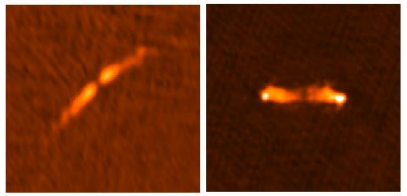
Scientific explorations of TGSS

Huib Intema | Leiden Observatory

December 14, 2017

Sterrewacht Leiden

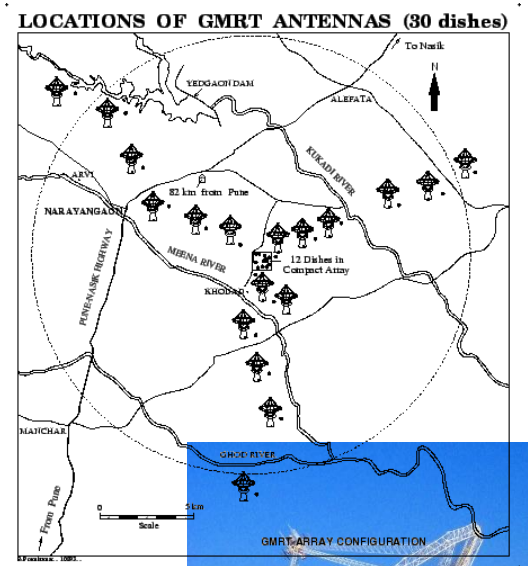
TGSS
Alternative Data Release

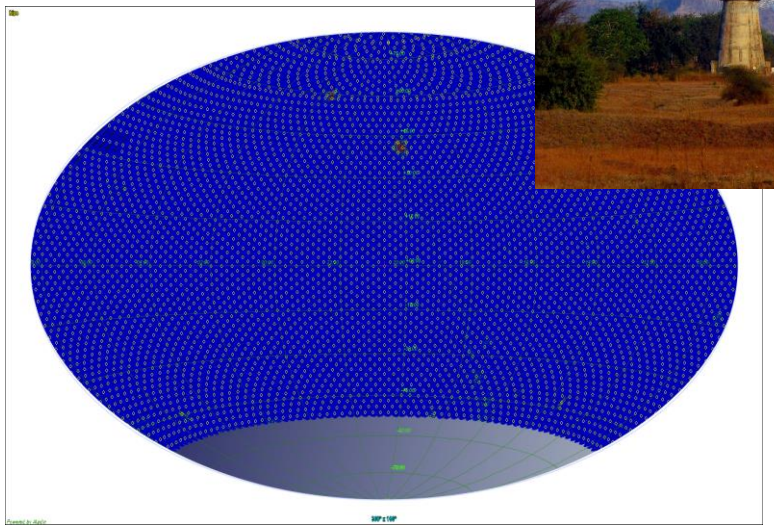


Universiteit Leiden
The Netherlands

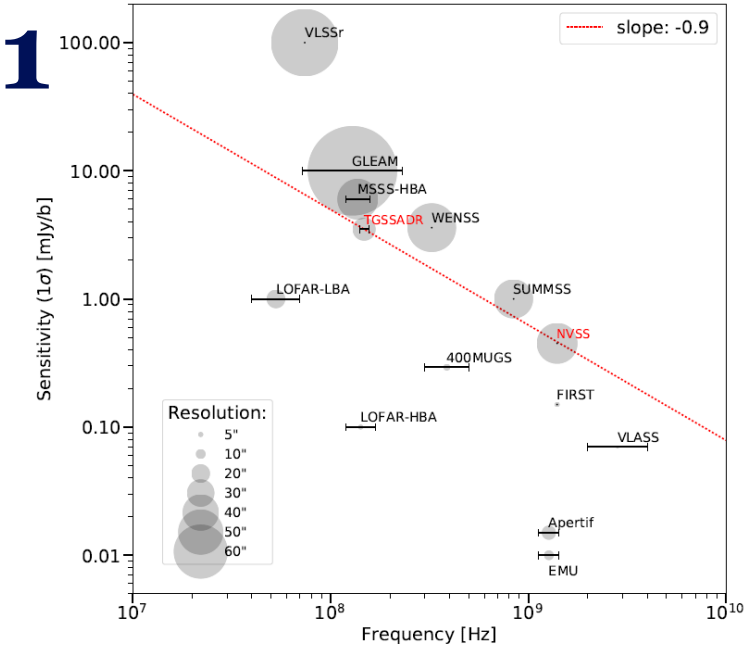
Overview of the TGSS

- TGSS = TIFR GMRT Sky Survey
  (core team: S. Sirothia (PI), Ishwara-Chandra, N. Kantharia, Gopal-Krishna)
- Continuum survey at 150 MHz with the Giant Metrewave Radio Telescope
  - 30-dish low-frequency radio interferometer located near Pune, India (+19° latitude)
  - 14 antennas within central square km, 16 antennas in approximate Y-pattern
  - Baselines ranging from 50m to 25km, 45m diameter dishes, wired mesh surface
- 16 MHz bandwidth at 150 MHz, ~20” resolution, ~3 degree FoV
- 5,336 pointings covering -55° to +90° DEC, 15 minutes/pointing
  - Anticipated 5-7 mJy/beam median noise
- 2,000 hours granted and observed between 2010-2012
- Largest-area radio-interferometer survey to date
  - 37,000 square degrees = 90 percent of the radio sky
  - Highest-resolution large-area radio survey after FIRST
    (~10,000 square degrees)





TGSS Alternative Data Release 1

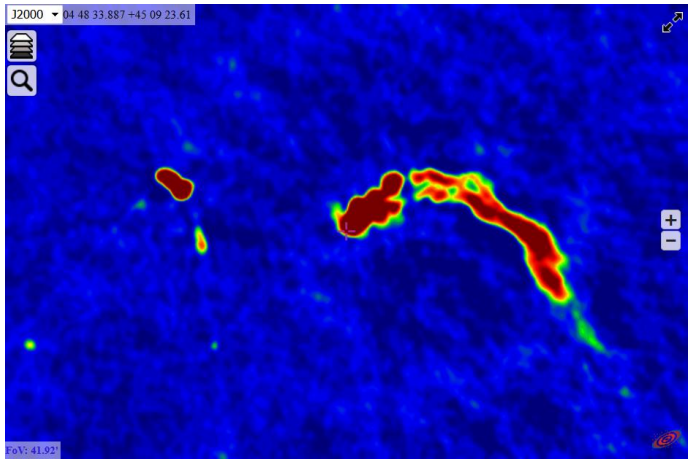


(Intema, Jagannathan, Mooley & Frail, 2017, A&A, 598A, 78)

- TGSS ADR1 (released 03/2016) consists of
  - 5,336 mosaicked radio continuum images at 25" resolution, covering the sky north of -53° Declination
  - Majority of pointing images have background noise levels between 2-5 mJy/beam
  - Catalog of 0.62 Million radio sources with a positional accuracy better than 2" and a flux density accuracy of ~10 percent(*)
- Data products are easily accessible via webpage and various standard platforms

http://tgssadr.strw.leidenuniv.nl

Interactive access through CDS Aladin

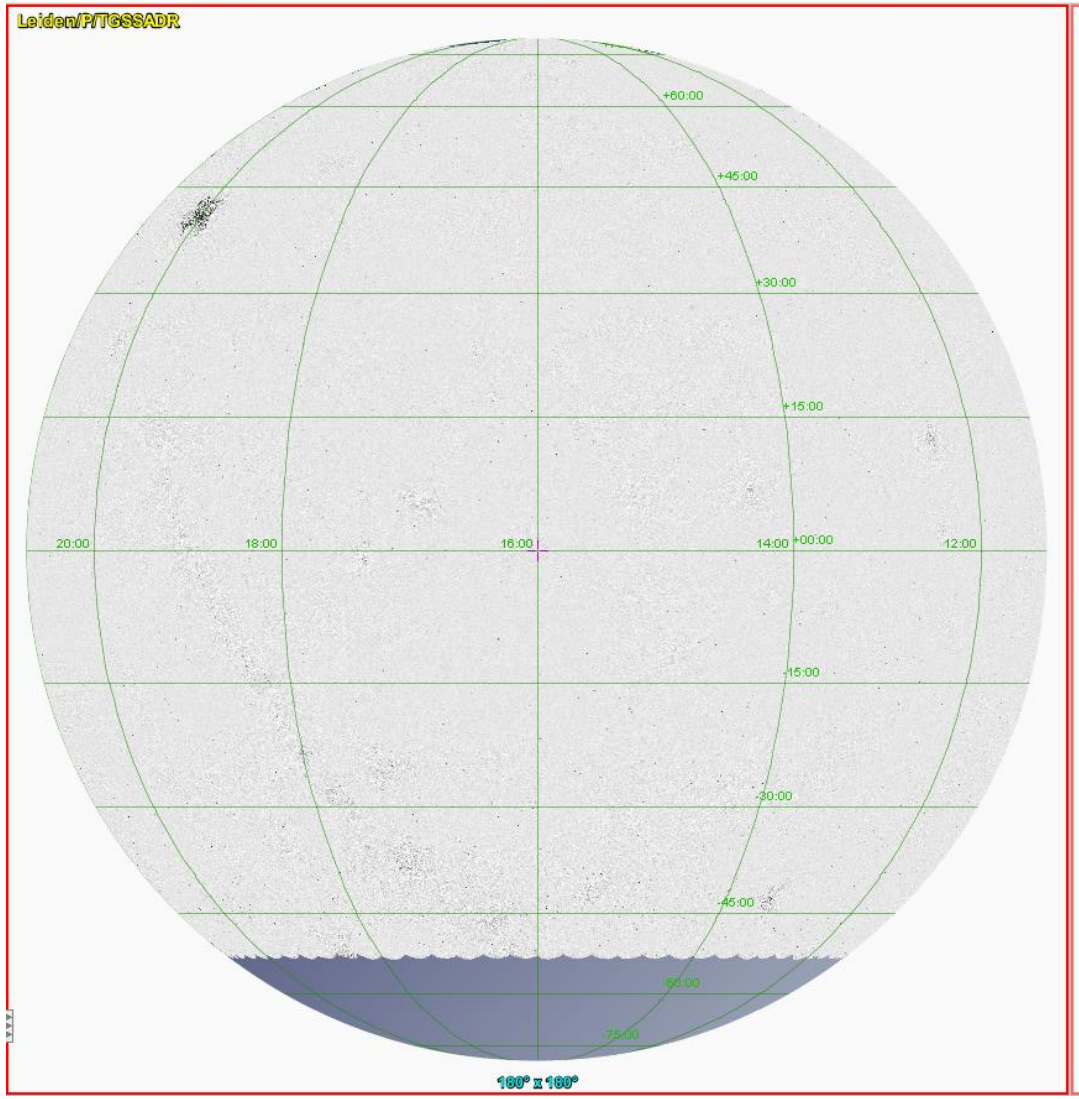


Mosaicking options via NASA SkyView, powered through ASTRON VO

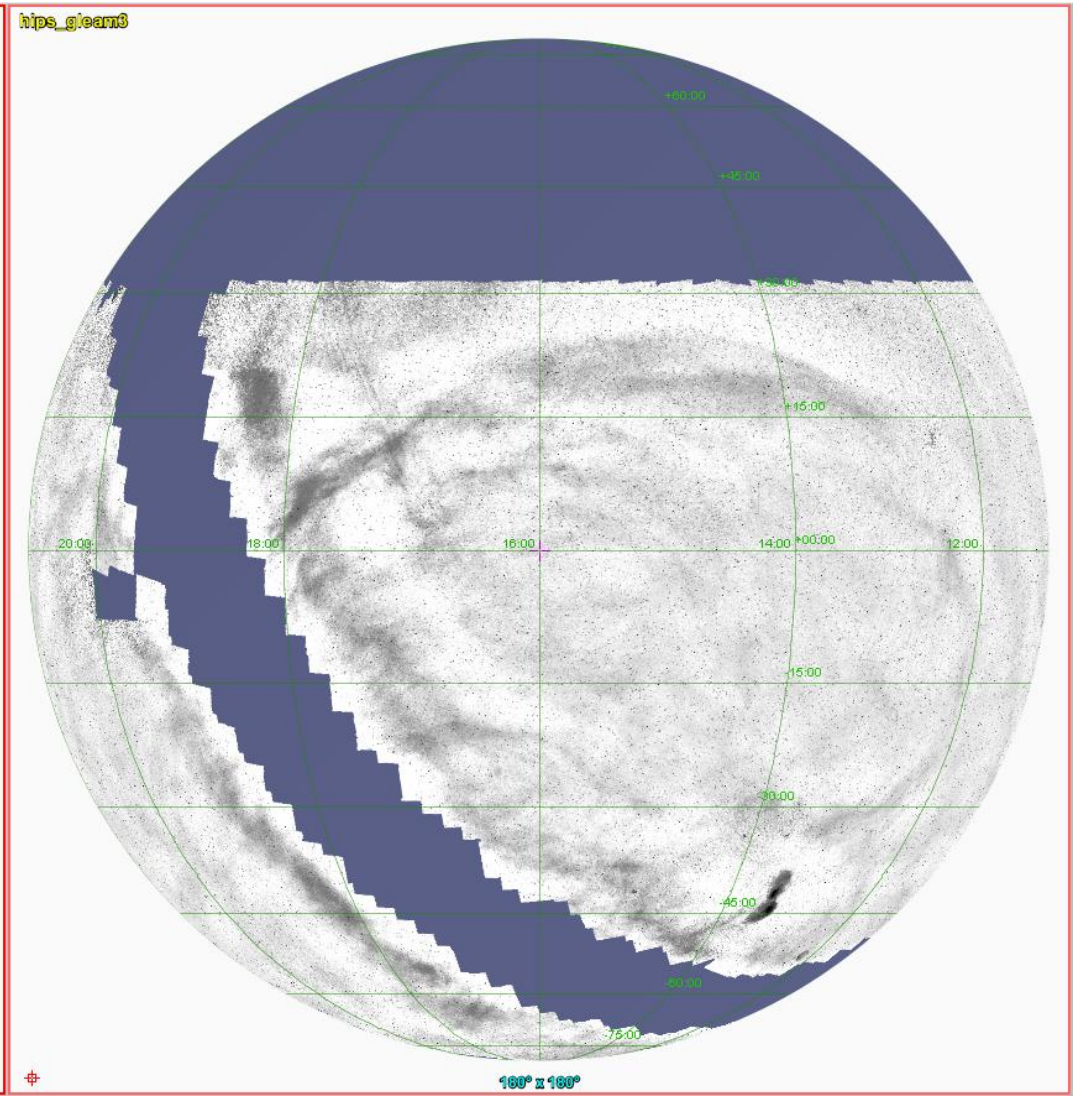
SkyView
The Internet's Virtual Telescope

(*) a subset of pointings has larger flux scale errors

TGSS ADR has large(st) sky coverage



TGSS ADR sky coverage

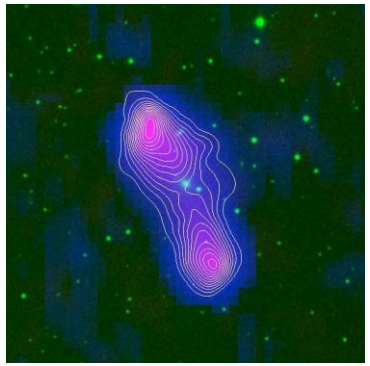


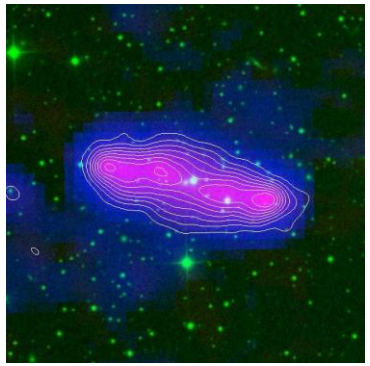
current GLEAM sky coverage

Usage of TGSS ADR

Steady stream of visitors to the TGSS ADR website

- Largest user groups located in India, USA, and the NL
- Increasing interest from non-mainstream countries
- Indian citizen e-science through RAD@home project https://www.facebook.com/groups/RADathome

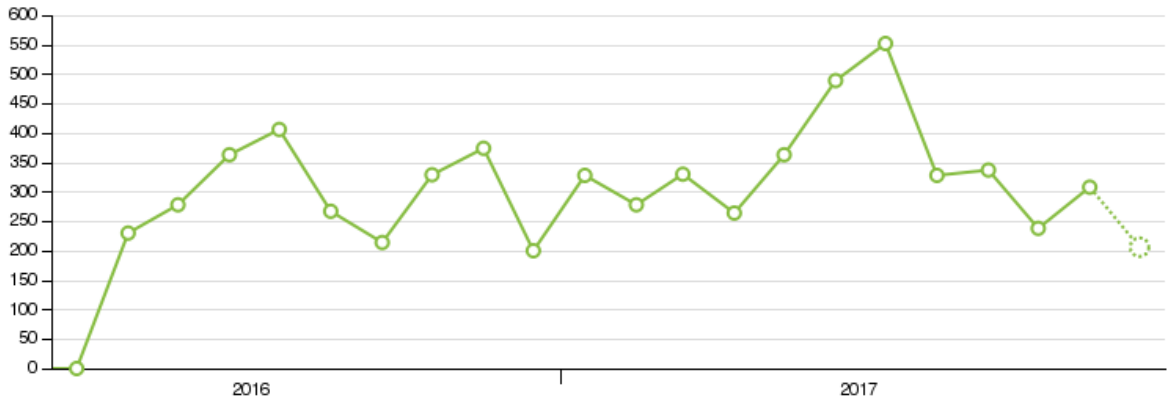




78 ADS citations to survey paper to date

3 PhD students in Leiden working on TGSS follow-up

Monthly TGSS ADR website visitors



		Country
165	33.00%	India
70	14.00%	United States
64	12.80%	Netherlands
33	6.60%	Italy
31	6.20%	Germany
29	5.80%	United Kingdom
20	4.00%	Australia
16	3.20%	South Africa
15	3.00%	France
13	2.60%	Poland

Demographics over last 5 weeks

Wide range of scientific topics

Cosmology through number counts and alignments: Contigiani+ 2017, Bengaly+ 2017, Tiwari+ 2016

EoR foreground characterization: Choudhuri+ 2017, Trott & Wayth 2017, Procopio+ 2017, Ewall-Wice+ 2016

HzRGs as tracers for proto-cluster environments: Saxena+ 2017

MPS sources: Coppejans+ 2017, Callingham+ 2017

Galaxy cluster sources (relics and halos): Duchesne+ 2017, George+ 2017, Parekh+ 2017, Gasperin+ 2017

Recurrent AGN activity / GRGs: Jamrozy+ 2017, Singh+ 2016

Transient searches: Murphy+ 2017, Mooley+ in prep.

Extragalactic star formation: Brown+ 2017

Galactic SNRs and HII regions: Kothes+ 2017

Continuum emission from pulsars: Bhakta+ 2017, Frail+ 2016, 2017

Stars and (exo)planets

Characterization of the ionosphere

TGSS-NVSS all-sky spectral index

"There's nothing quite as useless as a radio source." – Jim Condon (SPARCS – Sept. 2013)

- Add resolution, spectral information, polarization, timing; match to multi-wavelength counterparts

NVSS and TGSS are the two largest radio interferometer surveys in terms of area

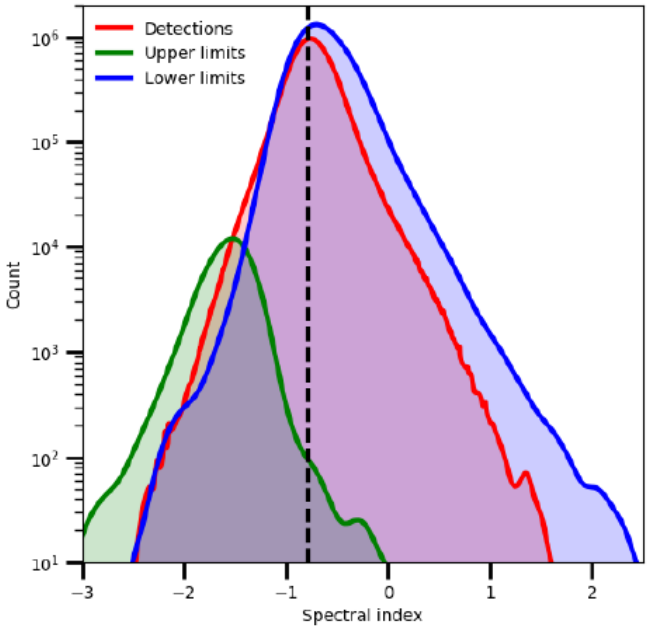
- Common TGSS-NVSS sky coverage is over 3π steradians (80% of total sky)
- Resolution and (point source) sensitivity are somewhat similar

Simple catalog match yields 0.55 Million spectral indices

- Affected by mismatches in image resolution and source extraction

New project to map 80% of the radio sky in spectral index between NVSS and TGSS

- Created new set of TGSS mosaics matching NVSS resolution and gridding
- Made pixel-by-pixel spectral index maps
- Extracted common catalog of fluxes and spectral indices, including limits
- 1.4 Million catalog entries



A radio spectral index map and catalogue of 80 percent of the sky from TGSS and NVSS

F. de Gasperin[1], H. T. Intema[1], D. A. Frail[2]
[1] *Leiden Observatory, Leiden University, P.O.Box 9513, NL-2300 RA, Leiden, The Netherlands*
[2] *National Radio Astronomy Observatory, 1003 Lopezville Road, Socorro, NM 87801-0387, USA*

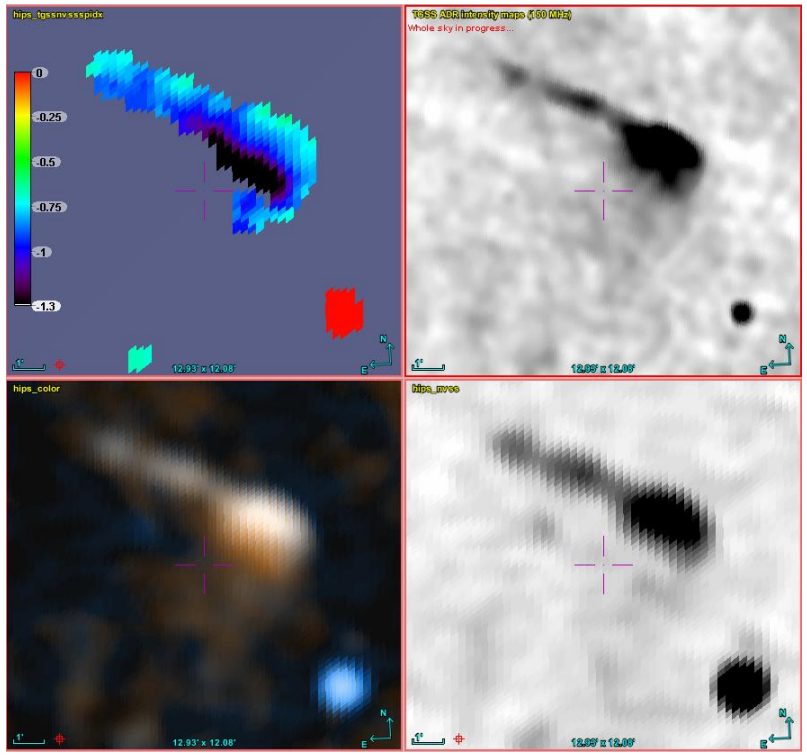
MNRAS accepted
arXiv:1711.11367

Resolved spectral index mapping

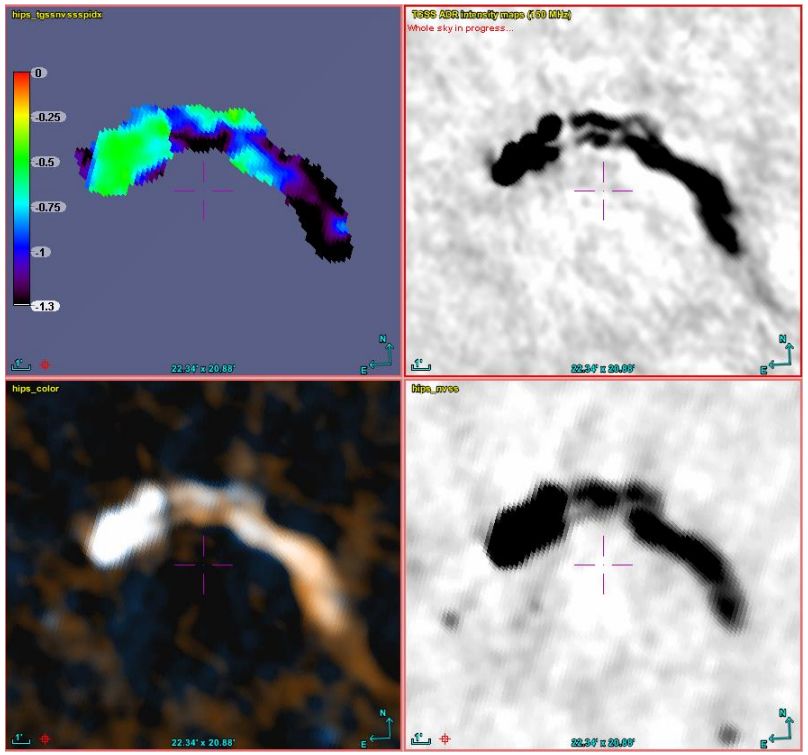
Spectral properties of bright, well-studied sources are reproduced to reasonable accuracy

Resolution and frequency span is several times higher than GLEAM; more suitable for extragalactic work

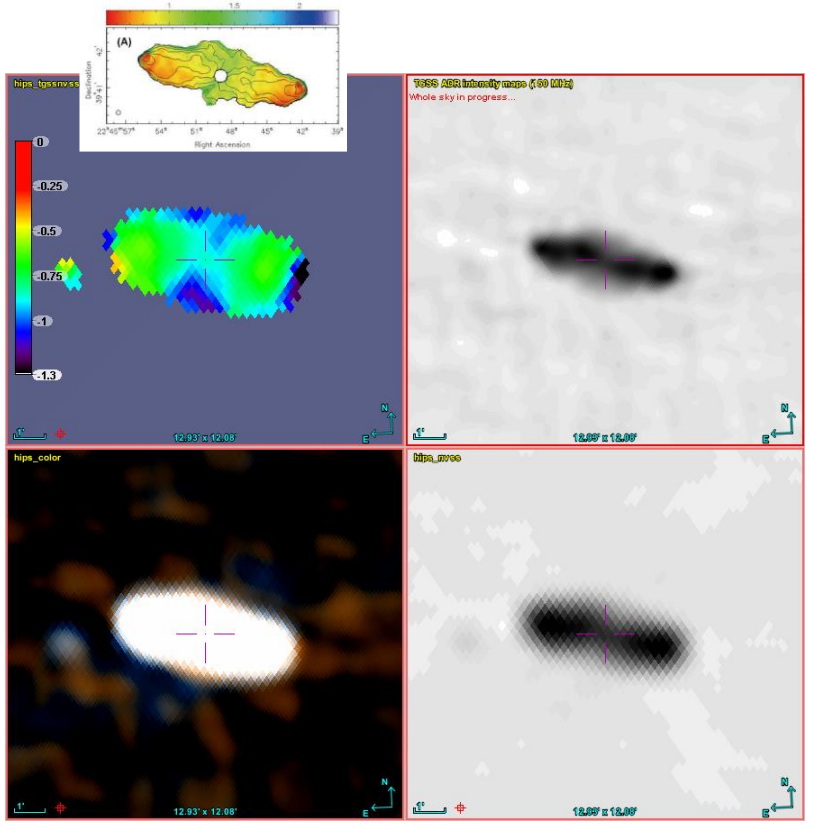
Enables search for interesting sources based on their spectral morphology



Toothbrush cluster



3C 129



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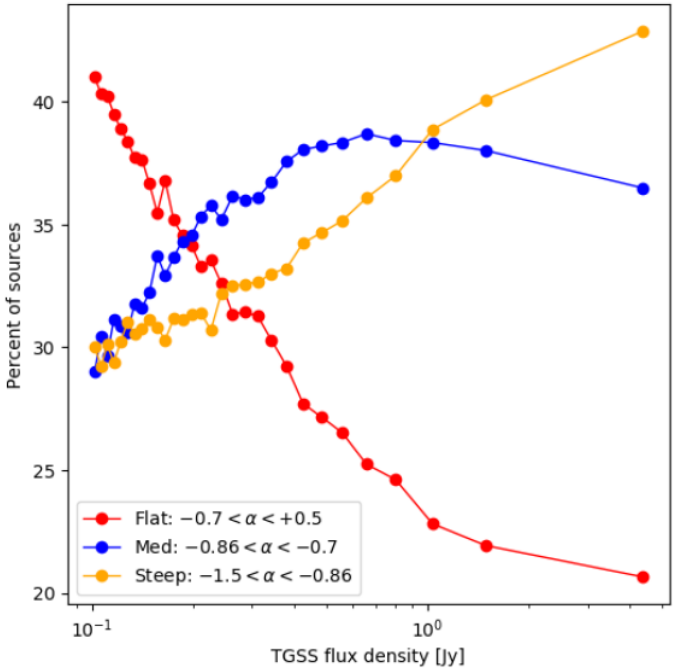
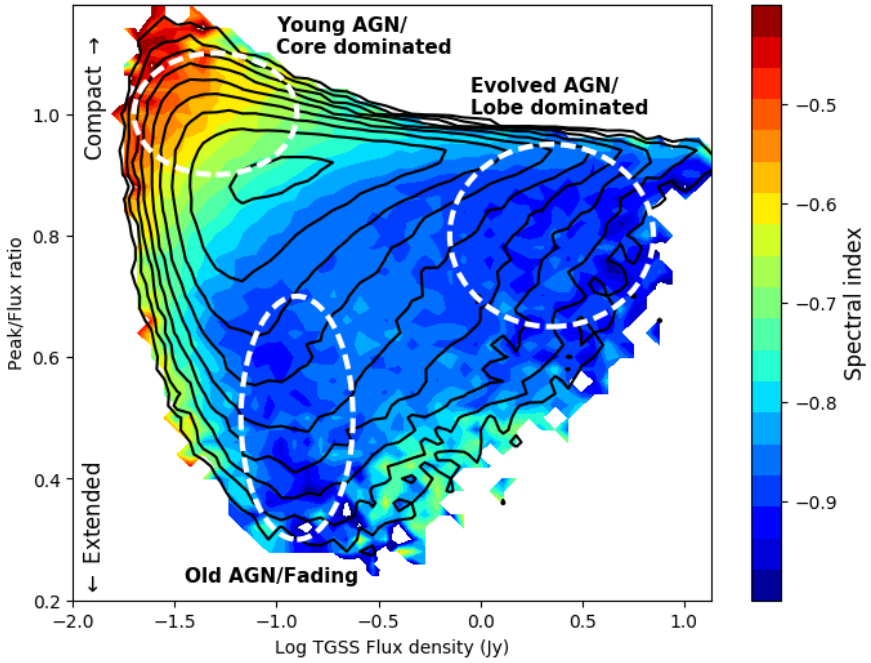
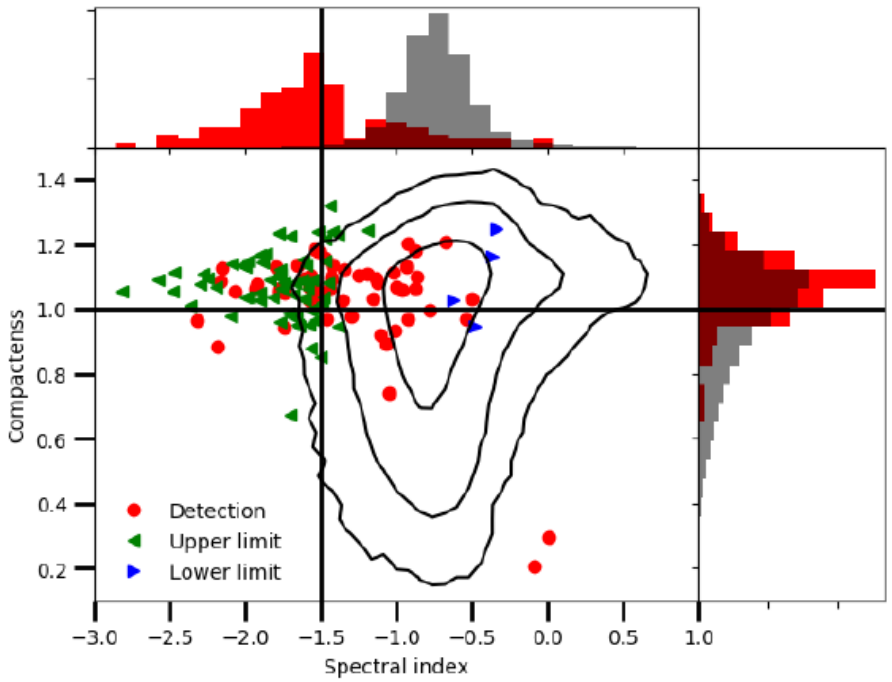
Some spectral index applications

- Discover new HzRGs, cluster halos and relics, fossil AGN, SNRs, and PSRs
- Evolution of radio source populations with flux density
- How radio luminosity and spectral index change with optical/IR properties







TGSS-NVSS spectral index project: http://tgssadr.strw.leidenuniv.nl/spidx/

Finding MSPs through radio continuum

Of the known pulsars, a fraction is detected in TGSS and generally have steep radio spectra (Frail+ 2016)

Attempt to find new MSPs by looking for compact, USS radio counterparts at Fermi 3FGL/4FGL unassociated source locations

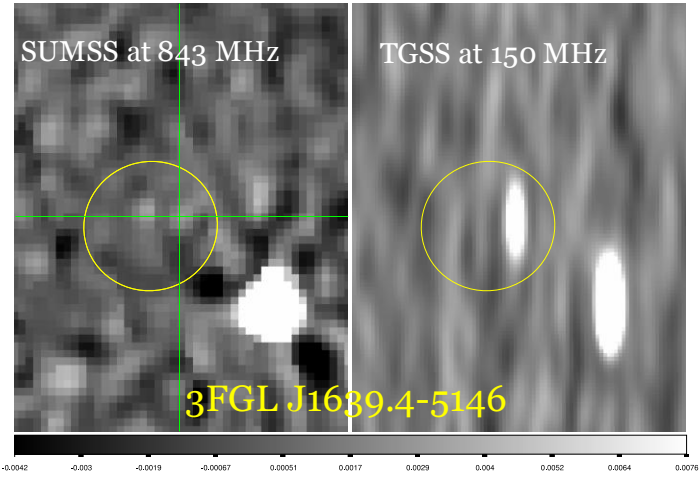
- Method selects without regard to period, DM, orbital parameters and scattering
- Candidates searched for pulsations in γ-ray (Fermi) and radio (GBT, Parkes, VLA)
- Discovery of 7 new MSPs, and one 'ordinary' pulsar (Frail+ submitted) (one is an MSP with a 1.7 ms period, also a USS source in GLEAM)

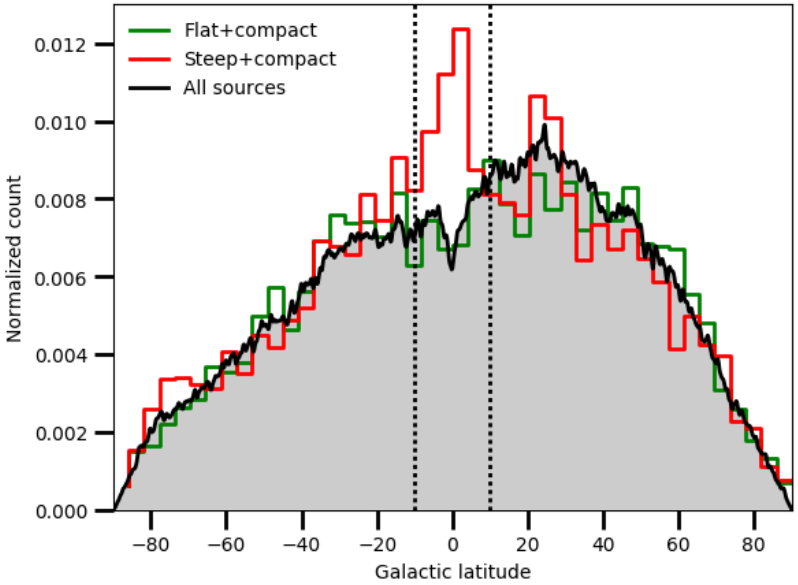
A significant excess of compact, steep-spectrum radio sources is located at low galactic latitude

- Pulsars are a prime candidate

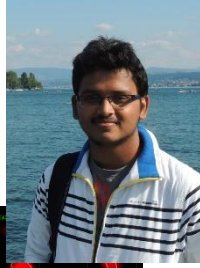
GMRT pulsation search follow-up of 200 near-galactic plane candidates to verify this potentially powerful alternative method to find pulsars

- Core team: Gupta (NCRA), Frail (NRAO), de Gasperin, HTI (Leiden)





USS sources in galaxy clusters



Systematic search for extended USS sources in TGSS-NVSS with spectral index < -2, and correlated with known optical / X-ray / SZ cluster positions

Pilot set of 7 sources selected for follow-up with GMRT at 325/610 MHz (PI Mandal) confirms steep-spectrum nature

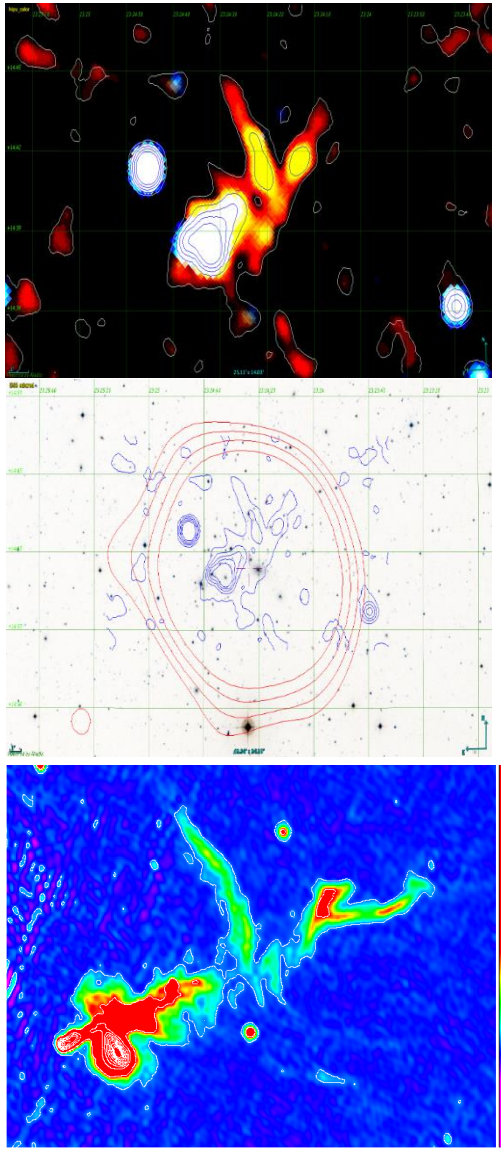
Most sources appear to be tailed radio galaxies that have disrupted and enhanced tails, indicative of cluster merger activity

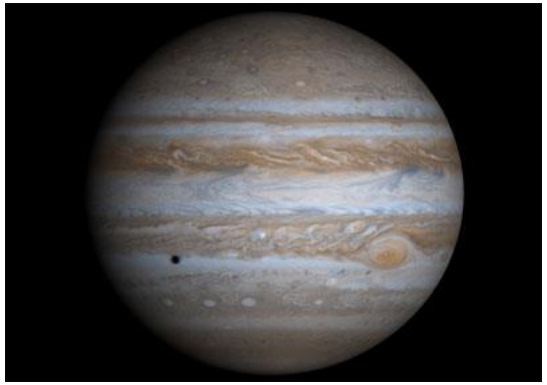
More ongoing radio follow-up for higher resolution and spectral index mapping, which will provide more clues on the nature of these objects

Likely to be 'tip of the iceberg', with many more to be revealed in deeper surveys (LOFAR, SKA-LOW)

Can provide insight into the contribution of radio galaxies to the pool of relativistic electrons in the ICM

USS extended sources can be used to locate new clusters



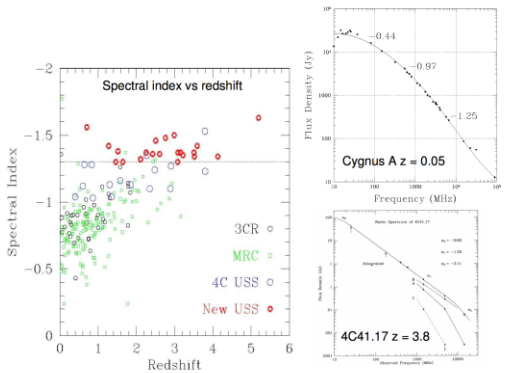


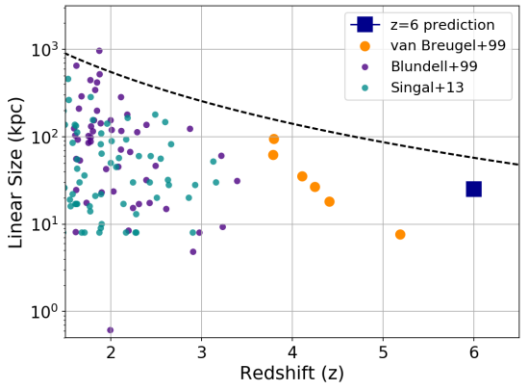
High-z extreme spectrum project

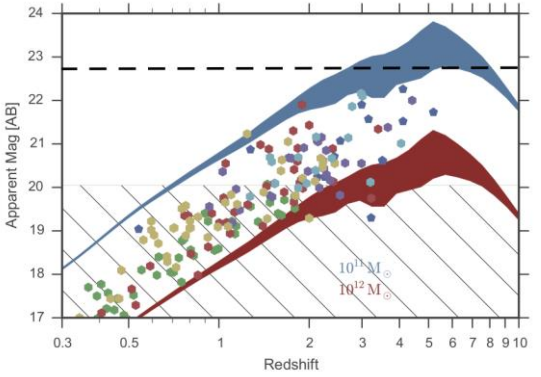
Attempt to find the first HzRG at very high redshift (z>6) to probe HI absorption during the Epoch-of-Reionization (PI Saxena)

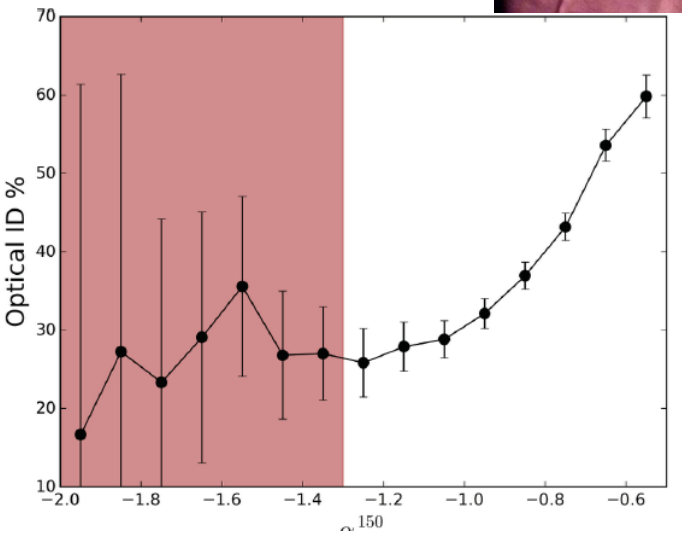
- Selected compact USS sources with TGSS-NVSS spectral index < -1.3 (HzRGs tend to have steeper spectral indices)
- Matched to FIRST to select on compactness and obtain good astrometry (HzRGs are not expected to be larger than 10-15 arseconds on the sky)
- Ensure no optical and/or IR counterparts in all-sky optical/IR surveys (K - z correlation: HzRGs are dominated by light from old stars)
  - Including SDSS, PanSTARRs, WISE, and UKIRT

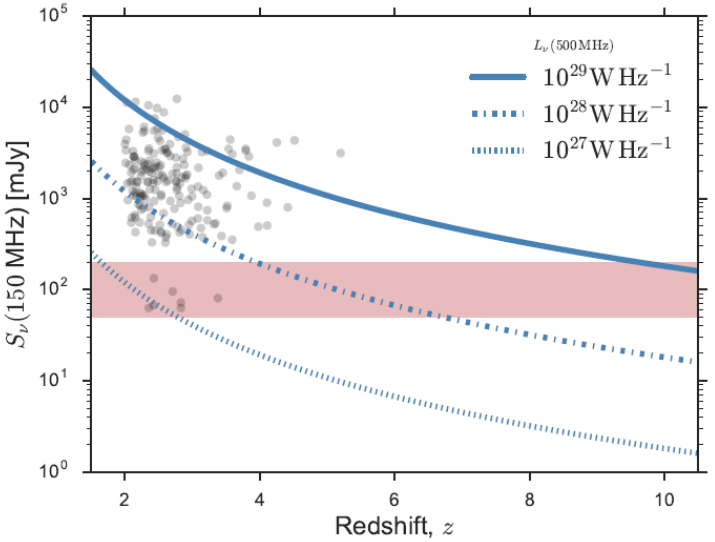
With TGSS sensitivity, sample probes unexplored area in parameter space





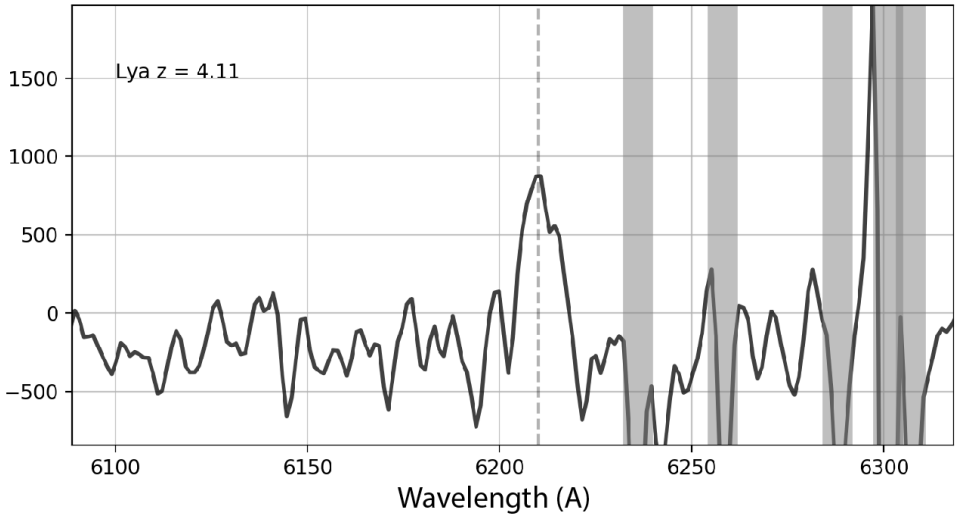


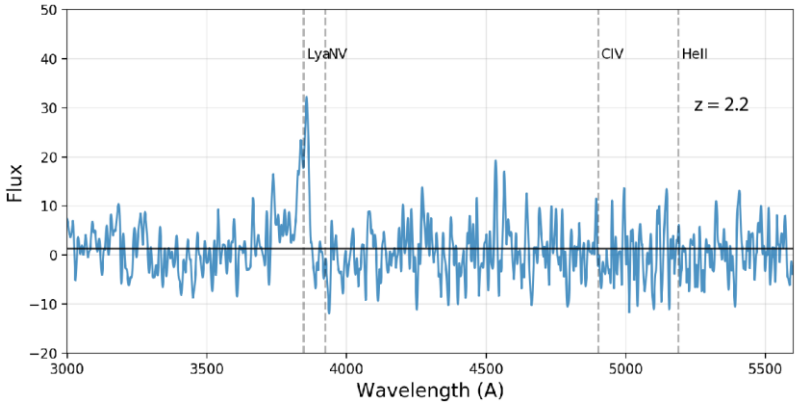


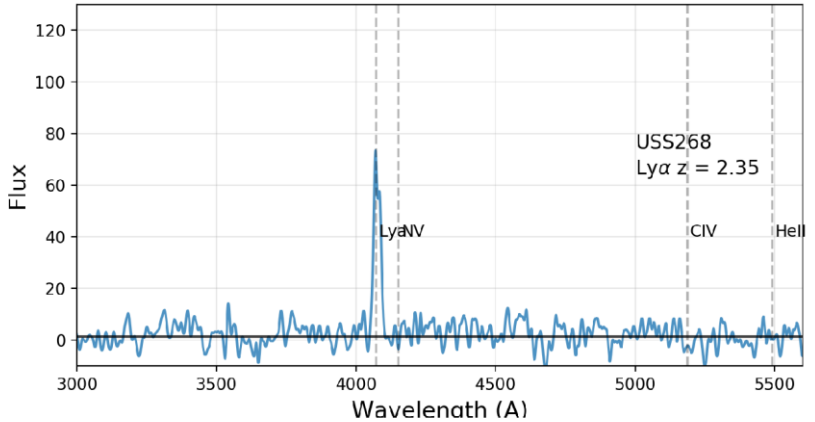


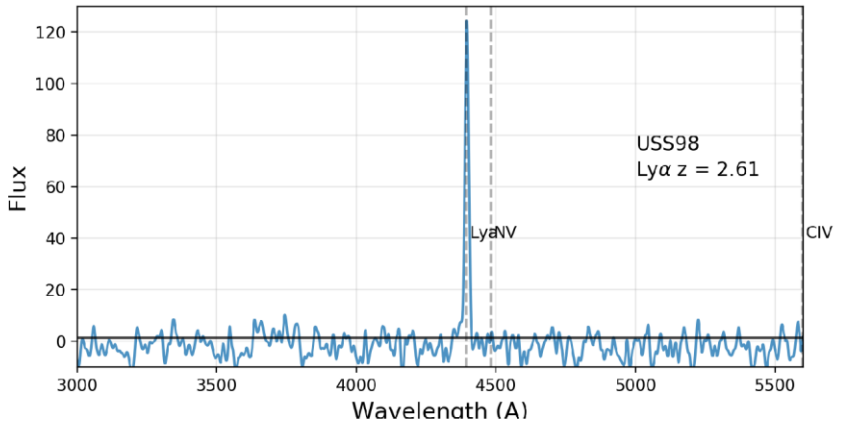
HzRG candidate follow-up

- Selected 33 new USS sources for various follow-up (radio, optical/IR)
- JVLA L- and P-band follow-up in A-configuration to confirm spectral index, compactness, and improve positions
- Ongoing optical/IR photometry and spectroscopy of ~20 candidates
  First results are coming in – stay tuned!









Summary

The TGSS survey is actively used for scientific explorations

- Largest area survey of a single interferometer (3.6π sr, or 90 percent of the sky)
- Characterizes the bright end of the 150 MHz radio sky at 25” resolution
- Active follow-up of steep-spectrum sources, aimed at finding HzRGs, pulsars, halos & relics, old AGNs, etc.
- Calibration reference for LOFAR and other low-frequency arrays
- Release of large-area 150-1400 MHz spectral index maps and catalog (3π sr)
- New data release (ADR2) will replace low-quality and missing observations and improve flux scale accuracy

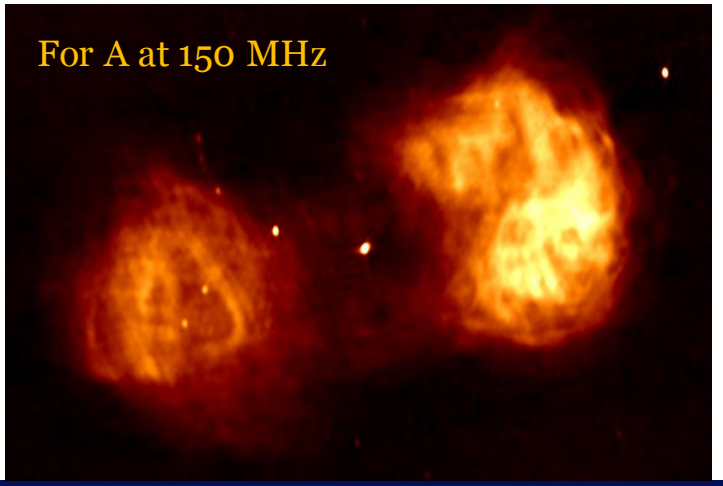
TGSS ADR2

One of the goals of TGSS ADR was (and is) to make good quality survey data products openly available to the community in a timely fashion, without any proprietary period

- Scientific exploration by a large group of people adds to the success of the survey (and the telescope)
- Feedback from the community helps to improve the quality of the survey in subsequent data releases

New alternative data release (ADR2) is scheduled for ~~fall of 2017~~ first semester of 2018, which will include

- Replacement of low-quality and missing observations (70 hours of GMRT observing awarded and completed)
- Improved flux scale accuracy in selected areas (replacement observations and pipeline changes)
- Targeted observations for extremely bright sources (with J. Riding)
  "A-team" sources like CasA, CygA, HyaA, PicA, SgrA*, …
- Improved reconstruction of emission on larger scales
- Possible extension of science-ready data products by including calibrated visibilities – user feedback appreciated



GMRT Archive Processing Project

New application for SPAM pipeline to process all legacy continuum observations in the GMRT archive

GAPP core team: Ishwara-Chandra, Y. Wadadekar (NCRA) and HTI (Leiden)

- Aims at delivering (near-) science-ready data products to the astronomical community
- Project data older than 5 years will be automatically processed on a best effort basis
  - Prioritized processing of data can be requested
  - Newer data can be processed on request by PI
- Existing Indian compute and storage infrastructure will be used
- Estimated success rate >50-70 percent (biased by old HW-correlator data)
- Data products will be linked to observations regular GMRT archive interface
- Pilot underway on cycle 20 & 23 data, initial results look very encouraging