Exoplanets from Sounding Rockets: The PICTURE Experience and Some Random Thoughts

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When normalizing to the nominal values for a discovery class mission: D=1.5 m, T=1 h, Eff=5% and sl=10^{-9} (assuming an integrated null depth of 1e-6), we get for a Jupiter analog orbiting a Sun-like star at a distance (Dist) of 10 pc:

$$SNR = 14.2(\frac{D_{in\,m}}{1.5}).(T_{in\,h})^{0.5}.(\frac{Eff}{0.15})^{0.5}.(\frac{10^{-9}}{sl})^{0.5}.(\frac{10}{Dist_{in\,pc}}).(\frac{1.4}{Reso})^{0.5} \quad (8)$$

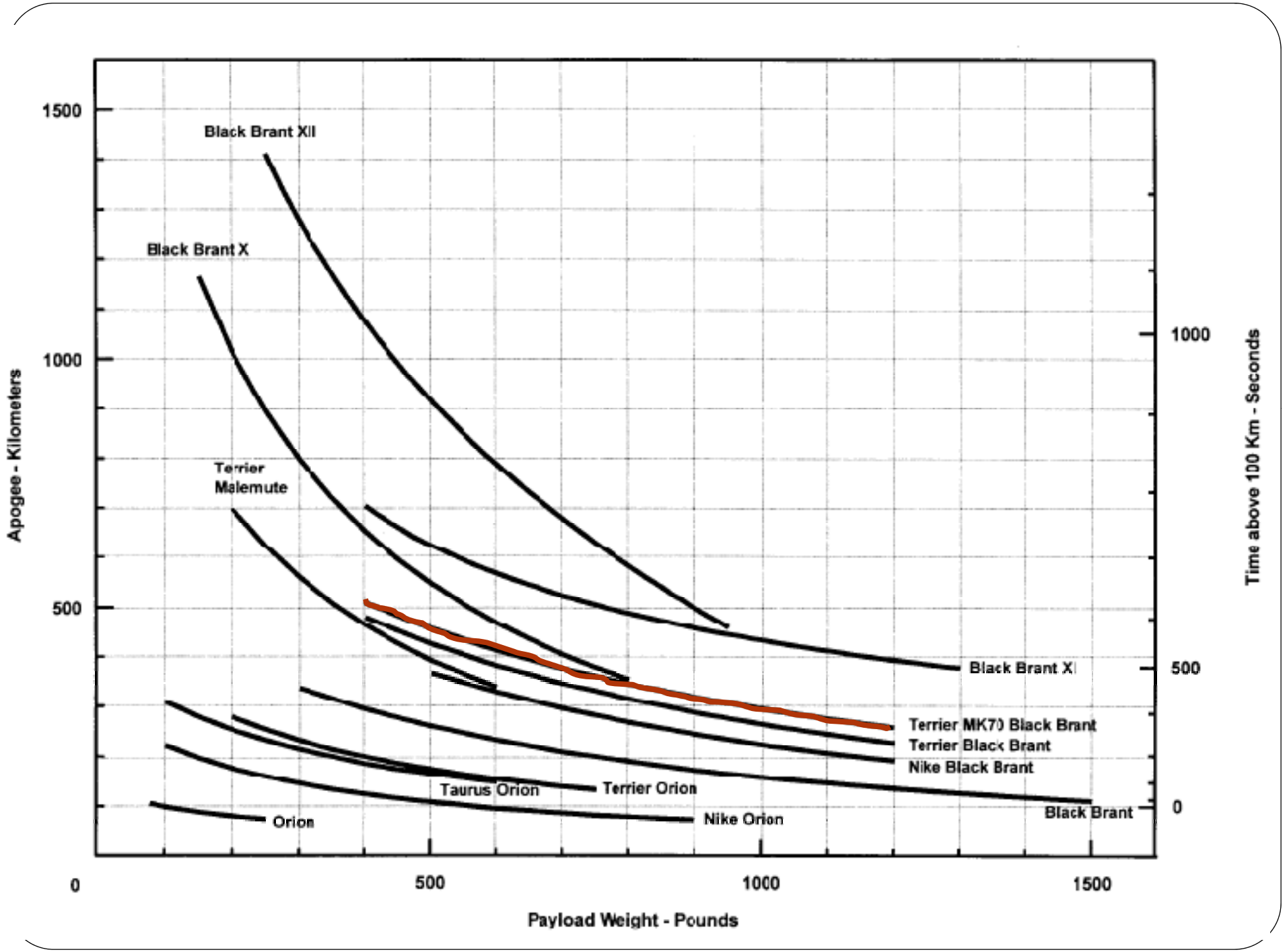
Looking at the general case of an exo-Jupiter with a given separation Sep in A.U. from a central star with flux F^*, and assuming pure stellar reflection with Jupiter's albedo, we get:

$$SNR = 14.2(\frac{D_{in\,m}}{1.5}).(T_{in\,h})^{0.5}.(\frac{Eff}{0.15})^{0.5}.(\frac{10^{-9}}{sl})^{0.5}.(\frac{10}{Dist_{in\,pc}}).(\frac{1.4}{Reso})^{0.5}.(\frac{5.2}{Sep})^{2}.(\frac{F^*}{F_{Sun}})^{0.5} \quad (9)$$

and the integration time T_{int} for broadband detection of exo-Jupiters is:

$$T_{int} = 7\ mn\ .(\frac{SNR}{5})^{2}.(\frac{1.5}{D})^{2}.(\frac{0.15}{eff}).(\frac{sl}{10^{-9}}).(\frac{Dist_{in\,pc}}{10})^{2}.(\frac{Reso}{1.4}).(\frac{Sep}{5.2})^{4}.(\frac{F_{sun}}{F^*}) \quad (10)$$

One can note the strong dependency on the planetary separation. A Jupiter "analog" orbiting at 2 AU from a solar type star 10 pc away can be detected at 5σ in less than a minute.

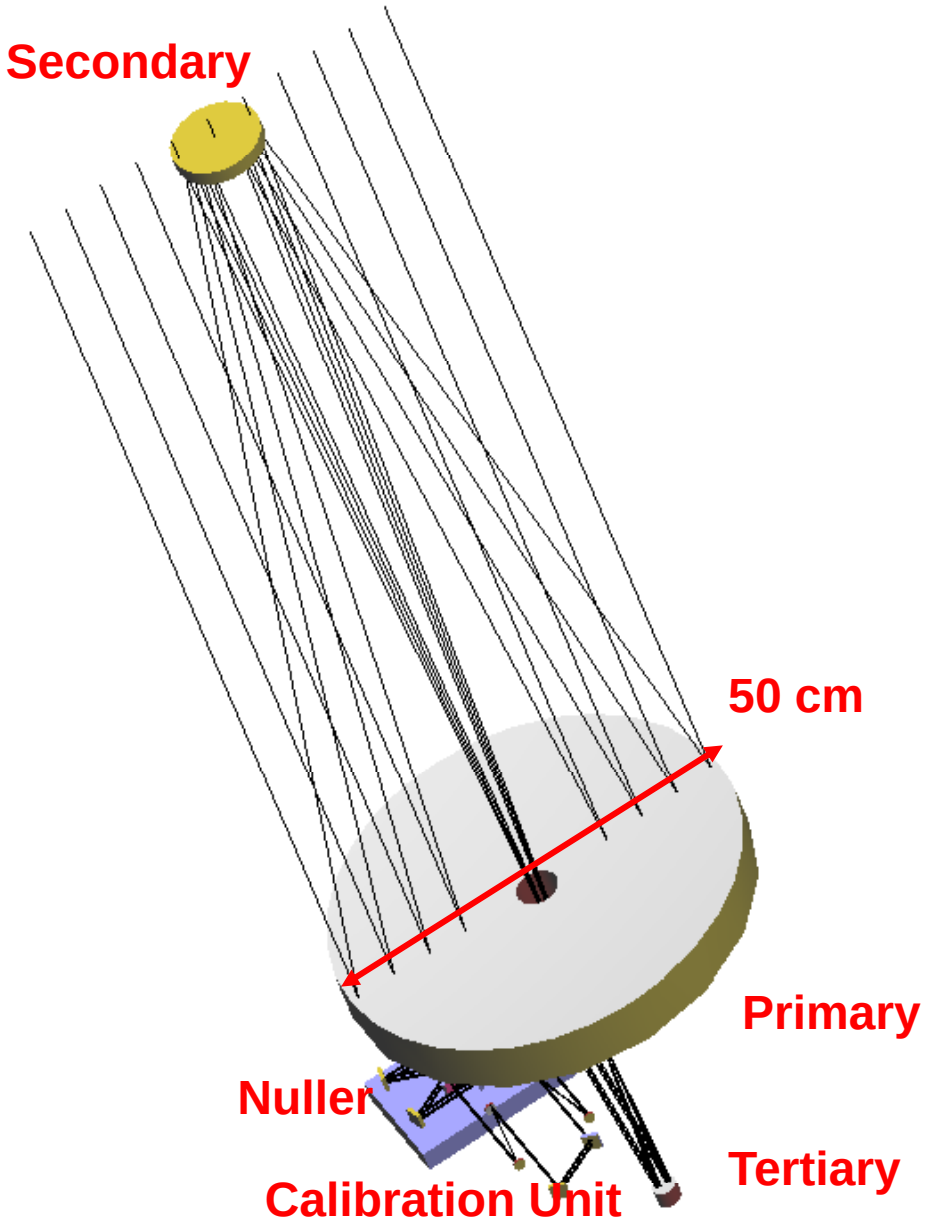

Black Brant XII
Black Brant X
Terrier
Malemute
Black Brant XI
Terrier MK70 Black Brant
Terrier Black Brant
Nike Black Brant
Taurus Orion
Terrier Orion
Nike Orion
Orion
Black Brant
1500
1000
500
0
500
1000
1500
Apogee - Kilometers
Payload Weight - Pounds
Time above 100 Km - Seconds

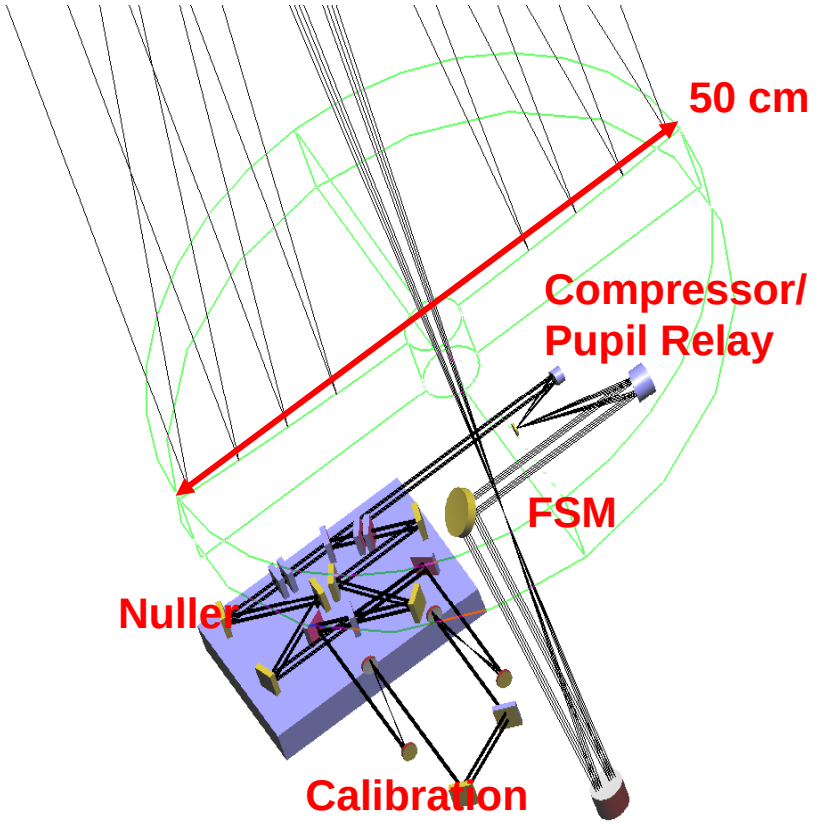
PICTURE Plans

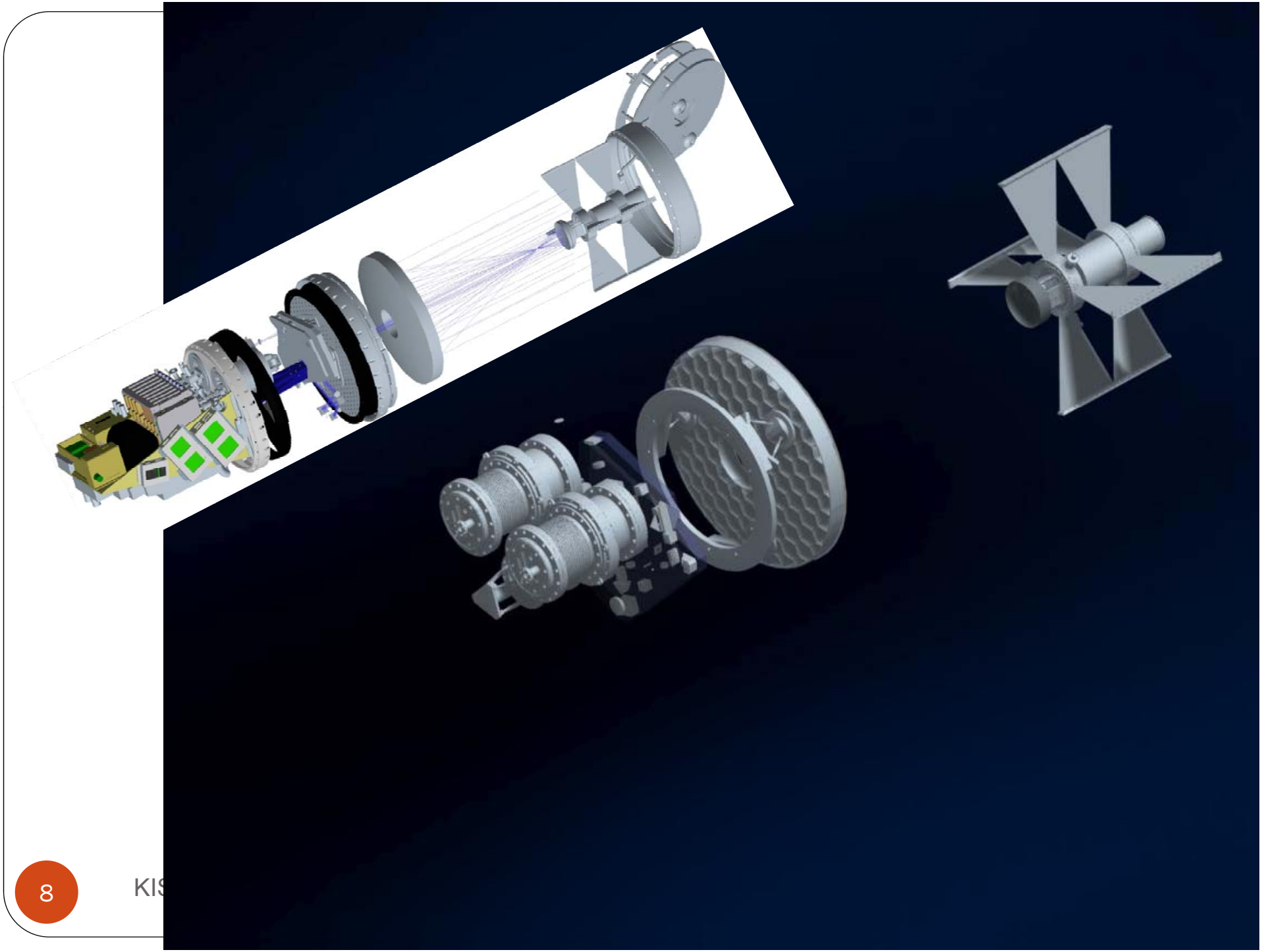
Event	Time (sec)	Altitude (km)
Launch	0	0
Burn out	57	70
Separation	75	100
ACS on Rigel	105	165
End in-flight Cal.	145	250
ACS on ε ERI	165	340
Apogee	340	425
Shutter Close	620	100

Expected Image

Optics Overview

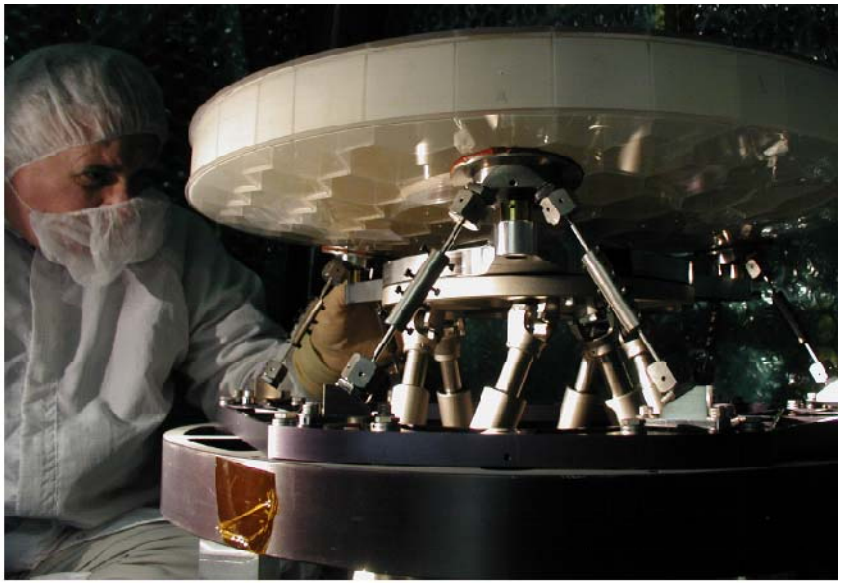


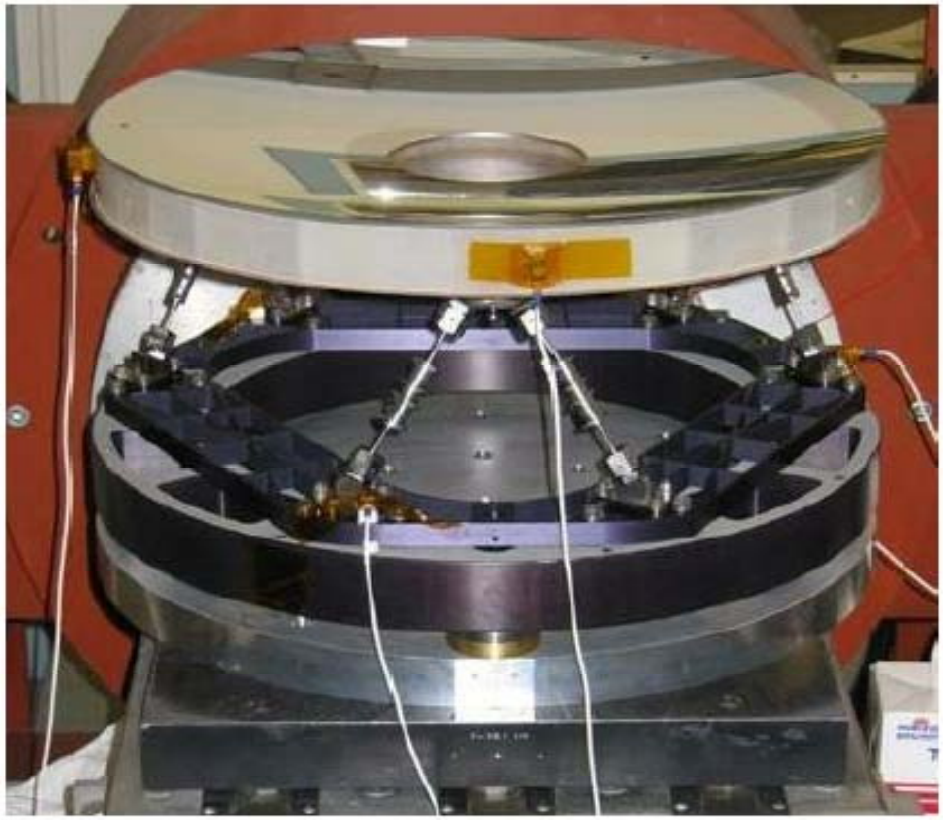




The PICTURE primary mirror

Solar High Angular Resolution Photometric Imager (SHARPI)
– designed for 0.2” res. over 70” FOV at 120 nm (7 nm rms figure error)

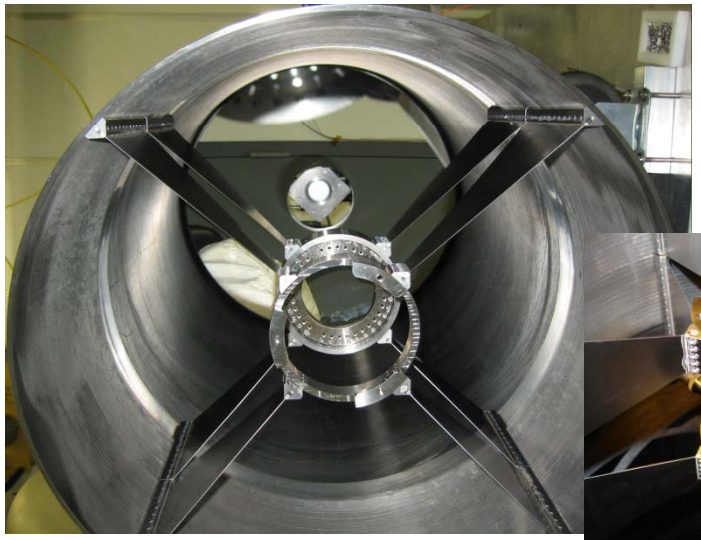


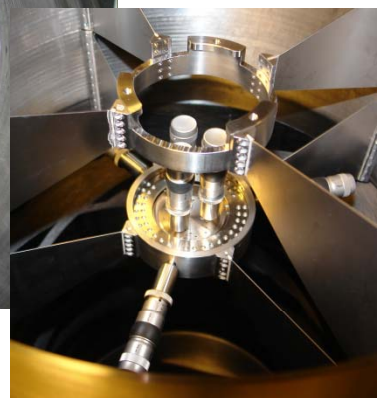


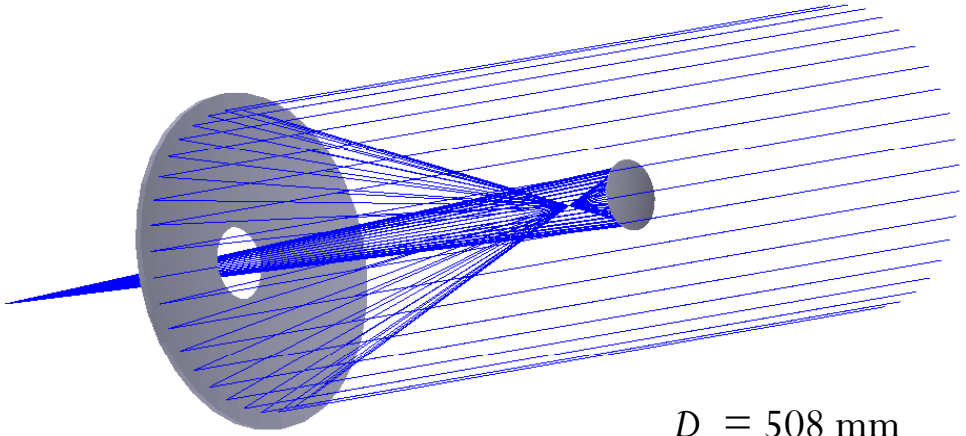
- Protected silver coating
- Lightweight (~5 kg)

The PICTURE telescope

- Gregorian design (k_p = -1, k_s = -0.66)
  - invar, Ti, carbon fiber structure







$D_p = 508$ mm

$F_p = 1.26$

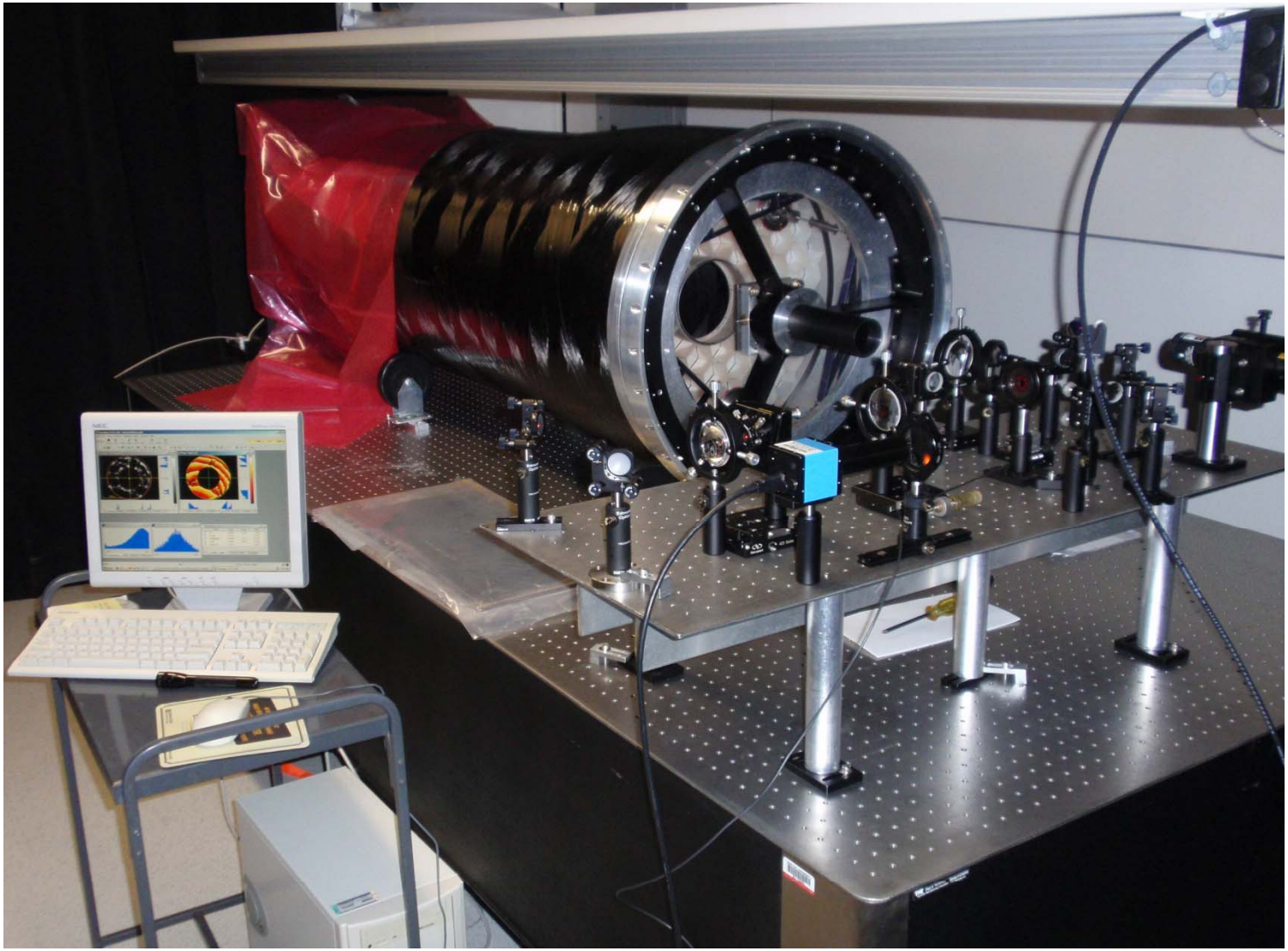
$F = 12.3$

$S = 763$ mm

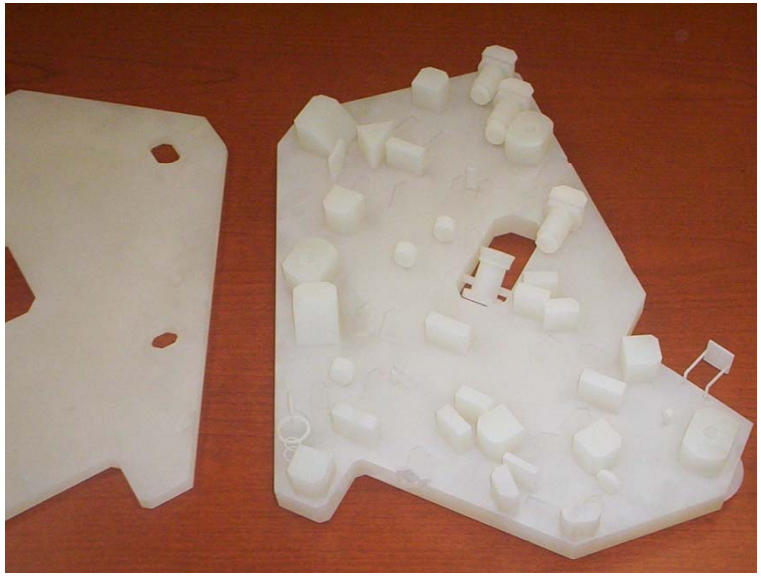
$B = 459$ mm

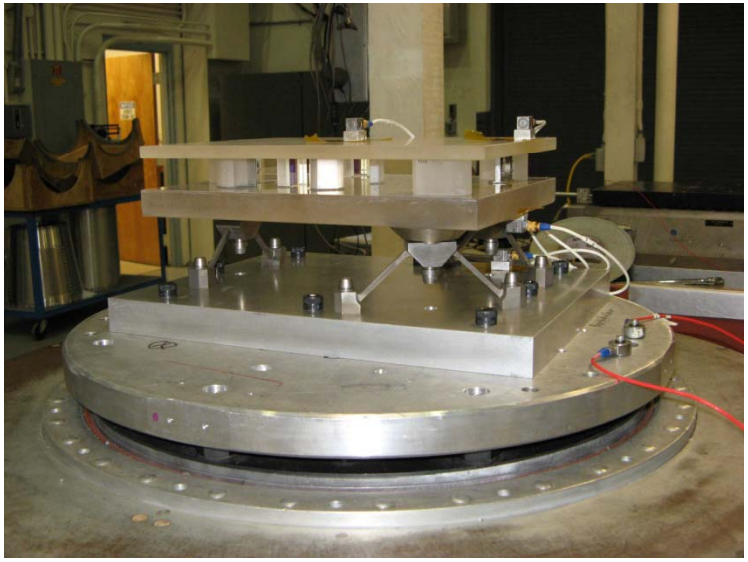
$\varepsilon = 0.25$

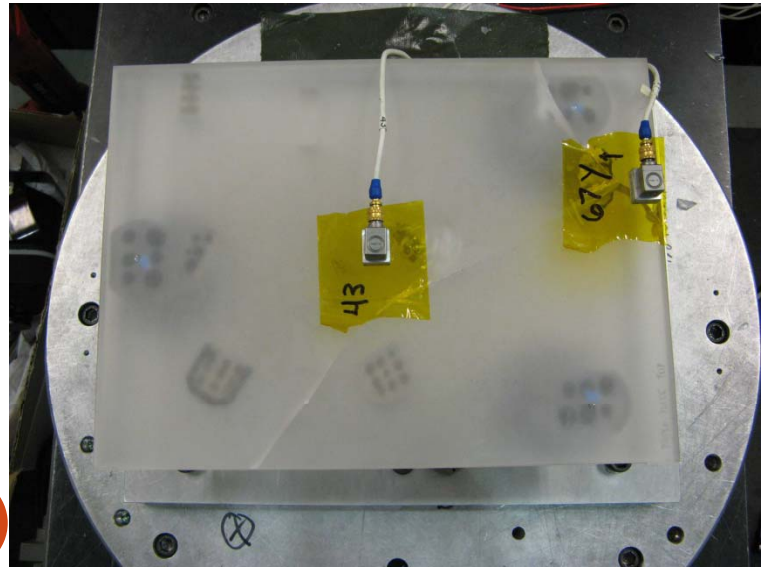
Horizontal alignment in 1g

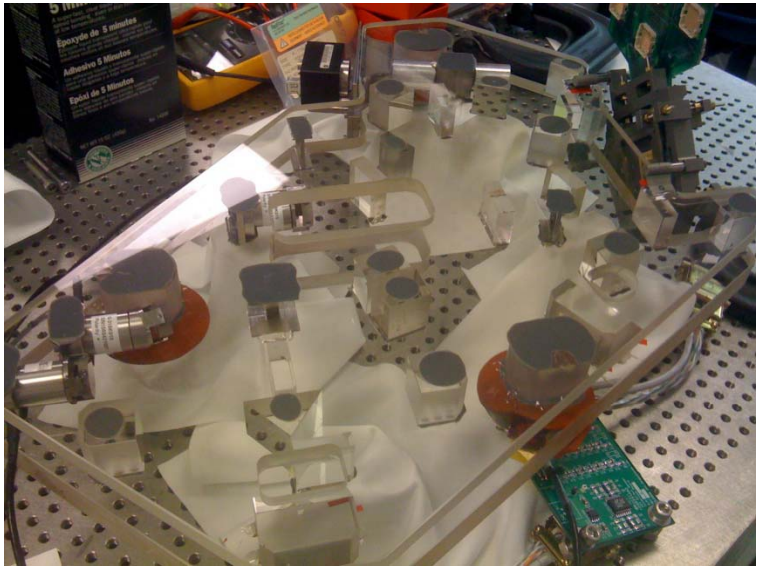


Development and tests of the nuller









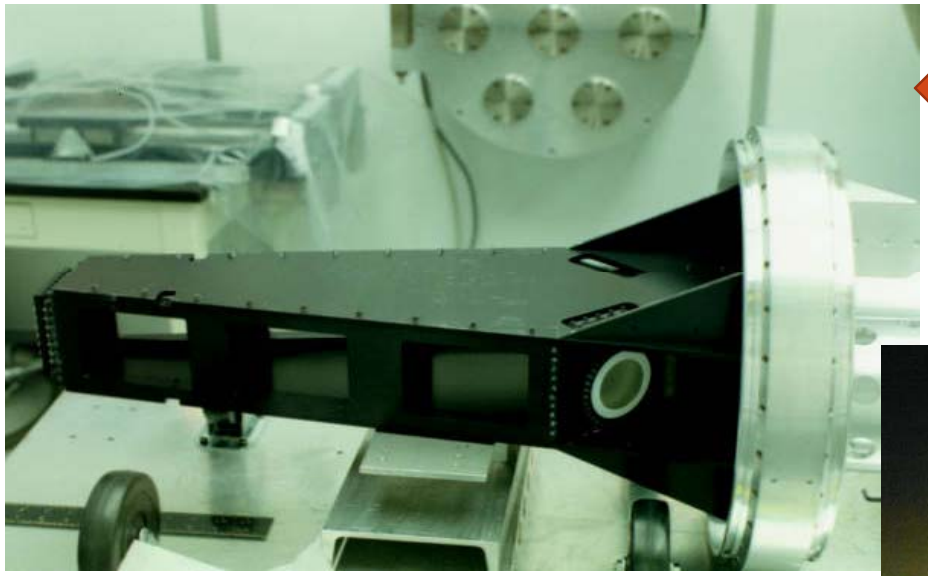
PICTURE Current Status

- Started 2005
- Met with NASA Wallops – people responsible for rocket support
  - Almost got cancelled – our required pointing stability (0.2") unavailable
- The team relaxed pointing requirement to 2"
- Telescope assembly begins at GSFC – unfortunately, runs out of funds
- 2008: Planet not observable until 2013-4 – new science: exo-zodi
- Telescope aligned by BU after building necessary test equipment
- NASA Wallops flight-demonstrated sub-arc-sec pointing
- Nuller developed, tested and delivered by JPL in Sept, 09
- Integration on-going, hoping to launch in 2010

Now, some random thoughts

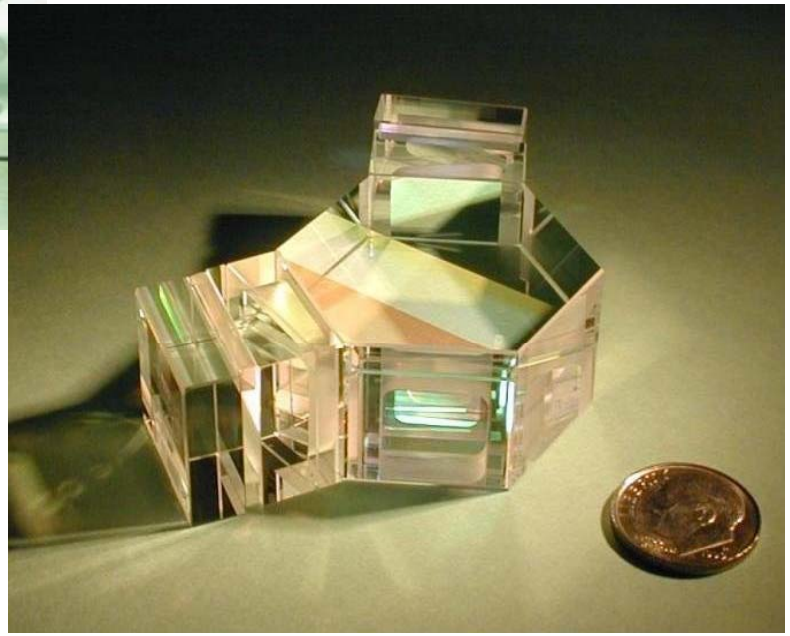
…. On Enabling Technologies

SCARI/SHS to SHIMMER



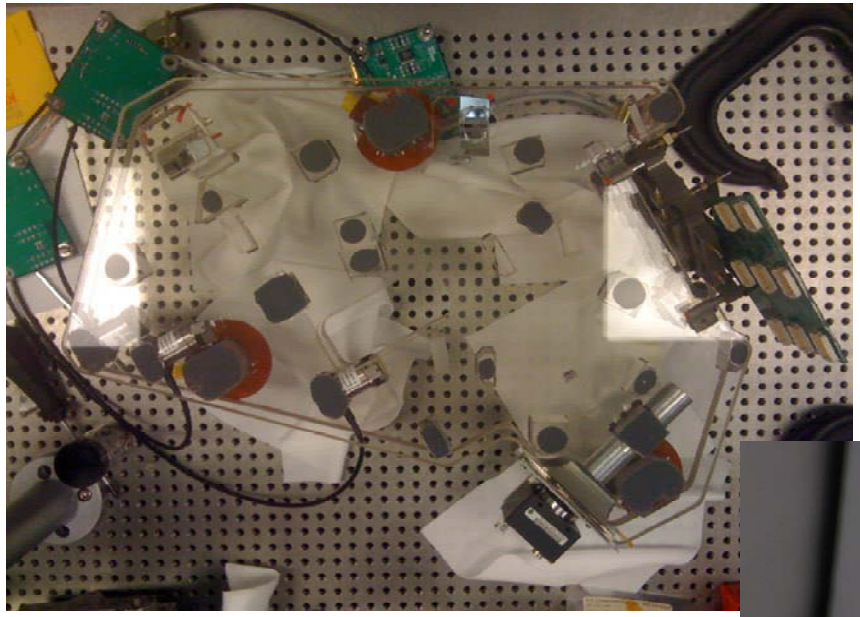
Self Compensating All-Reflection Interferometer (SCARI) - 1216Å
(Spatial Heterodyned Spectrometer)

SHIMMER (Spatial Heterodyne Imager for Mesospheric Radicals):



Monolithic construction
Suitable for high resolution spectroscopy
Flew on STS-112 in 2002

PICTURE Nuller to MANIC



- Rotationally shearing nulling interferometer

Monolithic achromatic nulling interference coronagraph: design and performance

Brian Hicks,[1,*] Timothy Cook,[1] Benjamin Lane,[2] and Supriya Chakrabarti[1]

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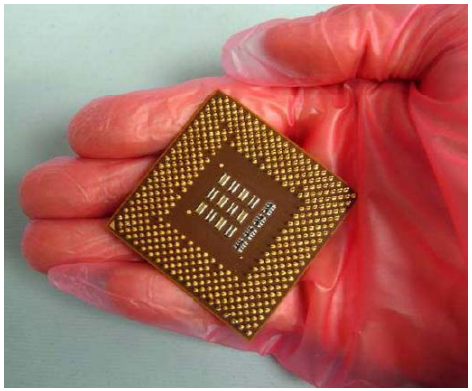
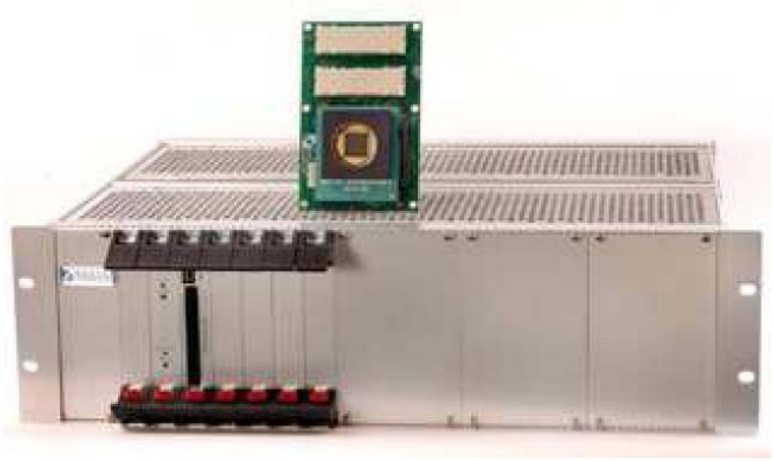
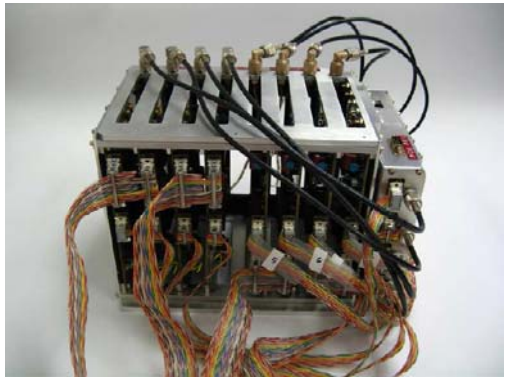
Another Key technology Development







A Novel ASIC Integrating Latching (NAIL) deformable mirror controller

A NASA TDEM proposal currently under consideration

Finally, Extended Duration Sounding Rocket: Yet Another Technology on the Horizon

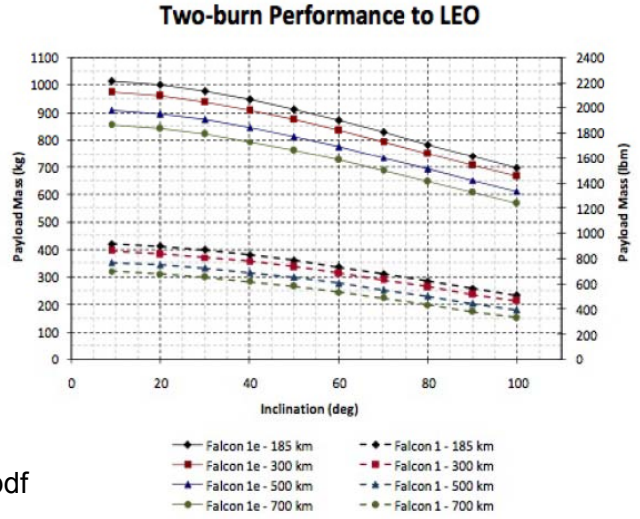
- **Experiment Mass:**
  - ~ 150 kg (without subsystems)
- **Experiment Volume:**
  - 2.2 m length, 0.56 m diameter
- **Data Rate (primary science):**
  - 0.5 -- 1 Gbyte day^{-1}
- **Experiment Power (orbit avg)**
  - 3.25 Amps @ 28 Volts
- **Pointing**
  - 1″ -- 2″ stability per orbit
  - 1′ accuracy
- **Duration**
  - 1 day for minimum success
  - 1 month for comprehensive success

Table 2 – Recurring Cost Estimates

SYSTEM	RECURRING COST
WFF Support Systems	$ 3,300 K *
Launch Vehicle & Range Cost	$ 10,000 K **
Experiment Cost (mod for orbital flight)	$ 1,000 K
On-Orbit Ops Cost	$ 100 K
Misc / Contingency	$ 1,000 K
TOTAL	$ 15,400 K

*Cost Based on WFF OSR Study, 1/15/2009. Development+1st flight demonstration = $26M

**Launch vehicle cost based on Space X response to inquiry.



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