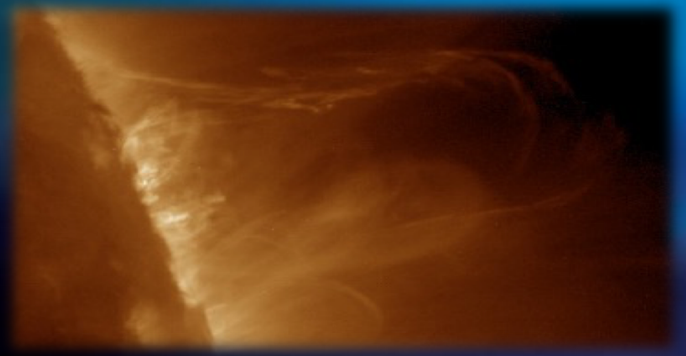
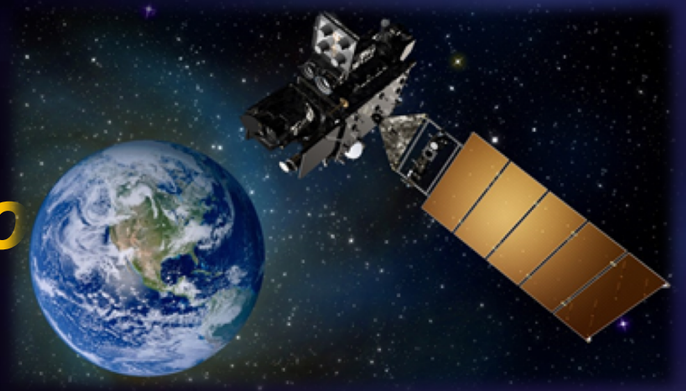
LOCKHEED MARTIN





Advanced Technology Center

Driving the Future Through Innovatio

Earth Science Technology Forum
June 13, 2019

Dr. Nelson Pedreiro
Vice President, LM-ATC

ADVANCED TECHNOLOGY CENTER

R&D Laboratory for Lockheed Martin Space

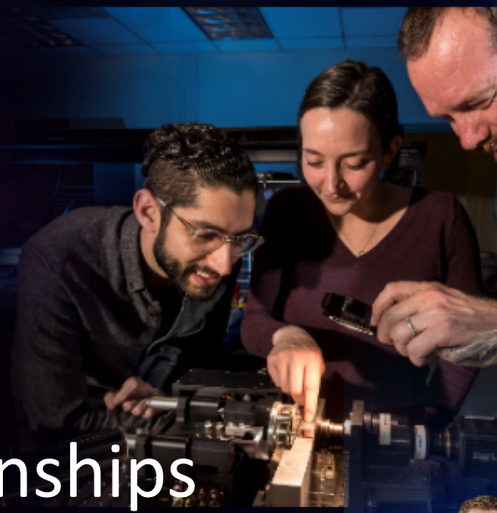
60+ years of scientific discovery and technology innovation enabling our customer missions

OUR TEAM & PARTNERS

Headquartered in Palo Alto, CA

500 Scientists & Technologists

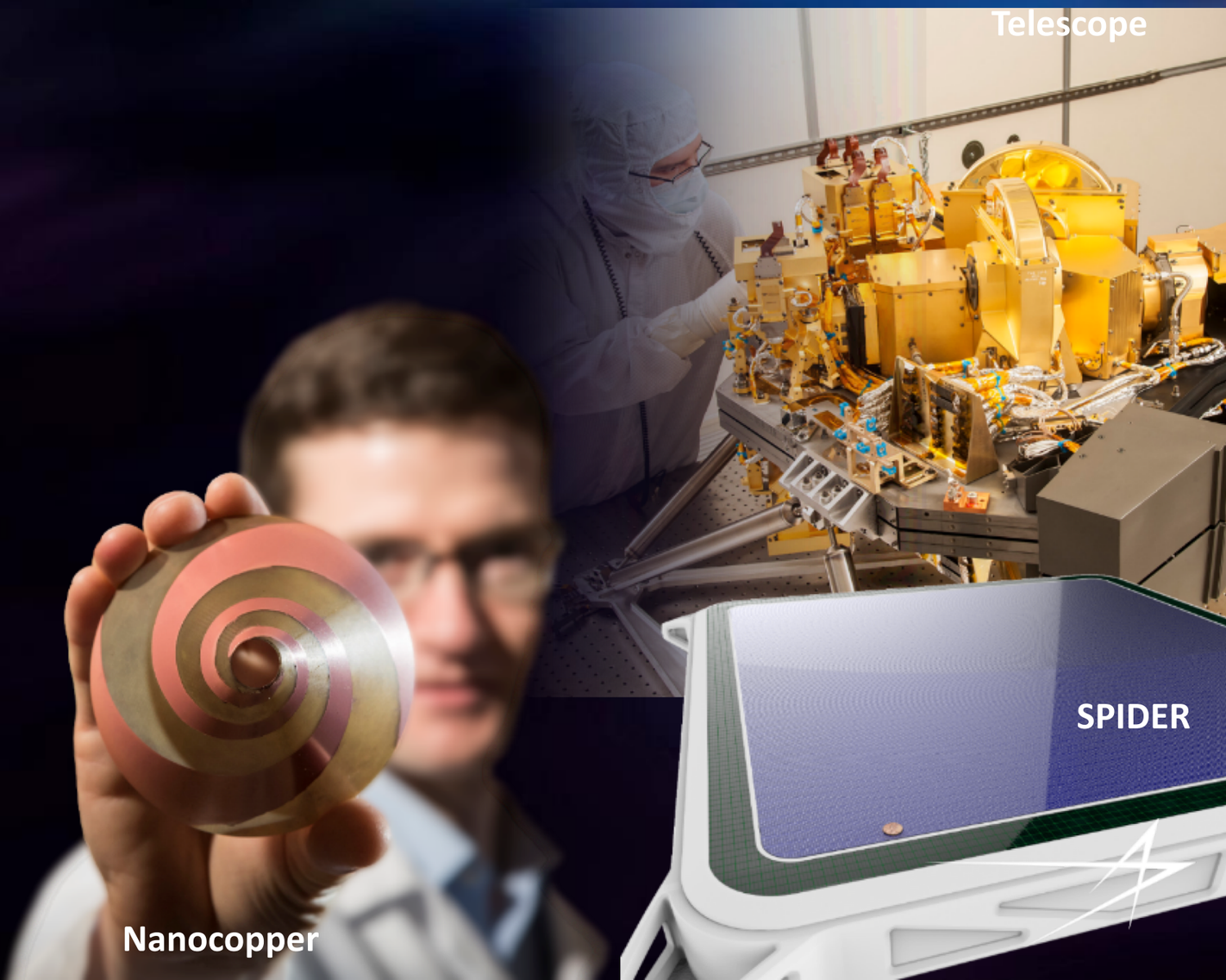
Accelerating R&D through relationships with multiple organizations and universities



U.S. & International Universities • Government Research Centers • Defense Laboratories • Industry Partners

OUR APPROACH

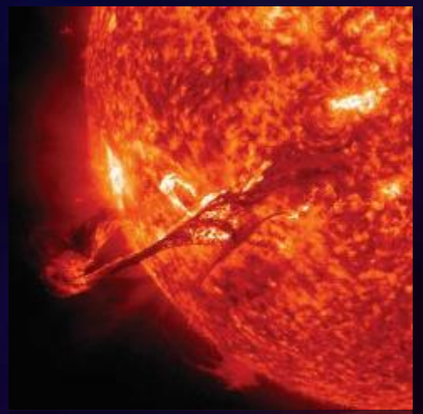
- Mission relevance
- Innovation and transition
- Accelerate development



WEATHER & EARTH SCIENCE MISSIONS

- For over 60 years we have been working alongside NASA…
- From the launch of TIROS-1 in 1960, our nation's first weather satellite, we have provided over 100 satellites to monitor our weather and environment
- GOES-16 and -17 are operational over the East and West Coast of US, respectively
- Geo-Lightning Mapper (GLM) instrument on GOES-R series
- Developing the Geostationary Carbon

ATC PORTFOLIO



SPACE SCIENCES & INSTRUMENTATION

OPTICS & LASER TECHNOLOGY

AI, DATA ANALYTICS & EXPLOITATION

SPACE SECURITY & COMMUNICATIONS

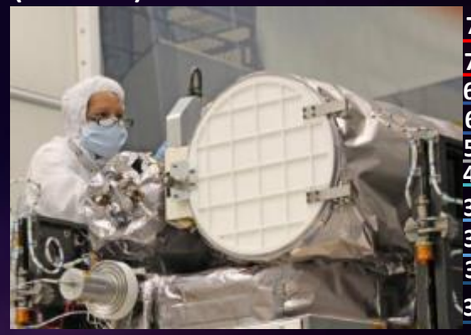
HYPERSONICS & ADVANCED MATERIALS

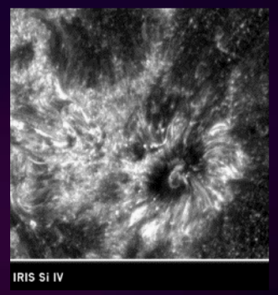
SPACE SCIENCES

180+ space instruments over six decades
800+ Years of Operation in Space

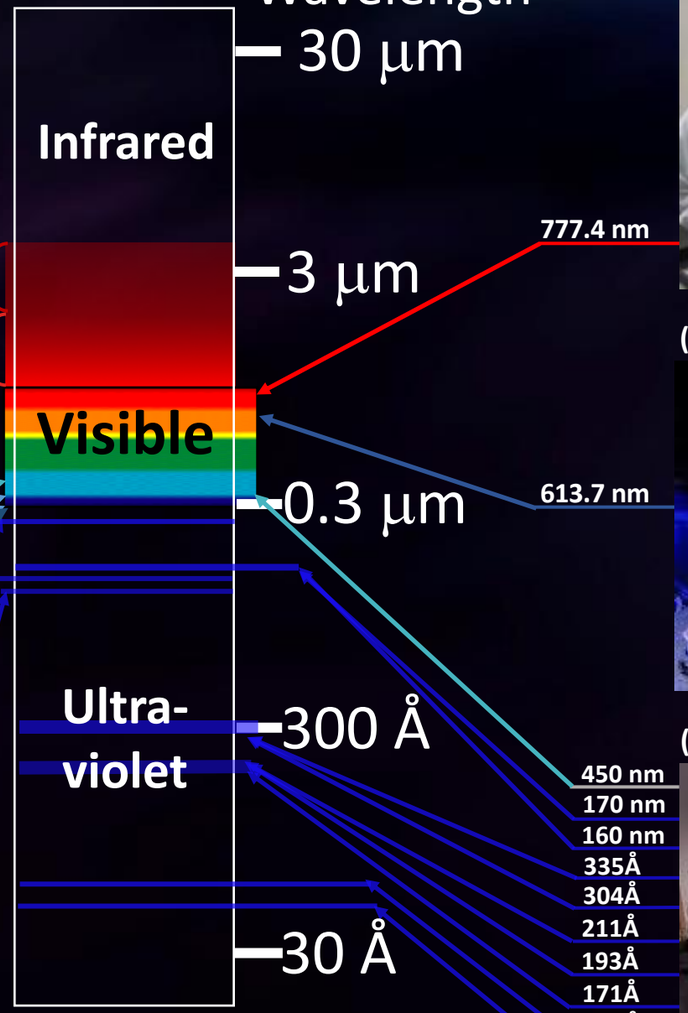
(JWST) NIRCAM Launch 2021

(DSCOVR) EPIC Launch 2015

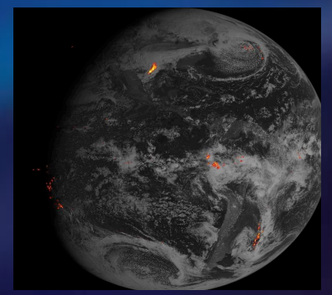




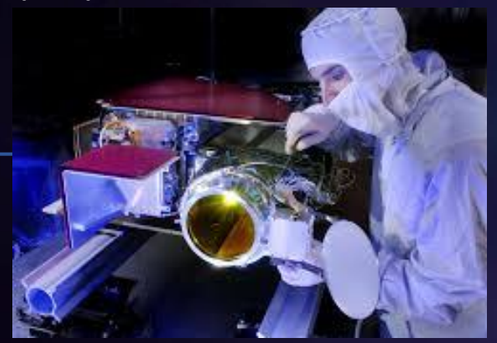
(IRIS) IRIS Launched 2013

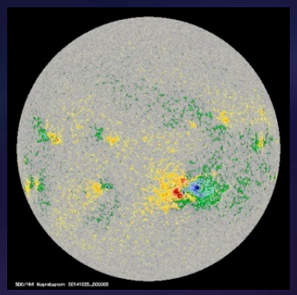


(GOES-R) GLM Launch 2016

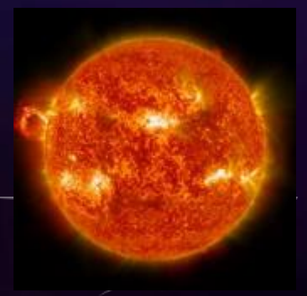


(SDO) HMI Launched 2010





(SDO) AIA Launched 2010



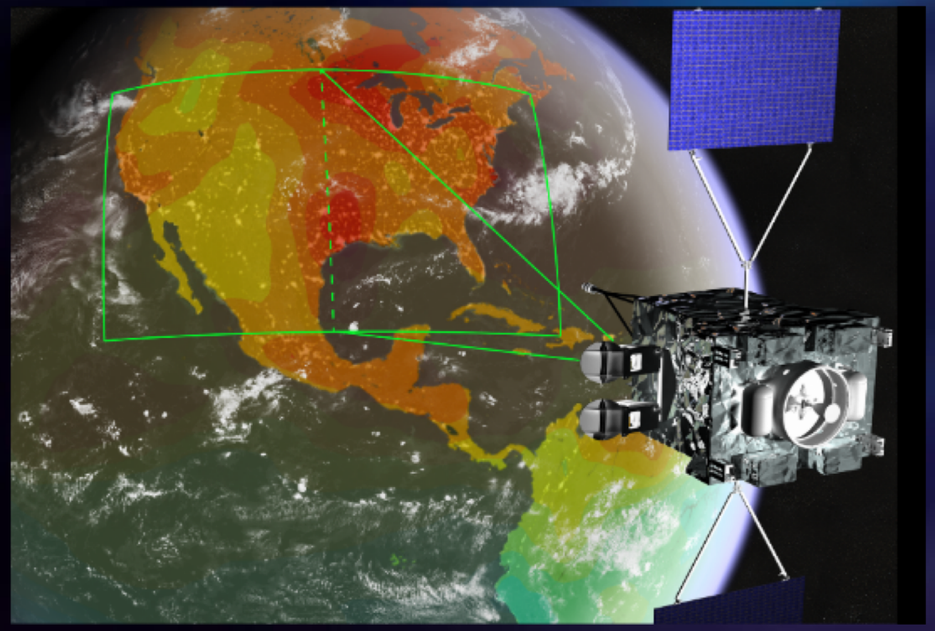
GEOSTATIONARY CARBON OBSERVATORY (GEOCARB)

Persistent Observations for Transformational Advance in Our Understanding of the Global Carbon Cycle

- Geostationary hosted payload designed to measure the most critical carbon gases: Carbon Dioxide (CO2), Methane (CH4), and Carbon Monoxide (CO)

- Measures Solar chlorophyll Induced Florescence (SIF): an indicator of how well a plant is undergoing photosynthesis (early indicator of plant stress with agricultural applications)

- These combined observations enable identification of sources, sinks, and attribution allowing us to disentangle natural and human contributions to the carbon balance



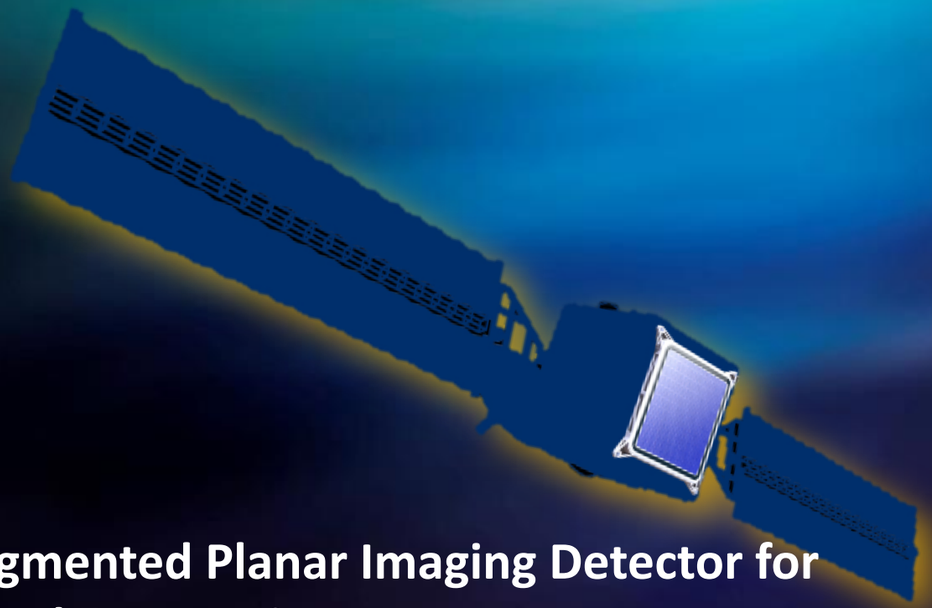
Earth Venture Mission-2 (EVM-2) – 2022 Launch

Hosted on SES Government Solutions communication satellite

Single slit, four-channel near-IR spectrometer

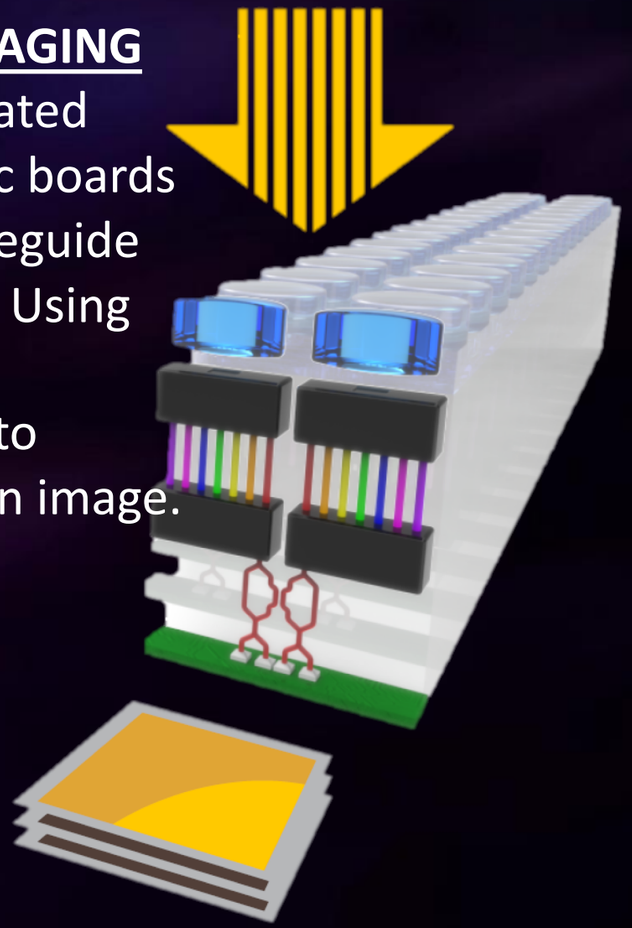
COMPUTATIONAL IMAGING

Re-inventing imaging sensors



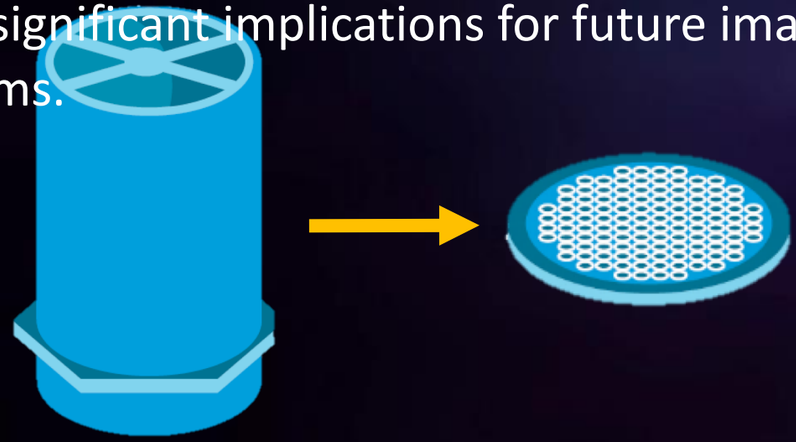
COMPUTATIONAL IMAGING

PIC's (Photonic Integrated Circuits) are electronic boards with microscopic waveguide segments embedded. Using PIC's we can interfere incoming light waves to digitally reconstruct an image.



SPIDER - Segmented Planar Imaging Detector for Electro-optical Reconnaissance

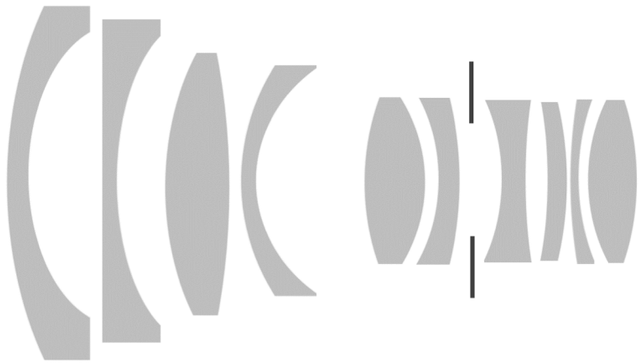
Using PIC's and Computational Imaging, the ATC is developing the SPIDER system which can take the capabilities of a traditional space telescope and package it into a versatile low-SWAP circuit board with significant implications for future imaging systems.



THIN FILM OPTICS

Replacing complex optical systems with low-cost, thin film optics that can be rapidly manufactured

Replace these…



… with this

- Single element
- Thin film on substrate
- Low-cost
- Arbitrary lens profile
- Designs that cannot otherwise be manufactured

The technology has been demonstrated for visible, infrared, and mid-wave optics

CRYOGENICS

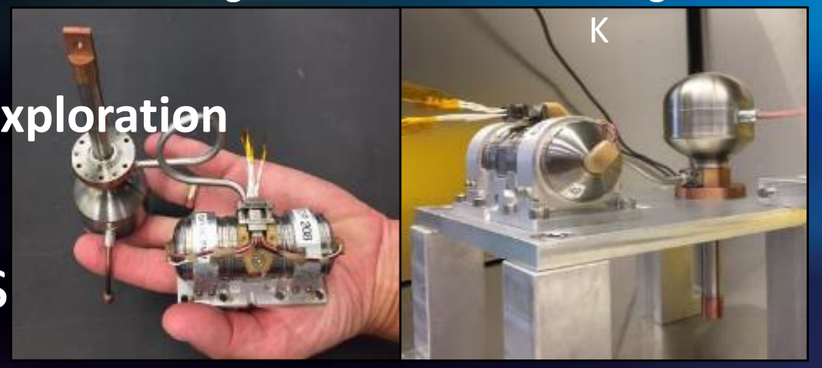
Enabling space sciences, remote sensing and space exploration

- Smallest, lightest space cryocoolers enable new missions: CubeSats, harsh deep space environments, long-life tactical cooling

- Large multiple-stage coolers enable long-life active cooling to below 4 K for space science with extremely low disturbance to sensitive optical systems

1 W Cooling at 85 K

0.3 W Cooling at 35 K

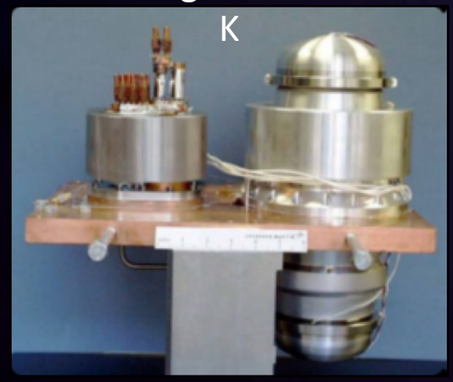


CubeSat-Sized 475 gram Microcryocooler for Space Missions:
Europa Clipper, Psyche, LunIR

Cooling at 7 K

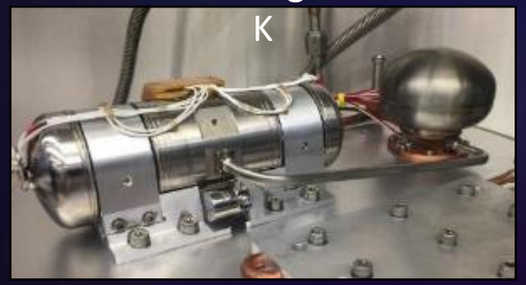
Hydrogen Cryostat:
WISE, WIRE

Cooling to Below 4 K



20 kg Mega Cryocooler for Large, Very Cold Instruments (Lynx, OST)

2 W Cooling at 100 K



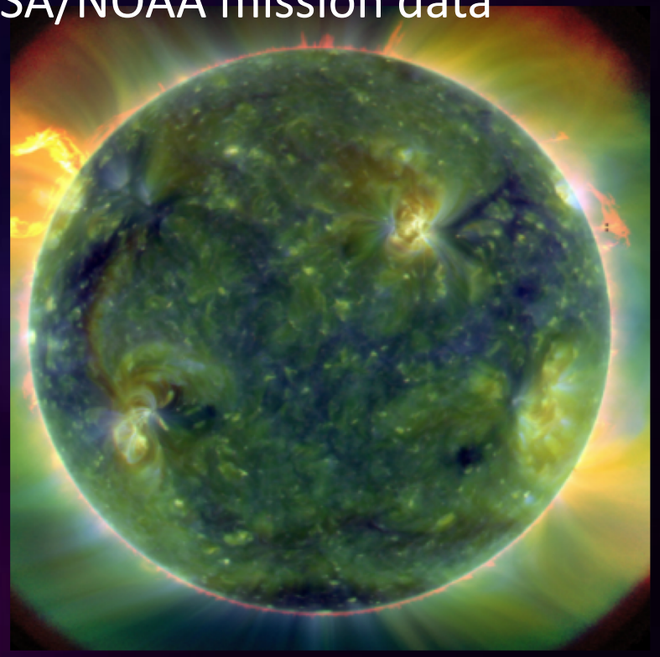
1.8 kg LCOS Mini Cryocooler

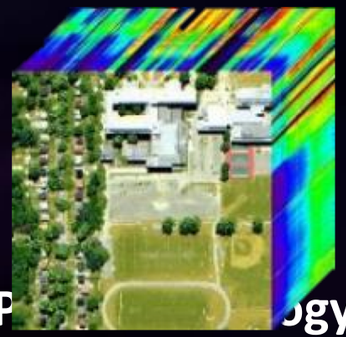
AI, DATA ANALYTICS & EXPLOITATION

Developing autonomous/cognitive systems for space that leverage physics-based understanding of observables

Space Sciences

First-principles, massively parallel numerical models for understanding NASA/NOAA mission data

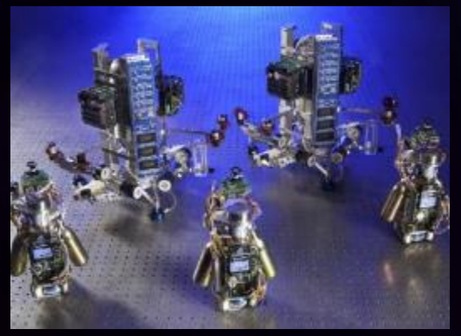




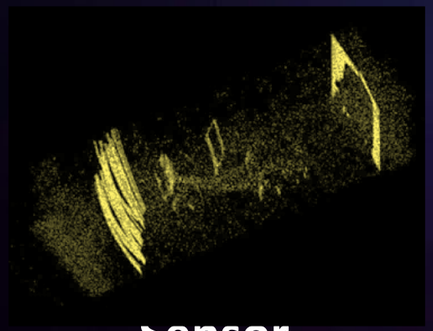
P ogy & Mission Architecture

Computing Technologies

Cognitive Sensing



Autonomy & Robotics



Sensor Information & Extraction

SPACE SITUATIONAL AWARENESS

Protecting military, civil, and commercial space assets

Unique capabilities in interferometric imaging and laser remote sensing provide information about objects in space and understanding of specific events

SPOT FACILITY - SANTA CRUZ, CA

STILT TRAILER

EOS FACILITY - AUSTRALIA

UKIRT - HILO, HI

NANOMATERIALS

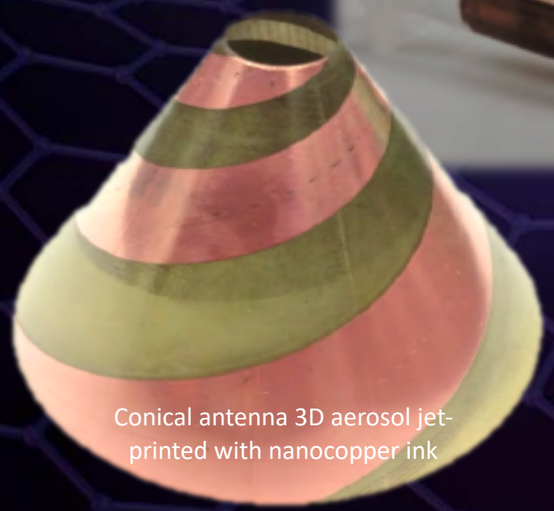
Creating novel capabilities and advancing manufacturing

- Graphene and 2D materials
  - Unique wafer-scale CVD graphene synthesis and transfer
  - Nanomembrane fabrication and characterization
  - Advanced electronics and optoelectronics development

- NanoCopper
  - Flowable metal adhesive copper paste and printable ink
  - High performance solder paste replacement

Wafer-scale graphene sheet (one atom thick) synthesized at LM-ATC, embedded in silicone for handleability

Nanocopper metal-adhesive “solder” paste



Conical antenna 3D aerosol jet-printed with nanocopper ink