



Jet Propulsion Laboratory
California Institute of Technology

NASA Exoplanet Exploration Program Updates

Gary Blackwood
Program Manager

ExoPAG 13, January 3, 2015

227th Meeting of the AAS, Kissimmee FL

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NASA Exoplanet Exploration Program

A Program within the NASA Astrophysics Division



Purpose described in 2014 NASA Science Plan

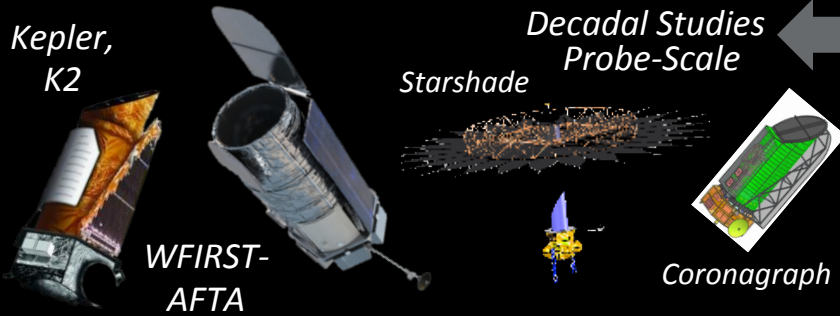
1. Discover planets around other stars
2. Characterize their properties
3. Identify candidates that could harbor life

The Search for Life in our Galaxy

ExEP serves the science community and NASA APD by
Implementing NASA's space science vision for exoplanets

NASA Exoplanet Exploration Program

Space Missions and Mission Studies



Public Communications



Supporting Research & Technology

Key Sustaining Research



Large Binocular Telescope Interferometer



Keck Single Aperture Imaging and RV



NN-EXPLORE

Technology Development



Coronagraph Masks

High-Contrast Imaging



Deployable Starshades

NASA Exoplanet Science Institute



Archives, Tools, Sagan Fellowships, Professional Engagement

Kepler Close Out

Delivering Kepler's Legacy

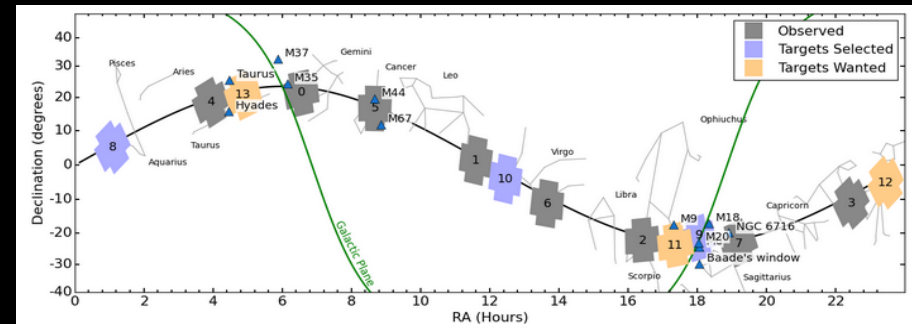
- Front page news in July: Kepler 452b
- Held successful Hack Week (Oct 2015)
- Kepler closeout and final data processing continues steadily within overall schedule margin.
 - Level 1 milestones completed since last ExoPAG:
 - SOC 9.2 Q1-Q17 Activity Table Closure
 - SOC 9.2 Final Occurrence Rate Products Delivered
 - Pipeline Development for SOC 9.3 Completed
 - SOC 9.3 Q0-Q17 Long Cadence Light Curves to MAST
 - Final data processing (SOC 9.3) underway; on track for
 - SOC 9.3 Q0-Q17 Short Cadence Light Curves to MAST (May 2016)
 - Documentation Completeness Review (Oct 2016)
 - SOC 9.3 Final Occurrence Rate Products (April 2017)



Kepler K2

Extending Kepler to the Ecliptic

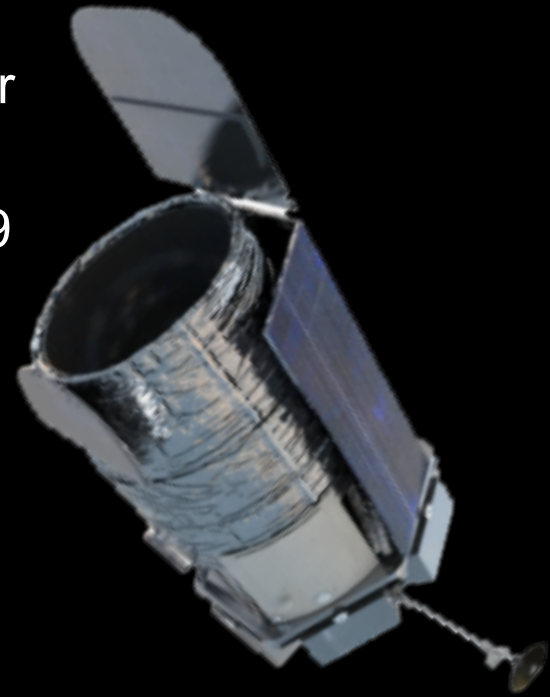
- Since last ExoPAG:
 - Data released for campaigns 3, 4, and 5. Campaign 6 data to be released in late January.
- High-value exoplanets: small, rocky, nearby (46 pc), orbiting bright stars. Some highlights:
 - 32 confirmed exoplanets in 23 systems; >300 candidates
 - About 50 likely rocky, 6 are in the habitable zone; of these 5 are suitable for atmospheric characterization first by HST and then by JWST
- Campaign 9 (Microlensing) starts in April, NASA funding UKIRT time. Early experiment for WFIRST
- Spacecraft is healthy: completed campaign 7 downlink and begins campaign 8 (today, Jan 3). Estimate: sufficient fuel for at least 17 campaigns
- K2 does much more than exoplanets!
- **K2 Special Session: Tuesday 1/5, 7:30pm, Room “Sun A”**



Progress towards 2010 Decadal Survey Priorities

WFIRST / AFTA

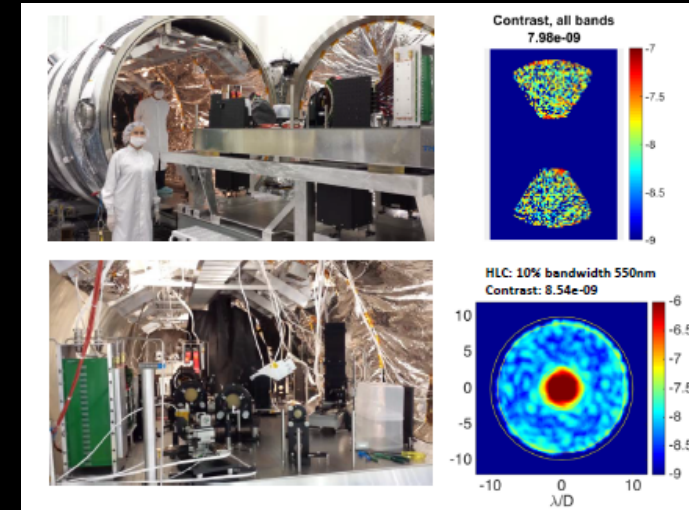
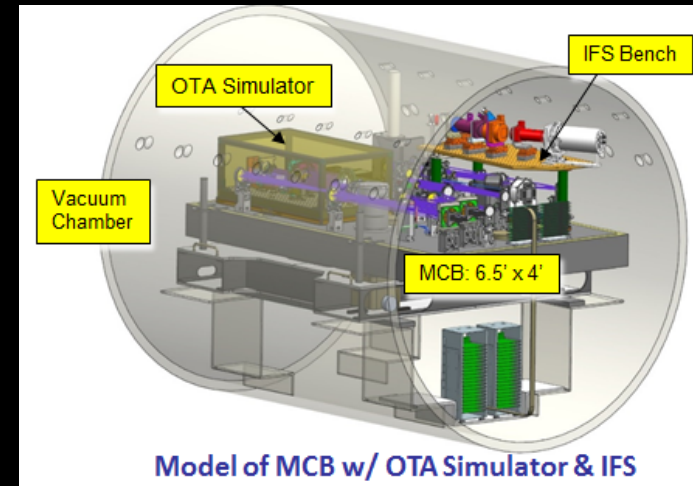
- WFIRST technology (Coronagraph and IR detectors): All milestones completed per plan.
- Completed latest design cycle (L2 orbit) – basis for Mission Concept Review (MCR) design reference.
- Successful Mission Concept Review (MCR) 12/8-9
- FY16 Omnibus Appropriations Bill: \$90M for WFIRST
- WFIRST Formulation Science Team Announced: ten Science Investigation Teams (SITs) and two Adjutant Scientists: D. Spergel (Widefield) and J. Kasdin (Coronagraph).
- 12/18: Notice provided by GSFC for four-month Wide Field Instrument Industry Concept Study
- NASA Key Decision Point (KDP)-A planned for 2/17: Agency approval to enter Formulation



Technology - Coronagraph

All WFIRST technology milestones met on schedule

- Delivered a modelable coronagraph bench to WFIRST Coronagraph team
- Demonstrated broadband (10% at 550nm) high raw contrast ($<1e-8$) in a static environment for both
 - SPC (Shaped-Pupil Coronagraph) with WFIRST telescope pupil
 - HLC (Hybrid Lyot Coronagraph)
- Demonstrated low-order wavefront error sensing and close-loop tip/tilt correction (<0.4 mas rms per axis)
- Next: milestones for detector, PIAACMC, coronagraph raw contrast in dynamic environment



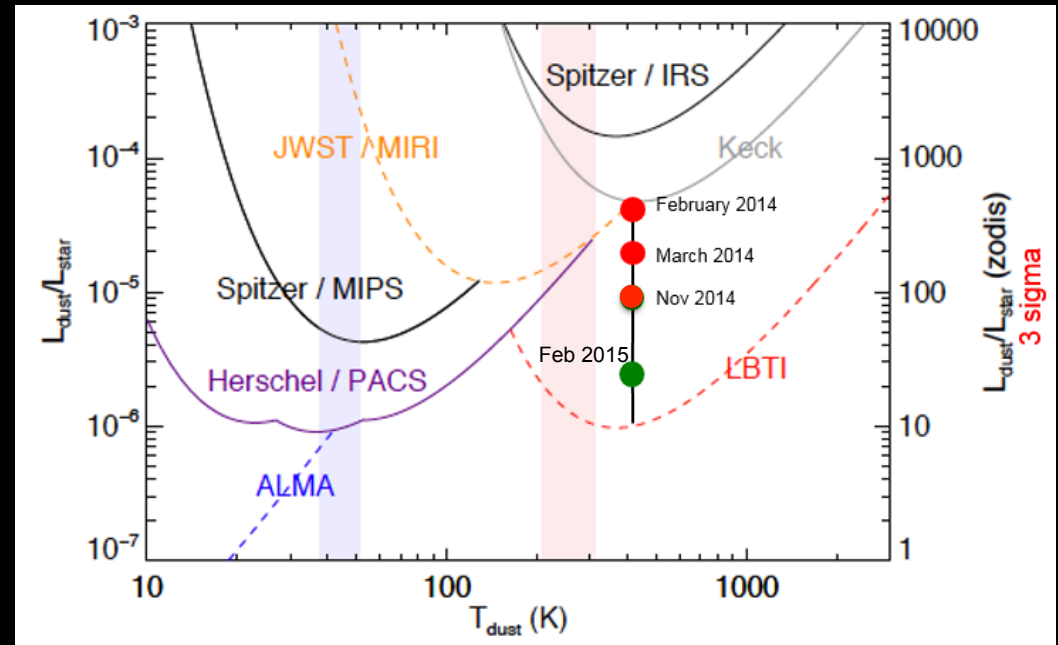
Large Binocular Telescope Interferometer

Measures exozodiacal dust in habitable zones

Phil Hinz, PI



LBTI Performance



- Demonstrated 12 zodi sensitivity for a solar twin at 10 pc at May 2015, <6 zodi single star sensitivity planned for April 2016 Science Operations Review
- HOSTS survey interrupted by glycol leak in secondary mirror but repairs are nearly complete and binocular operation will restart January 2016
- Plan for 32 star survey giving <2 zodi mean uncertainty over survey population
- Results of HOSTS survey to inform next decadal survey on direct exoplanet imaging: [Survey deliveries Sept 2016 and Sept 2017](#)



Motivation

- 2010 Decadal Survey calls for precise ground-based spectrometer for exoplanet discovery and characterization
- Follow-up of current missions (K2, TESS, JWST, WFIRST)
- Observations inform design/operation of future missions

Scope:

- Extreme precision radial velocity spectrometer (<0.5 m/s) for WIYN telescope is in procurement
 - Downselect of competing proposals March 18
 - Winning team will be invited to deliver telescope port adapter
 - Instrument to be commissioned by July 2019
- Ongoing Guest Observer program using NOAO share of telescope time for exoplanet research



PI: G. Furesz



PI: S. Mahadevan



3.5m WIYN Telescope
Kitt Peak National Observatory
Arizona

Strategic Astrophysics Technology - TDEM

Reports for completed and active TDEMs: <http://exep.jpl.nasa.gov/technology/>
Reviewed and approved by ExoTAC, Alan Boss (chair)

- Active TDEMs

- 2010

- (Bierden) Environmental Testing of MEMs DMs
 - (Helmbrecht) Environmental Testing of MEMs DMs
 - (Lyon) Visible Nulling Coronagraph Testing

- 2012

- (Casement) Starshade Edge Scattering
 - (Kasdin) Optical and Mechanical Verification of External Occulter

- 2013

- (Bendek) Enhanced Direct Imaging with Astrometric Mass
 - (Cash) Development of Formation Flying Sensors
 - (Kasdin) Formation Flying of External Occulters
 - (Lyon) Segmented Aperture Nulling Coronagraph

Optical shield testbed, JPL



Starshade perimeter truss/2.0



Glassman TDEM-12

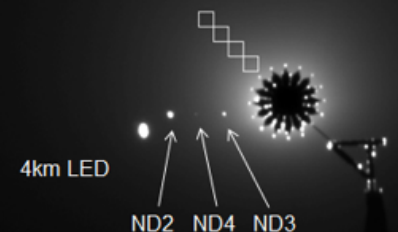


Image courtesy of NGAS

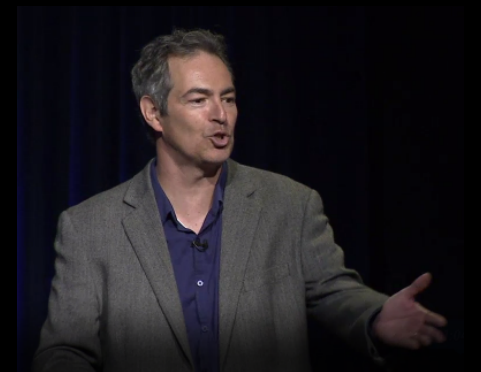
Strategic Astrophysics Technology - TDEM

Advancing Technology Readiness towards next Decadal Survey

- New TDEMs (2014)
 - (Thomson) Starshade Optical Shield
 - (Bolcar) Next Generation Visible Nulling
 - (Serabyn) Broadband Vector Vortex Coronagraph
- TDEM 2015 Pre-Proposal Briefing: Jan 19, 1pm ET

Please attend to contribute and learn:
[Technology Gap Assessment for
Coronagraphs and Starshades –
Nick Siegler, ExEP Chief Technologist](#)

[Monday, Jan 4, 3:30-4:30, Orange
Blossom Ballroom](#)



Preparations for Next Decadal Survey

Preparing for Astro 2020

- ExEP supports exoplanet science for HabEx and LUVOIR (and Far IR surveyor too)
 - Technology Gap Lists extended to HabEx and LUVOIR architectures, and now include telescope stability and detectors which apply to all architectures
 - Segmented Coronagraph Design & Analysis: program-funded study (active now) to find coronagraph designs suitable to segmented apertures

(more on both of these from Nick Siegler on Monday)
- Other initiatives - introducing:
 - The Starshade Technology Project
 - The Starshade Readiness Working Group (SSWG)
 - The Exoplanet Standards and Evaluation Team

The Starshade Technology Project

- Purpose: achieve TRL5 by 2019
- Directed funding and reprogramming of competed funds
- KDP-A (to enter Formulation) February 19
- Managed by ExEP at JPL for APD, as a technology project
- Intent is broad institutional participation and funding

The Starshade Readiness Working Group (SSWG)

<http://exep.jpl.nasa.gov/sswg/>

- Require a risk reduction plan for technology validation of starshades to enable starshade flight science missions to be considered in 2020 Decadal Survey
- Will answer these questions and deliver recommendation to APD:
 - How to go from TRL 5 to ~TRL6,7
 - Do we need a tech demo, and if so, what is it?
- Will adopt the Exo-S probe “Starshade Rendezvous” as representative motivation of technology requirements
- Kickoff telecons January 12 and 15 (TBC), active through July 2016
- Chairs: G. Blackwood (ExEP/JPL), S. Seager (MIT)
- Steering Group: N. Siegler (ExEP/JPL), K. Stapelfeldt (ExEP/JPL), T. Hyde (GSFC), R. Soummer (STScI), T. Greene (ARC), M.C. Noecker (JPL), M. Melton (GSFC)
- Members (consensus group) – being contacted now for charter
- Observers welcome

The Exoplanet Standards Definition and Evaluation Team

- Recommended by ExoPAG in 10/6/2015 large mission study report
- Need transparent, unbiased, common exoplanet yield estimates for Decadal large missions (HabEx, LUVOIR) and any exoplanet probes. Same yardstick, honest broker.
- Customer is APD; will be chartered by APD to provide periodic apples-to-apples comparisons to APD.
- Use Program tool (D. Savransky's open-source ExoSIMs plus module additions) and include other tools (e.g. AYO) for validation.
- Relation to decadal large mission STDTs: Standards team is more descriptive than prescriptive, though by consensus will promote and adopt common definitions and metrics with STDTs – leverages work of SAG13.
- Small team of community experts – will include at least one member of HabEx and LUVOIR Study Teams. Preliminary membership: R. Morgan (lead, JPL), B. Macintosh (Stanford, senior scientist), D. Savransky (Cornell), C. Stark (STScI), R. Belikov (ARC), J. Krist (JPL), TBD (GSFC).

Other Program Updates

Other Program Updates

- NExSci: ~140 participants at 2015 Summer workshop
- Next workshop: week of 7/18
“Is there an exoplanet in my data?”
- Probe Extended Studies – active through March 2016
 - Explore larger-aperture coronagraphs and further study of the WFIRST starshade rendezvous concept
 - Exo-C-ES (K. Cahoy, MIT)
 - Exo-S-ES (S. Seager, MIT)



Program Staffing Updates

- Keith Warfield, JPL, appointed as ExEP Chief Engineer
- Phil Willems, JPL, appointed Project Manager of LBTI and NN-EXPLORE
- Phil Barela, JPL, appointed as the project manager for the WFIRST-JPL project (coronagraph, telescope, elements of science center and IR detector)
- Wes Traub appointed as Project Scientist of the WFIRST-JPL project
- Karl Stapelfeldt starts as ExEP Chief Scientist at JPL on February 1
- GSFC will soon advertise the Exoplanet/Stellar Lab Chief position
- Open advertisement for ExEP Deputy Chief Scientist: <https://jobregister.aas.org/search/node/exoplanet>

Exoplanet Travel Bureau

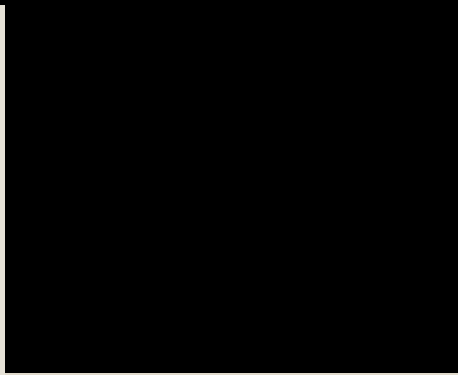
Now available at <https://thejplstore.com/>

Exoplanet Travel Bureau

EXPERIENCE THE GRAVITY OF HD 40307g A SUPER EARTH

The only exoplanet in its host system, HD 40307g is about twice the volume of Earth and eight times more massive, making it something in between a "super-Earth" and a "mini-Neptune". Planets in these categories were thought to be absent by the Kepler mission, a serendipitous result that suggests our galaxy contains an abundance of small worlds. The "Super Earth" exoplanet Super-Earths and mini-Neptunes aren't well-understood at this point, so the "your staff may be limited" on Exoplanet here, in a more habitable world of gas and ice.

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Exoplanet Travel Bureau

RELAX ON KEPLER 16b

**THE LAND OF TWO SUNS
WHERE YOUR SHADOW ALWAYS HAS COMPANY**

Like Luke Skywalker's home planet Tatooine in "Star Wars," Kepler 16 is a pair of stars at a very close distance — about 3 times farther from the center of the star pair than the stars are from each other. Captured here as a terrestrial planet, Kepler 16 is thought to be a gas giant like Saturn. Prospects for life on this unusual world aren't great, as there is a temperature variation that's hot or dry hot, but the discovery indicates that the movie's iconic double-sunset is anything but science fiction.

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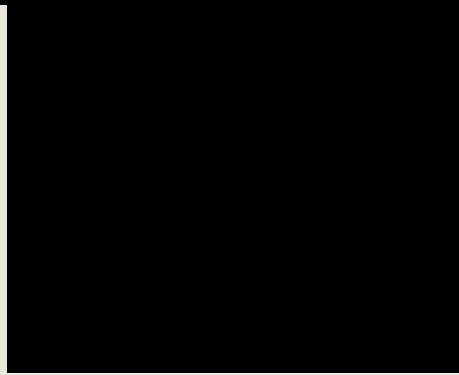
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Kepler-186f

WHERE THE GRASS IS ALWAYS REDDER ON THE OTHER SIDE

Kepler 186f is the first Earth-size planet discovered in the proximity of a habitable zone around another star, where liquid water could exist on the planet's surface. It also is much smaller and closer than our Sun. Except for the stars and one planet the Kepler 186f exoplanet system has been influenced by the star's fast magnetic rotation, making for a star profile that's very different from the planets on Earth. This discovery was made by NASA's Kepler Space Telescope.

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Exoplanet Travel Bureau

VISIT THE PLANET WITH NO STAR

PSO J318.5-22

WHERE THE NIGHTLIFE NEVER ENDS!

Discovered in October 2013 using direct imaging, PSO J318.5-22 belongs to a special class of planets called rogue, or free-floating, planets, wandering alone in the galaxy. They do not orbit a parent star, but much is known about how these planets come to exist, but astronomers suspect that they may be able to detect planets similar to these young systems after an encounter with another planet. These rogue planets glow faintly from the heat of their formation. Only free-floating ones, they will be drifting in the dark. Confirmed and candidate exoplanets and all available data are listed in the NASA Exoplanet Archive.

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Latest Travel Bureau Poster

Celebrates 20th Anniversary of Discovery of First Exoplanet



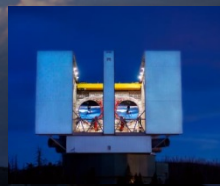
The fifth poster in the Exoplanet Travel Bureau series was released on October 20th in conjunction with the 20th Anniversary activities

"While there is much debate over which exoplanet discovery is considered the "first," one stands out from the rest. In 1995, scientists discovered 51 Pegasi b, forever changing the way we see the universe and our place in it. The exoplanet is about half the mass of Jupiter, with a seemingly impossible, star-hugging orbit of only 4.2 Earth days. Not only was it the first planet confirmed to orbit a sun-like star, it also ushered in a whole new class of planets called Hot Jupiters: hot massive planets orbiting closer to their stars than Mercury. Today, powerful observatories like NASA's Kepler space telescope will continue the hunt of distant planets."

Exoplanet Missions



W. M. Keck Observatory



Large Binocular Telescope Interferometer



NN-EXPLORE

Ground Telescopes with NASA participation

¹ NASA/ESA Partnership

² NASA/ESA/CSA Partnership

³ CNES/ESA



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Pasadena, California

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