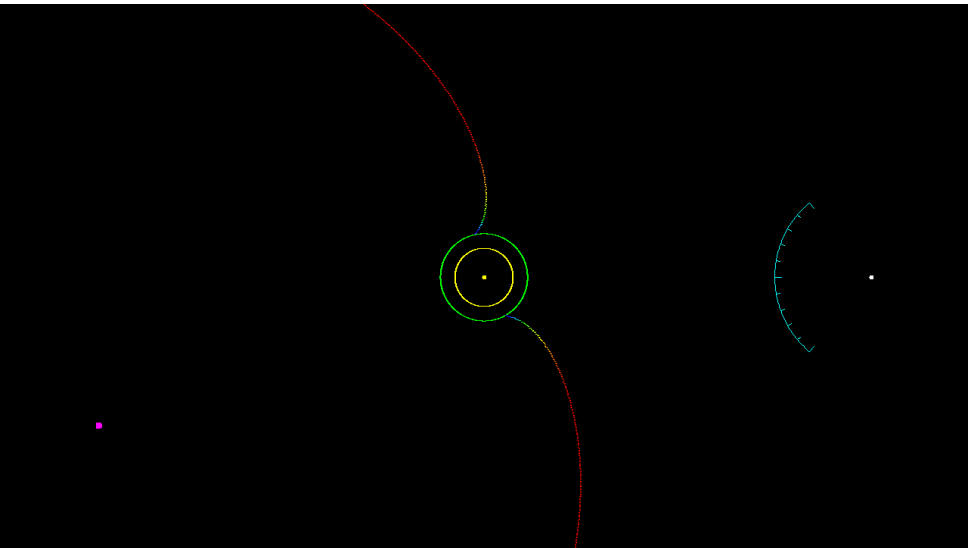


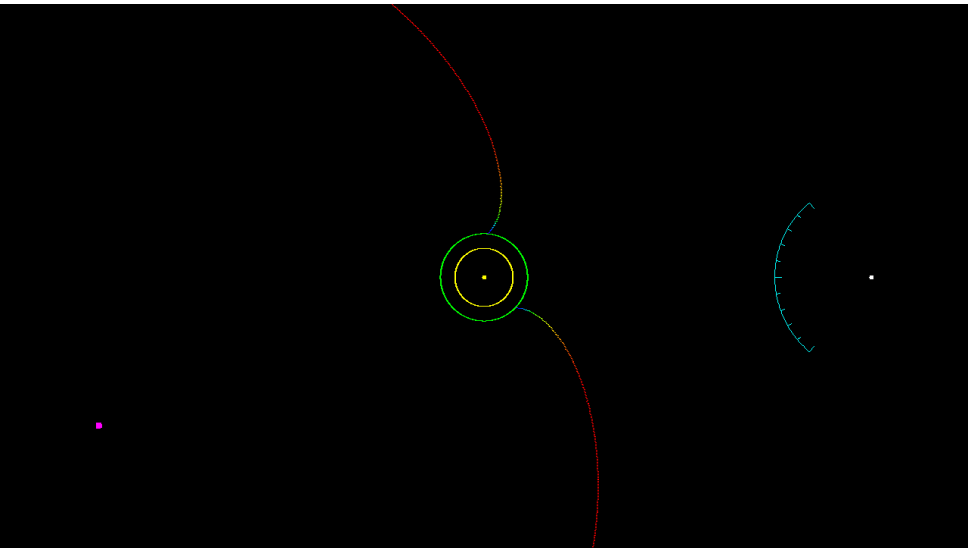


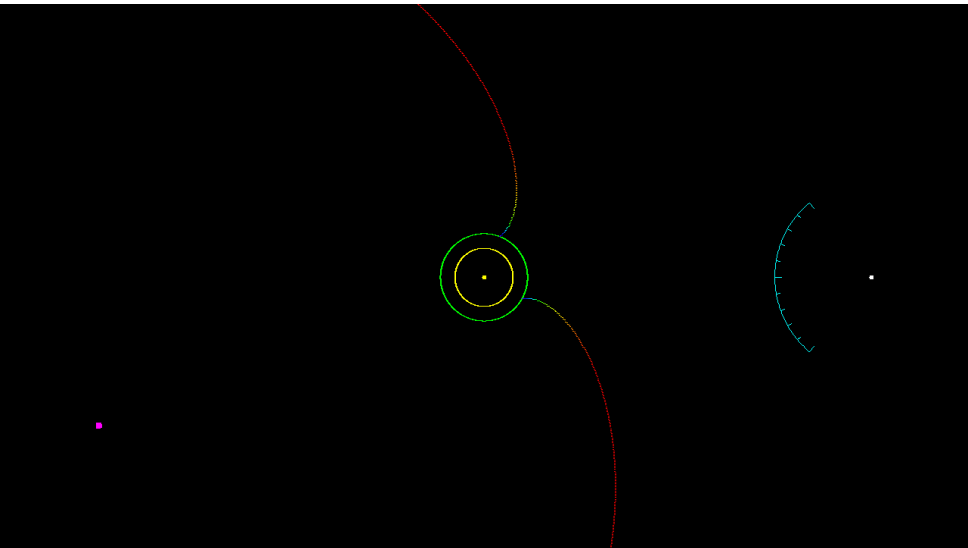


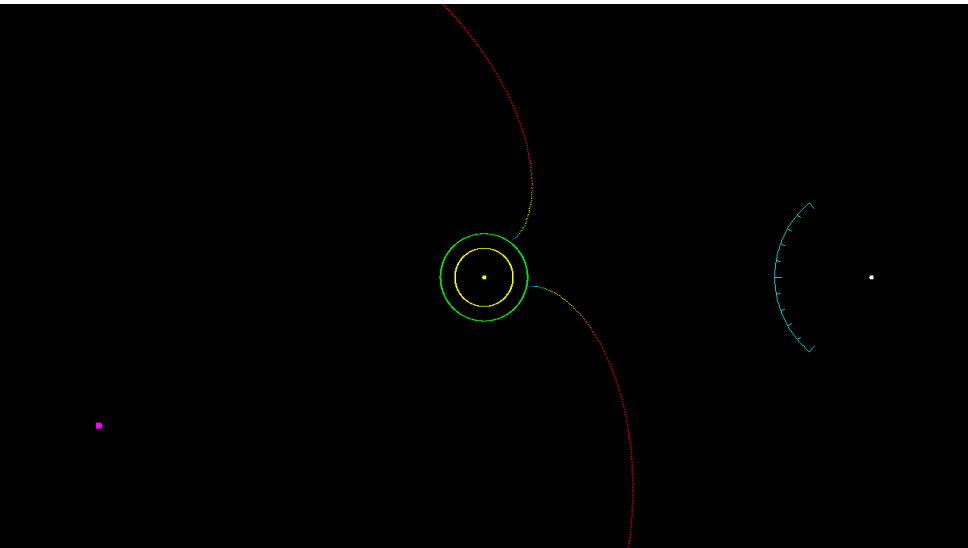


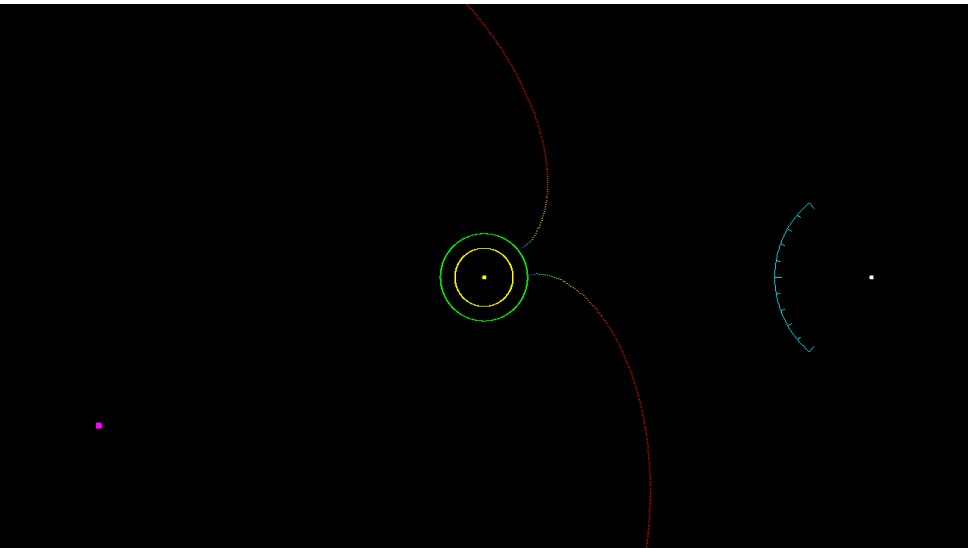


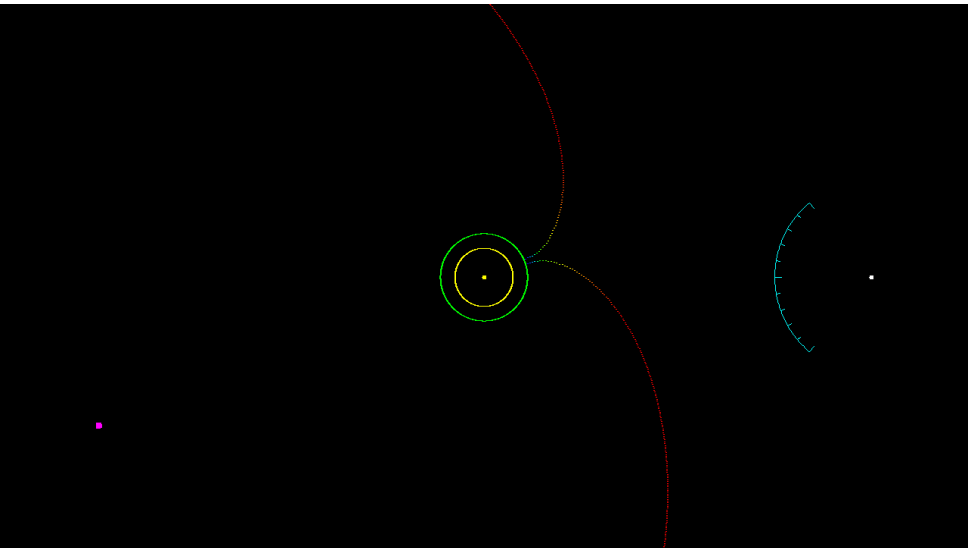


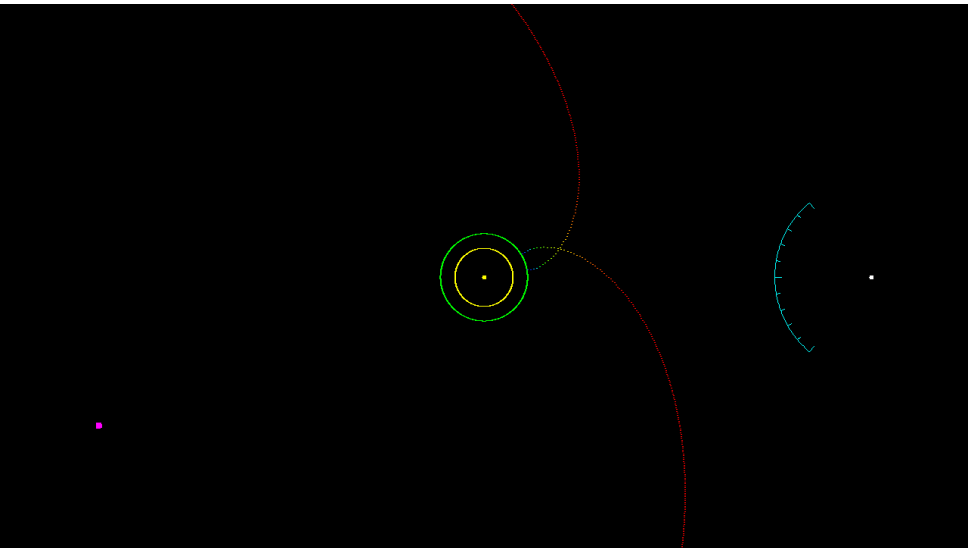


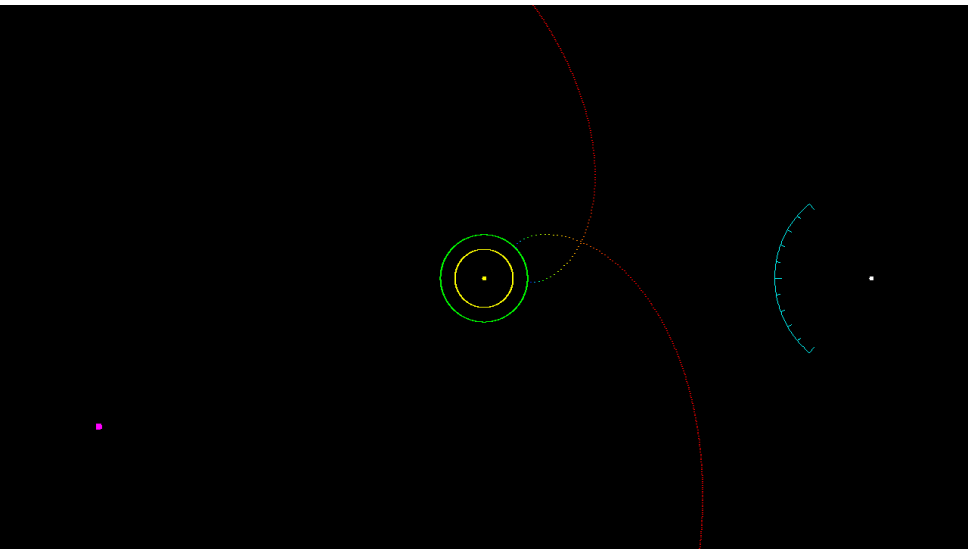


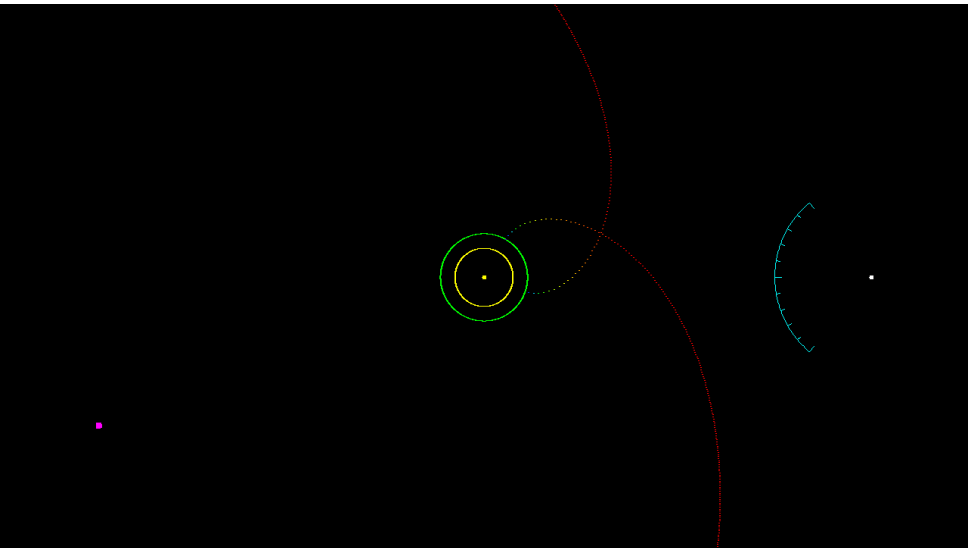


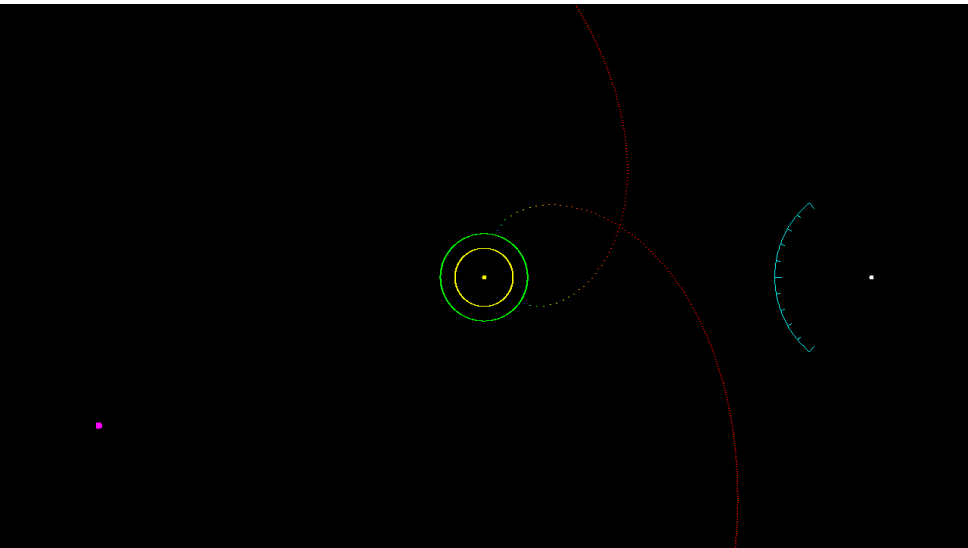


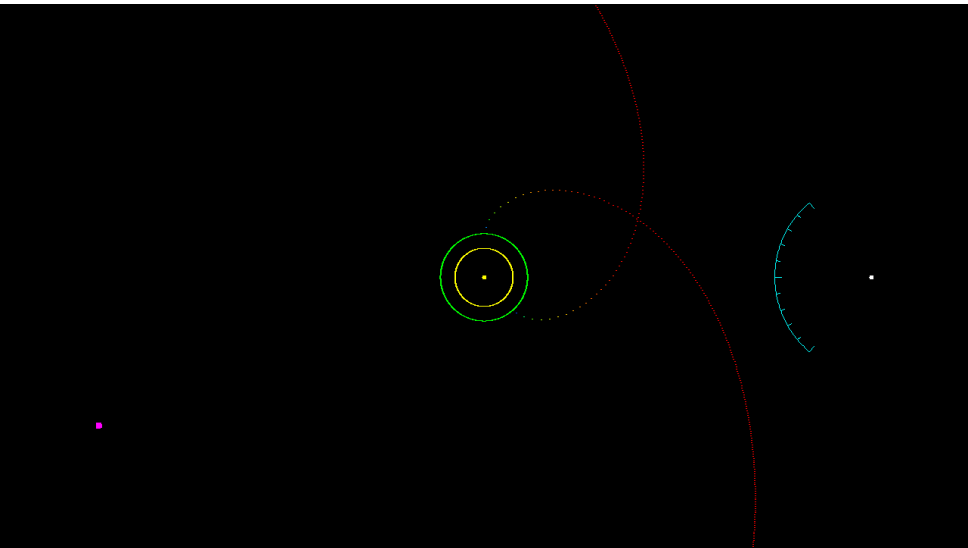


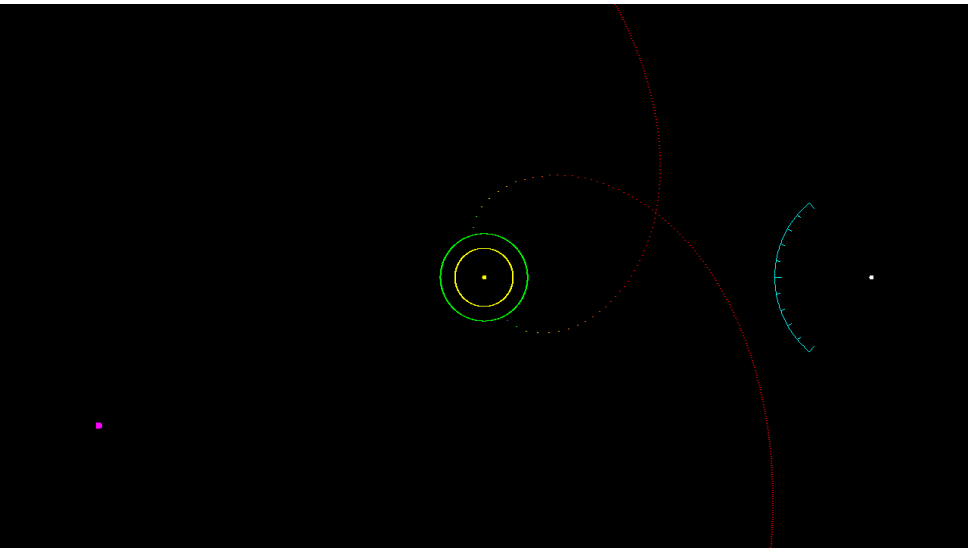


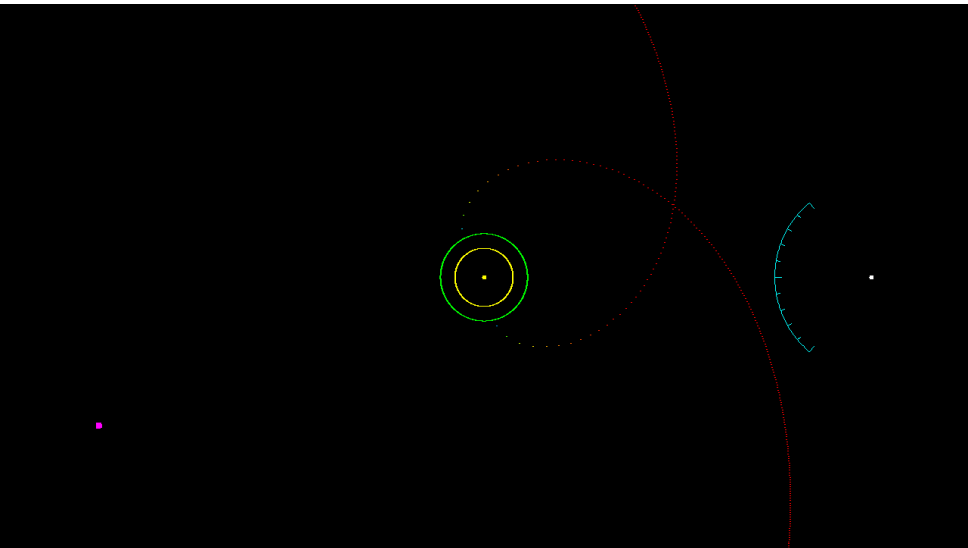


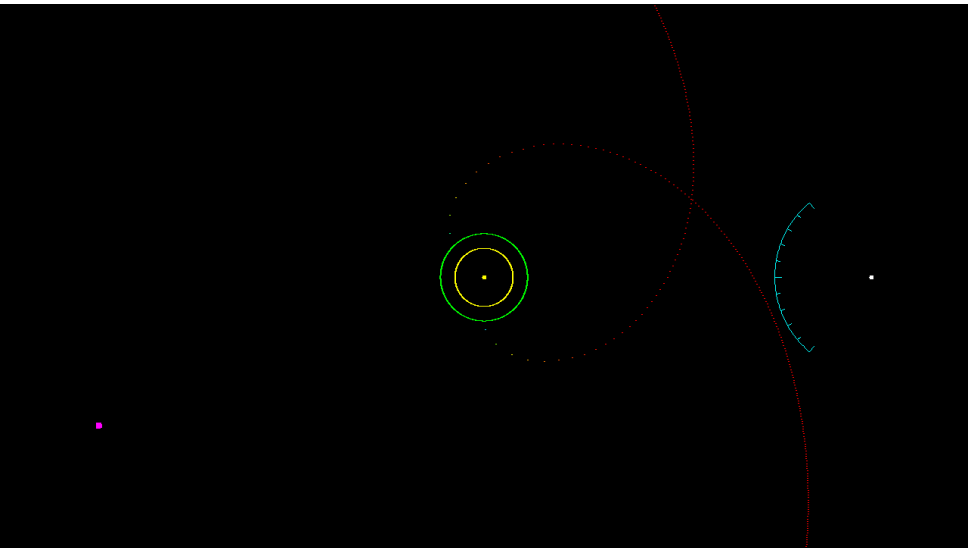


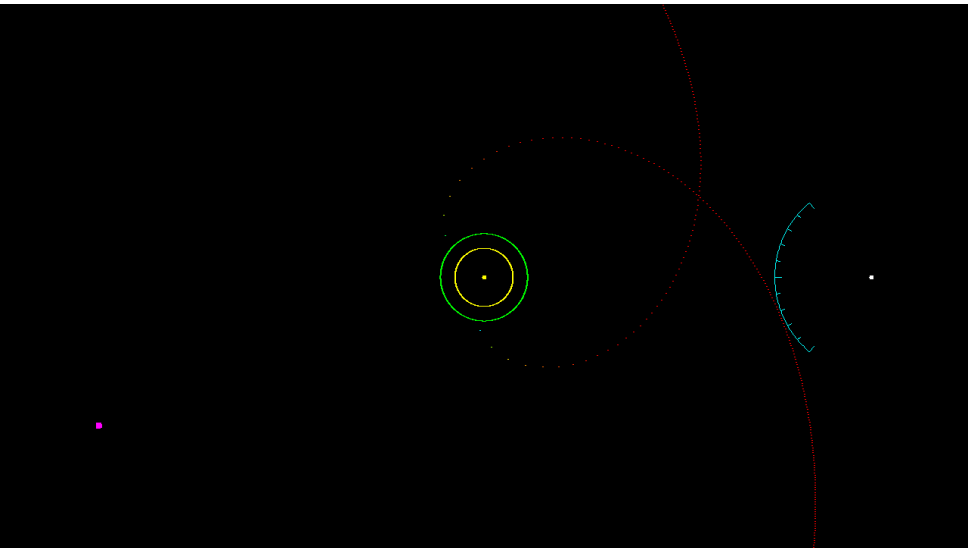


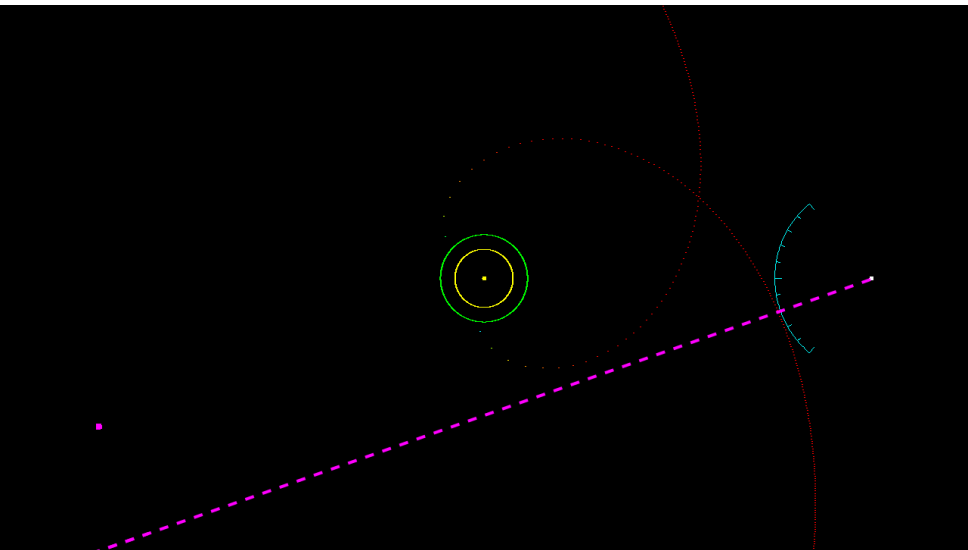


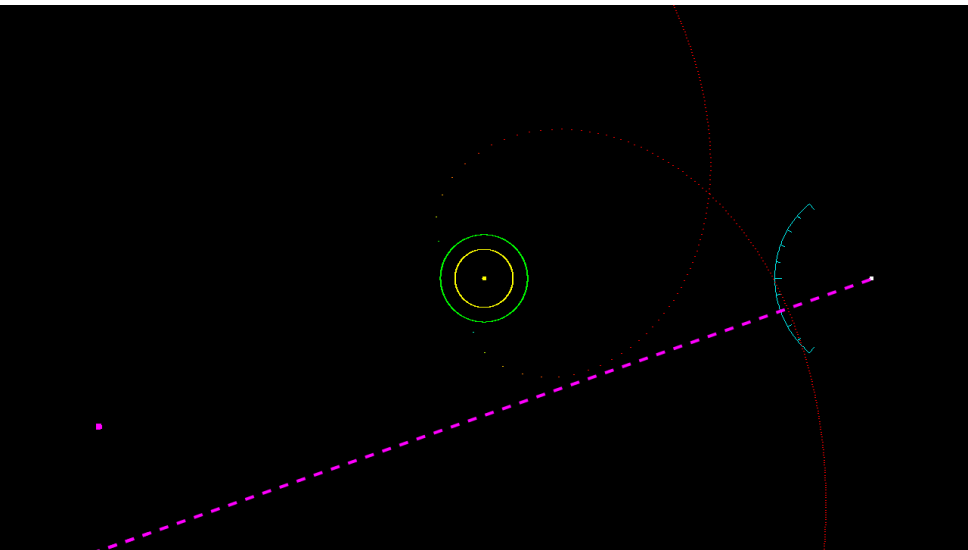


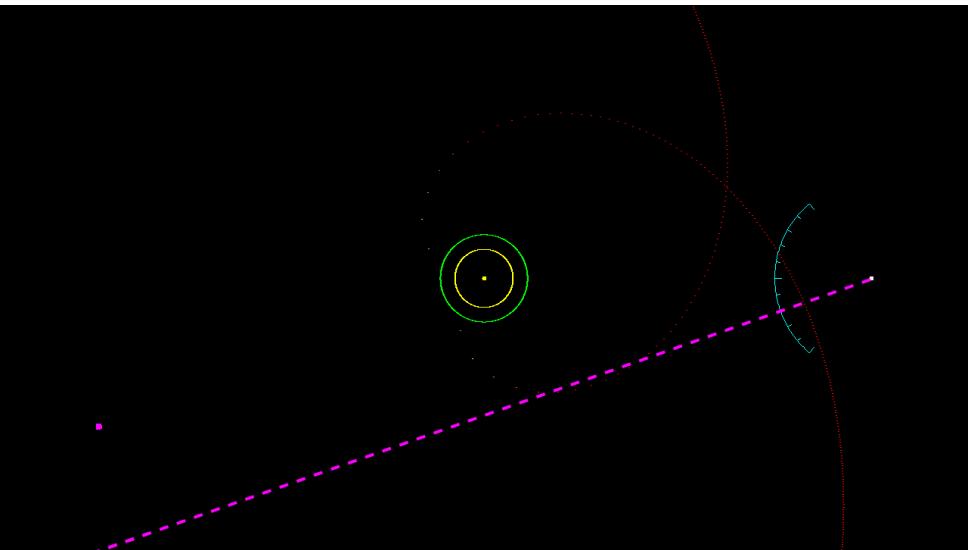


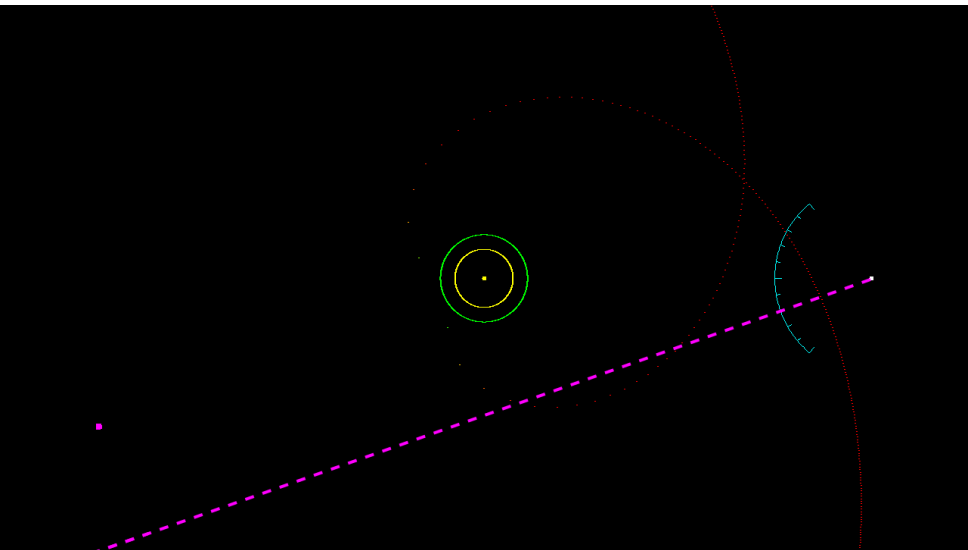


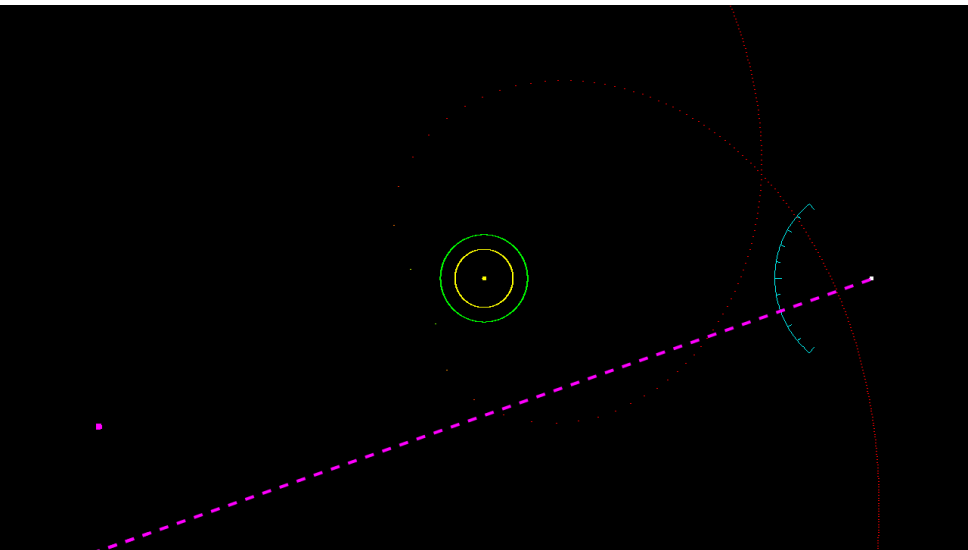


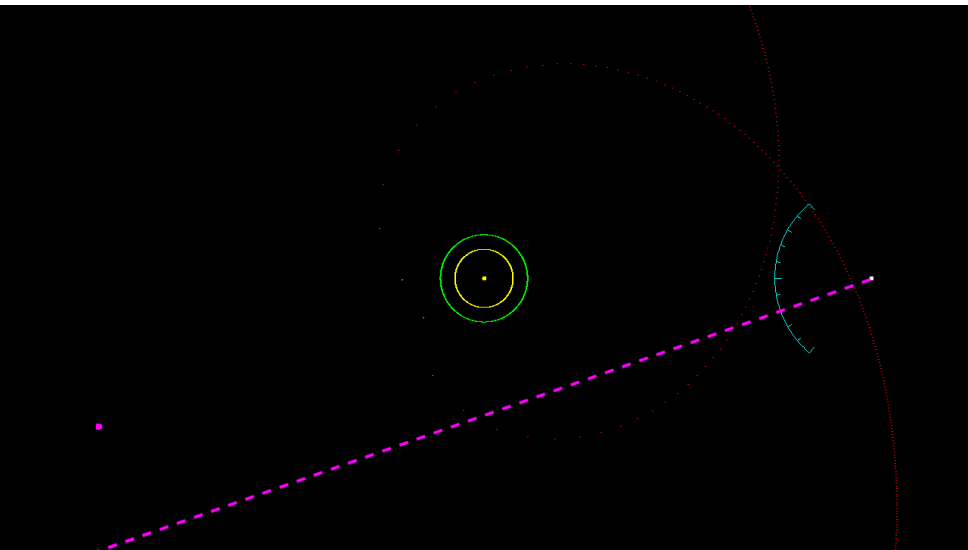


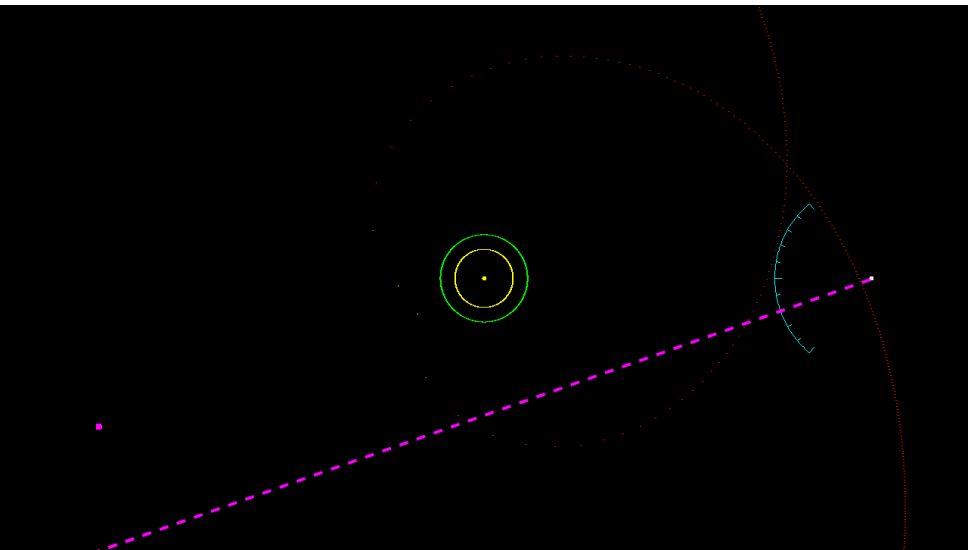


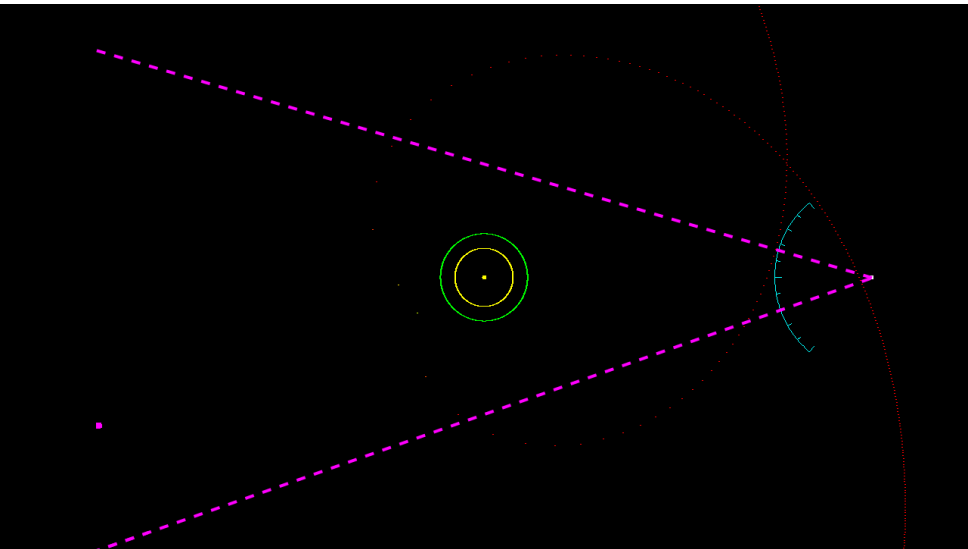


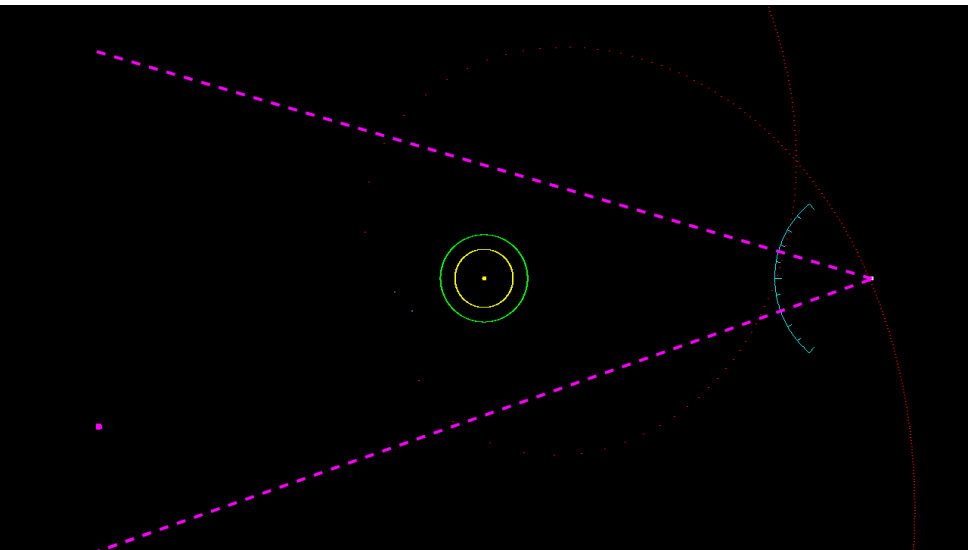


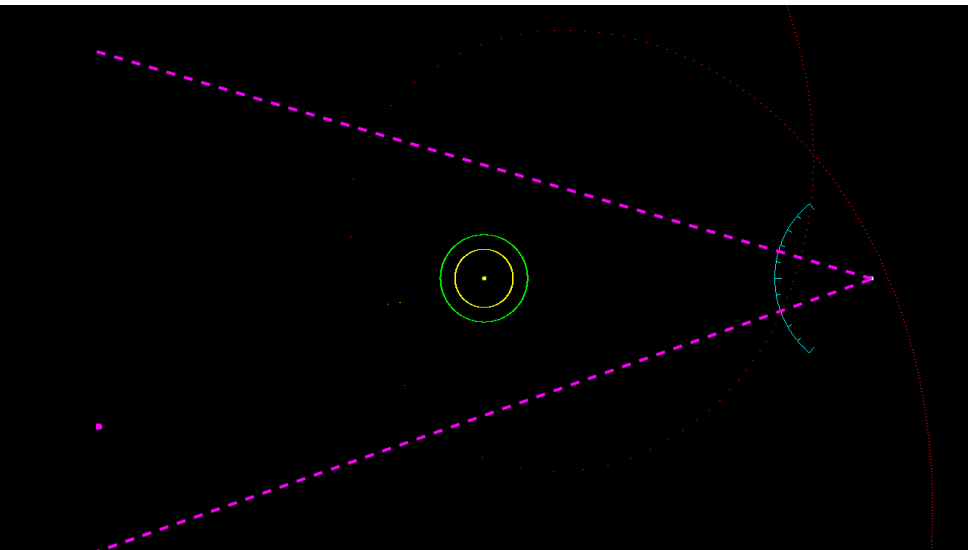


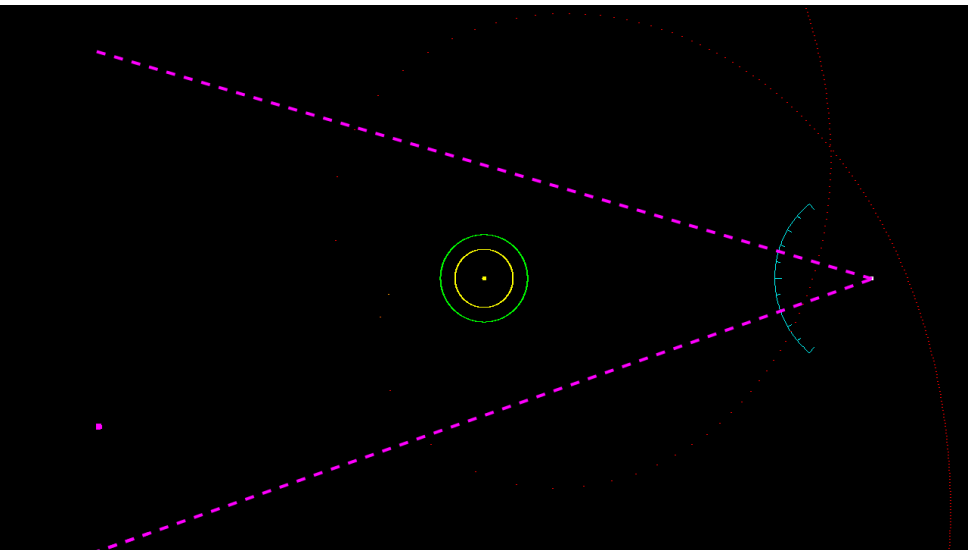


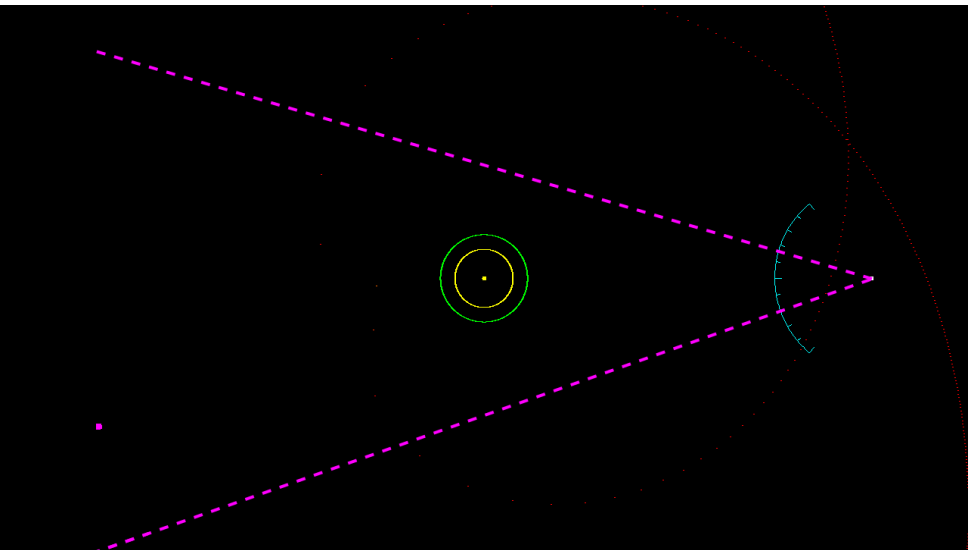




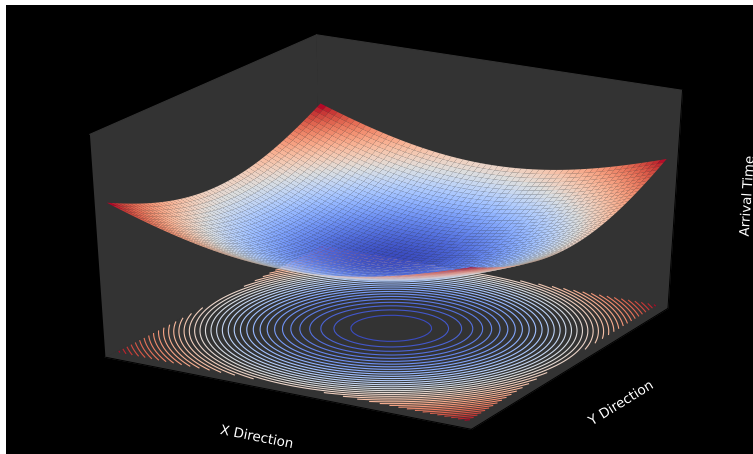


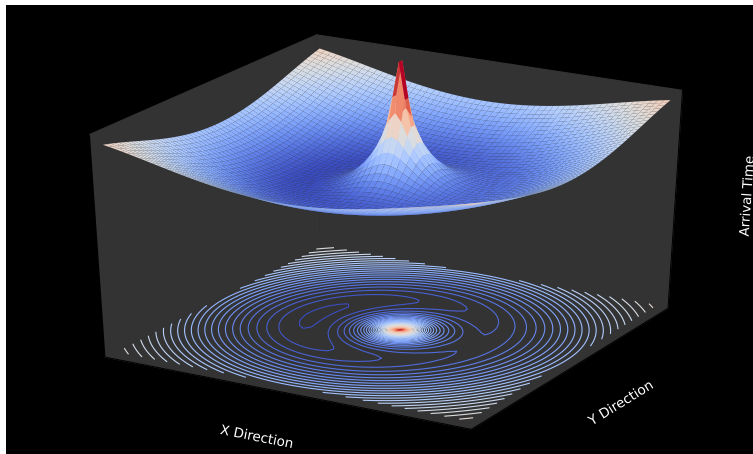






Simulation program: `gravlens` by C. Huwiler





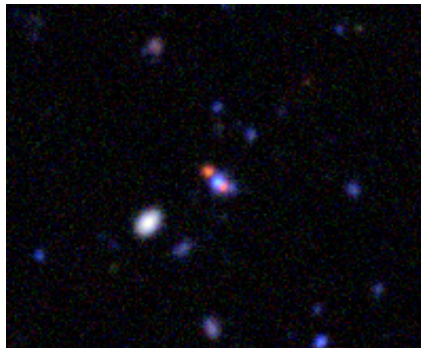
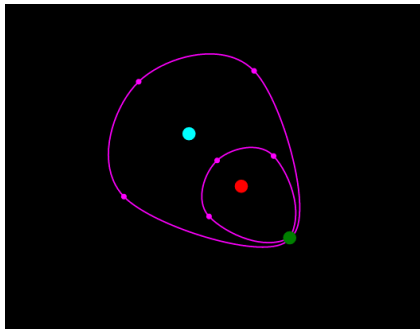
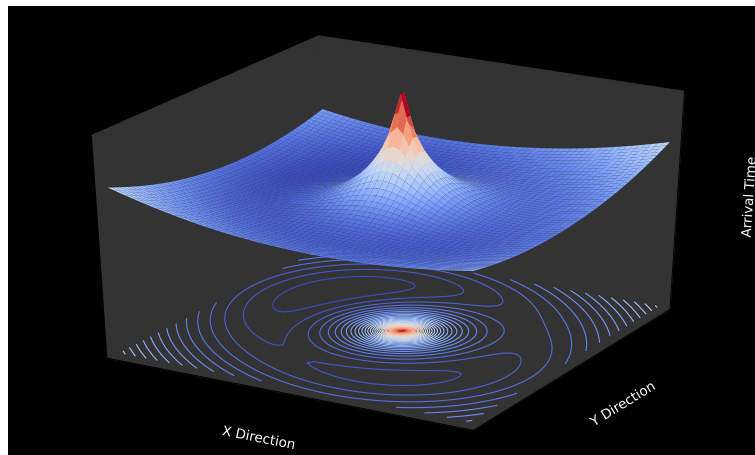


Figure: ASW0004q9e (SpaceWarps)



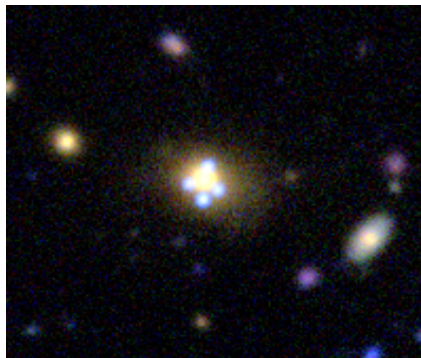
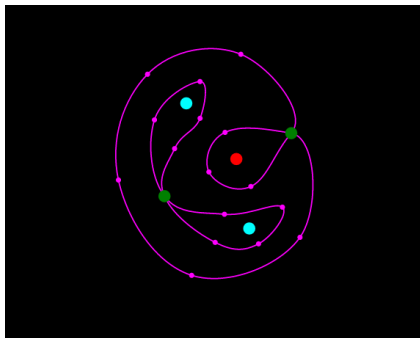
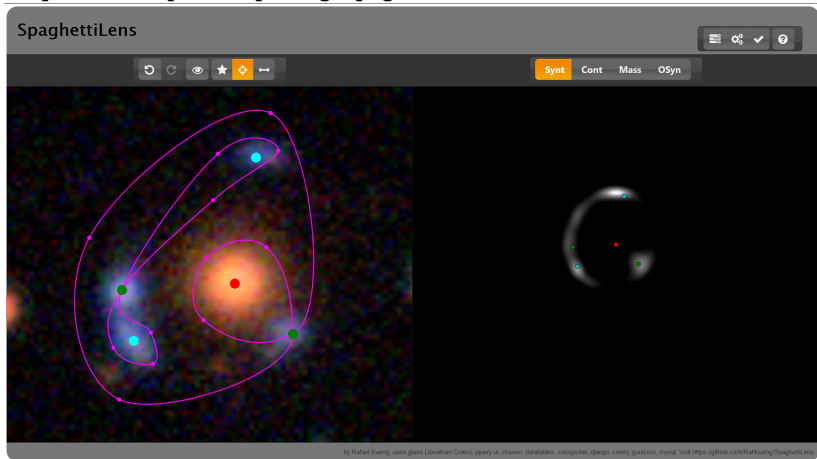


Figure: ASW0001a8c (SpaceWarps)

SpaghettiLens

<http://labs.spacewarps.org/spaghetti/>



SpaghettiLens Results: Test of Performance

- Use simulated lenses
- Let volunteers model them
- Recover and compare Einstein Radii Θ_E
- Volunteers perform well!

arxiv:1502.00008

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(MN \LaTeX style file v2.2)

Gravitational Lens Modelling in a Citizen Science Context

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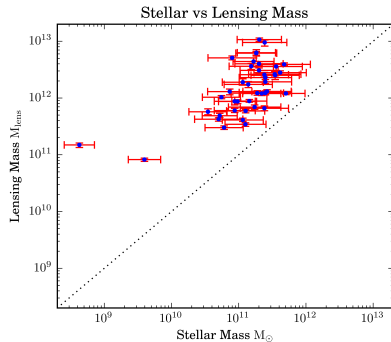
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⁷Sub-department of Astrophysics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford, OX1 3RH, UK

SpaghettiLens Results: Stellar vs Lensing Mass

- Lensing mass against the stellar mass of the candidate lens galaxies
- Stellar mass fraction of order 20 percent
- With decreasing trend for the most massive galaxies
- Expected for early type galaxies
- Outliers? Maybe non-lenses (not yet spectroscopically confirmed)



Conclusions and Outlook

Conclusions:

- SpaghettiLens is set up and works

We are currently working on:

- Increase the number of users
- Fit parametrized models to the free-form mass distributions³
- Determination of photometric red shifts
- Estimate stellar populations (using galfit, SExtractor)⁴
- Your idea!

³Lucy Oswald; University of Oxford

⁴Dominik Leier; University of Bologna

Questions?

Questions?

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Appendix