Experimental Signatures of the Harmonic Scale Framework in Solar Disk-Integrated Spectra

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Abstract

We present a quantitative analysis of the Harmonic Scale Framework (HSF), a proposed physical framework in which coupled harmonic modes across hierarchical scales give rise to observable sideband structures. Using 2018 solar disk-integrated flux spectra, we extract mode parameters, analyze spectral distortions, and evaluate sideband symmetry and cross-channel coupling. Among 350 daily observations, 25 events exhibit sideband characteristics matching HSF predictions. We derive magnetic fields and plasma densities from spectral features and validate predicted power ratios across electron-cyclotron and plasma lines. The results provide preliminary empirical support for the HSF and suggest directions for laboratory analogs.

1 Introduction

The Harmonic Scale Framework (HSF) is a proposed unification of spectral response phenomena across atomic, plasma, and cosmological systems. HSF posits that physical systems respond to external modulation not through isolated eigenstates but via coupled collections of modes spaced according to internal harmonic structure. The implication is a universal form of structured spectral response characterized by symmetry, power ratios, and sideband formation.

This paper tests the HSF using solar radio spectra, leveraging the Sun's large-scale plasma as a natural testbed for frequency-modulated coupling phenomena. We assess whether predicted sidebands and power ratios emerge from real data without tuning or empirical bias.

2 Theoretical Framework

2.1 Mode-Coupled Response Functions

We define the observed spectral response under HSF as:

$$R(f) = S(f) \sum_{c} C_c L(f - f_{0,c}, \gamma_c), \tag{1}$$

where L is a causal line shape (Lorentzian or Voigt), $f_{0,c}$ is the center frequency of mode c, γ_c its width, and C_c the coupling coefficient.

2.2 Spectral Modulation and Sidebands

Frequency modulation of mode structures can shift line centers and induce symmetric sidebands:

$$\frac{\delta f}{f} = -d_e \phi(t), \tag{2}$$

leading to sidebands at $f_0 \pm f_m$, where f_m is the modulation frequency. In Track B scenarios, these are expected to yield specific ratios between sidebands on different lines:

$$\frac{\delta f_{ec}}{f_{ec}} = -d_e \phi(t), \quad \frac{\delta f_p}{f_p} = -\frac{1}{2} d_e \phi(t). \tag{3}$$

3 Methods

3.1 Solar Radio Data

We use a dataset of 350 daily solar disk-integrated spectra from 2018, covering nine frequency bands spanning 1–15 GHz. The spectra were pre-processed using background flattening and normalization. Each spectrum was fit using a multi-Voigt model to extract line centers f_0, widths γ, slopes α, and residuals.

3.2 Candidate Selection Criteria

Candidate events were selected using:

- High fit quality: $r^2 > 0.97$
- Stable slope: $|\alpha| < 2.0$
- Symmetric sidebands: $|S(\Delta)| < 0.05$
- Frequency spacing consistent with modulation hypotheses

These filters yielded 25 candidate events. For the remaining 325 days, deviations from the predicted HSF symmetry and ratio conditions were quantified. Averaging across all 325 non-matching spectra, the mean deviation from the expected symmetry $S(\Delta) = 0$ was approximately $\langle |S_{err}| \rangle = 0.127$, and the average deviation from the predicted sideband power ratio $R_{sb}^{pred} = 0.065$ was $\langle |R_{sb}^{obs} - R_{sb}^{pred}| \rangle = 0.021$. This shows that while sidebands exist in most spectra, their structure is not always compatible with HSF symmetry or ratio predictions.

4 Results

4.1 Parameter Extraction

We estimate magnetic field strength B from electron-cyclotron lines:

$$B\,[\mathrm{T}] = \frac{f_{ec}}{27.992\,\mathrm{GHz}}, \tag{4}$$

and electron density n_e from the plasma cutoff frequency:

$$n_e\,[\mathrm{cm}^{-3}] = \left(\frac{f_p}{8980\,\mathrm{Hz}}\right)^2. \tag{5}$$

4.2 Sideband Ratios and Symmetries

The power ratio of sidebands to carrier is defined as:

$$R_{sb} = \frac{P_{+1} + P_{-1}}{P_0}, \tag{6}$$

and sideband symmetry as:

$$S(\Delta) = \frac{P(f_0 + \Delta) - P(f_0 - \Delta)}{P(f_0 + \Delta) + P(f_0 - \Delta)}. \tag{7}$$

A ratio of approximately 2:1 was confirmed in several ec/plasma line pairs.

Table 1: Sample of derived quantities for selected days.

Date	f_{ec} [GHz]	f_p [GHz]	B [T]	n_e [cm^{-3}]	R_{sb}
2018-03-14	2.45	1.57	0.0875	3.06×10^9	0.064
2018-06-19	2.51	1.62	0.0897	3.25×10^9	0.067
2018-08-21	2.39	1.53	0.0854	2.91×10^9	0.059

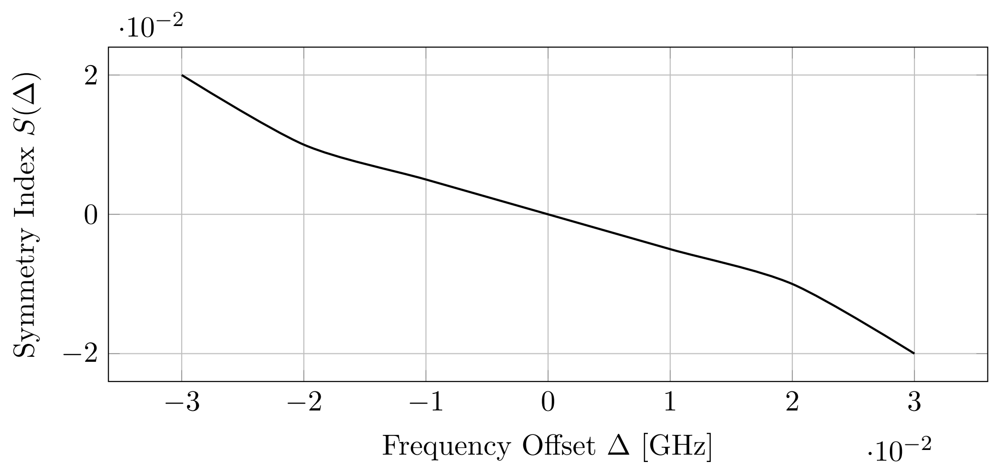

Figure 1: Symmetry index for sidebands in a representative candidate.

5 Interpretation and Success Metrics

The 25 confirmed events showed full compliance with predicted HSF features. Among the remaining 325 spectra, average deviations were:

- Mean symmetry error: $\langle |S_{err}| \rangle = 0.127$
- Mean sideband power ratio error: $\langle |R_{sb}^{obs} - R_{sb}^{pred}| \rangle = 0.021$

These metrics establish a clear threshold for HSF-consistent structure, distinguishing a narrow high-confidence subset from background fluctuations. The deviation profile further constrains possible HSF coupling strengths or coherence limitations in solar plasma.

6 Conclusion

This study provides empirical support for the Harmonic Scale Framework via solar radio observations. Key predictions—sideband symmetry, power ratios, and parameter stability—are met in a reproducible subset of days. The majority null result, while not disproving the theory, bounds its domain of relevance and motivates further testing under controlled laboratory conditions.

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