TEAM X REPORT #1401
EXOPLANET CORONAGRAPH STDT STUDY 2013-06

CUSTOMER: KEITH WARFIELD
JUNE 2013
FINAL REPORT (Public Release Version)

Jet Propulsion Laboratory, California Institute of Technology

This study was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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Study Summary

Study Info

Customer: Keith Warfield

Partners: none

Study Type: mission trade study

Study Dates: June 13, 2013

Context: 1 session; in-session comments

Purpose: trade space exploration

Mission Summary

Launch Date: December 2022

Launch Vehicle: Falcon 9 v1.1, Atlas 401

Target Body: L2

Science: direct imaging exoplanets

Instruments: Lyot coronagraph

Architecture: commercial bus with a telescope and coronagraph

Key Results

	Original ACCESS	Option 1	Option 2
Payload Mass	923kg	787kg	603kg
Launch Mass	2,684kg	2,457kg	2,111kg
Payload Peak Power	742W	596W	370W
Peak Power	1,928W	1,693W	1,331W
Launch Vehicle	Atlas 401	Falcon 9	
Cost ($FY15)	$1,137M	$960M	$878M

Trades

Number of Options Studied: 2 additional

	Original ACCESS	Option 1	Option 2
Telescope Aperture	1.5m	1.3m	1.0m
Reliability	Class B		
Mission Life	5 Years		

Key subsystem trades: telescope aperture vs. launch mass vs. mission cost

Team X Participants

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Executive Report

(1401) Exoplanet STDT 2013-06
June 13, 2013

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Executive Summary
Study Overview

- **This study was a fast turn-around look at a focused design trade:**
  - How does the total mission cost change with the aperture of the telescope?
  - The trade is in support of a NASA directed report on the feasibility of a direct imaging Exoplanet mission for a $1B cost cap.
- **The study took the 2009 ACCESS (Report # 990) study option 2 and, 1) updated it with the latest Team X design and cost models, 2) then resized just the telescope from 1.5m to 1.3m, 3) then resized the telescope to 1.0m.**
  - Team X re-estimated the mass, power and cost for each of the above scenarios
- **The work was done with a partial team (only chairs considered likely to be involved in the trade) augmented with optics support from the instrument design team. The systems engineers provided inputs for mission team chairs not present.**
- **Telescope cost and sizing tools were provided by Div 38.**

Executive Summary
Mission Architecture and Assumptions

- **Mission Architecture (the same for all scenarios)**
  - 3-axis commercial spacecraft with a telescope and coronagraph payload
    - Vibration isolation and fine pointing upgrades added to bus
- **Assumptions**
  - 5 year mission at L2
  - Class B reliability
  - DSN communications

Executive Summary
Option Comparison

	Original ACCESS	Option 1	Option 2
Telescope Aperture	1.5m	1.3m	1.0m
Reliability	Class B		
Mission Life	5 Years		
Payload Mass	923kg	787kg	603kg
Launch Mass	2,684kg	2,457kg	2,111kg
Payload Peak Power	742W	596W	370W
Peak Power	1,928W	1,693W	1,331W
Launch Vehicle	Atlas 401	Falcon 9	
Cost ($FY15)	1137M	$960M	$880M

Executive Summary
Technical Findings

- **Getting off the Atlas 401 saves $105M**
- **Each 10cm reduction in aperture saves about $25-35M**
  - Savings is greatest at the largest diameters
- **Cost savings for power and structure reduction are small compared to telescope cost savings and launch vehicle savings**
- **Pointing is not effected by the reduction in aperture**

Systems Report

(1401) Exoplanet STDT 2013-06
June 13, 2013

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Options Overview

Study Goal:

- Re-examine the 990 ACCESS 2009-01 Team X study by inputting the old design into the new Team X workbook and examine some variations of the instrumentation

Objectives:

- Vary the telescope aperture area to determine the affect on mass and cost
  - Backend Coronagraph remains the same size, reduction of telescope only
- Examine the spacecraft design to determine whether or not a change in power or thermal architectures would affect the spacecraft pointing
  - Examine methods for removal of the Vibration Isolation system
- Examine whether or not the spacecraft would fit on the Falcon 9 Launch Vehicle

Options:

- Examined two variations of the 2009 ACCESS Team X mission concept
  - Option 1 – Reduction of the instrument from 1.5m to 1.3m diameter
  - Option 2 – Reduction of the instrument from 1.5m to 1.0m diameter

Systems
Design Requirements

- **All Mission/System Level requirements taken from the 990 ACCESS 2009-01 Team X study Option 2**
  - Schedules durations remain the same but launch date was adjusted from 2015 to 2022
  - Fiscal year of estimate changed from FY09 to FY15
- **Launch Date: December 2022**
  - Technology cut off August 2019
- **Mission lifetime: >/= 5 years**
- **Redundancy:**
  - Dual String
  - Cold spare
- **>/= TRL 6 technology by start of phase A (2018)**
- **Expected Science data Collection:**
  - 54.4 Gbits per week (7.8 GBytes/wk)
  - Expect 1 D/L per week, plan for data storage of at least ~8 GBytes
- **Expected TID of 26 krad**
- **Use of commercial tracking network (USN or equivalent) to return quick-look science data twice a week**

Systems
Design Assumptions

- **Key Dates:**
  - Phase A start: 2/1/2018
  - Phase B start: 8/1/2018
    - Telescope and Instrument begin during Phase B
  - Phase C start: 8/1/2019
    - PDR – 6/1/2019
    - CDR – 5/1/2020
  - Phase D start: 6/1/2021
    - ARR – 9/1/2022
  - Launch: 12/1/2022
- **Power Modes:**
  - Launch: 1 Hour
  - Deployment: .5 hour
  - Cruise: 24 Hours
  - Science+Telecom: 24 hours
  - Science + Telecom + Re-target: 24 hours
  - Safe: 3 hours

Systems
System Guidelines

- **The guidelines table shown below is a compilation of the system level requirements and assumptions used within the study. The guidelines are propagated to all subsystem chairs**
  - This ensures that all subsystems are working from the same system level requirements and assumptions
  - Some parameters are defined by subsystem chairs based on their design

Target Body	Exo Planets
Science	**Coronagraphic Astronomy**
Launch Date	**12/1/2022**
Mission Duration	**5 Years**
Mission Class	**B**
Tech Cutoff	**2019**
Flight System Development Mode	**In-House**
Launch Vehicle	**Falcon 9 Block 2**
Tracking Network	**DSN**
Redundancy	**Dual (Cold)**
Spares Approach	**Selected**
Stabilization	**3-Axis**
Heritage	**Kepler, EOS**
Total Radiation Dose	**25.7 krad behind 100 mil. of Aluminum, with an RDM of 2**
Hardware Models	**Protoflight S/C, EM Instrument**
Parts Class	**Commercial + Military 883B**
Launch Site	**KSC**
Cost Target (Fiscal Year)	**$700M FY15**

Systems Sheet – Baseline

Exoplanet STDT 2013-06 Spacecraft Mass Summary	Mass (kg)	Subsys Cont. %	CBE+ Cont. (kg)	Mode 1 Power (W) Launch	Mode 2 Power (W) Deploy	Mode 3 Power (W) Cruise	Mode 4 Power (W) Science + Telecom	Mode 5 Power (W) Science + Calibration + Retarget	Mode 6 Power (W) Safe
Power Mode Duration (hours)				*1*	*0.5*	*24*	*24*	*24*	*3*
Payload on this Element									
Instruments	923.3	0%	923.3	0	0	0	742	742	148
Payload Total	923.3	0%	923.3	0.0	0.0	0.0	742.0	742.0	148.4
Additional Elements Carried by this Element				0.0	0.0	0.0	0.0	0.0	0.0
Other Element Allocation	0.0	0%	0.0						
Carried Elements Total	0.0	0%	0.0	0	0	0	0	0	0
Spacecraft Bus									
Attitude Control	101.4	7%	108.2	38	70	70	238	238	238
Command & Data	21.6	6%	22.8	24	35	41	41	41	28
Power	45.5	30%	59.2	77	88	88	214	214	142
Propulsion1	55.0	4%	57.2	1	17	17	17	17	0
Structures & Mechanisms	392.5	30%	510.3	0	0	0	0	0	0
S/C-Side Adapter	7.9	30%	10.3						
Cabling	58.5	30%	76.0						
Telecom	20.2	15%	23.3	54	54	54	54	54	54
Thermal	29.7	3%	30.7	42	42	42	42	42	42
Bus Total	732.3	23%	897.9	236	306	312	606	606	504
Spacecraft Total (Dry)	1655.6	10%	1821.2	236	306	312	1348	1348	652
Subsystem Heritage Contingency	165.6	10%							
System Contingency	546.3	33%		101	132	134	580	580	280
Spacecraft with Contingency	2368			337	438	447	1928	1928	933
Propellant & Pressurant1	276.0		For S/C mass =	3480.0		Delta-V, Sys 1	150.0	m/s	
Spacecraft Total (Wet)	2644								
L/V-Side Adapter	40.3								
Launch Mass	2684								
Launch Vehicle Capability	3035	Atlas V 401							
Launch Vehicle Margin	351.2	12%							
NASA Calculated Margin	51%								
JPL Design Principles Margin	40%								

Systems
Design Summary – Option 1

- **ACS**
  - Sun Sensors, IMUs, Star Tracker for Attitude Determination
  - RWAs, 2-stage Vibration Isolation for pointing control and stability
  - Mass: 101.4 kg
- **CDS**
  - MSAP based avionics architecture
  - 96 Gb SSR
  - Mass: 21.6 kg
- **Power**
  - Two Rigid GaAS Solar Arrays
    - Array Area = 6.6 m^2
  - Mass: 44.1 kg
- **Propulsion**
  - Monoprop Blowdown System
  - N2H4 Fuel Mass = 276 kg
  - Prop System Mass = 55.0 kg
- **Structures**
  - Primary Structure Mass = 223.0 kg
  - Secondary Structure Mass = 29.3 kg
  - Sunshield and Support Structure = 40 kg
  - Vibration Isolation supports = 37 kg
  - Mechanisms
    - Solar Array and MGA Gimbals = 15 kg
- **Telecom**
  - Direct to Earth Communication
  - 1 m fixed X-band HGA
  - Two fixed S-band LGA
  - Mass = 20.2 kg
- **Thermal**
  - Passive and active thermal control
  - Mass = 29.7 kg
- **Instruments**
  - 1.3 diameter telescope = 664.7 kg
  - Lyot Coronagraph = 122.5 kg
- **Ground Systems**
  - Ground Network = DSN
  - X passes per week at 2 Mb/s

Systems

Systems Sheet – Option 1

Exoplanet STDT 2013-06 Spacecraft Mass Summary	Mass (kg)	Subsys Cont. %	CBE+ Cont. (kg)	Mode 1 Power (W) Launch	Mode 2 Power (W) Deploy	Mode 3 Power (W) Cruise	Mode 4 Power (W) Science + Telecom	Mode 5 Power (W) Science + Calibration + Retarget	Mode 6 Power (W) Safe
Power Mode Duration (hours)				*1*	*0.5*	*24*	*24*	*24*	*3*
Payload on this Element									
Instruments	787.2	0%	787.2	0	0	0	596	596	119
Payload Total	**787.2**	0%	**787.2**	**0.0**	**0.0**	**0.0**	**596.0**	**596.0**	**119.2**
Additional Elements Carried by this Element				0.0	0.0	0.0	0.0	0.0	0.0
Other Element Allocation	0.0	0%	0.0						
Carried Elements Total	**0.0**	0%	**0.0**	**0**	**0**	**0**	**0**	**0**	**0**
Spacecraft Bus									
Attitude Control	101.4	7%	108.2	38	70	70	238	238	238
Command & Data	21.6	6%	22.8	24	35	41	41	41	28
Power	44.1	30%	57.3	77	88	88	195	195	139
Propulsion1	55.0	4%	57.2	1	17	17	17	17	0
Structures & Mechanisms	376.4	30%	489.3	0	0	0	0	0	0
S/C-Side Adapter	7.7	30%	9.9						
Cabling	55.6	30%	72.2						
Telecom	20.2	15%	23.3	54	54	54	54	54	54
Thermal	29.7	3%	30.7	42	42	42	42	42	42
Bus Total	711.6	22%	871.0	236	306	312	588	588	501
Spacecraft Total (Dry)	1498.8	11%	1658.1	236	306	312	1184	1184	620
Subsystem Heritage Contingency	159.4	11%							
System Contingency	485.1	32%		101	132	134	509	509	267
Spacecraft with Contingency	**2143**			**337**	**438**	**447**	**1693**	**1693**	**887**
Propellant & Pressurant1	276.0	For S/C mass =		3480.0		Delta-V, Sys 1	150.0	m/s	
Spacecraft Total (Wet)	**2419**								
L/V-Side Adapter	37.5								
Launch Mass	**2457**								
Launch Vehicle Capability	**2490**	Falcon 9 - Block 2							
Launch Vehicle Margin	**33.3**	1%							
NASA Calculated Margin	**34%**								
JPL Design Principles Margin	**32%**								

Systems
Design Summary – Option 2

- **ACS**
  - Sun Sensors, IMUs, Star Tracker for Attitude Determination
  - RWAs, 2-stage Vibration Isolation for pointing control and stability
  - Mass: 101.4 kg
- **CDS**
  - MSAP based avionics architecture
  - 96 Gb SSR
  - Mass: 21.6 kg
- **Power**
  - Two Rigid GaAS Solar Arrays
    - Array Area = 5.2 m^2
  - Mass: 41.9 kg
- **Propulsion**
  - Monoprop Blowdown System
  - N2H4 Fuel Mass = 276 kg
  - Prop System Mass = 55.0 kg
- **Structures**
  - Primary Structure Mass = 189.9 kg
  - Secondary Structure Mass = 23.8 kg
  - Sunshield and Support Structure = 40 kg
  - Vibration Isolation supports = 37 kg
  - Mechanisms
    - Solar Array and MGA Gimbals = 15 kg
- **Telecom**
  - Direct to Earth Communication
  - 1 m fixed X-band HGA
  - Two fixed S-band LGA
  - Mass = 20.2 kg
- **Thermal**
  - Passive and active thermal control
  - Mass = 29.7 kg
- **Instruments**
  - 1.0 diameter telescope = 480.5 kg
  - Lyot Coronagraph = 122.5 kg
- **Ground Systems**
  - Ground Network = DSN
  - X passes per week at 2 Mb/s

Systems

Systems Sheet – Option 2

Exoplanet STDT 2013-06 Spacecraft Mass Summary	Mass (kg)	Subsys Cont. %	CBE+ Cont. (kg)	Mode 1 Power (W) Launch	Mode 2 Power (W) Deploy	Mode 3 Power (W) Cruise	Mode 4 Power (W) Science + Telecom	Mode 5 Power (W) Science + Calibration + Retarget	Mode 6 Power (W) Safe
Power Mode Duration (hours)				*1*	*0.5*	*24*	*24*	*24*	*3*
Payload on this Element									
Instruments	603.0	0%	603.0	0	0	0	370	370	74
Payload Total	**603.0**	0%	**603.0**	**0.0**	**0.0**	**0.0**	**370.0**	**370.0**	**74.0**
Additional Elements Carried by this Element				0.0	0.0	0.0	0.0	0.0	0.0
Other Element Allocation	0.0	0%	0.0						
Carried Elements Total	**0.0**	0%	**0.0**	**0**	**0**	**0**	**0**	**0**	**0**
Spacecraft Bus									
Attitude Control	101.4	7%	108.2	38	70	70	238	238	238
Command & Data	21.6	6%	22.8	24	35	41	41	41	28
Power	41.9	30%	54.5	77	88	88	169	169	134
Propulsion1	55.0	4%	57.2	1	17	17	17	17	0
Structures & Mechanisms	328.4	30%	426.9	0	0	0	0	0	0
S/C-Side Adapter	7.3	30%	9.5						
Cabling	51.5	30%	66.9						
Telecom	20.2	15%	23.3	54	54	54	54	54	54
Thermal	29.7	3%	30.7	42	42	42	42	42	42
Bus Total	656.9	22%	799.9	236	306	312	561	561	496
Spacecraft Total (Dry)	1259.9	11%	1402.9	236	306	312	931	931	570
Subsystem Heritage Contingency	143.0	11%							
System Contingency	398.8	32%		101	132	134	400	400	245
Spacecraft with Contingency	**1802**			**337**	**438**	**447**	**1331**	**1331**	**816**
Propellant & Pressurant1	276.0	For S/C mass =		3480.0		Delta-V, Sys 1	150.0	m/s	
Spacecraft Total (Wet)	**2078**								
L/V-Side Adapter	33.3								
Launch Mass	**2111**								
Launch Vehicle Capability	**2490**	Falcon 9 - Block 2							
Launch Vehicle Margin	**379.0**	15%							
NASA Calculated Margin	**58%**								
JPL Design Principles Margin	**43%**								

Systems
Additional Comments – Mass Margins

- ***Note:*** *Technical resource margins exist to deal with uncertainties, e.g. those known and others yet to be discovered, and to facilitate the design integration performed by system engineering. JPL's margin guidelines are experienced-based, and have been borne out in a variety of mission/system applications.*
- **JPL Design Principles Margin: >/=30% for projects in development prior to PDR**
- **Definitions**
  - System dry mass margin definitions - The following definitions are used for determining system dry mass margins.
    - Dry Mass Margin = Dry Mass Allocation - Dry Mass Current Best Estimate (CBE)
    - Dry Mass Margin (%) = 100 * (Dry Mass Margin/Dry Mass Allocation)
  - Dry Mass Allocation is defined relative to the launch vehicle payload allocation, as follows:
    - Dry Mass Allocation = L/V Payload Allocation - Mass of S/C Propellant(s)

	LV capability (kg)	Propellant mass (kg)	System dry mass CBE (kg)	JPL Design Principles margin (%)	LV Margin (kg)	LV Margin (%)
Option 1	**2490**	**276**	**2143**	**32%**	**33**	**1%**
Option 2	**2490**	**276**	**1802**	**58%**	**379**	**15%**

Instruments Report

(1401) Exoplanet STDT 2013-06
June 13, 2013

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STATUS: Ready

Instruments
Design Assumptions

- **Coronagraph Mass & Cost unchanged with Aperture Size**
- **Telescope Mass and Cost Scale Simply with Aperture Size**
  - 800 kg Mass as ~ the geometric mean of by circumference (baffle) and by area (mirrors)
    - 1.3/1.5 ~ 83%
    - 1.0/1.5 ~ 60%
  - $171 M Costs scale according to 2008 Division 38 telescope model $\$ \sim \text{TelescopeDiameter}^{2.53}$
    - 1.3/1.5 ~ 70%
    - 1.0/1.5 ~ 36%

Instruments
Telescope Option Comparison

- **1.5 m ACCESS Baseline**
  - Mass 800 kg
  - Power 760 W
  - Cost $ 171 M
- **1.3 m ACCESS Baseline**
  - Mass 665 kg
  - Power 554 W
  - Cost $ 120 M
- **1.0 m ACCESS Baseline**
  - Mass 480 kg
  - Power 328 W
  - Cost $ 62 M

ACS Report

(1401) Exoplanet STDT 2013-06
June 13, 2013

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ACS
In-session comments

- Changing aperture diameters will not change ACS design.
- Pointing requirement is not a problem but stability requirement is very tight. Active isolation system will be needed as well as SSIRU IMU to meet the stability requirement (as done in ACCESS)

Power Report

(1401) Exoplanet STDT 2013-06
June 13, 2013

Author: R. Hall
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Power
Design Requirements – Option

- **Mission:**
  - ACCESS mission (ref. study 990 Option 2) with a smaller telescope and other “flow-through” changes
  - L2 orbit
  - No Eclipses
- **Stabilization: 3-Axis**
- **Option 1: 1.3m diameter telescope**
- **Option 2: 1 m diameter telescope**

Summary – Reference Study 990 Option 2

Power Summary Chart

Subsystem/Instrument	Power [W]					
	Launch	Deploy	Cruise	Science + Telecom	+Calibration + Retarget	Safe
ACS	38.0	70.3	70.3	238.3	238.3	238.3
C&DH	31.7	38.2	40.8	40.8	40.8	33.5
Instruments	0.0	0.0	0.0	742.2	742.2	148.4
Other Elements	0.0	0.0	0.0	0.0	0.0	0.0
Propulsion System 1	0.7	16.7	16.7	16.7	16.7	0.0
Propulsion System 2	0.0	0.0	0.0	0.0	0.0	0.0
Propulsion System 3	0.0	0.0	0.0	0.0	0.0	0.0
Structures	0.0	0.0	0.0	0.0	0.0	0.0
Telecomm	54.0	54.0	54.0	54.0	54.0	54.0
Thermal	42.2	42.2	42.2	42.2	42.2	42.2
Power Subsystem	38.0	46.0	46.5	167.3	167.3	88.6
TOTALS	204.5	267.4	270.4	1301.4	1301.4	605.0
Subsystem Contingency	43%	43%	43%	43%	43%	43%
Subsystems with Contingency	**292.4**	**382.4**	**386.6**	**1861.0**	**1861.0**	**865.2**
Systems with Contingency	292.4	382.4	386.6	1861.0	1861.0	865.2
Duration (published by Systems, **hours**	1.0	0.5	24.0	24.0	24.0	3.0
Duration (Used in Array Calc, **hours**)	**0.3**	**0.5**	**24.0**	**24.0**	**24.0**	**3.0**

Power

Summary – Option 1 *1.3m Diameter Mirror*

Power Summary Chart

Sizing Mode Power Estimate dropped from 1861W to 1693W

Subsystem/Instrument		Power [W]					
		Launch	Deploy	Cruise	Science + Telecom	Science + Calibration + Retarget	Safe
ACS		38.0	70.3	70.3	238.3	238.3	238.3
C&DH		23.7	35.3	41.1	41.1	41.1	27.7
Instruments		0.0	0.0	0.0	596.0	596.0	119.2
Other Elements		0.0	0.0	0.0	0.0	0.0	0.0
Propulsion System 1		0.7	16.7	16.7	16.7	16.7	0.0
Propulsion System 2		0.0	0.0	0.0	0.0	0.0	0.0
Propulsion System 3		0.0	0.0	0.0	0.0	0.0	0.0
Structures		0.0	0.0	0.0	0.0	0.0	0.0
Telecomm		54.0	54.0	54.0	54.0	54.0	54.0
Thermal		42.2	42.2	42.2	42.2	42.2	42.2
Power Subsystem		77.4	87.7	88.2	195.4	195.4	138.7
TOTALS		**235.9**	**306.2**	**312.5**	**1,183.6**	**1,183.6**	**620.1**
Systems Contingency	%	43%	43%	43%	43%	43%	43%
Calculated Contingency (Override)	%	43%	43%	43%	43%	43%	43%
Subsysem Contingency	W	**101.4**	**131.6**	**134.4**	**509.0**	**509.0**	**266.6**
Subsystems with Contingency		**337.4**	**437.8**	**446.8**	**1,692.6**	**1,692.6**	**886.7**
Systems with Contingency		337.4	437.8	446.8	1,692.6	1,692.6	886.7
Duration (published by Systems, **hours**)		1.0	0.5	24.0	24.0	24.0	3.0

Power
Summary – Option 2 *1m Diameter Mirror*

Power Summary Chart

Sizing Mode Power Estimate dropped from 1861W to 1331W

Subsystem/Instrument		Power [W]					
		Launch	Deploy	Cruise	Science + Telecom	Science + Calibration + Retarget	Safe
ACS		38.0	70.3	70.3	238.3	238.3	238.3
C&DH		23.7	35.3	41.1	41.1	41.1	27.7
Instruments		0.0	0.0	0.0	370.0	370.0	74.0
Other Elements		0.0	0.0	0.0	0.0	0.0	0.0
Propulsion System 1		0.7	16.7	16.7	16.7	16.7	0.0
Propulsion System 2		0.0	0.0	0.0	0.0	0.0	0.0
Propulsion System 3		0.0	0.0	0.0	0.0	0.0	0.0
Structures		0.0	0.0	0.0	0.0	0.0	0.0
Telecomm		54.0	54.0	54.0	54.0	54.0	54.0
Thermal		42.2	42.2	42.2	42.2	42.2	42.2
Power Subsystem		77.4	87.7	88.2	168.7	168.7	134.2
TOTALS		**235.9**	**306.2**	**312.5**	**931.0**	**931.0**	**570.3**
Systems Contingency	%	43%	43%	43%	43%	43%	43%
Calculated Contingency (Override)	%	43%	43%	43%	43%	43%	43%
Subsysem Contingency	W	**101.4**	**131.6**	**134.4**	**400.3**	**400.3**	**245.2**
Subsystems with Contingency		**337.4**	**437.8**	**446.8**	**1,331.3**	**1,331.3**	**815.6**
Systems with Contingency		337.4	437.8	446.8	1,331.3	1,331.3	815.6
Duration (published by Systems, **hours**)		1.0	0.5	24.0	24.0	24.0	3.0

Power
Design – Array

- **Array configuration and articulation the same a those for the reference study #990:**
  - 2 wings
  - 6º array off point
  - 64ºC
- **Total Active Area across two wings**
  - Reference Study: 7.4m total
  - Option 1, 1.3 m diameter mirror: 6.6m total
  - Option 2, 1 m diameter mirror: 5.2m total

Power
Design – Battery and Electronics

- **Battery capacity kept the same a those for the reference study #990:**
  - 28ah total battery capacity
- **Electronics:**

Development and Sparing for Costing			Card / Slice Costs	
EM Systems	Prototypes	Spares	**# Flight**	Parts cost factors (relative to FM parts)
2	1	1	**2**	**Array Segment Switches* [for 2 Distinct Array Panels]**
1	1	1	**1**	**Power Control***
2	1	1	**2**	**Pyro Switches***
2	1	1	**2**	**Thruster Drivers***
2	1	1	**2**	**Houskeeping DC-DC Converters***
6	1	1	**6**	**Load Switches**
2	1	1	**2**	**Battery Control**
0	0	0	**0**	**High Voltage Down Converter***
0	0	0	**0**	**ARPS (Stirling) Controller***
1	1	1	**1**	**Diodes**

Power
Mass Summary

Reference study # 990:	48kg
Option 1:	44kg
Option 2:	42kg

Power

Cost Assumptions – The Same as Those for the Reference Study #990

	User Input
Distinct S/C Power Subsystem Designs	Main S/C in Multi-S/C Mission
Mission Class for the Cost Estimate	B
Spacecraft Complexity	4 - Moderately Low
Spacecraft Heritage (% New or Modified Design)	1 - 0% to 5% (Build to Print, eg. commercial bus, JPL reflight)
Solar Array Complexity	3 - Moderately Low
Solary Array Heritage (% New or Modified Design)	4 - 61% to 80% (Extensive modification - but some reuse throughout subsystem)
Power Electronics Complexity	4 - Moderately Low
Power Electronics Heritage (% New or Modified Design)	5 - 81% to 100% (New design or new design with some inherited design approaches)
Battery Parameters	
Secondary Battery Complexity	3 - Moderately Low
Secondary Battery Heritage (% New or Modified Design)	2 - 21% to 80% (Moderate to significant mods to previously flown design)

Power
Cost – Option 1

All costs in fiscal year 2015 $k	Cost							
	A Concept Study 6 months	B Prelim Design 12 months	C1 Ph C Design 9 months	C2 Ph C Fab 7 months	C3 Ph C S/S I&T 6 months	Total Cost	Non-recurring Cost	Recurring Cost
Power Subsystem	**298**	**2,251**	**10,065**	**13,480**	**2,344**	**28,438**	**14,185**	**14,253**
Management and System Engineering	14	61	46	36	14	170	138	31
Solar Arrays	30	379	531	3,498	328	4,766	1,666	3,100
Nuclear Power Sources	-	-	-	-	-	-	-	-
Storage	-	50	879	1,118	251	2,299	1,351	948
Power Electronics	254	1,559	8,206	6,838	1,379	18,236	9,219	9,017
Bench Test Equipment	-	-	252	1,558	-	1,811	1,811	-
Subsystem I&T	-	202	151	433	371	1,157	-	1,157

Power
Cost – Option 2

All costs in fiscal year 2015 $k	A Concept Study 6 months	B Prelim Design 12 months	C1 Ph C Design 9 months	C2 Ph C Fab 7 months	C3 Ph C S/S I&T 6 months	Total Cost	Non-recurring Cost	Recurring Cost
	Cost							
Power Subsystem	**298**	**2,251**	**10,012**	**12,823**	**2,344**	**27,728**	**14,001**	**13,727**
Management and System Engineering	14	61	46	36	14	170	138	31
Solar Arrays	30	379	478	2,840	328	4,056	1,482	2,574
Nuclear Power Sources	-	-	-	-	-	-	-	-
Storage	-	50	879	1,118	251	2,299	1,351	948
Power Electronics	254	1,559	8,206	6,838	1,379	18,236	9,219	9,017
Bench Test Equipment	-	-	252	1,558	-	1,811	1,811	-
Subsystem I&T	-	202	151	433	371	1,157	-	1,157

Thermal Report

(1401) Exoplanet STDT 2013-06
June 13, 2013

Author: Eric Sunada
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Thermal
Design Assumptions

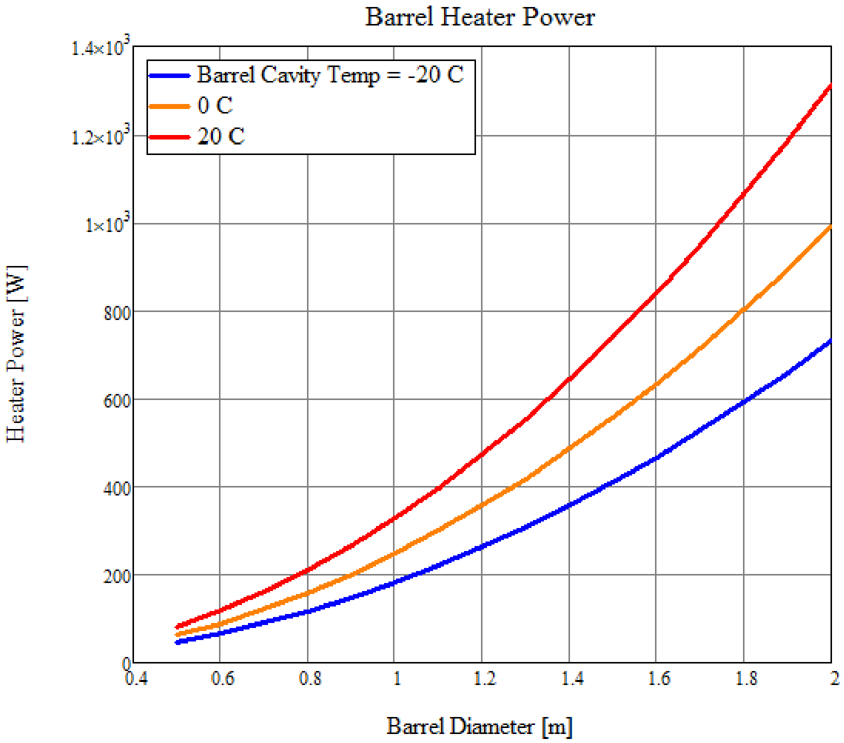
- **Thermal design is based on the old thermal sheet for 990 ACCESS**
  - The Instrument Sun Shield will be on the Instrument, and the mass and cost for the thermal portion of the Sun Shield is carried in the thermal sheet (real structure is still book kept in the instrument cost).
  - Assumed that 500 W can be radiated from the bus panels being used as radiators
- **Option 1: 1.3 m Telescope**
- **Option 2: 1.0 m Telescope**

Thermal
Description

- The spacecraft thermal design is kept the same as the 990 ACCESS study
- Changes to telescope size from 1.5 m (990 ACCESS) to the 1.3m (Option 1) and 1.0 m (Option 2) do not significantly affect the thermal design and cost of the spacecraft thermal subsystem
- Charts from the 990 ACCESS study are included here for reference

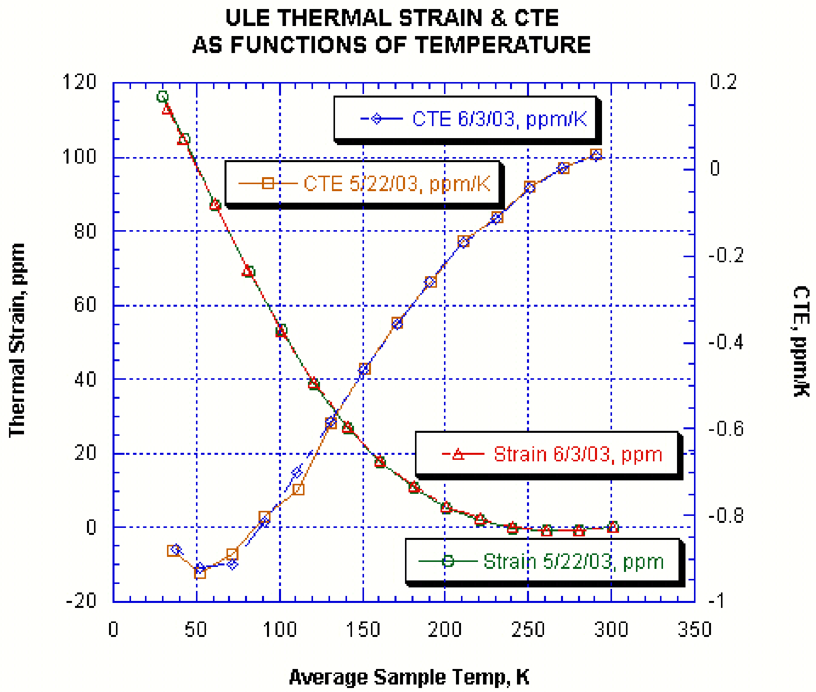
Telescope Heater Power

- **Original 990 ACCESS study assumed the M1, M2, and all other hardware within the barrel was maintained at 20C**
  - Heater power sizing was approximated as black body radiation out of the clear aperture diameter
- **Maintained this paradigm for the current study**
  - Telescope heater power required is shown on the graph to the right



Optimizing the system

- **Significant heater power savings can be realized if the telescope is run at colder temperatures**
  - Need to trade against CTE increase for ULE and other telescope materials
  - Need to trade against the ΔT when going from the room temperature ground condition to the colder on-orbit condition
    - Likely just to be a focus change, so any provisions to adjust for this on-orbit?
  - Note that on-orbit thermal stability is not expected to be any worse at colder temperatures



Thermal
Optimizing the system (cont'd)

- **Significant heater power savings can also be realized by locally heating those components which drive wavefront error**
  - E.g., locally heating the Primary, Secondary, and support structure could reduce heater power usage **by an order of magnitude**
  - Need to trade against the loss of temporal temperature stability and increase in static spatial gradient due to the enclosure (barrel) not being heated. But note that milli-Kelvin temperature control can still be maintained by local heating.

Cost Report

(1401) Exoplanet STDT 2013-06
June 13, 2013

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Cost Disclaimer

- Cost estimates described or summarized in this document were generated as part of a preliminary, first-order cost class identification as part of an early trade space study, are based on JPL-internal parametric cost modeling, assume a JPL in-house build, and do not constitute a commitment on the part of JPL or Caltech.
- JPL and Team X add cost reserves for development and operations. Unadjusted estimate totals and cost reserve allocations would be revised as needed in future more-detailed studies as appropriate for the specific cost-risks for a given mission concept.
- The costs presented are based on Pre-Phase A design information, which is subject to change.

Cost Assumptions and Requirements

The primary objective of this study was to update the cost of the 990 ACCESS 2009-03 Team X study and compare the cost benefits of reducing the instrument telescope size

Requirements

- **Fiscal Year: FY 2015**
- **Mission Class: Class B**
- **Schedule:**
  - Phase A – 6 months
  - Phase B – 12 months
  - Phase C/D – 41 months
  - Phase E/F – 63 months
- **Mission Type: Directed**
- **Flight System Development Mode: In-House**
- **Flight System Redundancy: Dual**
- **ACS Stabilization: 3-axis**
- **Telecom Band: S-only**

Assumptions

- **Mission category: Large**
- **Number of Flight System Testbeds: 2**
- **Flight Software Heritage: Identical Design**
- **Launch Vehicle: Falcon 9 Block 2**
- **Wrap Factors**
  - Phases A-D Reserves 30% - Not calculated on LV and Tracking costs
  - Phases E-F Reserves 15% - Not calculated on LV and Tracking costs
  - E&PO 1% - Not calculated on LV

Cost
Baseline Total Cost

Baseline Costs

- Costs estimated by taking the 990 ACCESS 2009-03 Team X study and:
  - Inserting the design into the new, institutional cost models (ICMs)
  - Inflate the costs to FY2015 dollars
  - Change LV from Atlas V to Falcon 9 Block 2

COST SUMMARY (FY2015 $M)	Team X Estimate		
	CBE	Res.	PBE
Project Cost	$938.3 M	21%	$1137.1 M
Launch Vehicle	$237.3 M	0%	$237.3 M
Project Cost (w/o LV)	$701.0 M	28%	$899.8 M
Development Cost	$630.7 M	30%	$819.3 M
Phase A	$6.3 M	30%	$8.2 M
Phase B	$56.6 M	30%	$73.5 M
Phase C/D	$566.0 M	30%	$735.4 M
Operations Cost	$70.3 M	14%	$80.5 M

Cost

Total Cost – Option 1 and 2

- Option 1 – Reduced Telescope aperture to 1.3m

COST SUMMARY (FY2015 $M)	Team X Estimate		
	CBE	Res.	PBE
Project Cost	$776.8 M	24%	$959.7 M
Launch Vehicle	$128.9 M	0%	$128.9 M
Project Cost (w/o LV)	$647.9 M	28%	$830.9 M
Development Cost	$578.1 M	30%	$751.0 M
Phase A	$5.8 M	30%	$7.5 M
Phase B	$52.0 M	30%	$67.6 M
Phase C/D	$520.4 M	30%	$676.0 M
Operations Cost	$69.8 M	14%	$79.9 M

- Option 2 – Reduced Telescope aperture to 1.0m

COST SUMMARY (FY2015 $M)	Team X Estimate		
	CBE	Res.	PBE
Project Cost	$715.4 M	23%	$880.1 M
Launch Vehicle	$128.9 M	0%	$128.9 M
Project Cost (w/o LV)	$586.6 M	28%	$751.2 M
Development Cost	$517.3 M	30%	$672.0 M
Phase A	$5.2 M	30%	$6.7 M
Phase B	$46.6 M	30%	$60.5 M
Phase C/D	$465.7 M	30%	$605.0 M
Operations Cost	$69.2 M	14%	$79.2 M

Cost
Option Comparisons

Overall Project Comparison

WBS Elements	Baseline	Option 1	Option 2
Project Cost (including Launch Vehicle)	$1137.1 M	$959.7 M	$880.1 M
Development Cost (Phases A - D)	$819.3 M	$751.0 M	$672.0 M
01.0 Project Management	$15.7 M	$15.7 M	$15.7 M
02.0 Project Systems Engineering	$18.2 M	$18.2 M	$18.2 M
03.0 Mission Assurance	$21.7 M	$21.7 M	$21.7 M
04.0 Science	$10.0 M	$10.0 M	$10.0 M
05.0 Payload System	$252.4 M	$201.5 M	$143.4 M
06.0 Flight System	$237.8 M	$236.3 M	$233.9 M
07.0 Mission Operations Preparation	$20.0 M	$20.0 M	$20.0 M
09.0 Ground Data Systems	$20.8 M	$20.8 M	$20.8 M
10.0 ATLO	$23.5 M	$23.5 M	$23.5 M
11.0 Education and Public Outreach	$2.2 M	$2.1 M	$1.9 M
12.0 Mission and Navigation Design	$8.4 M	$8.4 M	$8.4 M
Development Reserves	$188.7 M	$172.9 M	$154.7 M
Operations Cost (Phases E - F)	$80.5 M	$79.9 M	$79.2 M
01.0 Project Management	$5.7 M	$5.7 M	$5.7 M
02.0 Project Systems Engineering	$0.0 M	$0.0 M	$0.0 M
03.0 Mission Assurance	$1.0 M	$1.0 M	$1.0 M
04.0 Science	$16.4 M	$16.4 M	$16.4 M
07.0 Mission Operations	$31.0 M	$31.0 M	$31.0 M
09.0 Ground Data Systems	$9.6 M	$9.6 M	$9.6 M
11.0 Education and Public Outreach	$6.7 M	$6.2 M	$5.6 M
12.0 Mission and Navigation Design	$0.0 M	$0.0 M	$0.0 M
Operations Reserves	$10.2 M	$10.1 M	$10.0 M
8.0 Launch Vehicle	$237.3 M	$128.9 M	$128.9 M
Launch Vehicle and Processing	$237.3 M	$128.9 M	$128.9 M
Nuclear Payload Support	$0.0 M	$0.0 M	$0.0 M

Detailed Payload and Flight System Comparison

WBS Elements	Baseline	Option 1	Option 2
Project Cost (including Launch Vehicle)	$1137.1 M	$959.7 M	$880.1 M
Development Cost (Phases A - D)	$819.3 M	$751.0 M	$672.0 M
05.0 Payload System	$252.4 M	$201.5 M	$143.4 M
5.01 Payload Management	$0.0 M	$0.0 M	$0.0 M
5.02 Payload Engineering	$0.0 M	$0.0 M	$0.0 M
Element 01	$252.4 M	$201.5 M	$143.4 M
Lyot coronagraph	$81.8 M	$81.8 M	$81.8 M
Telescope	$170.6 M	$119.7 M	$61.6 M
06.0 Flight System	$237.8 M	$236.3 M	$233.9 M
6.01 Flight System Management	$3.7 M	$3.7 M	$3.7 M
6.02 Flight System Systems Engineering	$28.9 M	$28.9 M	$28.9 M
Element 01	$198.6 M	$197.1 M	$194.7 M
6.04 Power	$28.9 M	$28.4 M	$27.7 M
6.05 C&DH	$22.8 M	$22.8 M	$22.8 M
6.06 Telecom	$22.5 M	$22.5 M	$22.5 M
6.07 Structures (includes Mech. I&T)	$37.9 M	$36.9 M	$35.2 M
6.08 Thermal	$7.5 M	$7.5 M	$7.5 M
6.09 Propulsion	$12.2 M	$12.2 M	$12.2 M
6.10 ACS	$51.1 M	$51.1 M	$51.1 M
6.11 Harness	$3.2 M	$3.2 M	$3.2 M
6.12 S/C Software	$11.7 M	$11.7 M	$11.7 M
6.13 Materials and Processes	$0.7 M	$0.7 M	$0.7 M
6.14 Spacecraft Testbeds	$6.6 M	$6.6 M	$6.6 M
Operations Cost (Phases E - F)	$80.5 M	$79.9 M	$79.2 M
8.0 Launch Vehicle	$237.3 M	$128.9 M	$128.9 M

Cost Rationale

Cost Drivers

- The primary cost driver was the telescope
  - Even with the reduction in telescope aperture, the ACS system still required the vibration isolation system that drove the subsystem costs
  - The major cost reduction came from the telescope itself, the accommodation costs, spacecraft structure, thermal and power all had minimal cost savings due to the reduction in size

Cost Potentials

- **Potential Cost Savings**
  - Optimization of the thermal system could potentially decrease the size of the power system required
    - Reduction of the solar array area will have minimal impact on the ACS design
- **Potential Cost Uppers**
  - None discussed