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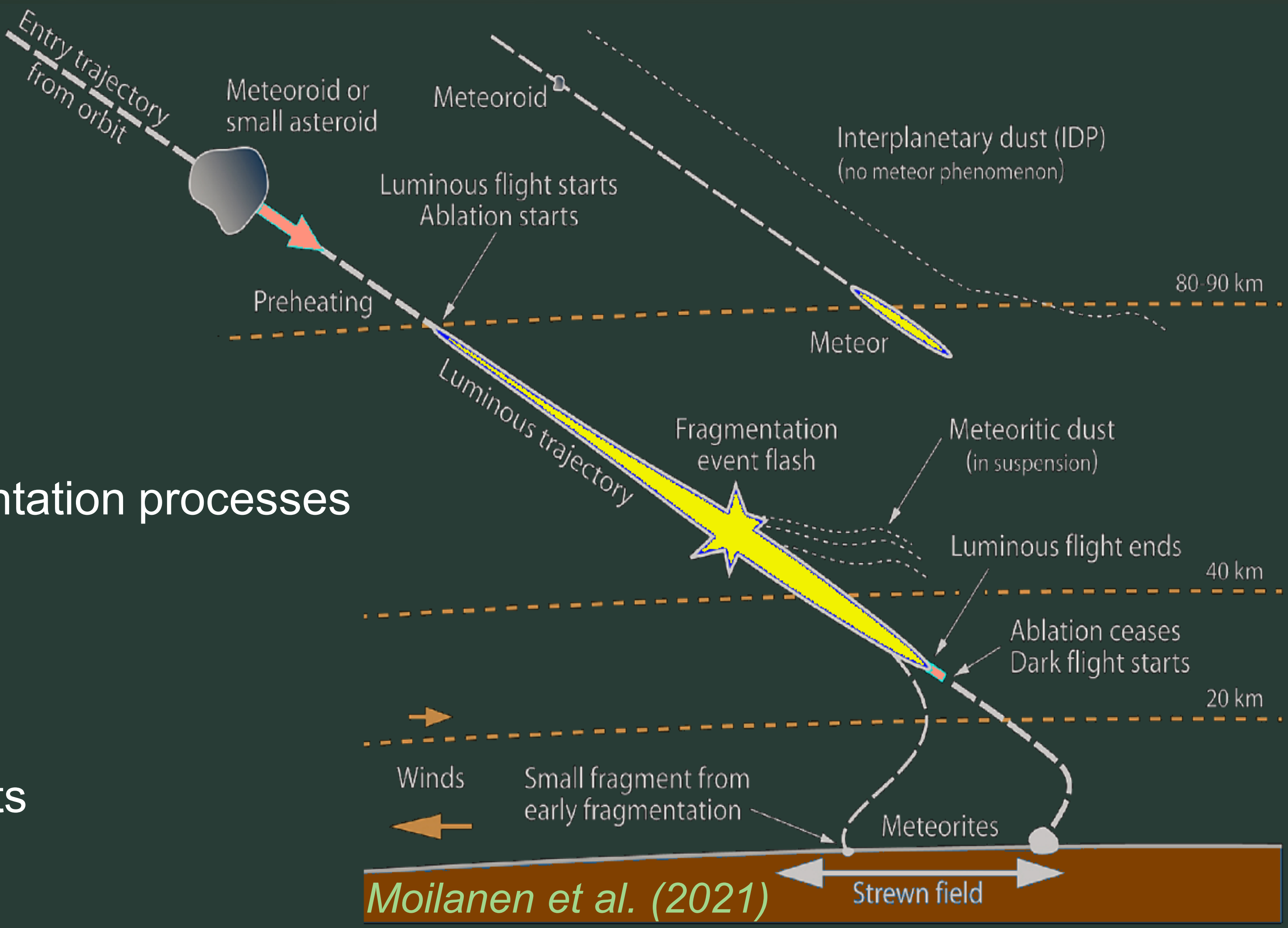
METEOROID DYNAMICS AND LIGHT EMISSION MODELING

USING GROSS-FRAGMENTATION AND DIFFERENTIAL ABLATION

Presentation outline

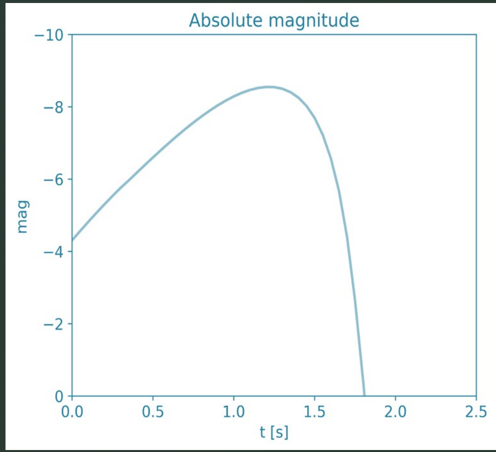
1. Light curves
2. Ablation and fragmentation processes
3. Differential ablation
4. Our model and results

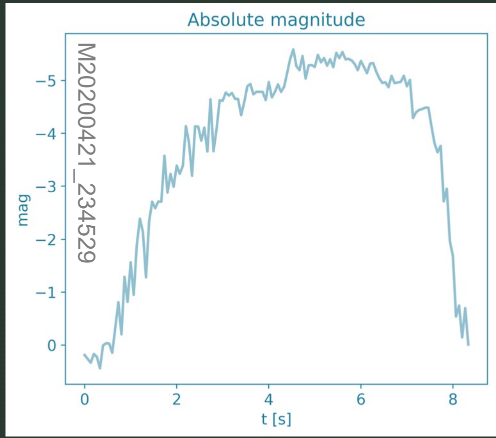


Moilanen et al. (2021)

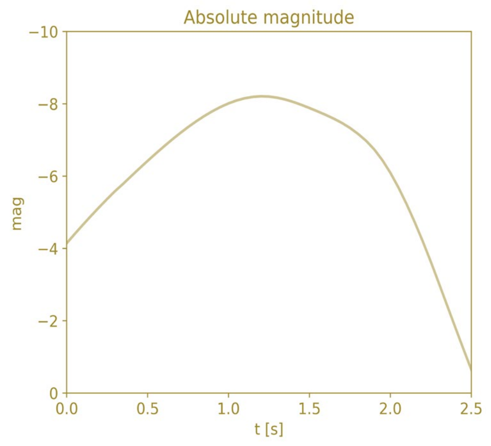
Light curves (LC)

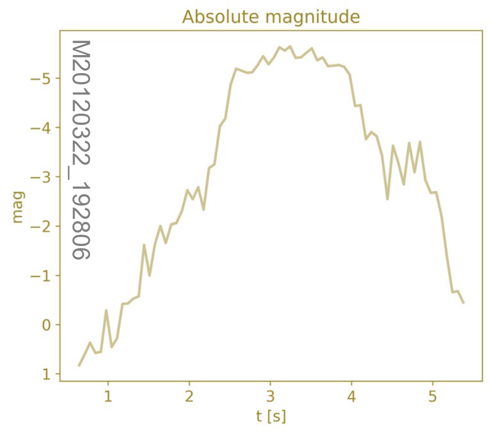
classical



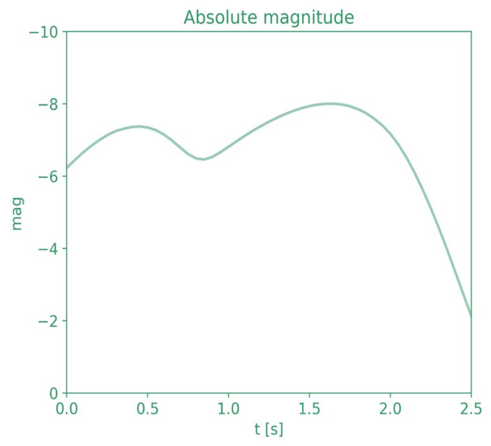


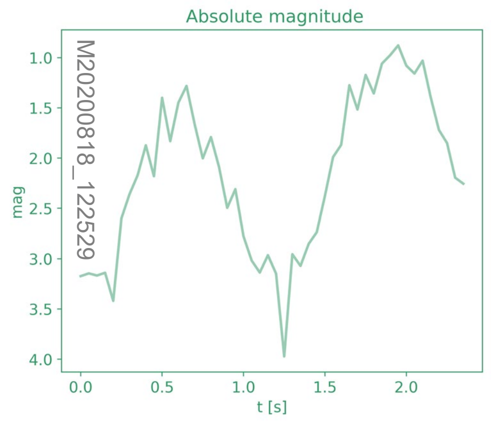
symmetrical



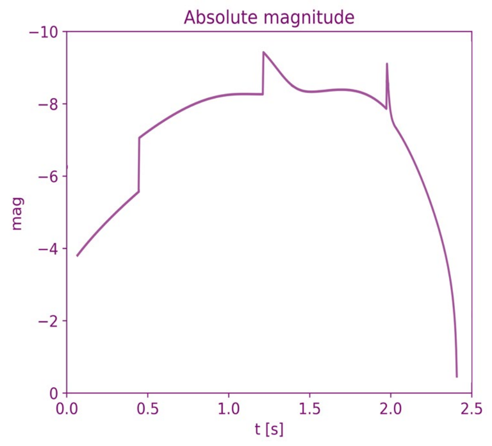


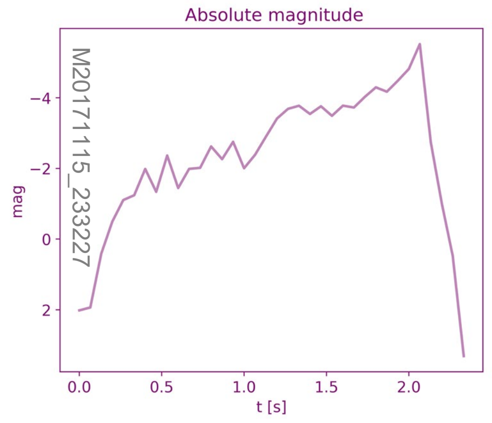
double-peaked





with flare-ups



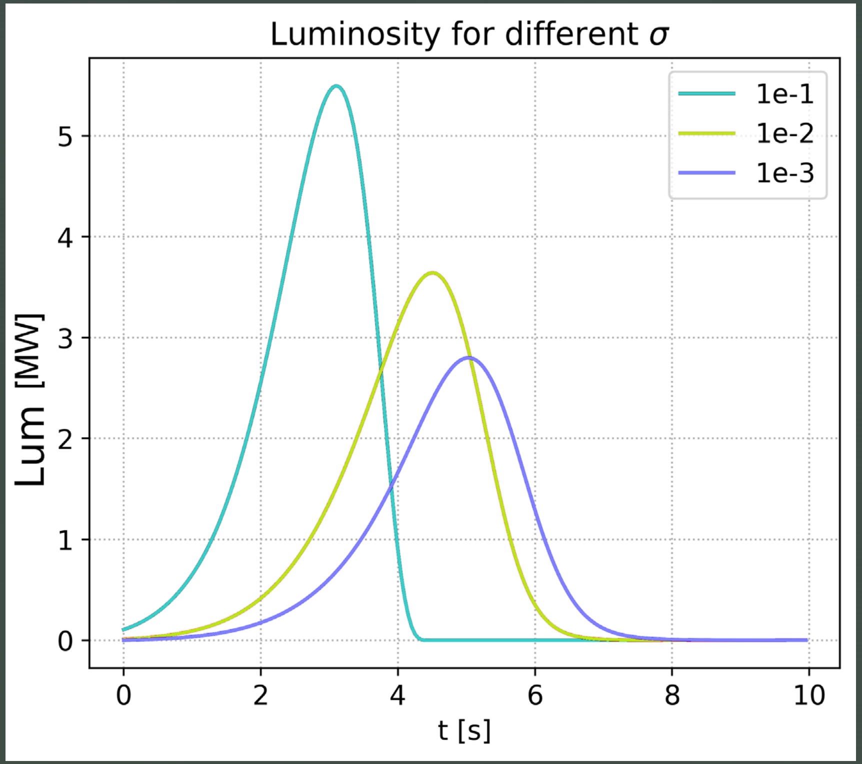


Fragmentation

- Detachment of solid parts,
  indicates the inner structure and strength
- From dust grains to large fragments
- Brightness increases due to larger surface area
- Gross-fragmentation – instantaneous;
  flares on LC
- Erosion – quasi-continuous;
  narrower symmetric LC

Ablation

- (Thermal) mass loss from the meteoroid‘s surface – melting and evaporation
- Rate given by σ [kg/MJ]
- Affects the brightness and duration of LC
- Connected to the material
- Intrinsic vs effective value
- Generalised to any mass loss process can „hide“ fragmentation



Weak cometary material

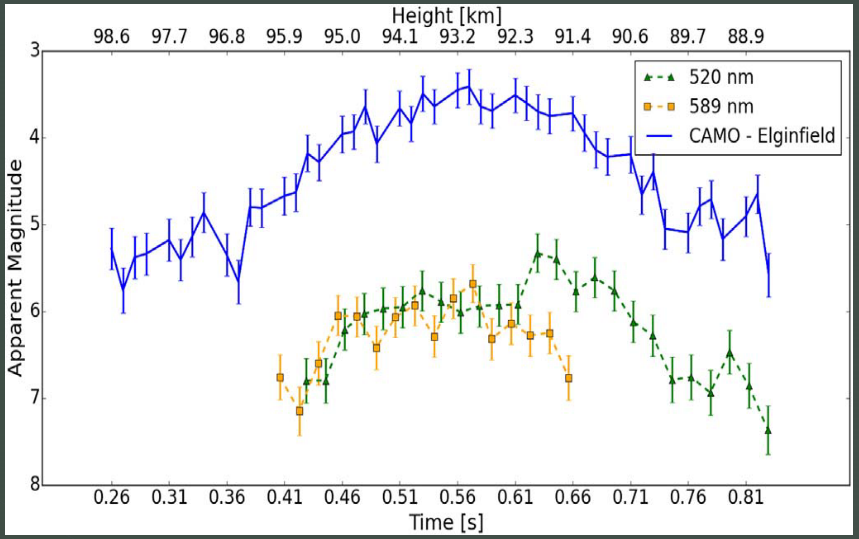
Asteroidal material

Intrinsic values

Differential ablation

- Inhomogeneous body – components with different ablation rates
- Wider LC or multiple maxima
- Dustball meteoroid model – grains held together by a „glue“
  - Roberts et al. (2013) – grains released in two stages; problem – insufficient erosion on LC
  - Subasinghe et al. (2019) – volatile „glue“ responsible for the early peak; problem – no evidence for a physical „glue“

Bloxam et al. (2017)



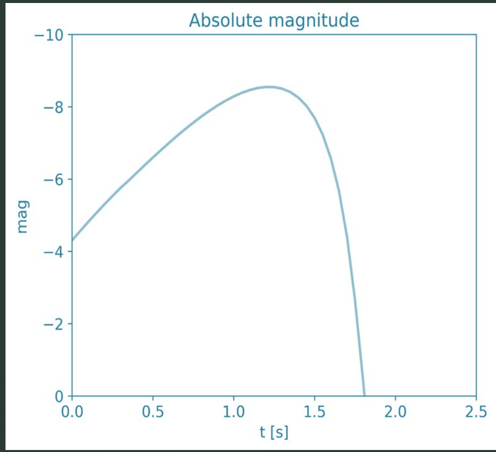
Overall LC

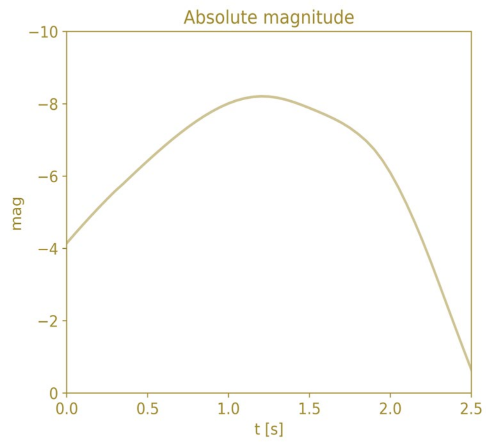
Sodium

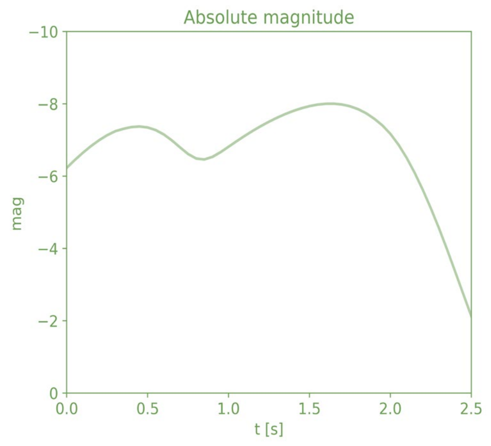
Magnesium

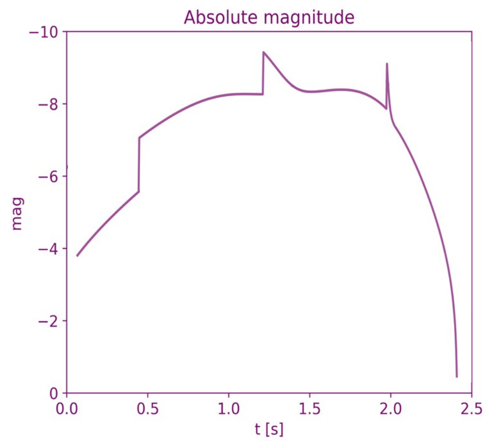
Light curves (LC)

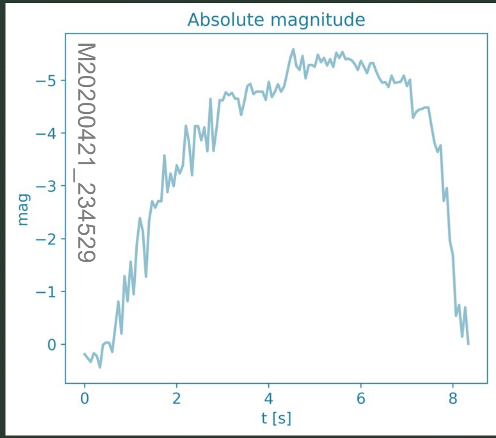
classical	symmetrical	double-peaked	with flare-ups
ablation	differential ablation / erosion	differential ablation / erosion	gross-fragmentation

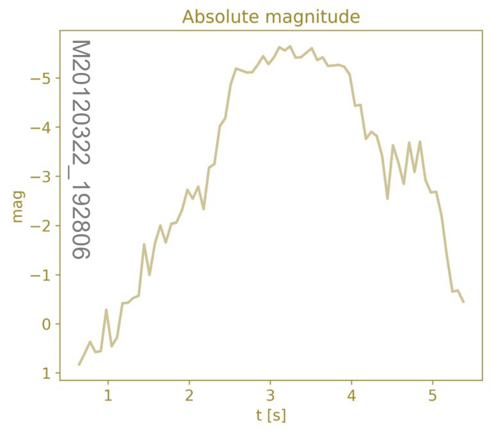


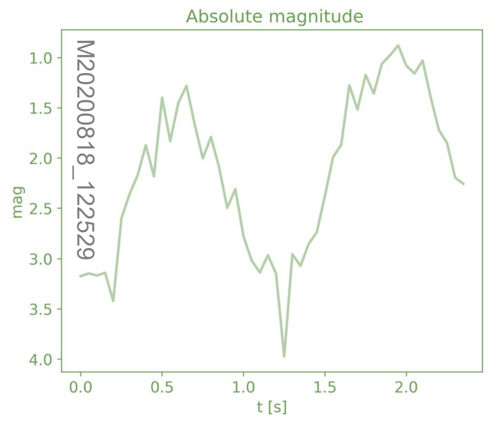


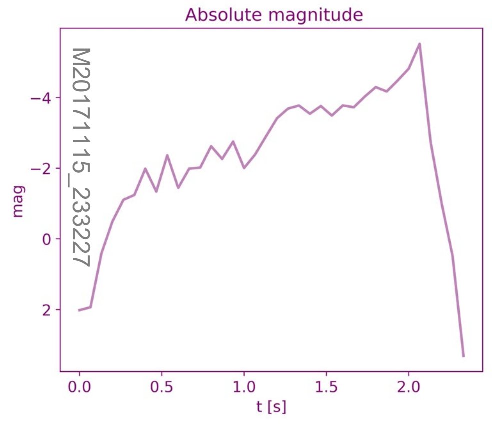










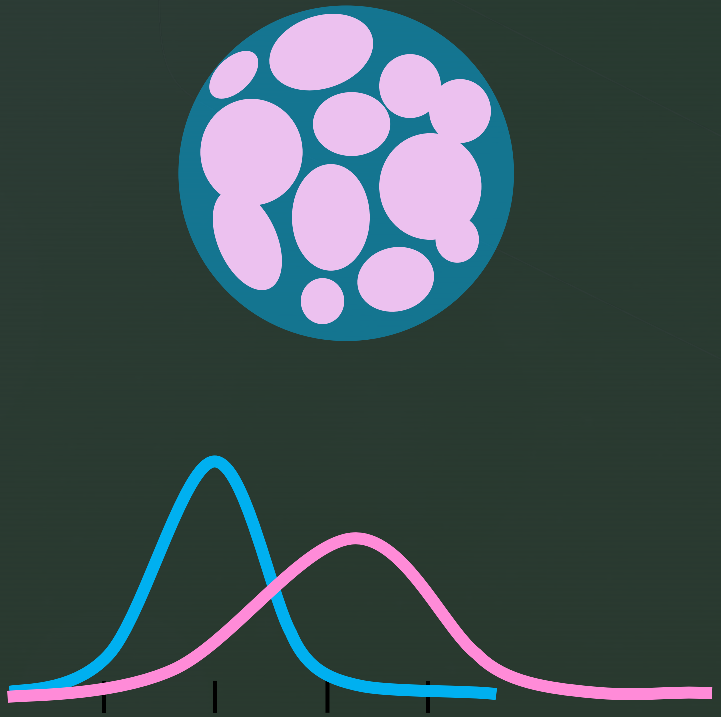


Our model and simulations

- Based on model by Ceplecha et al. (1998) for a single non-fragmenting spherical body
- Set of differential equations for the entire atmospheric flight
- Includes effects: the Earth‘s rotation, semi-empirical atmospheric model (NRMSIS-E-00), wind profile from weather-balloon data (University of Wyoming)
- Code in Python, 4th order Runge Kutta method
- Manual fit of both dynamics and light emission
- Separate codes for discussed processes (diff. abl. / erosion / gross frag.)
- **Two approaches to model differential ablation (two components)**

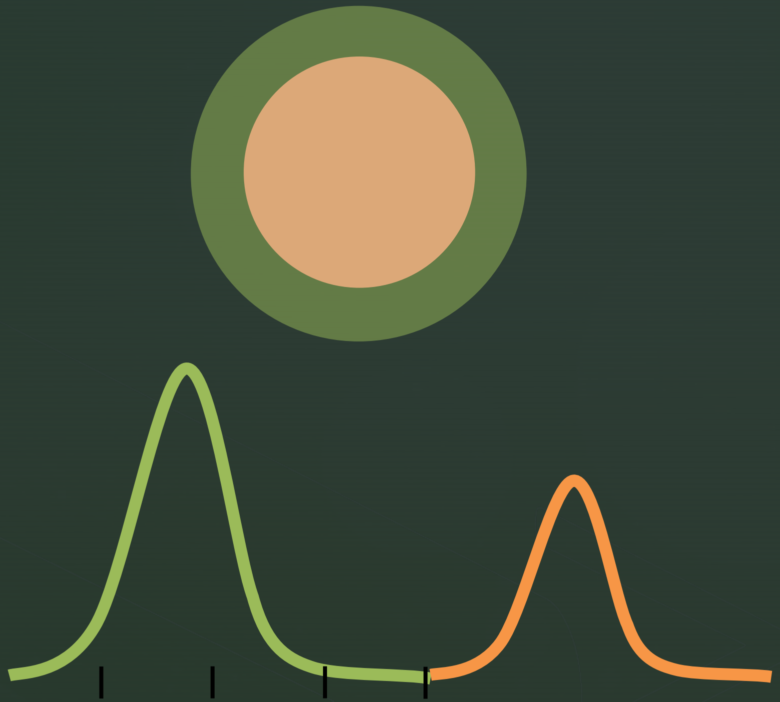
Dustball model

- Well-mixed material (glue+grains)
- Heats and ablates at the same time



„Avocado“ model

- Two layers of different materials



Results

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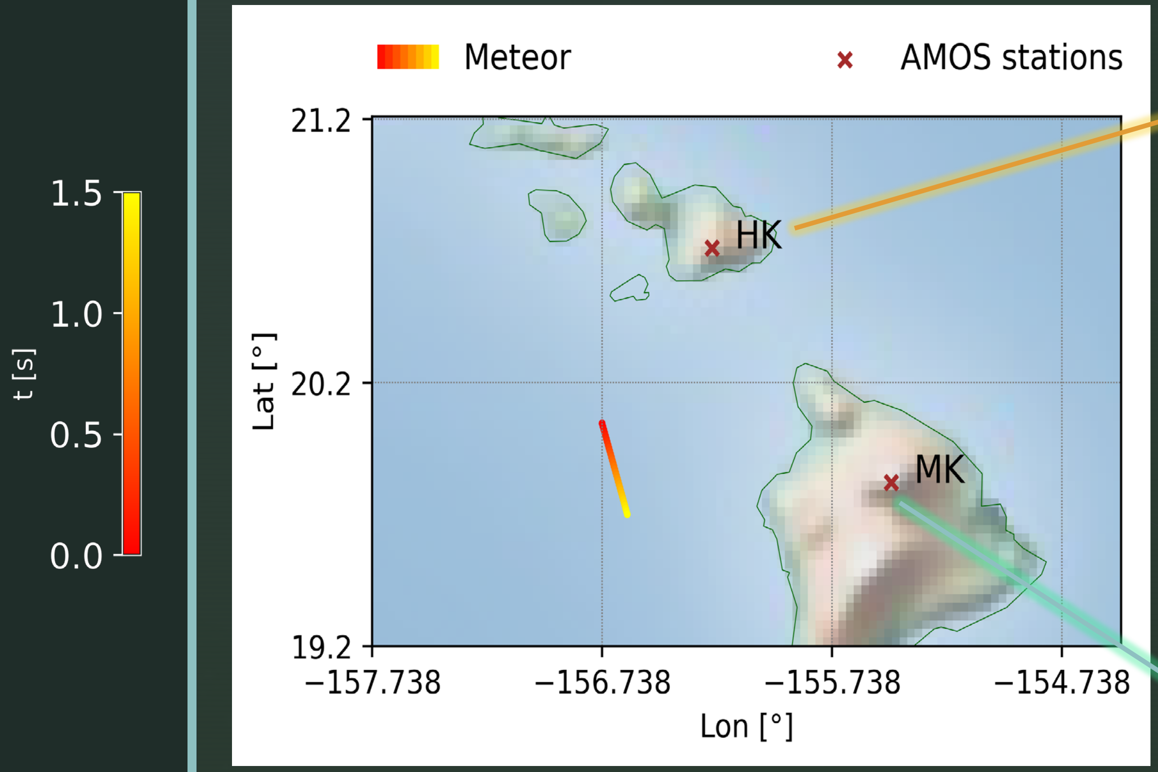

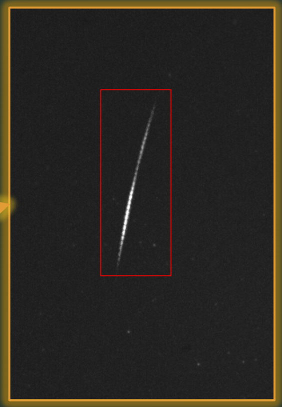

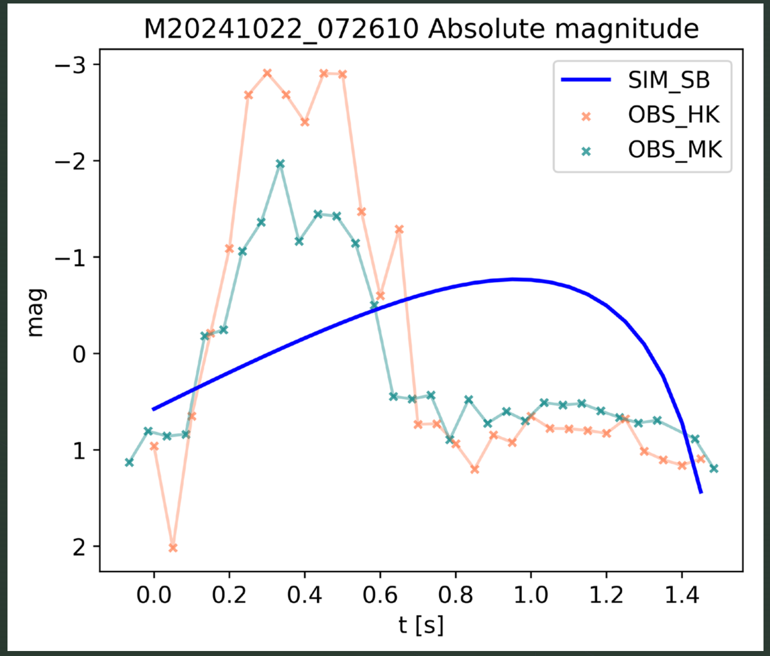

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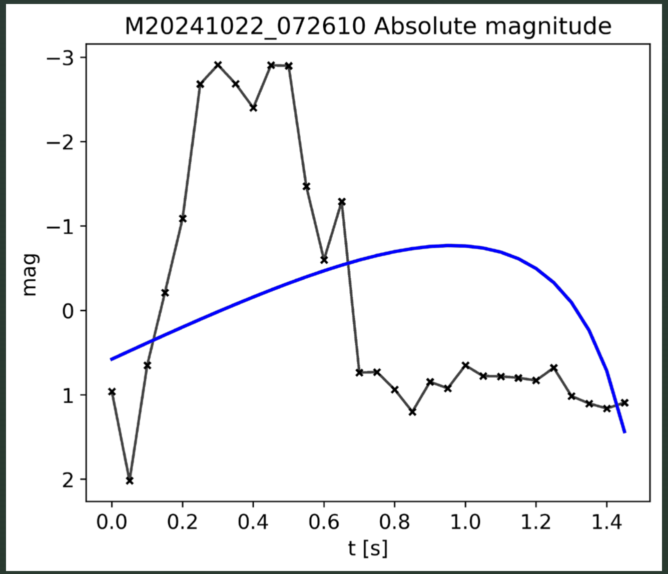
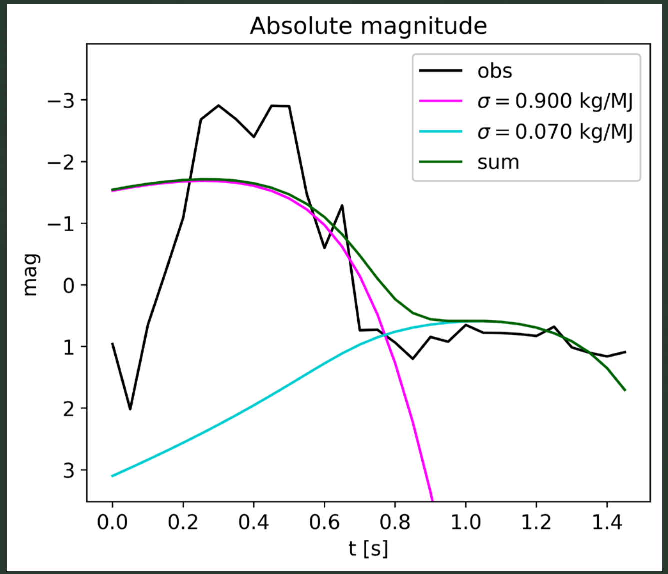
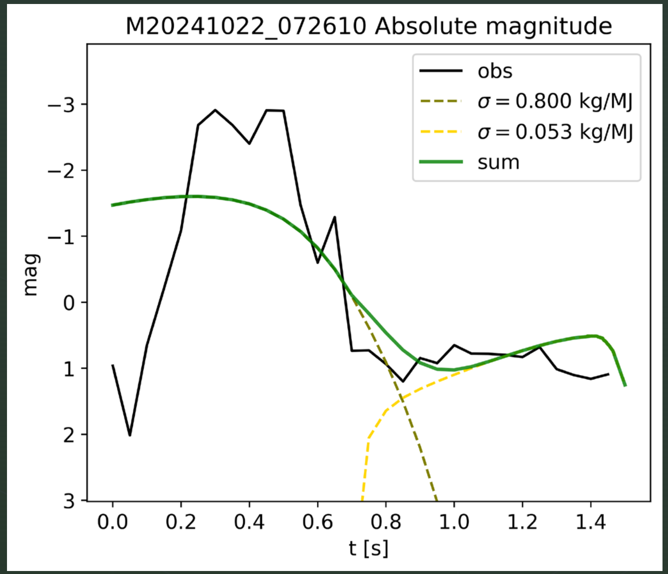
Uniform ablation	Differential ablation – dustball	Differential ablation - avocado
Initial mass = 0,9 g	Initial mass = 1,6 g Mass ratio 9:1	Initial mass = 1,4 g Mass ratio 8:2
Density = 700 kg/m3	Densities (kg/m3) = 1400, 1000	Densities (kg/m3) = 400, 600
Ablation coef. = 0.10 kg/MJ	Ablation coef. (kg/MJ) = 0.90, 0.07	Ablation coef. (kg/MJ) = 0.80, 0.05







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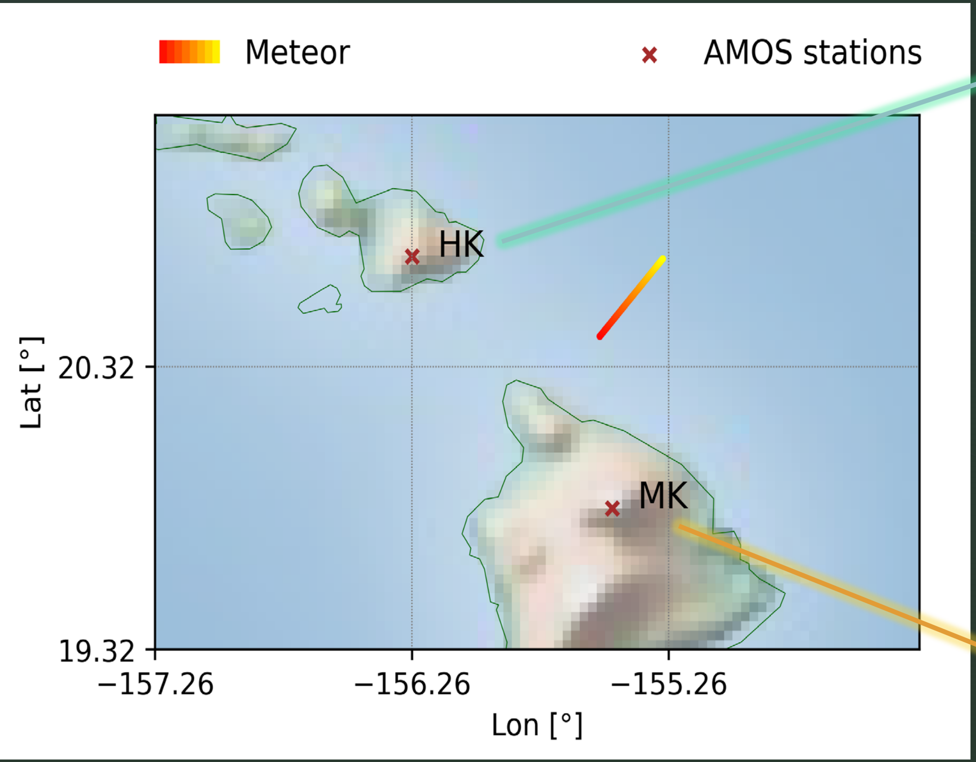

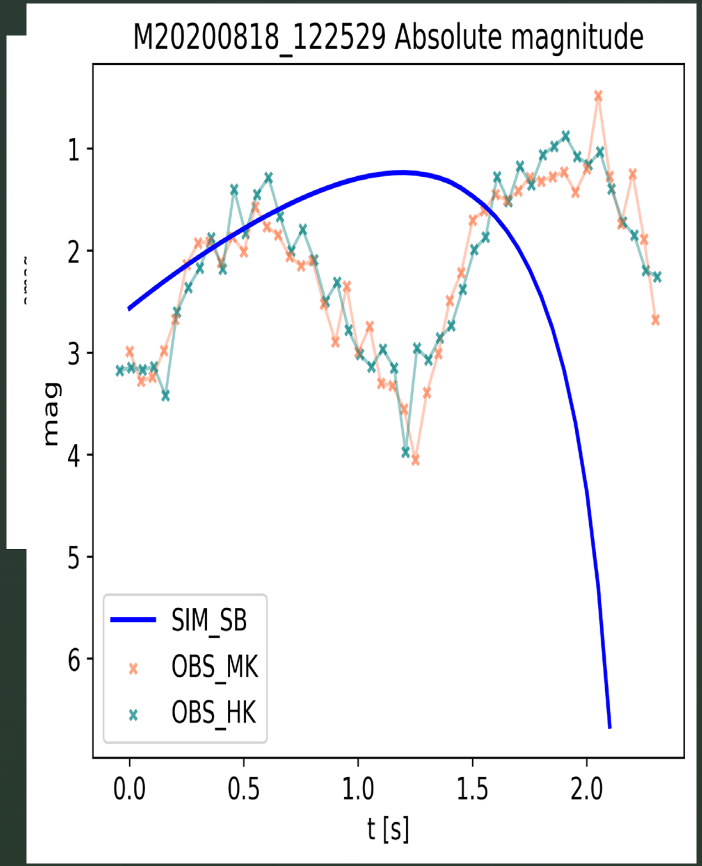

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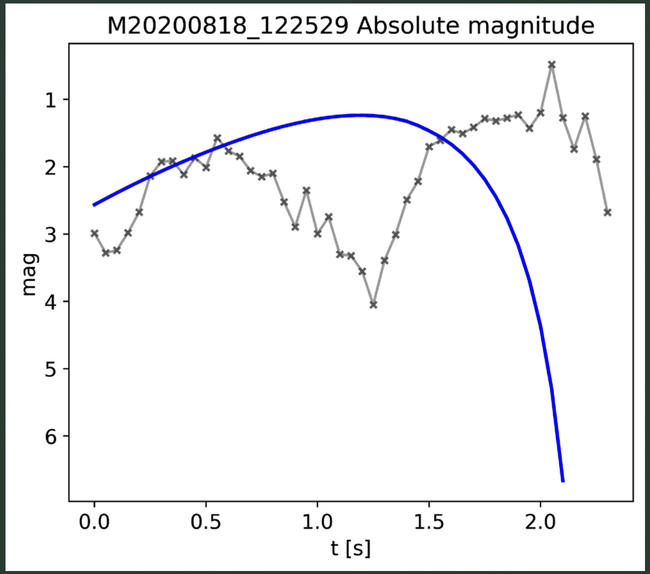
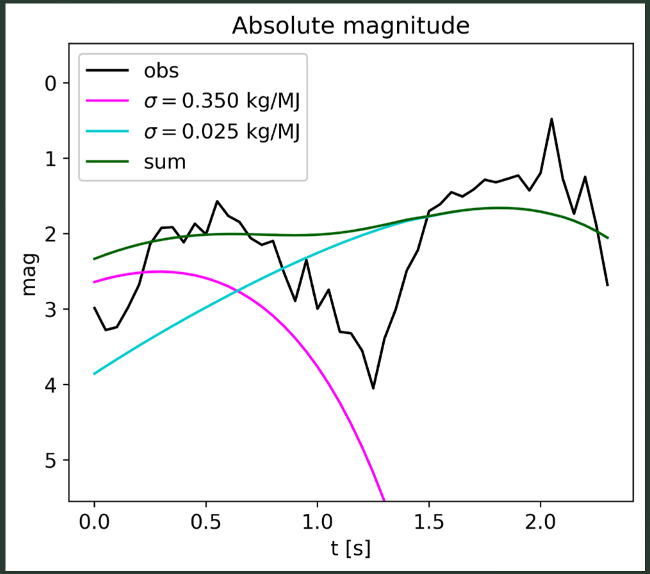
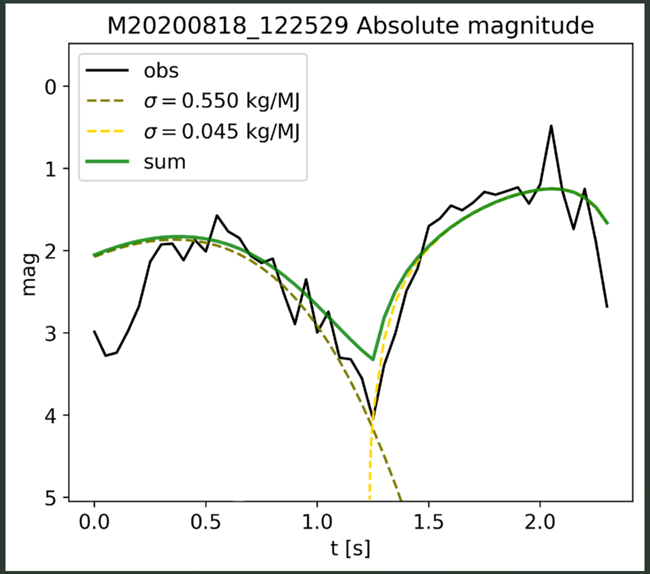
Uniform ablation	Differential ablation – dustball	Differential ablation - avocado
Initial mass = 0,3 g	Initial mass = 0,3 g Mass ratio 1:4	Initial mass = 0,3 g Mass ratio 4:6
Density = 1200 kg/m3	Densities (kg/m3) = 800, 1400	Densities (kg/m3) = 1000, 1200
Ablation coef. = 0.071 kg/MJ	Ablation coef. (kg/MJ) = 0.350, 0.025	Ablation coef. (kg/MJ) = 0.550, 0.045







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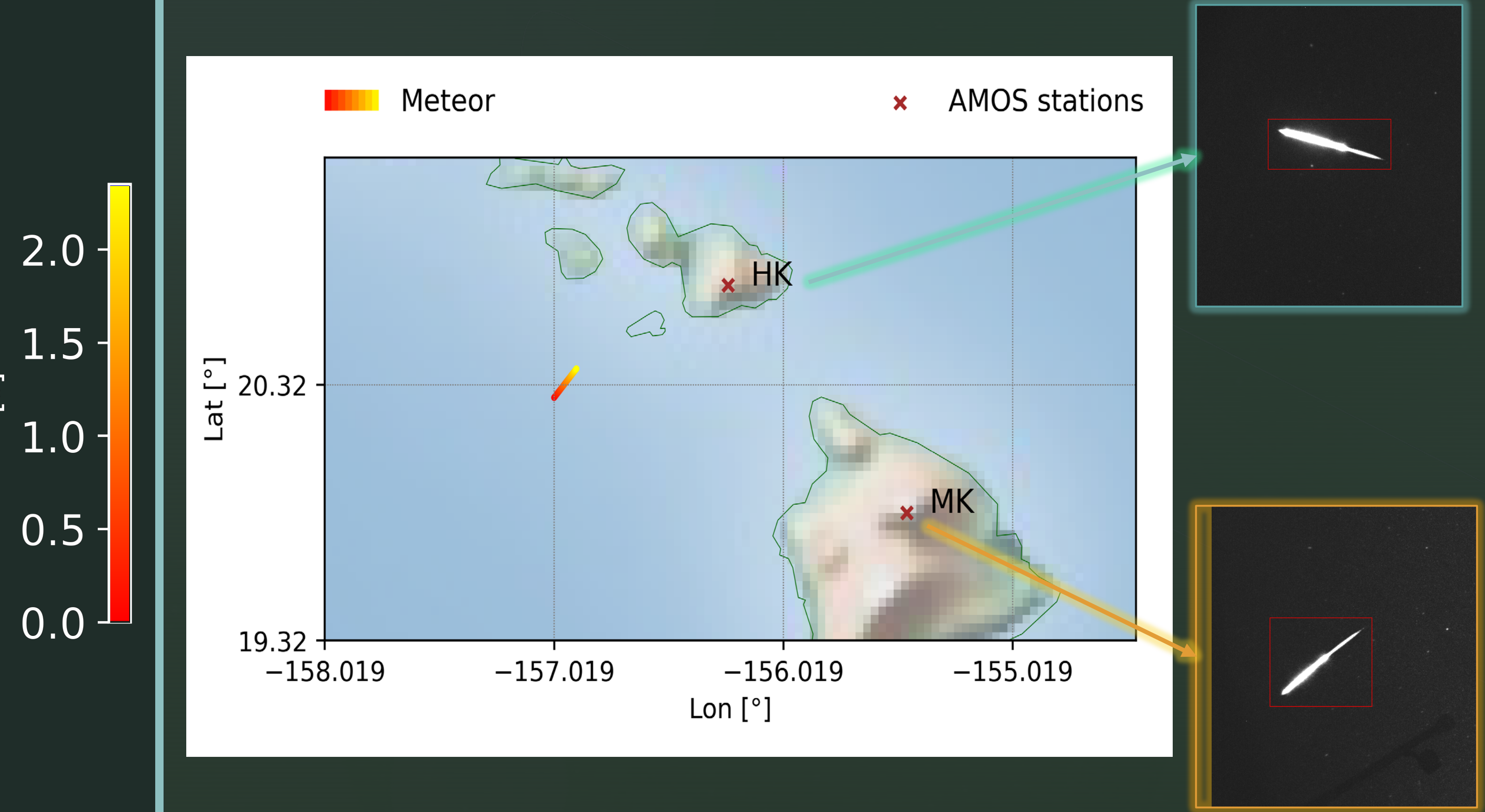
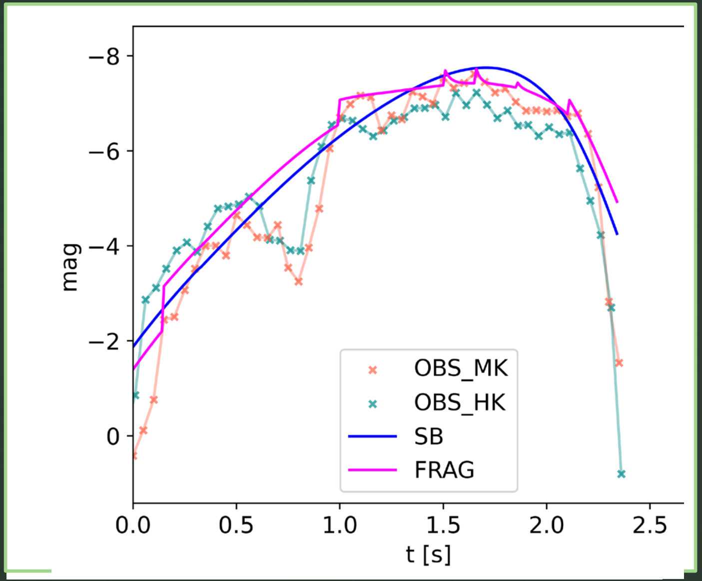
Ca rich meteor





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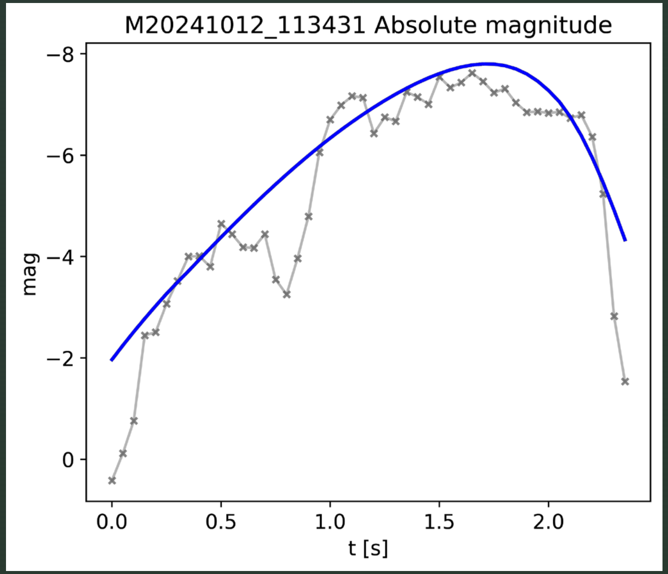
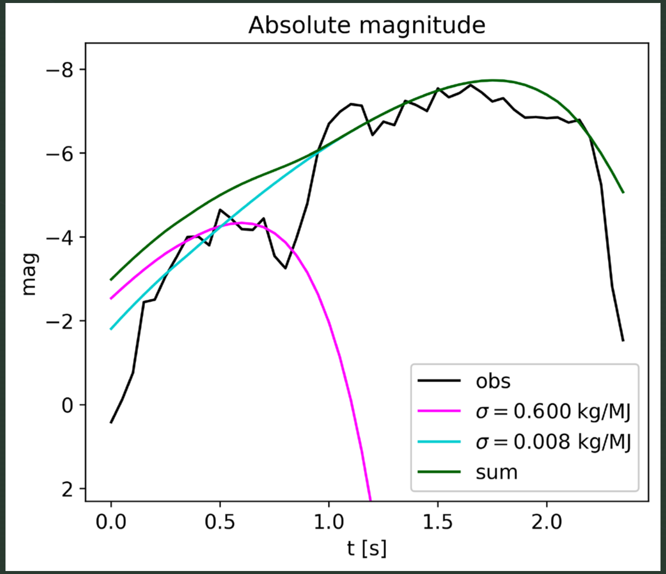
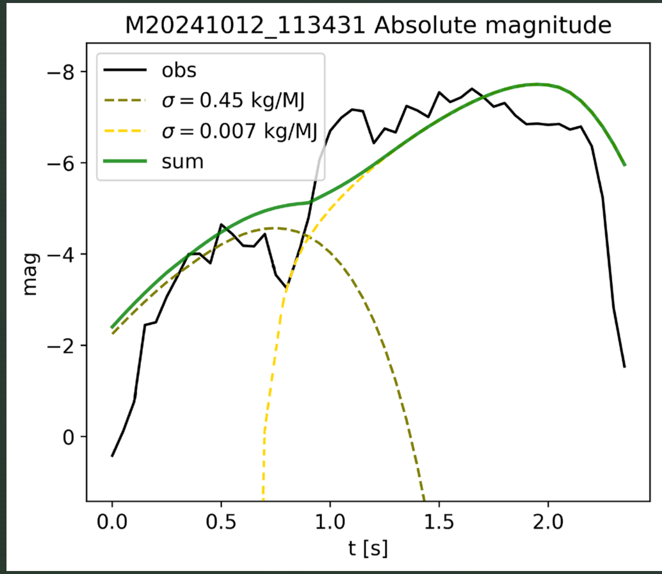
Uniform ablation	Differential ablation – dustball	Differential ablation - avocado
Initial mass = 600 g	Initial mass = 580 g Mass ratio 3:97	Initial mass = 512 g Mass ratio 5:95
Density = 4000 kg/m3	Densities (kg/m3) = 400, 3700	Densities (kg/m3) = 300, 3800
Ablation coef. = 0.10 kg/MJ	Ablation coef. (kg/MJ) = 0.600, 0.008	Ablation coef. (kg/MJ) = 0.450, 0.007





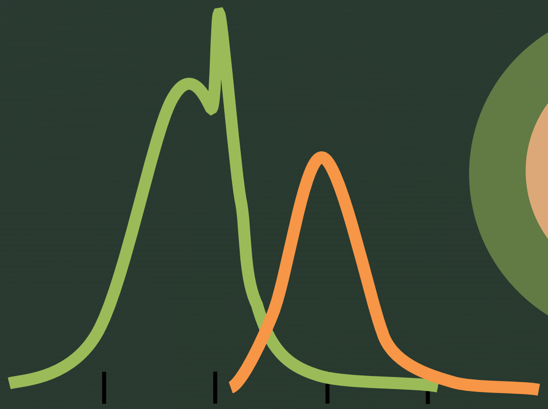


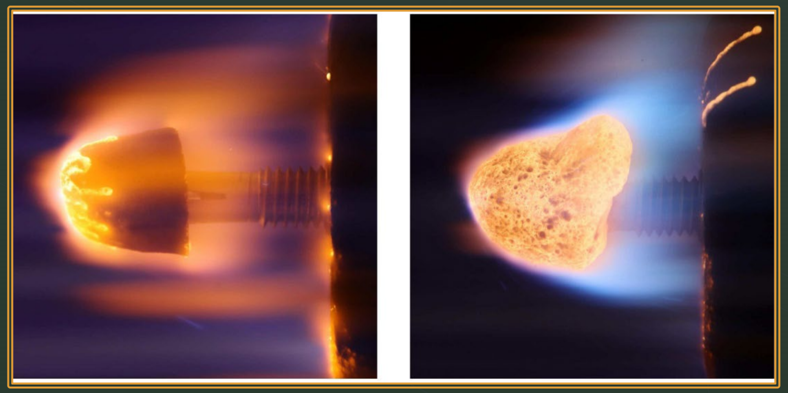
Conclusions and future work

- Inclusion of differential ablation improves the LC fit, dynamics stay comparable to the single-body results
- Layered „avocado“ model can be used on meteoroids regardless of their size, density is in better agreement with the estimated meteor type
- Resulting LCs are too wide, with high ablation coefficients

Conclusions and future work

- Combine of fragmentation and differential ablation into one model
- Determine the time delay between consequently ablating layers
- Examine the connection between fragmentation and differential ablation





Grigat et al. (2024)

Thank you for your attention

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