Life Cycle of Stars

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http://www.astronomysource.com

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What do we need to build a Star?
Some Very Small Parts

Proton

Electron

Hydrogen atom

Masses:

Proton
1.672 621 777 x 10^{-24} g

Electron
9.109 382 913 x 10^{-28} g

Hydrogen
1.673 532 715 x 10^{-24} g

[g] = grams
"... every mass in the universe attracts every other mass with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them..."

Newtons Law: \( F_1 = F_2 = G \frac{m_1 \times m_2}{d^2} \)

Facts:
- \( F \) = Force of attraction between the masses in Newton [N]
- \( G \) = Gravitational constant: \( 6.674 \times 10^{-11} \frac{m^3}{kg \cdot s^2} \)
- \( m_1, m_2 \) = masses in kilograms [kg]
- \( d \) = distance between the masses in meters [m]
Gravity – What if the Masses were...

Hydrogen atoms?
134,000,000 Years

Dices?
1.07 hours

Sun-like stars?
3,571,000 Years

...and we put them at a certain distance in space - how long would it take until they touch...?

Masses [kg]
- Atom H: $1.672 \times 10^{-27}$
- Dice: $2 \times 10^{-3}$
- Sun-like star: $2 \times 10^{30}$

Distances [m]
- H atoms: $10 \times 10^{-3}$ (a bit less than ½ inch)
- Dices: $10 \times 10^{-3}$ (a bit less than ½ inch)
- Sun-like stars: 1 LY

Gravitational constant:
$6.674 \times 10^{-11} \text{ m}^3 \text{kg}^{-1} \text{s}^{-2}$

$t = \sqrt{\frac{(2d^3)}{(Gm)}}$
Why is Jupiter not a Star?

Facts:

- Jupiter is a gas giant
- Mass: 318 x Earth
- Diameter: 11.2 x Earth
- Largest planet in the solar system (mass 2.5 times that of all other planets combined)
- Same elements stars are made of: 89.8 % Hydrogen (H) 10.1% Helium (He)

Credits: NASA

Astro Rally Object: 3
...it’s still not large enough!

Facts:

Mass of Jupiter is \( \frac{1}{1047} \) of the sun mass.

Credits: NASA / Solar Dynamics Observatory
BIG Planets, Brown Dwarfs & Stars

Facts:

Celestial bodies up to 12 Jupiter masses are still considered a giant planet.

Between 12 and 65 Jupiter masses, Deuterium, and from 65 to 80 Lithium starts to fuse. These objects are considered brown dwarfs.

Mass in excess of 80 Jupiter masses allow the ignition of Hydrogen fusion. This is what we consider a “star”.

Jupiter mass

- up to 12 x = Giant Planet
- 13 to 80 x = Brown Dwarf
- from 81 x = Star
The Closest Star
The Sun is made of Hydrogen and Helium, the two lightest elements in the Universe but...

the density of the Sun is greater than that of water...

How can that be?
Sun Observation

Facts:

June-6-2011: The sun unleashes the most spectacular prominence eruptions ever recorded.

It resembled actually a prominence explosion.

The prominence expanded to a volume of 75 times as big as the earth.

Credit: NASA
Sun Observation - JHELIOVIEWER

Facts:
JHelioviewer (free) allows to:
- Observe the sun in quasi real time
- Explore 15+ years of SOHO data
- Browse high-res SDO data
- Create movies of the sun

SOHO: Solar & Hemispheric Observatory (ESA & NASA)

SDO: Solar Dynamics Observatory

Credit: http://www.jhelioviewer.org/
Layers of Stars
Facts:

1 to 5 Million Kelvin: Li, Be, B split to He

From 5 Million Kelvin: Hydrogen fusion to He

From 15 Million Kelvin: Carbon – Nitrogen cycle

The sun converts mass to energy at a rate of 4.2 Mill tons per second (equivalent to 42 aircraft carriers USS Nimitz class)

Since its existence 4.5 billion years ago, the sun has “burned” 0.3% of its mass.
Energy carried by photons is radiated away from the heat source:

- Photon leaves core
- Hits an electron or atom within ~ 1mm and gets scattered.
- Slowly staggers to the surface in a random "walk"

On average, it takes about 200,000 years for a photon to travel from the core to the surface.

Credits: Richard Pogge, Ohio State University
Peeking Inside a Star

Facts:

- Asteroseismology, or stellar seismology, provides insight into the structure of stars. By studying the oscillations in pulsating stars, astronomers can peer into the core of stars.
- Combining rate and amplitude of pulsations with other information, such as spectra, reveals internal compositions of stars.

http://asteroseismology.org/
The "Sound" of Stars

Facts:
- Resonance period of the sun is about 5 minutes.
- This translates into a frequency of about 0.0033 Hz which is not audible for humans.
- To be audible, tones are played 42000 times faster.

Credits: High Altitude Observatory (HAO/NCAR)
http://asteroseismology.org/
Star Characteristics
Magnitude and Luminosity
Apparent Magnitude

Facts:

- More light (more FLUX) falls on the eye from the brighter star (the upper star). If this star would have an apparent magnitude of 1, the fainter star would have a magnitude greater than 1 (like 2 or 3).
- The upper star is drawn larger only to represent the fact that it is brighter, not necessarily that it is bigger.
- FLUX is the amount of energy that falls into a certain area.
Magnitude Scale

- The scale represents the brightness of stars and other astronomical objects.
- **Naked eye** (6) can see Sirius, Canopus (-1), Polaris (2), and Vega (0.0), Betelgeuse (0.4).
- **3" Telescope** (11) can see M42 Orion Nebula (4.0), 51 Pegasi (5.5), and Gliese 581 (10.5).
- **4" Telescope** (12) can see M51 Whirlpool Galaxy (8.4) and M31 Andromeda Galaxy (10.5).
- **8" Telescope** (13) can see Venus (-4), Jupiter, brightest (-1.6), Saturn, brightest (-0.24), and Uranus, brightest (5.3).
- **Visual limit large telescopes** (18) can see M13 Hercules Cluster (5.8) and M105 Hercules Cluster (10.2).
- **CCD imaging large telescopes** (27) can see Quasar 3C48 (16.2) and Red Dwarf: OLGE-2005_BGL-169L (20.4).
- **Hubble HST** (30) can see Neutron star, RX J1856.5-3754L (25.6) and Most distant Galaxy ever discovered UDFj-39546284 (30.1).

**Facts:**

- **Number of Stars:**
  - Mag -1 2
  - Mag 0 6
  - Mag 1 14
  - Mag 2 71
  - Mag 3 190
  - Mag 4 610
  - Mag 5 1929
  - Mag 6 5946
  - Mag 7 140,062
  - Mag 8 409,194
  - Mag 9 15,126,390
  - Mag 10 29,457,184
  - Mag 11 1,823,573
  - Mag 12 5,304,685
  - Mag 13 10,126,390
  - Mag 14 17,848,866,544

- 51 Pegasi - 51 LY, first exoplanet
- Gliese 581 - 20 LY, many planets

[http://www.stargazing.net/david/constel/howmanystars.html](http://www.stargazing.net/david/constel/howmanystars.html)
**Luminosity**

Luminosity is the radiant power (power emitted in the form of photons) of the sun and other stars.

\[ L_{(\text{star})} = x \times L_{(\text{sol})} \]

<table>
<thead>
<tr>
<th>Star</th>
<th>Apparent Magnitude</th>
<th>Luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>-27.5</td>
<td>1</td>
</tr>
<tr>
<td>Piazzi’s Flying Star</td>
<td>6.05</td>
<td>0.1</td>
</tr>
<tr>
<td>51 Pegasi</td>
<td>5.45</td>
<td>1.3</td>
</tr>
<tr>
<td>Alcor</td>
<td>2.33</td>
<td>12</td>
</tr>
<tr>
<td>Megrez</td>
<td>3.32</td>
<td>20</td>
</tr>
<tr>
<td>Sirius</td>
<td>-1.46 (A)</td>
<td>25.4 (A)</td>
</tr>
<tr>
<td>Polaris</td>
<td>1.97</td>
<td>2,200</td>
</tr>
<tr>
<td>Spica</td>
<td>1.04</td>
<td>12,100</td>
</tr>
<tr>
<td>Betelgeuse</td>
<td>0.42</td>
<td>105,000</td>
</tr>
</tbody>
</table>

**Facts:**

The sun’s luminosity is: \[3.9 \times 10^{26}\] Watts.

Piazzi’s Flying (double) star has a large velocity of 108 km/s or 65 miles/s relative to our solar system.

Piazzi’s star approaches us relatively quickly and will get as close as 9 LY in around 18,000 years before receding again.
The Sun – In Comparison
Facts:
The sun is an average star in most aspects. However it rotates rather "slowly":
Equator – 25 days
Poles – 34 days

That equals a speed at the equator of 7140 km/h or 4275 mph.
Sun in Comparison I

- Sun
- Sirius (Jupiter is about 1 pixel in size)
- Pollux
- Arcturus (Earth is invisible at this scale)
Sun in Comparison II

Betelgeuse

Antares

Jupiter is invisible at this scale

Sun (1 pixel)

Sirius

Arcturus

Rigel

Aldebaran
Sun in Comparison: VY Canis Majoris
Sun in Comparison: OGLE-TR-122b

Facts:
OGLE-TR-122 is a binary system star system. The main star is about the size of the sun. The smaller star (122b) is about 100 Jupiter masses. It was discovered with Gravitational Lensing techniques.

It's small size comes however with high density (about 50 times that of the sun)
Star Classification
Hertzsprung-Russel Diagram
Star Types – M13

Facts:
M13 – Hercules Globular Cluster contains over 300,000 stars of all types.

Magnitude: 5.8
Distance: 25,000 LY
Diameter: 168 LY
Age: 14 Billion yrs.
Mass: 600,000 x sun

Astro Rally Object: 17

The Arecibo message was sent to M13 in 1974, it communicated existence of humans to hypothetical extraterrestrials.

Credit: NASA, ESA, Hubble Heritage Team (STSC/AURA) http://www.nasa.gov/multimedia/imagegallery/image_feature_1552.html
Hertzsprung-Russel Diagram II

Facts:

The Hertzsprung-Russel (H-R) diagram presents the distribution of stars with luminosity on the y-axis and surface temperature on the x-axis.

Spectral Classification:

O B A F G K M

Memory hook: „Oh Be A Fine Girl/Guy Kiss Me“

O-Type: Ultra hot, electrons are not bound to atoms, no H-lines
Stars:
- Sun
- Vega (Astro Rally Object 13)
- Altair (Astro Rally Object 9)
- Polaris (Astro Rally Object 12)
- Spica
- Betelgeuse
- Rigel
Multiple Star Systems
Multiple Star Systems

**Facts:**

- The term „double star“ is used for binary star systems, but also for stars that optically just appear close to each other.
- Binary star systems are very important references for astronomers: Their orbits allow to determine their masses, which again allows to calculate radius and density.
- Resulting mass-luminosity relationship (MLR) can be applied for single stars.
Double Stars a Galactic Accident?

How many stars belong to double or multiple star systems?

- 70% ✓
- 7%
- 0.7%

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Sirius A and Sirius B
Double Stars

Molecular Nebula

Facts:
70% of all stars are double or multiple star systems.

Credits: dtv Atlas Astronomy
**Spectacular Sunsets at HD188753**

**Facts:**

HD188753 [3]  
Cygnus, 149 LY

A gas giant with an orbital period of 3.3 days has been discovered using the Keck Telescope atop Mauna Kea in Hawaii.

The image shows an artists conception of the breathtaking view from a hypothetical moon.

Credits: NASA / JPL-Caltech  
http://photojournal.jpl.nasa.gov/catalog/PIA03520
Astro Rally: Multiple Star Systems

Facts:

Astro Rally shows the following double and multiple stars:

- **Polaris [3]**
  - Alpha Ursae Minoris
- **The Double Double [10]**
  - Epsilon Lyrae
- **Algieba [2]**
  - Gamma Leonis
- **Bootes Xi [2]**
- **Ras Algheti [2]**
  - Alpha Herculis
- **Gamma Delphini [2]**
- **Almach [4]**
  - Gamma Andromedae

Hubble Space Telescope ACS/HRC – NASA, ESA, N.Evans (Harvard-Smithsonian CfA), and H.Bond (STScI)
Star Formation
**Facts:**

- **Protostar:** a large mass that forms by contraction out of the gas of a giant molecular cloud.

The energy source of Protostars is gravitational contraction (as opposed to hydrogen burning in main-sequence stars).

- **Accretion:** Growth of massive objects by gravitationally attracting more matter, typically gaseous (dust, molecules).
Protostar: HOPS-68 in Orion

Facts:

- It takes about 100,000 years to reach a density of 100,000,000 molecules per cm$^3$ in the core of a protostar. From this point on the temperature increases quickly.

- In comparison: Orion Nebula has 600 atoms per cm$^3$

- The air (we breathe) has $30,000,000,000,000,000,000$ or $3 \times 10^{19}$ molecules per cm$^3$
Stars Are Born

Facts:

M42 – The Orion Nebula is a star crib. Many stars are just getting born.

Magnitude: 4.0 (visible with bare eyes)
Distance: 1,340 LY
Diameter: 24 LY

Credit: Wolf Damm
NASA HST
Pillars of Creation

Facts:

The “Pillars of Creation” are part of the Eagle Nebula (M16) 7000 LY from earth.

The pillars were formed through UV radiation of nearby young stars.

A supernova probably destroyed the pillars 6000 years ago. In 1000 years we will see the destruction when the light reaches us. However Astronomers believe that the shockwave will compress pillars’ dust and with that giving birth to new stars.

Credit: NASA / Hubble Space Telescope / Spitzer Space Telescope

http://www.youtube.com/watch?v=AF6xG9-d61A
Birthplaces of Stars: M81 Galaxy

Facts:
M81 – Bode’s Galaxy
12 Million LY from Earth
250 Billion stars
Magnitude: 6.9
Super massive black hole
70 million times mass of sun

Credit: NASA / Hubble Space Telescope
M81 Galaxy – Infrared Image

Facts:

- **Red**: heated dust in interstellar medium observed @ 24 um. Stars are born here.
- **Blue**: stellar emission observed @ 3.6 um
- **Green**: polycyclic aromatic hydrocarbons (PAH)* observed @ 8 um

* PAH: basically carbon based / pollutants. Candidate molecule to act as basis for earliest forms of life.
Life Cycle
Solar Life Cycle

Life Cycle of the Sun

Birth 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Billions of Years (approx.)

Now Gradual warming Red Giant Planetary Nebula

White Dwarf

not to scale
Life Cycle of Stars

- Protostar
- Stellar Nursery
- Blue Supergiant
- Supernova
- Black Hole
- Type II Supernova
- Neutron Star
- Type Ia Supernova
- White Dwarf
- Planetary Nebula
- Red Dwarf
- Brown Dwarf
- Sun-Like Star
- Red Giant
- Brown Dwarf
Black Holes
Facts:

- **Quiet region:** negligible gravitational influence
- **Ergosphere:** Gravitational forces start to influence objects movements.
- **Event Horizon:** (Schwarzschild Radius) escape velocity is higher than the speed of light.
- **Singularity:** With equations at hand, it is not possible to describe location and ruling conditions mathematically. All equations result in infinity.
M87 - Jet

Facts:

- Jet of super hot gas is racing away from the nucleus of M87
- Speed: 99 percent speed of light
- Size: Several thousand light years.

Finding Black Holes:

- Object movement in the vicinity
- X-Ray emission
- Gravitational lensing

Credit: NASA / Hubble Heritage team (STSci/AURA)
THANK YOU!

Wolfgang Damm

http://www.astronomysource.com