NASA ESTO InVEST : Strategic Directions and Lessons Learned

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Outline

- ESTO Background
- ESTO InVEST Portfolio Status – 1U, 3U, 6U
- Challenges & Lessons Learned
- Summary – Observations, Strategies & Future Implications

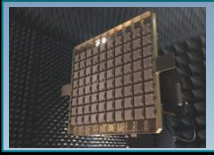
Earth Science Technology Program Office (ESTO)

*has a **targeted, science-driven, competed, and actively managed technology portfolio.***

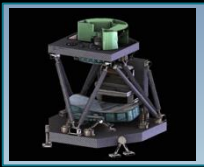
ESTO manages, on average, 120 active technology development projects. Most are funded through the primary program lines below. Nearly 700 projects have completed since 1998.

Observation

Instrument Incubator Program (IIP)
robust new instruments and measurement techniques, miniaturization – reduce SWaP
17 new projects added in FY16



Advanced Component Technologies (ACT)
critical components and subsystems for instruments and platforms
*11 new projects added in FY14 – **FY17 solicitation now open, proposals due 6/19/17***

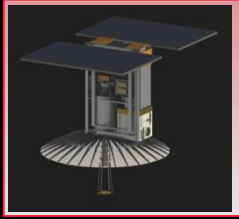


Sustainable Land Imaging-Technology (SLI-T)
new technologies and reduced costs for future land imaging (Landsat) measurements
First 6 awards in FY16

Information

Advanced Information Systems Technology (AIST)
innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products
*24 new projects added in FY15, **FY16 solicitation proposals in review***

Validation



In-Space Validation of Earth Science Technologies (InVEST) – ***next solicitation FY18***
on-orbit technology validation and risk reduction for small instruments and instrument systems that could not otherwise be fully tested on the ground or airborne systems
6 new projects added in FY16

Observation and Information Technology programs serve as the pipeline for InVEST which serves to help technologies overcome "the valley of death" to enable science missions

ESTO U-Class Pilot Program

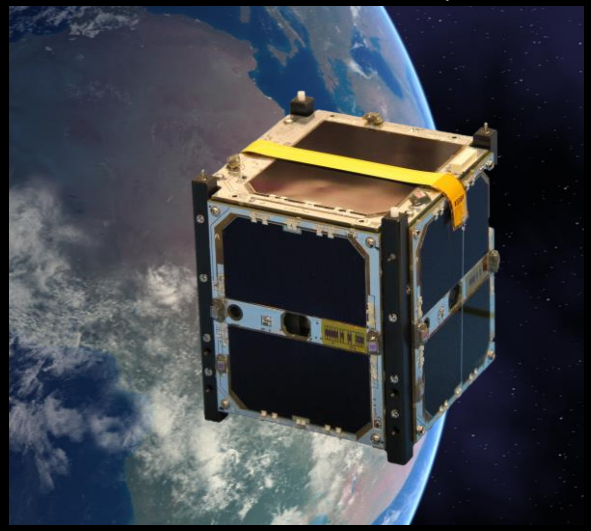
ESTO Technology Payloads Validated on U-Class Spacecraft

- Established ground work for InVEST program

Operational

M-Cubed/COVE-2

Launched VAFB: Dec. 5, 2013



Polarimetry Processing for ACE

On-board instrument signal processing technology to support aerosol and climate science

Non-Operational

IPEX

Launched VAFB: Dec. 5, 2013

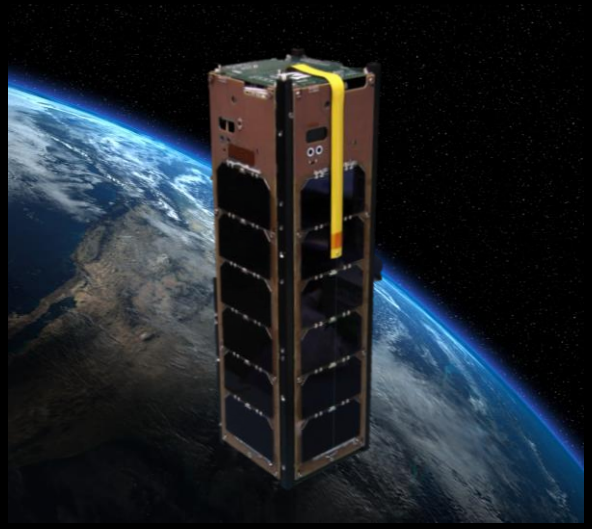
Autonomy Technology for HyspIRI

Autonomous science product generation and near real-time product delivery technologies

Operational

GRIFEX

Launched VAFB: Jan. 31, 2015



ROIC Technology for GEO-CAPE

Imaging technology enabling atmospheric chemistry and pollution transport science from GEO

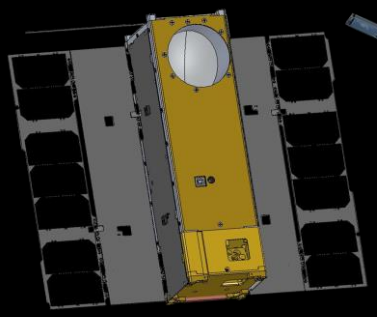
ESTO InVEST 2012 Program – 3U passive

U-Class Satellites Advancing TRLs for Future Earth Science Measurements

- Mitigate risk for components/instruments on missions
- Pathfinders for constellations

MiRaTA

MIT / MIT-LL
Launch NET 9/23/17



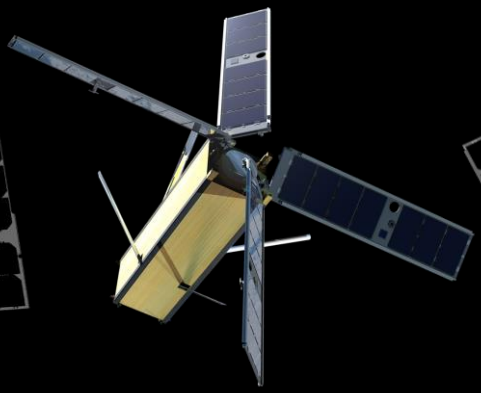
3 Frequency Radiometer and GPSRO

Validate new microwave radiometer and GPSRO technology for all-weather sounding

Operational

RAVAN

APL-JHU
Launched 11/11/17



Vertically Aligned Carbon Nanotubes (VACNTs)

Demonstrate VACNTs as radiometer absorbing material and calibration standard for total outgoing radiation

1st demo of BCT Bus

On ISS

IceCube

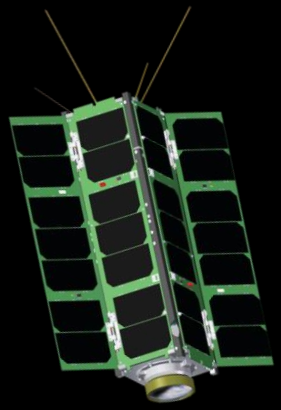
GSFC
Launched 4/18/17

883 GHz submm-Wave radiometer

Validate sub-mm radiometer for spaceborne cloud ice remote sensing

HARP

UMBC
Launch NET 8/1/17



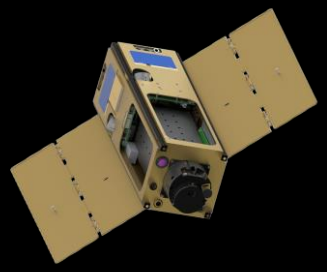
Wide FOV Rainbow Polarimeter

Demonstrate 2-4 km wide FOV hyperangular polarimeter for cloud & aerosol characterization

SDL Bus

LMPC

The Aerospace Corp
Launch TBD



Photon Counting InfraRed Detector

Demonstrate linear mode single photon detector at 1, 1.5, and 2 microns in space environment

RAVAN CubeSat Mission – Status

PI: Bill Swartz, APL-JHU

The Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat mission launched on **November 11, 2016** as a secondary payload on a ULA Atlas V rocket from Vandenberg AF Base.

RAVAN is intended to demonstrate new technology for measurements of Earth's radiation budget.

Accomplishments and Current Status:

- 2 way communications established
- All data looks nominal for s/c and instrument (BCT bus)
  - 1st in-space demonstration of BCT bus
- Unlocked radiometer doors, this is done only 1x using same stepper motor to open doors
- Confirmed black body performance in orbit
- Opened doors and acquiring data since 1/25/17
- Mitigated SD card failure by updating instrument firmware to store data in instrument RAM
- Acquiring solar calibration data under various radiometer settings
- APL press release showing 1st light radiometer data
- Expect to compute Calibrated Earth irradiances over next 2 months.

Technology Readiness Level Assessment

- Payload doors TRL 7
- Gallium black bodies TRL 7
- VACNTs as radiometer absorbers TRL 7
- Climate accuracy TRL 5 (requires solar calibration, analysis)
- Stability on orbit TRL 5 (requires solar calibration over time, analysis)

RAVAN was one of seven CubeSats aboard the Atlas 5A rocket that carried the WorldView-4 satellite into orbit.
(Credit: United Launch Alliance/Lockheed Martin)

Top Right: Part of the VACNT Radiometer. The dark patch in the center is a small "forest" of nanotubes. Middle Right: An illustration featuring the RAVAN instrumentation. Bottom Right: A model of the RAVAN spacecraft with fully deployed solar panels

NASA ESTO InVEST 2015, Venture Tech Programs – 6U

U-Class satellites advancing TRLs for Decadal-Class measurements

CIRAS
JPL

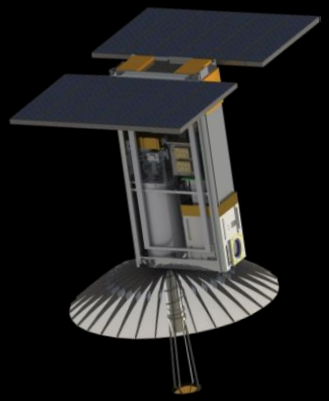
BCT Bus

Infrared Atmospheric Sounder

Demonstrate ability to measure spectrum of upwelling infrared radiation in 4-5 micron spectral region

RainCube
JPL

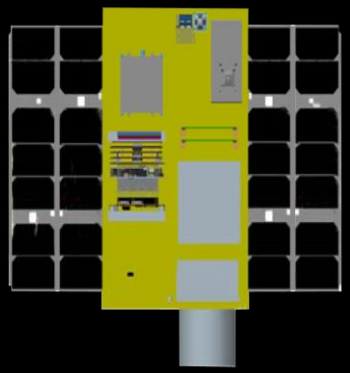
Tyvak Bus



Precipitation Profiling Radar

Validate Ka-band (35.75 GHz) radar payload using new deployable antenna and processing technologies

CubeRRT
The Ohio State University
JPL , GSFC (Co-Is)
BCT Bus

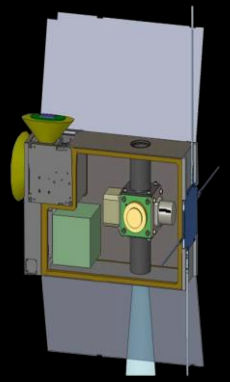


Radiometer Radio Frequency Interference

Demonstrate wideband RFI mitigation technologies vital for future space-based microwave radiometers

CIRIS
Ball Aerospace

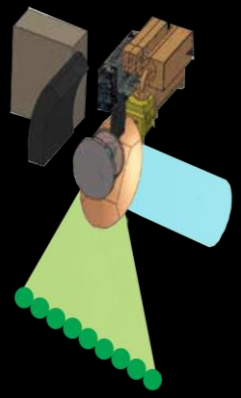
BCT Bus



Infrared Radiometer

Validation of an uncooled imaging infrared (7.5-13 um) radiometer for high radiometric performance in LEO

TEMPEST-D
Colorado State University
JPL (Co-I)
BCT Bus



5 Frequency mm-Wave Radiometer

Technology demonstrator measuring the transition of clouds to precipitation

Venture Tech

ESTO InVEST Manifest Status

Project	NET Launch Date	Vehicle	Status	Mission
RAVAN	November 11, 2016	Atlas-V (NRO)	Launched Operational	WorldView-4 / Digital Globe 600 km sun-synch
IceCube	April 18th, 2017	NASA ISS (Cygnus OA-7)	Launched Stowed - ISS	ELaNa-17 400 km at 51.6 deg. inclination
HARP	August 1st, 2017	NASA ISS (Dragon SpX-12)	Manifest	ELaNa-22 400 km at 51.6 deg. inclination
MiRaTA	September 23rd, 2017	Delta-II (JPSS-1)	Manifest	ELaNA-14 440 x 811 km sun-sync
LMPC	TBD	TBD	TBD	TBD
TEMPEST-D	~Q1/Q2 2018	NASA ISS	Manifest	ELaNa-23 400 km at 51.6 deg. inclination
CubeRRT	~Q1/Q2 2018	NASA ISS	Manifest	ELaNa-23 400 km at 51.6 deg. inclination
RainCube	~Q1/Q2 2018	NASA ISS	Manifest	ELaNa-23 400 km at 51.6 deg. inclination
CIRiS	TBD	TBD	TBD	ELaNa-?? TBD
CIRAS	TBD	TBD	TBD	ELaNa-?? TBD

InVEST Program Knowledge Sharing

Lesson 1 – Foster open communication among projects

The InVEST program, by design, encourages interaction and sharing of technical experience and engineering best practices amongst the teams (in a collaborative non-competitive way) to support flight system design. There are many examples some of which include:

- Experiences from the pilot program projects helped build important relationships with NASA LSP, USGRWG, universities, and others
- CIRAS is benefitting from scanning mirror motor mechanism and control design discussions with TEMPEST-D team
- IceCube and HARP have received telecom technical support from the MiRaTA team on components such as the Cadet-U radio and ClydeSpace solar panels
- CubeRRT has benefitted from TEMPEST-D interface development on the BCT bus
- IceCube ground station GSE work will positively impact telecom support for HARP, MiRaTA, and other InVEST projects using the WFF facility.
- Identification and resolution of RAVAN flight anomalies are feeding into spacecraft bus design updates for all InVEST projects in development with Blue Canyon Technologies, Inc. *(Includes CIRAS/JPL, CIRiS/BATC, CubeRRT/OSU and also other CubeSat developments such as TEMPEST-D/CSU)*

If something can go wrong it will

Lesson 2 – expect the unexpected

- **Deployment release mechanisms**
  - Finding failures with thermal knife drivers some of the circuits can fail after as little as 5 uses
    - SDL discovered the issue, designed a replacement and has adopted for HARP
  - Use UV sensitive tie downs in case of deployment failures
- **Single Event Upsets**
  - Likely due to radiation effects on COTS electronics
    - Experiencing SD card failures, RAVAN had to update firmware in orbit to store data in instrument RAM – and it worked!!!!
  - Need regular scheme of system resets
- **Communications**
  - 450 – 470 MHz band can be very noisy
    - Ground stations need more robust amplification
  - Carry a backup radio if you can
  - Consider S-band, Ka-band, X-band
  - Submit frequency license ASAP and *use integration date not launch date*

Not every launch opportunity is the same

Lesson 3 – timing in life is everything….

- It is very likely that you may have to plan for a button down/bath tub period due to launch delays…..*& you might end up needing that time after all*
  - JPSS1 was supposed to launch Fall of 2016 and now it's September 2017

- A launch delay can be a blessing in disguise
  - It can provide time to get your frequency license because you put the launch date and not the integration date on your application, Oooops!
  - It can provide time to fix things that have gone wrong during environmental testing because we all know that happens, *but you have to plan on being able to pay for it*

- From an integration perspective a launch opportunity as a secondary on a NASA launch is not the same as a NASA ISS resupply or NRO as a secondary – different concerns regarding safety and protocols, *do no harm*

- Getting your system commissioned takes a lot longer then expected, be prepared and don't panic when things don't work out immediately

- Publicity materials are becoming more important, consider videos and simulations

Summary

Observations, Strategies and Future Implications

- Successes in InVEST projects will show that you can do Earth Science in small packages – *CubeSats are gaining credibility and momentum with the Earth Science community – timing is right*
- The 2nd NRC Earth Science Decadal Survey is due end of 2017 calendar year – expect CubeSats and SmallSats to have a role – *this study will strongly influence the InVEST-18 solicitation*
- InVEST-15, projects are relying on industry to provide buses which allows more focus on the instrument to enable science measurements – *NASA ESTO solicitations Science Driven*
  - Future projects may need more capability from the bus and if industry is not yet operationalized there will likely be strong interest to work with the university community to support these missions
- Hoping for more launch opportunities, such as slots on ESPA rings, VCLS etc. to be affordable
- The collaborative nature of the InVEST PIs with respect to sharing knowledge and helping each other is a reflection of the nature of the CubeSat community at large – *Thank You*

All InVEST lessons learned will be shared with Small S/C Systems Virtual Institute

Quote from an InVEST PI

“A success-oriented schedule is not easy to maintain when you are doing something for the first time”