The Transient Universe with The Square Kilometre Array

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On behalf of the SKA Transients Science Working Group
Extreme Astrophysics

- Collapsing stars, relativistic remnants
- Extremes of density, pressure, gravitational curvature
- Searchlights shining over cosmological distances
Two flavours of radio transients

Incoherent synchrotron emission
- Relatively slow variability
- Brightness temperature limited
- Associated with all explosive events

Find these (mostly) in images

Coherent emission
- Relatively fast variability
- High brightness temperature
- Often highly polarised
- Sometimes very steep spectra

Find these (mostly) in pulsar modes

Early branch in classification pipelines
A menagerie of synchrotron flares

Pietka, Fender & Keane (2015)
Variability timescales of synchrotron events (explosive/kinetic feedback)

\[ L_{\text{peak}} = 10^{30.96 \pm 1.49} \tau_{R}^{-4.94 \pm 0.11} \]

Pietka, Fender & Keane (2015)
Including coherent events, exploring parameter space

Pietka, Fender & Keane (2015)
SKA timeline

- 2013 SKA phase 1 baseline released
- 2013/14 Science and Engineering working groups review
- 2014 Costing comes in considerably over 650MEuro cost cap
- “Rebaselining” is now taking place
- Board decision on new design next month
- 2017-2021 MeerKAT and ASKAP 5-year surveys
- 2021-... SKA phase 1 operations
The SKA Transients Science Working Group

- **Goal:** optimise SKA for transients and variables
- **Chairs:** Fender and Macquart
- **Core membership:** Trott, Stappers, Law, Deller, Chatterjee, Murphy, Corbel, Hessels, Paragi, Karastergiou, Woudt, Rupen
- **Advisors:** Keane, Hallinan, Buitink, Swinbank, Armstrong, van Leeuwen, Miller-Jones, Lazio, Siemion, Kuulkers, Perez-Torres, Morrisson, Bignall, Rushton, Burlon, Rossi, Stanway, Petroff, Anderson, Ghirlanda, Donnarumma, Agudo, Grainge, Bell, Wilkinson, Chandra, Wijers, Croft, Buitink, Wu, Zhi

Open to requests to join from community
The sensitivity of SKA1 will be fantastic for transients: 
**Survey speed figure of merit ~ x50 JVLA and x100 LOFAR**
It will be an order of magnitude better still if optimised as follows:
Top two recommendations from the Transients SWG for the SKA1 design:

- **Commensal Transient Searches**
- **Rapid (robotic) Response to Triggers**
Predicted rates for SKA (assuming 100% efficient commensal)

Tidal Distruption Events
GHz (MID & SURVEY): ~1 / week

Fast Radio Bursts
GHz (MID & SURVEY: ~ 1 / day)
MHz (LOW): lots?? none??

GHz rates for some classes of object ~well estimated, and will be very large for SKA

Lorimer et al. (2007), Thornton et al. (2013), van Velzen et al. (2014)
See recent arXiv papers by Donnarumma et al. and Macquart et al.
So what's happening now?

- SKA-like wide-field transient searches at low frequencies with LOFAR and MWA
- Development of commensal transient modes for MeerKAT
- Implementation of robotic radio telescope
- Development of basic classification techniques
First wide-field searches for transients using SKA pathfinders

- First **low-frequency** SKA-style wide-field (pseudo-)automatic transient searches have been carried out by LOFAR and MWA

Bell et al. (2014), Stewart et al. (in prep), Broderick et al. (in prep), Fender et al. (in prep)
Unidentified LOFAR Transient at the north celestial pole

~20 Jy ~10 minute transient at 60 MHz | 100s per day with SKA-Low?
Discovered a year 'late' | Doesn't repeat | No optical counterpart
From radio alone could be anything from flare star to scattered FRB
→ highlights the need for early discovery and rapid response
(Stewart, Fender et al. *in prep*)
SS433 with LOFAR (Broderick, Fender et al. *submitted*)

Slowly-varying synchrotron jet source
Commensal Transient Searches

- Single highest priority for Transients
- Increases rate of events by at least one order of magnitude
- Cost to implement much less than scale of re-/de-scopes being currently considered (30%)
- Not implementing is more damaging than scrapping an entire SKA1 component
- Politics are surmountable
MeerKAT commensal system design

REAL TIME SYSTEM

POST-OBSERVATION
(slower, deeper)

All daytime observations will have simultaneous optical images from MeerLICHT

Armstrong et al. (in prep)
In an ideal world...

Telescope monitors sky...
Software finds new transient source!

Interesting?
Appropriate follow-up?

radio
X-ray

Analyse / re-evaluate / feedback (IA)
ALARRM: the world's first robotic radio telescope

Timescale from Swift detection of first photon to observing command sent to follow-up telescope: 30s

AMI on-target typically 4min

Staley, Titterington, RF et al. (2013)  Anderson et al. (2014)
ALARRM

GRB 130427A

Rise to radio peak detected at 0.6 days: probable early time reverse shock

Nearly a day ahead of JVLA

~5 other possible early-time detections

Anderson et al. (2014)
Robotically following every *Swift* trigger delivers surprises and discoveries (as well as GRBs..)

Gamma-ray flare from DG Cvn – nearby (8pc) extremely young (30 My) dM43e+dM4e binary. Very prompt radio transient.

**First time** a radio flare has been associated with such a superflare

A robotic SKA transient mode would deliver breakthrough science
ALARRM: lots of surprises from a bit of flexibility

Plus now a large number of GRB afterglows (including at least two early-time reverse shock signatures), a slowly evolving nova, some X-ray binaries...
Towards preliminary classification from radio light curves

Functional fits to rise rates of events from PFK15 sample (highly biased sample)

Convolved with estimated sky rates

Pietka et al. (in prep)
MeerLICHT

Additional classification from optical photometry

Radio Flux / mJy

Optical R Band Magnitude

Optical Flux / mJy

(Stewart, Munoz-Darias & Fender in prep)
The SKA will find many radio variables and transients, which will lead us to the sites of the most extreme astrophysics in the universe.

Such events lead to new physics, a better understanding of feedback over cosmic time, and can act as searchlights over cosmological distances.

The current design provides the collecting area and frequency coverage (at least by SKA$_2$) to revolutionise this area.
However, the scientific yield for transients and variables could be increased by an order of magnitude or more by including **commensal** and (robotic) **rapid-response** modes.

Many experiments (e.g. AMI-ALARRM, MeerKAT+MeerLICHT are showing that this can be done, and has scientific rewards).

If (when) this is done, the future is very bright for radio transients with the SKA.