Supplementary Methods

The cavity is illustrated in the Figure 8 as a lumped LC network which is critically coupled to a sensing antenna (housed externally in a waveguide for impedance matching). The cavity is also weakly coupled (when the measurements are not carried out) to a high-frequency RF source (Agilent 8474 E) and a PC-based spectrum analyzer (Aaronia GmBH) for calibration and test signal injection and analysis. The sensing antenna is made in the form of a tuning fork topology, developed using gold plated 24 SWG copper wires. The signals sensed by the antenna are conveyed to a Josephson parametric amplifier (JPA) made with two SQUIDs (as explained in detail in the text), which serves as the first amplification stage. The *ac*-coupled output of the JPA is further amplified by a high-gain amplification block, designed around a resonant tunneling diode (RTD) and a pair of matched HEMT MMICs, a set of LNF-LNC-1.5-6 A 1.5–6 GHz cryogenic LNAs, with noise temperature of around 2.1 K (~0.031 dB noise figure) and a gain of 26dB, working at 2 K. The current LNA device shall be replaced soon by a lower noise temperature LNC_4 with a 1.2 K noise, reducing the amplifier chain noise further. Since the signal has not reached the sufficient strength to be read out by the RF detector, a room temperature LNA stage follows, comprising a 60K noise temperature HEMT amplifier (PE15A1010 2–6GHz LNA 0.9dB NF, 40dB gain LNA @ 290K, Pasternack, Irvine, CA), which is coupled to an RF detector stage (via a YIG RF filter).

This stage consists of a low-barrier Schottky type power law detector (Agilent/Keysight*8471E* 0.01–12 GHz planar-doped barrier diode detector) which produces a stream of voltages corresponding to the detected RF power from the cavity. The detected RF signal is conveyed to a 2MHz DSP Lock-in Amplifier (Stanford Research SR865A) for noise minimized phase-sensitive detection which generates *dc* voltages corresponding to the measured power, which are in turn conveyed to a computer via a commercial high-precision 16-bit 1MHz data acquisition (DAQ) system, which also performs online FFT analysis on the measured samples.

A precise and low-distortion carrier signal (with modulation index $A_{sig}/A_{mod} \leq 1/2$) is generated by a Stanford SR260 ultra-low-distortion signal generator and given to both the LIA as well as to the cavity sensing and routing circuit. This is a specially designed cryogenic circuit, named sensing and routing hub (SRH), analogous to a bias Tee but with added functionality. It serves the purpose of connecting the cryogenic HEMT output to the RTD and in turn to the second stage LNA (which is kept at 290K temperature by cooling with a Peltier cooling system) while capacitively coupling the carrier modulation signal to the *ac* line, as well as providing an isolated bias voltage to the RTD coming from a precision voltage source (designed around a precision current source device from Maxim semiconductor).

For probing higher axion mass values, we plan to employ CIT112/CIT412 (Cosmic Microwave Technology (Formerly Caltech Microwave), Lawndale, CA) and Low-Noise Factory LNF-LNC-23-42WB HEMTs, which are precision cryogenic low-noise amplifiers, with 1 to 12 GHz and 23 to 42 GHz operational regions, respectively, to probe axion masses till around 112.5 eV.