Astromaterials in Accreting Neutron Stars

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U.S. DEPARTMENT OF ENERGY | Office of Science

NUCLEI
Nuclear Computational Low-Energy Initiative

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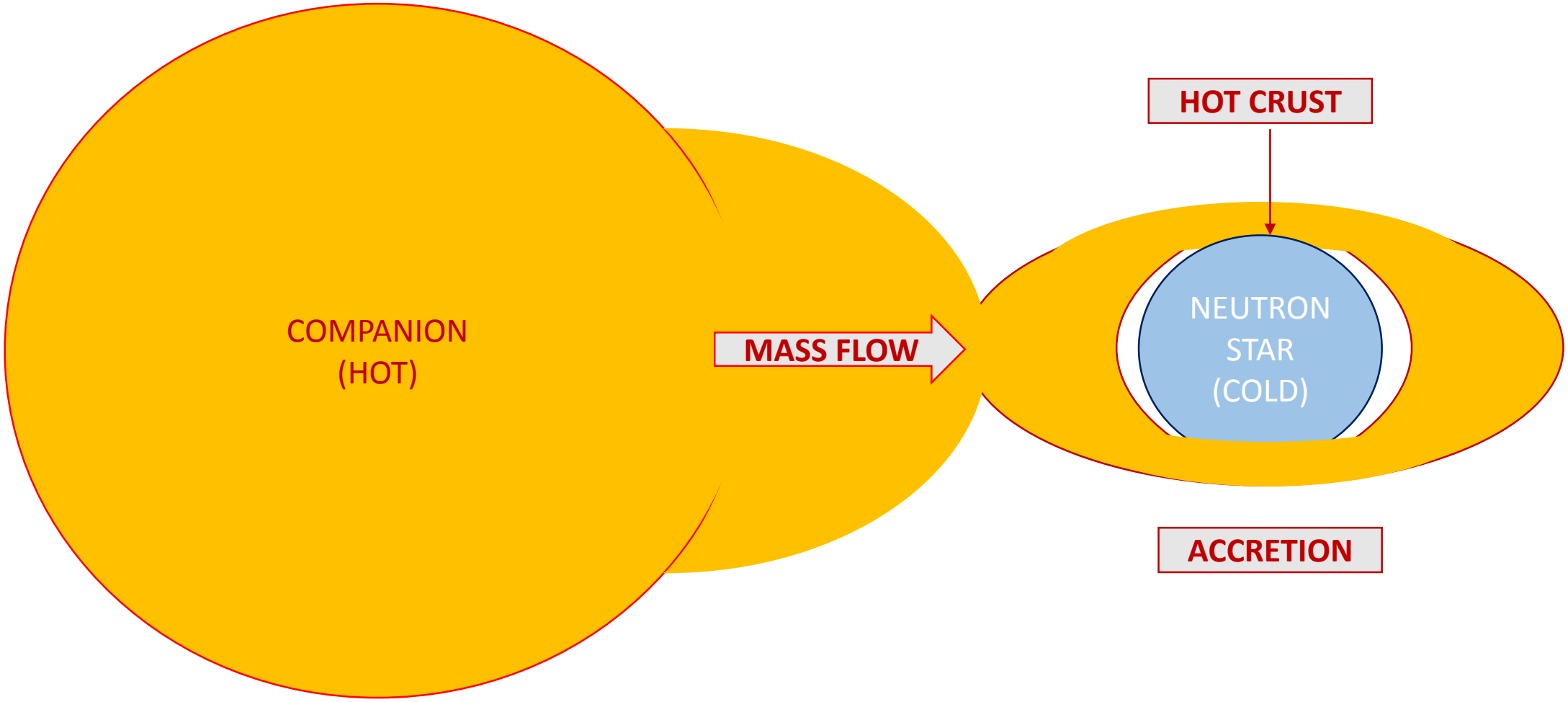
X-Ray Binaries

Low Mass X-Ray Binaries



Quiz 1

Hydrogen on the surface of a neutron star is being heated and compressed.

What happens now?

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A: Explosive nuclear burning.

(Similar to a WD nova)

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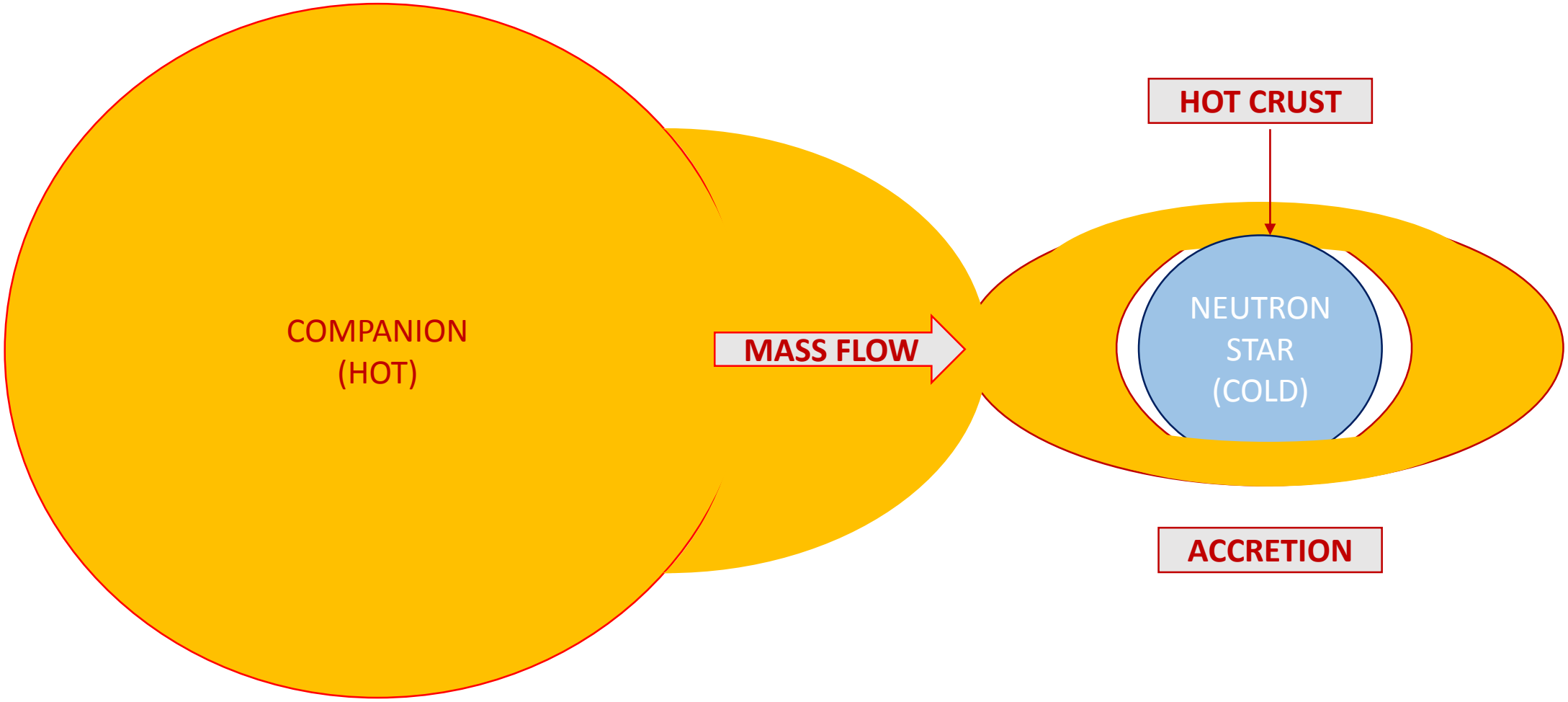

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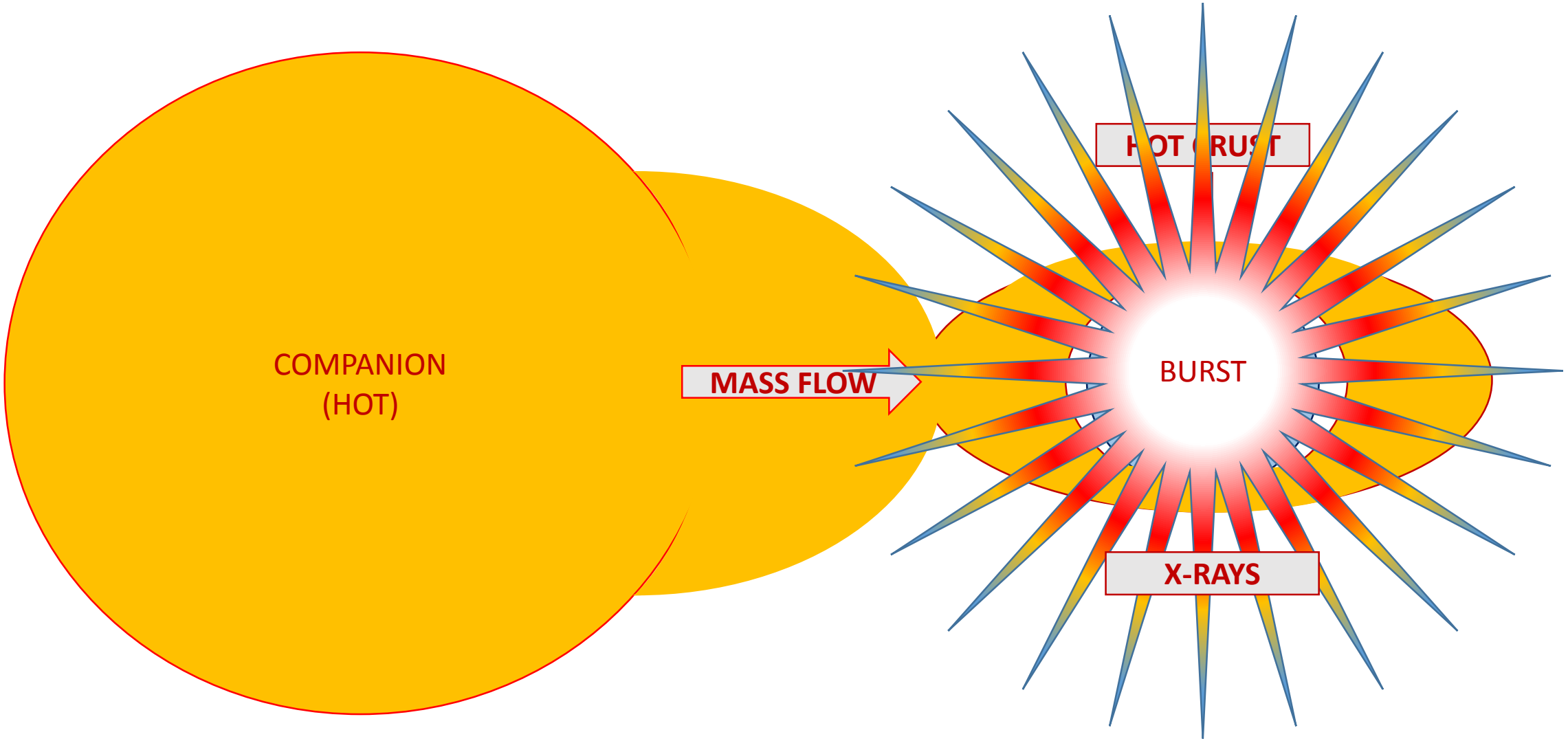

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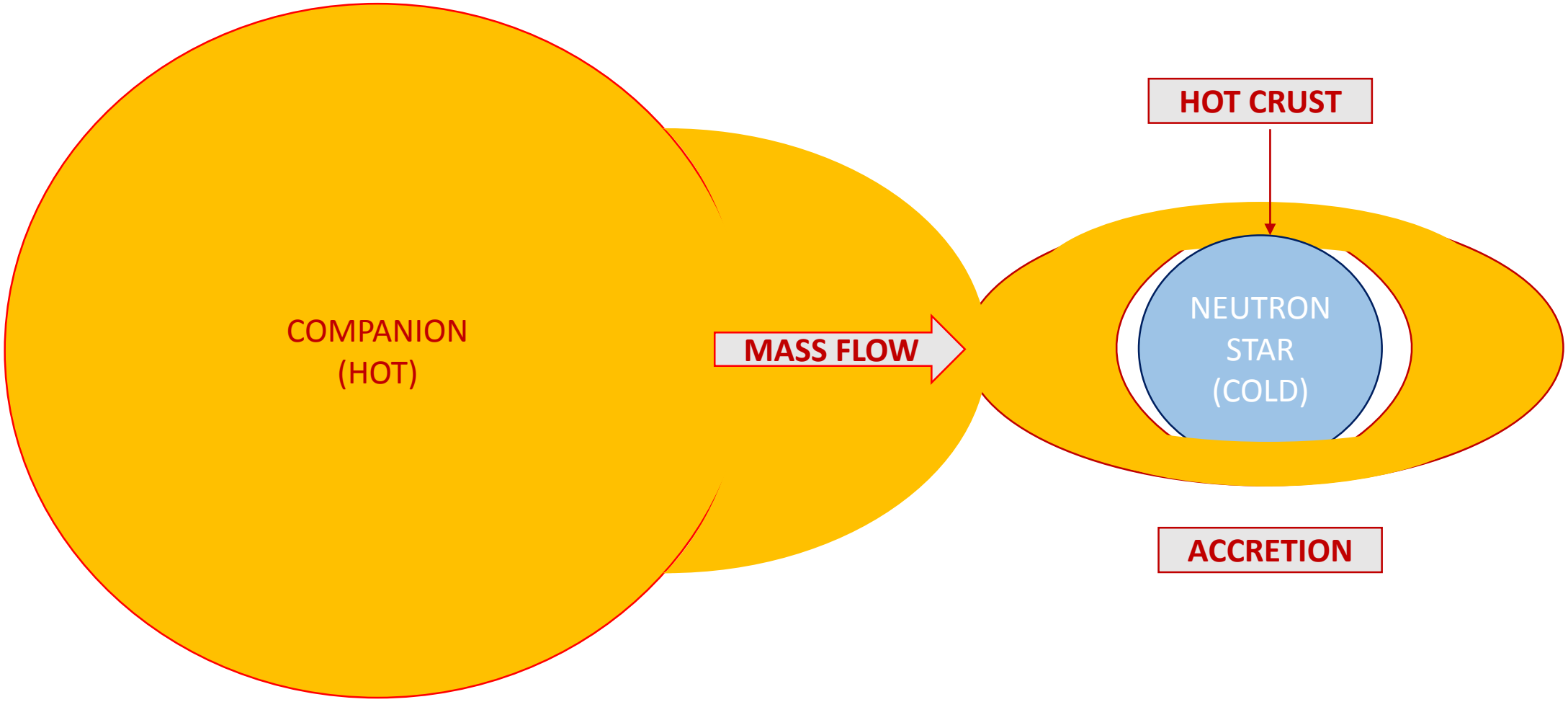

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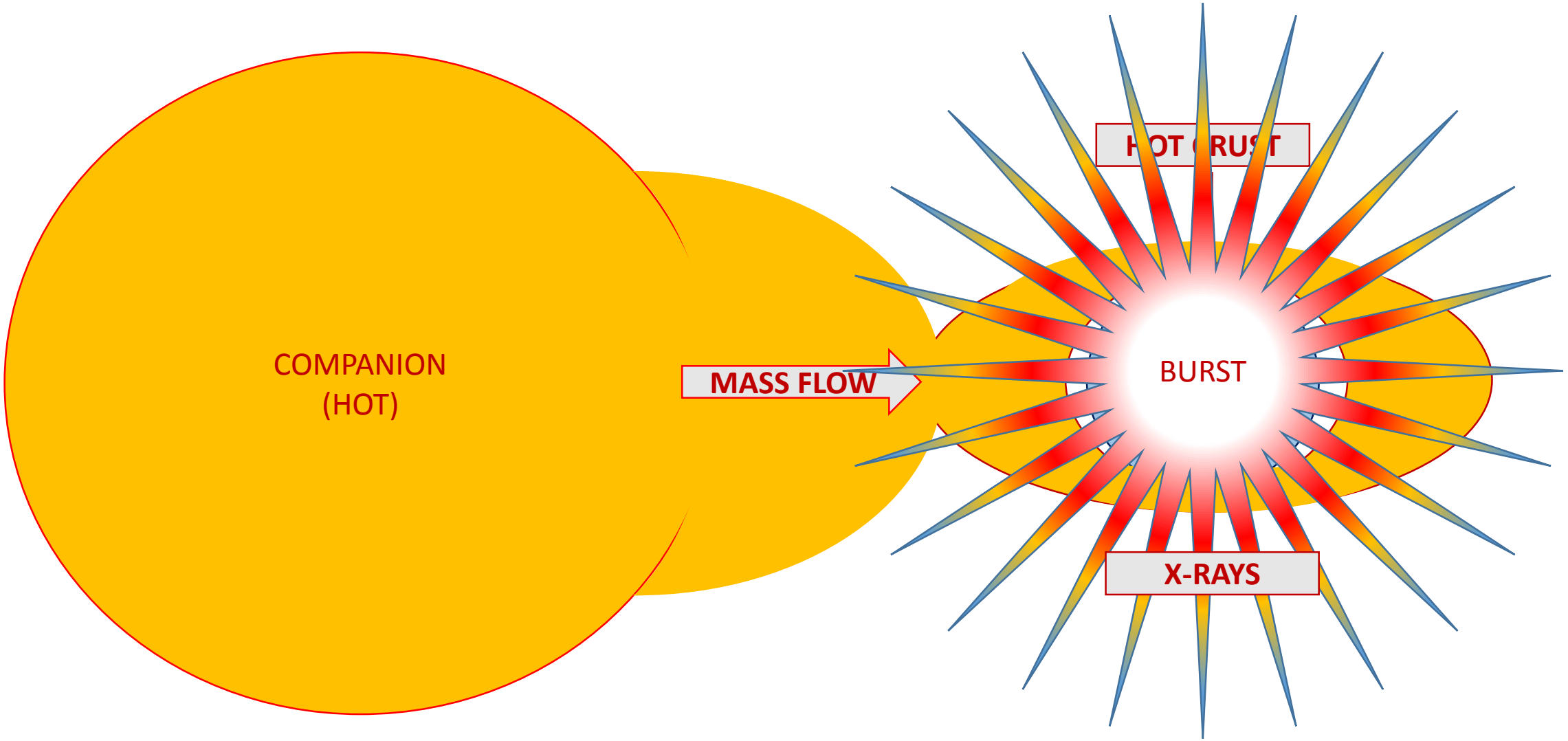
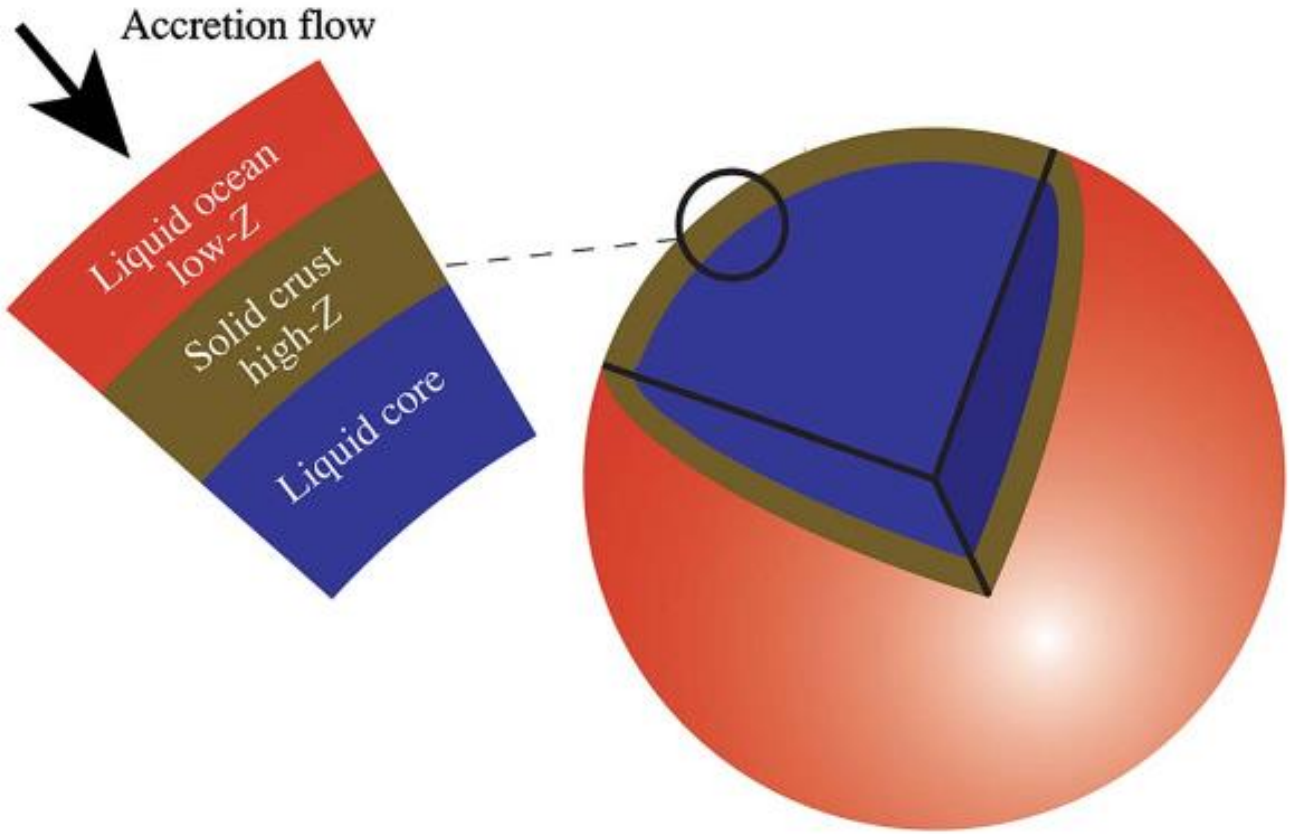


X-ray bursts

- As matter accretes, it is compressed, buried, and heated
- Explosive nuclear burning produces a mix of heavy nuclei (rp-process), and an X-ray burst
- Ash is buried, and crystallizes
- This matter forms the crust



Quiz 2

What is a material?

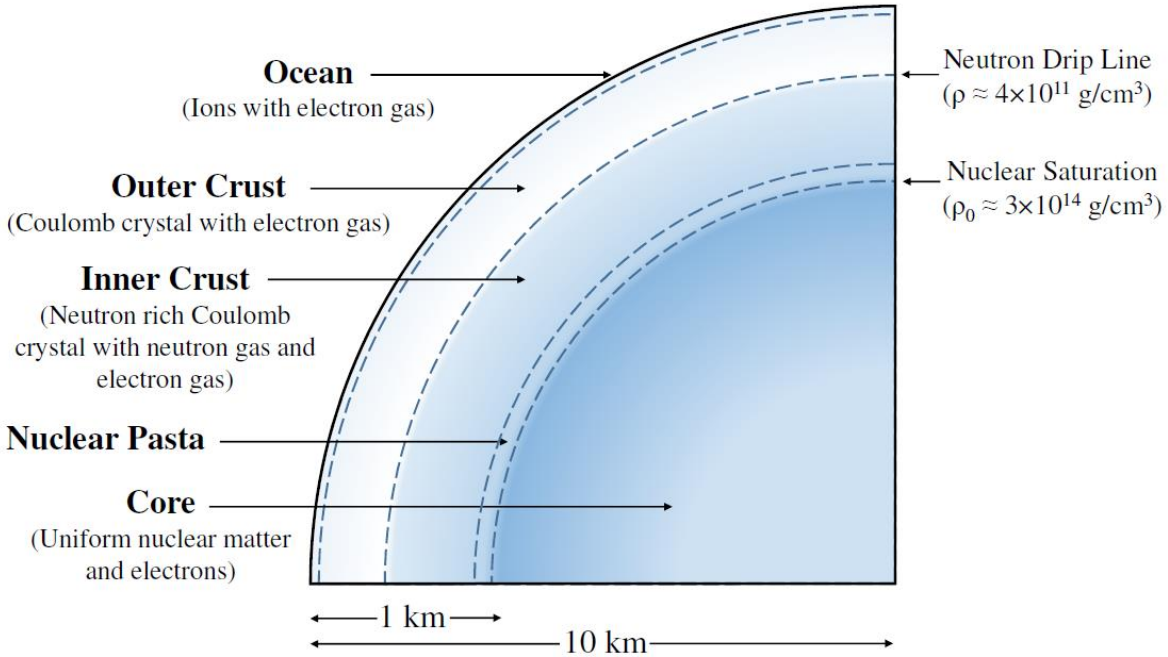
Quiz 2

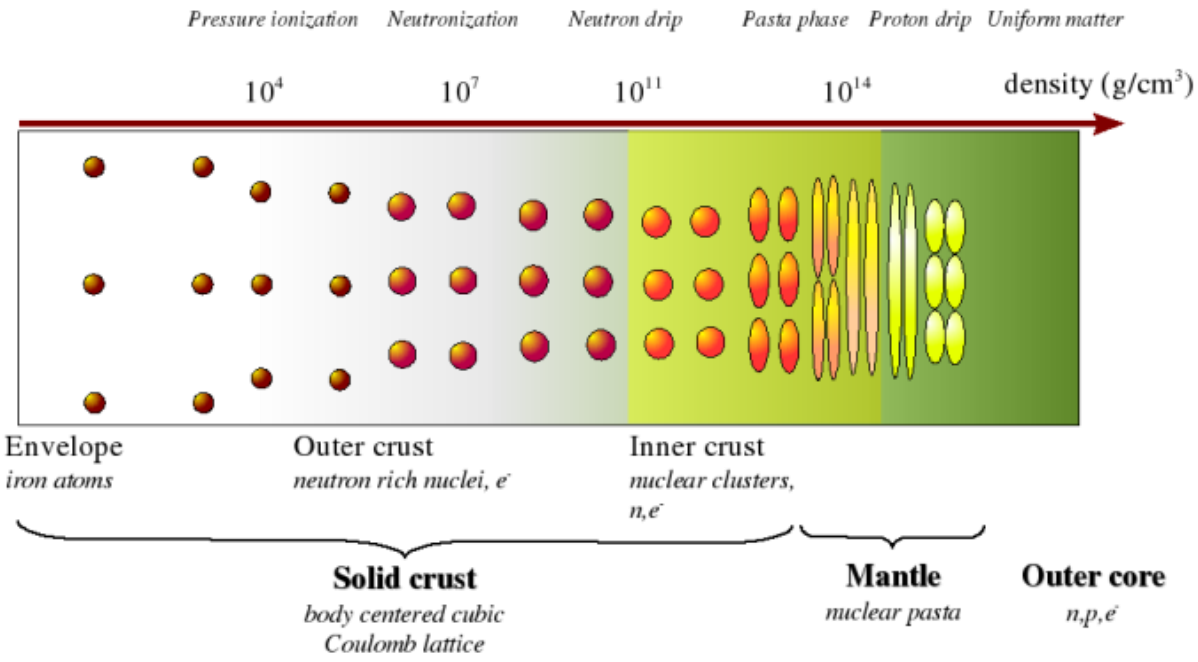
What is a material?

A: Hard to define. But, at least, a material is not a fluid.

Neutron Star Structure

- What's inside a neutron star? Crust and core, similar to earth…

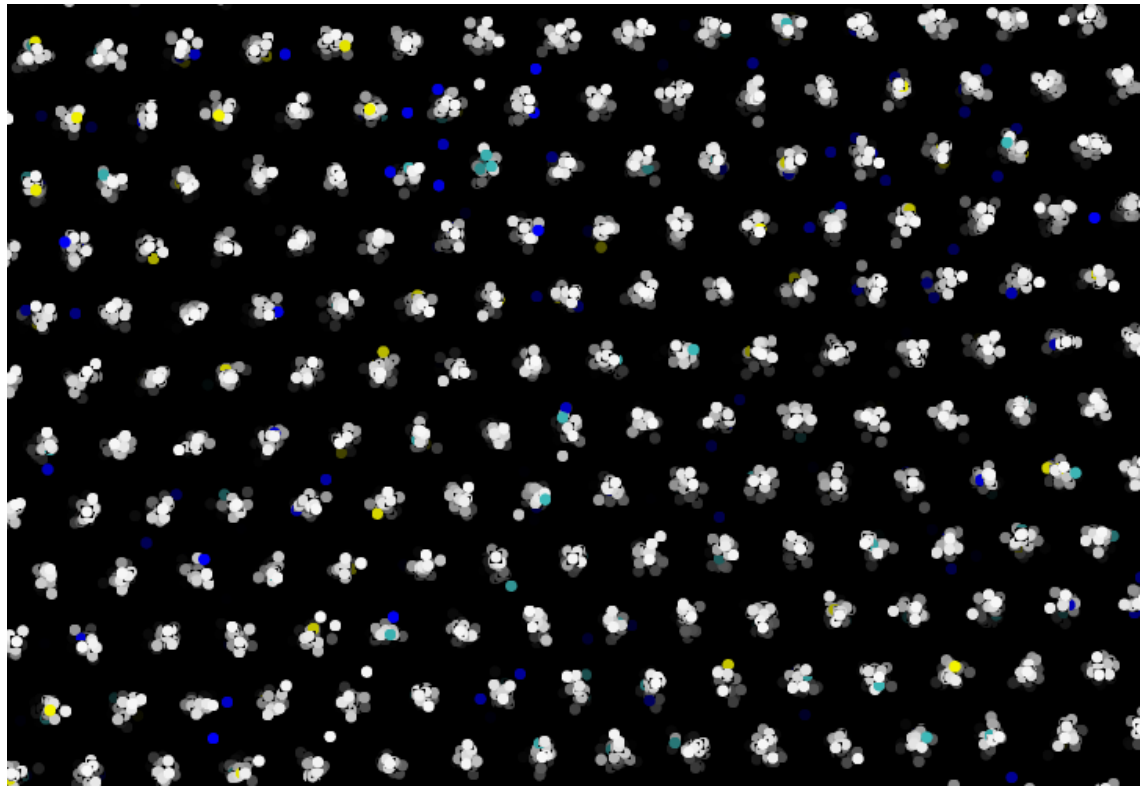




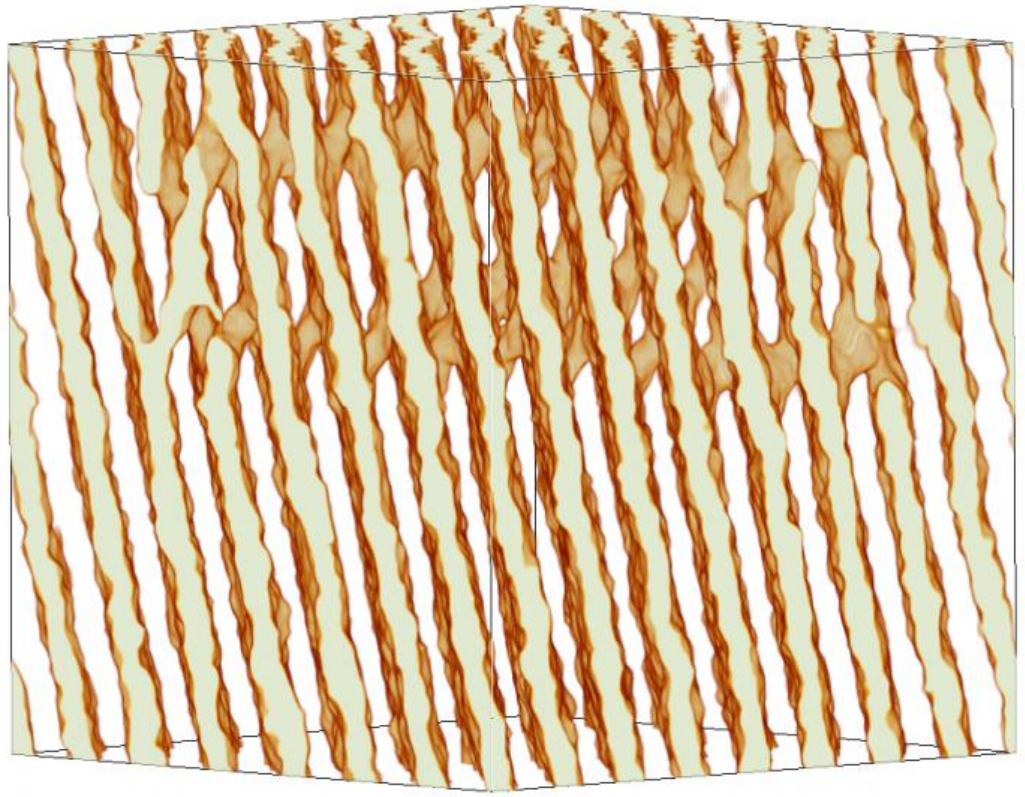
- Not just a "giant nucleus in space!"

Astromaterials

- The neutron star crust contains *materials*, like a crystalline outer crust, and a ‘gooey’ inner crust of nuclear matter, like a liquid crystal.



HARD (Outer Crust)



SOFT (Inner Crust)

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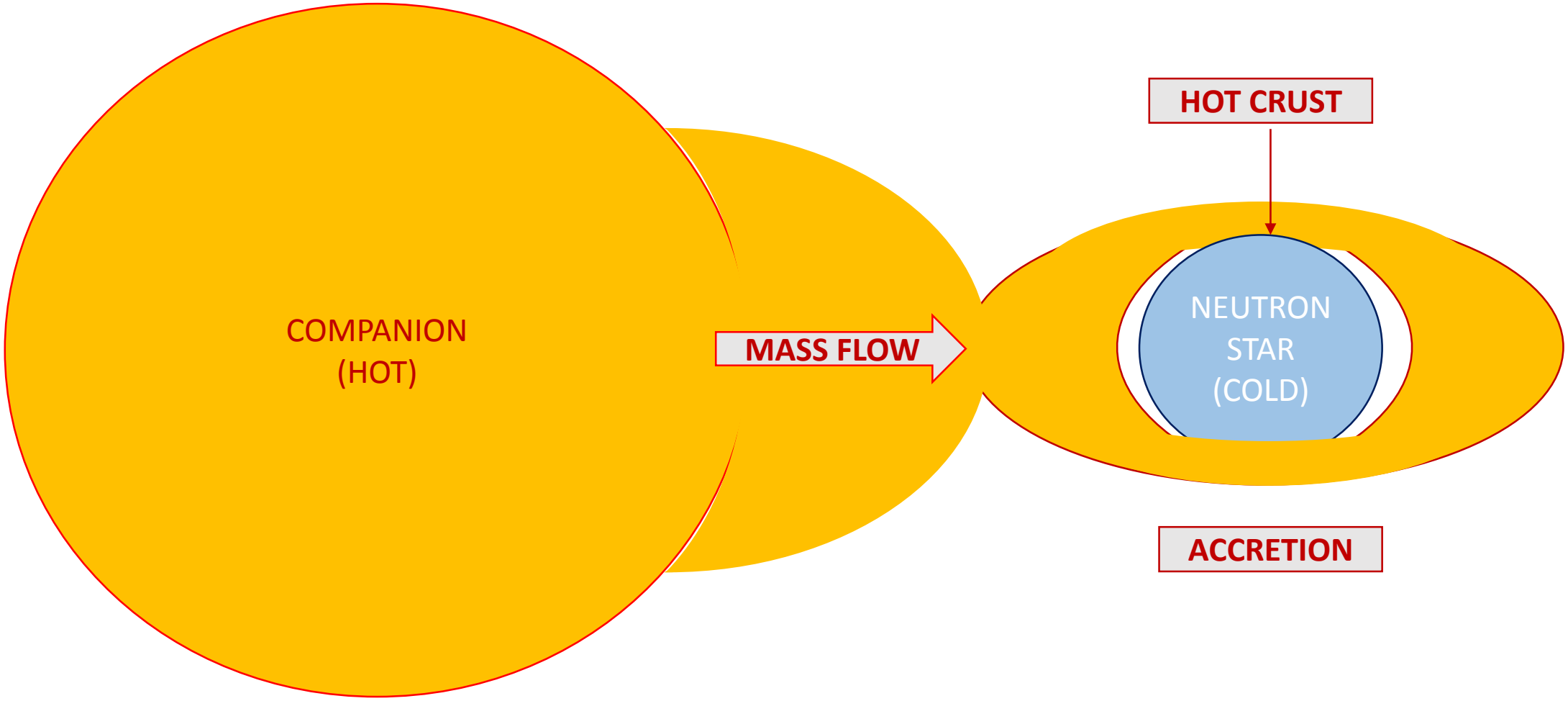

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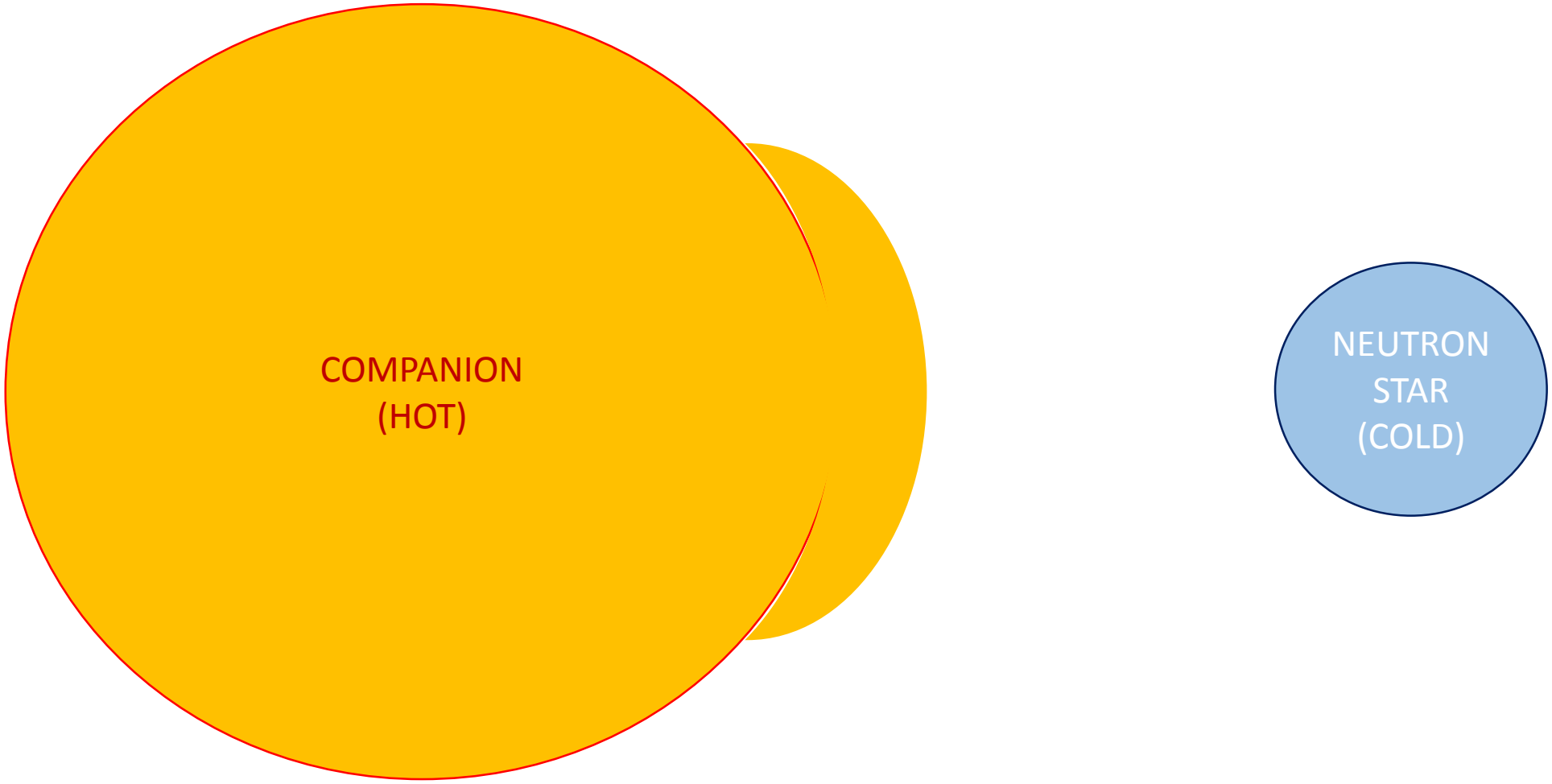


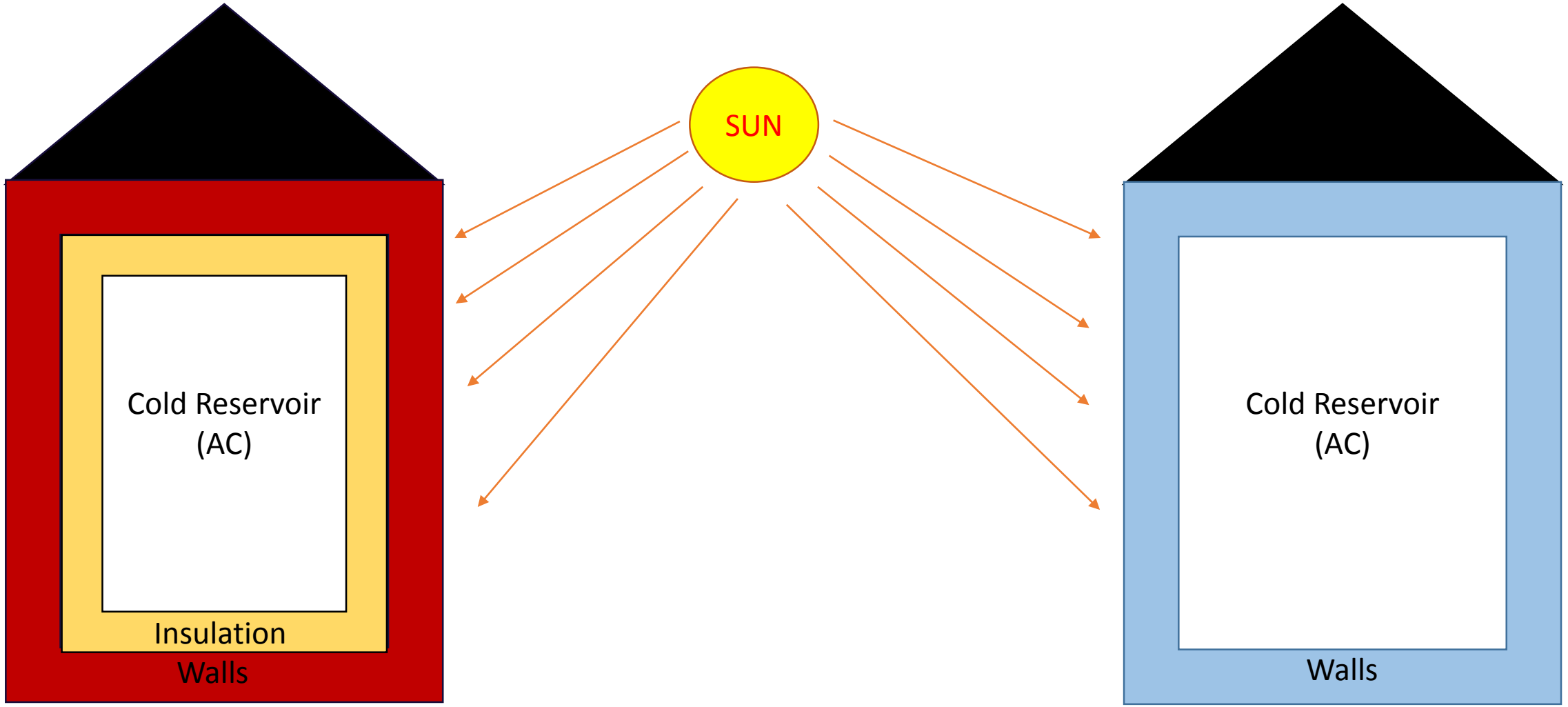
Quiz 3

Suppose the accretion stops.

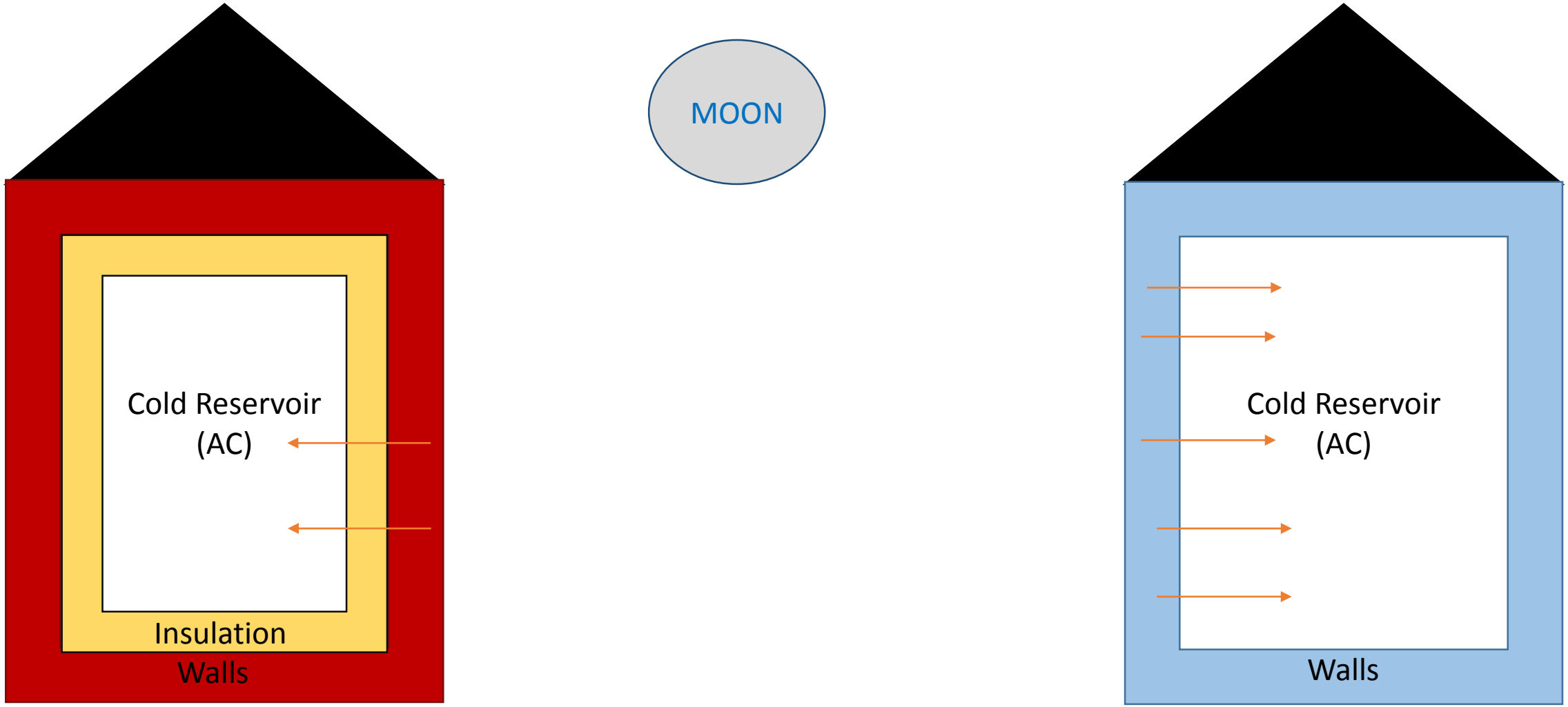
What happens now?

A: The neutron star crust cools.

An Example


SUN
Cold Reservoir
(AC)
Insulation
Walls
Cold Reservoir
(AC)
Walls

An Example


MOON
Cold Reservoir
(AC)
Insulation
Walls
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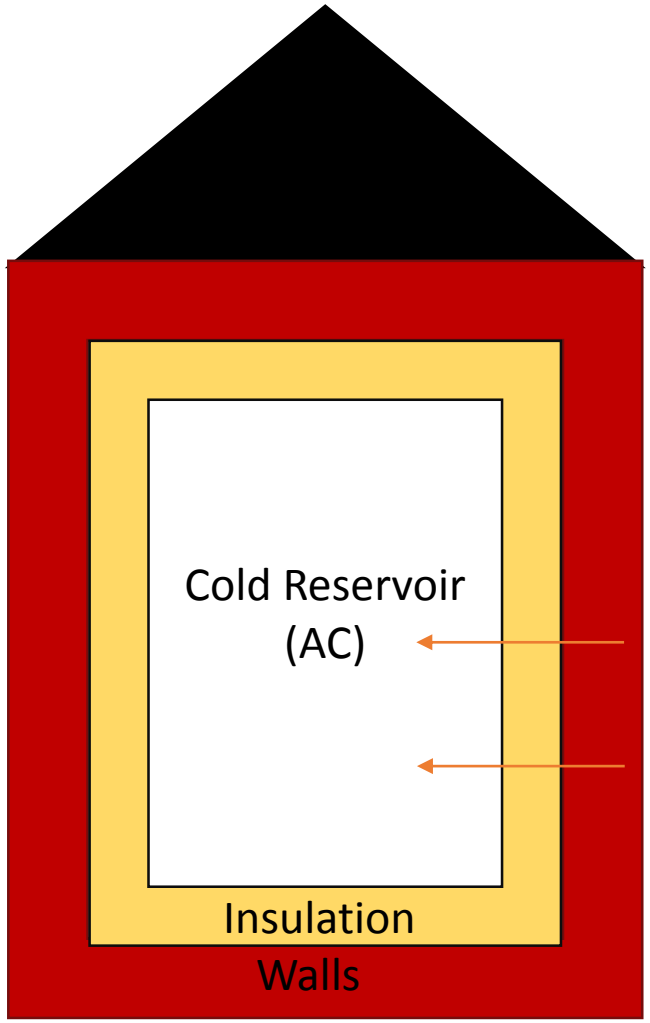
Walls

An Example


Cold Reservoir
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Insulation
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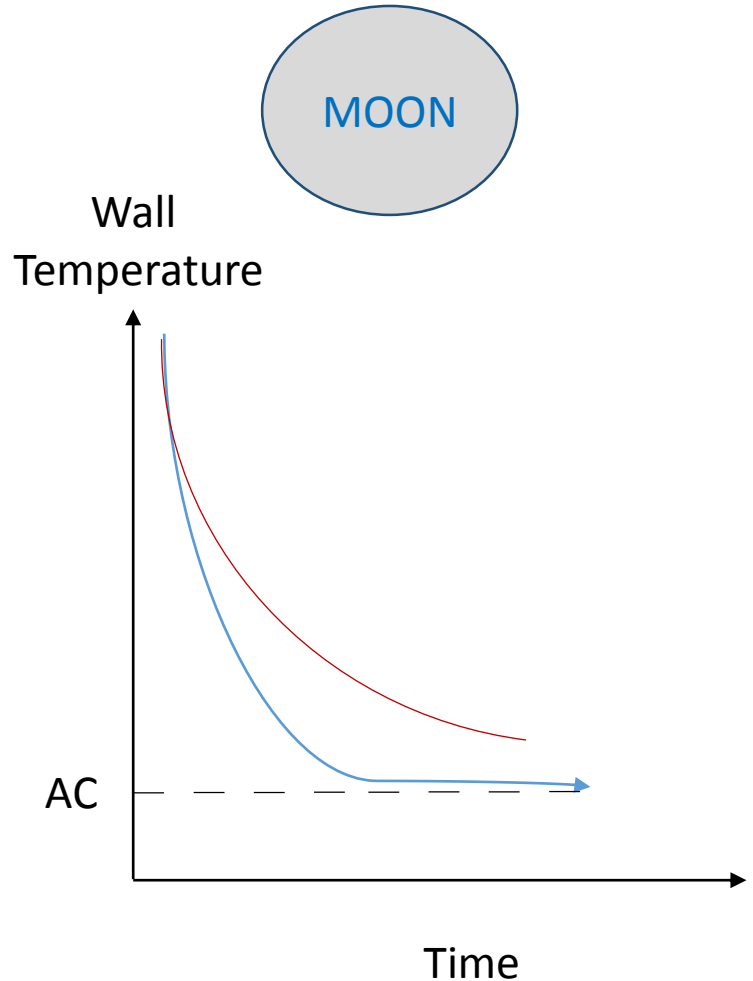
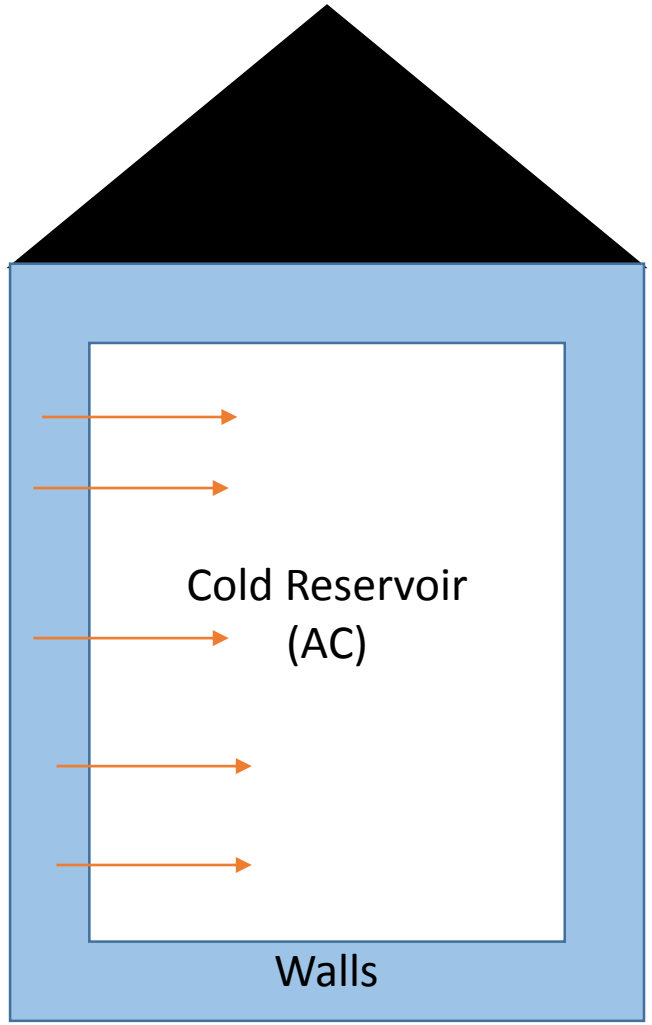

MOON
Wall
Temperature
AC
Time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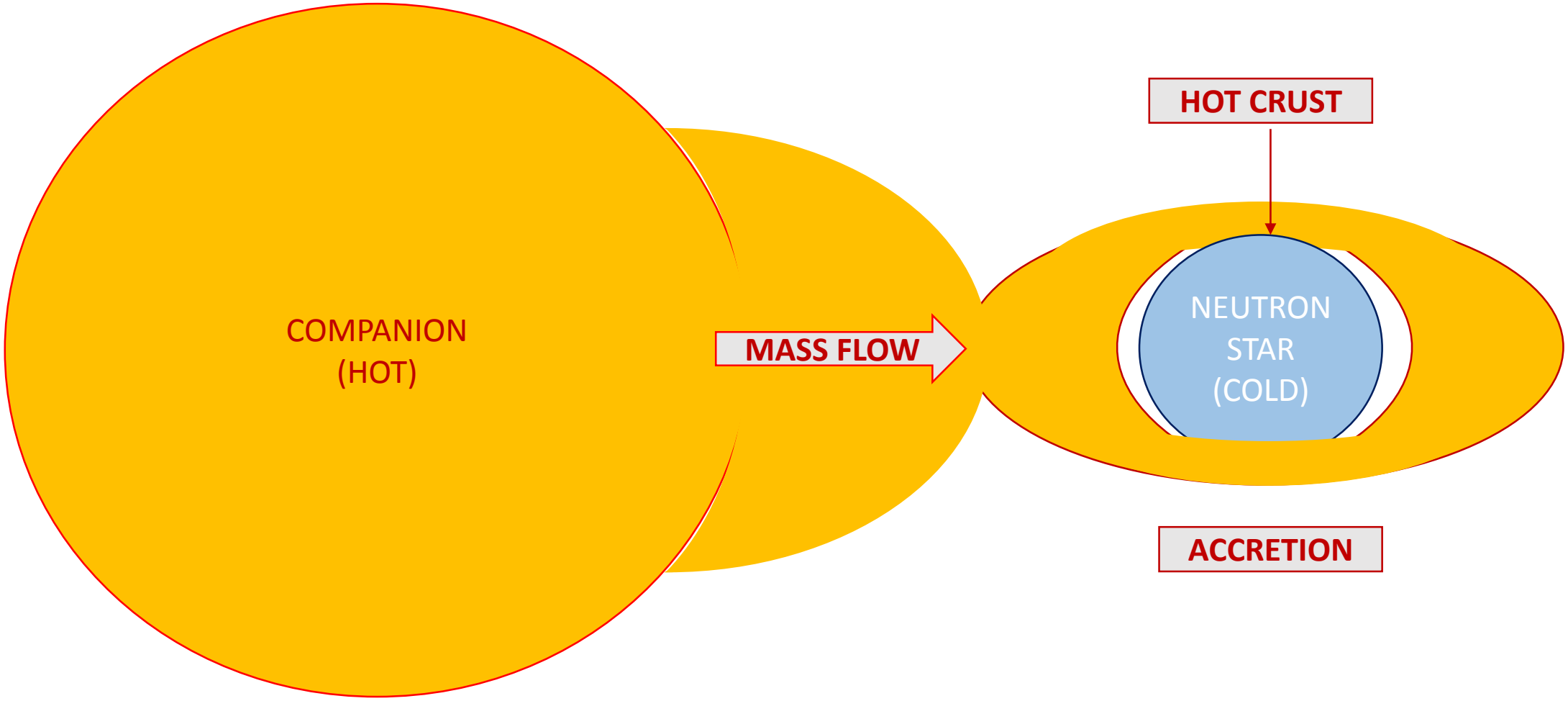

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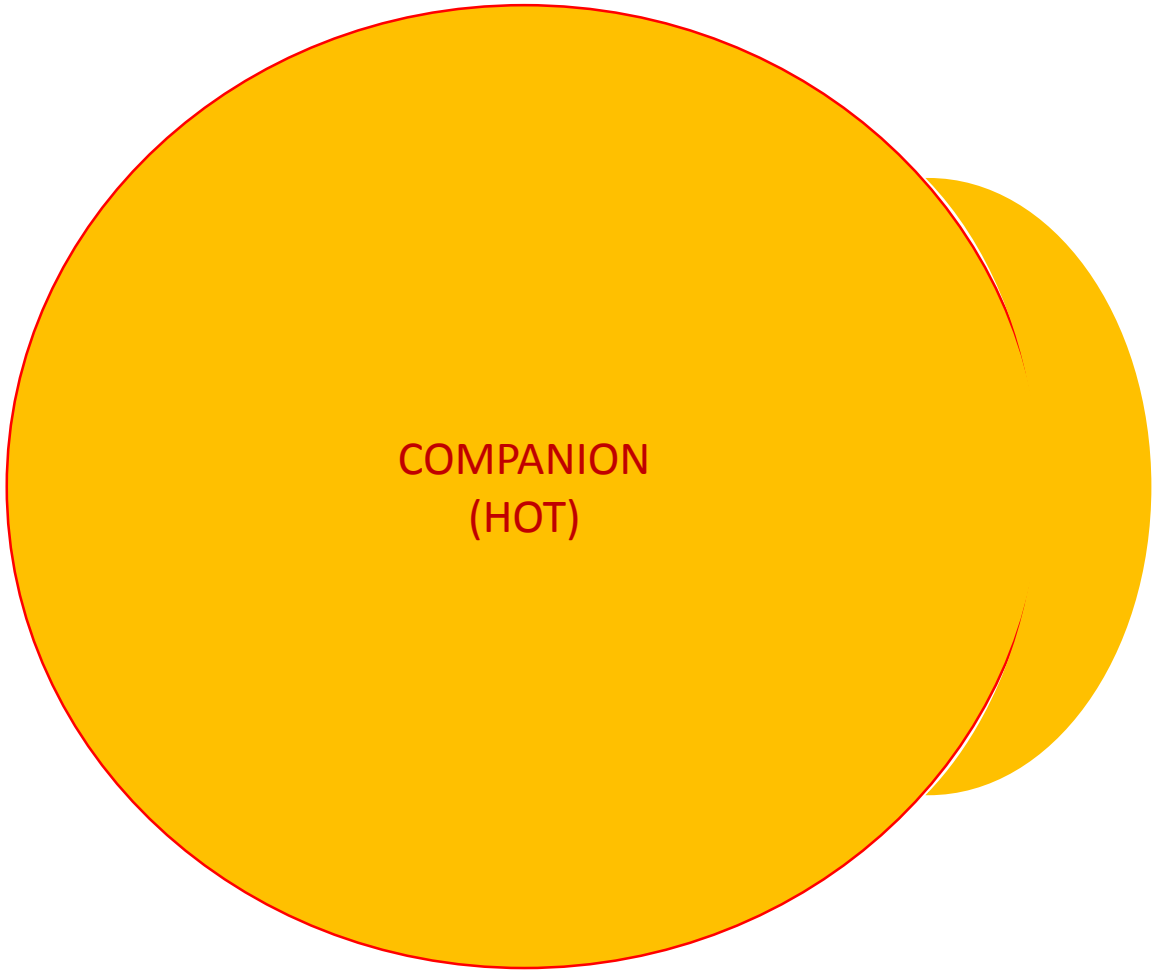
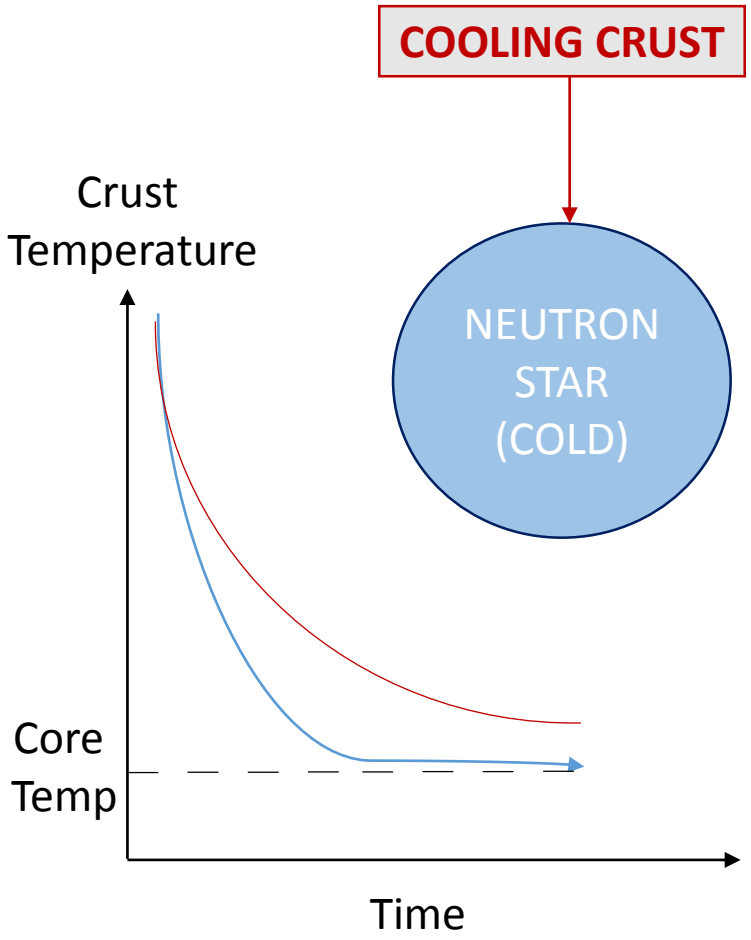


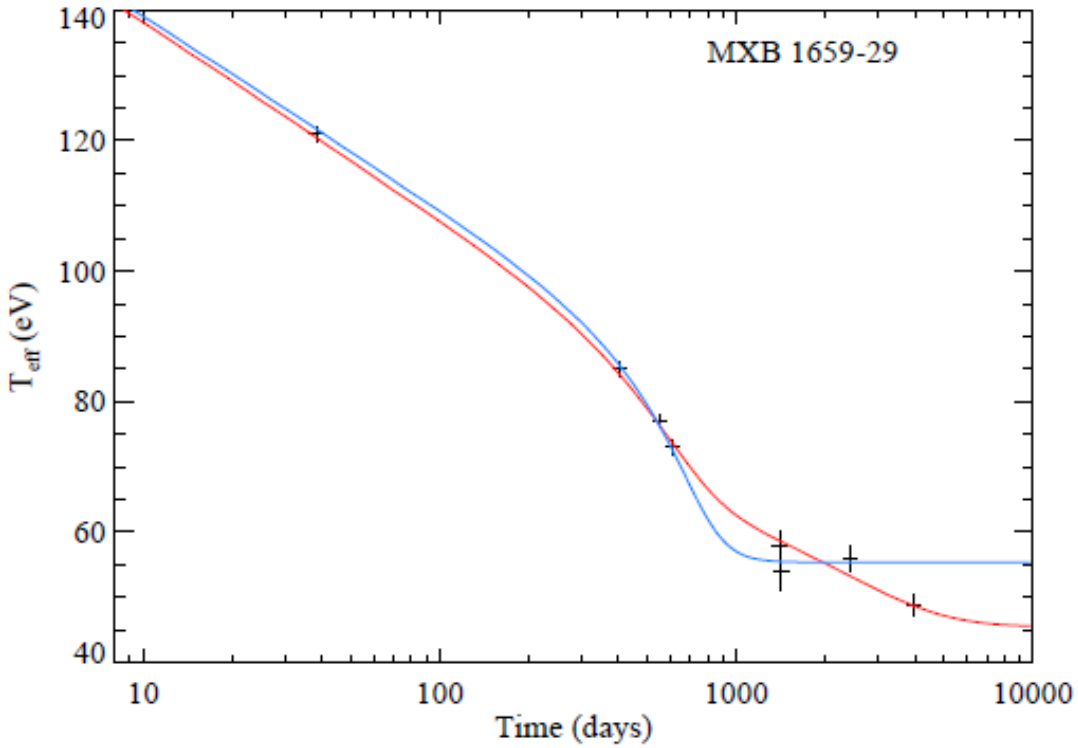


Observables – Thermal Properties

- Use our models to study neutron star interiors from their cooling
- Cooling curves: low mass X-ray binary MXB 1659-29

$$Q_{\rm imp} \equiv n_{\rm ion}^{-1} \sum_i n_i (Z_i - \langle Z \rangle)^2$$

  - Blue: Model with only a conductive crust
  - Red: Model with conductive crust, a deep insulating layer



(Horowitz *et al.* 2014)

Quiz 4

What should we do next?

Quiz 4

What should we do next?

A: Find more sources, make more observations.

Summary

To interpret observations of neutron stars, we much first develop microscopic models of their interiors. By simulating the kinds of matter we expect to find in the crust we can calculate properties of the star, allowing us to interpret observations.