Fresnel Lens Gamma Ray Telescope

System Overview

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Outline

- Overall Assessment
- Baseline Configuration
- Options Considered
- Comments, Issues, and Concerns

Overall Assessment

- **Study started with two known difficulty areas**
  - Orbits and required propulsion; and Pointing acquisition and required Metrology
- **1: Orbits / Propulsion**
  - Favorable findings: a viable mission may be feasible even using existing techniques
- **2: Pointing / Metrology**
  - Unfavorable findings: a suitable metrology system couldn't be identified
  - An entire class of like missions struggles w/ very similar problems; research is underway
  - A study for a sub-microarcsecond star sensor will be performed in the ISAL in a few weeks

- **Conclusion**
  - The message is loud and clear: a breakthrough in metrology is required, before credible mission plans can be formulated for this class of missions

Baseline Configuration Summary

Study Configuration Summary - System Page

Launch	Date	LV	Mass [kg]	LV Cost [2002 $M]	Dispersion	
	7/1/2012	**Delta IV Heavy, 5m x 19m fairing**	**LV Capability = 9306 (C3=0)**		**negligible,** absorbed by orbit maint.	
Orbit	Altitude	Inclination	Asc. Node	Eclipe	Separation	
	Heliocentric / Offset Heliocentric; leading or trailing Earth at .1AU	**Lens in the Ecliptic; Detector +/- 1M km above / below**	**n/a**	**n/a**	**between s/c: 750,000 - to 1 M km**	
	In one month to exit Earth grav. Field.					
Lens s/c	Mass [kg]	Size [m]	Shape	Construction	Orbit Avg Power [W]	Data Volume
	923 kg (2 Lenses = 600 kg)	**5.5 tall x 4.5 dia (lens is 4.5 m tall)**	**Octagonal**	**Al / Honeycomb**	**260 W**	**Only 4 kbps hskp**
Detector s/c	Mass [kg]	Size [m]	Shape	Construction	Orbit Avg Power [W]	Data Volume
	1285 kg dry (Detector = 200kg)	**3 tall x 3 dia**	**Octagonal**	**Al / Honeycomb**	**6400 W** (det. 200 W)	**1 kbps sci + 4 kbps hskp**
Design Life	Required [years]	Goal [years]	Size Consumables For [yrs]	Redundancy		
	3	**5**	**5**	**Selective**		
Disposal	Type	Casualty Area [m2]	Delta - v req'd			
	Not Required	**n/a**	**n/a**			

Baseline Configuration Summary

Study Configuration Summary - Subsystems Page - Lens Spacecraft					
ACS	**Type**	**Sensors / Actuators**	**Wheels**	**Moment Unload, Actuators**	
	3 axis stab. w/ ~ arcmin. cntl & knldg	Full complement, no torquers	4 x "A" wheels	Cold gas prop.	
Metrology System	**Cost [$M]**	**Mass [kg]**	**Power [W]**		
	30	*50*	*200*		
	Laser Beacon towards Detector s/c. *Numbers in red/italics are PLACEHOLDERS only!*				
Power	**Arrays**	**Cell Efficiency**	**Array Drive**	**Energy Storage**	**Bus**
	Body mounted panels, 10.8 m2 total,	35%	n/a	10 Ah LiIon, few cycles (not an issue)	28V; 600W max. required
Thermal	**Radiators**	**Approach**	**Lens**		
	S/c has dark side for radiators	Traditional	Lens covered w/ MLI		
Propulsion	**System**	**Total Delta V [m/s]**	**Tank**	**Thrusters**	**Propellant Margin**
	Cold gas system (Isp = 70 s)	Small (< 10 m/s), used for momentum unload only)	5 kg gas	8 ea., sized a.r. for "A" wheels	Generous
Data Syst	**CPU**	**Storage**	**Redundancy**	**Resources**	
	One unit for C&DH, ACS, & Sci	1.6 Gbits (holds 2 days)	Full, internal	12 kg / 18 W	
RF Comm	**Downlink 1**	**Downlink 2**	**Contacts**	**Antennas**	**Inter s/c comm**
	X/Ka to DSN 34m; Command/telemetry/ranging to 1 AU	S Band for backup & Near Earth	Store data & dump 15 minutes/day	1.5 m gimbaled	Not Defined
Miss. Ops	**MOC**	**Staffing**	**Protocol**	**Error Correction**	
	COTS-based	8x5	IP	Reed-Solomon	

Baseline Configuration Summary

Study Configuration Summary - Subsystems Page - Detector Spacecraft

ACS	Type	Sensors	Wheels	Moment Unload, Actuators	
	3 axis stab. w/ ~ arcmin. cntl & knldg	Full complement, no torquers	4 x "A" wheels	Cold gas prop.	
Metrology System	Cost [$M]	Mass [kg]	Power [W]		
	100	*100*	*100*		
	Numbers in red/italics are PLACEHOLDERS only!				
Power	Arrays	Cell Efficiency	Array Drive	Energy Storage	Distribution
	2 wings, 46.66 m2	35%	Single Axis	60 Ah LiIon, few cycles (not an issue)	28V; 13 kW load bus
	S/C rolled to point at sun at all times				
Thermal	Radiators	Approach	80 K Passive Cooler		
	S/c has dark side for radiators	Traditional	2Pi steradian unobstructed view		
Propulsion	System	Repoint Thrusters	Orb. Mainten. Thrusters	Fine Pos. Thrusters	Tanks
	3 size class Thrusters	6 ea. .165 N XIPS 25's (25 cm dia; 4.5 kW; Isp = 3800 s; life 8000 hrs, restarts few thou times)	14 ea. .34 N Hall Thrusters (4.5 kW; Isp = 1500 s; life 10000hrs)	Micro cold gas system (Isp = 70 s)	6 tanks total 3.65 m3, custom made; volume for 7300 kg, loaded to ~5000 kg
Data Syst	CPU	Storage	Redundancy	Resources	
	One unit for C&DH, ACS, & Sci	1.6 Gbits (holds 2 days)	Full, internal	12 kg / 18 W	
RF Comm	Downlink 1	Downlink 2	Contacts	Antennas	Inter s/c comm
	X/Ka to DSN 34m Command/telemetry/ranging to 1 AU	S Band for backup & Near Earth	Store data & dump 15 minutes/day	1.5 m gimbaled	Not defined, depends on Metrology Syst.
Miss. Ops	MOC	Staffing	Protocol	Error Correction	
	COTS-based	8x5	IP	Reed-Solomon	

Baseline Configuration
Launch Vehicle

- **The following launch vehicles were considered (details in LV presentation):**
  - Ariane 4
  - Ariane 5
  - Atlas III
  - Atlas V's
  - Delta II's
  - Delta III's
  - Delta IV's

- **Delta IV Heavy baselined**

Baseline Configuration
Orbit Properties

- **Earth leading/trailing drift away orbit baselined. Drift rate is .1 AU/year.**
  - Slowing or "stopping" .1AU drift rate is constrained, not really an option
- **Alternate mission orbits exist, must be fully explored**
  - Distant retrograde orbits
  - Solar-libration: "kite-like" solar sail "floating" on a toroid-like pseudo-libration surface which envelops L1 between Sun-Earth
- **Summary conclusions**
  - Mission is feasible, even with "brute force" orbit baselined
  - Refinement and target planning may vastly improve on baselined orbit
  - Other orbit options may prove even better
  - Extensive detailed orbit R&D work is required for this mission

Baseline Configuration
Bus Subsystems Mass

Bus Structure	74.0	183.0
RF Masts, Dishes, Gimbals	18.0	18.0
ACS	33.4	38.4
Metrology System	*50.0*	*100.0*
C&DH	12.0	12.0
Power System	30.2	380.0
Solar Arrays	incl	incl
Bus Harness	10.0	25.0
Thermal Hardware	22.0	22.0
RF Communications	61.0	61.0
Separation System, spacecraft side	8.0	8.0
Propulsion	20.0	400.0
Propellant	-	5000.0
DPAF	143.0	-
Total	**338.6**	**6247.4**

Note: Det S/A upscaled to 46.66 m2

Baseline Configuration
Overall Mass Summary

PAYLOAD TOTAL	800.0
BUS SUBSYSTEMS TOTAL	6586.0
ACTUAL LAUNCH MASS	7386.0
CONTINGENT MASS (ACT. LAUNCH MASS + 20%)	8863.2
Delta Iv Heavy capability to C3 = 0	9306.0
Margin against actual mass [kg]	1920.0
Margin against actual mass [%]	26.0
Margin against contingent mass kg]	442.8
Margin against contingent mass [%]	5.0

Baseline Configuration
Bus Subsystems Cost

Mechanical Cost		
Mechanical Labor		
Power System Hardware		
Power System Labor (Procurement, I&T)		
Harness		
C&DH Materials Cost		
C&DH Labor Cost		
Flight Software Test Bed Hardware		
Flight Software Labor		
ACS Hardware		
ACS Design, Analysis, SS I&T		
Metrology System		
RF Communication Hardware		
RF Communication Labor (I&T, CTV test)		
Propulsion Hardware		
Tanks		
Thermal Hardware		
Thermal Labor		
Total		

Note: Det S/A upscaled to 46.66 m2

Baseline Configuration
Mission Integration and Ops Costs

MISSION SYSTEMS ENGINEERING [$M]	
System Engineering	
Trajectory Analysis and Orbital Dynamics Labor	
Safety, Reliability	
NASA Independent Assessment Teams (NIAT)	
IV&V	
Total	
ATLO & MISSION READINESS [$M]	
I&T Facilities & Associated Labor	
Test conductors	
I&T Technicians	
Launch Vehicle Integration	
End-To-End Performance Verification and Rehearsals	
Total	

LAUNCH VEHICLE [$M]	
Launch Vehicle	
Total	
OPERATIONS FOR 3 YEARS [$M]	
Ground Station Costs	
Mission Operations Costs	
Total	

Baseline Configuration
Overall Cost Summary

Mission crude est. cost w/o any science element:

SPACECRAFT BUS SUBSYSTEMS	
MISSION SYSTEMS ENGINEERING	
ATLO & MISSION READINESS	
LAUNCH VEHICLE	
OPERATIONS	
TOTAL MISSION "NON-SCIENCE" COST	

Mission cost w/o any science element and w/o metrology hw:

SPACECRAFT BUS SUBSYSTEMS	
MISSION SYSTEMS ENGINEERING	
ATLO & MISSION READINESS	
LAUNCH VEHICLE	
OPERATIONS	
TOTAL MISSION "NON-SCIENCE" COST	

Options and Trades Considered
Bipropellant Propulsion System

- **Original Requirement**
  - Reorient line of sight by 20 degrees / week (1000 kg dry nominal s/c)
- **Derived Requirement**
  - 4 N thrust force, 2400 m/s delta v
- **Bipropellant propulsion system Isp = 320**
- **Propellant required for one maneuver**
  - 115% x dry mass = 1150 kg
- **Propellant required for 10 maneuvers**
  - 2110 x dry mass = 2110000 kg
- **CONCLUSION**
  - Original Requirement unattainable using bipropellant propulsion system

Options and Trades Considered
Solar Sail Propulsion System

- **Original Requirement**
  - Reorient line of sight by 20 degrees / week (1000 kg dry nominal s/c)
- **Derived Requirement**
  - 4 N thrust force, 2400 m/s delta v
- **Solar sail thrust is 4.5 10^{-6} N / m2**
- **Size of solar sail required**
  - ~1 million m^2 (a square 1 km on a side)
- **Additional difficulties:**
  - Repositioning in some directions is difficult using solar sail. To deal w/ this, both s/c should have sails and alternately "leapfrog" each other.
  - Technology immature, untested
- **CONCLUSION:**
  - Baselining a solar sail thrust system would require excessive technology development
  - Option dismissed

Options and Trades Considered
Electrical Propulsion System

- **Original Requirement**
  - Reorient line of sight by 20 degrees / week (1000 kg dry nominal s/c)
- **Derived Requirement**
  - 4 N thrust force, 2400 m/s delta v
- **Boeing high thrust XIPS-25 xenon ion prop (best, state of the art)**
  - Isp = 3800, thrust = .165 N, requires 4.5 kW power
  - Used on PAS-5, similar unit used on Deep Space-1
- **Number of XIPS-25 thrusters required**
  - 25 units
  - Note: XIPS design is upscaleable for higher thrust, but will loose a bit on Isp
- **Power required**
  - 112 kW requiring a solar array ~1100 m^2
- **Lifetime issues:**
  - Each XIPS engine's lifetime is ~ 8000 hours
  - Must increase on-board numbers for lifetime spares
- **CONCLUSION**
  - Using this propulsion system to attain original requirement is unrealistic
  - Descoped requirement may be met

Options and Trades Considered Descoped Requirement w/ EPS

- **Descoped Requirement**
  - Using one XIPS-25 with .165 N, force (that is 1/25th of 4 N) will take 5 times longer (square-root relation) to reorient by 20 degrees (5 weeks)
- **Number of max. repoints per year**
  - 8 (w/ 2 weeks observe, 5 weeks repoint)
- **S/c power required**
  - ~ 10 kW (4.5 kW for a XIPS-25 thruster alone)
  - Initial mass estimate of s/a system ~ 500 kg
- **Lifetime issues:**
  - XIPS engine's lifetime is ~ 8000 hours (that is < 30 weeks)
  - May have to stack several for lifetime / redundancy
- **CONCLUSION**
  - Descoped requirement met using a single XIPS-25 propulsion system

Options and Trades Considered
Comments on Metrology System

- **Radio interferometry**
  - Not very promising, nor well suited, for this mission
- **Laser/beacon with micro-arcsecond star tracker telescope**
  - Method: looking out from the Detector s/c using the star tracker telescope, reposition the Detector s/c until the beacon on the Lens s/c appears over the target. At that point, the line of sight is on the target.
  - Ideal concept for this mission
  - Use commercial arc-minute star sensor for initial rough positioning
  - FOV of the micro-arcsecond star tracker telescope must be at least wide enough to work seamlessly with rough positioning system
  - Near-insurmountable problem is the narrowness of the FOV of such a star tracker telescope for another reason:
    - No guarantee that bright stars will be in FOV around the target area
    - To work with faint stars, the micro-arcsecond star tracker telescope must either have extremely large aperture (10-100m dia) or have extremely long integration times (100-10000 sec) to collect enough (10^9) photons

Options and Trades Considered
Comments on Metrology System

- **Combine a very fine gyro with micro-arcsecond resolution with small aperture micro-arcsecond star tracker telescope**
  - Lower sensitivity of star tracker is OK, if reference frame can be acquired using brightest stars, then s/c pointing is controlled only using the gyro
  - Periodic need to re-sync, due to gyro drift, complicates operations
  - Gyros with arcsecond resolution exist
- **Ultra-low drift hyper-gyro**
  - Set reference frame in hyper-gyro on the ground, and maintain it throughout the entire mission

Options and Trades Considered
Sun Avoidance

- **Reorienting 20 degrees per 7 weeks doesn't keep up with movement along the heliocentric orbit**
  - Therefore, sun may come in view of detectors / radiators
  - May have to stop observing for some to assume "sun avoidance" attitude when sun enters exclusion zone (turn away detector and s/c cold side from the sun)
  - Exclusion zone is a function of s/c design (narrow exclusion zones with solar shields, etc.)
  - Design s/c carefully, and Plan pointing carefully to minimize or avoid sun impingement periods

Comments, Issues and Concerns Instrument, ACS, Power

- **Instrument**
  - Detector passively cooled to 80K
  - Feasible, but requires 2Pi steradian unobstructed view
  - Difficult to build, difficult to test, and constrains pointing
  - Consider electrical cryo-cooler
- **Power**
  - 10 kW is not a trivial size
- **Mechanical**
  - Bus volume density on "high normal" side of usual range
- **Thermal**
  - Thermal effects on science of major dissipators: propulsion system, metrology system / laser beacon, RF comm, and 6 kW s/a's must be taken into consideration
- **RF Comm**
  - Refine inter s/c comm req's

Comments, Issues and Concerns Additional Considerations

- **Assess effects of varying focal length**
  - 750,000 – 1,000,000 km
- **Assess use of 3 or more spacecraft**
  - "Multiplying" s/c may be counter-intuitive, yet there are indications that using 2 Detector s/c is beneficial, because the dominant mass is propellant, and w/ 2 s/c the wet/dry mass ratio can be reduced
  - Complicates formation flying and mission ops
- **More propulsion / orbit work needed**
  - Factor-is wet mass > depletion > dry mass
  - Model all significant forces, continuous low thrust
  - Factor in all secondary effects, such as orbit drift-away, etc.
- **Refine inter s/c communications concept**
  - Largely a function of the pointing/attitude control and metrology method selected
  - Some information must definitely pass between the two s/c. but perhaps it could be routed thru the ground

Comments, Issues and Concerns I&T

- **Any end-to-end testing / verification of the critical subsystems is very difficult or near-impossible**
  - Verification of orbit maintenance and formation flying capabilities difficult
  - Verification of metrology system difficult
  - Verification of gamma ray beam focus and alignment is difficult
- **Other than the above, I&T is "relatively" straightforward**
  - What is usually regarded as difficult (such as testing an 80K passive radiative cooler w/ helium targets) is dwarfed by larger problems

Technologies, TRL

- Significant progress in technology required for propulsion system
- Major leap in technology required for metrology system
- Overall TRL Level is 2

Supporting Data

- **Supporting spreadsheets / tools**
  - Mission summary
    - "FLGammaRay_Configuration_Summary.xls"
  - Typical NASA mission's complete Work Breakdown Structure:
    - Generic_WBS_Template_by_GSFC_NOO.doc
- **Useful web sites**
  - Access to Space
    - http://accesstospace.gsfc.nasa.gov/ provides launch vehicle performance information and other useful design data.
  - Rapid Spacecraft Development Office
    - http://rsdo.gsfc.nasa.gov/ provides spacecraft bus studies and procurement services.

System Summary

- **GSFC Contact:** Gerry Skinner
- **Phone Number in France:** 011-33-561-558561
- **Mission name and Acronym:** Fresnel Lens Gamma Ray Telescope
- **Authority to Proceed (ATP) Date:** 2003 - 2004
- **Earliest Mission Launch Date:** 7/1/2012
- **Transit Cruise Time (months):** 1
- **Mission Design Life (months):** 36 required, 60 goal
- **Length of Spacecraft Phase C/D (months):** TBD
- **Bus Technology Readiness Level (overall):** 3
- **S/C Bus management build:** n/a
- **Observatory Mass:** 1000 kg Lens / 6400kg Detector
- **Orbit Average Power:** 260W Lens / 6400W Detector