Thermal Ion Measurements for the KiNET-X Mission

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Abstract

Observations of the thermal properties of ionospheric ions can provide a more complete understanding of the underlying physics. Petite-Ion Probes (PIPs) are small retarding potential analyzers (RPAs) whose data consist of a series of measured anode current vs applied screen voltage (IV) curves over time. Scalar thermal ion properties of the measured plasma can be determined by forward modeling IV curves for a PIP on a (sub-)payload charged to a potential (Vs) in a drifting Maxwellian plasma, with ion temperature (Ti) and density (ni), to these measured PIP IV curves. However, the results of a fit to a single PIP's data is highly sensitive to changes in the defined assumptions for the range and initial estimated values of the scalar parameters. As most investigations employ multiple collocated PIPs with different look directions, the uncertainty in the resulting scalar thermal ion parameters can be reduced by finding a plasma distribution that best fits multiple PIPs' simultaneously collected IV curves. The Kinetic-scale energy & momentum transport experiment (KiNET-X) investigated kinetic-scale ionospheric plasma transport for a known input energy & momentum by measuring ionospheric perturbations near sounding rocket barium releases. The diagnostic payload, launched May 2021 from Wallops, carried four pairs of main-payload-mounted PIPs onboard. We will present visualizations of the phase space distributions of the thermal ions from the combined measurements from multiple onboard PIPs. Additionally, we will show how these can guide assumptions for the scalar fitting and results of our improved scalar fitting method.

Introduction

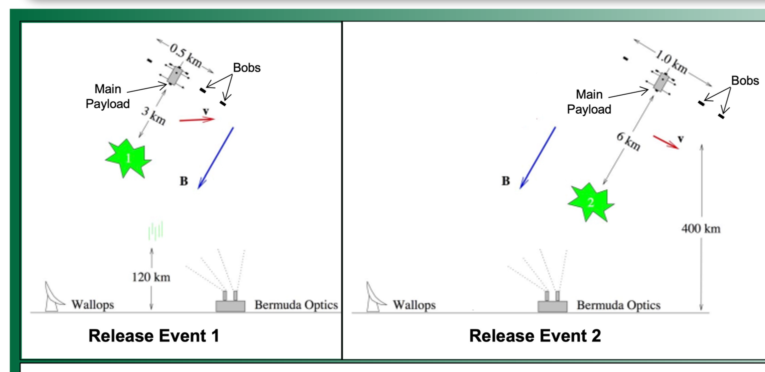


Figure 2. KiNET-X instrumentation & release geometry. (Modified version of figure from P. Delamere.)

KiNET-X Mission Description

- Goal: Investigate kinetic-scale ionospheric plasma transport for a known input energy & momentum
- The KiNET-X sounding rocket launched from Wallops in May 2021
- During the descent phase, the rocket made two barium releases which were measured by instruments onboard the main payload and onboard two deployed instrument packages.

- The main payload instruments included:
  - Eight Petite-Ion-Probes (PIPs), connected in pairs to four shields
  - DC Electric field probes from GSFC
  - Two Electron Retarding Potential Analyzers (ERPAs) from UNH
- Also, the Millstone Hill Incoherent Scatter Radar (ISR) made measurements in the region of interest.

PIP Design and Data Analysis Introduction

- A Petite-Ion-Probe (PIP) is a small, subsonic retarding potential analyzer (RPA) that measures anode current (I) as a function of screen voltage (V_b).
- PIP data consists of a measured anode current vs the sweep voltage (IV) curve at each timestamp.
- An IV curve contains **coupled** information on:
  - ion density (n_i)
  - ion temperature (T_i)
  - payload potential (V_s)
  - flow velocity ($\mathbf{v}_{flow}$)
- **Non-trivial** to determine and separate coupled thermal plasma parameters.

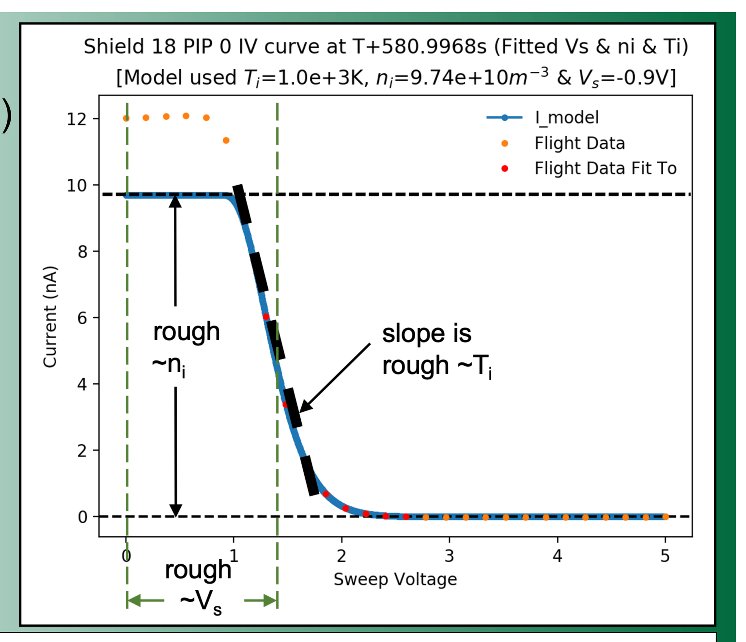


Figure 2. Annotated example of a measured and fitted IV curves with rough indication of scalar parameter effects on fitted curve.

- **Solution:** forward model PIP IV curves to measured ones using the python LMFit library and PIP-axes attitude solution (Fraunberger et al., 2020).
- Modeled current at screen bias V_b for a PIP traveling at sub-sonic velocity through plasma consisting of i-species (Roberts et al., 2017)

$$I = \sum_i \eta e \int_0^h \int_0^w \int_{-z\frac{v_x}{L}}^{(h-z)\frac{v_x}{L}} \int_{-y\frac{v_x}{L}}^{(w-y)\frac{v_x}{L}} \int_{\sqrt{\frac{2e(V_b+V_s)}{m_i}}}^{\infty} v_x f_i(\vec{v}-\vec{v}_D)\, dv_x\, dv_y\, dv_z\, dy\, dz$$

- Goal: find $f(\vec{v}-\vec{v}_D)$ that gives best-fit curve to data using LMFit (Fraunberger et al., 2020).
- Assumptions:
  - bulk flow velocity: $\vec{v}_{D,ENU} = \frac{\vec{E}_{DCE} x \vec{B}_{IGRF} - \vec{v}_{RAM}}{|\vec{B}_{IGRF}|^2}$
  - best-fit curve is the one that minimizes:

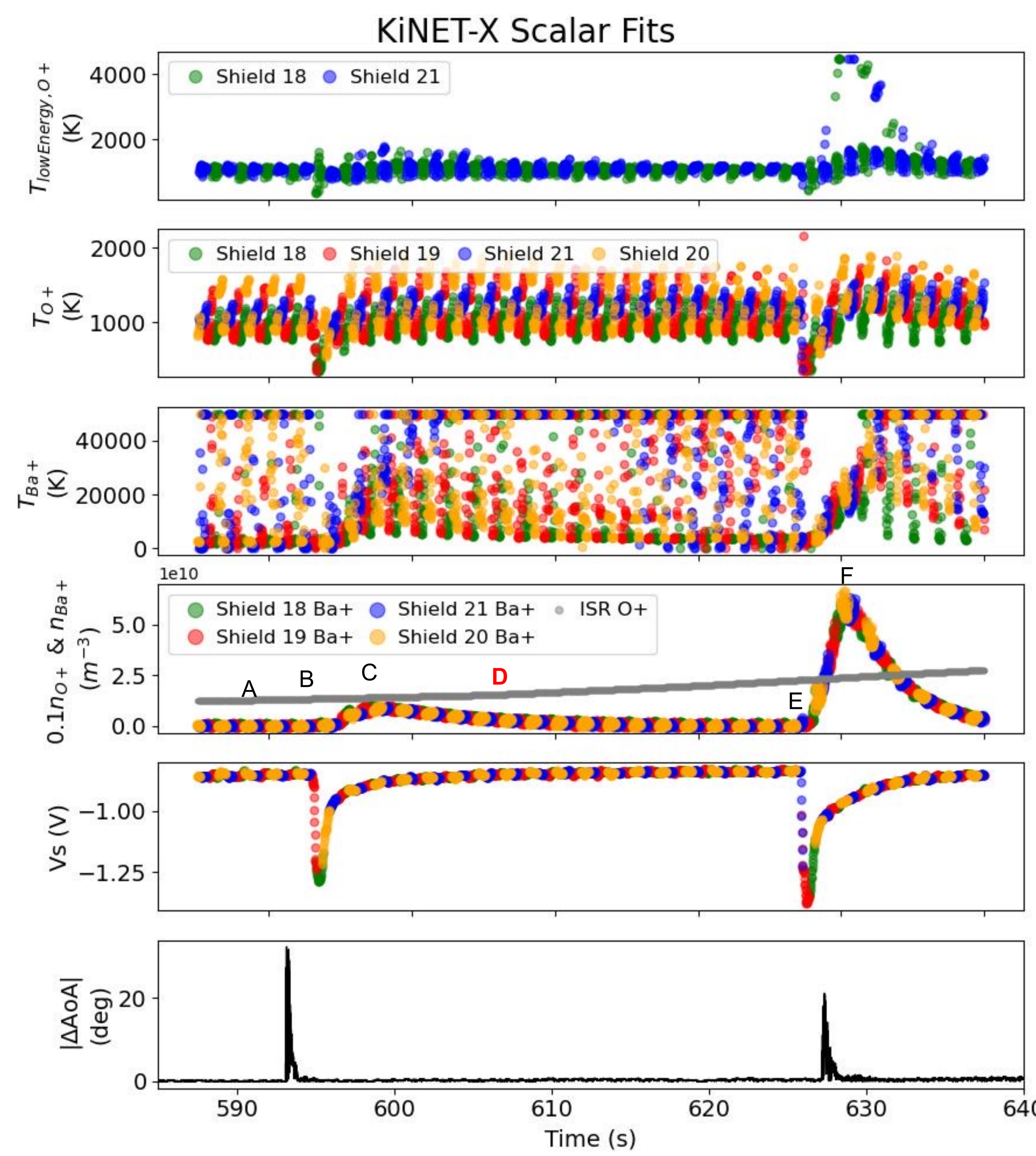
$$residual = \left| \frac{I_{true}[V_{b,min} \le V_b \le V_{b,max}] - I_{fit}[V_{b,min} \le V_b \le V_{b,max}]}{I_{error}} \right|^2$$

  - ion density is set to the profile measured by the Millstone Hill ISR
  - spacecraft potential is equal to 5*kT_e + Work Function (T_e measured by the ERPA)
  - $f_i(\vec{v}-\vec{v}_D)$ follows a Maxwellian distribution

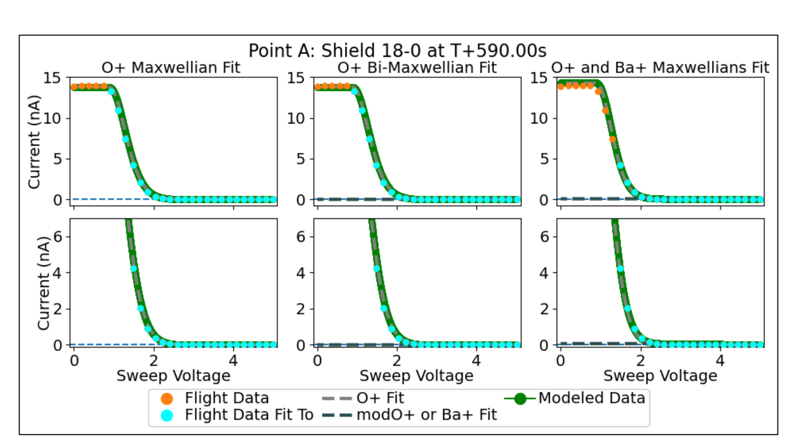
Scalar Fits

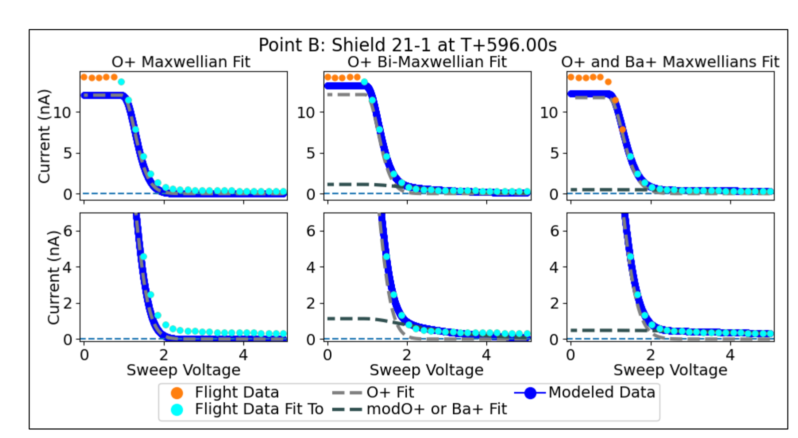
- **O+ Maxwellian Fit**: Fit for the O+ temperature of a single species Maxwellian
- **O+ Bi-Maxwellian Fit**: Fit for two O+ populations' temperatures (i.e. a Bi-Maxwellian distribution) and the second O+ population's density
- **O+ and Ba+ Maxwellians Fit**: Fit O+ temperature, Ba+ temperature and Ba+ density.

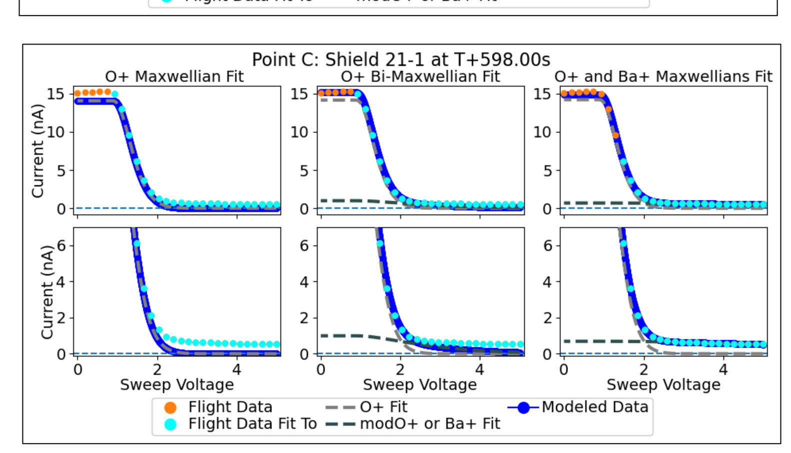
KiNET-X PIP Data

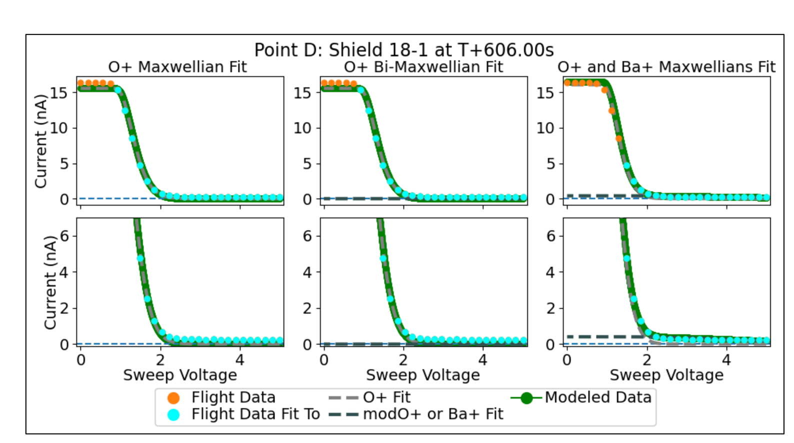


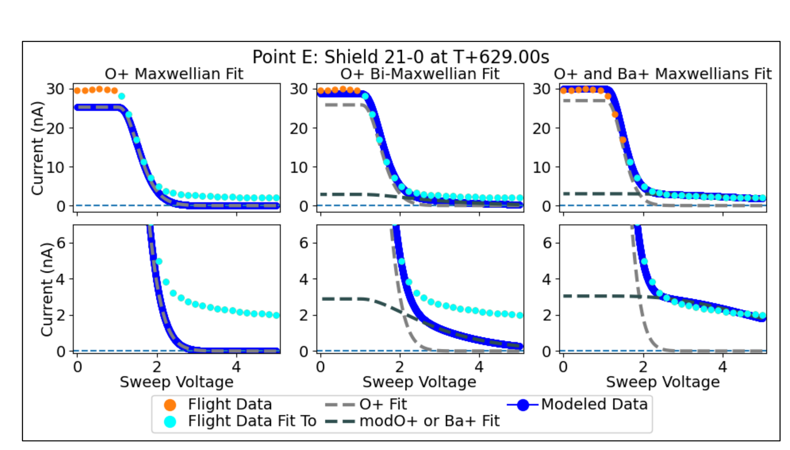
- Three possible models are shown below for six different times
- The single fit works well before the events but not during them
- The two temperature oxygen fit does not work well
- The barium fit works the best during the events

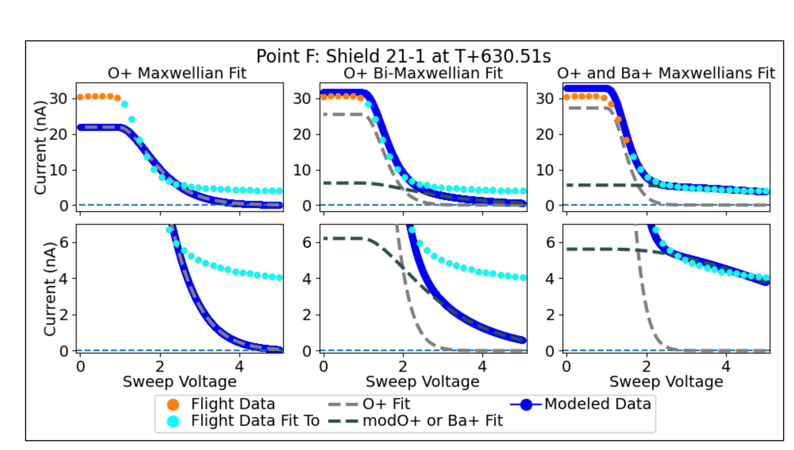






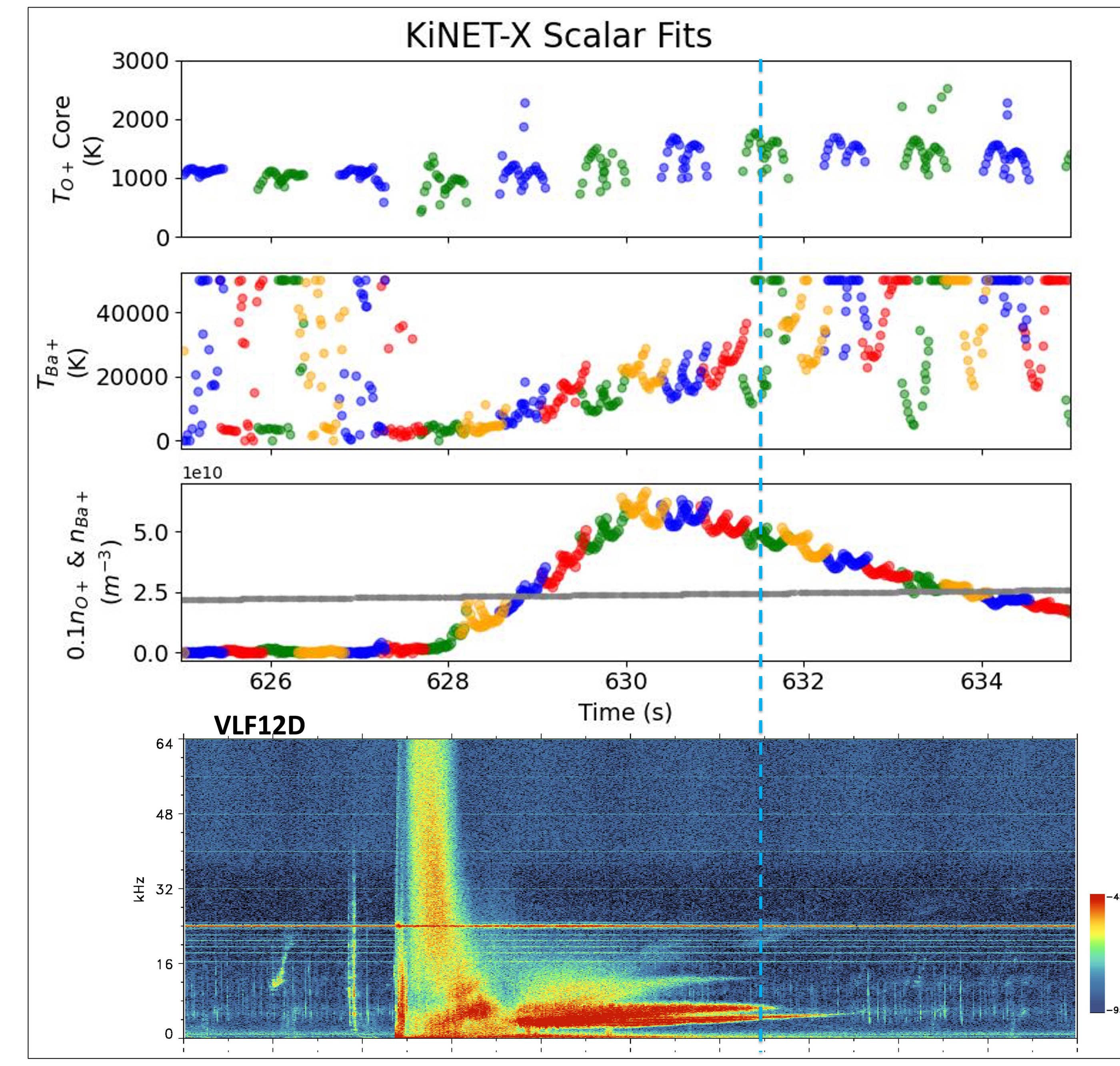


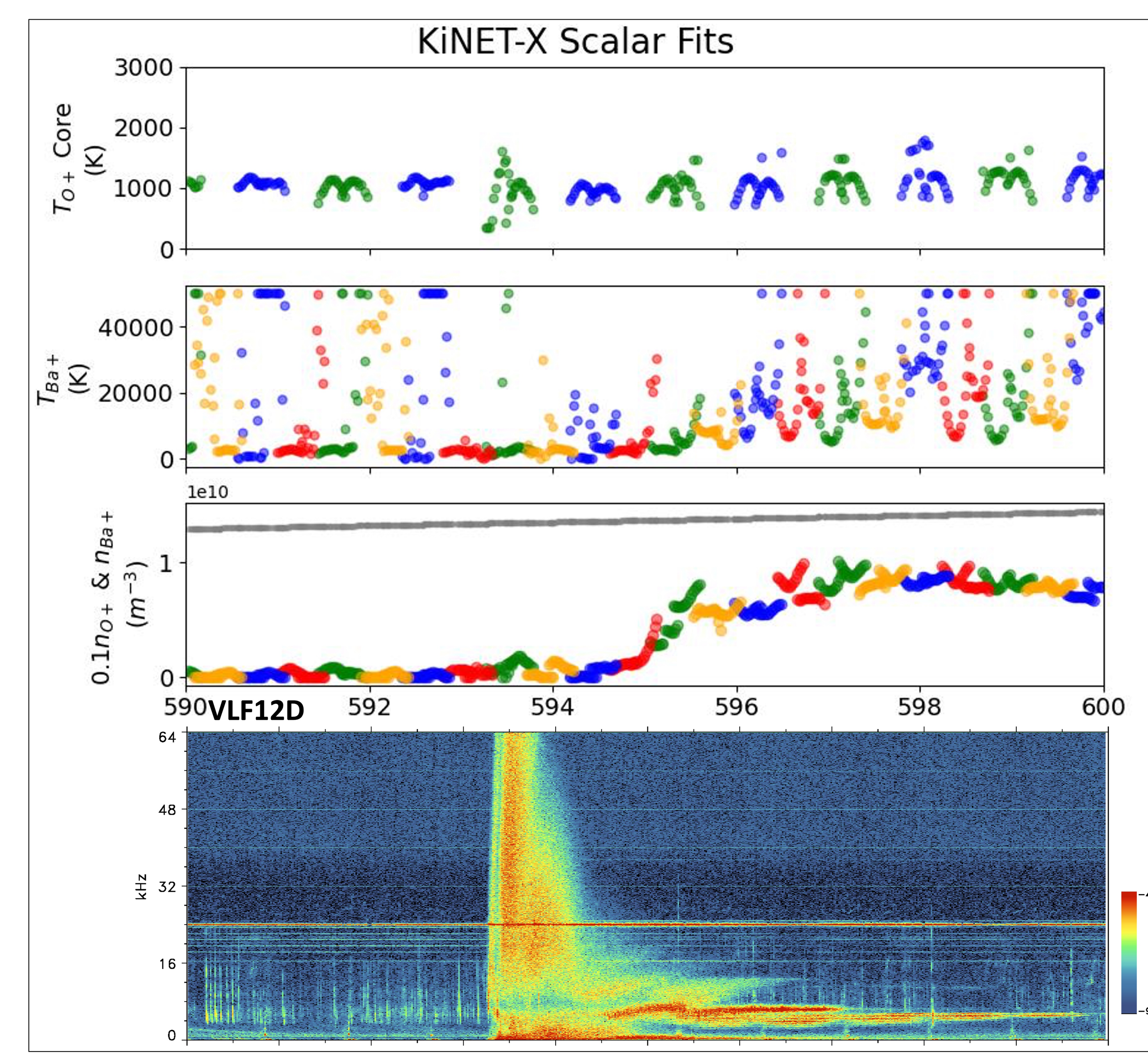




Ion Heating vs Wave Power

- Event 2: larger temperature increase and larger wave power
- Event 1: smaller temperature increase and smaller wave power





References and Acknowledgments

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NASA LCAS Sounding Rocket Program; NSROC Personnel at Wallops Island

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