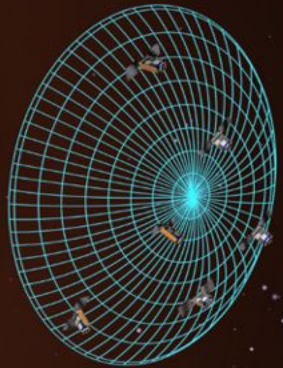
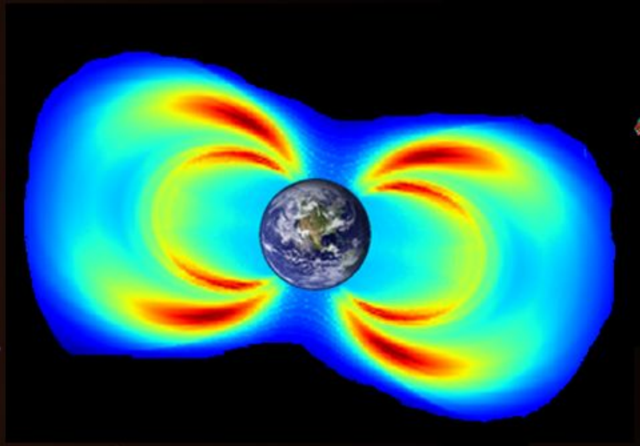
Localizing the Source of Type II Emission Around a CME with SunRISE & MHD Simulations





Dr. Alexander Hegedus

NESS Site Visit

11/30/20

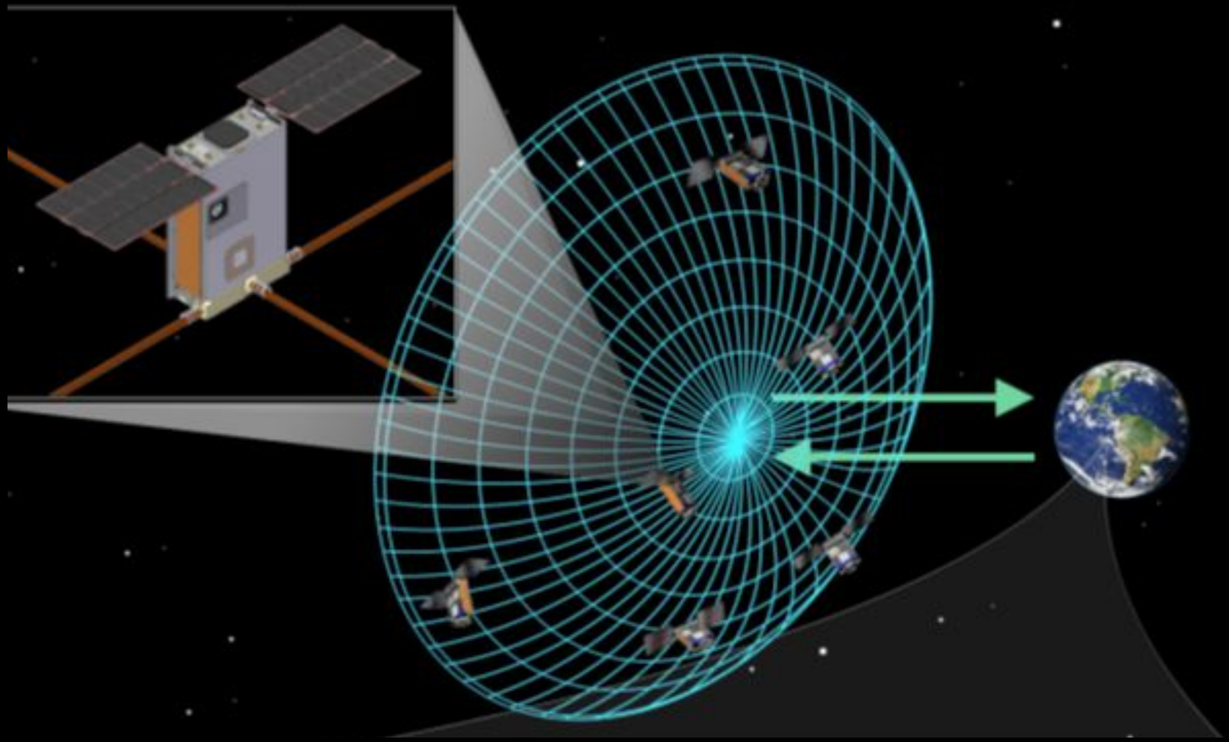
UNIVERSITY OF MICHIGAN

OUTLINE

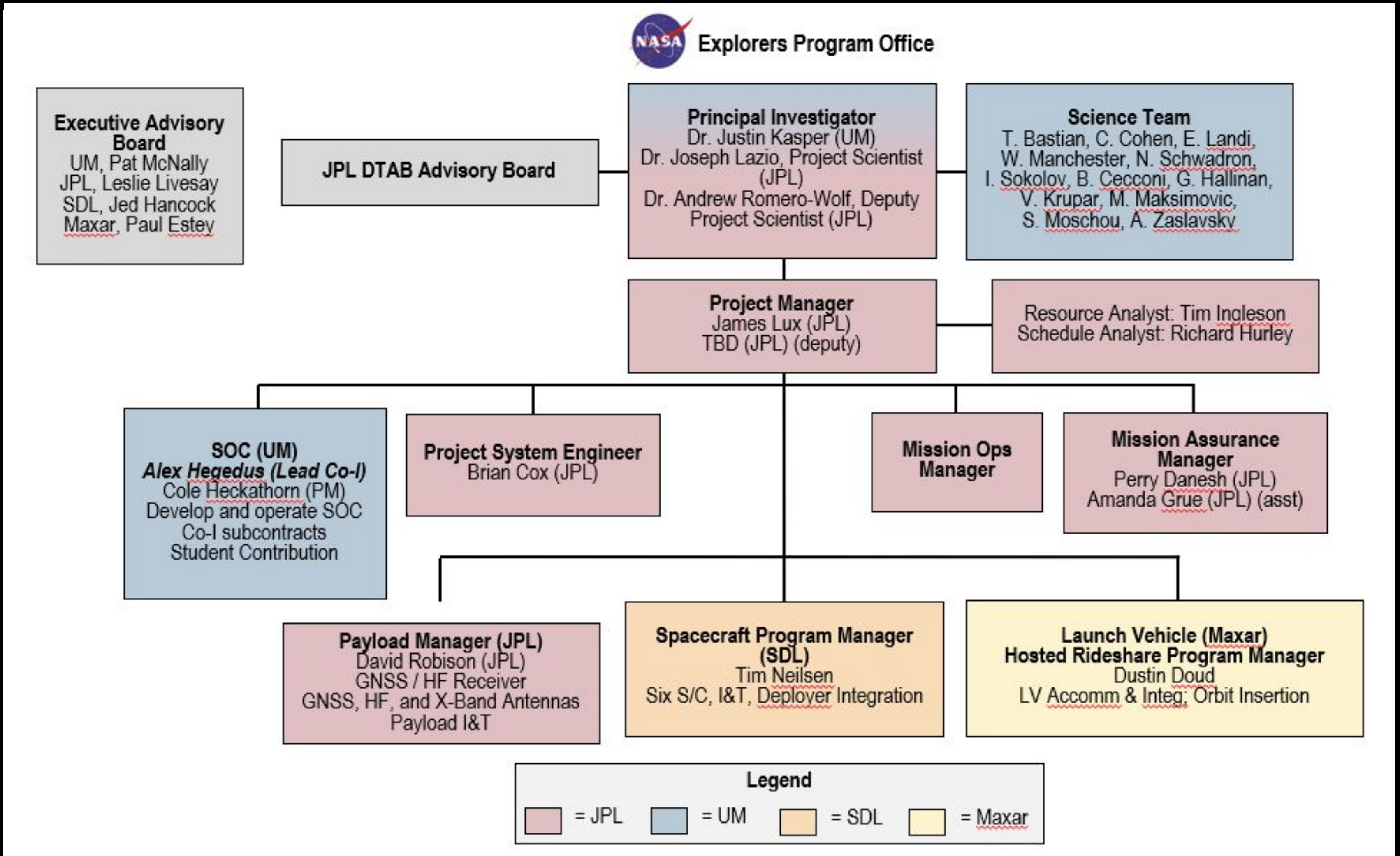
- SunRISE’s Primary Science
- Intro to MHD and SunRISE Pipeline
- Making & Scoring Synthetic Spectra
- Geometrical Data Cuts
- Geometrical and Plasma Parameter Data Cuts
- Discussion & Conclusions

SUNRISE INTRODUCTION

- SunRISE – Sun Radio Interferometer Space Experiment
- Heliophysics Explorers Mission of Opportunity ($55 M)
- Almost done with Phase B
- Will launch mid 2023
- 6 CubeSats in GEO Graveyard Orbit
- Can see below Ionospheric Cutoff

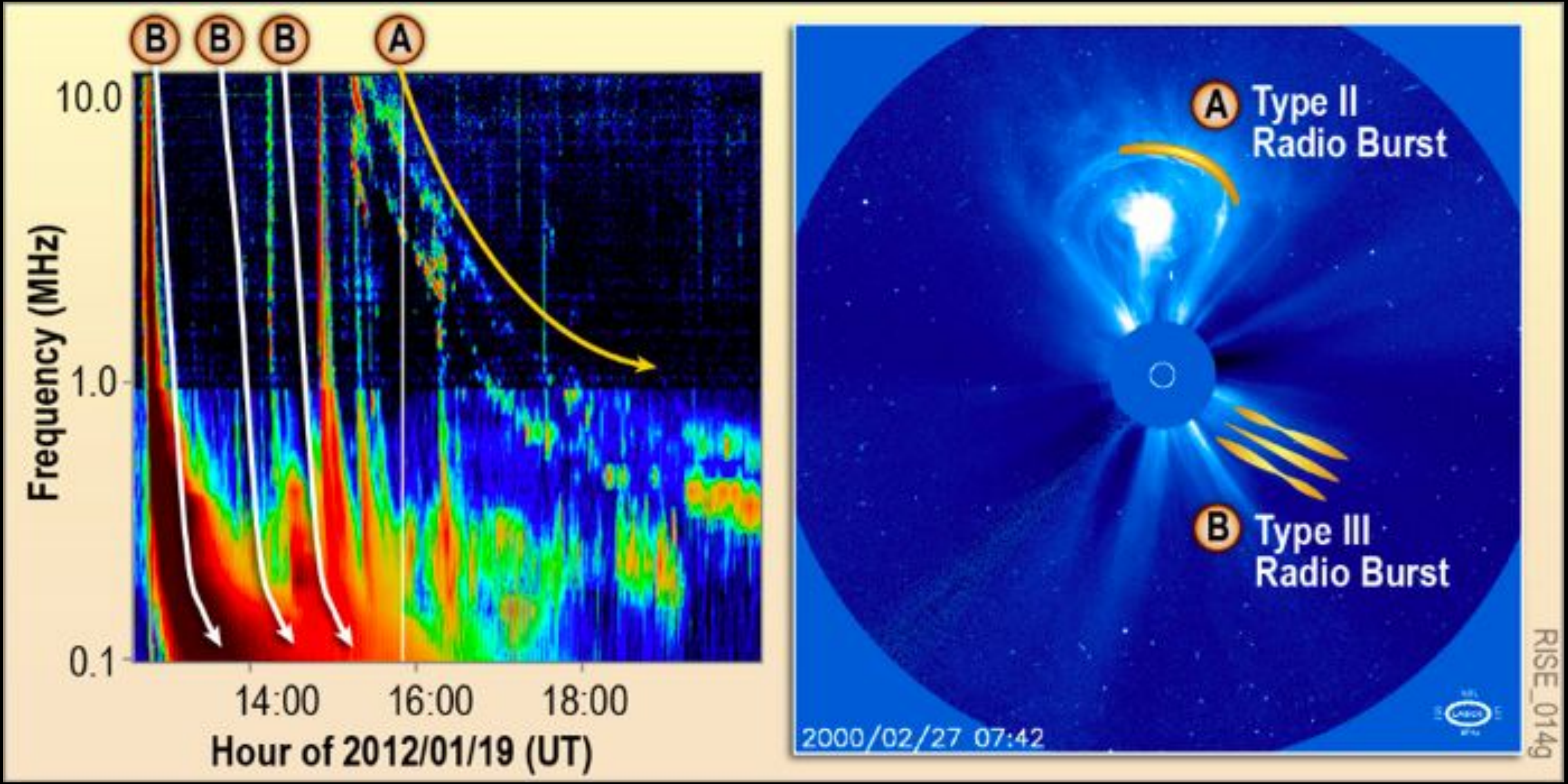


SUNRISE ORG CHART



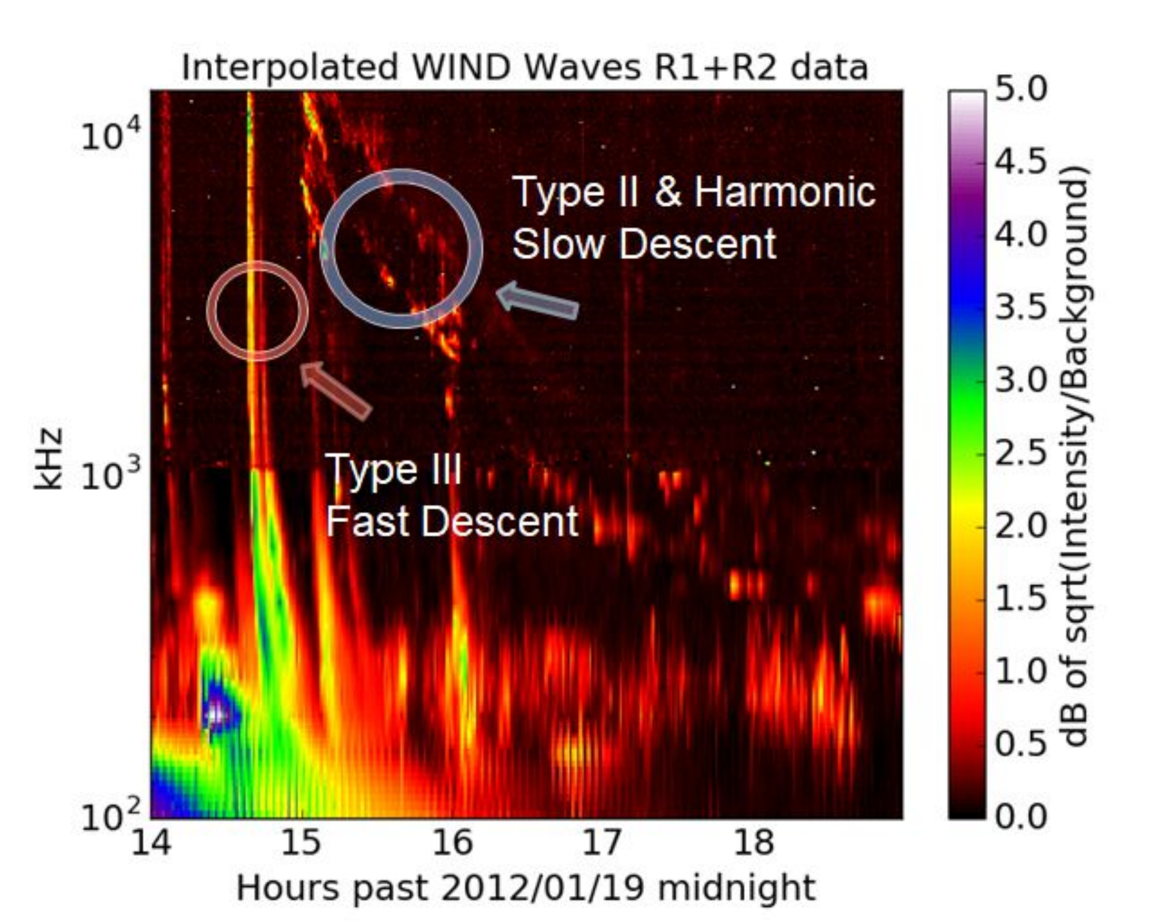
PRIMARY SCIENCE: SOLAR TYPE II & III BURSTS

$$f\,(\mathrm{kHz}) = f_p = 9\sqrt{n\left(\mathrm{cm}^{-3}\right)}$$



CMES AND SEPS

- 2 types of SEP events: gradual and impulsive
- Gradual SEP events linked to Type II Bursts Generated near CME driven shock?
- Impulsive SEP events linked to Type III Bursts Generated by electron beams from jets?
- Frequency drift marks speed of wave generation site through the heliosphere



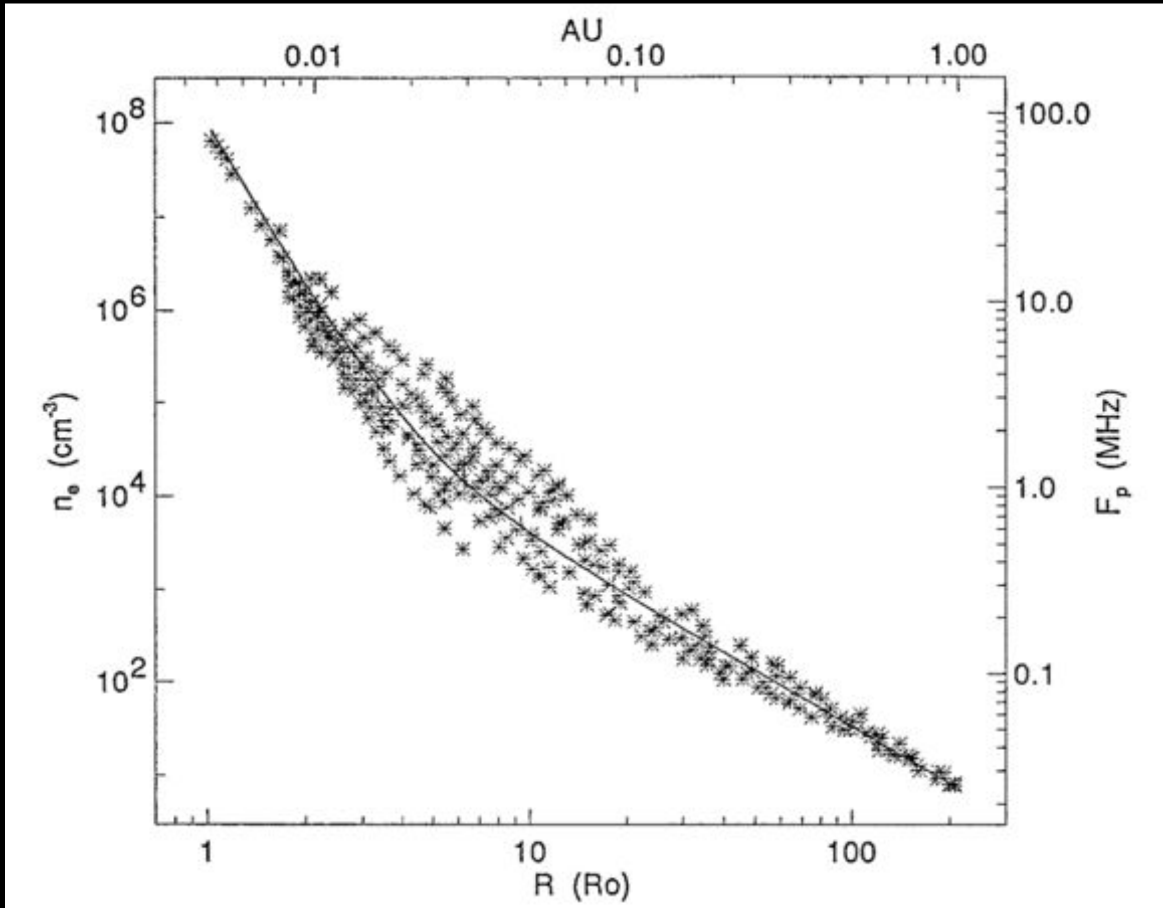
PLASMA FREQUENCY

- Frequency drift marks speed of wave generation site through the heliosphere

- Local Plasma Frequency depends on local electron density

$$\omega_{pe} = \sqrt{\frac{n_e e^2}{m_e \epsilon_0}} = 8.98\mathrm{kHz}\sqrt{n_e/cm^3}$$

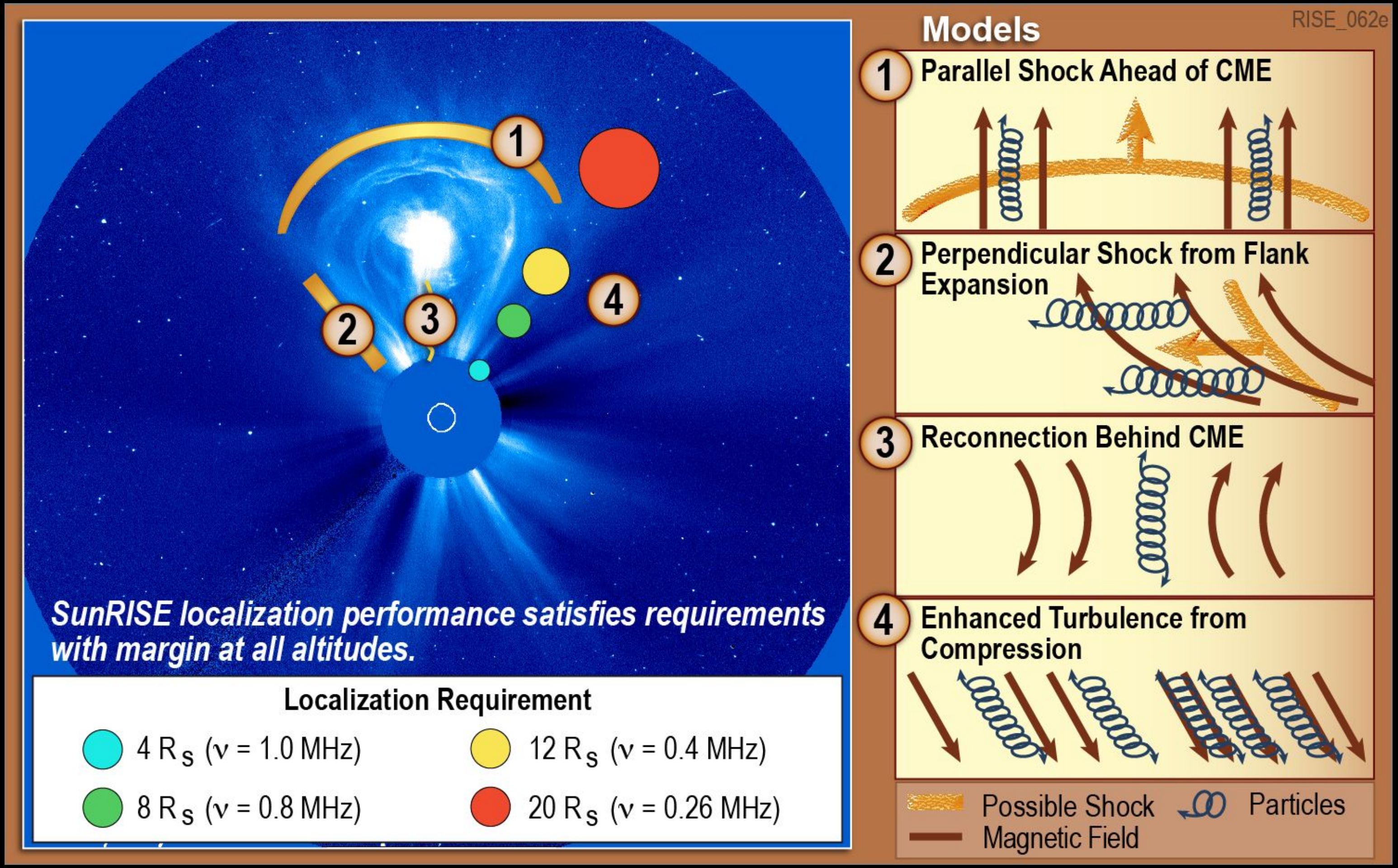
- Type III data used to create average density profiles over 1 AU (LeBlanc et al.)



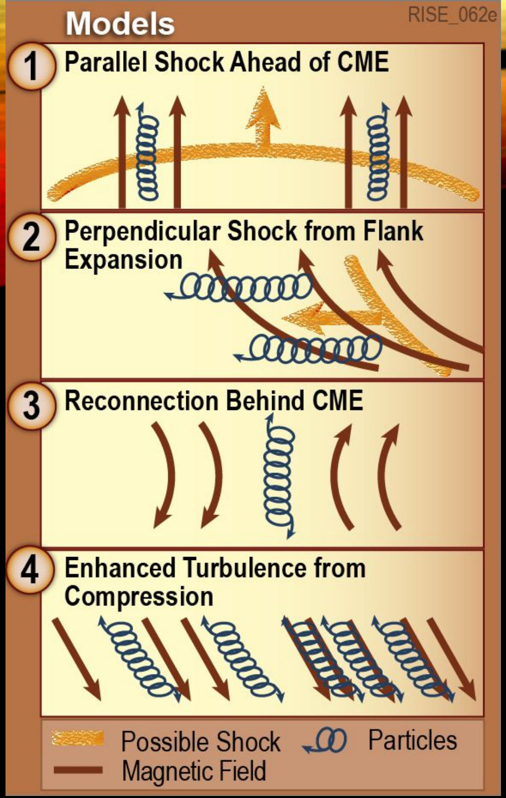
CONNECT EVOLUTION OF RADIO BURST TO ONE OF FOUR MODELS

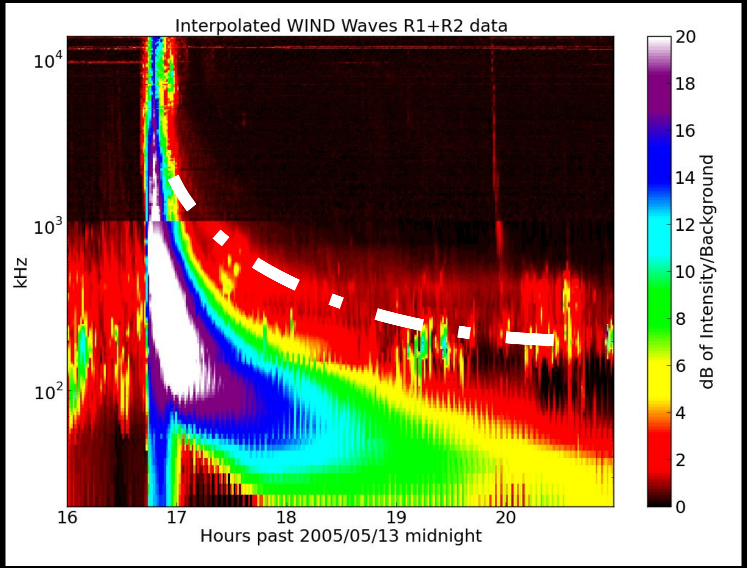
SunRISE Objective 1

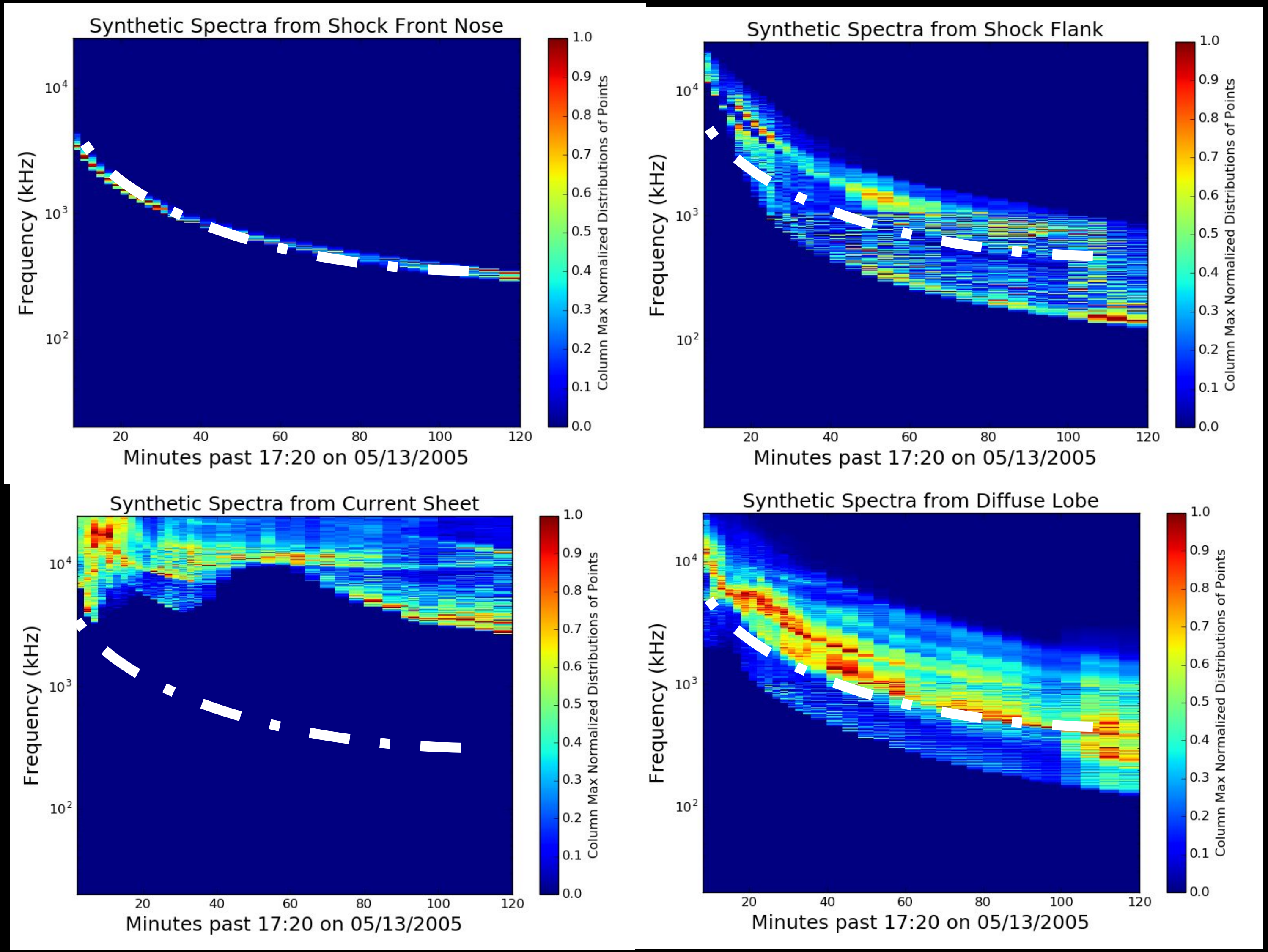
Discriminate competing hypotheses for the source mechanism of CME-associated SEPs by measuring the location and distribution of Type II radio emission relative to expanding CMEs 2–20 Rs from the Sun, where the most intense acceleration occurs.



PAST SYNTHETIC SPECTRA FROM MHD



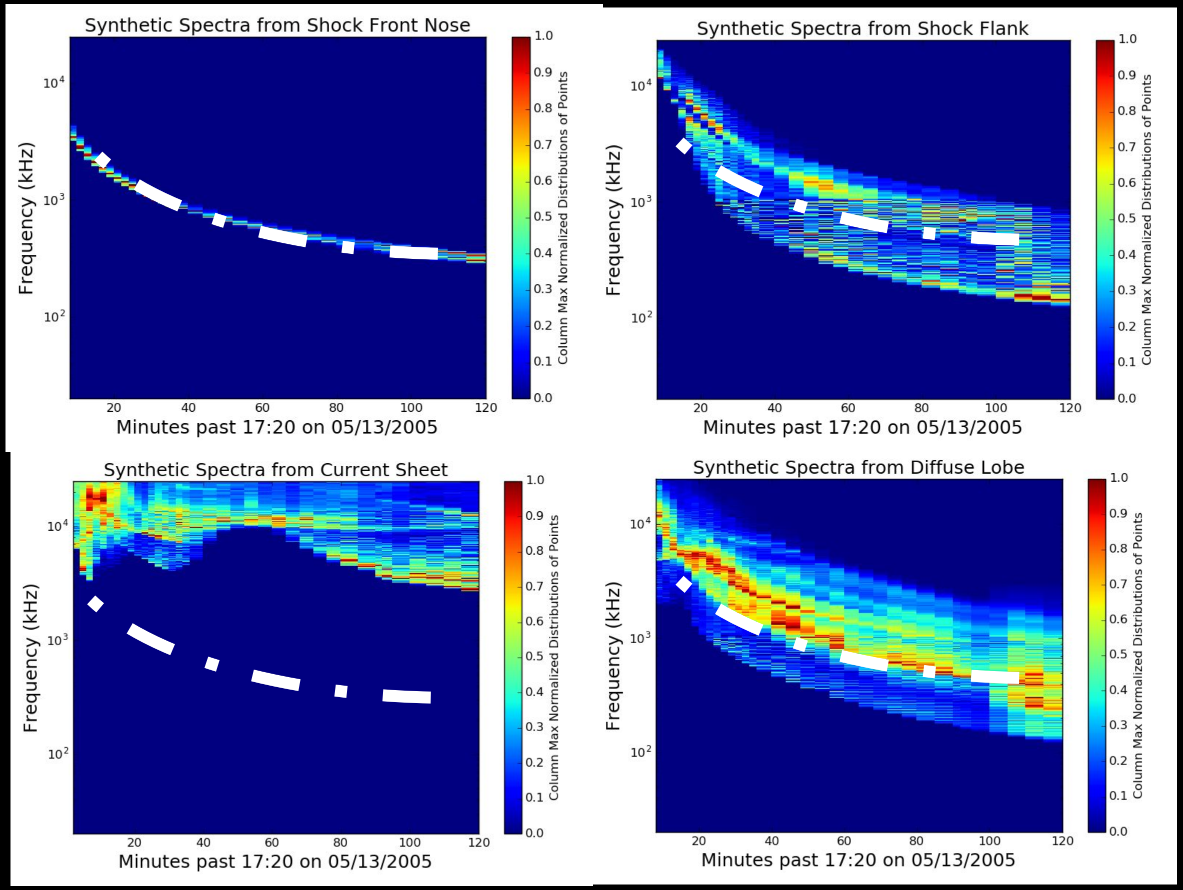




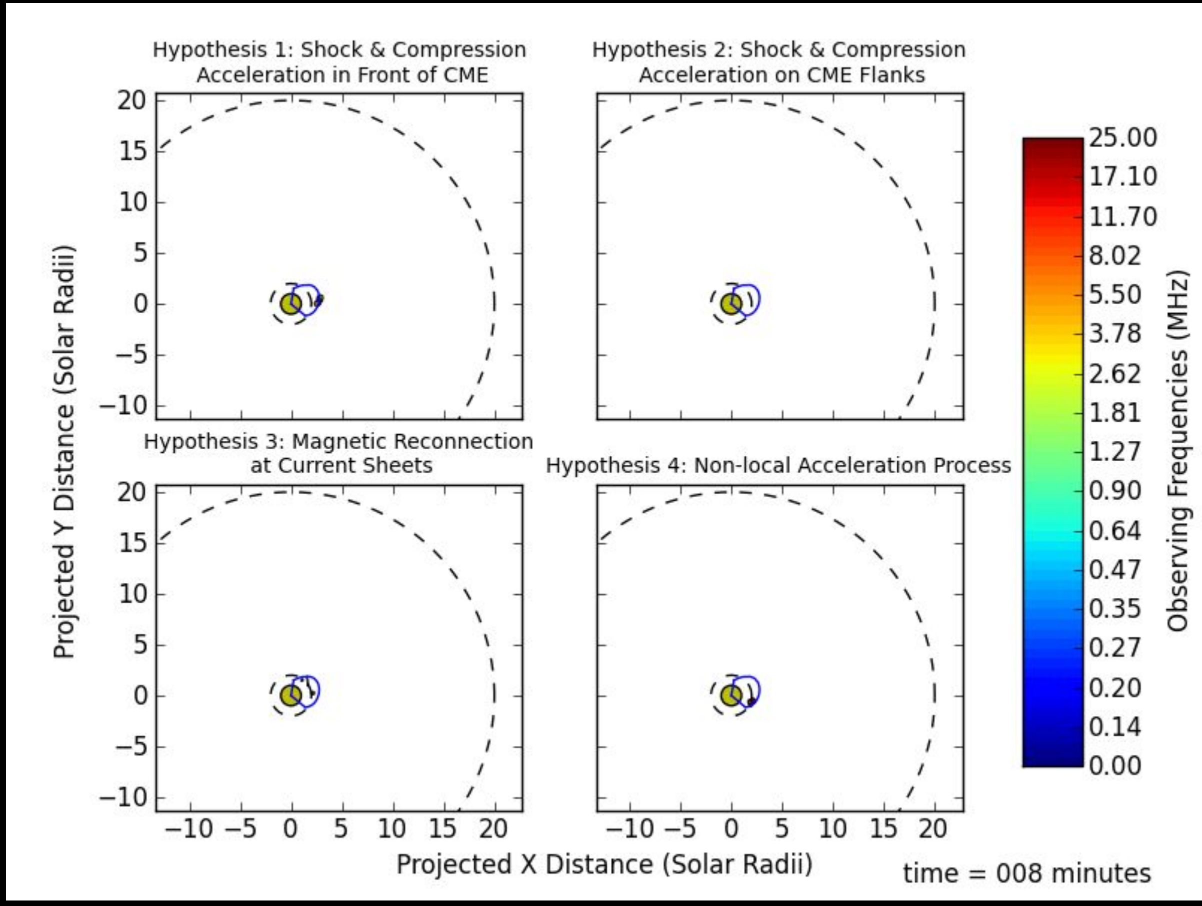
SUNRISE RECOVERED RADIO EMISSION

Previous version used rotated simulation to show limb event

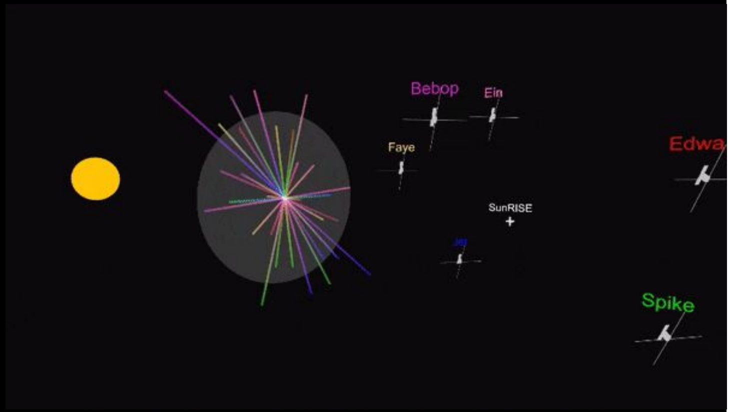
MHD Geometrical Derived Synthetic spectra

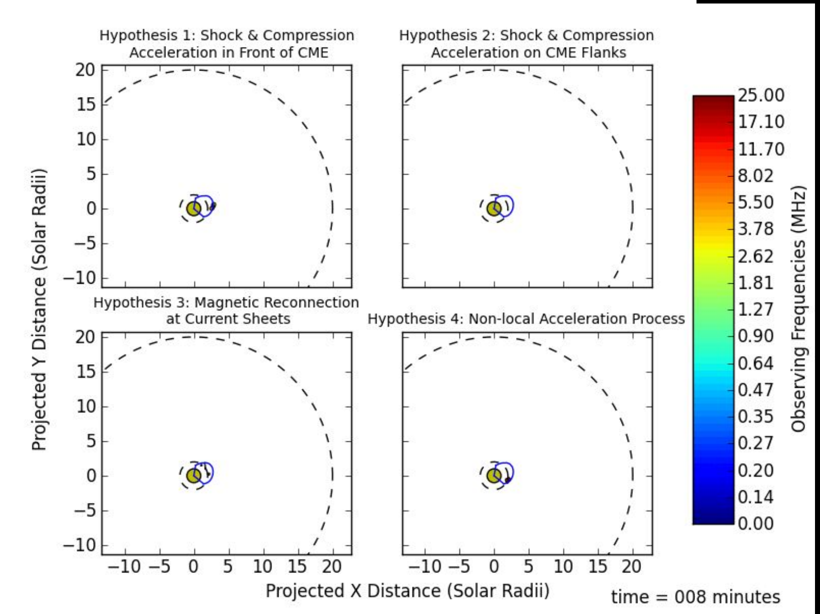


Visual Proof of Scientific Sufficiency: SunRISE recovered localizations over time

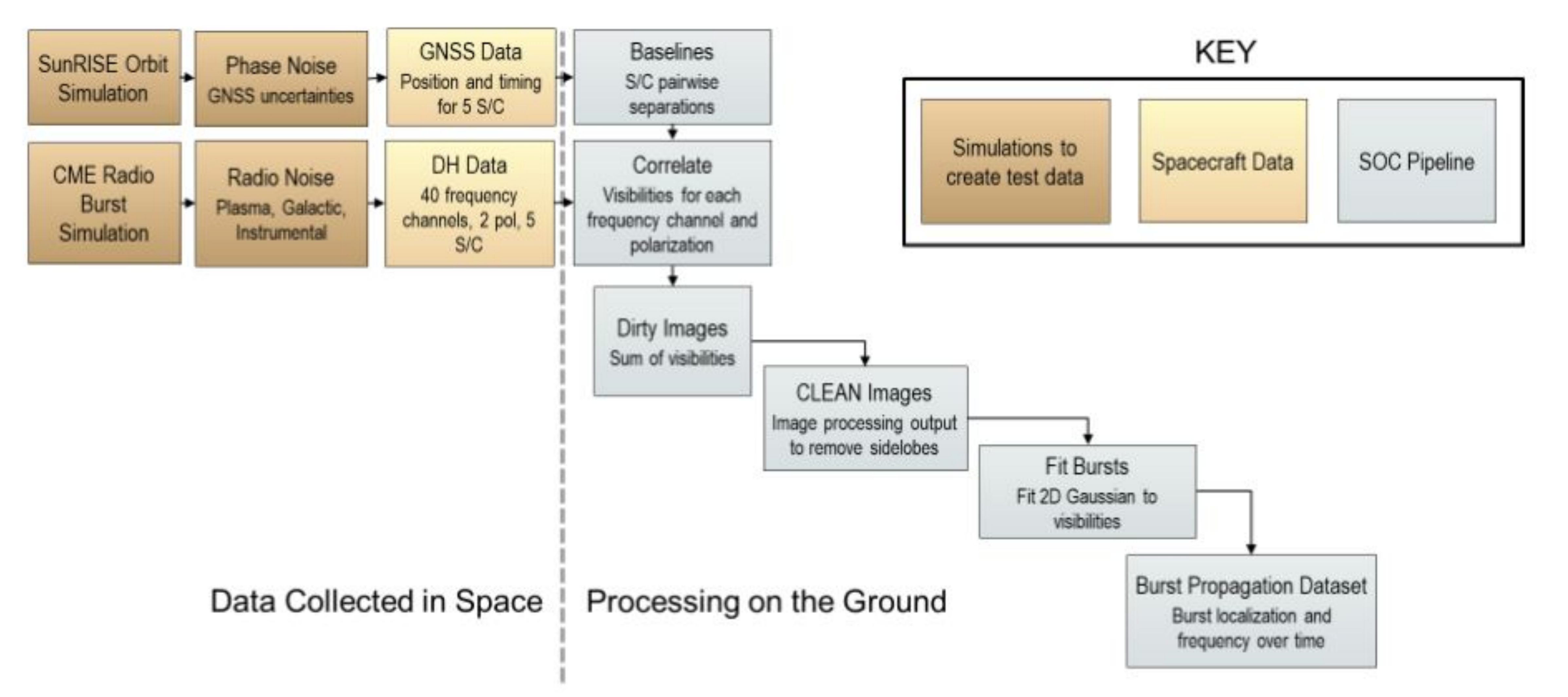


HIGH LEVEL PIPELINE TESTING OVERVIEW



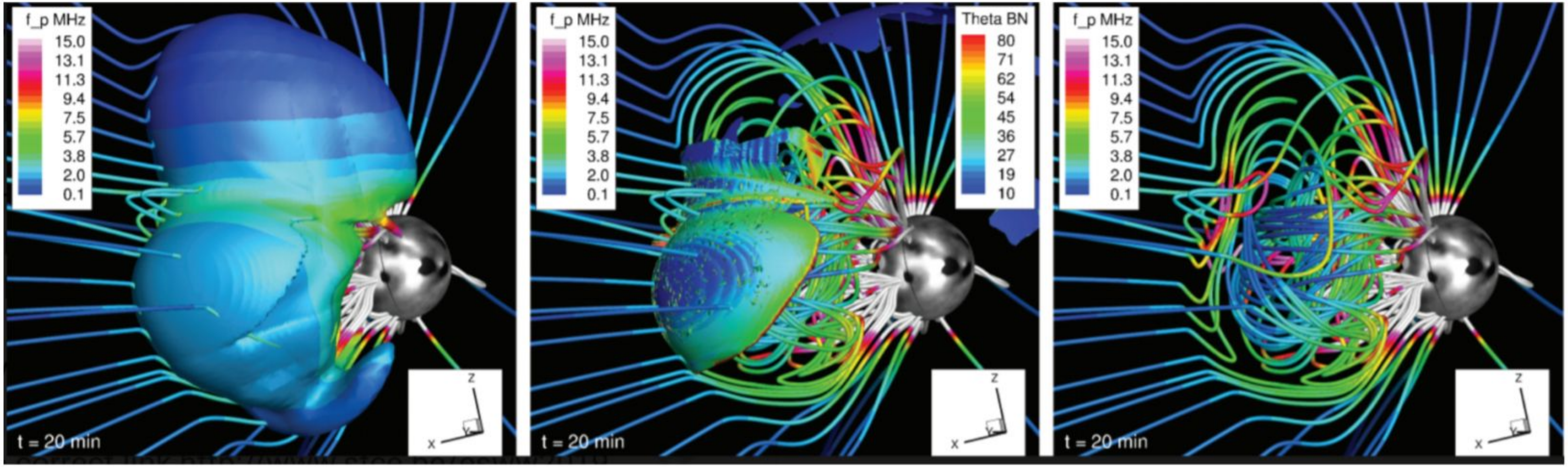


PIPELINE OVERVIEW



MHD CME SIMULATION

CME Density Enhancement | Entropy Derived Shock | Magnetic Field

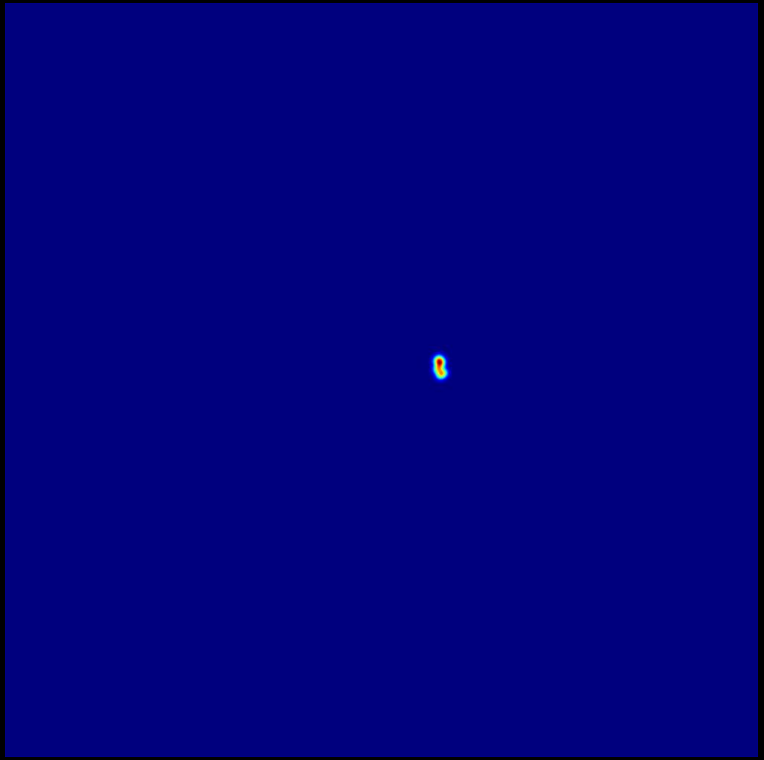


Snapshots from a AWSoM 2-Temperature MHD Simulation of a Radio-Loud CME on May 13, 2005

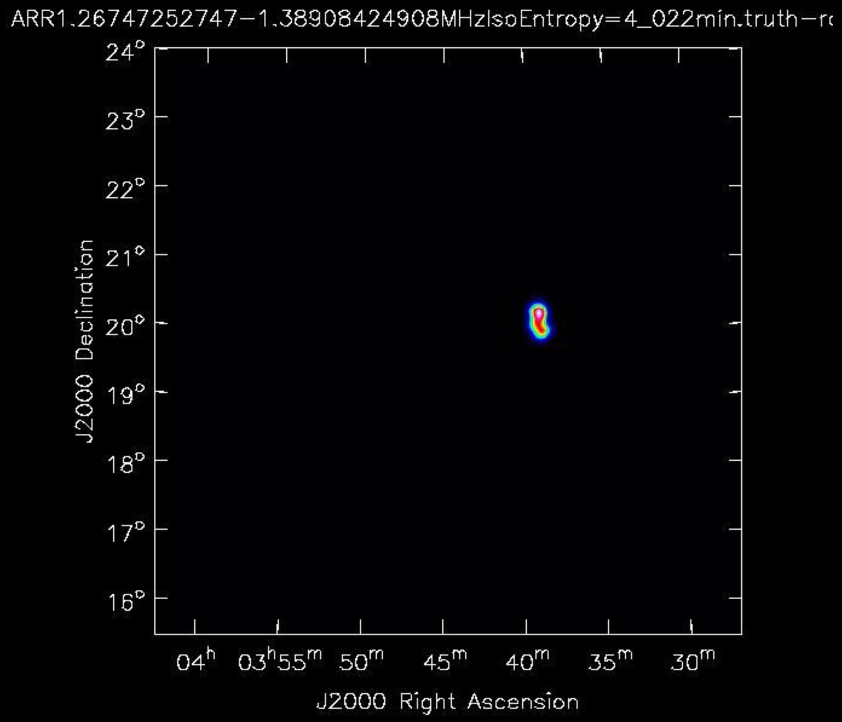
Manchester et al. 2014

EXAMPLE OF MHD EXTRACTION TO SUNRISE

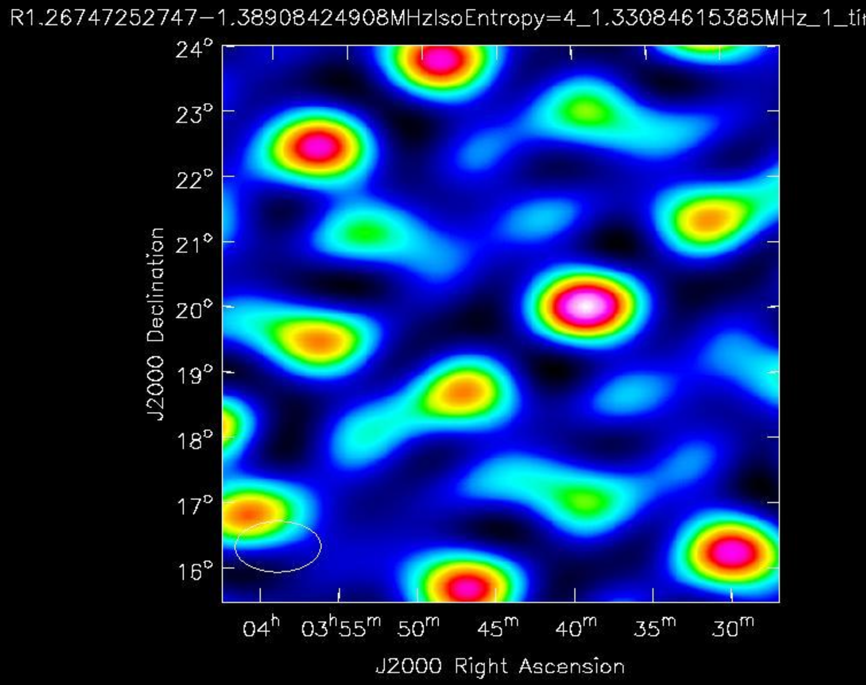
Gaussian convolved binary map over 6 kHz range



Imported to CASA truth image, given flux value

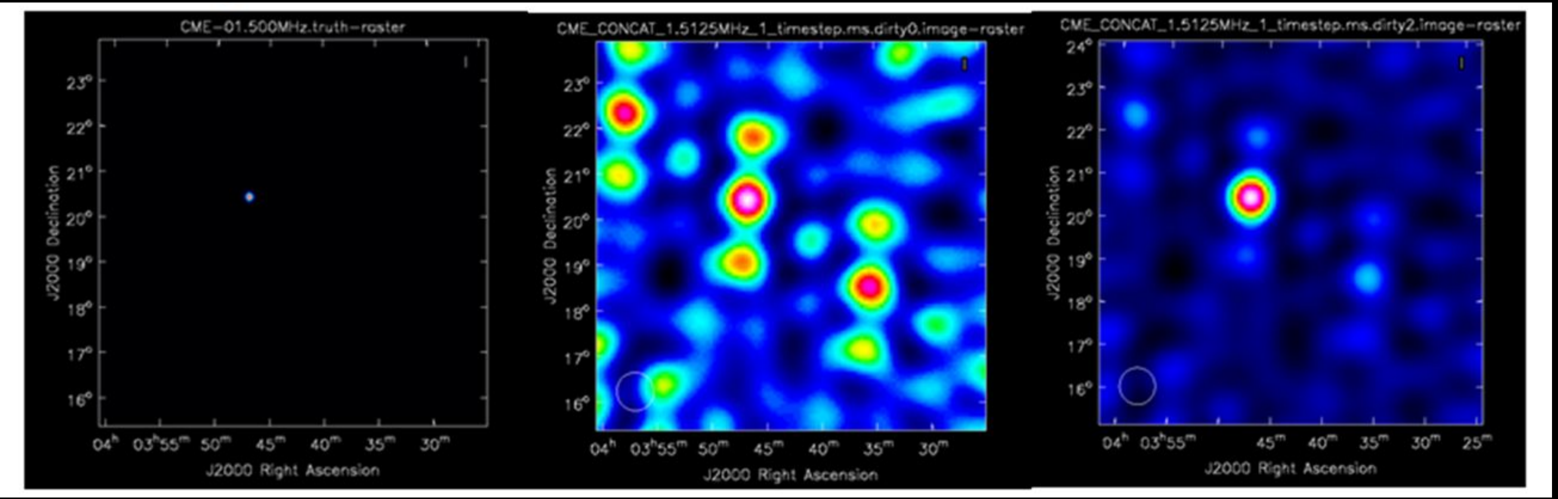


Run through SunRISE pipeline & extract Gaussian fit

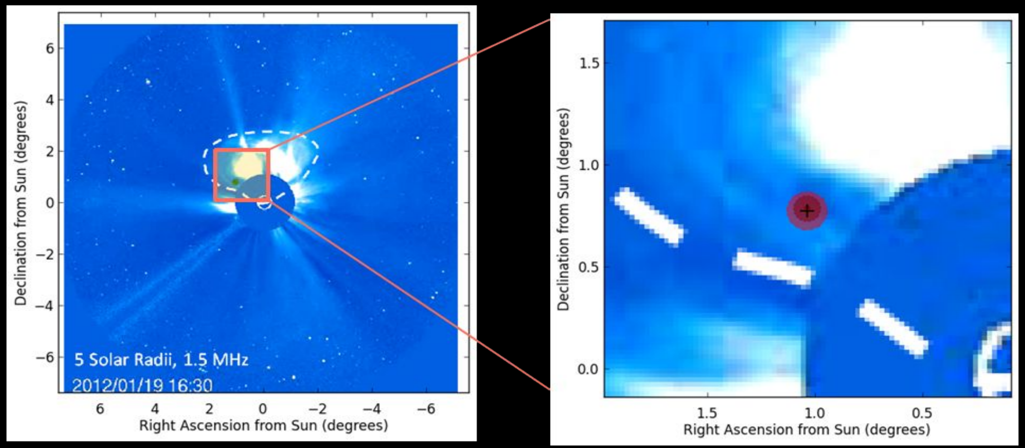


IMAGING PIPELINE AT 1.5 MHZ

1 2 3



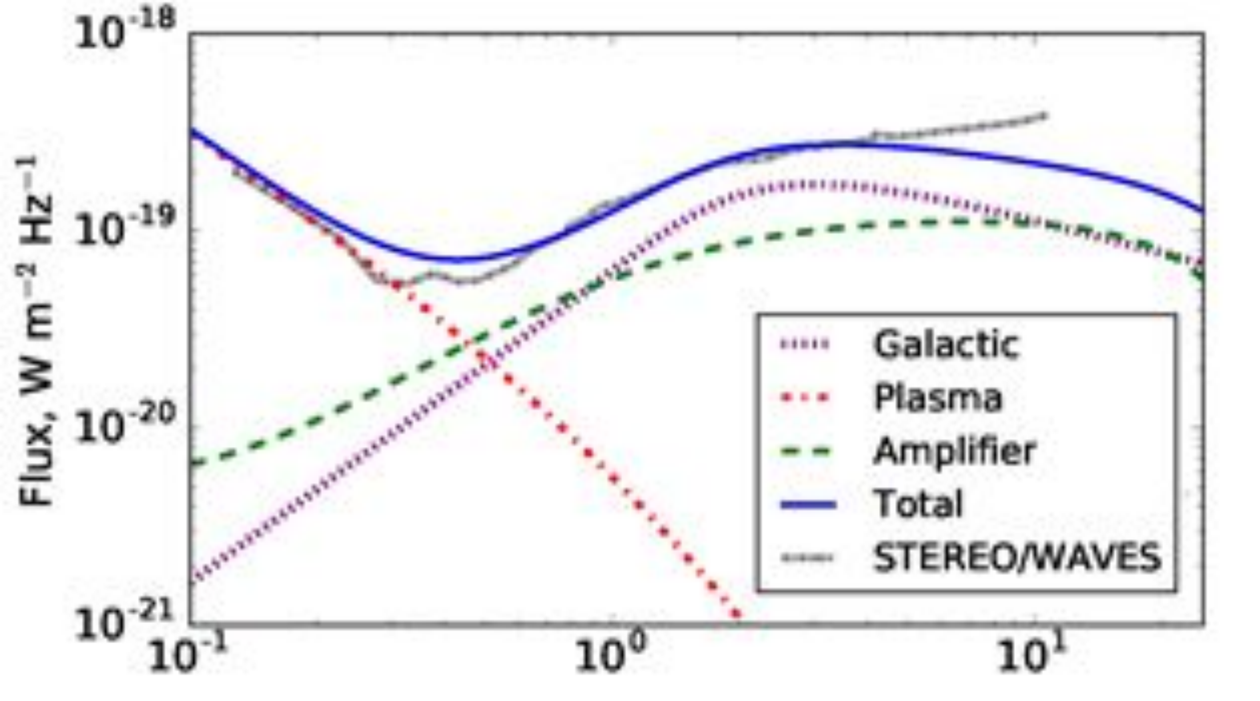
4



1. Simulation informed input emission distribution
2. Dirty Image with sidelobes
3. CLEANed Image with sidelobes removed
4. 2D Gaussian fit to data & put into context of CME Coronagraph Movie

SIGNAL TO NOISE CALCULATION

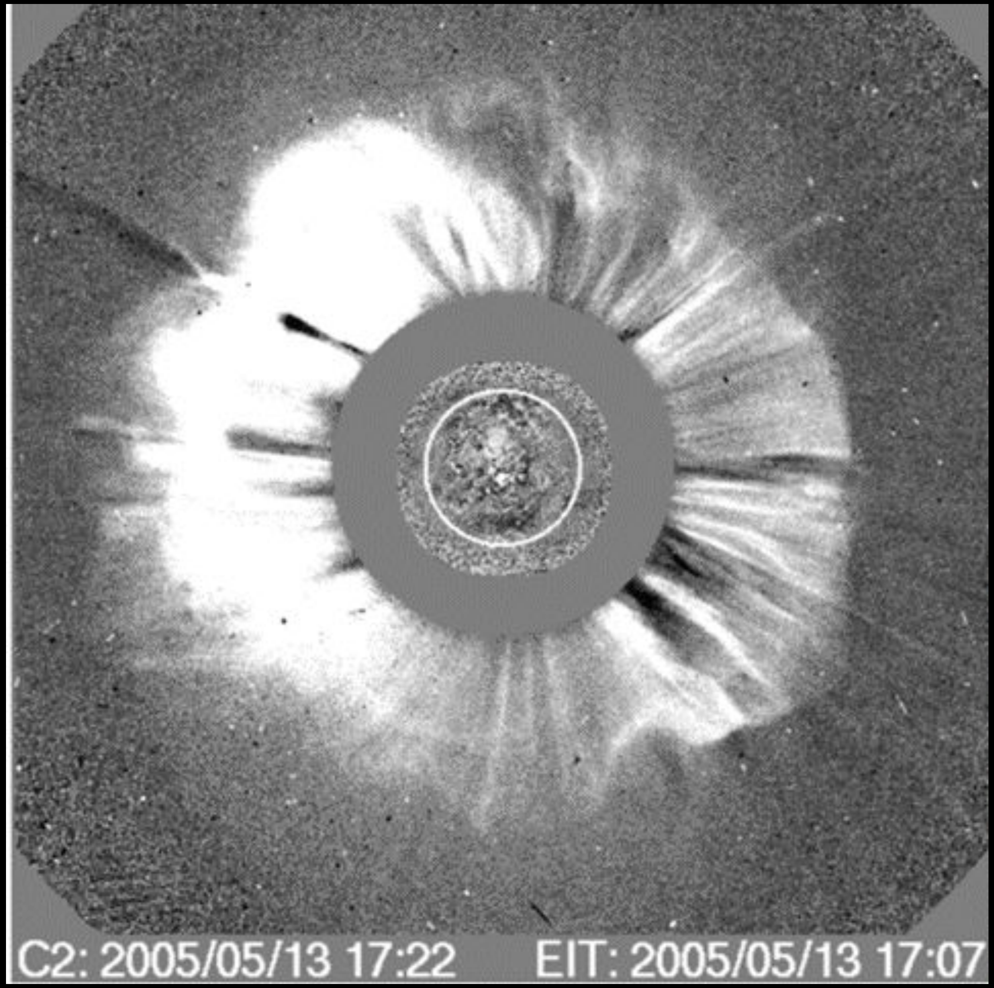
- Assume 5 m dual polarization isotropic dipoles (electrically short)
- 4096 channel Polyphase Filter Bank, 0-25 MHz, 6100 Hz channels, 6.6 ms / sec integration, 0.1 sec cadence
- Type II Signals ≈ Galactic & Plasma Noise
- Array: 6 spacecraft, 2 polarizations improves the sensitivity by a factor of 8.5

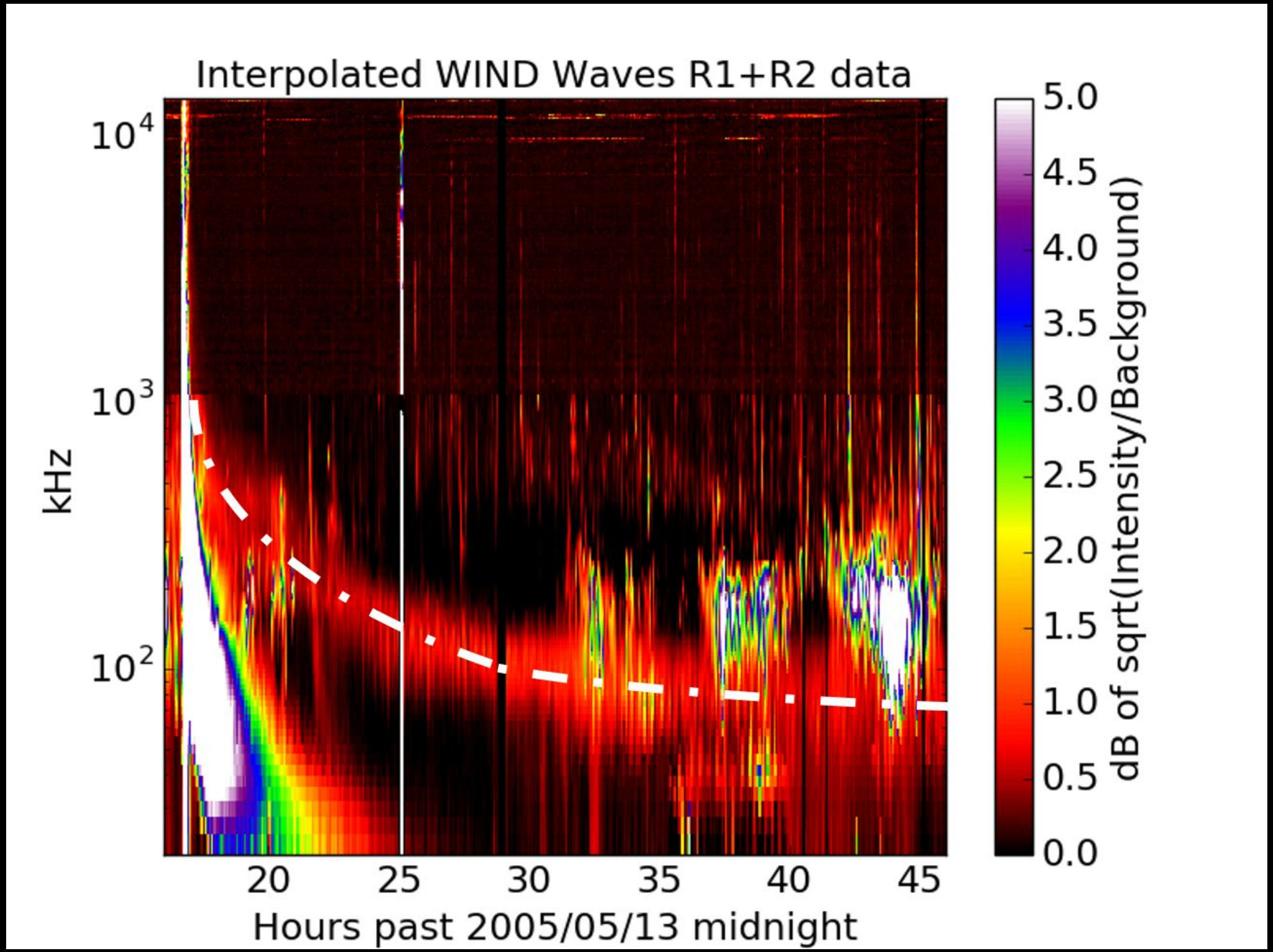


Taken from SunRISE CSR

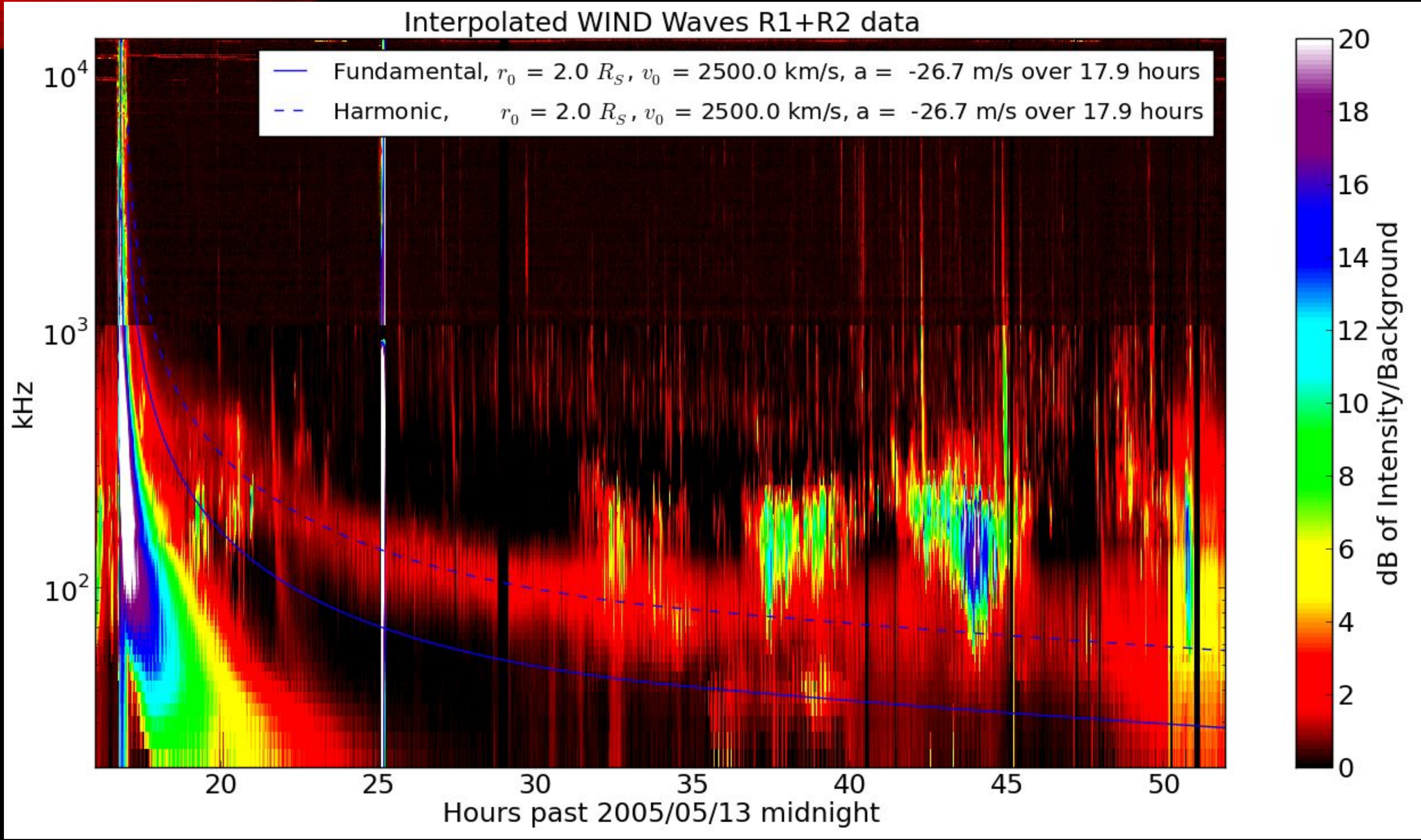
$$\sigma = \frac{2\,k_B\,T_{sys}}{\eta_s\,A_{eff}\,\sqrt{N(N-1)(N_{IF}\,\Delta T\,\Delta\nu)}}$$

CASE STUDY: 2005/05/13 CME



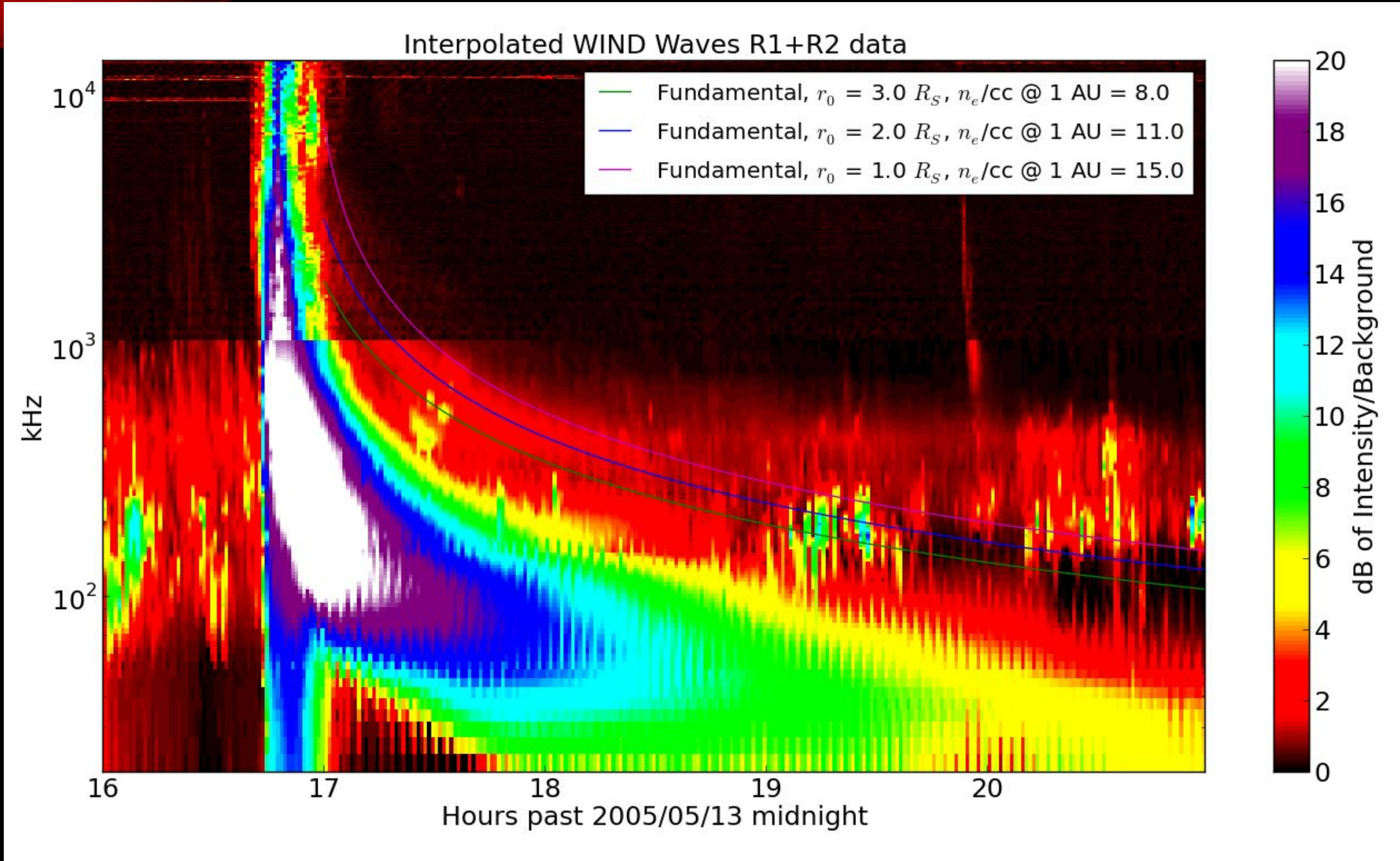


REAL WIND DATA & FIT CME PROFILE

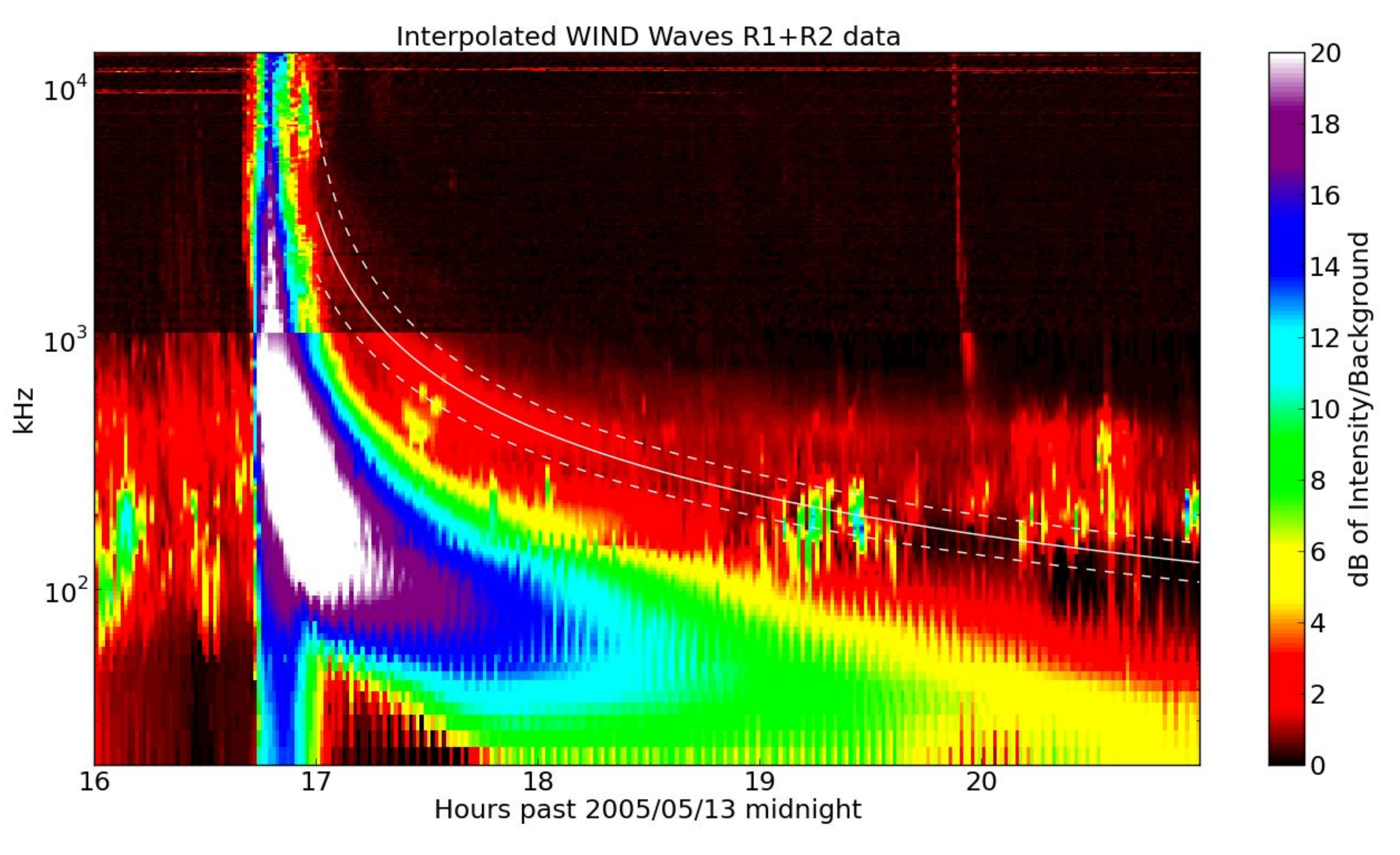


Reiner 2007 velocity fit

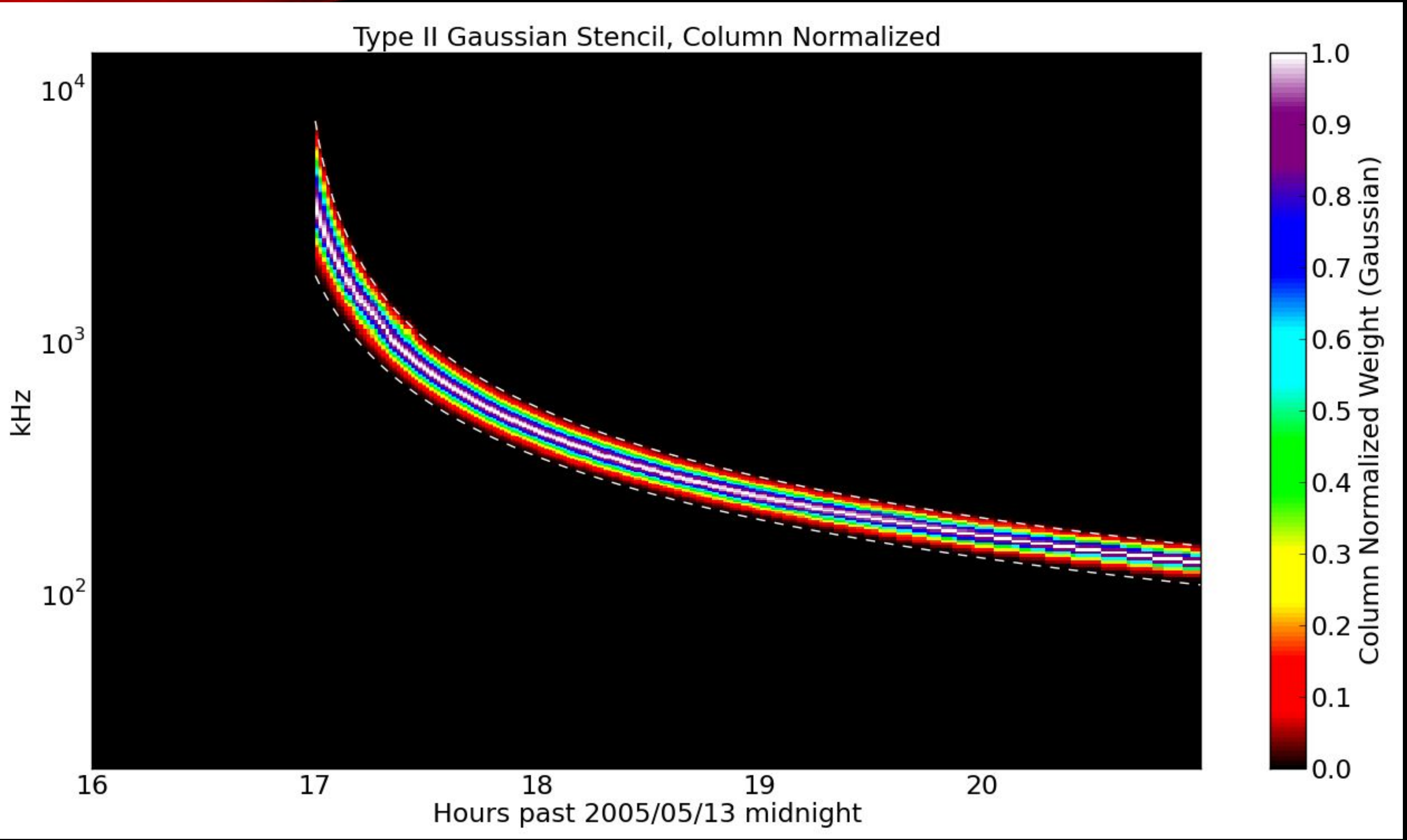
CREATING AN ANALYTIC GAUSSIAN PROFILE



CREATING AN ANALYTIC GAUSSIAN PROFILE



CREATING AN ANALYTIC GAUSSIAN PROFILE



Yields "Scoring Stencil"

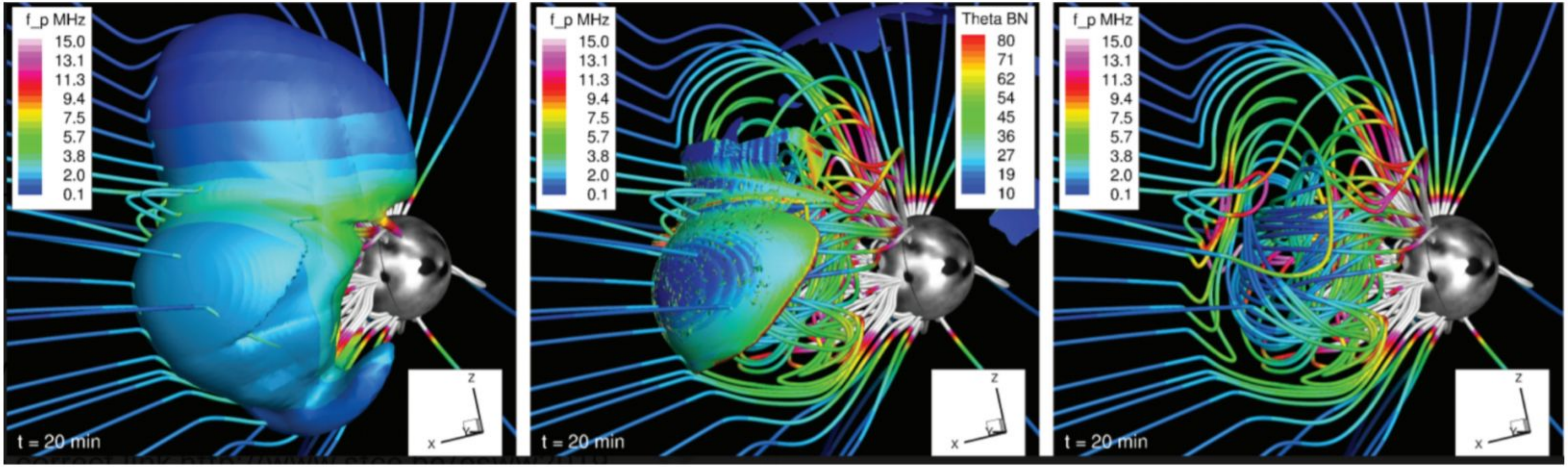
May be compared to synthetic spectra

Normalized so 1 point/ timestep possible

Rewards spectra matching middle frequency

MHD CME SIMULATION

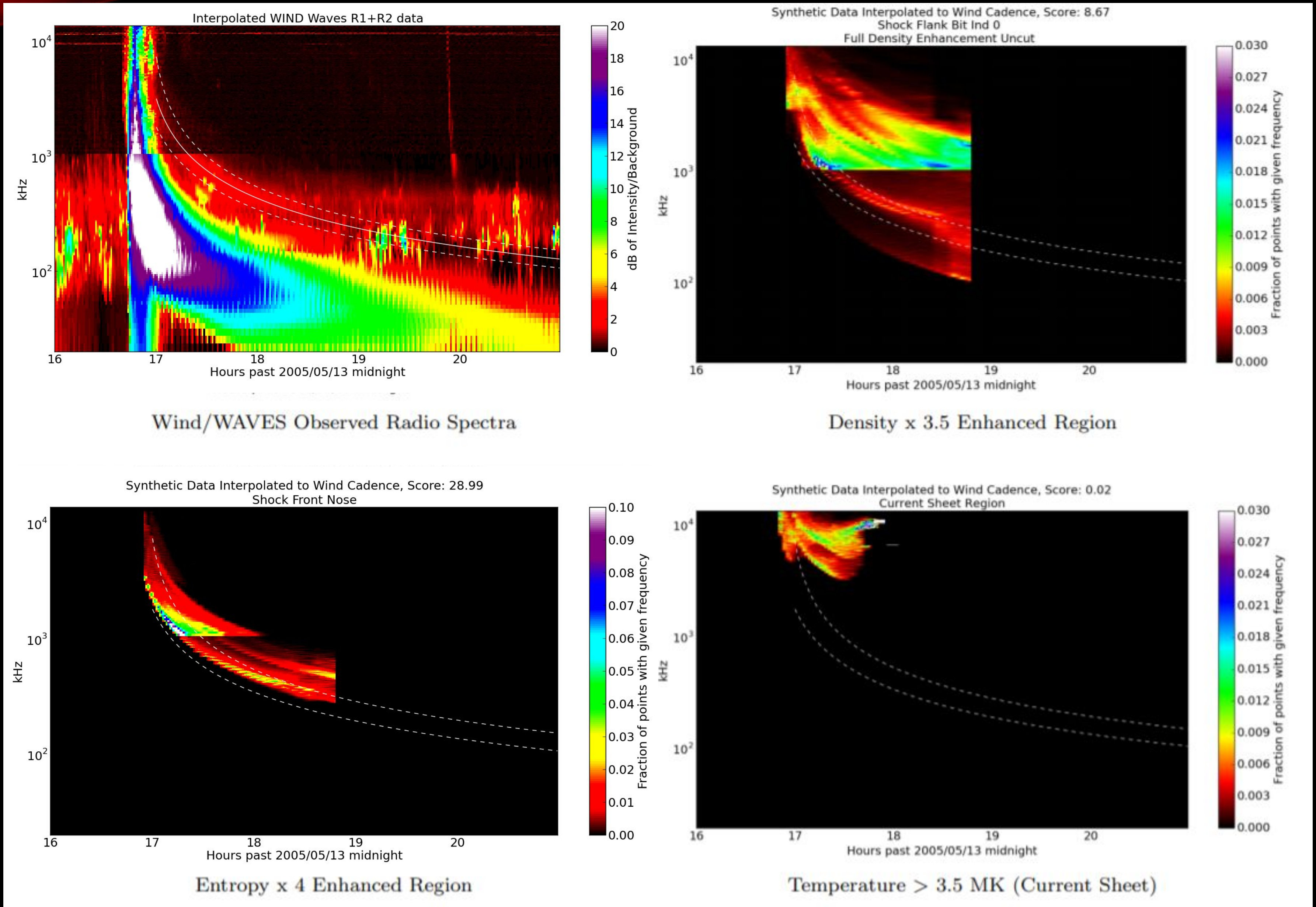
CME Density Enhancement Entropy Derived Shock Magnetic Field



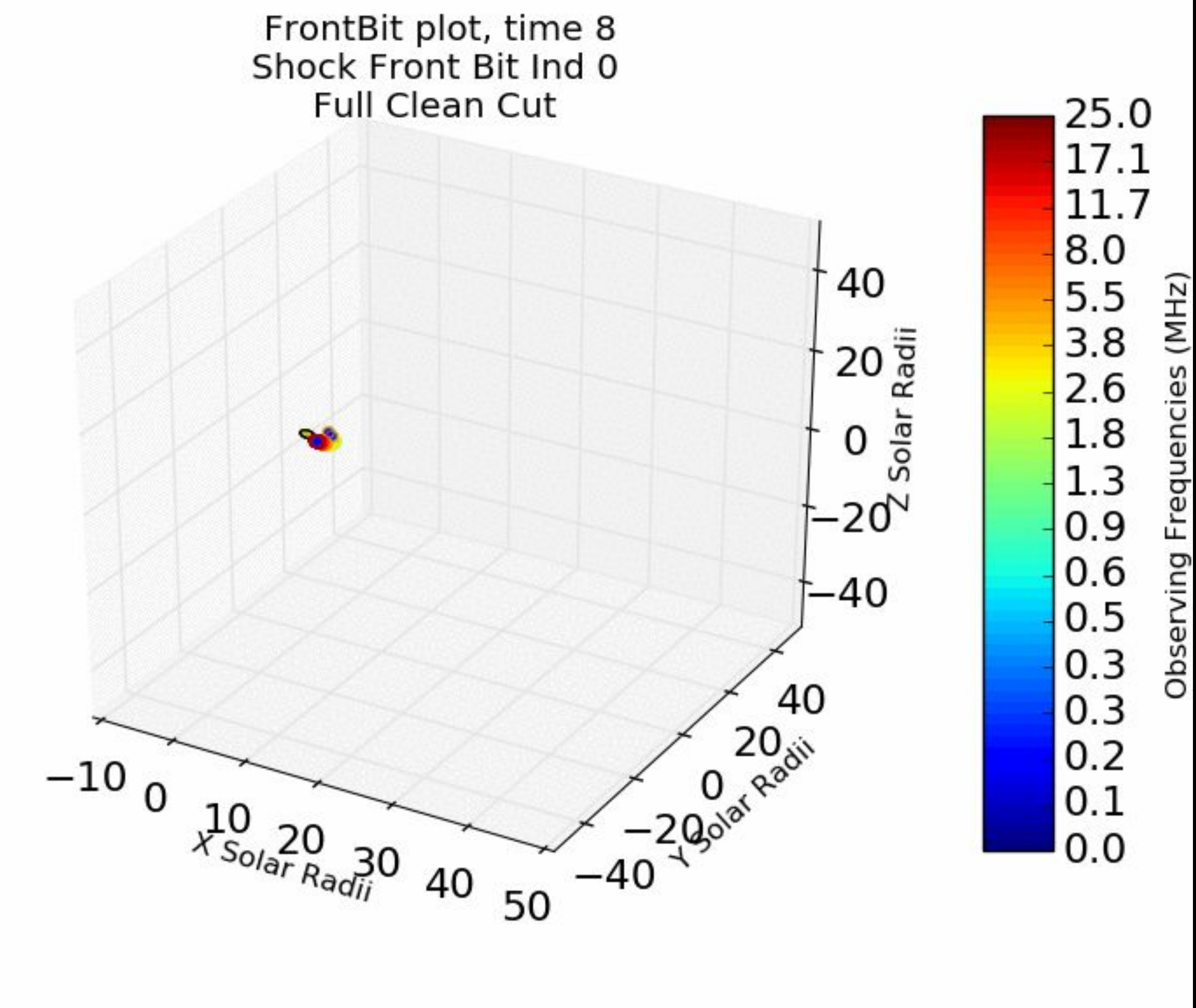
Snapshots from a AWSoM 2-Temperature MHD Simulation of a Radio-Loud CME on May 13, 2005

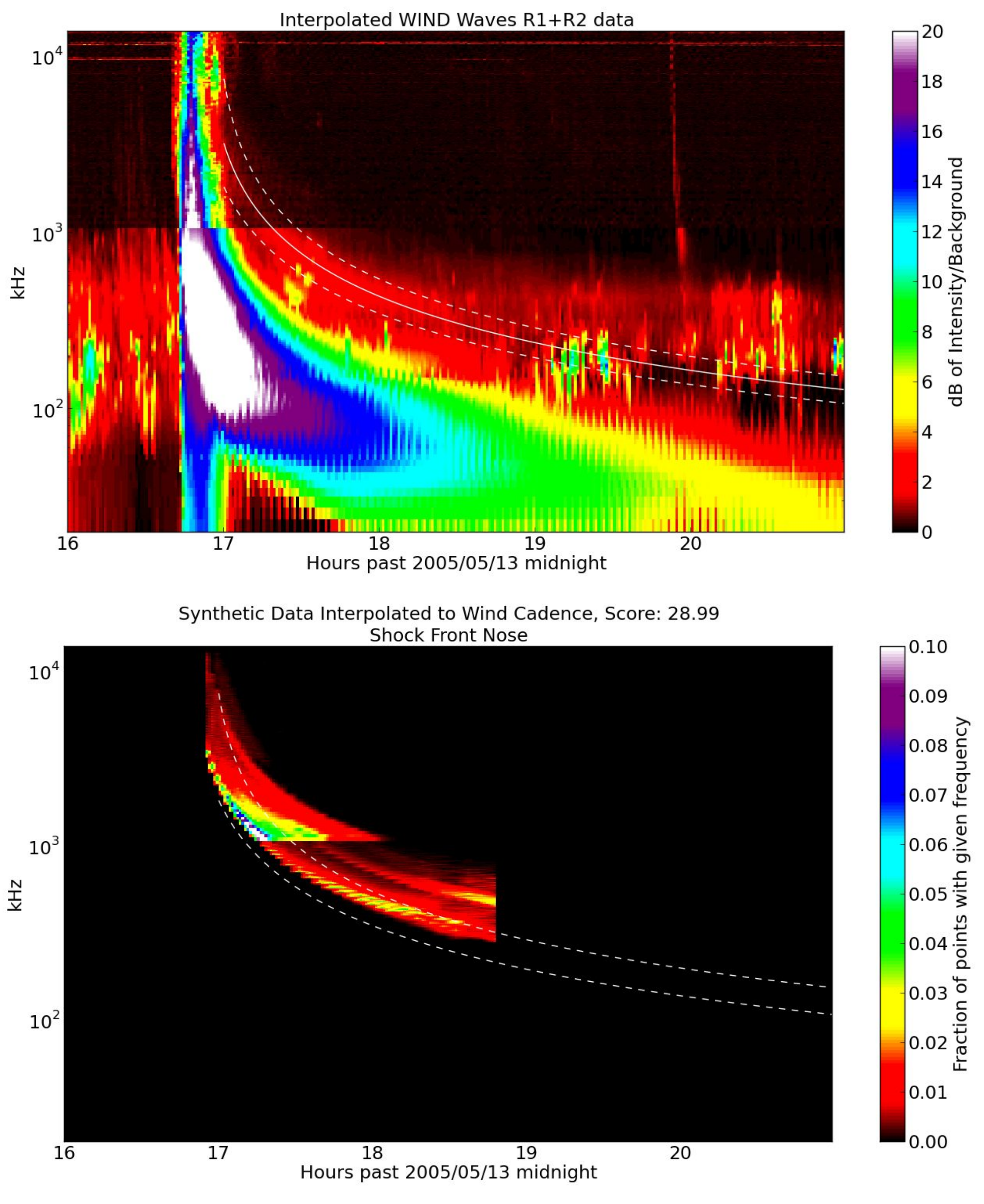
Manchester et al. 2014

SYNTHETIC SPECTRA OF MHD DATA CUTS

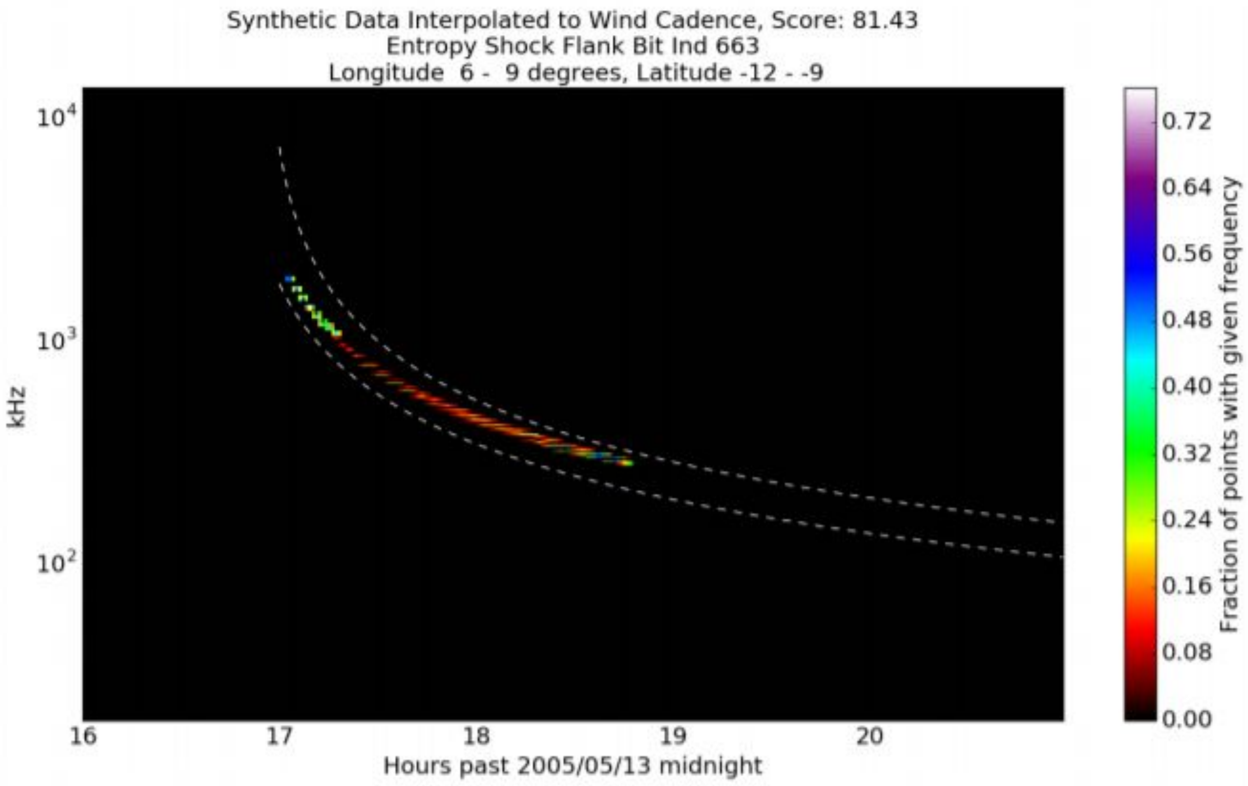


ZOOMING INTO ENTROPY SHOCK

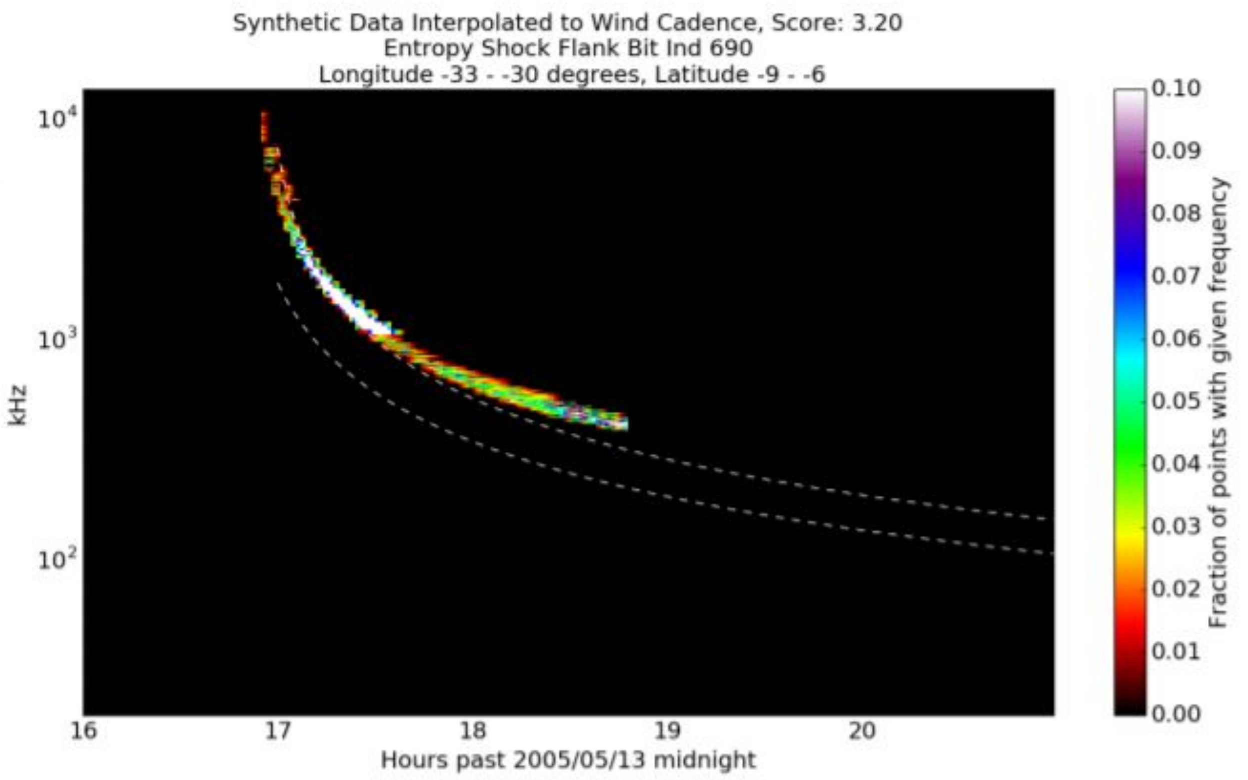




GEOMETRICAL DATA CUTS

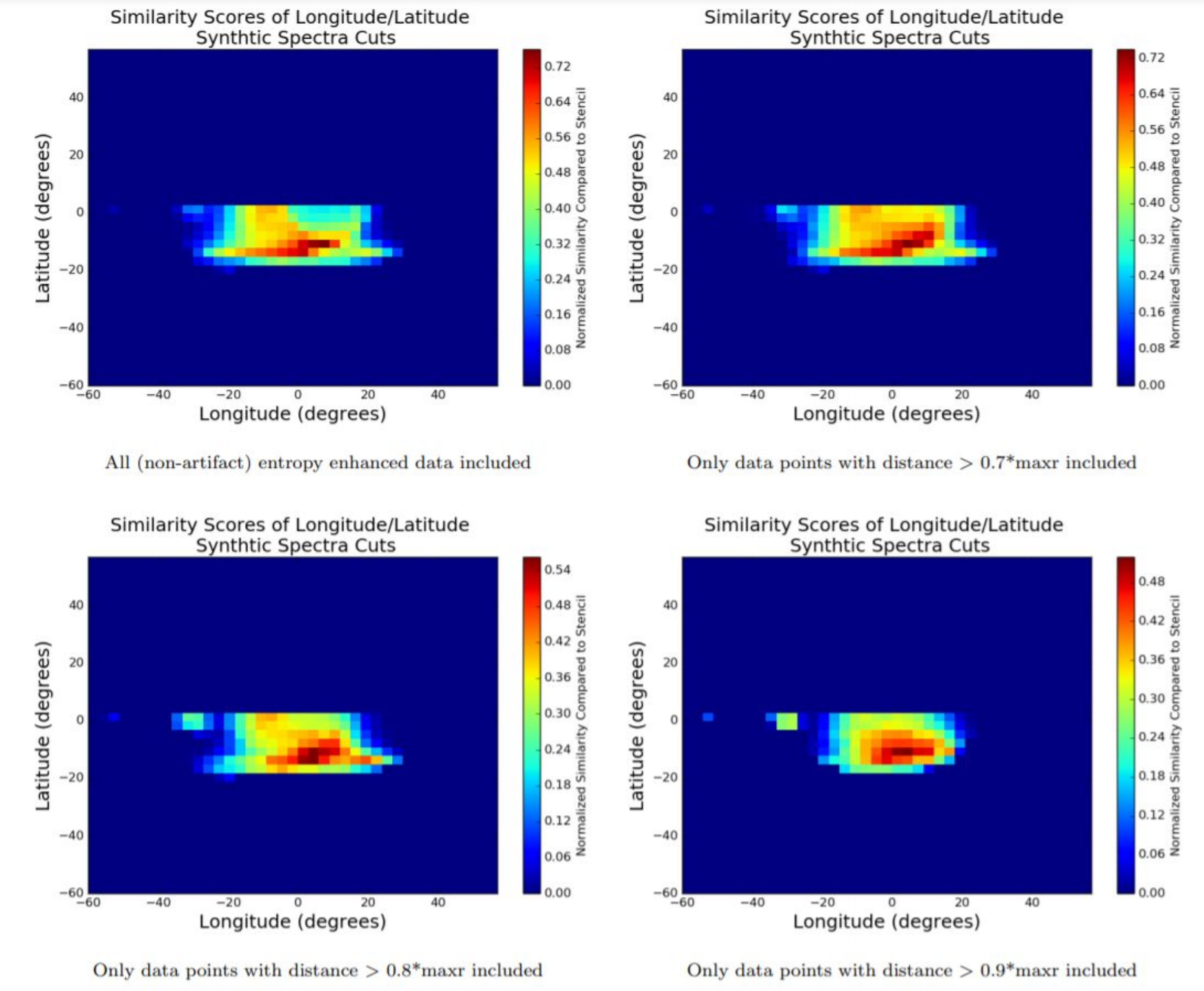


Good Cut, No radial cut, 3x3 chunk around $(6°, -12°)$

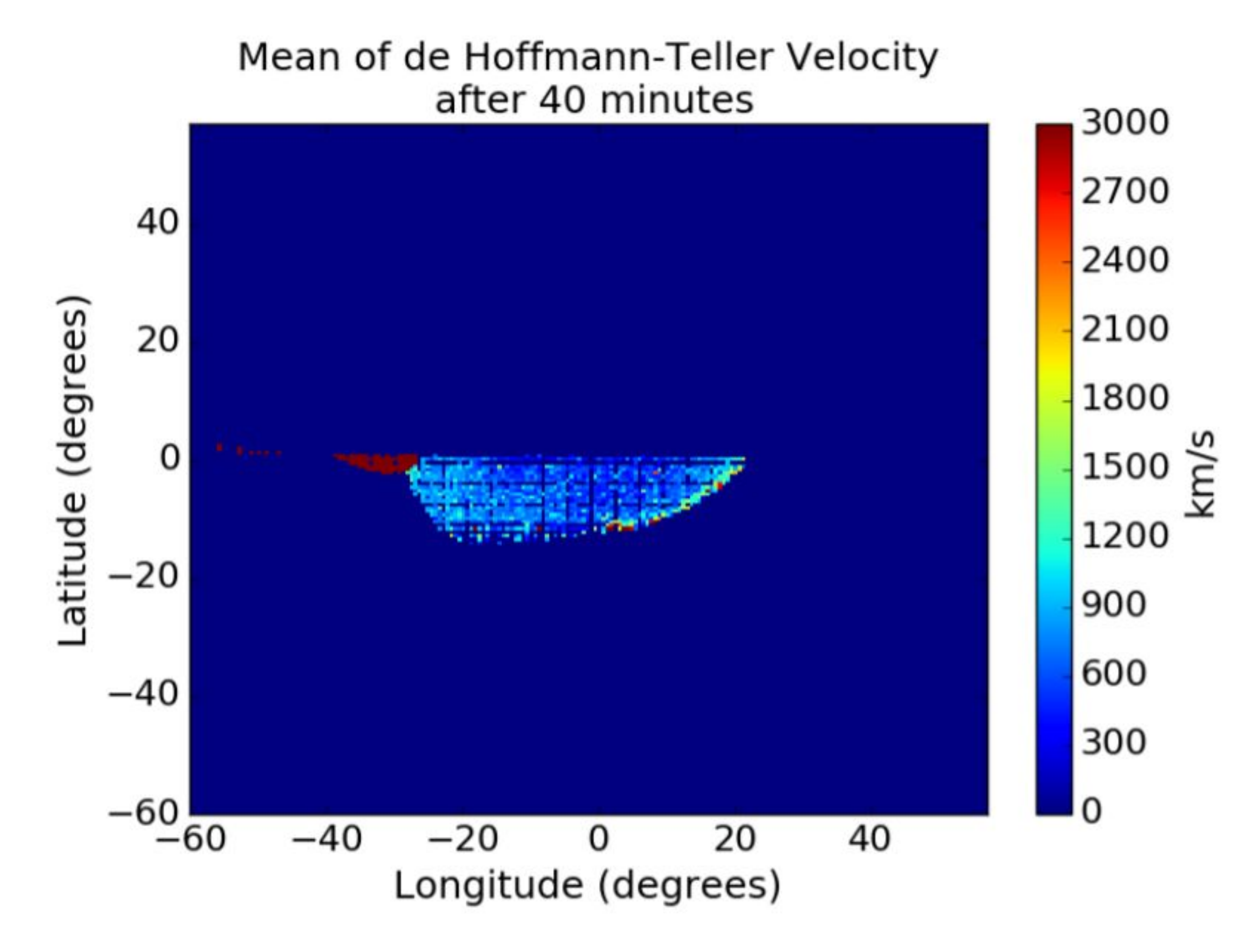


Bad Cut, No radial cut, 3x3 chunk around $(-42°, -3°)$

SCORING SPECTRA SIMILARITY OVER SHOCK GEOMETRY



WHAT MATCHES THIS SIMILARITY STRUCTURE?



$$\mathbf{V}_{HT} = \frac{\hat{\mathbf{n}} \times (\mathbf{V_u} \times \mathbf{B_u})}{\mathbf{B_u} \cdot \hat{\mathbf{n}}}$$

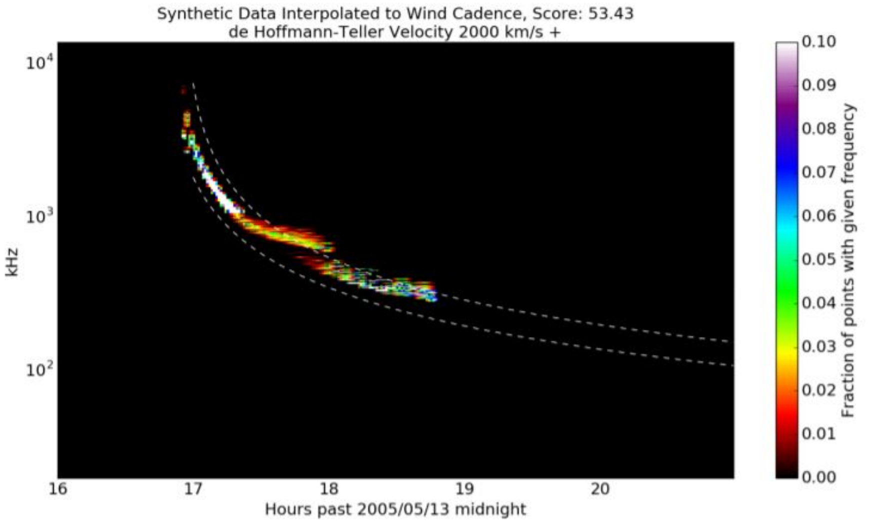
de Hoffmann-Teller frame velocity?

Frame where the convective electric field vanishes on both sides of the shock

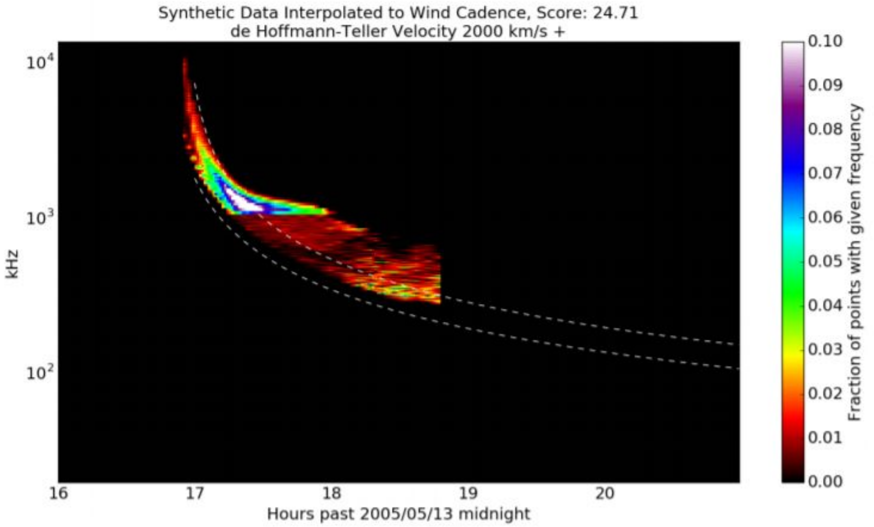
Highly correlated with in situ Langmuir Waves (Pulupa et al. 2010)

Features of this over shock surface matches similarity structure

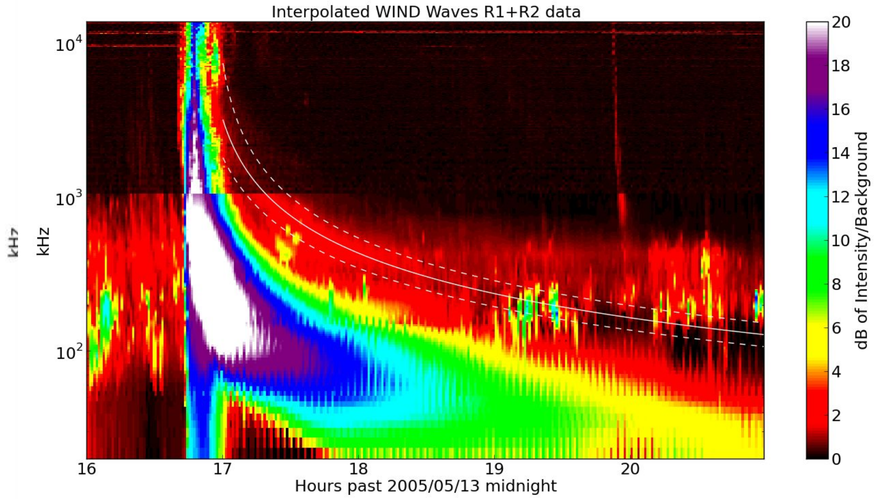
GLOBAL SPECTRA WITH DE HOFFMANN-TELLER THRESHOLD



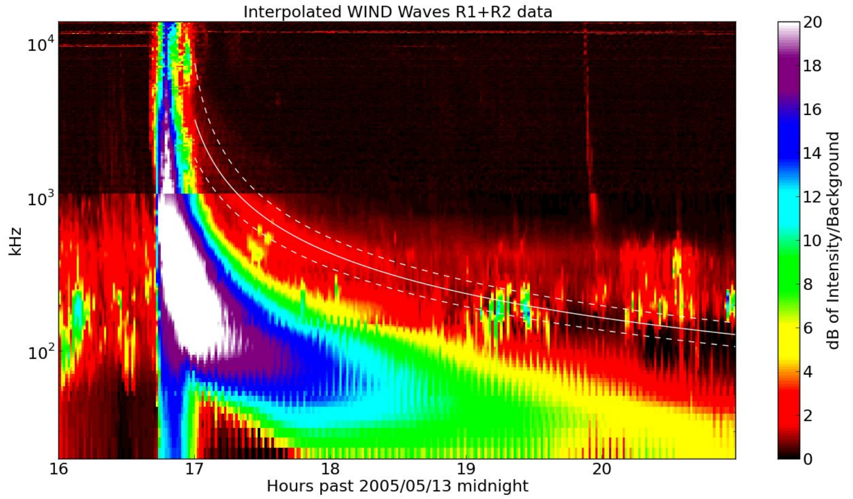
$r > 0.9^{*}maxr, V_{HT} > 2000$ km/s



$r > 0.7^{*}maxr, V_{HT} > 2000$ km/s

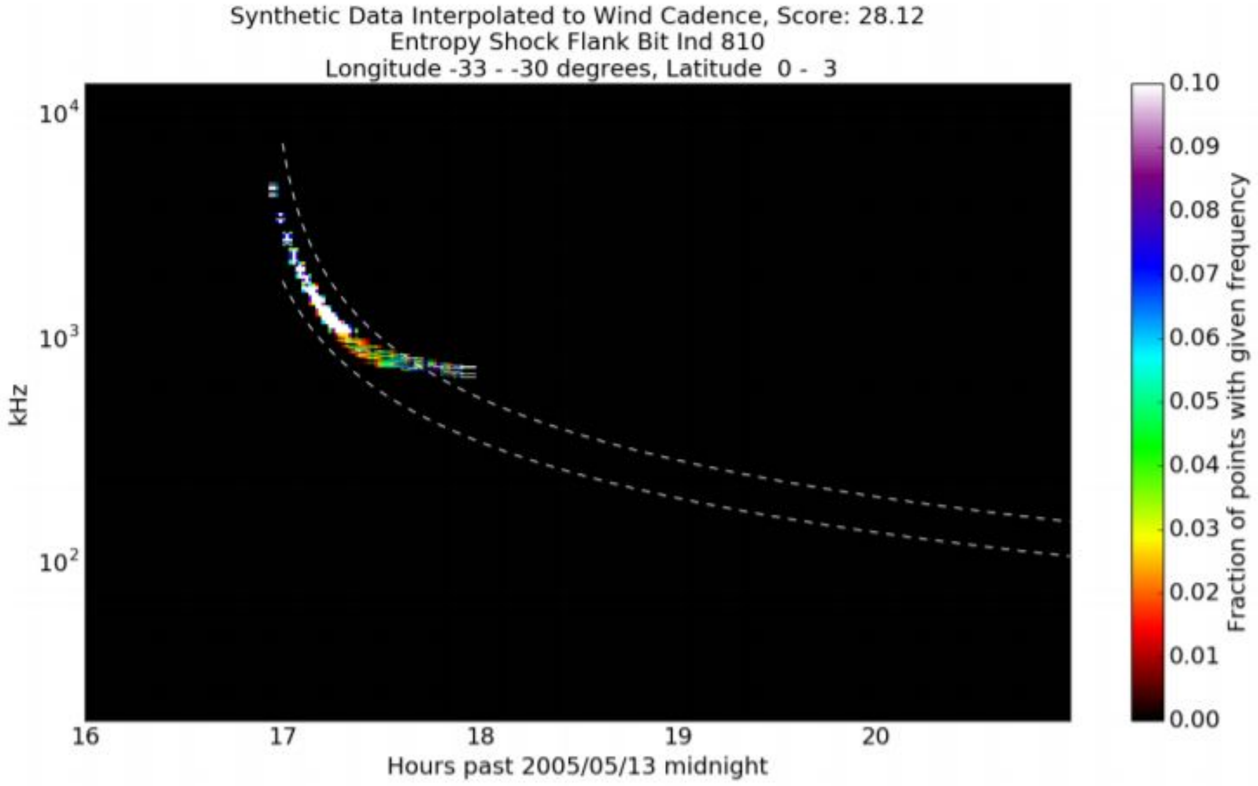


Wind/WAVES Observed Radio Spectra

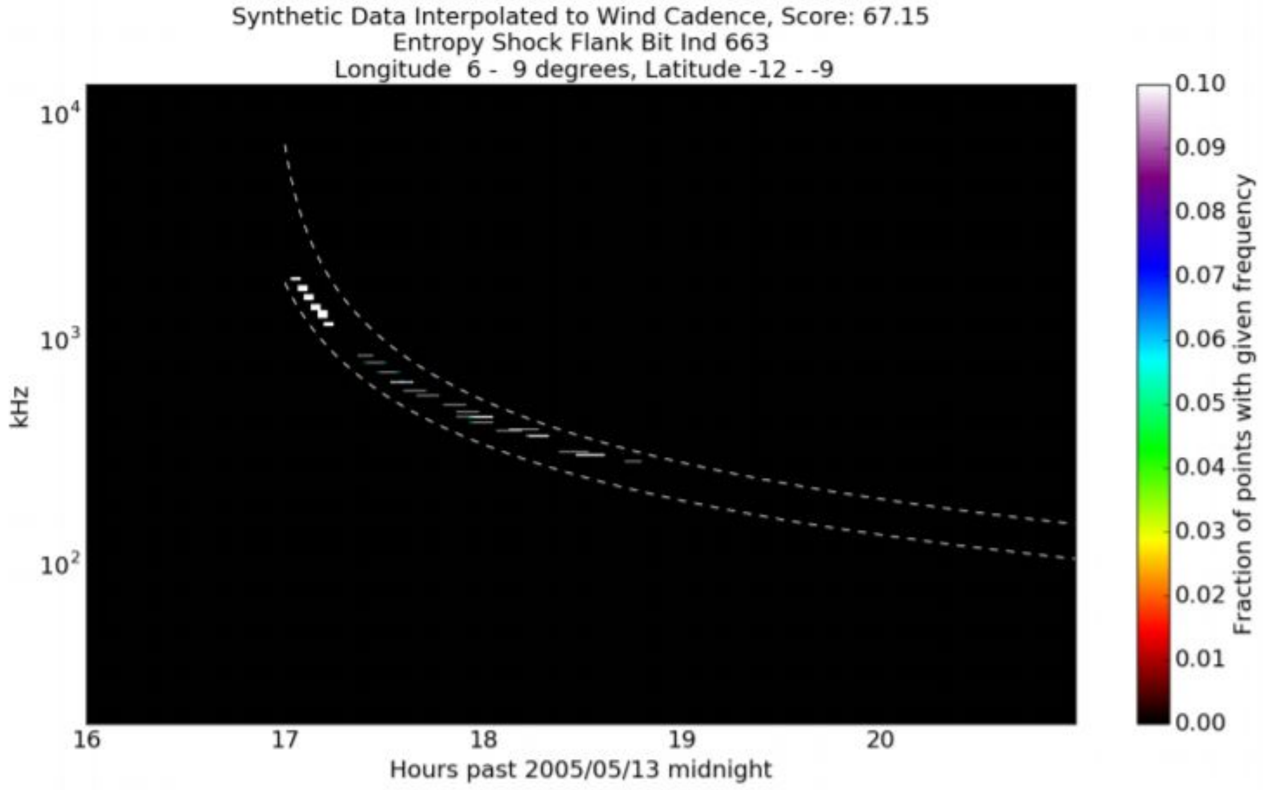


Wind/WAVES Observed Radio Spectra

LOCAL GEOMETRIC & DE HOFFMANN-TELLER THRESHOLD

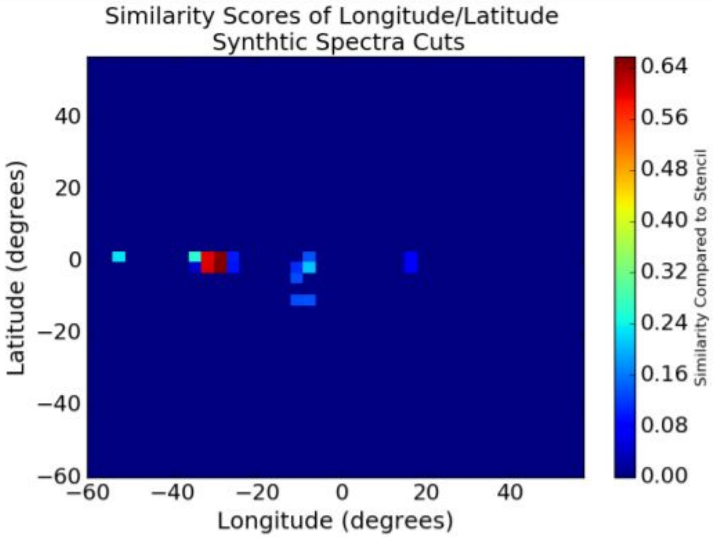


3x3 chunk around $(-30°, 0°)$, r > 0.9*maxr, $V_{HT} > 2000$ km/s

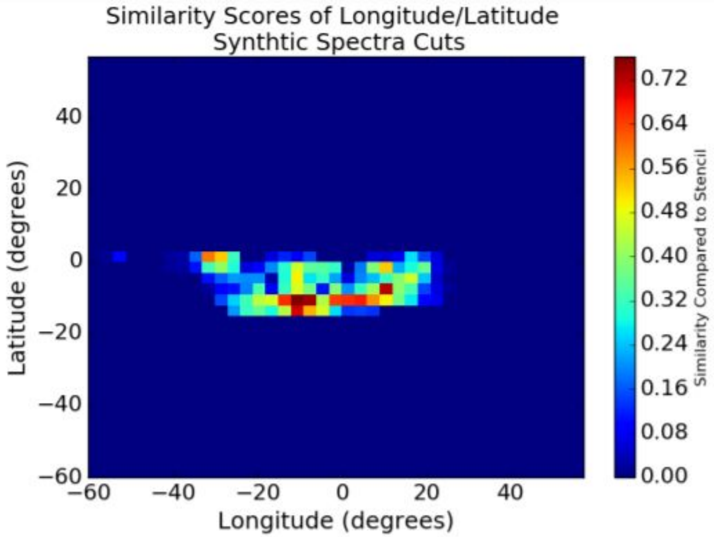


3x3 chunk around $(6°, -12°)$, r > 0.7*maxr, $V_{HT} > 2000$ km/s

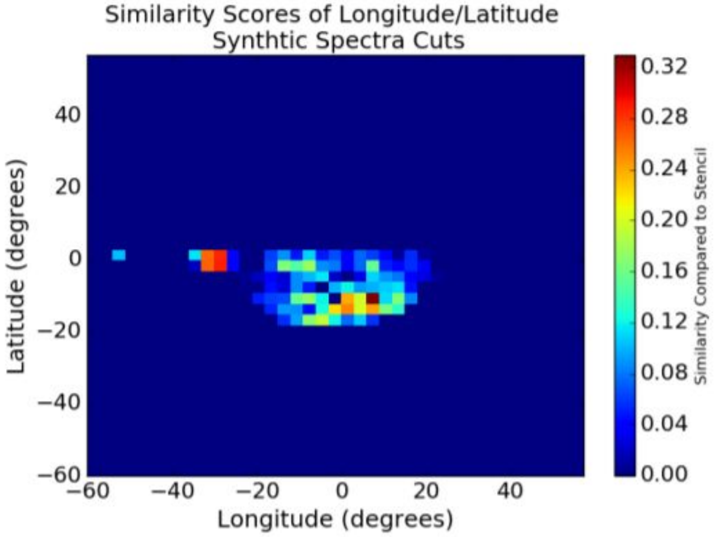
SIMILARITY SCORES WITH DE HOFFMANN-TELLER THRESHOLD



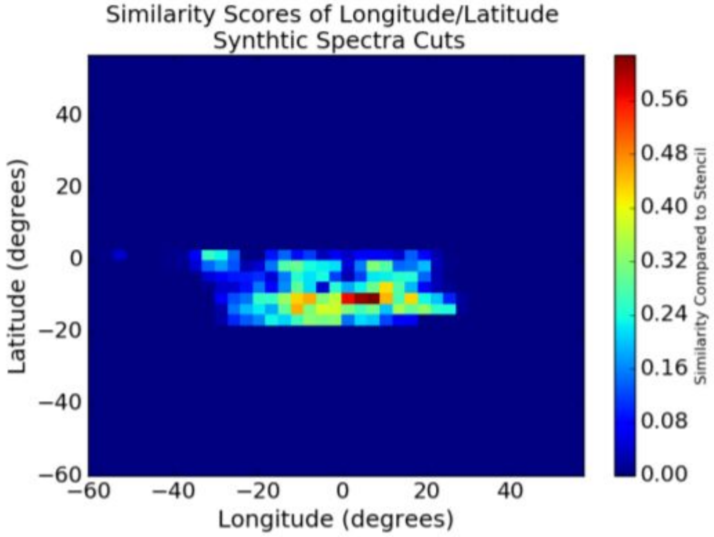
1 hour normalized, r > 0.9*maxr, V_{HT} > 2000 km/s



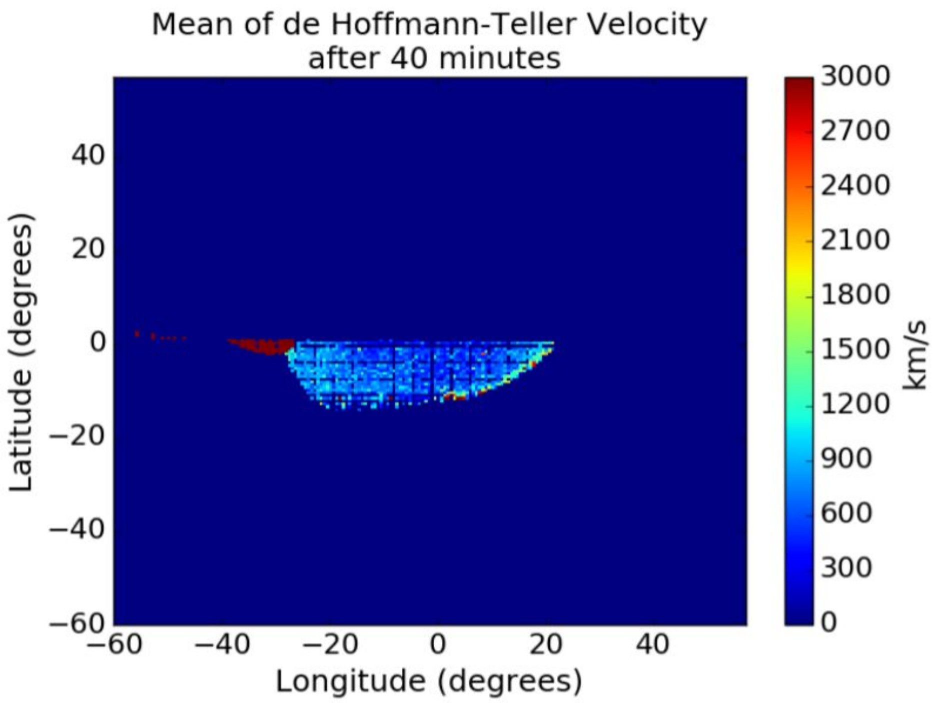
1 hour normalized, r > 0.7*maxr, V_{HT} > 2000 km/s



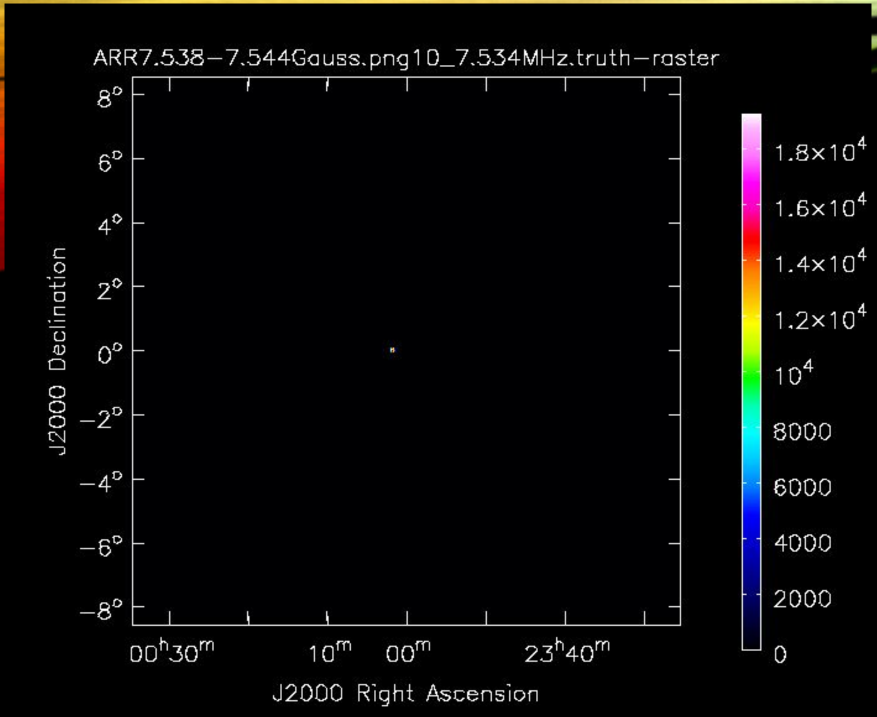
2 hour normalized, r > 0.9*maxr, V_{HT} > 2000 km/s

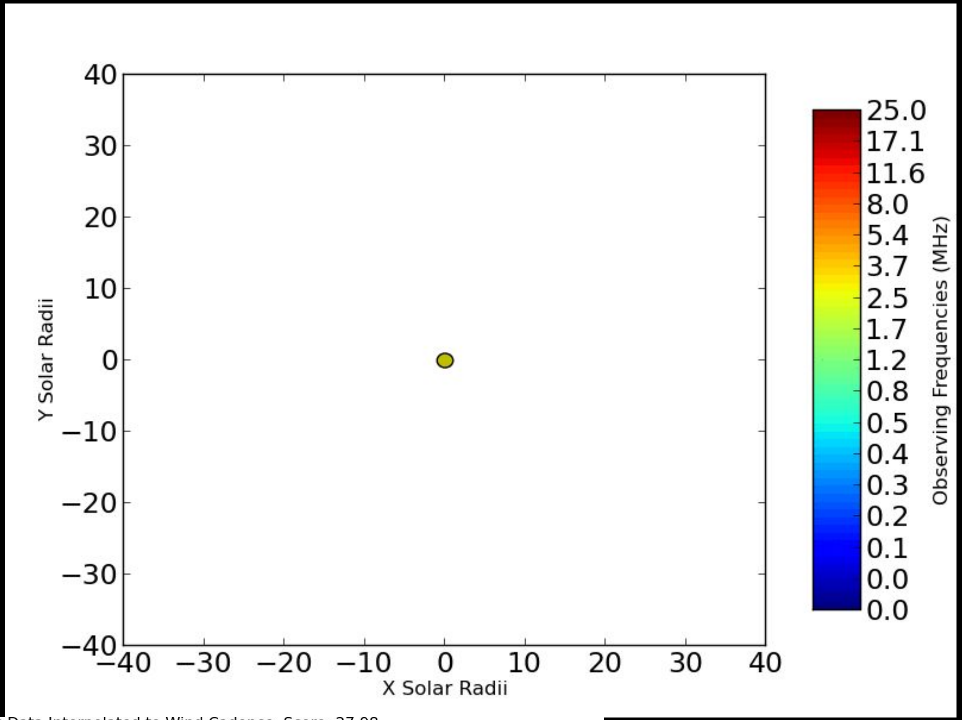


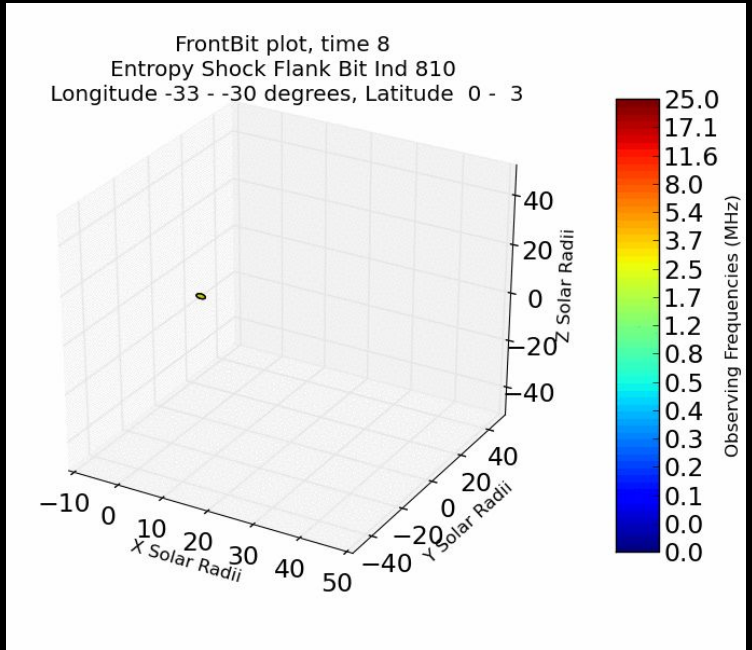
2 hour normalized, r > 0.7*maxr, V_{HT} > 2000 km/s

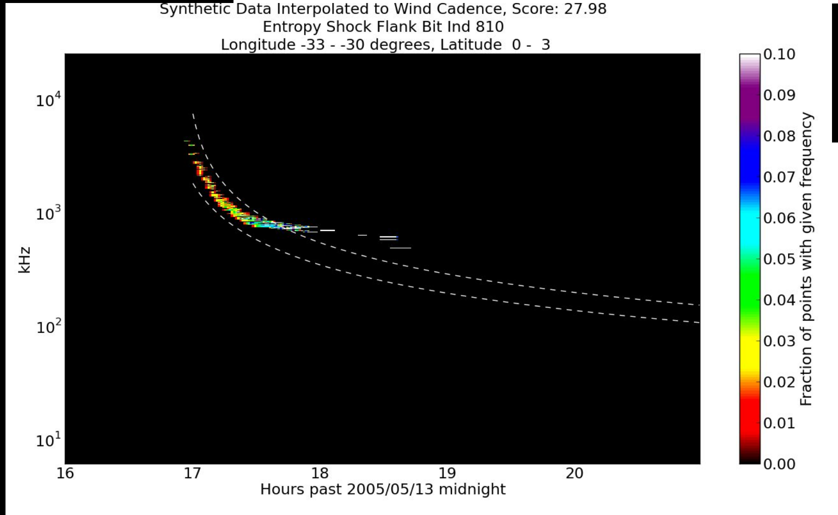


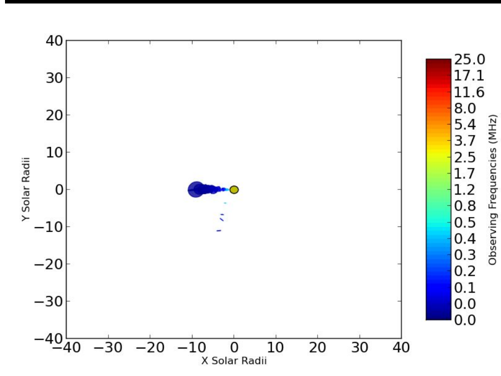
RECOVERED EMISSION 1



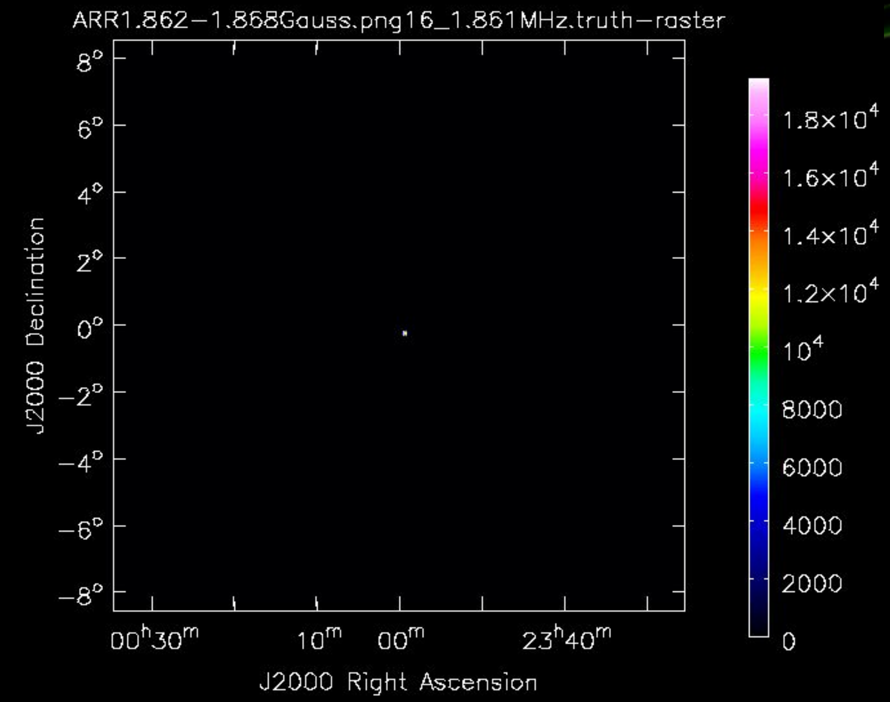


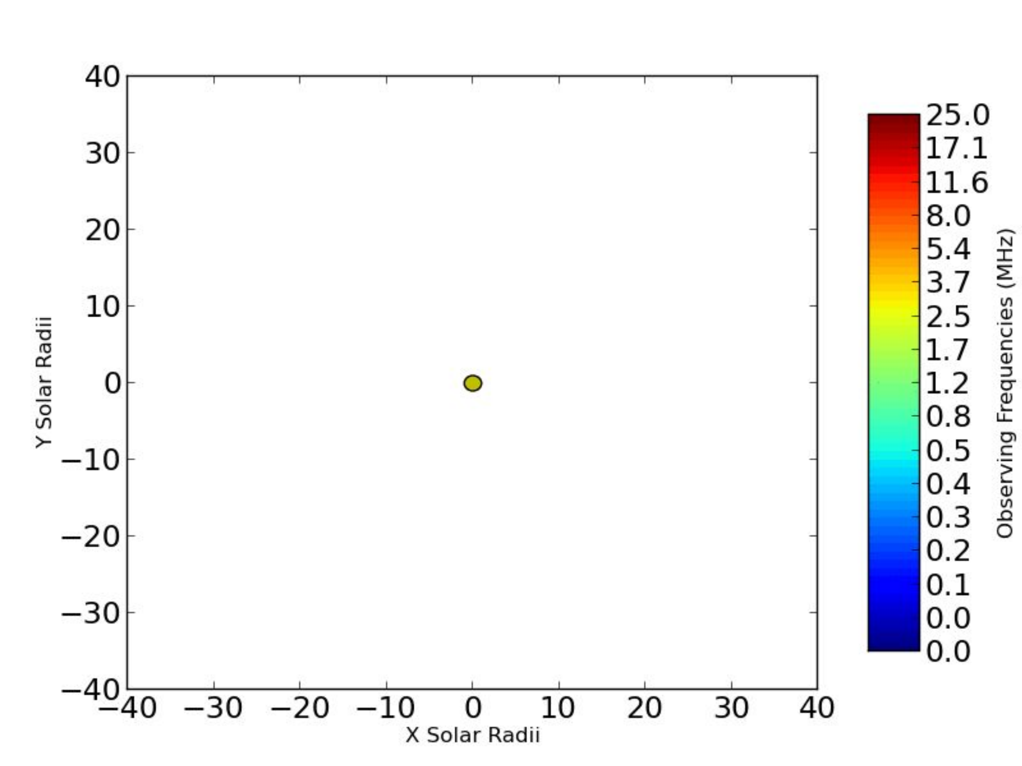


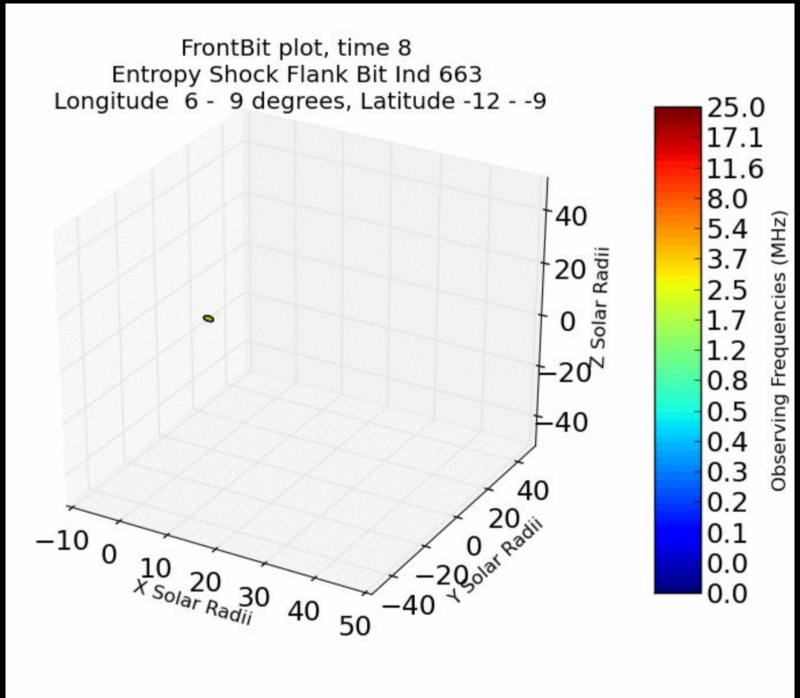


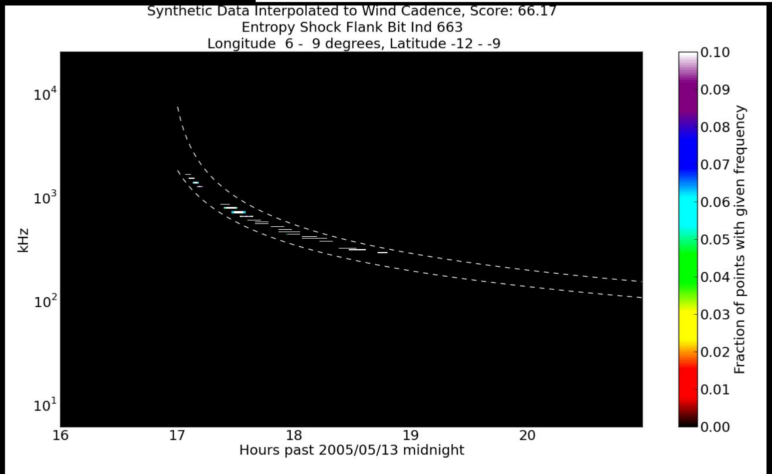


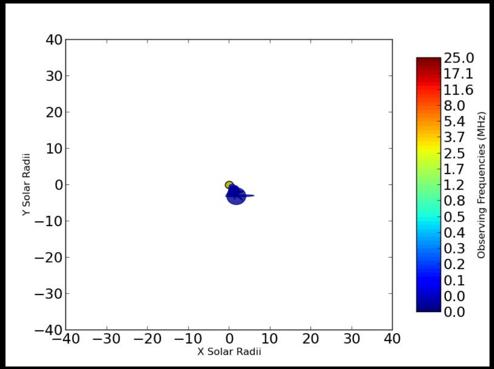
RECOVERED EMISSION 2







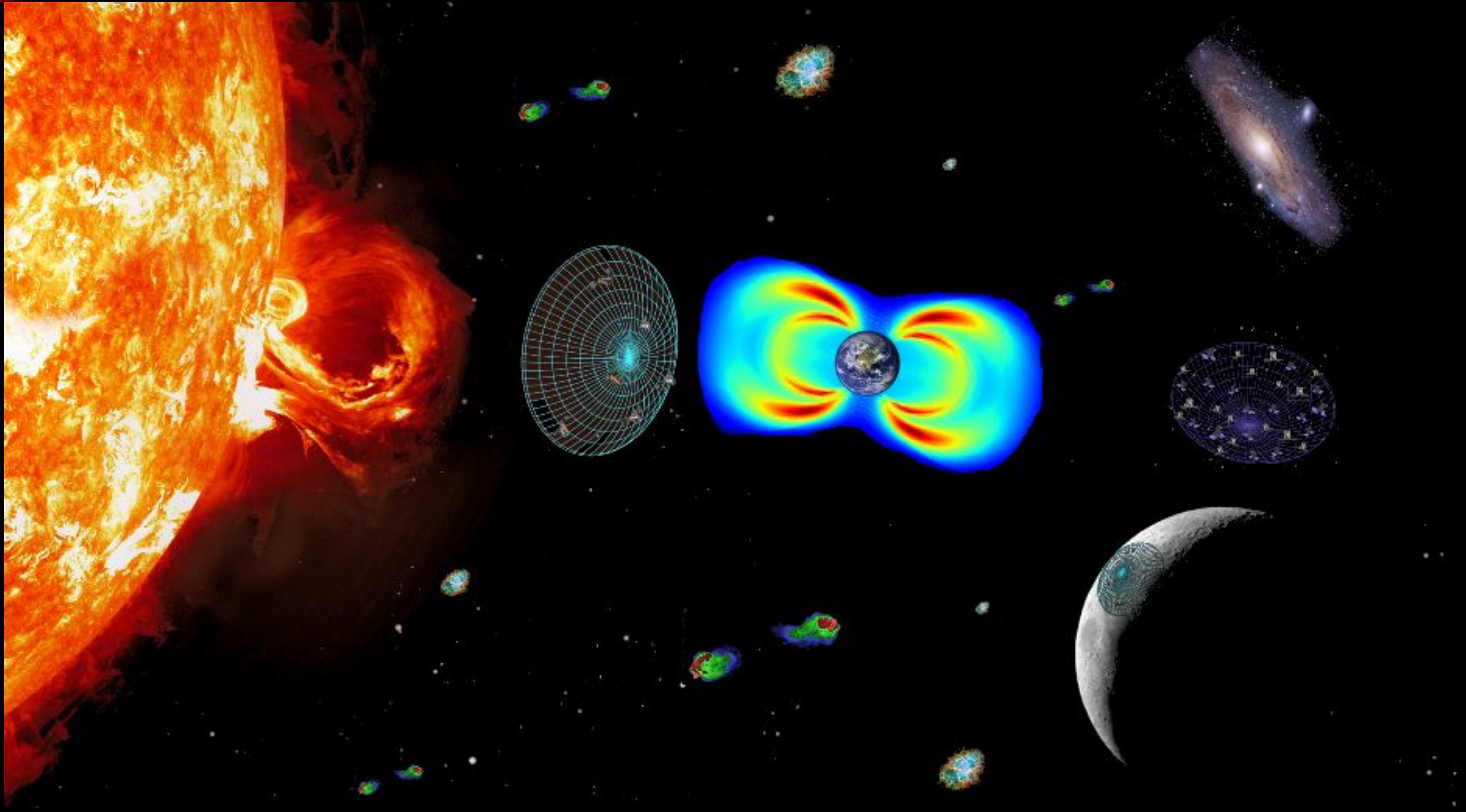




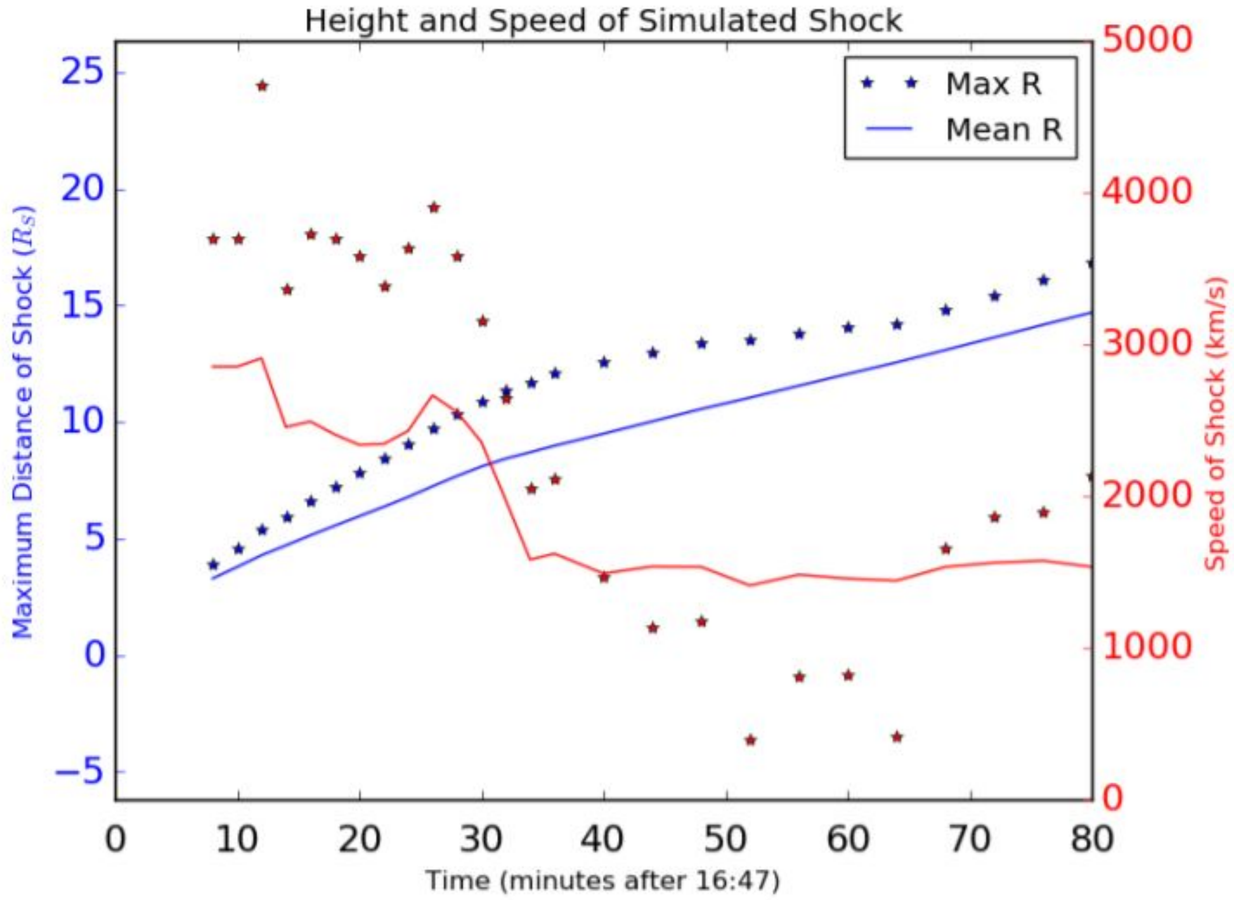
DISCUSSION

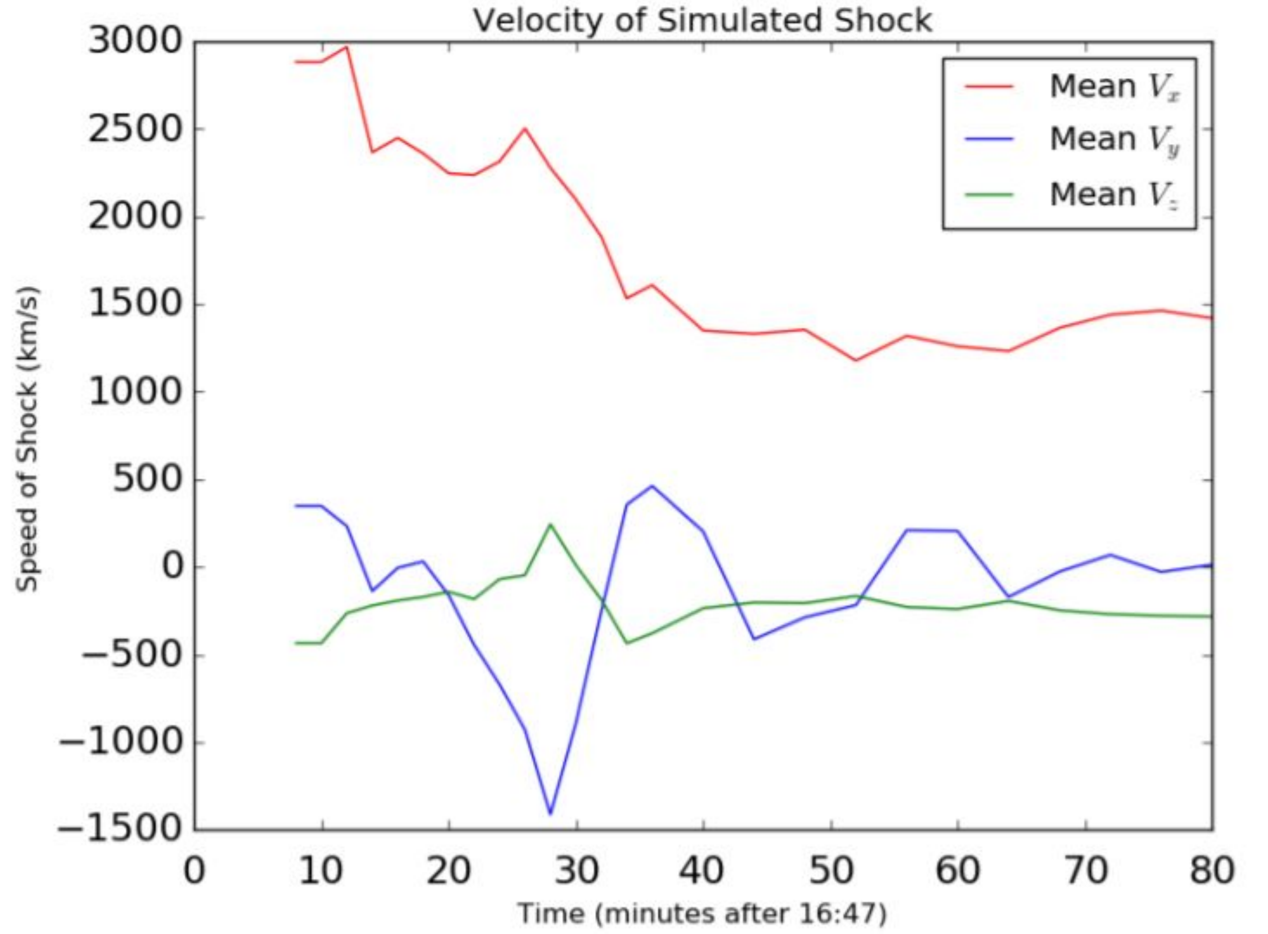
- SunRISE can distinguish between different theories of type II emission at CMES, informing theories of particle acceleration.
- Together with MHD simulations, SunRISE can inform what plasma parameters are important for particle acceleration
- Preliminary simulations indicate the emitting parts of the shock are likely those with high VHT ,
- For 2005 case study, the eastern edge (left) of the shock is active in the first 40 minutes or so dominating the emission, then falling off
- The western and southern edges of the shock are also seen to have points with consistently high VHT , with a maximum similarity centered around (6° , -12°)

QUESTIONS?



VELOCITY OF SIMULATED CME SHOCK





SCATTERING

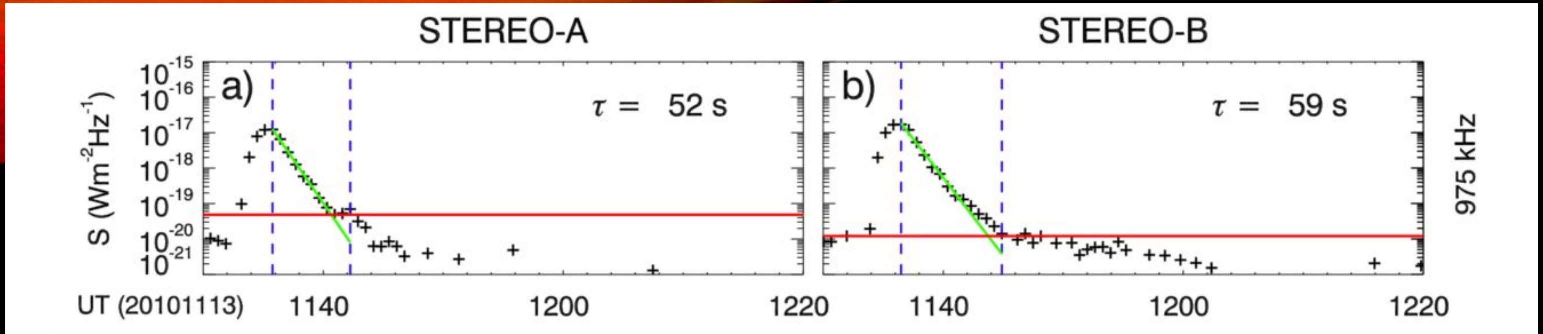
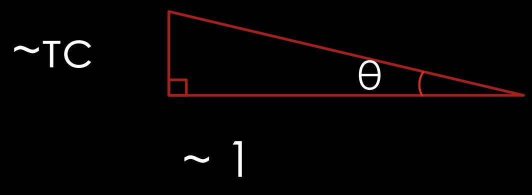


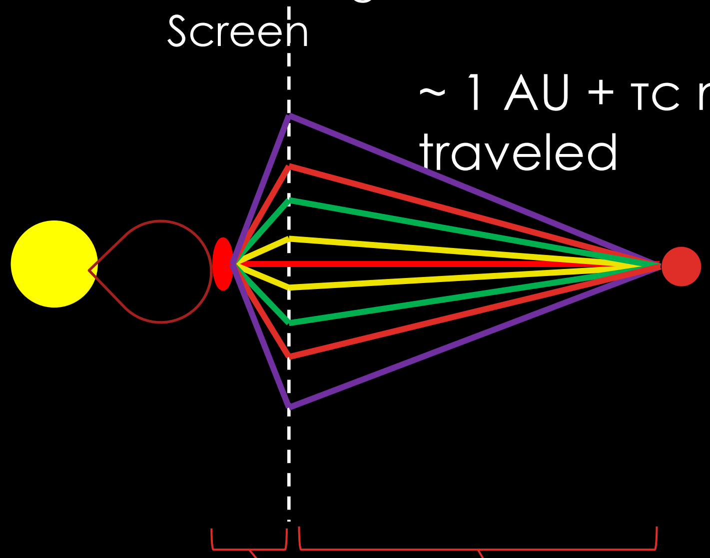
Figure 2. Radio measurements of the 2010 November 13 type III burst. (a)–(h) Fixed-frequency light curves of the radio flux density recorded by *STEREO-A* and *STEREO-B* for four frequency channels. The red lines show median values in the given time intervals. The dashed lines denote peak fluxes and last points above the median values. The green lines show the results of decay time fitting (Equation (1)).

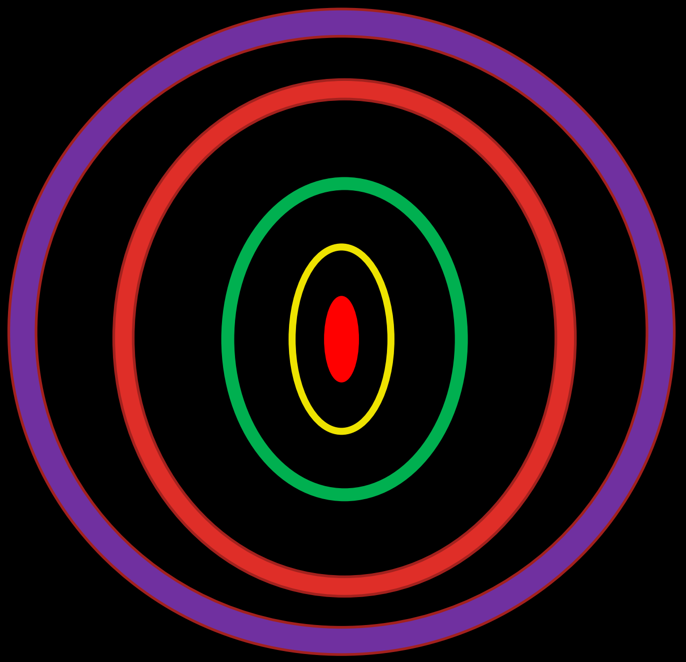
Krupar 2018 + 2020



$$\Theta \approx \arctan\left(\frac{\tau c}{1\ AU}\right) \approx \frac{\tau c}{1\ AU}$$ Scattering Angle

Valid for τc << 1 AU down to 0.3 MHz

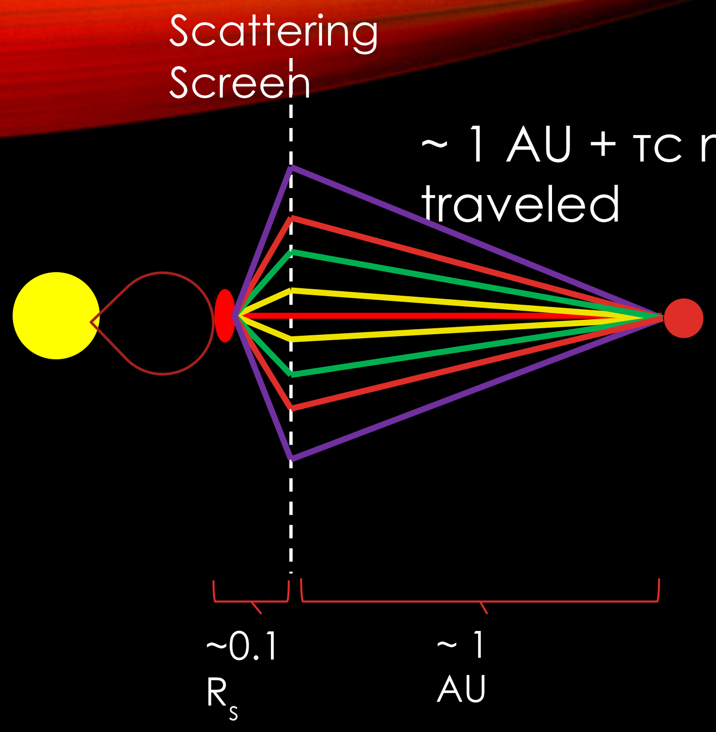


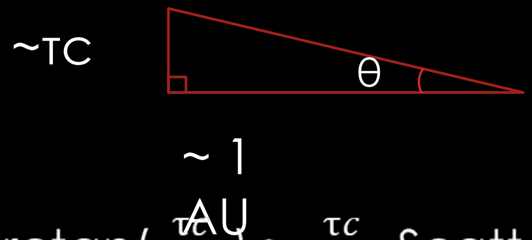


Bastian 94, Eqn

Sky View, Rings expand over time from

SCATTERING





$\Theta \approx \arctan(\frac{\tau c}{1\,AU}) \approx \frac{\tau c}{1\,AU}$ Scattering Angle

Valid for τc << 1 AU down to 0.3 MHz

Also 0.1 Rs distance to scattering screen << 1 AU, implying near right angle in propagation triangle (Bastian 1994, Eqn

$\Theta \approx \arctan(\frac{\tau c}{1\,AU}) \approx \frac{\tau c}{1\,AU}$ radians is *Maximum* scattering angle width in sky for e-folding time τ,

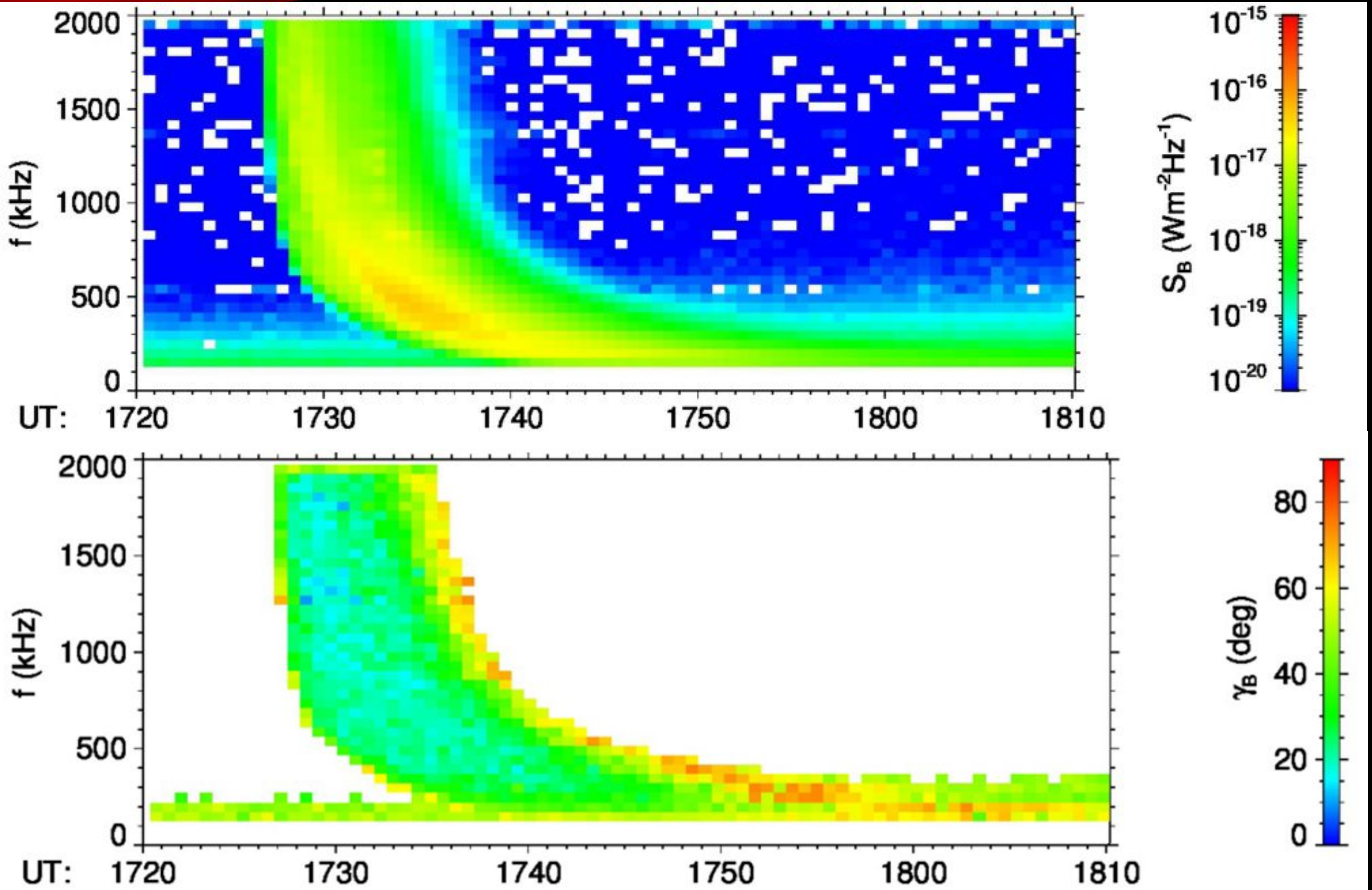
Valid for τc << 1 AU down to 0.3 MHz

Or angular distance of scattered light out from source after τ sec limited by speed of light

Θ = 6.8 deg at 1 e-folding time τ = 60 sec at 1 MHz (STEREO data 2018)

Θ = 1.47 deg at 1 e-folding time τ = 13 sec at 10 MHz (PSP data 2020)

SCATTERING



Krupar et al. 2014
17:20 to 18:10 UT on 28 January 2008
apparent source size γ_B and flux density of a Type III

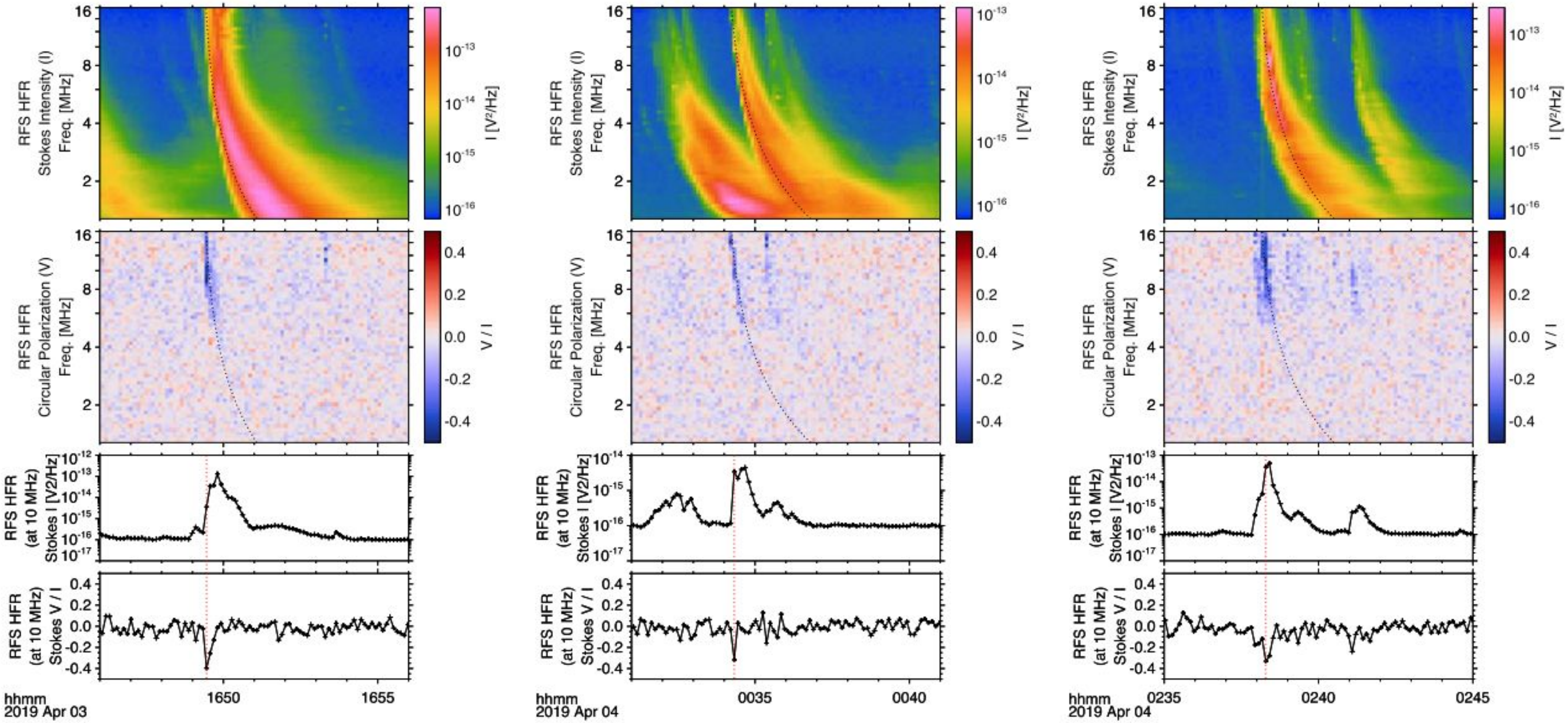


Figure 5. Example radio bursts displaying circular polarization above ∼6 MHz. In each plot, the top panel shows the Stokes intensity (*I*), while the second panel shows the relative circular polarization Stokes V/I. Negative *V*, in blue, indicates RHC polarization. In each spectrogram plot, the dotted line indicates the time profile of the leading edge of the burst. The bottom two panels show time profiles of *I* and V/I at a frequency of 10 MHz, showing how the polarization is localized near the leading edge of the burst and is absent at later times. The time of maximum circular polarization is indicated in these panels with a red dotted line.