The Life Cycles of Stars

Dr. Jim Lochner, NASA/GSFC

May 15, 2001
Twinkle, Twinkle, Little Star ...
How I Wonder What You Are ...

Stars have

- Different colors
  - Which indicate different temperatures
- Different sizes
- Different masses

The bigger it is, the hotter and the faster a star burns its life away.
Stellar Nursery

Space is filled with the stuff to make stars.
Stars start from clouds

Clouds provide the gas and dust from which stars form.

But not this kind of dust

Rather: Irregular Grains Of Carbon or Silicon
Stars begin with slow accumulation of gas and dust.

• Gravitational attraction of Clumps attracts more material.

\[ F = \frac{G m_1 m_2}{r^2} \]

• Contraction causes Temperature and Pressure to slowly increase.
Nuclear Fusion!

At 15 million degrees Celsius in the center of the star, fusion ignites!

$4 \, (^{1}H) \rightarrow ^{4}He + 2 \, e^{+} + 2 \, \text{neutrinos} + \text{energy}$

Where does the energy come from?

Mass of four $^{1}H > \text{Mass of one} \, ^{4}He$

$E = mc^2$
Fusion by the Numbers

$4 \, (^1\text{H}) \rightarrow ^4\text{He} + 2 \, \text{e}^+ + 2 \, \text{neutrinos} + \text{energy}$

Mass of $4 \, ^1\text{H} = 4 \times 1.00794 \, \text{amu} = 4.03176 \, \text{amu}$

Mass of $1 \, ^4\text{He} = 4.002602 \, \text{amu}$

Difference in mass $= 0.029158 \, \text{amu} = 4.84 \times 10^{-29} \, \text{kg}$.

$E = Dmc^2 = (4.84 \times 10^{-29} \, \text{kg})(3 \times 10^8 \, \text{m/s})^2$

$E = 4.4 \times 10^{-12} \, \text{J}$
$4 \left( ^1\text{H} \right) \rightarrow 4\text{He} + 2\text{e}^+ + 2\text{neutrinos} + \text{energy}$

Energy released = 25 MeV

= $4 \times 10^{-12}$ Joules

= $1 \times 10^{-15}$ Calories

But the sun does this $10^{38}$ times a second!

Sun has $10^{56}$ H atoms to burn!
A Balancing Act

Energy released from nuclear fusion counter-acts inward force of gravity.

Throughout its life, these two forces determine the stages of a star’s life.
New Stars are not quiet!

Expulsion of gas from a young binary star system
All Types of Stars

Annie J Cannon (1863-1941)

Oh Big And Ferocious Gorilla, Kill My Roommate Next Saturday!

Oh! Be One Be a Fine Kiss Me & Be Bright Me Now Sweetheart!
Reprise: the Life Cycle

Sun-like Stars

Massive Stars
The beginning of the end: Red Giants
After Hydrogen is exhausted in core,

• Core collapses, releasing energy to the outer layers
  · Outer layers expand

• Meanwhile, as core collapses,
  · Increasing Temperature and Pressure ...
At 100 million degrees Celsius, Helium fuses:

$$3 \, (^4\text{He}) \rightarrow ^{12}\text{C} + \text{energy}$$

(Be produced at an intermediate step)
(Only 7.3 MeV produced)

Energy sustains the expanded outer layers of the Red Giant
The end for solar type stars

After Helium exhausted, outer layers of star expelled

Planetary Nebulae
White dwarfs

At center of Planetary Nebula lies a White Dwarf.

• Size of the Earth with Mass of the Sun “A ton per teaspoon”

• Inward force of gravity balanced by repulsive force of electrons.
Fate of high mass stars

After Helium exhausted, core collapses again until it becomes hot enough to fuse Carbon into Magnesium or Oxygen.

\[ ^{12}\text{C} + ^{12}\text{C} \rightarrow ^{24}\text{Mg} \]

OR \[ ^{12}\text{C} + ^{4}\text{H} \rightarrow ^{16}\text{O} \]

Through a combination of processes, successively heavier elements are formed and burned.
### Periodic Table

<table>
<thead>
<tr>
<th>Light Elements</th>
<th>Heavy Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H</strong></td>
<td>He</td>
</tr>
<tr>
<td>Li Be</td>
<td>B C N O F Ne</td>
</tr>
<tr>
<td>Na Mg</td>
<td>Al Si P S Cl Ar</td>
</tr>
<tr>
<td>K Ca Sc Ti V Cr Mn Fe</td>
<td>Co Ni Cu Zn Ga Ge As Se Br Kr</td>
</tr>
<tr>
<td>Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe</td>
<td></td>
</tr>
<tr>
<td>Cs Ba Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn</td>
<td></td>
</tr>
<tr>
<td>Fr Ra Rf Db Sg Bh Hs Mt</td>
<td>Uun Uuu Uub</td>
</tr>
<tr>
<td>La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu</td>
<td></td>
</tr>
<tr>
<td>Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr</td>
<td></td>
</tr>
</tbody>
</table>

- **28Si** + **56Fe**
Massive stars burn a succession of elements. Iron is the most stable element and cannot be fused further.

- Instead of releasing energy, it uses energy.
Supernova!
Supernova Remnants: SN1987A

- **a) Optical - Feb 2000**
  - Illuminating material ejected from the star thousands of years before the SN

- **b) Radio - Sep 1999**

- **c) X-ray - Oct 1999**

- **d) X-ray - Jan 2000**
  - The shock wave from the SN heating the gas
Supernova Remnants: Cas A

Optical

X-ray
What’s Left After the Supernova

Neutron Star (If mass of core < 5 x Solar)
  • Under collapse, protons and electrons combine to form neutrons.
  • 10 Km across

Black Hole (If mass of core > 5 x Solar)
  • Not even compacted neutrons can support weight of very massive stars.
A whole new life: X-ray binaries

In close binary systems, material flows from normal star to Neutron Star or Black Hole. X-rays emitted from disk of gas around Neutron Star/Black Hole.
SN interaction with ISM

Supernovae compress gas and dust which lie between the stars. This gas is also enriched by the expelled material.

This compression starts the collapse of gas and dust to form new stars.
Which Brings us Back to ...
Materials for Life Cycles of Stars

This presentation, and other materials on the Life Cycles of Stars, are available on the Imagine the Universe! web site at:

http://imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html