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An Ensemble Modeling Framework for Propagating Solar Wind Conditions to Jupiter

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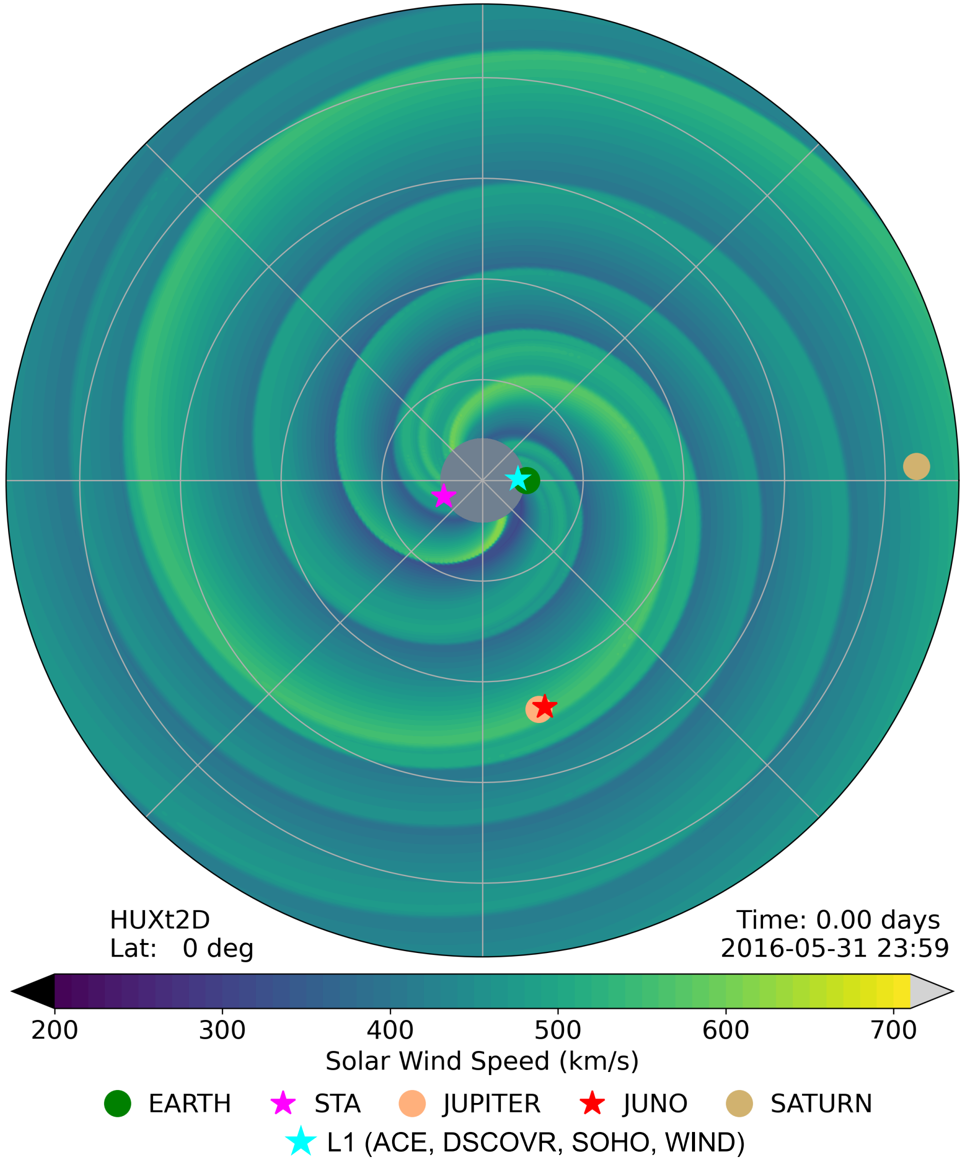
SOLAR WIND UNCERTAINTIES: JOVIAN PERSPECTIVE

- Sources of solar wind information
  - Upstream monitors: outer heliosphere spacecraft
    - 6 in-situ monitors, 33 months of hourly coverage over last 50 years (~5%) at Jupiter
  - Upstream monitor proxies: solar wind models
    - Propagation of near-Earth or Solar data over large physical domain

    ➡ **Significant timing uncertainties (≤4+ days)** (e.g. Tao+ 2005, Zieger+ 2008)

➡ Difficulty in establishing causality, interaction timescales



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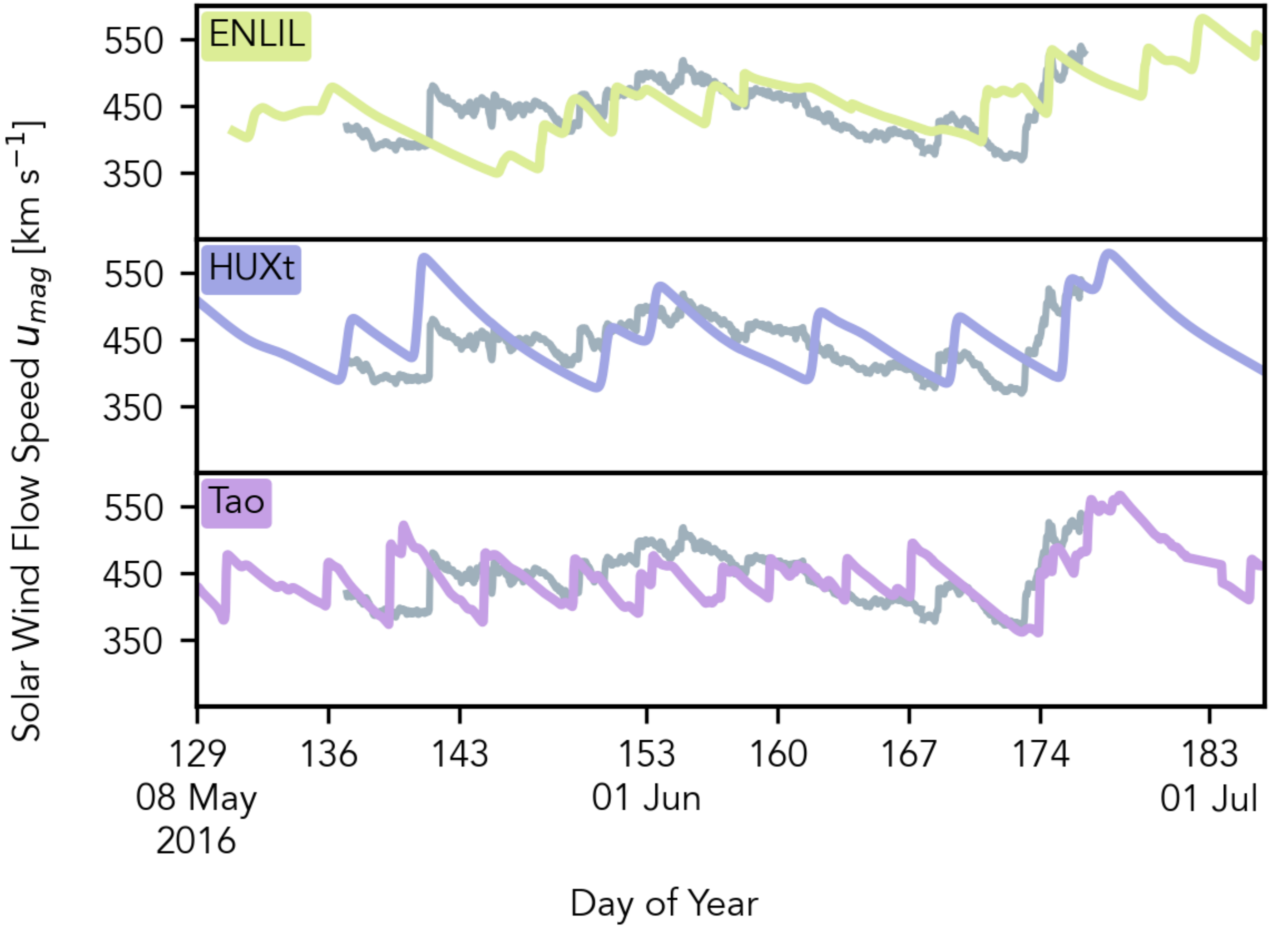
MULTI-MODEL ENSEMBLE SYSTEM FOR THE (OUTER) HELIOSPHERE (**MMESH**): OBJECTIVES

1. Characterize uncertainties
2. Identify causes of biases
3. Mitigate impacts of biases and uncertainties
   - Through multi-model ensembling

- Here, consider three models: ENLIL (Odstrcil 2003), HUXt (Owens+ 2020, Barnard+ 2022), and Tao (Tao+ 2005)



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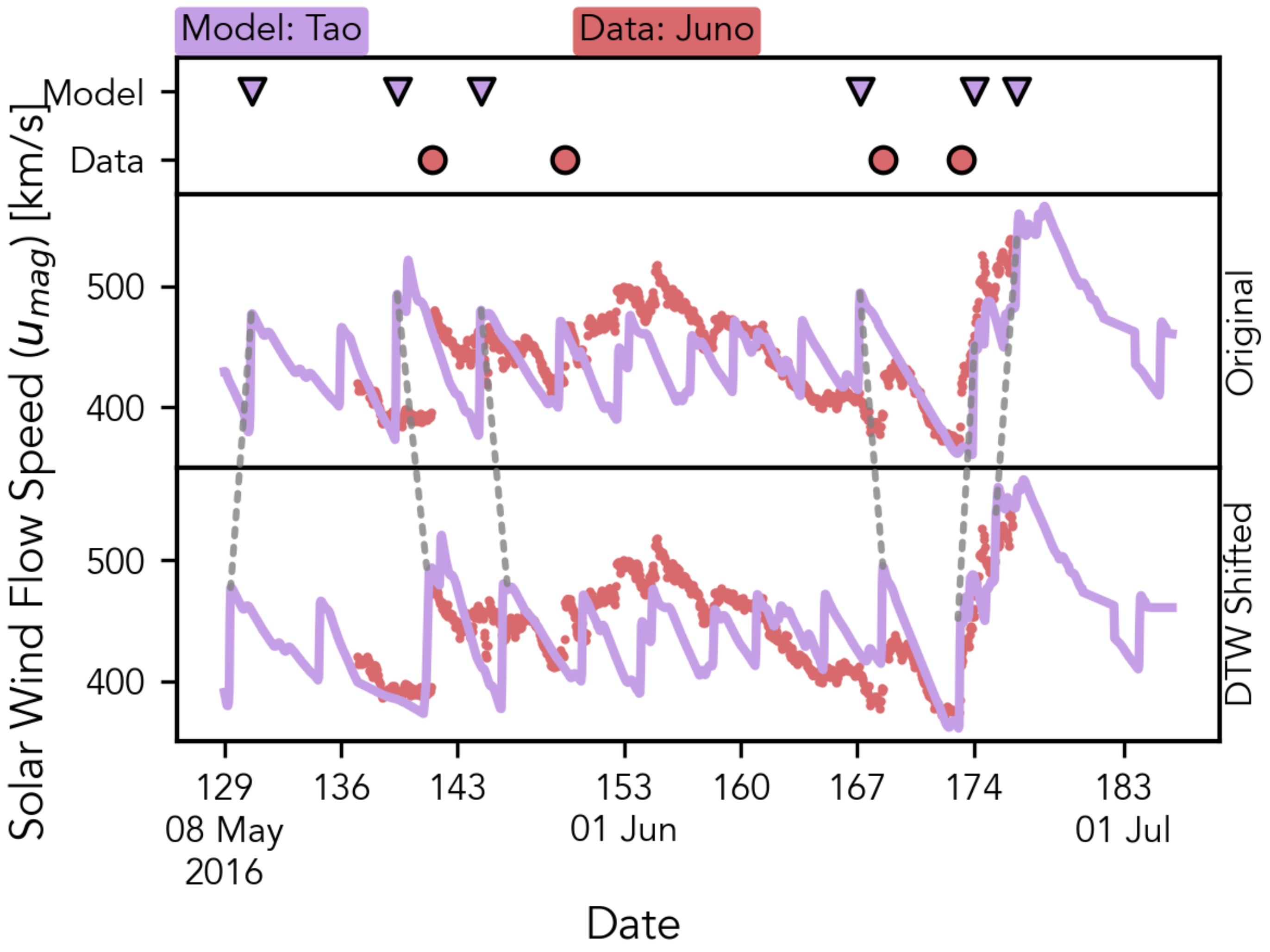
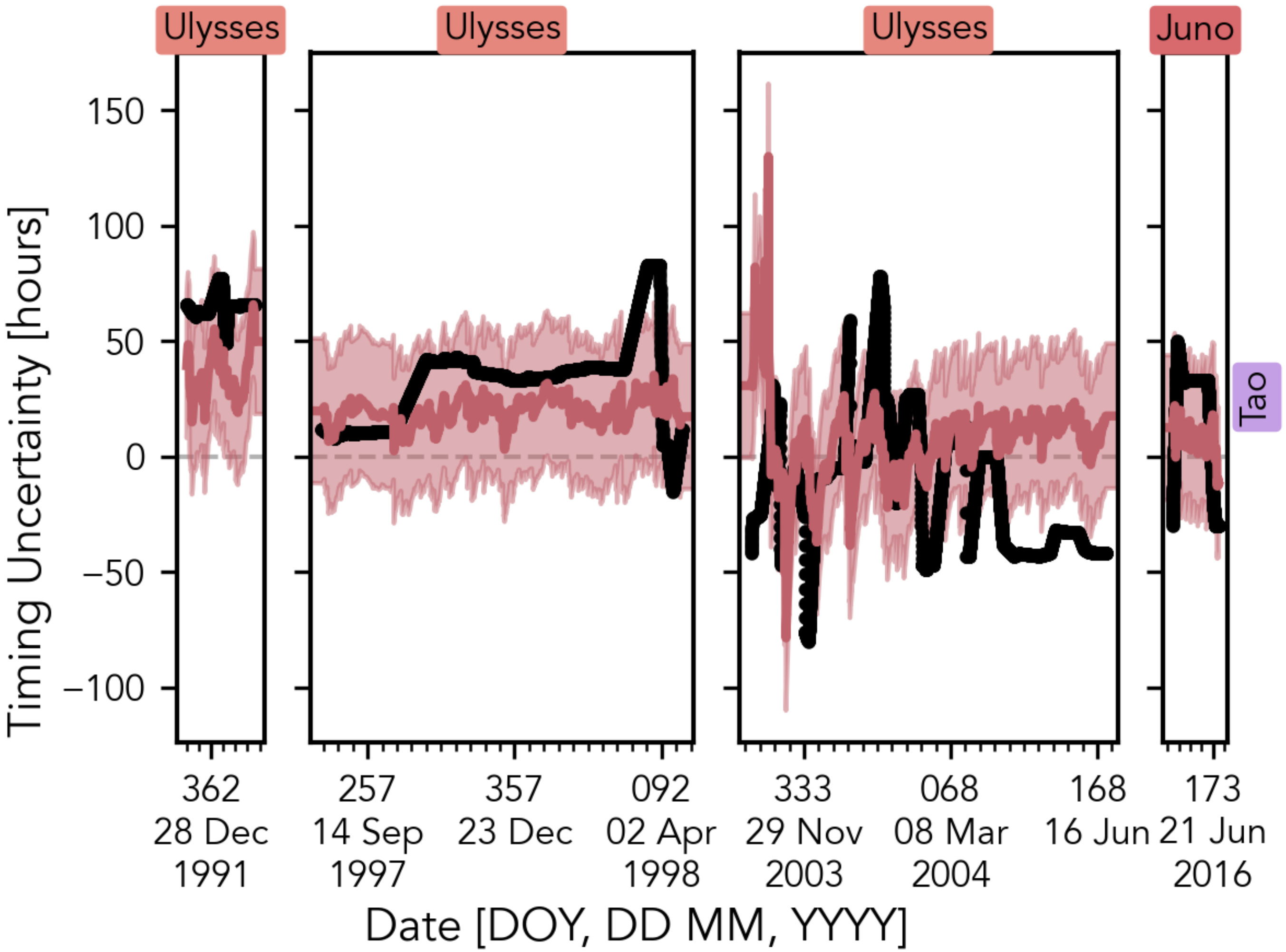
CHARACTERIZING UNCERTAINTIES: ARRIVAL TIMES

- Automatic 'feature' identification
  - Based on normalized time-derivative of solar wind flow speed (u_{SW})
- Model-data comparison over any timescale
  - Dynamic time warping (e.g. Giorgino 2009, Samara+ 2022)
    - Aligns model with data
    - Provides timing offsets (uncertainties)



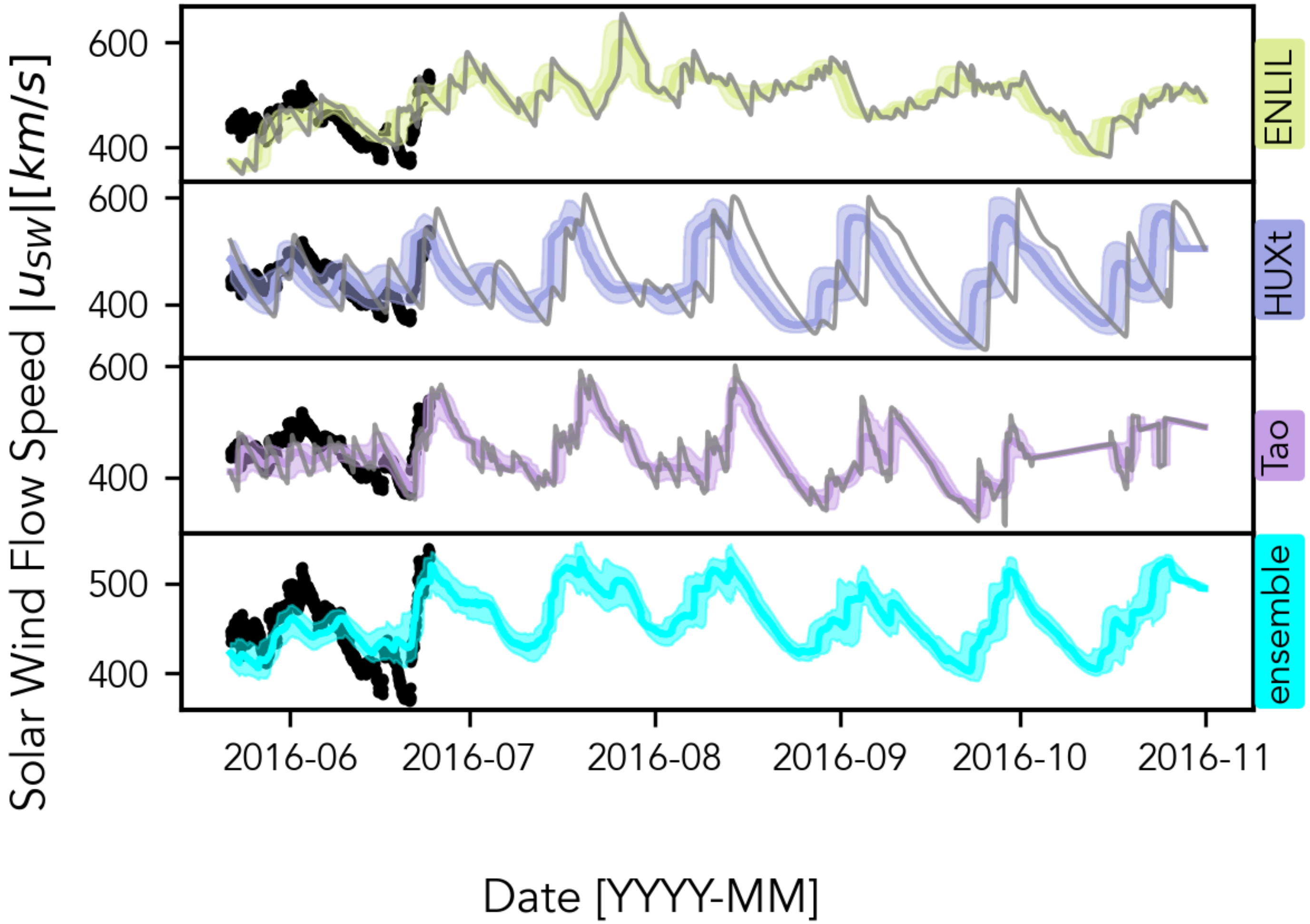
IDENTIFYING CAUSES OF SYSTEMATIC UNCERTAINTIES

- Multiple linear regression (MLR) analysis
  - Correlate timing biases with parameters known to affect propagation models
    - Solar cycle phase (F10.7 flux)
    - Separation in heliolon., heliolat.
    - Modeled u_{SW}
- Consider multiple spacecraft epochs
  - Robust fitting between epochs
  - Prevent overfitting



MITIGATING IMPACTS USING MMESH

- Combine de-trended (shifted) models
  - Equal weighting (Guerra+ 2020)
  - Propagated timing uncertainties
- Compared to input models (vs. *Juno* in-situ data):
  - 80%-105% better in *r*
  - 25%-37% better in RMSE



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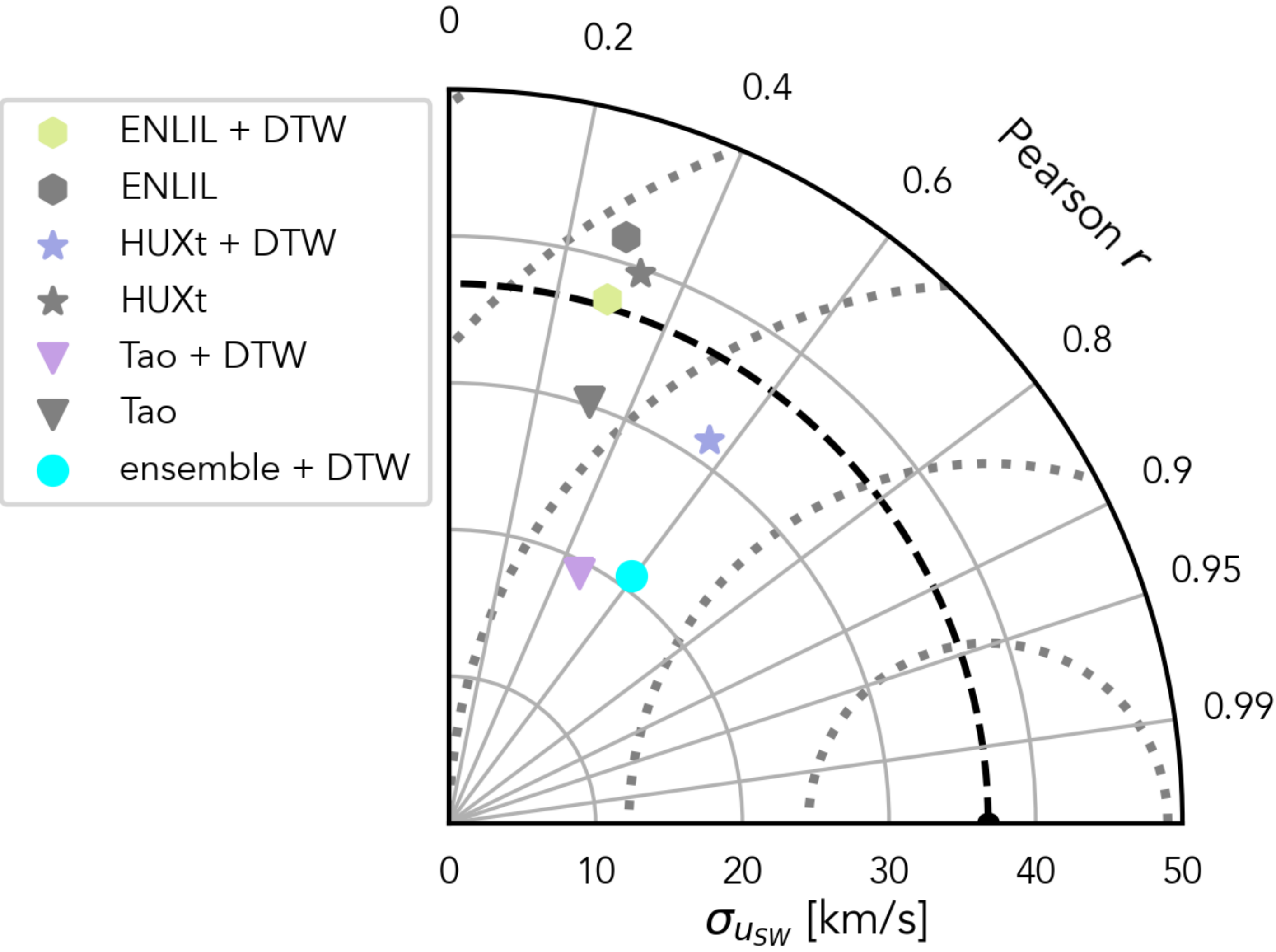
SUMMARY

- **MMESH** aligns, ensembles models:
  - 80%-105% better in *r*
  - 25%-37% better in RMSE
- **MMESH** code, *Juno*-epoch dataset to be released with Rutala+ 2023 (*in prep.)*
  - ➡ Deeper statistical analyses of solar wind-magnetosphere interactions in data-poor regions
- Timing bias MLR analysis accounts for less than 36% of variation
  - Some causes of uncertainty addressed
  - Additional significant, unmodeled causes still to be found



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