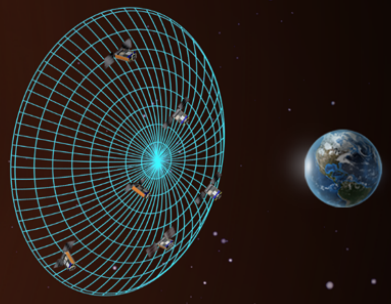
Using SunRISE as a Pathfinder for Detecting Low Frequency Radio Emission from Extrasolar Planets with Space Based Radio Arrays



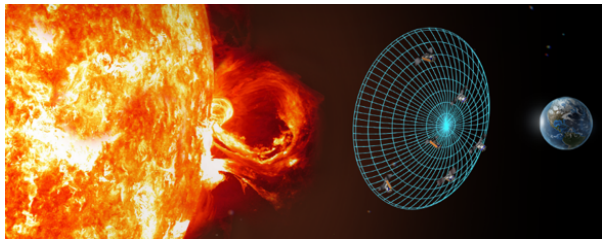
Alexander M. Hegedus*[1], Justin C. Kasper[1], Joseph Lazio[2], Andrew Romero-Wolf[2], Timothy S. Bastian[3]

[1]Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI
[2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
[3]National Radio Astronomy Observatory, Charlottesville, VA

SunRISE
Sun Radio Interferometer Space Experiment

PRINCIPAL INVESTIGATOR: Justin C. Kasper (University of Michigan)

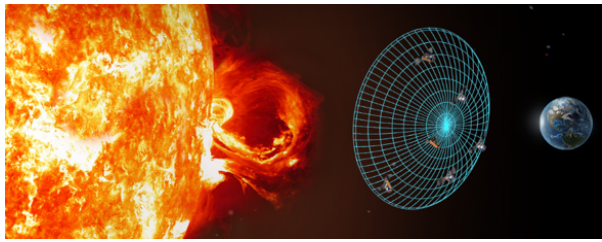
URSI 2019 Session J3: Radio Emission from Extrasolar Planets



Talk Outline

SunRISE
Sun Radio Interferometer Space Experiment

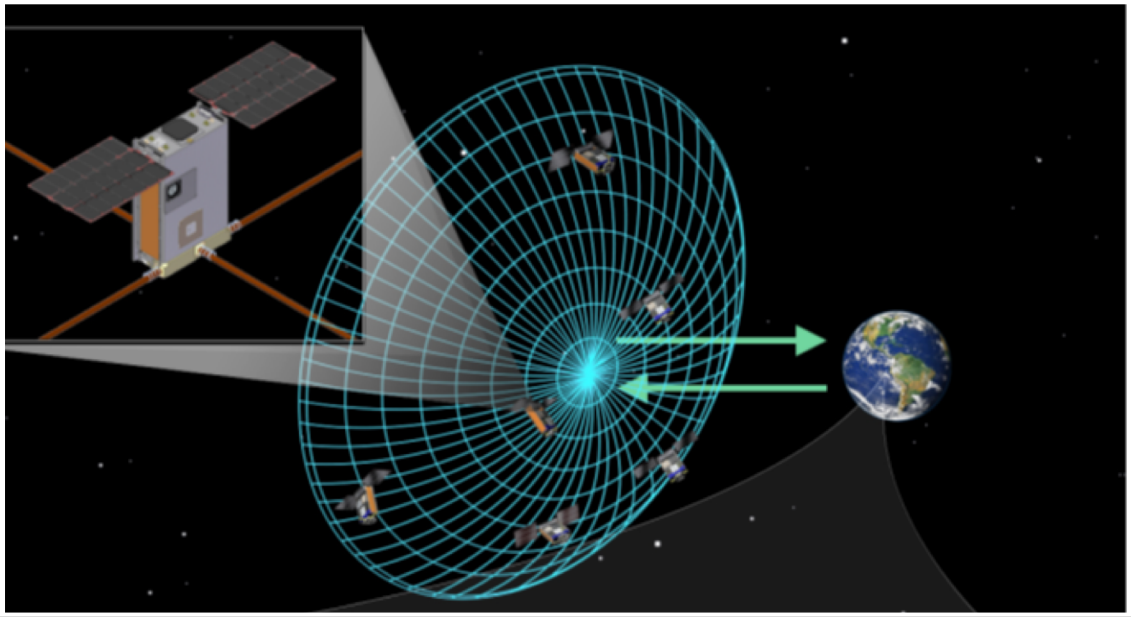
- Introduction to SunRISE
- Primary Science Objectives
- Science Operation Pipeline
- Additional Science Targets
- Preliminary Sky Maps
- Planetary Emission & Other Weak Sources



SunRISE Introduction

SunRISE
Sun Radio Interferometer Space Experiment

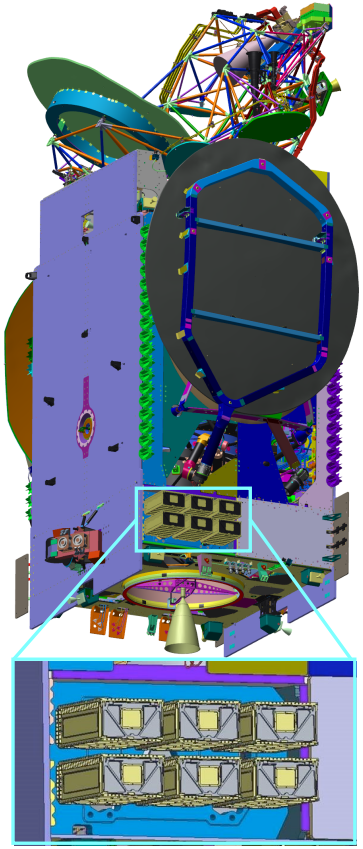
- SunRISE – Sun Radio Interferometer Space Experiment
- Heliophysics Explorers Mission of Opportunity ($55 M)
- Done with Phase A
- Will launch 2022 if funded
- 6 CubeSats in GEO Graveyard Orbit
- Can see below Ionospheric Cutoff

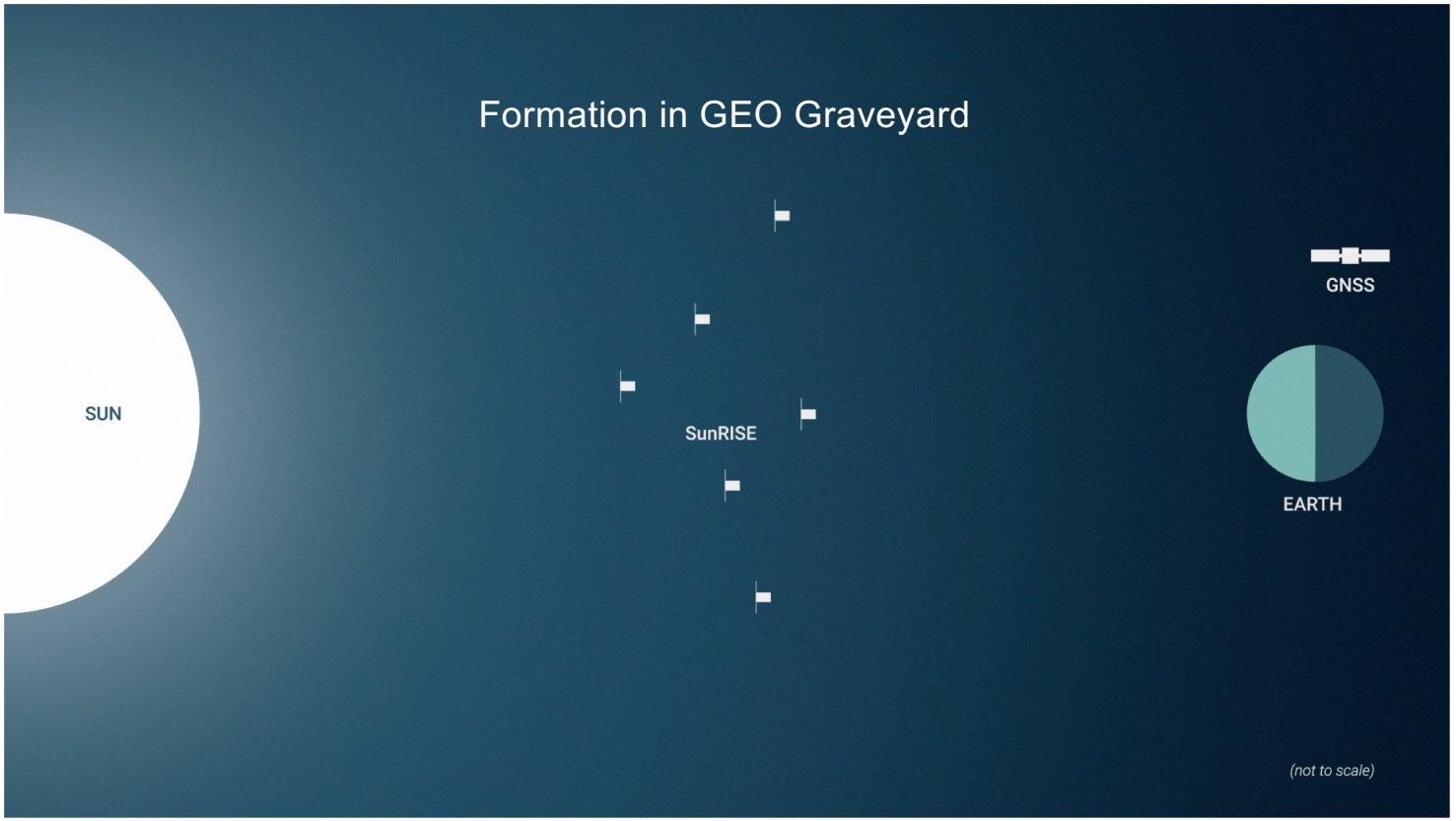



UNIVERSITY OF MICHIGAN
JPL
Jet Propulsion Laboratory
California Institute of Technology
SunRISE
Sun Radio Interferometer Space Experiment
SSL
A MAXAR COMPANY
Space Dynamics LABORATORY
Utah State University Research Foundation

SunRISE Orbital Access & Operations

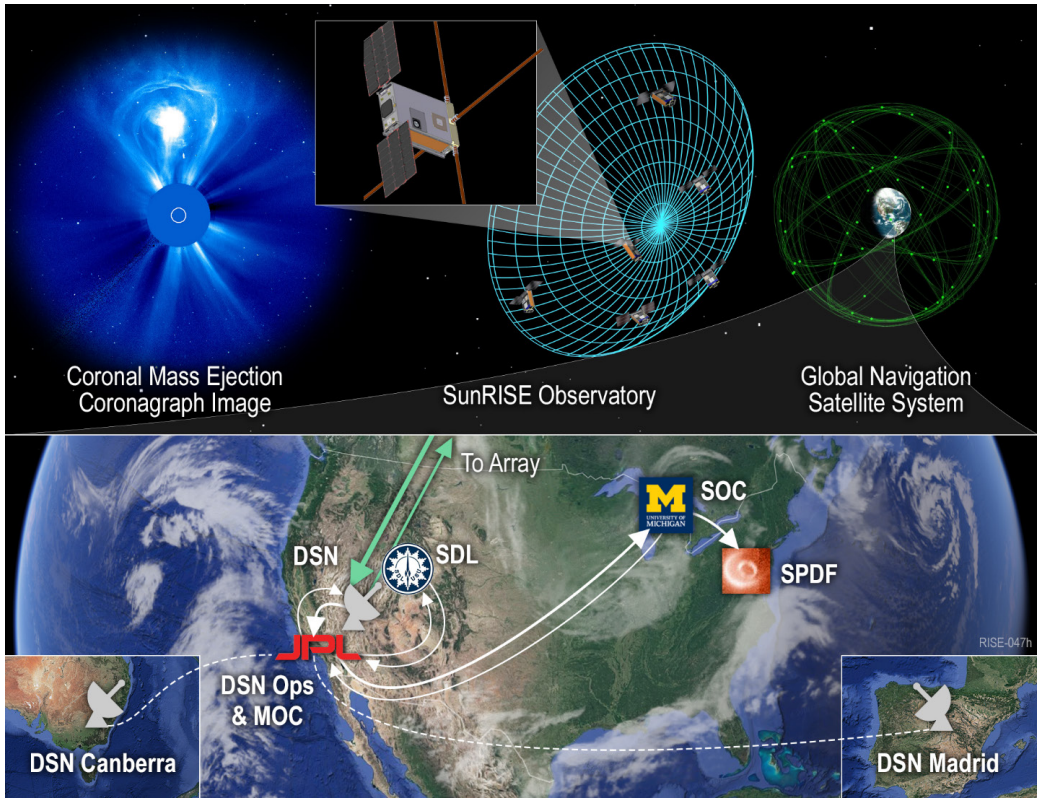
SunRISE
Sun Radio Interferometer Space Experiment



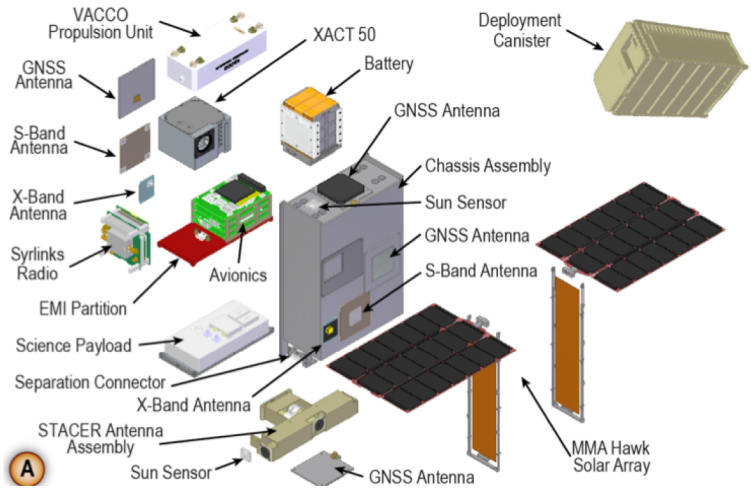


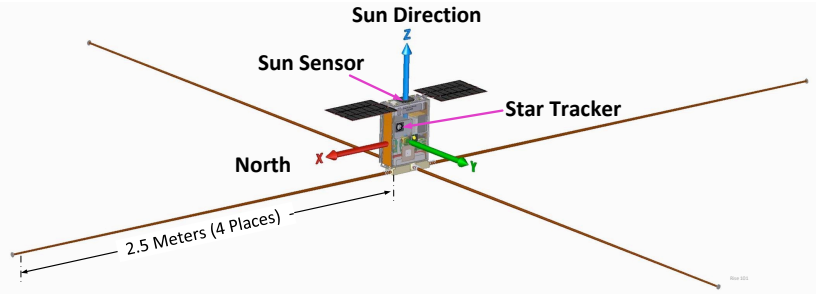
SunRISE Mission & Spacecraft

SunRISE
Sun Radio Interferometer Space Experiment



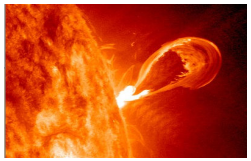
CSR Fig. D-1





Regular and Routine SunRISE Operations

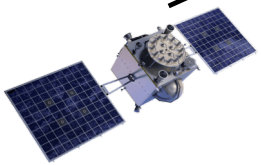
SunRISE
Sun Radio Interferometer Space Experiment



DH Radio Emissions

24/7

GNSS Broadcast Signals



Observatory

Spacecraft

Spacecraft

Space Dynamics Laboratory
Utah State University Research Foundation

Simultaneous DH & GNSS recording

JPL Jet Propulsion Laboratory California Institute of Technology

Once a week

DSN

Mission Operations Center

JPL Jet Propulsion Laboratory California Institute of Technology

GNSS Orbit Determination

Precision Timestamping

Science Operations Center

UNIVERSITY OF MICHIGAN

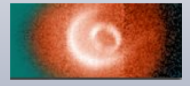
Correlation

Visibility, Burst, CLEAN

Localization

NASA

Space Physics Data Facility

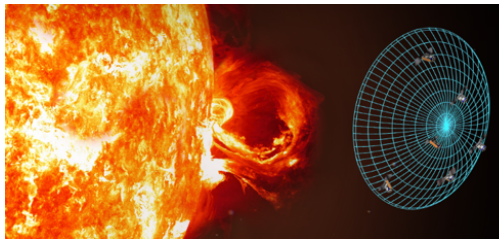


Radio Signals

Raw Observation Data

Time Stamped Data
Precise Time Position

Science Data Products



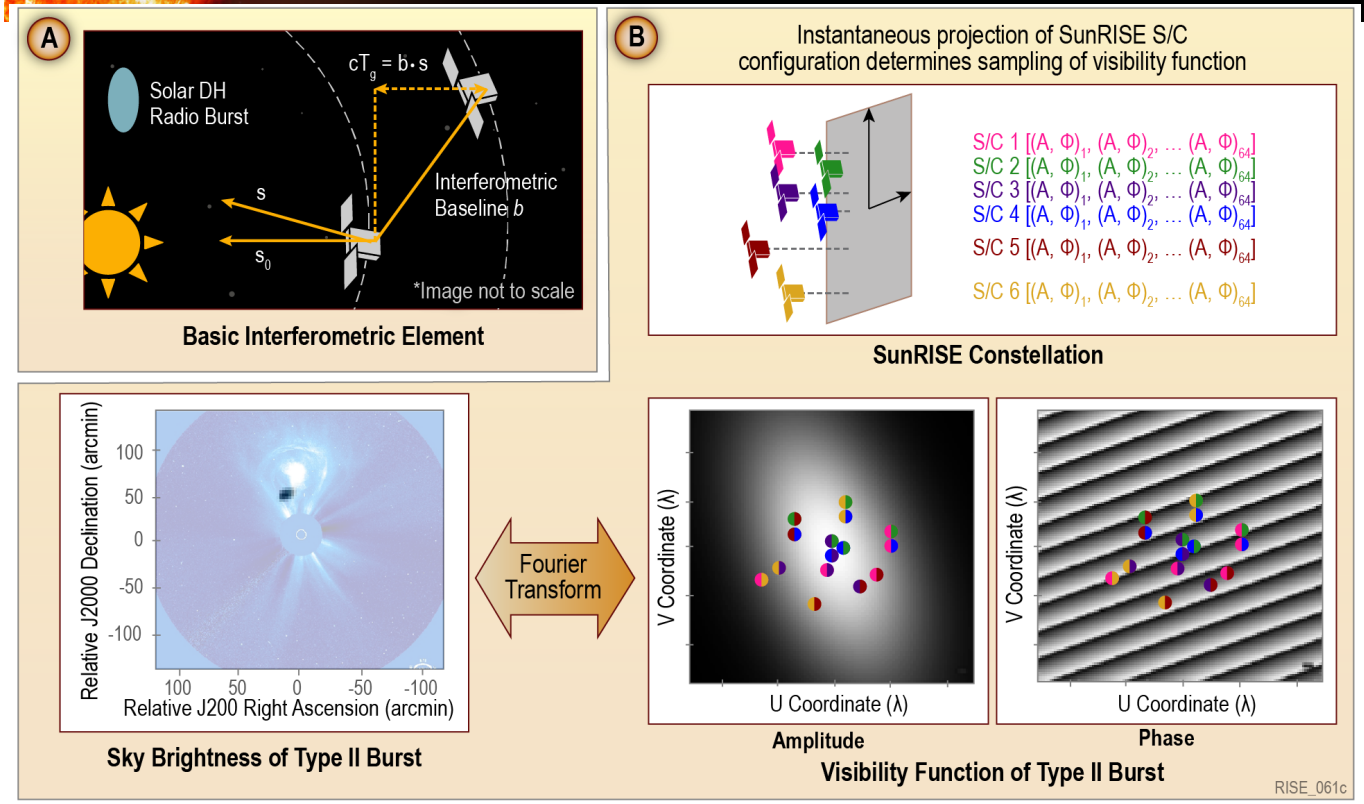
Weekly Downlink Budget Allocation

SunRISE
Sun Radio Interferometer Space Experiment

Data Type	Description	Cadence	Volume per downlink
Solar DH	Science Spectra (64 specified sub-bands × 2 pol. × complex amp. × 8 bits + 128 bit header)	10 Hz	13.2 Gb
	Diagnostic Spectra (4096 sub-bands × 2 pol. × 2 complex amp. × 24 bits + 128 bit headers)	0.3 mHz (1/hour)	66 Mb
	Diagnostic output (ADC samples; 32k × 24 bits + 128 bit headers)	12 mHz (1/day)	7 Mb
GNSS	Observables (phase, pseudo-range; 12 ch. × 2216 bits)	0.1 Hz	1.6 Gb
	On-board Navigation Solution (2088 bits)	0.1 Hz	0.13 Gb
Auxiliary	Log Messages (2776 bits)	0.1 Hz	0.17 Gb
	Housekeeping (1688 bits)	17 mHz (1/minute)	17 Mb
Total			15.2 Gb

Radio Interferometry Basics

SunRISE
Sun Radio Interferometer Space Experiment

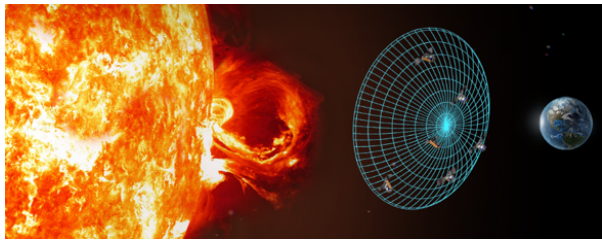


$$\mathcal{V}(u,v,w) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} A_N(l,m) I(l,m) \times \exp\left\{-j2\pi\left[ul + vm + w\left(\sqrt{1-l^2-m^2}-1\right)\right]\right\} \frac{dl\,dm}{\sqrt{1-l^2-m^2}}.$$

- Compute UVW from GPS Files
- Compute Visibilities from Integral definition
- Insert into CASA MS file
- Add Thermal & Phase Noises
- Image & Analysis

Taken from SunRISE CSR

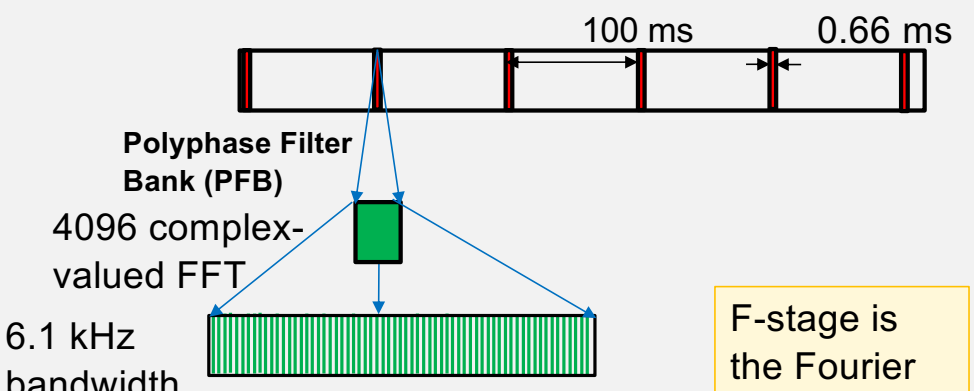
CASA by McMullin, J. P., et al. 2007, Astronomical Data Analysis Software and Systems XVI, 127.



FX Correlation

SunRISE
Sun Radio Interferometer Space Experiment

Spacecraft (×**6**)



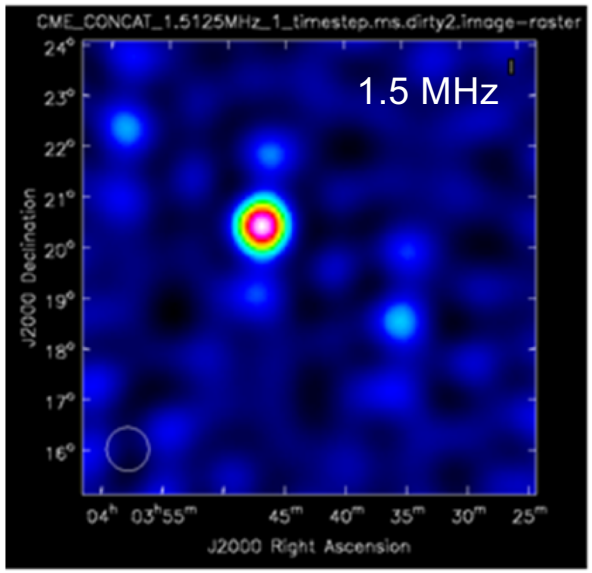
F-stage is the Fourier Transform

All spacecraft synchronized by GNSS.

Data telemetered to ground

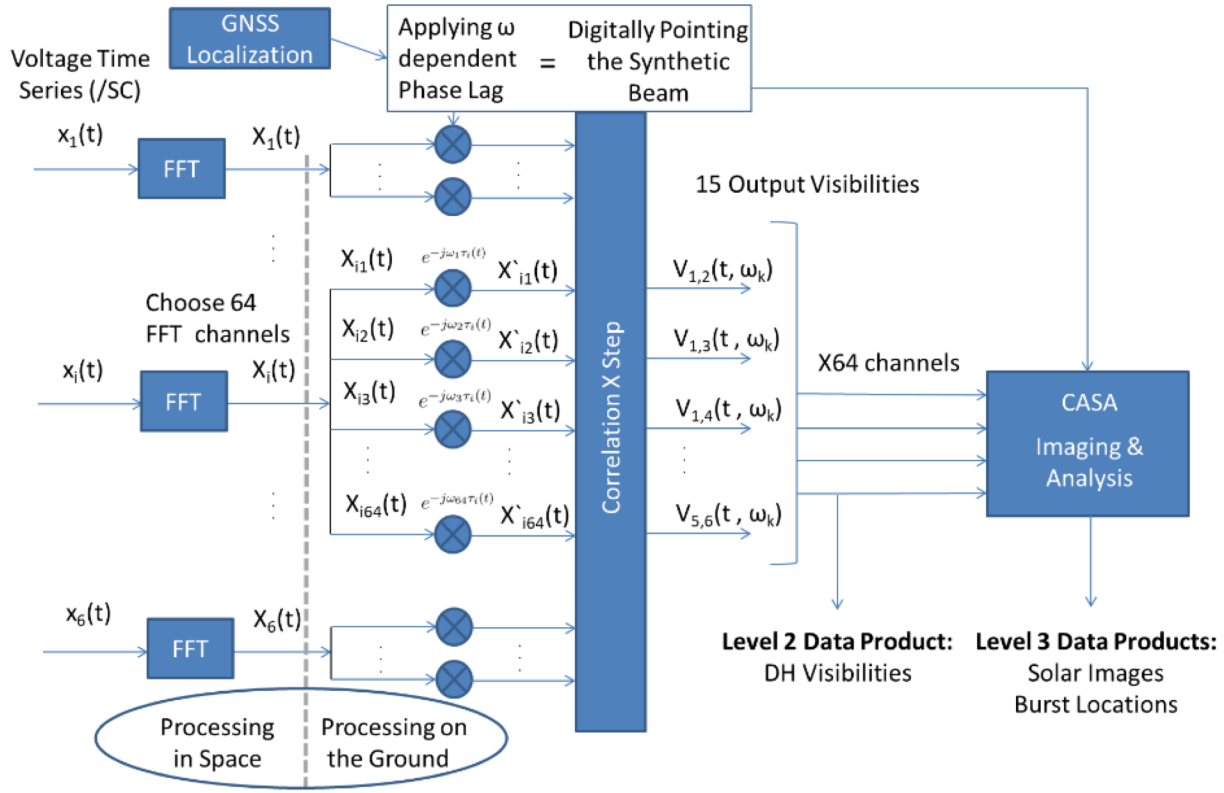
X-stage is the Correlation

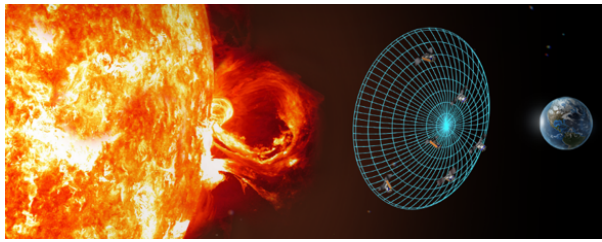
Fourier amplitudes are combined to form visibilities to form the CLEANed image.



FX Correlation cont.

SunRISE
Sun Radio Interferometer Space Experiment

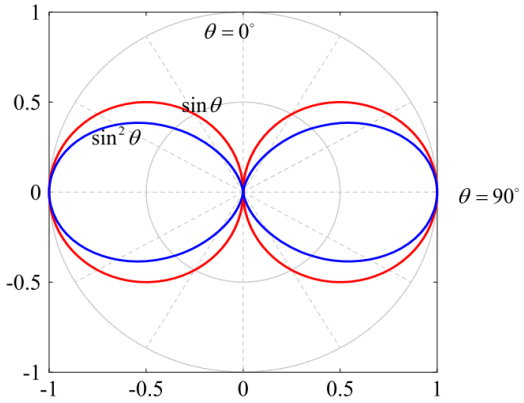


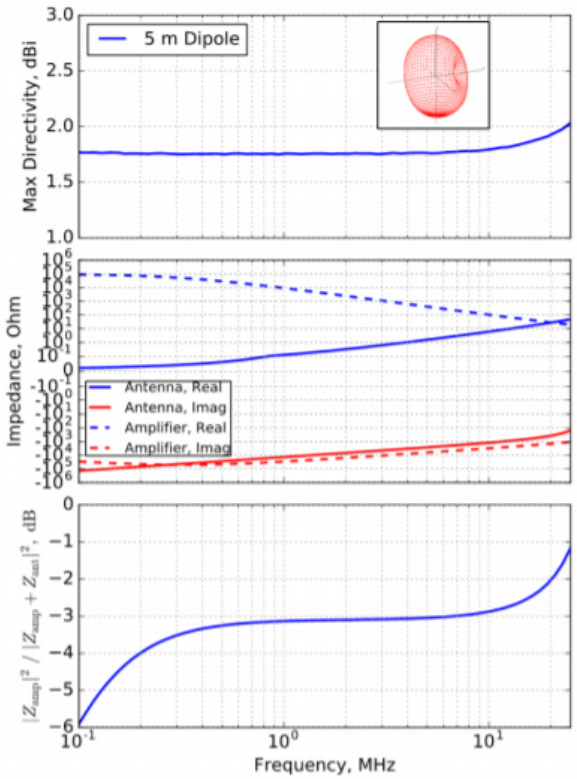


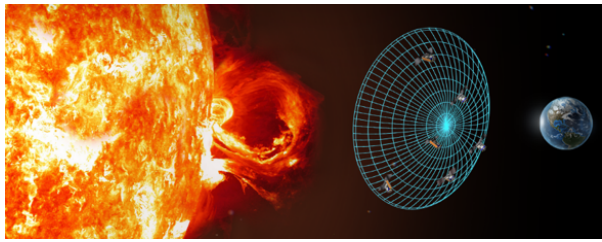
Antenna Patterns

SunRISE
Sun Radio Interferometer Space Experiment

- Directivity of the Solar DH antenna as determined from a NEC2 simulation
- Directivity is 1.7 dBi, as expected from a short dipole
- Below, theoretical response for short dipole (red, sin(θ)), and a Half Wavelength dipole (blue, $\sin^2(\theta)$)



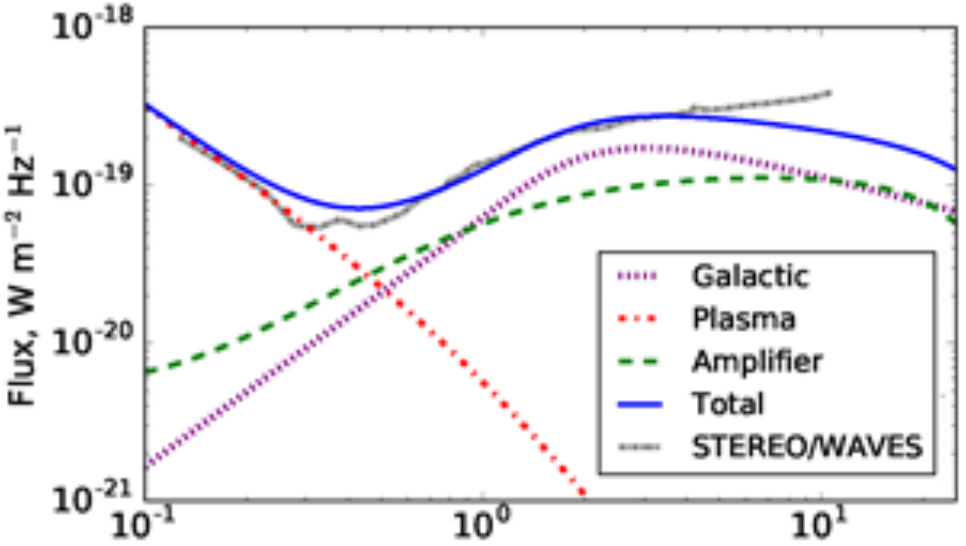




Signal to Noise Calculation

SunRISE
Sun Radio Interferometer Space Experiment

- 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

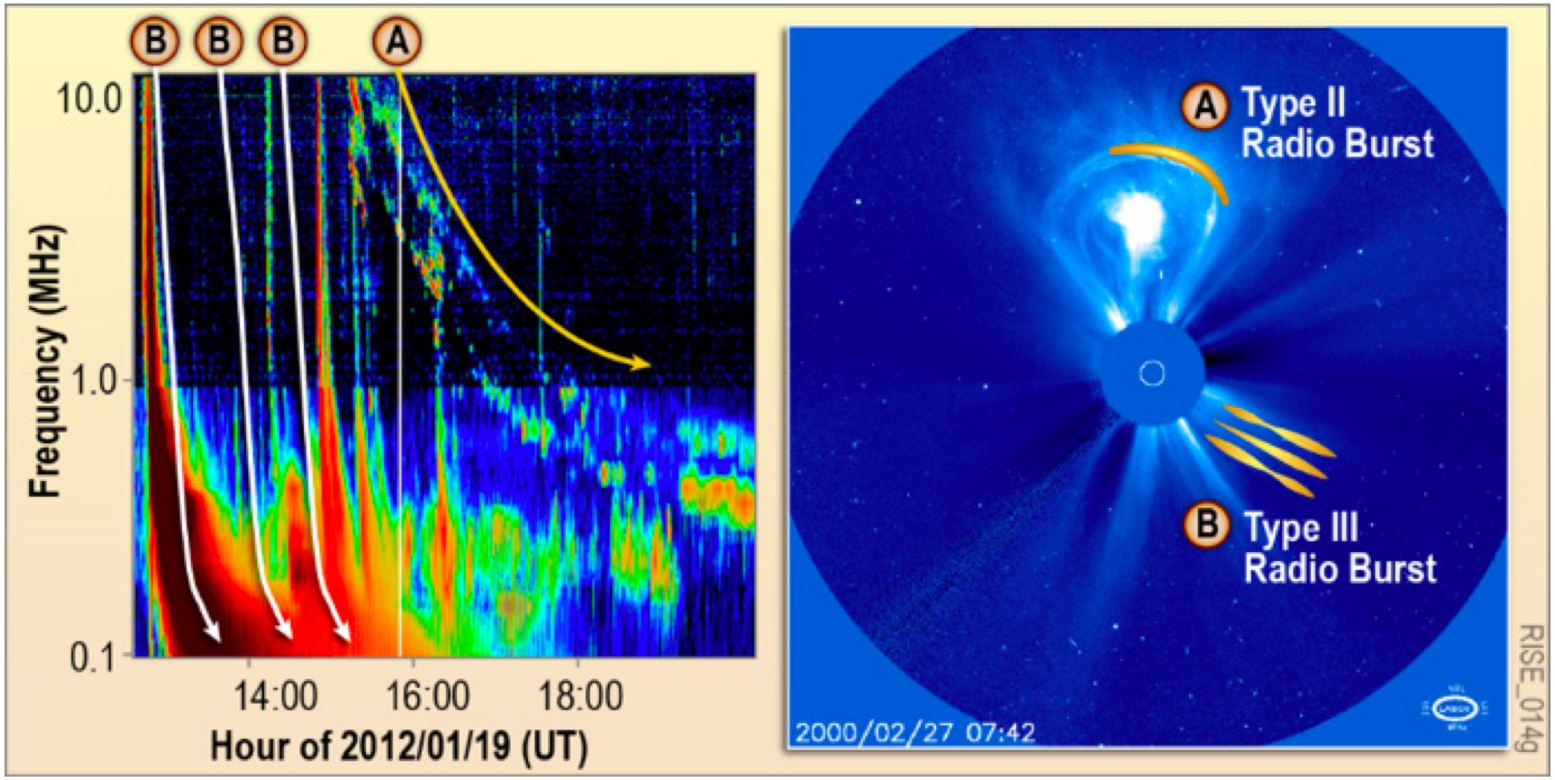


Taken from SunRISE CSR

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

Primary Science: Solar Type II & III Bursts

SunRISE
Sun Radio Interferometer Space Experiment

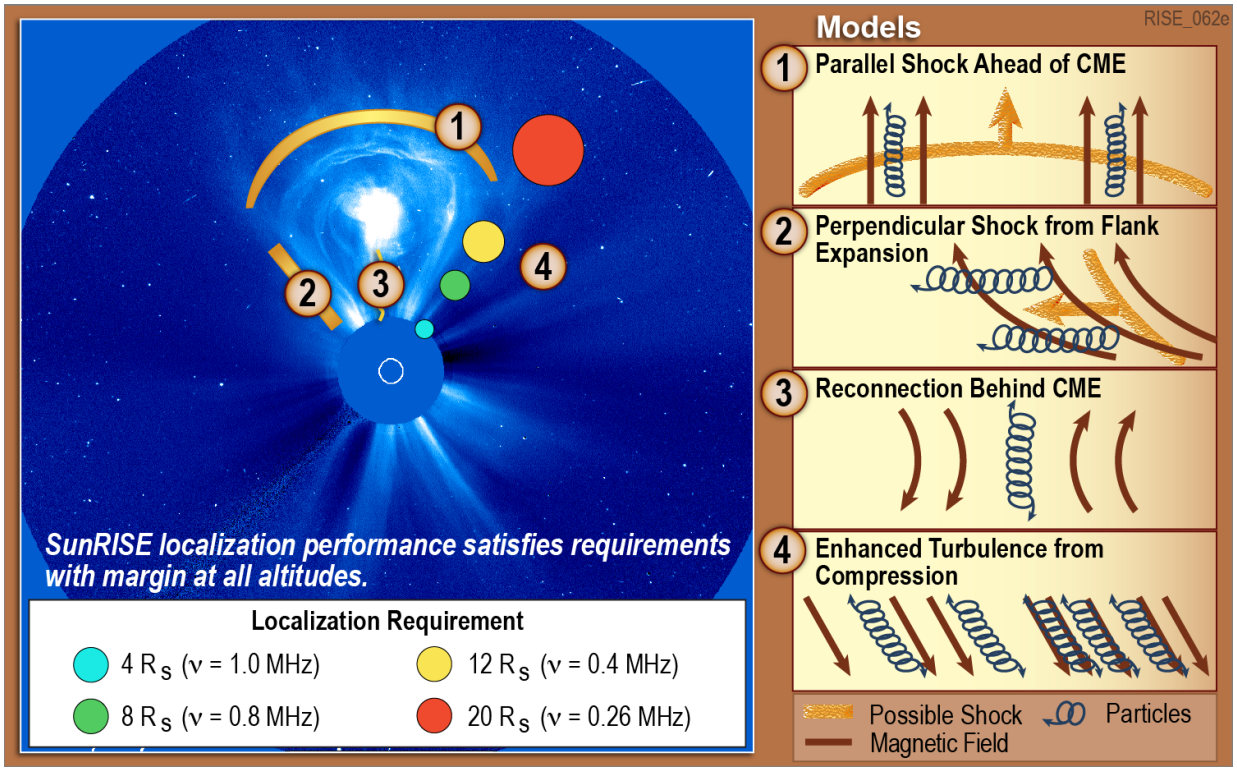


Connect Evolution of Radio Burst to One of Four Models

SunRISE
Sun Radio Interferometer Space Experiment

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.



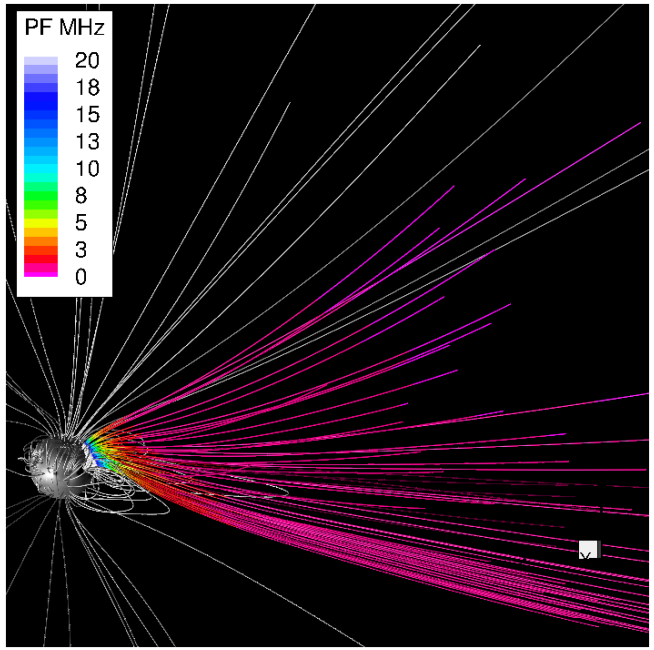
Mapping Magnetic Field Lines

SunRISE
Sun Radio Interferometer Space Experiment

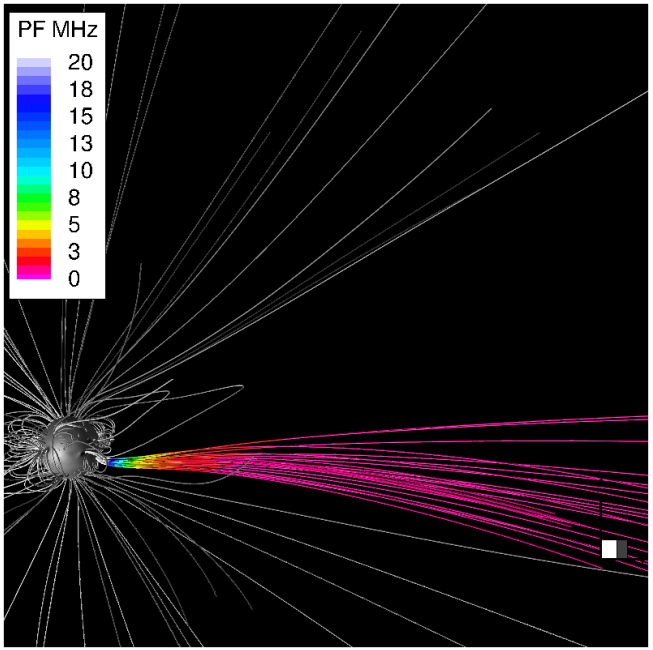
SunRISE Objective 2

Determine if a broad magnetic connection between active regions and interplanetary space is responsible for the wide longitudinal extent of some flare and CME SEPs by imaging the field lines traced by Type III bursts from 2–20 Rs.

Separatrix-web Scenario (i)

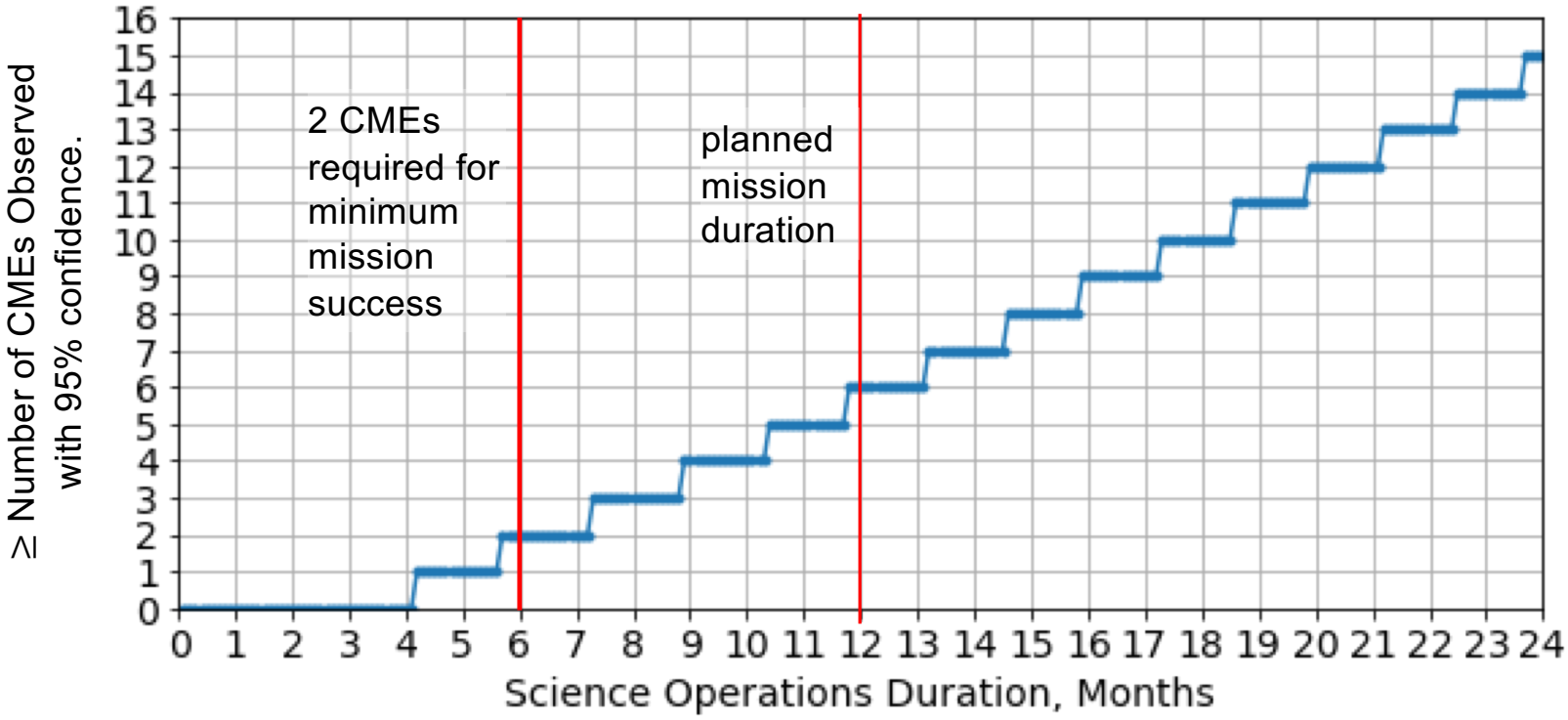


Random Walk Scenario (ii)



Number of CMEs and Mission Duration

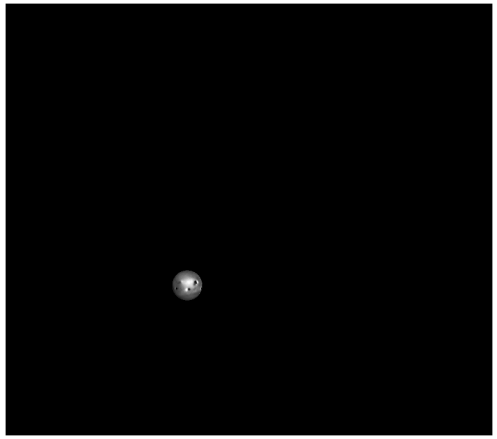
SunRISE
Sun Radio Interferometer Space Experiment

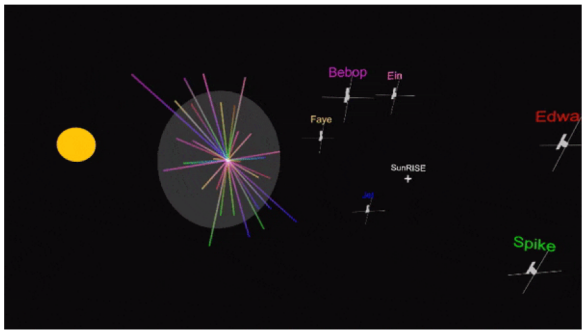


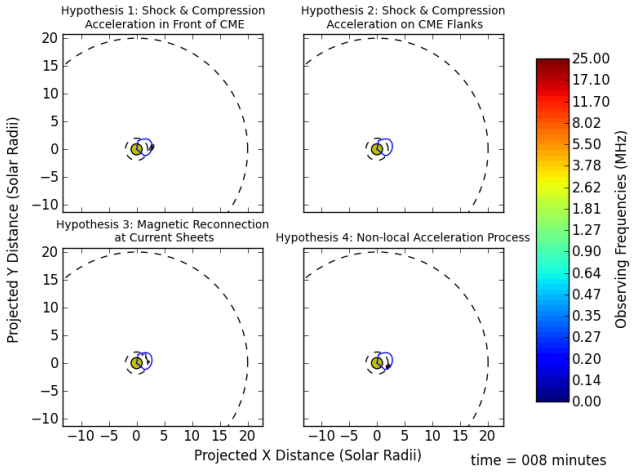
High Level Pipeline Testing Overview

SunRISE
Sun Radio Interferometer Space Experiment

MHD CME Simulation → SunRISE Simulation → Science Operation Center Analysis Pipeline

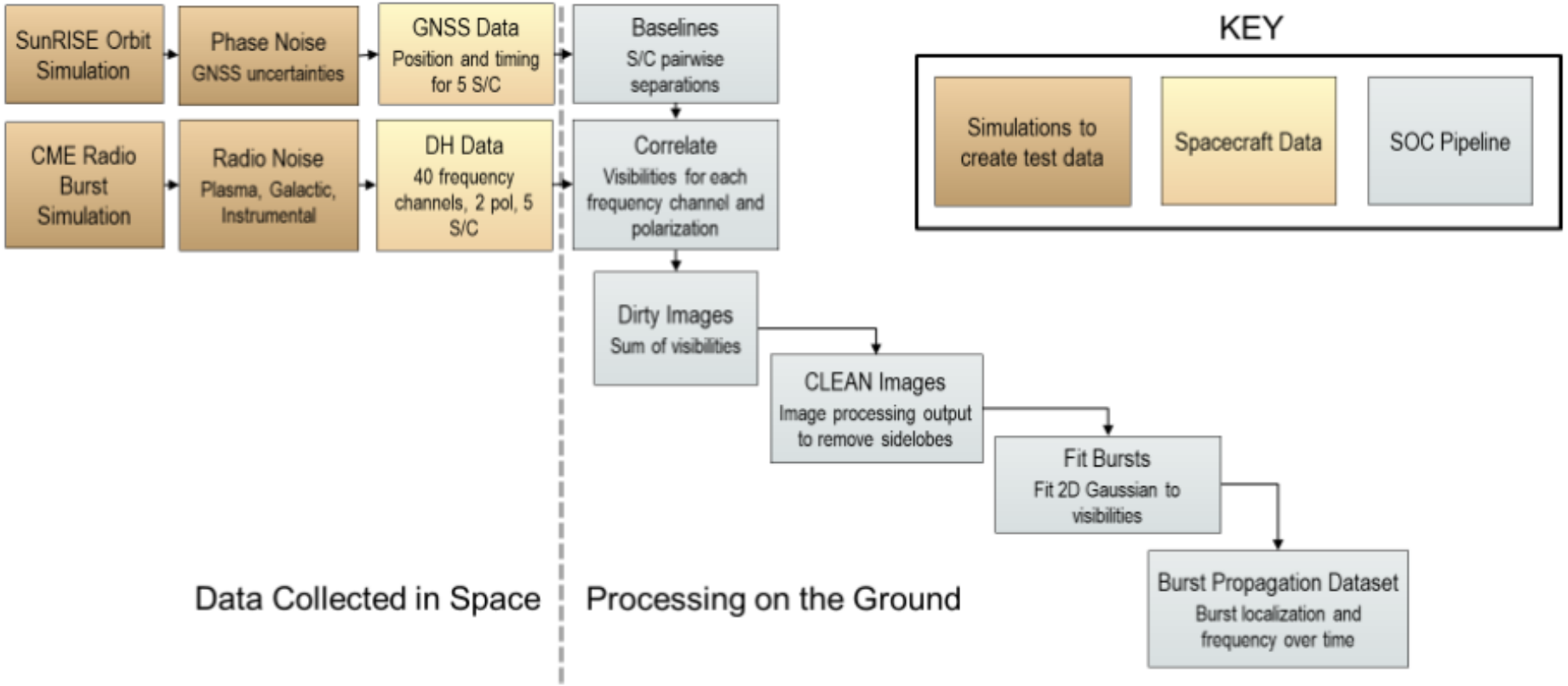






Pipeline Overview

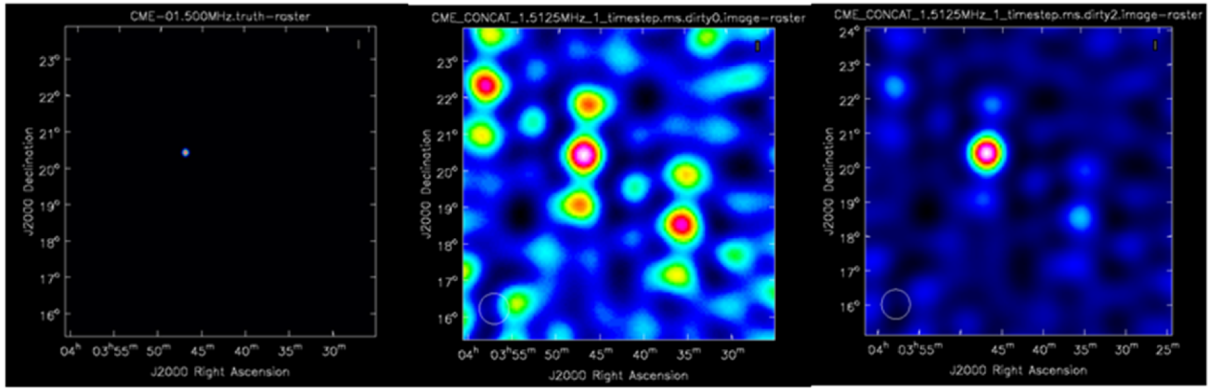
SunRISE
Sun Radio Interferometer Space Experiment



Imaging Pipeline at 1.5 MHz

SunRISE
Sun Radio Interferometer Space Experiment

1 2 3



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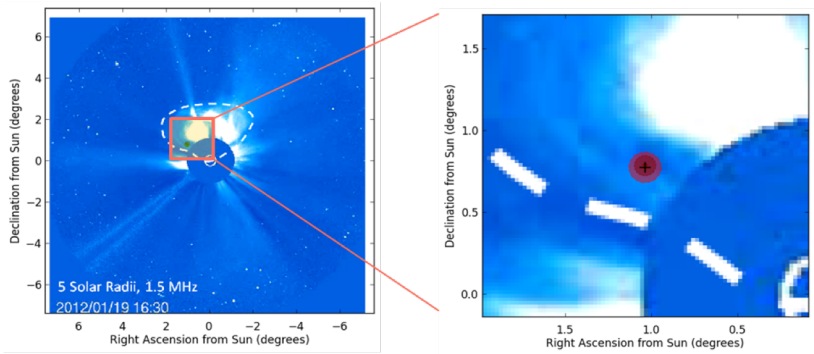

1. Simulation informed input emission distribution
2. Dirty Image with sidelobes
3. CLEANed Image with sidelobes removed
4. 2D Gaussian fit to data & put into context of CME Coronagraph Movie