Astronomical Institute of the Czech Academy of Sciences

Ablation of small iron meteoroids
first results

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talk outline

- introduction
- mathematical model
- boiling of iron drop
- breakup of liquid iron drop
- immediate removal of liquid layer
- conclusions

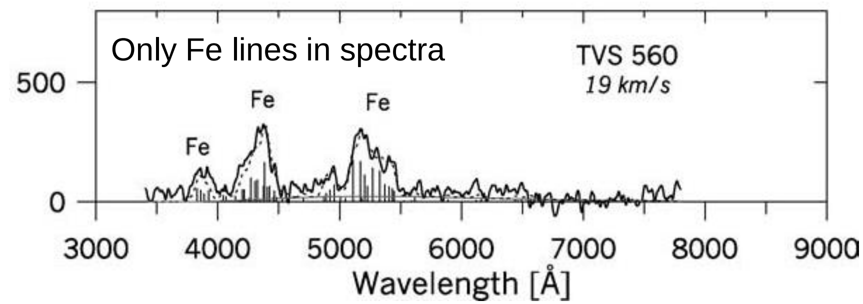
Small iron meteoroids

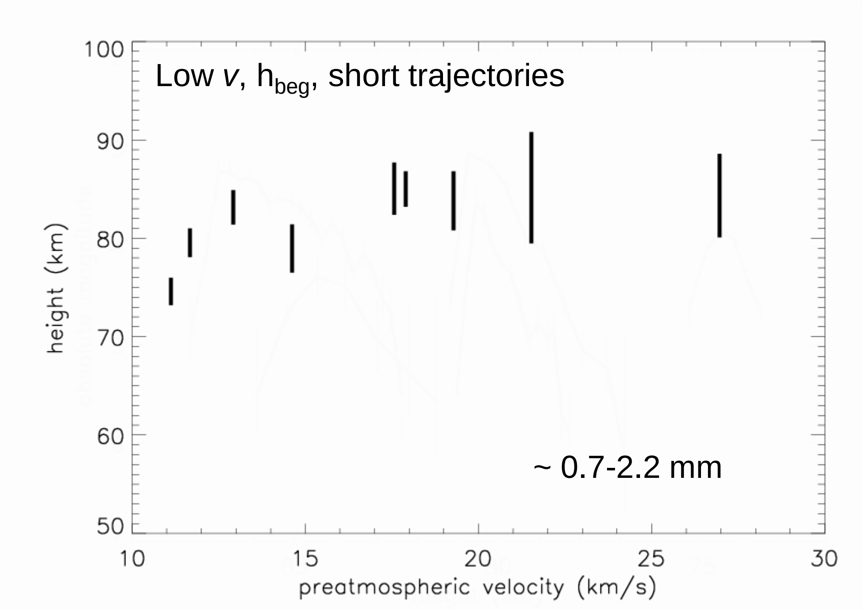
Borovička, J. et al. (2005), *Icarus*, **174**, 15-30

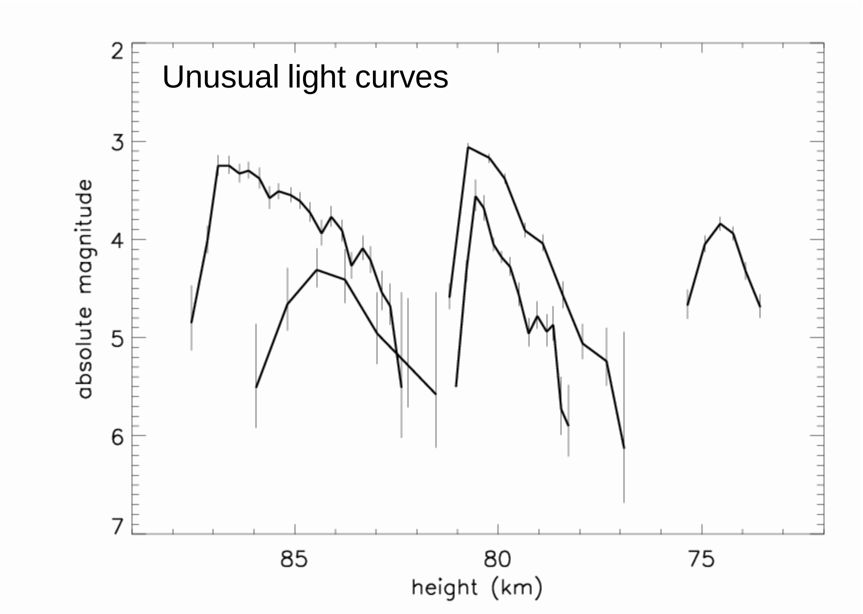
Hypothesis:

- Fe meteoroid – high thermal conductivity
- throughout heating and complete melting
- fast ablation of liquid iron drop

Borovička et al. (2005), fig. 7





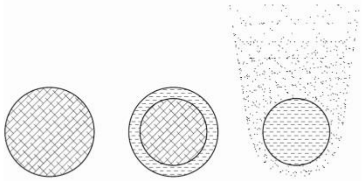


The model

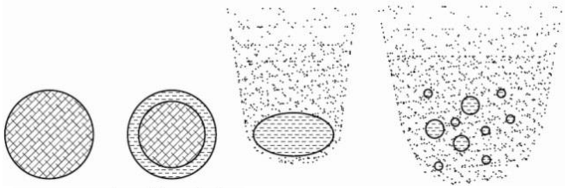
- Spherical meteoroid,
- Radially symmetric temperature field
- Thermophysical parameters for pure iron (not Ni-Fe alloy, not oxides)
- Heat diffusion problem - numerically
- Deceleration of meteoroid
- Density of atmosphere: NRLMSISE
- Free molecular flow regime

- Ablation process

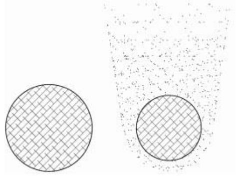
    1. Vaporization of liquid iron



    2. Breakup of liquid iron drop due to aerodynamic loading

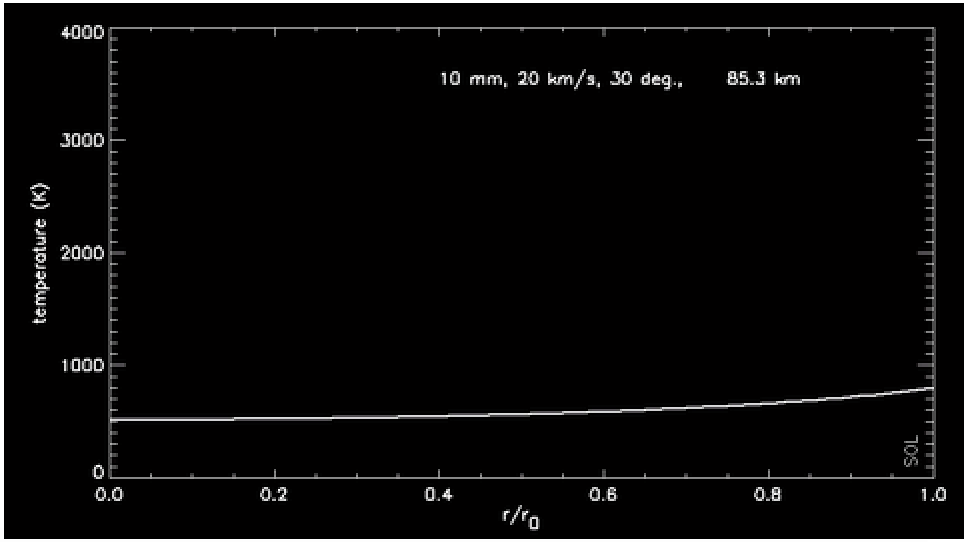


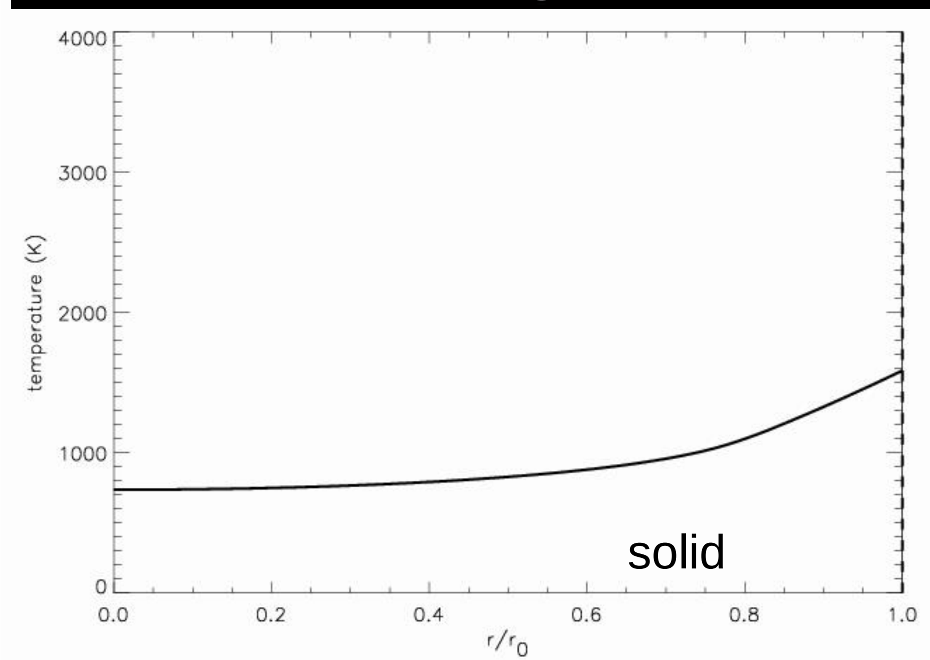
    3. Immediate removal of liquid layer from the meteoroid surface



Vaporization of liquid iron - model

example: temperature profile in 10mm meteoroid (too big!)





Preheating

Heat diffusion equation: $\rho c \dot{T} = \nabla \cdot (K \nabla T)$

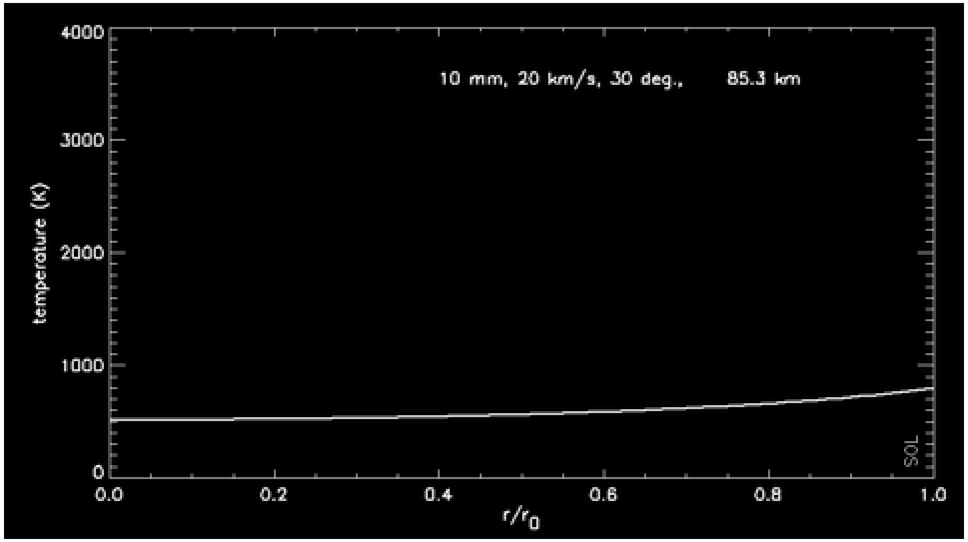
Boundary condition in the center: $\nabla T = 0$

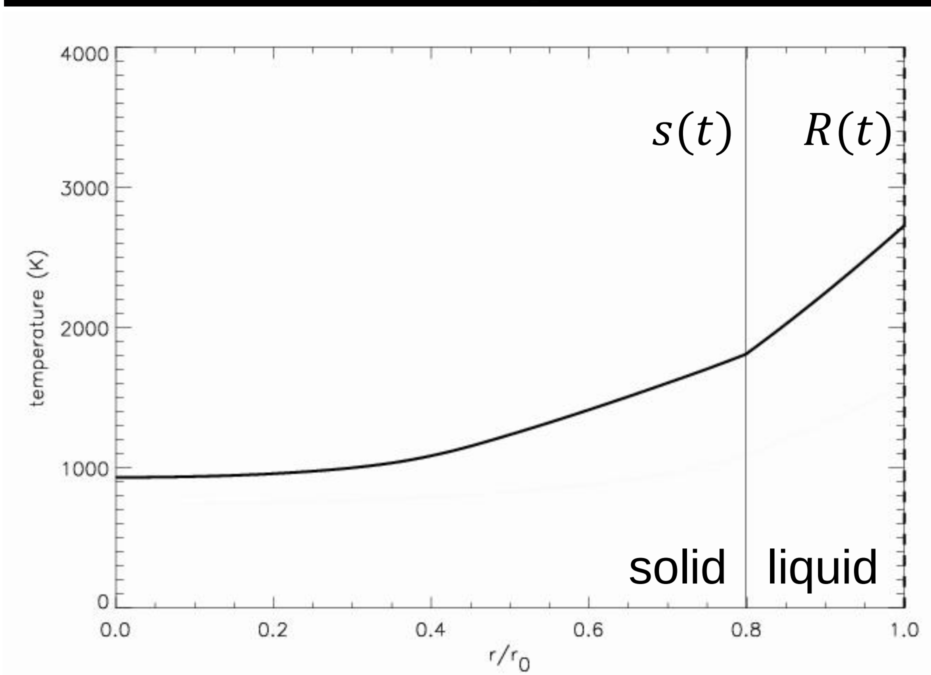
Surface boundary condition:

$$K \nabla T + \varepsilon \sigma T^4 = \frac{1}{8} \Lambda \rho_A v^3$$

Vaporization of liquid iron - model

example: temperature profile in 10mm meteoroid (too big!)





Melting… $T\big(R(t)\big) \geq T_{\text{fusion}} = 1811\text{K}$

Heat diffusion equation: $\rho c\dot{T} = \nabla\cdot(K\nabla T)$

Boundary condition in the center: $\nabla T = 0$

Moving phase boundary $s(t)$:

$$\ell_F \rho_S \dot{s} = K_S \nabla T|_{s-} - K_L \nabla T|_{s+}$$
$$T(s(t)) = T_{\text{fusion}}$$

Evaporation rate (Hertz-Knudsen equation):

$$\dot{m} = -\eta p_0 \sqrt{\frac{M}{2\pi\bar{R}\mathrm{T}}}\, 4\pi R^2$$

Surface boundary condition:

$$K\nabla T + \varepsilon\sigma T^4 = \frac{1}{8}\Lambda\rho_A v^3 + \dot{m}\ell_V$$

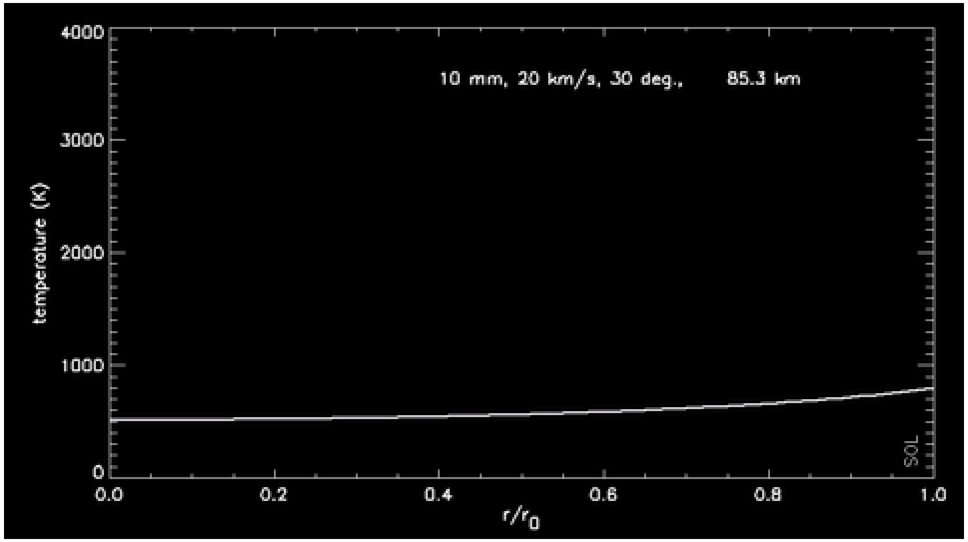
p_0(T) – vapor pressure

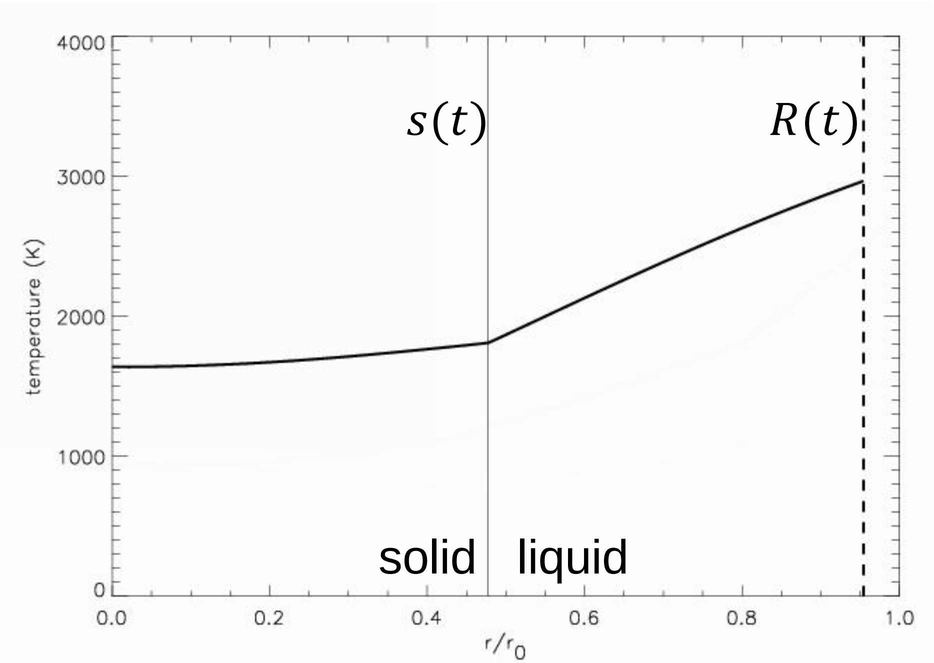
ℓ_F – latent heat of fusion

$\ell_V(T)$ – latent heat of vaporization

Vaporization of liquid iron - model

example: temperature profile in 10mm meteoroid (too big!)





<u>Boiling</u>… $T\big(R(t)\big) = T_{\text{boiling}}(p)$

Heat diffusion equation: $\rho c\dot{T} = \nabla\cdot(K\nabla T)$

Boundary condition in the center: $\nabla T = 0$

Moving phase boundary $s(t)$:

$$\ell_F \rho_S \dot{s} = K_S \nabla T|_{s-} - K_L \nabla T|_{s+}$$
$$T(s(t)) = T_{\text{fusion}}$$

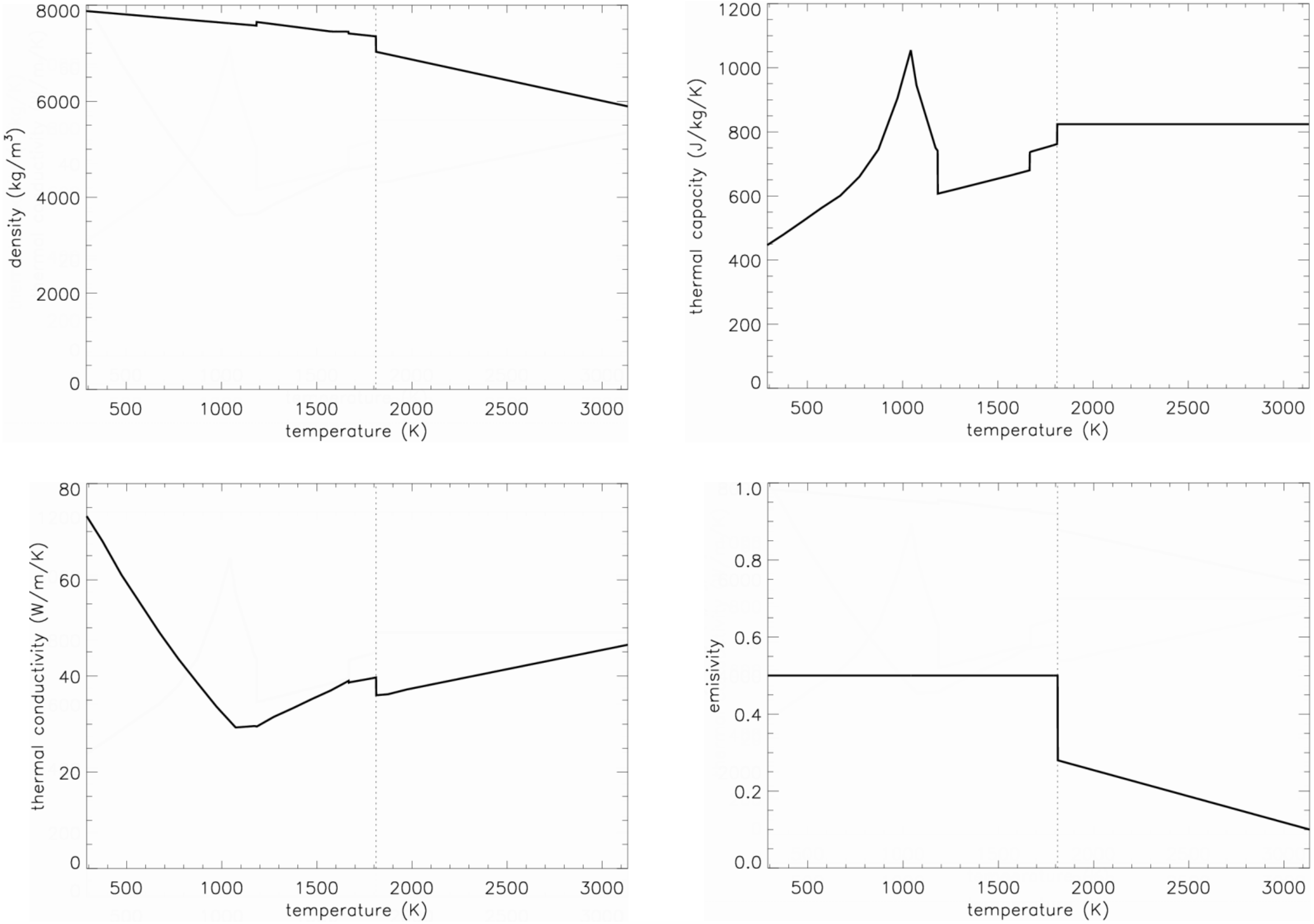
Evaporation rate – from surface boundary condition:

$$\dot{m} = -\frac{1}{\ell_V}\left(\frac{1}{8}\Lambda\rho_A v^3 - K\nabla T - \varepsilon\sigma T^4\right)$$
$$T\big(R(t)\big) = T_{\text{boiling}}(p)$$

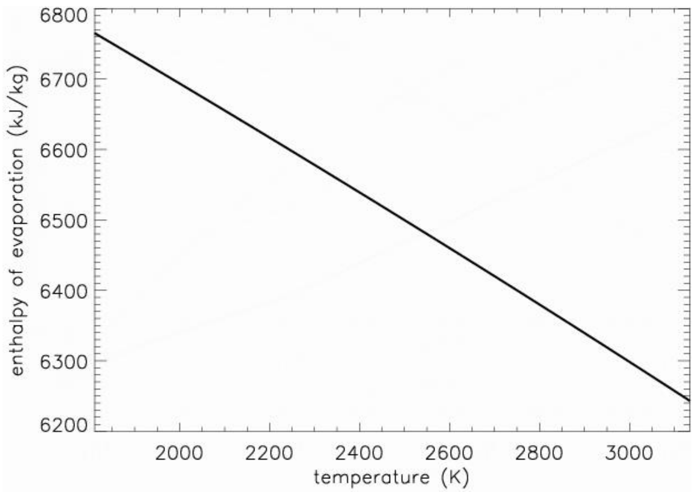
Radiation:

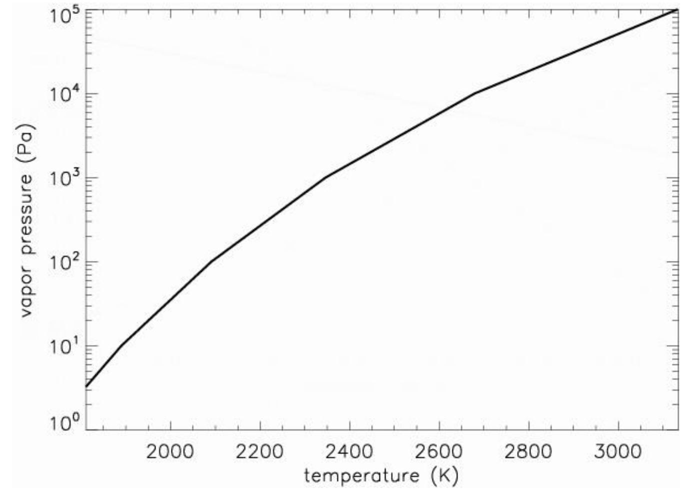
$$I = -\frac{1}{2}\tau\dot{m}v^2$$

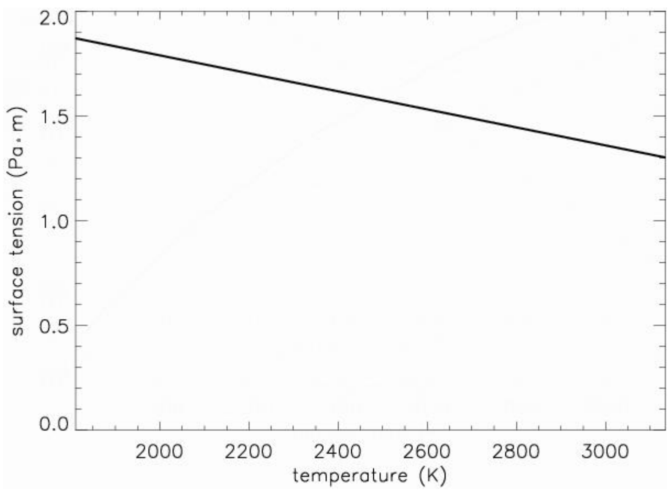
Iron material parameters

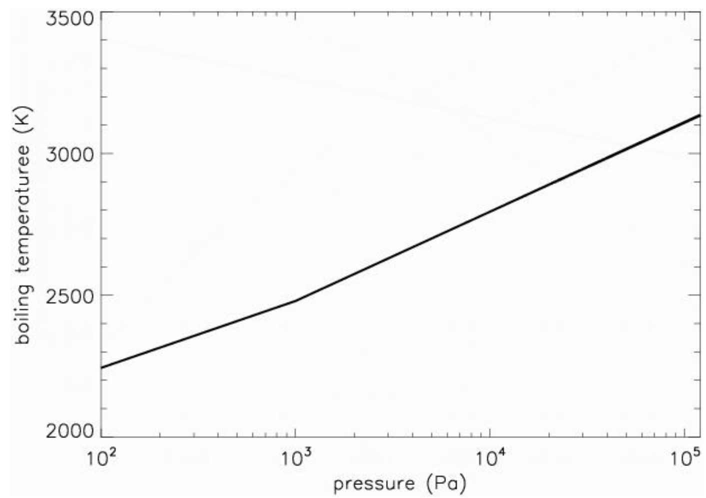


Iron material parameters

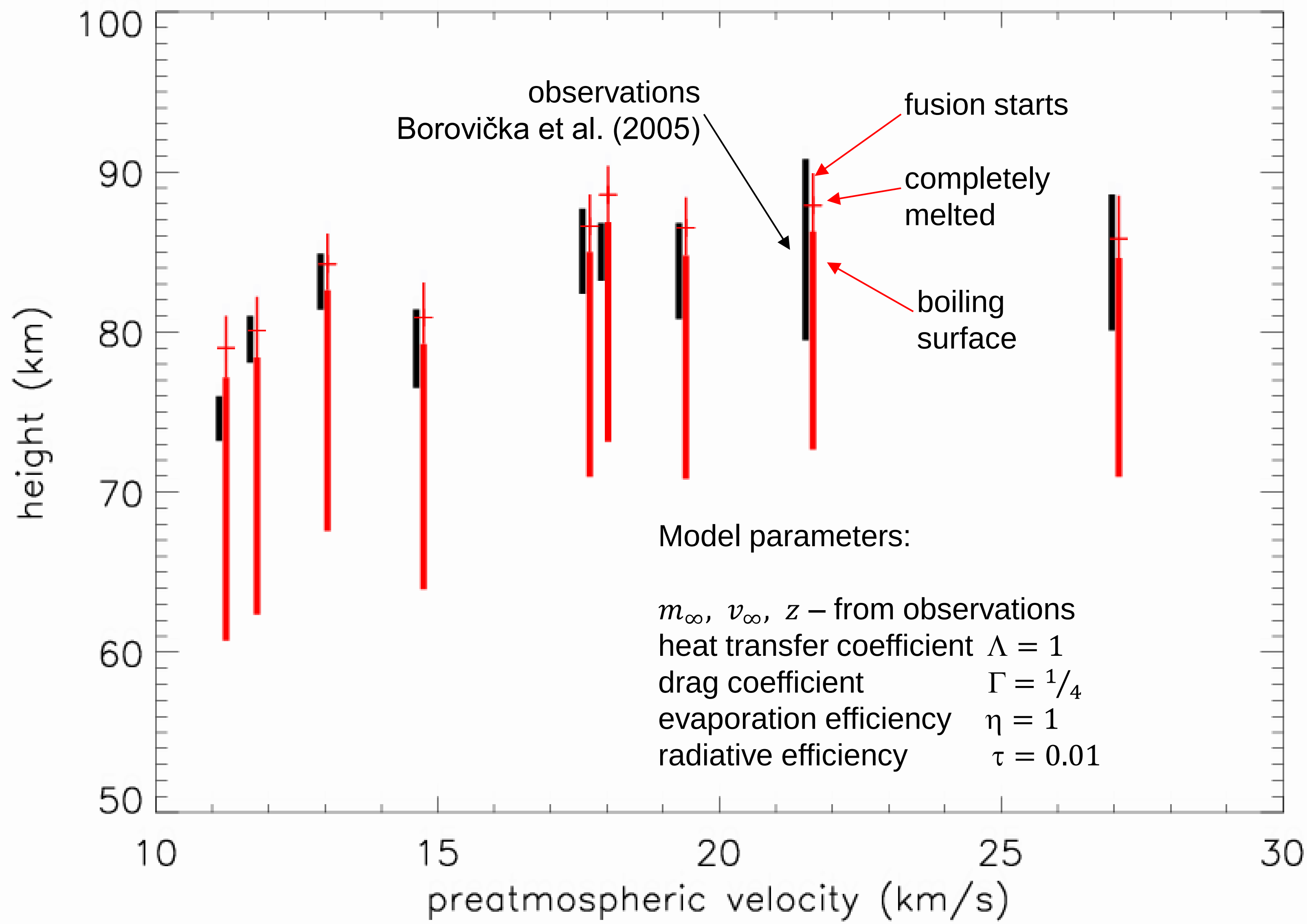






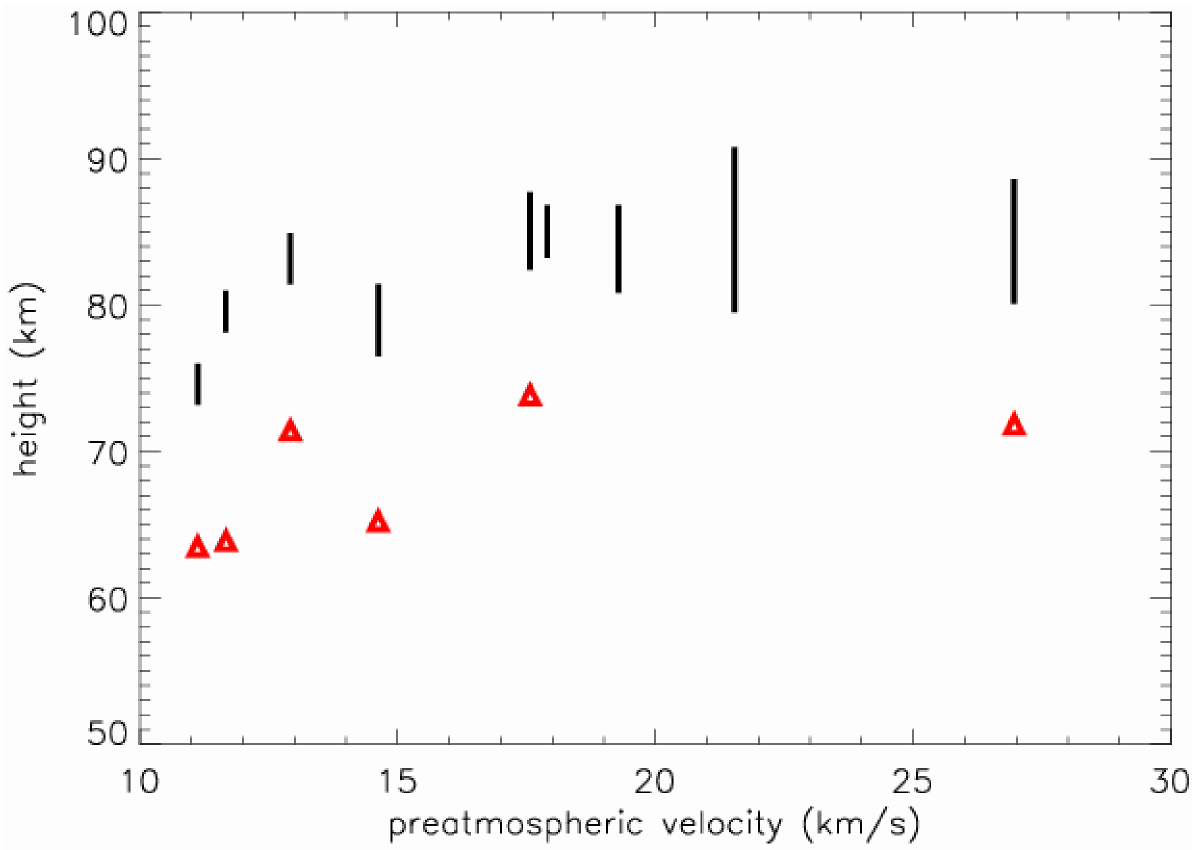


Vaporization of liquid iron - results



Breakup of liquid iron drop - results

- Due to aerodynamic loading
- Breakup conditions described by Weber number:



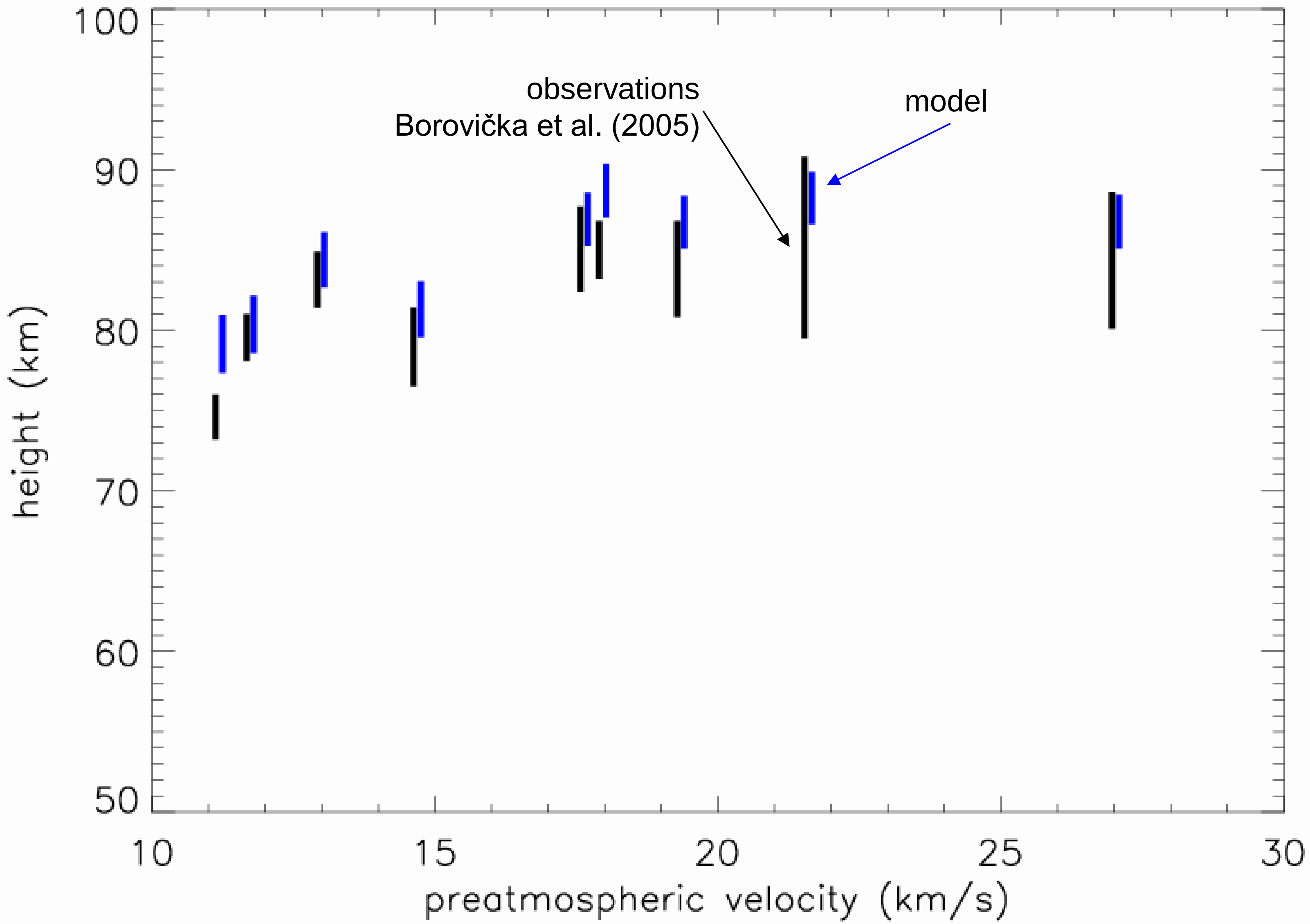
$$We = \frac{2R\rho v^2}{\sigma} \geq 12$$

$2R$ – drop size

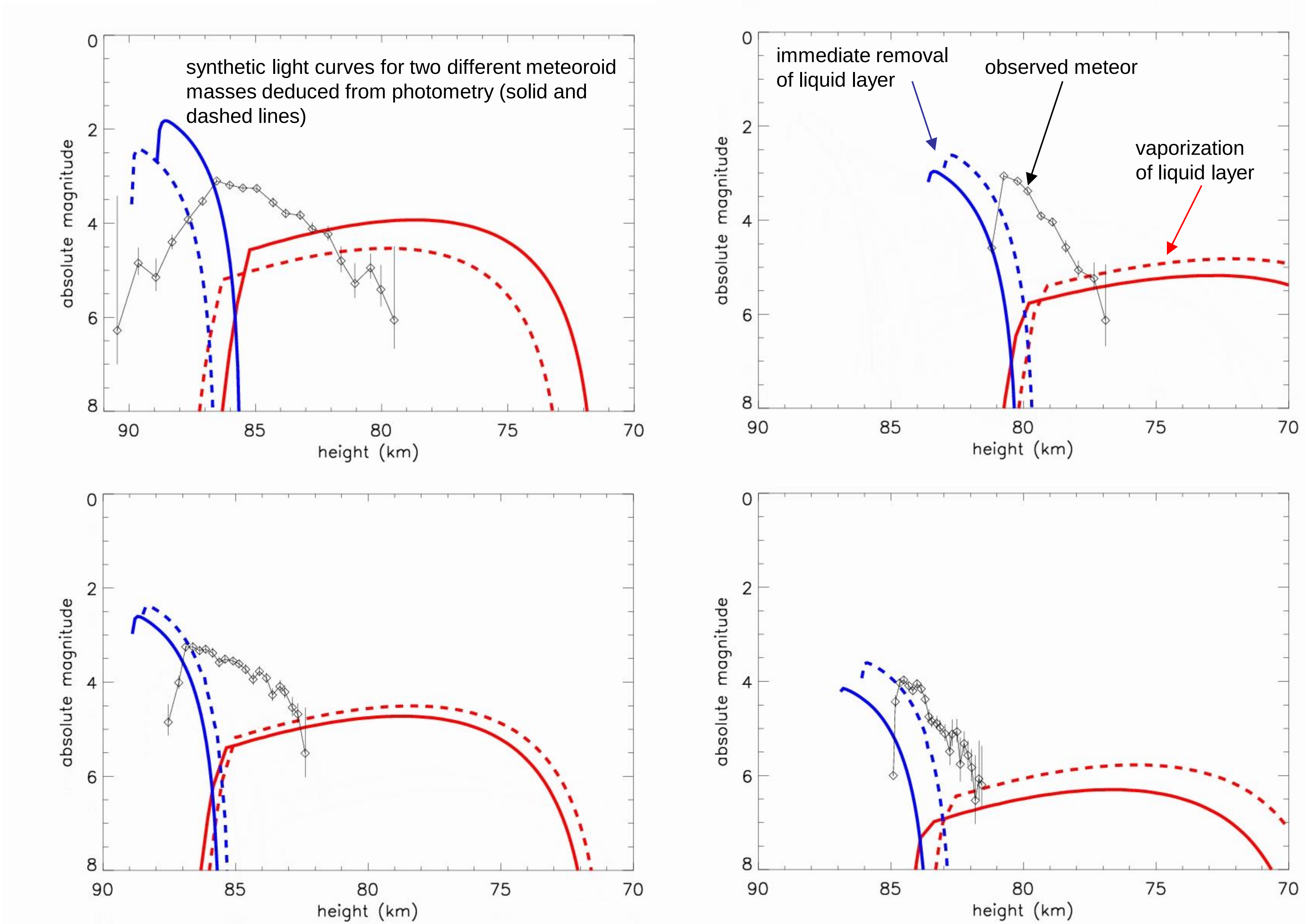
ρv^2 - dynamic pressure

σ - surface tension

Immediate removal of liquid layer - results



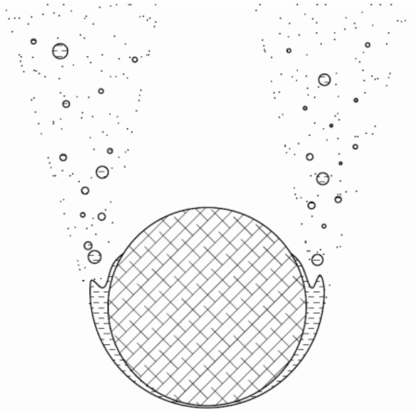
Light curves comparison



Conclusions + future work

- *Vaporization of liquid Fe drop* or *Breakup of liquid Fe drop* can not explain observed iron meteors (too slow or occurs too late).
- Immediate removal of liquid Fe layer – can explain come features

- We will focus on dynamics of layer of liquid Fe and its shedding from the meteoroid.



Assumed model improvements:

- Oxidation of molten layer
- Termophysical parameters for Ni-Fe alloy (and oxides) instead of pure Fe.
- Variation of model parameters (Λ, τ) and initial masses.

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