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PEPSci
Planetary and
Exoplanetary Science

Transit depth and wavelength dependence of disintegrating exoplanets

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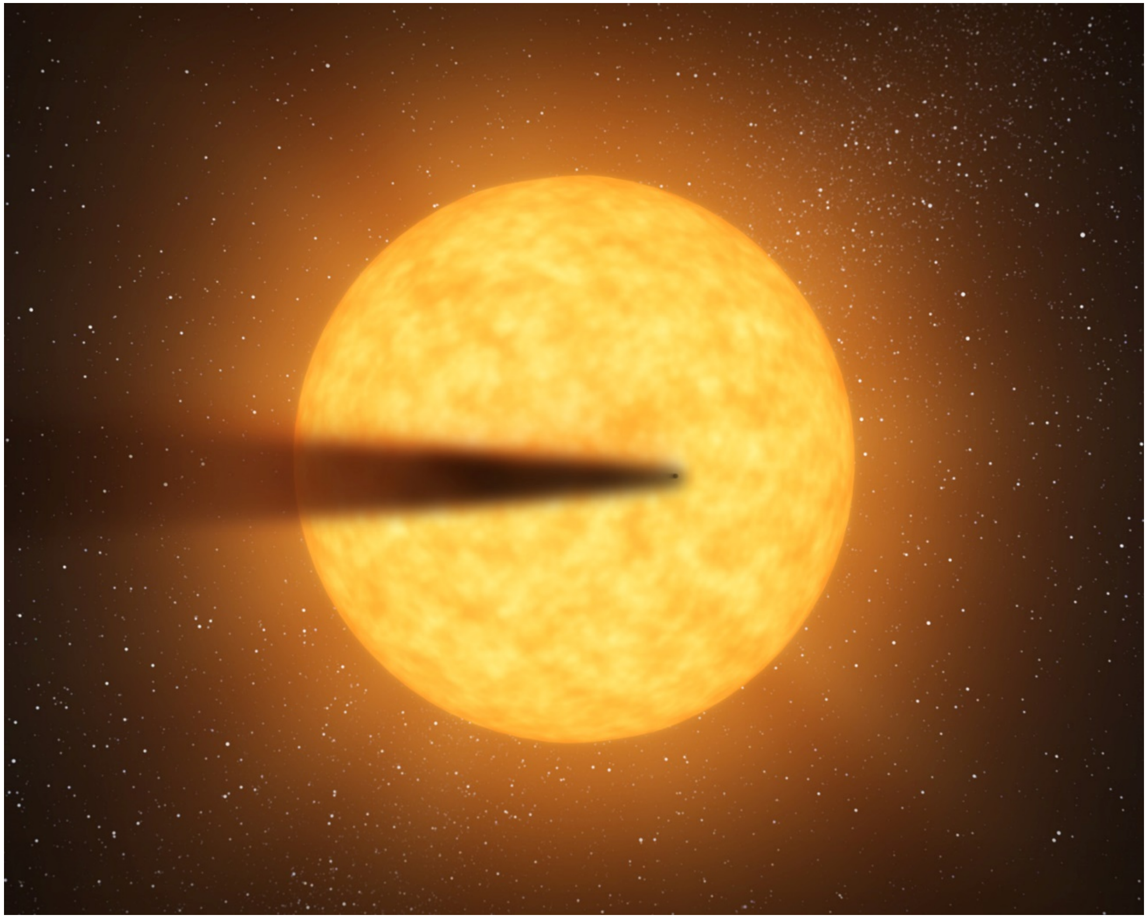
R. van Lieshout, I.A.G. Snellen**

EWASS 2017, Prague

Disintegrating rocky exoplanets



Credit: NASA/JPL-Caltech

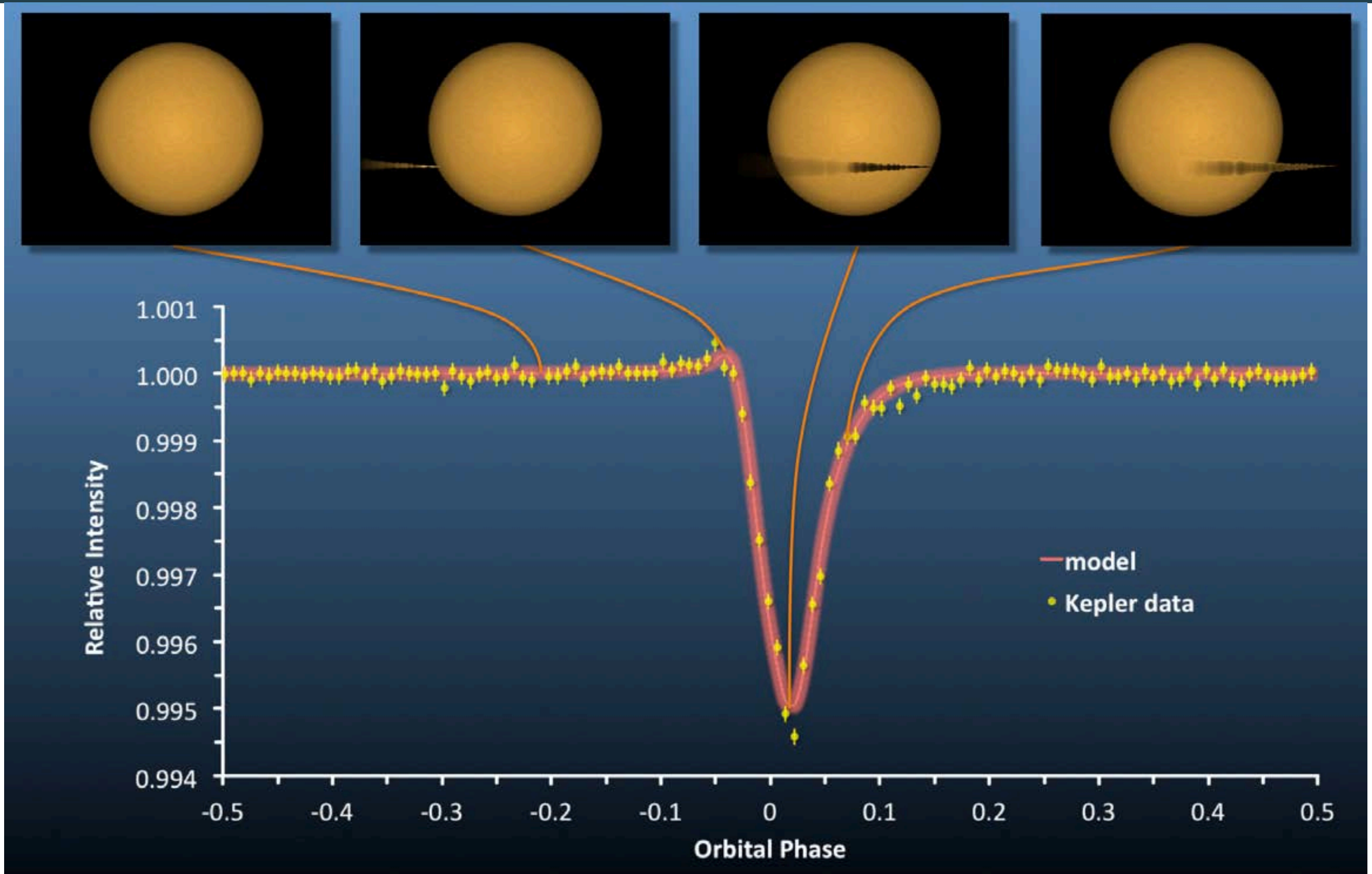
Observe dust

↓

probe surface/interior exoplanet material

Characteristic transit light curve: Kepler-1520 b *

* Formerly known as KIC 12557548 b

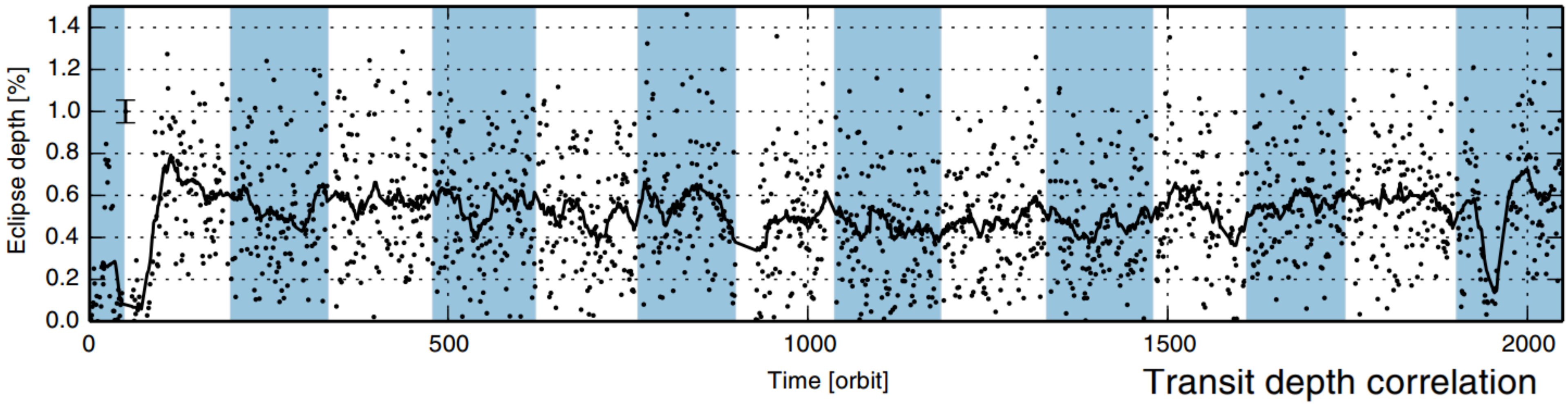


Explanation of Lightcurve of Disintegrating Exoplanet KIC 12557548 (Brogi et al. 2012)

Image credit: C.U.Keller (2012), Leiden Observatory, Leiden University, keller@strw.leidenuniv.nl

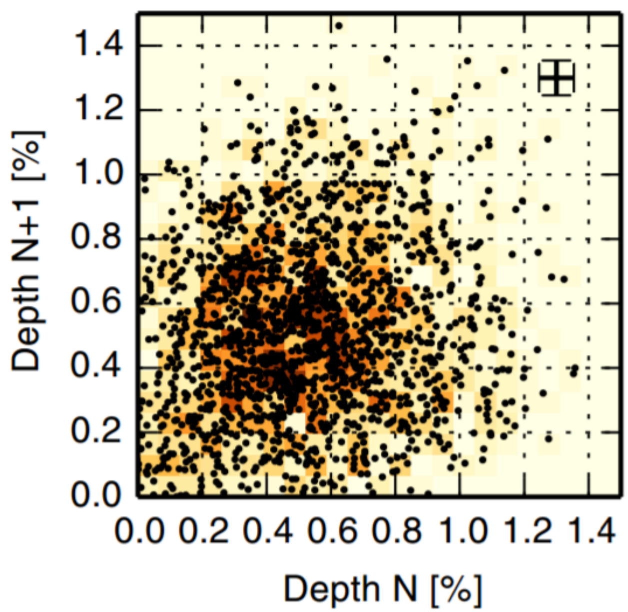
Variable transit depths: Kepler-1520 b *

* Formerly known as KIC 12557548 b



Transit depth over 15 quarters of Kepler data

Transit depth correlation



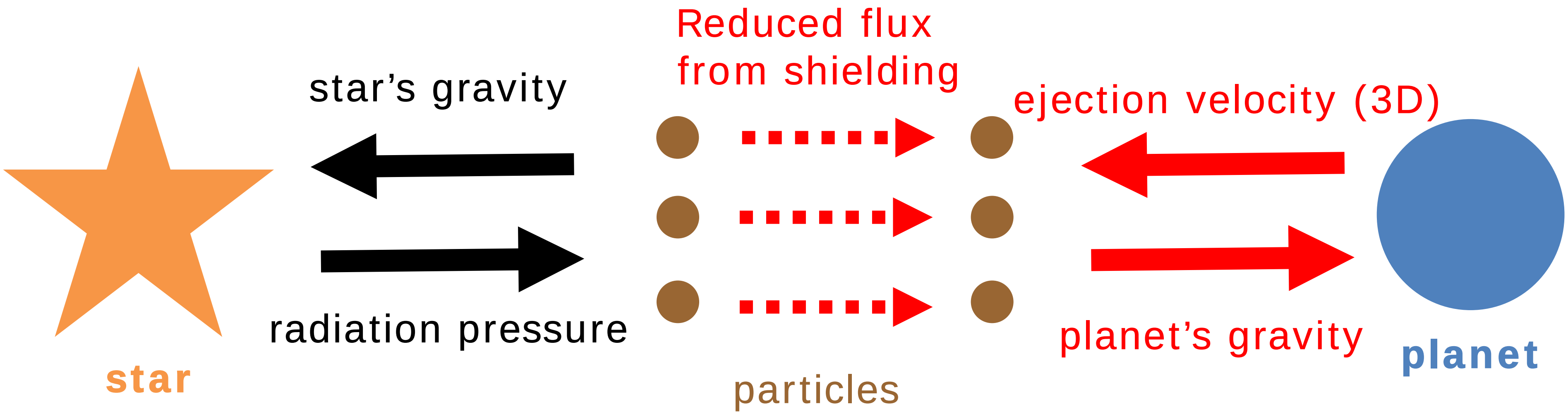
No correlation between consecutive transit depths

van Werkhoven *et al.* (2014)

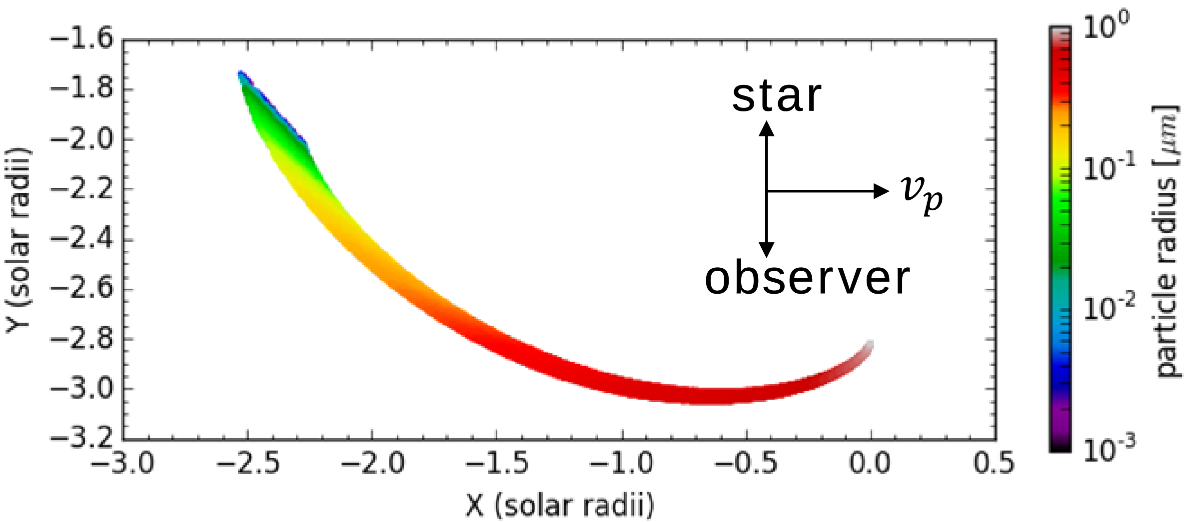
Particle dynamics model (3D)

New

Previously considered

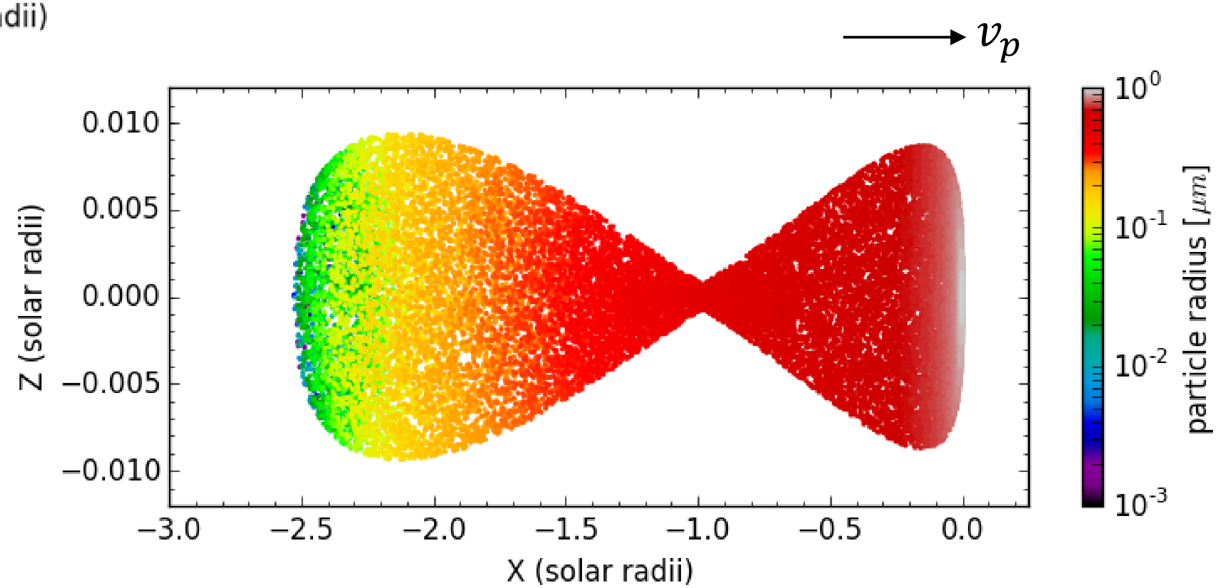


Simulated optically thin tail



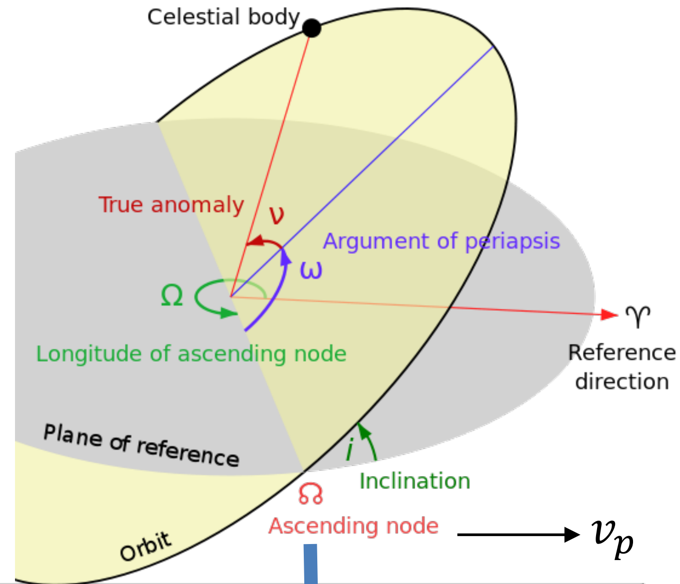
Tail viewed from above

Tail viewed from side
(unequal scales)

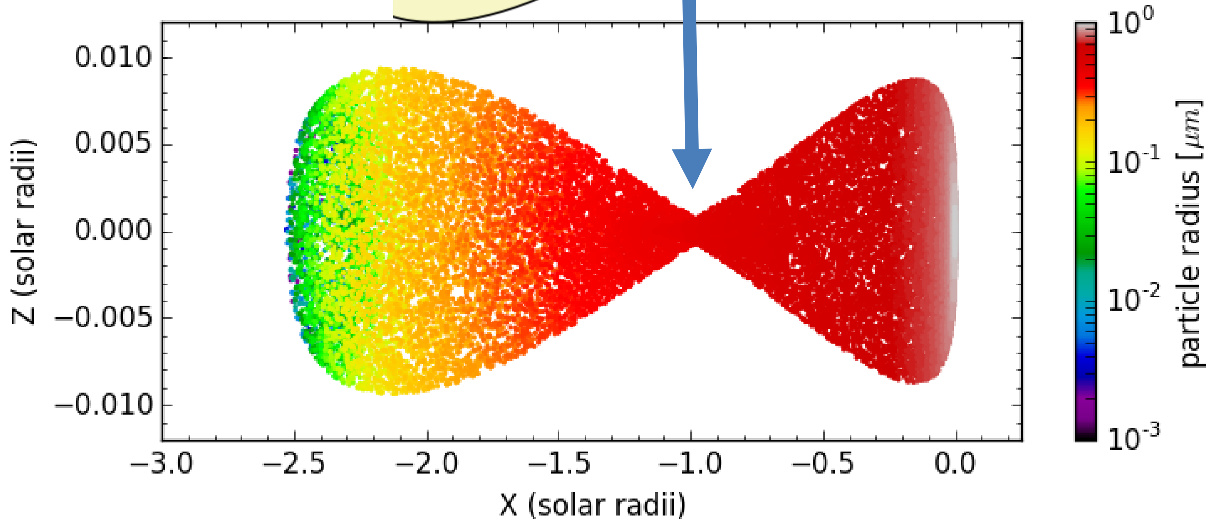


Ridden-Harper *et al.* in prep.

Example of a simulated tail

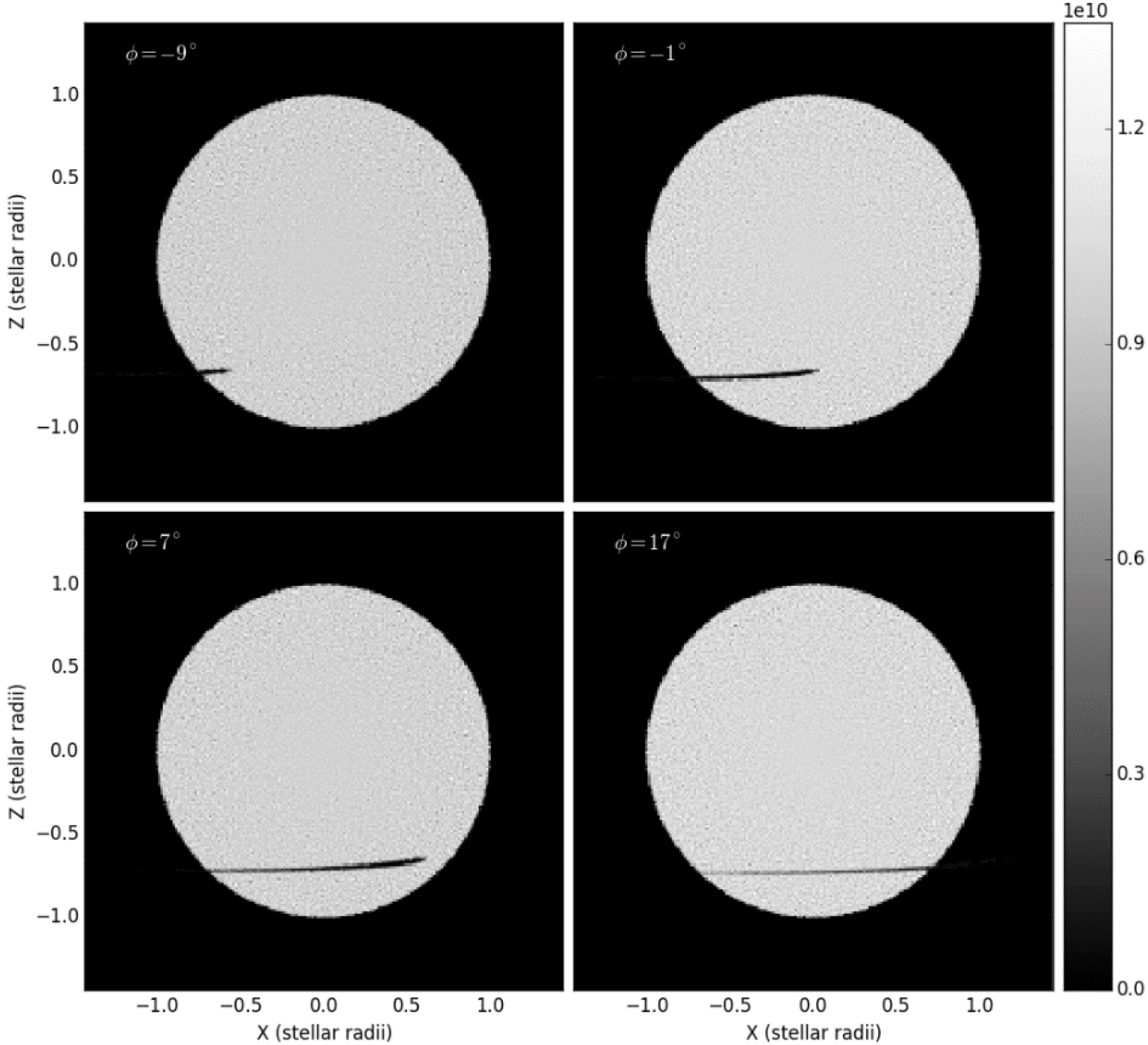


Tail viewed from side
(unequal scales)



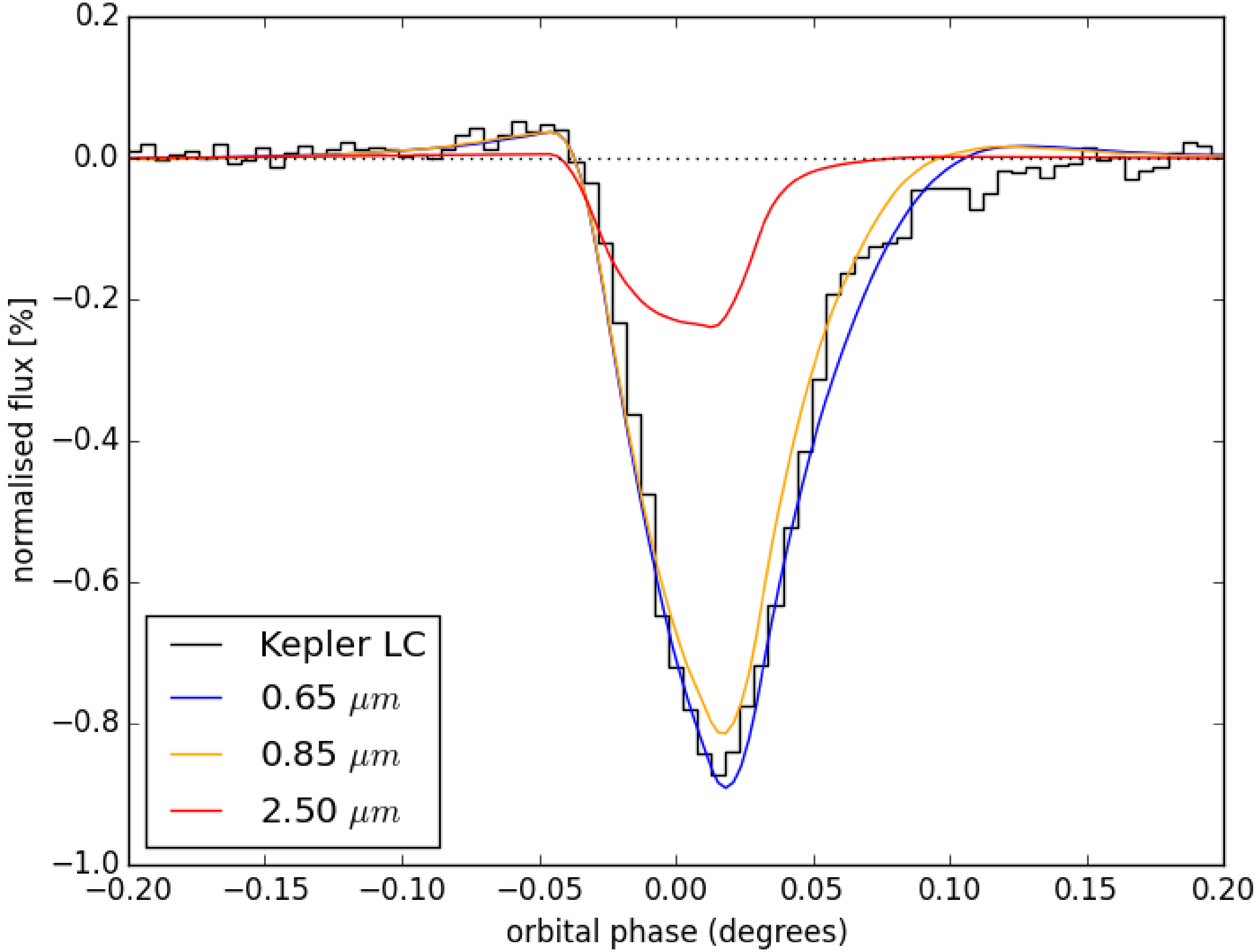
Ridden-Harper *et al.* in prep.

Ray tracing with Michiel Min's MCMax3D



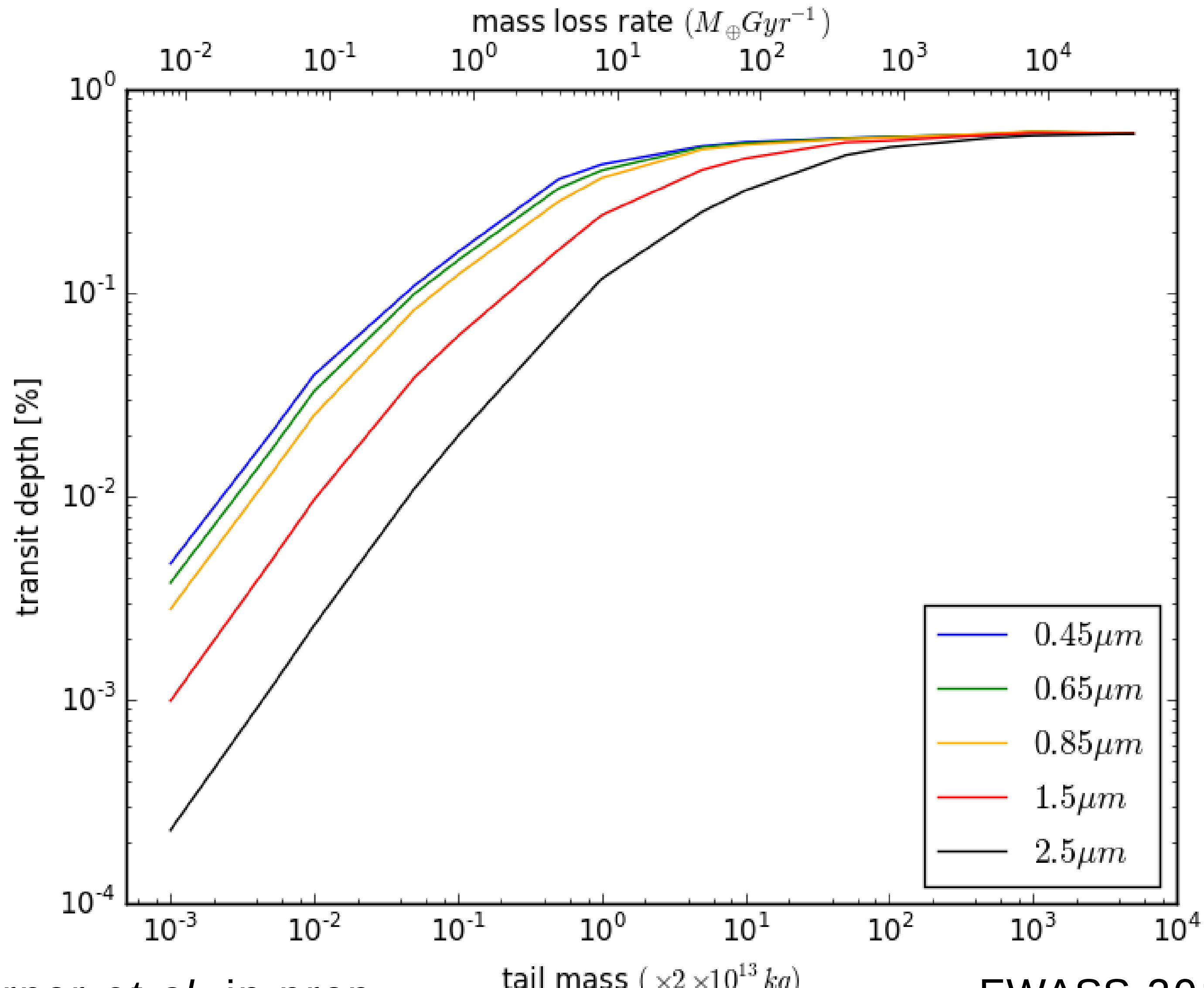
Ridden-Harper *et al.* in prep.

Light curve from MCMax3D (many viewing angles)



Ridden-Harper *et al.* in prep.

Wavelength dependence as a function of tail mass



Ridden-Harper *et al.* in prep.

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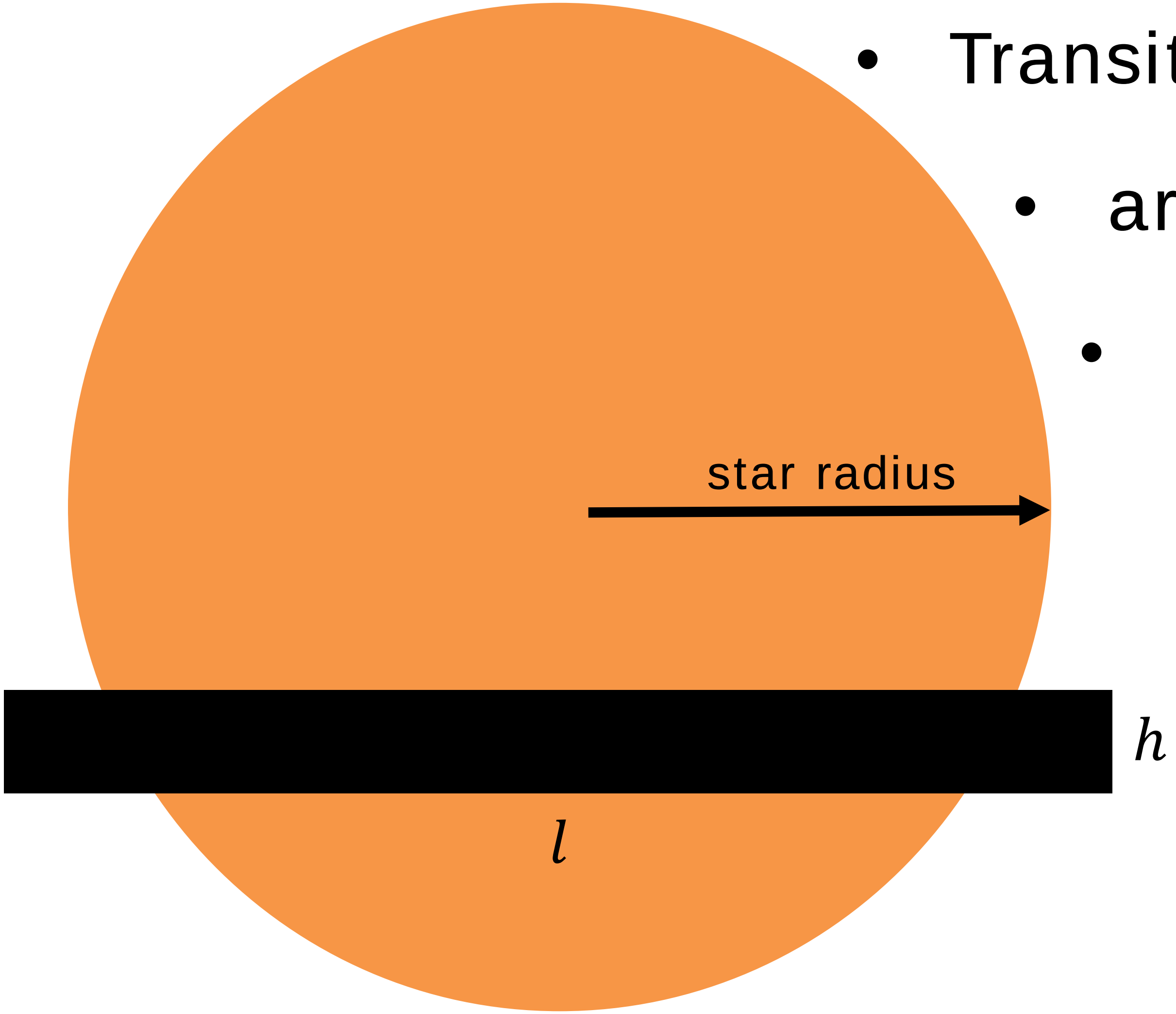
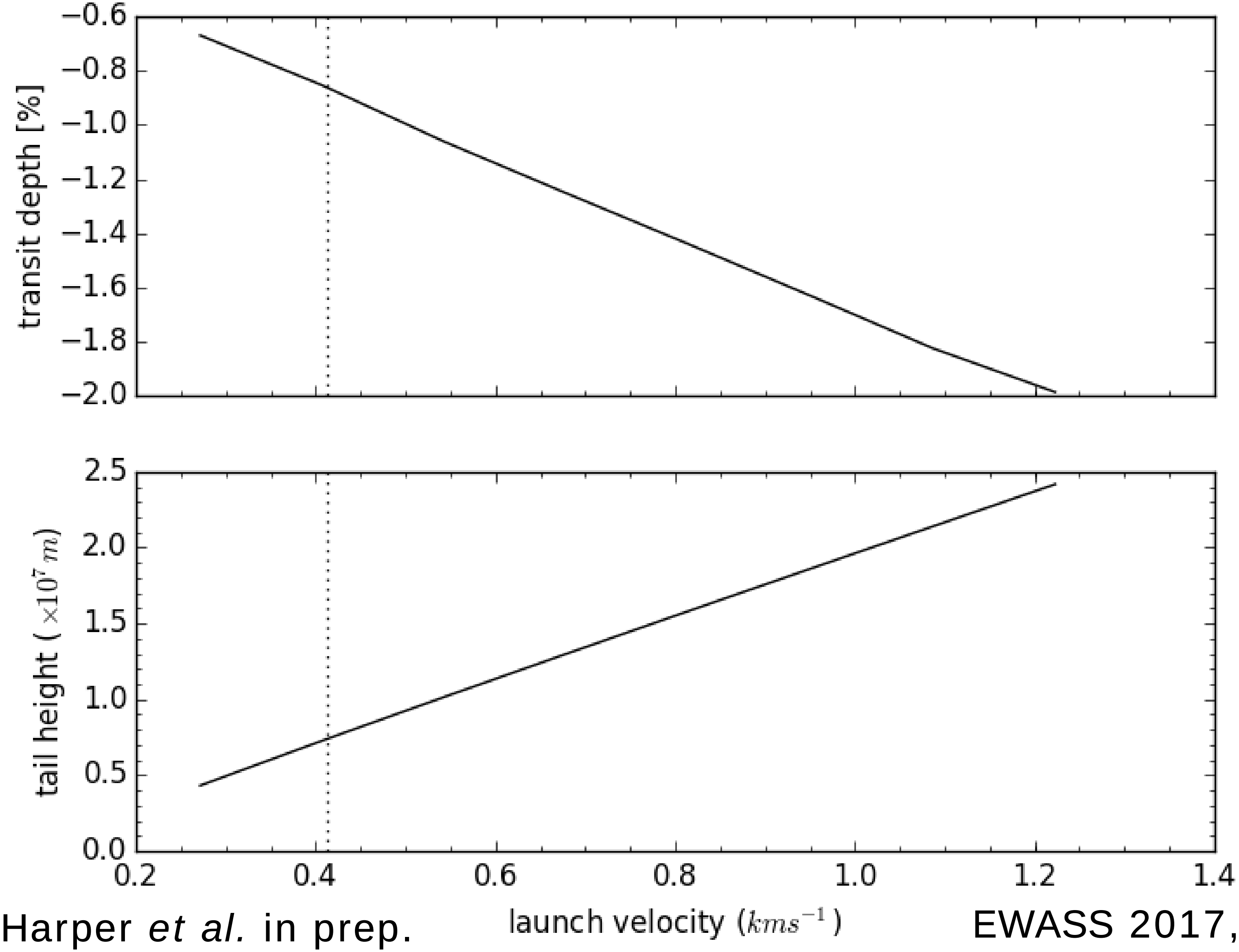
Derive minimum tail height from transit depth



- Transit depth ∝ area
  - area ∝ height
    - height ∝ velocity

transit depth → minimum ejection velocity out of plane



Ridden-Harper *et al.* in prep.

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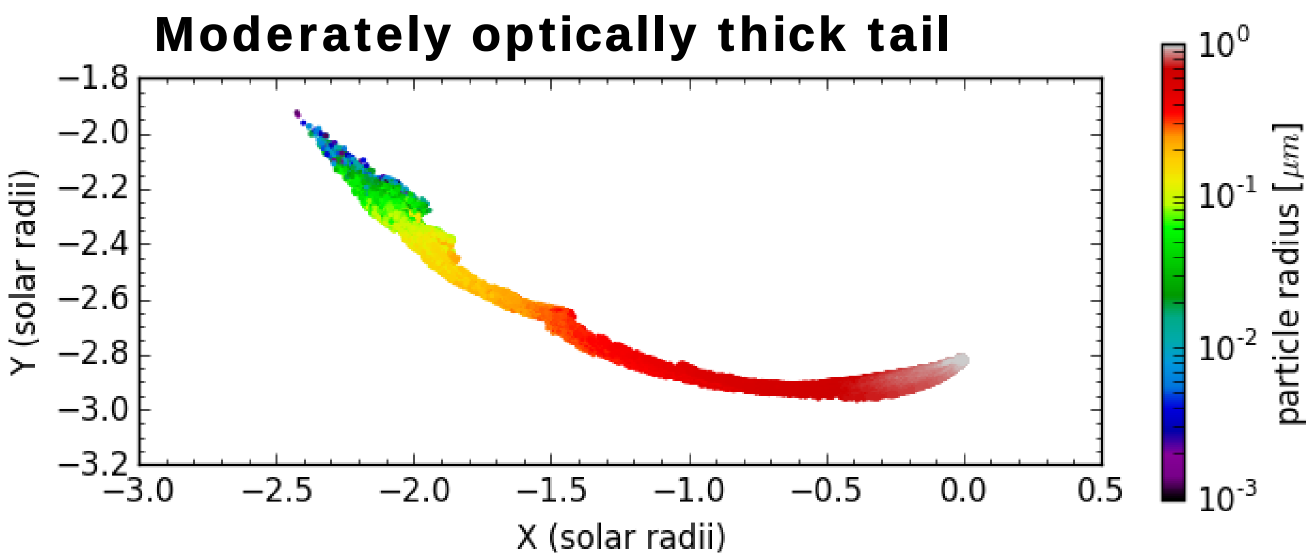
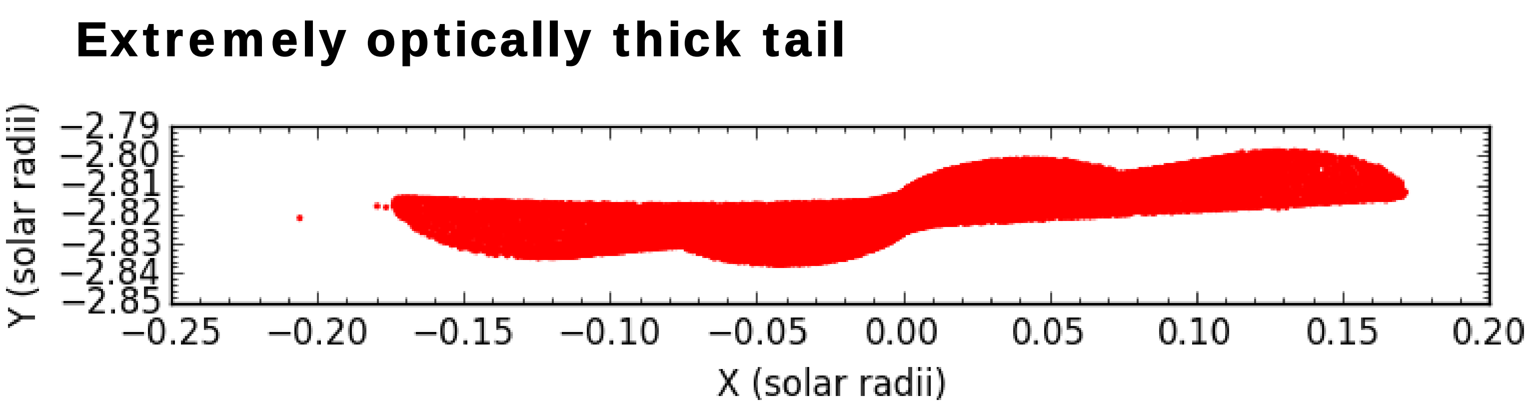
Optical depth in particle dynamics (preliminary)





Ridden-Harper *et al.* in prep.

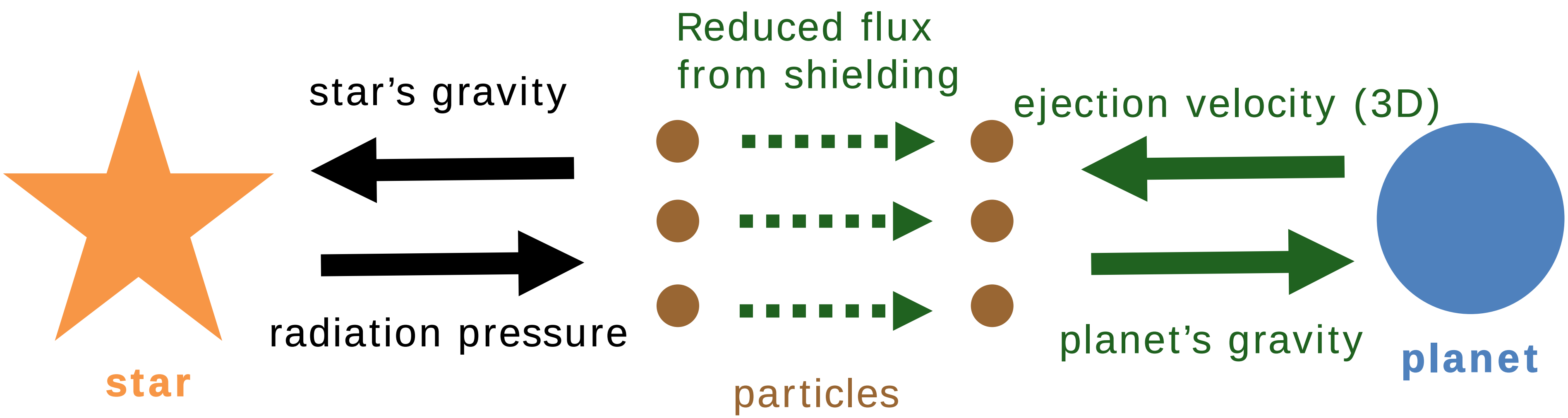
Conclusions

- From transit depth
  - Minimum particle ejection velocity perpendicular to plane
  - Constrain ejection mechanism
- Large wavelength dependence in transit depth
  - Look in the K-band (2.0 – 2.4 μm)
- Optically thick
  - Transit depth not indicative of mass
- Large mass loss rates → very high shielding
  - Investigating effect on tail particle dynamics

Particle dynamics model (3D)

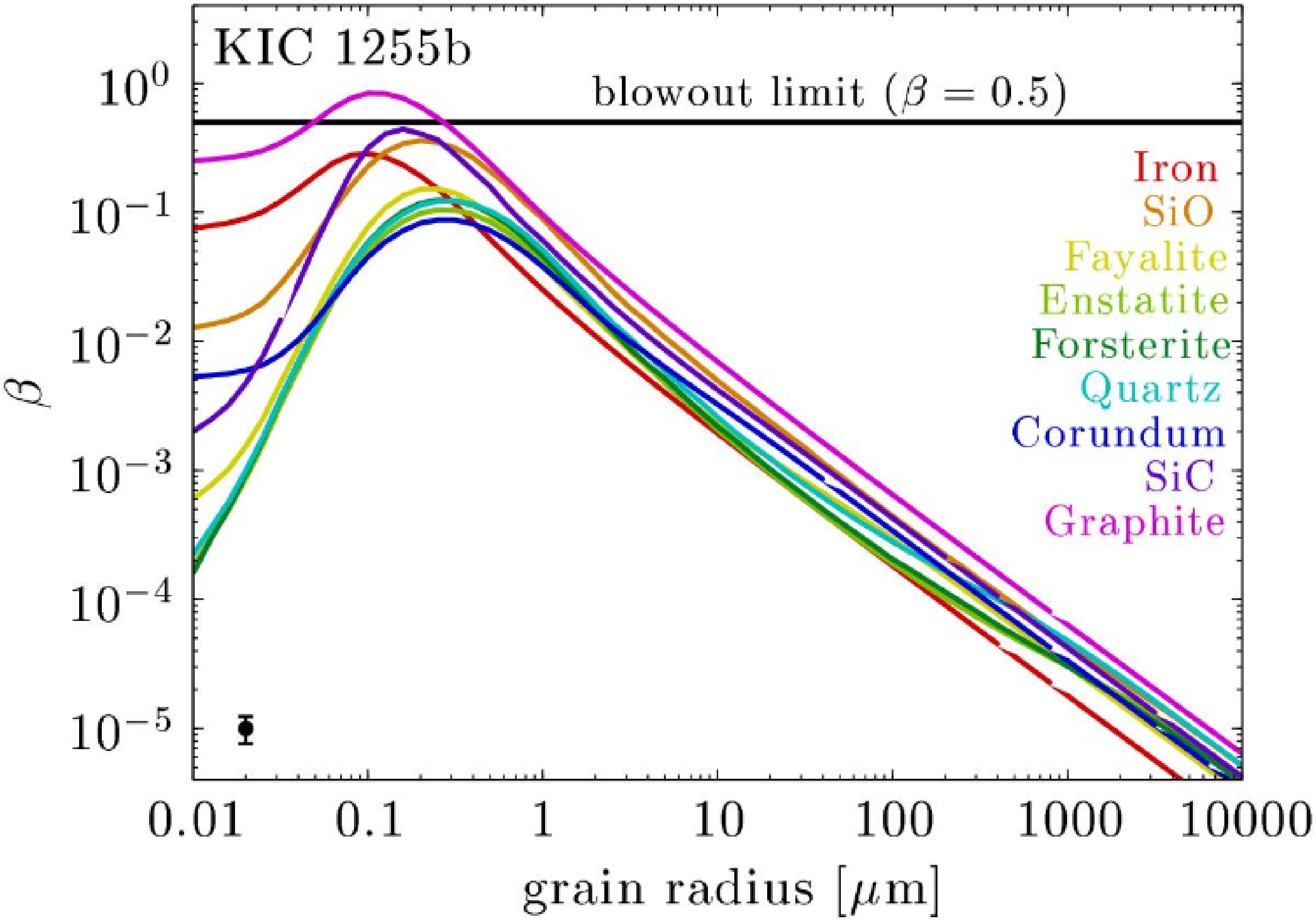
New

Previously considered



$$\frac{F_{\text{radiation presure}}}{F_{\text{star gravity}}} = \beta(\text{particle radius})$$

β values



Large particles of $r > 50\ \mu m$

Very small β

Particles can go in front of planet

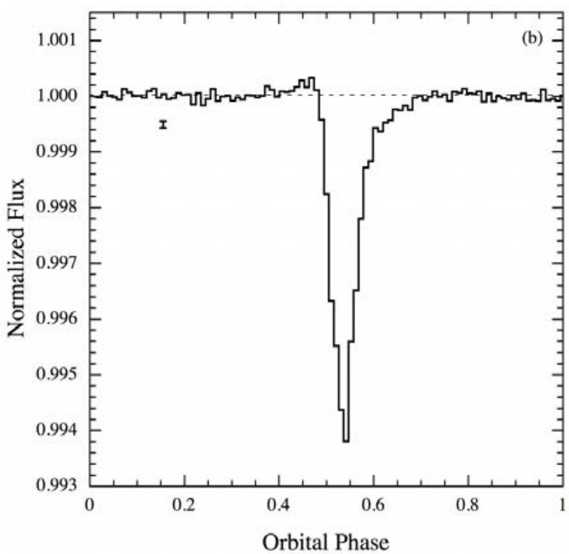
van Lieshout *et al.* (2014)

Insignificant forces that were neglected

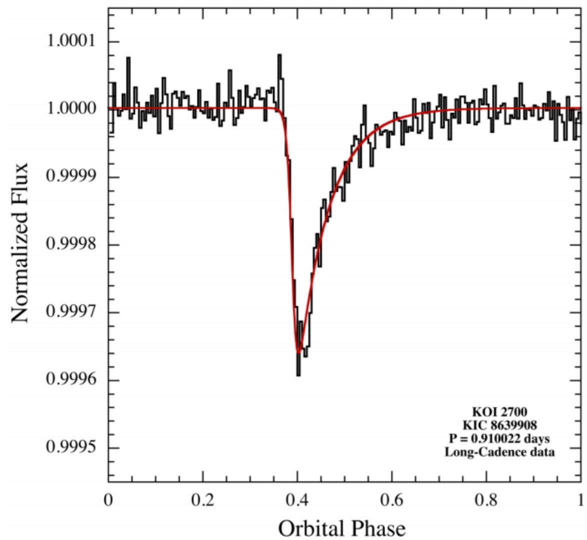
- Poynting-Robertson drag
  - Small so only relevant over many orbits
- Stellar wind pressure
  - Order of magnitude smaller than radiation pressure (Rappaport+ 2014)
- Gas drag from the planetary outflow
  - Assumed to diminish rapidly

Known cases: asymmetric light curves from tail

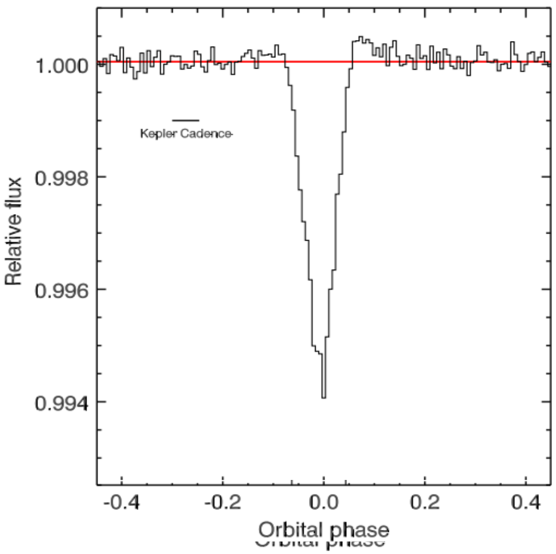
Kepler-1520 b (15.7 hr)
(or KIC 12557548 b)
(Rappaport et al. 2012)



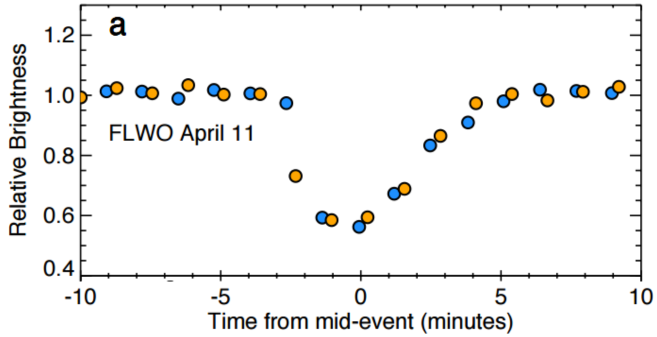
KOI-2700b (21.8 hr)
(Rappaport et al. 2014)



K2-22b (9.1 hr)
(Sanchis-Ojeda et al. 2015)



WD 1145+017 (4.5 – 4.9 hr)
(Vanderburg et al. 2015)

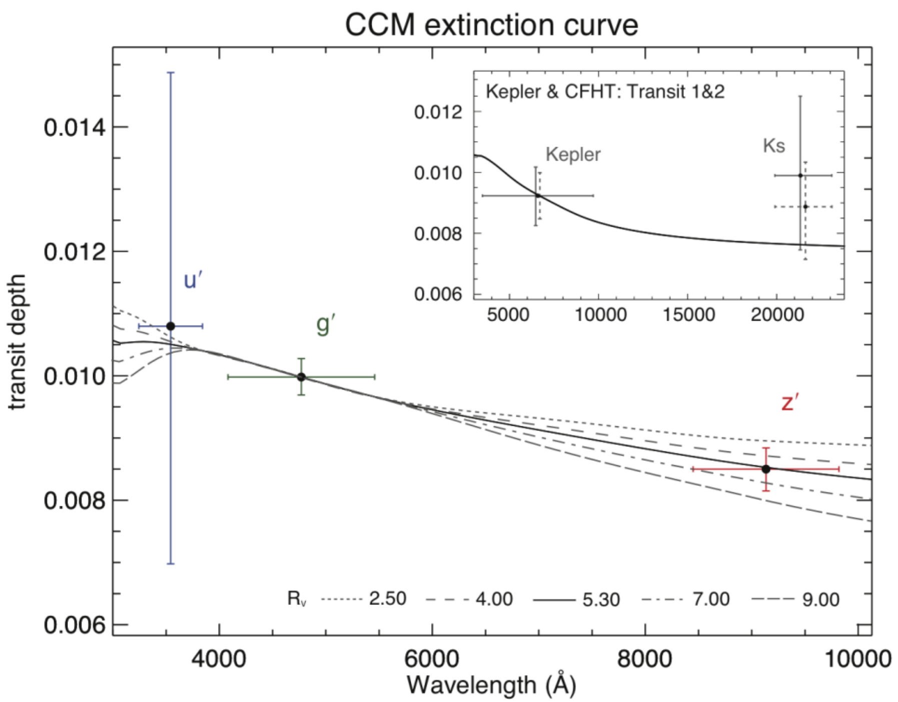


Kepler-1520 b: Transit wavelength dependence?

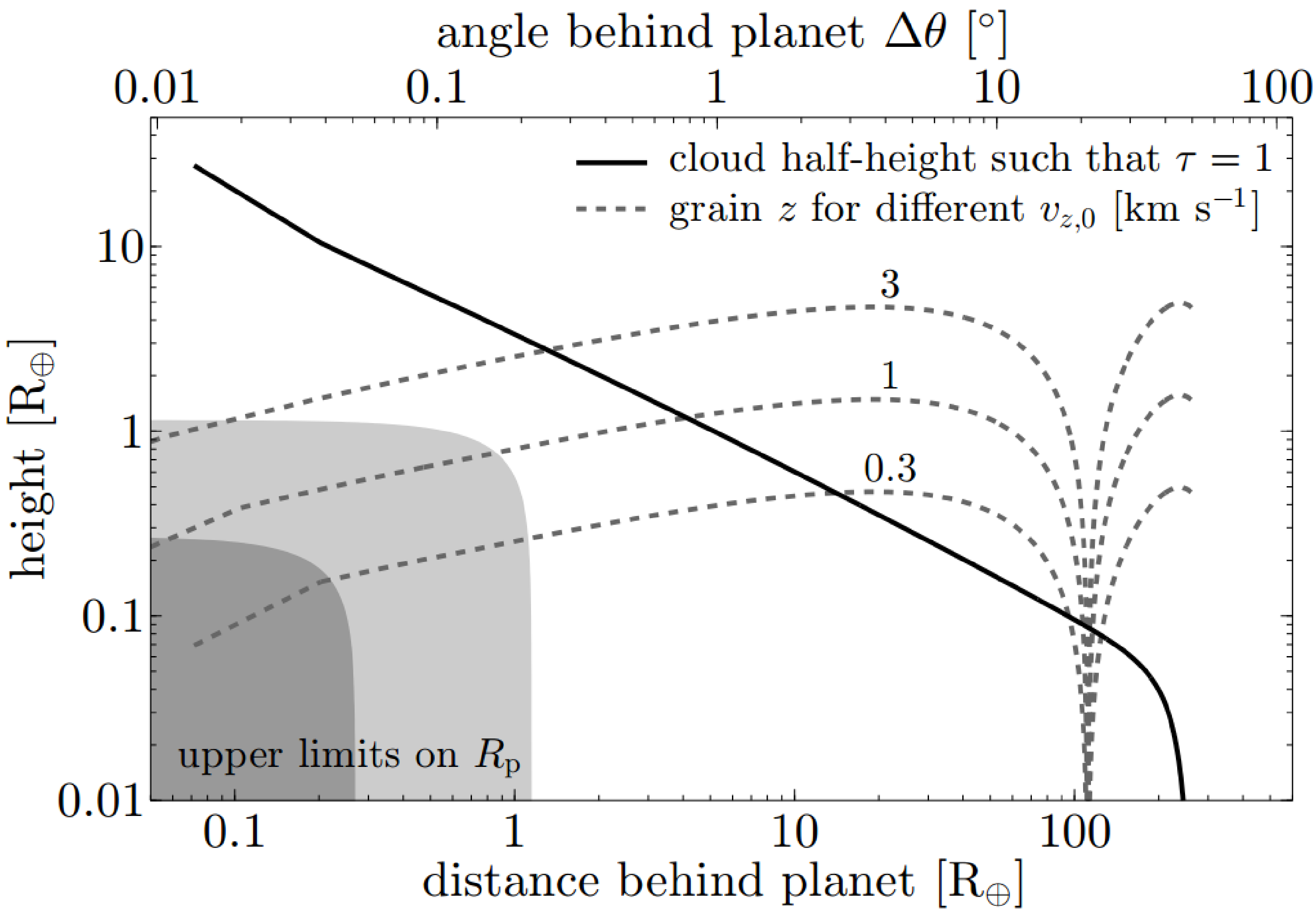
- No wavelength dependence
  - Croll el al. (2014)
  - Schlawin et al. (2016)
  - Felipe, PhD thesis, (2013)

- Hint of wavelength dependence

  - Bochinski et al. (2015)

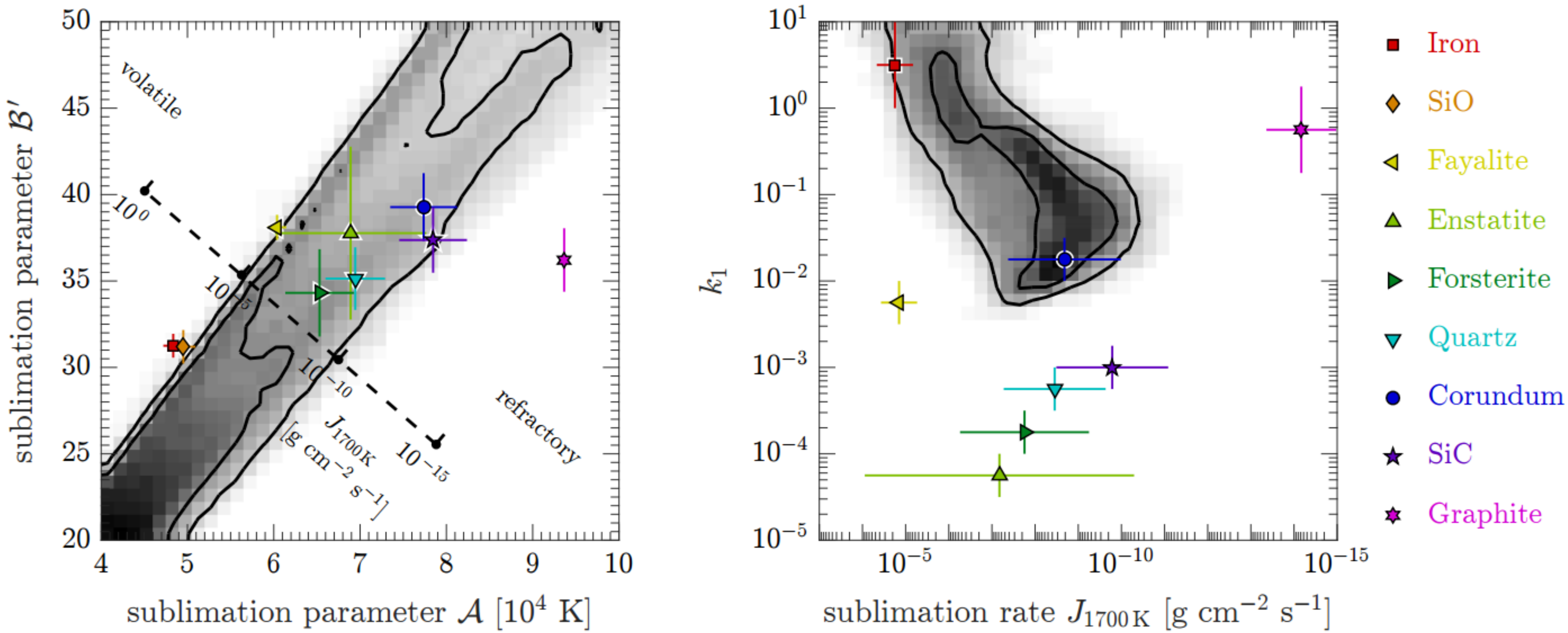


Likely optically thick close to planet



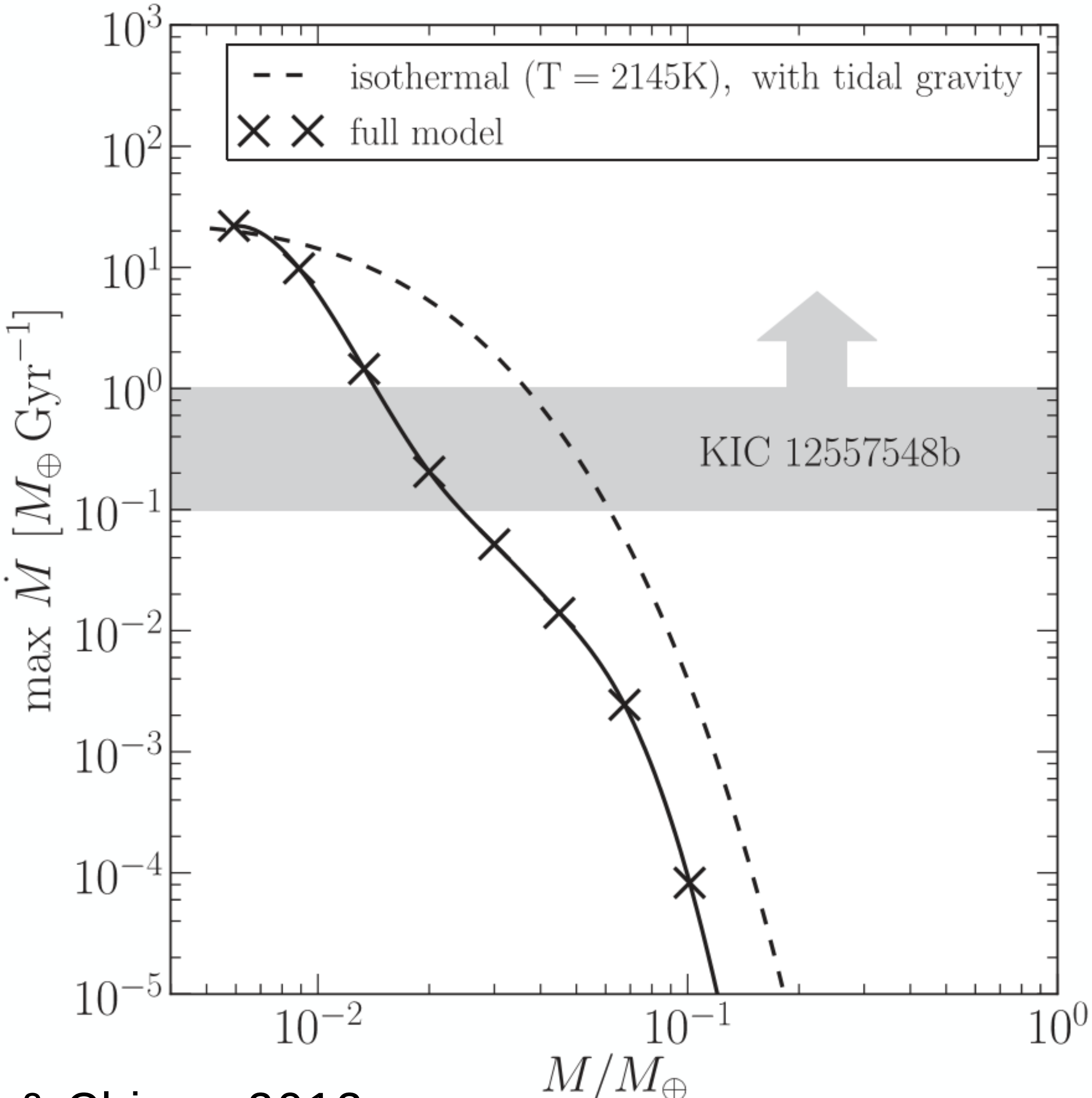
van Lieshout et al. 2016

Constraints on composition:



van Lieshout et al. 2016

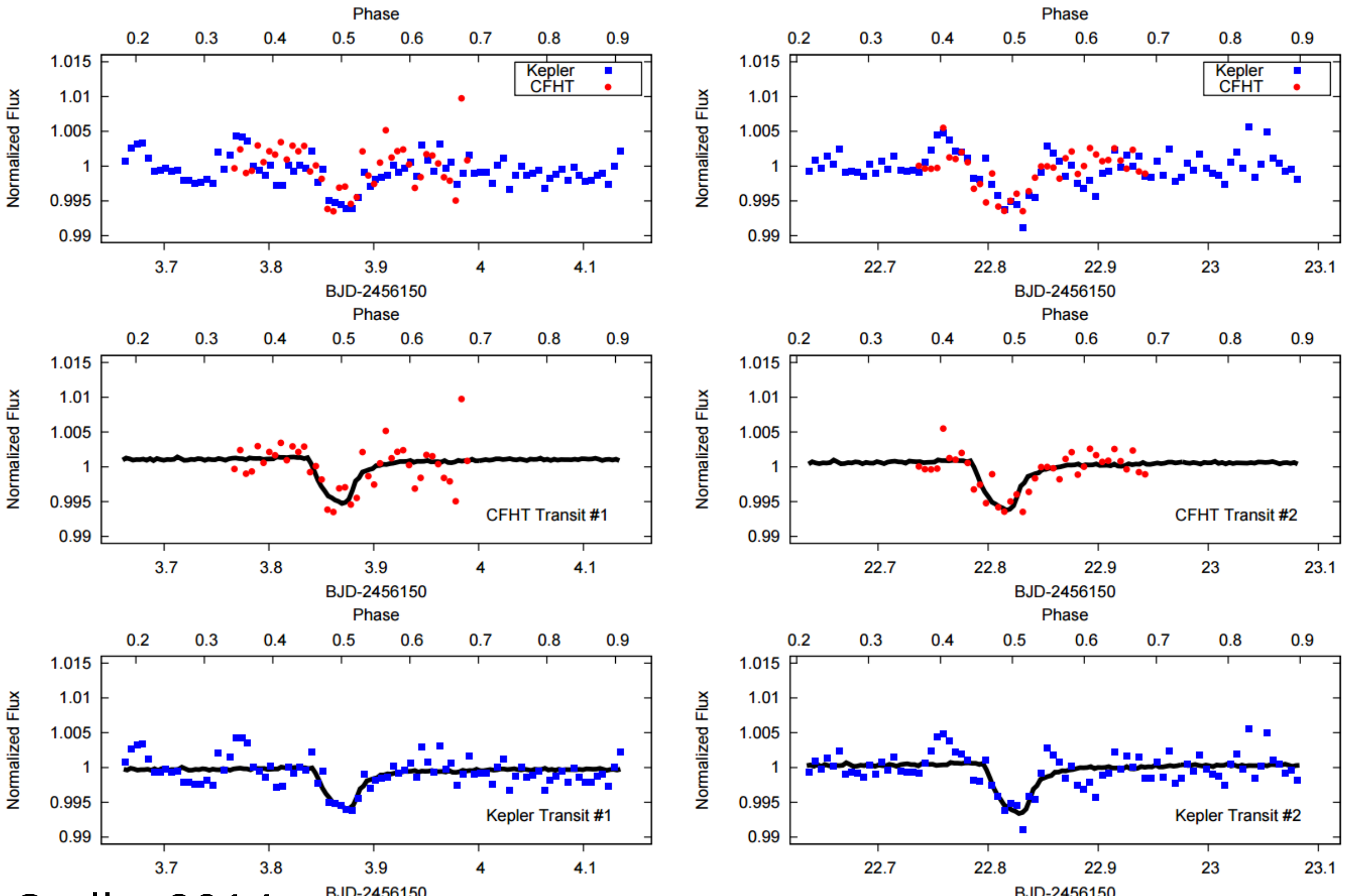
Mass loss rate can constrain mass (optically thin)



Perez-Becker & Chiang 2013

No wavelength dependence of KIC1255b (0.5μm particles)

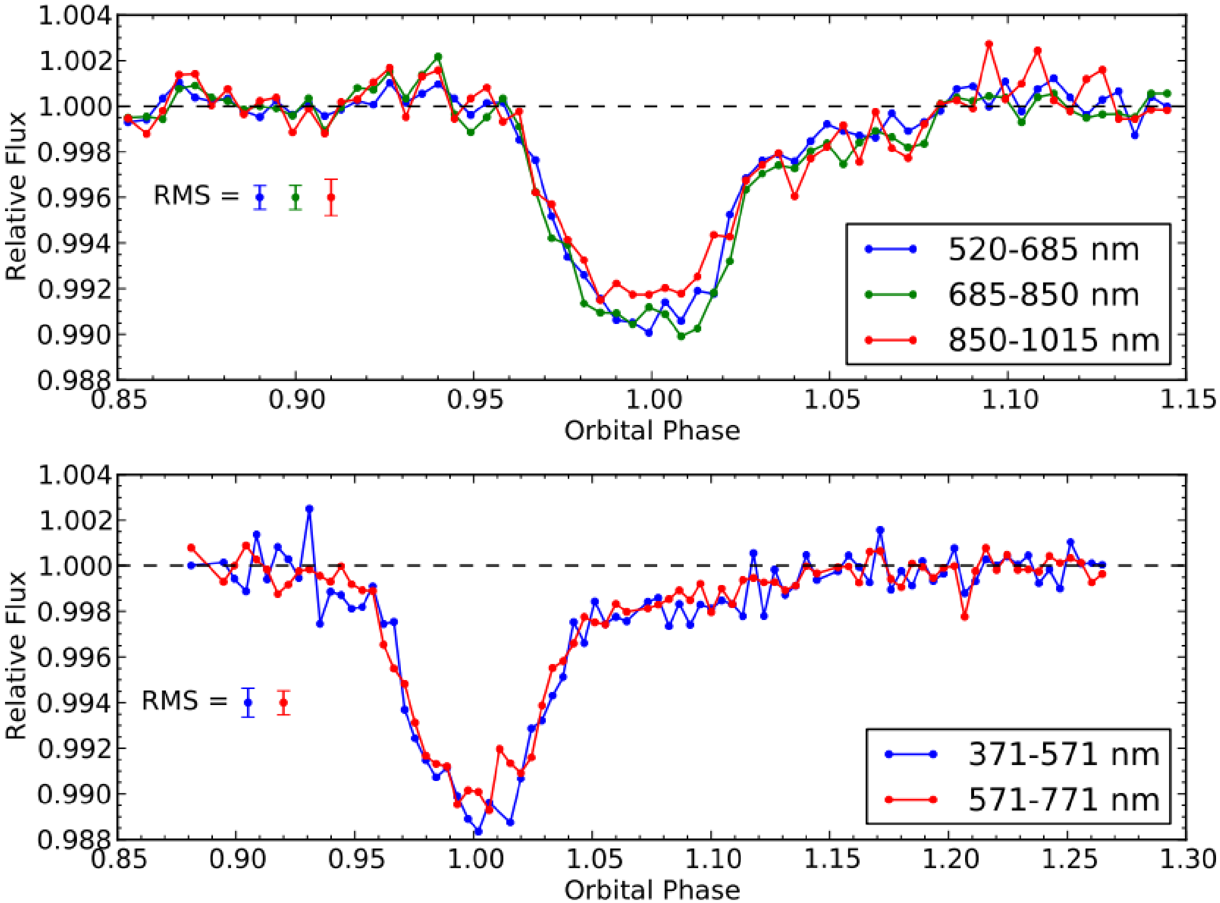
Canada-France-Hawaii Telescope/Wide-field InfraRed Camera (CFHT/WIRCam) at 2.15 μm and the Kepler space telescope at 0.6 μm



Croll+ 2014

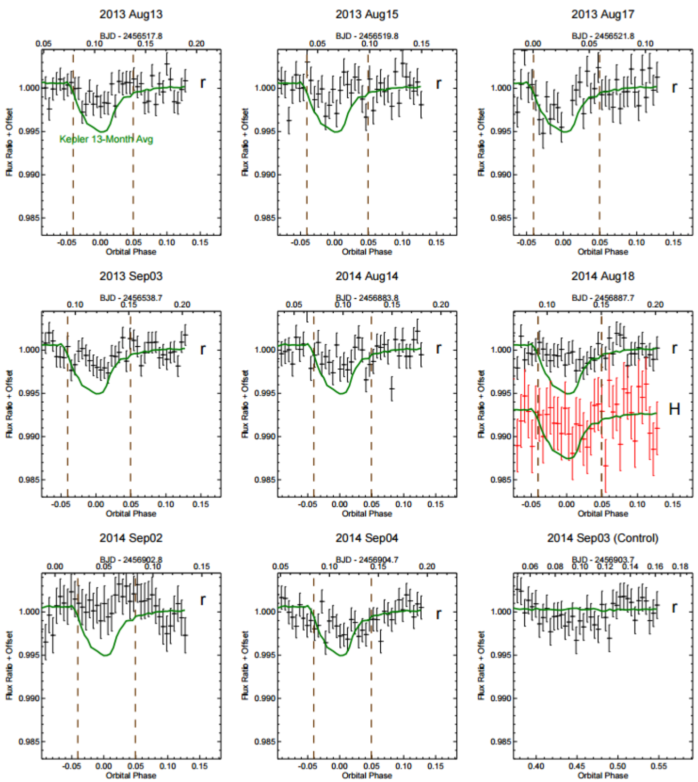
No wavelength dependence of KIC1255b

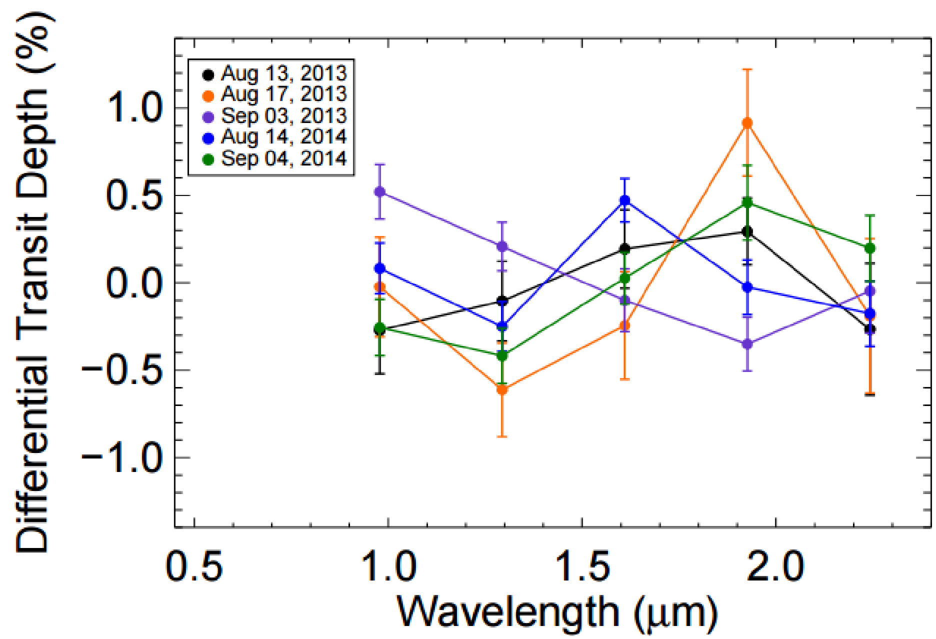
- (slightly higher red likely instrumental)



Murgas, PhD thesis, 2013

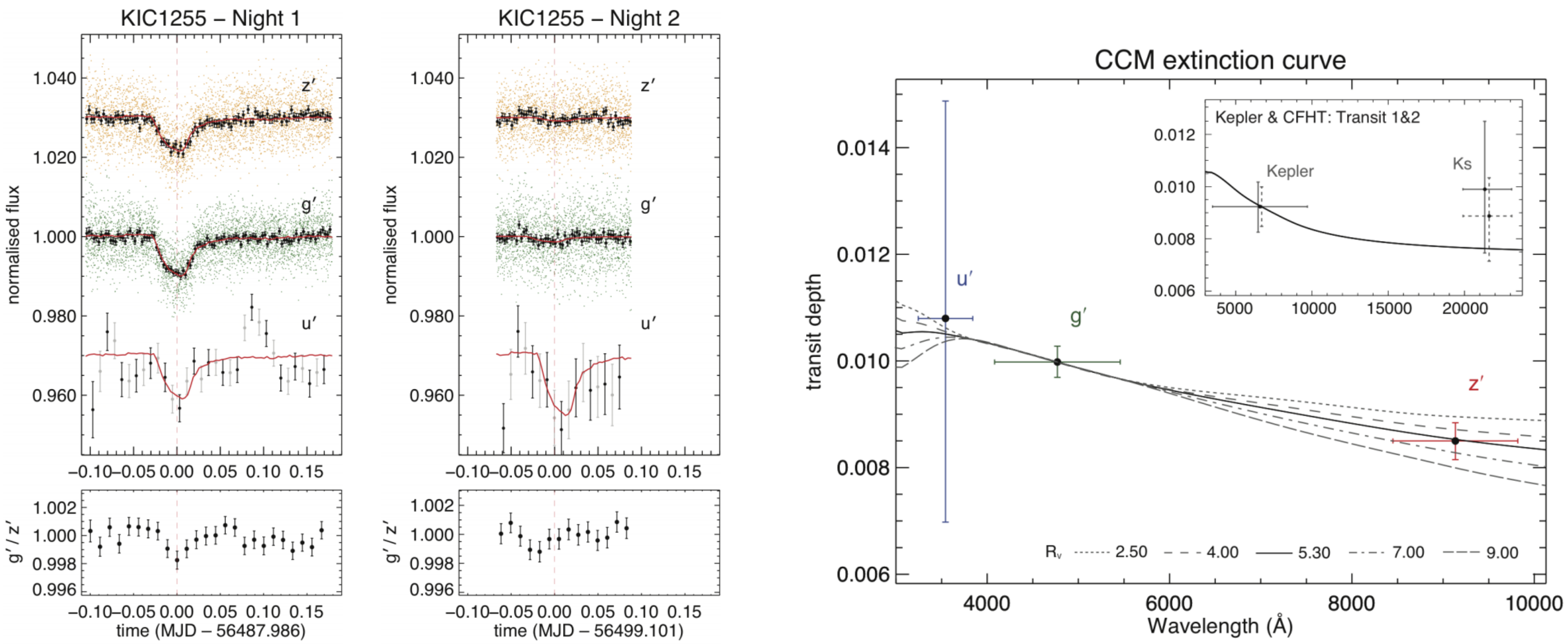
No wavelength dependence of KIC1255b: (0.5 – 1 μm particles)





Schlawin+ 2016

Wavelength dependence of KIC1255b (0.25 – 1 μm particles)



Bochinski+ 2015

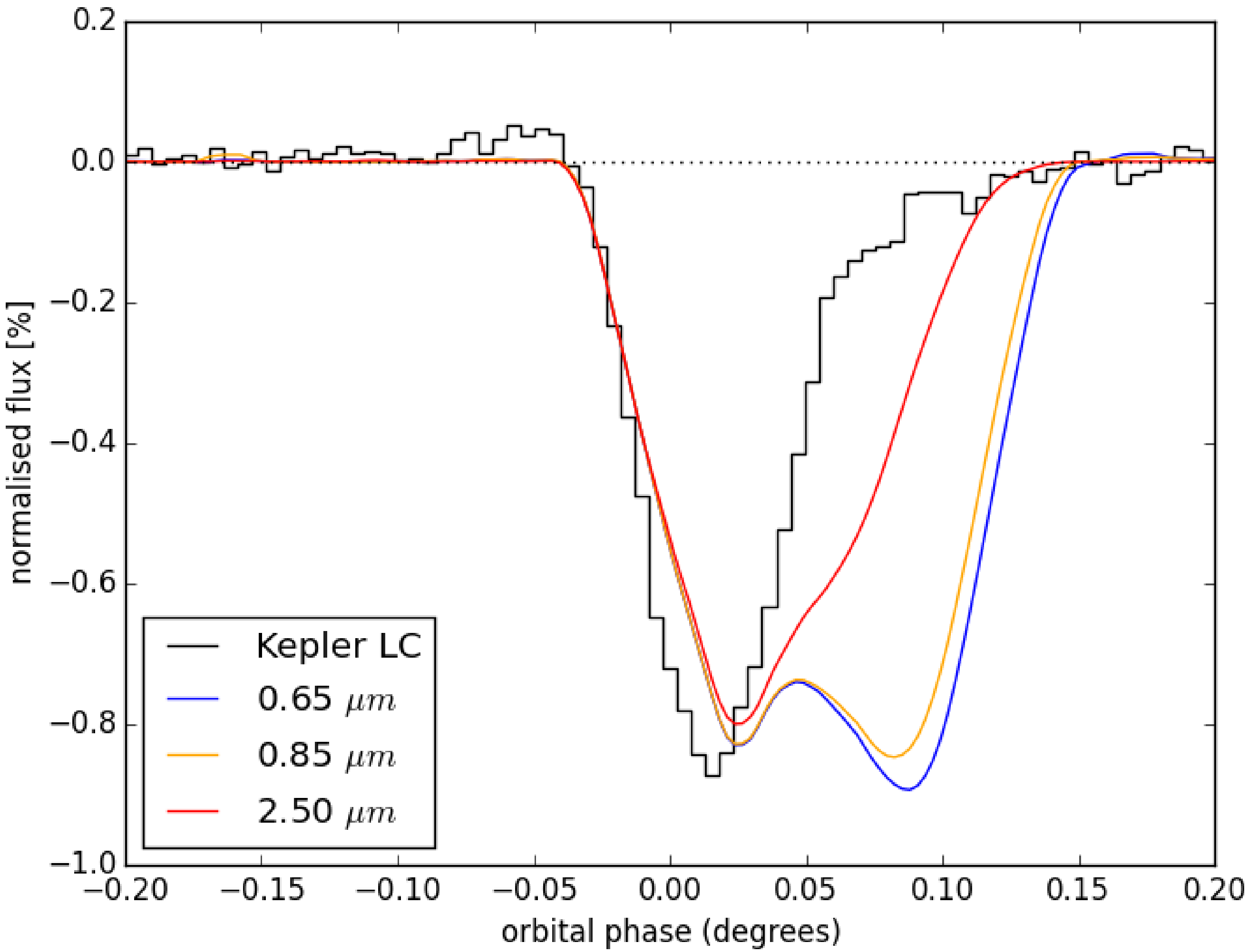
Could geophysical processes result in these velocities?

Solar System body	Typical volcanic eruption velocity (m/s)
Earth	300 (Wilson & Head, 1983)
Mars	500 (Wilson & Head, 1983)
Venus	100 (Wilson & Head, 1983)
Io	500 – 1000 (McEwen & Soderblom, 1983)

Hydrodynamic models with particles being dragged from the planet by escaping gas give velocities of ~1 km/s (Perez-Becker & Chiang, 2013)

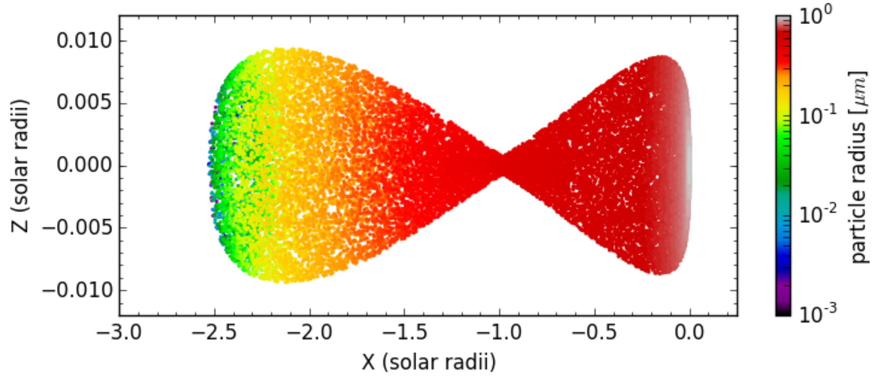
Any other ideas from geophysicists?
e.g. bursting bubbles on a boiling magma ocean?

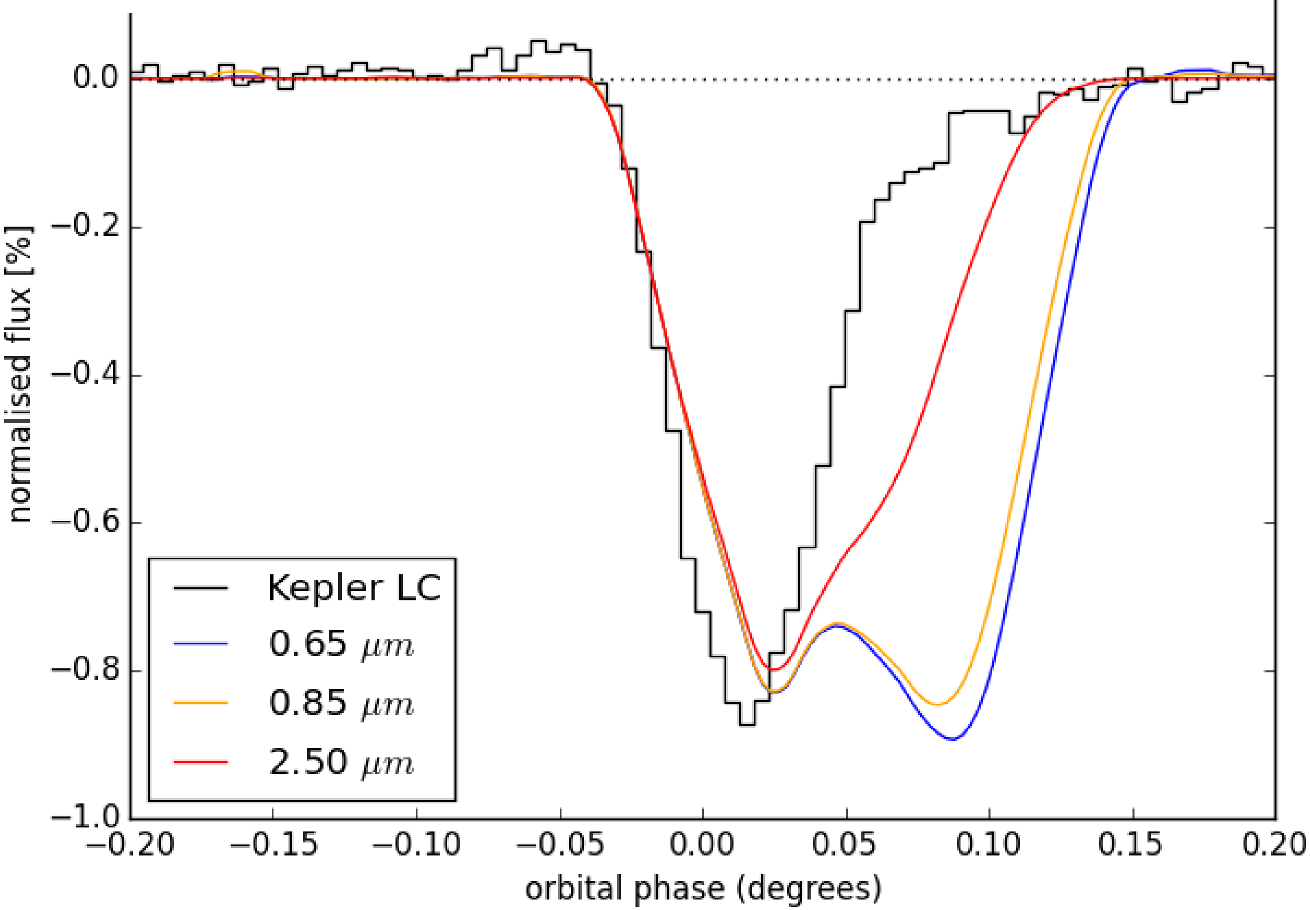
600x more tail mass (1μm particles) makes it "optically thick"



- Tail is opaque
- Adding more mass does not increase absorption
- Transit depth is determined by tail cross-section
- Reduced cross-section at waist gives "double dip" shape

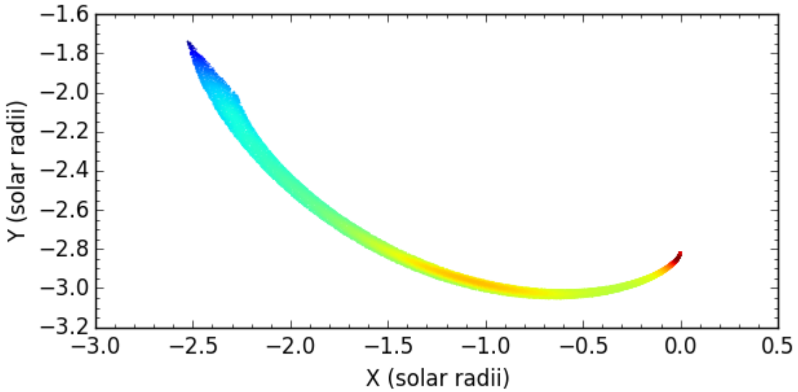
rticles) makes it “optically thick”

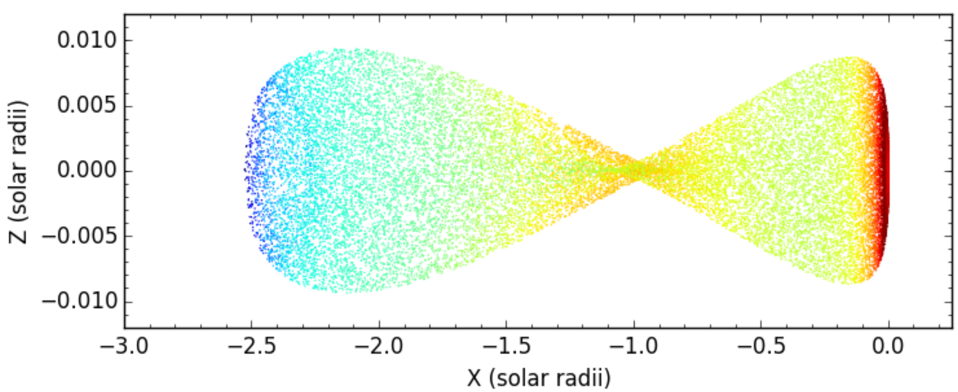




- Tail is opaque
- Adding more mass does not increase absorption
- Transit depth is determined by tail cross-section
- Reduced cross-section at waist gives “double dip” shape

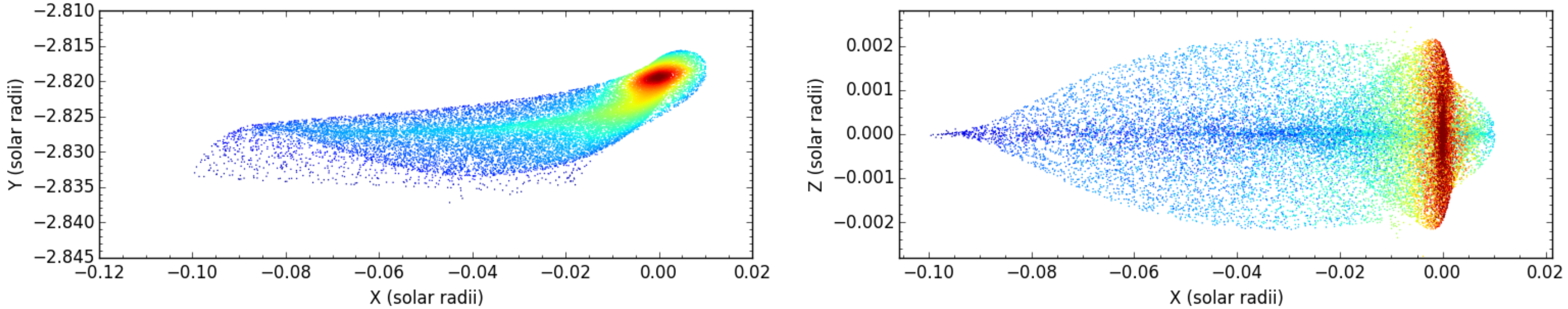
Density plots for long optically thin tail



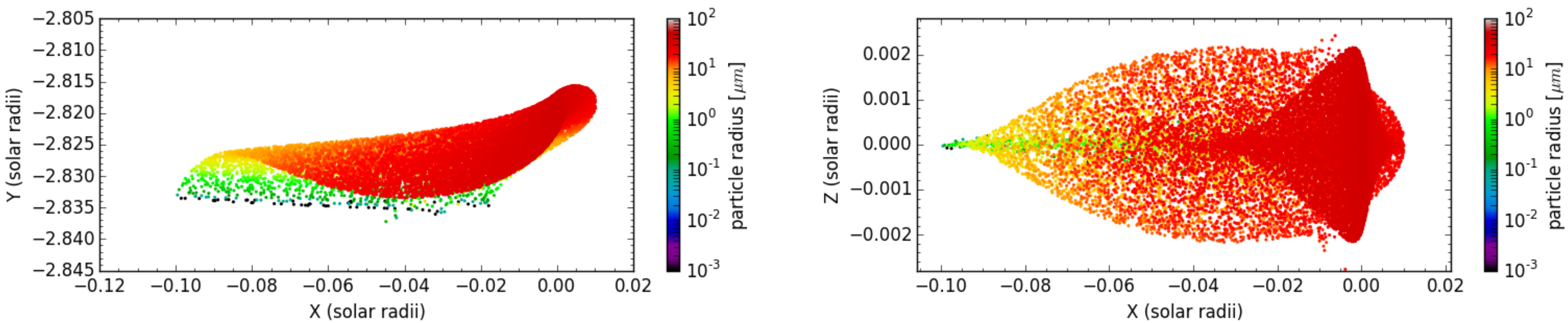


Simulated tail: initial particle size $50\mu m$ (20x shorter)

Colour proportional to square root of density

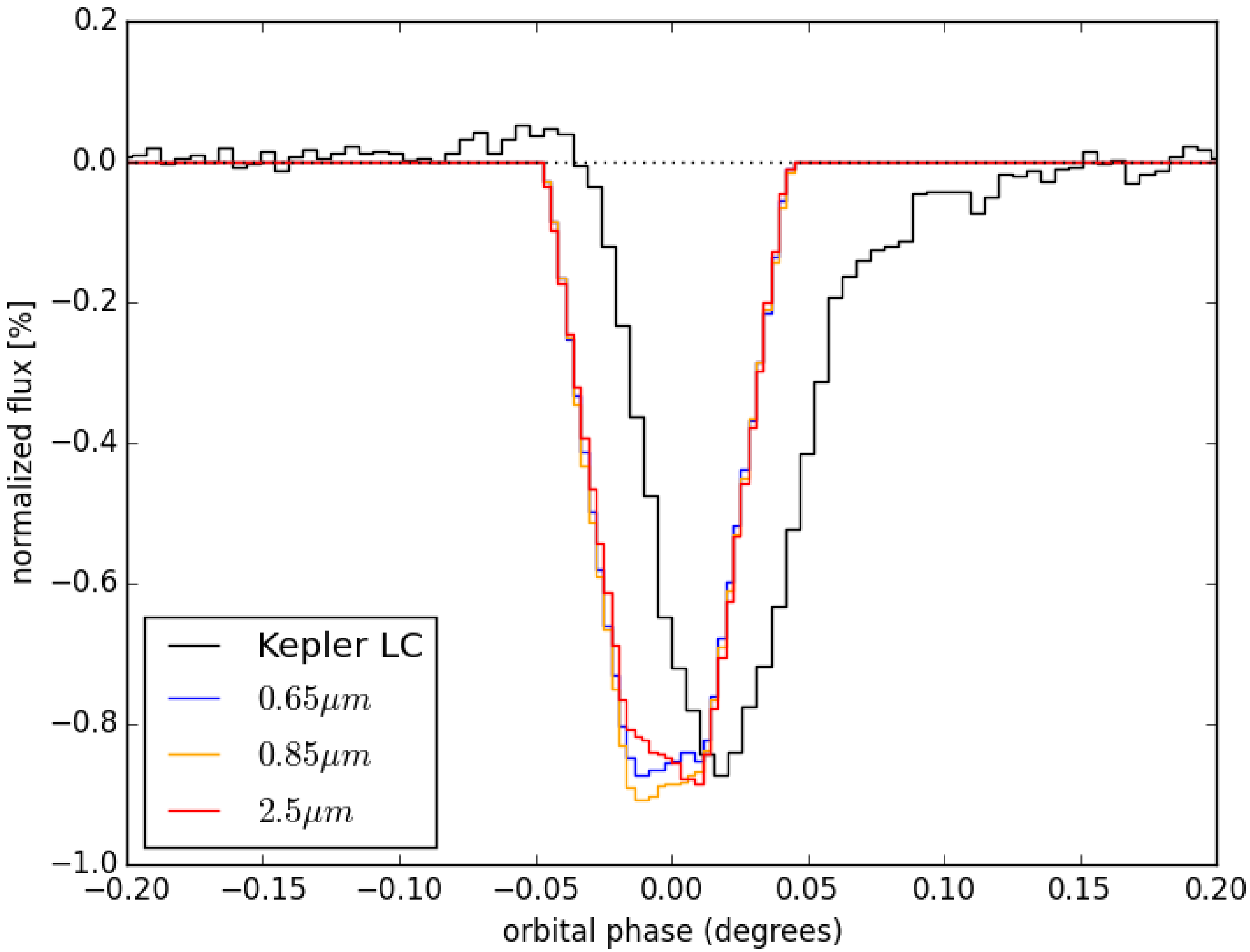


Colour Particle radius



- Particles in front of the planet
- Very shot tails is starting to form from sublimated particles

Transit light curve for large particles (scaled by 14x)



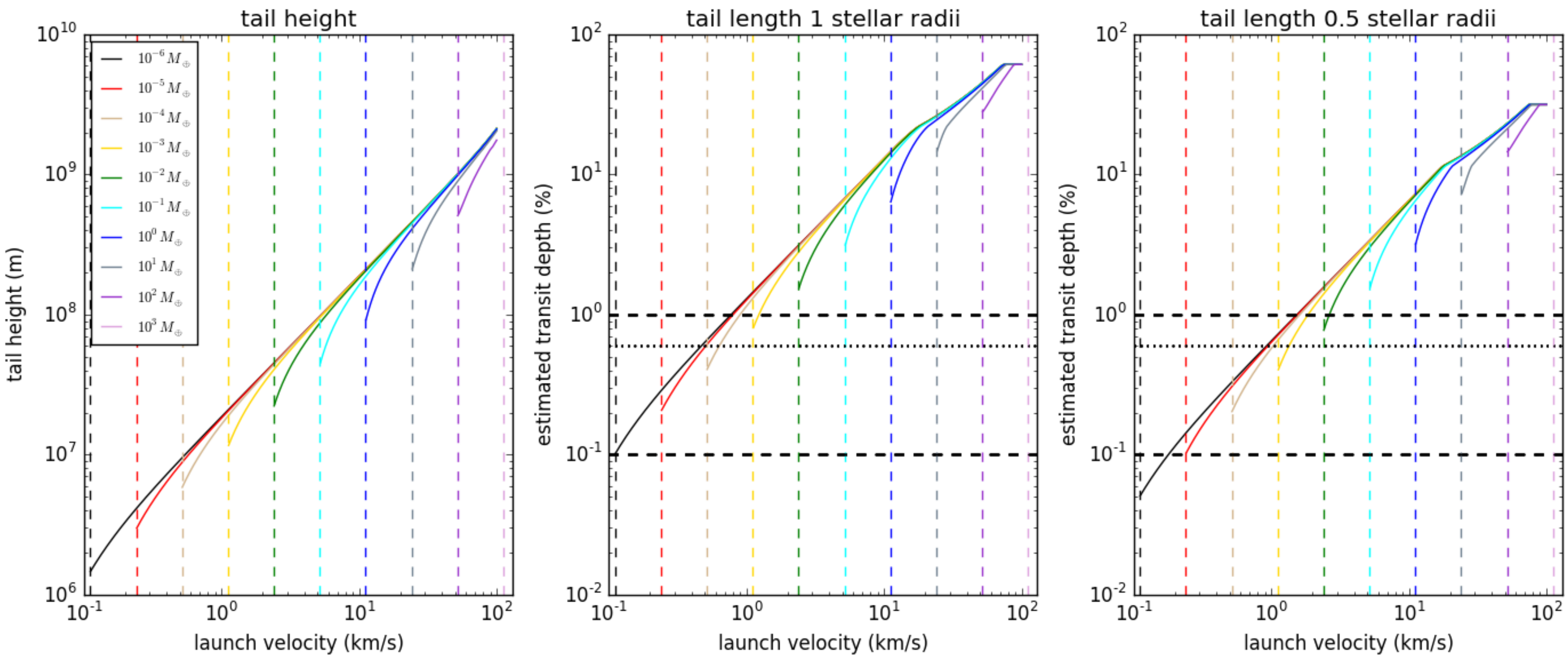
- Very short tail
  - Symmetric shape
  - Shallow transit (scaled by 14x)
- No wavelength dependence
- Particles must be $\sim 1\mu m$

Absorption from an optically thick tail

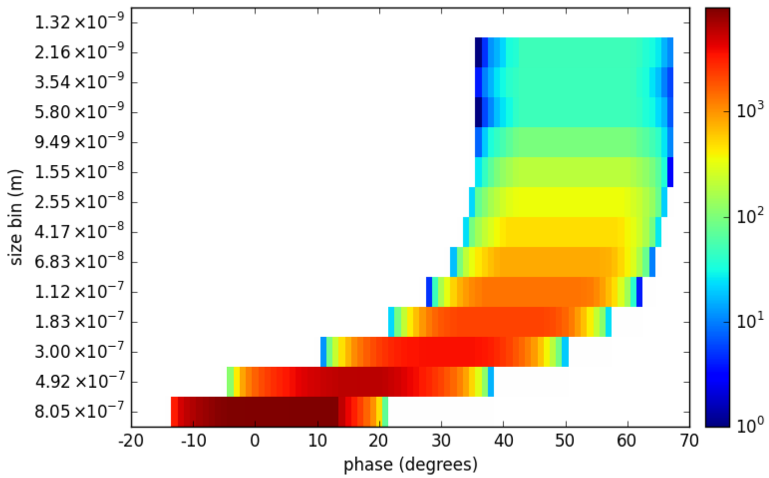
- Transit depth depends on
  - Tail length, l
  - Tail height, h
  - Tail transmission, $T = (1 - f)$
  - with $0 < f < 1$ where $f = 1$ for an optically thick tail and $f < 1$ for an optically thin tail

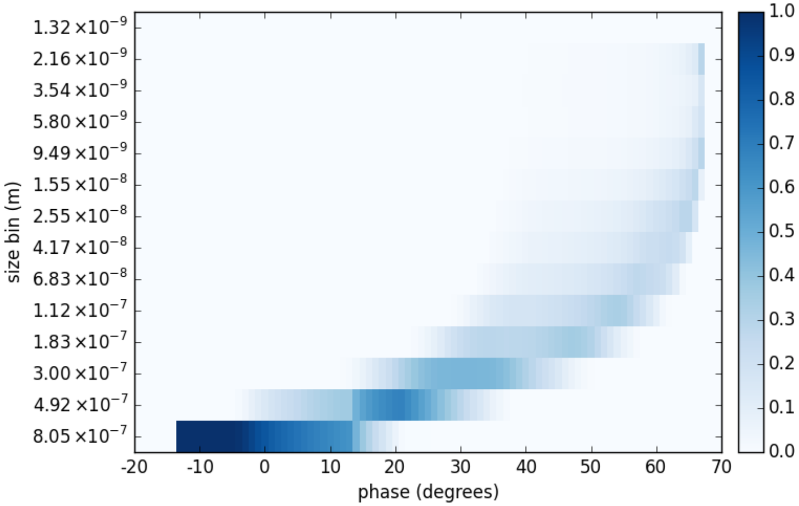
- For optically thick and long tail
  - Decreasing tail height at waist decreases absorption

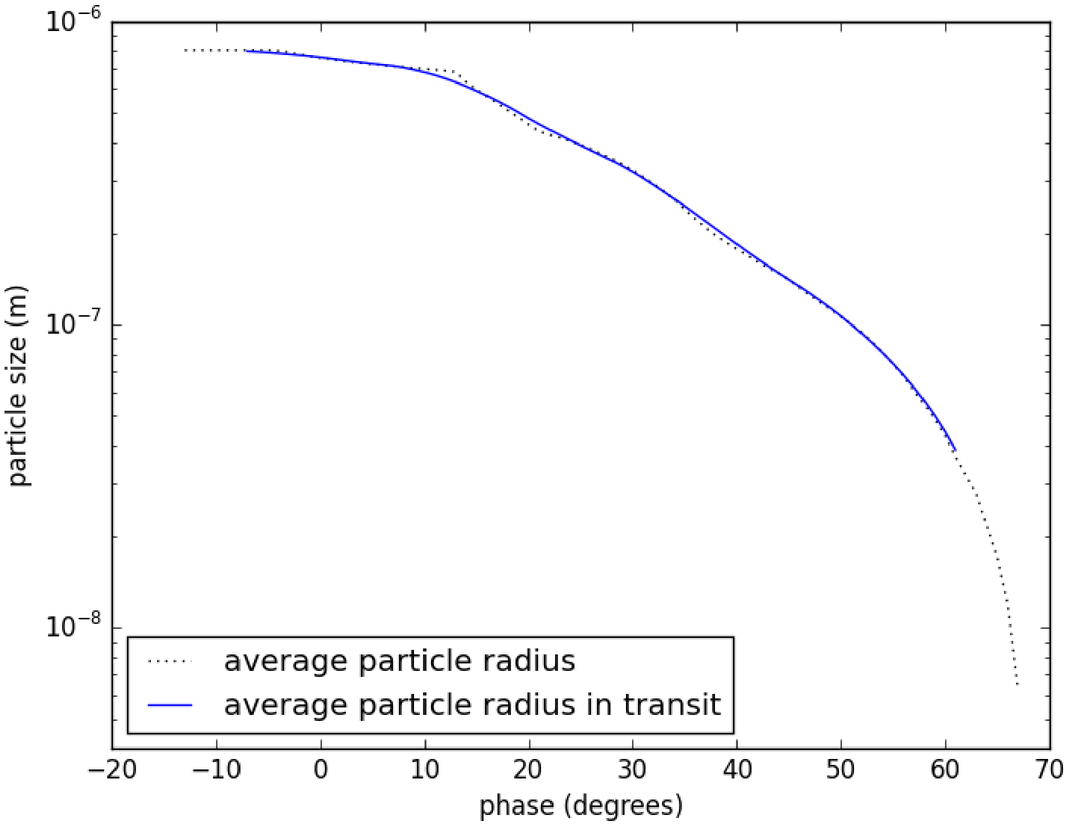
Tail heights with a larger velocity and planet mass range



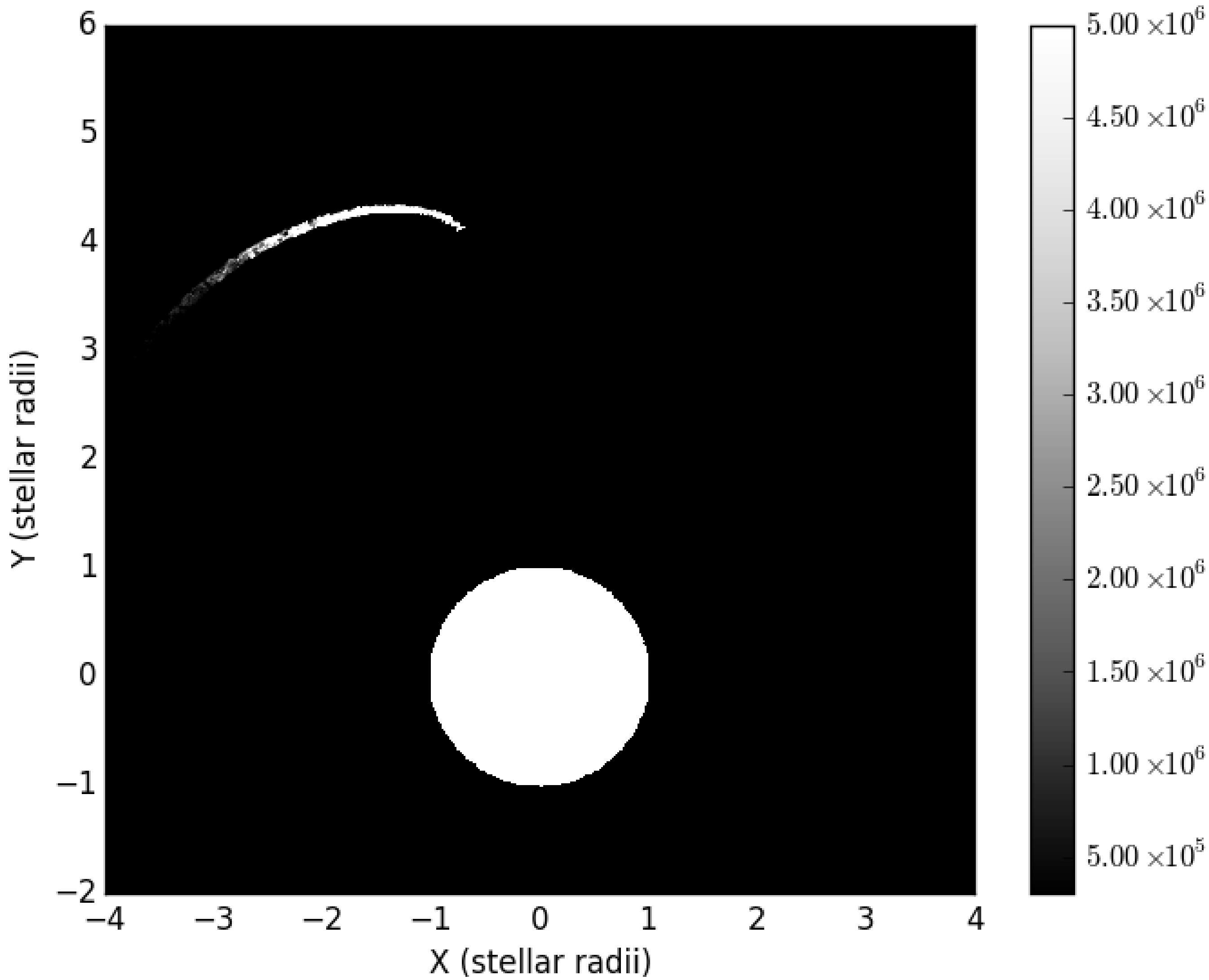
Particle distributions for optically thick tail







Ray tracing top-down

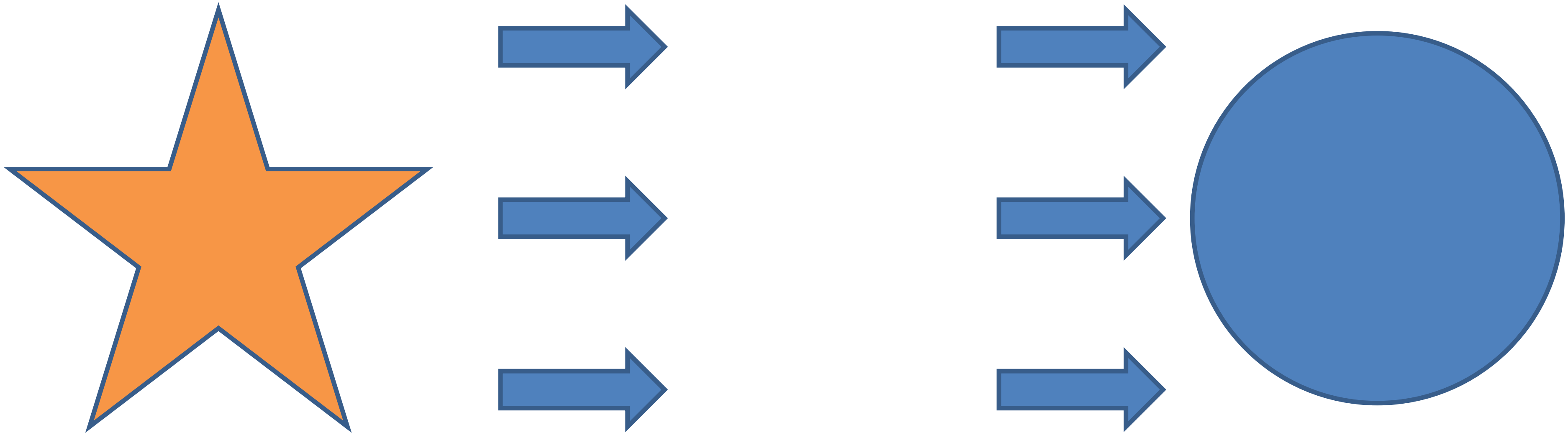


Dust ejection mechanism

- Self limiting cycle
  - Simulated with 1D hydrodynamic modes by Perez-Becker & Chiang (2013)
- Needs to be punctuated with unpredictable outbursts
  - Consecutive transit depths are uncorrelated

Dust ejection mechanism: limiting cycle

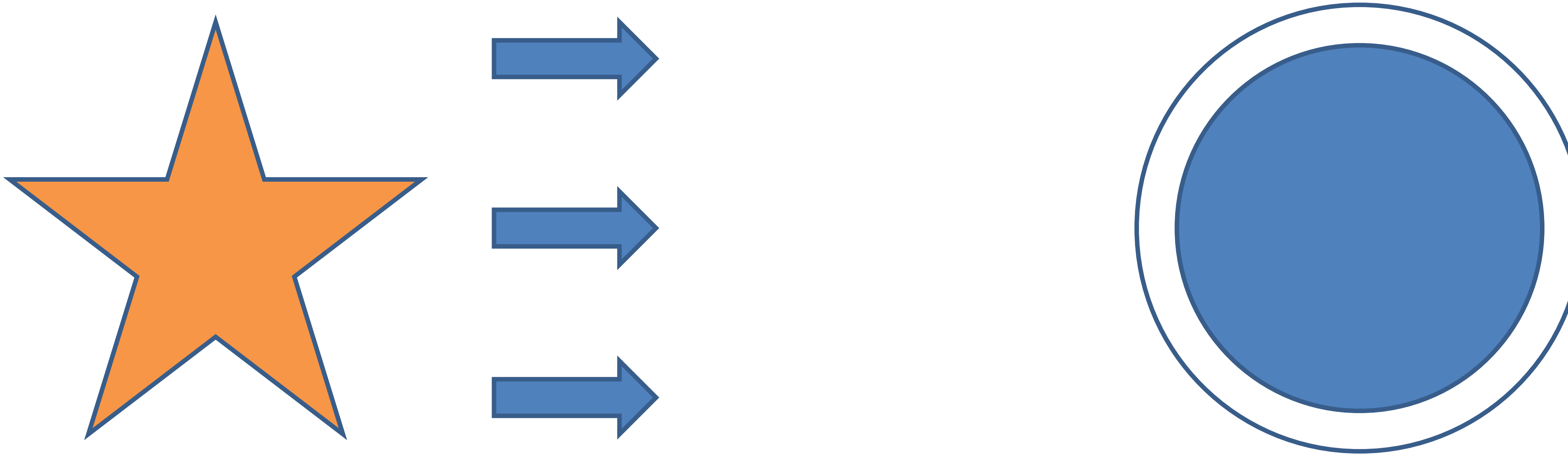
High flux on surface of planet



Has been simulated with 1D hydrodynamic modes by Perez-Becker & Chiang (2013)

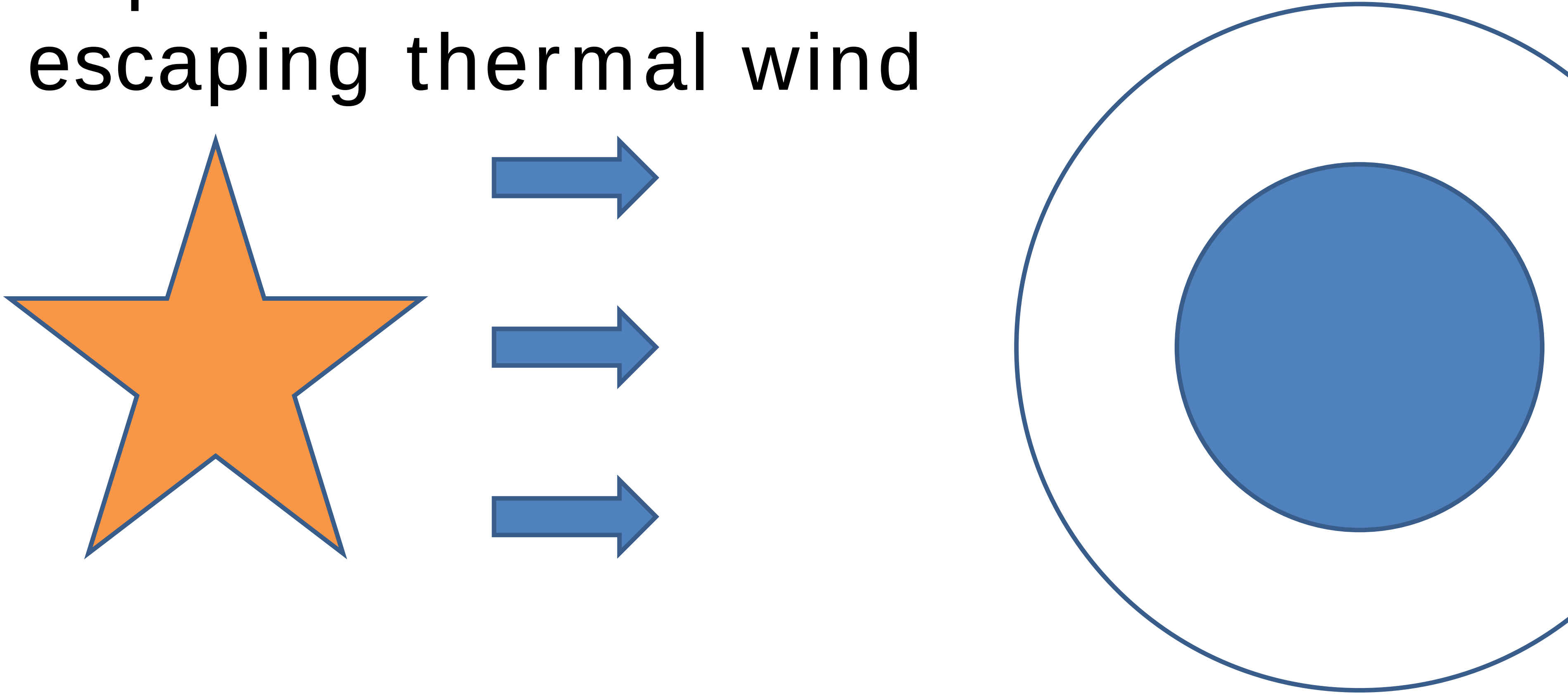
Dust ejection mechanism

Vaporises surface and drives an escaping thermal wind



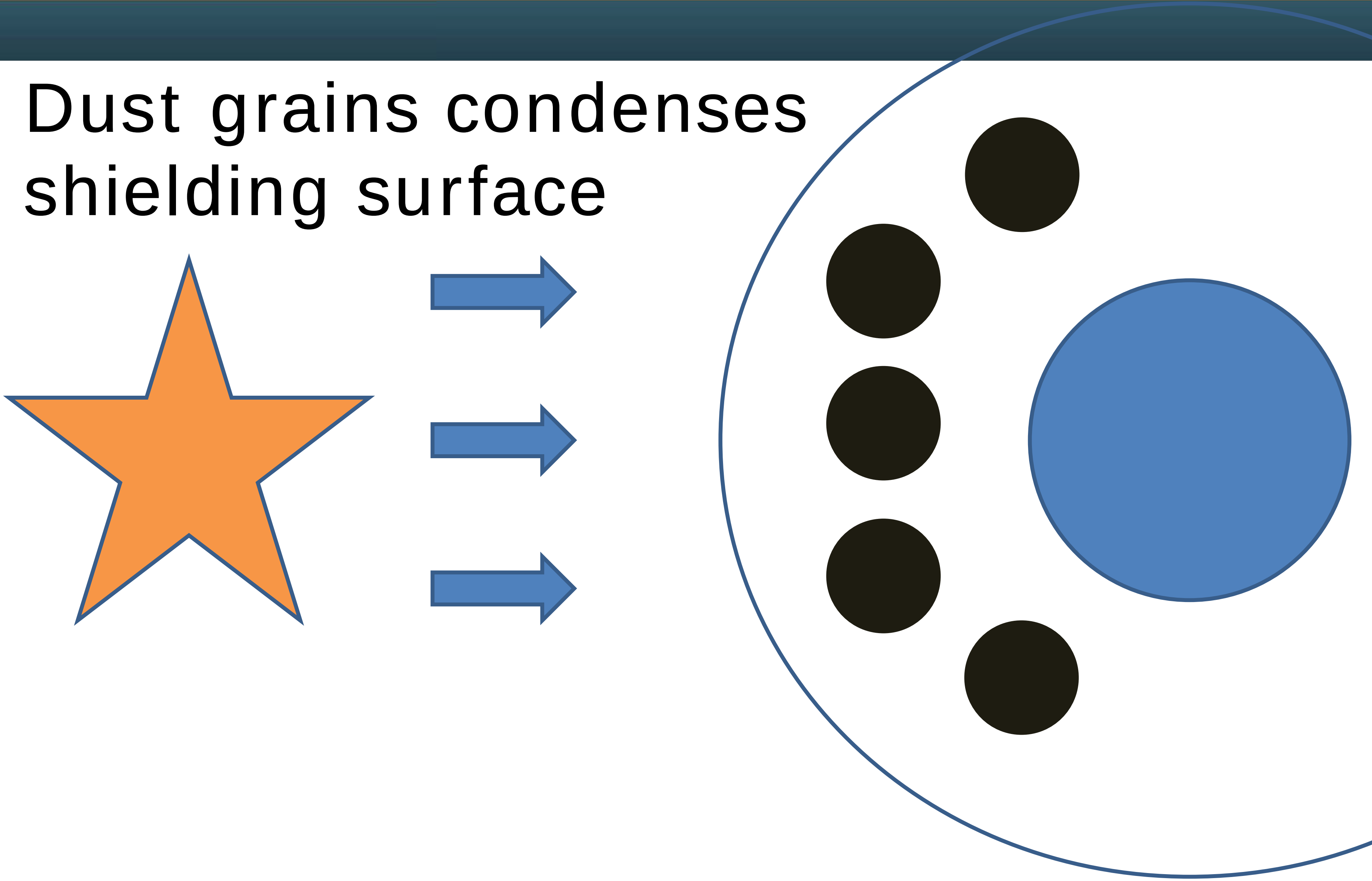
Dust ejection mechanism

Vaporises surface and drives an escaping thermal wind



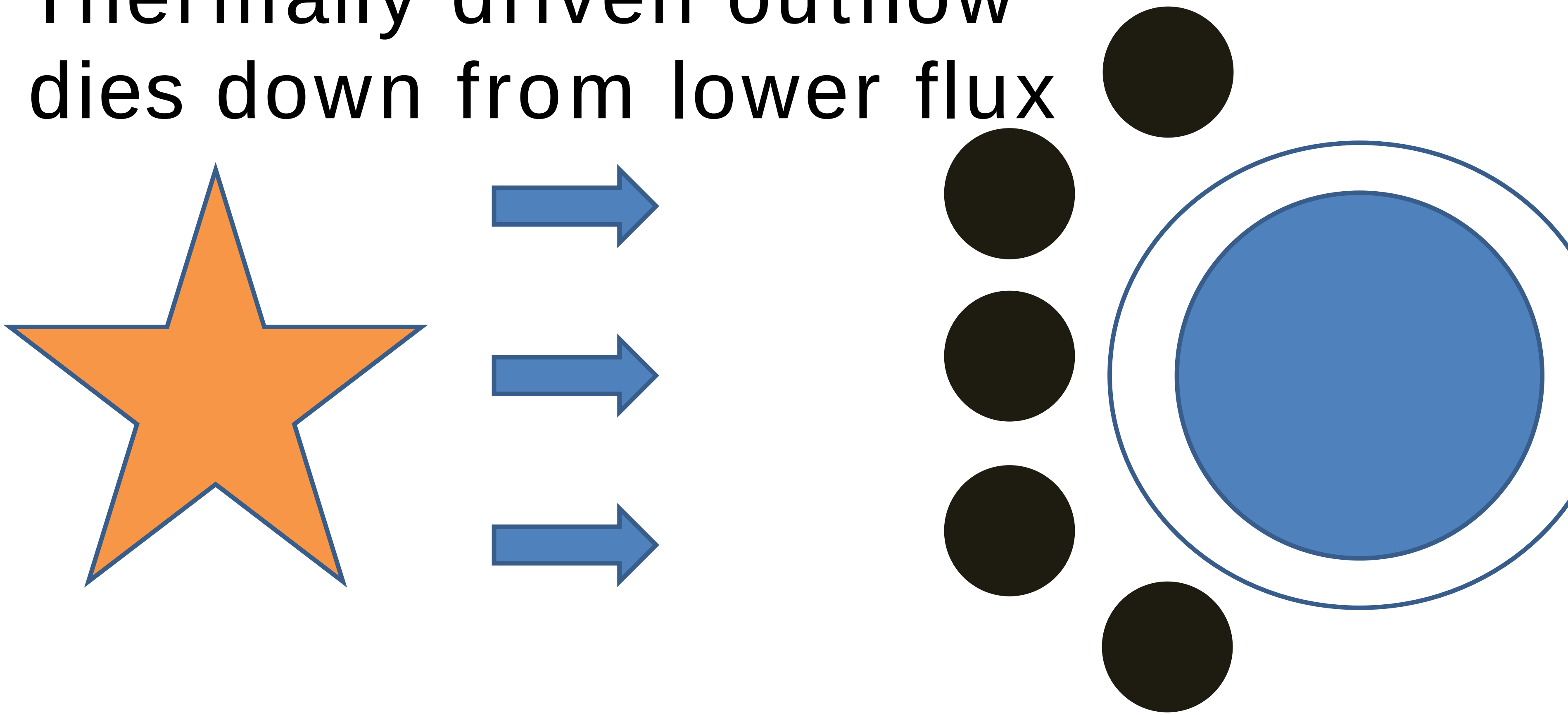
Dust ejection mechanism

Dust grains condenses shielding surface



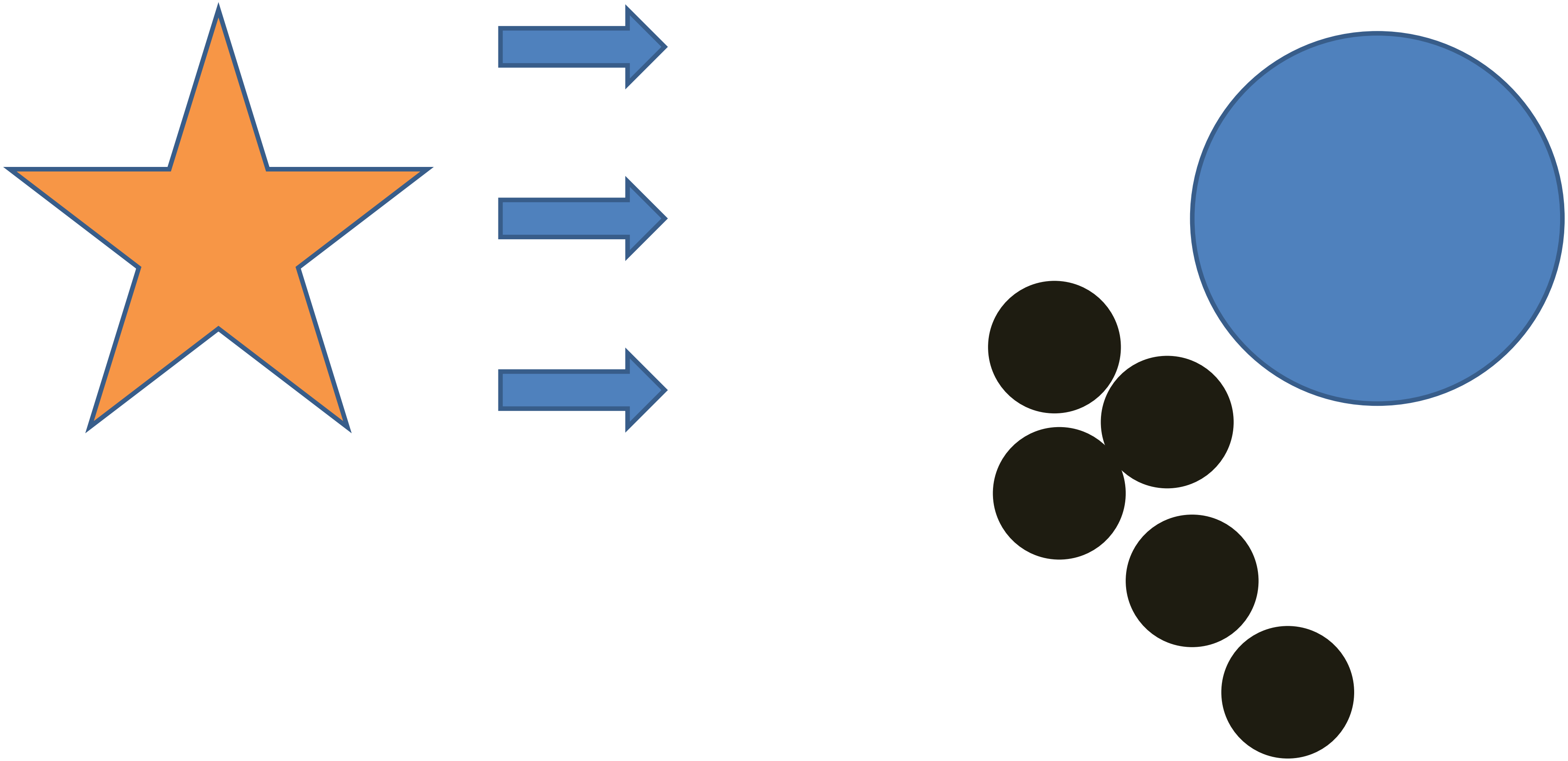
Dust ejection mechanism

Thermally driven outflow dies down from lower flux



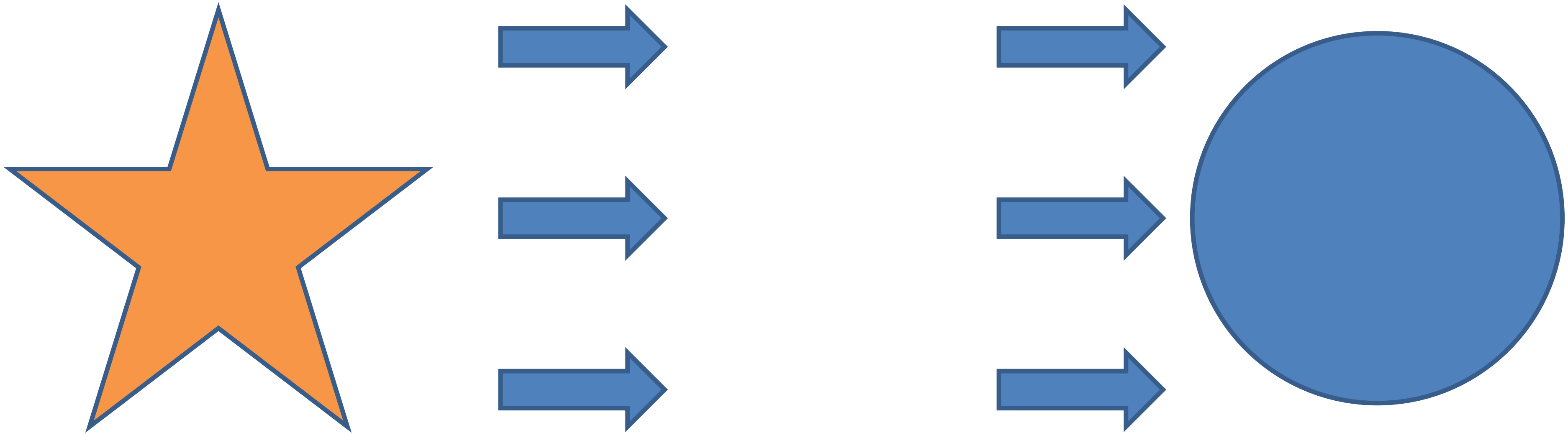
Dust ejection mechanism

Dust particles sublimate or are pushed away by radiation pressure



Dust ejection mechanism

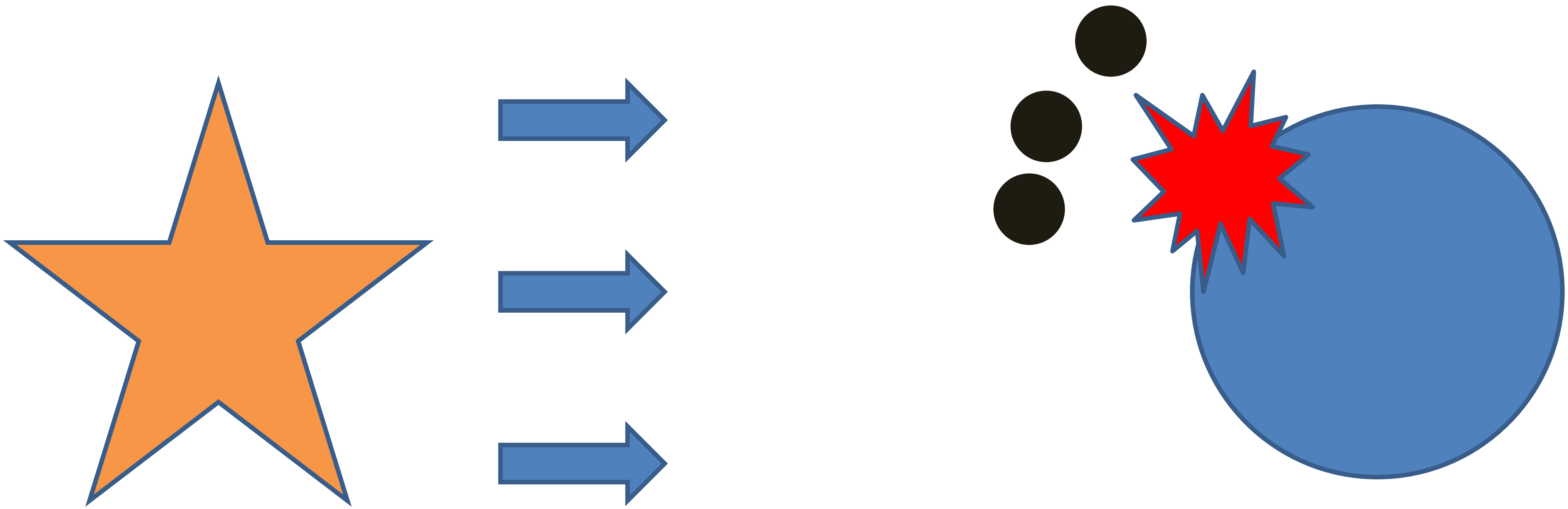
Allowing the cycle to star again



However, this would lead to a regular transit depth variation

Dust ejection mechanism

Unpredictable outbursts required



Possibly of geological or volcanic origin. Suggestions are welcome!