Searching for Radio Transients with ASKAP (and MWA)

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on behalf of Dave Kaplan & the VAST collaboration

Context

- As with optical astronomy, the decreasing cost of data gathering, analysis and storage has made more efficient radio survey instruments feasible
- Long-term goal is the Square Kilometer Array (SKA), expected to begin construction in 2016 and be complete in 2023

The road to SKA

- Science priorities call for a square kilometer of collecting area covering a frequency range of 70 MHz to 10 GHz
- No single antenna type can cover this range
- Current design has nested arrays of up to three antenna types; dishes, and mid- and low-frequency aperture arrays
- http://www.skatelescope.org

Technology demonstrators

- SKA requirements have (partially) driven development of several new instruments

Instrument	Frequency	Field of view	Website
LOFAR	30–80 & 120–240 MHz	~400 deg^2	www.lofar.org
MWA	80–300 MHz	All sky	www.mwatelescope.org
ASKAP	700 MHz–1.8 GHz	~30 deg^2	www.atnf.csiro.au/projects/askap/
MEERKAT	600 MHz–1.7 GHz, 8–15 GHz	6–0.5 deg^2	www.ska.ac.za/meerkat/

Transients with ASKAP & MWA

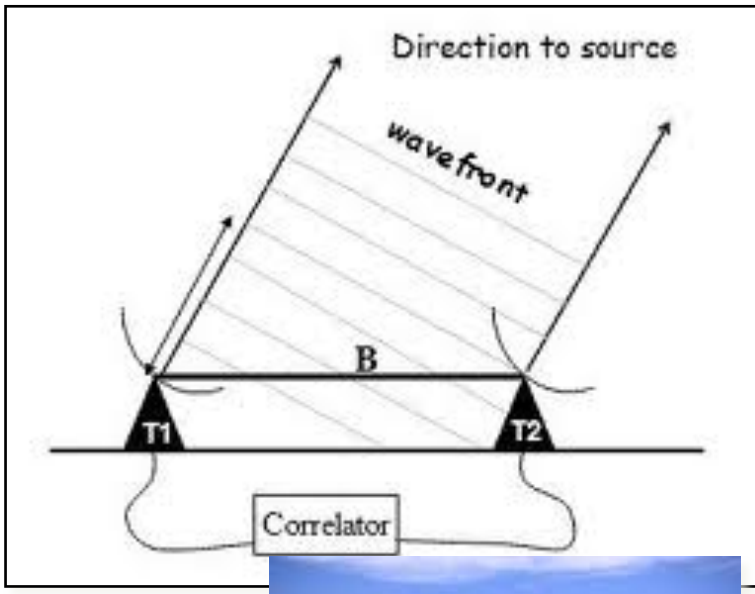
- Time domain astronomy offers a rich discovery space. e.g.
  - All-sky surveys at high energies; ROSAT, CGRO, Fermi, etc.
  - Synoptic optical surveys - LSST etc. e.g.,
  - Multi-messenger surveys (GW, neutrinos)
- ASKAP = **Australian Square Kilometer Array Pathfinder**
- MWA = **Murchison Widefield Array**
- Enable synoptic radio surveys with high sensitivities. Our goals:
  - To explore the transient sky at radio wavelengths.
  - To find new variable and transient phenomena, from the local to the cosmological.
  - To boldly go where no radio survey has gone before.

Advantages for GW

- Real-time, sensitive radio surveys
- Large sky coverage, large field of view, good localization
- Extremely well-suited for radio followup of GW triggers

Interferometers

- Add together multiple small antennae
- $\theta=\lambda/B$, where B=distance between antennae (100 m to 1000 km)
- Resolution of 1" (for VLA) to 0.0001" (for VLBA)
  - 1" is good for optical astronomy from the ground
- Plus this gives an image with many pixels!
- Don't have to be dishes

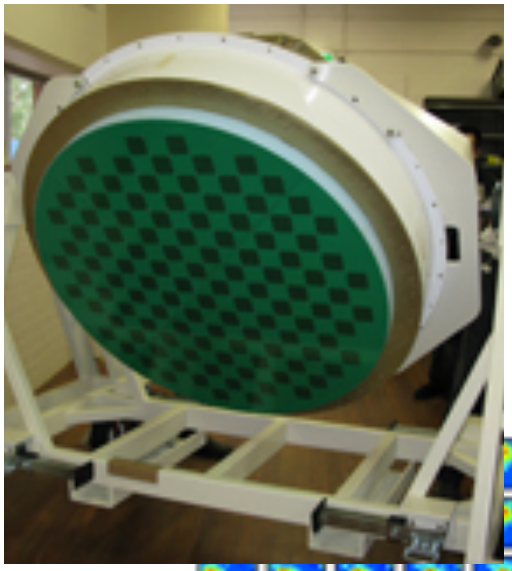


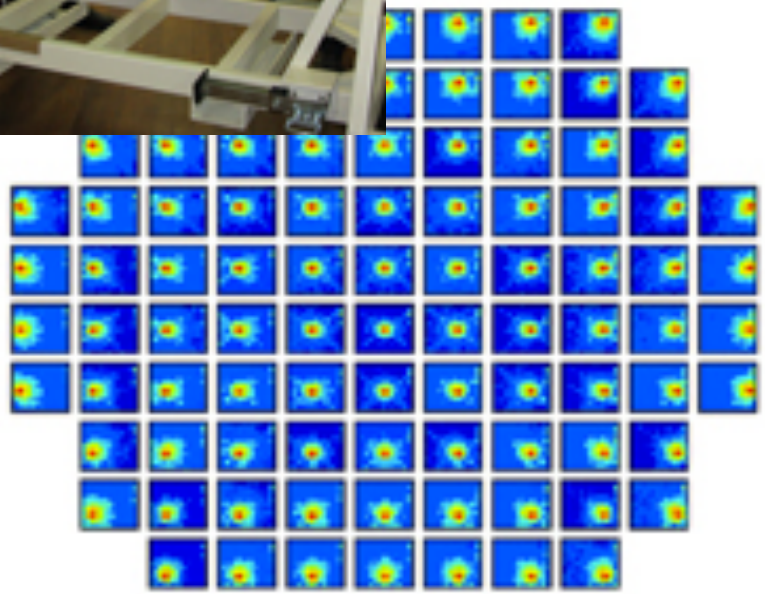
ASKAP design specifications

No. of dishes	36
Dish diameter (m)	12
Dish area (m^2)	113
Total collecting area (m^2)	4000
Aperture efficiency	0.8
System temperature (K)	50
Field-of-view (deg^2)	30
Frequency range (MHz)	700–1800
Bandwidth (MHz)	300
Maximum channels	16384
Maximum baseline (km)	6

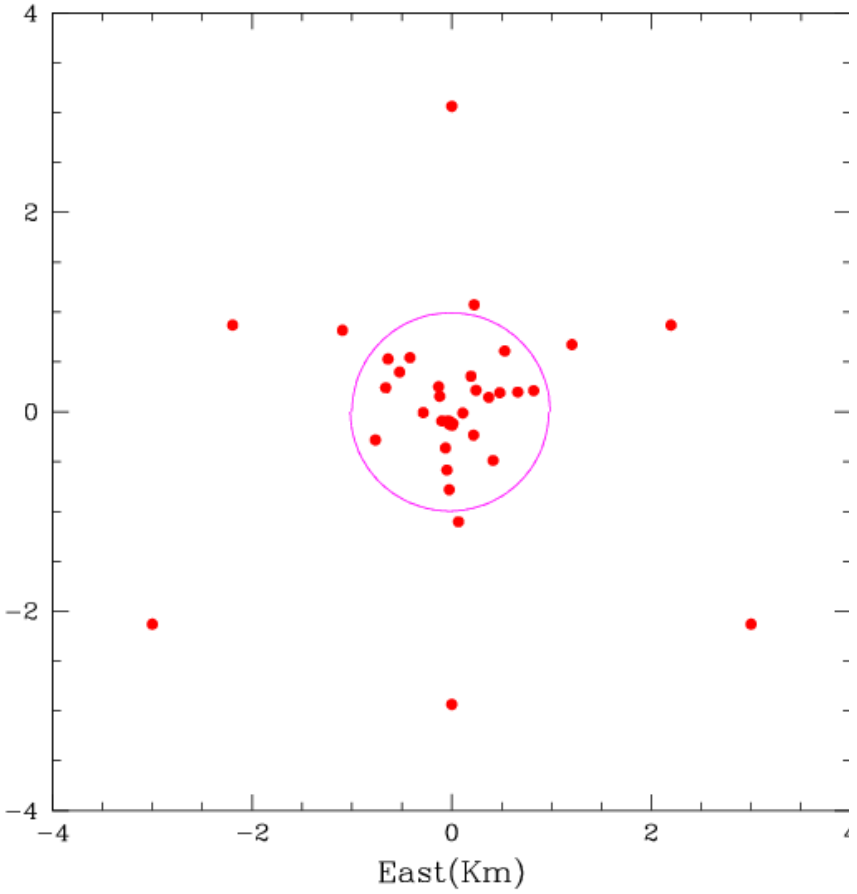
Novel receiver technology

- Phased Array Feed (PAF) receivers provide 30 separate (simultaneous) beams
- Under active development even as construction is ongoing





Antenna layout



MWA design

No. of dipole antennas	2048
No. of tiles	128
Field of view (steradians)	~4
Tile beam width (deg)	15-50
Total collecting area (m^2)	~2000
Frequency range (MHz)	80-300
Bandwidth (MHz)	32
Maximum baseline (km)	3

Location

Murchison shire in Western Australia

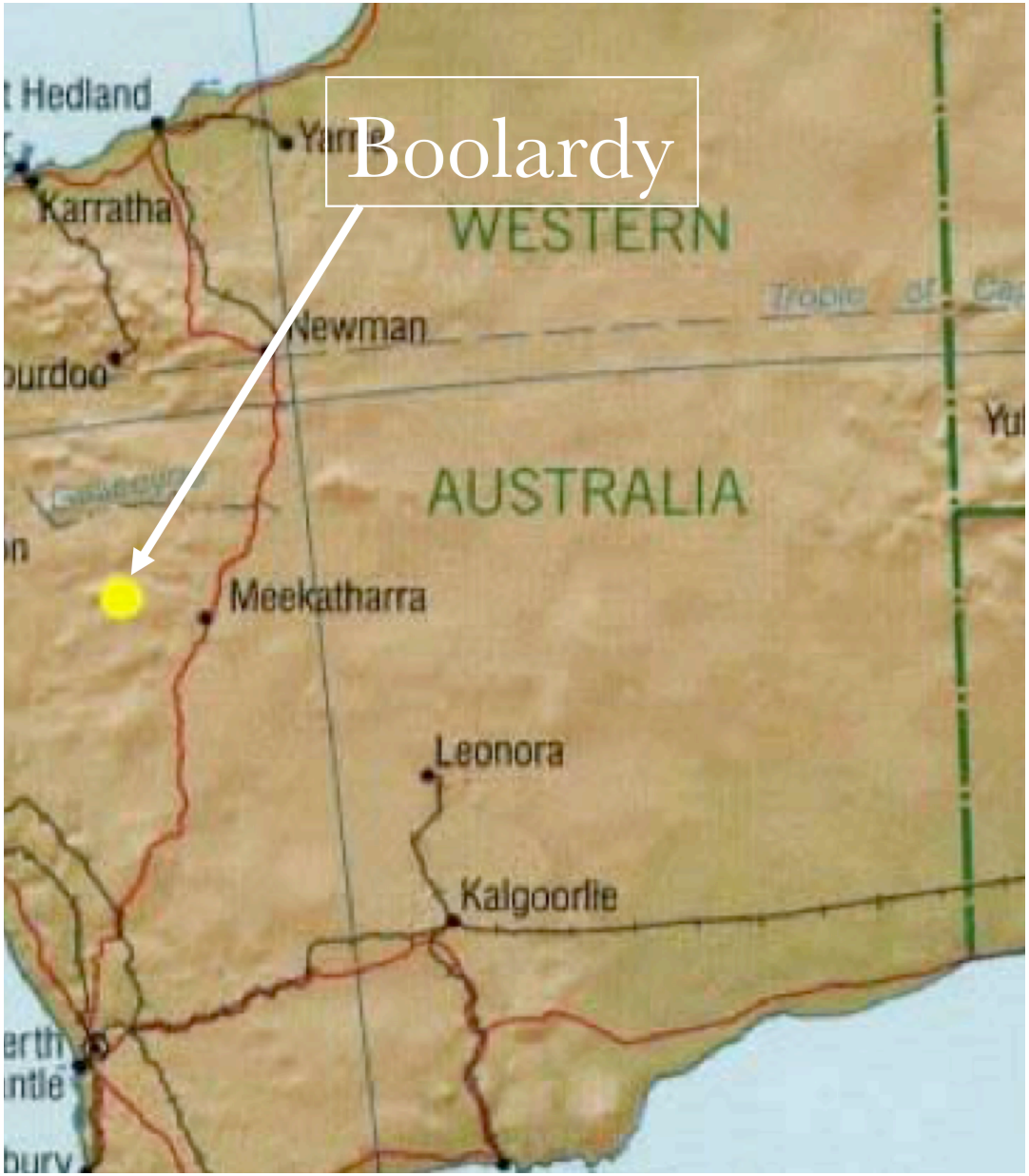
Area 50,000 sq. km (20,000 sq. miles); bigger than Netherlands, Switzerland or Maryland.

Towns: none

Population: ~160

Extremely radio-quiet; essential since low-frequency range include FM, TV bands

Protected as the future site of the SKA low-frequency arrays; significant future investment in infrastructure



Variables and Slow Transients

- Commensal observing during the 9 other Survey Science Programs (SSPs) as well as (some) dedicated observing time
- Substantial technical challenges
  - Flagging genuine transients and variables
  - Classifying and identifying
  - Prioritising for followup
- www.physics.usyd.edu.au/sifa/vast

Survey strategy

	VAST-Wide	VAST-Deep		VAST-GP
Observing time (hrs)	4380	3200	400	600
Survey area (deg sq)	10 000	10 000	30	750
Time per field	40 s	1 hr	1 hr	16 min
Repeat	daily	7 times	daily	64 times
Observing freq (MHz)	1150–1450	1150–1450	1150–1450	1150–1450
Bandwidth (MHz)	300	300	300	300
RMS sensitivity	0.5 mJy/bm	50 μJy/bm		0.1 mJy/bm
Field of view (sq deg)	30	30	30	30
Angular resolution	10″ (Maximum possible)			
Spectral resolution	$\sim$ 10 MHz			
Time resolution	5 seconds (Maximum possible)			
Polarisation products	IQUV	IQUV	IQUV	IQUV

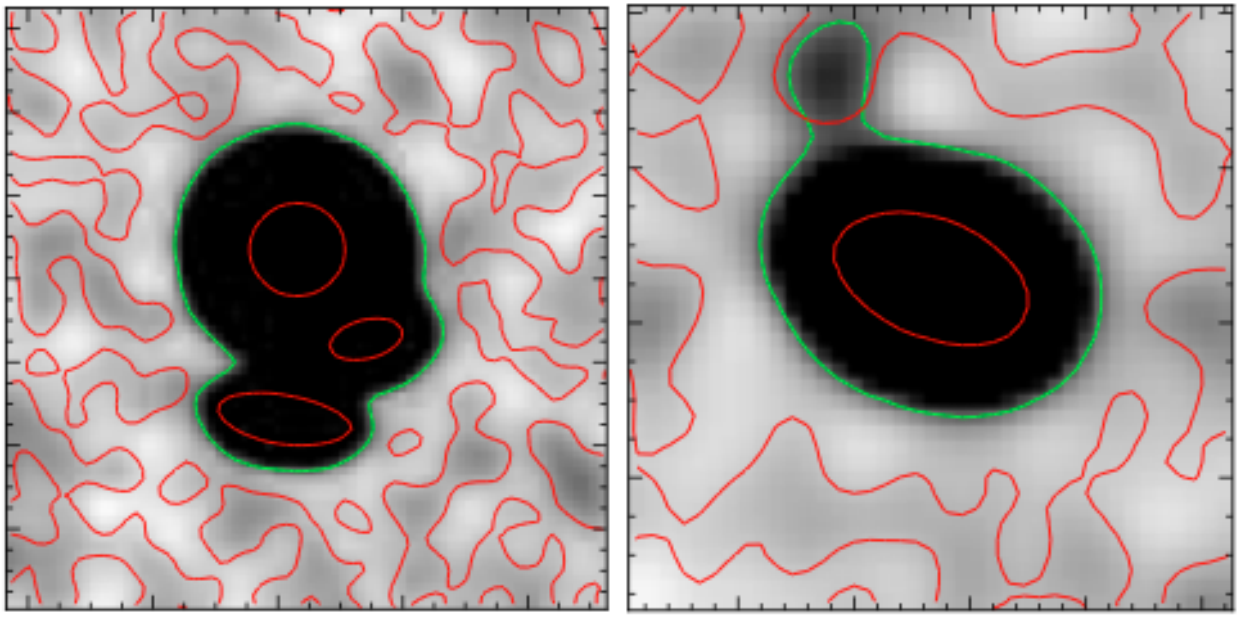
VAST memo #1 @ http://www.physics.usyd.edu.au/sifa/vast

Challenges: a data deluge

- ASKAP will produce 2.5 GB of visibility data per second, transformed into one 8GB image cube every 5 seconds
- Each cube will contain approximately twenty 100 megapixel images with 100s of radio sources detected in each epoch
- The VAST pipeline must identify and characterise all of these sources, detect variables and new transients and generate alerts

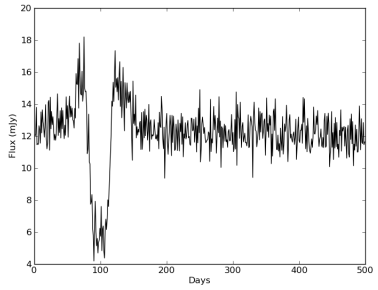
Challenges: source finding

- Accuracy of most source finders is high
- BUT with many images, a significant source of false detections in transient searches

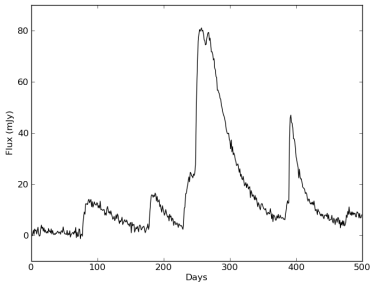


Performance of new source finder AEGEAN (Hancock et al. 2012, MNRAS 422, 1812)

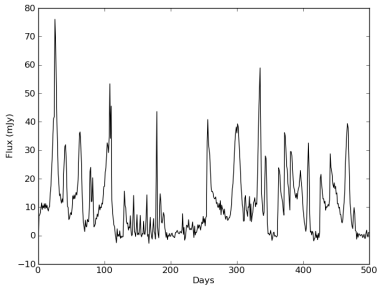
Challenges: source characterisation



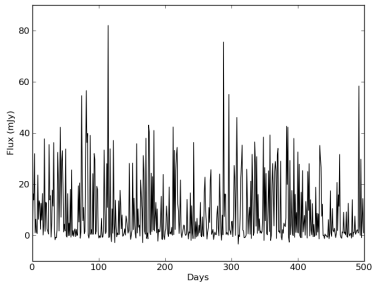
Extreme Scattering Events (ESEs)



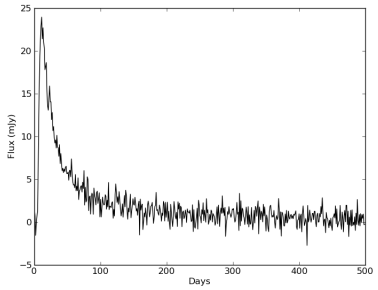
X-ray binaries



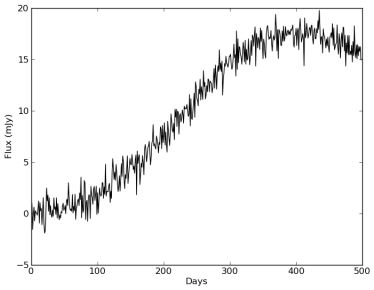
RS CVn type flare stars



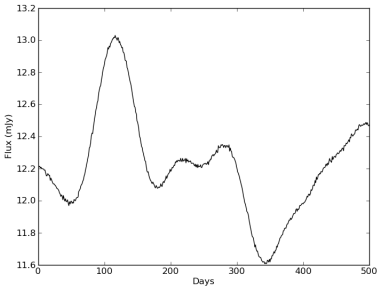
dMe type flare stars



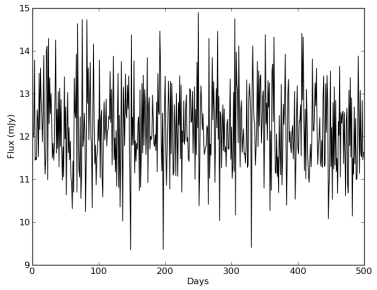
Radio Supernovae



Novae



Intra-day Variables



Background

Exploring machine learning techniques to automatically classify light curves (Lo & c)

Pipeline development

Source 32 MWAX_0809-1027

RA 08:09:01.78 Dec -10:27:08.73 search SIMBAD NED
Cross-match this source with the imported survey catalogues.

Bands: 143 150 154 158 166

Polarisations: I IC XX YY

Types: Detection Fit Calculated (MWA) Upper-limit

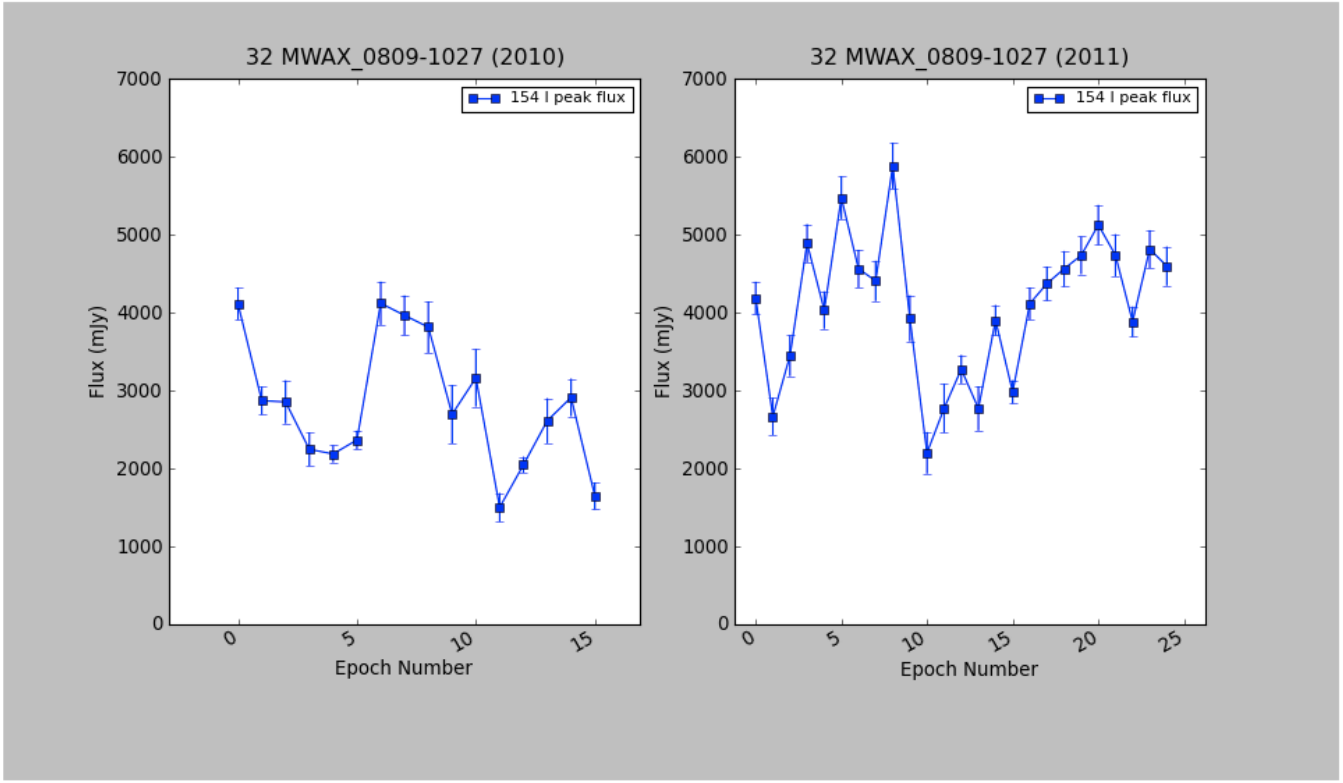
Postage stamps: ☑

Hide invalid: ☐

Date scale: ☐

Show uncorrected: ☐

Submit



Banyer & Murphy 2012, arxiv:1201.3130

Lots going on

- Currently working on:
  - Simulated data (from Paul Hancock)
  - Molonglo data (from Keith Bannister)
  - ATA data (from Steve Croft)
  - MWA X14, X15, X16 fields (Hydra A and Pic A)
- Capacity testing
  - Currently prototyped in Python
  - Functionality will be wrapped as modules for ASKAPSoft
  - Need to evaluate capacity requirements for BETA
- Future developments
  - Integrate with VO: Topcat plotting etc.
  - Comprehensive database of surveys for cross-matching
  - SED generation
  - Post-hoc field-to-field calibration (Bannister et al. 2011)
  - Incorporate transient identification algorithms

ASKAP status

- PAF testing on the 12m antenna at Parkes
- 10 antennas in place at MRO as of Oct 2011; 36 antennas expected to be complete in 2012
- Boolardy Engineering Test Array (BETA) consisting of 6 antennas equipped with PAFs commencing observations in 2012
- Science observations commencing Mar 2013
- Additional funding required for full complement of receivers

MWA status

- 32-tile prototype array observing in engineering mode since 2009
- First science results! Williams &c http://arxiv.org/abs/1203.5790
- Full complement of 128 tiles currently (early '12) under construction
- Facebook page has 2360 "likes"

The bottom line

- Prospects for radio followup of GW events is excellent
- Since the likely error regions for triggers are so large, every followup is a “survey”
- Instruments currently under construction/ development are optimised for high survey speed
- ASKAP &c also have transients as a science priority

Coming soon...

Square Kilometer Array - Site Decision

SKAI Survey
Australia / NZ

SKA Mid
South Africa

SKA Low
Australia / NZ

SKA Aper. Array
South Africa

A majority of the members agree the following dual-site implementation for SKA1 and SKA2:

SKA1		SKA2	
SKA1_LOW	ANZ	SKA2_LOW	ANZ
SKA1_MID	RSA	SKA2_MID	RSA
SKA1_SURVEY	ANZ	SKA2_AA	RSA