The Eight-meter-wavelength Transient Array

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http://www.ece.vt.edu/swe/eta
ETA is...

- A new radio telescope designed specifically to detect the radio-frequency emission associated with the explosions of a broad class of astronomical objects ("transients")

- An NSF-funded project begun August 2005

- A collaboration between the Virginia Tech Departments of Electrical & Computer Engineering and Physics

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The Dynamic Radio Sky

- Historically – and understandably – we tend to think of astronomical events unfolding over very long time scales.

- So, discovery of astronomical events occurring over shorter timeframes tends to be a surprise.

- One of several examples is ...

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Pulsars

- Periodic pulsed emission from neutron stars was predicted, but unexpected
- First detected by Hewish and Bell (1967)
  - 2048 dipole antennas
  - $f = 81$ MHz
  - Search for quasars by scintillation
  - PSR 1919+21 ($P = 1.337$ s)
  - LGM, “pulsars”

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Pulsars

- ~ 1700 known

- $P_{\text{avg}} = 0.79$ s
  - $P_{\text{max}} = 8.5$ s (PSR J2144-3933) 0.12 Hz
  - $P_{\text{min}} = 56$ ms (PSR B1937+21) 642 Hz

- Brief pulses (typically few % of period)

- “Normal” pulsars
  - $P \sim 0.5$ s slowdown $dP/dt \sim 10^{-15}$ s/s
  - Some “glitch” - period changes abruptly
  - < 1% found in binary systems

- “Millisecond” pulsars
  - $P \sim 3$ ms $dP/dt \sim 10^{-20}$ s/s
  - ~ 80% found in binary systems

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**Pulsars = Rotating Neutron Stars**

- Mass $\sim$ 1.4 solar masses
- Radius $\sim$ 10 km (Type II supernova)
- The only periodic phenomena that can work!
  - $P_{\text{rot, min}} \sim 0.5$ ms (centrifugal acceleration $\sim$ gravitational acceleration)
  - $\frac{dP}{dt} > 0$
- Lighthouse model
  - Magnetic field $> 10^{12}$ Gauss for a normal pulsar
  - $\Rightarrow$ large induced $E$ ($F \gg$ gravity)
  - $\Rightarrow$ synchrotron radiation

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Pulsar Pulse Profiles

PSR 1133+16 (MPIfR)

Mode switching
Drifting subpulses
Nulling

PSR B1919+21

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# The Music of the Spheres

[Radio signals demodulated into audio]

<table>
<thead>
<tr>
<th>Pulsar</th>
<th>P (sec)</th>
<th>1/P (Hz)</th>
<th>Sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0329+54</td>
<td>0.71</td>
<td>1.4</td>
<td></td>
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<tr>
<td>B0833-45 (Vela)</td>
<td>0.089</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>B0531+21 (Crab)</td>
<td>0.033</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>J0437-4715</td>
<td>0.00575</td>
<td>174</td>
<td></td>
</tr>
<tr>
<td>B1937+21</td>
<td>0.00156</td>
<td>642</td>
<td></td>
</tr>
</tbody>
</table>

(Jodrell Bank)

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Crab Nebula

- Supernova observed in 1054 AD
- As bright as the full moon for one week
- Glows in every kind of light
- Distance = 2 kparsec

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Crab Pulsar

- Discovered by Staelin and Reifenstein 1968
  - 100 - 115 MHz
  - 0.1 MHz channels
  - 0.06 sec sampling

- $P = 0.0333 \text{ s}$

- $\frac{dP}{dt} = 4.21 \times 10^{-13} \text{ s/s}$

(Recorded by the Hubble space telescope)

(slope due to dispersion)

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Crab Giant Pulses

- 10 - 1000 times the mean pulse intensity
  - One 10x-mean GP per $10^3$ pulses (30 sec)

- Hankins and Rickett (1975), 430 MHz
  - Time scales $t < 100$ us
  - Mean pulse energy $S_v \sim 10^5$ Jy

- Hankins et al. (2003), 5 GHz
  - $T \sim 2$ ns
  - $S_v \sim 10^3$ Jy
  - “nano-giant” pulses

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Why Radio Transients Are Interesting

- Confirm / refine theoretical models for the progenitor objects, which are very strange
- They provide “search lights” for exploring the interstellar / intergalactic medium
- Strong + short duration implies extreme physics
  Ready-made laboratories for exploring the frontiers of physics
- Confirm / refine fundamental physics, including cosmology

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Why ETA?

- A dedicated search is very likely to reveal new sources of transient emission.
- The transient sky is mostly unexplored, since existing instruments are terrible for this.
- Maybe we should know what is going on in the 99.999…% of the radio sky we aren’t currently observing...?

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What Might a Dedicated Transient Search Find?

- More / stranger pulsars, through giant pulse emission
- Gamma Ray Burst prompt emission
- Supernovae (prompt emission)
- Exploding Primordial Black Holes
- Coalescing Neutron Star – Neutron Star Binaries
- Coalescing Neutron Star – Black Hole Binaries
- All the other stuff we don’t know about yet!

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Eight-meter-wavelength Transient Array (ETA)

Dish Station
(Loop Feed on 26 m Dish)

~ 1 km

Dipole Station
(12 Dual-Pol Dipoles)

Electronics Hut

Internet Access

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Eight-meter-wavelength Transient Array (ETA)

About 1/2 of the collecting area is in the form of an array which continually scans the entire sky using fixed “patrol beams”

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Eight-meter-wavelength Transient Array (ETA)

About 1/2 of the collecting area is from a dish that allows follow-up & more sensitive observation of a smaller portion of the sky

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Eight-Meter (29-47 MHz) Feed Modification
Artist’s Impression of “Core Array”
Antenna Array Work in Progress

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Dipole Array

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- RF
- A/D-IF
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- 2 Gb/s Serial Interconnect Matrix
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Active Balun
- 100-500 ft Coax
- 125 MSPS x 12-bit (Digital Receiver, Interference Mitigation)
- 432 Mb/s LVDS
- 16-Node FPGA Cluster (Beamforming)
- Gb/s Ethernet
- 4-Node PC Cluster (Dedispersion Search)

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Assembly and Test

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October 8, 2005: First ETA Antenna Gets a Glimpse of the Galaxy

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Measurements taken at PARI (Rosman, NC).

Spectrum analyzer (∆ν = 300 kHz) at end of feedline.

Interference Mitigation

Max Hold Integration

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Dispersion

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Other Propagation Effects

- Scattering
  - Pulse broadening
  - Scintillation
- Diffractive
- Refractive

(Lorimer and Kramer 2005)

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ETA Sensitivity Projections

Year 1 Goal

 UNS, $\Delta \tau = 66$ $\mu$s
  $5\sigma$, $l=12$ m

 DPS, $\Delta \tau = 3$ ms
  $5\sigma$, $l=100$ km

 DPS, $\Delta \tau = 1$ s
  $5\sigma$, $l=R_{\text{Sun}}$

 Crab nanogp
 Crab GP

 Virginia Tech

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Engineering Impact

- ETA advances the state-of-the-art in many areas simultaneously:
  - Ultrawideband antennas
  - High dynamic-range direct-sampling receivers
  - Real-time DSP using reconfigurable FPGA clusters
  - PC Cluster Computing
  - Interference Mitigation

For more information:
- Web site
- S. Ellingson (ECE), Antennas, Receivers, Signal Processing
- C. Patterson (ECE), Reconfigurable Computing
- J. Simonetti (Physics), Astrophysics

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