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While observing Jovian emissions near 20 MHz with a spectrograph, patterns characteristic of Faraday rotation are often observed. Presented here is a brief description of Faraday bands and how they are generated.

A Faraday Band Identification Guide

Have a look at the spectrogram in Figure 1. See those light and dark almost horizontal bands that slope gently downward from left to right? Those are Faraday bands. Sometimes Faraday bands are widely spaced, sometimes they're squished up. Sometimes they slope down, sometimes up, and sometimes they aren't sloped. Sometimes they don't even exist at all.

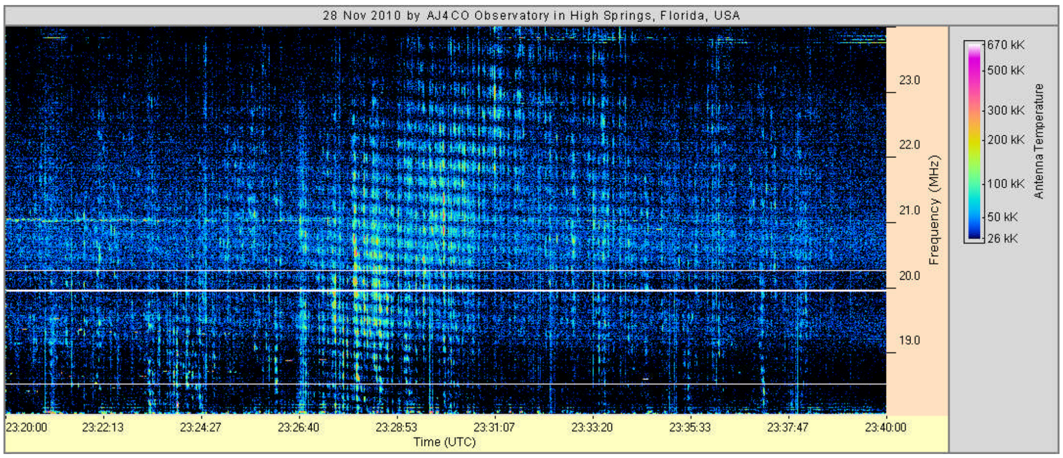

Fig. 1 – An Io-B event recorded by the author on Nov. 28, 2010.

Once in a while you might see them called Faraday lanes, but in Jovian radio astronomy the term "lanes" usually refers to "modulation lanes," bands of a different nature that are usually far more angled.[1,2] No one is sure what produces modulation lanes; however, several complex theories exist.[3] An example of modulation lanes is shown in Figure 2. There is no hard and fast rule to the terminology, however, phenomenology and classification being at the squishy end of any scientific endeavor.

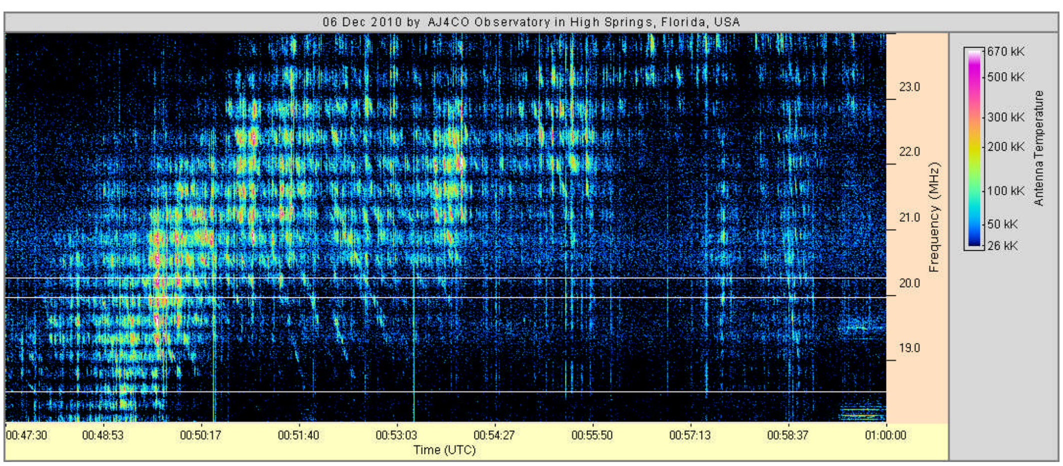

Fig. 2 – Modulation lanes sloped downward at about 70° in an Io-B event recorded by the author on 06 Dec 2010, as seen distinct from the nearly horizontal Faraday banding.

Why Faraday Bands Occur

In general, Faraday bands can occur in a spectrogram when an elliptically polarized extraterrestrial broadband noise burst is received by a linearly polarized antenna on Earth's surface. The question is why this happens.

Elliptical polarization is the general case for electromagnetic radiation. The amount of elliptical polarization is bounded by two extremes: 100% linear polarization on one hand and 100% circular polarization on the other. Plain elliptical polarization covers all the ground in between. If you're uncertain what "elliptical polarization" describes, see Whit Reeve's "Quick Tutorial #4 – Wavelength and Frequency" in the Oct/Nov 2010 issue of the SARA Journal.

Michael Faraday discovered that shooting polarized light through an electrically conducting medium embedded in magnetic field will rotate the light's direction of polarization. This has since come to be known as magnetic circular birefringence or Faraday rotation.

Since radio waves are the same thing as light, albeit at a much lower frequency, and since the ionosphere is an electrically conducting medium embedded in the geomagnetic field, all of this applies equally well to radio astronomy observations.

Mathematically, an elliptically polarized wave can be thought of as a superposition of a left hand circular polarization (LHCP) component and a right hand circular polarization (RHCP) component, the relative amplitude of each component determining whether the wave is pure circular (one component is zero) or pure linear (both components have equal amplitude) or elliptical (both components are non-zero and are unequal in amplitude). In the latter two cases, the phase relationship between the two components determines the direction in which the linear or elliptical polarization points. That is, changing the phase relationship doesn't change the amount of polarization, but it does change the direction of the polarization.

This mathematical sleight of hand has physical implications. When an elliptically polarized wave traverses Earth's ionosphere, its RHCP and LHCP components have different propagation velocities through the plasma.[4,5] As such, when the wave emerges from the ionosphere, the phase relationship between the RHCP and LHCP components will generally be different than it was before. The net effect is that the long axis of the polarization ellipse gets rotated in space. We say that the polarization was rotated or that the emission underwent Faraday rotation.

Equations 1 and 2 can be used to calculate the amount of rotation.[6,7,8,9]

For propagation roughly parallel to magnetic field lines:

$$\theta = \frac{k}{f^2}\int_0^r N(r)B_{\parallel}(r)\,dr \quad \text{where} \quad k = \frac{e^3}{8\pi^2\varepsilon_0 m^2 c} \tag{1}$$

For propagation roughly perpendicular to magnetic field lines:

$$\theta = \frac{k}{f^3}\int_0^r N(r)B_{\perp}^2(r)\,dr \quad \text{where} \quad k = \frac{e^4}{32\pi^3\varepsilon_0 m^3 c} \tag{2}$$

where

- θ = angle through which the polarization ellipse is rotated (radians)
- f = frequency of the electromagnetic radiation (Hz)
- e = charge on the particles in the plasma (for electrons, 1.602×10^{-19} C)
- ε_0 = permittivity of free space (8.854×10^{-12} F·m^{-1})
- m = mass of the charged particles in the plasma (for electrons, 9.109×10^{-31} kg)
- c = speed of light in a vacuum (2.998×10^{8} m·s^{-1})
- r = distance along the path of propagation in the direction of propagation (m)
- $N(r)$ = charged particle density at point r on the path of propagation (m^{-3})

$B_{\parallel}(r)$	=	magnetic flux density (T) in the direction parallel to the path of propagation at point r on the path of propagation
$B_{\perp}(r)$	=	magnetic flux density (T) in the direction perpendicular to the path of propagation at point r on the path of propagation

For our purposes here, it is not as important to be able to solve these equations explicitly as it is to note that the amount of rotation is inversely proportional to frequency f and directly proportional to charge density N, all other things being equal. The polarization ellipses at low frequencies undergo more rotation than those at high frequencies. That's the key to the creation of Faraday bands: the amount of energy a linearly polarized antenna captures from such a signal changes with wavelength as the polarization vector progressively goes in and out of alignment with the antenna over the observing bandwidth.

To see why that happens, imagine a lone dipole antenna about a quarter wavelength above the ground. Now imagine a linearly polarized electromagnetic wave coming in from a source at zenith in the sky. If the dipole is oriented so that its long axis is parallel to the wave's electric field—by convention this is the wave's polarization direction—the dipole sees 100% of the signal. If instead the wave's polarization happens to be 90° to the dipole, the antenna sees nothing at all.

Now imagine the same thing, but with an elliptically polarized wave. If the long axis of the polarization ellipse is parallel to the dipole, it sees almost all the wave; 90° to the dipole awards us almost no signal received. If the wave is almost wholly circularly polarized, then the difference is small. If the wave is purely circularly polarized, we see no difference at all, the antenna seeing exactly 50% of the wave's energy all the time.

So, if you have a spectrograph attached to a dipole or Yagi or any other linearly polarized antenna, you see Faraday bands when viewing an extraterrestrial broadband noise source that has at least some linear component to its polarization – for example, Jupiter's decametric emission You'll often see references stating that Jovian emission is circularly polarized, and that is mostly true—but it's really elliptical. The dark bands in the spectrogram are where the frequency is such that the polarization ellipse just happened to end up 90° to the antenna's elements. The brighter bands occur at frequencies where the polarization ellipse ended up parallel to the antenna.

This brings up the fact that if the extraterrestrial source has random polarization (e.g., a solar burst), then there are no Faraday bands because there's no polarization ellipse to get rotated. Same for 100% pure circular polarization: there are no Faraday bands because there is nothing linear about pure circular polarization—or rather, there is only one circular component with a non-zero value, so the propagation velocity of the other circular component is immaterial.

Observation of Faraday bands in a spectrogram is a great way to extract Jupiter emissions from local RFI. They don't show up for solar bursts, but solar emission is usually strong enough to stand on its own, head and shoulders above moderate RFI. Faraday bands can help you see a weak Jovian emission hidden in the grass of poor observing conditions because the bands are a dead giveaway that the source is extraterrestrial. One must be careful, though: the human visual cortex is an exceedingly adept pattern recognition engine, so good in fact that it sometimes sees things that aren't really there. Canals on Mars, for example.

The Dope on the Slope

Usually, the Faraday bands in a 15 minute spectrogram for Jovian emission are fairly horizontal, only slightly sloped if at all. Nothing much changes in such a relatively short period of time. Looking at Fig. 3, a spectrogram of the 07 Aug 2011 Io-B event, the Faraday bands appear with more slope than usual – certainly steeper than observations made in the dead of night or the middle of the day.

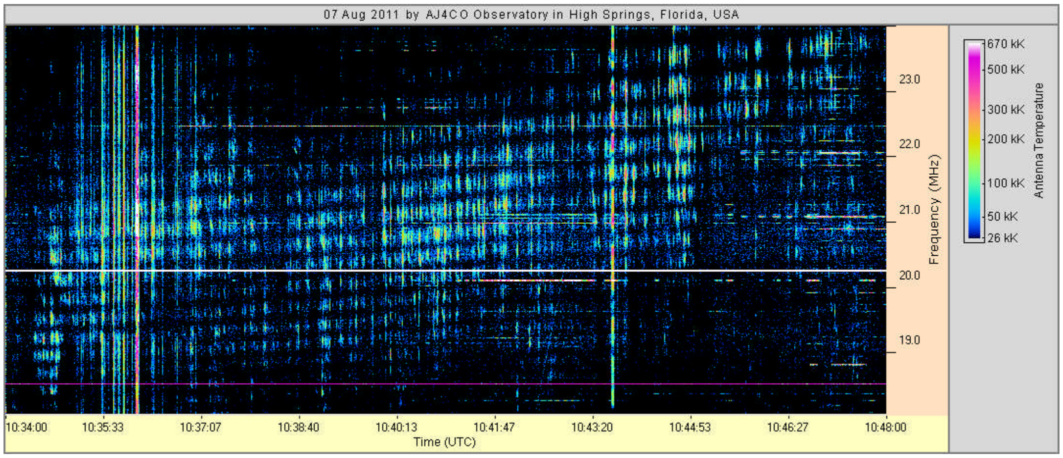

Fig. 3 – An Io-B event recorded by the author on Aug. 7, 2011 behind some local interference.

So why are the Faraday bands so steeply sloped? The explanation is that while our observatories were still in darkness down here on Earth's surface, the upper atmosphere was not. The Sun was only two degrees below our horizon. The ionosphere's F layer hundreds of miles above us was rapidly ionizing and splitting in twain, increasing the electron density along the path through which the Jovian emission had to propagate. From eqns. 1 and 2, we see that we should expect the rotation angle to increase with time as the ionosphere's charge density increases with time. This causes the Faraday bands to slope.

But why do they slope upward instead of downward? What's the difference? The equations tell the tale: as frequency increases, Faraday rotation decreases. Lower frequencies are affected more by Faraday rotation than higher frequencies, all other things being equal. As the ionosphere thickens, it increases the amount of Faraday rotation across the entire observation bandwidth, but not equally: the rotation at lower frequencies is increased more than the rotation at higher frequencies. Think of it as Faraday bands being added from the bottom of the spectrogram. The net effect is to produce an upward slope to the Faraday bands.

With this logic, we can predict that Jupiter emissions seen after local sunset will show a downward slope to the Faraday lanes as the ions within the ionosphere recombine and the F layer beds down for the night. It's simply a reversal of the process at sunrise, albeit somewhat slower. This is, it turns out, exactly what we see. To wit, Figure 1 at the beginning of this article.

So there we have it, Faraday bands for fun and profit. They're a useful tool because they only occur to extraterrestrial signals. The phenomenon of Faraday rotation is also used elsewhere in radio astronomy, as a probe for magnetic fields throughout the universe.

References for Further Study

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Suggested Additional Reading

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About the author: Dave Typinski, AJ4CO, has been involved with amateur radio astronomy and the Radio JOVE program since 2009. He lives in High Springs, Florida, where he runs a company that decorates ceramic tile. He may be contacted at AJ4CO Observatory, davetyp@typnet.net

A lesson in pronunciation: Wikipedia Online Definition of Andromeda Galaxy...

"The Andromeda Galaxy (pronounced /æn' drɒmədə/) is a spiral galaxy approximately . . ."

Wait a minute, how do you pronounce the backward a in "æn'"?

Clint Jeffrey, SARA member and Section Director of the Astronomical Society of Victoria, Radio Astronomy Section in Australia, reports that the Leon Mow Dark Sky Radio Observatory (LMRO, http://www.lmdsro.com/) has commissioned a 2.4 m (8 ft) long horn antenna for observations at 1420 MHz. The horn is shown below. The LMRO Radio JOVE antenna is in the background (image used with permission).