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How space probes view eclipses, transits and occultations at syzygy

Dimitri Veras, Elmé Breedt
Department of Physics, University of Warwick, Coventry CV4 7AL, UK
(d.veras@warwick.ac.uk)
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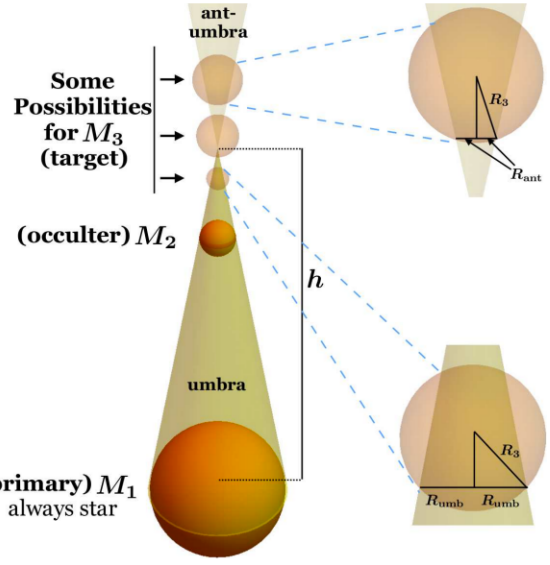
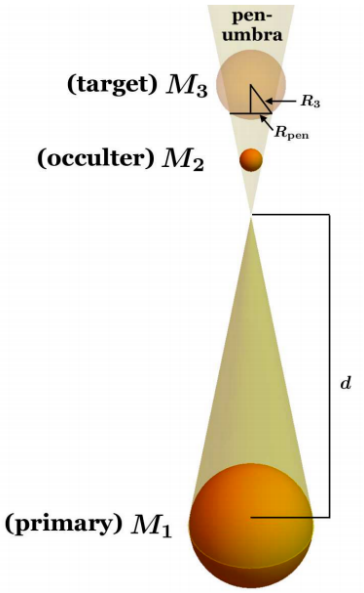
Abstract

Although conjunctions and oppositions frequently occur in planetary systems, eclipse-related phenomena are usually described from an Earth-centric perspective. Space missions to different parts of the Solar system, as well as the mounting number of known exo-planets in habitable zones and the possibility of sending featherweight robot spacecraft to them, prompt broader considerations. Here, we derive the geometry of eclipses, transits and occultations from a primarily exo-Earth viewpoint, and apply the formulation to the Solar system and three types of three-body extrasolar planetary systems: with 1 star and 2 planets (Case I), with 2 stars and 1 planet (Case II), and with 1 planet, 1 star and 1 moon (Case III). We derive the general conditions for total, partial and annular eclipses to occur at syzygy and exo-syzygy, and implement them in each case in concert with stability criteria. We then apply the formalism to the TRAPPIST-1, Kepler-444 and Kepler-77 systems -- the first of which contains multiple potentially habitable planets -- and provide reference tables of both Solar system and TRAPPIST-1 syzygy properties. We conclude by detailing a basic algebraic algorithm which can be used to quickly characterize eclipse properties in any three-body system.

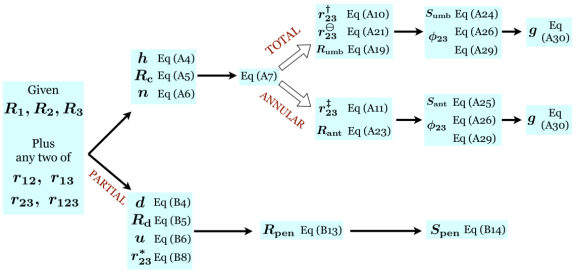




2. Specifics

In all cases, the radiation emanating from the primary will form two different types of cones with the occulter, because the latter is smaller than the former. The first type of cone, yielding total and annular eclipses, is formed from outer or external tangent lines (Figure on left). The second type of cone, yielding partial eclipses, form from the inner or internal tangent lines (Figure above). For all derivations, see [1].

As shown by the flow chart below, given the radii of the three objects in syzygy, plus any two of the distances, other relevant quantities, such as eclipse type and depth, can be derived.



This flowchart has enabled us to create tables of eclipses from various viewpoints [1], and can be used to quickly and algebraically obtain a first-order idea of what space probes sent to different bodies in the Solar system might see.

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References

[1] Veras, D., Breedt, E.: Eclipse, transit and occultation geometry of planetary systems at exo-syzygy, MNRAS, In Press, arXiv: 1703.03414.