Exoplanet Space Instrumentation Development and Demonstration

January 8, 2012

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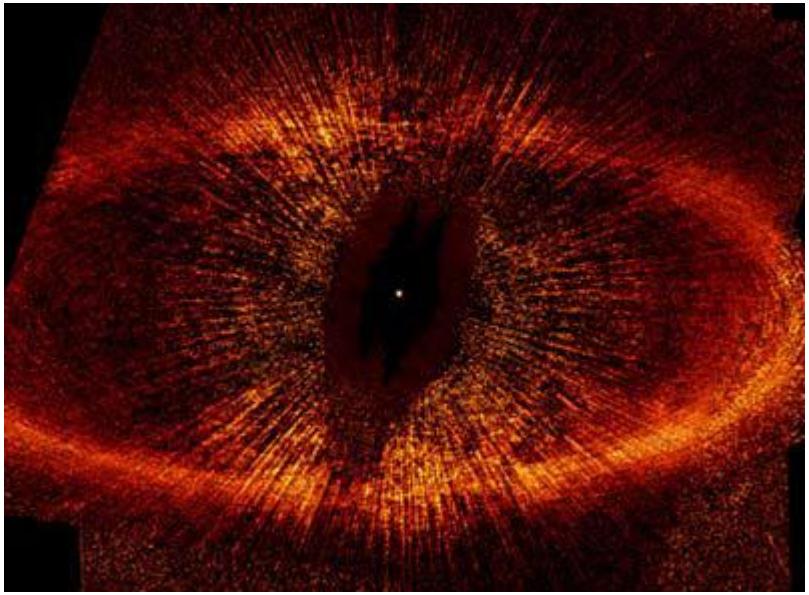
University of Colorado

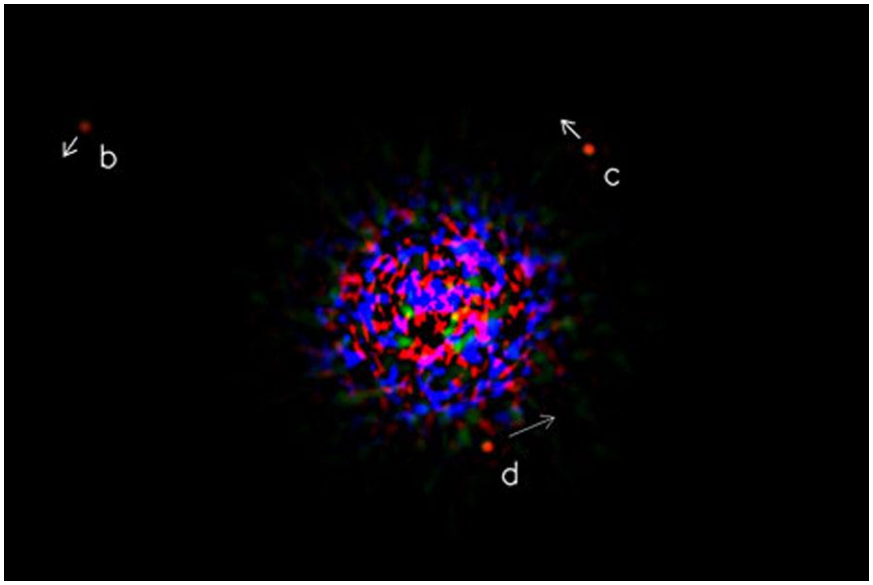
Exoplanets!

The community is seeing them already!



Fomalhaut
Seen with HST

HR 8799
From Ground Adaptive
Optic Telescope



Why are we here?
What Are We Trying to Accomplish?

Very simply put:

- **We are trying to systematically explore the solar neighborhood.**
- **To learn everything we can about planetary systems**
- **To search for habitable planets**
- **To search for signs of life**

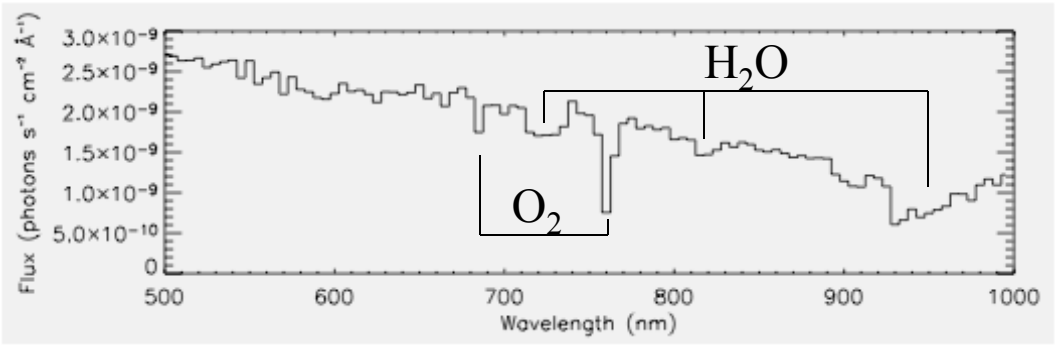
These are goals that are shared by nearly every human

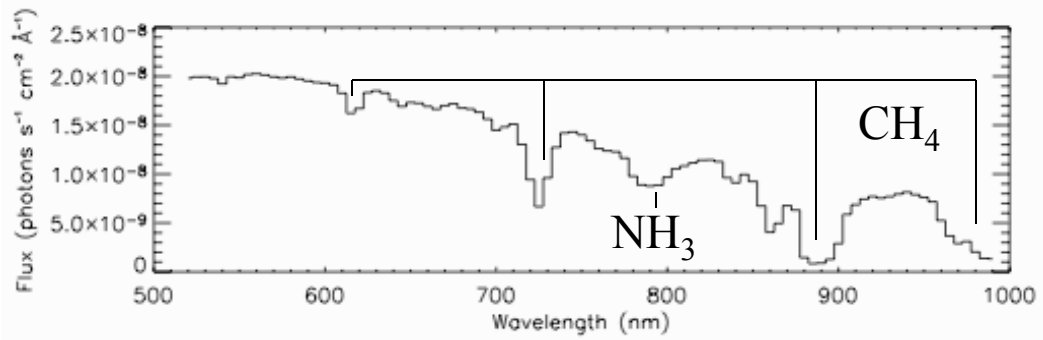
They should be:

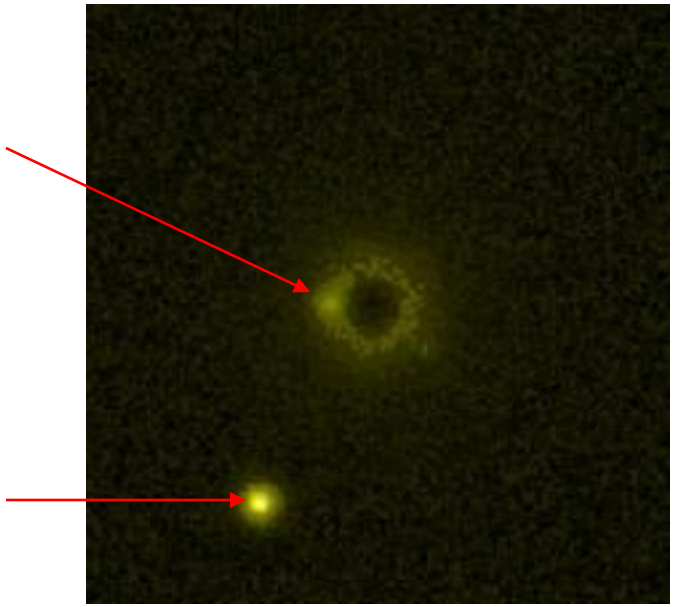
the highest science priority for NASA
among the highest priorities in all of science.

A FLAGSHIP MISSION SHOULD PROVIDE BREATHTAKING IMAGES

A Flagship Mission Should Provide Breathtaking Science







How do we accomplish that?

We need an awesome telescope capability

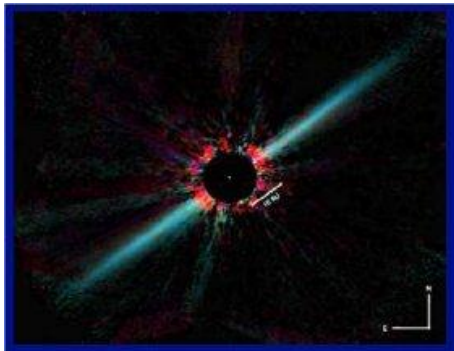
If it can be done from the ground, then it should be

Certainly cannot be done now. But 20 years from now?

Science and Exploration is a race, and we cannot falter

Why the Emphasis on a Flagship?

- Simply Finding Planets is No Longer Enough
  - Even Earths in HZ will no longer be cutting edge in 2020
- Goal is Spectroscopy of Earth-like Planets
- That is Going to Take a Large, Expensive Telescope!!!
- Must do spectroscopy of Earths against zodiacal light
  - Sky has 22mag/square arcsec -- Earth at 10pc is m=30
  - So Earth brightness equals sky in 25milliarcsecond spot
  - Diffraction limit of 25mas is achieved with 4m telescope at 0.5μ
  - Observing time rises as 4th power of diameter below that. Confusion issues make it worse
  - Observing time drops as square of diameter above that. Confusion is rapidly reduces.
- ***We Must have a 4m – that's a flagship!***



New Worlds Technology Development Program

- To achieve New Worlds objective – studying nearby, habitable exoplanets - need preliminary observations before choosing a flagship mission:
  - Planetary demography over wide range of conditions:
    - Kepler, WFIRST, integrated ground-based program
  - Measurement of zodiacal light:
    - Ground-based telescopes.
    - Sub-orbital and explorer mission opportunities.
- In parallel, need technology development for competing approaches to make informed choice in second half of decade
- **RECOMMEND $100-200M over decade**
- Planned integrated ground-space exoplanet program

In the Words of the Decadal

We “need preliminary **observations** before choosing a flagship”

Planetary Demography

Measurement of Zodiacal Light

- Ground Based Telescopes
- Suborbital and Explorer Missions

In parallel, need technology development for competing approaches to make informed choice in the second half of the decade

Planned integrated ground-space exoplanet program

The Current Program

- TDEMs
  - Interesting studies, but small and disconnected
- APRAs
  - Whatever the community can scrounge
- Un-competed and un-roadmapped funds to a center
- More architecture studies in a few years
  - We've already done many (eg ASMCS)
- Then downselect by unknown means
- No roadmap, no clear goals
- No identified options for solving the exozodi problem

Not what one would call a "Planned integrated ground-space exoplanet program"

An NWTDP Program

- **Many of the innovators got together**
  - **Avoid divide and conquer**
- **Do our own downselect**
  - **Do it publically**
  - **Actual Peers, Actual Numbers**
  - **Proper respect for IP and track records**
- **Do both internal and external coronagraphs – we should fly both**
- **Insist on full funding – why should we accept failure from the start?**

- **Stress Flight Demonstrations Doing Actual Astronomy!!!**
  - **Otherwise decadal won't believe us anyway**

- **All viable technology developed in home labs (not "facilities")**
- **When working in lab fly on shared balloon and rocket platforms**
  - **Work as a team toward successful mission**

Stress Demonstration

We must start actually using the new technology for its stated purpose – Astronomy.

DO NOT ATTEMPT TO COMPETE WITH FLAGSHIP MISSIONS (there's a problem there because we are peer reviewed by the customer base, not our actual peers. We need to ask NASA to change that.)

Go after the exozodi problem with a vengeance
Use those "suborbital and Explorer mission opportunities" to demonstrate the technology really works and can form the basis of

Science Goals

Measure Exozodiacal Light

from a statistical sample of nearby stars in the HZ

do it by 2019 in time to scale next decadal review

No Exozodi measurements, no flagship

Similarly need demonstrated direct spectra of exoplanets

Jupiters at 5pc should suffice

No Jupiter spectra, no credibility with decadal, no flagship

We cannot wait for a probe.

Indeed,

We need just as much credibility to get a probe.

Or even an Explorer. The bar is very, very high.

Study Group

Endorsed by Astrophysics Subcommittee of NAC

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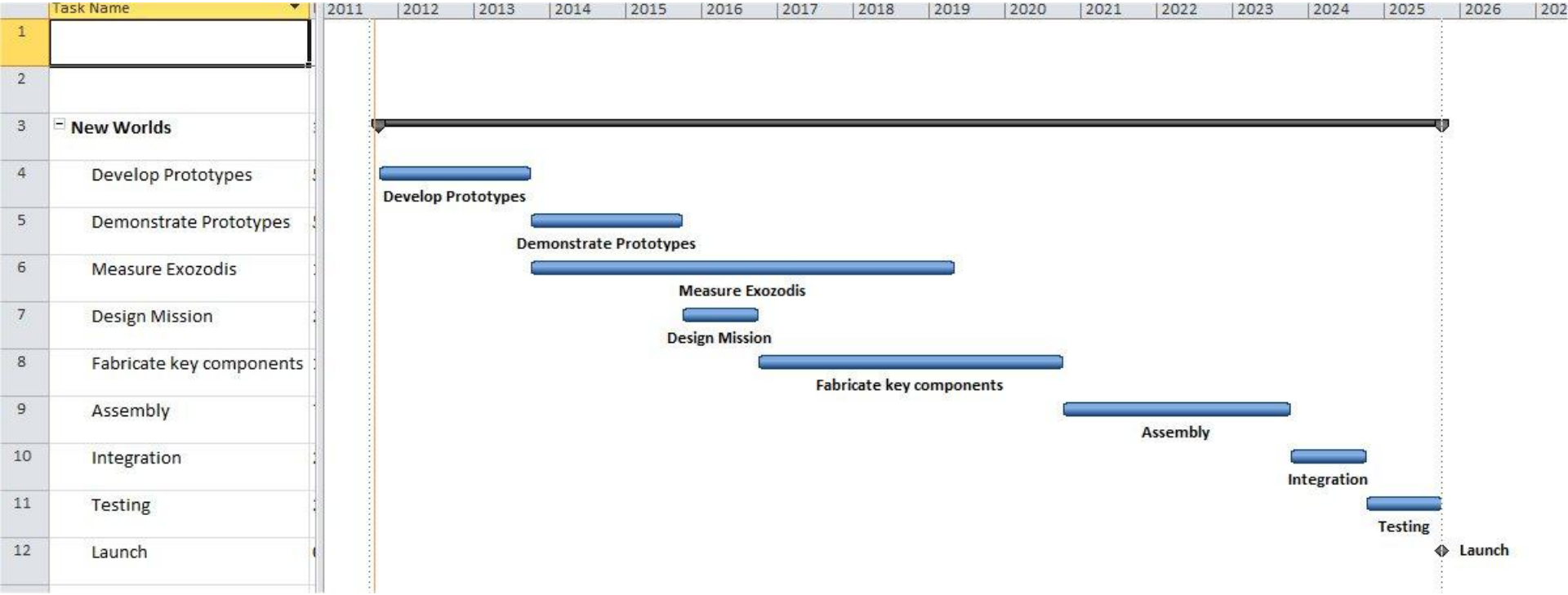
Overview of What Needs to be Done

To Launch Flagship in Timely Manner



Starshade Critical Technology

Enabling Technologies

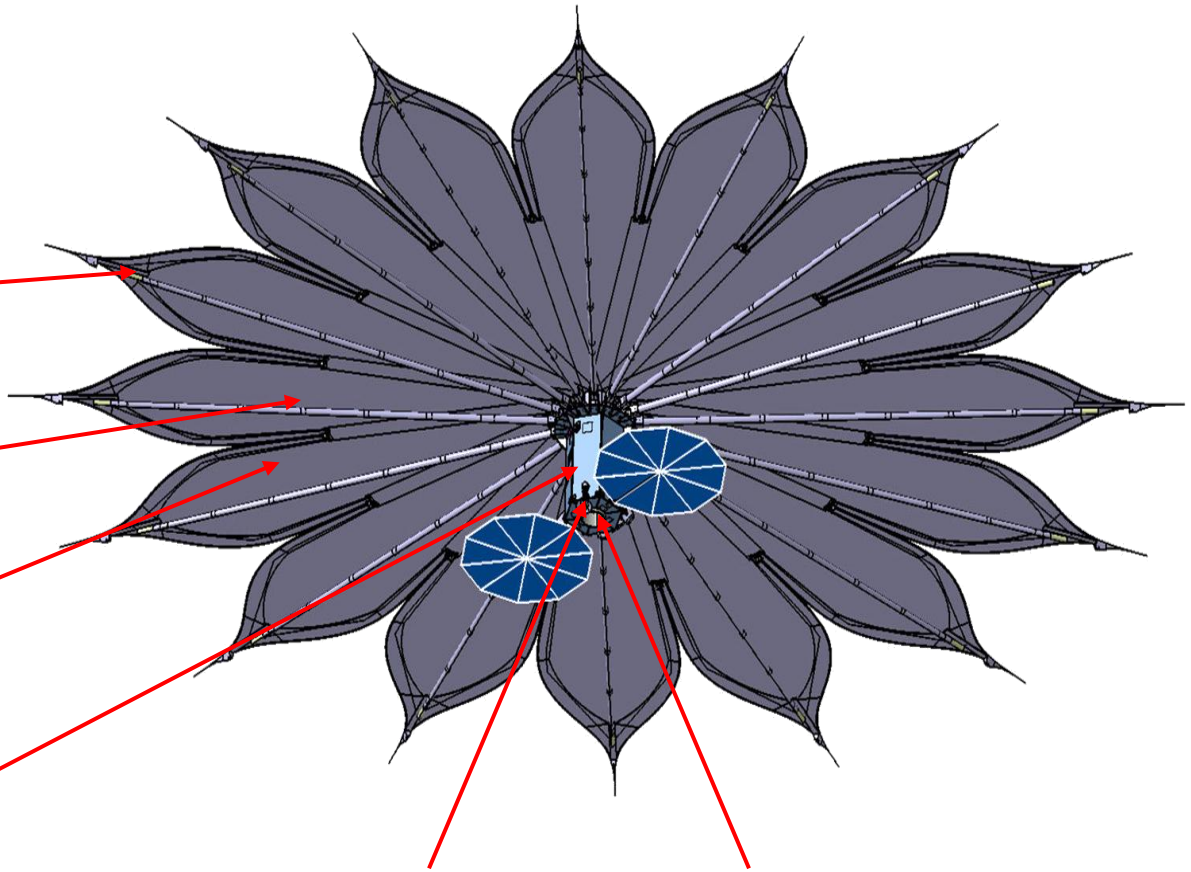
Precision Shape Control
- Maintain edge position
- Maintain structure shape

Thin Edge Treatment
- Maintain edge stability
- Minimize stray light

Precision Deployment
- Minimize jitter
- Maintain petal location

Opaque Membrane
- Maintain opacity
- Lightweight

2 Axes Formation Flying
- Maintain 1m alignment
- Minimize jitter



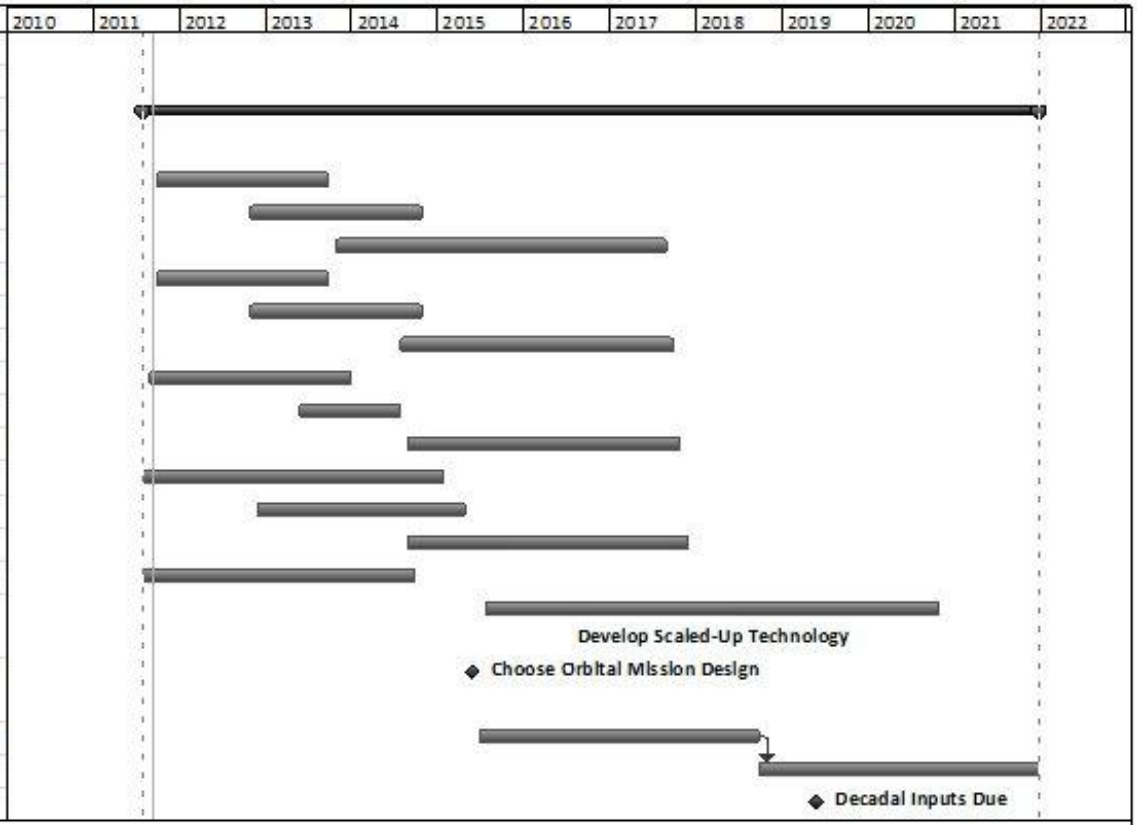
Solar Electric Propulsion
- NEXT engine
- Increase observable targets
- Reduce propellant mass

Lightweight S/C Structures
- Increase observable targets
- Reduce overall mass

Detailed Development and Demonstration Plan

Leading to Success in 2020 Decadal

ID	Task Name	Duration	Start	Finish
1				
2				
3	**New Worlds**	**2718 days**	**Mon 8/1/11**	**Wed**
4	Launch VNC Picture	1 day	Mon	Mon
5	Lab Starshades	522 days	Sat 10/1/11	Mon 9/30/13
6	Build Suborbital Starshade	522 days	Thu 11/1/12	Fri 10/31/14
7	Fly Starshades	1000 days	Fri 11/1/13	Fri 9/1/17
8	Lab Lyot Coronagraph	522 days	Sat 10/1/11	Mon 9/30/13
9	Build Lyot Coronagraph	522 days	Thu 11/1/12	Fri 10/31/14
10	Fly Lyot Coronagraph	826 days	Fri 8/1/14	Sun 10/1/17
11	Lab Vector Vortex	609 days	Thu 9/1/11	Wed 1/1/14
12	Build Vector Vortex	305 days	Sat 6/1/13	Fri 8/1/14
13	Fly Vector Vortex	827 days	Mon 9/1/14	Wed 11/1/17
14	Lab PIAA	915 days	Mon 8/1/11	Sun 2/1/15
15	Build PIAA	630 days	Sat 12/1/12	Fri 5/1/15
16	Fly PIAA	850 days	Mon 9/1/14	Fri 12/1/17
17	Build Balloon Telescope	827 days	Mon 8/1/11	Wed 10/1/14
18	Develop Scaled-Up Technology	1371 days	Sat 8/1/15	Sun 11/1/20
19	Choose Orbital Mission Design	0 days	Mon 6/1/15	Mon 6/1/15
20	Build Orbital Mission	848 days	Wed 7/1/15	Mon 10/1/18
21	Fly Orbital Mission	848 days	Mon 10/1/18	Wed
22	Decadal Inputs Due	0 days	Sat 6/1/19	Sat 6/1/19



The 2020 decadal review

If we stress demonstration and fly a small mission, then by 2020 we could have a slew of discoveries in the Astrophysical Journal

The 2020 Decadal review can pick it with confidence that

- **It can be built**
- **It will not overrun**
- **Will achieve the astronomy goals**
- **That there is an experience base for the mission**

The Technology Will Have Won Over the Customers!

Development of Coronagraphs

There are beautiful lab demos at 10^{-8} and below

We've shown they work in the lab
Nice applications are happening on ground telescopes
So do we let the ground community do all the science?
Why bother with space?

Need to fly the coronagraphs now!

Picture just launched.

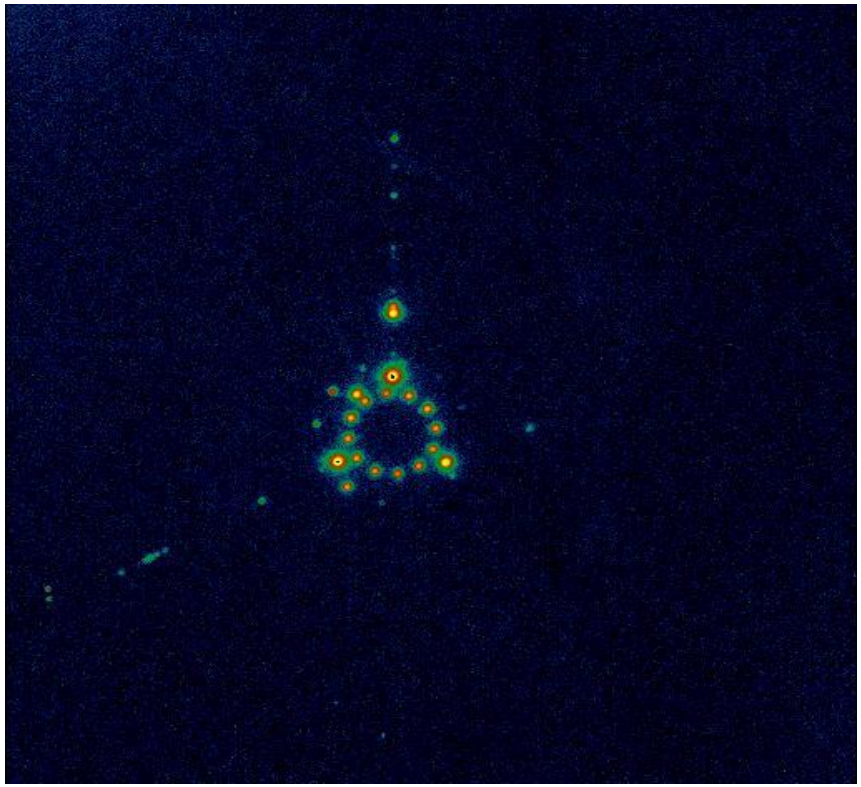
Proposals for coronagraphs going out there.

EXOPAG could endorse these concepts. We should say what we need to succeed.

Will concentrate on Starshades

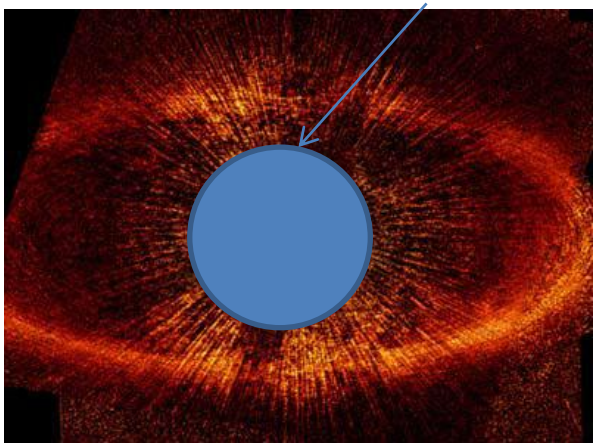
They're working in the lab.

Have shown contrast of 10^{-10}
Suppression of 10^{-8}

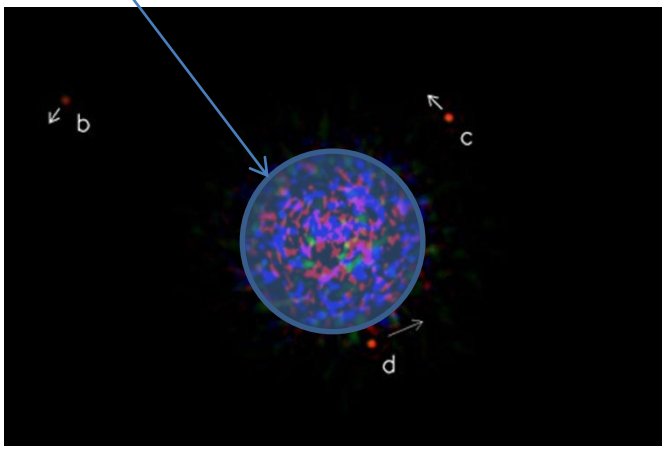


Demonstration of Starshades

- Bring the Starshade Closer
  - at the Expense of Inner Working Angle
- For example, at 4000Å and 300km separation, can achieve 10^{-10} at IWA of 0.67”.
  - Earth at α Cen, Jupiter at τ Ceti
- At 3km, 10^{-10} at 6.7”



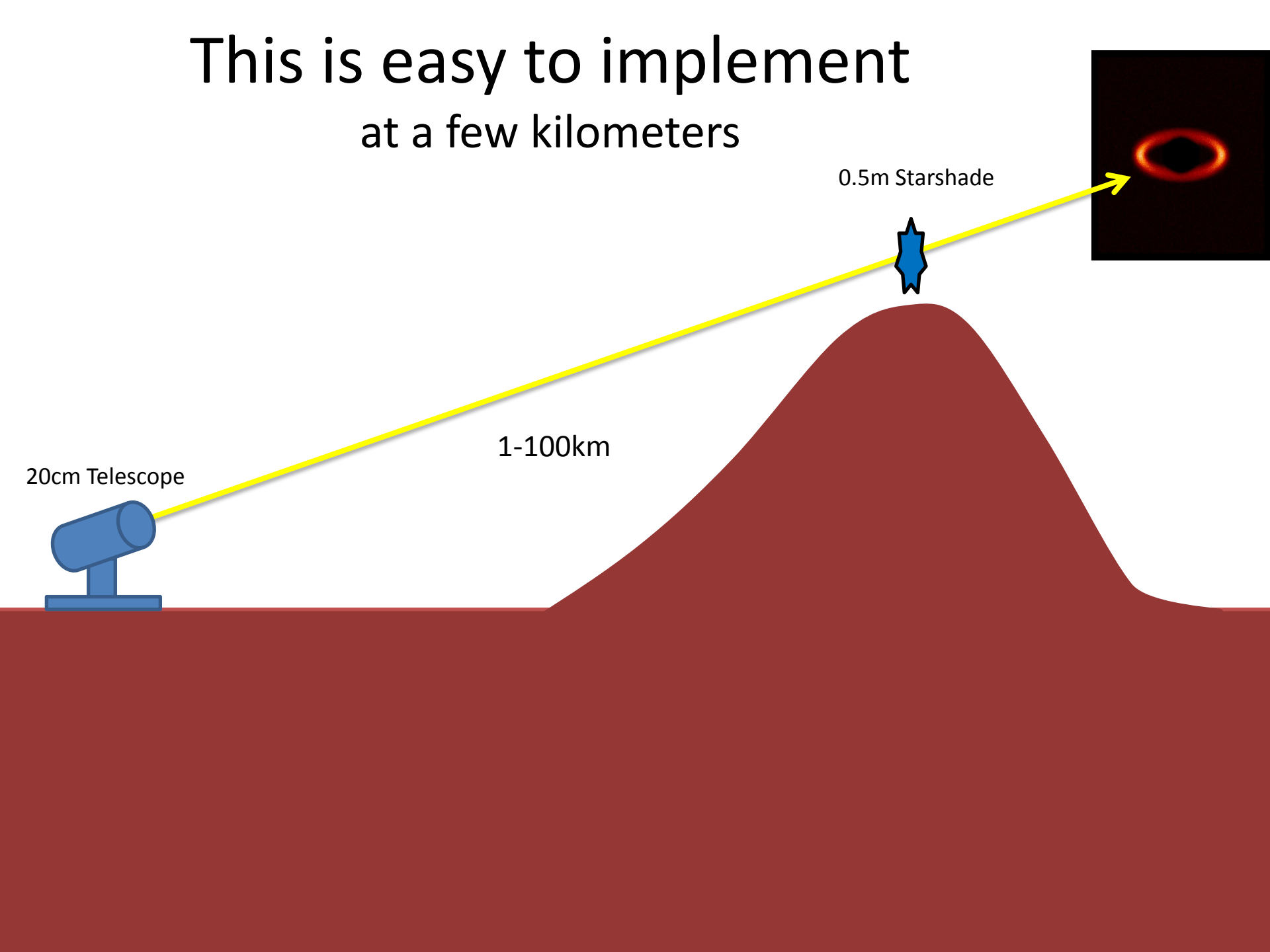
Fomalhaut



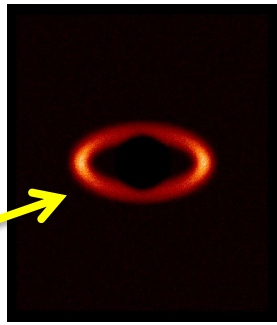
HR 8799

This is easy to implement

at a few kilometers



Telescope on Ground
Starshade on Dirigible



0.5m Starshade

1-100km

Hours on Target

20cm Telescope

Coolest Thing Just Happened
Got Funded to do this!

Airship Ventures Zeppelin

Concept

The particular shape of the star shade creates an pattern that reduces "fringes" and lets astronomers image the area very close to the star

star

Airship

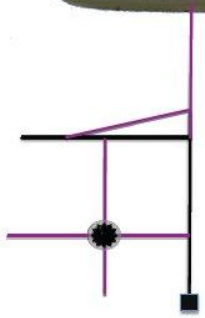
shade

The objective is to create a prototype of a long distance coronagraph to assist astronomers to image planets around distant stars.

The airship carries a black "daisy" shaped target and places this in a line between the telescope and the star. This is called a Star Shade

Ground based telescope

Star Shade Concept – Mounting to Airship

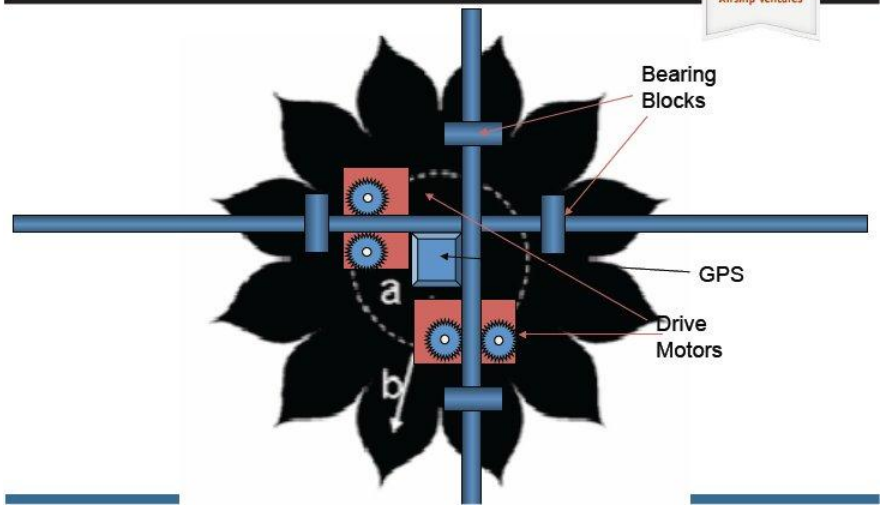


Rigid fibreglass pole mounted to bottom of airship via payload port – emergency cut away with a small parachute

System folds flat for deployment from gondola

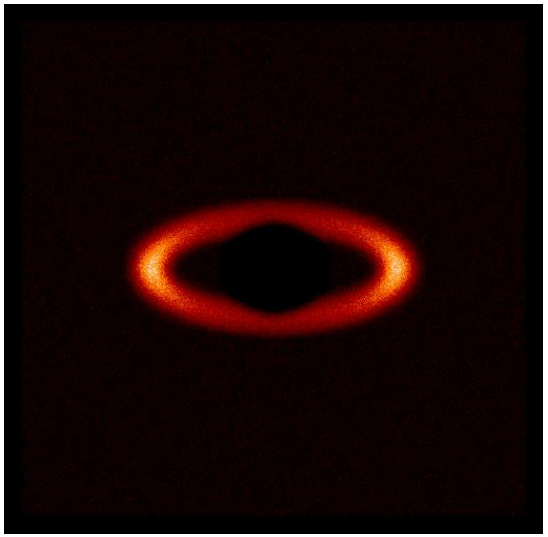
Flexible mounting with shear pin at the top to prevent damage to airship

Star Shade X-Y Drive



Astronomy By This Summertime!

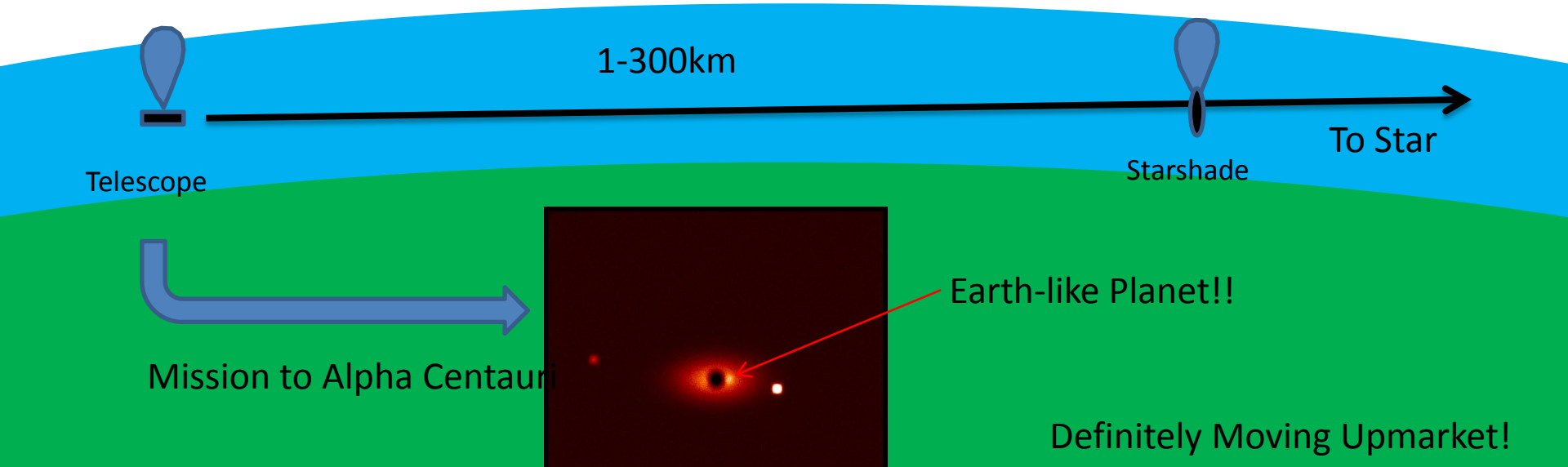
- Debris Disks
- Outer Planets and Brown Dwarfs
- Dozens of targets to about 5” IWA



Next step: To the Stratosphere

Balloons allow greater separation
and quieter atmosphere

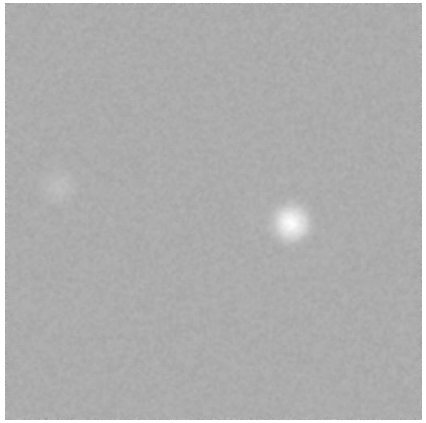
Two Balloons in Stratosphere
One is actually dirigible so it can it can hold position

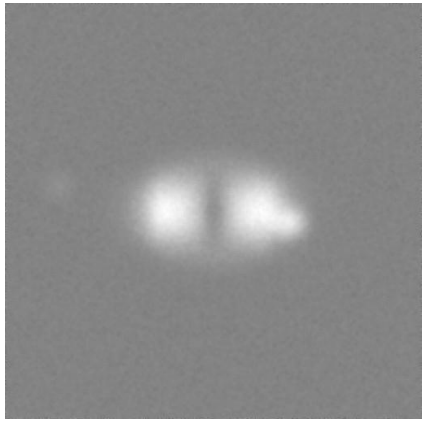


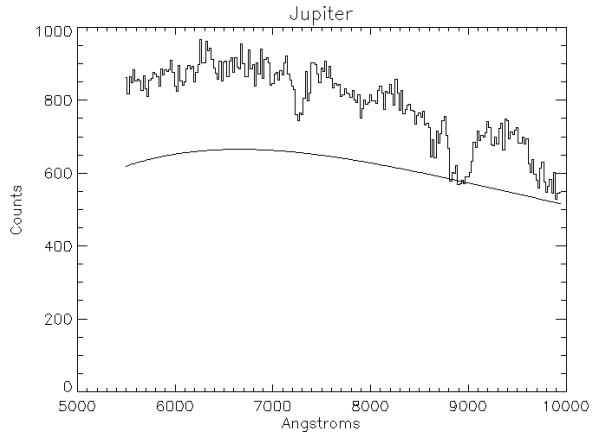
But We Have to Go Orbital

From “Alternative Starshade Missions”

Cash, Glassman, Soummer SPIE 2010







The Solar System as viewed from 10pc with a 0.5m diameter diffraction limited telescope at 4000Å. The left image is the case of no zodiacal light and the middle contains an exozodi comparable to the Solar System’s. The right image is a simulated spectrum of a Jupiter, as there is no capability of acquiring Earth spectra beyond two or three parsecs.

First Option for Explorer: HitchHiker

- Flying technology demonstrators without science goals can greatly cut costs.
- Take the “Orbital Sounding Rocket” Approach
- Build the 8m shade and 0.5m telescope
- Wrap low cost spacecraft around them and launch in a few years

- Even smaller than demonstrator
- No launch costs
- Perhaps no Jupiter spectra – just image exozodis

Second Option for Explorer: Technology Demonstrator

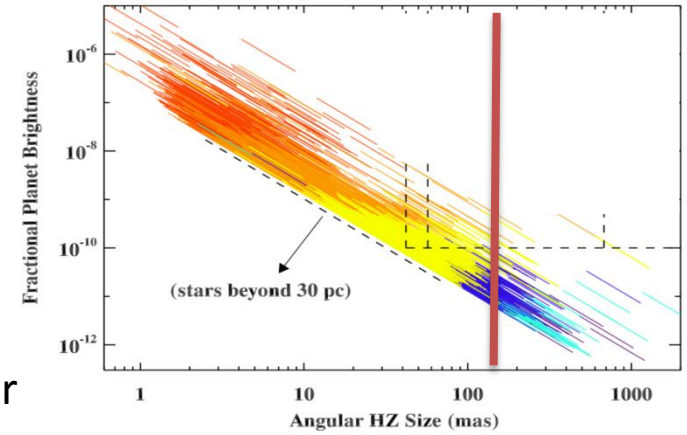
- Flying technology demonstrators without science goals can greatly cut costs.
- Take the “Orbital Sounding Rocket” Approach
- Build the 8m shade and 0.5m telescope
- Wrap low cost spacecraft around them and launch in a few years

- Payloads: 2 @ $10M
- Spacecraft: 2 @ $65M
- Launch: 2 @ $12M
- Total: $174M
- Work with Office of Chief Technologist?
  - Cross Cutting Technologies: Large Deployables, Formation Flying, Refueling etc

Third Option for Explorer: Small New Worlds

- Dedicated Telescope and Dedicated Starshade
- Needs to reach to 0.15” at 10^{-9} suppression to do the exozodi problem
- What is the smallest system that can achieve this?

- 8m diameter shade at 5000km
- 0.5m telescope diffraction limited at 4000Å



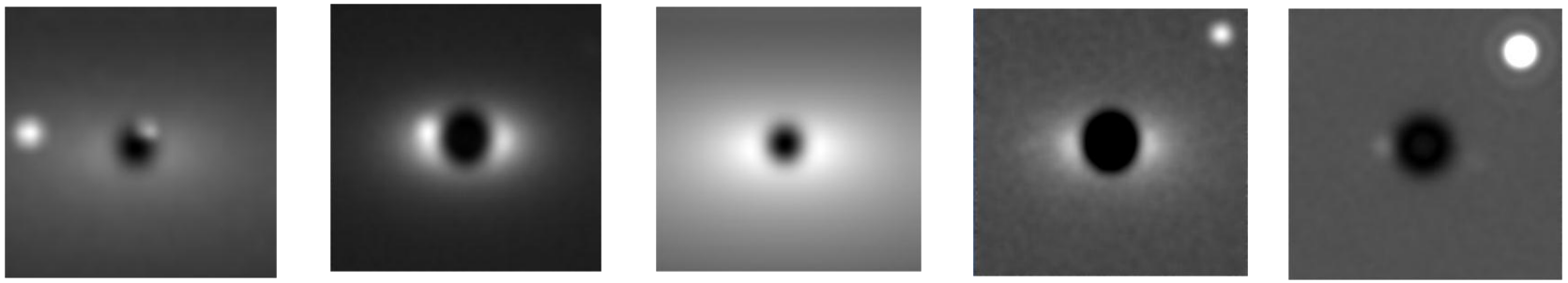
An 8m Starshade Can be built for the cost of an Explorer

A Half Meter Near UV Telescope can be built for the cost of an Explorer

$400M for two Explorers – A bit outside the box, but not crazy

Fourth Option for Explorer: New Worlds Probe

- JWST + Starshade
  - Have Done a Great Deal of Work on This
  - Yes. This can be done.
  - Can address the Earth problem by 2018.
  - Cost ~$750M with no precursor.
  - JWST must be passive and unmodified – increases difficulty
  - Smaller version could do exozodi problem for less (~$500M)



But If WE:

Fly Suborbital Missions in the next few years

Fly a very low cost orbital demonstrator mid-decade

Fly an exozodi Explorer-plus by late decade

We'll win that flagship

WE WILL FINALLY BE READY FOR PRIME TIME

And to do the most exciting science one can imagine

Perform spectroscopy of discovered planets

This will reveal their true natures