Hubble Science Briefing

23 Years of Exoplanets with the Hubble Space Telescope

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Hubble’s Studies of Planet Formation and Evolution in Dusty Disks around Stars

Dr. John Debes
HST Is Pivotal in Exoplanet Science
A Stellar Nursery Laid Bare

Protoplanetary Disks
Orion Nebula

HST · WFPC2

PRC95-45b · ST Cl OPO · November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA
First Peeks at Protoplanetary Disks

STScl-1999-05

STScl-2000-32
Complex Structures Hint at Planet Formation

Ardila et al., 2007

STScI-2013-20

TW Hya Disk
HST NICMOS/NIC2

Disk
Location of Star
Coronagraphic Spot
Gap

15 billion miles
160 AU
The Late Stages of Planet Formation

Macintosh, et al., 2014
The Late Stages of Planet Formation
Chemistry in Disks

Roberge et al., 2006
Chemistry in Disks

Xu et al., 2014

HST-2013-18
Hubble’s Direct Detections of Exoplanets

Dr. Rémi Soummer
Direct Imaging of Exoplanets

Mercury and Venus visible during solar eclipse

The goal is to reproduce this effect for another star, using optical instrumentation

http://apod.nasa.gov
August 2008 solar eclipse, seen from Mongolia
Case of a perfect telescope

Diffraction pattern of a star with perfect telescope
Case of a perfect telescope

Diffraction pattern of a star with perfect telescope, increasing the scaling
Case of a perfect telescope

Diffraction pattern of a star with perfect telescope, increasing the scaling
Case of a perfect telescope

Contrast:
how faint a detail can be seen next to a star

Young Jupiter: $10^{-6}$
Jupiter: $10^{-9}$
Earth: $10^{-10}$
Starlight suppression with coronagraph
Example with real telescope and coronagraph

Lyot Project Coronagraph + Extreme AO (2004)

M-star companion to Zeta-Vir
(Hinkley et al. 2010)

Earth-like planet: $10^{10}$ contrast
Young giant planet: $10^5$ to $10^7$ contrast

“residual speckles” are similar to real sources

Credit: R. Oppenheimer & Lyot Project
Reference star subtraction

HD 141569A  -  HD 129433 = HD 141569A - HD 129433
ACS/HRC  F606W  Clampin et al. 2003

AB Aur  -  GJ 273 = AB Aur - GJ273
NICMOS/NIC2  F110W  Perrin et al. 2009
HD 106906b

Large separation 11 Jupiter mass companion discovered using ground-based observations

 Bailey et al. 2014

Common Proper Motion was confirmed by HST archival data from several years ago i.e. it is not a chance alignment with background object
These results were made possible by post-processing speckle subtraction and achieve over an order of magnitude contrast improvement over the state of the art when the data was taken in 1998. Contrast of these images are in the range $10^4$ to $10^5$ to 1.
• The reference subtraction removes most of the star, but is not sufficient to detect the HR8799 planets

This is why these planets were not found in 1998
Focus changes on three timescales:
- HST 96min orbit
- Days/Weeks (temp driven)
- Long-term shrinkage (0.15mm total)

Temperature-driven variations are not actively corrected, only the long-term shrinkage is
Improved subtraction

Combining information from a library of reference PSFs

- “LOCI algorithm” subtraction linear combination of reference, least-square optimization (Lafrenière et al. 2007)
- “KLIP algorithm” principal component analysis (Soummer, Pueyo & Larkin 2012)
HR 8799 planetary system

Motion of three outer planets as measured over 10-year period from HST archival data and more recent ground-based telescopic data.
New images of debris disks

Soummer et al. 2014

Choquet et al., in prep.
Probing Exoplanet Atmospheres with Hubble

Dr. Nikole Lewis
Confirmed Exoplanet Population

Mass – Period Distribution

Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness Modulation

Mass [Jupiter Masses]

Period [days]
Transiting Exoplanets

Primary Eclipse
Measure size of planet
See star's radiation transmitted through the planet atmosphere

Secondary Eclipse
See planet thermal radiation disappear and reappear

Learn about atmospheric circulation from thermal phase curves

Figure credit: Prof. Sara Seager
Transiting Exoplanets

Figure credit: Winn (2011)
Transiting Exoplanets with HST
Detection of Sodium

Figure credit: Paul A. Wilson
Detection of Sodium

First Detection of an Exoplanet Atmosphere!

HD 209458b

STIS Observations
Charbonneau et al. (2001)
Detection of Molecules

First Detection of Molecules in Exoplanet Atmosphere!

HD 189733b

NICMOS Observations
Swain et al. (2008)
Detection of Haze

HD 189733b

STIS Observations
Sing et al. (2011)
Water in Exoplanets

WFC3 Observations
Madhusudhan et al. (2011)

Image Credit: NASA, ESA, University of Cambridge, and STScI
Probing a Super-Earth
Probing a Super-Earth

GJ 1214 b

WFC3 Observations
Kreidberg et al. (2014)
Mapping Exoplanets

Credit: NASA, ESA, and Z. Levay (STScI)
Mapping Exoplanets

WASP-43b        WFC3 Observations        Stevenson et al. (2014)
Mapping Exoplanets

WASP-43b GCM Model Kataria et al. (2015)
Evaporating Exoplanet Atmospheres

STIS UV Observations
Enrenreich et al. (2015)

Image Credit: NASA/ESA/STScI
The James Webb Space Telescope (JWST)