Suborbital Applications in Astronomy and Astrophysics

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Overview of Astronomy Applications

Astronomy applications could benefit from:

- Suborbital flights providing access to zero-g in a space environment
  - Demonstrating new technologies in a relevant environment
  - Flight testing of individual elements of a constellation
  - Raising the TRL of critical technologies for subsystems on future large missions
- High-altitude balloons (up to ~10 kg payload)
  - Access to near-space for wavelengths not observable from the ground
  - Raising the TRL of critical technologies for subsystems on future large missions
  - UV Detector testing

What Space Astronomers Really Want

- *Most new space astronomy missions want some combination of these elements:*

- Ability to launch large, massive payloads
- Escape from Earth orbit !
  - Earth orbit is very limiting for viewing restrictions, thermal, etc.
  - Earth-Sun L2, Earth-trailing
- Large diameter optics
  - Most regimes are photon-starved, so small telescopes limit the science
  - Very high quality optics for high-contrast imaging
- Precision pointing (much better than HST)
- Large format detectors
- High data rates to the ground

Not all Astronomy needs Large Optics

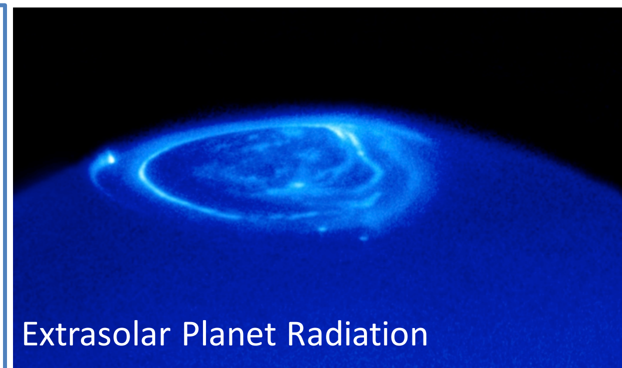
- *Low-frequency radio arrays* for heliophysics and astrophysics
  - Need multiple spacecraft – minimum ~10, ideally 50+
  - Operates in formation-flying (at low precision)
  - Each element has a very simple science instrument: dipole antenna and radio receiver
  - Attitude control needs are modest
  - Formation control needs are modest
  - Relative ranging needs are modest

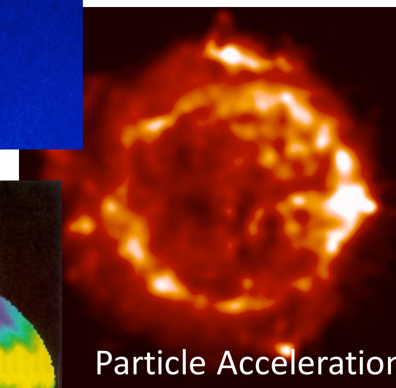
- *Transit spectroscopy* of bright stars for detection of exoplanets
  - Can be done with a simple camera and CCD detector
  - *Exoplanetsat* is a 3-U Cubesat under development at MIT (PI: Sara Seager) – observes one star at a time
  - Requires precision pointing

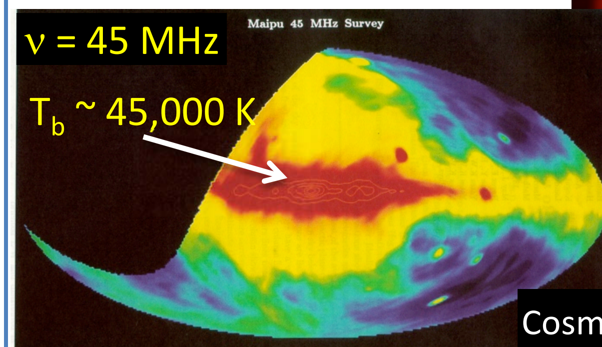
Low-Frequency Radio Arrays Using CubeSats

Science Drivers

- Cosmic Dawn pathfinders – probe spectral smoothness of Galactic and extragalactic foregrounds, confirm extent of shielded radio zone behind Moon
- Magnetically generated emissions from extrasolar planets – determine magnetic field strengths of extrasolar planets, assess impact for habitability
- Particle acceleration – image sites of Galactic and extragalactic particle acceleration, e.g., supernova remnants, halos and relics in clusters of galaxies


Extrasolar Planet Radiation


Particle Acceleration



Cosmic Dawn Foregrounds

Mission Concepts

- Cubesats carry dual polarization antenna and associated electronics
- Relevant frequency range ~ 1 to 150 MHz
  - Optimization possible depending upon science mission
- Cubesat numbers range from 1 to many
  - Constellations preferred, threshold missions involving single cubesat possible

Programmatic Considerations

- Science drivers responsive to Astronomy Decadal Survey and related NRC reports
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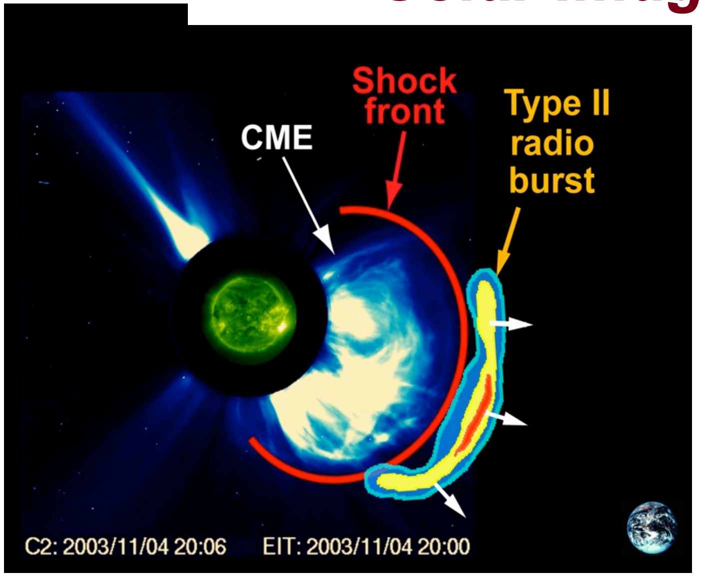
Example: Heliophysics Mission Solar Imaging Radio Array (SIRA)



SIRA will image radio emission from CME-driven shocks and flare electron beams propagating into the inner heliosphere at frequencies inaccessible to ground based radio telescopes.

Science Objectives:

- Enhance understanding of interplanetary propagation and evolution of coronal mass ejections (CMEs) using radio images of CME-driven shocks, plasmoids, and electron beams
- Enhance understanding of particle acceleration & transport using images of radio bursts produced by electrons
- Use radio imaging near Sun to predict hazardous space weather
- Obtain and analyze the first full-sky maps from 0.1 to 15 MHz

Associated RFAs:

F1. Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, ...

F2. Understand the plasma processes that accelerate and transport particles.

H1. Understand the causes and subsequent evolution of solar activity that affects Earth's space climate and environment.

Mission Implementation Description:

- Microsat constellation of 12-16 identical s/c
- Microsat: 30 kg (wet), 90 W, use of ST-5 bus
- Payload: 10 kg/sat, 10 W/sat
- Carrier/mother: buffers/xmits (Ka-band) d/l
- ΔV: 100 m/s (carrier), ~7 m/s (microsat)
- Ellipsoid constellation, 1 km diameter at L1
- 2 high-heritage antennas & receivers per s/c
- Image synthesis done on the ground at SIRA Science Centers

Measurement Strategy:

- Imaging at ~12 frequencies corresponding to ~2 R_{SUN} – 1 AU
- 2-bit Nyquist sampling at each frequency
- ~2.4 GB science data per day per microsat
- "Snapshot" processing on ground for space weather prediction

Enabling and Enhancing Technology Development:

- Low cost intersatellite ranging with 3 m accuracy to ranges of 50 km is simple to build, but has not been tested in flight
- SIRA and other Ka-band users need more ground station capacity

Low-Frequency Array - Requirements

- Orbit:
  - Mission cannot be done in LEO
  - Lunar L4/L5, solar L1, or distant retrograde orbit (170-220 R_E)
- Constellation: 10+ antennas
  - Array size: up to 100 km
  - Array control to ~10s meters
  - Low-precision ranging to ~3m precision
  - Relative velocity control to ~few mm/s
  - Fuel: delta-V ~1m/s monthly
  - Mother ship data relay to Earth
- Instrumentation
  - 3 orthogonal dipole deployed antennas (or dishes)
  - 3-axis stabilized to ~1deg pointing
  - Radio receivers: 1-30 MHz, with >10% bandwidth

Suborbital Demo of Array Element?

- Array control:
  - Testing of microthruster operation and performance in zero g
  - Microthruster charging and deposition
  - Needs appropriate environment – outside of vehicle?
- SmallSat flight testing
  - Deployment of large flexible antennas in zero g
- Would like to test if possible:
  - Attitude control with microthrusters
  - Electronics – RF receiver on a chip, low-power electronics, FPGA-based RF processing
  - Low-precision ranging

  - *These need appropriate environment: outside of vehicle*

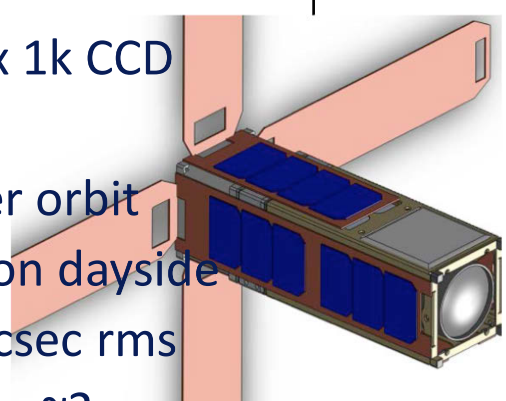
Exoplanetsat: Transit Survey with a Cubesat

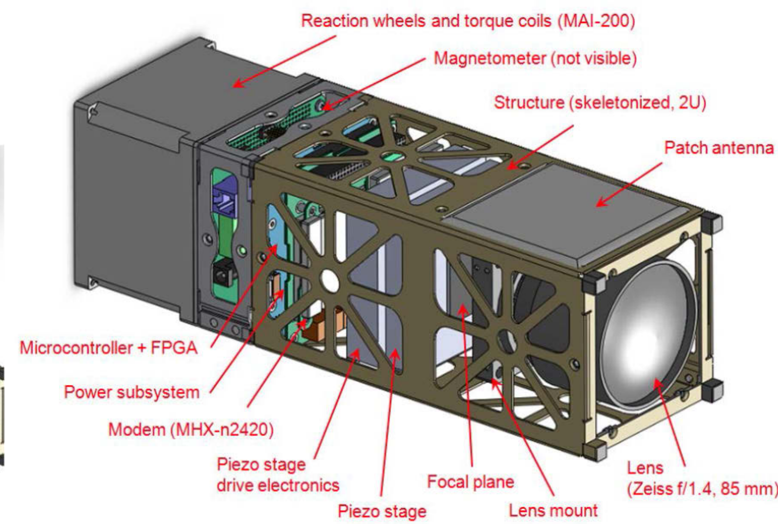
Astronomy and Physics Directorate

- Conduct a survey for transiting exoplanets around bright stars (V=0-5)
- Find exoplanets around the closest, brightest stars – suitable for followup with spectroscopy, astrometry, etc.
- Key drivers:
  - Need to observe many targets
  - Need long duration on-target
  - Precision pointing for control of photometry systematic errors

- *Exoplanetsat* approach
  - Developed by Sara Seager, MIT
  - Ready for launch in 2012
  - Requires LEO orbit

- ***Exoplanetsat*** design:
  - 77mm diameter Zeiss/Leica camera
  - Back-illuminated 1k x 1k CCD
  - CMOS guide arrays
  - Observes one star per orbit
  - Solar array charging on dayside
  - Pointing jitter ~60 arcsec rms
  - Piezo stage reduces to ~2 arcsec RMS

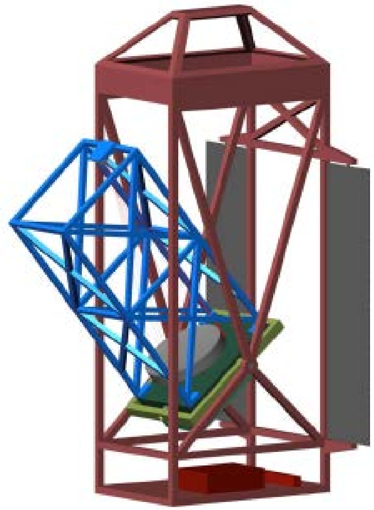


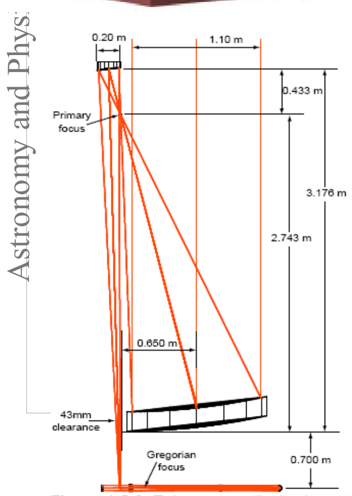


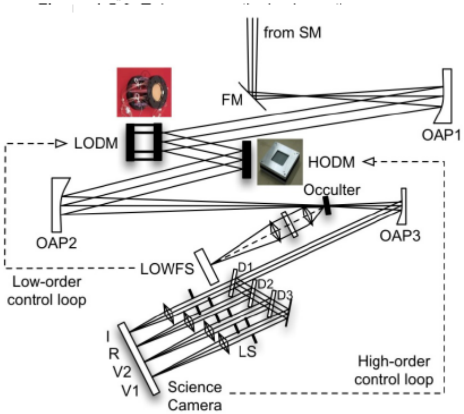
PICTURE: Planetary Imaging Concept Testbed Using a Rocket Experiment

- Sounding rocket experiment to image the exozodiacal dust disk of nearby bright star Epsilon Eridani in reflected visible light
- White-light nulling interferometer
- Terrier-Black Brant launched from White Sands Missile Range on Oct 8, 2011
- Unfortunately, no science data was recovered
- On-board diagnostic data showed fast (200 Hz) optical tracking system that provided 2 mas in-flight pointing stability, 1000x better than the ACS

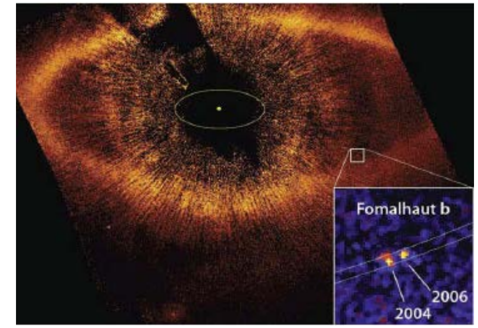
ZODIAC: Exozodiacal Disk Imaging from a High-Altitude Balloon (as proposed, 2011)



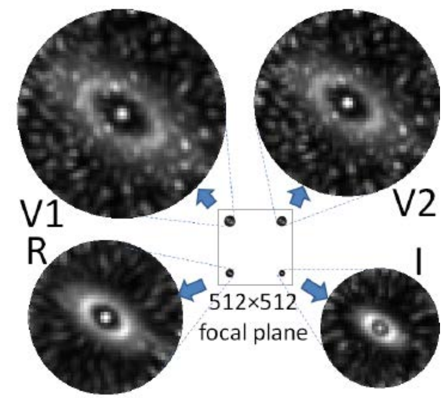




- **Hardware:**
  - Telescope & coronagraph
  - Above 99% of atmosphere to eliminate seeing and speckles
  - Images dust disks around nearby stars



- **Observations:**
  - Coronagraph suppresses starlight
  - Dust disk brightness is ~ 10^{-7} times star
  - Images in 4 visible-wavelength bands
  - 1-day flights (US) & 10-day flights



- **Science:**
  - Measure size, shape, brightness, color, & numbers of disks
  - First step toward direct imaging of exoplanets from space

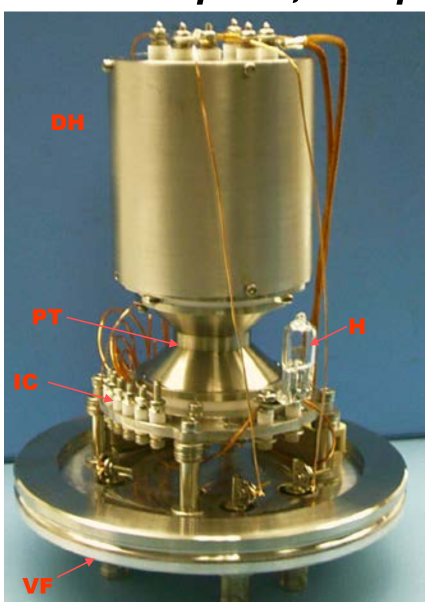
Technology:

- Establishes TRL-7 for deformable mirrors, coronagraphs and SiC mirrors for optical

MASS-SPECTROMETRIC MEASUREMENTS OF CLIMATE-CHANGE SPECIES IN THE MESOSPHERE AND "IGNOROSPHERE"

Dr. A. Chutjian, JPL/Caltech

- ***Explore the Earth's mesosphere (30-80 km) and the so-called "ignorosphere" (50-130 km) for climate-change species such as CO_2, CH_4, N_2O, $CFCl_3$, CCl_2F_2, $CHClF_2$, H_2O, and O_3 .***
- ***Observe concentration variations with altitude, latitude, meridian, day & night, and space weather; detection sensitivities are in the range 10 ppb to 10 ppm.***
- ***Use quadrupole ion trap (QIT) mass spectrometry in a CubeSat format and a suborbital spacecraft; mount QIT with its entrance aperture in the ram direction.***
- ***The QIT – with a gas chromatograph – has been aboard the ISS for the past two years monitoring 35 trace species and N_2, O_2, CO_2, Ar in the cabin atmosphere.***
- ***Instrument developments needed for this application are to reduce electronics to a CubeSat 2U template; and provide a regulated flow of ambient atmosphere into the QIT.***



Photograph of the flight quadrupole ion trap mass spectrometer subsystem presently aboard the ISS. The legend is: vacuum flange (VF), electron-impact ionizer connections (IC), the Paul Quadrupole Ion Trap (PT), detector housing (DH), and heater (H). For scale, the diameter of flange VF is 4.3".

Mass Spectrometer - Requirements

- Observation over a range of altitudes ~30 to ~150 km
- Access to space environment
- Design must ensure molecules from the environment are able enter the instrument
  - Collect from the ram direction?