FASR Science Case # WG2-1

Mapping Magnetic Fields in Post-Flare Loops and Arcades

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1 Science Goal(s)

Briefly summarize the key science goal(s) for this science case. A few sentences will be sufficient.

The primary goal of this science case is to measure and map magnetic-field strength in post-flare loops and arcades after magnetic reconnection during solar flares. Rather than attempting to cover all magnetic-field measurements during eruptions, this case focuses on the post-flare arcade as a concrete, observable target where microwave gyrosynchrotron spectra and circular polarization can constrain coronal magnetic fields and energetic-electron distributions. The key objective is to track how the field strength and microwave source morphology evolve as newly reconnected flare loops form, brighten, and cool.

2 Scientific Rationale

2.1 Scientific Importance

Provide a brief discussion on the scientific importance of this science case.

Post-flare loops and arcades are direct products of magnetic reconnection. Their magnetic-field strength controls the gyrosynchrotron spectrum, particle trapping, energy transport, and the evolution of the newly reconnected flare system. Quantitative coronal magnetic-field measurements in these structures would provide a practical observational test of how magnetic energy is converted into accelerated electrons, heating, and radiation after reconnection.

2.2 Uniqueness to FASR Capabilities

Is this science case uniquely addressed by FASR? Why can't other facilities address this science and achieve the same goal?

FASR offers a unique capability for post-flare arcade magnetometry because it can provide broadband imaging spectroscopy and circular polarization over the 2-20 GHz range at high cadence. Gyrosynchrotron spectra from flare-accelerated electrons encode magnetic-field strength, viewing geometry, and non-thermal electron properties. Stokes I provides the spatially resolved spectrum, while circular polarization provides an additional diagnostic of the coronal magnetic field. FASR therefore uniquely probes magnetic-field strength and topology inside flare loops and arcades during their rapid evolution.

2.3 Synergies

Describe potential synergies/complementarities between this FASR science case and those from current/future/planned facilities at all wavelengths (e.g., DKIST, MUSE, FIERCE, COSMO, ngGONG, etc.).

FASR post-flare arcade measurements should be interpreted within a broader multi-wavelength context. AIA, SUVI, MUSE, and related EUV/UV imagers and spectrographs can trace loop morphology, plasma flows, cooling, and temperature structure. DKIST, COSMO, ngGONG, and related magnetic-field facilities can provide photospheric, chromospheric, and off-limb coronal magnetic constraints. In particular, infrared coronal diagnostics can provide line-of-sight magnetic-field measurements for flare arcades near the limb, where scattering geometry and line formation are favorable. Hard X-ray observations can identify higher-energy electron precipitation and looptop acceleration sites. In contrast, microwave gyrosynchrotron emission allows FASR to measure magnetic-field strength and direction in flare loops and arcades regardless of flare location on the solar disk. Together, these observations place the FASR microwave magnetic-field measurements into a comprehensive flare energy-release and coronal magnetic-field context.

2.4 Measurements Required by FASR

Provide a description of the necessary measurements to be carried out by the FASR to adequately address this science case. Please coordinate these measurements with the Science Requirements table in Section III.

III. Science Requirements Tables

(A) Observational Target Description

Provide a brief discussion describing how these values are obtained/estimated, any trade-offs, interrelationships between the values, or anything else that is not captured in the following table.

(A) OBSERVATIONAL TARGET	
Type of observation (what defines a 'target')	Provide a brief description of the target: Gyrosynchrotron emission from flare-accelerated electrons in post-flare loops and arcades.
Number of targets	One to a few post-flare arcade systems per event.
Size of a single target (arcsec x arcsec)	$< 10''$-$100s''$
Distribution of all targets (arcmin x arcmin)	< 30 arcmin across the solar disk
Peak brightness (sfu/beam or Kelvin)	10^6–10^{10} K, depending on flare magnitude and frequency

(A) OBSERVATIONAL TARGET (continued)		
RMS brightness (sfu/beam or Kelvin)	10^5 K	
Expected circularly polarized flux density	Stokes V (sfu/beam)	
	V/I	$<$ 10% to 50%
Expected linearly polarized flux density	Stokes Q or U (sfu/beam)	N/A
	Q/I or U/I	N/A

(B) Spectro-Temporal Requirements Discussion

Provide a brief discussion describing how these values are obtained/estimated, any trade-offs, interrelationships between the values, or anything else that is not captured in the following table.

(B) SPECTRAL-TEMPORAL REQUIREMENTS	
Central Frequency (GHz)	2 to 20
Instantaneous Bandwidth (GHz/pol)	Broad simultaneous coverage across 2-20 GHz where possible.
Spectral resolution [MHz]	200
Temporal resolution (in seconds)	1

(C) Polarization Product Discussion

Provide a brief discussion describing how these values are obtained/estimated, any trade-offs, interrelationships between the values, or anything else that is not captured in the following table.

(C) POLARIZATION DATA PRODUCTS REQUIRED	
(y)	Stokes I
(n)	Stokes Q
(n)	Stokes U
(y)	Stokes V

(D) Imaging Requirements Discussion

Provide a brief discussion describing how these values are obtained/estimated, any trade-offs, interrelationships between the values, or anything else that is not captured in the following table.

The imaging requirements are set by the need to resolve post-flare loop and arcade magnetic fields, rather than by the need to image every structure in an eruption. The central science questions are: how does magnetic-field strength vary between loop-top, loop-leg, and arcade sources; how does it evolve as newly reconnected loops form and cool; and how do the spatially resolved microwave spectrum and circular polarization constrain the energetic-electron population and coronal magnetic field within those loops? More broadly, FASR must determine the spatial distribution and temporal evolution of coronal magnetic-field strength and topology in the flare core and surrounding arcade, identify compact sites of reconnection and particle acceleration, and establish how these regions are magnetically connected to the larger erupting structure. The instrumental requirements discussed below follow directly from these science goals and therefore provide the basis for the relevant system-design considerations.

Angular resolution is set by the need to distinguish compact footpoint or loop-leg sources from broader looptop and arcade emission. A simple back-of-the-envelope estimate can be obtained from magnetic flux conservation along a loop, $B_{\rm fp}A_{\rm fp} \approx B_{\rm lt}A_{\rm lt}$. If the source cross-section has a characteristic linear size w, this gives $w_{\rm lt} \approx w_{\rm fp}(B_{\rm fp}/B_{\rm lt})^{1/2}$. For arcsecond-scale footpoints with $w_{\rm fp} \sim 1''$–$3''$, rooted in fields $B_{\rm fp} \sim$ 500–1500 G, and for looptop fields $B_{\rm lt} \sim$ 50–150 G, the expected looptop size is typically a few to about 10 arcsec. This implies that arcsecond-class resolution is needed at the high-frequency end to resolve compact strong-field sources, while several-arcsecond resolution is needed at lower frequencies to separate and characterize looptop and arcade emission.

The mapped image size is driven by the need to image not only the bright flare kernel but the full active-region magnetic system, including surrounding arcades and connections to erupting structures. A mapped field as large as about 10 arcmin, roughly one-third of the solar-disk diameter, provides a conservative system-level envelope for preserving that context.

The required pixel scale is a derived imaging choice rather than a primary science requirement. To recover morphology and polarization structure reliably, the synthesized beam should be sampled by roughly 3-5 pixels across the FWHM. Thus a $10''$ beam at low frequency implies pixels of about $2''$–$3''$, while a $1''$ beam at high frequency implies pixels of about $0.2''$–$0.3''$. This gives a more direct science-based interpretation of the pixel-size requirement than treating pixel scale as an independent quantity.

Spectral imaging requirements are set by the physics of the spatially varying gyrosynchrotron continuum. The turnover frequency and low-frequency curvature encode magnetic field strength, characteristic electron energy, viewing angle, and possible low-frequency suppression or absorption, while the optically thin high-frequency slope constrains the nonthermal electron distribution and the spatial variation of circular polarization provides an additional magnetic diagnostic (Dulk 1985; Marsh et al. 1980). Broad instantaneous coverage is therefore essential, because the spectral peak can vary across the source and evolve rapidly in time, and in strong events may lie above 20 GHz or even continue rising toward 35 GHz (Marsh et al. 1980; Gary et al. 2018). At the same time, spatially resolved microwave spectra have already been shown to recover magnetic-field variations across reconnecting current sheets and erupting structures, so both sides of the turnover must be captured without stepping through frequency during a rapidly evolving event (Chen et al. 2020; Kou et al. 2022). By contrast, incoherent gyrosynchrotron spectra are broad and smooth, so a channel width of order 100 MHz is best regarded as a practical compromise between spectral sampling and data volume rather than a strict physics requirement. Such sampling is adequate for continuum-based magnetography, whereas substantially finer spectral resolution would be needed only if coherent fine structures are included in the science case (Dulk 1985).

Sensitivity and dynamic range are set by the need to recover weak, spatially extended coronal emission in the presence of much brighter compact flare sources. This is required because the flare-magnetometry problem is not limited to the brightest microwave kernels, but also includes looptop, current-sheet, arcade, and erupting-flux-rope structures whose brightness temperatures can be far lower than those of the compact core sources (Gary et al. 2018; Chen et al. 2020; Kou et al. 2022). Observed flare microwave sources commonly reach peak brightness temperatures of order 10^7–10^9 K, whereas weaker extended features of interest can lie near the 10^5–10^6 K level. A formal image dynamic range of at least 10^3 is therefore a reasonable lower bound, with higher values desirable for stronger or more morphologically complex events. In practice, however, solar snapshot imaging is limited not only by thermal noise but also by source self-noise, residual sidelobes, and image fidelity, so dynamic range alone is not a sufficient metric (Bastian et al. 2025). A brightness-temperature sensitivity of order 10^5 K per 100 MHz is a practical requirement, since it allows 10^6 K structures to be detected at signal-to-noise of order 10 while preserving useful imaging performance in the presence of much brighter flare emission (Bastian et al. 2025).

Polarization accuracy is required because the degree of circular polarization is itself part of the gyrosynchrotron diagnostic. In the optically thin regime, the fractional circular polarization depends on magnetic field strength, viewing angle, and the nonthermal electron distribution, so Stokes V/I provides information that is complementary to the total-intensity spectrum (Dulk 1985). Observed flare microwave polarization fractions are often of order 10%–50%, and measurements with substantially poorer accuracy rapidly lose quantitative diagnostic value; early observations with polarization accuracy of only about 20% already illustrate this limitation (Marsh et al. 1980). A polarization accuracy of about 5%–10% is therefore a practical requirement for coronal magnetometry: it keeps the instrumental uncertainty well below the typical signal amplitude while remaining realistic for dynamic imaging spectropolarimetry. This requirement feeds directly into gain stability, polarization leakage calibration, and overall image fidelity.

In summary, the science case drives FASR toward a broadband imaging spectropolarimeter with frequency-dependent spatial resolution, sensitivity to both compact and extended structures, stable polarization calibration, and enough spectral and temporal coverage to follow the rapid evolution of flare-related coronal magnetic fields.

(D) IMAGING REQUIREMENTS	
Required angular resolution (arcsec) (single value or range)	$10''$ at 2 GHz
Largest angular scale required (arcsec)	
Mapped image size (arcmin x arcmin)	Up to $10' \times 10'$
Required pixel resolution (arcsec)	$6''$ at 1 GHz and $0.3''$ at 20 GHz
Number of output/image channels	200
Output bandwidth (minimum and maximum frequency - GHz)	20 GHz
Channel width (MHz)	100

(D) IMAGING REQUIREMENTS (continued)		
Required rms (sfu/beam or Kelvin) [per channel] (if polarization products required define for each)	10^5 K	
Dynamic range within image (if polarization products required define for each)	1000:1	
Polarization accuracy (%)	5-10%	
Zero spacing/total power required?	y	
Required maximum latency (in seconds, or N/A)	N/A	
Required flux density scale calibration accuracy		1-3%
		5%
	x	10%
		20-50%

2.5 Other Performance or Functional Requirements

If there are any additional performance or functional requirements not captured above, describe them here. For example, beamforming array mode, phased array, etc.

3 Appendix

Please provide any other relevant material necessary to understand and substantiate this Science Case.

Reference

Tomczyk, S., E. Landi, J. T. Burkepile, et al. 2016. "Scientific Objectives and Capabilities of the Coronal Solar Magnetism Observatory." Journal of Geophysical Research (Space Physics) 121 (August): 7470–87. `https://doi.org/10.1002/2016JA022871`.

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Chen, B., C. Shen, D. E. Gary, K. K. Reeves, G. D. Fleishman, S. Yu, F. Guo, et al. 2020. "Measurement of Magnetic Field and Relativistic Electrons Along a Solar Flare Current Sheet." Nature Astronomy 4: 1140–1147. `https://doi.org/10.1038/s41550-020-1147-7`.

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Bastian, T., B. Chen, S. Mondal, and P. Saint-Hilaire. 2025. “Noise in Maps of the Sun at Radio Wavelengths II: Solar Use Cases.” Solar Physics 300: 90. https://doi.org/10.1007/s11207-025-02498-w.