



FASR Science Case # WG2-2

Determining the Source of Non-Thermal Emission in Supra-Arcade Downflows and Fans

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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 science goal is to determine whether non-thermal microwave emission is produced in or around supra-arcade downflows (SADs), the surrounding supra-arcade fan, and the above-the-loop-top interface during solar flares. The primary diagnostic is spatially resolved Stokes I gyrosynchrotron emission from accelerated electrons; thermal free-free and gyroresonance emission should be treated mainly as contextual components, with EUV/SUVI observations supplying much of the thermal morphology.

2 Scientific Rationale

2.1 Scientific Importance

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

How particles are accelerated and transported in solar flares is still somewhat of a mystery. Supra-arcade downflows and the bright supra-arcade fan provide a direct observational test of where accelerated electrons appear relative to reconnection outflows, downflow fronts and wakes, and the turbulent above-the-loop-top region. Identifying microwave nonthermal gyrosynchrotron sources in the fan/interface region can distinguish acceleration in the SAD cavity from acceleration around the SAD front, wake, or termination-shock-like interface above the post-flare arcade.

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?

Hard X-rays are an important complementary route to this problem, but current instruments generally lack the combination of dynamic range, sensitivity, and imaging context needed to search for faint supra-arcade sources next to much brighter flare emission. FASR's value is broad, simultaneous microwave imaging spectroscopy from 1–20 GHz, high cadence, and enough image fidelity to separate

SAD-front, wake, fan, and above-the-loop-top sources. This frequency range can capture the continuum shape of gyrosynchrotron emission and separate it from thermal free-free or possible gyroresonance contributions.

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.).

EUV/UV imaging from AIA, SUVI, MUSE, and related facilities provides the thermal morphology of the supra-arcade fan, SAD tracks, and post-flare arcade. MUSE adds spectroscopic constraints on plasma dynamics and heating, while hard X-ray observations from STIX-like or future instruments can identify higher-energy non-thermal sources where available. DKIST and other magnetic diagnostics provide broader active-region magnetic context. The key synergy is that EUV/UV observations define the fan/SAD geometry and thermal evolution, while FASR supplies the microwave non-thermal source location and spectrum.

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.

This case requires event-driven observations of solar flares. Target description: thermal free-free emission and gyrosynchrotron emission in supra-arcade fans during flares. Required frequency coverage: 1–20 GHz. Shortest temporal scale of interest: seconds. Requested polarization products: Stokes I, Stokes V.

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’)	<i>Provide a brief description of the target. Target type:</i> Nonthermal gyrosynchrotron emission in supra-arcade fans during solar flares.
Number of targets	Single flaring active region, ideally at the limb.
Size of a single target (arcsec x arcsec)	A few arcseconds
Distribution of all targets (arcmin x arcmin)	A few arcminutes

(A) OBSERVATIONAL TARGET (continued)		
Peak brightness (sfu/beam or Kelvin)	Non-thermal compact sources may reach $\sim 10^7$ K; faint fan/interface emission of interest may be near $\sim 10^5$ – 10^6 K.	
RMS brightness (sfu/beam or Kelvin)	10^5 K per 100 MHz channel in Stokes I.	
Expected circularly polarized flux density	Stokes V (sfu/beam)	Stokes V is desirable but not required for the primary detection/localization goal.
	V/I	N/A
Expected linearly polarized flux density	Stokes Q or U (sfu/beam)	Stokes Q or U not required.
	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)	5–20 GHz
Instantaneous Bandwidth (GHz/pol)	As broad as available across 1–20 GHz.
Spectral resolution [MHz]	100 MHz
Temporal resolution (in seconds)	1 s

(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
n	Stokes V

(D) Imaging Requirements Discussion

Imaging requirements for this science case are set by the need to determine where non-thermal electrons are energized relative to supra-arcade downflows (SADs), the bright supra-arcade fan, and the above-the-loop-top energy-release region. Published work does not yet support a strong claim that the dark SAD void itself is the acceleration site. Instead, current observations and modeling favor acceleration in the turbulent and shock-rich plasma around the downflows, especially in the interface below the reconnection outflow and near the flare termination shock above the arcade (Shen et al. 2022; Yu et al. 2020; Luo et al. 2021). EUV imaging studies likewise show that plasma in front of SADs and in the surrounding fan tends to heat or remain hot, with signatures consistent with adiabatic compression and local heating outside the dark cavity itself (Reeves et al. 2017; Xie and Reeves 2023). The imaging requirement is therefore to distinguish among emission from the SAD interior, the bright leading edge or wake of a downflow, and the surrounding above-the-loop-top interface region.

Angular resolution is driven by the observed and modeled sizes of SADs and their substructure. Published observations place SAD sizes at roughly 1–10 Mm, and radio calculations based on MHD models consider characteristic SAD sizes of about 2–12 Mm; the 2 Mm case corresponds to about 2.8 arcsec on the Sun (Zurbriggen et al. 2022). If the science question is whether the radio source lies within the void, at its front, or in the surrounding fan, the beam must be substantially smaller than a full SAD width and preferably able to resolve structure across the cavity/interface boundary. This argues for arcsecond to few-arcsecond resolution at the high-frequency end, so that SAD-associated sources can be separated from broader fan and looptop emission rather than detected only as a blended excess.

Temporal resolution is set by downflow kinematics and the impulsive nature of the associated energy release. SADs are reported at heights of about 40–150 Mm, with descent distances of about 10–20 Mm, speeds of about 50–500 km s⁻¹ and a characteristic average near 130 km s⁻¹, and lifetimes of a few minutes (Zurbriggen et al. 2022 and references therein). At 130 km s⁻¹, a 2–4 Mm structure evolves across its own width on roughly 15–30 s timescales. In parallel, recurring sunward outflows from discrete reconnection sites have been linked to impulsive microwave and X-ray brightenings as they reach the looptop region (Yu et al. 2020). A cadence of a few seconds is therefore physics-driven, and testing whether microwave brightenings are triggered when downflows reach the turbulent above-the-loop-top interface or flare arcade requires imaging at about 1 s cadence.

The mapped image size and largest recoverable scale are set by the need to image the entire supra-arcade system in context: the fan, the downflow track, the above-the-loop-top source region, and the underlying arcade. Because SADs occupy a region extending tens to more than one hundred Mm above the arcade, a mapped field of at least a few arcminutes is needed even for a single limb event, and adequate short-spacing response is important so that diffuse fan emission is not resolved out. Broad spectral coverage is likewise essential. The science, therefore, requires coverage from roughly 1–20 GHz, because that span is needed to separate non-thermal microwave component from any other emission source, such as thermal free-free and gyroresonance emission, and to determine whether the non-thermal source is localized in the SAD interior, at its front, or in the surrounding interface. Calculations from SAD/fan models show that the spectrum becomes largely optically thin above about 5 GHz, so the science requires broad simultaneous coverage rather than narrow tuning around one frequency (Zurbriggen et al. 2022).

Sensitivity and dynamic range should be set primarily by the non-thermal detection problem, while using thermal cases to define the backgrounds. For a purely thermal SAD/fan source, optically

thin free-free emission from hot plasma has a radio brightness temperature far below the plasma temperature, and the SAD remains a low-contrast structure against the surrounding fan (Dulk 1985; Zurbriggen et al. 2022). Thermal gyroresonance can become important only if the coronal magnetic field is strong enough for low harmonics of the gyrofrequency to fall in band and the optical depth is sufficient; in that case, the observed brightness temperature can approach the electron temperature. The relevant field is $B \approx 357\nu_{\text{GHz}}/s$ G, so the third harmonic corresponds to about 120 G at 1 GHz, 360 G at 3 GHz, and 1.2 kG at 10 GHz. This makes thermal gyroresonance plausible in lower, stronger-field flare loops, but much less likely for the weak-field SAD/fan plasma treated by Zurbriggen et al. (2022), where the field is only of order 10 G.

The more relevant and more demanding case is non-thermal gyrosynchrotron emission from electrons accelerated at the SAD front, in the wake, or in the above-the-loop-top interface. A useful benchmark is the 18 January 2022 flare, in which EOVS detected a compact supra-arcade/looptop microwave source with a spatially resolved spectrum consistent with non-thermal gyrosynchrotron emission; from Figure 8 of Lorincik et al. (2022), the source reached brightness temperatures of order a few $\times 10^7$ K and occupied a region of order 10–30 arcsec across the 3–18 GHz band. That is the brightness and size regime this science case needs to recover. The corresponding requirement is brightness-temperature sensitivity of order 10^5 K per image channel, image dynamic range of roughly 100–500:1, and modest Stokes V capability ($\sim 10\%$ polarization accuracy), so that a faint non-thermal source can be distinguished from adjacent thermal free-free or gyroresonance emission and localized within the supra-arcade system.

(D) IMAGING REQUIREMENTS		
Required angular resolution (arcsec) (single value or range)	20"/GHz	
Largest angular scale required (arcsec)	$\geq 300''$	
Mapped image size (arcmin x arcmin)	5' \times 5'	
Required pixel resolution (arcsec)	0.5''–1''	
Number of output/image channels	~ 200	
Output bandwidth (minimum and maximum frequency - GHz)	1–20	
Channel width (MHz)	100	
Required rms (sfu/beam or Kelvin) [per channel] (if polarization products required define for each)	$\sim 10^5$ K in Stokes I per 100 MHz channel	
Dynamic range within image (if polarization products required define for each)	100–500:1 in Stokes I	
Polarization accuracy (%)	10%	
Zero spacing/total power required?	Yes	
Required maximum latency (in seconds, or N/A)	N/A	
Required flux density scale calibration accuracy		1-3%
	x	5%
		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

Reference

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