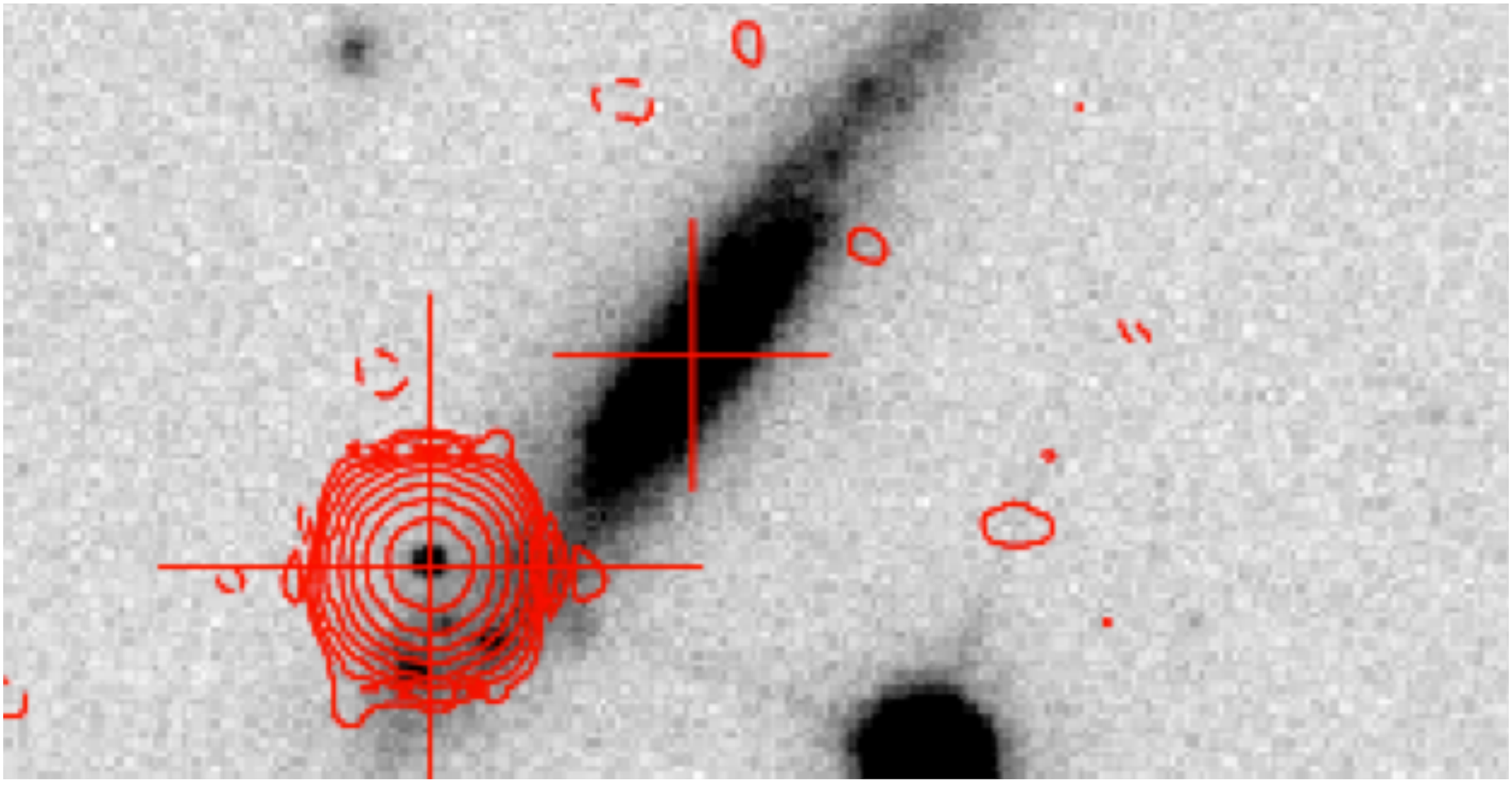


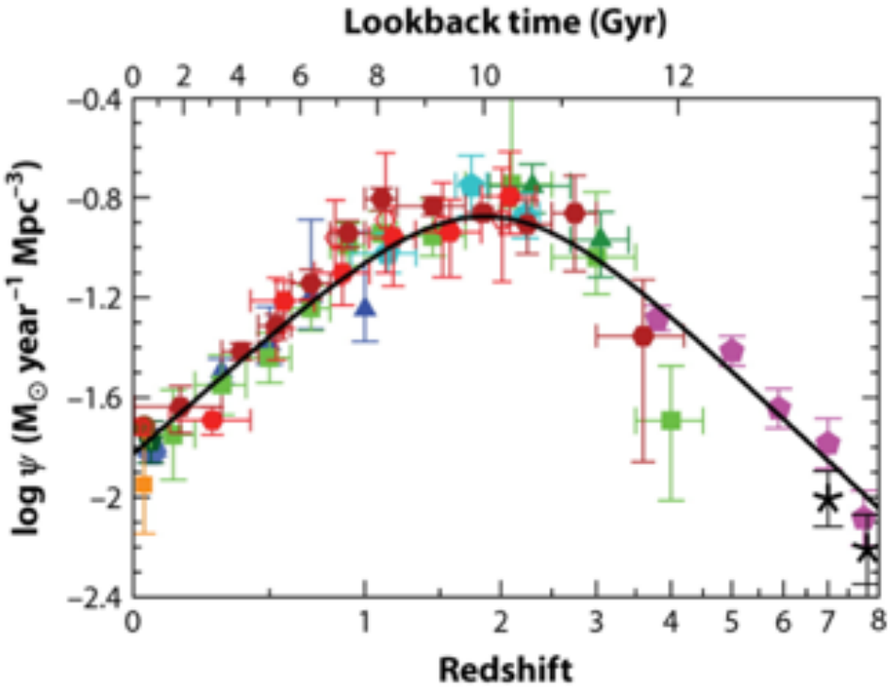
The MeerKAT Absorption Line Survey (MALS)

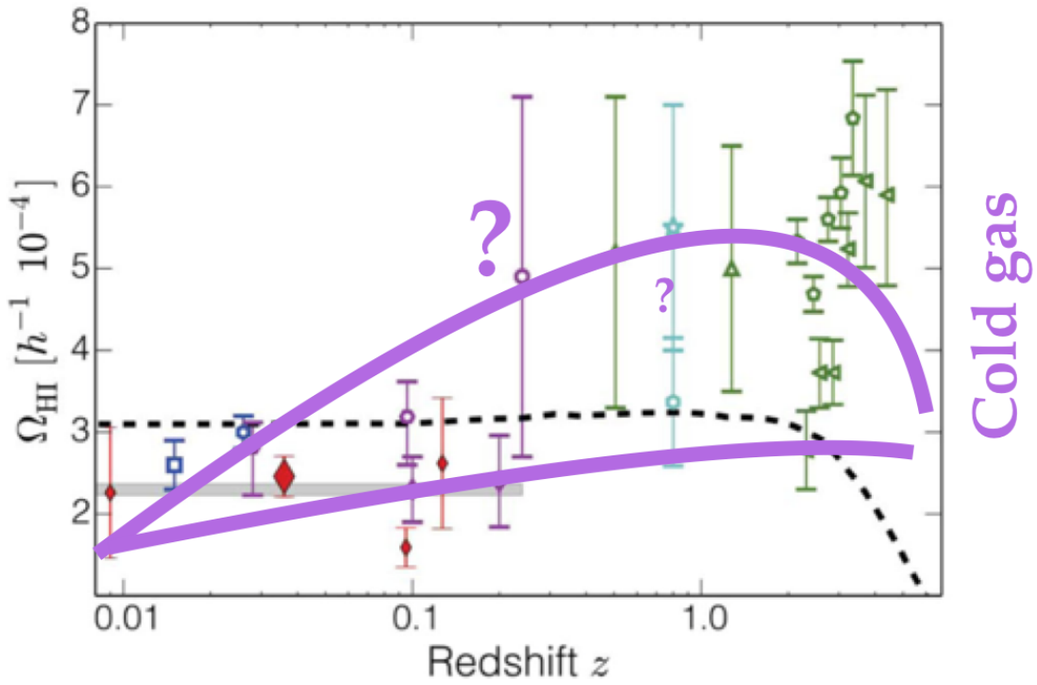
Neeraj Gupta (IUCAA)

PIs: N. Gupta and R. Srianand (IUCAA) http://mals.iucaa.in/

The MeerKAT Absorption Line Survey (MALS)

1655 hrs for the sensitive search of HI 21-cm and OH 18-cm absorption lines to map the evolution of cold atomic and molecular gas in galaxies at 0<z<2: the redshift range where most of the evolution in the star-formation rate density takes place.





MALS

The LSP review process completed.

The MeerKAT Absorption Line Survey (MALS)

MALS phase	Number of pointings	Time per pointing (mins)	Spectral rms† (mJy beam^{-1})	Continuum rms (μJy beam^{-1})	Total on-source time (hrs)
L-band (900-1670 MHz)	740	56	0.5	3	691
UHF-band (580-1015 MHz)	370	121	0.6	3	746

† 900-1670 MHz; ‡ 580-1015 MHz.

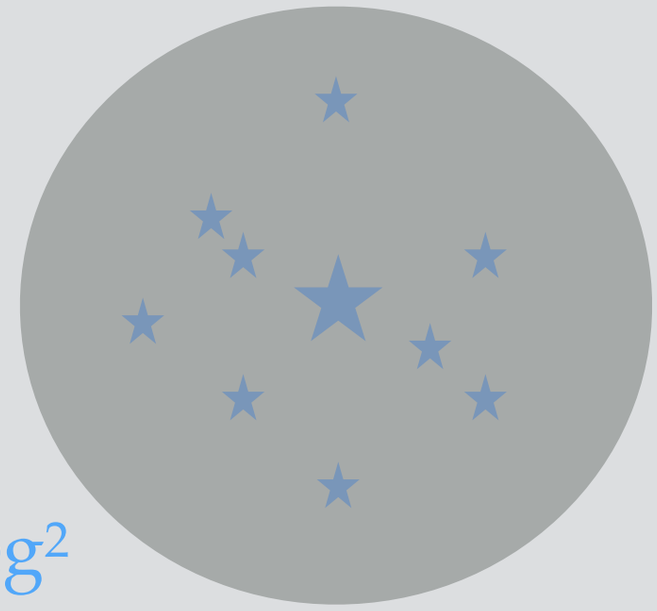
Estimated at ∼1200 MHz and ∼800 MHz for the full band split into 32768 channels.

The MeerKAT Absorption Line Survey (MALS)

Main science themes:

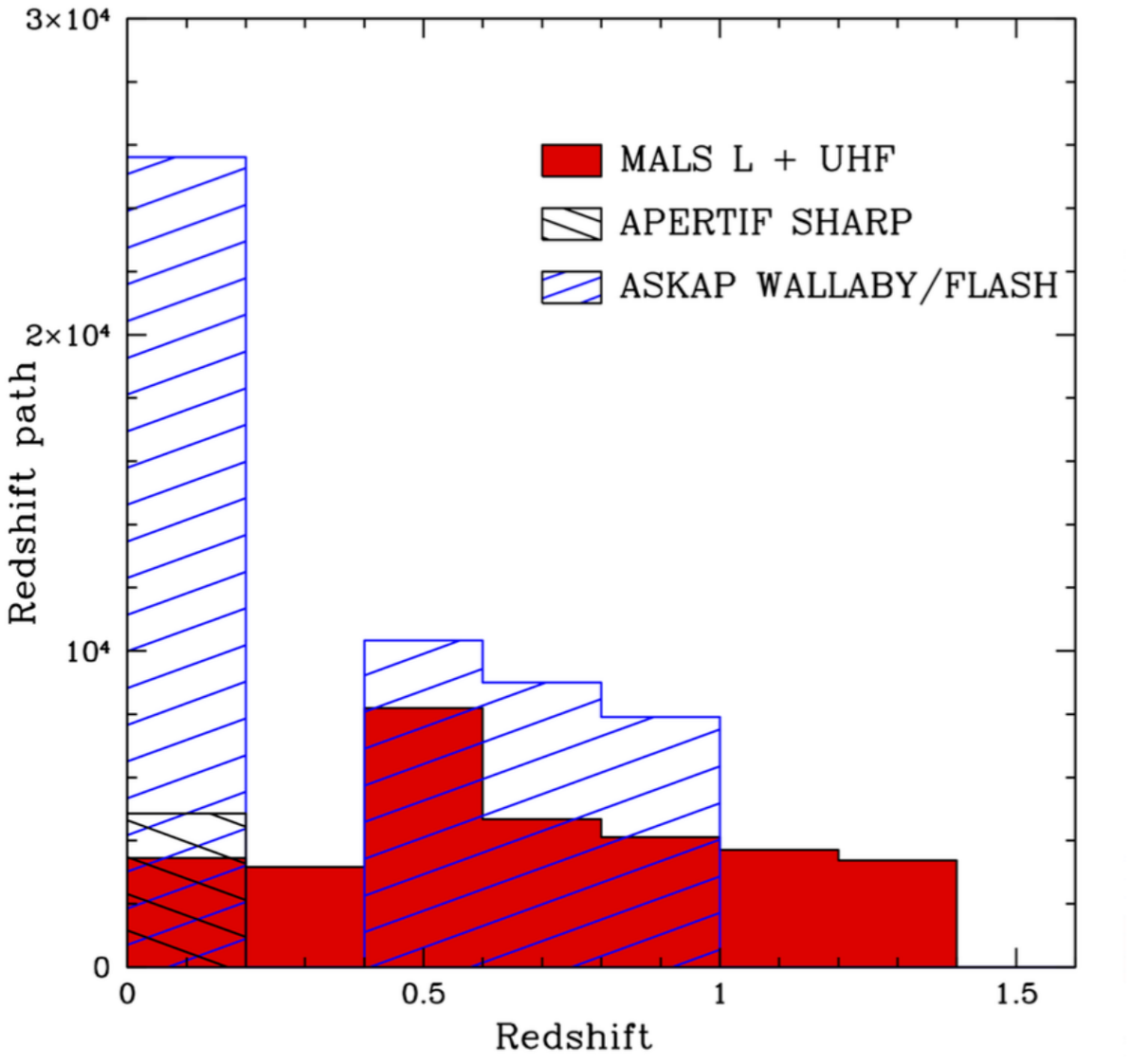
- Evolution of cold gas in galaxies and its relationship with SFR density **(~200 detections)**,
- Fuelling of AGN, AGN feedback and determining fraction of dust-obscured AGNs **(~500 detections)**,
- Variation of fundamental constants of physics: most stringent constraints (comparable to terrestrial atomic clocks).

Each pointing will be centered on a >400 mJy radio source.



L-band: 1 deg^2

Comparison with other surveys



Uniform coverage over 0<z<1.5

+ HI emission, and deep continuum and polarisation images

PROCEEDINGS OF SCIENCE

The MeerKAT Absorption Line Survey (MALS)

N. Gupta*[1], R. Srianand[1], W. Baan[2], A. Baker[3], R. Beswick[4], S. Bhatnagar[5], D. Bhattacharya[1], A. Bosma[6], C. Carilli[5], M. Cluver[7], F. Combes[8], C. Cress[9], R. Dutta[1], J. Fynbo[10], G. Heald[11], M. Hilton[12], T. Hussain[1], M. Jarvis[7,13] G. Jozsa[14], P. Kamphuis[15], A. Kembhavi[1], J. Kerp[16], H.-R. Klöckner[17], J. Krogager[18], V. Kulkarni[19], C. Ledoux[20], A. Mahabal[21], T. Mauch[14], K. Moodley[12], E. Momjian[5], R. Morganti[2], P. Noterdaeme[18], T. Oosterloo[2], P. Petitjean[18], A. Schröder[22], P. Serra[23], J. Sievers[12], K. Spekkens[24], P. Väisänen[22], T. van der Hulst[25], M. Vivek[26], J. Wang[11], O.I. Wong[27] and A.R. Zungu[12]

http://adsabs.harvard.edu/abs/2016mks..confE..14G

MALS: data processing and archiving

- **Data products**

  (1) Full spectral resolution (32K) XX, YY and then stokes I data cubes (absorption + emission)

  (2) Wide-field, wide-band, IQUV (~3 uJy) images

  (3) Absorption: catalog of radio sources upto 1 mJy and their spectra

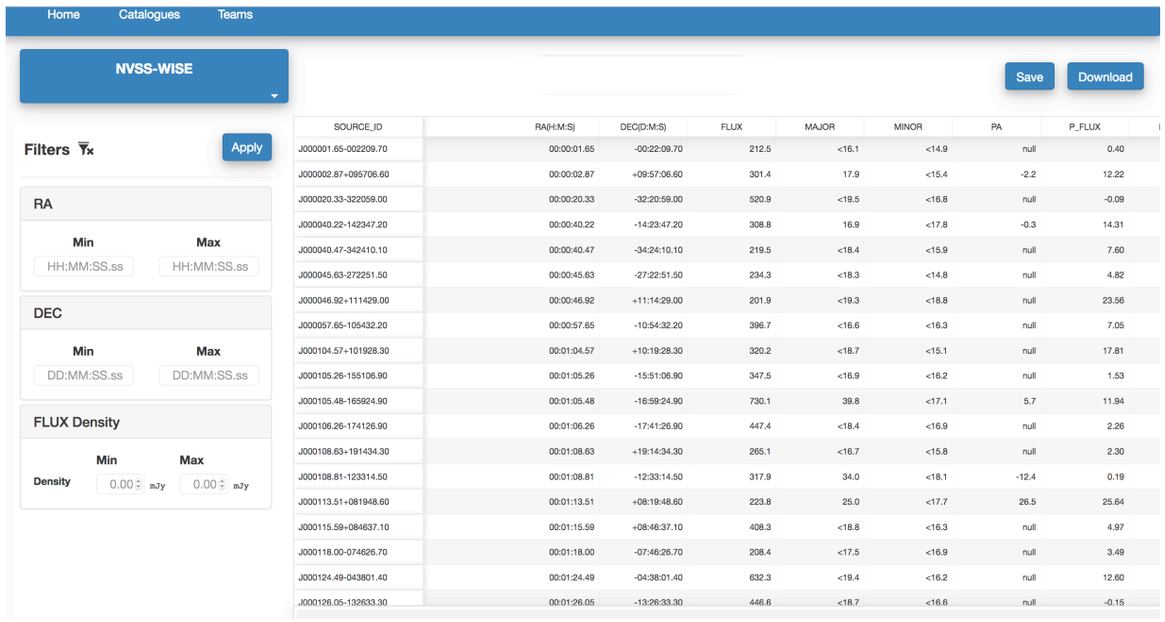
  (4) L-band: HI emission images; and value added data products.

- **Archive**

  (1) 4 PB raw visibility (4s integration) storage: ~1500 LT06 tapes (250 - 500 TB shipped every few months)

  (2) 12 PB for processed data + data products i.e. calibrated visibilities + cubes

  (3) Images (not cubes) and spectra to be served through a live database



Multi-wavelength database: refreshing the target list.

MALS: data processing and archiving

◆**Processing**

(1) ARTIP: Automated Radio Telescope Imaging Pipeline (CASA-based)

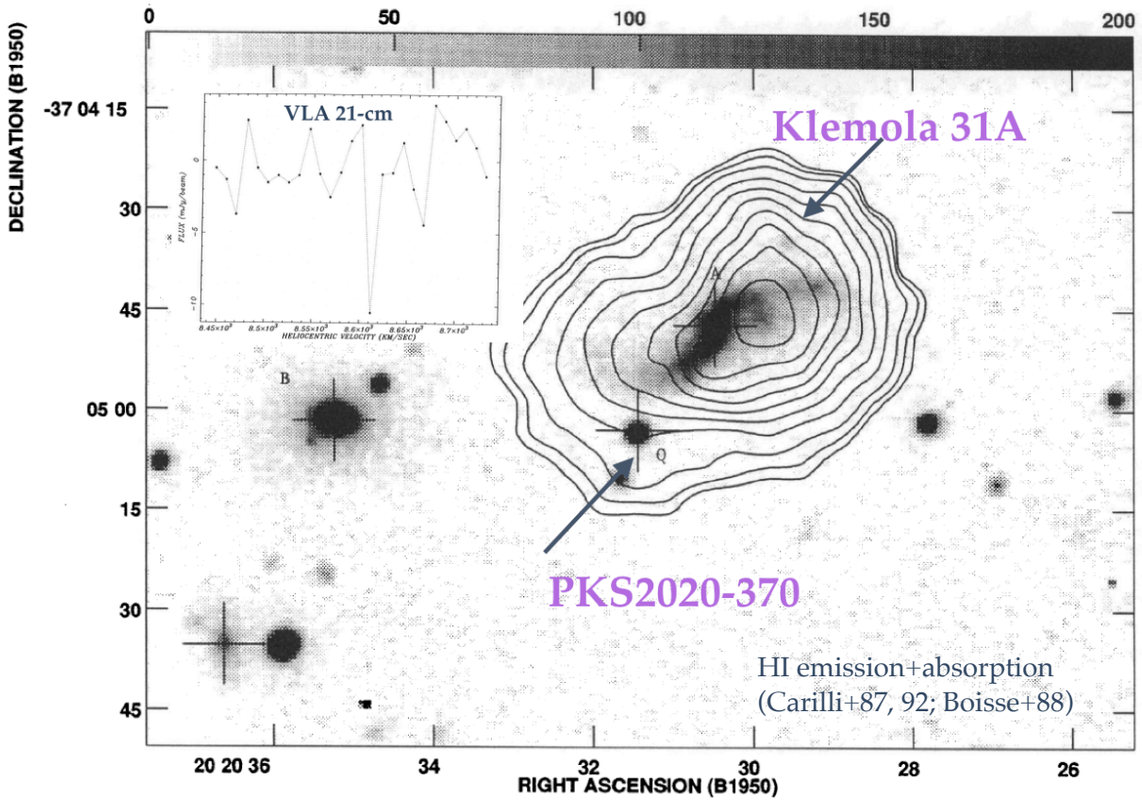
- CASA-based pipeline developed by IUCAA+ThoughtWorks
- Narrow-band imaging version: https://github.com/RTIP/artip
- ARTIP-CUBE: specialised for spectral line processing (development stage)

(2) Cluster at IUCAA for development and processing

- **VROOM:** 16-node cluster for MALS commissioned (1 + 1 PB)

Hardware	Details	Dell Cluster
Compute Nodes	14 Compute nodes	Manufacturer: Dell. Product Name: R640 (12 compute nodes) Product Name: R740 (2 GPU nodes)
Processor	Processor Details	Intel® Xeon® Gold 6126 Processor (19.25M Cache, 2.60 GHz)
Memory	Total Memory in each node	384 GB (12 X 32 GB) DDR4-2666 R ECC memory
IB	InfiniBand	Mellanox ConnectX-4, Single Port, VPI EDR, QSFP28 Adapter
MPI	Intel MPI	INTEL-Intel Parallel Studio XE Cluster Edition 2018 u3
Storage	File system type and interconnect used	Lustre over InfiniBand
Disk	Disk info	600GB 10K RPM SAS Drive
OS Version	RHEL	RHEL 7.3

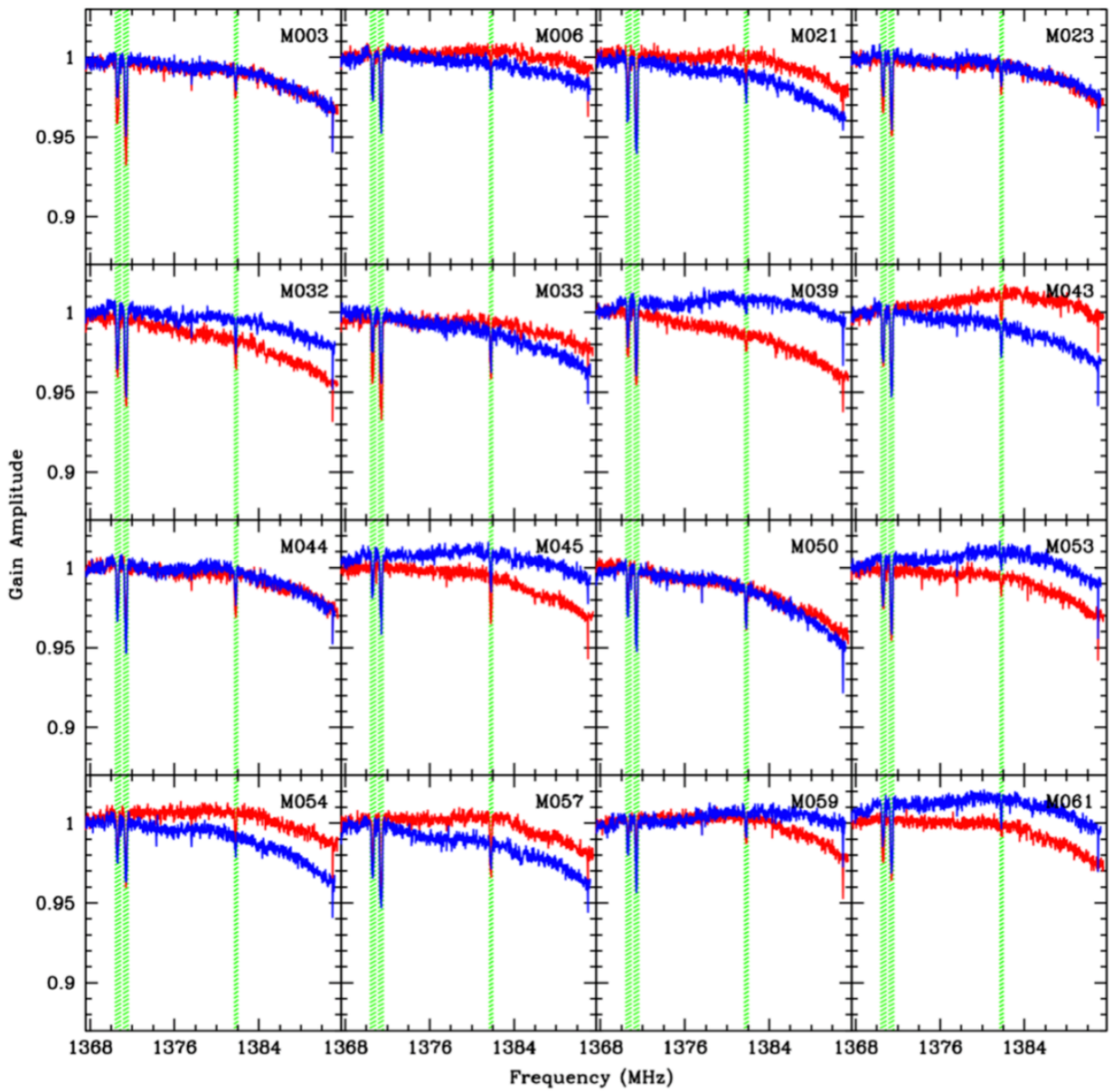
MALS: commissioning (PKS2020-370)



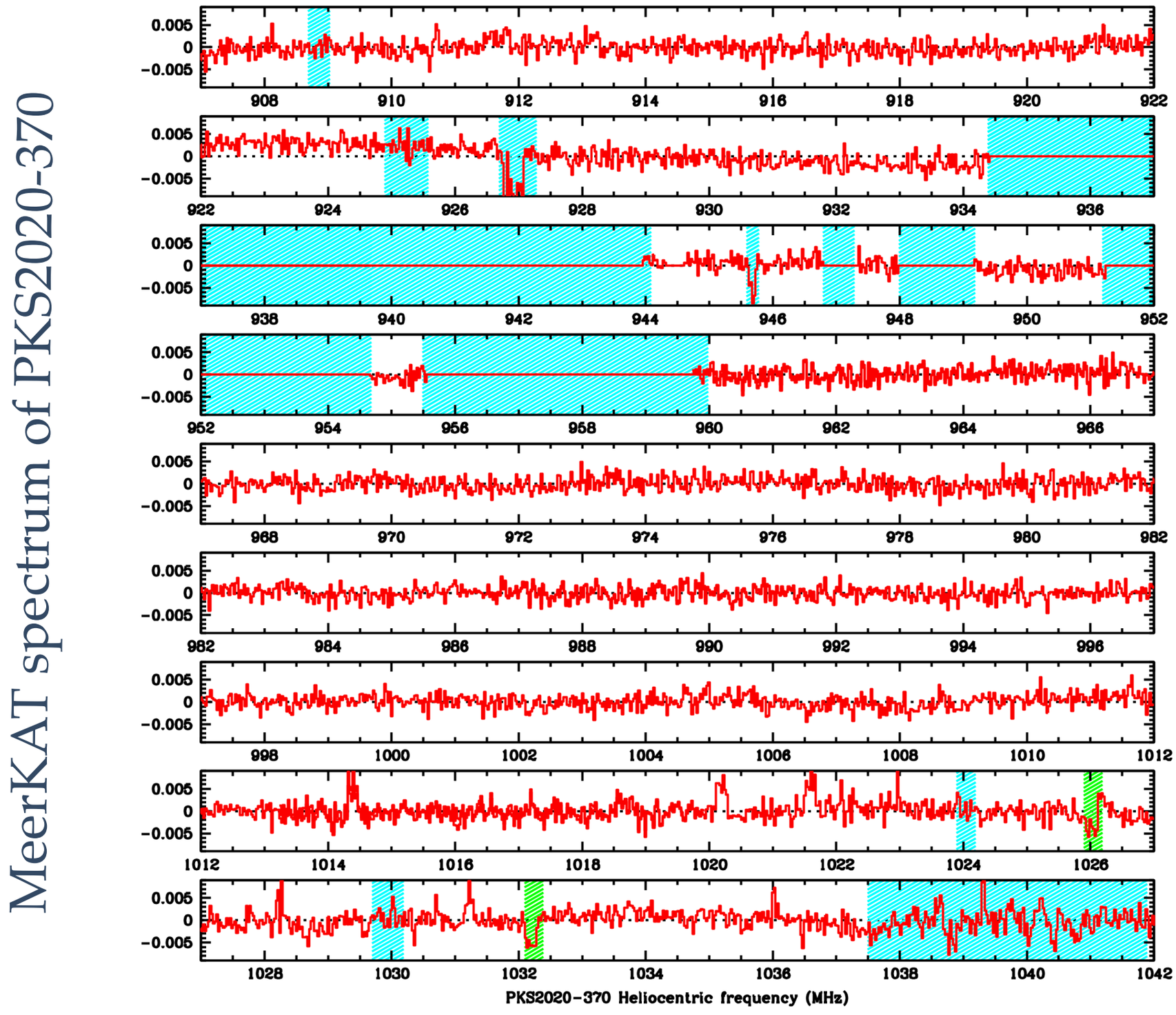
- MeerKAT-16
- Lband: 856 MHz
- ROACH-2 correlator: 32K mode
- Flux/BP: PKS1934-638
- Gaincal: PKS1954-388
- On-source time: 5.8 hrs
- Data Volume: 700 GB

Date of observation	Antennas
D1: Nov 7, 2017 (UTC 15:23 – 21:40)	16 antennas: m003, m006, m021, **m023**, **m032**, m033, **m039**, **m043**, **m044**, **m045**, **m050**, **m053**, m054, m057, m059, m061
D2: Nov 9, 2017 (UTC 17:30 – 21:28)	14 antennas: m003, m006, **m011**, m021, m033, **m048**, **m051**, **m052**, m054, **m055**, m057, m059, m061, **m062**

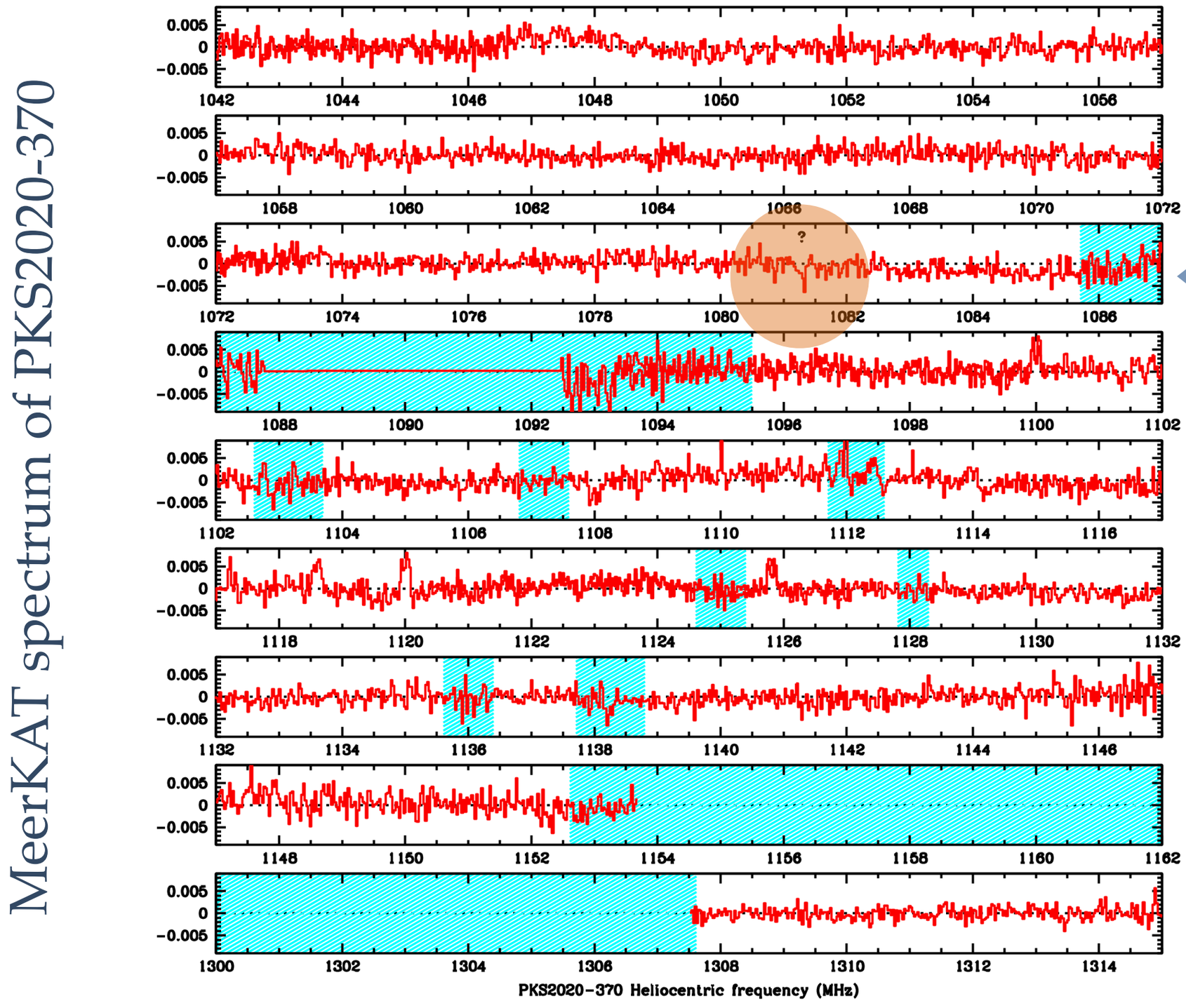
MALS: commissioning (PKS2020-370)



MALS: commissioning (PKS2020-370)

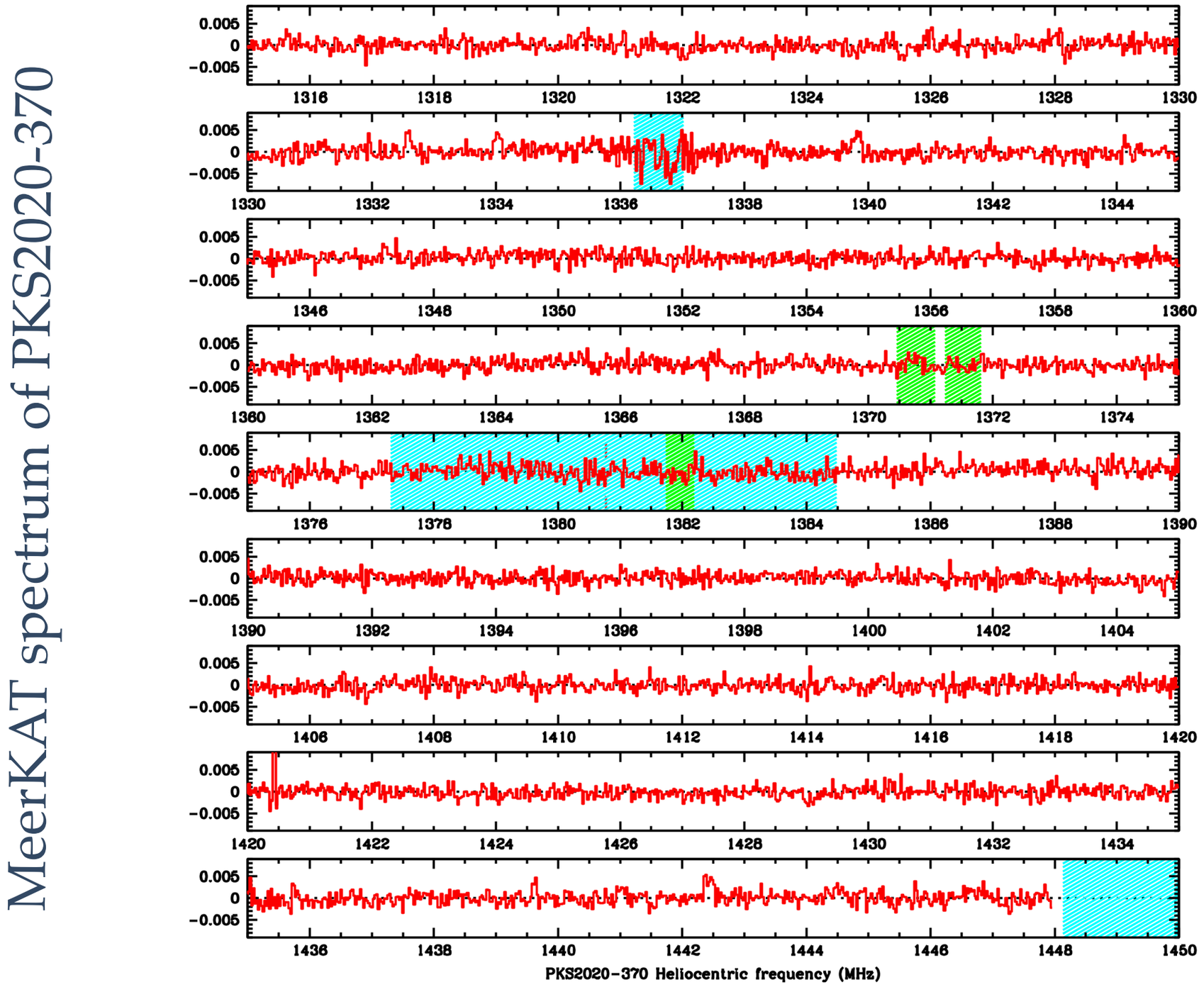


MALS: commissioning (PKS2020-370)



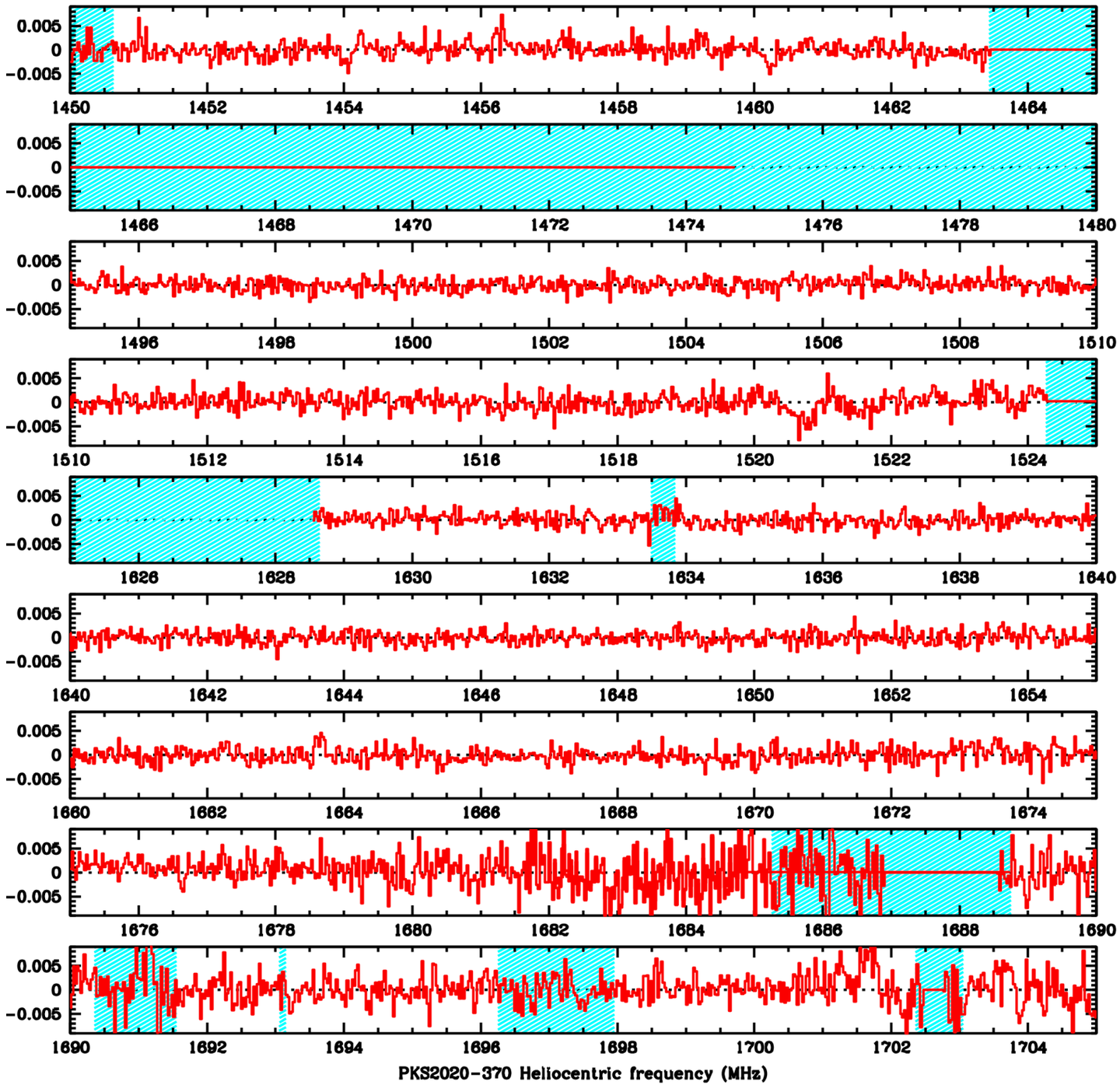
Tentative

MALS: commissioning (PKS2020-370)



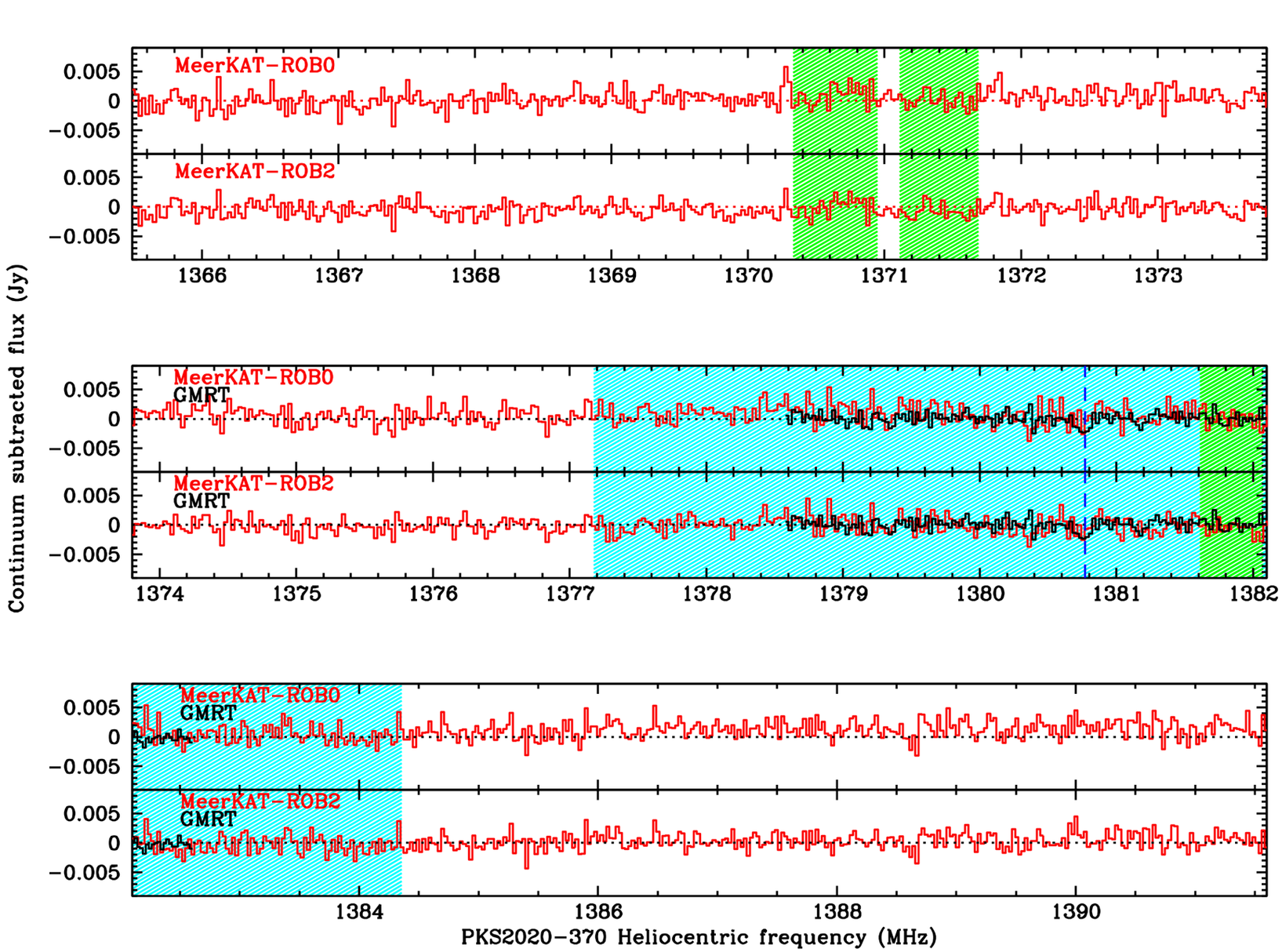
MALS: commissioning (PKS2020-370)

MeerKAT spectrum of PKS2020-370



MALS: commissioning (PKS2020-370)

MeerKAT spectrum of PKS2020-370



MALS: commissioning (PKS2020-370)

MeerKAT spectrum of PKS2020-370

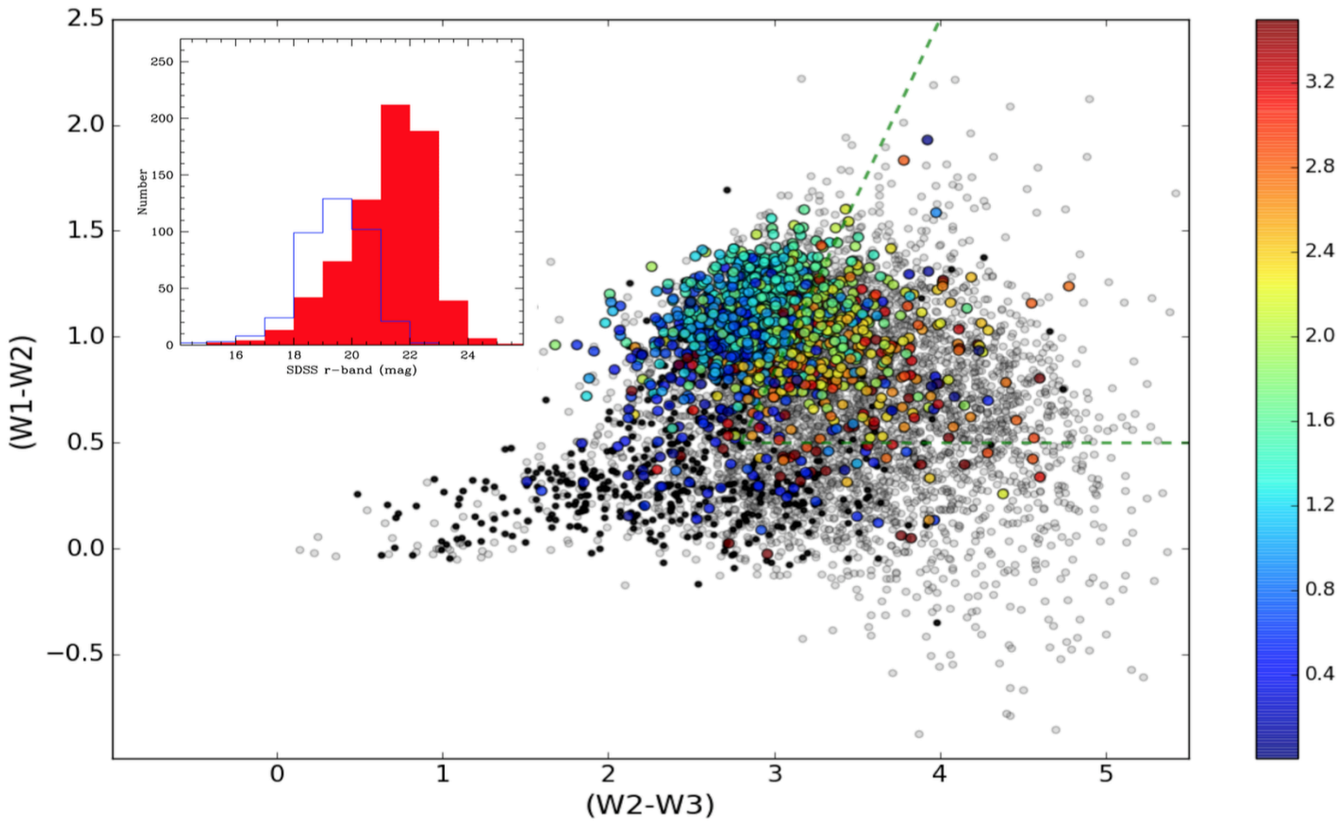
- Variability of HI 21-cm line
- Spectral rms higher by 1.3 - 1.5 (only in 32K mode)

Frequency (MHz)	Observed spectral rms (mJy/beam)	Theoretical spectral rms (mJy/beam)	Flux density (mJy)
1000	1.4	1.1	362
1150	1.4	0.9	353
1400	1.2	0.9	355
1650	1.2	0.9	355

Looking forward to SKARAB 32K mode.
Better optical spectrum (NaI, CaII) of PKS2020-370.

MALS: SALT/NOT survey (Phase-I)

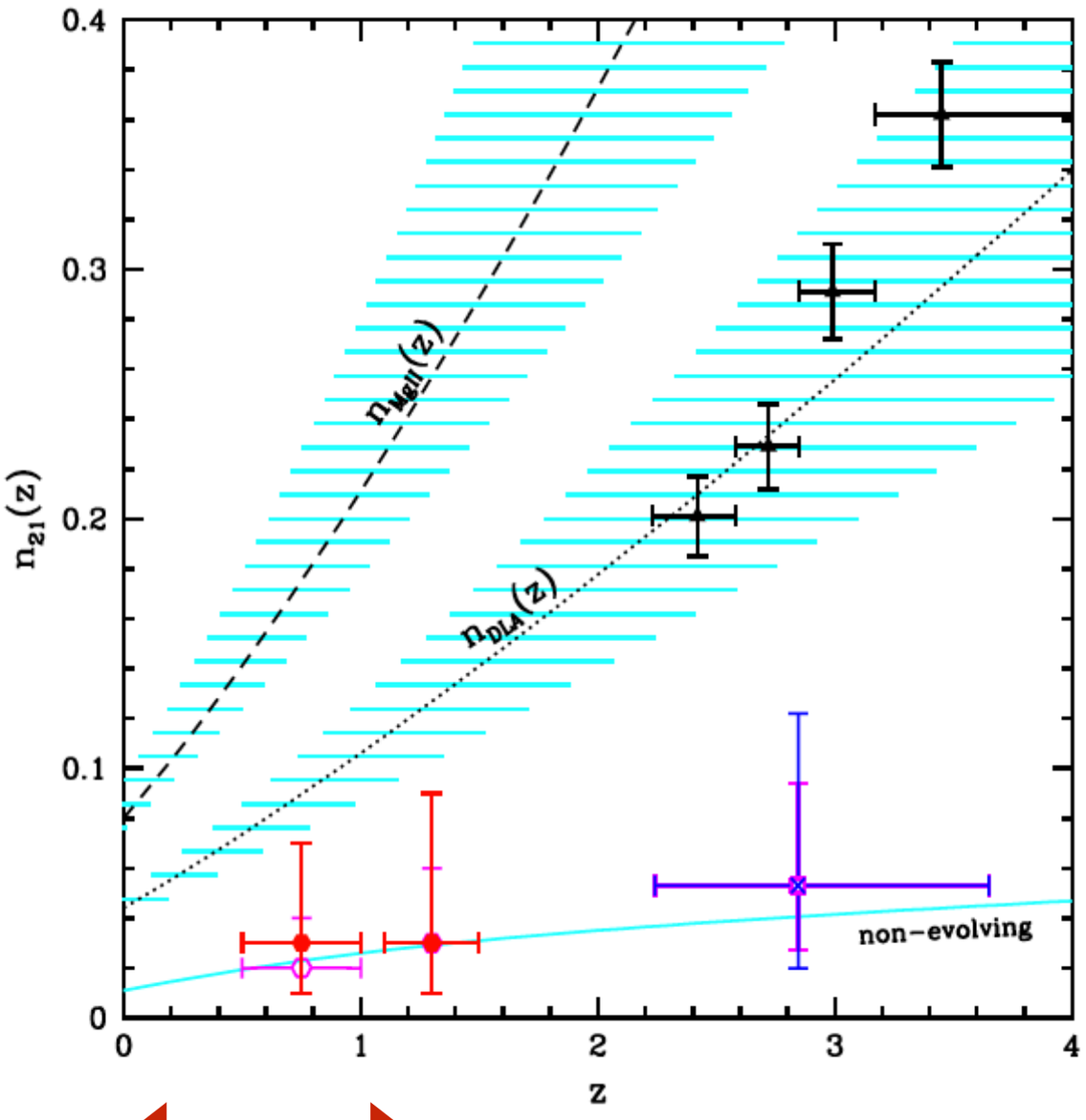
- Scarcity bright high-z quasars in the southern hemisphere
- Lack of uniform spectroscopic catalog



252 new RLQs: 102 at z>2.5

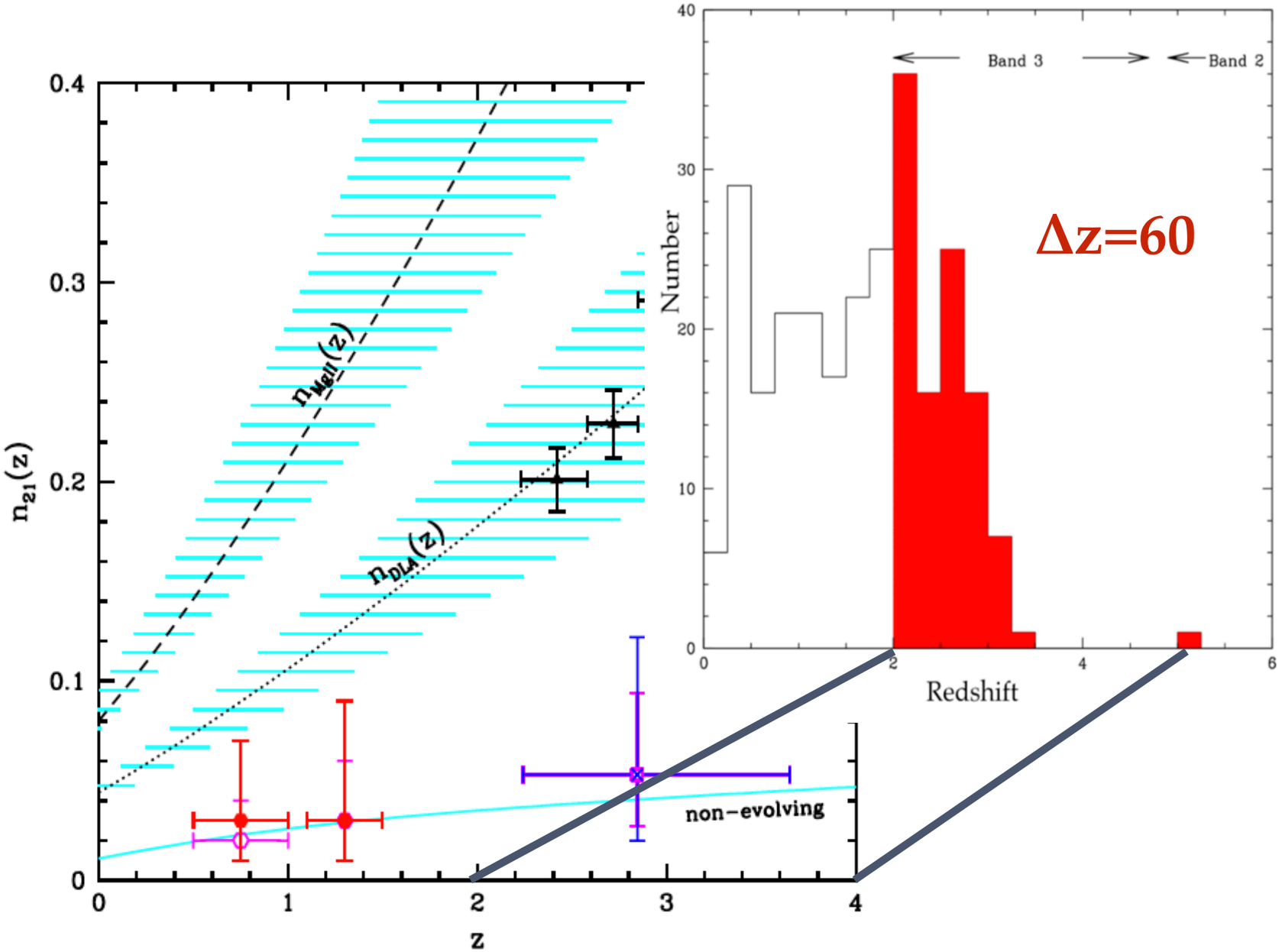
(Collaboration between IUCAA, Rutgers and South Africa)

SALT/NOT survey (Phase-I): uGMRT band-2,3 follow-up



MALS

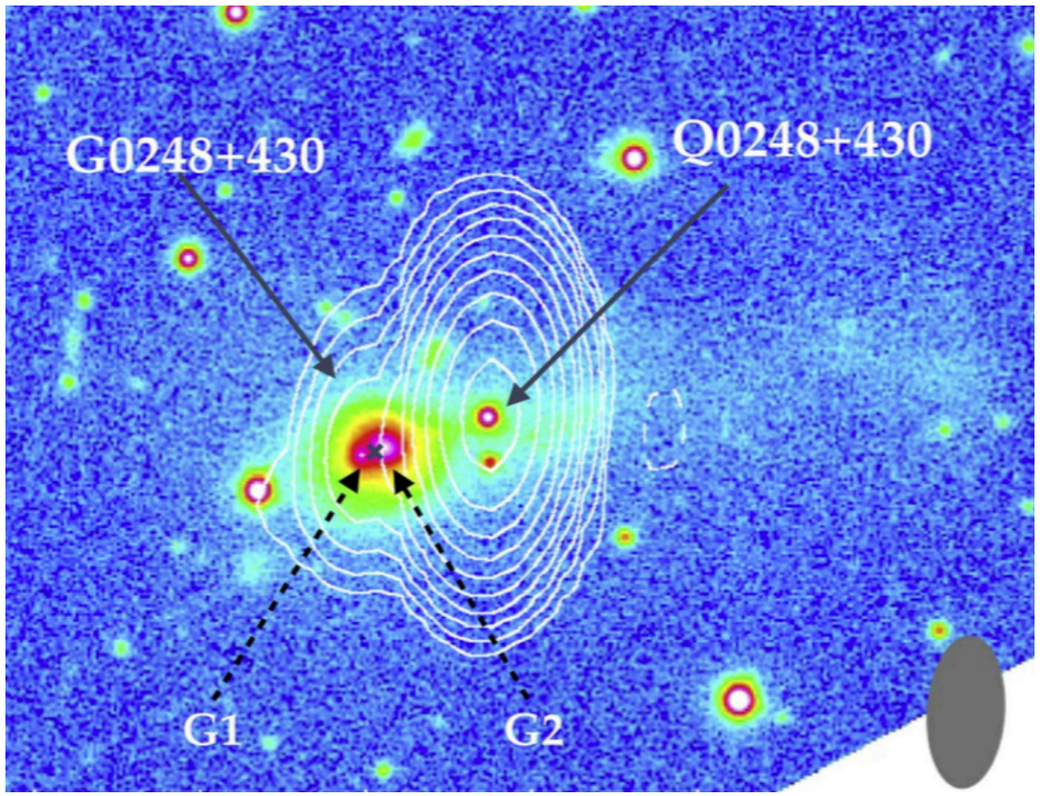
SALT/NOT survey (Phase-I): uGMRT band-2,3 follow-up

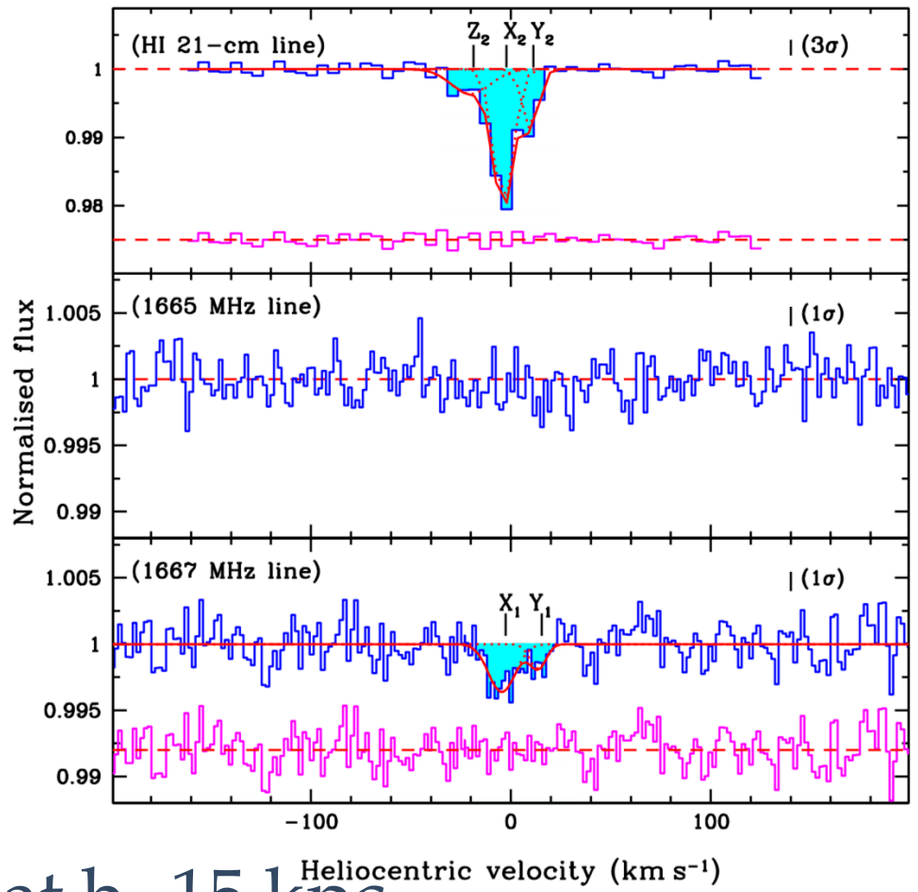


The Astrophysical Journal Letters, 860:L22 (6pp), 2018 June 20 https://doi.org/10.3847/2041-8213/aac9cd

Discovery of OH Absorption from a Galaxy at $z \sim 0.05$: Implications for Large Surveys with SKA Pathfinders

N. Gupta[1], E. Momjian[2], R. Srianand[1], P. Petitjean[3], P. Noterdaeme[3], D. Gyanchandani[4], R. Sharma[4], and S. Kulkarni[4]
[1] Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India; ngupta@iucaa.in
[2] National Radio Astronomy Observatory, P.O. Box O, 1003 Lopezville Road, Socorro, NM 87801, USA
[3] UPMC-CNRS, UMR7095, Institut d'Astrophysique de Paris, F-75014 Paris, France
[4] ThoughtWorks Technologies India Private Limited, Yerawada, Pune 411 006, India
Received 2018 March 16; revised 2018 May 22; accepted 2018 May 31; published 2018 June 18





Detected from a tidal tail at b~15 kpc

OH in nearby galaxies

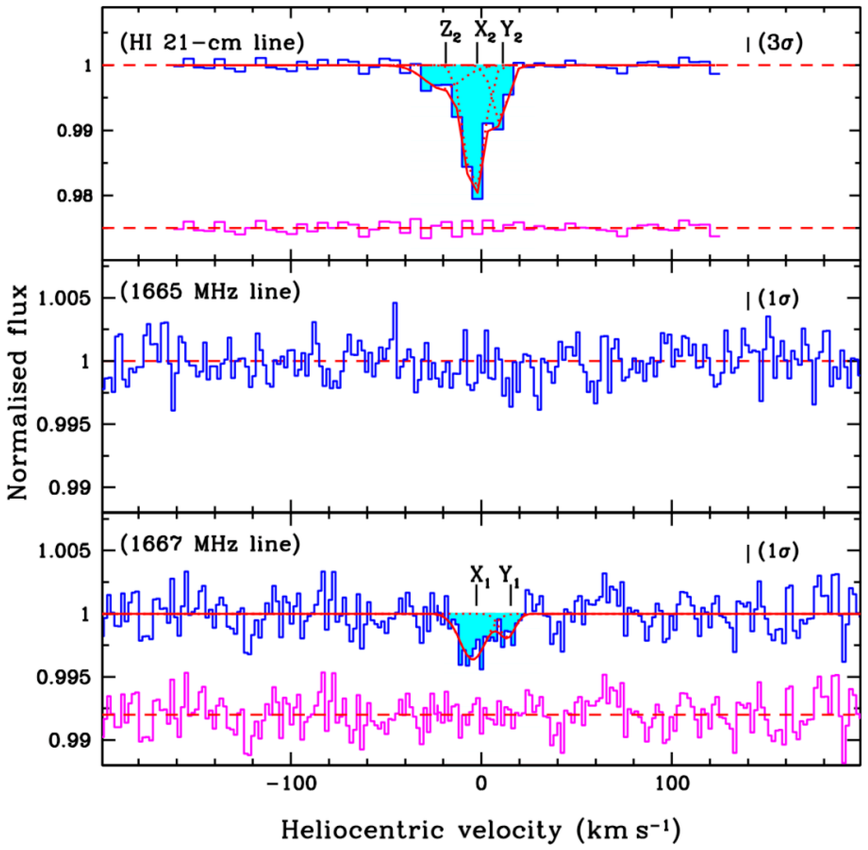
(Sample of 21-cm absorbers in nearby galaxies)

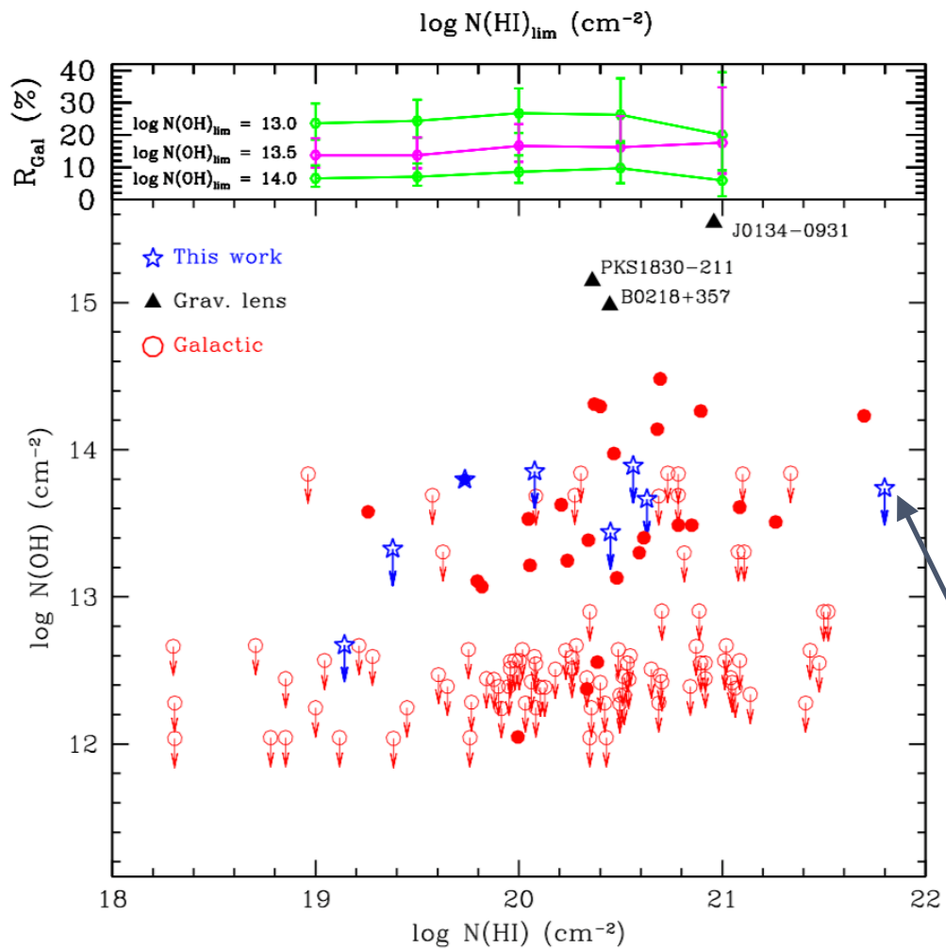
Quasar	Galaxy	z_q	z_g	$\int \tau dv$(H I) ($km\,s^{-1}$)	Ref.*	Peak flux density ($mJy\,beam^{-1}$)	Spectral resolution ($km\,s^{-1}$)	Spectral rms ($mJy\,beam^{-1}$)	$\int \tau_{1667} dv$(OH)$^{\diamond}$ ($km\,s^{-1}$)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Quasar-galaxy pairs									
3C232	NGC3067	0.530	0.0049	0.11	1	1563	1.4	1.7	<0.006
Q0248+430	G0248+430	1.313	0.0519	0.43	2	1207	1.5	2.1	**0.08±0.01**§
J084957.97+510829.0	J084958.10+510826.6	0.584	0.3120	0.95	3	200	0.9	3.9†, 4.4‡	<0.091
J104257.58+074850.5	J104257.74+074751.3	2.665	0.0332	0.19	5	295	1.5	1.5	<0.027
J124157.54+633241.6	J124157.26+633237.6	2.625	0.1430	2.90	6	67	1.6	1.2	<0.099
J124355.78+404358.5	124357.15+404346.5	1.520	0.0169	2.24	7	187	1.4	1.3	<0.035
J144304.53+021419.3	Emission-lines	1.820	0.3714	3.38	3	144	2.0	1.4	<0.059
J163956.35+112758.7	J163956.38+112802.1	0.993	0.0790	15.7	8	152	1.6	1.4†	–
Merging galaxy pair									
J094221.98+062335.2	-	-	0.1230	49.9	4	112	3.3	1.1†, 1.0‡	<0.070

Observed with GMRT, JVLA and WSRT

(typically 10 hrs / per object)

OH absorption in G0248+430 (z=0.05)





$f_c << 90$ pc

First extragalactic detection of diffuse OH !

$$\Delta\alpha/\alpha(z = 0.052) = (1.7 \pm 1.4)\times10^{-6}$$

$$\Delta n(\mathrm{OH};\ z\sim0.1) = 0.008\ ^{+0.018}_{-0.008}\ ;\ \log N(\mathrm{OH})>13.6$$

Expect $10^{(-10/+20)}$ such absorbers from MALS.

Summary

- MALS LSP review completed: ~1650 hrs for HI+OH at z<2.
- Processing and Archiving infra in place:
  - DB and ARTIP-CUBE in advanced development stage.
- First commissioning observations done:
  - Variable 21-cm absorption + one tentative detection.
  - SKARAB 32K mode expected later this year.
- MALS SALT-NOT phase-I completed
  - ~250 new RLQs; 200 at z>0.5
  - z: 2 - 5.2 coverage using uGMRT bands 2 and 3.
- First systematic OH search completed
  - Expect 10-30 diffuse OH absorbers from MALS.

MALS reference for details

http://adsabs.harvard.edu/abs/2016mks..confE..14G

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http://mals.iucaa.in/