The “Virtual” Space Telescope: A New Class of Science Missions

Neerav Shah and Philip Calhoun
NASA Goddard Space Flight Center
Presentation at SSWG
February 25, 2016
Many science investigations proposed by GSFC require two spacecraft alignment across a long distance to form a “virtual” space telescope.

Astrophysics:
- Milli Arc Second X-ray imaging
- Micro Arc Second X-ray imaging
- Calibration Telescope
- Starshade

Planetary:
- Exo-planet finder
- Near Earth Objects

Heliophysics:
- X-ray imaging of solar flares
- High-resolution UV/EUV imaging
- Next generation solar coronagraph

State-of-Art science platforms

Advances in GNC for separated S/C

Optics / Occulter Spacecraft (OSC)

Virtual Telescope concept
What’s the Problem?

To pass KDP-C, and for credible science proposals \(\Rightarrow\) TRL 6

- **Perception:**
  - Engineers and Technologists: *It's been done already*
    - \(\Rightarrow\) MMS, A-Train, GRAIL, PRISMA, CAN-X 4 5, EO-1, Hubble Servicing, etc.
  - Scientists and Program Managers: *Precision formation alignment too risky*
    - \(\Rightarrow\) Multiple launches, multiple spacecraft, never collected science

- **Gap:**
  - Component technologies have been developed (some being developed) and tested (some still to be tested)
  - Relative spacecraft navigation and control demonstrated
  - Never formed a virtual science instrument
  - End-to-End System-level capability currently at TRL 4 \(\Rightarrow\) *Need a system demo*

- **Approach:** \(\text{Min}($) + \text{CubeSats} = \text{Low-cost In-Space Demonstrations}\)
Roadmap to NASA Science using CubeSats

**Ground/Lab Demo**
- Component-level testing and development
- Goal: TRL 5

**In-Space Engineering Demonstration**
- Integrated system level demonstration in space
- Goal: TRL 6/7

**In-Space Science Demonstration**
- Integrated system level demonstration including a science instrument
- Goal: TRL 8/9

**Current Status:**
- Inertial Alignment System
- Lateral sensing
- Micro Propulsion
- Inertial Alignment Navigation Algorithms

- CANYVAL-X (NASA + Yonsei + GWU) CubeSat Technology Demonstration Mission
  - Build confidence and decrease risk for science-class missions

- VTXO (2015 EpScore UNM + NMSU + GSFC)
- mDOT (Stanford, et.al.)

Relevant to StarShade Working Group
CANYVAL-X: The CubeSat Astronomy by NASA and Yonsei using Virtual Telescope Alignment experiment

Mission Description
• CANYVAL-X: CubeSat mission as an Engineering Proof of Concept for the “Virtual” Telescope
• Validate GN&C architecture for precise dual-spacecraft inertial flight along a line-of-sight.
• **Goal:** Solar Alignment < 1 arc-min (Accuracy & Stability (5 sec)) ➞ 0.3 cm

Status
• GWU design and build mCAT
• GSFC delivered: Sun Sensor (May 2015), thrusters (mCAT) (Oct 2015)
• Yonsei Univ. building 2U and 1U spacecraft
• KARI completed Thermal Vacuum testing
• Launch on Falcon9 in mid-2016
Inertial Alignment

- **Formation Transition:**
  - Differential drag, GPS, and terminal point control to get into string of pearls at 10 m range and 30 cm lateral

- **Formation Acquisition and “Science”**
  - Alignment system drives inertial alignment to 0.3 cm → hold alignment for 10 minutes

- ~ 2 week inertial alignment experiment
## Mission-Requirement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>JERRY (1U S/C)</th>
<th>TOM (2U+ S/C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Distance</td>
<td>&gt;= 10m</td>
<td>9.22° (NanoCam C1U Field of View)</td>
</tr>
<tr>
<td>Payload Angle</td>
<td>120°(±60°) (Half Intensity Beam Angle)</td>
<td></td>
</tr>
<tr>
<td>Orbit Control</td>
<td>None</td>
<td>30cm (1 DOF μCAT x4+3axis Reaction Wheel)</td>
</tr>
<tr>
<td>Orbit Determination</td>
<td>Each Axis±10cm (GPS)</td>
<td>Each Axis±10cm (GPS)</td>
</tr>
<tr>
<td>Attitude Control</td>
<td>5 °(Magnetorquer) 10m x tan(5°)= 88cm</td>
<td>1° (Reaction Wheel) 10m x tan(1°)= 18cm</td>
</tr>
<tr>
<td>Attitude Determination</td>
<td>&lt; 1 arcmin (GSFC Sun Sensor)</td>
<td>&lt; 1 arcmin (GSFC Sun Sensor)</td>
</tr>
</tbody>
</table>
- **CANYVAL-X** demonstrates a similar formation architecture.

- Optic replaced with Commercial Camera.

- Inertial reference is sun instead of stars.

- EKF to fuse sun and laser delta beta.

**NOTE:** CANYVAL-X is an engineering proof of concept using CubeSats, not designed to achieve the fine precision required of a full-scale mission.
Final Thoughts

• Tech Demos that try to “do it all” get cancelled (paraphrase Chip Barnes presentation to SSWG on 2/11)

• Formation flying for over 50 years, but no one has ever built a formation flying science instrument
  ➔ No mission has made a science measurement using a “virtual” space telescope

• Seeking to reduce risk through system demonstrations on low-cost platforms. CubeSats are enabling.

• CANYVAL-X is an engineering proof of concept
Backup
Goddard Space Flight Center

Sun Direction

Orbit

Jerry (1U)

GPS

UHF Up/Down link

Vision Alignment System

UHF Inter-Satellite Link

Tom (2U)

GPS

UHF Up/Down link

UHF Up/Down link

CANYVAL-X Operational Concept
CANYVAL-X CubeSat 2U (TOM)

### TOM(2U)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Life Time</td>
<td>3-6 Month</td>
</tr>
<tr>
<td>Payload</td>
<td>Visible Camera (NanoCam)</td>
</tr>
<tr>
<td>Payload Performance</td>
<td>2048 x 1536 pixels CMOS sensor</td>
</tr>
<tr>
<td></td>
<td>35mm lens / F1.9</td>
</tr>
<tr>
<td>GN&amp;C</td>
<td>MCAT, Sun Sensor, NanoCam, Reaction Wheels, Mag TorqRods</td>
</tr>
<tr>
<td>Data Rate</td>
<td>Uplink: 4.8kbps(UHF)</td>
</tr>
<tr>
<td></td>
<td>Downlink 100kbps(S-band)</td>
</tr>
<tr>
<td>Mass</td>
<td>2.7 kg</td>
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</tbody>
</table>
## CANYVAL-X CubeSat 2U (JERRY)

### JERRY(1U)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Life Time</td>
<td>3-6 Month</td>
</tr>
<tr>
<td>Payload</td>
<td>4 Laser Diodes</td>
</tr>
<tr>
<td>Payload Performance</td>
<td>Half Intensity Beam Angle = ±60° Minimum angle(15.5°) intensity &gt; 96%</td>
</tr>
<tr>
<td>ADCS Performance</td>
<td>(Magnetorquer, sun sensor)</td>
</tr>
<tr>
<td>Data Rate</td>
<td>Up/Downlink : 4.8kbps(UHF)</td>
</tr>
<tr>
<td>Mass</td>
<td>1.0 kg</td>
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