CRAFT
reborn
Keith Bannister
Jean-Pierre Macquart
How to make ASKAP the Kim Kardashian of telescopes

Crucial [forthcoming] new results
FRBs
- Source counts (accurate fluences)
- Origin (position)
- Evolution (position)

Other known unknowns
[Gravitational Waves (position)]

The CRAFT roadmap - Keith’s talk
What is an FRB?
What is an FRB?

slope of time-frequency sweep -
direct measure of plasma column:
DM = 944 pc cm⁻³

Burst cannot have come from our Galaxy

\[ \Delta t \propto \nu^{-2} \int n_e(z) dz \]

FRB 110220 as reported by Thornton et al. 2013
Extraordinary FRB properties

**Bright** Fluences up to ~10 Jy ms
- >21 events at Parkes (Lorimer et al. 2007; Thornton et al. 2013; Champion et al. 2016)
- 1 at Arecibo several times (Spitler et al. 2014)
- 1 at Green Bank

**Distant** Extremely high dispersion measures for objects above the Galactic plane (375-1500 pc/cm$^3$)
- Not obviously associated with nearby galaxies

**Common** Inferred event rate ~ 2-5 x10$^3$ sky$^{-1}$ day$^{-1}$

**Scattered** Many exhibit temporal smearing of order several milliseconds (much larger than expected due to scattering in the Milky Way)
Fast transients as cosmological probes

We can

- directly detect every single baryon along the line of sight!
- use the DM-redshift relation as a cosmic ruler
- measure turbulence on sub $10^8$ m scales at distances of $\sim 1$ Gpc
- probe IGM physics: primordial magnetic field & energy deposition

see both Macquart et al., Fender et al. in the SKA Science book
Where are the missing baryons?

FRB dispersion can directly answer this question

- Missing baryons location an important element of galaxy halo accretion and feedback
- Most dark matter found in galaxy halos, but most baryonic matter outside this scale (>100 kpc)
- How do we determine its distribution?

\[ \gamma \]

\[ P(DM) \]

McQuinn 2014
Dark Energy - FRBs as cosmic rulers

FRBs measure the dark energy equation of state:

\[ w = \frac{p}{\rho} \]

How does \( w \) evolve with time?

\[ \text{DM} = \int n_e dl \rightarrow \int n_e \left| \frac{c dt}{dz} \right| dz \]

- The term \( c \frac{dt}{dz} \) is a ruler that measures the curvature of the Universe
- Measure the DM as a function of redshift

\[
\left< \text{DM}_{\text{IGM}}(z) \right> = \Omega_b \frac{3H_0 c}{8\pi G m_p} \int_0^z \left[ (1 + z') f_{\text{IGM}} \left( \frac{3}{4} X_{e,H}(z') + \frac{1}{8} X_{e,He}(z') \right) \left[ \Omega_M (1 + z')^3 + \Omega_{DE} (1 + z')^3[1+w(z')] \right]^{1/2} \right] dz'
\]

- Universe curvature terms
- \( H \) and \( He \) ionization fractions
- Baryonic density
- Curvature due to matter
- Curvature due to dark energy
- \( w(z) \): equation of state
Host ID difficult without good localisation

(Keane et al. 2016)

ID’ed FRB150418 with a z=0.492 galaxy

BUT…
**BUT…**

The source is just an Intra-day variable source

At the \(\sim 100 \, \mu \text{Jy}\) level of the counterpart there are:

- \(\sim 300\) sources/sq.deg. of which \(\sim 10\%\) compact and of these expect \(\sim 20\%\) to scintillate

Expect \(\sim 6\) IDVs/sq.deg.

- Consistent with STRIPE-82 survey findings (Mooley et al. 2016)

Of sources varying on timescales < \(1\) week, 14 (out of 3652) exceed 50\% modulations (mainly <1 mJy sources). Expect 1.2 sources/sq.deg. with a modulation index exceeding 50\% at the 100 \(\mu\text{Jy}\) level.

PDF of the intensity variations vs. expected ISS distribution
Location, location, location…

Top Level Requirement: localisation

Cosmic web
- 1000 FRBs per redshift bin, so need to accumulate at least 10000 FRBs in total

Cosmic rulers
- At least 1000, but precision increased with more events and only a fraction will be at $z>2$ (but note recent Parkes detections)

ASKAP will provide accurate fluences (unlike Parkes multibeam)
- 0.1-1.0” localisation needed: to uniquely ID an event with its host galaxy at $z\sim1$
  - At 1GHz this requires baselines 6 km for a 20$\sigma$ event
  - LSST will have redshifts of all galaxies out to $z\sim1.5$
Are FRBs Cosmological?

Spitler et al. (2016) report a repeating FRB

- Spectrum is all over the place
- Argue that it favours magnetar origin - but magnetars are not bright enough to be visible at cosmological distances
- Are there two populations of FRB?
FRB properties

Determination of origin from source counts

If the events are not cosmological but extragalactic, their differential source counts scale as $S_\nu^{-5/2}$:

- With a sensitivity to events down to flux density $S_\nu$ we detect events of luminosity $L$ out to distance $D_{\text{max}} = \sqrt{\frac{L}{4\pi S_\nu}}$

The number of events we detect per $S_\nu$ bin is

$$\frac{dR}{dS_\nu} = \frac{4\pi}{3} \rho \frac{d}{dS_\nu} \left[D_{\text{max}}^3\right] \propto S_\nu^{-5/2}$$

If source counts deviate from $S_\nu^{-5/2}$ either
1. non-Euclidean geometry matters (i.e. at high $z$) or
2. they must be distributed inhomogeneously with distance (i.e. at high $z$)
Evidence of FRB Cosmological Origin

Observations show there is a 4.7:1 difference in the detection rate between high (>30 deg) and low latitude (Petroff et al. 2014)

<table>
<thead>
<tr>
<th>latitude</th>
<th>Hours on sky</th>
<th>Events</th>
<th>Rate (h/event)</th>
</tr>
</thead>
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<td>b</td>
<td>&lt;15$</td>
<td>1927.7</td>
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<tr>
<td>30&lt;$</td>
<td>b</td>
<td>&lt;45$</td>
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<tr>
<td>$</td>
<td>b</td>
<td>&gt;45$</td>
<td>1030.0</td>
</tr>
</tbody>
</table>

Interstellar scintillation explains this dependence: also implies source counts are non-Euclidean ($dN/dS_v \sim S_v^{-3.5}$) (Macquart & Johnston 2015)
ASKAP will settle this almost immediately

...even without localisation capabilities

This is because we can get ~1-4 events/day (see Shivani’s and Keith’s talks)

Accumulate enough event statistics to determine the source counts

Of the ~23 events detected, only ~5 exceed the 2 Jy ms completeness limit

Even the rate at which we find events yields source counts info (relative to Parkes detection rate)
Key CRAFT doers

Keith Bannister (co PI; scientist/engineer)
Ryan Shannon (hardcore pulsar astronomer)
Wayne Arcus (new PhD student)
Jean-Pierre Macquart (co PI; theorist)
Ewan Barr (GPU)
+ a cast of engineers and ASKAP commissioning staff