Radio transients: Recent results and future prospects

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Outline

• Review of the different expected classes of radio transients

• Recent observational results on new classes of transient
  – GCRT J1745-3009 – the “burper” source
  – RRATs - Rotating Radio Transients
  – Lorimer burst – is it real?
  – Survey results
  – Bower transients and revised significance

• Detecting new radio transients: surveys
  – ATA
  – V-FASTR
  – The LOFAR Transients Key Science Project
  – ThunderKAT
  – ASKAP-VAST, ASKAP-CRAFT
What’s all the excitement?

• Physics in extreme environments
• Probes of the intergalactic medium
• Unexplored parameter space
• Radio regime:
  – Unaffected by intervening dust and gas
  – Ground-based
  – New technology and processing power expanding available fields-of-view
  – Immediate localization with arcsecond precision
Classes of radio transients

- Well-studied sources ("known knowns")
- Many new types of source discovered in recent years ("known unknowns")
  - GCRT J1745-3009
  - RRATs
  - Tidal disruption events (Swift J1644+57)
- Separate by timescale and duration (Frail et al. 2011)
- Timescale:
  - Short (< few s): coherent emission (high $T_B$)
  - Long (> few s): incoherent (synchrotron) emission
- Location
  - Galactic: repeated events
  - Extragalactic: cataclysmic events

Hyman et al. (2005)
McLaughlin et al. (2006)
Zauderer et al. (2011)
Fast transients (<1s): time series

- Pulsars and NS phenomena (RRATs, nulling pulsars)
- Solar bursts (Type II and III)
- Flare stars
- Brown dwarfs
- Planets (Jupiter, Saturn, exoplanets)
- “Lorimer” bursts
- Annihilating black holes
- Coalescing NS
- EM counterparts to GW sources
- ETI signals?

Kramer et al. (2006)
Fischer et al. (2011)
Transient phase space

- Short timescales imply coherent processes

\[ T_B = \frac{c^2 S_v}{2\nu^2 k_B \Omega} \]

Keane et al. (2011)
Issues with fast transient detection

- Data processing
- Propagation effects in the ISM:
  - Temporal broadening
  - Dispersion
  - Worse at low frequencies (where FOV is highest!)

Macquart (2011)
GCRT J1745-3009: the “burper”

- Discovered in 330-MHz Galactic Centre monitoring
- 77-min periodicity
- ~7% detection rate
- Never detected at any other frequency
- Steep-spectrum (coherent?) emission
- $T_B = 10^{12} K(d/70\text{pc})^2$
- High CP suggests possible subsolar flare star progenitor

Hyman et al. (2005, 2007)
Rotating radio transients (RRATs)

- Single, dispersed bursts of duration 2-30ms
- Repeat with same DM
- Recurrence time 4min-3h
- Periodicities 0.4-7s
- Concentrated towards the Plane
- Peak flux densities 0.1-3.6 Jy
- Likely rotating NSs

$DM = \int n_e \, dl$

McLaughlin et al. (2006)
RRATs continued

• One X-ray counterpart showing pulsations

• Also extended emission (PWN morphology)

• Evidence for glitches

• Possible link (B, P) with magnetars/XDINs
  – Tail end of intermittency distribution?
  – In process of turning off?
  – High B, long P?

Miller et al. (2011)
The Lorimer burst

- 30 Jy burst, <5ms in duration
- Detected in 3 independent beams at Parkes
- 3 degrees from SMC
- Dispersed:
  - Lower frequencies delayed ($\nu^{-2}$)
  - Pulse broadened at lower frequencies ($\nu^{-4}$)
- Inferred DM 375 cm$^{-3}$ pc
  - Implies extragalactic origin ($z=0.3$)
- Must be coherent emission from a compact region

Lorimer et al. (2007)
The Lorimer burst: astronomical?

• 16 similar swept-frequency bursts detected by Burke-Spolaor et al. (2011): *perytons*

• Clearly terrestrial:
  - Deviations from dispersive delay law (“kinks”)
  - All occurred in daylight
  - Natural or man-made?

• Is the Lorimer burst a peryton?
  - Similar delay
  - Perytons didn’t show pulse width evolution

• Second, non-terrestrial burst seen at DM of 745 cm\(^{-3}\)pc (Keane et al. 2011)
Slow transients (>1s): imaging

- Primarily explosive events or outflows
- Often synchrotron emission (occasionally thermal)
- Known source classes
  - Novae
  - Cataclysmic Variables (CVs)
  - X-ray Binaries (XRBs)
  - Magnetar outbursts
  - Supernovae (SNe)
  - Active Galactic Nuclei (AGN)
  - Tidal disruption events
  - Gamma-ray bursts (GRBs)
- Also scintillation (non-intrinsic variability) and ESEs
  - Probe of the scattering medium (ISM/IGM)
Incoherent synchrotron processes

- Shock-accelerated electrons and magnetic fields
- Become optically thin later at lower frequencies
- Limited to $10^{12}$ K (caveat beaming)
- Timescales: source size/outflow velocity

van der Horst et al. (2008)
Scattering and the ISM

• Interstellar scintillation creates intra-day variability of compact sources

• Probes $\mu$as source structure and scattering medium
  – Are AGN emitting above the Compton brightness limit?
  – Does ISS vary as a function of redshift?
    • Probing properties of IGM

• Extreme scattering events
  – Galactic lenses refracting emission
    – $n_e$, $d$, $v$ of lenses
Slow transient surveys review

- Ofek et al. (2011) reviewed the transient survey literature
- Mainly upper limits; 3 surveys detected significant numbers of transients
- Radio sky quieter than $\gamma$-ray sky (0.1-3% of persistent sources are highly variable in the 0.1mJy-1Jy range)

### Table 1

<table>
<thead>
<tr>
<th>$\nu$ GHz</th>
<th>Area deg$^2$</th>
<th>Direction deg</th>
<th>$\Delta \theta$ $''$</th>
<th>$N_{\text{ep}}$</th>
<th>$\delta t$</th>
<th>$\Delta t$</th>
<th>rms mJy</th>
<th>Sources</th>
<th>Tran.</th>
<th>Var.</th>
<th>Ref.</th>
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<tr>
<td>0.84</td>
<td>2776</td>
<td>$\delta &lt; -30$</td>
<td>$\sim 45$</td>
<td>2$^a$</td>
<td>12 hr</td>
<td>1 day–20 yr</td>
<td>2.8</td>
<td>29730</td>
<td>15</td>
<td>$\sim 10$</td>
<td>[14]</td>
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<tr>
<td>1.4</td>
<td>0.22</td>
<td>$l = 150$, $b = +53$</td>
<td>4.5</td>
<td>3</td>
<td>6 hrs</td>
<td>19 d, 17m</td>
<td>0.015</td>
<td>$\ldots$</td>
<td>0</td>
<td>2%</td>
<td>[1]</td>
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<tr>
<td>1.4</td>
<td>2.6</td>
<td>$l = 151$, $b = +24$</td>
<td>60</td>
<td>16</td>
<td>12 hrs</td>
<td>1-12 d, 1-3 m</td>
<td>0.7</td>
<td>245</td>
<td>0</td>
<td>$\sim 1%$</td>
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<td>1.4</td>
<td>120</td>
<td>S. Galactic Cap</td>
<td>5</td>
<td>2</td>
<td>days</td>
<td>7 yr</td>
<td>0.15</td>
<td>9086</td>
<td>0</td>
<td>1.4%</td>
<td>[3]</td>
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<tr>
<td>1.4</td>
<td>2500</td>
<td>$b \gtrsim 30$</td>
<td>45</td>
<td>2</td>
<td>days</td>
<td>$\sim$ years</td>
<td>0.45</td>
<td>7181</td>
<td>1</td>
<td>$\ldots$</td>
<td>[5,6,7]</td>
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<td>1.4</td>
<td>2870$^b$</td>
<td>$+32 &gt; \delta &gt; +42$</td>
<td>$24' \times 2.4'$</td>
<td>$\sim 1000$</td>
<td>4 min</td>
<td>1 d</td>
<td>300</td>
<td>$\ldots$</td>
<td>11</td>
<td>$\ldots$</td>
<td>[8,9,10,11]</td>
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<td>1.4</td>
<td>0.2</td>
<td>$l = 57$, $b = +81$</td>
<td>20</td>
<td>1852</td>
<td>minutes</td>
<td>1 day–23 yr</td>
<td>2</td>
<td>10</td>
<td>0</td>
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<td>1.4</td>
<td>690</td>
<td>$l = 70$, $b = +64$</td>
<td>150</td>
<td>12</td>
<td>$&gt; 1$ day</td>
<td>days–months</td>
<td>38</td>
<td>4408</td>
<td>0</td>
<td>$\lesssim 0.1%$</td>
<td>[4]</td>
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<td>690</td>
<td>$l = 70$, $b = +64$</td>
<td>150</td>
<td>5</td>
<td>min</td>
<td>days-years</td>
<td>1</td>
<td>$\ldots$</td>
<td>0</td>
<td>$\ldots$</td>
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<tr>
<td>1.4</td>
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<td>phase calibr.</td>
<td>$\ldots$</td>
<td>151</td>
<td>5 min</td>
<td>days-years</td>
<td>0.25</td>
<td>425</td>
<td>1$^c$</td>
<td>$\ldots$</td>
<td>[12]</td>
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<td>3.1</td>
<td>10</td>
<td>$l = 57$, $b = +67$</td>
<td>100</td>
<td>2</td>
<td>months</td>
<td>15 yr</td>
<td>0.05</td>
<td>425</td>
<td>1$^c$</td>
<td>$\ldots$</td>
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</tr>
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<td>4.9</td>
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<td>$\ldots$</td>
<td>$\sim 390^d$</td>
<td>5 min</td>
<td>days-years</td>
<td>1$^d$</td>
<td>$\ldots$</td>
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<td>$\ldots$</td>
<td>[21]</td>
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<td>4.9</td>
<td>0.09</td>
<td>Extragalactic</td>
<td>0.5-15</td>
<td>2</td>
<td>60 min</td>
<td>1-100d</td>
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<td>$\ldots$</td>
<td>0</td>
<td>$\ldots$</td>
<td>[15]</td>
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<tr>
<td>4.9</td>
<td>23.2</td>
<td>$</td>
<td>b</td>
<td>&lt; 0.4$</td>
<td>5</td>
<td>3</td>
<td>90 s</td>
<td>2 m–15 yr</td>
<td>0.2</td>
<td>2700</td>
<td>0</td>
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<tr>
<td>4.9</td>
<td>500</td>
<td>$</td>
<td>b</td>
<td>&lt; 2$</td>
<td>180</td>
<td>16</td>
<td>2 min</td>
<td>1 day–5 yr</td>
<td>4.6</td>
<td>1274</td>
<td>1</td>
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<tr>
<td>4.9</td>
<td>19924</td>
<td>$75 &gt; \delta &gt; 0$</td>
<td>210</td>
<td>2</td>
<td>$\sim$ week</td>
<td>1 yr</td>
<td>5</td>
<td>75162</td>
<td>0</td>
<td>$&gt; 40$</td>
<td>[17]</td>
</tr>
<tr>
<td>4.9</td>
<td>0.07</td>
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<td>5</td>
<td>626</td>
<td>20 min</td>
<td>1 week–22 yr</td>
<td>0.05</td>
<td>8</td>
<td>7$^e$</td>
<td>0</td>
<td>[13]</td>
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<td>8.5</td>
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<td>3</td>
<td>599</td>
<td>20 min</td>
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<td>4</td>
<td>1$^f$</td>
<td>0</td>
<td>[13]</td>
</tr>
<tr>
<td>8.5</td>
<td>0.04</td>
<td>phase calibr.</td>
<td>$\ldots$</td>
<td>$\sim 308^g$</td>
<td>5 min</td>
<td>days-years</td>
<td>1</td>
<td>$\ldots$</td>
<td>0</td>
<td>$\ldots$</td>
<td>[21]</td>
</tr>
<tr>
<td>4.9</td>
<td>2.6</td>
<td>$</td>
<td>b</td>
<td>\approx 7$</td>
<td>15</td>
<td>16</td>
<td>50 s</td>
<td>1 d–2 yr</td>
<td>0.15</td>
<td>$\sim 200$</td>
<td>1</td>
</tr>
</tbody>
</table>
Archival surveys

- DRAO (GRB monitoring)
- NRAO 91-m telescope 7-beam receiver
- Fields of view around VLA phase calibrators
- Comparison of NVSS and FIRST
- Allen Telescope (ATATS/PiGSS) – see later
- Very low transient yields on all of the above (0-1 transients)

Ofek et al. (2011)
i) NASU transients

- 4 drift-scanning interferometers
- Match fringe period to scanning Dec and baseline to ensure celestial and stationary source
- 9 transients >1 Jy over 2 years
- 1.4 GHz
- $32^\circ<\delta<42^\circ$
- High and low $l$
- Possible AGN?

Matsumura et al. (2009)
ii) Molonglo archival survey

• 22-yr MOST survey at 843 MHz
• 5σ sensitivity <14 mJy/beam
• Covers 2776 deg² south of -30°
• Out of 30,000 sources, 53 highly variable, 15 transient
• Of the transients:
  – 2 XRBs
  – 3 probable scintillating AGN
  – 1 radio supernova (SN 1987A)
  – 1 possible flare star
  – 1 possible RSN/GRB afterglow
  – 7 unknown sources (6 with no optical counterpart)

Bannister et al. (2011)
iii) The Bower transients

- VLA imaging observations of a calibration field
- 944 epochs over 22 years
- 10 transients detected (FDR algorithm expects 1)
- 8 single epoch, 2 in 2-month bins
- Only 2 have host galaxies
- Areal density 1.5 deg$^{-2}$ above 0.37 mJy at any time
  - Order of magnitude greater than known classes of source

Bower et al. (2007)
Defines the expected log N-log S

- Most other surveys only set upper limits on transient rates

Bell et al. (2011)
Reanalysis: only 1 good detection

- Reanalysis by Frail et al. (2011)
  - 5 transients are artefacts
  - 1 not detected
  - 4 have reduced SNR
- Significantly reduced probability of being real

Frail et al. (2011)
So what might we expect?

- We can estimate the rates of known physical phenomena
  - Tidal disruption events
  - Orphan GRBs
  - Mergers
  - Supernovae

- Anything with substantially different rates may be a new source class

- Might the GHz and MHz populations be different?
  - LOFAR
Radio transient survey projects

- V-FASTR
- The LOFAR Transients Key Science Project
- Allen Telescope Array
- ThunderKAT
- ASKAP-VAST
- ASKAP-CRAFT

Credit: Terrace photographers
Allen Telescope Array

• Large N-Small D array
  – Fast moving
  – Low-cost
  – Large field of view (2.5° at 1.4 GHz)
• 42 x 6m dishes
• Compact configuration ($b_{\text{max}}=300\text{m}$)
• Broadband feed (0.5-11 GHz)
• Located at Hat Creek, CA
• Operated by RAL Berkeley and the SETI Institute
ATA surveys: slow transients

• ATA Twenty centimetre Survey (ATATS)
  – 1.4 GHz survey of 700 deg$^2$
  – Transient rate <6x10$^{-4}$ deg$^{-2}$
    (>350 mJy, minutes-days timescales)
• Pi Gigahertz Sky Survey (PiGSS)
  – 3.1 GHz survey
    • 10$^4$ deg$^2$ at b>30° twice
    • 11 deg$^2$ fields multiple times
  – No transients found
  – 20% of sources show variability

Bower et al. (2011)
ATA surveys: fast transients

• Fly’s Eye:
  – Point all 42 dishes in different directions
  – 450 h, 150 deg², 1.43 GHz
  – Trades off sensitivity for FoV
  – No new transient pulses detected (650 μs to 5s)
  – Transient rate < 2 sky⁻¹ hr⁻¹ (>44 Jy)

Siemion et al. (2011)
V-FASTR

- Commensal, blind search of all incoming VLBA data
- Searches for short (ms), dispersed radio bursts
- Uses flexibility of DiFX software correlator
- Dispersed antennas robust against RFI
- Automatic imaging capability and high-precision localization

Credit: NRAO/AUI and the SeaWiFS Project NASA/GSFC and ORBIMAGE

Wayth et al. (2011)
V-FASTR

- RFI excised from total power data on a per-antenna basis
- Incoherent de-dispersion across many trial DMs
- Transient detection with robust estimator
- Short segments of data saved around transient event
- Imaging using all ten antennas

Wayth et al. (2011)
Receiver-Operator Characteristic (ROC) curves

- Single-pulse transients must be searched in an automated fashion
- ROC curves characterise detector algorithm performance
- Shows all possible values of false-positive versus true-positive detections
- Set false detection threshold
  - achievable performance is on ROC line

Thompson et al. (2011)
Robust detectors

- Use decision boundaries in signal-strength space
  - Remove strongest/strongest and weakest signals
  - Improves detector performance
- Large $n_{\text{ant}}$ and receiver separation helps!
V-FASTR: summary

• 1-σ sensitivity is 0.3 Jy in 1ms; easily sufficient to detect the Lorimer burst

• No new detection to date

• Field of view: 0.27 square degrees

• On-sky time: 4400h to date, and ongoing

• All VLBA frequency bands (1.2-90 GHz)

• Key advances:
  – Fully commensal, no load on existing instrument
  – Ability to localize transients to mas-precision
  – Geographical extent provides good RFI mitigation
LOFAR

- A wide-field software telescope operating from 10-240 MHz
- Dipole antennas of two types
  - LBAs (10-90 MHz)
    - 48/96 per station
  - HBAs (110-240 MHz)
    - 48/96 4x4 tiles per station
- Hierarchically arranged in stations
- Sparse array
  - Dense core in Exloo
  - 40 Dutch stations
  - 8 international stations (France, Germany, Sweden, UK)

Image credit: www.lofar.org
LOFAR: a software telescope

Traditional radio astronomy: delays allow signals from different dishes to be combined to image in one direction.

In LOFAR, simple antennae will be sensitive to whole sky, and introducing different delays allows beam-forming in (multiple) different directions.
**LOFAR: key numbers**

<table>
<thead>
<tr>
<th></th>
<th>Frequency (MHz)</th>
<th>Collecting area (m²)</th>
<th>(T_{\text{rec}}) (K)</th>
<th>(T_{\text{sky}}) (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBA</td>
<td>10-90</td>
<td>75200</td>
<td>500</td>
<td>320000-1000</td>
</tr>
<tr>
<td>HBA</td>
<td>110-240</td>
<td>57000</td>
<td>140-180</td>
<td>630-80</td>
</tr>
</tbody>
</table>

- Up to 48 MHz of instantaneous bandwidth
- Up to 244 independent beams (= number of sub-bands)
- Declinations >-30°

Stappers et al. (2011)
LOFAR Key Science Projects

- Epoch of reionization
- Deep extragalactic surveys
- Transients
- Ultra-high energy cosmic rays
- Solar science and space weather
- Cosmic magnetism
The LOFAR Transients Key Science Project (TKP)

• “Exploring and understanding the explosive and dynamic universe by observing transient and variable radio sources”

• Census of particle acceleration in the local Universe

• Studying extreme physics

• Cosmic feedback processes

• Determining the range and origin of coherent phenomena

• Sensitive northern pulsar survey
Classes of transients

- Flare stars, brown dwarfs, active binaries
  - Coherent emission giving highly circularly-polarized bursts

- Planets
  - Jupiter’s magnetosphere and radiation belts
  - Planetary lightning
  - Extrasolar planets?

- Pulsars
  - Survey of new pulsars and fast transients
  - Pulsar timing, pulse profiles and spectra

- Jets
  - Synchrotron emission from CVs, XRBs, SNe, GRBs, AGN

- Serendipity

Osten & Bastian (2006)
Transient detection strategy

• Pointed observations
  – Includes tied-array beamforming
• Commensal observations ("piggybacking")
  – Interrogate all incoming LOFAR data for transients
• Radio sky monitor
  • Tile out a large fraction of the sky
    • All-sky
    • Zenith
    • Galactic Plane
Radio sky monitor

• To tile out the whole hemisphere requires:
  – ~100 pointings at 30 MHz
  – ~1600 pointings at 120 MHz
  – Several minutes per day, giving ~mJy sensitivity

• Zenith monitoring maximizes sensitivity and beam stability
  – Needs ~20/30 pointings at 30/120 MHz
  – Observing each field for ~1h gives sub-mJy sensitivity

• Galactic Plane scans:
  – XRBs, neutron stars concentrated towards the Plane
  – Dispersed, but rich hunting ground for transients
  – 120 MHz only
Transient detection strategy

- Standard imaging pipeline delivers image cubes on a range of timescales
- Python source finding (FDR algorithm)
- MonetDB database generates light curves
- Classification based on LCs and source properties
- VOEvent notification

Swinbank (2011)
Follow-up

• Rapid, accurate localization and follow-up is critical

• Multi-messenger working group has proposals/agreements sampling full SED
  – Gamma-rays: Fermi, MAGIC, HESS
  – X-rays: RXTE, XMM-Newton
  – Optical: WHT, Liverpool Telescope
  – Infrared: PAIRITEL
  – Radio: EVLA, VLBA (no e-VLBI yet!)

• Short-timescale transients necessarily compact
  – VLBI provides only hope of resolved imaging
MeerKAT

- South African SKA pathfinder
- Located in the Karoo region
- KAT-7 now being commissioned
- MeerKAT to follow (complete by 2018)
- Eventually 64 x 13.5m dishes, Gregorian offset feeds
MeerKAT specifications

- Deployment in 3 phases
- Low-frequency (1 GHz) and high frequency (8-14.5 GHz) bands
- Large instantaneous bandwidths for sensitivity

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2016</th>
<th>2018</th>
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</thead>
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<tr>
<td><strong>Precursor (KAT-7)</strong></td>
<td><strong>MeerKAT Phase 1</strong></td>
<td><strong>MeerKAT Phase 2 &amp; 3</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Number of dishes</strong></td>
<td>7</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td><strong>Receiver bands (GHz)</strong></td>
<td>0.9 - 1.6</td>
<td>1.00 - 1.75</td>
<td>0.58 - 1.015</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1.00 - 1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8 - 14.5</td>
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<td><strong>Max processed BW (GHz)</strong></td>
<td>0.256</td>
<td>0.75</td>
<td>2 (goal 4)</td>
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<td><strong>Max baseline (km)</strong></td>
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<td>8</td>
<td>20</td>
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<tr>
<td><strong>Min baseline (m)</strong></td>
<td>20</td>
<td>29</td>
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</table>
MeerKAT transients projects

- Fast transients:
  - TRAPUM: TRA/nsients and PUlsars with MeerKAT (Stappers, Kramer; 3080 hr)

- Slow transients:
  - ThunderKAT: The HUNt for Dynamic and Explosive Radio Transients with MeerKAT (Woudt, Fender; 3000 hr)
TRAPUM

- Targetted pulsar surveys (3000 hr)
  - Globular clusters (MSP-rich)
  - SNRs, PWNe (young, energetic pulsars)
  - Galactic Plane (expect 1000 new pulsars and 100 MSPs)
  - Galactic Centre (expect 100s of pulsars; high $\nu$ required)
  - Extragalactic searches (normal pulsars in 15 nearby galaxies)

- Fast transients
  - Commensal searching of all MeerKAT data

- Small dishes implies large FoV
  - Fast surveys
  - Repeated sweeps of the Plane for higher sensitivity
  - More sensitivity to intermittent phenomena (RRATs/eccentric binaries)
ThunderKAT

• All transient synchrotron sources in the Southern Sky

• 100 min/day for 5 years, plus commensal searching
  – 12 deg$^2$ Galactic Bulge survey for faint XRBs ($5\sigma=10\mu$Jy)
  – Surveys of 3 nearby Galaxies (~4 Mpc) (1/day for 150d)
  – Target-of-opportunity observations for outbursting sources
  – Dedicated monitoring of known sources

• LOFAR transients detection pipeline ported for use in ThunderKAT
Commensal observing: the spigot

The ThunderKAT spigot

Correlator

User

CPU cluster running standard imaging pipeline

Data rate for full f.o.v. and full b/w ~700 Mb/sec

≤1 sec cycles

Collaborators / outside world (via e.g. VOEventNet)

Source finding

Imaging (cluster)

Report if interesting

Analysis
ASKAP

- The Australian SKA Pathfinder
- At the Murchison Radio Observatory, in Western Australia
- Phased-array feed technology provides huge field of view
- Commissioning of ASKAP-BETA underway
ASKAP

- 36 x 12m antennas, equipped with PAFs
- 700 – 1800 MHz (instantaneous bandwidth 300 MHz)
- 30 square degree field of view
- Maximum baseline 6km
- Sensitivity 30 μJy/beam in 1 hour
- Resolution 7.5 arcseconds
ASKAP transients projects

- Fast transients:
  - CRAFT: The *Commensal Real-time ASKAP Fast Transients survey* (Macquart, Hall)

- Slow transients:
  - VAST: An ASKAP survey for *Variables and Slow Transients* (Murphy, Chatterjee)
CRAFT

• Purely commensal survey

• Aims to detect <5s transients
  – Giant pulses
  – RRATs
  – Magnetars
  – Lorimer-type bursts

• Large field of view gives high survey figure of merit

• Huge data volumes remain a challenge; trade-off sensitivity, field-of-view, time and frequency resolution

Lundgren et al. (1995)
VAST

• 3 surveys:
  – VAST-wide: $10,000 \text{ deg}^2$ (400 pointings) for 40s each, every day for 2y
  – VAST-deep: VAST-wide: $10,000 \text{ deg}^2$ (400 pointings) for 1h
  – VAST-GP: 750 deg$^2$ (30 pointings) in the Plane, plus the LMC and SMC for 16 min each, weekly, for 1yr

• Commensal observations

• Target sources:
  – Orphan GRBs
  – Unbiased SNe census
  – Propagation effects: IDVs and ESEs
  – Accreting sources (AGN, XRBs, CVs)
  – Flare stars
  – Magnetar outbursts
And finally...the SKA

- 1 million square metres of collecting area
- 3 technologies:
  - Dishes
  - Dense aperture array
  - Sparse aperture array
- To be located in Australia or South Africa
- Construction to begin 2016
- Phase 1 complete by 2020
- Phase 2 complete by 2024

Image credit: SKA website
SKA science

• 5 key science projects:
  • Investigating galaxy evolution, dark energy and cosmology
  • Strong-field tests of gravity using pulsars and black holes
  • The cradle of life; searching for planets
  • Probing the dark ages; the first stars and black holes
  • Investigating the origin and evolution of cosmic magnetism
Instrumental comparison

• Pushing to wider fields and more sensitive instruments
• The SKA is the ultimate goal

Fender (2012)
Prepare for the flood

- How many transients might we expect? (Fender & Bell (2011))

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Snapshot rate (deg$^{-2}$)</th>
<th>Rate per year (deg$^{-2}$ yr$^{-1}$)</th>
<th>Yield (yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKA Phase 2 (Mid)</td>
<td>9.7×10$^5$</td>
<td>5.0×10$^7$</td>
<td>5.0×10$^7$</td>
</tr>
<tr>
<td>SKA Phase 2 (Low)</td>
<td>6.7×10$^3$</td>
<td>3.5×10$^5$</td>
<td>7.0×10$^7$</td>
</tr>
<tr>
<td>MeerKAT</td>
<td>6.9×10$^2$</td>
<td>3.6×10$^4$</td>
<td>3.6×10$^4$</td>
</tr>
<tr>
<td>WSRT + APERTIF</td>
<td>5.0×10$^1$</td>
<td>2.6×10$^3$</td>
<td>2.0×10$^4$</td>
</tr>
<tr>
<td>ASKAP</td>
<td>5.0×10$^1$</td>
<td>2.6×10$^3$</td>
<td>7.8×10$^4$</td>
</tr>
<tr>
<td>LOFAR (HBA) Full</td>
<td>9.8</td>
<td>5.0×10$^2$</td>
<td>1.2×10$^4$</td>
</tr>
<tr>
<td>LOFAR (HBA) Full ($\alpha = -0.7$)</td>
<td>1.0×10$^2$</td>
<td>5.3×10$^3$</td>
<td>1.3×10$^5$</td>
</tr>
<tr>
<td>LOFAR (HBA) Full ($\alpha = -2$)</td>
<td>8.9×10$^3$</td>
<td>4.6×10$^5$</td>
<td>1.2×10$^7$</td>
</tr>
<tr>
<td>SKA Phase 2 (Low) ($\alpha = -0.7$)</td>
<td>5.5×10$^4$</td>
<td>2.8×10$^6$</td>
<td>5.7×10$^8$</td>
</tr>
<tr>
<td>SKA Phase 2 (Low) ($\alpha = -2$)</td>
<td>2.4×10$^6$</td>
<td>1.2×10$^8$</td>
<td>2.5×10$^{10}$</td>
</tr>
</tbody>
</table>

- Uses the Bower et al. (2007) log N-log S
- Scale down by a factor ~10
Some follow-up considerations

- Multi-wavelength follow-up crucial to identifying counterparts
- May be fading by the time (low-frequency) transients detected
- Provides information on physical nature, distance
- High-resolution imaging (VLBI) can provide morphology, proper motion
- Must be available in real time (cf archival studies)
- Pick and choose follow-up candidates (automated classifiers)
- This is where the real physics can be done!
Conclusions

• The field of radio transients is broad, and rapidly-expanding

• Interesting and fundamental physics to be gleaned from transient research

• Primary distinction into fast and slow transients is both physics- and technique-driven

• Enhanced technical capabilities are opening up new regions of parameter space

• With LOFAR, ASKAP, MeerKAT, and, eventually, SKA, we are poised to make major advances in the field of radio transients