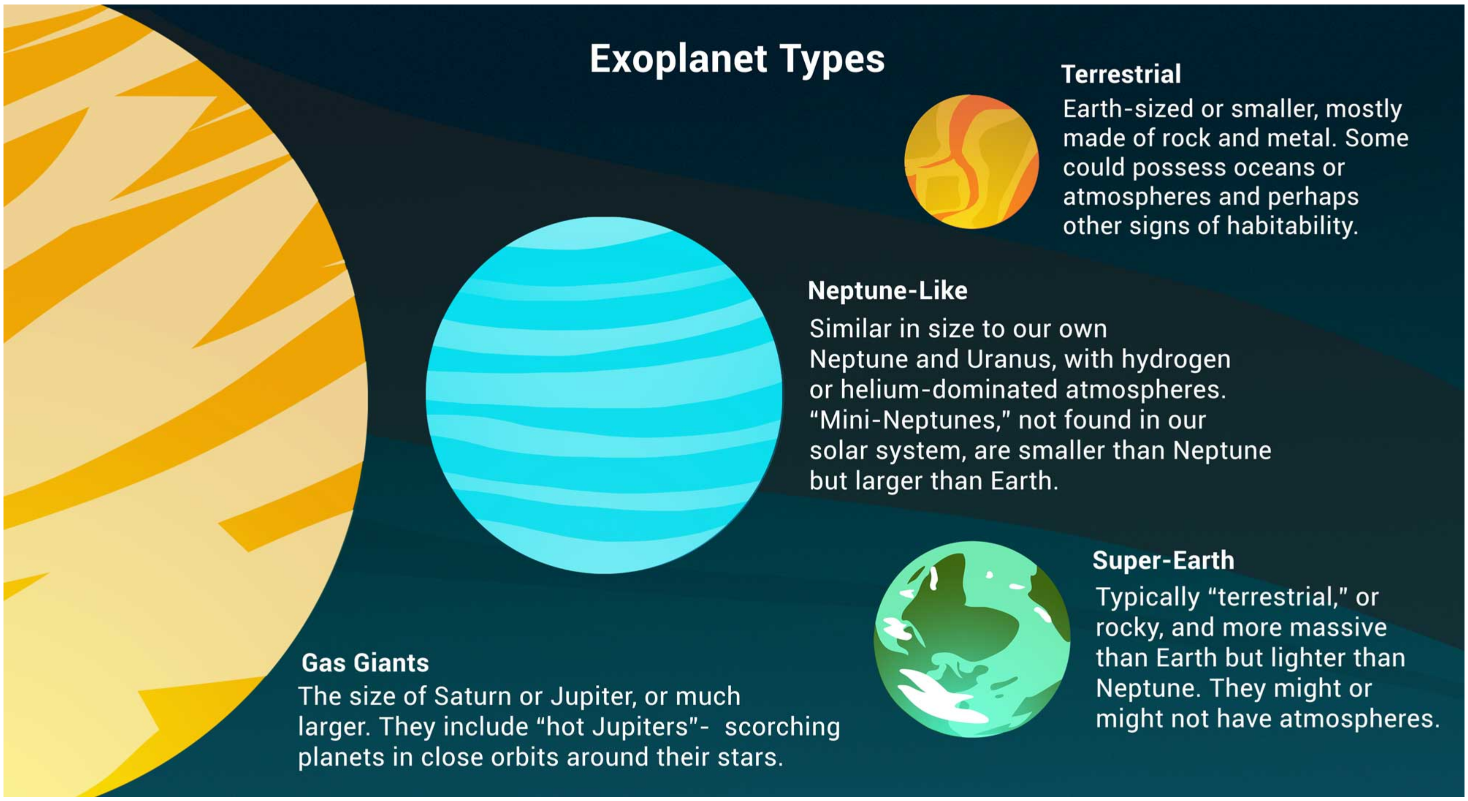
Lecture 34 : The Exoplanets

The area of research that has attracted great attention in recent years is that of planet formation, recognised by the awarding of (2/3rd of) the 2019 Nobel prize to Michel Mayor and Didier Queloz "for the discovery of an exoplanet orbiting a solar-type star". In the past decade, NASA's Kepler Space Telescope has detected more than 3000 exoplanets ranging from sub-Earth-sized planets to huge gas giants that dwarf even our Jupiter, with densities ranging from that of styrofoam to iron. Astronomers find them close to their parent or host stars with scorching temperatures, to a great number in the so-called 'habitable zone' in which life (as we know it) can flourish.



[Image Credit : NASA/JPL-Caltech/Lizbeth B. De La Torre]

Even before Newtons time, there were assertions that the stars were just like the sun, but far away. Some even went on to conjecture that there must be planets orbiting many of the stars. The first extra-solar planet was found in 1995. Today, nearly 6,000 exoplanets have been discovered. This lecture discusses some of the current ideas on how planets form from gas and dust, left over from the formation of the host star.

23 December 2022

Astronomy & Astrophysics : An Introductory Survey

A lecture series by Prof. G. Srinivasan

A 'Golden Jubilee Celebration' Event of the Astronomical Society of India

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[Supplementary Material : Dr. Sushan Konar]

Suggested Problems

1. A useful resource for exoplanet research is the NASA Exoplanet Archive. The following set of problems considers the currently known exoplanet population using the site's *"Confirmed Planets Plotting Tool"* accessed through the "Tools" tab. It could be helpful to study the pre-generated plots at the Caltech site. [In this context, exoplanets.org is another site with good plotting tools, though the data may not be updated as regularly as the NASA site.]

   (a) Make a plot of the planetary mass vs. planetary orbital semi-major axis.

   (b) Add the following solar system planets to this plot - Mercury, Earth, Jupiter, Saturn, Uranus, and Neptune. How do most of the planets (especially transiting ones) compare with Mercury's semi-major axis?

   (c) Let us consider whether the detected planets are representative of the Galaxy's planet population or whether there exists serious observational biases. Consider the transiting planets in this plot. There appears to be a pile up of transiting giant planets with periods of a few days and much fewer transiting planets at periods beyond 100 days. Given that the probability of observing a transit is R*/a (radius of star divided by the semi-major axis), compute the probability of transit of a planet on a 3 day orbit compared to a 365 day orbit. Assume a star with solar mass and solar radius. Do you think the lack of transiting giant planets detected beyond 100 days is real?

   (d) The limits on the RV (relative velocity / Doppler) method. In the 1-5 AU range, there are many giant planets but not a lot of small ones. We wish to know if the lack of small planets with this separation is simply due to the detection limit or if these planets just do not form. Today, instruments can reliably measure 1 m/s radial velocities. If a planet has a semi-major axis of 1 AU, what is the magnitude of the radial velocity signal? Draw a line on your original plot to mark the RV detection limit. Hint: Now that you have a point (the minimum mass sensitivity at 1 AU), compute the minimum mass at another point and connect them with a line. Now that you have the RV detection limit, answer the original question: Do you think there is truly a lack of planets below 0.1 M_J in the 1-5 AU region? The RV planet population drops off very quickly beyond 5 AU, even though Jupiter mass planets at 10 AU would still cause RV signals greater than 1 m/s. Why do you think this is the case?

2. Sketch the radial velocity curve that the following hypothetical exoplanet system would have.
   A planet that is about the mass of Jupiter, takes 20 days to orbit its Sun-like star, and is on a highly elliptical orbit. The eccentricity of the elliptical orbit is such that the planet spends about half the time at perihelion as it does at aphelion .The system is oriented in such a way that it is viewed perfectly edge-on.

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