X-ray absorption and occultation in LS 5039

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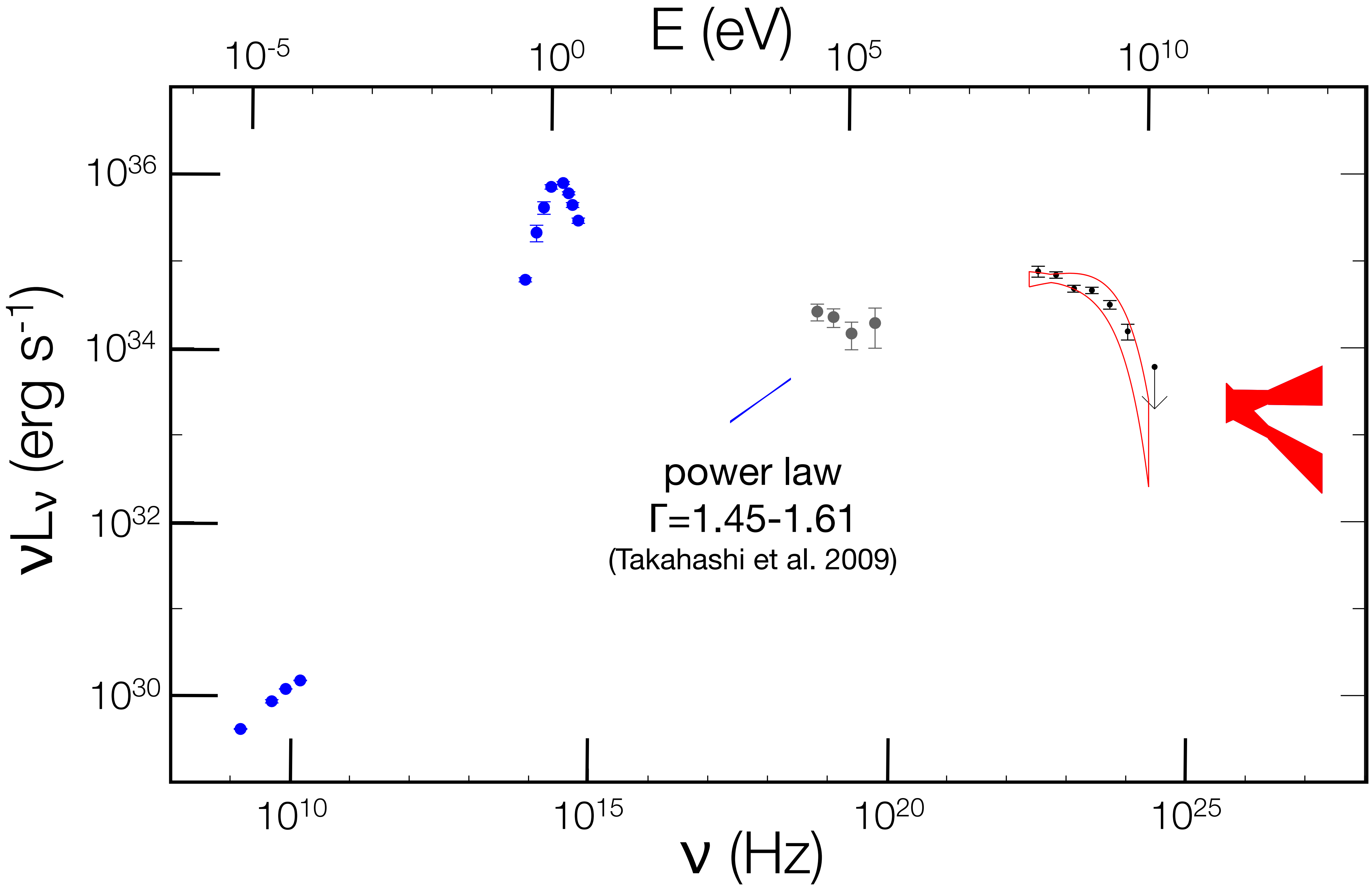
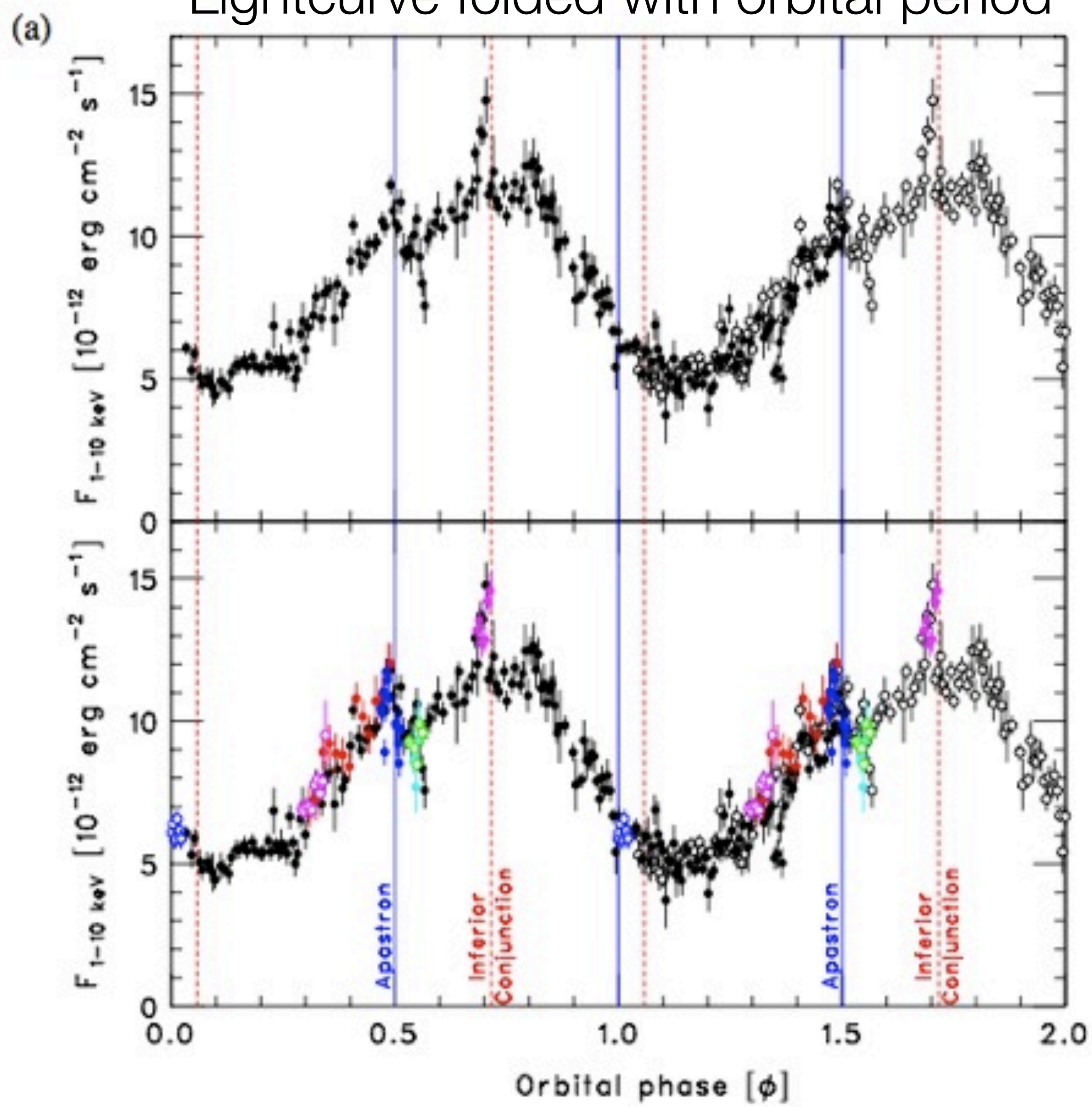
Spectral energy distribution of LS 5039

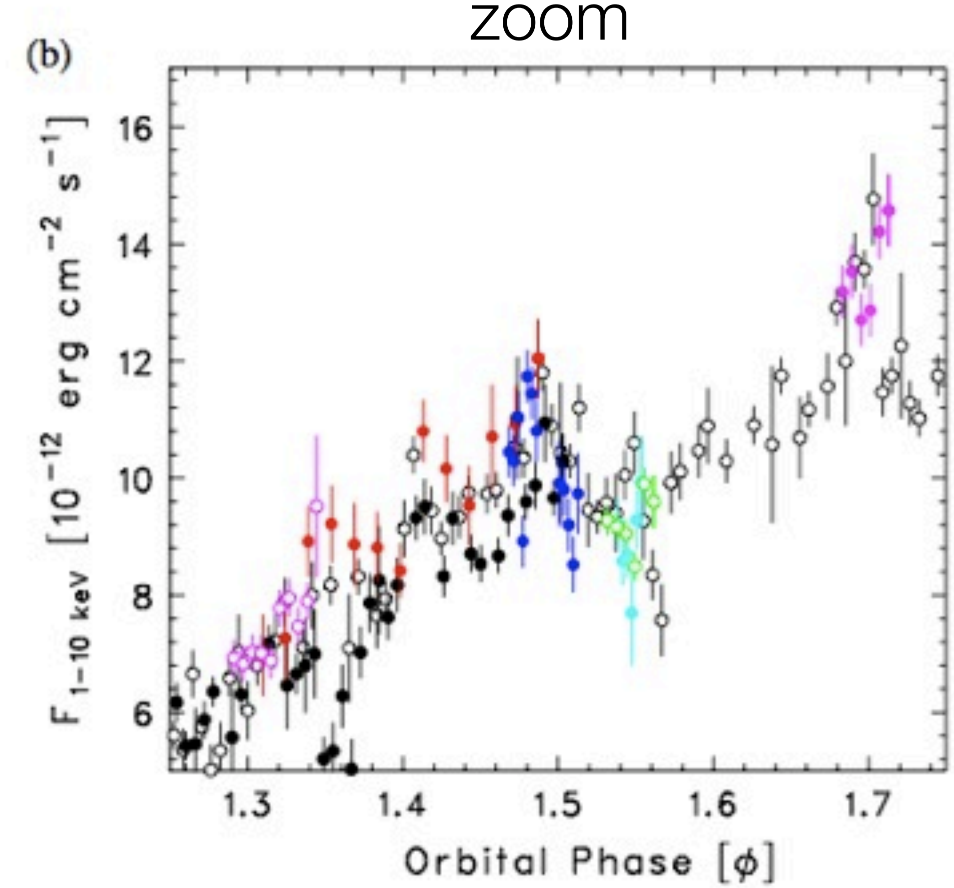


X-ray lightcurve of LS 5039 is very stable on long timescales.

Lightcurve folded with orbital period



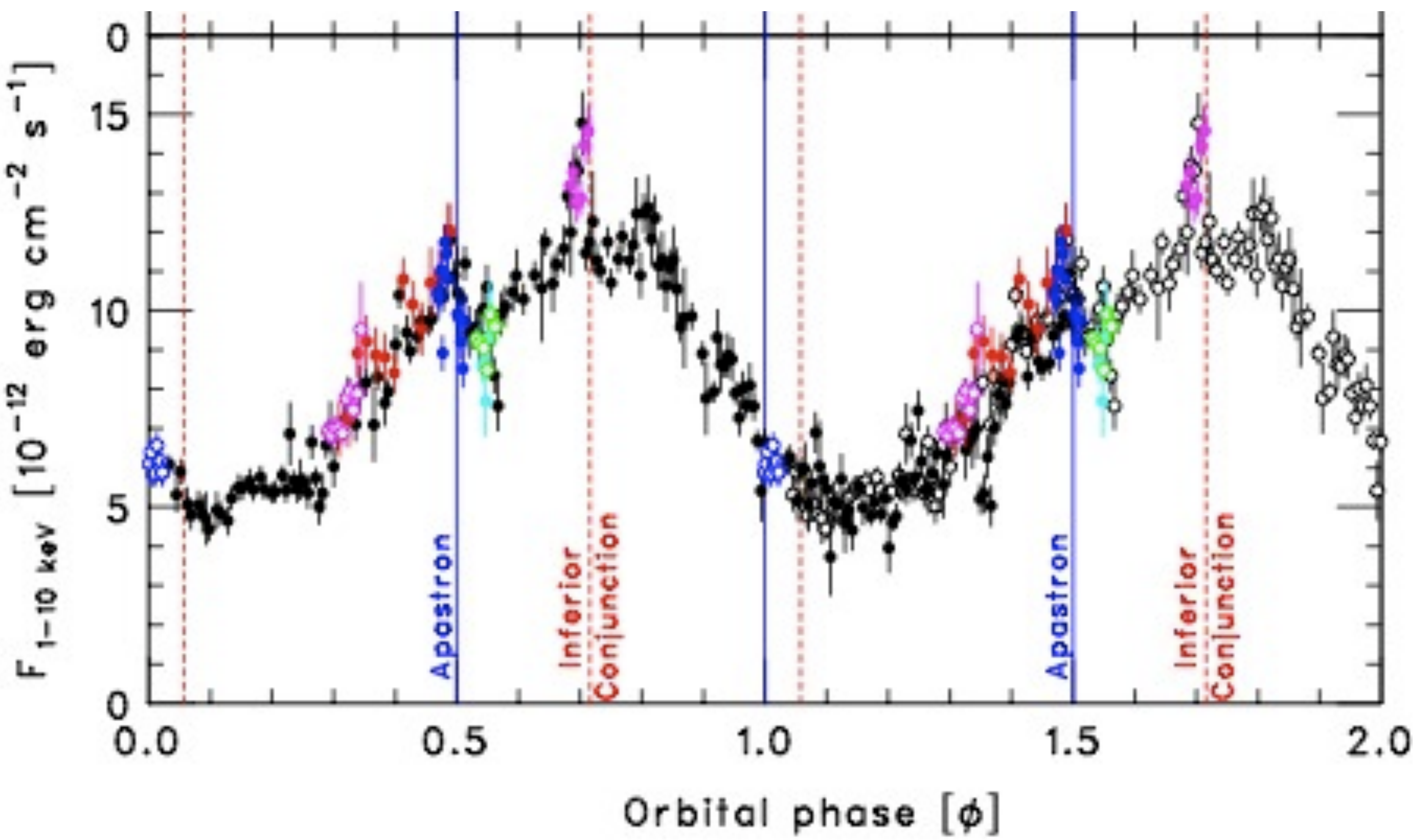
zoom



1-10 keV, 1999-2007, Kishishita et al. 2009

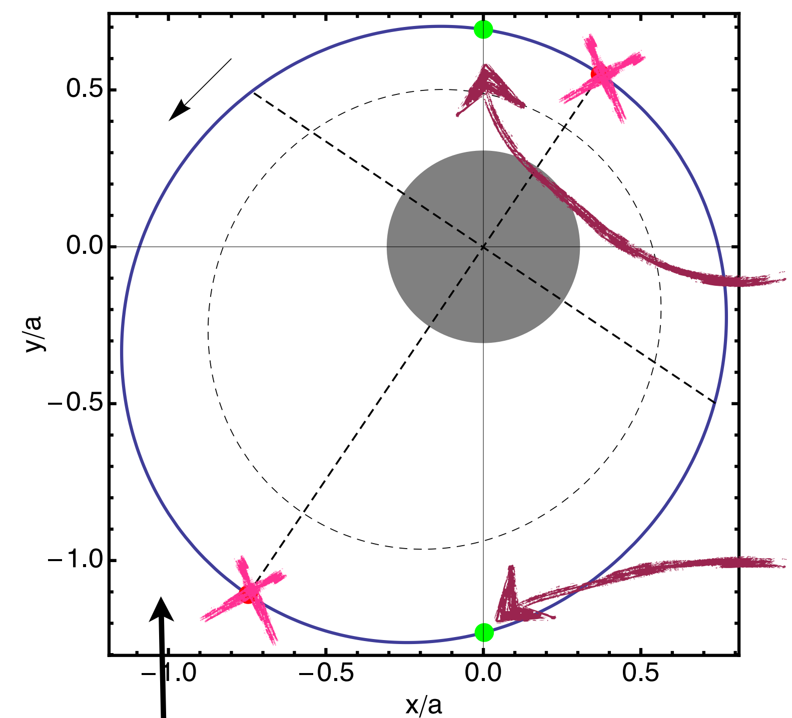
X-ray lightcurve extrema occur during conjunctions, NOT during periastron or apastron.

LS 5039 - Suzaku



Takahashi et al. 2009

LS 5039 - orbit



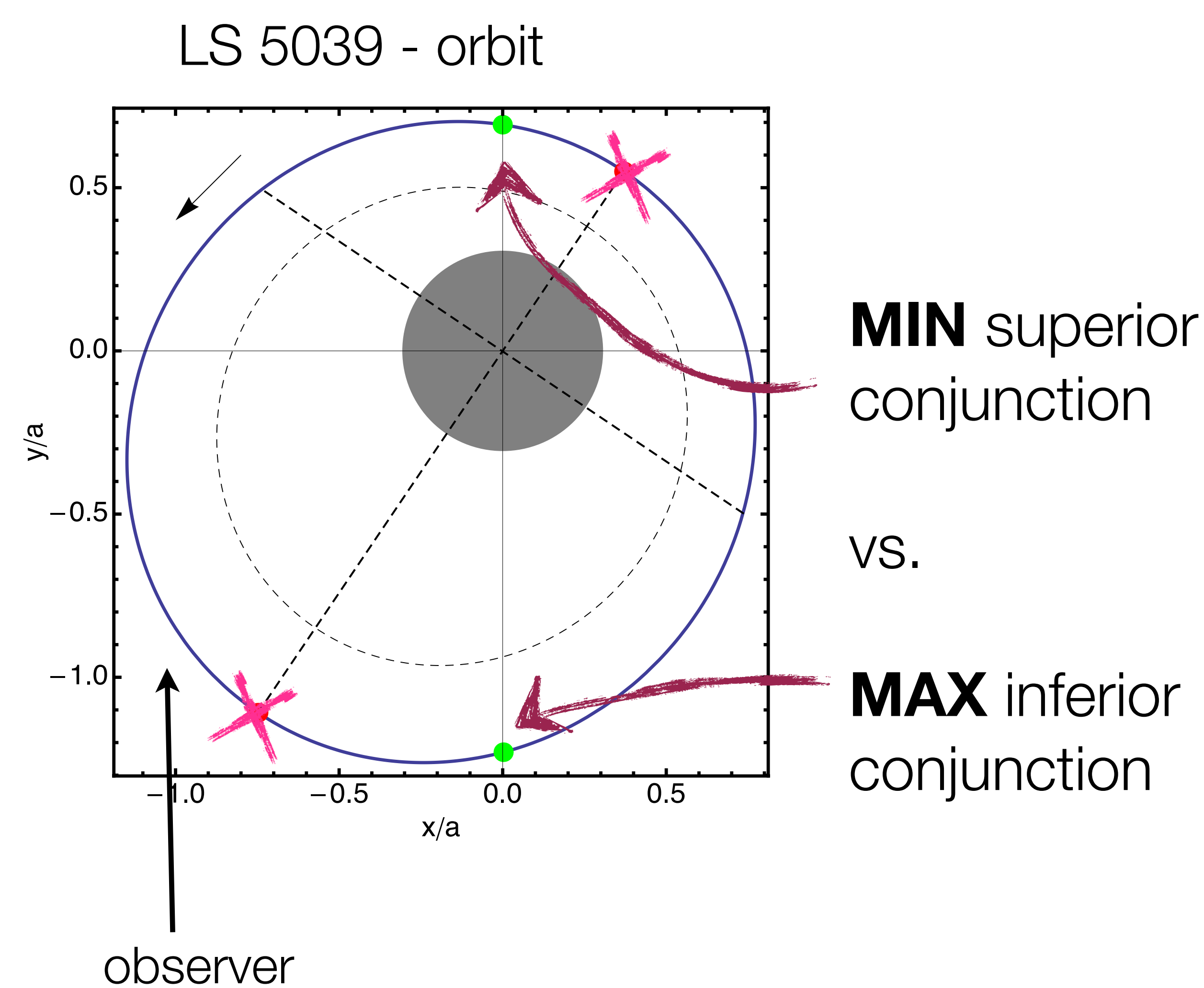
The modulation is a geometrical effect not related to physical changes when compact object travels on its orbit

Two example effects could be responsible for orbital modulation.

1. Photoelectric absorption of X-rays in the stellar wind

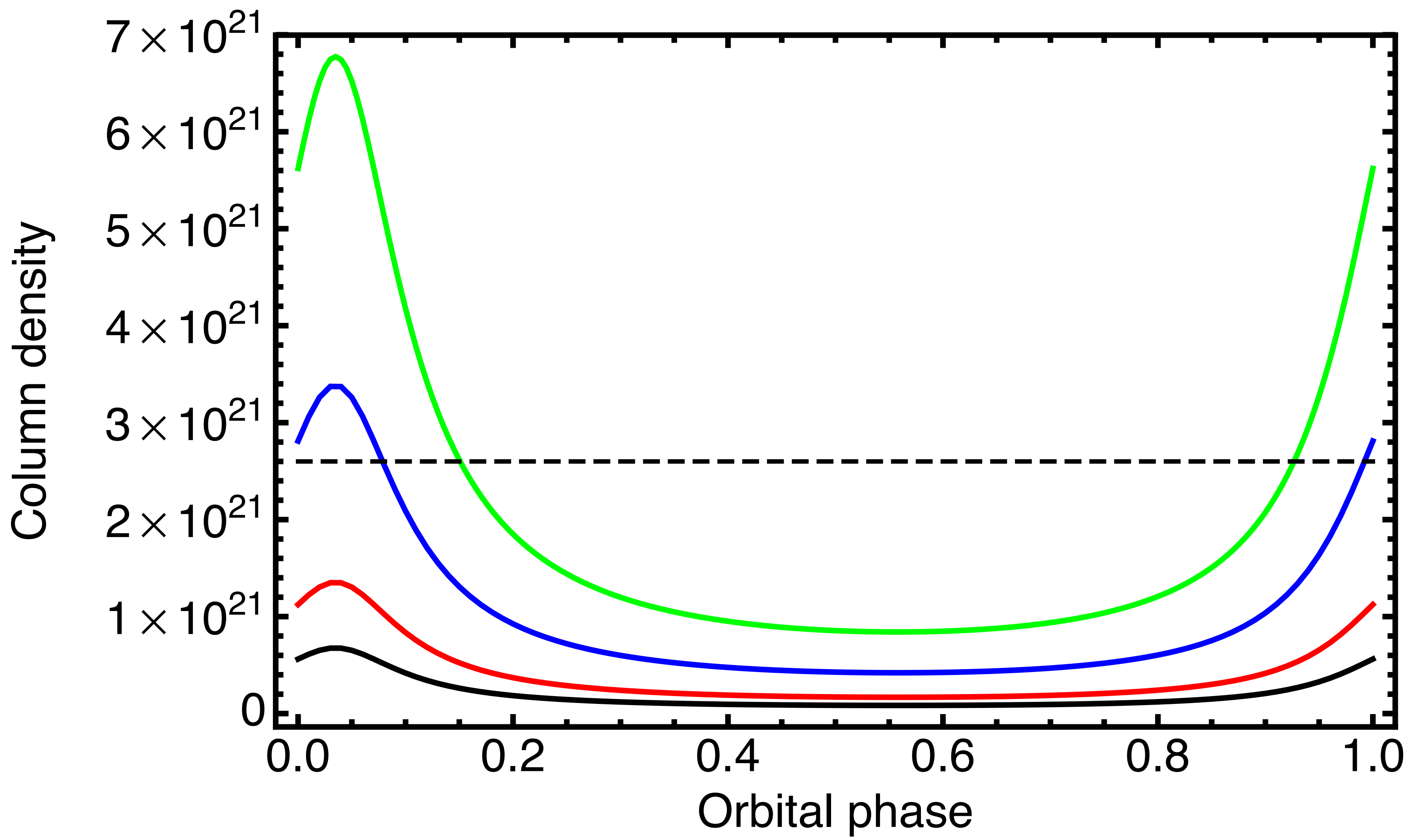
2. Occultation of X-ray emitting region by a massive star

Both produce extrema at correct orbital phases



For X-ray point source at compact object, absorption effects can be seen only around superior conjunction.

Hydrogen column density across the stellar wind



at $i = 40^o$

$\dot{M} = 10^{-8}\ M_\odot\ yr^{-1}$

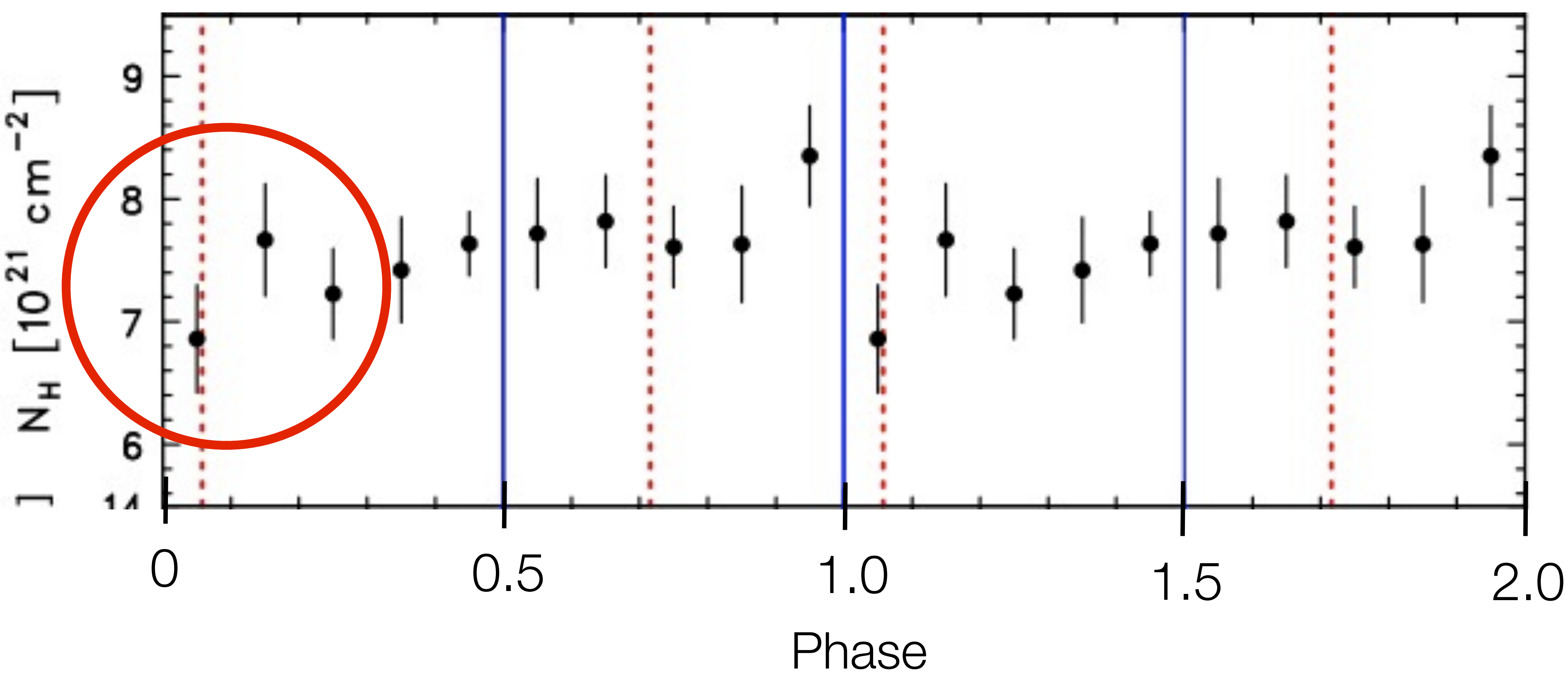
$\dot{M} = 2 \times 10^{-8}\ M_\odot\ yr^{-1}$

$\dot{M} = 5 \times 10^{-8}\ M_\odot\ yr^{-1}$

$\dot{M} = 10^{-7}\ M_\odot\ yr^{-1}$

In LS 5039 absorbing column density N_H does not change with orbital phase.

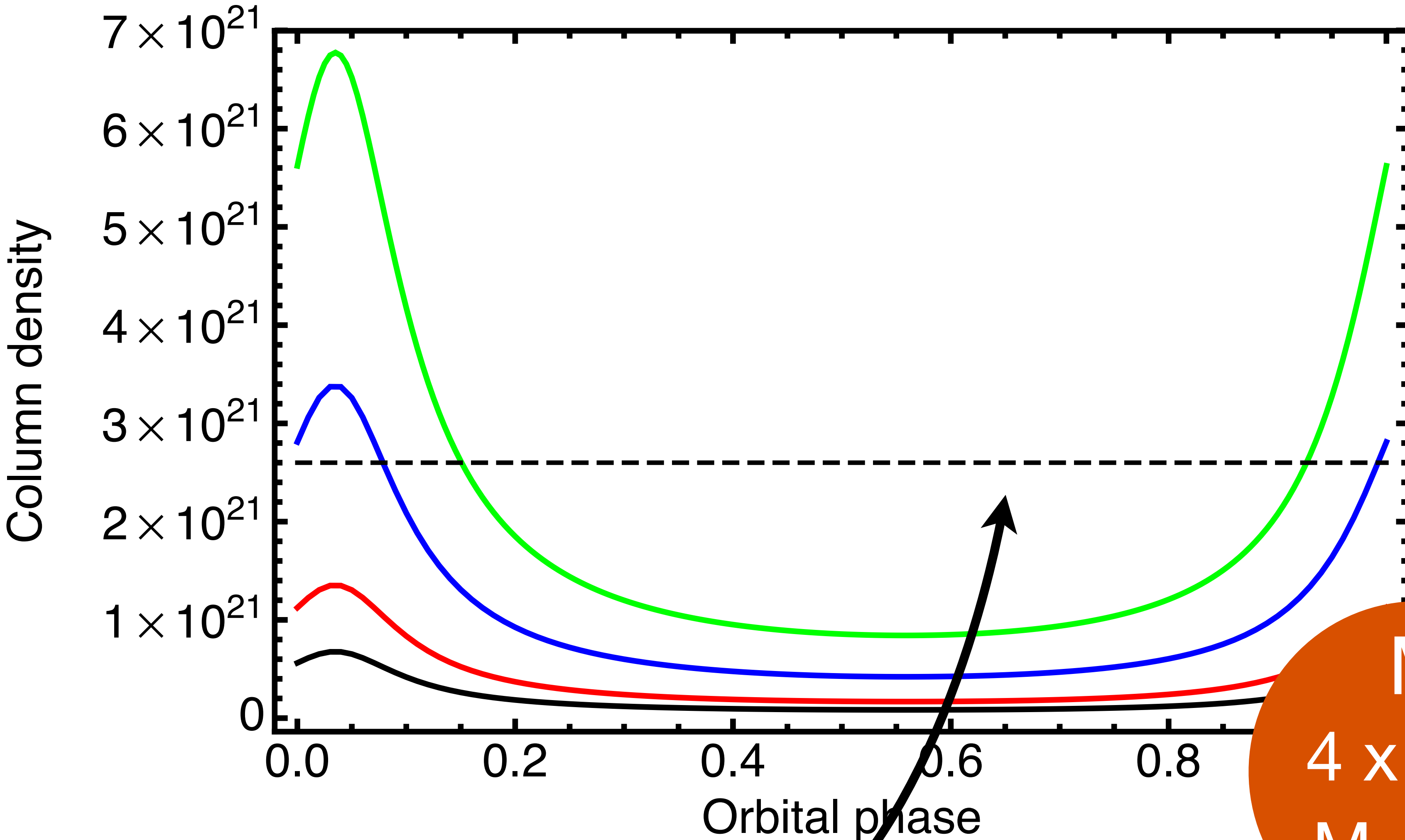
Best fit N_H to Suzaku spectra



Takahashi et al. 2009

Taking into account absorption in ISM,
upper limit on intrinsic column density
$N_H^{max} = 2.6 \times 10^{21}$ cm^{-2}
(Bosch-Ramon et al. 2007, Takahashi et al. 2009)

For X-ray point source at compact object, mass-loss rate upper limit is low, ~ 4 x 10^{-8} $M_\odot$ yr^{-1}.



at i = 40°

$\dot{M}$ = 10^{-8} $M_\odot$ yr^{-1}
$\dot{M}$ = 2 x 10^{-8} $M_\odot$ yr^{-1}
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$\dot{M}$ = 10^{-7} $M_\odot$ yr^{-1}

$\dot{M}$
4 x 10^{-8}
$M_\odot$ yr^{-1}

$\dot{M}$ at lower end for Galactic O stars
(~10^{-8} - 10^{-6} $M_\odot$ yr^{-1})
(Mokiem et al. 2007)

Upper limit on intrinsic column density
N_H^{max} = 2.6 x 10^{21} cm^{-2}
(Bosch-Ramon et al. 2007, Takahashi et al. 2009)

$\dot{M}$ for LS 5039 in literature
3 x 10^{-8} - 7.5 x 10^{-7} $M_\odot$ yr^{-1}
(McSwain & Gies 2002; Casares et al. 2005)

There is also no evidence for occultation in LS 5039

From the absence of X-ray eclipses
Upper limit on binary inclination is

65^o

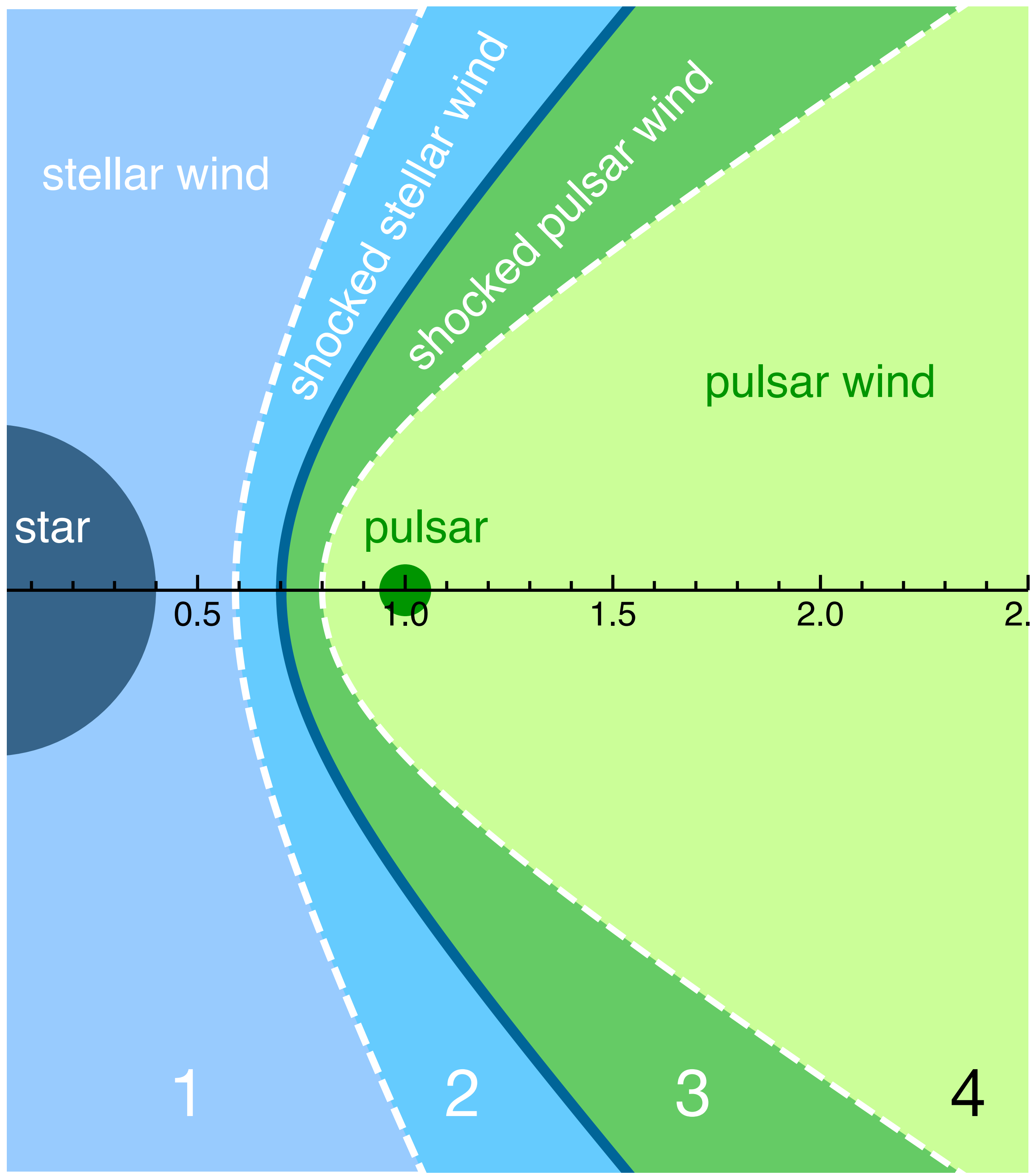
(Casares et al. 2005)

If the X-ray source is extended, the strict limits on $\dot{M}$ and binary inclination are not valid anymore.

Motivation

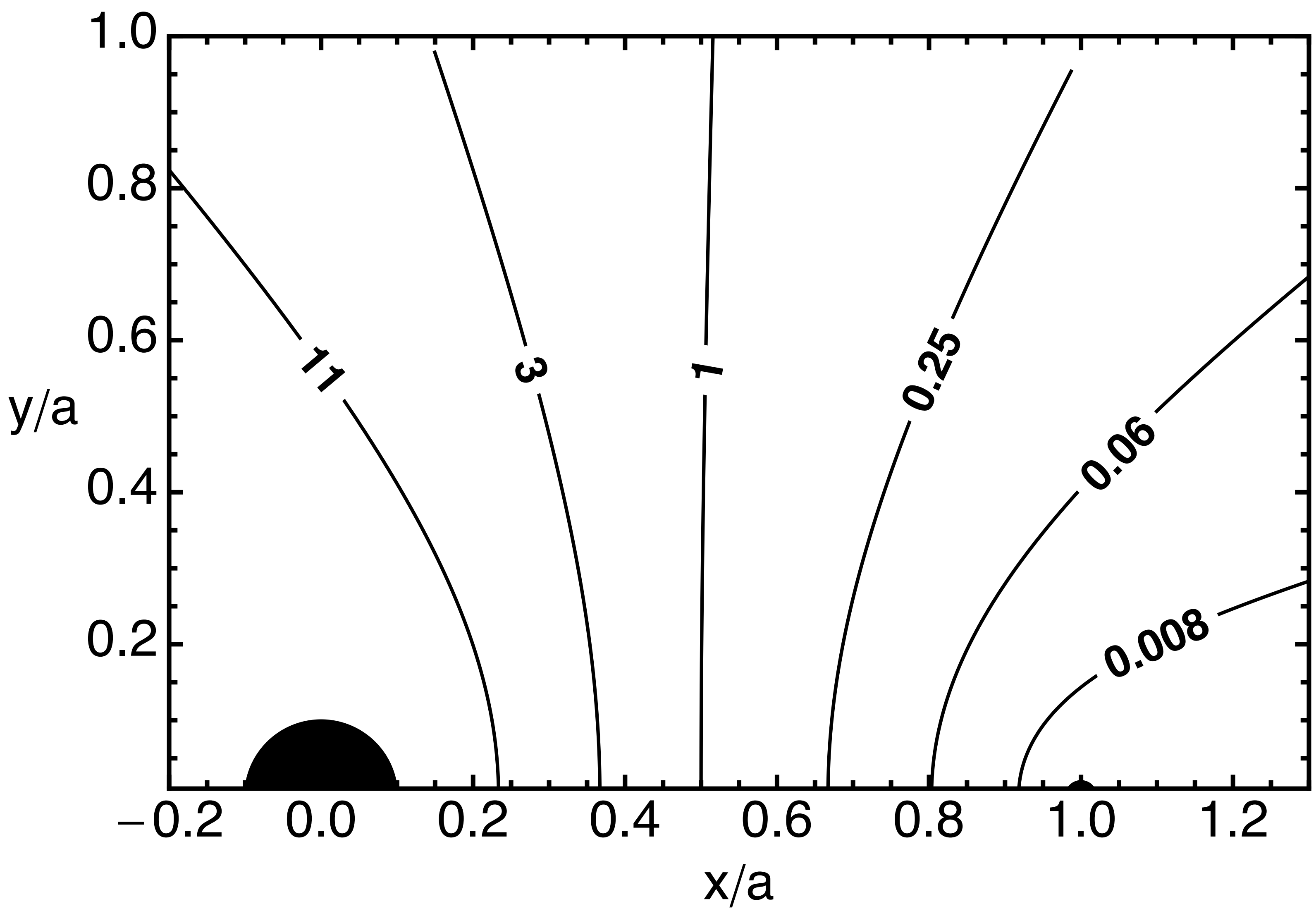
To derive constraints on the binary parameters from the lack of absorption and occultation signatures in the observed lightcurves and assuming the X-ray source is extended.

We created a toy model of LS 5039 in the framework of pulsar wind scenario.



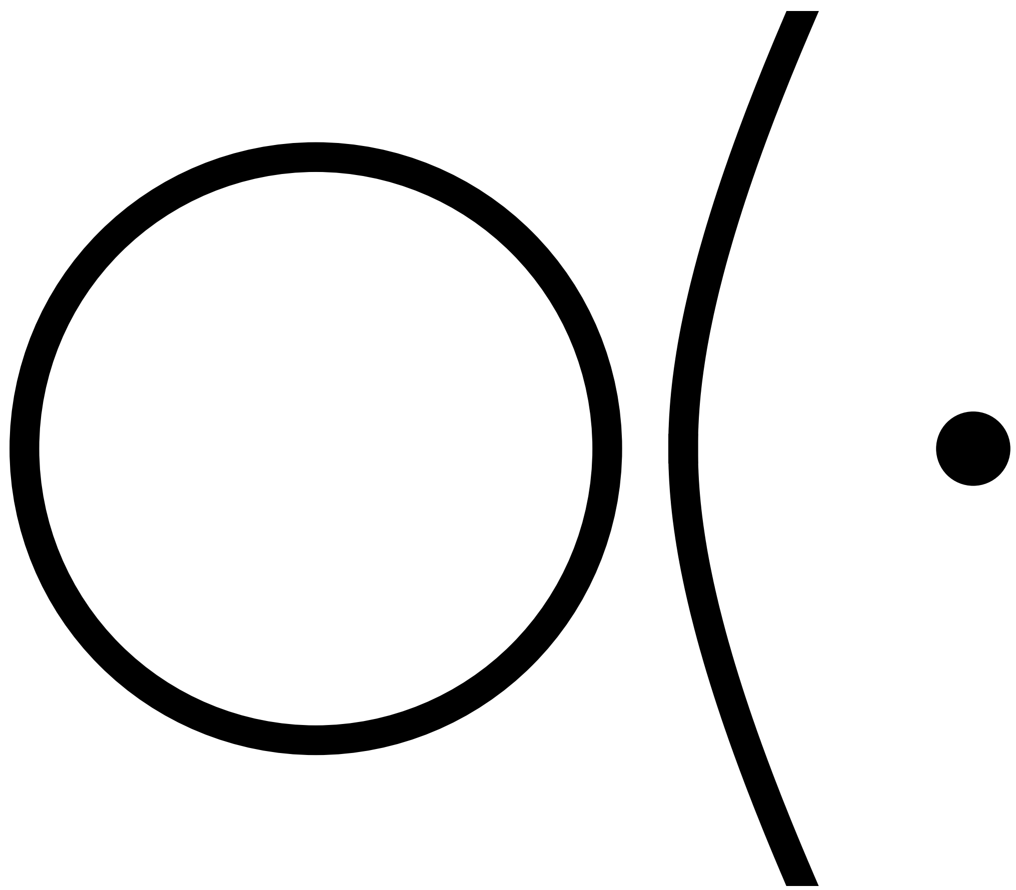
In general, shape of the CD is parametrized by parameter η_0

$$\eta_0 = \eta(R_s, a - R_s) = \frac{\dot{E}}{\dot{M} v(R_s) c} = \frac{(a - R_s)^2}{R_s^2}$$



If $\dot{E}$ is to large, the pulsar wind impacts the star surface, just like in black widow pulsars.

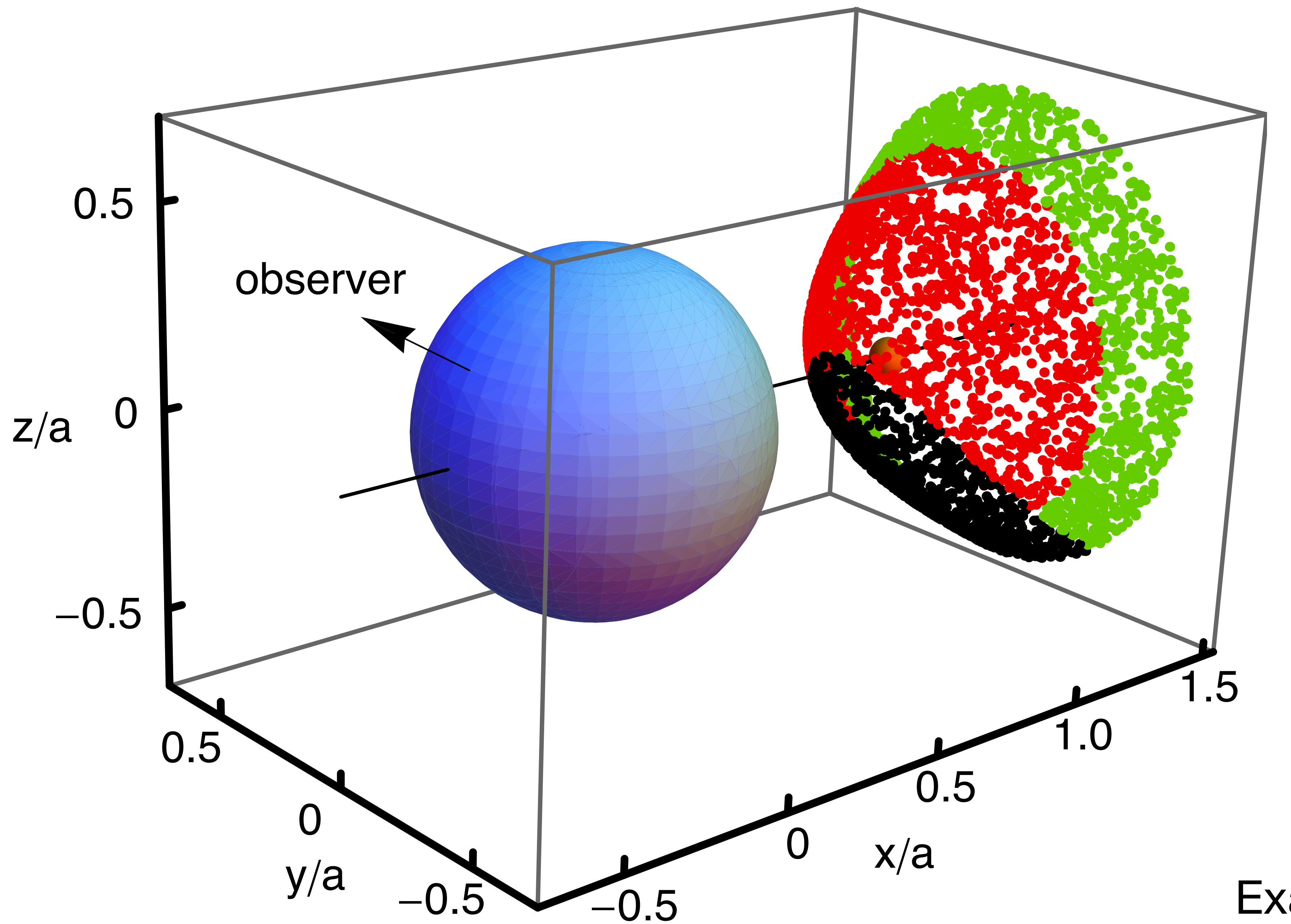
Assuming it does not happen: in LS 5039 η_0 never exceeds 0.6. CD opening angle < 62^o



For a range of $\dot{M}$,

$\dot{E}$max = 1.5 x 10^{36} erg s^{-1} - 3.8 x 10^{37} erg s^{-1}

A 3D model of an extended X-ray source.



Example
SUPC, i=45°, η_0=0.1

Absorption study

In the model absorption depends on $\dot{M}$, i, η_0, R_{out} (size of X-ray emission region)

Assumption: the observational data (point vs. extended source) are not distinguished by spectral fitting (e.g. xspec) if equal at 1 keV

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$$\frac{1}{N}\sum_{j=1}^{N}\exp[-\sigma(1\mathrm{keV})N_{\mathrm{H}j}(i,\phi)] = \exp[-\sigma(1\mathrm{keV})N_{\mathrm{H}}^{\mathrm{max}}]$$

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Absorption of 1 keV photons from a point source by the not ionized homogeneous cloud with $N_H^{max} = 2.6 \times 10^{21}$ cm^{-2}

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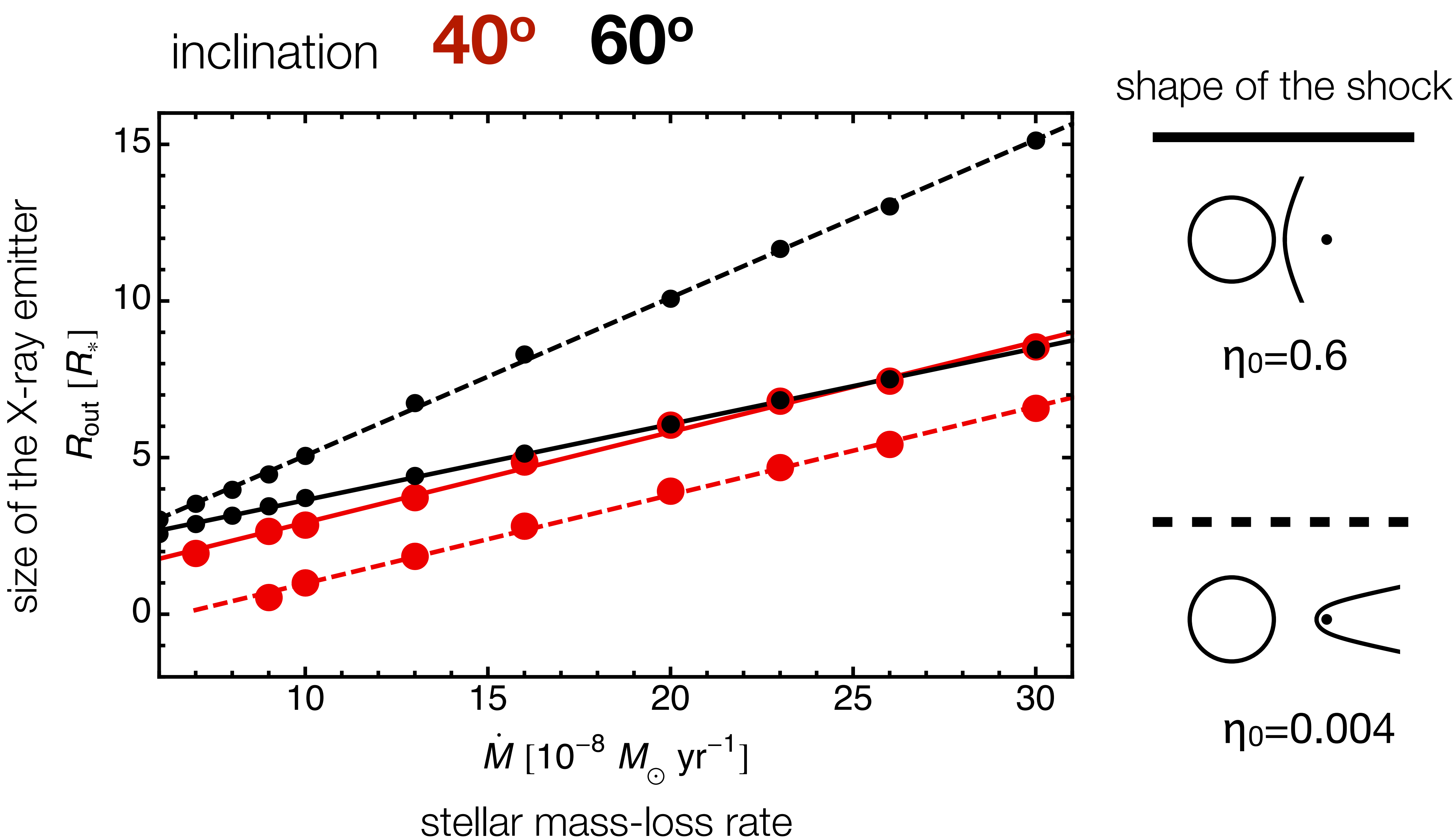
Exact absorption of a 3D source in the not ionized stellar wind at SUPC at 1 keV

Absorption of 1 keV photons from a point source by the not ionized homogeneous cloud with $N_H^{max} = 2.6 \times 10^{21}$ cm^{-2}

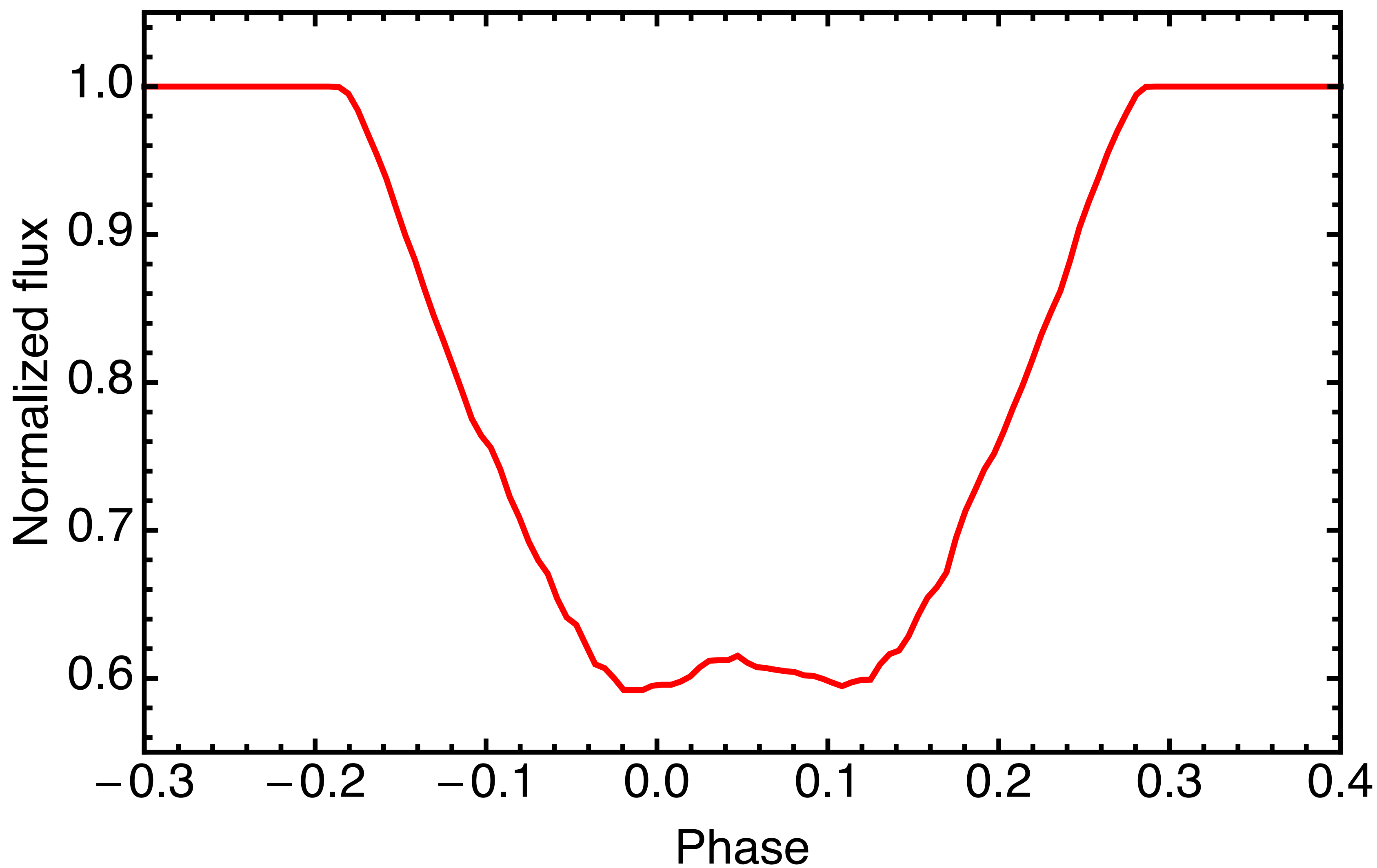
Estimate based on absorption limit:
The higher the $\dot{M}$ the larger the emitter size



Occultation study

In the model occultation depends on:
i, η_0 , R_{out}

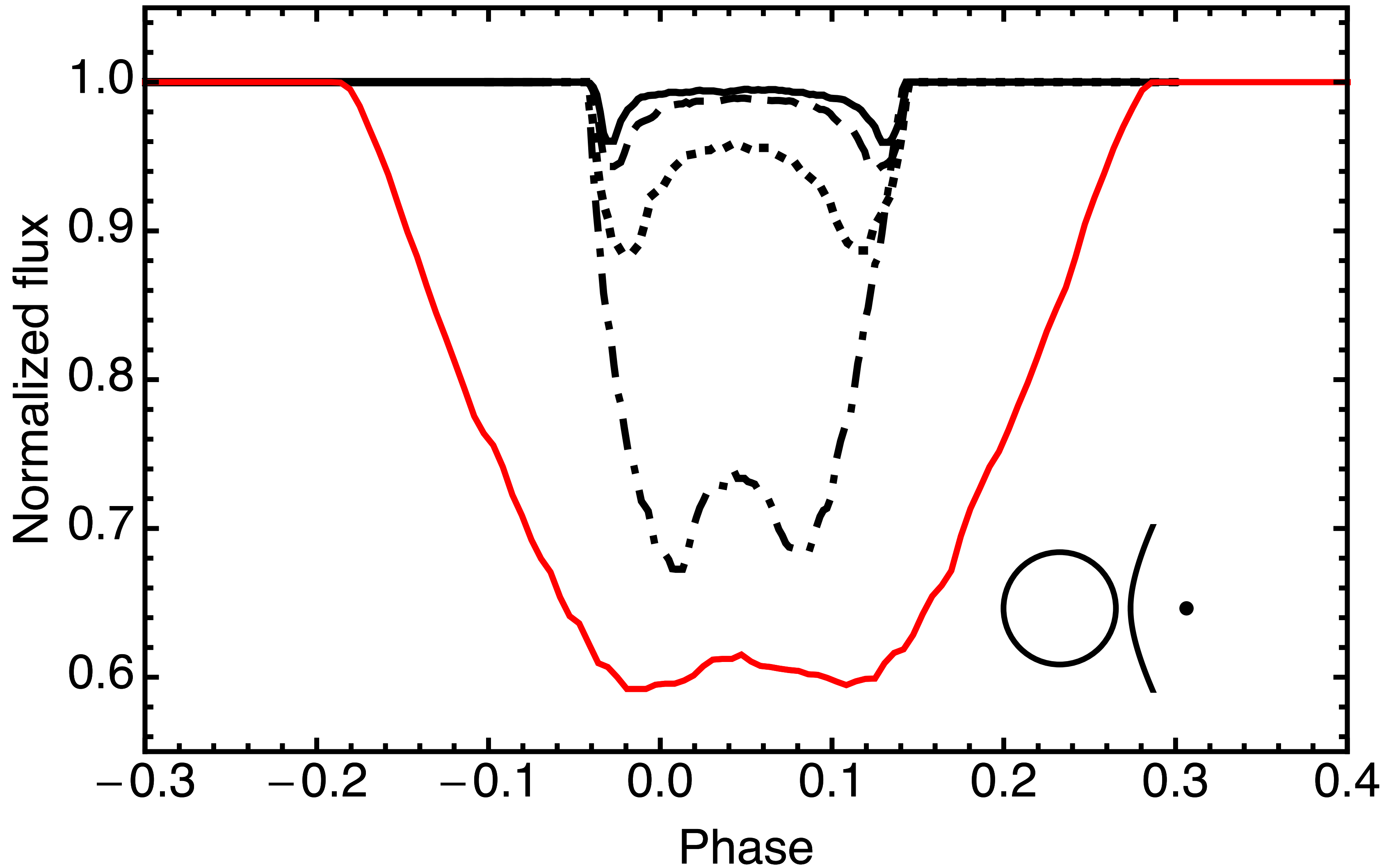
For example: circular orbit, η_0>1



In the model occultation depends on:
i, η_0 , R_{out}

Occultation in LS 5039, in the most favorable condition

η_0=0.6, i=60°, R_{out} = 2R★, 5R★,10R★, 15R★

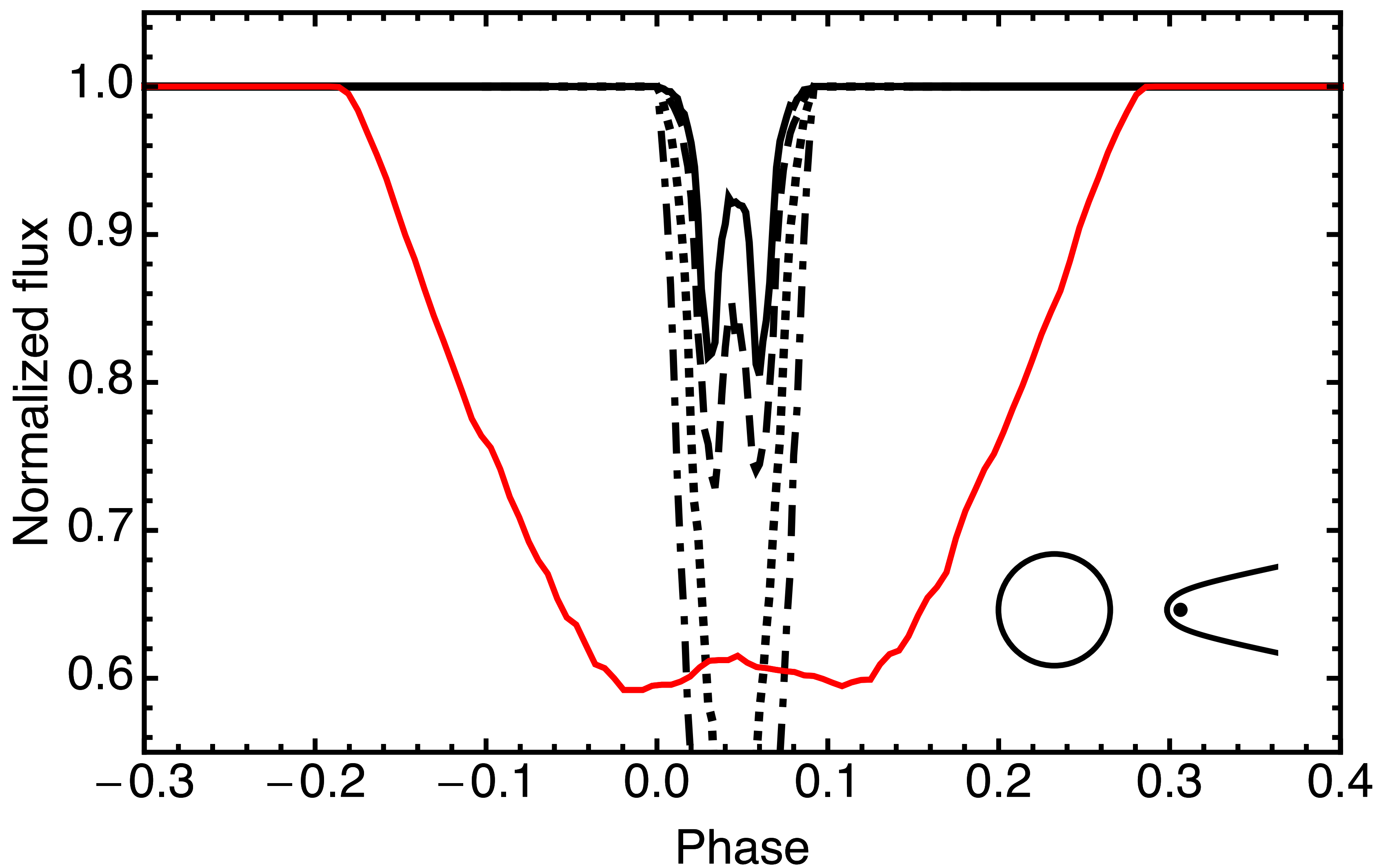


Workshop, Variable Galactic Gamma-Ray Sources, Heidelberg, 30.11-3.12.2010

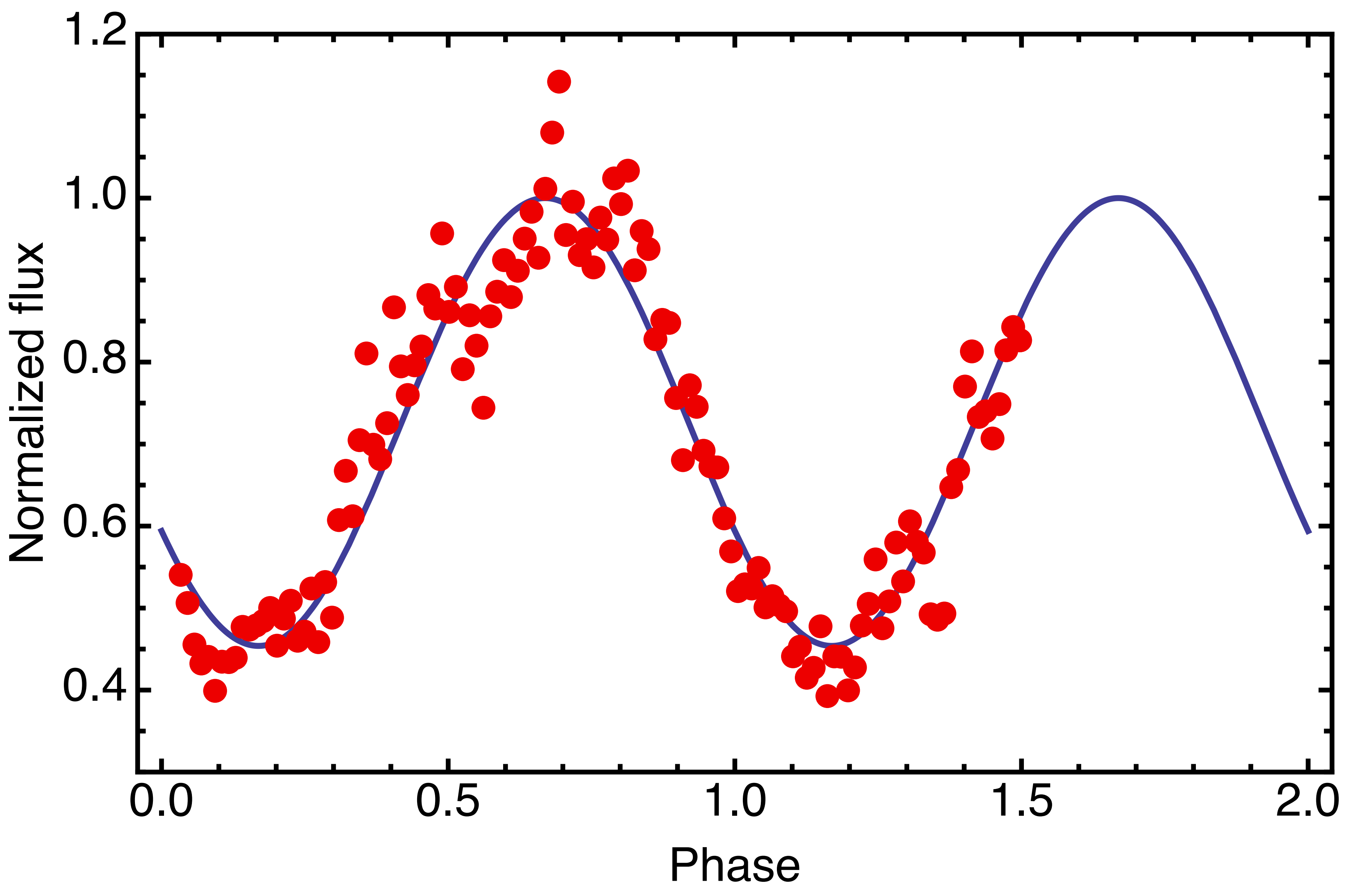
In the model occultation depends on:
i, η_0, R_{out}

Occultation in LS 5039, the less favorable condition

η_0=0.004, i=90°, R_{out} = 2R★, 5R★,10R★, 15R★



We assume 3 sigma upper limit on the depth of occultation dip.



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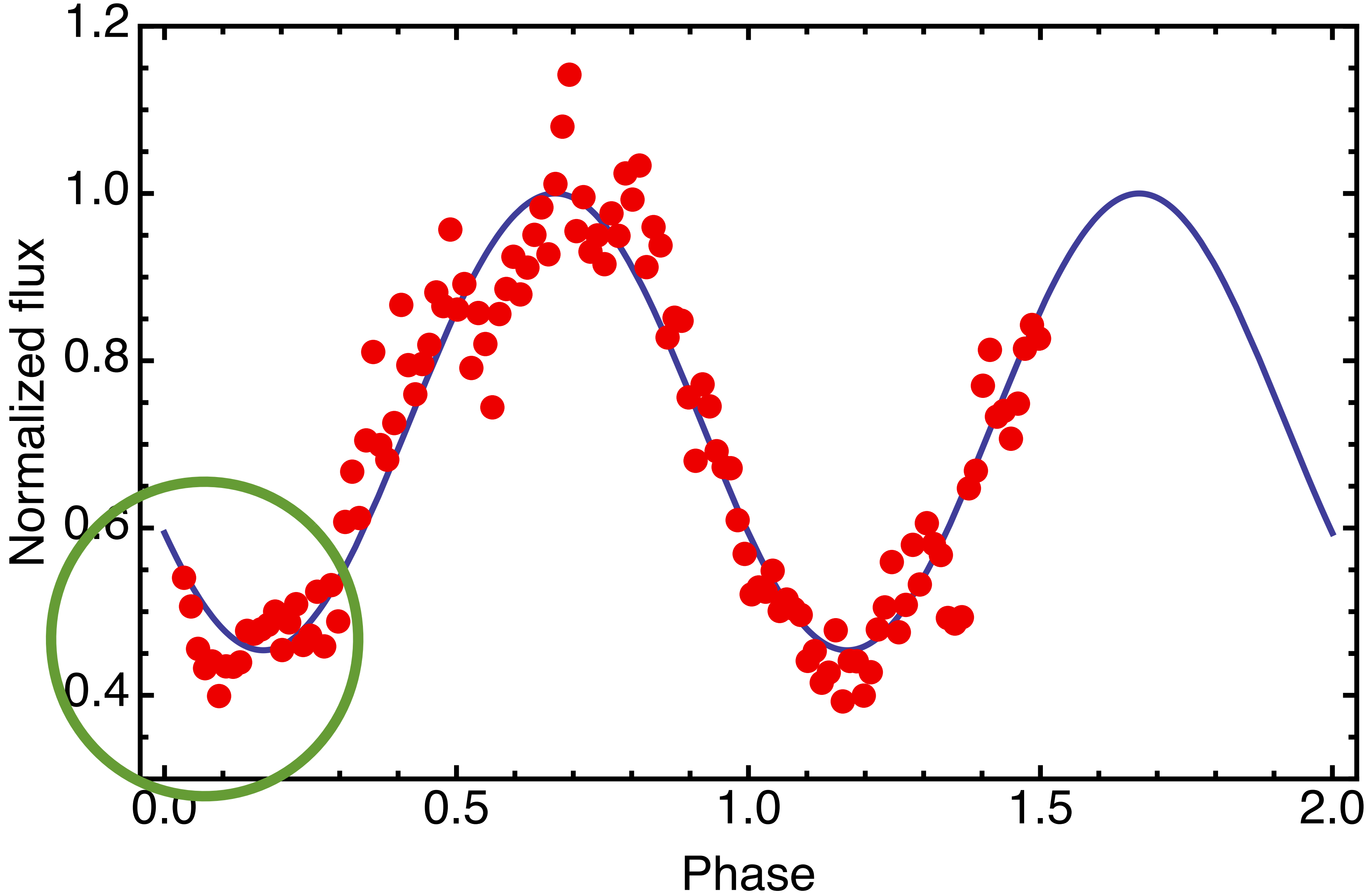

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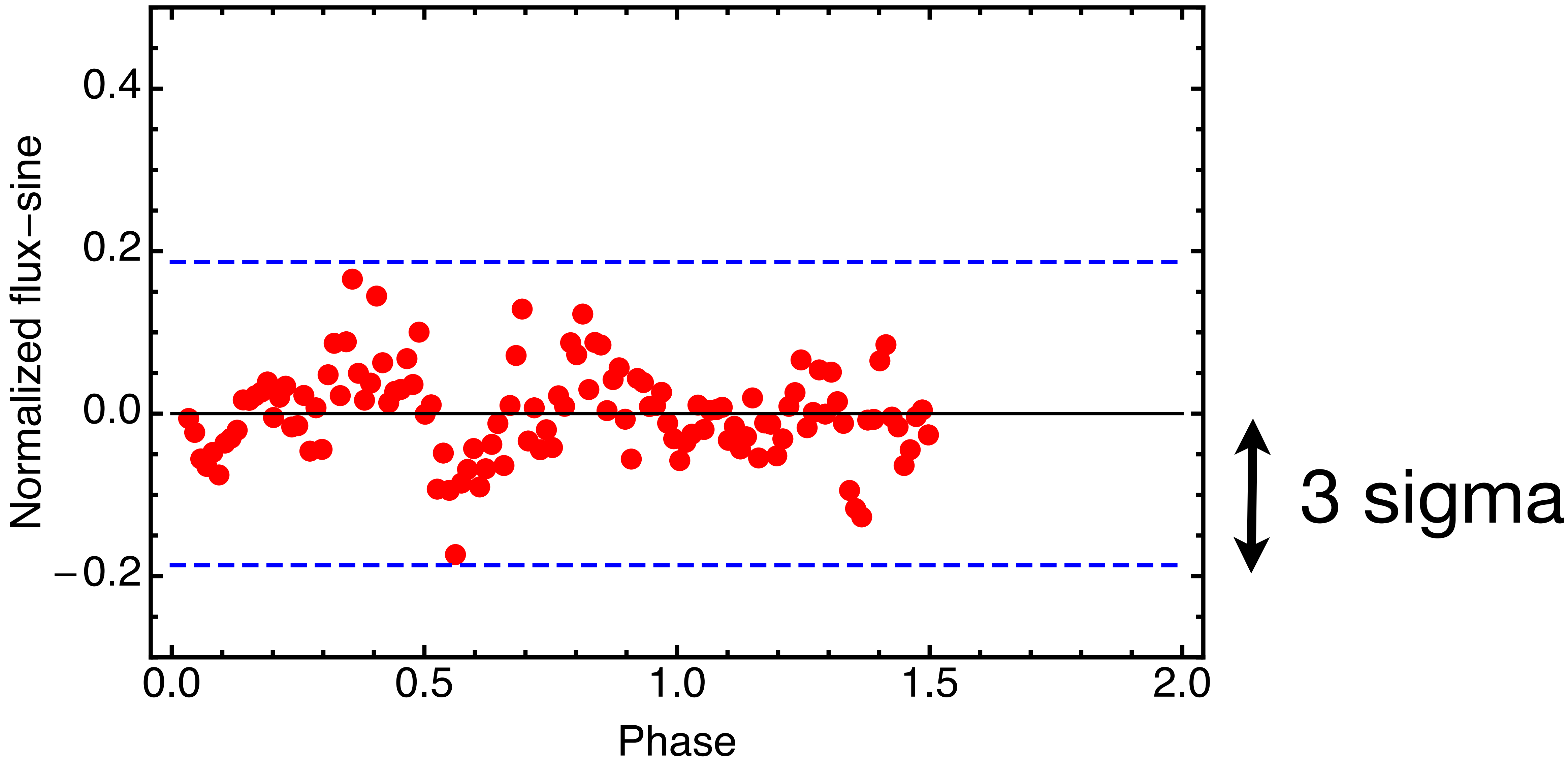
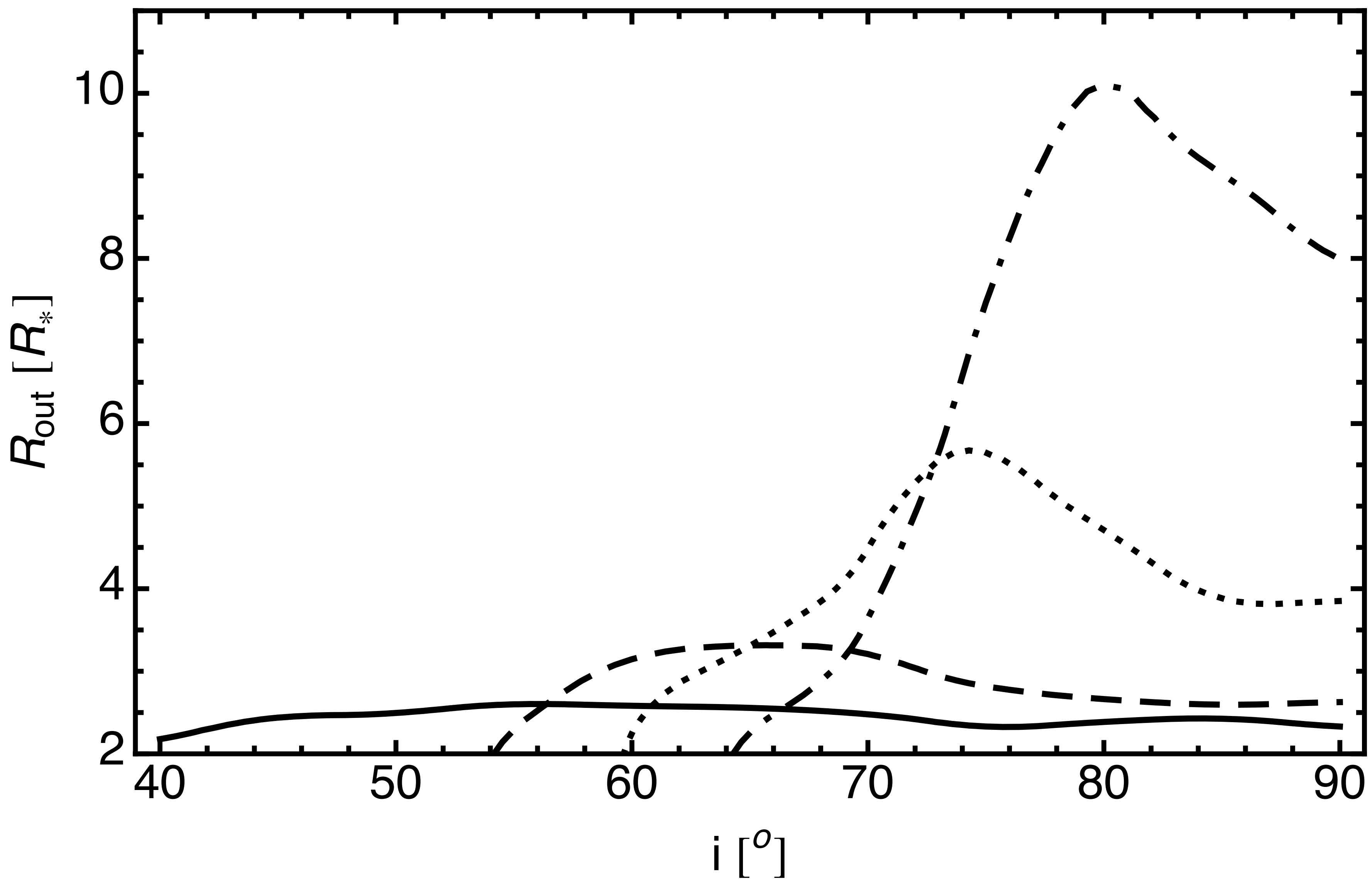


Occultation for different η_0

Allowed emitter size is above each curve



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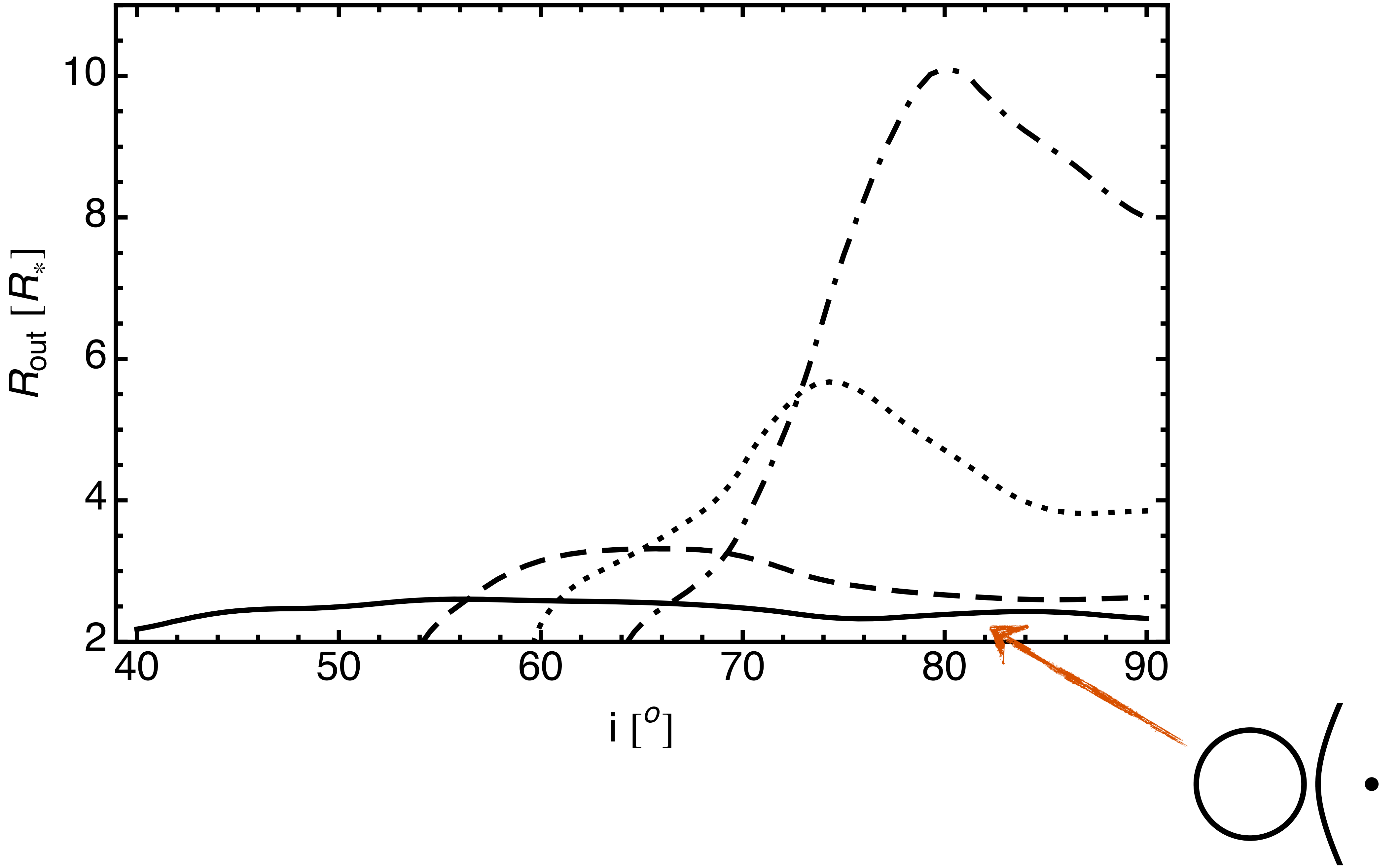

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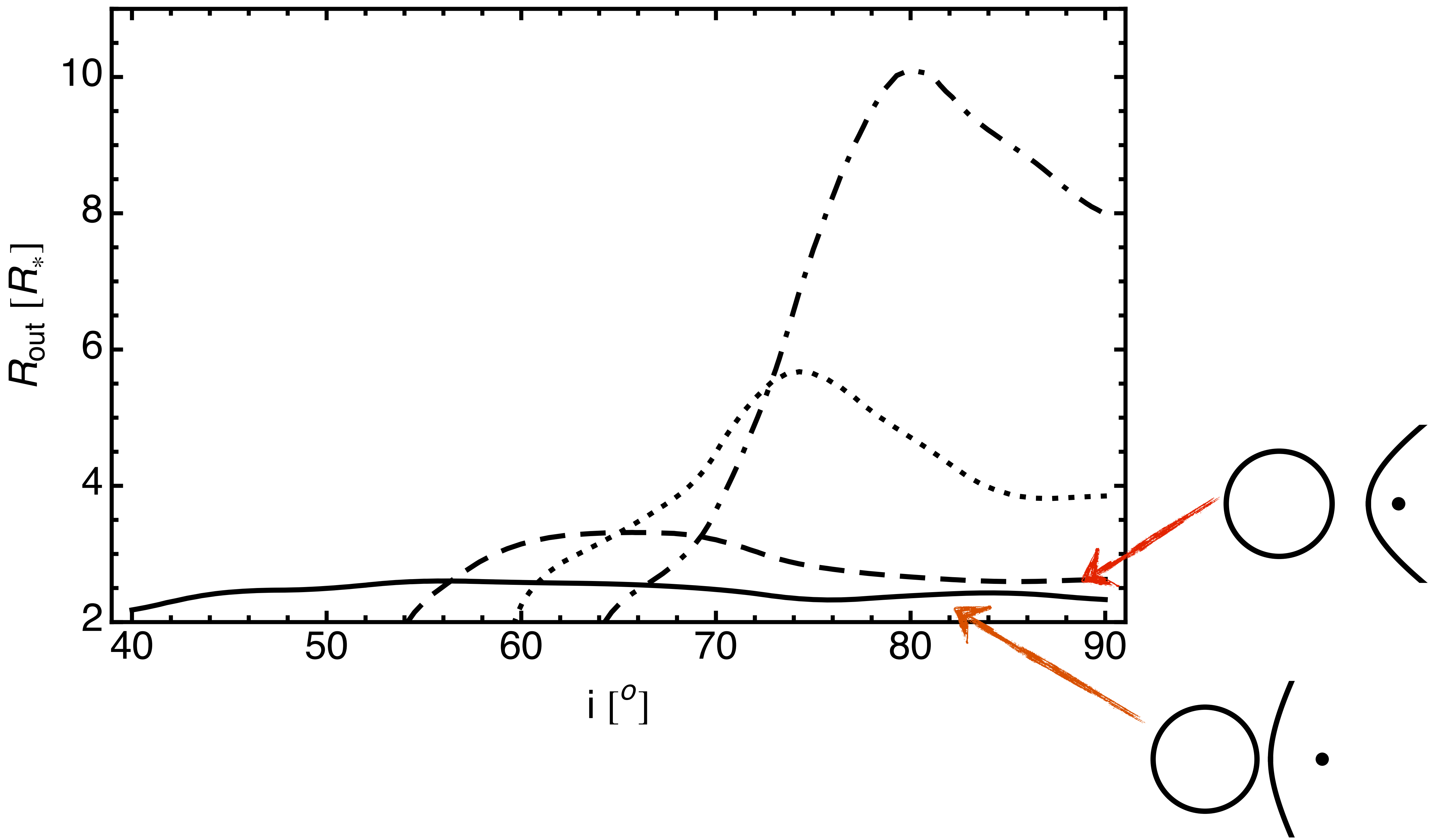

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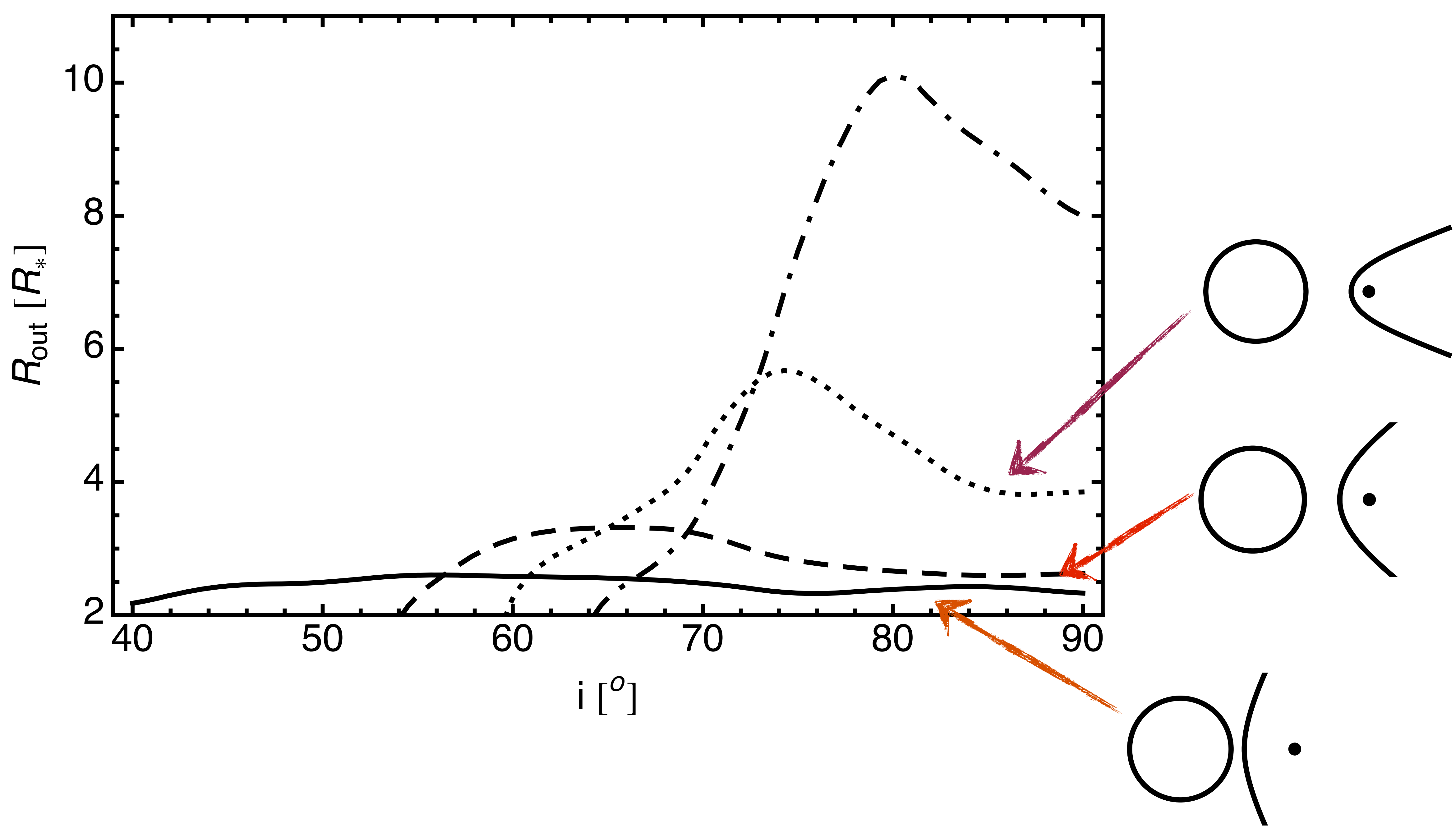

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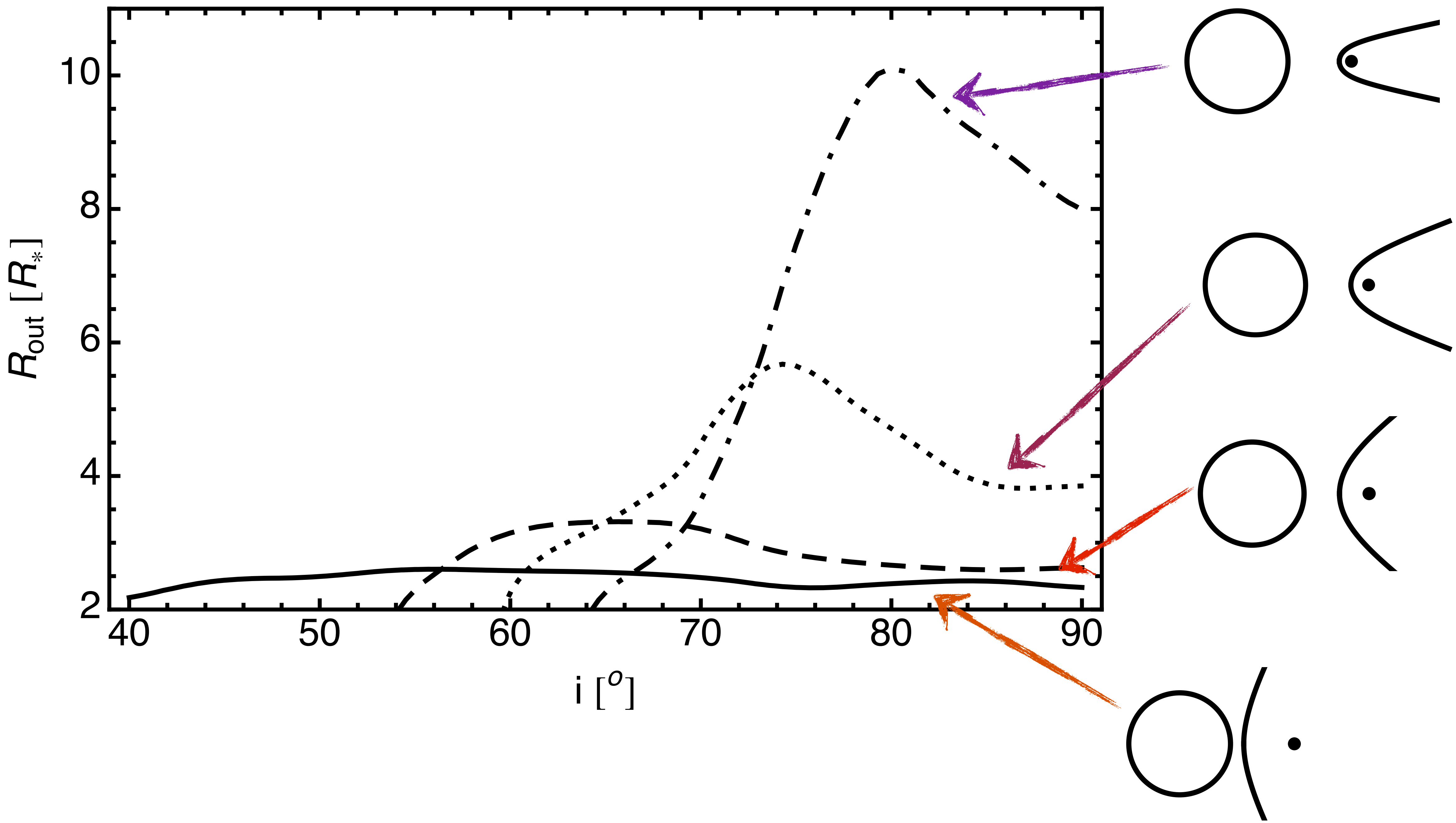

Summary

An extended X-ray source appears necessary.

- Minimum size of X-ray emitting region, varies between 3-10 $R_\star$
- Inclination limit of 60º is not valid if Rout > 4 $R_\star$
- Order of magnitude higher stellar mass-loss rates are possible
- The extended X-ray source is expected in the pulsar wind scenario

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