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International Centre for Radio Astronomy Research

Transients with SKA-survey

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Achieve International Excellence

Change Requests

- Preface: Hard to exploit the entire FoV at full sensitivity for fast transients
  - can incoherently sum antenna powers but lose sqrt(96) of sensitivity

- Fast Imaging
  - 10s ideal for slow transients
  - 1ms for fast transients - a dream?
- Full Commensality
- Transient Buffers
  - ~30s at this frequency fine for high DMs
- Ability to Issue and Respond to Triggers

There is no substitute for Field of View

- For most survey science the appropriate metric of telescope performance is the survey speed

$$\text{Survey Speed} \propto \Omega \times \left(\frac{A_{\rm eff}}{T_{\rm sys}}\right)^2$$

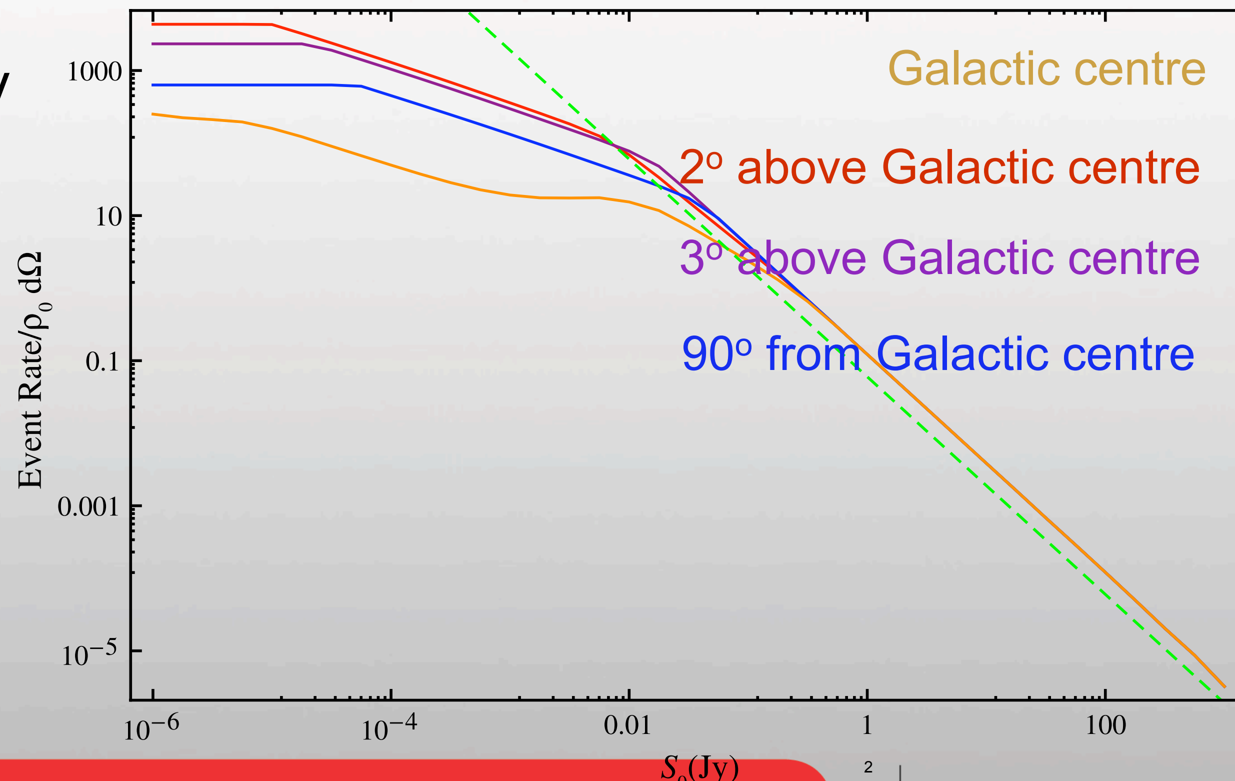
- But for transients a better metric is the event detection rate

$$\mathcal{R} \propto \Omega S_0^{-3/2+\delta}$$

where δ=0 for a homogeneously distributed population with no evolution

δ>0 if interstellar or intergalactic scattering alter the pulse shape (fast transients only)

-0.3 < δ < 0.5 for evolution in a cosmological population



Why SKA-Survey for Transients?

- This rate-based metric underscores the importance of field of view vs sensitivity
- Compare SKA-survey and SKA-mid

Survey metric	$R \propto S_0^{-2}\ \Omega$	$R \propto S_0^{-3/2}\ \Omega$	$R \propto S_0^{-1}\ \Omega$
$R_{\text{SKA-survey}}/R_{\text{SKA-mid}}$	2.1	4.3	8.8
$R_{\text{SKA-survey}}/R_{\text{SKA1-low}}$	0.10	0.16	0.26

This table uses the numbers in Table 1 of the Baseline Design document, and ignores the additional sky contribution to T_{sys} for SKA1-low, and it assumes SKA1-low forms only a single station beam on the sky.

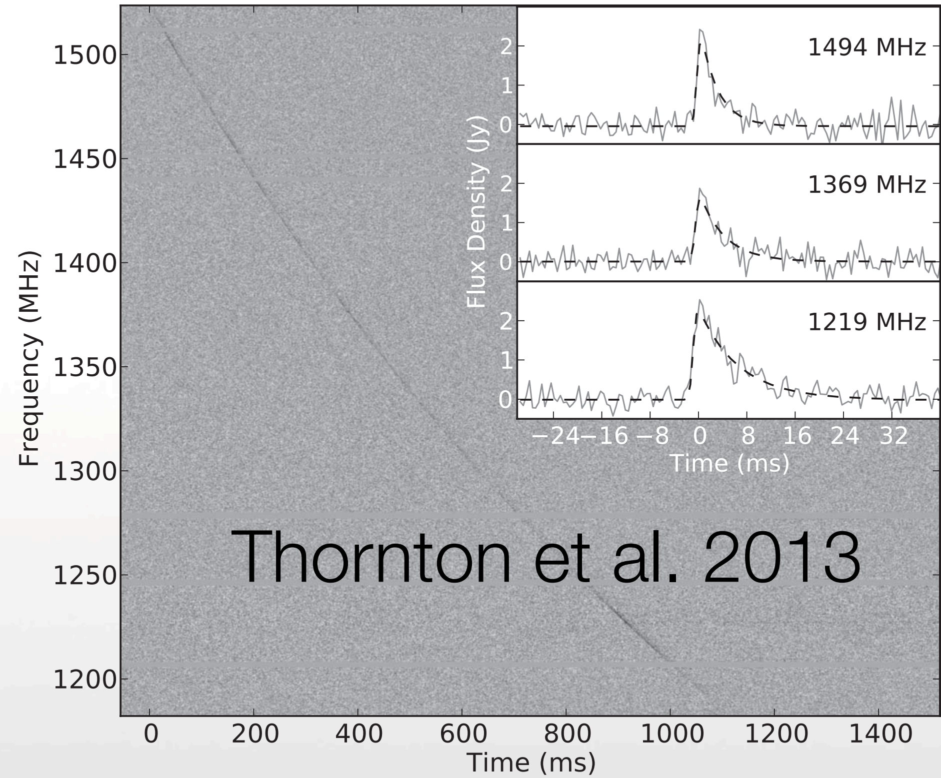
Once temporal smearing is important (at low frequency) the S/N of an impulsive event degrades as ν^{-2}. There is a factor **34** degradation between 1160 and 200 MHz if scattering evident at 1.2 GHz.

FRBs and other Fast Transients may not be detectable with SKA1-low

– Both the Lorimer burst and the brightest of the Thornton FRBs exhibit ~ 1 ms of temporal smearing at ~1.3 GHz

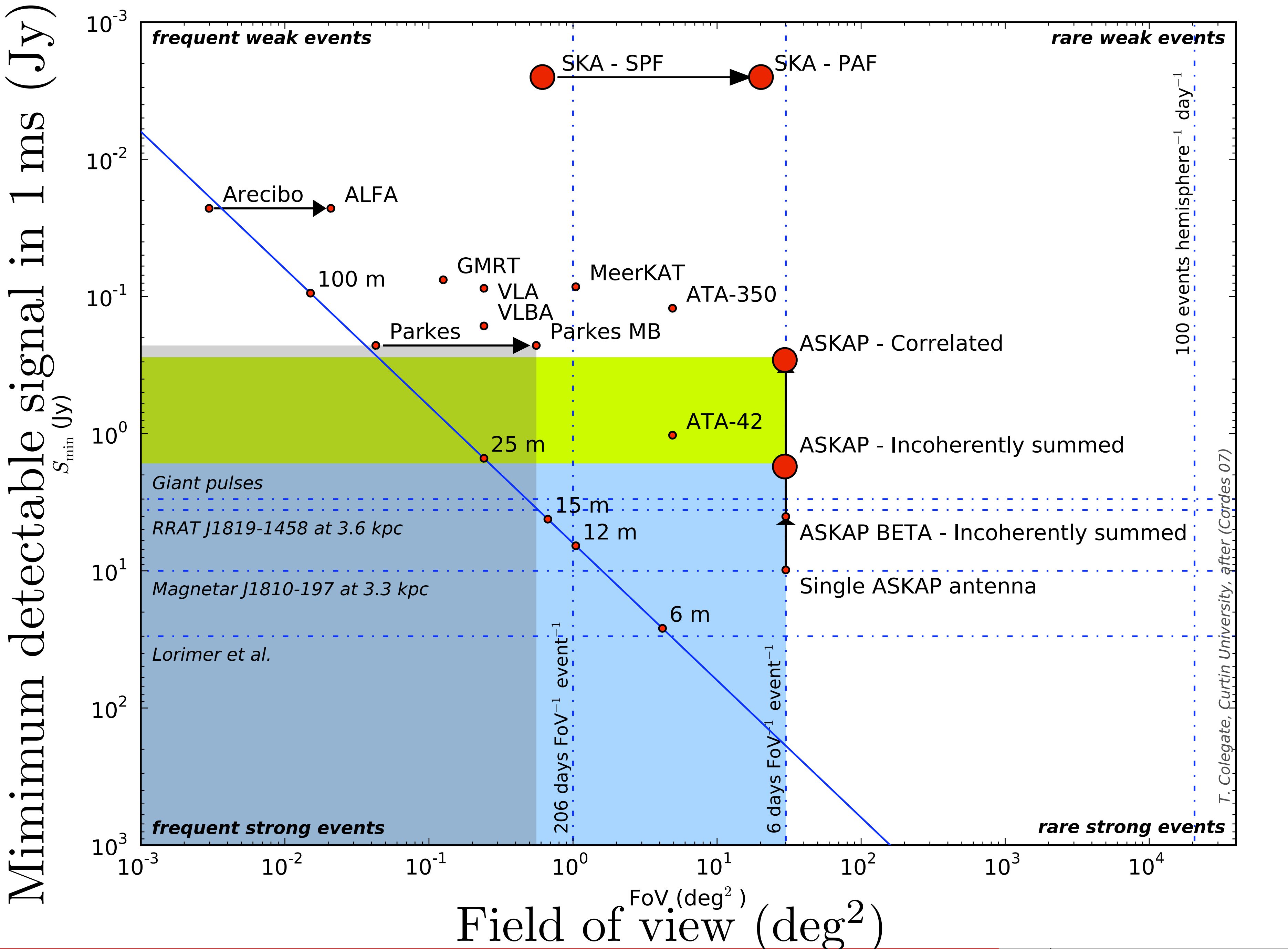
– Smearing scales as $\nu^{-4\pm0.4}$ so would last ~2 s at 200 MHz and S/N would decrease a factor 42

– FRB science may only be feasible with SKA-survey
  - SKA-mid is too slow (poor FoV)
  - SKA1-low: scattering effects deleterious



Pulse width increases as $\nu^{-4.0}$: scattering in a turbulent plasma but effect too large to be our Galaxy's ISM

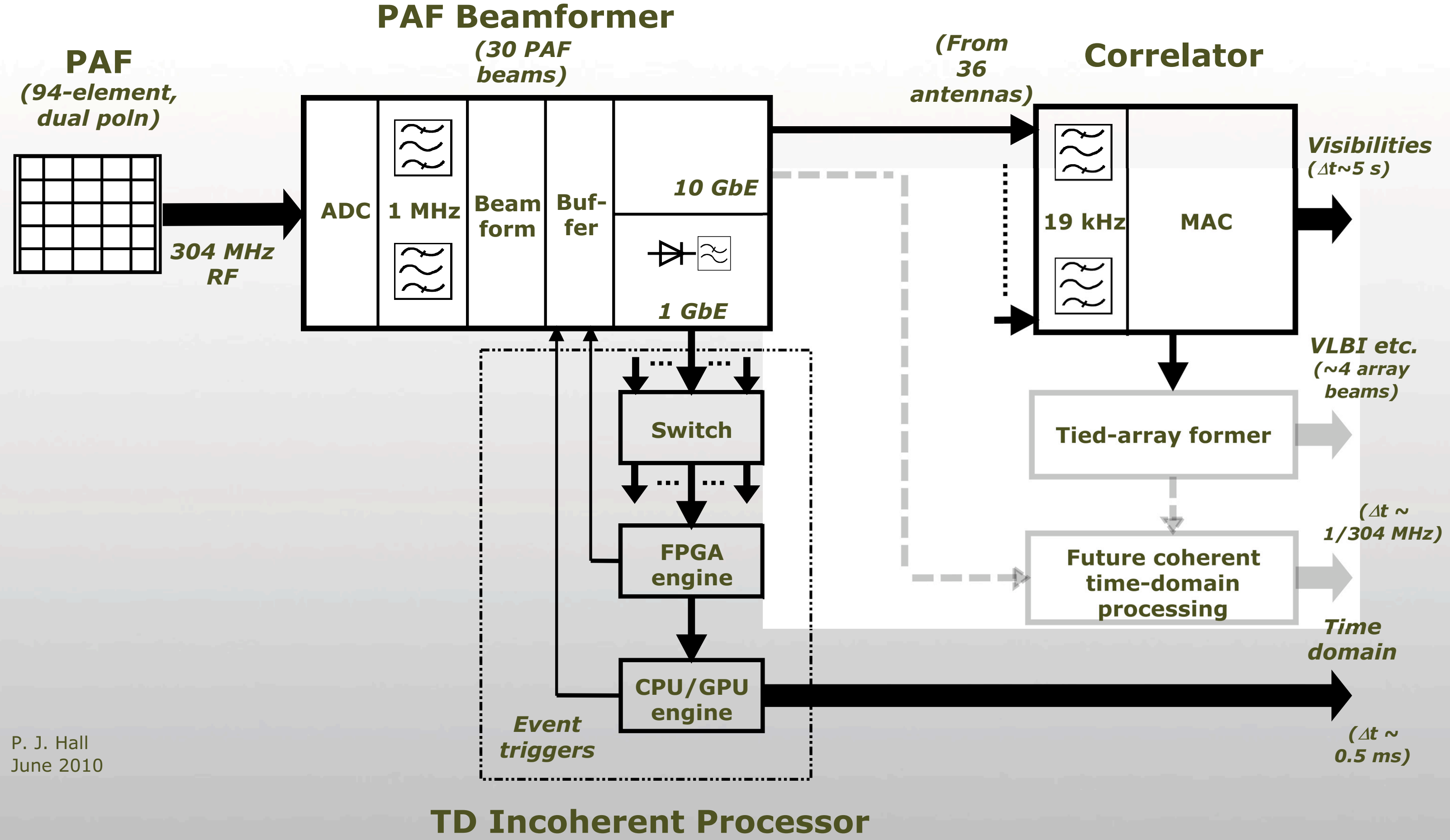
What does a PAF buy you?



Possible Fast Transients Implementation

Cannot tile entire FoV with tied-array beams (3x10^8 beams required) so process total powers of each beam

- send alerts back to buffers once an event is detected
- unless a ~1ms imaging mode is implemented



Verification, Localisation & Followup

The Importance of a Transients Buffer

- 1" localisation needed: to uniquely ID an event with its host galaxy at z~1
- 0.9" resolution of SKA-survey ideal

- Transient buffers are *essential* for this telescope due to necessity of performing much fast transients searching with total powers
  - Such capability naturally provided in the beamformers, where some buffering is required

Imaging Science
benefiting from wide fields of view

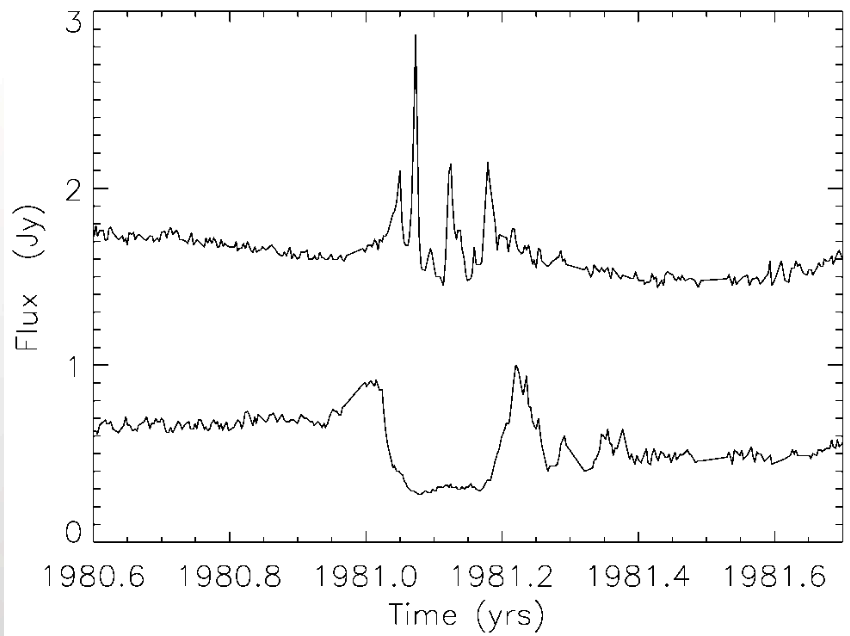
- Grav Wave counterparts
  - SKA-survey FoV good match to the 10-100 sq. deg. uncertainty in grav wave events
  - emission possible if burst occurs in a dense environment
    - electrons in shock-heated plasma fireball emit synchrotron radiation which peaks at GHz frequencies (Nakar & Piran 2011)
  - At 300 Mpc a merger would be ~1mJy at 1GHz and detectable by Advanced LIGO
  - ~6 detectable NS-NS mergers detectable at any time
- Tidal Disruption Events
  - when a star is tidally shredded in the gravitational field of a black hole
  - sudden increase in BH accretion rate
  - often accompanied by relativistic jets, so picked up in radio

Imaging Science
benefiting from wide fields of view

- GRB orphan afterglows
  - detect the rare but (important) nearby (500Mpc) events
  - how many whose jet was initially pointed away from us?
    - beaming fraction of GRBs
    - open up many more objects for study: insight into jet structure and lack of jet breaks for some objects observed by *Swift*
- Unbiased census of local SNe
  - needed to get accurate star formation rate
    - some SNe are obscured in optical and IR
- Accreting Neutron Stars and Black Holes (XRBs)
- Classical Novae
  - white dwarf accreting matter from a companion
  - radio emission lasts years, can estimate total ejecta mass
- Flare Stars, Pre-Main-sequence stars & Rotation-driven stellar activity
  - argued that radio is best way to estimate stellar magnetic field (Berger 2006)

Imaging Science
benefiting from wide fields of view

- Quasar Intra-Day Variability
  - High brightness temperature quasar emission
  - Intermittency of Interstellar Turbulence
  - >50% of all flat/inverted spectrum sources exhibit IDV during the course of a year
  - >1% of all radio source
- Extreme Scattering Events
  - 1 event/source/(70 years)
  - inferred to be caused by clouds in ISM
  - (i.e. $>10^4$ clouds per pc^3)
  - optics require high plasma density
  - objects $>10^3$ overpressured wrt ionized ISM
  - origin unclear
  - rapid detection and VLBI followup required



An ESE detected at 2 and 8 GHz

Survey Implementation

Likely to be very similar to the ASKAP fast & slow transients surveys, **CRAFT** & **VAST**

– Both surveys are fully commensal

- CRAFT
  - Non-imaging
  - Buffer+dedicated hardware attached to a data spigot
  - 1ms - 5 s resolution (backend hardware limited)
  - coarse spectral channels (but finer resolution req'd for high DM events)
  - fully piggybacks off current observations

- VAST
  - Imaging
  - Utilises standard image processing pipeline
  - >5 s resolution
  - coarse spectral channels
  - prefer a variety of survey strategies
    - Deep (10^4 sq.deg. to 0.05mJy)
    - Wide (10^4 sq.deg./day to 0.5mJy)
    - Galactic (750 sq.deg. to 0.1mJy)

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SKA1-low super widefield

Sum all the dipoles incoherently?

See 1/7th of the entire sky!

$$S_{\mathrm{min}} = 2k_B \frac{T_{\mathrm{sys}}}{A_{\mathrm{eff}}\sqrt{n_{\mathrm{pol}}\,\Delta\nu\,\tau}}$$

$$A_{\mathrm{eff}}/T_{\mathrm{sys}} = 1000\,\mathrm{m\,K^{-1}},\ \tau = 5\,\mathrm{ms},\ \Delta\nu = 300\times10^{6}\,\mathrm{Hz}$$

$$\Rightarrow S_{\mathrm{min}} = 1.6\,\mathrm{mJy}$$

Incoherently sum all 250000 antennas:

$$\Rightarrow S_{\mathrm{min}} = 0.8\,\mathrm{Jy}$$

Get logN-logS of transient population in a few days! Tells you how to configure survey to get best transient science

SKA1-low super widefield

350-675 MHz performance

$$A_{\rm eff}/T_{\rm sys} = 700\,{\rm m\,K^{-1}},\ \tau = 5\,{\rm ms},\ \Delta\nu = 300\times 10^{6}\,{\rm Hz}$$

$$\Rightarrow S_{\rm min} = 2.3\,{\rm mJy}$$

Incoherently sum all 250000 antennas:

$$\Rightarrow S_{\rm min} = 1.1\,{\rm Jy}$$

Get logN-logS of transient population in a few days! Tells you how to configure survey to get best transient science