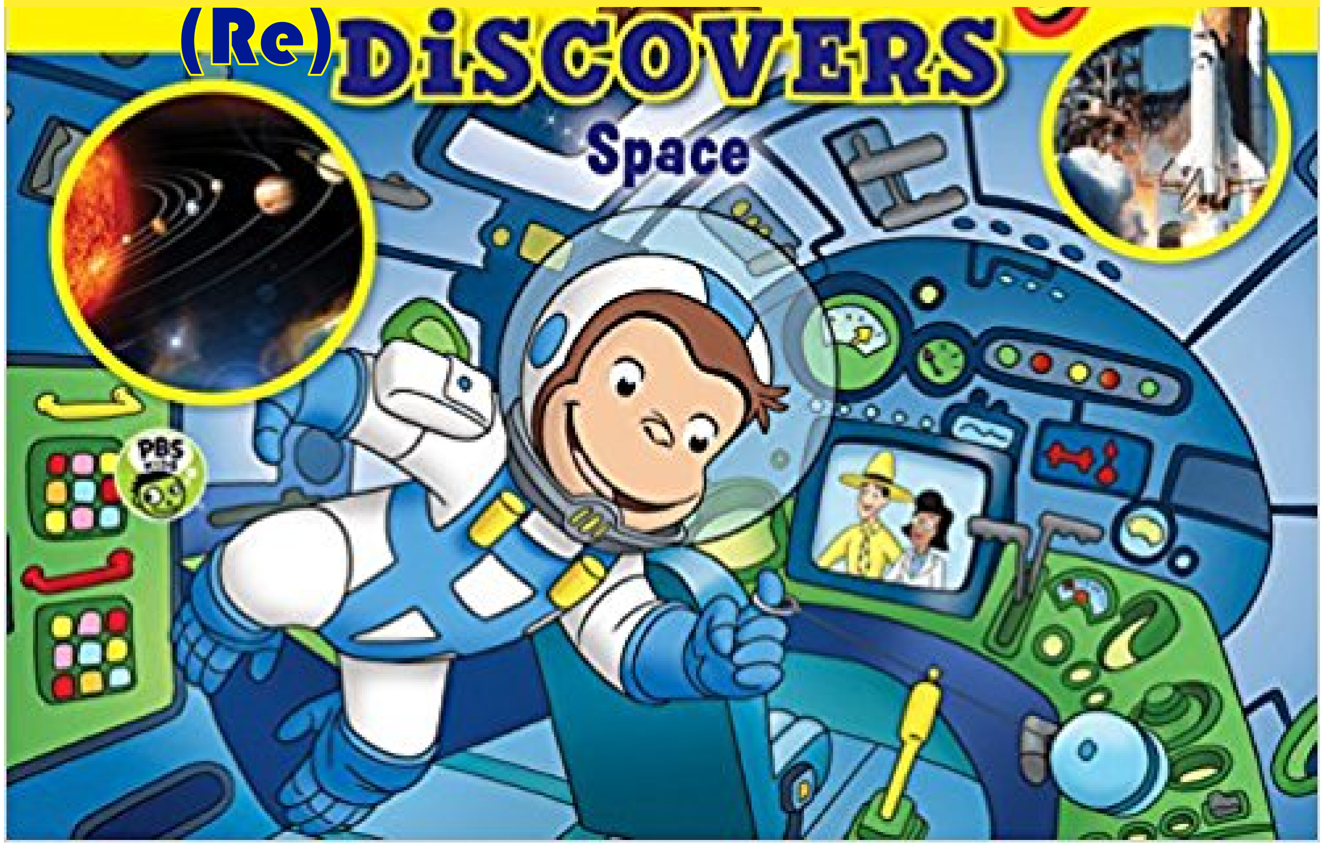
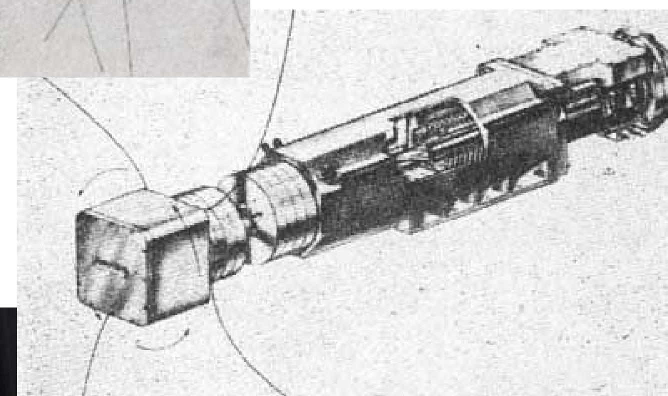
MIT
HAYSTACK
OBSERVATORY

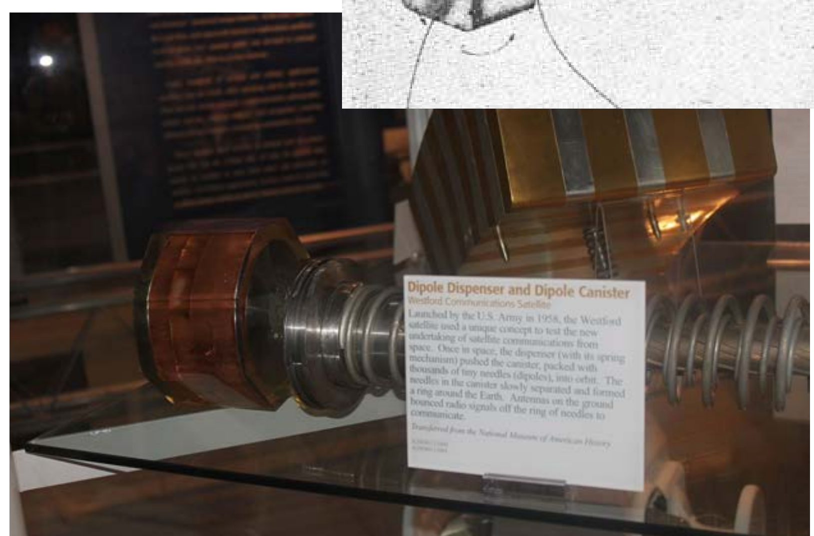


Michael Hecht
Assoc. Dir. For Research Management

Project West Ford (aka Project Needles)

- In 1961 and 1963, our Lincoln Lab predecessors launched 480 *million* small copper dipoles into a medium Earth orbit (3600 km).
- Using 18.5 m antennas,they successfully demonstrated communication at ~20 kbits/sec from Millstone (the present-day Haystack site) to Camp Parks, CA.
- Half-wave dipoles were designed to carry 7.75 and 8.35 GHz and to be separated by an average of 0.3 km
- Goal was jam-proof communications



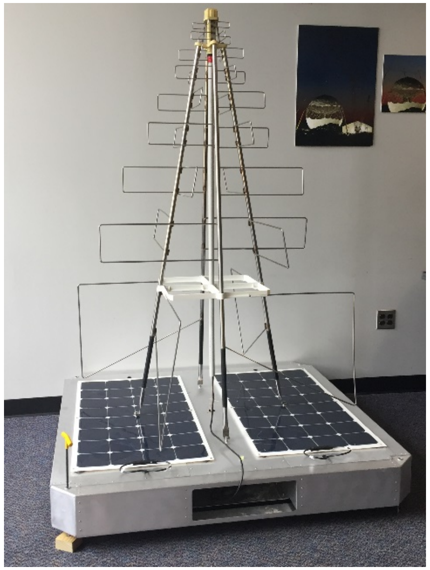


Why is space important for us?

- Compelling science, relevant to our expertise, e.g.
  - Low frequency science not possible below the ionosphere
  - Longer VLBI baselines than possible on Earth
- Growing opportunities within NASA
  - NASA is embracing small tag-along missions ($5-$50M) with relatively aggressive risk posture (SIMPLEx, SALMON, etc.)
  - In comparison, NSF radio opportunities are static or shrinking
- Radio bands on Earth are increasingly polluted
  - Equivalent to the Dark Sky problem for optical astronomy
- Doesn't take a NASA Lab! (Though they can help). Several NEROC Institutions already hosting missions.

How can we play? What's our edge?

- Local technologies
  - Haystack
    - RAPID-related technologies
  - Lincoln Lab
    - ✓ Vector sensors & radios
    - Laser comm
    - Directed laser energy
- Local facilities
  - Mission science enhancement
    - ✓ Ionosphere with MHGF (Van Allen Probes)
    - ✓ Jupiter emissions with RAPID (JUNO)
    - Radio bursts with RAPID (SunRISE)
  - Ground support
    - Ground stations (Westford)
    - ✓ Scientific databases such as Madrigal
- Limited only by your imagination

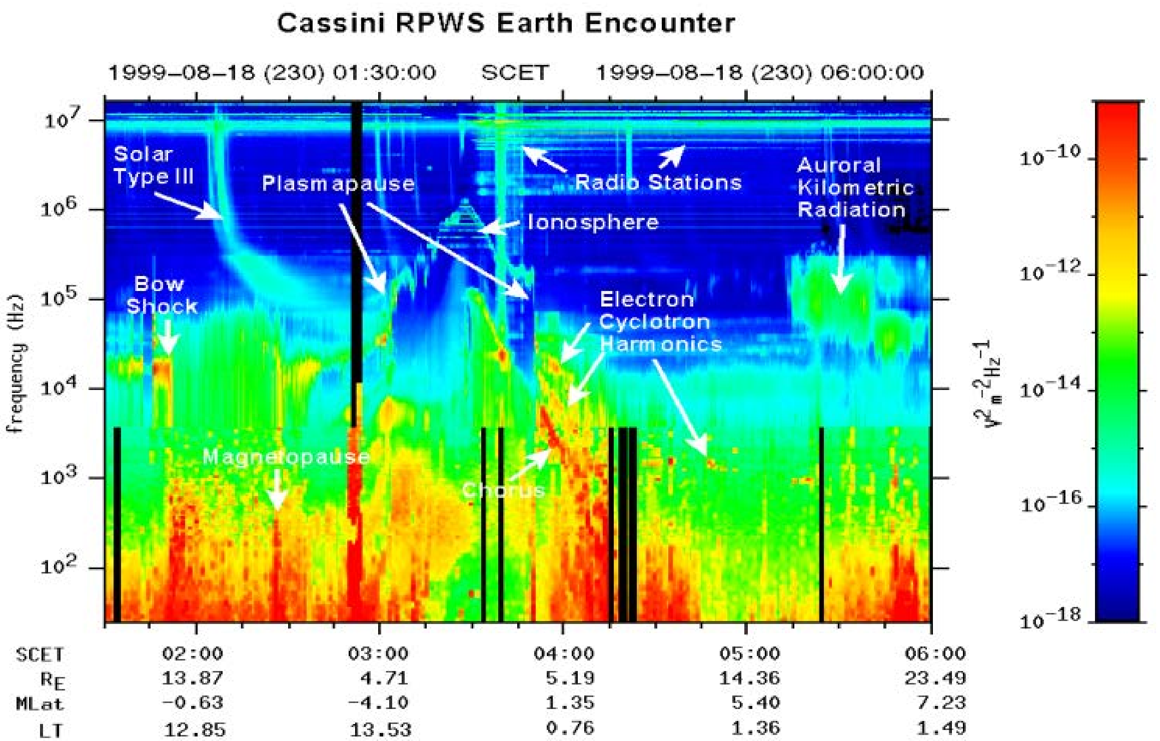


Still, it's not so easy…

- Proposals are high payoff, but long odds
  - Can take several tries before winning with a particular concept
- NASA is struggling with SmallSat risk posture
  - As SmallSats evolve from educational vehicles to mainstream scientific platforms, NASA is under pressure to accept less formal risk management and mission assurance.
  - But NASA labs and aerospace organizations are getting into the high-end SmallSat science business.

Focus on HF:
For <10 MHz, you need to go to space

- Radio Astronomy Explorers (RAE) I & II
- Electric field probes (Ulysses, WIND, Cassini, STEREO)
- Interferometry on CLUSTER measured AKR angle of arrival

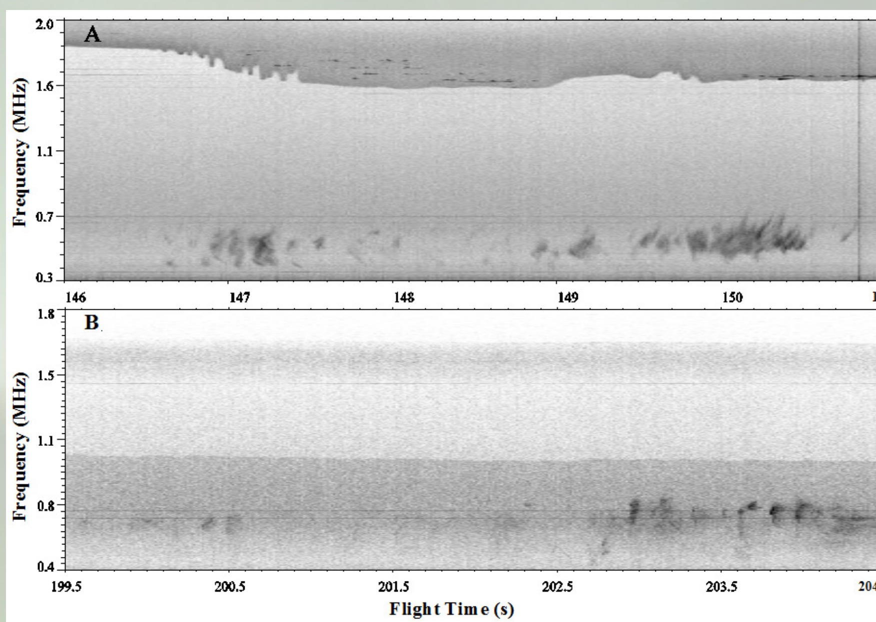


The Auroral Emission Radio Explorer (AERO)

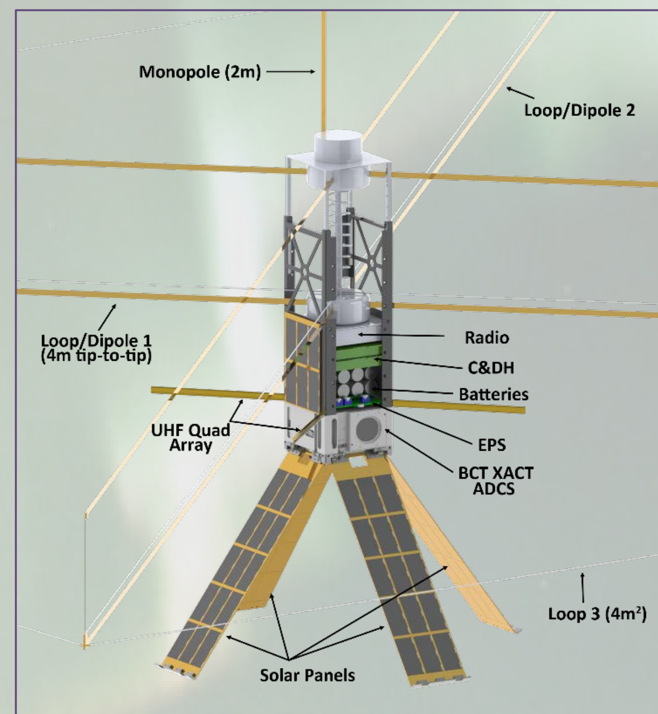
AERO
AURORAL EMISSIONS
RADIO OBSERVER

Dr. Philip J. Erickson, Principal Investigator

The Auroral Emission Radio Observer (AERO) is a 90-day CubeSat mission in polar orbit that will qualify and validate a novel electromagnetic vector sensor (VS) while answering key scientific questions about the nature and sources of auroral radio emissions. *These questions cannot be addressed from the ground due to shielding by the ionosphere*.

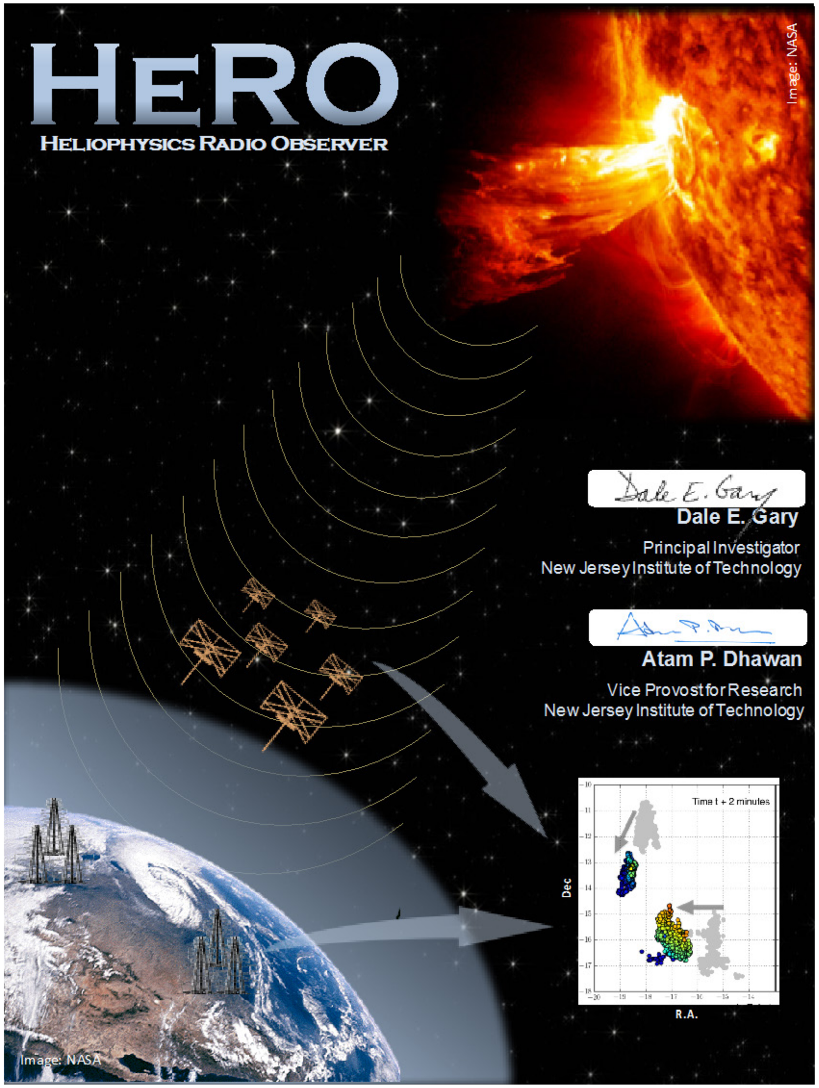


Radio spectrograms, typical of what AERO may encounter, measured with a sounding rocket



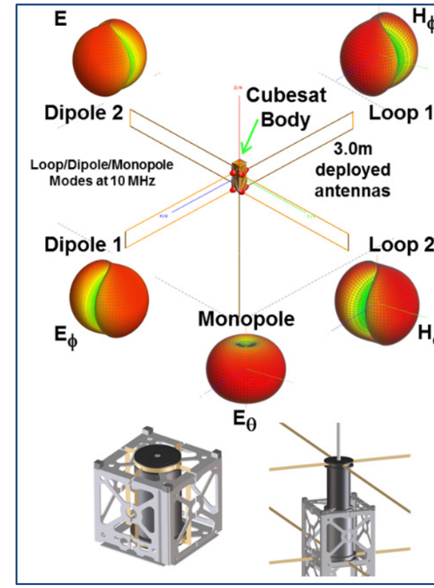
HeRO

- Science target was radio bursts at low frequency (farther from sun) as indicators of acceleration phenomena at shock front
- Significant ground element based on RAPID
- Proposed to SMEx/SALMON
- Similar mission (SunRISE) was selected

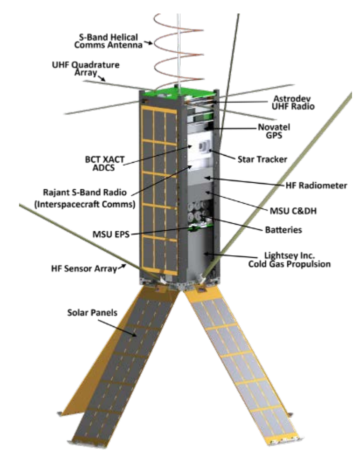


How to build an HF Interferometer in space

- At least 4 CubeSats separated by 1 -10 km
- Frequency band: 50 kHz-20 MHz
- Geosynchronous orbit to get above ionosphere
- Propulsion to hold approximate positions (& desaturate reaction wheels)
- Either GPS or an internal beacon system to accurately determine positions
- Antennas (electrically short 3-axis monopole or vector sensor)
- Correlation: On the ground or in space?
- Timing: Chip-scale atomic clock?

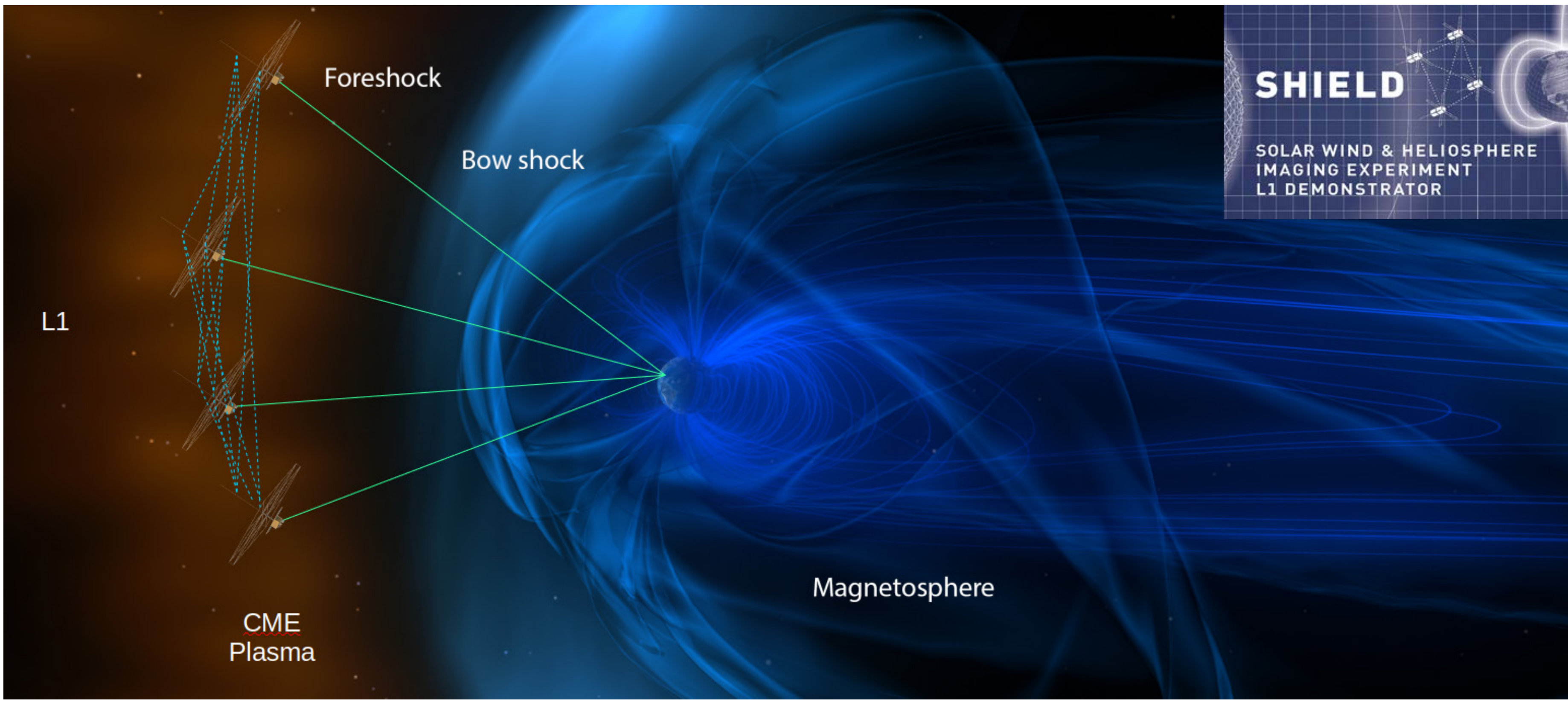


Vector antennas



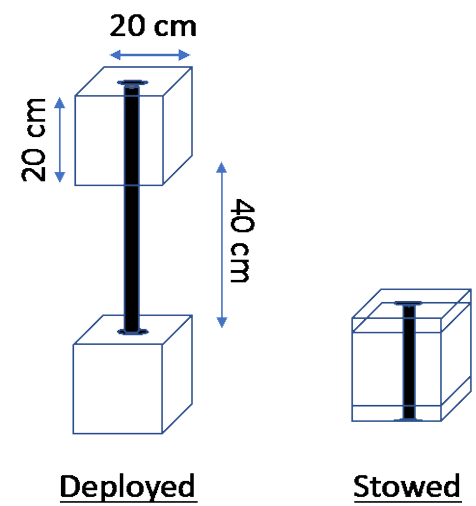
How about an HF tomograph?

- BeaconSats and SensorSats (or Simultaneous Transmit & Receive)
- Determine 4D structure of solar wind
- Measure electron current density and Faraday rotation along Tx/Rx path
- Monitor ICMEs incoming to Earth

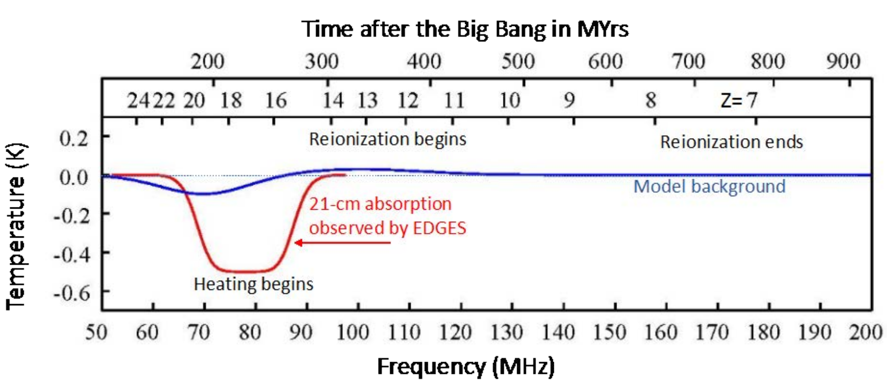


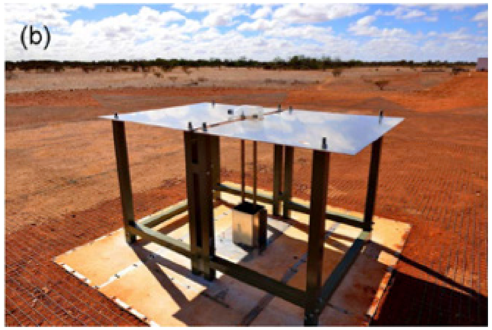
Or astrophysics?

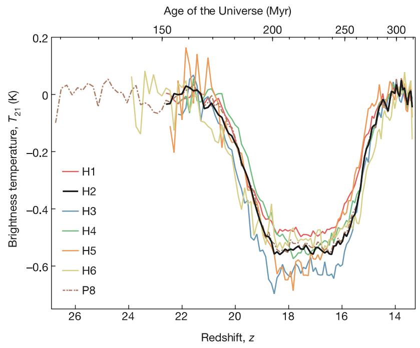
- EDGES observed 21-cm absorption from first stars!
- Confirmation behind moon (away from Earth foreground noise) is very attractive
- Can be achieved with CubeSat 1000 km above lunar surface (to put moon in null of dipole).



CoDEx CubeSat approach

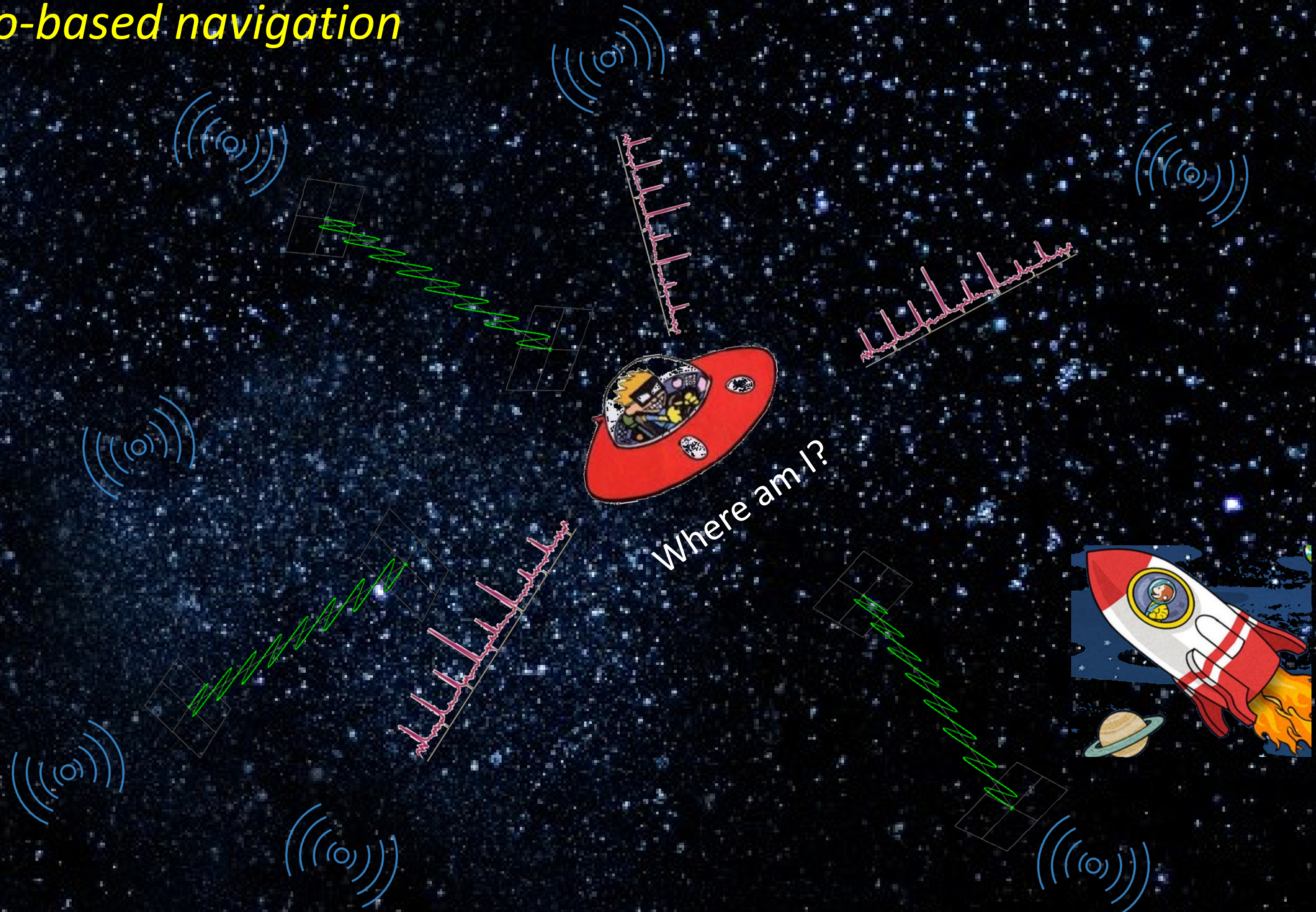






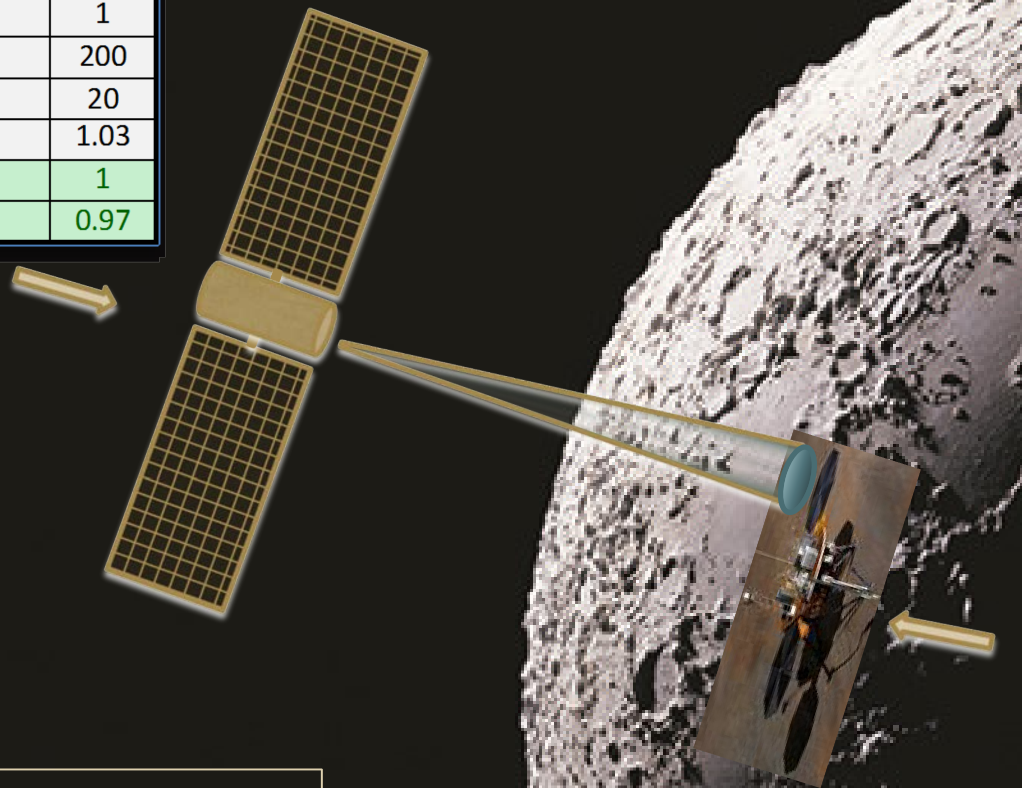

Space Logistics (deWeck group)
Exploration Infrastructure
NASA

Radio-based navigation



Space Solar Power for the Moon?

Spot size	
Pointing accuracy (arcsec)	1
Wavelength (µm)	1
Orbit height (km)	200
Mirror diameter (cm)	20
Dispersion (arcsec)	1.03
Minimum spot size (m)	1
Pointing accuracy (m)	0.97



Broadcast power	
Link time per orbit (min)	4
Orbit period (min)	132
Orbiter panel area (m^2)	2.5
Solar constant (W/m^2)	1361
Orbiter panel efficiency (%)	25%
Illumination duty cycle	50%
Energy collected (kW-hr/orbit)	0.94
Laser wall plug efficiency (%)	50%
Radiated power (kW)	7.0
Lander panel efficiency (%)	50%
Geometric collection efficiency	80%
Surface illumination (kW/m^2)	8.9
Average surface power (W)	108.3

- 7 kW radiated power in 1 meter spot
- Usable power comparable to MMRTG
- Conventional surface station
- SmallSat-scale orbiter
  - 1-3 kW-hr battery
  - 2.5 m^2 solar panel

Getting Mark Watney home

MOXIE
Mars Oxygen
ISRU Experiment

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J. Hoffman, *MIT (DPI)*
G. Sanders, *JSC*
D. Rapp, *Consultant*
B. Yildiz, *MIT*
G. Voecks, *JPL*
K. Lackner, *ASU*
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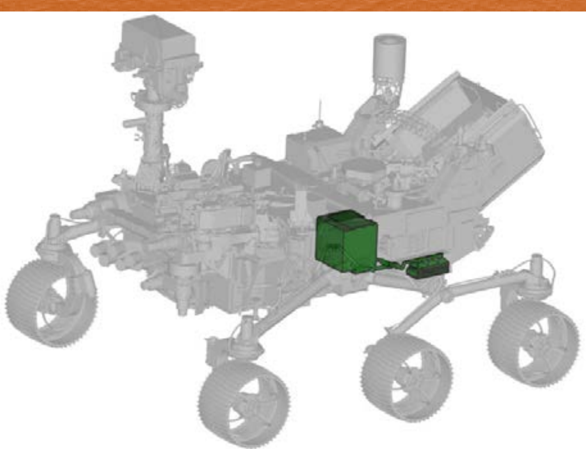
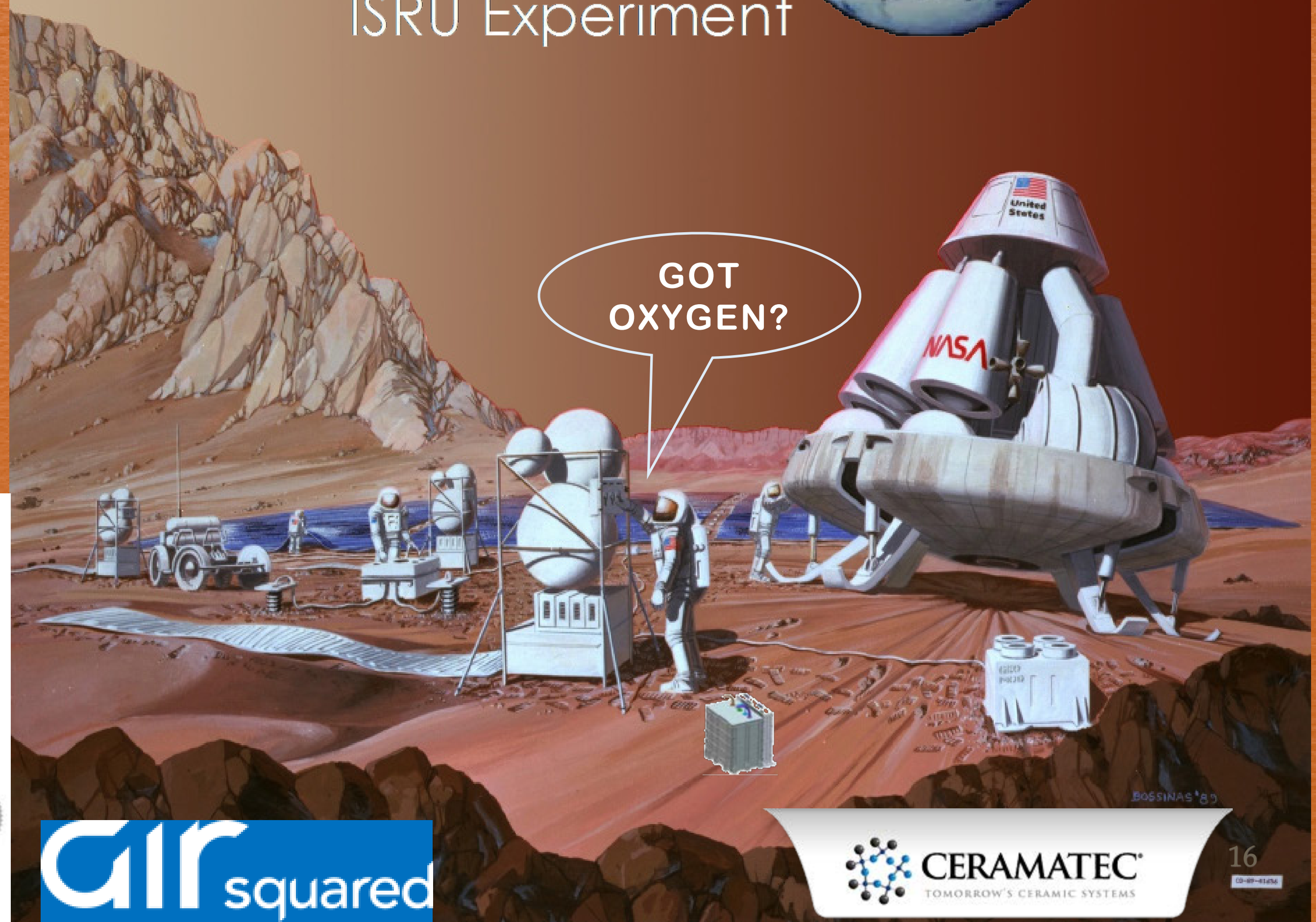
P. Smith, *Space Expl. Instr.*
W. T. Pike, *Imperial Coll.*
M. Madsen, *U. Copen.*
C. Graves, *DTU (Coll.)*
M. de la Torre Juarez, *JPL (Coll.)*

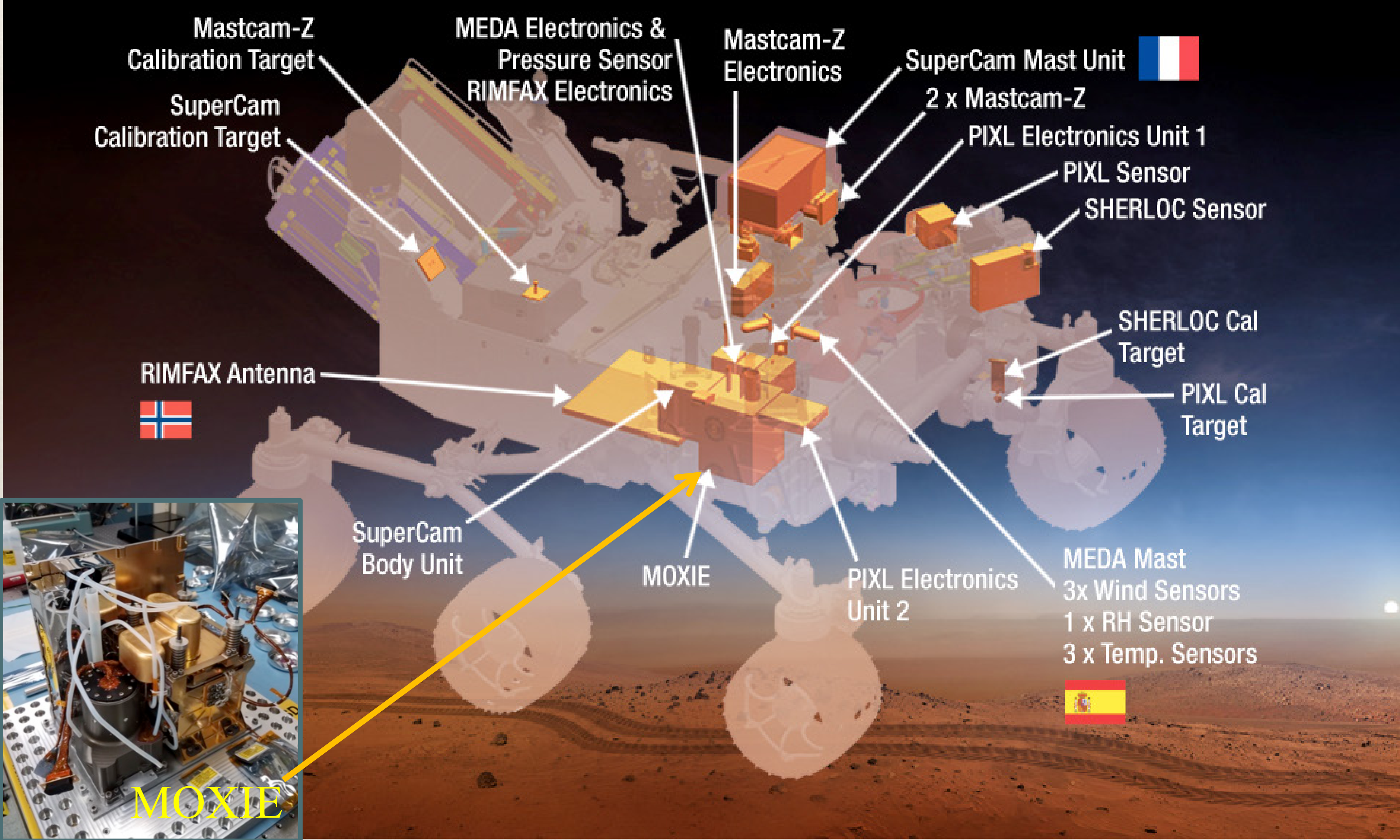


Jet Propulsion Laboratory
California Institute of Technology
J. Mellstrom , Project Manager

MOxIE
Mars Oxygen ISRU Experiment

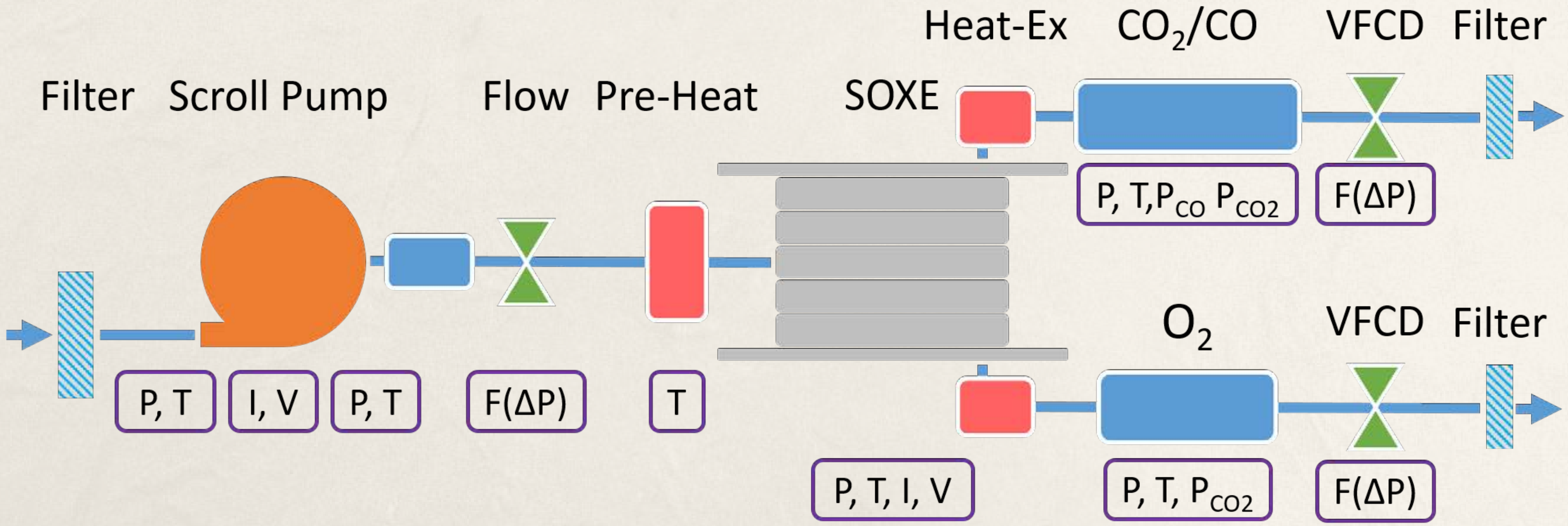


Mars 2020 Rover

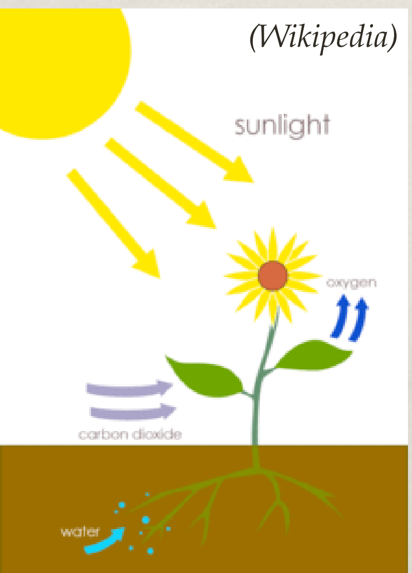


What's in MOXIE?

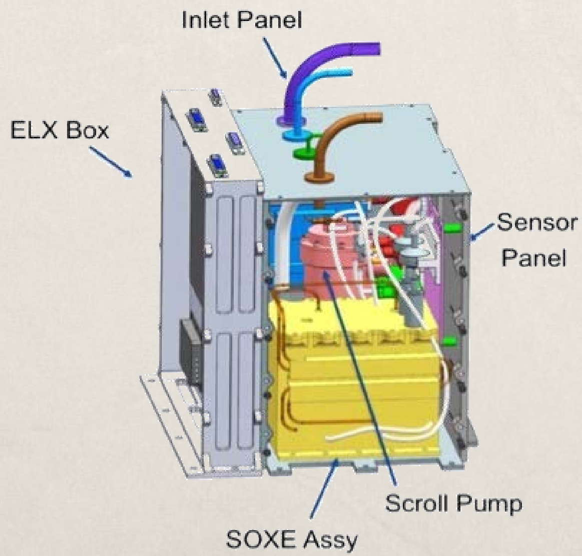
MOXIE
Mars Oxygen
ISRU Experiment

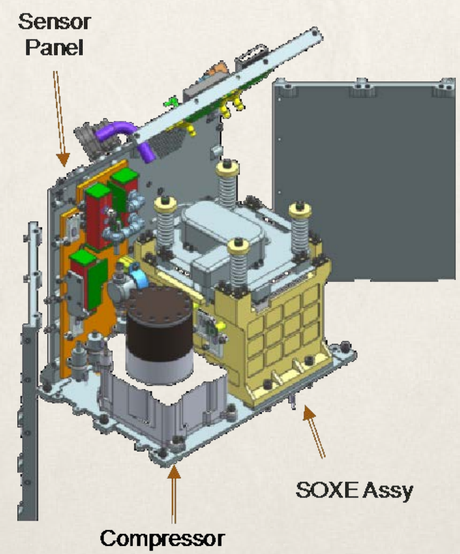


Meyen (2015)

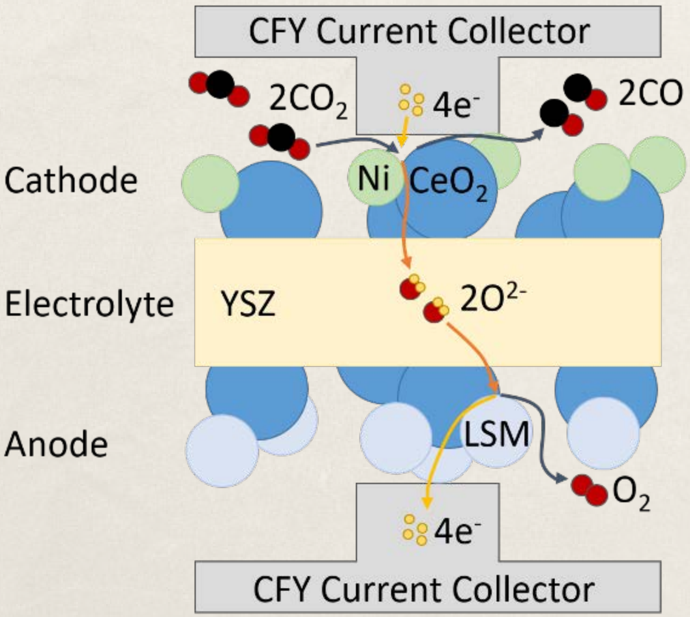


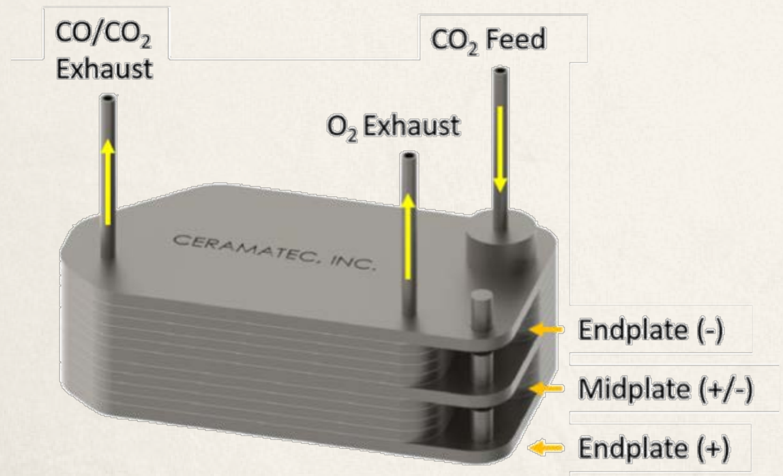
(Wikipedia)

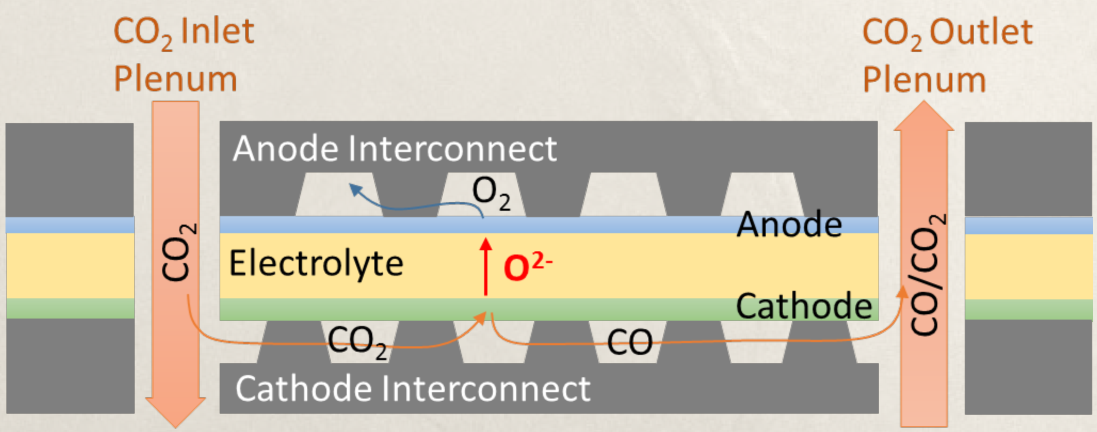




Making O_2 with SOXE







What will MOXIE do?

MOXIE
Mars Oxygen
ISRU Experiment

* MOXIE is a 1:200 scale model of an ISRU plant for a human mission
* When running, MOXIE will make 6-10 g of oxygen per hour (about half as much as you need to breathe)
* MOXIE will run for about an hour, approximately one day out of every 2 months.

Backup: More MOXIE

Packing for Mars…

MOXIE
Mars Oxygen ISRU Experiment

- Cargo mission
  - HABitat
  - Descent/Ascent Vehicle (DAV)
  - Mobility systems (pressurized & unpressurized rovers)
  - Power systems (Kilopower reactor? Photovoltaic?)
  - Propellant (Fuel & oxidizer) or ISRU plant
- Human mission
  - Mars Transfer Vehicle
  - The Crew
  - Toothbrush, etc.

The Itinerary…

The luggage…

MOXIE
Mars Oxygen
ISRU Experiment

Surface Systems	Quantity	Habitat Lander System Mass (kg)	DAV Lander System Mass (kg)
Crew Consumables	-	1,500	4,500
Science	-	-	1,000
Robotic Rovers	2	-	500
Drill	1	-	1,000
Unpressurzed Rover	2	-	500
Pressurized Rover	2	8,000	-
Pressurized Rover Growth	-	1,600	-
Pressurzed Rover Power	2	-	1,000
Traverse Cache	-	-	1,000
Habitat	1	16,500	-
Habitat Growth	-	5,000	-
Stationary Power System	2	7,800	7,800
ISRU Plant	2	-	1,130
Total Surface Systems	-	**40,400**	**18,430**

Plus: Propellant to leave Mars!

- ***27 tons of O_2***
- ***7 tons CH_4***