



1° Conferenza
Italiana Plasmi



**Fabio Reale, University of Palermo&INAF/OAPa, on behalf of
the PI Bart De Pontieu and the MUSE team:**

Lockheed Martin Solar & Astrophysics Laboratory (LMSAL)

Harvard Smithsonian Astrophysical Observatory (SAO)

Goddard Space Flight Center (GSFC)

Montana State University (MSU)

UC Berkeley Space Sciences Laboratory (UCB)

Roseland Center for Solar Physics, University of Oslo (RoCS)

Science Co-Is: High Altitude Observatory, Naval Research Laboratory, NASA-MSFC, National Solar Observatory, University of Northumbria, Stockholm University, University of Glasgow, St. Andrews University, INAF/OACT

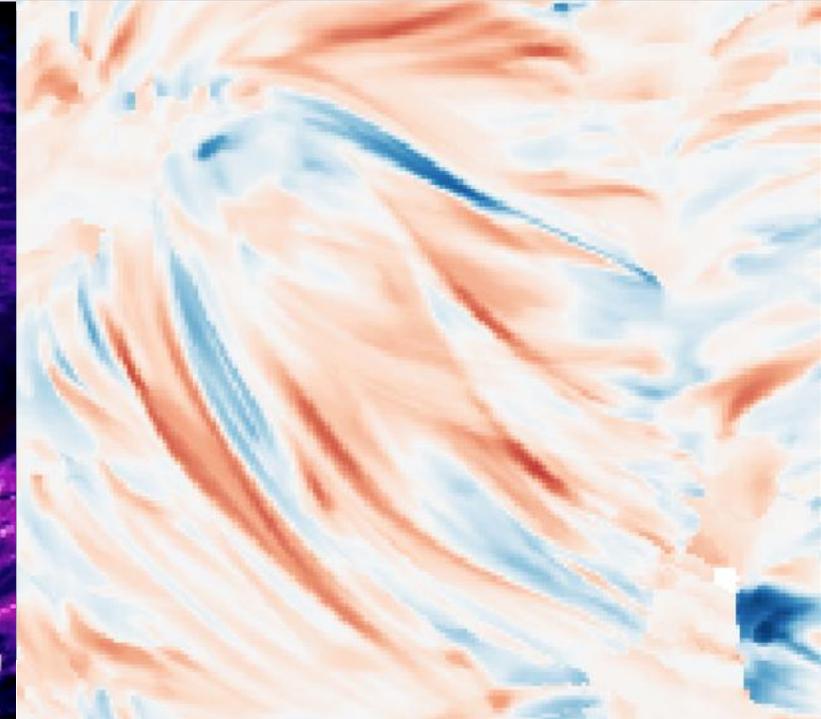
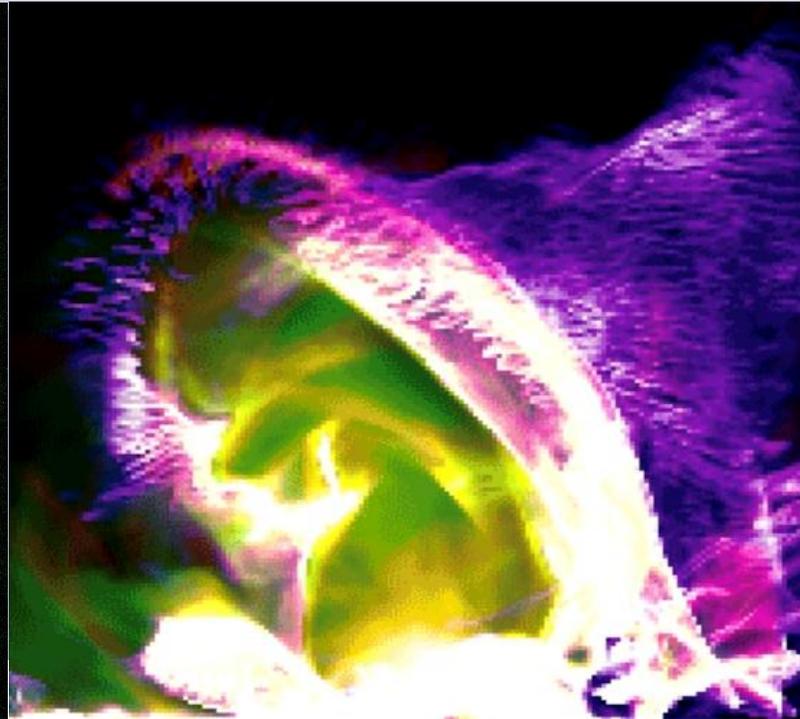
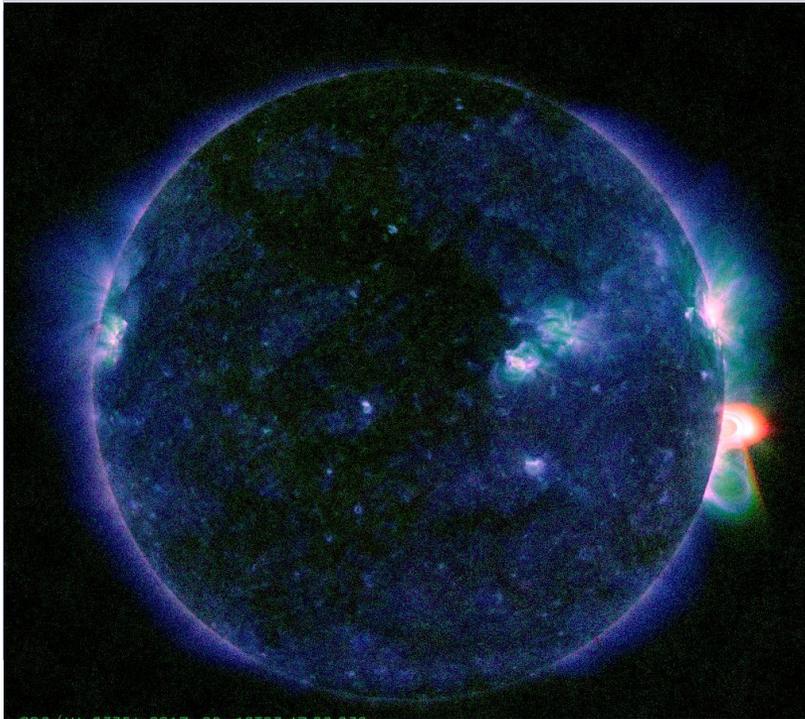
International Partners: Norwegian Space Agency (NOSA), Italian Space Agency (ASI), German Aerospace Center (DLR), Max Planck Institute for Solar System Physics



1. Determine which mechanism(s) heat the solar corona and drive the solar wind

2. Understand the origin and evolution of the unstable solar atmosphere

3. Investigate fundamental physical **plasma** processes





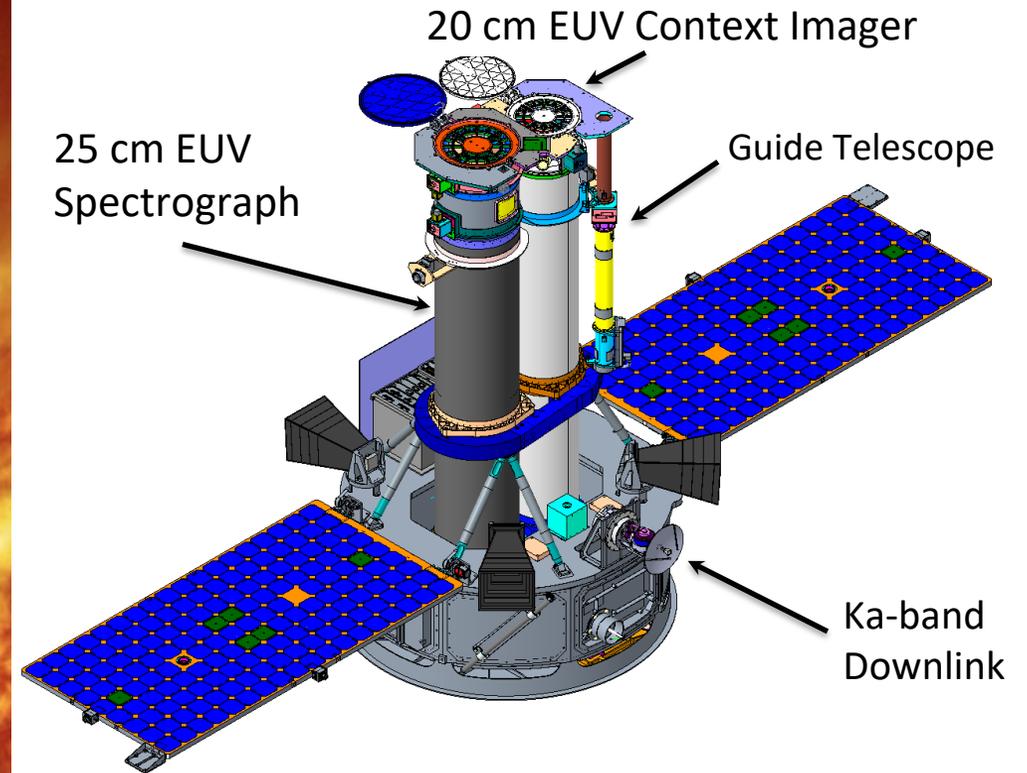
Clues of MUSE

What?

- NASA Medium-class Explorer (MIDEX): launch no earlier than 2027
- EUV spectrograph & context imager to measure coronal **plasma** properties at 0.5" scales **>35x faster** through multi-slit design
- For the first time freezes coronal evolution under slits, resolving multi-scale coupling in solar atmosphere
- MUSE addresses its science objectives by itself, synergies with Solar-C/EUVST & DKIST (Next Generation Solar Physics Mission (NGSPM) constellation)

More information can be found in these papers

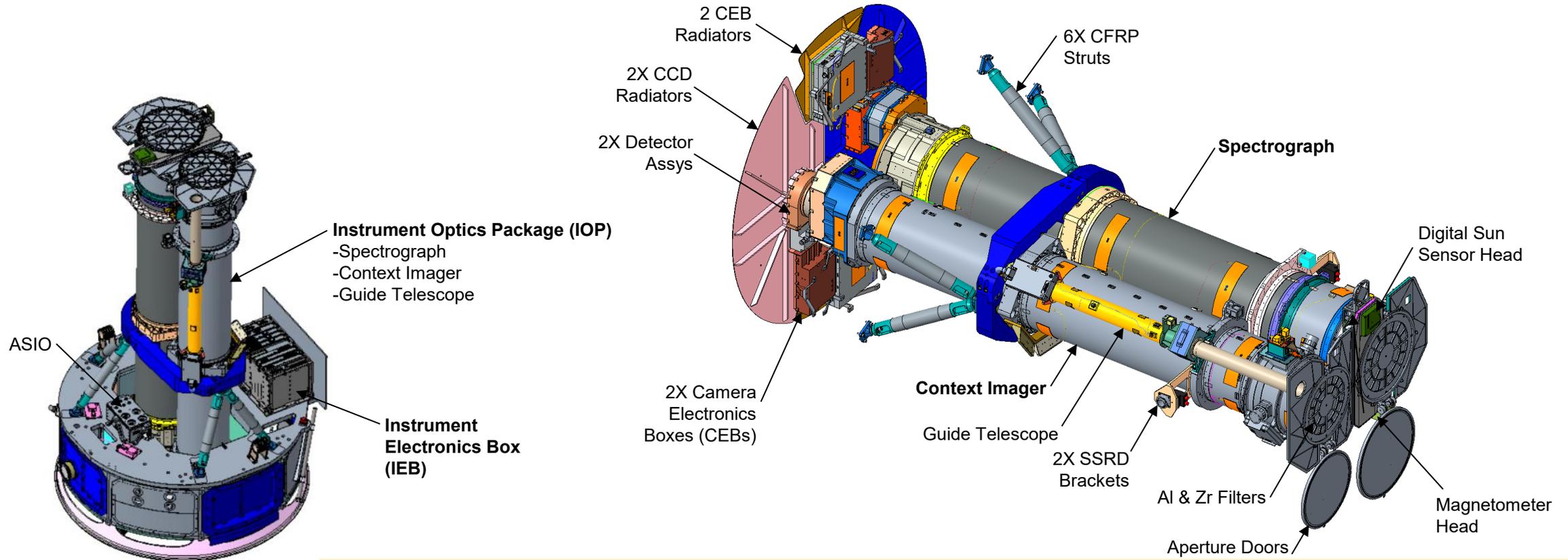
- De Pontieu et al., 2022, ApJ, 926, 52D
- Cheung et al., 2022, ApJ, 926, 53C
- De Pontieu et al., 2020, ApJ, 888, 3D
- Cheung et al., 2019, ApJ, 882, 13C



IRIS-like spacecraft in 640 km sun-synchronous orbit

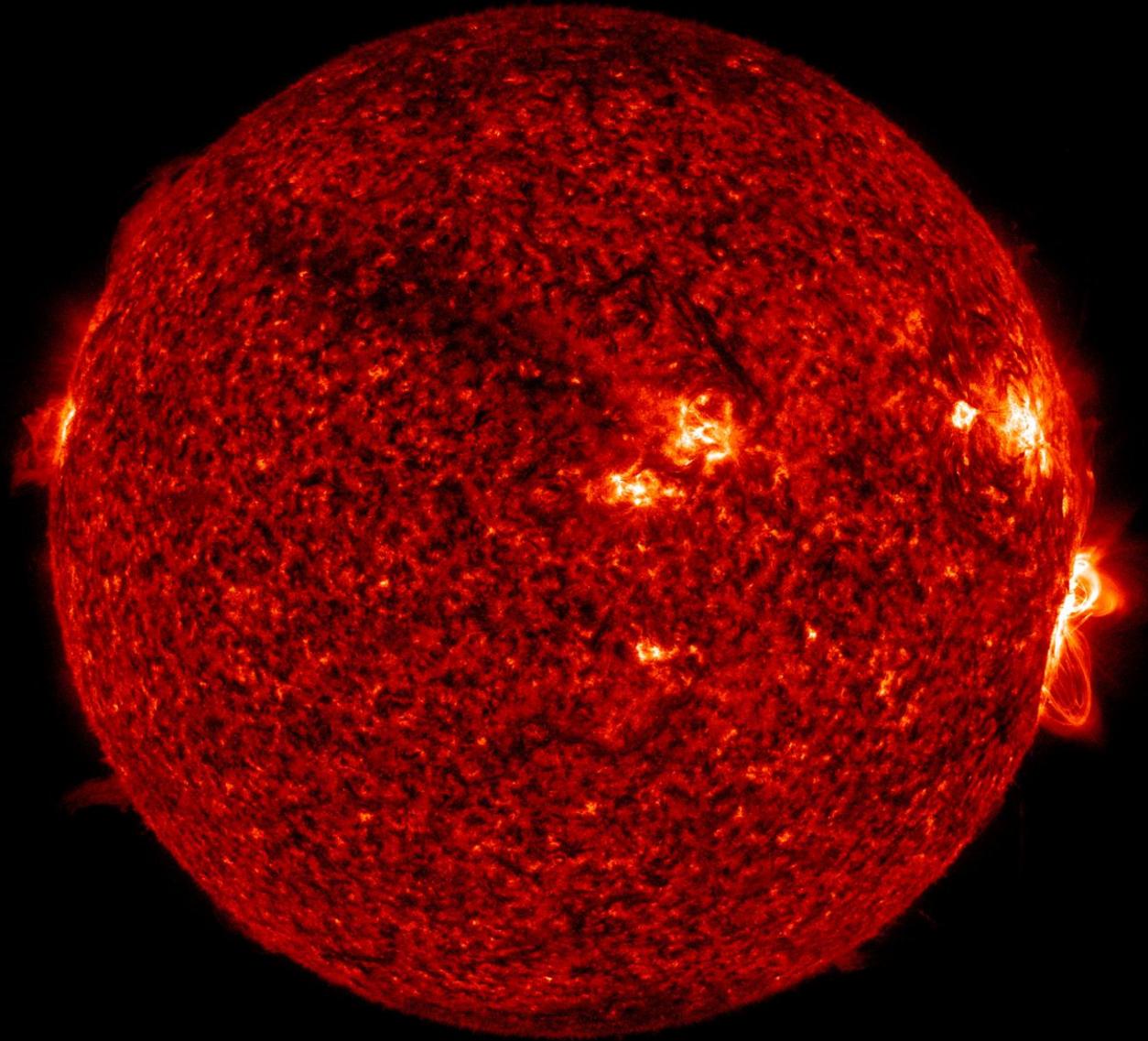
How?

- MUSE is a single spacecraft in sun-synchronous polar LEO
- Two EUV telescopes, feeding a multi-slit spectrograph and a context imager, guide telescope for instrument stabilization

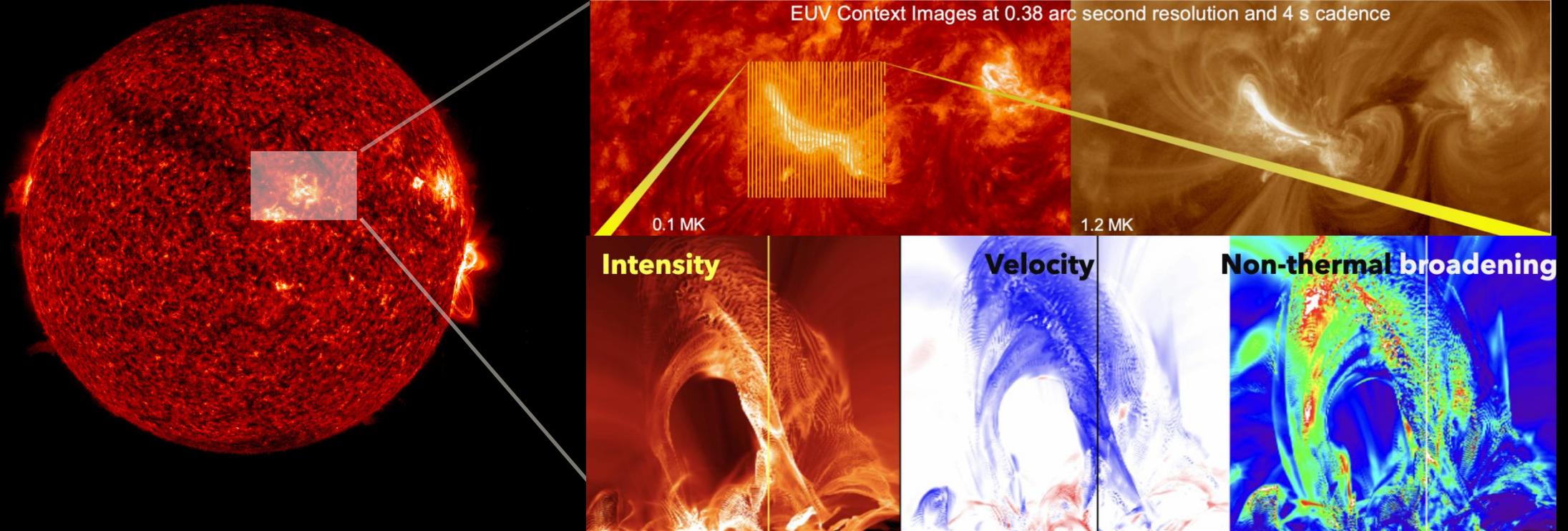


MUSE Observatory
(Solar Arrays not shown)

- **Spectrograph (SG)**
 - 25 cm aperture, 3 channel design (108, 171, 284Å), common grating substrate
 - multiple (35) slit design, **0.44 arcsec resolution, slit width: 0.4", FOV: 151"x175"**
 - **Centroiding resolution <5 km/s**
- **Context Imager (CI)**
 - 20 cm aperture, dual bandpass (195, 304Å), **0.38 arcsec resolution, FOV: 585"x292"**
 - Modified SDO-AIA design w/lessons learned from IRIS & Hi-C

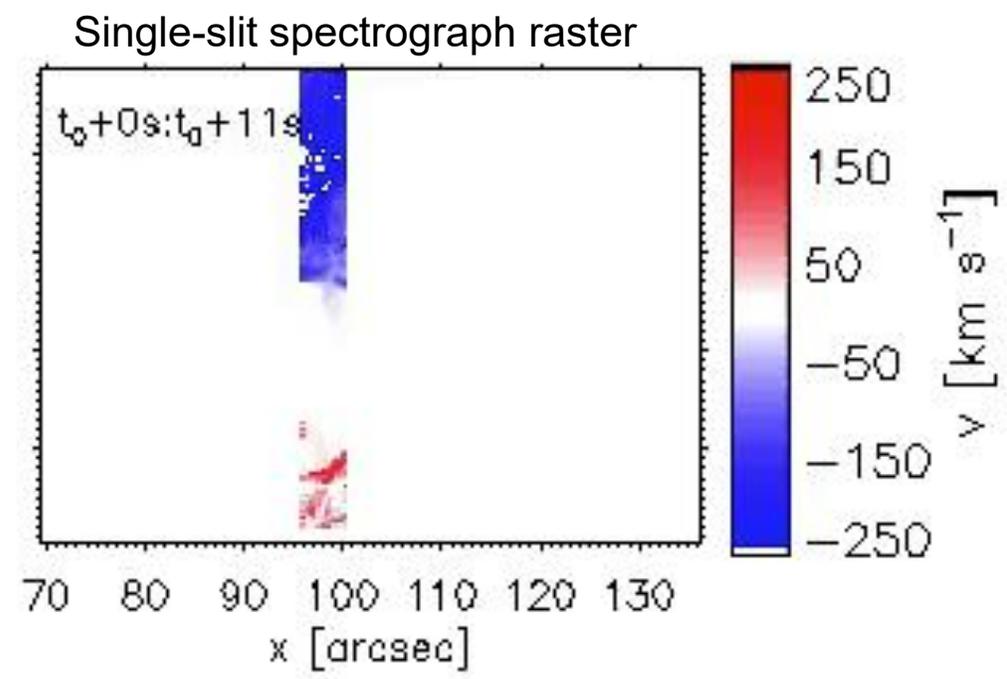


Breakthrough in Resolution (x4) & Cadence (x35-100)



- MUSE's high throughput, multi-slit approach and sensitivity to high temperatures are a major improvement over IRIS and SDO/AIA.
- For the first time captures multi-scale physical processes from driving scales at 0.5" (350 km) to 9x Earth diameter, on short time scales (20s)
- Multi-slit spectrograph reveals process invisible to imagers:
 - intensity (temperature/density), velocity, linewidth to diagnose various physical processes like magnetic reconnection, flows, waves, heating

Why multislit imaging spectroscopy?



Breakthroughs in:

- cadence: 35-100x faster & larger FOV than current/planned spectrographs — **for the first time freezes “coronal evolution” under spectrograph slits**
- spatial resolution: 10x higher than AIA, 25x better than EIS or SOLO/SPICE

Italian contribution: ASI/INAF Agreement 2022-2025

D. Perrone, ASI

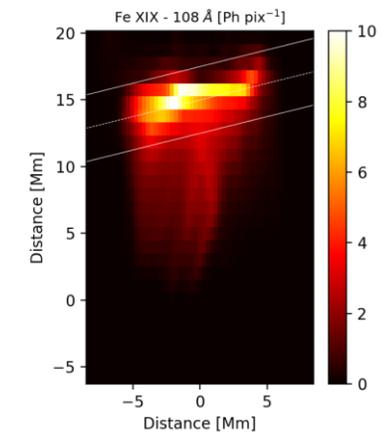
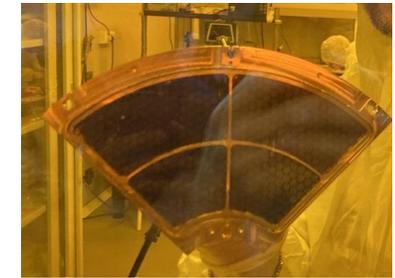


• Hardware:

- EUV Filters (M. Barbera, UniPa, INAF/OAPa)
- Mirrors (D. Spiga, INAF/OA Brera)
- Test coating (M. Pelizzo, CNR/IFN)

• Scientific support:

- UniPa (F. Reale) Co-I
- INAF/OACT (D. Spadaro) Co-I
- INAF/OACN (V. Andretta)
- UniCal (F. Malara)



MHD modeling of coronal loops

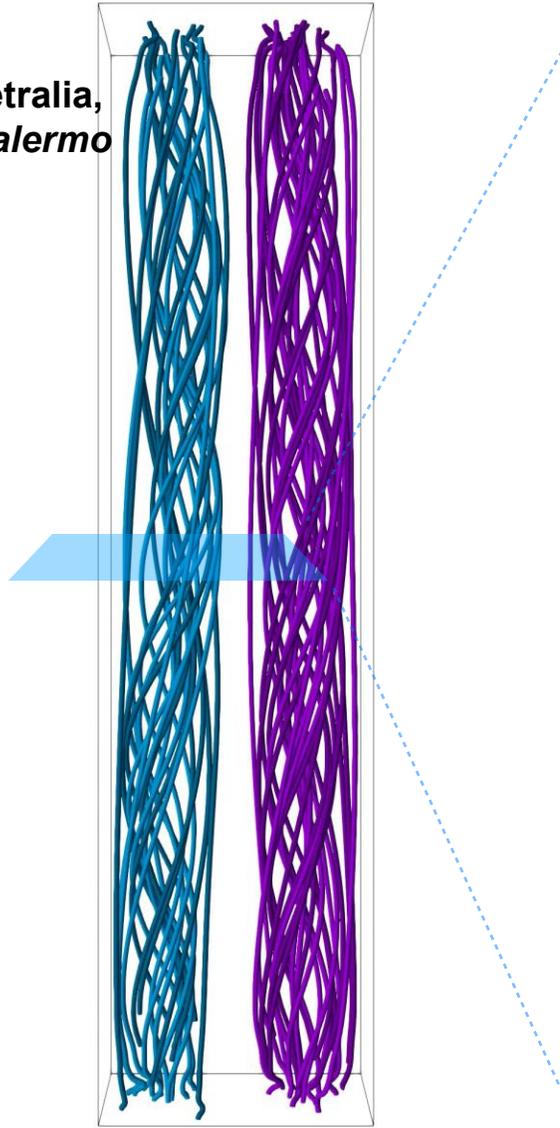
F. Reale, P. Pagano, G. Cozzo, F. Rappazzo, C. Argiroffi, A. Petralia,
University of Palermo & INAF/Osservatorio Astronomico di Palermo

Loop kink instability and MHD avalanches (Cozzo+ 2023, 2024, 2025a)

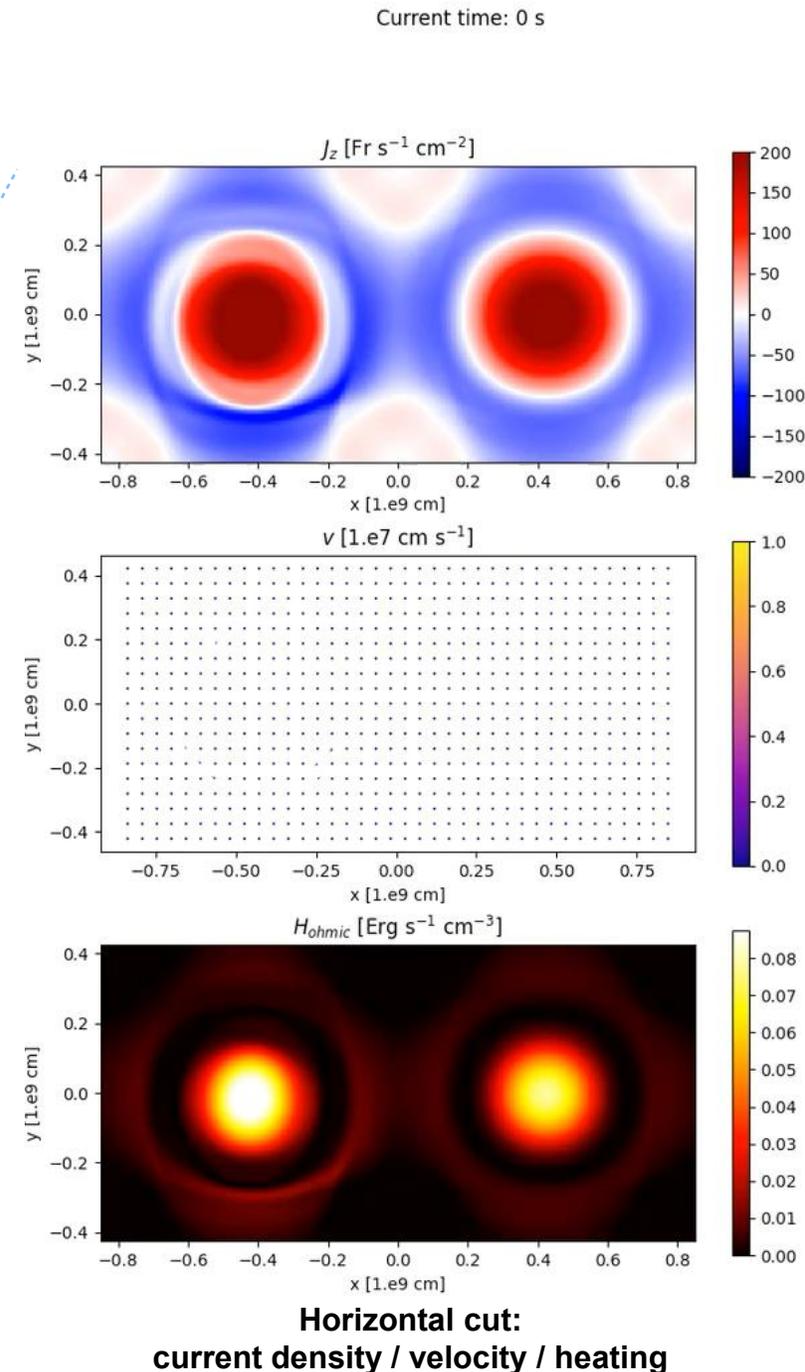
- Two nearby flux tubes are progressively twisted by footpoint rotation at different speed
- The faster becomes kink unstable and propagate to the other
- **Kink Instability** can trigger an MHD avalanche.



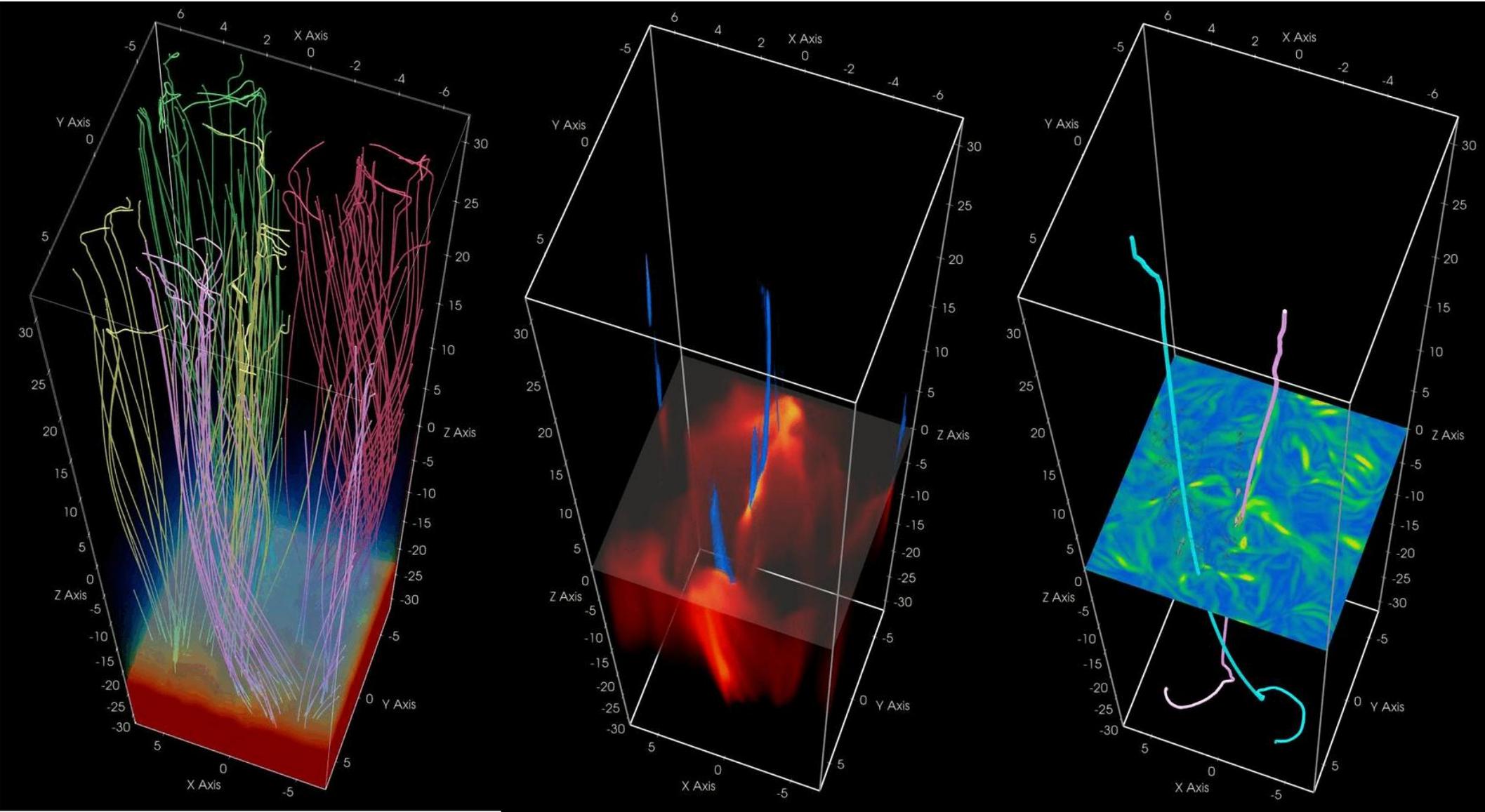
Unstable loop v.s.
 nearby stable loop



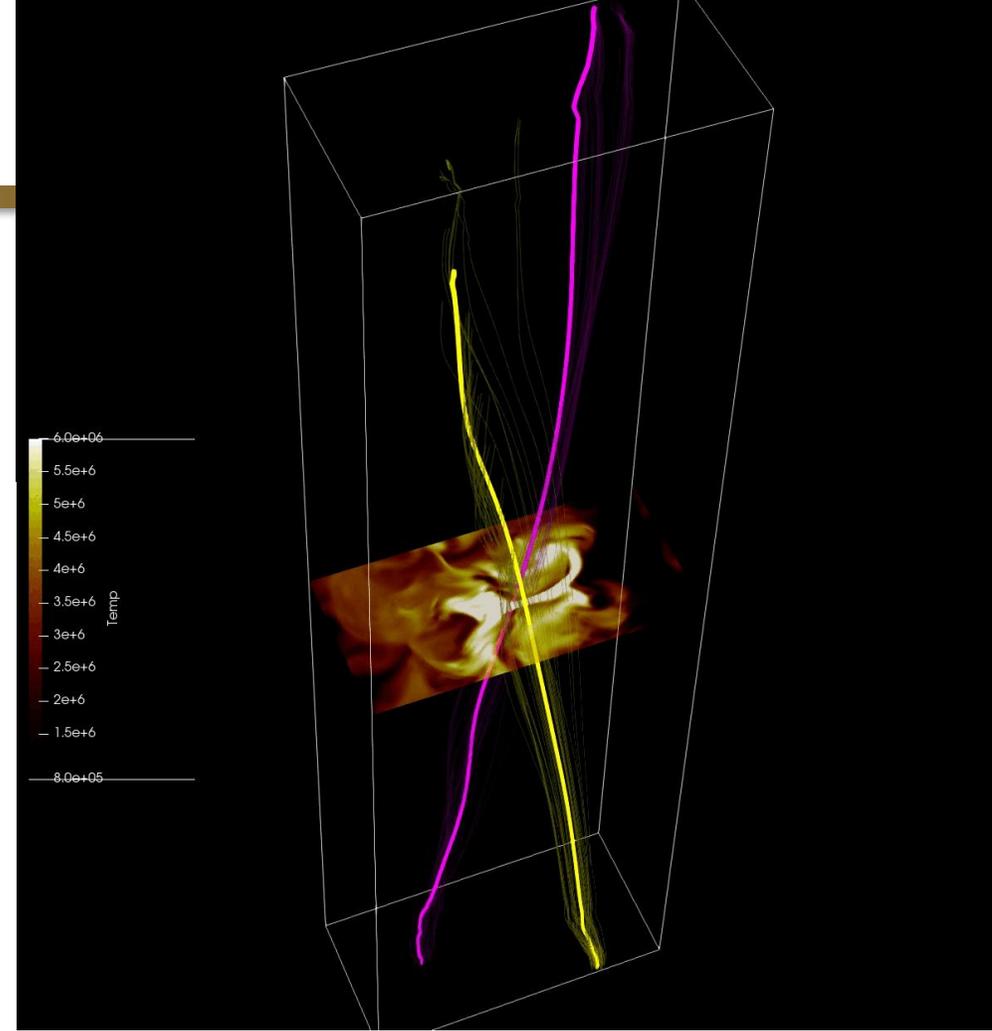
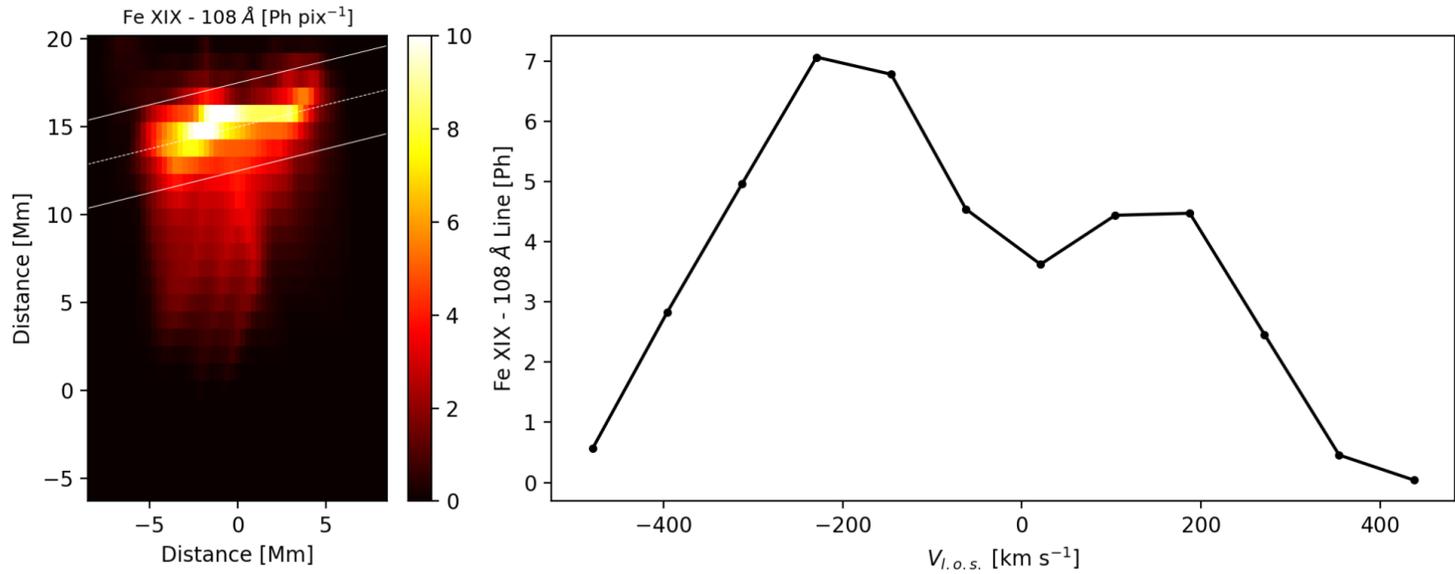
Full 3D multi threaded coronal loops



Four unstable interacting flux tubes: jets (Cozzo+ 2026a,b,ApJ,in press)



- Bidirectional plasma flow from reconnection leads to line splitting, detectable with MUSE!!!





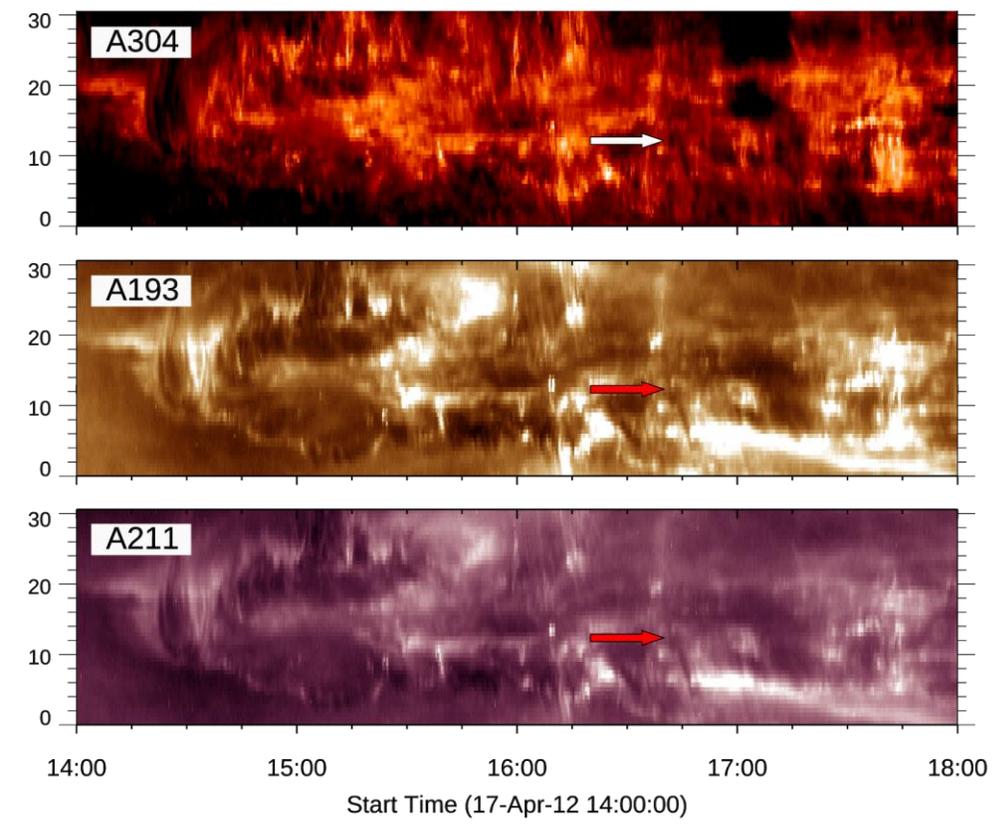
Diagnostics of eruptive events from small to large scales

D. Spadaro, V. Guglielmino, P. Romano, F. Ferrente

INAF/OACT

- *Flare spectropolarimetry* on data and MHD model along the Fe I 630.2 nm and Ca II 854.2 nm lines.

Useful for coordinated ground-based/MUSE observations!

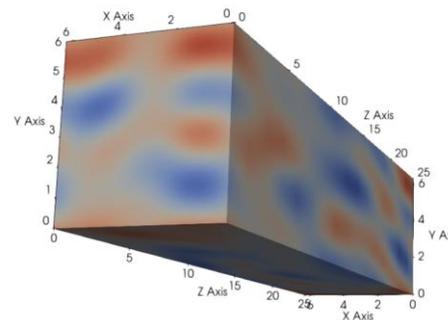
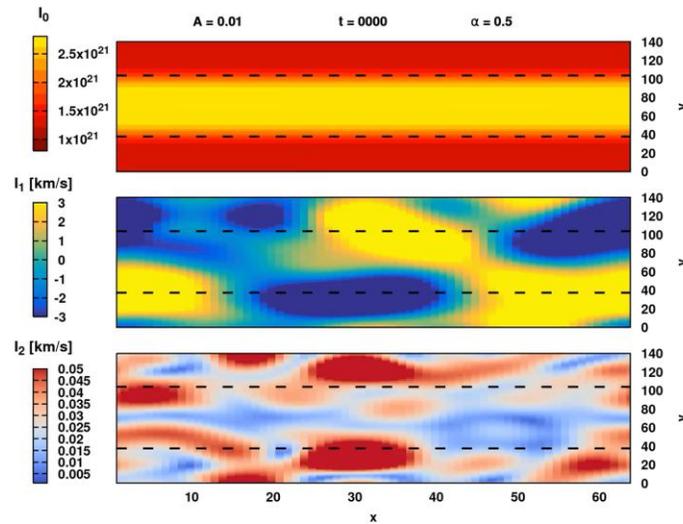
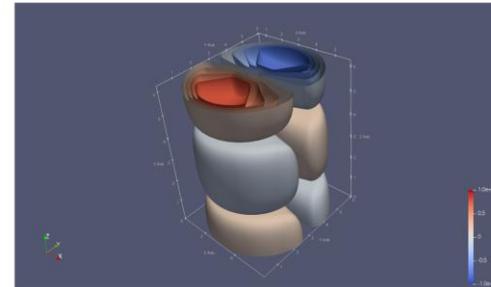
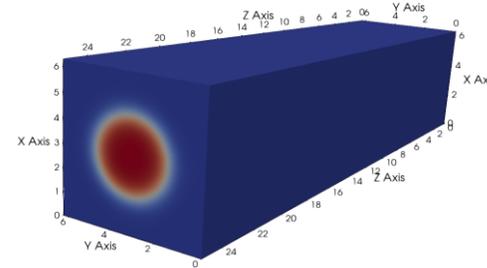




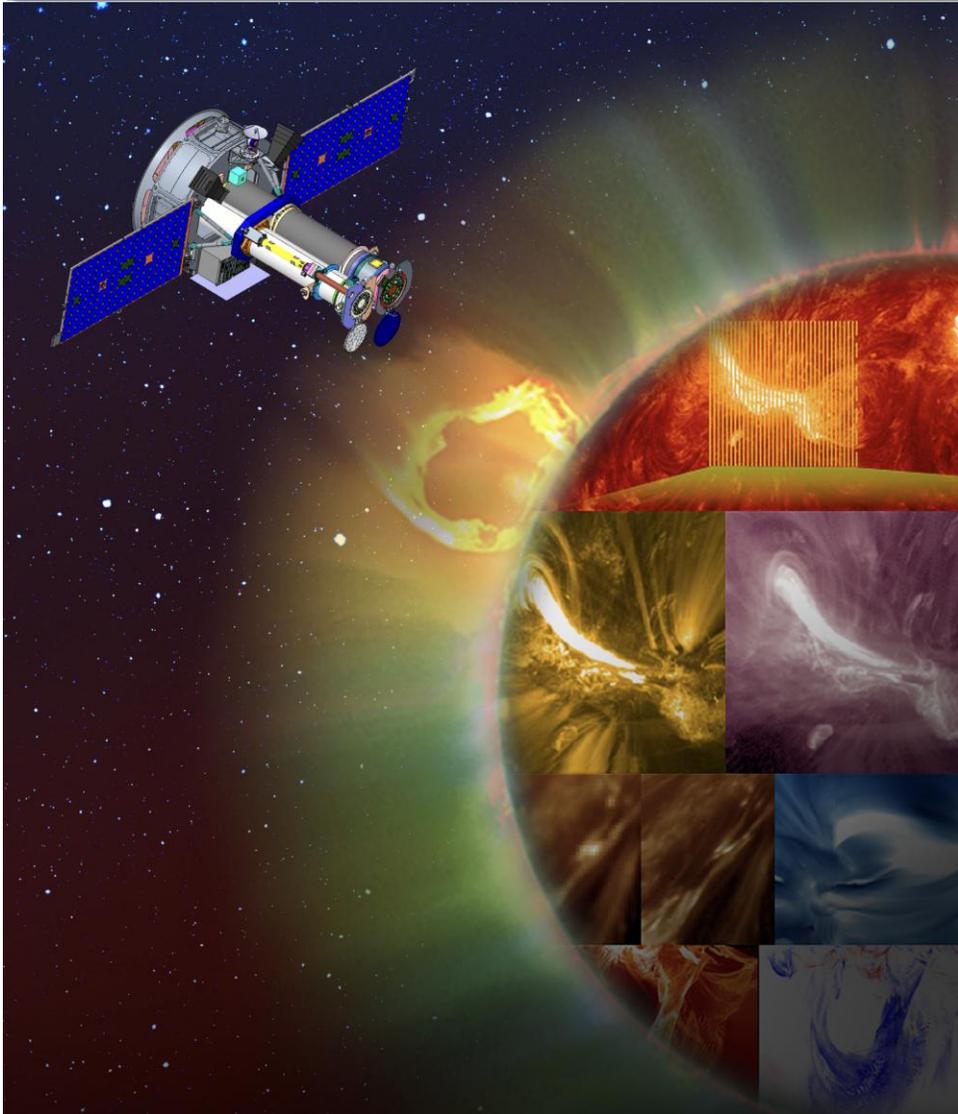
Numerical simulations of evolution of waves and turbulence in inhomogeneous coronal loops

F. Malara, F. Feraco, G. Nisticó, Univ. of Calabria

- 3D-MHD numerical code COHMPA, Unical
- Heating effects due to dissipation of fluctuations
- MUSE observables



MUSE summary and issues



- **NASA MUSE will spectroscopically capture the multi-scale nature of coronal heating and solar flares and eruptions by providing:**
 - Spectroscopy at **6x higher resolution** (0.44 arcsec) & **>35x higher cadence** (12s) than current or planned spectrographs within a FOV of 156"x170"
 - Currently in phase C with launch in 2027
- **MUSE addresses studies of:**
 - Heating of the solar corona and plasma from braiding, waves, spicules, flux emergence
 - Physics of flares and eruptions: triggers, reconnection/current sheet, non-thermal particle properties, flare energy thermalization, etc.
 - Fundamental physical processes: instabilities, non-thermal particle acceleration
- **MUSE Data Analysis:**
 - Data pipeline work including (Multi)Gaussian fitting, and spectral disambiguation approaches
 - Open access
- **Italian contribution (ASI-INAF):**
 - Filters and mirrors
 - Science: MHD modeling of reconnection, eruptions/flares, waves and turbulence
- **Key issues:**
 - *Investigation of impulsive magnetic reconnection and plasma events on many scales*

Work in progress: **Rappazzo, A.F., Pagano, P. Reale, F., Cozzo, G., Testa, P.**

Investigate current sheets (CS) formation in 2.5D Ideal MHD compressible turbulence simulations. Fast magnetic reconnection is linked to an exponential decrease of CS thickness in time. CS form between magnetic islands. Constraints and diagnostics from MUSE observations.

