Development of the Fabry-Perot Spectrometer Application

Kathryn Browne

Code 587

Overview

- Fabry-Perot Spectrometer (FPS)
- Conclusion

Overview

- **Fabry-Perot Spectrometer (FPS)**
- Conclusion

SpaceCube

- Radiation hardened flight processors can be one to two generations behind
- Science data does not need to be perfect all the time especially if you can collect and process more data using newer technology
- Uses processors that are not radiation hardened and can recover from radiation induced upsets when they occur
- Is a high performance reconfigurable science data processor based on Xilinx Virtex FPGAs
  - Hybrid processing – CPU, DSP, and FPGA logic
  - Integrated "radiation upset mitigation" techniques
  - Critical function watchdogs

International Space Station SpaceCube Experiment Mini

- **SpaceCube Mini (Virtex 5 FPGA)**
  - Demonstrate performance
  - Earth Science on-board processing algorithm development
  - Demonstrate 300 to 1 data reduction

- **Fabry-Perot Spectrometer (FPS)**
  - Demonstrate a smaller and cheaper way to measure methane in the atmosphere
  - Measure absorption by atmospheric gases in sunlight reflected off the Earth
  - Demonstrate measurements of atmospheric methane from space

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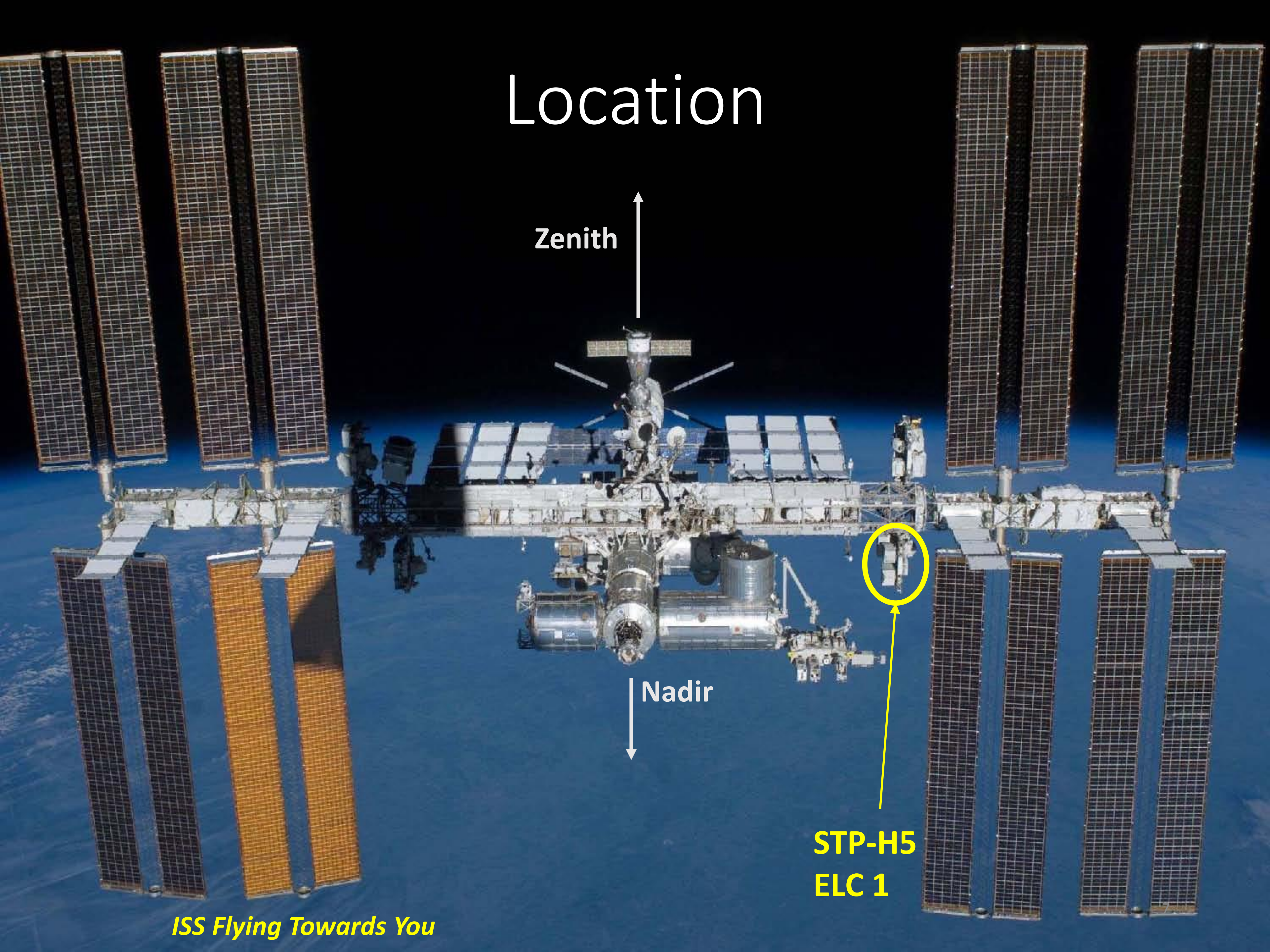
- **Electro Hydro-Dynamic (EHD) Thermal Experiment**
  - EHD pumping of liquids in embedded mirco-channels using electrical fields
  - Provide advanced thermal control for "power dense" electronics systems

- **CHREC Space Processor**
  - Demonstrate next generation processor

Space Test Program – Houston 5

- Next DoD STP external ISS payload
  - Build upon successes of MISSE 6/7/8, STP-H3, and STP-H4
- Launch June 2016 on SpaceX Commercial Resupply Service 10 (SpX-10)
- Operate 2 years on ISS Express Logistics Carrier 1 (ELC)
- STP – H5 Includes 14 experiments
  - ISS SpaceCube Experiment – Mini (ISEM) (NASA GSFC)
    - Electric Hydro-Dynamic
    - Fabry-Perot (Upper Atmosphere) Spectrometer for Methane
    - SSCO Raven (Vis, IR, Flash Lidar, Gimbal) (Satellite Servicing Capabilities Office)
    - Innovative Coatings Experiment (Materials Exposure, req's crew imagery)
    - CSP – CHREC Space Processor (Demo next gen processor)

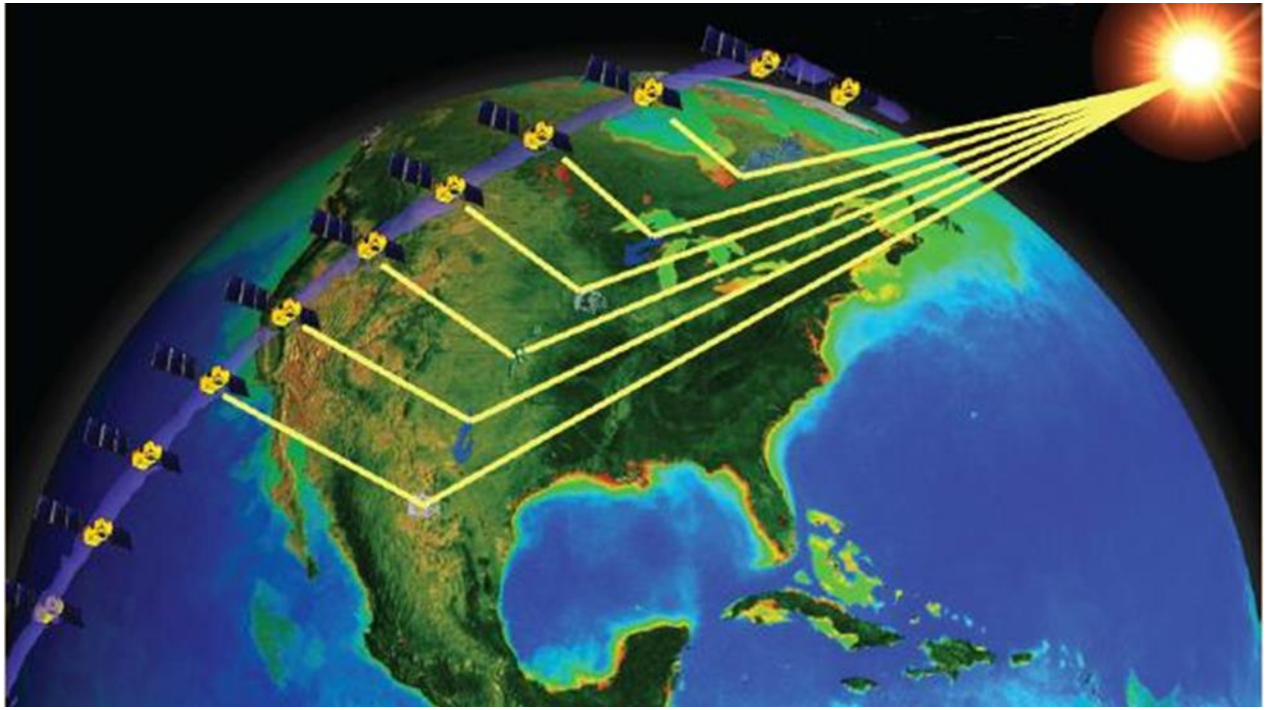
Location



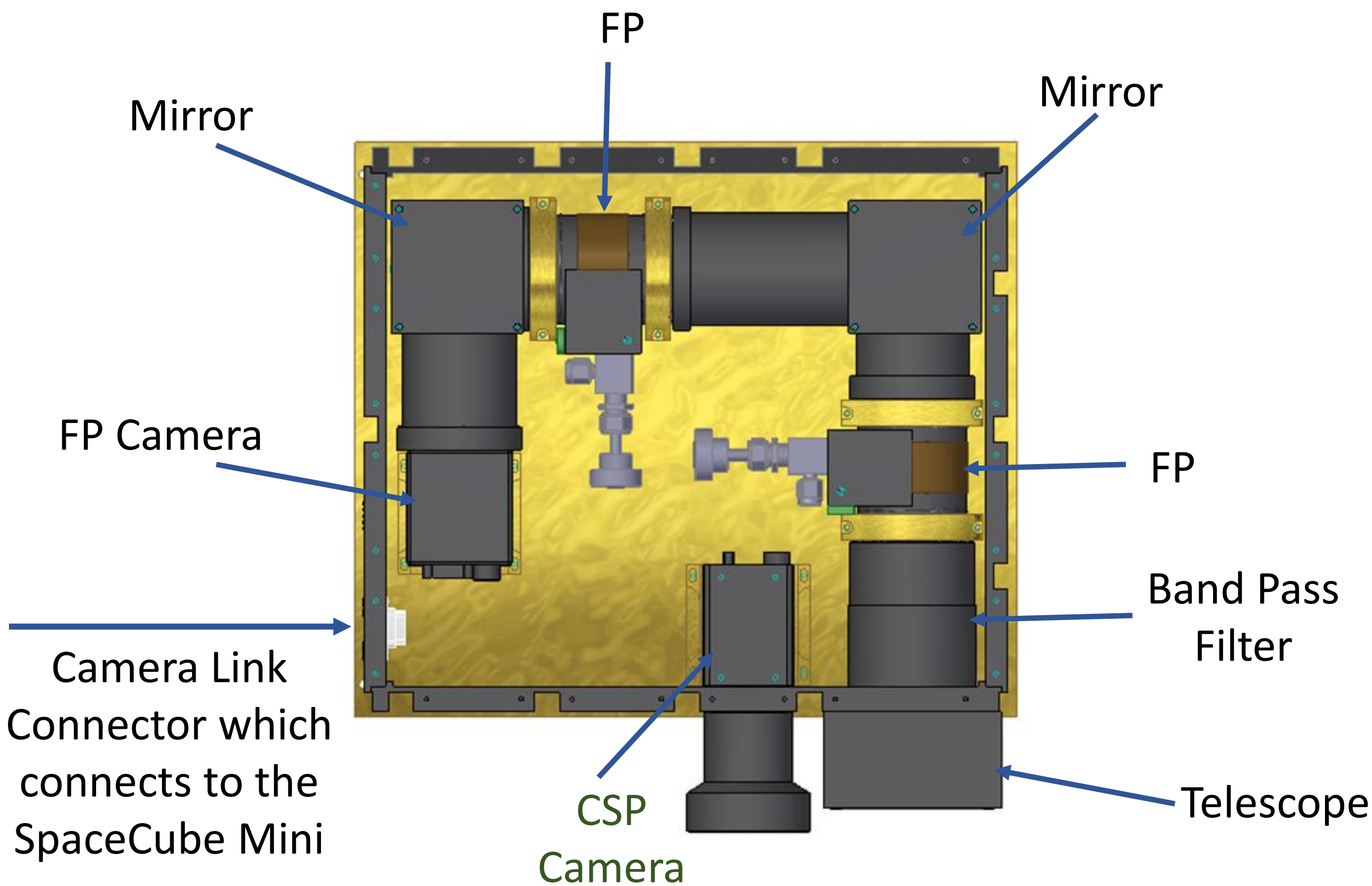
Importance of the Fabry-Perot Spectrometer for Measuring Methane

- Methane's global warming effects are 20 times worse than that of carbon dioxide
- Measuring methane from melting permafrost and methane hydrates can help with global warming calculations
- There is currently an aircraft mission to measure methane being released from the permafrost but it can't provide continuous monitoring
- No plans to develop instruments that monitor methane over the next 10 years

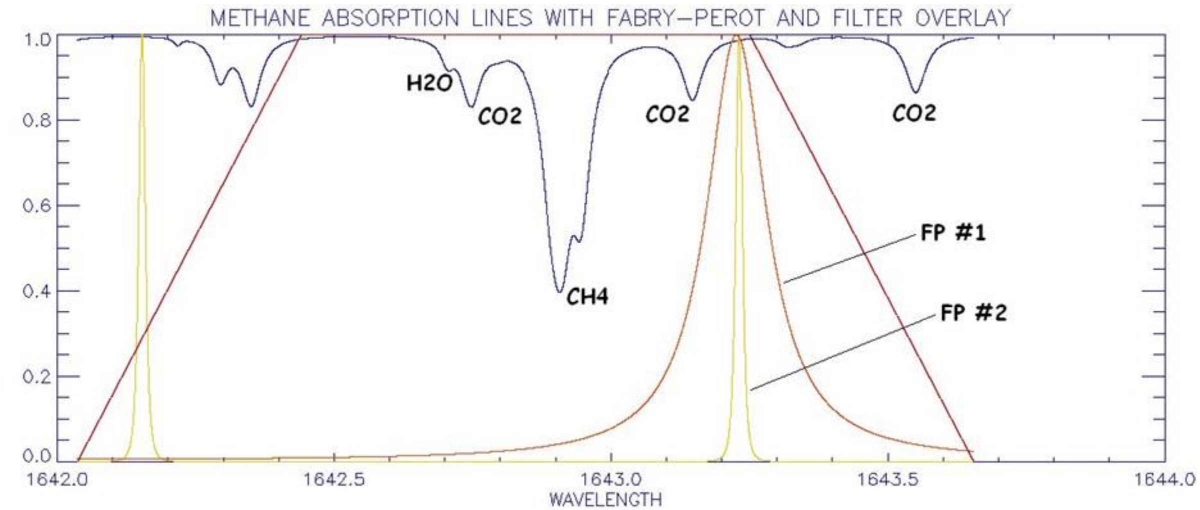
How?

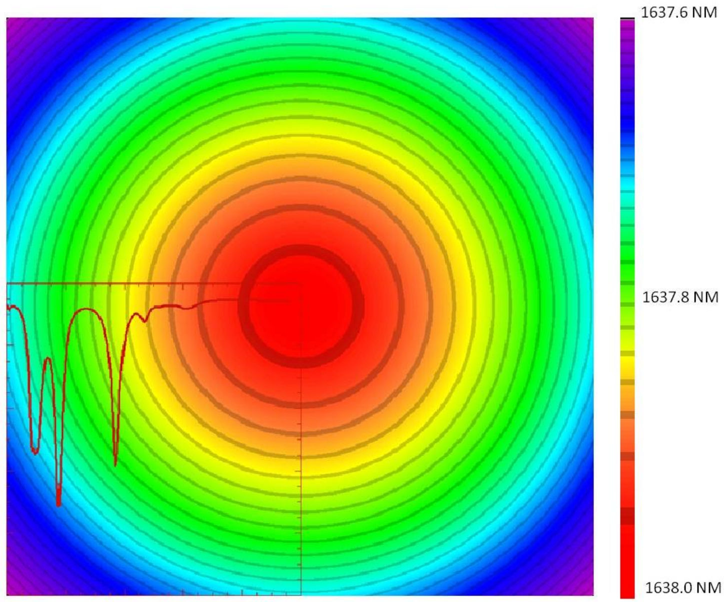


FPS Box

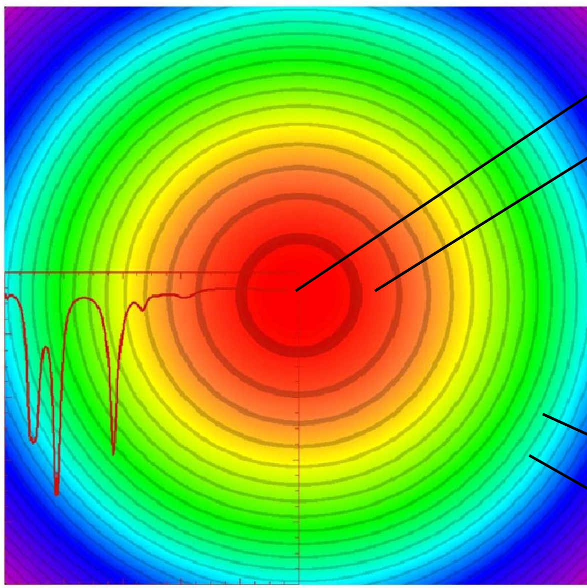

FP
Mirror
Mirror
FP Camera
FP
Band Pass Filter
Camera Link Connector which connects to the SpaceCube Mini
CSP Camera
Telescope

FPS


METHANE ABSORPTION LINES WITH FABRY–PEROT AND FILTER OVERLAY
1.0
0.8
0.6
0.4
0.2
0.0
1642.0
1642.5
1643.0
1643.5
1644.0
WAVELENGTH
H2O
CO2
CO2
CO2
CH4
FP #1
FP #2


1637.6 NM
1637.8 NM
1638.0 NM

Spectrum



Ring 1: 2291

Ring 2: 2232

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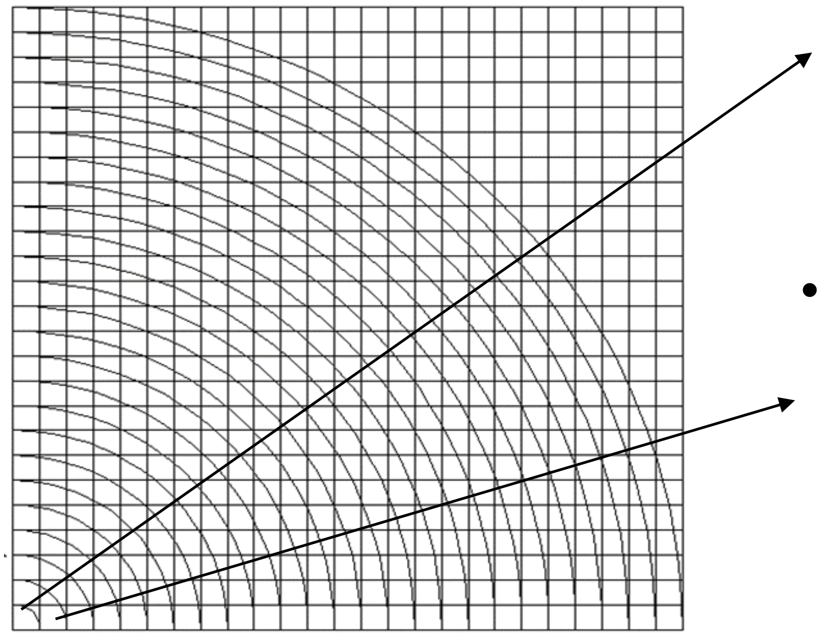
Ring 39: 1248

Ring 40: 1240

Ring Percentages

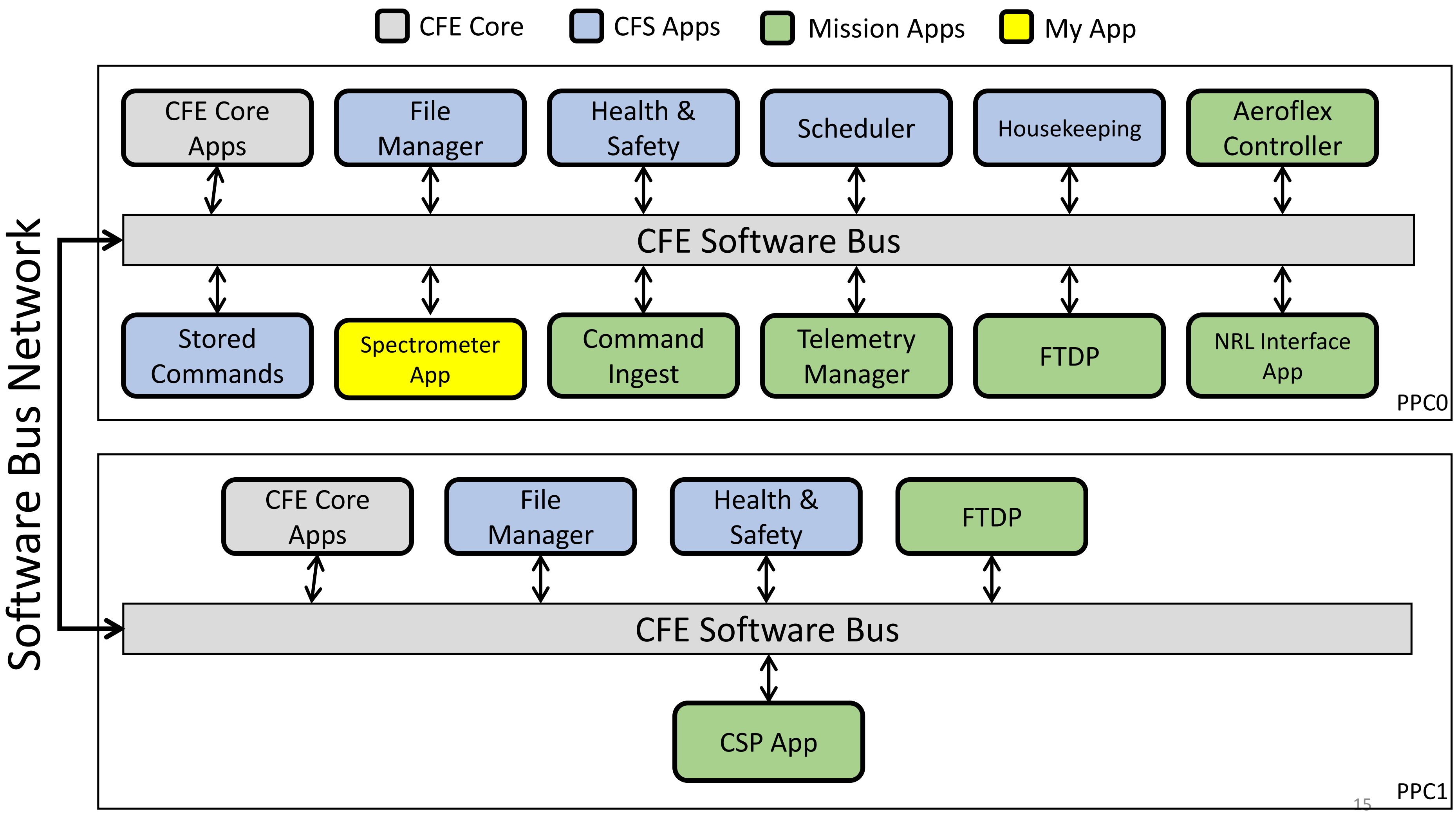


- Pixel 1:
  - Location: 0, 0
  - Ring #: 1
  - Percent 1: 79
  - Percent 2: 21
  - Percent 3: 0
- Pixel 2:
  - Location: 0, 1
  - Ring #: 2
  - Percent 1: 91
  - Percent 2: 9
  - Percent 3: 0

Core Flight Executive (cFE)

- A set of *mission independent, re-usable, core* flight software services and operating environment
  - Provides standardized Application Programmer Interfaces (API)
  - Supports and hosts flight software applications (CFS Apps)
  - Applications can be added and removed at run-time (eases system integration and FSW maintenance)
  - Supports software development for on-board FSW, desktop FSW development and simulators
  - Supports a variety of hardware platform
  - Contains platform and mission configuration parameters that are used to tailor the cFE for a specific platform and mission
- Provides:
  - Executive services
  - Software bus services
  - Event services
  - Time services
  - Table services
  - File services

ISEM Software



FPS App Development Schedule

- Release 0 – 12/1/2014
  - Interfacing with the camera
  - Science algorithms
  - Sending data down
- Release 1 – 1/30/2015
  - Commanding
- Release 2 – 3/27/2015
  - Wish list features

Development Platform

- Image processing code was prototyped using Java and OpenCV
- FPS Application code written in C
- ML510 board
- SpaceCube Linux

FPS Application

- 3 operation modes
  - Silent Mode
  - Image Mode
  - Science Mode

- Algorithms
  - Find Circle
  - Calculate Ring Percentages
  - Calculate Average Background Intensity (Spectrum Correction)
  - Calculate Spectrum

Commanding

- Change Number of Averaged Spectrums
- Change Execution Mode
- Find Circle
- Change Average Background Location
- Change Time Between Averaging Background
- Change Image Send Rate
- Change Time Between Frame Captures
- Change Time Between Image HRT Packets
- Change Dead Pixel Mode
- Load New Dead Pixel Locations
- IR Camera Pass-Through Commands
- Set Center and Radius
- Load New Lookup Table

FPS Startup

- Startup in silent mode
- Initialize counters
- Read certain variables from flash

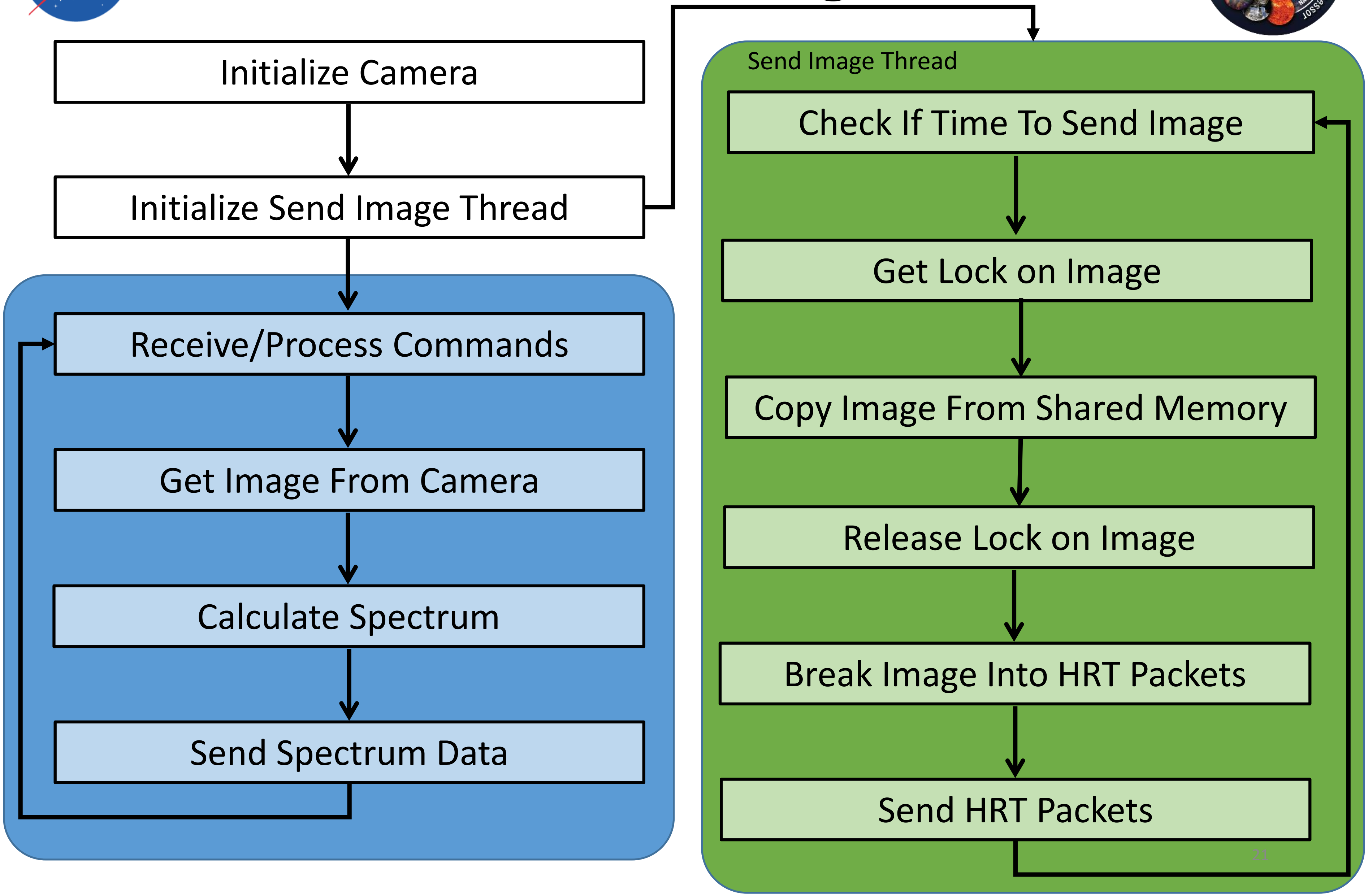
Ring Percentages Table File

- Radius
- Center x, y location
- Number of pixels
- Table entries
    - Pixel location in image
    - First ring in pixel
    - Ring percentage
    - Ring + 1 percentage
    - Ring + 2 percentage

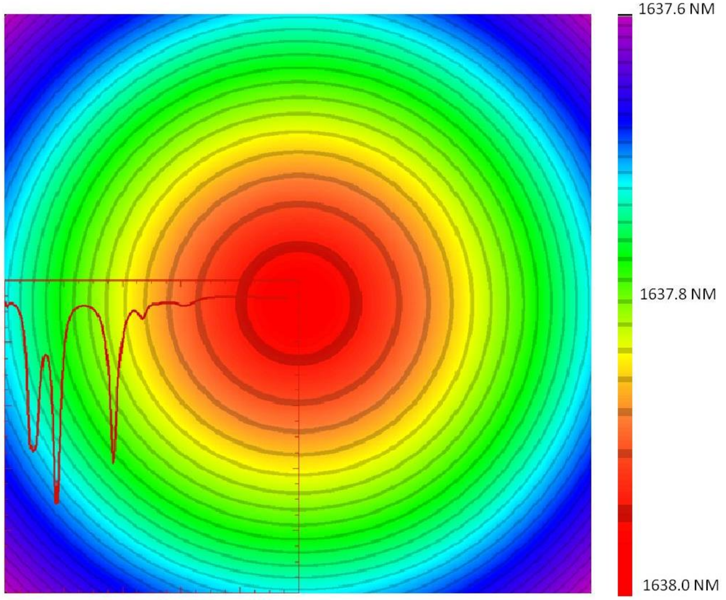
Configurable values file

- Spectrums averaging mode
- Number spectrums to average
- Milliseconds spectrums to average
- Location of Background and Size
- Send image rate
- Calculate background rate
- Time between frames

Science Mode Program Flow



Find Centroid



Find Centroid Cont.

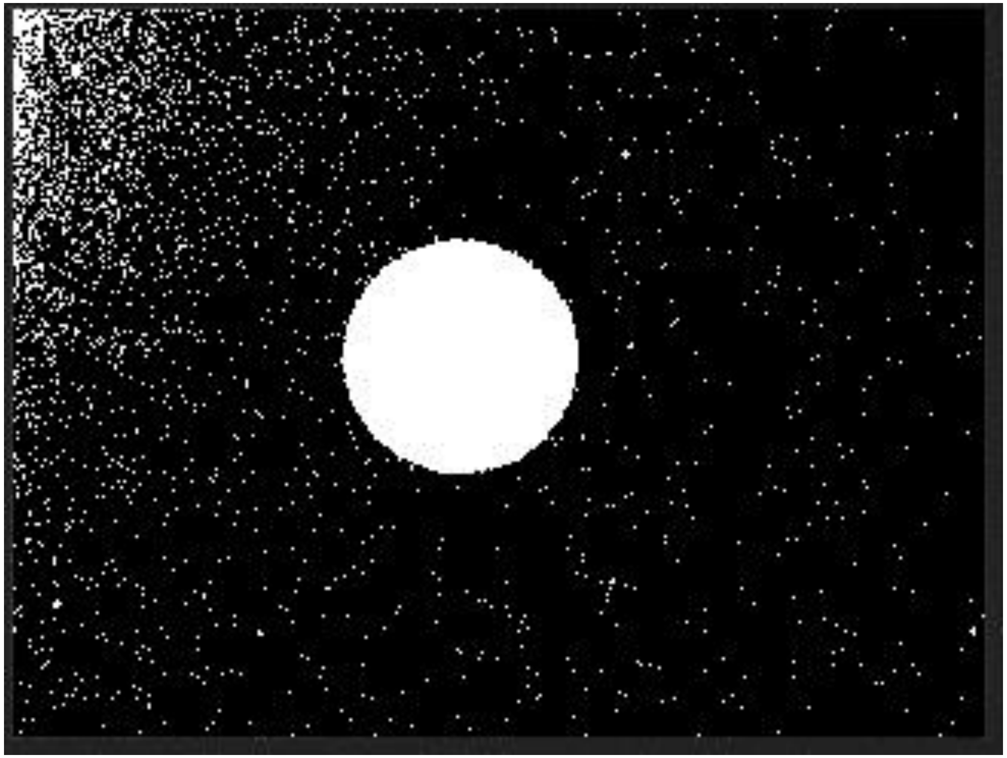
- Tried:
  - Canny edge detector
    - Image too noisy
  - Hough Circles
    - Many false circles and none fit the actual circle
  - Blur/mask procedure
    - 3x3 mask took 40 min
    - 5x5 mask took 2 hours 8 min
- Ended up implementing my own method

Find Centroid Cont.

- Get average value of the four corners

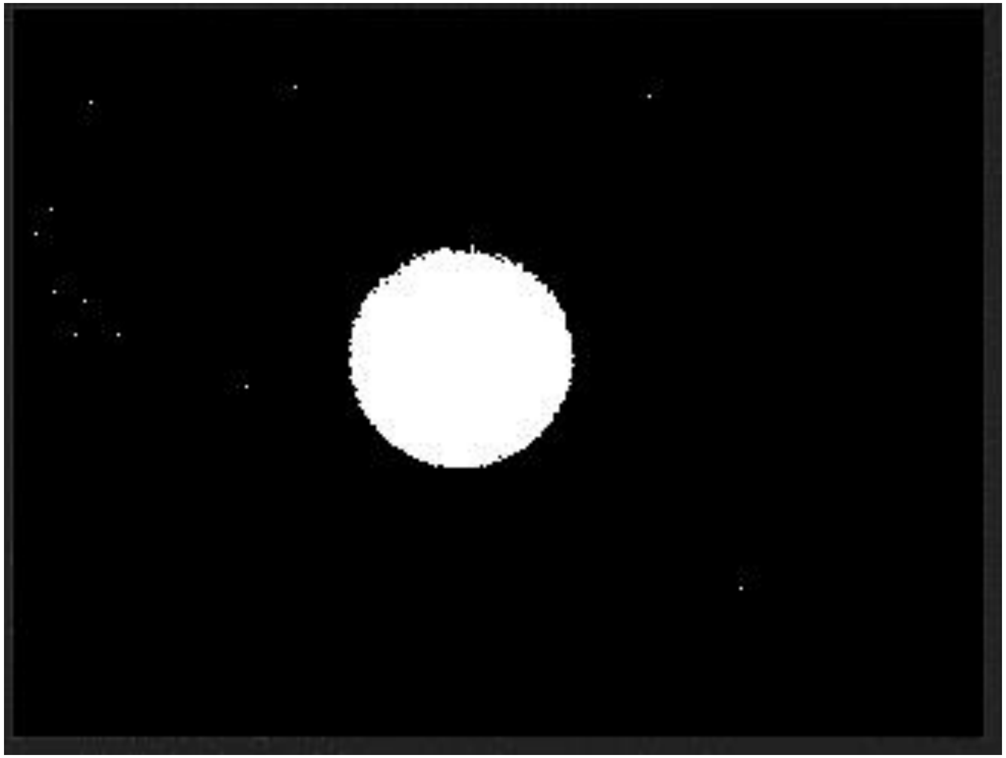
Find Centroid Cont.

- Choose the maximum corner average value and use as threshold



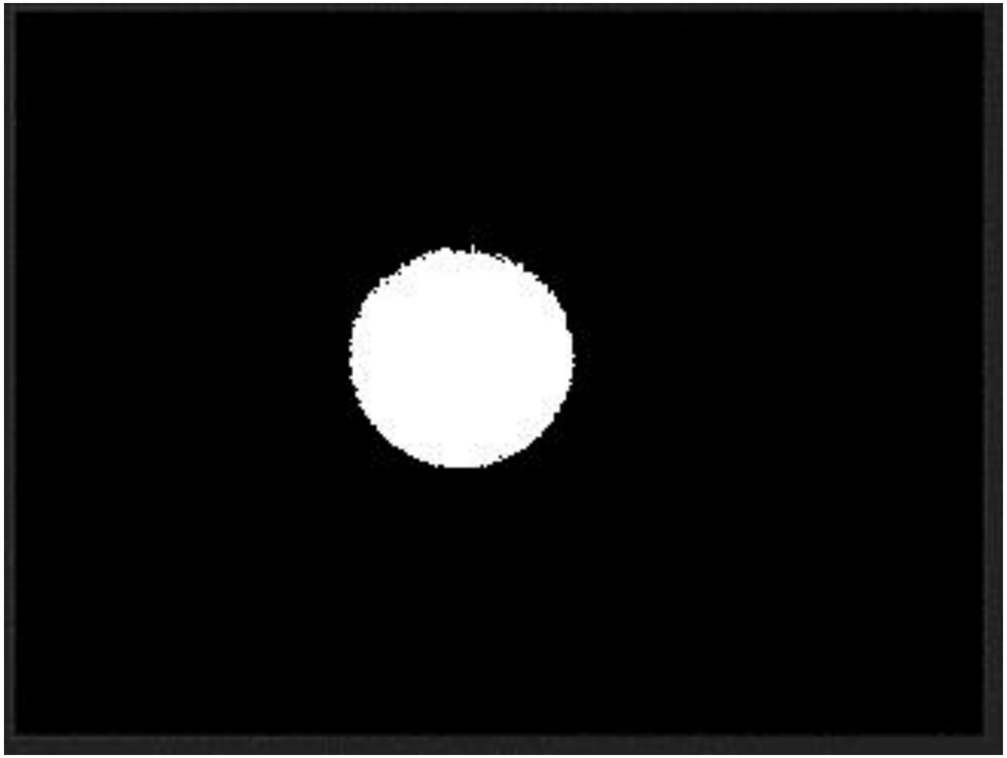
Find Centroid Cont.

- Calculate average of values greater than the previous threshold and use as new threshold



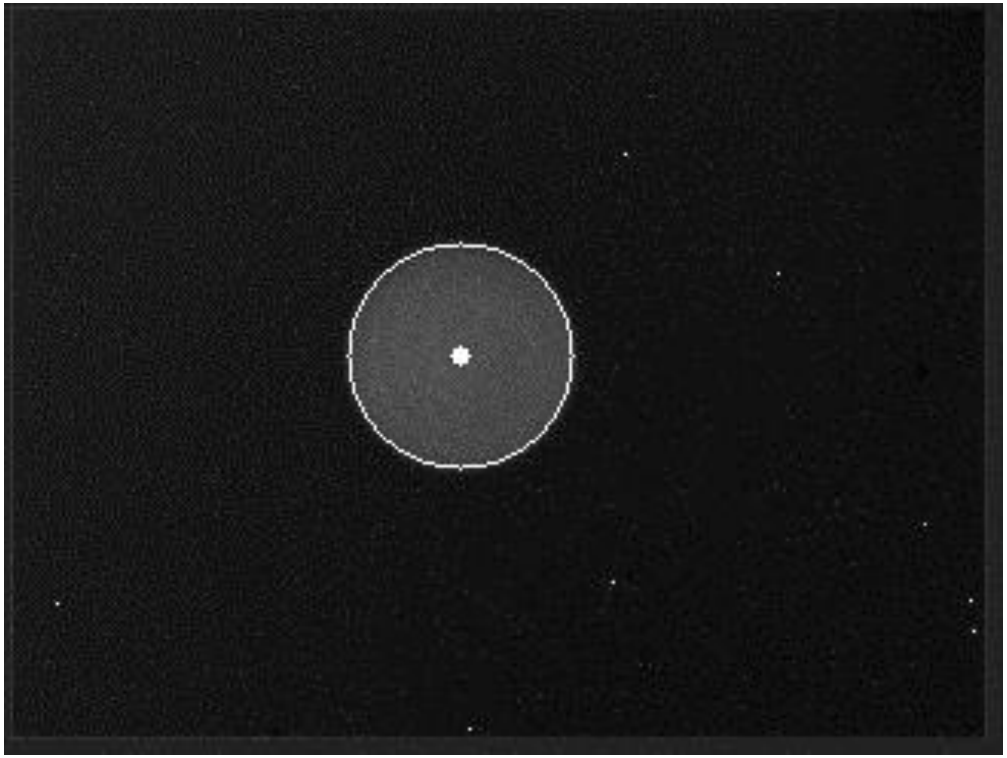
Find Centroid Cont.

- Visit all pixels above threshold and check if its neighbors are also above the threshold

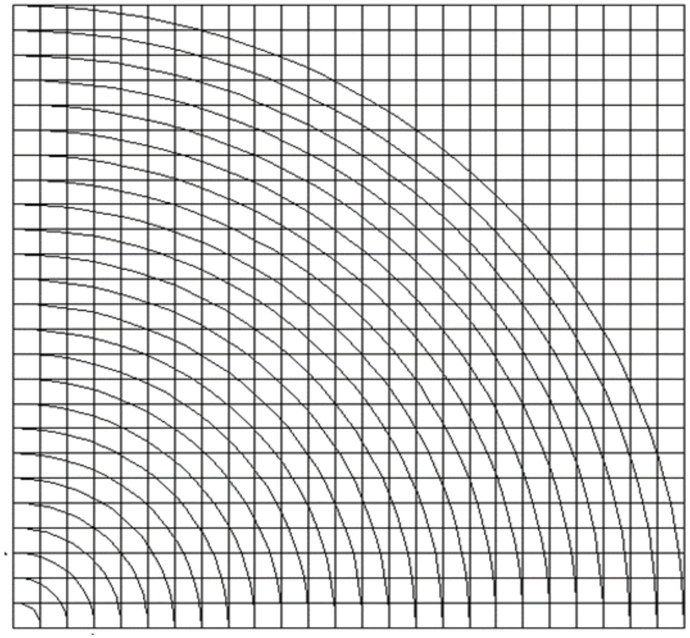


Find Centroid Cont.

- Find edge points and subtract to find the center and radius



Calculate Ring Percentages



- Calculate ring-pixel intersection
- Calculate area under ring
- Calculate area under pixel
- Subtract areas
- Project percentages

Calculate Spectrum

- Check time to see if the average background value needs to be calculated
  - If it does, calculate it
- Go through ring percentages table and multiply percentages to pixels while keeping a sum for each ring
- Calculate averages and add to HRT packet
  - Data Reduction
    - Image Size = 320 pixels * 240 pixels = 76800 pixels * 2 bytes = 153600 bytes
    - Number of rings = 40 * 4 bytes = 160 bytes
    - 153600 bytes/160 bytes = ~960 to 1
- If HRT packet filled, send packet

Calculate Spectrum Cont.

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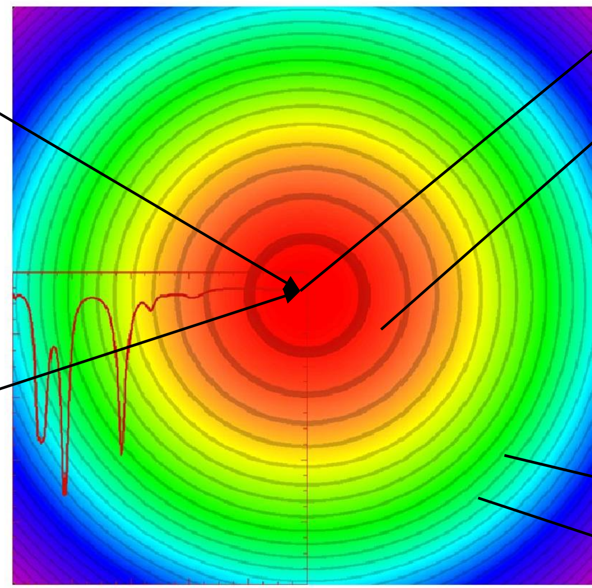

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Lessons Learned

- cFE/cFS Apps
- Working with and testing hardware
  - Xilinx Tools
  - Slow down of float values
- Not all gray-scale images have 8 bit pixel values
- Working with scientists

Questions