My credentials (RNZ = Radio New Zealand)

SCIENCE

Planet Hunter, Michael Albrow

From Jesse Mulligan, 1–4pm, 2:27 pm on 4 July 2016
As 13-yr old planet hunter in 1957:

Jan 10\textsuperscript{th} 08:20 hrs. “I did not expect to see Mercury this morning as it will not be in a favourable position for a week and although I looked I did not see it.”

“Venus itself was silvery bright about 3.5° above the south-east horizon”

Jan 27\textsuperscript{th} 20:55-21:03 hrs. “I found Uranus as magnitude 5.5 star west of Praesepe. It was at opposition two days ago.”

Jupiter 1957

Comet Arend-Roland

Telescope inverts

Anti-tail “discovery” (dust) – only seen one night (binoculars) Drew comet nightly for 3 weeks + Sputniks I, II, III

I only ever saw Neptune on a photo I took years later

LGAS - choice
Scene on exoplanet Trappist-1f --- Artist’s Impression of course
SOME THINGS:

Our own **Solar System**: Planets, moons, transits and wobbles

**Light**: Brightness (Intensity) and Color (Wavelength)

**Spectral lines** – the bar codes. Elements, temperature, speed (Doppler - shift)

**Exoplanets** found from stars **wobbling**

**Transits**: Mercury, Venus, Earth & Moon (eclipse), Exoplanets

Earth-bound successes

Satellites: **KEPLER** and others

**Life** in the Goldilocks Zone. How many? How to detect? Civilizations? SETI

Life in the **Universe**? In the **Multiverse**?

WOW!
Our own Solar System

Showing Sun and eight planets – sizes to scale but not distances

Distances to scale:

Lots more things: Dwarf planets, minor planets, moons, asteroids, comets, dust, gas ...
Distances to planets: Now on a logarithmic scale – factors of x 10

Voyager at 100 AU, Earth at 1 AU (definition).

Earth $\rightarrow$ Sun = 8 light minutes & Earth $\rightarrow$ Nearest Star = 4.25 light years

Planet Proxima Centauri b is roughly Earth sized and may be in Goldilock zone, with water.

Proxima = close, in constellation of Centaurus, b == first planet found there.

Close encounters of “Dirty snowballs” in Oort cloud: Expulsion or Sent in to visit Sun
$\rightarrow$ Occasional non-periodic comets.

(Jan Oort on bus)

Can you see a centaur?
What were those shepherds smoking?

Tennis ball- grain of rice @7m – 1800km (1150 miles)
Bar chart of *exoplanet* discoveries by year, through 2015-01-01, indicating the *discovery method* using distinct colors: 
- radial velocity (dark blue)
- transit (dark green)
- timing (dark yellow)
- direct imaging (dark red)
- microlensing (dark orange)

Discovery Method 1

RADIAL VELOCITY
Isaac Newton ~ 1672

Wollaston, English chemist, noticed (1802) Fraunhofer (re)discovered 1814, studied systematically. Kirchhoff and Bunsen: lines correspond to elements emitting specific wavelengths

Bright emission lines in sun’s Chromosphere (“atmosphere”) Helium discovered as bright yellow line by Lockyer. Gk: Helios = Sun

Solar spectrum with Fraunhofer lines as it appears visually.

PHYSICISTS LOOK DIFFERENT NOW

@ Dark Matter & Dark Energy Workshop 2018
HARPS = High Accuracy Radial velocity Planet Searcher

Mountain top at La Silla, Chile

3.6m telescope
The **frequency comb**: **HARPS** on European Southern Observatory 6m telescope in Chile

**Spectrum of the light from the two-laser frequency combs installed on the** [High Accuracy Radial Velocity Planet Searcher](https://www.eso.org/sci/facilities/everything/harps/)

A precision in stellar radial velocities of better than **2 cm/second**. By comparison, the amplitude of the radial velocity induced in the Sun by the Earth as it orbits is **9 cm/second**, so the new laser frequency combs in principle enable the detection of Earth-like planets in Earth-like orbits.
Discovery Method 2

TRANSITS
Transits of Mercury and Venus and Earth-Moon

Johannes KEPLER first predicted that Mercury and Venus should pass in front of the Sun.

Transit of Mercury first seen November 1631 by Pierre Gassendi (always May or November).
High precision timing – Mercury’s orbit precesses –
Another inner planet VULCAN? General Relativity explained it!

Transit of Venus from NASA’s Solar Dynamics Observatory
June 5th 2012. Previous transit 2004, next 2117
In 1771: Distance Earth-Sun 153 Mkm (1%)
Total light dimming = 0.1% (same for distant star)
**Transits: Venus and Earth**

Venus’ atmosphere: Mostly CO$_2$, some N. Known, but measurable in transit (?)

*Photo: Pioneer Venus Orbiter*

**Total Lunar Eclipse**

27 July 2018 – not visible here

If on moon you would see an eclipse of the Sun by the Earth.
Transit, except Earth covers Sun completely

Why is it red?
HD 209458 b (nickname "Osiris")

First exoplanet found by transit method, by Hubble 1999: **A HOT JUPITER**

- 15% light dimming – it is big and close to star
- Hydrogen blow-off – 10,000 tons/second, Sodium, and C and O detected by spectroscope

"Chthonian planets"? Like Jupiters but with all gases blown away
The Hubble Space Telescope as seen from the departing Space Shuttle *Atlantis*, flying STS-125, HST Servicing Mission 4.
Size comparison of Jupiter and the exoplanet TrES-3b. TrES-3b has an orbital period of only 31 hours\(^3\) and is classified as a Hot Jupiter for being large and close to its star, making it one of the easiest planets to detect by the **transit method**.

Radial velocity confirms it!

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The **Trans-atlantic Exoplanet Survey** or TrES, uses three 4-inch (10 cm) telescopes located at Lowell Observatory, Palomar Observatory, and the Canary Islands to locate exoplanets. It was made using the network of small, relatively inexpensive telescopes designed to look specifically for planets.
The KEPLER space telescope

The mission goal: a combined differential photometric precision (CDPP) of 20 (→ 29) ppm for a \( m(V) = 12 \) Sun-like star for a 6.5-hour integration. Continuously monitors 150,000 main sequence stars for brightness changes. (fist)
Pointing direction Cygnus, Lyra, Draco (Milky Way) and off ecliptic (Sun never shines on it)
If habitability is related to distance from Galactic centre, look here!
The first rocky planet discovered by Kepler, 1.4 x Earth size & 3 x Earth mass
Scorching hot: perhaps oceans (and rivers?) of molten lava

Not much bigger than Earth, but much hotter!
First rocky planet found in habitable zone (Goldilocks) allowing liquid water
“f” means 4th, after b,c,d,e

Not too hot and not too cold but just right!
Kepler-22b

A possible “WATER WORLD”
Kepler-16b

A “circumbinary” planet: orbiting two stars (a binary star)
First compact multi-planet system discovered by Kepler.
At least 5 planets, closer in than Mercury
Note: dimming does not depend on how far away star is from us.
This particular arrangement of planets with a double-transit reflect an actual configuration of the system during the 21 days of observations made by NASA's Spitzer Space Telescope in late 2016.

7 planets: at least 3 in Goldilocks Zone!
Show Trappist-1 video
NASA's Spitzer Space Telescope and the ground-based TRAPPIST (TRA nsiting Planets and PlanetesImals Small Telescope) telescope

Days since launch: 5457
Kilometers from Earth: 246,874,725

5 years planned - 15 years & counting

Detection of water vapor in atmosphere (this year)

WASP-39b “hot Saturn”
700 LY away in Virgo
4-day orbit – very hot!
Low density - 0.18 x water
Eight planets known orbit this Sun-like (G-type) star in constellation Draco (the Dragon). First system known to have 8 planets like Solar system.
All closer to star than Earth – Sun, probably too hot for water/life?
Maybe more cooler planets further out. 2500 light years away, 14th magnitude.
Kepler-90i (14.4 day orbit) discovered in transit by Google Machine Learning!
Update December 14th 2017

Now we know that there are more planets in our galaxy than stars.
~ 100,000,000,000. One hundred thousand million!
Pc = parsec = 3.36 light years (3/4 way to nearest star)
At a distance of 1 parsec Earth’s orbit subtends 1 second of arc = 1/60 x 1/60 x 1 degree
17th observing mission of Kepler’s K2: March 1st to May 8th 2018

Observing 30,000 objects in Constellation Virgo
Comparison: most brown dwarfs are only slightly larger than Jupiter (10–15%) but up to 80 times more massive due to greater density. The Sun is not to scale and would be larger.
Hubble spots giant planet orbiting tiny star (USA TODAY HEADLINE)

Binary system: one brown dwarf mass $35 \times M(\text{Jupiter})$
companion mass $10 \times M(\text{Jupiter})$ – Brown dwarf or huge planet?
Comparison of sizes and effective temperatures of planets, brown dwarfs, and stars. Displayed are the Sun, the red dwarf star Gliese 229A, the young brown dwarf Teide 1, the old brown dwarf Gliese 229B, the very cool brown dwarf WISE 1828+2650, and the planet Jupiter. Graphic after American Scientist/Linda Huff using NASA satellite images (Sun, Jupiter) and NASA artist work (Gliese 229A + B, Teide 1, WISE1828+2650).
Discovery Method 3

GRAVITATIONAL LENSING
OGLE-2016-BLG-1540: A free-floating planet candidate from the OGLE and KMTNet surveys

Current microlensing surveys are sensitive to free-floating planets down to Earth-mass objects. All published microlensing events attributed to unbound planets were identified based on their short timescale (below 2 d), but lacked an angular Einstein radius measurement (and hence lacked a significant constraint on the lens mass).

We report the discovery of a Neptune-mass free-floating planet candidate in the ultrashort ($t_E = 0.320 \pm 0.003$ d) microlensing event OGLE-2016-BLG-1540. The event exhibited strong finite source effects, which allowed us to measure its angular Einstein radius of $\theta_E = 9.2 \pm 0.5$ uas. There remains, however, a degeneracy between the lens mass and distance. The combination of the source proper motion and source-lens relative proper motion...
Method 4

DIRECT OBSERVATION
Direct observation of an exoplanet – VERY HARD!

For the first time, astronomers have been able to directly follow the motion of an exoplanet as it moves to the other side of its host star. The planet has the smallest orbit so far of all directly imaged exoplanets, lying as close to its host star as Saturn is to the Sun.

The team of astronomers used the NAOS-CONICA instrument (or NACO), mounted on one of the 8.2-metre Unit Telescopes of ESO’s Very Large Telescope (VLT), to study the immediate surroundings of Beta Pictoris in 2003, 2008 and 2009. In 2003 a faint source inside the disc was seen, but it was not possible to exclude the remote possibility that it was a background star. In new images taken in 2008 and spring 2009 the source had disappeared! The most recent observations, taken during autumn 2009, revealed the object on the other side of the disc after having been hidden either behind or in front of the star. This confirmed that the source indeed was an exoplanet and that it was orbiting its host star. It also provided insights into the size of its orbit around the star.

The above composite shows the reflected light on the dust disc in the outer part, as observed in 1996 with the ADONIS instrument on ESO's 3.6-metre telescope. In the central part, the observations of the planet obtained in 2003 and autumn 2009 with NACO are shown. The possible orbit of the planet is also indicated, albeit with the inclination angle exaggerated.
Exoplanet **HIP 65426b** is the first discovered planet around star **HIP 65426**

The exoplanet HIP 65426b — the first to be seen by the SPHERE instrument on ESO’s Very Large Telescope. The image of the parent star has been removed from the image for clarity, and its position marked with a cross; the circle indicates the orbit of Neptune around the Sun on the same scale. The planet is clearly visible at the lower-left in this remarkable image.
The three known planets of the star HR8799, as imaged by the Hale Telescope. The light from the central star was blanked out by a vector vortex coronagraph.
LIFE?
With so many planets in our galaxy, how many have life?

Life = complex molecule capable of self-reproduction or template for reproduction (protein). Carbon atom is the only one of all elements known to be capable of such complexity. Silicon-based life is when electronics and/or robots take over the world. Not natural.

Drake Equation (Fermi problem: how many piano tuners in Chicago)
Search for extraterrestrial Intelligence – SETI by listening to radio

How many ETI’s might be detectable by listening for radio signals?
N = multiply together guesses for each of these factors:

- $R_*$ = the average rate of star formation in our galaxy
- $f_p$ = the fraction of those stars that have planets
- $n_c$ = the average number of planets that can potentially support life per star that has planets
- $f_i$ = the fraction of planets that could support life that actually develop life at some point
- $f_i$ = the fraction of planets with life that actually go on to develop intelligent life (civilizations)
- $f_c$ = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space
- $L$ = the length of time for which such civilizations release detectable signs into space[^5][^6]

Now we get to know the first three and $f_p$ is close to 1!
No idea about the last four except not exactly 0
May 3rd 2006: Jill Tarter gave Colloquium on SETI here

The Allen Telescope Array:  
42 Is More Than The Answer To Life, The Universe, And Everything  
Fermilab  
May 3, 2006  

Jill Tarter  
Director, Center for SETI Research --- SETI Institute  
Bernard M. Oliver Chair for SETI  

http://vmsstreamer1.fnal.gov/VMS_Site_03/Lectures/Colloquium/060503Tarter/vf001.htm

Paul Allen, co-founder of Microsoft, donated > $30M

Arecibo radio telescope  
in Puerto Rico  
– 300m fixed dish

42 -> 360 ; 6m dishes
What is SETI@home?

SETI@home is a scientific experiment, based at UC Berkeley, that uses Internet-connected computers in the Search for Extraterrestrial Intelligence (SETI). You can participate by running a free program that downloads and analyzes radio telescope data.

Join SETI@home
High-redshift galaxy candidates in the Hubble Ultra Deep Field 2012

Area on sky
$1/100^{th}$ Moon
1mm x 1mm @ 1m

Exposure $10^6$ secs
= 12 days

...a galaxy. Think 10 – 100 billion planets each?? !! much younger then, so ... who knows?
What did I say?

Earth was once unique. This was the **WORLD**.
Then: one of several planets in solar system, but still unique
Then came **SCIENCE**.

**PHYSICS**: Telescopes & satellites; Gravity wobbles by spectra, transits, gravity lensing
Now: one of many **thousands of discovered planets** around other suns. Still unique?
Surely: Many **billions of planets in our own Milky Way** galaxy in Goldilocks zone.

Extremely likely that some form of life has originated on at least millions of planets.
We may know in our (your) lifetime.

But: what are the chances of **multicellular life** then **evolving to sentient creatures**?
Then: what are the chances that something like a civilization arises and survives a while?

All we know: it is **not ZERO**. But we could be alone. **What a responsibility!**

- And there are a hundred billion galaxies in the visible Universe

**WOW!**
THANK YOU

QUESTIONS?