Lensing Galaxies in the CFHT Legacy Survey

Rafael Küng[1] Prasenjit Saha[1] Elisabeth Baeten[2] Jonathan Coles[3]
Claude Cornen[2] Christine Macmillan[2] Phil Marshall[4] Anupreeta More[5]
Surhud More[5] Aprajita Verma[6] Julianne K. Wilcox[2]

[1]Physik–Institut, University of Zurich, Zurich, Switzerland
[2]Zooniverse, c/o Astrophysics Department, University of Oxford, Oxford, UK
[3]Exascale Research Computing Lab, Bruyeres-le-Chatel, France
[4]Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, USA
[5]Kavli Institute for the Physics and Mathematics of the Universe, University of Tokyo, Kashiwa-shi, Japan
[6]Sub-department of Astrophysics, University of Oxford, Oxford, UK

MG14 – 17. July 2015

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!

$\Rightarrow$ SpaceWarps citizen science project

SpaceWarps Results and Outlook

- CHFT Legacy Survey: 150 deg^2
- 50'000 volunteers; 11 mio classifications
- 59 candidates found (29 promising)[1]

$\Rightarrow \approx$ 1 lens every few deg^2

- DES, Pan-STARRS (now); LSST, Euclid, ... (2020+)
- more area, better resolution, deeper images

$\Rightarrow$ 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

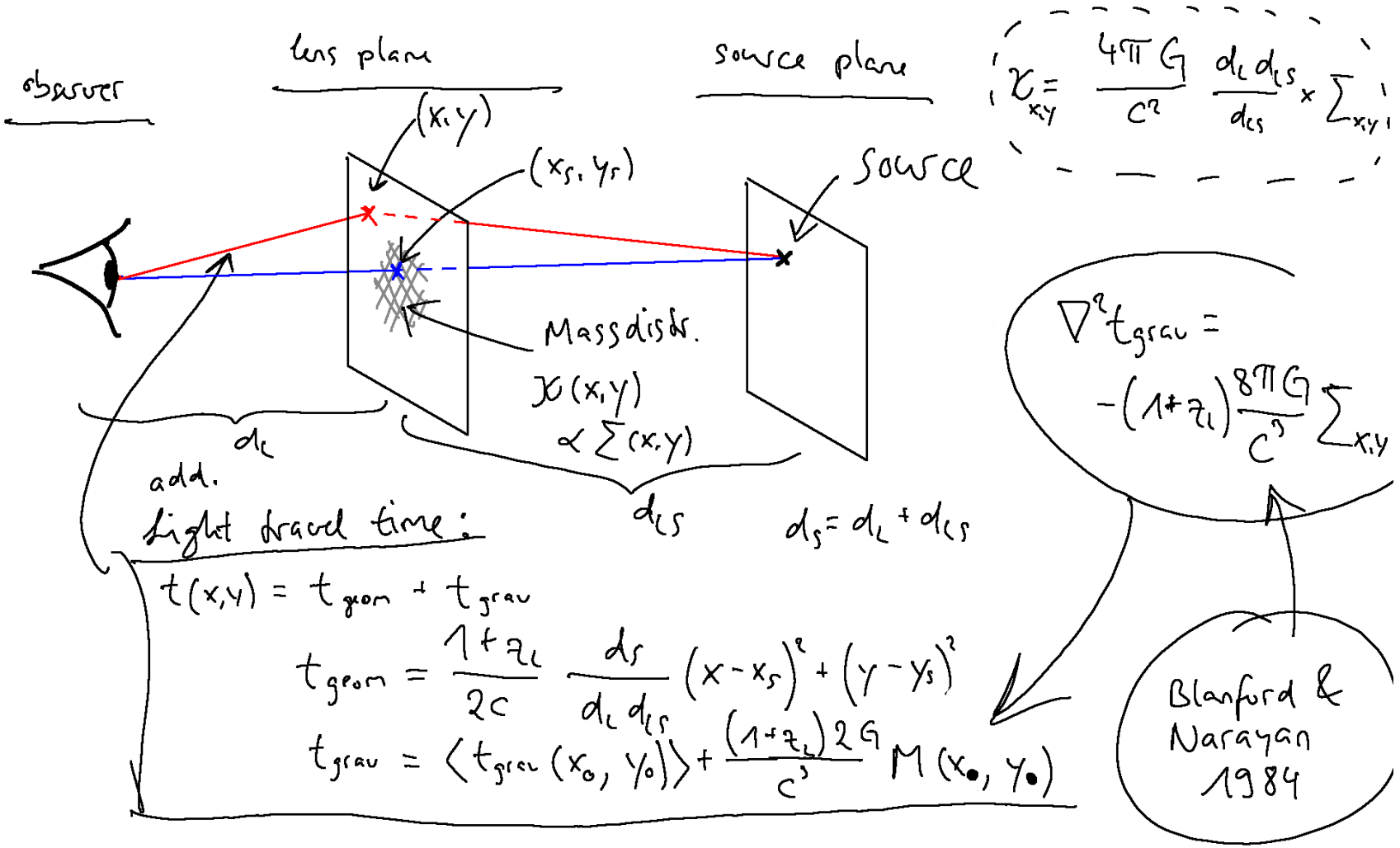
Post processing?

- Robots not there (yet?)

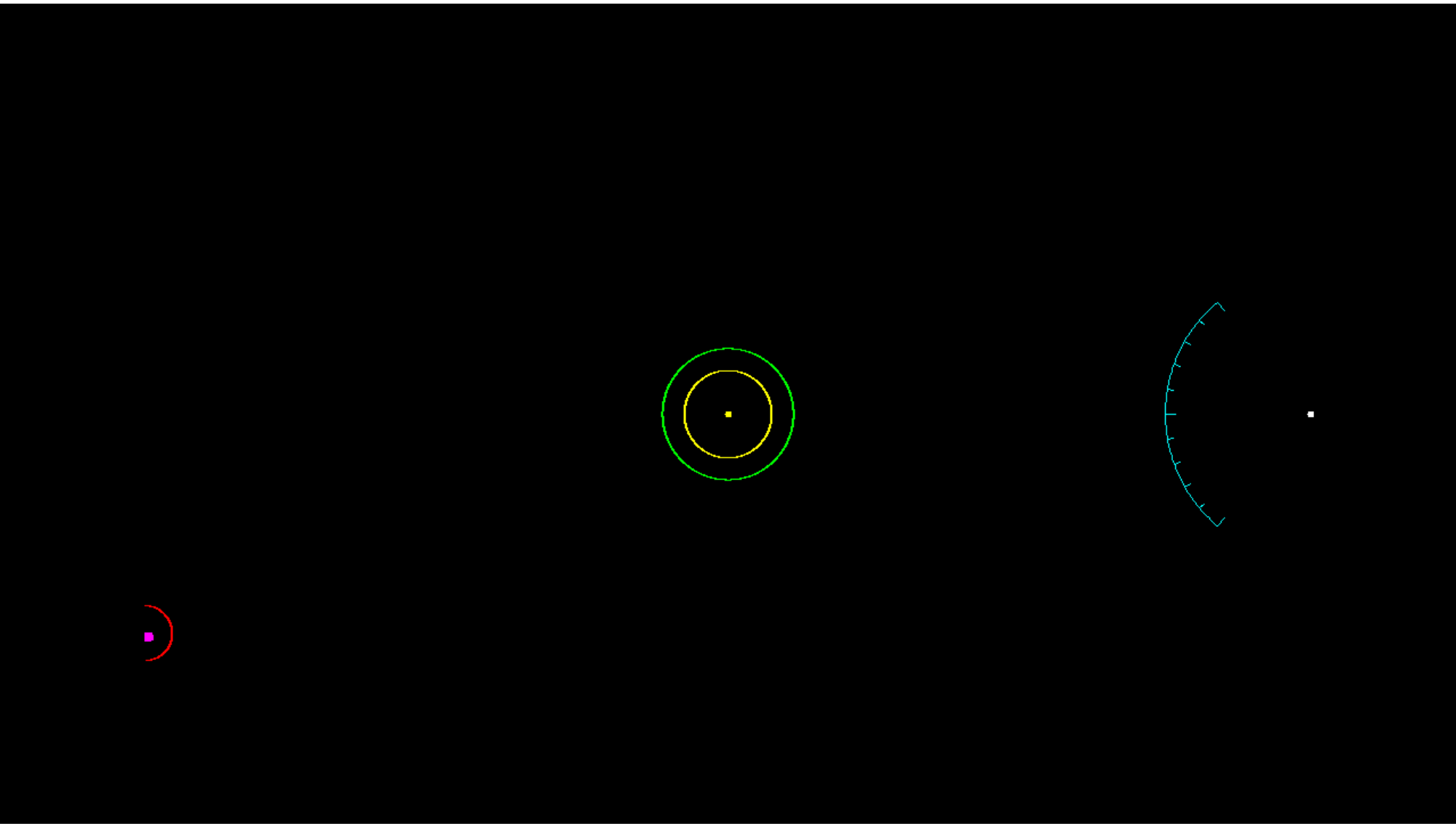
$\Rightarrow$ Citizen science: SpaghettiLens

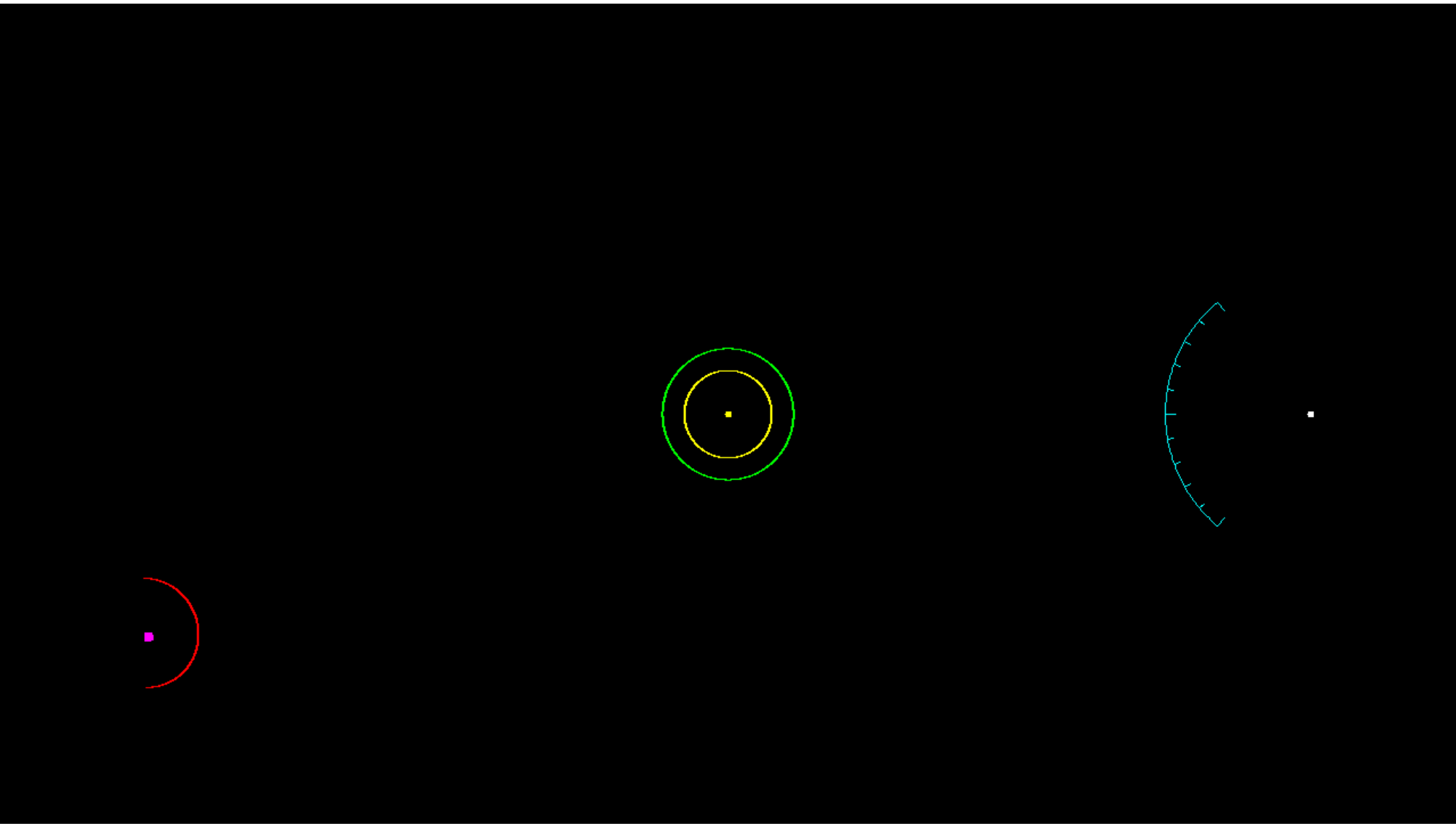
Theory

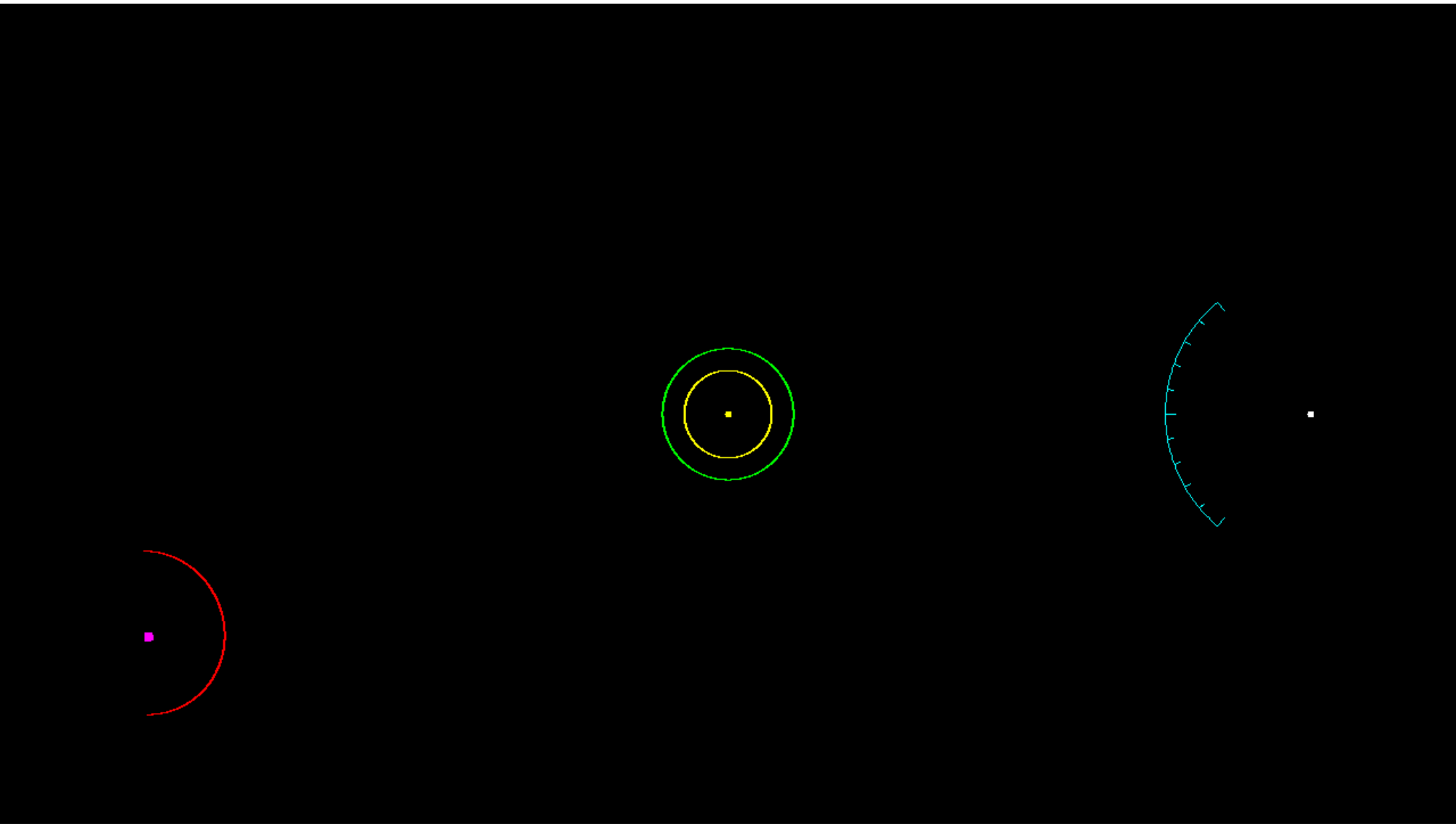
Setup

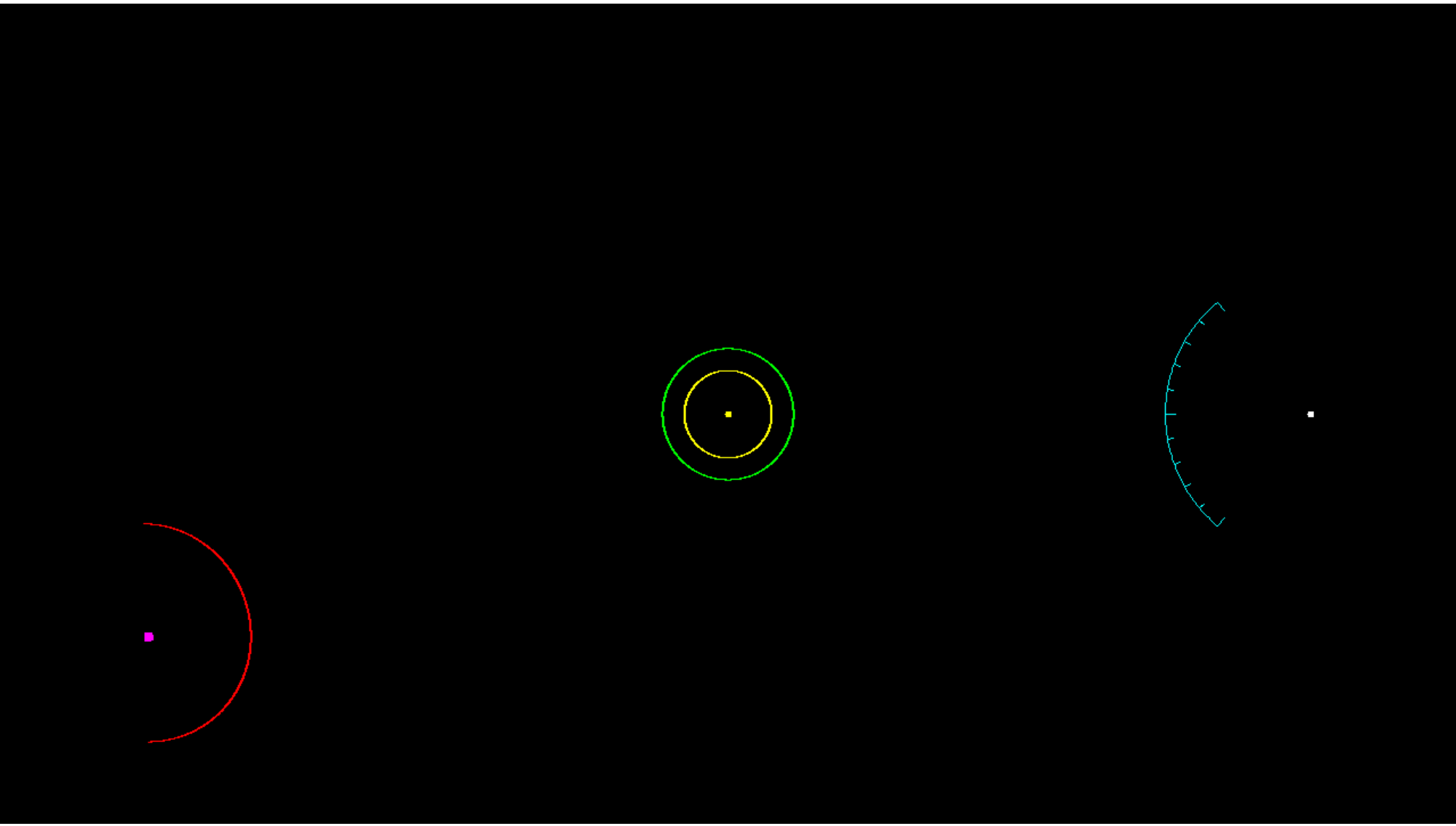

observer
lens plane
source plane
(x, y)
(x_s, y_s)
source
Mass distr.
Σ(x, y)
∝ Σ(x, y)
d_l
d_ls
d_s = d_l + d_ls
add. light travel time:
t(x,y) = t_geom + t_grav
t_geom = (1+z_l)/2c · d_s/(d_l d_ls) ((x − x_s)² + (y − y_s)²)
t_grav = ⟨t_grav(x_0, y_0)⟩ + (1+z_l) 2G/c³ M(x_•, y_•)
χ_{x,y} = 4πG/c² · d_l d_ls/d_s × Σ_{x,y}
∇² t_grav = −(1+z_l) 8πG/c³ Σ_{x,y}
Blanford & Narayan 1984

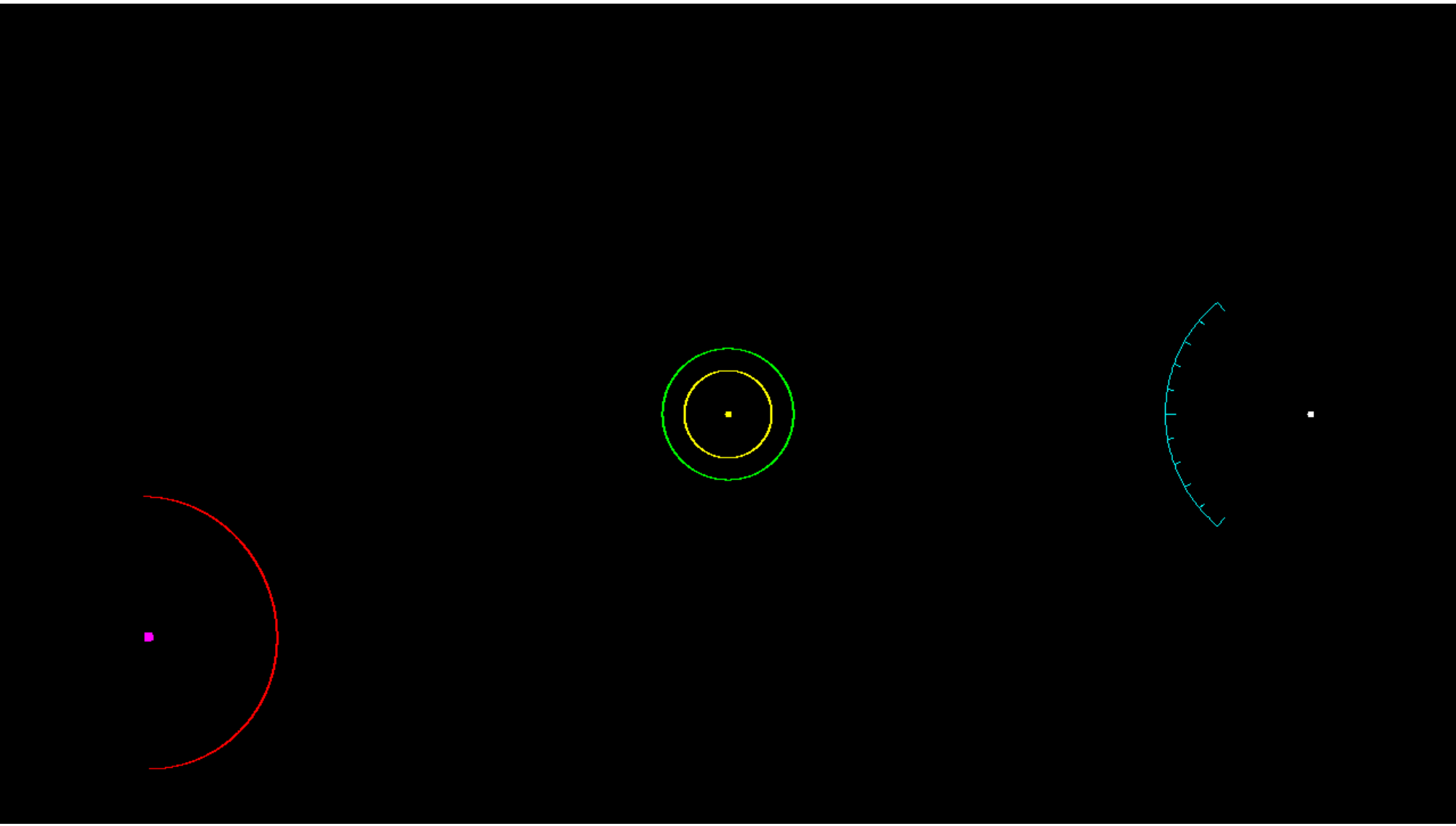
Alternative explanation

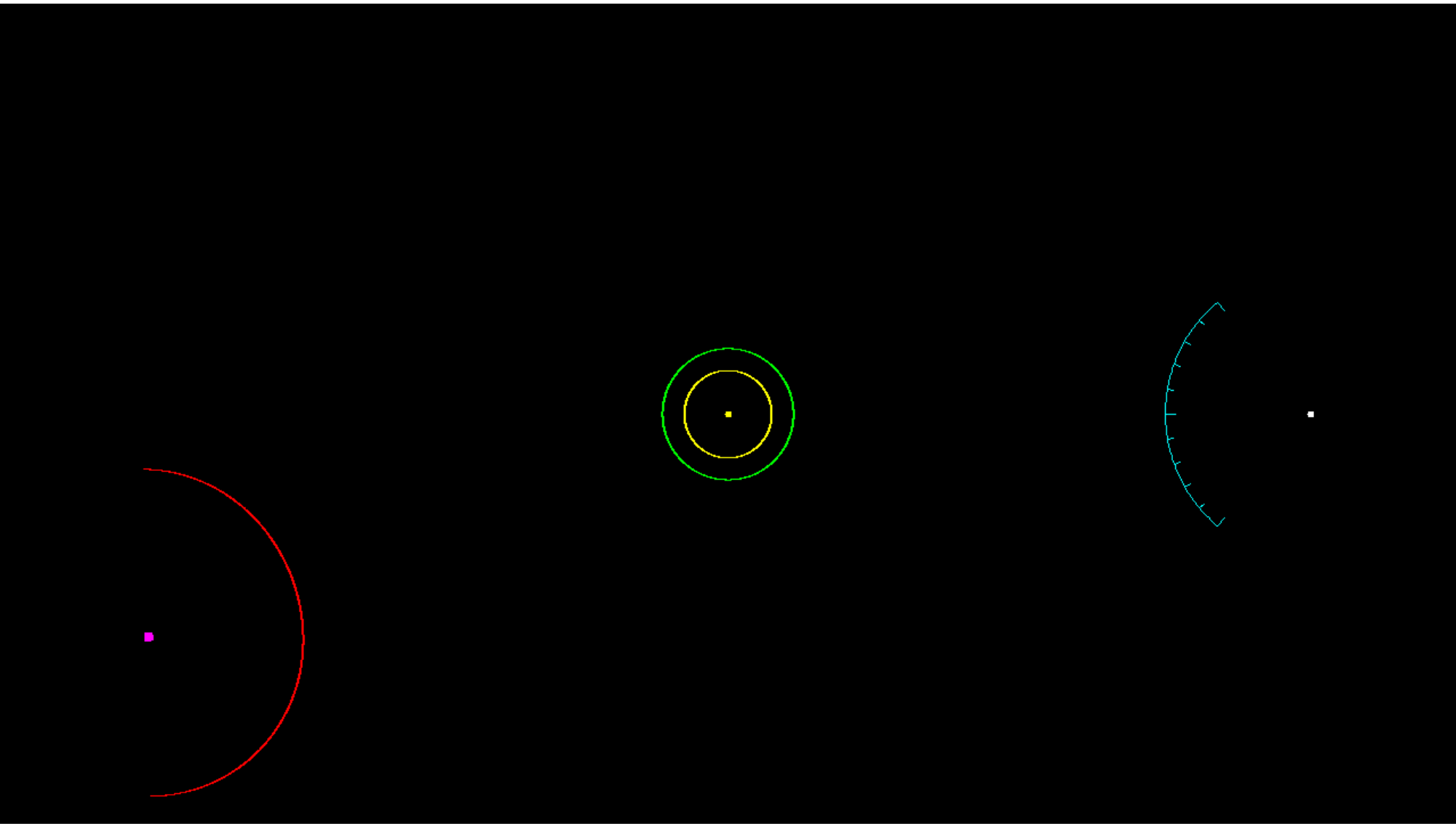


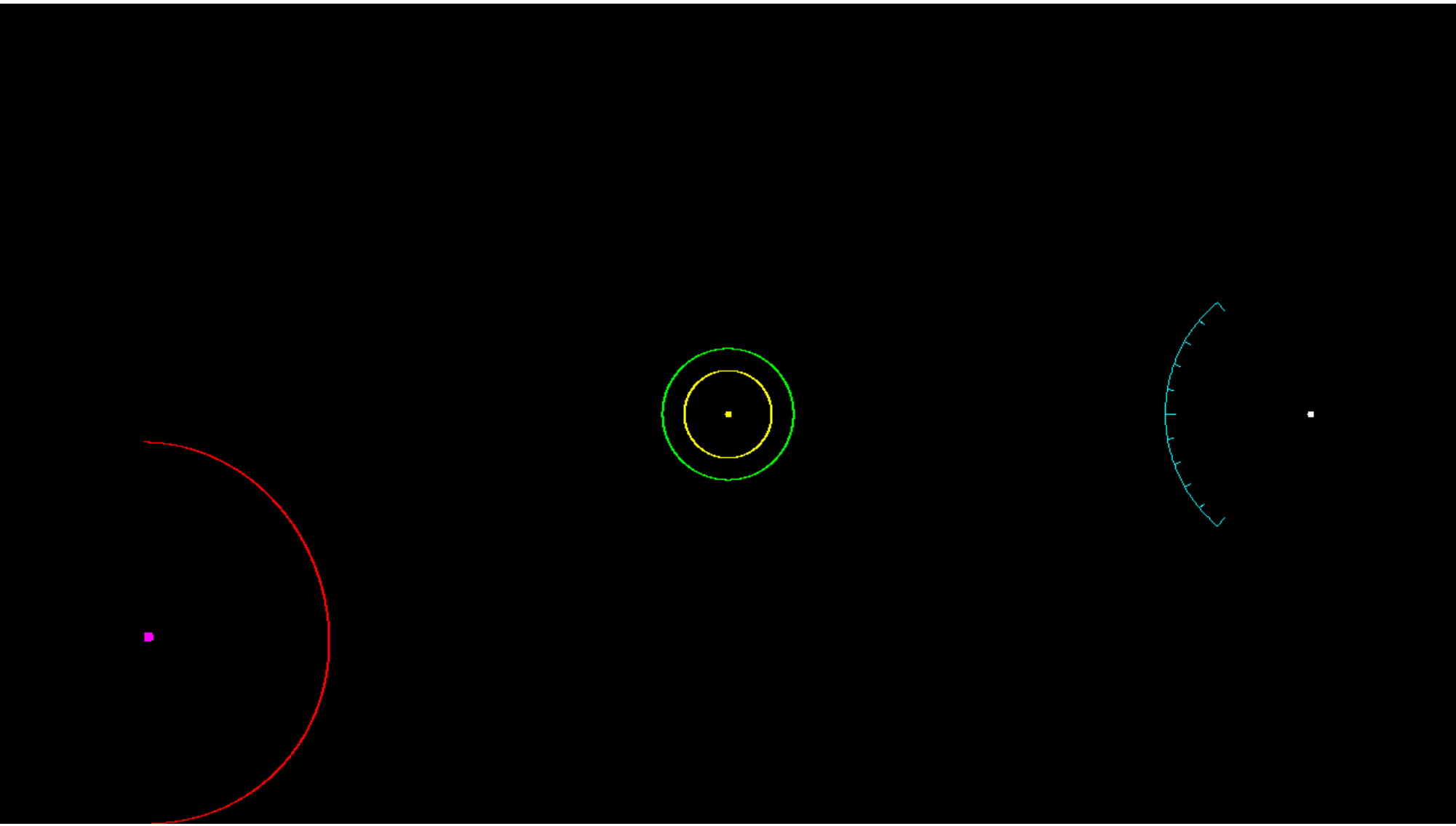


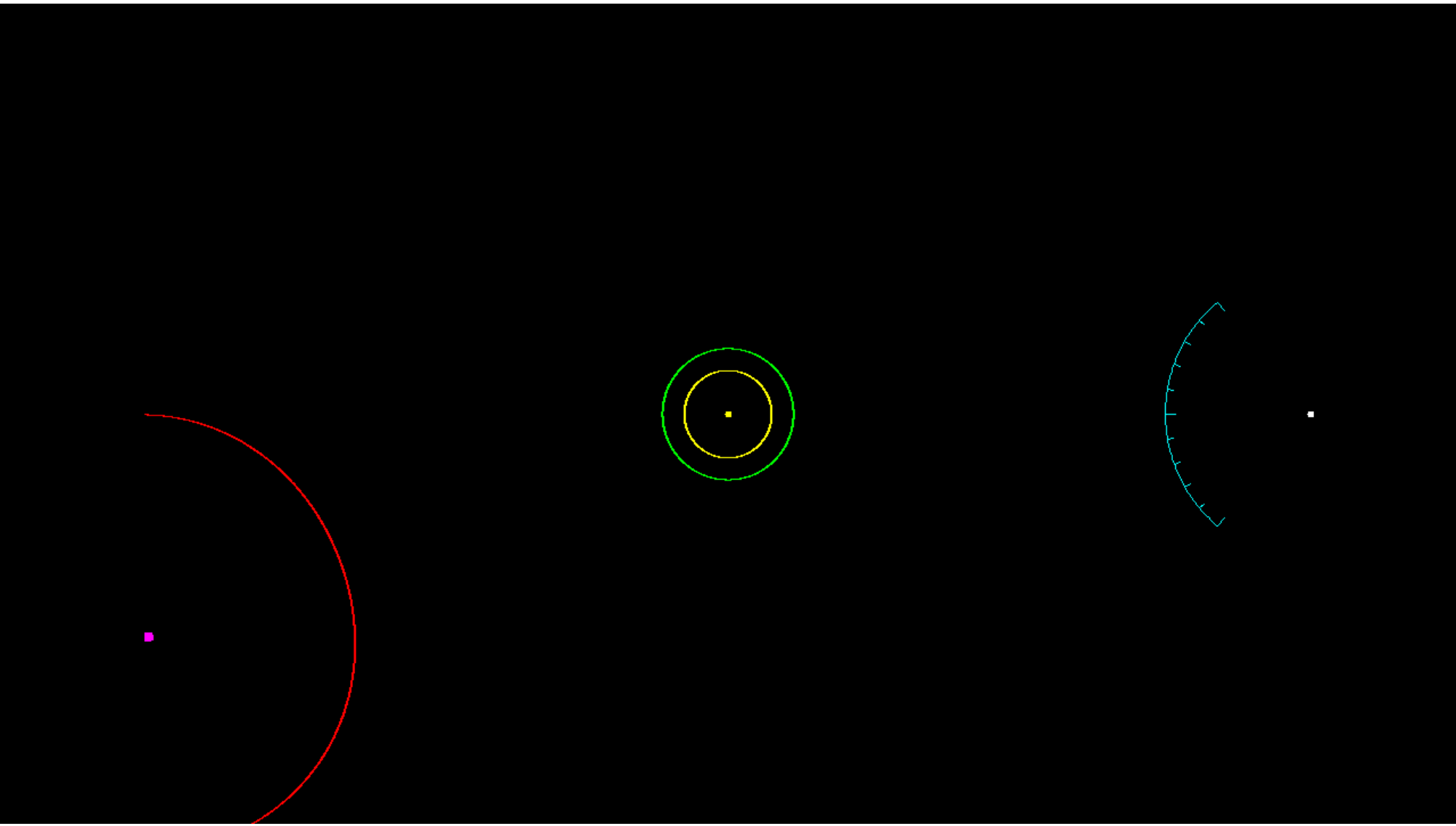


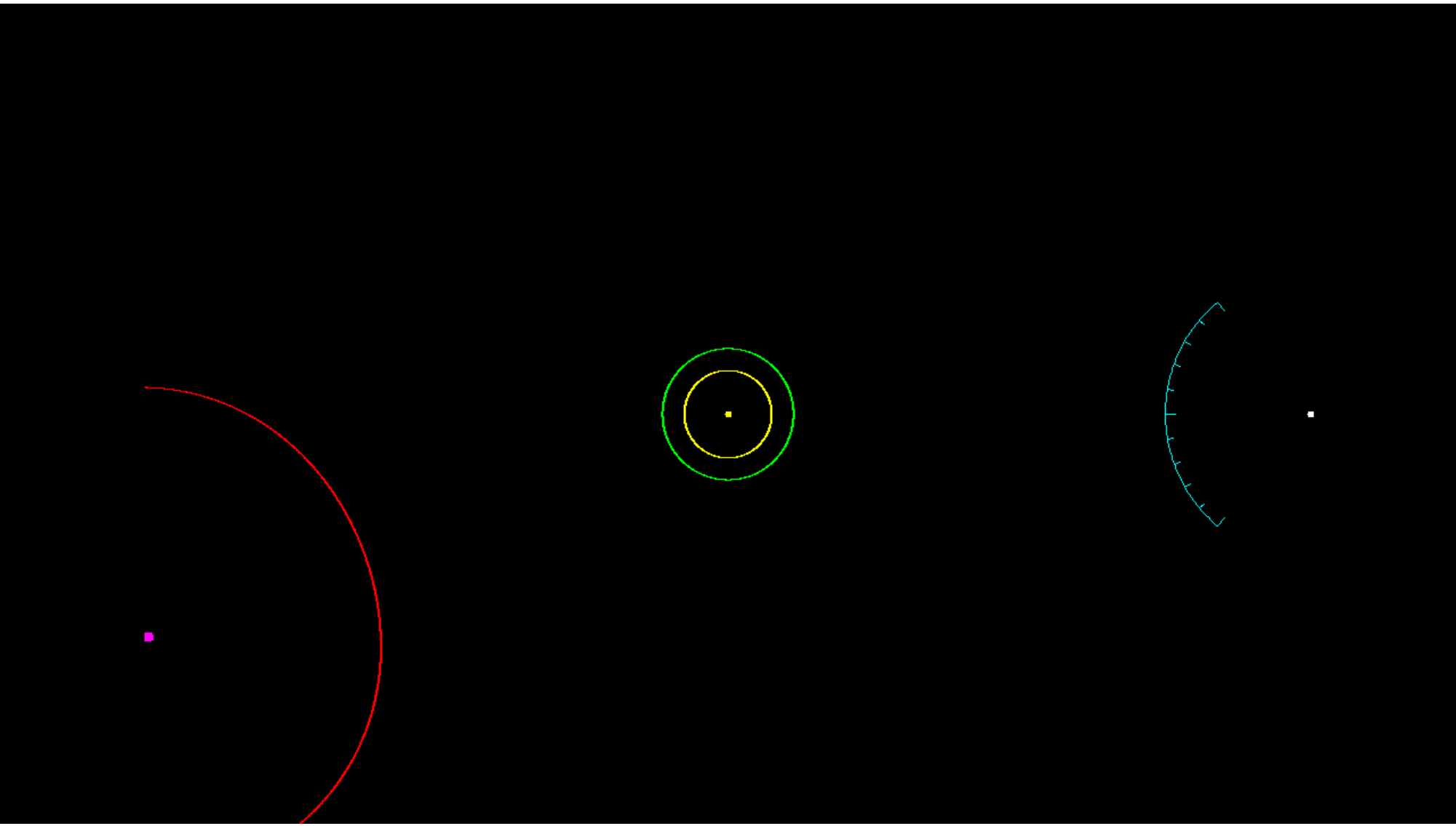


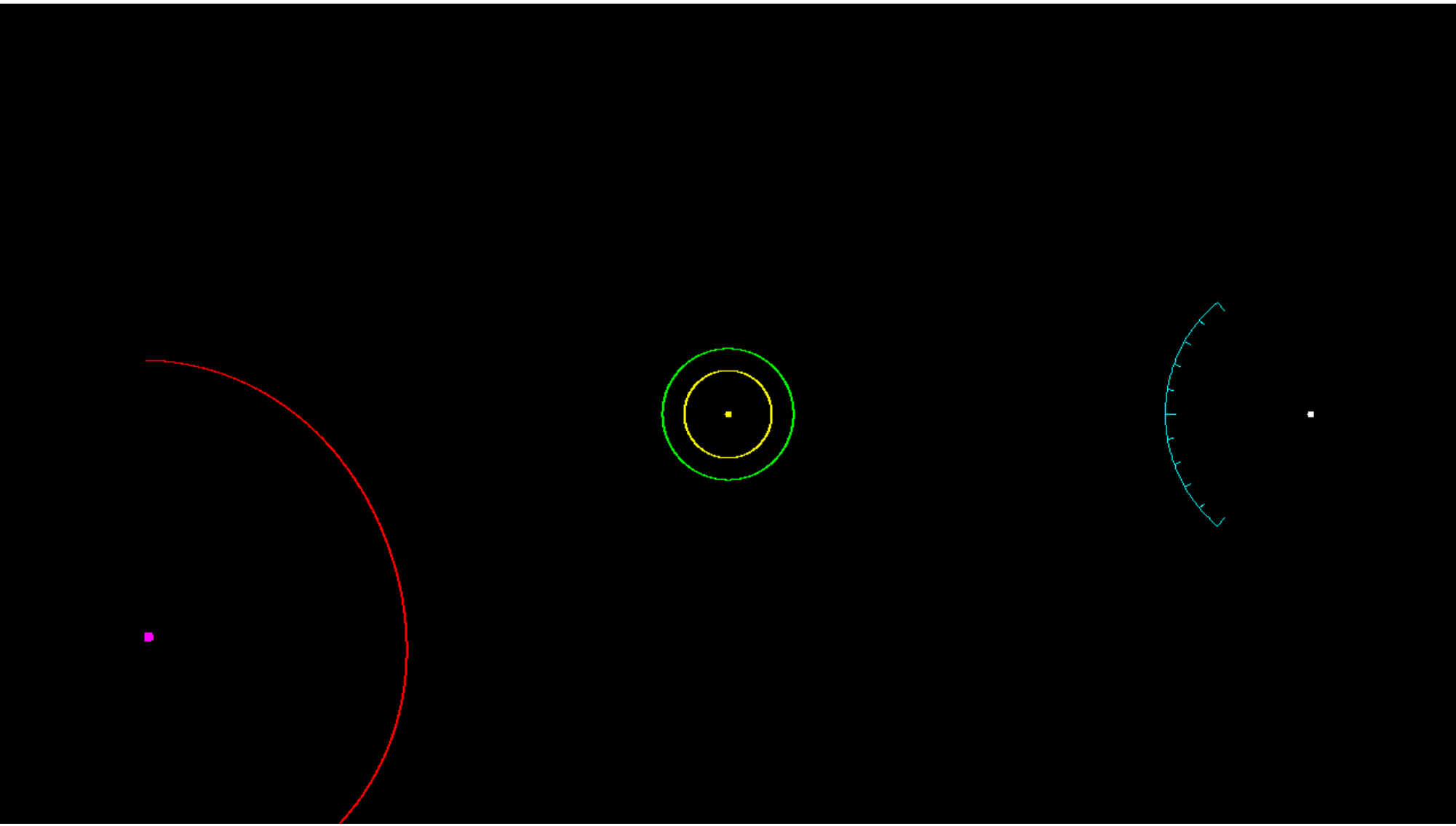


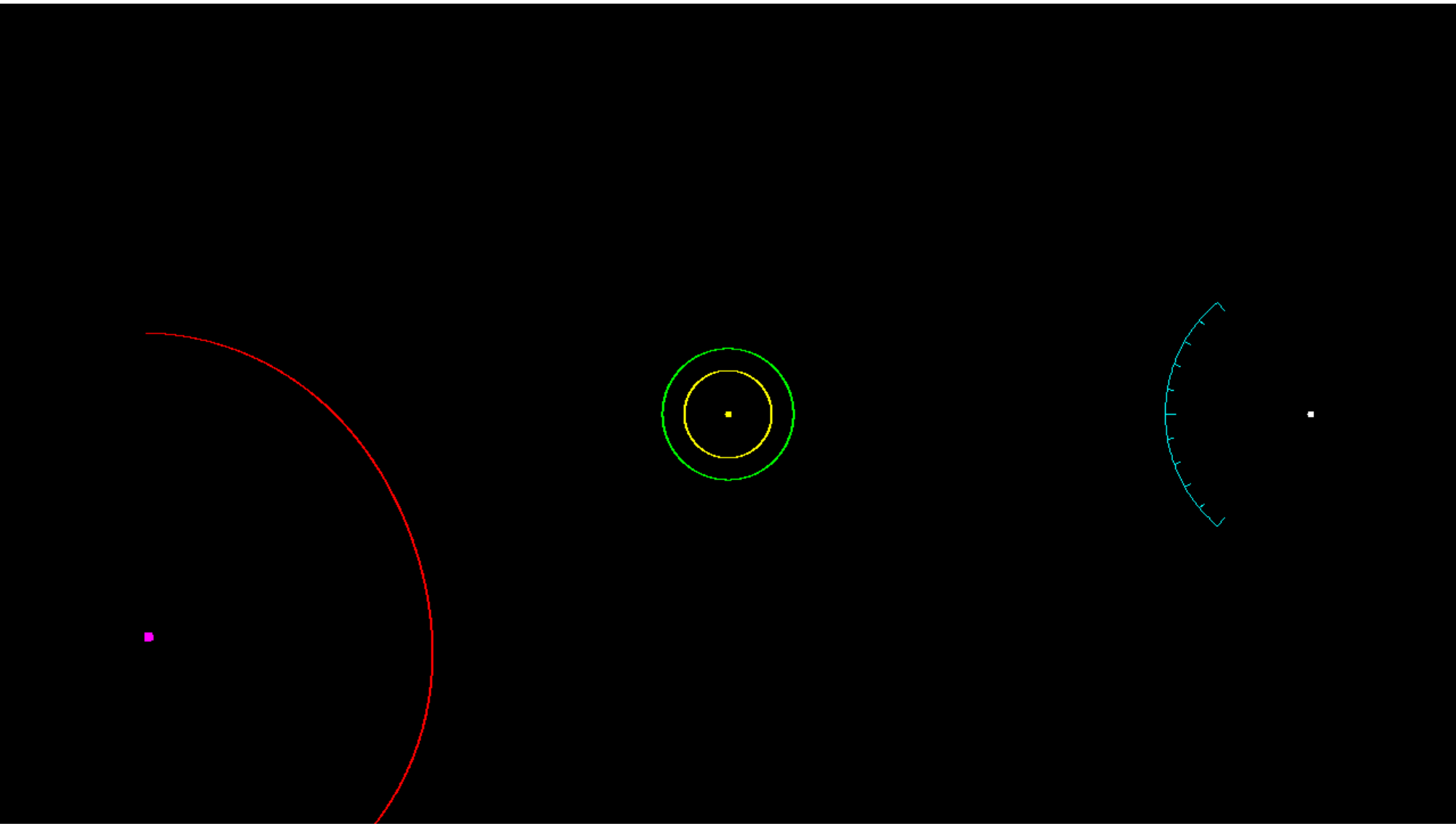


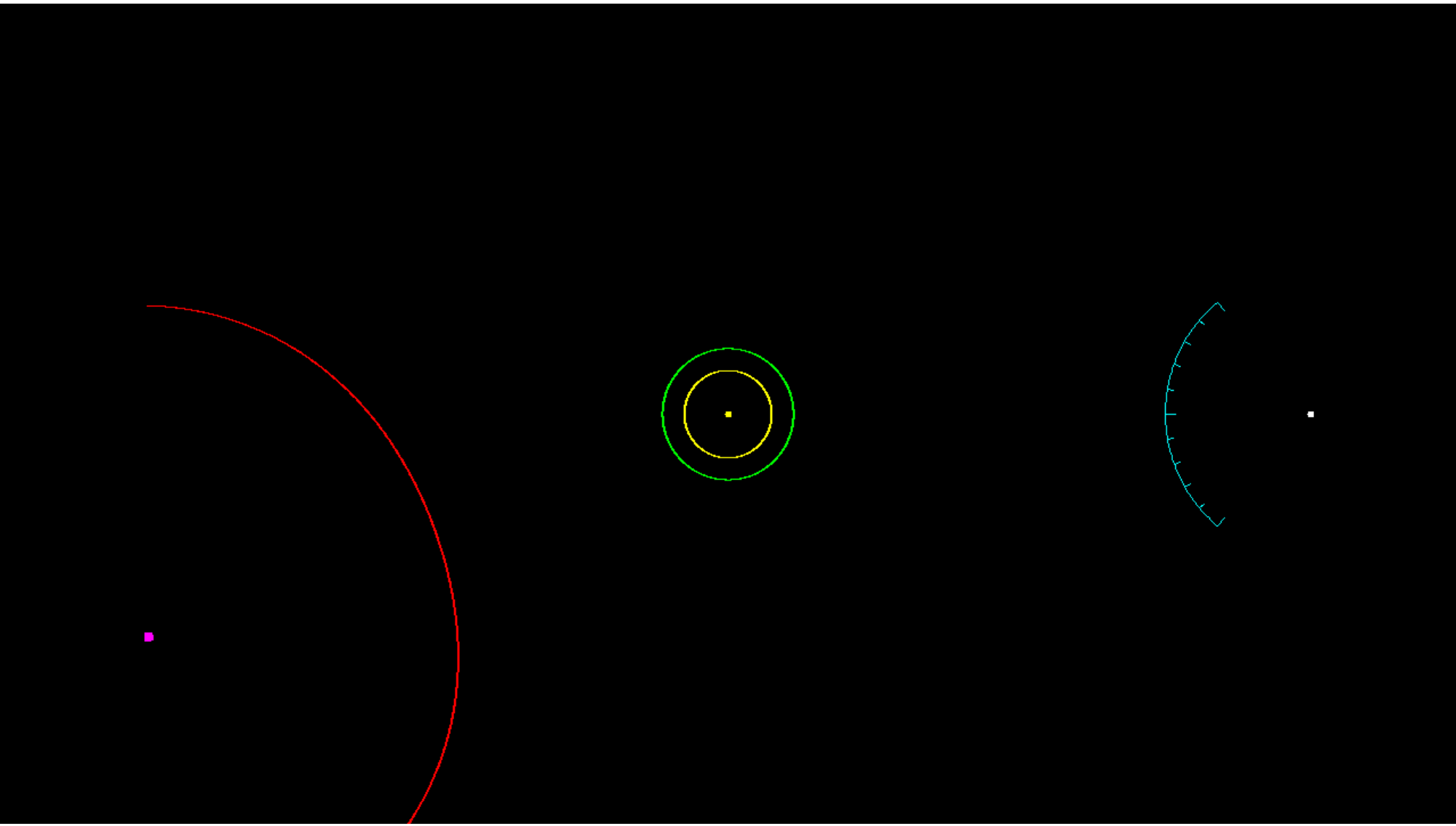


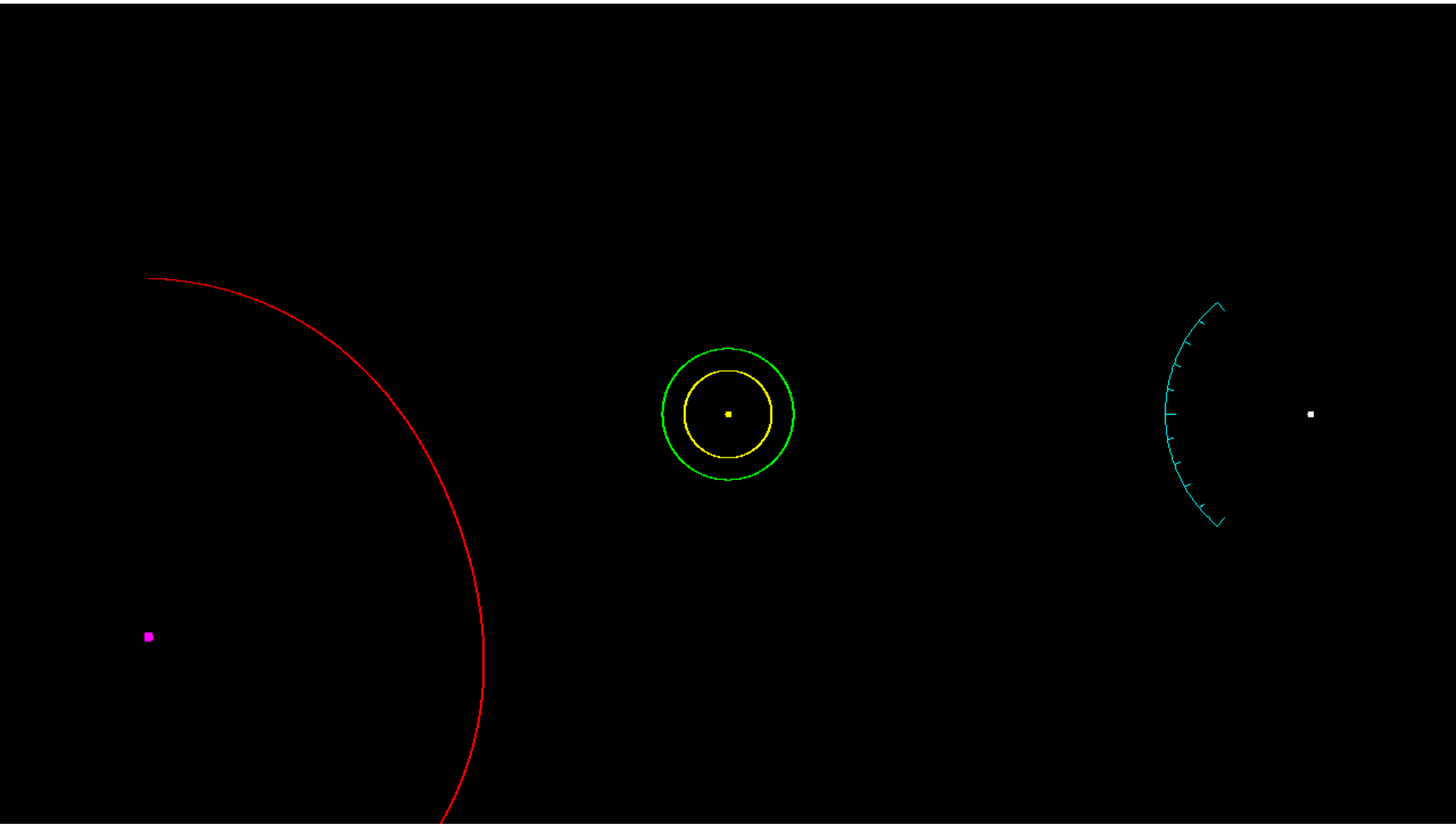


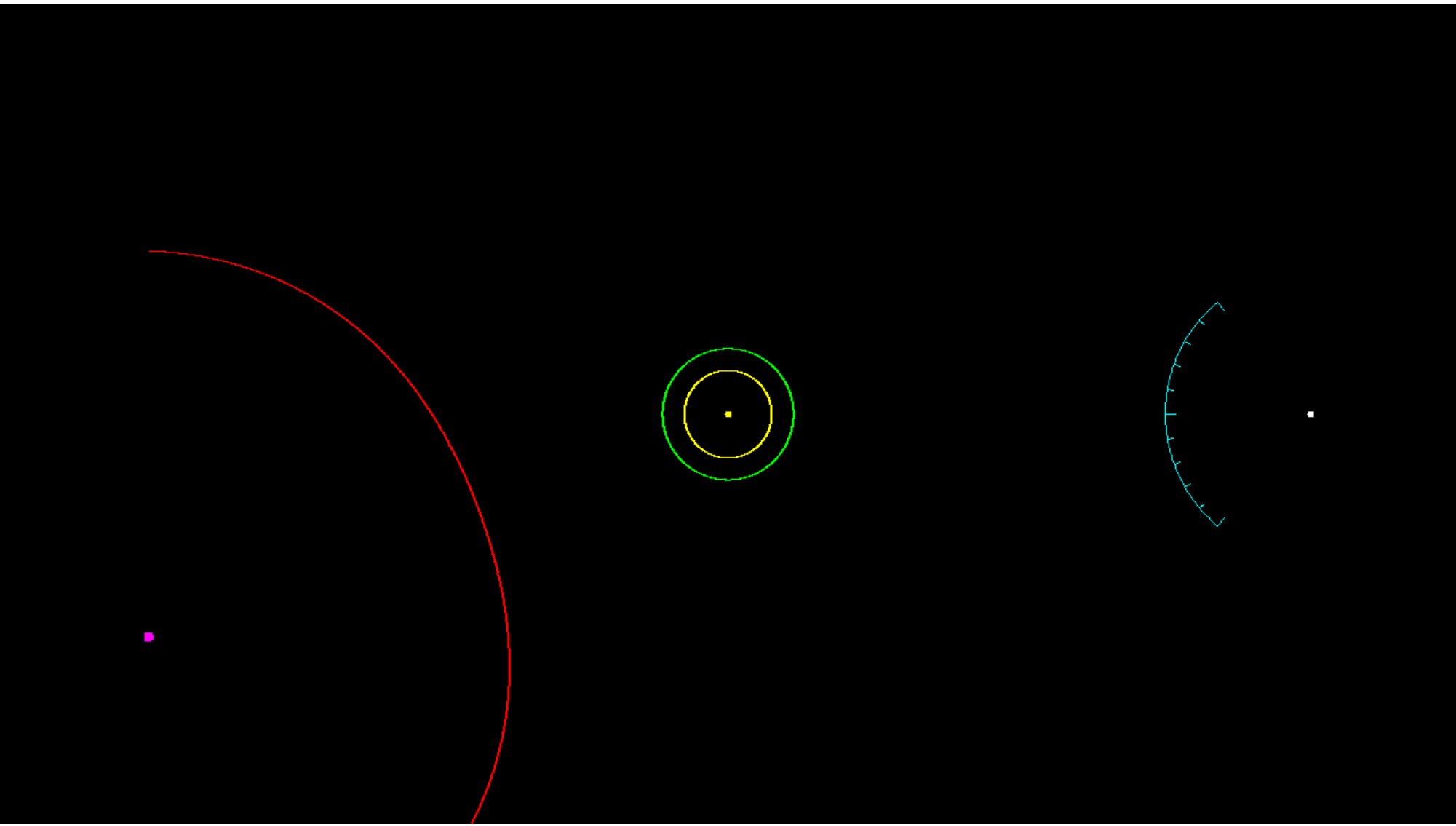


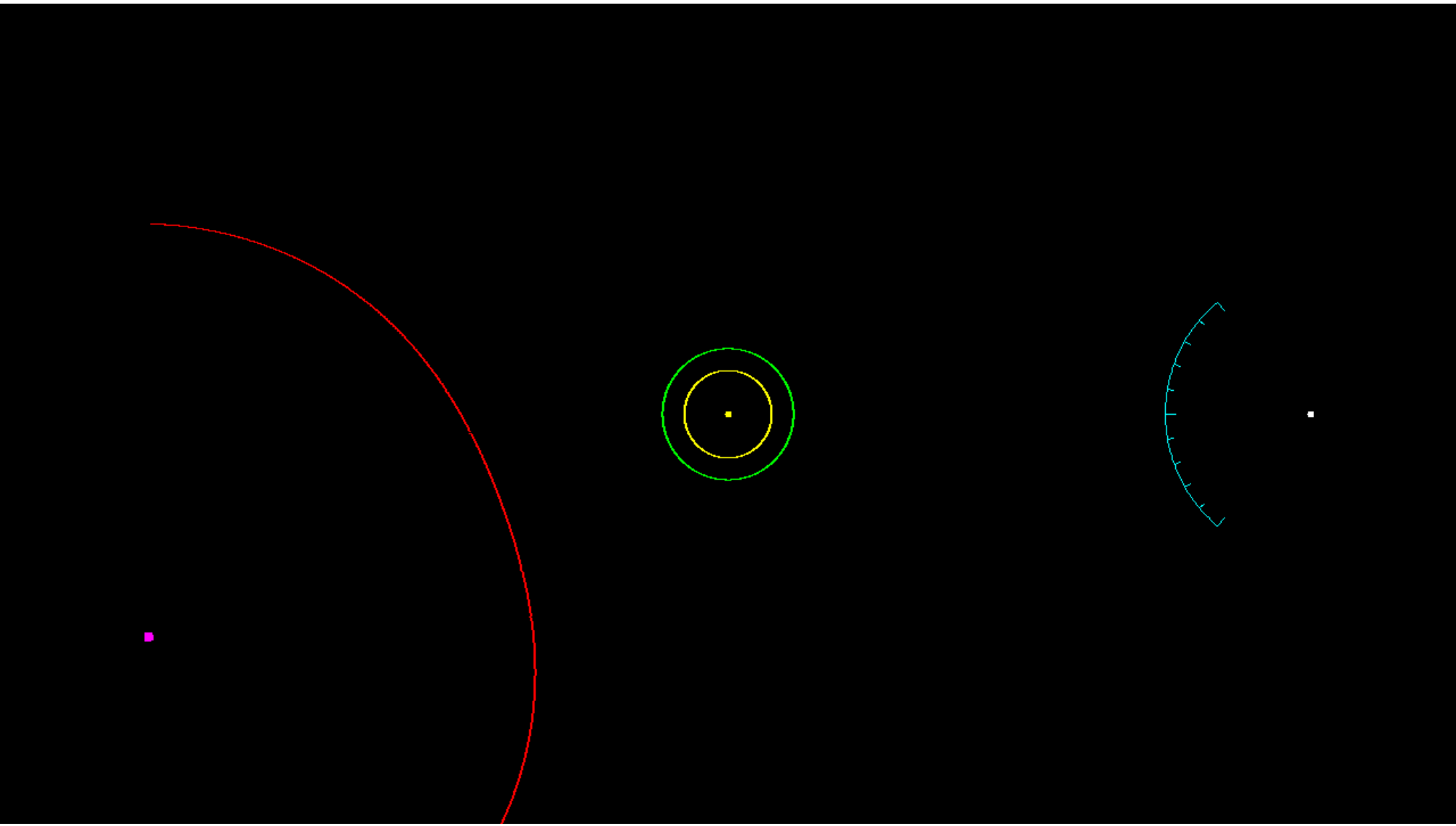


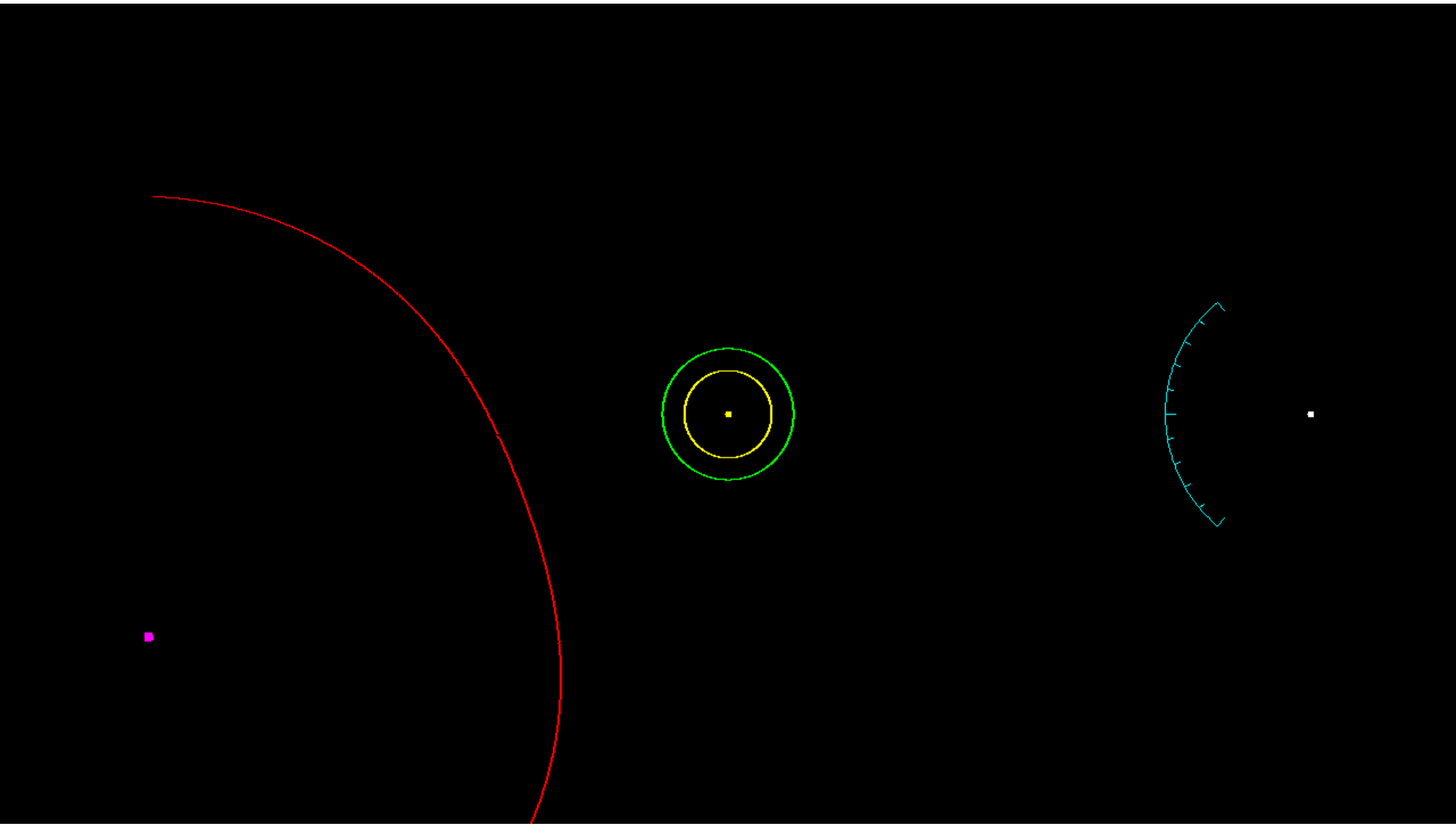


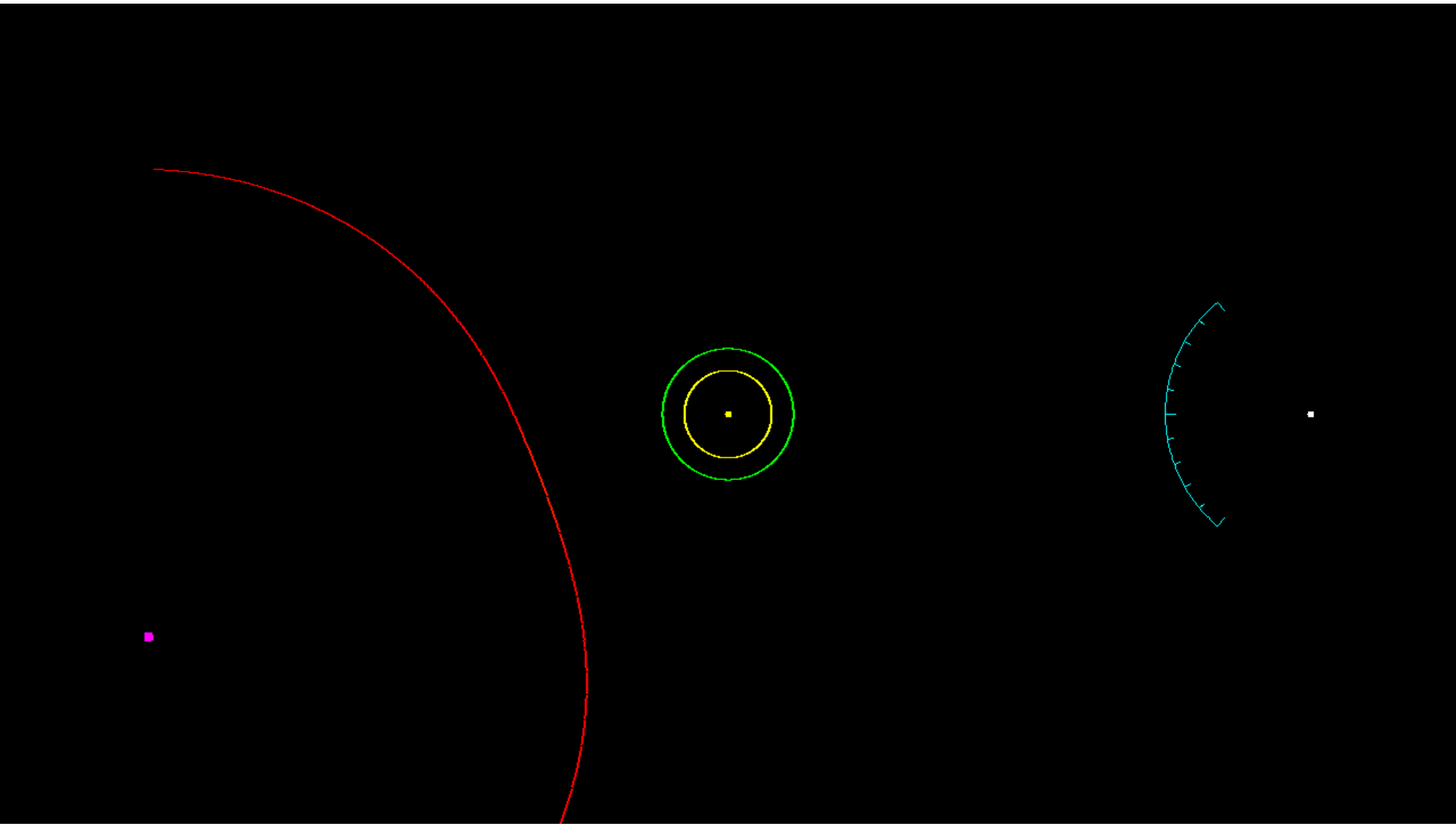


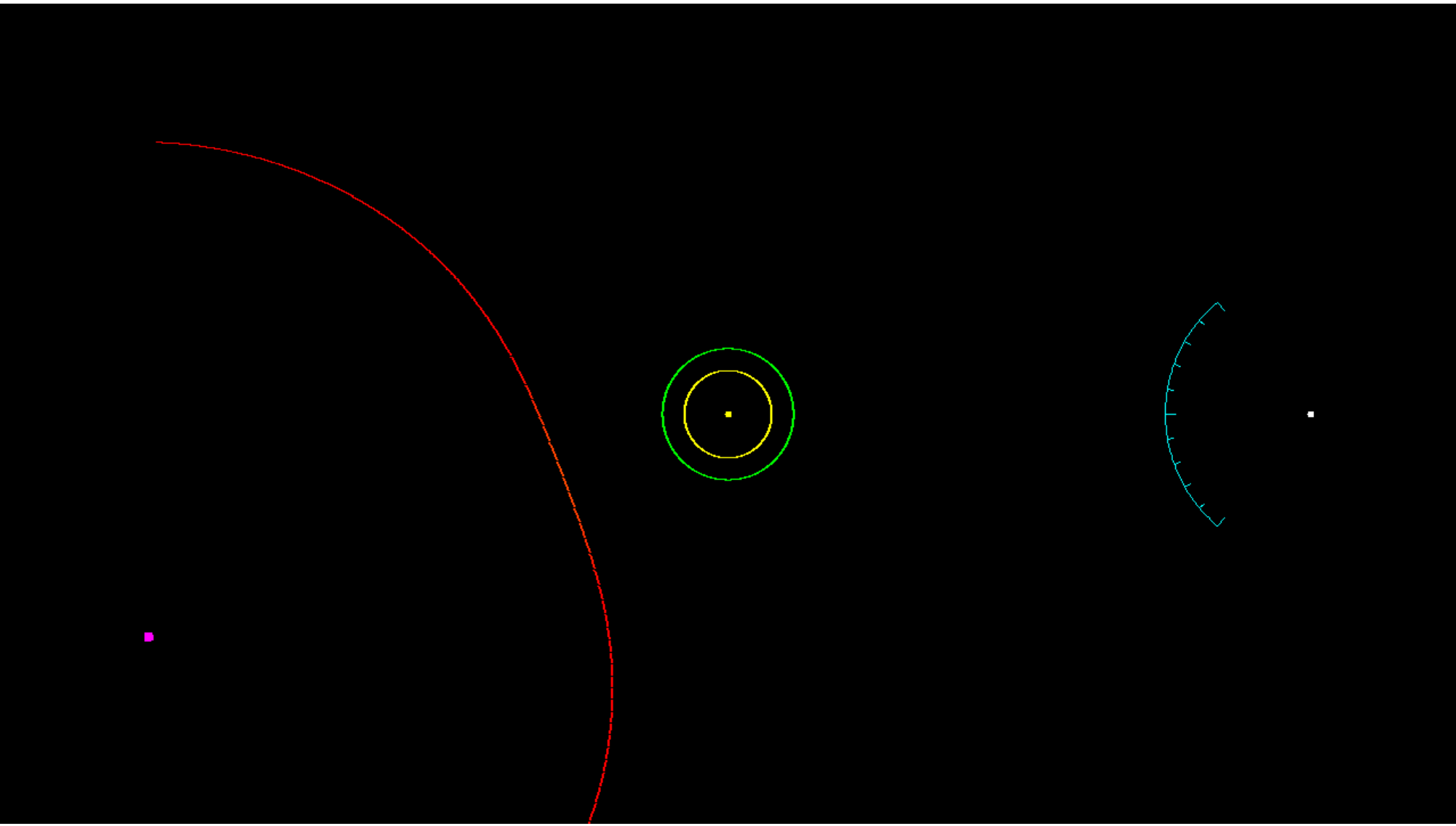


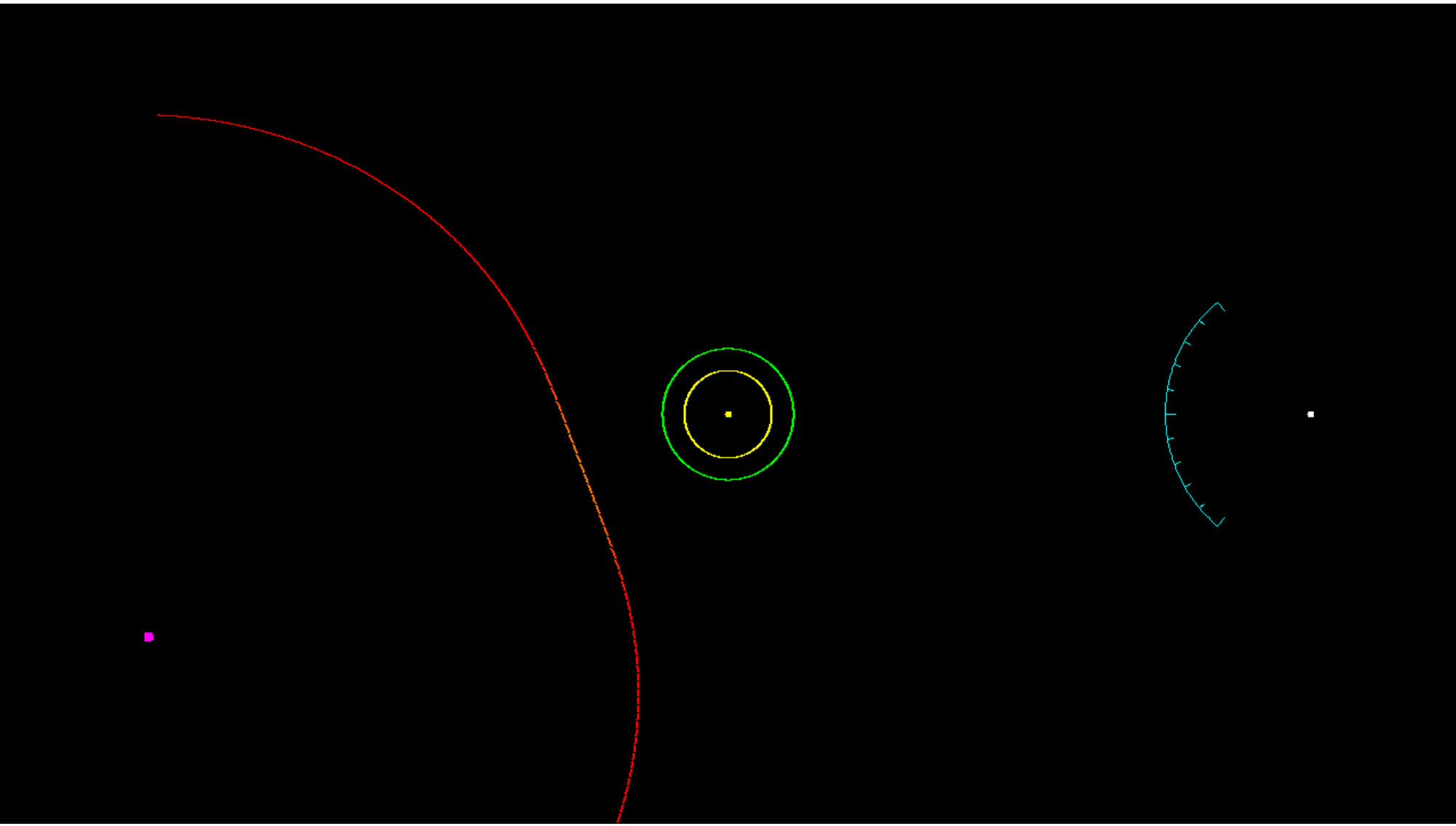


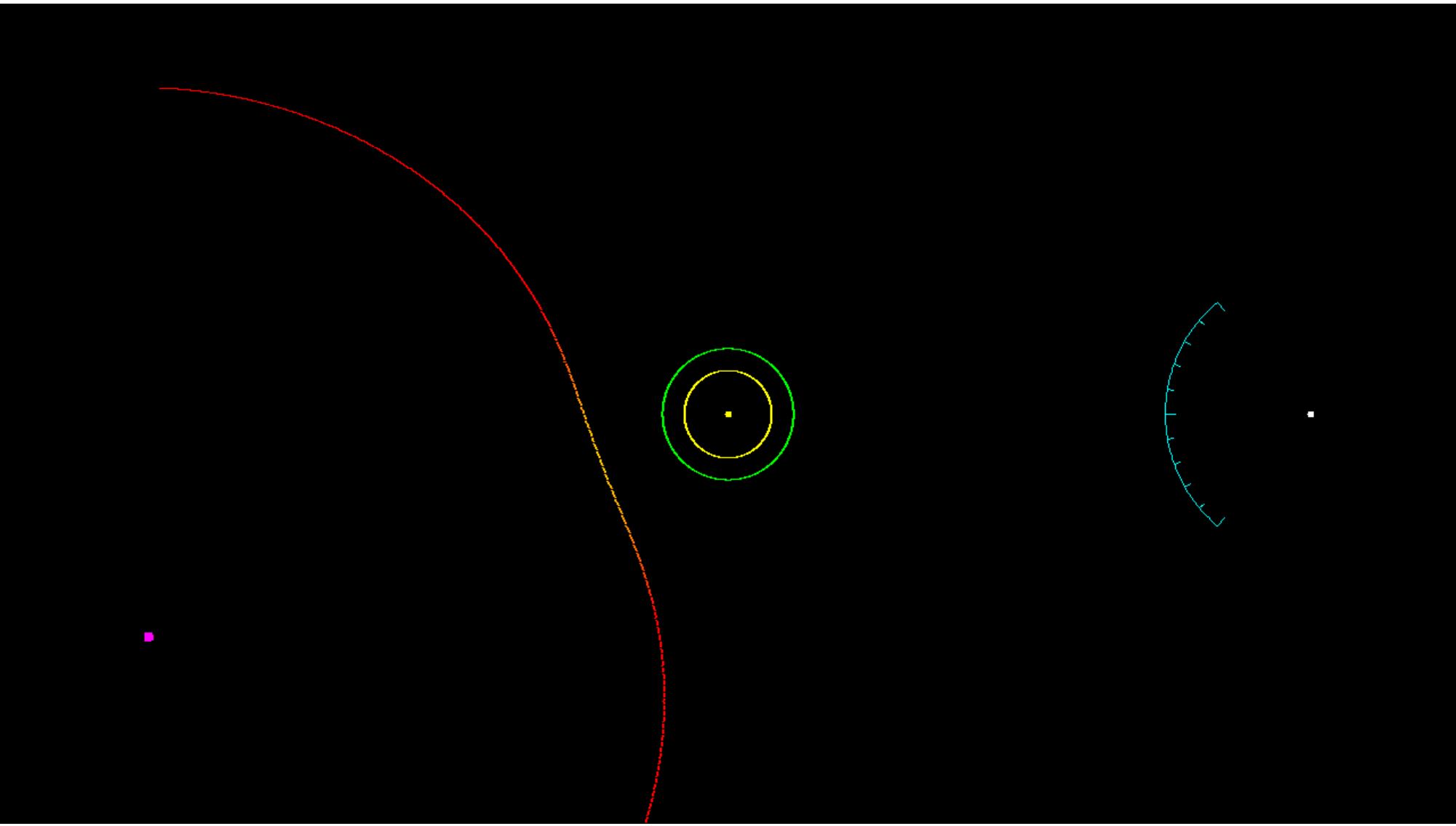


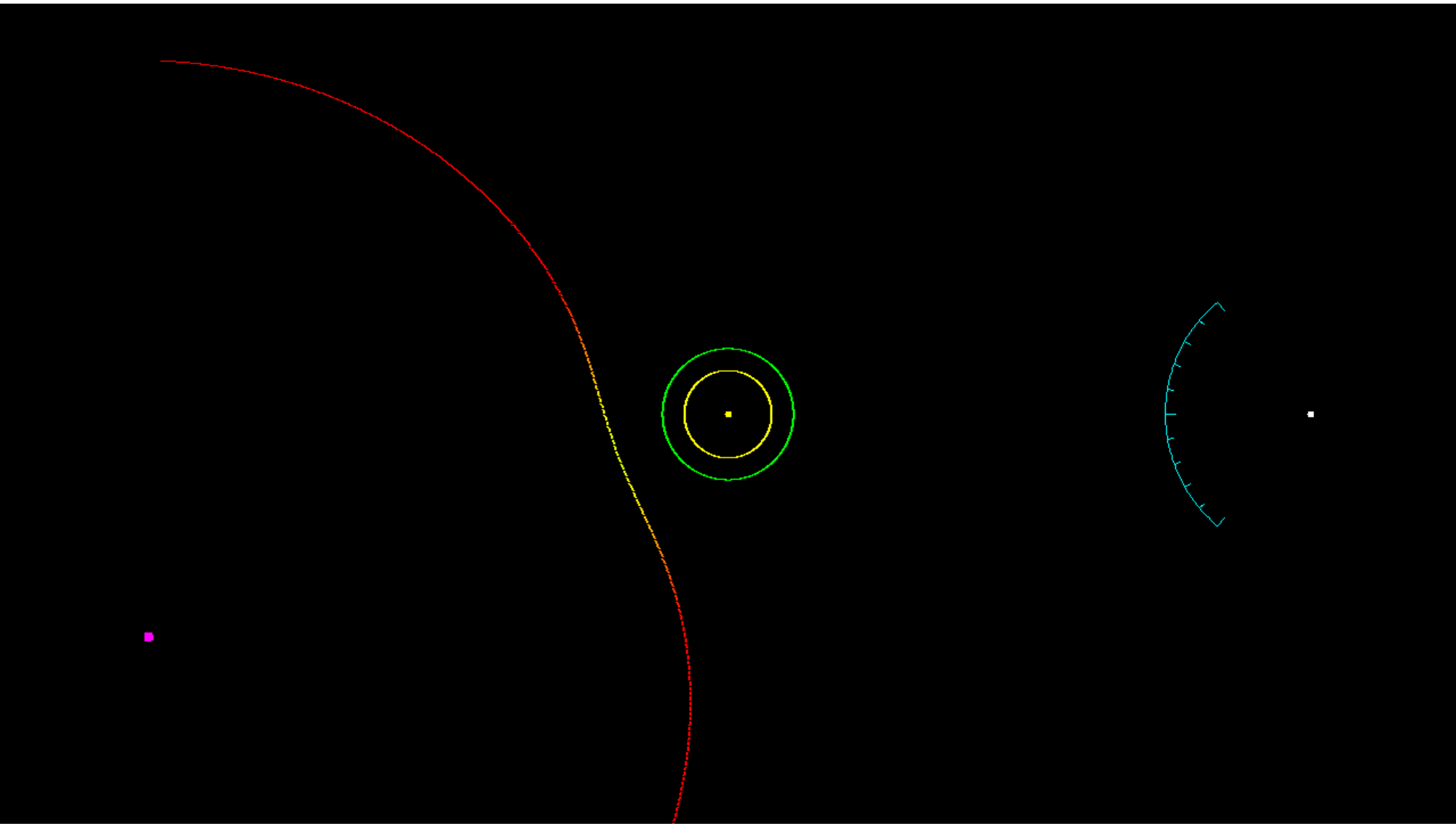


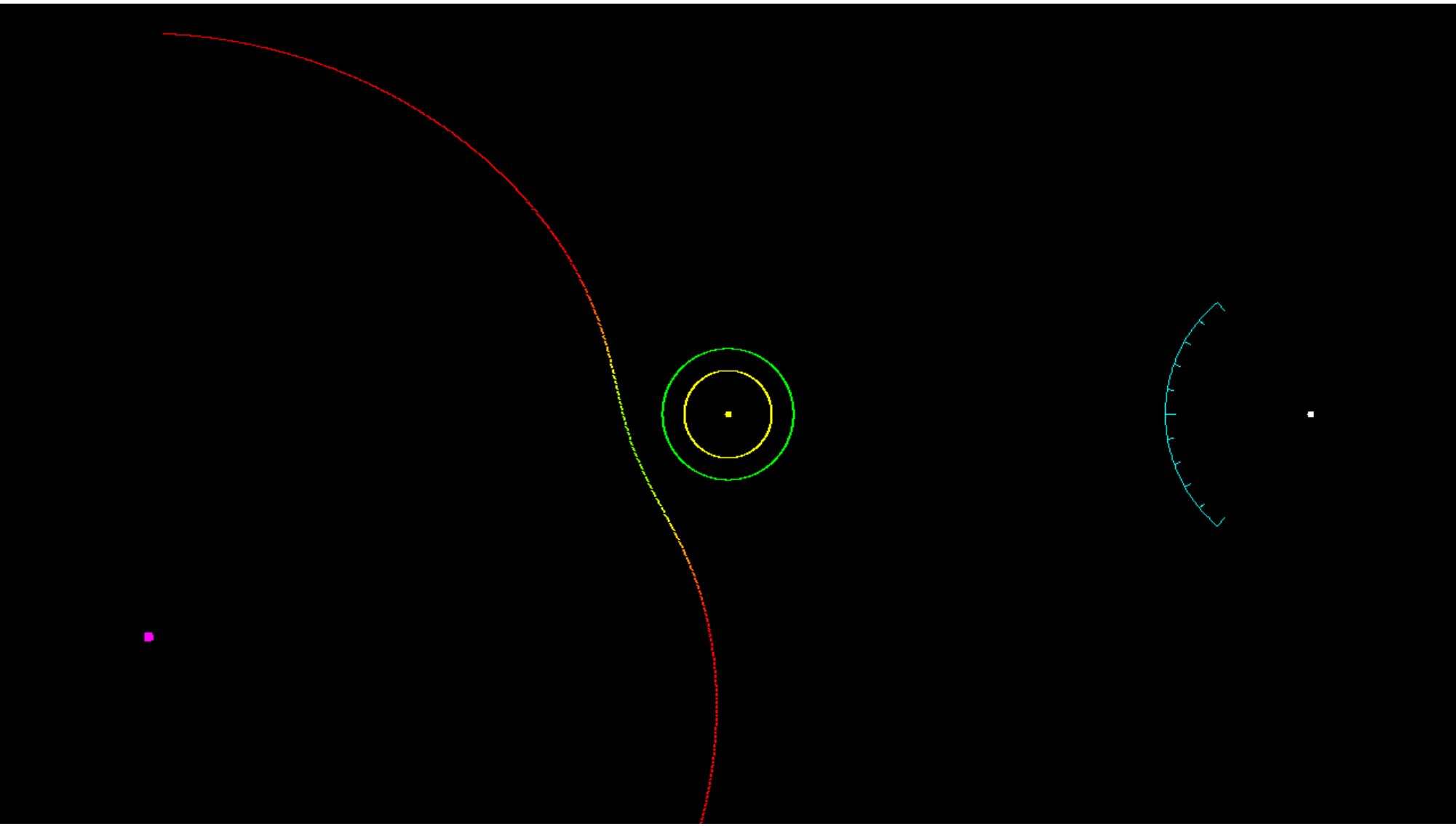


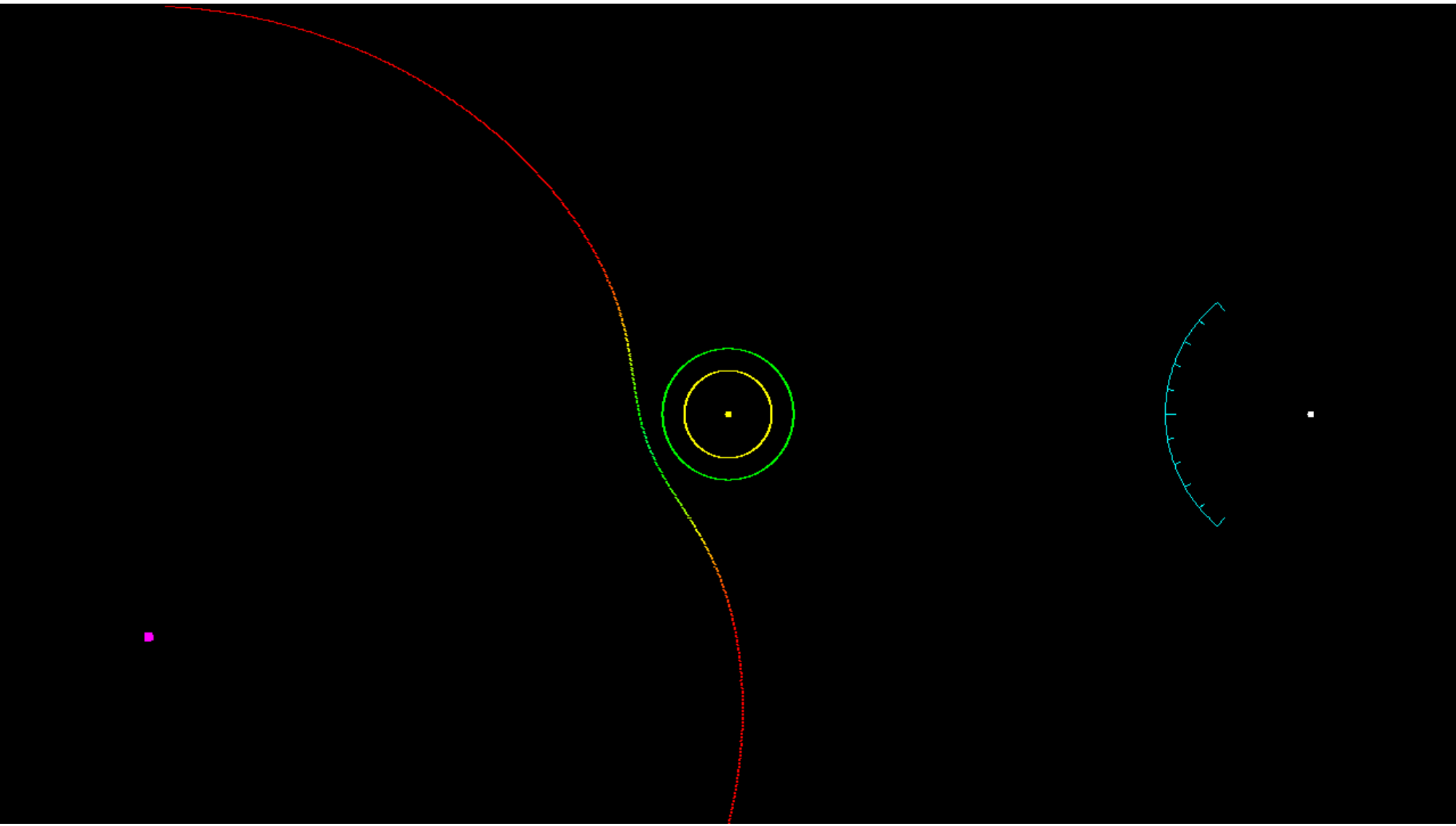


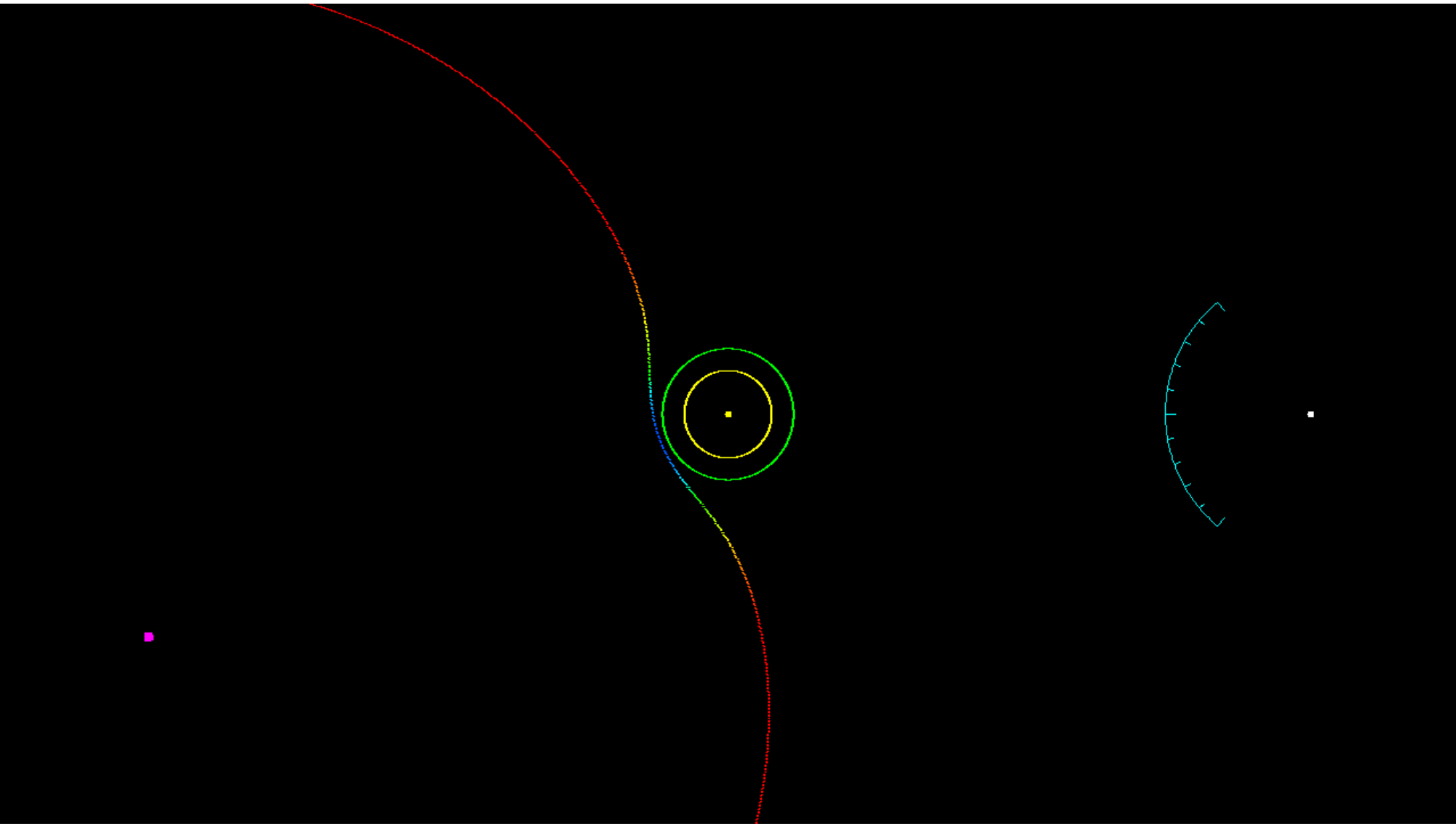


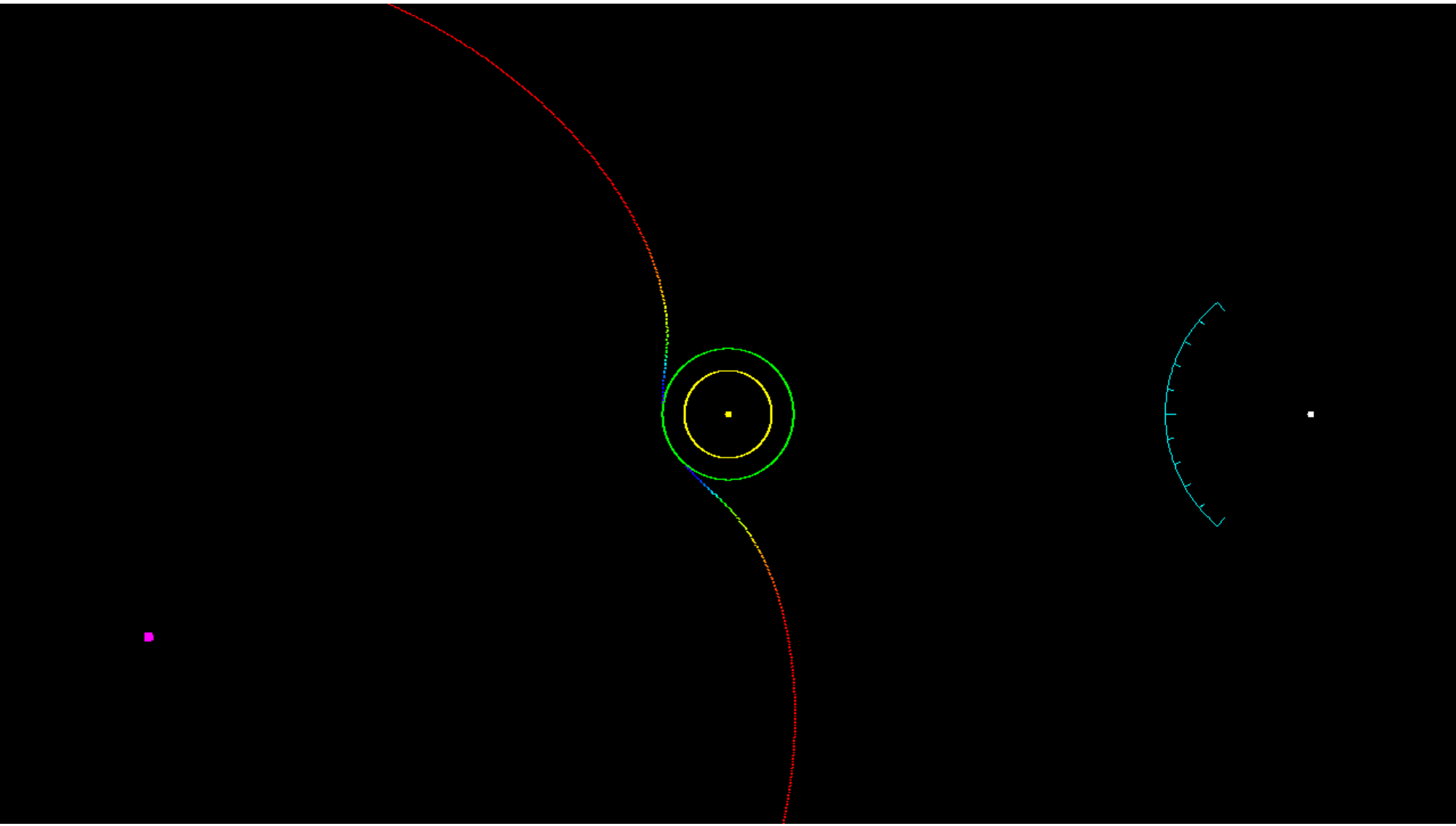


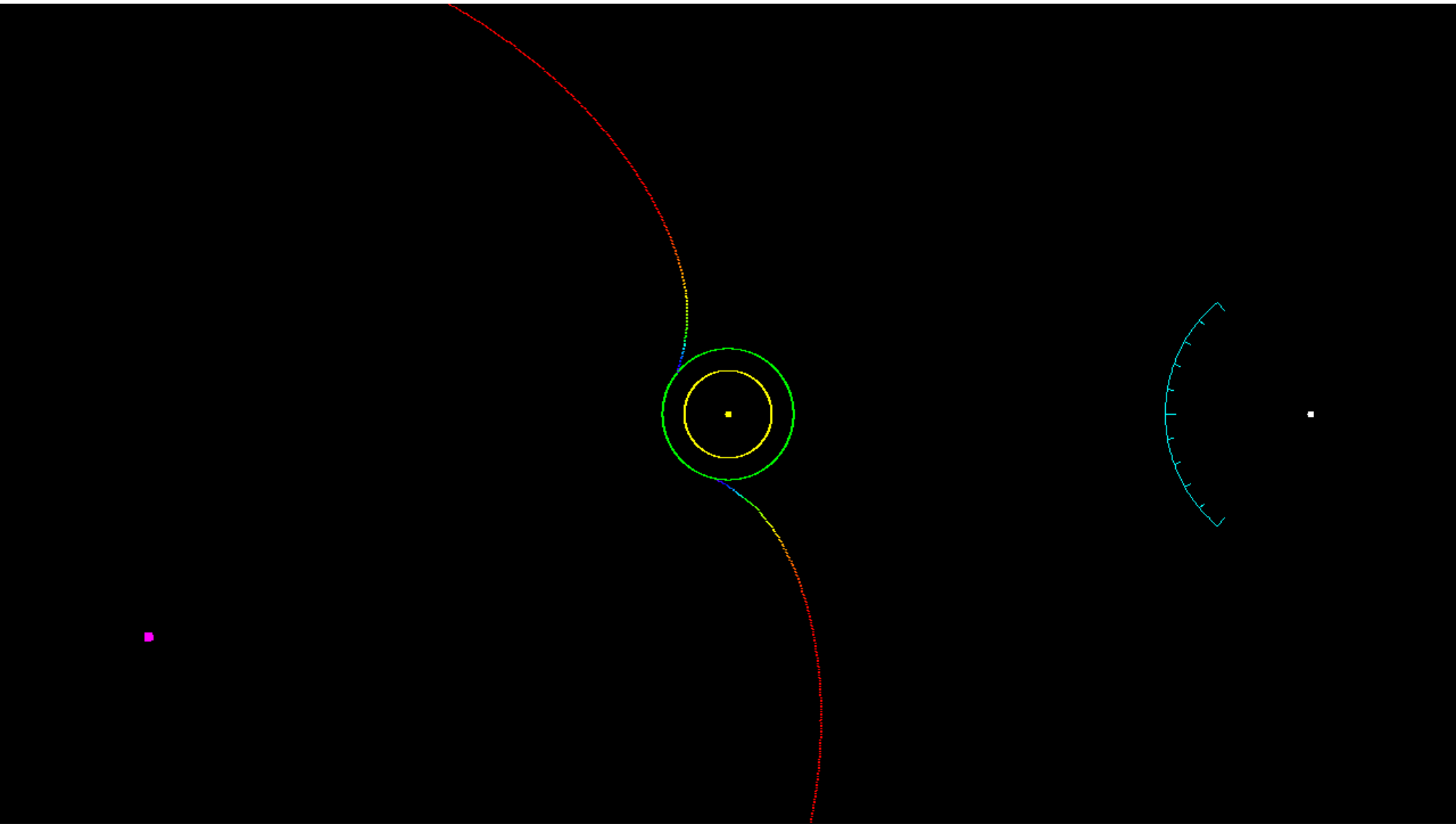


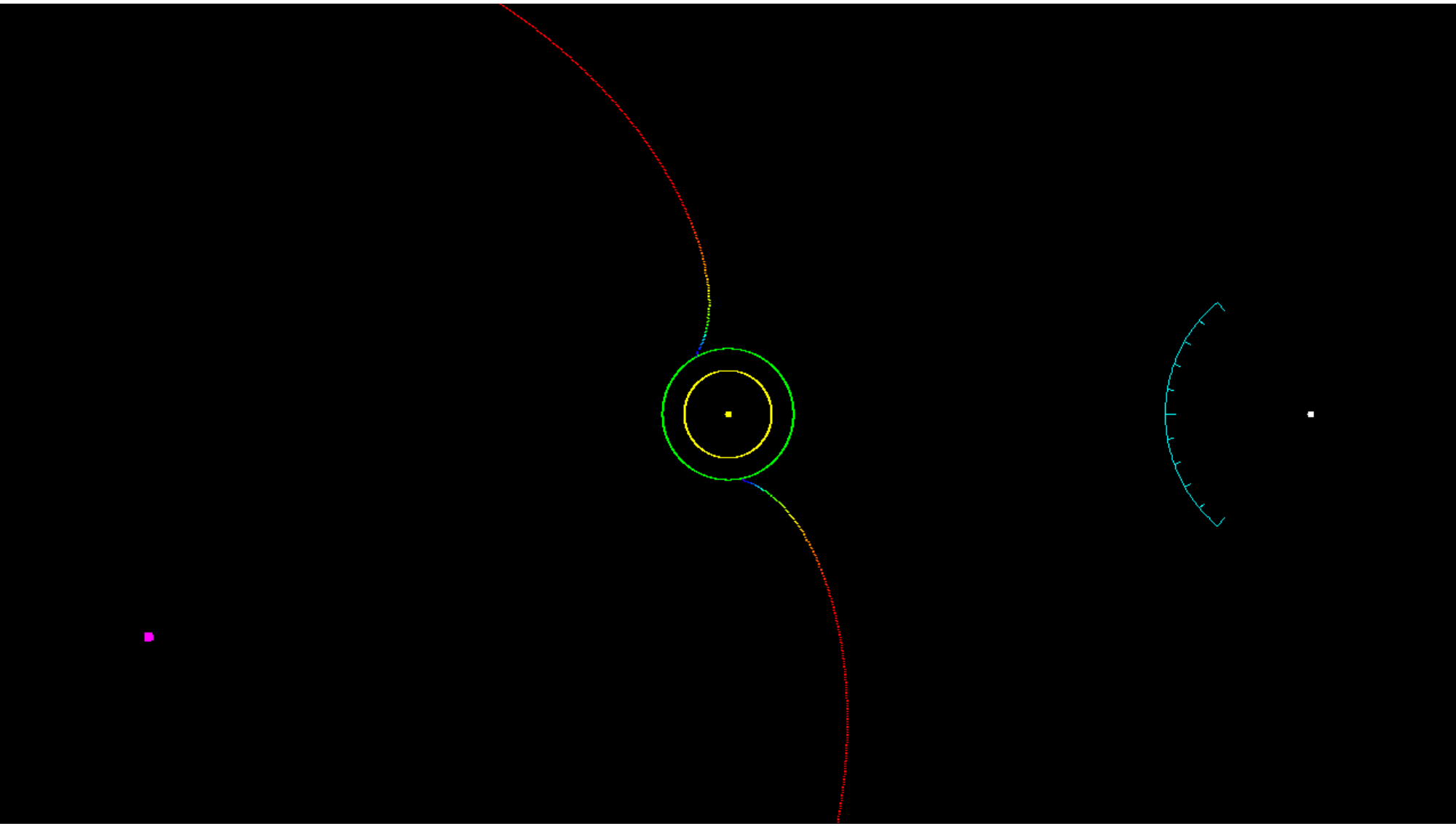


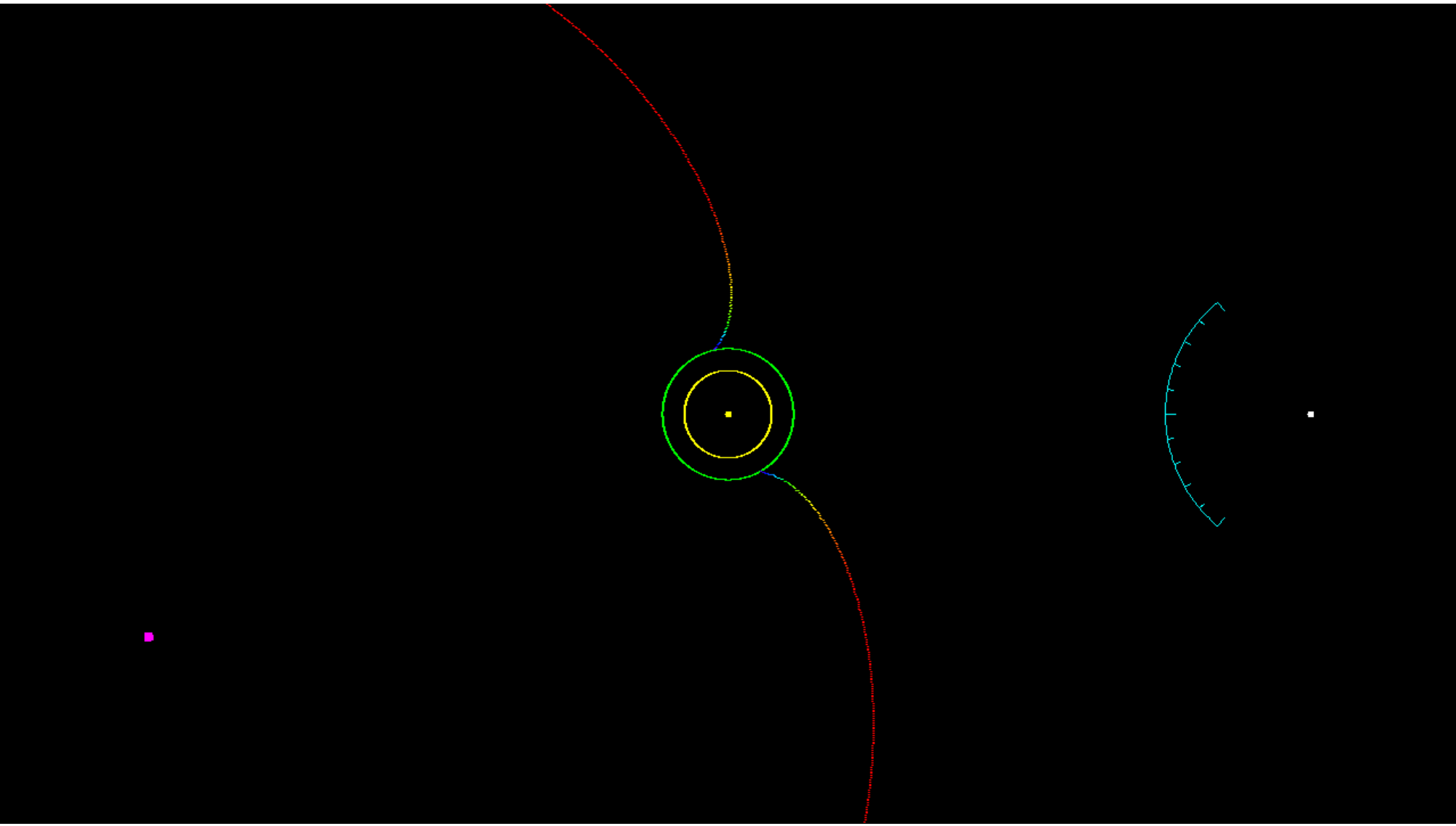


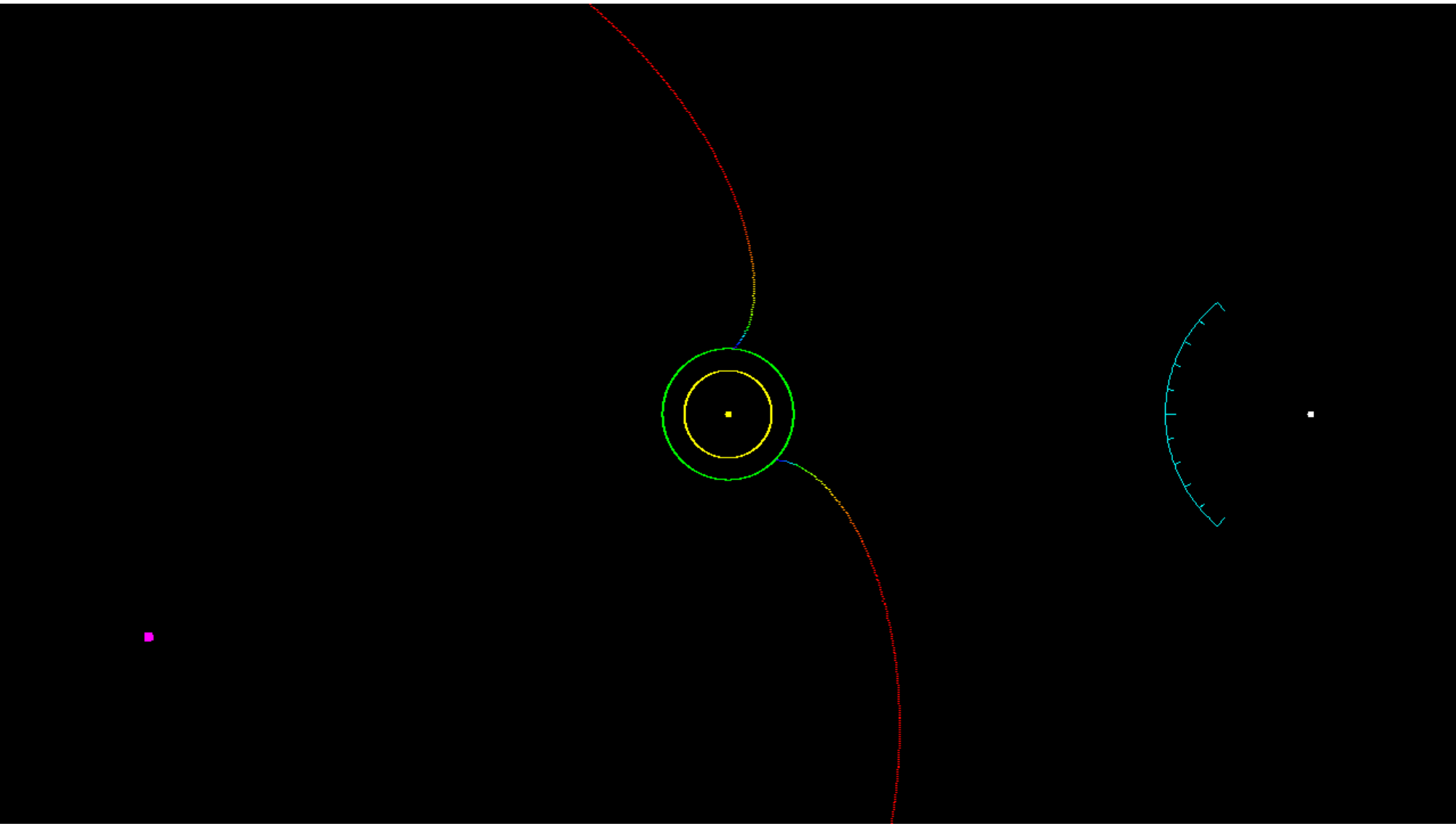


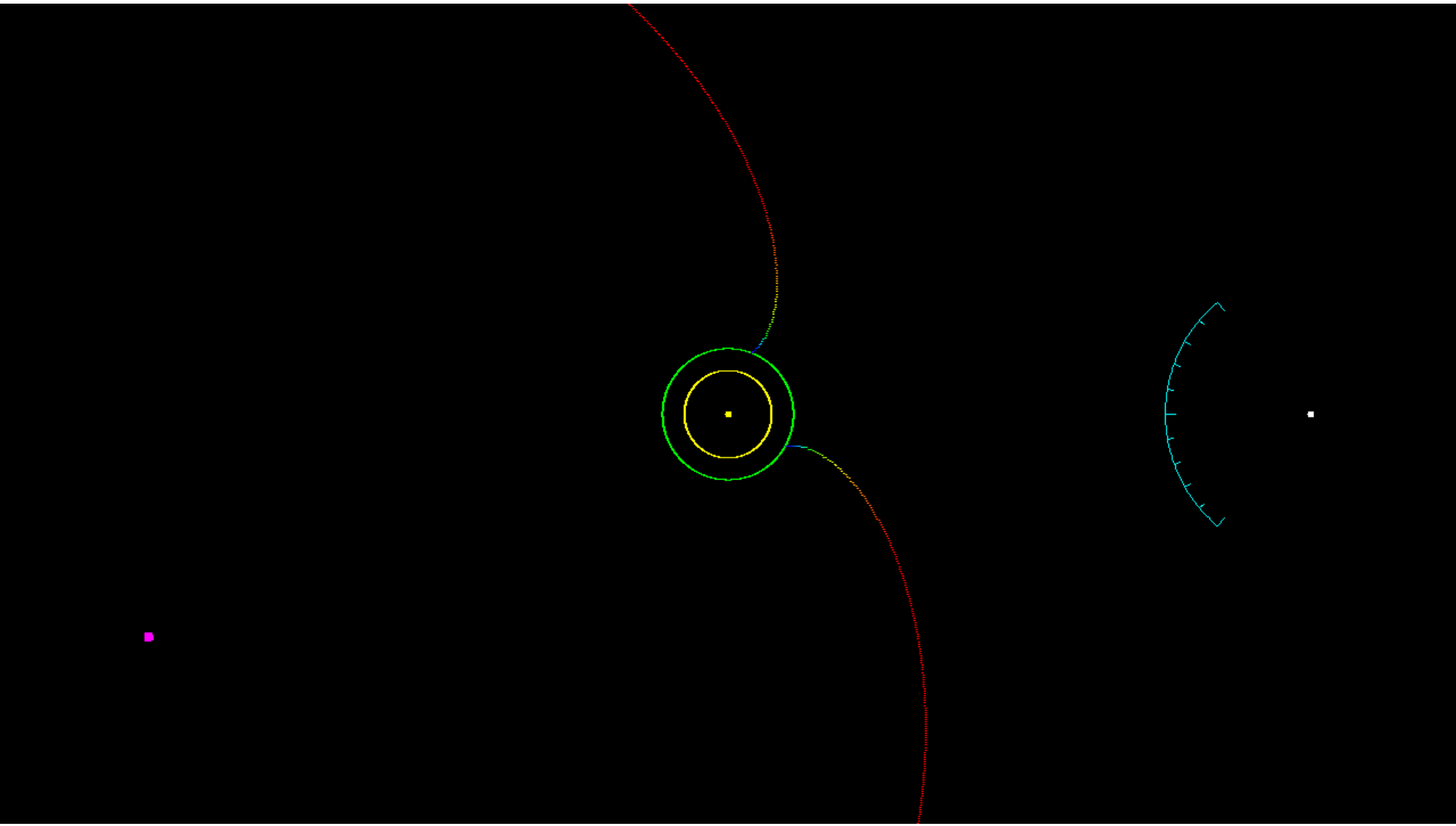


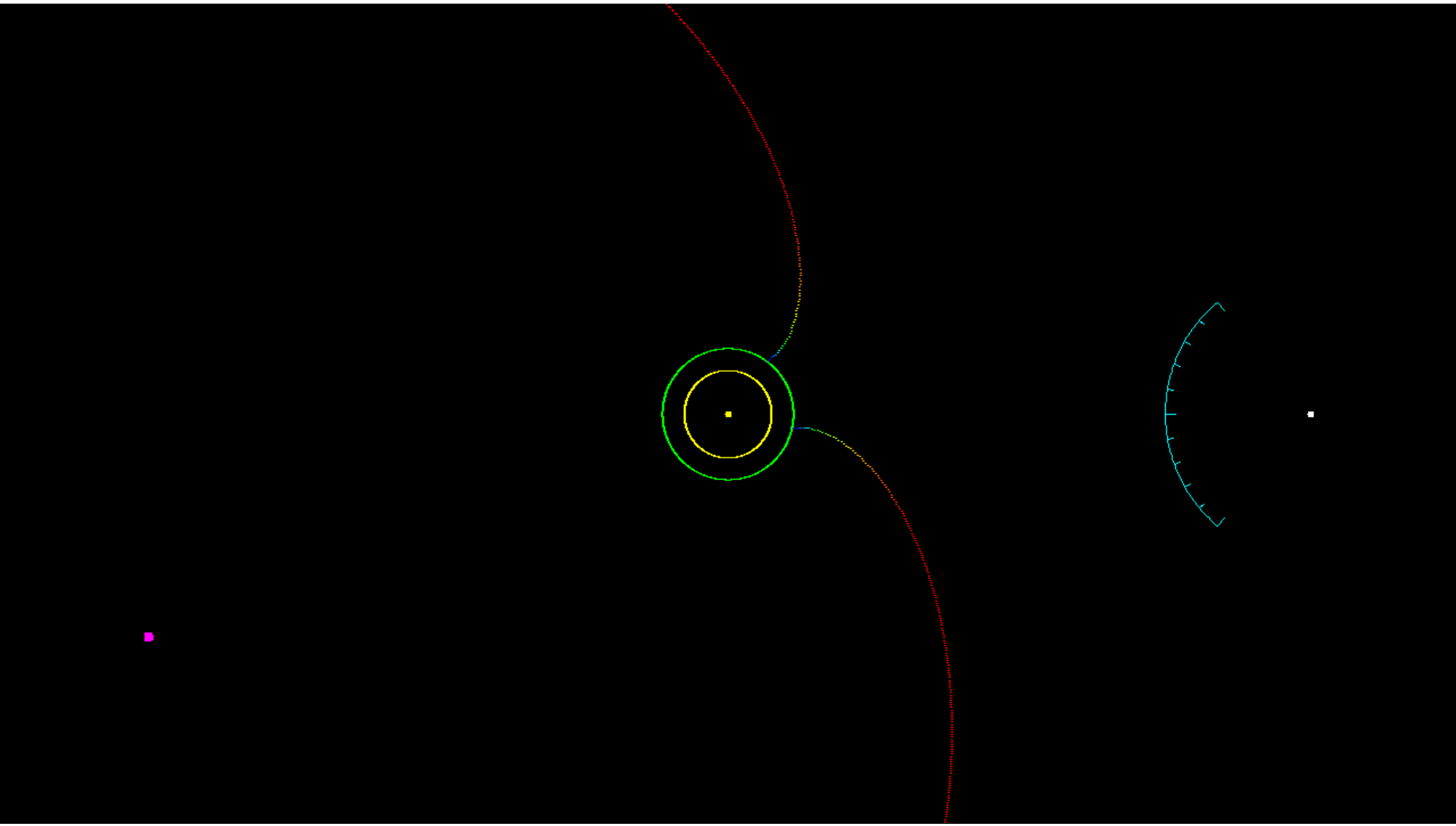


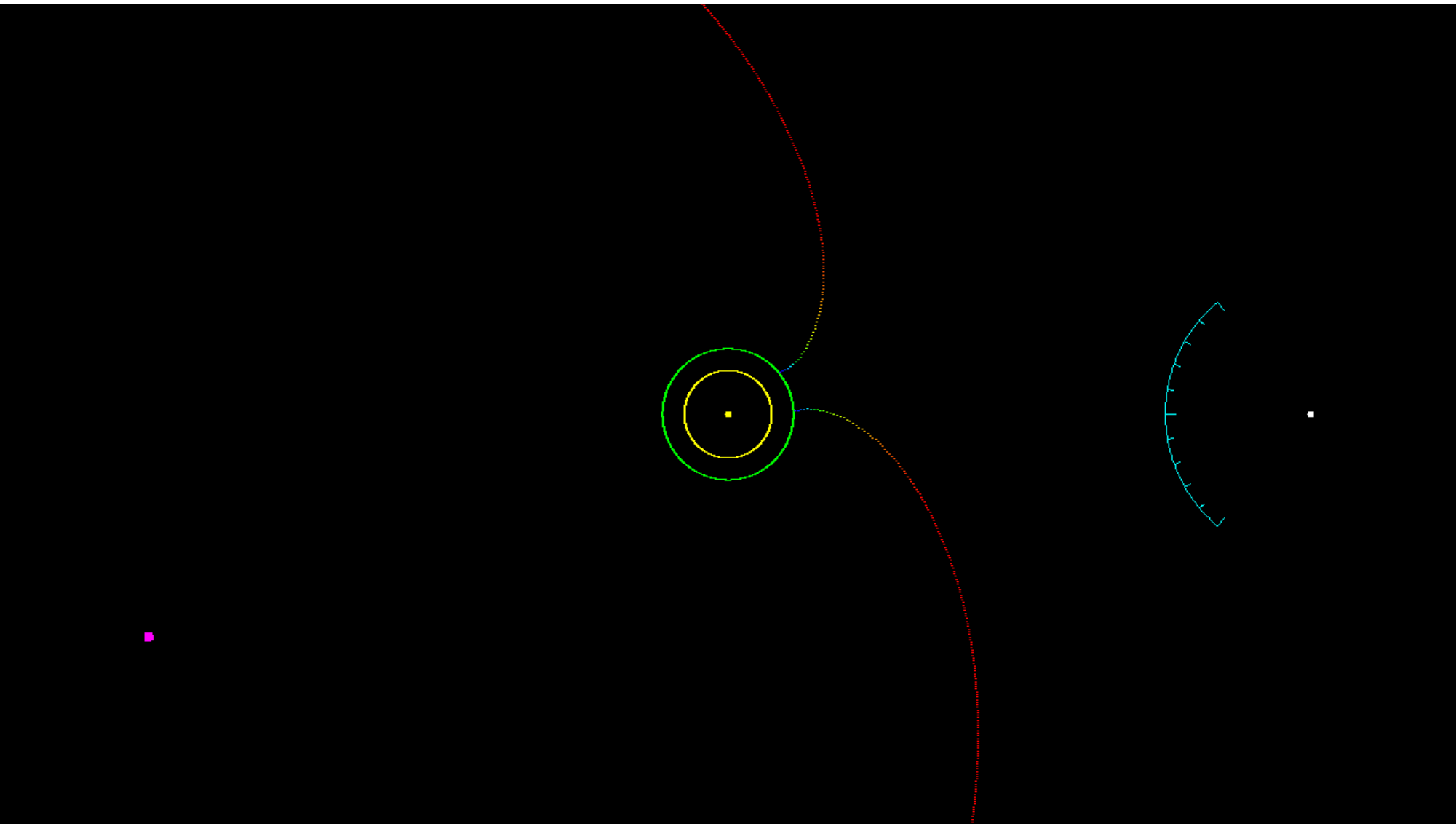


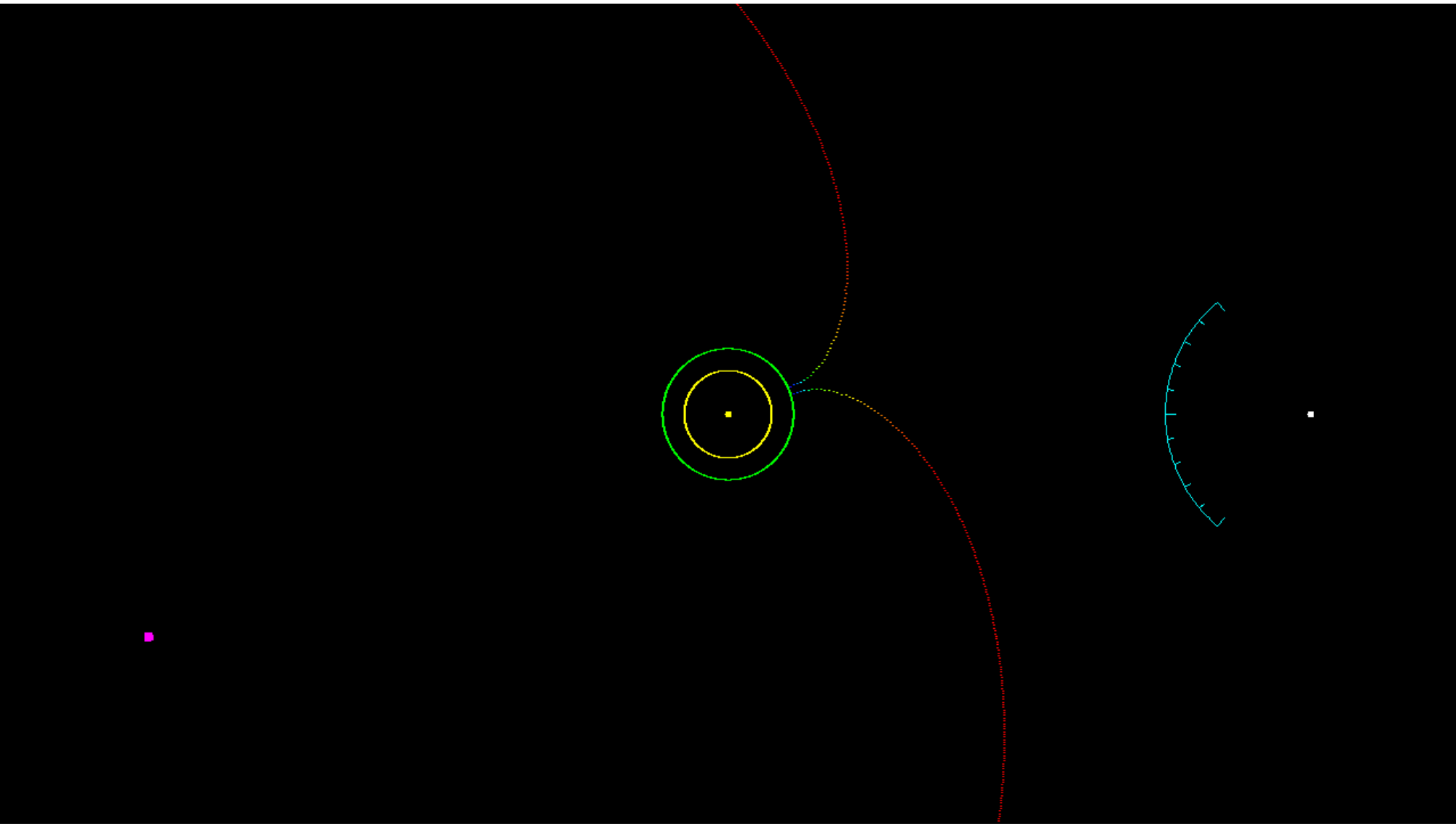


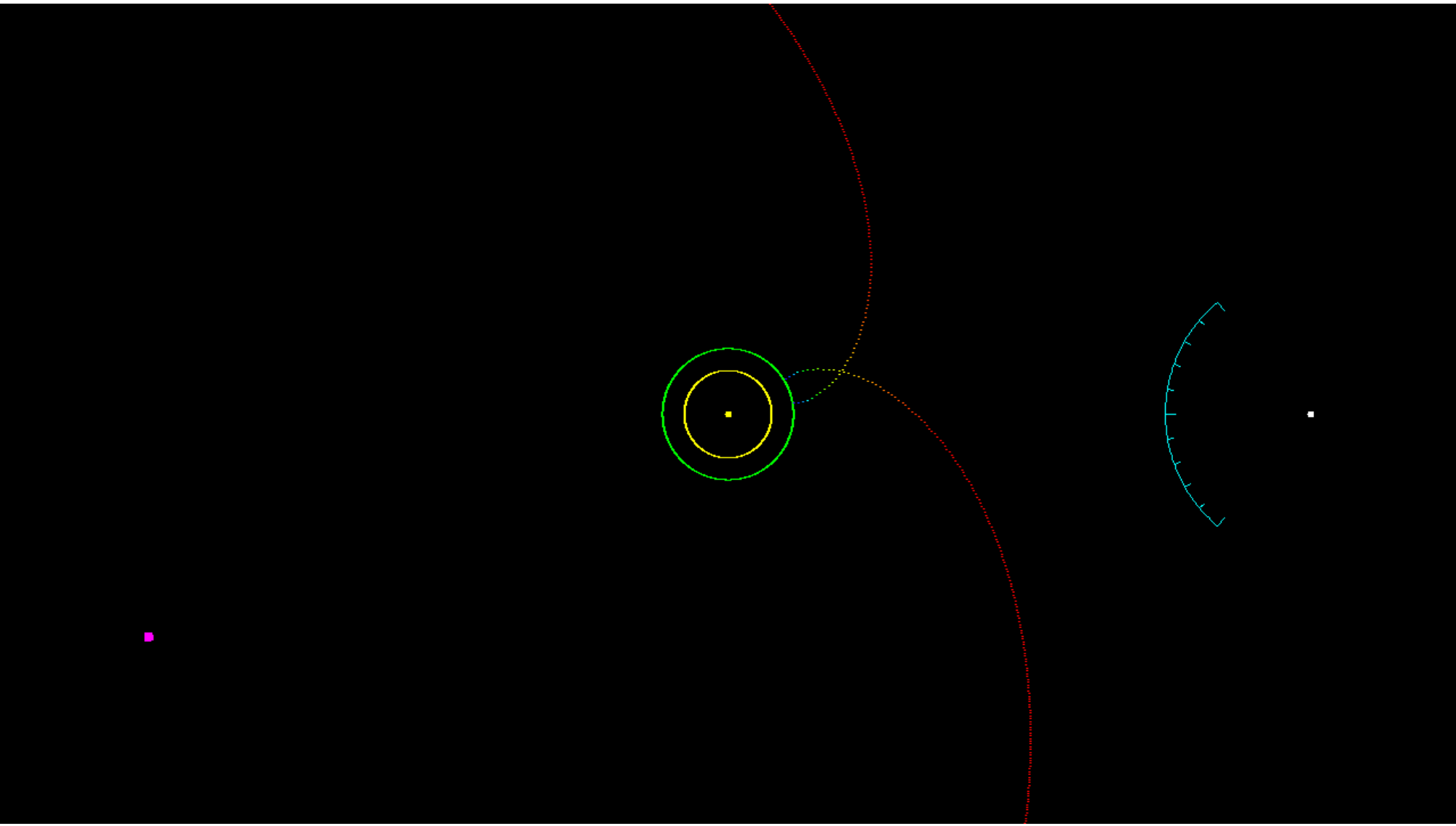


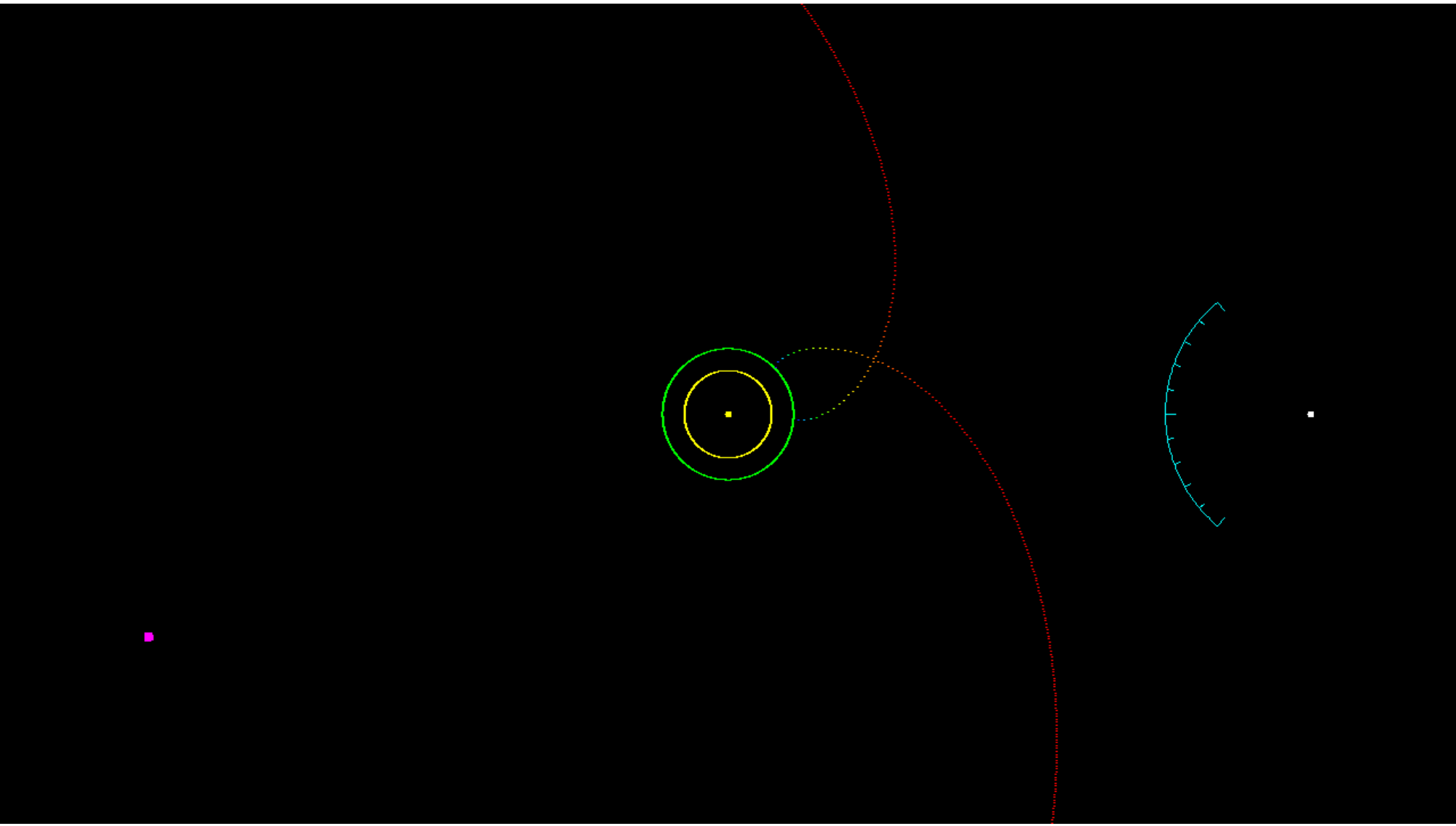


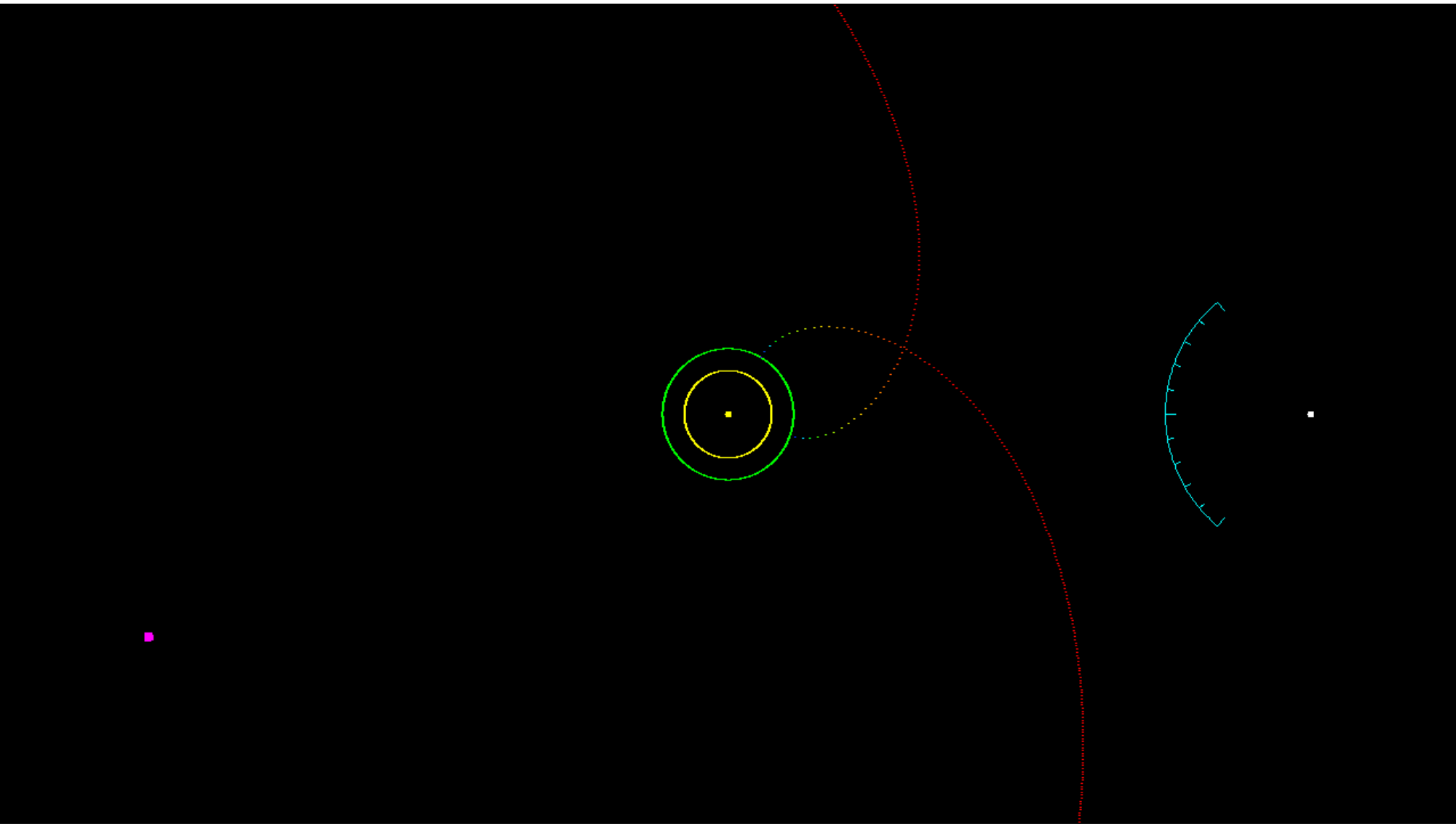


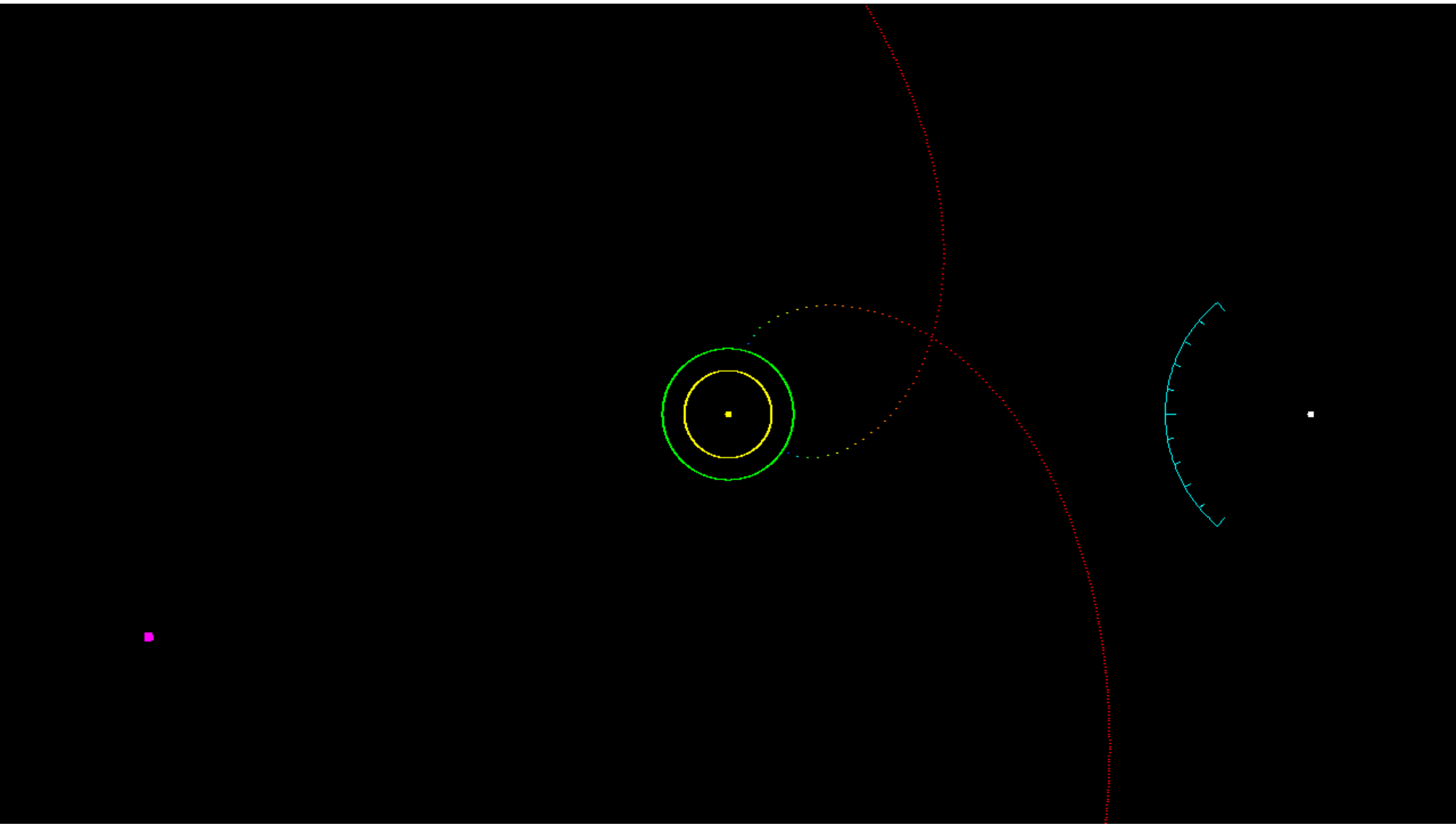


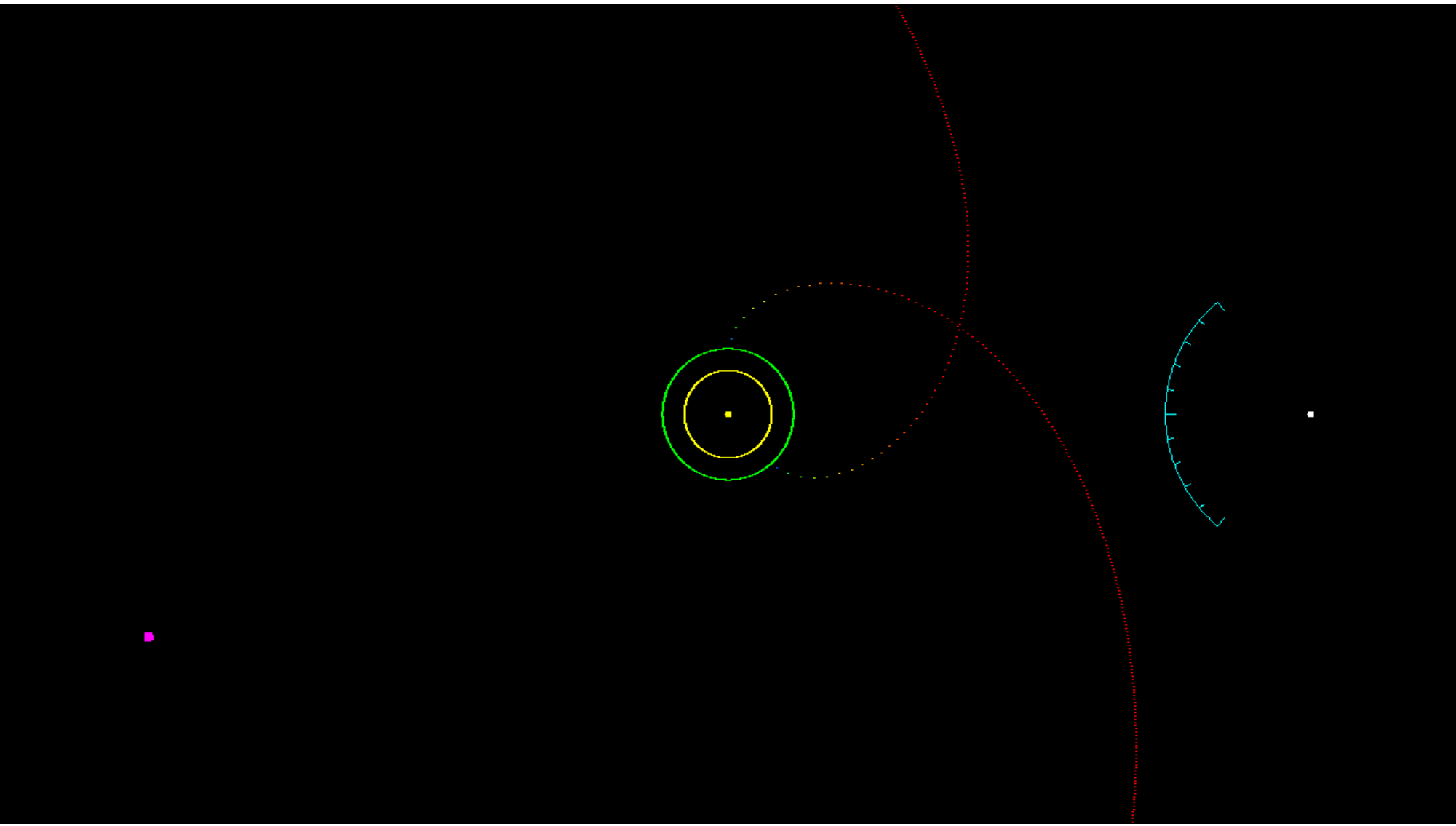


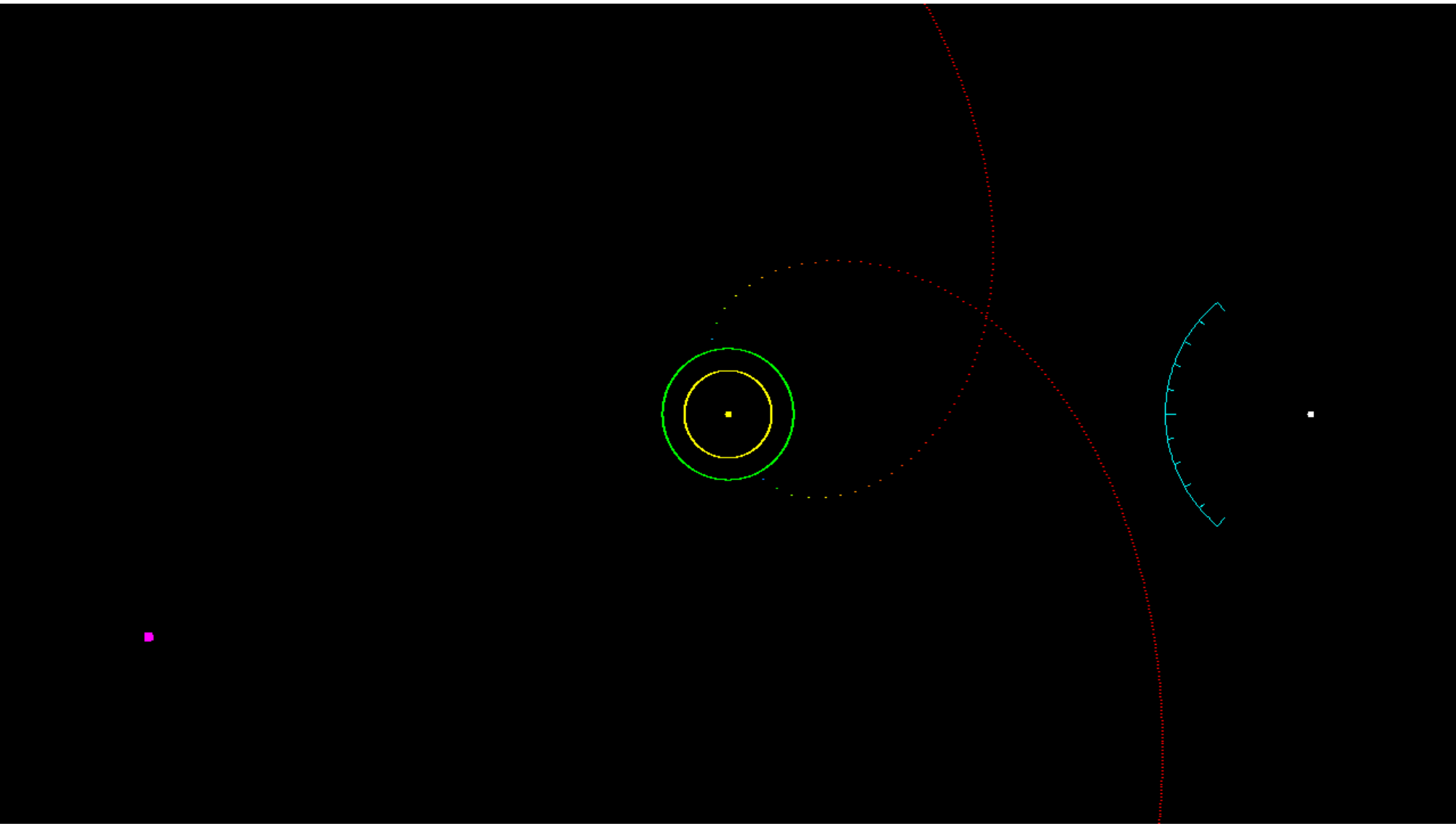


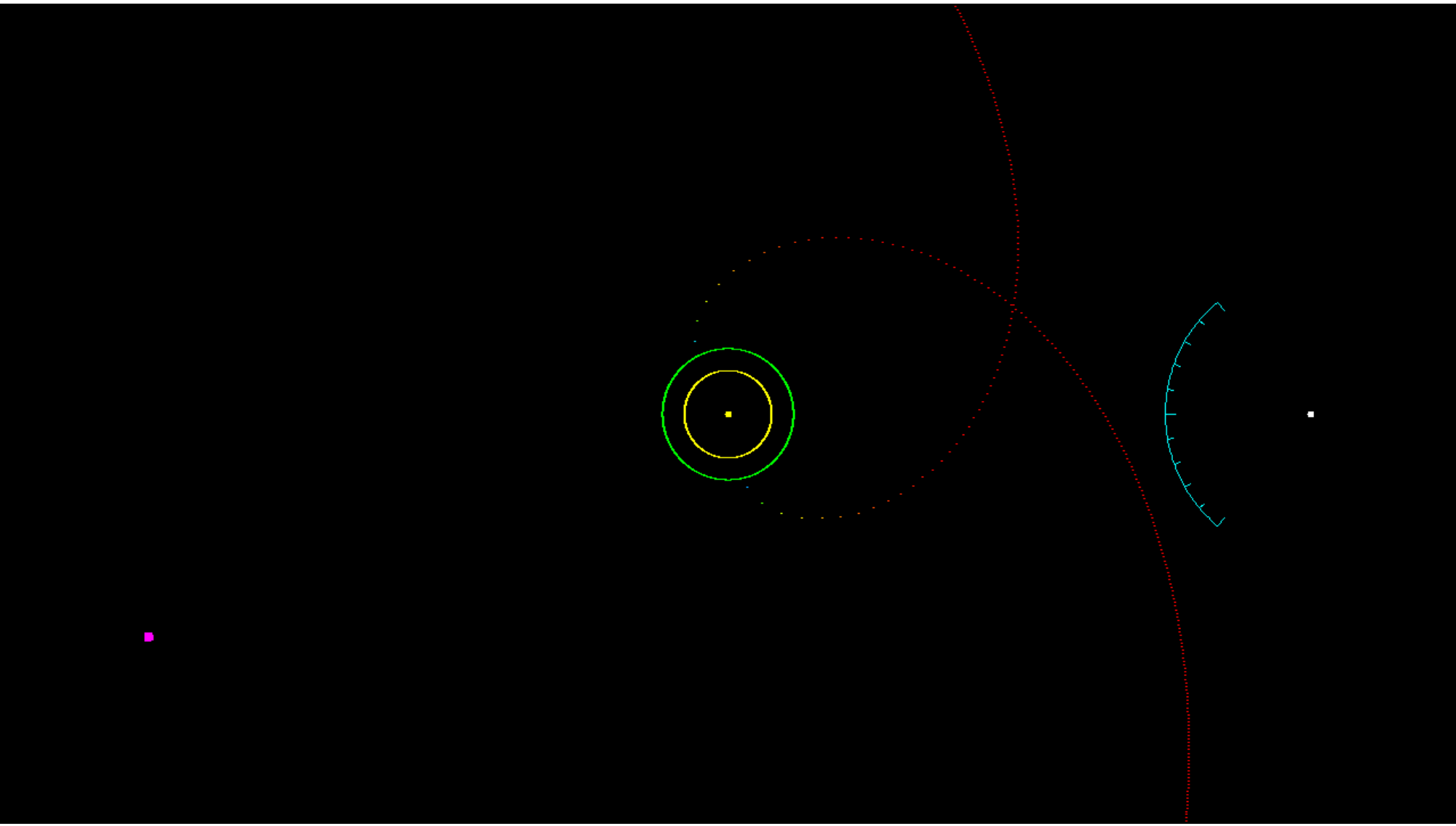


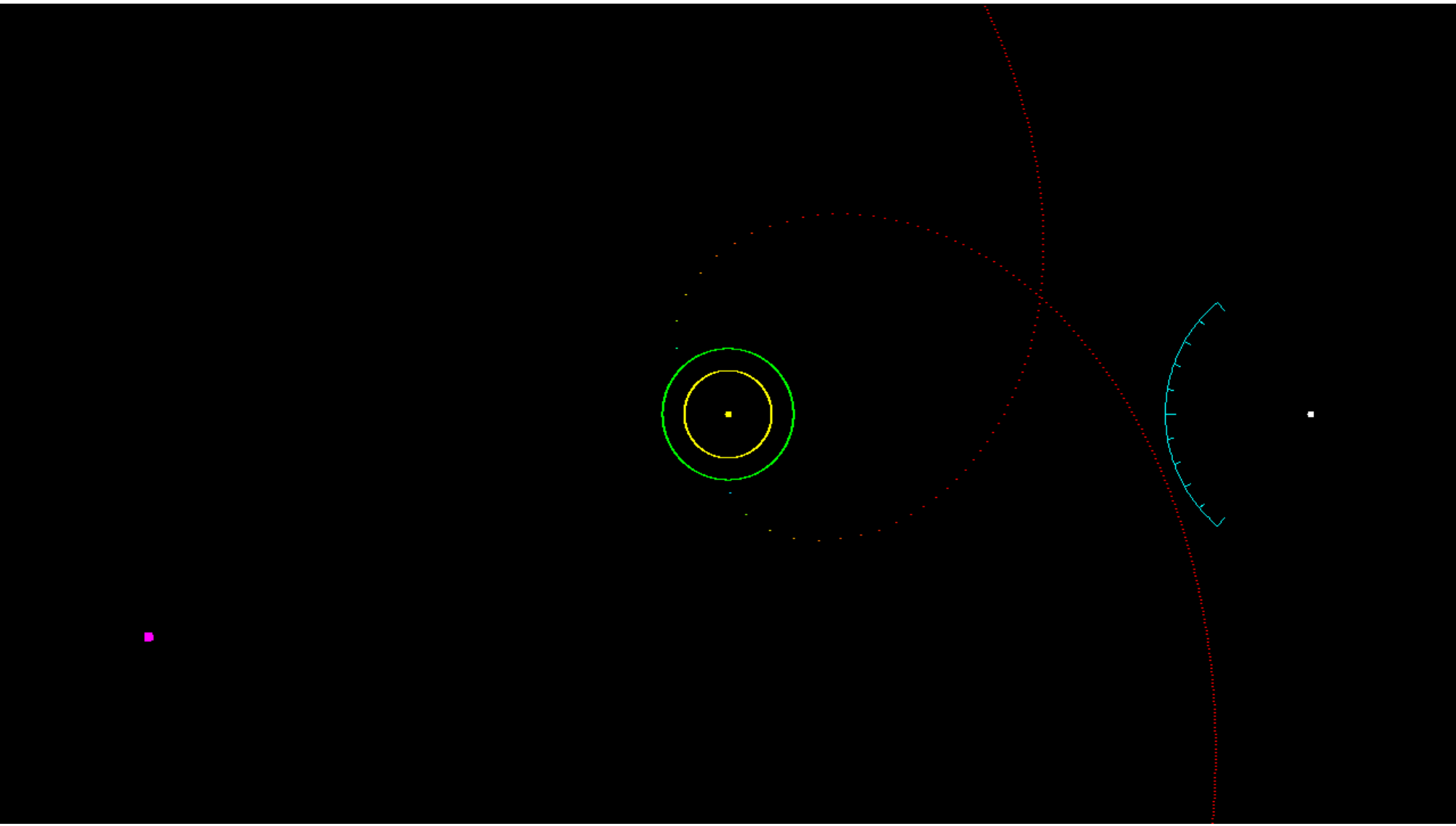


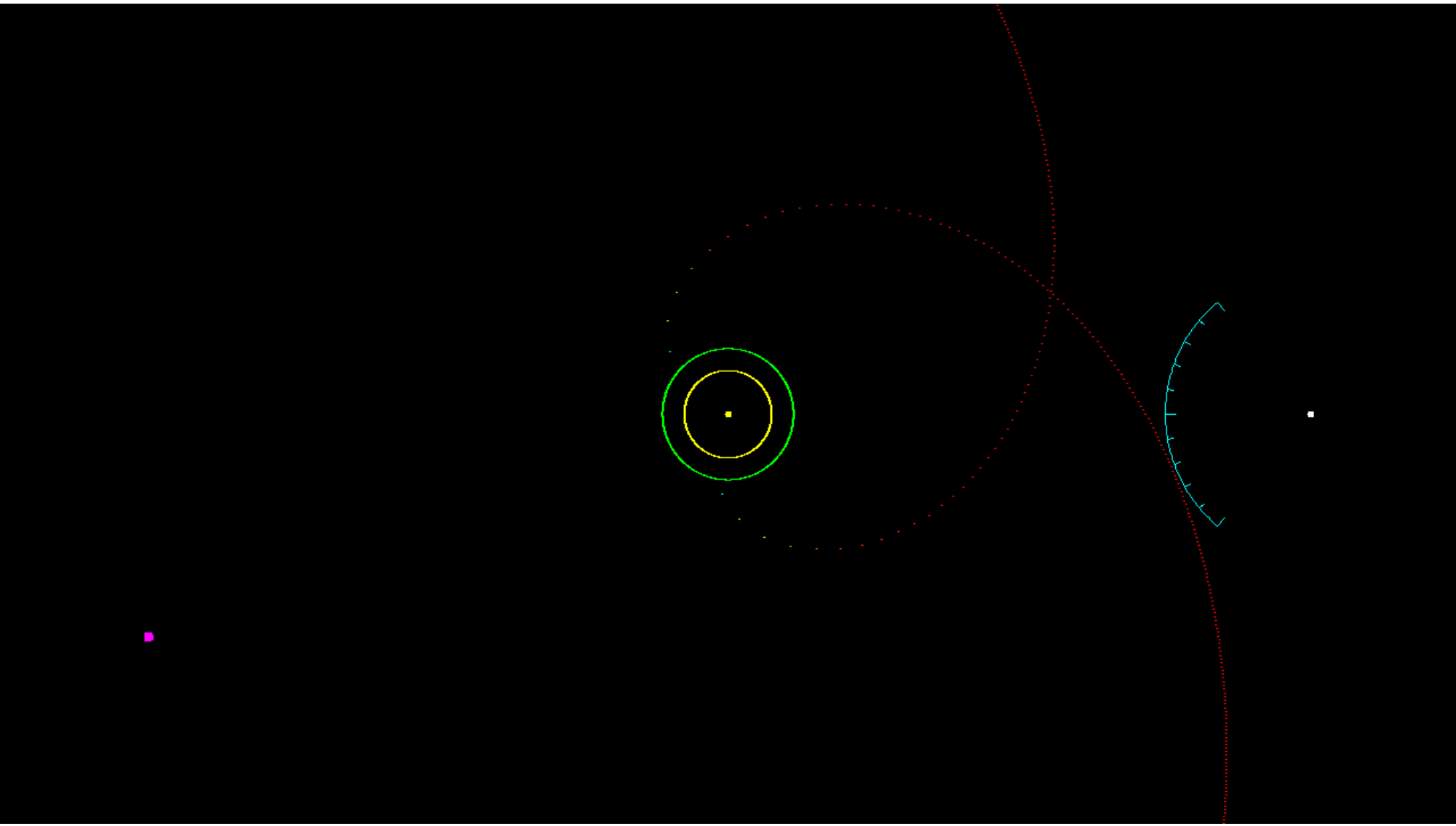


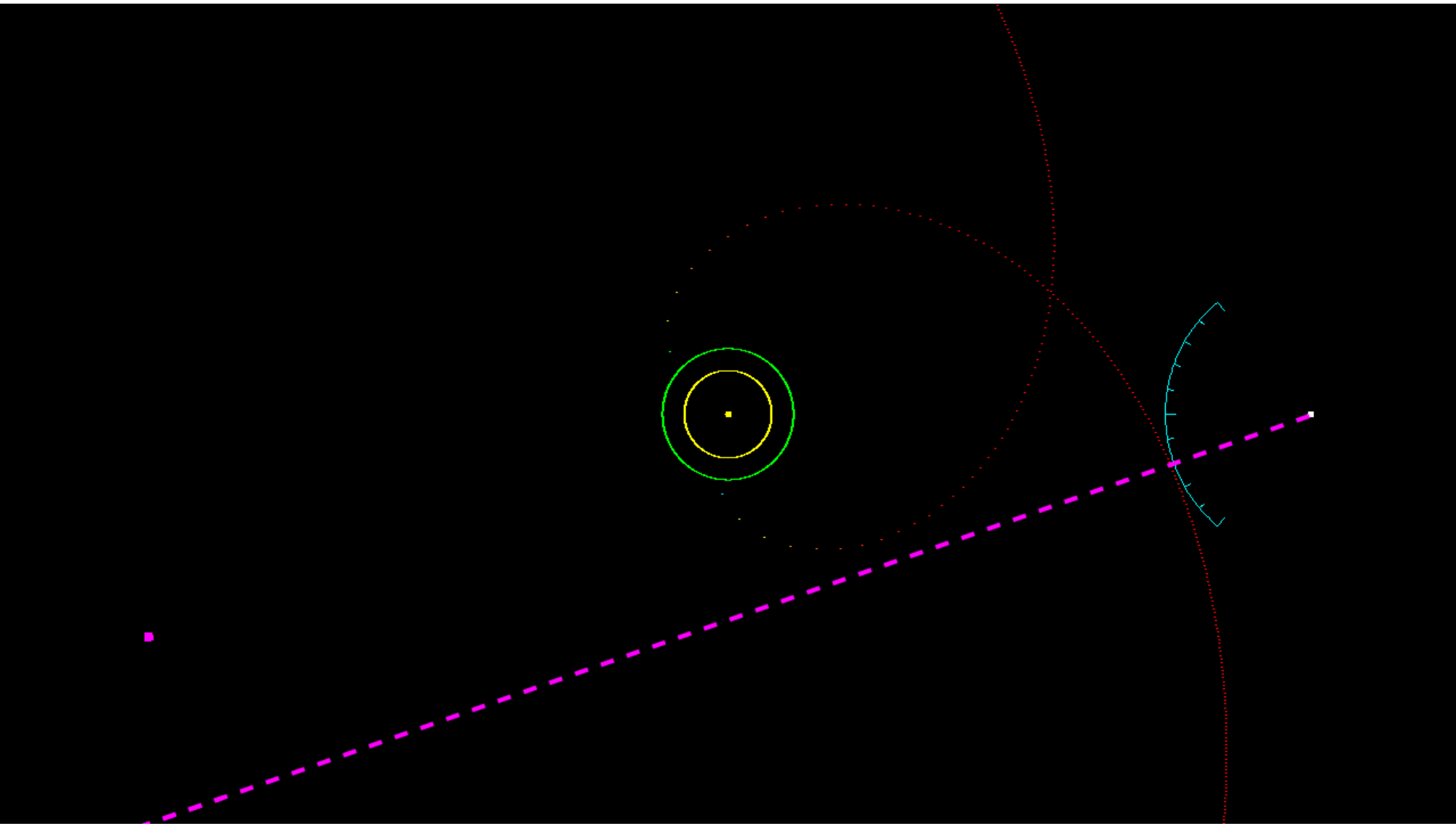


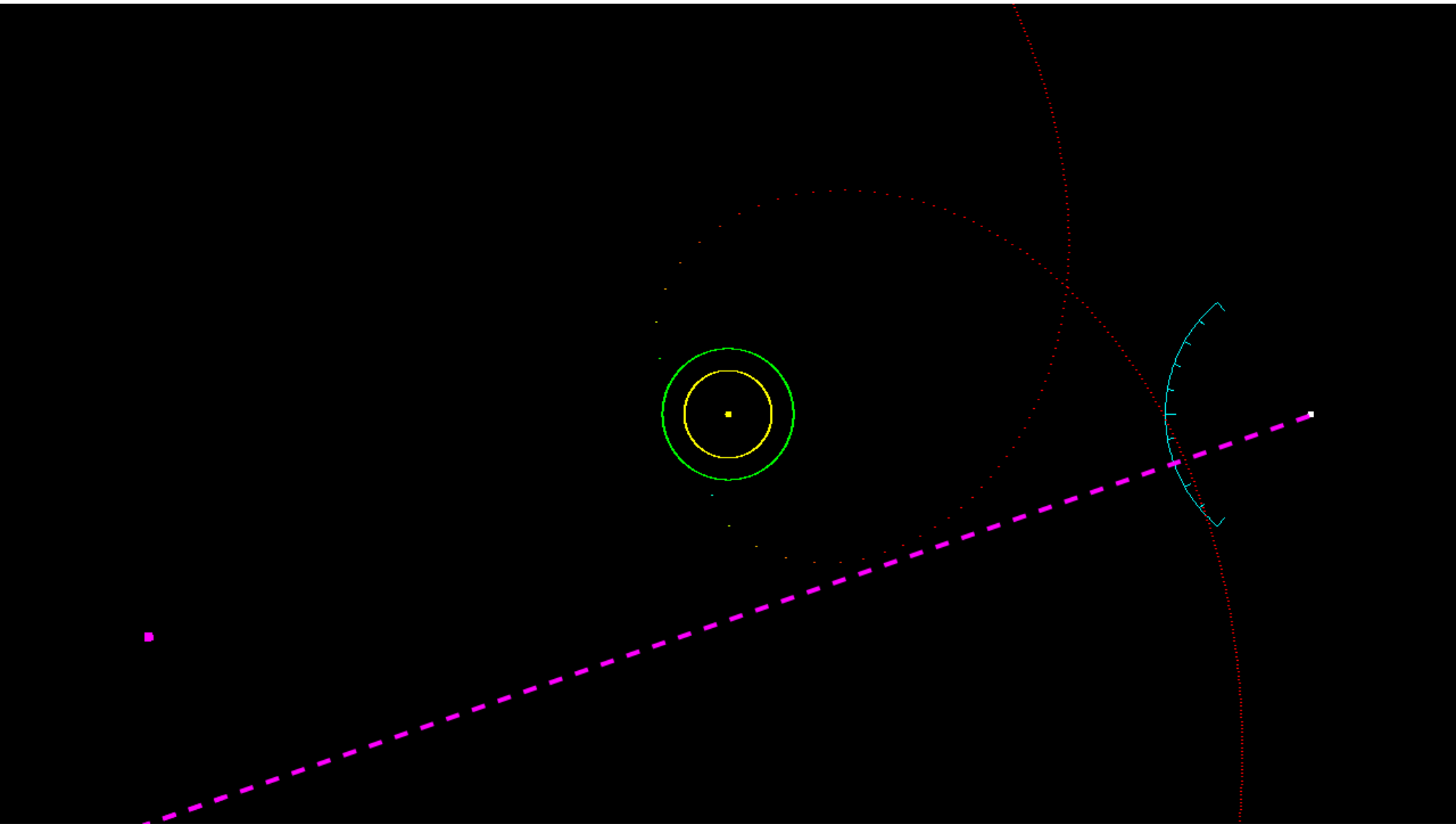


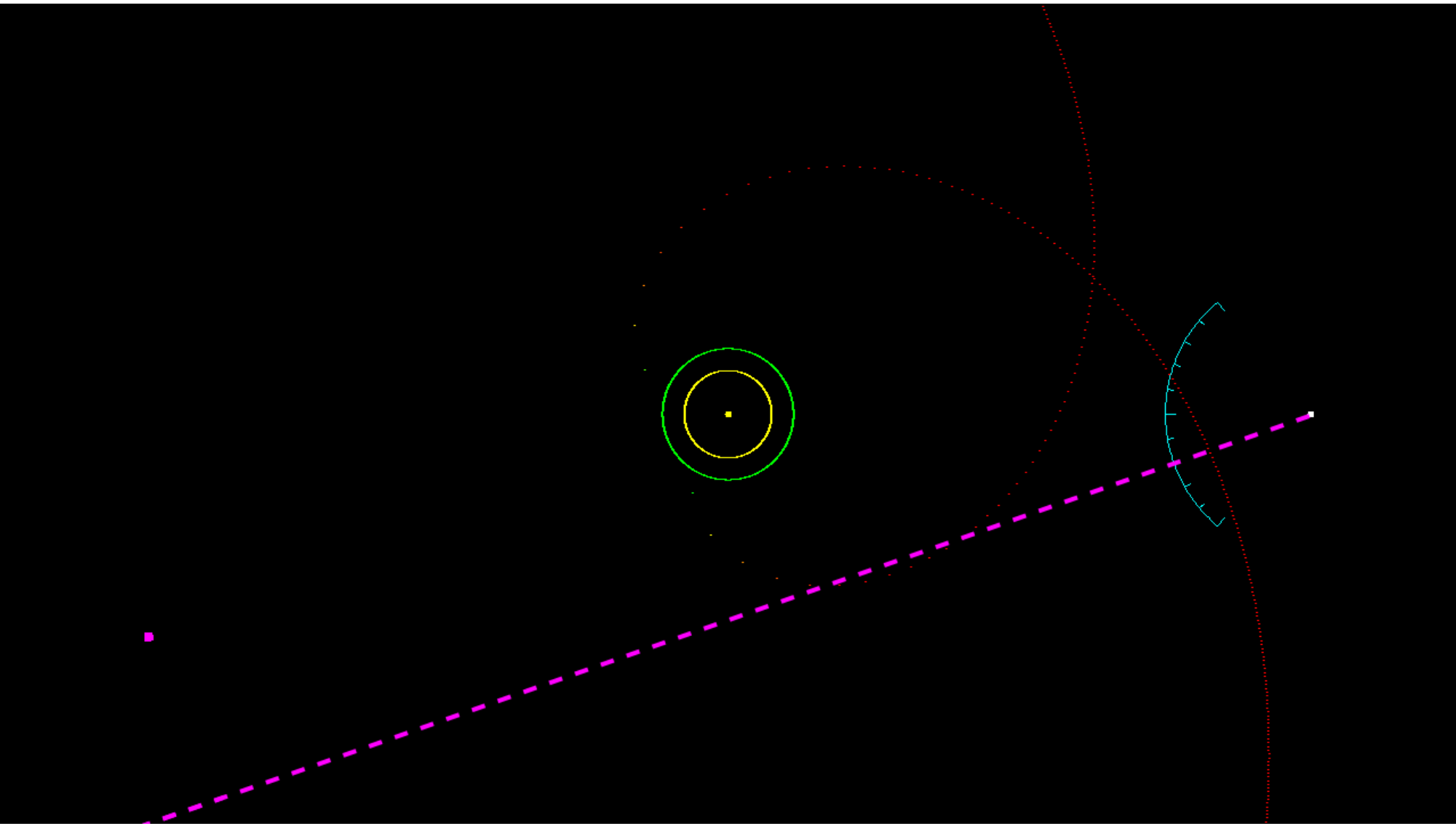


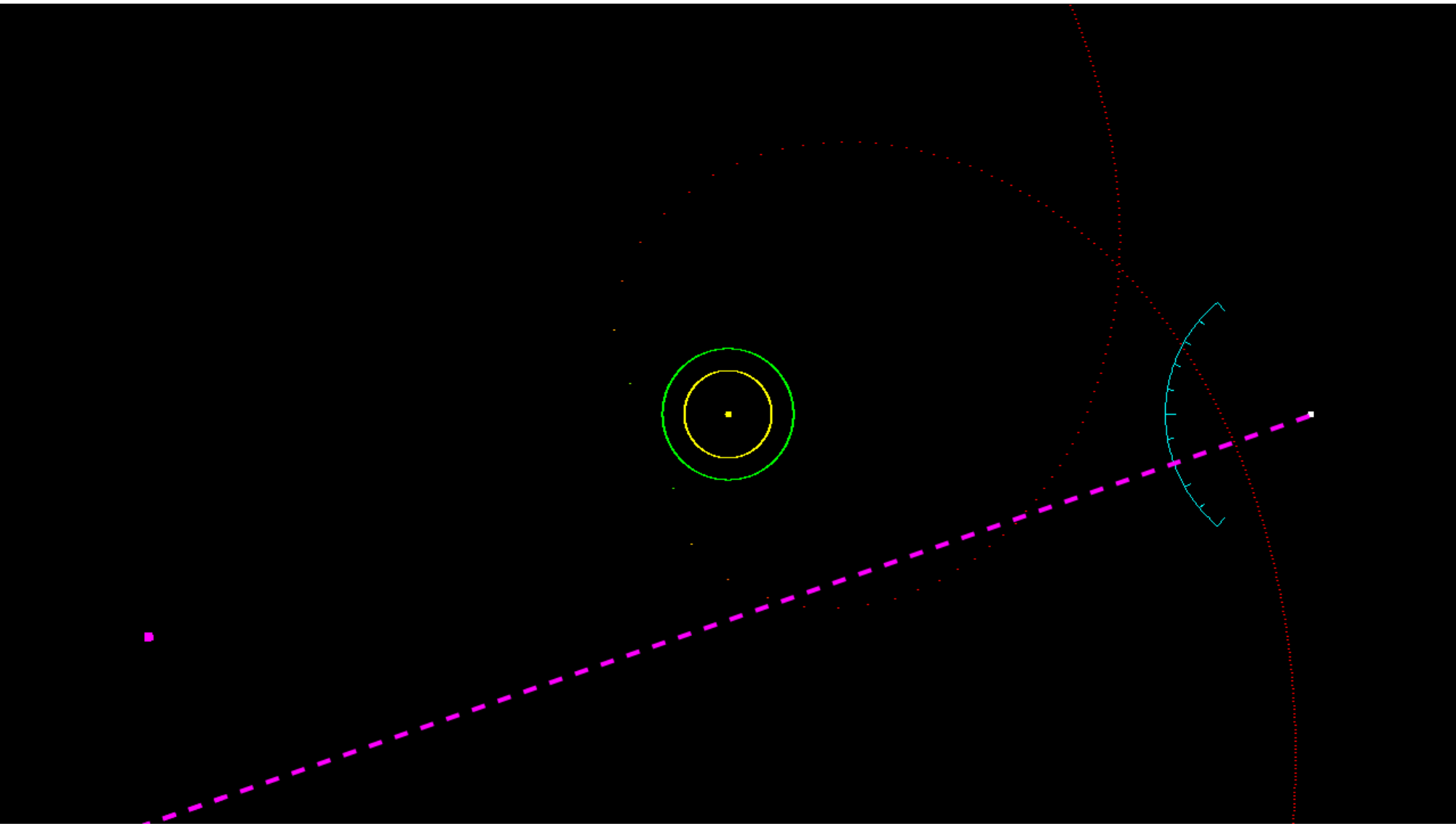


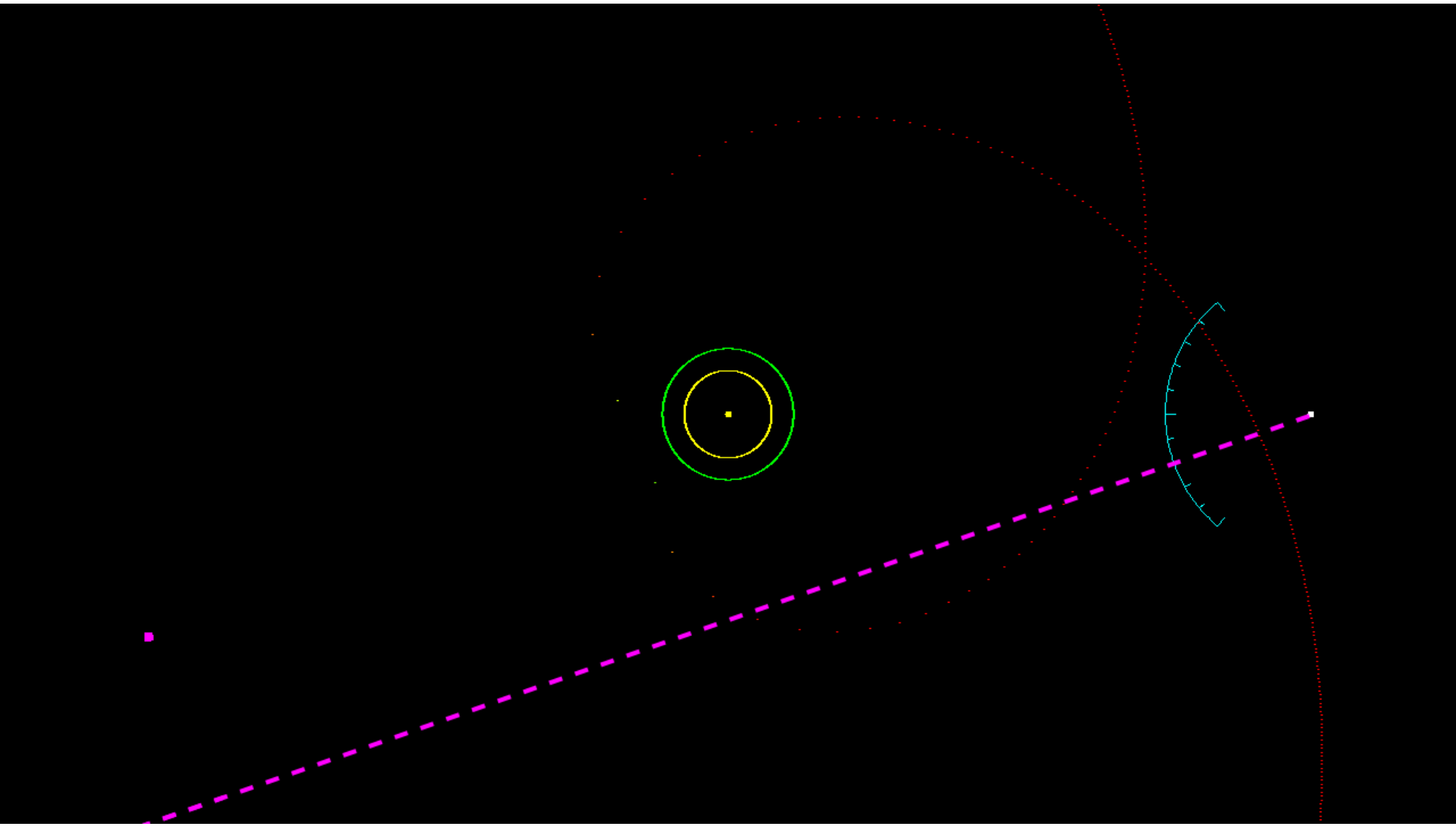


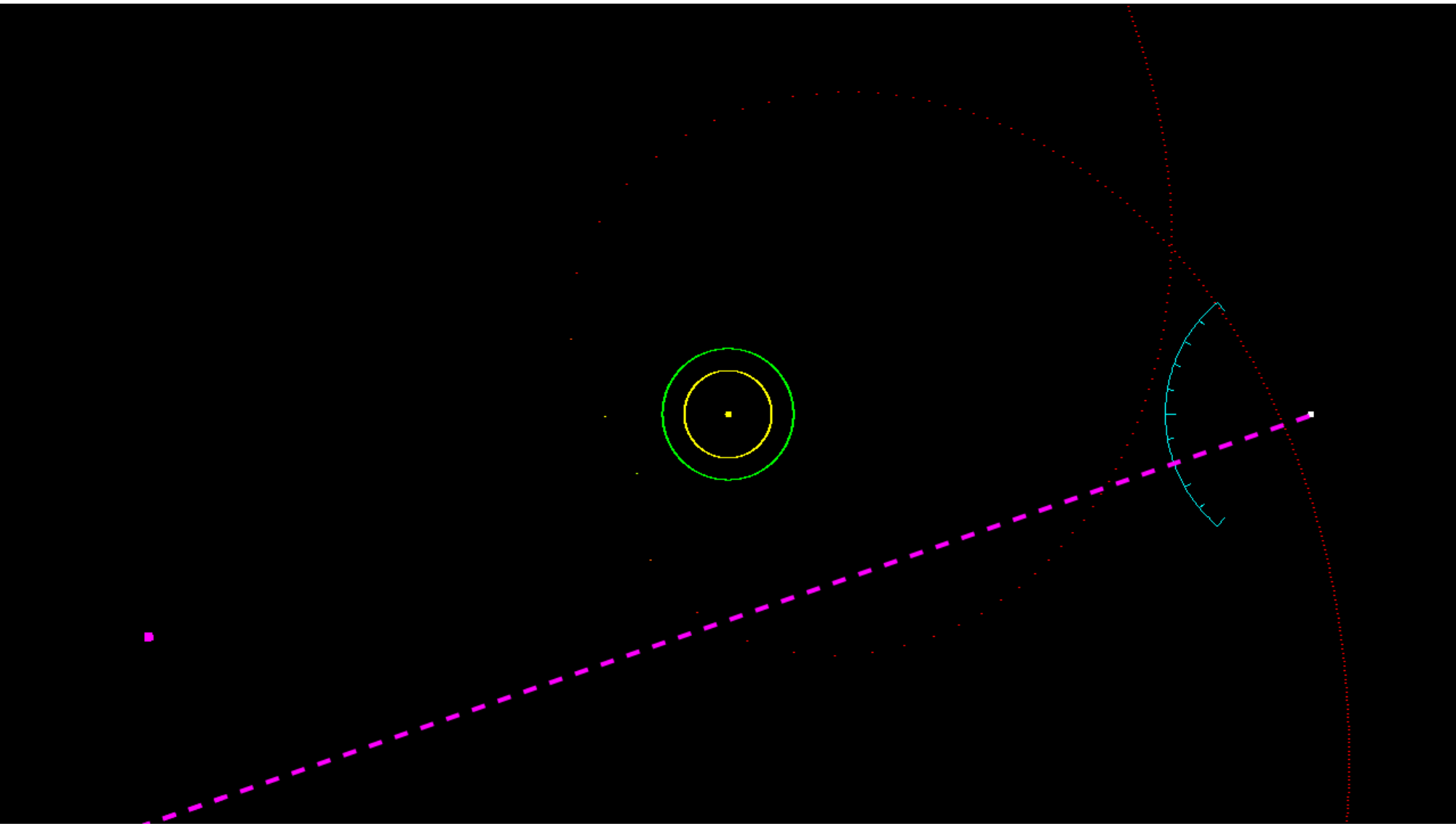


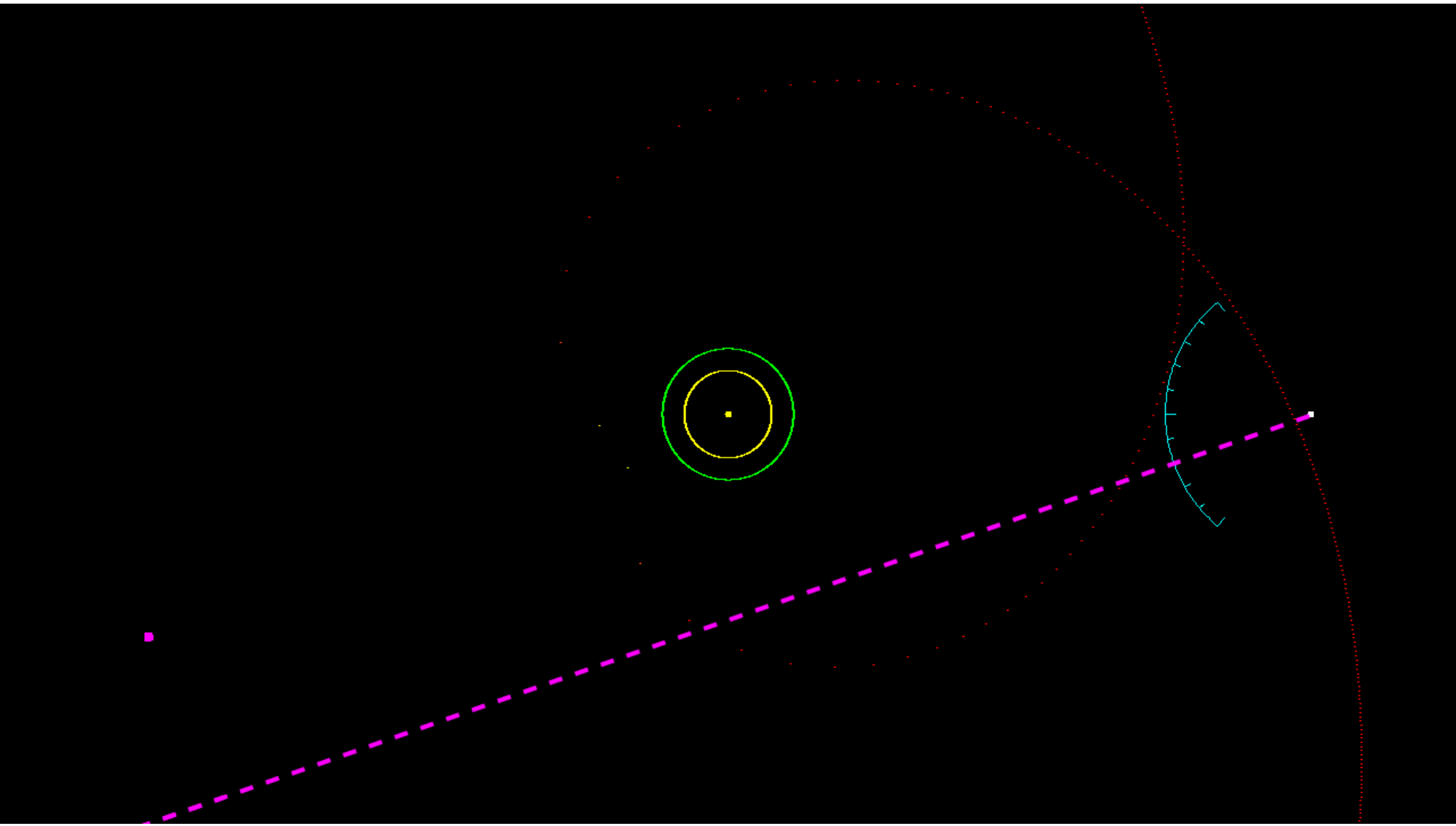


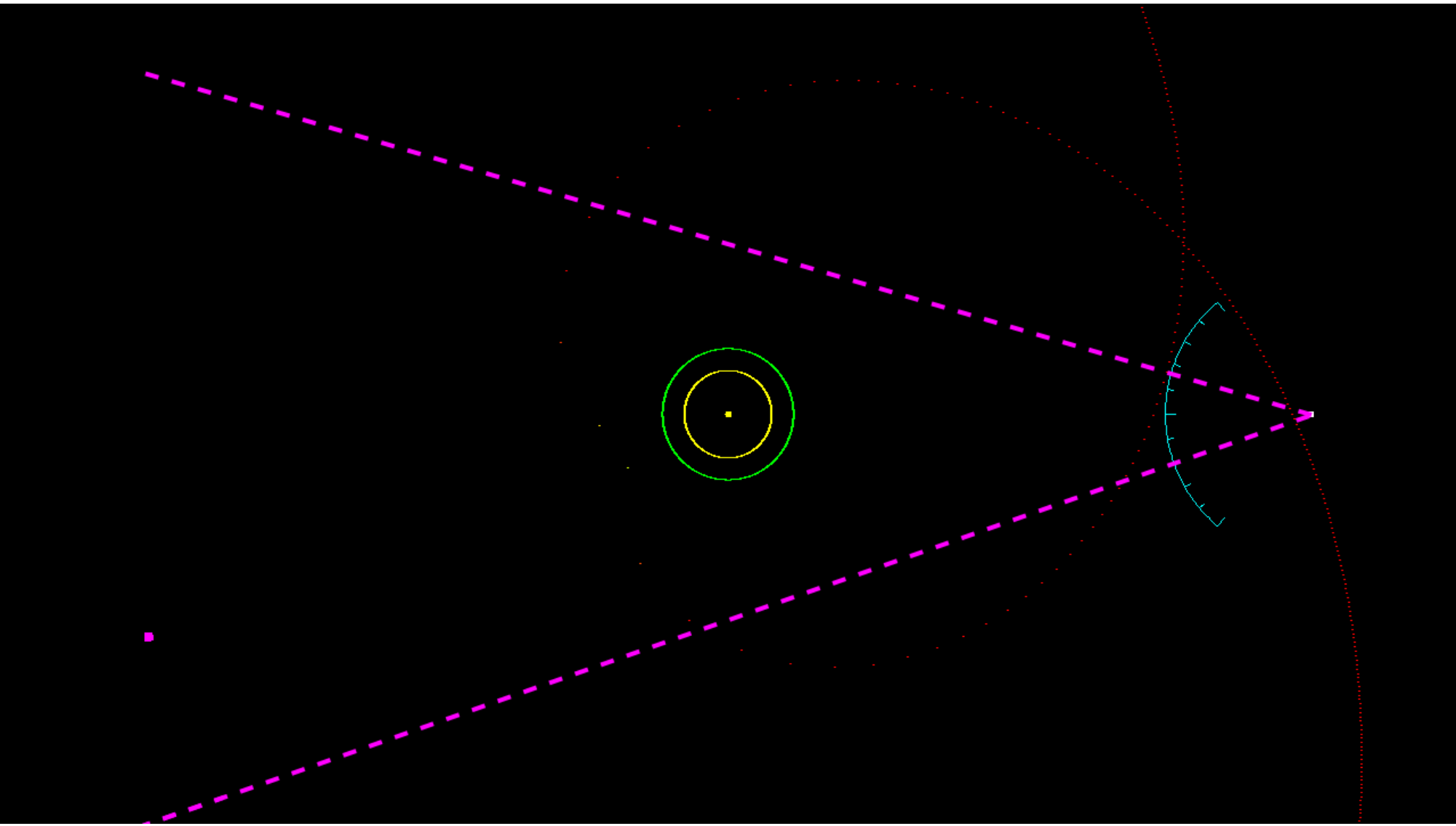


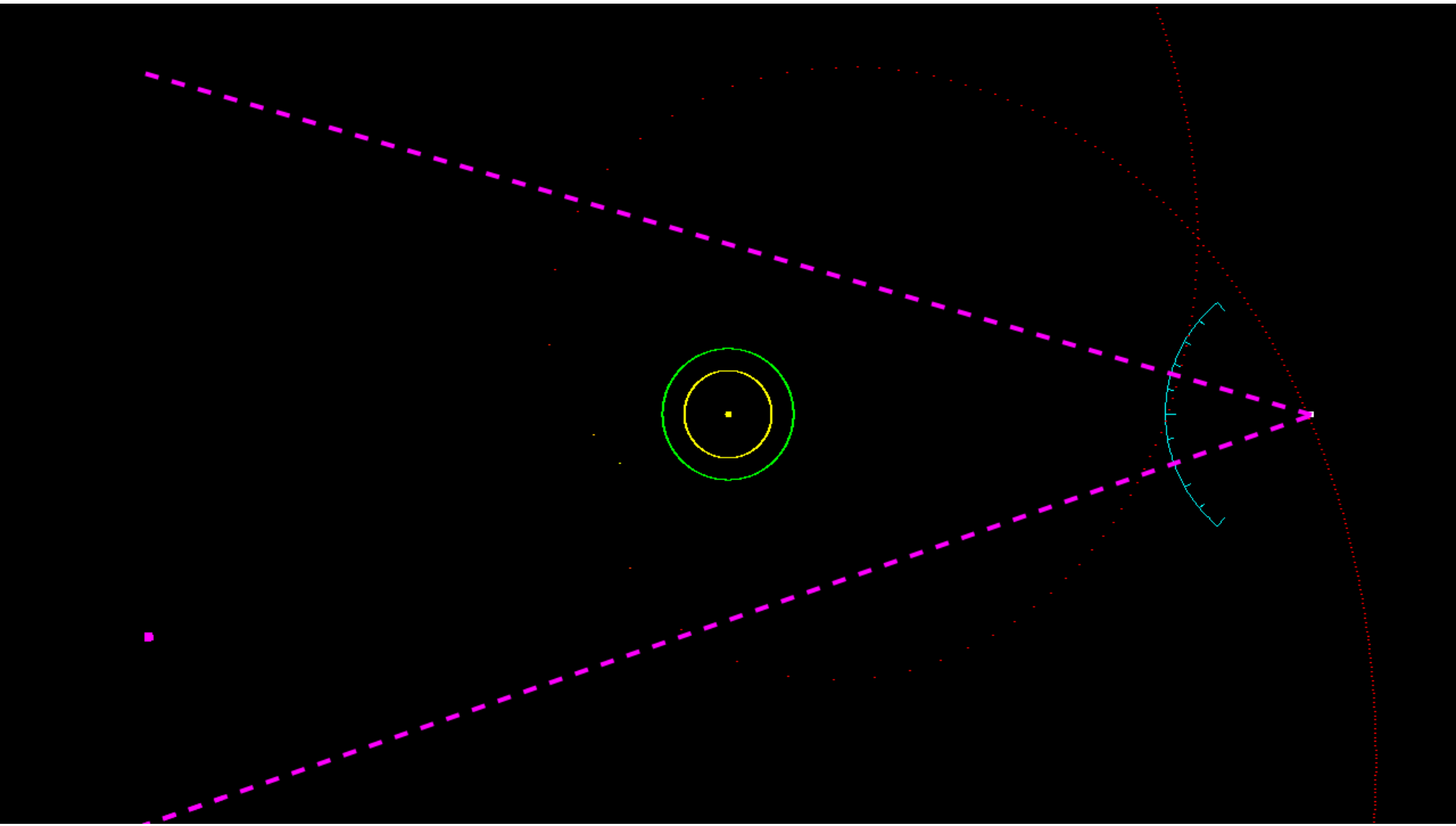


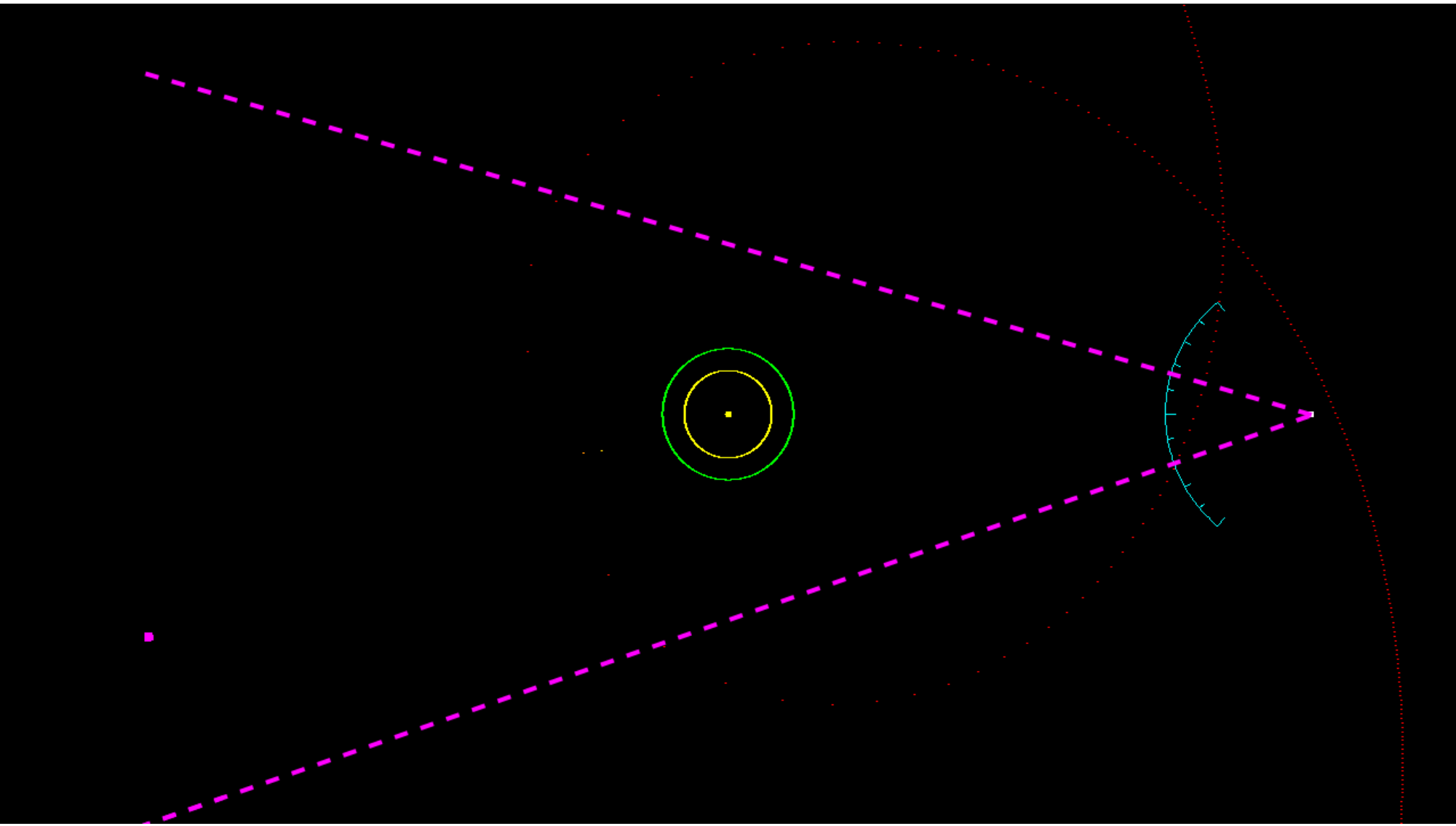


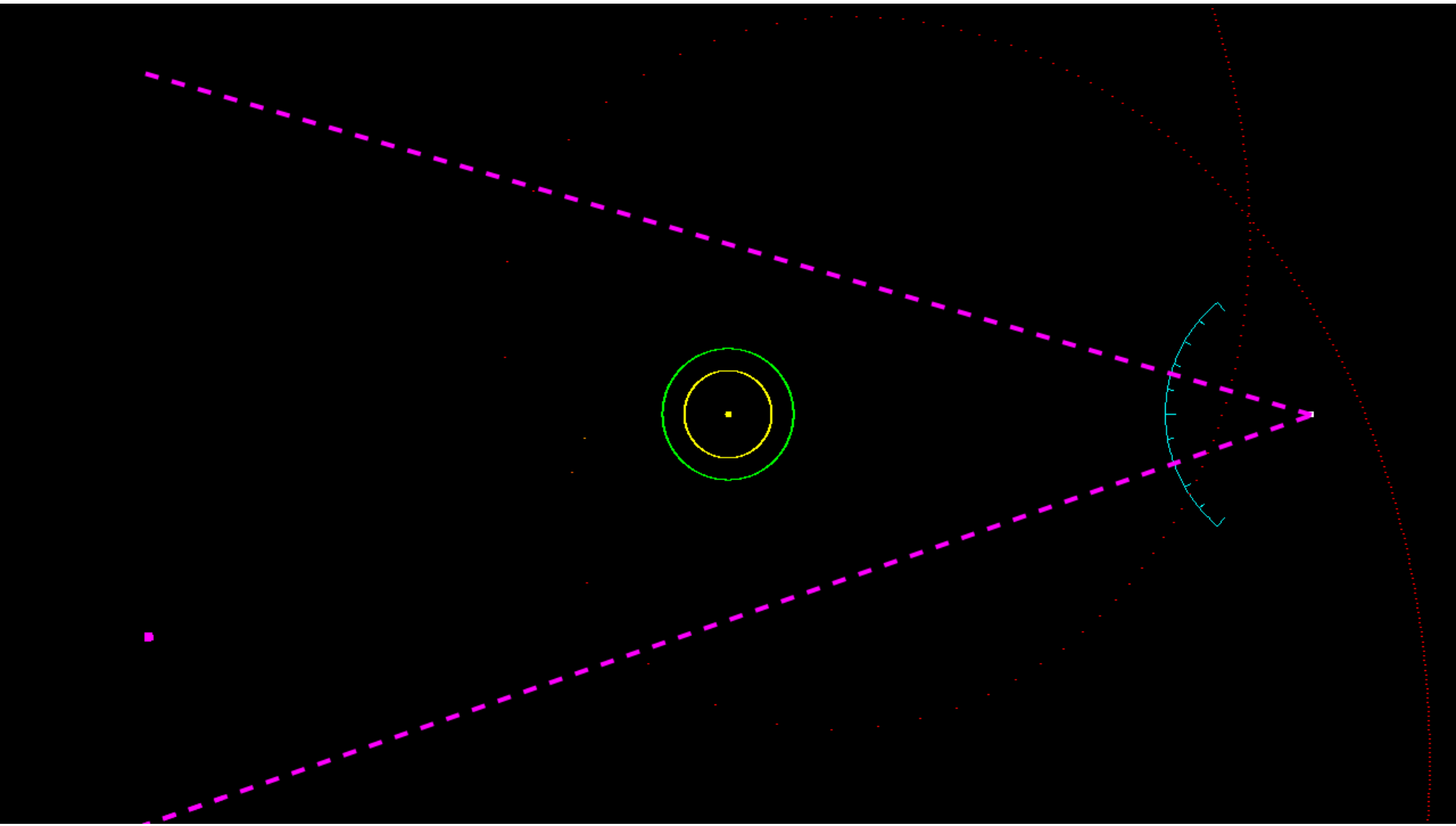


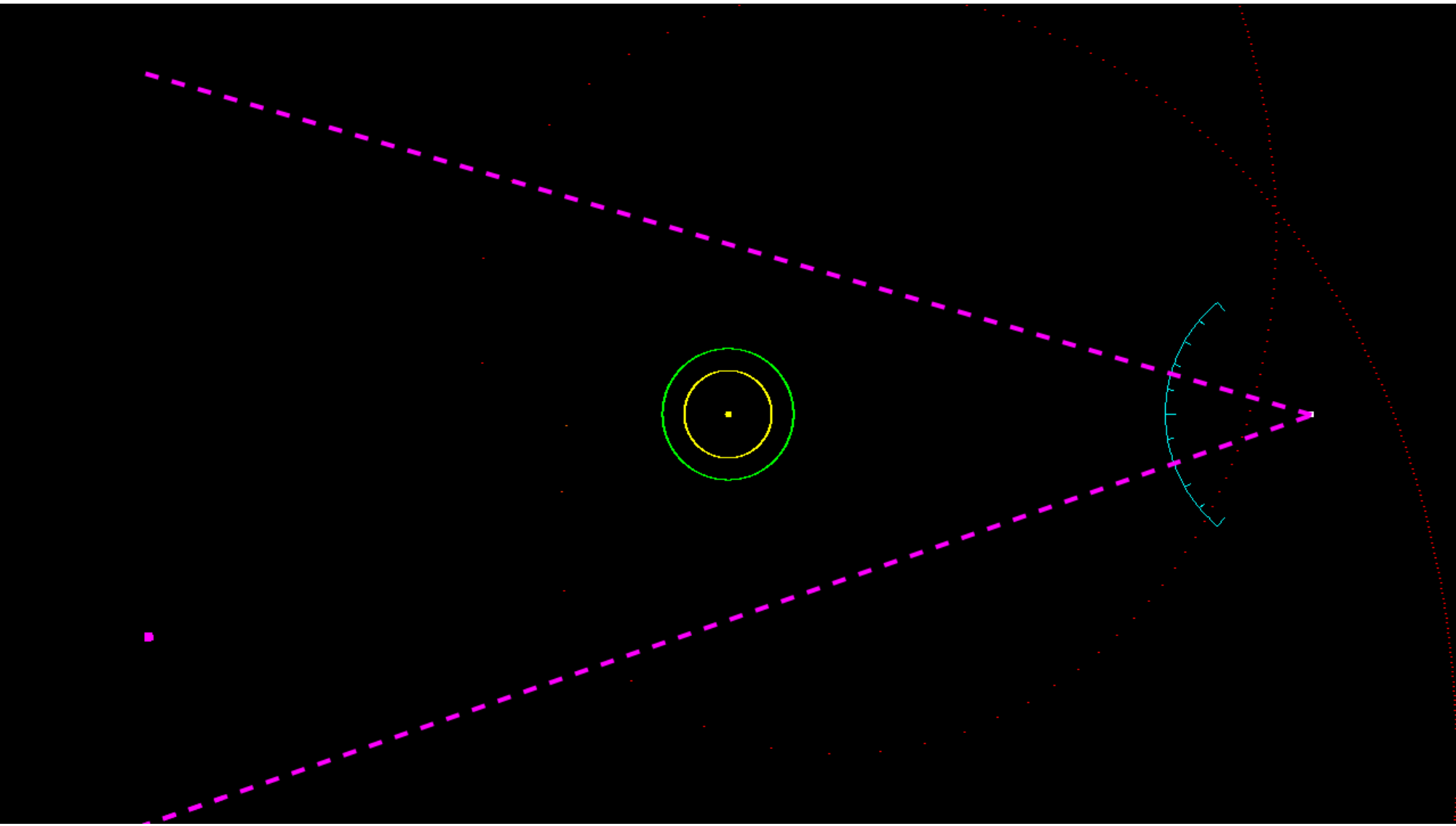




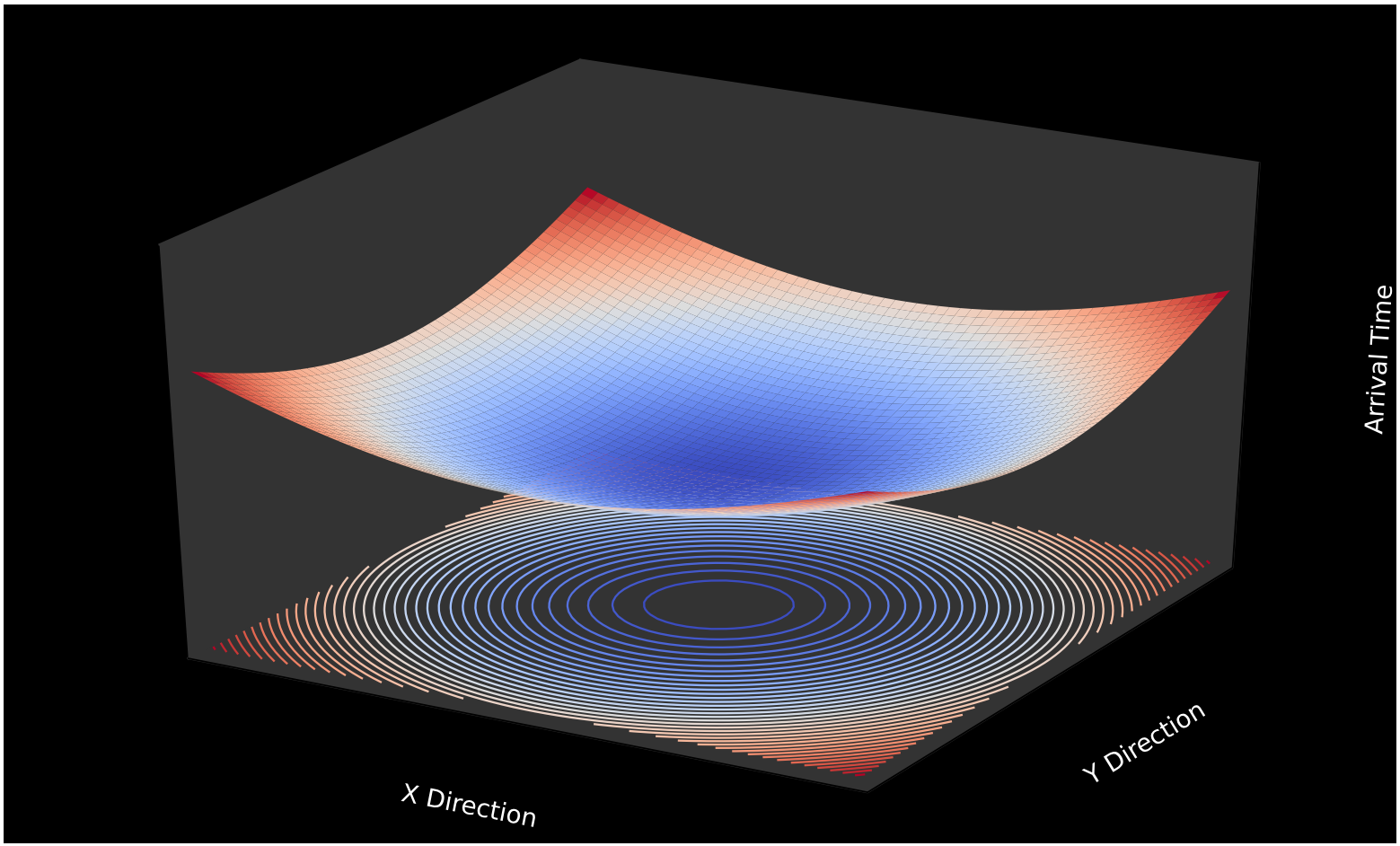


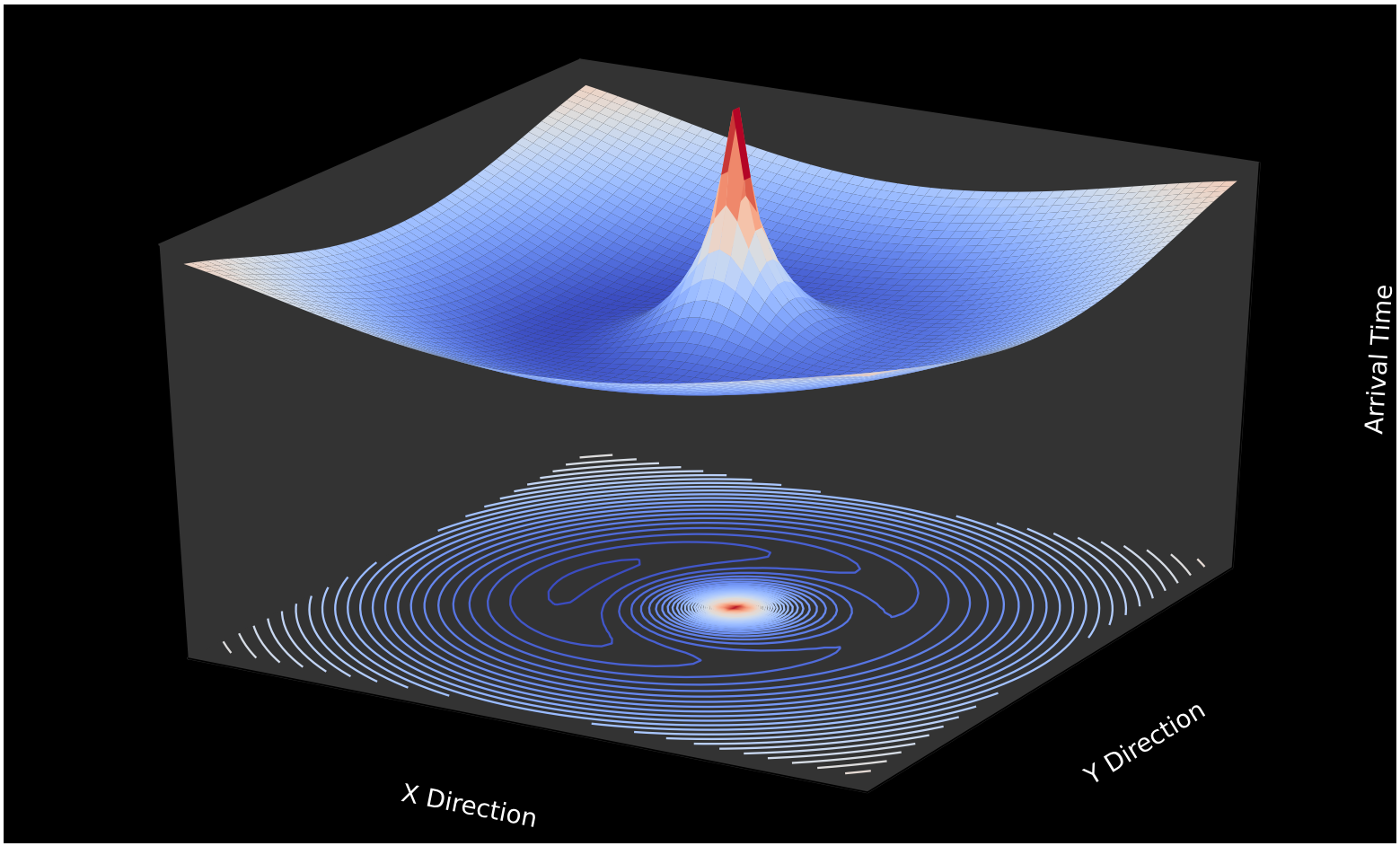


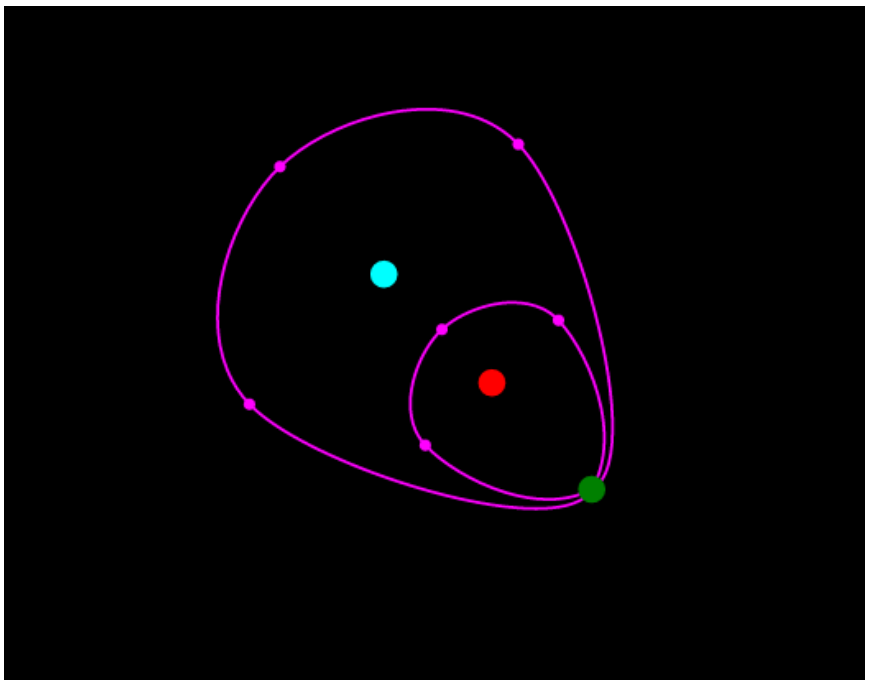




Simulation program: `gravlens` by C. Huwiler


Arrival Time
X Direction
Y Direction


Arrival Time
X Direction
Y Direction



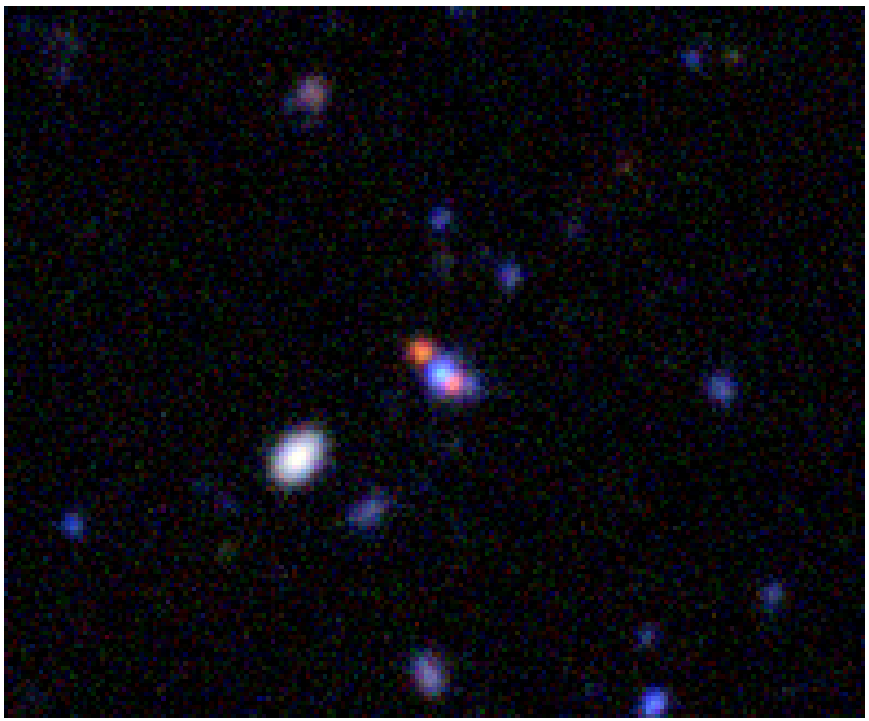
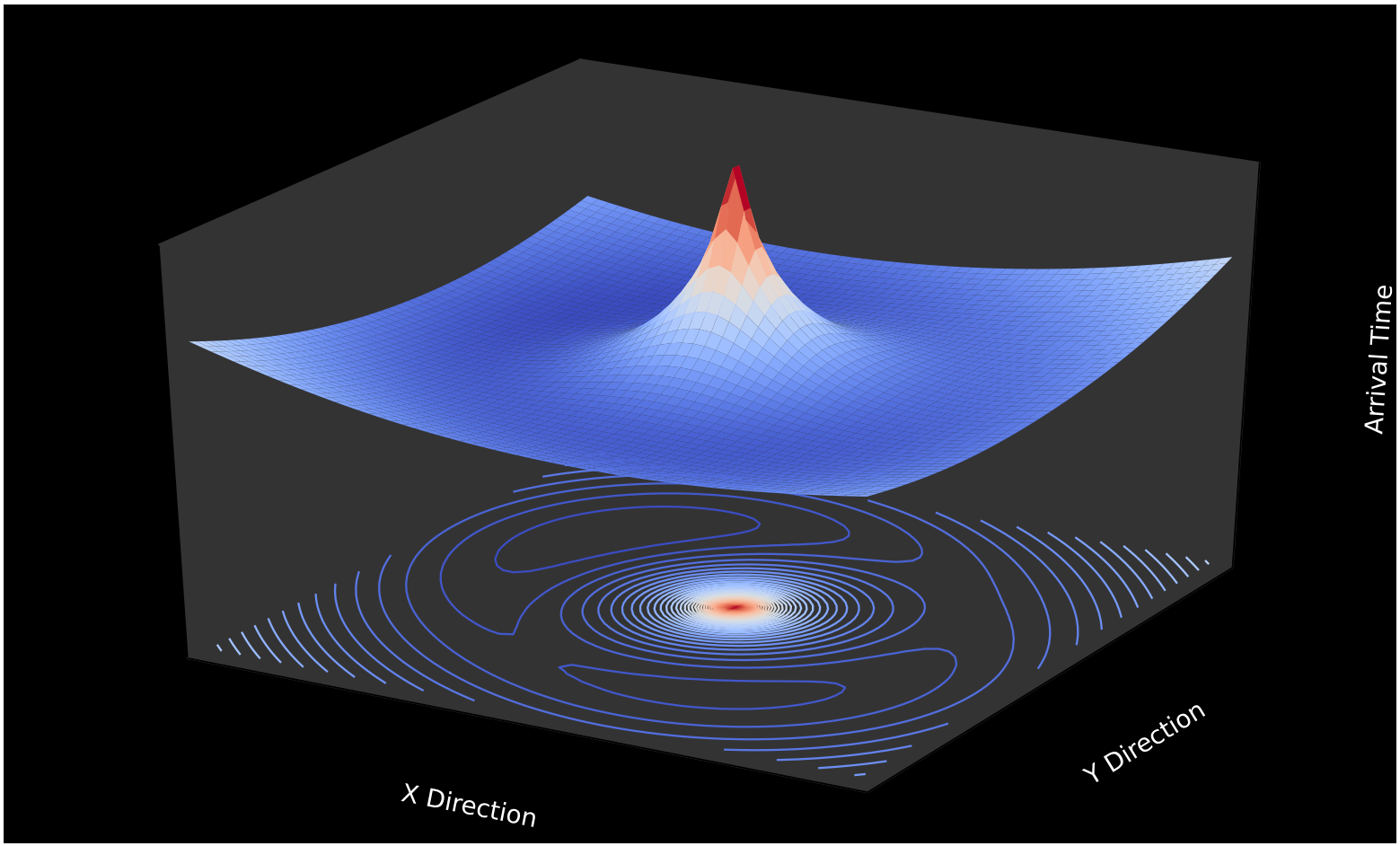
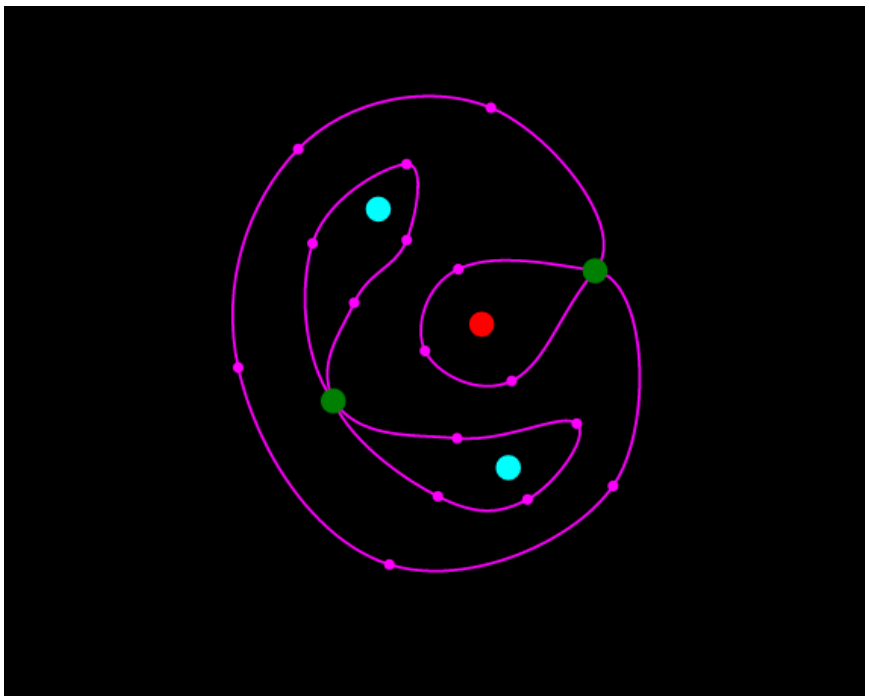


Figure: ASW0004q9e (SpaceWarps)


Arrival Time
X Direction
Y Direction



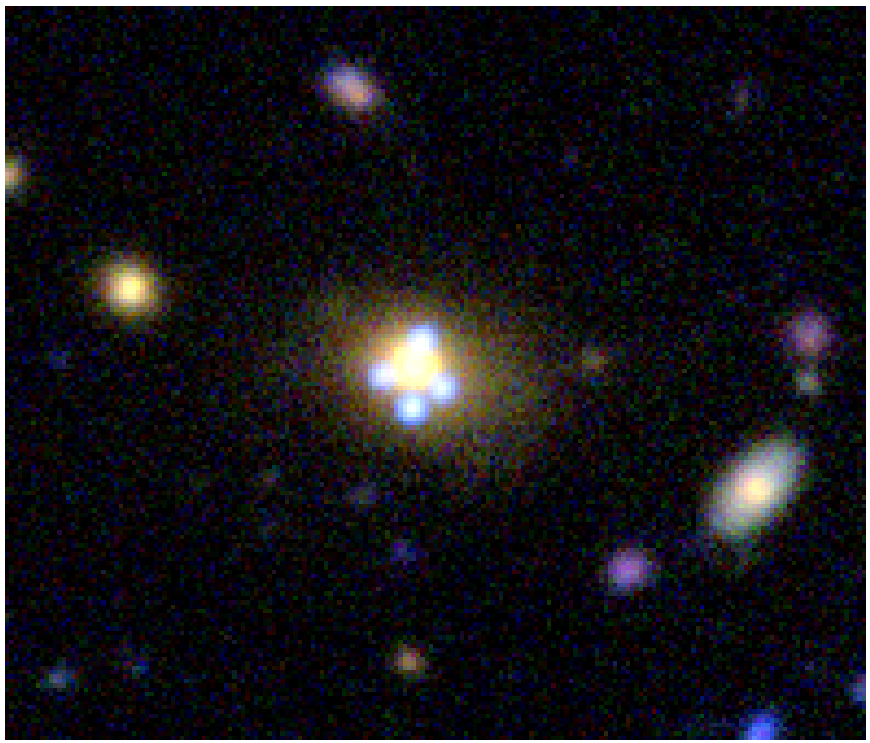
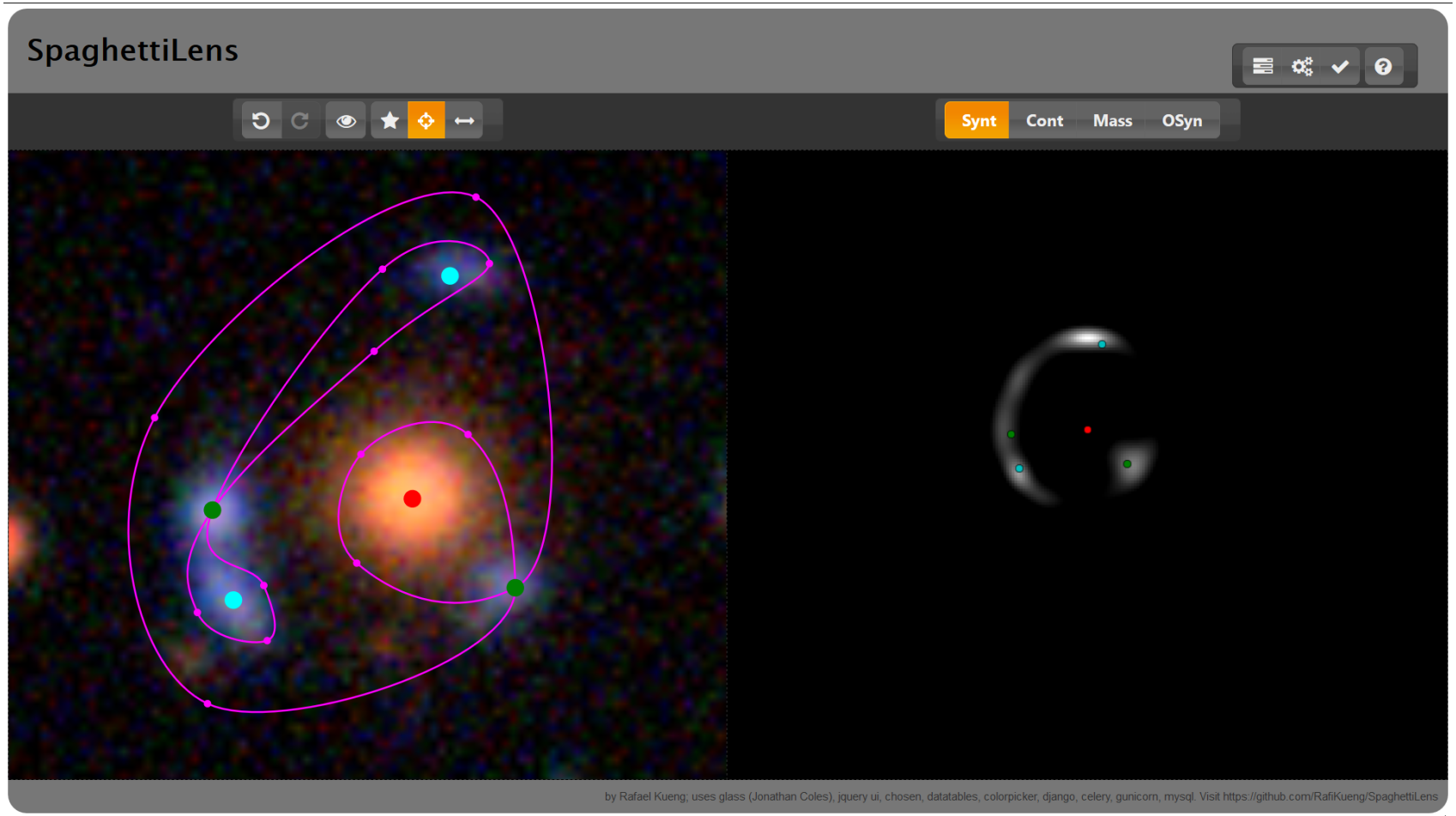


Figure: ASW0001a8c (SpaceWarps)

SpaghettiLens

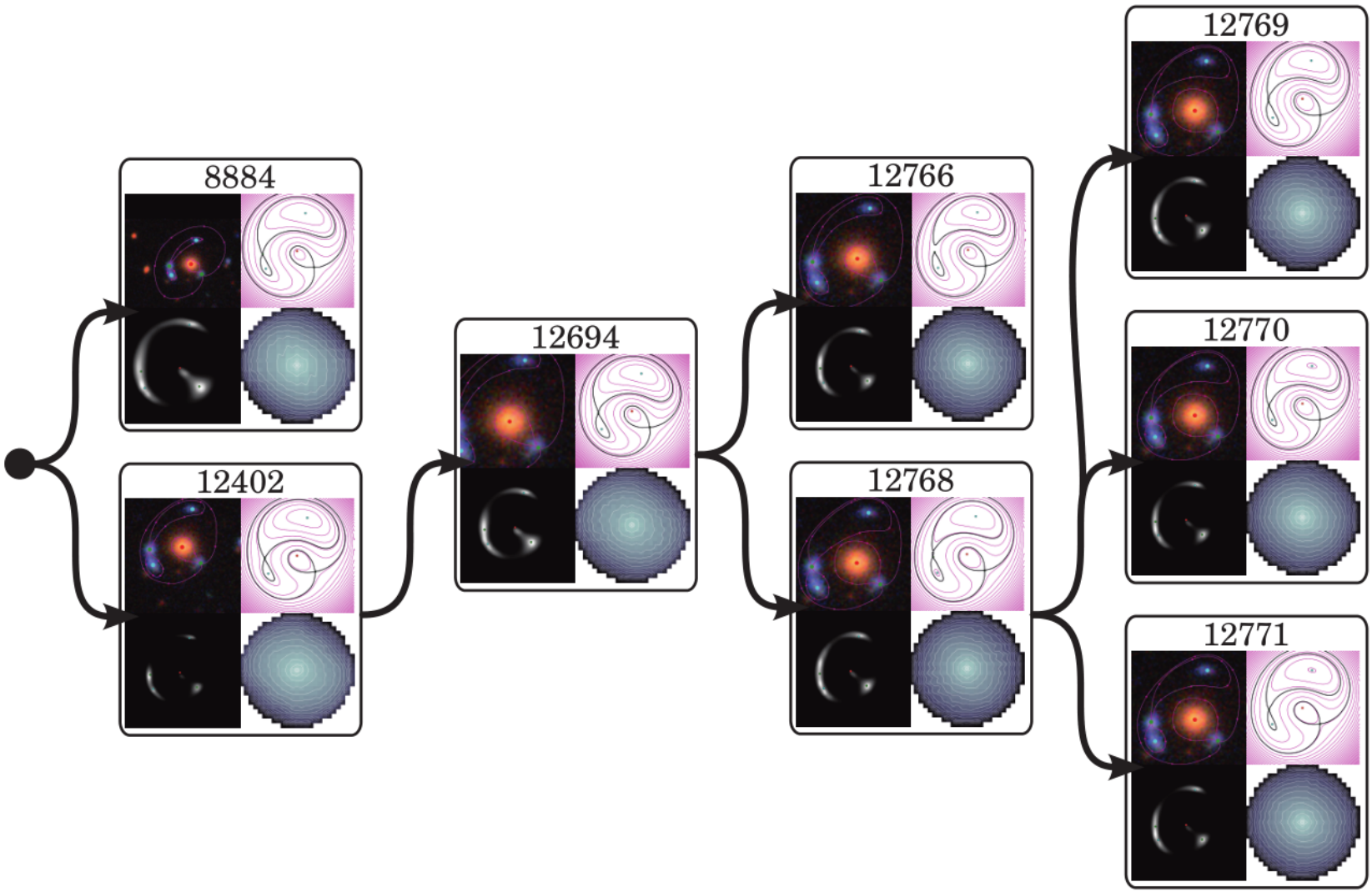
http://labs.spacewarps.org/spaghetti/



SpaghettiLens: Model Result

http://labs.spacewarps.org/spaghetti/model/AJIBCHQ6EM

SpaghettiLens: Model Tree



SpaghettiLens Results: Test of Performance

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

arxiv:1502.00008

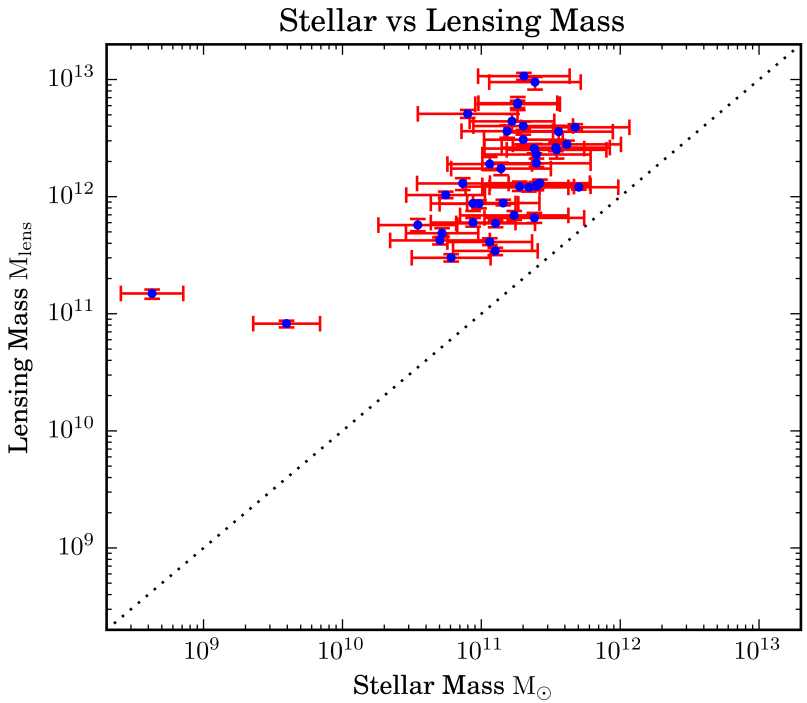
Mon. Not. R. Astron. Soc. **447**, 2170–2180 (2015) Printed February 3, 2015 (MN LATEX style file v2.2)

Gravitational Lens Modelling in a Citizen Science Context

Rafael Küng,[1] Prasenjit Saha,[1] Anupreeta More,[2] Elisabeth Baeten,[3]
Jonathan Coles,[4] Claude Cornen,[3] Christine Macmillan,[3] Phil Marshall,[5]
Surhud More,[2] Jonas Odermatt,[6] Aprajita Verma[7] and Julianne K. Wilcox[3]
[1] *Physik-Institut, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland*
[2] *Kavli Institute for the Physics and Mathematics of the Universe, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa-shi 277-8583, Japan*
[3] *Zooniverse, c/o Astrophysics Department, University of Oxford, Oxford OX1 3RH, UK*
[4] *Exascale Research Computing Lab, Campus Teratec, 2 Rue de la Piquetterie, 91680 Bruyeres-le-Chatel, France*
[5] *Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, 452 Lomita Mall, Stanford, CA 94035, USA*
[6] *Kantonsschule Zug, Lüssiweg 24, 6300 Zug, Switzerland*
[7] *Sub-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 distributions[2]
- Fit source profile to optimize resemblance to images
- Determination of photometric red shifts[3]
- Estimate stellar populations (using galfit, SExtractor)[3]
- Your idea!

[2] Lucy Oswald; University of Oxford
[3] Dominik Leier; University of Bologna

Thank you for your attention

Questions?

rafael.kueng@uzh.ch