

Cassiopeia A Scintillation Observed by Radio Jove Participants

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In December 2013, Dave Typinski recorded a spectrogram with some ghostly sweeping features in it. Discussion with the Radio Jove Spectrograph Users Group (SUG) suggested that since there was a CME impact at the time, the weird spectrogram was probably a result of a geomagnetic disturbance.[1] In October 2014, Typinski again noticed more of these features appearing almost every other night in his spectrograms. More discussion within the SUG ensued, whereupon the emissions were oh-so cleverly dubbed “weird nighttime events” or WNE’s. Thomas Ashcraft started noticing WNE’s in his spectrograms, as did Wes Greenman. We all scratched our heads. There were no coronal mass ejection (CME) impacts, but the Sun was rather active. “What *are* these things?” we all wondered.

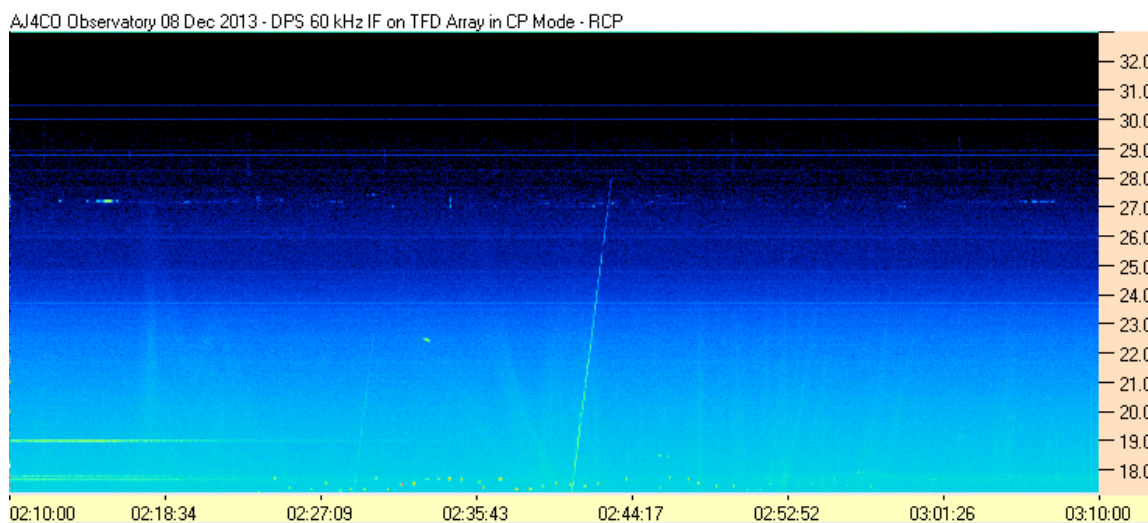


Figure 1 – The spectrogram that started it all, a WNE observed in December 2013. Horizontal bands are radio stations, the bright angled trace is a radar sweep. Cas A scintillation is seen as a series of nearly vertical wispy, somewhat curved and angled sweeping features. The antenna array was steered to zenith at this time.

Ashcraft suggested that maybe we were seeing Cassiopeia A or Cygnus A scintillation. He noted the similarity of the the WNE’s to scintillation events observed by the KAIRA research instrument in Finland.[2] At the same time, Dr. Francisco Reyes was working out the transit time, flux density, and locations of Cas A and Cyg A and provided strip charts of Virgo A beam transits he made in 1991-93 using the large 26 MHz array at the University of Florida Radio Observatory. These showed that sometimes the scintillation was strong and other times it was nearly absent. Dr Reyes also noted that since Cyg A transits a bit earlier than our observed WNE’s, Cas A scintillation was the best candidate for the observed WNE’s. He suggested that Typinski steer his 8-element array toward Cas A, which was done on October 30. Lo and behold, the wispy, sweeping features appeared much stronger (Fig. 2 below) and looked very similar to the KAIRA spectrograms. The mystery was solved: the weird nighttime events were scintillation of Cas A’s emission. To our knowledge, this is the first time the dynamic spectra of Cas A scintillation in the HF band has been intentionally observed by an amateur radio astronomer.

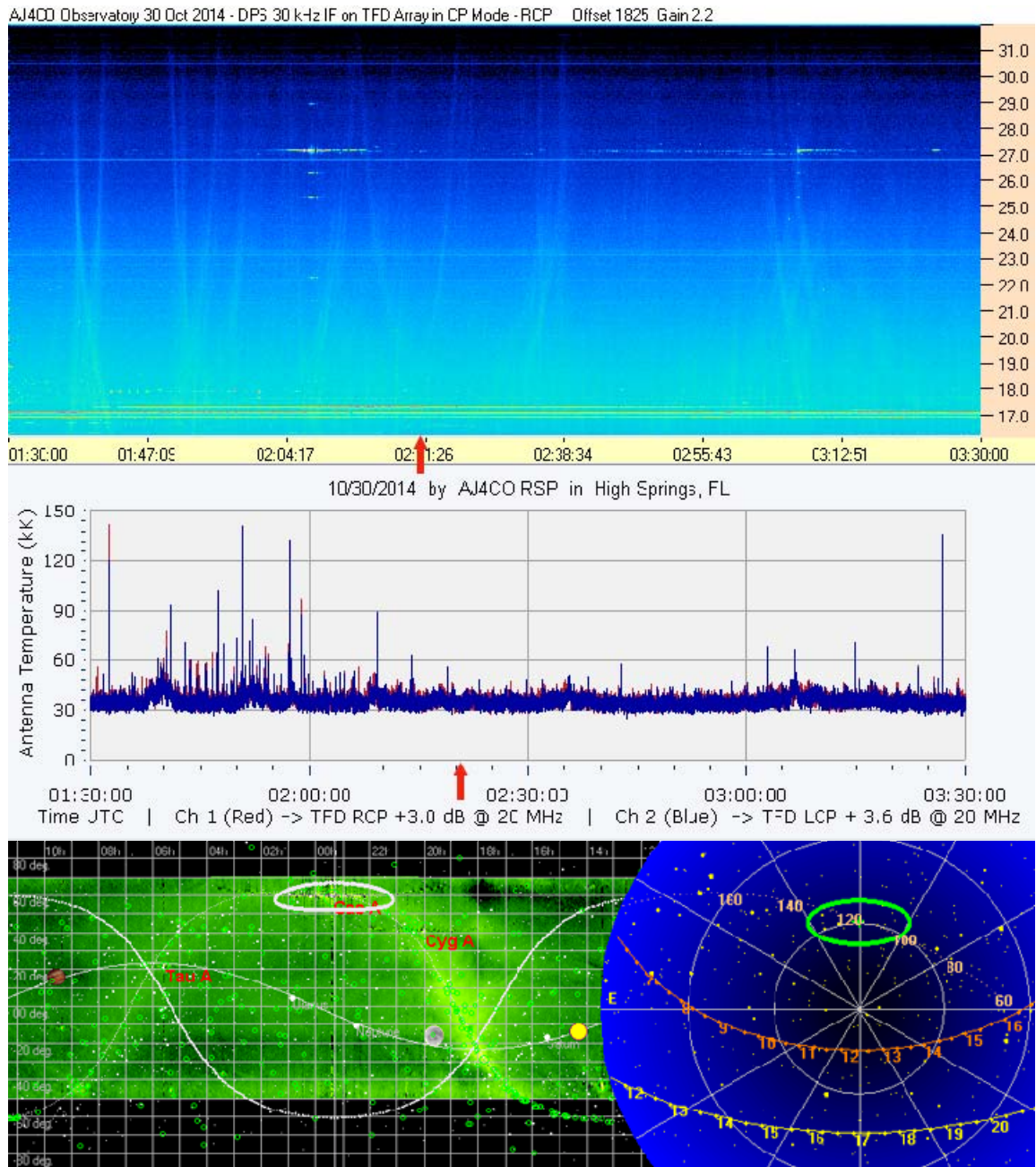


Figure 2 – Cas A scintillation observed by Dave Typinski (High Springs, Florida) on 30 Oct 2014 with an 8-element terminated folded dipole (TFD) array, the dual polarization radio spectrograph (DPS), and two Jove receivers. The antenna beam was steered to 0° azimuth and 60° elevation. Cas A transited at 0221 UTC (represented by red arrows). 20 MHz half power beam width (HPBW) is 15° NS and 35° EW; directivity for emissions with random polarization (such as Cas A) is approximately 14 dBi. Top: Spectrogram with time on the horizontal axis, frequency in MHz on the vertical axis (this spectrogram has 300 frequency channels), and signal power represented by color. Scintillation is seen as nearly vertical sweeping lines. The horizontal streaking is interference from radio stations. Middle: Single frequency (~ 20.1 MHz) strip chart with time on the horizontal axis and antenna temperature on the vertical axis. Bottom left: Radio Eyes plot at observing time. Bottom right: Radio Jupiter Pro sky view at observing time. Ovals represent the array's 20 MHz HPBW.

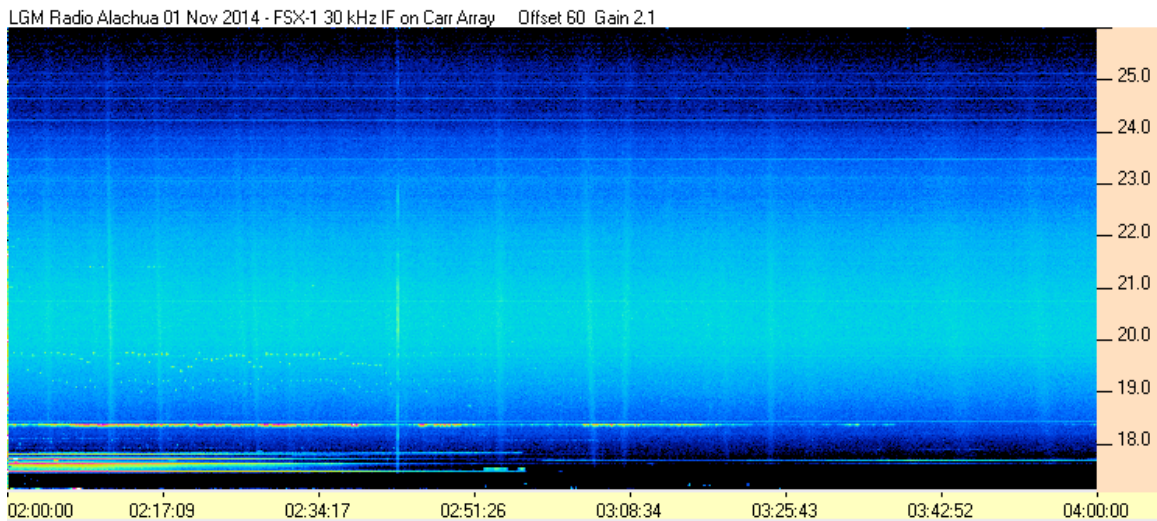


Figure 3 – Cas A scintillation observed by Wes Greenman (Alachua, Florida) on 01 Nov 2014 with the dual dipole Carr array (1½-inch diameter aluminum tubing element arms cut for 20.7 MHz with 25-foot element spacing) and the FSX-1 radio spectrograph. Beam was steered to 0° azimuth and 60° elevation and the array directivity was about 8 dBi.

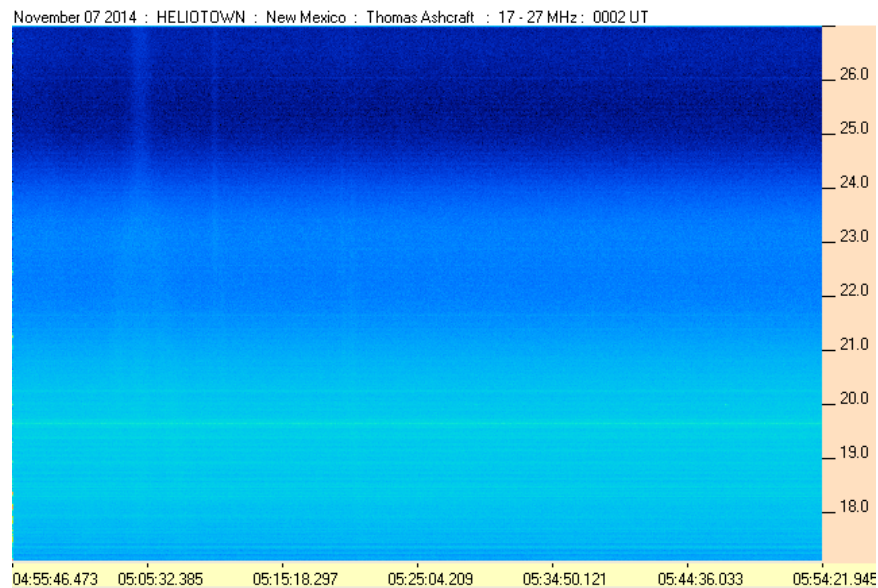


Figure 4 – Cas A scintillation observed by Thomas Ashcraft (Lamy, New Mexico) on 07 Nov 2014 with a Radio Jove dual dipole array and the FSX-4 radio spectrograph. Beam was steered to zenith and the array directivity was about 8 dBi.

Cas A scintillation explains why we have not observed such phenomena at other times of the year. It is visible only when Cas A is in the antenna beam, far enough from the Sun to avoid daytime band noise, and not so far into the night that the ionosphere has smoothed out to a large extent. We suspect there is perhaps a two or three month window where observation of Cas A scintillation is possible for the 8-element terminated folded dipole (TFD) array. We also suspect a possibility of observing scintillation in the emission from Cygnus A. Observational checks of these ideas will have to wait until next year when Cas A and Cyg A are in the proper positions relative to the Sun.

Cassiopeia A is a supernova remnant roughly 11,000 light years away (about 3.4 kiloparsecs). Discovered by amateur radio astronomer Grote Reber in 1947, it has a 20 MHz flux density of 65,000 Janskys, similar in strength to weak Jovian emission, and is the strongest radio source outside our solar system.[3]

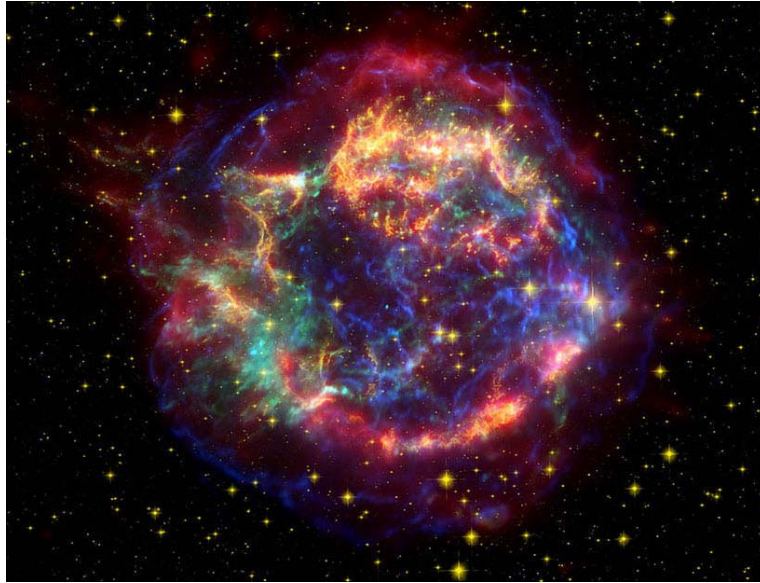


Figure 5 – Cassiopeia A in three frequency bands. Infrared data from the Spitzer Space Telescope are colored red; visible data from the Hubble Space Telescope are yellow; and X-ray data from the Chandra X-ray Observatory are green and blue. The central neutron star is the tiny turquoise dot at center of the shell of gas. Image and text credit JPL-Caltech.[4]

Cas A is located at right ascension 23h 23m and +59° declination. To find the proper beam elevation, we have:

$$\text{Source elevation at } 0^\circ \text{ azimuth (northward)} = 90^\circ - \text{source declination} + \text{observer latitude}$$

Typinski's latitude is 30° N, so his array's beam was steered northward to 60° elevation. A few degrees either way for small arrays with their relatively large half power beam widths (HPBW's) makes no practical difference, so we went to the nearest 5° elevation increment.

Since Cas A is a point source, it is very difficult to detect in the HF band with modest antenna arrays despite its high flux density. The strip chart in Figure 2 shows the variations for this particular observation are only 1 dB or so above the galactic background with an 8-element array. While the scintillation observed with Wes Greenman's Carr array steered to 60° N elevation (Fig. 3) shows up fairly well, the scintillation observed with Ashcraft's dual dipole Jove array steered to zenith (Fig. 4) is just barely distinguishable in the spectrogram. Quiet observing conditions help greatly, especially when using small arrays. Even so, single-frequency (Jove receiver, strip chart) observers using a dual dipole array would have great difficulty seeing and recognizing scintillation in Cas A emission.

In fact, if the scintillation did not exist, we would not have been able to recognize Cas A emission even with the 8-element TFD array. It would be difficult unto impossible to see a bell-shaped curve in a strip chart as Cas A moved through the antenna beam. To find out how long a radio source takes to cross an antenna's beam, we have:

$$\text{Beam transit time in hours} = \frac{\text{beam width in degrees}}{15^\circ/\text{hour} \times \cos(\text{declination})}$$

For the TFD array's 35° east-west HPBW, Cas A crosses the beam in about 4 hours 30 minutes. For the roughly 70° east-west HPBW of the Jove dual dipole array, the time is 9 hours. These long transit times make it nearly impossible to separate Cas A's emission from the diurnal variation in galactic background. Scintillation, however, acts on a much shorter time scale – on the order of a few minutes – making it discernable in a strip chart or spectrogram.

Radio scintillation is just like the twinkling of a star in the optical spectrum as starlight is refracted by density variations in the Earth's atmosphere. One cause of radio scintillation is spatial and temporal dynamic variation of the charge density within Earth's ionosphere. There may be other causes as the emission passes through the interstellar and interplanetary mediums (ISM and IPM). We restrict the following discussion to the terrestrial ionosphere; however, similar phenomena may be occurring to some degree in the ISM and/or IPM, possibly with different intensities and on different time scales.

The ionosphere is anything but flat and smooth; it is more like lumpy oatmeal. Charge density variations (lumps in the oatmeal) move around within the ionosphere and can act like lenses for radio waves, intermittently focusing more of Cas A's radio emission on the aperture of a ground-based HF radio telescope, briefly increasing the power received by the antenna. We believe this is what causes the nearly vertical sweeping streaks in the spectrograms in Figures 1 through 4. As the ionospheric disturbances move around, once in a while the lens effect sweeps past Cas A from the observer's viewpoint, briefly increasing the received signal strength. The streaks in the spectrogram are not perfectly vertical because ionospheric effects are frequency dependent – at any given time, a good ionospheric lens for Cas A at one frequency may not be so good at another frequency.

A disturbed ionosphere can cause the observed scintillation. High solar activity or a CME impact will stir up the ionosphere. However, sometimes when the Sun is active, Cas A scintillation is not observed. The fine structure and variability of the ionosphere with solar activity is very much a field of current research. Instruments like the LWA and LOFAR are observing ionospheric scintillation in the emission from distant sources like quasars. Cas A scintillation is one probe of the ionosphere's dynamics.

[1] <http://www.radiojove.org/SUG/>

[2] <http://kaira.sgo.fi/2012/10/ionospheric-scintillation-with-kaira.html>

[3] Baars, et al., The Absolute Spectrum of Cas A, A&A (1977)

[4] <http://www.spitzer.caltech.edu/images/1445-ssc2005-14c-Cassiopeia-A-Death-Becomes-Her>