Pickup Ions in the Heliosphere and Beyond
SHINE-2019 Session 14 (Conveners N. Pogorelov & M. Zhang)

Motivation:
1. Interstellar PUIs are created when a neutral atom of the LISM origin loses an electron due to charge exchange with another ion, photoionization, electron impact ionization, etc.
2. PUIs gain thermal energy from the solar wind (SW) kinetic energy, which ultimately exceeds the thermal energy of original SW (R > 20 au), although their density is lower. Production of PUIs removes the LISM neutral atoms, but creates secondary atoms: the neutral SW and the hot population born in the heliosheath.
3. When a PUI experiences the secondary charge exchange, an energetic neutral atom is born, which may return back into the inner heliosphere and detected (IBEX, Cassini/INCA, SOHO/HSTOF).
4. PUIs can be further accelerated at the heliospheric termination shock and in the heliosheath creating anomalous cosmic rays.
5. PUI observations can be used to derive the direction of the LISM flow (Sarah Spitzer’s presentation).
The subjects discussed at the session:
A. Measurements (mostly covered by David McComas, the first scene-setting speaker)
1. In situ PUI measurements are now available to about 40 au, due to New Horizons.
2. There is a good observation-based understanding of the PUI behavior at PUI-dominated collisionless shocks: (1) core SW ions lose $\sim$85% of their energy flux across the shock, (2) PUIs preferentially heated and PUI tail observed downstream of shock, such that the energy flux of all PUIs is $\sim$6 times that of core SW ions.
3. The updated analysis of Ulysses/SWICS data (Zhang et al., 2019) provides us with the PUI ion distribution functions in the SW frame and makes it possible to derive the PUI properties more accurately.
4. Knowledge of the PUI properties is essential for understanding ENA measurements by IBEX.

NH/SWAP data (McComas et al., 2017) Ulysses/SWICS data revised (Zhang et al., 2019) ENA fluxes from IBEX
B. Modeling (scene-setting speaker Vadim Roytershteyn).

1. PUI are not Maxwellian and require kinetic modeling. Test-particle and hybrid simulations tend to reproduce major properties of collisionless shocks, while Particle-in-Cell simulations tend to overestimate heating of the core SW ions.

2. PIC simulations of the realistic PUI distribution function behavior beyond the heliopause show that instabilities are quickly saturate within a day or less, which is favorable for the major scenarios of the IBEX ribbon, but further analysis is necessary to see if this result persists until the next charge exchange (2 years) occurs in the presence of LISM turbulence.

3. The effect of SW/PUI energy separation at shocks was modeled (Bishwas Lal Shrestha).

4. Modeling reproduces NH observations.

Challenges: (1) 3-D distribution functions of protons, alphas, and electrons should be measured for deeper understanding of non-thermal ions and their shock crossings (Parker Solar Probe!); (2) accurate, time-dependent simulations of non-Maxwellian SW plasma are required to interpret ENA measurements from IBEX and future IMAP missions; (2) kinetic structure of collisionless shocks should be further investigated to ensure proper Rankine-Hugoniot conditions at collisionless shocks; (3) the behavior of PUIs in the heliosphere and beyond it is crucial for the interpretation of Voyager data.