Exoplanet Mission Concept Study

Briefing to Steve Howell

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Our Goal and Charge

- **Our Goal: Develop a mission concept and technology development requirements for the first scientific robotic exploration mission to an exoplanet**

- **Our Charge: Think out of the box, be creative, and have fun, but be prepared to back up our innovative ideas with sound physics**

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Status as of Aug 2017

- Study effort kicked off on April 13
  - 9 of 10 planned topic areas covered so far (full list next page)
    - NEW: Technical Interchange meeting with Breakthrough Starshot on Sept. 7
- Multi-center team established, including academia and independent institutions
  - JPL, ARC, GRC, MSFC, Glenn, APL, Boston U., Wesleyan, SETI, 3 consultants
  - Great support from 7x, including John Callas, Eric Mamajek, and Phil Willems
  - Full team list in backup
- Paper on our findings has been accepted to the Tennessee Valley Interstellar Workshop (Oct. 2018)
  - Rep. Culberson plans to attend

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Topics Covered

Session	Topic
1	Kickoff
2	Mission Objectives
3	Science Objectives
4	Target Selection and Expected Apriori Target Knowledge
5	Interstellar and Exoplanet Environment
6	Instrumentation
7	Communication
8	Propulsion
9	Power
10	Navigation
~~11~~	~~Operations/ Autonomy~~ Ran out of time
12	Wrap-Up

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Key Finding

- **In response to an early driving question:**
  - ***What makes this mission compelling (in terms of science return) with respect to what we will be able to do in a few decades with near-Earth large telescopes, enormous space-based interferometers, and/or a mission to the Solar Gravity Lens Focus?***

The team determined that much of what we traditionally learned from reconnaissance missions will be gleaned from future near-Earth telescopes or a mission to the SGLF, leaving one big science goal:

To confirm and characterize life

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To Confirm and Characterize Life

- **This objective was profound and drove the study architecture**

- **Biosignatures (as we know them today) cannot confirm life**
  - **Recent paper[1] showed how Proxima Centauri Beta, in it's star's habitable zone, could have an O2 atmosphere but no possibility of life due to massive solar wind exposure**

- **The only[2] method <u>today</u> of confirming life is to land and sample**
  - **This drives the mission to at least slow down and most probably to brake and orbit to perform landing site selection and deploy a lander, which in turn severely limits our know propulsion options**
  - **This does not preclude precursor flyby missions to explore the interstellar medium (ISM) and/ or validate key technologies**
    - **Exploration of the ISM is a required precursor to the exoplanet mission in order to better characterize the ISM environment to inform system design**

[1]Schwierteman et al., Identifying Planetary Biosignature Impostors: Spectral Features Of Co And O4 Resulting From Abiotic O2/O3 Production, Astrophysical Journal Letters 819:L13, 2016, doi:10.3847/2041-8205/819/1/L13

[2] Aside form seeing lights turning on and off in images or SETI contact

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Intelligent Life?

- A Solar Gravity Lens mission with 10 km imaging resolution could plausibly detect artificial illumination, if present.

- However, the exoplanet may be a world where there is not yet advanced intelligent life to produce electric light.
  - Intelligent life capable of producing lights, radio signals, structures, etc. only recently appeared on the Earth and so there is a low chance of finding life in that state.
  - Those technologies have only existed on Earth for about 100 years. So for the Earth, advanced intelligent life has only been detectable on a world with a measurable bio-signature for 1 part in 5 million (~2x10-7).

- Thus, as a proxy for other exo-worlds, there is a very small likelihood of finding advanced life, and there is a very small number of candidate exo-worlds available within 15 LY.

- Although photosynthetic life on Earth started at least 3.5 BY ago, the presence of free O2 in the Earth's atmosphere (a potential bio-signature) has been present for less than 1 BY.

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Target Selection - 1

- With over 3000 candidates to select from today, and thousands more in the future, selection criteria for choosing the target exoplanet will be important
- These criteria will evolve with our understanding of life and habitability
- The exoplanet characterization required to meet the criteria the implementation of large near-Earth telescopes that are currently in the Astronomy and Astrophysics roadmap
- A mission to the Solar Gravity Lens Focus is also highly desired, if not required, for characterization

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Target Selection - 2

- Given our knowledge today, the following target selection criteria were suggested:
  - Exoplanets that are in their Sun's Habitable Zone
  - Exoplanets with masses > Mars mass (rocky planets with a decent chance for an atmosphere)
  - Exoplanets that experience roughly the same solar radiation as our Earth
  - Detection of a biosignature from the exoplanet plus at least 1 pixel image of the exoplanet (ideally 1000 x 1000 pixel image)
  - The current age and expected lifetime of the star should be such that life will have had a chance to form
    - Current thinking is that the star should be at least [1] Byr old and preferably older
  - The exoplanet's star should be close to a G2V Class (our Sun)

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Science Objectives

- Ultimate objectives will be determined by Decadal Survey and NASA Working Groups

- 5 main categories of science objectives were suggested:
  - Heliosphere Boundaries
  - The Interstellar Medium (ISM) and other Science En Route
  - Astrosphere of the Target Star
  - The Solar System of the Target Exoplanet
  - The Target Exoplanet

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Instrumentation

- First 3 categories can be achieved with mostly the same instrumentation (similar to Voyager, with informed measurement requirements)

- Science objectives involving the solar system of the target star are numerous and involve the typical basic reconnaissance/ characterization objectives that missions in the solar system have had
  - Composition and mapping, atmospheres, moons, rings, dust, asteroids/ comets, refinements of size and mass, spin rates, etc.

- Science objectives involving the target exoplanet can include many of the basic categories listed above
  - An orbiting mission can resolve rivers, forest, deserts, and oceans.
  - A key mission requirement is to confirm and characterize life, which requires to be developed life detection experiments on a lander
  - Other landed instruments include imaging cameras, metrology station

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Mission Concept Architecture Highlights

- 2-stage light sail for propulsion
  - Easiest propulsion technology development path
  - Only option that doesn't require massive on-board power
  - Lasers at Earth can be improved over mission lifetime
- 2.5-m on-board lasercomm system
  - 100-m lightbuckets in space
  - Onboard power to 4 kW for 100 bits/sec downlink
- Autonomous on-board navigation
  - Required due to one-way light times of years
  - Proven on Deep Impact
  - NEW: on-board autonomous mission replanning capability (think autonomous landing site selection and execution)
- Very advanced RTGs and power conversion systems for power
  - Pu-238-based or Americium
  - Would love to have a reactor, but the reliability is not there today for 70 yr mission

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Backups

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Key Mission Concept Requirements - 1

1. The flight time to the target must be < 50 years, pending confirmation of a suitable target

- **Rationale: The mission must be politically and humanly palatable**

2. There shall be meaningful science return at least every decade en route to the exoplanet

- **Rationale: There should be a mission conducted during the flight to the exoplanet to keep the science community engaged**

3. The primary objective of the mission shall be to confirm and characterize life at the exoplanet

- **Rationale: Per NASA's strategic objective: Discover how the universe works, explore how it began and evolved, and <u>search for life on planets around other stars</u>**

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Key Mission Concept Requirements - 2

4. The threshold data shall arrive at Earth within <70 yrs from launch

- **Rationale: The threshold data must come back within the professional lifetime of someone born around launch; this person can grow up learning about the mission and be inspired by it, and eventually join the team and be ready to interpret the data when it comes back to Earth**

5. The first bit of exoplanet science data shall arrive at Earth 5 – 10 yrs after exoplanet arrival

6. The exoplanet target shall be within 15 LY of Earth

- **Rationale: If the spacecraft is travelling at a low fraction of the speed of light (0.1 – 0.2c), the exoplanet target must be within 15 LY of Earth (50 yr travel time and 10 - 20 years) to send back the threshold data**

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Key Mission Concept Requirements - 3

7. Per the 100th anniversary of Apollo, the launch date shall be no later than July 15, 2069

- **Rationale: Rep. Culberson, who is a champion of an interstellar mission, proposed this!**

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Key Mission Concept Assumptions

- The exoplanet target has been previously observed and resolved 1000x1000 pxl or to 1 pxl with promising bio-signature lines
  - We will have an idea of which instruments to bring and their performance specifications
  - We will have TBD accuracy on the ephemeris

- We are not constrained to today's technology, but there shall be a reasonable, physics-based path toward realizing the needed technology
  - Example: Flying 3-D printers to replace worn parts
  - Trying to stay away from "and a miracle occurs…"

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THE STARS ARE CALLING AND WE MUST GO

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