Exoplanet Observations with CubeSats

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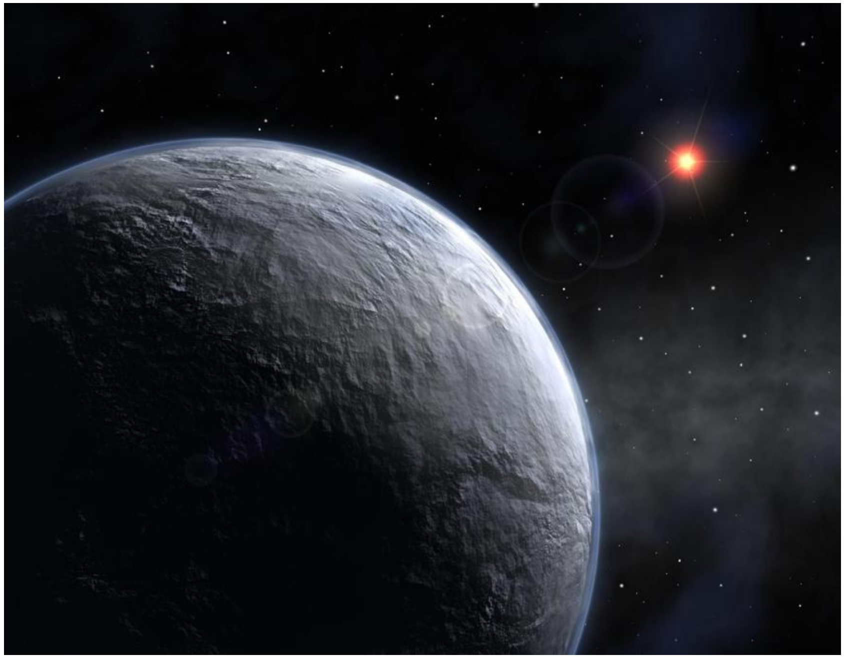
Exoplanets & Detection

Exoplanets: Planets orbiting stars other than the sun

What can we learn from exoplanets?

- **Whether life exists elsewhere in the galaxy**
- Solar system and planet formation
- Frequency of planets like Earth



ExoplanetSat will search for Earth-sized planets which are well-suited to supporting life

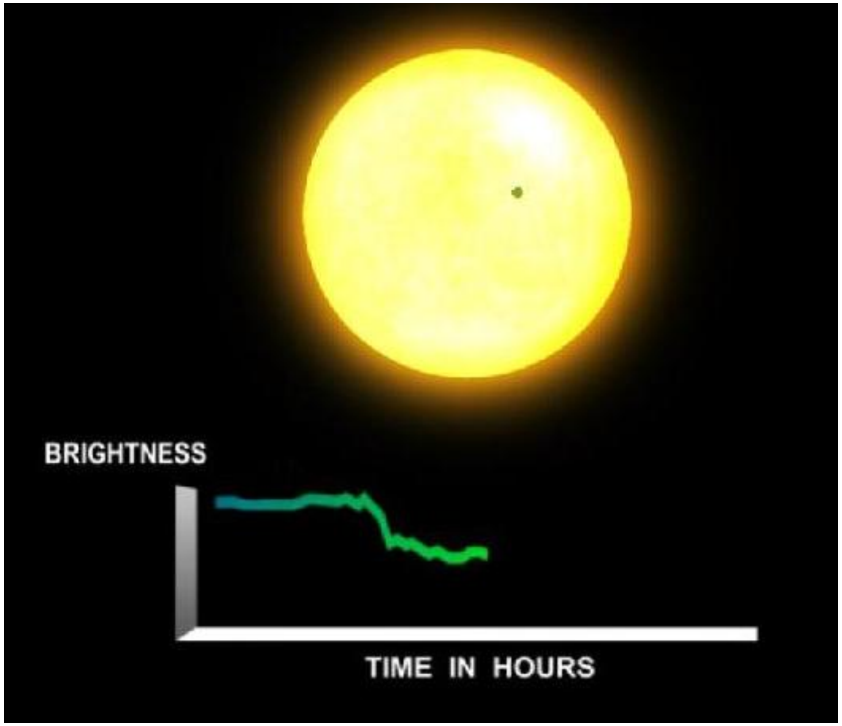
- CubeSat form factor
  - Low cost
  - Frequent launch opportunities
  - Short development time

- Focus on brightest stars so that planets can be characterized

- Use constellation to study many stars and increase probability of planet detection

Transit Method

Transit method: detects drop in stellar brightness as a planet passes in front of the stellar disk



Earth-sized planet transiting a Sun-like star = **84 ppm** drop in star brightness

Top science goal for exoplanet research:

- Find Earth-sized planets (1-2 Earth radii) in the habitable zone (where liquid water can exist)
- Study their atmospheres for signs of life

Spectroscopy may be used to study exoplanet atmospheres **if the parent star is bright enough**

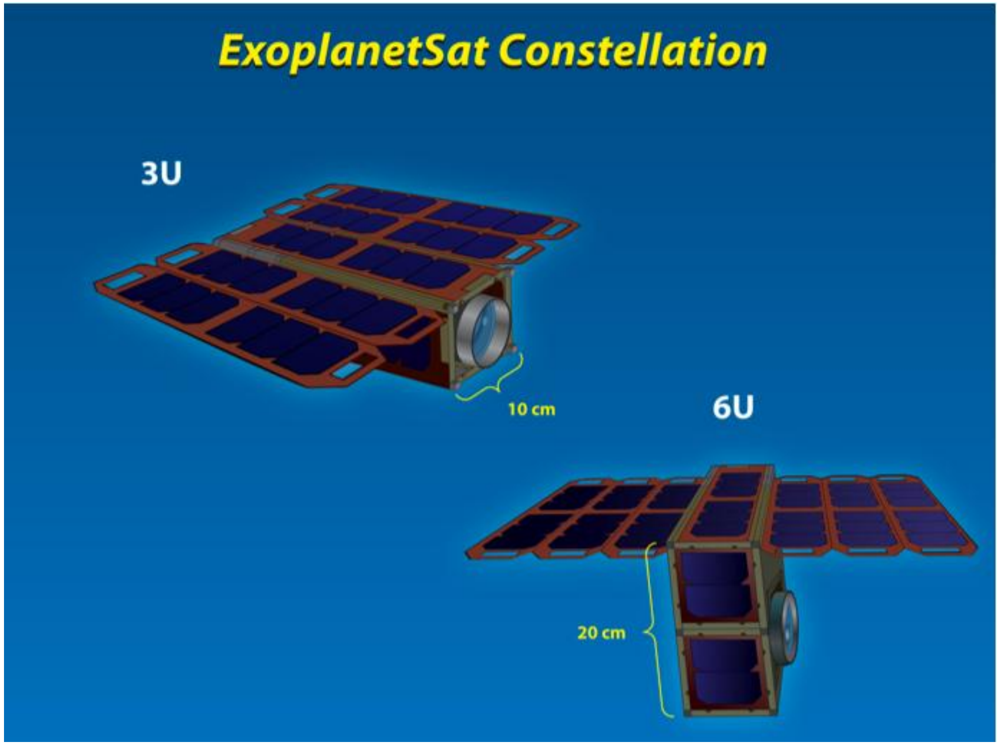
No current mission monitors the brightest Sun-like stars over long durations for Earth-sized transiting planets.

System Goals

The ExoplanetSat Constellation will search the brightest Sun-like stars in the sky for Earth-sized transiting planets in their star's habitable zone.

Key Performance Parameters:

- 100 ppm photometric precision over 10 minutes
- Few arcsecond pointing precision
- Monitor each star for 2+ years
- Constellation: Survey enough stars for 95% confidence of 3 or more detections



The CubeSat Platform

Bright Star Transit Search

↓

Dedicated Fleet of Small Telescopes

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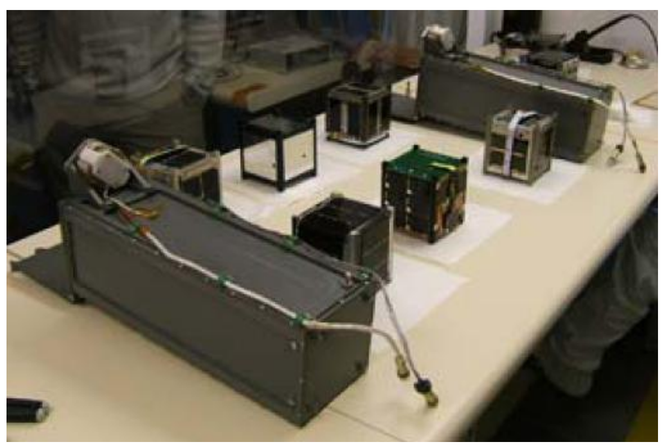
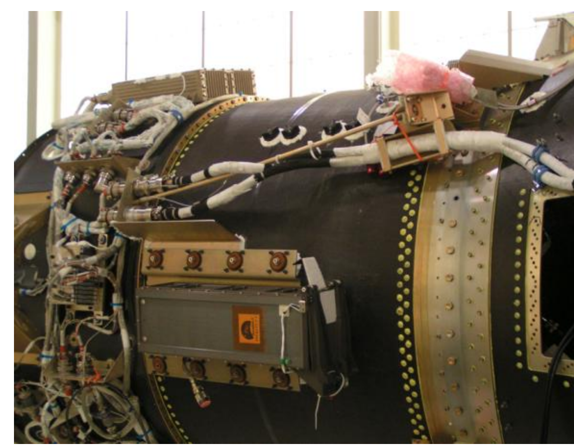
CubeSat Platform

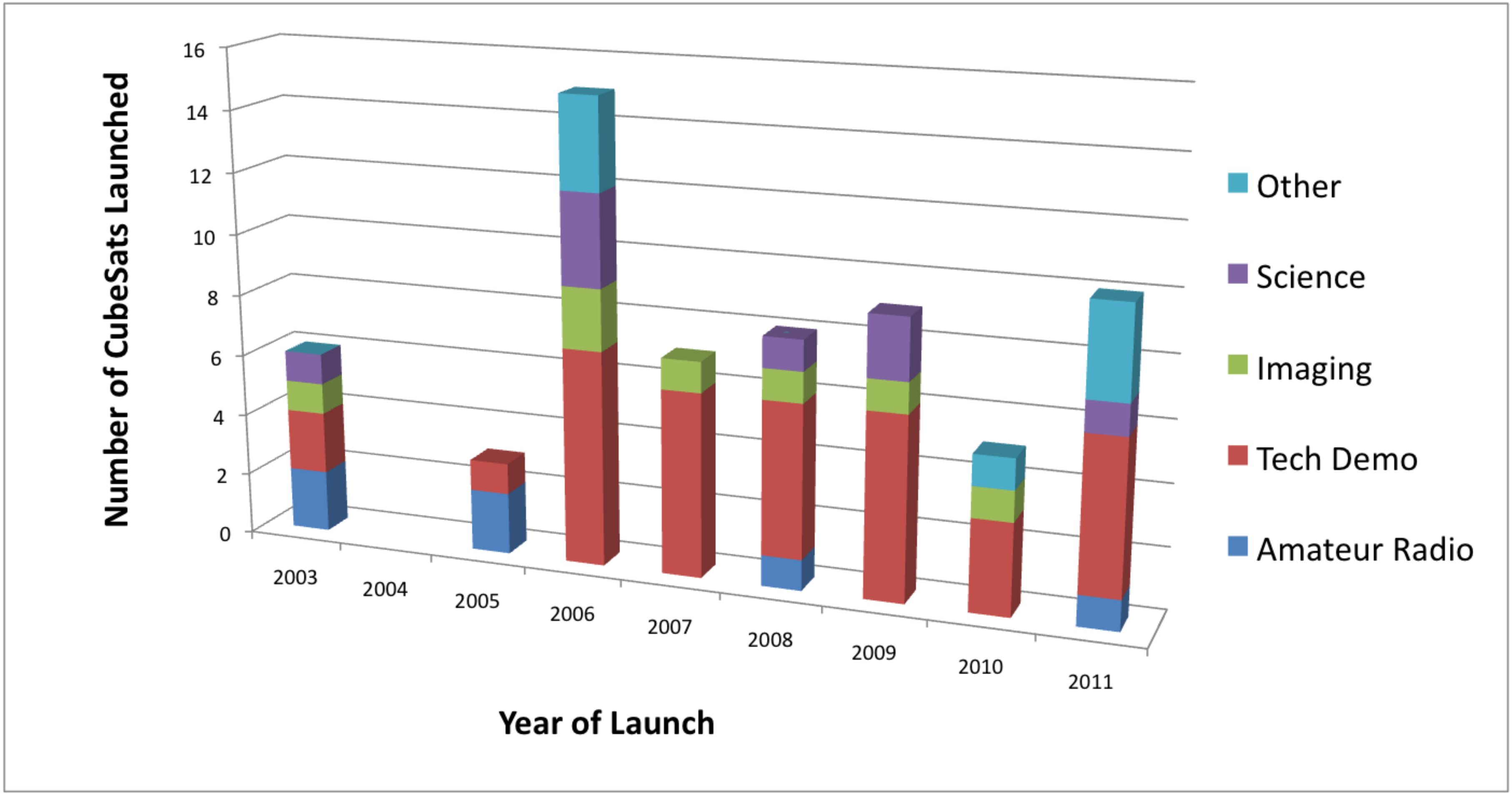
- Standardized form factor developed by Stanford and Cal Poly San Louis Obispo in 2000
- 1U = 10 cm x 10 cm x 10 cm, 1.33 kg
- Fits within the Poly-Picosatellite Orbital Deployer (P-POD) for launch as a secondary payload
- Low cost (or free) launch opportunities
- Off the shelf components readily available
- Established and rapidly growing developer community



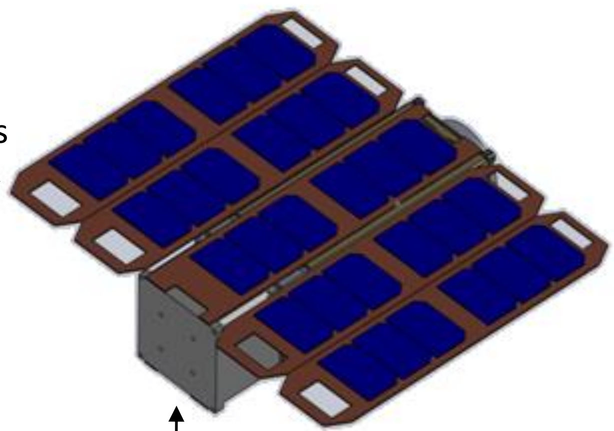


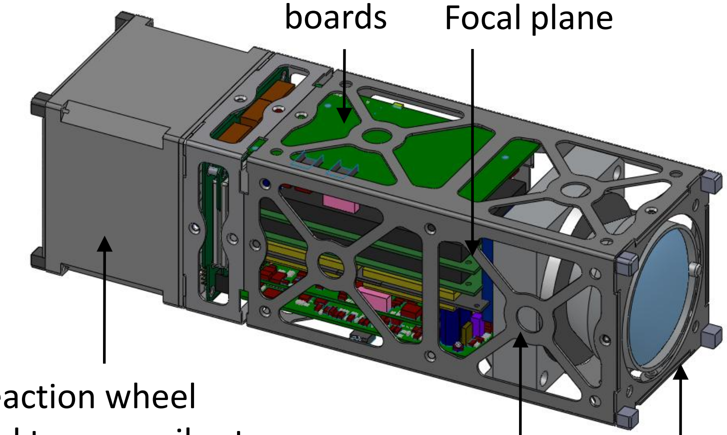
CubeSat Design Specification

Past CubeSat Missions



The ExoplanetSat Prototype

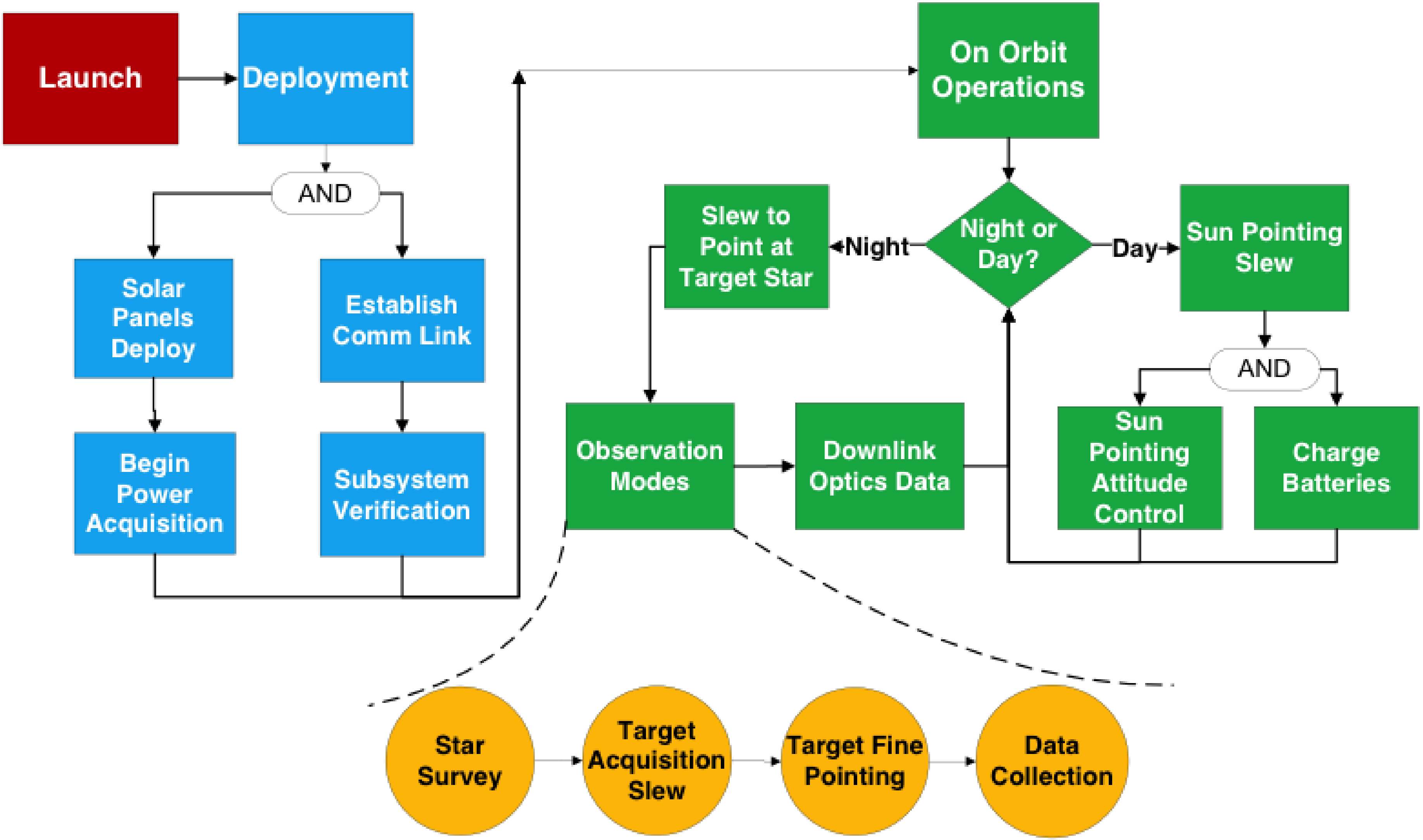




- Payload:
  - 85 mm lens
  - CCD with co-mounted CMOS sensors
- Attitude Determination and Control (ADCS)
  - Requirement: Target star motion < 0.14 pixels or 5.0 arcseconds (3σ)
  - Reaction wheels, torque coils
  - Piezoelectric stage
  - MEMS Gyroscopes
- Avionics:
  - 32-bit microcontroller, FPGA
  - SDRAM and flash memory

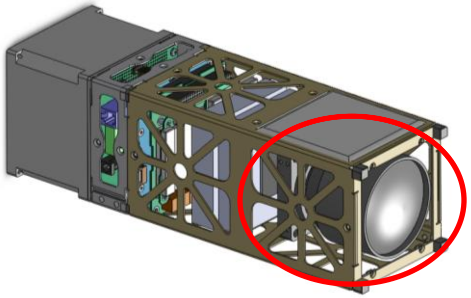
- Communication:
  - S-band transceiver
  - Two patch antenna
- Power:
  - Deployed solar panels (up to 30 W)
  - Lithium ion/polymer batteries
- Structure:
  - Custom 2.3U chassis

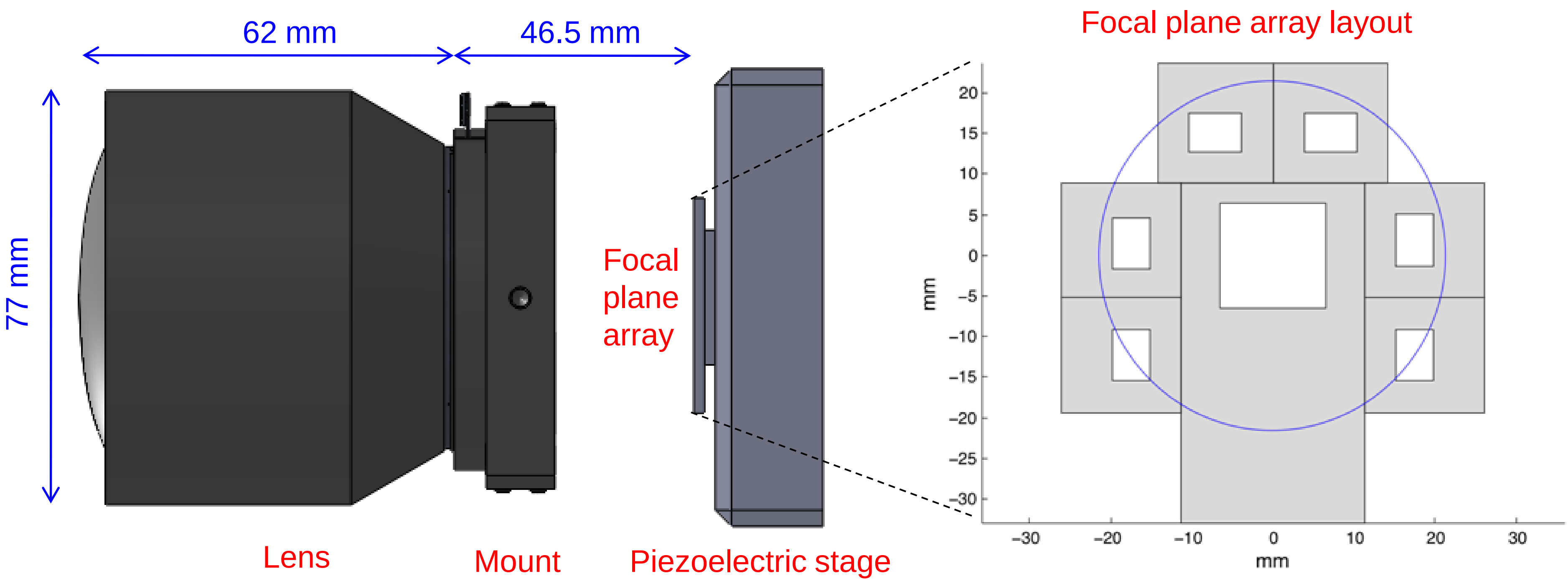
Concept of Operations



Optics

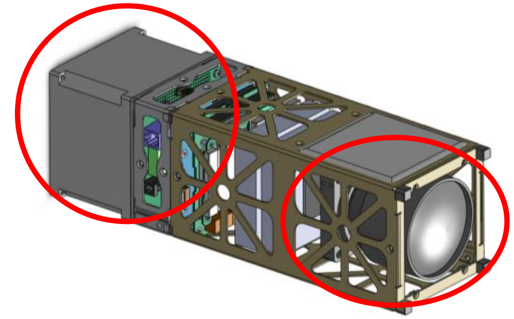
- Optical payload
  - Zeiss 85 mm f/1.4 SLR camera lens
  - Science: back-illuminated frame transfer CCD (1K x 1K with 13.3 µm pixels, 2 e- RMS read noise, 12.5 e-/pixel/s dark current at 0° C, 12.5° diagonal FOV)
  - Star tracking: Tiled CMOS sensors (2.6K x 1.9K with 1.3 µm pixels)





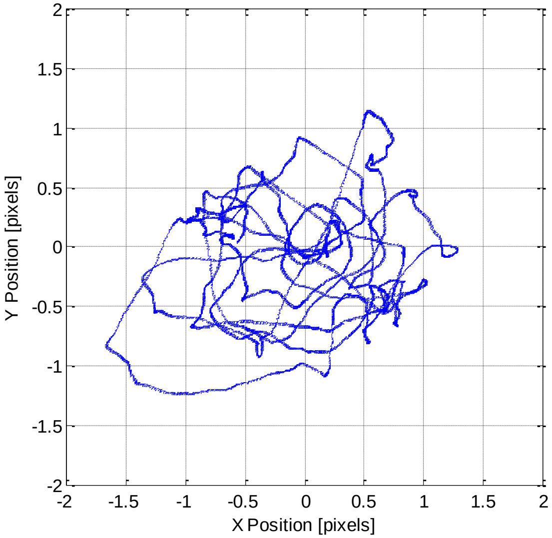
ADCS

- Attitude determination and control (ADCS)
  - Reaction wheels for coarse pointing (~60 arcseconds)
  - Piezoelectric nanopositioning stage removes residual error for fine pointing (1.8 – 3.3 arcseconds)
  - Sensors: star tracking CMOS detectors + rate gyros

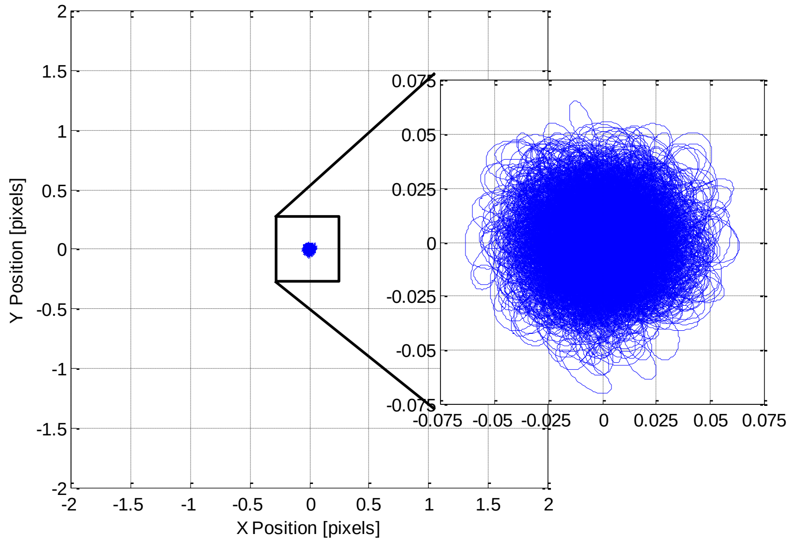


MAI-200

Coarse star motion on CCD (MAI alone)

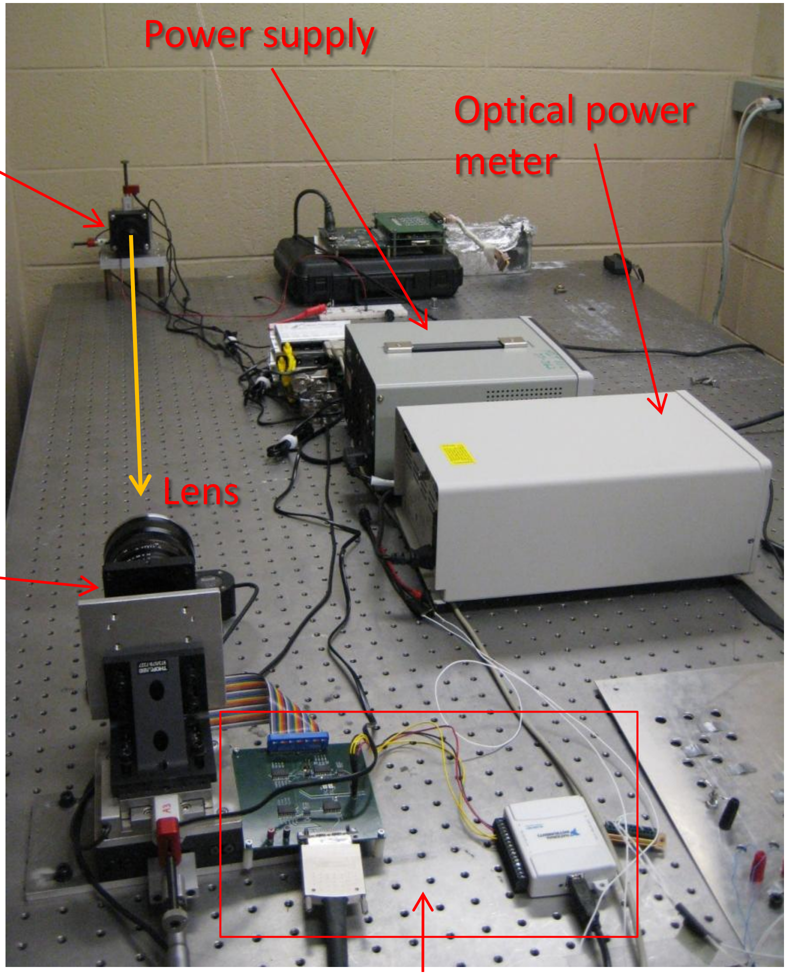


Fine star motion on CCD (MAI + piezo stage)



See Pong *et al.* " Achieving high-precision pointing stability on ExoplanetSat" (2010) [7731-68]

ADCS Testbed



- Objective: Determine centroid error as a function of
  - Guide star magnitude
  - Integration time

Results for 80 ms integration (12.5 Hz max rate):

V Mag	Centroid error [pixels RMS]
0	0.036
1	0.048
2	0.064
3	0.070
4	0.094
5	0.27
6	0.63

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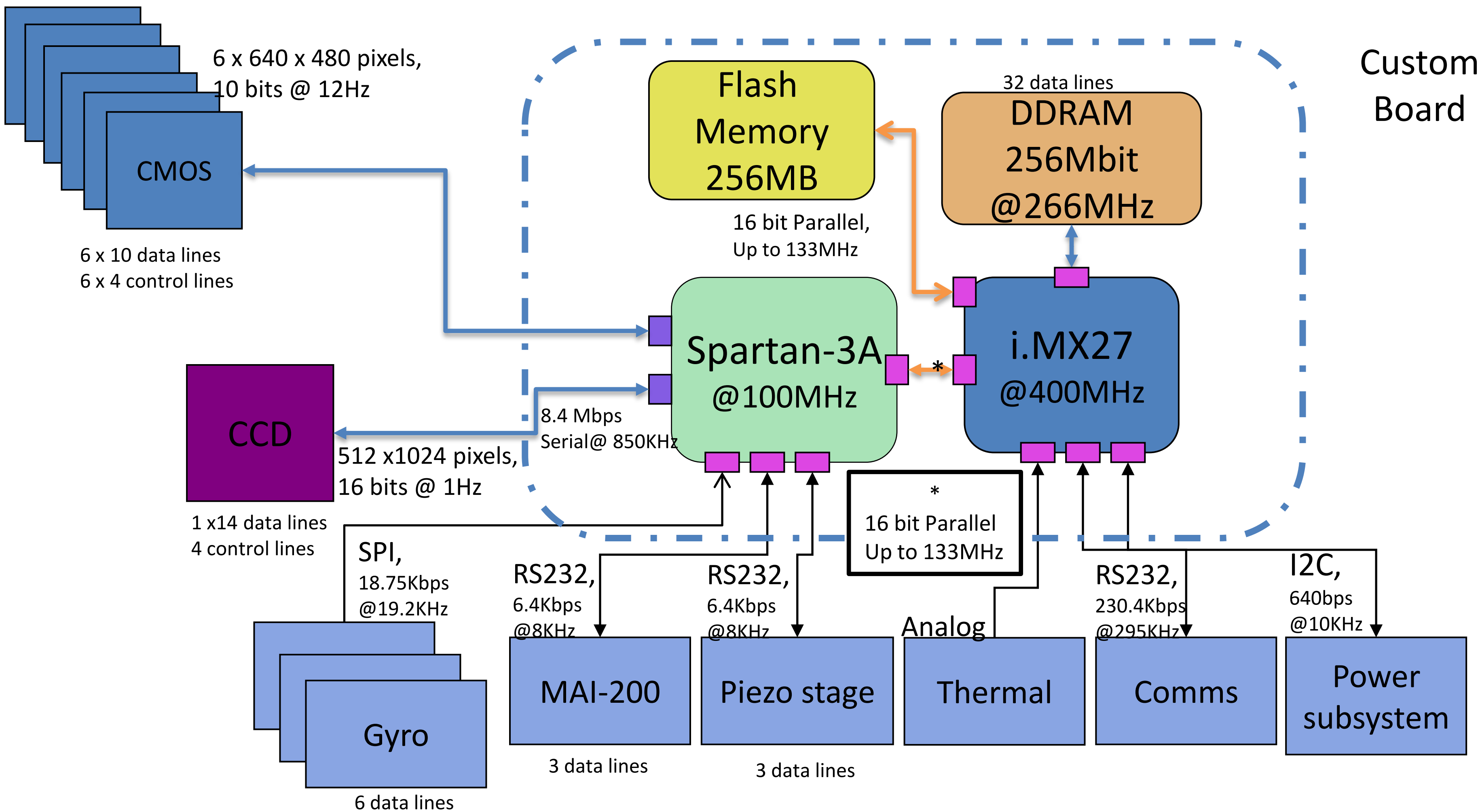
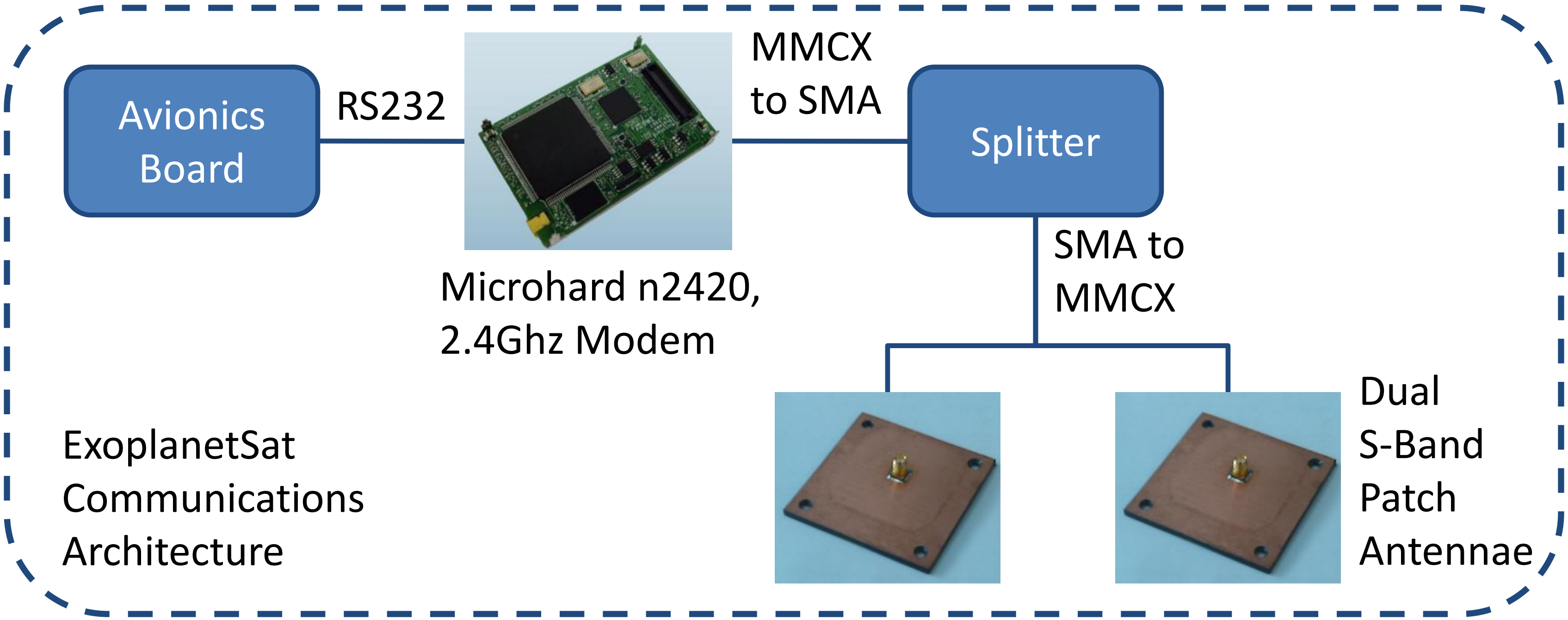
Avionics



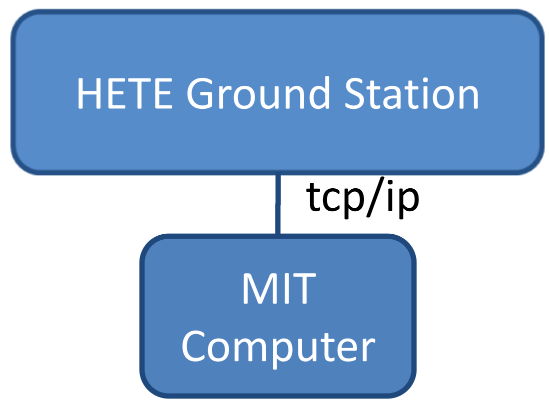
6 x 640 x 480 pixels,
10 bits @ 12Hz
CMOS
6 x 10 data lines
6 x 4 control lines
Flash Memory 256MB
16 bit Parallel,
Up to 133MHz
32 data lines
DDRAM 256Mbit @266MHz
Custom Board
Spartan-3A @100MHz
i.MX27 @400MHz
*
CCD
8.4 Mbps
Serial@ 850KHz
512 x1024 pixels,
16 bits @ 1Hz
1 x14 data lines
4 control lines
*
16 bit Parallel
Up to 133MHz
SPI,
18.75Kbps
@19.2KHz
RS232,
6.4Kbps
@8KHz
RS232,
6.4Kbps
@8KHz
Analog
RS232,
230.4Kbps
@295KHz
I2C,
640bps
@10KHz
Gyro
6 data lines
MAI-200
3 data lines
Piezo stage
3 data lines
Thermal
Comms
Power subsystem

Communications



Considerations and Design Choice:

- High data rate due to science imaging
- Extensive link budget analysis
- Coverage analysis using STK

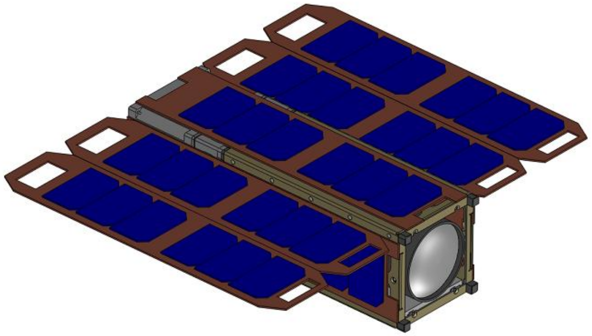


Power

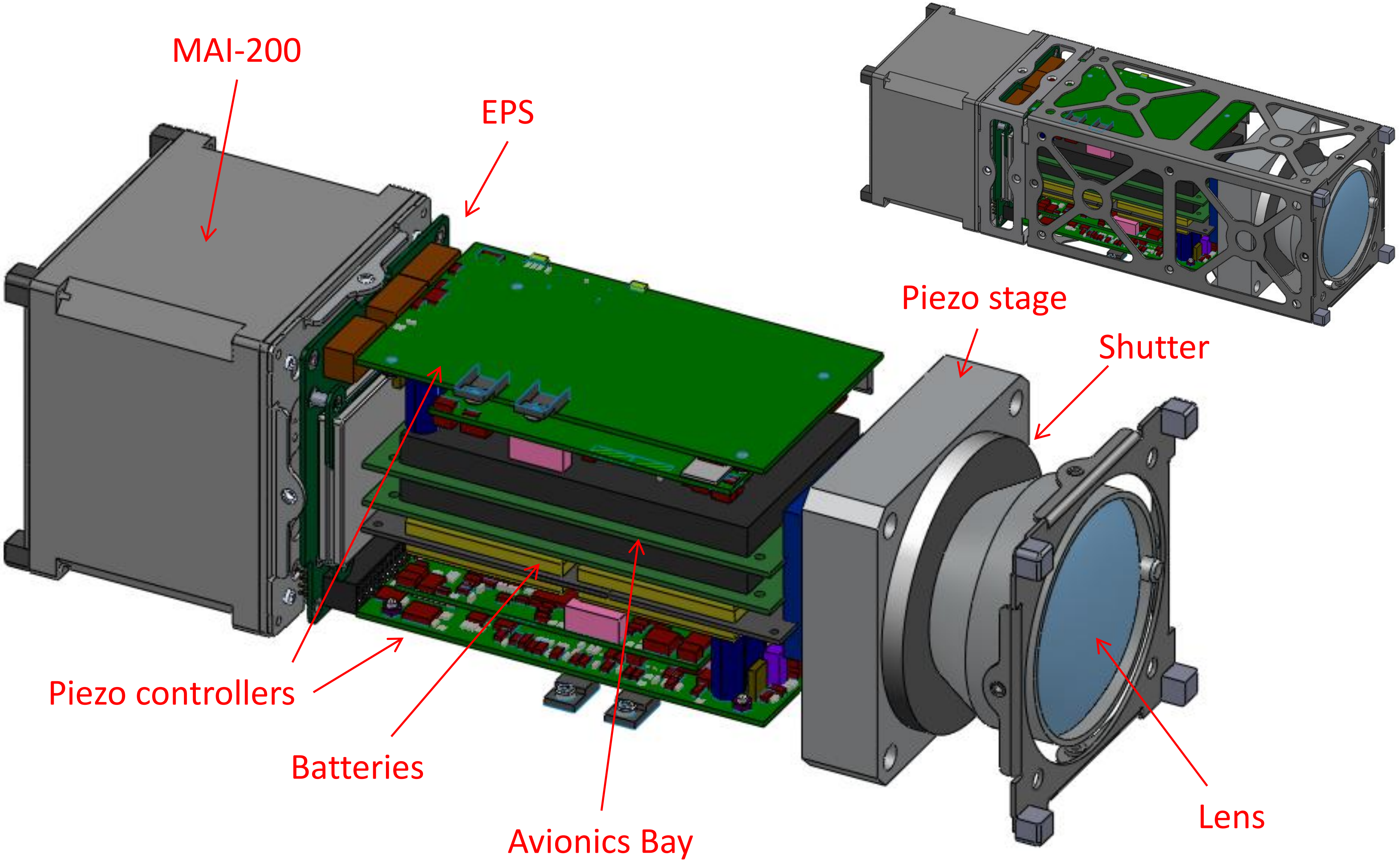
- Modified Clydespace 3U CubeSat EPS
  - 3.3V, 5V, 12V
- Pumpkin Solar Wings
  - 4 Deployable solar panels, 2 body mounted
  - Each panel contains 7 Spectrolab UTJ solar cells
- 40 Whr semi-custom flat battery from Clydespace

Orbital Night	Unmargined	Margined
Total Whr:	9.55	11.46
Average power (W):	15.92	19.11
Battery capacity (Whr):	47.77	57.32

Orbital Day	Unmargined	Margined
Total Whr:	23.69	26.13
Average power (W):	26.32	29.04

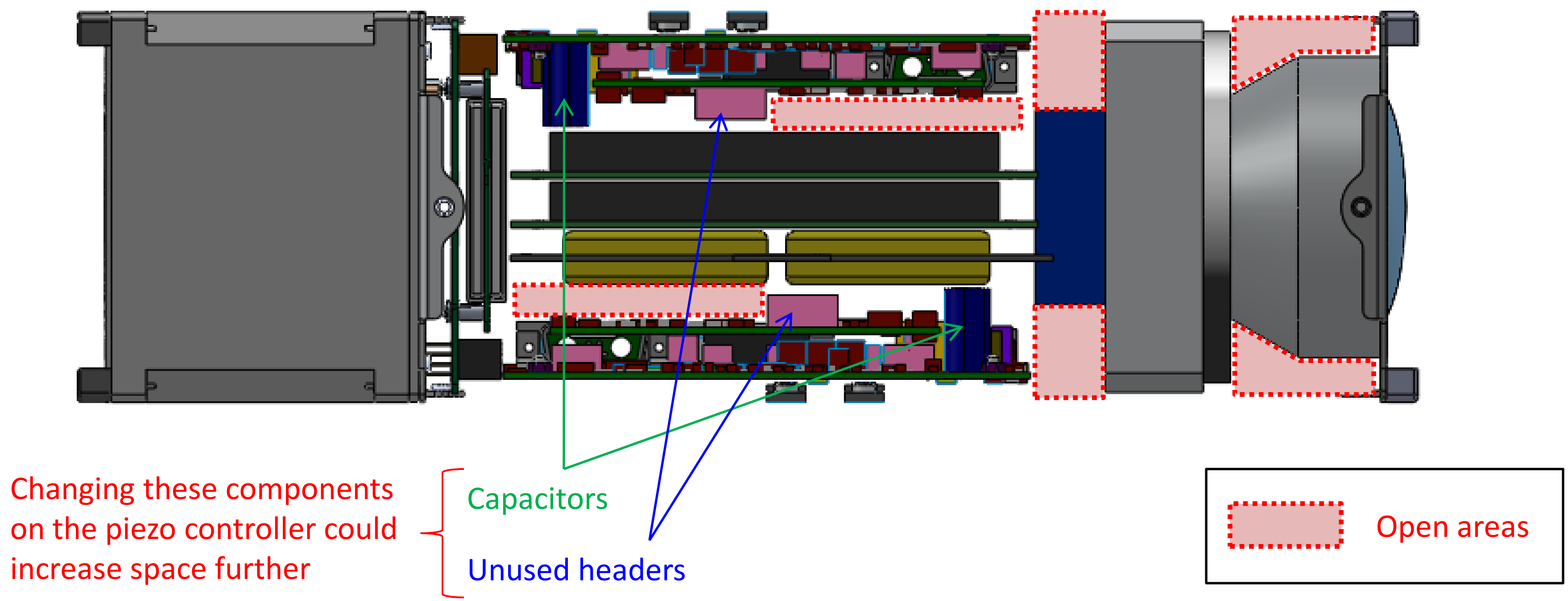


Layout Overview

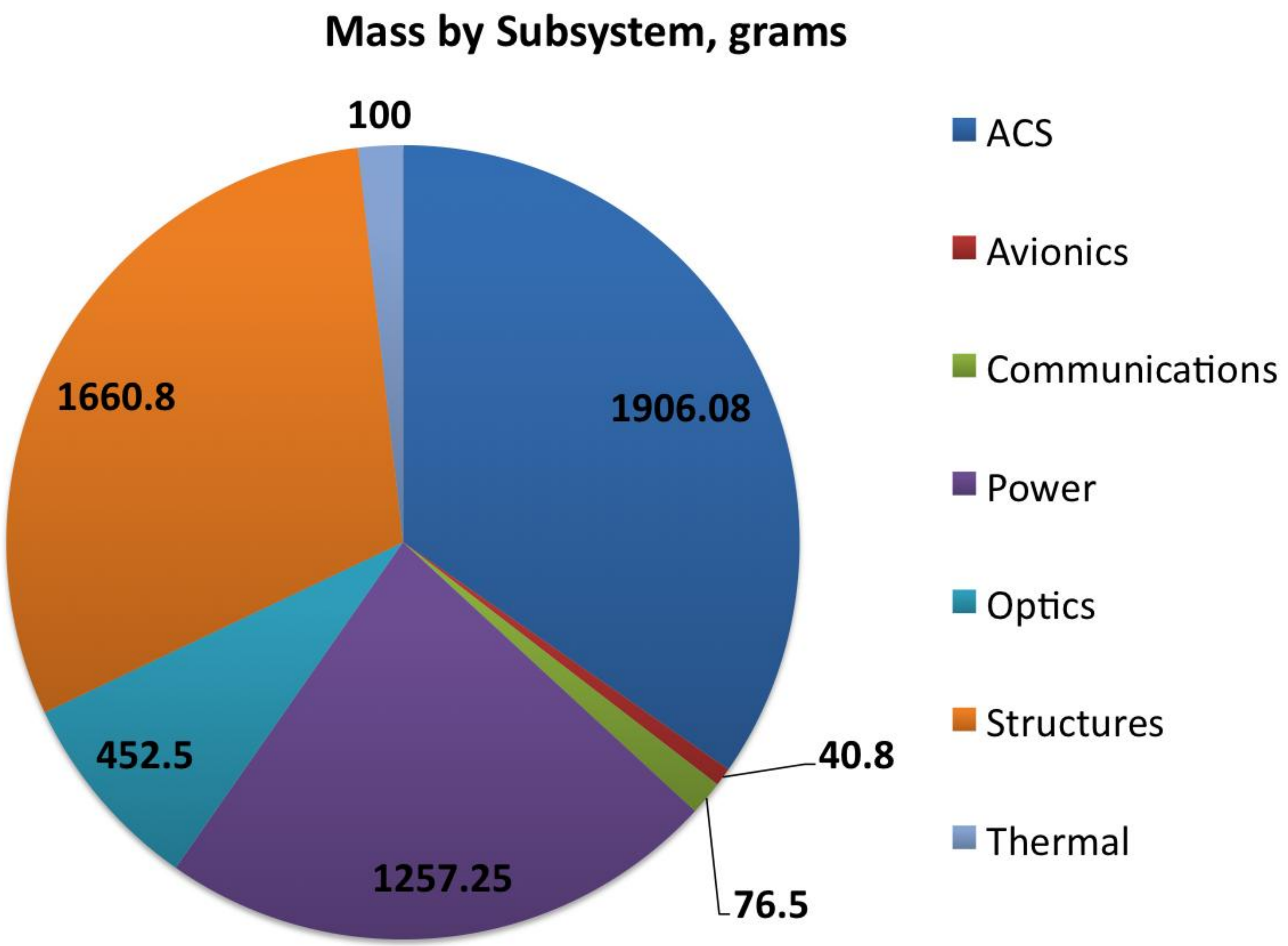


Missing Items and Unused Volume

- Components not shown
  - MEMS gyros
  - Magnetometer (approx. 25 x 25 x 5 mm)
  - RF splitter for comm antennas
  - Baffle
  - Shutter controller (could be part of avionics board)
  - <u>Wiring harnesses</u>



Mass Budget



Total: 5.49 Kg

Constellation – Phases I & II

Phase I: A single 3U ExoplanetSat prototype will observe:

• Stars with known planets (discovered by radial velocity method) – see chart)

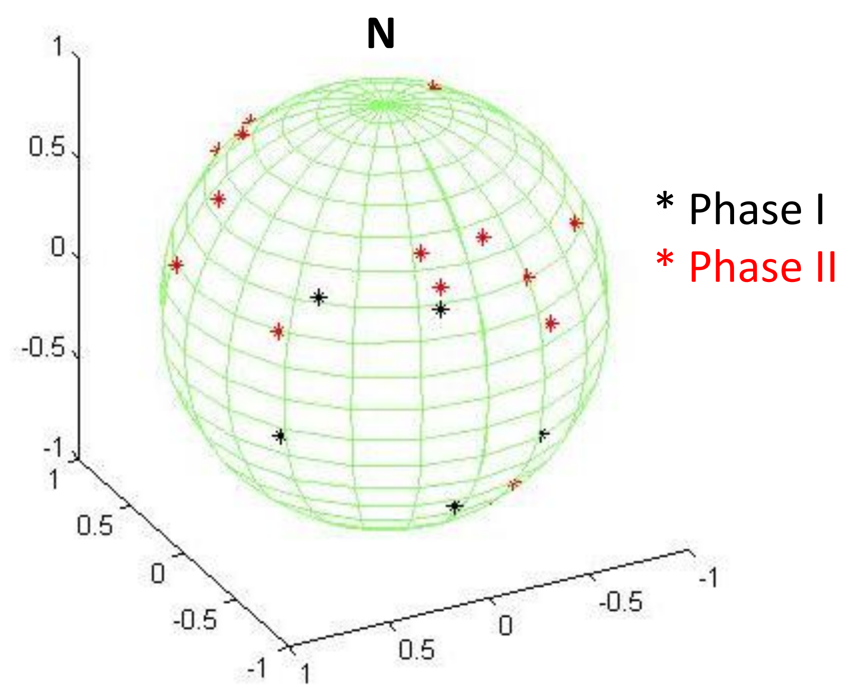
•Alpha Centauri (brightest, nearest Sun-like star)

Planet Name	Mass (Earth Masses)	Period (days)	Vmag
61 Vir b	5.1	4.2	4.7
HD 102365 b	15.9	122.1	4.9
mu Ara c	10.6	9.6	5.2
55 Cnc e	7.6	2.8	5.9
HD 69830 b	10.5	8.7	5.9
HD 69830 c	12.1	31.6	5.9
HD 97658 b	8.3	9.5	6.3
HD 4308 b	12.8	15.6	6.5
HD 1461 b	7.6	5.8	6.6

Phase II: Add 3U models as well as 6U models with 120 mm apertures

• Observe 20 brightest stars for Earth-sized transits

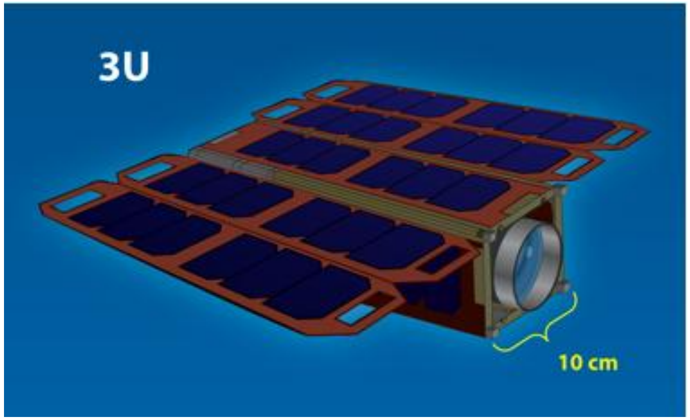
• 10-15 spacecraft needed

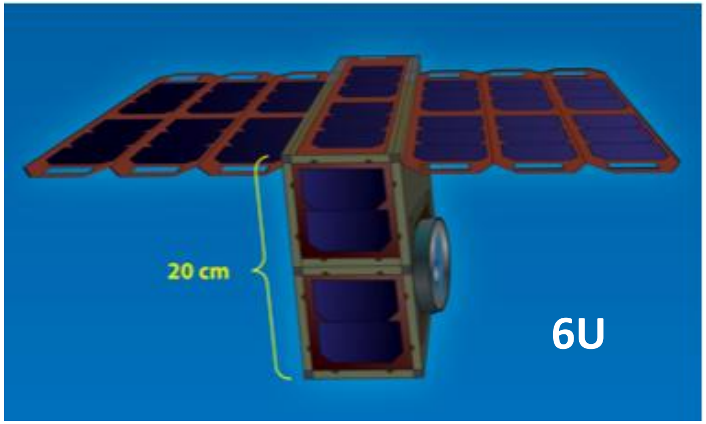


ExoplanetSat's Target Stars

Constellation – Phase III

- Phase III: Planet detection survey
  - Observe bright stars to V = 8
  - 95% confidence of 3+ planet detections
  - Need 1000 candidate stars
  - Down-select stars from initial list by spin axis inclination (inclination close to 90 most likely to show transits)
  - Observe 250 stars
  - Use existing 3U/6U constellation, possibly add larger units





Conclusion

- ExoplanetSat will combine the low cost CubeSat platform with two stage attitude control to detect Earth-sized planets around the brightest stars
- The 3U prototype is under development with a potential launch date in 2012 through the CubeSat Launch Initiative
- The engineering breakthrough is the extremely high precision pointing for a small satellite
- ExoplanetSat demonstrates the graduated growth of a constellation, with the final phase being 100 satellites surveying bright stars for other Earths

Acknowledgements

Professor Sara Seager

Dr. Wes Traub

Matthew W. Smith

Christopher Pong

Professor David Miller

MIT 16.83x Class

Alessandra Babuscia

Dr. Alvar Saenz-Otero

Paul Bauer

Dr. Joel Villasenor

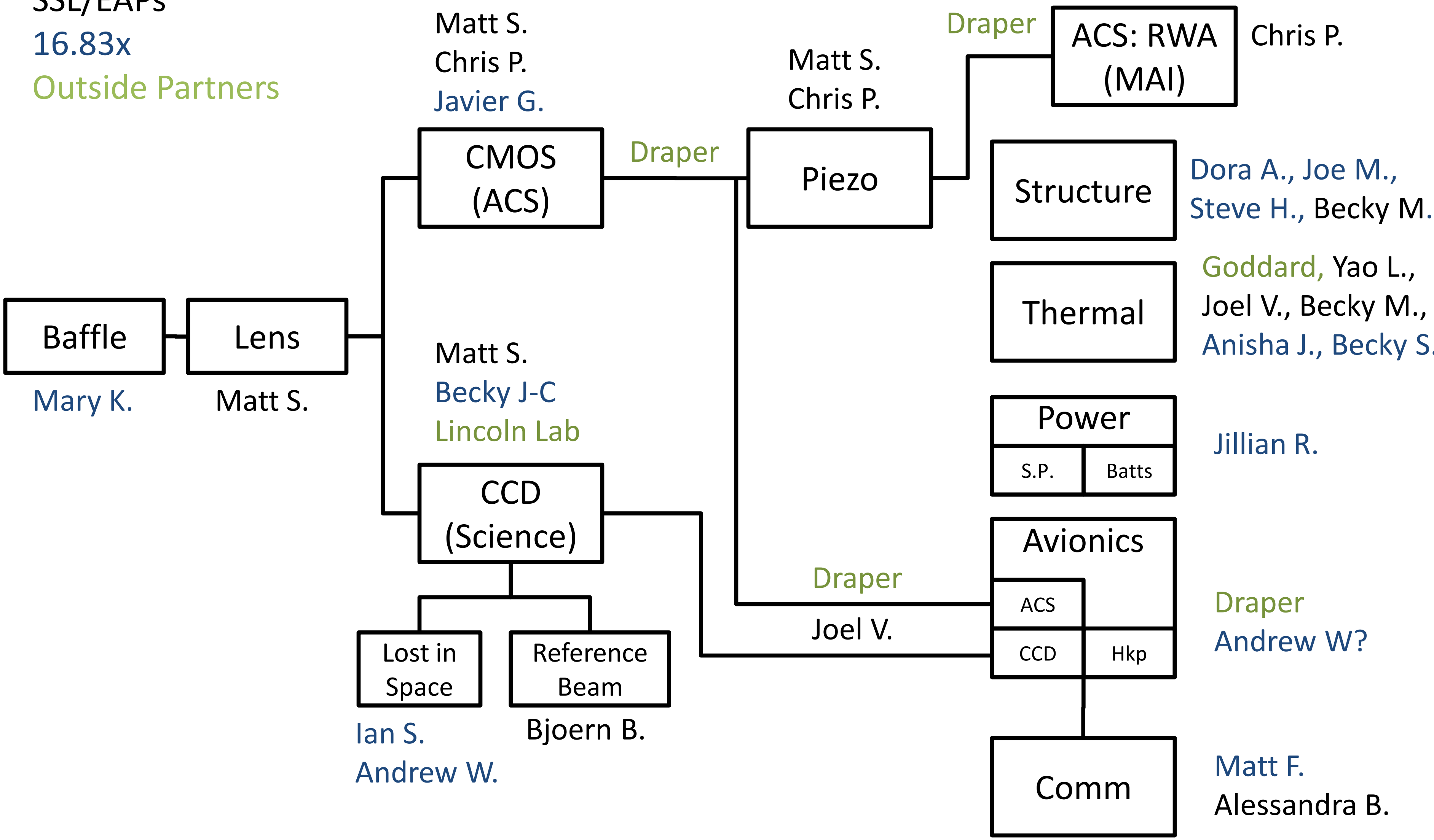
Space Systems Laboratory

Draper Laboratory

Lincoln Lab

Organizational Structure

SSL/EAPs
16.83x
Outside Partners



Artificial Reference Star