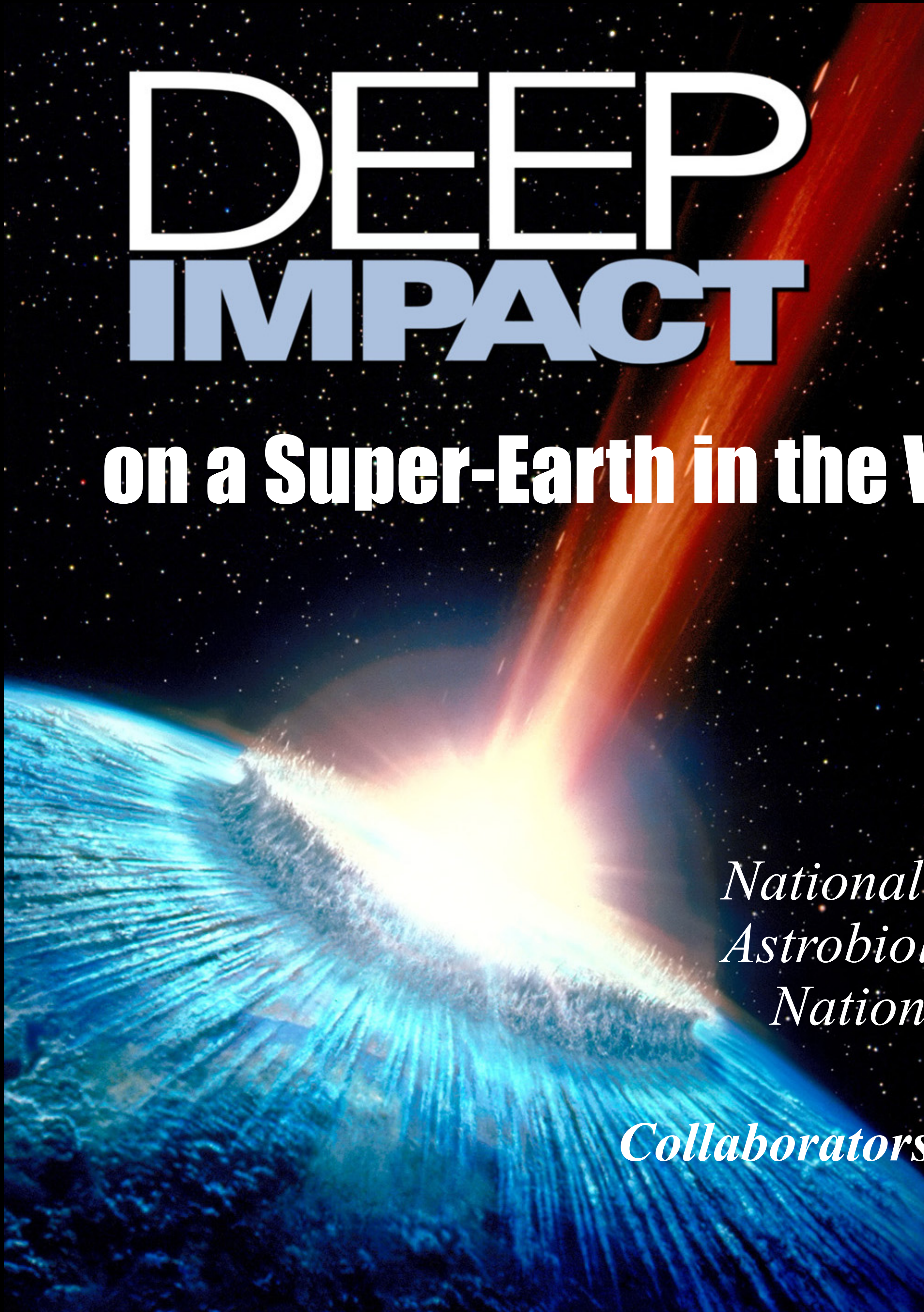

on a Super-Earth in the Vicinity of a Central Star

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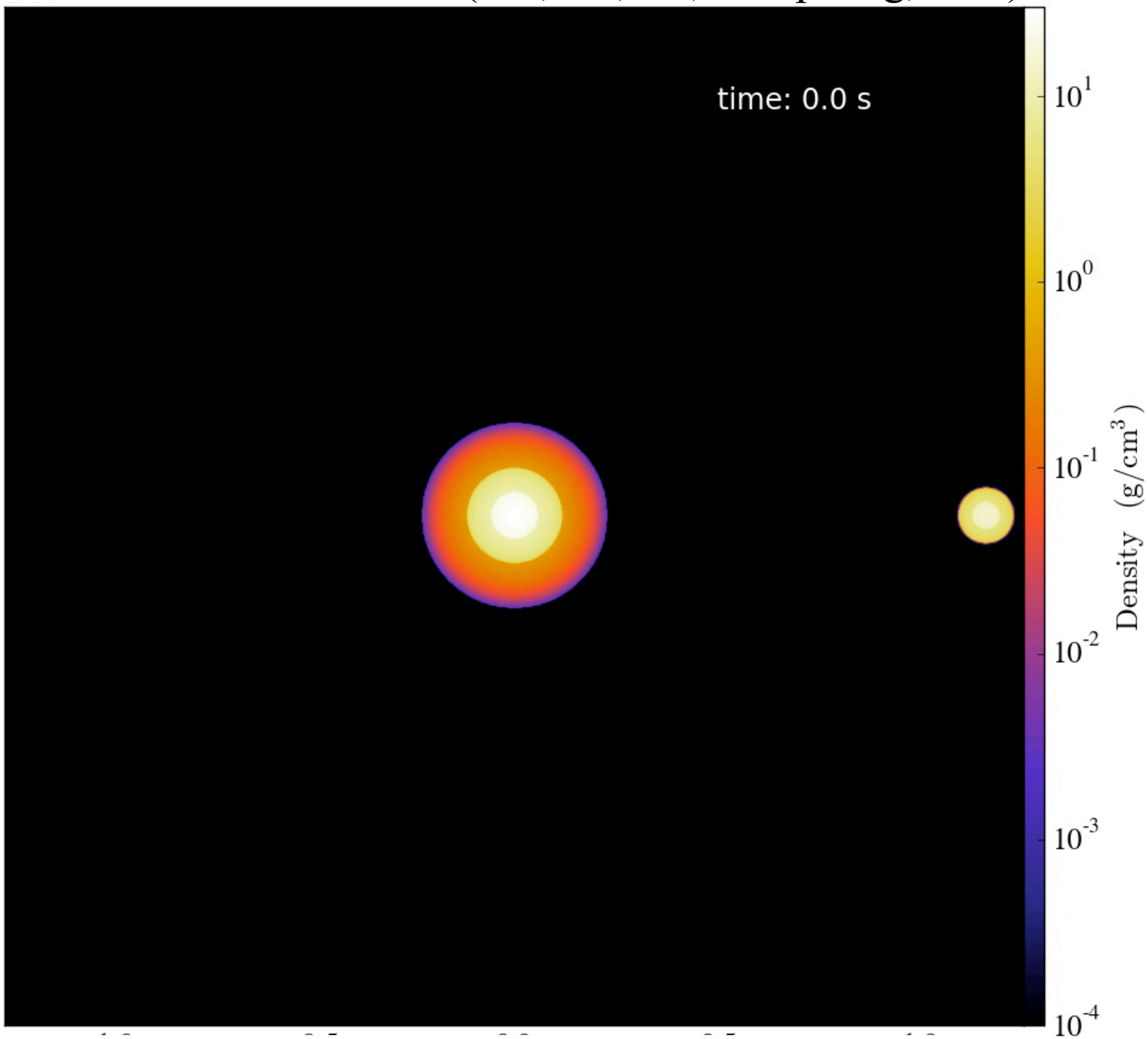
Erik Asphaug (Arizona State Univ.)

CfCA Users' Meeting on Jan. 29, 2016

What We did on Cray XC 30 : Giant Impact Simulations

(Liu,YH,Lin,& Asphaug,2015)



XC-B user

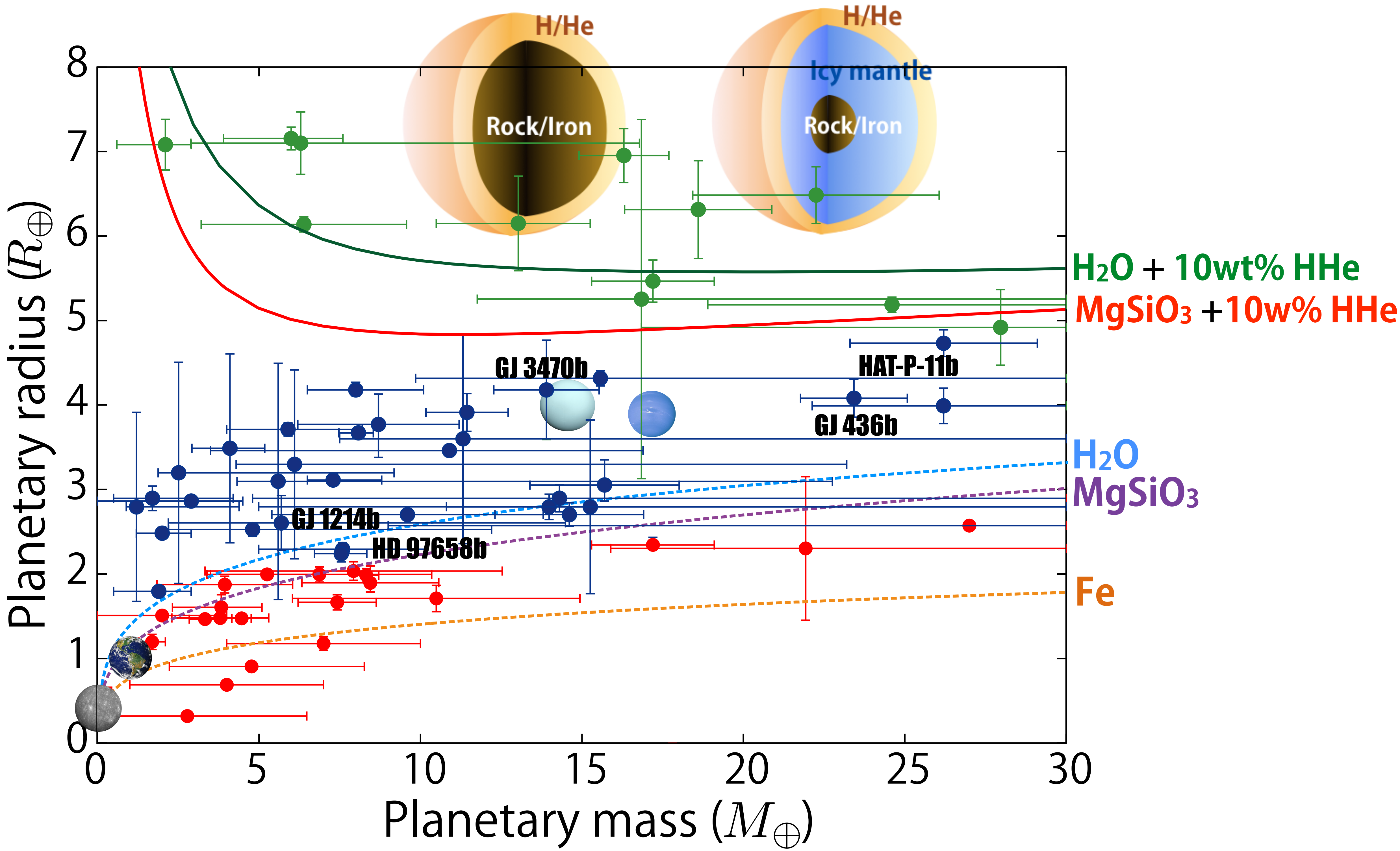
- 100-200 CPUs per run
- 2-3 weeks

↓

1 paper ***published***
2 papers ***in prep.***

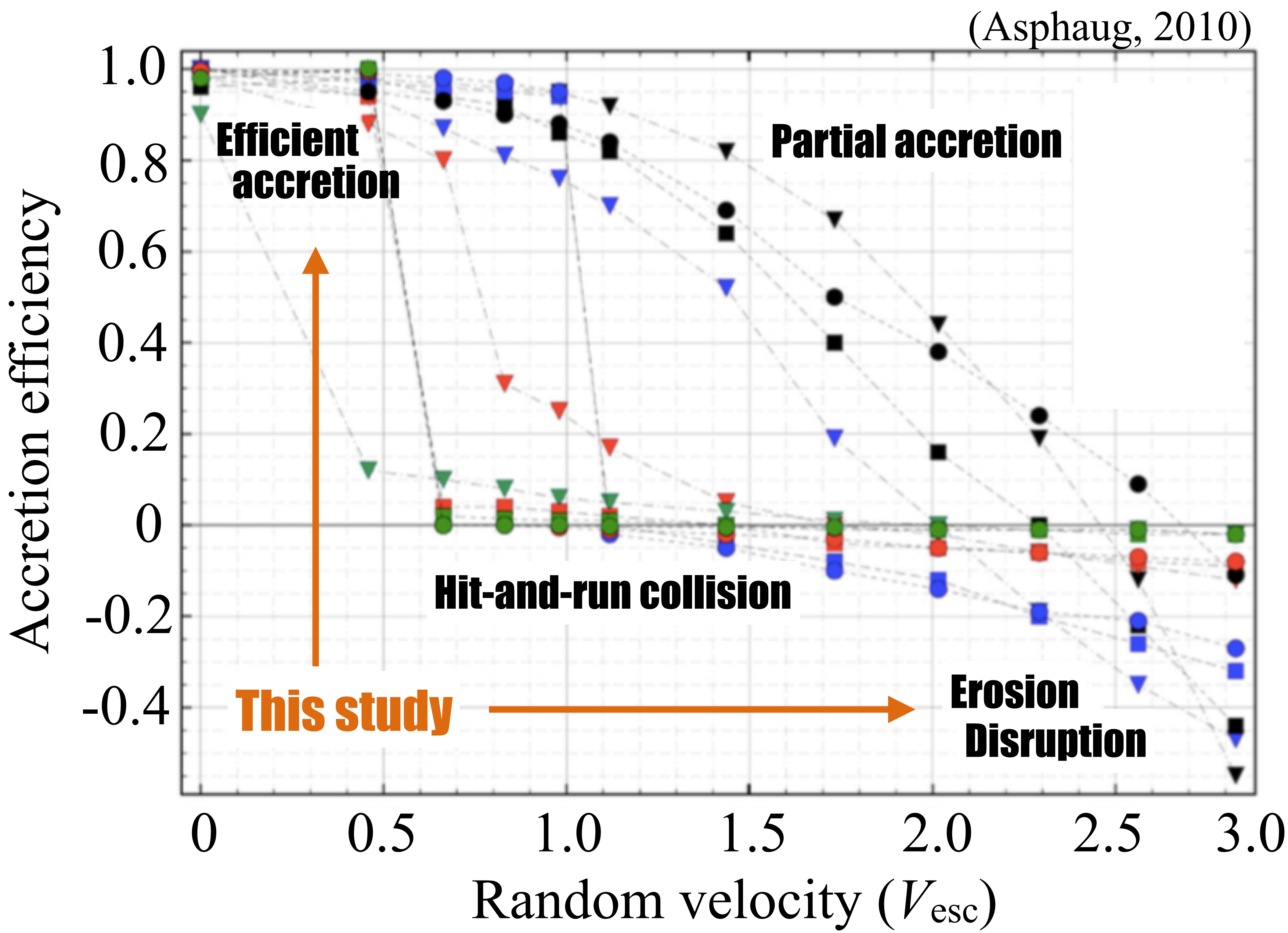
Compositional Diversity of Low-mass Planets

Mass-radius relationship of transiting planets with mass of $< 30\ M_\oplus$



Giant Impacts: Accretionary and Destructive

Accretion efficiency as a function of mass ratio (0.1▼, 0.5■, 1.0●), impact angle (0, 30, 45, 60°), and impact velocity



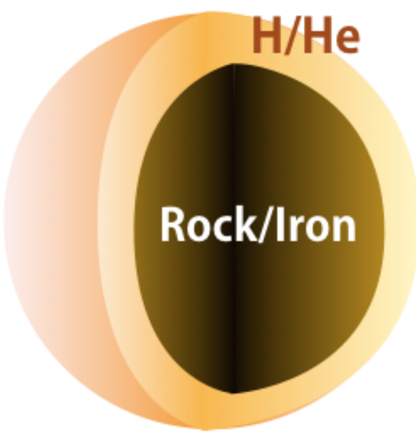
Modeling of a Giant Impact

Three-dimensional hydrodynamic simulations : FLASH with the AMR

(Fryxell *et al.*, 2000)

- A pair of planets' center of mass frame
- The width of a computational domain ~ 1 AU
- include the tidal force from a central star
- impose an open boundary condition

Three-Layered interior structures of a target and an impactor



Tillotson EoS for rocky and iron material (Melosh, 1989)

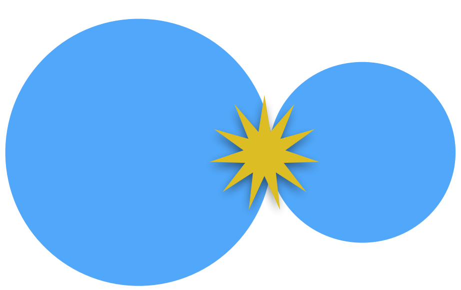
rock (silicate) : iron = 2:1

Only a target has an atmosphere (7.5wt%)

Polytropic-type EoS for H/He gas (H_2 : He = 7 : 3)

(Liu *et al.*, 2013)

Giant impacts (@ 0.1 AU)



head-on collision

(1) Low-speed model (accretion regime) : $V_{\rm imp} = V_{\rm esc}$

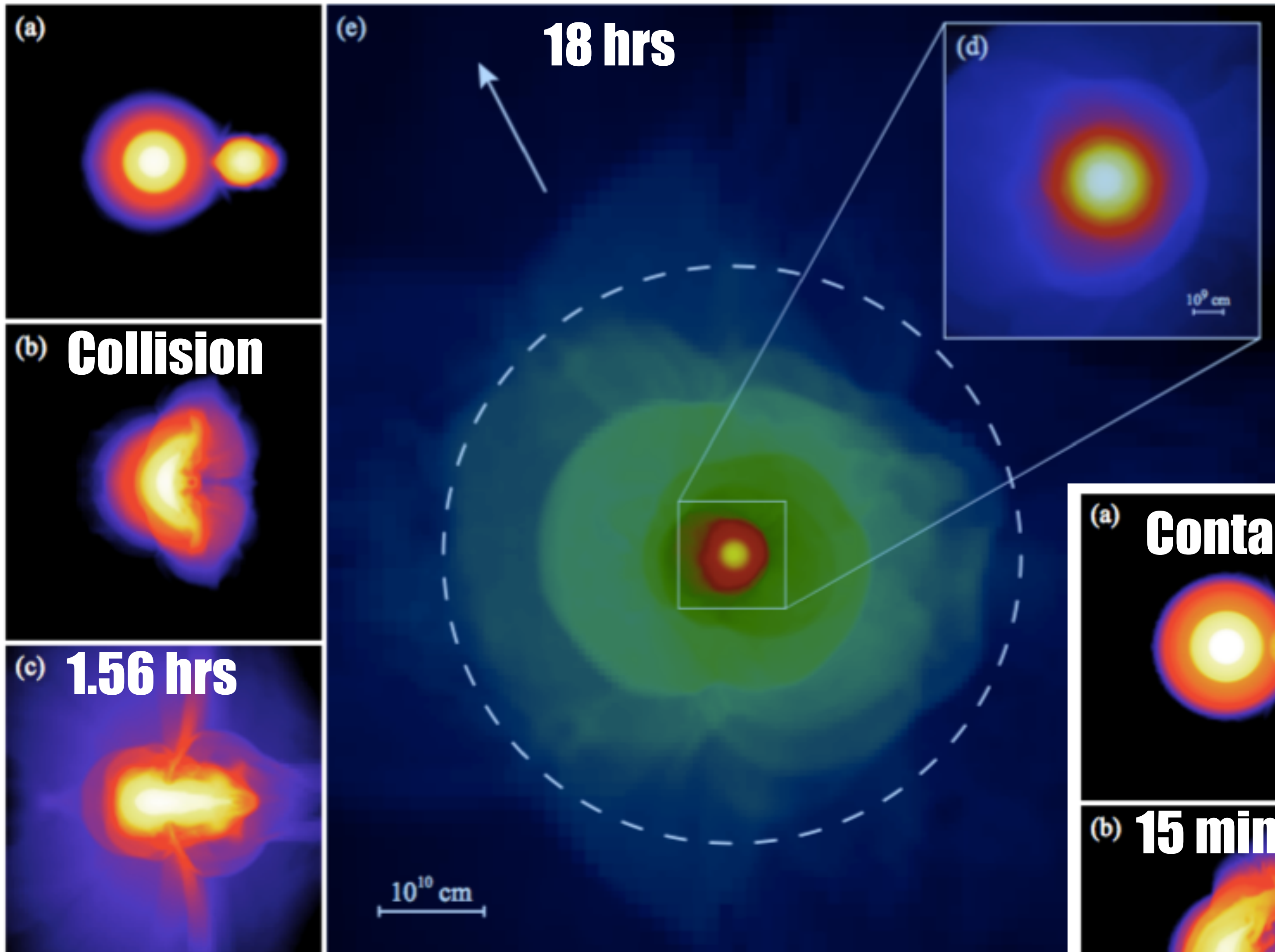
$$4.3\,M_\oplus \;\&\; 1.0\,M_\oplus$$

(2) high-speed model (destructive regime) : $V_{\rm imp} = 3V_{\rm esc}$

$$10\,M_\oplus \;\&\; 1.0\,M_\oplus$$

Snapshots of Two Head-On Collisions : Density Contours

(Liu, YH, Lin, & Asphaug, 2015)

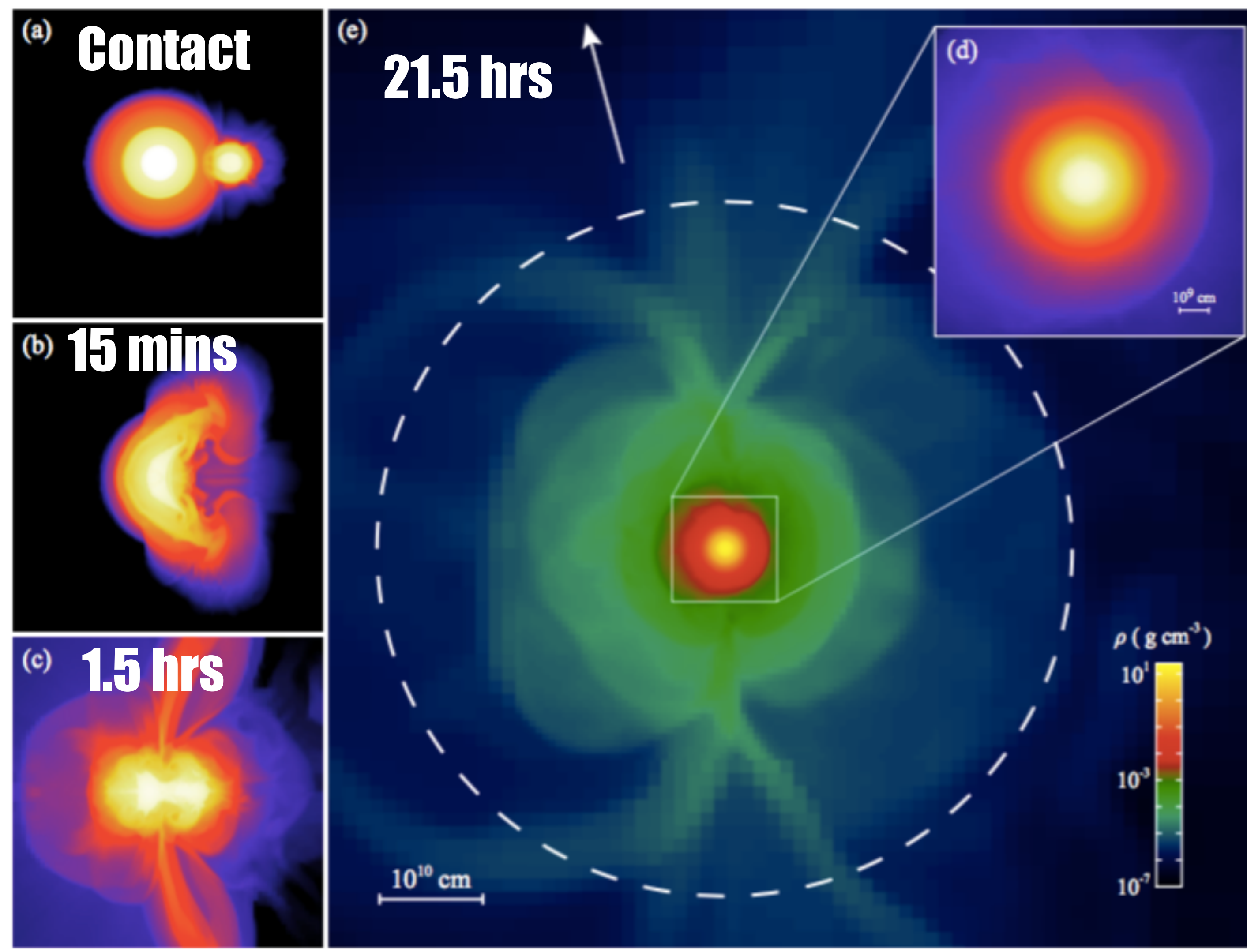


Low-speed impact

~30% of the initial atmospheric mass evaporated via an impact

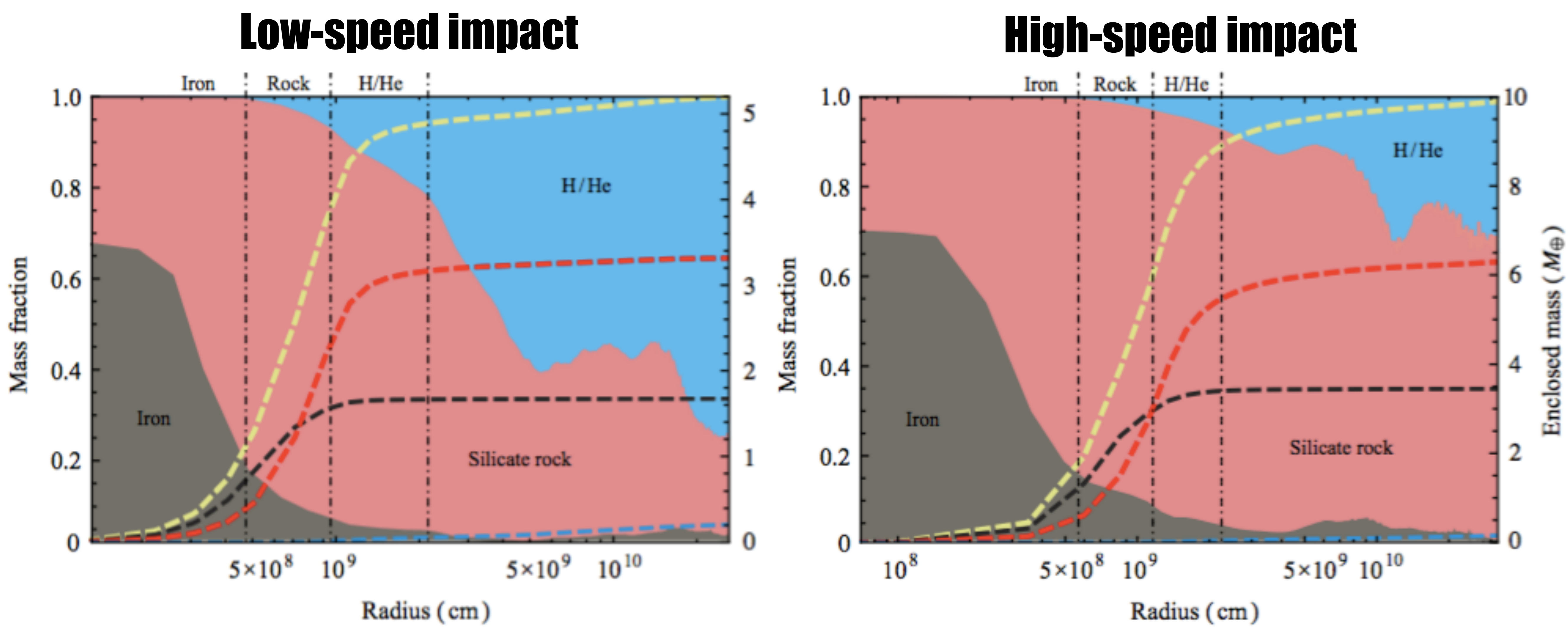
The atmosphere is lost by ~80%

High-speed impact



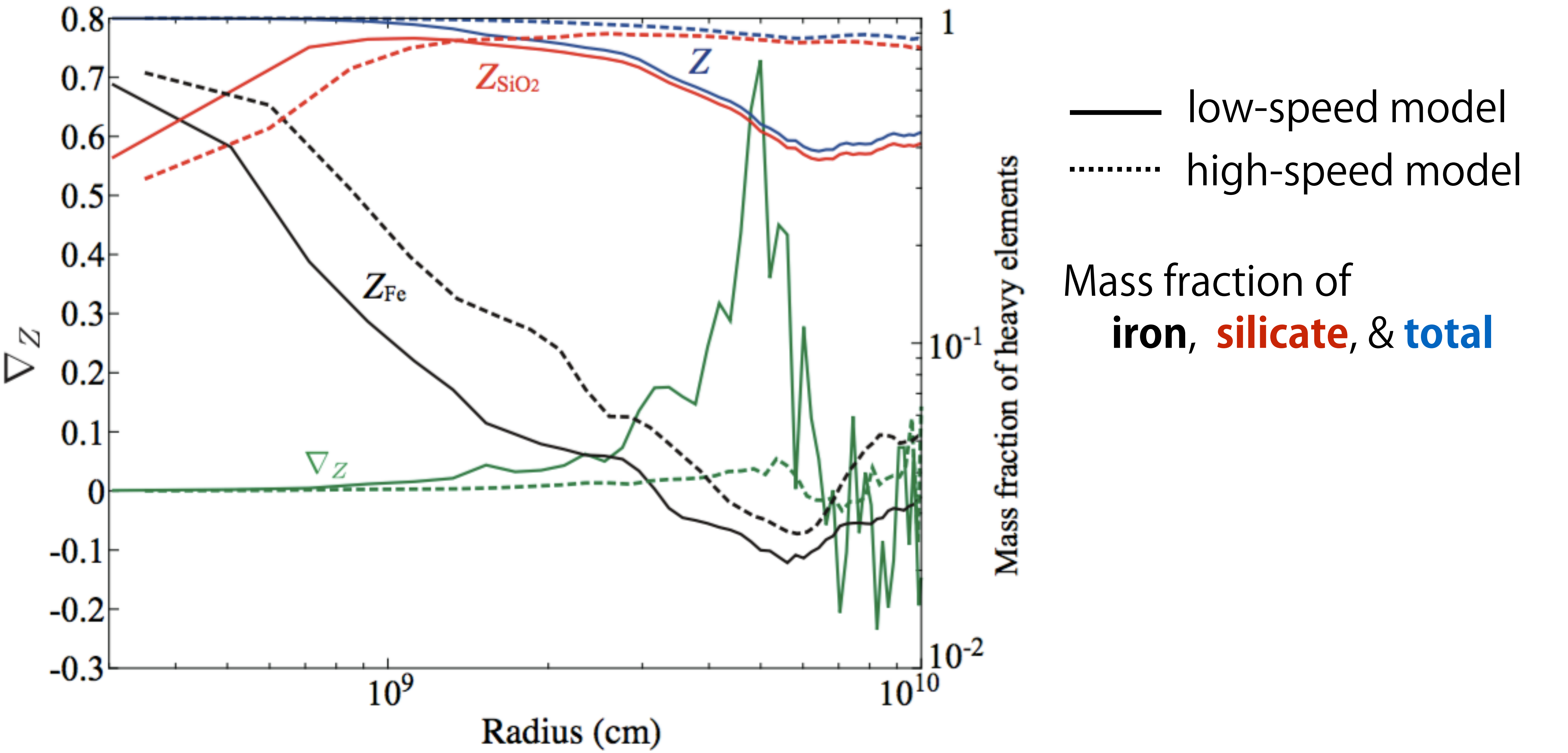
A hot atmosphere extends beyond the Hill radius and continues to lose via **the Roche-lobe overflow**

Radial Distribution of Each Species After a Collision



- An initial layered structure is partly maintained after the collision
- An iron core of the target survives from the impact in both cases and grows in a coalescence manner
- A fraction of rocky material is dredged up in a H/He atmosphere
  → the remaining atmosphere is polluted with heavy elements

Compositional Gradient Inside a Target After an Impact

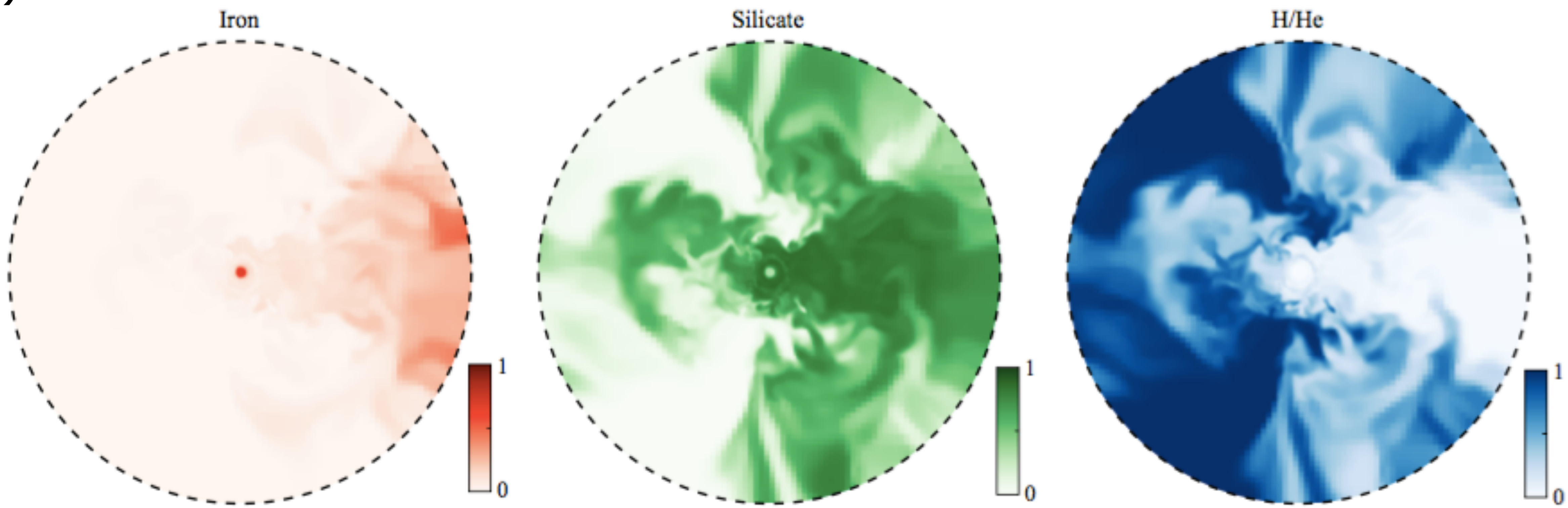


A low-speed head-on collision develops a hot and inhomogeneous interior
→ **a steep, positive compositional gradient** suppresses efficient heat transfer(?)

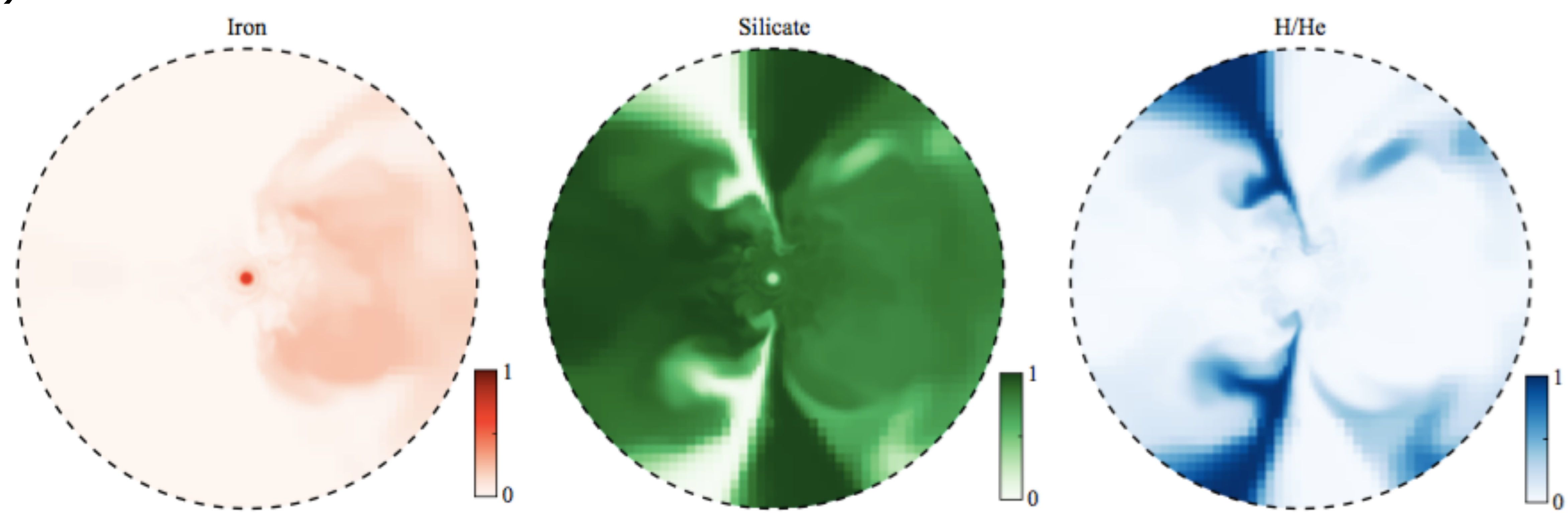
For a high-speed head-on collision,
refractory material is homogenized in the target's interior

Snapshots of Material Mixing After Giant Impacts

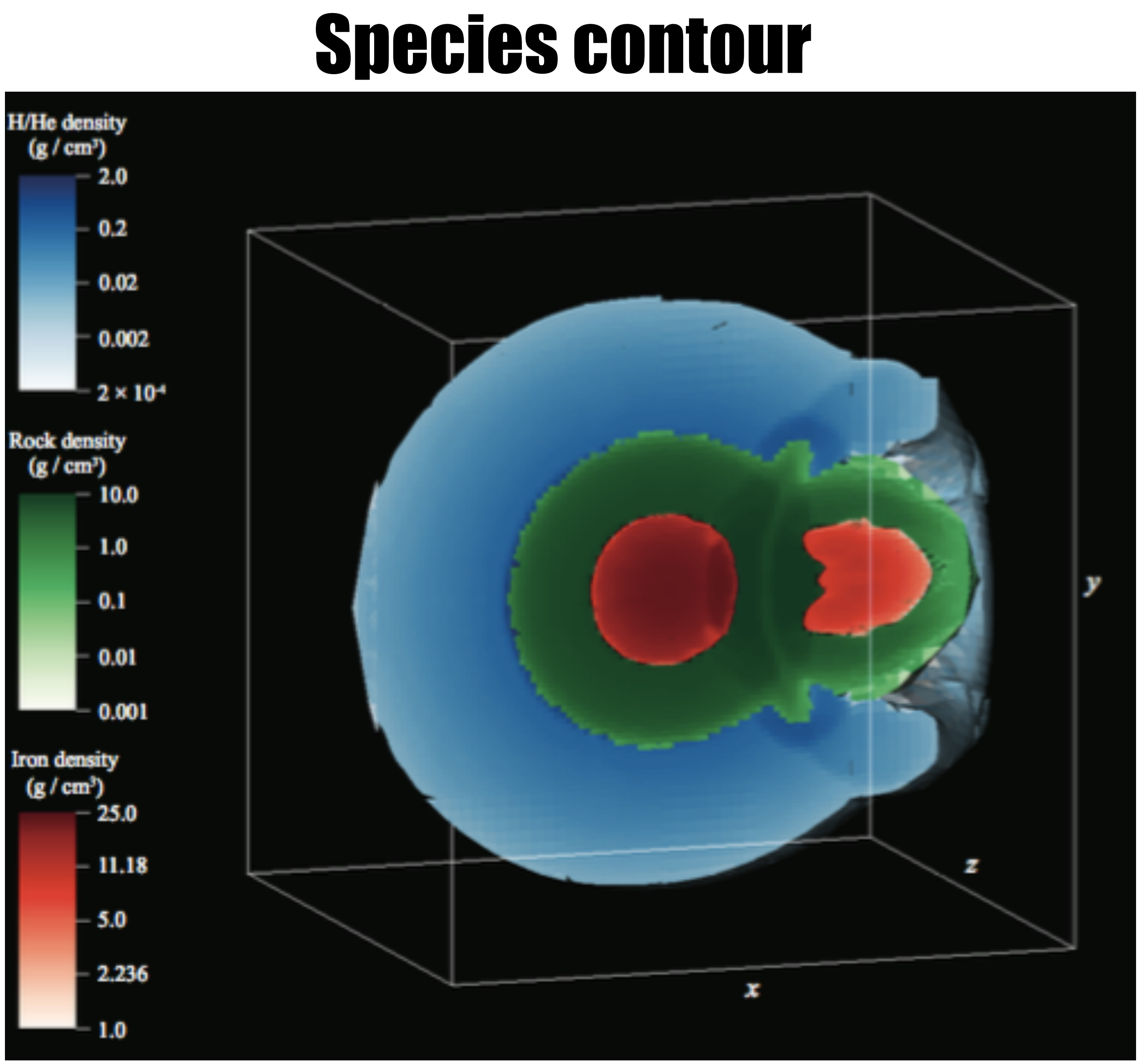
(a) 18 hrs after a low-speed impact

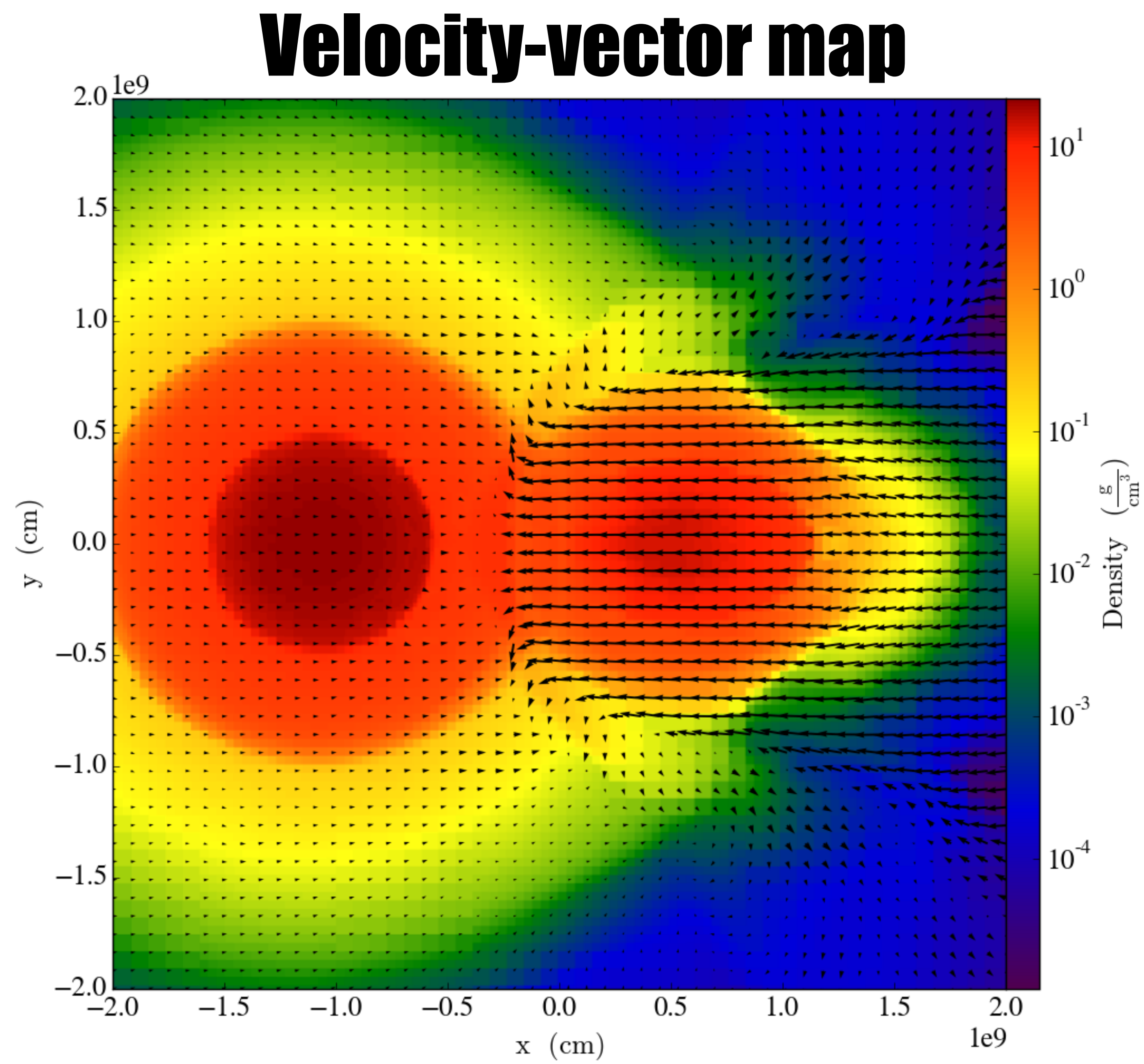


(b) 21.5 hrs after a high-speed impact



Turbulence or Hydrodynamic Instability?





- **A velocity shear** at the interface between two species after an impact → **K-H instability** (at least for short wavelengths)
- **An impact-induced shock wave propagation** → **R-T instability**

However,

An impact-driven turbulence is responsible for **the global mixing**

Take-Home Messages

Different histories of giant impacts result in

(1) **compositional diversity** of super-Earths(Inadmar & Schlichting,2015)

(2) **homogeneous or inhomogeneous** interior

→ suppresses efficient heat transfer

(e.g.) double diffusive convection

(3) **a hot and inflated atmosphere** (extended beyond the Hill radius) which **enhances mass loss** via photo-evaporation or a Parker wind

(4) **the survival of a planetary iron core** through a merger

(5) **dredge-up of rocky material into a H/He atmosphere** caused by turbulence driven by an impact-induced shock wave

(6) **a partial disruption of a three-layered structure**