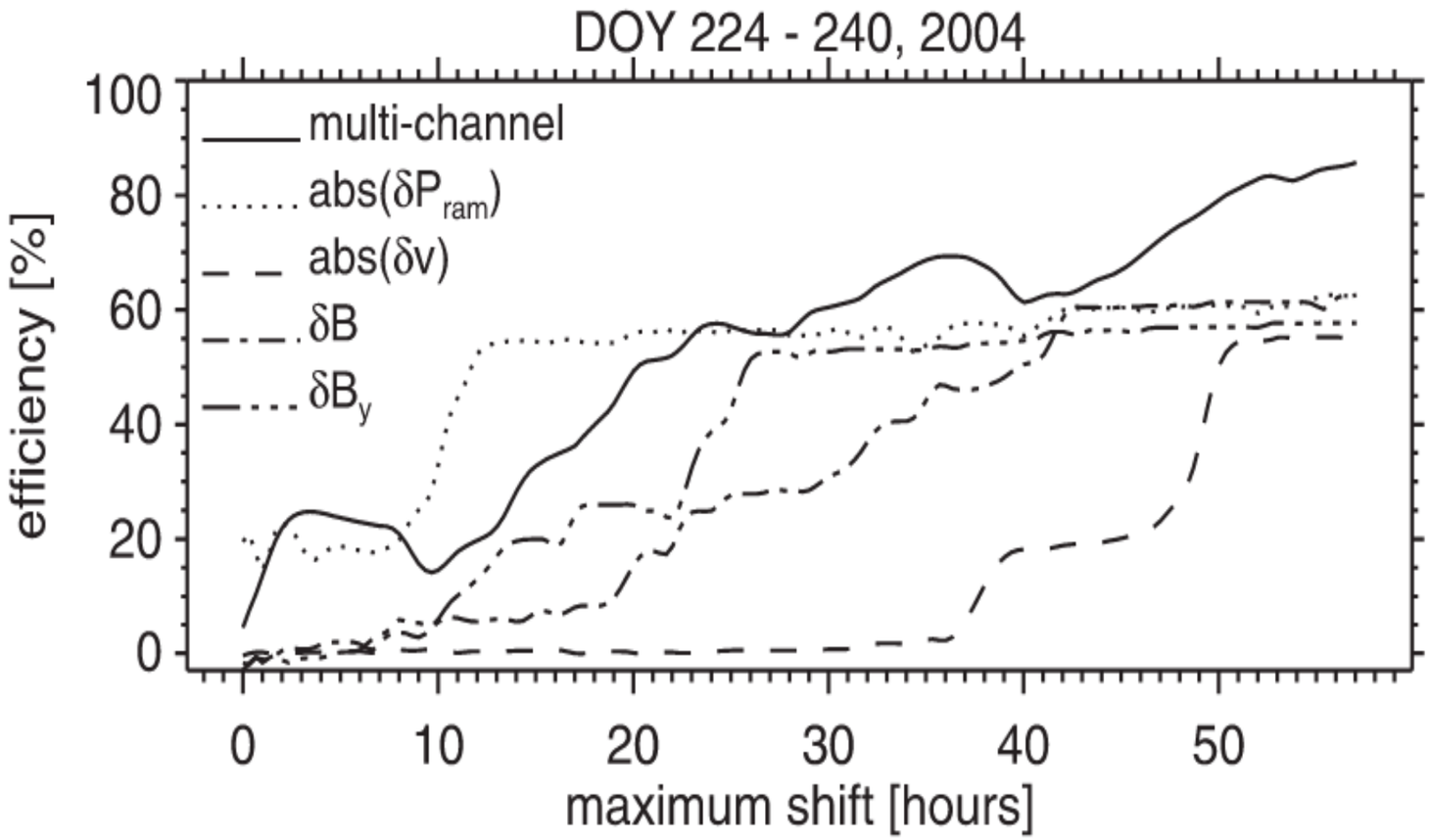
# Forecasting the Outer Heliosphere Solar Wind using Gas Giant Radio Aurorae

Matthew J. Rutala (Dublin Institute for Advanced Studies)

Caitríona M. Jackman (DIAS), Alexandra R. Fogg (DIAS), Mary Knapp (MIT Haystack), Lenny Paritsky (MIT Haystack), Erika Palmerio (Predictive Science Inc.), Mathew J. Owens (University of Reading)

# The State of the Art

- Radio aurorae of Jupiter, Saturn respond to changes in the solar wind
  - bKOM (e.g. Barrow+ 1987, Zarka+ 2021, Collet+ 2025, …)
  - SKR (e.g. Taubenschuss+ 2006, Kurth+ 2016, Palmerio+ 2021, Cecconi+ 2022, …)



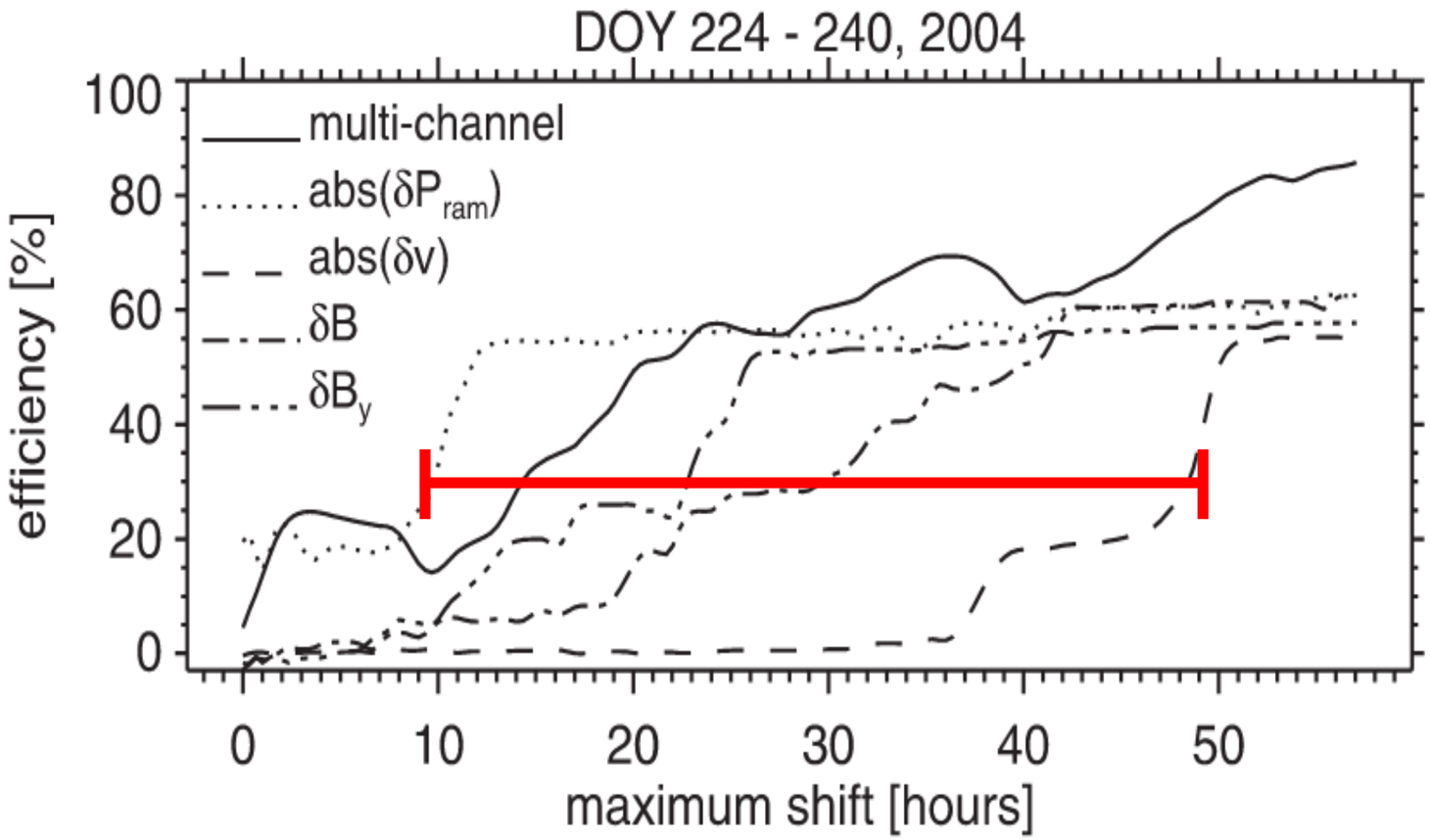

*e.g., from Taubenschuss+ (2006)*

# The Need for Better Solar Wind Models

- Solar wind propagation models have errors ~ lag times of maximum correlation efficiency (e.g. Rutala+ 2024)
- Many available solar wind reconstructions at Jupiter, Saturn ignore ICMEs

→Difficult to probe different solar wind, magnetospheric conditions

→Difficult to back out statistical relationships




*e.g., from Taubenschuss+ (2006)*

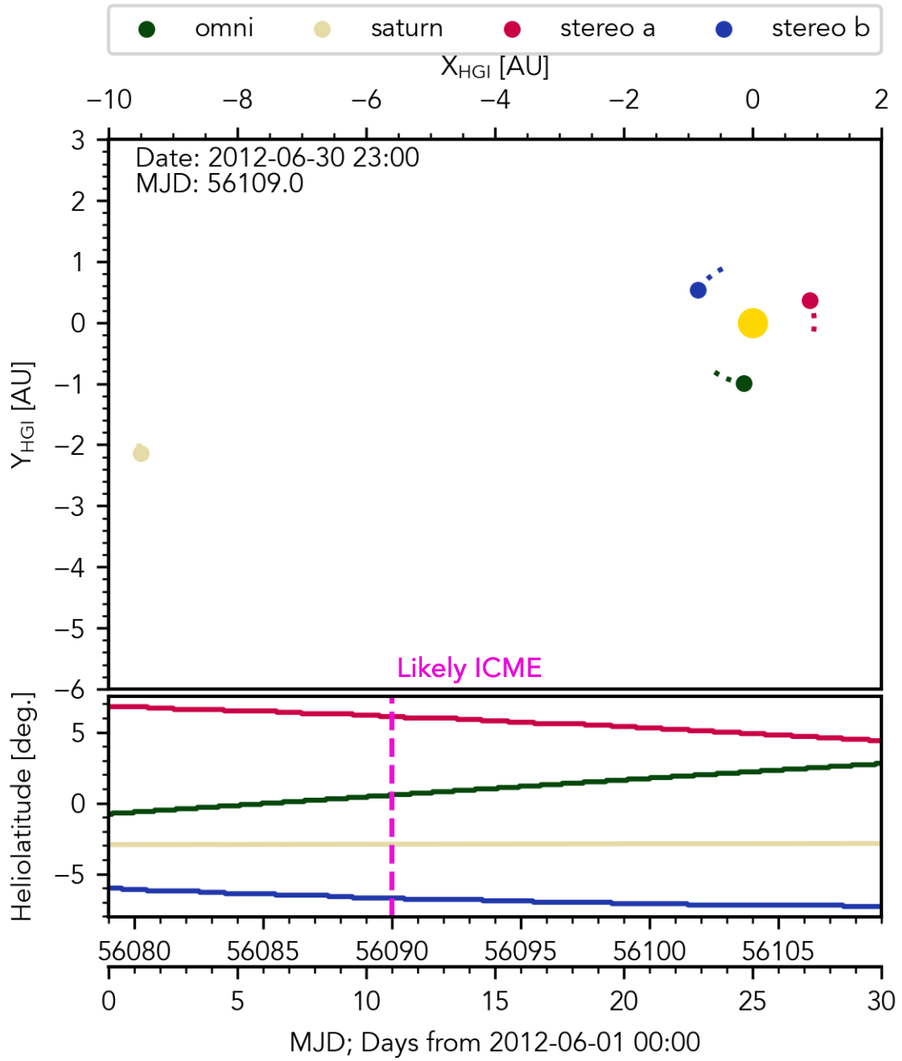
# Outer Heliosphere Solar Wind Propagation: Major Issues

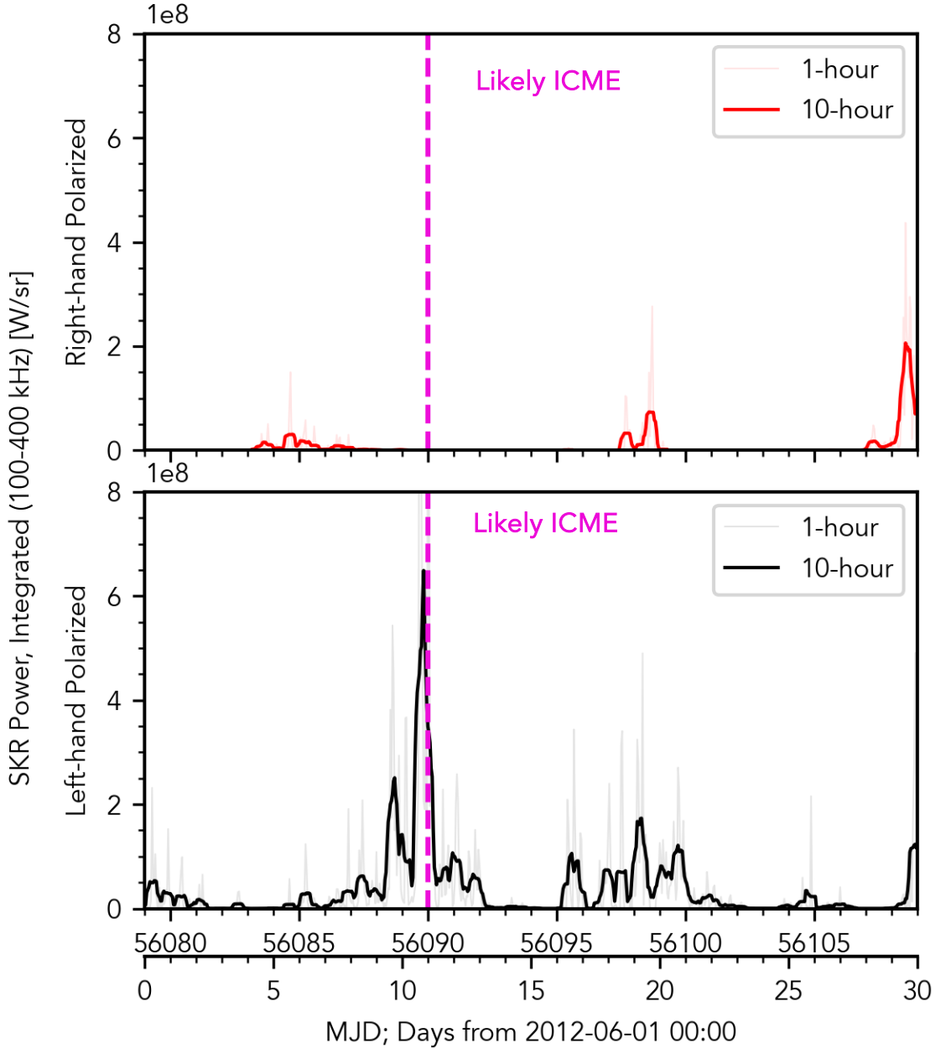
1. ICME removal from input
2. Heliolatitude (& Heliolongitude) sensitivity
3. Identification of relevant CMEs
4. Uncertainties ICME evolution

For example:

Probable ICME @ Saturn

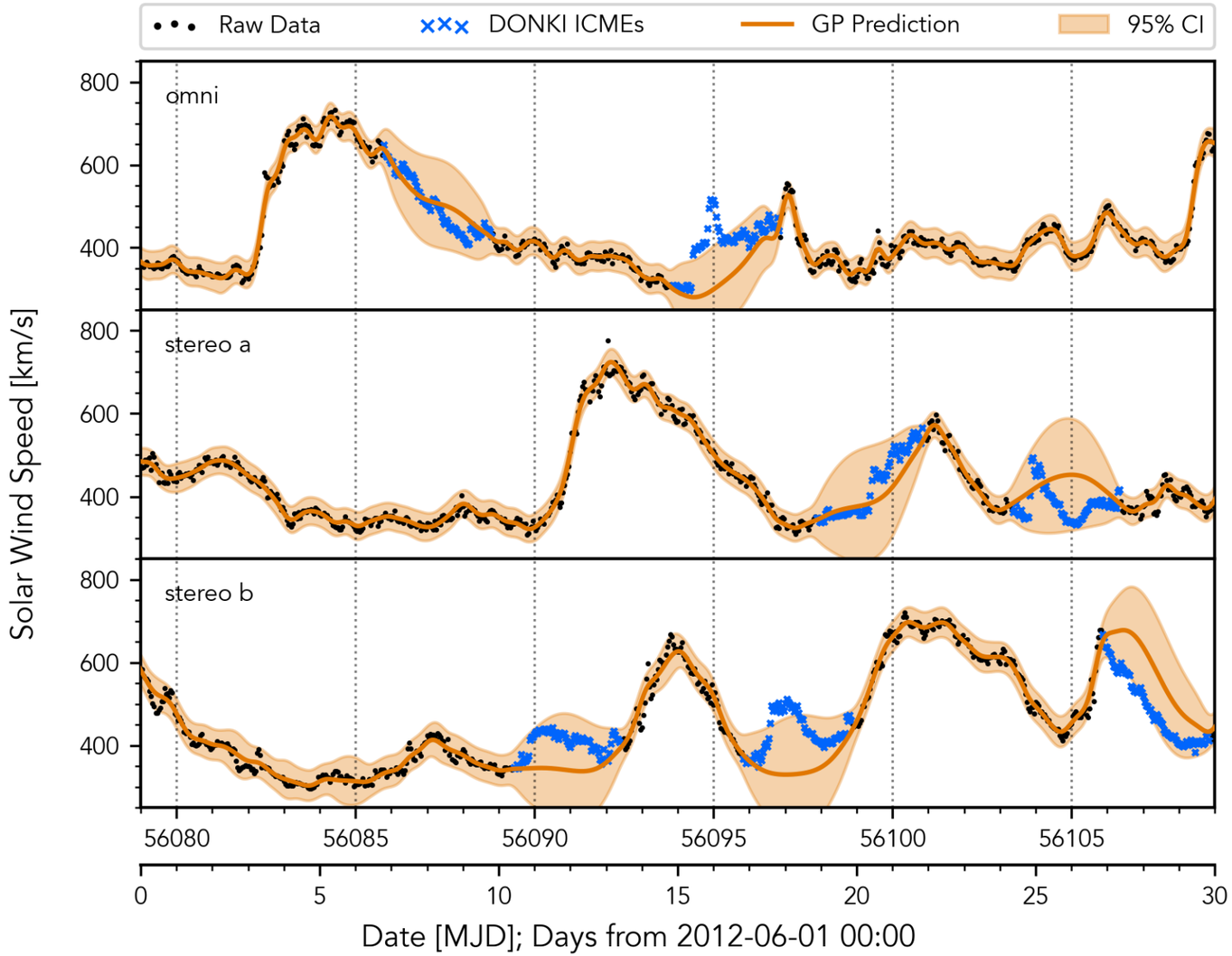
June ~12-13, 2012 (Palmerio+ 2021)



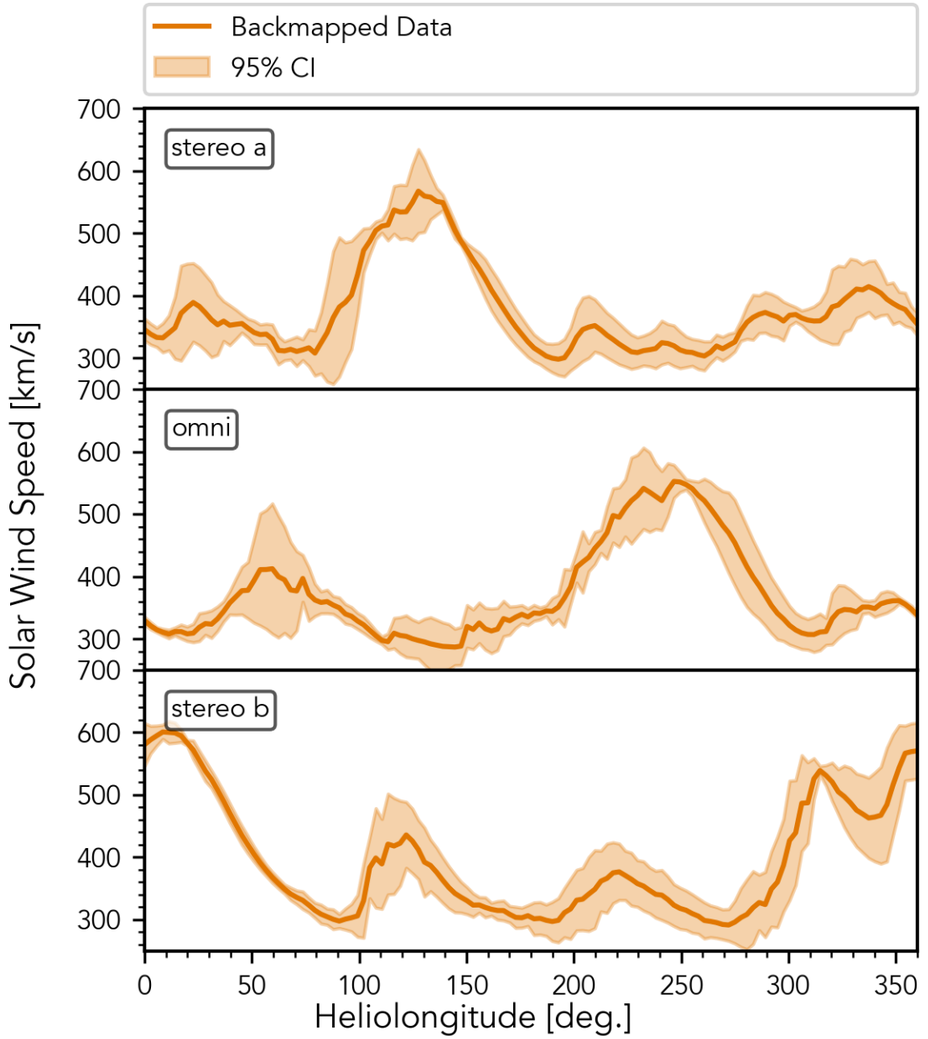
# ICME Removal From In-Situ Data

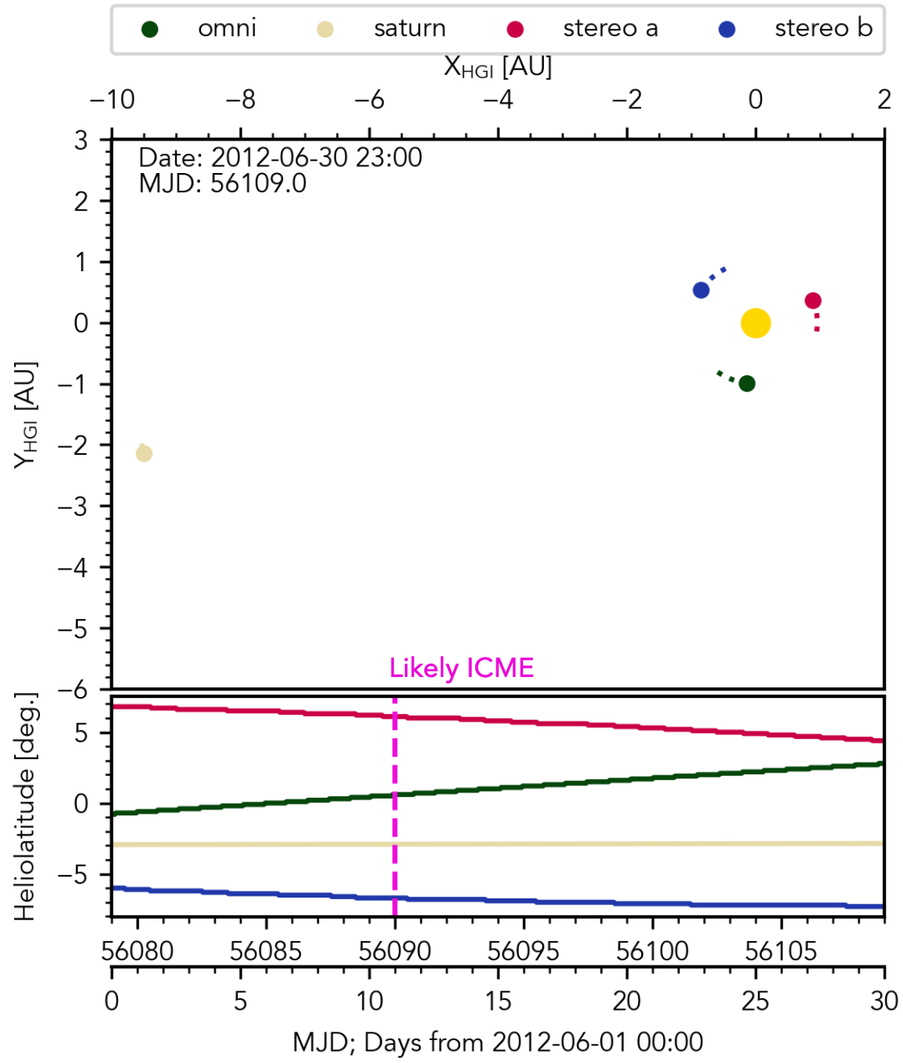
- Solar wind data: OMNI, STEREO-A, STEREO-B
- ICME lists: DONKI
  - Duration of ~4 days from arrival
- Resulting gaps filled by Gaussian Process (GP) Regression
  - Nonparametric, Bayesian method
  - Local and long-term behavior
  - Probabilistic ambient solar wind conditions



# Probabilistic Boundary Conditions

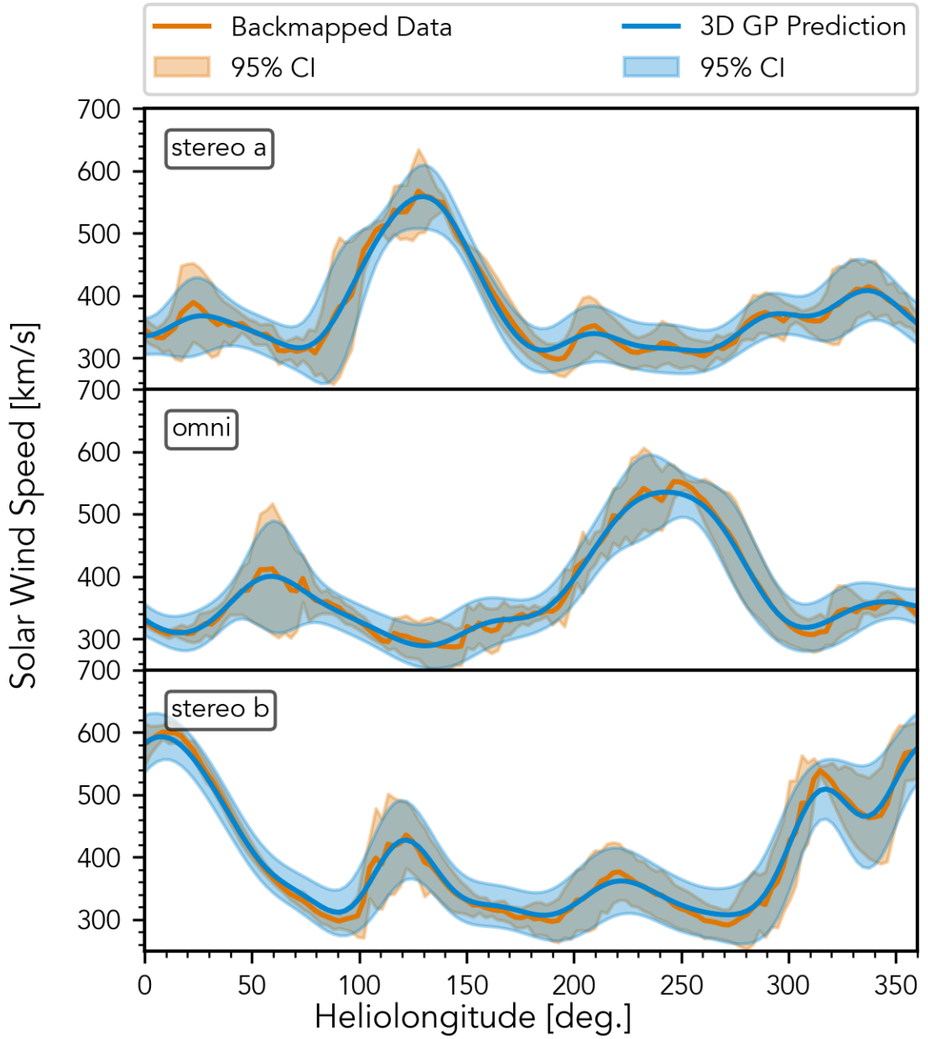
- Solar wind backmapped to 21.5 $R_S$
  - Variable uncertainty in boundary conditions relate to ICME removal
- Different behavior across heliolatitudes

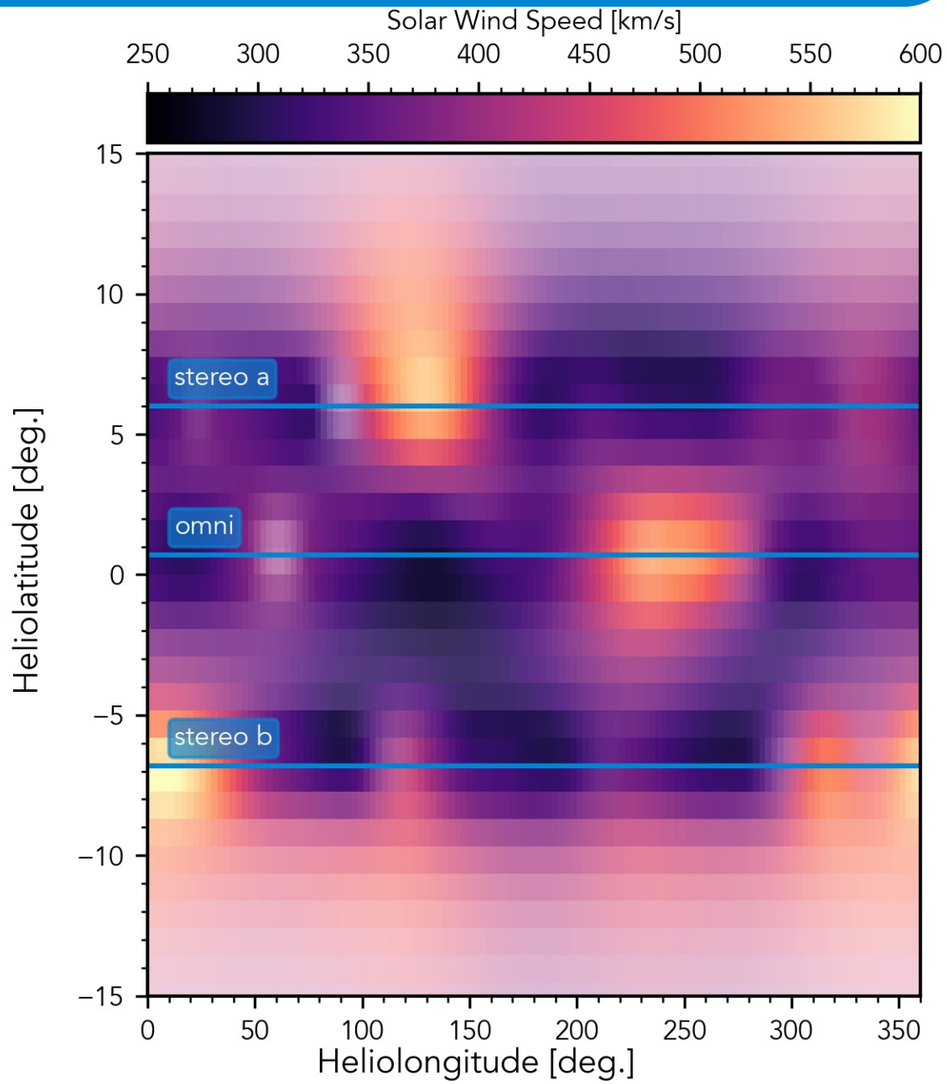


# Reconstructing Variations in Heliolatitude

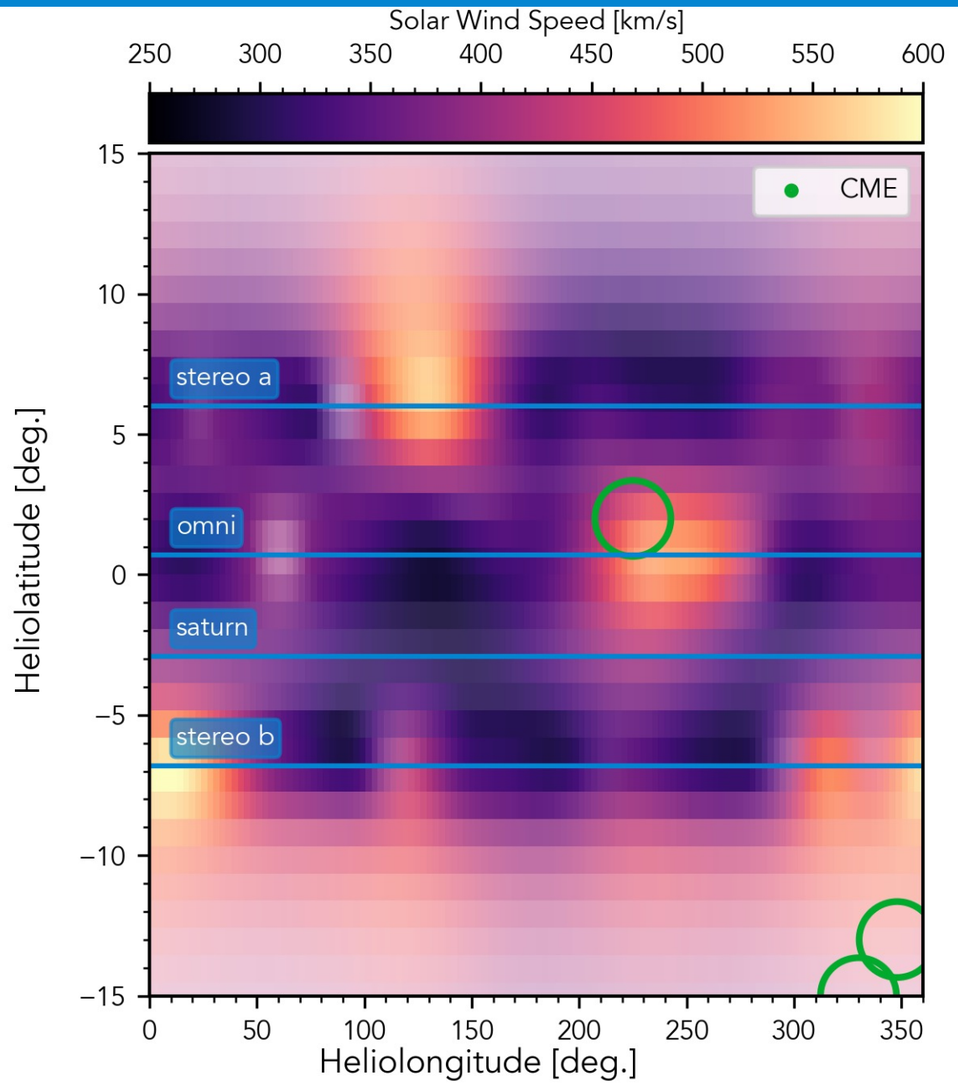
- Heliolatitude gaps filled with GP Regression
- Independently & jointly fit trends in:
  - Heliolatitude
  - Heliolongitude
  - Time
- High uncertainty far from measurements
  - →Better boundaries with more in-situ measurements



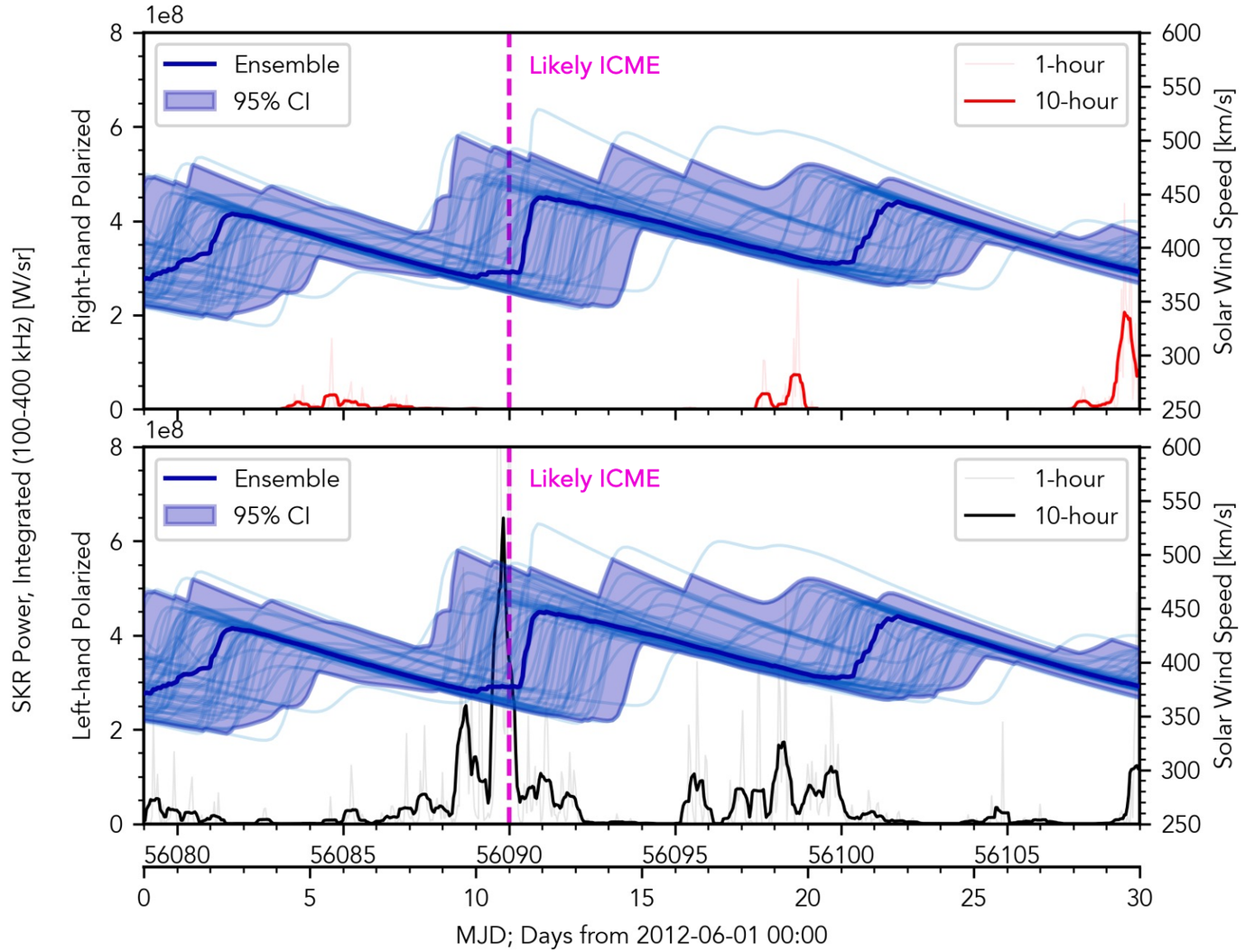
# Reconstructing Variations in Heliolatitude

- CMEs from DONKI modeled from 21.5RS boundary
  - Assume normally distributed launch time, speed, size, shape
- Extract the resulting boundary condition + CMEs at Saturn



# SKR Data Assimilation: Before

- Propagation with HUXt solar wind propagation model (Owens+ 2020)
- Ensemble (n=64)
  - Probabilistic boundary conditions
  - Probabilistic CME parameters
  - ~±2 day arrival time errors



# SKR Data Assimilation: After

- Boundary, CME probabilities reweighted
  - Weights from corr. coef. with SKR within, maximum 15 hour shift
- Ensemble (n=64)
  - ~±1 day arrival time errors
  - Arrival time moved forward, now occurs ~10 hours before spike in LH SKR power

Next steps:

- More points of comparison
  →Further model improvement
- Different coupling functions
  →Improve reweighting