DUNLAP INSTITUTE
for ASTRONOMY & ASTROPHYSICS

Wide-Field Radio Astronomy and the Dynamic Universe

Bryan Gaensler / @SciBry
Dunlap Institute
University of Toronto

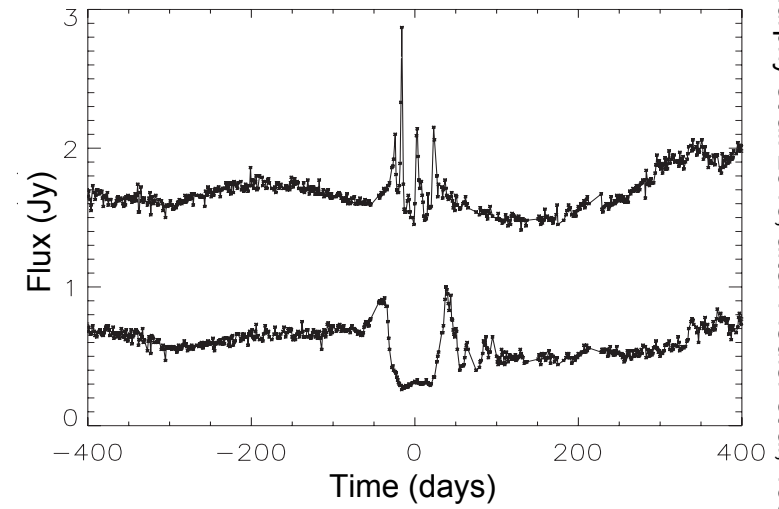
with Cleo Loi, Kitty Lo,
Martin Bell, Keith Bannister,
Paul Hancock, Tara Murphy
and the MWA Collaboration

MWA
MURCHISON
WIDEFIELD
ARRAY

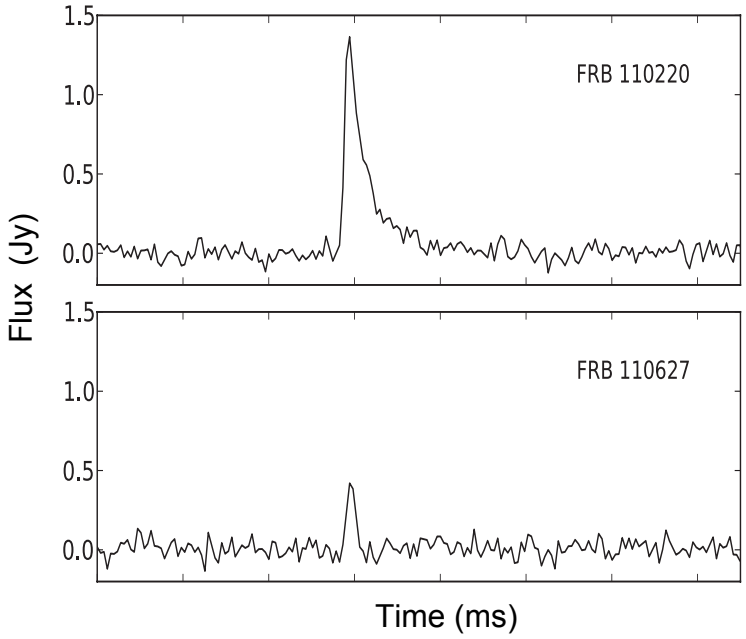
The Dynamic Radio Sky

Dunlap Institute for Astronomy & Astrophysics
UNIVERSITY OF TORONTO

- Variability ↔ *unique view of extreme physics*
- Variability at radio wavelengths
  - no extinction, extreme sensitivity & resolution
  - small fields of view; e.g. VLA = 0.2 deg^2
- **Explosions** (relatively rare; Metzger et al. 2015)
  - supernovae, GRBs, orphan afterglows
  - mass-loss history, beaming
- **Propagation** (relatively common; Lo et al. 2013)
  - scintillation, **extreme scattering events**
  - probes of turbulence; baryons in the IGM
- **Accretion**
  - X-ray binaries, AGN, quasars
  - disk/jet connection
- **Magnetospheres**
  - pulsars, magnetars, flare stars, exoplanets
  - reconnection, particle acceleration
- **The Unknown**
  - **fast radio bursts** (1 every 10 seconds!)



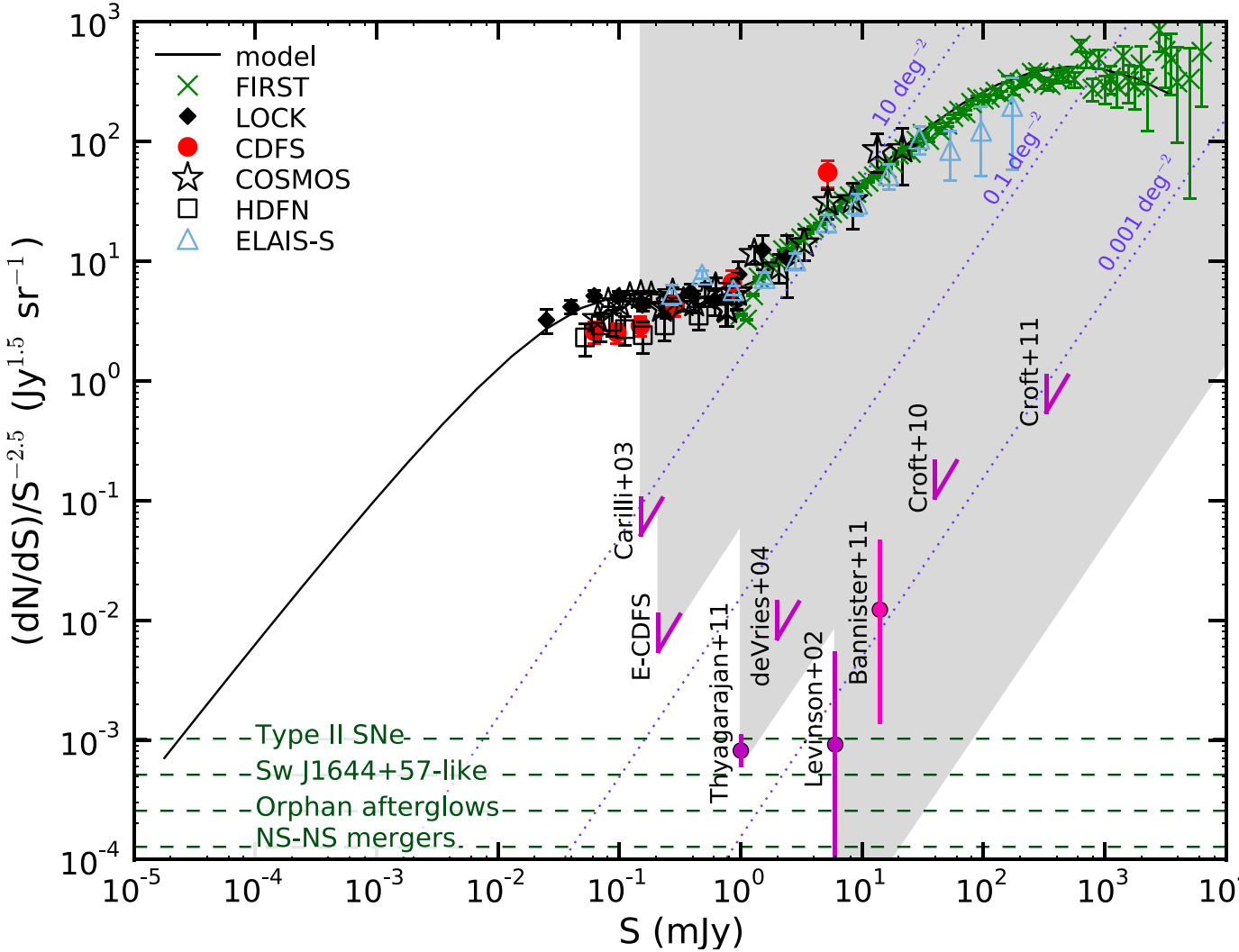
Extreme scattering event
(Murphy et al. 2013, after Fiedler et al. 1987)



Fast radio bursts
(Thornton et al. 2013)

Transient Event Rate at 1.4 GHz

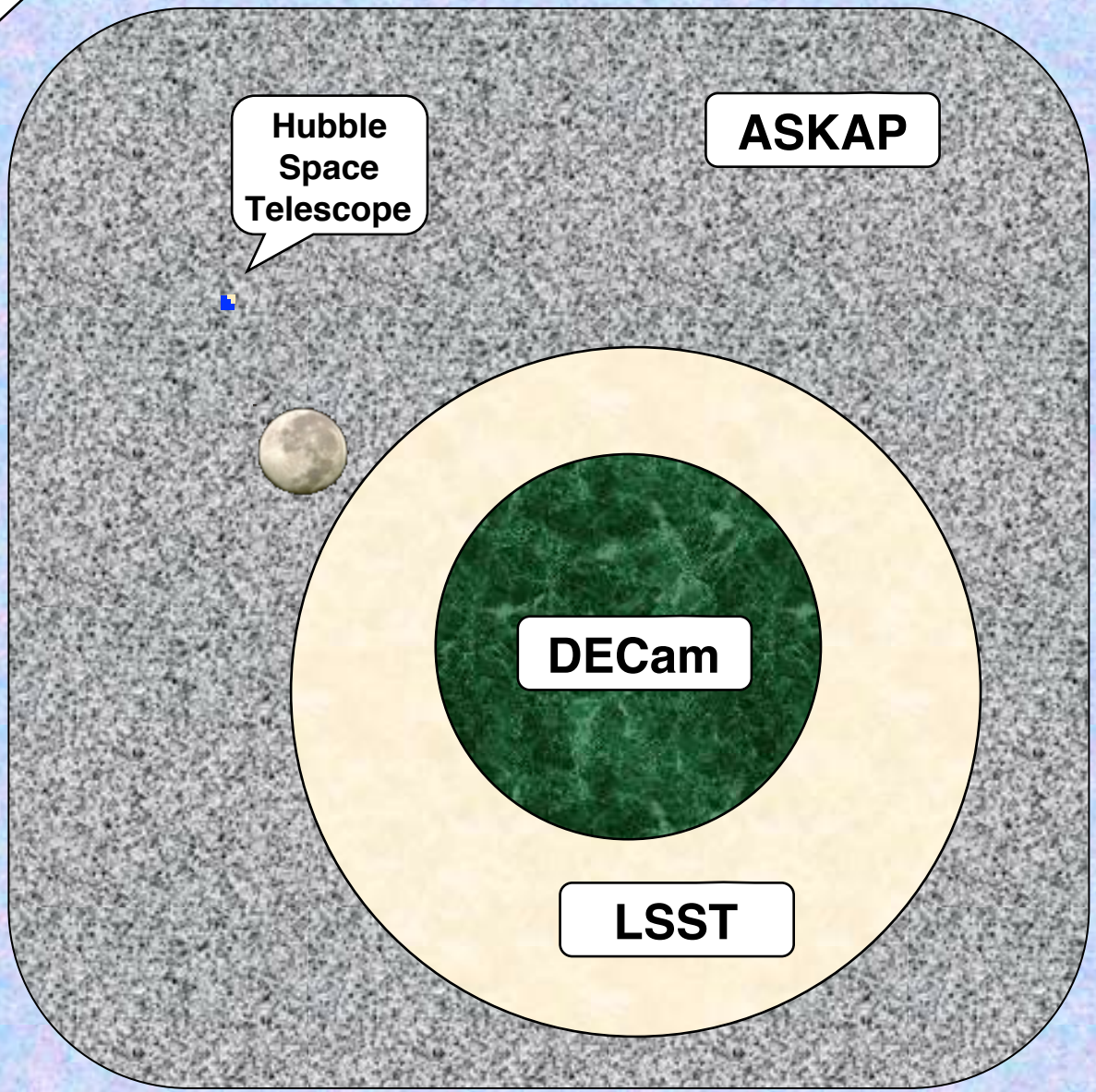
Dunlap Institute for Astronomy & Astrophysics
UNIVERSITY OF TORONTO



Mooley et al. (2013)

Wide-Field Radio A

- Many small antennas c
  - MWA, LOFAR,
  - wide fields, r
    enormous
  - → dedi
  - → n
  - →

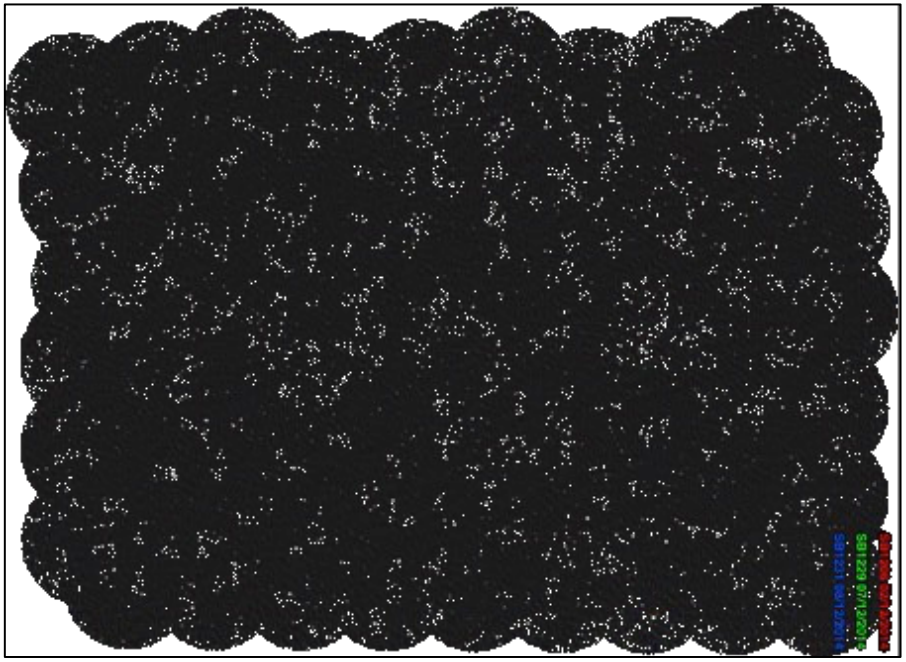


MWA

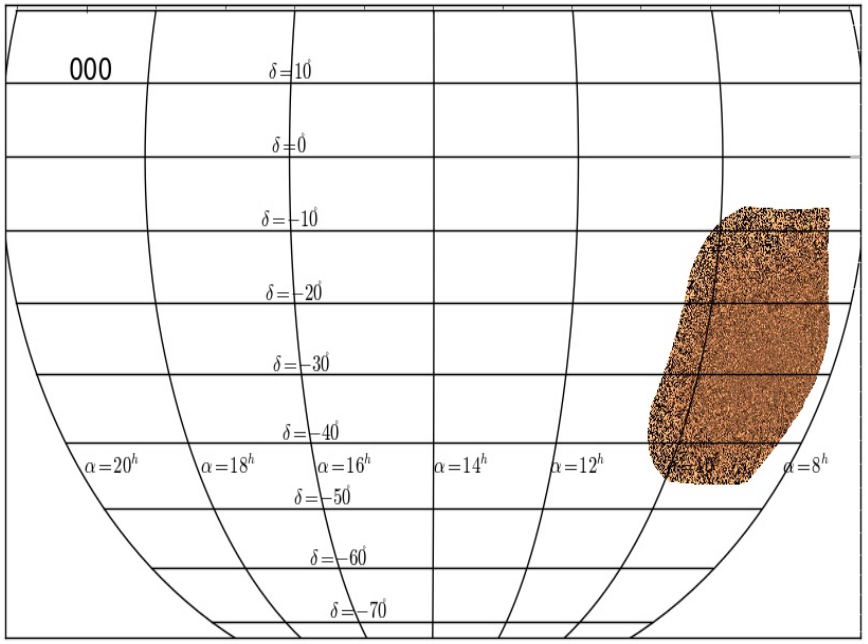
Wide-Field Radio Astronomy

Dunlap Institute for Astronomy & Astrophysics
UNIVERSITY OF TORONTO

- ASKAP Tucana survey (6/36 dishes)
  (Heywood et al. 2015)
  - 150 deg^2 in 12 hrs at 1.4 GHz
  - 3 epochs to 1 mJy; 2000 sources
  - all-sky image database: ~50 PB
- MWA Transients Survey
  (MWATS; Bell et al. 2014)
  - 16000 deg^2 in 10 hrs at 150 MHz
  - 24 epochs to 10 mJy;
    20000 sources



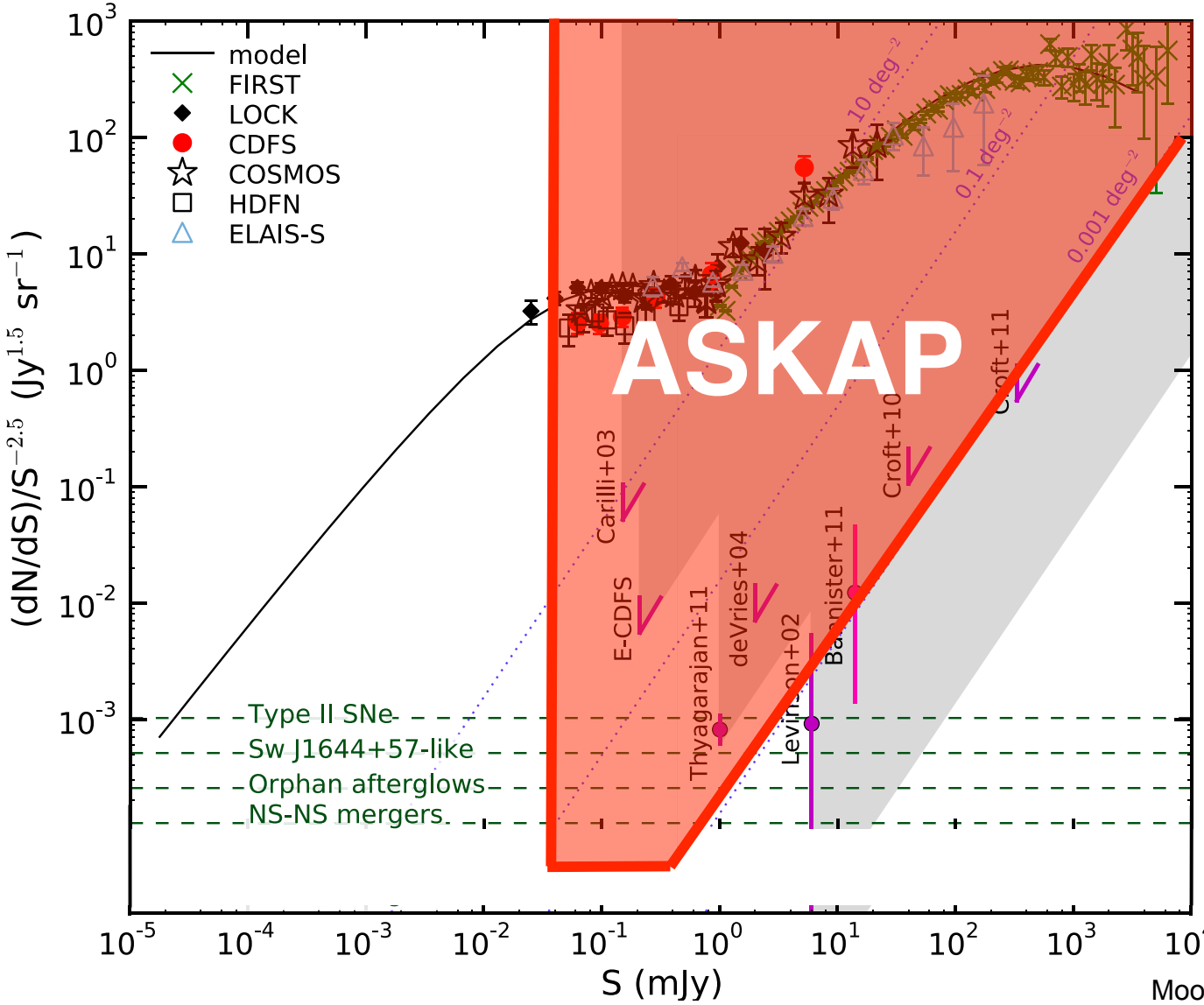
Ian Heywood / ACES / CSIRO



David Kaplan / MWATS

Transient Event Rate at 1.4 GHz

Dunlap Institute for Astronomy & Astrophysics
UNIVERSITY OF TORONTO



Mooley et al. (2013)

Challenge I : Ionosphere

Dunlap Institute for Astronomy & Astrophysics
UNIVERSITY OF TORONTO

- Spatial and temporal fluctuations in plasma density produce position shifts, defocusing, scintillation

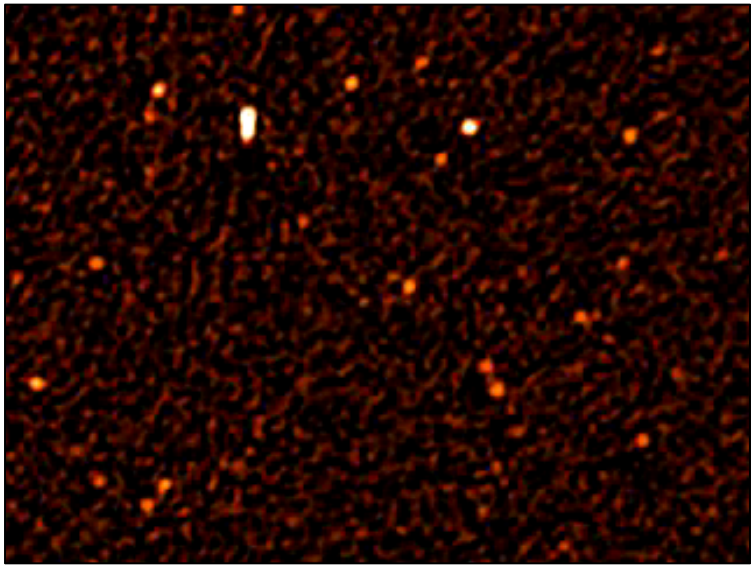
- Huge instantaneous MWA field of view (~1000 deg^2)
  - track 1000 source positions at 2-minute cadence
  - map vector offsets as function of time (Loi et al. 2015a, 2015b)
  - robust correction for ionospheric refraction

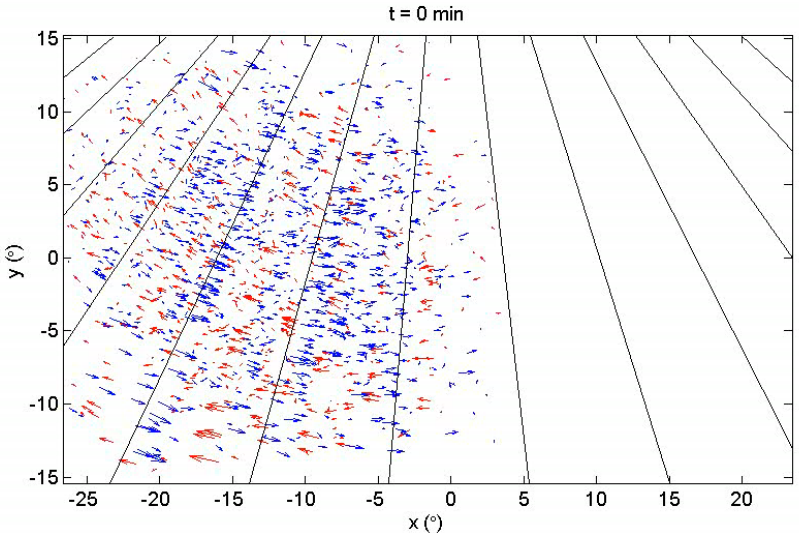
- Organized strips of alternating position shifts
  - bands of underdensity and overdensity
  - aligned with projection of Earth's magnetic field
  - stereoscopic imaging: h = 570 ± 40 km

  → cylindrical density ducts, coupling ionosphere and plasmasphere via whistler waves

  → direct 4D visualization of bulk plasma drifts

MWA time series (Natasha Hurley-Walker)



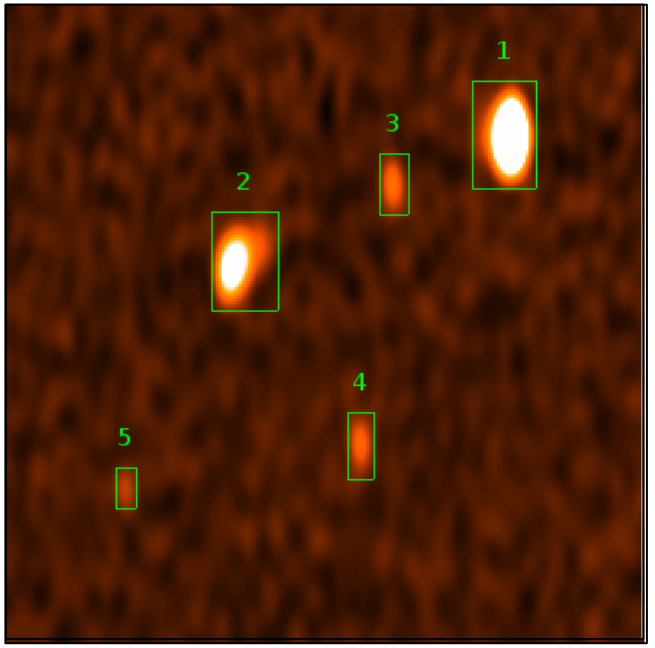


Loi et al. (2015a)

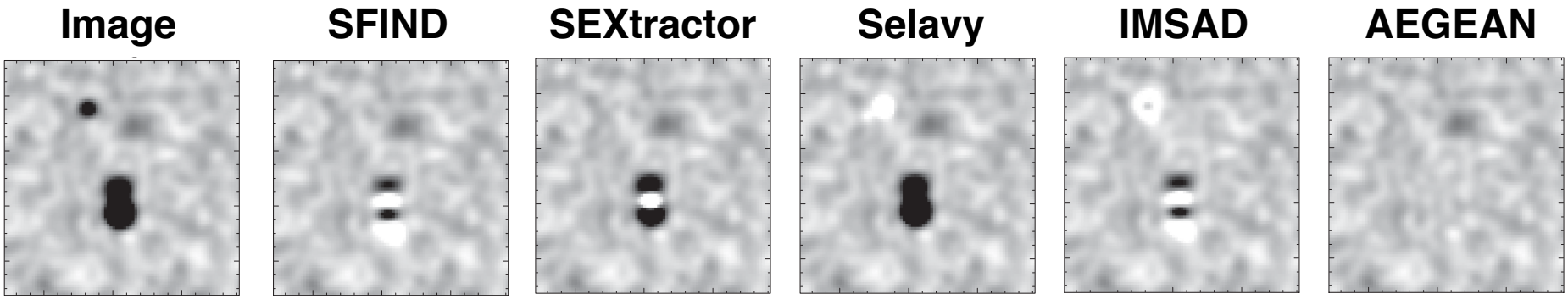
Challenge II : Source Finding

Dunlap Institute for
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

- Identification of interesting events needs to be catalogue-based, not image-based
  - missed/blended sources will trigger huge numbers of false alarms
  - 99% accuracy is not good enough!
- BLOBCAT (Hales et al. 2012; github)
  - flood-fill: superior to gaussian fitting
- AEGEAN, BANE & MIMAS
  (Hancock et al. 2012, 2015; github)
  - AEGEAN: Laplacian for robust component separation
  - BANE: fast & accurate background estimation
  - MIMAS: describe/combine/mask regions



Hales et al. (2012)



Hancock et al. (2012)

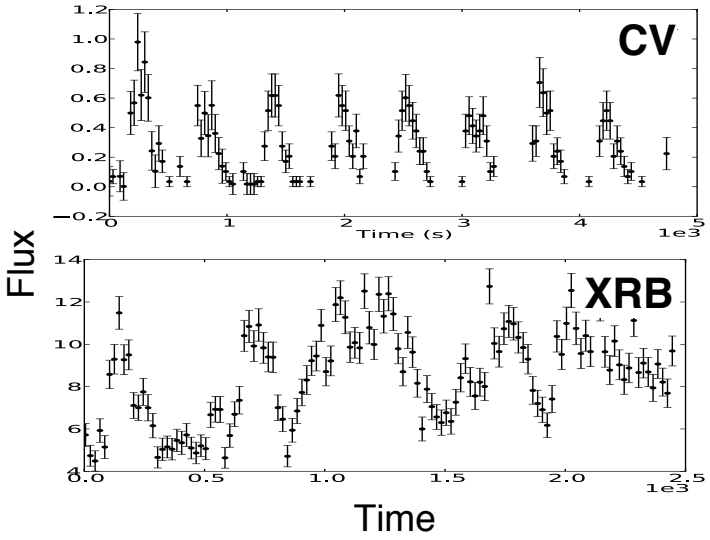
Challenge III : Source Classification

Dunlap Institute for Astronomy & Astrophysics
UNIVERSITY OF TORONTO

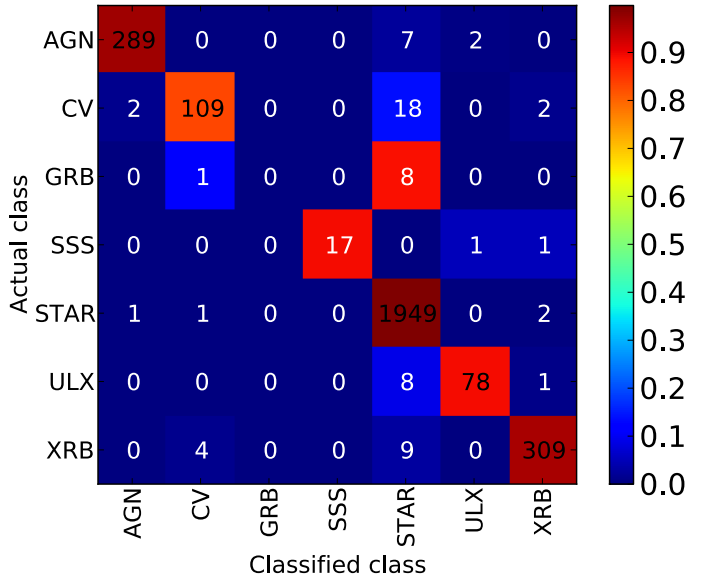
- ASKAP event rate will be large, ~50 per night
  - need prompt classification & follow-up
- Random forest machine-learning algorithm (Lo et al. 2014; Farrell et al. 2015)
  - variable light curves taken from 3XMM
  - 869 identified sources used as training set (AGN, CV, GRB, SSS, star, ULX, XRB)
  - input: time-series plus contextual features

  → 92% – 96% classification accuracy
- Apply algorithm to 2876 other 3XMM sources
  - compare to 101 sources with known IDs

  → agree in 93 cases; most others ambiguous
  - identification of ~20 “outlier” sources



Lo et al. (2013)

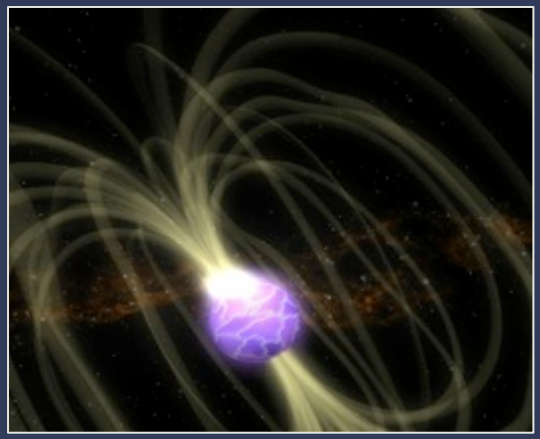


Lo et al. (2013)

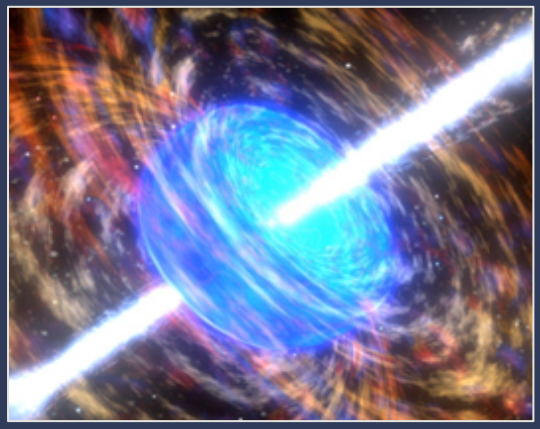
Summary

Dunlap Institute for Astronomy & Astrophysics
UNIVERSITY OF TORONTO

- Time-domain astronomy is rapidly evolving
- Wide-field surveys: unique strengths & challenges
  - atmospheric distortions can now be precisely characterized … and contain new science
  - robust source fitting and cataloging
  - automatic classification of both expected categories and outlier sources
- Goal: address major topics in fundamental physics and astrophysics
  - unbiased census of cosmic explosions
  - propagation as unique probe of turbulence and baryonic matter
  - high-time-resolution Universe: a new frontier
- 2020- : Exploration of full Dynamic Universe with the Square Kilometre Array


NASA


CSIRO / Swinburne


NASA/Dana Berry/Skyworks Digital