PODS – 03/04/2020

Agenda

- SPEC(ifications) Tables
- Your CubeSat discoveries!

Spec Tables

- Optical Designers use them to communicate design requirements
- Tables to organize key design constraints
- Enables ***CLEAR COMMUNICATION*** between design collaborators

	A	B	C	D
2	Name		Jaren N. Ashcraft	
3	Date		March 1st, 2020	
4	Project Title		PODSat - A Cubesat Concept	
5	Brief Description		A CubeSat payload for variable objectives	
7			Value	Note
9	Aperture	=	300 mm	Entrance Pupil Diameter. This is a segmented telescope that uses this effective EPD, but is composed of two square mirror apertures of 100x100mm
10	Field	=	0.9 deg	Calculated from IFOV
11	Wavelength	=	d,F,C	Optical Design Wavelengths in the Visible
13	Focal Length / Magnification	=	1380 mm	To 2*sample the Nyquist Frequency
14	Detector		Raspberry Pi UV-Vis imaging camera ($25)	Datasheet: https://cdn.sparkfun.com/datasheets/Dev/RaspberryPi/ov5647_full.pdf
15	Detector Size	=	2.27mm half-diagonal	Detector Datasheet
16	Pixel Pitch	=	1.4 x 1.4 um	Detector Datasheet
17	Nyquist	=	714 lp/mm	1/Pixel Pitch
18	Other Detector Info		Paper using detector for 310nm observations	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5087437/pdf/sensors-16-01649.pdf
20	Image Quality	<=	2.8 um	RMS Spot Size
21	Distortion	<	1%	
22	Min/Max Ray AOI on surfaces		N/A	Contingent on Coatings
23	Telecentricity / Chief Ray Angle on Detector	<	25 deg	Detector Datasheet
24	Relative Illumination / Vignetting		N/A	
25	Other Performance Requirements		Primary Mirror Co-Phasing	
27	Semi-Aperture [optical / mechanical]	<	35 mm	Optical, must fit in 1U package
28	Length	<	250 mm	Mechanical length
29	Filters / Windows		N/A	
30	Other Packaging Requirements		Contain w/in a 3U+ volume	

Key Specifications

- What 3 parameters are the *most vital* for optical designers?

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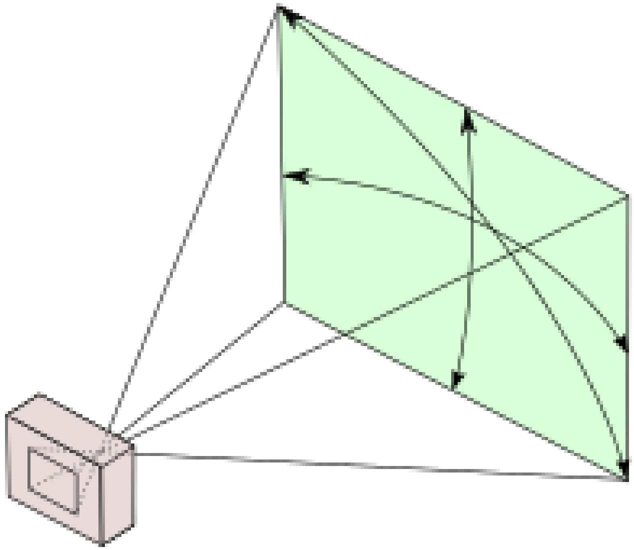
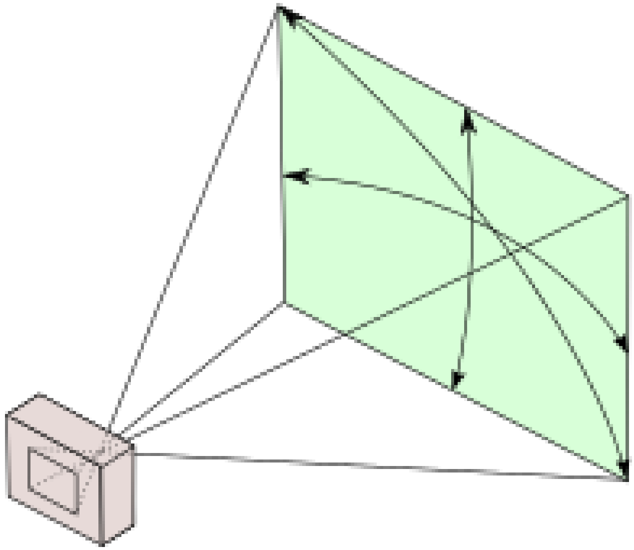


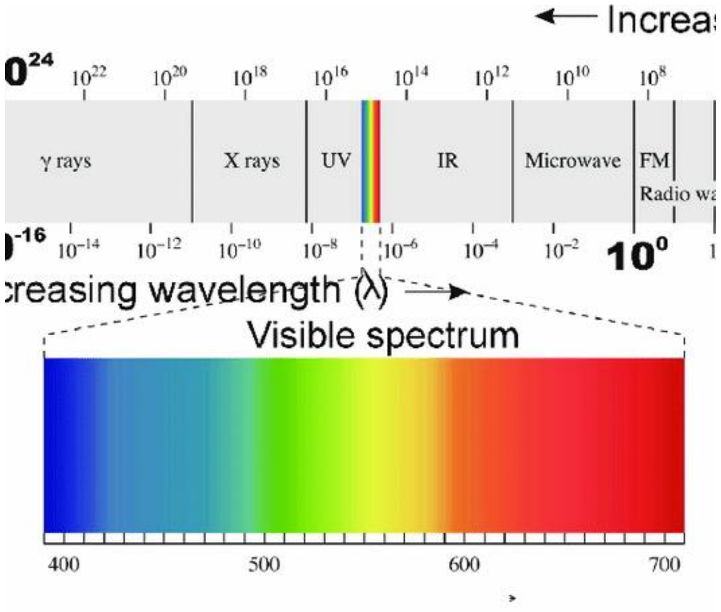
Key Specifications

- What 3 parameters are the *most vital* for optical designers?

Aperture



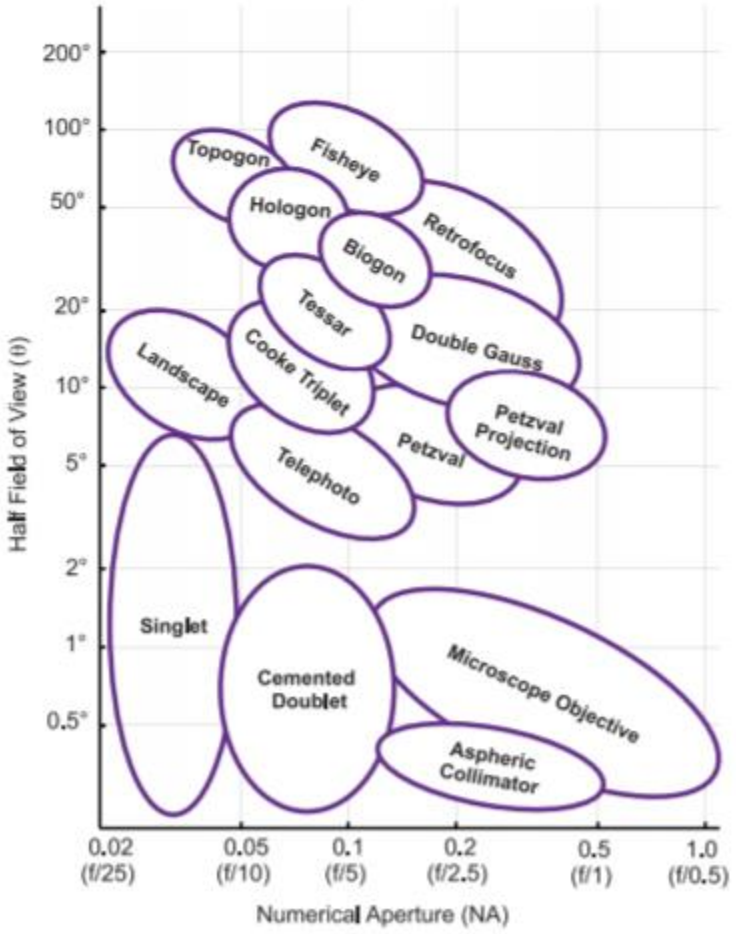
Field



Wavelength

Constraining The Design Space

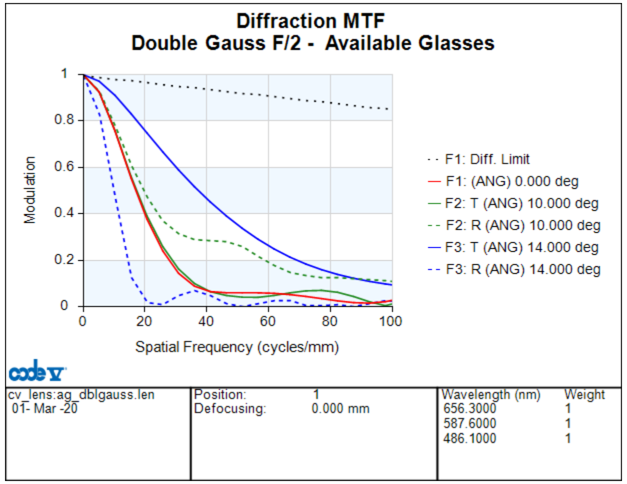
- Aperture & Field constrain your design variant
- Wavelength constrains your available material
- Any “Black Box” system will have at least these three parameters

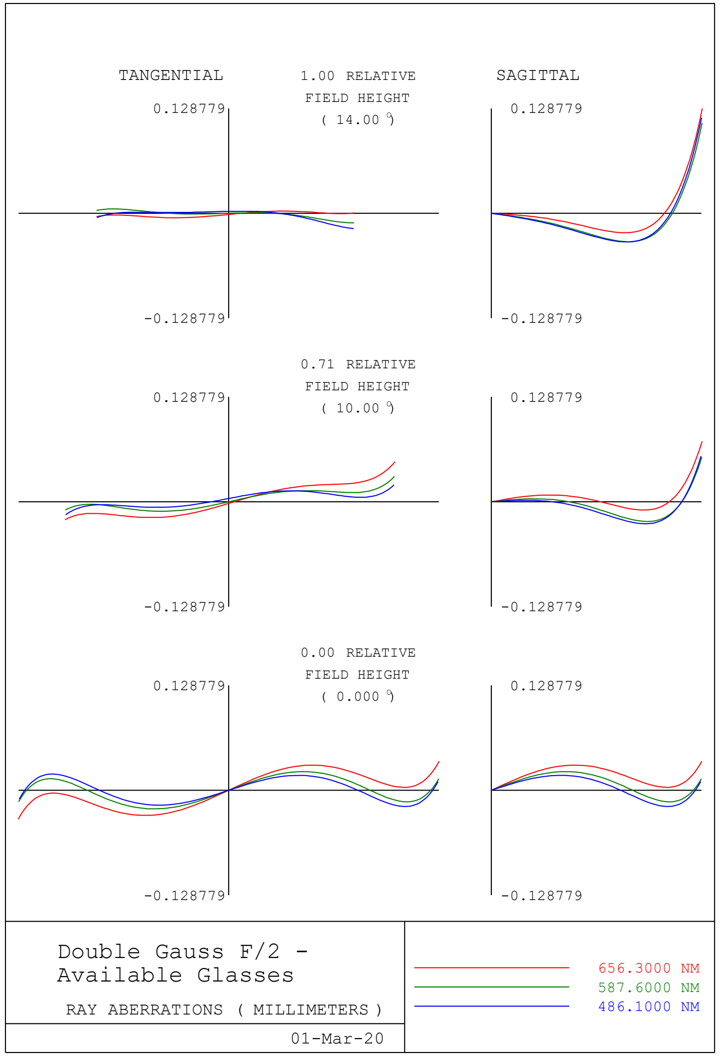


Source: *Field Guide to Lens Design, Bentley (2012)*

Performance Requirements

- Detector (pixel size, Nyquist frequency)
- Image Quality (MTF, RMS Wavefront, Spot Size)
- Distortion
- Ray angles (AOI, AOR, Telecentricity)
- Relative Illumination
- Vignetting





Packaging Requirements

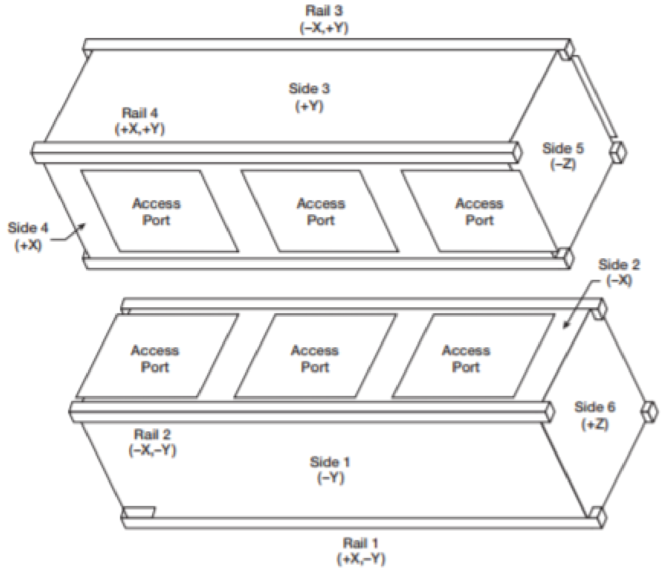
- Regrettably – optics don’t float perfectly in space
- Leave room to hold your optics!
- Glasses also have blanks of finite size
  – Cost contribution
- This is particularly relevant in CubeSats where space is VERY LIMITED

3U+ CubeSat Acceptance Checklist

Project: Date/Time: Engineers:
Organization: Location:
Satellite Name: Satellite S/N: *Revision Date: 02/20/2014*

Mass (< 4.00 kg)	________	**RBF Pin** (≤ 6.5 mm)	________
Spring Plungers (Depressed)	Functional Y / N Flush with Standoff Y / N	**Rails Anodized**	Y / N
Deployment Switches (Depressed)	Functional Y / N Flush with Standoff Y / N	**Deployables Constrained**	Y / N

Mark on the diagram the locations of the RBF pin, connectors, deployables, and any envelope violations.



Authorized by:
IT 1: ________
IT 2: ________
Passed: Y / N

3U+ Volume
Length (Z): ____ ≤ 36 mm
Diameter: ____ ≤ 64 mm
3U+ Centered: Y / N

Sample Spec Table

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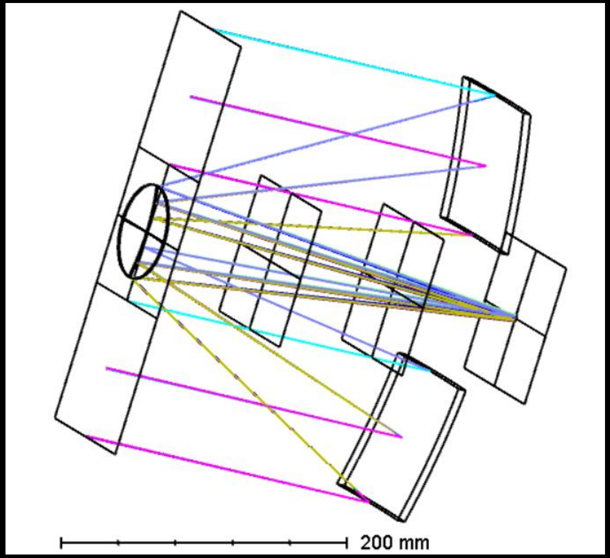
- Missing anything?
- Is the information clear?
- Link to reference material for transparency
- Could benefit from pictures



THE UNIVERSITY OF ARIZONA
Wyant College
of Optical Sciences

CubeSat Spec Inspiration

NEO Identification

- Shao M. et al. (2017) A constellation of SmallSats with synthetic tracking cameras to search for 90% of potentially hazardous near-Earth objects
- Constellation of Solar-Orbiting 9U CubeSats using "Synthetic Tracking"
  - No Optical Design!
  - NO W A V E L E N G TH *ANGRY GRAD STUDENT NOISES* (Other reading has me thinking MWIR)
  - 3.6x3.6 deg FOV, 20cm EPD w/ 8K detector, 10cm EPD w/ 4K

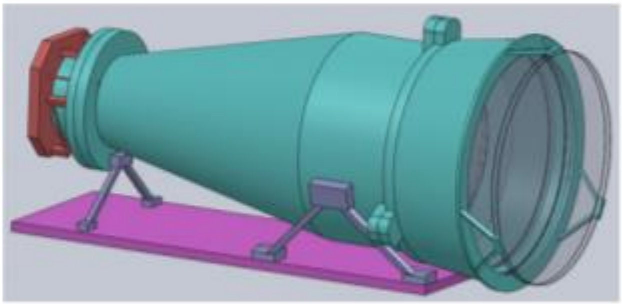


Fig. B.1. A CAD design for the synthetic tracking camera for a CubeSat.

Table 1. Parameters for an advanced synthetic tracking camera.

Parameters	Value	Units
Telescope Diameter	20	cm
Image	2X	diff limit
Pixel size	1.6	arcsec
Effective background	2.8	arcsec
Magnitude limit	22.15	mag
Integration time	800	s
Number of satellites	**9**	
EG size	50	m
H magnitude	24.24	mag

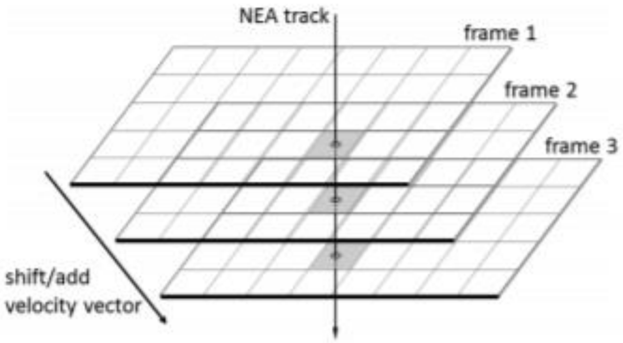
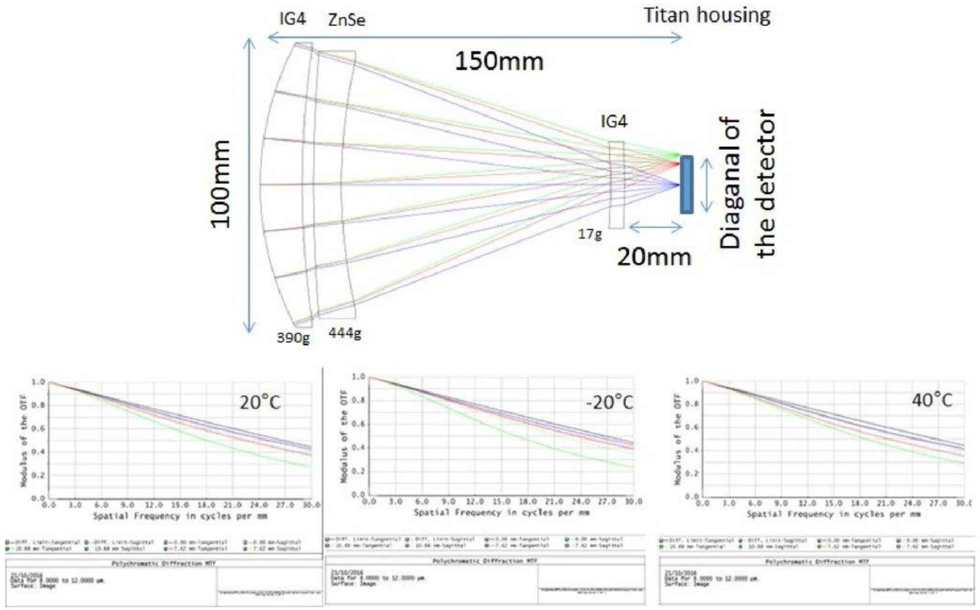
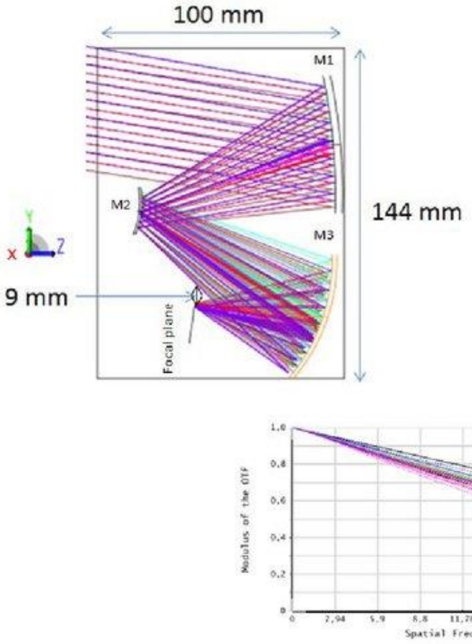


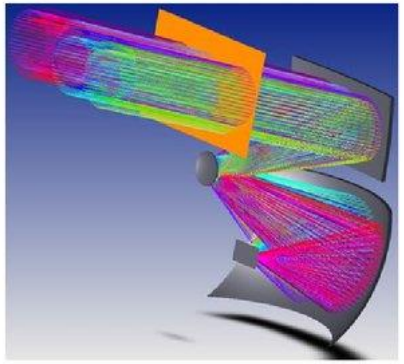
Fig. A.1. Schematic showing the integration of frames by using synthetic tracking. Frames are displaced according to the velocity of a NEO so that it is at the same location in all the frames during the integration (adopted from Shao et al. 2014).

LWIR Thermal Imaging of Earth

- Druart G. et al. (2018) [Study of infrared optical payloads to be integrated in a nanosat]
- Environmental / Industrial Monitoring
- 2U, F/1.5, 11x1 deg pushbroom FOV
- Study that inspired this project – compared refractive & reflective solution







CubeSat

Uses, Missions, Goals

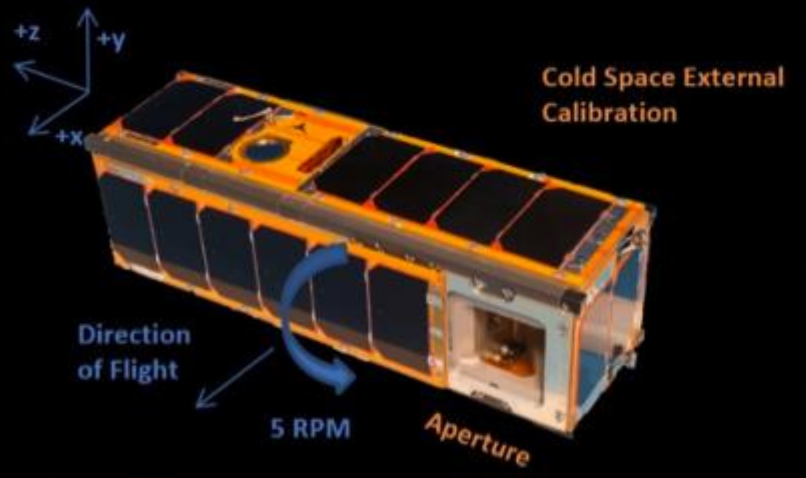
JPL CubeSat Missions

- RACE: Radiometer Atmospheric CubeSat Experiment (3U)
  - Measures liquid water path and precipitable water vapor that is pertinent to the water cycle and Earth energy budget
  - Microwave radiometer primarily observing the 183 GHz water vapor line
- GRIFEX: GEO-CAPE ROIC In-Flight Performance Experiment (3U)
  - Perform engineering assessment of a JPL-developed all digital in-pixel high frame rate Read-Out Integrated Circuit (ROIC)
  - High throughput capacity enables proposed Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission concept
    - Make hourly high spatial and spectral resolution measurements of rapidly changing atmospheric chemistry and pollution transport with the Panchromatic Fourier Transform Spectrometer (PanFTS) instrument in development
- M-Cubed/COVE-2: Michigan Multipurpose Minisatellite/CubeSat On-board processing Validation Experiment (1U)
  - Image the Earth at mid-resolution, approximately 200m per pixel, carrying the JPL developed COVE technology validation experiment
  - Validate an image processing algorithm designed for the Multiangle Spectropolarimetric Imager (MSPI) utilizing the first in-space application of a new radiation-hardened-by-design Virtex5-QV FPGA by Xilinx
- IPEX: Intelligent Payload Experiment (1U)
  - VSWIR hyperspectral imaging spectrometer and a thermal infrared imager that would perform global mapping producing approximately 5TB of data per day
  - Advance technology required for future spaceborne IPM for near real-time low-latency autonomous product generation relevant to climate, ecosystems, fire, geological resource, and coastal ocean science

RACE Mission Operations Concept

Mission	Value
Launch	ELANA-8/ORB-3
Launch Date	Oct 2014
Orbit Altitude	~415 km
Orbit Inclination	51.6°
Primary Mission	~60 days

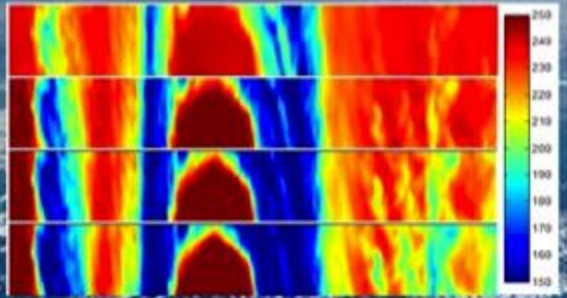
NanoRacks ISS Deployment

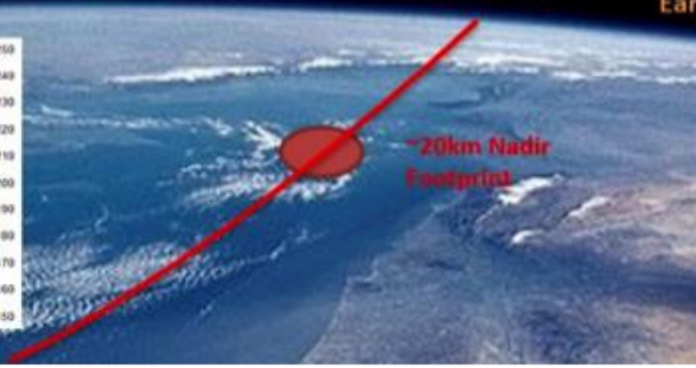


RACE	Value
Nadir Footprint	~20 km
Instrument	Radiometer
Frequency	183 GHz
Channels	2
NEΔT	<1 K
Science	Water Vapor T_Bs

CubeSat	Value
Payload Power	< 1.5 W
Data	~100 MB
Energy Storage	39 W-hr
OAP Body	~4.5 W
Pointing Accuracy	<10°
Pointing Knowledge	<1°

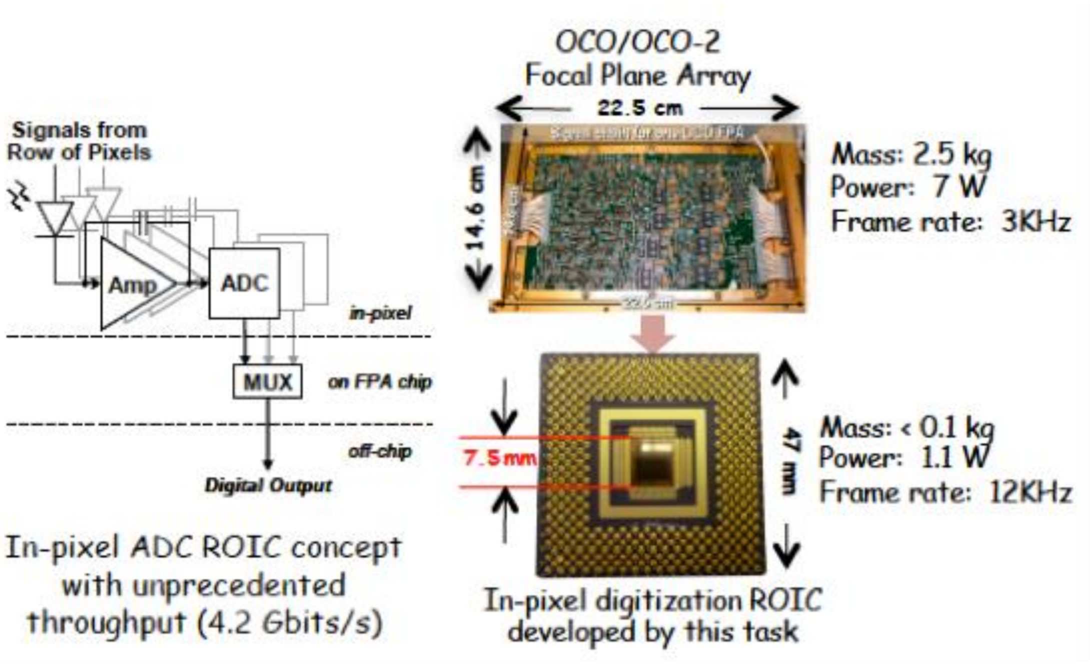
Sample HAMSR brightness temperature data from Hurricane Karl (2010). Four 183 GHz channels are shown at a higher spatial resolution. RACE would measure 2 channels and basically integrate the swaths shown into pixels.

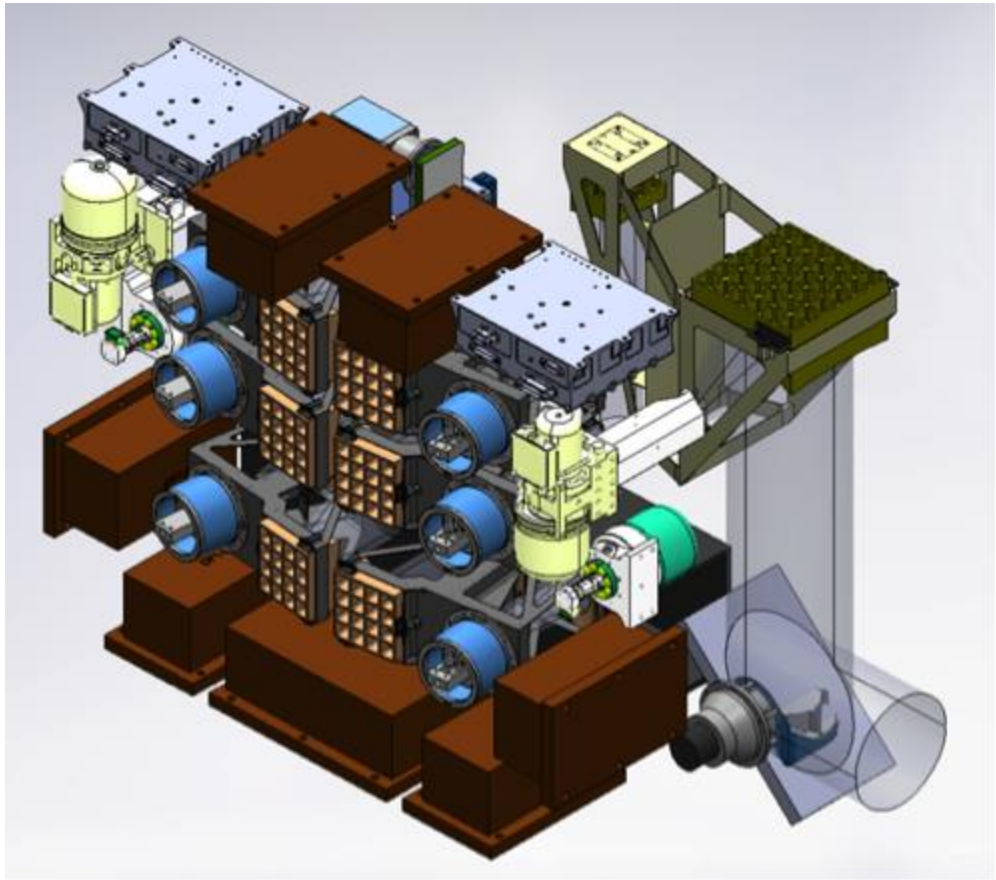


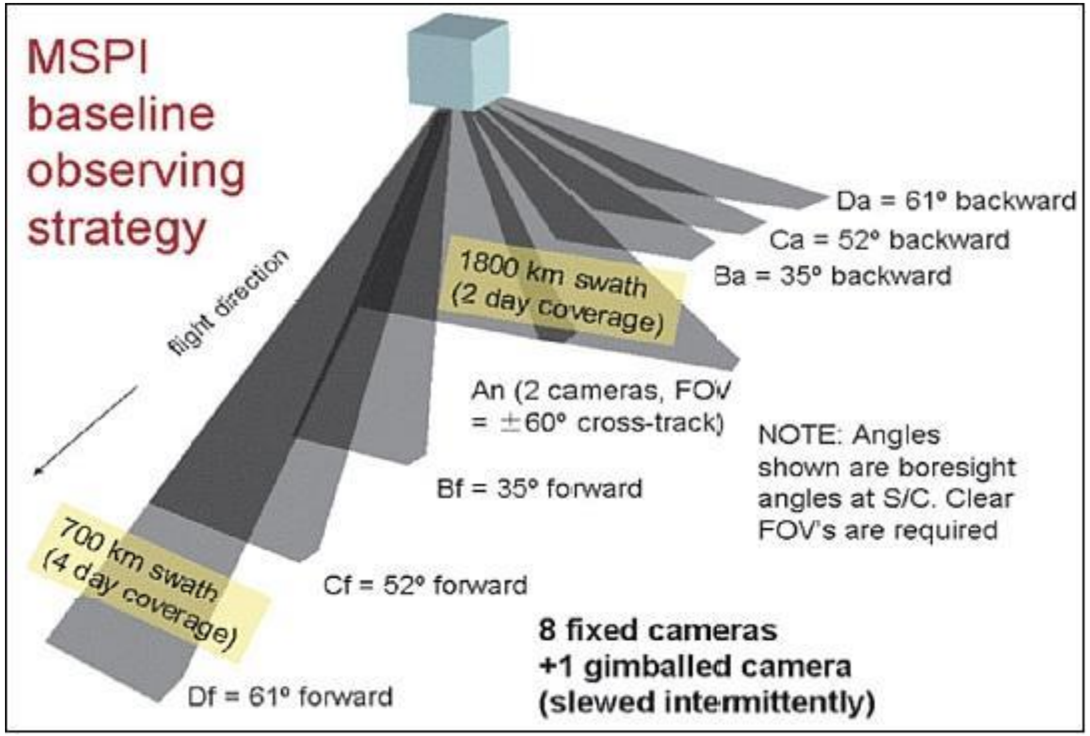


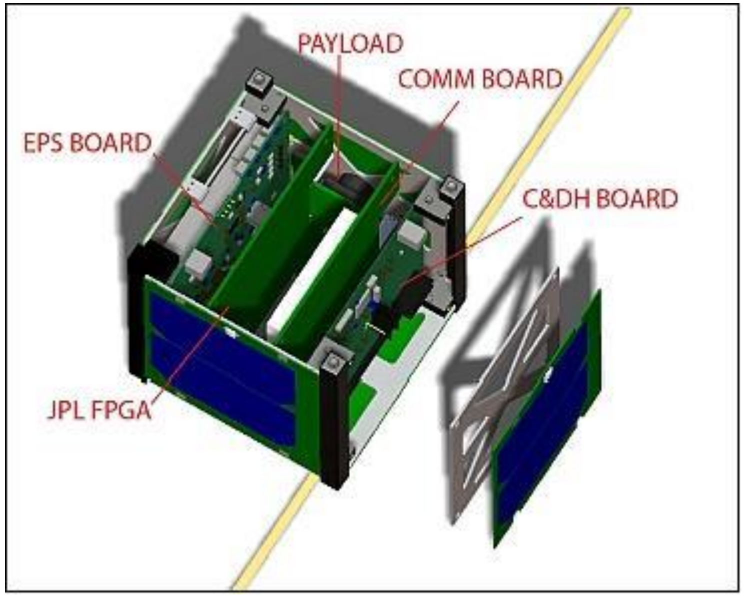
Ground Station :
University of Texas at Austin
Backup : JPL

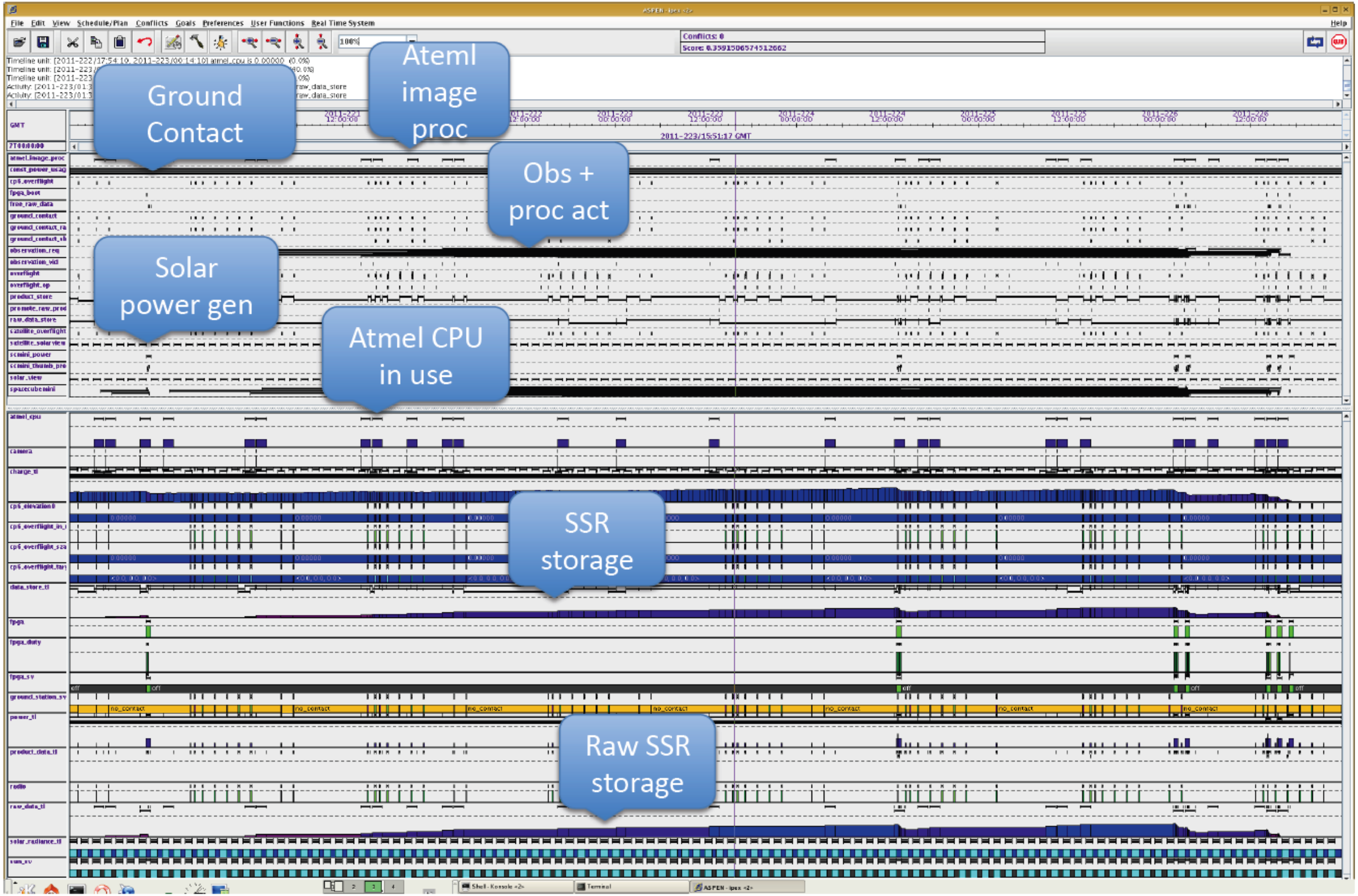
*Not to scale
09/16/2014


Signals from
Row of Pixels
Amp
ADC
in-pixel
MUX
on FPA chip
off-chip
Digital Output
In-pixel ADC ROIC concept
with unprecedented
throughput (4.2 Gbits/s)
OCO/OCO-2
Focal Plane Array
22.5 cm
14.6 cm
Mass: 2.5 kg
Power: 7 W
Frame rate: 3KHz
7.5mm
47 mm
Mass: < 0.1 kg
Power: 1.1 W
Frame rate: 12KHz
In-pixel digitization ROIC
developed by this task




MSPI
baseline
observing
strategy
flight direction
Da = 61º backward
Ca = 52º backward
Ba = 35º backward
1800 km swath
(2 day coverage)
An (2 cameras, FOV
= ±60º cross-track)
NOTE: Angles
shown are boresight
angles at S/C. Clear
FOV's are required
Bf = 35º forward
700 km swath
(4 day coverage)
Cf = 52º forward
8 fixed cameras
+1 gimballed camera
(slewed intermittently)
Df = 61º forward


PAYLOAD
COMM BOARD
EPS BOARD
C&DH BOARD
JPL FPGA


File Edit View Schedule/Plan Conflicts Goals Preferences User Functions Real Time System
Help
Conflicts: 0
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Obs + proc act
Solar power gen
Atmel CPU in use
SSR storage
Raw SSR storage
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PODS

What are cubesats used for?

What are cubesats used for?

- “The idea for the CubeSat came in part from the miniature toy craze of the day, Beanie Babies, according to Spaceflight Now. Inspired by the individualized stuffed animals, Twiggs' idea was to allow students to build their own miniature satellites.” https://www.space.com/34324-cubesats.html
- **Space walkie talkies**
  - “One of the MarCO spacecraft will serve as a relay satellite to send data back to Earth during InSight's entry, descent and landing operations at the Red Planet in September 2016. The other spacecraft will serve as a backup.” https://www.space.com/29489-marco-cubesats-mars-landing-2016.html
  - IceCube – measurements of ice clouds in space to assist with weather and climate models.
- **Weather walkie talkies**
  - RainCube – monitor severe storms on earth
- **Space sensors**
  - CubeSat Compact Radiation Belt Explorer – High energy particle Measurement in earth’s radiation belt
- **Low Risk Proofs Of Various Concepts**
  - CubeSail – deployment and control of solar sail blade
  - Shields 1 – demonstrate radiation shielding
- **Planet Probers**
  - CUVE – Collect data about Venus’ atmosphere.
  - Lunar Flashlight – lasers to search for water ice on the south pole of the moon.

https://solarsystem.nasa.gov/news/834/10-things-cubesats-going-farther/

Existing CubeSat Optical Design

- Refractive (Example: AtmoCube A1, 6U)

    Limitation: Shorter focal length, limiting sample distance

- Reflective

    Limitation: Difficult to fit mirror mounts into the cube

    - Ritchey-Chretien (Example: EOSESS LLC design, 3U, Visible through MWIR)

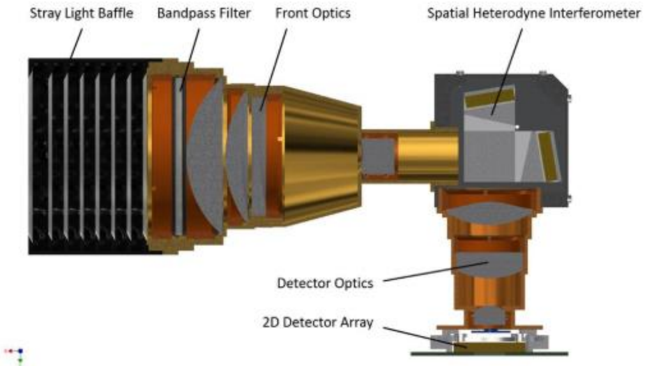
        Limitation: Aperture size, reduced MTF in mid-frequency

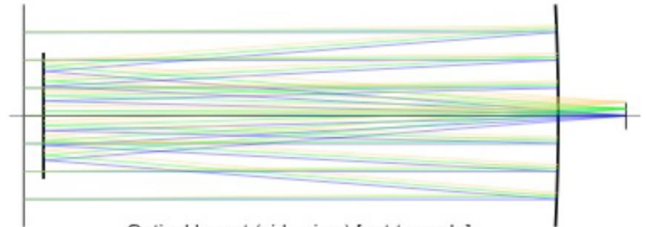
    - Off-axis Ritchey-Chretien (Example: KAIST design, 3U, Visible)

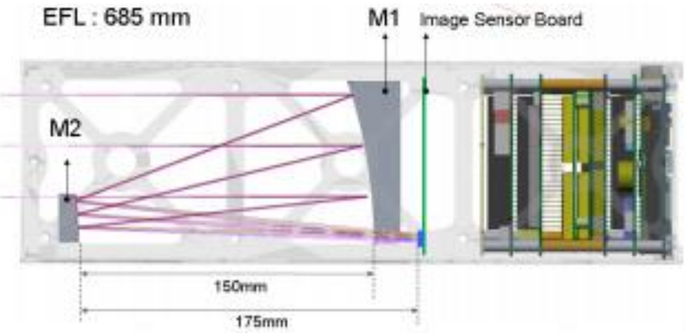
        Limitation: Aperture size

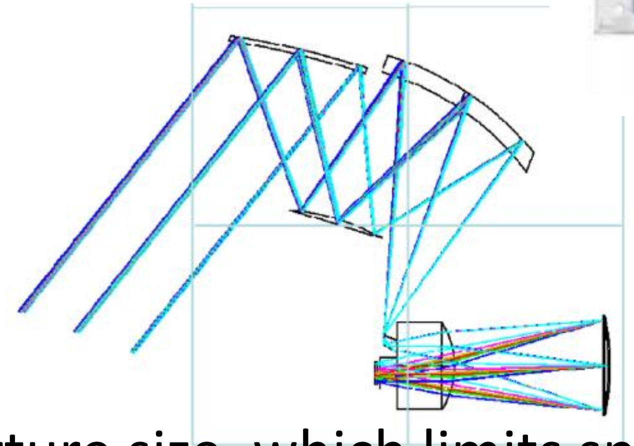
    - TMA (Example: PRISM, 6U, 350-1700 nm)

        Limitation: Large size




Optical layout (side view) [not to scale]





Problems:

Small satellite payload limits optical aperture size, which limits spatial resolution.

References

- CubeSat Image Resolution Capabilities with Deployable Optics and Current Imaging Technologies, J. Champagne, Space Dynamics Lab
- Friedhelm Olschewski, Martin Kaufmann, Klaus Mantel, Oliver Wroblowski, Martin Riese, and Ralf Koppmann "Advances in the optical design of a spatial heterodyne interferometer deployed on a 6U-CubeSat for atmospheric research", Proc. SPIE 11131, CubeSats and SmallSats for Remote Sensing III, 111310B (30 August 2019); https://doi-org.ezproxy1.library.arizona.edu/10.1117/12.2529968
- Pantazis Mouroulis, Byron Van Gorp, Robert O. Green, and Daniel W. Wilson "Optical design of a CubeSat-compatible imaging spectrometer", Proc. SPIE 9222, Imaging Spectrometry XIX, 92220D (15 September 2014); https://doi.org/10.1117/12.2062680
- Timothy L. Howard, “A Flexible Cubesat-based Optical Design for Earth Imaging Missions”, AIAA SPACE Forum 2014.
- Ching-Wei Chen and Chia-Ray Chen "Optical design and tolerance analysis of a reflecting telescope for CubeSat", Proc. SPIE 9602, UV/Optical/IR Space Telescopes and Instruments: Innovative Technologies and Concepts VII, 96020P (22 September 2015); https://doi.org/10.1117/12.2188734
- Ho Jin, Juhee Lin, Youngju Kim, and Sanghyuk Kim, “Optical Design of a Reflecting Telescope for CubeSat”, Journal of Optical Society of Korea, Vol. 17, No. 6, December 2013, pp. 533-537.

A couple ideas...

- Biggest limitations: Aperture diameter and packaging s
  - Deployable Mirrors

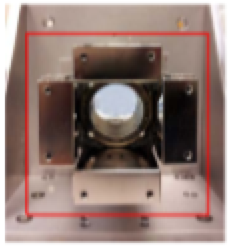


Figure 4: Stowed Primary Mirror with 10 cm x 10 cm Cross-Section Outlined in Red

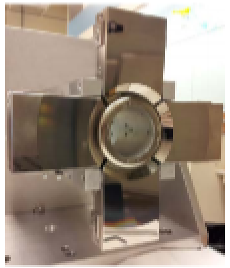


Figure 3: Deployed Primary Mirror

- Big future application of cubesats: Laser Comm
  - How to align?
  - Small telescopes on each CubeSat with LED beacon for rough alignment?
    - Current Pointing Accuracy 0.05 deg. Can we do better? (based on 2017 Article)
- Still a big hyperspectral imaging fan...
  - Optical->SWIR(~2um)
    - Multipurpose: identifying/mapping oil spills, crop health, etc

- FYI: NASA CubeSat Launch Initiative