Solar **O**bserving **L**ow-frequency **A**rray for **R**adio **A**stronomy (***SOLARA***)

Exploring the last frontier of the EM spectrum

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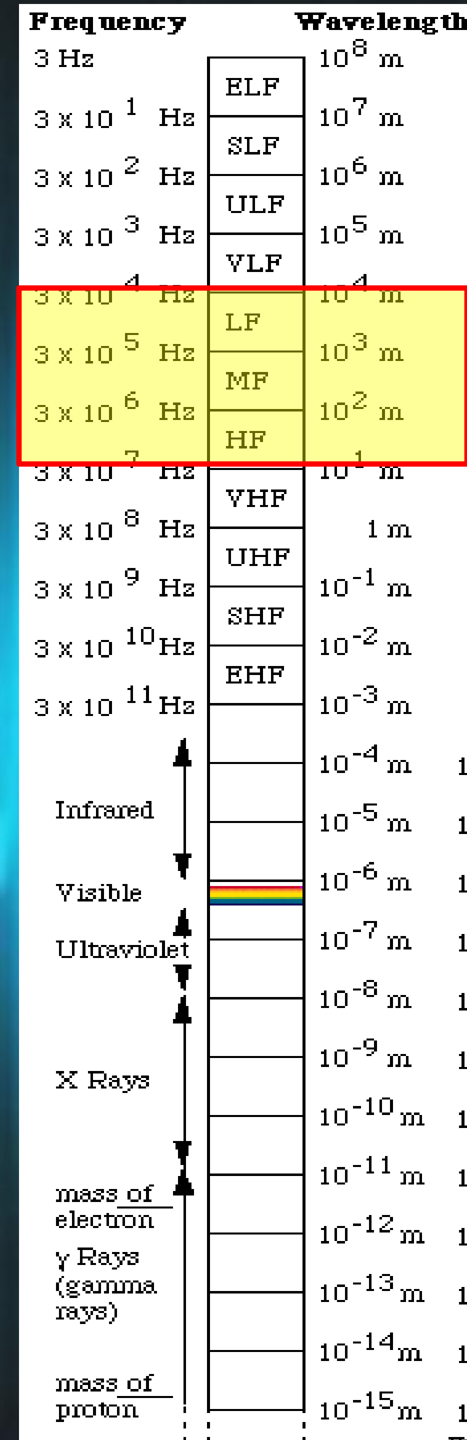
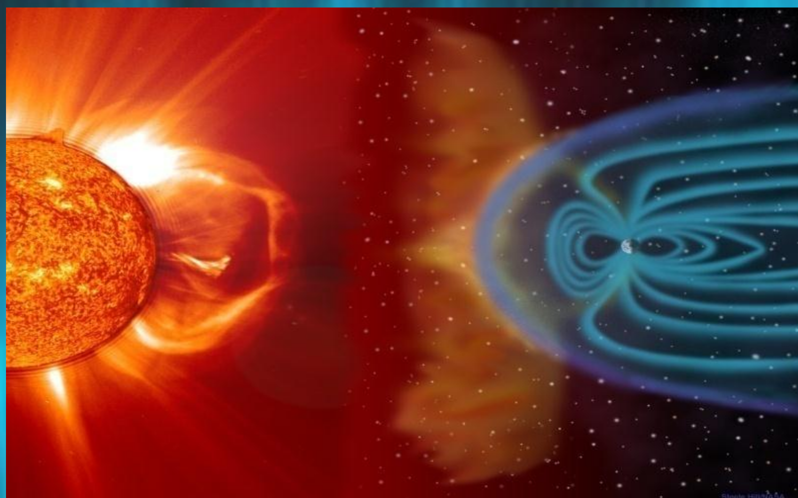
From the beginning of astronomy to recent times, **only light visible to the human eye** could be observed

Ultra Low Frequency Observations

- Ionosphere blocks/reflects wavelengths below ~10 MHz
  - ➢ Space-based observatory
- Long wavelengths require large apertures for angular resolution ***(ϑ = λ/D)***
- Monolithic apertures are impractical
  - ➢ ***INTERFEROMETRY (sparse aperture)***
- Interferometer baseline measurement requirements easier at long wavelengths ***(μ ~ λ/10)***
- **Solution: *<u>CubeSat interferometer in space</u>***



Astronomy at long wavelengths: **Coronal Mass Ejections (CMEs)**



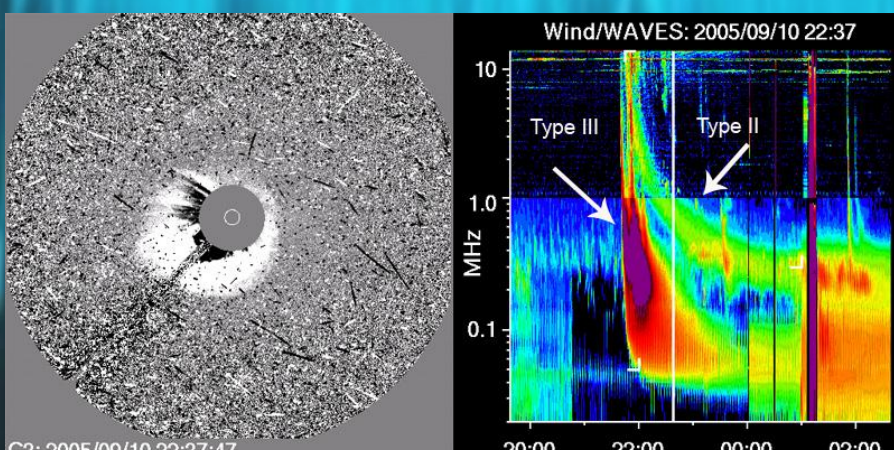


Image Credit: NASA/ESA

- Danger to spacecraft, astronauts, and terrestrial power grids
- SOLARA can track CMEs in 3D by monitoring radio bursts generated by shock waves
- Type of radio burst indicates how dangerous a solar storm will be to Earth

Astronomy at long wavelengths: **Giant Planet Magnetospheres**

- **5 planets with strong magnetic fields** in the solar system: Earth, Jupiter, Saturn, Uranus, Neptune
- **No** spatially resolved imaging of radio sources below ionospheric cut-off
- Voyager s (launched 1973) were **first** and **last** to study long wavelength radio emissions from all giant planets

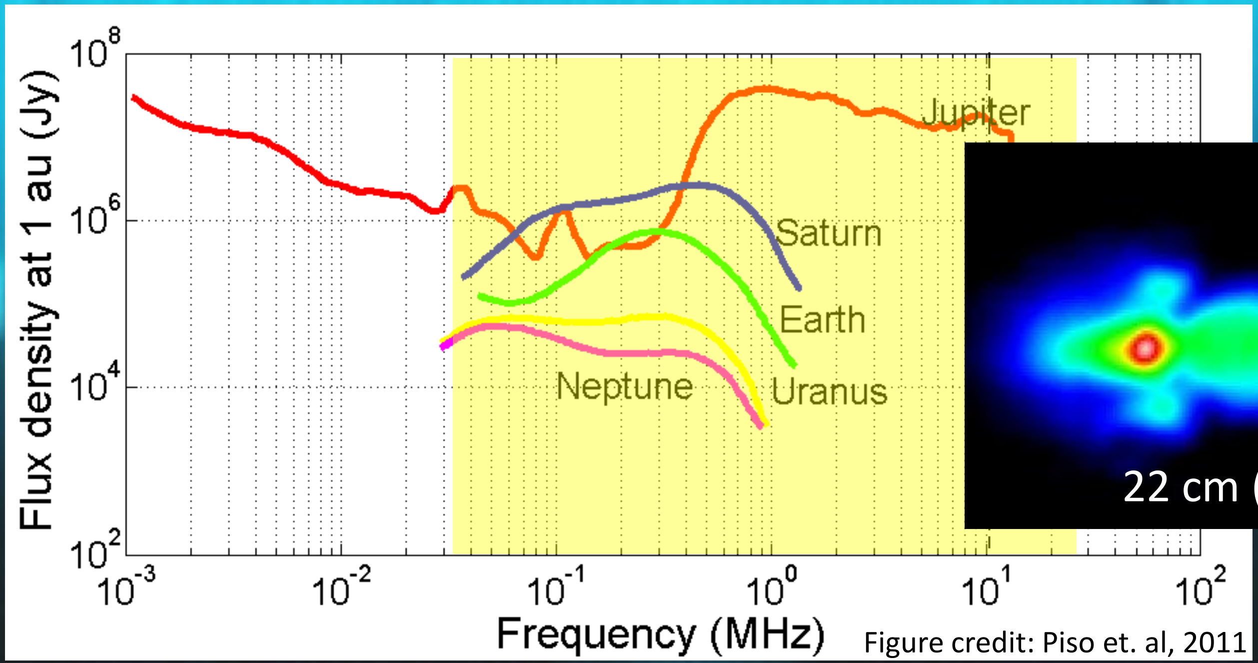


Figure credit: Piso et. al, 2011

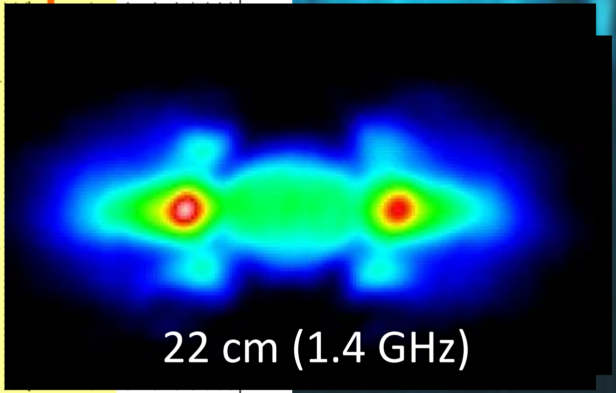
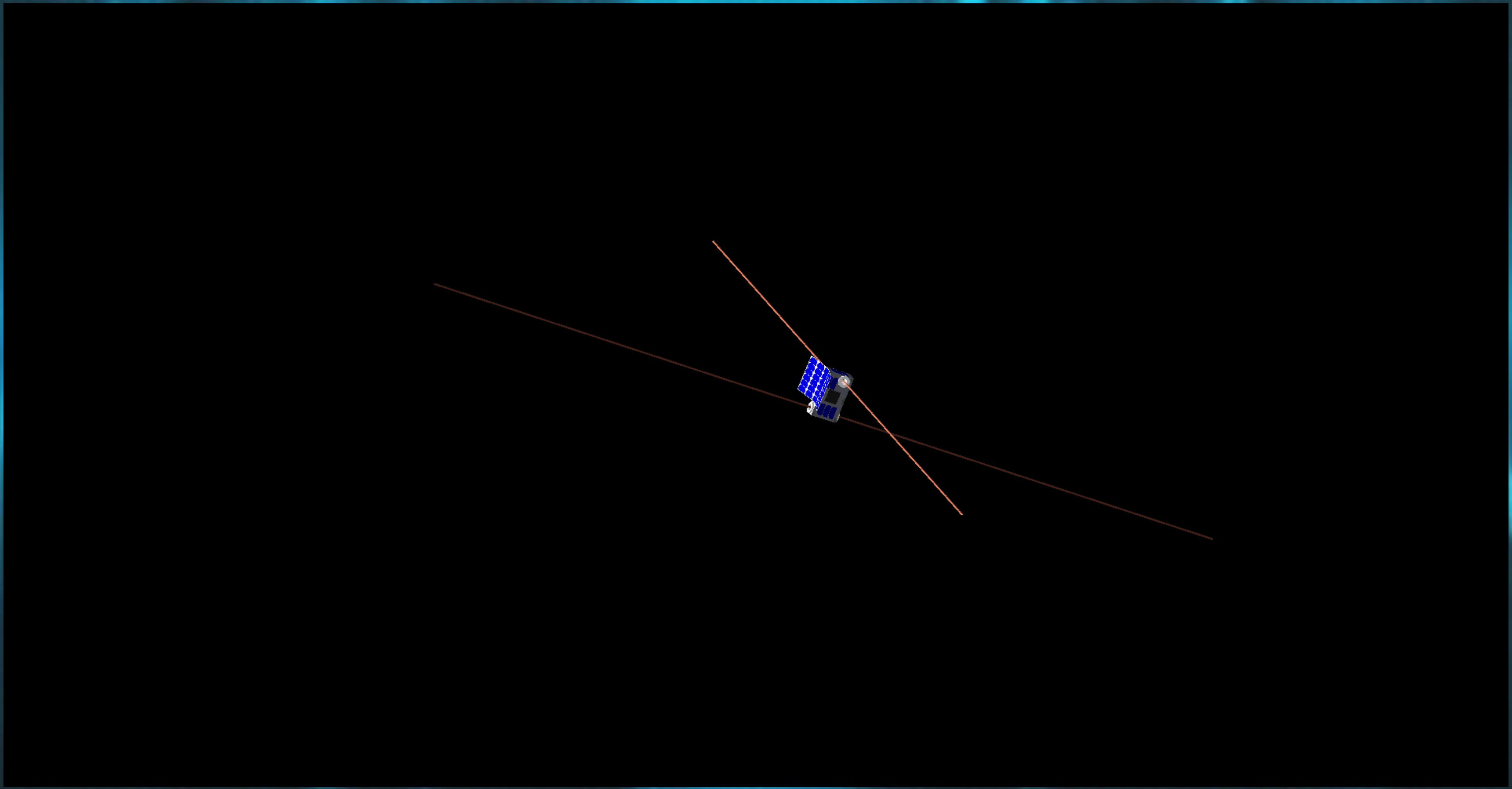


Image credit: CSIRO

CubeSat Implementation



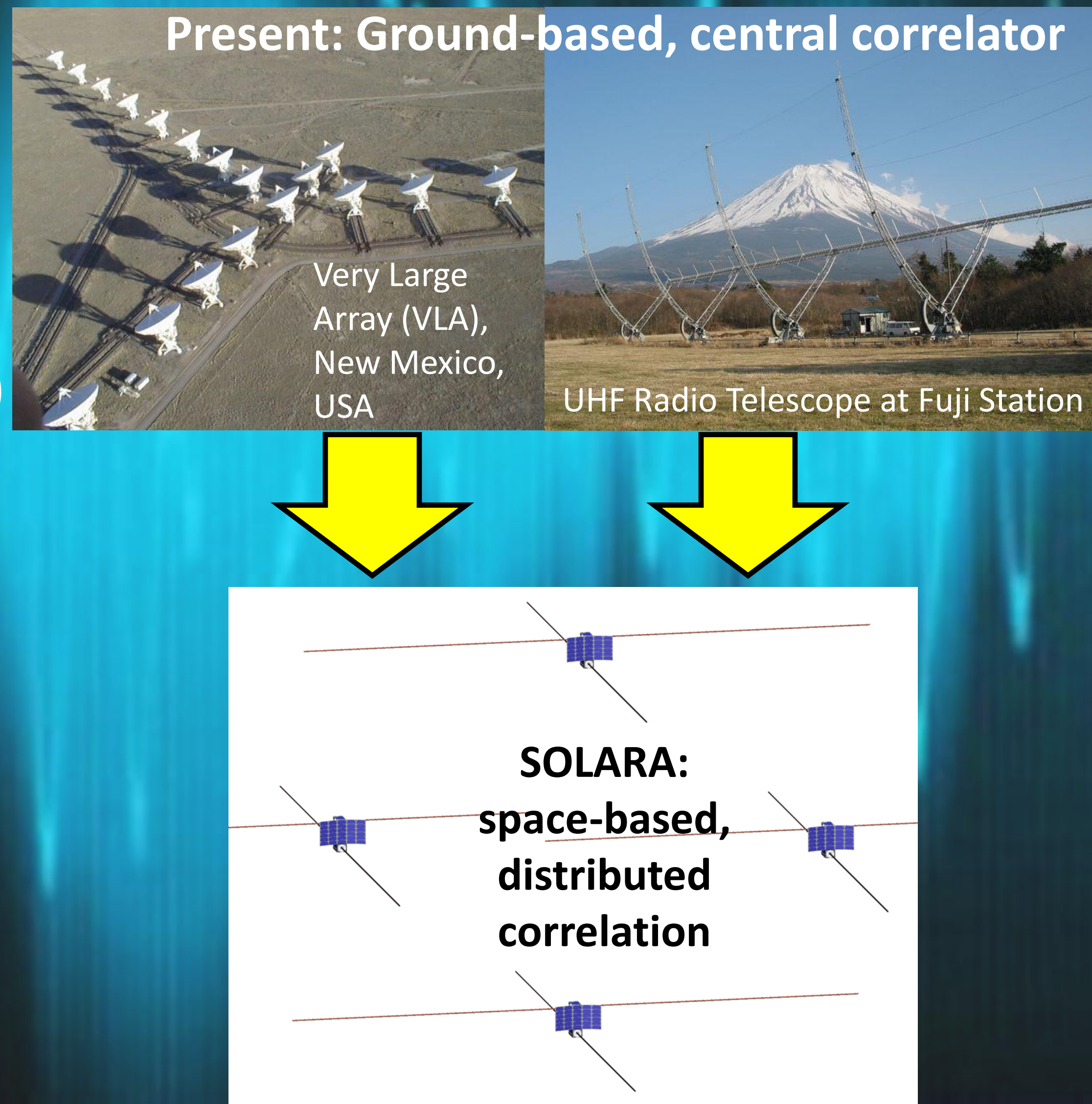
Radio Science Instrument

- 2 deployable "active" BeCu dipole antennas (6 m) orthogonal to each other
- Low-noise amplifier
- Payload and Telemetry System (PTS): customized radio receiver
  - FPGA-based
  - 1 Hz frequency tuning
  - Bandwidths from 1 kHz to 10 MHz
  - Optimized for 100 kHz to 10 MHz

Stored Tubular Extendible Member (STEM) deployable antenna (Northrop-Grumman)

Interferometry

- Aperture synthesis interferometry
- **Distributed correlator** – no central hub
- 190 unique baselines (20 spacecraft
- Array will grow over time, increasing angular resolution
  - 1 – 60 arcminutes @ 1 MHz



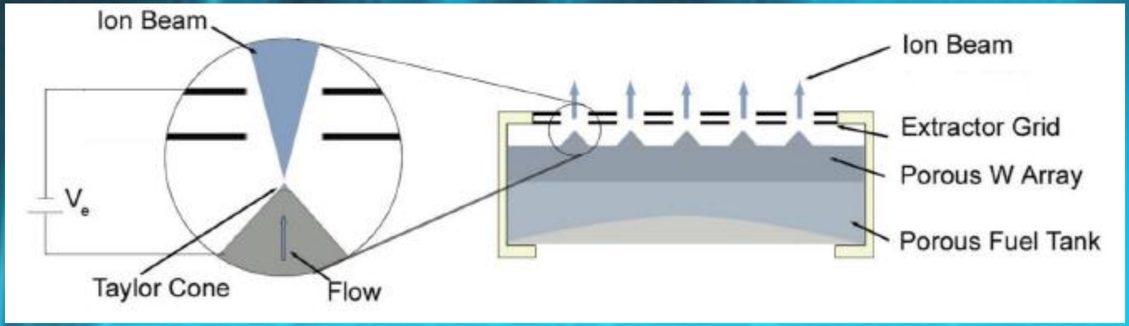
Formation Flight (Lite)

- Relaxed metrology requirements – accurate baseline measurement necessary, but NOT control
- “Beginner” formation flight – only occasional corrections/adjustments required, not constant formation maintenance (open loop)
- Intersatellite ranging: SARA (S-band)
- Constellation orientation - aggregated star tracker measurements

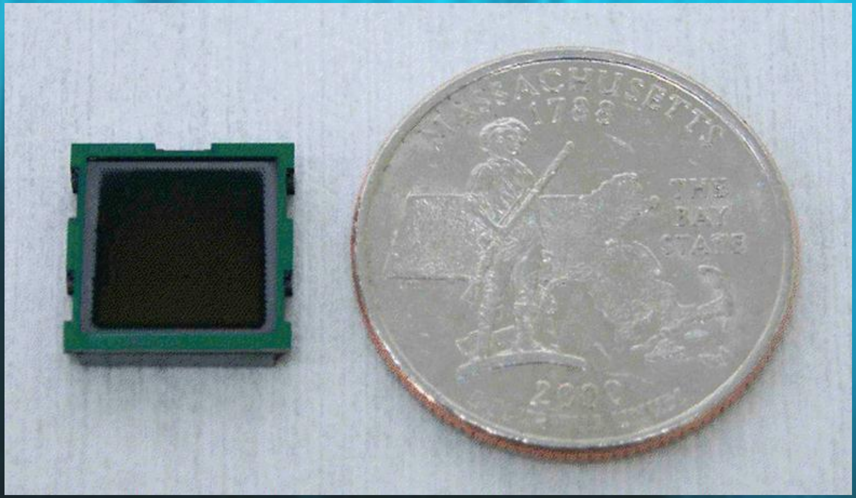
Communication: SARA

- **S**eparated **A**ntennas **R**econfigurable **A**rray (**SARA**) will use the SOLARA constellation as a platform to test the technology of MIMO systems in space.
- **Key idea**: multiple antennas opportunely aggregated to form a highly directional array by combining signals in phase.
- 2 S-Band channels for each spacecraft:
  - One for Earth communication
  - One for inter-satellite links
- Master-slave configuration
  - Comm to Earth (time, data) coordinated by master
  - Intersatellite clocks and ranges exchanged frequently
- **SARA gain: 23 dB, 57 kpbs from LL1** vs. CubeSat gain: 6dB, 2.4 kbps from LL1

Propulsion:
Electrospray Patch Thrusters



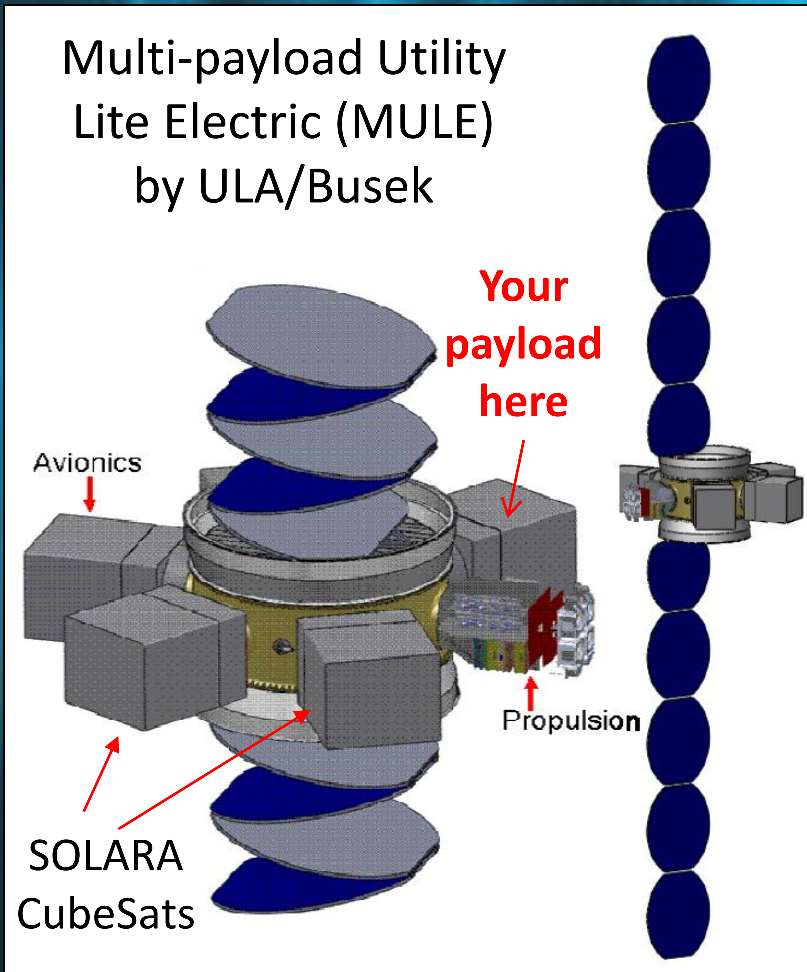
Electrospray thrusters developed by **Prof. Paulo Lozano** of MIT's Space Propulsion Lab



Images adapted from Lozano & Courtney, 2010

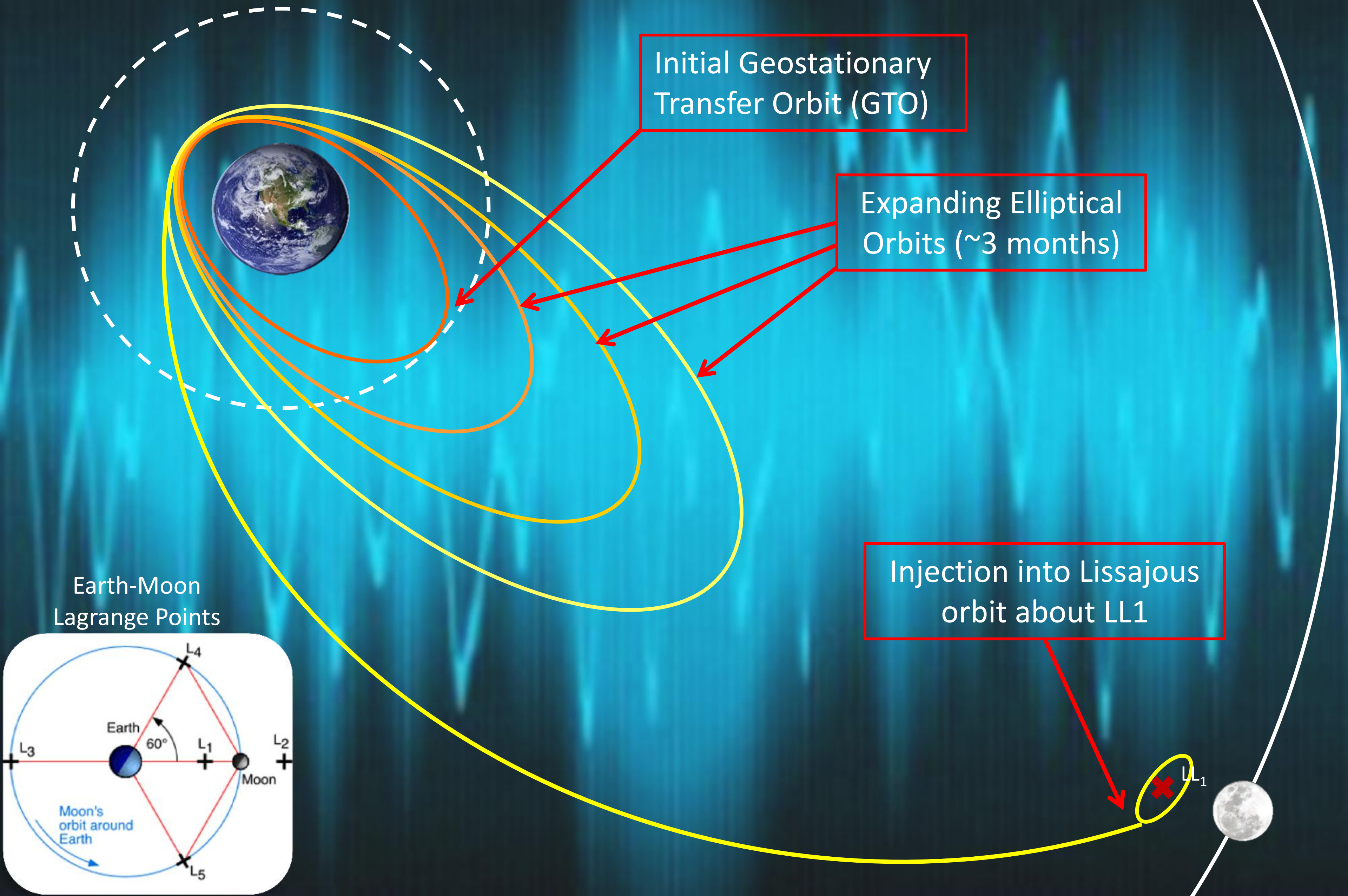
- High voltage grids (**1-2 kV**) accelerate ions to provide thrust
- Small footprint (1 cm^2)
- Ionic liquid propellant:
  - No vapor pressure
  - No pressure vessels or plumbing
  - No combustion
- High Isp (**~3500**), low propellant mass
- ~ 1 µN per thruster
- Thrusters will be tested in precursor missions

Carrier Vehicle – GTO to LL1 transfer



- Transports SOLARA/SARA CubeSats to LL1 destination
- Radiation protection while in transit
- High gain communications
- Back-up central hub for array

Journey to LL_1

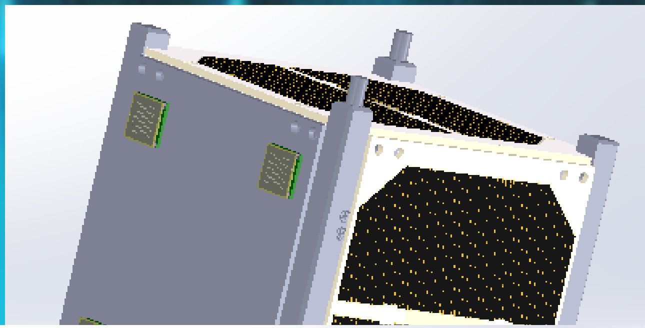


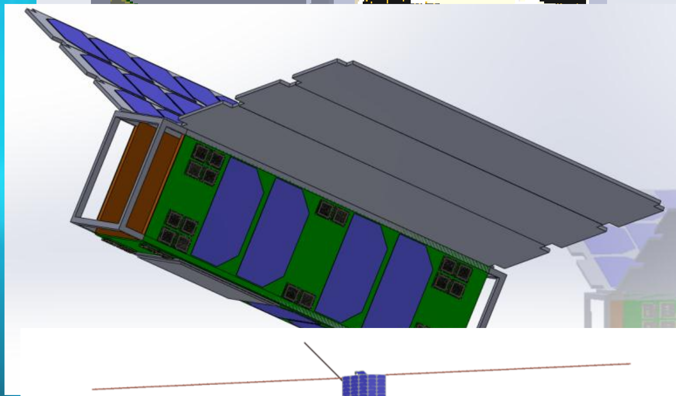
Subsystems

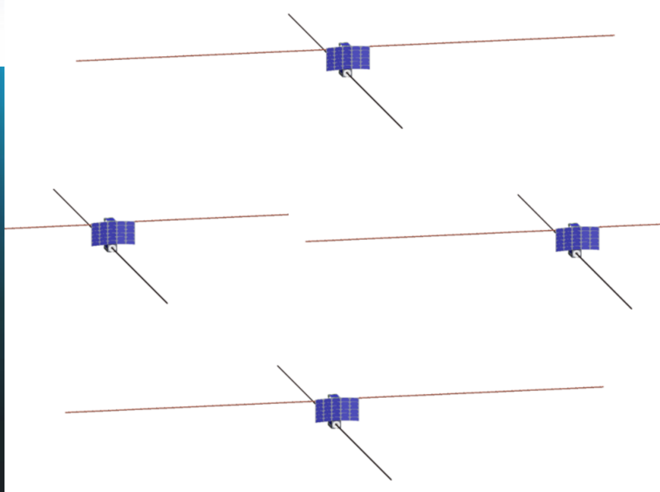
- **ADCS** – thrusters are actuators, star tracker, sun sensors, gyros provide attitude estimate
- **Power** – deployable solar wings provide 30 W power. Orbit allows near-continuous sunlight
- **Avionics** – ARM7-based flight computer will provide ADCS calculations and housekeeping
- **Structure** – custom 6U structure manufactured from aluminum
- **Thermal** – LL1 orbit and sun-pointing solar panels provides a stable thermal environment. Antisun-facing spacecraft sides used as radiators

Strategy and Schedule

- Three-phase implementation:
  - Phase 1: Thruster demonstration precursor mission - 2014
  - Phase 2: Science payload demonstration in LEO (2-3 CubeSats) – 2015-2017
  - Phase 3: Full array launch and deployment in LL1 – 2018-2020







Conclusions

- ➢ Ambitious but feasible – **high risk, high reward**
- ➢ Precursor missions reduce risk and raise TRL of novel technologies
- ➢ Full redundancy – no single point of failure, tolerant to CubeSat losses
- ➢ Convergence of technologies to make SOLARA/SARA possible – **<u>paradigm shift</u>**

- **<u>Existing Technologies</u>**:
  - Deployable STEM antennas
  - S-band inter-satellite ranging (PRISMA)
  - CubeSat star tracker
  - ADS sensor-enabled solar panels
  - FPGA-based correlation
  - Multi-CubeSat delivery
- **<u>Novel/developing Technologies:</u>**
  - SARA
  - Electrospray thrusters
  - PTS (radio science receiver)

Acknowledgements

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This work references NASA proposals for the ALFA and SIRA missions

Back-Up Slides

Frequency	Wavelength	θ @ 10 km	θ @ 100 km	θ @ 1000 km	θ @ 10,000 km
30 MHz	10 m	3.4’	20.63”	2.06”	0.2”
10 MHz	30 m	10.31’	1’	6.19”	0.62”
1 MHz	300 m	1.719°	10.31’	1’	6.19”
100 kHz	3000 m	17.19°	1.719°	10.31’	1’
30 kHz	10,000 m	57.29°	5.73°	34.38’	3.43’

CubeSat Implementation