Eight-meter-wavelength Transient Array

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http://www.ece.vt.edu/swe/eta
The Dynamic Low-Frequency Radio Sky?

- **Discovery of astronomical events occurring over short timeframes tends to be a surprise.** Examples:
  - Pulsar periodic emission (GP emission, NanoGP emission...)
  - GRBs
  - Recent (many low-frequency) transient detections

- **Reasonable to expect continued detections of new sources at low radio frequencies – especially if we look**
  - Exploding primordial black holes
  - GRB prompt emission
  - Supernovae (prompt emission)
  - Coalescing exotic binary systems: NS–NS / NS–BH / BH-BH
  - All the other stuff we don’t know about yet...

- **Interesting!**
  - Large dispersion yet strong enough to be detected → Extreme physics
  - Ready-made laboratories for exploring the frontiers of physics?
  - Probes for exploring the interstellar / intergalactic medium

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Continuous, all-sky, low-frequency, “source agnostic” search for single pulses

- Array of 12 38-MHz resonant dual-polarized dipoles \( (A_e \sim 476 \text{ m}^2) \)
- 26-m dish fitted with 38 MHz dipole feed \( (A_e \sim 100 \text{ m}^2) \)
- At Pisgah Astronomical Research Institute (PARI), a rural & mountainous site in Western North Carolina (35N 83W)

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**ETA Array System Design**

- **Dipole Array**
  - AB x2
  - Active Balun
  - Long Coax

- **RF**
  - 125 MSPS x 12-bit
  - (Digital Receiver, Channelization, RFI Mitigation, Calibration)

- **A/D-IF**
  - 432 Mb/s Serial LVDS

- **Node**
  - Reconfigurable Computer Cluster (RCC)
  - (Beamforming, RFI Mitigation, Dedispersion)

- **2 Gb/s Serial Interconnect Matrix**
  - Parallel LVDS

- **PC**
  - 4-Node PC Cluster (Really part of RCC)

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Search Parameters

~ 10 “Patrol Beams”

Beamwidth: ~ 30°
(38 MHz @ zenith)

Continuum sensitivity: 48 Jy
(Δν = 1 MHz, τ = 1 min, 5σ)

“Long” pulse sensitivity: 861 Jy
(Δν = 18 MHz, τ = 10 ms, 5σ, incoherent dedispersion, 10-100 pc cm⁻³)

“Short” pulse sensitivity: 8 kJy
(Δν = 18 MHz, τ = 66 μs, 5σ, no dedispersion)

Pattern of One Patrol Beam

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Array Construction

- All cable in buried conduit
- Core array in RG-58, lengths up to about 40 m
- Outriggers in RG8X (78 m) and LMR400 (156 m)
Dipole arms are ¾” x ¾” x 1/8” Al angle stock

16 m diameter (2λ @ 38 MHz)

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Active Balun

- Modified NRL / Hicks Design
  - Higher bias current
  - Low-cost ($5) transformer
  - Reworked layout / form factor

- Measured Performance
  - T: about 250 K
  - Gain: 24 dB gain
  - $P_{1dB}$: -2.8 dBm @ 38 MHz
  - BW: < 5 MHz to > 95 MHz
  - 160 mA @ 12V (per dipole)
  - About $45 (small quantities)

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What an ETA Dipole Sees

At Antenna Terminals, $\Delta v = 300$ kHz

- Ubiquitous HF Hash
- ETA Search Bandwidth
- TV2
- TV3
- TV4
- FM

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A/D Conversion & Digital IF Processing (DigIF)

- Altera Stratix EP1S25 Eval Board
  - 2 x ADI AD9433 (12b @ 125 MSPS)
  - 1 x Stratix EP1S25 FPGA
  - One board easily handles two polarizations (We use 13 boards)
Direct-Sampled A/D Output

Raw A/D output from East Outrigger (over 156 m coax), 16K FFT with Bartlett Window
Spectral Occupancy

8-m (37.5-38.25 MHz)
Radio Astronomy Allocation

ETA Search Bandwidth
Reconfigurable Computing Cluster (RCC)

- 16-node “Virtual FPGA”
  - Each node is a development board with Xilinx XC2VP30 FPGA
  - Edge nodes (“E”) catch streaming LVDS from DigIFs
  - Center nodes (“C”) route between RCC nodes & push results to PC cluster
  - PPCs internal to FPGAs run Linux, perform GPP-type functions

- PC cluster
  - 4 Dell SC430 Linux Servers
  - 300 GB Ultra320 HDs for hours of transient buffering
  - 200 GB LTO2 tape drives for archiving
Aurora: Infiniband physical (electromechanical) layer
+ Xilinx’s streamlined data link layer
= 3.125 Gb/s per cable
RCC Integration / Testing

Conducting RFI test on Installation of first 8 RCC nodes

(so far, so good...)
Eight-Meter (29-47 MHz) Feed Modification

Antenna Wire is 1.9 m (75") long

View looking down on feedbox In West Service Position

Insulated Tie-Off
Milestones

- 22 May 2004: Initial use of site for pilot experiments
- 15 Aug 2005: NSF Project Start
- 08 Oct 2005: Demonstration of Galactic background-limited Antenna / Front End
- 01 Nov 2005: Cable installation complete
- 05 Nov 2005: First core array dual-dipole complete
- 18 Nov 2005: Dish feed installed
- 20 Nov 2005: First outrigger dual-dipole complete
- 21 Nov 2005: Demonstration of direct sampling of ETA search bandwidth (12 bits @ 104 MSPS) from first four dipoles
- Spring 2006: Commissioning test: Monitoring Crab GPs
- Summer 2006: Commence dedicated 24 x 7 search

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ETA Commissioning Using Crab Pulses

At 8 meters wavelength…

…170 s for pulse to sweep 47-29 MHz (pulses effectively 100% overlapped)

…But GIANT pulses should be detectible

Lyne & Graham-Smith (1998)

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Argyle and Gower (1972)
RFI Mitigation

- Transient Searching and RFI Mitigation *are the same thing*!
- Must be automated or detection logistics quickly get out of hand

- **Continuous Processing**
  - Patrol beam pattern design
  - Initial channelization into two 9 MHz bands with tight digital filters
  - Asynchronous pulse blanking
  - Bin blanking / blacklisting (multiple timescales)
  - Dedispersion: Normally require DM > 10 pc cm\(^{-3}\) to discriminate against RFI

- **Detection Follow Up**
  - Reprocess buffered data to determine DOA, apply spatial filtering, etc.
  - Outriggers
    - Discriminate against site RFI (e.g., “equal magnitude” criterion)
    - Resolution elements (improved DOA / TOA)
  - Dish
    - Anticoincidence

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PARI Site (35° N, 83° W)

Low-sensitivity RFI measurement on ridge:

Low sensitivity RFI Measurement in bowl (Core Array site):

...10-15 dB reduction in strong (linearity-threatening) RFI

Array site near bottom of “bowl” formed by surrounding terrain

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Virginia Tech Campus Farm Operation / Kentland Farm – Near Radford, VA
Candidate ETA Anti-Coincidence Site

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