National Aeronautics and Space Administration

Optical Navigation With Deep Space Optical Communication Terminals

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Program: Strategic Initiative

Project Objective:

To expand the scope of the currently conceived and developed deep space optical communications (DSOC) transceiver to include on-board astrometry functions to enable autonomous optical navigation (OpNav).

Design Challenge:

The challenge is to address design deficiencies in current deep space optical transceivers, namely by: (i) providing a large (~10x10 mrad^2) field-of-view (FOV) focal plane; (ii) sensors with broadband sensitivity to detect visible Magnitude 9 asteroids with integration times of ~1 second. By contrast, the DSOC optical transceiver under current development has a 256 µrad FOV and uses a photon-counting sensor with very fast temporal response (~ 2 µs) and a spectrally narrow filter with a noise-equivalent bandwidth of 1 nm centered at 1064 nm.

FY18/19 Results: Not applicable; task started in FY20

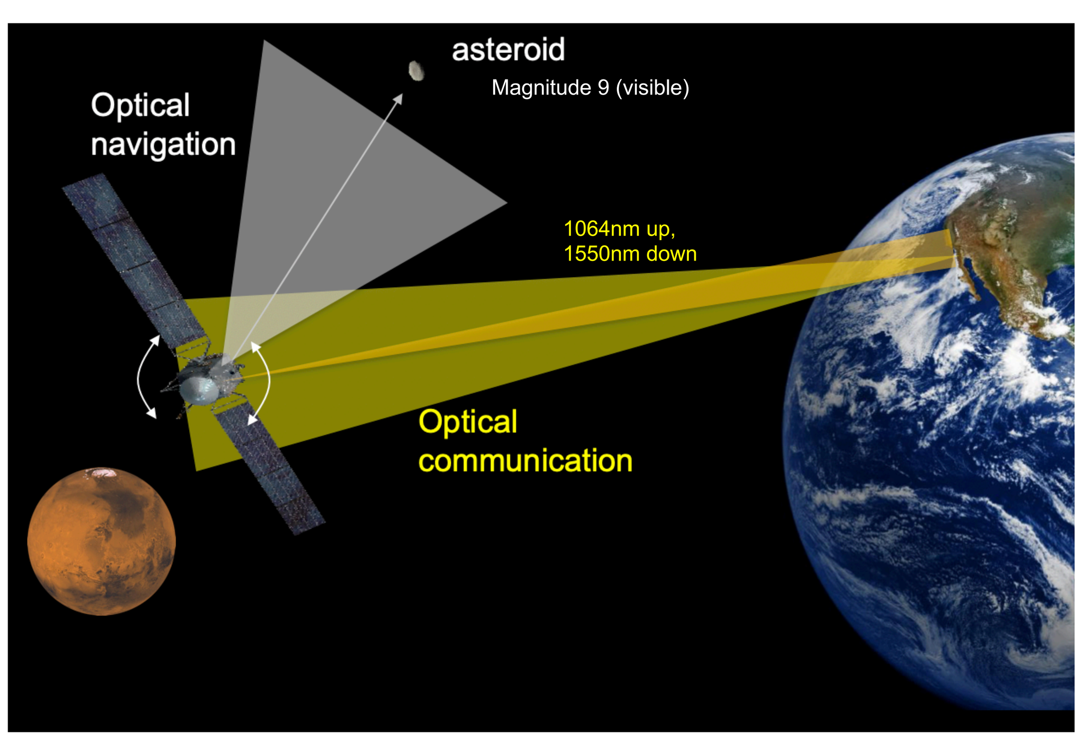
Base Assumptions:

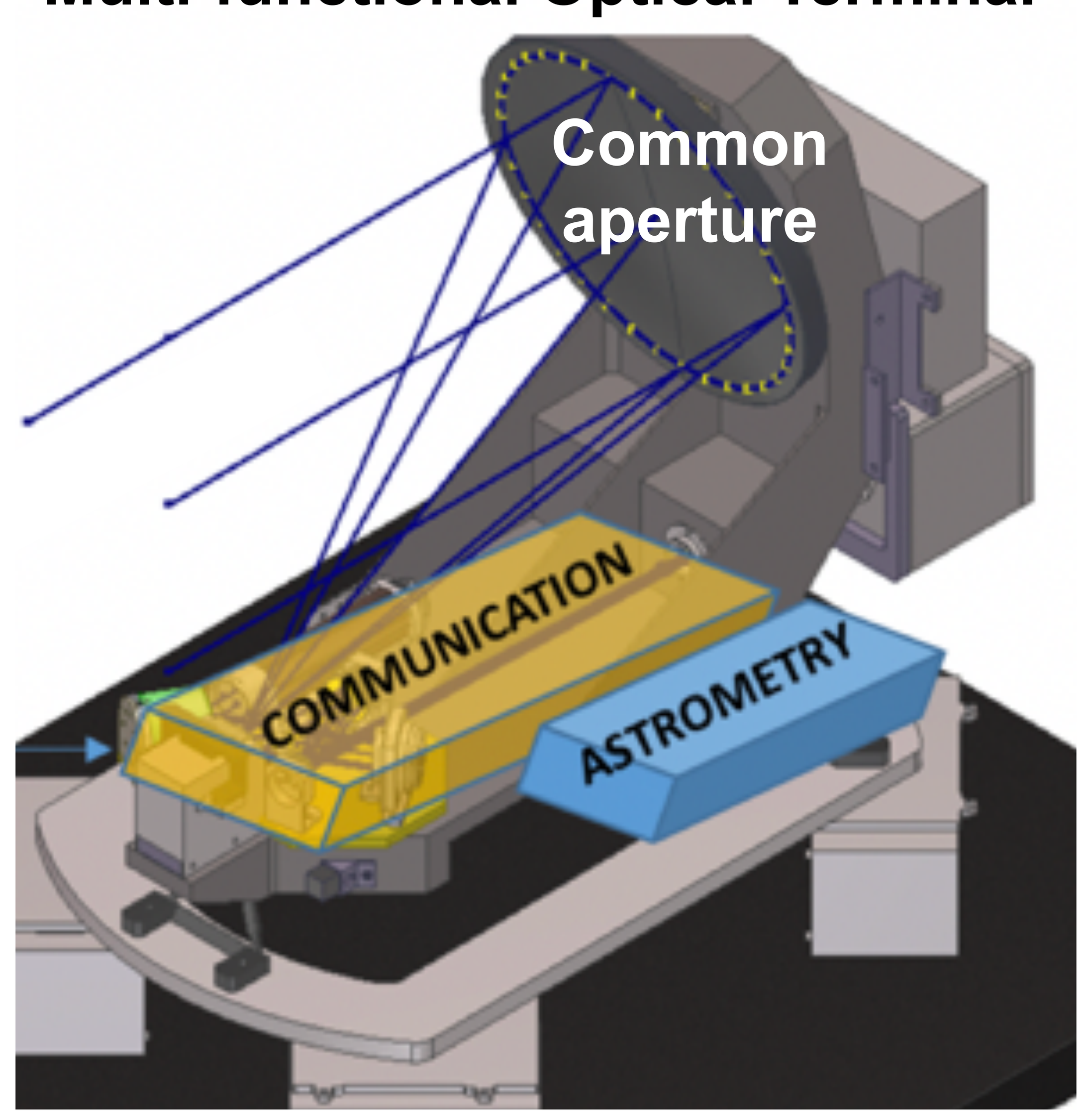
DSOC performance *cannot* be compromised when adding astrometry

- **Uplink acquisition and pointing**: The PCC must accurately detect and track the uplink beacon from Earth as a pointing reference, so that the downlink can be precisely pointed to the ground receiver. Required background mitigation techniques include lock-in detection of the beacon modulation and spectral filtering with a 1-nm bandpass filter. *Adding astrometry cannot degrade the uplink acquisition accuracy.*
- **Stray Light:** Stray light for DSOC is limited with a 1-mrad field stop at the entrance to the aft optics. This is too narrow for OpNav. This work acknowledges the need for a larger field stop (e.g. dichroic field stop with a larger FOV for OpNav), but does not yet have a recommended detailed design. *Adding astrometry cannot increase stray light*

Multi-functional Optical Terminal

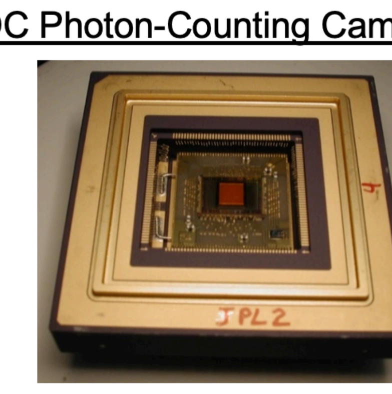
Operational Modes



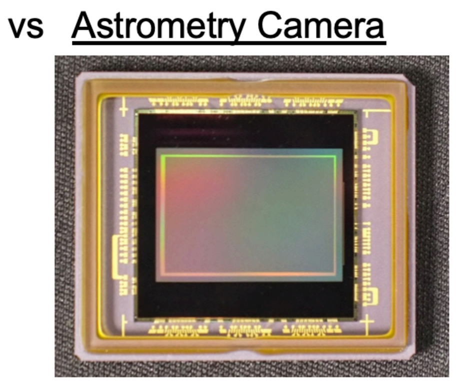


Current Detector Technology

DSOC Photon-Counting Camera (PCC) vs Astrometry Camera



- Focal Plane Array
  - 32×32 pixel
  - InGaAsP Geiger-Mode APD
  - NIR, 1.3 µm-cutoff, 1-nm bandpass
  - 2us frame rate, 2ns time resolution
    - Complex, timing-sensitive read-out circuit



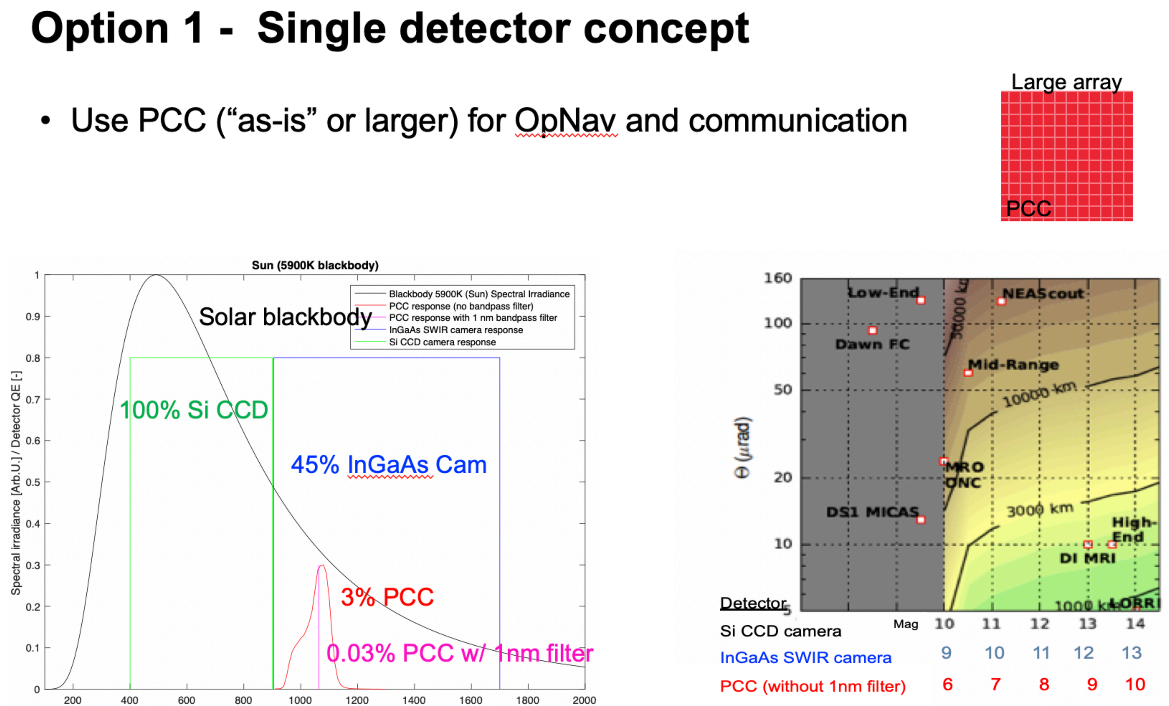
- Focal Plane Array
  - 10MegaPixels
  - CCD Array
  - Visible wavelengths, broadband
  - >1s frame rate
    - Simple read-out circuit

Approach and Results:

Considered three options for implementing an on-board astrometry capability for DSOC

Option 1 - Single detector concept

- Use PCC ("as-is" or larger) for OpNav and communication

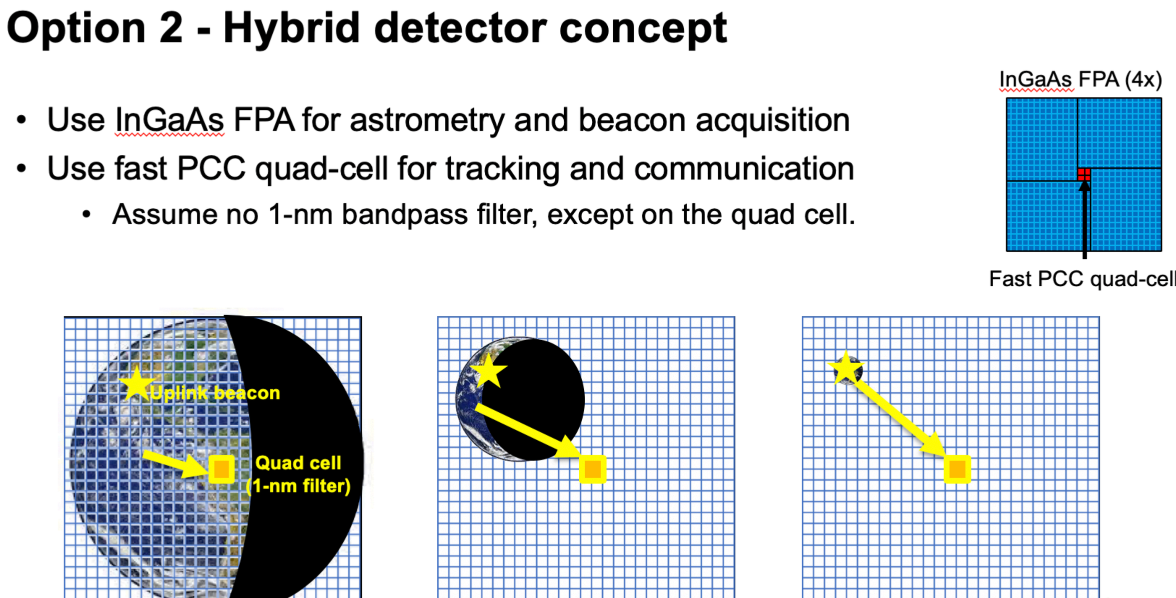


- High spectral loss from limited PCC detection bandwidth
- Loss increases required object brightness for OpNav

High spectral loss prohibits use of PCC for OpNav. ✗

Option 2 - Hybrid detector concept

- Use InGaAs FPA for astrometry and beacon acquisition
- Use fast PCC quad-cell for tracking and communication
  - Assume no 1-nm bandpass filter, except on the quad cell.

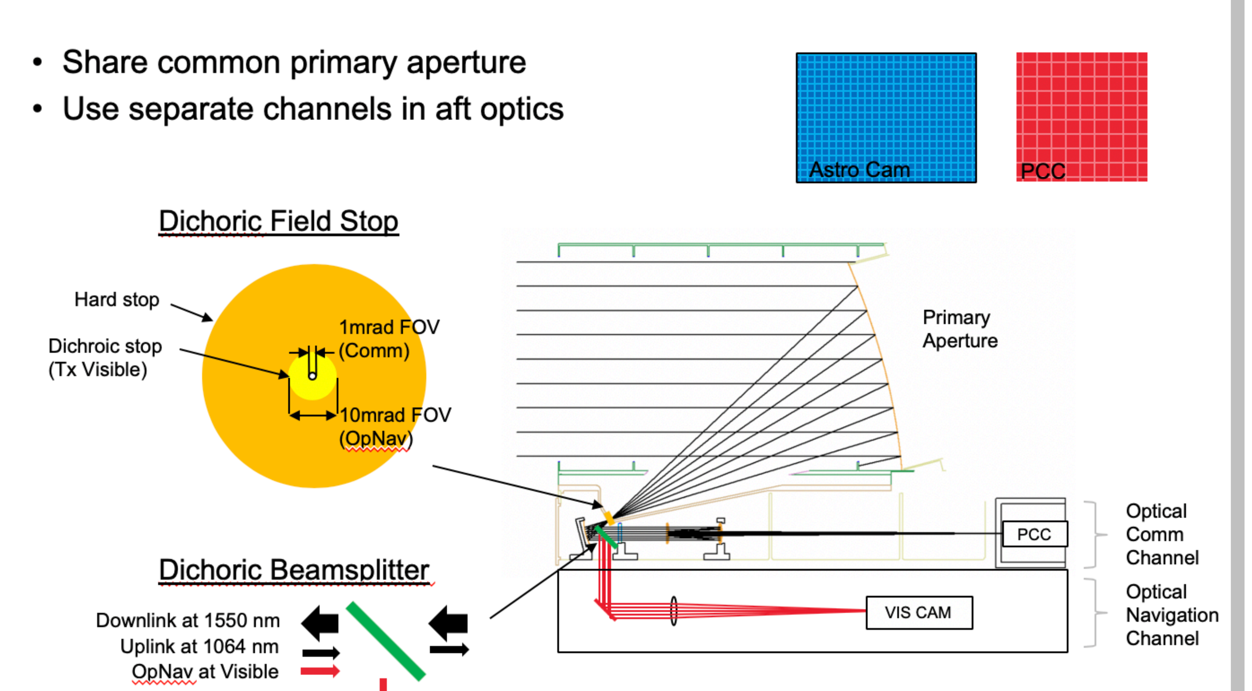


- Earth fills substantial area on FPA
- Centroiding on earth image will not guarantee centroiding on the uplink beacon onto the center quad cell
- Requires step-stare scan pattern for uplink acquisition
- Removal of the 1-nm filter significantly reduces acquisition SNR by >20dB!
- Earth covers a few pixel area, which is small enough to centroid accurately on
- The 1nm bandpass filter on the center quad can reject the earth illumination and acquire the beacon

Narrowband filter required for uplink acquisition prohibits hybrid detector ✗

Option 3 - Separate detector concept

- Share common primary aperture
- Use separate channels in aft optics



Separate channels to optimize communication and OpNav independently ✓

Benefits to NASA and JPL (or significance of results):

The significance of this R&TD research is that astrometry and communication can be supported in a future DSOC terminal sharing a common large aperture. However, due to opposing design requirements, optical navigation and communication shall be implemented with separate back-end optical channels with dedicated detectors. Optical navigation should be viable for magnitude 9 asteroid targets within the solar system based on preliminary signal-to-noise calculations in this feasibility study. Future work is to proceed with the detailed optical design of the optical navigation channel and develop a compatible concept-of-operations with communications.

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Publications: None

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