A Distributed Command and Data Handling Architecture for KYSat-2

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- Partnerships: COSMIAC, Kentucky Space

Overview

- Space Systems Lab
- K-Bus Distributed Communications and Power
- KySat-2 Overview
- Imaging Payload

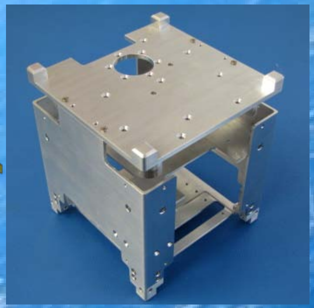
Space Systems Lab Missions

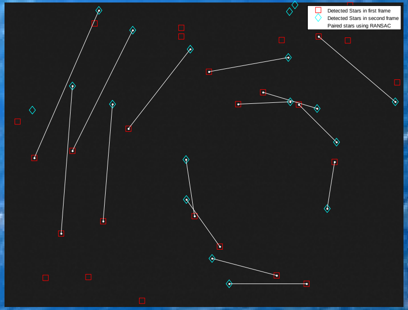



New NanoRacks/CubeLab Standard on the ISS, July 2010

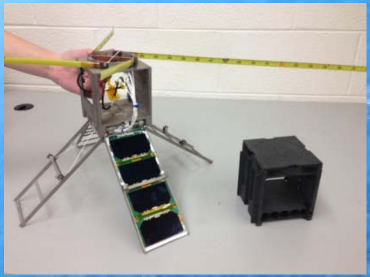
KYSat-1 2006

KYSat-2 2013





First CubeSats Ejected into Sub-Orbital Space, March 2010



PRINTSat and RAMPART 2012

High Altitude Balloons (Background Image)

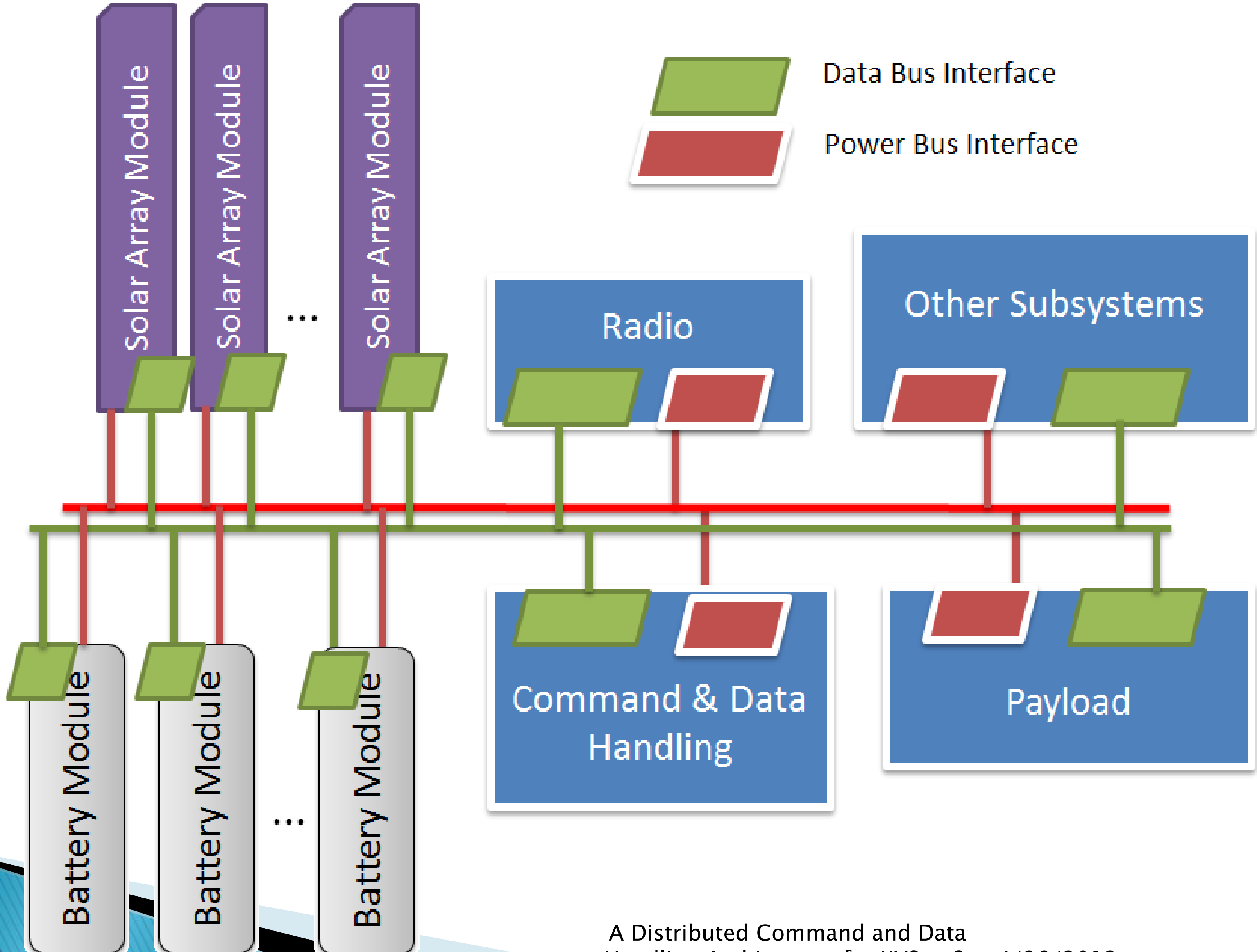
Garvey P-12A

First Flight, Composite Super Loki, December 2007

Kentucky-Bus (K-Bus)

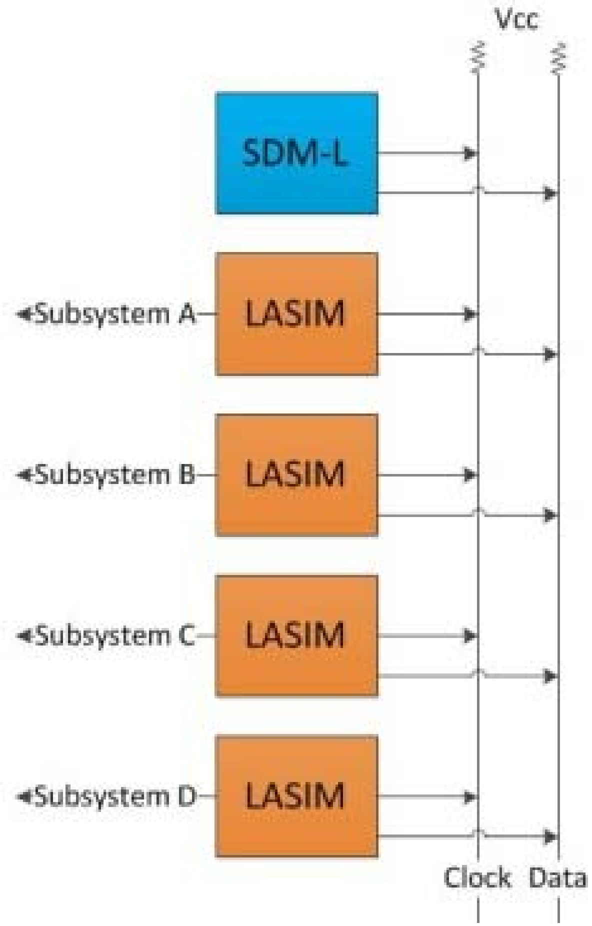
- Develop a standard bus for communications for small spacecraft
- Develop a standard bus for power for small spacecraft
- Combine these into K-Bus
  - Communications leverage plug-and-play SPA SDM-Lite infrastructure
  - Modular plug-and-play power system

K–Bus


Data Bus Interface
Power Bus Interface
Solar Array Module
Solar Array Module
...
Solar Array Module
Radio
Other Subsystems
Command & Data Handling
Payload
Battery Module
Battery Module
...
Battery Module

K-Bus Communications

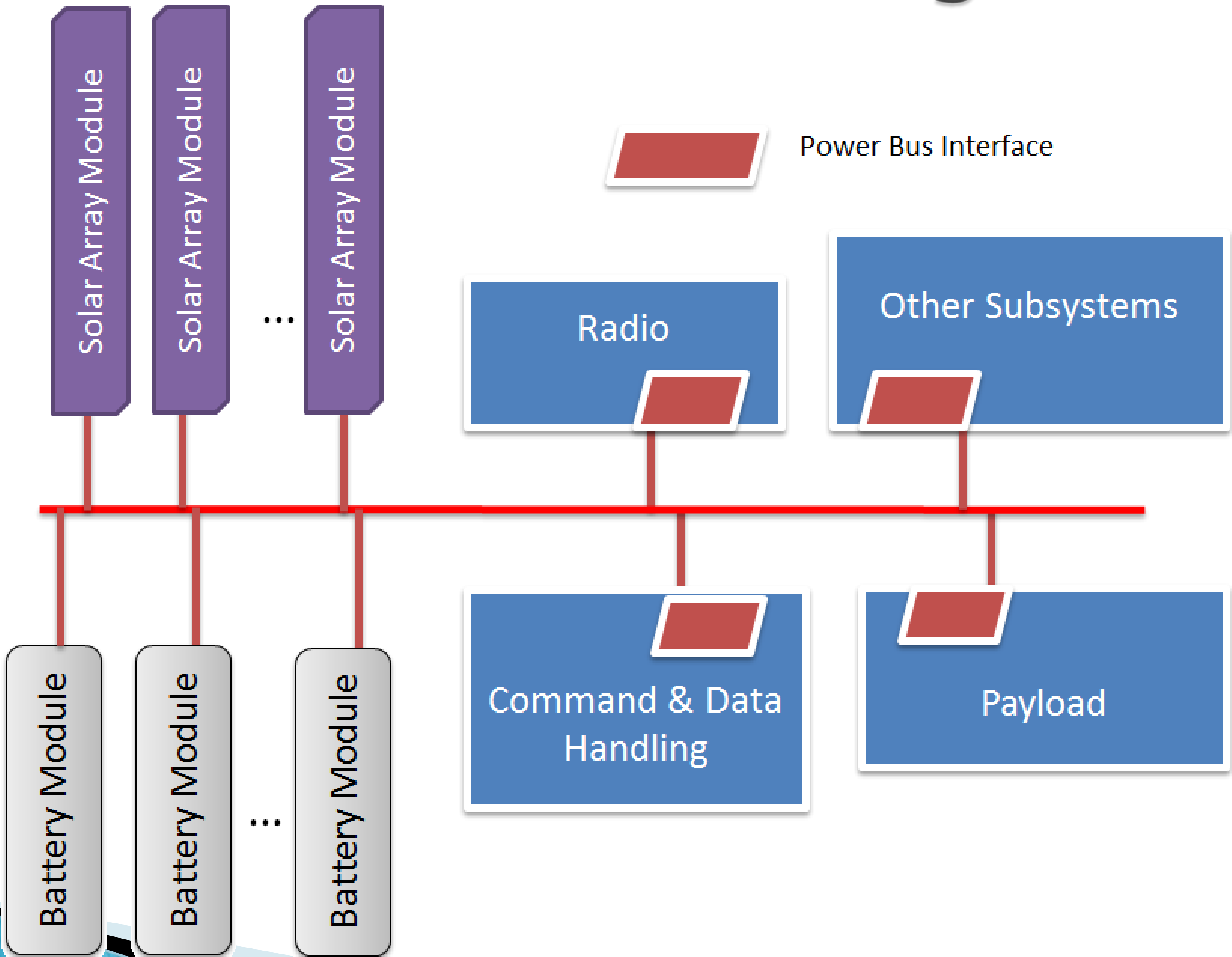
- SPA-based SDM-Lite developed by COSMIAC and the SSL
  - Utilizes I^2C as communication layer between SDM and ASIM
  - Implemented on COSMIAC's Trailblazer, KySat-2, and on the CubeLab Bus on the ISS



K-Bus Power Features

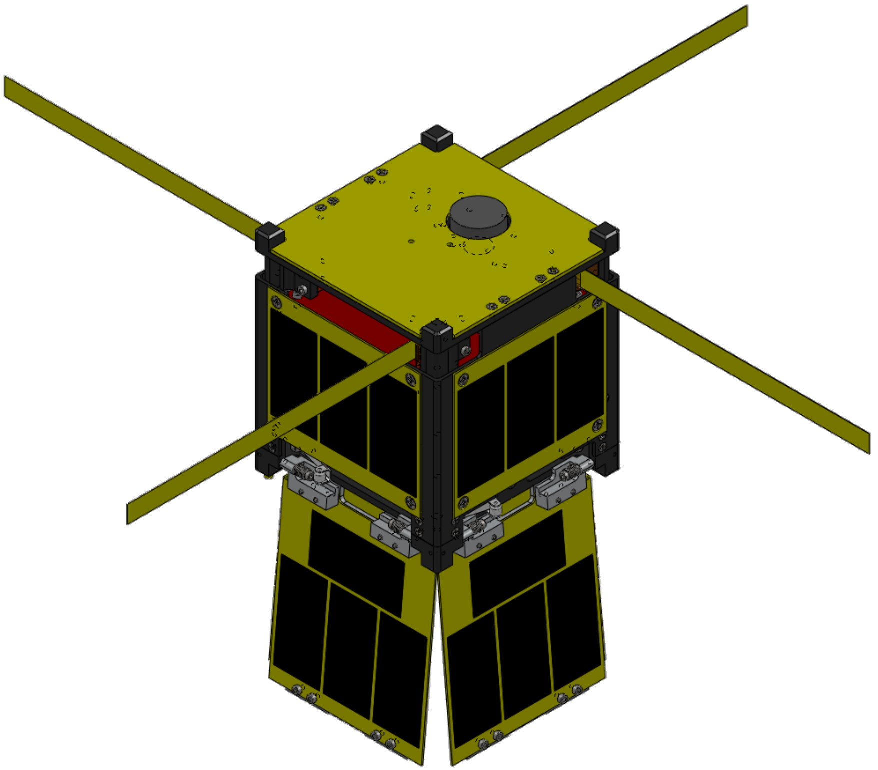
- Modular, scalable distributed EPS technology
- Point of Load Regulation
  - Subsystems receive battery power, provide regulation themselves
- Incorporate DET as solar array interface
- Over voltage, over discharge, under voltage battery protection
- Battery, solar panel, and payload telemetry reporting

K-Bus Power Block Diagram

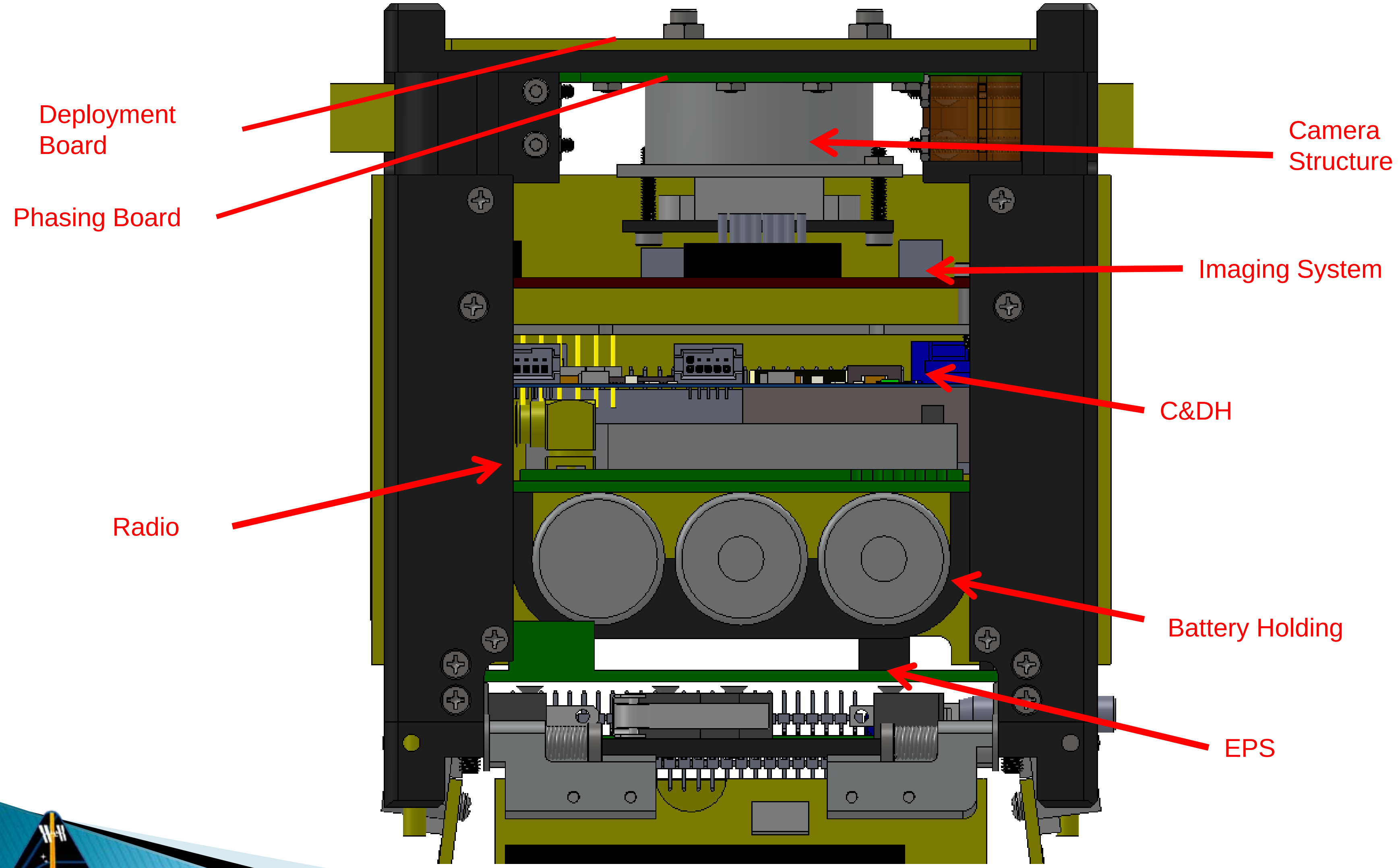


KySat-2 Mission

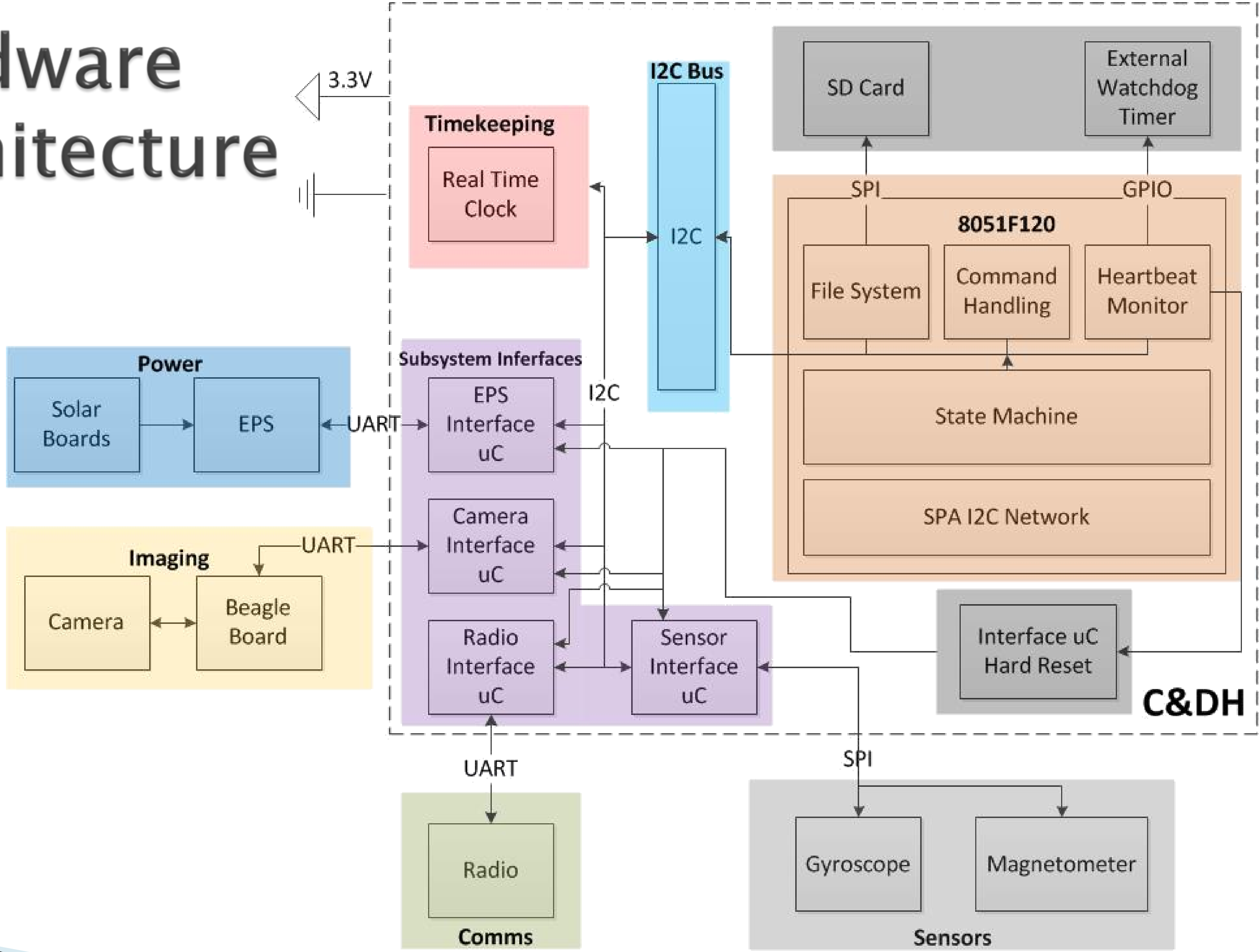
- Goals:
  - Distributed processing architecture
  - Educational/Public Outreach through photos and sensor data for K-12
  - Stellar Gyroscope Payload



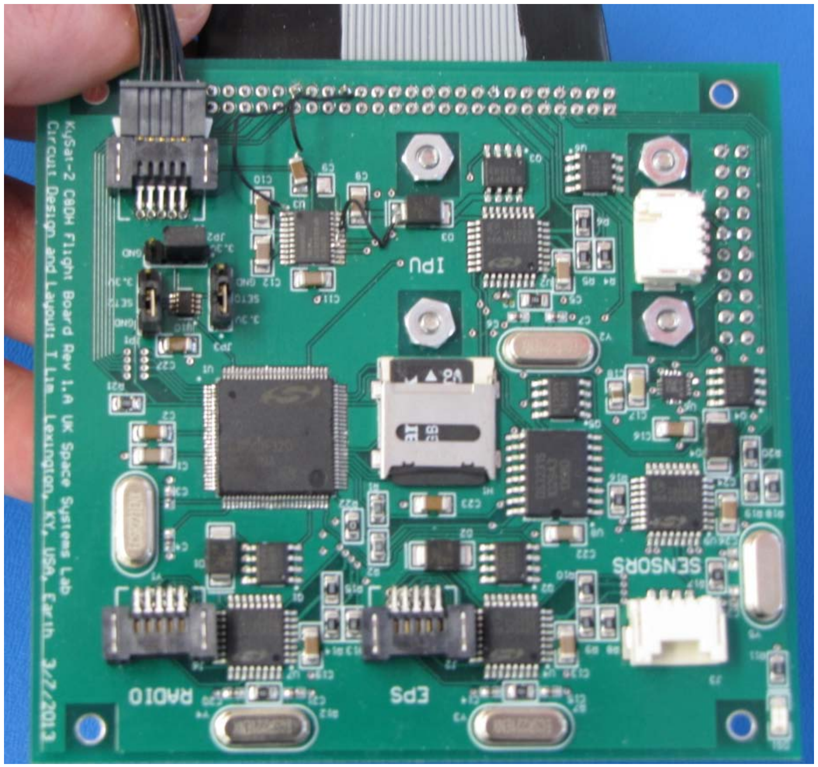
Board Stackup



Hardware Architecture



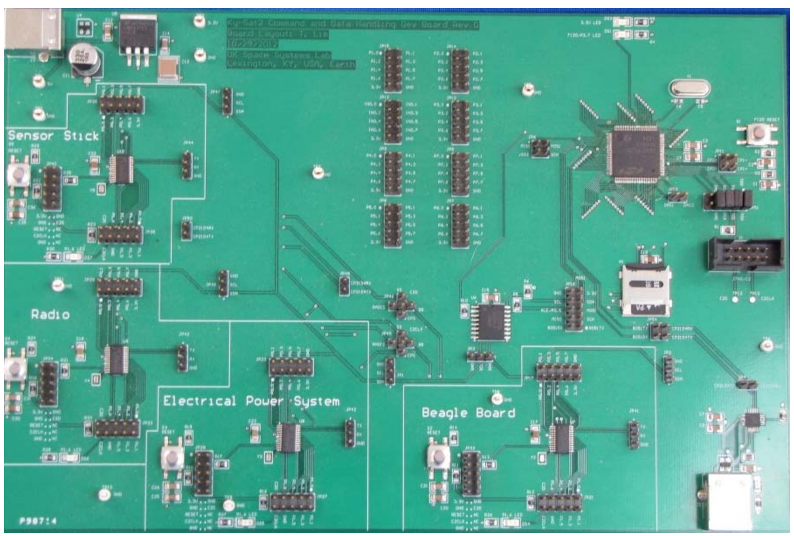
KySat-2 C&DH

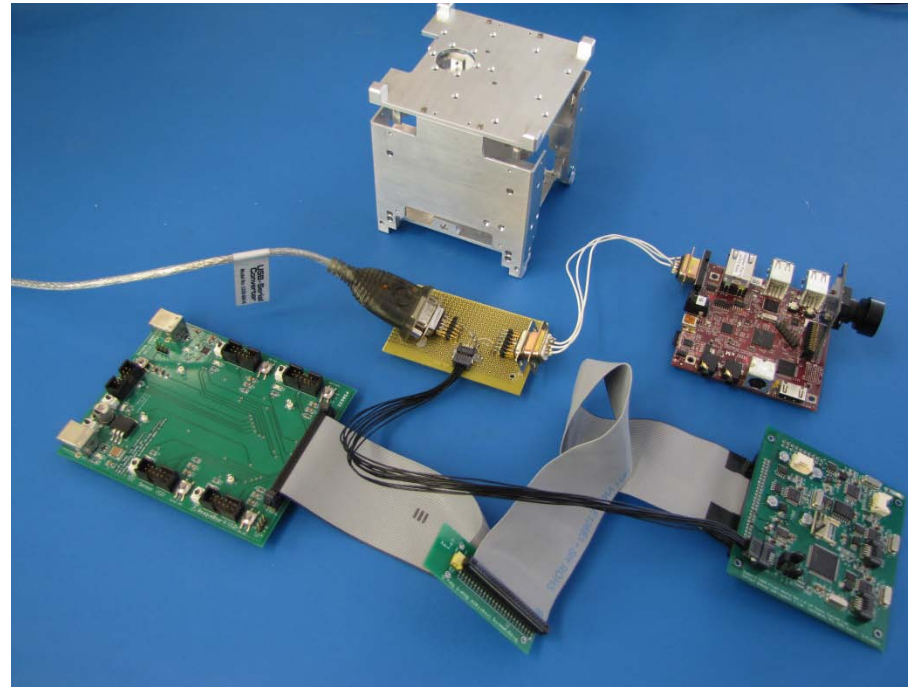


- Custom Command and Data Handling system created by the Space Systems Lab
- Integrates mission and interface processors, storage, fault tolerance
  - Command API
  - Data exchange API

Development Process

- Development board (below)

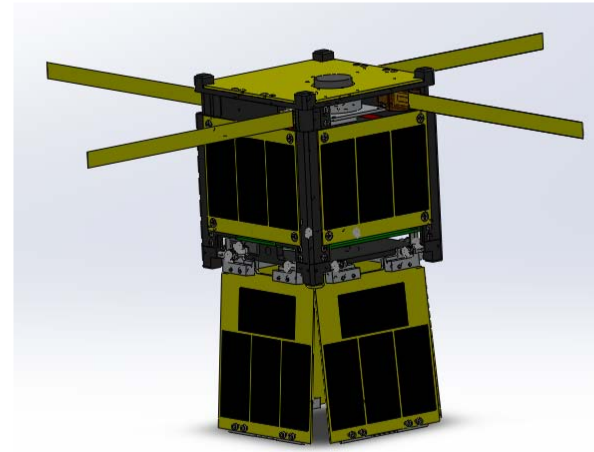


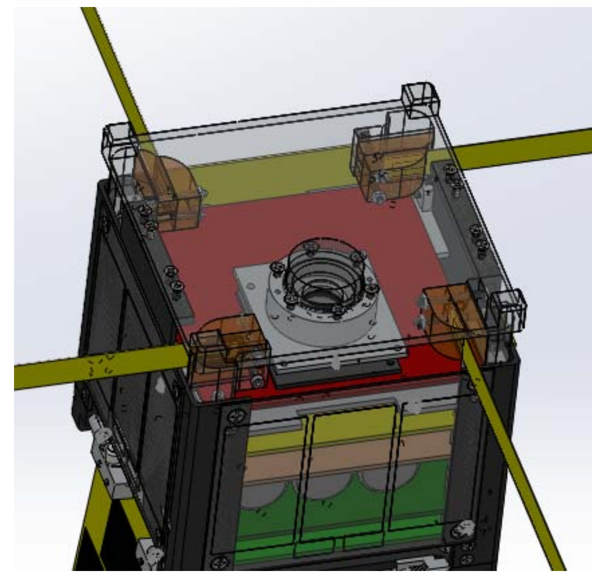


- FlatSat under test (above)

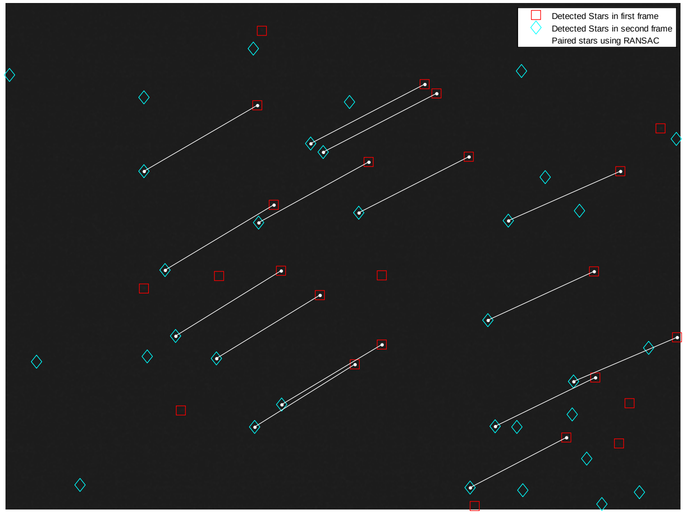
KySat-2 Payload

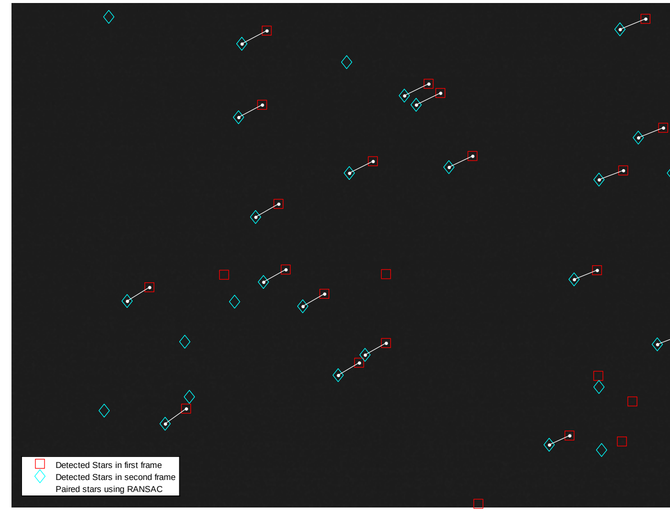
- Infer attitude change from successive star images
- Take star-field image sets
  - With timestamps (to tell rate)
  - With MEMS gyro rate data in between (to compare image estimate with propagation)
- To download more data, star coordinates and magnitude measurements can be downloaded as text files

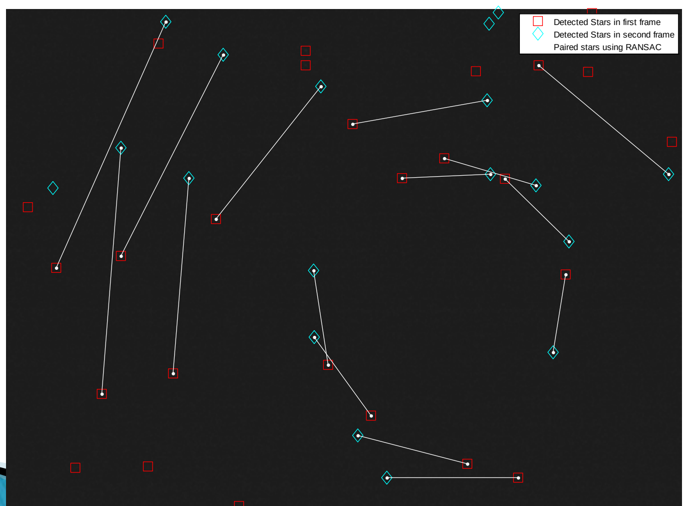


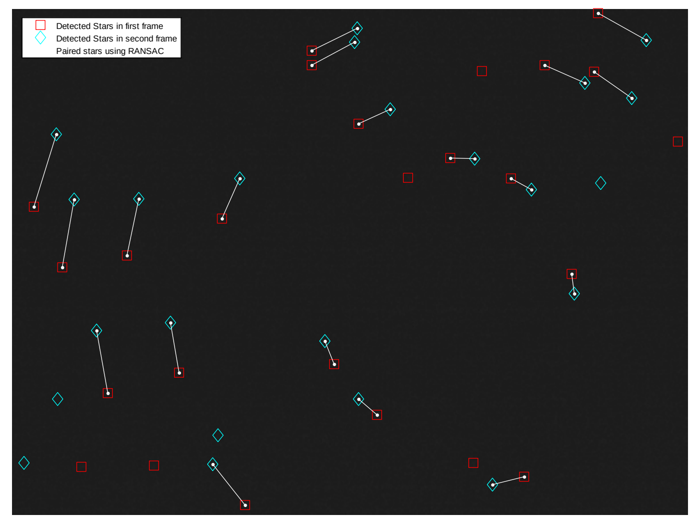


Stellar Gyroscope Examples





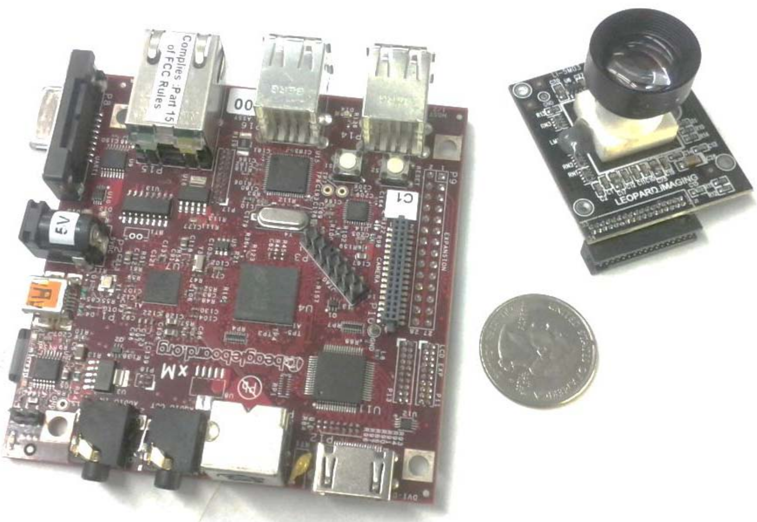




Imager Specifications

- CMOS Sensor with S-Mount Lens
- Single board Linux computer running OpenCV image processing library
- Gain and exposure control

Parameter	Value
System	Beagle Board running Angstrom Linux
Sensor	Aptina MT9P031 5 MP CMOS detector
Optics	16 mm focal length, Aperture F/1.2
Field of View	15° by 20.2°
ADC Resolution	12 bits
Pixel Size	2.2 x 2.2 μm



Summary

- K-Bus is combination of modular, plug-and-play data and power bus for small spacecraft
- KYSat-2 has a distributed command system and stellar gyroscope payload
- Papers:
  - Providing a Persistent Space Plug-and-Play Avionics Network on the International Space Station
    - http://uknowledge.uky.edu/ece_etds/16/
  - S. A. Rawshdeh, J. E. Lumpp, Jr., James Barrington-Brown, Massimiliano Pastena, “A Stellar Gyroscope for Small Satellite Attitude Determination”, 26th Annual AIAA/USU Conference on Small Satellites, 2012, Logan, UT

Thank you

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Backup Slides

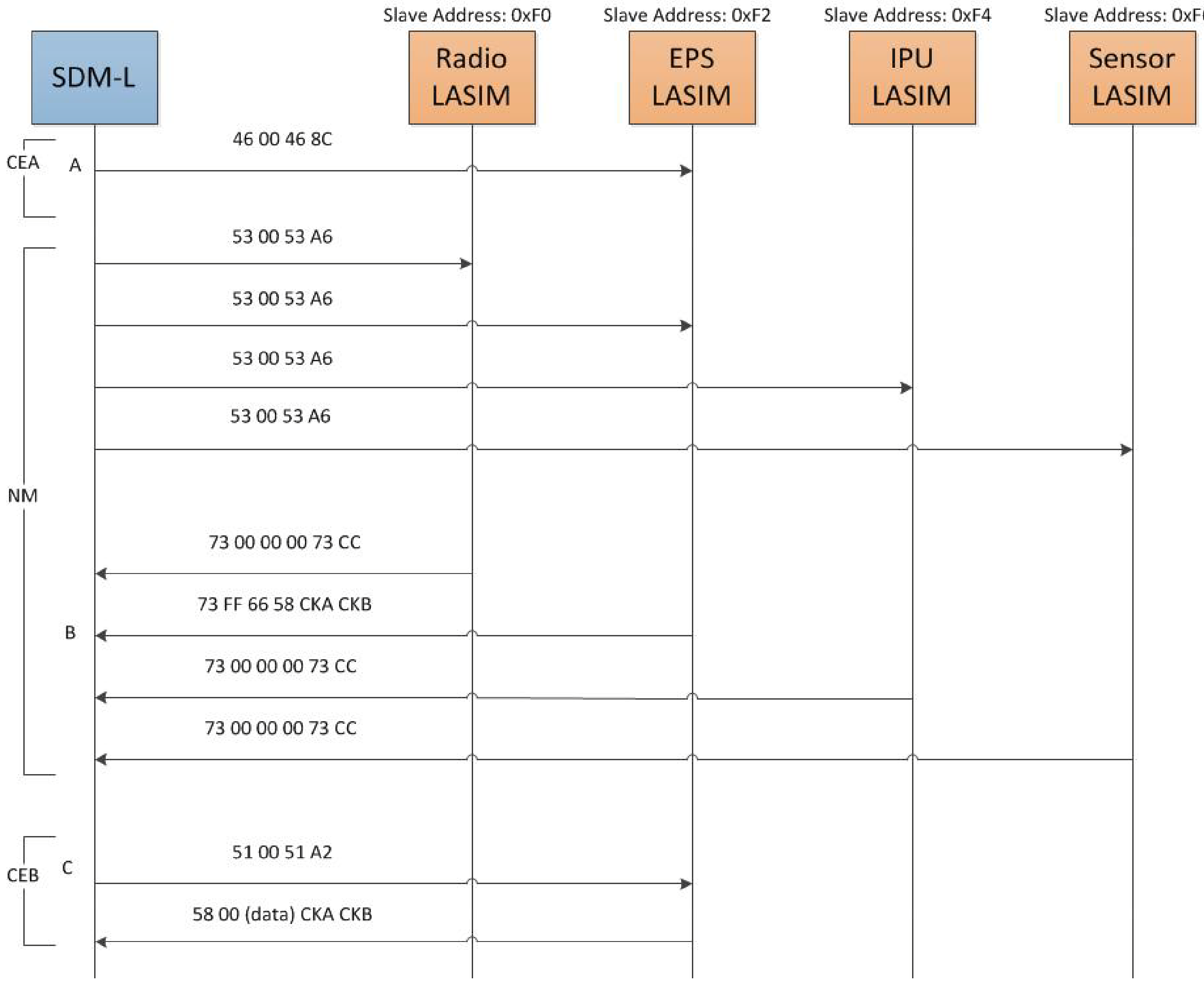
Direct Energy Transfer

Table 6: Overall Solar Cell to Battery Efficiencies

Solar Interface	No BCR	With Expected BCR Efficiency		
	Spin 1°/s, No Radiation		Spin 20°/s, No Radiation	Spin 1°/s +Radiation
Fractional	99.1%	84.2%	67.9%	84.1%
P&O	98.6%	83.8%	52.6%	83.9%
dP/dV	98.9%	84.1%	46.7%	84.0%
Fixed	95.7%	81.3%	51.2%	57.2%
TC Fixed	99.2%	84.3%	29.1%	66.4%
DET (No BCR)	86.5%		86.5%	91.0%

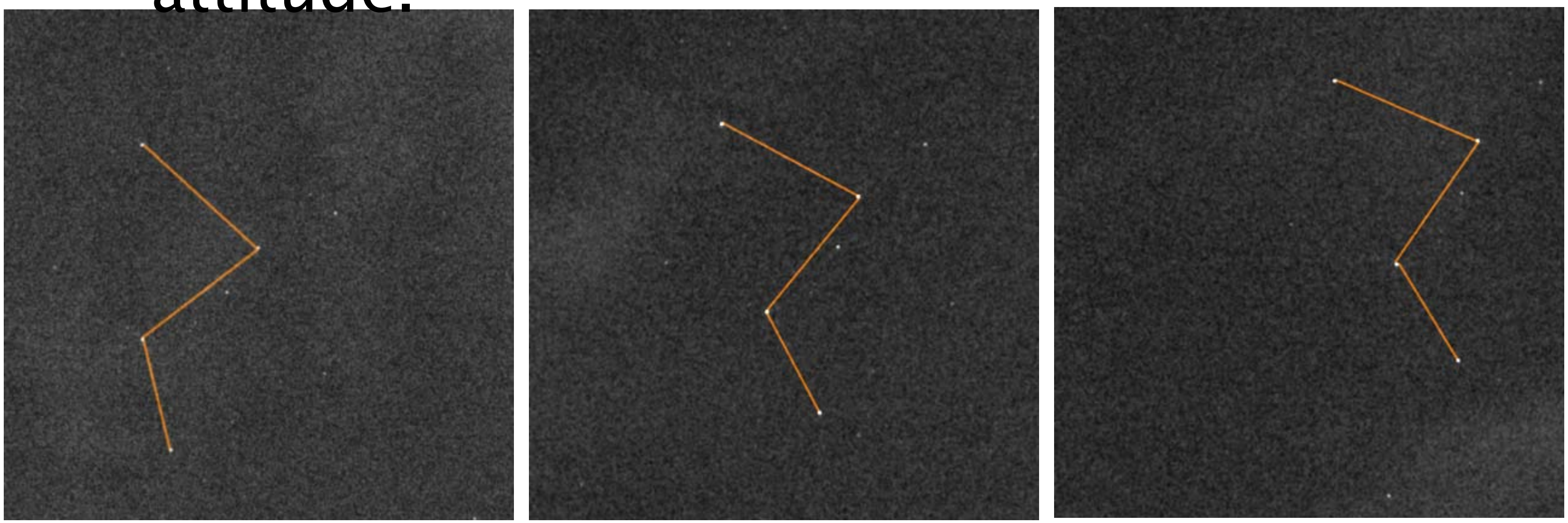
- *Fractional*: operating at a set fraction of the open-circuit voltage
- *P&O*: Perturb and Observe
- *dP/dV*: Seeking maximum power by varying operating voltage
- *Fixed*: Fixed operating voltage
- *TC Fixed*: Temperature-compensated fixed operating voltage
- *DET*: Direct Energy Transfer

Erb, Daniel Martin, "EVALUATING THE EFFECTIVENESS OF PEAK POWER TRACKING TECHNOLOGIES FOR SOLAR ARRAYS ON SMALL SPACECRAFT" (2011). University of Kentucky Master's Theses. Paper 656.


Slave Address: 0xF0
Slave Address: 0xF2
Slave Address: 0xF4
Slave Address: 0xF6
SDM-L
Radio LASIM
EPS LASIM
IPU LASIM
Sensor LASIM
CEA
A
46 00 46 8C
53 00 53 A6
53 00 53 A6
53 00 53 A6
53 00 53 A6
NM
73 00 00 00 73 CC
73 FF 66 58 CKA CKB
B
73 00 00 00 73 CC
73 00 00 00 73 CC
CEB
C
51 00 51 A2
58 00 (data) CKA CKB

Concept of Stellar Gyroscope

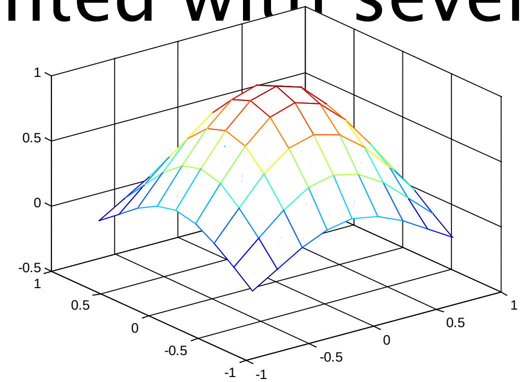
Observe the motion of stars in camera's field of view to infer changes in satellite's attitude.

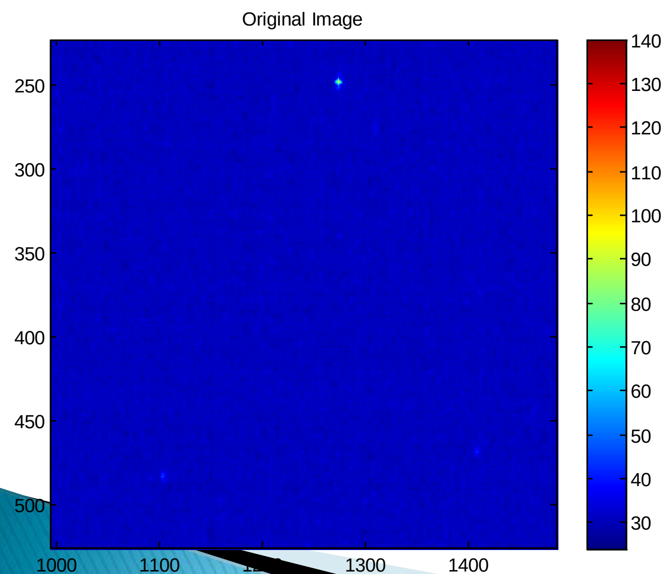


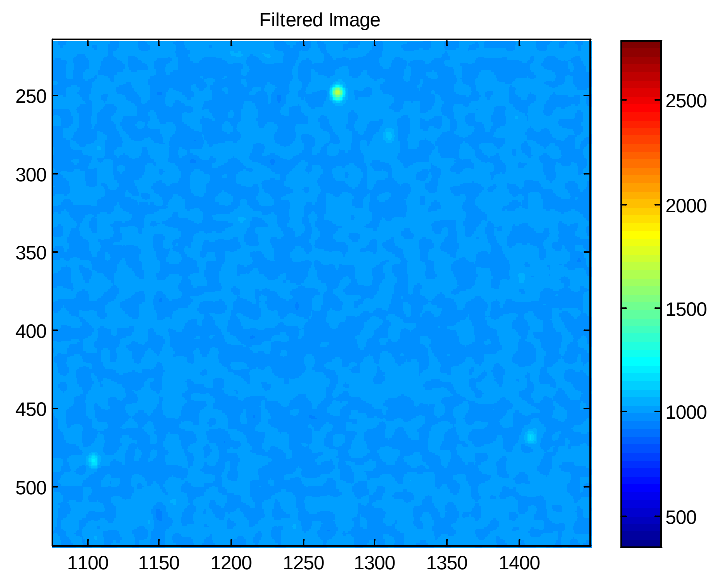
- Measures relative attitude between exposures with common stars
- Tolerates large amount of noise, allowing low cost assembly and small form factor

Star Detection

- Convolution filter, experimented with several mask sizes and shapes.
  - Minimizing false positives
  - Extracting dim stars
- Best so far: Sinc function





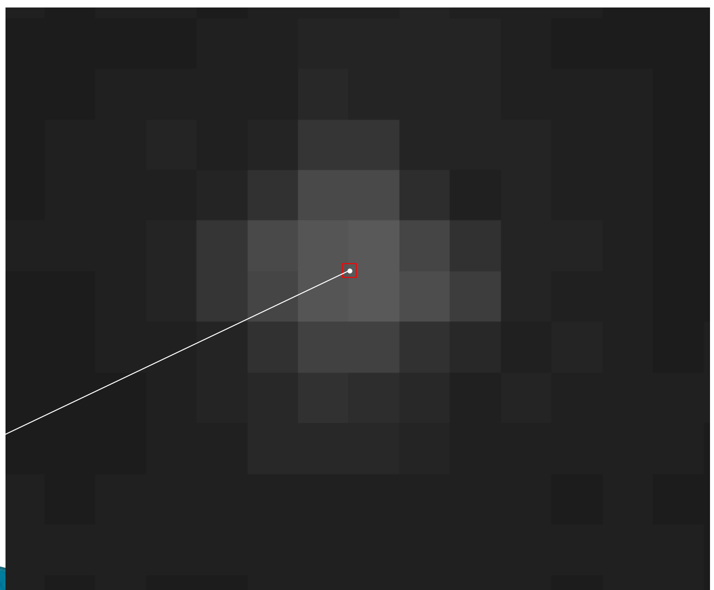


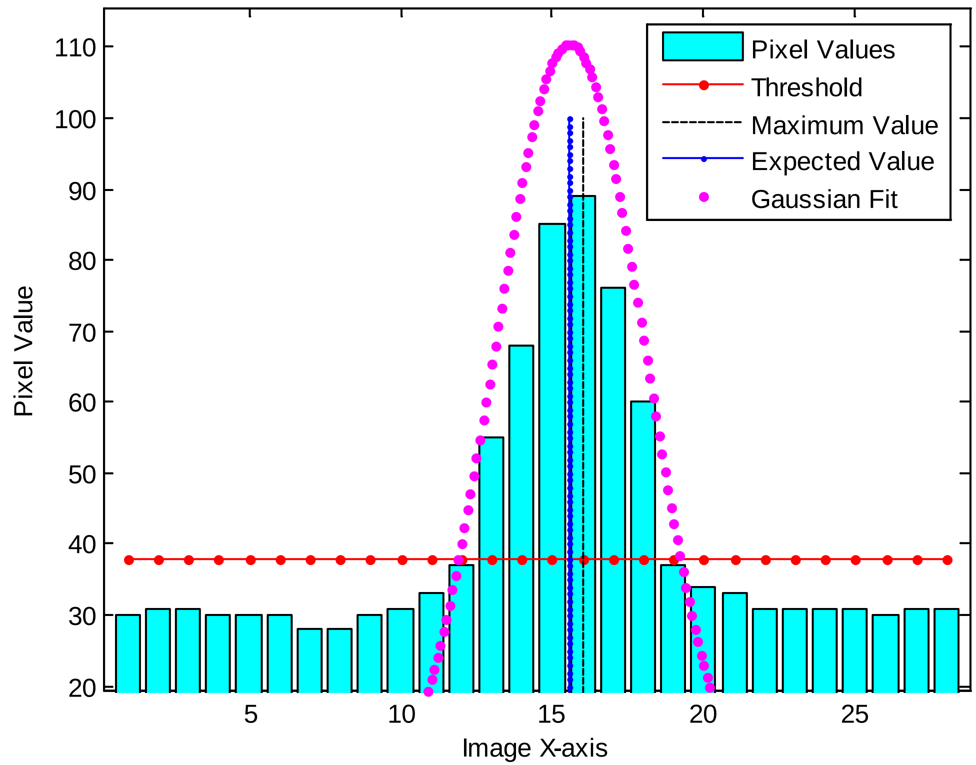
Centroiding

- "Centroiding", aka Expected Value

$$E(x) = \sum x \cdot f_x(x)$$

$$f_x(x) = \sum_y f_{xy}(x, y)$$





Solving the Relative Attitude Problem

- Using the Direction-Cosine-Matrix (DCM) notation, the attitude change between two frames satisfies:

$$\overrightarrow{\mathbf{v}^{\boldsymbol{b}}} = \boldsymbol{C}^{ba}\,\overrightarrow{\mathbf{v}^{\boldsymbol{a}}}$$

- The goal is to find the rotation matrix (C^{ba}) that defines the rotation between frame *a* and frame *b*, by minimizing the cost function:

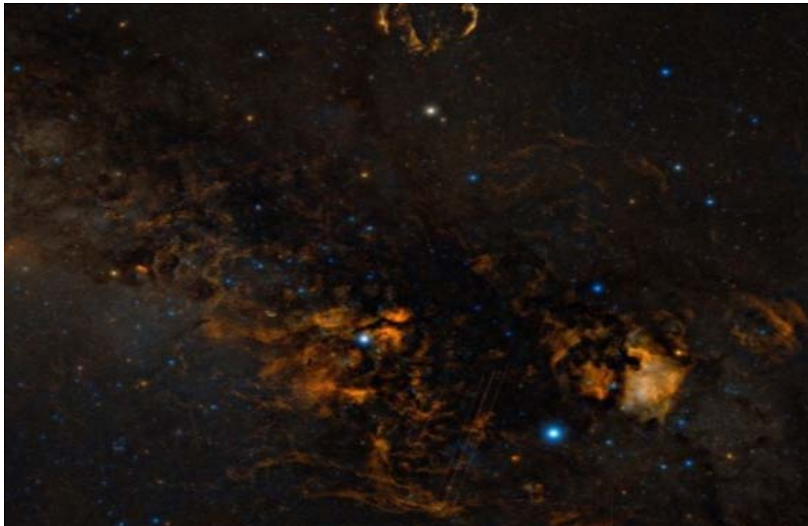
$$J(\mathbf{C}^{ba}) = \sum_{k=1}^{L} w_k \left|\mathbf{v}_k^{\boldsymbol{b}} - \mathbf{C}^{ba}\,\mathbf{v}_k^{\boldsymbol{a}}\right|^2$$

- Given at least two vector measurements (two stars before-and-after), The Q-Method is used to find the analytically optimal relative attitude estimate.

Random Sample Consensus (RANSAC)

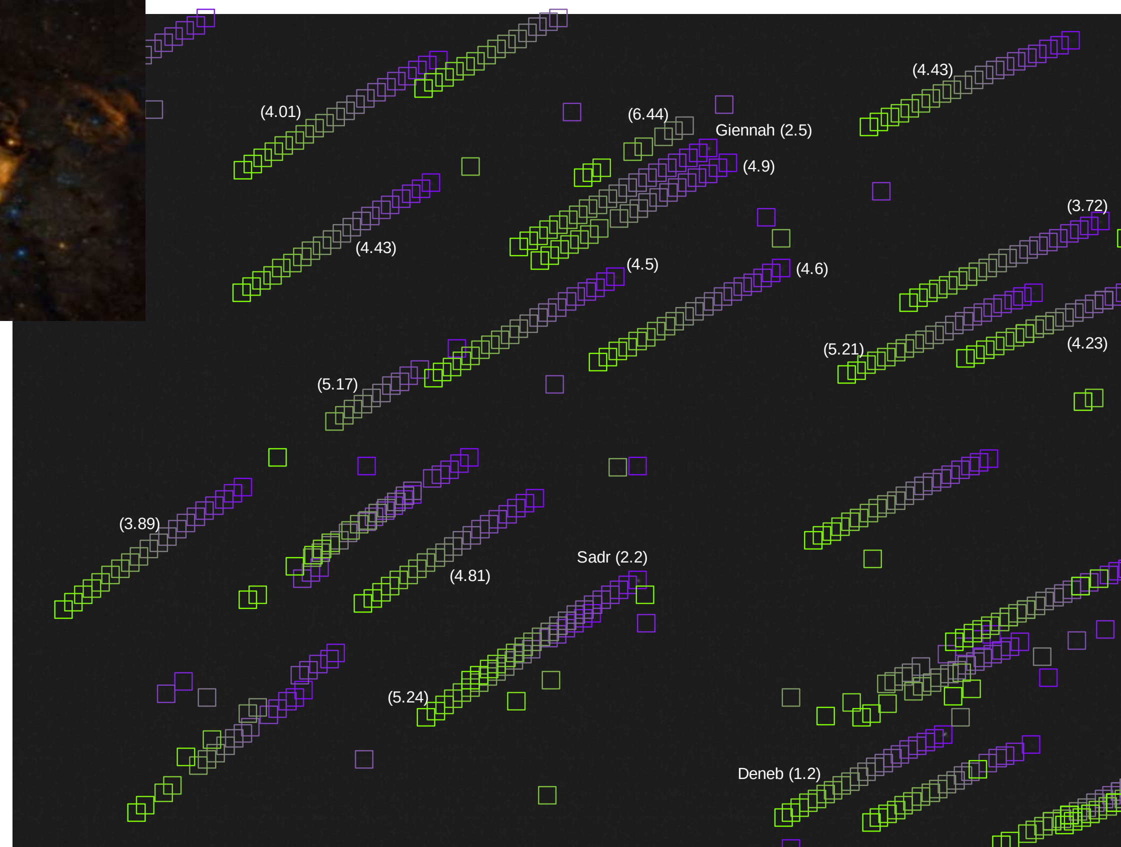
- RANSAC: iterative method to estimate parameters of a mathematical model from a set of observed data which is contaminated a large number of outliers that do not fit the model.
- The steps of RANSAC can be summarized as
  - **Hypothesize**: A hypothesis rotation is based on MEMS rate information, or calculated using randomly selected star pairs across frames.
  - **Test**: The estimated rotation matrix is tested against all the stars in the two frames. Stars that show consensus are counted towards the Consensus Set (CS).
  - **Iterate**: RANSAC iterates between the above two steps until a random hypothesis finds "enough" consensus to some selected threshold.

Dataset from Raven Run Area



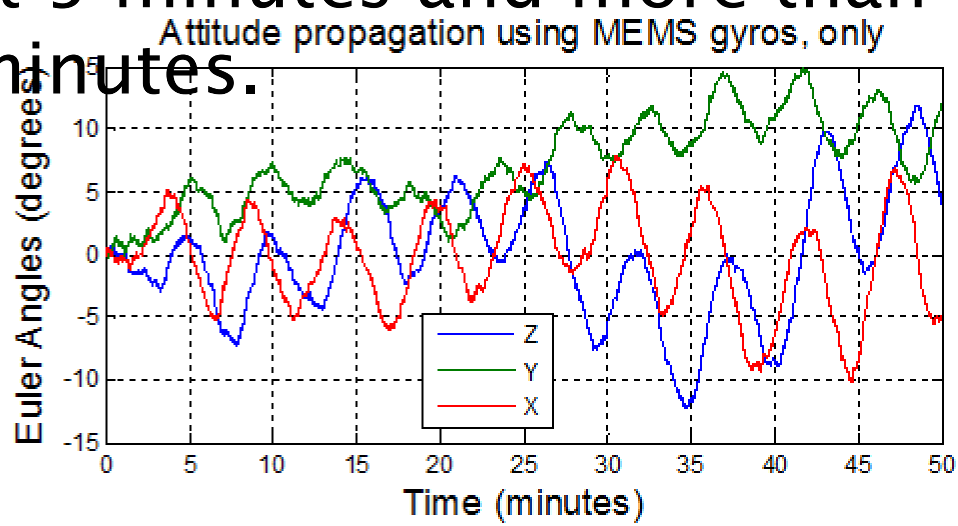
www.sky-map.org image of same region

Stellar Gyroscope Camera



Attitude Response in Eclipse: MEMS only

- Assuming perfect attitude knowledge before entering eclipse
- MEMS rate gyro: 50Hz, ±80 °/second, 12-bit ADC, Noise 0.1 °/second RMS
- Attitude knowledge error increases up to 5 ° in the first 5 minutes and more than 10 ° after 35 minutes.



MEMS assisted by Stellar Gyroscope

- Assuming perfect attitude knowledge before entering eclipse
- Stellar gyro generates attitude estimates ($\sigma = 0.1°$), at 15 second increments, relative to the first photo taken at the beginning of eclipse.
- Drift is maintained below 1°