MEME-X
Mechanisms of Energetic Mass Ejection

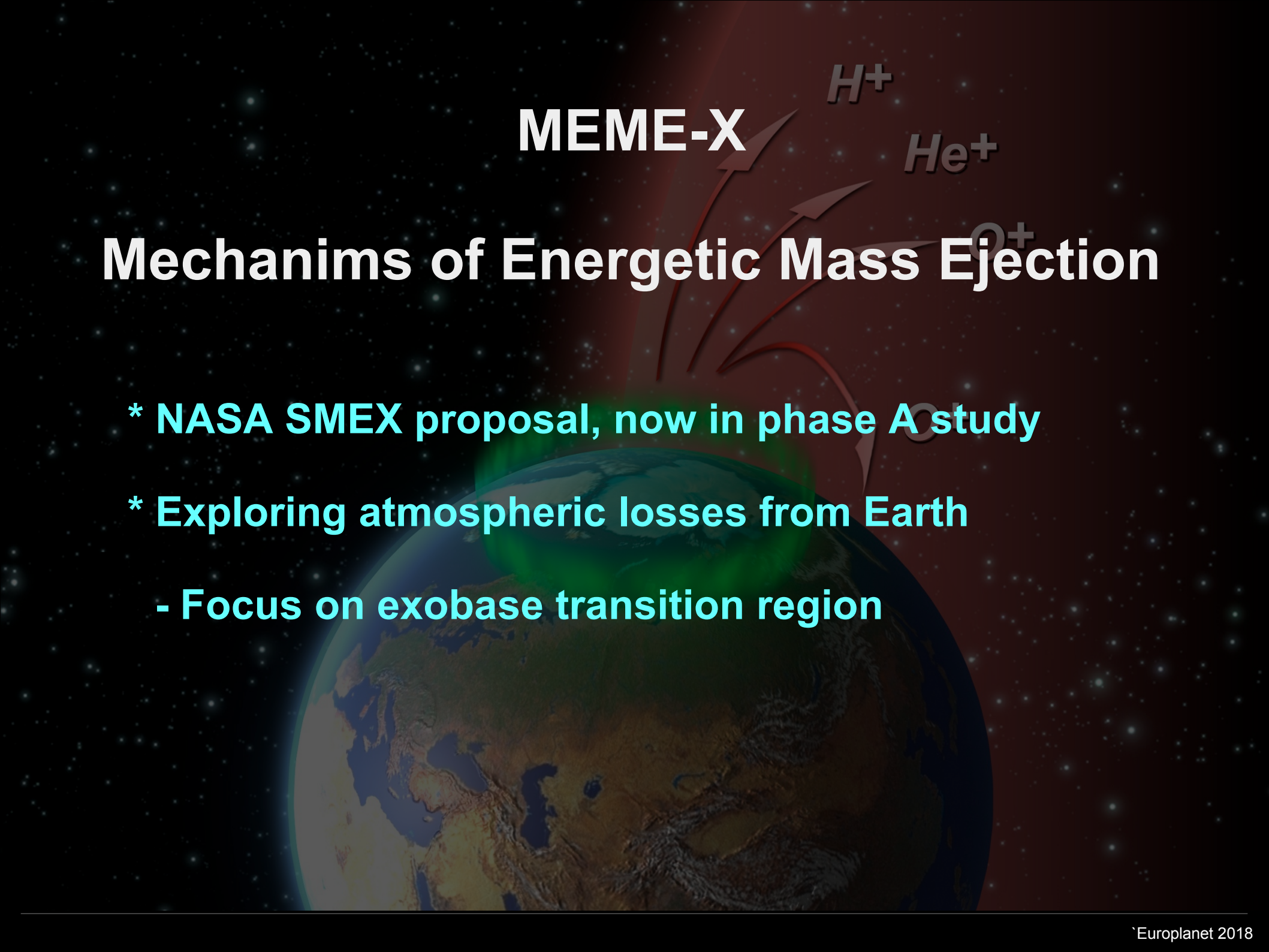
The MEME-X team

(Presented by Stein Haaland [1,2])

[1] Birkeland Centre for Space Science, Univ of Bergen
[2] Max-Planck Institute for Solar System Research

MEME-X

Mechanims of Energetic Mass Ejection



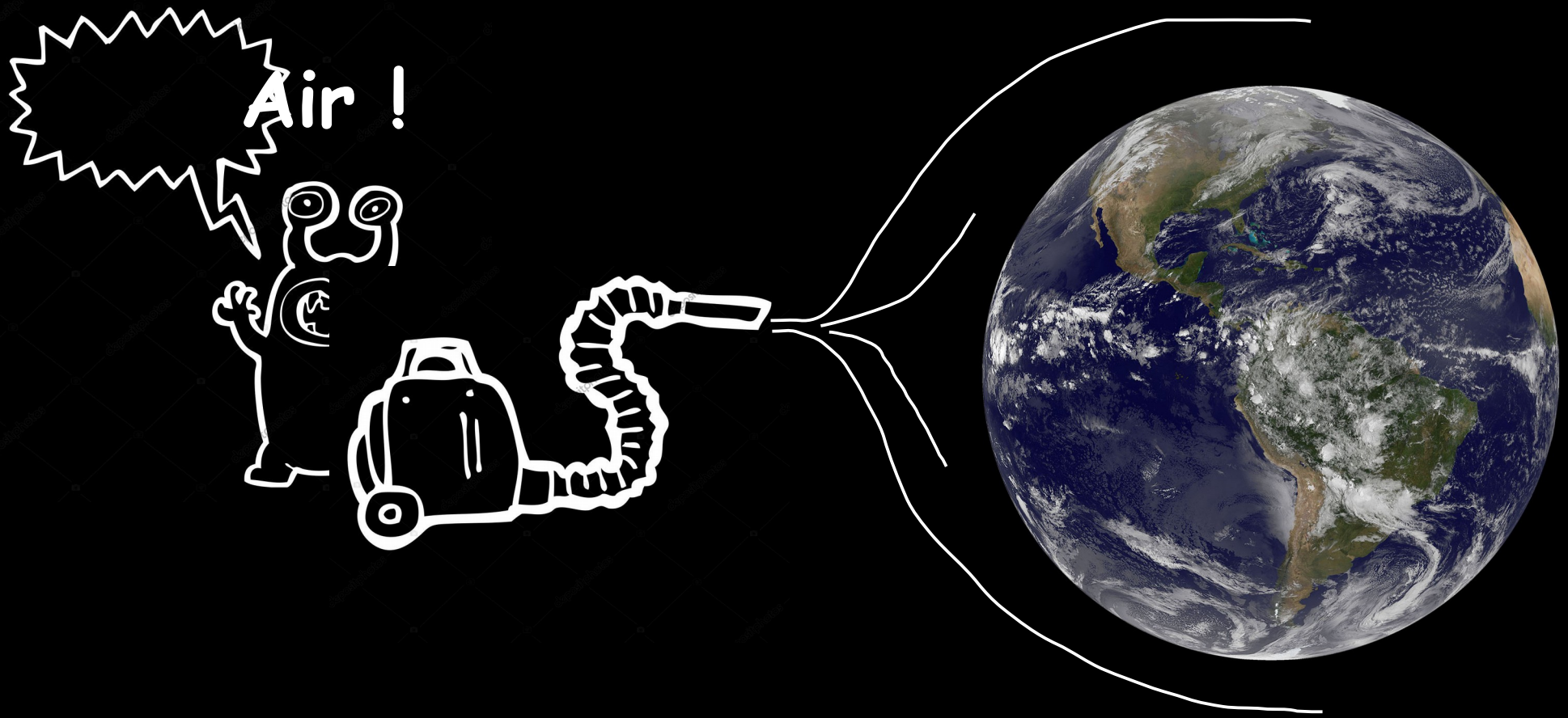
* NASA SMEX proposal, now in phase A study
* Exploring atmospheric losses from Earth
  - Focus on exobase transition region

MEME-X team:

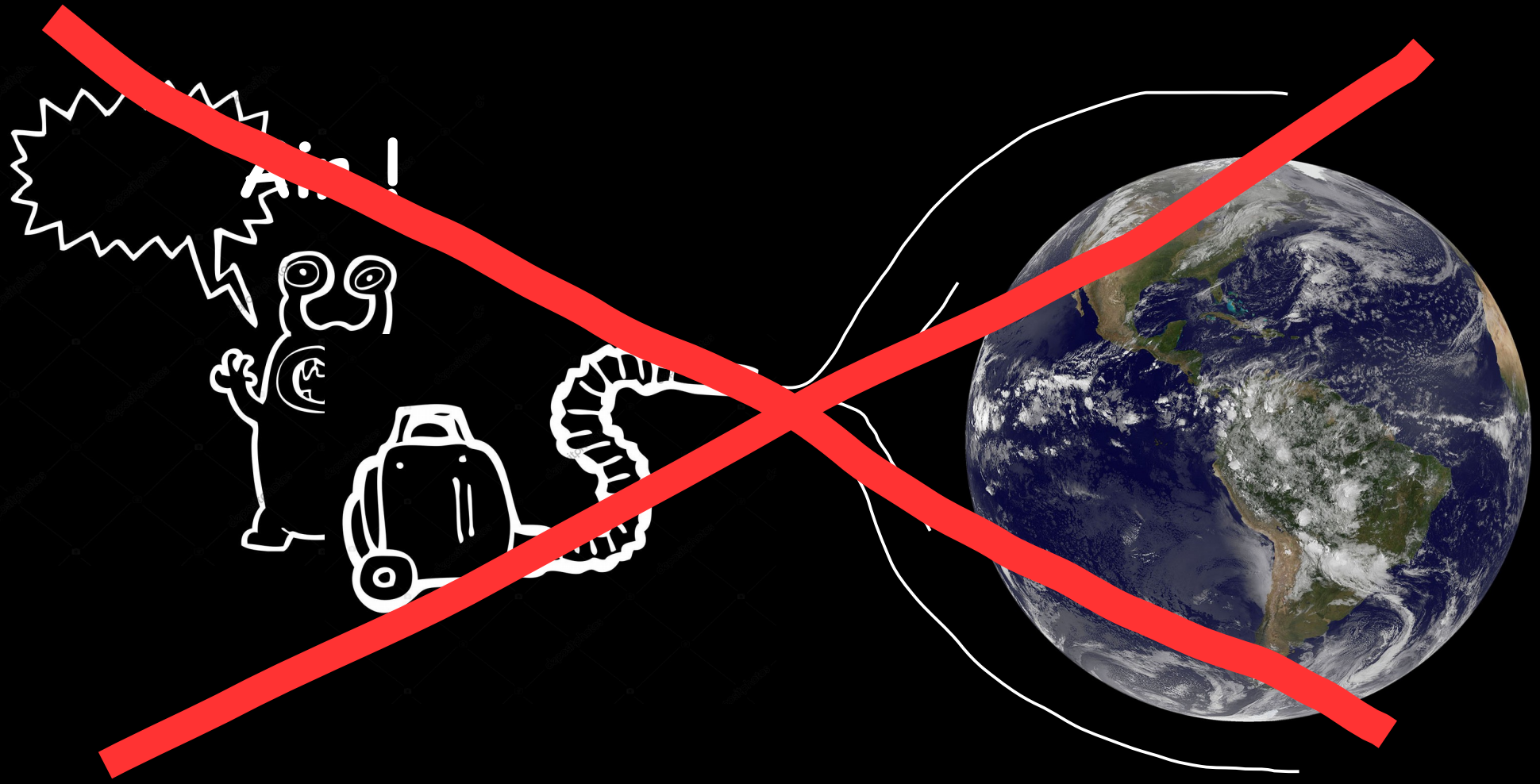
Science Team Member	Role	Responsibility
Dr. Thomas Moore	PI	Mission Leadership, CPA lead
Dr. Douglas Rowland	DPI	Mission Leadership, VELPI team
Dr. Mark Adrian	Inst. Sci.	CPA-e sensor lead
Dr. David Brain	Co-I	Theory and data analysis
Dr. Michael Chandler	Inst. Sci.	Data analysis
Dr. Rick Chappell	Co-I	Data analysis
Dr. James Clemmons	Co-I	RANGE lead
Dr. Victoria Coffey	Co-I	CPA/HPA Calibration lead
Dr. Glyn Collinson	Inst. Sci.	CPA team
Dr. Katherine Garcia-Sage	Inst. Sci.	Theory and Modeling
Dr. Daniel Gershman	Inst. Sci.	CPA-i sensor lead
Dr. Alex Glocer	Co-I	Theory & Modeling lead (PWOM)
Dr. Larry Kepko	Proj. Sci.	Project Scientist
Dr. Lynn Kistler	Co-I	HPA lead
Dr. Jeffrey Klenzing	Inst. Sci.	VELPI LP sensor lead

Science Team Member	Role	Responsibility
Dr. Marc Lessard	Co-I	HPA team, St. Collab. & GMAG
Dr. Leon Ofman	Co-I	Theory & Modeling (Ofman)
Dr. Nicholas Paschalidis	Co-I	CPA imaging / Time of Flight lead
Dr. Robert Pfaff	Co-I	VELPI lead
Dr. Ennio Sanchez	Co-I	ISR lead
Dr. Robert Strangeway	Co-I	MFP lead
Dr. Jiannan Tu	Co-I	Theory & Modeling (DyFK)
Dr. Roger Varney	Inst. Sci.	Theory & Modeling (IPWM), ISR
Dr. Matthew Zettergren	Co-I	Theory & Modeling (GEMINI-TIA)
Dr. Eric Donovan	Int. Part.	Ground-based multiscale analysis
Dr. Stein Haaland	Int. Part.	Data analysis
Dr. David Knudsen	Int. Part.	Data analysis
Dr. Romain Maggiolo	Int. Part.	Data analysis
Dr. Yasunobu Ogawa	Int. Part.	EISCAT lead
Dr. Joshua Semeter	Collab.	ISR / ASI studies

Cold pull (vacuum) or a hot push (pressure) ?

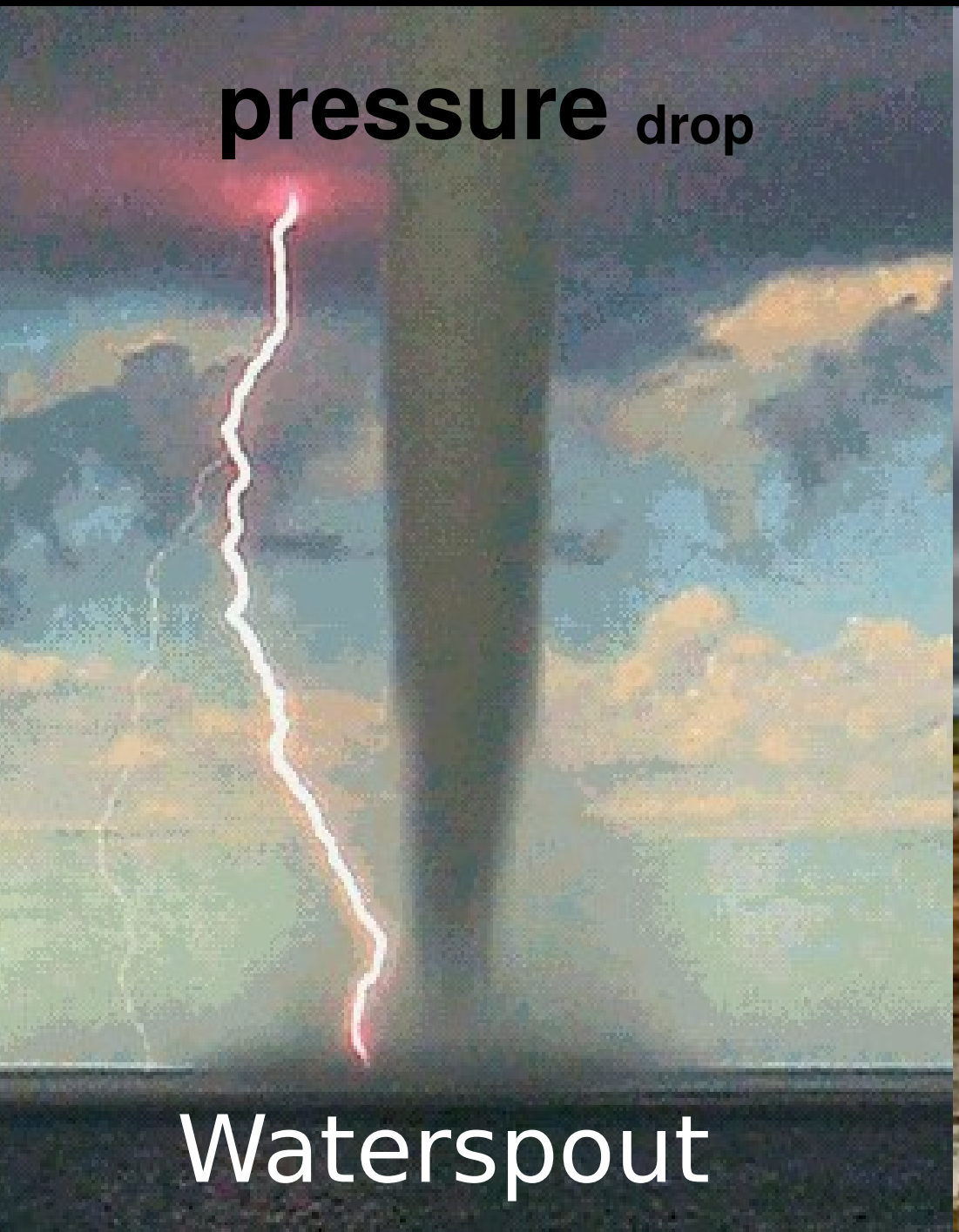


Cold pull (vacuum) or a hot push (pressure) ?



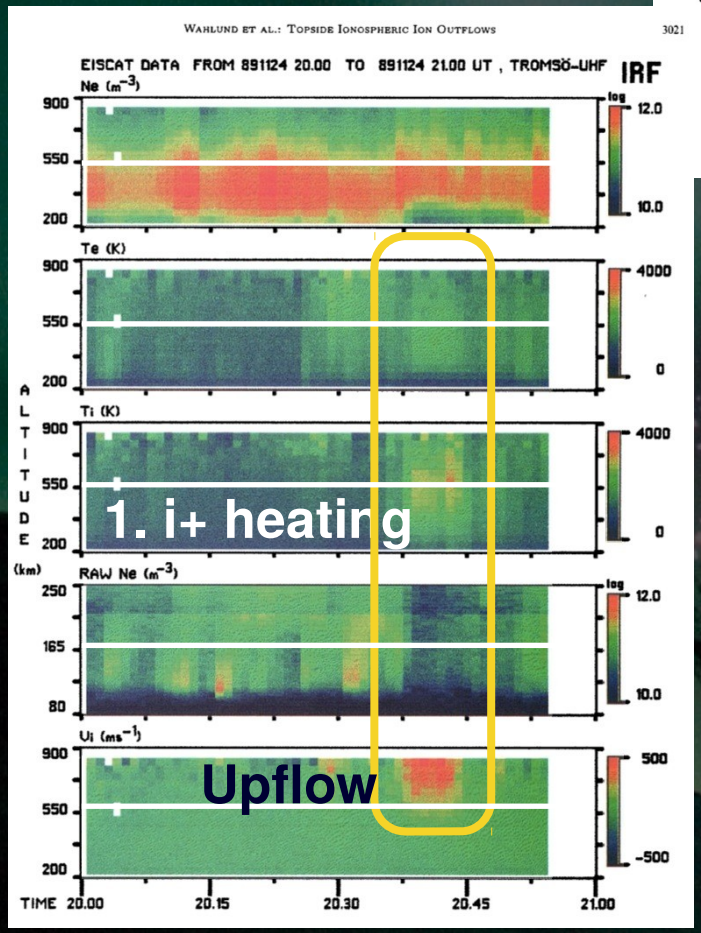
..space is already a nearly perfect vacuum ...

Cold pull or a hot push: atmospheric analogy



EISCAT Radar Discoveries

Type 1 upflows hot push



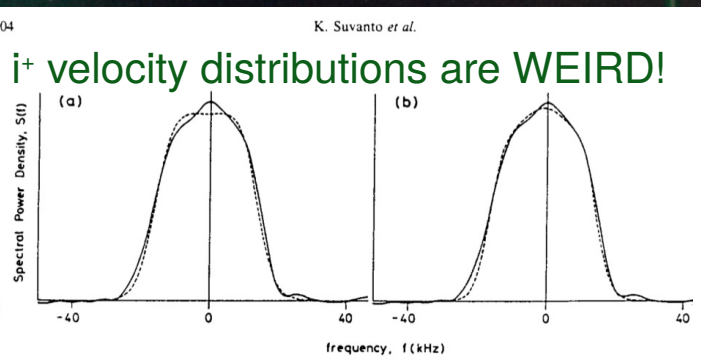
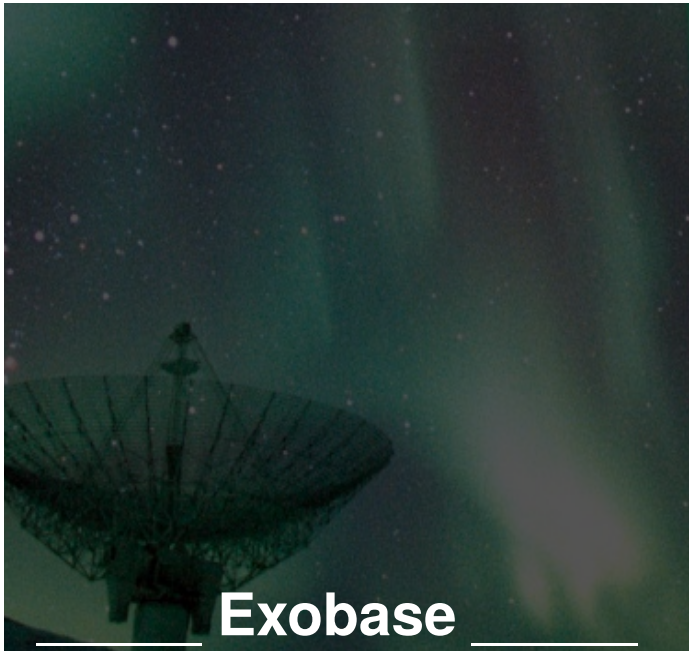
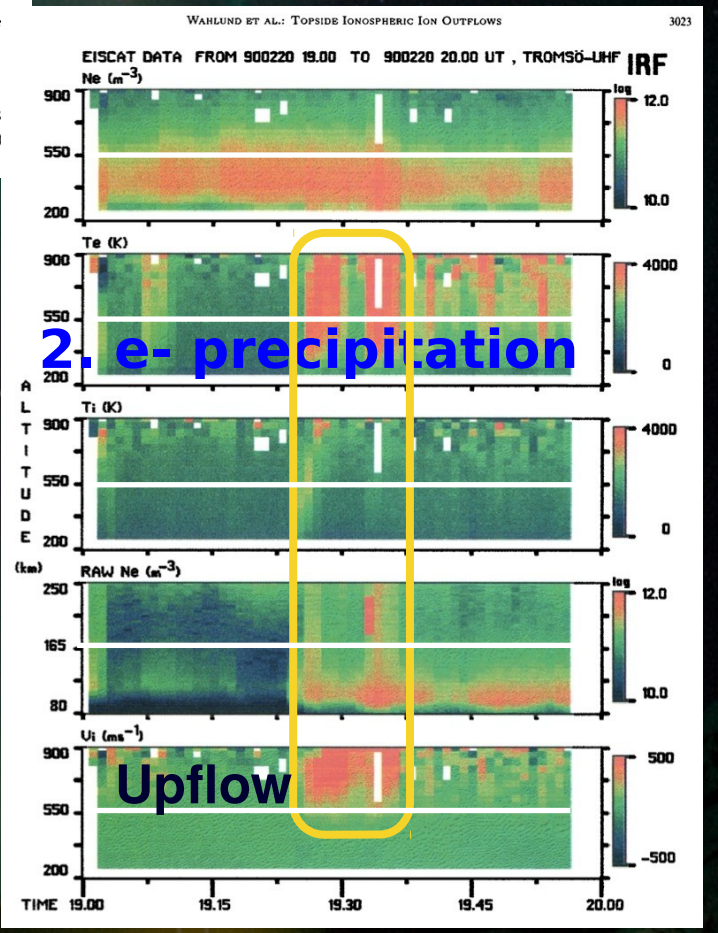
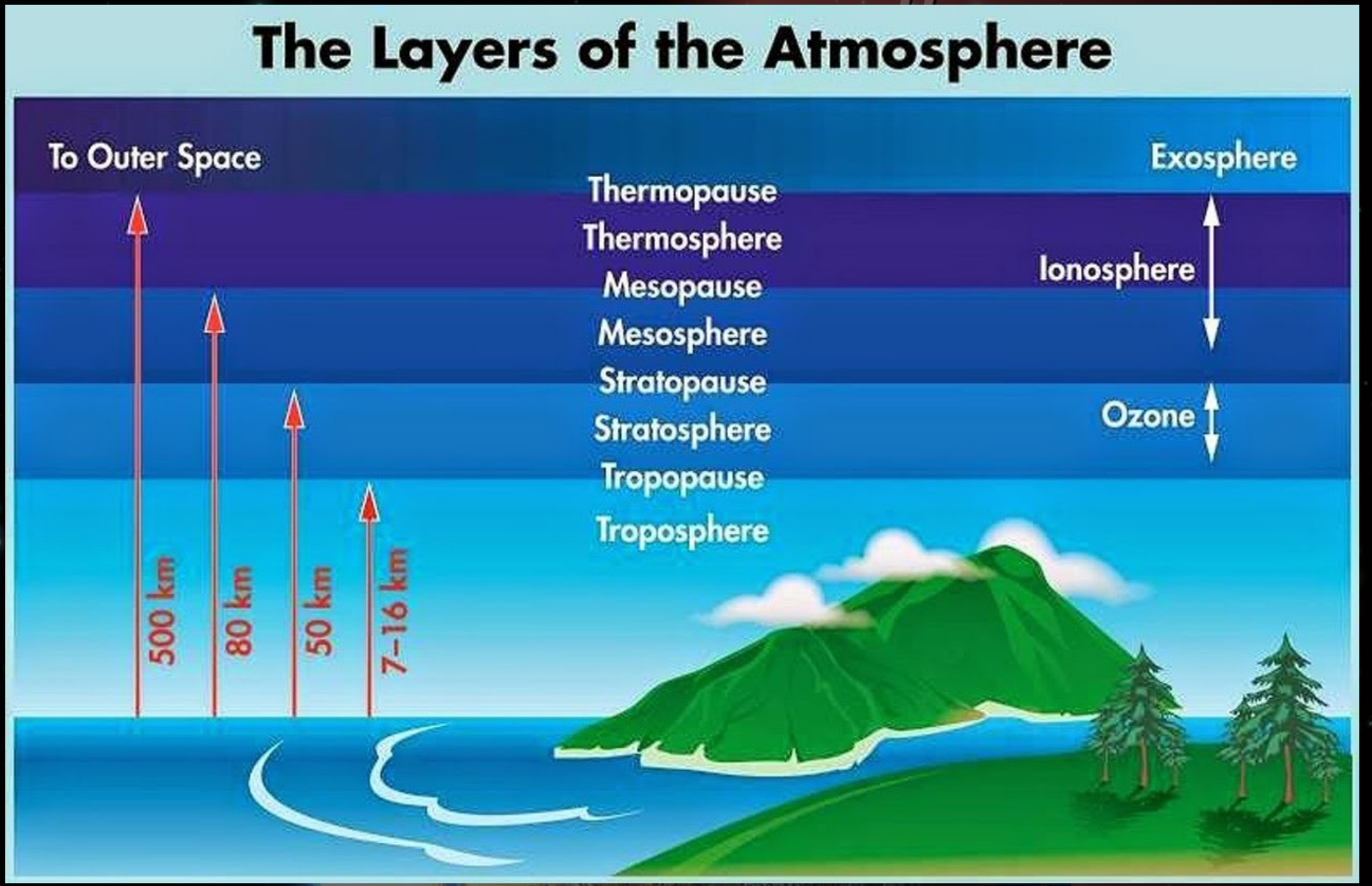


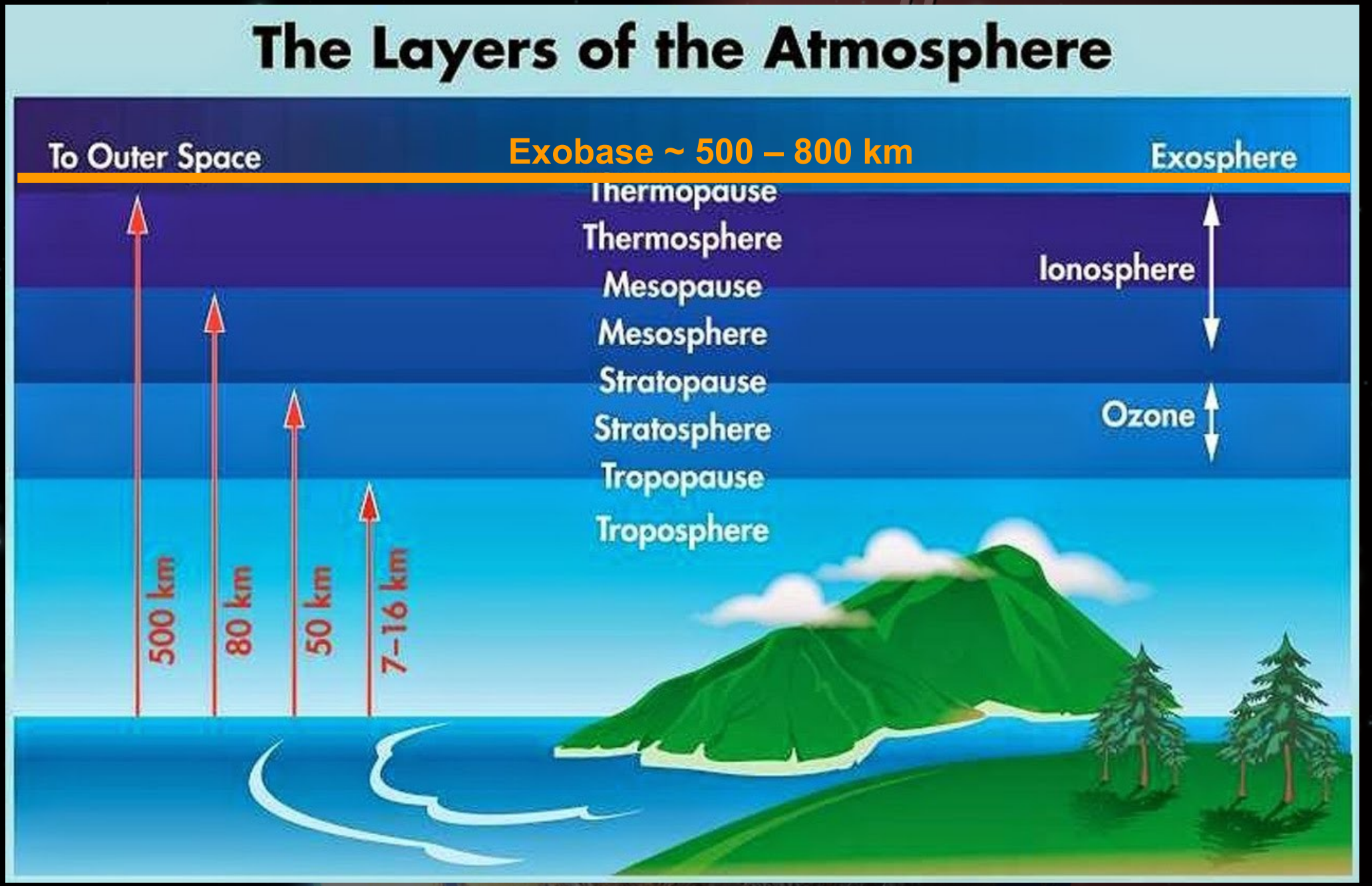
Fig. 1. Solid lines: a spectrum observed by Common Programme CP-4 and post integrated over a period of one minute (10:45:50–10:46:50 on 12 January, 1988) Dashed lines: the best (a) Maxwellian and (b) non-Maxwellian fits.

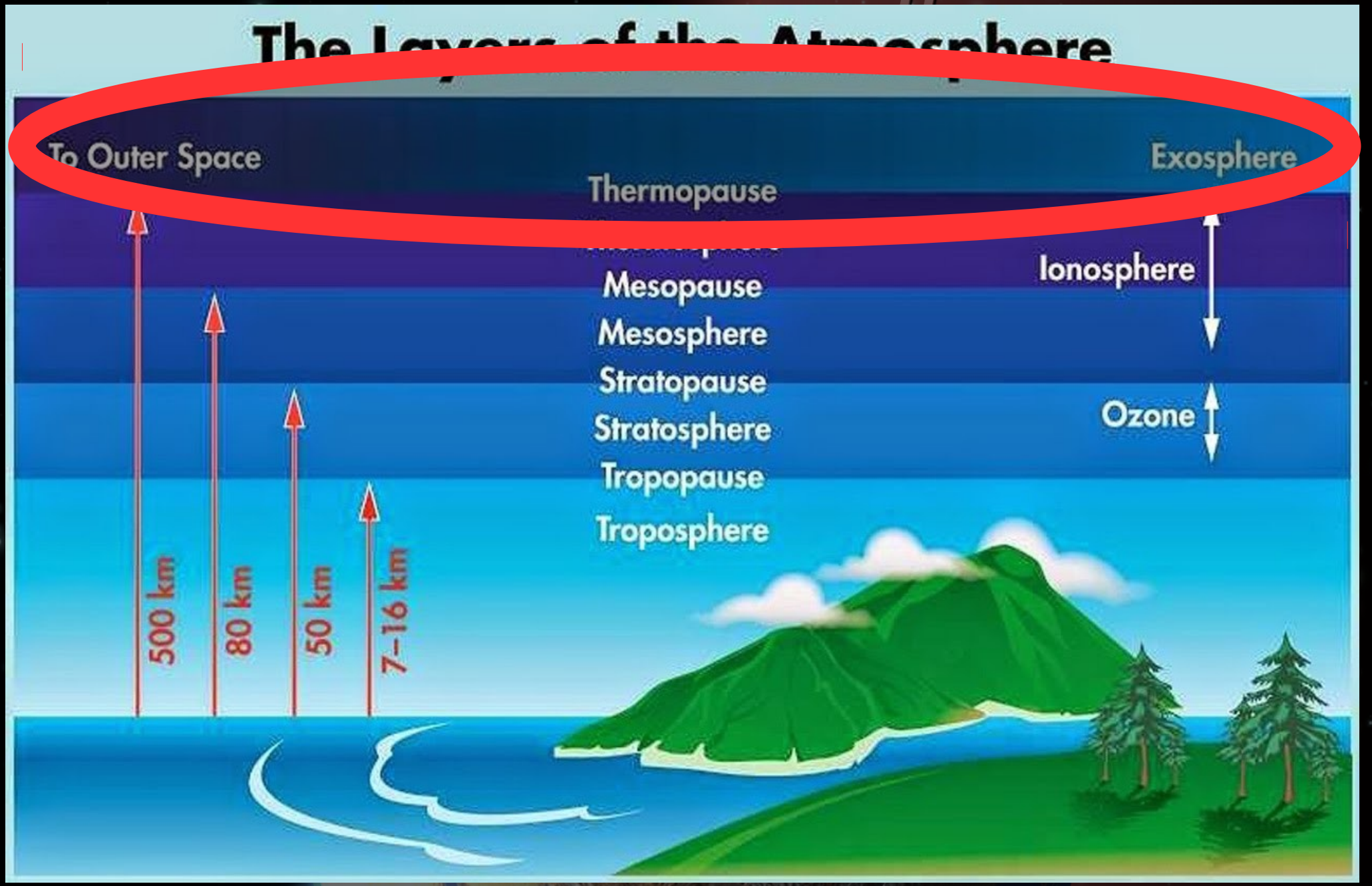


Type 2 upflows cold pull (well, ions anyway)




The Layers of the Atmosphere
To Outer Space
Exosphere
Thermopause
Thermosphere
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Troposphere
Ionosphere
Ozone
500 km
80 km
50 km
7–16 km


The Layers of the Atmosphere
To Outer Space
Exobase ~ 500 – 800 km
Exosphere
Thermopause
Thermosphere
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Troposphere
Ionosphere
Ozone
500 km
80 km
50 km
7–16 km


H+
The Layers of the Atmosphere
To Outer Space
Exosphere
Thermopause
Ionosphere
Mesopause
Mesosphere
Stratopause
Ozone
Stratosphere
Tropopause
Troposphere
500 km
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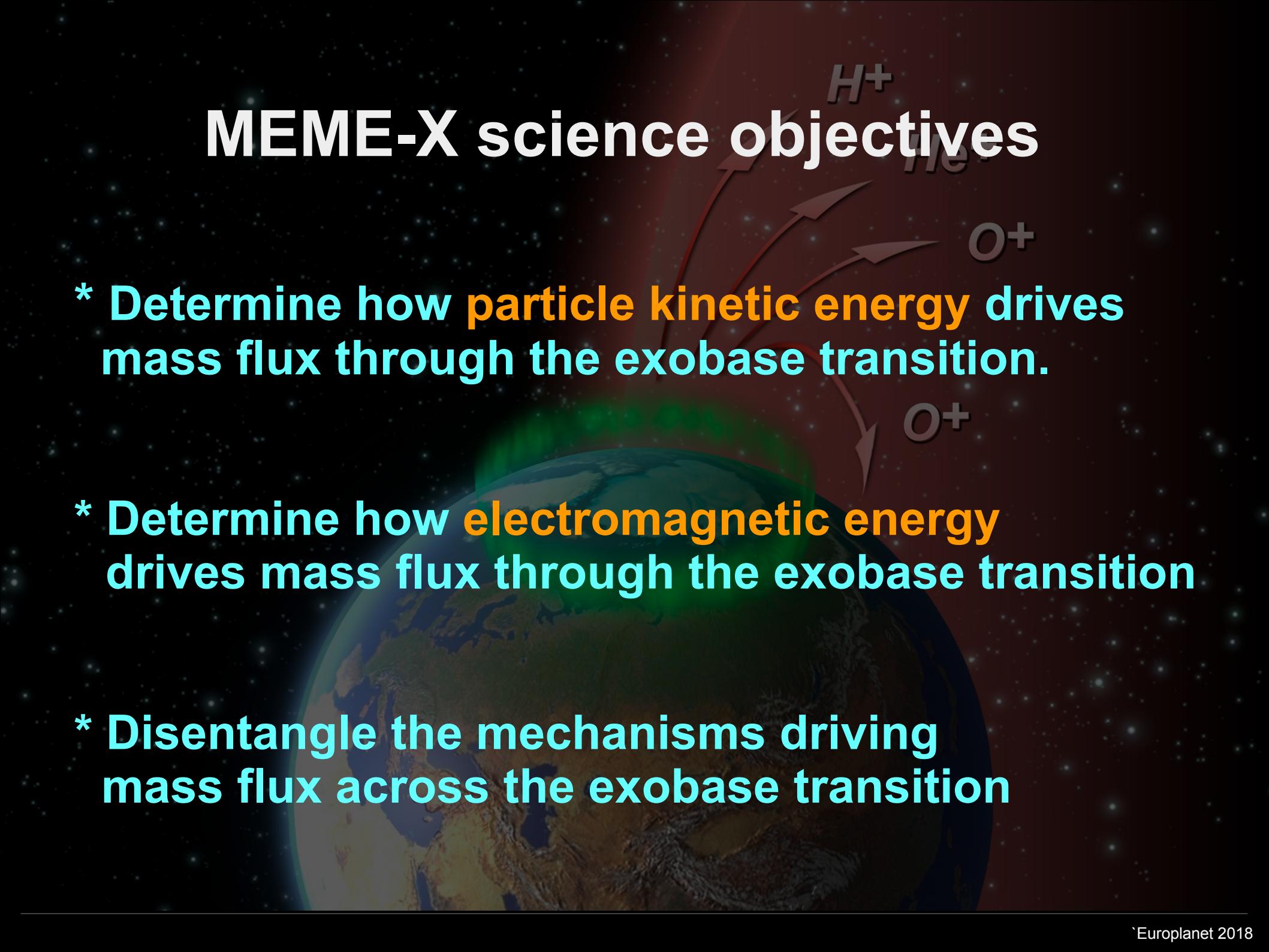
MEME-X science objectives



* Determine how particle kinetic energy drives mass flux through the exobase transition.

* Determine how electromagnetic energy drives mass flux through the exobase transition

* Disentangle the mechanisms driving mass flux across the exobase transition

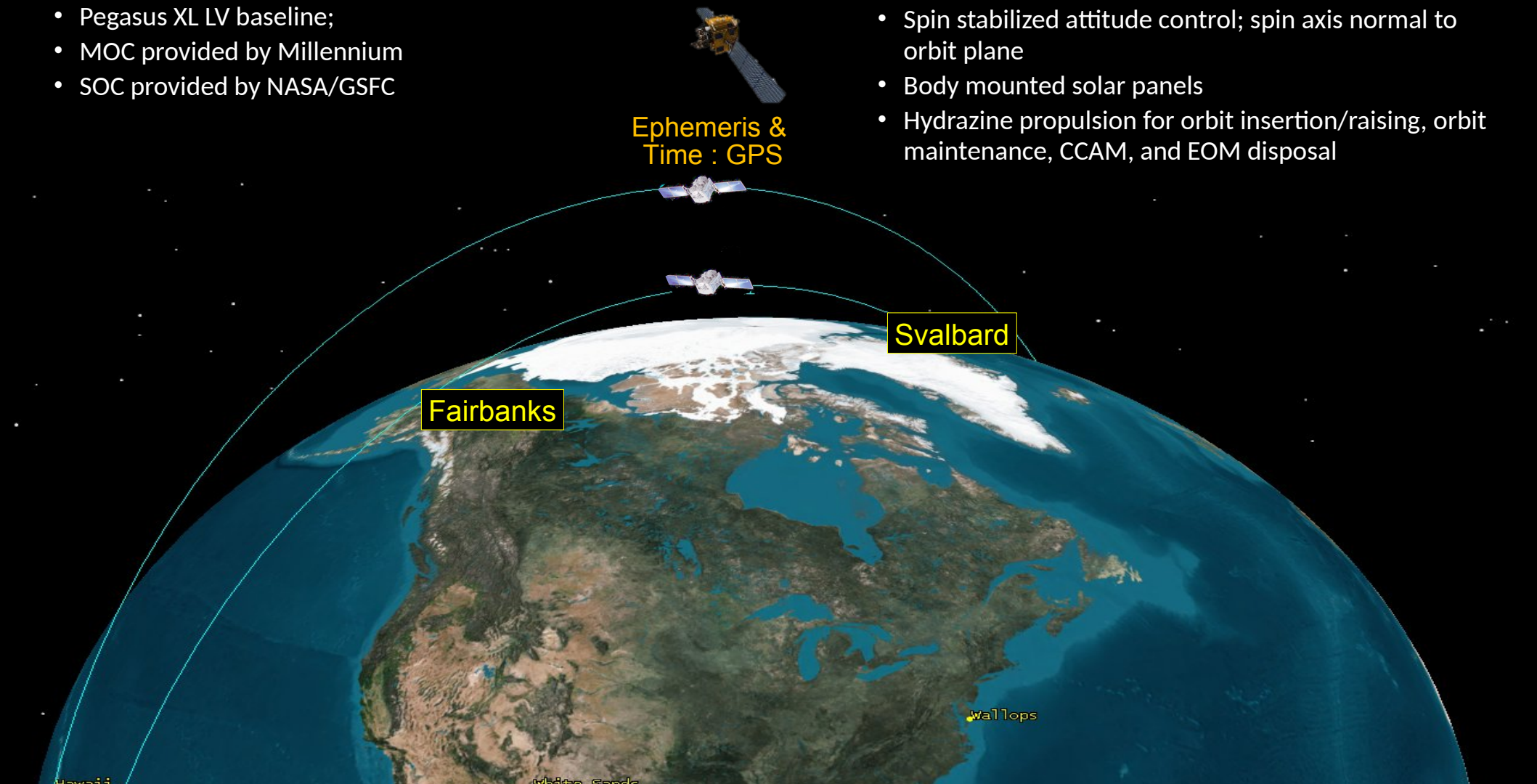
MEME-X Mission Concept

Mission Design

- Two Identical MEME-X Observatories
- 350 X 1250 km , 83° inclination orbits, elliptically opposed
- 25-month design life, extended mission option
- NEN ground stations for S-band science data downlink
- Pegasus XL LV baseline;
- MOC provided by Millennium
- SOC provided by NASA/GSFC

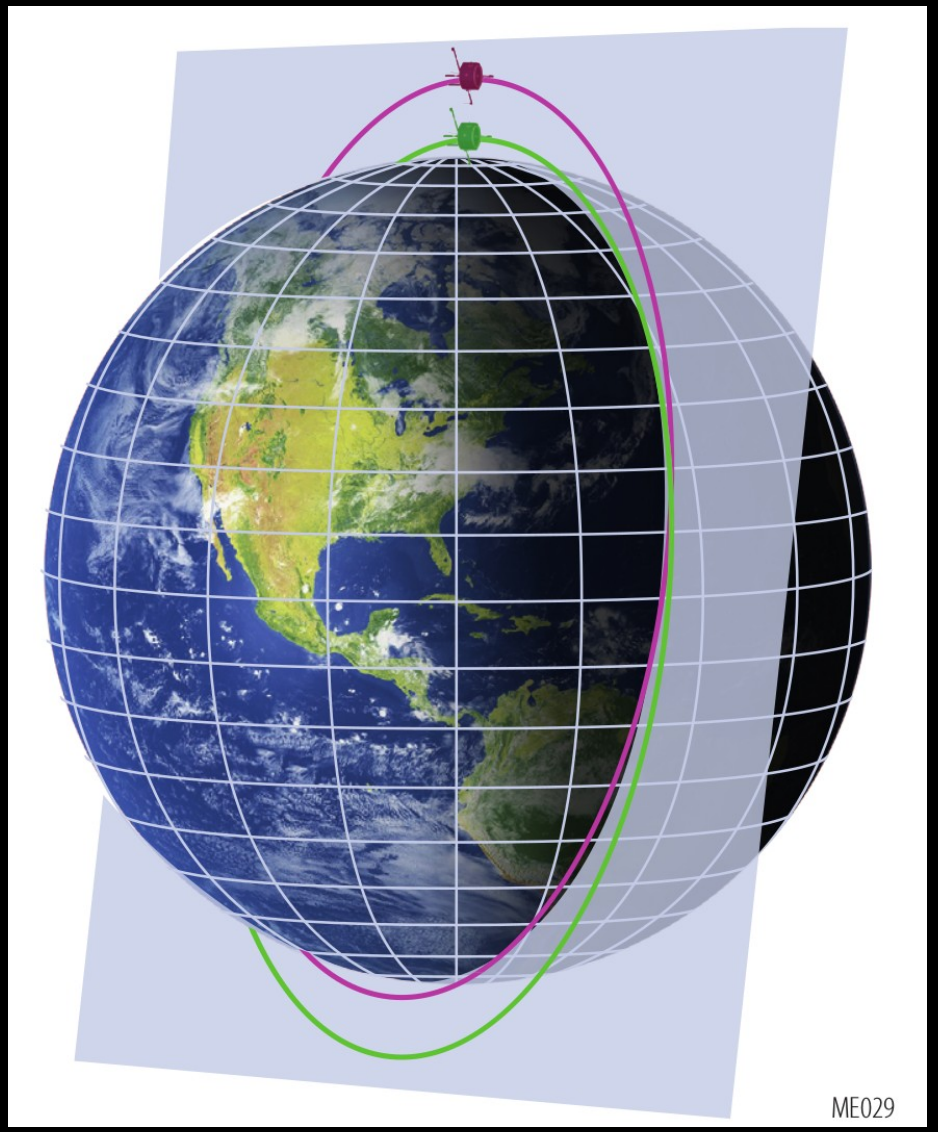
MEME-X Observatories (2)

- 161 kg Observatory (MEV) including 30 kg propellant
- Instrument suite consisting of HPA, MFP, CPA, VELPI, and RANGE Instruments and central IDPU
- Spacecraft based on Millennium's ALTAIR Spacecraft
- Spin stabilized attitude control; spin axis normal to orbit plane
- Body mounted solar panels
- Hydrazine propulsion for orbit insertion/raising, orbit maintenance, CCAM, and EOM disposal



MEME-X “Mirror” Orbits

- In phase twin 350 x 1200 km orbits, one w/ reflected apsides
- Spanning the transition from atmosphere to space (exobase)
- Vertical soundings & temporal dynamics with ISR support
- Global scale conditions from ground based ASI mosaic
- Local time sampling with seasonal rotation of Xgsm



MEME-X Spacecraft

* 2 nearly identical SC

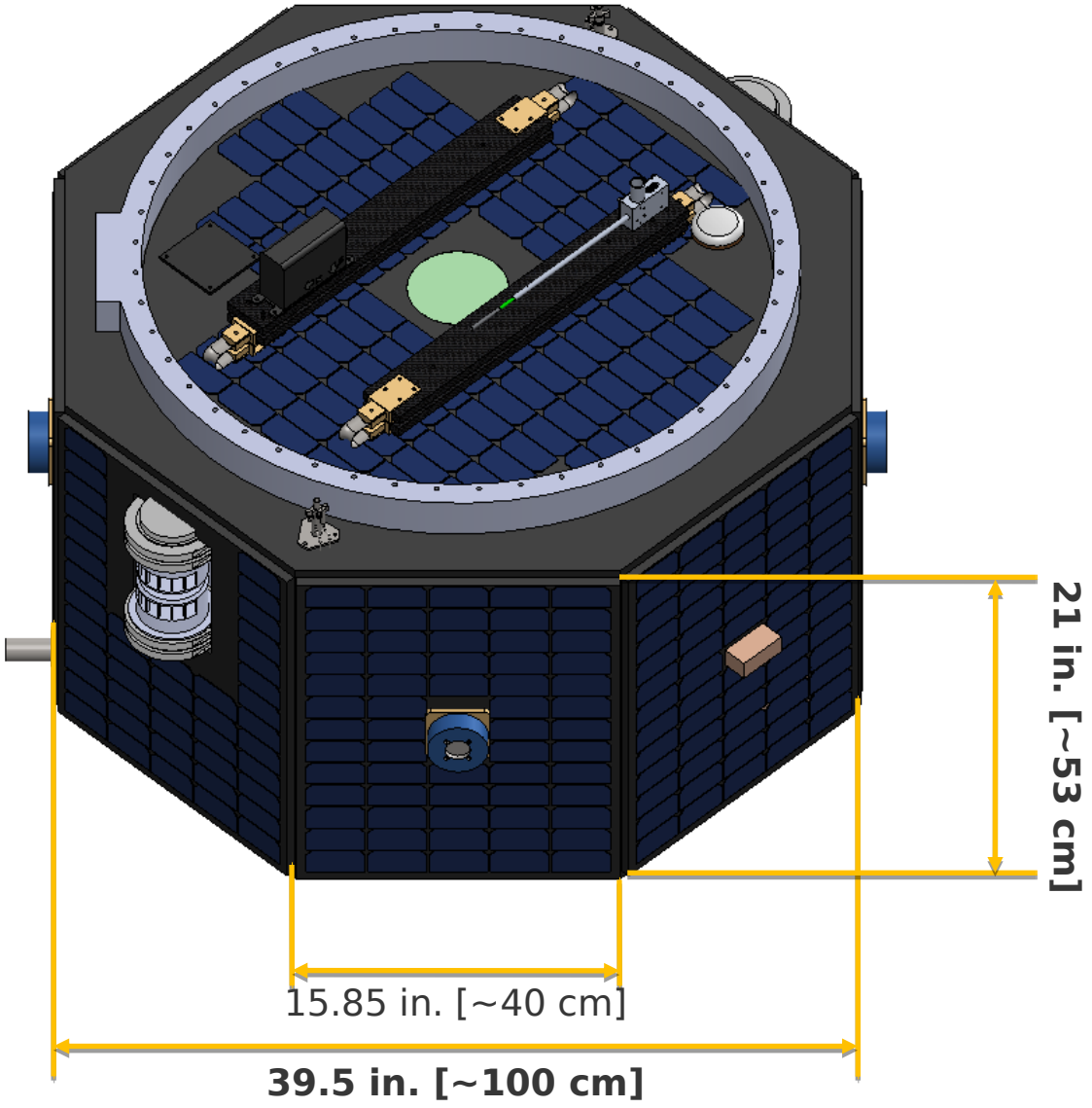
* 161 kg Observatory (MEV)
  - including 30 kg propellant

* 350 x 1250 km , 83° inc. orbits,
  - elliptically opposed

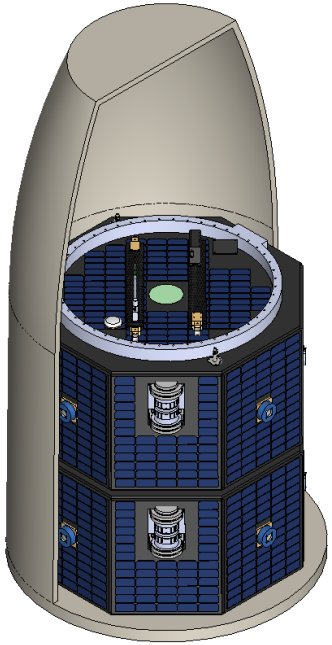
* 25-month design life,
  - extended mission option

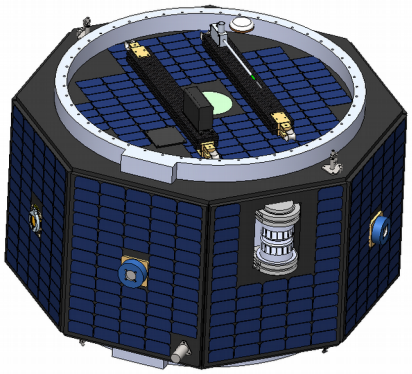
* Small Explorer Proposal

* ~ 165 M US$

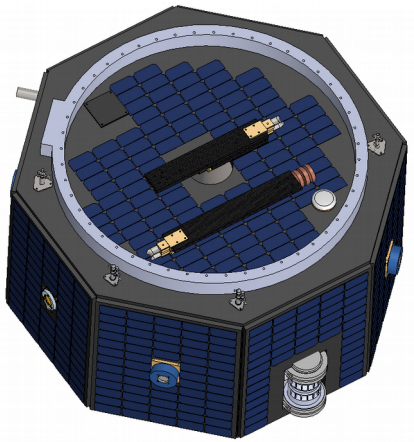


MEME-X Spacecraft

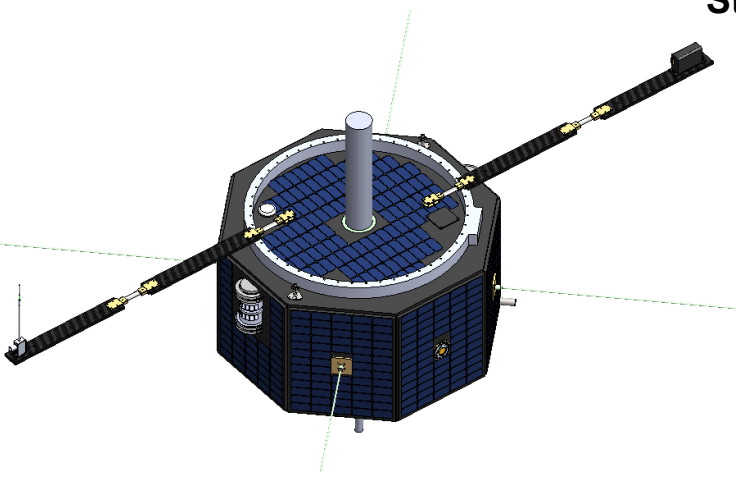




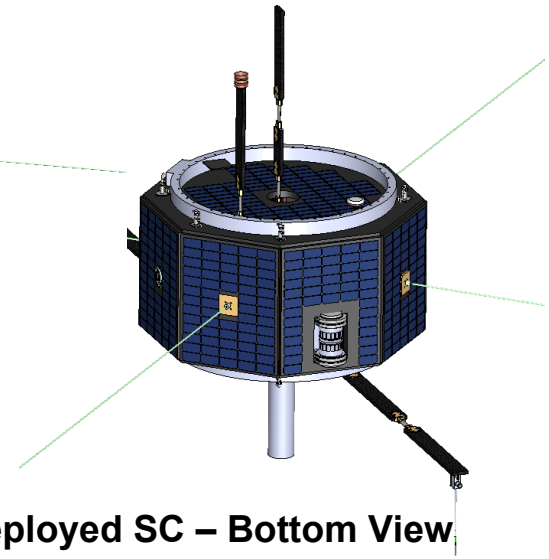
Stowed SC – Top View



Stowed SC – Bottom View



Deployed SC – Top View



Deployed SC – Bottom View

Two identical spacecraft launched on Pegasus XL® Launch Vehicle from VAFB

MEME-X Launch: Pegasus XL

MEME-X Instrumentation

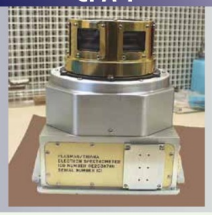
Heritage

RANGE

MFP

IDPU

CPA-i



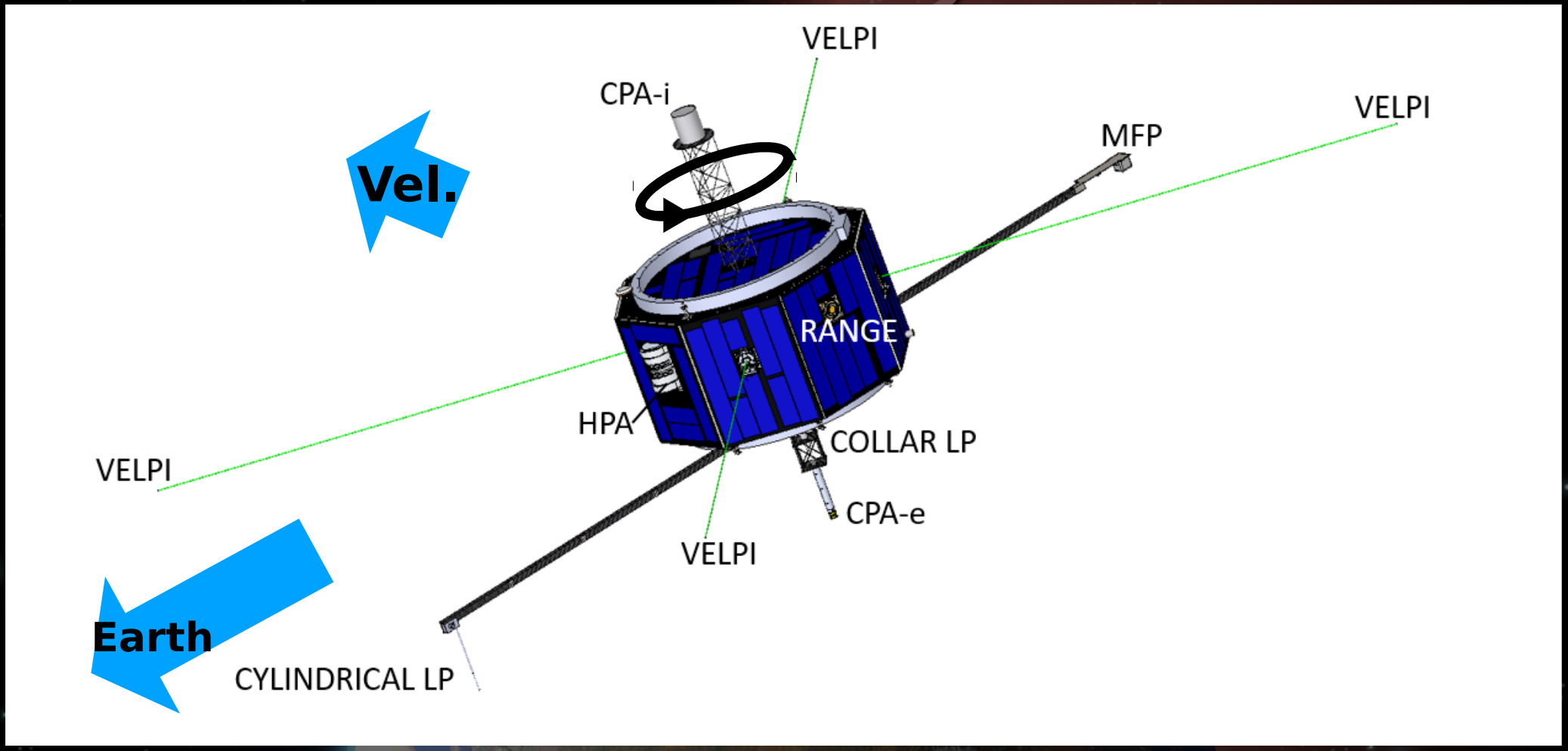
HPA

VELPI

CPA-e

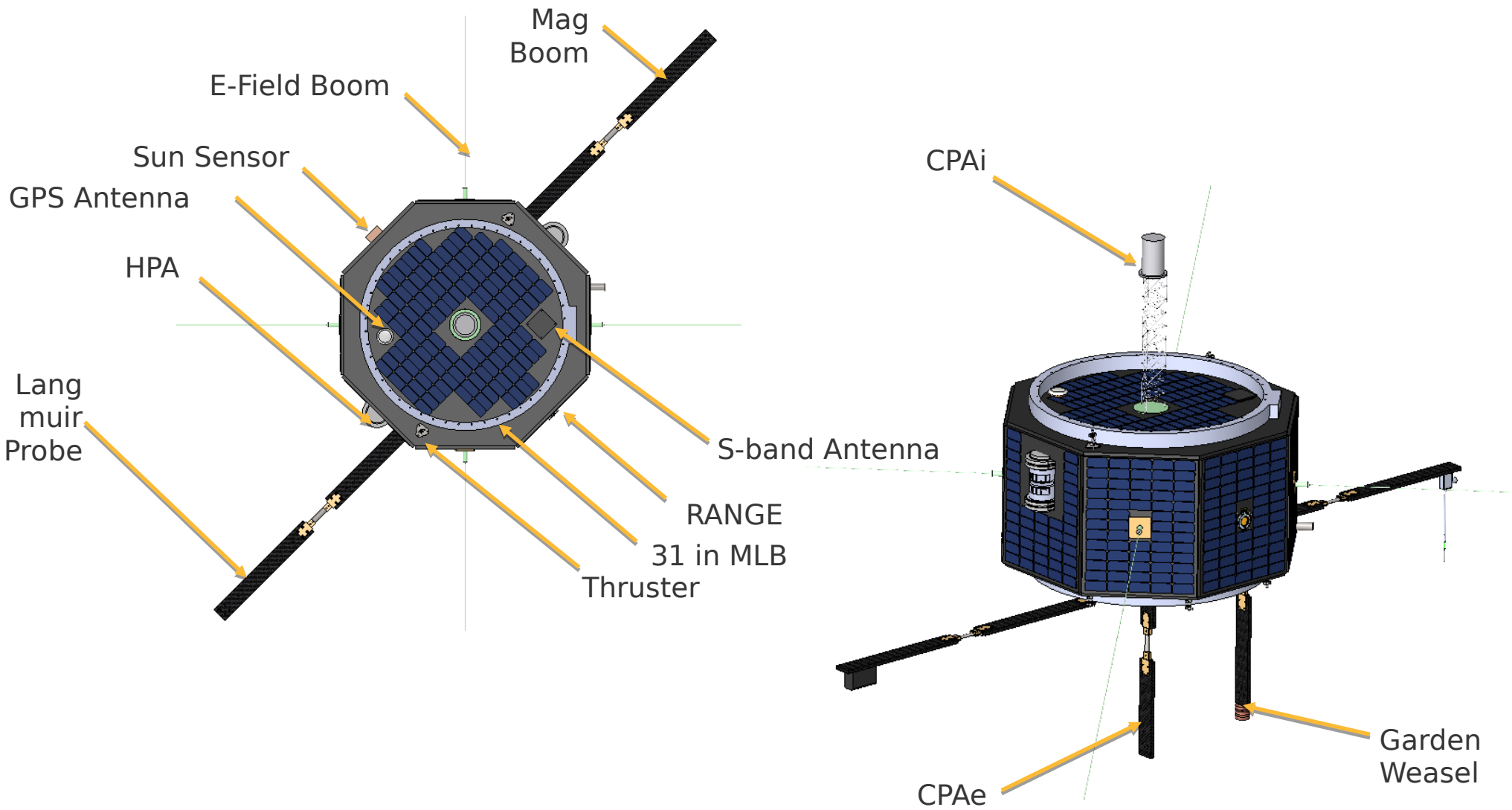
Instrument Acronym	Instrument Name	Institution	Instrument Type
CPA	Core Plasma Analyzer	GSFC	Two tophat ESAs for ions (with 3-D, TOF) and electrons (2-D) for energies 0.1 to 100 eV
RANGE	Rapid Atmospheric Neutral Gas Experiment	Aerospace	Bayard-Alpert ionization gauge to measure neutral gas density
HPA	Hot Plasma Analyzer	UNH	Two dual tophat ESAs for ions and electrons (2-D distributions) for energies 20 eV to 20 keV
VELPI	Vector Electric field and Langmuir Probe Instrument	GSFC	Spin-plane double-probe electric field instrument and cylindrical Langmuir Probe to measure electric field (DC to MHz), plasma density, and electron temperature
MFP	Magnetic Field Probe	UCLA	Triaxial fluxgate magnetometer to measure magnetic field signatures of waves and currents

MEMEX Spacecraft & Instruments



- IDPU merges Survey/Hi-Res.
- 3D **B**
- 2D **E**, LPs
- Gas pressure
- Core plasma on axial boomlets
- Hot plasma full pitch angle view

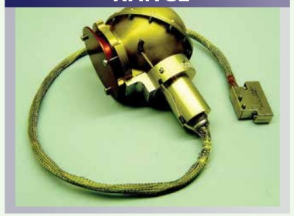
MEME-X configuration, deployed



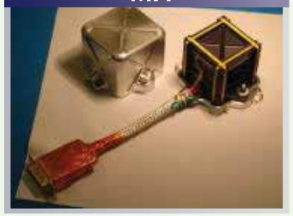
RANGE – neutral gas density

Heritage

RANGE

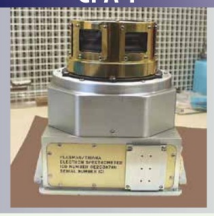


MFP



IDPU

CPA-i



HPA

VELPI

CPA-e

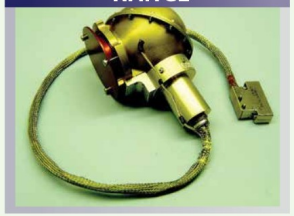
RANGE Parameter	Value
Measurement	Neutral gas density
Measurement cadence	20 Hz sampling, spin fit to produce density every spin period (3 seconds)
Absolute density accuracy	20% (quadrature sum of error sources)
Relative accuracy	0.1%
Dynamic range	2.5×10^6 to 8×10^9 cm^{-3} (below 500 km)
FOV	$\pm 85°$

Rapid Atmospheric Neutral Gas Experiment

MFP – magnetic fields

Heritage

RANGE



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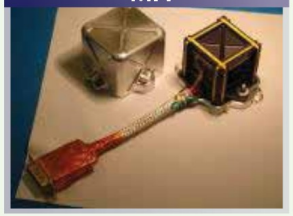

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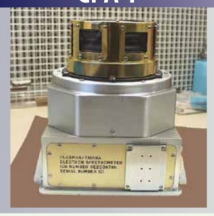
CPA-i



HPA

VELPI

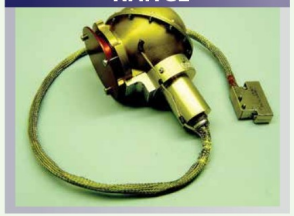
CPA-e

MFP Parameter	Capability
Native sampling cadence	128 Hz
Survey Data Product cadences	Fast: 64 Hz Slow: 16 Hz
Dynamic Range	± 60,000 nT
absolute accuracy	10 nT
sensitivity	60 pT from 3-60 Hz
resolution for dB measurements of FAC	2 nT

CPA – cold ions and electrons

Heritage

RANGE



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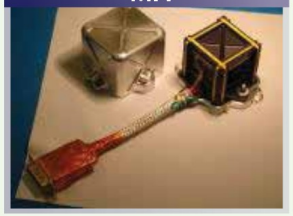

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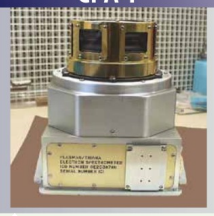
CPA-i



HPA

VELPI

CPA-e

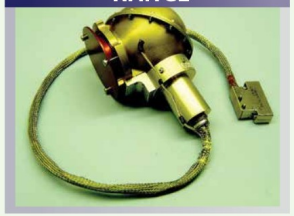
CPA-i parameter	Value
Species	H^+, He^+, O^+, "heavy" ions
Number of energy steps per scan	32, 0.1 to 100 eV @ 10 bit accumulation
Number of deflection steps per scan	8
Energy resolution	15%
Geometric Factor	$5x10^{-6}$ cm^2 sr eV / eV / pixel - $5x10^{-7}$ cm^2 sr eV/eV/pixel electrostatically adjustable
Angular resolution	Azimuthal: 1° x 10° native, 11.25° x 10° with onboard accumulations; Polar: 11.25° with deflection
FOV	360° x 10° native, 360° x ± 45° with deflection
Number of TOF bins	4 (H^+, He^+, O^+, "heavies"), dM/M 25%
Time cadence for 3-D energy/ angle/mass distributions	100 ms

CPA-e parameter	Value
Species	electrons
Number of energy steps per scan	32, 0.1 to 100 eV @ 16 bit accumulation
Energy resolution	15%
Geometric Factor	2.56×10^{-6} cm^2 sr eV / eV / pixel
Angular resolution	Azimuthal: 11.25° x 10° native
FOV	360° x 10°
Time cadence	100 ms

HPA – hot ions and electrons

Heritage

RANGE



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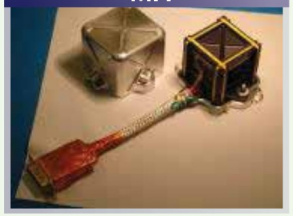
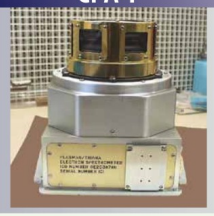


IDPU

CPA-i



HPA

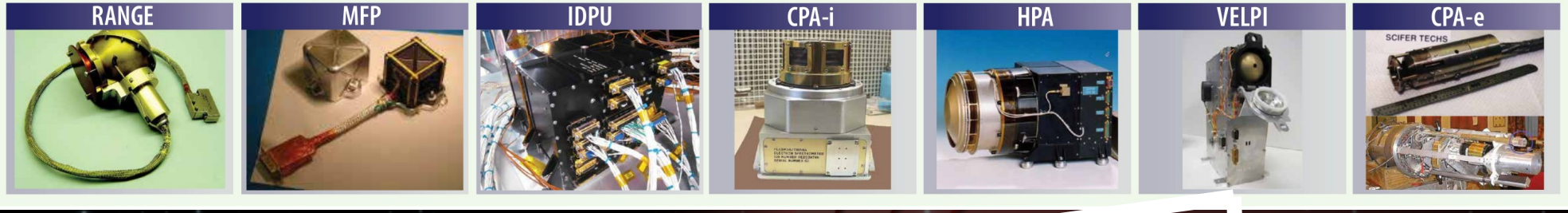
VELPI

CPA-e

HPA Parameter	Capability
Species	ions, electrons
Number of energy steps per scan	64, 20 eV to 20 keV @ 10-bit accumulation
Energy resolution	12% (FWHM)
Geometric Factor (ions)*	4×10^{-3} cm^2 sr dE / E (2.8×10^{-4} / pixel)
Geometric Factor (electrons)*	1.2×10^{-3} cm^2 sr dE / E (8.6×10^{-5} / pixel)
Angular resolution	Azimuthal: 12.8 °
FOV (intrinsic)*	5° x 180 °
FOV (with deflection)*	30° x 180 °
Time cadence for 3-D energy/ angle/mass distributions	107 ms

VELPI – AC/DC electric fields

Heritage



VELPI AC E parameter	Value
Native Sampling Cadence	2048 Hz
Survey Product Temporal Resolution	Fast: 512 Hz Slow: 128 Hz
Dynamic Range	± 200 mV/m
Absolute accuracy	10 µV/m
Sensitivity	1 µV/m
VLF FFT spectral resolution	1024 frequencies 30 Hz - 16 kHz
VLF FFT cadence	2 / second
VLF dynamic range	70 dB from 10^{-4} mV/m/root (Hz) @ 10 kHz
VLF Burst recording sampling	32768 samples per second, 3 channels (Ex, Ey, Ne) for 60 sec/orbit
HF FFT spectral resolution	1024 frequencies 300 Hz - 4 MHz
HF FFT cadence	2 / second
HF dynamic range	70 dB from 10^{-5} mV/m/root (Hz) @ 1 MHz
HF Burst recording sampling	8M samples per second, 1 channel (Ex or Ey) for total of 1 sec / orbit

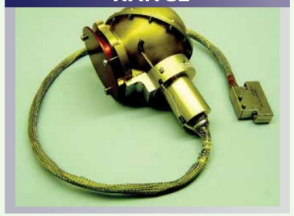
VELPI DC E parameter	Value
Native Sampling Cadence	High Resolution: 512 Hz Fast Survey: 128 Hz Slow Survey: 16 Hz
Dynamic Range	± 1 V/m
Absolute accuracy	2 mV/m
Sensitivity	20 µV/m

NB! "Cartwheel" spin → $E_{||}$

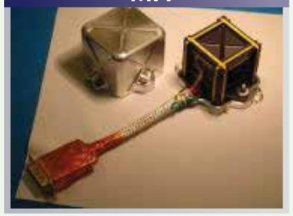
VELPI – Langmuir probe

Heritage

RANGE

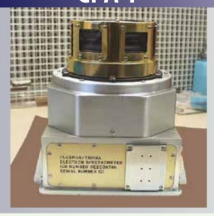


MFP



IDPU

CPA-i



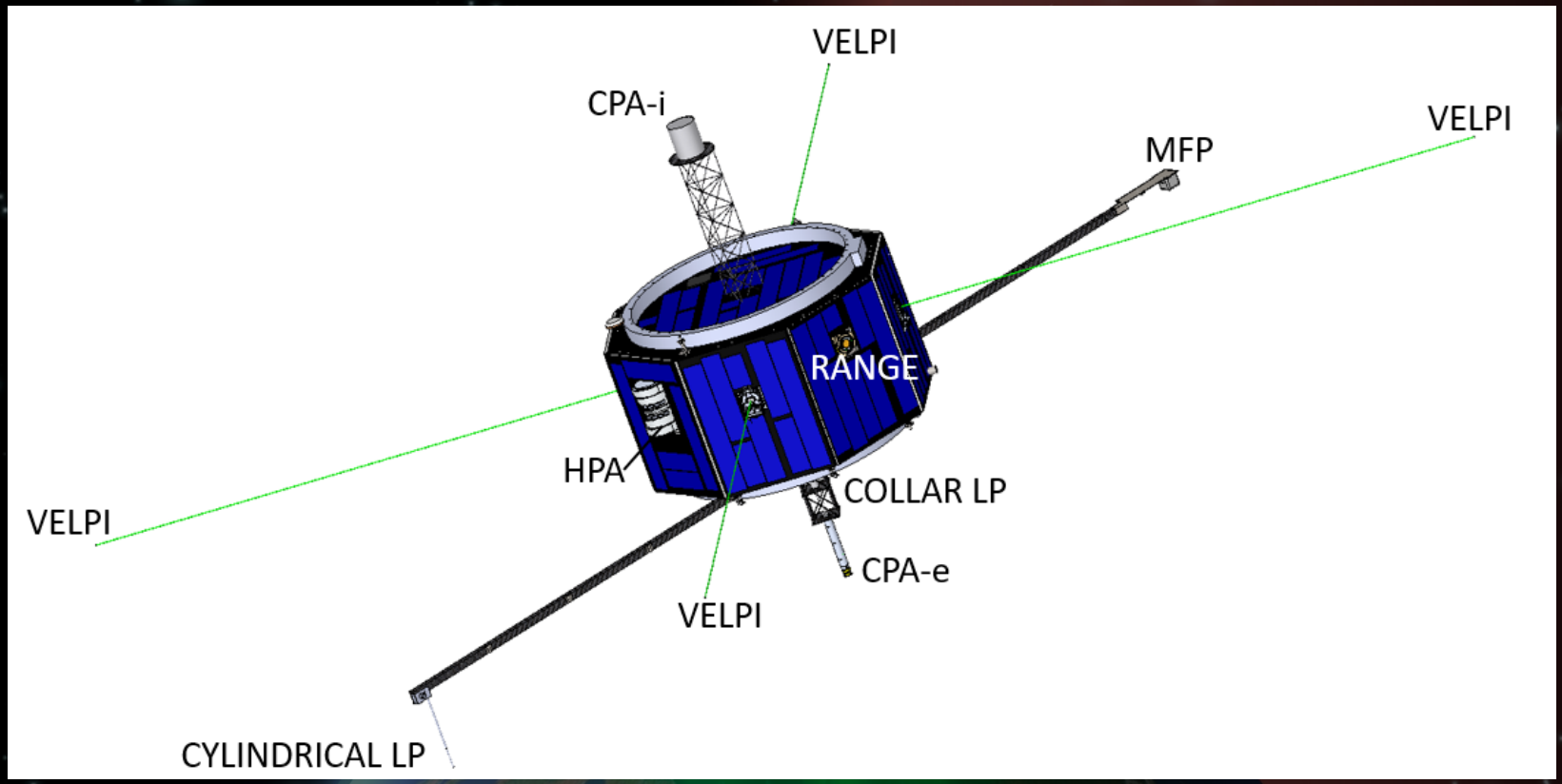
HPA

VELPI

CPA-e

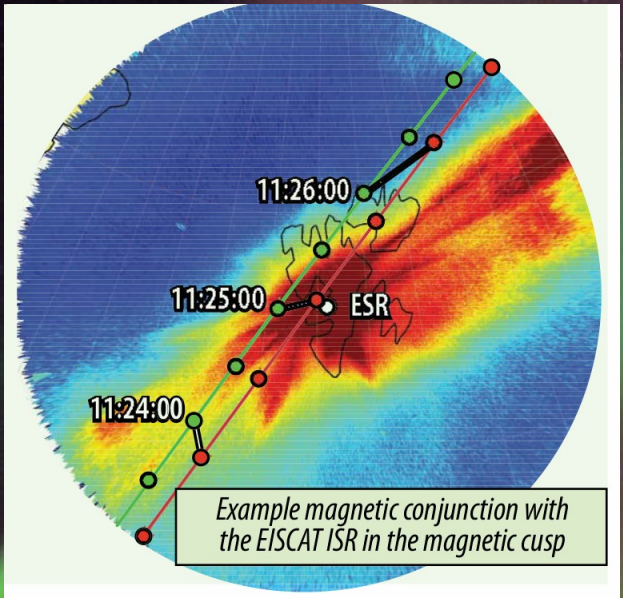
VELPI LP parameter	Value
Native Ne sampling cadence	1024 Hz
Survey Data Product cadences	Fast: 64 Hz Slow: 16 Hz
Ne Dynamic Range	100 - 5 x 10^6 / cc
Ne absolute accuracy	Larger of 1000/cc or 10%
Ne Sensitivity	larger of 100/cc or 1%
Te sampling cadence	6 seconds
Te Dynamic Range	500-10,000 K
Te Absolute Accuracy	larger of 200 K or 5%
Te Sensitivity	Larger of 100K or 2%

MEME-X Instrumentation



Instrument Acronym	Instrument Name	Institution	Instrument Type
CPA	Core Plasma Analyzer	GSFC	Two tophat ESAs for ions (with 3-D, TOF) and electrons (2-D) for energies 0.1 to 100 eV
RANGE	Rapid Atmospheric Neutral Gas Experiment	Aerospace	Bayard-Alpert ionization gauge to measure neutral gas density
HPA	Hot Plasma Analyzer	UNH	Two dual tophat ESAs for ions and electrons (2-D distributions) for energies 20 eV to 20 keV
VELPI	Vector Electric field and Langmuir Probe Instrument	GSFC	Spin-plane double-probe electric field instrument and cylindrical Langmuir Probe to measure electric field (DC to MHz), plasma density, and electron temperature
MFP	Magnetic Field Probe	UCLA	Triaxial fluxgate magnetometer to measure magnetic field signatures of waves and currents

MEME-X Ground support



Example magnetic conjunction with the EISCAT ISR in the magnetic cusp

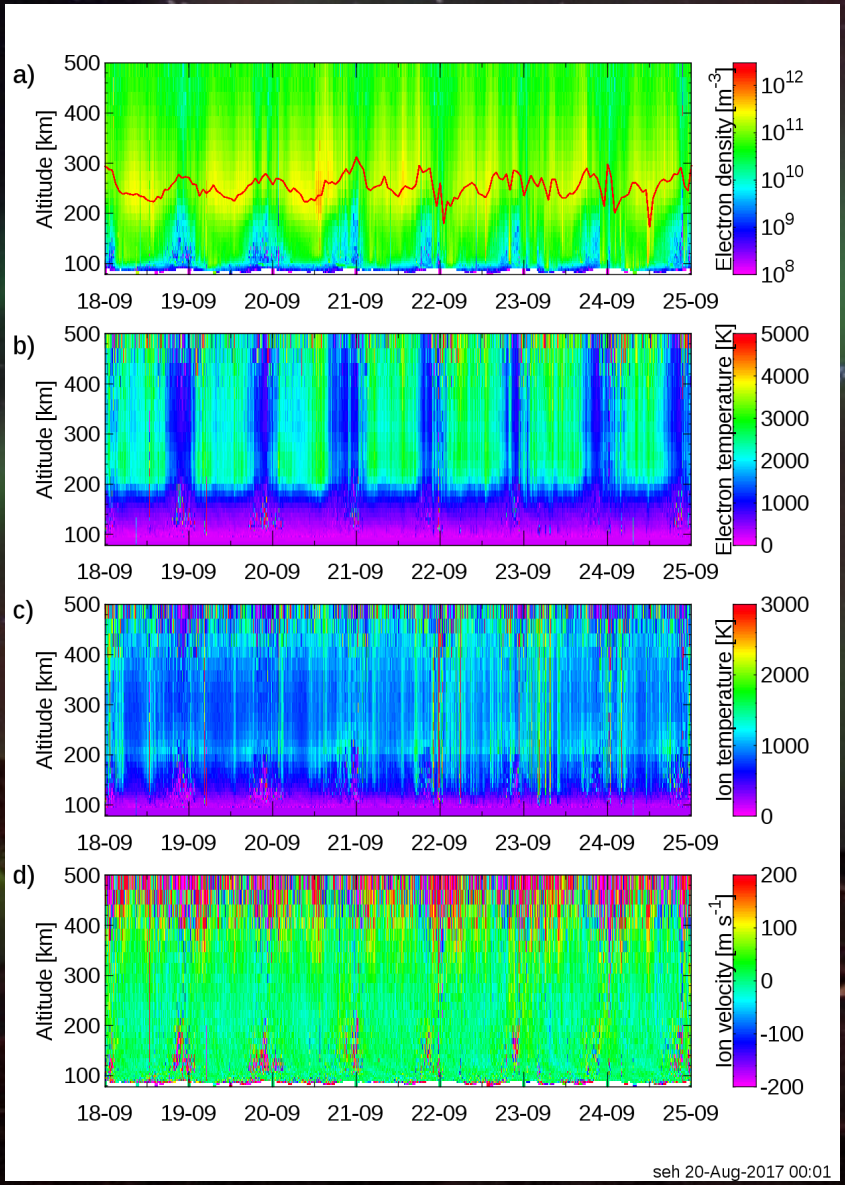
MEME-X Ground support

Ne

Te

Ti

$V_{||}$

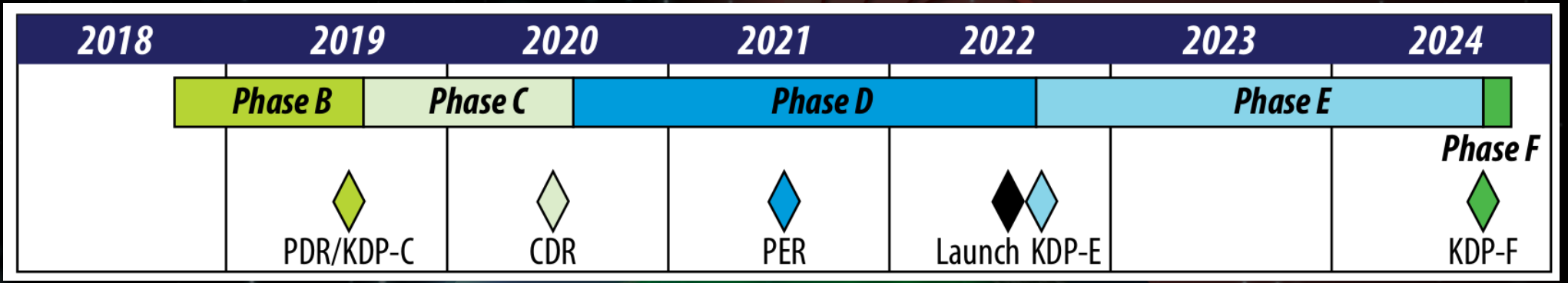


Incoherent Scatter Radar (ISR)

Height profiles of

* plasma density
* electron temperature
* ion temperature
* upflow velocity
* 1 min time resolution
* up to ca 1000 km

MEME-X time schedule:



(phase B : April 2019)