SEARCHING FOR EXTRA-SOLAR PLANETS

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Ideas about other solar systems and life elsewhere aren’t new...

Giordano Bruno 1548-1600. Italian philosopher. Executed (bbq’d) in Rome for heresy

Christian Huygens (b1629 Holland). The first person to:
- measure the size of another planet
- speculate Venus is covered in clouds
- recognize the nature of Saturn's rings
- observe Titan, Saturn's largest moon
- estimate distances to nearest stars
- sketch Mars’ surface and determine its rotation period (~24 hrs). He believed in life on planets around other stars.. And even wrote a book about it...... in 1690!
Our Galaxy (The Milky Way)

**DISTANCE MEASUREMENTS**

1 “parsec” = 30 million million km
1 Light Year = 9 million million km

**STRUCTURE**

**DISK:** Spiral Arms, Gas, Stars, Dust

**CENTRAL BULGE**

**HALO:** Gas, Individual Stars, Globular Clusters

**ASPECT RATIO IS ~ 100.**

**OUR POSITION AND ORBIT**

**SUN:** ~ 2/3 out from centre, orbiting at ~ 220 km/s (Moving towards Constellation of Cygnus, ~ 90° away from Galactic Centre)

**ROUND TRIP = 63 kpc OR 210,000 Ly**

**IT TAKES ~ 290 MILLION YEARS TO GO AROUND ONCE!**

( MAX. OF 50 REVOLUTIONS SINCE THE BIG BANG)
The Hubble Ultra-Deep Field

The region of sky chosen carefully avoids contamination from bright foreground objects, in, or not far from our own Galaxy.

The target for the Hubble Deep Field was a carefully selected piece of sky near the handle of the Big Dipper (part of the northern circumpolar constellation Ursa Major — the Great Bear). The field is far from the plane of our galaxy and so is “uncluttered” of nearby objects, such as foreground stars. The target field is, by necessity, in the continuous viewing zone (CVZ) of Hubble’s orbit, a special region where Hubble can view the sky without being blocked by Earth or interference from the Sun or Moon.
The Hubble Deep Field uncovered much fainter objects in the universe (down to nearly 30th magnitude) than seen previously from ground-based telescopes. Some of the dim objects along Hubble's line-of-sight may be intrinsically faint, foreground galaxies. Others, however, are dim because they are extremely distant. Some of the faintest galaxies in the survey existed when the universe was a fraction of its present age.
The Ultra Deep Field observations - a deep view of the cosmos.

Peering into the Ultra Deep Field is like looking through an eight-foot-long soda straw.

In ground-based photographs, the patch of sky in which the galaxies reside (1/10th the diameter of the full Moon) is largely empty.

In these images, blue and green correspond to colors that can be seen by the human eye, such as hot, young, blue stars and the glow of Sun-like stars in the disks of galaxies.

Red represents near-infrared light, which is invisible to the human eye, such as the red glow of dust-enshrouded galaxies.

The image required 800 exposures taken over the course of 400 Hubble orbits around Earth. The total amount of exposure time was 11.3 days, taken between Sept. 24, 2003 and Jan. 16, 2004.
Dust rings: planets are probably not rare

- Rings seen in reflected light
- 3 times the mass of the Sun
- Disk initially detected in IR
- Star is relatively young (~1% of its lifetime)

Is the dark gap a region swept out or caused by a planet?

(NB - solar system size = 6 billion miles)
Another example

The narrow rings around Saturn are held in place by the gravitational effects of moons orbiting nearby.

Are narrow rings like these held in place by unseen bodies? (otherwise why would they remain intact?)
Are We Alone?

The Habitable Zone (where liquid water can exist)

HZ moves outwards as star evolves

Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto
Methods for detecting extrasolar planets

1. Astrometry (measuring stellar positions)

2. Doppler method (planet and star orbit a common centre of mass)

3. Gravitational lensing (spacetime distortion)

4. Reflected light (like looking at the planets from Earth)

5. Eclipses
It’s difficult to detect a faint planet near a bright star:

Brown Dwarf Gliese 229B

Compare this to the Sun-Earth configuration

100x fainter than Sun!

1000x brighter than Earth and 40x further away

Palomar Observatory
Discovery Image
October 27, 1994

Hubble Space Telescope
Wide Field Planetary Camera 2
November 17, 1995

PRC95-48 • ST ScI OPO • November 29, 1995
T. Nakajima and S. Kulkarni (CalTech), S. Durrance and D. Golimowski (JHU), NASA
Indirectly detecting planets - the Astrometric technique

An Earth-mass planet orbiting in an earth-like orbit around a solar-mass star 33 light years from us would produce 0.0003 arcsecond wobble in the star's position.

Jupiter (300X the mass of the Earth and 5X its orbital distance) would produce a signature 1500X as strong – 0.5 arcsecond
Indirectly detecting planets via the Doppler effect (the Radial Velocity Technique)

Star position “wobbles” backwards and forwards towards the planet

Starlight is blue shifted

Starlight is red shifted
One of the first extra-solar planets (found using the radial velocity technique)

Mayor & Queloz
23 Nov 1995
Einstein’s Theory of General Relativity predicts that the presence of a massive object changes the geometry of the Universe in its immediate vicinity.

“GRAVITATIONAL LENSING” (Predicted by Einstein ~ 1914) is a consequence of G.R: -

As the sun passes in front of a background star, the light from the star should be gravitationally deflected by the sun.

**PROBLEM:** Sun is bright!

**SOLUTION:** Wait for a Solar Eclipse.

The effect was discovered experimentally in 1919.
Light from a distant star can be “focused” by a foreground object (gravitational lensing).

“Dark” star moves across line of sight to background star.

1st detections of “MICROLENSING” in 1993. (Events are rare. Need many observations). ⇒ “MACHO” (Massive Astronomical Compact Halo Object)

Results suggest $M_{\text{MACHO}} \approx 3\% - 30\% M_\odot$
Einstein's Gravitational Lensing

Possible “problems”:
- typical lenses are low mass, so HZ is small, so chances of life are small
- low mass also means few heavy elements, which are required for life
GOT TO HERE 22/8/06
A few facts:

The planet is ~5.5x Earth’s mass, probably rocky.

OGLE-2005-BLG-390Lb, is probably too cold to support life as we know it.

Surface temperature = -220°C, nearly as cold as Pluto.

Orbits a red dwarf ~28,000 Ly away.

Red dwarfs are ~1/5x the Sun’s mass, and ~50 times fainter.

But they are common stars, so rocky worlds may be common!
Reflected light method

(like Venus, Mars, etc!)

Star spectrum
“static”

Planet spectrum
(10,000 times fainter!)

<table>
<thead>
<tr>
<th>planet</th>
<th>albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>0.46</td>
</tr>
<tr>
<td>Saturn</td>
<td>0.39</td>
</tr>
<tr>
<td>Uranus</td>
<td>0.60</td>
</tr>
<tr>
<td>Neptun</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Planet spectrum, oscillates as planet orbits star
The Transit Method

Planetary orbit must be aligned with line of sight to Earth

First ever transit detection
Nov 7th 1999!
Planetary Transit Search using the Automated Patrol Telescope (APT), Siding Spring, NSW, Australia

- Current detector: 2 x 3 sq. deg.  Pixel size approx. 10”
- New CCD: 5.7 x 5.7 sq. deg.  Pixel size approx. 4” (2006)
- Data collection rate: approx. 3GB per night!
- Computing: dedicated SUN E4500 system, 10 processors, 8GB RAM, Tb of HDD
- Project members: Jessie Christiansen, Duane Hamacher, Marton Hidas, Michael Ashley, Andre Phillips, Mitchell Kardan, John Webb, plus collaborators at Cambridge.
Maybe we can detect an atmosphere!
Similar to Schmidt camera, but uses a 3-element lens to achieve a wide, corrected field of view.

The APT has 0.5m aperture f/1 optics which produce a 5 degree flat field, of which a 2X3 degree field is utilised by the CCD currently installed.

Imaging can be done either unfiltered or through B, V, R and I broad-band filters.
Automated Patrol Telescope image.

Courtesy Marton Hidas, UNSW
HD 209458

Jupiter+Sun

Earth+Sun

rms (millimag)

V Magnitude
Detection of the planetary transit of HD 209458 using the APT at Siding Spring

APT mirror diameter = 1m

The integration time per point plotted is about 2 minutes

The transit depth is $1.6 \pm 0.2\%$

Planet mass = 0.62 M(Jupiter)

Planet-star distance is 0.05AU
FIRST RESULTS:

ARE THESE OUR FIRST TRANSIT DETECTIONS?
Could we detect $O_2$ in the atmosphere of a transiting extra-solar Earth-like planet?\(^1\)

**Why $O_2$?**

- $O_2$ is a potential indicator of life
- $O_2$ produces a strong absorption band at optical wavelengths
- The individual $O_2$ lines are narrow and may be offset from terrestrial lines (by the host stars peculiar velocity)

Discussion of whether $O_2$ indicates life or not, Leger et al 1999

\(^1\)Webb & Wormleaton, astro-ph/0101375
Once we do identify the planet directly, how do we know if there is life there? (1)

This will be done by studying the planet’s spectrum (which means its atmosphere). We must therefore be able to recognise the “signature of life”.

To do this it is useful to understand how our own atmosphere was formed and how it has evolved due to the presence of life in Earth.

1. How did Earth get its atmosphere?

• Probably happened at a *late* stage in Earth’s formation. Meteorites & comets (similar to those in the solar system today), rich in “volatile” (easily vapourised) compounds, heated up and vapourised on impact, forming the primitive atmosphere.

• There would have been little H or H₂ around - any of the originally accreted gases would have escaped from Earth during the first 100 million years.
Comet Shoemaker-Levy impact on Jupiter

(a) just before impact
(b), (c) just after impact
(d) 20 minutes after impact

Image taken with Calar-Alto 3.5m telescope in Spain
2. How did Earth’s atmosphere subsequently evolve?

- H locked up in heavier molecules (eg. H₂O vapour) would not have escaped gravity - but would have been zapped by the Sun’s UV radiation ("photodissociation") and then escaped (combined with other elements).

- Simultaneous reaction between the primitive crust and atmosphere would have taken place. The combined effect of all this produced the initial atmosphere (mostly CO, CO₂, N₂ and H₂O).

- Once the H escaped, remaining O atoms could form O₃ and start shielding the Earth against UV. The atmosphere was still very different to today (which is mainly N₂ and O₂, small quantities of H₂O and CO₂, and very little CO).
Once we do identify the planet directly, how do we know if there is life there? (3)

3. How did Earth’s atmosphere end up like it is?

- The CO₂ eventually combined with other compounds to form rocks (calcium carbonates - chalk, limestone) (e.g. on the sea bed - using CO₂ in dissolved in the water) - this process eating up most of the remaining CO₂ in the atmosphere. Life assists this (shells etc) (but is not required for it to happen).

- O₂ began to enter the atmosphere only once life began (from photosynthesis).

- Ultimately we end up with 21% O₂, 78N₂ + 1% other stuff.
Spectral signature of life on Earth
Spectra of Earth, Venus, Mars

Are We Alone?

- The spectral shape shows the temperature of the planet and it is right for water to be liquid.
- The strong carbon dioxide band shows we have a planet with an atmosphere.
- The ozone band shows plentiful oxygen, probably produced by life.
- The spectral features of water show abundant water, indicating a planet with an ocean.
Upper plot: terrestrial O₂ A-band, real data (note extra absorption due to “contamination” by line-of-sight absorption)
Lower plot: model of the above, based on HITRAN database, and described by a single parameter, N
Theoretical calculation of oxygen in an extrasolar planet atmosphere
TPF - terrestrial planet finder

- IR interferometer, cooled 3.5m mirrors
- ~75-1000 m baseline
- Separate spacecraft for configuration flexibility
  - 1 milli-arcsec (mas)
  - Spectral Resolution 20-300
- Operate at 1 AU for 5 years
- Launch date 2014?

What does 1 mas mean? If you put TPF on Earth, you could resolve a man's face on the Moon! (For comparison, the AAT could only just resolve the building we are in).
TPF – “to fly before 2020”

Goal: to detect and characterise Earth-like planets around as many as 150 stars up to 45 light-years away.

Visible-light coronagraph

Formation-flying infrared interferometer

Will the discovery of life elsewhere look like this?
TPF eliminates light from host star using “NULLING”

1. Simulated target
2. Target through TPF interference fringes
3. Time-series as TPF rotates
TPF reconstructs images and spectra using multiple baselines & wavelengths

4. Reconstructed images

5. Spectrum of planet (from best reconstruction - lower RH panel)
Is there life elsewhere?

The pessimist: we will only ever discover “hot Jupiters” or other unsuitable planets, where life simply can’t exist.

The middle ground: Actually, unfortunately, we happen to be the last generation NOT to know the answer!

The optimist: Atmospheric spectral signatures are already within technological capabilities – it’s purely a matter of time!