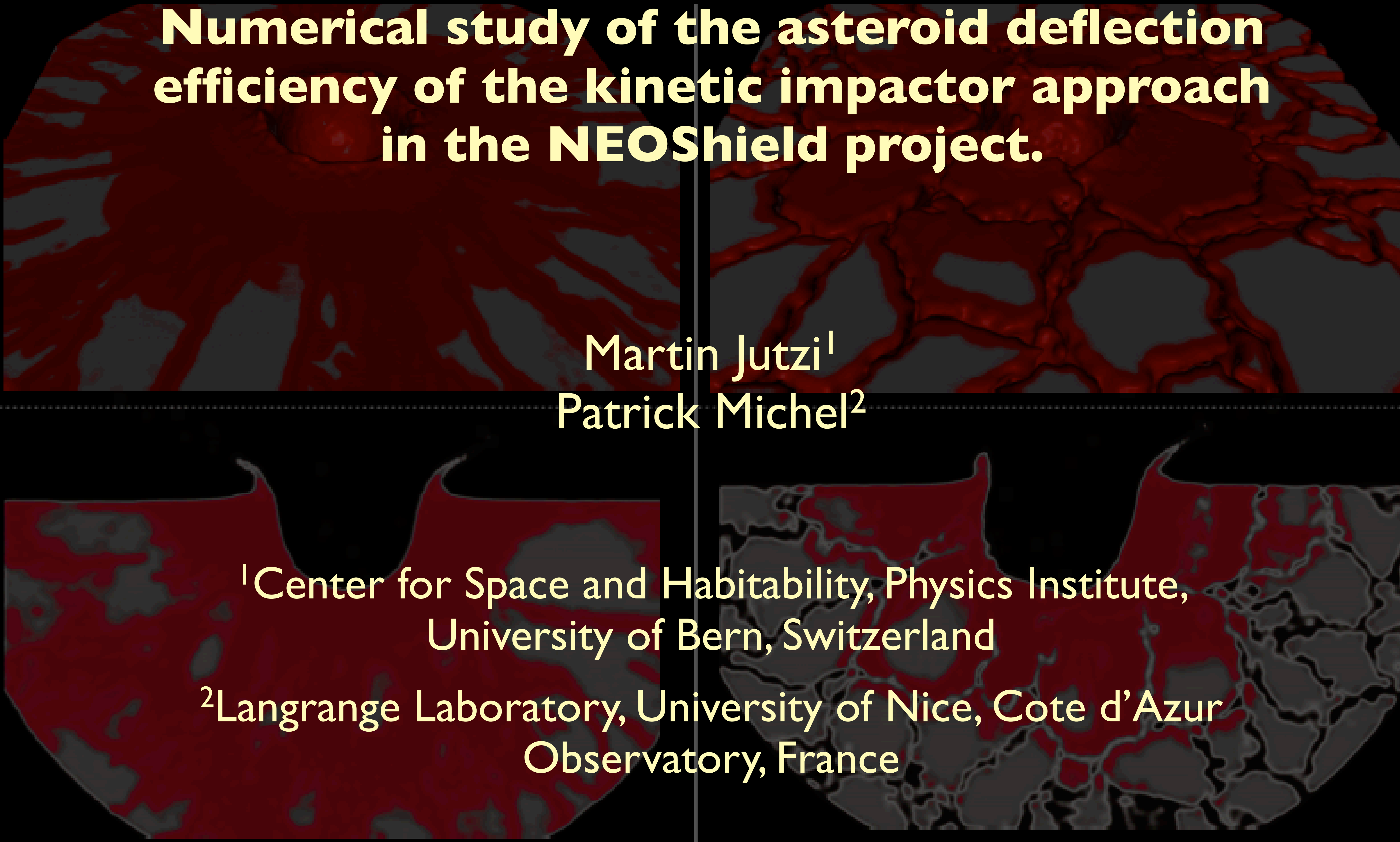


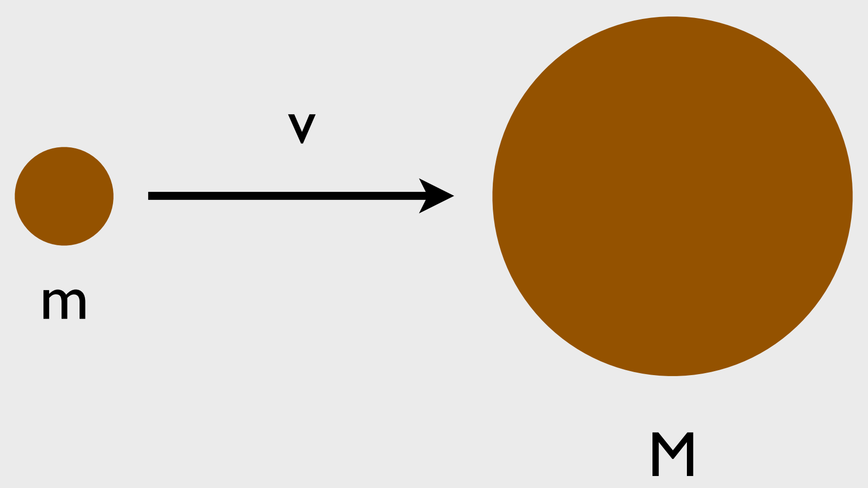
Numerical study of the asteroid deflection efficiency of the kinetic impactor approach in the NEOShield project.

Martin Jutzi[1]
Patrick Michel[2]

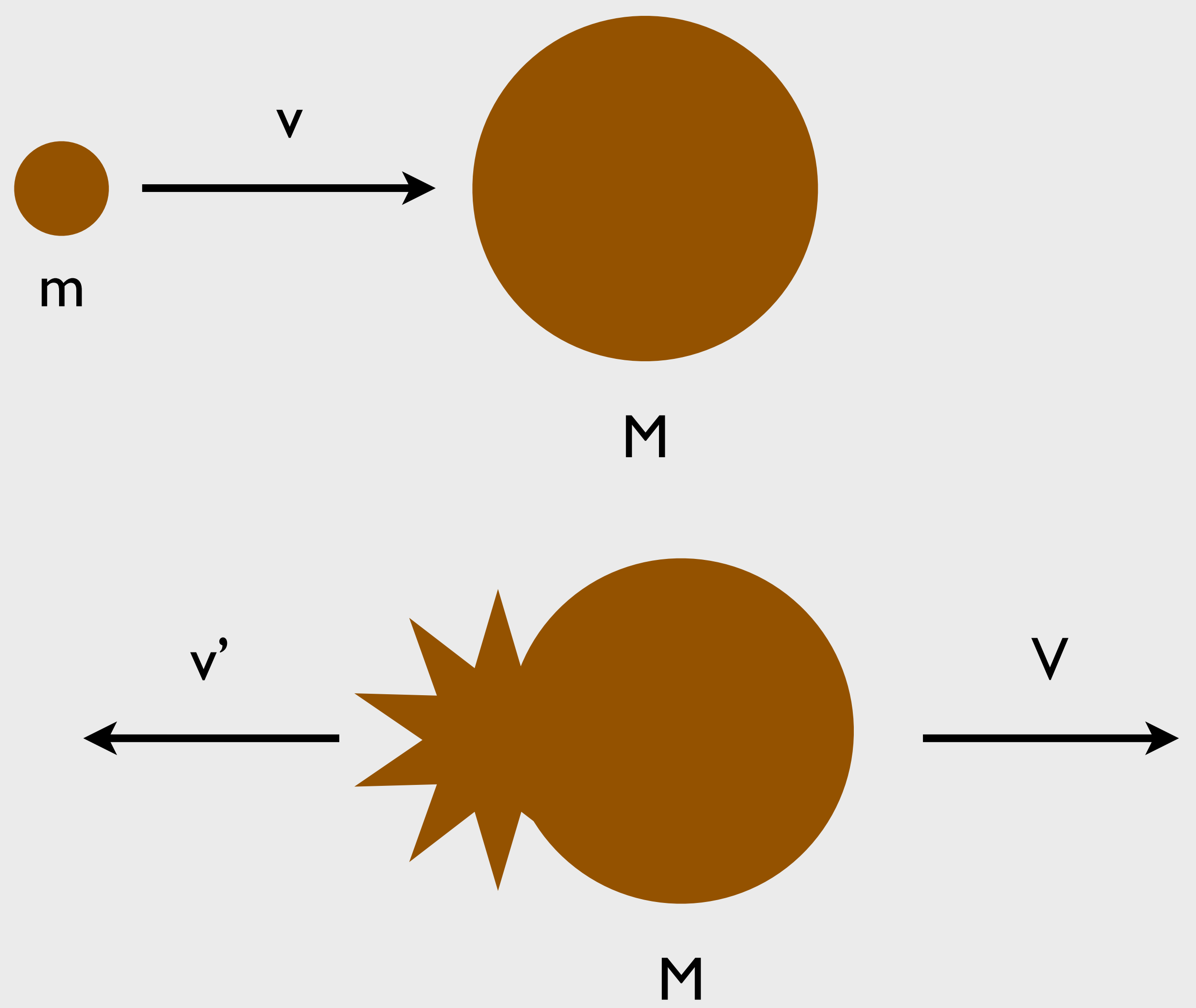
[1]Center for Space and Habitability, Physics Institute, University of Bern, Switzerland

[2]Langrange Laboratory, University of Nice, Cote d'Azur Observatory, France

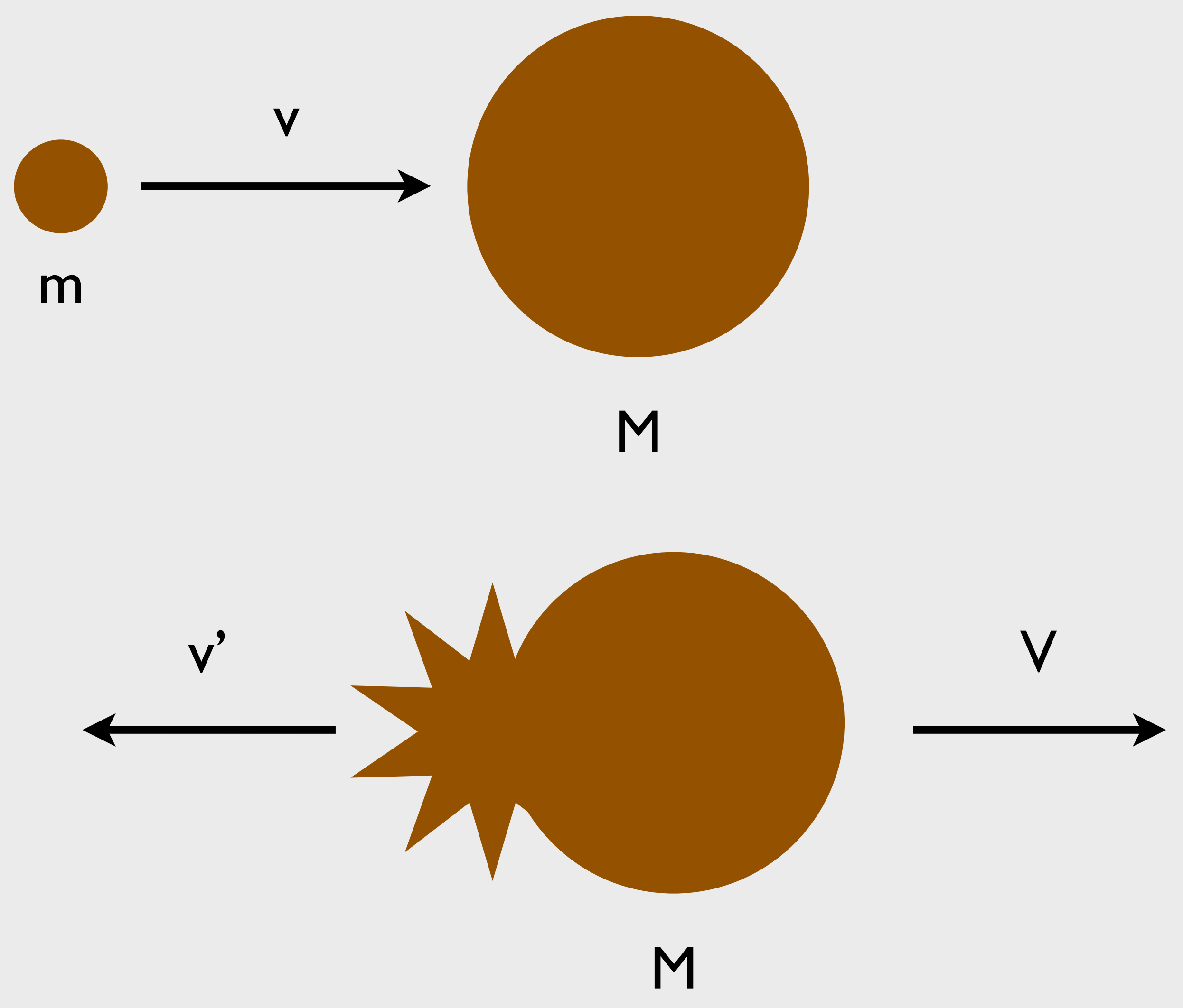
Kinetic impactor method



Kinetic impactor method



Kinetic impactor method



Momentum transfer:

$$\vec{P}_{target} = \vec{P}_{projectile} + \vec{P}_{ejecta} > \vec{P}_{projectile}$$

Momentum transfer

- Normalized with projectile momentum

$$P_{target} = 1 + P_{ejecta} \equiv \beta \geq 1$$

- Change of target velocity

$$\Delta V = \frac{P_{projectile}}{M_{target}} \times \beta$$

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- Change of target velocity

$$\Delta V = \frac{P_{projectile}}{M_{target}} \times \beta$$

- ➡ Target structure
- ➡ Material Properties
- ➡ Impact velocity
- ➡ Target size etc.

Numerical modeling of impacts

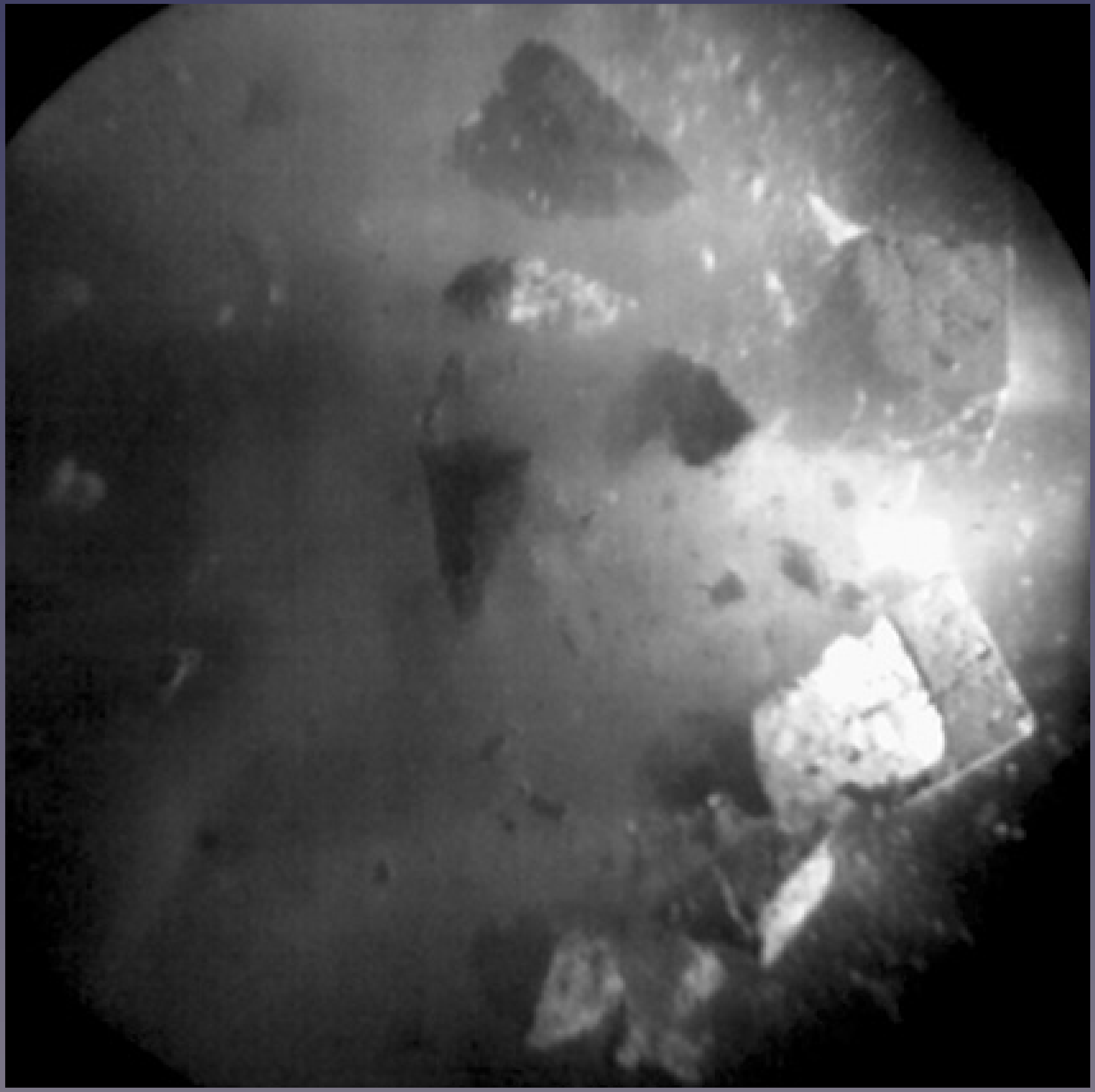
- Smooth Particle Hydrodynamics impact code
  - Benz and Asphaug (1994, 1995), Jutzi et al. (2008, 2009), Jutzi and Asphaug 2011

- To model impacts and collisions we include
  - Strength + friction (Drucker-Prager like yield criterion)
  - Porosity (based on P-alpha model)
  - (self-gravity)
  - Equation of State: Tillotson or ANEOS

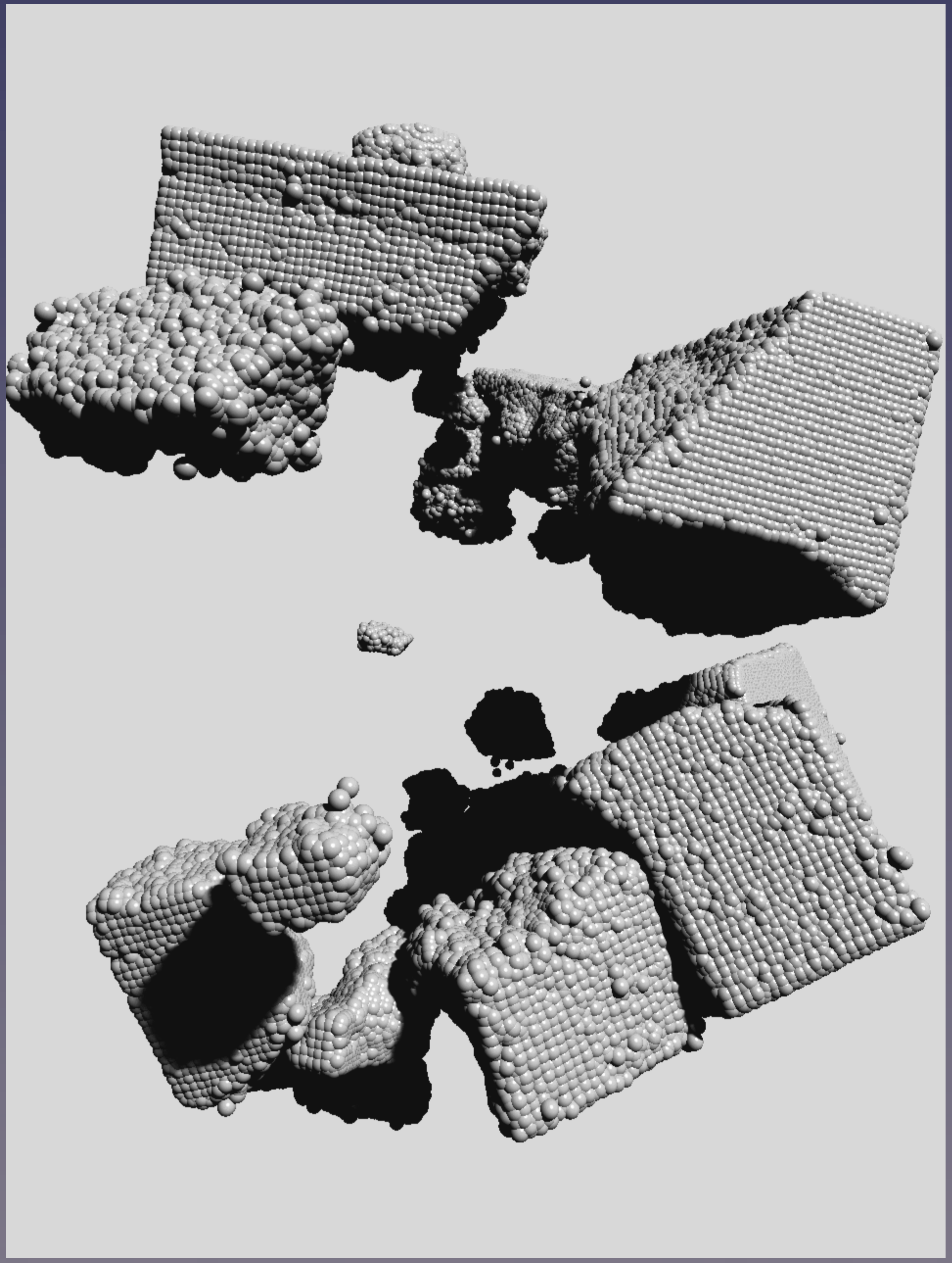
Comparison with laboratory experiments

T = 8.0 ms

Experiment (Kobe University)

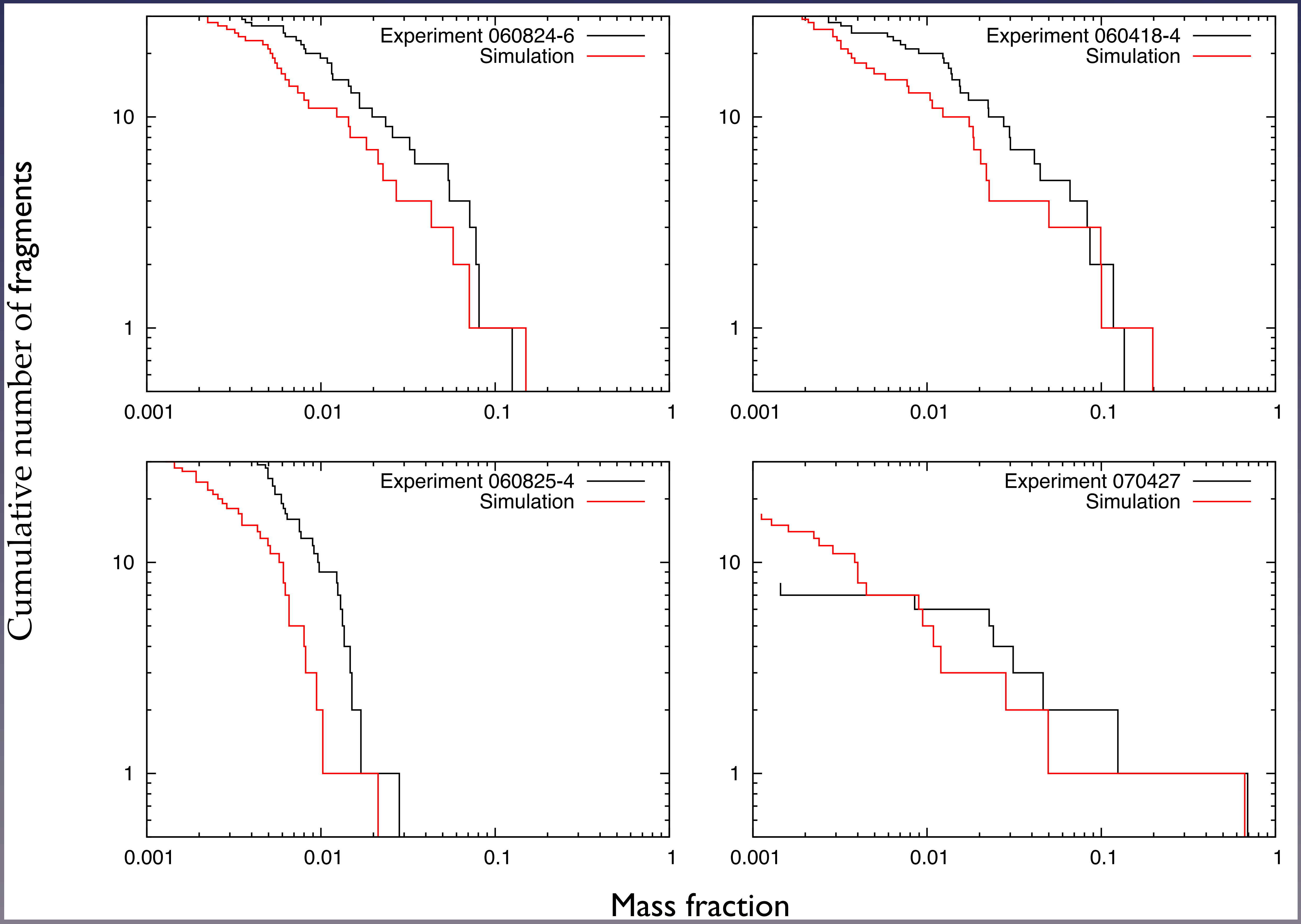


Simulation



Jutzi et al., 2009

Comparison with laboratory experiments



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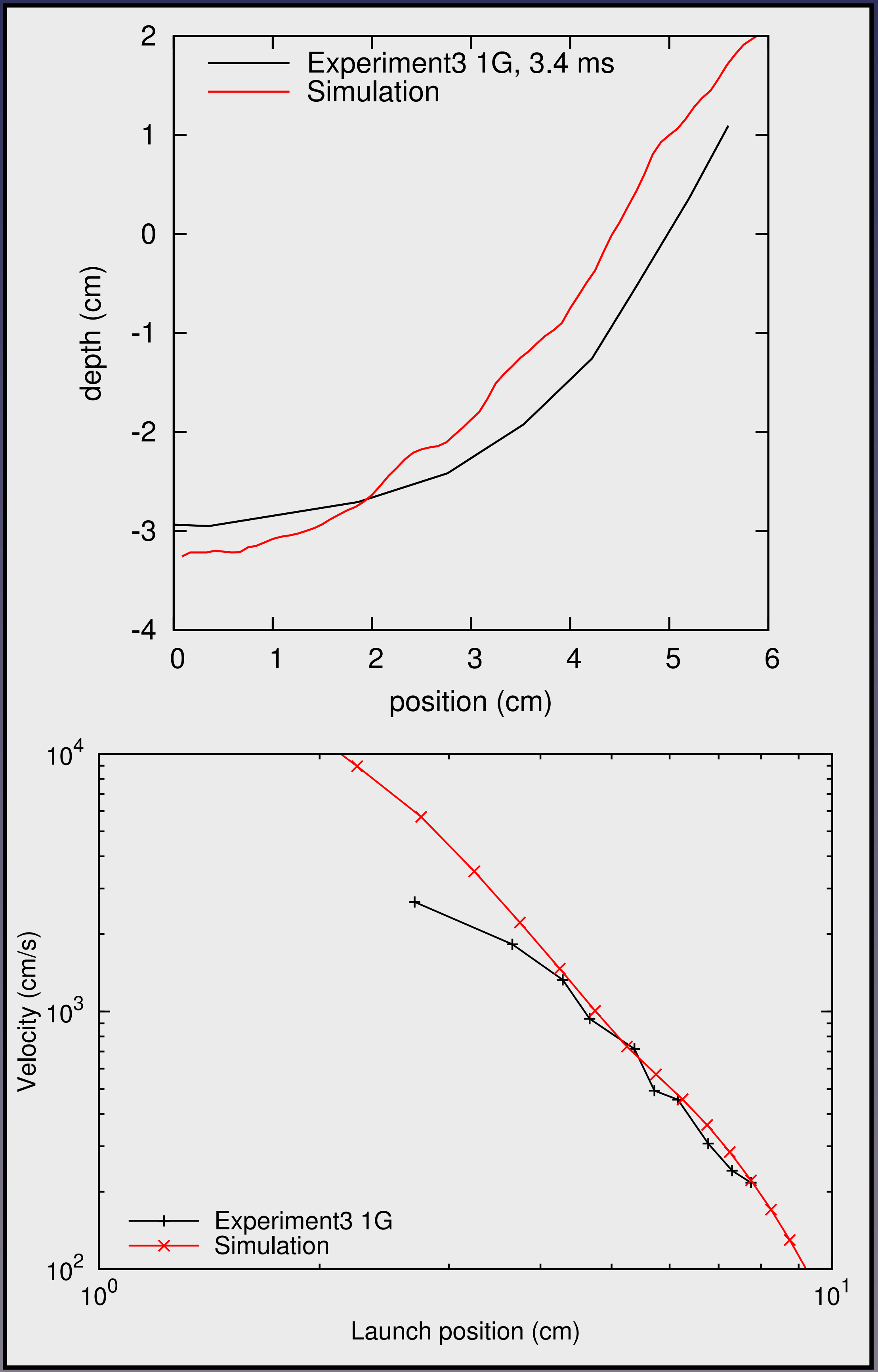
Comparison with laboratory experiments



Impacts in Sand
1G or 464 G

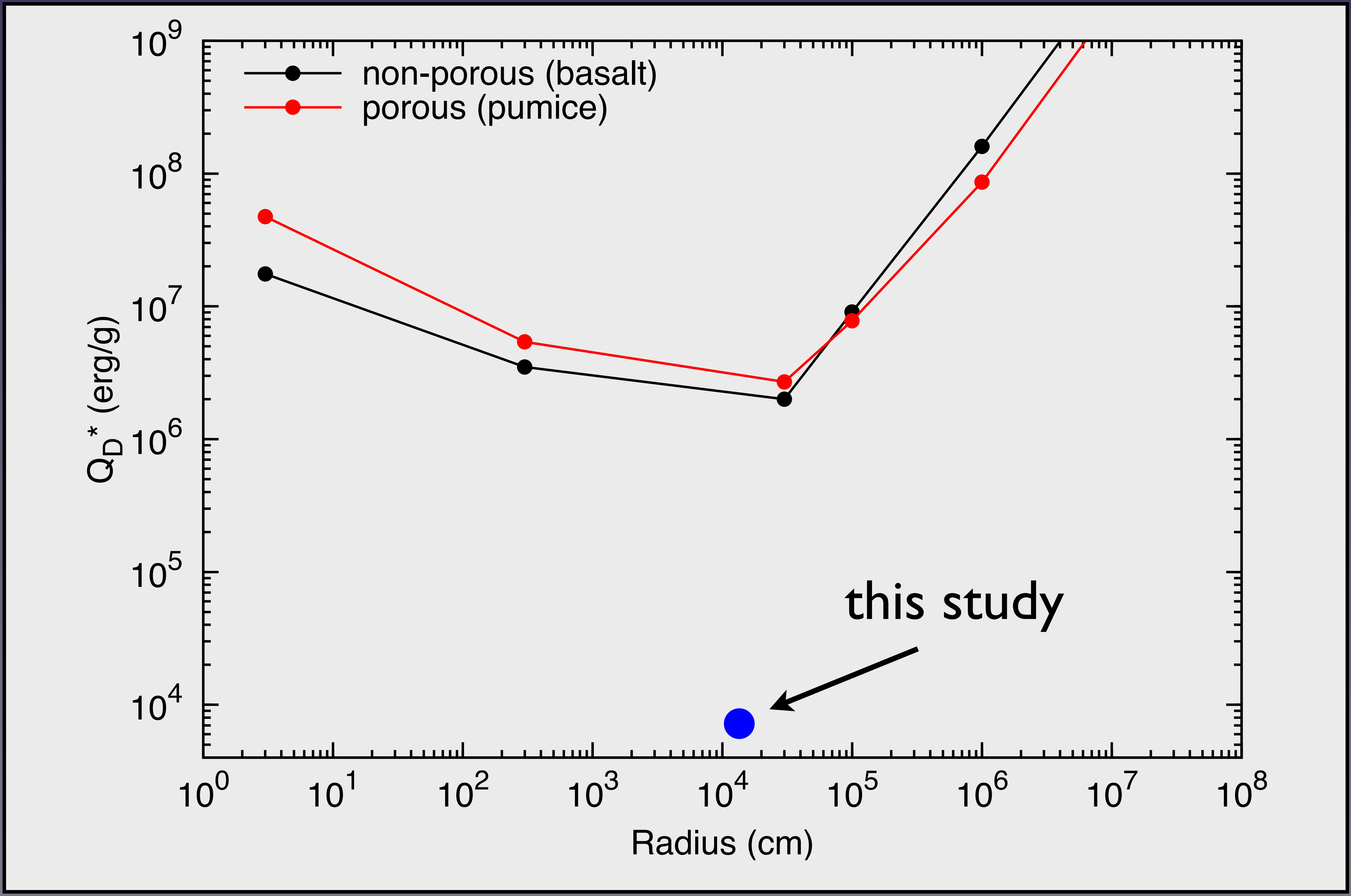
Experiments by Kevin Housen
(IMPACT HYDROCODE BENCHMARK AND VALIDATION PROJECT)

Kinetic Impact Simulations

- Initial conditions:
  - **Target**
    - D = 300 m asteroid
    - Two different target types are investigated:
      - Micro-porous (pumice with 50% porosity)
      - Micro-porous + macroscopic cracks (inhomogeneity)
  - **Projectile**
    - 400 Kg
    - varying impact velocities (0.5 .. 15 km/s)
    - aluminium sphere ($\rho = 2.7\ g/cm^{3)}$

Impact simulations

Specific impact energy needed
for disruption



Impact simulations

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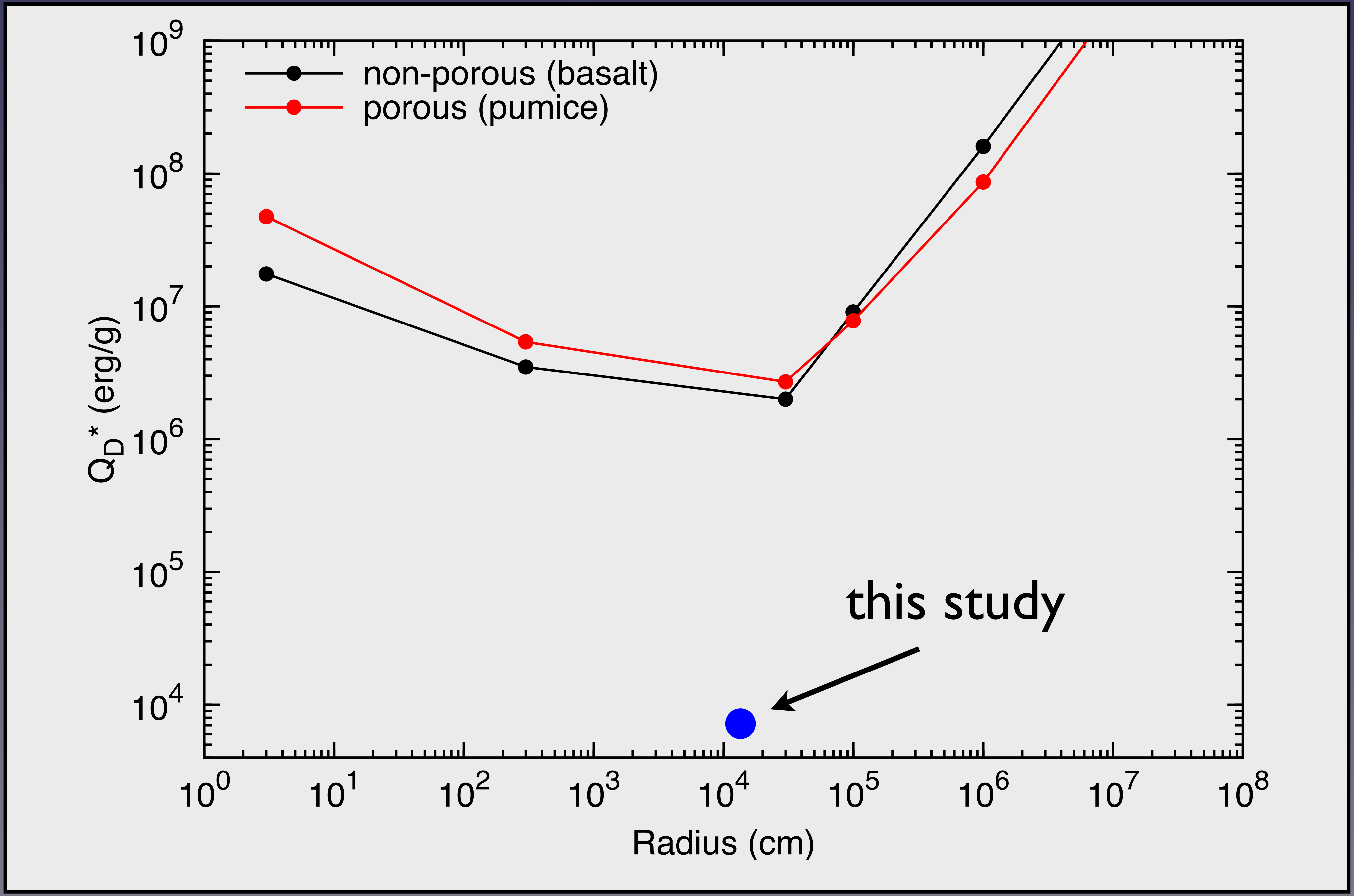
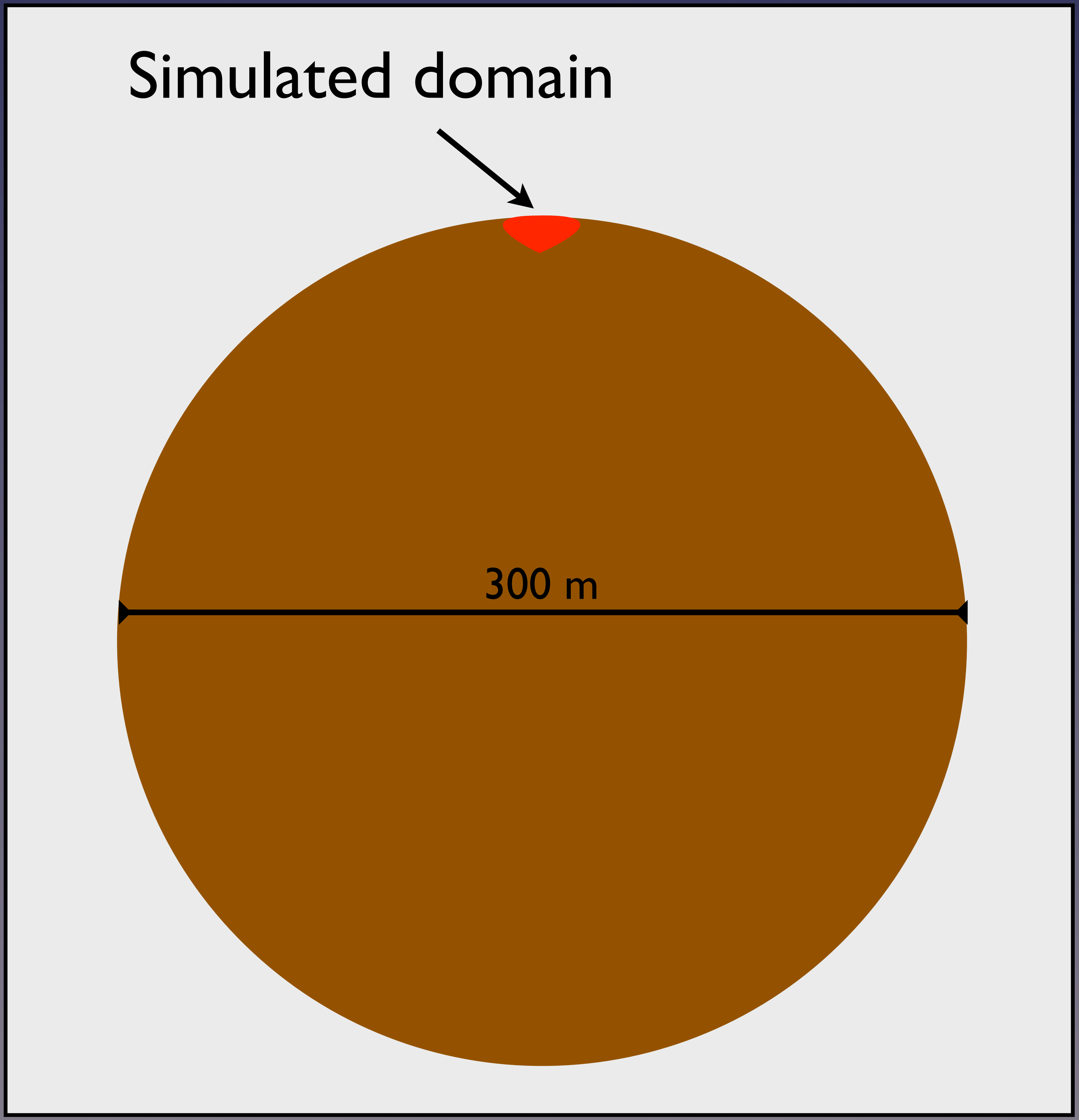
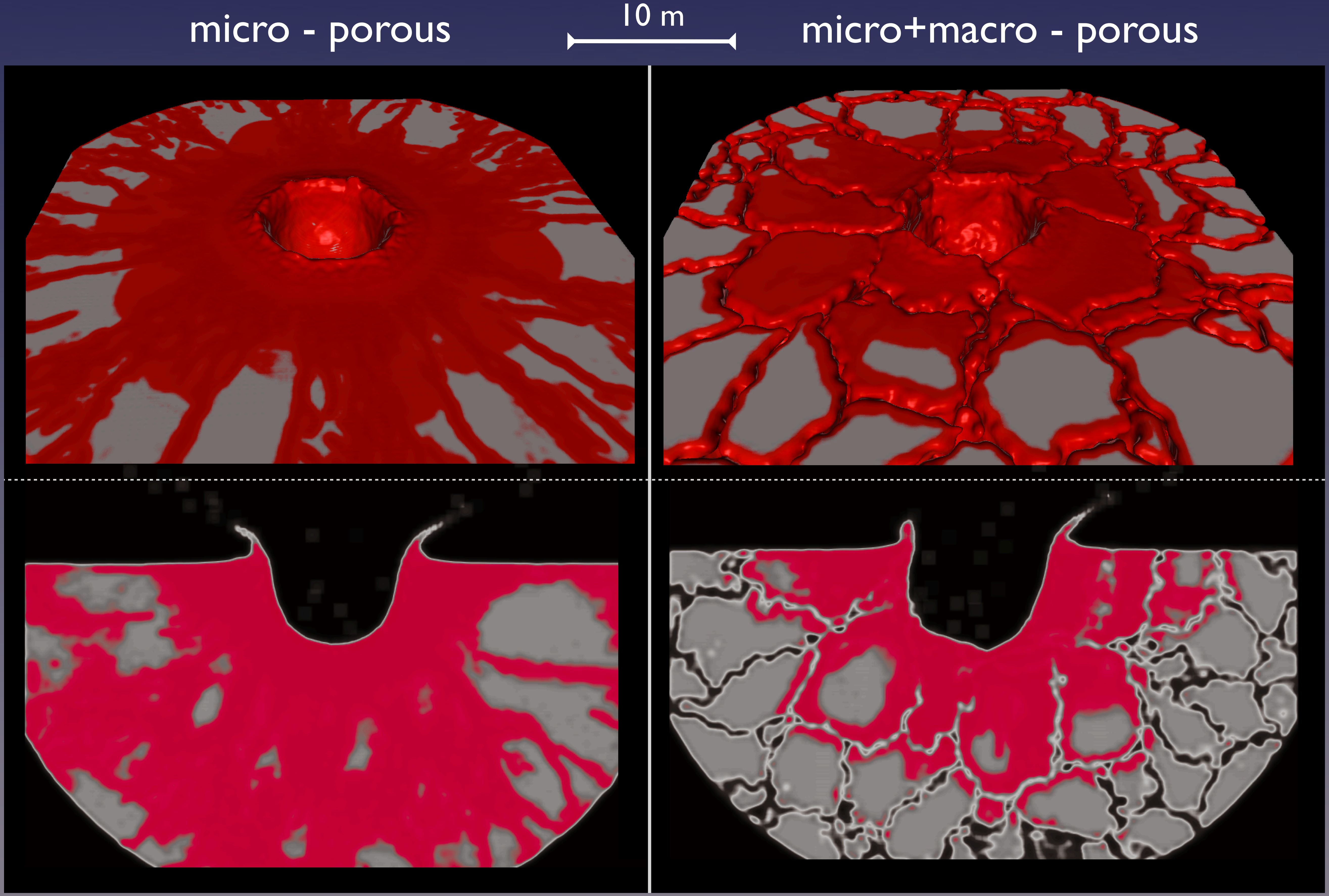


→ Cratering regime

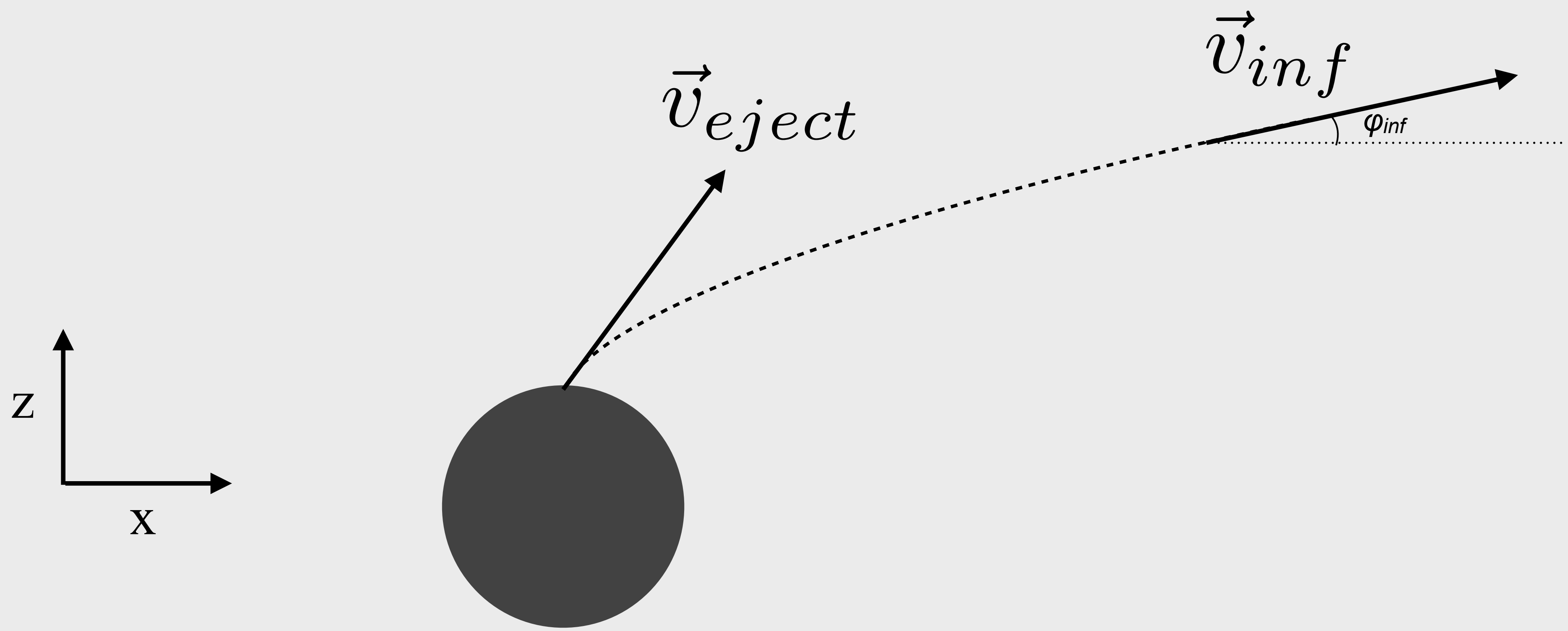
Impact simulations



Impact simulations (10 km/s impact)



Beta computation



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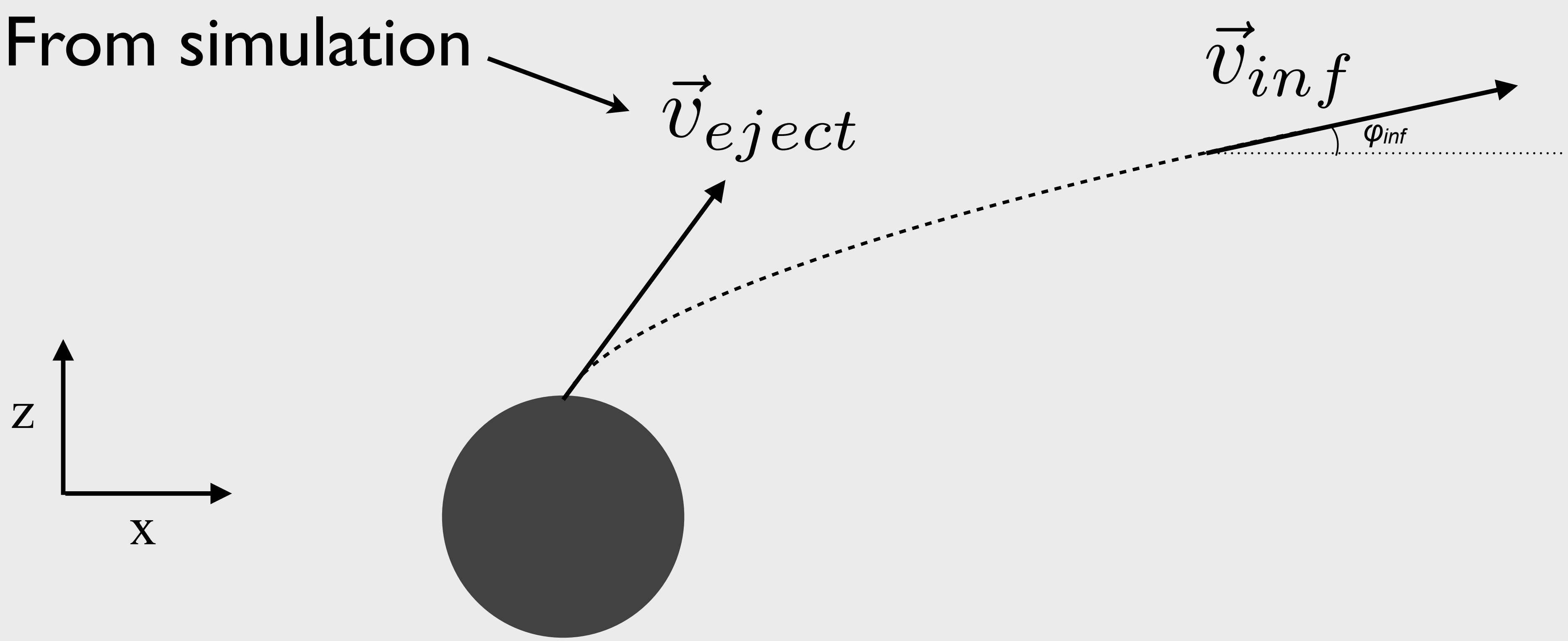

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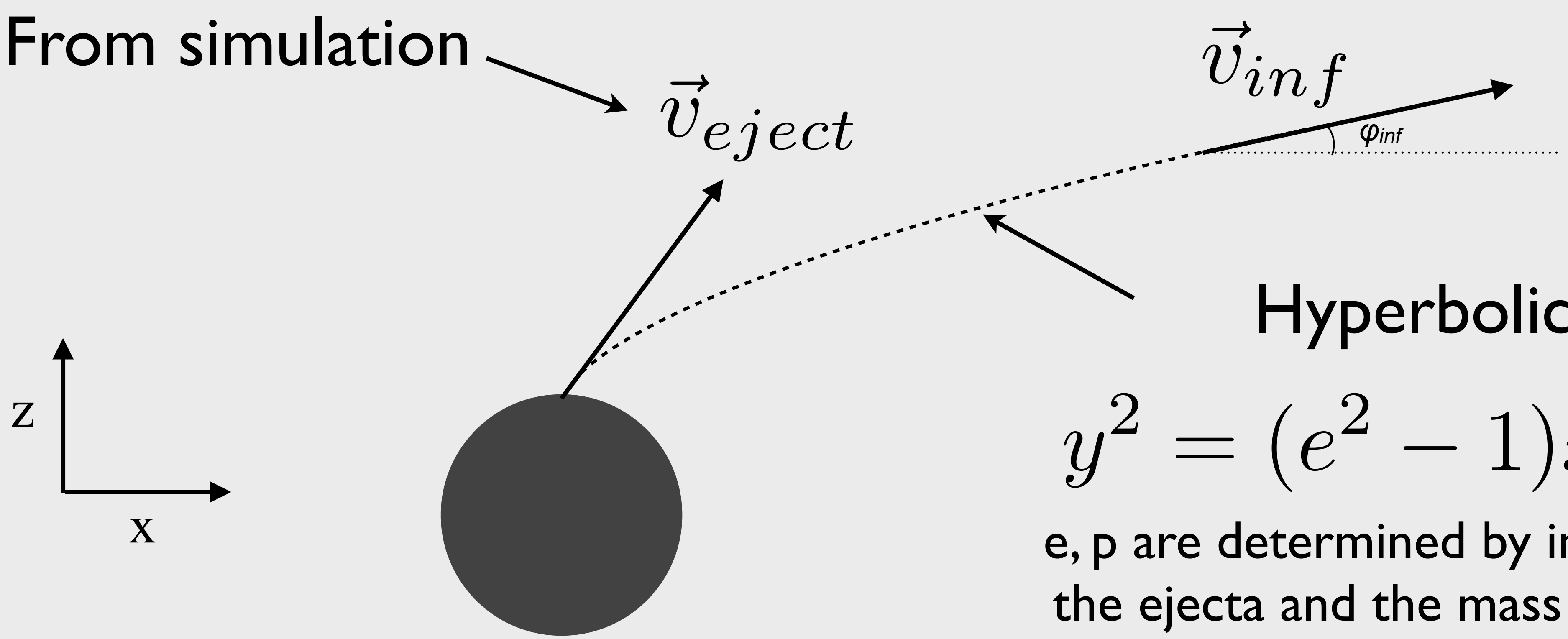
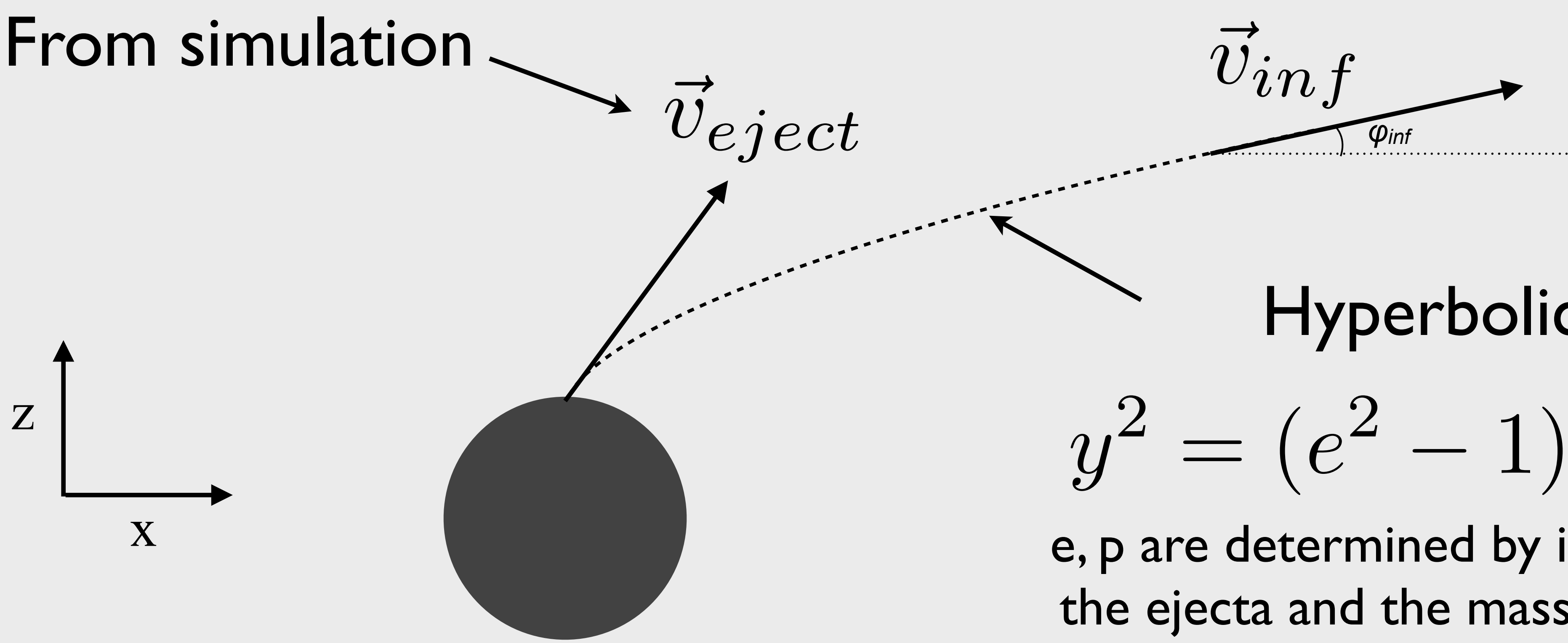


Hyperbolic orbit:

$$y^2 = (e^2 - 1)x^2 - 2epx + p^2$$

e, p are determined by initial position and velocity of the ejecta and the mass and the radius of the target

Beta computation



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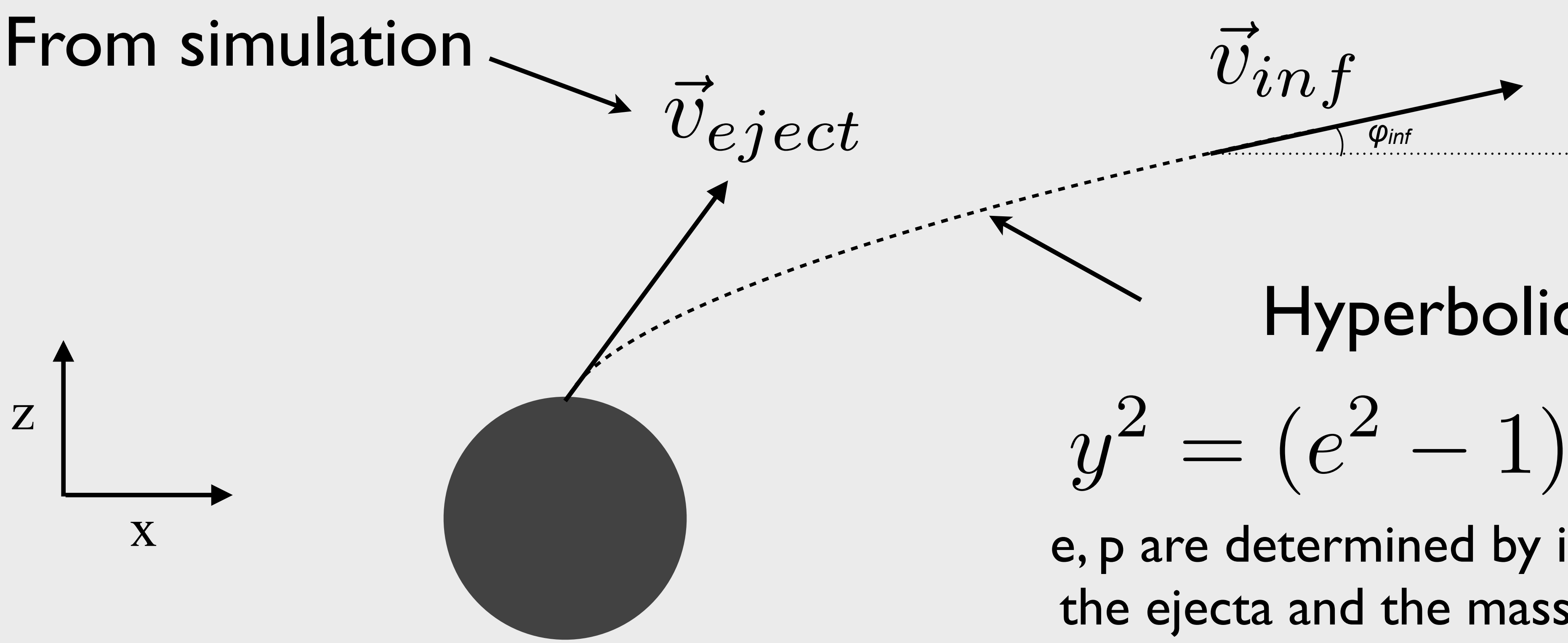
$$v_{inf}^2 = v_{eject}^2 - v_{esc}^2 \qquad vz_{inf} = sin(\phi_{inf}) \times v_{inf}$$

Beta computation



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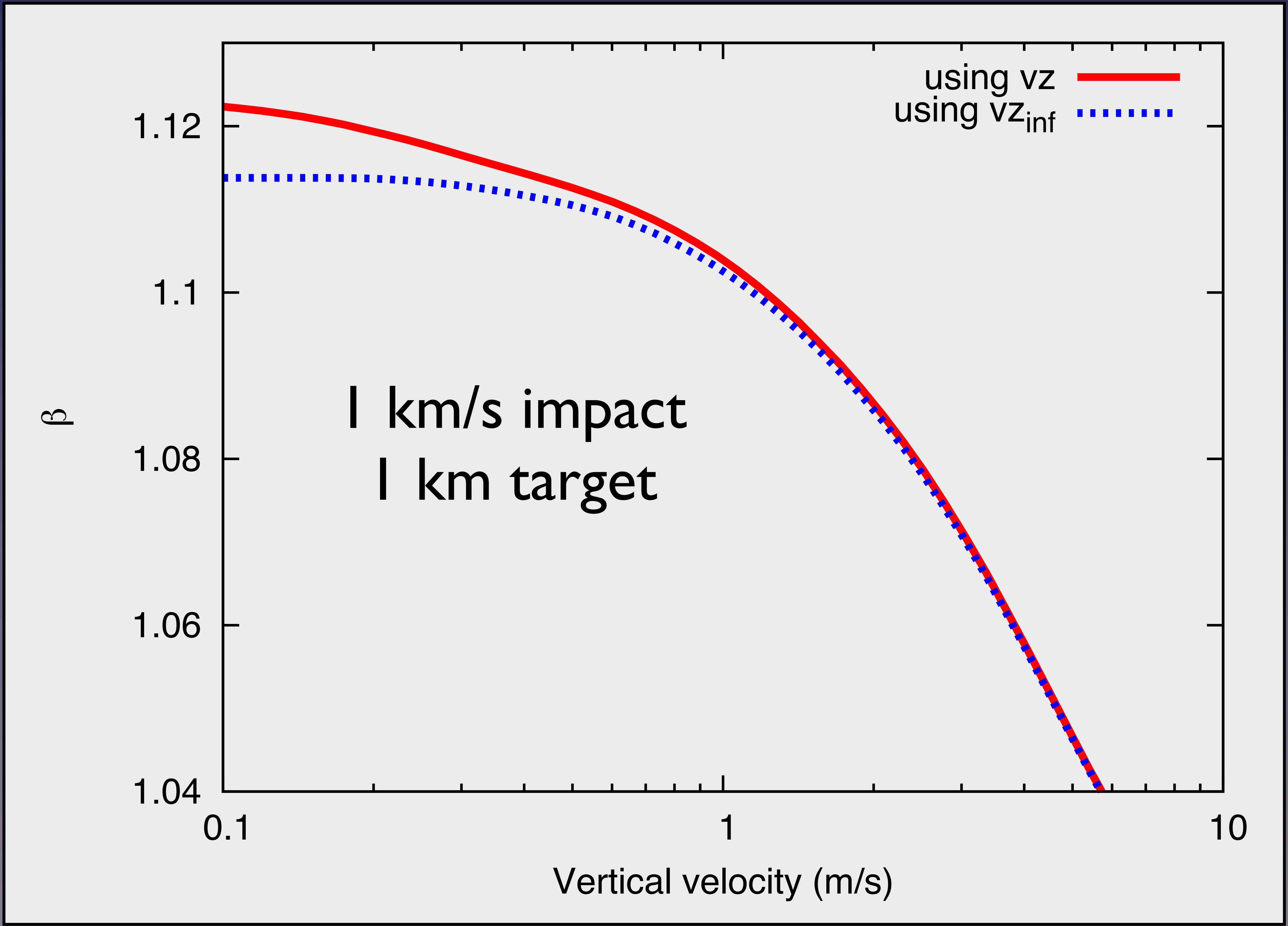
Similar to Holsapple and Housen 2012

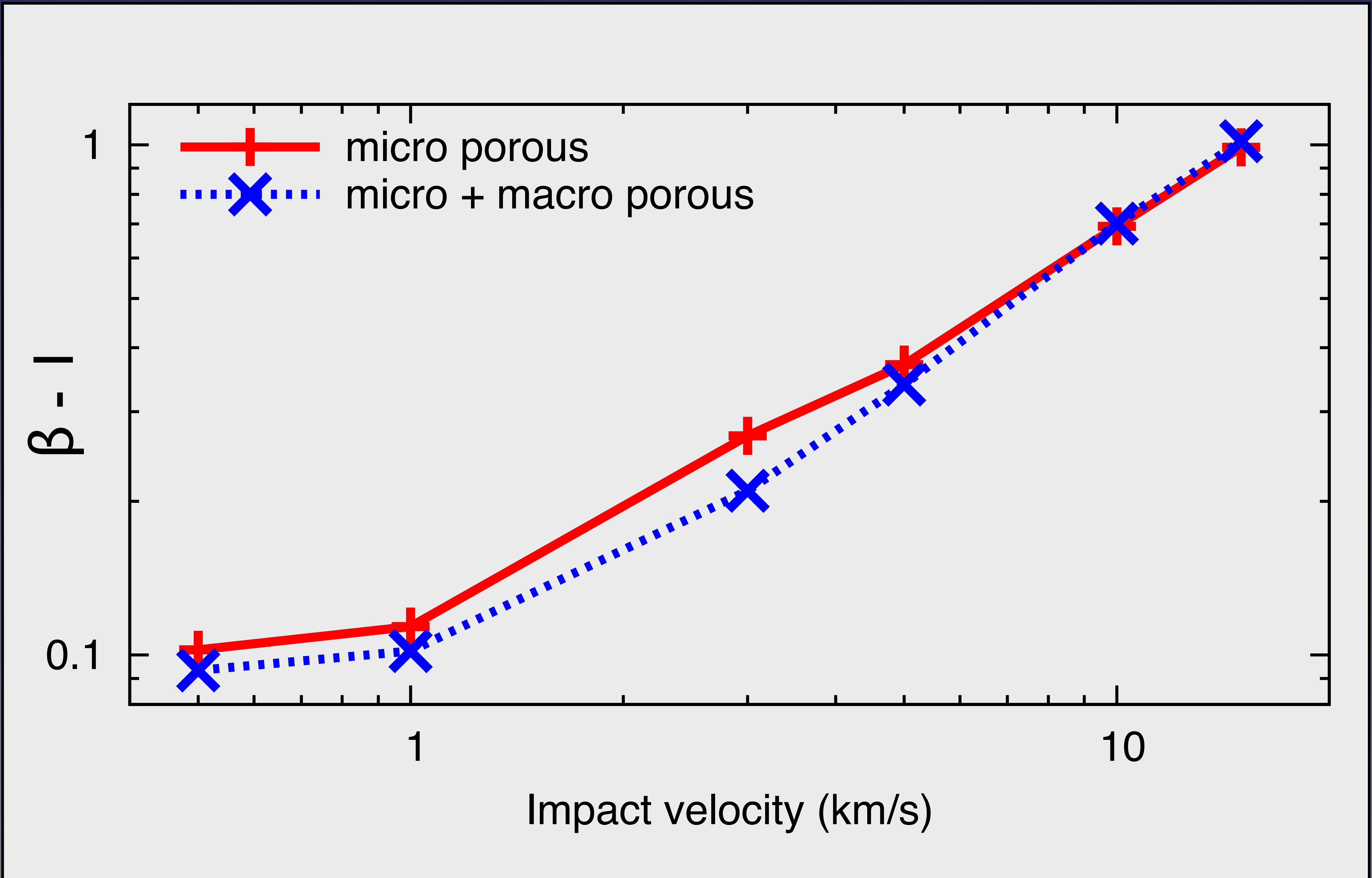
Momentum of ejecta using *vz* at infinity:

$$p_{ej} = \sum_i m_i \times vz_{inf,i} \qquad \beta = 1 + p_{ej}/(M_p v_p)$$

Effect of velocity correction (v_{eject} vs. v_{inf})



Momentum multiplication factor



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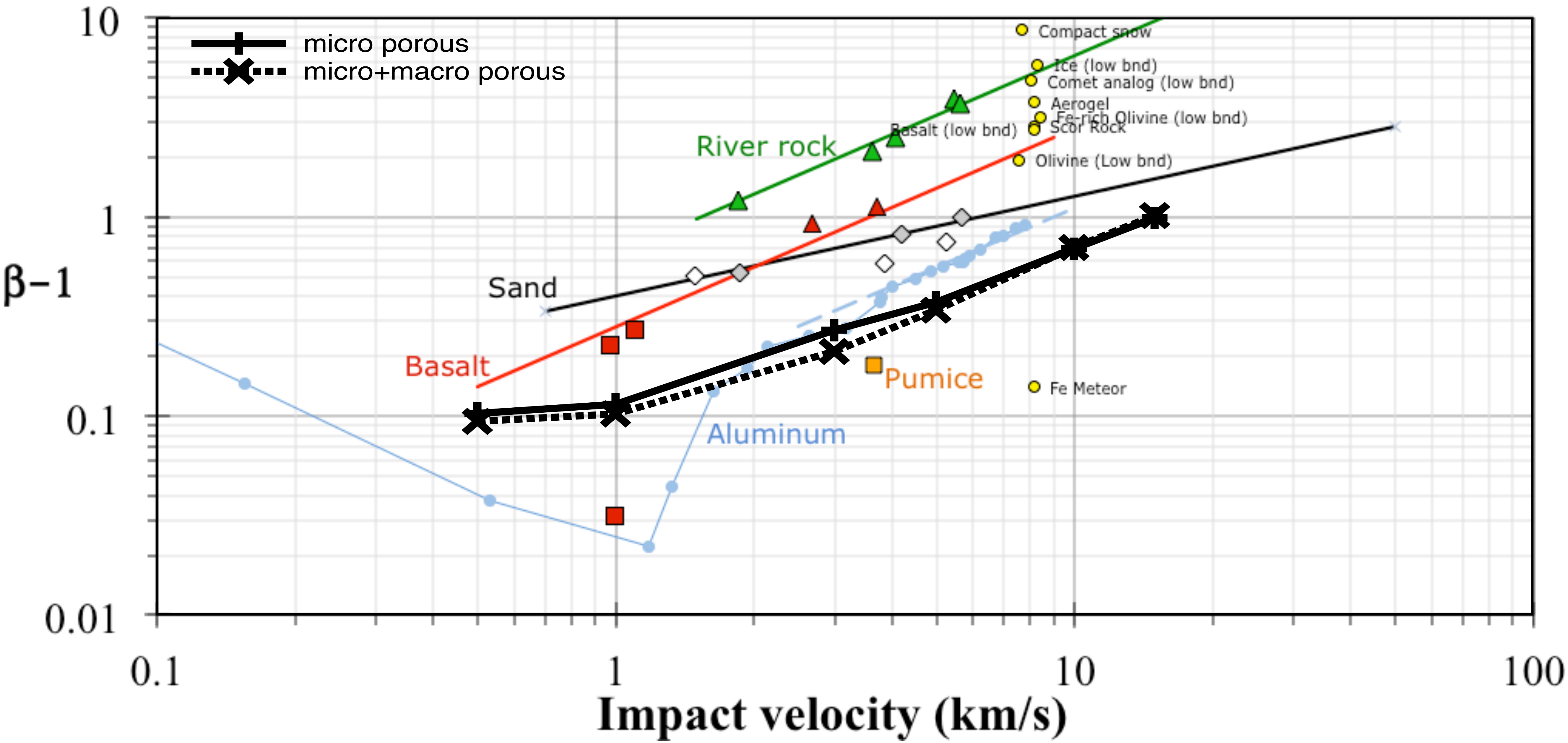
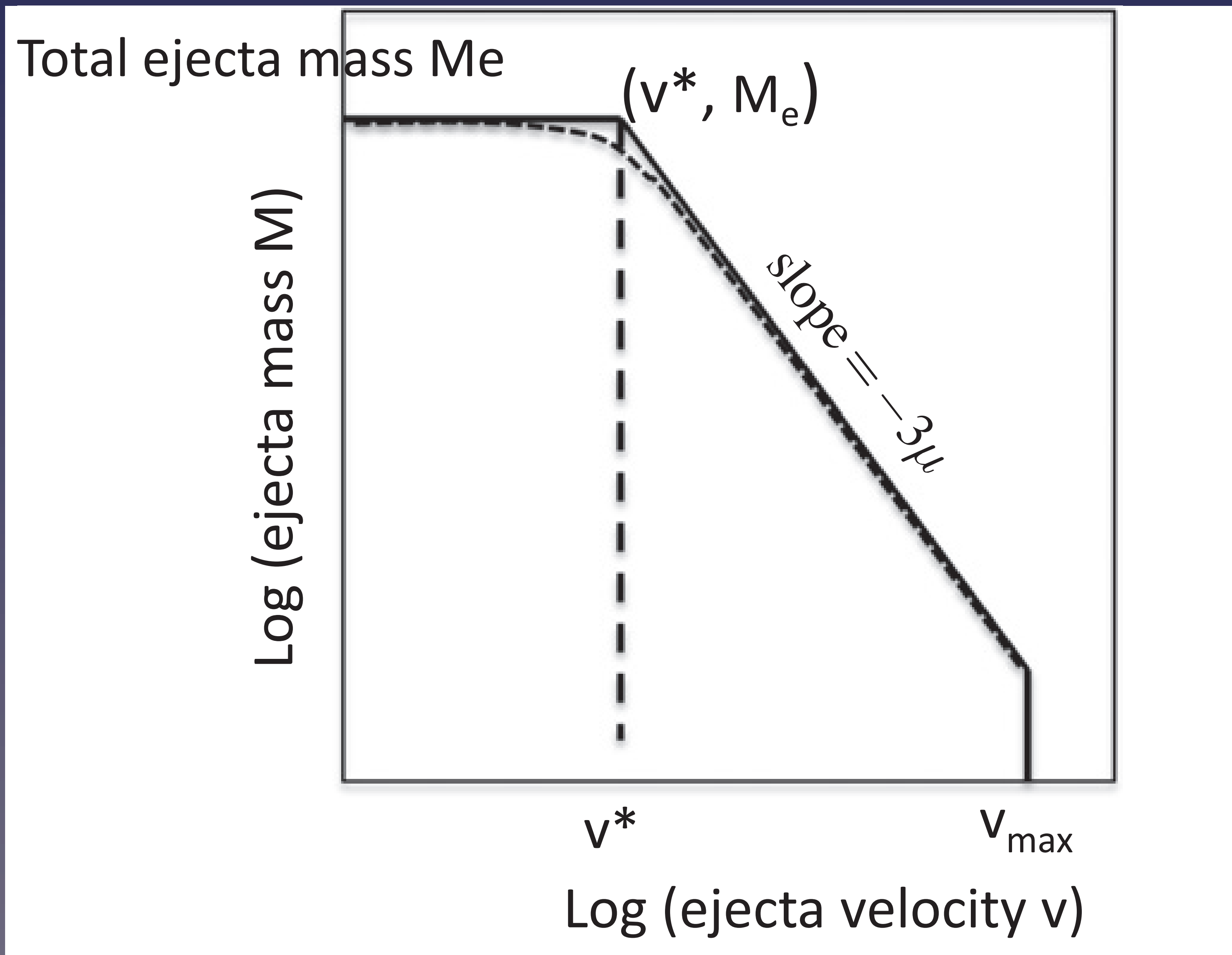


From Housen&Holsapple, LPSC 2012

Scaling laws for idealized cases



Scaling laws are based on an idealized ejecta velocity distribution

Slope μ: 1/3 - 2/3
~ 0.4 for porous materials
~ 0.6 for solid materials

Holsapple&Housen 2012

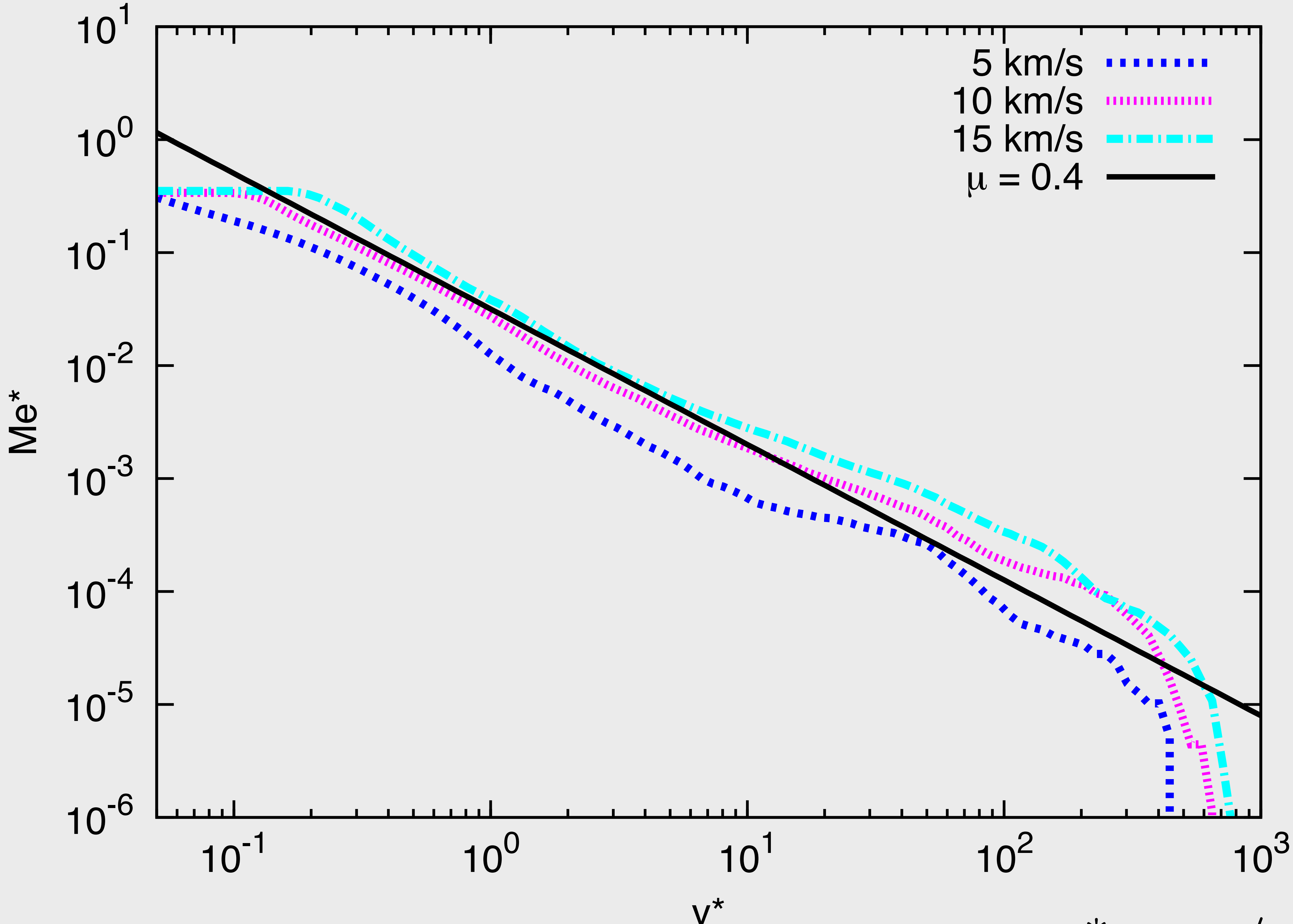
$$P = K_{ps}\left[mU\left(\frac{U}{\sqrt{Y/\rho}}\right)^{3\mu-1}\left(\frac{\rho}{\delta}\right)^{1-3v}\right] F_{esc}\left[\frac{v_{esc}}{v^{*}}\right]$$

$$\beta - 1 \sim U^{3\mu-1} \times F_{esc}$$

Velocity distribution

Mass *M* ejected with a velocity greater than *v*

$$M_e^* = \frac{M}{m_p}\left(\frac{U}{\sqrt{Y/\rho}}\right)^{-3\mu}\left(\frac{\rho}{\delta}\right)^{-3\nu-1}$$



$$v^* = v/\sqrt{Y/\rho}$$

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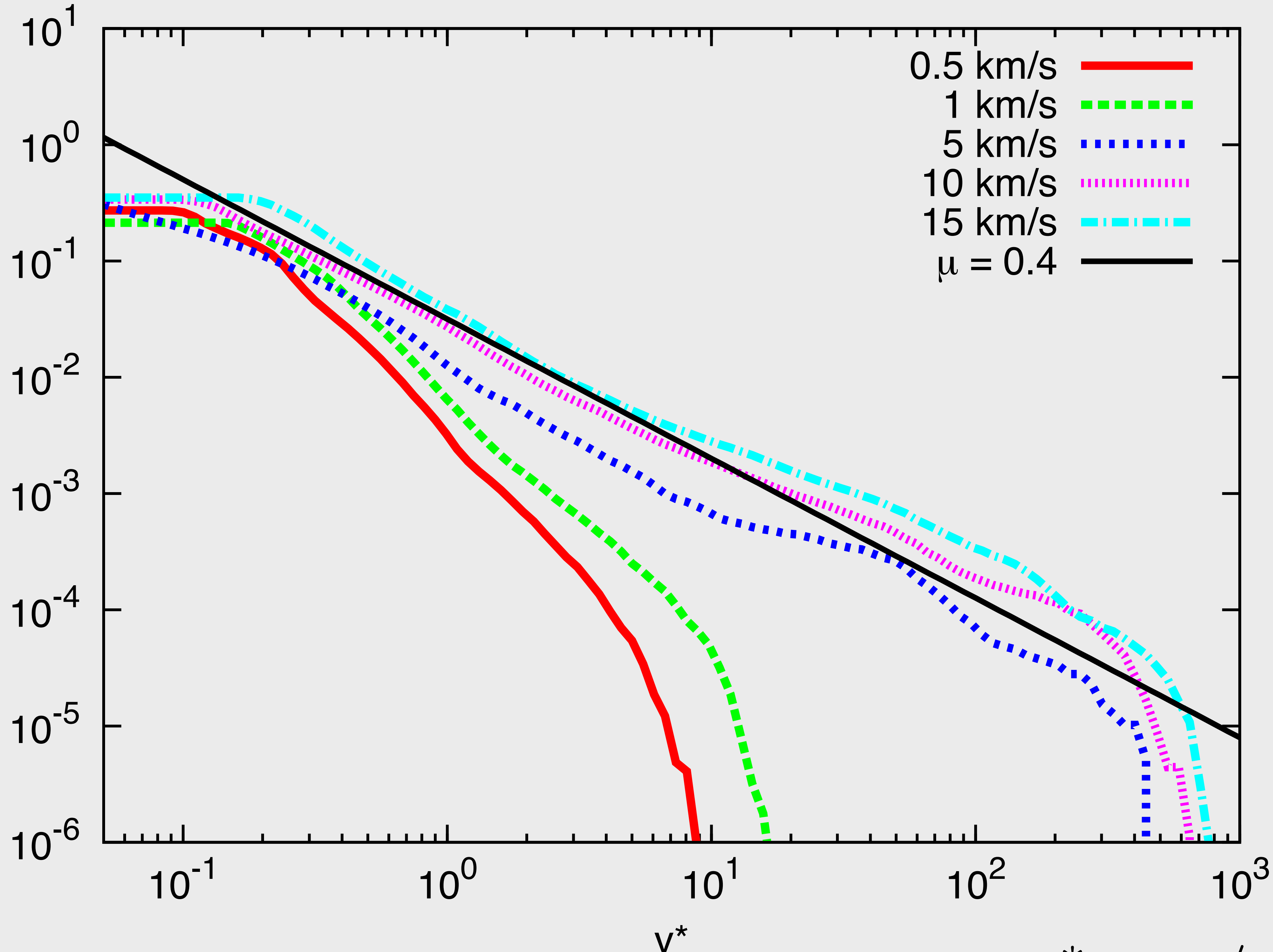
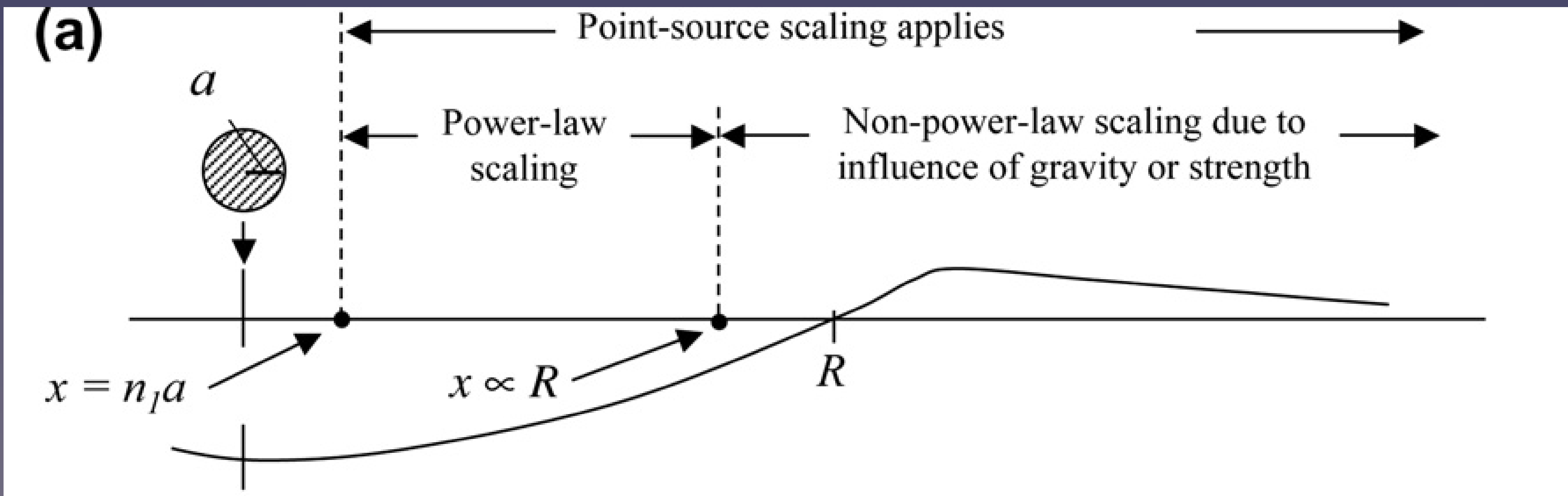


$$v^* = v/\sqrt{Y/\rho}$$

Point-source scaling limits



Housen&Holsapple 2011

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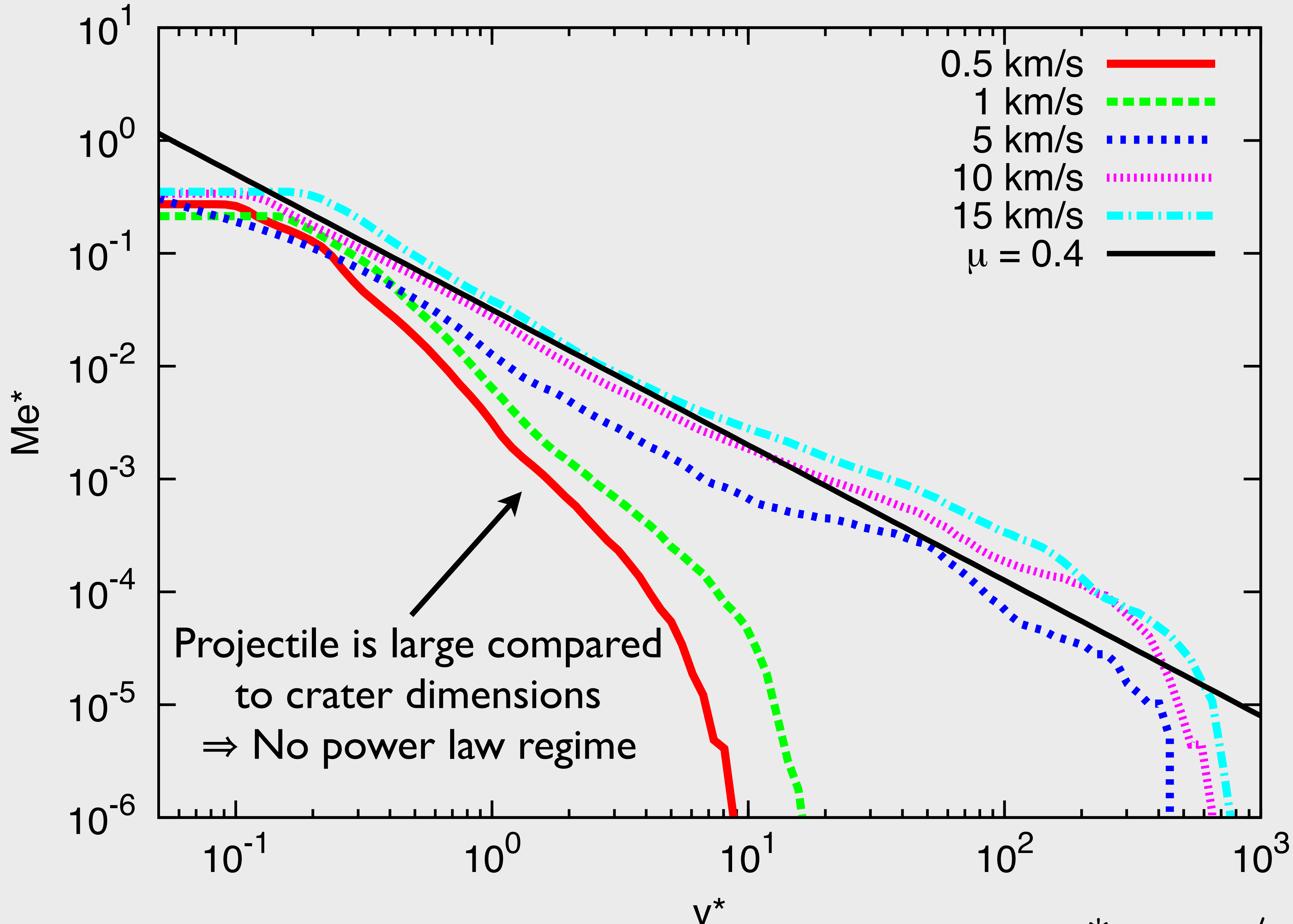
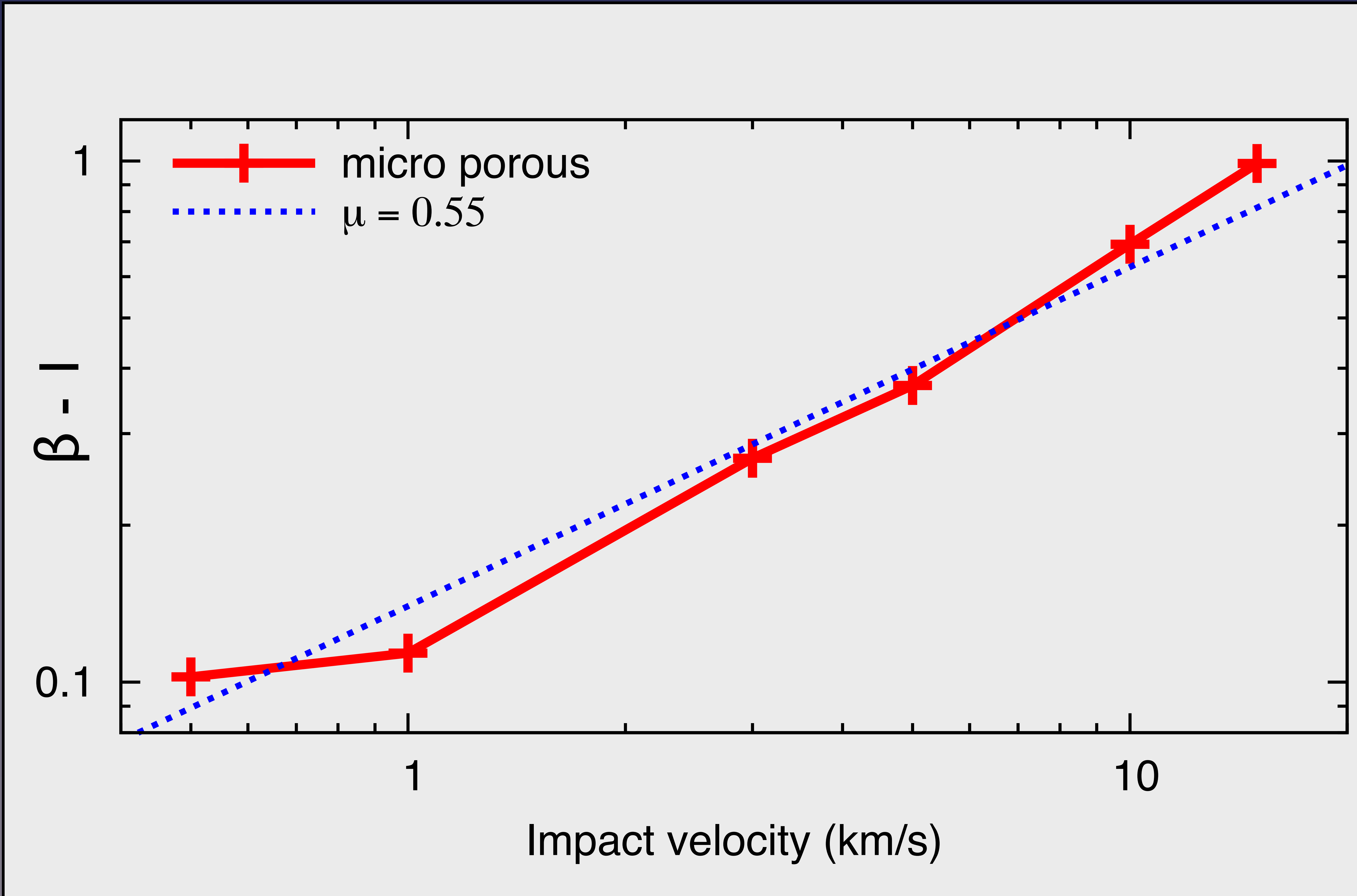
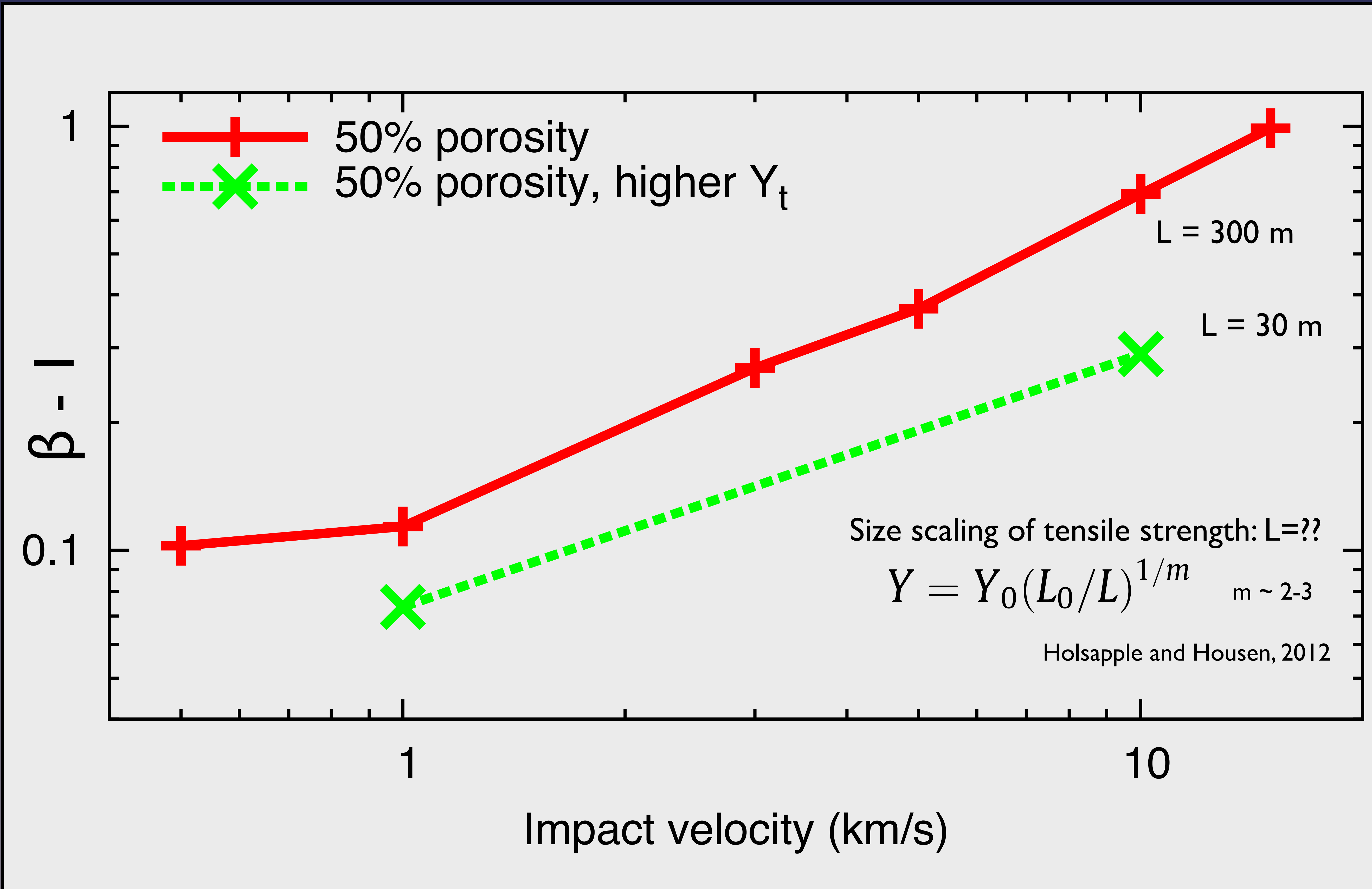


$$v^* = v/\sqrt{Y/\rho}$$

β - scaling with velocity



Effects of strength and porosity



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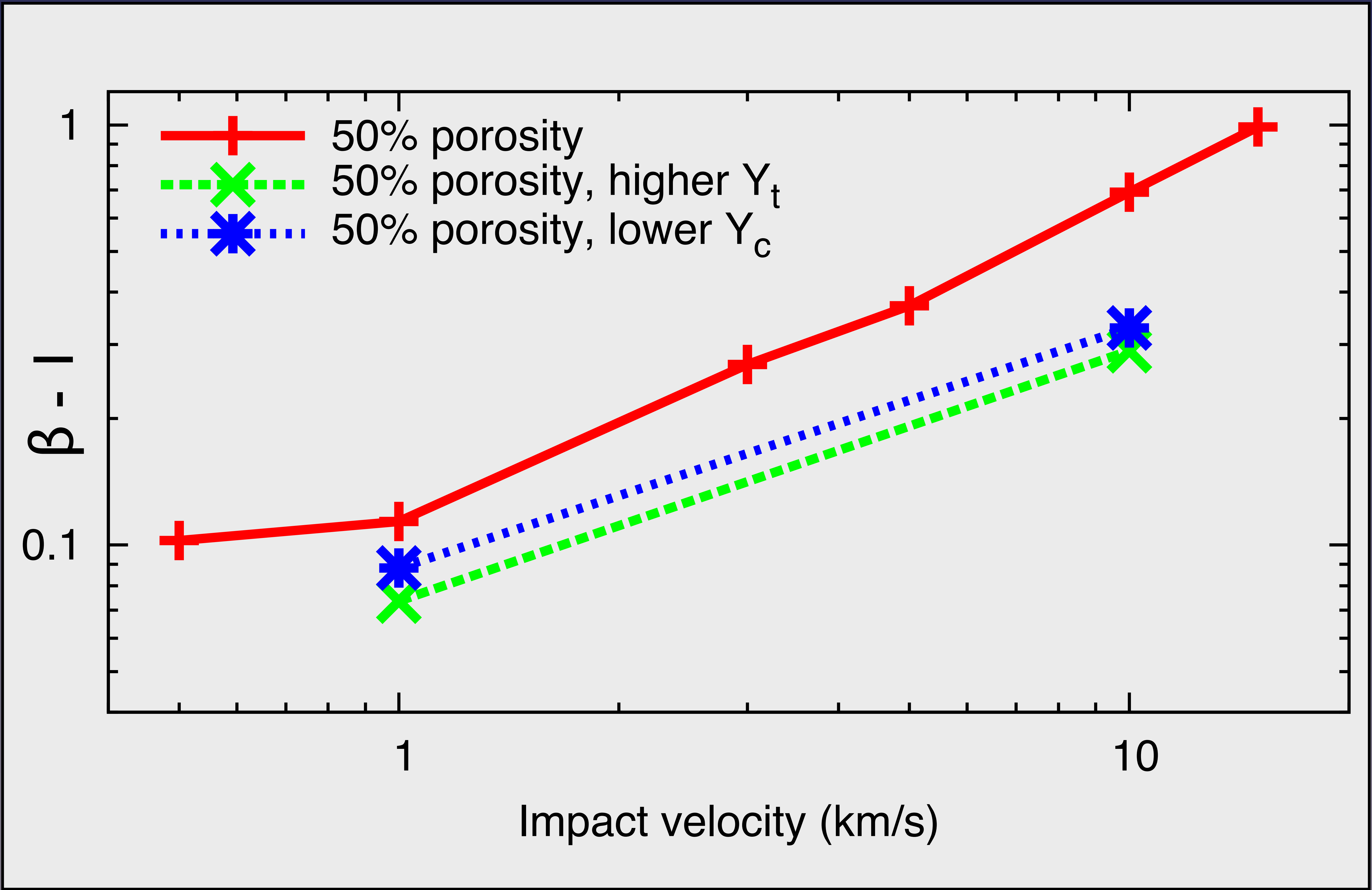

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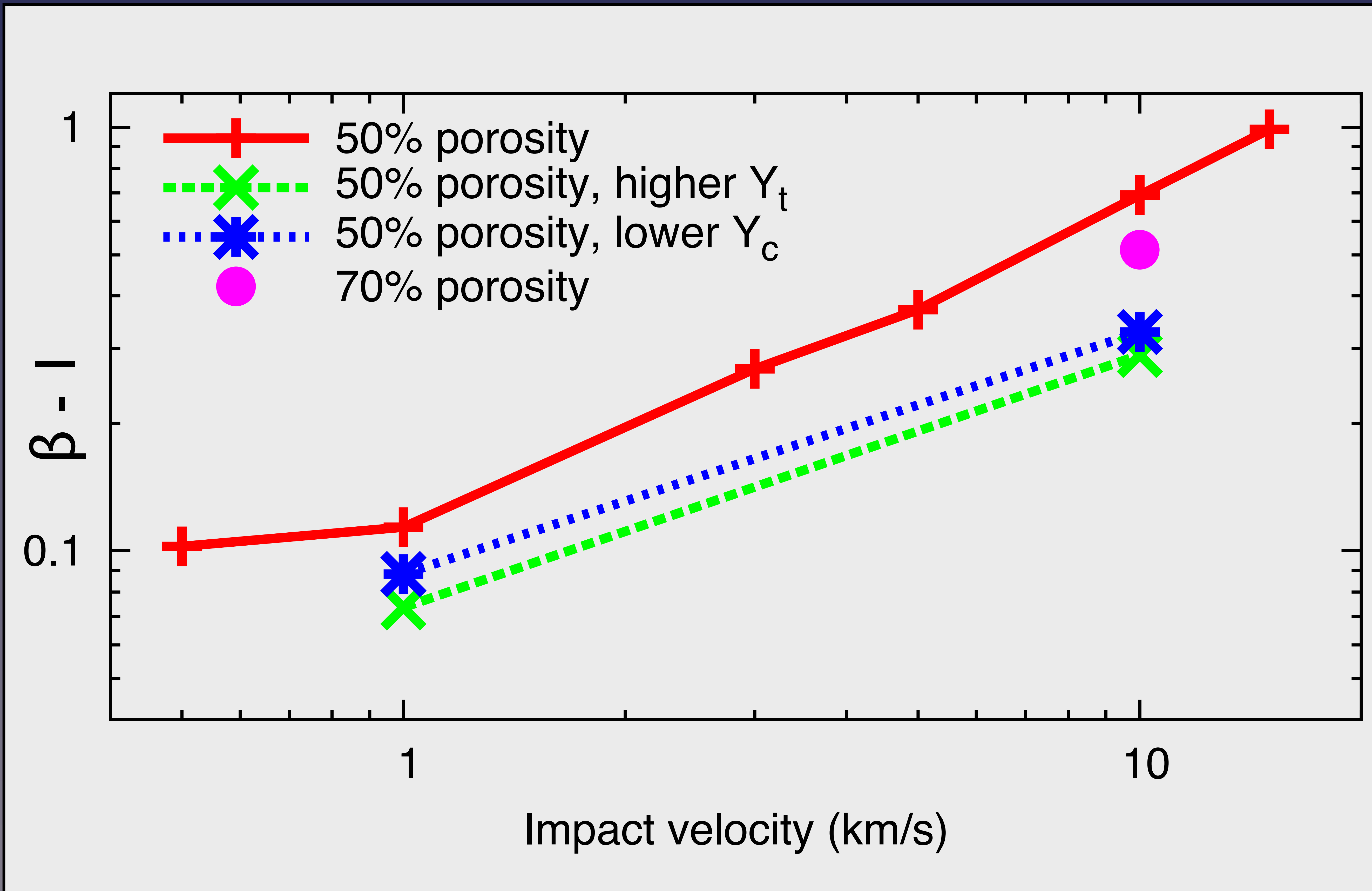

Summary

- Momentum multiplication factor is small for porous materials ($\beta < 2$ for $v < 15$ km/s)
- Effects due to macroscopic inhomogeneities disappear at high impact velocities
- Strength (tensile and crushing) is important
- Comparison to scaling laws:
  - Slope in velocity distribution is as predicted
  - Slope of β vs. impact velocity is slightly higher

Outlook

- Investigation of different material properties
  - very low strength (tensile, crushing)
  - very high porosities
- Higher impact velocities
  - using more sophisticated ANEOS
- Surface and structural inhomogeneities

Questions?