Development of "Ion Mode" for the Strofio Neutral Mass Spectrometer

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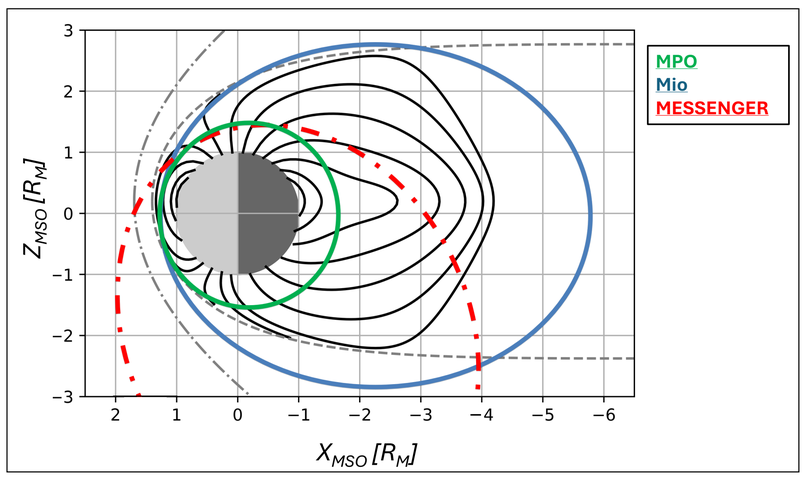
Key Points

- BepiColombo's Mercury Planetary Orbiter (MPO) carries the Strofio neutral mass spectrometer, which can also measure ions.
- Used SIMION and a particle swarm optimization (PSO) algorithm to generate, test voltage sets.
- Found electrode voltage sets enabling observation of ultra low-energy ions (10 – 20 eV/e) with >30 m/dm at 23 amu by Strofio.
- Lab testing and calibration work is ongoing.

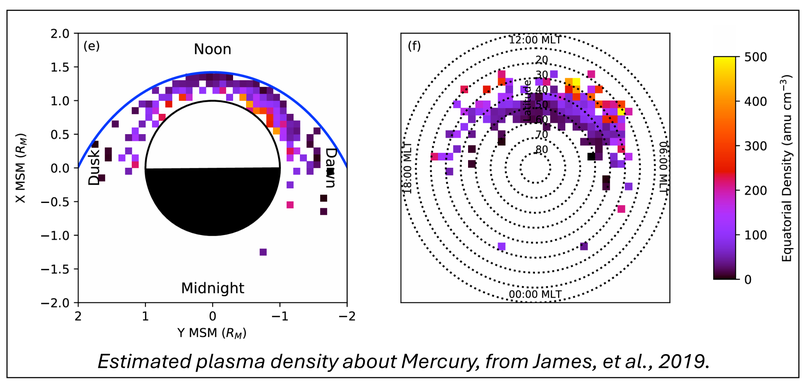
Background

- BepiColombo is comprised of two spacecraft that will operate independently: the Mercury Planetary Orbiter (MPO) and Mio (formally the Mercury Magnetospheric Orbiter).



Strofio is carried by the BepiColombo/MPO spacecraft and is designed for study of Mercury's neutral exosphere.

- Strofio is a time-of-flight (TOF) neutral mass spectrometer that uses a rotating electric field to "stamp" the Start signal onto the particle's trajectory, and a microchannel plate (MCP) for the Stop signal. This results in a high mass resolution ($m/\Delta m > 100$) and nearly 100% duty cycle (Gurnee, 2012).



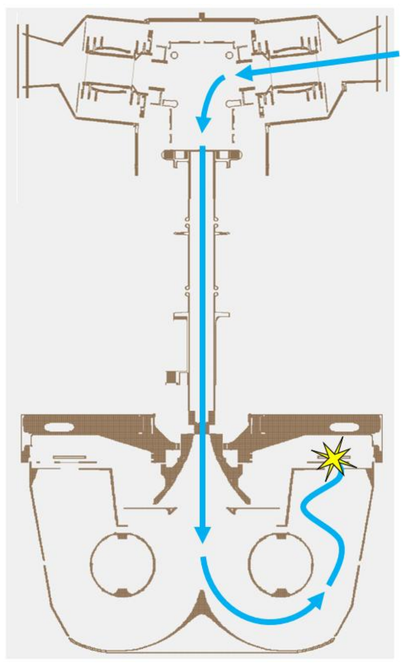
Estimated plasma density about Mercury, from James, et al., 2019.

- **Plasma density in Mercury's dayside is highly uncertain, varying from 10s to 100s of ions/cm^{-3} (James et al., 2019).**
- This is expected to be largely composed of recently-photoionized planetary ions, in the energy range 1-15 eV/e (Raines et al., 2013).
- Understanding the plasma makeup of the dayside, Mercury's primary photoionization center, has significant implications for the lifecycle of planetary ions and the transport of plasma and magnetic flux.

Planetary ions with energies 1 – 15 eV/e are not detectable by other plasma instruments aboard BepiColombo (Orsini et al., 2008; Saito et al., 2008). Strofio Ion Mode completes the picture.

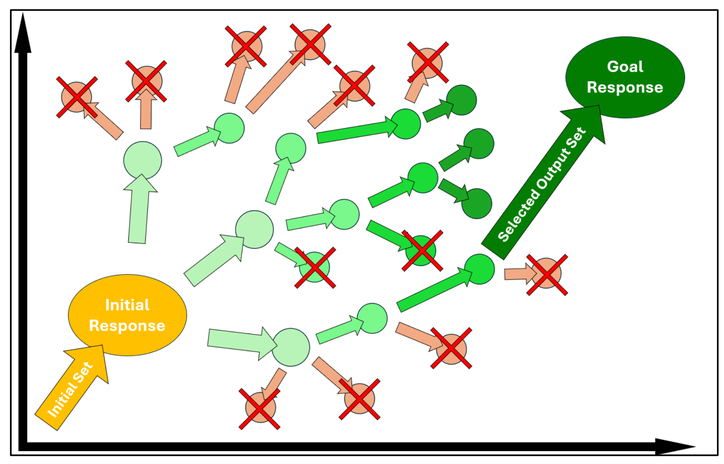
SIMION

- **SIMION was used to simulate ion trajectories, with a Strofio ion optical model based on original CAD files.**

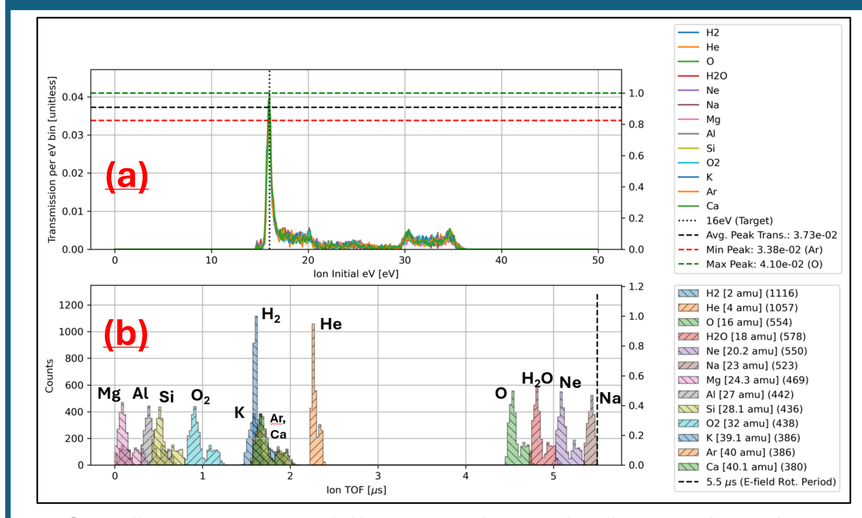


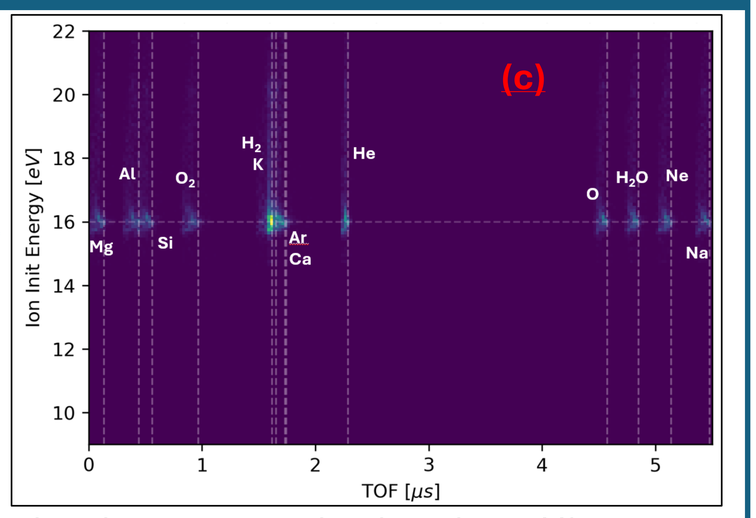
Particle Swarm Optimization

- Strofio contains >20 electrodes, with 13 needing modified for Ion Mode – this presents a 13-variable optimization.
- **PSO was utilized to generate and optimize electrode voltage sets for singular target energies, producing one voltage set per eV/e.**
- **These are based on an initial set and its performance regarding several factors:**
  - Energy passband peak location, width, and height.
  - Number of ions reaching the MCP with energies outside the target.
  - Overall MCP counts.
- **PSO tests and perturbs the initial set into new sets based on the initial results, then continually iterates new sets based on the overall best and the recent best until a voltage configuration is found that meets the requested criteria.**



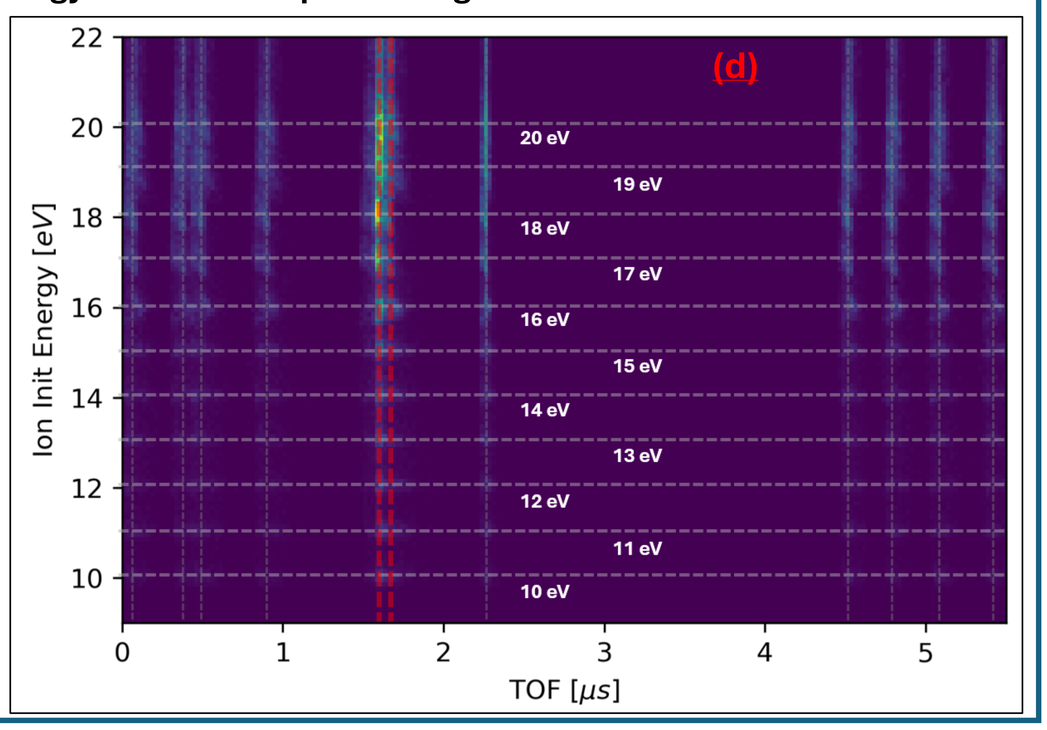
Ion Mode Voltage Results





- Strofio cannot rapidly scan through electrode voltages, so single voltage sets are developed per eV/e.
- Voltage sets are tested over 0 – 50 eV/e for masses 2 – 40.1 amu (H_2 – Ca) for singly-charged ions.
- **Voltage sets for 10 – 20 eV/e (11 sets) have been developed. For an example, see 16 eV/e (above).**
- **(a): Energy passbands for each mass, where we see narrow peaks centered at 16eV for each. (b): TOF distributions for each mass, which are well-separated (>30 m/dm at 23 amu) except for K, Ar, and Ca (39.1, 40, and 40.1 amu). (c): TOF and energy distributions plotted together.**

- **By combining test results from all 11 voltage sets over all test species, we can draw full "energy traces" for each test ion species – see (d).**
- The masses are located the same as in (c), so energies are marked instead.
- Note that each energy set would be operated separately, not smoothly blending from one to the next, such that overlapping "tails" of the distributions do not overlap.
- Vertical red lines indicate overlapping signatures from H_2 and K (left) as well as Ar and Ca (right).



Discussion

- Higher energies higher transmission fractions, such that the peak transmission is ~4.6% for 20 eV/e and ~2.0% for 10 eV/e. Work to improve these to a minimum of 5-10% is ongoing.
- However, ions < 39 amu+ have very narrow energy passbands (e.g., see H_2 and He).
- All simulations shown here fly ions initially parallel to Strofio's chosen boresight axis (for two entrances) to characterize basic responses.

Future Work

- Work is ongoing to test and calibrate Strofio Ion Mode using the Strofio Engineering Model at the Southwest Research Institute (SwRI) in San Antonio, Texas, using a low-energy ion beam facility constructed for this purpose.
- Electrode voltage sets for 21 – 30 eV/e are under development. Development of voltage sets 32 – 50 eV/e are under consideration.