International Centre for Radio Astronomy Research

Transients: Imaging & Detection

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What are radio transients?

Anything that varies, bursts, pulses, appears, dissappears …

Tends to mark compact sources or the locations of explosive or dynamic events.

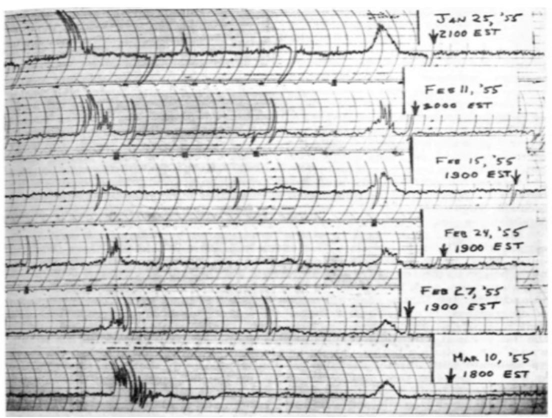
Compared to other wavelengths, radio provides:

- Measures kinetic energy feedback in relativistially moving ejecta
- Characterises intervening ionised media via scattering, dispersion & polarisation changes
- Provides precise localisation across wide field of views

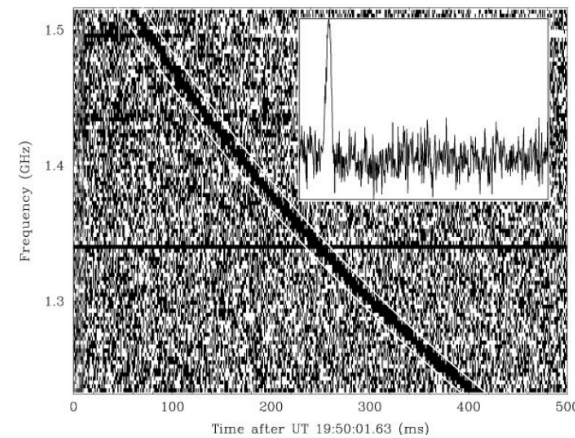
Radio variability discoveries

Many unexpected astrophysical phenomena revealed or better understood through observations of radio variability:

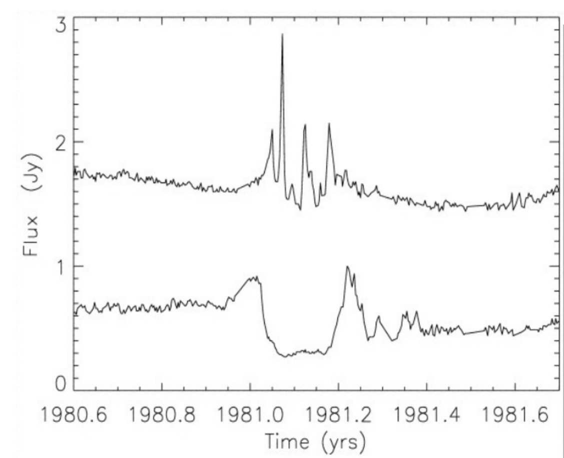
Jovian bursts (Burke & Franklin 1955)



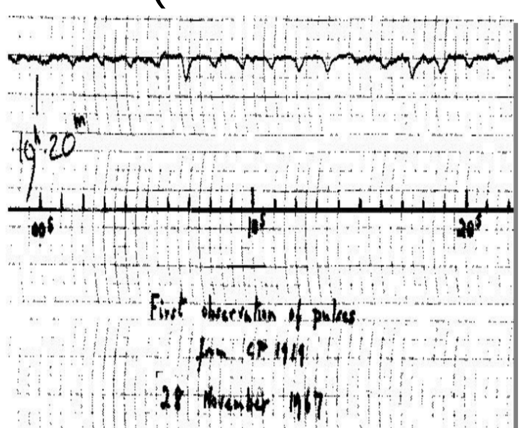
Fast radio bursts (Lorimer et al. 2007)



Extreme scattering events (Fiedler et al. 1987)



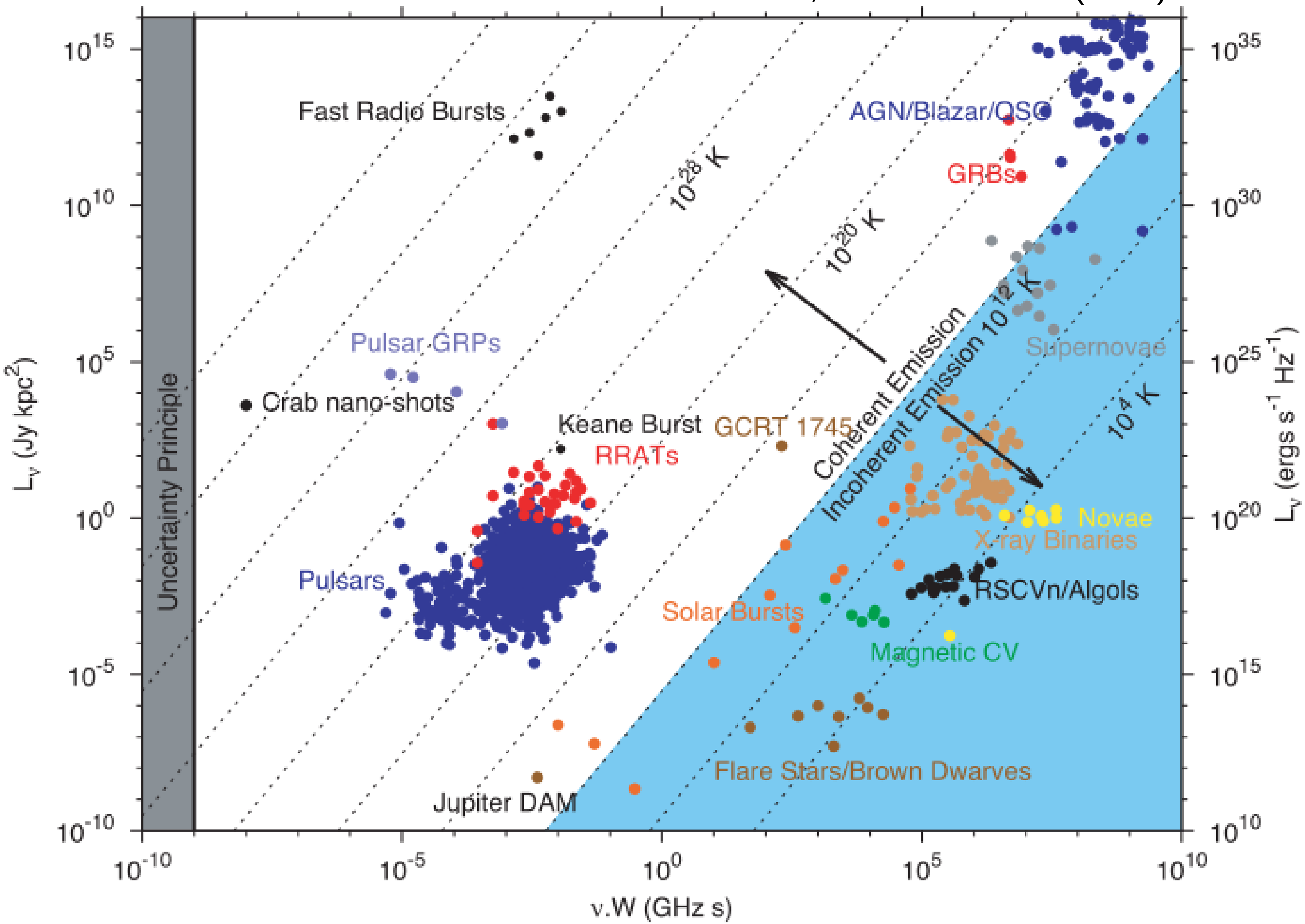
Pulsars (Hewish et al. 1968)



(See Fender et al. 2015 arXiv:1507.00729)

Types of radio transients

Pietka, Fender & Keane (2015)



Synchrotron (incoherent) sources

Assocaiated with explosive kinetic feedback & particle accleration

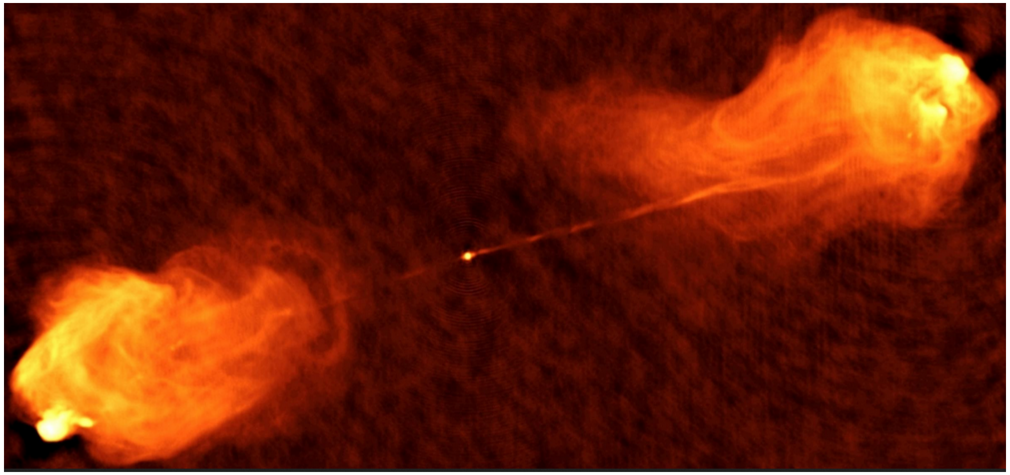


Image credit: NRAO / AUI

Examples: AGN & microquasar jets; Supernova & GRB afterglows, stellar flares

Brightness temprature (T_B) limited to < 10^{12} K

Timescale often longer than single observation

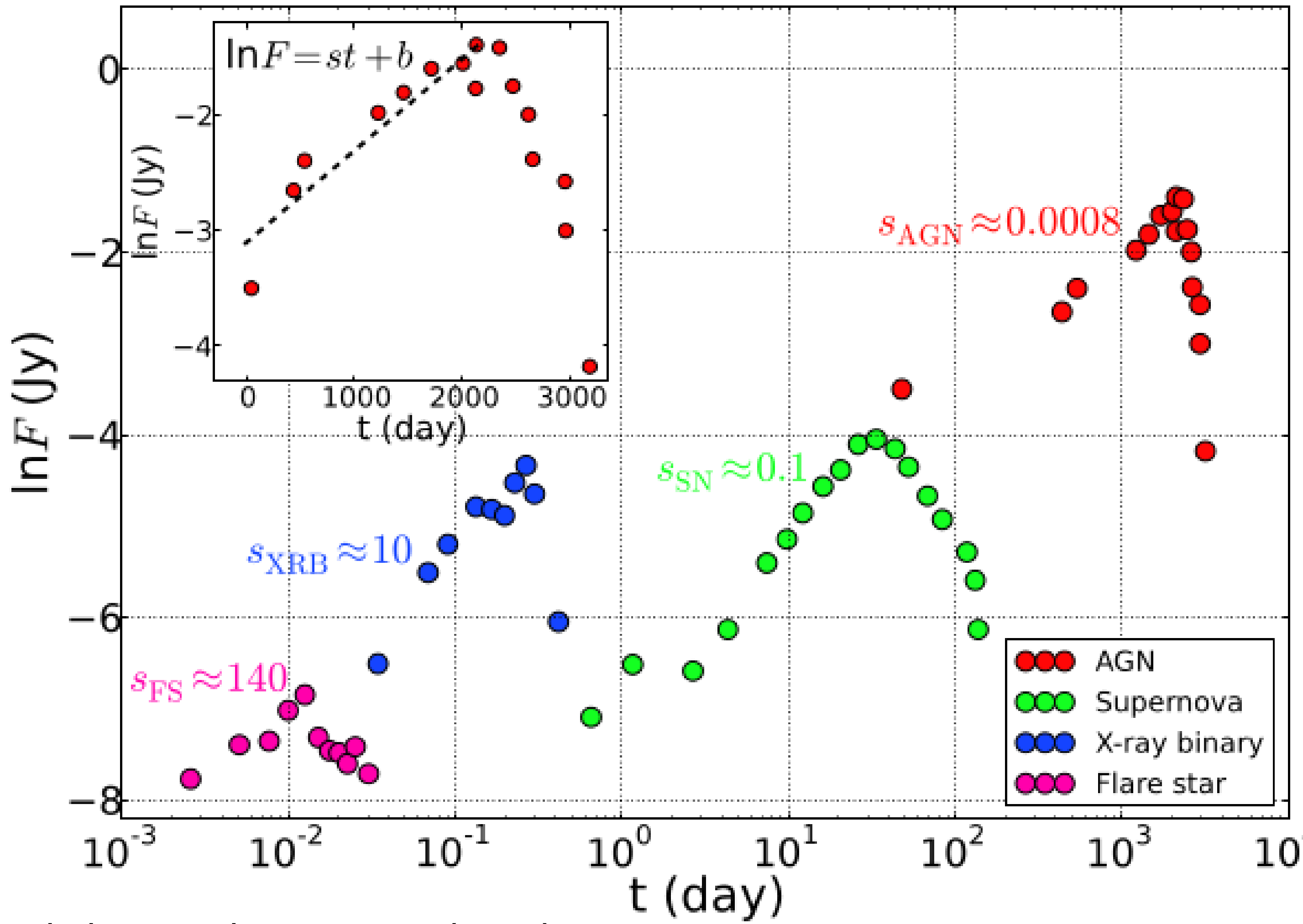
Typically have rich multiwavelength counterparts

Timescales of synchrotron bursts

Due to T_B limitation, more luminous sources must be physically bigger and vary more slowly.

$T_B \sim F\ (\Omega)^{-1}$

F = Flux density
Ω = Solid angle



Pietka, Fender & Keane (2015)

Coherent sources

Examples: Pulsars, Planetary masers, Fast Radio Bursts

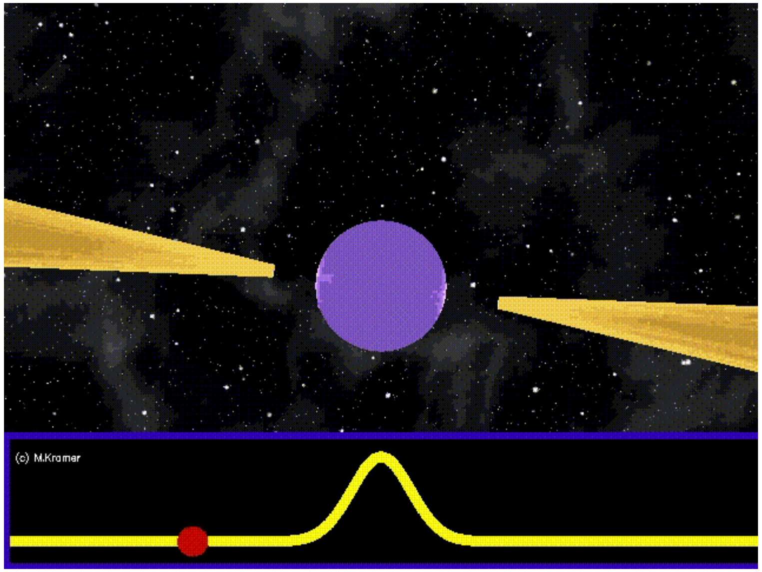


Image credit: Michael Kramer (JBCA, Unversity of Manchester)

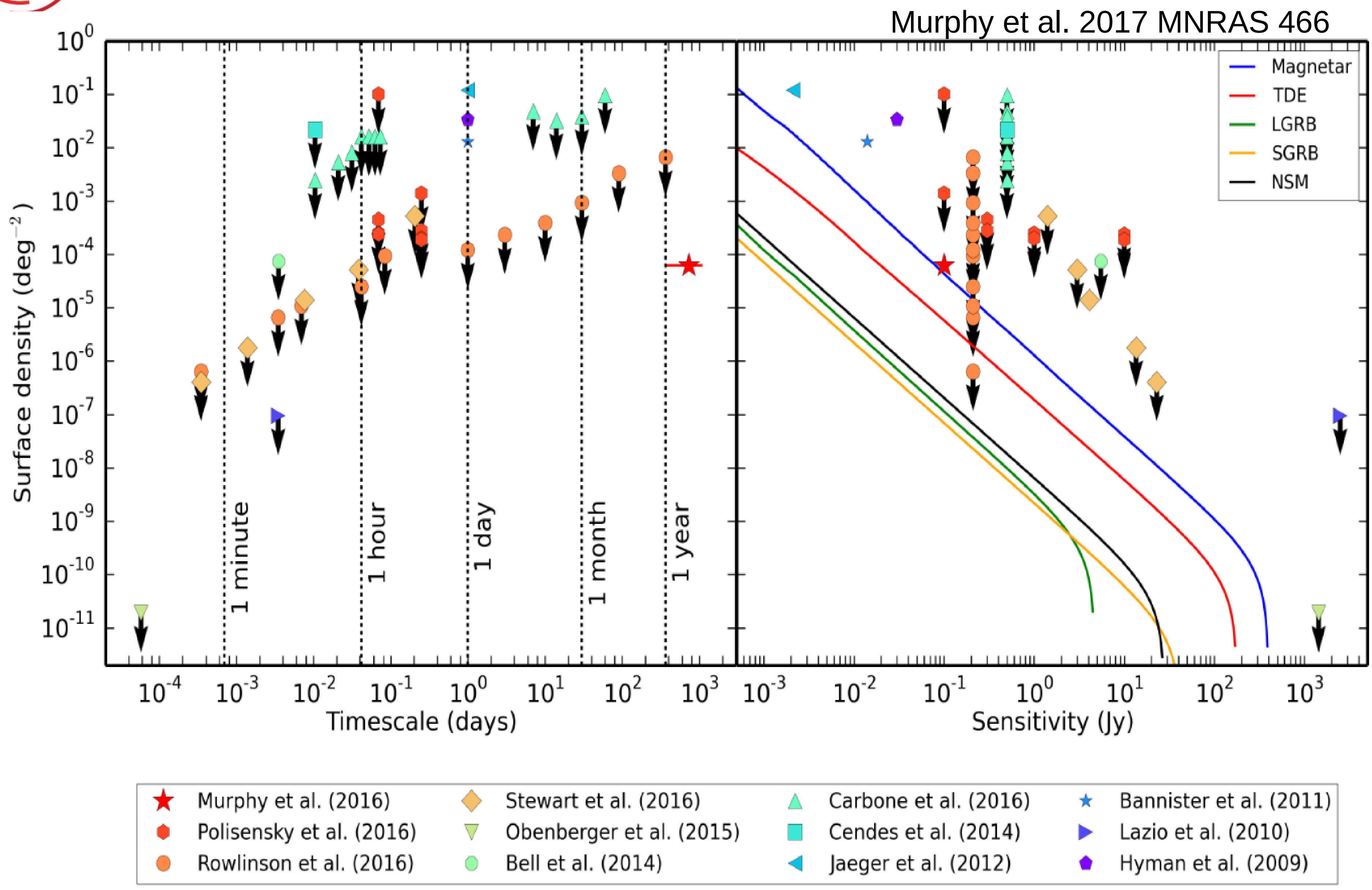
Can achieve much higher T_B (timescales ~ ns to minutes).

Not usually associated with energy release on scale of most luminous synchrotron events.

Commonly used to characterise emission sites and intervening material (via propagation effects).

Often (but not always!) observed via beamforming.

Radio transient rates



How do we detect transients?

Two main methods:

(1) Image plane searches (both)

(2) Beamforming (coherent)

This talk will focus on image plane techniques (sorry to those who prefer beamforming...)

Survey strategies

In general surveys for transients want:

$$A\Omega\left(\frac{T}{\Delta t}\right) = \text{large}$$

A = collecting area

Ω = solid angle coverage

T = total duration of observations

Δt = time resolution

Many new radio telescopes are trying to maximise sky coverage (Ω) while keeping small time resolution.

Imaging considerations

For a fixed number of infrequent events occuring during an observation, increasing integration time T:

$$\text{Signal} \sim 1/T$$

$$\text{Noise} \sim (1/T)^{1/2}$$

$$\Rightarrow S/N \sim (1/T)^{1/2}$$

There is some optimal integration time based on the duration/frequency of bursts you expect for your source – longer integrations reduce significance of signal!

Blind searches

Uses large amount of data to find a source that varies or appears briefly (no previous knowledge).

Dedicated surveys (e.g. Hyman et al. 2005 Nature 434, Lazio et al 2010 AJ 140)

Archival data (e.g. Bower et al. 2007 ApJ 666, Bannister et al. 2011 MNRAS 412)

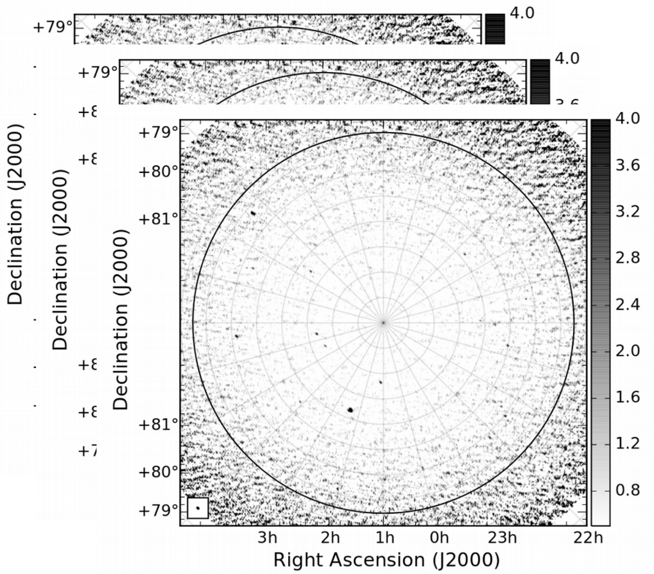
Commensal data (e.g. Stewart et al. 2016 MNRAS, Rowlinson et al. 2016 MNRAS 458)

Catalogues from surveys (e.g. Thyagarajan et al. 2011 ApJ 742, Murphy et al. 2017 MNRAS 466)

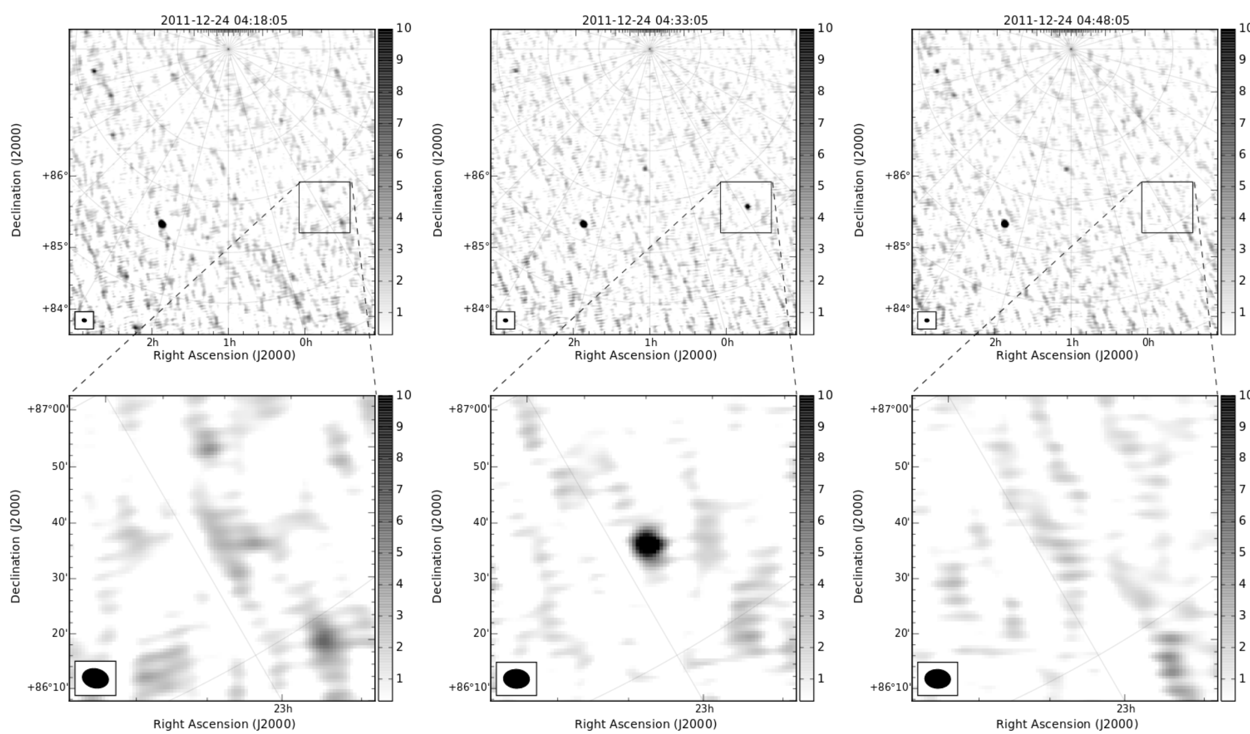
Many other references … check out Fender & Bell 2011 BASI 39

Determining variability

New wide field radio images contain 10s - 1000s of sources – how do we find the transients?



Stewart et al. 2016 MNRAS 456



Determining variability

General transients pipeline:

Find → Associate → Monitor → Determine variability

Variability statistics:

$$\eta_\nu = \frac{1}{N-1}\sum_{i=1}^{N}\frac{(I_{\nu,i}-\xi_{I_\nu})^2}{\sigma^2_{\nu,i}}$$

Chi-square probability of constant flux

$$V_\nu = \frac{s}{\overline{I_\nu}} = \frac{1}{\overline{I_\nu}}\sqrt{\frac{N}{N-1}\left(\overline{I_\nu{}^2} - \overline{I_\nu}^2\right)}$$

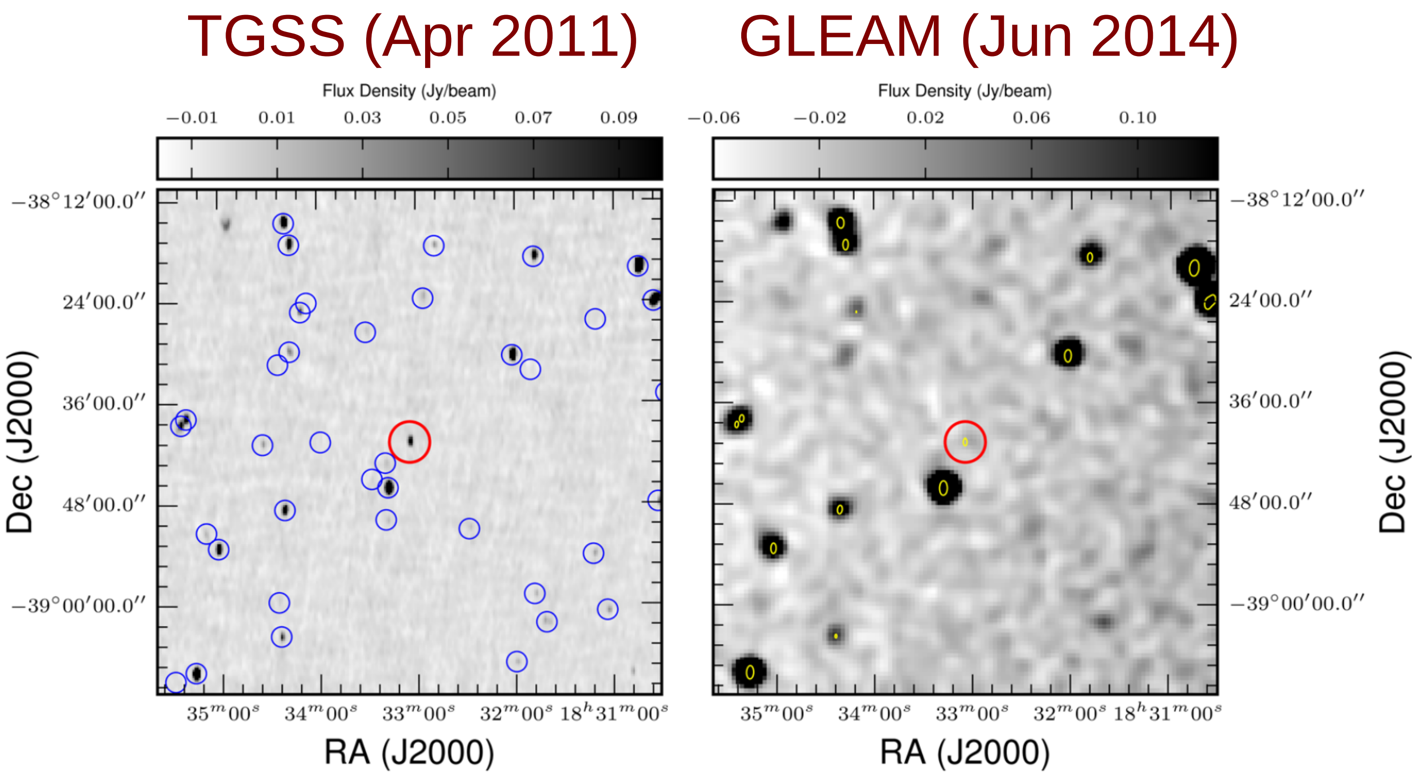
Coefficient of variation (modulation)

Final steps:
(1) Source testing
(2) Source identification

TraP (Swinbank et al. 2015 Astronomy and Computing 11)

VAST (Murphy et al. 2013 PASA 30; Bell et al. 2014 MNRAS 438)

Catalog comparisions



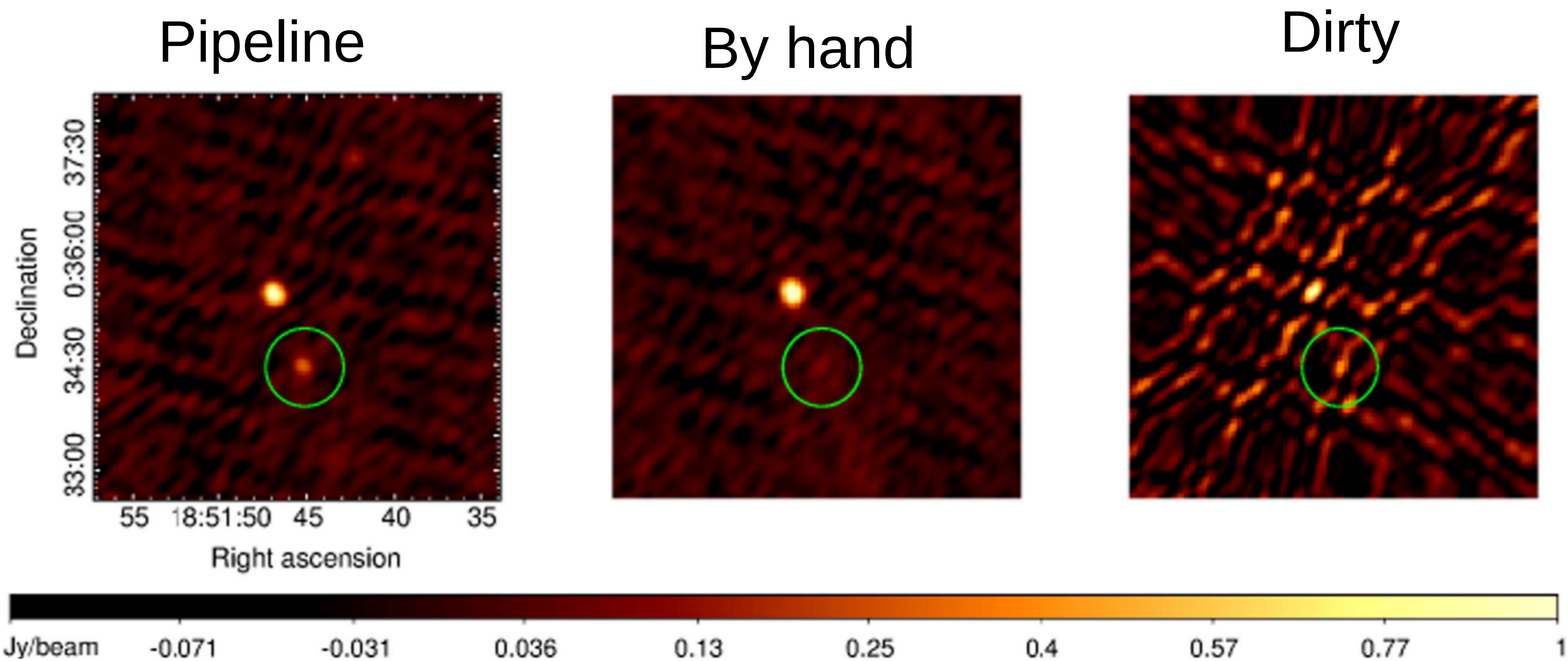
Murphy et al 2017 MNRAS 466

Cross-matching catalogues of sources with similar sky coverage

Need to be aware of differences in sensitivity & resolution which can result in false positives.

Caution!

Blindly looking for transient sources tends to reveal errors – good test of data!



Polisensky et al. 2016 ApJ 832

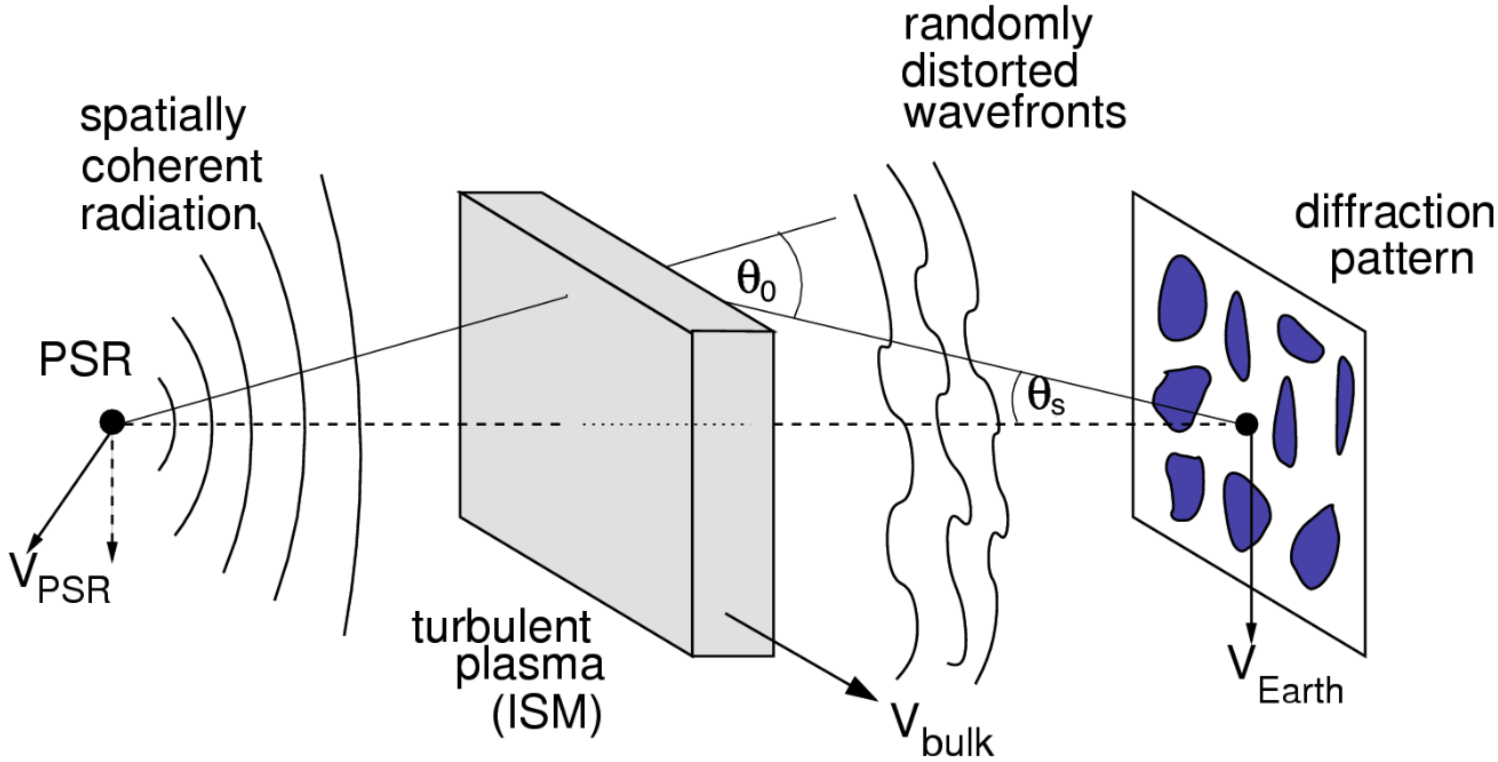
Making the search easier …

Is there a way to eliminate most of the image sources leaving the transient?

Could be source specific (e.g. polarisation) – use what you know about the transient source of interest.

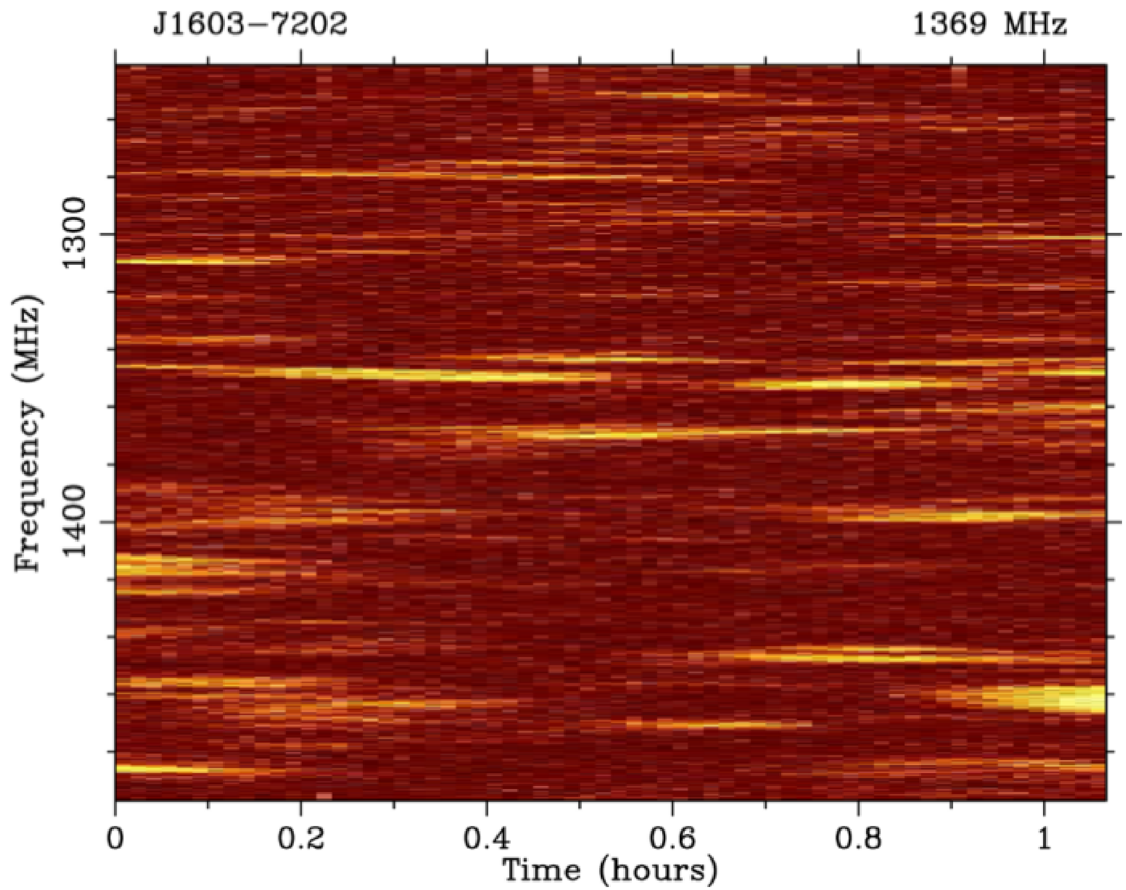
Could be clever imaging technique (e.g. image subtraction).

Interstellar scintillation



Lorimer & Kramer (2005) Handbook of Pulsars Astronomy

Pulsars & scintillation

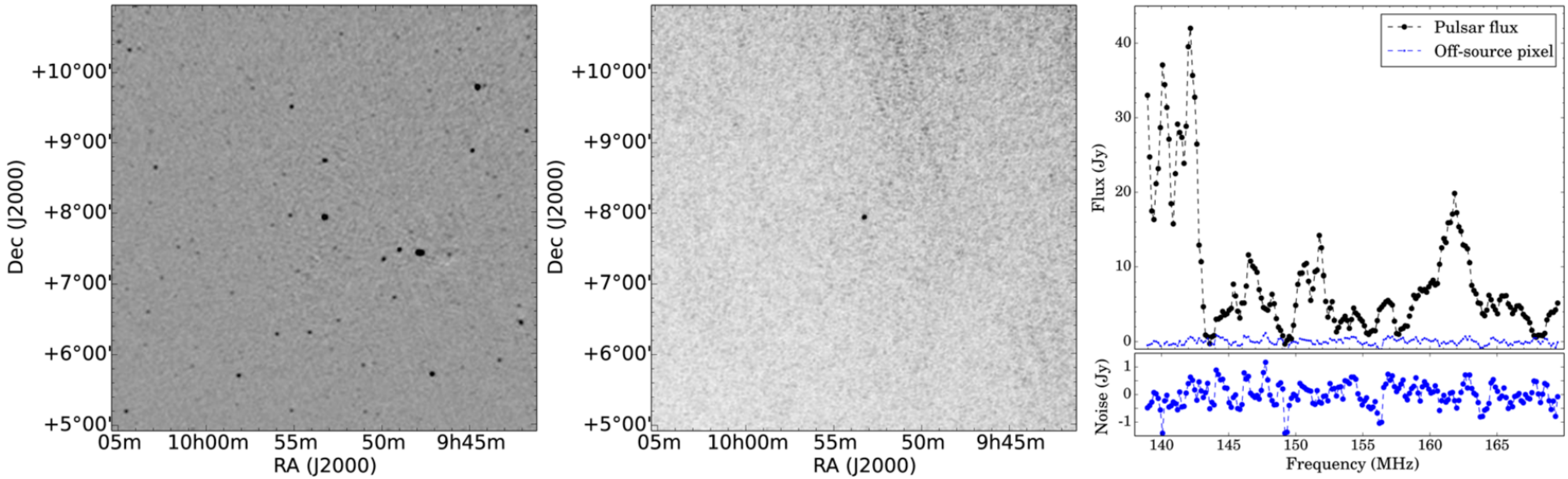


Dai et al. 2016 MNRAS 462

Pulsars are only known source compact enough to show diffractive interstellar scintillation.

Variance imaging in frequency

Stokes I | Variance



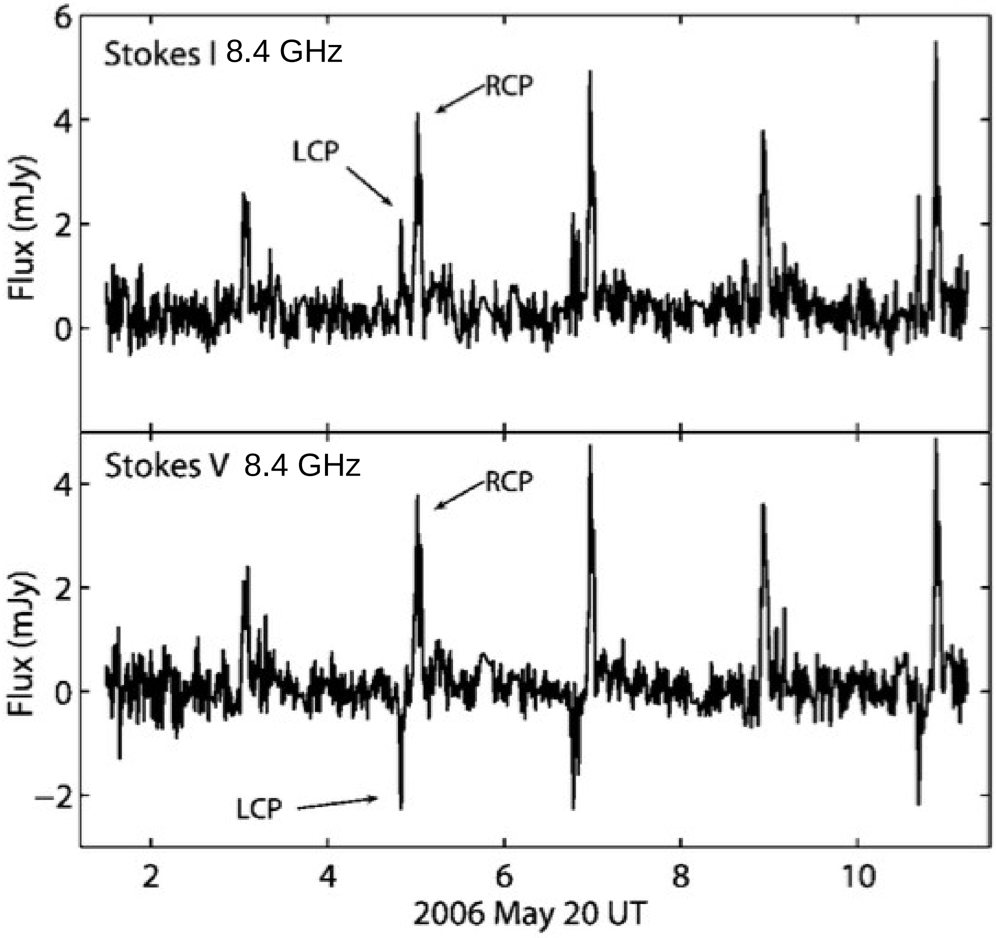
Dai et al. 2016 MNRAS 462

Most sensitive to pulsars with scintillation bandwidth and time-scales close to the channel bandwidth and subintegration time.

Need to construct a set of variance images with different channel bandwidth and subintegration time.

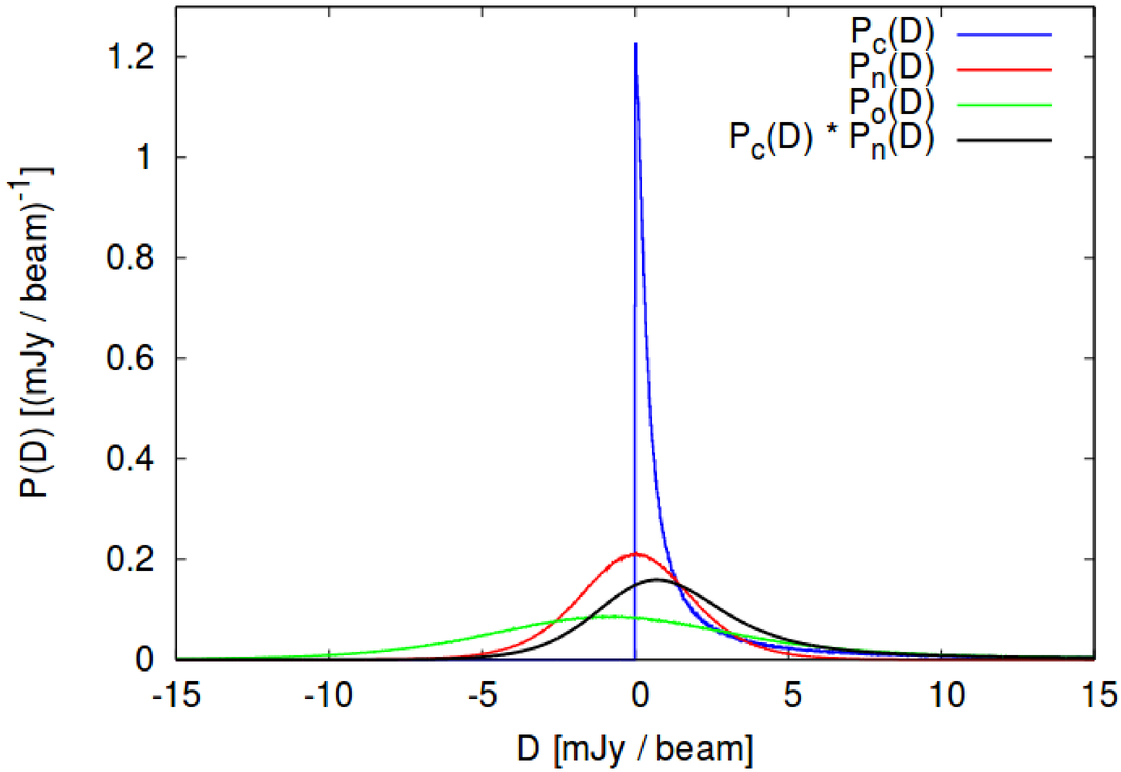
Circularly polarised transients

Hallinan et al. 2007 ApJ 663



Very few astronomical sources produce strong circular polarisation (stellar objects, planets, pulsars).

Additional benefit



$$P_o(D) = P_n(D) * P_c(D) * P_s(D)$$

$P_n(D)$ = Guassian noise

$P_c(D)$ = Confusion

$P_s(D)$ = Sidelobes

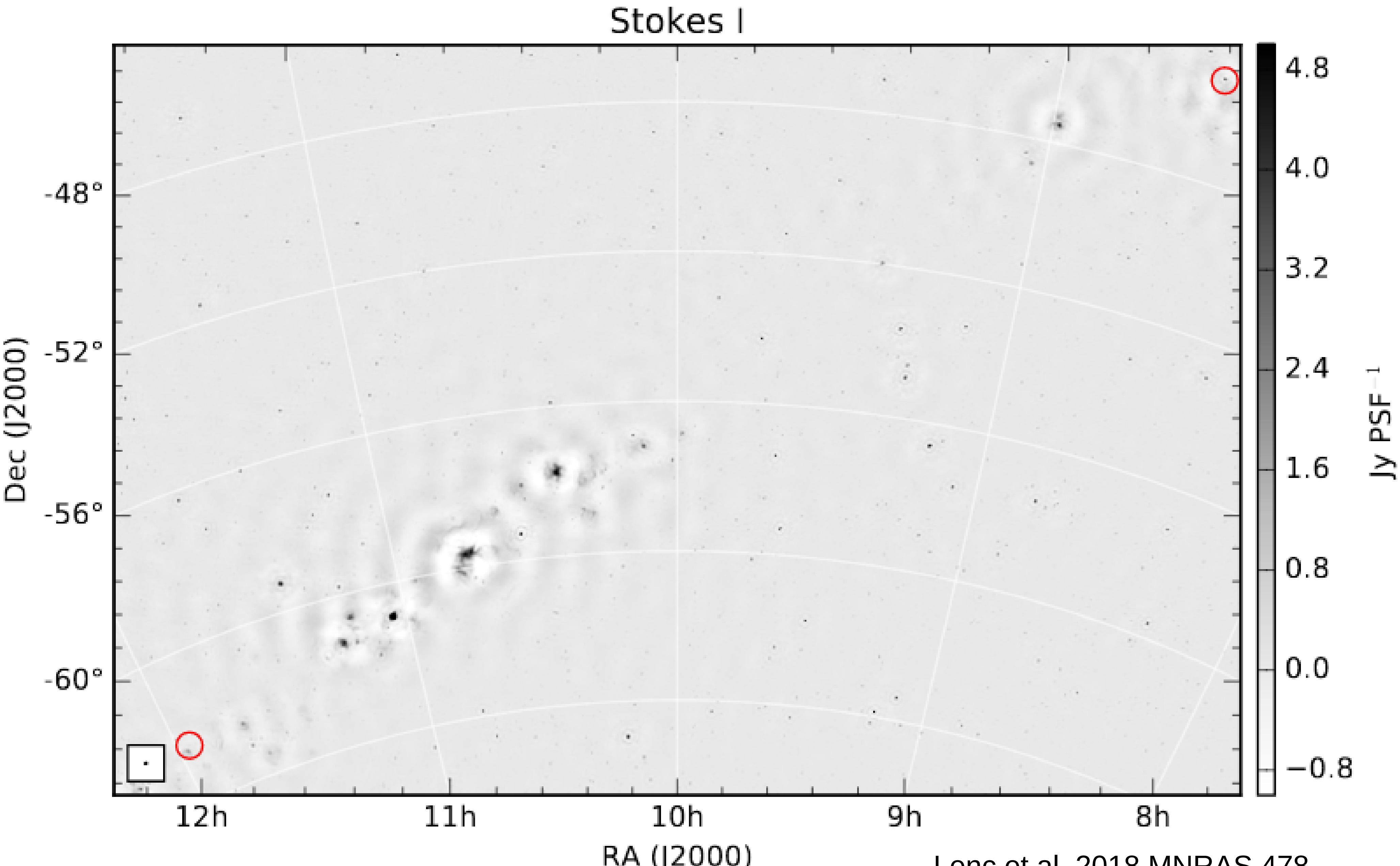
Franzen et al. 2016 MNRAS 459

Telescopes limited by confusion noise in total intensity (MWA), longer integrations not helpful.

BUT circular polarisation can get around confusion & slidelobe noise.

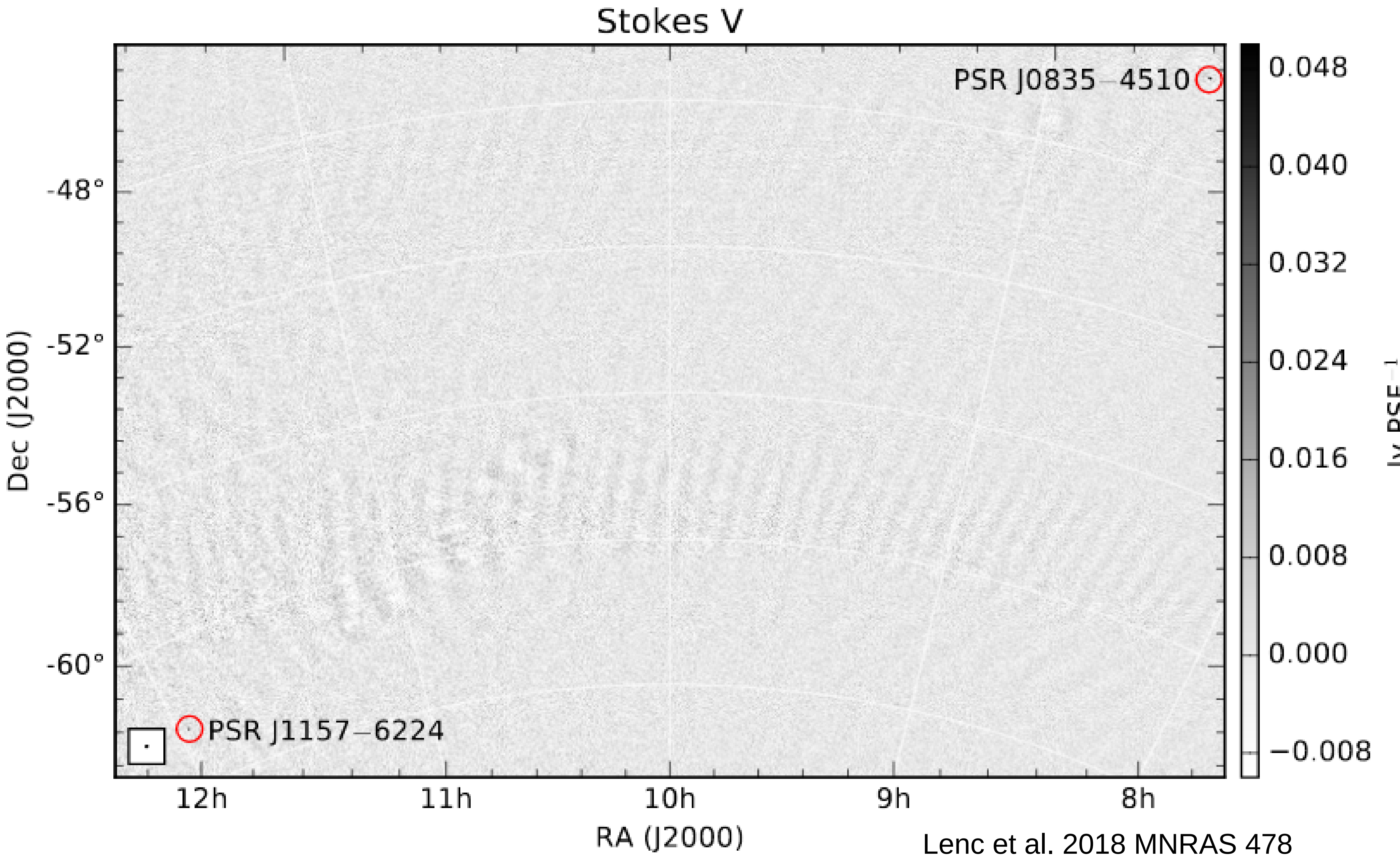
(For more on confusion noise see Condon et al. 1974 ApJ 188 or https://www.atnf.csiro.au/projects/askap/newdocs/condon_memo.pdf)

Total intensity sky



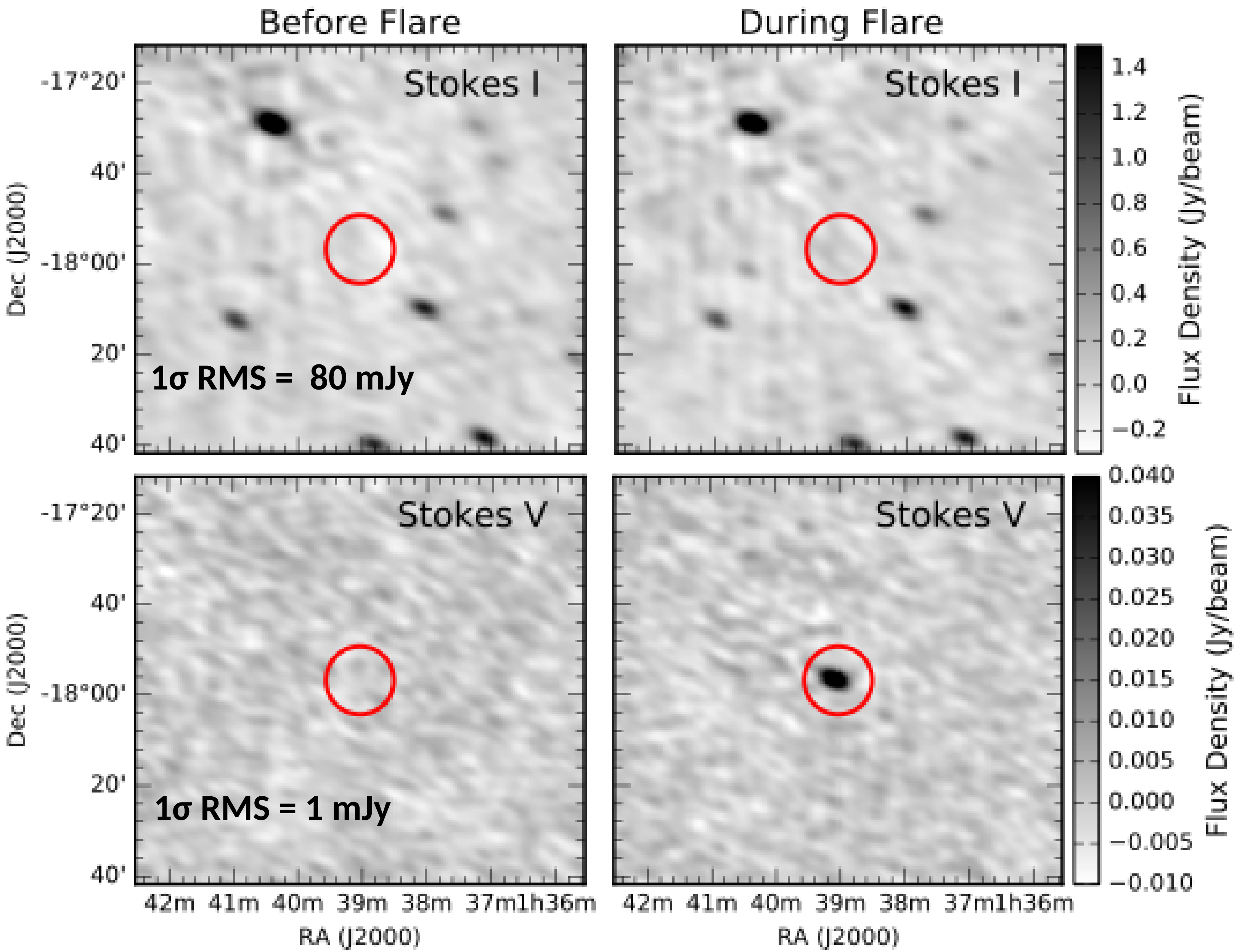
Lenc et al. 2018 MNRAS 478

Circularly polarised sky



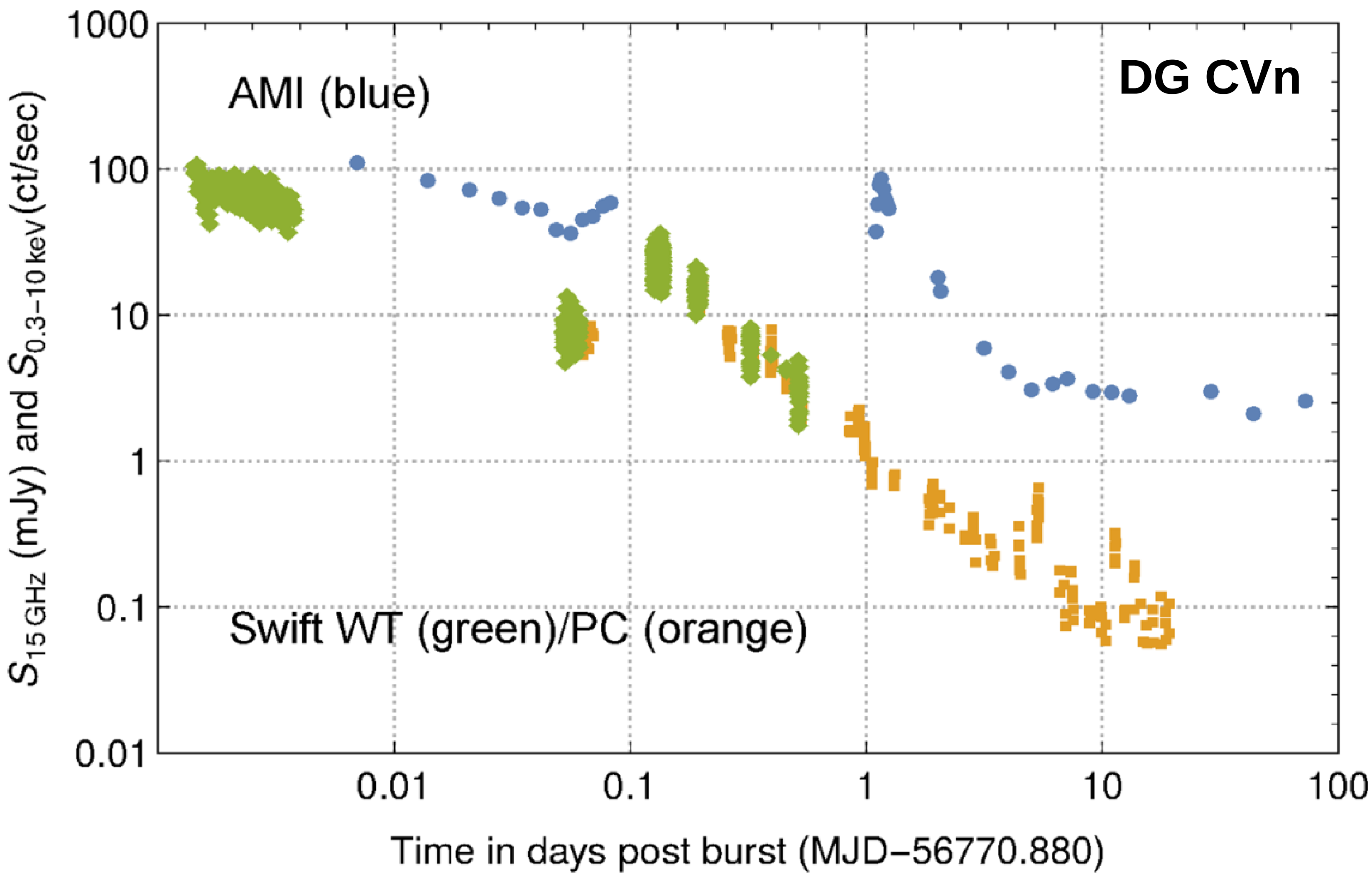
Lenc et al. 2018 MNRAS 478

Flare star UV Ceti



Lynch et al. 2017 ApJL 836

Multiwavelength triggering



Fender et al. 2015 MNRAS 446

Summary:

Many different types of transient sources (incoherent & coherent).

Usually tell us about the most extreme astrophysical phenomena/environments.

Searching for transients is a data management problem – how to identify an unusal source among 100s of others.

Identifying transients can also be a good test of your data and processing pipelines.

Understanding your data & your sources can make your search easier – be creative!