# ASTROCHALLENGE 2016 SUMMARY BOOKLET

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The Beginning of Everything

In the beginning, there was nothing.
Then, there was something...

Starring: Everything we know, and everything that we don’t (dark matter and dark energy)

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<th>Time, T+...</th>
<th>Description</th>
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| 0 | **BANG!**
For the first few moments, conditions are so intense, we simply can’t describe them well with our familiar laws of physics. |
| $10^{-37}$s | **Cosmic Inflation**
In this period, space itself expands rapidly. Like a sheet being pulled taut, the end result is a universe that’s largely *homogeneous*. However, quantum fluctuations during this period mean that the Universe is not perfectly smooth. |
| 10s | **Big Bang Nucleosynthesis**
Shortly after inflation ends, the first protons and neutrons form. These protons and neutron fuse to create the first elements (H, He & Li). |
| 20 min | **Cooling**
By this time, the Universe is too cool to sustain nuclear fusion, yet still too hot for actual atoms to form. At this stage, space contains a hot plasma of free electrons and atomic nuclei. No light could travel through this chaotic mess: all radiation is constantly being absorbed and emitted by plasma particles. |
| 50,000 yrs | **Clumping**
Around this time period, the Universe has cooled sufficiently for gravity to finally start organizing the matter in the Universe. **Cold dark matter** clumps start to form, which attracts nearby ordinary matter. This begins the long process of *structure formation*, leading to the formation of galactic superclusters and voids on the largest scales. |
| 380,000 yrs | **Recombination**
By this point, the Universe is finally cool enough for electrons and atomic nuclei to recombine, producing our first atoms. Without swarms of pesky free electrons to efficiently absorb radiation, light is finally free to travel across the Universe. This light is visible to us today in the form of the **Cosmic Microwave Background**. |
| 200 million yrs | **The first stars and galaxies**
After millions of years of cooling, the densest gas clouds finally collapse under their own gravity and form the first stars. This ends the Astronomical **Dark Ages**, and marks a new era for the Universe. |
### Types of Galaxies

<table>
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<th>Elliptical Galaxies</th>
<th>Spiral Galaxies</th>
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<tr>
<td>– Very few young stars; very little gas and dust.</td>
<td>– 2 distinct regions</td>
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<tr>
<td>– Contain primarily old, red stars</td>
<td>– Disk of the galaxy contains spiral arms</td>
</tr>
<tr>
<td></td>
<td>– Region for star formation with great amount of gas and dust</td>
</tr>
<tr>
<td></td>
<td>– Central bulge is devoid of gas and dust</td>
</tr>
</tbody>
</table>
**Irregular Galaxies**

- Galaxies that don’t fit into either of the above classification.
- Wide variety of shapes and characteristic.
- Frequently the result of collisions between galaxies or gravitational interactions between galaxies

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**Basic Celestial Mechanics**

1. **Motion of celestial bodies**
   
   (A) Newtonian mechanics - Newton’s laws, gravitational force, gravitational potential energy (things you encounter in classical mechanics)

   (B) Keplerian Orbits:
   
   - Kepler’s three laws (laws of orbit, area and period), Kepler’s problem
   - Orbital energies for different orbits (depend on eccentricity)
   - Binary stars system, two-body problem (reduced to equivalent one-body)

   (C) Rotational motion - Circular motion, centripetal force and acceleration, angular momentum

2. **Gravitational and Kepler’s Laws**

   - **Gravitational force**
     \[
     \vec{F} = -\frac{G m_1 m_2}{r^2} \hat{r}
     \]

   - **Gravitational potential energy**
     \[
     E = -\frac{G m_1 m_2}{R}
     \]

   - **Gravitational binding energy of a uniform sphere**
     \[
     E = -\frac{3}{5} \frac{G M^2}{R}
     \]

   - **Kepler’s laws**
     
     1\textsuperscript{st} law: \[ r = \frac{a(1-\epsilon^2)}{1+\epsilon \cos \theta} \]

     2\textsuperscript{nd} law: \[ r^2 \frac{d\theta}{dt} = (1 - \epsilon^2)^{1/2} \omega a^2 \]

     3\textsuperscript{rd} law: \[ GM = \omega^2 a^3 \]
     
     where \( \omega = \frac{2\pi}{T} \)

   - **Orbital eccentricity**
     \[
     \epsilon = \frac{r_a - r_p}{r_a + r_p}
     \]

3. **Concept of the coordinate system and orbits of planets**

   (A) Celestial sphere (locate position of stars), orbits of planets (conic sections, energy, eccentricity, other related properties)

   (B) Terminology such as conjunction, opposition, elongation, apoapsis, periapsis, mean anomaly,
time of periapsis passage, etc.

4. Relation between orbital motion and its consequences
   (A) Earth’s orbital motion, the difference between solar and sidereal day, tropical and sidereal year, and the analemma (inclination, eccentricity)
   (B) Earth’s axial tilt and precession with basic astronomical timekeeping, seasons
   (C) Basis of lunar and solar calendars (astronomical basis behind)
   (D) Occurrence of transits, moon phases, lunar and solar eclipses (total, partial, or annular, relation with Earth/ Moon orbits)

The Solar System and Extrasolar Systems

1. Nebular hypothesis
   (A) The gravitational collapse of a small part of a giant molecular cloud. Moon orbits
   (B) Most of the collapsing mass collected in the center, forming the Sun, while the rest flattened into a protoplanetary disk out.
   (C) Over a few million years there were about $10^9$ objects called planetesimals. Over time the planetesimals continued to collide and join together, which are called protoplanets.

2. Solar System
   (A) The system comprising the Sun and the objects that orbit it.
   (B) The four smaller inner planets, Mercury, Venus, Earth and Mars, are terrestrial planets, being primarily composed of rock and metal.
   (C) The four outer planets are giant planets, being substantially more massive than the terrestrials.
      - The two largest, Jupiter and Saturn are composed mainly of hydrogen and helium.
      - The two outermost planets, Uranus and Neptune are composed mostly of substances such as water, ammonia and ethane.
3. **Roche Limit:**
   (A) The minimum distance to which a large satellite can approach its primary body without being torn apart by tidal forces.
   
   (B) If satellite and primary are of similar composition, the theoretical limit is about 2½ times the radius of the larger body.

4. **Comets:**
   (A) A very small solar system body made mostly of ices mixed with smaller amounts of dust and rock.
   
   (B) The nucleus, the main body of the comet, contains water, methane, nitrogen and other ices.
   
   (C) When a comet is heated by the Sun, its ices begin to sublimate. The mixture of ice crystals and dust blows away from the comet nucleus in the solar wind, creating a pair of tails.
   
   - The dust tail is what we normally see when we view comets from Earth.
   - A plasma tail also forms when molecules of gas are “excited” by interaction with the solar wind. The plasma tail is not normally seen with the naked eye, but can be imaged.

5. **Moon’s formation:**
   Five serious theories have been proposed for the formation of the Moon

<table>
<thead>
<tr>
<th><strong>The Fission Theory</strong></th>
<th>The Moon was once part of the Earth and somehow separated from the Earth early in the history of the Solar System.</th>
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<tbody>
<tr>
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<td>The Moon was formed somewhere else, and was later captured by the gravitational field of the Earth.</td>
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<thead>
<tr>
<th><strong>The Condensation Theory</strong></th>
<th>The Moon and the Earth condensed together from the original nebula that formed the Solar System.</th>
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</table>

   | **The Colliding Planetesimals Theory** | A planetesimal the size of Mars struck the earth, ejecting large volumes of matter which eventually condensed to form the Moon in orbit around the Earth. |

6. **Ring system:**
   (A) Around Saturn, Jupiter, Uranus, Neptune
   
   (B) Formation:
   
   - from the protoplanetary disk that was within the Roche limit of the planet.
   - from the debris of a moon that was disrupted by a large impact.
   - from the debris of a moon that was disrupted by tidal stresses when it passed within the planet’s Roche limit.

   (C) Composition: rock, ice, and dust that range in size from sand grains to the size of a house.

   (D) Decay: The rate depends sensitively on the amount of material impacting the rings, a
quantity that is presently poorly constrained.

7. **Hypothetical planets:**
   (A) Planet X: a hypothetical planet beyond Neptune. Initially employed to account for supposed perturbations in the orbits of Uranus and Neptune, belief in its existence ultimately inspired the search for Pluto.

   (B) Vulcan: a hypothetical planet once believed to exist inside the orbit of Mercury. Initially proposed as the cause for the perturbations in the orbit of Mercury.

   (C) Nemesis: a hypothetical red dwarf or brown dwarf originally postulated to be orbiting the Sun at a distance of about 95,000AU (1.5 light-years), somewhat beyond the Oort cloud, to explain a perceived cycle of mass extinctions in the geological record, which seem to occur more often at intervals of 26 million years.

8. **Exoplanets:**
   (A) Detection methods:
       – Direct imaging: Planets orbiting far enough from stars to be resolved reflect very little starlight, being detected through their thermal emission.
       – Indirect method: Transit method, Doppler method, Transit timing variation, Transit duration variation, Gravitational microlensing, Astrometry, Pulsar timing.

**Stellar Evolution**

1. **Preface**
   (A) Stars go through a similar life cycle as humans
       – They are born, mature, and eventually grow old and die.
       – The mass of a star determines their lifetime; the greater the mass, the shorter the lifespan.
       – The Main-sequence lifetime of a star of mass M is directly proportional to $1/M^2$.
       – Interstellar gas clouds are the birthplaces of stars.
       – The mass of a star will also determine how it will evolve over its lifetime.

   (B) Stars are divided into 3 basic groups:
       – Low mass : $0.08 \, M_{\text{Sun}} < M < 2 \, M_{\text{Sun}}$
       – Intermediate mass : $2 \, M_{\text{Sun}} < M < 8 \, M_{\text{Sun}}$
       – High mass : $8 \, M > M_{\text{Sun}}$

2. **Before Main Sequence**
   (A) Collapse of interstellar cloud into protostars
       – In an interstellar cloud, aggregates of relatively small molecular clouds called dense cores begin to collapse.
       – The collapsing gas cloud begins to form a protostar and accretion disc.
(B) From Protostars to the Main Sequence

- As the accretion process ends, contraction resumes, in a struggle between Density and Temperature.
- When hydrogen begins to fuse in the core of the star, the protostellar phase ends and the transition to Main Sequence begins.

3. **Main Sequence**

(A) In this phase, stars are in equilibrium between thermal pressure and gravity (and radiation pressure in massive stars); this lasts for roughly 90% of a star’s life.

(B) This phase lasts between the time when core temperatures exceed 10 million K to the time when the star exhausts its hydrogen fuel. In main sequence, Helium is produced in the core by the proton-proton chain process (T < 20 million K) or CNO cycle (dominant at T > 20 million K).

(C) The energy transferred by radiation and convection may take a million years to reach the surface. In very low mass stars, there is a deep convection zone and intense flare activity. In high-mass stars, however, there is no convection near the surface.

4. **After Main Sequence (Low-mass stars)**

(A) Process leading to Hydrogen shell burning: At the end of main sequence, Hydrogen is depleted in the core, and the Helium core shrinks. This causes a rise in temperature around the core, enabling hydrogen fusion to occur in the region surrounding the core. The energy production from H fusion continues at a faster rate inside this shell, and the star becomes brighter.

(B) Star growth: As the envelope expands, the star cools down while the core shrinks and heats up.

(C) Very-low-mass stars: They end their lives as Helium white dwarfs (with electron degeneracy pressure maintaining their size).

(D) Sunlike stars: He burning to C in the core starts with a flash when T = 10^8 K. The core expands and the luminosity decreases as the star moves to the horizontal branch of the HR diagram.

5. **After Main Sequence (Intermediate and High mass stars)**

(A) Higher mass stars lead a much shorter and violent life.

(B) Faster rate of stellar evolution: The greater the mass of the star, the faster the p-p chain proceeds. At higher temperatures, the presence of C, N and O accelerates H fusion via the CNO cycle.

(C) Fusion phases after main sequence: Firstly, H shell burning occurs, followed by the gradual onset of He burning in the core. After He in the core is exhausted, He shell burning occurs. For intermediate mass stars, the process stops here.

(D) For C burning in the core, a temperature of 600 MK or an initial mass of 8 suns is required. This produces heavier elements. Following which, the last significant process of Si burning
and Fe piling up in the core occurs. Fe cannot fuse into heavier elements.

6. **After Main Sequence (Very massive stars)**
   (A) Stars heavier than 20 solar masses emit such strong stellar winds that they appear surrounded by their ejected matter.

7. **Final Stages (Low-mass stars)**
   (A) Planetary nebula: The Helium shell flashes and ejection of the star’s envelope occurs, subsequently being ionized by the star’s UV radiation.
   (B) Dying star: By this time, the star has shed almost half its mass, and no more matter remains around it, including nearby planets it may have had.
   (C) White dwarf: Formed from the hot remnant of the Carbon core that cools over time. It is Earth-sized but with the Sun’s mass, with its internal material stabilized by electron degeneracy pressure.

8. **Final Stages (Intermediate and High mass stars)**
   (A) Photodisintegration: With \( T = 10 \) billion K, nuclei turn back into protons and neutrons.
   (B) Core collapse: \( e + p \rightarrow n + n \). Core collapses from sudden release of pressure.
   (C) Supernova: The star is blown apart by an explosion from the core bounce, or neutrino shock wave. Debris spreads the heavy elements, which are recycled in newer star generations.
   (D) Final state: We see the Supernova’s remnant as a nebula, and the core remains as a compact object such as a neutron star or a black hole.

Relativity

NB: Questions pertaining to relativity will only be asked in relation to an astronomical setting. General Relativity will only be tested in a non-qualitative sense while adequate formulas will be provided for Special Relativity.

Recall the postulates of General Relativity and Special Relativity:

1. **The Principle of Relativity**
   (A) The laws of physics are the same in all inertial frames of reference. – *Qn: What is meant by “inertial frames of reference”?*

2. **The Constancy of Speed of Light in Vacuum**
   (A) The speed of light in vacuum has the same value \( c \) in all inertial frames of reference.
(B) Implies that the speed of light is a constant in all inertial frames of reference regardless of
the motion of the source. It is also implied that it is impossible for an inertial observer to
travel at c, the speed of light in vacuum.

3. **Principle of Equivalence**

(A) There is no way for an observer to distinguish locally between at rest in a uniform
gravitational field and undergoing uniform acceleration in the absence of any gravitational
field. Or that the gravitational mass for each body in the universe can be consistently and
universally chosen to equal its inertial mass.

4. **Principle of covariance**

(A) In the special theory, all inertial observers are equivalent. In the general theory, it extends
our idea in the special theory to include non-inertial observers. This principle states that all
observers, inertial or not, observe the same laws of physics.

5. **Correspondence principle**

(A) In weak gravitation fields with velocities much smaller than the speed of light, the general
theory should make predictions similar to Newtonian gravity to first order approximation.
As gravitational fields go to zero, the correspondence principle then states that the
predictions of the general theory should approach those of the special theory.

6. **Consequences of General Relativity and Special Relativity**

(A) Understand the effects of GR and SR, and also the differences with classical mechanics.

7. **Perform calculations using the Lorentz factor and transformations**

(A) Mass variation: introduction of the rest mass being the mass of an object in a frame of
reference at rest.

\[- E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} \text{, where } E_0 = mc^2 \text{ is the rest mass energy.} \]

\[- \text{This is known also commonly known as the Mass-Energy Equivalence.} \]

\[- \text{This relationship may be derived from the Energy-Momentum Relation.} \]

\[- \text{That being } E^2 = (mc^2)^2 + p^2 c^2 \]

(B) Length contraction: the length of an object moving with a speed v (as seen from a supposed
stationary observer) is seen to contract (apparent, not physical) along the direction of
motion.

(C) **Given a problem, how do we know which length is l_0 and which is l?** Proper length l_0 is the
distance between two events occurring at the SAME time points (simultaneous). i.e. The
length of the object in the frame in which it is at rest.

\[ l = \frac{l_0}{\gamma}, \quad \text{where } \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \]

The length l of a moving object is shorter by the factor \( \gamma \) than its length \( l_0 \) in the frame in
which it is at rest. Take note that the length contraction only occurs in the direction of motion.

(D) Given a problem, how do we know which time is $\Delta t_0$ and which is $\Delta t$? Proper time is the time interval $\Delta t_0$ in which the events occurs at the SAME space point.

$$\Delta t = \gamma \Delta t_0, \quad \text{where} \quad \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Time dilation means that the $\Delta t$ that passes between two events in another frame is longer by the factor $\gamma$ than $\Delta t_0$ in the frame in which the events occurs at the same location.

(E) Newtonian relativity

- There are notions of absolute space and absolute time.
- Galilean transformation

(F) Einsteinian relativity

- Space and time are both relative.
- Space and time are both treated as coordinates.
- Lorentz transformation

Practical Astronomy

1. Telescopes

(A) Refractors are usually long tubes that uses lens elements and have the eyepieces at the end. They are the simplest design, but the cost of production is higher, due to the high-precision of manufacturing needed.

(B) Reflectors are compact telescopes that utilises a series of mirrors. The eyepiece is usually attached to the side of the tube. This design is also commonly known as a Newtonian. Reflectors are the cheapest to produce.

(C) Catadioptrics consist of refractive and reflective elements in their design. These telescopes are usually compact, and have the capability to have much longer focal lengths. Despite the advantages of size, they are usually quite heavy and have slower optics.

2. Mounts

(A) Altazimuth (Altaz) mounts are mounts which utilise the yaw and pitch movement. They are relatively low cost, and can handle higher payloads. However, due to its axes of freedom, tracking would require both of its axes.

(B) Equatorial (EQ) mounts are mounts that utilise the yaw and the roll movement, called the declination axis and the right ascension axis respectively. The right ascension rotates with the Earth’s rotational axis, making tracking easy with an EQ mount. However, they are more costly and require more technical understanding.

3. Terms

(A) The field-of-view (FOV) is the extent of the observable world that can be seen at any given moment. The actual FOV is usually determined by the eyepiece and the focal length of the telescope.
(B) The exit pupil is the size of the opening, or aperture, that the light is exiting from. More light is able to exit from a larger exit pupil. Hence the image would appear brighter to our eyes.

(C) The focal length is the measure of how strongly a system diverges or converges light, and determines the FOV. A longer focal length would mean a narrower FOV, or the more ‘zoomed in’ the image will look.

(D) The focal ratio is the ‘speed’ of the optics, found by dividing the focal length by the aperture. A slower lens (larger f/#) would usually mean a dimmer image being formed.

(E) Magnification is a measure of the ‘power’ of the telescope, and is found by dividing the focal length of the telescope by the focal length of the eyepiece. A higher magnification would mean a more enlarged but dimmer image. Ideally the maximum usable power is 2x the aperture of the telescope (in mm). A common misconception is that magnification is key. Even with a high magnification, if the image formed is too dim, we still are not able to see it.

(F) Light gathering power is the more crucial component. An analogy to this would be to imagine a telescope as a bucket, and the star’s light as water droplets. A larger amount of water ‘collected’ would mean more light entering our eyes. Hence, the more we are able to view dimmer objects.

4. Aberrations

(A) Chromatic Aberration: Optical trains which utilise glass suffer from chromatic aberration, also known as purple fringing, which creates a blue halo around stars.

(B) Spherical Aberration: Because the lens/mirror has to be spherical in order to converge light, light coming through the edges and near the principal axis of the optics do not focus at the same point. The way to correct for spherical aberration is to use non-spherical optics.

*C*slow clap*

(C) Coma: A star will not show up as a point of light, rather its image is a conical shape similar to a tiny comet that points towards the centre of the frame.

(D) Field Curvature: The focal length at the edges of the field is different from the focal length at the centre of the field, hence the images at the edge would not be in focus.

(E) Astigmatism: Similar to field curvature, astigmatism would cause the image to form a line instead of a point source.

(F) Distortion: Inward (pincushion) and outward (barrel) distortion causes lines or points in the image to look bent.

5. Maintenance

(A) For telescopes, great care should be taken in ensuring that they are kept in dry environments to prevent fungus. In addition, one MUST NOT touch the surface of any optical instruments; some lenses/mirrors have nano-coatings on them, and our skin oil will degrade this coating. This might sound gimmicky to you, but rest assured that the manufacturers are not lying. It would also be best to send the optics for authorised repair/cleaning rather than doing it yourself.

(B) For mounts and tripods, keep the axes loosened in storage so that additional stress would
not be placed on the gears. They should also be kept in a dry location, lest rust form on them.

6. Polar Alignment

(A) Polar alignment is the practice of aligning your mount axis, usually the right ascension axis, such that it points parallel to the Earth’s rotational axis. It ensures that the stars remain pinpoint and in our FOV. Polar alignment is usually done by pointing at the Earth’s North or South celestial pole, or through drift alignment. This is especially important for astrophotography.

7. Astrophotography (AP) Basics

(A) Cameras are usually able to see much more than our eyes. By leaving the camera shutters open for longer periods, we are able to capture faint details of celestial objects. However, if there is no tracking, ie. the camera is not polar aligned and does not follow the stars’ ‘movement’ across the sky, the stars would form streaks instead of pinpoint sources. There are generally 3 methods for astrophotography: fixed tripod, tracked and guiding. These methods are listed in ascending orders of difficulty. In general, the narrower the FOV of the camera, the better the tracking and alignment has to be.

Observational Techniques in Astronomy and Empirical Applications

The central problem in astronomy is distance determination. An object’s distance provides important context to our observations. For instance, we can obtain an object’s luminosity if we know its apparent magnitude and distance.

This section combines insights from 3 main fields in astronomy:

- Astrometry: which aims to precisely measure the positions and velocities of stars
- Photometry: which aims to precisely measure the brightness of objects
- Spectroscopy: which aims to precisely measure the spectral features of objects

By working together across these disciplines, astronomers hope to identify standard candles, which are objects of known luminosity. Once we measure the apparent brightness of these objects, determining the distance to these objects becomes a simple exercise in math.

Standard candles are valuable tools because we cannot directly measure the distances to most objects (parallax is only detectable for nearby stars). Therefore, astronomers utilise the concept of a cosmic distance ladder in order to measure the distance of an object. Each step of the ladder helps to calibrate the next step of the ladder. For instance, we do not know the luminosity of Cepheid variables beforehand. However, if we can measure the distances to a few Cepheids through parallax, we get a good guess of their intrinsic luminosity. This tells us how “bright” Cepheids are, allowing us to use Cepheids to measure distances.

By calibrating the cosmic distance ladder, we end up with a useful toolbox for measuring the distance of celestial objects.
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<tr>
<th>Method</th>
<th>Description</th>
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<tbody>
<tr>
<td>Hubble’s Law</td>
<td>By using Hubble's law, which relates redshift to distance, one can estimate the distance of any particular galaxy</td>
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<tr>
<td>Type 1a Supernovae</td>
<td>White dwarves transform into Type 1a supernovae when they approach the Chandrasekhar limit, suggesting that their luminosities are all similar.</td>
</tr>
<tr>
<td>Cepheid Variables</td>
<td>Cepheid variables demonstrate a clear relationship between their luminosity and the pulsation period.</td>
</tr>
<tr>
<td>RR Lyrae</td>
<td>Similar to Cepheid Variables, these stars found in globular clusters demonstrate periodic variability in luminosity.</td>
</tr>
<tr>
<td>Spectroscopic Parallax</td>
<td>By studying the spectrum of the star, it is possible to determine its approximate location on an HR diagram. Reading off the HR diagram, we thus obtain an estimate of the star’s luminosity.</td>
</tr>
<tr>
<td>Main Sequence Fitting</td>
<td>If we have two star clusters (only one whose distance is known), we can identify their distance by plotting the stars of both clusters on the same color-magnitude diagram. By comparing the main-sequence stars of both clusters (by relative brightness), we can estimate the distance modulus of the unknown cluster.</td>
</tr>
<tr>
<td>Parallax</td>
<td>As the Earth orbits the Sun, the apparent positions of nearby stars appear to shift over the course of a year. Using simple geometry, we can translate these shifts into actual distances.</td>
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<tr>
<td>Radar ranging</td>
<td>By bouncing radio waves off the solid surfaces of the inner planets, we can accurately determine the length of the Astronomical Unit. This initial step is required to calibrate all steps of the cosmic distance ladder.</td>
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Astrobiology

Life in the Universe/SETI/METI

Participants are encouraged to have a good biological background in regards with this topic and should understand the conditions for life in relation to an astronomical setting. Memorising of specific exoplanets are not required.

1. **Understand why Earth is the most suitable planet for carbon based lifeforms in the solar system**

   (A) Note: Earth is the only confirmed celestial object to us which sustains life.
   - Earth thus serves as a model to study and predict life elsewhere in the solar system, while serving as a baseline to compare exoplanets in their own planetary systems

   (B) Composition of Earth’s Crust is similar to chondrite meteorites in composition
   - Chondrites are meteorites which contain chondrules: left-over debris from the formation of the solar system
   - Predominantly made of silicate rocks (i.e. ‘stony’ meteorites), with less metal content than metallic meteorites
   - Some contain Carbon and Carbon compounds (KIV: Pseudo Panspermia).
   - Late heavy bombardment delivered these chondrites rich in carbon, as well as water from comets

   **KIV: Origin of life on Earth**

   (A) Earth is a planet which exists within the “Goldilocks’ zone”, also known as the Habitable zone
   - Defined as the distance away from a star in order for a planet’s orbit to allow for the existence of Liquid water.
   - The term Goldilocks’ zone is an allegory to the tale of Goldilocks, where the temperature is just right for liquid water; too close to the star, and water evaporates; too far away, and water freezes.
   - Water acts as a universal solvent for many important biochemical reactions, especially for organic (carbon-based) life.

   (B) Earth has a fair number of unique qualities conducive for life
   - The Sun is a stable star which provides stable heat and light, keeping Earth within the habitable zone.
   - Large moon shields earth and provides axial tilt for variation in seasons.
   - Gas giants shield Earth from bombardment by asteroids.
   - Strong electromagnetic field acts as an additional protective layer against dangerous particles from the solar wind and allows ozone layer formation.
   - Ozone layer acts as a shield against UV radiation, which is otherwise capable of damaging DNA.
– Right amount of greenhouse gases for a temperature that allows for liquid water.

**KIV: Rare Earth Hypothesis**

(A) Earth acts as a model for life elsewhere in the universe
– Extremophiles on Earth broadens the search criteria for life.
– Deep-sea hydrothermal vents form unique communities that do not rely on the sun for energy; rather, they rely on chemicals and geothermal heat.
– Possible origin of life (KIV: Iron-Sulfur world).
– Europa and Enceladus: underwater oceans beneath ice sheets could possess the same type of habitats.
– Exoplanets can be thought of as variants of Earth with different parameters.
– Search for habitable Exoplanets is a ‘search for a 2\textsuperscript{nd} Earth-like planet’.

**Additional online resources:**
Why is Earth just right for life?
http://science.howstuffworks.com/life/evolution/earth-just-right-for-life.htm

2. **Appreciate the different theories for the origin of life on Earth**

(A) Abiogenesis: the process by which organic molecules and eventually the first form of life is formed from non-living/inorganic precursors
– Organic molecules: possesses carbon, excluding simple gaseous molecules (e.g. CO\textsubscript{2}) or elemental carbon (e.g. Diamond).
– End products of interest are Lipids, Nucleic acids, and Proteins.

(B) Urey-Miller Experiment: Tested possibility of life forming from simple chemicals under primordial Earth conditions
– Water (H\textsubscript{2}O), methane (CH\textsubscript{4}), ammonia (NH\textsubscript{3}), and hydrogen (H\textsubscript{2}) were added to a closed system, which undergoes heating, condensation, and passage through a spark which simulated lightning.
– Many organic products, from amino acids to sugars were formed.
– Supported Abiogenesis from primordial Earth’s atmosphere.

(C) Hydrothermal vents: Perfect sites for abiogenesis to occur
– Formation of fatty acids from Glycerol backbone.
– Lipids in water will aggregate to form micelles: membrane bound structures.
– Part of the Iron–sulfur world hypothesis.

(D) Iron–sulfur world hypothesis
– Biochemistry for Life began with catalytic transition metals, simple inorganic molecules and organic compounds near Hydrothermal vents.
– Primitive lipids eventually enclose these catalytic centers and compounds.
(E) Panspermia: Hypothesis that life can exist throughout the Universe, distributed by meteoroids, asteroids, comets, planetoids, and even spacecraft by microorganisms

(F) Classical Panspermia: The first lifeform on Earth was another lifeform elsewhere

- Allan Hills 84001 Meteorite: fossilized ‘bacteria’ was found, but not confirmed as they might be contamination/ geological features.
- Some claims even postulates that life was seeded, intentionally or accidentally by another alien civilization.

(G) Pseudo Panspermia: The development of life was accelerated by organic material synthesized in space and brought to Earth subsequently

- Most accepted mode of panspermia to supplement Abiogenesis.
- The Murchison meteorite contains many important carbon compounds, such as PAHs, Amino acids (Protein precursors), Nucleotides which served as Precursors to RNA and DNA (KIV: Importance of Carbon for life).
- UV radiation and high vacuum in space creates unique reaction conditions to promote formation of many of these compounds.

(H) RNA world hypothesis: Early life started as Ribonucleic acid (RNA) molecules which are capable of replication, eventually forming the rest of life we know of today.

- Most widely accepted hypothesis: but many possible variants remain on how RNA is formed and how the first cell actually arrived.
- Related to PAH world hypothesis: abundant polycyclic aromatic hydrocarbons (PAH), which are abundant in space first helped synthesis of RNA molecules, leading into the RNA world, but this is not well supported.
- RNA is both a catalytic molecule and an information carrier.
- The first RNA could be formed de-novo by abiogenesis on clay/ in hydrothermal vents, or carried to Earth by Pseudo- panspermia, or a combination of them.
- Relatively reactive and unstable compared to DNA; DNA ended up being more feasible for long term information storage.
- Proteins display better catalytic and structural functions than RNA
- Replaced by the DNA \( \rightarrow \) RNA \( \rightarrow \) Protein (Central Dogma) world in modern organisms today.
- HIGHLY RECOMMENDED: Read online resources to learn more if interested. Refer to section on Astrobiology in Further Readings.

**Additional online resources:**

3. **Understand the risks due to near-earth asteroids**

(A) Large ones: Mass-extinction events (duh) and the end of the world as we know it

- Likely caused the Cretaceous–Paleogene extinction event (a.k.a. the one which ended non-avian Dinosaurs).
- Besides death from direct impact, long-term changes due to climate will persist.
- Highly improbable event – but highly drastic if it occurs.

(B) Present day near-earth objects

- Any asteroid/comet with a perihelion of less than 1.3 astronomical unit (AU).
- About thirteen thousand near-Earth asteroids (NEAs) have been documented, and more than one hundred near-Earth comets (NECs) and counting.
- NASA formed the Planetary Defense Coordination Office to track large objects to mitigate these threats.
- Many close approaches have happened, but no crashes of significant damage has happened thus far since the past decade.

(C) The Torino Scale

- Developed as a measure to categorize the threat level of impacts.
- An object is assigned a threat value between 0 to 10, based on the probability of a collision event and the kinetic energy (expressed in megatons of TNT) resulting from the possible collision.

(D) Potentially hazardous objects (PHOs)

- An object with an orbit that is close to the Earth and of significant mass to cause significant damage to Earth.
- More are being added to the catalogue, but none will fall on Earth anytime soon.

(E) Asteroid impact avoidance: How can we save Earth in an emergency?

- Destroy it and hope its fragments cause less damage (NOT recommended)
  
  i. Nuclear explosive devices. Lots of them.
  
  ii. Pros: It’s a last resort that works in an emergency.
  
  iii. Cons: We are in trouble if we fail to destroy it; Creates space junk.

- Deflect it and make it miss Earth (Impulse/ sudden deflection)
  
  i. Kinetic impact using a spacecraft.
  
  ii. Nuclear deflection (Intended to knock asteroid off course and not wreck it).

  iii. Pros: Less destructive method.

  iv. Cons: Not effective against a sufficiently large object.
- Slowly nudge it out of its current orbit
  i. Gravity tractors, Ion beam shepherd, Rockets, etc.
  ii. Pros: Best chance to save Earth and minimize damage.
  iii. Cons: Prior detection and forecast needed since process takes time.

Additional online resources:
Near Earth Objects and Impact Hazard: [http://star.arm.ac.uk/impact-hazard/](http://star.arm.ac.uk/impact-hazard/)

4. **Appreciate the importance of the Carbon atom to life**
   (A) The carbon backbone is able to form many types of bonds with other elements and itself, which results in a large diversity of carbon-based compounds known to us
   - 4 possible bonds on one carbon atom.
   - Relatively abundant in the universe.

Forms many key classes of organic compounds, as follow:

(A) Lipids
   - Modern day: Phospholipids retain a role in cell membranes.
   - Other lipids make up fats/ energy stores.

(B) Nucleic acids (Refer to [RNA World Hypothesis](http://star.arm.ac.uk/impact-hazard/))
   - DNA is more stable than RNA and encodes genetic information of life.
   - RNA now serves as an intermediate messenger or performs catalytic functions instead of acting as a store of genetic information.

(C) Proteins
   - Bulk of functional products for living systems.
   - Formed from amino acids.
   - Involved in many catalytic pathways to ensure survival.
   - Structural proteins make up important building blocks of organisms.

(D) Carbohydrates
   - Effective energy store/ currency, especially in the form of sugars.
   - Structural support for plants in the form of Cellulose.

5. **Alternative Biochemistry: Could life be composed of other elements?**
   (A) Why not Silicon?
   - silicon is relatively abundant and forms the same number of bonds as Carbon.
   - However, Silicon has a larger mass and atomic radius, and thus is less likely to form double bonds.
- Too reactive with water, but viable as supporting skeletons, e.g. Diatoms on Earth use Silicon Dioxide as an exoskeleton.
- Another type of ‘silicon lifeform’: self-replicating machines/spacecrafts (Von Neumann Probes): Can they be considered to be alive?

(B) Why not Ammonia?
- Abundant in the universe, able to accept/donate Hydrogen ions.
- Weaker hydrogen bonds, reducing its surface tension and heat whereby it vaporizes, i.e. requires colder temperatures.
- Possible on planets/moons with much higher gas pressures and cooler temperatures beyond the habitable zone.

(C) What else are there?
- Sulfur, Boron Metals were suggested as alternative backbones.
- Methane, Hydrogen Sulfide, Supercooled gases.
- Each of these are either too reactive or unreactive; will be extremely different from life on Earth.

Additional online resources:
Why carbon?

Alternative biochemistry

6. Appreciate Drake’s equation and its significance in relation to extraterrestrial life (memorisation of formula is not required)

\[ N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L \]

- \( N \) = number of civilizations in the Milky Way whereby communication is plausible
- \( R^* \) = average rate of star formation in the Milky Way
- \( f_p \) = fraction of stars with planets
- \( n_e \) = average number of planets that are capable of supporting life in some form or another
- \( f_l \) = fraction of life supporting planets whereby life actually begins to develop
- \( f_i \) = fraction of life on these planets which develop intelligent life (i.e. forms a civilization)
- \( f_c \) = fraction of civilizations with a technology that releases detectable signals of their existence into space
- \( L \) = length of time needed for detectable signals by these civilizations to transmit into space

The Drake equation is a compilation of all factors which affects the odds of us finding an extraterrestrial civilization, and values can range over many orders of magnitude.
(A) The following are various evaluations, criticisms and supporting theories centered on the Drake Equation:

- Definition of habitable planets can be loose: Tidally locked planets can easily be habitable, and moons of gas giants (Europa, Titan) are potentially life supporting

- Large error bar: Equation can generate values from near improbability of aliens to the question of the Fermi paradox: why are there no aliens despite such large probabilities?

- Rare Earth Hypothesis: Life might be a much rarer occurrence than we expect; many factors are necessary for life on Earth to not go extinct (and are left out of the Drake Equation)

\[
N = N^* \times n_e \times f_g \times f_p \times f_{pm} \times f_i \times f_c \times f_m \times f_j \times f_{me}
\]

\(N^*\) = number of stars in the Milky Way

\(n_e\) = average number of planets in a star's habitable zone

\(f_g\) = fraction of stars in the galactic habitable zone

\(f_p\) = fraction of stars with planets

\(f_{pm}\) = fraction of planets that are rocky ("metallic") rather than gaseous

\(f_i\) = the fraction of habitable planets where microbial life arises

\(f_c\) = fraction of planets where complex life evolves

\(f_l\) = fraction of the total lifespan of a planet during which complex life is present

\(f_m\) = fraction of habitable planets with a large moon

\(f_j\) = fraction of planetary systems with large Jovian planets

\(f_{me}\) = fraction of planets with a sufficiently low number of extinction events

Fermi Paradox: (named after Enrico Fermi) the apparent contradiction between high estimates of probabilities involving existence of extra-terrestrial civilizations in the Drake equation, yet lack of evidence for these civilizations

(A) Given high estimates for the Drake Equation: Why haven’t aliens visited Earth yet?

(B) Ways to Resolve the Paradox:

- Direct observation of an alien civilization on an exoplanet
- Finding a Von Neumann probe: Self-replicating spacecraft
- Alternatively, a Bracewell probe: Communicating spacecraft
- Finding a stellar scale artifact: E.g. Dyson sphere, Alderson disk, Matrioshka brain, or a Stellar engine (this list is FYI), which alter the spectrum of a star
(C) Kardashev scale: method of measuring a civilization’s level of technological advancement, based on the amount of energy a civilization is able to utilize

- Type I: Earth-like; uses energy from antimatter, fusion, or renewable sources
- Type II: Harnesses energy from a Star; likely to have stellar-scale artifacts
- Type III: Harnesses energy from galaxies; exploits black holes and other high energy objects (e.g. Quasars) for energy

(D) Reasons the Fermi Paradox is unsolved:

- Intelligent extra-terrestrial life is rare/doesn’t exist; See Rare Earth hypothesis
- Technology is insufficient for interstellar communication
- Intelligent life tends to destroy itself or others by war, pollution, or rogue AIs
- Natural extinction events tend to wipe out life
- Intelligent civilizations are just too far apart in space or time to communicate
- It is too expensive to move physically around the universe
- We have not existed long enough to be detectable or to detect signals properly
- Civilizations broadcast detectable radio signals for brief periods
- Advanced life will isolate themselves, e.g. lives in massive artificial virtual environments and ignores the physical universe altogether
- Aliens are incomprehensibly alien such that communication is impossible
- SETI paradox: it’s a bad idea to inform others you exist, but good to listen
- Zoo/Planetarium Hypothesis: Earth is deliberately left out of the loop because we are too primitive and should be given time to develop
- It is dumb and dangerous to communicate
- They are undetectable with our technology, even if they pass by

Additional online resources:
Various resources from SETI on the Drake Equation and Fermi Paradox
http://www.seti.org/drakeequation
http://www.seti.org/seti-institute/project/details/fermi-paradox

Rare Earth Hypothesis
http://www.teachastronomy.com/astropedia/article/Rare-Earth-Hypothesis

7. Understand why the water-hole region may be used for communication
(A) ‘Quiet region’ of the electromagnetic spectrum, i.e. not likely to be produced by a natural source
(B) Any transmissible signal in this region is likely the result of an artificial origin
The Fate of the Universe

1. **Dark Matter**

When we observe the luminous matter in our galaxy, we find that the mass of the Milky Way is around \( M = 10^{11} \, M_{\text{Sun}} \) approximately. However, from empirically measuring the orbital velocity of distant objects we find \( M = 10^{12} \, M_{\text{Sun}} \). This suggests that only 10% of the total mass of the galaxy comprises of stars, planets, dust and so on. The missing 90% of the Milky Way is hence believed to be made up of what’s called **dark matter**.

It is hypothesised that dark matter may be:

(A) Weakly Interacting Massive Particles (WIMPs): particles with mass but does not interact with the rest of the universe; similar to neutrinos in this aspect.

(B) Massive Compact Halo Objects (MACHOs): objects similar to Uranus and Neptune but are so cold they don’t emit radiation, or are small black holes.

2. **Dark Energy**

![Friedmann Universes](https://upload.wikimedia.org/wikipedia/commons/thumb/d/dc/Friedmann_universes.svg/400px-Friedmann_universes.svg.png)

(A) It was found that very distant galaxies have smaller redshifts than as predicted by the Hubble’s Law.

- This suggests that the Universe was expanding slower in the past than it is now.
- Hence, it is hypothesised that some kind of energy must be responsible for the increase in the rate of expansion. We then need to consider the matter density of the Universe \((\rho_M)\), the dark energy density of the universe \((\rho_\Lambda)\) and the critical density \((\rho_c)\).
– In general, if the density of the universe exceeds the critical density, the expansion of the Universe will slow and it will eventually collapse on itself (the **Big Crunch**).

– If the density of the Universe is close to the critical density, but there are significant amounts of dark energy ($\rho_\Lambda$), the expansion of the Universe will actually accelerate, and we will eventually head towards the **Big Rip**.

– In general, the combined density of the Universe ($\rho_M + \rho_\Lambda$) is exceedingly close to the critical density. In fact, this generates the **flatness problem** in cosmology: the Universe must have started off really close to the critical density at the Big Bang, otherwise runaway contraction/expansion would have occurred by now.

**Further Readings**

**THE SOLAR SYSTEM AND EXTRASOLAR SYSTEMS**


(B) [http://www.universetoday.com/85761/protoplanet-hypothesis/](http://www.universetoday.com/85761/protoplanet-hypothesis/)


(E) [http://abyss.uoregon.edu/~js/glossary/roche_limit.html](http://abyss.uoregon.edu/~js/glossary/roche_limit.html)

(F) [http://space-facts.com/comets/](http://space-facts.com/comets/)

(G) [http://csep10.phys.utk.edu/astr161/lect/moon/moon_formation.html](http://csep10.phys.utk.edu/astr161/lect/moon/moon_formation.html)


**RELATIVITY**

(A) [http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/relcon.html#relcon](http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/relcon.html#relcon)

(B) [https://en.wikipedia.org/wiki/Special_relativity](https://en.wikipedia.org/wiki/Special_relativity)

(C) Young & Freedman University Physics

**PRACTICAL ASTRONOMY**


(B) Catadioptric Variations: [https://en.wikipedia.org/wiki/Catadioptric_system](https://en.wikipedia.org/wiki/Catadioptric_system)


(D) Aberrations: [http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/aberrcon.html](http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/aberrcon.html)

(F) Tracking vs Guiding: http://www.jrjohnson.net/GDAC/BOOK/4_TAKE/403/403A/403A07/403A07.HTM

(G) Polar Alignment: https://starizona.com/acb/basics/using_polar.aspx

(H) Drift Alignment: http://www.backyardastronomy.net/drift_alignment.html

**ASTROBIOLOGY**

The following resources for Astrobiology are highly recommended for reference

(A) The water-hole region: http://www.setileague.org/general/waterhol.htm

(B) Hydrothermal vents: http://ocean.si.edu/ocean-videos/hydrothermal-vent-creatures

(C) How did water end up on Earth?: https://www.youtube.com/watch?v=_LpgBvEPozk

(D) The RNA world Hypothesis: https://www.youtube.com/watch?v=VYQQD0KNOis

(E) The Fermi Paradox:
   https://www.youtube.com/watch?v=sNhhvQGsMEc
   https://www.youtube.com/watch?v=1fQkVqno-ul