Comparison between Ground-based, Artificial "Pulsars" and Data from Pulsar Observations

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The S Team

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Statistics/Astronomy

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Analytical Mathematics/Invention/Astronomy

- Houshang Ardavan (Cambridge), Arzhang Ardavan (Oxford)

Speed Limit
299,792,458 m/s
IT'S THE LAW!

The sonic "boom"


Photo: BAE Systems

- Observed when high-performance aircraft accelerate through the speed of sound.
- In the aircraft's frame of reference, (low energy) sound is emitted over an extended period of time.
- All of this sound arrives at a distant location instantaneously, creating a very large and concentrated "BOOM".
- This is due to temporal focusing – focusing in the time domain.

We do the same, but with electromagnetic radiation: we make "electromagnetic booms"!

How do we get a faster-than-light source of radiation? Maxwell's equations III and IV

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J}_{\text{free}} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \frac{\partial \mathbf{P}}{\partial t}$$

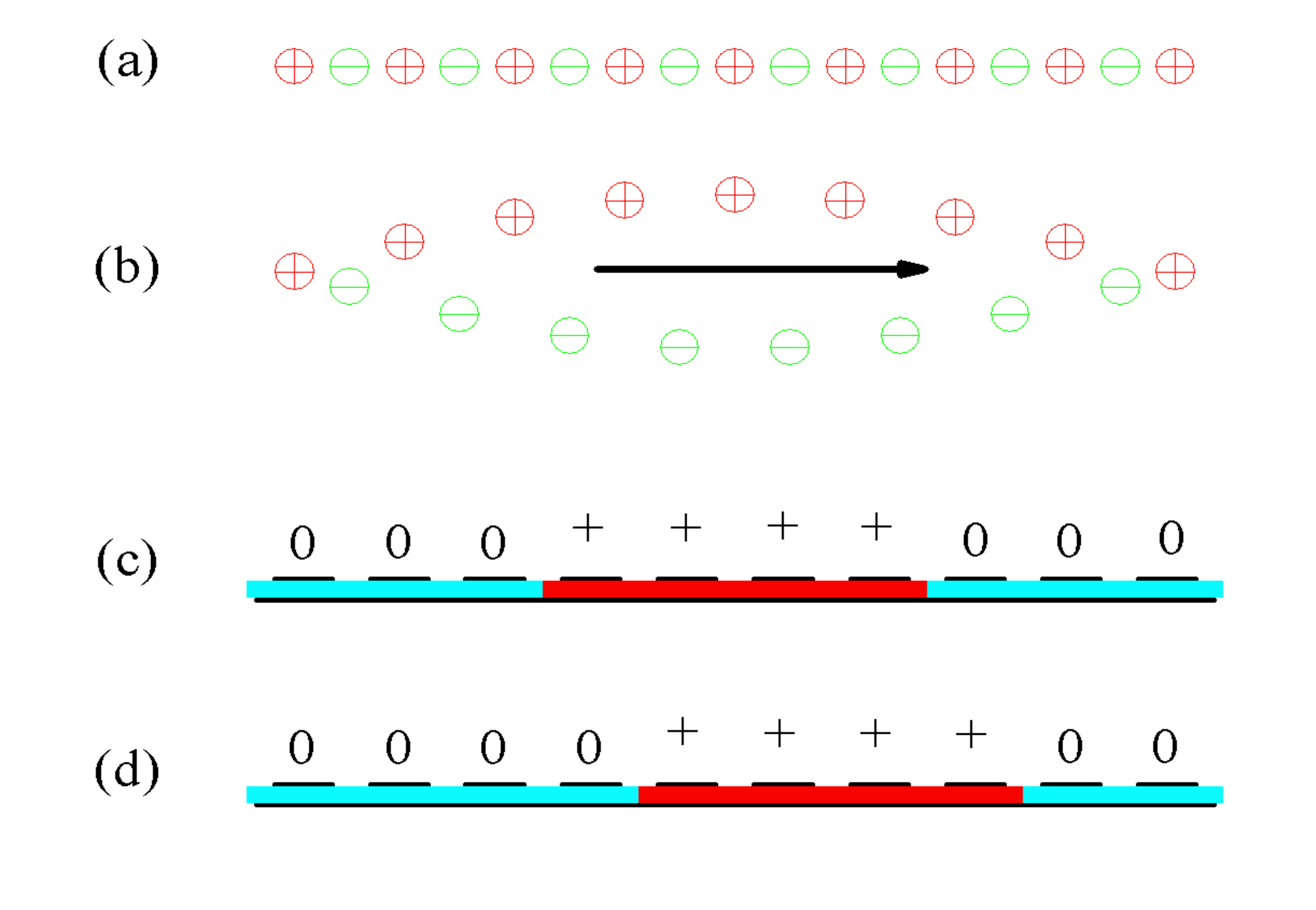
Green terms describe propagation of electromagnetic radiation.

Conventional radiators (synchrotrons, antennae) use free current $\mathbf{J}_{\text{free}}$ of electrons as source. But electrons restricted to $v < c$ (Einstein!).

Polarization current $\partial P/\partial t$ is an equally good source term, and it is not restricted to $v < c$. *This is our superluminal source.*

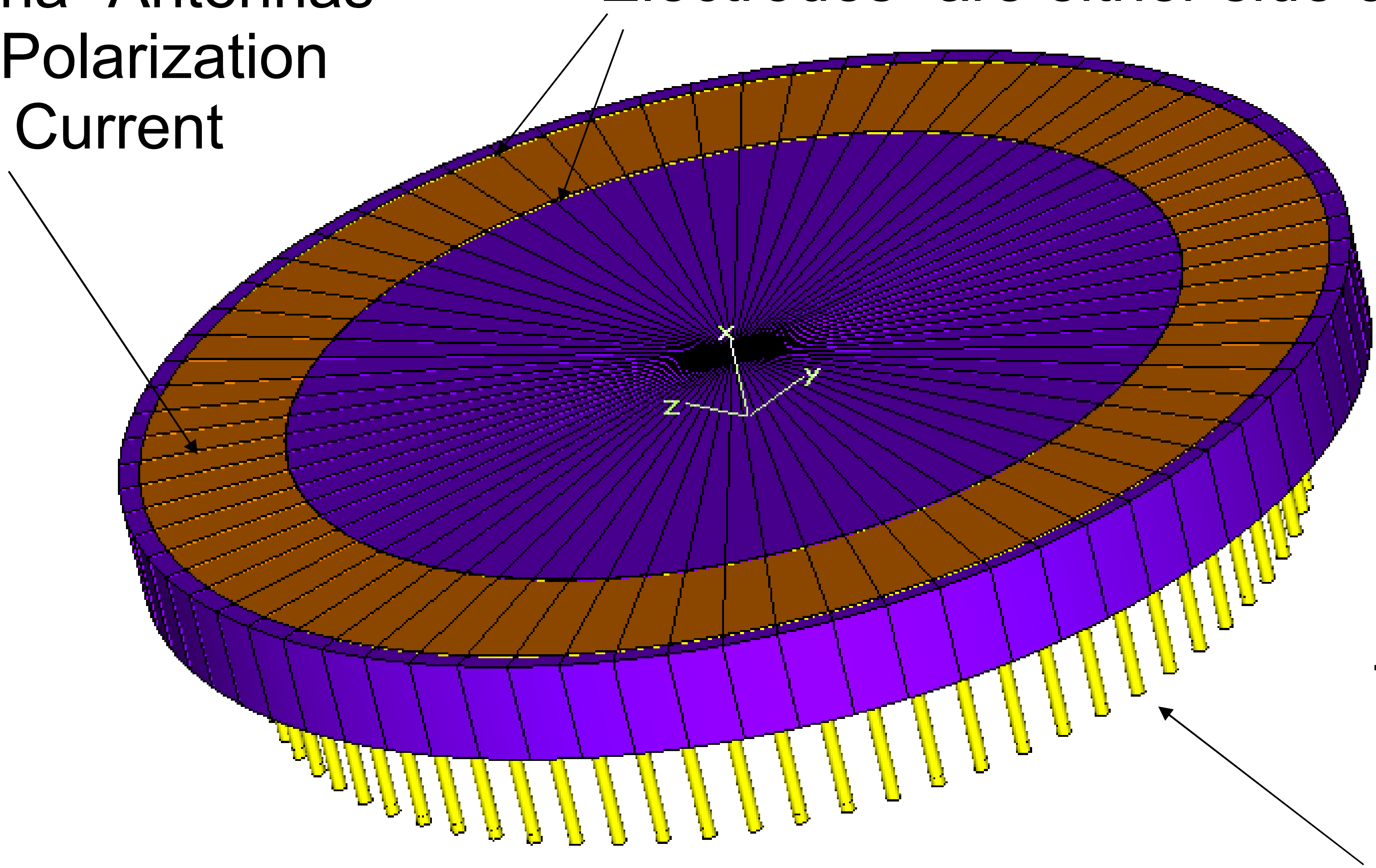
Practical superluminal sources: animating a faster-than-light polarization current

(a) Unpolarized solid containing ions.
(b) Turn on varying **E**-field => region of finite **P** that can be moved along arrow.
(c) Experimental realization; electrodes above and below a strip of dielectric.
(d) Switch plates on and off; polarized region moves.



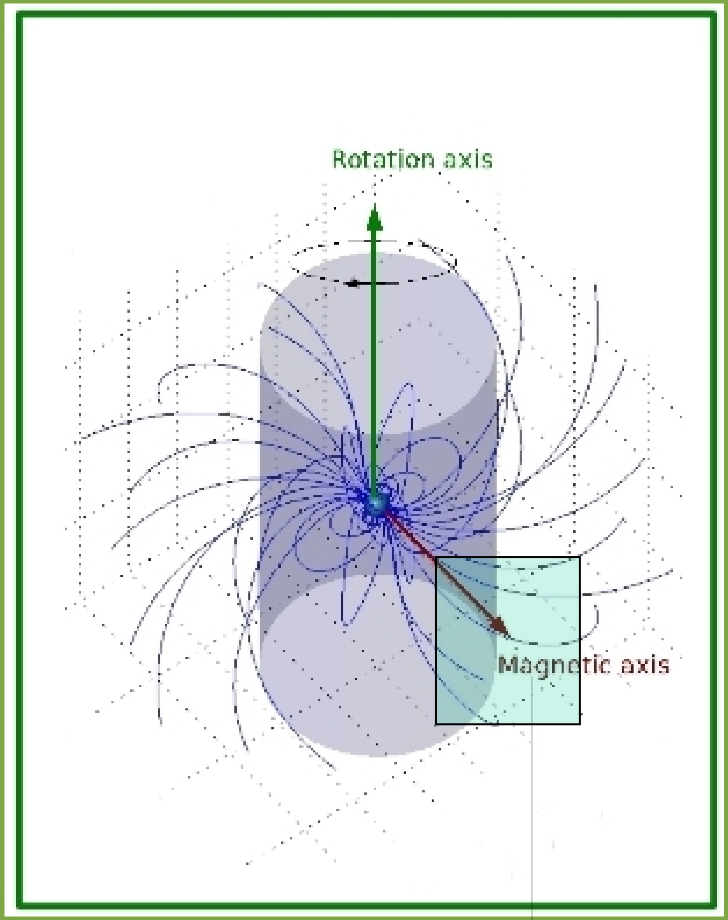
Moving a polarization current very fast is just a question of precise timing.

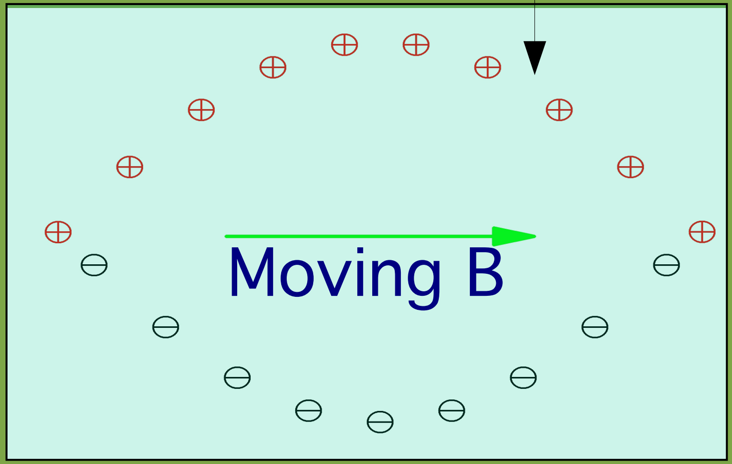
Superluminal machine with centripetal acceleration h TD1, a full-circle 72 element machine working at 2.2-2.6 GHz



Mean radius of alumina = 125 mm. Machine intended to demonstrate scalability of technology; convenient, portable. Short wavelength means some characterization can be done in anechoic chamber.

The future: Making a ground-based pulsar for THz emission.





Pulsar: rotating neutron star with huge magnetic field

Electromagnetism: moving magnetic field **B** has same effect as electric field.

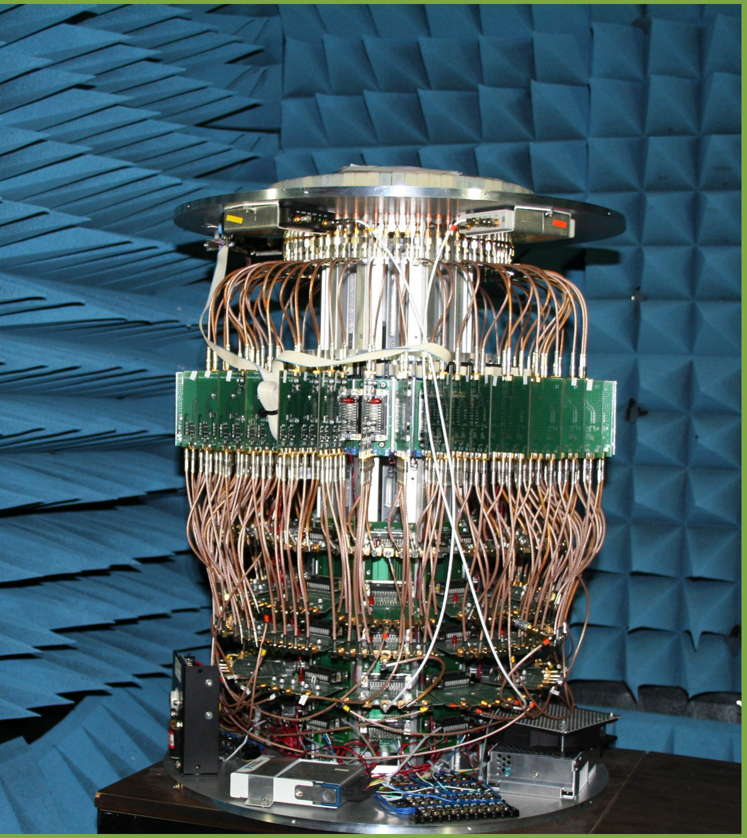
=>as **B** swings through pulsars's plasma "atmosphere", -ve and +ve ions displaced in opposite directions.

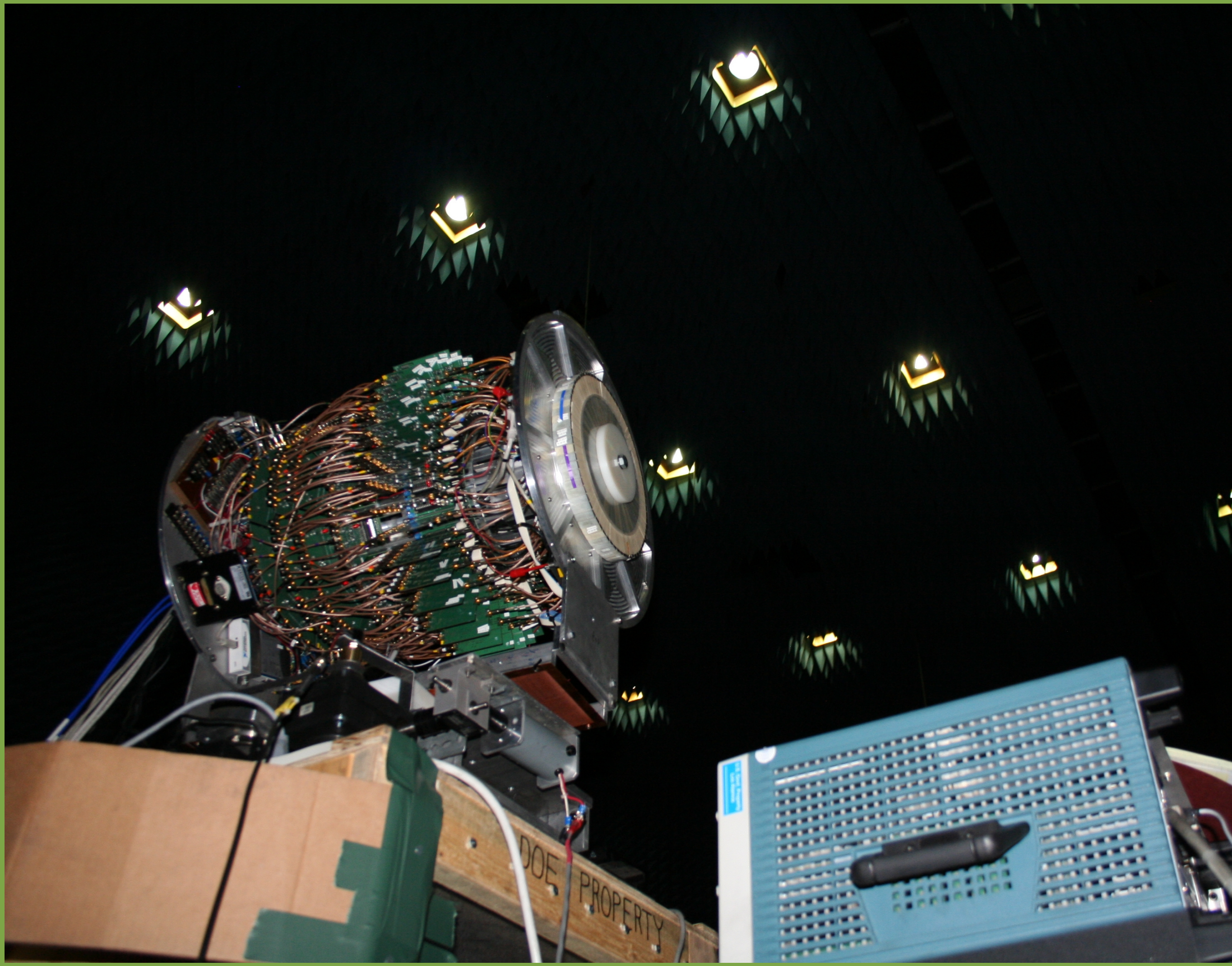
=>traveling region of electrical polarization **P** with speed *v.*

Trivial solutions of Maxwell's equations show polarized region must keep up with the magnetic field's rotation => $v > c$ for $r > c/\omega$.

NB: displacements small: speed of electrons and ions << *c*. **Polarized region can move faster than *c* even though ions do not.**

The completed TD-1 machine

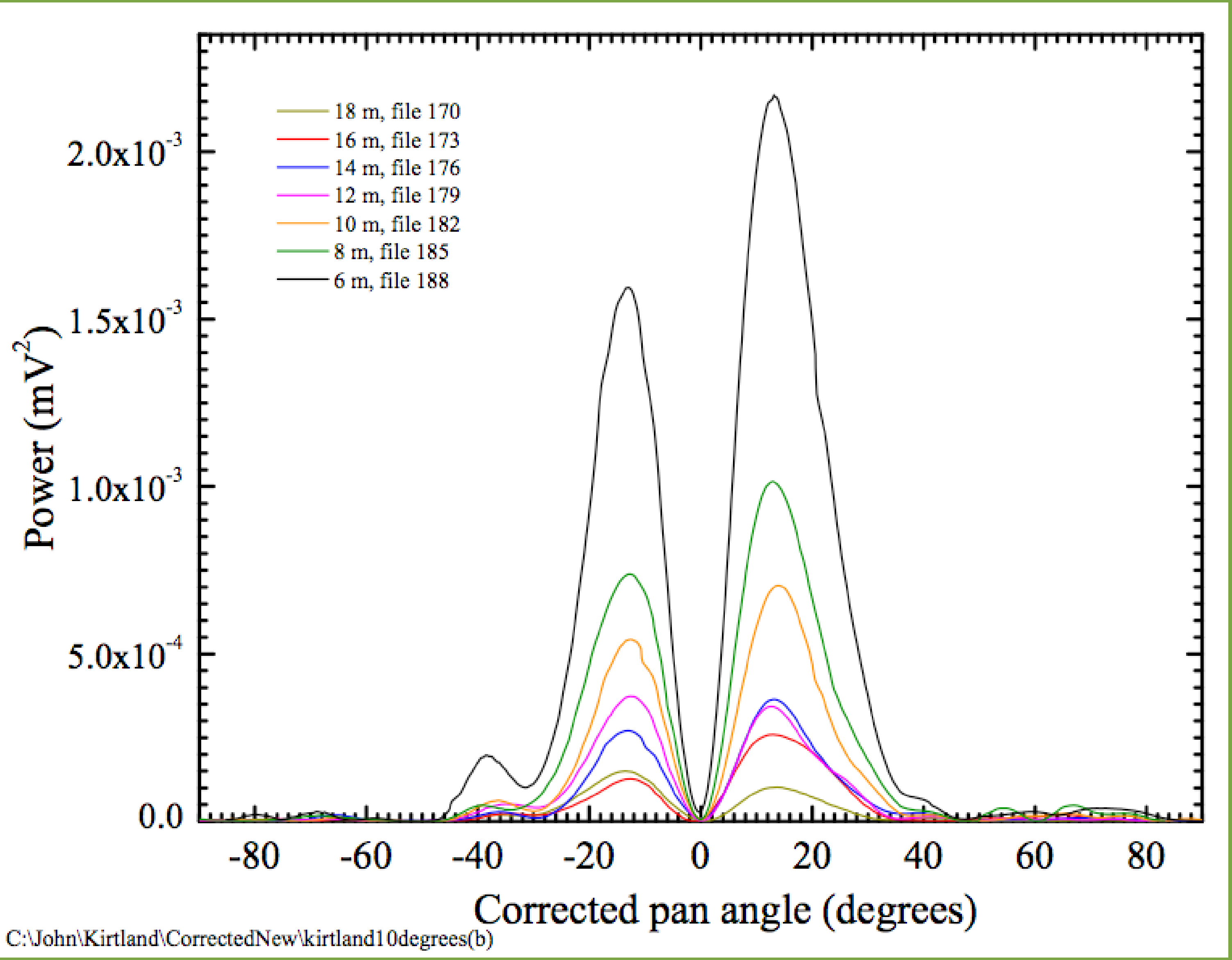


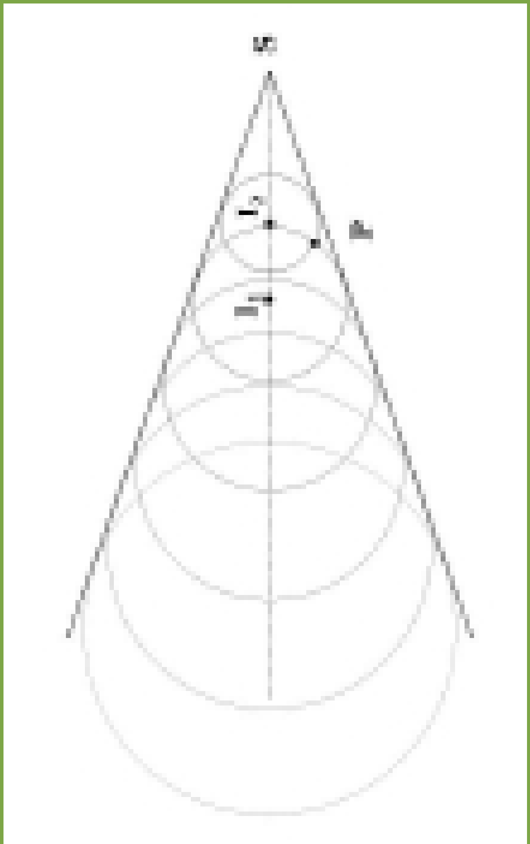


Note: (i) circular dielectric antenna array on the top; (ii) cylindrical arrangement of other components; (iii) turntable for radar/communications demos. All circuit boards designed and completed by Zhi-Fu Wang (ISR-6)

Subsequent tests at Los Alamos Airport and FARM range at SNL. Note phase-sensitive detector pair on cart, and Egli path blocker.

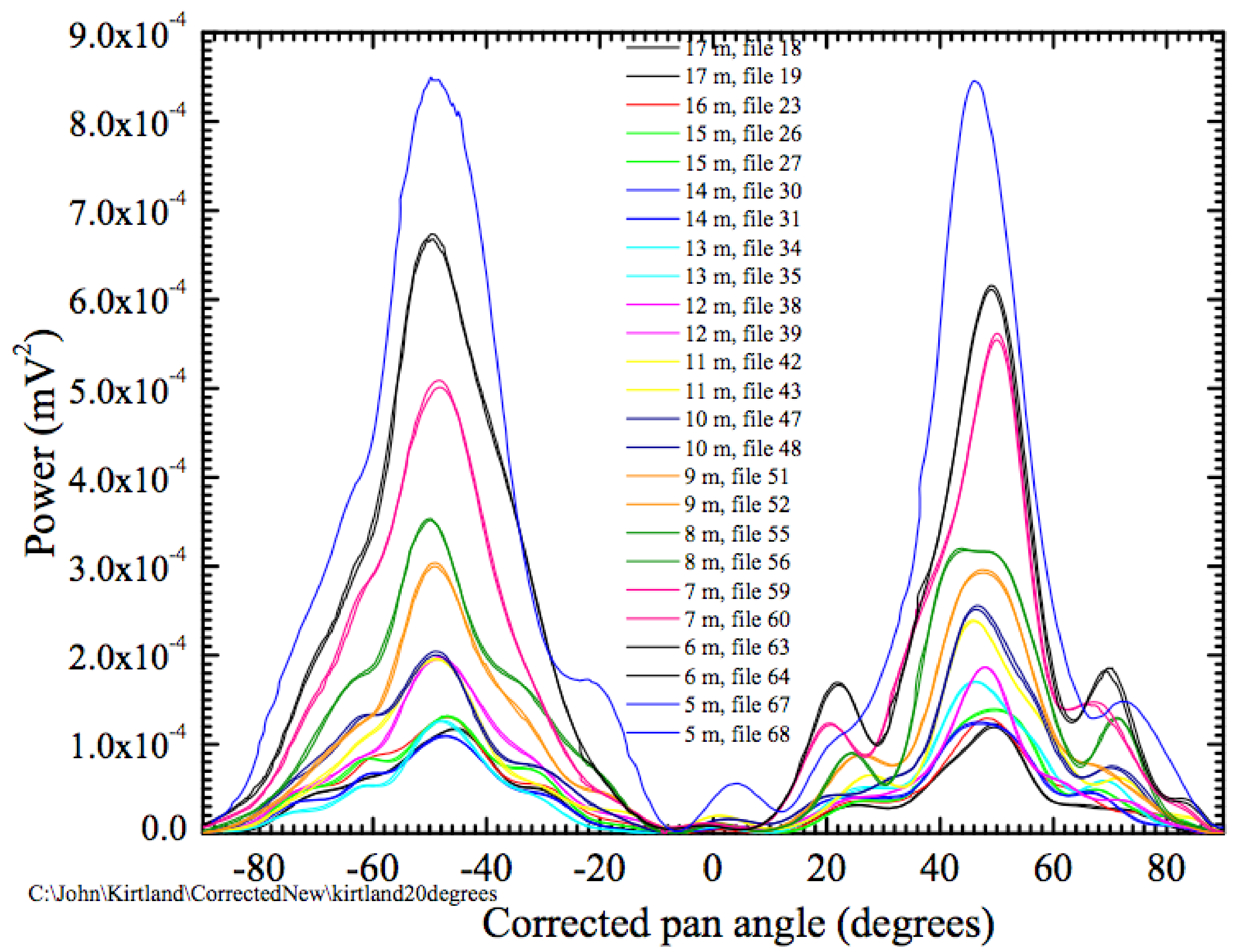
Test results (still being analyzed): Machine running at 2.6 GHz, vertical polarization, phase between elements = 10º: $v = 3.27\ c$





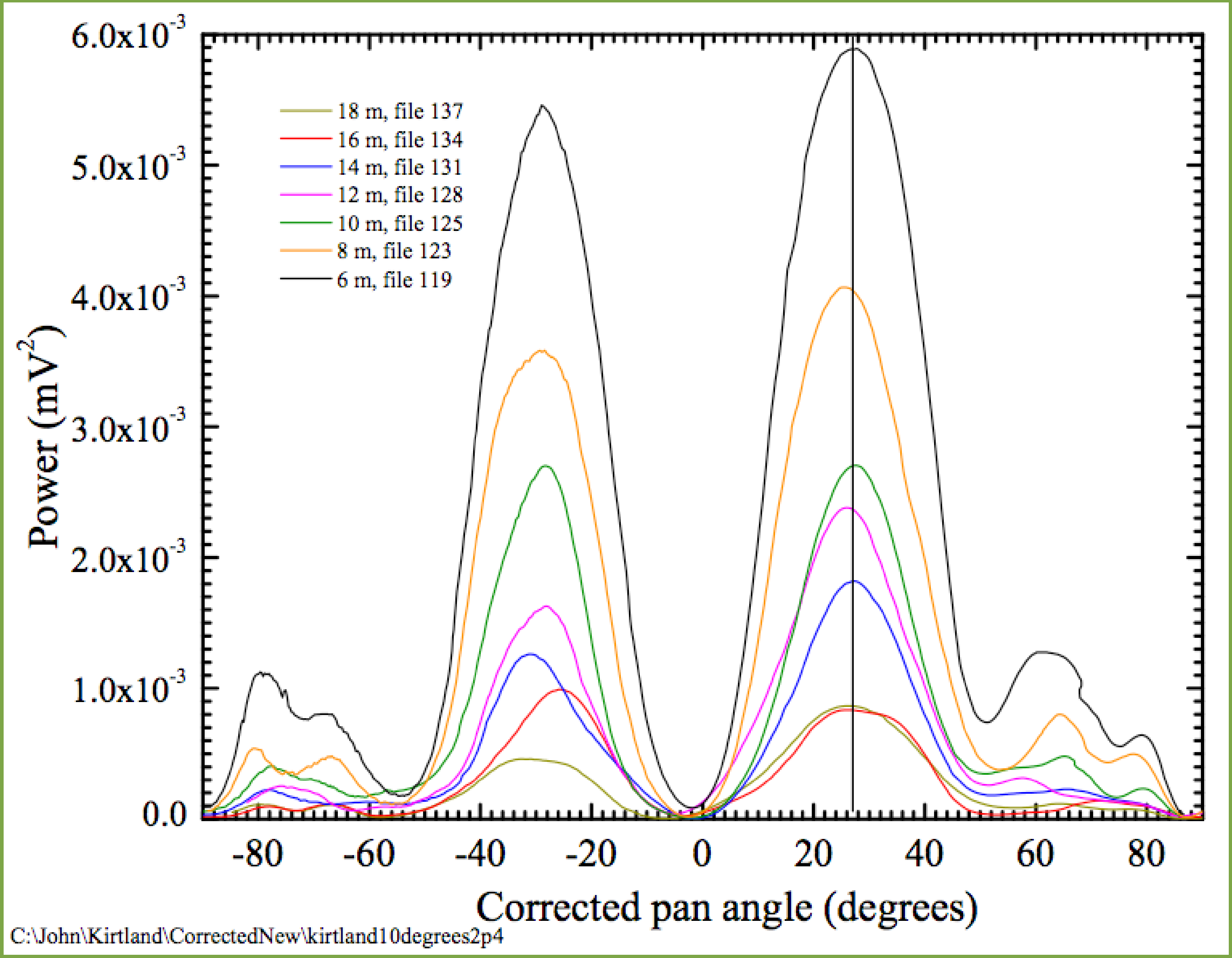
Near-field emission dominated by Cerenkov cones: source definitely going faster than *c* ! Lack of symmetry due to interference in chamber.

More data using slower speed: 2.6 GHz, vertical polarization, phase between elements = 20°: v = 1.64 c



Wider angular spread of Cerenkov emission due to slower speed; angles show precise speed control achieved. Can steer beams using speed control!

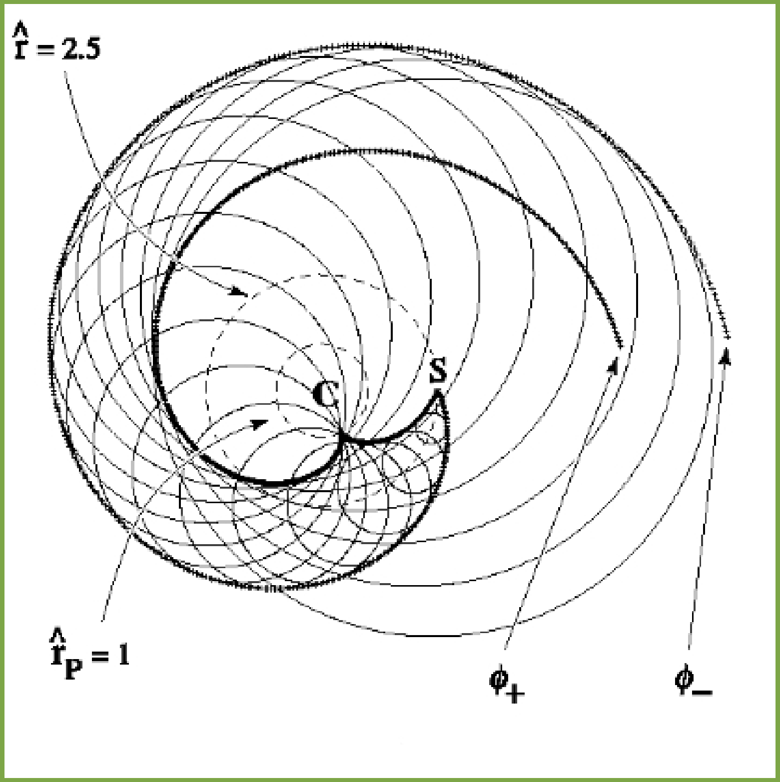
Can also steer beam using frequency: 2.4 GHz, vertical polarization, phase between elements = 10°: $v = 3.27\ c$



Note: wider spread of Cerenkov emission due to lower frequency; we have electronically-controlled (speed, frequency) directional emission.

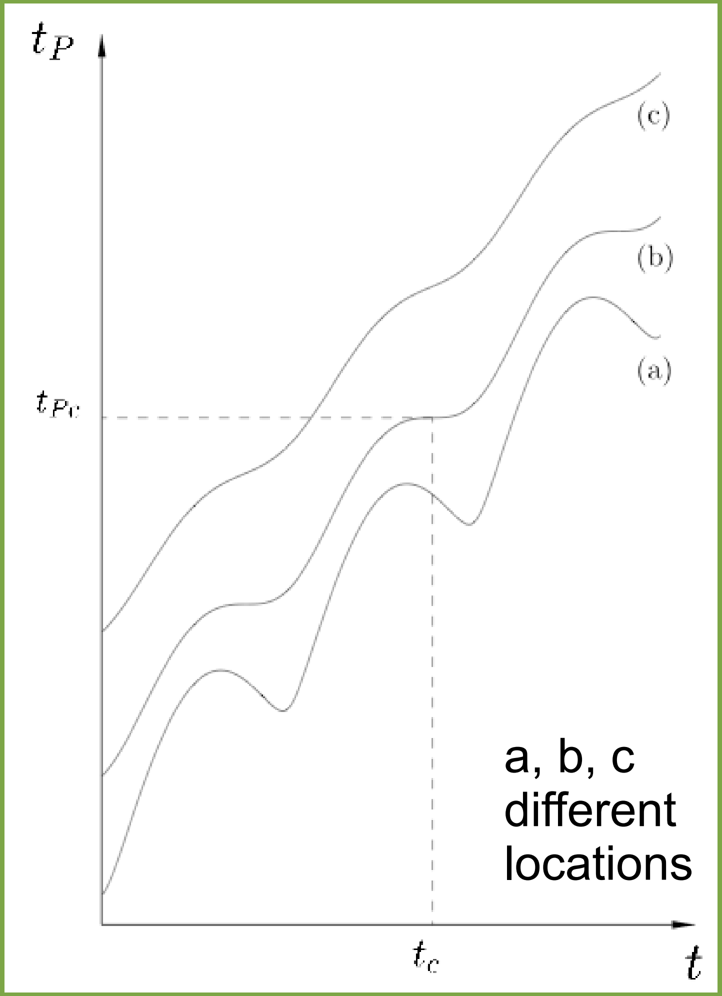
Why are we doing this? There's a special feature of superluminal sources: multiple retarded times, or even extended retarded times contribute to the signal received.

Simple example: rotating source.

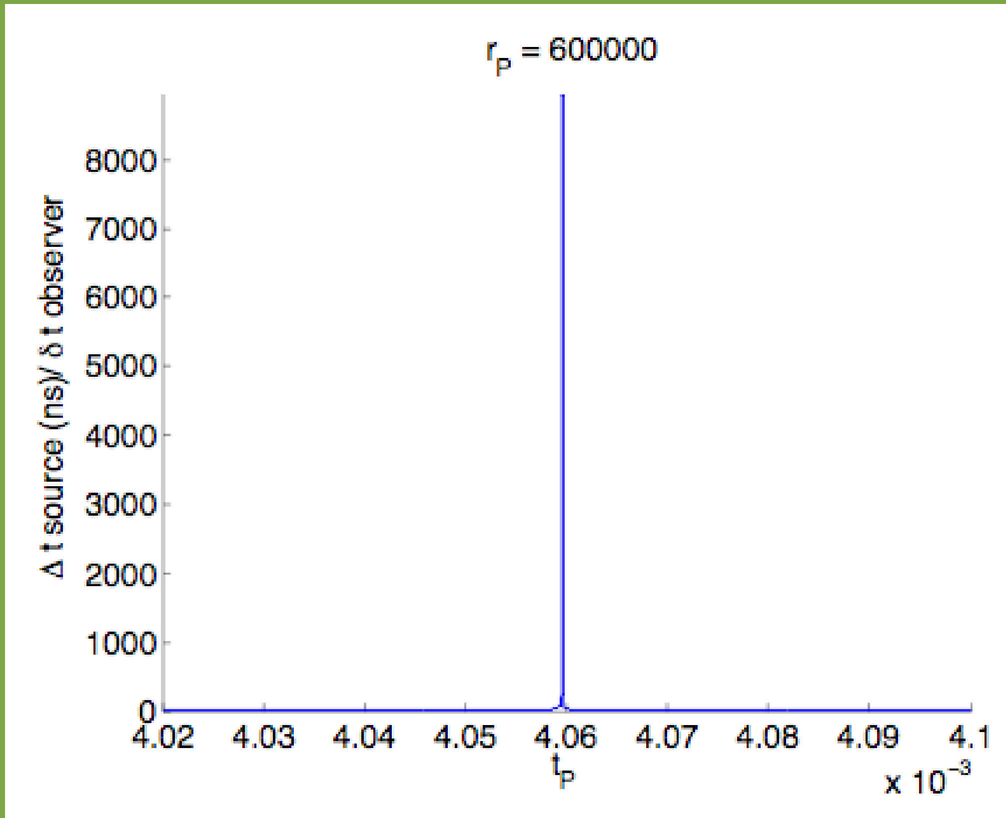


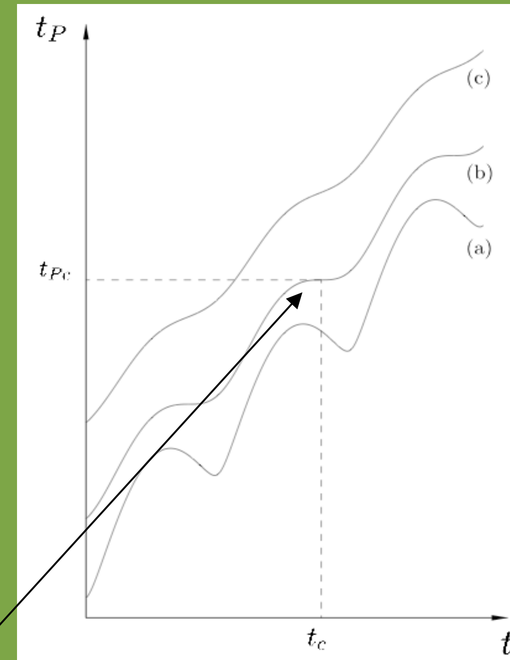
Obs. time t_P = source t + dist/c = $t + R_P/c$ =

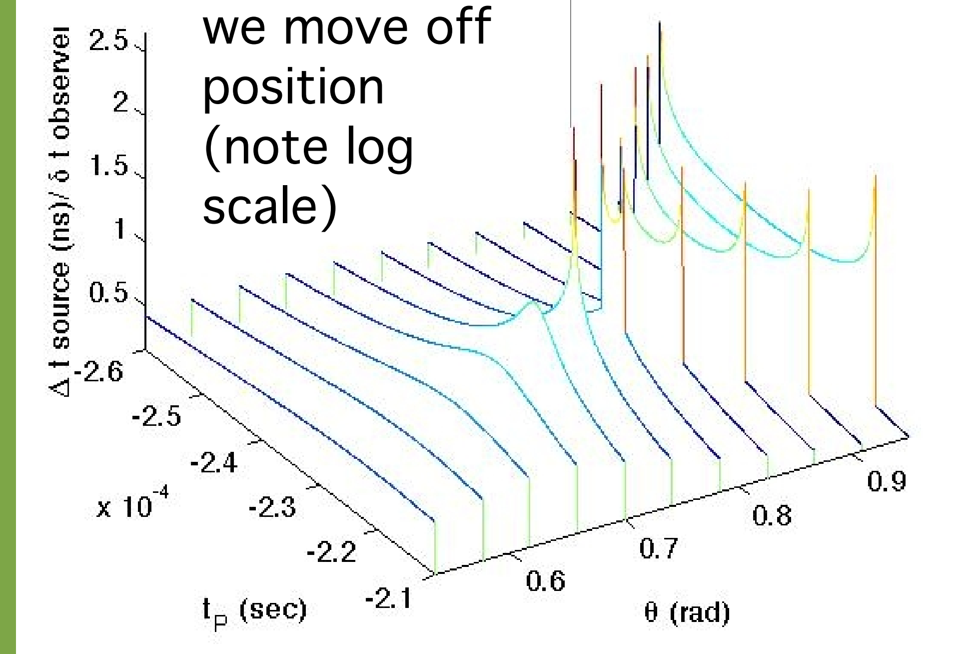
$$t+[(z_P-z)^2+{r_P}^2+r^2-2r_Pr\cos(\varphi_P-\hat{\varphi}-\omega t)]^{\frac{1}{2}}/c$$



Note that contributions from *three* retarded times received for case (a).





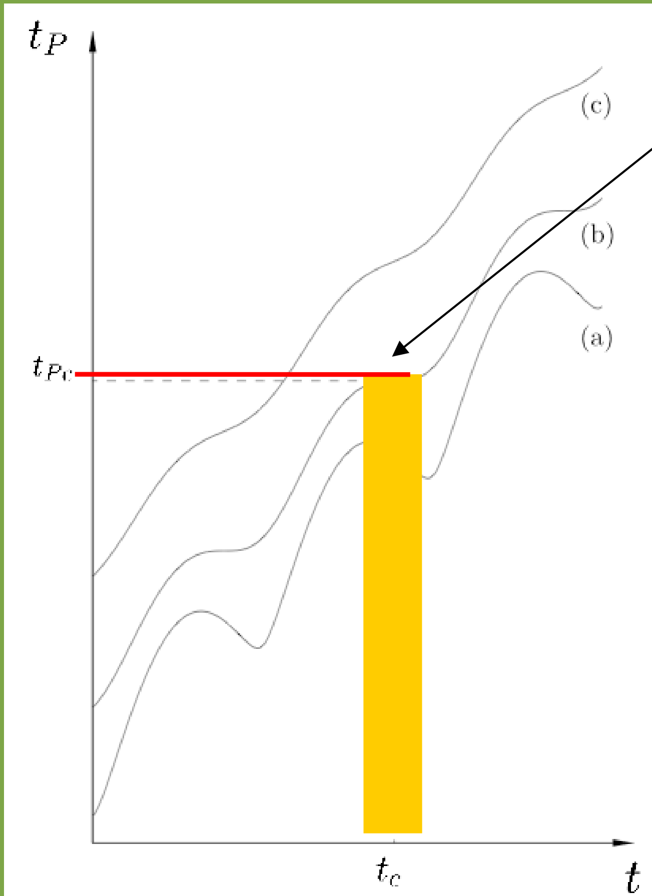


Effect lessens as we move off position (note log scale)

Temporal focusing

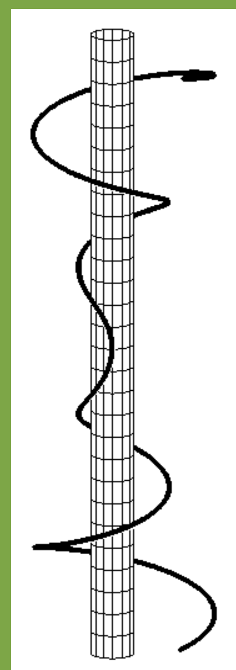
The really interesting case is the middle curve. At this position, emission from a long period of source time arrives all at once: in the above example, 9000 ns of source time arrive within 1 ns at the observer! There is an enormous focusing in time.

The electromagnetic “boom”

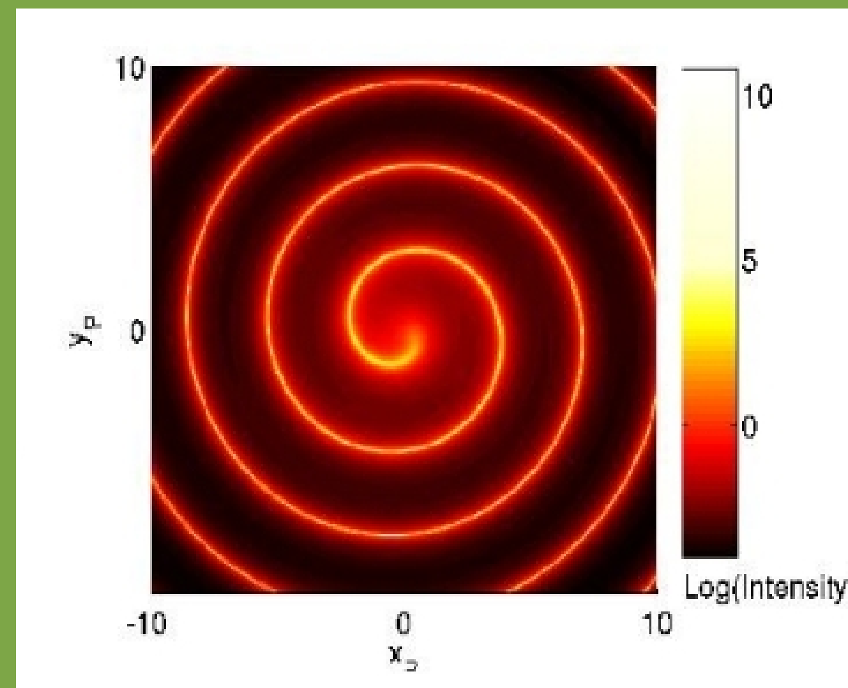


Observer receives radiation in a very short time period emitted over a much longer period of source time. There is a huge concentration of energy (temporal focusing).
This EM “boom” spirals out from the source. When it hits, receive a very short, intense pulse.

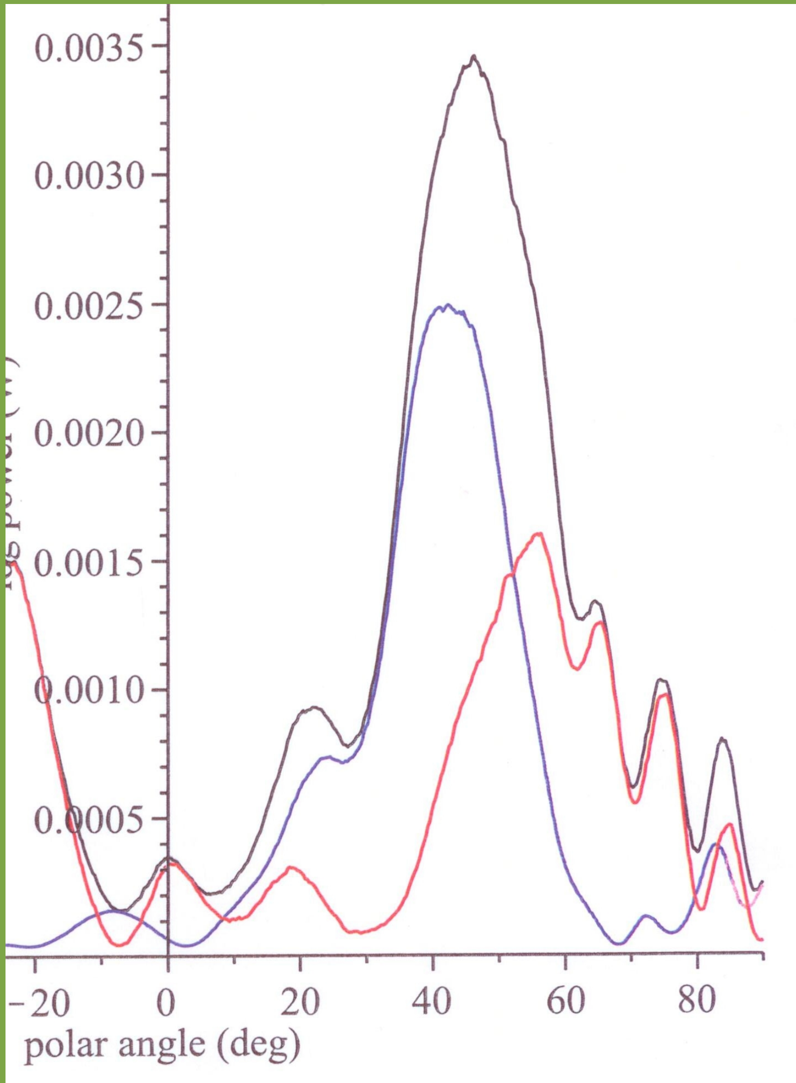
Locus of focussed “boom”

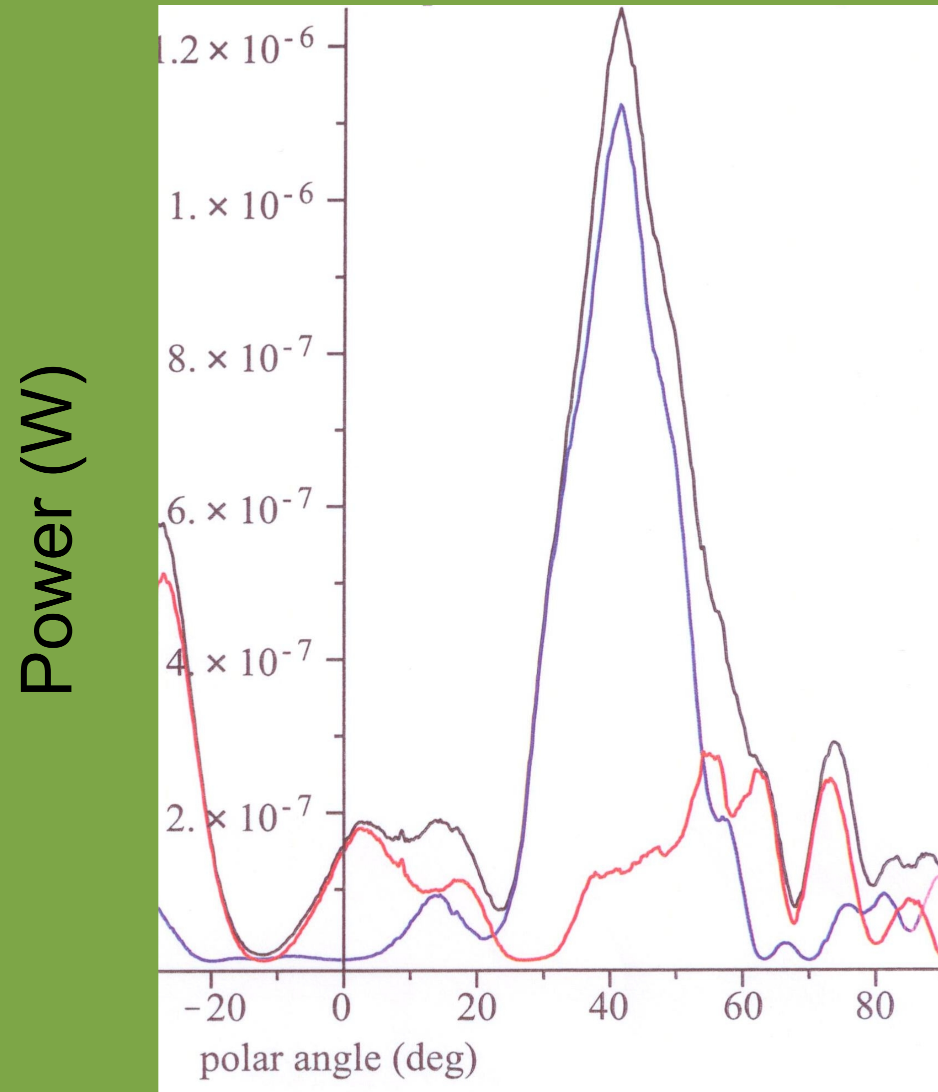


Flux on focussed “boom”

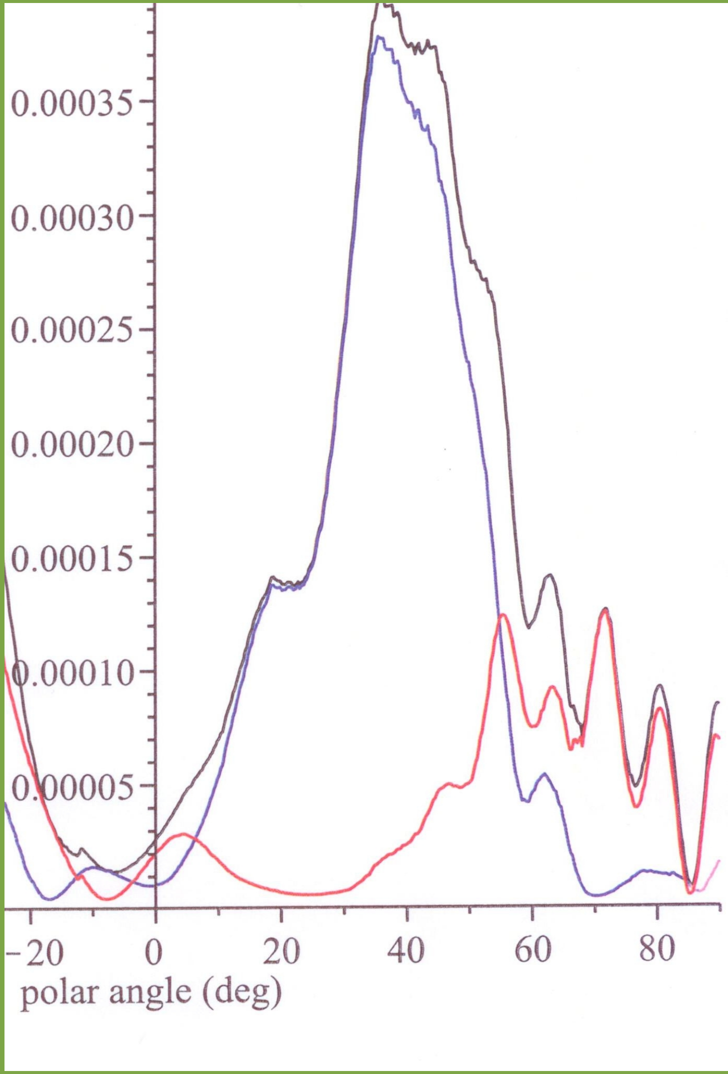


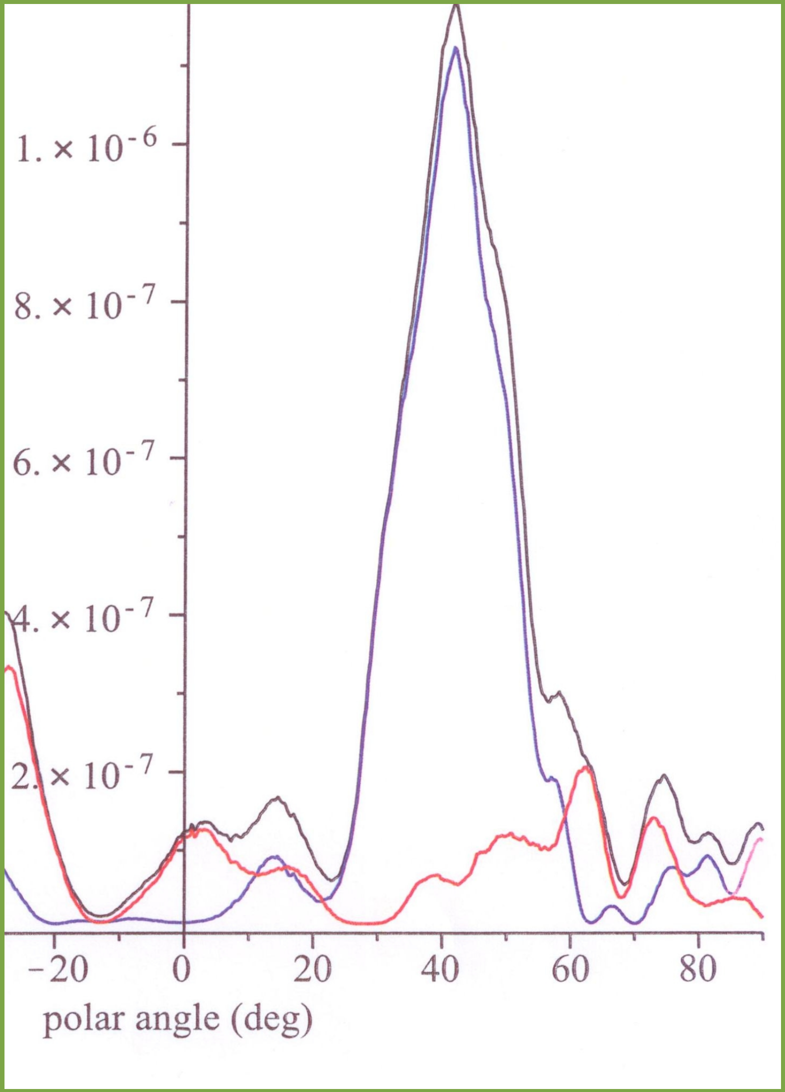
Simulations: this radiation has flux S 8 $1/d$ (d = distance), NOT S ▯ $1/d^2$ (inverse-square law). This is means the signal can travel long distances.
Analogue known in acoustics (left): intense, localized “boom” of an accelerated, supersonic ‘plane.



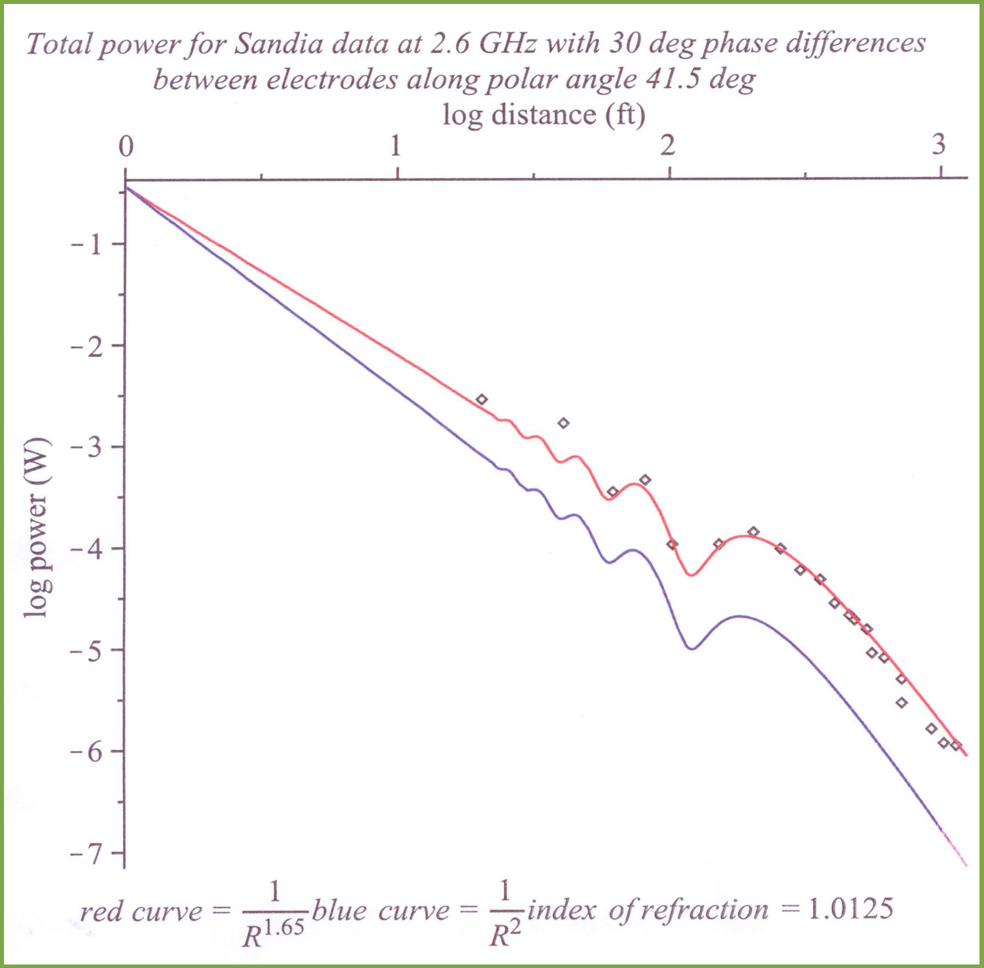


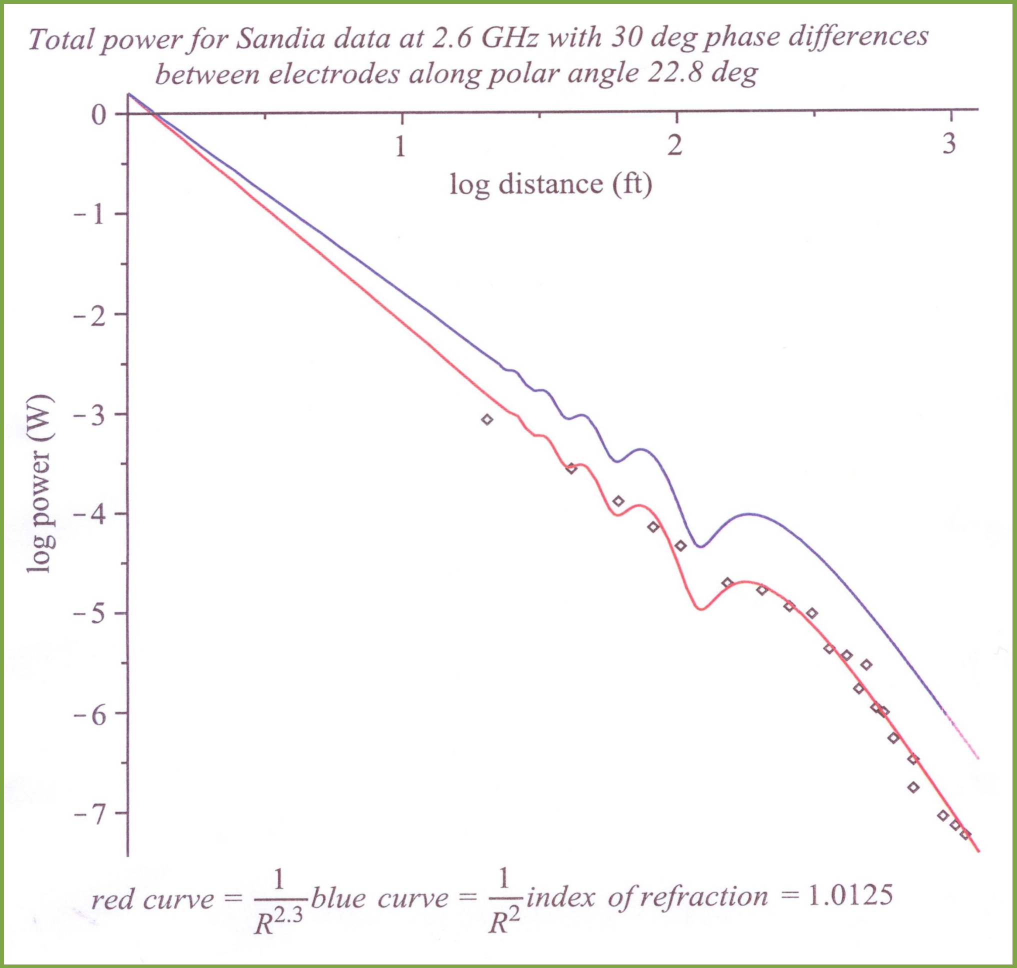
- Comparison of 20 ft and 1000 ft at FARM range; sum horizontal and vertical polarizations (to cope with circular polarization).
- Speed setting 30 degrees- 1.1 c.
- Notice visible effect of cusp: peak grows and sharpens at expense of surrounding stuff.





- Comparison of 60 ft and 1100 ft at FARM range.
- Speed setting 30 degrees.
- Notice visible effect of cusp: peak grows and sharpens at expense of surrounding stuff.

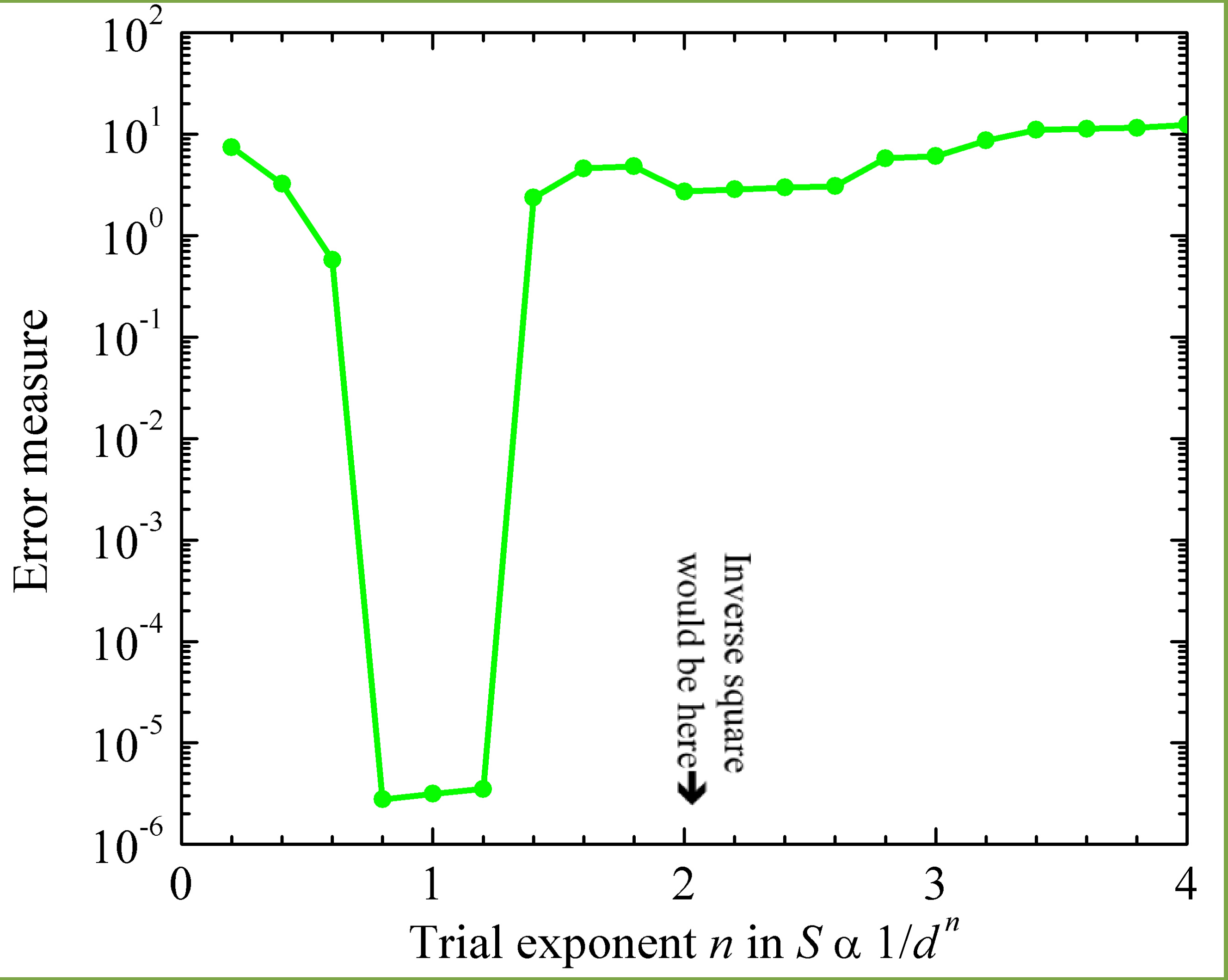


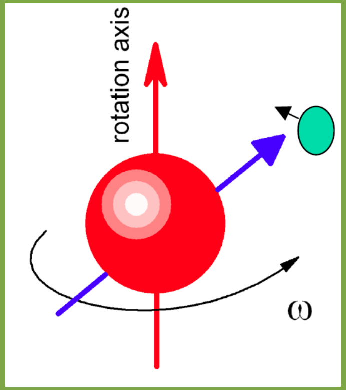


- Comparison of decays on the peak (left) and to the side of it (right); FARM range data.
- Blue is inverse-square.
- Peak due to cusp grows and sharpens at expense of surrounding stuff.

This effect – $S \propto 1/d$ - is seen in the emission of pulsars.

- Maximum likelihood analysis* of pulsars in Parkes multi-beam survey that show sharp, single pulses gives flux $S \propto 1/d$.
- Very efficient transmission of sharp pulses over long distances (see Mon. Not. Roy. Ast. Soc. 388 873, 2008, arXiv:0912.0350, arXiv:0908.1349).
- Pulses appear coherent; all phase information is collapsed in observer's frame.





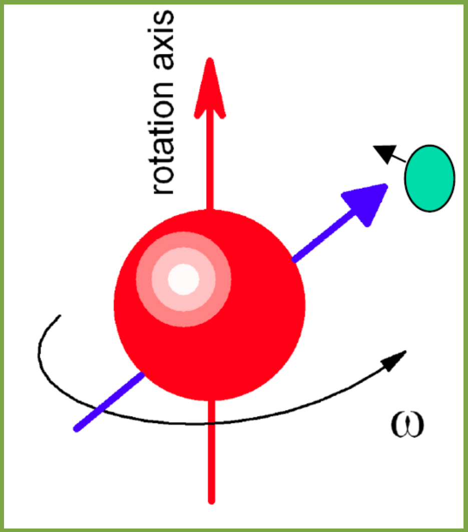
*Maximum likelihood analysis (MLA) attempts to find a luminosity function that describes all such pulsars. The luminosity L is found from $L = Sd^n$ The exponent n is varied and the minimum error measure (which gauges the success of the MLA) is found.

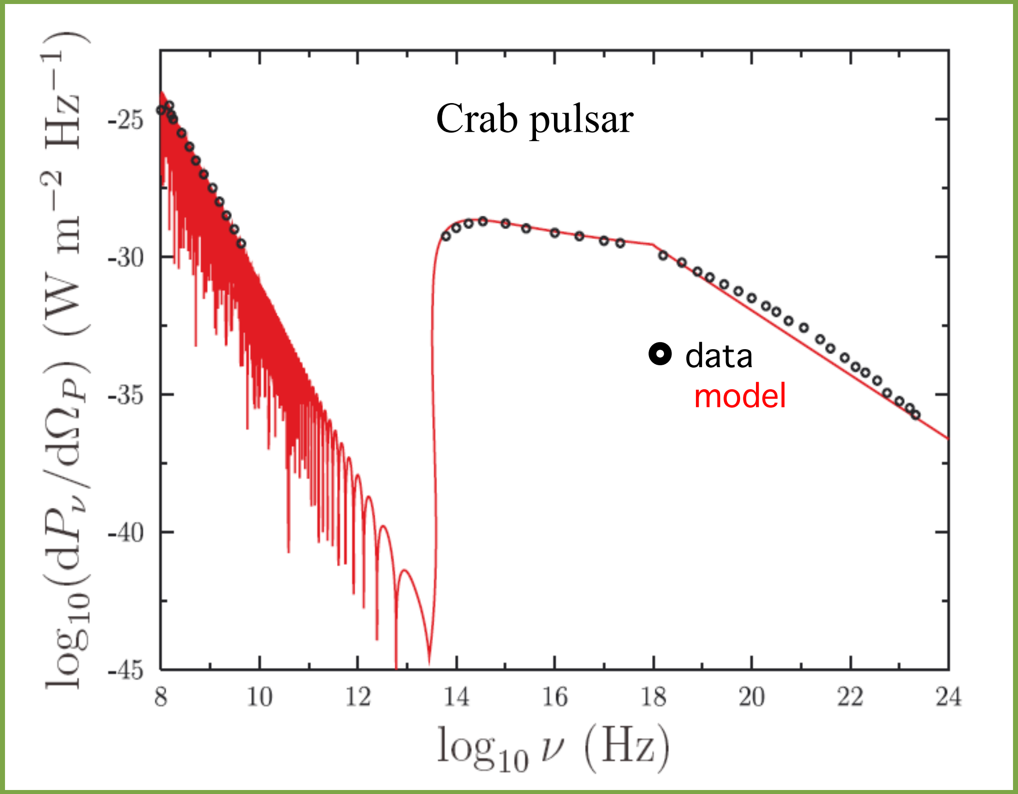
Superluminal and the broadband emission of pulsars.

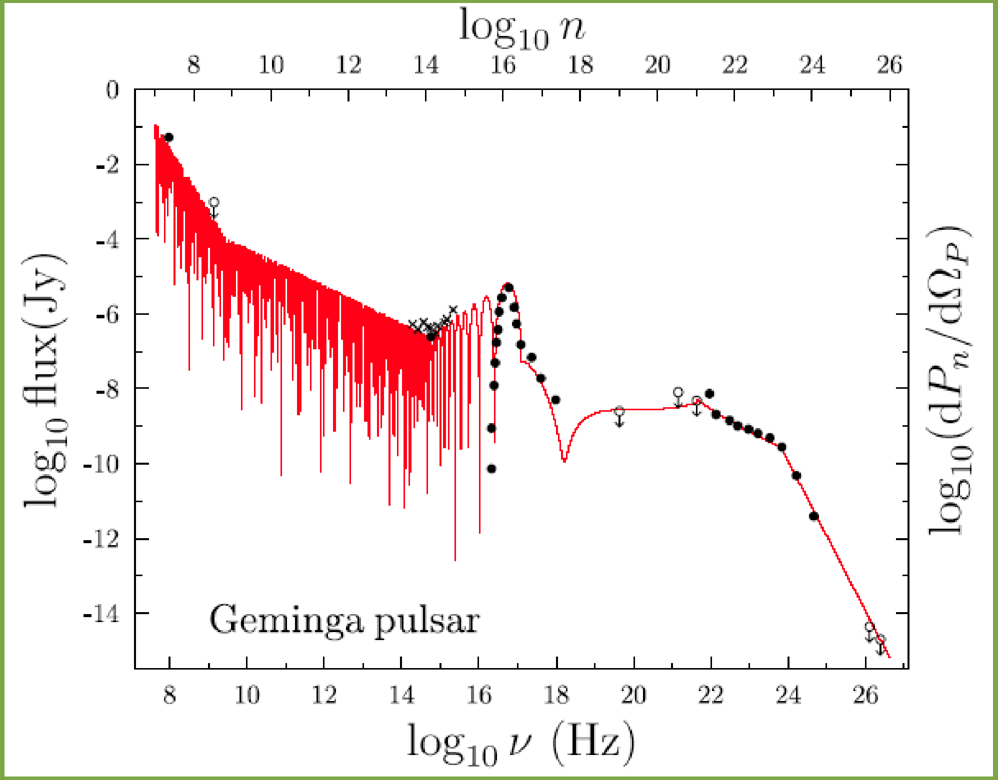
•Model based on a rotating superluminal polarization current reproduces broadband emission spectrum of the Crab pulsar and 9 others over 16 orders of magnitude using essentially 2 adjustable parameters, denoting resonances in permittivity of pulsar atmosphere.

•Can greatly enhance emission in a desired band by exploiting resonant response of material surrounding rotating field

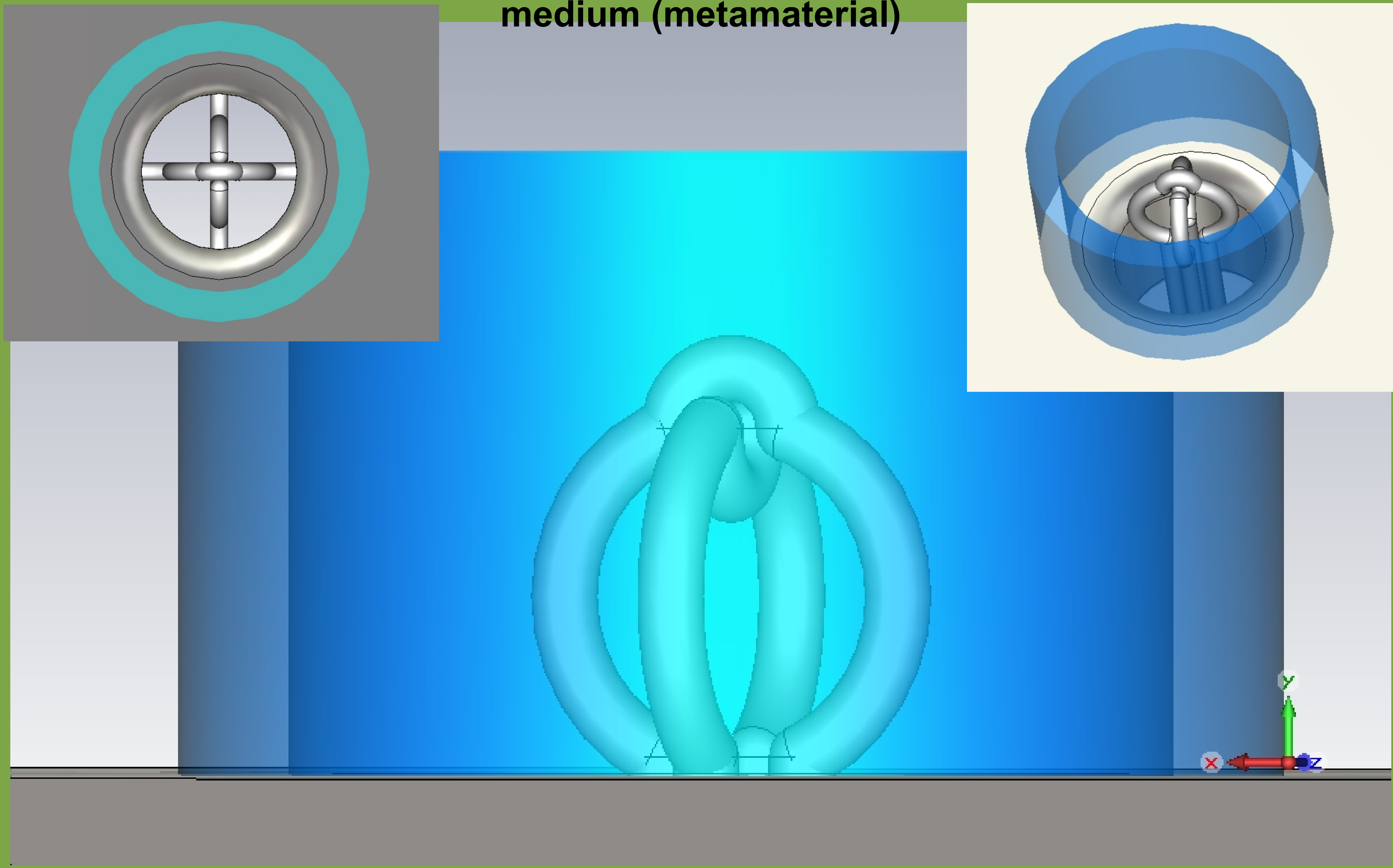
•(see Mon. Not. Roy. Ast. Soc. 388 873, 2008, arXiv:0912.0350, arXiv:0908.1349)







The future: Making a ground-based pulsar for THz emission: Orthogonal Coil Arrangement for Generation of Rotating EM-Field, surrounding polarization medium (metamaterial)



For a frequency of 2 GHz, the field travels faster than *c* beyond a radius of about 1 inch. The dielectric metamaterial hosts the superluminal polarization current. Its permittivity and/or permeability are tuned to give resonant enhancement in the THz regime.

Dynamic Picture of the Rotating EM Field Pattern (here E $_{absolute}$)