Exoplanets: in search of Earth 2.0 Dr Jayne Birkby Assistant Professor, Anton Pannekoek Institute for Astronomy



"The Earth is a very small stage in a vast cosmic arena." - Carl Sagan 1994



Neptune Uranus Pluto Makemake Comets PLANET SIZE TO SCALE (NOT DISTANCES)



Exoplanet: Extra-solar planet A planet outside our Solar system orbiting another star





$N = \mathbf{R}^* \times f_p \times \mathbf{n}_e \times f_l \times f_i \times f_c \times L$





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Drake equation $\mathbf{N} = \mathbf{R}^* \cdot \mathbf{f}_{\mathrm{p}} \cdot \mathbf{n}_{\mathrm{e}} \cdot \mathbf{f}_{\mathrm{l}} \cdot \mathbf{f}_{\mathrm{i}} \cdot \mathbf{f}_{\mathrm{c}} \cdot \mathbf{L}$

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Planets form in disks around young stars























500 AU (16x Sun-Neptune distance)





Planets clear gaps in protoplanetary disks

TW Hydra observed with ALMA

HD 135344 B observed with SPHERE at the VLT (taken by Tom Stolker @ API/UvA!)



Exoplanets are faint compared to their host stars





Exoplanets are faint compared to their host stars





Use a coronograph to block the light from the star







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Four gas giant planets orbiting HR 8799

2009 - 07 - 31



Jason Wang Christian Marois



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Doppler Effect



Doppler Effect

Movement changes the frequency of the waves emitted from the source


Doppler Effect

Movement changes the frequency of the waves emitted from the source

For light, change in wavelength, λ , is proportional to change in velocity, v

 $c = speed of light = 3x10^8 m/s$









A spectrum is one of astronomy's most powerful tools



Т	









































Time

The announcement was made in Florence on **Oct. 6 1995** at the Ninth "Cambridge" Workshop on "Cool Stars, Stellar Systems, and the Sun". - IAUC 6251



A Jupiter-mass companion to a solar-type star

Michel Mayor & Didier Queloz

Geneva Observatory, 51 Chemin des Maillettes, CH-1290 Sauverny, Switzerland

The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star's radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.



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Awarded the Nobel prize in Physics on 8 October 2019 "for the discovery of an exoplanet orbiting a solar-type star".





Transit of Venus from Hinode satellite in 2012



Transit method: Planet passes in front of star and blocks light - measures the radius of the planet





Transit method: Planet passes in front of star and blocks light - measures the radius of the planet





The most common exoplanets have no analogue in our Solar System



*Mercury orbital period = 88 days









The History of Exoplanet Detection



The History of Exoplanet Detection

The History of Exoplanet Detection

Ocean Worlds & Ice Gaints

Rocky Planets

0.1

Period (years)

Cold **Gas Giants**

Solar System

RVs.

Transits

Marolensing

maging

10

The Future of Exoplanet Detection

0.1

Period (years)

Solar System RVs.

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Occurrence rates for exoplanets:

50% of stars have super-Earths/mini-Neptunes At least 30% of planets are in multiple systems

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Ozone (O₃)

Water (H₂O)

Transmission spectroscopy: Planet filters starlight leaving spectral imprint

Star Planet Atmosphere

Transmission spectroscopy: Planet filters starlight leaving spectral imprint

Planet Atmosphere

The first heat map of a hot Jupiter showed an offset hot spot suggesting winds

Knutson et al. 2007

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Identify biosignatures

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Reflectivity: 0.4 - 1.0µm

Habitable CO₂-rich planet M Dwarf

CO

Desiccated CO₂-rich planet M Dwarf

GН

CO

Transmission: 0.6 – 2.5µm Reflectivity: 0.4 - 2.5µm

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Use Doppler shift of exoplanet to disentangle its spectrum from its host star and Earth's atmosphere

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Birkby 2018

Spectral resolution $\lambda/\Delta\lambda = 100,000$

0.6

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TRAPPIST-1: seven Earth-size planets!













TRAPPIST-1 planets are all Earth-sized and three could have liquid water on their surface





Gillon et al. 2017







Proxima b: a rocky planet orbiting in the habitable zone of the nearest star to the Sun



Anglada-Escudé et al. 2016



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Magnetosphere: Earth magnetic field protects us from harmful solar flares



Magnetosphere: Earth magnetic field protects us from harmful solar flares







~100 hours (10 nights)

GIANT MAGELLAN TELESCOPE Early 2020s, 25m



Detecting oxygen and other biosignatures in Proxima b with next generation telescopes

~40 hours (4 nights)

EUROPEAN EXTREMELY LARGE TELESCOPE 2024, 39m

THIRTY METER TELESCOPE Mid 2020s, 30m

~60 hours

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NETIS **Mid-infrared**

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Is there life closer to home?

Europa (Moon of Jupiter)



Enceledus (Moon of Saturn)

Is there life closer to home?

Europa (Moon of Jupiter)

Extremophiles



Enceledus (Moon of Saturn)



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"Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives...the history of our species lived there, on a mote of dust suspended in a sunbeam.

The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand.

It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known." - Carl Sagan 1994



