EUV Spectrometer Proto-Consortium Meeting

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Thermal Strategy

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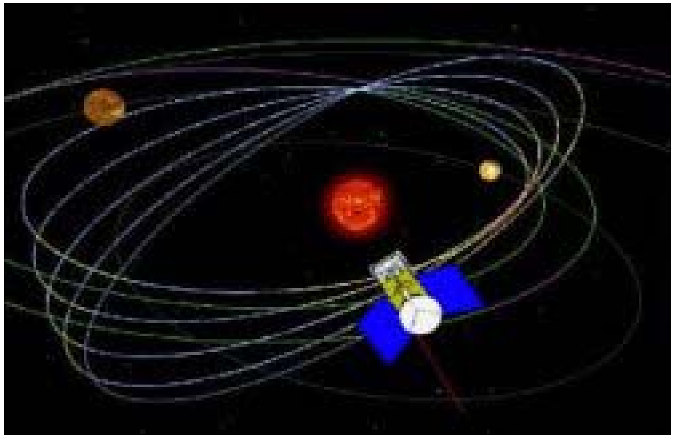
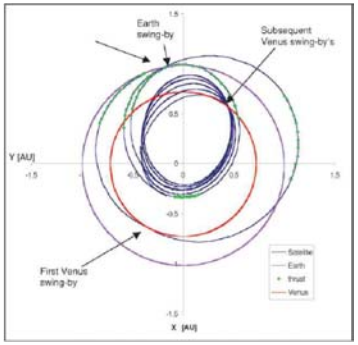
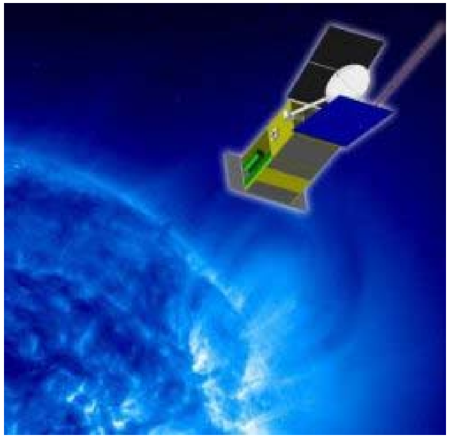


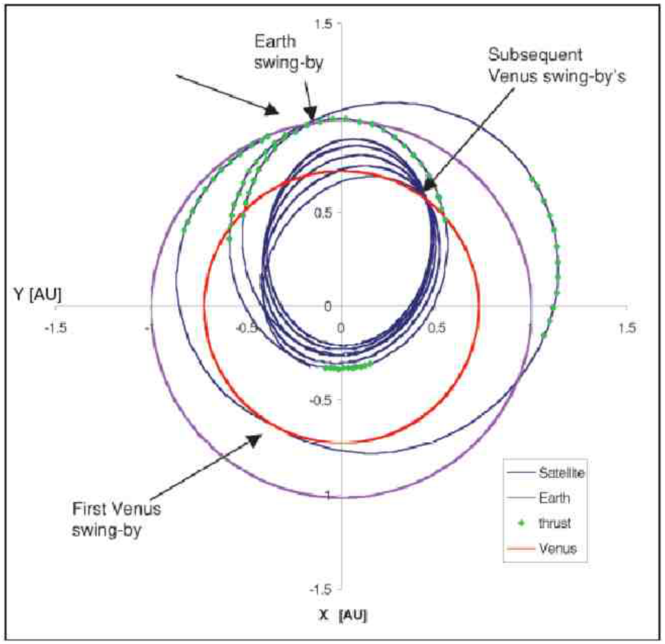




Mission Overview

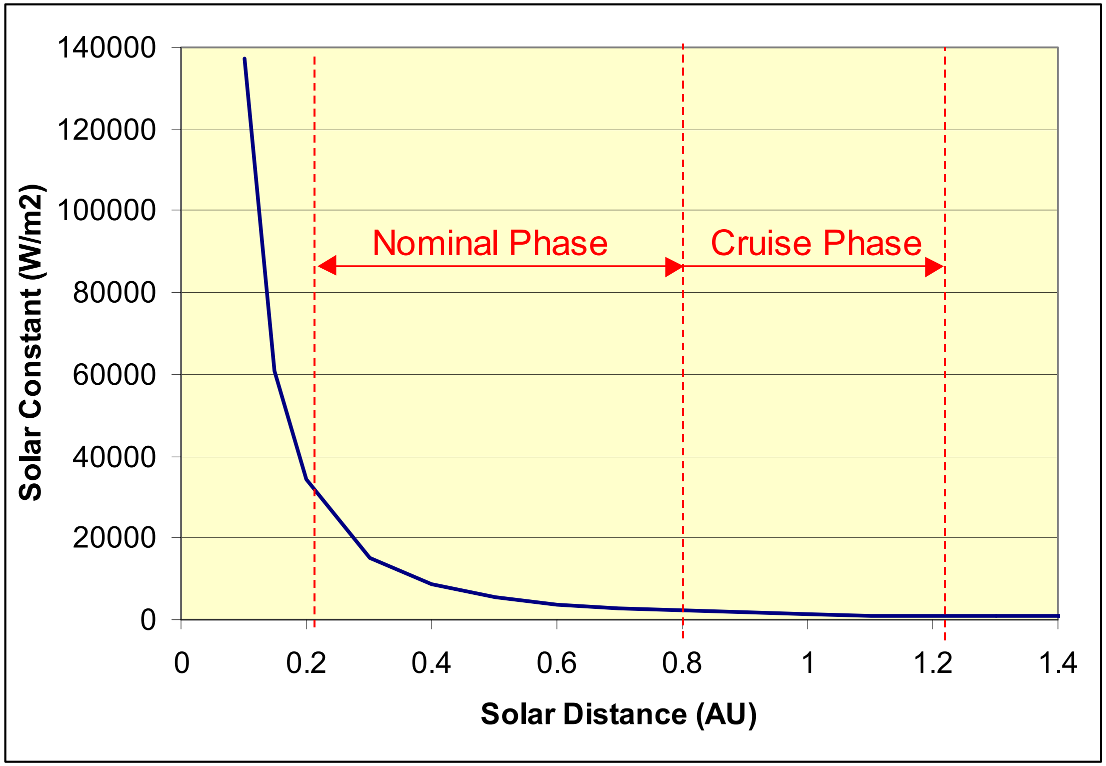
- Orbit:
  - Nominal Phase Solar Distance: 0.21 - 0.8AU.
  - Cruise Phase Maximum Aphelion Distance:1.21A.
  - 149 day orbital period.

- Mission Phases:
  - Cruise Phase: 0 -1.86 years
  - Nominal Mission: 1.86 -4.74 years
  - Extended Mission: 4.74 - 7.01 years



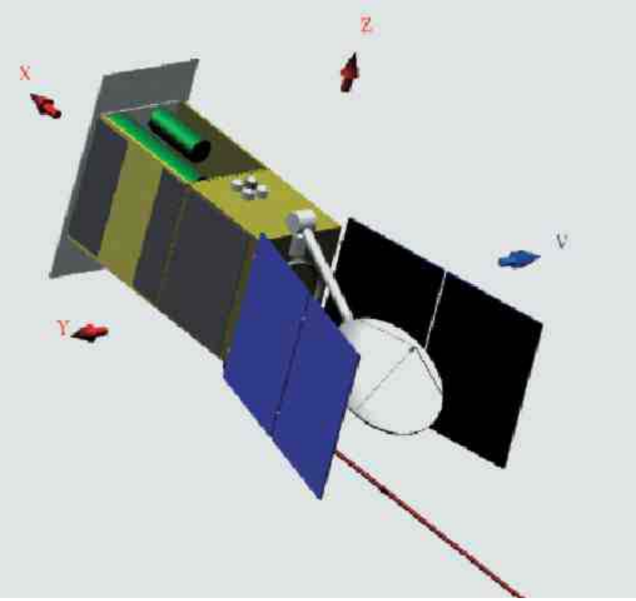
Mission Overview

- Solar Constant Variation with Distance From Sun:
  - 0.2AU: 34269W/m^2
  - 0.8AU: 2142W/m^2
  - 1.2AU: 952W/m^2



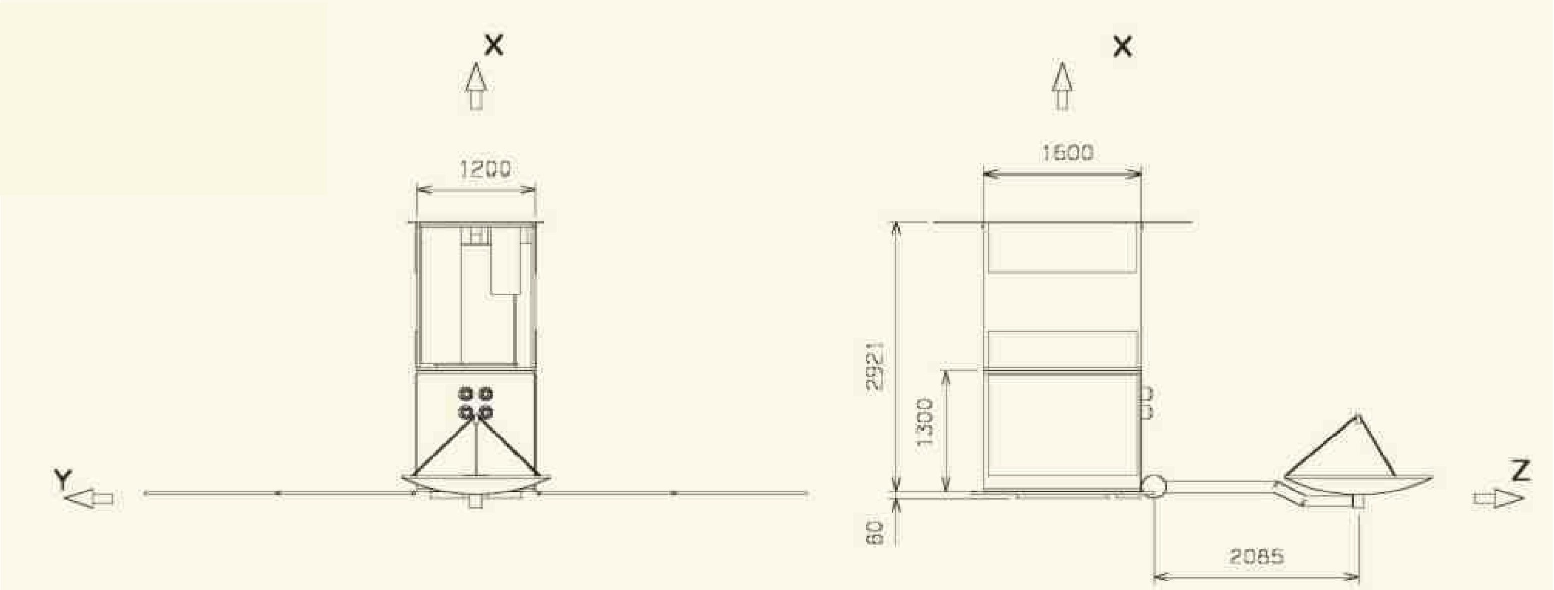
Spacecraft Design

- Three-axis stabilised.
- Always sun-pointing, except during SEP firing
- Sunshield on +x (sun facing) surface, shadows spacecraft walls during thruster firing.
- Spacecraft radiators on +/-y faces used to cool sunshield in conjunction with heat pipes.
- Instruments isostatically mounted on +z S/C face, open to space on +z face.
- Z-facing surfaces have view to rear of sunshield.

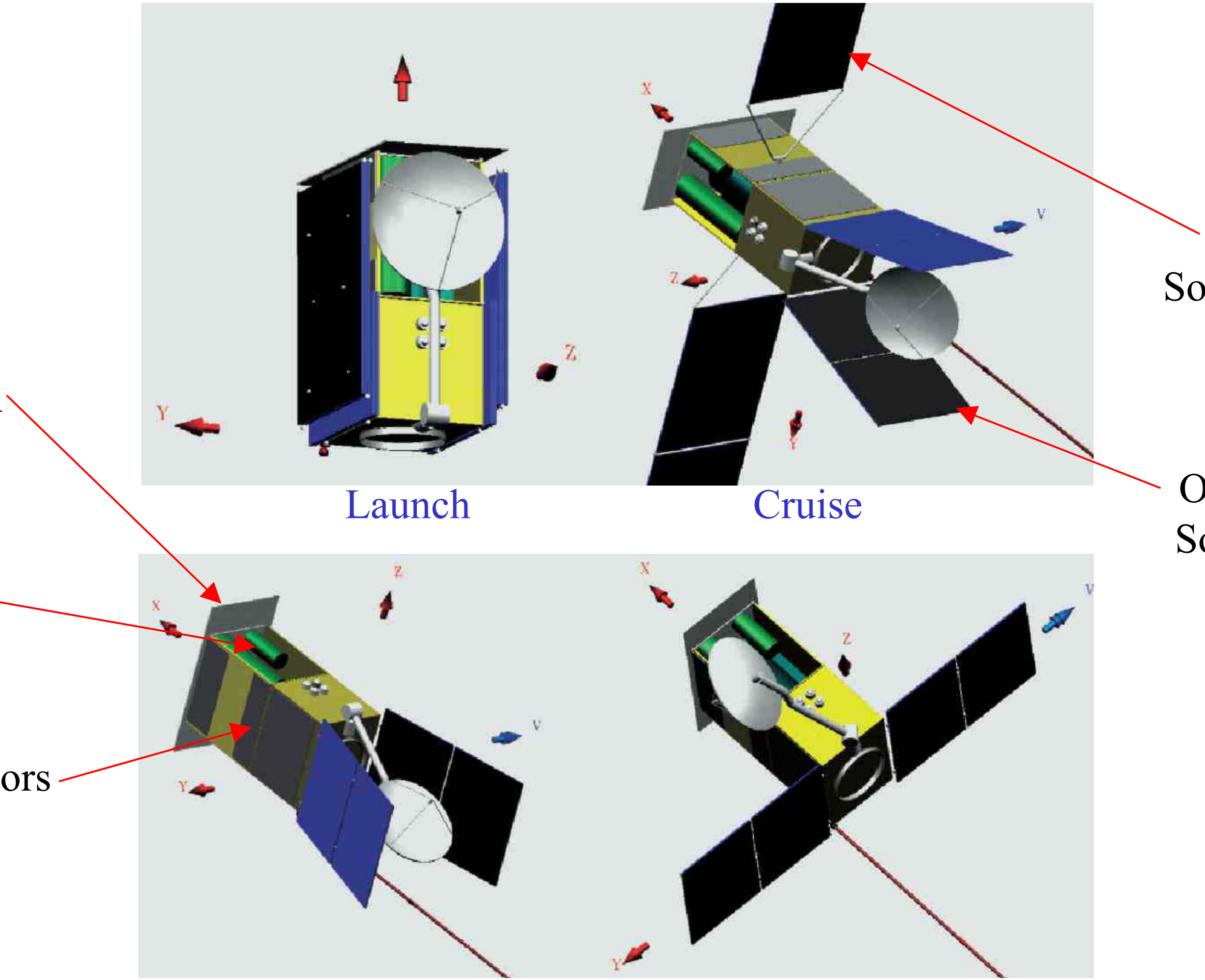


Spacecraft Design

- Cruise solar arrays jettisoned after last firing of solar electric propulsion module.
- Observation solar arrays on +/-y faces (Tmax = 150deg.C)
  - folded back during Cruise and Observation Phases.
  - extended during Downlink Phase.



Spacecraft Design



Cruise Solar Arrays

Observation Solar Arrays

Sunshield

Payload

S/C Radiators

Launch

Cruise

Observation

Downlink

Instrument Thermal Requirements

- Thermal control system must accommodate changes in solar constant from **952W/m^2 (1.2AU) to 34,269W/m^2 (0.2AU)**.
- Structure and Optics Temperature:
  - Multilayer coatings on optics are assumed to be the limiting factor in defining the instrument bulk temperature.
  - A temperature limit for such coatings of **<100deg.C** is assumed.
- Detector Temperature: target<-80deg.C, requirement **<-60deg.C**.
- Minimise temperature gradients through instrument.
- Minimise temperature fluctuations around orbit / throughout mission.
- Size and mass limitations (e.g. instrument radiators).
- Heater power limitations (cruise/aphelion)
- Control heat loads to/from spacecraft to ‘acceptable’ level.

Thermal Design -General

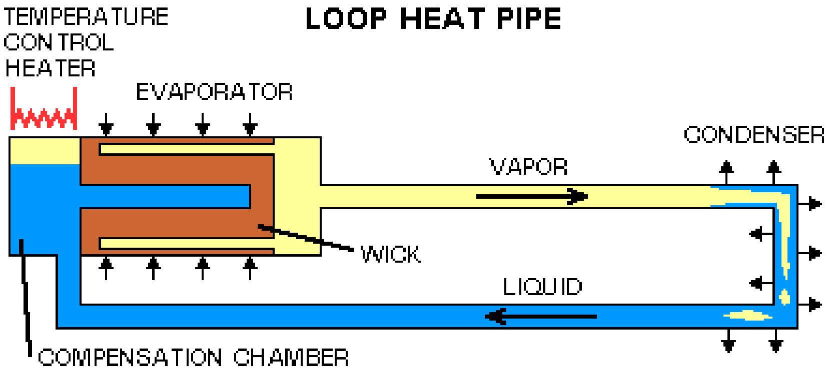
- Aperture size: minimise as far as possible.
- Reflect incoming solar load to Space where possible.
- Multilayer Coatings -control absorbed thermal load on optics.
- Optics absorbed loads dumped to Space via radiators on +z face.
- Dedicated cold radiator for detector cooling.
- High conductance cold fingers or looped heat pipes (LHP) to radiators.
- Heat switches / LHPs used to disconnect radiators during cold periods, as necessary.
- Use of compensating heaters during Nominal Phase (around aphelion), and Cruise Phase.
- High conductivity materials for main structure, or radiative isolation of structure, to reduce temperature gradients.
- Low CTE materials for structure (CFRP, SiC)

Hardware: Radiator Conductive Links

- High conductance links required in order to transfer absorbed heat from optics components to instrument radiators with minimum temperature differential.
- Necessary to disconnect radiators during cold phases to limit survival heater power and temperature fluctuations.
- Options:
  - Conventional Cold Finger and Heat switch: relatively low conductance. Heat switch results in additional thermal impedance in link -not suitable for very high loads due to high resulting temperature differential.
  - Looped Heat Pipe (LHP): Two-phase, passive heat transfer device - small temperature differentials and high heat transport power densities.

Hardware: Looped Heat Pipes

- Passive device with no moving parts and high reliability.
- Simple and robust start-up compared to CPLs. LHP starts as soon as a minimal temperature gradient exists between the compensation chamber and the evaporator.
- Wick complexity only in evaporator therefore tubing from cooled components to radiator may be smooth-walled and flexible.
- Controlled to maintain fixed evaporator temperatures for range of powers by controlling the compensation chamber temperature. Circulation can be stopped by heating the compensation chamber above the evaporator temperature by about 1-3 °C.
- Suitable working fluids for this application limited by instrument temperatures at 0.2AU and 1.2AU
  - Ammonia (-40deg.C<T<+80deg.C)
  - Methanol (+55deg.C<T<+140deg.C)



Hardware: Looped Heat Pipes

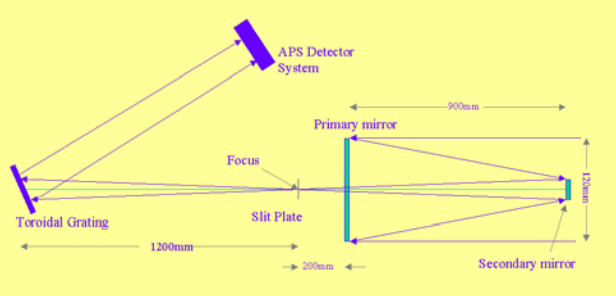
Application	Transport Length	Working Fluid / Temp Range	Casing Material	Wick Material	Maximum Heat Load	Maximum Evaporator Heat Flux	Evaporator-Condenser Delta T
Avionics	0.6 m	Ammonia -40 to 80°C	SS	Nickel, POREX	200 W	5 W/cm²	15 K
High Heat Flux Electronics	0.6 m	Ammonia -40 to 80°C	SS	Nickel, Titanium	500 W	100 W/cm²	35 K
Solar Energy	2 m	Methanol 55 to 140°C	SS	SS	1 kW	15 W/cm²	20K
Anti Icing	1 m	Ammonia -40 to 80°C	SS	Nickel	1.5 kW	15 W/cm²	15K
Cryogenics LHPs	1 m	Oxygen 55 to 150K	SS	Nickel	10 W	1 W/cm²	15K
Electronics	1 m	Water 90 to 250°C	Copper	Copper	175 W	20 W/cm²	25K
Space Radiator	2 m	Ammonia -40 to 80°C	SS	Nickel	500 W	12 W/cm²	10K

Hardware: Multilayer Technology

- Incoming thermal loads on the various optics surfaces can be controlled through the use of coatings with specific thermo-optical properties, which also meet optical requirements.
- Optical surfaces must reflect in the imaging wavelength ranges:
  - 17nm-22nm, 58nm to 63nm and >91.2nm.
- In order to control the thermal load from the sun, the surfaces must either reflect or absorb in the range 0.3μm to 2.5μm.
  - Reflective Multilayer:
    - Si-C/Gold/10 layers Silicon-Platinum/Silicon/Carbon
    - reflectivity (vis/IR) = 0.9
    - reflectivity (imaging) = 0.24
  - Absorbing Multilayer:
    - Si-C/Gold/10 layers Silicon-Platinum/Platinum
    - reflectivity (vis/IR) = 0.3
    - reflectivity (imaging) = 0.24

Instrument Thermal Design Options

- **Design 1a - ‘Straw-man -Original Concept’**
  - Original thermal concept from Assessment Study Report, July 2000.
  - Reject solar load back to Space through reflective surfaces (α**=0.2**) on Primary and Secondary Mirrors.
  - Assumes that only **20% of reflected load from Primary falls onto Secondary**. 80% is reflected to Space through the aperture.
- **Design 1b - ‘Straw-man - Reflective Optics’**
  - As Design 1a but **Secondary Mirror receives 86% of reflected load from Primary**. The remainder is reflected to Space through the aperture.
  - Primary and Secondary Mirrors have highly reflective (α**= 0.1**) surfaces.

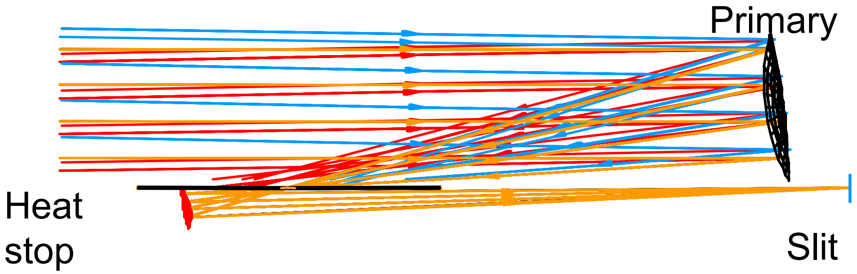


Instrument Thermal Design Options

- **Design 1c -'Straw-man -Absorbing Optics'**
  - Since cooling of the Secondary Mirror or Slit Plate appears challenging, Primary Mirror surface made absorbing (α**=0.7**).
  - Heat absorbed by Primary transferred to radiator via looped heat pipe.
  - **Secondary Mirror receives 86% of reflected load from Primary**. The remainder is reflected to Space through the aperture.
  - Secondary Mirror reflecting (α**= 0.1**).
  - Heat absorbed by Secondary transferred to radiator via cold finger.
  - Slit Plate loads conducted to radiator via cold finger.
- **Design 1d -'Straw-man -Absorbing Optics'**
  - As Design 1c except Secondary Mirror absorbing (α**= 0.7**) in the thermal infra-red.

Instrument Thermal Design Options

- **Design 2 ‘Front End Grating’**
  - Reject solar load using gold grazing incidence grating as 1st element.
  - Grating has high reflectivity (α**=0.1)**
  - Heat absorbed by grating is conducted to radiator via cold finger.
- **Design 3 ‘Off-Axis Telescope’:**
  - Primary Mirror highly reflecting (α**=0.1)**.
  - Reflective Heat Stop/Slot between Primary and Secondary -reflects 90% of incident heat back to Space.
  - Heat absorbed by Heat Stop is conducted to radiator using cold finger.
  - 1% of incident heat passes through slot onto Secondary.



Thermal Analysis

- Limited thermal analysis of the designs has been performed using Excel spreadsheets. Aim is to assess the thermal implications of the various optics designs.
- Solar loads calculated within spreadsheet, with inputs on beam path from optics team.
- Optics Assumptions
  - Aperture Diameter 0.12m
  - Primary Mirror Diameter 0.12m
  - Secondary Mirror Diameter 0.02m
- Results show approximate radiator areas required for cooling of optics components at the 0.2AU perihelion case.

Thermal Analysis

- Generally aim to maintain optics at approximately 80deg.C (20deg.C margin on multilayer Tmax).
- However where LHPs are used the temperature is reduced in order that working fluid maximum temperature is not exceeded (ammonia Tmax = +80deg.C).
- Calculations of radiator areas assume emissivity of 0.9 and perfect view to Space.
- In fact radiators on the +z surface have a significant view (~20%) to the rear face of the Spacecraft Sunshield.
- Therefore actual radiator sizes will be larger than those calculated.

Thermal Analysis - 0.2AU Case

	Design 1a	Design 1b	Design 1c	Design 1d
	Straw-man a	Straw-man b	Straw-man c	Straw-man d
Grating Absorbed Load (W)	-	-	-	-
Grating Temperature (°C)	-	-	-	-
Primary Mirror Absorbed Solar Load (W)	62	52	284	264
Primary Mirror Temperature (°C)	*(70)*	85	65	65
Primary Radiator Link	Aluminium Cold Finger S/L = 0.02m	Aluminium Cold Finger S/L = 0.02m	Looped Heat Pipe	Looped Heat Pipe
Primary Radiator Temperature (°C)	70	70	50	50
Primary Radiator Area (m2)	0.11	0.074	0.511	0.475
Secondary Mirror Absorbed Solar Load (W)	9.9	37	15.7	72.9
Secondary Mirror Temperature (°C)	*(83)*	81	75	81
Secondary Radiator Link	Aluminium Cold Finger S/L = 0.02m	Aluminium Cold Finger S/L = 0.02m	Aluminium Cold Finger S/L = 0.02m	Aluminium Cold Finger S/L = 0.04m
Secondary Radiator Temperature (°C)	83	70	70	70
Secondary Radiator Area (m2)	0.012	0.052	0.022	0.103
Slit Incident Solar Load (W)	39.8	205	59.2	22.9
Slit Temperature (°C)		65	87	77
Slit Radiator Link		Looped Heat Pipe	Aluminium Cold Finger S/L = 0.02m	Aluminium Cold Finger S/L = 0.02m
Slit Radiator Temperature (°C)		50	70	70
Slit Radiator Area (m2)		0.370	0.084	0.032
TOTAL Radiator Area (m2)	0.122+?	0.496	0.617	0.611

Thermal Analysis - 0.2AU Case

	Design 2 Front End Grating
Grating Absorbed Load (W)	39
Grating Temperature (°C)	61.4
Grating Radiator Link	Aluminium Cold Finger S/L = 0.02m
Grating Radiator Temperature (°C)	50
Grating Radiator Area (m2)	0.07
TOTAL Radiator Area (m2)	0.07

	Design 3 Off-Axis Telescope
Primary Mirror Absorbed Solar Load (W)	39
Primary Mirror Temperature (°C)	61
Primary Radiator Link	Aluminium Cold Finger S/L = 0.02m
Primary Radiator Temperature (°C)	50
Primary Radiator Area (m2)	0.070
Heat Stop Absorbed Solar Load (W)	35
Heat Stop Temperature (°C)	61
Heat Stop Link	Aluminium Cold Finger S/L = 0.02m
Heat Stop Radiator Temperature (°C)	50
Heat Stop Radiator Area (m2)	0.063
Secondary Mirror Absorbed Solar Load (W)	2.4
Secondary Mirror Temperature (°C)	50.7
Secondary Radiator Link	Aluminium Cold Finger S/L = 0.02m
Secondary Radiator Temperature (°C)	50
Secondary Radiator Area (m2)	0.004
Slit Incident Solar Load (W)	1.0
Slit Temperature (°C)	50.3
Slit Radiator Link	Aluminium Cold Finger S/L = 0.02m
Slit Radiator Temperature (°C)	50
Slit Radiator Area (m2)	0.002
TOTAL Radiator Area (m2)	0.14

Analysis Summary

- **Design 1:** Straw-man Optical Design (1a-d) requires large radiator area (>0.6m2) and LHPs to maintain optics at approximately 80deg.C at 0.2AU.
  - Design 1a
    - **Since shown that sizing of Secondary Mirror to receive 20% of reflected signal is unacceptable to the optics design.**
  - Design 1b
    - **Slit Plate loads unacceptable? - beam highly focussed at this point. LHP required on Primary.**
  - Design 1c
    - **High Slit Plate load - beam highly focussed at this point. LHP required on Primary.**
  - Design 1d
    - **High Secondary and Slit Plate loads. Issue of removing heat from Secondary. LHP required on Primary.**

Analysis Summary

- **Design 2:**
  - Significantly reduced instrument absorbed loads and hence radiator sizes and temperatures.
- **Design 3:**
  - Significantly reduced instrument absorbed loads and hence radiator sizes and temperatures.
  - Easier to remove heat from Heat Stop and Secondary since not in Primary beam.
  - Focussed load on Heat Stop may be cause for concern.

Summary

- Radiators used to dump absorbed optics heat to Space.
- Straw-man design requires radiator area of >0.6m^2 for 80deg.C optics.
- Alternative designs have significantly smaller radiators and lower temperatures.
- Separate cold (<-80deg.C) detector radiator.
- High couplings from optics to radiators -may require LHP system.
- Radiators may require decoupling during cold phases.
- Compensation heaters required during cold phases.
- Multilayers must control thermal/IR load in addition to imaging wavelengths.

Future Work

- More detailed analysis of various design options, with iterations of current optical designs / alternative designs.
- Transient analysis of orbital fluctuations.
- Assessment of survival heater power requirements during Cruise and Nominal Phases.
- Confirmation of maximum temperature of multilayers.
- Further investigation of looped heat pipes -feasibility/ design/ working fluid/ temperature limitations/ performance/supplier/ mass/ volume, etc.
- Further investigations into heat switches -feasibility/ design/ temperature limitations/ performance/supplier/ mass/ volume, etc.
- Assessment of heat loads onto detector module and resulting detector radiator design.
- Spacecraft interface...