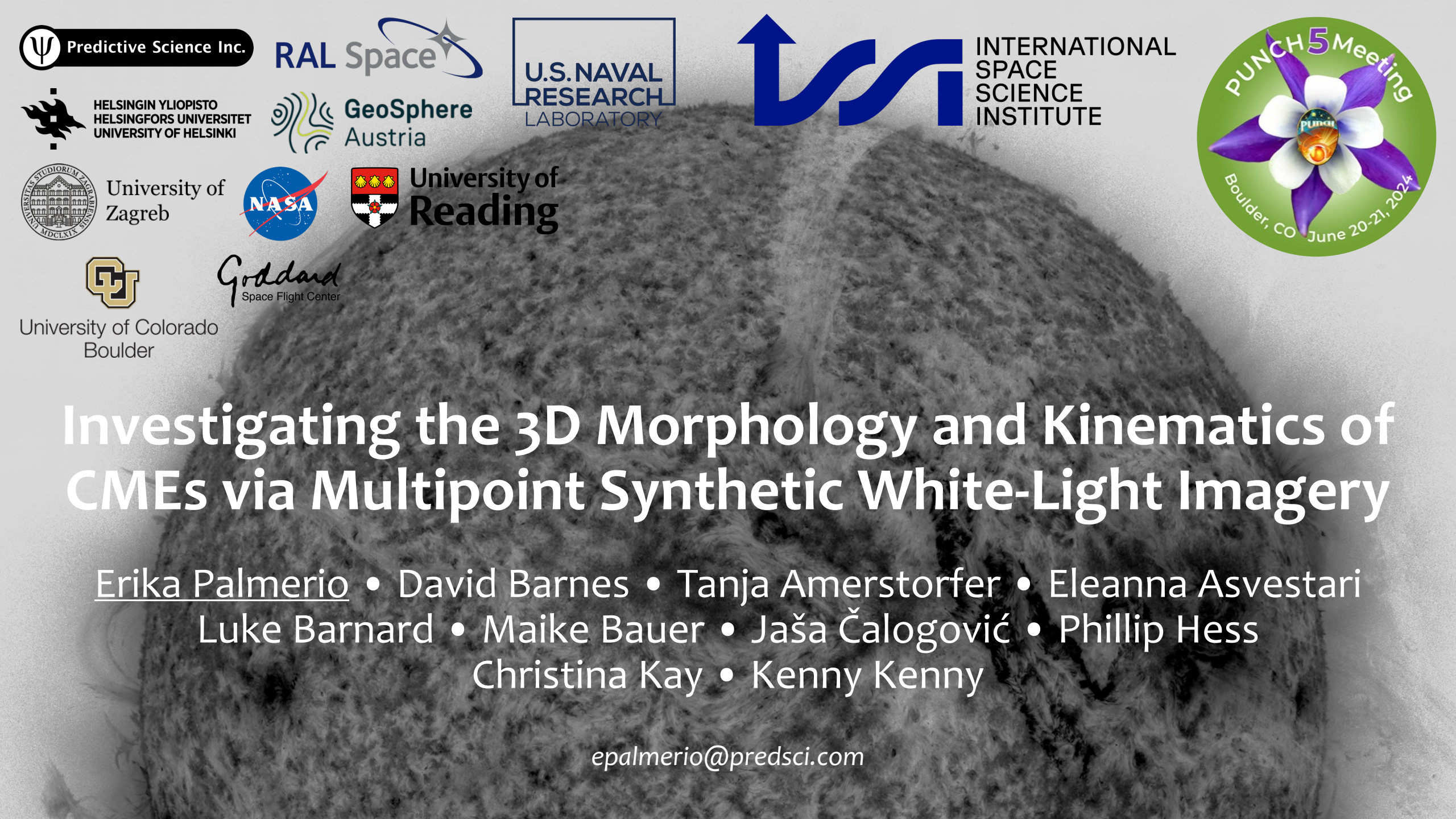

Investigating the 3D Morphology and Kinematics of CMEs via Multipoint Synthetic White-Light Imagery

Erika Palmerio • David Barnes • Tanja Amerstorfer • Eleanna Asvestari
Luke Barnard • Maike Bauer • Jaša Čalogović • Phillip Hess
Christina Kay • Kenny Kenny

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The Hard Life of a CME Chaser 🥲

- Major issue in coronal mass ejection (CME) forecasts: Most input parameters for prediction models—usually derived from remote-sensing obs—are not well constrained and have large uncertainties
- CMEs are observed in white light via coronagraphs and wide-angle heliospheric imagers (HIs)
- Usually, forward-modelling techniques are applied to these data to derive CME morphology and kinematics—often used as input parameters for CME propagation models
- BUT #1: Forward-modelling has to assume a parameterised CME shape, doed not always work well
- BUT #2: Not enough viewpoints (atm, usually 2–3) to properly constrain our models

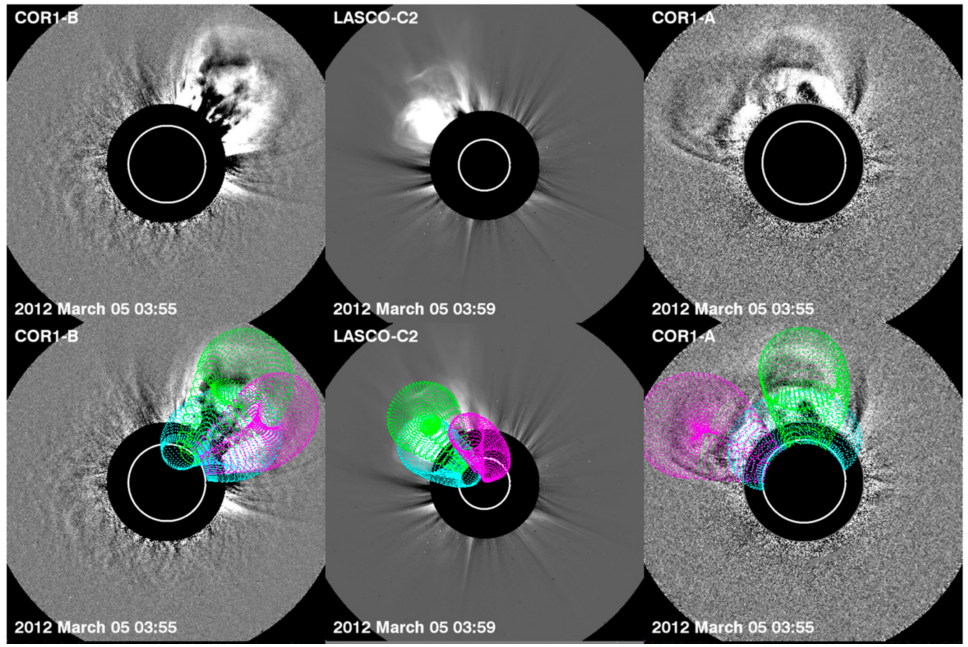


Figure: Colaninno et al. [2015]

Graduated Cylindrical Shell (GCS)

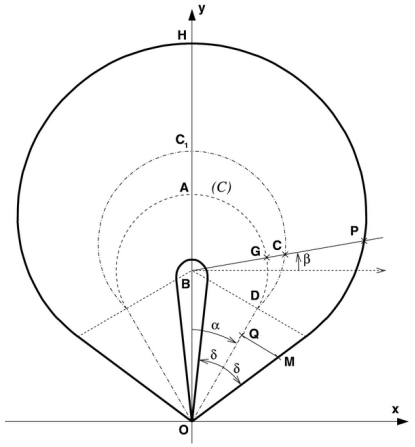


Figure: Thernisien [2011]

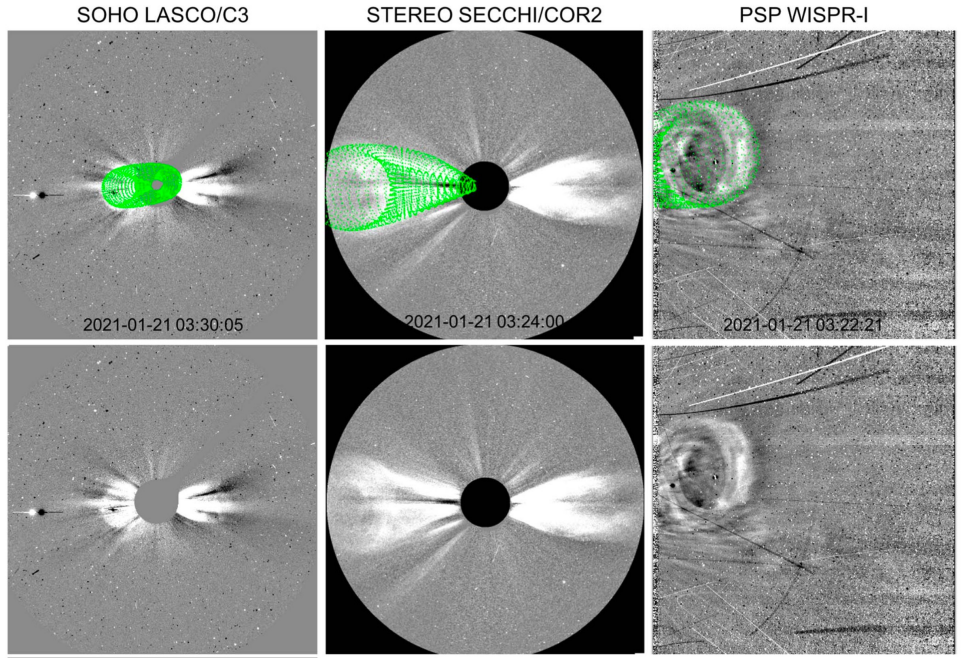
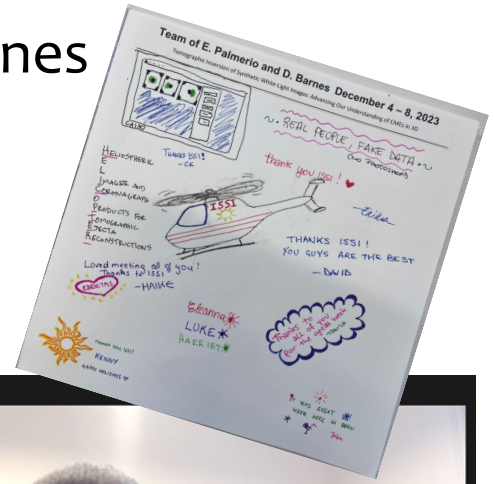


Figure: Braga et al. [2022]

So… We put together an ISSI team to play with fake CMEs!

"Tomographic Inversion of Synthetic White-Light Images: Advancing Our Understanding of CMEs in 3D"

- Leaders: E. Palmerio & D. Barnes
- Team selected in 2023
- 1st meeting: Dec 2023



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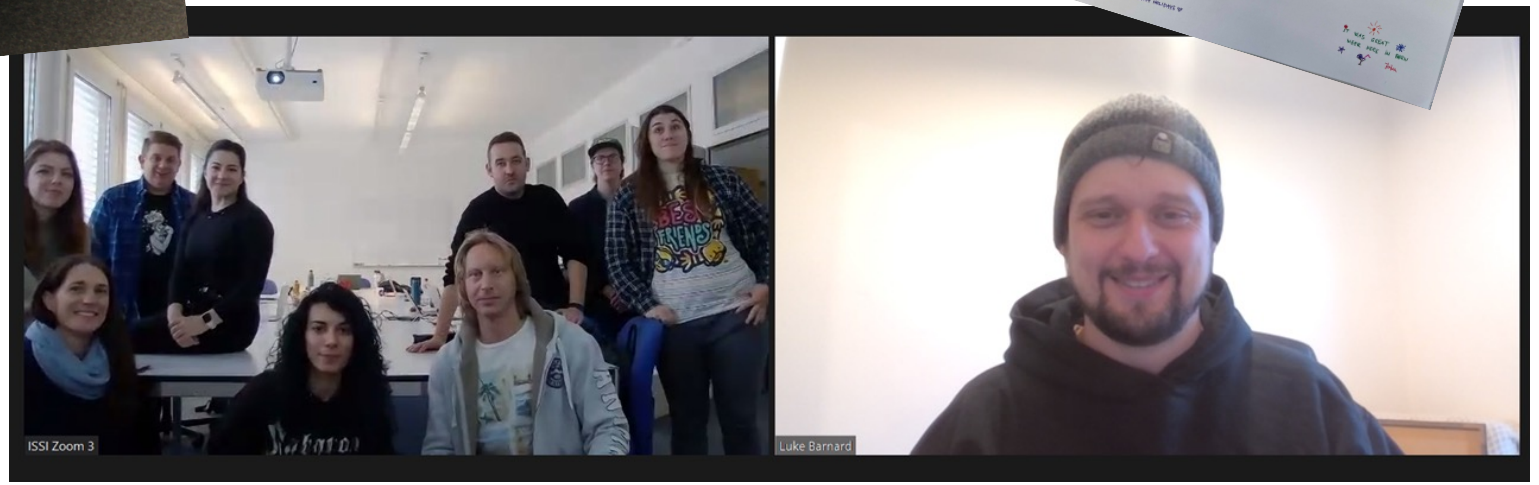
Team webpage



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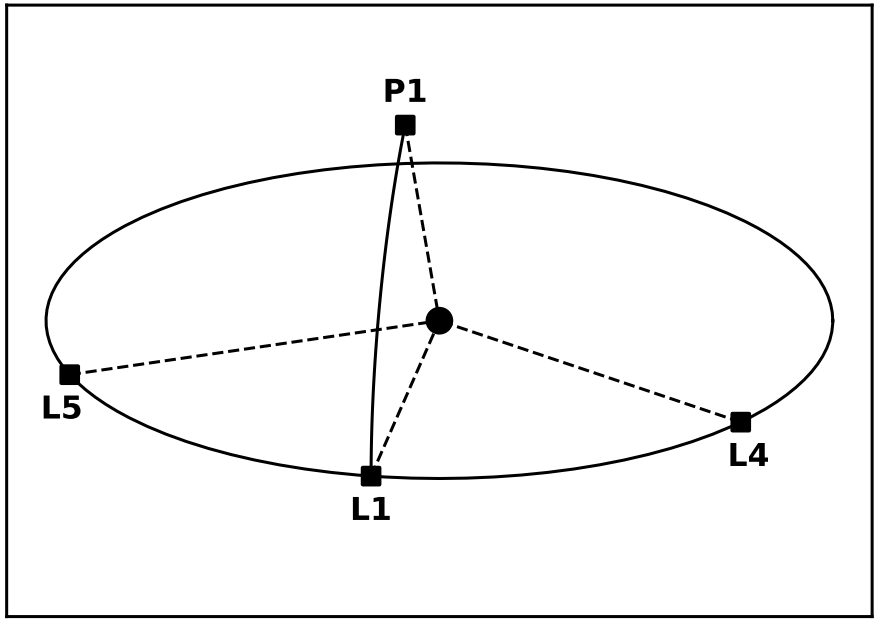
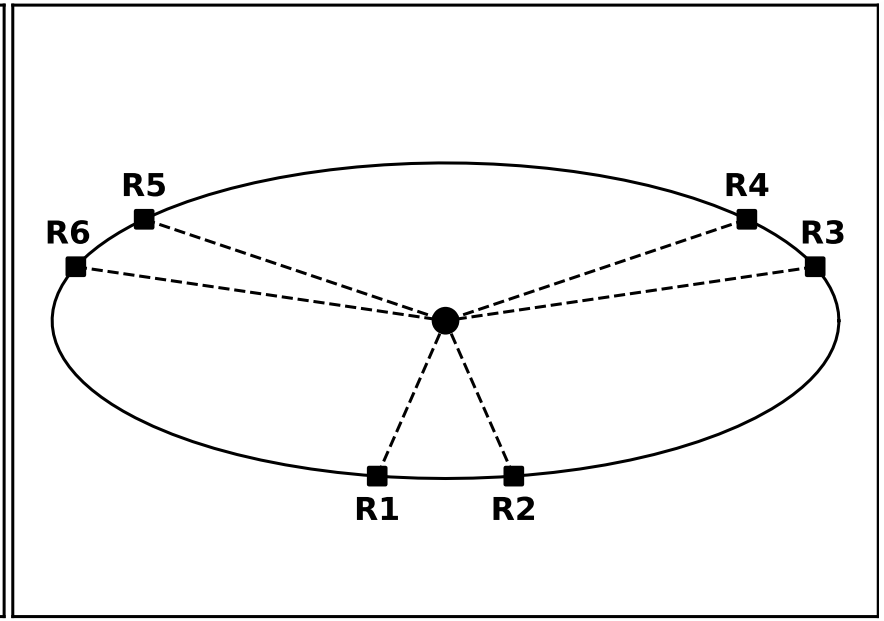
Overview of Our Research Questions and Project

- Simulated Sun-to-1 au CMEs with state-of-the-art, 3D MHD modelling (MAS/CORHEL)
- Synthetic spacecraft through the sim domain! No limitations → the heliosphere is your oyster
- Do more observers make a difference when evaluating CMEs in 3D with forward modelling?
- Can we retrieve the irregular shape of CMEs with inverse modelling? And with how many s/c?
- Does all of this make a difference in actual space weather applications (CME models assume simplified shapes as input conditions to begin with)?

(a) 3L + Polar



(b) Solar Ring



We have decided to begin our efforts using these two s/c configurations (1 au) —not attained as of yet, but still technologically realistic and economically feasible (no sci-fi regime!)

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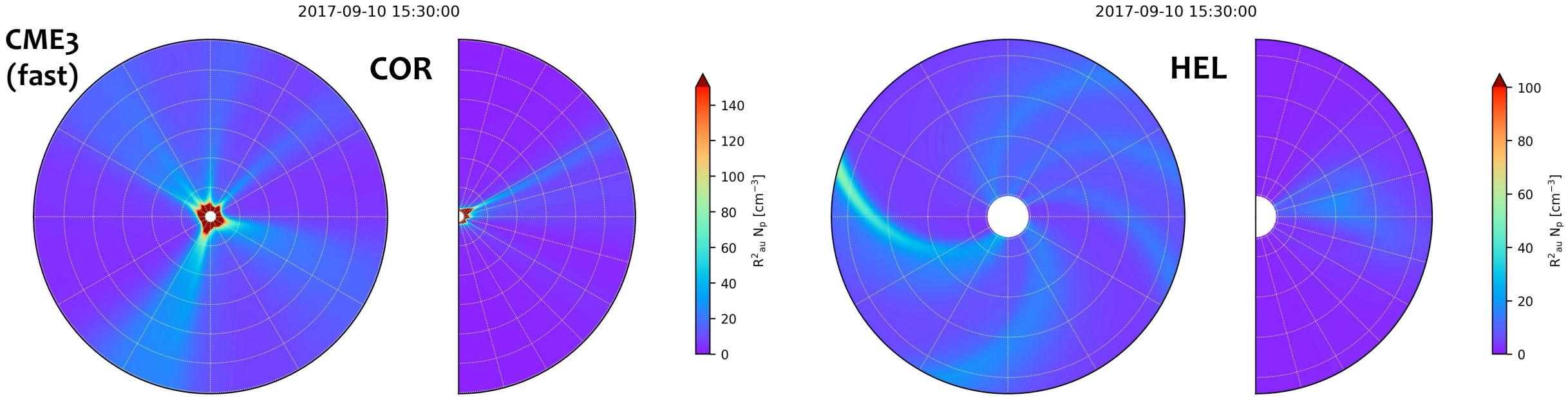
Simulating the CMEs: The MAS/CORHEL Model

- **MAS** = Magnetohydrodynamic Algorithm outside a Sphere (the code), **CORHEL** = Coronal Heliospheric (the model)
- MHD code that can model the coronal magnetic field, the solar wind, and the propagation of CMEs through them
- 2 domains: COR (usually 1–30 $R_\odot$) and HEL (usually 28–230 $R_\odot$)
- CMEs modelled from their eruption at the Sun with a full flux-rope description [here RBSL; Titov et al. 2018]
- The runs for this project utilised CORHEL-CME [Linker et al. 2024], our tool to model the eruption and propagation of CMEs with MAS/CORHEL via a web-based interface—[PS: it's available for runs-on-requests at CCMC!]
- We modeled 3 CMEs "inspired" by real events, generating a slow (~800 km/s), a medium (~1500 km/s), and a fast (~2500 km/s) sample event—inspiration from 2021-10-28, 2020-11-29, and 2017-09-10, respectively



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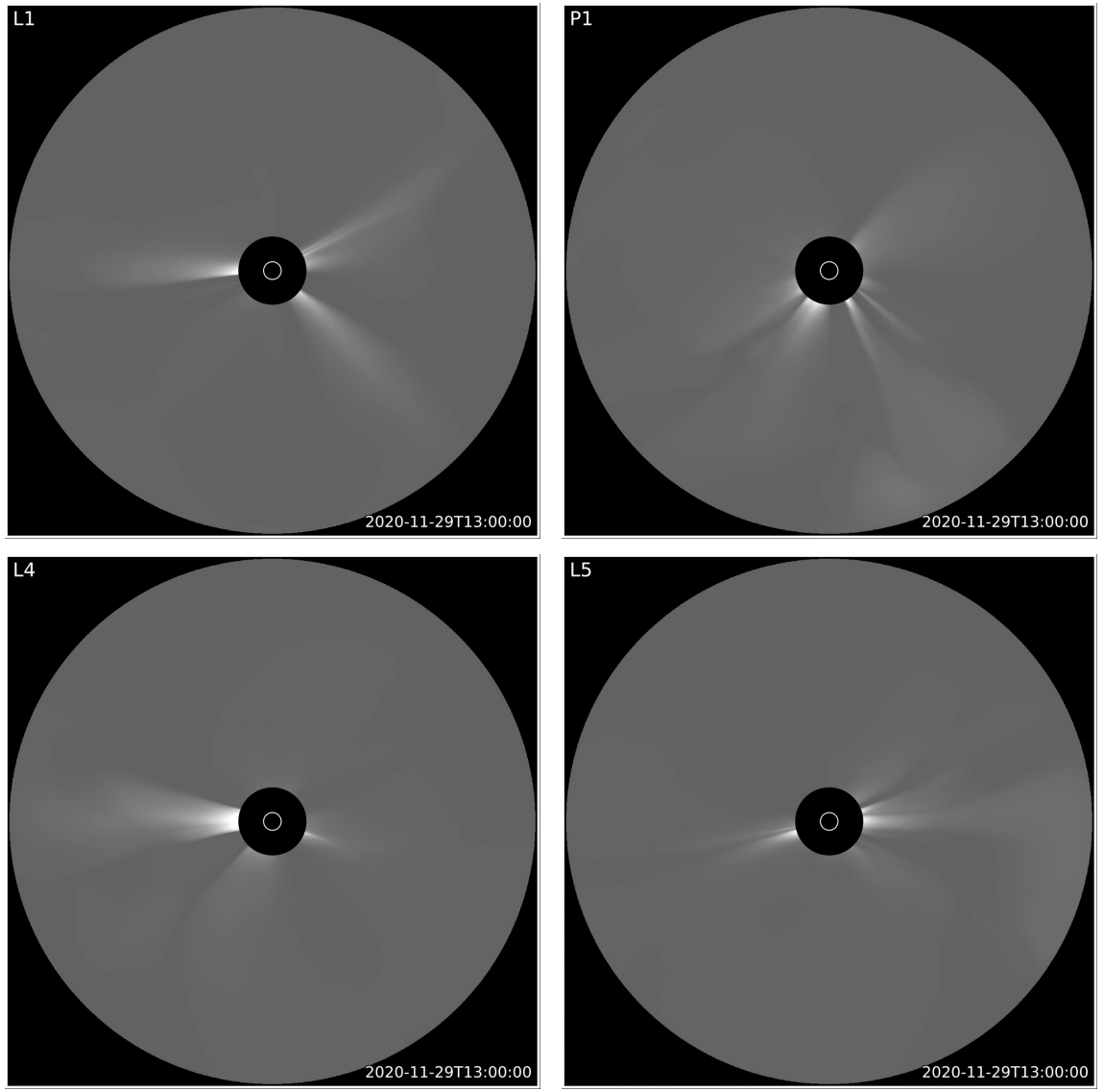
Producing White-Light Images From CORHEL Simulations

By solving Equations (29) and (17) in Howard & Tappin [2009], we can obtain the total and polarised brightness for any observer that is looking at a specific volume of the simulation time-dependent data cubes
→ line-of-sight integration involved



Our initial work has focussed on coronagraph-like synthetic images with a field of view of 30 $R_\odot$ (and that we have nicknamed Fake-C3—but Fake-NFI also works 😛)

(Fake) heliospheric imagers will be the main focus of our 2nd ISSI meeting in October 2024 (but watch out for a sneak peek at the end of this talk!)

CME2 (medium)

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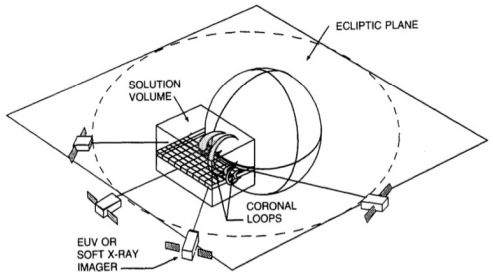
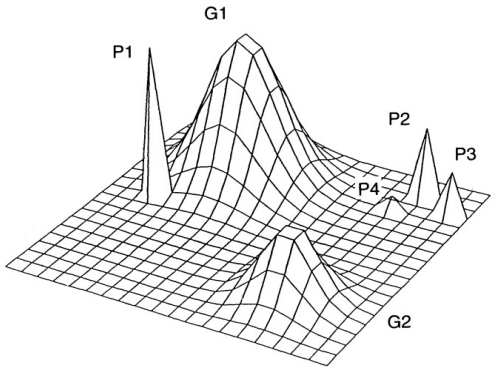
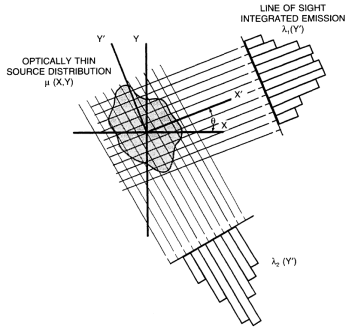
The Inverse-Modelling Technique: Discrete Tomography

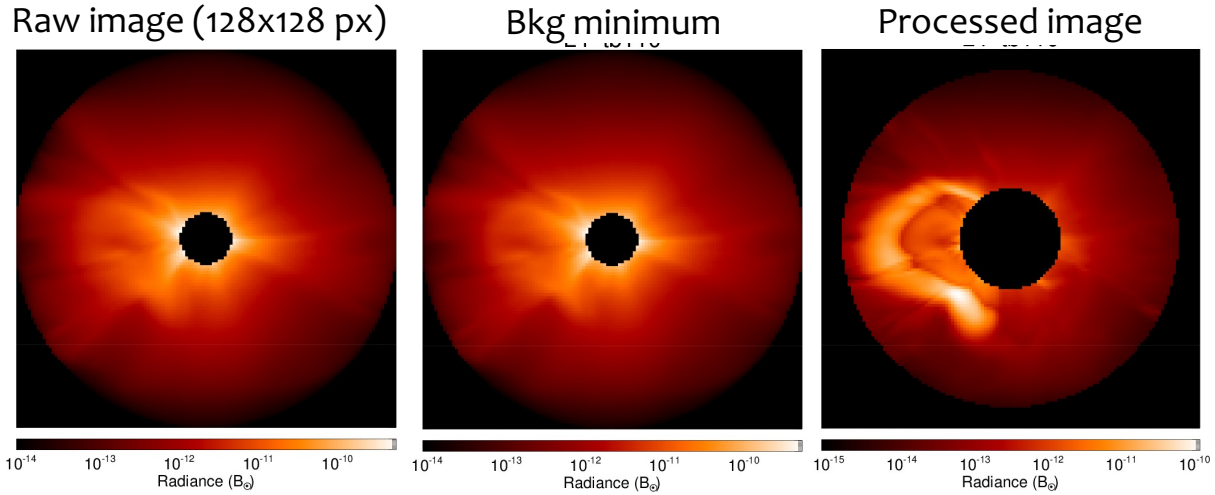
Figures: Davila [1994]







- Tomography in general: Inversion problem
- By defining a grid over the heliosphere (or the specific FOV of an instrument), the LOS integral can be approximated as a sum
- Each spacecraft measures different intensities based on the angle at which it observes structure
- These are used to constrain density in each grid cell
- It is expected that the multiple-spacecraft method would require 4+ vantage points to permit CME reconstructions



Discrete tomography pipeline

Solving inverse equation **y = H.x**

- **y** is an array containing data
- **x** is unknown density distribution over grid
- **H** is a physical operator relating **y** to **x**

(1) Process images to reveal CME structure
(2) Re-sample data over a grid
(3) Calculate **H**
(4) Solve for **x**

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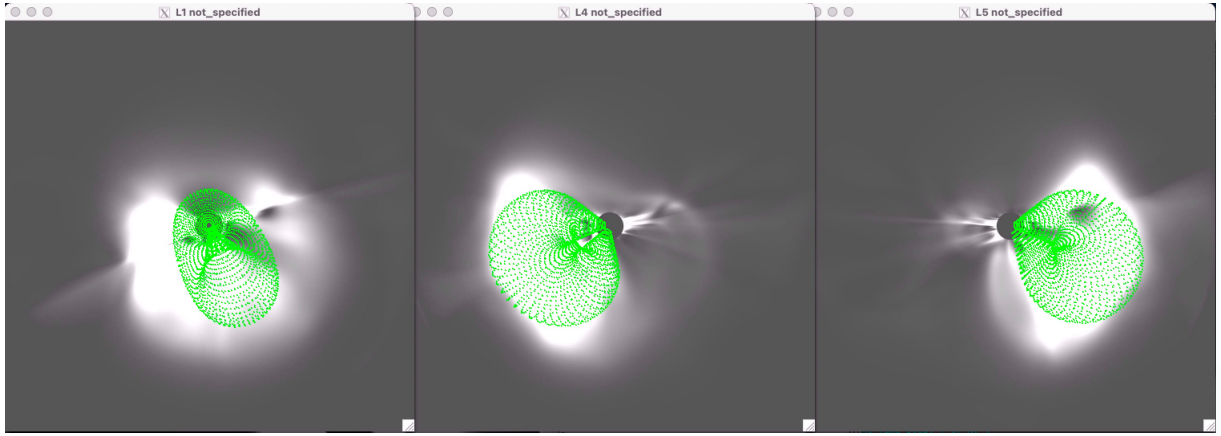
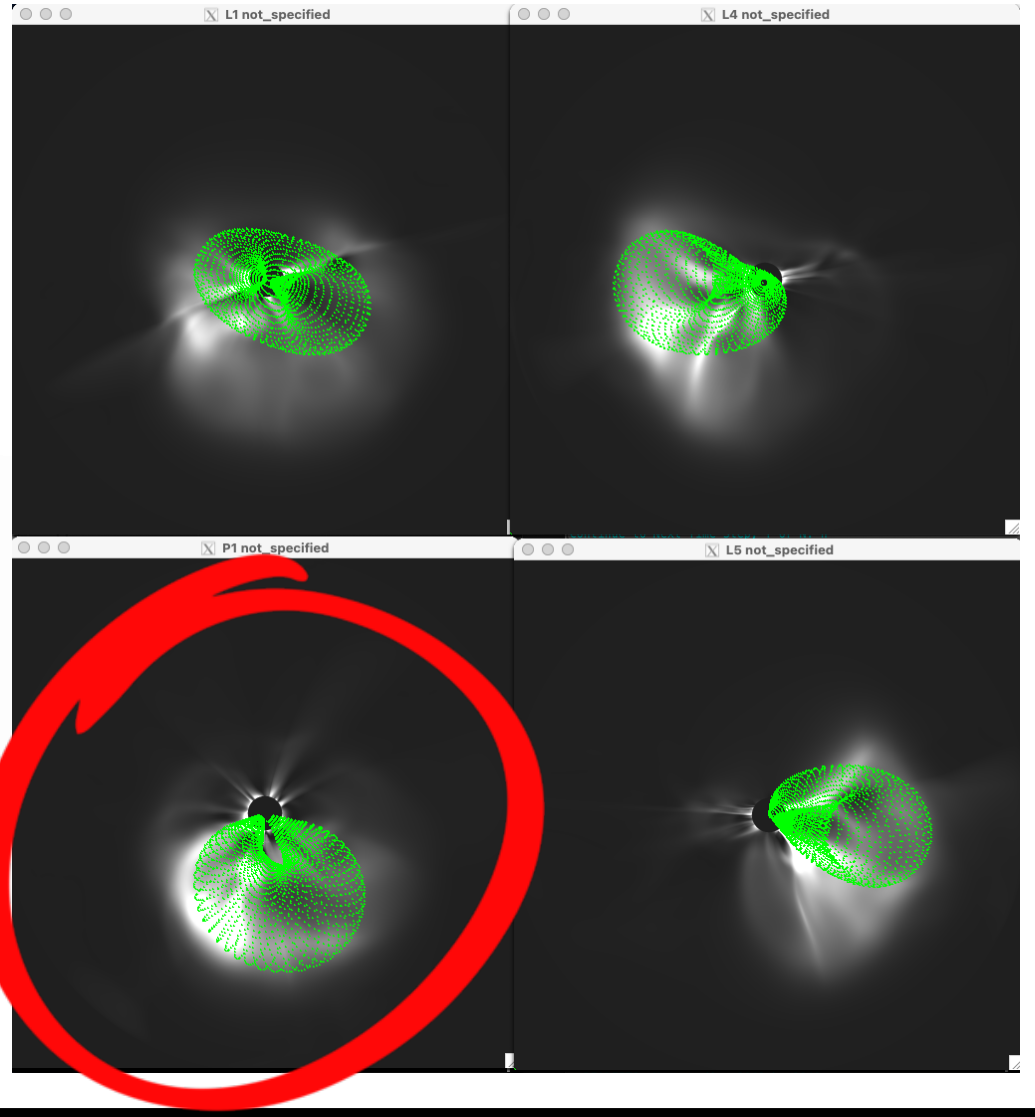
First of All: How Do These CMEs & Observers Do With Forward-Modelling?

3 observers: L1, L4, L5



…adding the polar view:



- First impressions: We have found that 3 vs 6 s/c on the ring does not make much of a difference in fitting, but adding the polar view to the 3 Ls does
- Btw: CME shape not very GCS-friendly!

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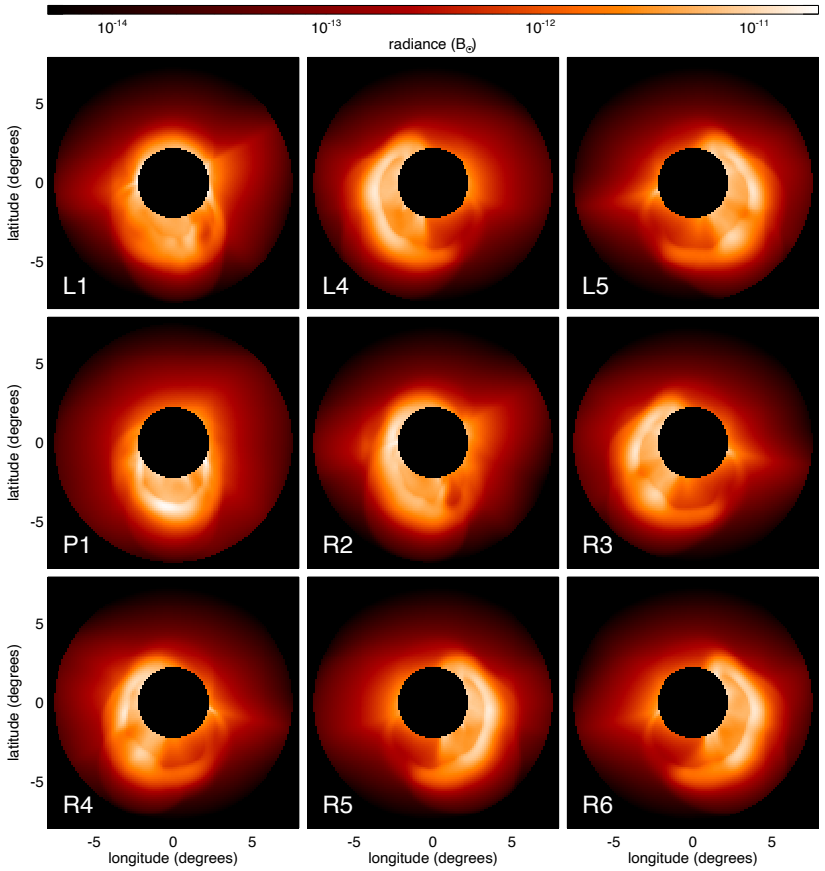
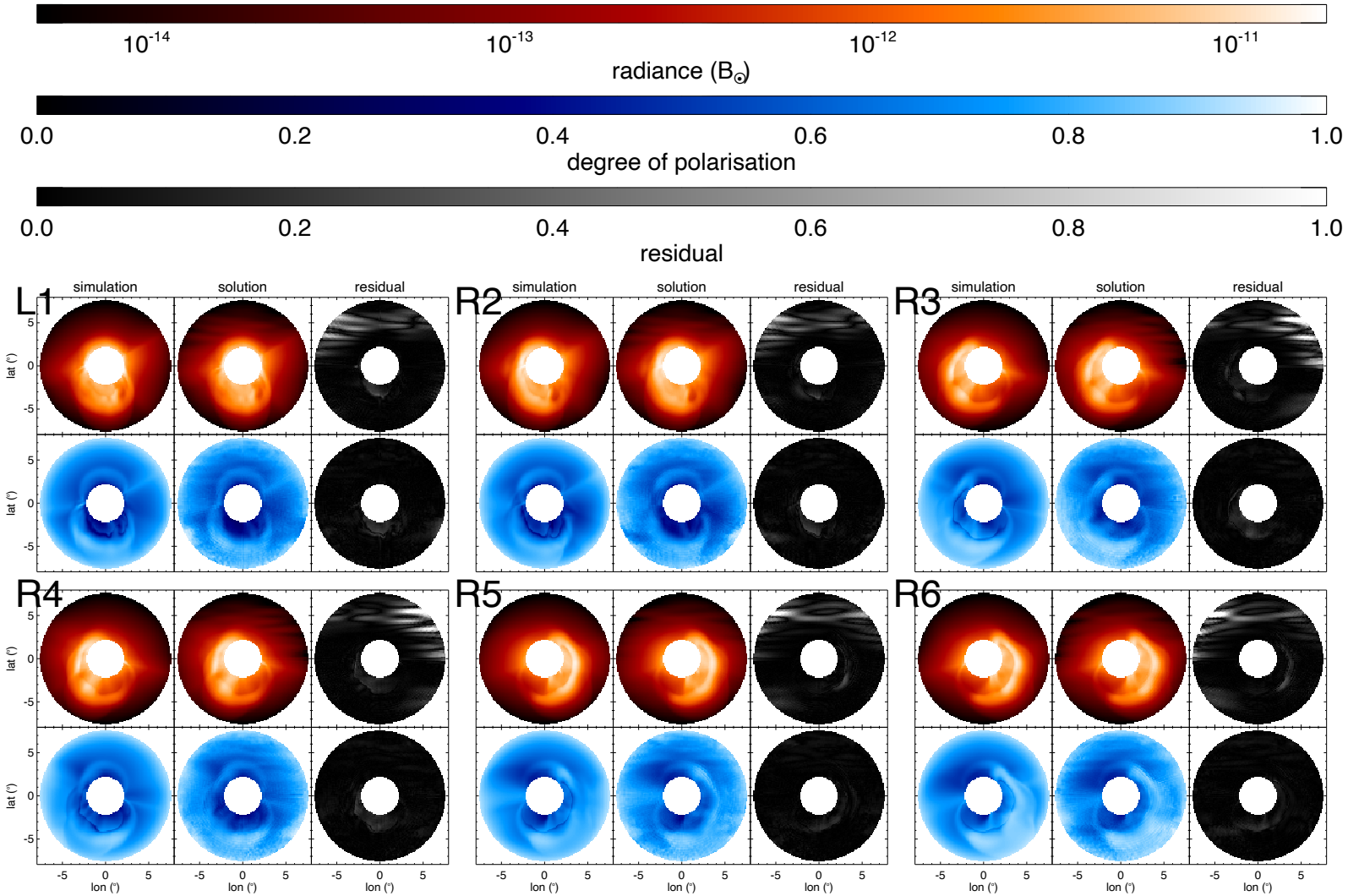
Preliminary Results With Discrete Tomography: Simulation vs Inversion

Comparing CORHEL imagery of the CME with tomography-reconstructed images from the same views



CME2 (medium) rebinned to 128x128



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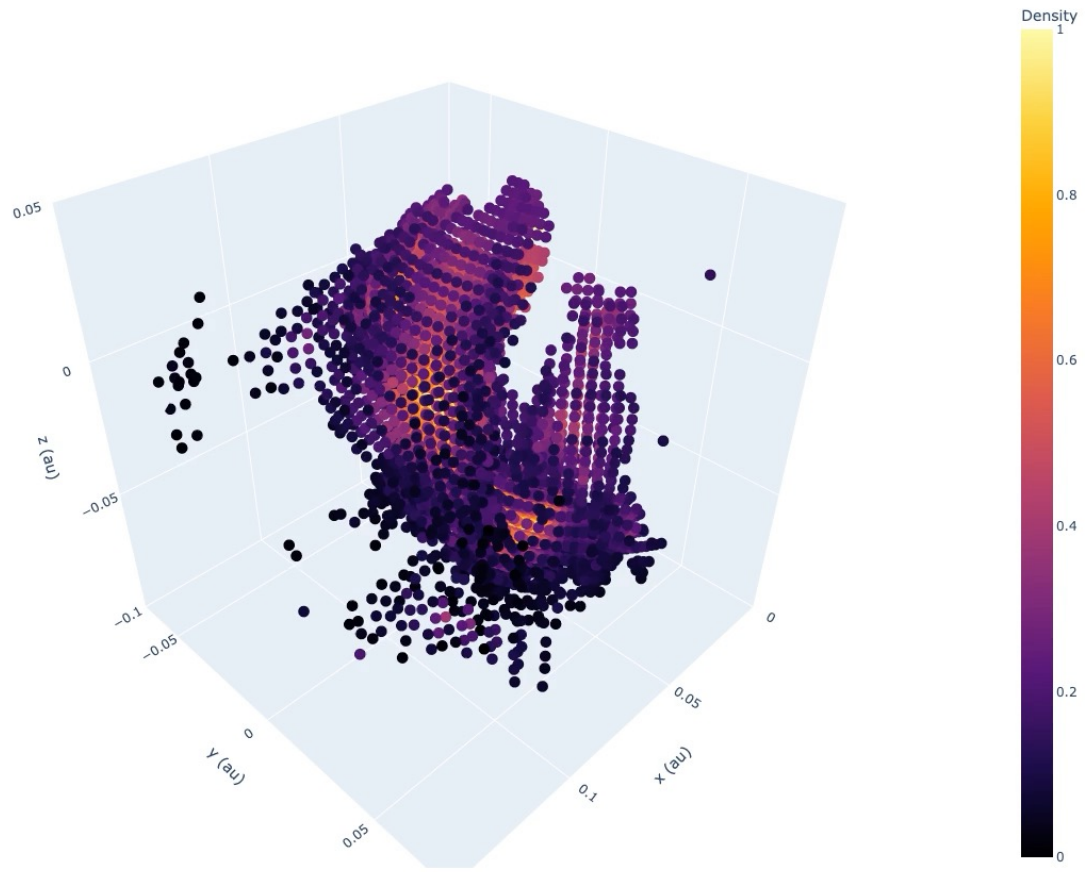
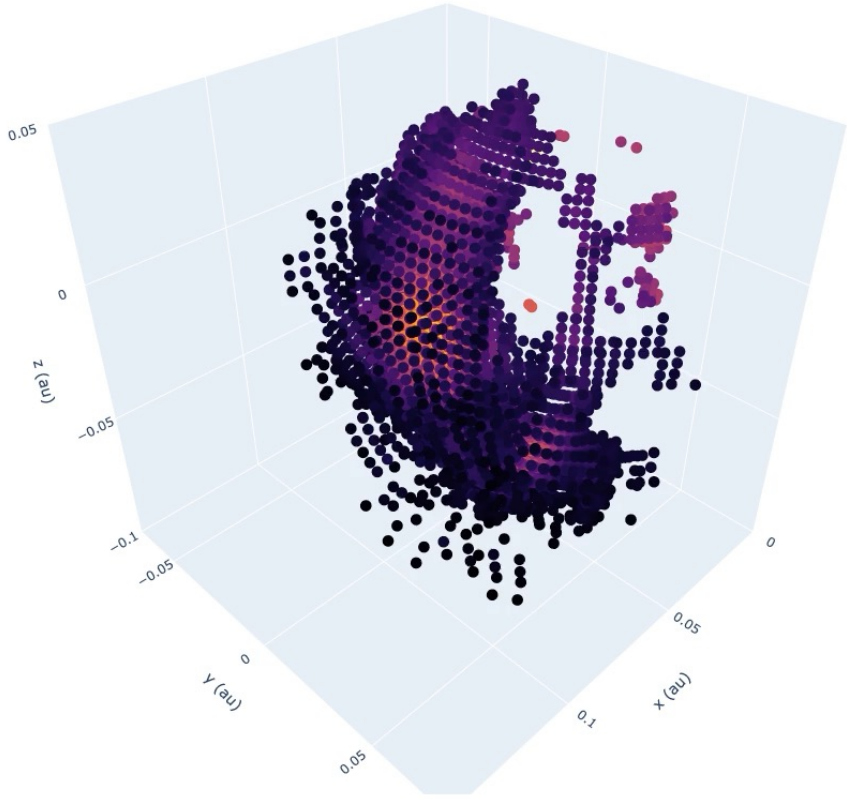
Preliminary Results With Discrete Tomography: Effect of the Number of s/c

tb, 3 spacecraft



pb, 3 spacecraft



The number of s/c employed for the inversion has a big effect on the reconstructed 3D structure and on the “noise” level

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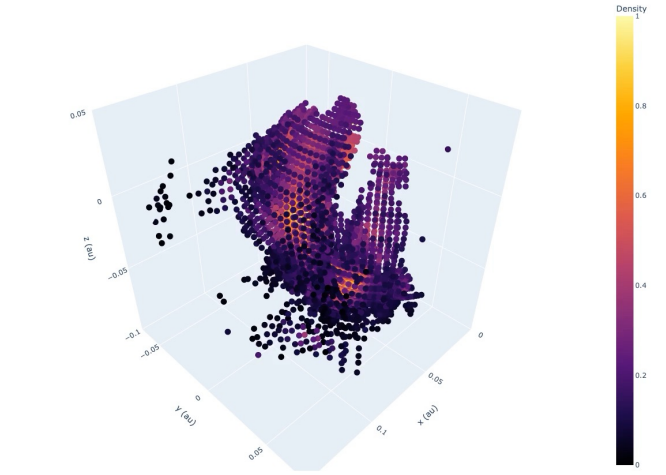
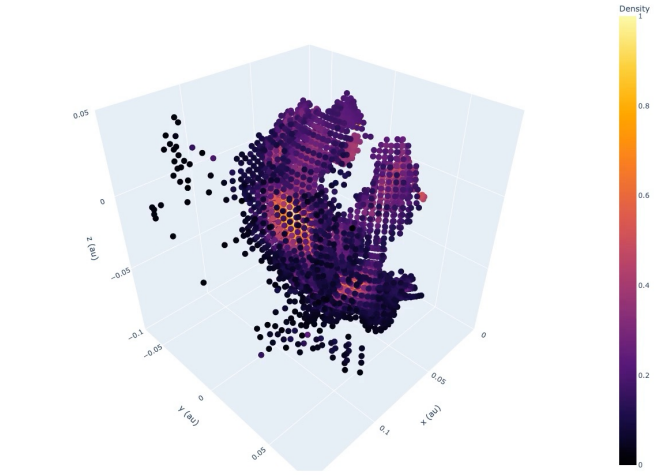
Preliminary Results With Discrete Tomography: Total vs Polarised Brightness

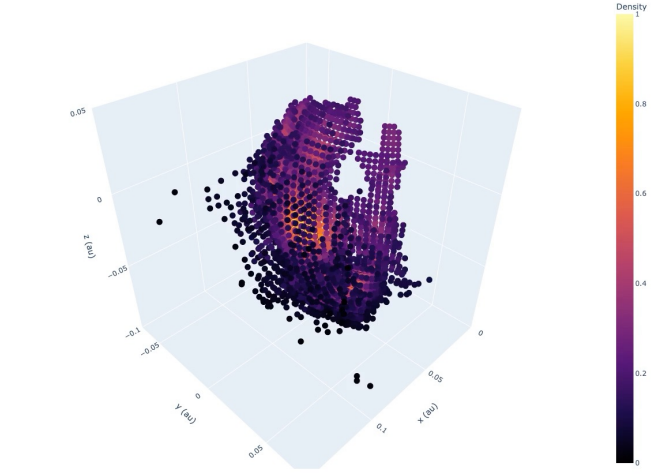
tb, 3 spacecraft



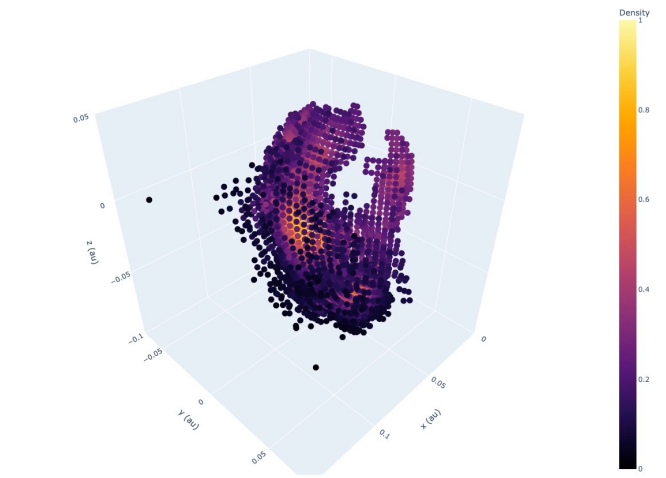
tb, 4 spacecraft



tb, 6 spacecraft



tb, 7 spacecraft



Employing total versus polarised brightness images seems to have a larger effect with decreasing number of spacecraft, with polarised brightness giving cleaner results

Important implications in real life, since we are unlikely to get 6,7,…10+ imagers out there in the near future 😅

Future instrumentation should carry polarisers to enhance our inverse reconstruction capabilities (good job PUNCH!)

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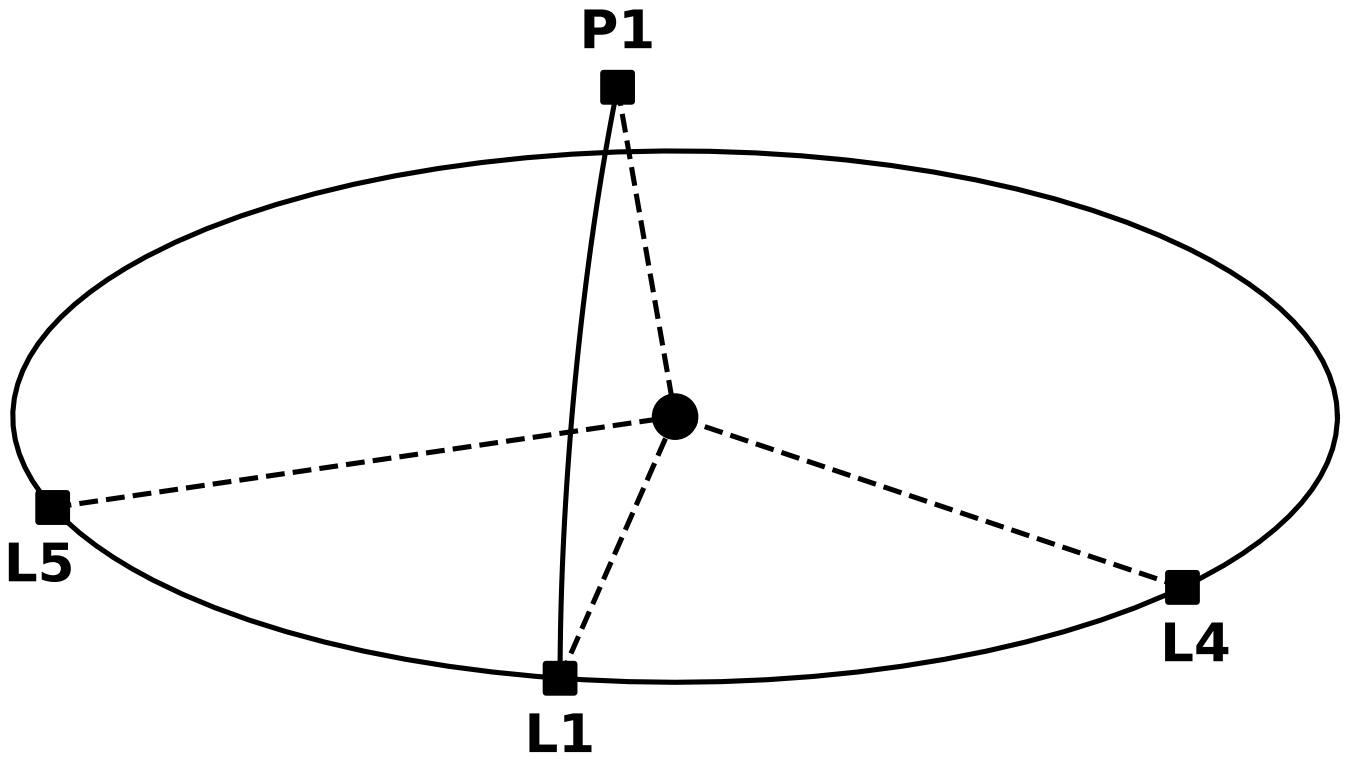
Sneak Peek: A Fake-HI Extravaganza



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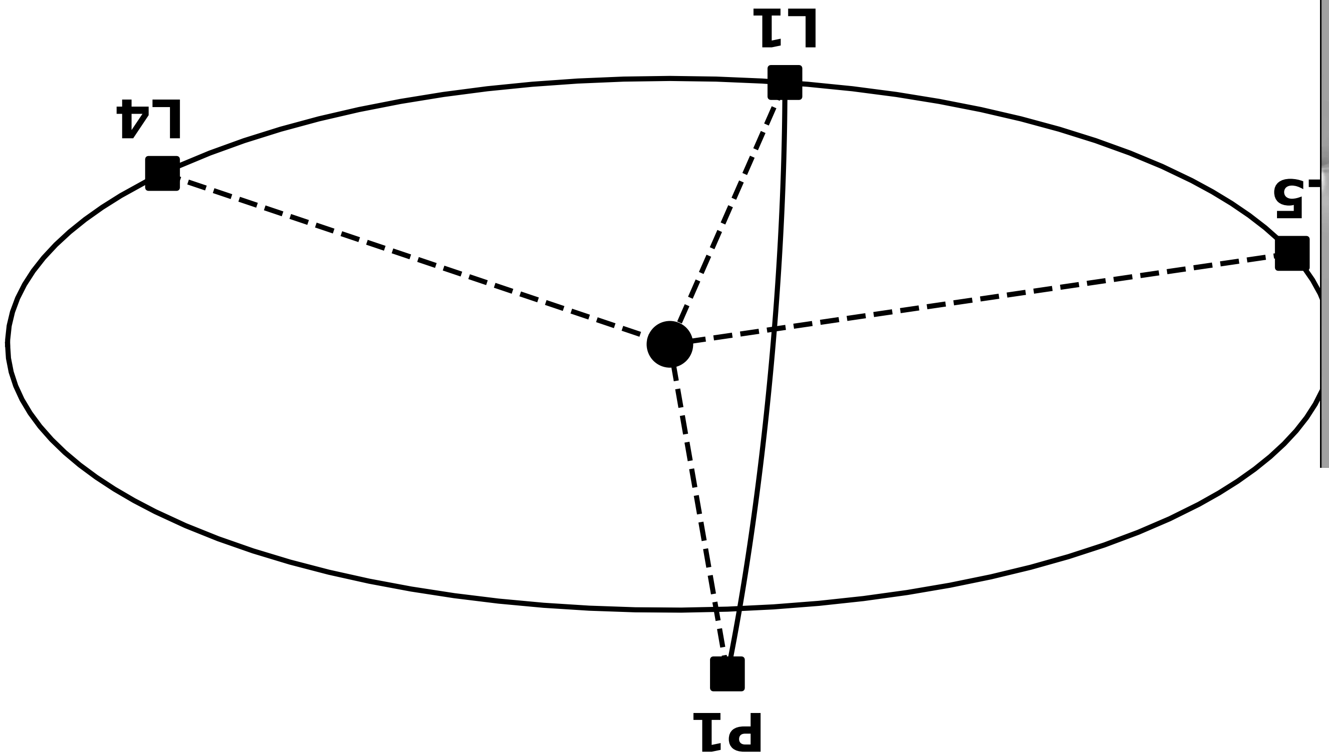

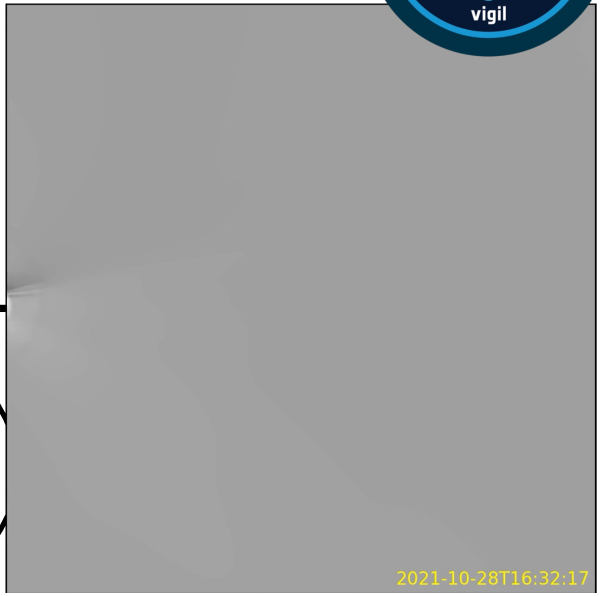

CME1
(slow)

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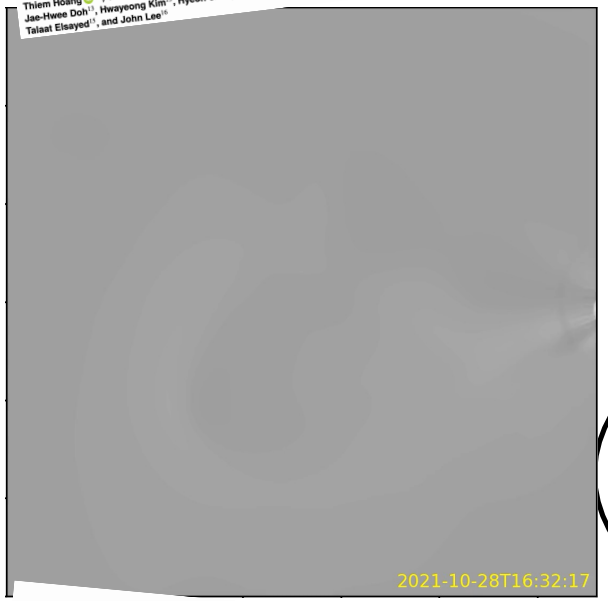
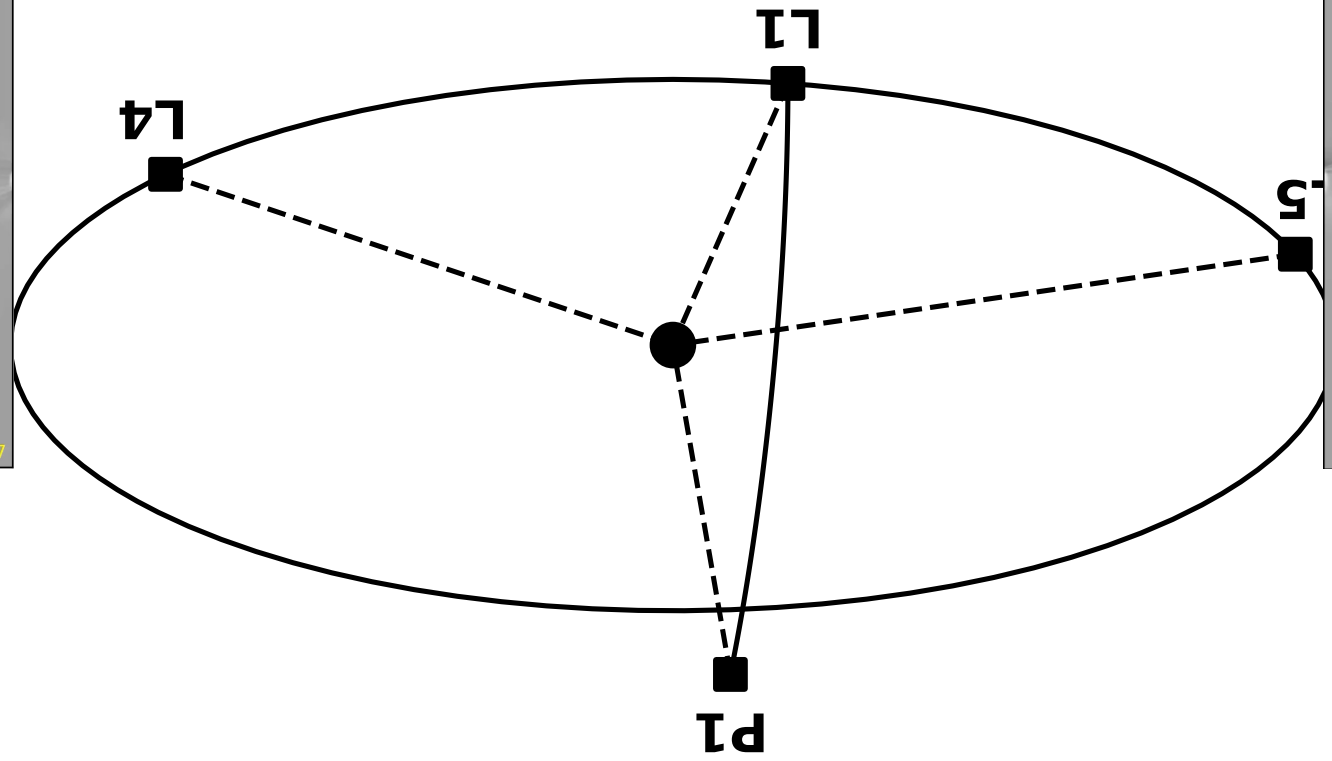
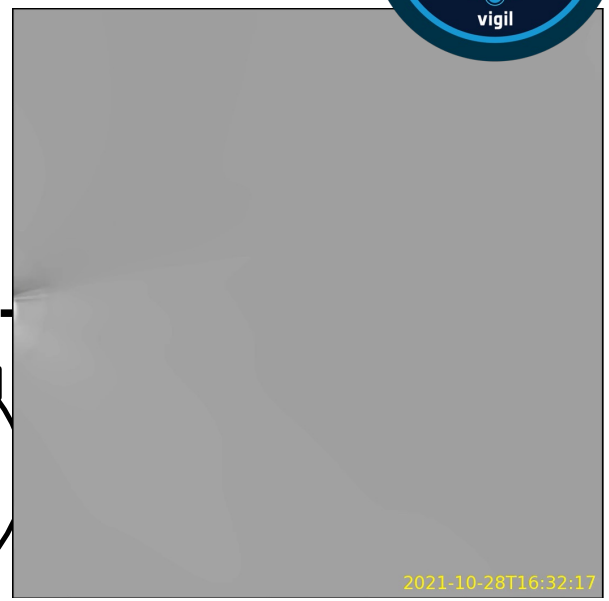
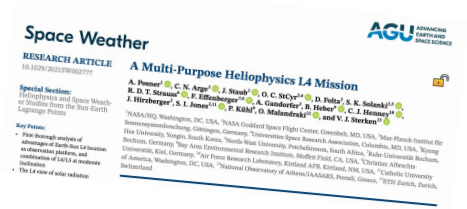
Kyung-Suk Cho[1,2*], Junga Hwang[1,2], Jeong-Yeol Han[1,2], Seong-Hwan Choi[1], Sung-Hong Park[1], Eun-Kyung Lim[1], Rok-Soon Kim[1], Jungjoon Seough[1,2], Jong-Dae Sohn[1], Donguk Song[1,3], Jaeung Lee[4], Kwangsun Ryu[3], Jongho Seon[3], Ji-Hye Baek[1], Jaejin Lee[1], Jinseung Lee[4], Kwangsun Ryu[3], Jongho Seon[3], Ho Jin[3,4], Sung-Jun Ye[1], Yong-Jae Moon[3], Dae-Young Lee[3], Peter H. Yoon[10], Thiem Hoang[1,2], Veerle Sterken[11], Bhuwan Joshi[12], Chang-Han Lee[13], Jongjin Jang[13], Jae-Hwee Doh[13], Hwayeong Kim[13], Hyeon-Jeong Park[13], Natchimuthuk Gopalswamy[14], Talaat Elsayed[15], and John Lee[16]








Space Weather
RESEARCH ARTICLE
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AGU ADVANCING EARTH AND SPACE SCIENCE

A Multi-Purpose Heliophysics L4 Mission

A. Posner[1], C. N. Arge[2], J. Stough[3], O. C. St.Cyr[3,4], D. Foltz[5], S. K. Solanki[6,7], R. D. T. Strauss[8], F. Effenberger[9,10], A. Gandorfer[7], B. Heber[11], C. J. Henney[12], J. Hirzberger[7], S. J. Jones[13], P. Kühl[6], O. Malandraki[14], and V. J. Sterken[15]

Special Sections:
Heliophysics and Space Weather Studies from the Sun-Earth Lagrange Points

Key Points:
- First thorough analysis of advantages of Earth-Sun L4 location as observation platform, and combination of L4/L5 at moderate inclination
- The L4 view of solar radiation

[1]NASA/HQ, Washington, DC, USA, [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [3]Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, [4]Universities Space Research Association, Columbia, MD, USA, [5]Kyung Hee University, Yongin, South Korea, [6]North-West University, Potchefstroom, South Africa, [7]Ruhr-Universität Bochum, Bochum, Germany, [8]Bay Area Environmental Research Institute, Moffett Field, CA, USA, [9]Christian Albrechts-Universität, Kiel, Germany, [10]Air Force Research Laboratory, Kirtland AFB, Kirtland, NM, USA, [11]Catholic University of America, Washington, DC, USA, [12]National Observatory of Athens/IAASARS, Penteli, Greece, [13]ETH Zurich, Zurich, Switzerland

CME1
(slow)

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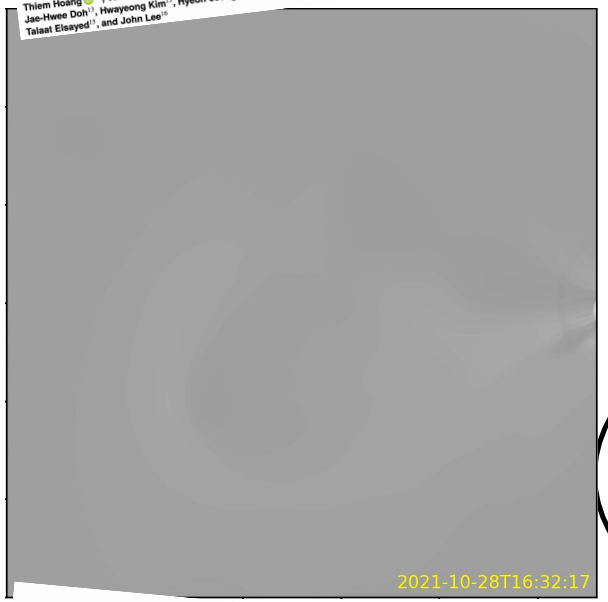

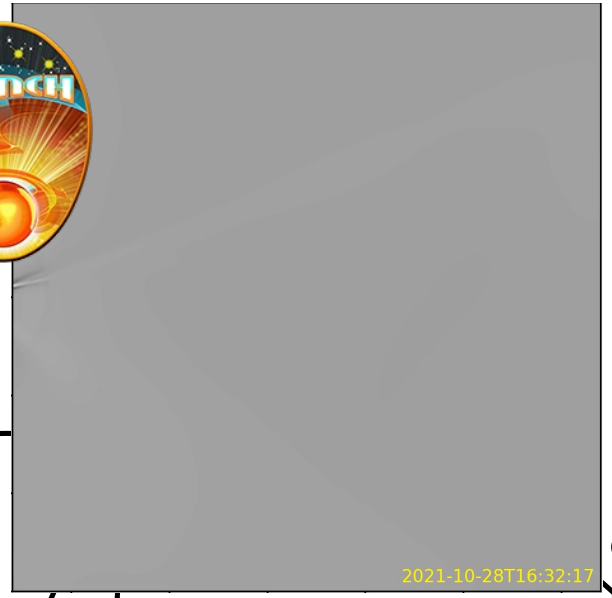

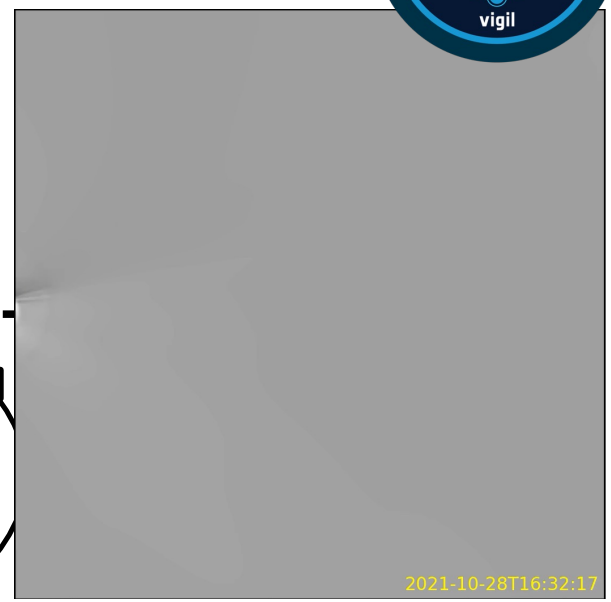

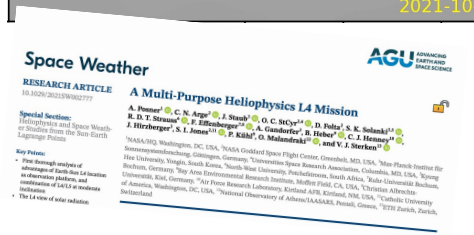
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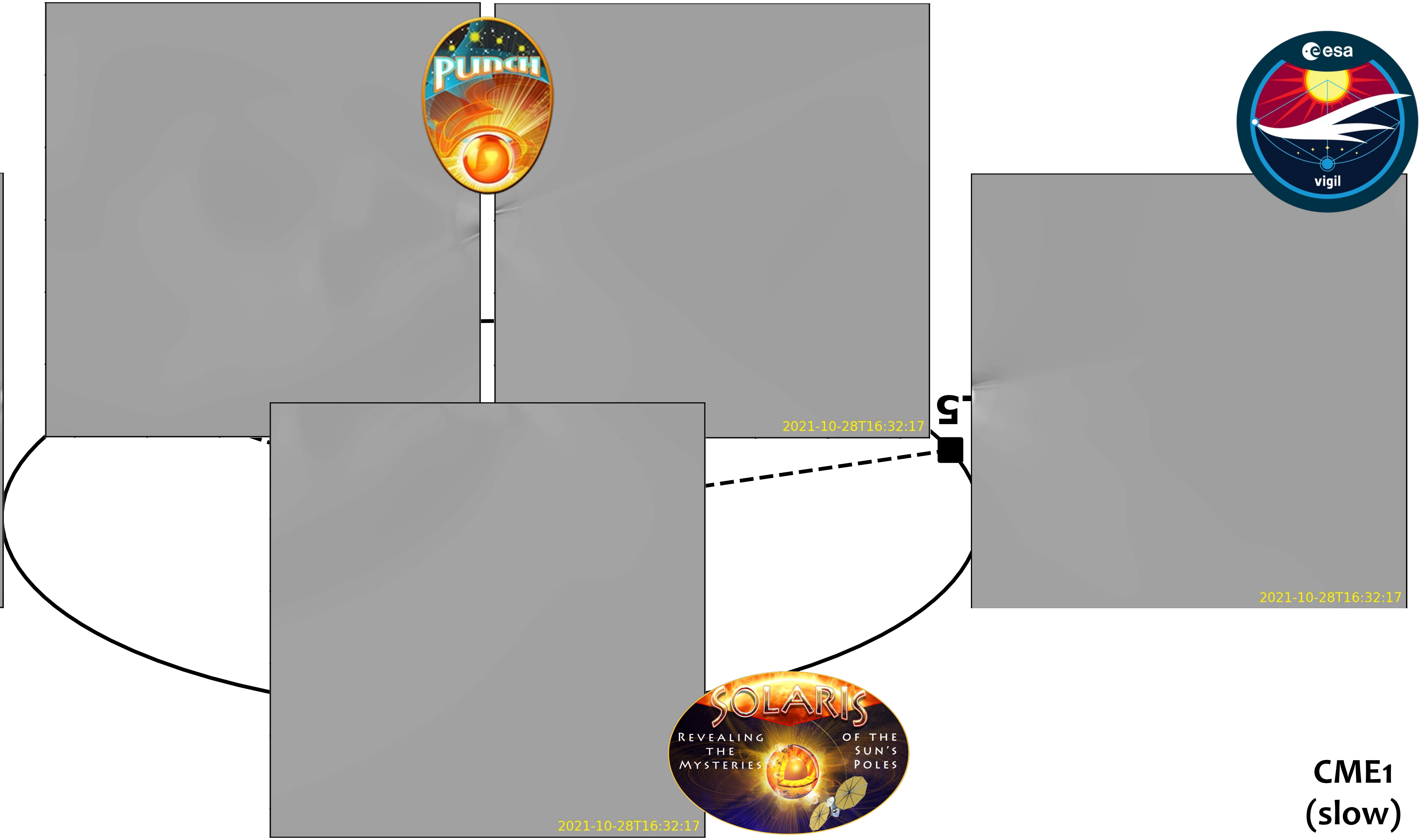
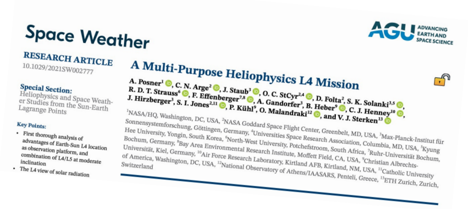
Opening New Horizons with the L4 Mission: Vision and Plan

Kyung-Suk Cho[1,2,*], Junga Hwang[1,2], Jeong-Yeol Han[1,2], Seong-Hwan Choi[1], Sung-Hong Park[1], Eun-Kyung Lim[1], Rok-Soon Kim[1], Jungjoon Seough[1], Jong-Dae Sohn[1], Donguk Song[1,3], Jae-Young Kwak[1,2], Yukinaga Miyashita[1,2], Ji-Hye Baek[1], Jaejin Lee[1], Jinsung Lee[4], Kwangsun Ryu[5], Jongho Seon[6], Ho Jin[6], Sung-Jun Ye[7], Yong-Jae Moon[8], Dae-Young Lee[9], Peter H. Yoon[10], Thiem Hoang[1,2], Veerle Sterken[11], Bhuwan Joshi[12], Chang-Han Lee[13], Jongjin Jang[13], Jae-Hwee Doh[13], Hwayeong Kim[13], Hyeon-Jeong Park[13], Natchimuthuk Gopalswamy[14], Talaat Elsayed[15], and John Lee[16]



Space Weather
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Special Section:
Heliophysics and Space Weather Studies from the Sun-Earth Lagrange Points

Key Points:
- First thorough analysis of advantages of Earth-Sun L4 location as observation platform, and combination of L4/L5 at moderate inclination
- The L4 view of solar radiation

A Multi-Purpose Heliophysics L4 Mission

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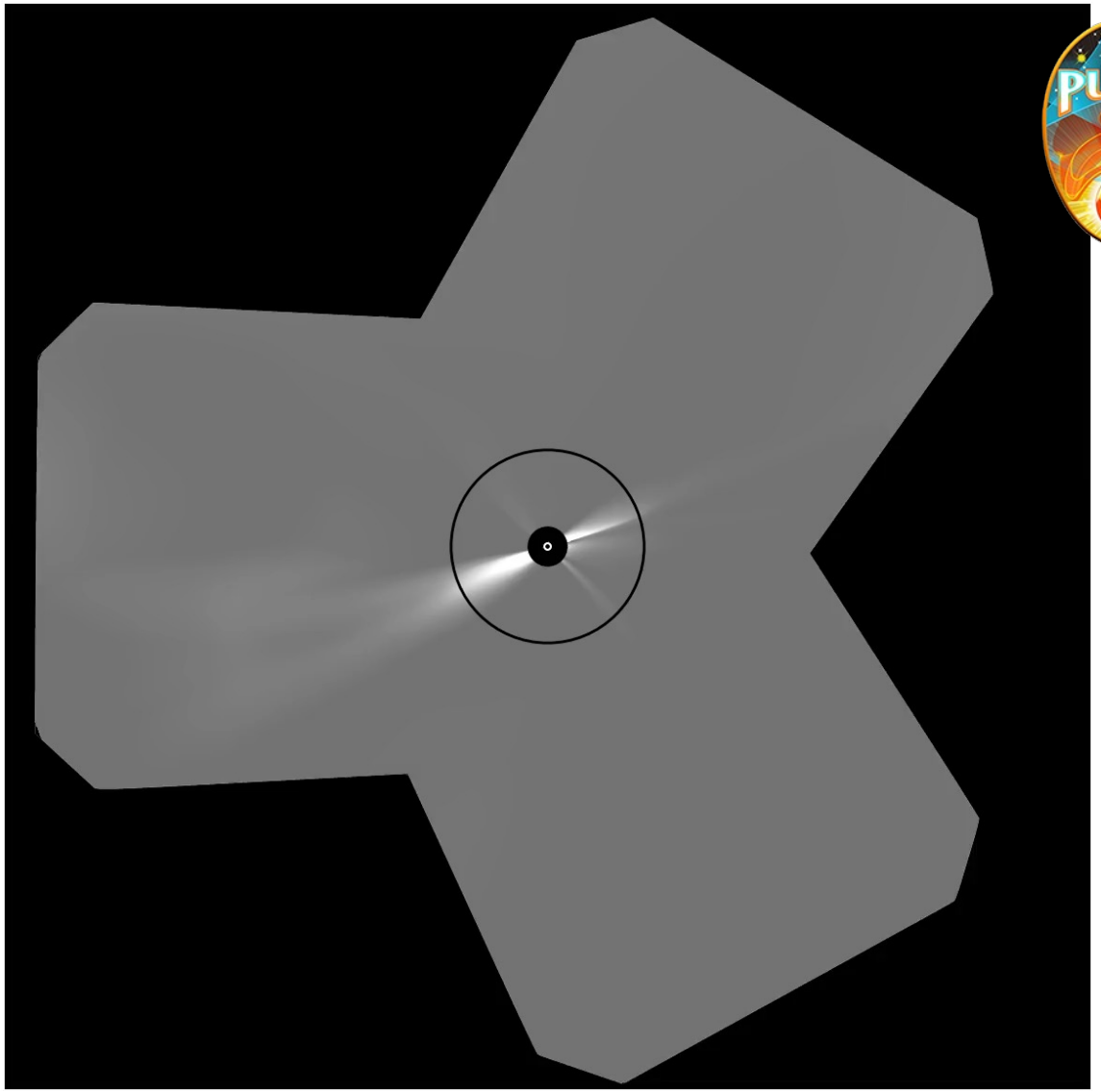
CME1
(slow)

Future Team Plans & Bonus “Fake-PUNCH” Movie

Future plans include:

- Tomography analysis using the fake-HI fields of view
- Creation of a possible realistic future scenario: Using ephemeris data for some time in 2025–2026, generate (and analyse) synthetic imagery for STEREO-A, Parker, SolO, & PUNCH



View from PUNCH of a halo CME!!

The “all-around” view afforded by PUNCH will allow us to observe CMEs in the heliosphere in a whole new way!

For context:

- Frame Δt: 1 hour
- Movie time: ~4 days

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Thank you for your attention!

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