SKA Transients SWG

R. Fender (chair), H. Bignall, S. Chatterjee, S. Corbel, A. Deller, J. Hessels, A. Karastergiou, C. Law, J.-P. Macquart, I. Morrison, T. Murphy, Z. Paragi, B. Stappers, C. Trott

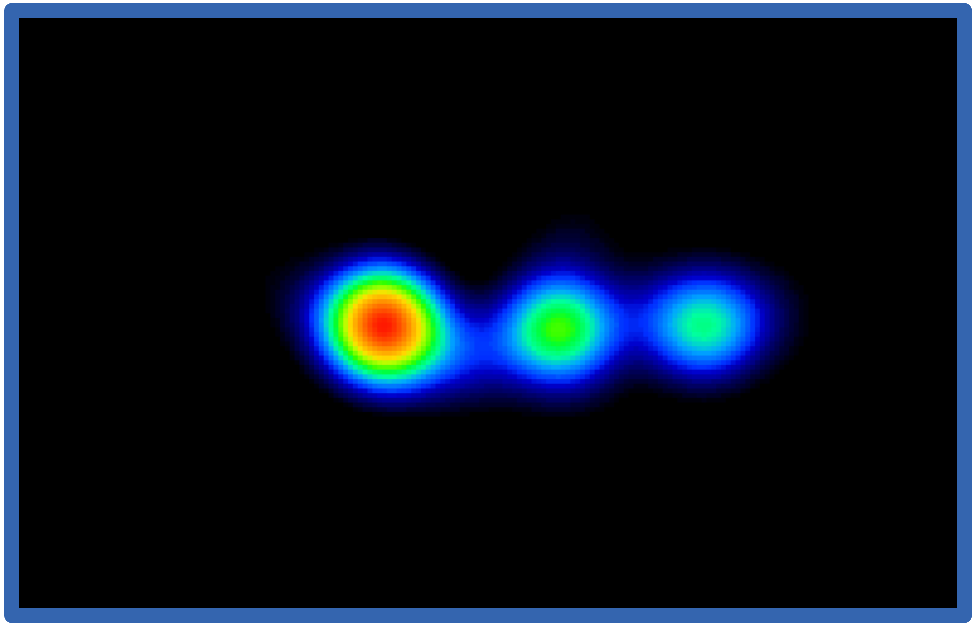
+ advice from E. Kuulkers, A. Siemion, J. van Leeuwen

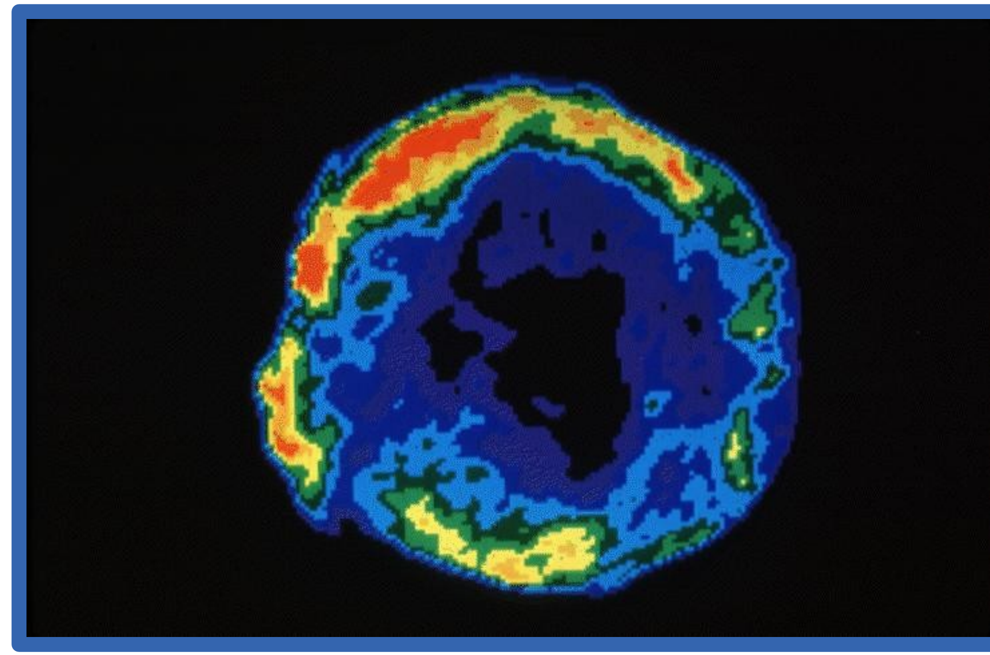
Science Assessment workshop ~Jan 2014

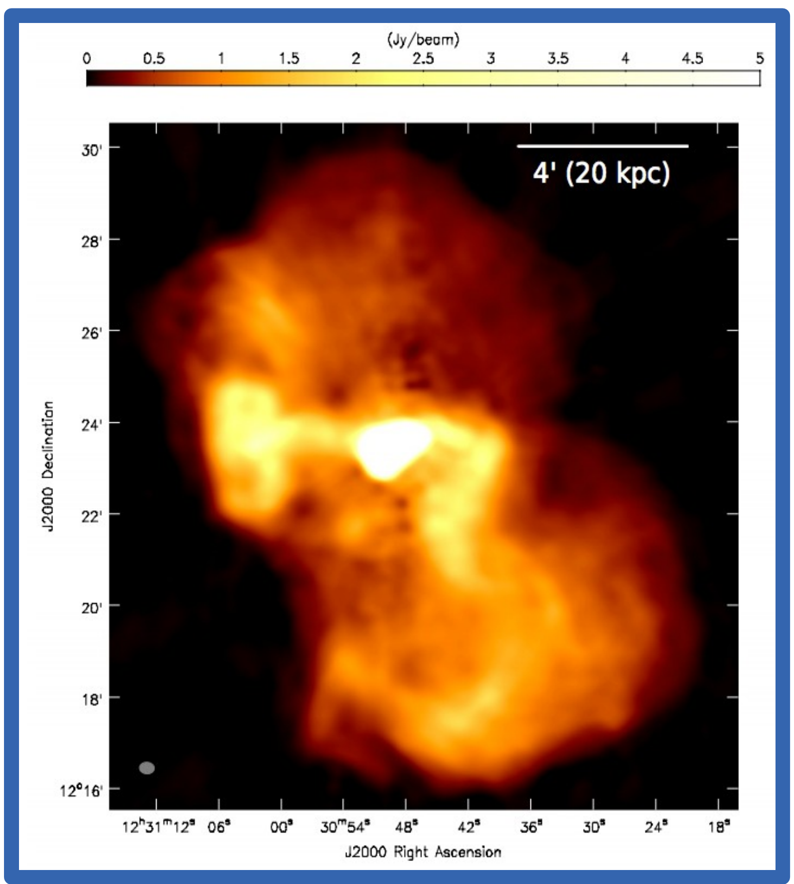
Transients: the science

- Not a KSP-level part of the original SKA science case (although partially covered by 'exploring the uknown')
- However, since then all major facilities en route to SKA – LOFAR, MWA, ASKAP, MeerKAT – have adopted Transients as key science
- Very large potential for high-impact/early science (→ *Nature/Science* papers)

Extreme Astrophysics: Synchrotron transients





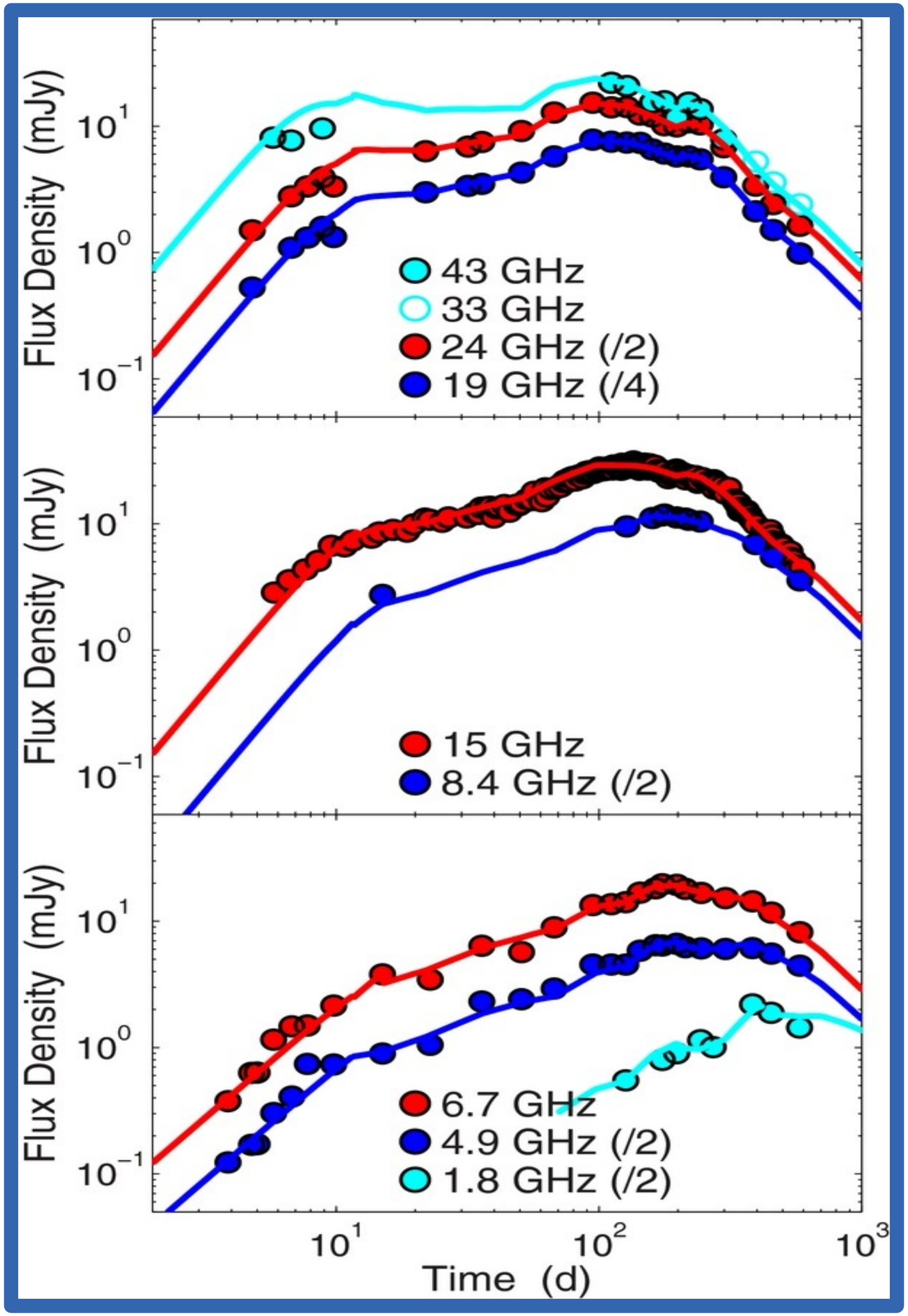


Extremes of temperature, pressure, density, gravity

Highly relativistic flows

Very bright variable events visible to cosmological distances

Tidal disruption events

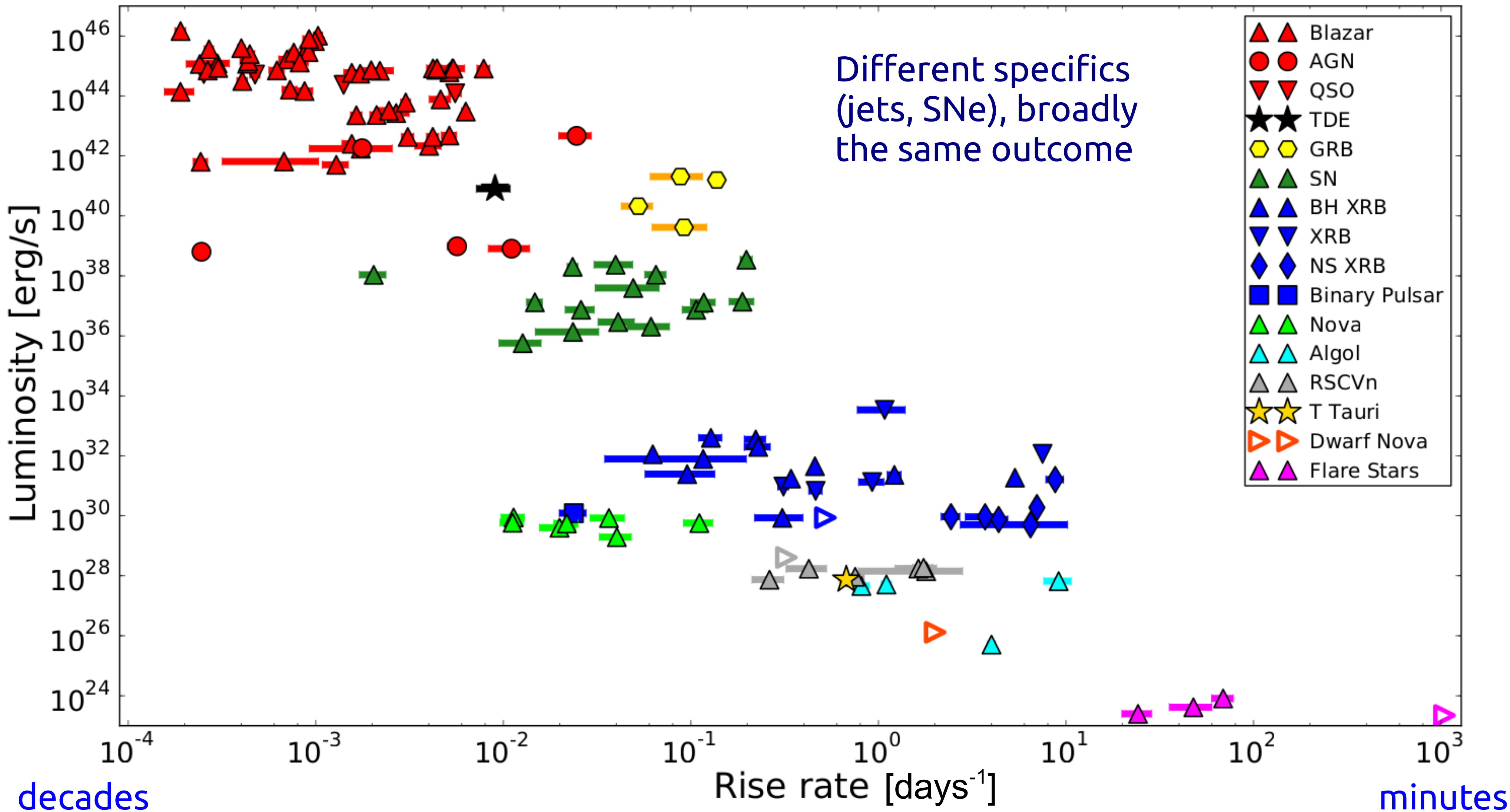


Bright radio flaring occurring during transient Eddington-level accretion onto supermassive black holes

Key to understanding transient accretion onto supermassive black holes → kinetic feedback over cosmological time

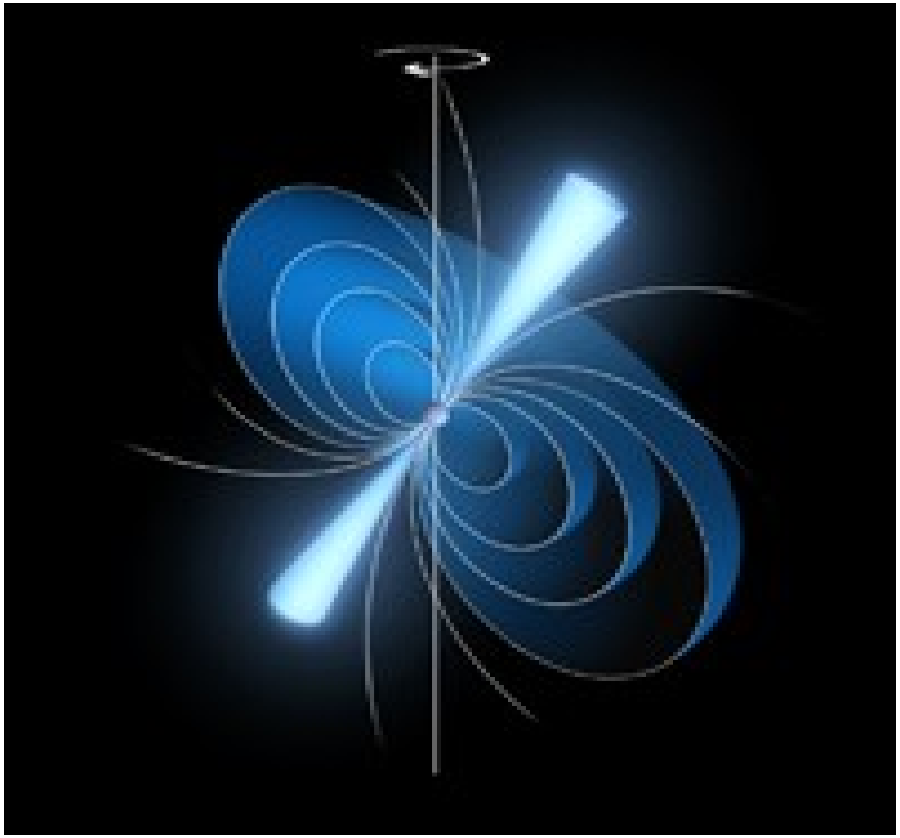
Swift J164449, z=0.35
Zauderer et al. (2013)

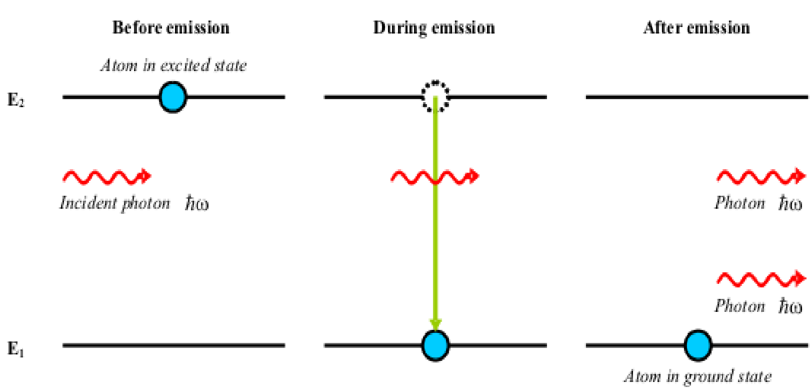
A census of variable (synchrotron) radio emission can give you the rate of (local) kinetic energy injection (also class. tool)

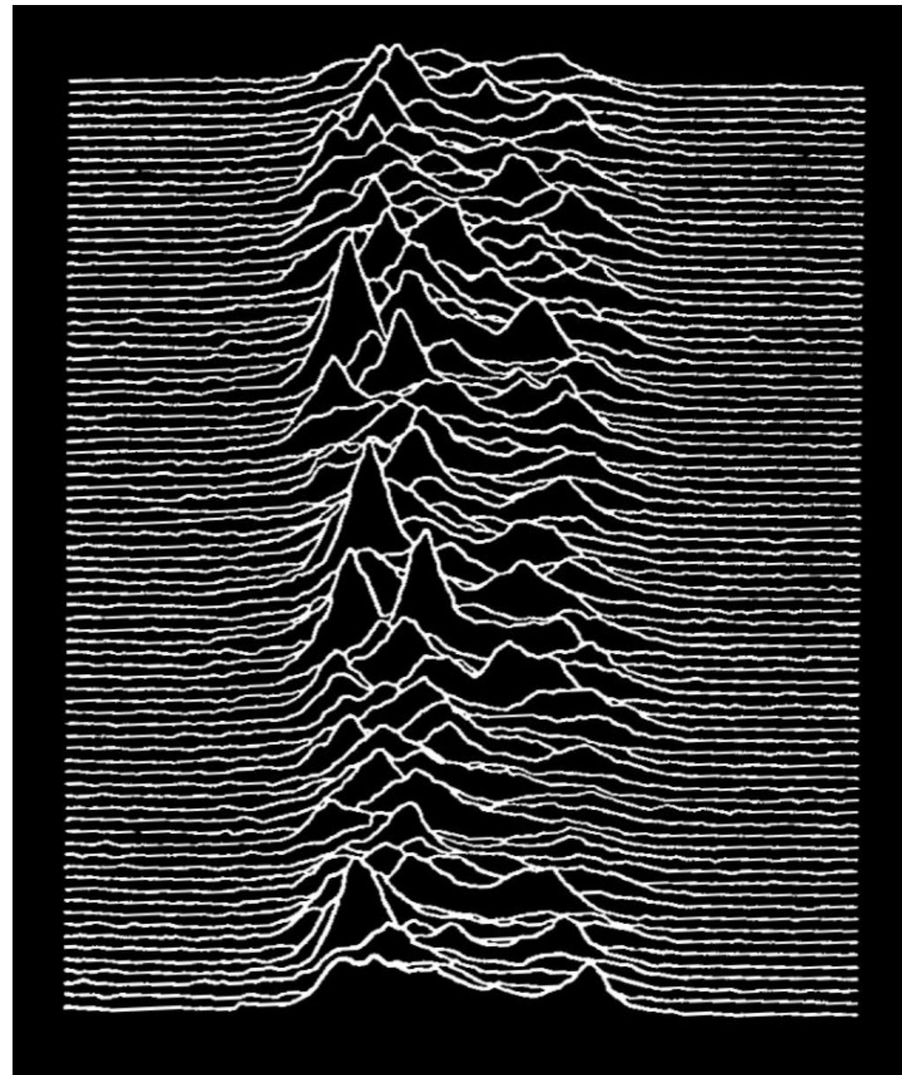


Pietka, Fender & Pretorius (in prep)

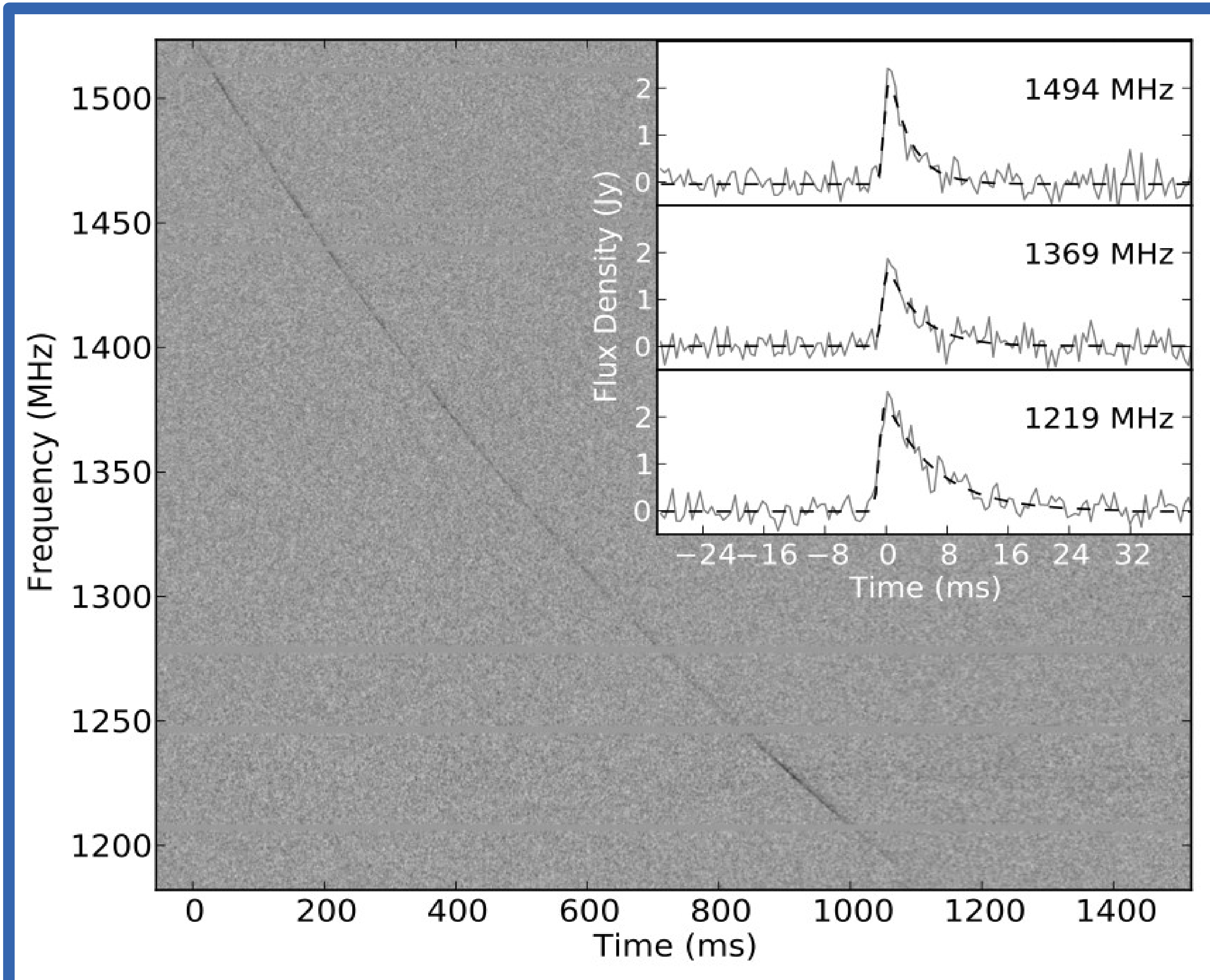
Brighter, faster: coherent emission







Coherent bursts from cosmological distances



Non-repeating highly dispersed and scattered bursts orginating at distances of

0.4 – 3.2 Gpc
(0.1 < z < 1.0)

Consistent with cataclysmic event **– possible GW counterparts**

Unique probe of the IGM

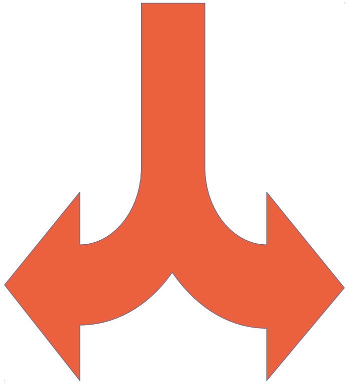
High predicted rates for next-generation facilities

Lorimer et al. (2007), Keane et al. (2011), Thornton et al. (2013)

Two types, two methods (sort of)

Incoherent synchrotron emission

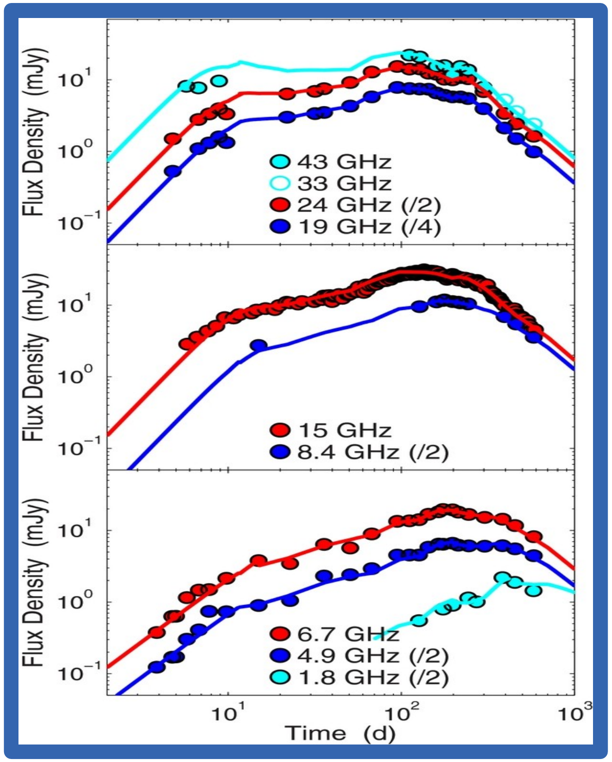
Relatively slow variability
Brightness temperature limited
Associated with all explosive events



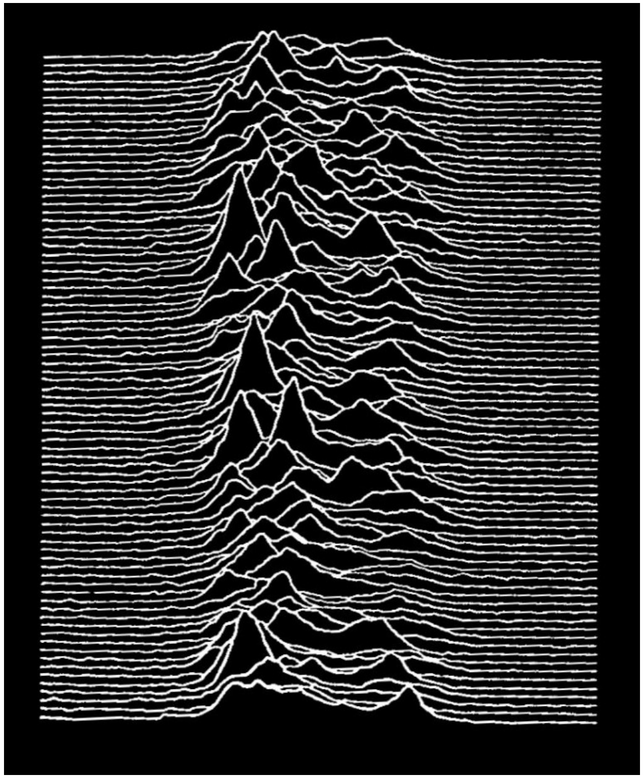
Coherent emission

Relatively fast variability
High brightness temperature
Often highly polarised

Early branch in classification pipelines



Lower frequencies: smoother and later



Find these (mostly) in images and at higher (ν> 1 GHz) frequencies

Find these (mostly) in time series, usually peak at lowish (0.1<ν<1 GHz) frequencies

Transients and the SKA1 baseline design

Summary of main considerations. We need:

- System flexibility for real-time inspection of (all) data for transients, ability to (robotically) respond to alerts (internal and external)

- Beamforming: multiple beams highly desirable. Capability for simultaneous imaging and beamformed modes – highly advantageous for coherent transients

System flexibility
(a.k.a. Piggybacking / Commensal observing)

Real-time automatic inspection of **<u>all</u>** data for transient events

Issues:

- Requires dedicated hardware/software – software infrastructure for handling post-processed data already exists in prototype form

- May also require dedicated manpower?

- Ability to store/access low-level data products – keep future options as open as possible (e.g. later implementation of closure/bispectrum analysis)

- Politics of looking at “someone else's” data?

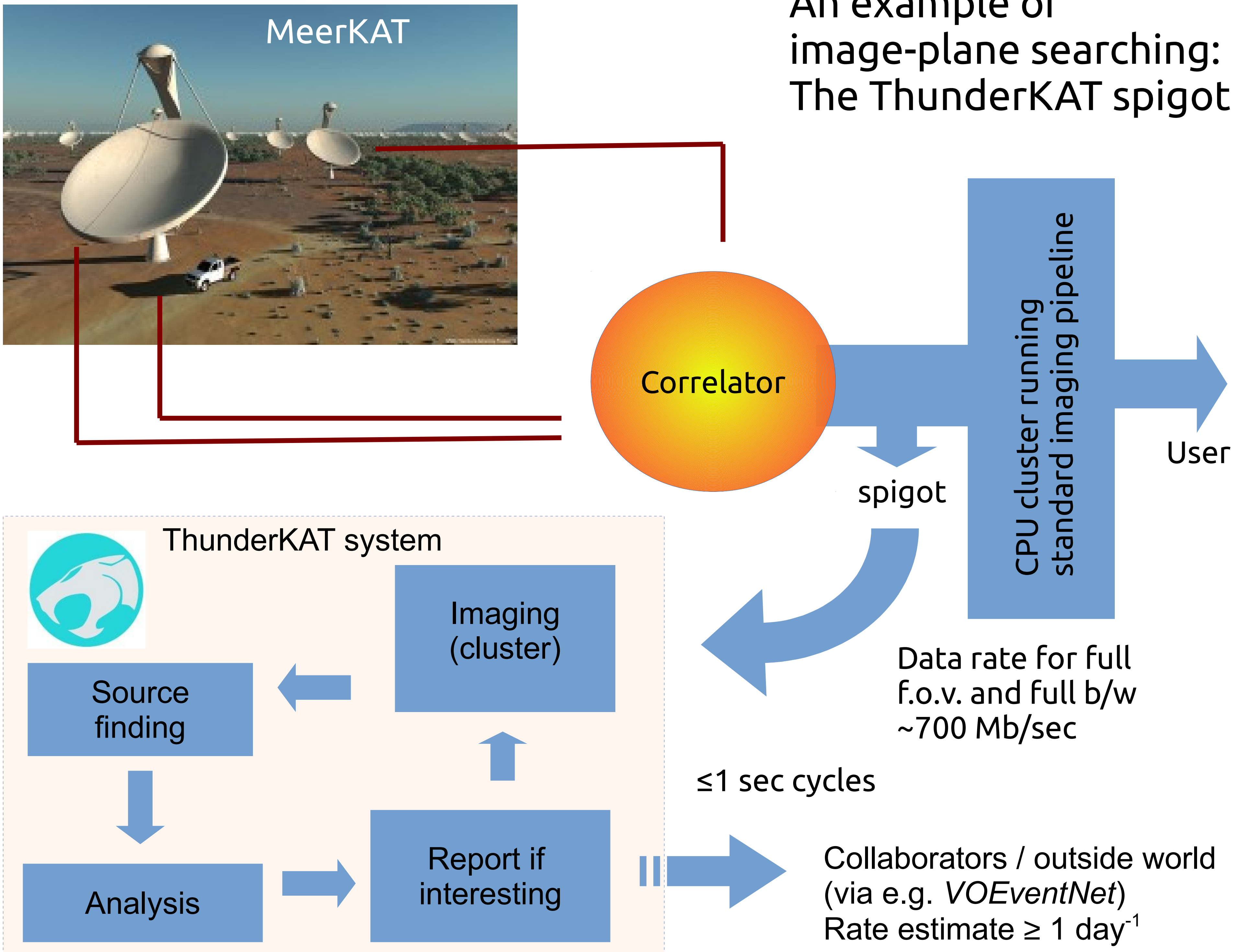
Traditional data rights mean everything in your data is your science. This severely hampers transient searches.

What solutions?

1. Award observations only for particular science? This model is employed by e.g. INTEGRAL. Possibly open to gaming of the system, requires subjective judgement by TAC/Director.

2. Have a close-to-fully automated transient search system which publicly reports events (e.g. via *VOEvent* protocol) → whole world benefits. Policy used to great effect by NASA. More objective but requires more technical work beforehand.

An example of image-plane searching: The ThunderKAT spigot



System flexibility

Rapid (robotic) response to alerts

- Pre-allocate robotic-ToO time of varying priorities in a system which is completely flexibly scheduled (in some sense a crude prototype for this has been implemented in the roboticisation of AMI-LA)
- Ability to freeze buffers
- Minimal overheads/dead time: Fast slew speed (especially for SKA1-Mid) and software-reconfigure time
- Good snapshot *u-v* coverage

Beamforming

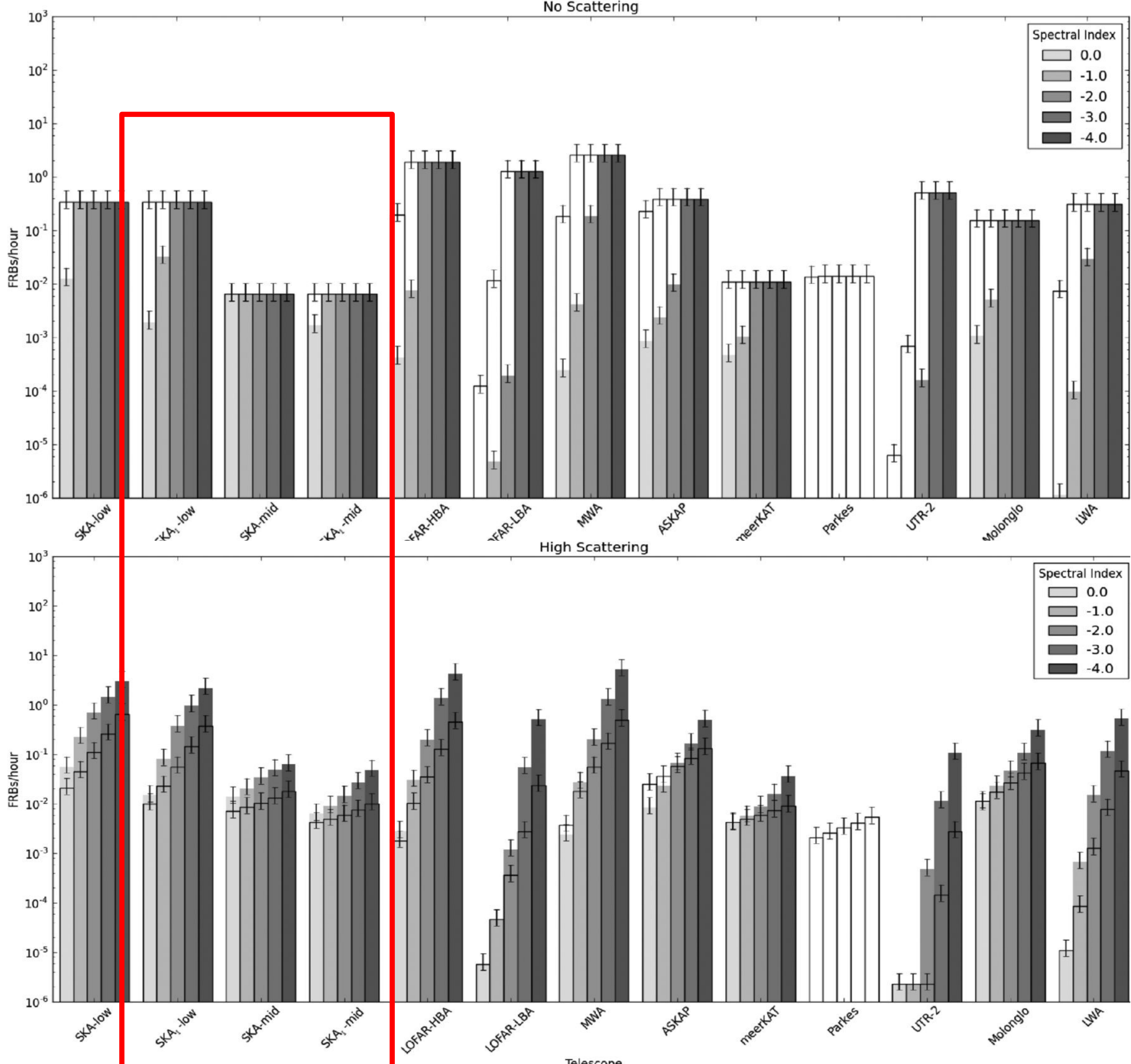
- Multiple beams highly desirable! Figure-of-merit scales from $N^{1/4}$ for fixed bandwidth (station beams) to N^{1} for no trade off with bandwidth (core/tied array beams)

- Large numbers of tied-array beams required for coherent burst searches – same requirements as pulsars SWG → want fast transients searches as part of the pulsar processing chain

- Simultaneous imaging and beamformed modes are extremely valuable for coherent transients – spans parameter space in the same observation between events in which the lightcurve is dispersion-dominated and those which are scattering-dominated → full possible range of parameter space explored in any given observing time allocation

Imaging

Beam-forming



Hassall et al. (2013)
– see also Trott et al., Lorimer et al.

Transient rates

- Still highly uncertain, parameter space still being explored. Take cases of **tidal disruption events** (TDEs) and **fast radio bursts** (FRBs)

- SKA1-Low/-Mid should find FRBs at rates between 10^{-2}–10^{0} per hour (Hassall et al. 2013) combined imaging/BF

- SKA1-Mid/-Survey should find TDEs at rates 10^{-2} – 10^{0} per hour (Frail et al. 2011) in images

→ huge amounts of 'free' science if real-time commensal transient searches are supported from the start

Fast public global alerts (like NASA) would provide fantastic PR for SKA and radio astronomy

Transients and the SKA1 baseline design

Component-specific considerations

SKA1-Low

- Multiple station beams!
  Sixteen station beams doubles FoM

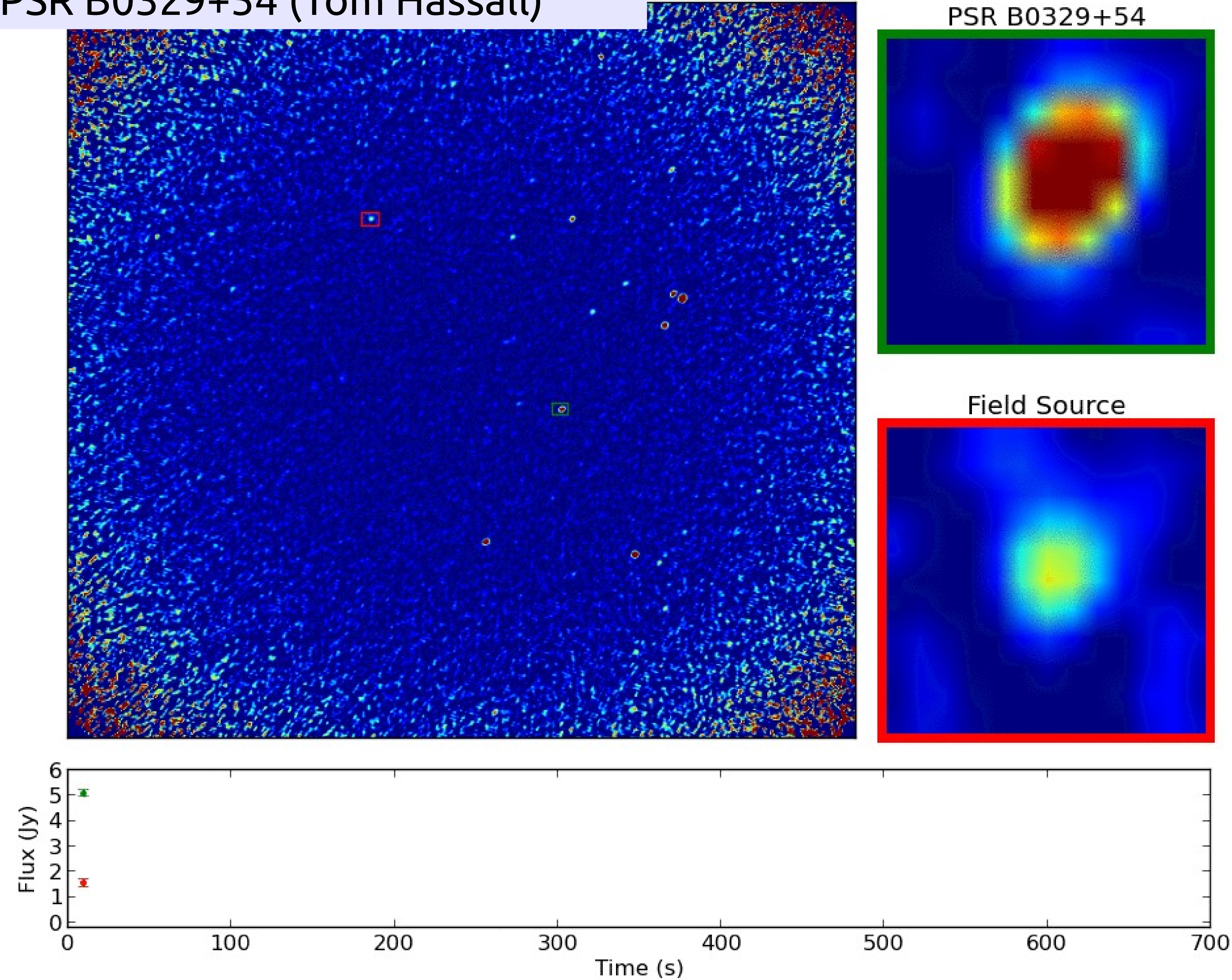
- Strongly support suggested relay of all dipole signals to central processing

- Strong directionality of dipoles some concern
  (once-in-a-lifetime event unlikely to occur at the zenith)

- Since EoR will only run ~20% time its crucial that array is flexible and powerful for other science

- Lessons from LOFAR
  - Transients hard to find (need clever software)
  - Confusion limit not well understood at these freqs

PSR B0329+54 (Tom Hassall)



SKA1-Mid

- In all likelihood the main follow-up facility for longer-lasting synchrotron transients – needs to be able to respond fast and efficiently (= robotically) to transients

- Superb for finding coherent transients (search all the tied-array beams all the time!)

SKA1-Survey

- Probably comparable rate of synchrotron transients to SKA1-Mid (precise frequency dependence unclear)

	Image plane (synchroton) transients	Beamformed (coherent) transients
SKA1-Low	Synchrotron transients slow and flat at these frequencies → not so good Multiple station beams to increase FoM	**Very exciting prospects** Multiple station beams and (large numbers of) tied-array beams essential Transport of all antenna data to central processing
SKA1-Mid	**Best prospects** Much better for synchrotron transients – the higher frequency the better (> 5GHz ideally)	**Very exciting prospects** Large numbers of tied-array beams essential
SKA1-Survey	**Good for synchrotron transients**	OK for highly-scattered coherent transients Incoherent beam simultaneous with imaging?

SKA1 (all components)	Commensal searches → public alerts, Robotic response to external alerts, Simultaneous imaging and beamformed modes, spigot-style flexibility built-in from start

Other considerations

- SKA1 baseline design currently has almost **no** requirements/commitments for spigots/transients. We want to see minimum requirements written in, in addition to 'best effort' promises.

- Wrong figure of merit for transient events

  FoM ~ $s^{-3/2}$ should be used (not s^{-2})

  (e.g. Macquart 2011) – would like to see future documents also providing this figure

- Sub-arraying? Again increased flexibility (multiple targets / multiple frequencies on same target) for investigation of rapidly-varying events

Other considerations

- Long baselines/VLBI modes very important for transients (localisation, resolved imaging) – support Deller et al. document for Pulsars WG. Important that SKA1-Mid/Survey can be used as sensitive elements of a wider network.
- Synchrotron transients are much more interesting at higher frequencies – likely to find more events at 5 or even 15 GHz than at 1 GHz. Is there **<u>any</u>** chance of having some of SKA1-Mid equipped with 5 GHz receivers? If MeerKAT gets high-frequency receivers, how will these be used during the SKA1 phase?
- Where is discussion of archive? Crucial feature for transients and much other science

Other considerations

- SKA will exist at the same time (and in the same hemisphere) as many other 'next-generation' astronomical observatories such as E-ELT, LSST, Advanced LIGO etc.

  Transients is (not uniquely) a multiwavelength business and we must consider how we can share information (transient alerts) and even programmes between the facilities. LSST will effectively be releasing all its data pseudo-publicly → real-time transient searches → we should do the same.

  Perhaps SKA-Survey could even observe sky in a coordinated way with LSST?

Summary

SKA1 as a set of three telescopes can be a powerful facility for discovery and follow-up of astrophysical transients → high profile 'free' science return

However, this potential could be diminished or thrown away if flexibility* is not built in from the start
(*e.g. central relay of all antenna signals in SKA1-low, near-real-time commensal searches of all data from all telescopes, robotic rapid-response modes, data spigots for as-yet-undreamt-of future advances).

Bottom line: A revised baseline design should have stronger technical commitment to supporting transients/system flexibility and political commitment to fast commensal searches of all data for transients.