The Interaction between Radio Waves and Solar Eclipses to Study the Ionosphere

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Radio Wave and Solar Eclipse Interaction

The **Total Solar Eclipse on Aug. 21st, 2017** provides an excellent opportunity to observe radio wave interaction with the ionosphere across the continental U.S.

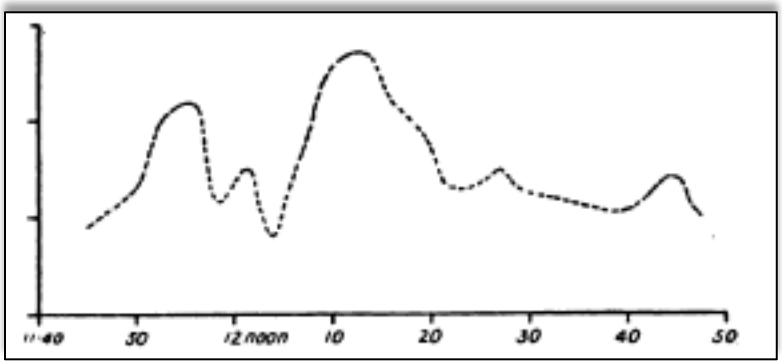
Presentation Outline

- Eclipse Background
- Historical Efforts
- Proposed Efforts
  - Eclipse Mob (LF: 55.5 kHz, 60.0 kHz and 135 kHz)
  - Georgia Tech (VLF/LF: 1 – 450kHz)
  - HAMSci (1.8 MHz to 54 MHz)
- Conclusion

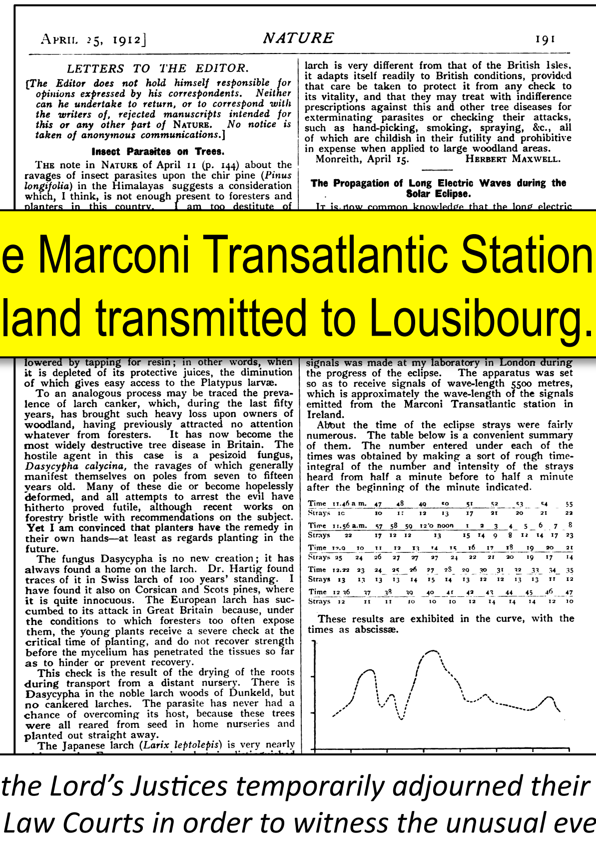
Eclipse Background

Historical Perspective

- Spatial and temporal effects of **solar eclipses** on **radio wave propagation** continues to be of interest almost 100 years after the first reported study.
  - **During the Eclipse on April 17, 1912,** William Henry Eccles[1] (1875 – 1968) a prominent British electrical engineer and scientist recorded discharges – clicks –strays.
  - Wavelength 5,500 Meters (Frequency approximately (54.545 kHz)
  - Published in Nature[2], 1912



Rough time Integral of the intensity and duration of strays



APRIL 25, 1912] NATURE 191

LETTERS TO THE EDITOR.

[The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, or to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. *No notice is taken of anonymous communications.]*

Insect Parasites on Trees.

THE note in NATURE of April 11 (p. 144) about the ravages of insect parasites upon the chir pine (*Pinus longifolia*) in the Himalayas suggests a consideration which, I think, is not enough present to foresters and planters in this country. I am too destitute of

lowered by tapping for resin; in other words, when it is depleted of its protective juices, the diminution of which gives easy access to the Platypus larvæ.

To an analogous process may be traced the prevalence of larch canker, which, during the last fifty years, has brought such heavy loss upon owners of woodland, having previously attracted no attention whatever from foresters. It has now become the most widely destructive tree disease in Britain. The hostile agent in this case is a pesizoid fungus, *Dasycypha calycina,* the ravages of which generally manifest themselves on poles from seven to fifteen years old. Many of these die or become hopelessly deformed, and all attempts to arrest the evil have hitherto proved futile, although recent works on forestry bristle with recommendations on the subject. Yet I am convinced that planters have the remedy in their own hands—at least as regards planting in the future.

The fungus Dasycypha is no new creation; it has always found a home on the larch. Dr. Hartig found traces of it in Swiss larch of 100 years' standing. I have found it also on Corsican and Scots pines, where it is quite innocuous. The European larch has succumbed to its attack in Great Britain because, under the conditions to which foresters too often expose them, the young plants receive a severe check at the critical time of planting, and do not recover strength before the mycelium has penetrated the tissues so far as to hinder or prevent recovery.

This check is the result of the drying of the roots during transport from a distant nursery. There is Dasycypha in the noble larch woods of Dunkeld, but no cankered larches. The parasite has never had a chance of overcoming its host, because these trees were all reared from seed in home nurseries and planted out straight away.

The Japanese larch (*Larix leptolepis*) is very nearly

larch is very different from that of the British Isles, it adapts itself readily to British conditions, provided that care be taken to protect it from any check to its vitality, and that they may treat with indifference prescriptions against this and other tree diseases for exterminating parasites or checking their attacks, such as hand-picking, smoking, spraying, &c., all of which are childish in their futility and prohibitive in expense when applied to large woodland areas.

Monreith, April 15. HERBERT MAXWELL.

The Propagation of Long Electric Waves during the Solar Eclipse.

IT is now common knowledge that the long electric

signals was made at my laboratory in London during the progress of the eclipse. The apparatus was set so as to receive signals of wave-length 5500 metres, which is approximately the wave-length of the signals emitted from the Marconi Transatlantic station in Ireland.

About the time of the eclipse strays were fairly numerous. The table below is a convenient summary of them. The number entered under each of the times was obtained by making a sort of rough time-integral of the number and intensity of the strays heard from half a minute before to half a minute after the beginning of the minute indicated.

Time	11.46 a.m.	47	48	49	50	51	52	53	54	55			
Strays	10	10	11	12	13	17	21	20	21	22			
Time	11.56 a.m.	57	58	59	12'0 noon	1	2	3	4	5	6	7	8
Strays	22	17	12	12	13	15	14	9	8	12	14	17	23
Time	12.9	10	11	12	13	14	15	16	17	18	19	20	21
Strays	25	24	26	27	27	27	24	22	21	20	19	17	14
Time	12.22	23	24	25	26	27	28	29	30	31	32	33	34	35
Strays	13	13	13	13	14	15	14	13	12	12	13	13	11	12
Time	12.36	37	38	39	40	41	42	43	44	45	46	47	
Strays	12	11	11	10	10	10	12	14	14	14	12	10	

These results are exhibited in the curve, with the times as abscissæ.

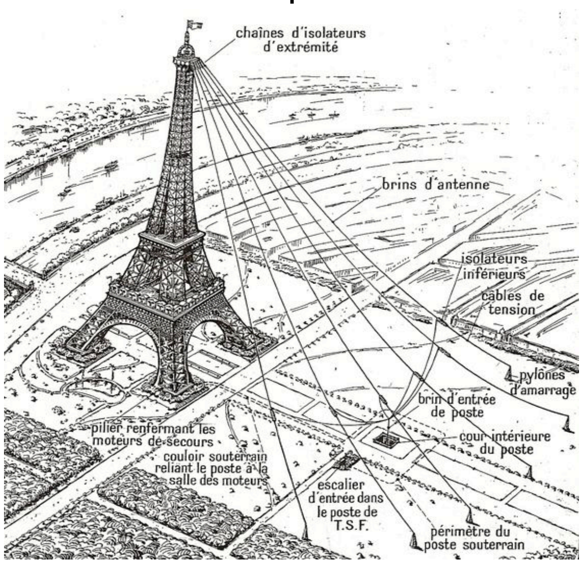
The Marconi Transatlantic Station in Ireland transmitted to Lousibourg.

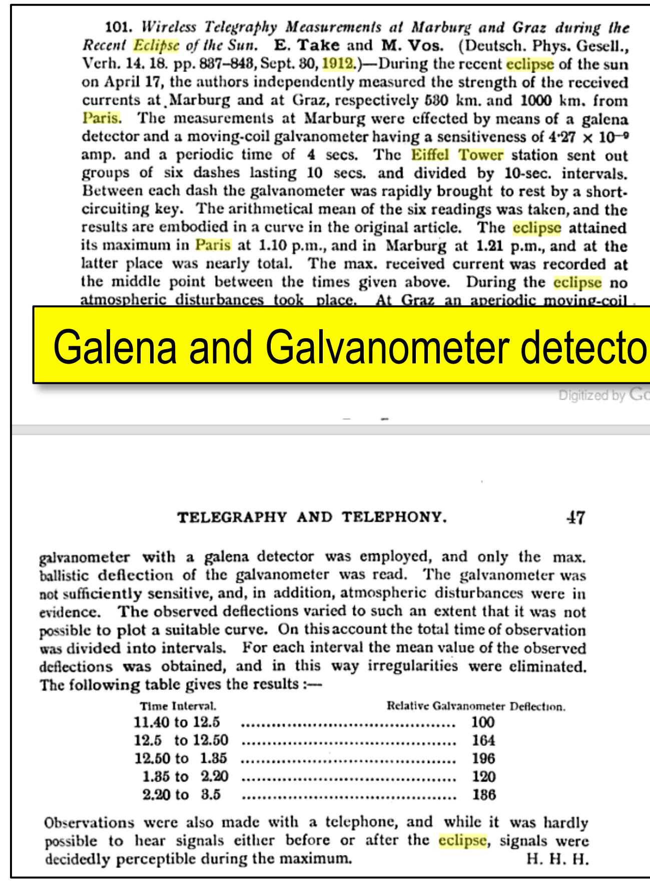
"Even the Lord's Justices temporarily adjourned their sittings at the Law Courts in order to witness the unusual event."

[1] Fellow of the Royal Society, President of the Physics Society, President of the Institute of Electrical Engineers and President of the Radio Society of Great Britain
[2] W. H. Eccles, "Propagation of Long Electric Waves during the Solar Eclipse" Nature, April 25th 1912

Other 1912 Solar Eclipse Studies

- The 1912 solar eclipse was also collected in France and Denmark using the transmitter at the **Eiffel Tower** in Paris.
  - The transmitter had a frequency of 115 kHz (wavelength approximately 2,608 meters)
  - UK study was done at 54.545 kHz and French and Demark studies were done at 115 kHz, **difficult** for data comparison.





101. *Wireless Telegraphy Measurements at Marburg and Graz during the Recent Eclipse of the Sun.* **E. Take** and **M. Vos.** (Deutsch. Phys. Gesell., Verh. 14. 18. pp. 837–848, Sept. 30, 1912.)—During the recent eclipse of the sun on April 17, the authors independently measured the strength of the received currents at Marburg and at Graz, respectively 530 km. and 1000 km. from Paris. The measurements at Marburg were effected by means of a galena detector and a moving-coil galvanometer having a sensitiveness of $4{\cdot}27 \times 10^{-9}$ amp. and a periodic time of 4 secs. The Eiffel Tower station sent out groups of six dashes lasting 10 secs. and divided by 10-sec. intervals. Between each dash the galvanometer was rapidly brought to rest by a short-circuiting key. The arithmetical mean of the six readings was taken, and the results are embodied in a curve in the original article. The eclipse attained its maximum in Paris at 1.10 p.m., and in Marburg at 1.21 p.m., and at the latter place was nearly total. The max. received current was recorded at the middle point between the times given above. During the eclipse no atmospheric disturbances took place. At Graz an aperiodic moving-coil

TELEGRAPHY AND TELEPHONY. 47

galvanometer with a galena detector was employed, and only the max. ballistic deflection of the galvanometer was read. The galvanometer was not sufficiently sensitive, and, in addition, atmospheric disturbances were in evidence. The observed deflections varied to such an extent that it was not possible to plot a suitable curve. On this account the total time of observation was divided into intervals. For each interval the mean value of the observed deflections was obtained, and in this way irregularities were eliminated. The following table gives the results :—

Time Interval.	Relative Galvanometer Deflection.
11.40 to 12.5	100
12.5 to 12.50	164
12.50 to 1.35	196
1.35 to 2.20	120
2.20 to 3.5	136

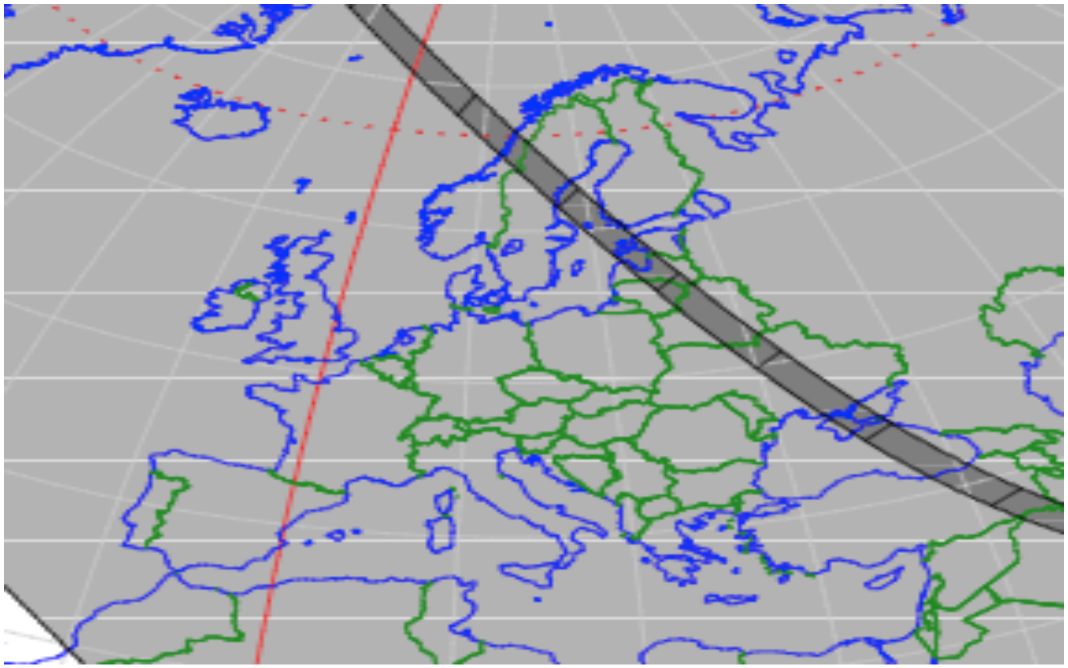
Observations were also made with a telephone, and while it was hardly possible to hear signals either before or after the eclipse, signals were decidedly perceptible during the maximum. H. H. H.

Galena and Galvanometer detector

[1] Images from de.wikipedia.org
[2] Telegraphy and Telephony, 1912

Early Attempt at Group Collection

- First Group Effort on Eclipse Affecting Radio
  - Planned for August 21, 1914
  - WWI impacts data collection and analysis
  - Group activity envisioned early on



[1] http://astro.ukho.gov.uk/eclipse/0311914/S1914Aug21.pdf

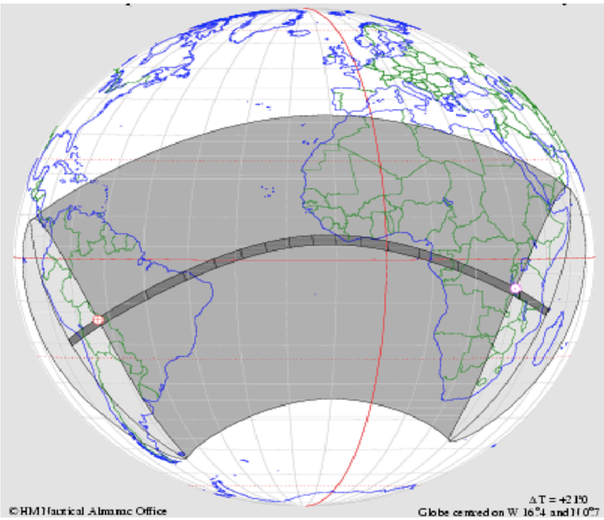
First Theory Paper

- Hantaro Nagaoka, “Effects of Solar Eclipse on Wireless Transmission,” Mathematico-Physical Soc., Tokyo, Proceedings 7, pp 428-430 December 1914

- Note: The word Ionosphere did not exist until created by Robert Watson Watt in 1926

Second Try

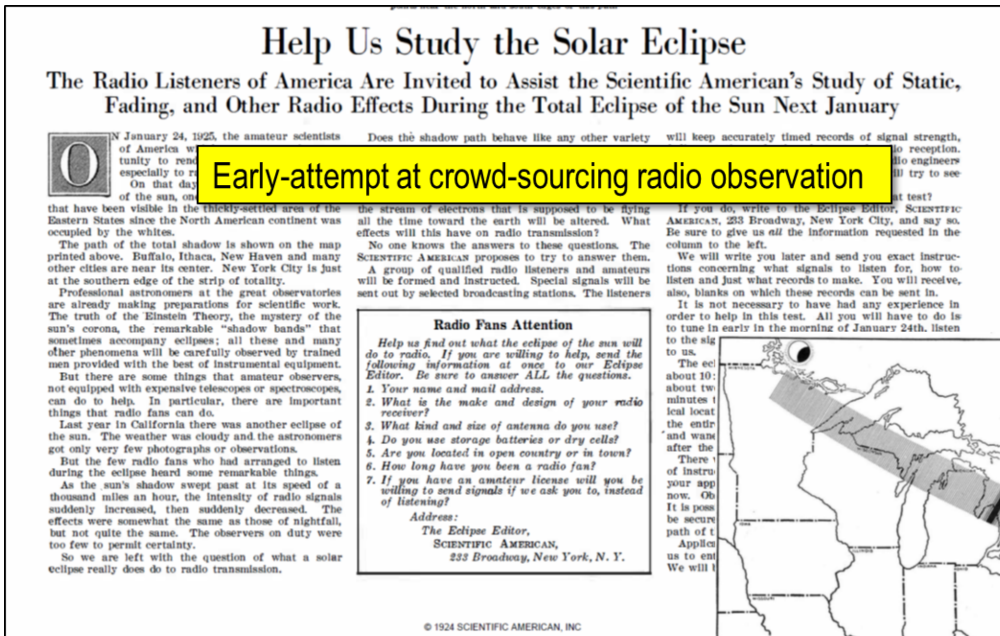
- During solar eclipse on May 29, 1919, increased signal strength was noticed in daytime between Meudon, Paris and Ascension
  - Wavelength 4,700 meters (approx. 63.829 kHz)
- Hypothesis: increased strength was due to the diminishing effect of solar radiation
  - No particular change in intensity was noticed for most transmit/receive pairs
  - Many different receivers coupled with different transmitters
  - Only anecdotal reporting!



[1] http://astro.ukho.gov.uk/eclipse/0211919/

Early Crowdsourcing Effort

- January 25, 1925 Solar Eclipse
  - Teamed with Scientific American
  - Noticed 75 meter daytime signals arrived with intensity associated with nighttime signals - Many **errors** in reporting[1]
  - Over 2,000 BCB reporters and co-operation from BCB transmitters



Help Us Study the Solar Eclipse

The Radio Listeners of America Are Invited to Assist the Scientific American's Study of Static, Fading, and Other Radio Effects During the Total Eclipse of the Sun Next January

ON January 24, 1925, the amateur scientists of America w… tunity to rend… especially to r…

On that day… of the sun, on… that have been visible in the thickly-settled area of the Eastern States since the North American continent was occupied by the whites.

The path of the total shadow is shown on the map printed above. Buffalo, Ithaca, New Haven and many other cities are near its center. New York City is just at the southern edge of the strip of totality.

Professional astronomers at the great observatories are already making preparations for scientific work. The truth of the Einstein Theory, the mystery of the sun's corona, the remarkable "shadow bands" that sometimes accompany eclipses; all these and many other phenomena will be carefully observed by trained men provided with the best of instrumental equipment.

But there are some things that amateur observers, not equipped with expensive telescopes or spectroscopes, can do to help. In particular, there are important things that radio fans can do.

Last year in California there was another eclipse of the sun. The weather was cloudy and the astronomers got only very few photographs or observations.

But the few radio fans who had arranged to listen during the eclipse heard some remarkable things.

As the sun's shadow swept past at its speed of a thousand miles an hour, the intensity of radio signals suddenly increased, then suddenly decreased. The effects were somewhat the same as those of nightfall, but not quite the same. The observers on duty were too few to permit certainty.

So we are left with the question of what a solar eclipse really does to radio transmission.

Does the shadow path behave like any other variety … the stream of electrons that is supposed to be flying all the time toward the earth will be altered. What effects will this have on radio transmission?

No one knows the answers to these questions. The SCIENTIFIC AMERICAN proposes to try to answer them.

A group of qualified radio listeners and amateurs will be formed and instructed. Special signals will be sent out by selected broadcasting stations. The listeners

Radio Fans Attention

Help us find out what the eclipse of the sun will do to radio. If you are willing to help, send the following information at once to our Eclipse Editor. Be sure to answer ALL the questions.

1. *Your name and mail address.*
2. *What is the make and design of your radio receiver?*
3. *What kind and size of antenna do you use?*
4. *Do you use storage batteries or dry cells?*
5. *Are you located in open country or in town?*
6. *How long have you been a radio fan?*
7. *If you have an amateur license will you be willing to send signals if we ask you to, instead of listening?*

Address:
The Eclipse Editor,
SCIENTIFIC AMERICAN,
233 Broadway, New York, N. Y.

will keep accurately timed records of signal strength, …o reception. …lio engineers …ll try to see … …at test?

If you do, write to the Eclipse Editor, SCIENTIFIC AMERICAN, 233 Broadway, New York City, and say so. Be sure to give us *all* the information requested in the column to the left.

We will write you later and send you exact instructions concerning what signals to listen for, how to listen and just what records to make. You will receive, also, blanks on which these records can be sent in.

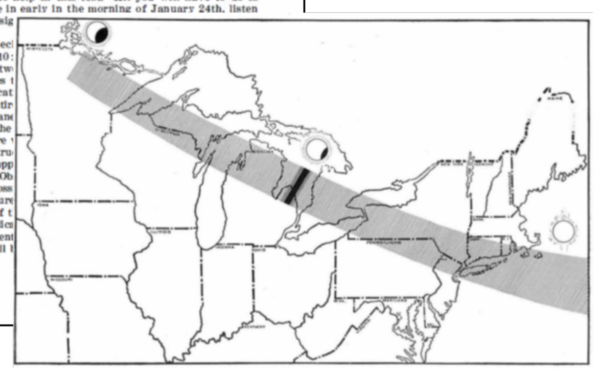
It is not necessary to have had any experience in order to help in this test. All you will have to do is to tune in early in the morning of January 24th, listen to the sig… to us.

The ec… about 10:… about tw… minutes … ical locat… the entir… and wan… after the…

There … of instru… your app… now. Ob… It is poss… be secure… path of t…

Applic… us to en… We will …

Early-attempt at crowd-sourcing radio observation



[1] Reports in Scientific American and QST

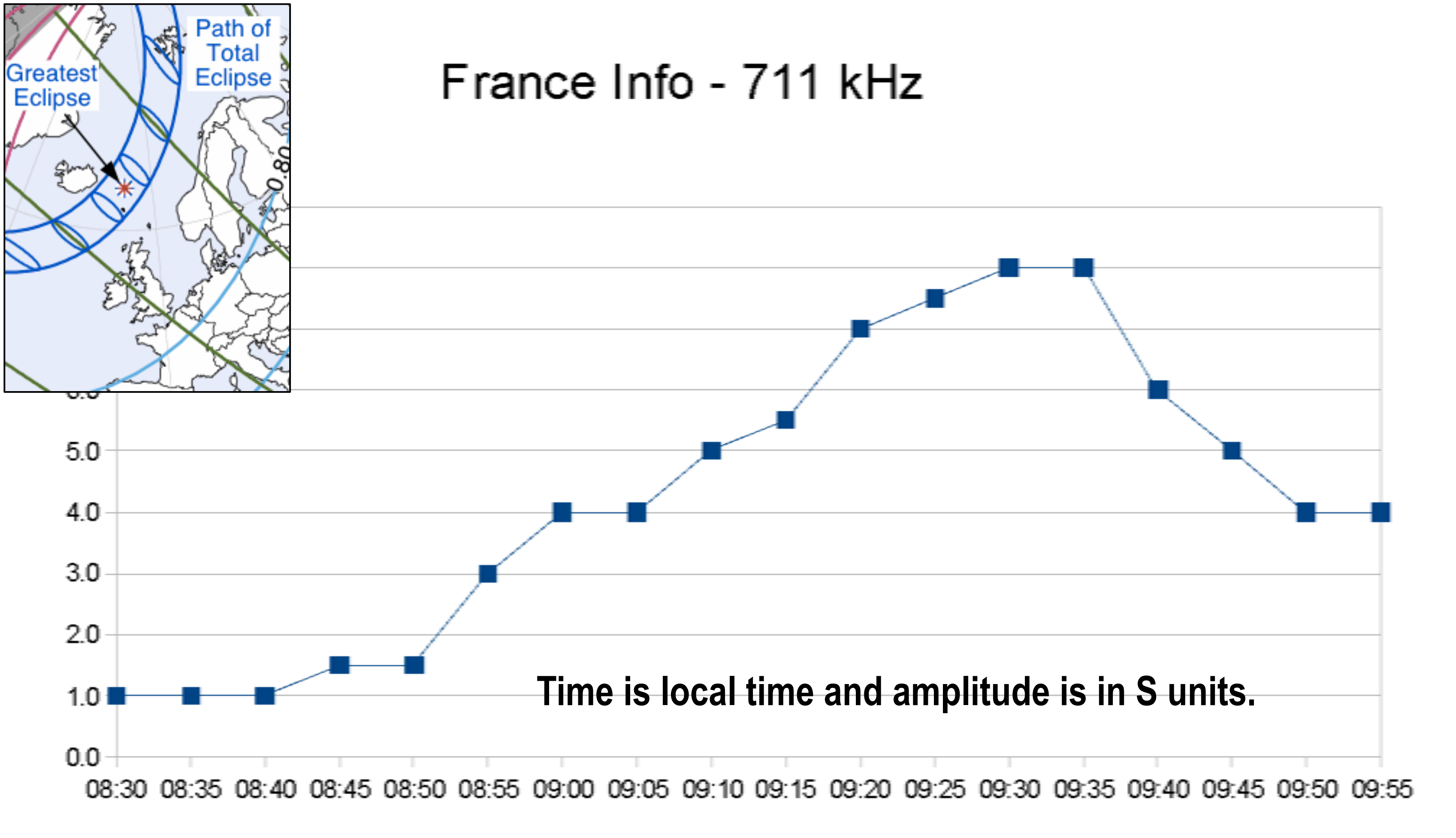
Ionosphere Ionization Experiment

- In the 1920s, it was understood that the sun caused the ionization of the ionosphere. Two possible mechanisms were hypothesized:
  1) electromagnetic waves emitted by the sun
  2) particles emitted by the sun
- Sir Edward Appleton (Nobel Prize in Physics in 1947 for ionosphere studies) proposed an experiment where the moon during a solar eclipse would stop both the electromagnetic waves and the particles.

Electromagnetic waves travel at the speed of light (3,000,000 km/sec)
Particles travel much slower (approx. 1,000 to 2,000 km/sec)

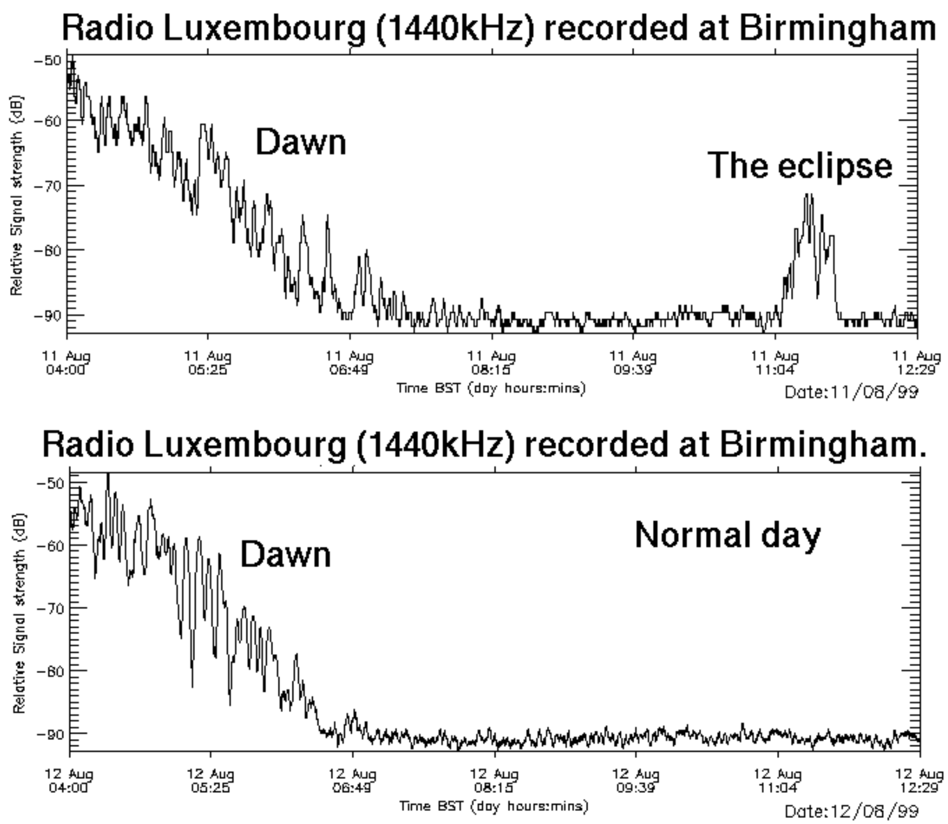
If the ionosphere becomes re-ionized quickly after the eclipse, then due to electromagnetic waves.

Wolverhampton Grammar School



[1] Eclipse 2015 – RSGB Experiment downloaded from http://forums.thersgb.org/index.php?threads/early-results-from-eclipse-experiments.128/

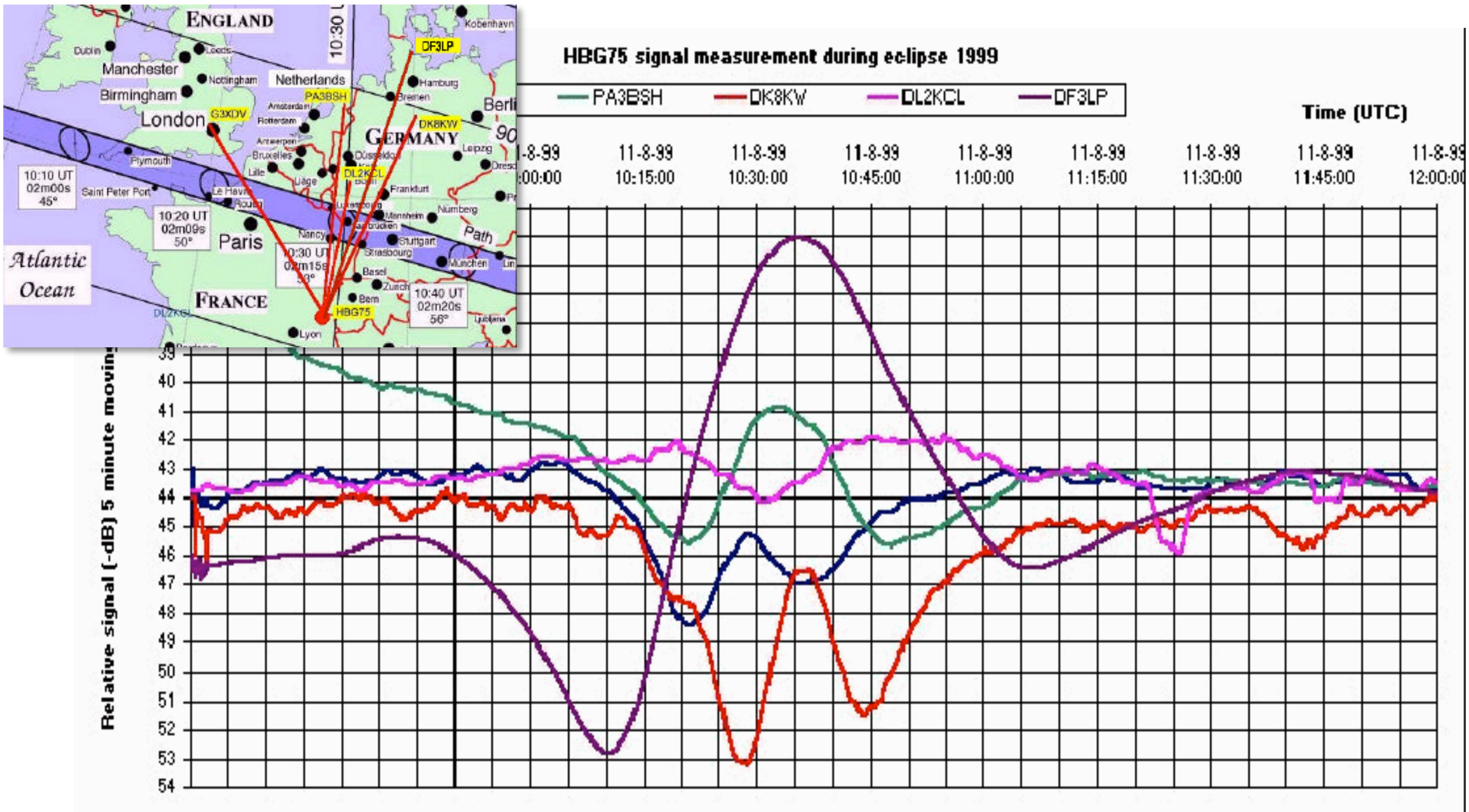
BCB band during the 1999 eclipse



Plot of the variation in the received CW radio signal as recorded in Birmingham RA Regional Office in the UK of the 1440 kHz (±1.4 kHz) carrier emanating from Radio Luxembourg at Marnach (a) for the morning of the total solar eclipse and (b) the day after the eclipse

[1] Image from ofcom.org.uk
[2] “Radio and the 1999 UK Total Solar Eclipse”, Dr. Ruth Bamford, May 2000

Reports of 75 kHz reception during 1999 solar eclipse

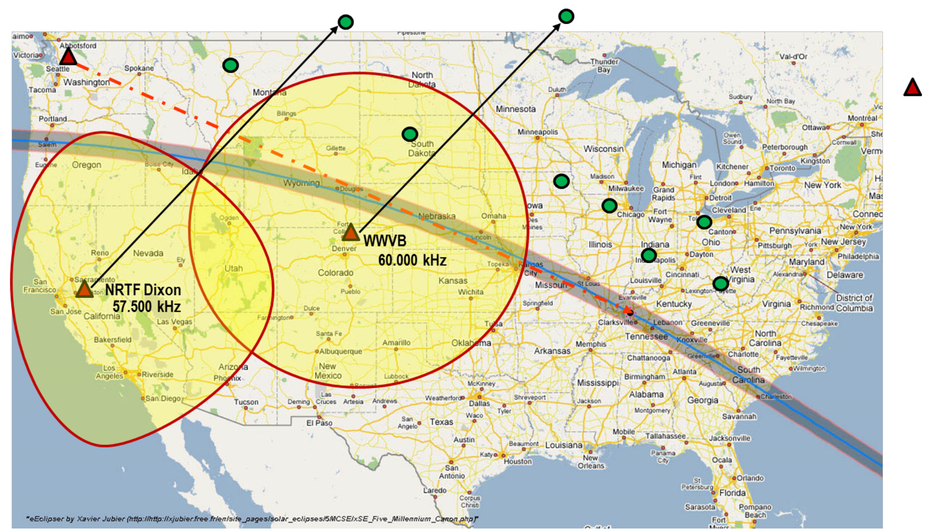


[1] M. Sanders, 1999. "Solar eclipse effect on the propagation of LF radio signals" from December 3rd 1999, available at URL: http://www.xs4all.nl/~misan/eclipse.htm.

Eclipse Mob Consortium

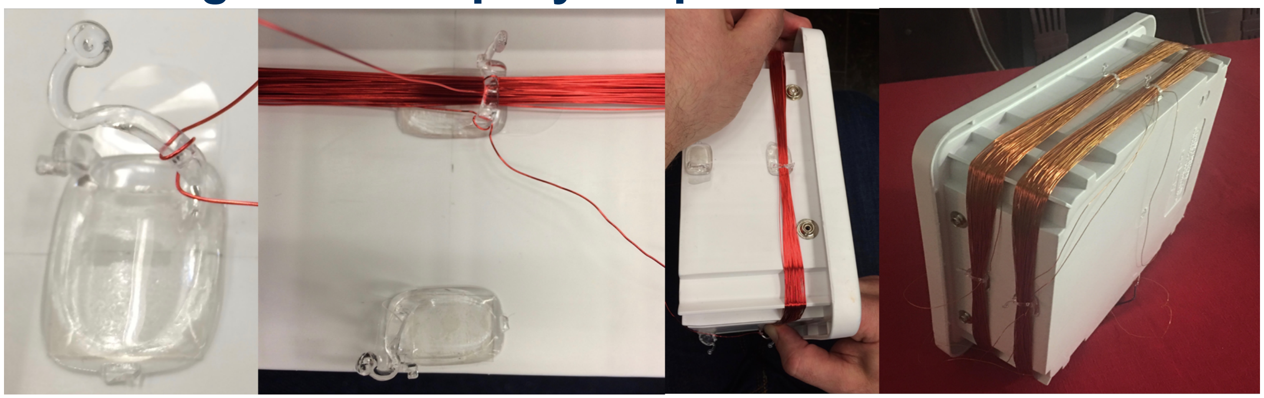
- The **2017 Total Solar Eclipse**: Excellent opportunity to observe propagation interaction with the ionosphere across the continental U.S.
  - Propose a crowd-source collection of signals across a number of different **short**, **medium** and **long-paths**.
  - **Signals** will be collected before, during and after the total eclipse.
  - **Amplitude** changes reported at each location.
  - **Goal:** Disseminate **large data collection** across the **scientific community**.

Tools for **collection** are available at eclipsemob.org <http://eclipsemob.org>

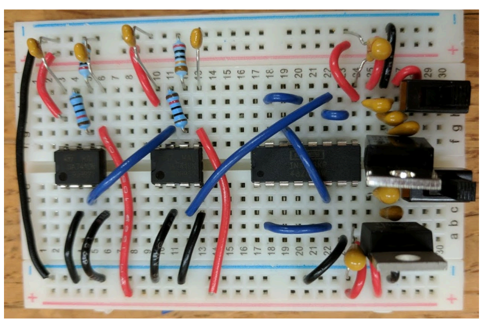


DIY Eclipse Mob Kits & Instructions

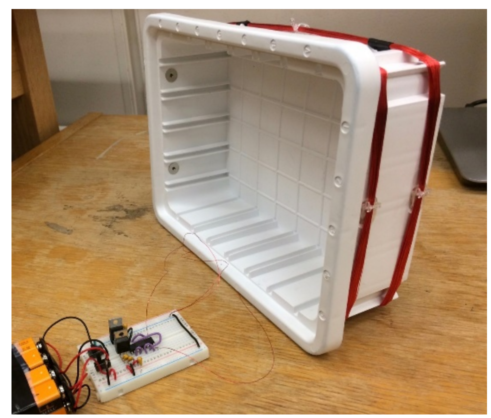
- **Antenna design with step-by-step instructions**



- **Available receiver kits (Free!)**



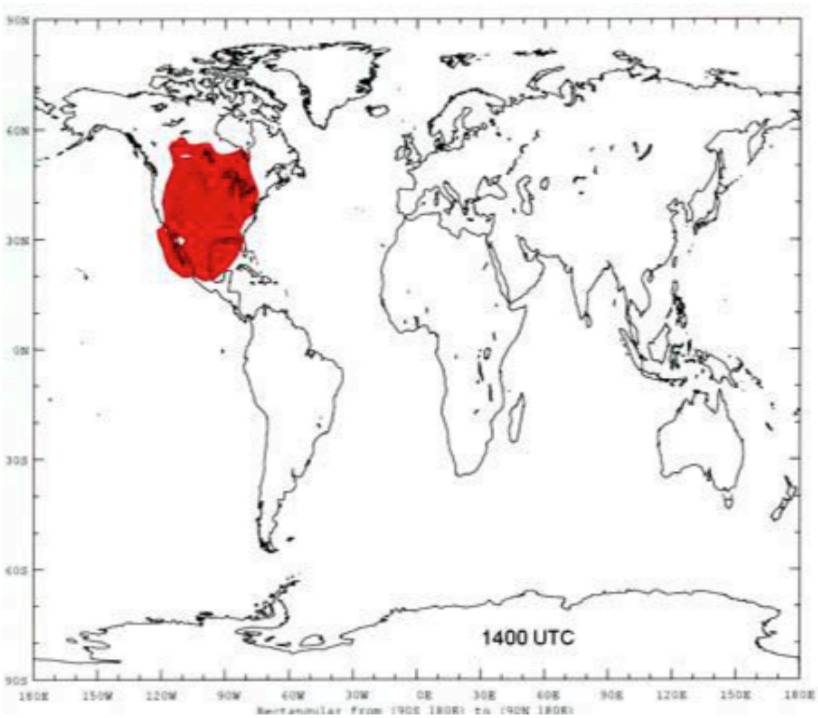
- **Integration**



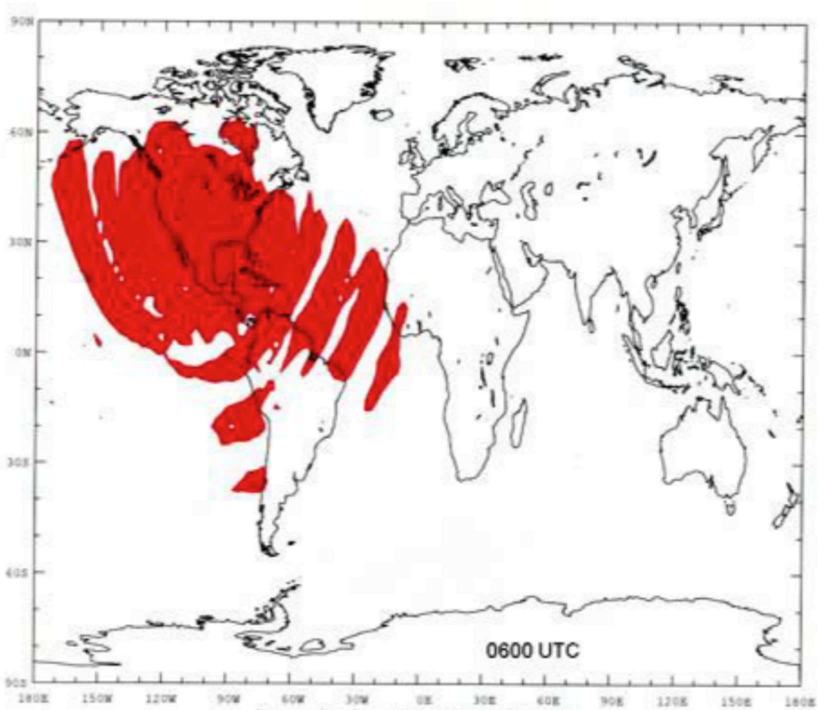
[1] Hagen, Tom. "A Portable, Calibrated VLF Field Strength Measurement Receiver and Loop Antenna." Society of Amateur Radio Astronomers Association West Conference, 2015.

Coverage Plots

- WWVB Coverage Plots during Day and Night



Daylight Coverage Area

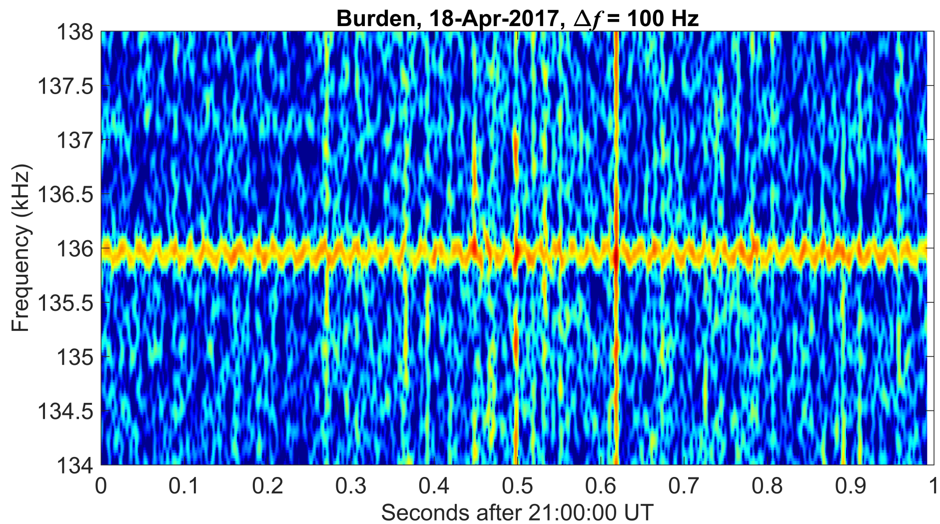


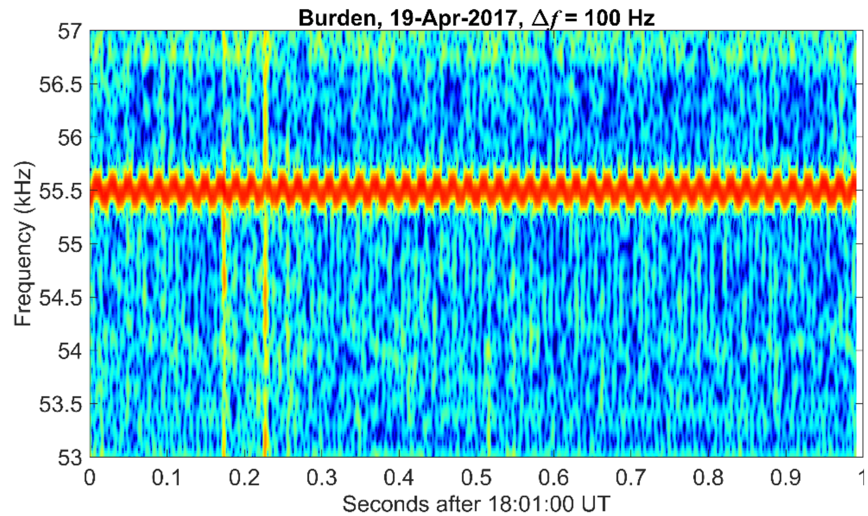
Nighttime Coverage Area

[1] source NIST.gov

Pre-event transmission tests

▼ Periodic transmissions during 2017 for event preparation

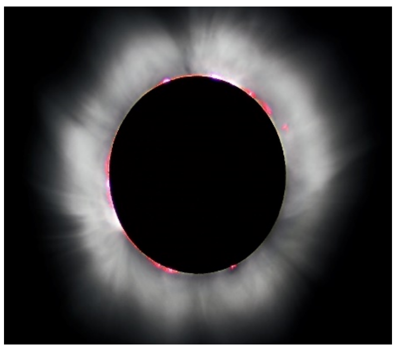


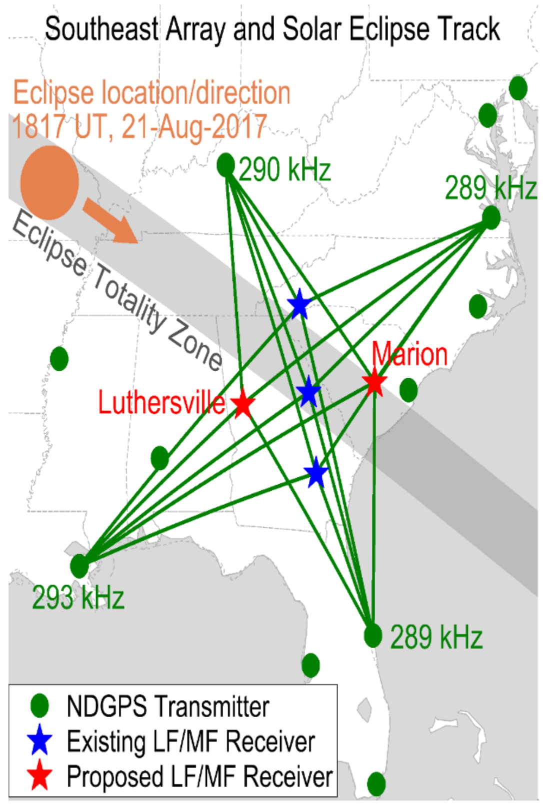


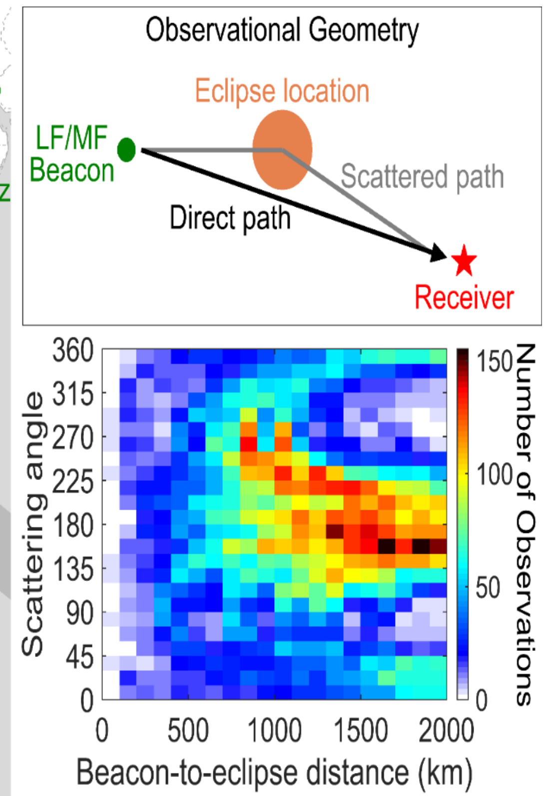
55.5 kHz and 135 kHz collections in Kansas using Georgia Tech AWESOME Instrument

Georgia Tech Solar Eclipse Effort

- Tracking Impact of Solar Eclipse with LF
  - Eclipse forms moving patch of “night”, surrounded by day
  - Radio scattering problem using web of transmitters/receivers at 300 kHz



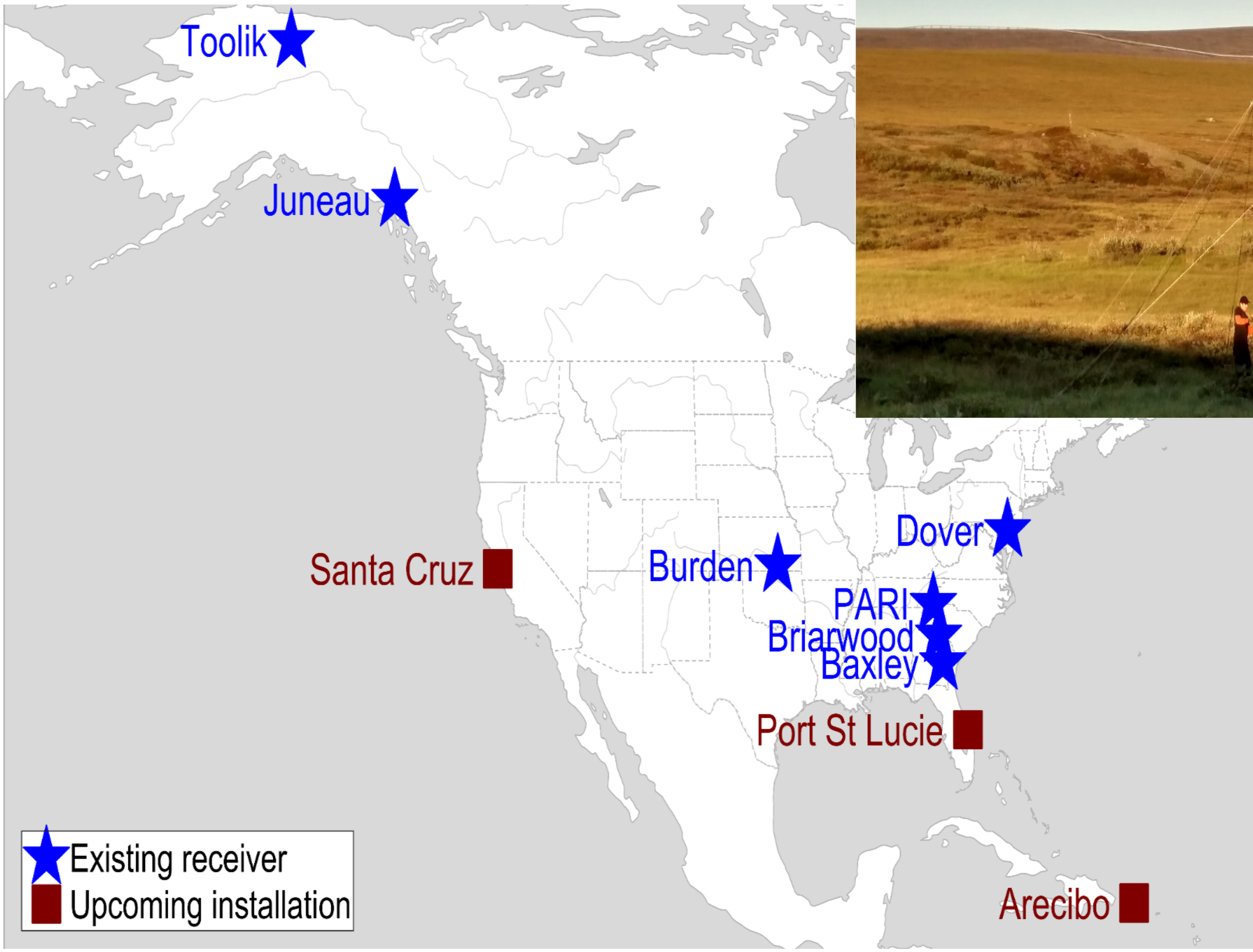




Georgia Tech AWESOME Instrument

- AWESOME Instrument **Detects** VLF/LF Waves Pretty Efficiently
  - 1 MHz sampling
  - 1-450 kHz band
  - Two orthogonal wire loop channels
  - 25 ns timing accuracy
  - 96 dB dynamic range
  - Sensitivity ~0.03 fT/rt-Hz

Current Radio Receiver Field Sites



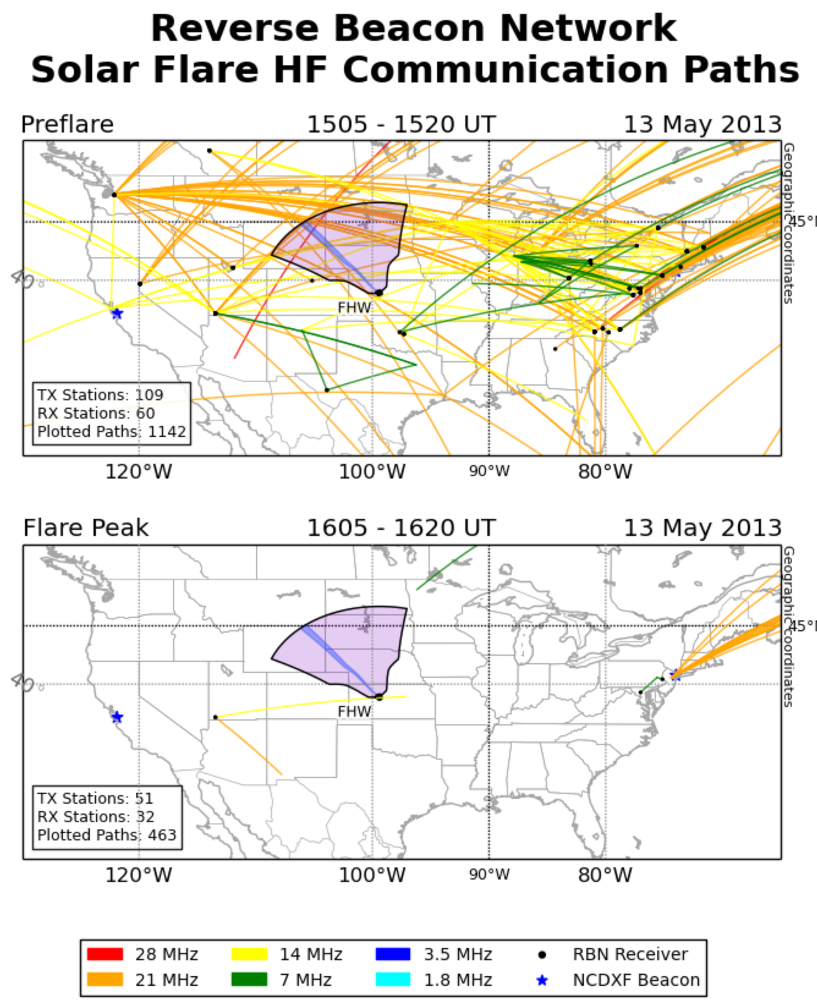
HamSCI: 2017 Eclipse Experiment

- Eclipse Experiment Methodology
  - Illuminate the ionosphere with an Eclipse QSO Party.
  - Use networks such as the Reverse Beacon Network to collect data.
  - Use amateur radio data to complement data from other sources.

- Eclipse Experiment Preparation
  - Expand the Reverse Beacon Network
  - Publicize the Eclipse QSO Party
  - Do more preliminary studies to establish a baseline

Radio Beacon Network

- RBN is an amateur radio reporting system comprised of a network of automated receiving stations.
  - Scans and decodes portions of the radio spectrum (Morse code, some digital signals).
  - Network has large spatial resolution in US.
- RBN has the ability to detect space weather events over large areas.
  - A demonstration of this ability is sharp decrease in the number of stations the RBN heard in the US, associated with the arrival of a solar flare.



Conclusions

- In the past, many studies investigated radio wave and solar eclipse interactions
- A number of tools and methodologies exists today to perform improved studies
- This presentation outlined three studies to be undertaken during the August 21, 2017 Solar Eclipse

- We welcome participation!

(1)EclipseMob.org
Info@eclipsemob.org <mailto:Info@eclipsemob.org>

(2) HamSCI.org