FUEGO Mission Concept

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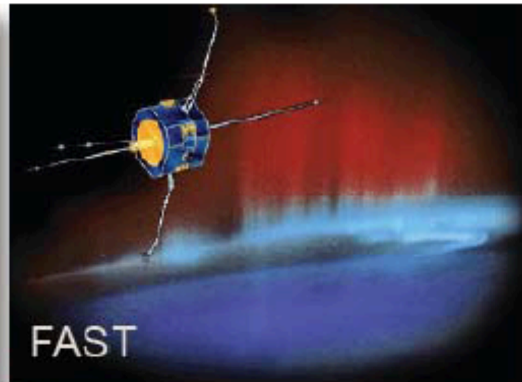
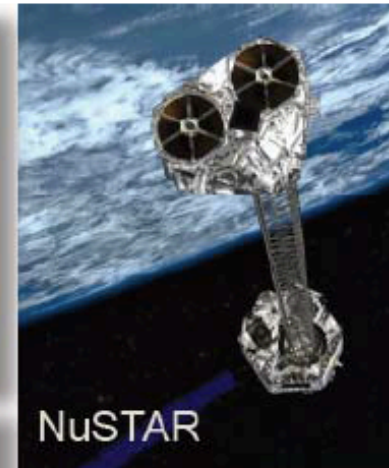
With updates for CubeSat Workshop 16 Oct 2018

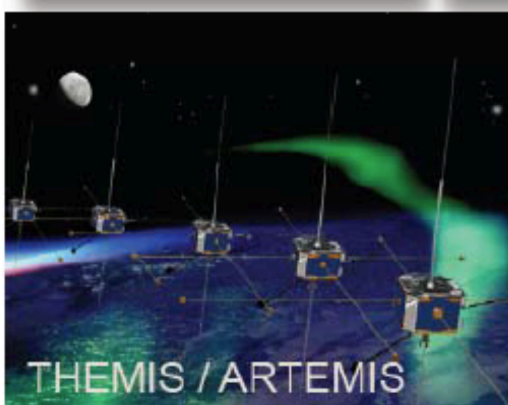
image: Cedar Fire, San Diego, 27 Oct 2003; NASA MODIS (TERRA)

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**

Traditional Fire Detection from Above

- *Smoke, by day*
  - *Strong signature at visible wavelengths*
  - *daytime only*
  - *simple silicon CCD or CMOS sensors work great:*
    - *lightweight, low power, cheap, shovel-ready*
    - *sensitive: work at the quantum limit*
  - *but easily hindered by clouds*
- *Heat, by night*
  - *Strong signature in the infrared*
  - *Daytime suffers only slightly from sunlight*
  - *Works 24/7 with less trouble from clouds*
  - *but sensors are more difficult*
    - *microbolometer arrays are cheap, lightweight, but not sensitive*
    - *HgCdTe diode arrays are sensitive but need significant cooling*

What is *FUEGO?*

Fire Urgency Estimation from Geosynchronous Orbit

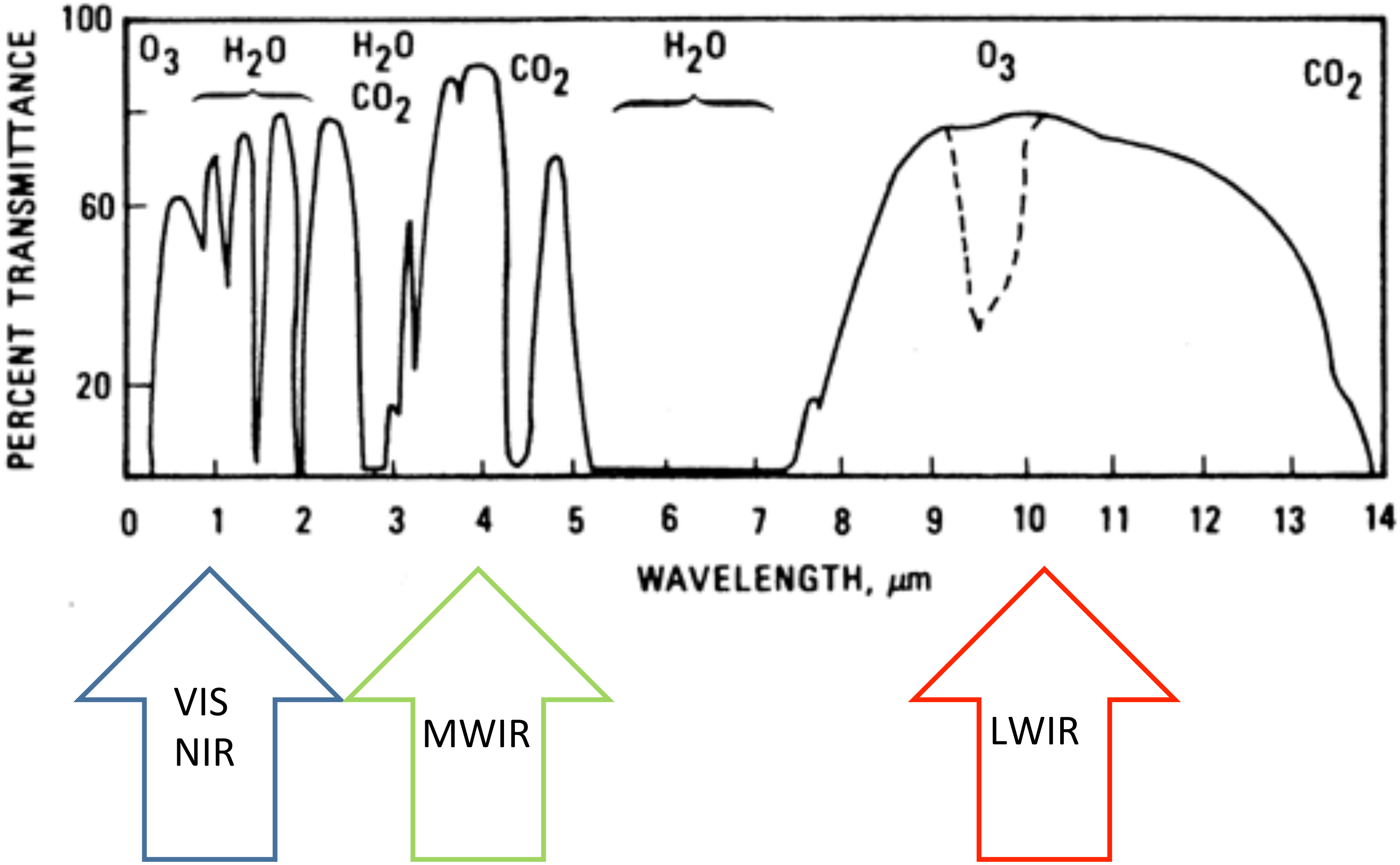
- Early detection of outdoor fires
  - natural; accidental; terrorist
- Potentially very valuable for California
- Applicable to other locales!
- Geosynchronous orbit for 24/7 coverage
- Supplement ground & air forest watch services
- Supplement other spaceborne geo observatories
- Requires real-time assessment of **urgency.** ***recent work by WIFIRE team***
  - 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.

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.

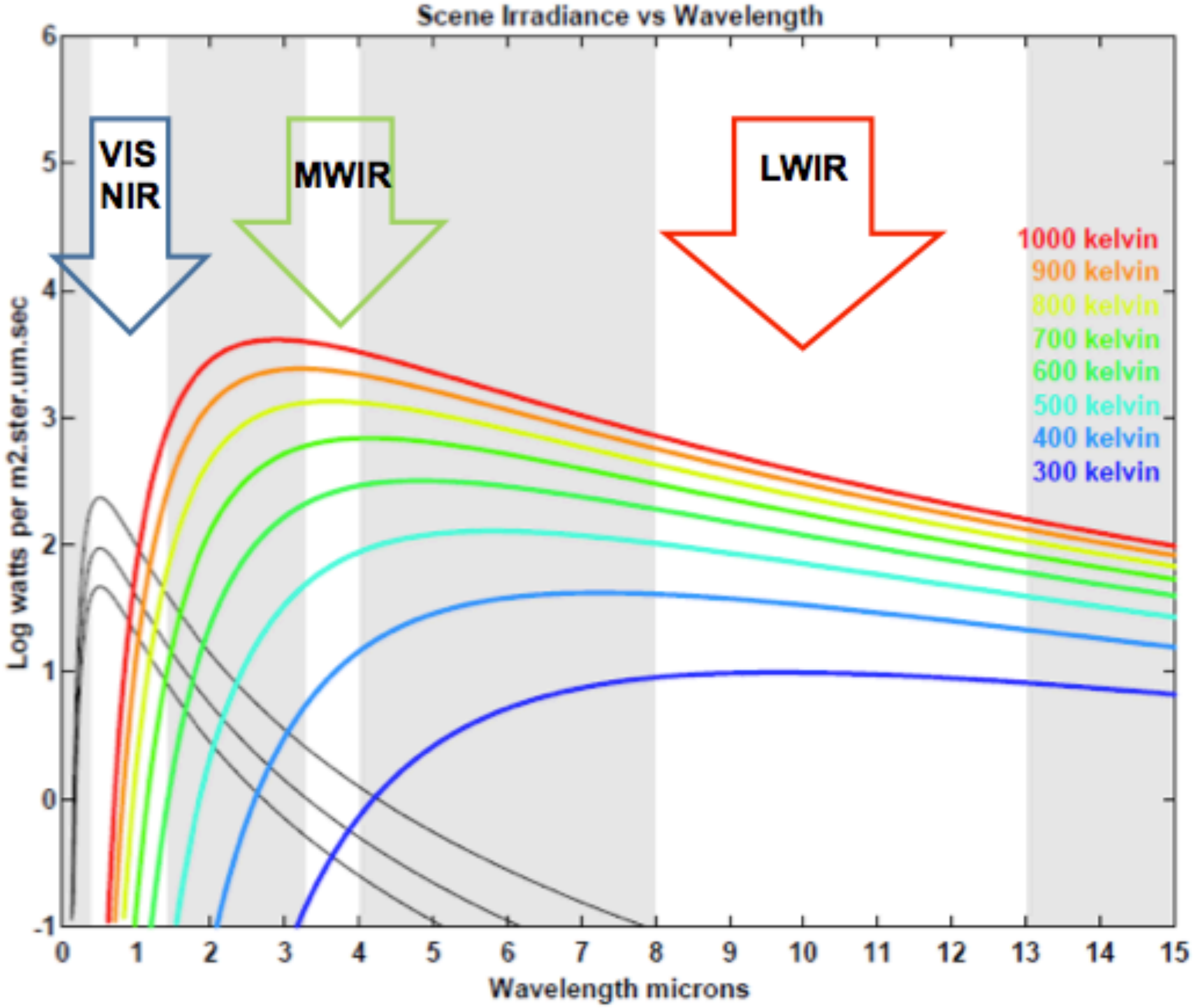
Atmospheric Transmission vs Wavelength

http://www.fao.org/docrep/003/t0355e/t035



Irradiances in Three Wavebands

Black: Noon Earth, Albedo=0.1, 0.2, 0.5
Blue: 300K, ε=1, Earth day or night
Other colors: Fire signatures increasing effective temperatures



M.Lampton April 2014

VIS:

- Excellent scene context
- Excellent angular resolution
- Huge applications & market
- Cheap lenses & sensors
- But ... little or no fire signal

MWIR:

- Best possible fire S/N ratio
- Good angular resolution
- But...cooled sensors
- And... heavy, bulky, hungry
- Tiny market
- Still most costly technology

LWIR

- OK fire S/N ratio
- Variety of lenses and sensors
- Midsize market
- Not too costly

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Article

FUEGO — Fire Urgency Estimator in Geosynchronous Orbit — A Proposed Early-Warning Fire Detection System

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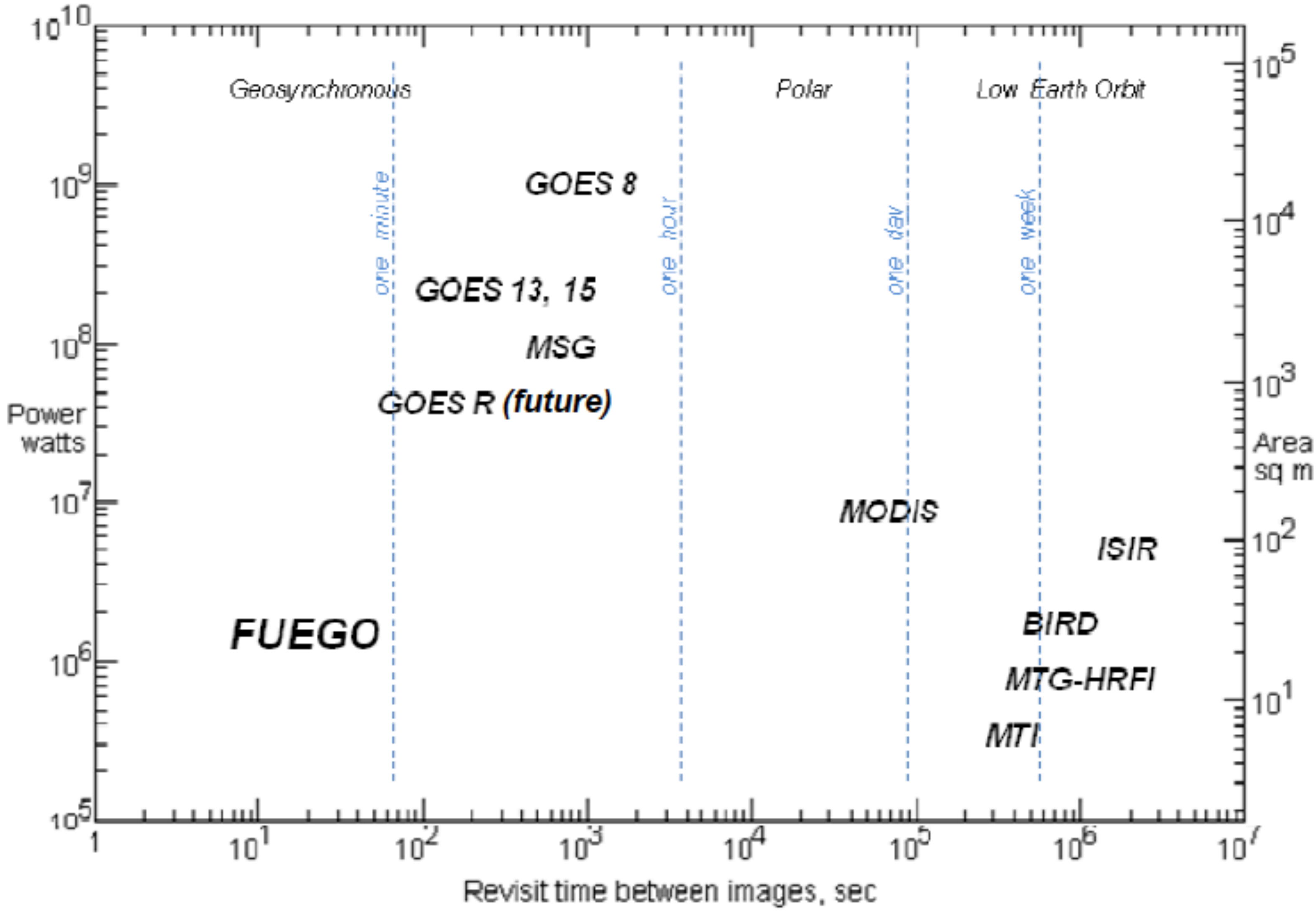
Detecting Fires from Space

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



Designing a Heat-Sensing Mission: Start with the Requirements…

FUEGO Heat-Sensing Mission Comparison		inputs
M.Lampton 3 December 2013		outputs

ref 1: Dennison P.E., and Matheson,D.S., "Comparison of fire temperature…"Remote Sens. Envir. v.115 (2011)
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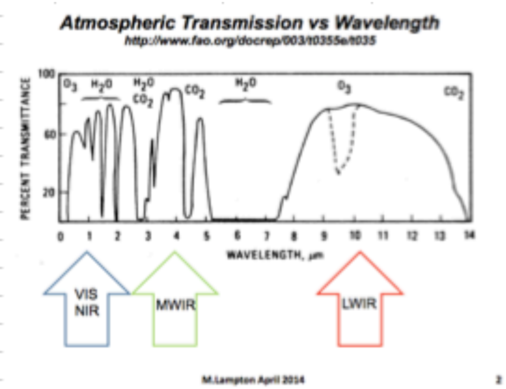
ref 3: Fiete R.D., Optical Engineering v.38#7 1229-1240 (1999).
ref 4: Kozlowski & Kosonocky "Infrared Detector Arrays," Handbook of Optics, Third Ed., v2 ch33 (2008)
ref 5: Lampton M., "FUEGO Airborne," 2nd Intl FUEGO Workshop, Berkeley (2014)
ref 6: Sprafke, T., and Beletic, J.W., "IR FPAs for Space Applications," OPN (June 2008)



WAVEBAND	Wavelength λ, µm=	**4**	**4**	**4**	**4**	**10**
	Bandwidth Δλ, µm=	**1**	**1**	**1**	**1**	**4**
	Photon energy at this wavelength, J=	4.98E-20	4.98E-20	4.98E-20	4.98E-20	1.99E-20
SMALL (1MEGAWATT) FIRE	Area, m^2=	25	25	25	25	25
	Temperature, K=	1000	1000	1000	1000	1000
	Emissivity, ε=	0.7	0.7	0.7	0.7	0.7
	Gray body spectral radiance, W/m^2.ster.µm=	2285	2285	2285	2285	259
	Gray body spectral intensity, W/ster.µm=	57129	57129	57129	57129	6466
	Gray body intensity in band, W/ster=	57129	57129	57129	57129	25864
	Total Power, MW=	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**
BACKGROUND	NIGHT: Warm Earth (300K, ε=1) spectral radiance, W/m^2.ster.µm=	0.71	0.71	0.71	0.71	9.87
	DAY: Noon sun (albedo=0.5) spectral radiance, W/m^2.ster.µm=	1.80	1.80	1.80	1.80	0.05
MISSION	Mission=	**Geostationary**	**LEO**	**LEO**	**Airborne**	**Airborne**
	Observing Mode=	**fixed target**	**pushbroom**	**pushbroom**	**pushbroom**	**pushbroom**
	Observing Altitude H, km=	35800	500	500	20	20
	which is miles=	22196	310	310	12	12
	Effective ground speed V, m/s=	0	6900	6900	140	140
	which is mph=	0	15435	15435	313	313
	Visits per day=	continuous	2	2	As needed	As needed

CubeSats are mostly Low Earth Orbit

...continue with the payload definition...

OPTICS	Optical aperture diameter D, m=	0.25	0.1	0.1	**0.025**	**0.025**
	Optical f/number giving good sampling =	5	5	6	6	2.5
	Net throughput including quantum efficiency=	0.5	0.5	0.5	0.5	0.5
	Diffraction limit angle λ/D, µrad=	16	40	40	160	400
	Optical focal length, m=	1.25	0.5	0.5	0.15	0.0625
	Diffraction radius at focus, µm=	20	20	20	24	25
	Optical cutoff freq at focus, cycles/mm=	50	50	42	42	40
	Plate scale at nadir, µm/km=	35	1000	1000	7500	3125
SENSOR	Technology =	**cooled MCT***	**cooled MCT***	**uncooled VOX**	**uncooled VOX**	**uncooled VOX**
	Pixel pitch p, µm=	10	10	12	12	12
	Number of pixels across track=	2000	2000	1000	1000	1000
	Number of pixels along track =	2000	2000	1000	1000	1000
	Frame rate, frames/sec=	1	1	60	60	60
	Full well diode capacity, Teledyne DI process, e/pixel=	1.00E+06	1.00E+06	NA	NA	NA
	Read noise, Teledyne DI process, e_rms/pixel=	1000	1000	NA	NA	NA
	Noise Equivalent Bolometric Power, W=	NA	NA	1.50E-09	1.50E-09	1.50E-09
	Dark internal rms noise/pixel, J=	1.00E-15	1.00E-15	2.50E-11	2.50E-11	2.50E-11
	Jones specific detectivity D*, cm√Hz/W=	typ 1E12	typ 1E12	6.20E+06	6.20E+06	6.20E+06
		*Cooled MCT assumes ideal 4π cold environment except for scene heat				

...and estimate the mission performance. Here, SNR:

Very useful plate scale: 10 meters per pixel

PERFORMANCE	Plate scale at nadir, meters/pixel	**286**	**10**	**12**	**1.60**	**3.84**
	Pixels needed to span fire =	1	1	1	**10**	**2**
	Nadir ground swath per exposure, km=	573	20.0	12	1.6	3.84
	Update rate, images per day=	downlink limit	2 passes/day	2 passes/day	as needed	as needed
	Fiete samples/FWHM = λ•fnumber/p =	**2.0**	**2.0**	**2.0**	**2.0**	**2.1**
		(we want to have approximately 2 samples per diffraction FWHM)				
Overload Tmax	Fire power in band per pixel, W=	1.09E-12	8.97E-10	8.97E-10	3.59E-09	9.36E-09
Overload Tmax	Background photon power in band per pixel, W=	3.95E-12	3.95E-12	3.95E-12	3.95E-12	3.59E-10
Overload Tmax	Total (fire + bkg) photon rate per pixel, ph/sec=	1.01E+08	1.81E+10	1.81E+10	7.22E+10	4.88E+11
Overload Tmax	Maximum pixel exposure time for full well, sec=	9.86E-03	5.52E-05	NA	NA	NA
Motion Tmax	Time in which vehicle ground motion is half a pixel, sec=	NA	7.25E-04	8.70E-04	5.71E-03	1.37E-02
Net Tmax	**Computed exposure time, sec=**	**9.86E-03**	**5.52E-05**	**8.70E-04**	**5.71E-03**	**1.37E-02**
	This exposure time limit is due to =	**overload**	**overload**	**motion**	**motion**	**motion**
	Fire energy in band per pixel, J=	1.08E-14	4.95E-14	7.80E-13	2.05E-11	1.28E-10
	Fire photons in band at pixel, ph/pix=	2.17E+05	9.96E+05	1.57E+07	4.12E+08	6.45E+09
	Background energy in band per pixel, J=	3.90E-14	2.18E-16	3.44E-15	2.26E-14	4.93E-12
	Background photons in pixel =	7.83E+05	4.39E+03	6.90E+04	4.54E+05	2.48E+08
	Background photon shot noise = sqrt(Nphotons) =	885	66	263	674	15732
	Total read and photon RMS noise in pixel, J=	1.00E-15	1.00E-15	2.50E-11	2.50E-11	2.50E-11
	SNR in a single frame, single pixel =	11	50	0.0312	0.82	5.13
	SNR in a single frame, coadded pixels =	**11**	**50**	**0.0312**	**2.6**	**6.7**
	How many frames shall we coadd? =	10	1	100	100	100
SIGNALTO NOISE RATIO	Total SNR with coadded pixels and frames =	**34**	**50**	**0.312**	**26**	**67**

CubeSat with a cooled HgCdTe sensor: good SNR per visit

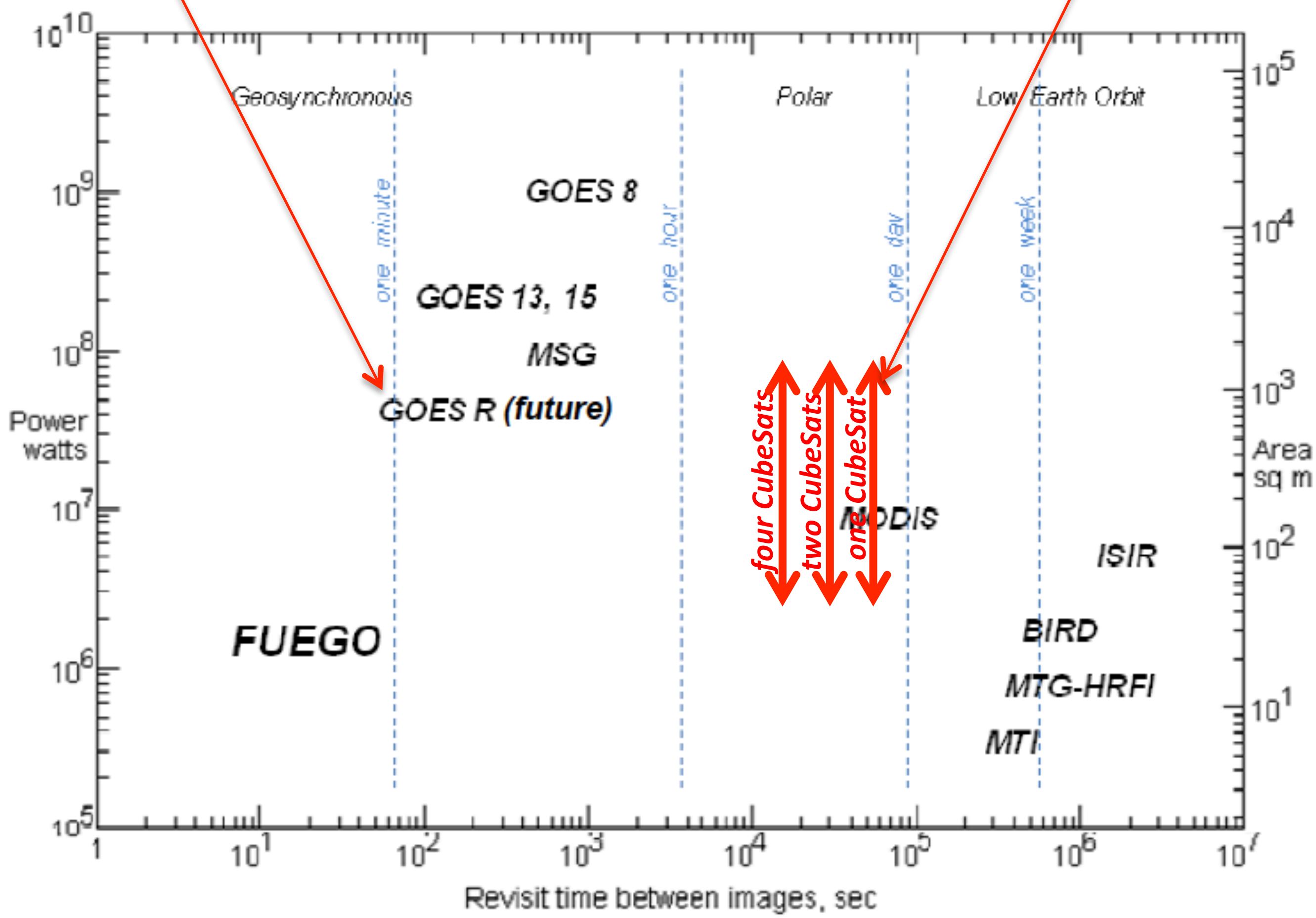
CubeSat with an uncooled microbolometer sensor: no good for megawatt fires but OK for 100 MW fires

GOES-R is no longer "future!"
GOES-16 (E) launched 19 Nov 2016
GOES-17 (W) launched 1 March 2018
Both have ABI's with 3.9um band.
Both have 24h available coverage

Usual CubeSat orbit inclinations are 28° to 52°.
Usual orbit period is 90 minutes.
24h offers 3 to 5 successive orbits viewing California,
followed by 10 to 12 orbits too far south for California.

Detecting Fires from Space

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



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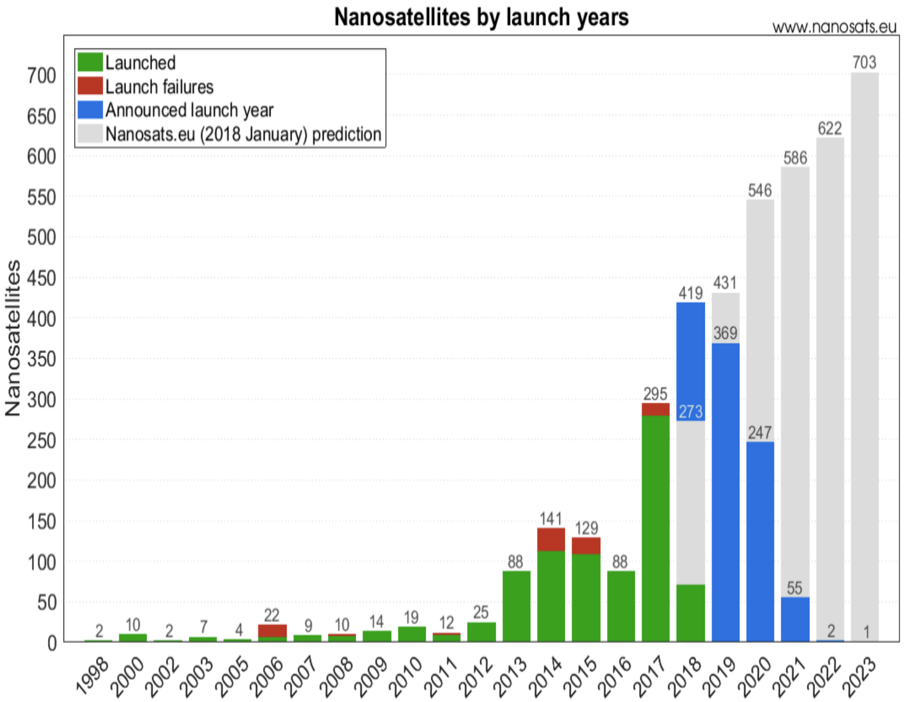
Useful Fire Detection with CubeSats?

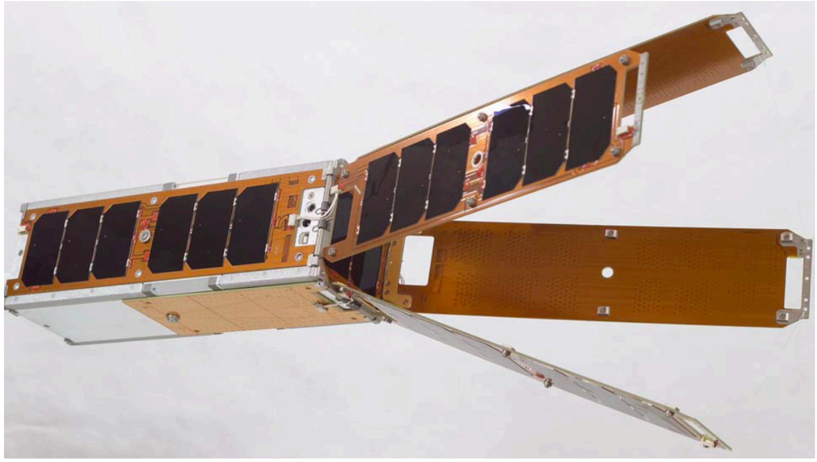
- *Decision: Smoke or Heat or Both?*
- *Decision: Day or Night or Both?*
- *Decision: Visible or NIR or TIR or Combo?*
- *Decision: low-tech or cooled sensor?*
- *Big Task: the "Urgency Estimation" or prioritization*
- *Big Task: Validation for false alarm rate*
- *Big Task: integrating with existing fire data base systems*
  - *https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms*
  - *https://www.nifc.gov/*
  - *https://www.fs.fed.us/eng/rsac/*
  - *https://www.nesdis.noaa.gov/site-map*
  - *https://wifire.ucsd.edu/*
- *Starting point: understanding previous small fire mission concepts and flights*
  - *FIRESAT (1996, USA + NASA)*
  - *FUEGOSAT (2002, ESA)*
  - *BIRD (2004, Germany + ESA)*
- *Then: understand strengths & weaknesses of the many current spaceborne fire detection systems*
  - *https://www.nasa.gov/feature/goddard/2018/nasa-covers-wildfires-from-many-sources*

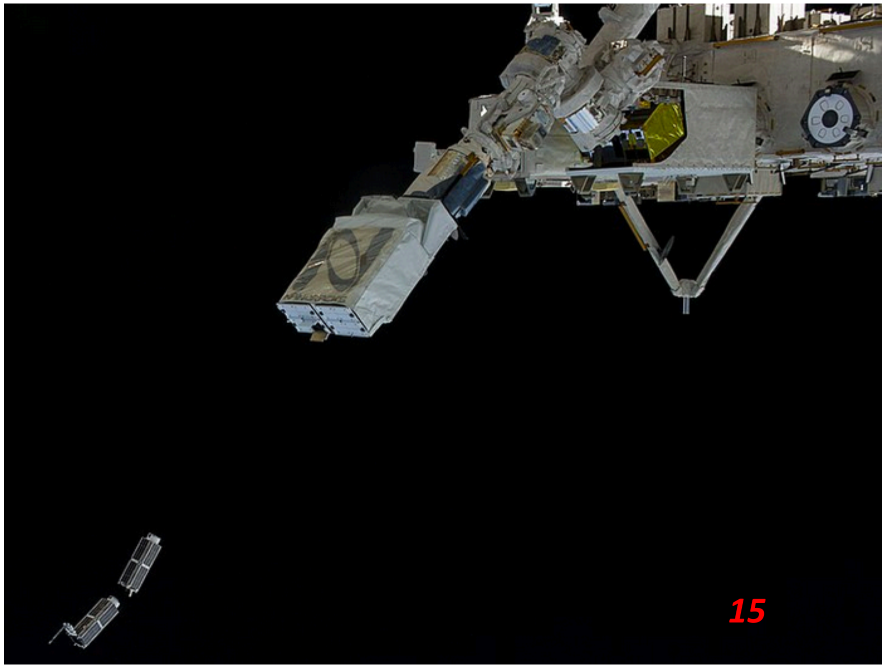
  -- *AQUA/AIRS; MODIS; TERRA/ASTER * TERRA/MISIR; NPP/VIIRS; CALIPSO; MSG; GRACE; GPM; SMAP; Sentinel; MOPITT*

  --- *International Space Station (400km altitude, 52 deg inclination) with its many Earth observing systems*
- *CubeSat Benefits: Student participation; Good Ground Resolution, Rapid turnaround; Technology Testbed*

CubeSat Facts







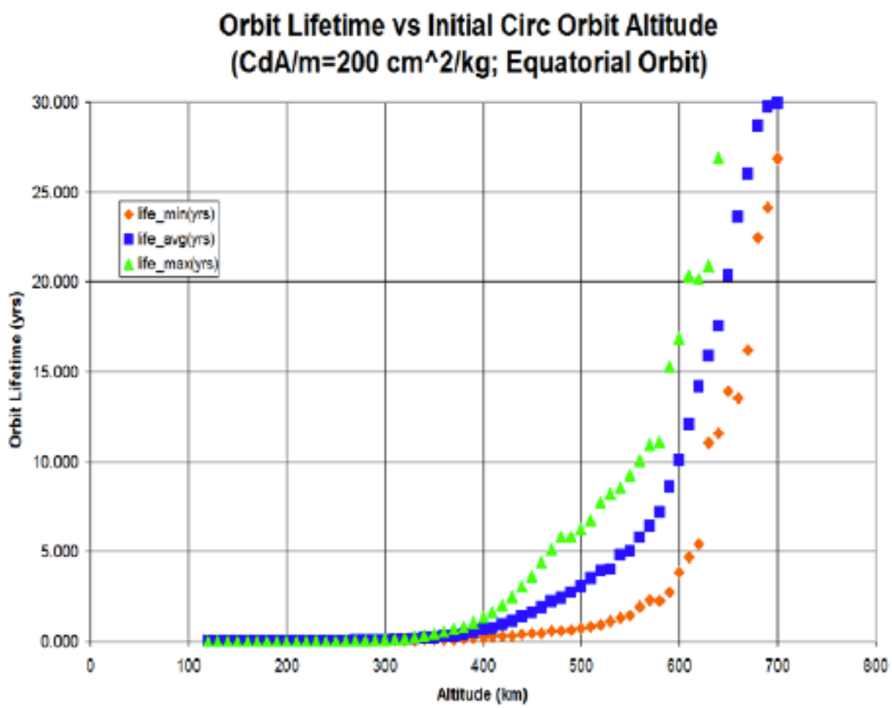
CubeSat Community

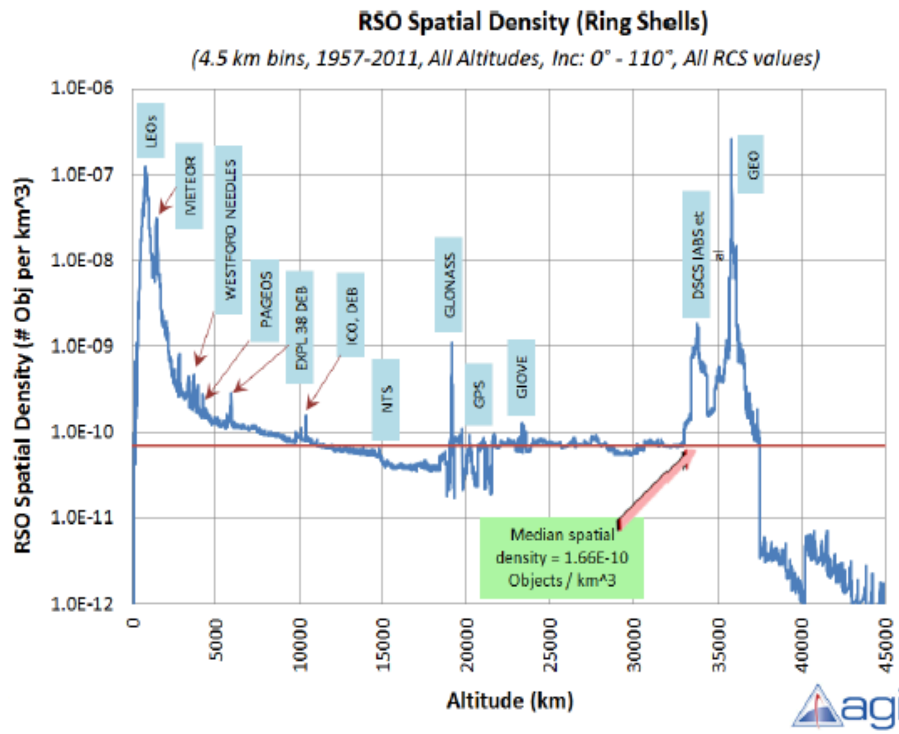
https://en.wikipedia.org/wiki/List_of_CubeSats

- NASA Mission Directorate supports development through its Centers
  - http://www.nasa.gov/smallsats/
- CubeSat Developers Workshops CalPoly
  - http://www.cubesat.org/workshop-information/
  - held in April: 2015, 2016, 2017, 2018, upcoming 2019
- European Nanosatellite Database
  - https://www.nanosats.eu/
  - 2200 missions listed each with short description, sponsor, participants, links

CubeSat Orbit Considerations

- *Low orbits, <400km, re-enter quickly from atmospheric drag*
- *High orbits, >600km, suffer Van Allen Radiation Belt damage*
  - *Garbage Removal is an Internationally Regulated Issue*
- *Low inclination orbits, < 40deg, fail to cover California*
- *ISS is at 400km, 52 degrees*





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CubeSat Campuses and Industry: Partners, Vendors, Component & System Suppliers

- *Uplink, downlink, antennas, ground stations*
- *Onboard solar power, batteries, thermal control*
- *Attitude control: gyros, reaction wheels, mag torquers*
- *Cameras, image processors and compressors*
- *Hardware, software, integration & test plan and execution*
- *Roster of suppliers: http://www.cubesat.org/new-index/*
- *Right here in the Bay Area:*
  - *Planet: https://www.planet.com/company/*
  - *Capella: https://www.capellaspace.com/*
  - *CINEMA: UC Berkeley Space Sciences Lab*
  - *STAC (Berkeley students): https://stac.berkeley.edu/home/*
  - *Stanford: https://stanfordssi.org/teams/satellites*
  - *Irvine Public School System: https://ipsf.net/what-we-do/irvine-cubesat/*
  - *UCLA "ELFIN": https://elfin.igpp.ucla.edu/*

Appendix: A Few Useful References

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