Radio Emission Signatures from Stellar Activity Simulations

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Outline

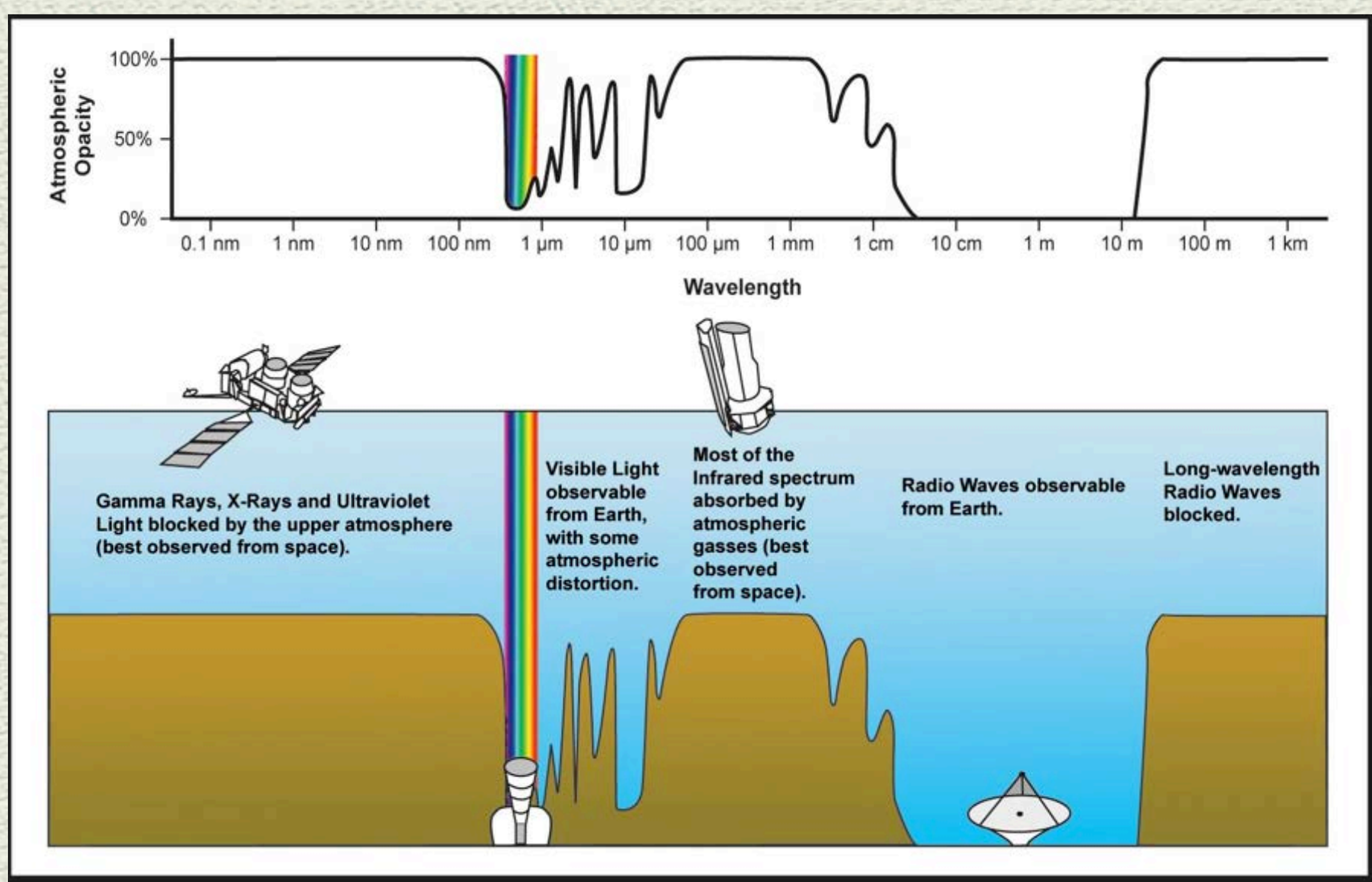
- Motivation
- CME-flare scenario
- Radio emission mechanisms
- Radio Solar & Stellar observations
- Radio Synthetic images
- Future work
- Conclusions

Motivation

- **Magnetic reconnection**: fundamental process ubiquitous in the universe, e.g. stellar coronae, accretion disks, planetary magnetospheres

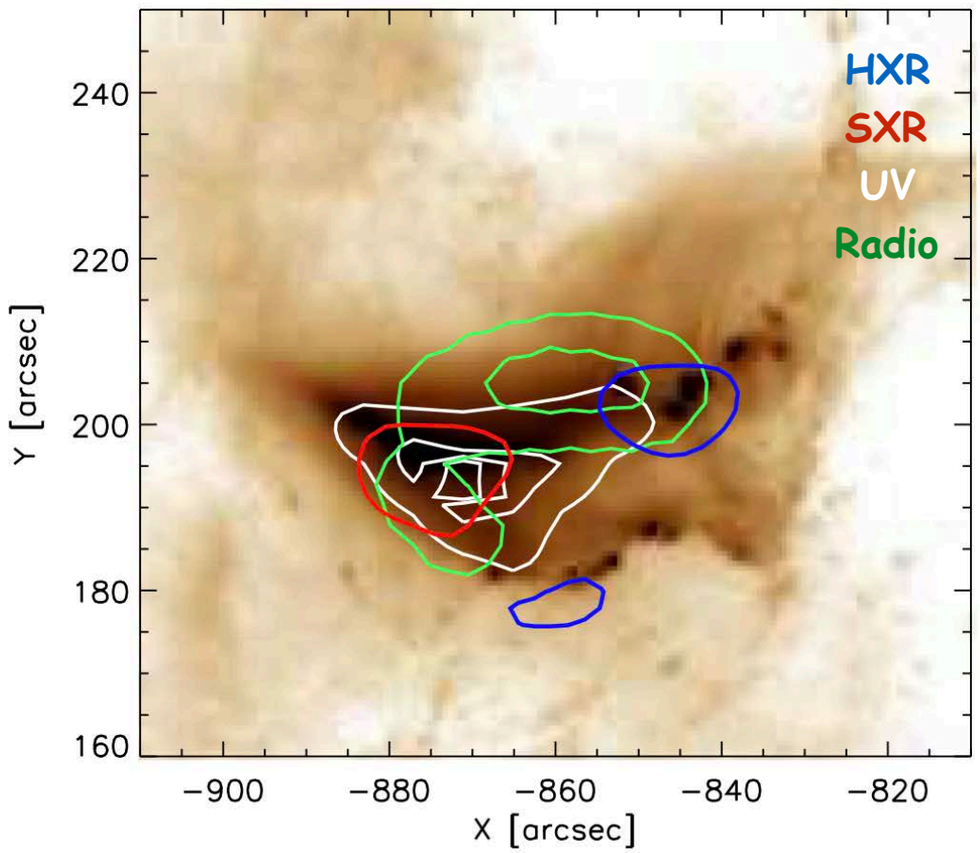
Motivation

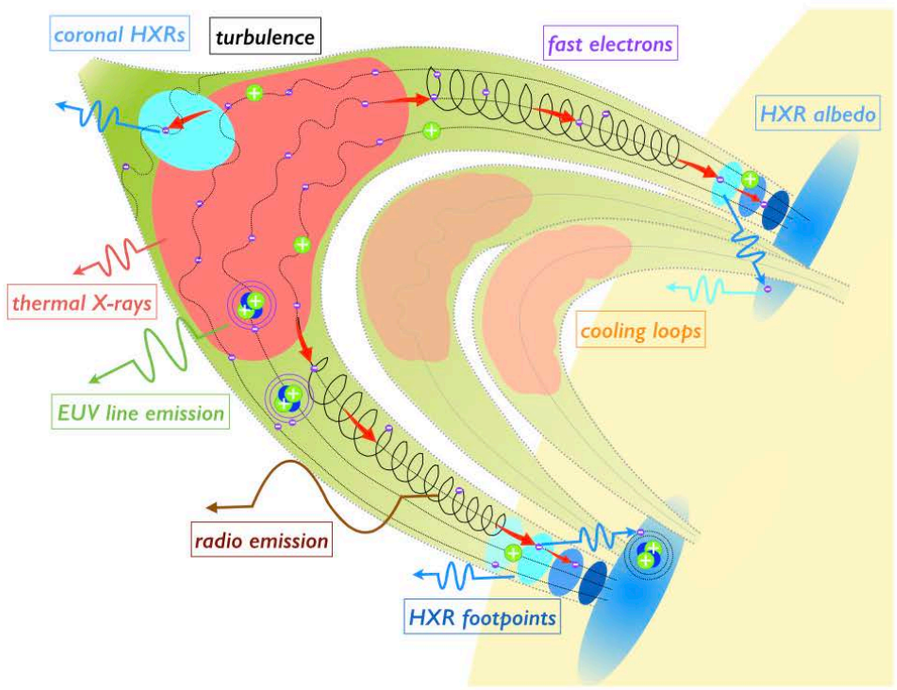
- **Radio observations**: favorable atmospheric window
- **Observations Stellar CMEs**: using Radio waves
- Exoplanetary environments **hostile or hospitable?**



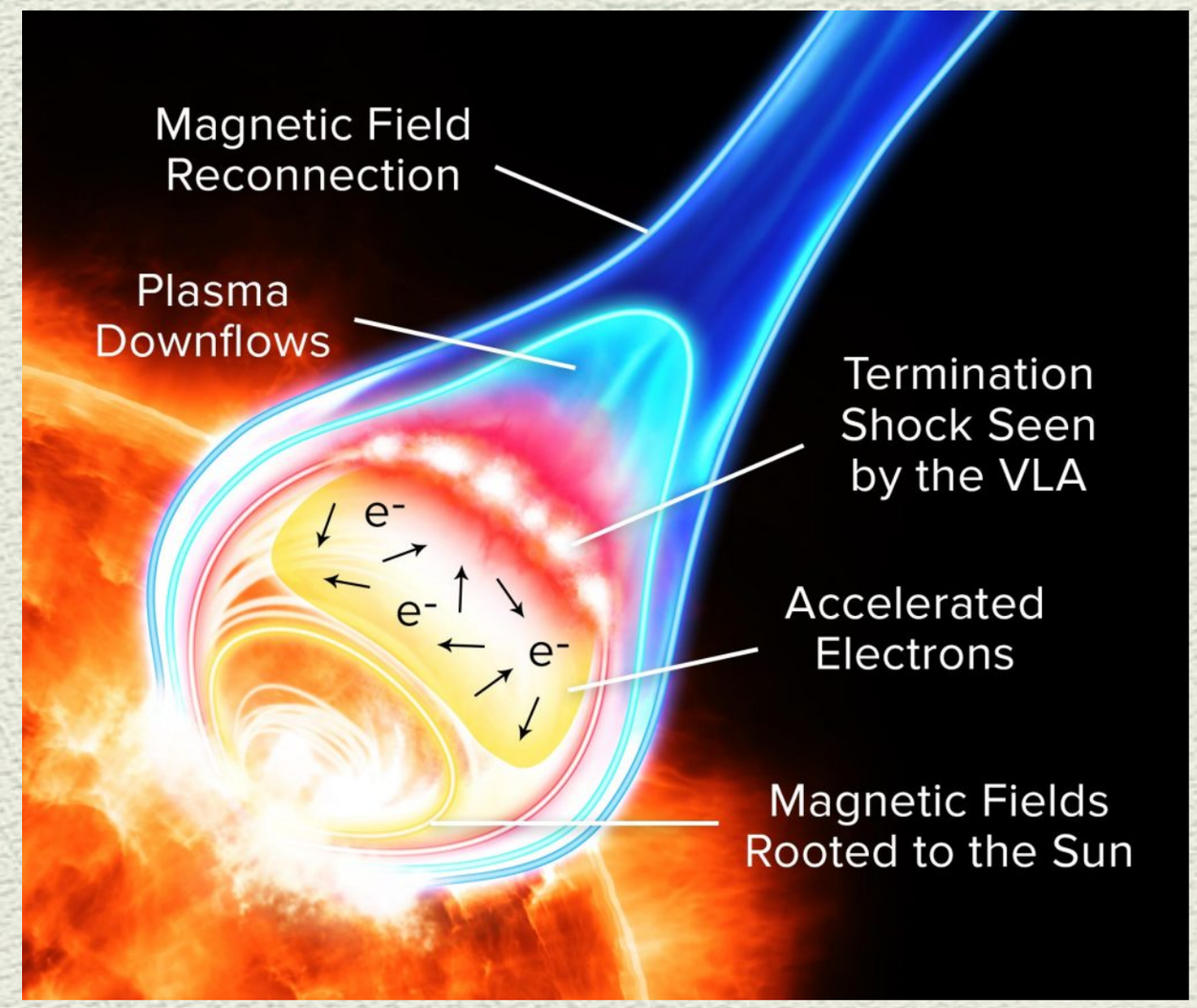
Credit: NASA/IPAC

CME-flare scenario



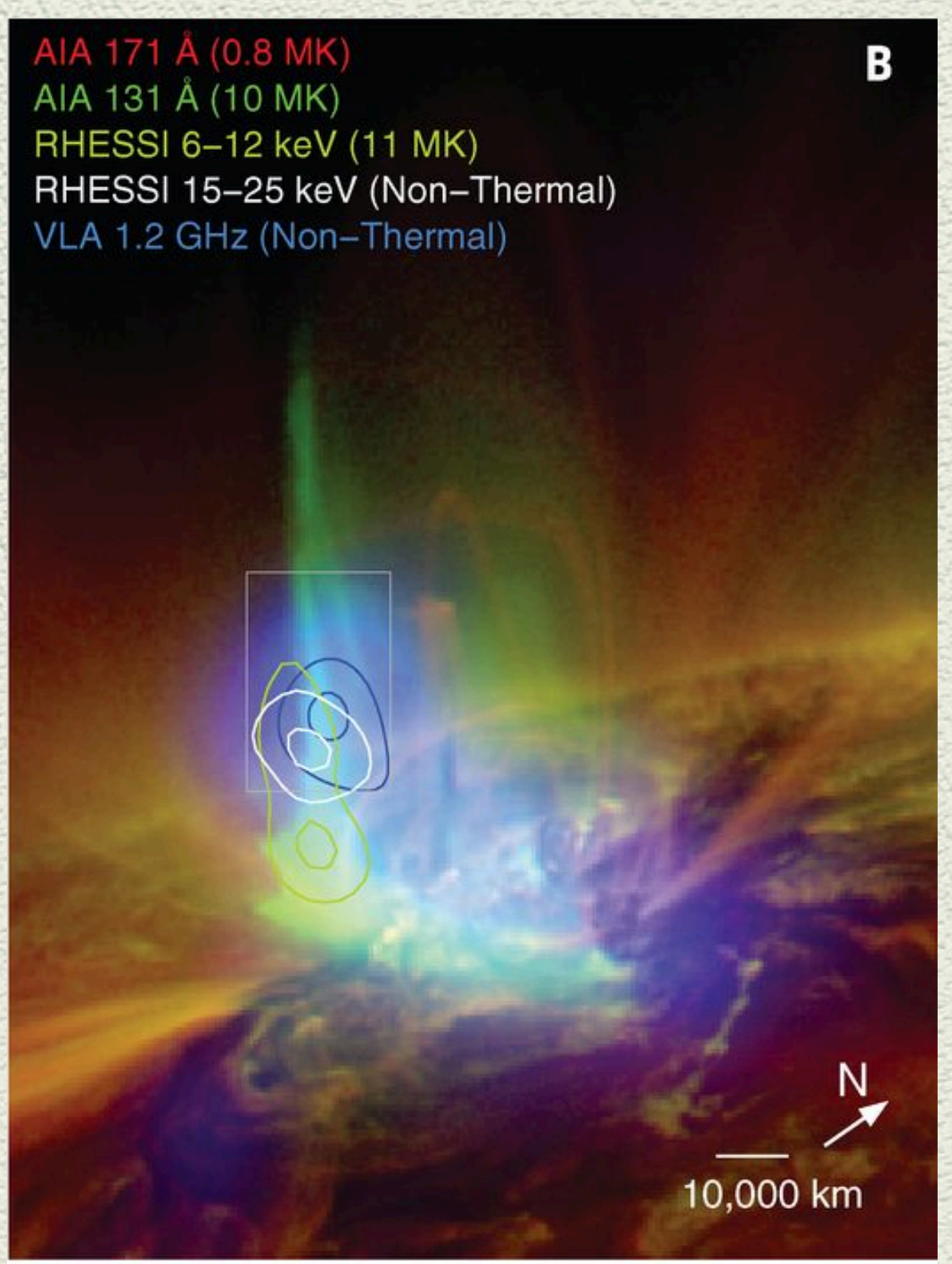


Kontar et al., PRL, 2017

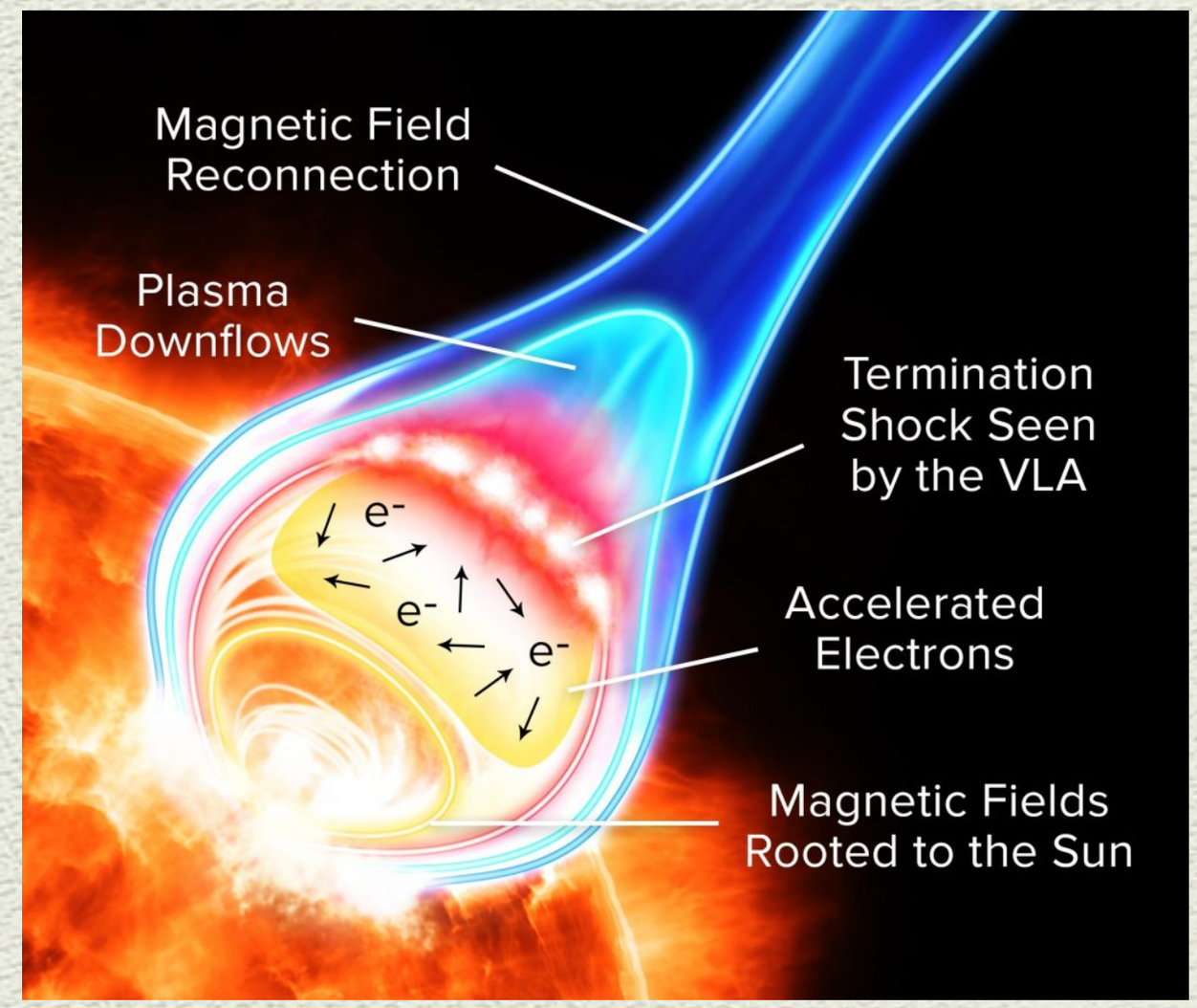


Credit: Alexandra Angelich (NRAO/AUI/NSF).

CME-flare scenario



Chen et al., Science, 2015



Credit: Alexandra Angelich (NRAO/AUI/NSF).

Radio emission mechanisms

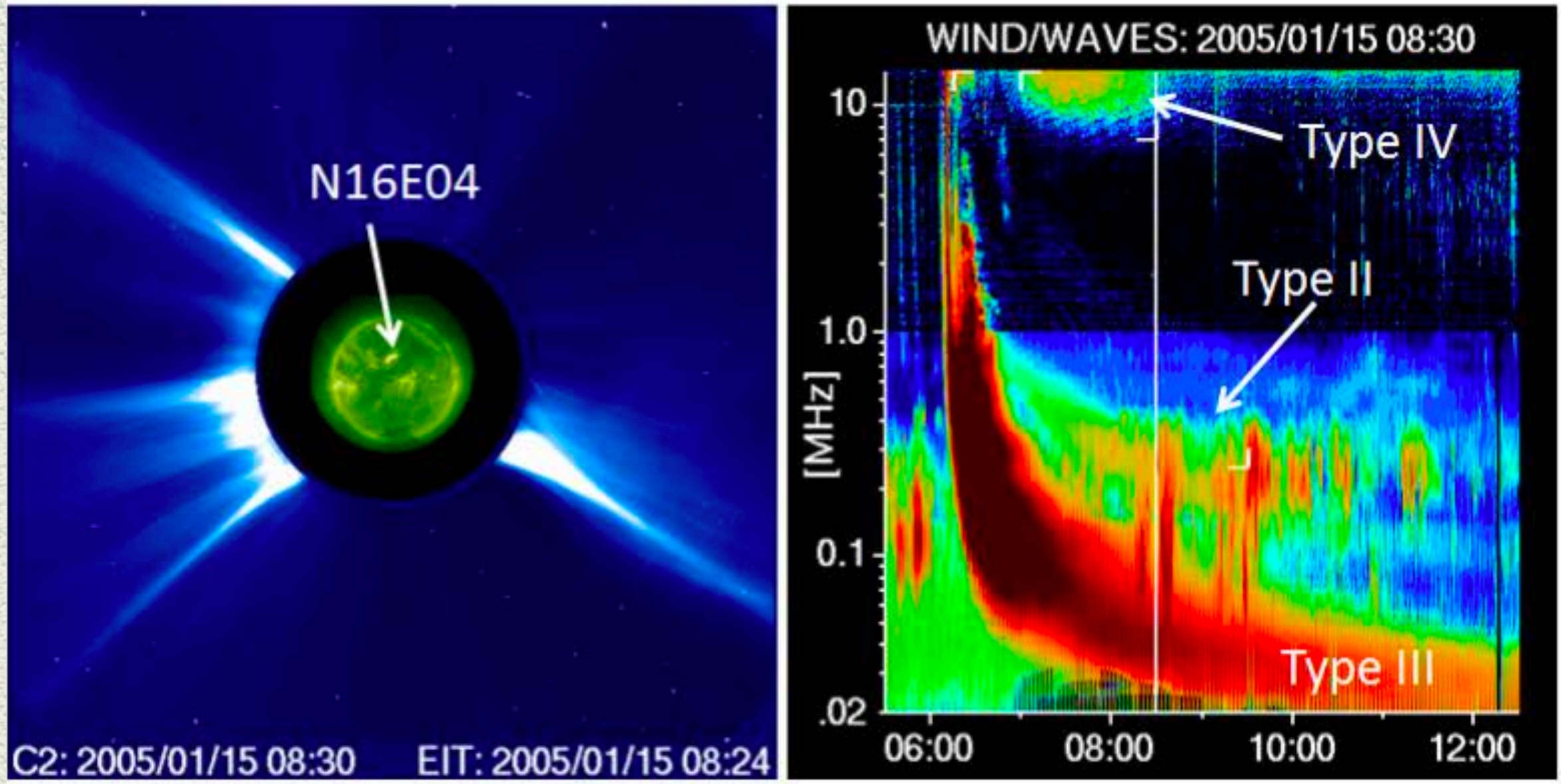
Bremsstrahlung radiation : a) ion-electron collisions (free-free), b) provides insights into plasma density and temperature.

Gyromagnetic radiation : a) e- acceleration due to the Lorentz force. b) Subcategories: i) thermal gyroresonance emission and ii) thermal or non- thermal gyrosynchrotron emission. c) cm-m-λ

Plasma radiation : a) excitation of plasma waves by e.g., electron beams (Type III bursts) or MHD shocks (Type II bursts), b) E/M waves ω_{pe} , $2\omega_{pe}$. c) Radiation at dm-m-λ.

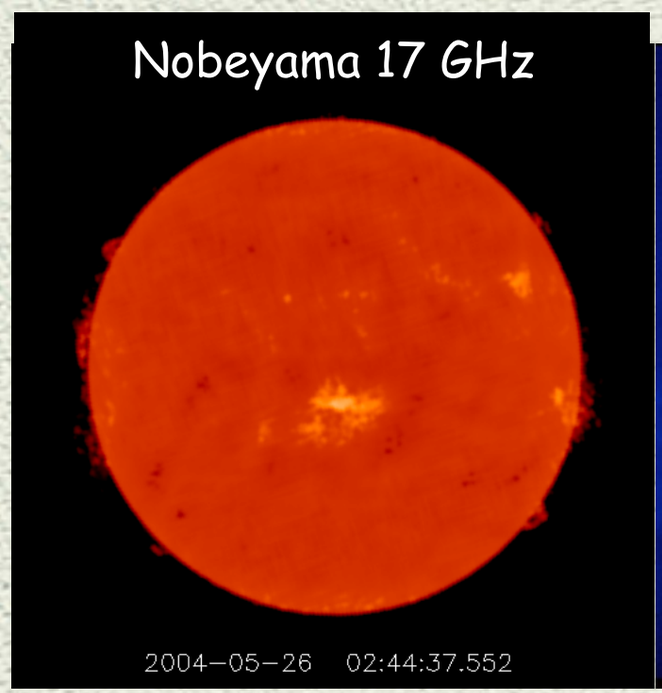
Solar Radio Observations

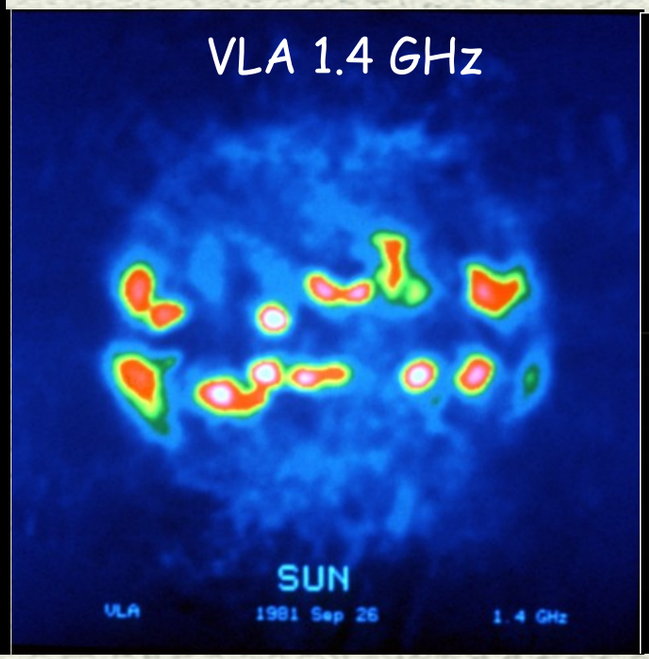
Spectroscopy

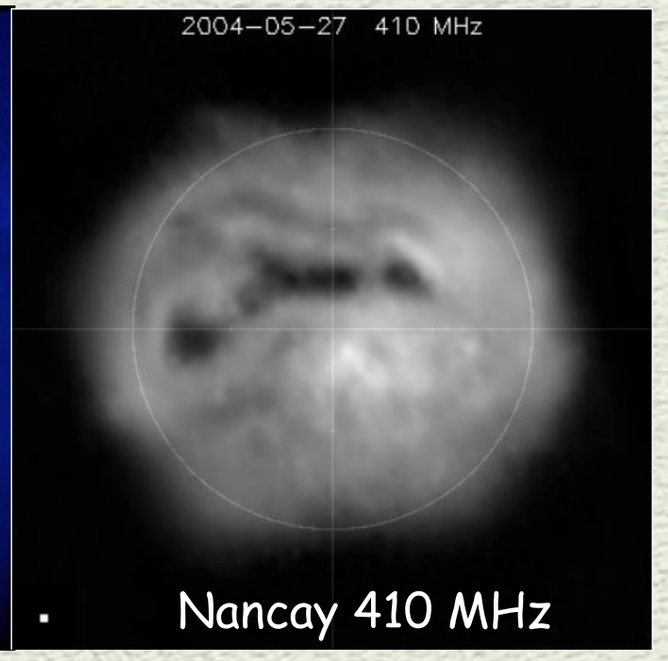


Gopalswamy, ARXIV, 2016

Solar Radio Observations

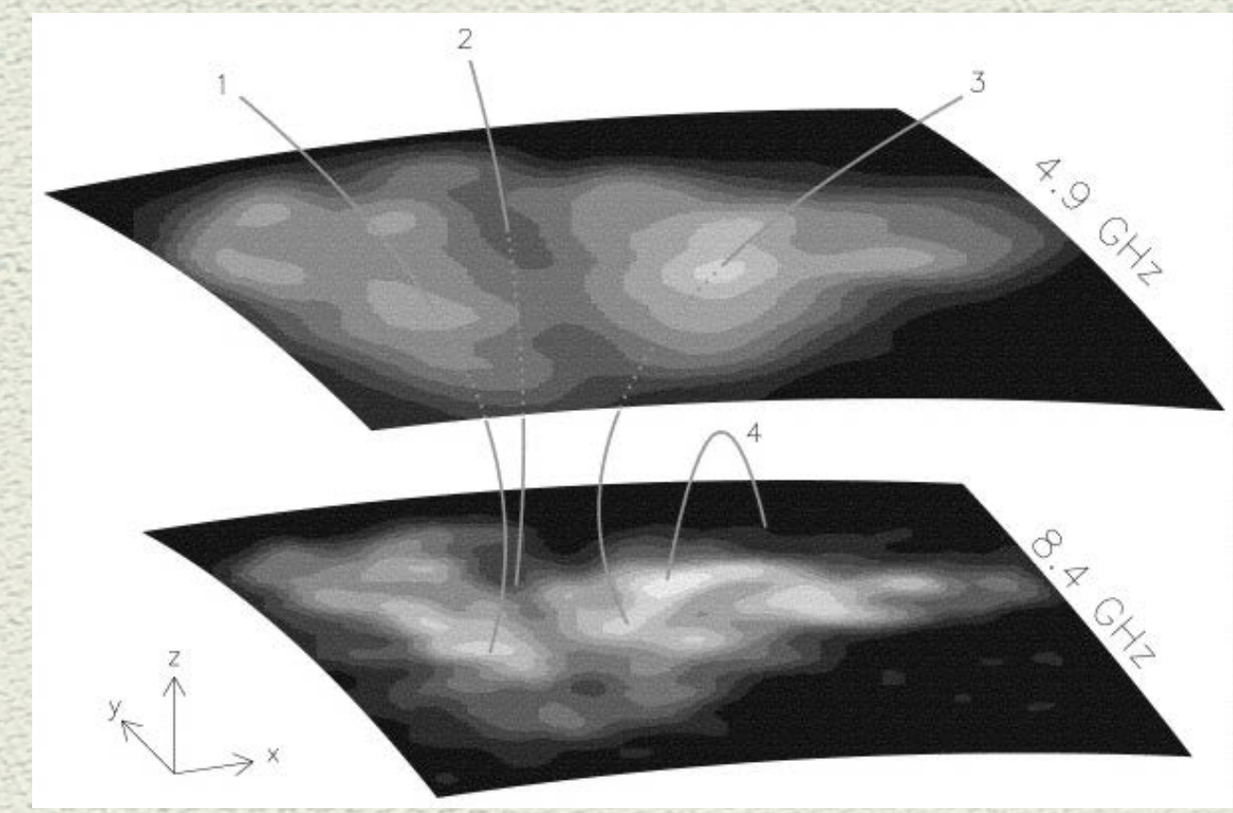






Dulk & Gary, 1983

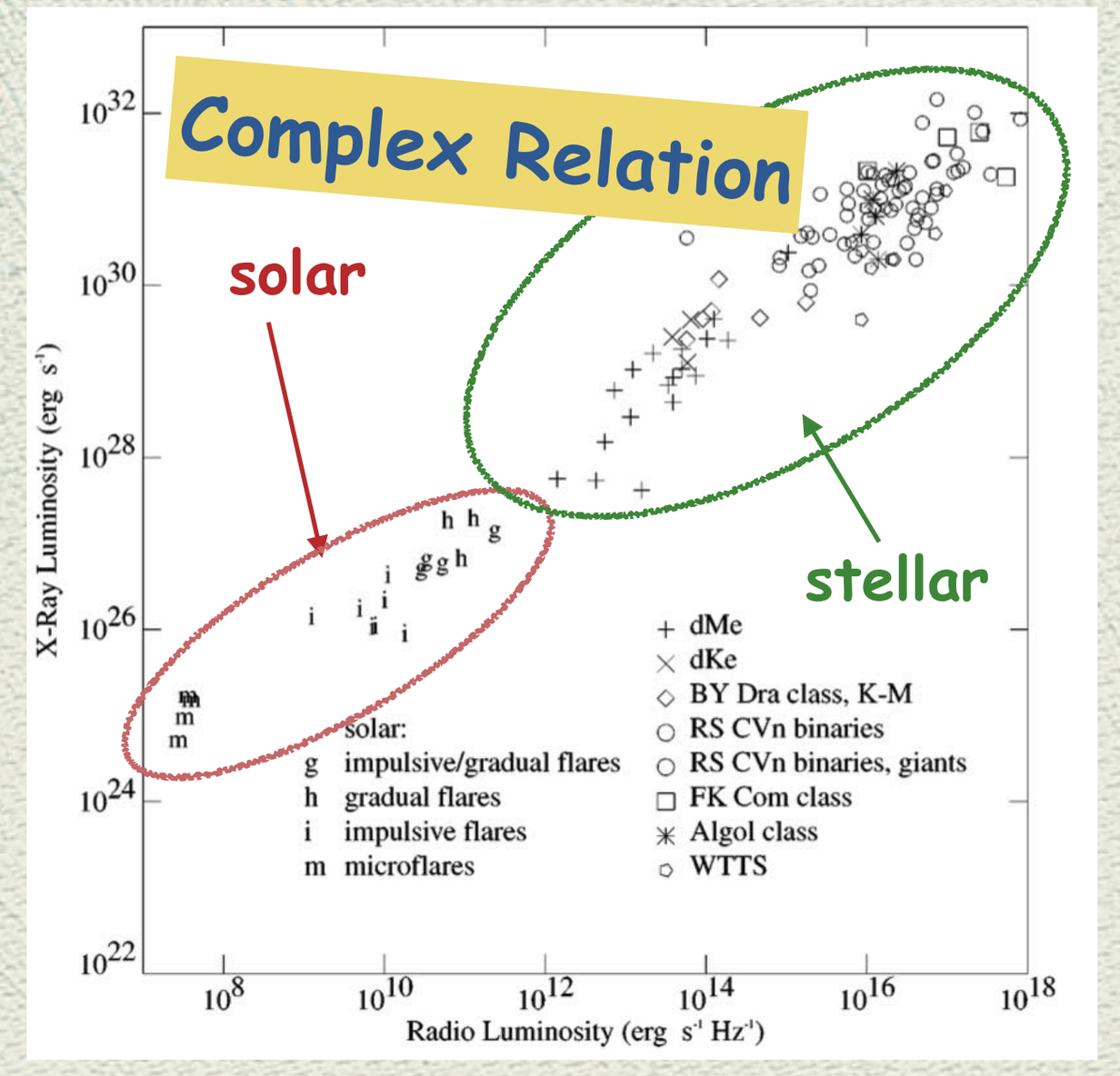
Mercier & Chambe, 2015



Lee et al. 1999, ApJ

Stellar Radio Observations

Radio & X-Ray:
Activity Indicators



Benz & Gudel, A&A, 1994

- Incoherent stellar flares, Radio bursts in both Sun-like (FGK)-stars (e.g. Gudel et al. 1998) and in M-dwarfs (e.g. Bastian 1990)
- Long-lasting (~1h) coherent stellar flares (e.g. van den Oord & de Bruyn 1994) and several coherent flares in M-dwarfs in lower frequencies (e.g. Kundu et al. 1988/ VLA)
- Limited imaging capabilities: spatial scales not well resolved

Radio Synthetic Images

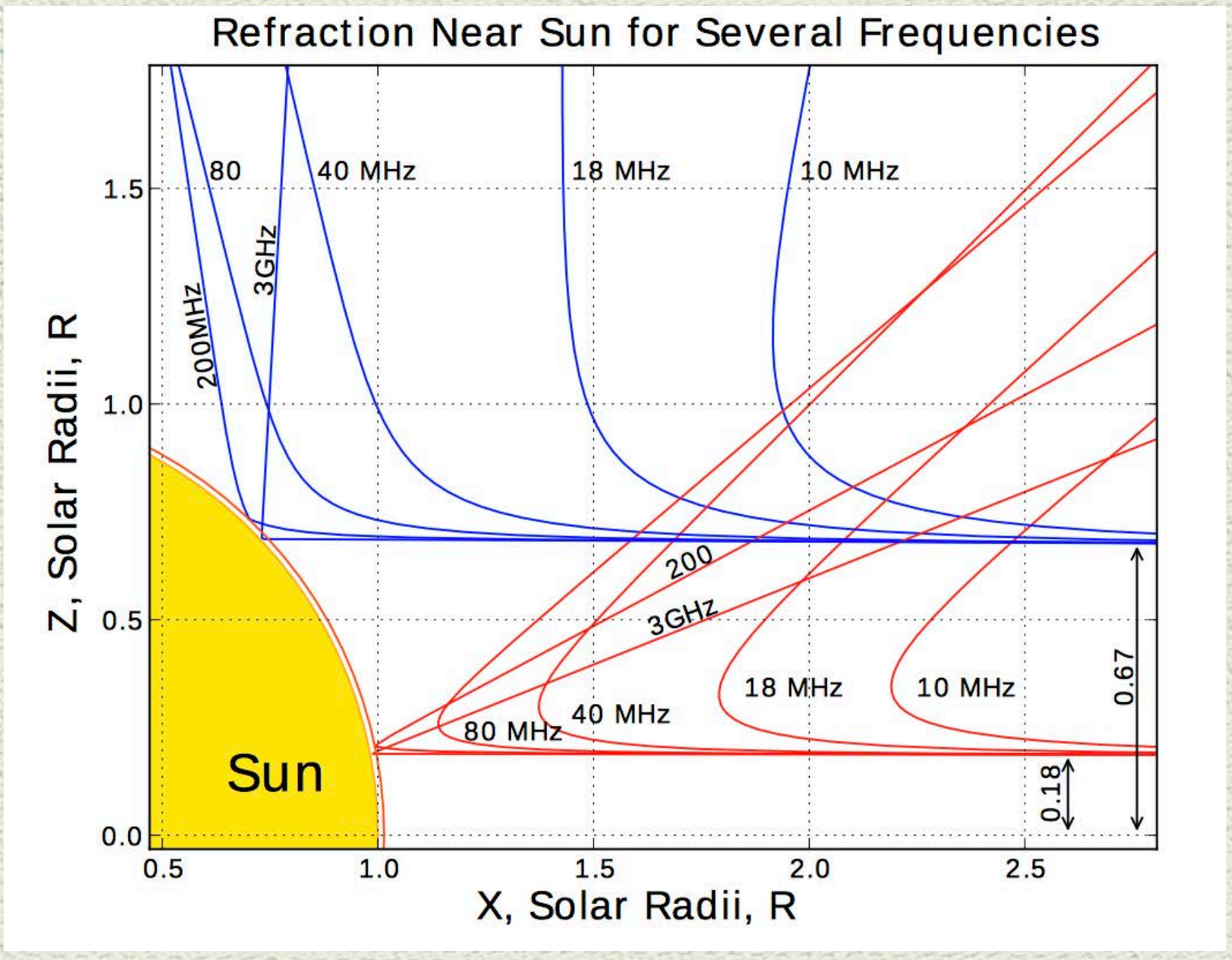
Computational tools

SWMF (Space Weather Modeling Framework)

- BATS-R-US: Global MHD Simulation of CME
- Synthetic Radio Images:
  - Benkevitch, Sokolov, et al. 2010: Cartesian Grid
  - Sokolov, et al. 2017 (prep.): Spherical Grid & AMR optimization
  - Concurrent computation of Radio intensity at each pixel
  - Intensity proportional to integral of Radio emissivity along the "rays", i.e. curved for Radio waves.
  - Modified Bremsstrahlung emission

Refraction of Radio waves

Refraction governed by gradient of the dielectric permittivity ε.



$$\varepsilon = 1 - \frac{\rho}{\rho_{cr}} = 1 - \frac{\omega_p^2}{\omega^2},$$

$$\omega_p = (4\pi e^2 n_e / m_e)^{1/2}$$

$$\rho_{cr} = \frac{m_p m_e \omega^2}{4\pi e^2}$$

Critical Surface:

For $\rho=\rho_{cr}$: $\varepsilon=0$

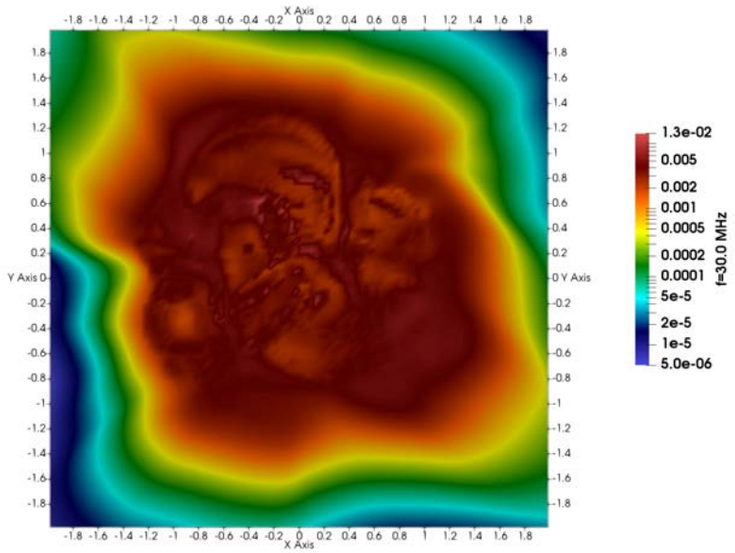
E/M rays cannot travel in:

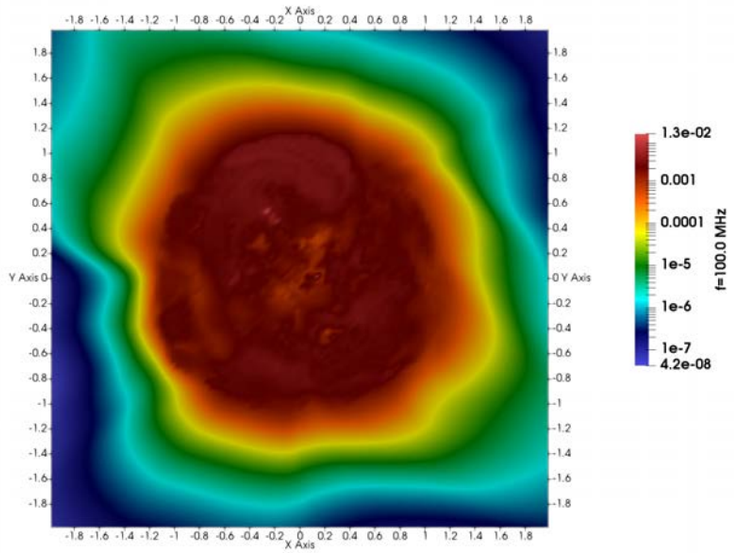
$\omega_p>\omega$, i.e. $\rho>\rho_{cr}$

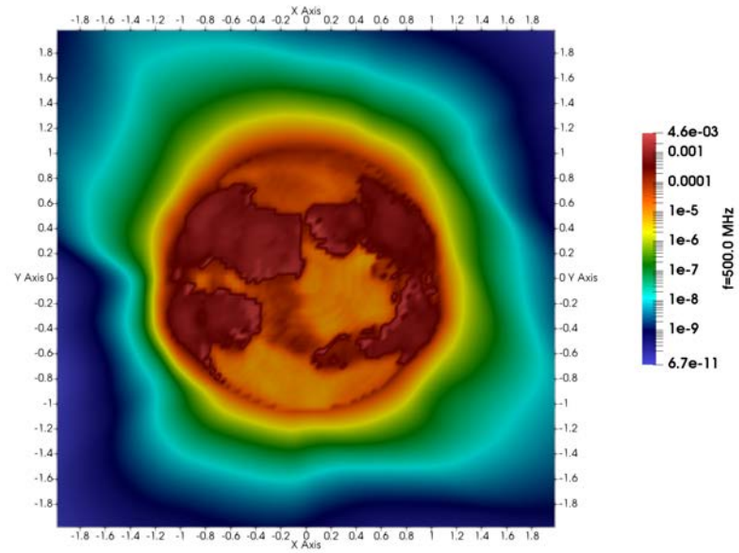
Rays -> the critical surface undergo strong refraction bending away ~ reflection

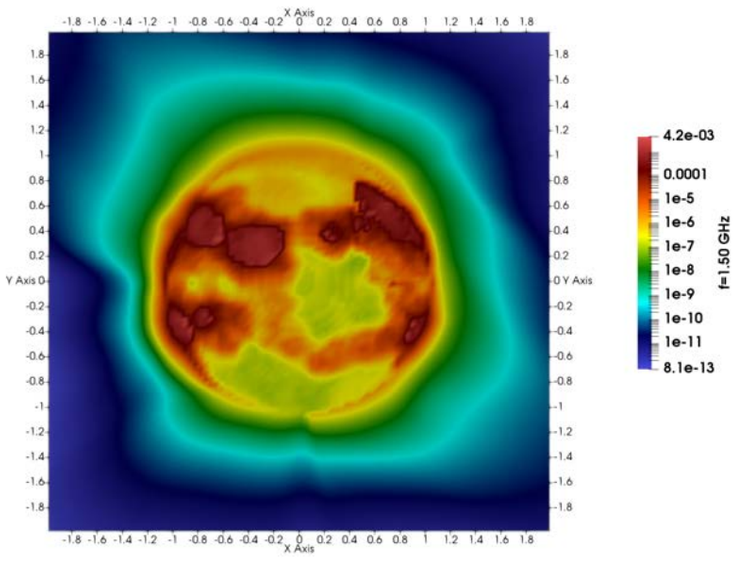
Benkevitch, Sokolov, et al. 2010

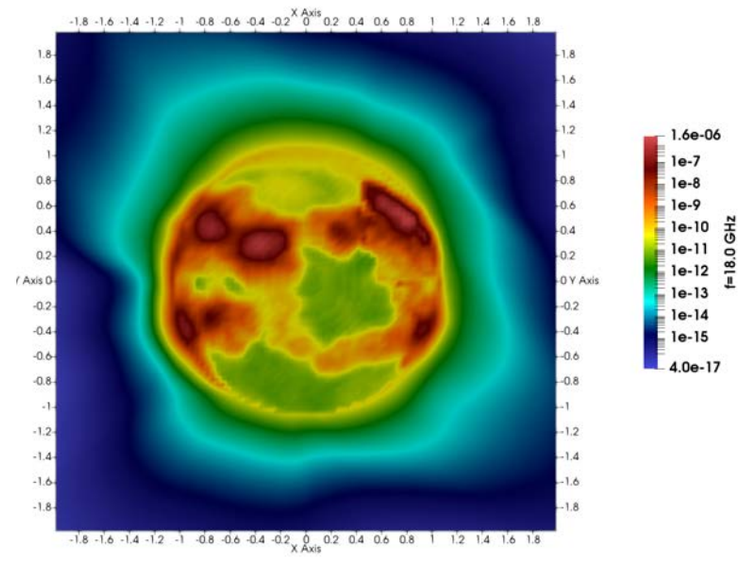
Quiescent Corona in Radio

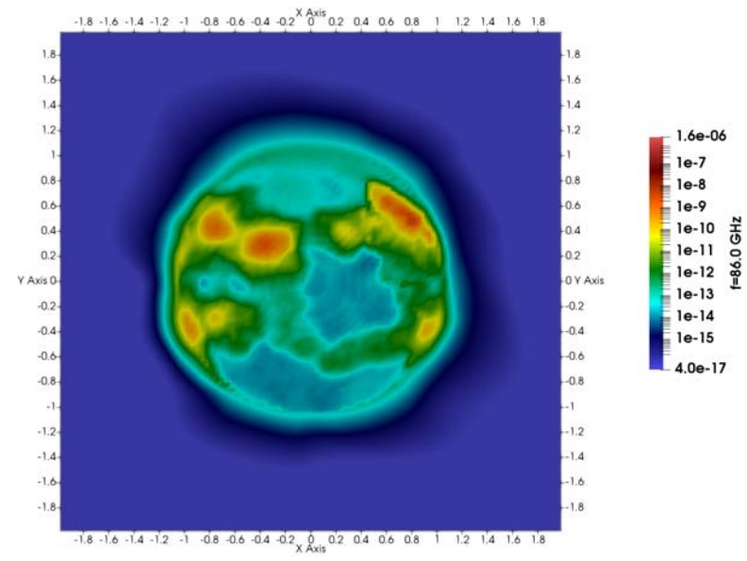




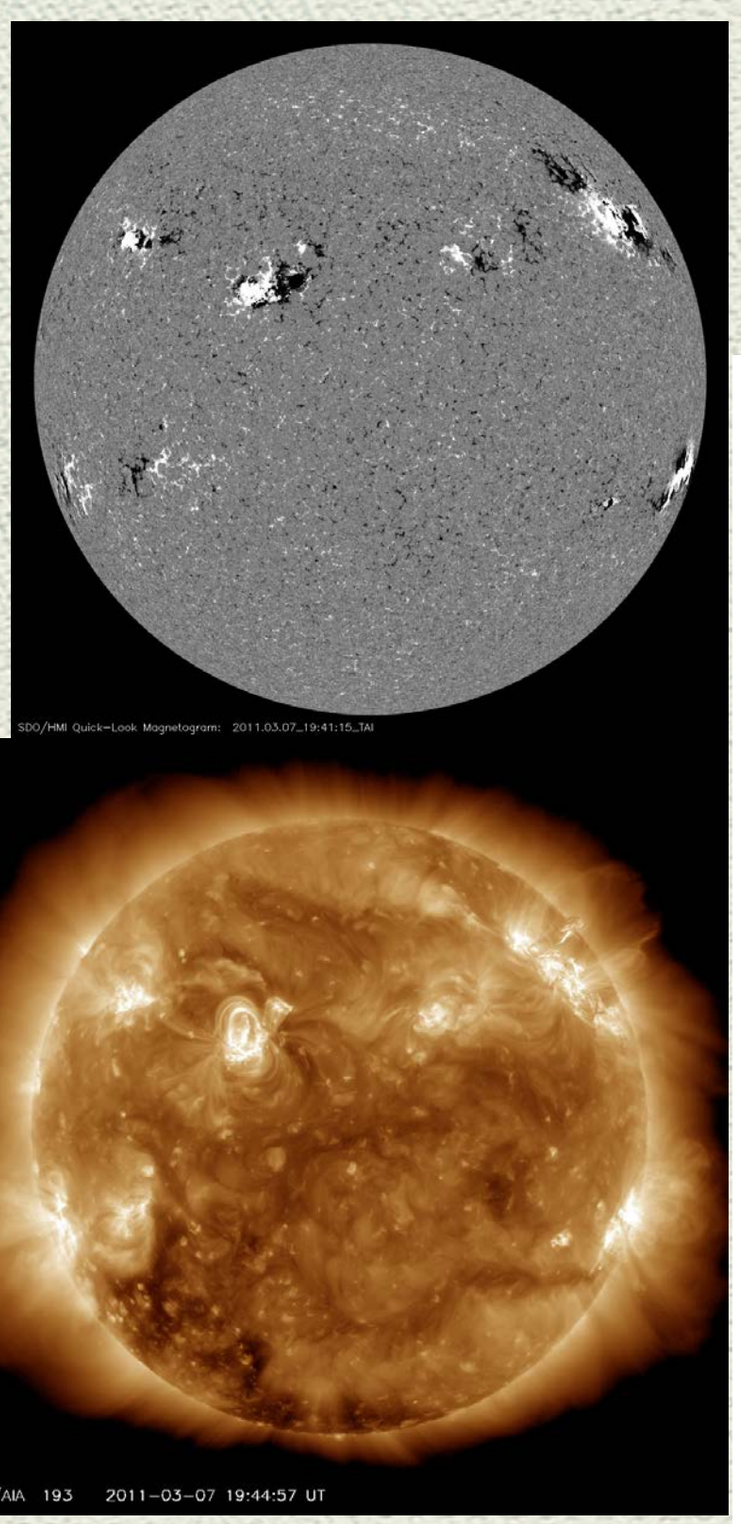


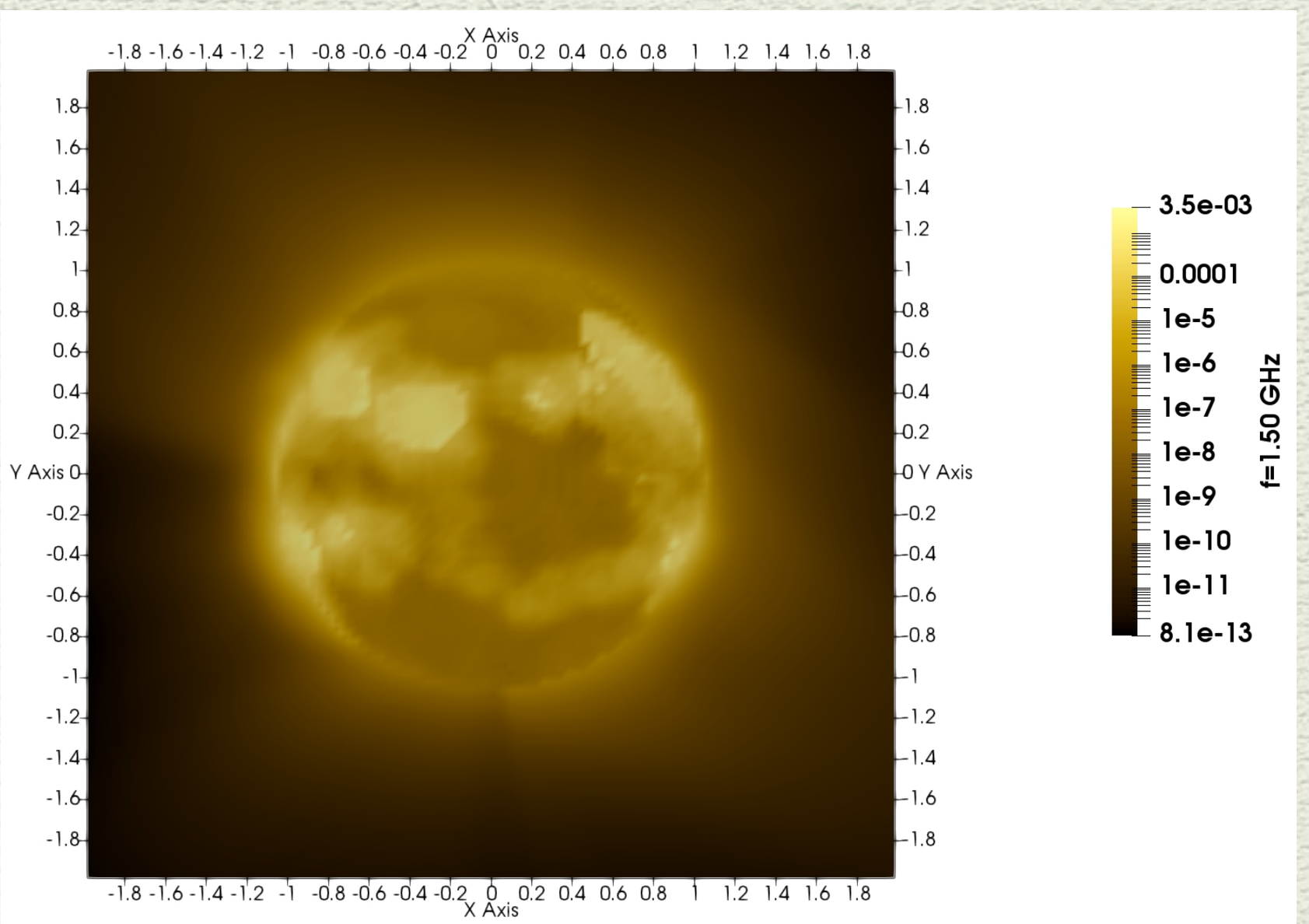






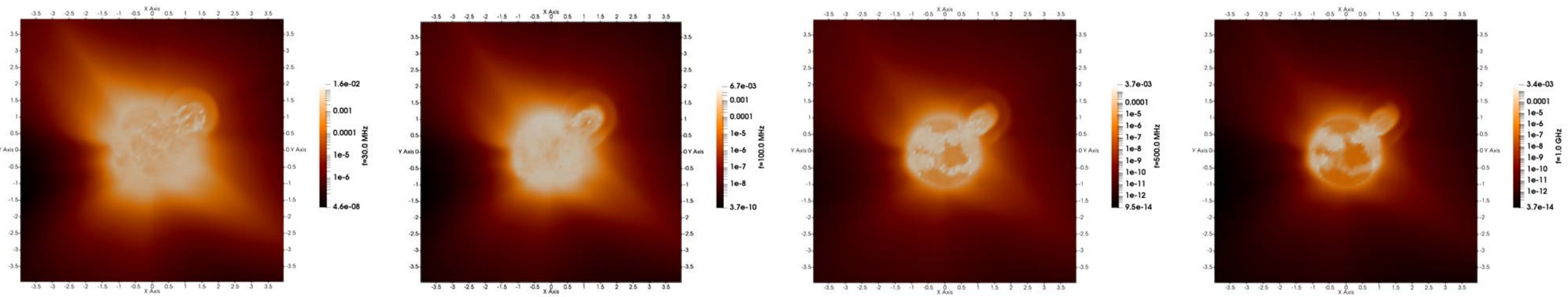
Quiescent Corona in Radio



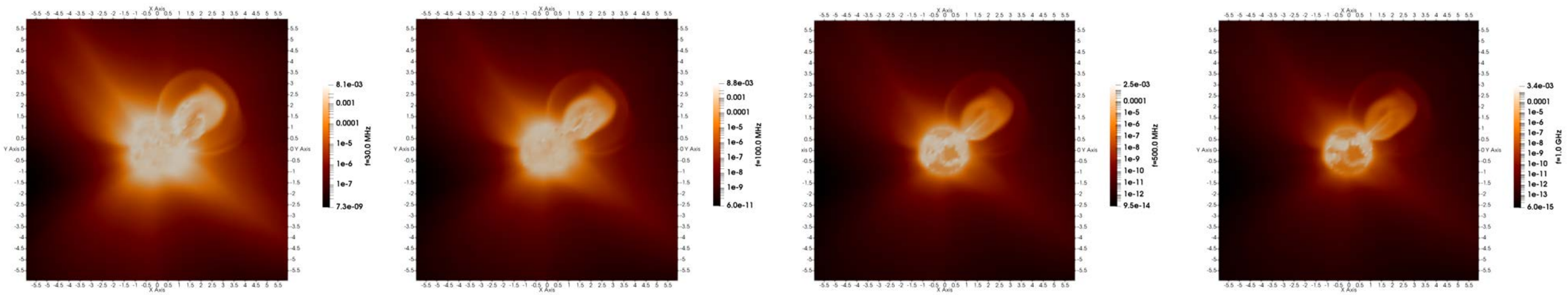


Transients in Radio

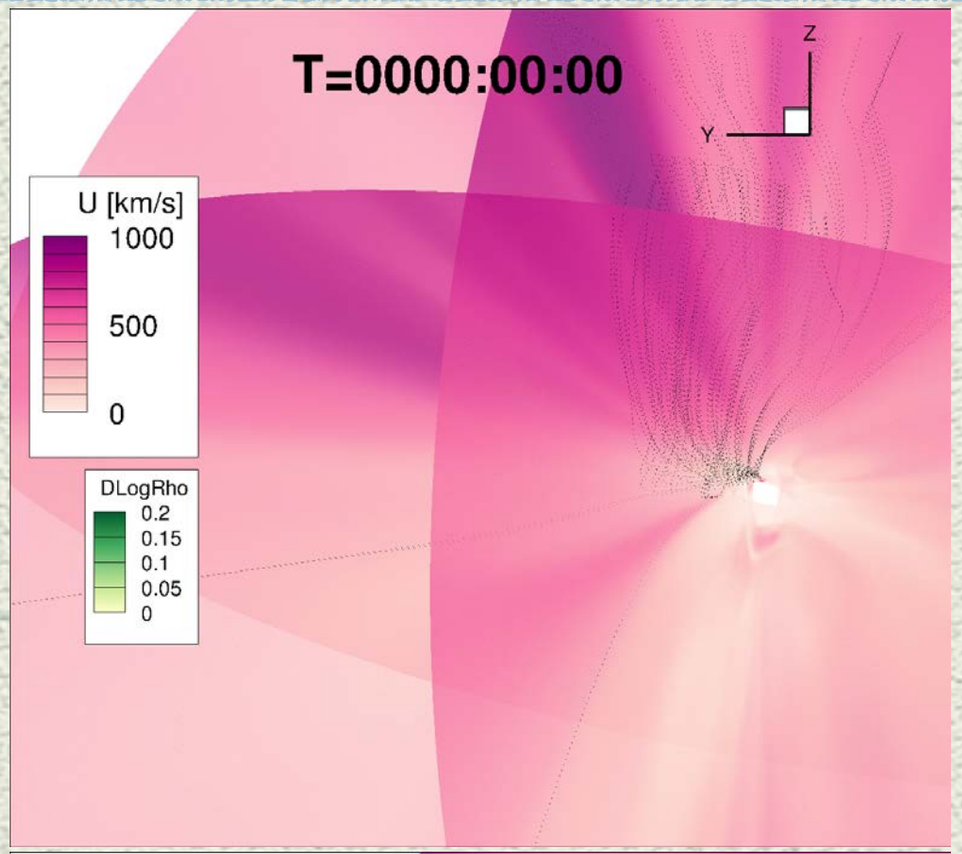
t_1=3.5 min



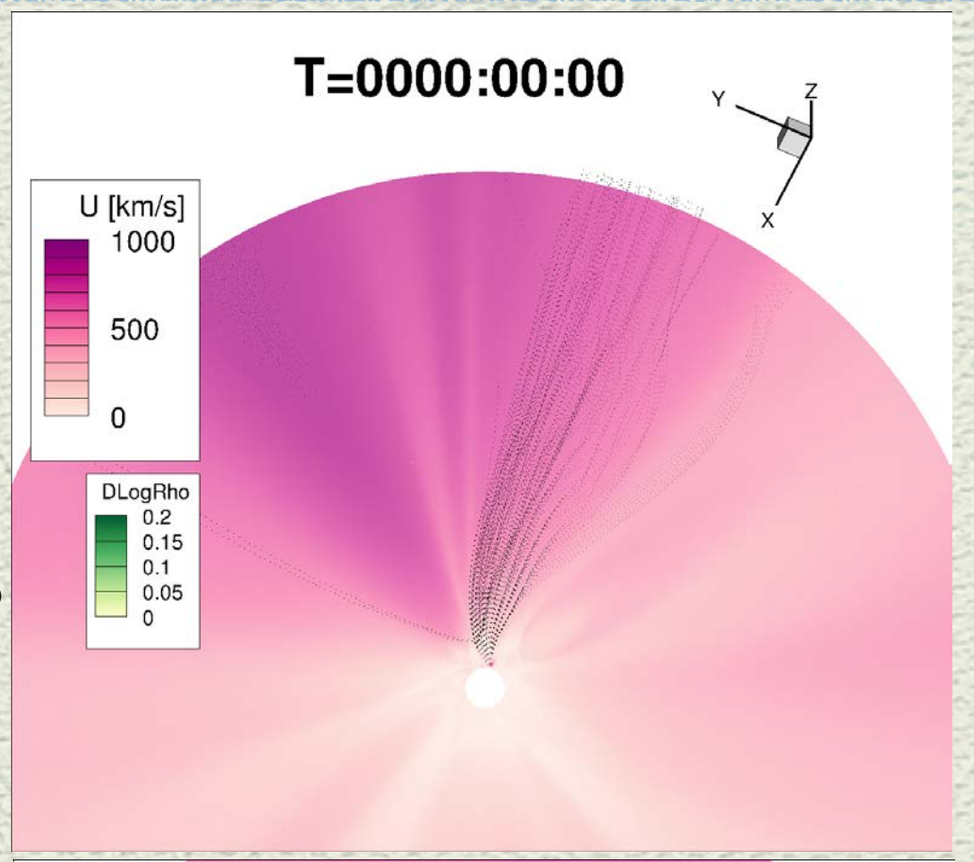
t_1=7 min

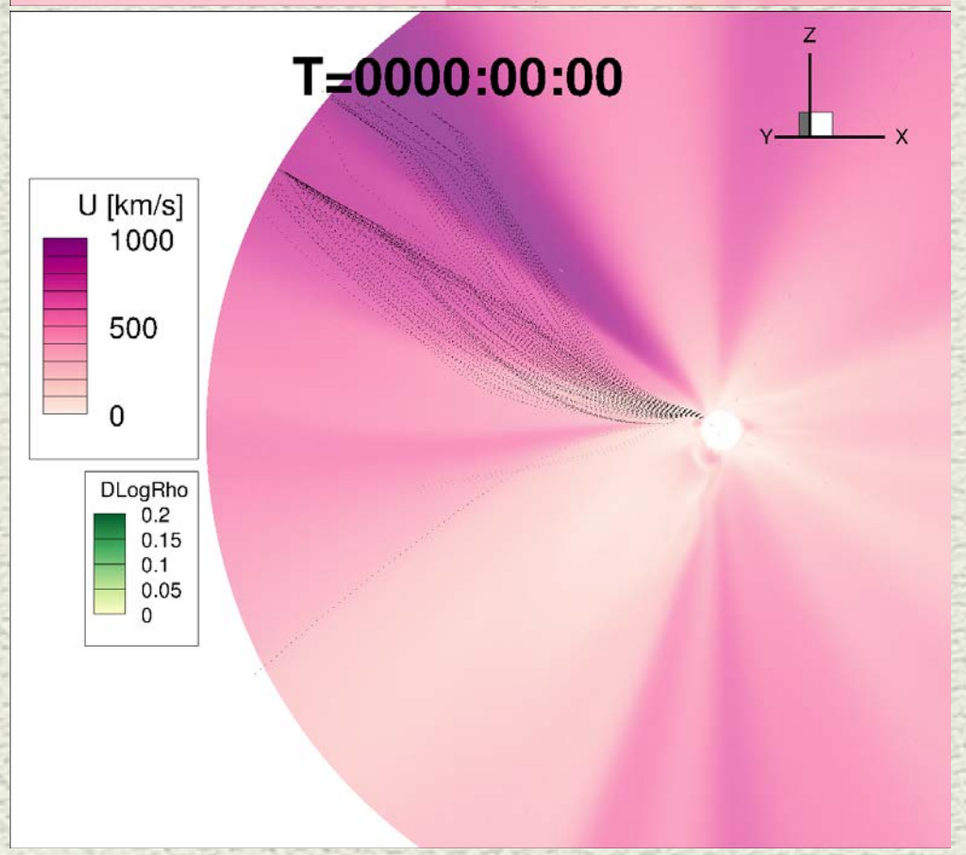


CME Shock Wave

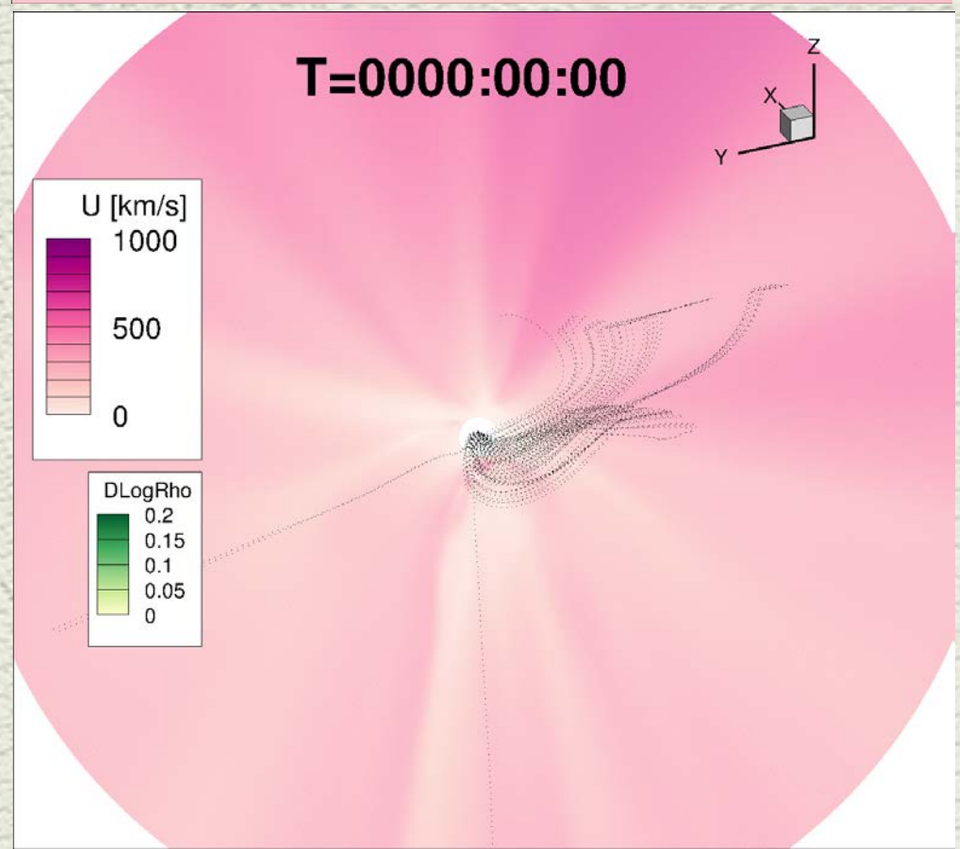


BATS-R-US
&
MFLAMPA

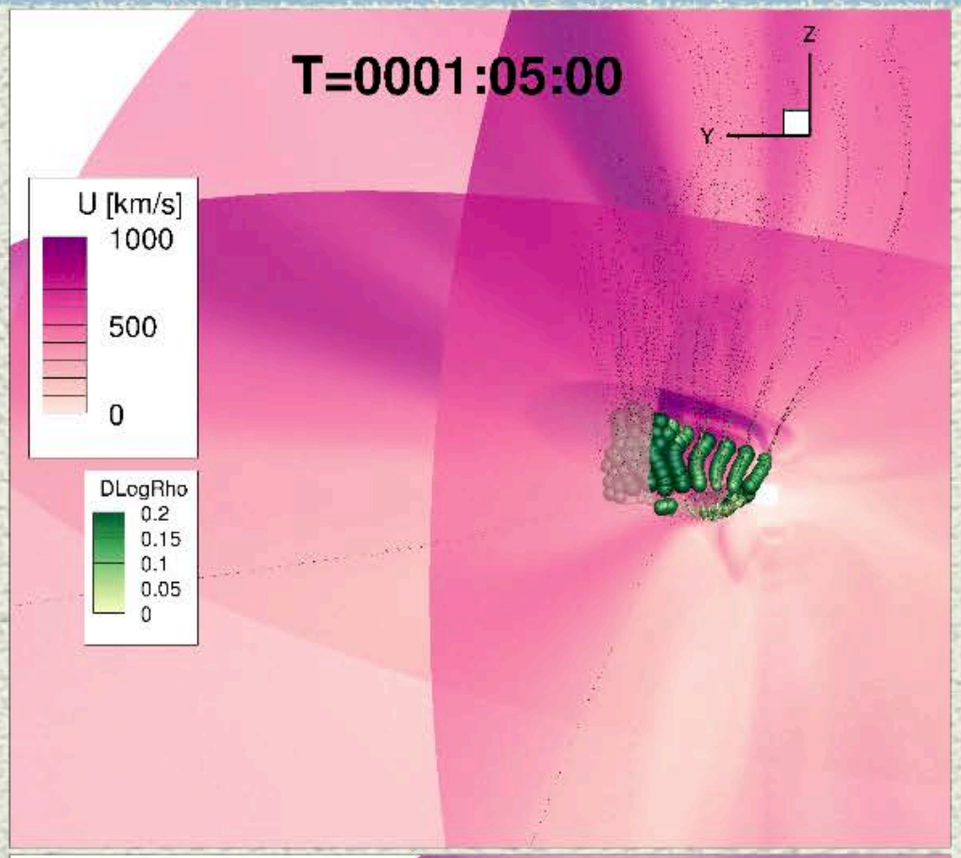




D.Borovikov



CME Shock Wave



BATS-R-US
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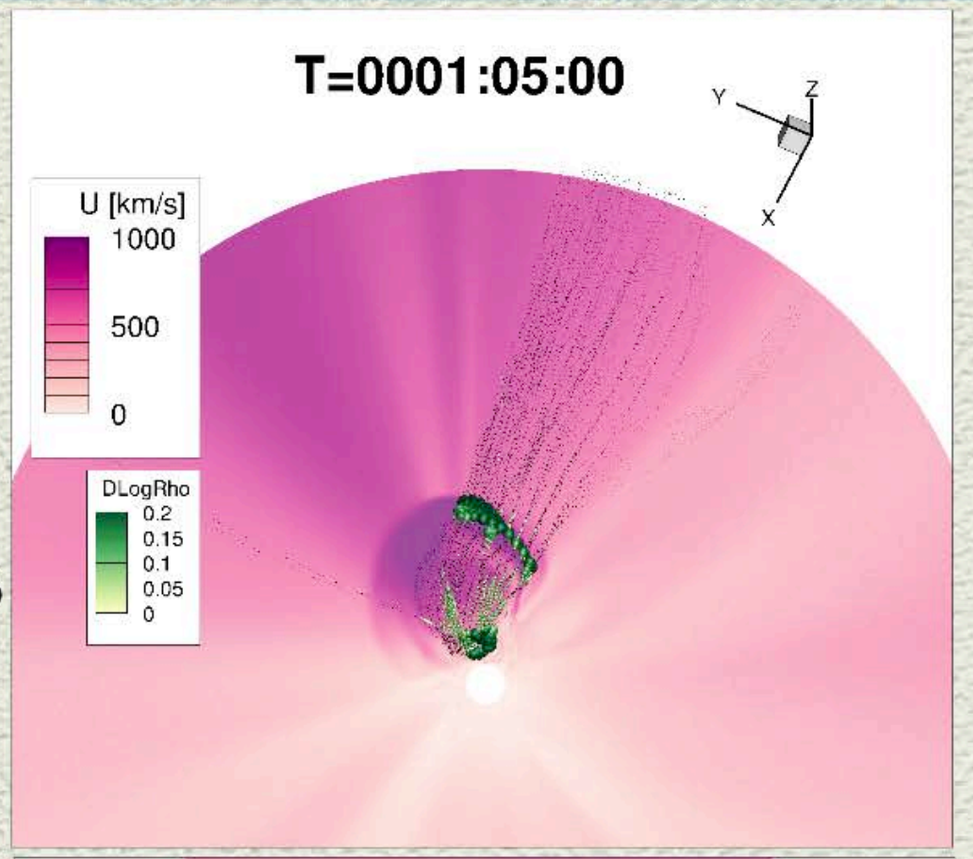
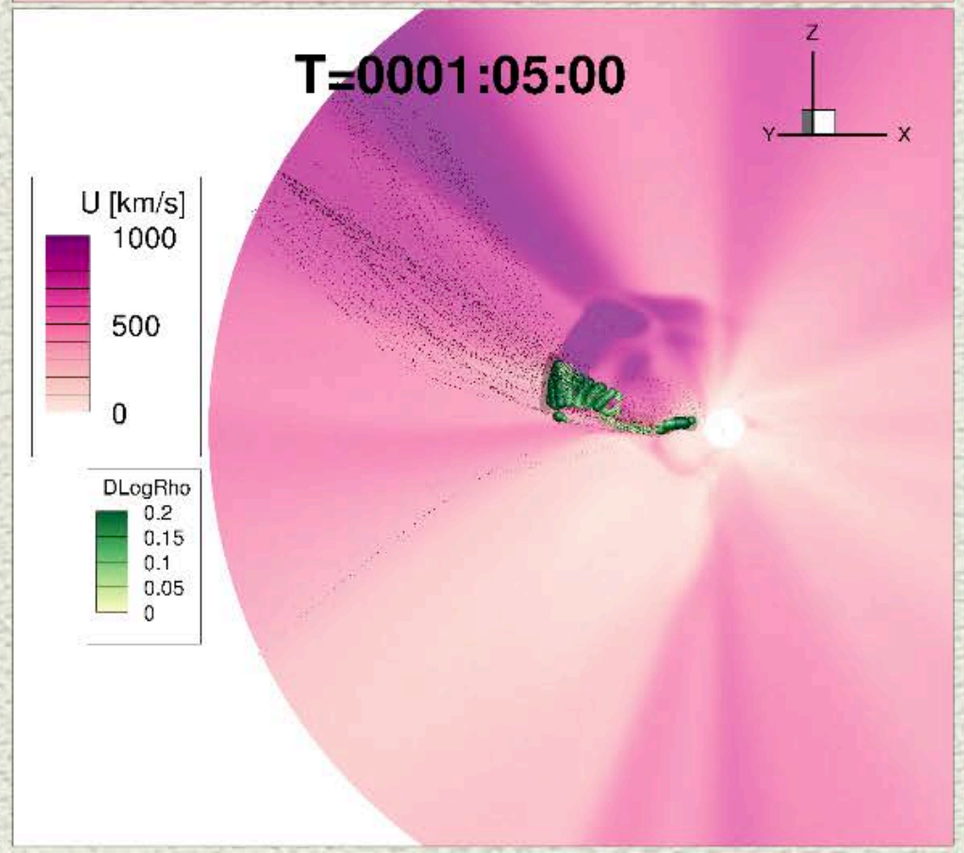
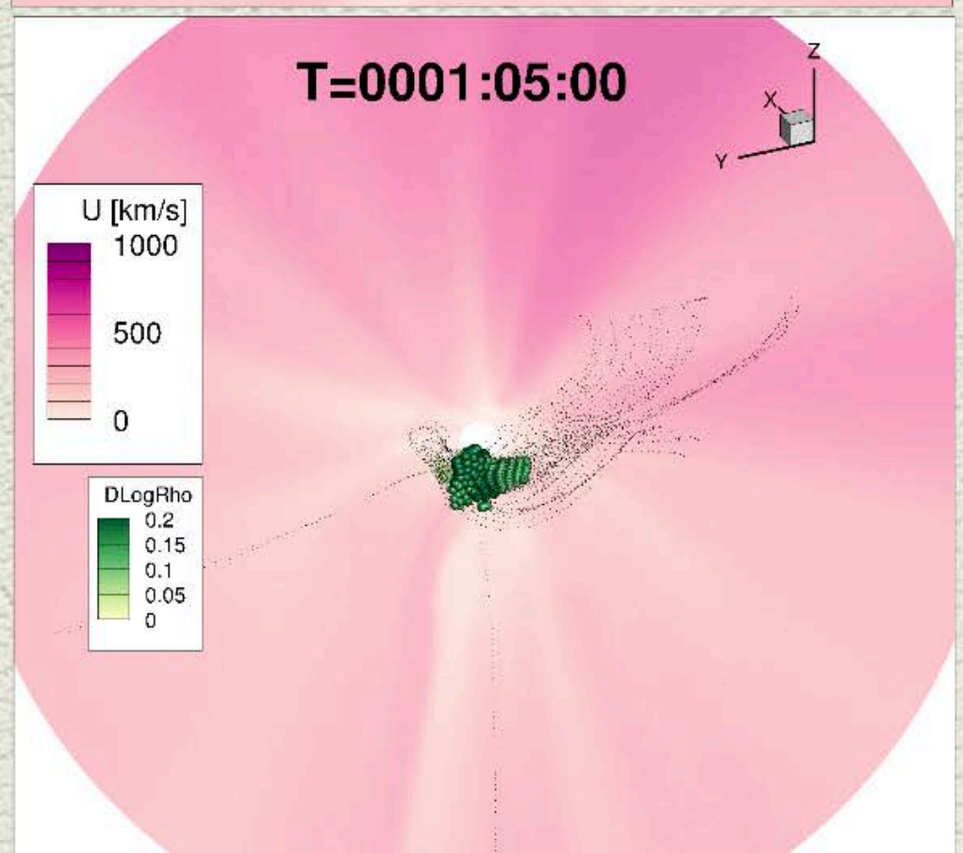


D. Borovikov





Conclusions

- We routinely reproduce Radio synthetic images in all Radio wavelengths
- Computationally efficient simulation
- Both Quiescent corona and Transients captured
- Goal: capture non-thermal signatures
- CME-flare relation enigmatic. Radio observations will provide insights into underlying processes. We need model to understand the observations.