Effects of Spatial Resolution on the Martian Pickup Ion Plume in Global Martian Plasma Simulations

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Abstract

A key to understanding the evolution of the Martian climate over its history is the study of how the Martian atmosphere escapes to space. Studying the near-Mars space environment allows us to better understand atmospheric escape processes. One of these important processes is ion escape, in which atmospheric particles that are primarily ionized by the solar radiation above the exobase region can escape from the planet. Various model results, as well as MAVEN observations, have shown several important channels for ion escape in the Martian plasma environment. One of these channels forms when pickup ions are accelerated away from the planet by a motional electric field, creating a "plume" of escape organized by the upstream solar wind electric field. Although plasma models have predicted the existence of this plume before, only recently have we been able to regularly identify it in observations. Relatively little work has been done on how modeling choices influence the morphology of the plume. Here we present a comparison of two BATS-R-US multi-fluid MHD simulations, each with different spatial resolution, run using input conditions taken from a single MAVEN orbit in which the plume signature was clearly identified. Our analysis primarily focuses on differences seen in the location and morphology of the ion plume. While the two simulations match well at low altitudes, location differences in the ion plume become clear at high altitudes. We also analyze the effect of different spatial resolution on the simulated ion escape rates. Detailed investigation of the plume region in these simulations has also provided us with a better understanding of the underlying physics that shape and act on the ion plume. We have analyzed and identified regions where the v x B force accelerates ions while the J x B force confines them. This in turn allows us to identify the location of the plume. This study highlights the importance of choices in spatial resolution when modeling features in the Martian magnetosphere.

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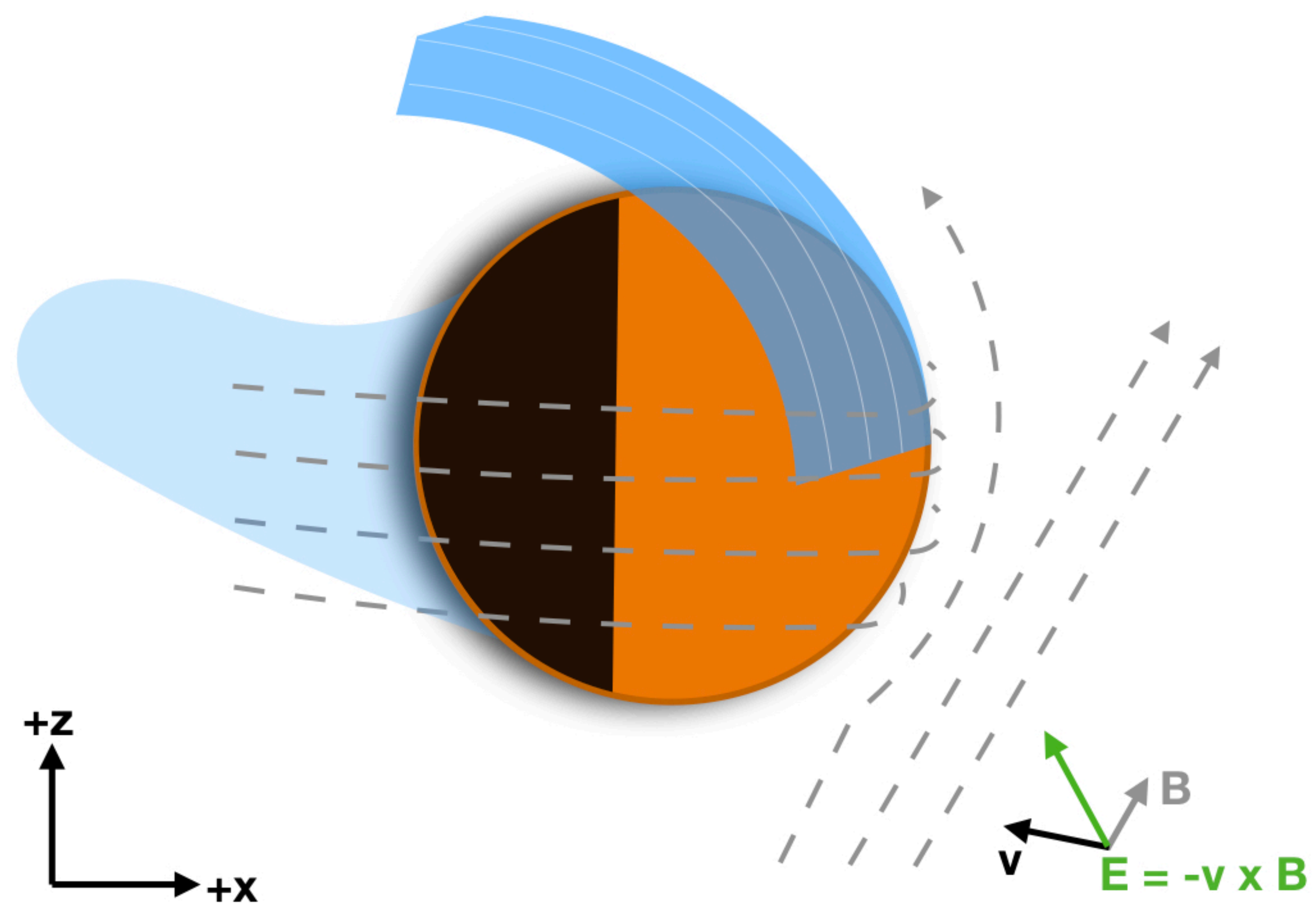
Introduction

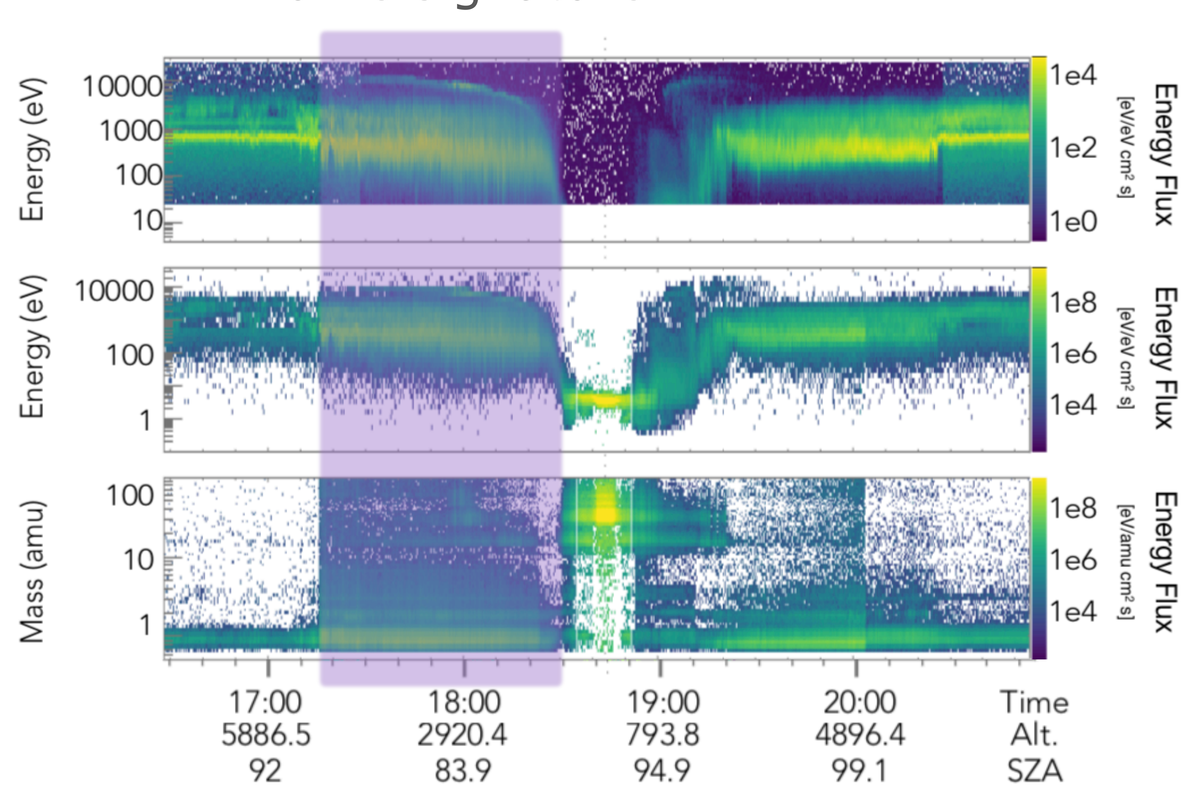
- Solar wind interactions with the Martian ionosphere create a motional electric field where accelerated particles can escape
- MAVEN measurements and previous model challenges have shown a polar pickup ion plume in the Northern hemisphere to be a key component of ion loss at Mars
- Comparing BATSRUS multi-fluid MHD simulations of different resolution shows variation in plume location



Upstream Conditions	
B	[-0.74, 5.46, -0.97] nT
v	[-350, 0, 0] km/s
n_p	4.9 cm^{-3}
n_a	0.14 cm^{-3}
T_p	59200 K
SSL	170°

- Model conditions were chosen to match MAVEN orbit #2349 (below) where plume signatures have been observed

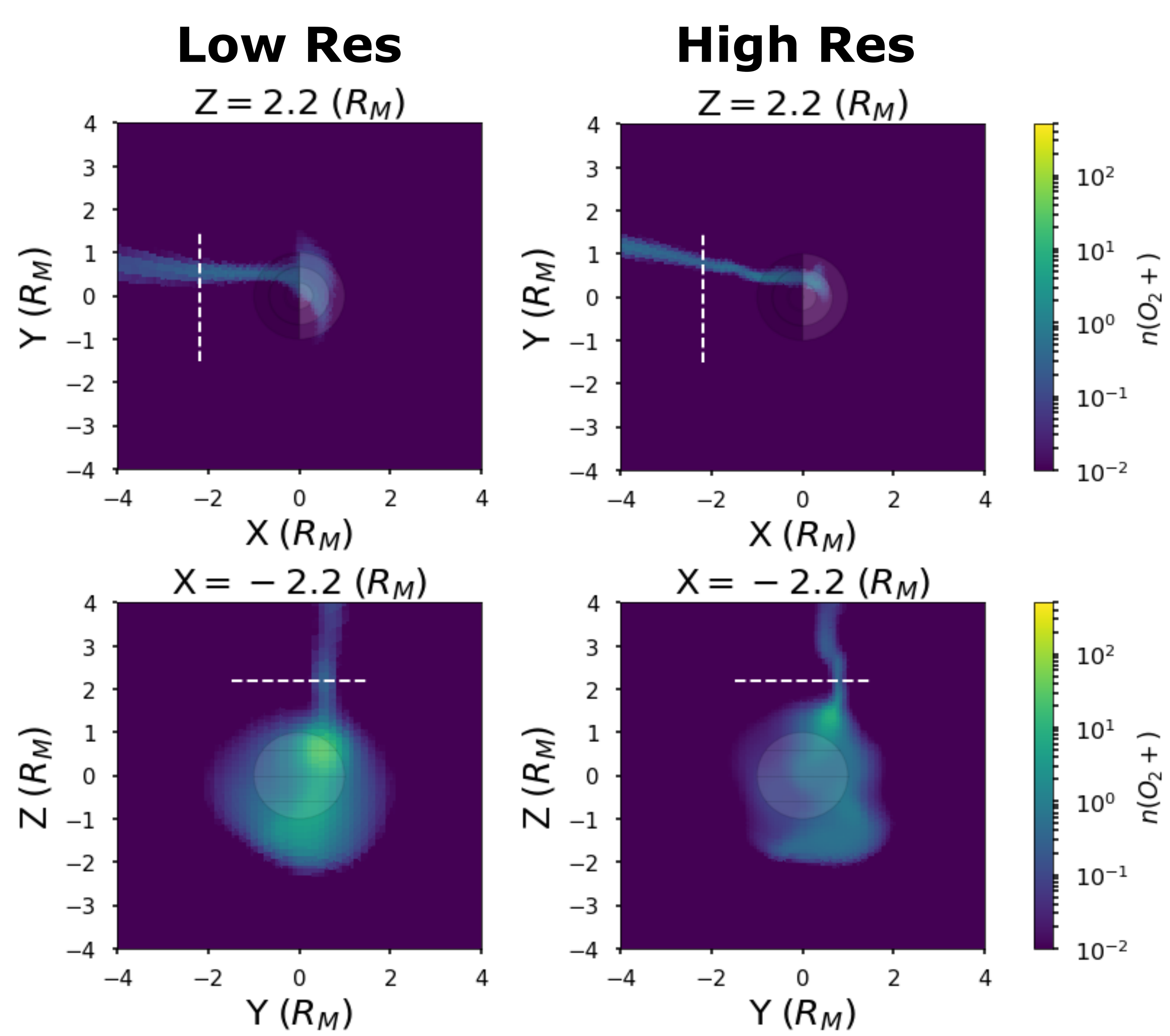
Plume signature



- Model resolution is changed by changing spatial refinement of boxes in a spherical grid

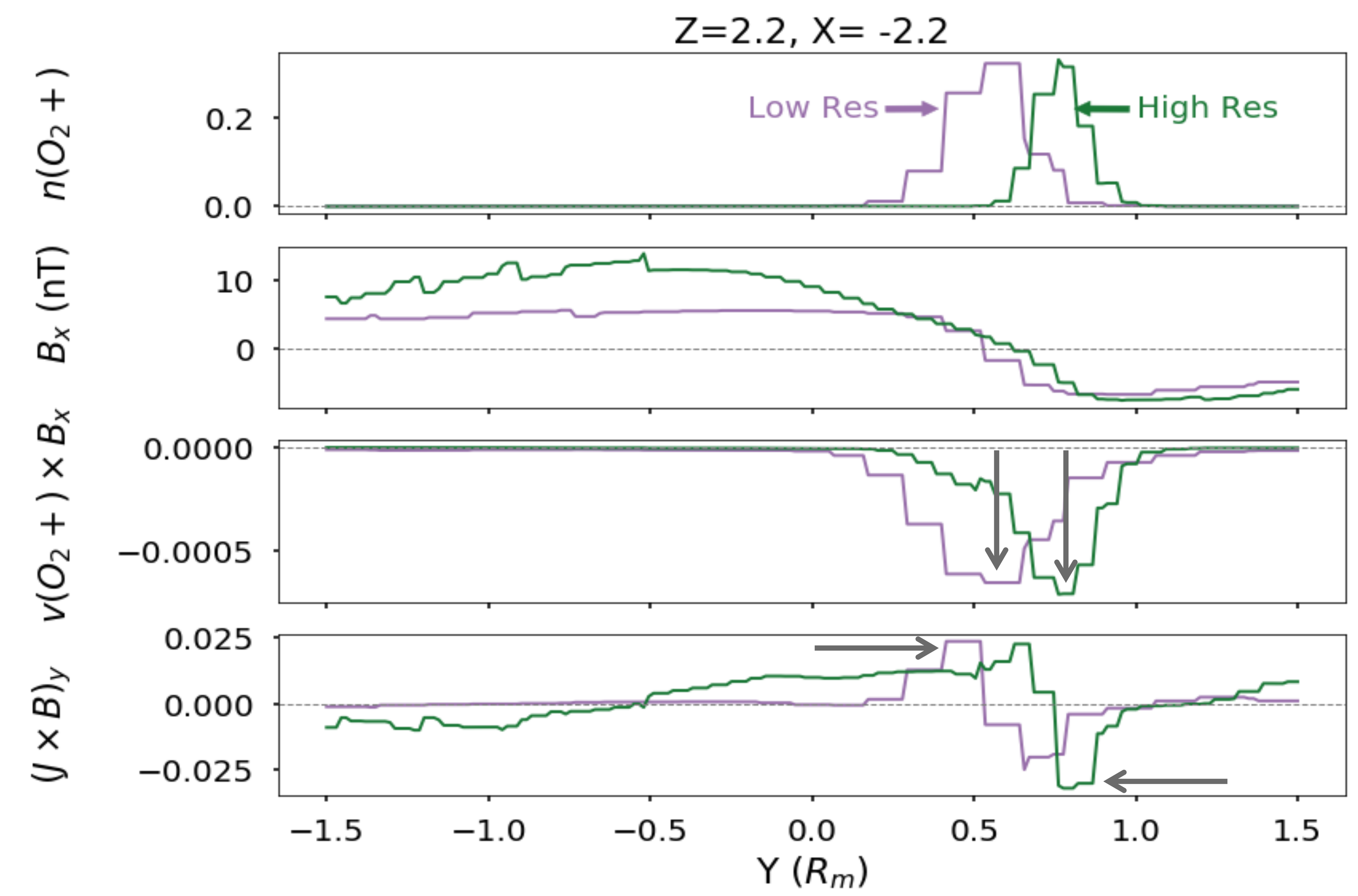
Simulation Resolutions		
Resolution	Radial	Angular
Low	10 km	3°
High	5 km	1.5°

Resolution choice affects spatial variability



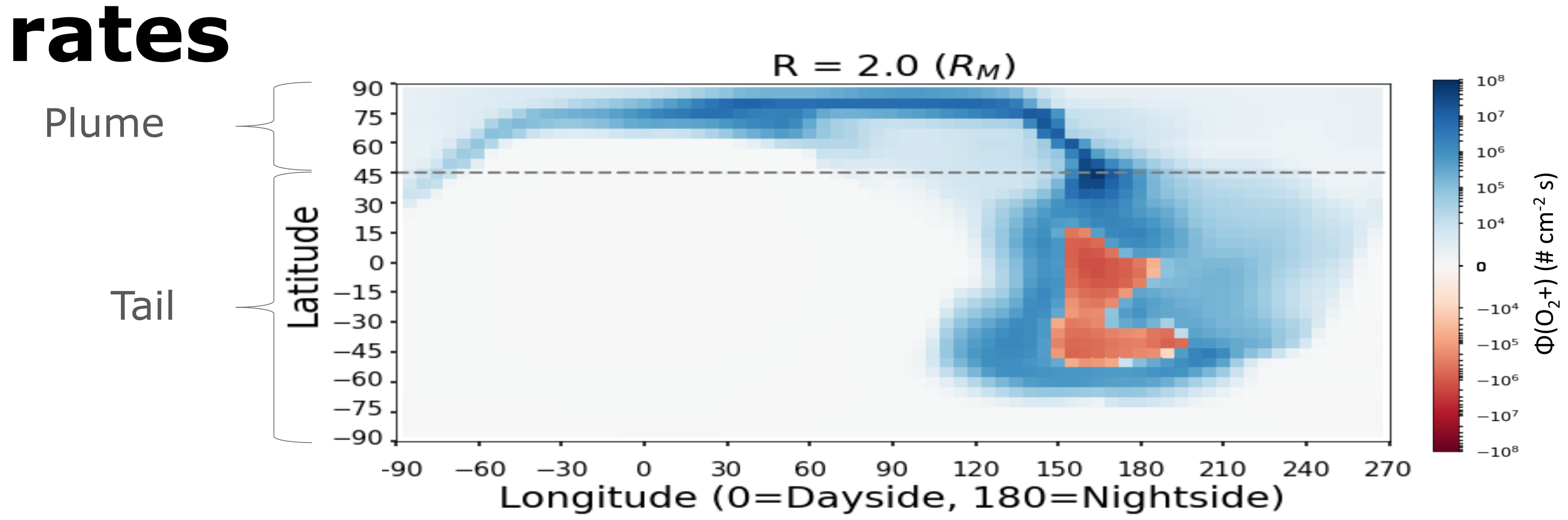
- Simulations of different resolution produce a plume in different locations, sometimes separated by up to ~0.2R_M

Electromagnetic fields affect plume location



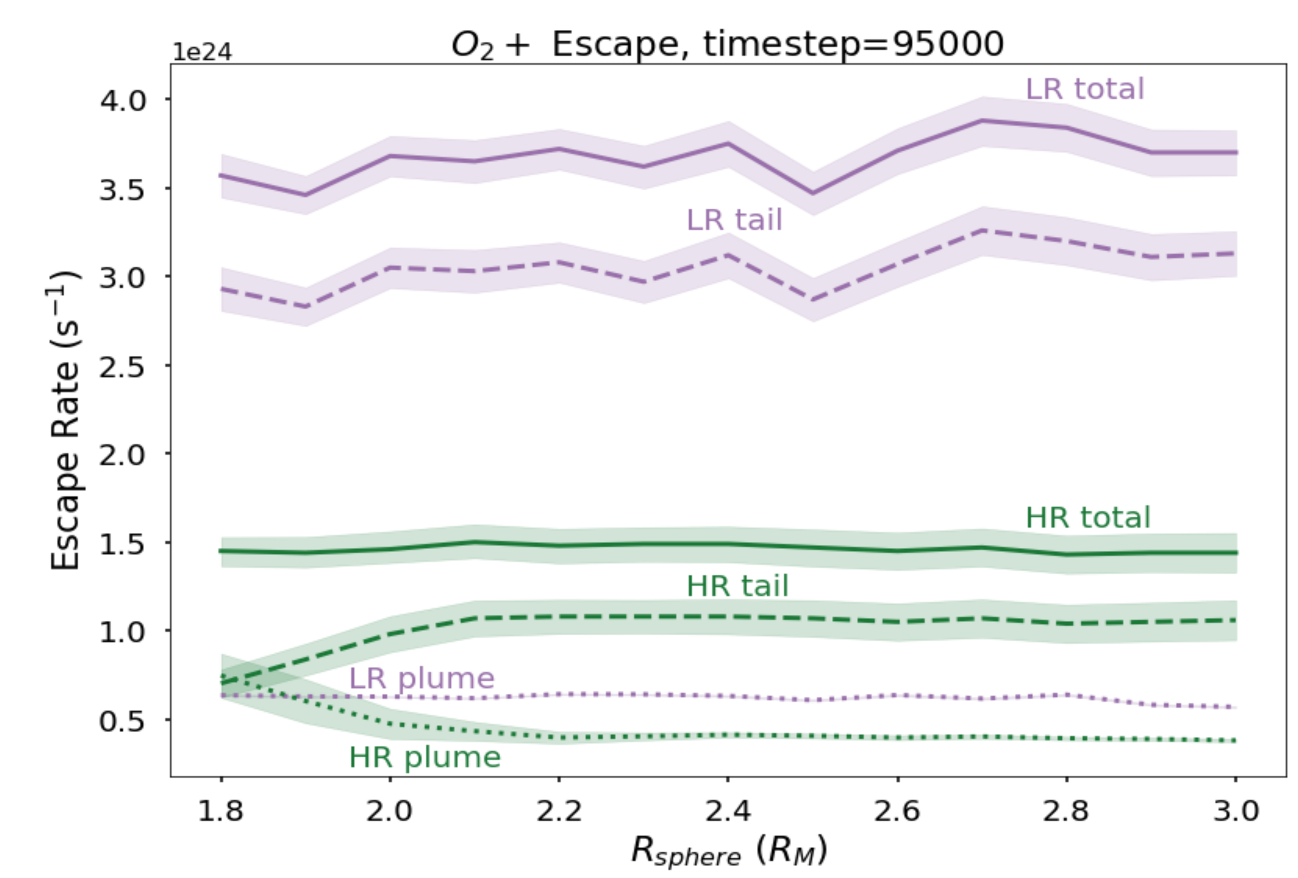
- VxB forces accelerate ions "down" plume
- JxB forces collimate plume

Resolution choice affects escape rates



High res simulation O_2+ flux map showing sampled regions used for escape calculations

- Low resolution simulation produces higher O_2+ escape in plume, tail, and total
- Resolution choice changes O_2+ escape in plume, tail, and total by ~1.5, 3 and 2.5 times, respectively



O_2+ escape rates calculated from 1.8-3.0 R_M. Shaded regions represent 1σ uncertainty calculated across all timesteps