ICRAR

International Centre for Radio Astronomy Research

Transients with the SKA

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on behalf of the Transients SWG

Curtin University

The University of Western Australia

Transients as a physics lab

Why do we care?

The physics of the extreme

- Cosmology
- Extreme gravity and states of matter
- Accretion physics

Transients taxonomy

- Image plane - “synchrotron/thermal” mechanisms
- Time-domain - “coherent” mechanisms

Precursors charting the landscape

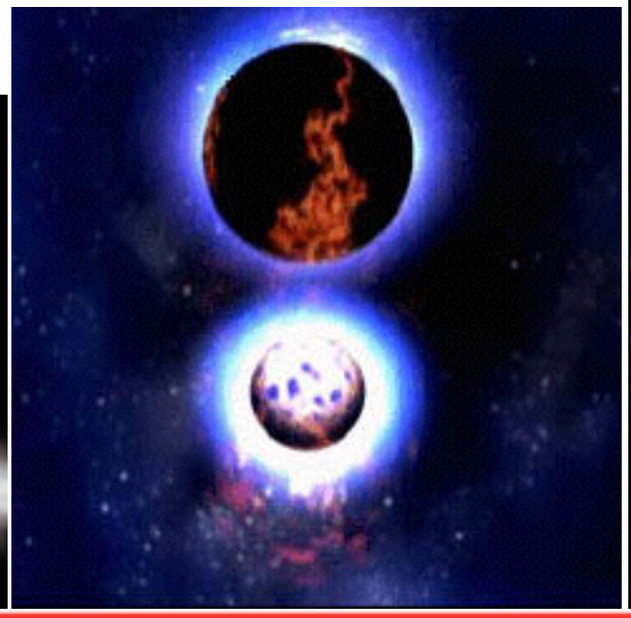
- Lessons learnt

Transients Science in the SKA era

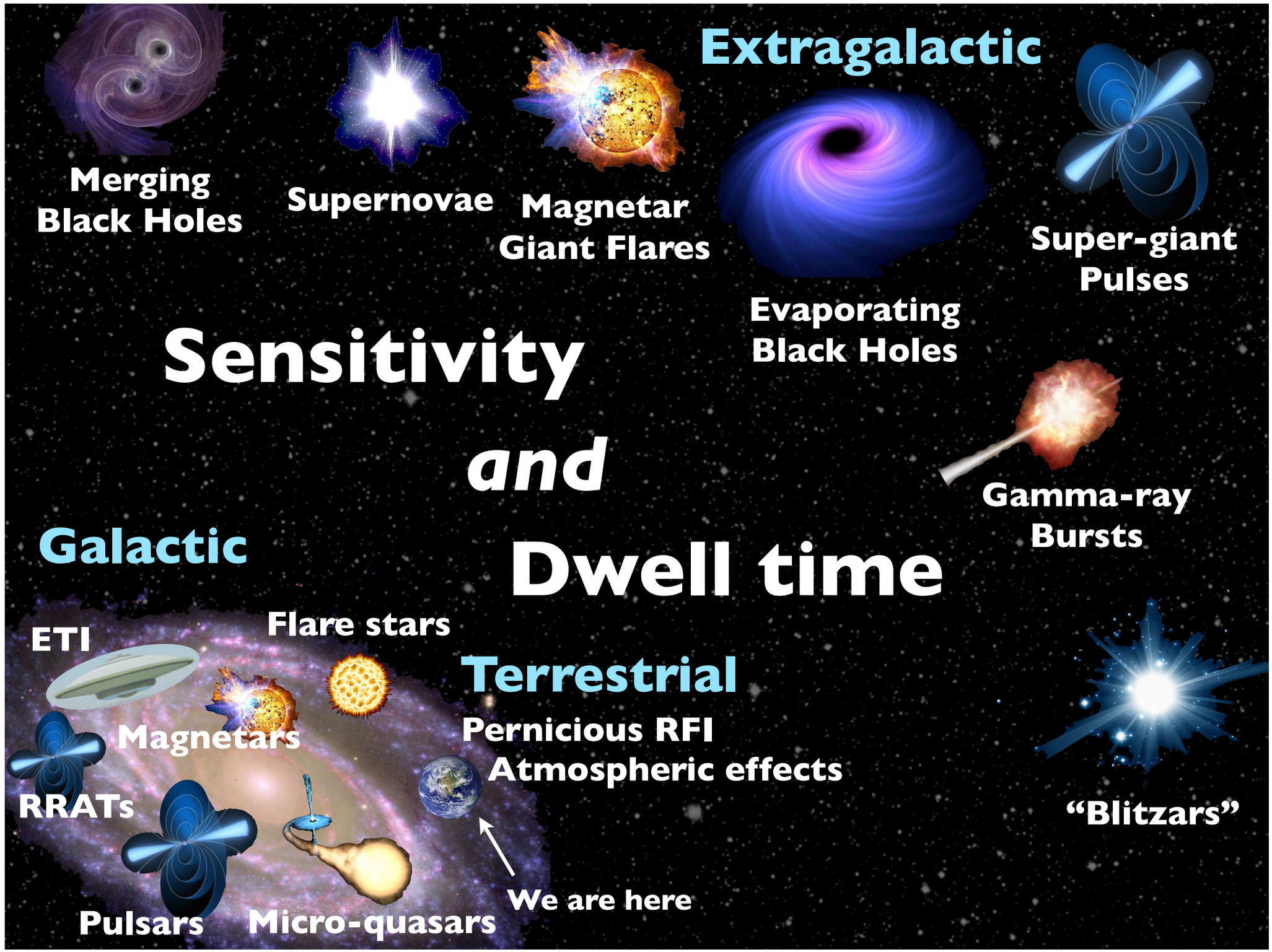
- An explosion of time-domain capabilities
- The SKA’s place in global time-domain astrophysics

Scientific Motivation

- Transients probe
  - high brightness temperature emission
  - extreme states of matter
  - physics of strong gravitational fields
  - physics of accretion
  - extreme energy densities
- Impulsive transients are subject to a range of propagation effects that are exquisitely sensitive probes of
  - the IGM
  - the spacetime metric on cosmological scales



Broad scope & diverse phenomena



Courtesy Jason Hessels

Known Knowns & Known Unknowns

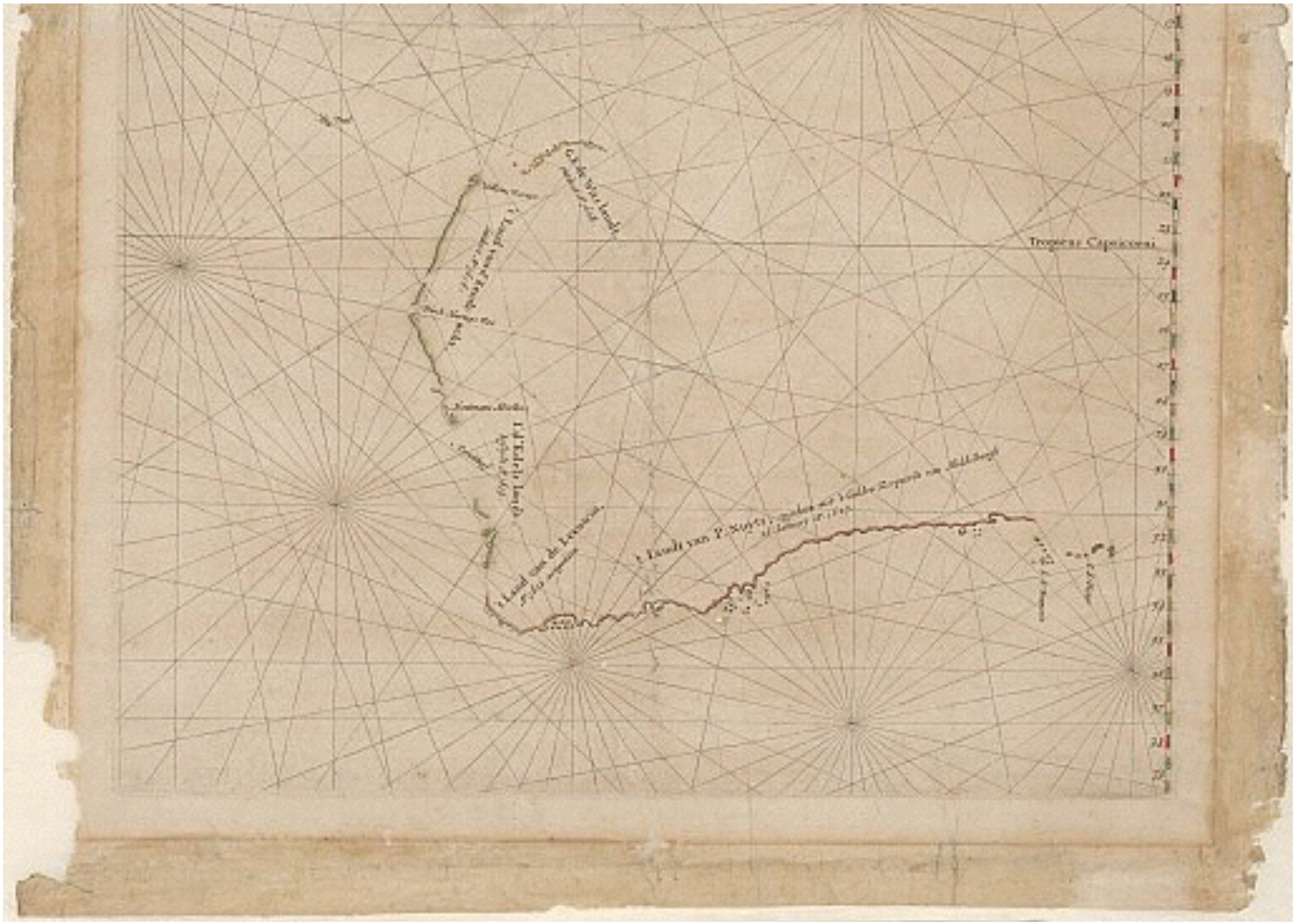
Time-domain - bursty and generally coherent

- Pulsars including Magnetar bursts, Transitional XRBs, Giant Pulses, RRATs
- Fast Radio Bursts
- Bursty emission from exoplanet-star systems, brown dwarfs

Image domain - incoherent synchrotron or thermal

- X-ray binaries
- Tidal Disruption Events
- Novae & Flare stars
- Intra-day variable quasars/Extreme Scattering Events
- System mergers/gravitational wave events

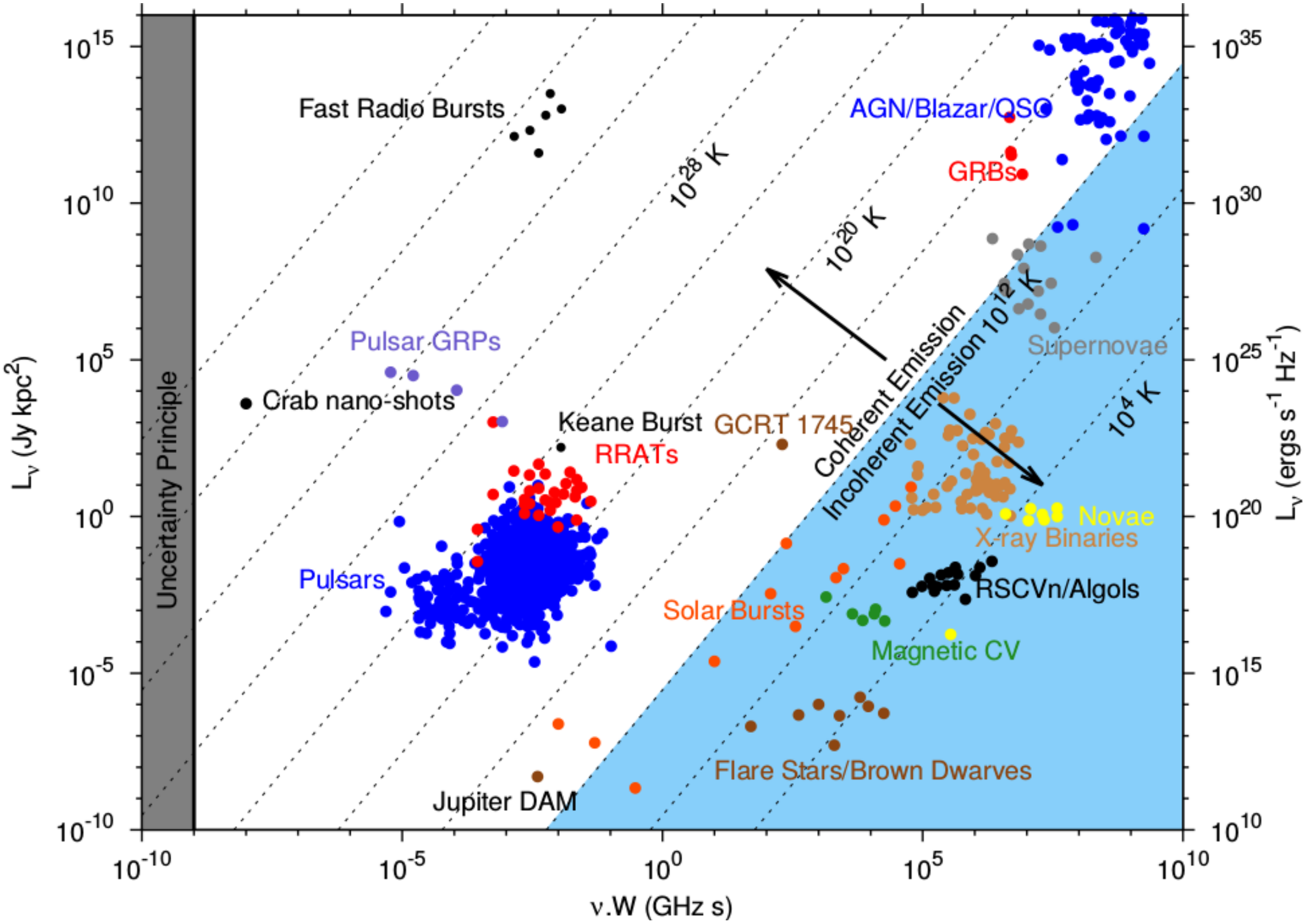
Transients Cartography



Map of Australia
Hessel Gerritsz (1618), cartographer of the Dutch East India Company

Transients Cartography

Pietka, Fender & Keane 2015



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What's new in the Transients Universe?

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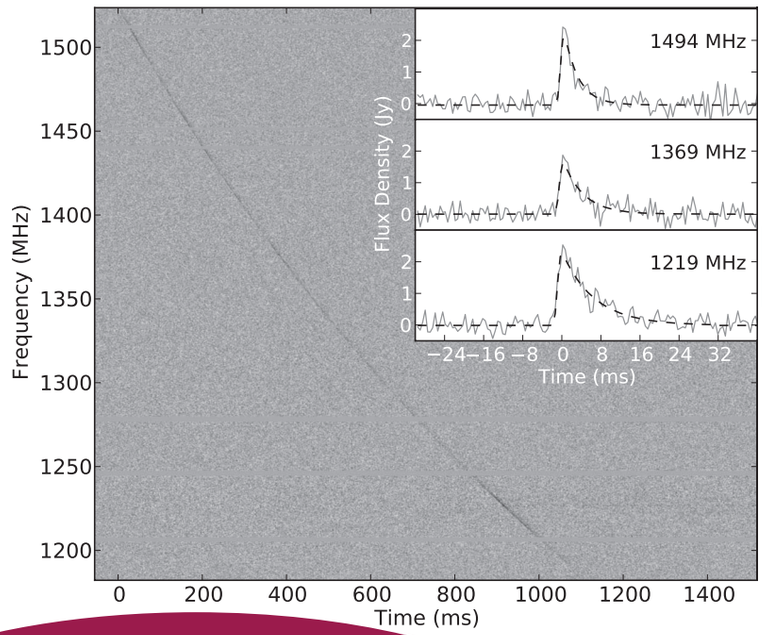
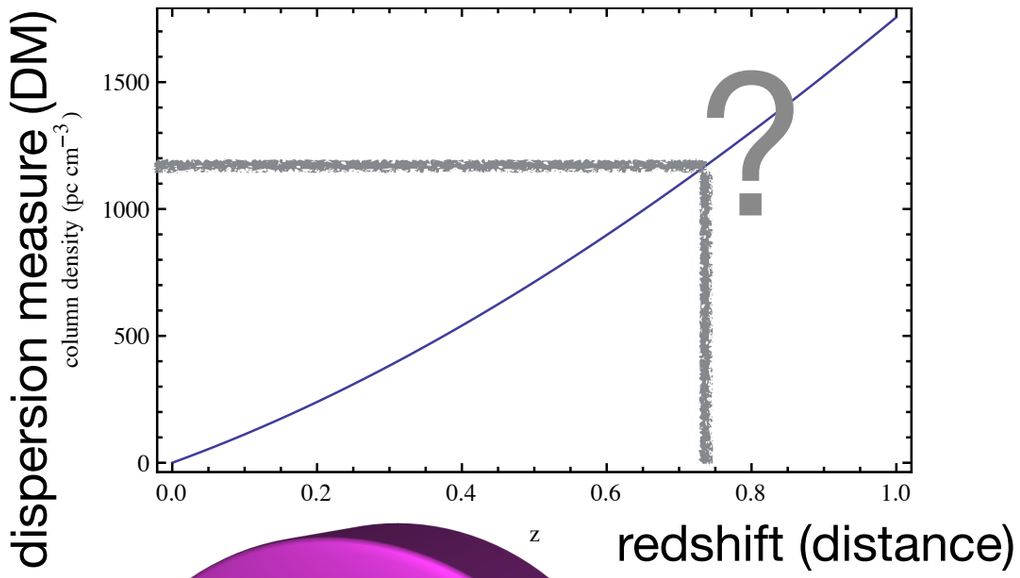
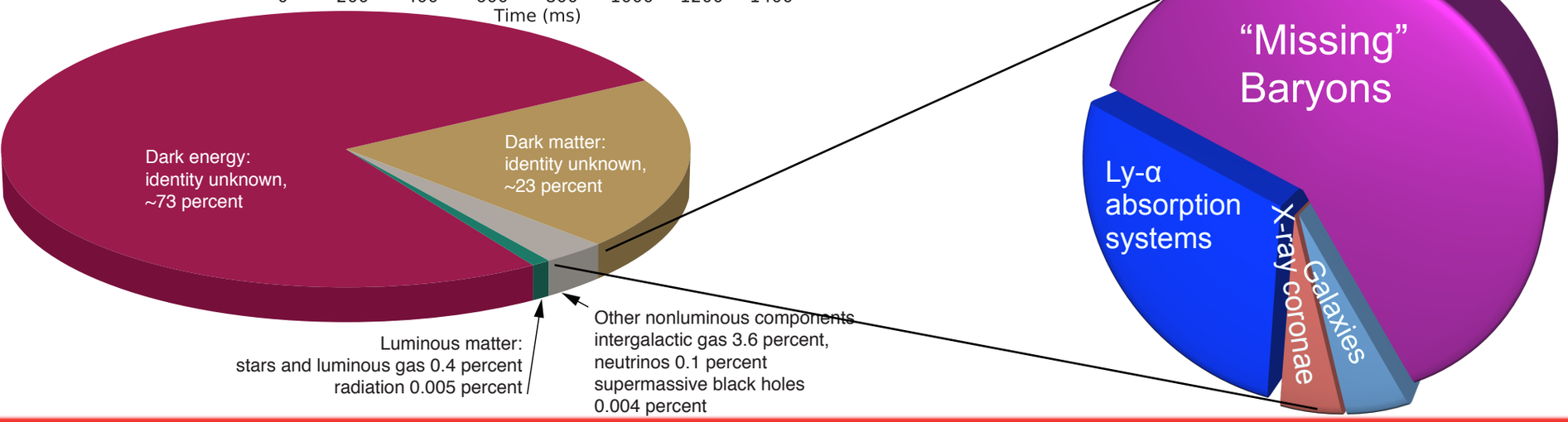
FRBs as cosmological probes

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 10^8m scales at distances of ~1Gpc
- probe IGM physics: primordial magnetic field & energy deposition







Evidence of FRB Cosmological Origin

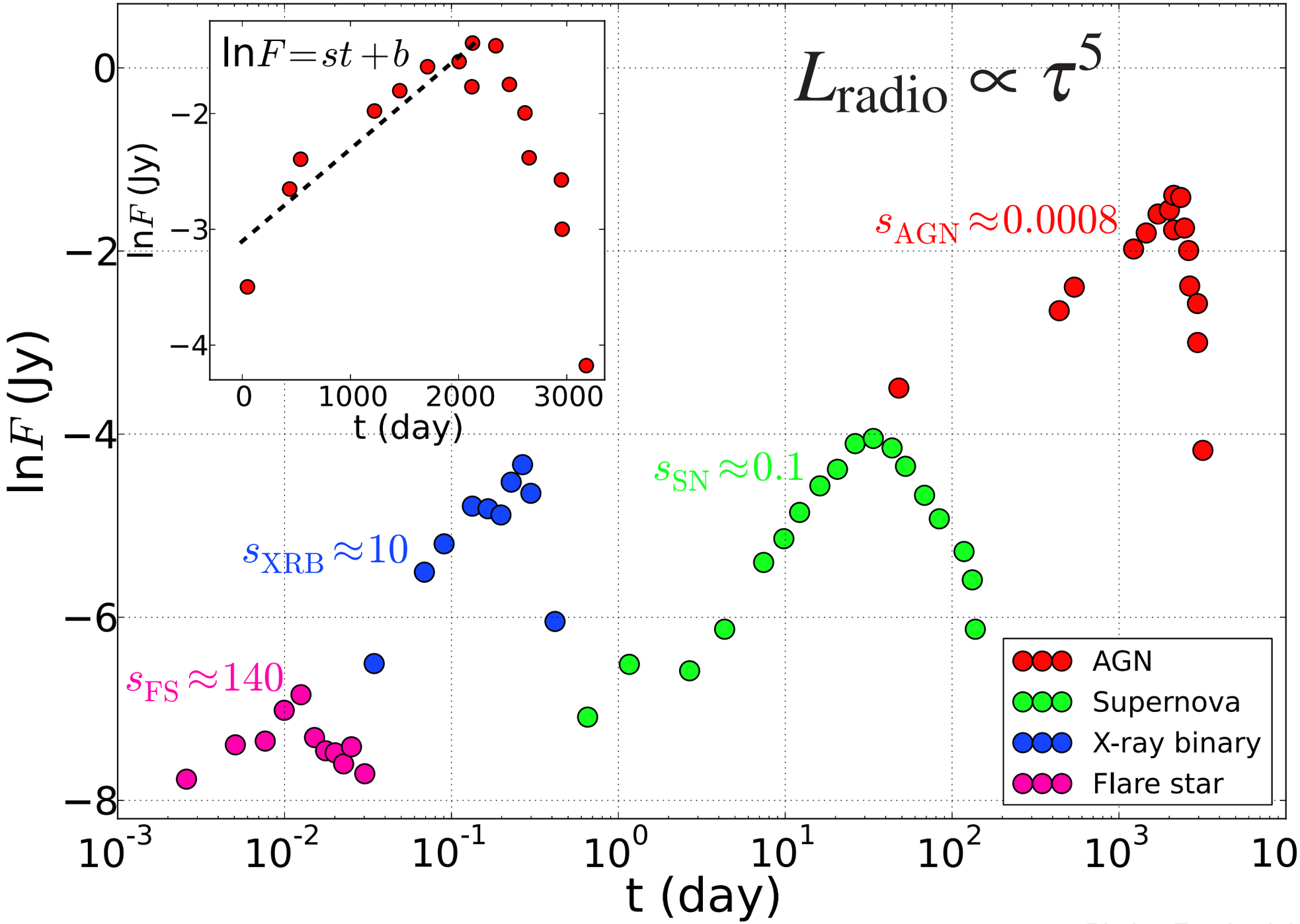
Observations show there is a 4.7:1 difference in the detection rate between high (>30 deg) and low latitude (*Petroff et al. 2014*)

latitude	Hours on sky	Events	Rate (h/event)
|b|<15	xxx	2	—
30<|b|<45	xxx	7	—
|b|>45	xxx	6	—

Interstellar scintillation explains this dependence: also implies source counts are non-Euclidean ($dN/dS_\nu \sim S_\nu^{-3.5}$) *(Macquart & Johnston 2015)*

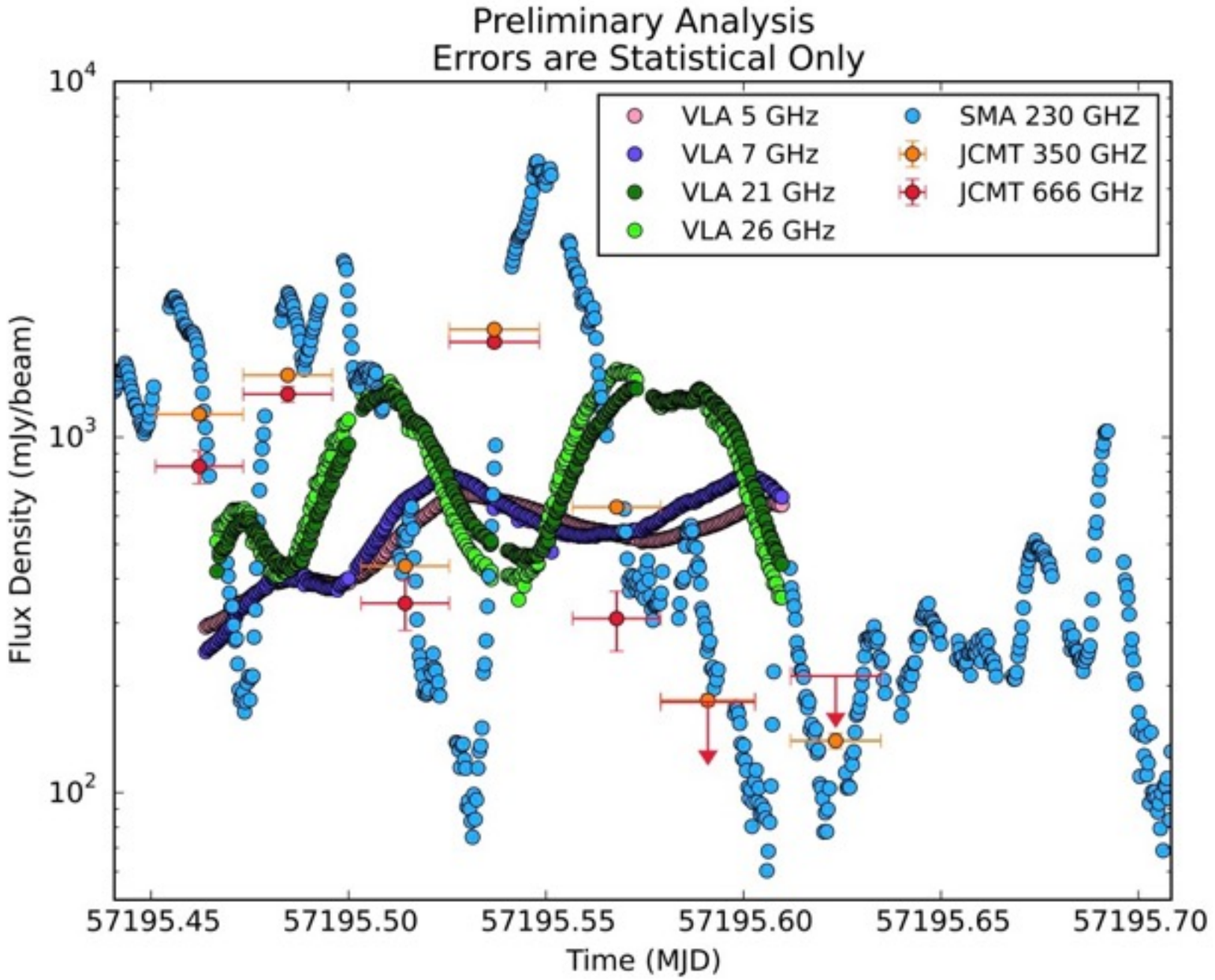
A Universe of Synchrotron Bursts

Incoherent synchrotron flares from a variety of objects on a large range of different timescales



Pietka, Fender & Keane 2015

Rapid variability in BHs



A light curve of simultaneous VLA, SMA and JCMT observations of V404 Cyg. The recent outburst of the black hole XRB V404 Cygni showed strong and rapid variability at all wavelengths.

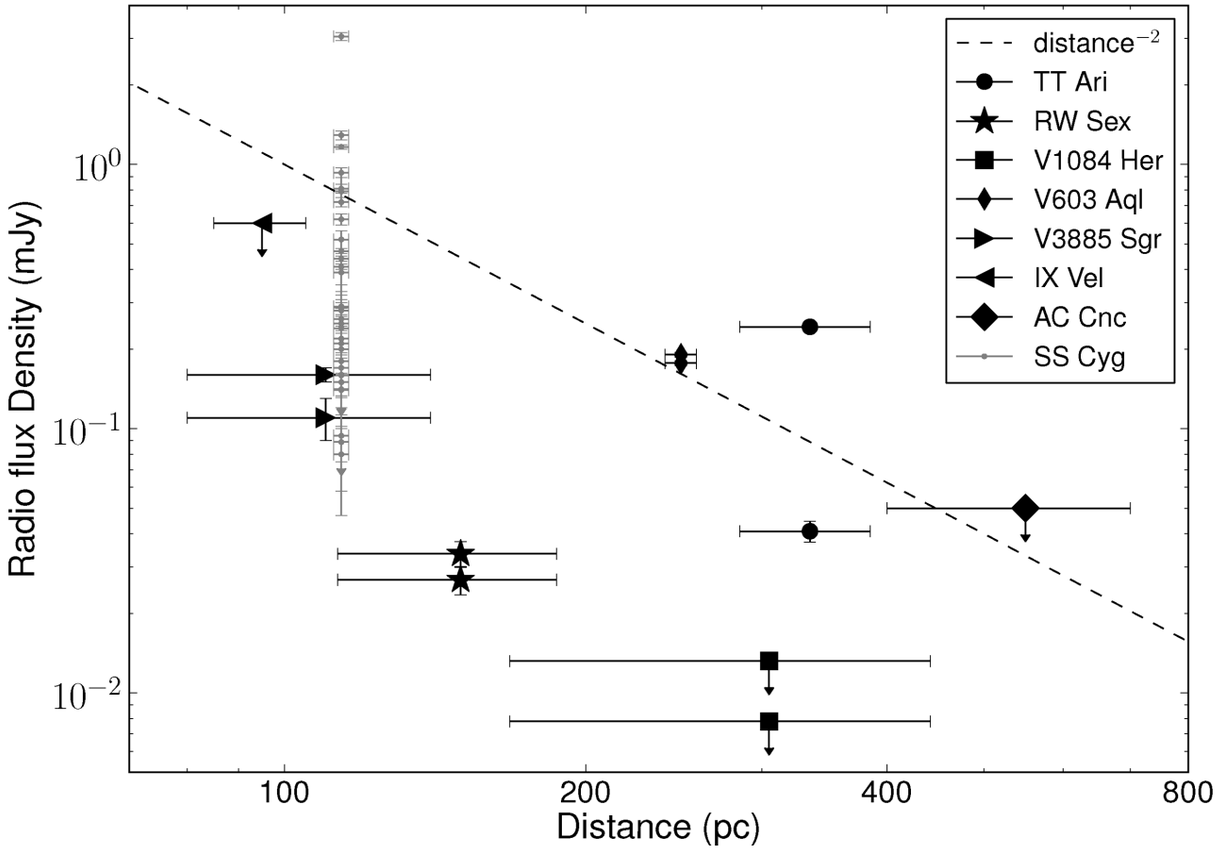
Tetarenko et al. 2015, ATel 7708.

CVs are radio emitters

A survey of dwarf novae *in outburst* found that all 5 of the observed systems were detected by the VLA, with flux densities of 15-50 uJy/beam (distances of 100-330 pc)

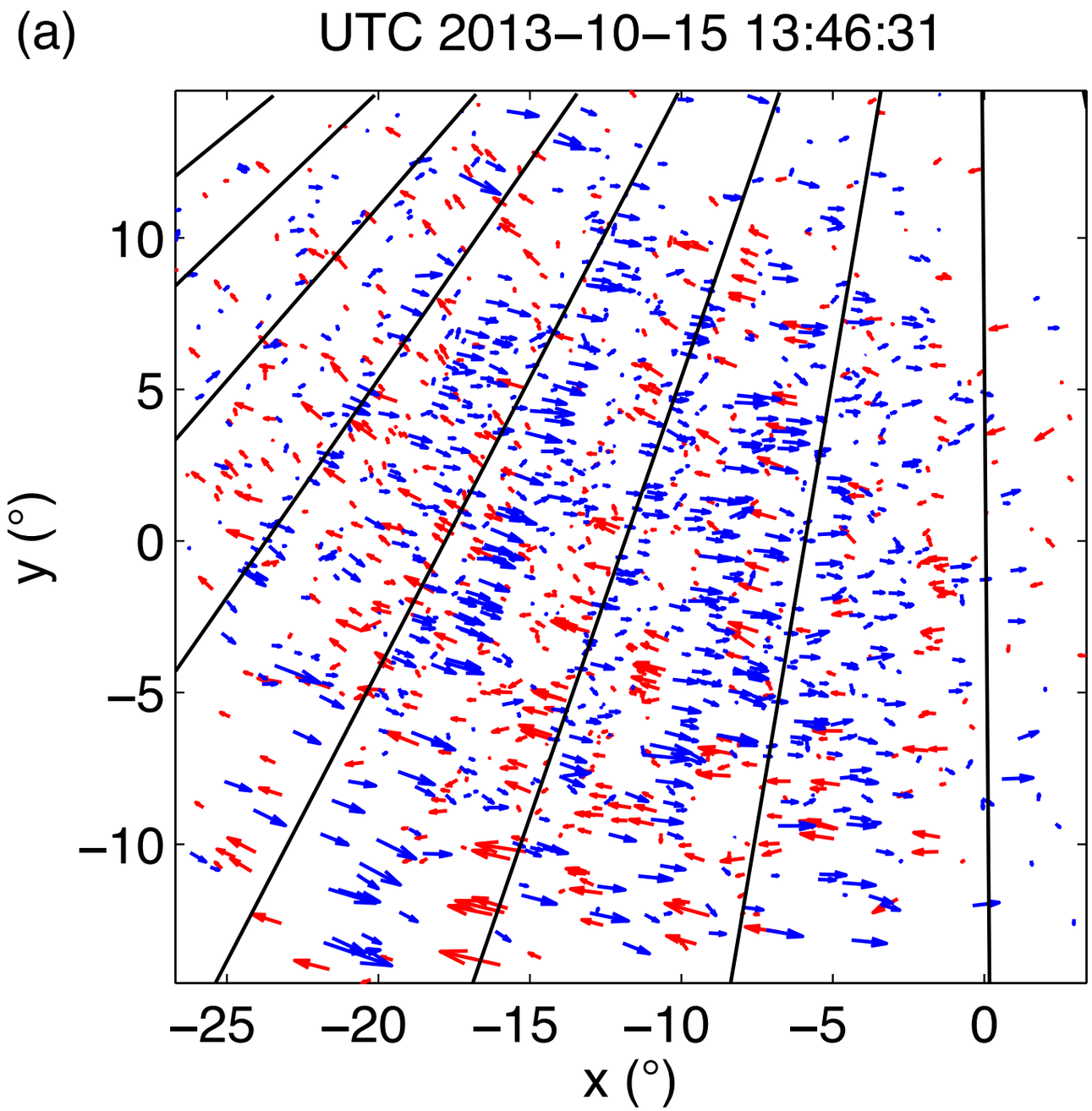
If they behave like SS Cyg, they will be undetectable in quiescence, implying they would be picked up as transients.

Dwarf novae are numerous, nearby, and non-relativistic accretion laboratories —
Provide a new probe of the accretion/ejection connection.
Comparison with neutron star and black hole systems can probe how jet launching is affected by the depth of the gravitational potential well.



Radio flux density of all high-sensitivity observations of non-magnetic CVs as a function of distance. (Coppejans et al. in prep.)

Ionospheric Ducts



The vector field of celestial source offsets, overplotted with the geomagnetic field lines (black solid lines) at an altitude of 600km. (Loi et al., Geo.Res.Lett., 2015)

A potent instrument: e.g. FRBs and the SKA

Parkes detects an FRB at a rate of
1 every ~10 days

SKA-mid has 1 sq. deg. FoV but high sensitivity

- Coherent detection (fast imaging): 260 times more effective than Parkes
  - Assuming rate scales as $\Omega\ S_{min}^{-3/2}$ (Euclidean space, no evolution)
  - If rate scales as $\Omega\ S_{min}^{-2.5}$ the advantage is ~ 6000
- SKA-low >18 sq. deg. FoV so even more potent
  - but temporal smearing and spectral index make it hard estimate advantage
  - MWA is placing limits on this already

"This station is now the ultimate power in the Universe. I suggest we use it."

Update from SKA precursors

MWA

- Limits on image plane event rate: 10^{-7} sq.deg.$^{-1}$ @ 28s cadence at 180MHz (Rowlinson et al. in prep.)
- Discovery of intermittent IPS very far from Sun (CMEs?)
- Ionospheric scintillation due to large organised structures (Loi et al.)

LOFAR

- LOTAAS LOFAR Tied-array All-sky survey - 219 beams (9 sq. deg).
  - Already doing an SKA-low beam formed survey to within a factor of 2 of the number of beams

MeerKAT

- commensal interrogation of MeerKAT data for transients was embraced by *all* PIs of the MeerKAT Large Survey Projects

VLA/VLBA

CVs

Ongoing high-time resolution searches (FRBs)

V-FASTR

STRIPE-82 (Kunal Mooley et al.)

Crossover with other science

Everybody will be doing Transients Science for us.

Pulsars

- High time resolution

EOR

- A contaminant that needs to be removed from data

Continuum

- IDV present in >50% of all flat-spectrum AGN

Our Galaxy

- Novae, flare stars, X-ray binaries

Cosmic Rays

- All-sky at sub-ms Δt/Shares several technical requirements

VLBI

- An essential component of followup for some science

HI/Spectral line

- Variable HI absorption by intervening galaxies

SKA as an effective machine

Respond to (and issue) triggers

- To what extent should we “respond”?

Real-time commensal time-domain & image plane search

- ~10x more time on sky than a dedicated project
- Find 10x more events, and events that are 10x rarer

Buffer - images & voltages

- A time machine to respond to triggers with some latency (e.g. from our own detection systems)

VLBI: an essential followup component

Archive

Which events are the real gems?

SKA will see huge numbers of transients, but need enough information to sort the wheat from the chaff.

SKA-era Transients Landscape

***Relevance* is key:**

We must have the capacity to link our objects to the rest of the electromagnetic spectrum

Optical in the era of…

- LSST
- OWLs
- *Desert Transients Factory*

Do we want our own dedicated telescope? *(MeerLicht)*

JWST

ALMA

X-ray/gamma-ray

Advanced LIGO

Should we be looking to obtain a database of Kepler-like exquisite light-curves?

The  message

Transients science will make the SKA productive out of the blocks

- Significant discoveries while large-scale surveys are still ramping up
- Spot defects & issues in the data that you might not otherwise know exist
  - A means of bedding down the instrument — for free!

Most Transients science can be commensal

- Possible exceptions are surveys of particular targets, e.g. Galactic Centre, nearest [insert name of favourite target here]

What is the raison d'être for a *transients* KSP?

- A group that requires significant front-end resources? ("directs the telescope pointing")
- A group that requires significant observatory resources? (Archives, voltage capture buffers, triggering functionality,…)
- An identifiable entity capable of netting significant third-party resources for the SKA?