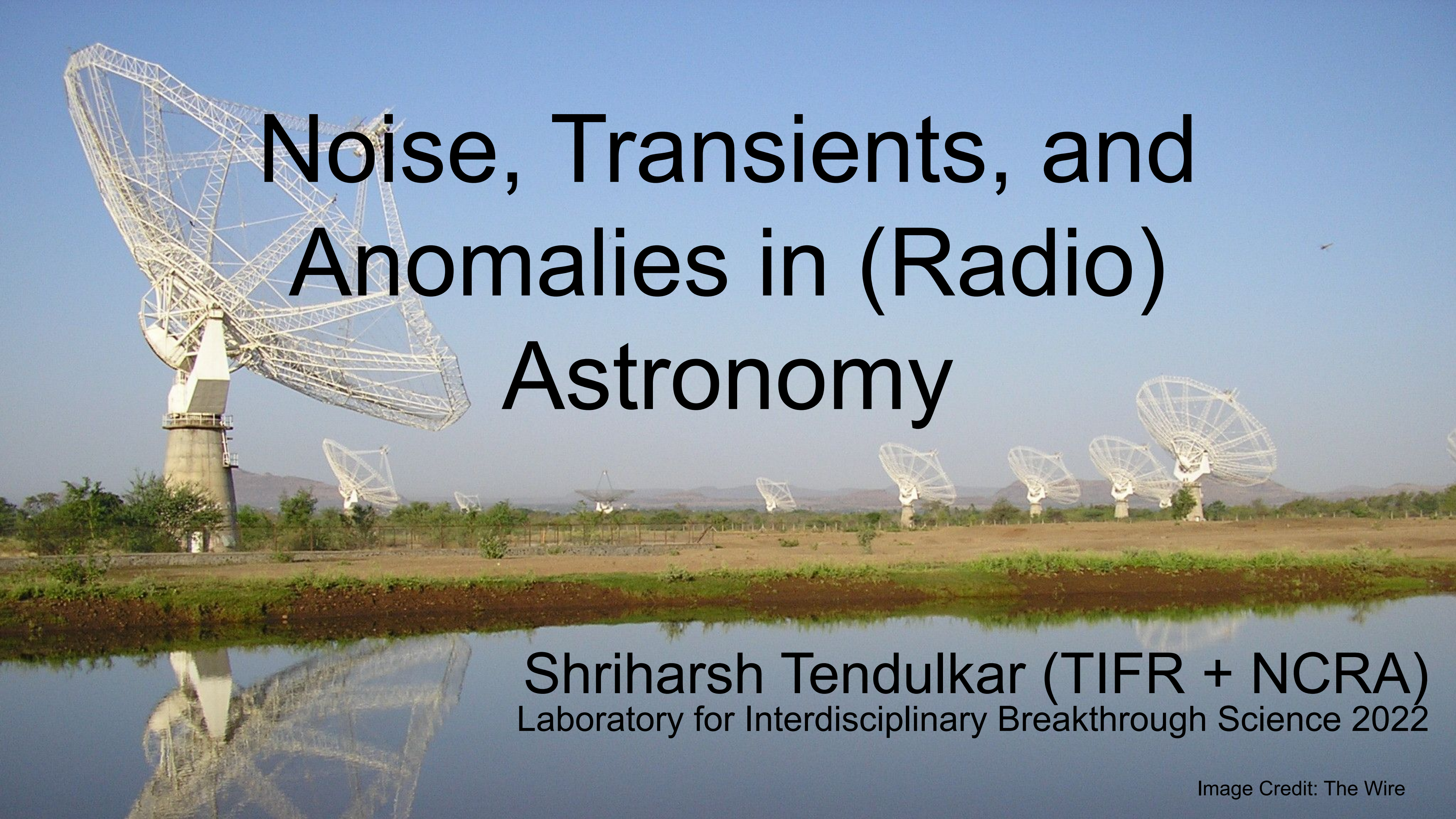


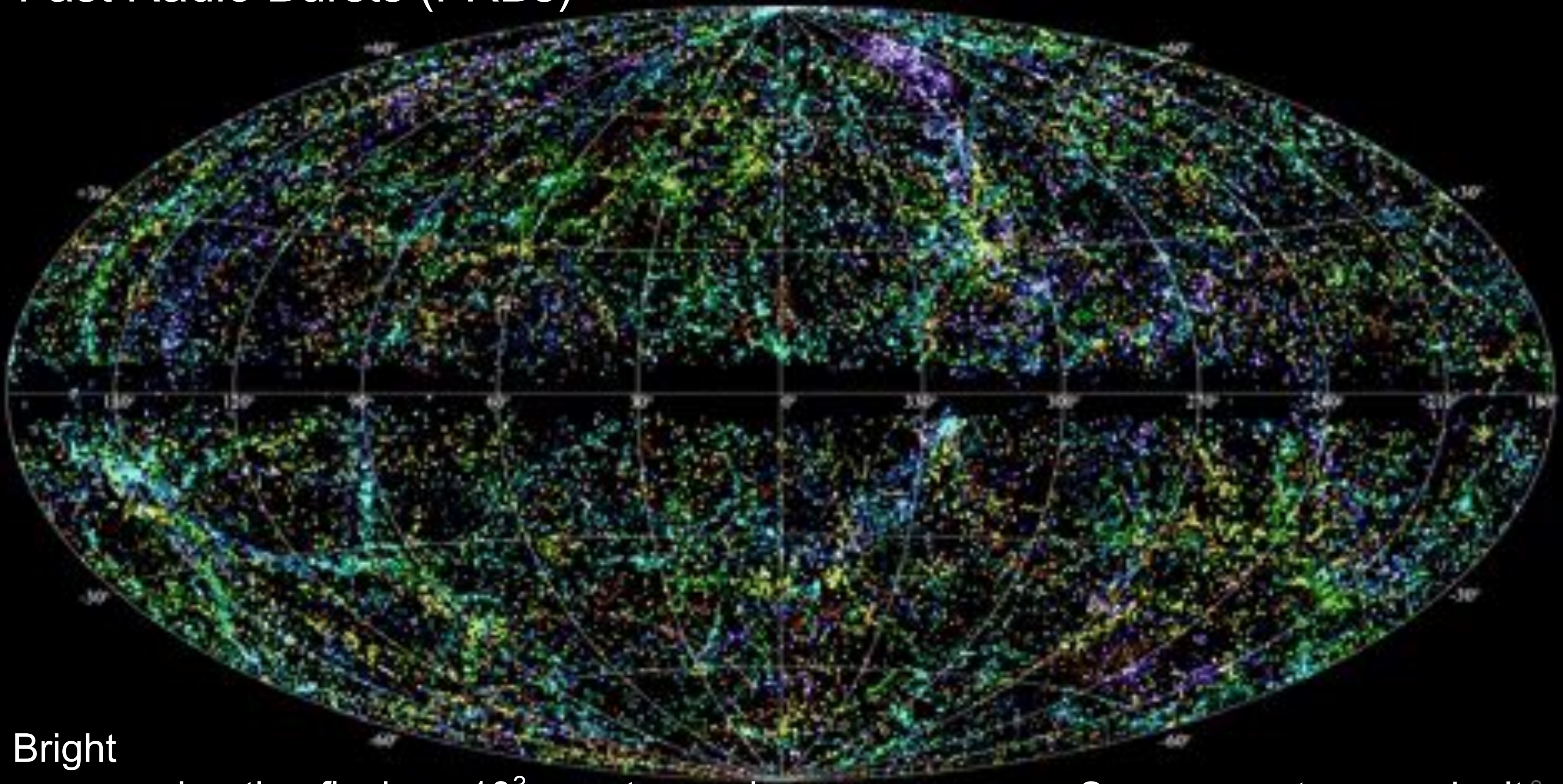
Noise, Transients, and Anomalies in (Radio) Astronomy

Shriharsh Tendulkar (TIFR + NCRA)

Laboratory for Interdisciplinary Breakthrough Science 2022

Image Credit: The Wire

Fast Radio Bursts (FRBs)

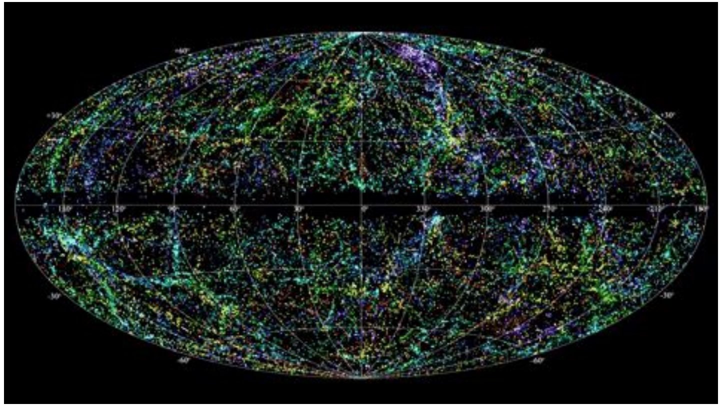


Bright

μs – ms duration flashes, 10^3 events per day

Some repeat, some don't

Fast Radio Bursts (FRBs)



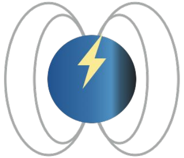
Why are they interesting?

Cosmological distances

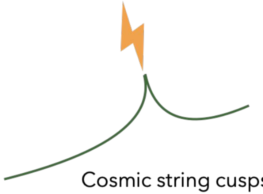
Trillion (10^{12}x) more luminous than pulsars

Potential probes of matter, magnetic field and structure formation in the Universe

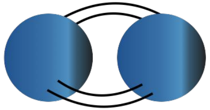
Links to other transients



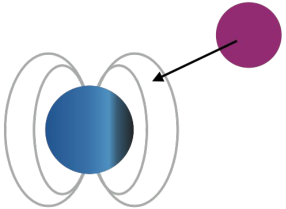
Magnetic field reconnection/ star quake



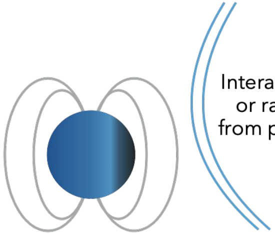
Cosmic string cusps



Merger/Coalescence

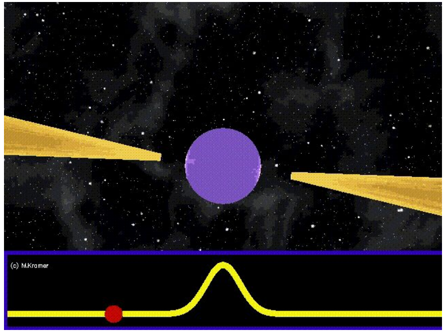


Interaction with asteroid/ axion nugget



Interaction with winds or radiative shocks from pulsars, OB stars, AGNe

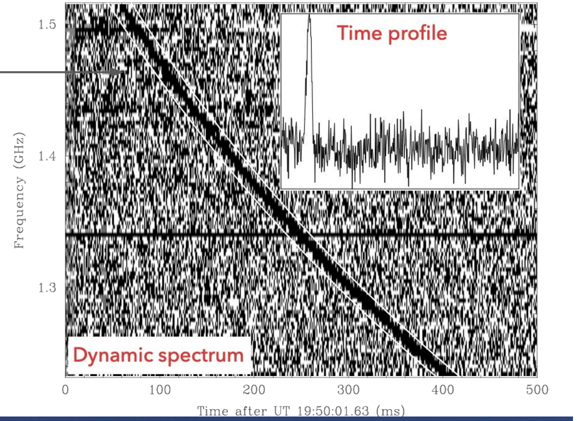
Most models involve neutron stars



The usual pulsar model with a rotating neutron star. (Mostly detectable only within our galactic neighbourhood)

Searching for FRBs

Dispersion sweep



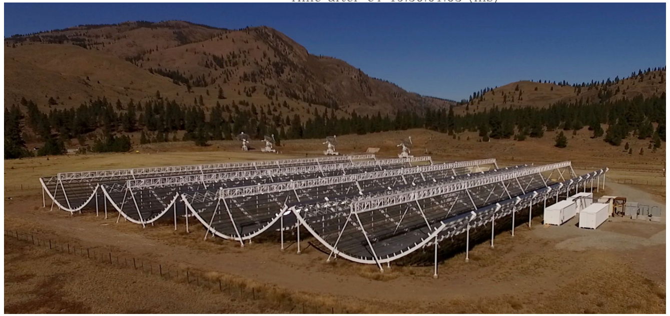
Dispersion → high frequency light travels faster

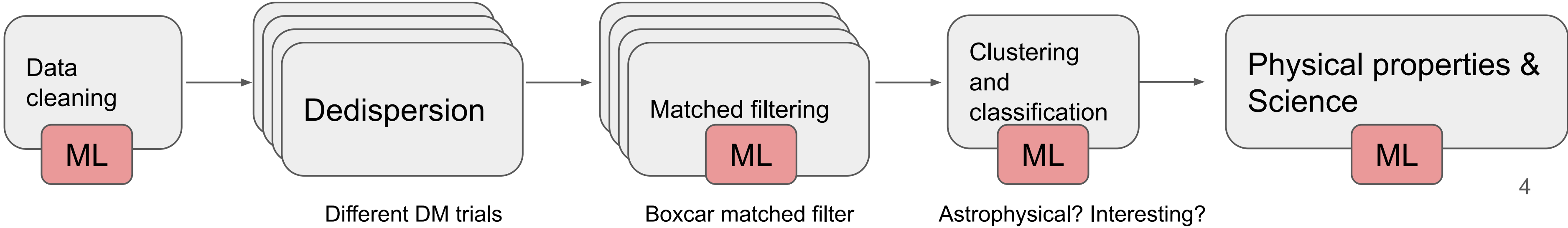
Signal is *extremely* sparse – few ms spread over 10–30 seconds ($\sim 10^4$ dilution)

16k frequency channels – per-channel SNR is $\sim 10^{-1}$

Video camera on the sky → 16k colours, 1000 fps, 1024 pixels (beams) — data rate of 800 GBps (~PB/20min), processed in real-time

Detect 2-3 FRBs/day





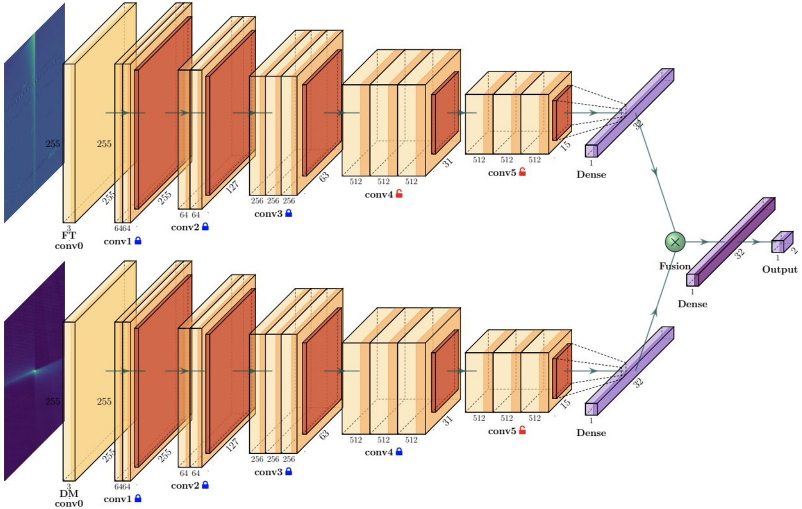
Searching for FRBs

ML used to classify RFI vs astrophysical ~1 part in 10^6 with 99% precision and 95% completeness (SNR dependent)

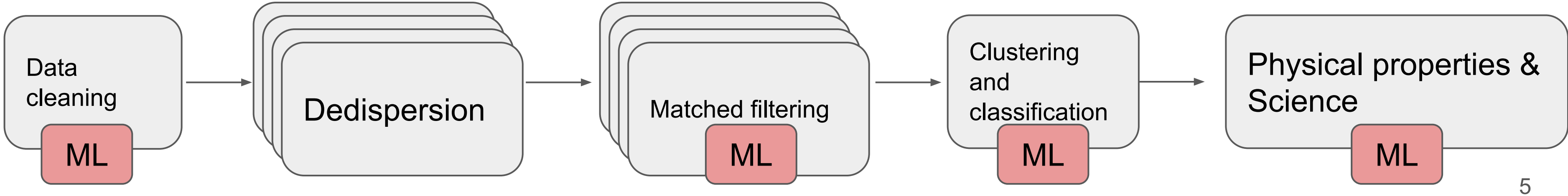
CNNs used to process dynamic spectra directly (w/wo dedispersion) →

Slowly used for scientific classification and physical properties (Yadav P. 2019, A. Kumar in progress)

(Talk to me about the details later)



[FETCH: Deep learning based classifier (Agarwal et al 2019)]

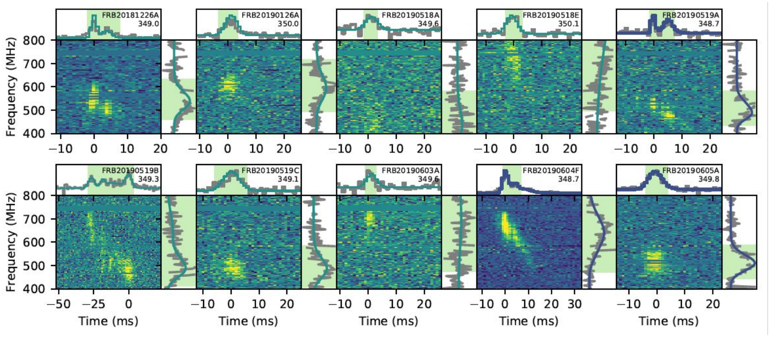


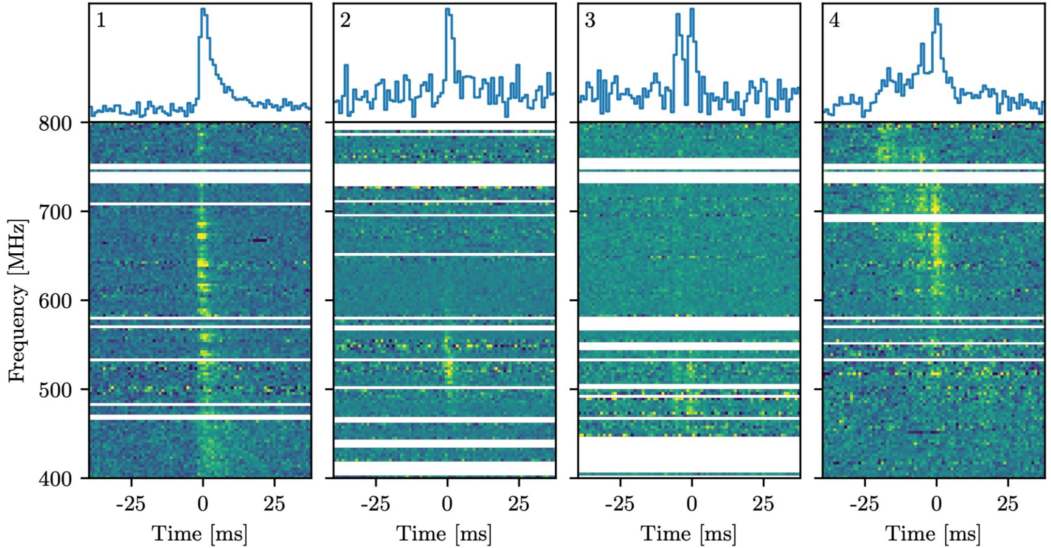
Different DM trials

Boxcar matched filter

Astrophysical? Interesting?

Different shapes of FRBs



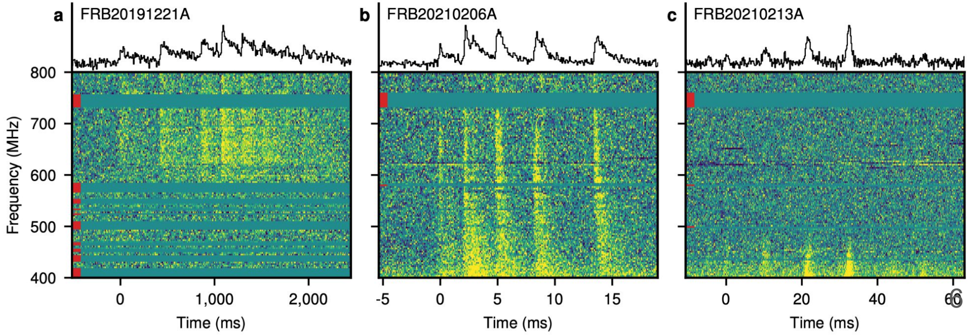


Often seen from non-repeaters

Often seen from repeaters

Could these be coming from different sources?

Could some of them be related to specific multi-wavelength transients?



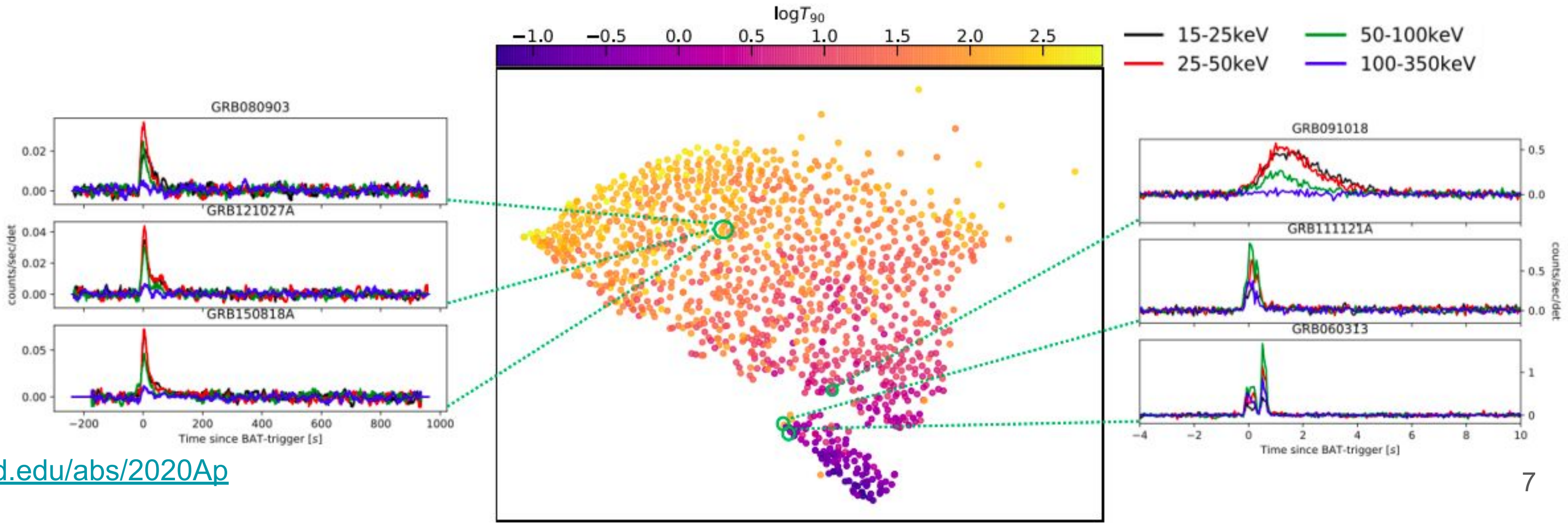
[CHIME/FRB Collaboration et al (2021)]

Classification of FRBs

Can we distinguish and categorize different types of FRBs from each other? (A. Kumar, A. Mahabal + SPT)

Similar to work on GRBs (gamma-ray bursts)

t-SNE clustering on GRB lightcurves at different energies



https://ui.adsabs.harvard.edu/abs/2020ApJ...896L..20J/abstract

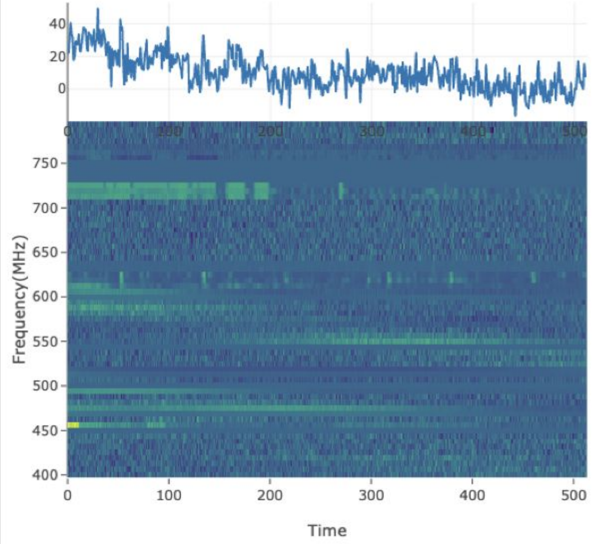
Radio Frequency Interference (RFI)

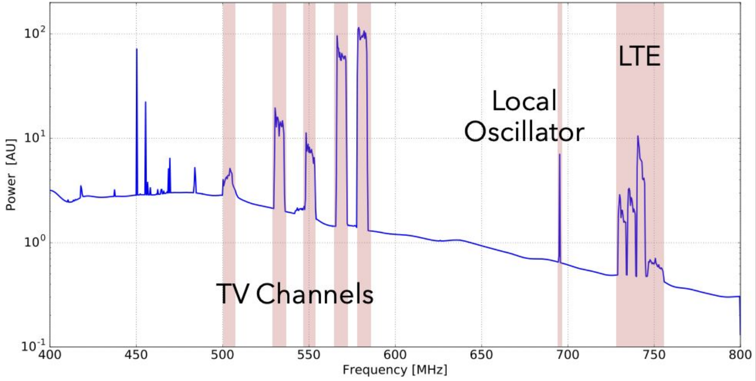
Anthropogenic signals wreak havoc in radio astronomy

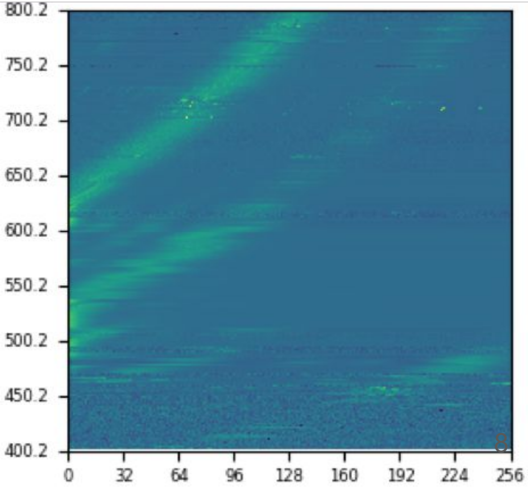
TV stations, cellphones, satellites, aircraft, cars, transformers etc.

For radio transients → hay to needle ratio ~$10^{6\text{–}7}$

ML to identify and separate RFI signals







Particularly important for uGMRT – sits in a very crowded, rapidly developing region

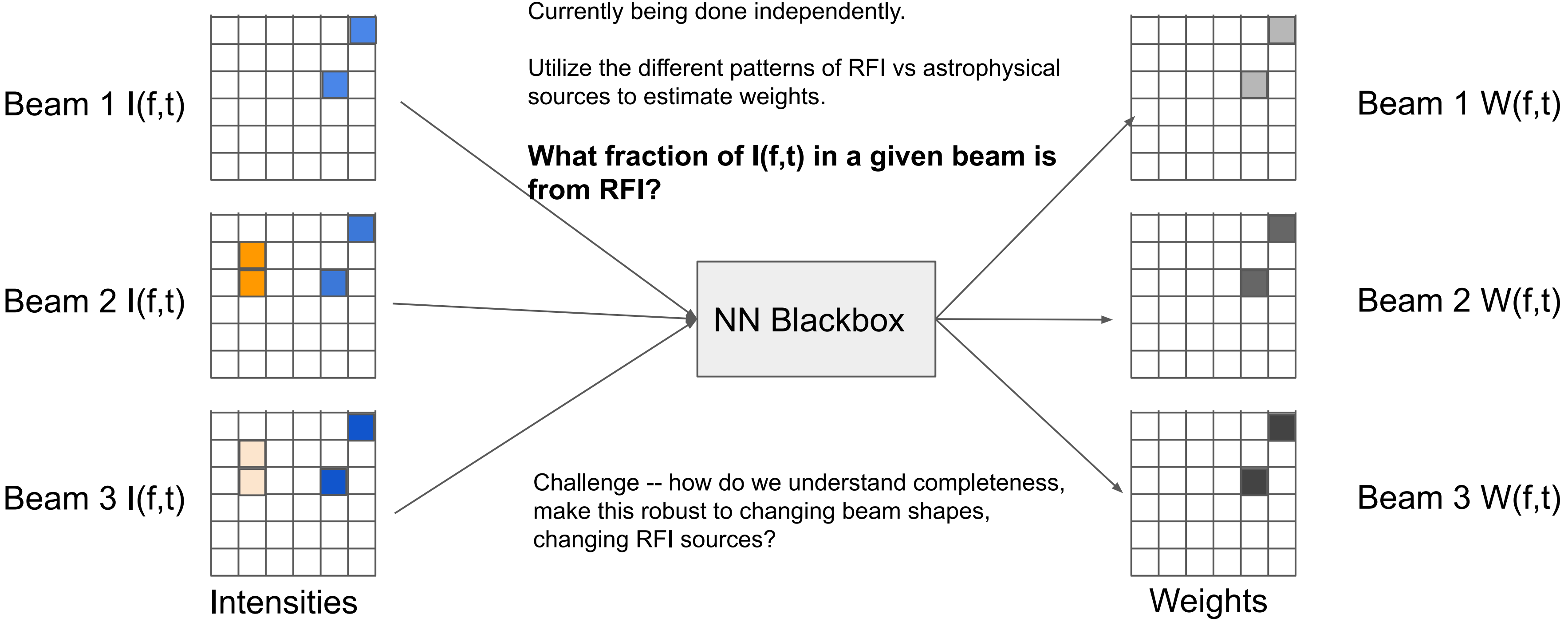
Separating RFI and astrophysical signals

Can we use CNNs and multi-pixel data streams to separate RFI?

Currently being done independently.

Utilize the different patterns of RFI vs astrophysical sources to estimate weights.

What fraction of I(f,t) in a given beam is from RFI?



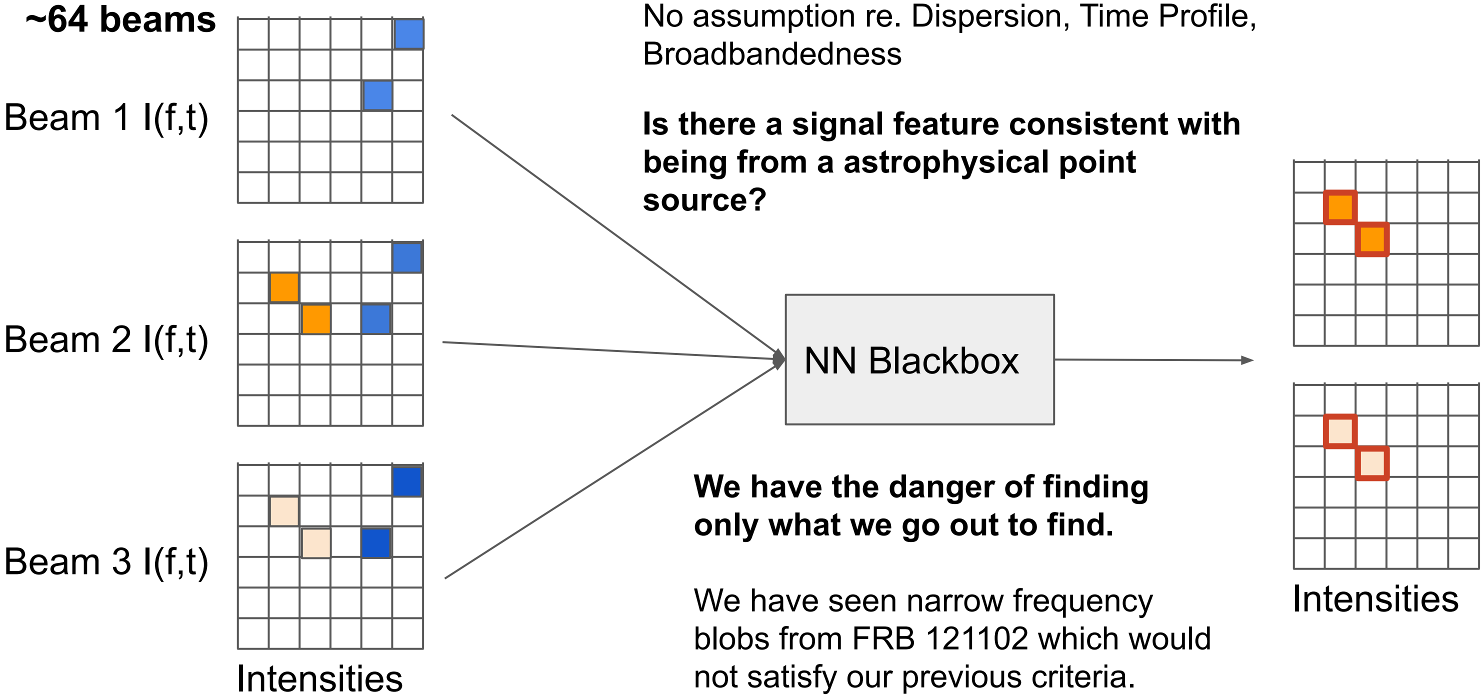
Challenge -- how do we understand completeness, make this robust to changing beam shapes, changing RFI sources?

Anomaly detection

Model independent transient searches

No assumption re. Dispersion, Time Profile, Broadbandedness

Is there a signal feature consistent with being from a astrophysical point source?



We have the danger of finding only what we go out to find.

We have seen narrow frequency blobs from FRB 121102 which would not satisfy our previous criteria.

RFI mitigation at uGMRT

Transformers, industries, cellphone towers all around uGMRT

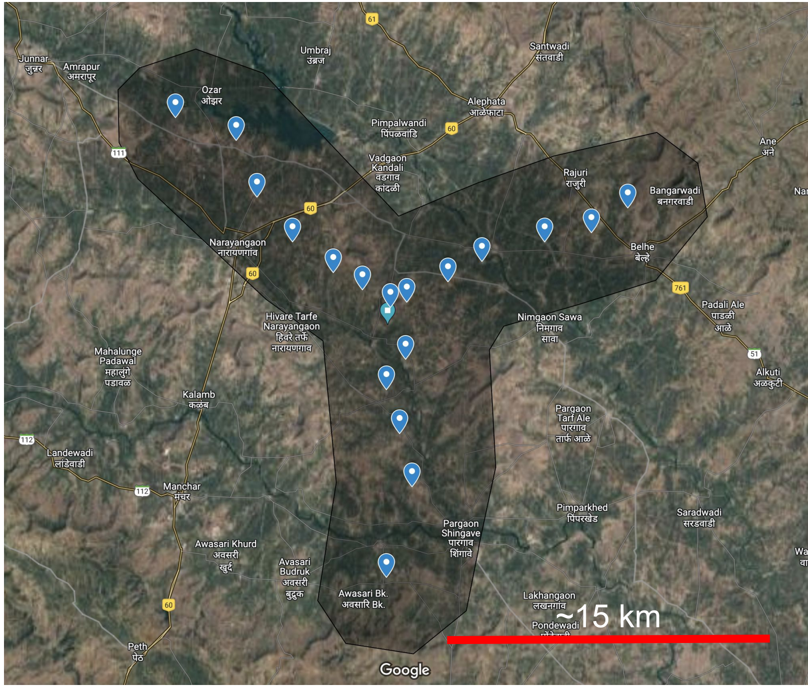
Not just transients but all astronomical observations. Reduces sensitivity, loss of data, time etc. Reduces the efficiency of uGMRT

Local outreach and education

RFI filtering (in analog systems) and digital systems (Buch et al 2019, 2022)

BUT new RFI keeps propping up!

1) Can we identify/locate new sources of RFI from antenna-level data?
2) Can we subtract RFI from data in real time?
3) Can we identify new industrial developments before they happen? (satellite imagery)



Slides from Prof. Yogesh Wadadekar (NCRA)

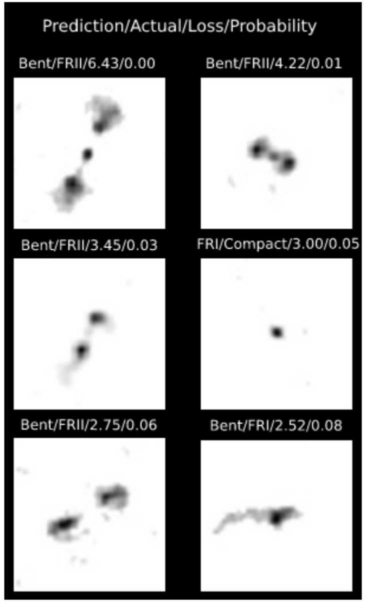
ML for studying galaxies

Classification

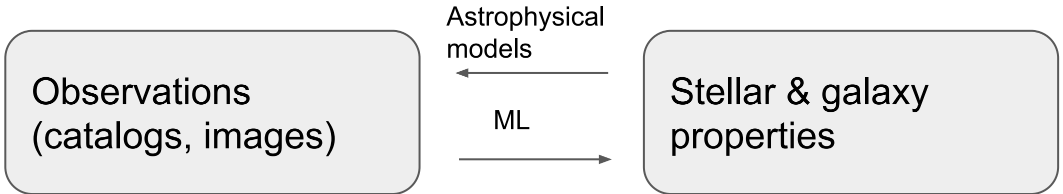
- Separate stars and galaxies in optical images (ANNs)
- Separate quasars from stars using optical colours (ANNs)
- Classify radio galaxy by morphology – compact, FR 1, FR 2, bent-tail using radio continuum images

Regression

- Predict photometric redshift of galaxies using broadband fluxes (SVM)
- Predict star-formation related properties of galaxies using broadband fluxes (deep learning)
- Predict bulge-to-total luminosity ratio of galaxies using multi-filter images (deep learning)



Samudre et al (2022)



Slides from Prof. Yogesh Wadadekar (NCRA)

Publications in international journals

Classification

- Philip, Wadadekar et al. (2002) A difference boosting neural network for automated star-galaxy classification A&A, 385, 1119
- Abraham et al. (2012) A photometric catalogue of quasars and other point sources in the Sloan Digital Sky Survey MNRAS, 419, 80
- Samudre et al. (2022) Data-efficient classification of radio galaxies MNRAS, 509, 2269

Regression

- Wadadekar (2005) Estimating Photometric Redshifts Using Support Vector Machines PASP, 117, 79
- Surana et al. (2020) Predicting star formation properties of galaxies using deep learning MNRAS, 493, 4808
- Grover et al. (2021) Predicting bulge to total luminosity ratio of galaxies using deep learning MNRAS, 506, 3313

Summary

High data rate, sparse signal searches

(preferably low power consumption, low-level implementation)

Anomaly detection

(what are we missing?)

Enabling all science (by RFI mitigation)

How to operate in an increasingly complicated world?

Inversion of complex modeling with sparse/incomplete data

(Forward modeling is easy, reversing is hard)