Concept for a Science-Driven Mission to an Exoplanet

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Pre-Decisional Information -- For Planning and Discussion Purposes Only

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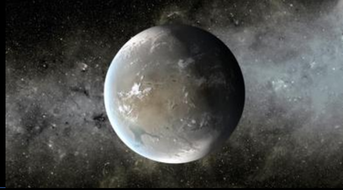


Background

- **A current count of 3,500 exoplanets, with thousands more to be discovered, begs the question: “When will a spacecraft be sent to investigate?”**
- **Our study team kicked off in April 2017 to develop a *mission concept* and for the first *scientific* robotic exploration mission to an exoplanet**
  - **A mission concept is needed to determine the technologies required for the mission**
  - **A science-driven mission would provide a compelling basis and justification for such a challenging undertaking**
    - **Precursor missions with lesser objectives would be necessary to develop technologies and provide information necessary to conduct the mission, e.g. to identify and characterize the target exoplanet(s)**
- **A Multi-center team was established, including academia and independent institutions - JPL, NASA Ames/ Goddard/ Marshall/ Glenn, APL, Boston U., Wesleyan, SETI, consultants**

Key Mission Concept Goals - 1

1. The flight time to the target should be < 50 years

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

2. There should be meaningful science return at least every decade enroute 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 would 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 search for life on planets around other stars**

Key Mission Concept Goals - 2

4. The threshold data should arrive at Earth within 70 years from launch

- **Rationale: The threshold data should 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 exoplanet science data should arrive at Earth 5 – 10 yrs after exoplanet arrival

- **This would need a target exoplanet within 15 LY of Earth**

6. The exoplanet target should be within 10 LY of Earth

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

Key Mission Concept Goals - 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!**

Key Mission Concept Assumptions

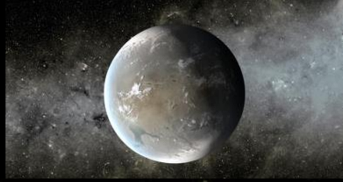
- The exoplanet target would have been previously observed and resolved 1000x1000 pxl or to 1 pxl with promising bio-signature lines
  - We would be able to determine needed instruments and their performance specifications
  - We would have adequate accuracy on the ephemeris

- We would not be constrained to today's technology, but there would need to be a reasonable, physics-based path toward realizing the needed technology
  - e.g. including 3-D printers to replace worn parts
  - Extrapolating to long-life electronics
  - Extrapolating to more powerful lasers, more efficient energy conversion, etc.
  - Not assuming technologies without a current basis to extrapolate from

To Confirm and Characterize Life

- This objective was the basis for the study architecture
- Biosignatures observed from Earth or by a flyby mission could suggest life, but would probably not be able to confirm it
- The most conclusive method of confirming life would be to land and sample
  - This would require the spacecraft to slow down at the target, perform landing site selection, and deploy a lander, which in turn would severely challenge our propulsion options
    - This would not preclude precursor flyby missions to explore the interstellar medium (ISM) and/or validate key technologies
    - Exploration of the ISM would be a precursor to the exoplanet mission in order to better characterize the environment and validate system design

Target Selection - 1



- With over 3,000 candidates to select from today, and thousands more in the future, selection criteria for choosing the target exoplanet would be important
- These criteria would evolve with our understanding of life and habitability
- Exoplanet characterization would require large space-based telescopes currently in the Astronomy and Astrophysics roadmap
- A mission to the Solar Gravity Lens Focus would also be highly desired for high resolution imaging and characterization

Target Selection - 2

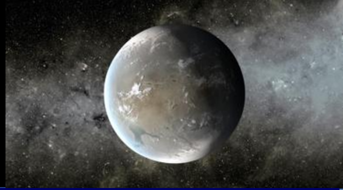
- The following target selection criteria were suggested:
  - Exoplanets that are in their star’s habitable zone
  - Exoplanets with masses < 2 Earth masses
    - Rocky planets with an atmosphere
    - Icy planets with a subsurface ocean
  - Exoplanets that experience roughly the same solar radiation as our Earth
  - Detection of a biosignature from the exoplanet plus at least 1 pixel image of the exoplanet (ideally 1,000 x 1,000 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 [4-5] Byr old
  - The exoplanet’s star should be close to a G2V Class (our Sun)

Science Objectives

- Ultimate objectives will be determined by Decadal Survey and NASA working groups

- 5 main categories of science objectives suggested:
  1. Heliosphere boundaries
  2. The Interstellar Medium (ISM) and other science enroute
  3. Astrosphere of the target star
  4. The planetary system of the target exoplanet
  5. The target exoplanet

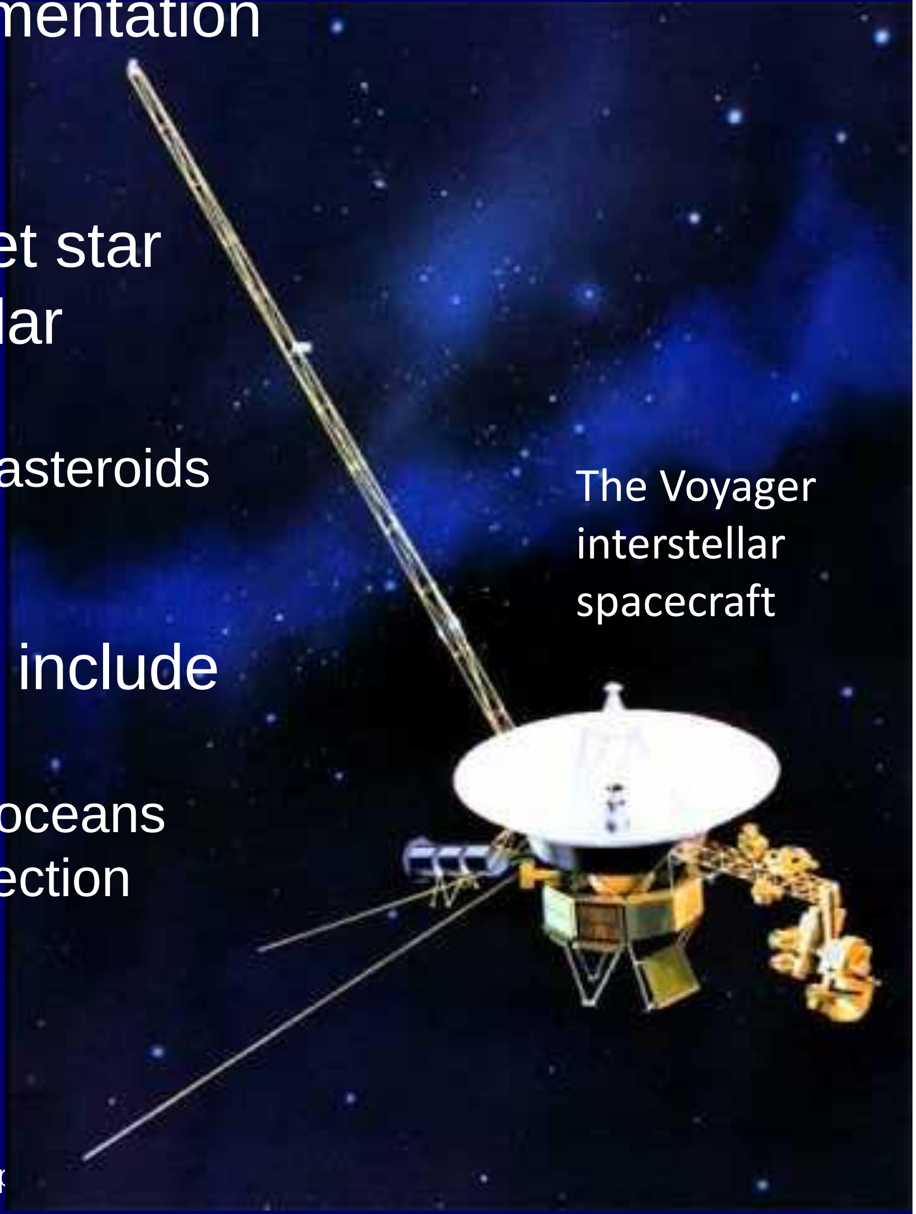
Instrumentation



- First 3 categories could be achieved with similar instrumentation (similar to Voyager, but with advanced capabilities)

- Science objectives for the planetary system of the target star would include typical objectives that missions in our solar system have had:
  - Composition and mapping, atmospheres, moons, rings, dust, asteroids and comets, refinements of size and mass, spin rates, etc.

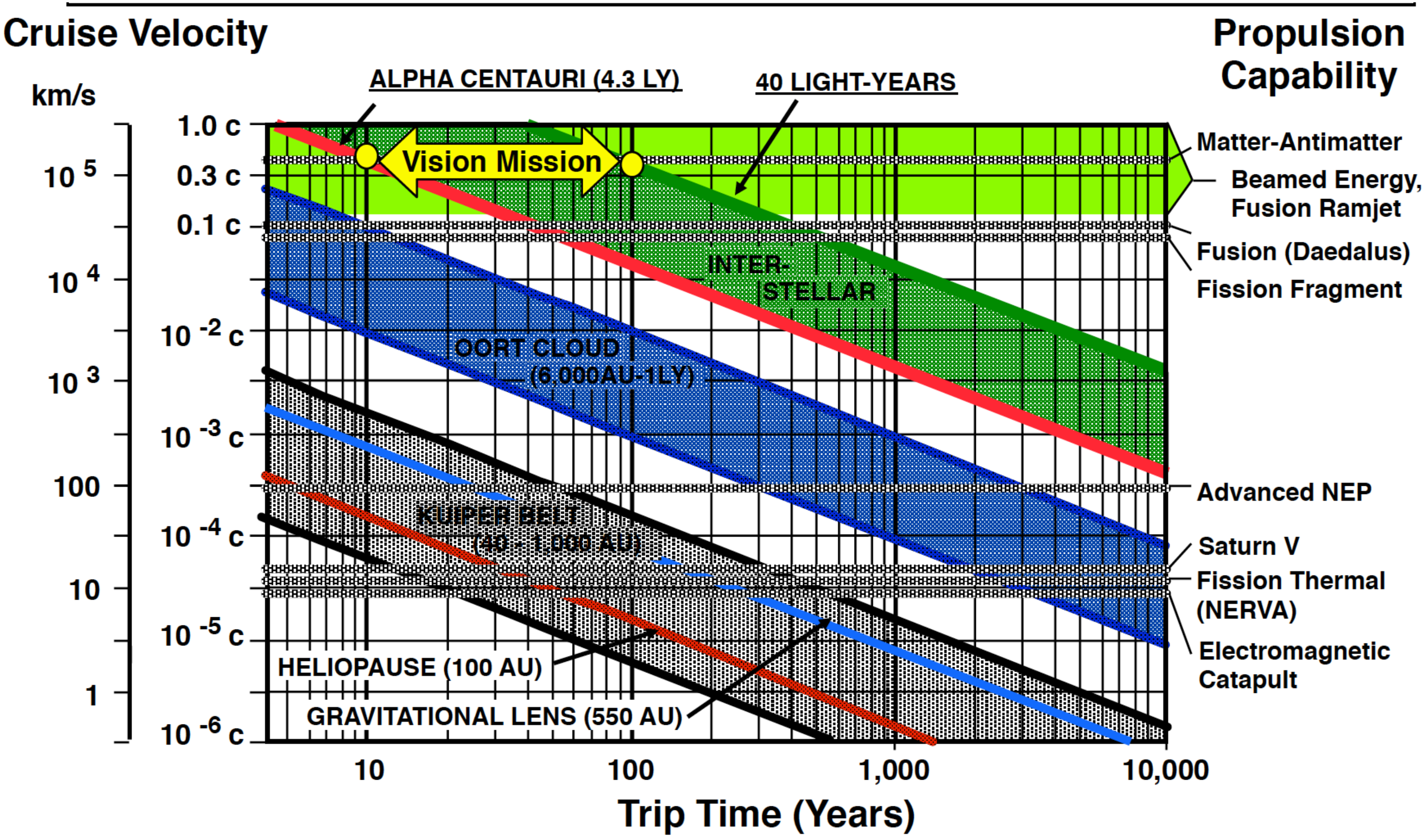
- Science objectives involving the target exoplanet could include many of the basic categories listed above
  - An orbiting mission could resolve rivers, forests, deserts, and oceans
  - Confirmation and characterization of life would require life detection experiments on a lander
  - Other landed instruments could include imaging cameras and meteorology sensors



The Voyager interstellar spacecraft

Propulsion Options: Reality Bites

- The vision mission for this study is extremely challenging
- Beamed energy sailcraft was the only identifiable technology we considered feasible in this century
- A greatly descoped mission might be feasible with very advanced electric propulsion

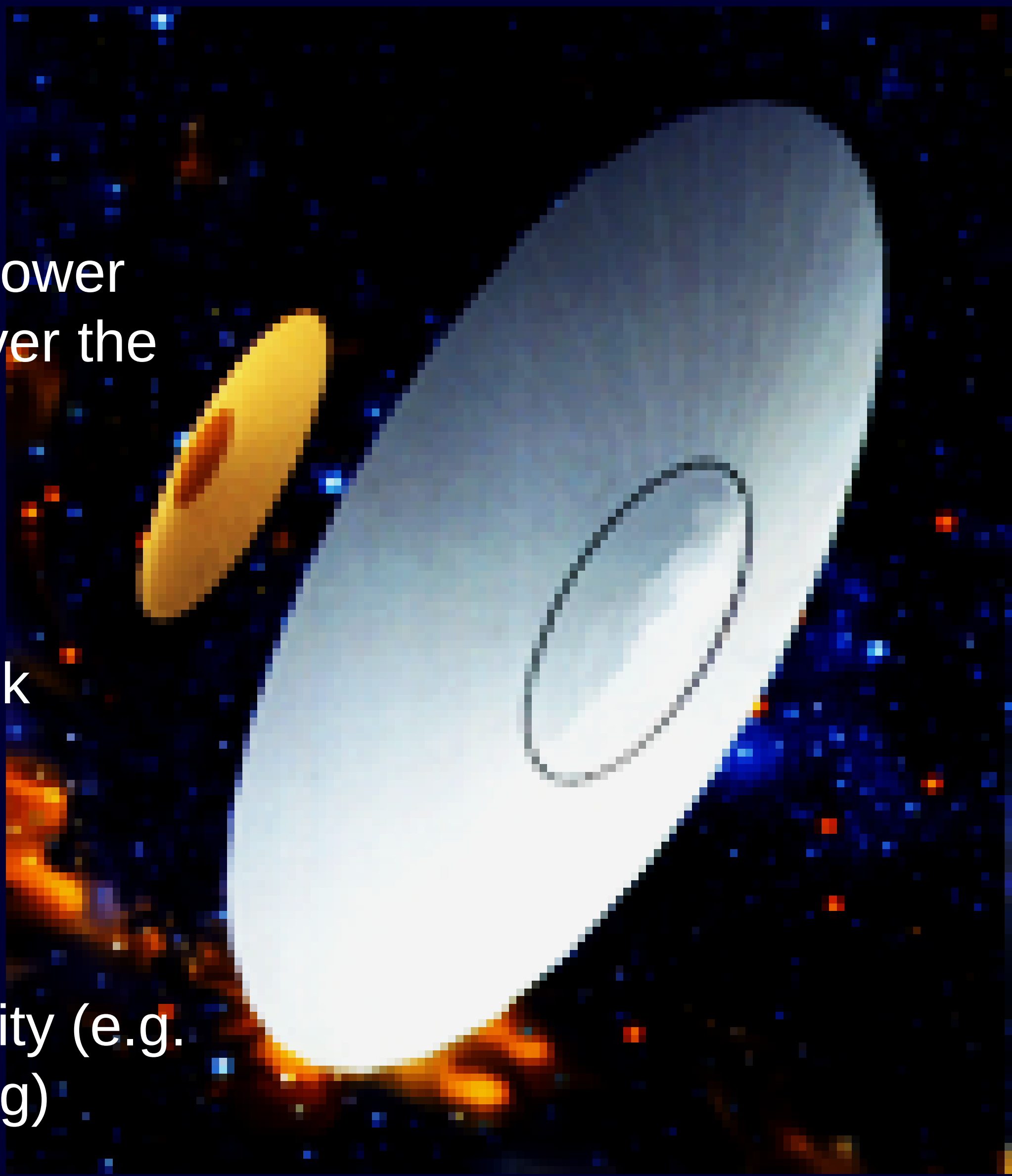


Key System Trades

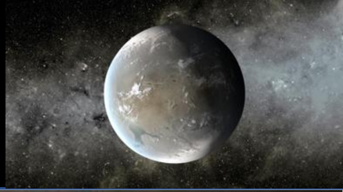
	Flight Time	TRL	Development Risk	Payload Mass	Pros	Cons	Comments
Mission design							
Fast flyby	Possibly <100 y	2	lower		Minimum ΔV requirement	Encounter time is too short	
Braking at target	>100 y	0	high		Adequate encounter time	Twice the ΔV of flyby	
Propulsion							
Very advanced NEP	~1,000 y	2	lower	large	Might fit on a single SLS		Requires very high I_{SP}
Beamed energy sail	Possibly 50 y	2	lower	very small		May require vast infrastructure	Ref. Starshot
Fission pulse	Possibly 200 y	2	high	large			Ref. Dyson Orion proj.
Beamed power EP	>500 y	1	high	large	Might fit on a single SLS	May require vast infrastructure	
Fusion pulse	Possibly 50 y	0	very high	large			Ref. BIS Daedelus
Bussard ramjet	Possibly 25 y	0	extreme	large	Minimal propellant required	No credible concepts	
Antimatter rocket	Possibly 25 y	0	extreme	large		No credible concepts for storing antimatter or directing thrust	
Telecom							
Optical com		4	lower				
Large aperture μ-wave		3	moderate		Might integrate with a sail	Difficult to maintain shape	
Power							
Radioisotope		6	low				
High power fission		4	moderate				
Beamed		1	high				
Antimatter		0	extreme				

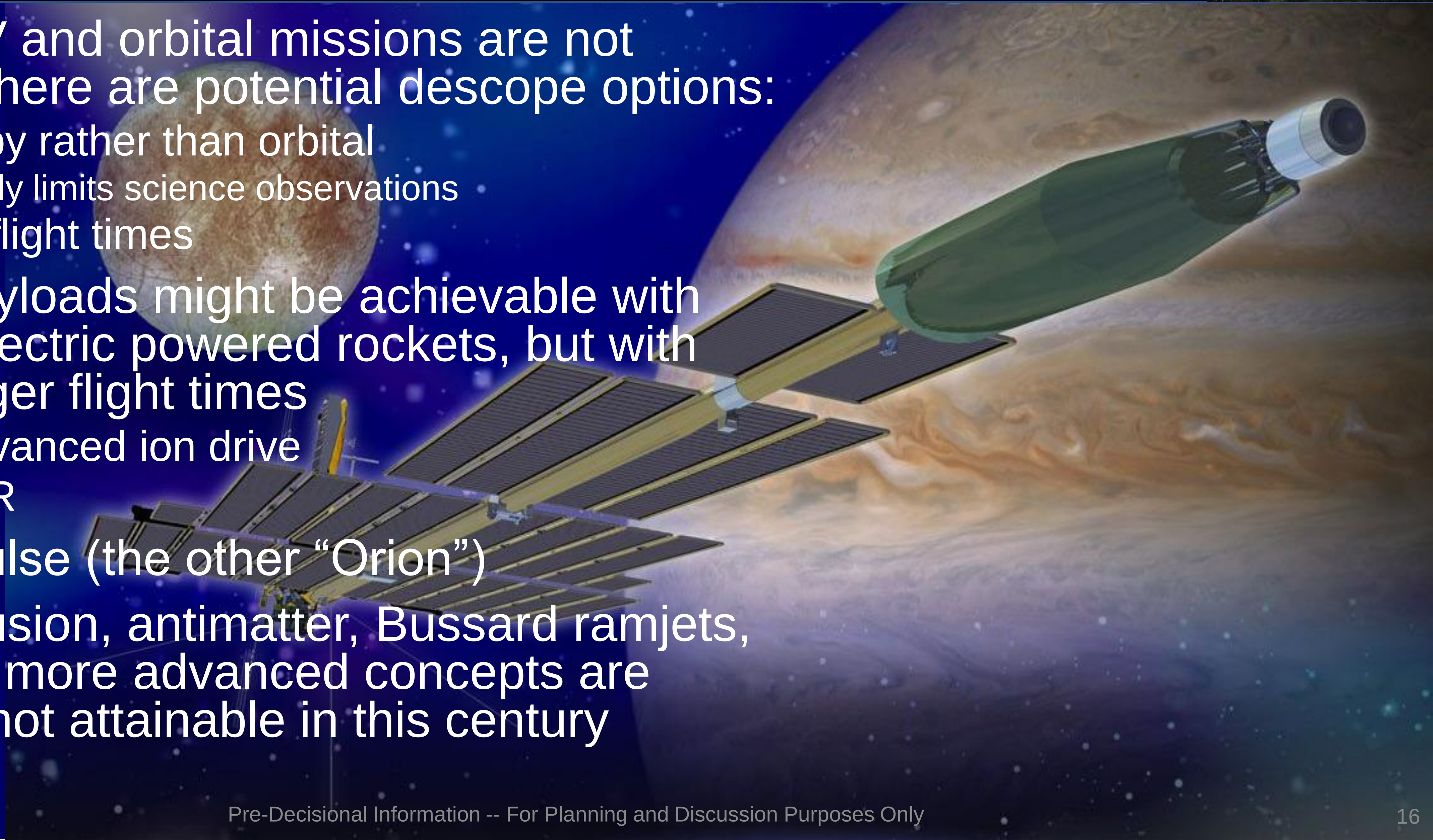
Mission Concept Architecture

- 2-stage light sail for propulsion
  - Would allow slowing down at the exoplanet
  - Credible propulsion technology development path
  - An option that doesn't require massive on-board power
  - Earth or space-based lasers could be improved over the mission lifetime
- 2.5 m class on-board lasercomm system
  - 100 m space-based receivers near Earth
  - Onboard power of 3.5 kW for 100 bits/sec downlink
- Autonomous on-board navigation
  - Required due to one-way light times of years
  - Similar technology was proven on Deep Impact
  - On-board autonomous mission replanning capability (e.g. autonomous site selection and execution of landing)



Other Potential Options





- If 0.1 c ΔV and orbital missions are not feasible, there are potential descope options:
  - Fast flyby rather than orbital
    - Greatly limits science observations
  - Longer flight times
- Larger payloads might be achievable with nuclear electric powered rockets, but with much longer flight times
  - Very advanced ion drive
  - VASIMIR
- Fission pulse (the other “Orion”)
- Nuclear fusion, antimatter, Bussard ramjets, and other more advanced concepts are probably not attainable in this century

Finding 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 artificial light.
  - Intelligent life capable of producing lights, radio signals, structures, etc. only recently appeared on Earth, so there might only be a low chance of finding life that advanced
  - These technologies have only existed on Earth for about 100 years, so for Earth, advanced intelligent life has only been detectable on a world with a measurable bio-signature for 1 part in 5 million (~2x10-7)
- If Earth is a proxy for other exo-worlds, there is only a very small likelihood of finding advanced life, and there are few candidate exo-worlds within 15 LY
- Although photosynthetic life on Earth started at least 3.5 billions years ago, the presence of free oxygen in the Earth's atmosphere (a potential bio-signature) has been present for less than 1 billion years

The stars beckon,
and
we must go.