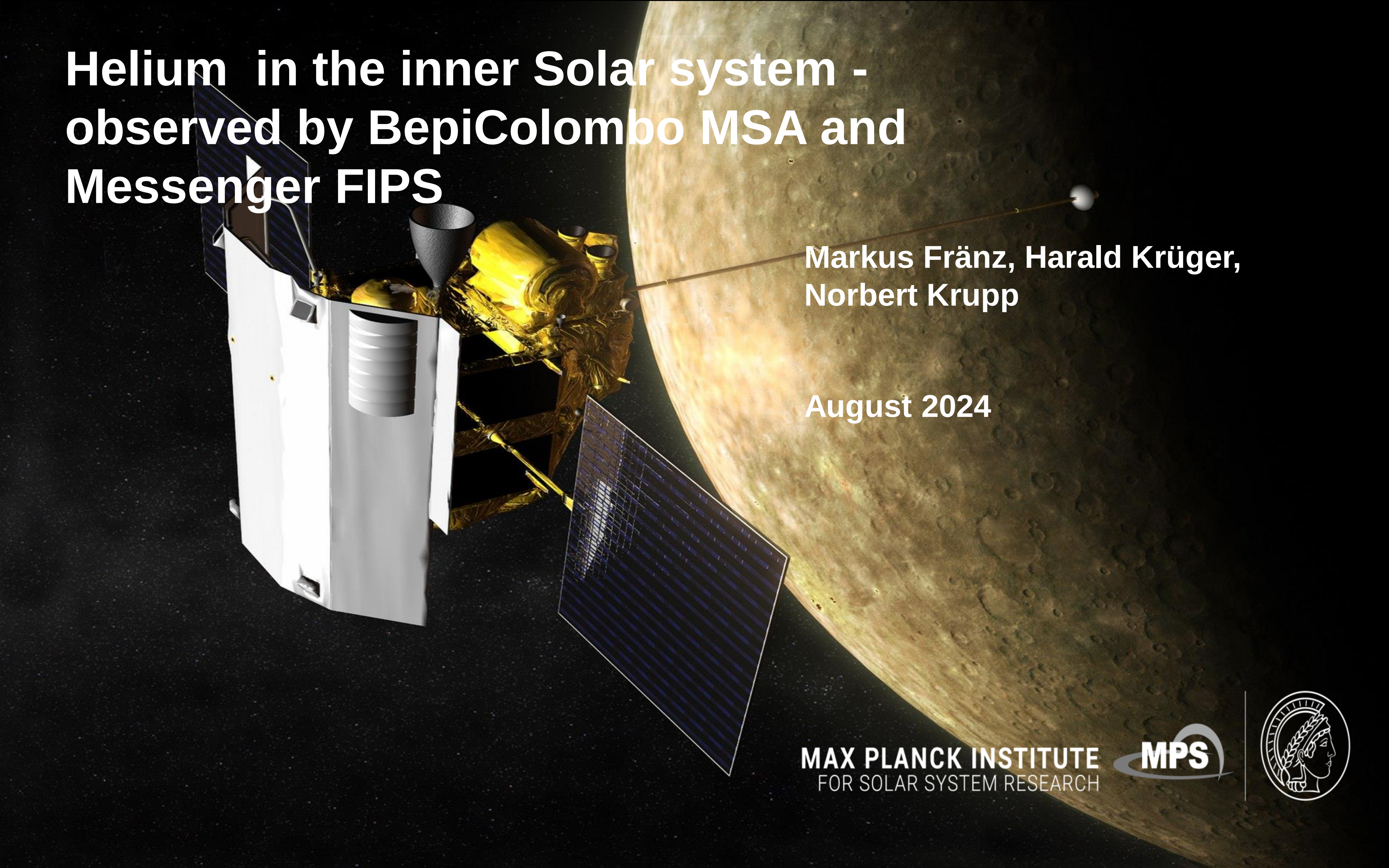
Helium in the inner Solar system - observed by BepiColombo MSA and Messenger FIPS



Markus Fränz, Harald Krüger, Norbert Krupp

August 2024

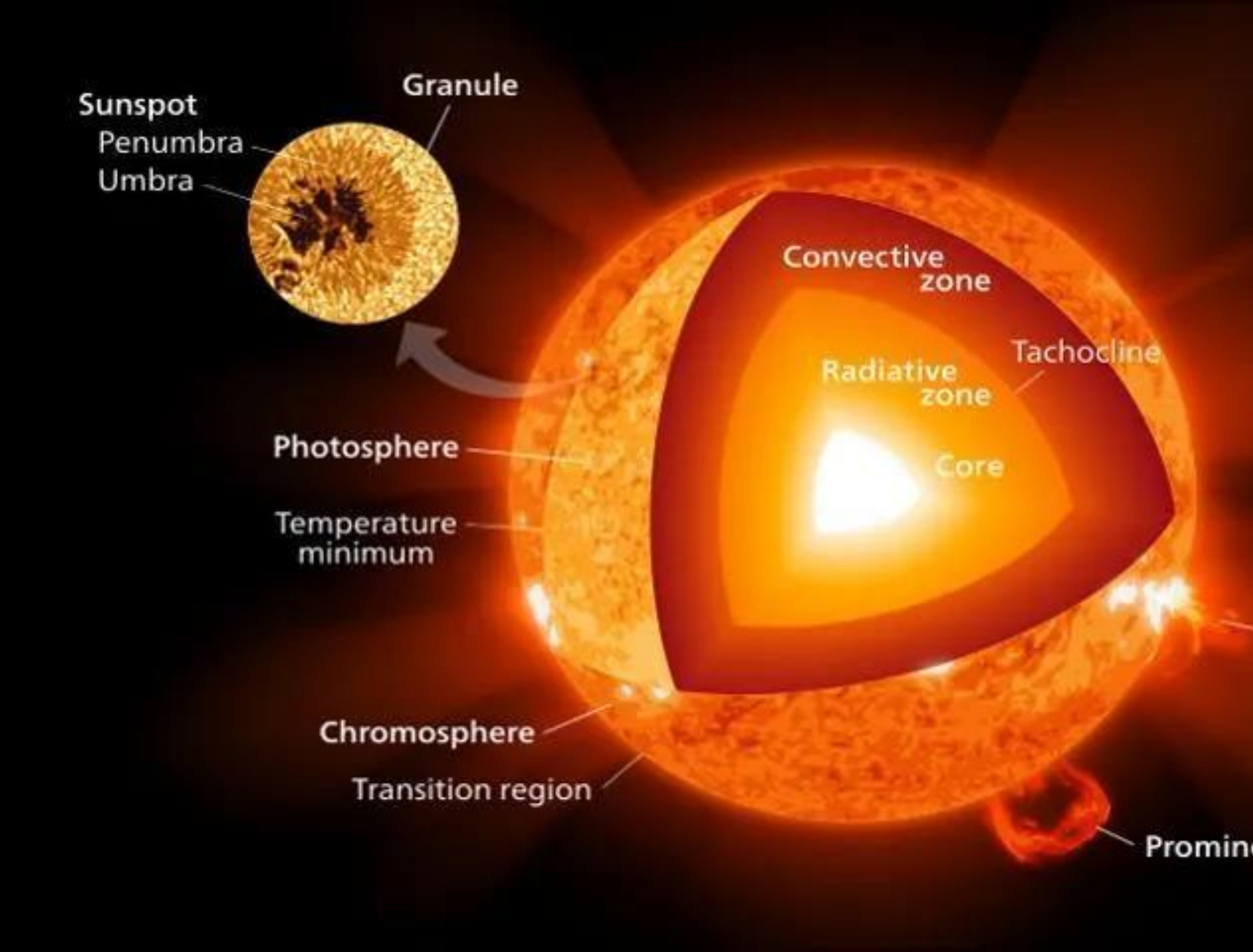
MAX PLANCK INSTITUTE
FOR SOLAR SYSTEM RESEARCH

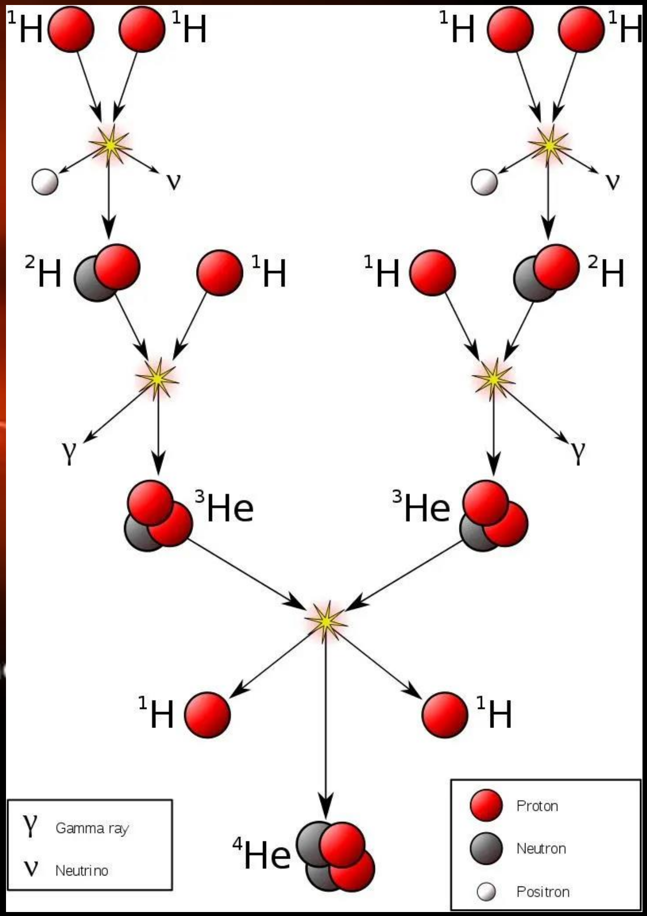
Launch of Sunrise III solar telecope with Helium balloon
July 2024

HELIUM IN THE INNER SOLAR SYSTEM - OVERVIEW

1) Sources of Helium
2) Helium at Venus, Earth and Mars
3) Interstellar Helium
4) The BepiColombo mission
5) The Messenger mission
6) Helium in Mercury’s magnetosphere

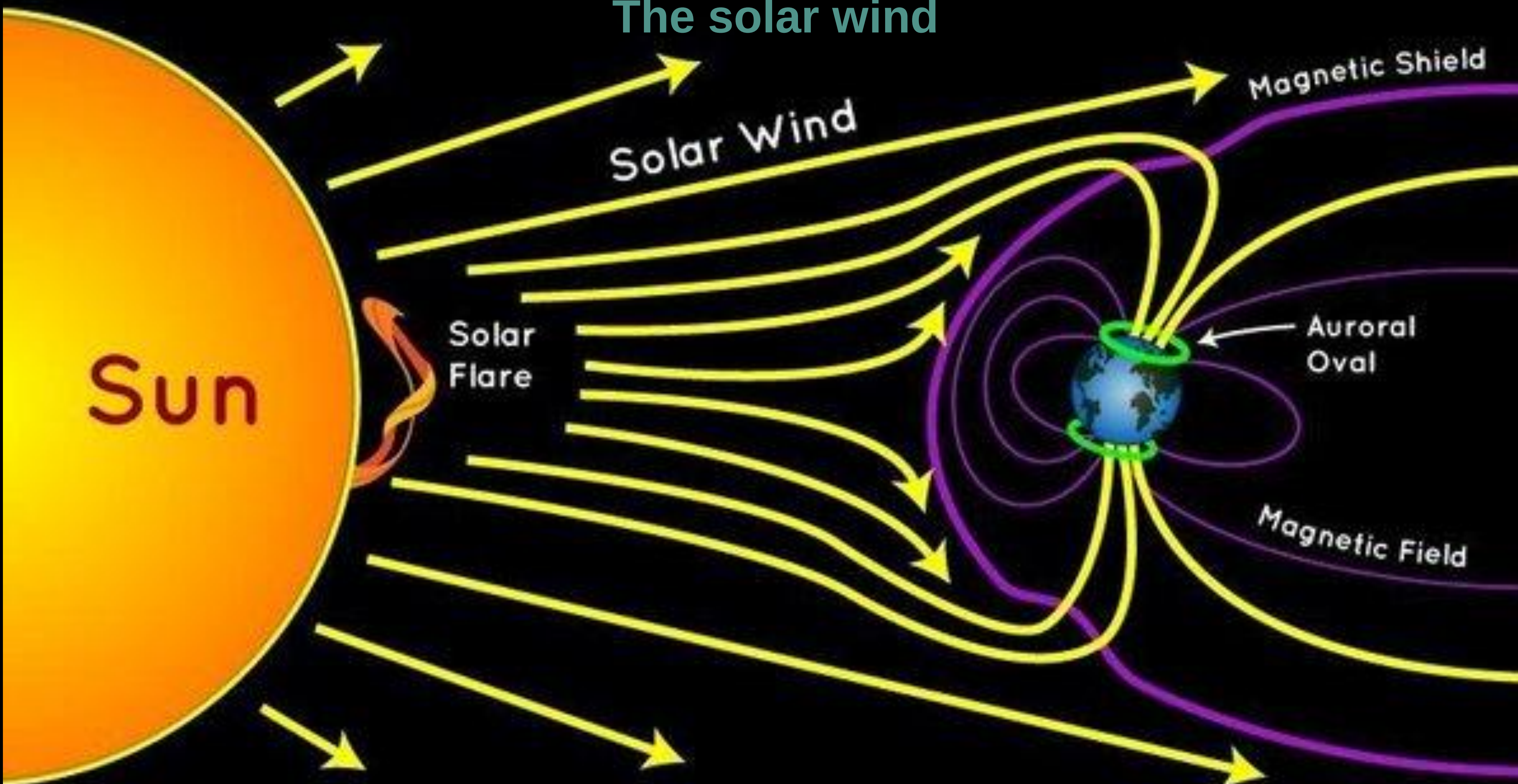
Solar Helium





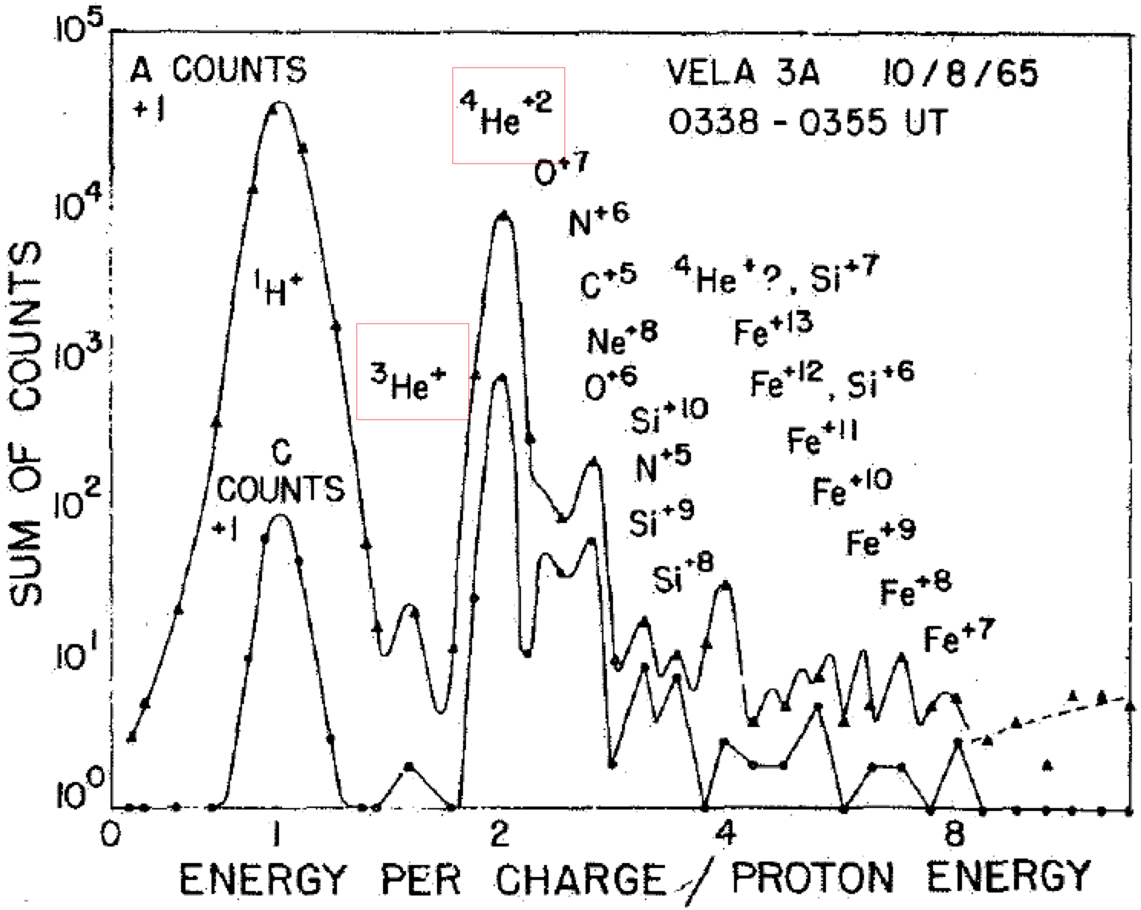
Nuclear fusion produces ^{3}He and ^{4}He in the solar core

The solar wind



Solar wind with a velocity of 200-1000km/s is produced by coronal heating and creates aurorae at the planets.

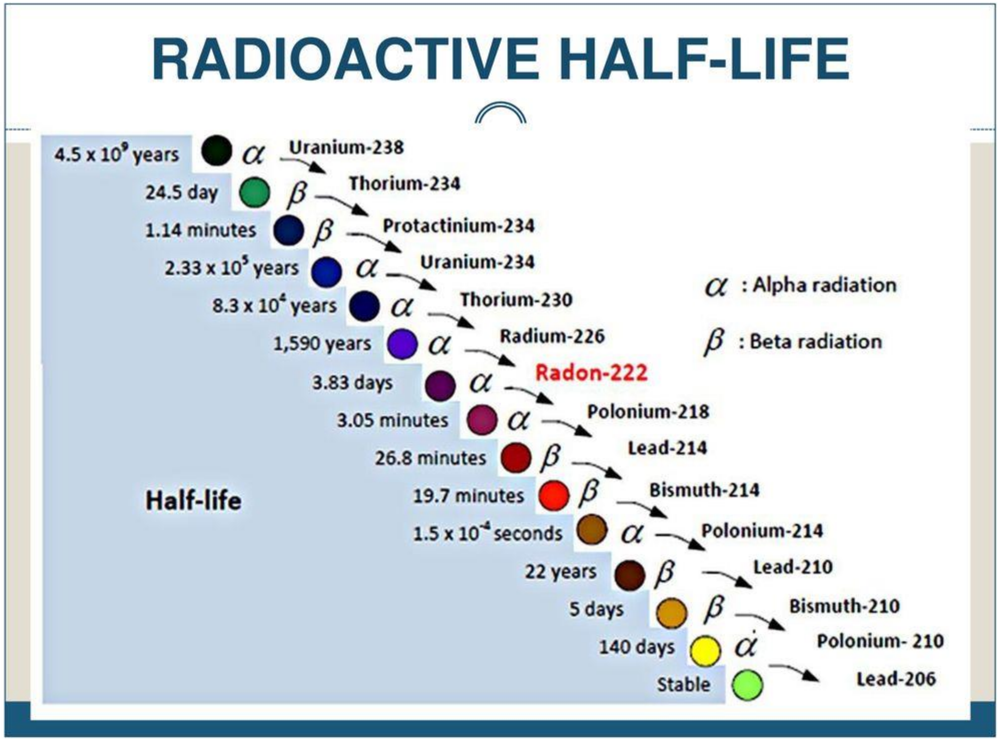
The solar wind composition



The solar wind is mainly composed of protons with about 4% of $^4He^{++}$ (alpha). But also $^3He^{++}$ and highly charged heavier ions occur (Bame et al. 2006).

Planetary Helium

Planetary radioactive decay



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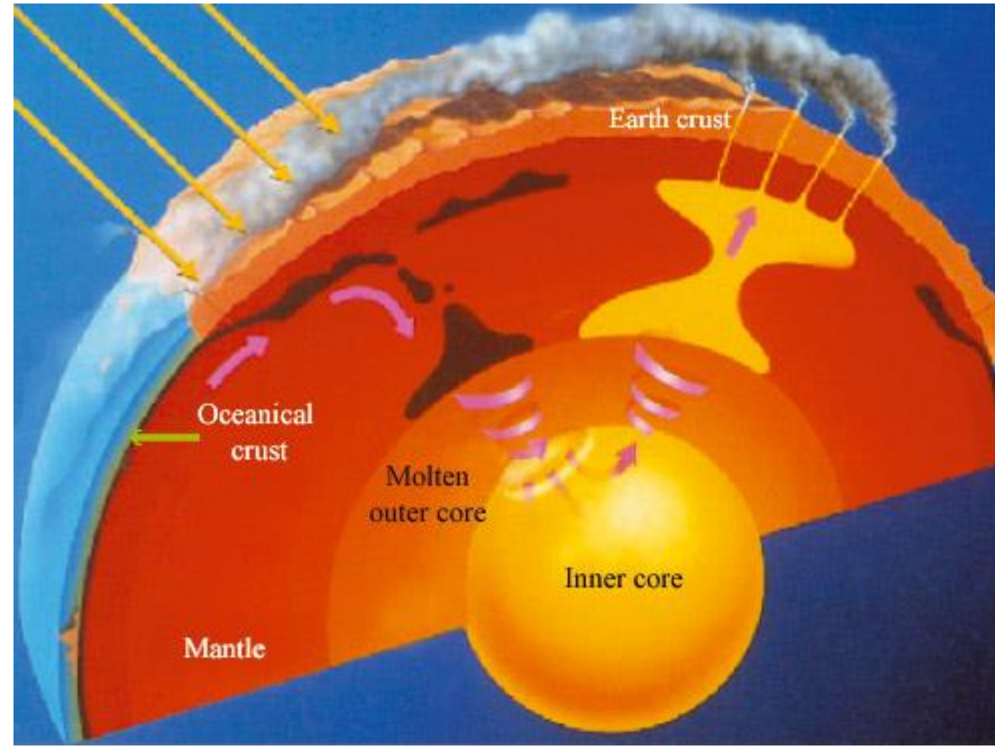

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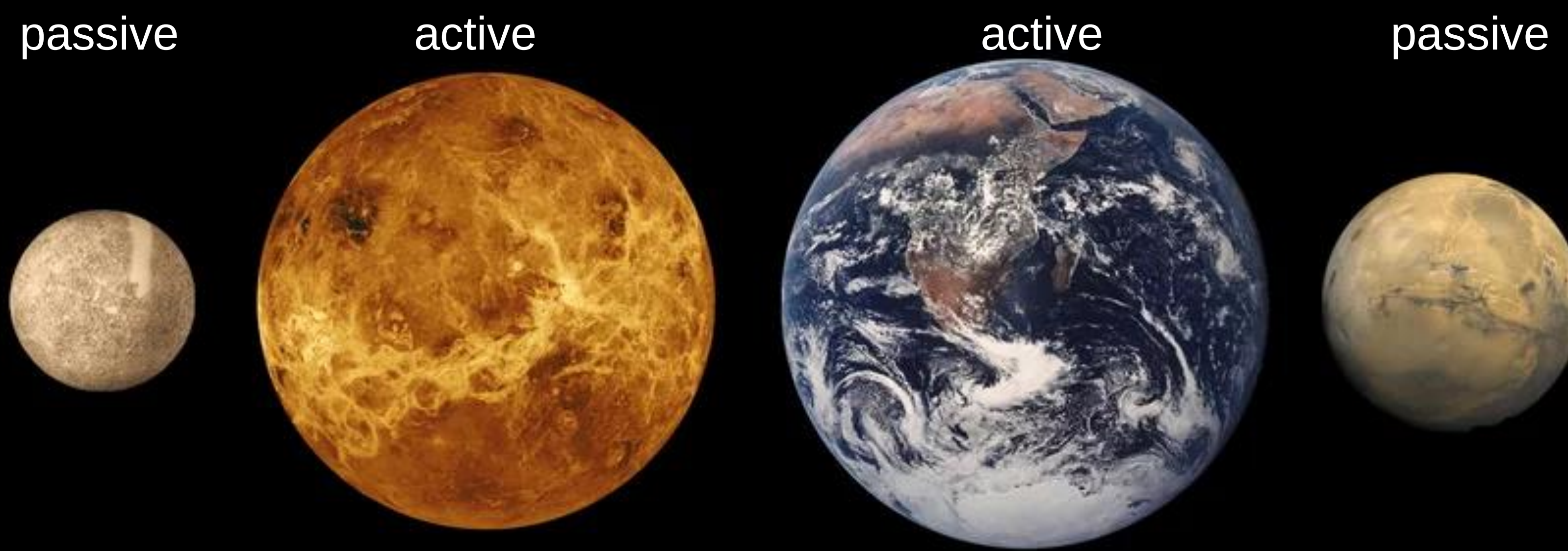
Primordial Uranium contained in planetary cores and mantle decays and releases ^{4}He (alpha) and Radon. The decay contributes about 50% to Earth's internal heat. Volcanic ^{4}He is the main source of atmospheric ^{4}He at Earth and Venus.

Volcanism at the terrestrial planets



Only Venus and Earth have active volcanism and Helium from internal sources in their atmosphere.

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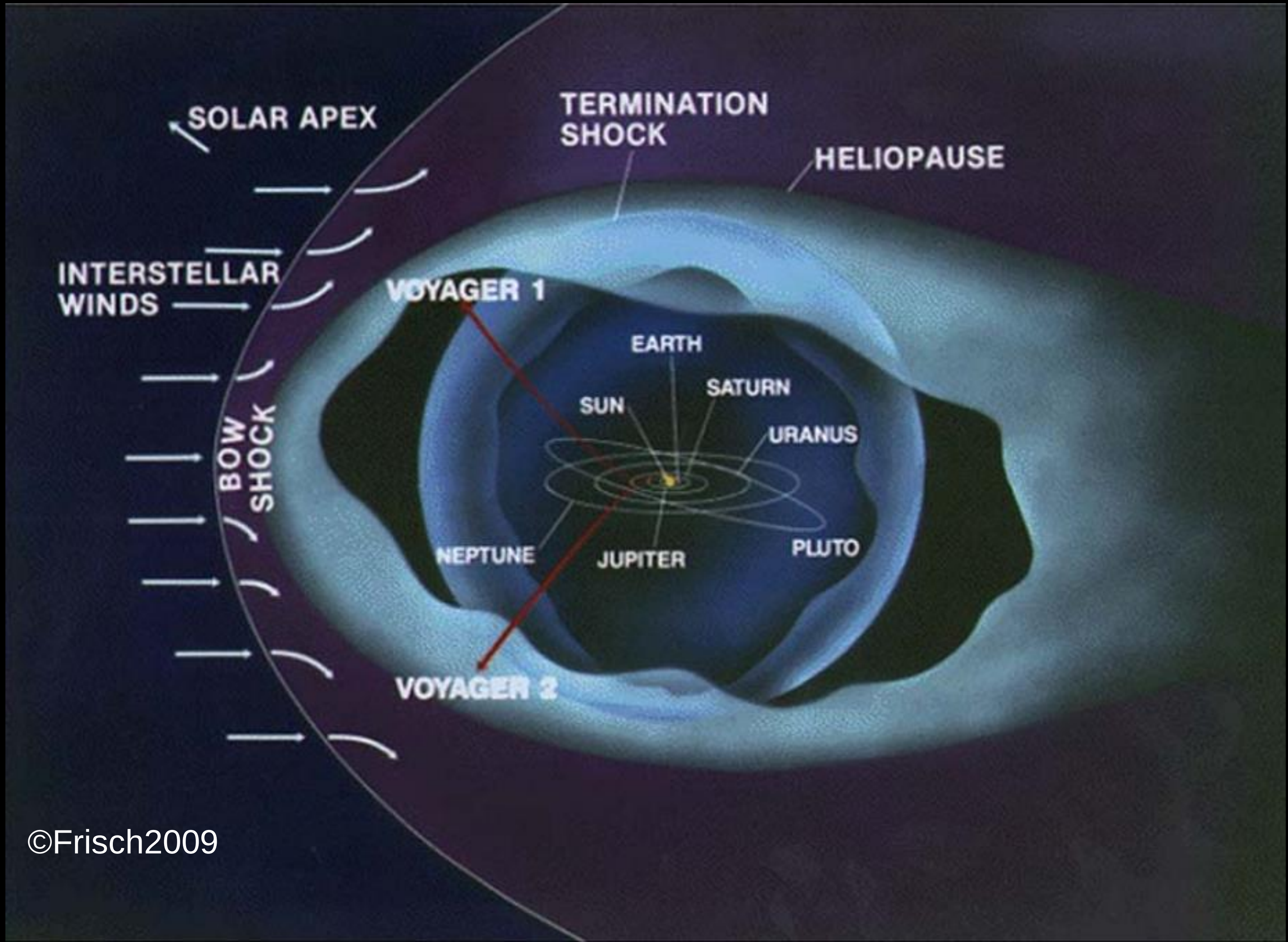
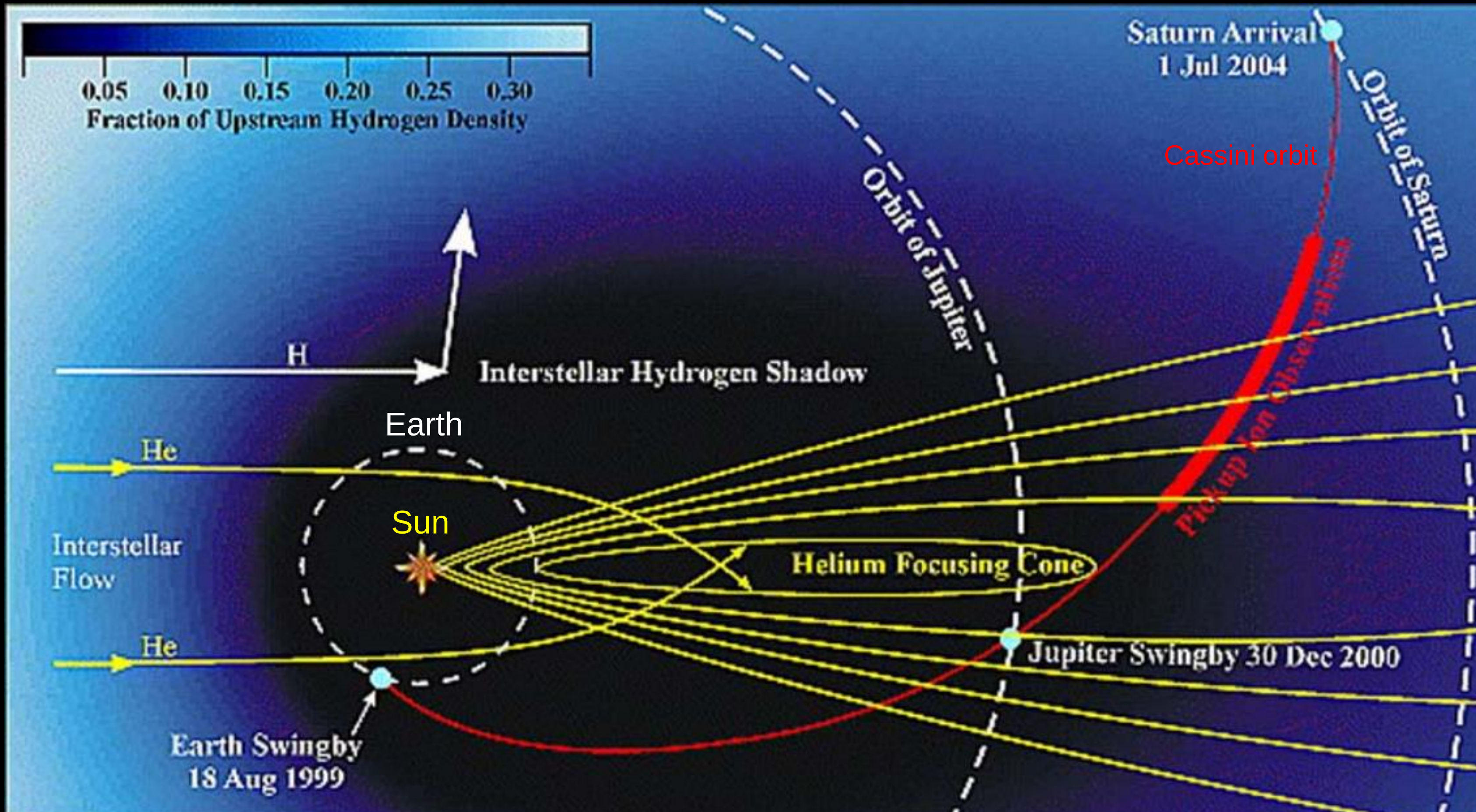
Interstellar Helium

Interstellar Wind



The solar system moves through the interstellar gas cloud at a velocity of 26km/s.
The solar wind causes a plasma cavity called the heliosphere.

Interstellar Wind interaction with the Sun



The interstellar gas consists mainly of neutral Hydrogen and Helium. The Hydrogen is ionized beyond the Earth orbit while Helium is focused behind the Sun by gravitation.

MODEL HE+ DISTRIBUTION IN THE INNER SOLAR SYSTEM

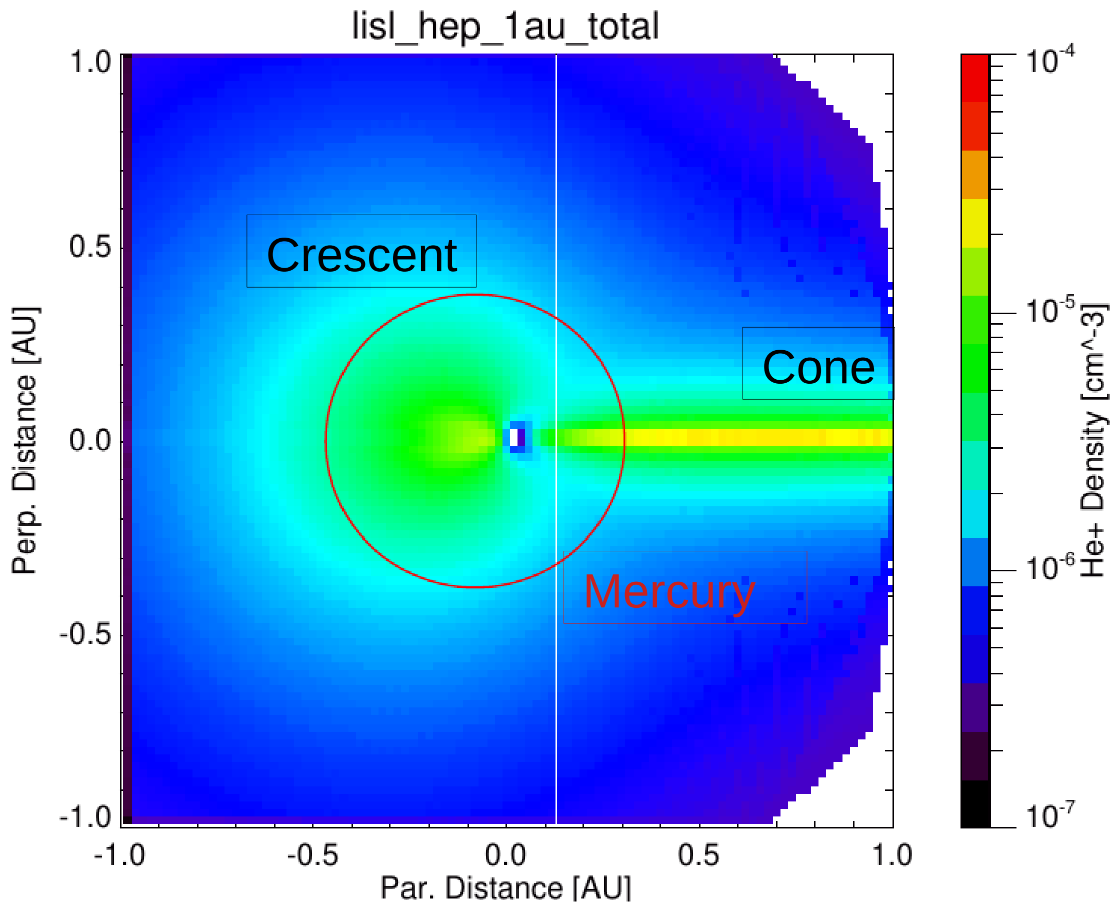
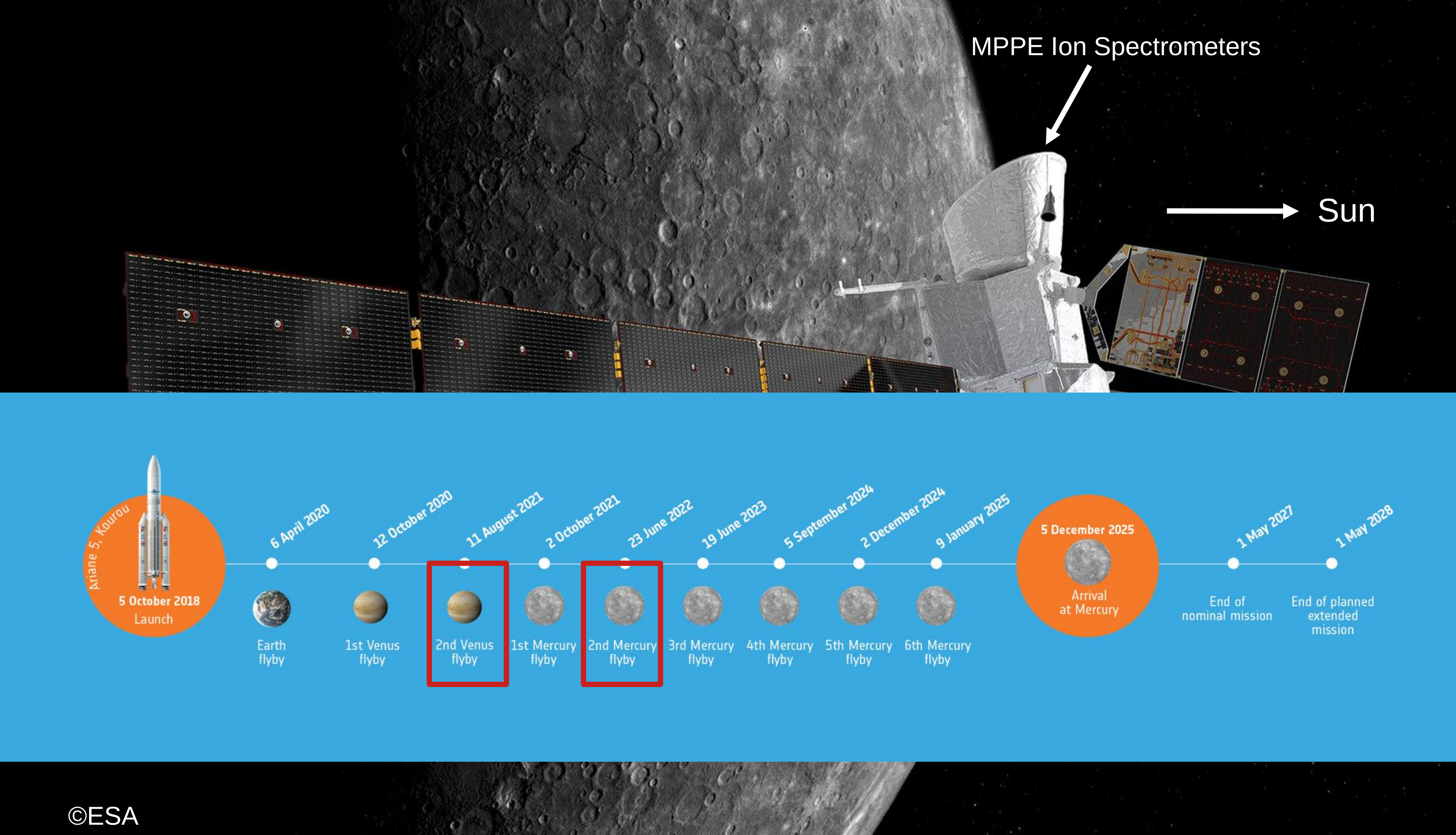


Fig. 1. Simple model of the interstellar He^{+} density distribution in the inner solar system in a coordinate system aligned with the interstellar helium flow direction. The red circle marks the Mercury orbit, and the interstellar helium approaches from the -x direction.

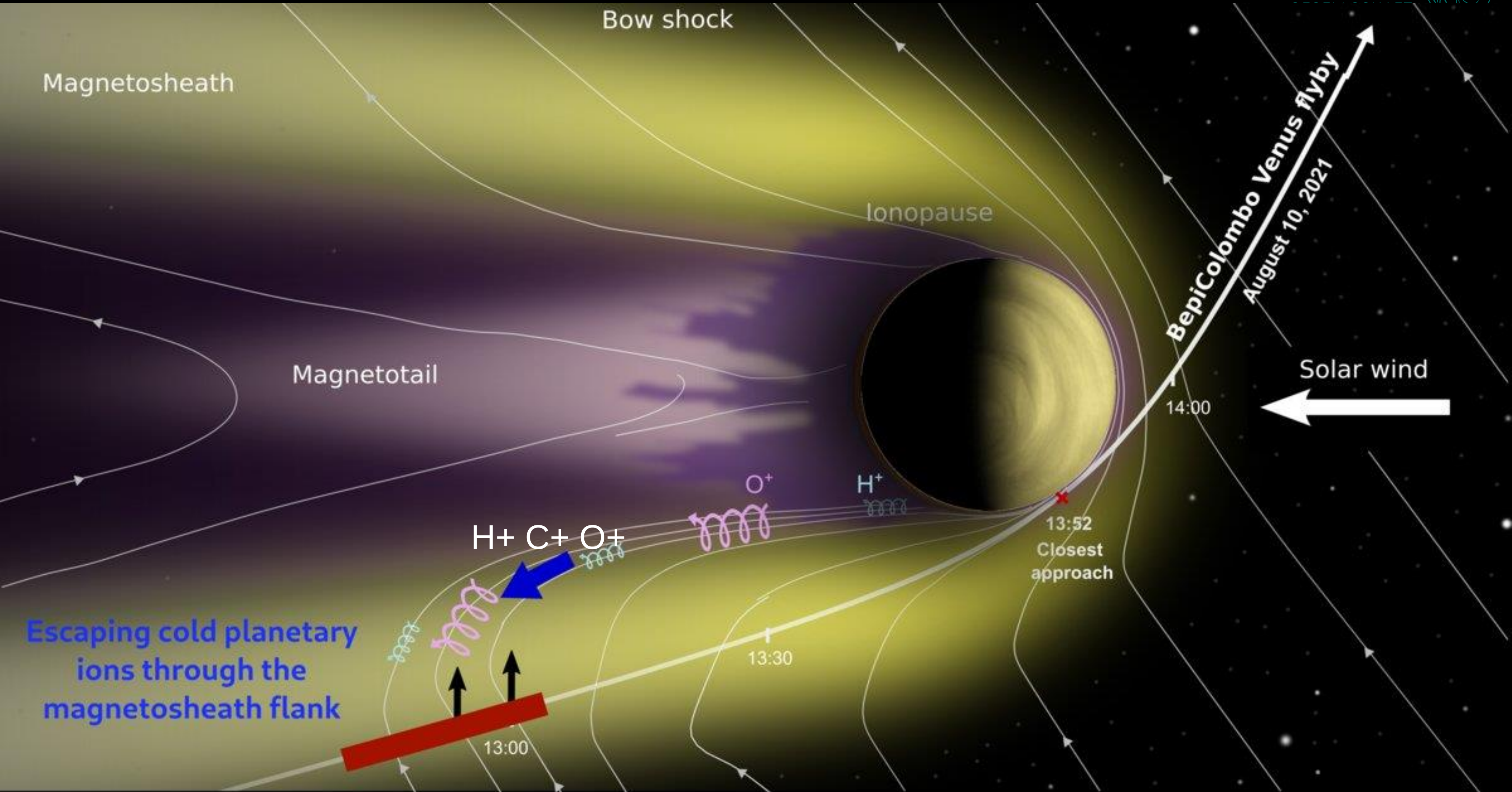
Models of the interstellar He+ distribution taking into account the ionization exposure time predict an upstream ‘crescent’ (Drews, 2012; Fränz, 2024).

The BepiColombo Mission

ESA/JAXA Mission BepiColombo to Mercury

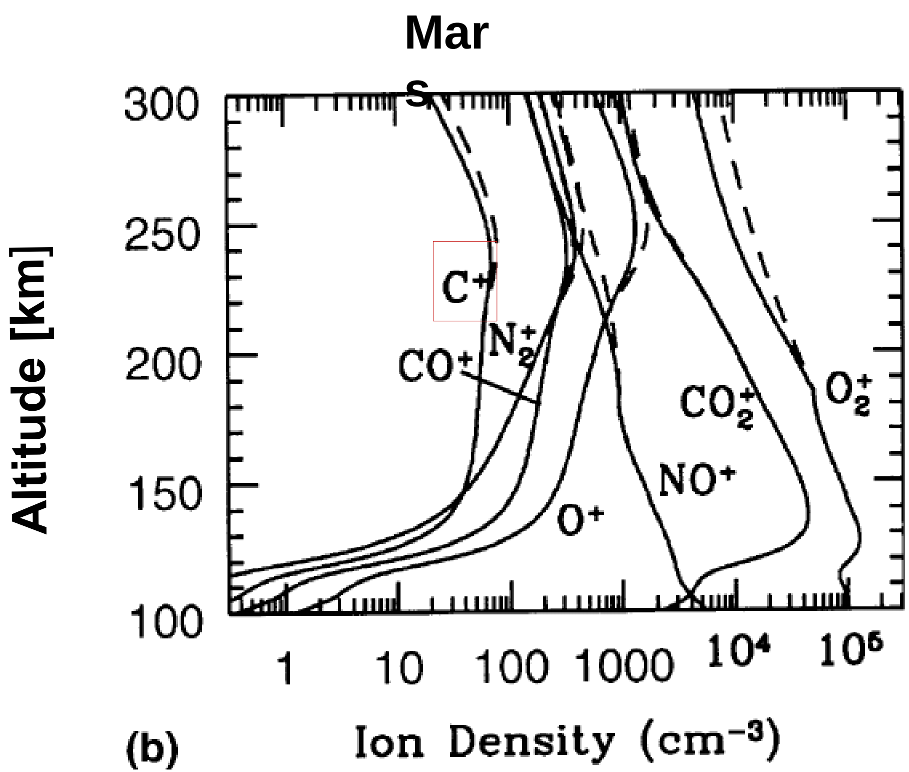


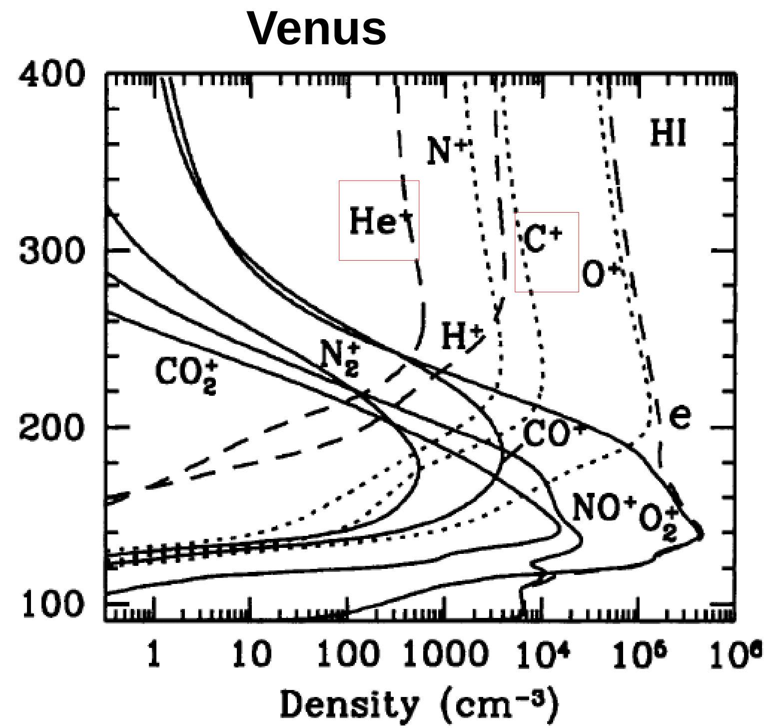
BepiColombo Venus FlyBy 10 August 2021



Apart from Hydrogen and Oxygen also Carbon is escaping from Venus. Why?

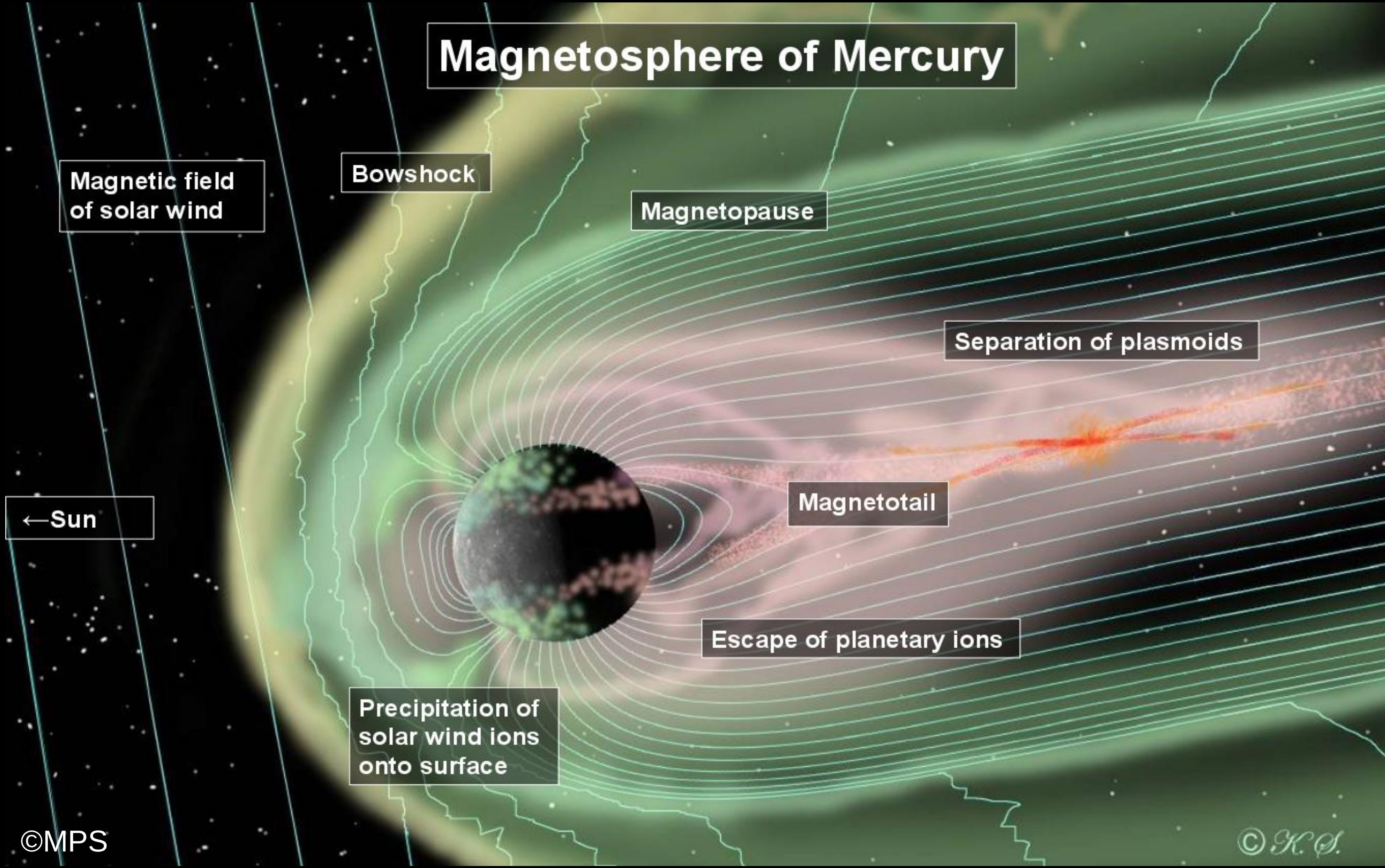
Composition of the Ionospheres of Mars and Venus





While at Mars atomic carbon plays no role at higher altitudes, at Venus a significant C^+ density is observed above 400km altitude (Fox 2004).
The reason is the reaction **$He^+ + CO \rightarrow He + C^+ + O$** involving the trace gas He which exists only in the Venus atmosphere in significant amounts.

Planet Mercury



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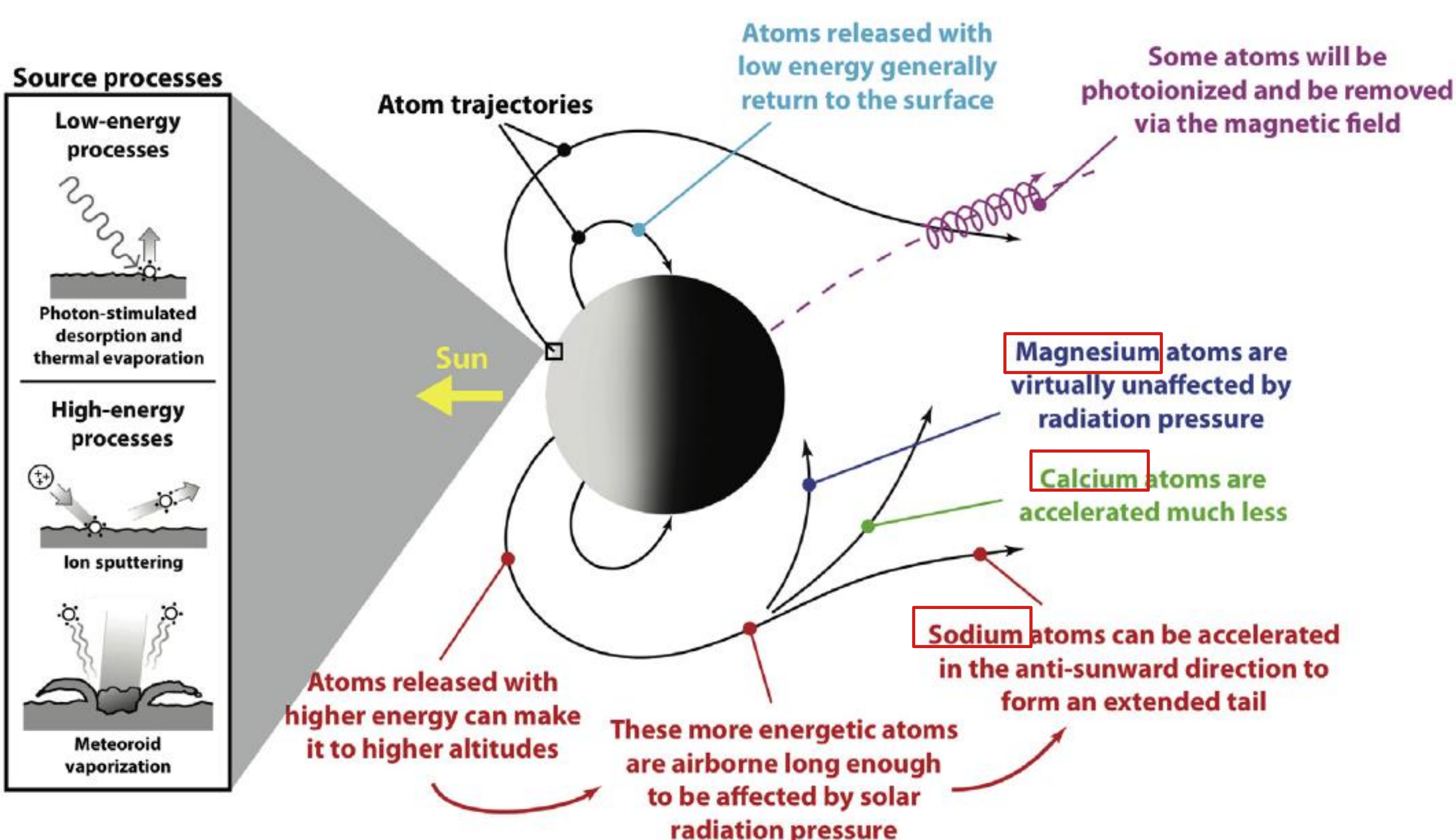
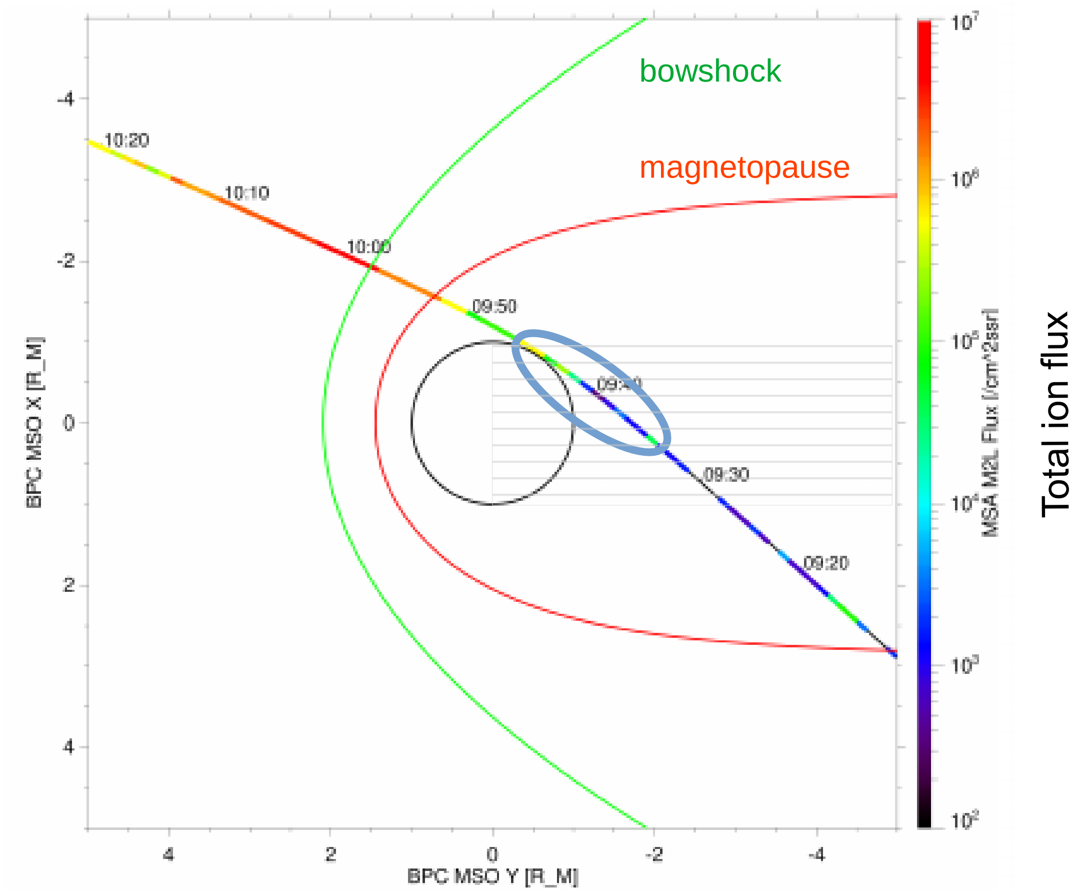
Mercury has a weak internal magnetic field creating a small magnetosphere with a complicated intercation between solar wind and surface.

Processes at work in Mercury's exosphere



Observation of He+ on the 2nd flyby of BepiColombo at Mercury on 23 June 2022



BepiColombo MPPE-MSA ion mass spectrometer principle

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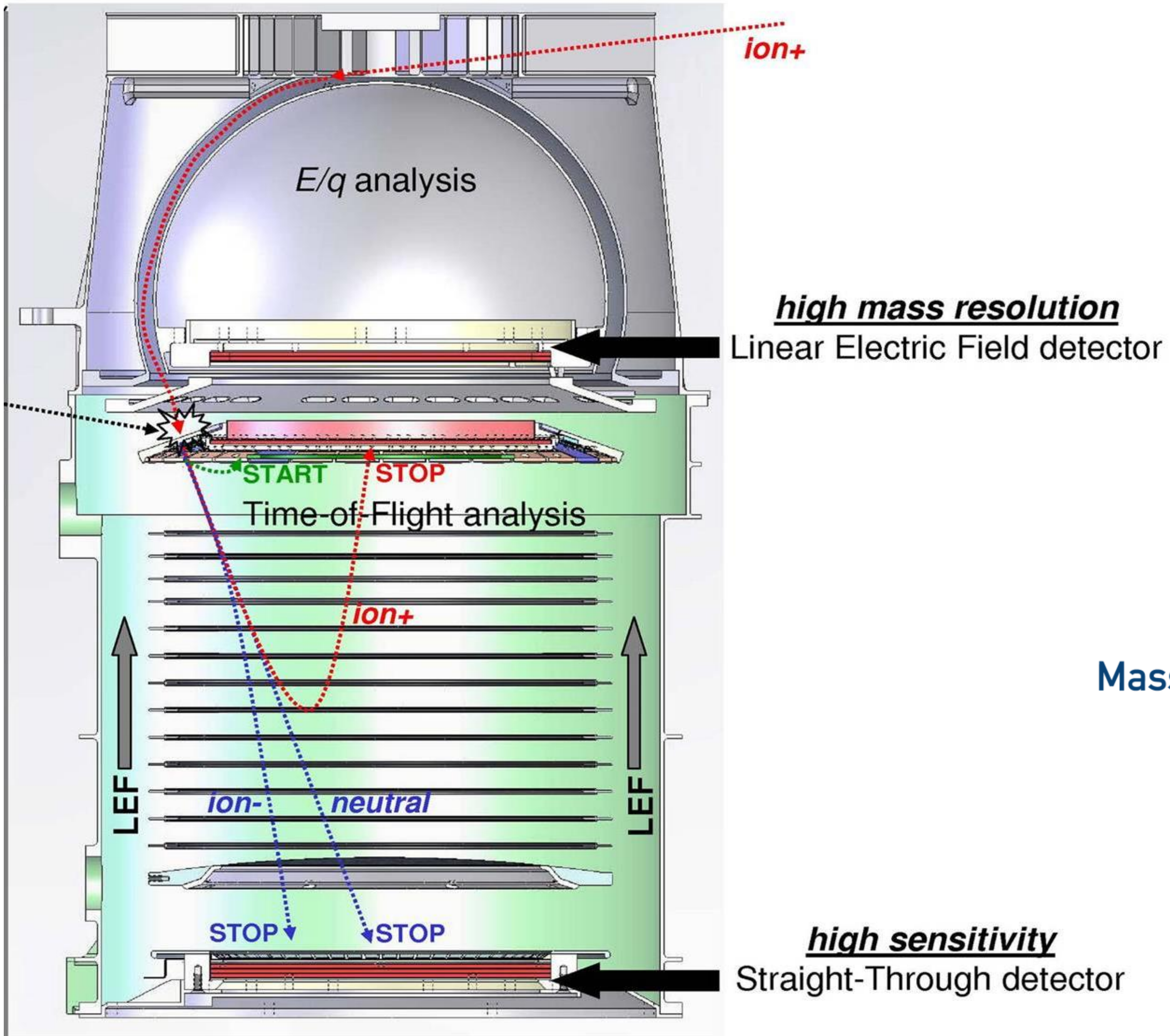
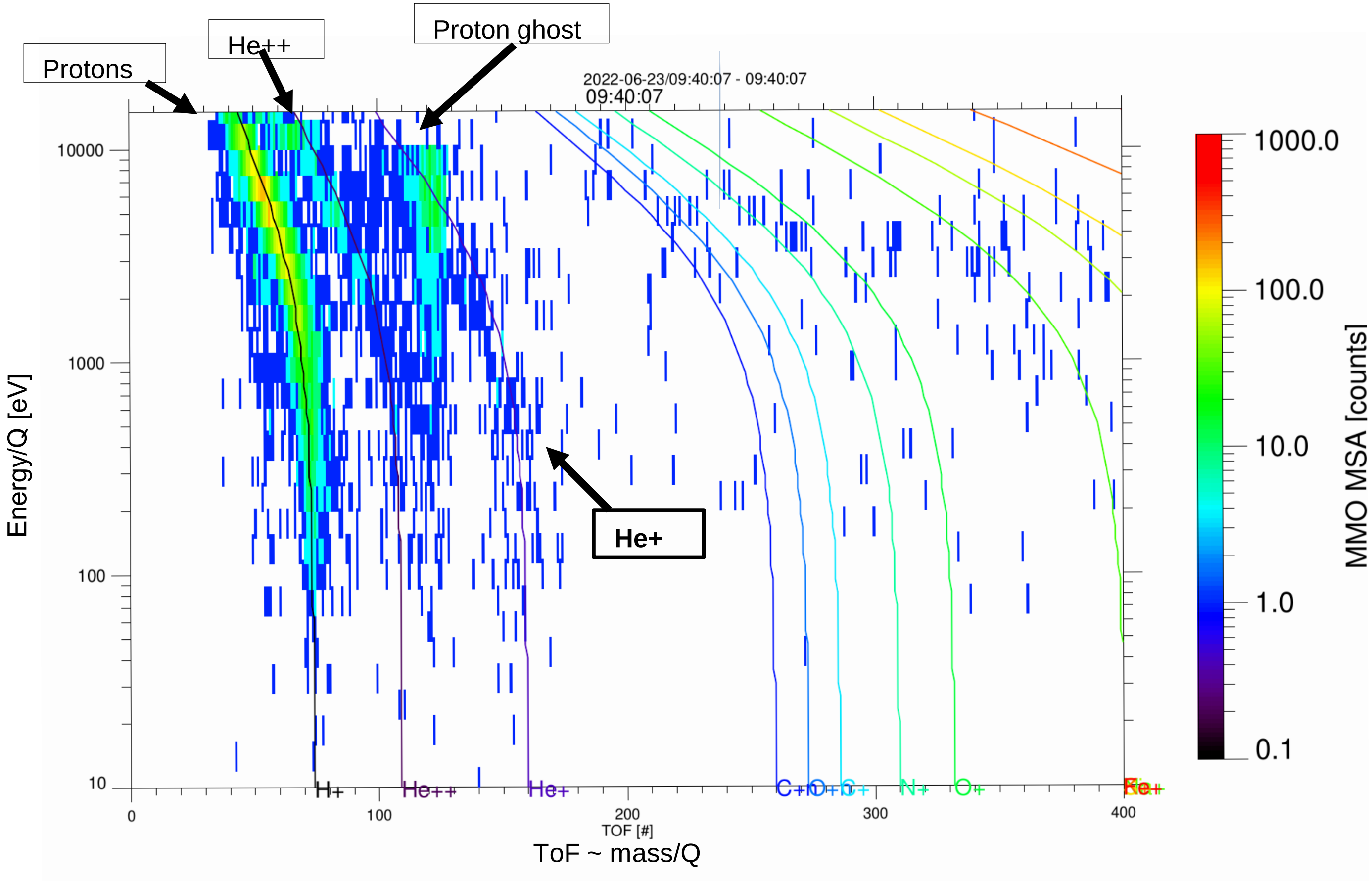


Ion mass spectrometers used in space consist of an energy filter and a time-of-flight (TOF) unit.

If the energy of an ion is known the mass can be determined by the time the ion needs to pass through the TOF unit.

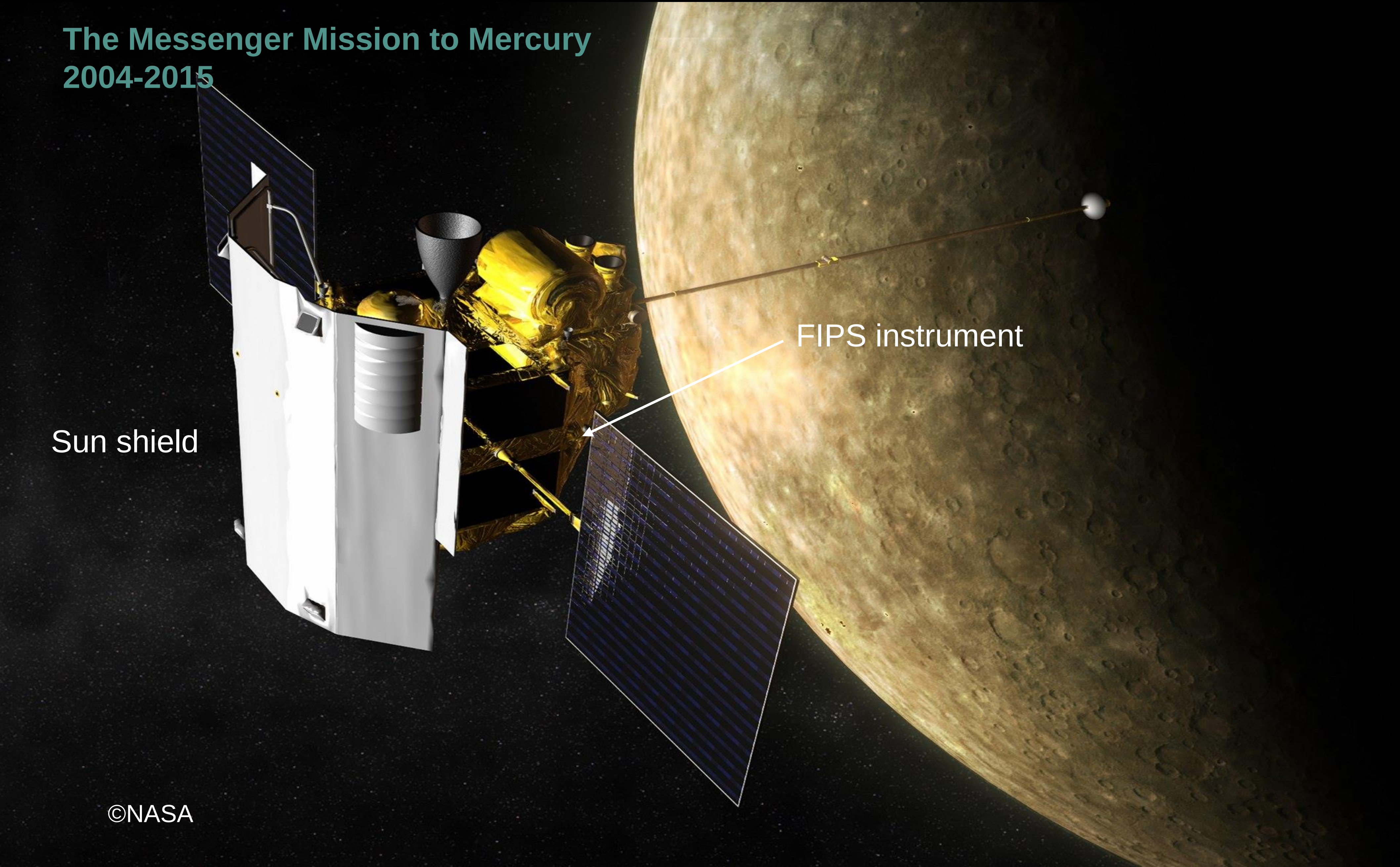
$$\text{Mass} = \frac{2 \times (\text{kinetic energy})}{\left(\frac{\text{distance}}{\text{time}}\right)^2} \qquad m = \frac{2KE}{(d/t)^2}$$

Observation of He+ on the 2nd flyby of BepiColombo at Mercury on 23 June 2022

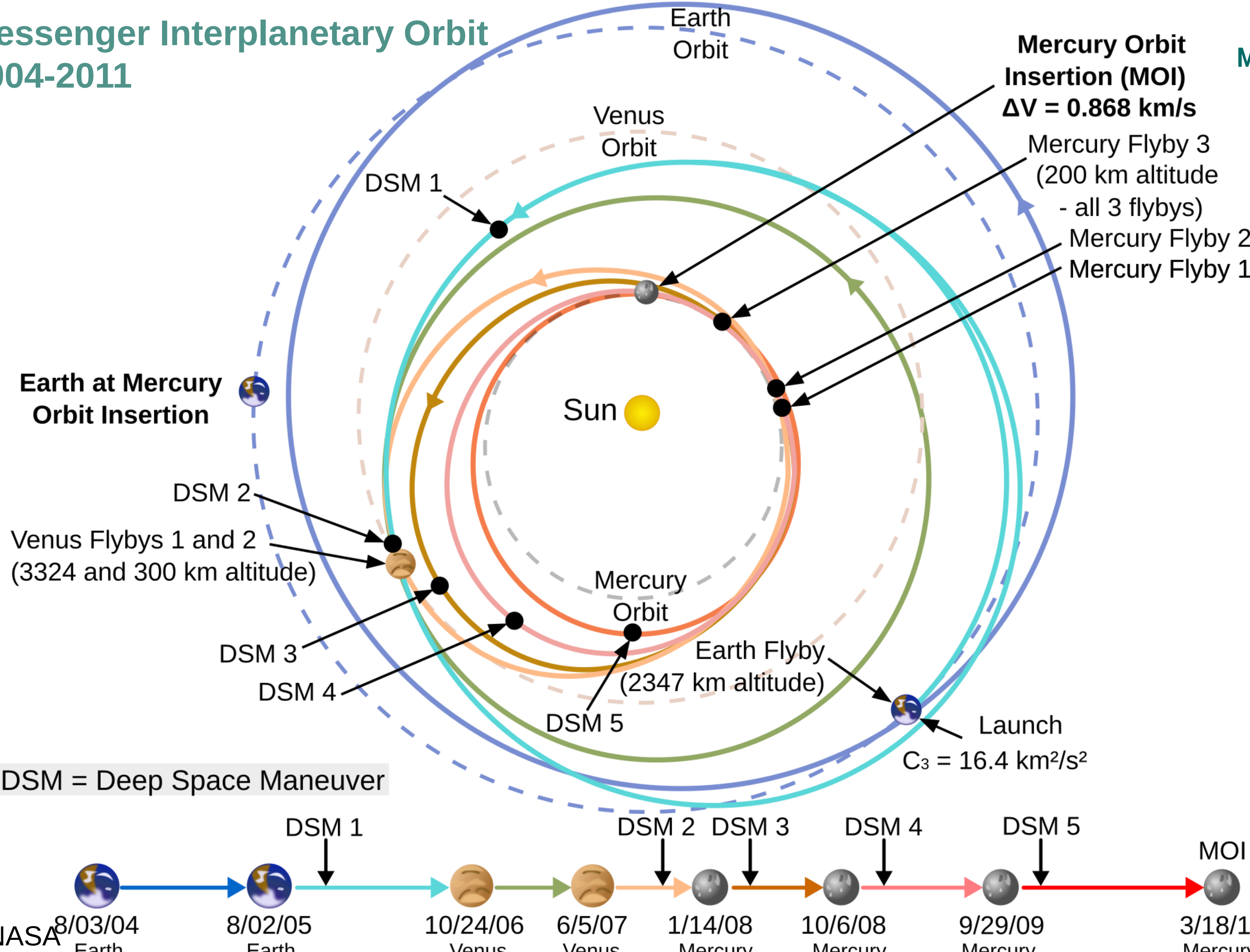


The MPPE-MSA instrument observed in the magnetotail a significant amount of He^{+}. Does it originate in solar wind, planetary surface or interstellar?

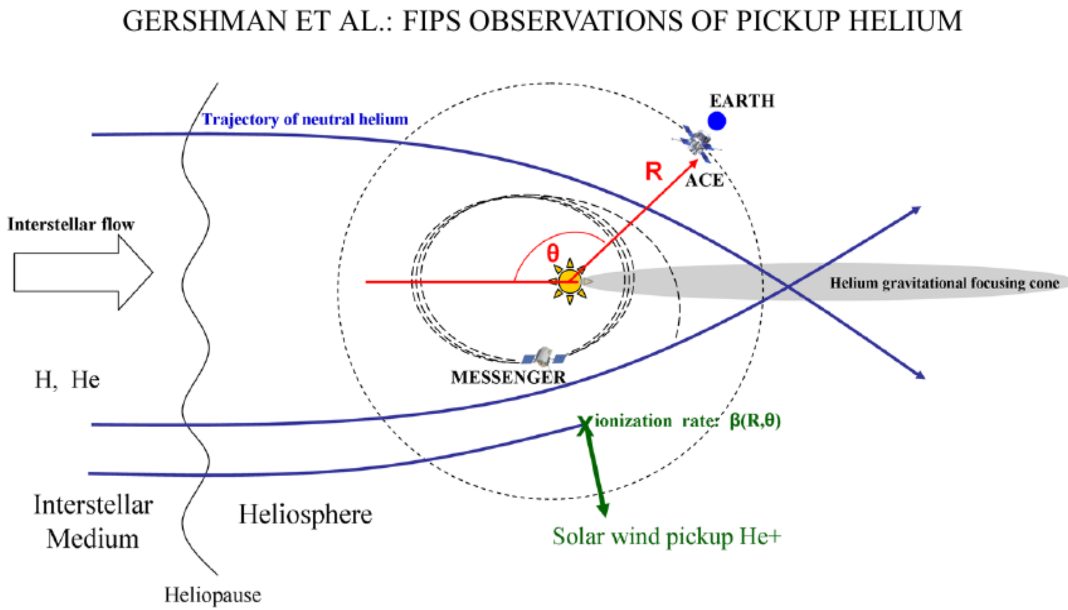
The Messenger Mission to Mercury 2004-2015

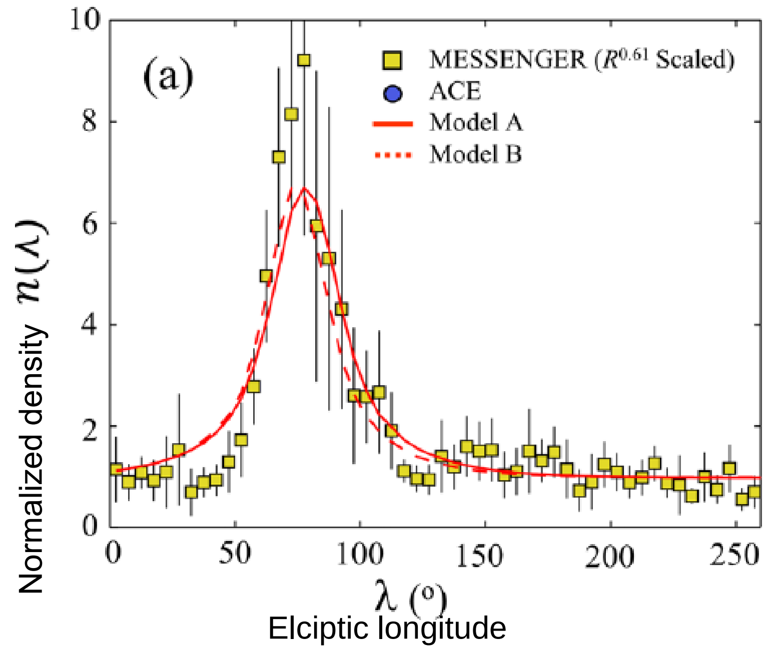


Messenger Interplanetary Orbit 2004-2011



MESSENGER FIPS REPORTS ON HE+





Gershman (2013) reports on He+ observations by FIPS during Messenger cruise phase 2007-2009 only. They mainly observed an intensity increase at the gravitational focusing cone.
Raines (JGR 2013) reports on He+ observations by FIPS in orbit around Mercury. They observe that He+ distribution is very different from O+ and Na+ ions and speculate that origin may be by charge exchange with He++ or by an extended exosphere.

NEW MESSENGER FIPS ANALYSIS OF HE+: CRUISE AND ORBIT PHASE

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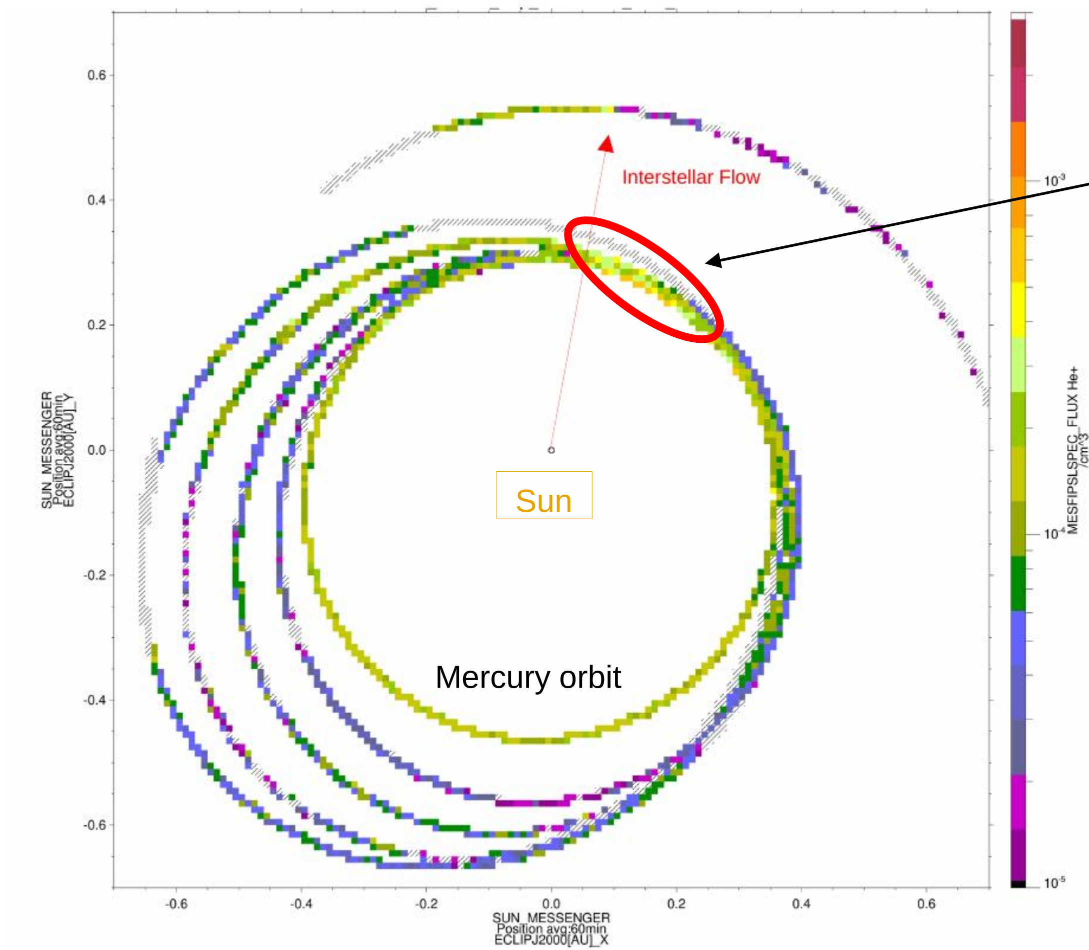
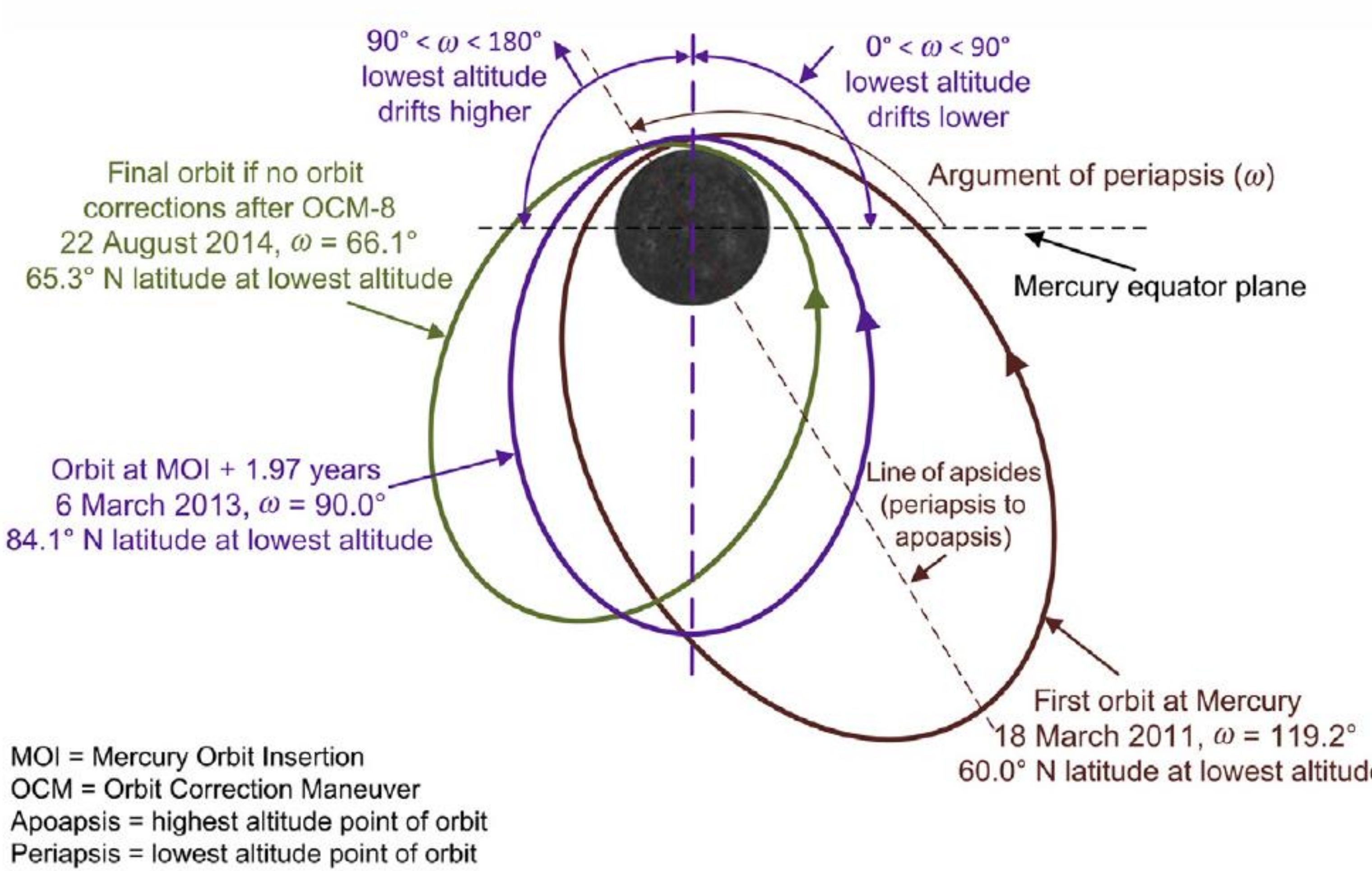


Highest He+ flux at perihel which is at similar longitude as the interstellar Helium cone

Plotting the total median He+ flux in ecliptic coordinates does show a flux increase at He-cone location but no clear signature of the upstream crescent. Fluxes in orbit are higher then in cruise phase.

Fig. 5. Median of MESSENGER/FIPS He^{+} density above 2 keV in different spatial bins around the Sun in ecliptic coordinates for the interplanetary mission phase (2007-2011) and the orbital mission phase at Mercury (2011–2015). The red arrow indicates the interstellar neutral helium flow direction.

Messenger Orbit around Mercury 2011-2015



NEW MESSENGER FIPS ANALYSIS OF HE+: RAW DATA

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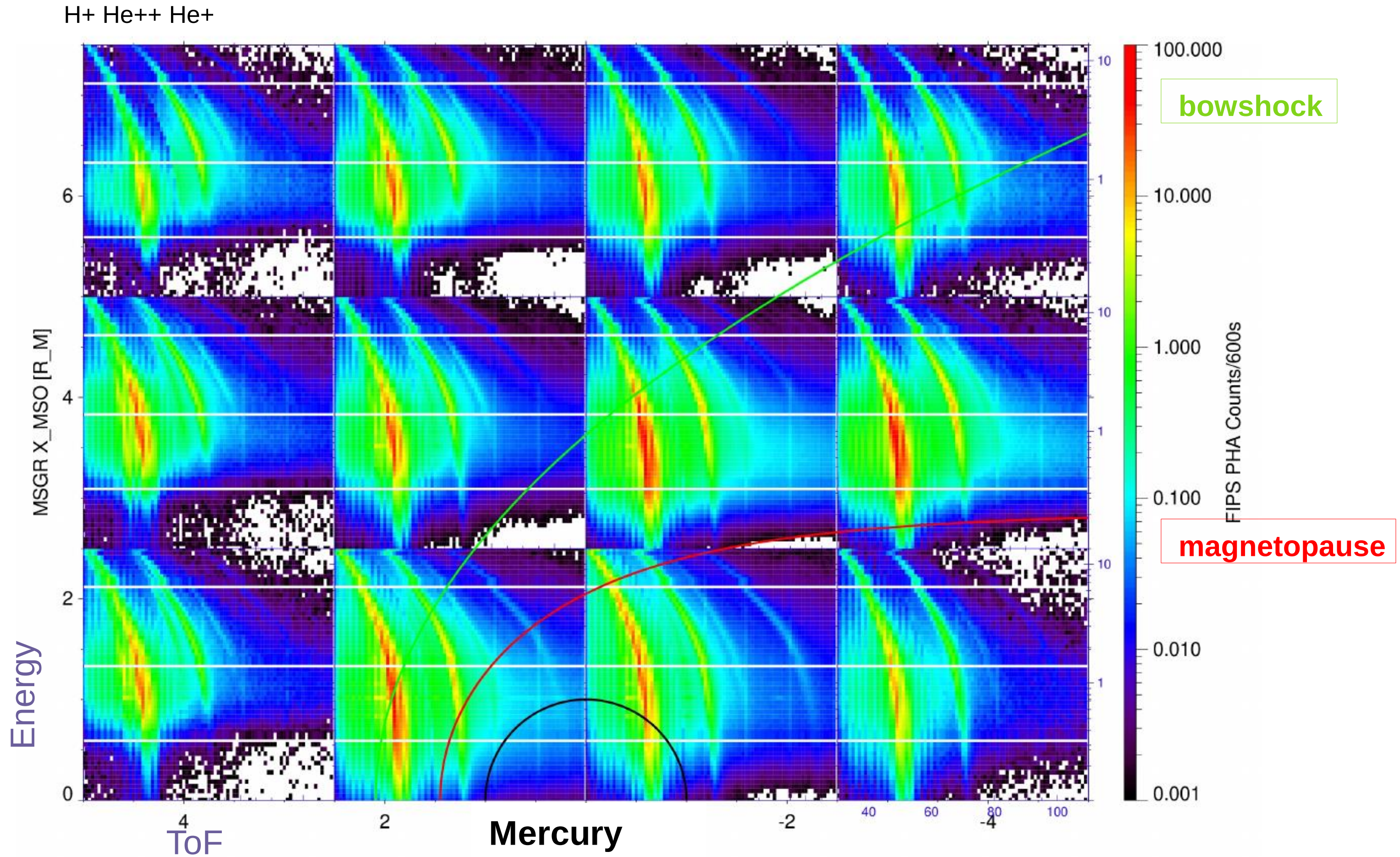

Summation of Messenger FIPS **PHA Energy/ToF** matrices in different spatial bins around Mercury for all mission data close to Mercury in MSO cylindrical coordinates. The observations show that the He+ trace is well visible up to high energies also at large distances. At solar wind energies the trace may be contaminated by TOF saturation (Fränz2024).

MESSENGER FIPS HE++-HE+ FLUX COMPARISON

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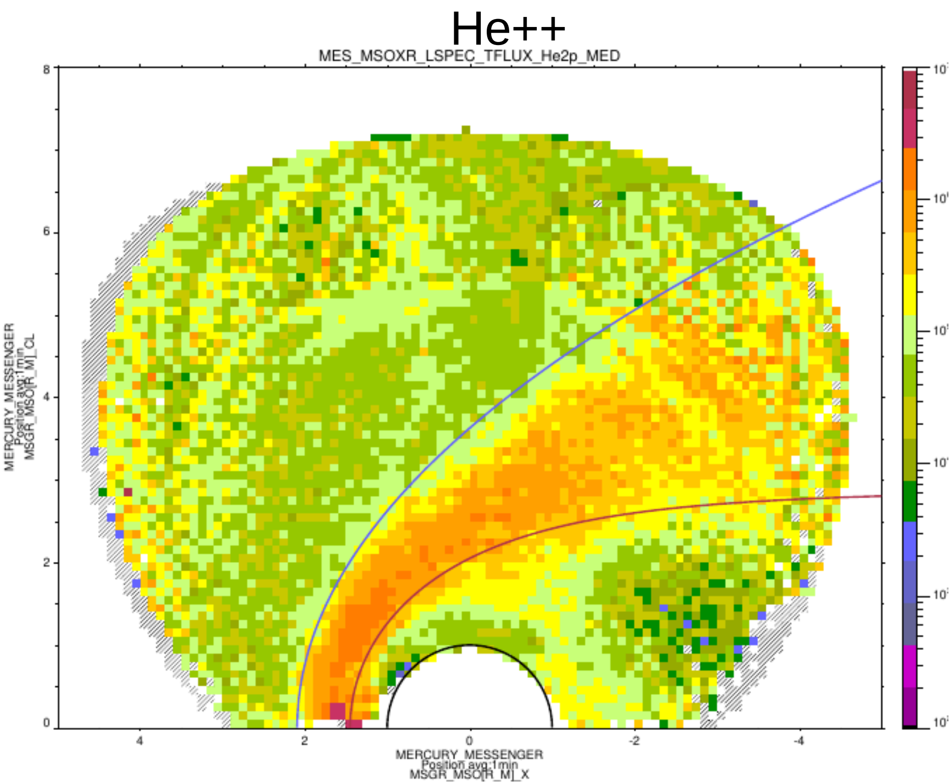

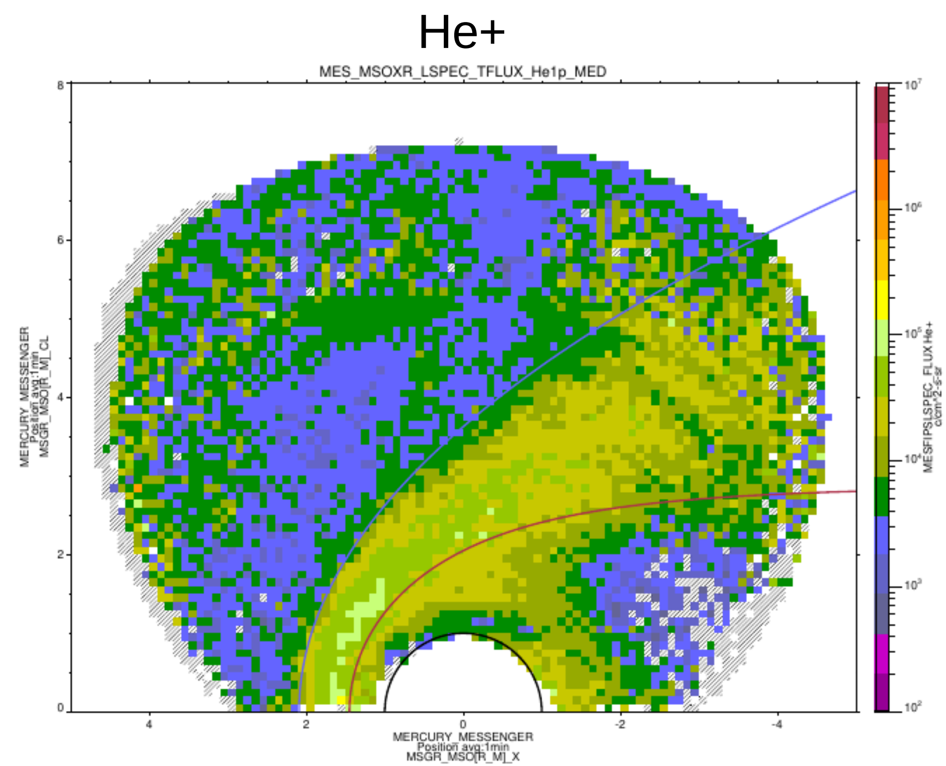

Median of MESSENGER FIPS PHA-SPEC He2+ (left panel) and He+ (right panel) total flux [/cm2ssr] in different spatial bins around Mercury 2011–2015 in cylindrical MSO coordinates. Mercury's surface, nominal magnetopause and bow shock (Winslow et al. 2013) are overplotted in black, red and blue.

We observe higher fluxes of both species in the magnetosheath and in the near-planet tail.

MESSENGER FIPS HE++-HE+ FLUX COMPARISON

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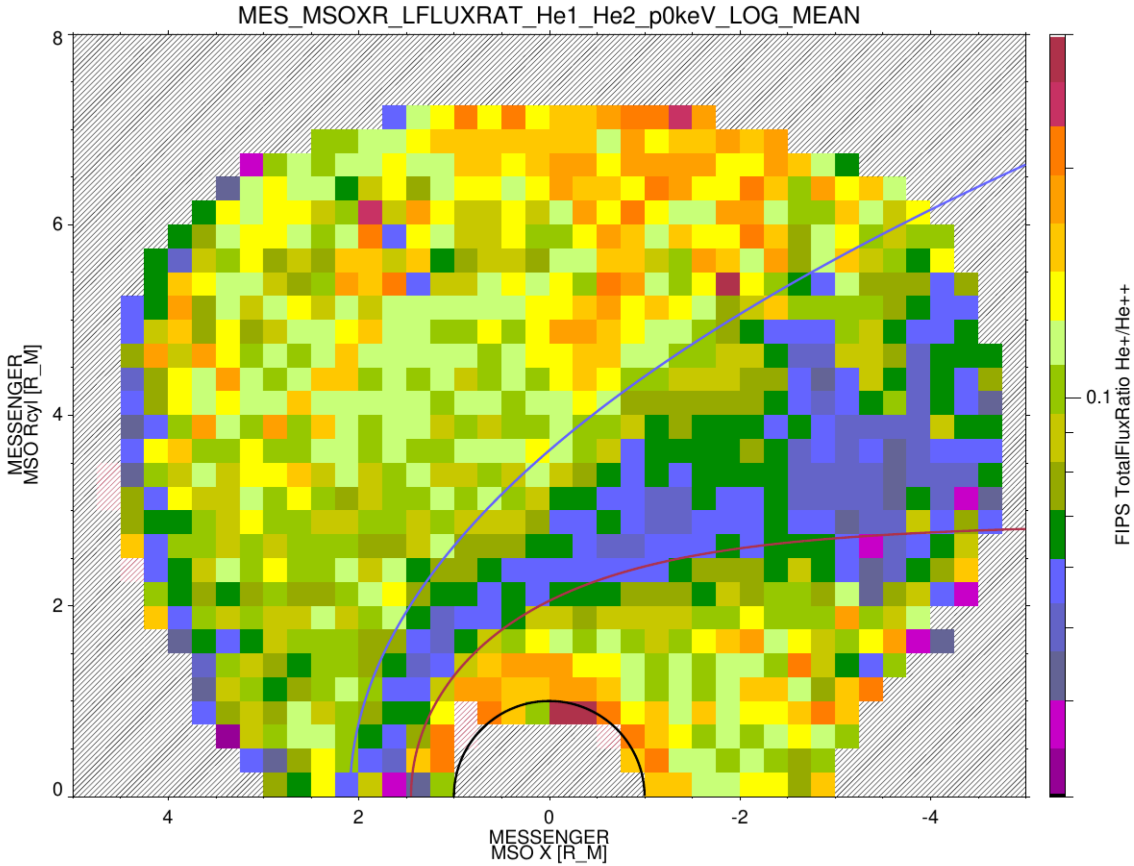
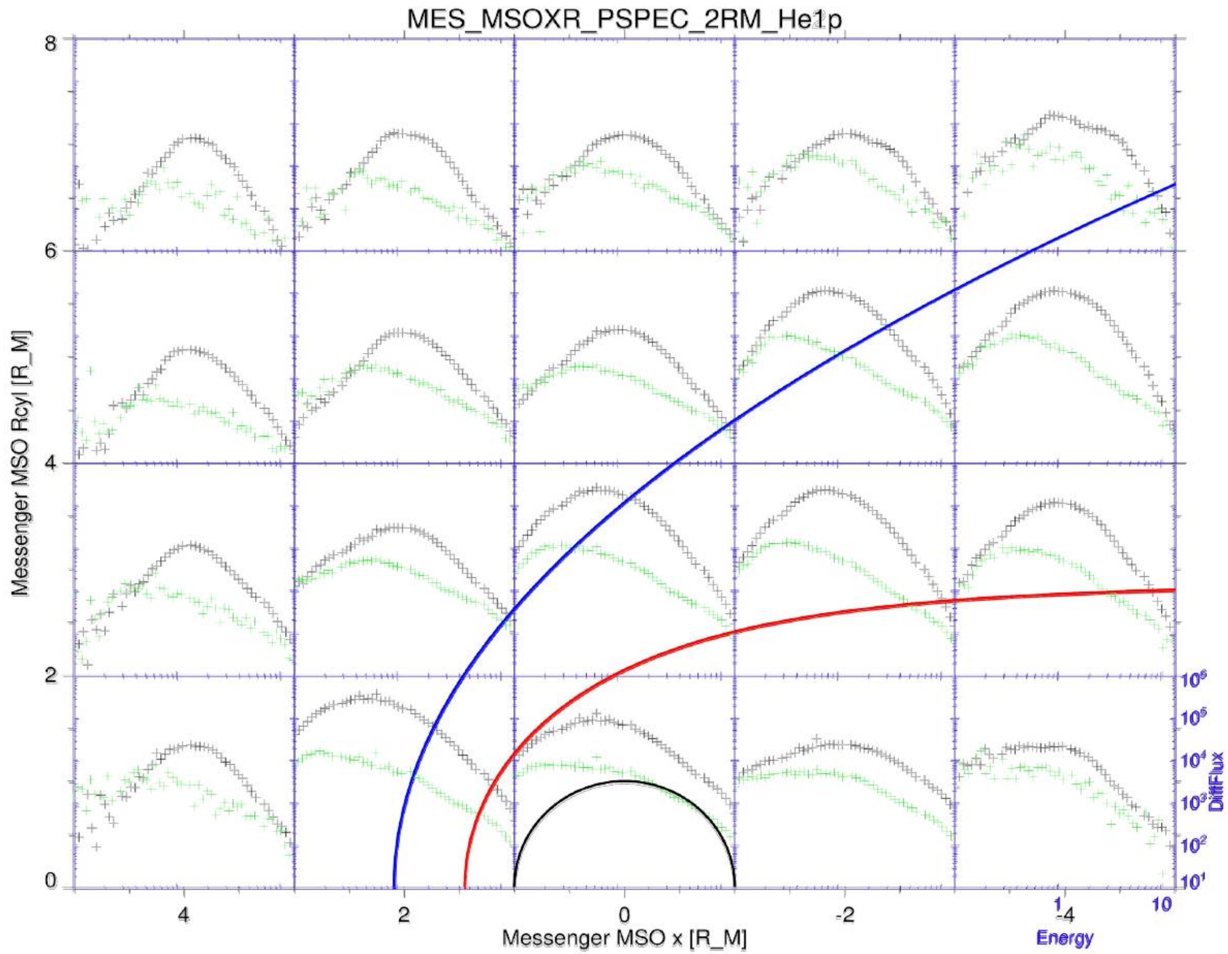


Mean of MESSENGER FIPS PHA-SPEC He+ /He2+ average total flux (/cm2ssr,0.1-14keV) **ratio** in different spatial bins around Mercury 2011–2015 in cylindrical MSO coordinates.
We observe a similar ratio outside of the bowshock and inside of the magnetopause, a reduced ratio in the magnetosheath.

NEW MESSENGER FIPS ANALYSIS OF HE+: SPECTRA



He++

He+

Mean MESSENGER FIPS PHA-SPEC He2+ (black) and He+ (green) differential flux [/cm2 ssrkeV] spectra as a function of energy/charge [keV/Q] in different spatial bins around Mercury for in-orbit mission data in cylindrical MSO coordinates. He++ spectra show a thermal spectrum (outide magnetopause) while He+ spectra show a pick-up spectrum. In the tail region both spectra are more similar in shape.

MESSENGER FIPS HE+/HE++ RATIO FLUX

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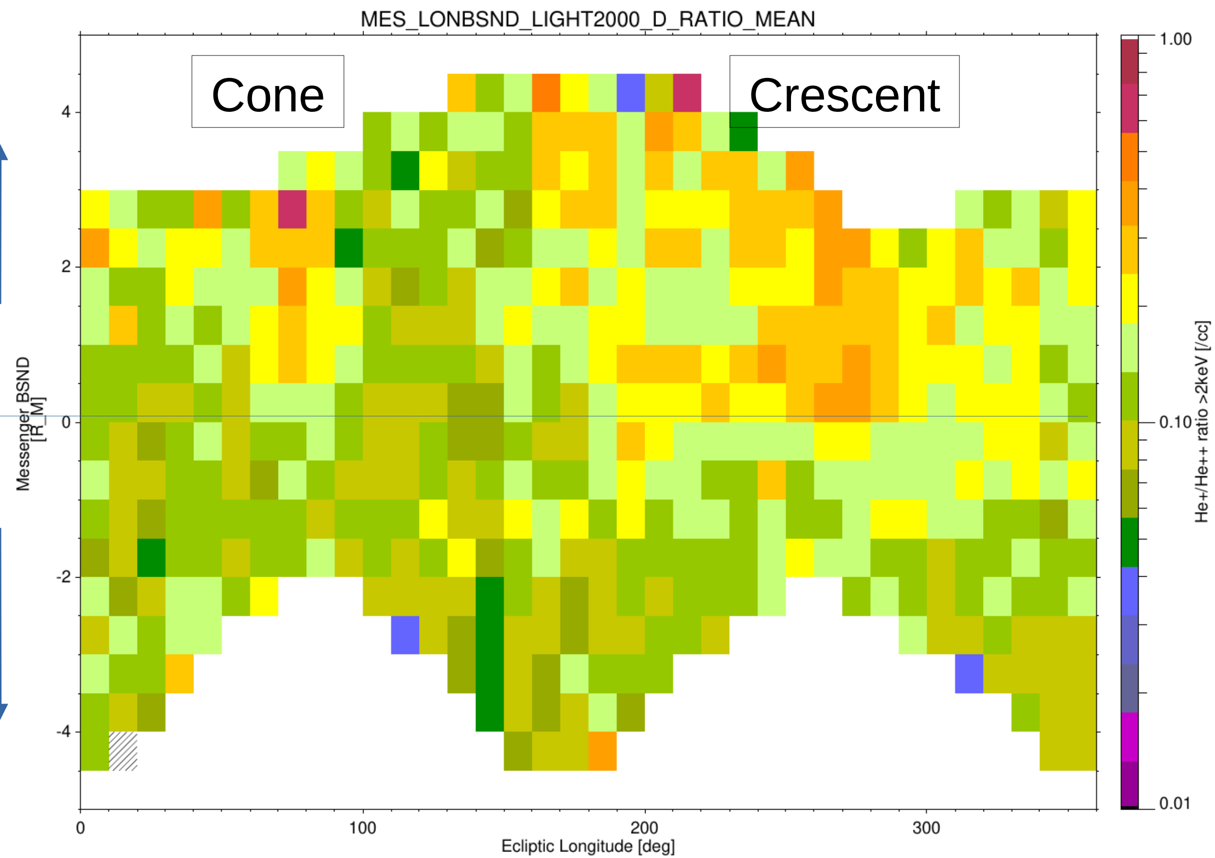
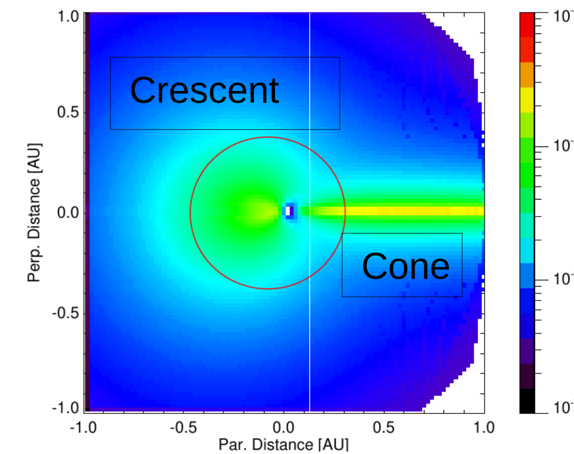
Above Bowshock

Below bowshock



Ecliptic longitude



Mean ratio of MESSENGER FIPS He+/He2+ density above 2 keV/q as a function of ecliptic longitude and distance from Mercury's nominal bow shock measured during the spacecraft's orbital mission around Mercury in 2011–2015.
We observe the expected high He+/He++ ratio in the Helium cone region, but also an increased ratio in the crescent region for observations outside of the Mercury bowshock. The ratio inside seems independent of longitude.

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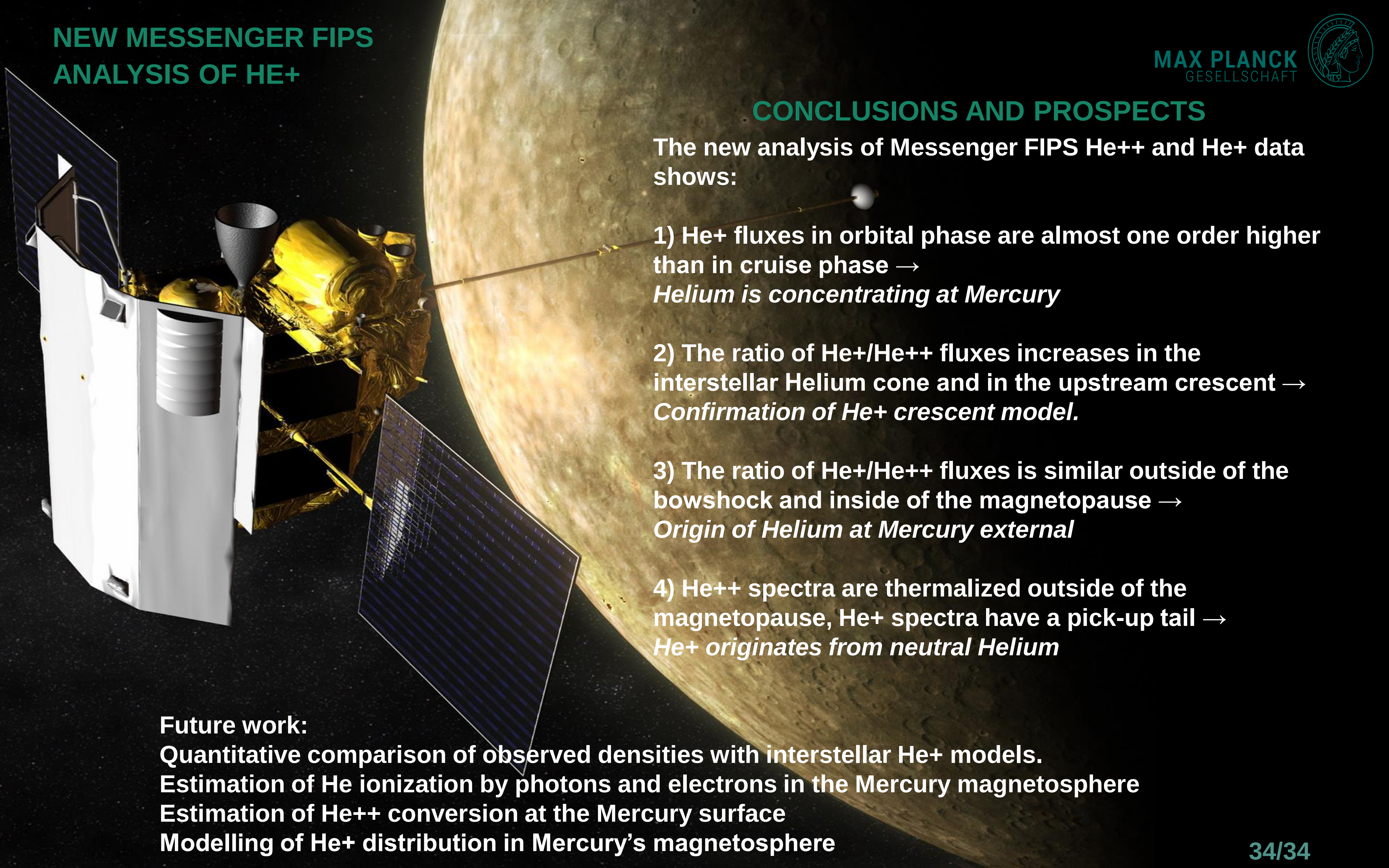

CONCLUSIONS AND PROSPECTS

The new analysis of Messenger FIPS He++ and He+ data shows:

1) He+ fluxes in orbital phase are almost one order higher than in cruise phase →
Helium is concentrating at Mercury

2) The ratio of He+/He++ fluxes increases in the interstellar Helium cone and in the upstream crescent →
Confirmation of He+ crescent model.

3) The ratio of He+/He++ fluxes is similar outside of the bowshock and inside of the magnetopause →
Origin of Helium at Mercury external

4) He++ spectra are thermalized outside of the magnetopause, He+ spectra have a pick-up tail →
He+ originates from neutral Helium

Future work:
Quantitative comparison of observed densities with interstellar He+ models.
Estimation of He ionization by photons and electrons in the Mercury magnetosphere
Estimation of He++ conversion at the Mercury surface
Modelling of He+ distribution in Mercury's magnetosphere