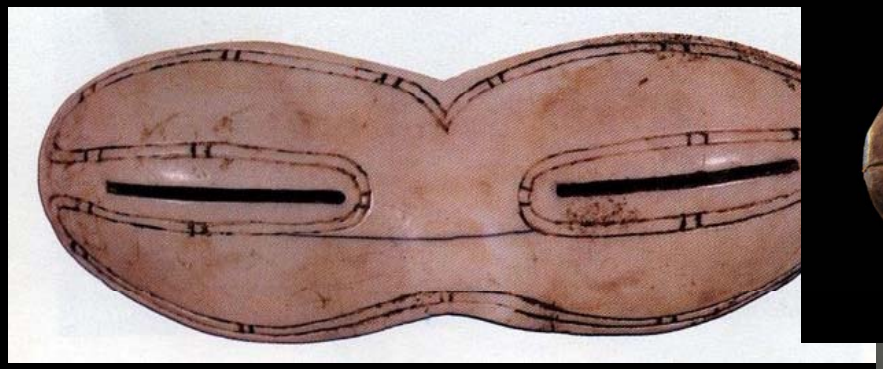
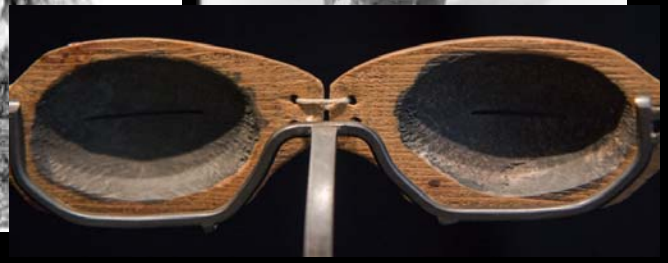
TELESCOPE STRAY LIGHT – FUNDAMENTAL OPTICAL PLUMBING & EARLY EXPERIENCE WITH SOFIA

SOFIA SCIENCE CENTER
PATRICK WADDELL
15FEB2017

STRAY LIGHT ENGINEERING: SUCCESSFUL SYSTEMS (STRUCTURES & COATINGS) FOR MILLENNIA





STRAY LIGHT ENGINEERING: NON-TRANSMISSIVE SOLUTIONS THROUGH MID-20TH CENTURY

STRAY LIGHT

FOR OPTICAL ASTRONOMY,
DETECTING AND ANALYZING SCIENCE TARGETS AND TARGET FEATURES REQUIRES DIRECT SOURCE MEASUREMENT, USUALLY TO SOME QUALITY, SUCH AS AT OR ABOVE A SPECIFIC S/N.

DEF. STRAY LIGHT IS LIGHT CAPTURED & MEASURED WITHIN A SYSTEM THAT IS NOT FROM THE INTENDED SOURCE(S) BASED ON THE SENSOR DESIGN. THIS UNINTENDED SIGNAL CONTRIBUTES AMPLITUDE ERRORS, AMPLITUDE RELATED FLUCTUATION NOISE (POISSON/SHOT NOISE), AND COMPLEX CALIBRATION PROBLEMS, SUCH AS CAUSTICS, AND VARIABLE CONTRIBUTIONS.

STRAY LIGHT

STRAY LIGHT SOURCE EXAMPLES:

- BRIGHT OBJECTS NEAR THE LINE OF SIGHT, MOON, PLANETS, ETC.
- SKY GLOW
- THERMAL RADIATION (IR APPLICATIONS)
- MICRO-ROUGH AND/OR CONTAMINATED OPTICAL SURFACES; “TURNED” EDGES
- REFLECTIONS FROM BAFFLES & STRUCTURES
- TRANSMISSIVE OPTICS INTERNAL REFLECTIONS; GRATING ORDER SEPARATION
- DESIGN FLAWS THAT PERMIT LIGHT TO ENTER AND HIT DETECTORS DIRECTLY

STRAY LIGHT

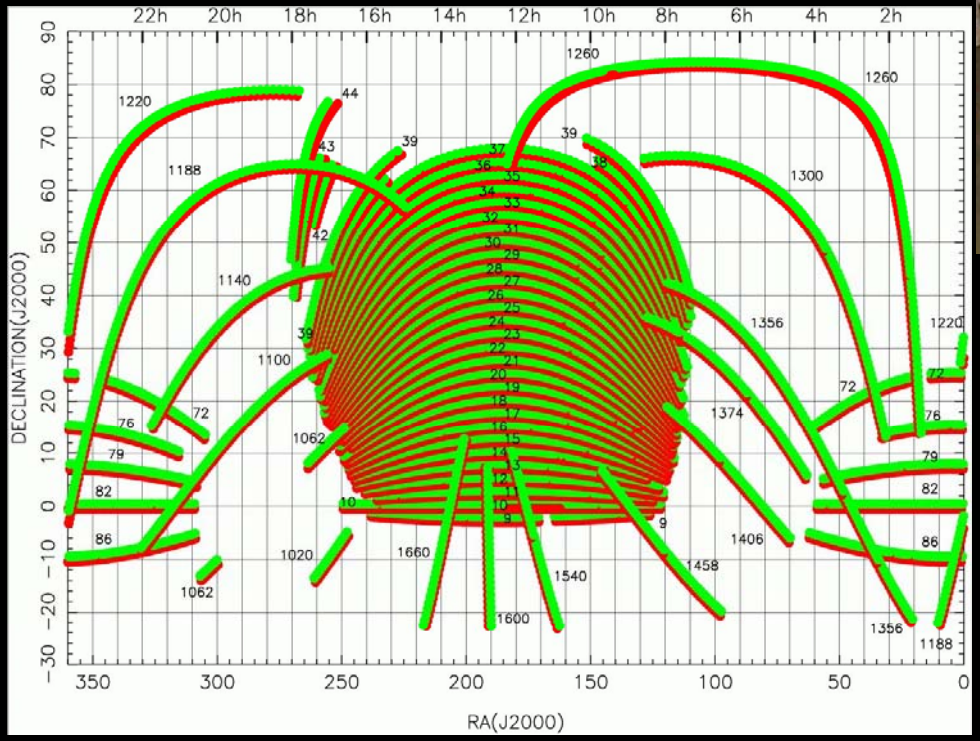
TO ACHIEVE THE DESIRED SCIENCE A NUMBER OF MEANS ARE EMPLOYED TO CONTROL BACKGROUND SIGNAL CONTRIBUTION:

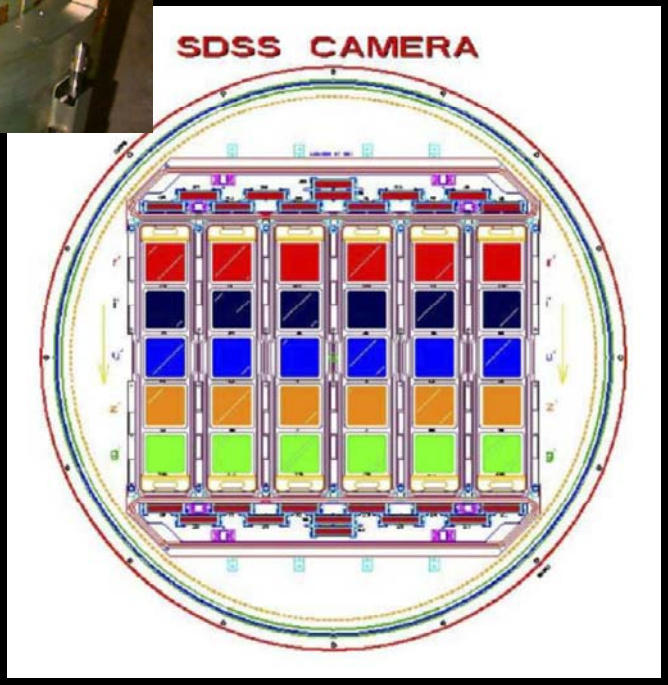
- BLOCKING: DESIGN & INCLUDE EFFECTIVE BAFFLES & STRUCTURES; DEFLECTION WITH SPECIAL OPTICS
- ATTENUATING/SCATTERING: PROVIDE SURFACES WITH ABSORBING COATINGS, ALSO DIFFUSE/LAMBERTIAN – NON-SPECULAR PROPERTIES
- REAL TIME MODULATION: CHOPPING & NODDING
- MODEL BEFORE COMMITTING TO BUILD TO REDUCE PERFORMANCE RISKS: ASAP, APART/PADE, ZEMAX

STRAY LIGHT – THE SDSS 2.5M

INDUSTRIAL SCALE IMAGING AND SPECTROMETRY
IMAGING WAS THE DRIVER, DEFINED SYSTEM CHALLENGES:

- **3 DEGREE** FIELD OF VIEW; SUBARCSECOND PERFORMANCE
- GREAT CIRCLE SCANS – CONTINUOUS STRIPS FOR HOURS TO IMAGE ¼ OF THE SKY IN 5 COLORS





STRAY LIGHT – THE SDSS 2.5M

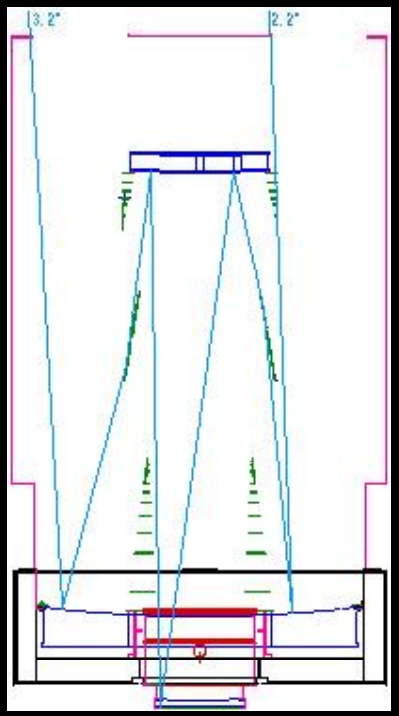
STRAY LIGHT REJECTION REQUIREMENTS;

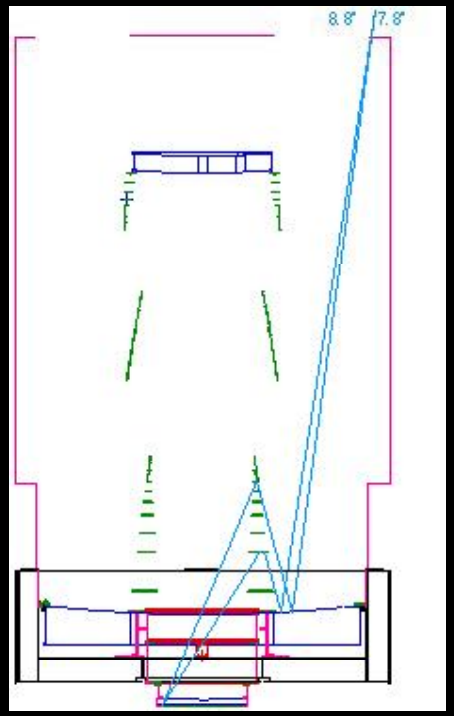
- MUST BAFFLE FOR CRESCENT MOON ≥ 30 DEGREES OFF AXIS AND CITY LIGHTS ON HORIZON
- POINT SOURCE NORMALIZED IRRADIANCE TRANSMISSION (PSNIT) < 2 X 10-6 (FOR SOURCES ≥ 30 DEGREES)
- UNIFORM FOCAL PLANE ILLUMINATION FROM NET INTEGRATED STRAY SOURCES
- MINIMIZE NET OBSCURATION

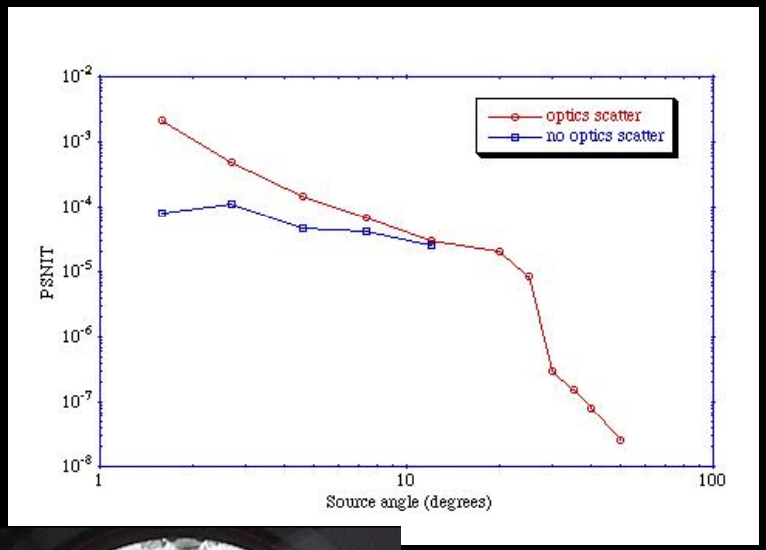
STRAY LIGHT – THE SDSS 2.5M

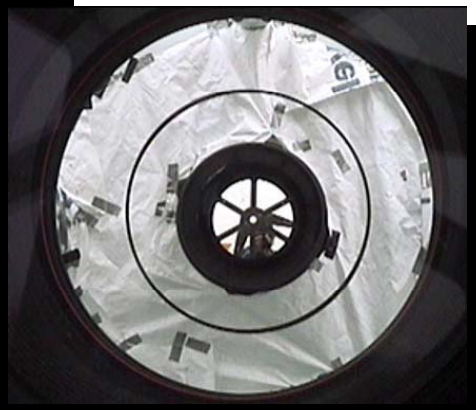
FRAMEWORK FOR DESIGN:

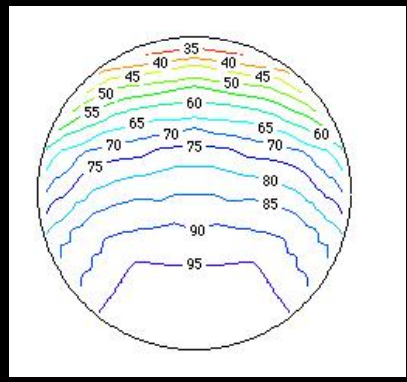
- DEVELOPED BAFFLES TOPOLOGY: PM, SM, CONICAL, OUTER
- USED ZEMAX MODEL TO DEFINE THE GEOMETRY AND IDENTIFY CRITICAL OBJECTS AND ILLUMINATED OBJECTS.
- DEVELOPED CAD MODEL; FED INTO ***APART*** FOR PSNIT AND FOCAL PLANE POWER DISTRIBUTION









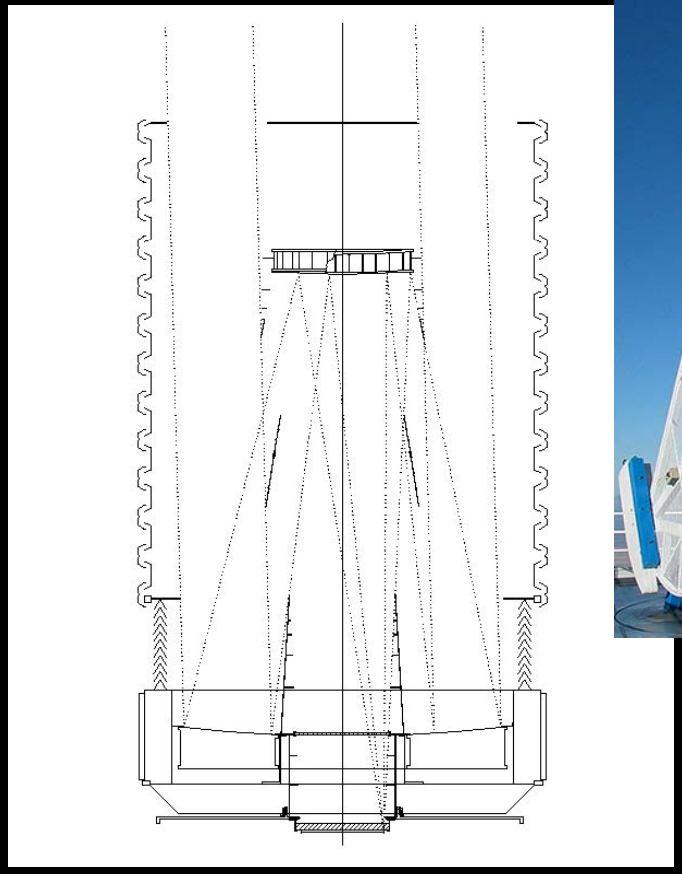


SIEGMUND, W.A., ET AL., PROC. SPIE 3352,1998

STRAY LIGHT – THE SDSS 2.5M

BAFFLES IMPLEMENTATION:

- OUTER LIGHT BAFFLE IS 25% POROUS AND A SEPARATELY DRIVEN ASSY, "THE DOME"



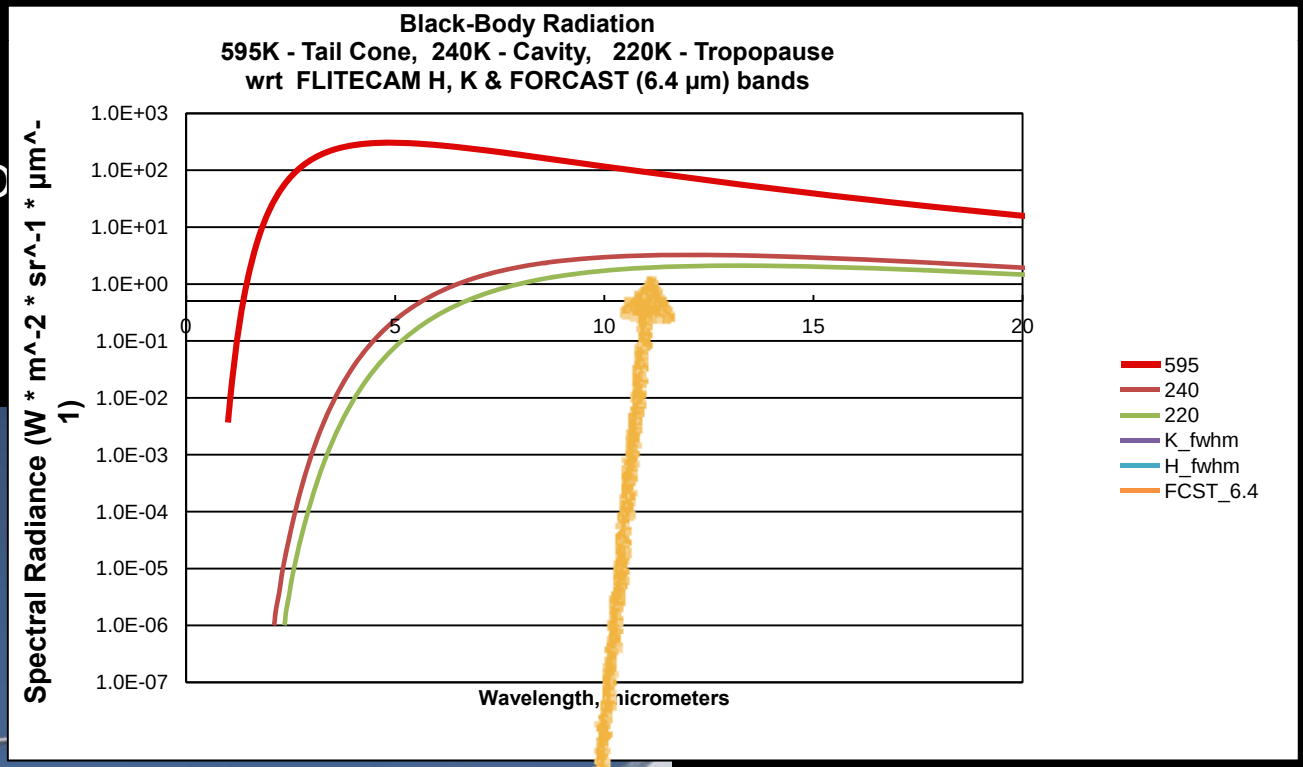
SIEGMUND, W.A., ET AL., PROC. SPIE 3352, 1998

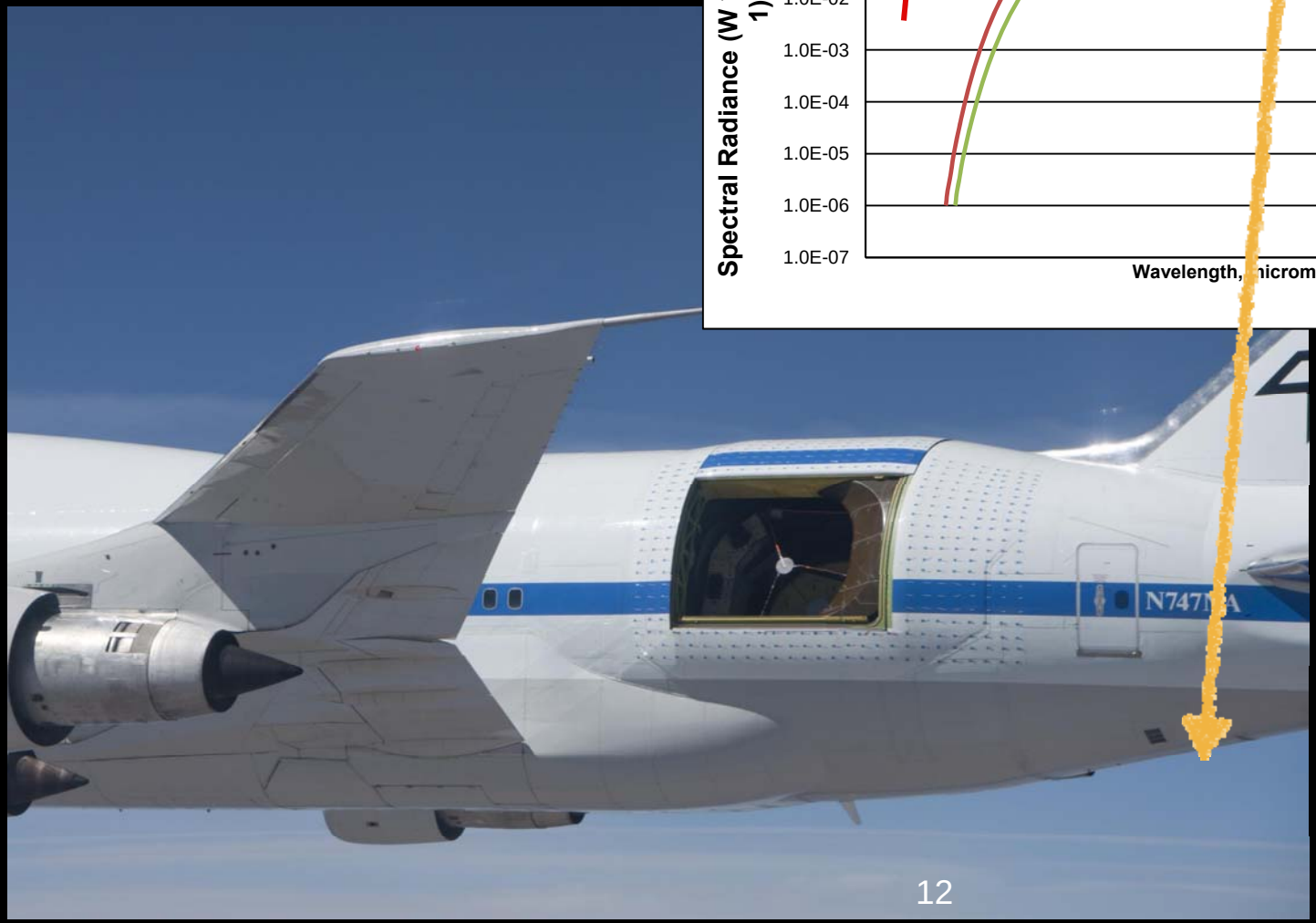
STRAY LIGHT – SOFIA 2.5M

EXPECTED SOURCES: POINTING TOWARD BRIGHT OBJECTS, MOON IN PERIPHERY… PLUS MUCH MORE!

STRAY LIGHT BACKGROUND IN CRUISE

SELECTED BACKGROUND SOURCES

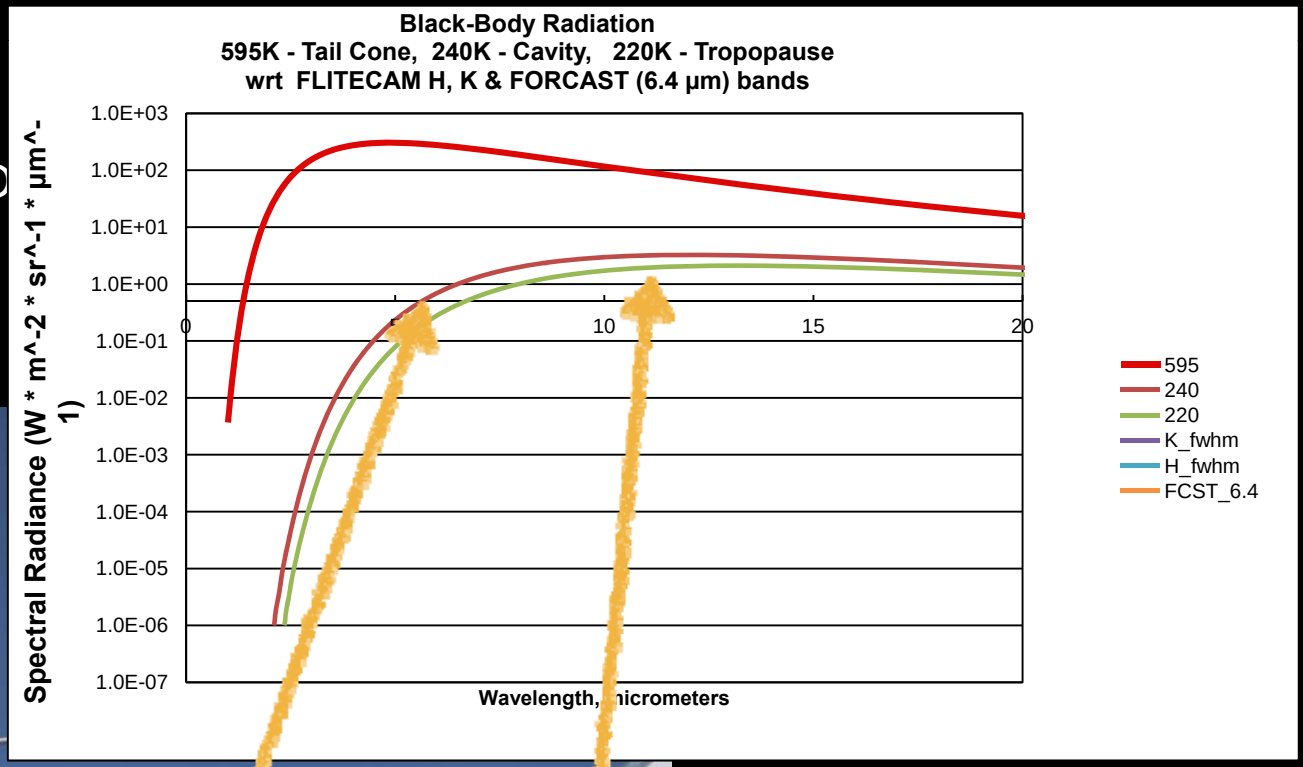


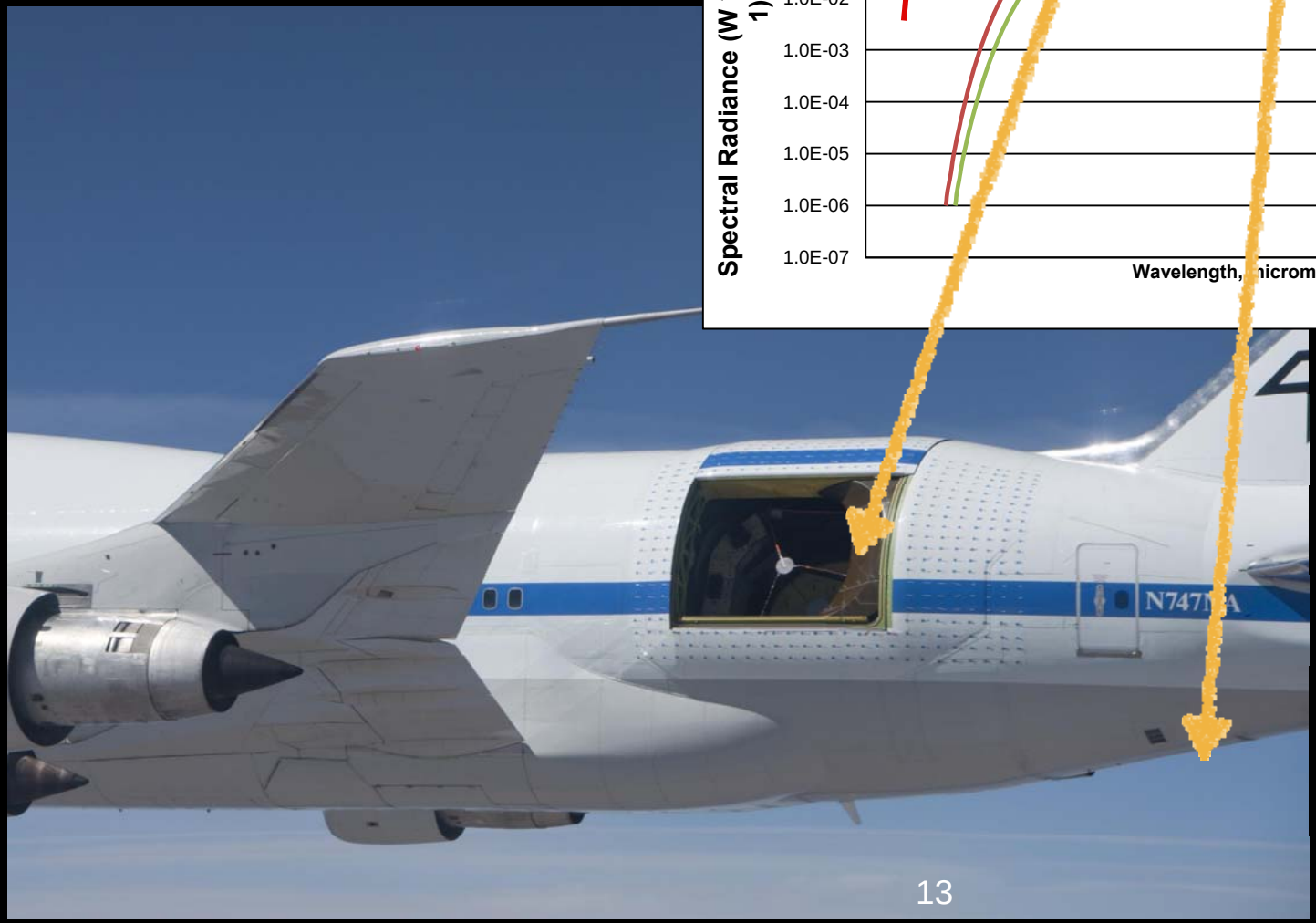


WARM EARTH & ATMOSPHERE

STRAY LIGHT BACKGROUND IN CRUISE

SELECTED BACKGROUND SOURCES



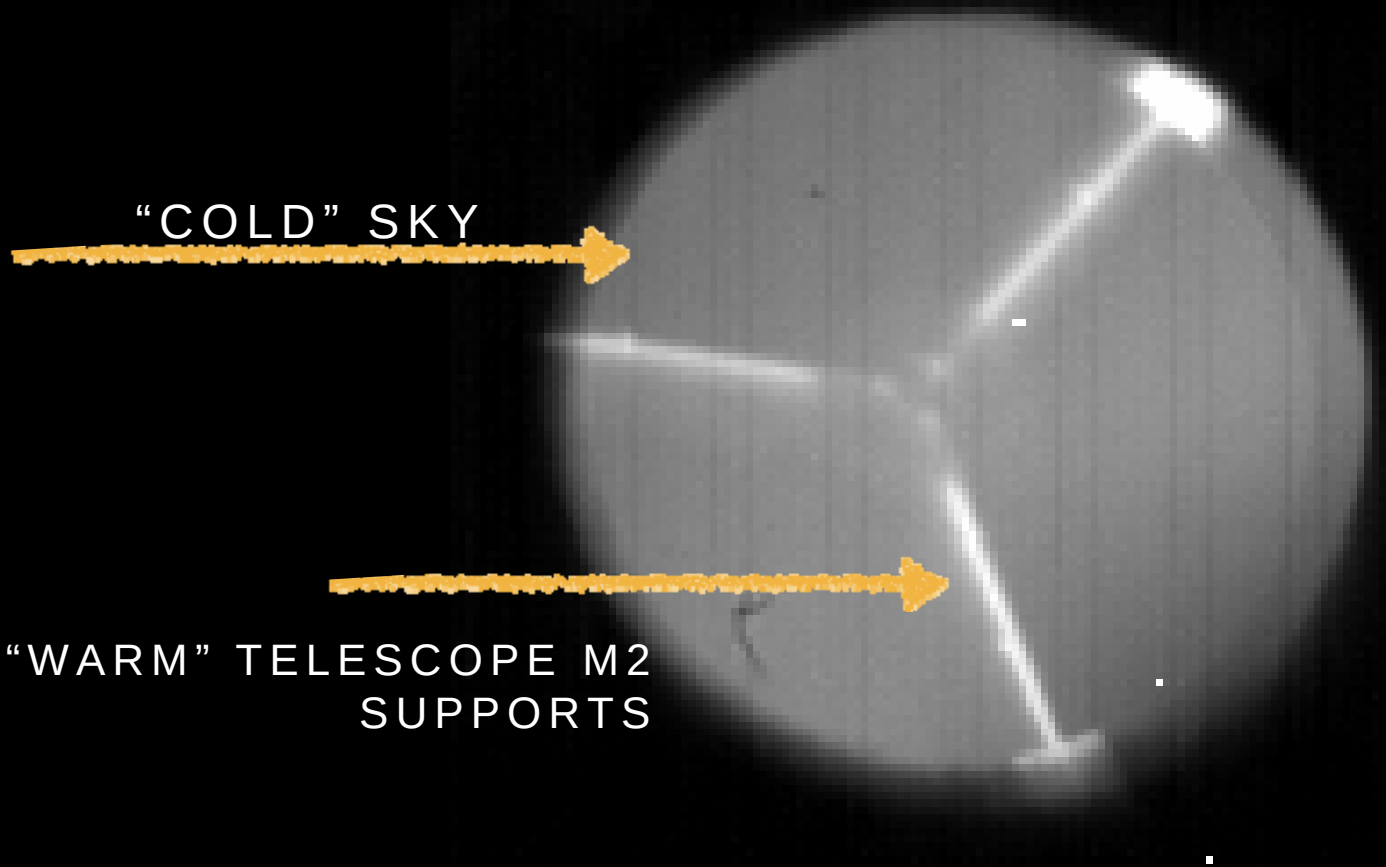


WARM EARTH & ATMOSPHERE

WARM CAVITY & TELESCOPE [LOTS OF THIS!]

STRAY LIGHT BACKGROUND IN CRUISE

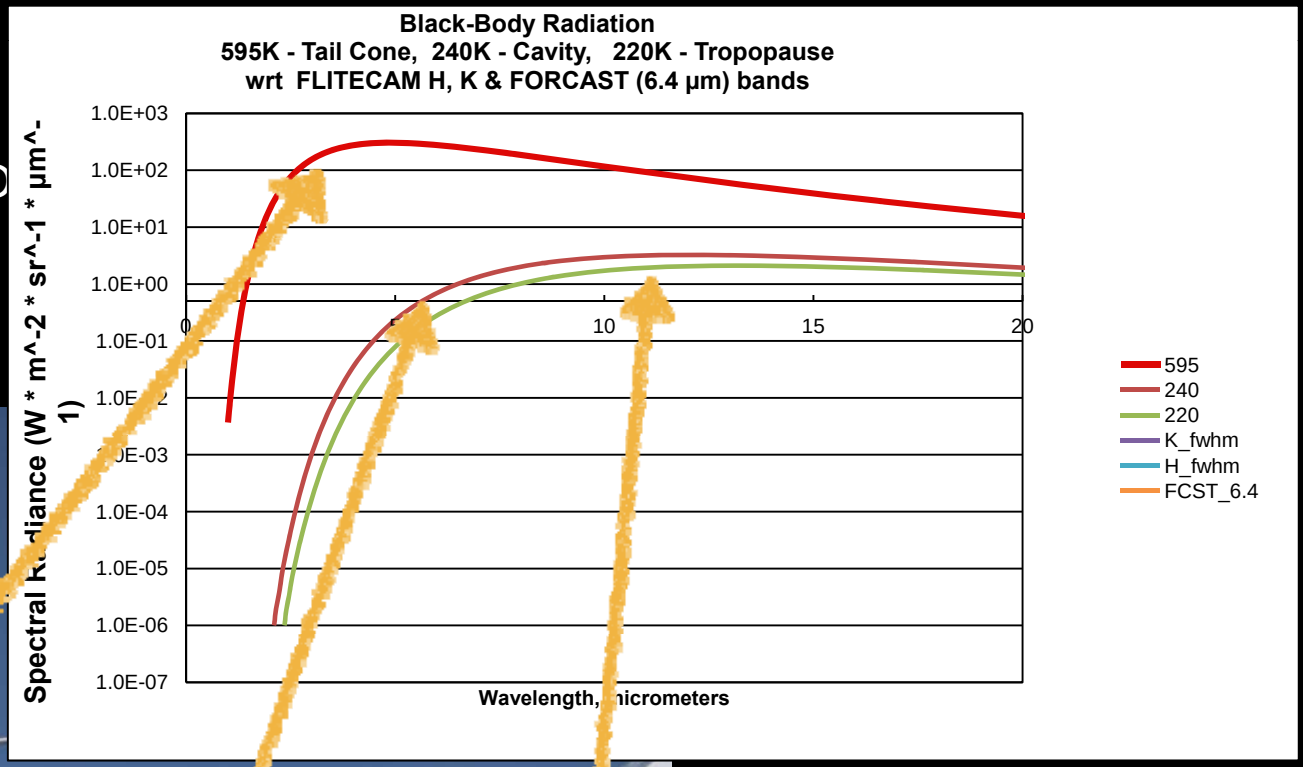
FORECAST PUPIL IMAGE AT 6.4 MICRONS WAVELENGTH

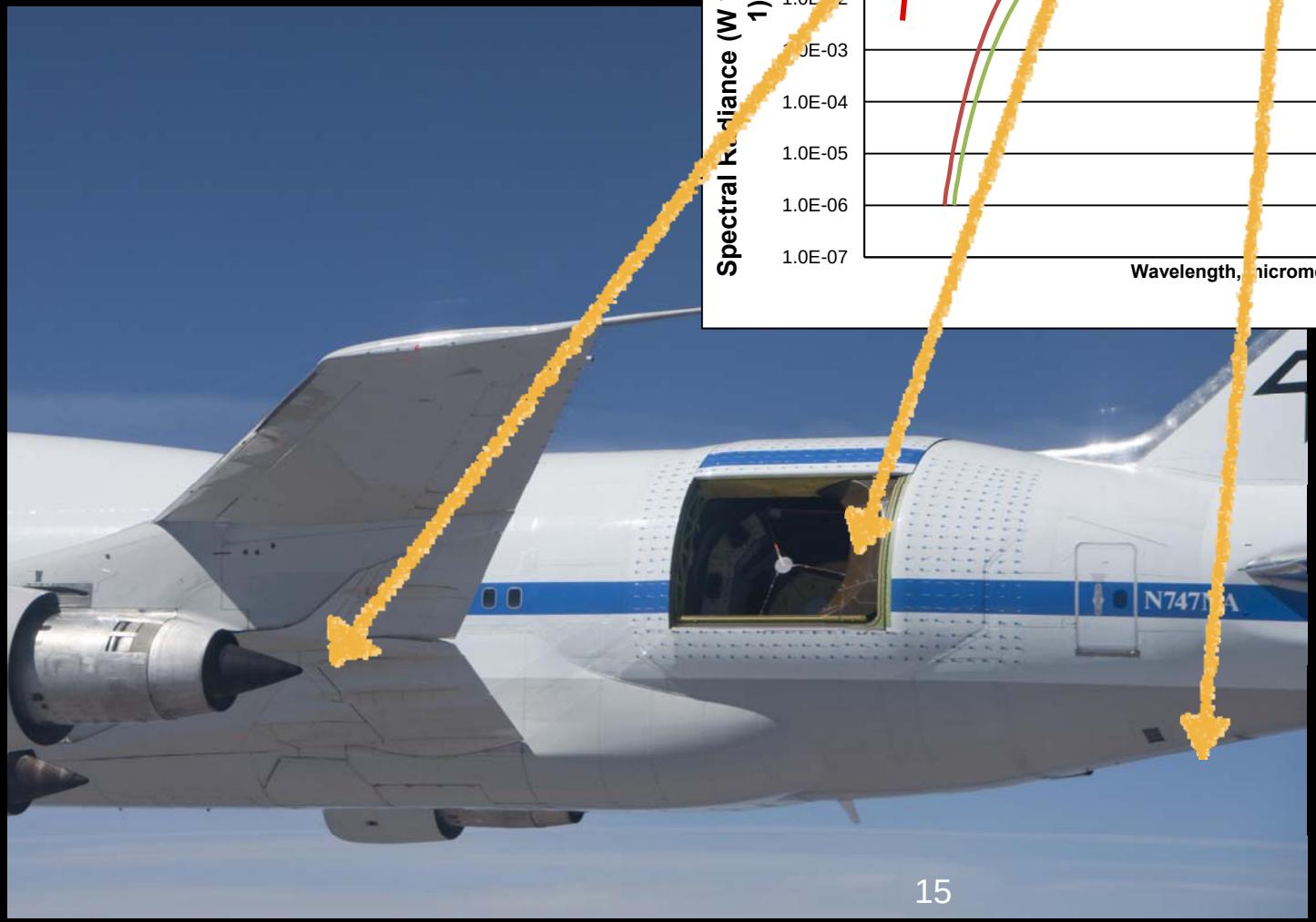


OPTIC ELEMENT TILTED AND VIEWS WARM TELESCOPE STRUCTURE

STRAY LIGHT BACKGROUND IN CRUISE

SELECTED BACKGROUND SOURCES





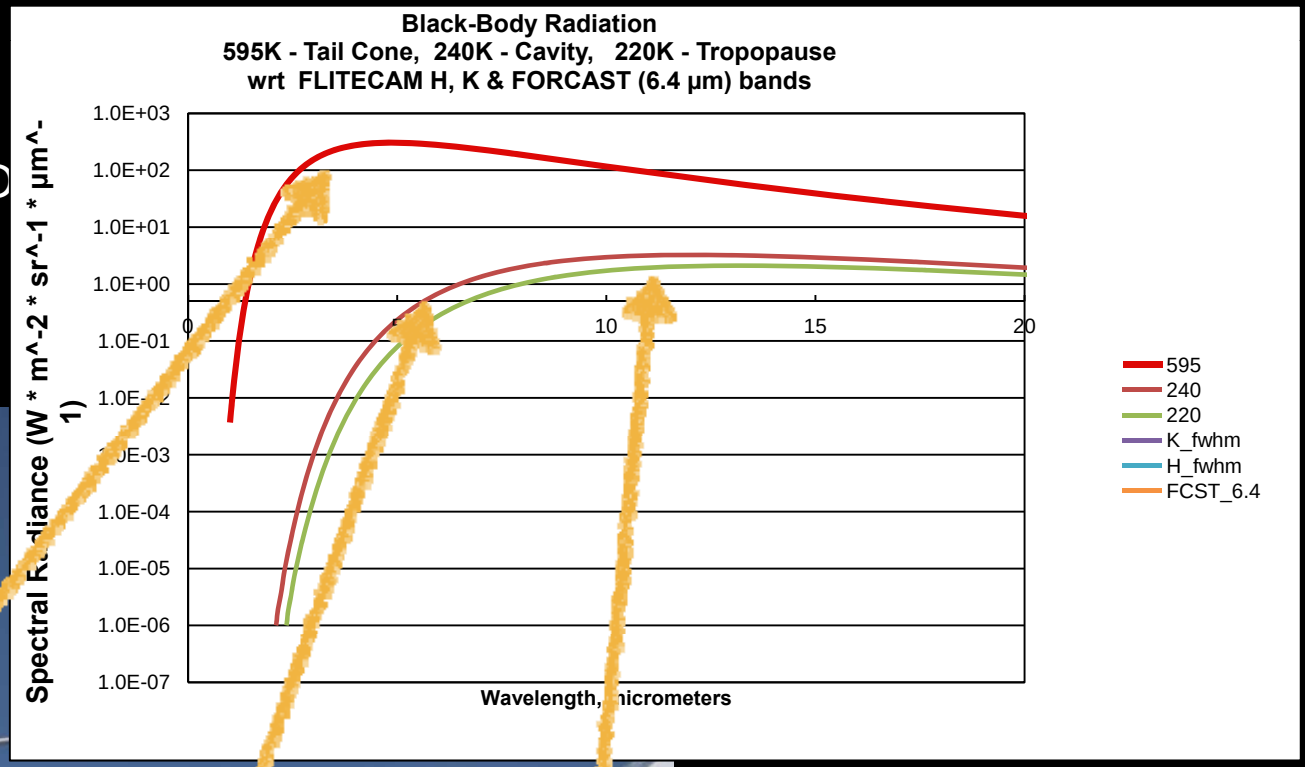
WARM EARTH & ATMOSPHERE

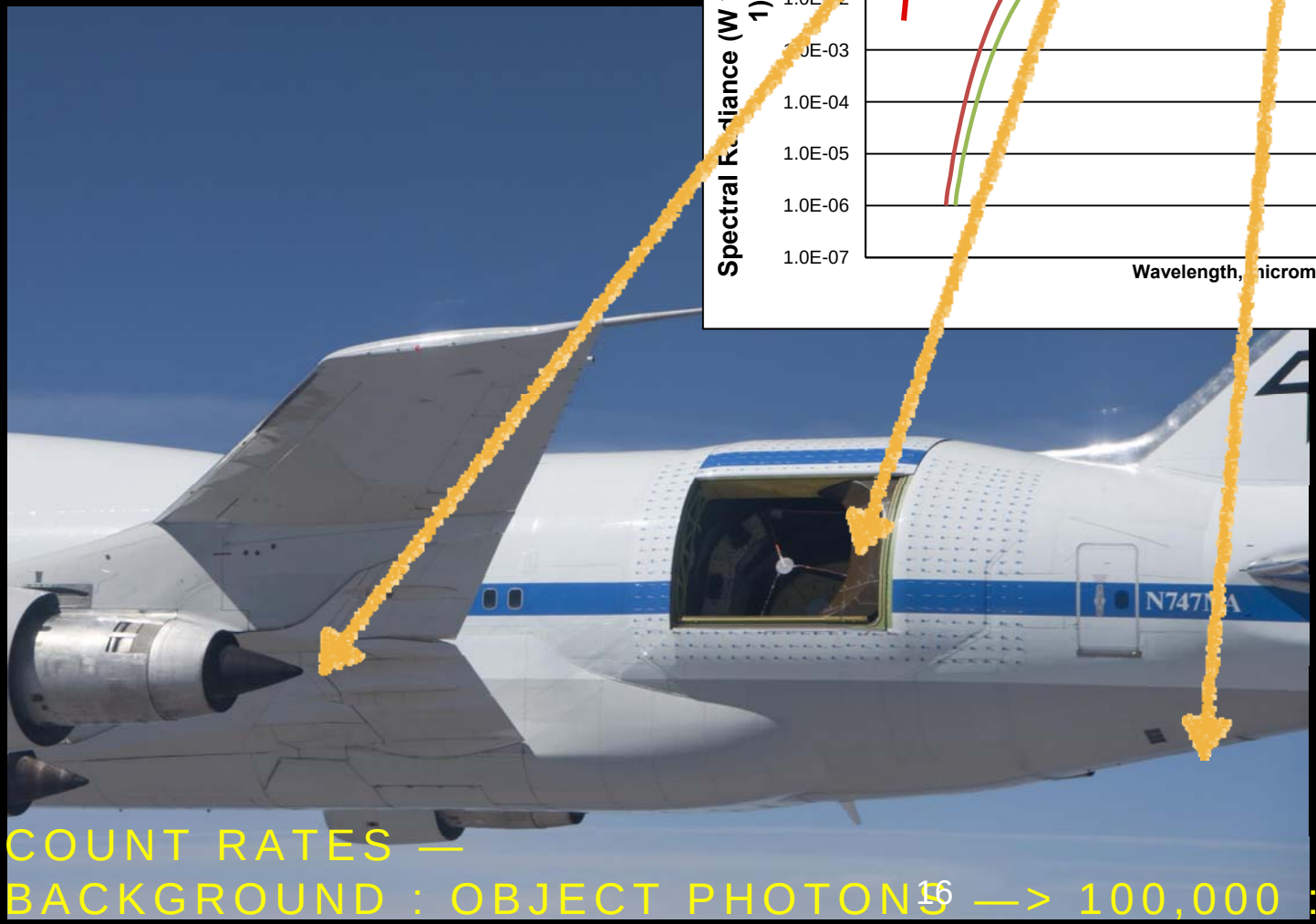
WARM CAVITY & TELESCOPE

HOT ENGINE & PLUME

STRAY LIGHT BACKGROUND IN CRUISE

SELECTED BACKGROUND SOURCES





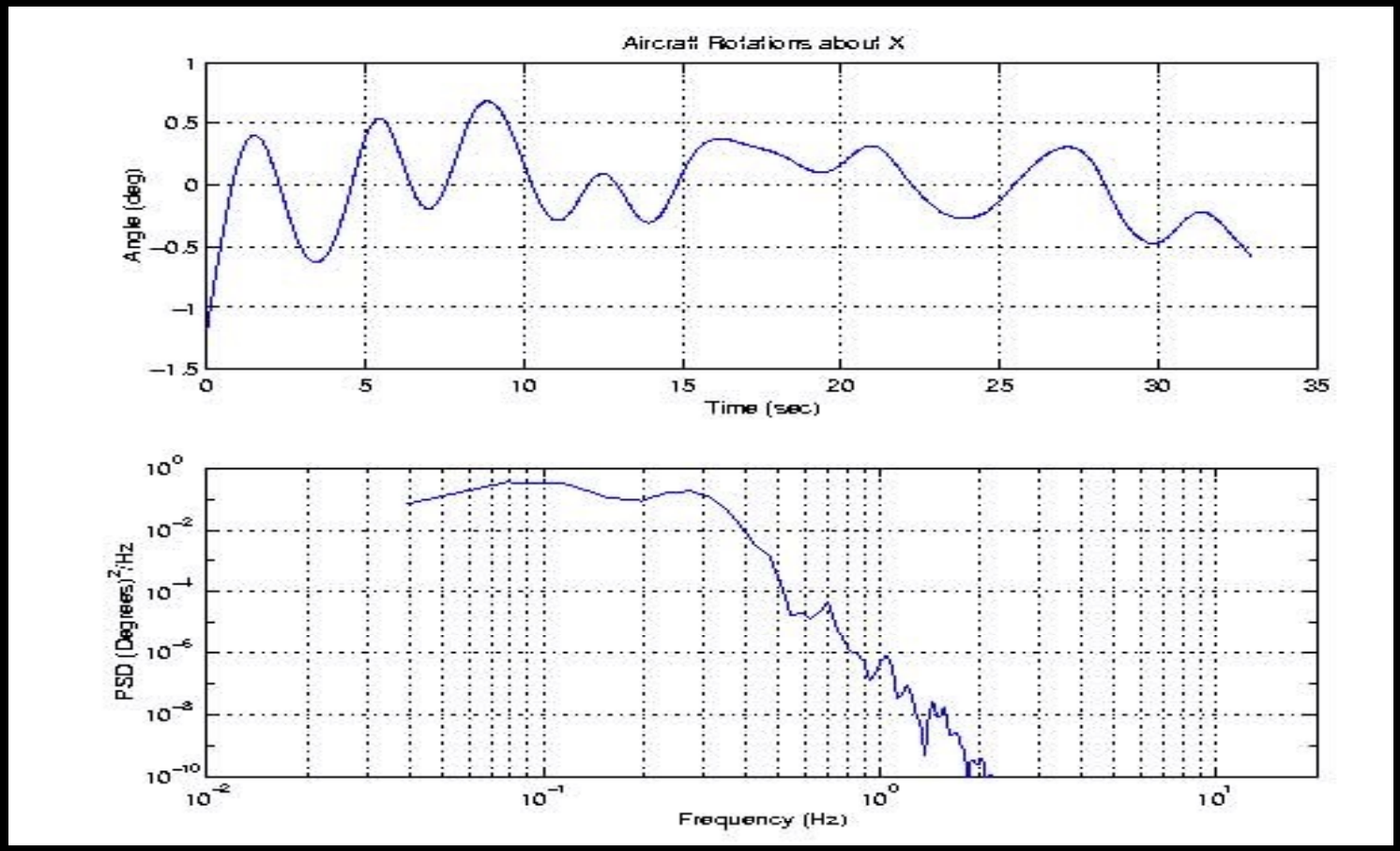
WARM EARTH & ATMOSPHERE

WARM CAVITY & TELESCOPE

HOT ENGINE & PLUME

COUNT RATES — BACKGROUND : OBJECT PHOTONS —> 100,000 : 1 IS TYPICAL

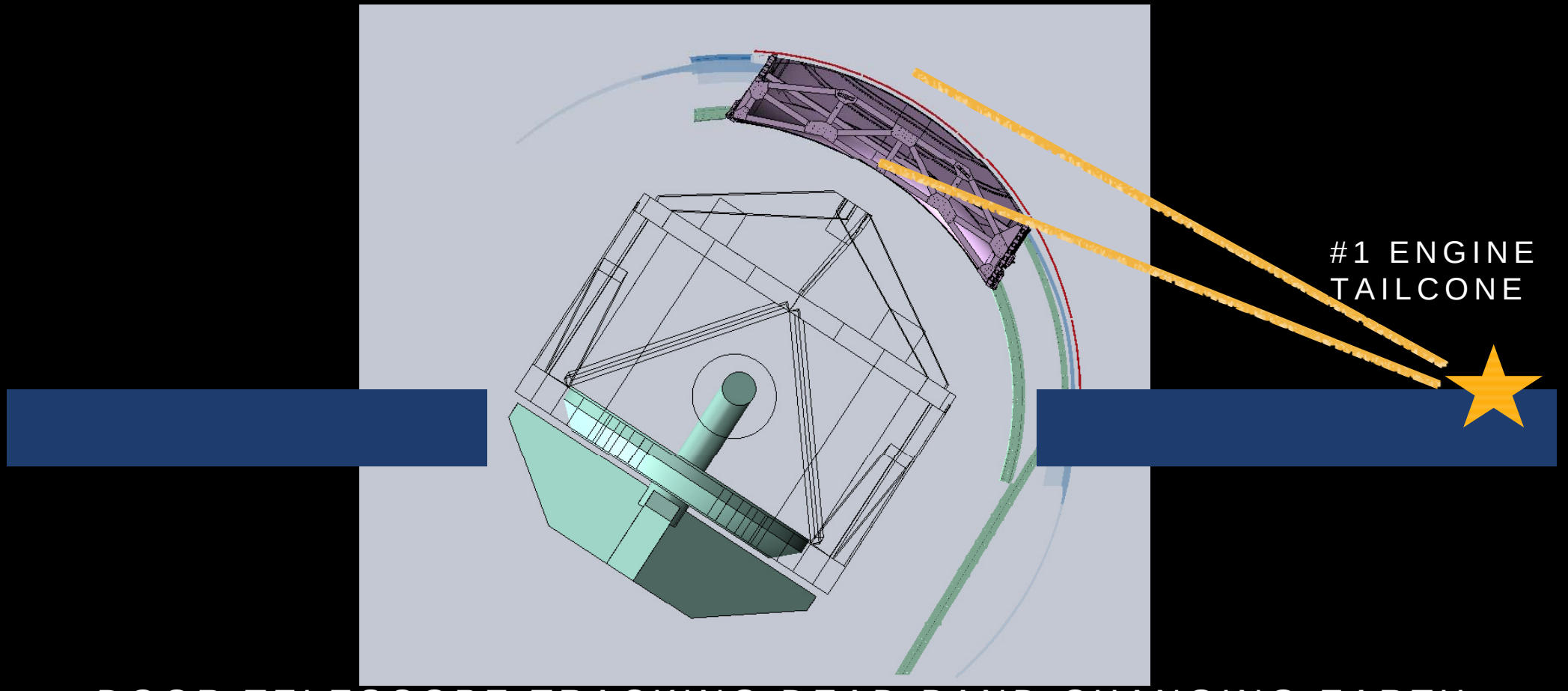
STRAY LIGHT BACKGROUND IN CRUISE



DYNAMIC STRAY LIGHT

DYNAMIC STRAY LIGHT

TELESCOPE INERTIALLY STABLE — AIRCRAFT ROLLS, YAWS —> CHANGING ANGLE WRT REFLECTING DOOR COMPONENTS



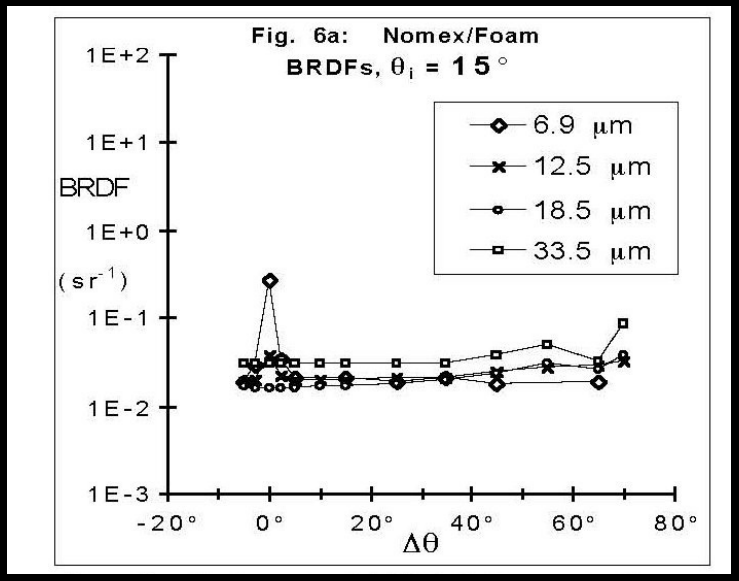
DOOR TELESCOPE TRACKING DEAD BAND CHANGING EARTH AND CAVITY REFLECTION: ADDITIONAL BACKGROUND EFFECTS

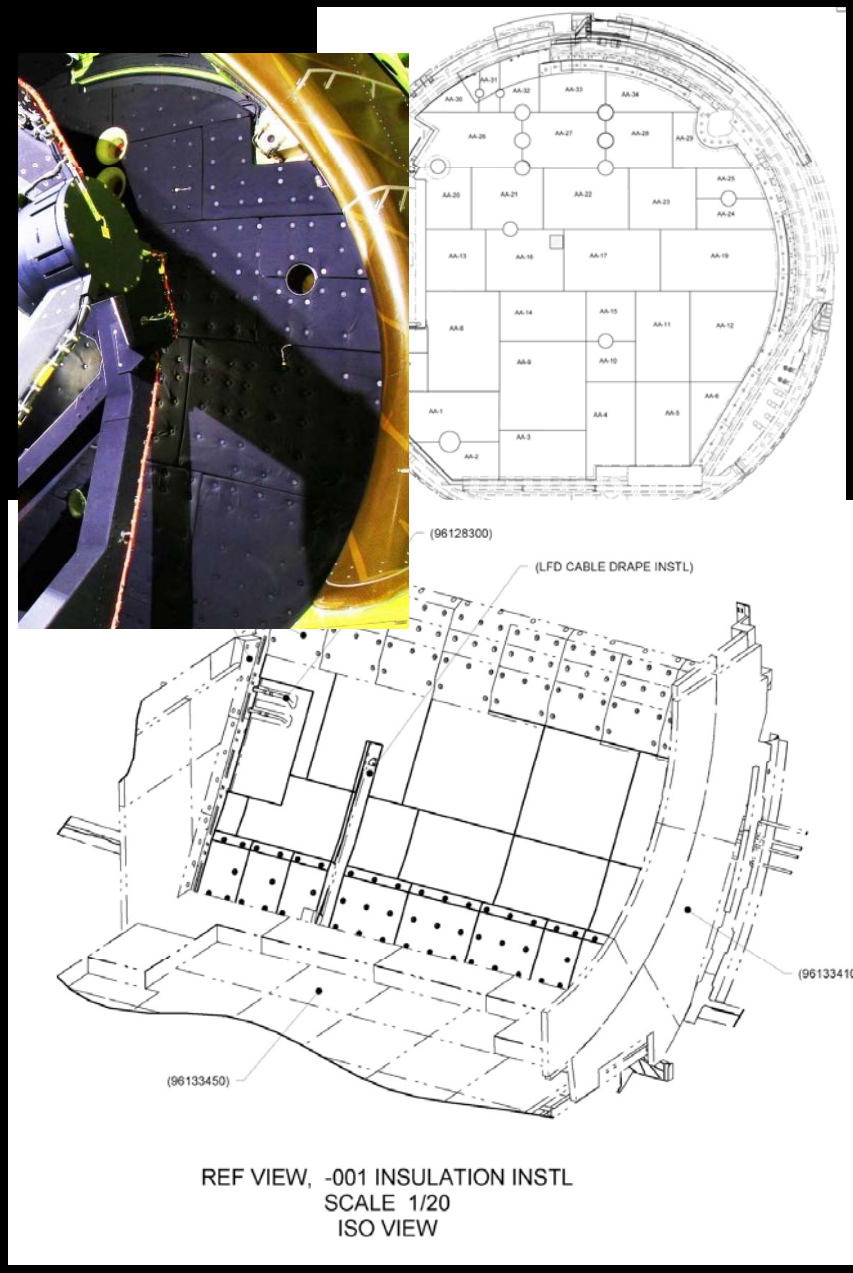
— STRAY LIGHT COATINGS MUST BE DIFFUSE

CAVITY: WALLS

COMBINATION OF FLEXIBLE AND RIGID PANELS
SMALL SIZE FOR AIRWORTHINESS/SAFETY

SELECTED FOR OPTICAL PERFORMANCE (PHASE A STUDIES)





FLEXIBLE: POLYDAMP HYDROPHOBIC MELAMINE FLEXIBLE FOAM (PHM-200)
NOMEX® FABRIC
RIGID: ROHACELL 51A (FIBERGLASS WITH POLYMETHACRYLIMIDE CLOSED CELL RIGID FOAM CORE)
FLAT BLACK: PRC-DESOTO CA 8271/F370381

CAVITY: DOOR

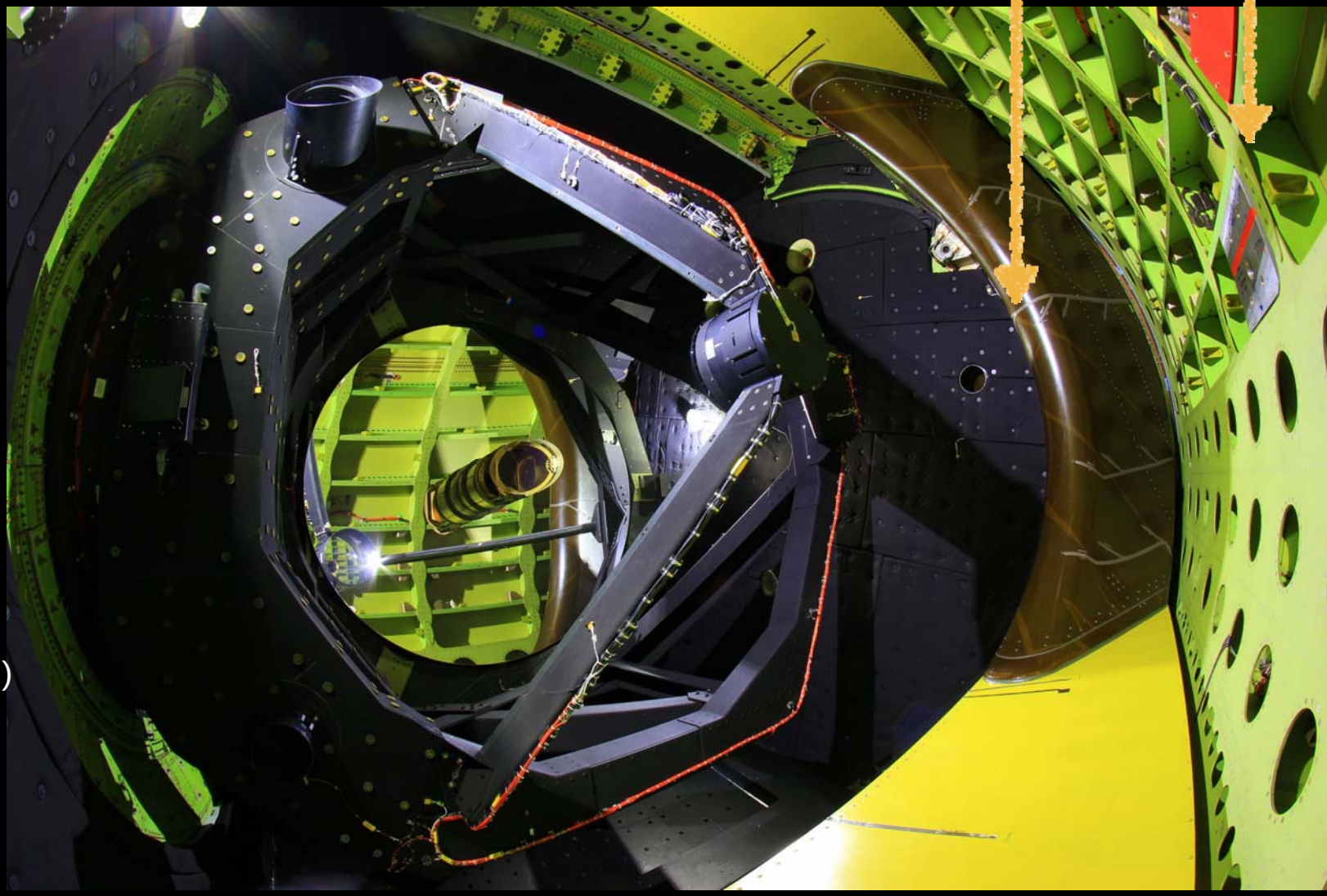
UPPER RIGID DOOR

APERTURE ASSEMBLY

LOWER FLEXIBLE DOOR

INTERNAL COATINGS DEFERRED TO TIME OF FIRST PRIMARY MIRROR RE-COAT, HOWEVER, CAVITY CLEANLINESS REGIMEN & OPTICS CARE AND MAINTENANCE MORE SUCCESSFUL THAN PLANNED

CAVITY & TELESCOPE



STRAY LIGHT COATINGS ON TELESCOPE STRUCTURES SURFACES, MIX OF:

- BIRB (BALL IR BLACK)

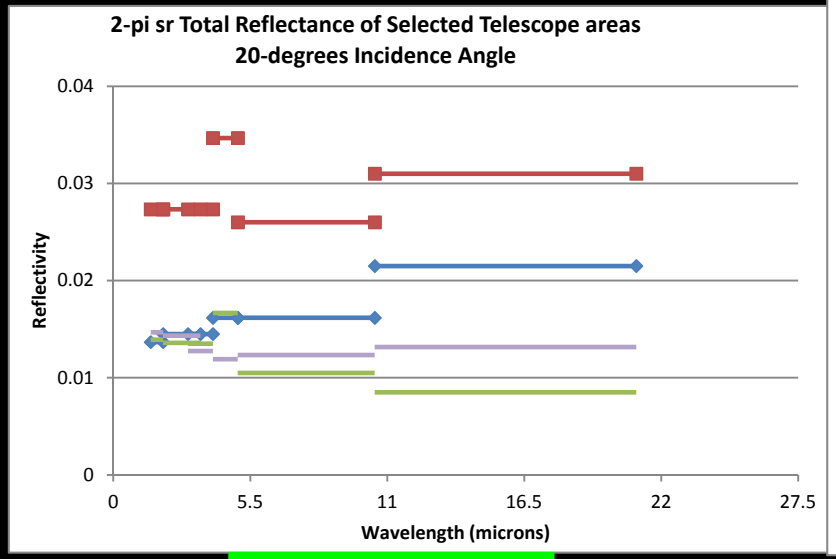
&

- J-BLACK (SOFIA PRODUCT)

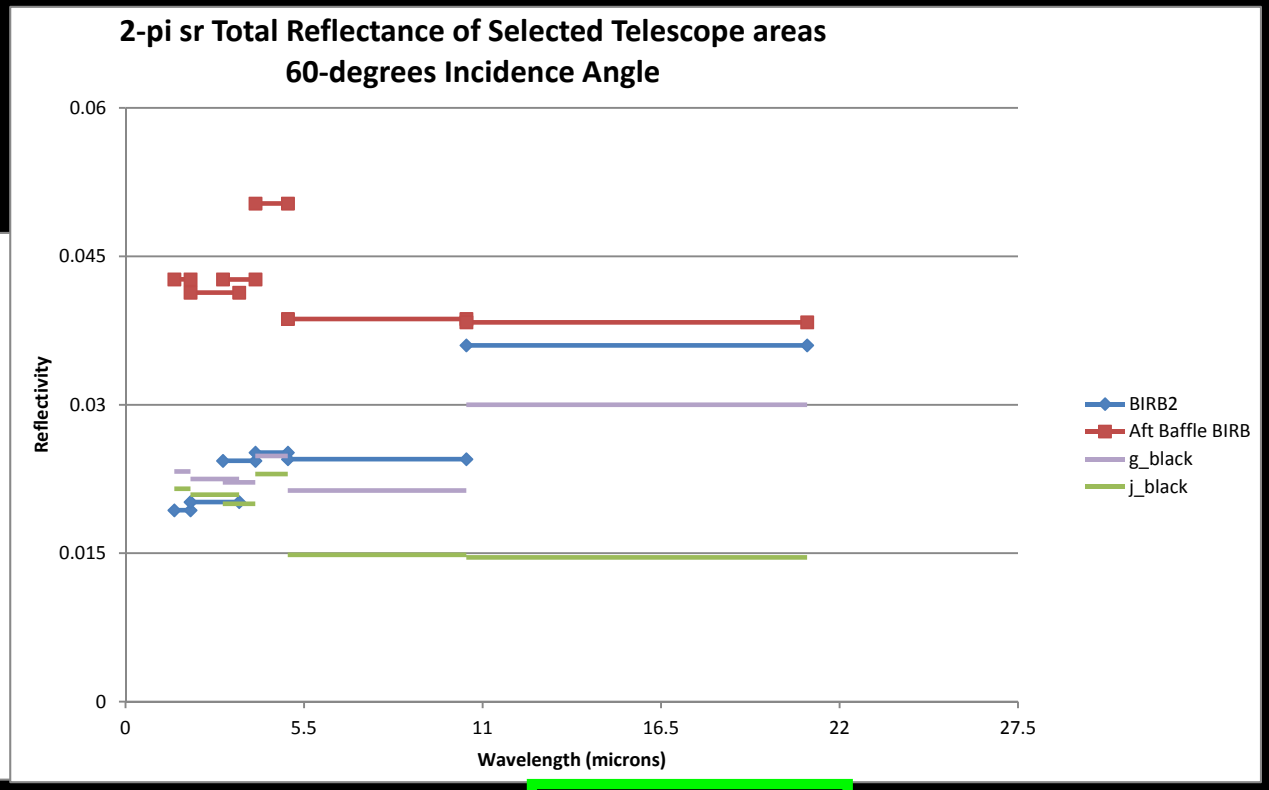
CURRENT CONFIGURATION SHOWN

CAVITY & TELESCOPE

STRAY LIGHT COATINGS ON TELESCOPE



20 DEG. INCIDENCE



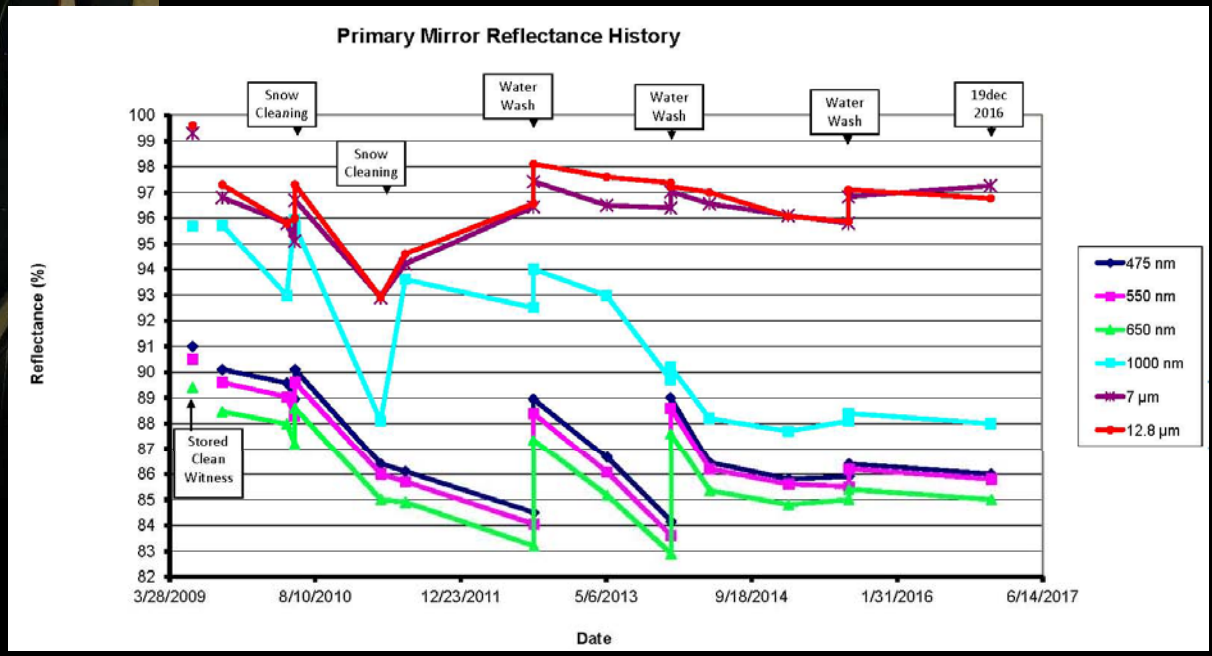
60 DEG. INCIDENCE

SURFACE OPTICS CORP. EMISSOMETER/REFLECTOMETER FOR COATING PERFORMANCE COMPARISONS

TARGET LOW REFLECTANCE VALUES AND SMALLER CHANGES WITH INCIDENCE ANGLES (20 VS 60 DEGREES)

TELESCOPE OPTICS

PRIMARY & SECONDARY — BARE ALUMINUM, NOW 8 YEARS IN OPERATIONS
DICHROIC TERTIARY — FUSED SILICA + GOLD + PROTECTIVE SAPPHIRE OVERCOAT



INITIALLY CO2 SNOW, NOW PERIODIC WATER/ORVUS WASHING.

TELESCOPE OPTICS PROTECTION

CAVITY ENVIRONMENT CONTROL (DESSICANT DRYER); MAINTAINING DEW POINT SPREAD THROUGH DESCENT IS CRITICAL.

CAVITY IS TREATED AS A CLEAN ROOM

DOOR IS RARELY OPEN WHEN IN THE HANGAR

TELESCOPE OPTICS PROTECTION

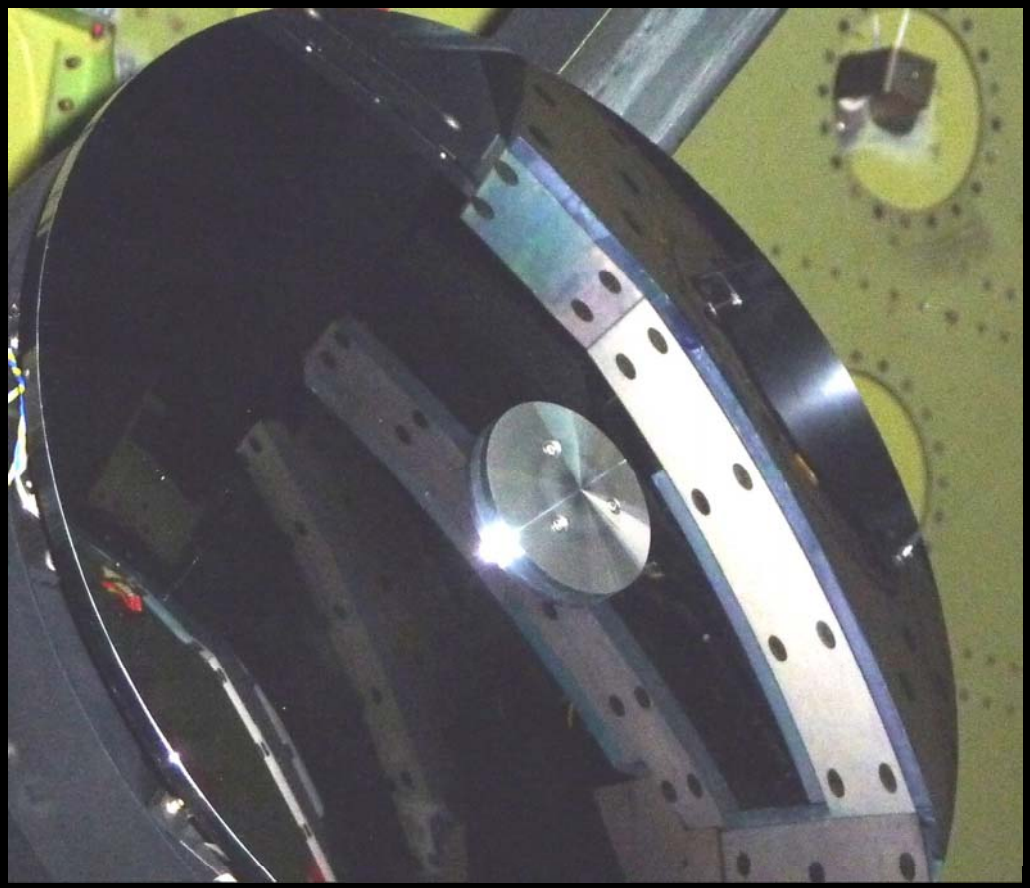
CAVITY ENVIRONMENT CONTROL (DESSICANT DRYER); MAINTAINING DEW POINT SPREAD THROUGH DESCENT IS CRITICAL.

CAVITY IS OPERATED AS A CLEAN ROOM

DOOR IS RARELY OPEN WHEN IN THE ~~HANGAR~~ AVIARY

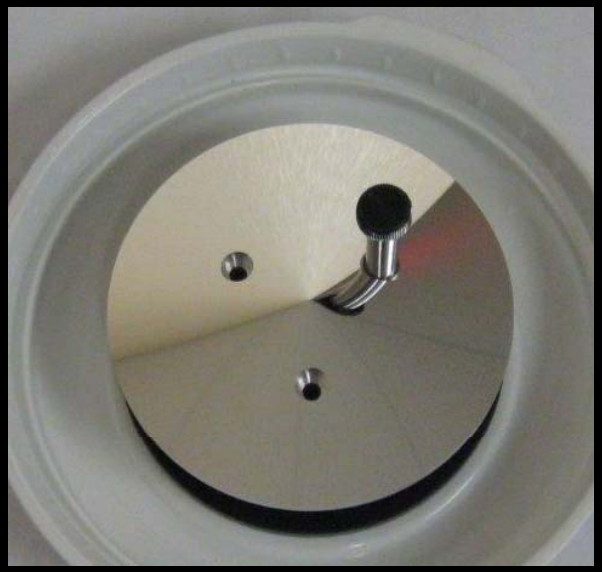
TELESCOPE SPECIAL OPTICS

SILICON CARBIDE M2 ACTUATED TO CHOP BETWEEN MULTIPLE POINTING DIRECTIONS; TYPICALLY UP TO 20 HZ, 5 ARC MINUTES; COMBINED WITH TELESCOPE NODS TO REMOVE HIGH BACKGROUND LEVELS.



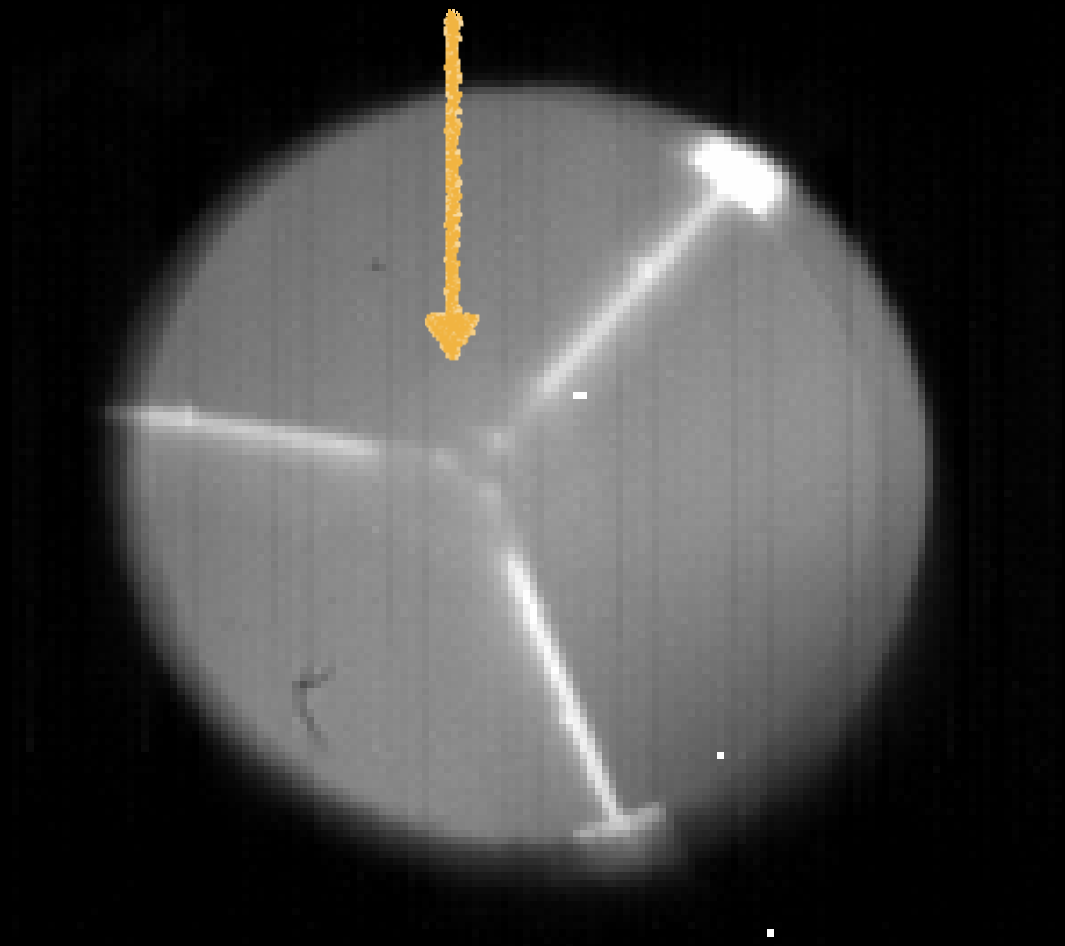
CASSEGRAIN CENTRAL OBSCURATION PRESENTS STRONG IR STRAY LIGHT SOURCE.

— CONICAL BUTTON BOUNCES SKY LIGHT AT THIS LOCATION OF THE ENTRANCE PUPIL



TELESCOPE SPECIAL OPTICS

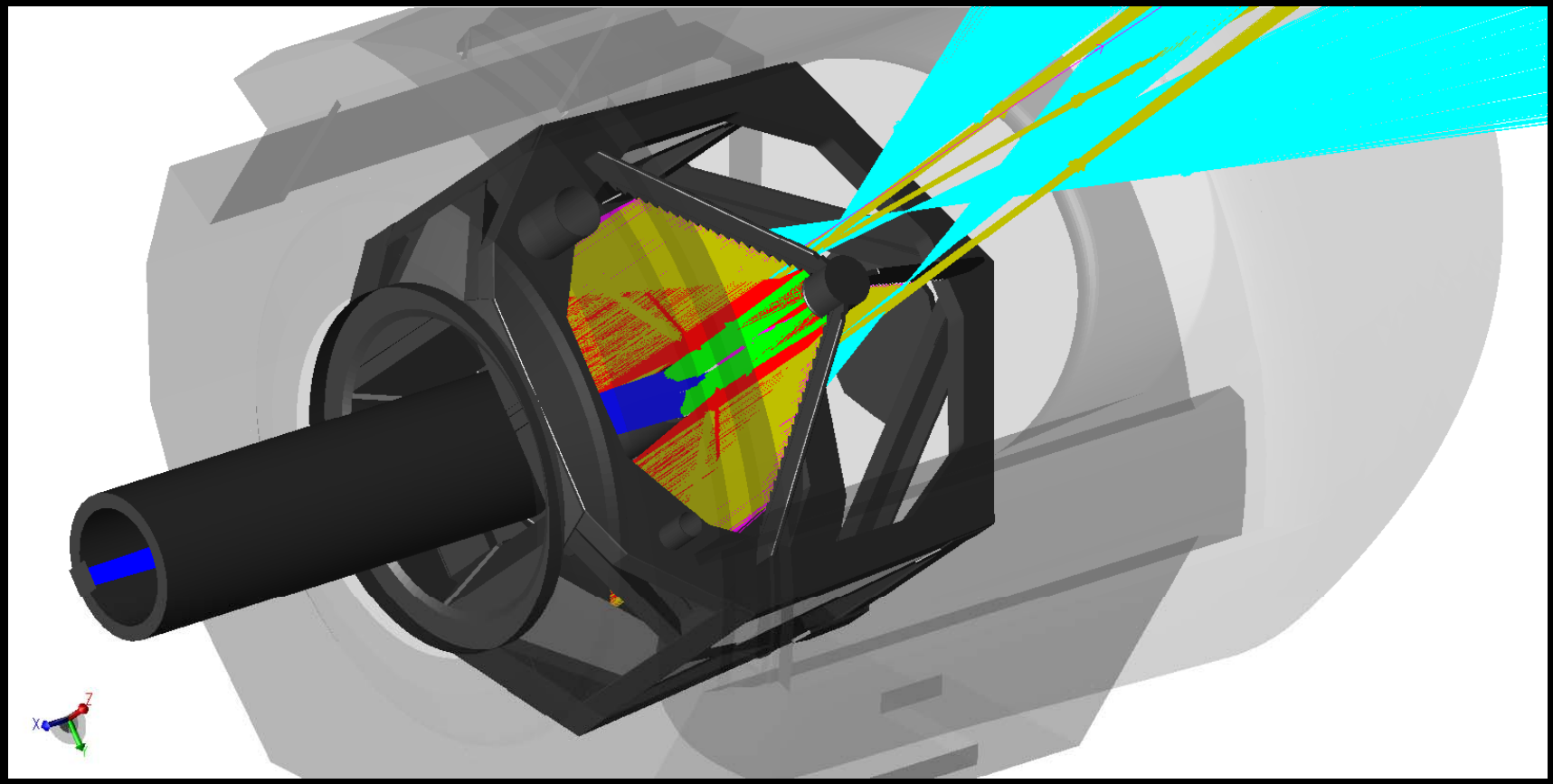
NOTE: SKY LIGHT IN THE CENTRAL OBSCURATION, WITH GLOWING MOUNTING BOLTS



BUT IT IS POSSIBLE TO MAKE THE SPIDERS DISAPPEAR TOO…

TELESCOPE SPECIAL OPTICS

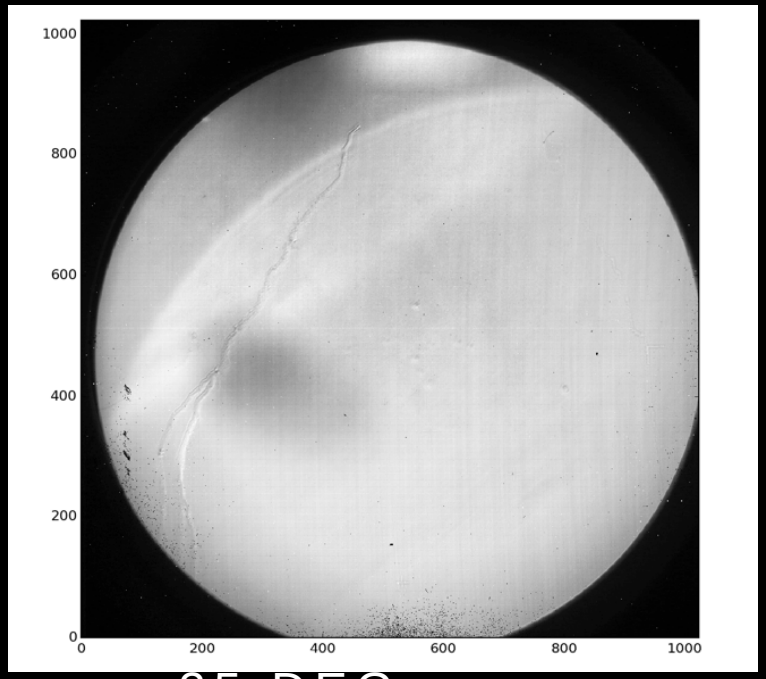
SPIDER COVERS WITH FACETED MIRRORS—
BOUNCED SKY LIGHT REPLACING WARM SPIDER EMISSION



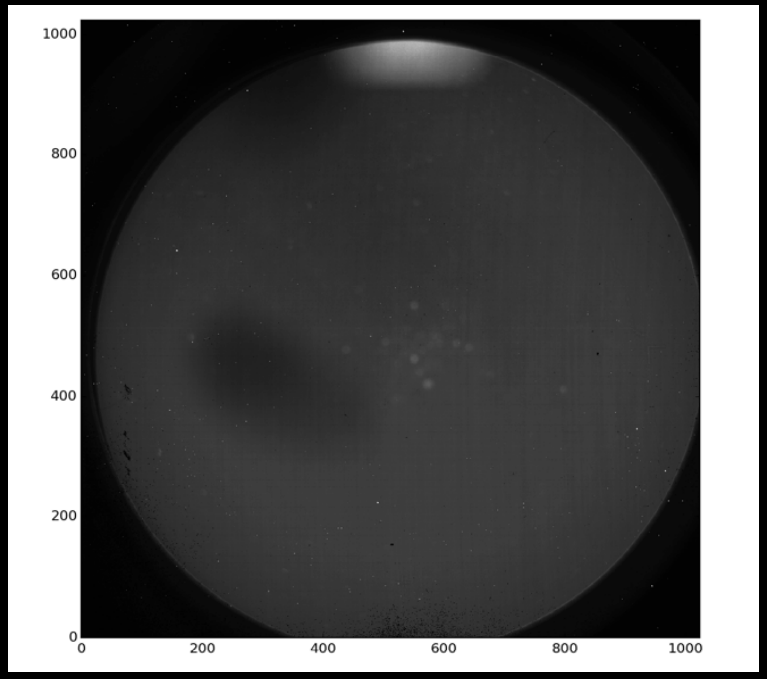
SPECIFIC STRAY LIGHT ISSUES

- DURING THE PLUTO OCCULTATION PRACTICE FLIGHT, AN EXTRA BACKGROUND AT 2.2 MICRONS WAS NOTED
- STRONGLY DEPENDENT ON TELESCOPE ELEVATION
- EXTRA BACKGROUND COULD BE EASILY SEEN AT 35 DEGREES AND VARIED AS THE PLANE TIPPED SLIGHTLY ~1 DEG; DISAPPEARED BY ~45 DEG

FLITECAM FOCAL PLANE IMAGES, 2.2 MICRONS



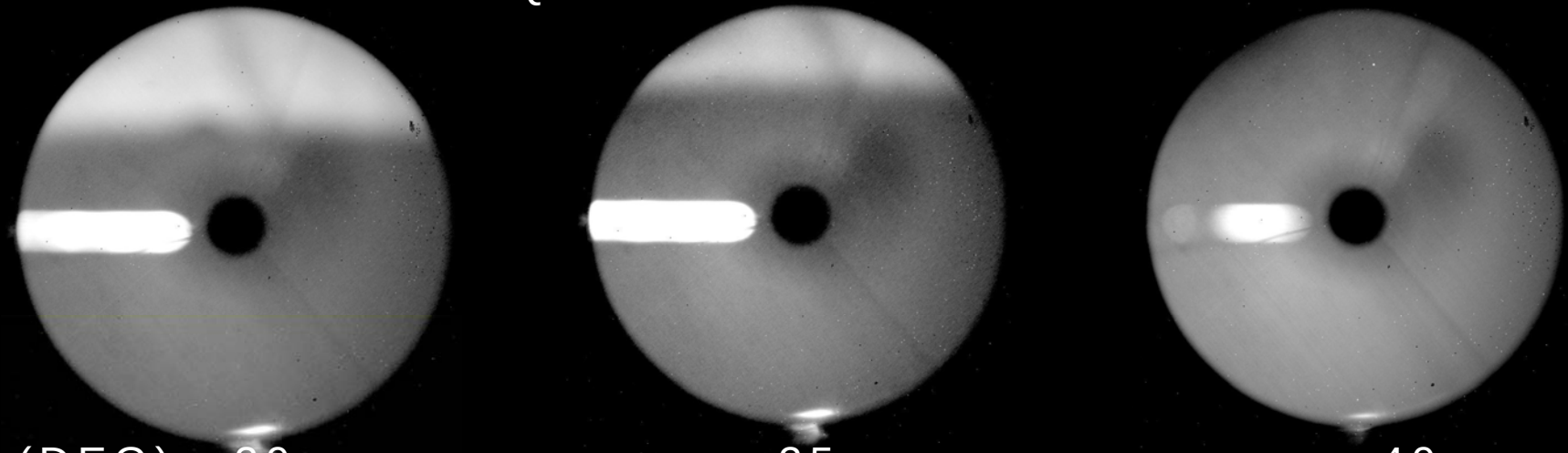
25 DEG, ELEV.



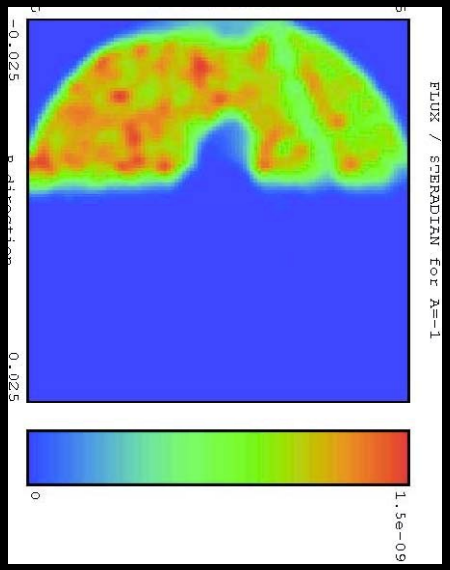
50 DEG, ELEV.

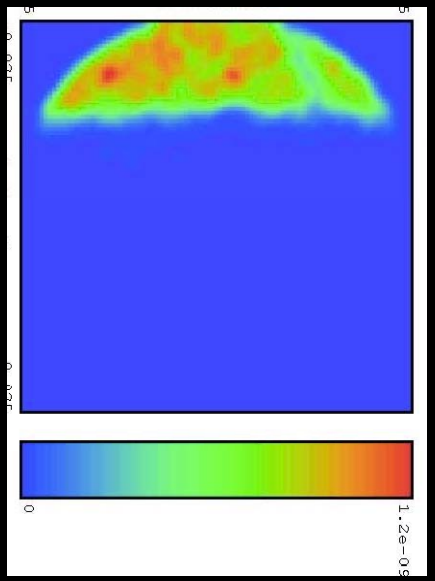
SPECIFIC STRAY LIGHT ISSUES

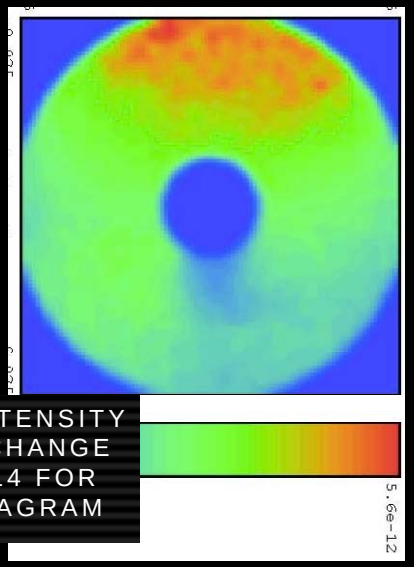
PUPIL IMAGES WERE ACQUIRED FOR THE SAME BAND



ELEV. (DEG) 20 25 40







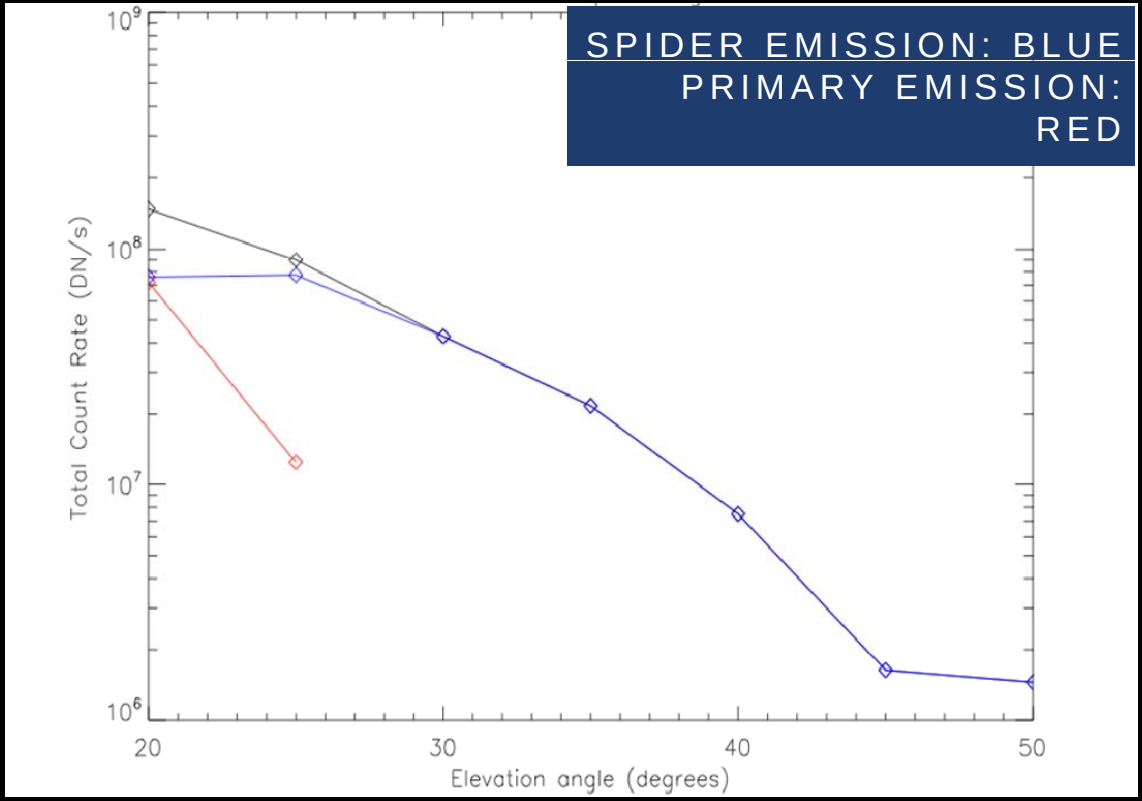
NOTE: INTENSITY SCALE CHANGE → 1/214 FOR THIS DIAGRAM

COMPARING IMAGES WITH BREAULT RESEARCH ORG. STRAY LIGHT STUDIES (5-7MICRON),1998

SOURCE APPEARED TO BE COINCIDENT WITH THE AFT SPIDER

SPECIFIC STRAY LIGHT ISSUES

SPIDER EMISSION WAS FOUND TO BE THE DOMINANT CONTRIBUTOR FOR MUCH OF THE AVAILABLE ELEVATION RANGE

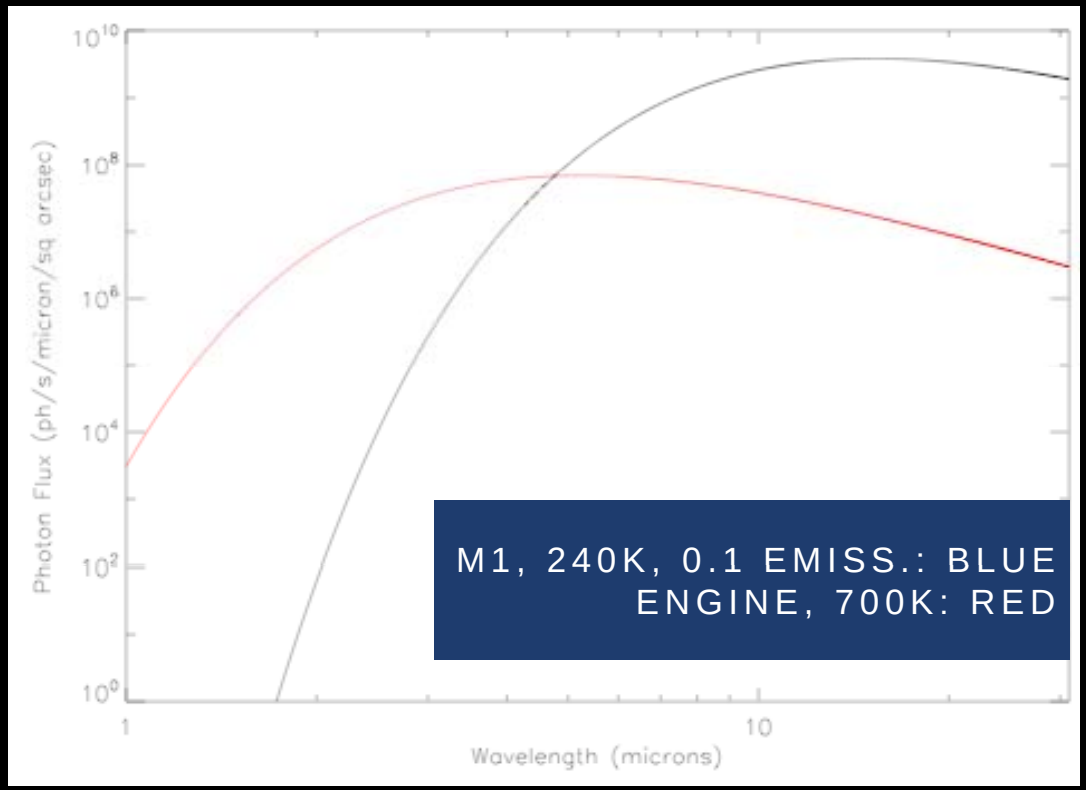


EARLIER STUDIES OF ENGINE EMISSION USING SHUTTLE CARRIER 747 (DINGER, ET.AL.) INDICATED THAT THE ENGINE TAIL CONE IS HIGHLY LUMINOUS

THUS ENGINE #1 TAIL CONE AS “LIGHTBULB” WAS IDENTIFIED AS THE LIKELY SOURCE.

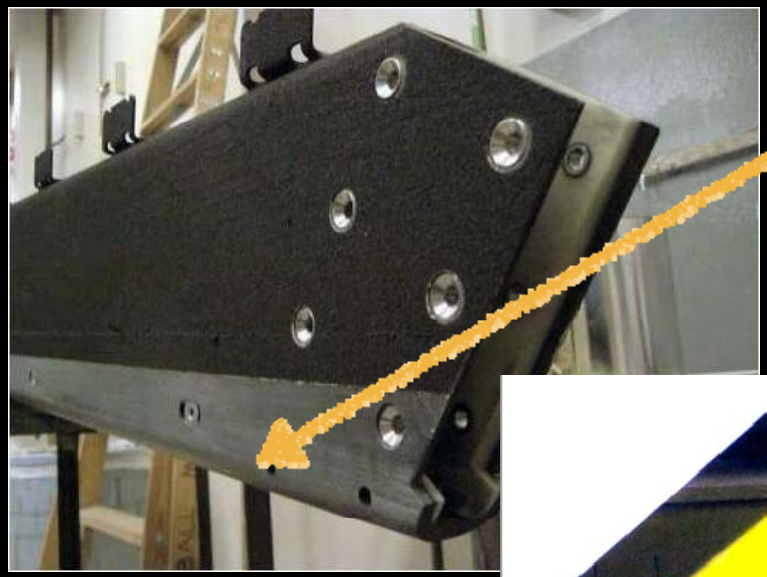
SPECIFIC STRAY LIGHT ISSUES

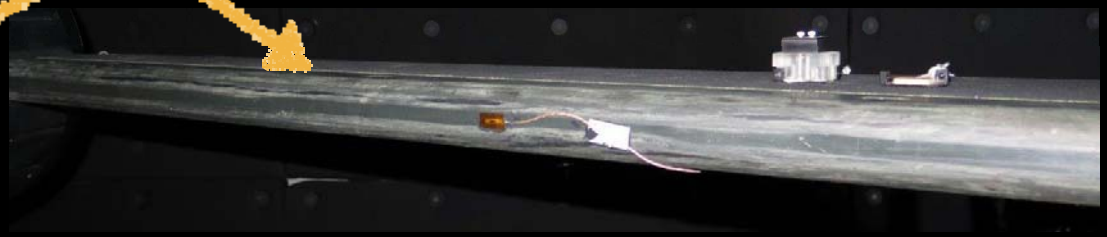
MEASUREMENTS FROM OTHER WAVELENGTHS INDICATED THE EMISSION WAS CONSISTENT WITH A COLOR TEMPERATURE OF 600K TO 700K; RANGE.
AMPLITUDE AT 1.6 MICRONS IS SLIGHTLY HIGHER THAN ATMOSPHERIC OH AND WAS USED TO SET THE RELATIVE THERMAL EMISSION CURVES BELOW.



SPECIFIC STRAY LIGHT ISSUES

SPIDERS WERE DESIGNED FOR COVERS (BAFFLES), BUT TASK HAD BEEN DEFERRED. INTERFACE HAS SMOOTH ROUNDED SURFACES

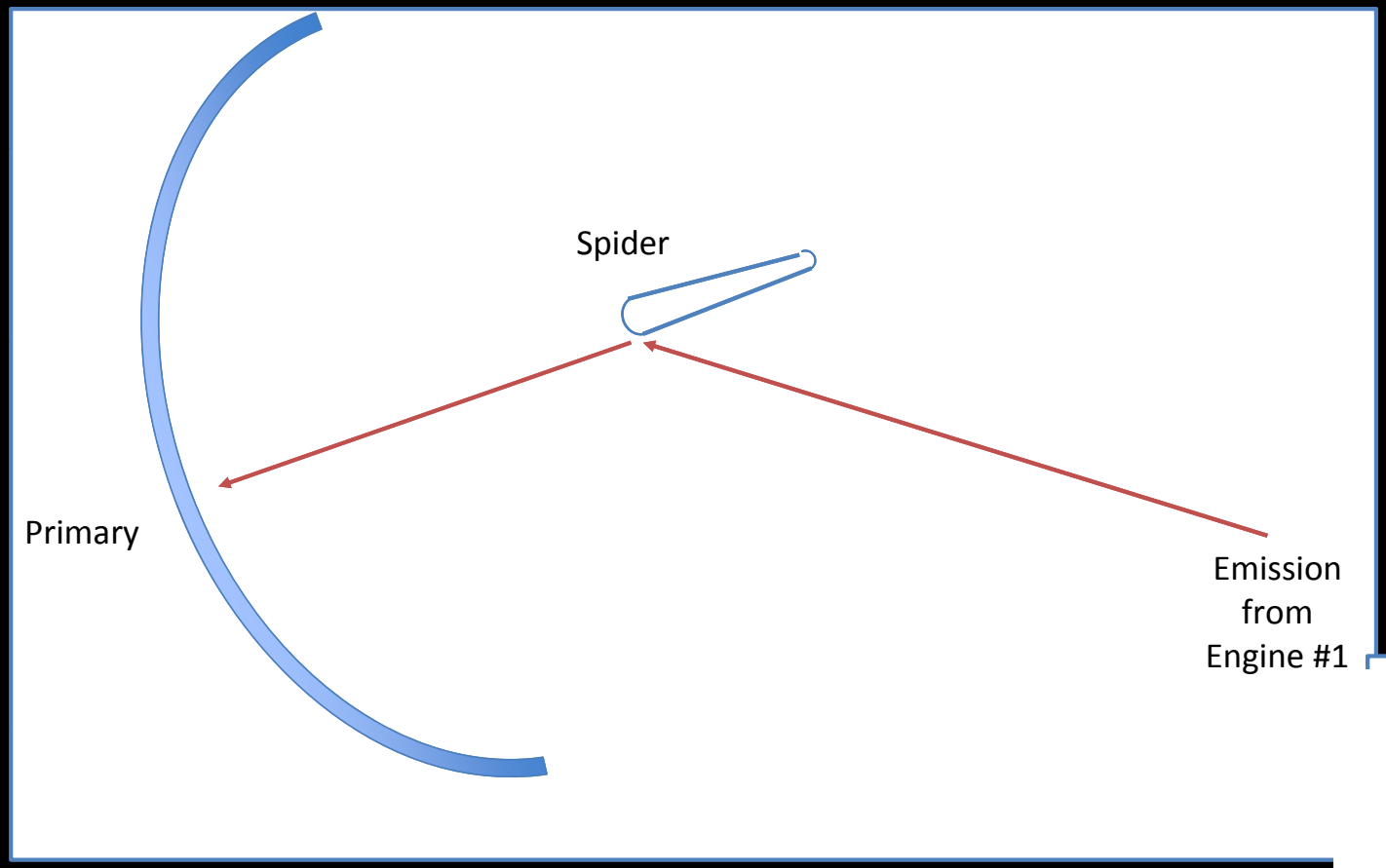


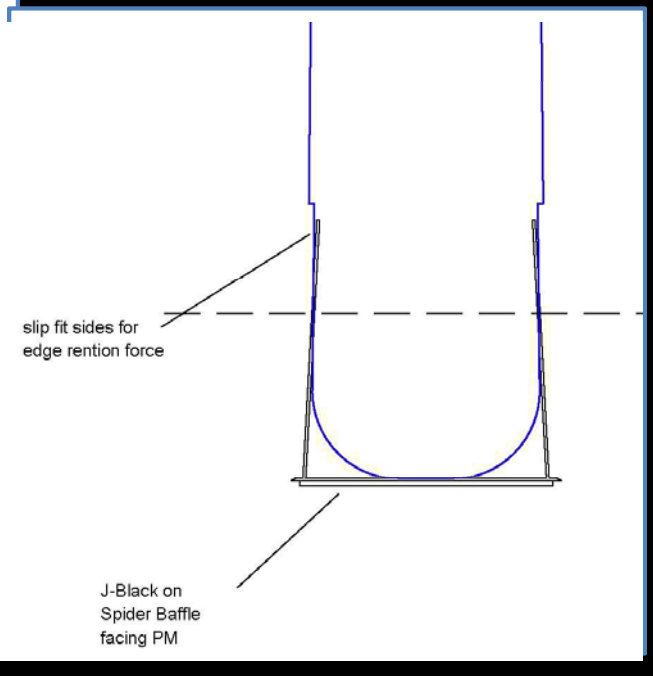


DURING LINE OPERATIONS FOR INSTRUMENT VERIFICATION TESTS, BRIGHT LIGHTS WERE USED TO SIMULATE EMISSION AND RECORDED WITH CAMERAS LOCATED AT THE TAIL CONE

SPECIFIC STRAY LIGHT ISSUES

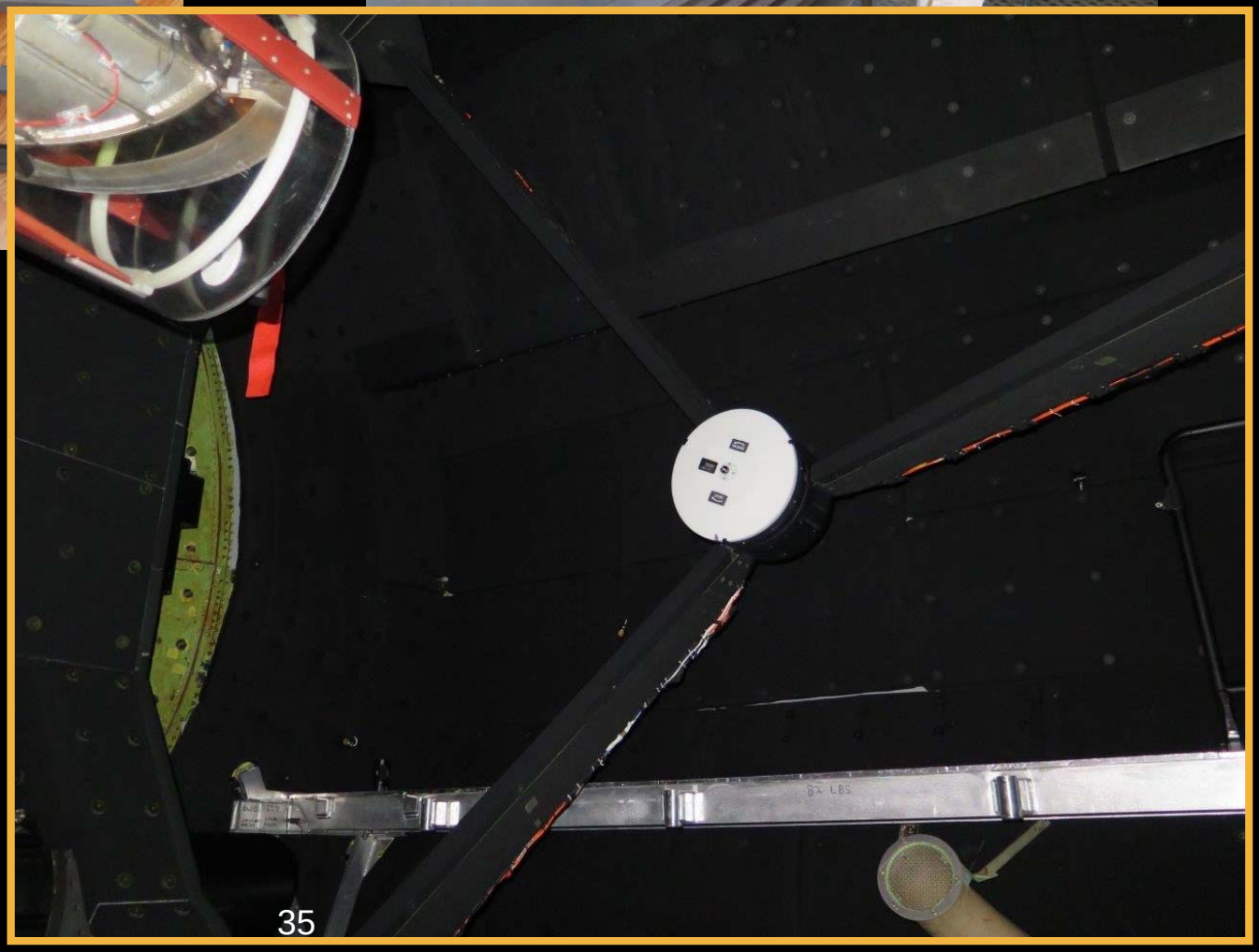
SIMPLE “SHINY POLE” SCENARIO EMERGES, AND WORK STARTED ON KNIFE EDGED BAFFLES TO BLOCK THE SOURCE





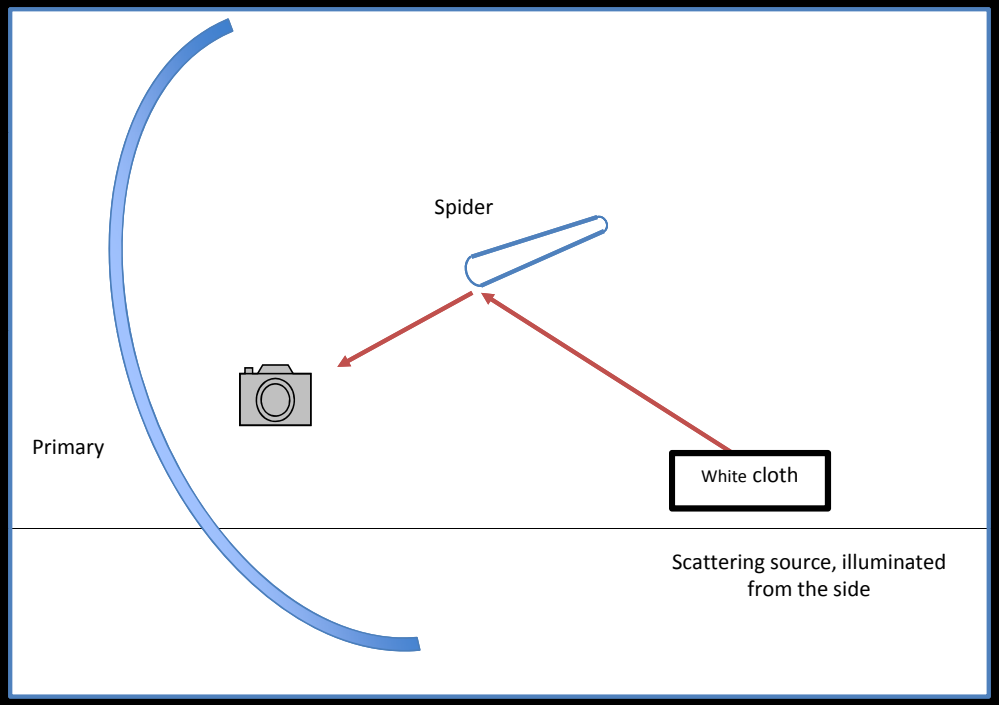
SPECIFIC STRAY LIGHT ISSUES

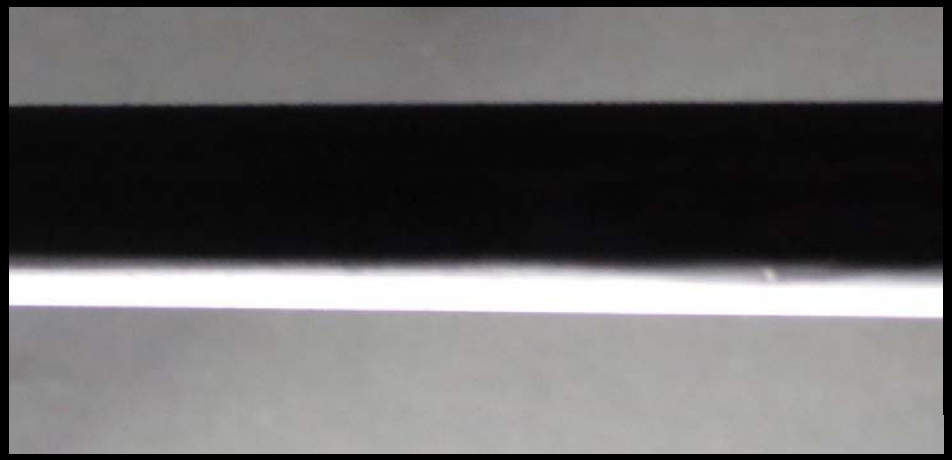
CARBON FIBER SET, INCL. SPARES COMPLETED, J-BLACK COATED, STRENGTH TESTED, FIT CHECKED



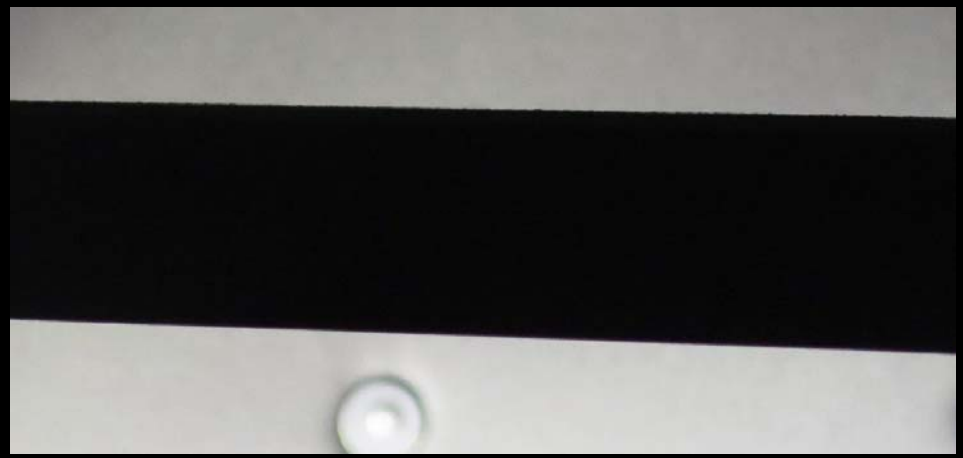
SPECIFIC STRAY LIGHT ISSUES

LIMITED OPTICAL TESTS LOOKED VERY PROMISING





WITHOUT BAFFLE

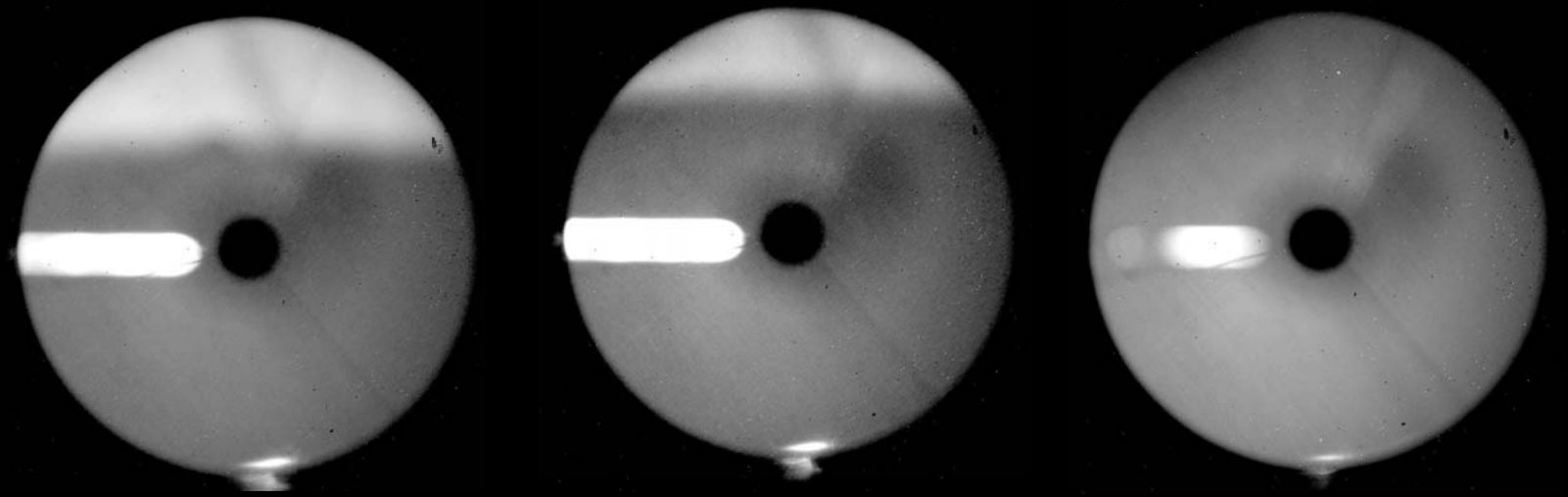


WITH BLACK SPIDER BAFFLE

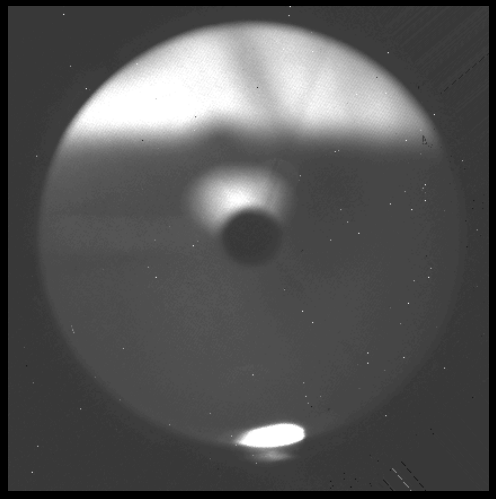
SPECIFIC STRAY LIGHT ISSUES

PREVIOUS FLITECAM PUPIL IMAGES VS NEW PUPIL IMAGES (WITH BAFFLES) OCT 2016

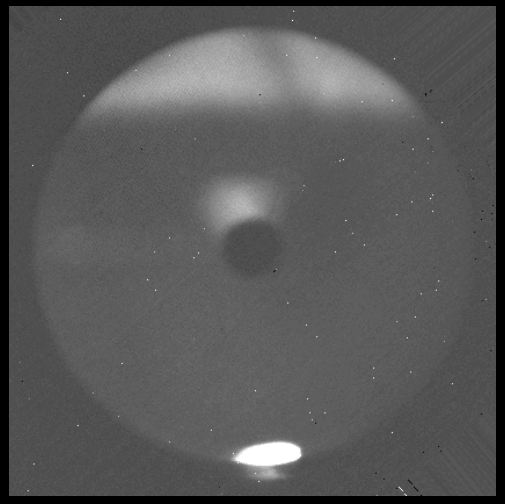
2015



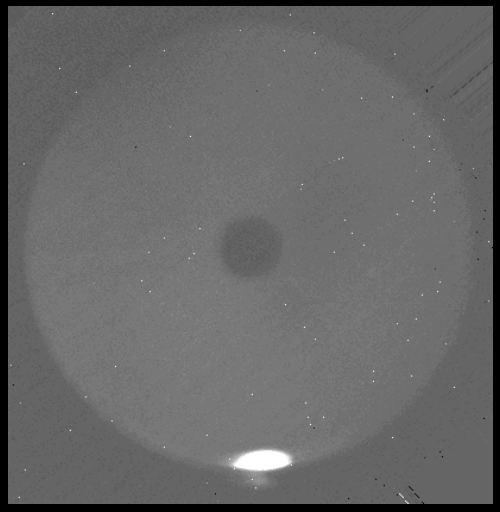
2016



20 deg EL



25 deg EL

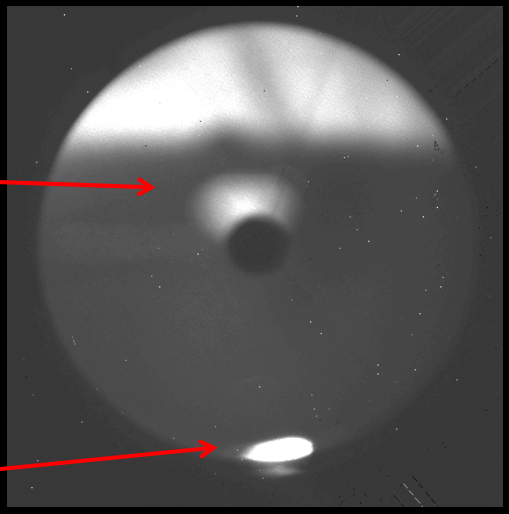


40 deg EL

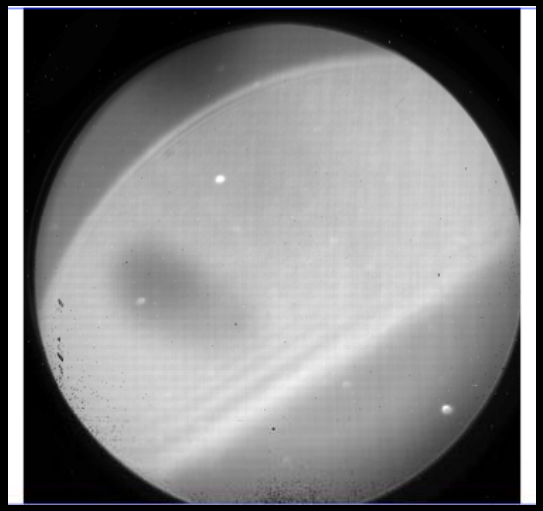
DATA REDUCTION IN PROGRESS; INITIAL NUMBERS SUGGEST SPIDER REFLECTION IS ATTENUATED BY A FACTOR OF ABOUT 100.

SPECIFIC STRAY LIGHT ISSUES

"NEW" ITEM IS M2 BUTTON REFLECTING SCATTERED PRIMARY MIRROR EMISSION

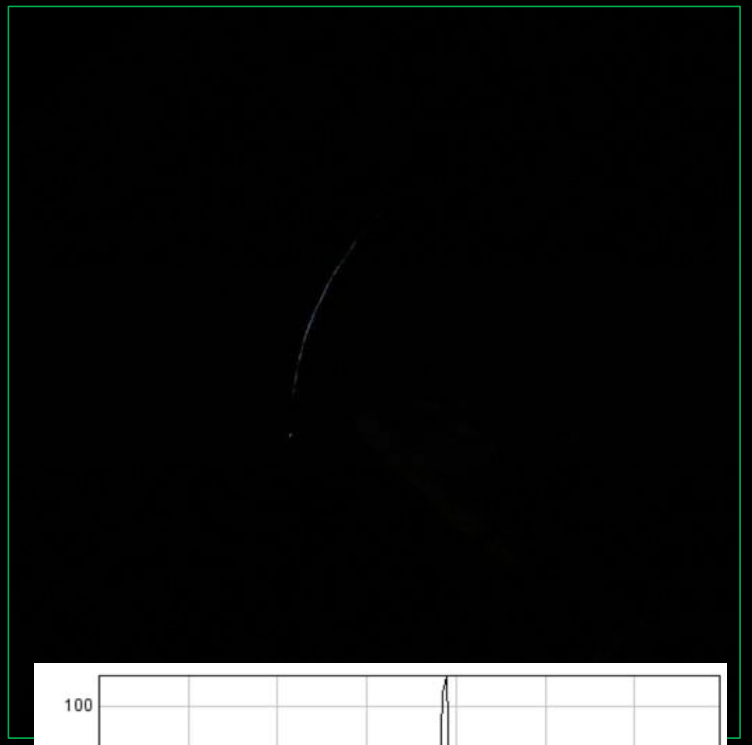


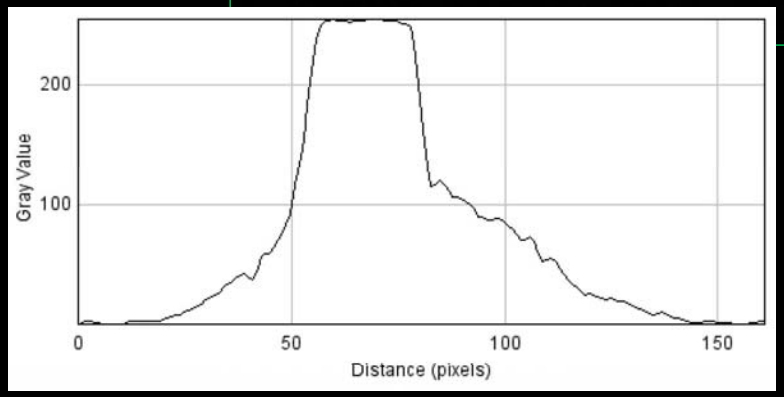
"OLD" ITEM, AND NEXT PROBLEM TO FIX, IS NOW BELIEVED TO BE ENGINE #1 GLINT FROM EDGE OF THE SECONDARY MIRROR THAT IS NOT SHARP AS EXPECTED, CREATING CAUSTIC PATTERN IN THE FOCAL PLANE.

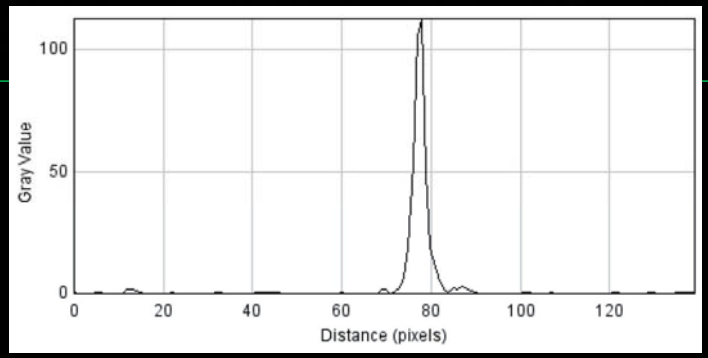


SPECIFIC STRAY LIGHT ISSUES

FURTHER CAVITY TESTS WITH SHARP EDGED TAPE BAFFLE TO ELIMINATE GLINT







QUESTIONS?