Nobel Prize in Physics for Accelerating Universe



- Awarded to Saul Perlmutter, Adam Riess, and Brian Schmidt for finding that the expansion of the Universe is accelerating rather than decelerating.
- First published in 1998.

# Ocean-like water in the comet 103P/Hartley 2

- Astronomer have found that comet Hartley 2 contains water similar to the water we find on Earth.
- "Similar" means that the fraction of heavy water is same as in our oceans.
- Heavy water is  $D_2O$  instead of  $H_2O$ , where D is deuterium which has a nucleus with one proton and one neutron.
- The comet comes from the Kupier belt (30-50 AU) while most comets come from the Oort cloud (> 5000 AU).

#### How Stars Evolve

- The fate of the Sun
  - Nuclear ash
  - Red giant phase
  - Planetary nebula
  - White dwarf
- Ages of star clusters

What would happen to a contracting cloud fragment if it were not able to radiate away its thermal energy?

- A. It would continue contracting, but its temperature would not change
- B. Its mass would increase
- C. Its internal temperature would increase
- D. It would be happy

#### The Fate of the Sun

- How will the Sun evolve over time?
- What will be its eventual fate?

#### Sun's Structure



Core – Where nuclear fusion occurs

Envelope

 Supplies gravity to keep core hot and dense

#### Main Sequence Evolution



- Core starts with same fraction of hydrogen as whole star
- Fusion changes  $H \to He$
- Core gradually shrinks and Sun gets hotter and more luminous

#### Gradual change in size of Sun



Now 40% brighter, 6% larger, 5% hotter

#### Main Sequence Evolution



- Fusion changes  $H \rightarrow He$
- Core depletes of H
- Eventually there is not enough H to maintain energy generation in the core
- Core starts to collapse

#### Red Giant Phase



- He core
  - No nuclear fusion
  - Gravitational contraction produces energy
- H layer
  - Nuclear fusion
- Envelope
  - Expands because of increased energy production
  - Cools because of increased surface area

#### Sun's Red Giant Phase





Now: hot core + warm surface; small size. Future: very hot core + cool surface. Large size but less mass; very bright.



Giant phase is when core has been fully converted to Helium

HR diagram

When hydrogen burning in the core stops, a star like the Sun begins to evolve

A) To higher surface temperature and higher luminosityB) To lower surface temperature and higher luminosityC) To higher surface temperature and lower luminosityD) To lower surface temperature and lower luminosityE) Up the main sequence to become an O star

### Helium Flash



- He core
  - Eventually the core gets hot enough to fuse Helium into Carbon.
  - This causes the temperature to increase rapidly to 300 million K and there's a sudden flash when a large part of the Helium gets burned all at once.
  - We don't see this flash because it's buried inside the Sun.
- H layer Envelope

#### After Helium Ignition

- He burning core

   Fusion burns He into C, O

   He rich core

   No fusion
- H burning shell
  - Fusion burns H into He
- Envelope
  - Expands because of increased energy production

#### Movement on HR diagram



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#### The Life of the Sun



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#### During double shell burning Sun loses mass via winds

• Creates a "planetary nebula"

 Leaves behind core of carbon and oxygen surrounded by thin shell of hydrogen – a white dwarf

#### White dwarf

- Star burns up rest of hydrogen
- Nothing remains but degenerate core of Oxygen and Carbon
- "White dwarf" cools but does not contract because core is degenerate
- No energy from fusion, no energy from gravitational contraction
- White dwarf slowly fades away...



#### Planetary Nebula IC 418







Planetary Nebula NGC 6853 (M 27) - VLT ANTU+FORS1



ESO PR Photo 38a/98 ( 7 October 1998 )

©European Southern Observatory



### Hourglass nebula

Which property of a star controls its formation, evolution, and demise?

A) LuminosityB) MassC) RadiusD) Temperature

### Once the core of a star ends hydrogen fusion, the core

A) expands and gets hotterB) shrinks and gets hotterC) expands and gets coolerD) shrinks and gets cooler

### Planetary nebulae are mostly composed of

A) hydrogen.B) helium.C) carbon.D) oxygen.

## How can we determine the age of a star cluster?



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#### Formation time for different masses



 High-mass stars form fast

 Low-mass stars form slowly

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Time on main sequence is set by mass

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#### Turn-off point of cluster reveals age



#### **Review Questions**

- What are the main stages in the evolution of solar mass star?
- What causes the star to move from one stage to the next?
- What does a solar mass star leave as a remnant?
- How can you determine the age of a star cluster?