FUEGO Mission Concept

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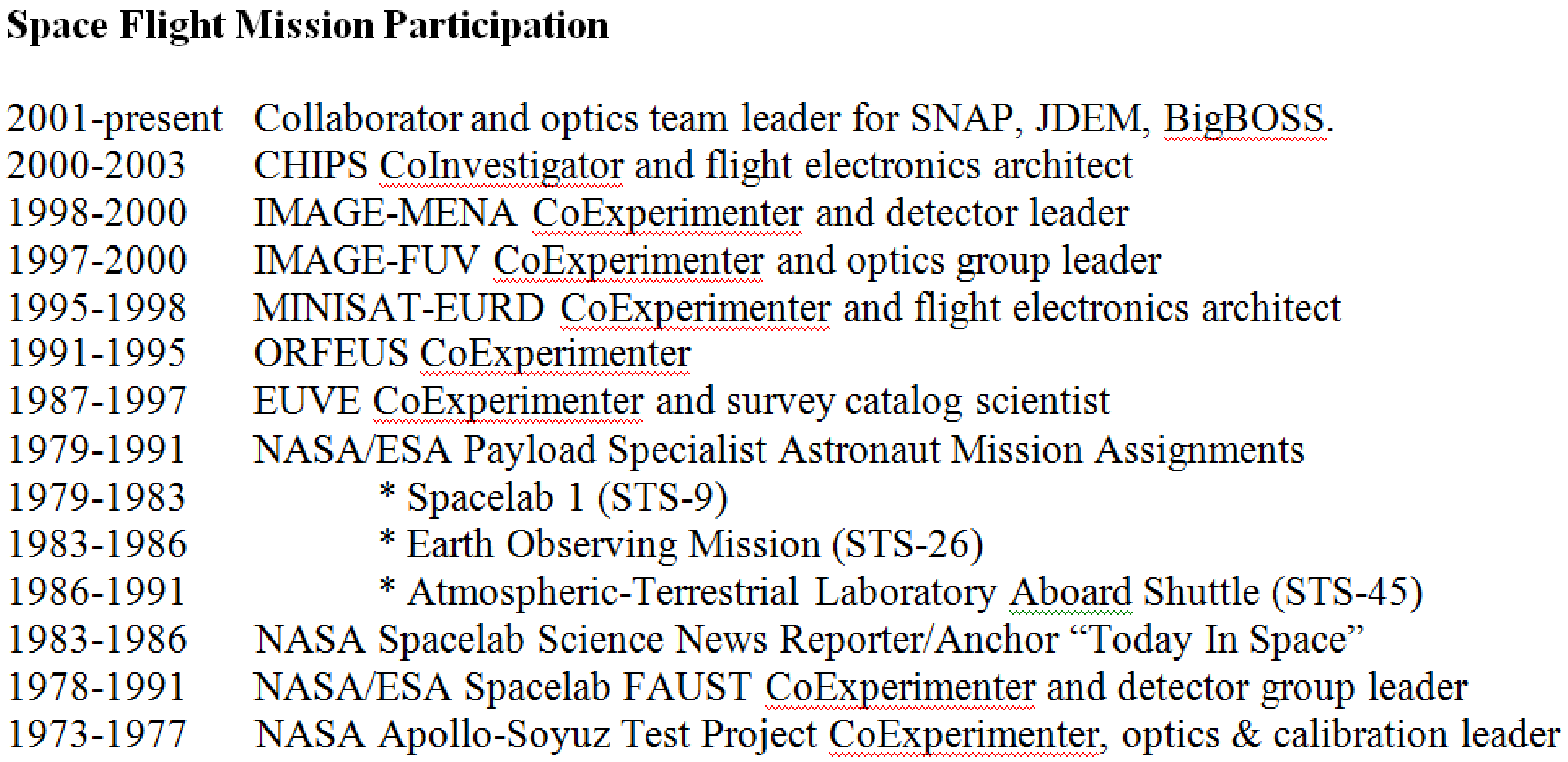
10 Dec 2013

image: Cedar Fire, San Diego, 27 Oct 2003; NASA MODIS (TERRA)

Who is Mike Lampton?

- Senior Research Fellow, UCB Space Sciences Lab
- Background in physics and astronomy (*very* remote sensing!)
- Visit www.MikeLampton.com for projects, old and current.



Space Flight Mission Participation

2001-present	Collaborator and optics team leader for SNAP, JDEM, BigBOSS.
2000-2003	CHIPS CoInvestigator and flight electronics architect
1998-2000	IMAGE-MENA CoExperimenter and detector leader
1997-2000	IMAGE-FUV CoExperimenter and optics group leader
1995-1998	MINISAT-EURD CoExperimenter and flight electronics architect
1991-1995	ORFEUS CoExperimenter
1987-1997	EUVE CoExperimenter and survey catalog scientist
1979-1991	NASA/ESA Payload Specialist Astronaut Mission Assignments
1979-1983	* Spacelab 1 (STS-9)
1983-1986	* Earth Observing Mission (STS-26)
1986-1991	* Atmospheric-Terrestrial Laboratory Aboard Shuttle (STS-45)
1983-1986	NASA Spacelab Science News Reporter/Anchor “Today In Space”
1978-1991	NASA/ESA Spacelab FAUST CoExperimenter and detector group leader
1973-1977	NASA Apollo-Soyuz Test Project CoExperimenter, optics & calibration leader

What is the UC Berkeley Spaces Sciences Lab?

Plan, develop, build, operate missions, disseminate data to user groups

AstroPulse A Search for Evaporating Black Holes

Atmospheric Emissions Group

BOINC Berkeley Open Infrastructure for Network Computing

Cassini INMS The Ion and Natural Mass Spectrometer (IN

CASPER - Center for Astronomy Signal Processing and El

CEA The Center for Extreme Ultraviolet Astrophysics

CHIPS The Cosmic Hot Interstellar Plasma Spectrometer

CISM Center for Integrated Space Weather Modeling

Cluster Small-scale spatial measurements

HENA High Energy Nuclear Astrophysics

HESSI High Energy Solar Spectroscopic Imager Spacecraft

tmospheric Lightning

Cosmic Gamma Ray Bursts

y Mission

ectroscopy

SPEAR Spectroscopy of Plasma

SPRG The Space Physics Resea

STARDUST@HOME

STEREO/IMPACT Solar-TErrest Transients

STEREO/WAVES

THEMIS Time History of Events a

Ulysses

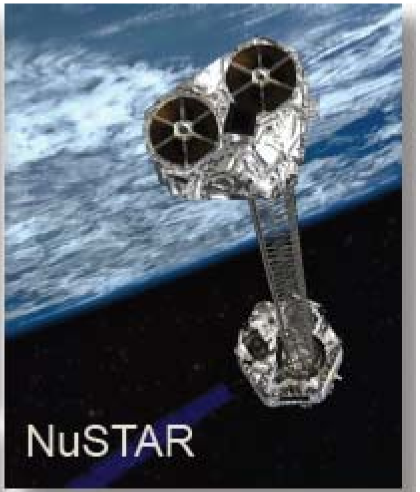
Wind

MAVEN launch to Mars 18 Nov 2013

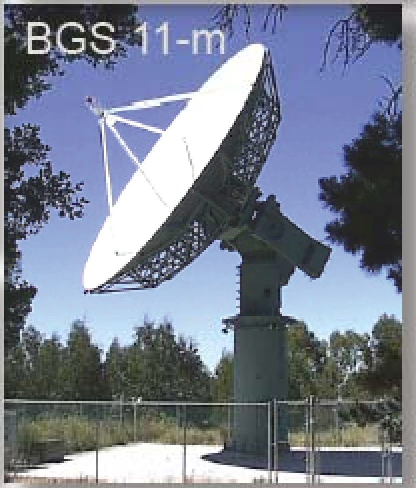
Van Allen Probes A and B launched 30 August 2012

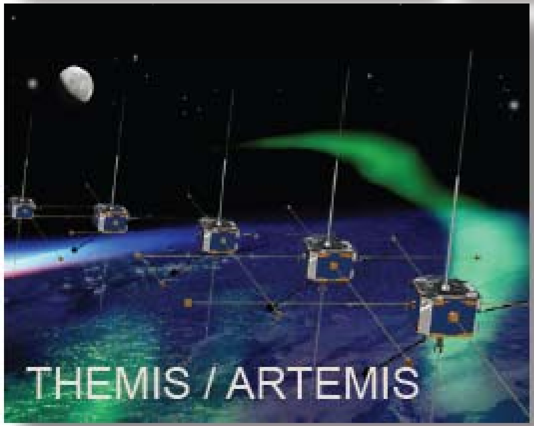
ICON Mission now being built

Satellite Tracking and Mission Data Support at UCB Space Sciences Lab



* EUVE	1991 - 2001
* FAST	1996 - 2009
* RHESSI	2002 - present
* CHIPS	2003 - 2008
* THEMIS	2007 - present
* ARTEMIS	2009 - present
* NuSTAR	2012 - present
* CINEMA 1	2012 - present
* CINEMA 4	Launch in 2015
* ICON	Launch in 2017





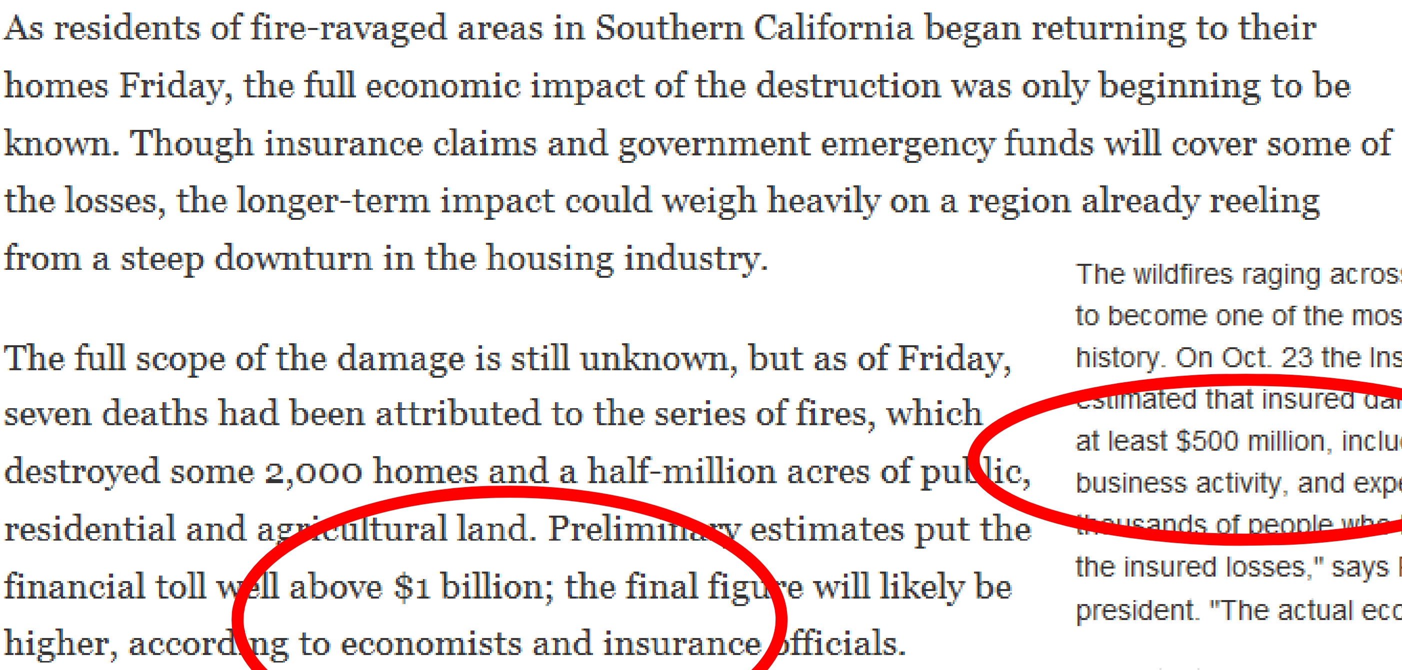
- Terrestrial Atmosphere and Magnetosphere
- Lunar studies: magnetism, solar wind....
- Solar physics and Interplanetary Medium
- Stellar Astronomy and Interstellar Medium
- Xray and Gamma Ray Astronomy

What is *FUEGO?*

Fire Urgency Estimation from Geosynchronous Orbit

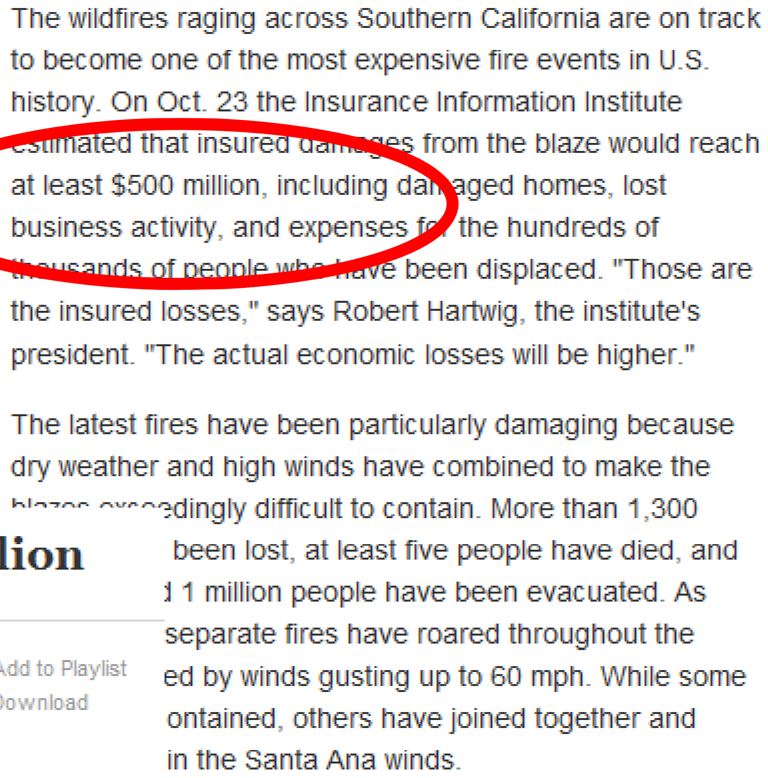
- Early detection of outdoor fires
  - natural; accidental; terrorist
- Potentially very valuable for California
- Applicable to other locales!
- Geosynchronous orbit for 24/7 coverage
- Supplement ground & air forest watch services
- Supplement other spaceborne geo observatories
- Requires real-time assessment of **urgency.**
  - Urgency is the key ingredient! *Must* be made quantitative!
  - Requires tight integration with **Geographic Information Systems**
  - UC Berkeley and Maggi Kelly's team are world leaders in GIS Development.

Why FUEGO?



As residents of fire-ravaged areas in Southern California began returning to their homes Friday, the full economic impact of the destruction was only beginning to be known. Though insurance claims and government emergency funds will cover some of the losses, the longer-term impact could weigh heavily on a region already reeling from a steep downturn in the housing industry.

The full scope of the damage is still unknown, but as of Friday, seven deaths had been attributed to the series of fires, which destroyed some 2,000 homes and a half-million acres of public, residential and agricultural land. Preliminary estimates put the financial toll well above $1 billion; the final figure will likely be higher, according to economists and insurance officials.



The wildfires raging across Southern California are on track to become one of the most expensive fire events in U.S. history. On Oct. 23 the Insurance Information Institute estimated that insured damages from the blaze would reach at least $500 million, including damaged homes, lost business activity, and expenses for the hundreds of thousands of people who have been displaced. "Those are the insured losses," says Robert Hartwig, the institute's president. "The actual economic losses will be higher."

The latest fires have been particularly damaging because dry weather and high winds have combined to make the blazes exceedingly difficult to contain. More than 1,300
been lost, at least five people have died, and
1 million people have been evacuated. As
separate fires have roared throughout the
ed by winds gusting up to 60 mph. While some
ontained, others have joined together and
in the Santa Ana winds.

Cost of California Wildfires Is More than $1 Billion

Hear Homeland Security Secretary Michael Chertoff talk about the disaster relief effort in Southern California on *Day to Day*

October 24, 2007

Wildfires in Southern California have caused at least $1 billion in damage in San Diego County alone — and that figure is expected to rise, officials warned Wednesday.

In just four days, the blazes have burned 410,000 acres and forced at least 500,000 people to flee

Wildfires Expected to Become Even More Severe

Pennypacker C.R. et al., 2013, Fig 1

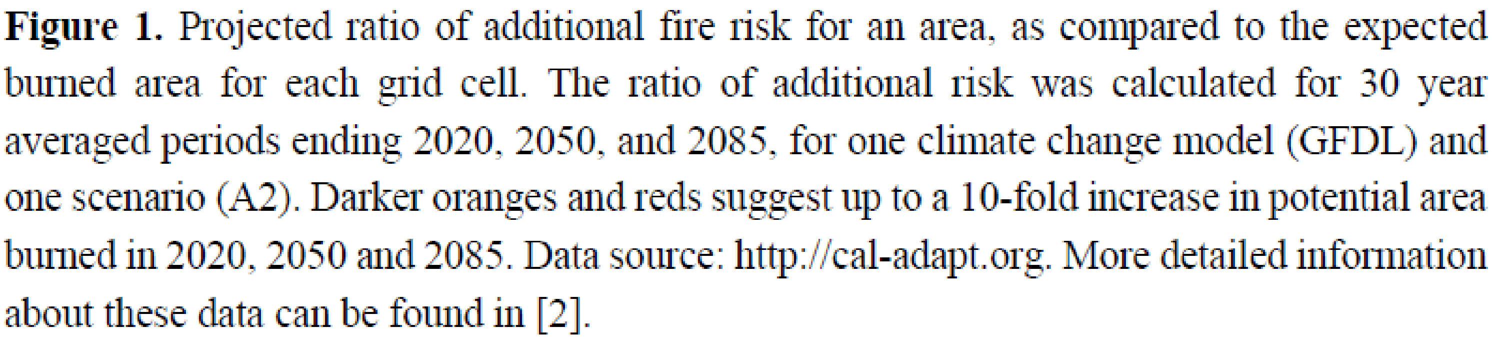
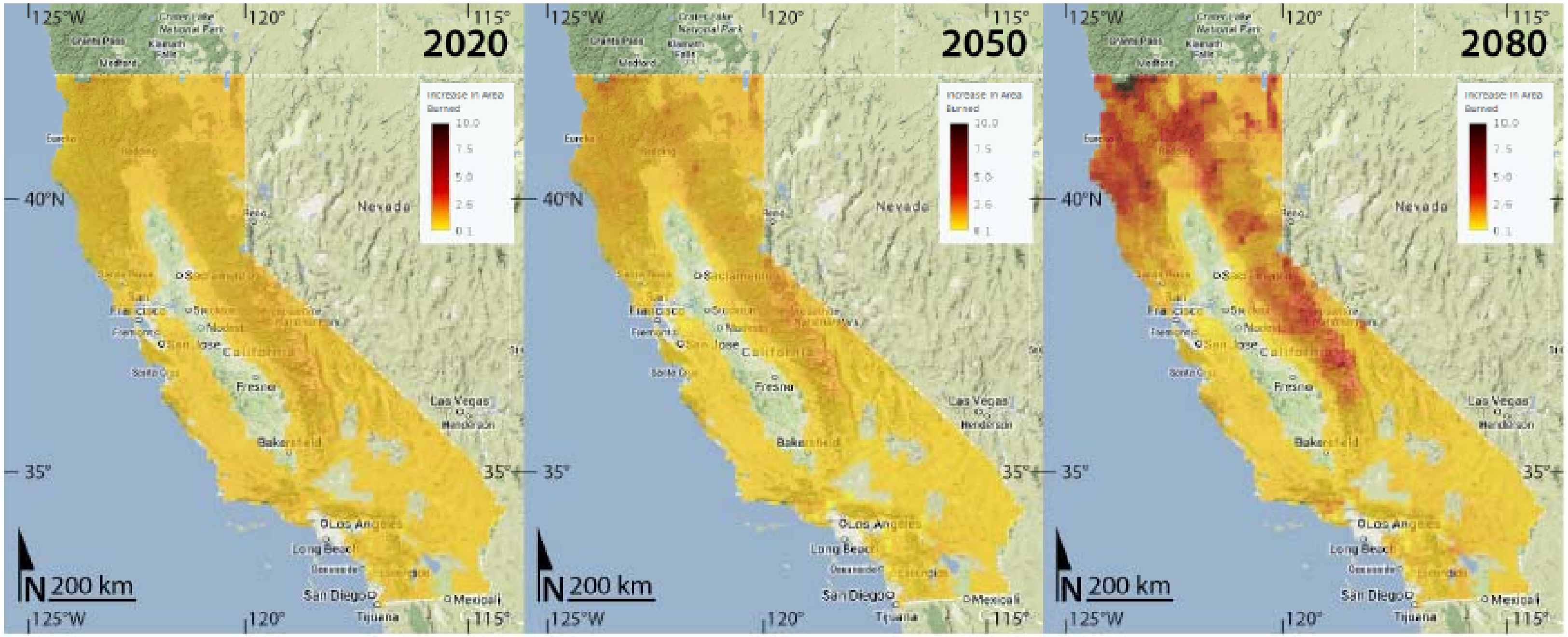


Figure 1. Projected ratio of additional fire risk for an area, as compared to the expected burned area for each grid cell. The ratio of additional risk was calculated for 30 year averaged periods ending 2020, 2050, and 2085, for one climate change model (GFDL) and one scenario (A2). Darker oranges and reds suggest up to a 10-fold increase in potential area burned in 2020, 2050 and 2085. Data source: http://cal-adapt.org. More detailed information about these data can be found in [2].

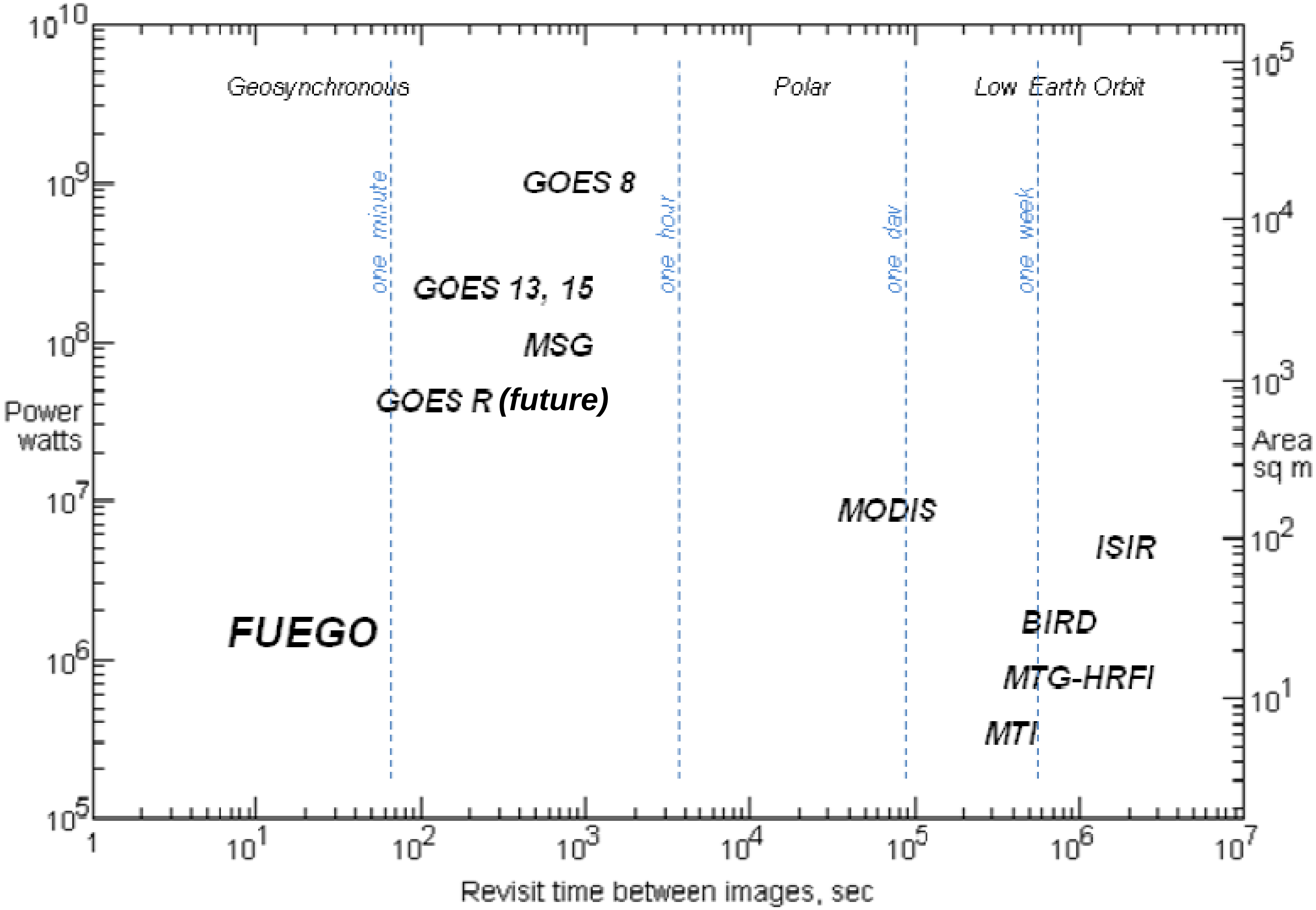


Many Satellites Already Observe Earth

- Low Earth Orbit (AQUA; TERRA; A-Train...) at altitude ~ 600km
  - can easily resolve 1 meter (IKONOS)
  - huge signal to noise detecting fires
  - but views each point on Earth only every 12 or 24 hours
- Geosynchronous Orbit (GOES; MSG; MTSAT ...) at 36000km
  - hovers over one longitude at equator
  - can view up to 35% of Earth
  - offers continuous viewing within its longitude field
  - but: distant! can resolve a few hundred meters.
  - signal-to-noise ratio is a problem detecting small fires.
  - Upcoming: GOES-R and its Advanced Baseline Imager

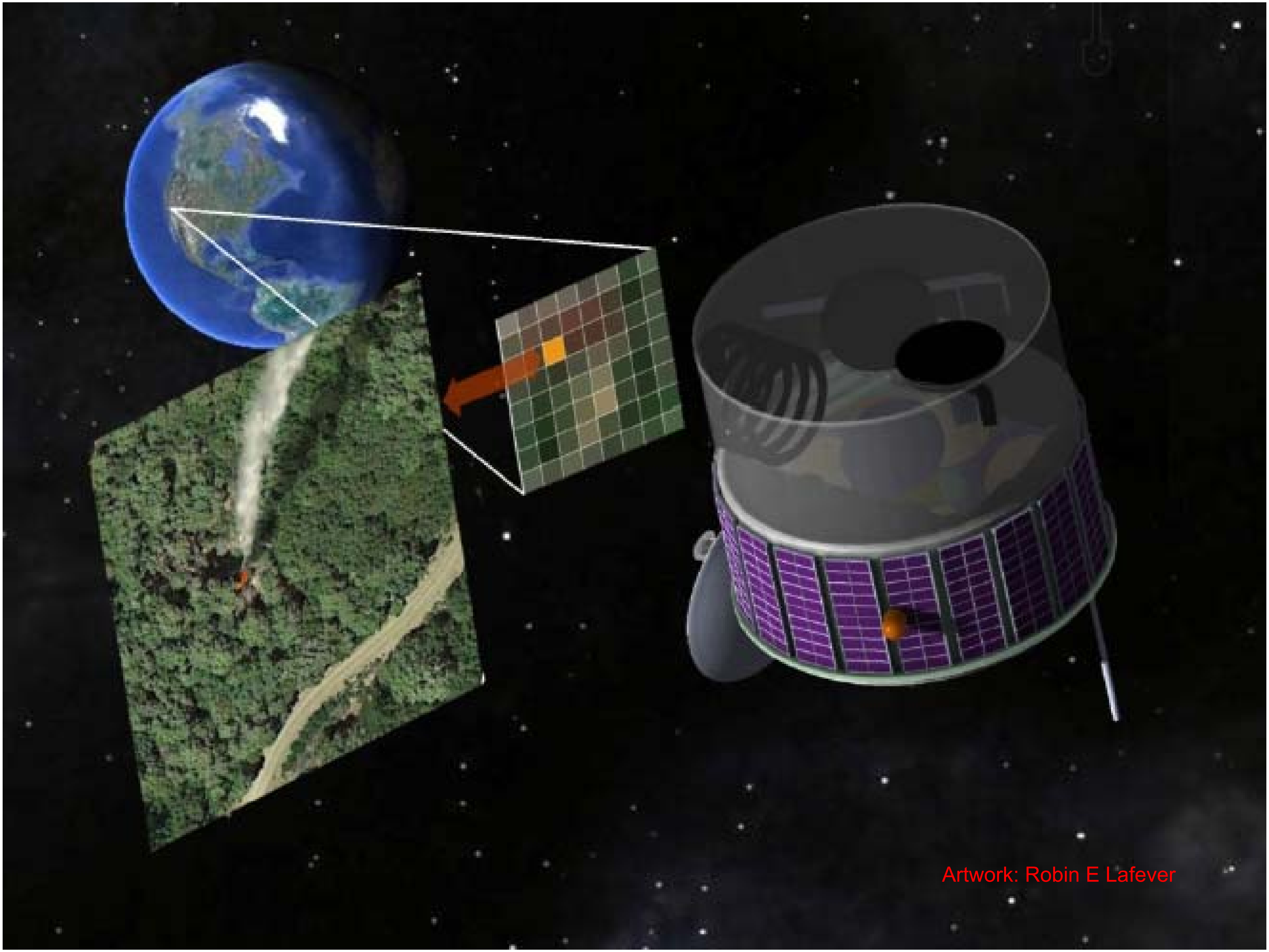
Detecting Fires from Space

Pennypacker C.R., et al., 2013, Fig 4



Developing a Space Flight Payload Concept Once the Requirements Have Been Specified

- Choosing an orbit
  - target field; time on target; viewing angles; latency...
- Choosing a set of wavebands
  - primary waveband: signal; noise; cloud/weather impact...
  - secondary wavebands: context, local conditions...
- Choosing a field of view and resolving power
  - minimum detectable flux; location accuracy....
- Choosing payload elements
  - optics; filters; sensors; cooling; data processing and compression....
- Choosing spacecraft bus elements
  - attitude control; power; data handling; command system....
- FUEGO represents a combination of these trades.



Artwork: Robin E Lafever

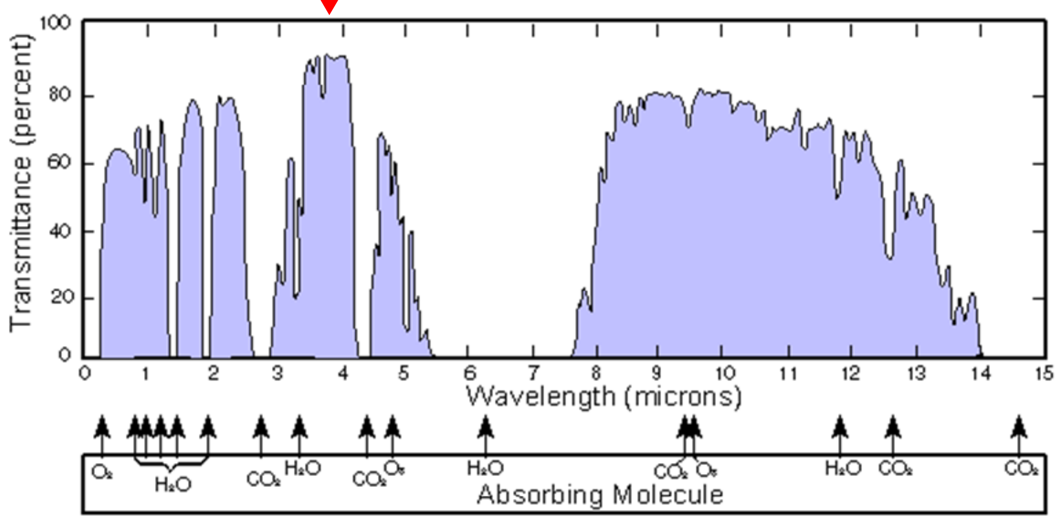
Examples of waveband selection using Atmospheric Wavelength Windows

Our work follows many published studies of fire detection from geosynchronous orbit..

Daytime: use smoke
Nighttime: use heat
Daytime: *also* use heat
easy on big fires
poor S/N small fires
sensor overload limit
dynamic range issues!

Primary FUEGO band: 3.5 to 4.1 microns

Visible and NIR wavebands are vital to gathering context



Limitations of Traditional Infrared Space Sensors

- Traditionally employ scanning pixel or pixels
  - inexpensive sensor, easily cooled
  - raster scan of terrestrial field
  - limited time (few μsec) on each target pixel
  - limited number of photons hence limited signal to noise ratio
  - poor detection thresholds
- Alternative: staring megapixel array
  - now: fully space qualified; “shovel ready”
  - allows longer exposure times, both night and day
  - allows *multiple* exposures to overcome dynamic range limit
  - allows precision *subtraction* of images to detect scene changes
  - allows vastly improved signal/noise and measurement accuracy
  - allows much improved sensitivity and reduced false alarm rate

Signal-to-noise ratio

- Type I error “false positive” alarm with no fire
- Type II error “false negative” ignores a real fire
- Signal: measurable deviation in image spectrum diagnostic over time
- Noise: non-reproducible feature of image spectrum diagnostic
- S/N contributes to both error rates
- S/N depends on the payload and the algorithms
- These factors mathematically determine the false alarm rate and hence the usability of detections
- **Worthless** without an urgency indication!

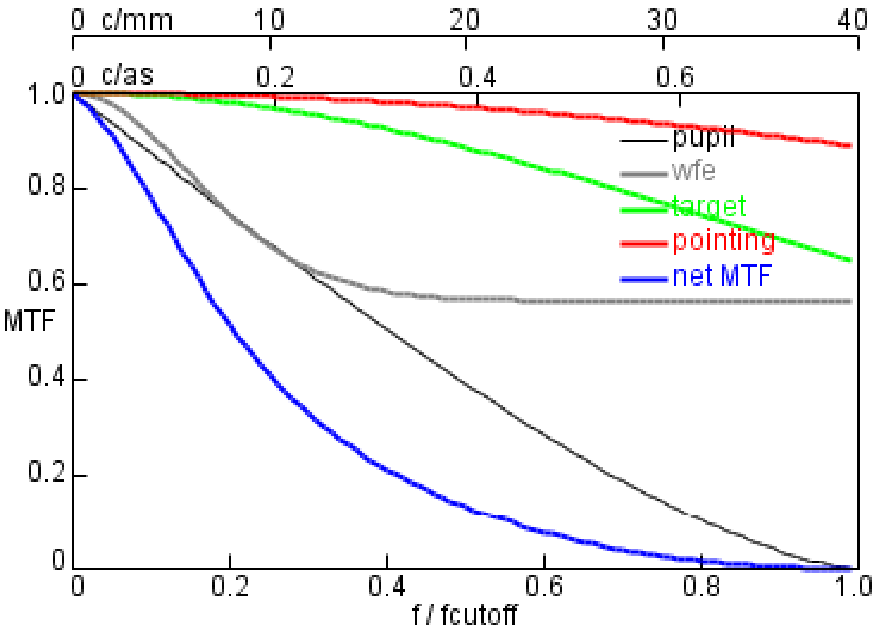
Image Sampling

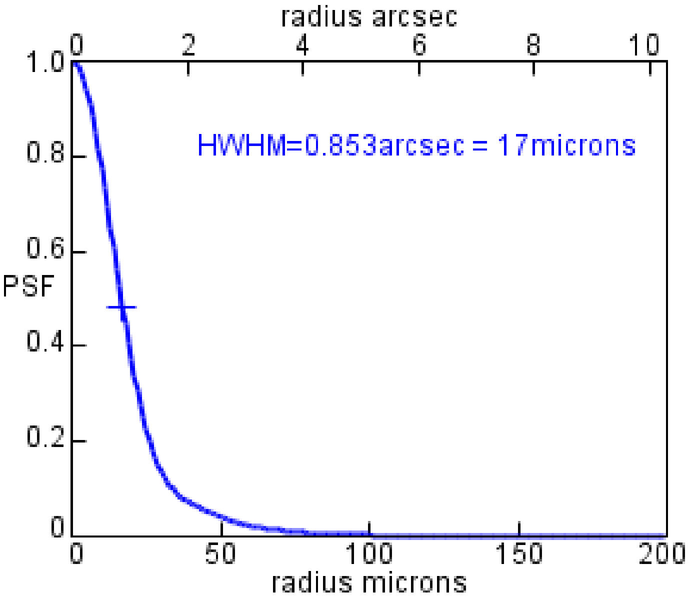
R.D.Fiete "Image quality and λ·Fnumber/p for remote sensing systems," Opt.Eng. v.38#7, 1229 (1999)

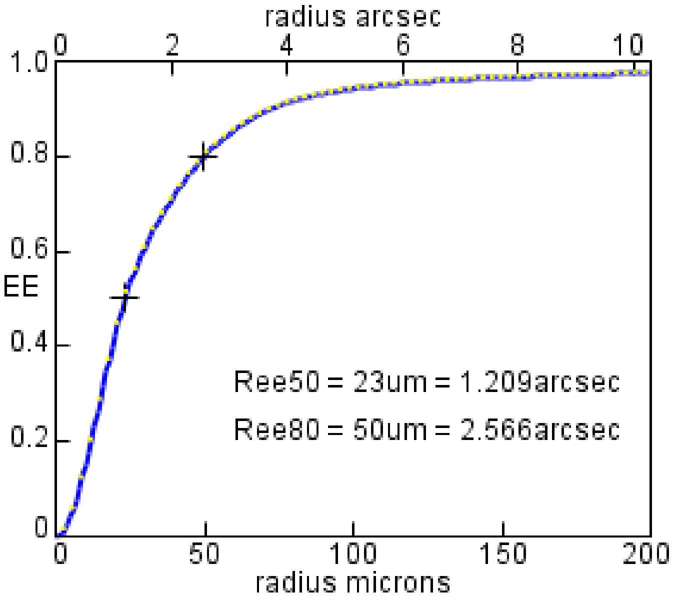
- **Diffraction limited images are continuous functions**
  - Orbit height H, optical pupil diameter D: ground resolution ≈ λH/D
  - Diffraction sets Fcutoff in image space = D/(λ·focalLength) = 1/(λ·fnumber)
- **Images are sampled by pixels**
  - will lose information if sampled too coarsely
  - pixel pitch "p" defines Fnyquist = 1/2p
- **No information is lost if Fcutoff < Fnyquist or λ·fnumber/p > 2**
- **λ is a compromise among several conflicting trade factors:**
  - longer wavelength benefits heat detection in presence of sunlight
  - longer wavelength requires more extreme sensor cooling
  - longer wavelength has worse diffraction blur
- **Pixel pitch "p" is mandated by commercial device availability: 18µm**
- **Choose fnumber ≈ 2p/λ.**

Image quality budget: MTF, PSF, and EE

Aperture, meter	0.400
EFL, meter	4.000
Linear obstruction	0.000
RMS WFE, microns	0.300
ACS 1 sigma jitter, as	0.100
Wavelength, microns	2.500
Target Ree50, arcsec	0.200
Pixel size, microns	18.000



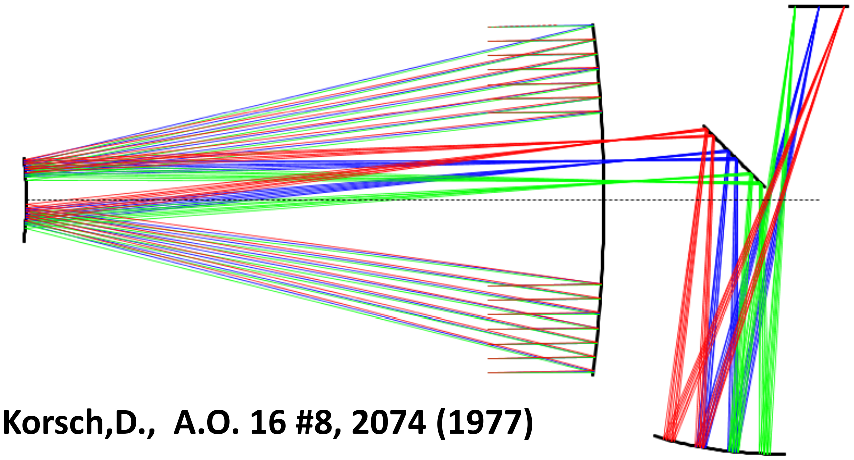




Trade: Obscured vs Unobscured Telescopes

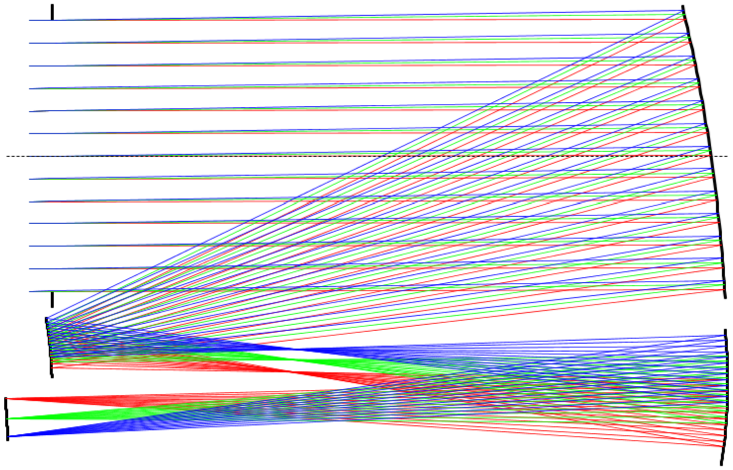
Lampton, M., et al., "Off-axis telescopes for Dark Energy Investigations," Proc SPIE v.7731 (2010)

Obscured, here with 1.2m aperture
f/11; 13mEFL 18um = 0.285"
FoV = 0.73x1.46deg =166 x 330mm
Easy fit to 4x8 sensors.
< 3umRMS theoretical PSF
Real Cassegrain image: control stray light
Real exit pupil: control of stray heat
Best with auxiliary optics behind PM;
Easy heat path for one focal plane.



Korsch,D., A.O. 16 #8, 2074 (1977)

Unobscured, also with 1.2m aperture
f/11, 13mEFL, 18um=0.285"
FOV = 0.73 x1.46deg = 166x330mm
Easy fit to 4x8 sensors.
< 3umRMS theoretical PSF
Real Cassegrain image: control stray light
Real exit pupil: control of stray heat
Easy heat path to cold side of payload for
entire SM-TM-FP assembly; can
accommodate several focal planes.

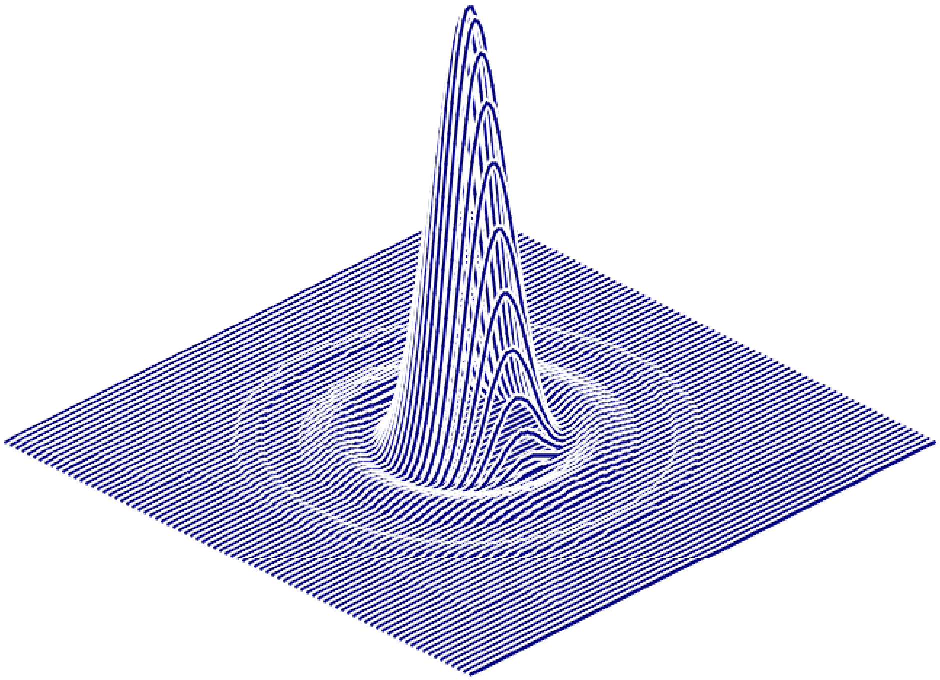


Cook,L.G., Proc.SPIE v.183 (1979)

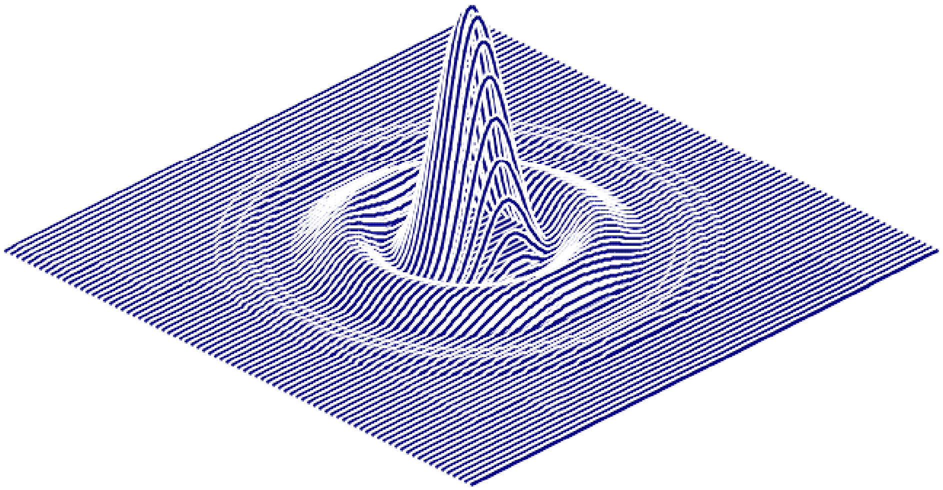
M Lampton Nov 2013

PSFs For Unaberrated Pupils

Scaled to include both obstructed light loss and diffraction
Fresnel-Kirchoff diffraction integral



Unobstructed

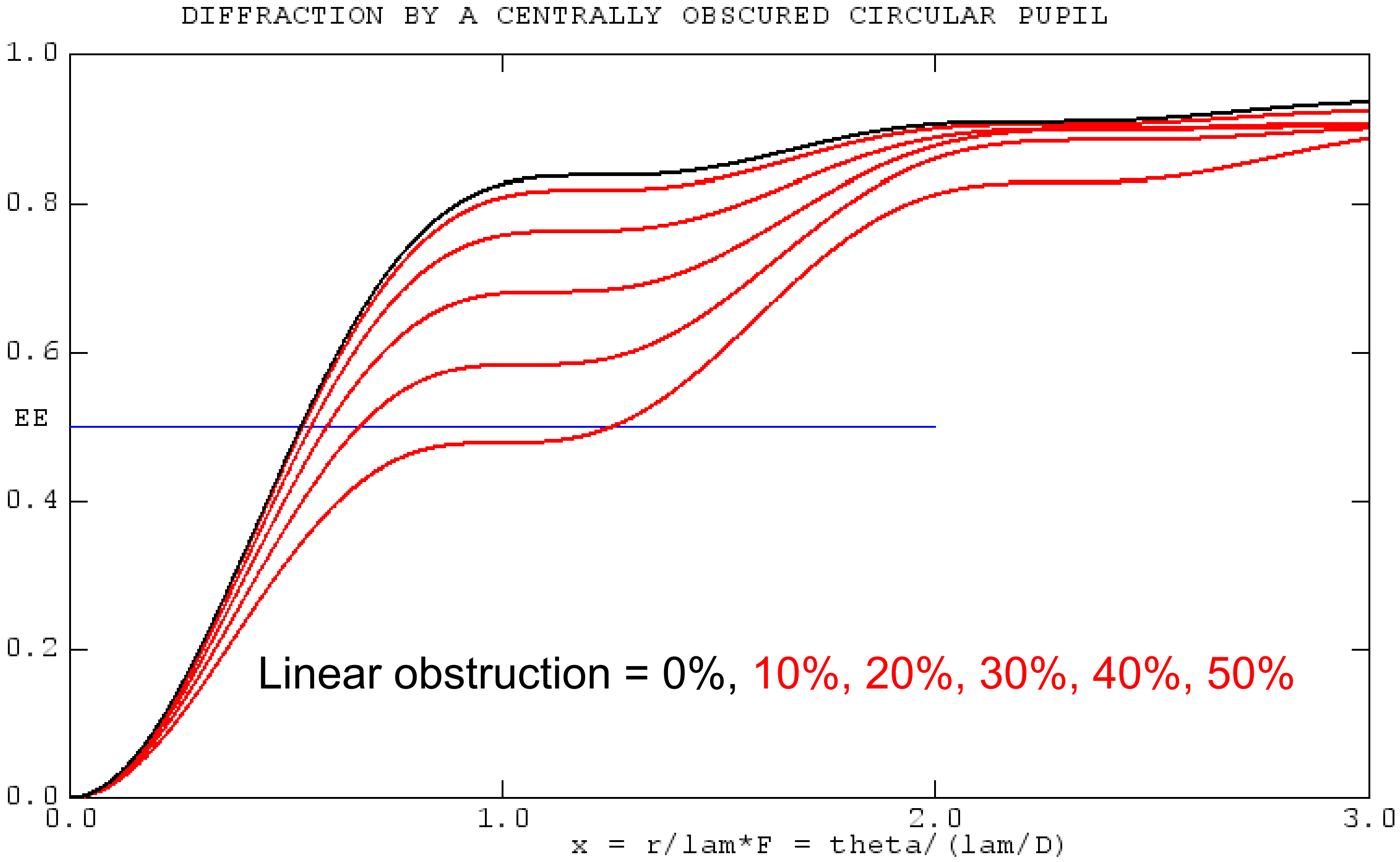


Obstructed: 50% linear, 25% area

Pupil obstruction trade study

Encircled Energy as a Fraction of the Total Transmitted Light

Fresnel-Kirchoff diffraction integral: Schroeder 10.2



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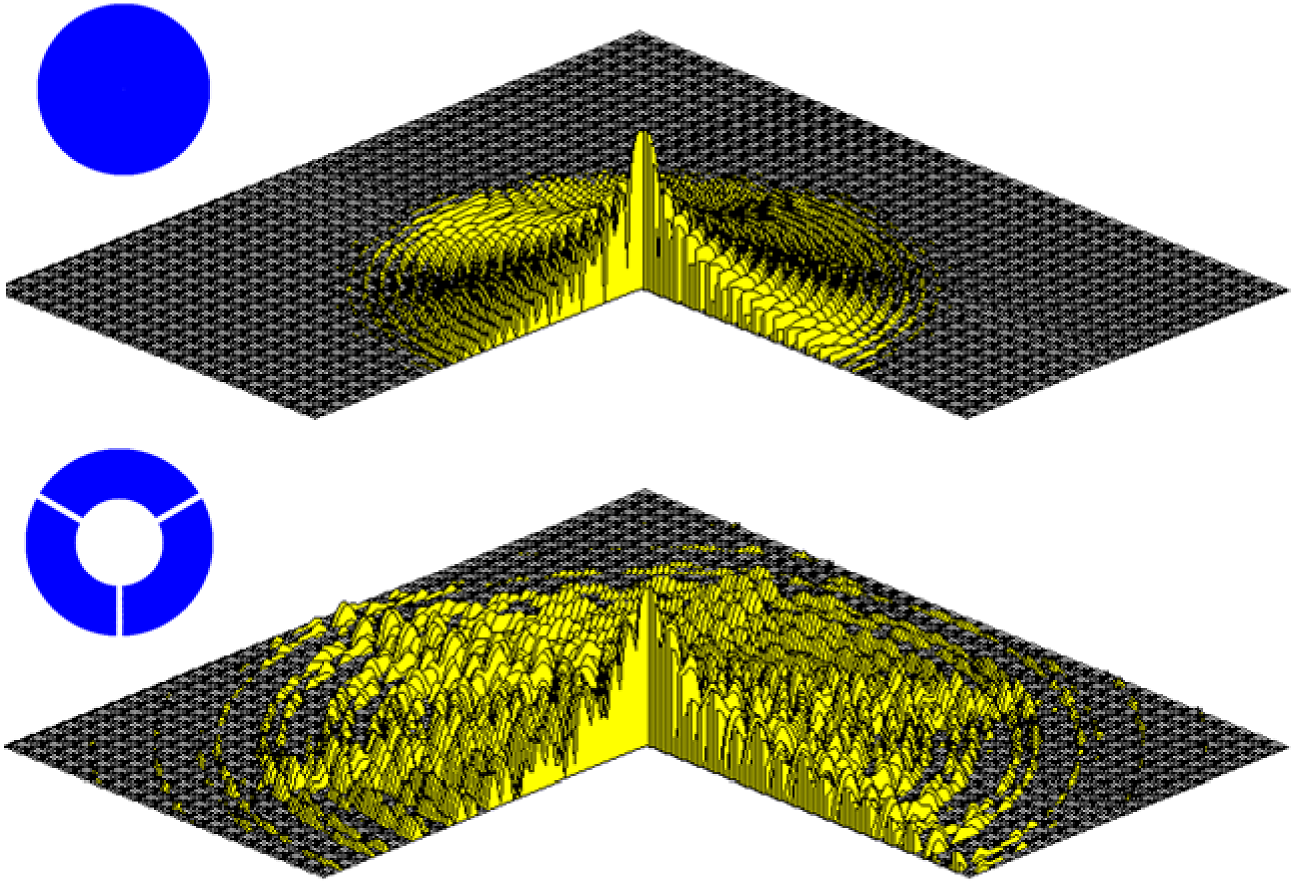
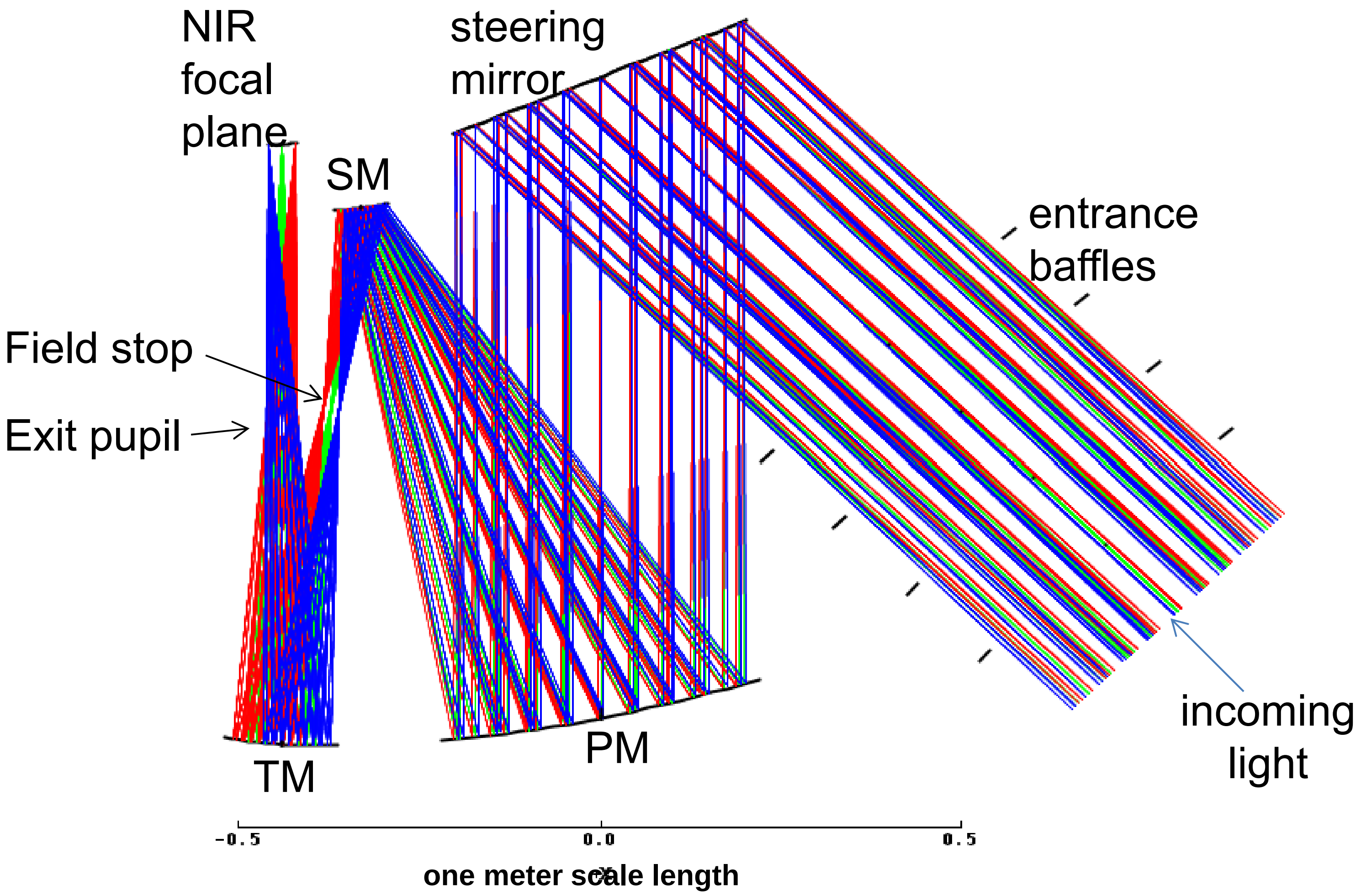
Eliminating the support spider legs for the secondary mirror removes the spikes caused by their pupil diffraction



For faint galaxies among bright stars, this can be a killer!
For Earth imaging, probably unimportant.

Unobscured "Fuego12" Optical Concept:

Provides clearances for baffling, esp. secondary and tertiary mirrors



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Unobscured TMA concept “Fuego12” prescription

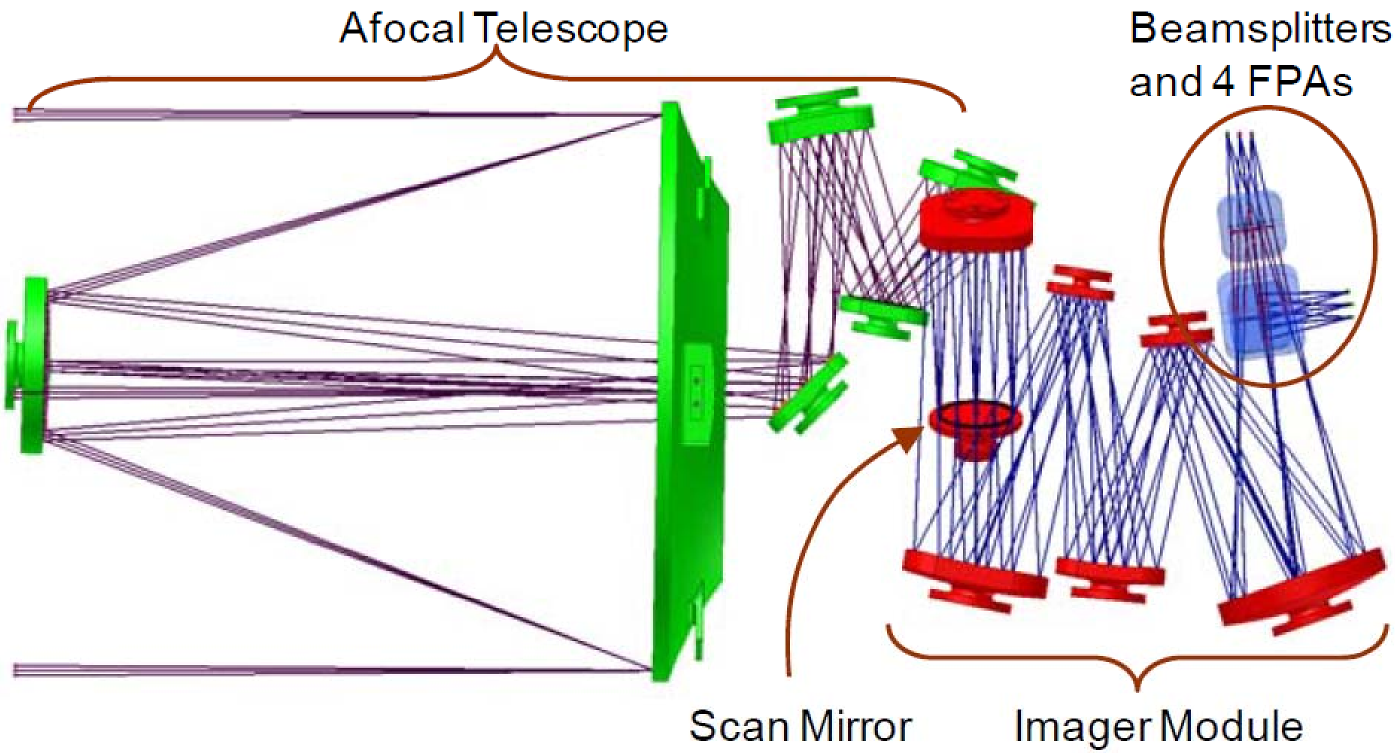
derived from TMA193.OPT

```
 5 surfaces   Fuego12.OPT    0.4m, f/10,  10x10mrad field;       0.3umRMS
      X           Z     pitch         Curve       Aspher     f Diam  OffOX  Type?
------.-------:---.----:----.-------:--.--------:---.-------:-:----::-----:------:--
      0       : -0.2   :   22.5     :   0       :   0       : :    ::     : mirSC:
    -0.40     :  0.8   :  -0.4319813?-0.53756885? -0.9384102? :0.44::+0.40: mirPM:
    -0.3909455? -0.0   :   0.7107505?-2.15710126? -4.8636293? :    ::+0.06: mirSM:
    -0.3708804?  0.8   :   2.2740759?-1.54665968? -0.3315489? :    ::-0.07: mirTM:
    -0.44     : -0.1   :   2.9906987?           :           :S:    ::     : FP   :
```

- Aperture = 0.4m, FL=4m, therefore final speed = f/10
- Pixel size = 18µm = 0.9arcsec on sky = 162 m on Earth @ geosynch
- Diffraction limit 2.4λ/D at λ=3µm is 3.7 arcsec = 4 pixels; λ·fnumber/p=1.67
- Field = 2Kx2K = 37 x 37mm = one silicon CCD (vis) and one Teledyne MCT
- Field = 0.7 x 0.7° on sky = 332 x 332 km on Earth @ geosynch
- 0.3 micron RMS theoretical aberration average over field
- Has a real Cassegrain image for field stop: excellent stray light control
- Has a real exit pupil for cold stop: excellent stray heat control
- Allows a warm telescope to feed a cold focal plane
- Dichroic beamsplitter at exit pupil allows simultaneous VIS & NIR bands

Obscured pupil concept: WISE

Sampath et al Proc SPIE v.7796 (2010)

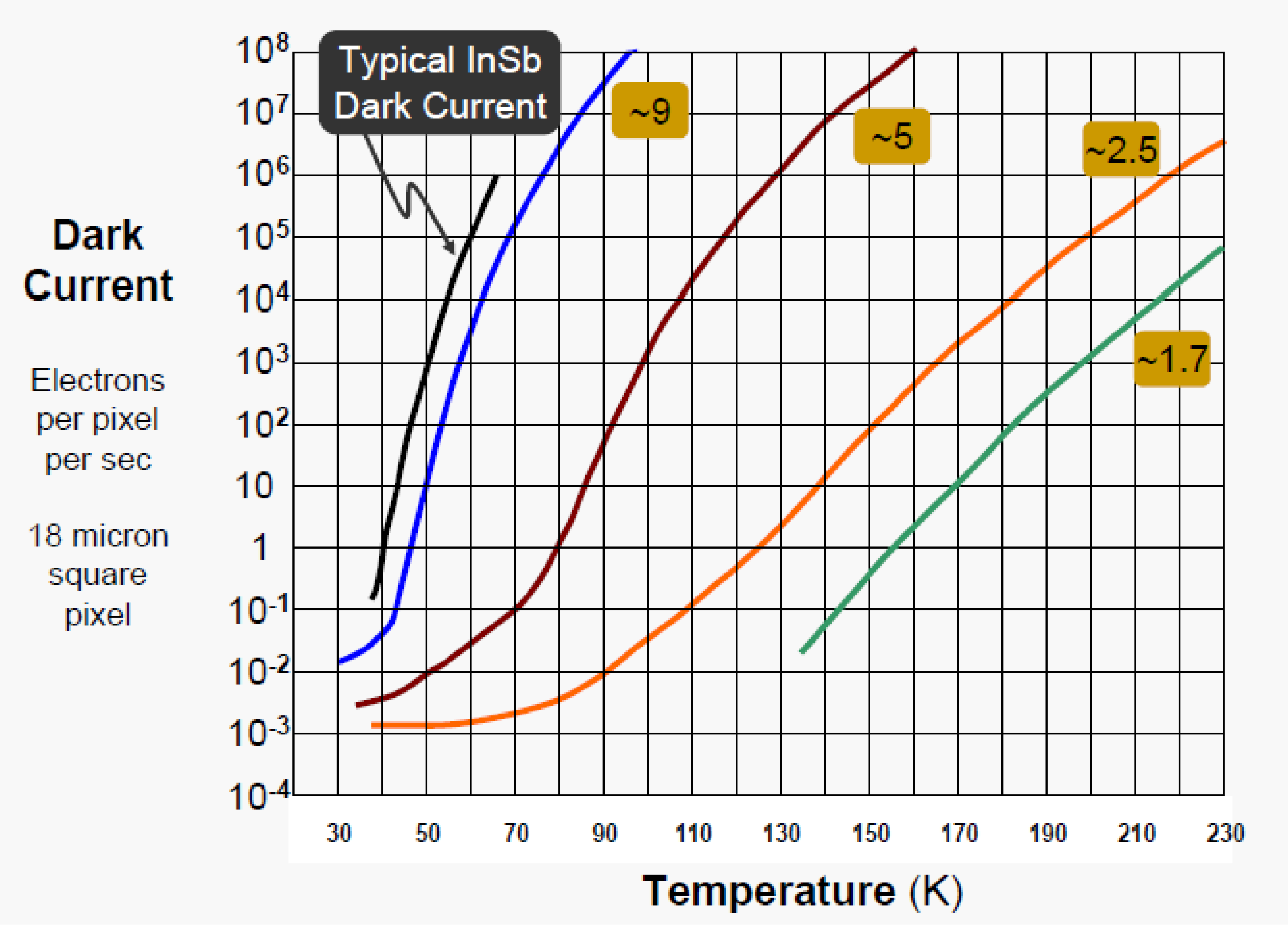


- Six mirror telescope front end delivers magnified afocal image
- Small scan mirror (marked) moves scene by up to 0.8 deg
- Seven-mirror camera + beamsplitters sense the images (four wavebands)
- Complicated, but the scan mirror is now tiny: at exit pupil not entrance pupil
- WISE is fully cryogenic, however might work with rear-end cryo, front end warm

Cutoff Wavelength Trade Study:

Dark Current per pixel of Teledyne MCT sensors; Various cutoff wavelengths

Beletic et al IEEE Photonics March 2010



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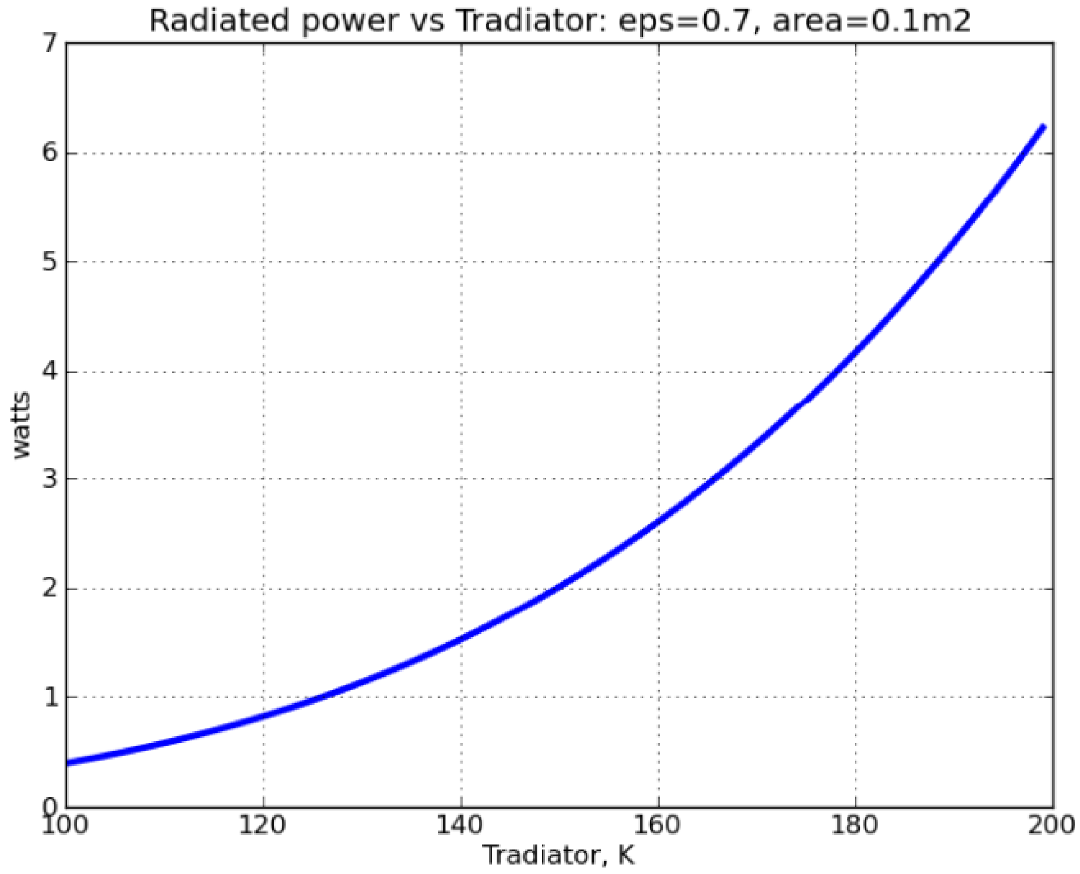
Cooler Trade Study: Passive Radiator vs. Active Refrigerator?

Passive Thermal Radiator will dump ~ 2W at 150K:
plenty cold enough for one MCT with 2.5um cutoff.
However λ=5μm MCT will require 100K; refrigerator?



Three Payload Opto-Mechanical Trades

- **Filter Wheel**
  - What bandpasses? How many?
  - Attenuated bandpasses for use in daytime to alleviate fast shutter requirement?
- **Shutter**
  - Noon: Texposure < 1 millisecond to satisfy our pixel full-well limit
  - Balanced Uniblitz-type shutters can only do ~ 100 msec
  - Attitude control disturbance is **critical**
  - Will drive need for attenuated bandpasses for daytime
- **Scene Stepping Alternatives**
  - **Option Zero:** Simple rigid optics; maneuver entire spacecraft to each field; accept settling time needed for sub-arcsecond smearing over a time interval corresponding to ~ 1 millisecond exposures.
  - **Option One:** Objective step mirror; > 0.4m diameter; attitude disturbance is perhaps not critical because we can afford to wait a few seconds after each maneuver, for settling on new target field.
  - **Option Two**: step mirror at exit pupil, like WISE, could be ~ 40mm diameter and so less attitude disturbance; but demands complex optics.

Example of a FUEGO Payload Parameter Set

Pennypacker C.R., et al., 2013 Table 1

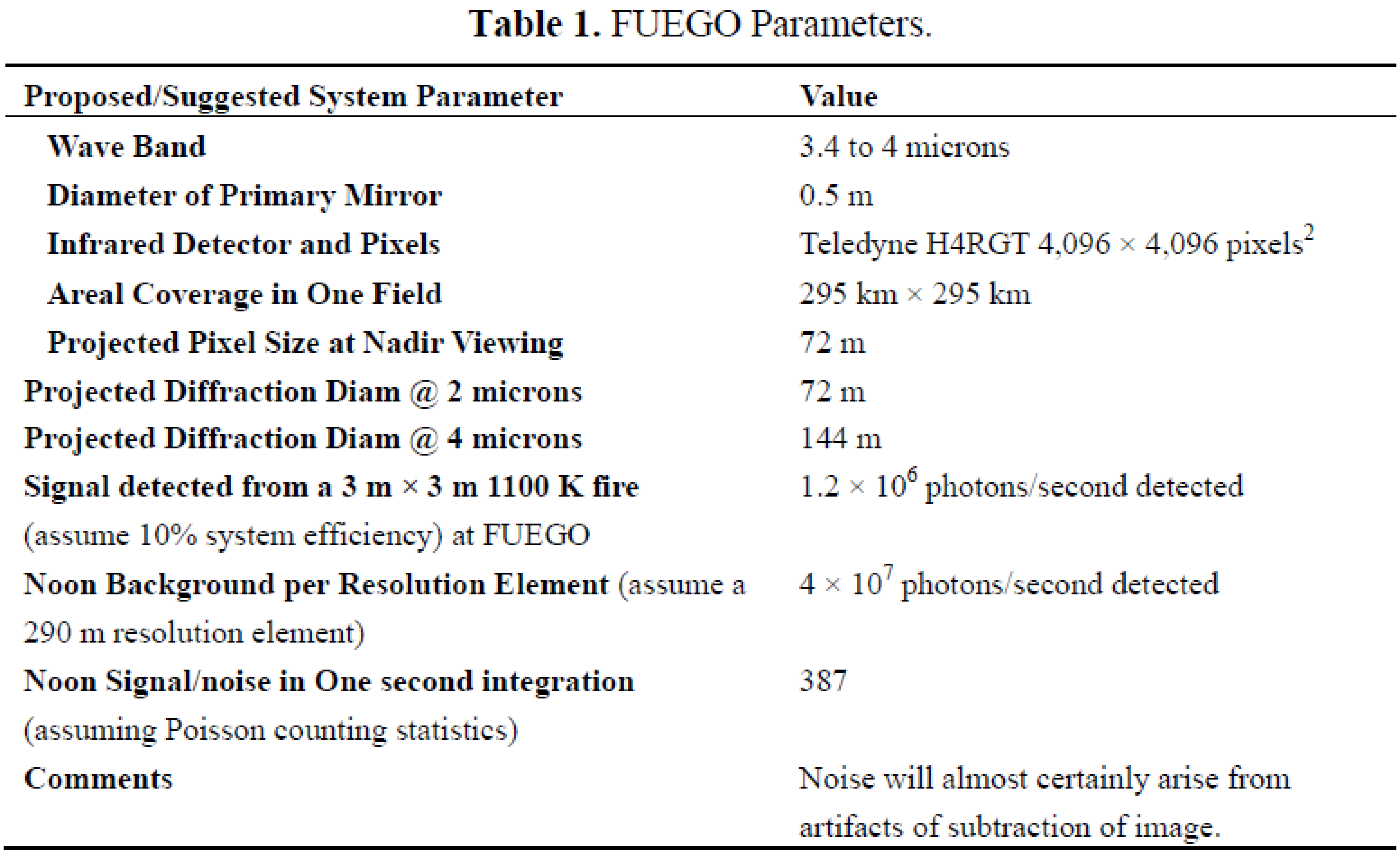
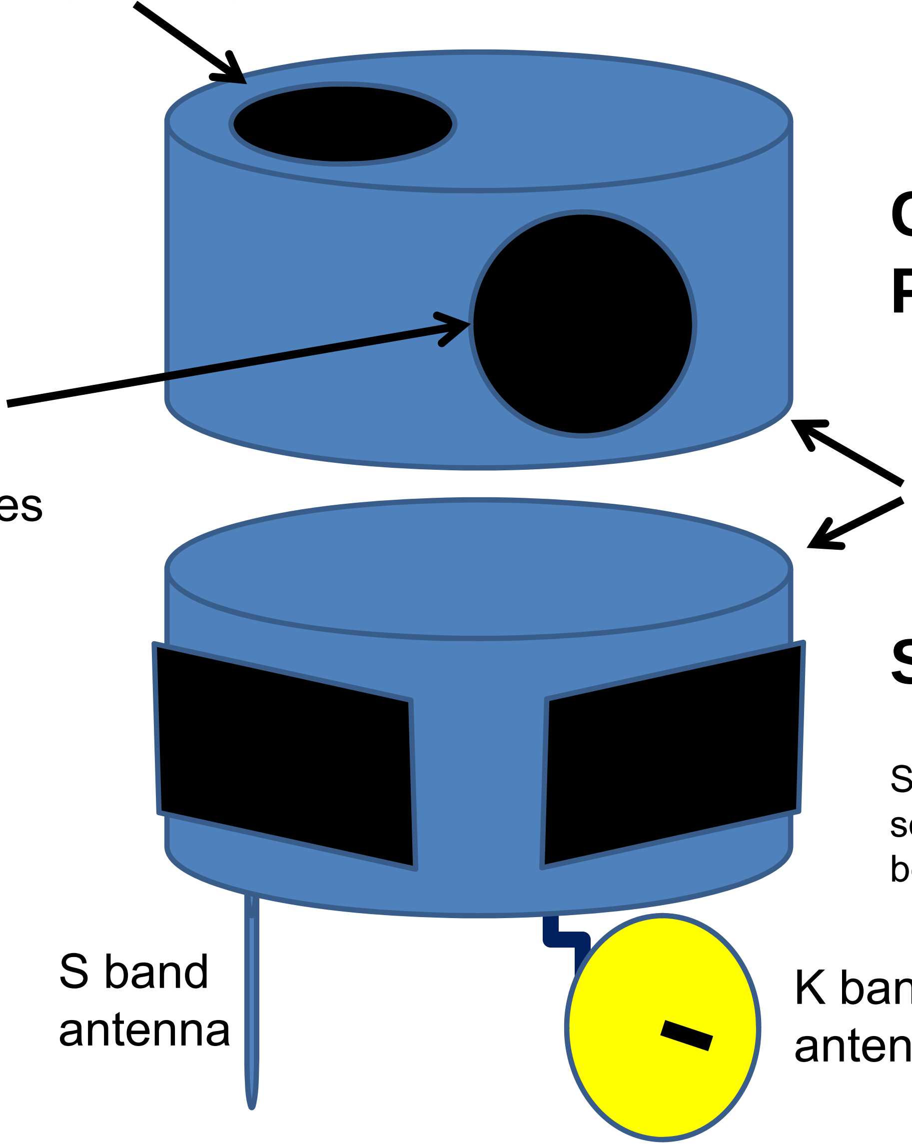


Table 1. FUEGO Parameters.

Proposed/Suggested System Parameter	**Value**
Wave Band	3.4 to 4 microns
Diameter of Primary Mirror	0.5 m
Infrared Detector and Pixels	Teledyne H4RGT 4,096 × 4,096 pixels^2
Areal Coverage in One Field	295 km × 295 km
Projected Pixel Size at Nadir Viewing	72 m
Projected Diffraction Diam @ 2 microns	72 m
Projected Diffraction Diam @ 4 microns	144 m
Signal detected from a 3 m × 3 m 1100 K fire (assume 10% system efficiency) at FUEGO	1.2×10^6 photons/second detected
Noon Background per Resolution Element (assume a 290 m resolution element)	4×10^7 photons/second detected
Noon Signal/noise in One second integration (assuming Poisson counting statistics)	387
Comments	Noise will almost certainly arise from artifacts of subtraction of image.

Sensor passive heat dump located on North face of payload
Must safeguard against summer sun elevation 23 degrees



Entrance aperture and stray light baffles

Conceptual Payload

Join these during integration

Spacecraft bus

Sides are surrounded by exterior solar panels; heat radiator is on bottom

S band antenna

K band antenna

The Requirements Flowdown Process

- Goals
  - driven by needs of the firefighting community
  - both qualitative and quantitative
  - defensible! history; future capabilities; feasibility
- Requirements
  - must be derived from goals
  - must be quantitative
  - often involves contractor support & experience
- Payload Conceptual Development
  - coordinate with spacecraft bus capabilies
  - show that the data system can interface with GIS
- Proposal
  - show that all these issues have been taken care of
  - show that the proposed work is “shovel ready”

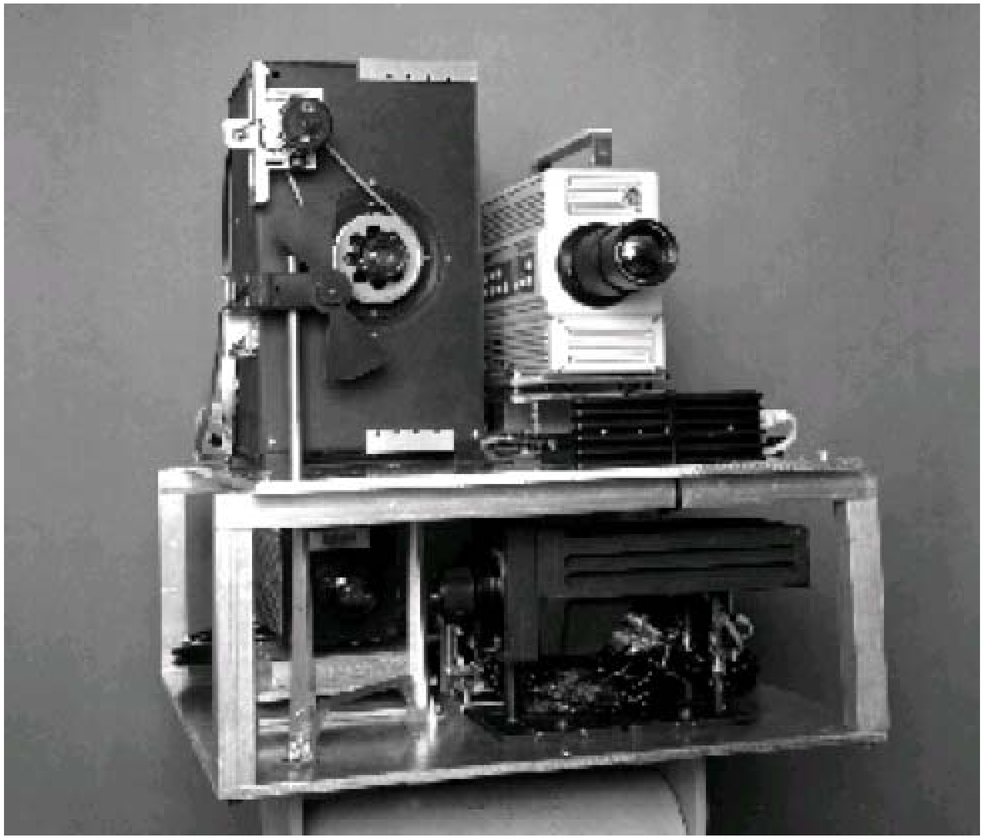
Some Ways Forward

- Studies of existing space data products
  - Already funded by UC's Vice Chancellor for Research : Marek Jubowski w/ Prof Maggi Kelly
  - Likely future funding for further analysis & algorithm development
- Obtain new multispectral fire-growth signatures
  - Groundbased, airplane based, controlled burns
  - Prof Scott Stephens & students
  - Algorithm development and testing
- Identify industry partners in airborne & spaceborne sensing
- Develop a multistep plan
  - Prove detection SNR & FAR ground-based sensor complement
  - Prove detection SNR & FAR airborne sensor complement
  - Demonstrate space flight readiness: sensors, algorithms, database tools
  - Approach State & National agencies for support

Research Topic: Build a library of images & spectral signatures for the earliest phases of controlled burns

Fay, D.A., et al., "Fusion of Multi-Sensor Imagery for Night Vision," Proc. 3rd Intl. Conf Information Fusion (2000)

An example of sensor fusion from 15 years ago...



MIT Lincoln Labs
CCD Camera

Raytheon Amber
MWIR Imager

Sensors Unlimited
SWIR Imager

Sanders/Lockheed
LWIR Imager

Appendix: A Few Useful References

Zhukov, B., et al “BIRD Detection and Analysis of High-temperature Events, First Results,” Prov. SPIE v.4886, 160-171 (2003).

Lorenz, E., et al., “Lessons Learned from Dedicated Active Fire Remote Sensing,” http://elib.dlr.de/18910/

Arino, O., and Paganini, M., “ESA activities related to forest fires: ATSR World Fire Atlas (WFA), GlobCarbon, and RISK-EOS,” Proc SPIE v.6742 (2007).

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