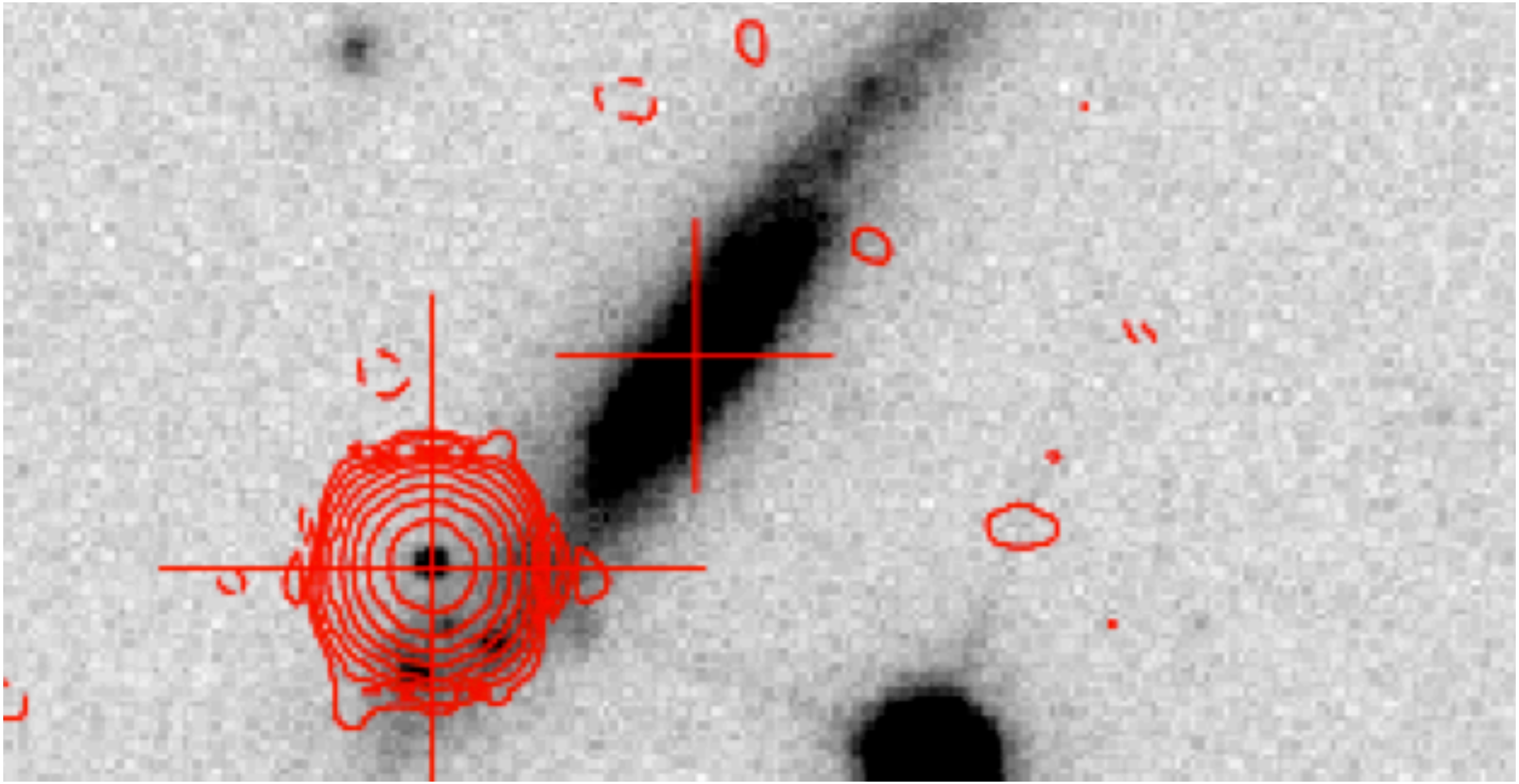


MeerKAT Absorption Line Survey

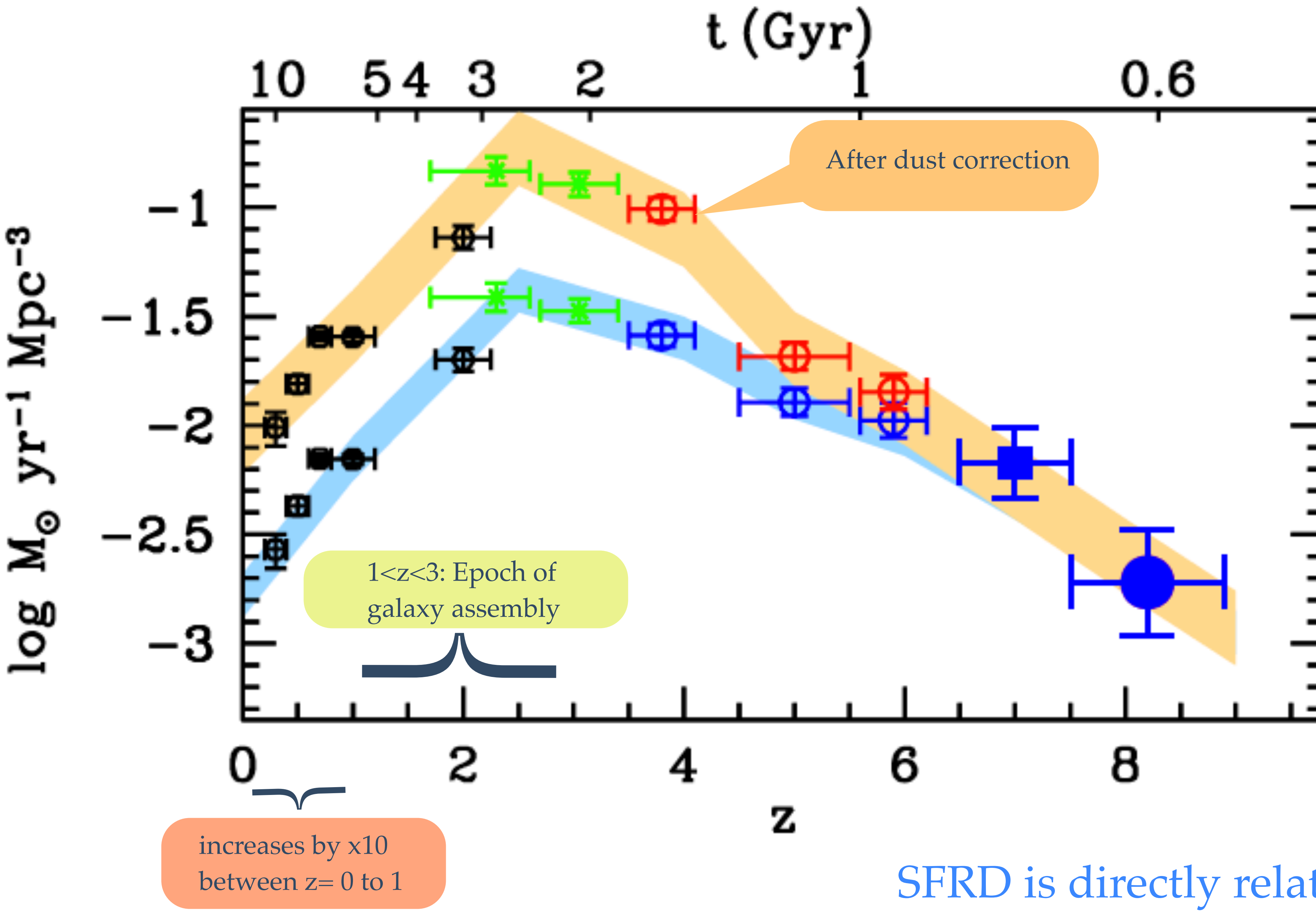
Evolution of cold gas in galaxies

Neeraj Gupta

Chile - 2011

ASTRON

Evolution of the Star formation rate density



SFRD is directly related to the amount and physical properties of cold gas in galaxies.

Bouwens et al. 2010

Star formation intimately related to Cold gas

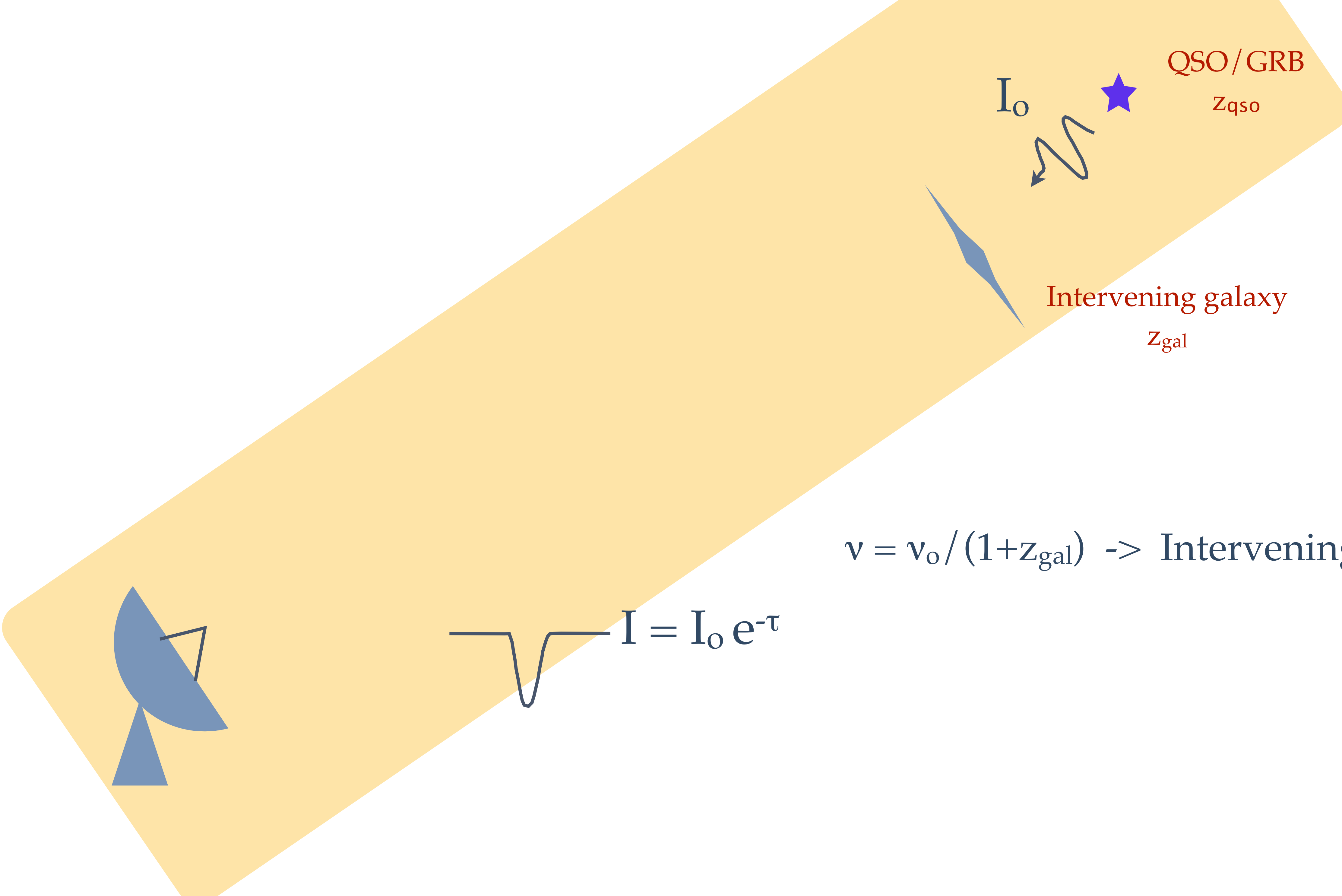
- Cold gas a precursor for star formation.
- SF influences physical conditions in and around galaxies: through radiative, chemical and mechanical feedbacks.

Little known about the cosmic evolution of Cold gas

- 21-cm HI emission studies limited to z<0.2.
- z >0.1 molecular emission line studies mostly limited to massive galaxies and AGNs.

.... will of course change with ALMA

Absorption lines as probe of cold gas

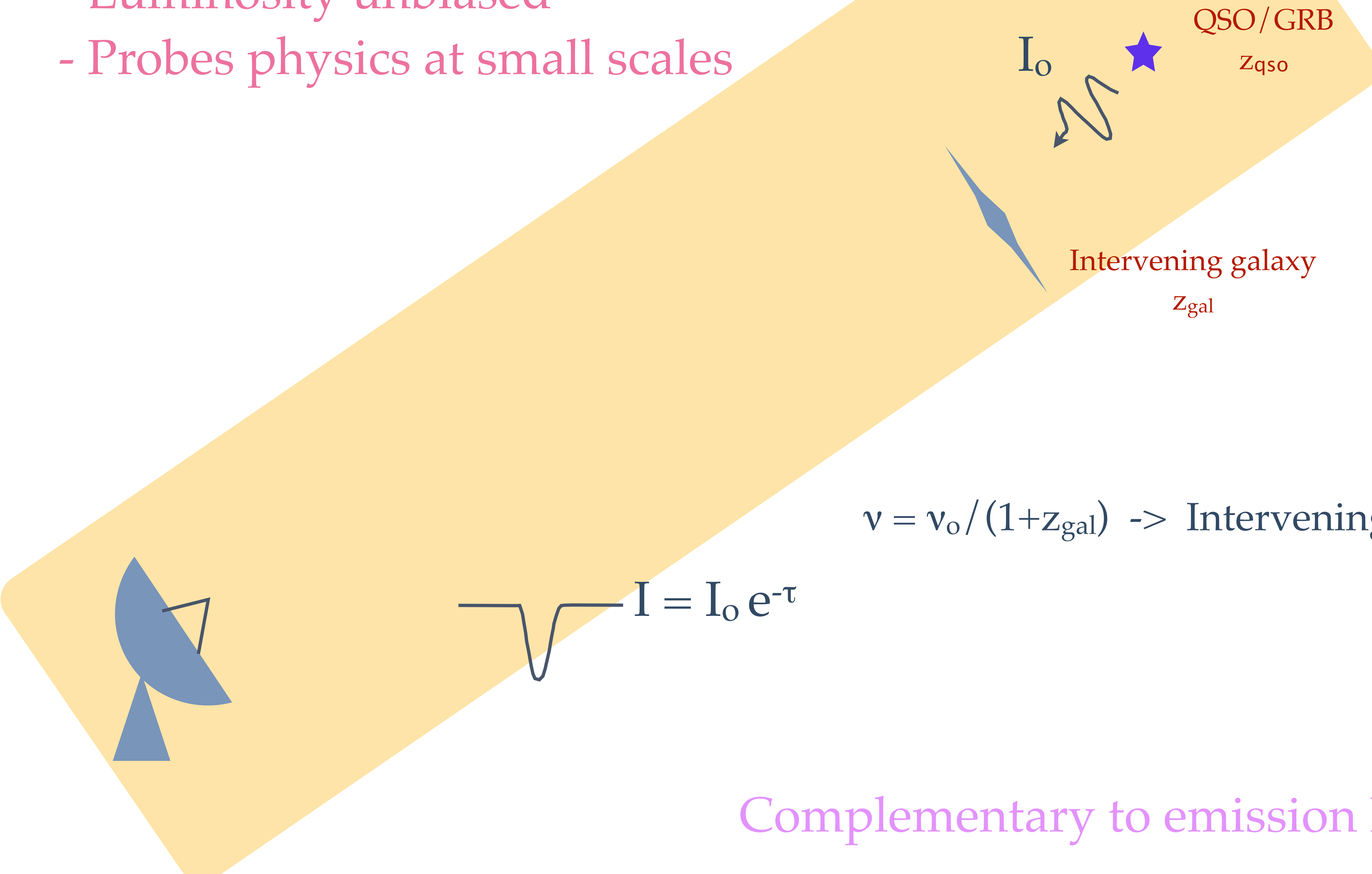


$\nu = \nu_o/(1+z_{gal})$ -> Intervening absorption

$I = I_o\, e^{-\tau}$

Absorption lines as probe of cold gas

- Luminosity unbiased
- Probes physics at small scales

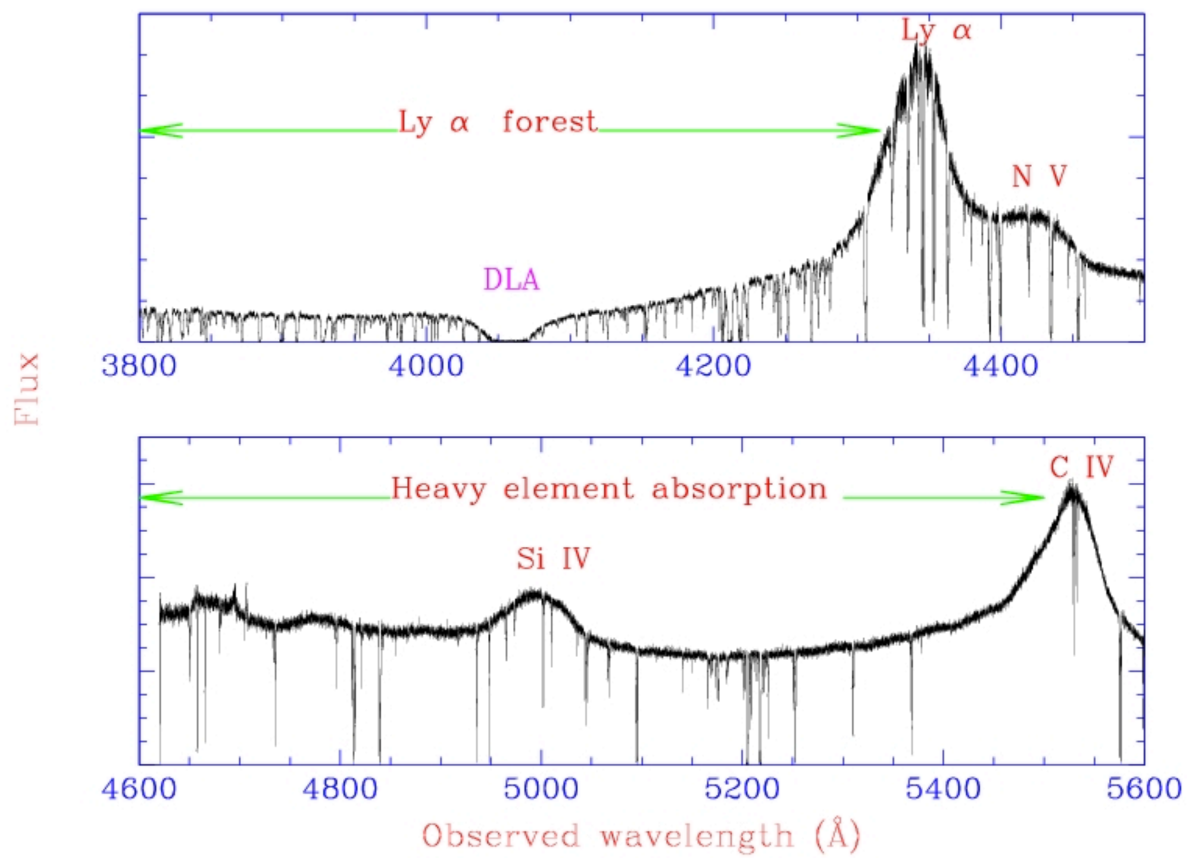


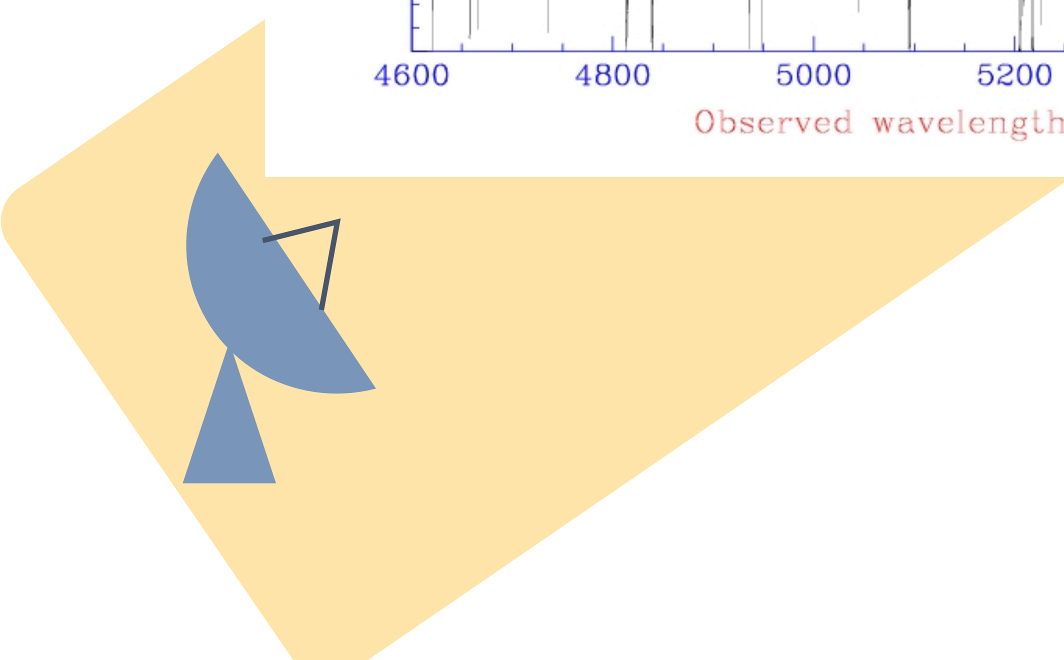
$I = I_o\, e^{-\tau}$

$\nu = \nu_o/(1+z_{gal})$ -> Intervening absorption

Complementary to emission line studies

Damped Lyman-α Absorbers (DLAs)





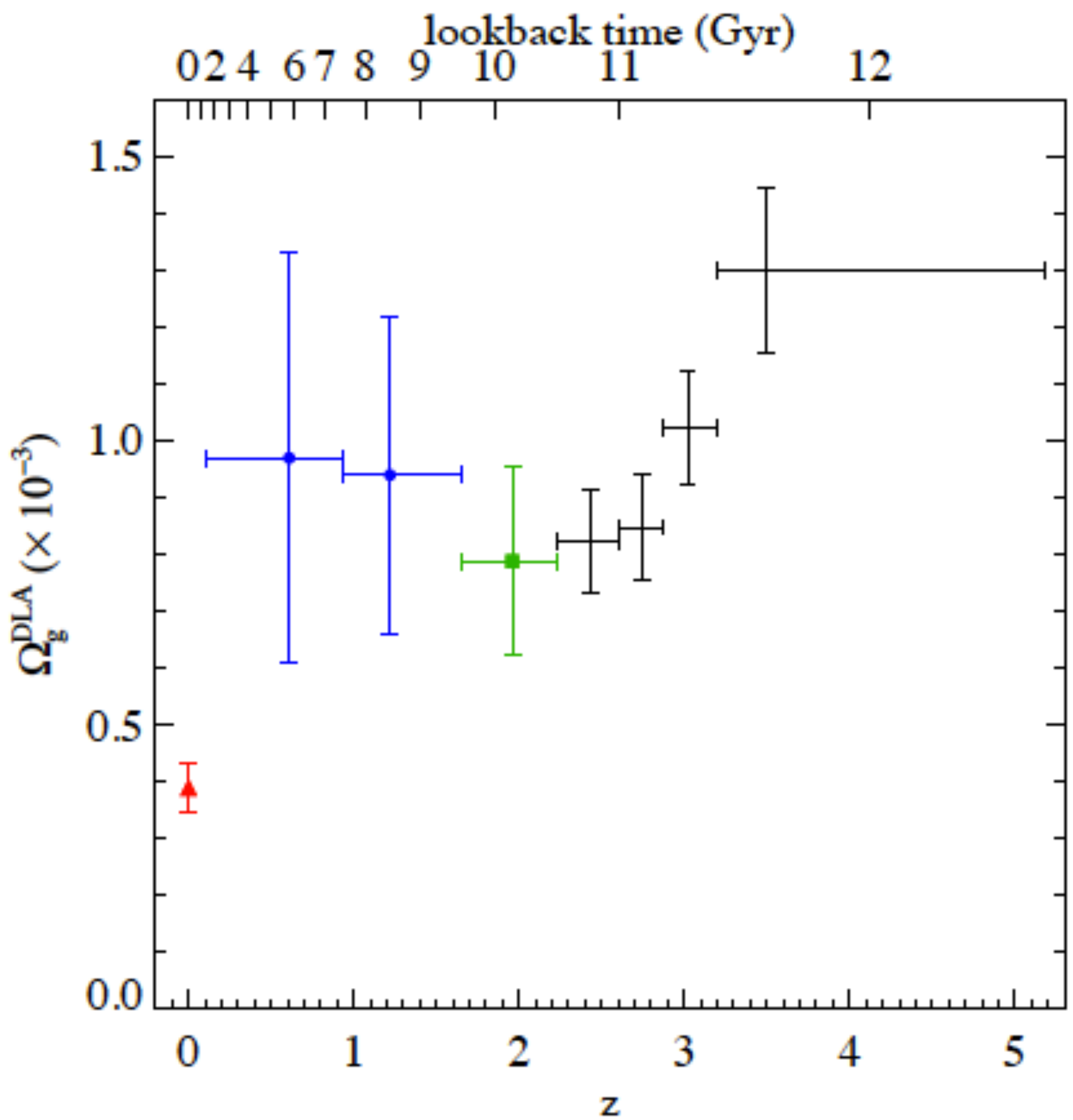
Lyman-α, λ_o=1215.67 Å

DLA: $\log N(HI) > 20.3$

Traces bulk of HI in the galaxies.

Thanks to SDSS, >1000 known at z>2.

Damped Lyman-α Absorbers (DLAs)



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Noterdaeme et al. 2009, Prochaska et al. 2009, Zwaan et al. 2005

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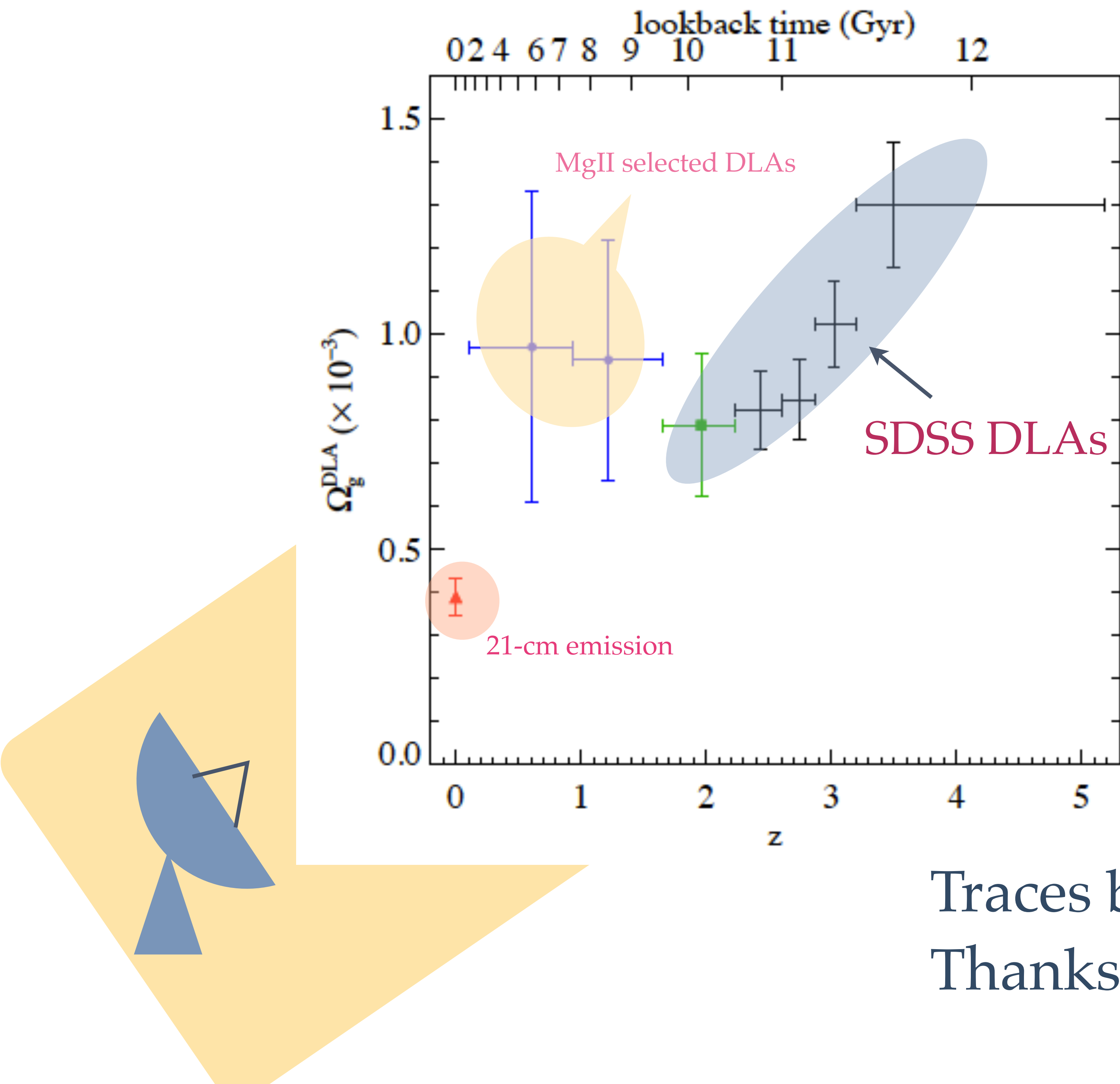
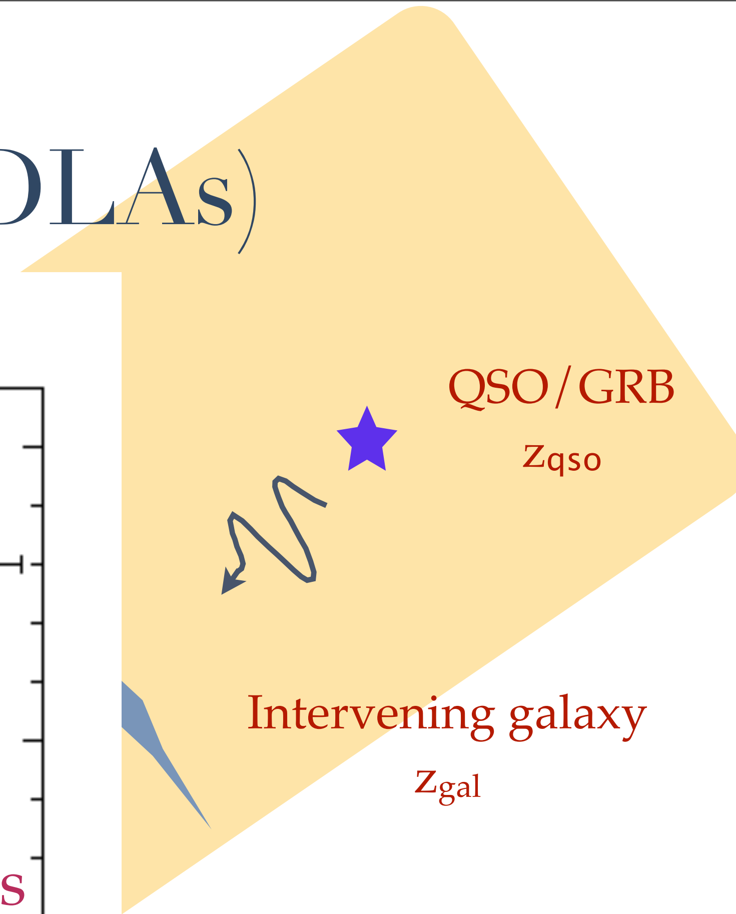


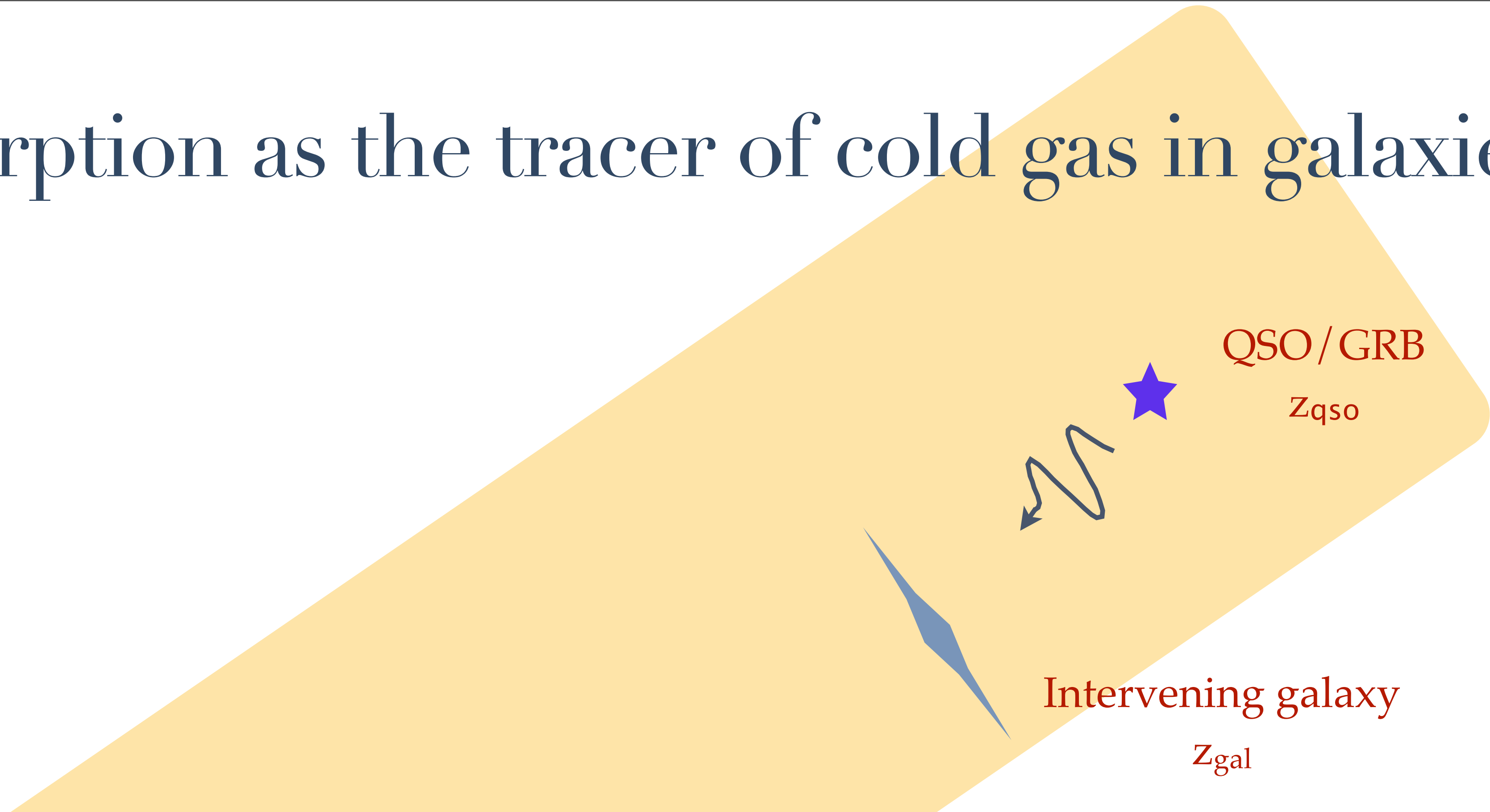


Traces bulk of HI in the galaxies.

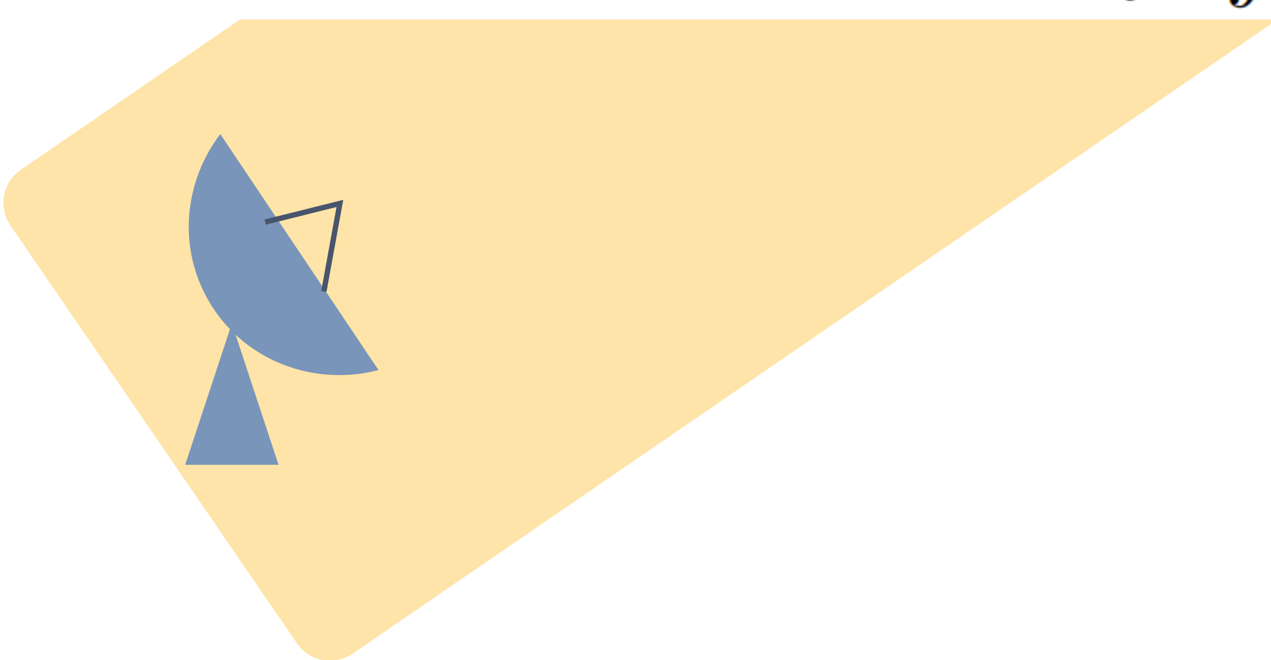
Thanks to SDSS, >1000 known at z>2.

Noterdaeme et al. 2009, Prochaska et al. 2009, Zwaan et al. 2005

21-cm absorption as the tracer of cold gas in galaxies



$$N(\mathrm{H\ I}) = 1.835 \times 10^{18}\ \frac{T_{\mathrm{s}}}{f_{\mathrm{c}}} \int\ \tau(v)\ \mathrm{d}v\ \mathrm{cm}^{-2}$$



λ_o=21-cm (1420.405752 MHz)

But 21-cm absorbers are very rare.

About a dozen known in pre-SDSS era.

Need systematic surveys of 21cm absorption

1) 21cm absorbers are rare and blind searches not possible.
2) Need to preselect the sight lines: indicators of high HI column density.
3) Possible with the following all sky surveys:

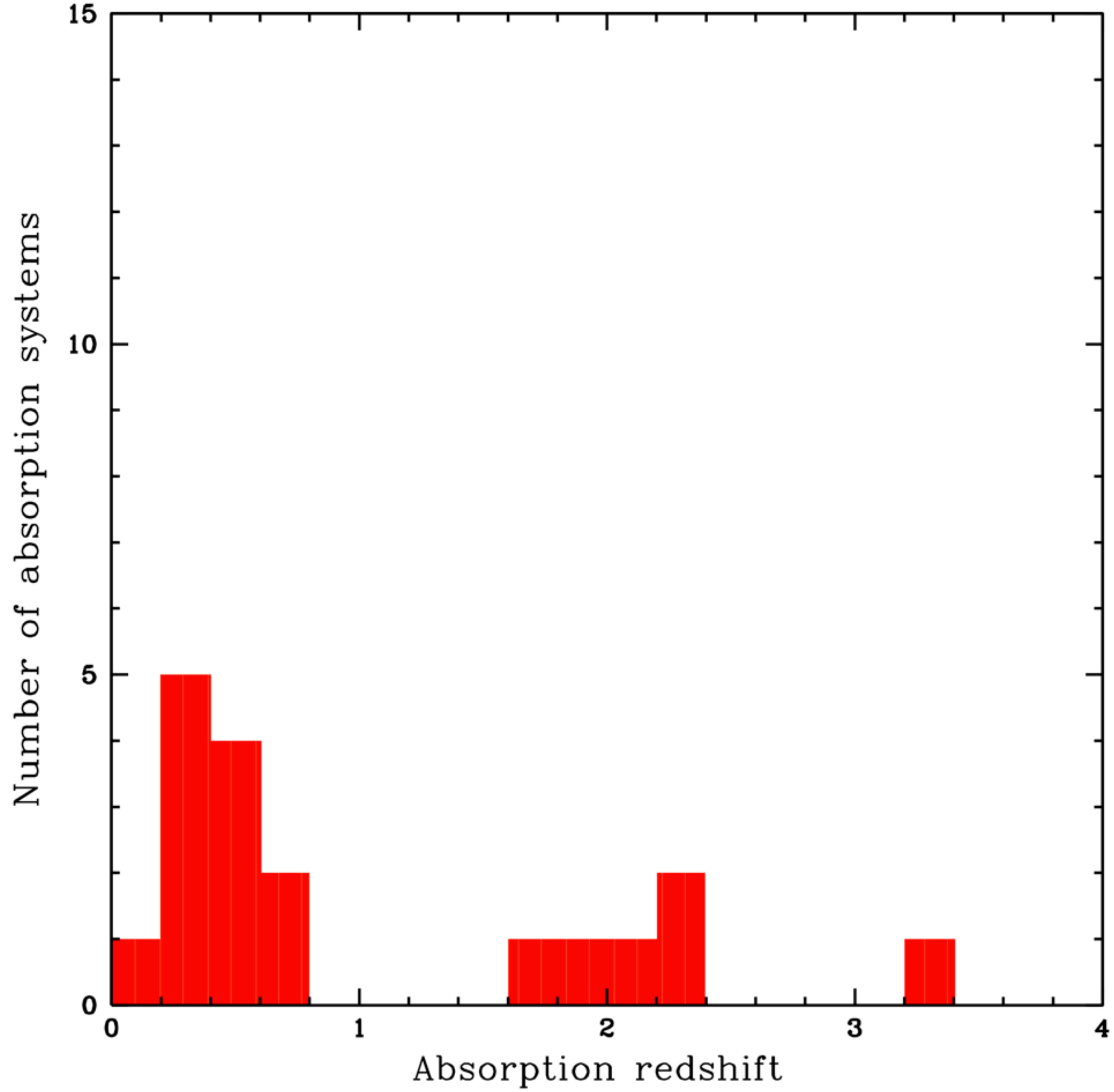
Sloan Digital Sky Survey (SDSS): deep optical multi-color images and spectroscopy over 8000 square degrees covering more than 930,000 galaxies and more than 120,000 quasars.

The NRAO VLA Sky Survey (NVSS): Entire sky north of -40 degrees declination with an rms of 0.45 mJy/beam (45 ʹʹ).

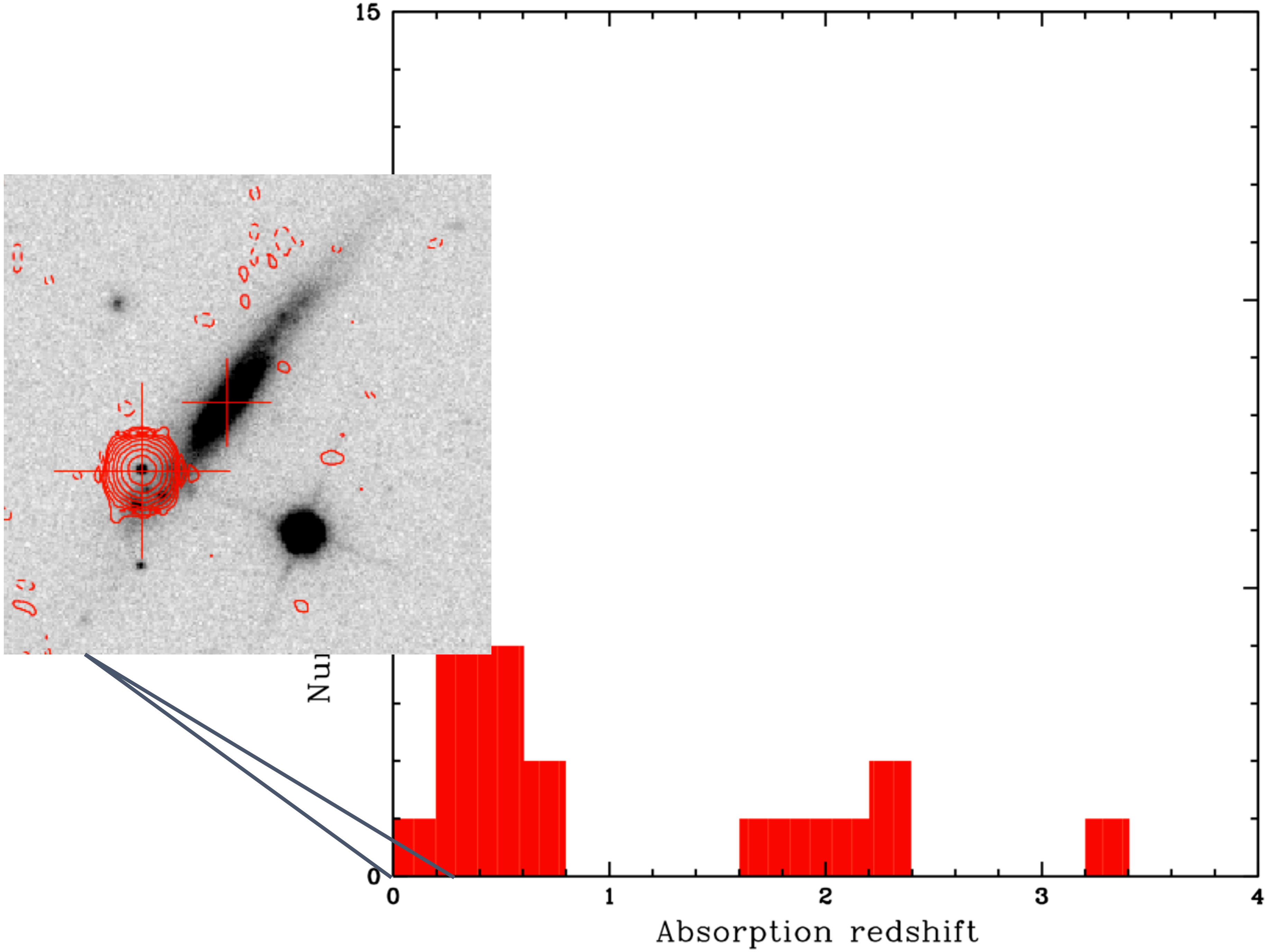
Faint Images of the Radio Sky at Twenty-cm (FIRST): 9900 square degrees with rms of 0.15 mJy/beam, and a resolution of 5ʺ.

with Srianand, Petitjean, Noterdaeme and Ledoux.

Preselecting sight lines for 21cm absorption



Preselecting sight lines for 21cm absorption



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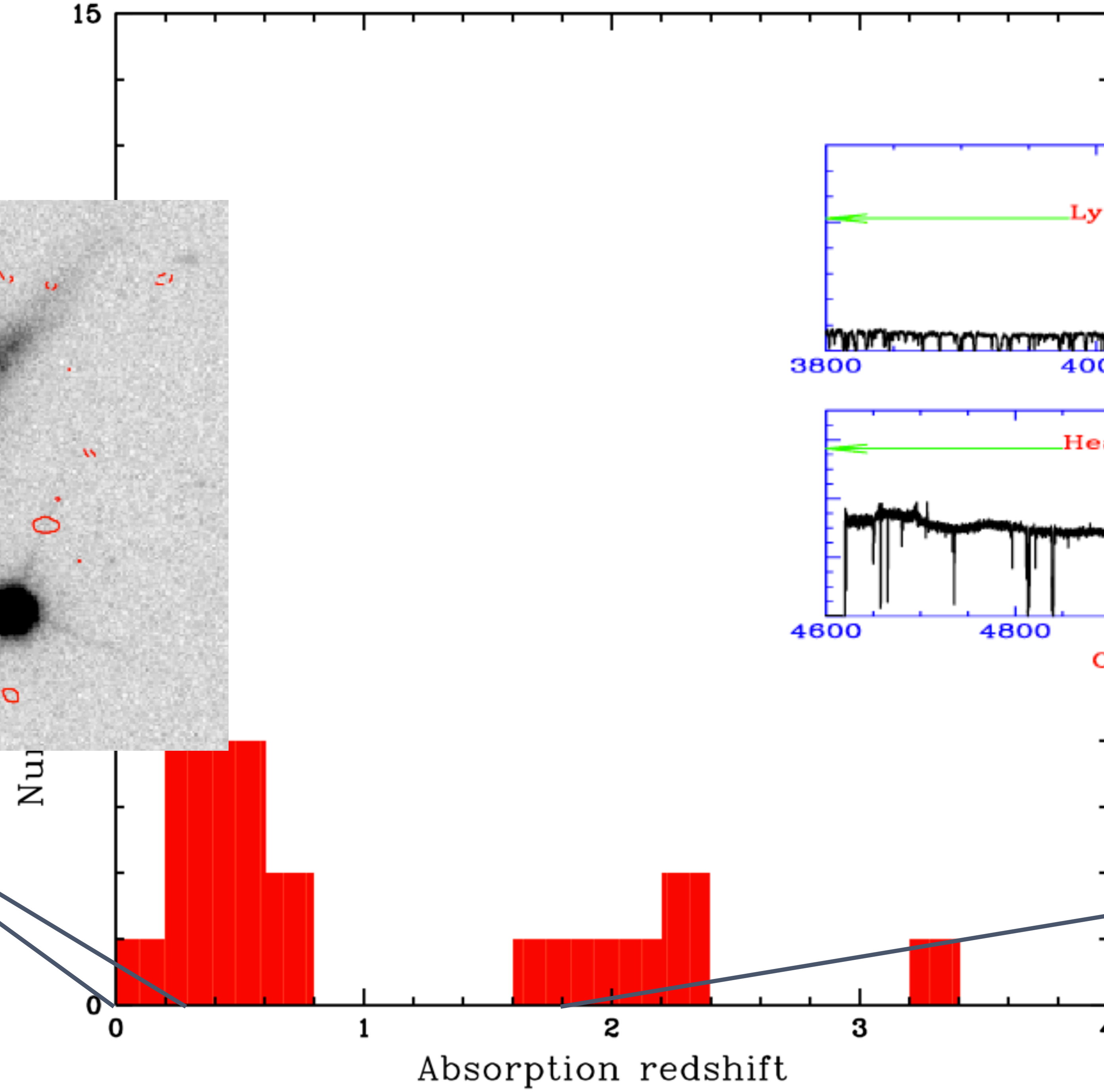
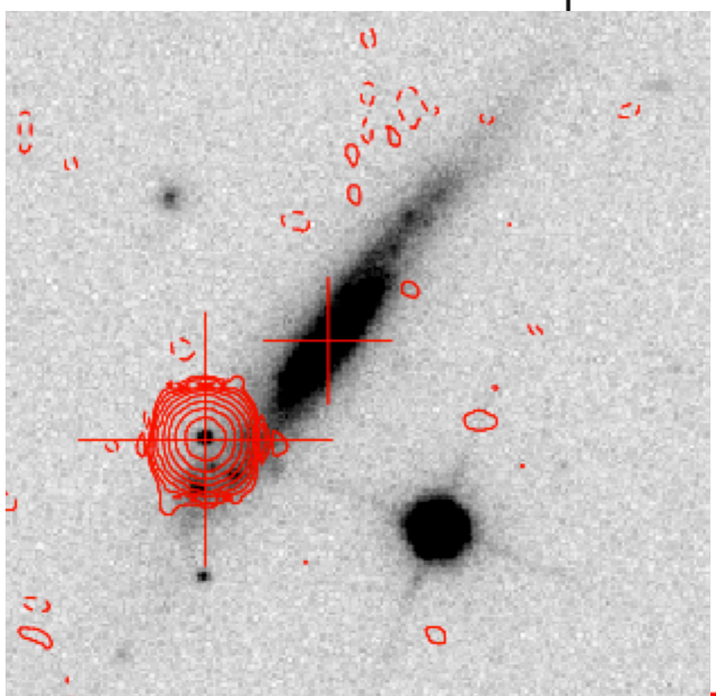
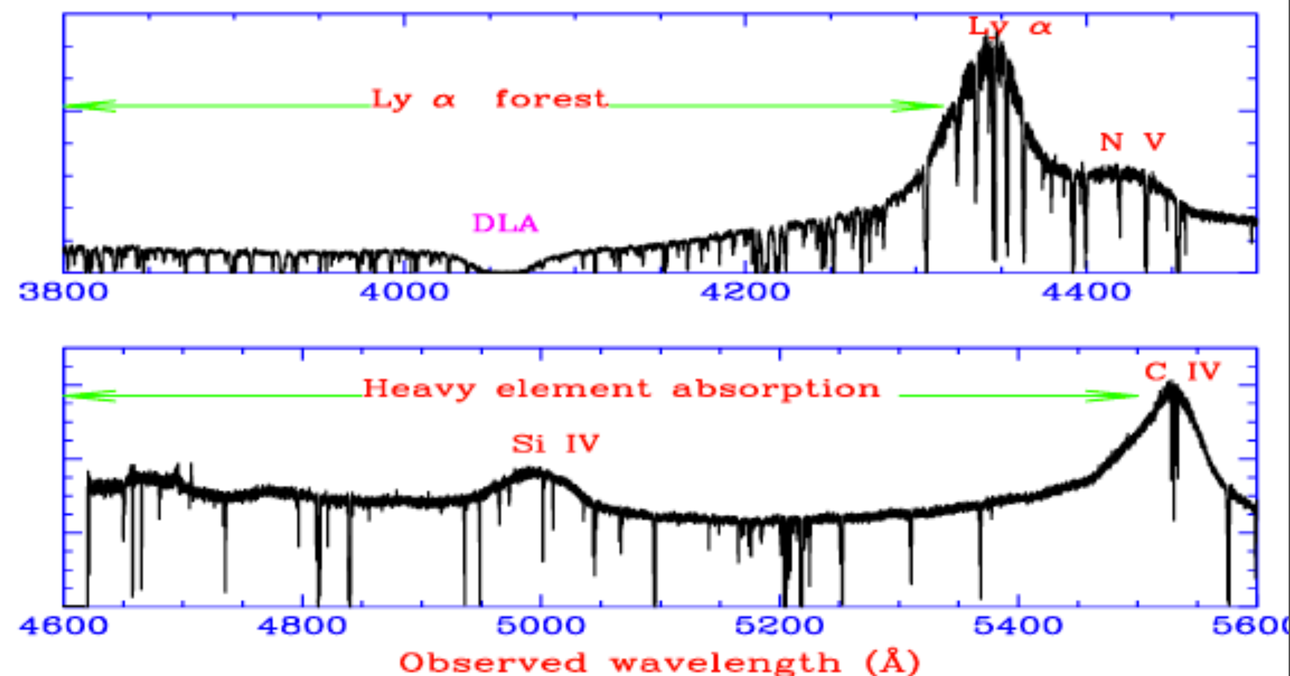
Preselecting sight lines for 21cm absorption

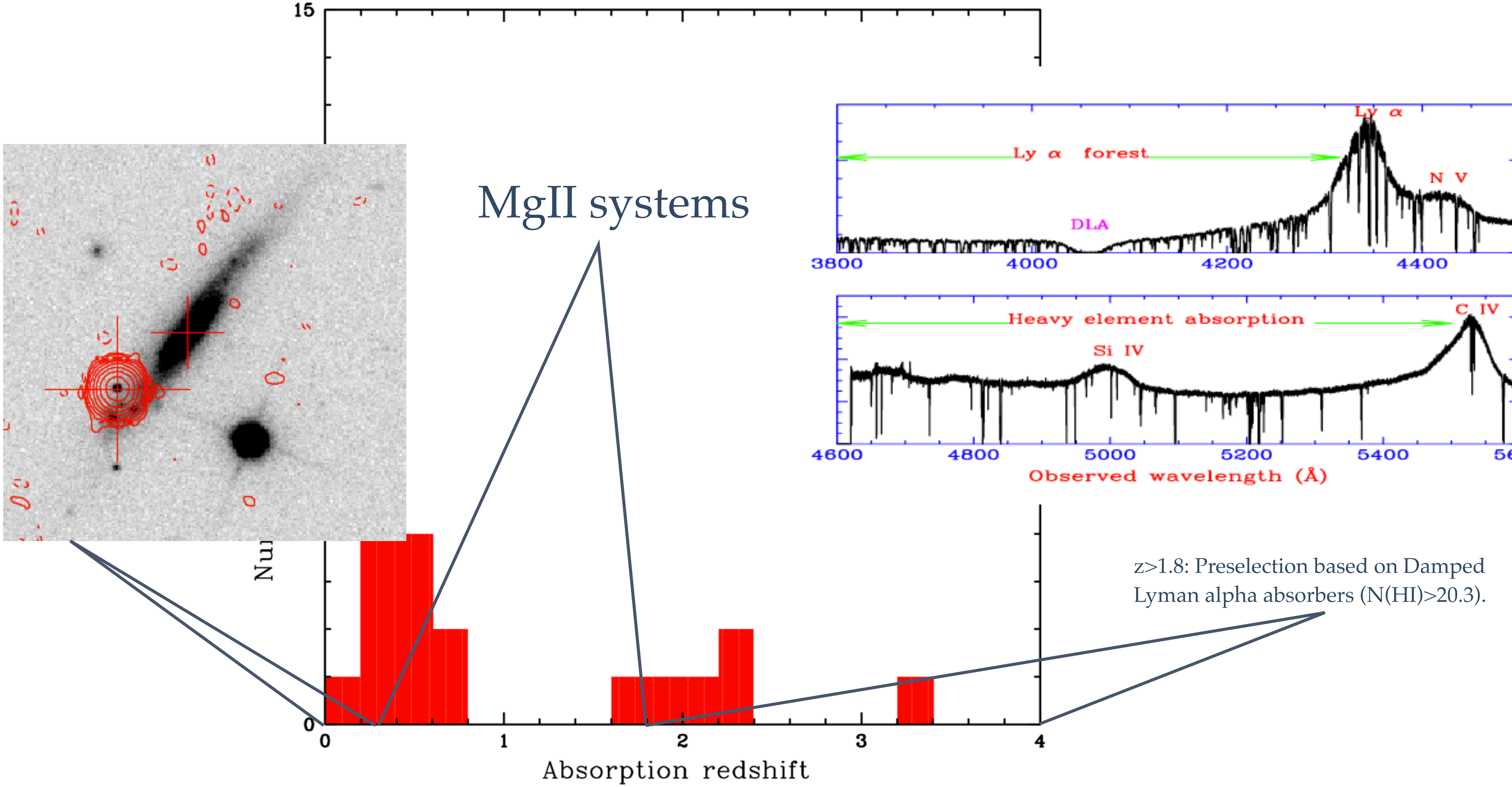






z>1.8: Preselection based on Damped Lyman alpha absorbers (N(HI)>20.3).

Preselecting sight lines for 21cm absorption



Our systematic surveys of 21cm absorption

1) Observed 60 sight lines at 0<z<3.5 based on preselection methods.
2) Using ~800 hrs of GBT, GMRT and WSRT.



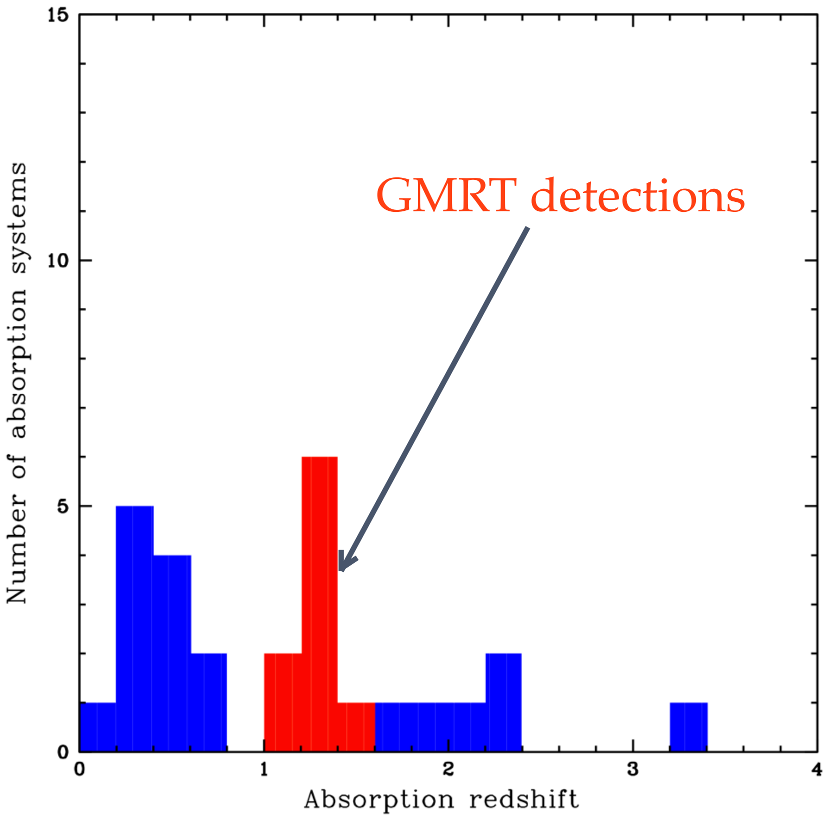
Detected 15 new 21cm absorbers !

Doubles the number of absorbers known in the pre-SDSS era.

Image credits: www.gb.nrao.edu, www.ncra.tifr.res.in, www.astron.nl

GMRT survey based on MgII systems

1) SDSS DR7: Automatic procedure to detect systems with W(MgII)>1Å.
2) Selected systems with 1.10<z<1.45: ~3000 MgII systems.
3) Cross-correlate with NVSS and FIRST: brighter than 50mJy.
4) GMRT observations ~400 hrs: 35 systems observed.
5) Nine new detections.



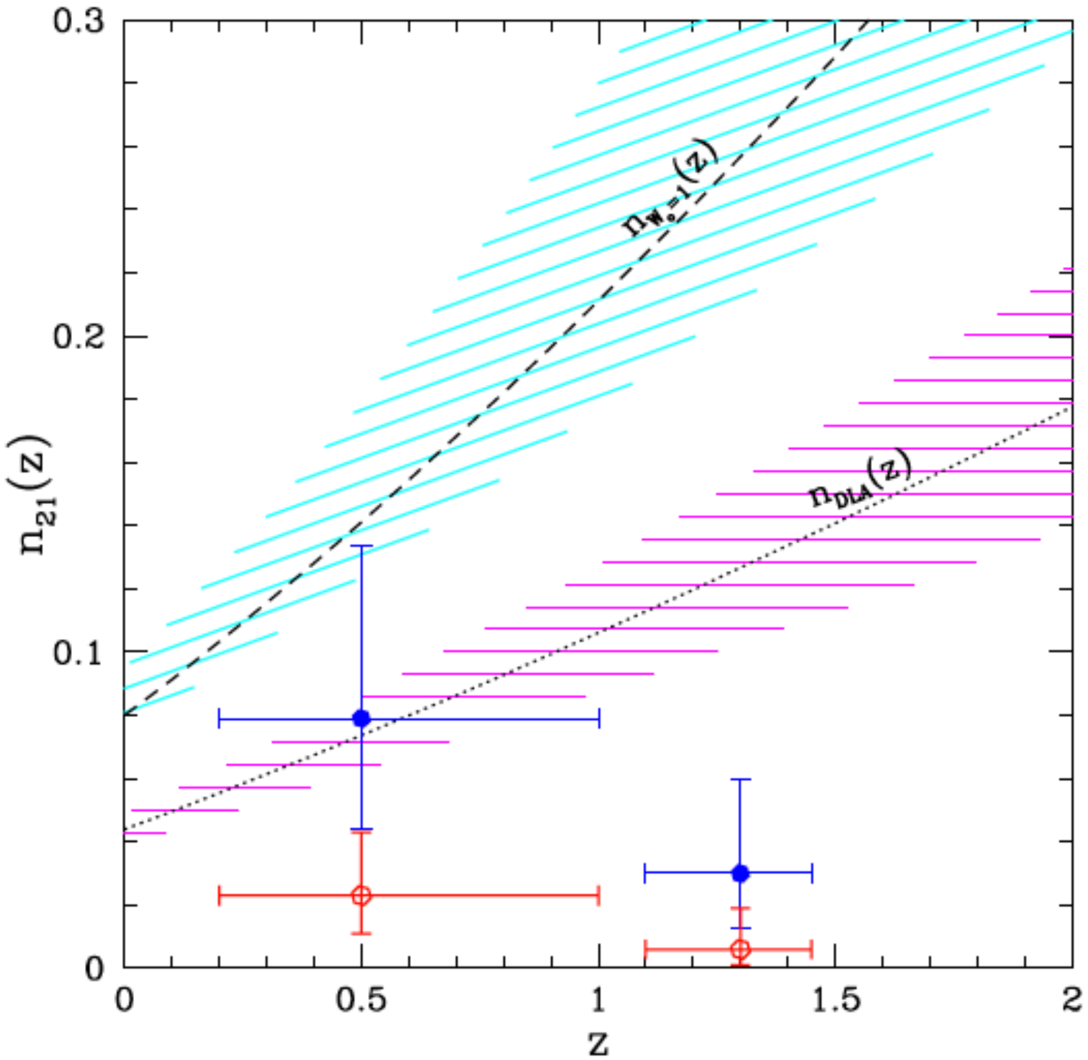
Equivalent width (measure of the strength of spectral line)

$$W_{obs} = \int \frac{I_c - I}{I_c} d\lambda = \int (1 - e^{-\tau(\lambda)}) d\lambda$$

Team: R. Srianand (PI), N. Gupta. P. Petitjean, P. Noterdaeme & D.J. Saikia.

Results published as: Gupta et al. 2009, MNRAS, 398, 201;
Srianand et al. 2008, MNRAS, 391, L69;
Gupta et al. 2007, ApJL, 654, 111.

Number density of 21-cm absorbers



Number per unit range of 21-cm absorbers for integrated 21-cm optical depth > 0.3 km/s and W_o = 1Å.

Estimating $n_{21}(z)$:

$$n_{21}(T_{21} \geq T_0, W_r \geq W_o, z) = C \times n_{MgII}(W_r \geq W_o, z)$$

Is the CNM fraction of W>1Å smaller at higher redshifts ?

Blind searches are ideal for this purpose.

Constraints on constants using radio absorption lines

- HI 21cm vs UV

$$x = \frac{\alpha^2 g_p}{\mu}; \frac{\Delta x}{x} = \frac{z_{UV} - z_{21}}{1 + z_{21}}$$

$= (0.63 \pm 0.99) \times 10^{-5}$ Tzanavaris et al. (2007)

$= (6.8 \pm 1.0) \times 10^{-6}$ Kanekar et al. (2010)

- HI 21cm vs Molecular

$$y = g_p \alpha^2; \frac{\Delta y}{y} = \frac{z_{mol} - z_{21}}{1 + z_{mol}}$$

$= (-0.18 \pm 0.50) \times 10^{-5}$

PKS1413+135 at z=0.2467
TXS0218+357 at z=0.6847
(Murphy et al. 2001;
Carilli et al. 2000;
Wiklind et al. 1997,
Varshalovich et al. 1996)

- OH 18cm vs HI 21cm

$$F = g_p (\alpha^2 \mu)^{1.57}$$

$= (2.25 \pm 0.84) \times 10^{-5}$

$= (3.5 \pm 4.0) \times 10^{-6}$

PMNJ0134-0931 at z=0.765
(Kanekar et al. 2005)
TXS0218+357 at z=0.6847
(Chengalur et al. 2003)

- OH 18cm satellite

$$G = g_p (\alpha^2 \mu)^{1.85}$$

$= (-1.18 \pm 0.46) \times 10^{-5}$

PKS1413+135 at z=0.2467
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Also Darling (2004) and
J0134-0931 at z=0.765.

- Ammonia

$$\frac{\Delta \mu}{\mu} = 0.289 \frac{z_{inv} - z_{rot}}{1 + z_{abs}}$$

$< 1.8 \times 10^{-6}$

$< 1.4 \times 10^{-6}$

TXS0218+357 at z=0.6847
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Radio absorption lines are more sensitive:
but only a few suitable absorbers know !

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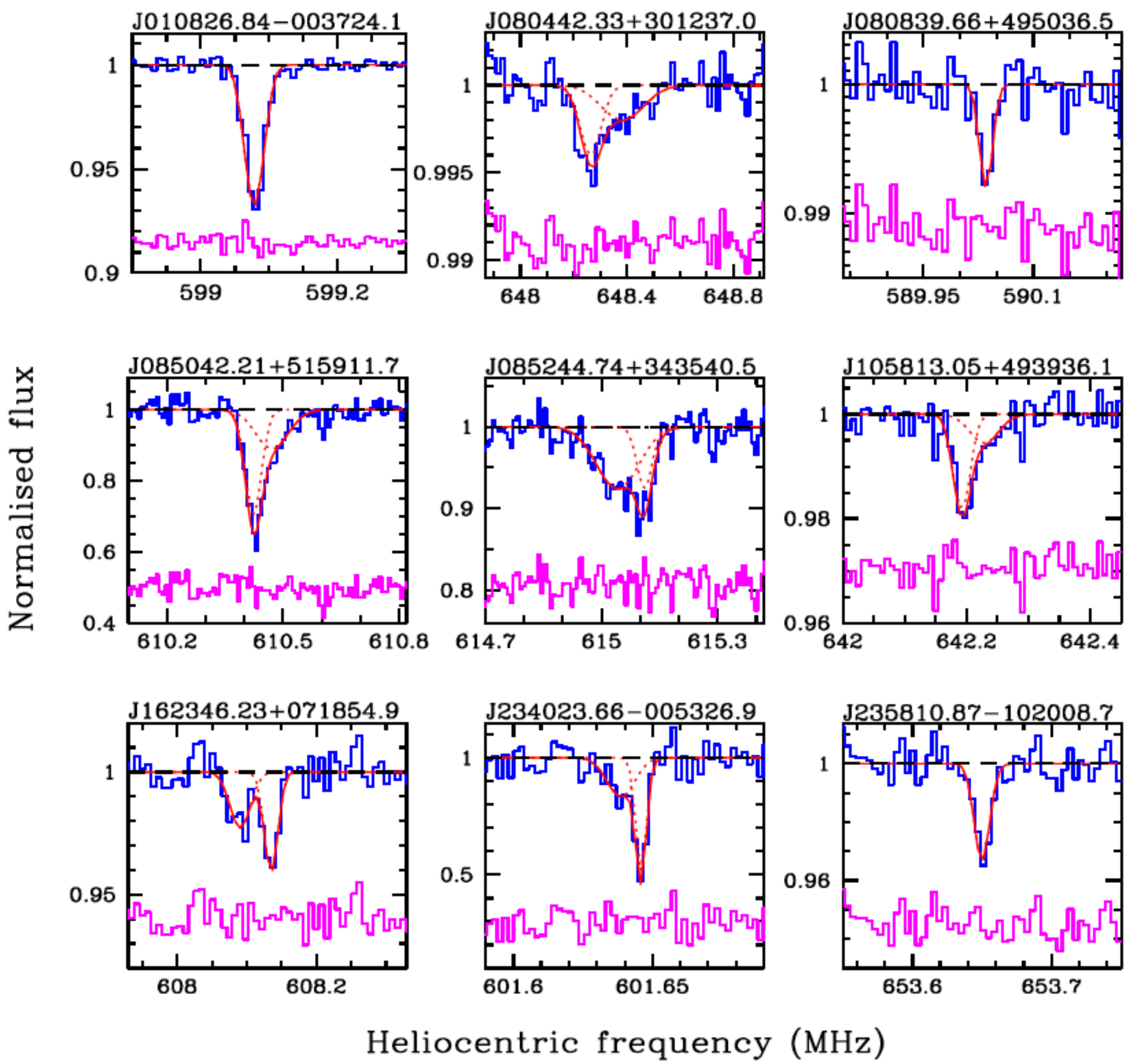
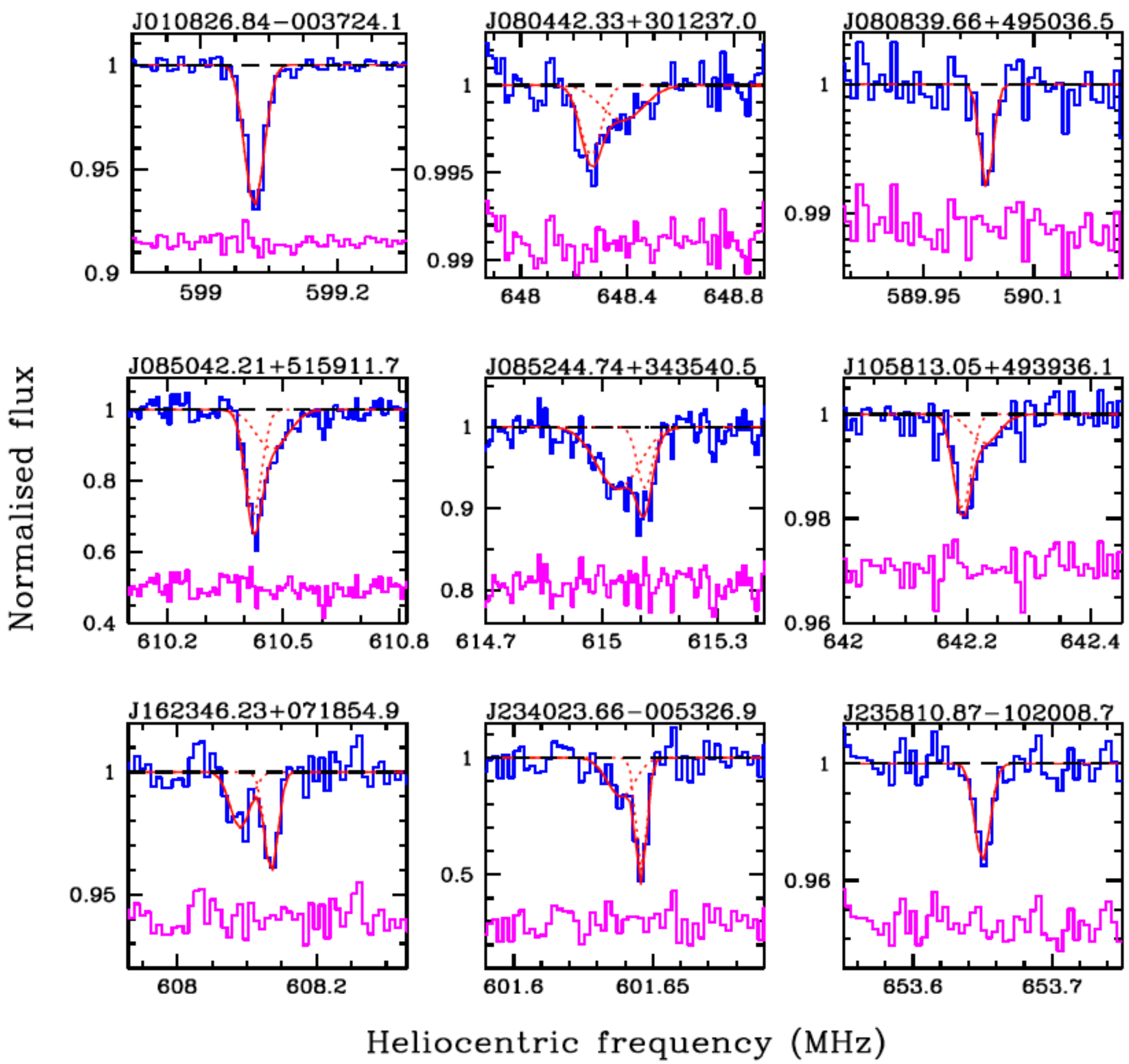
Using 21-cm absorbers for the fundamental constant studies



What is a good system for fundamental constant studies ?

Using 21-cm absorbers for the fundamental constant studies



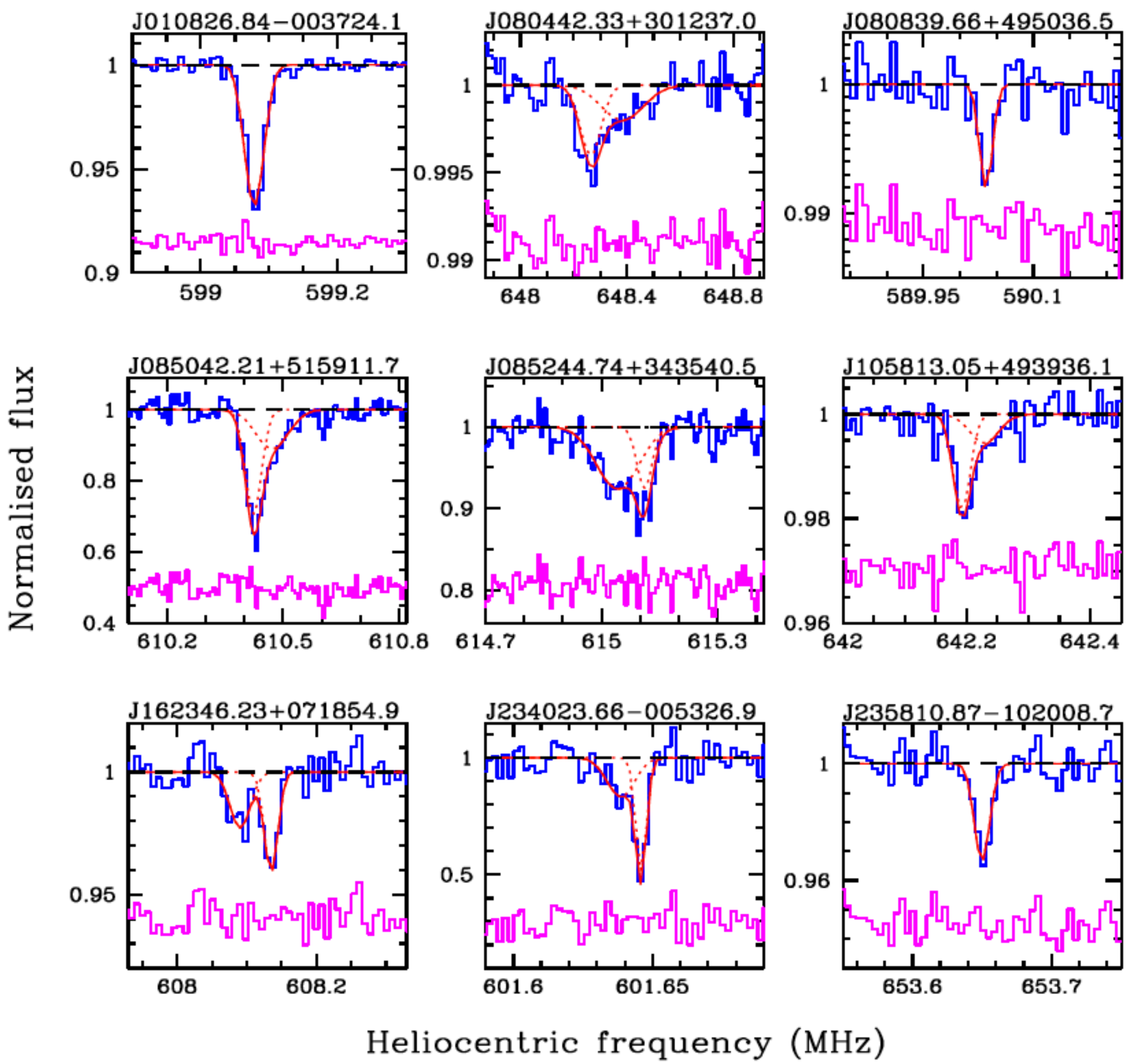
What is a good system for fundamental constant studies ?

Minimise uncertainity due to structure of the radio source.

Optical/UV source is compact (~AU scale) but radio sources show structure from pc to kpc scales (jets+lobes).

Need VLBI observations ... (milliarcsecond resolution)

Using 21-cm absorbers for the fundamental constant studies



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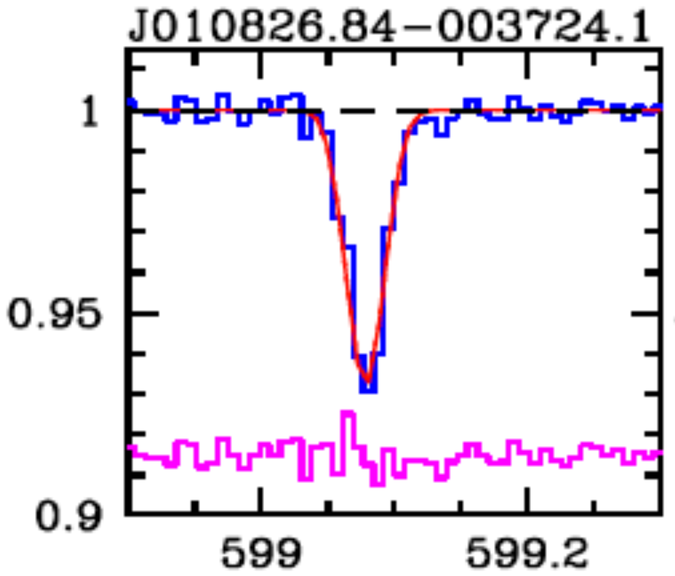
.... and of course high resolution optical spectroscopy.

Preliminary results: case of J0108-0037 (z=1.3710)



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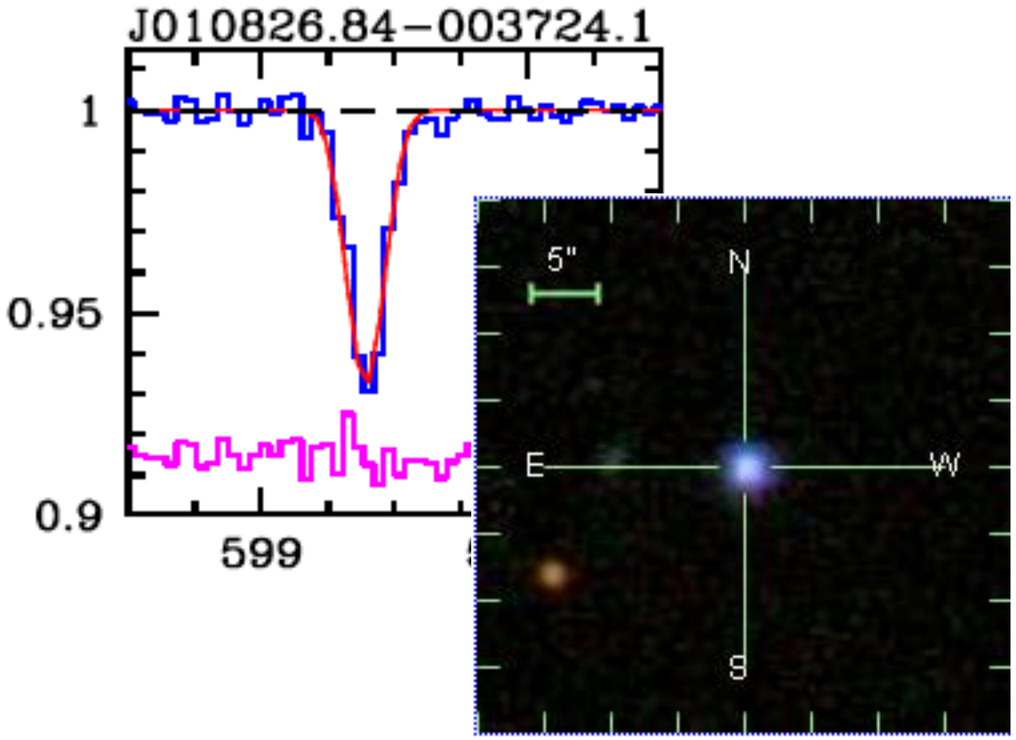

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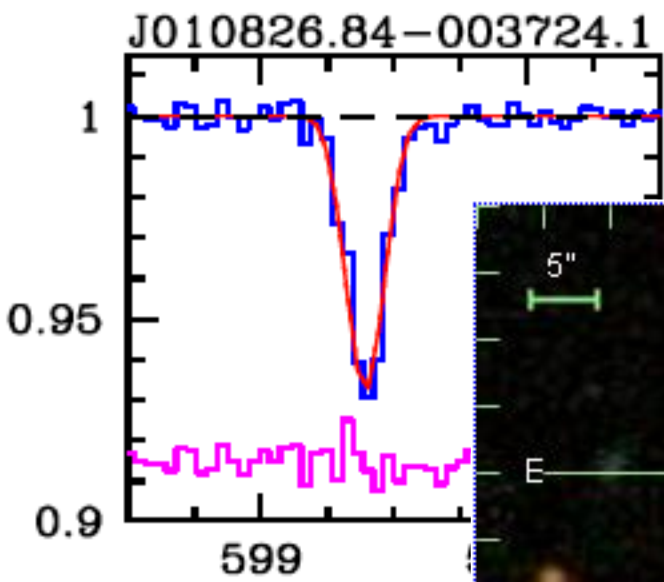

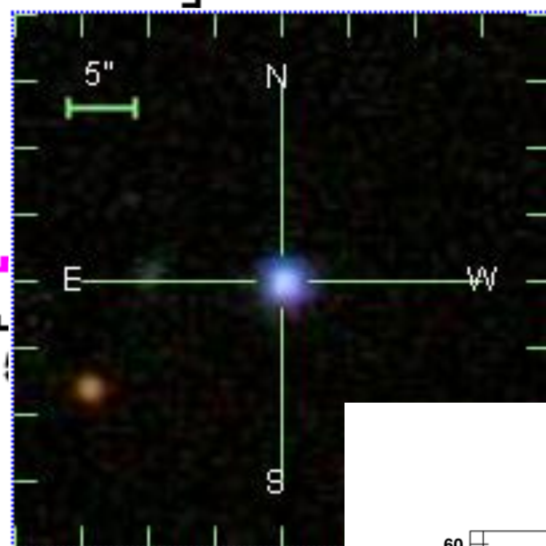

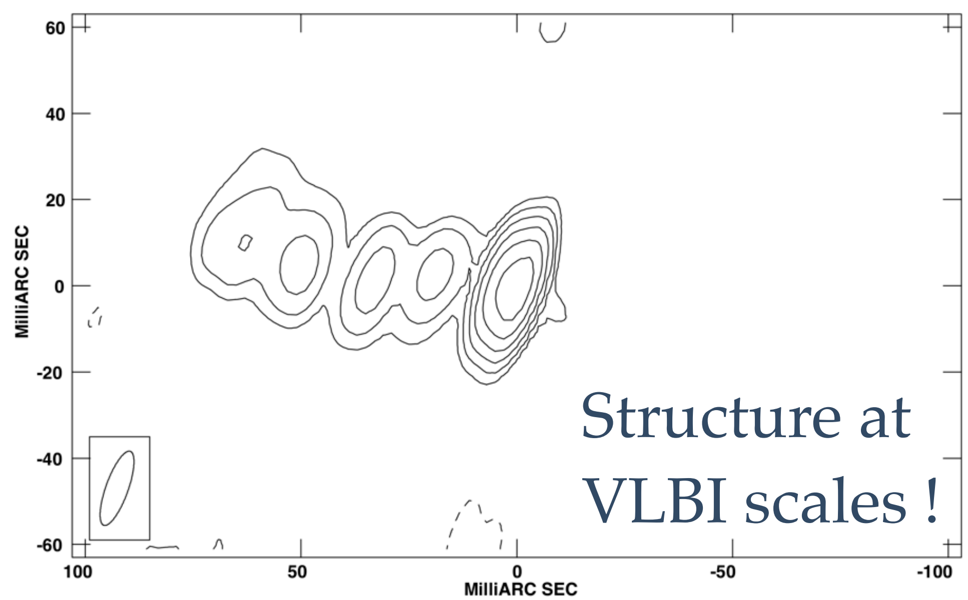

Structure at
VLBI scales !

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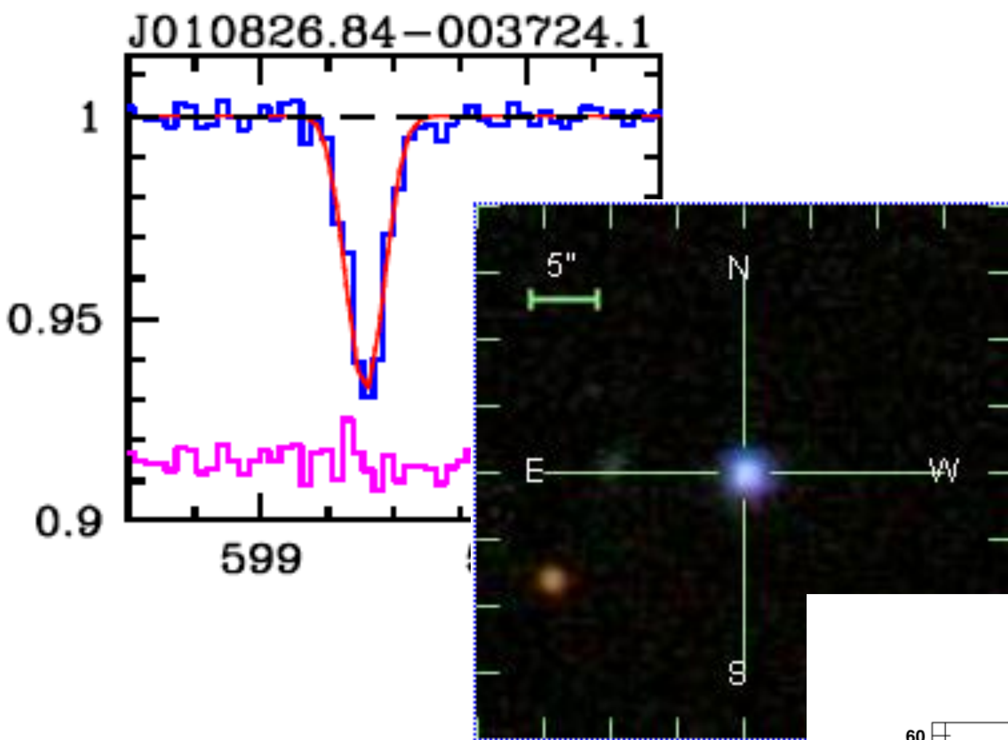
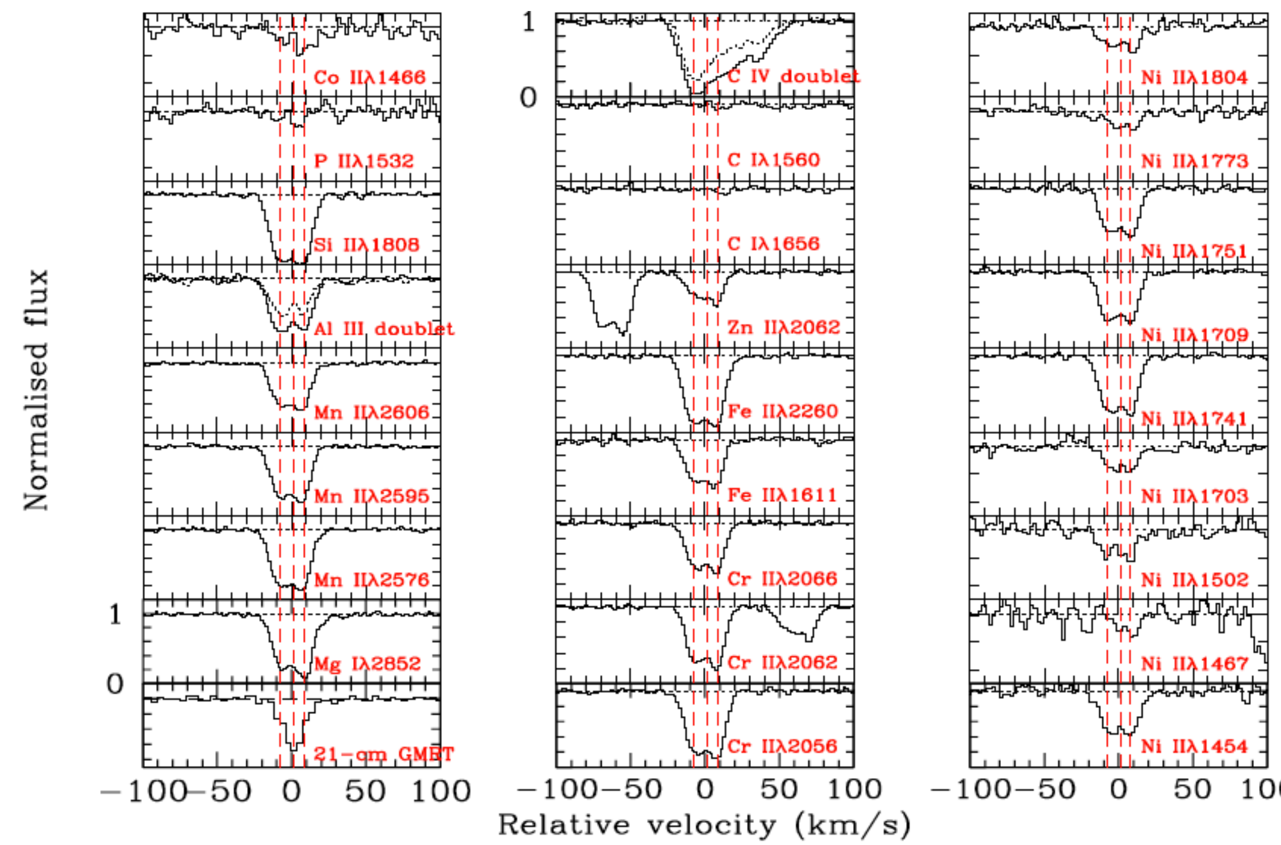
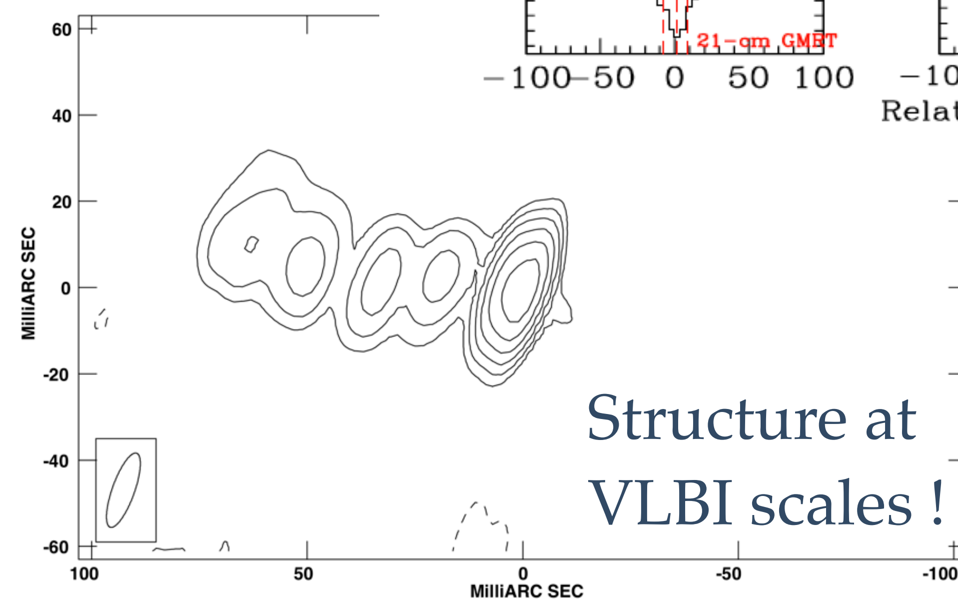


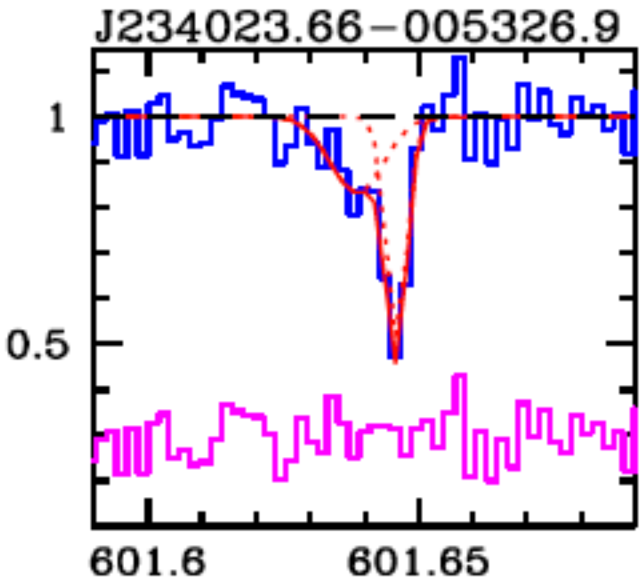




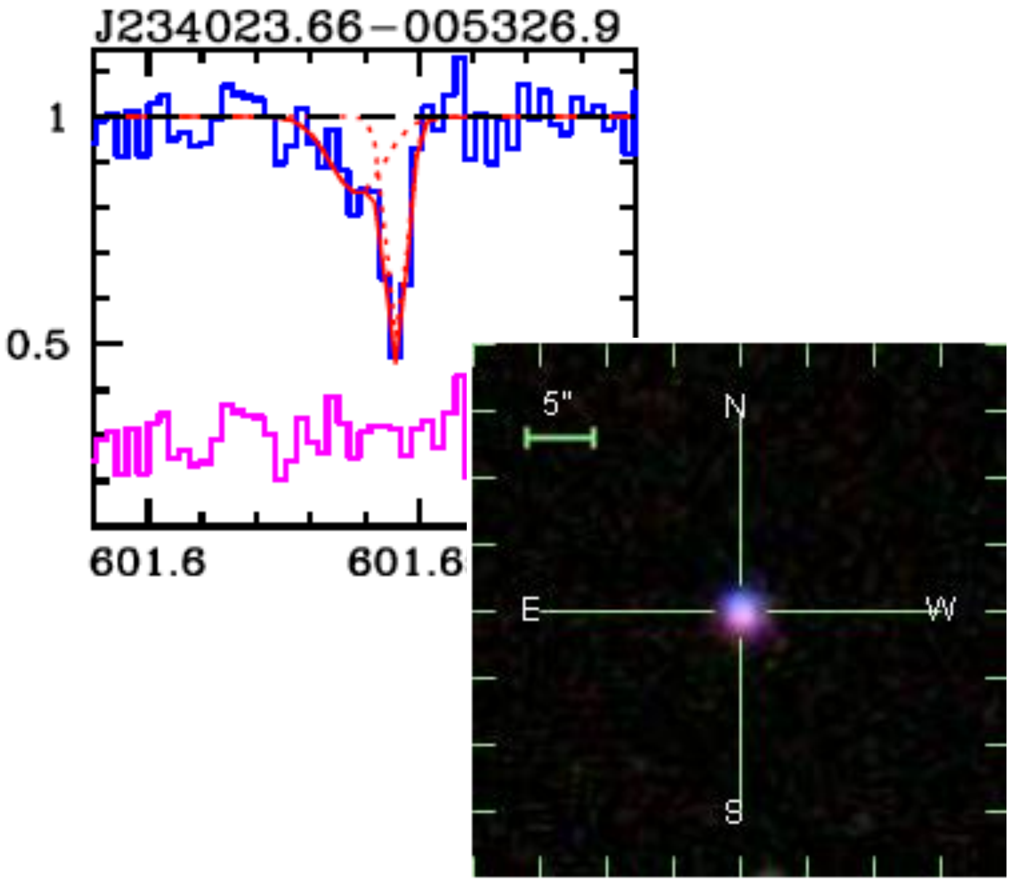
Structure at VLBI scales !

.... need to be careful.

Preliminary results: case of J2340-0053 (z=1.3603)



Preliminary results: case of J2340-0053 (z=1.3603)



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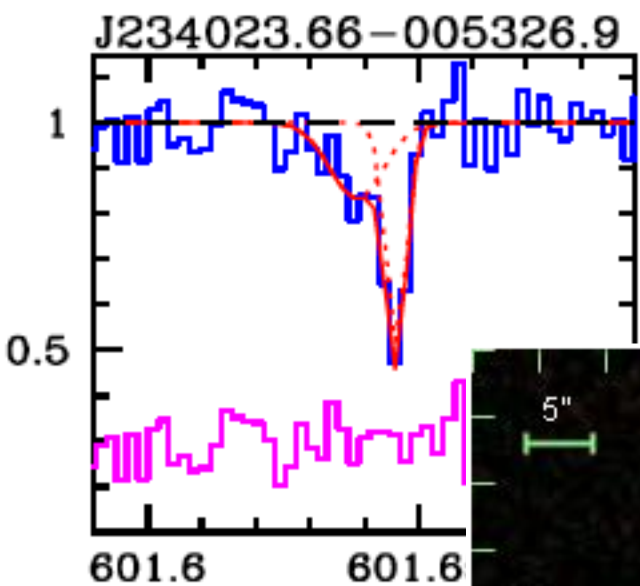

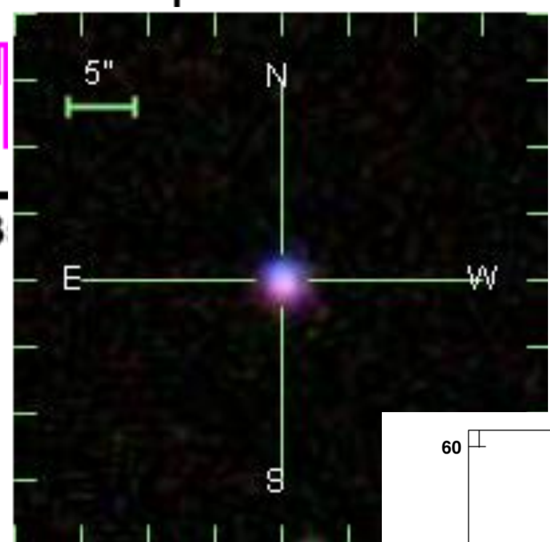

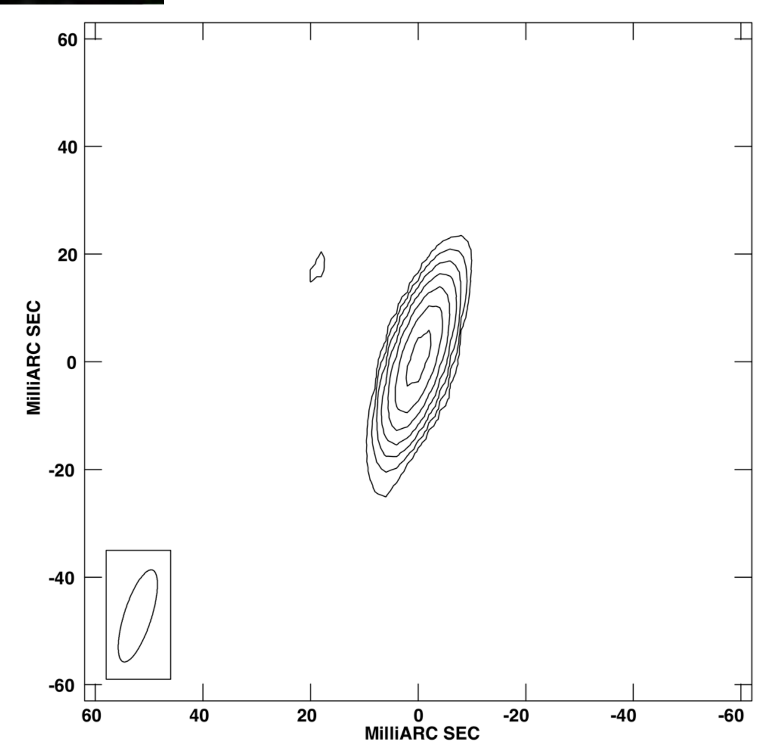

Compact at VLBI scales

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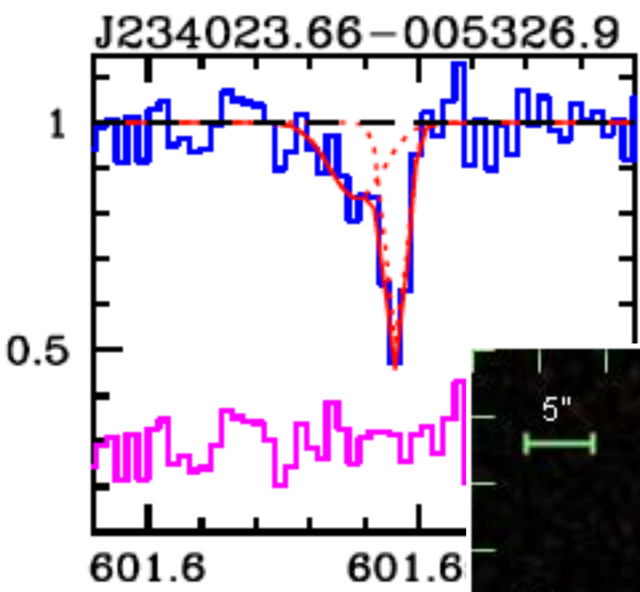

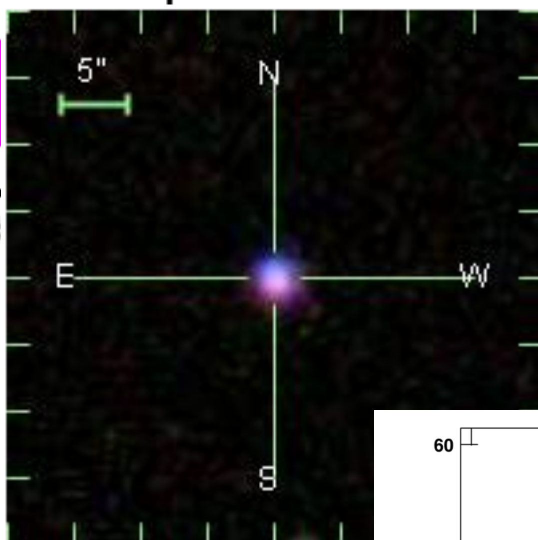

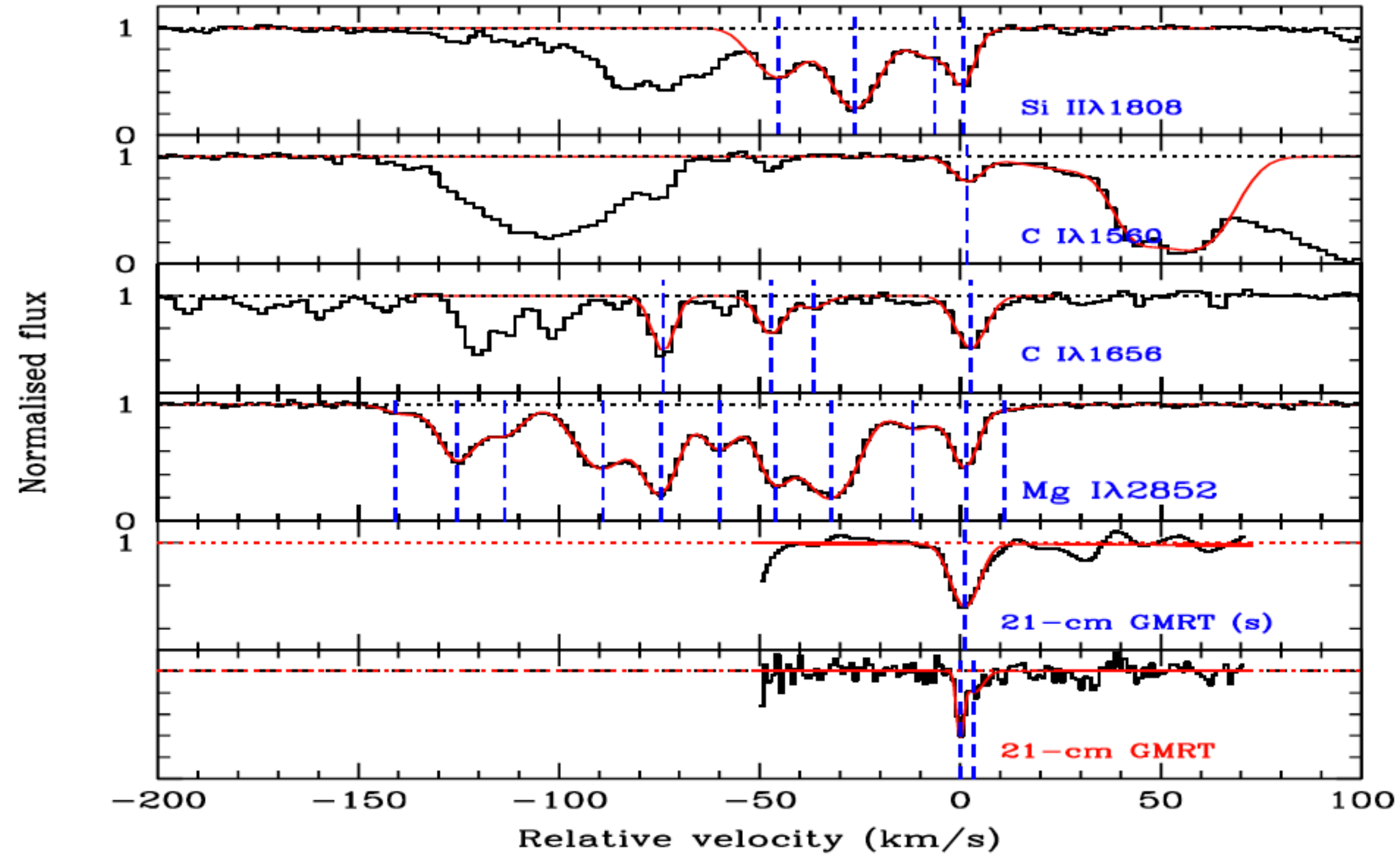

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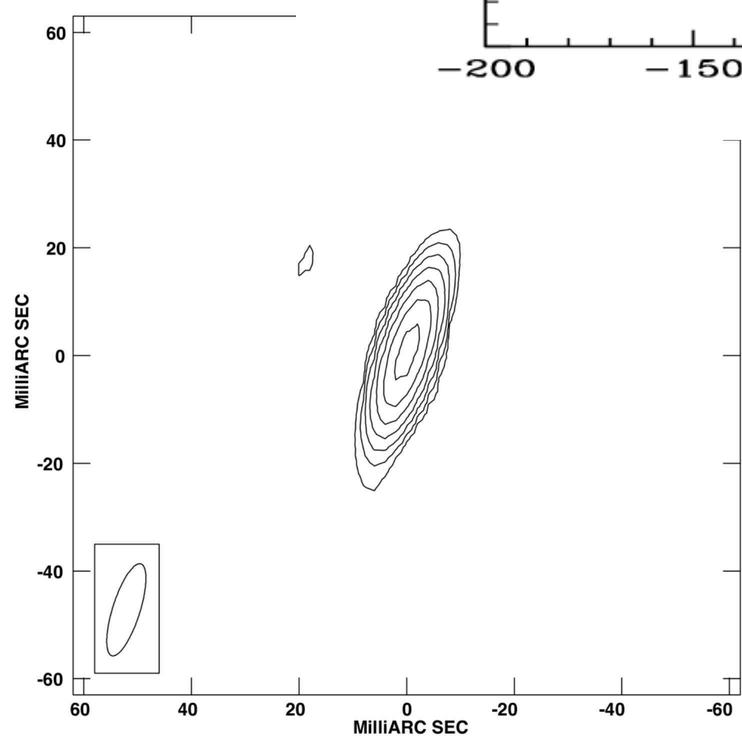


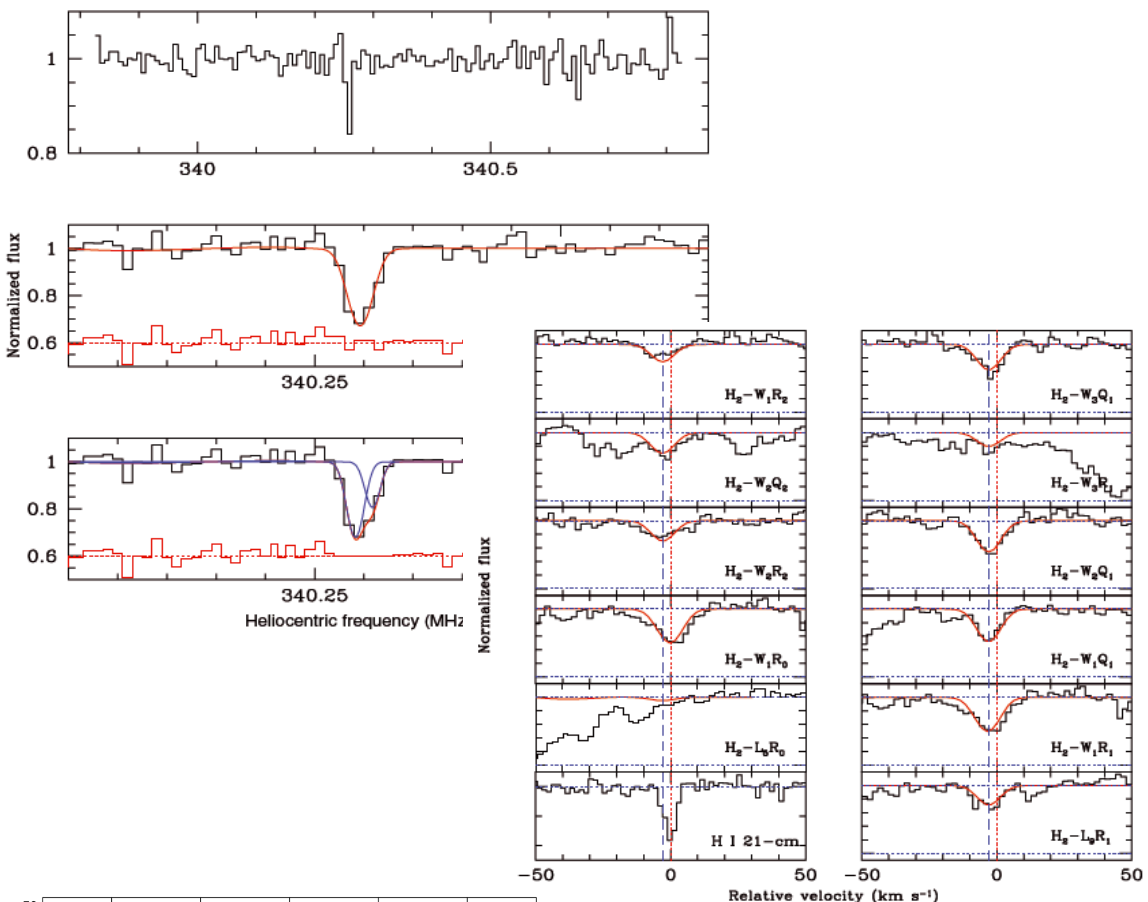
$$\frac{\Delta x}{x} = 0.0 \pm 0.6 \times 10^{-6}$$

Coming up ....

1) VLBA observations completed for all the sources.
2) 4 absorbers (z~1.3) with radio sources compact at mas.
3) VLT observations of 3 are completed and analysis in progress.

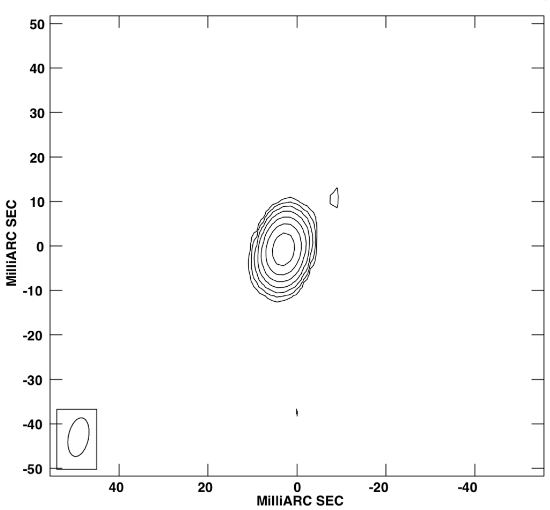
..... constraints at $z \sim 1.3$

DLA with molecular hydrogen and 21cm absorption at z=3.174



$$x = \frac{\alpha^2 g_p}{\mu}$$

$$\frac{\Delta\mu}{\mu} \leq 4.0 \times 10^{-4}$$



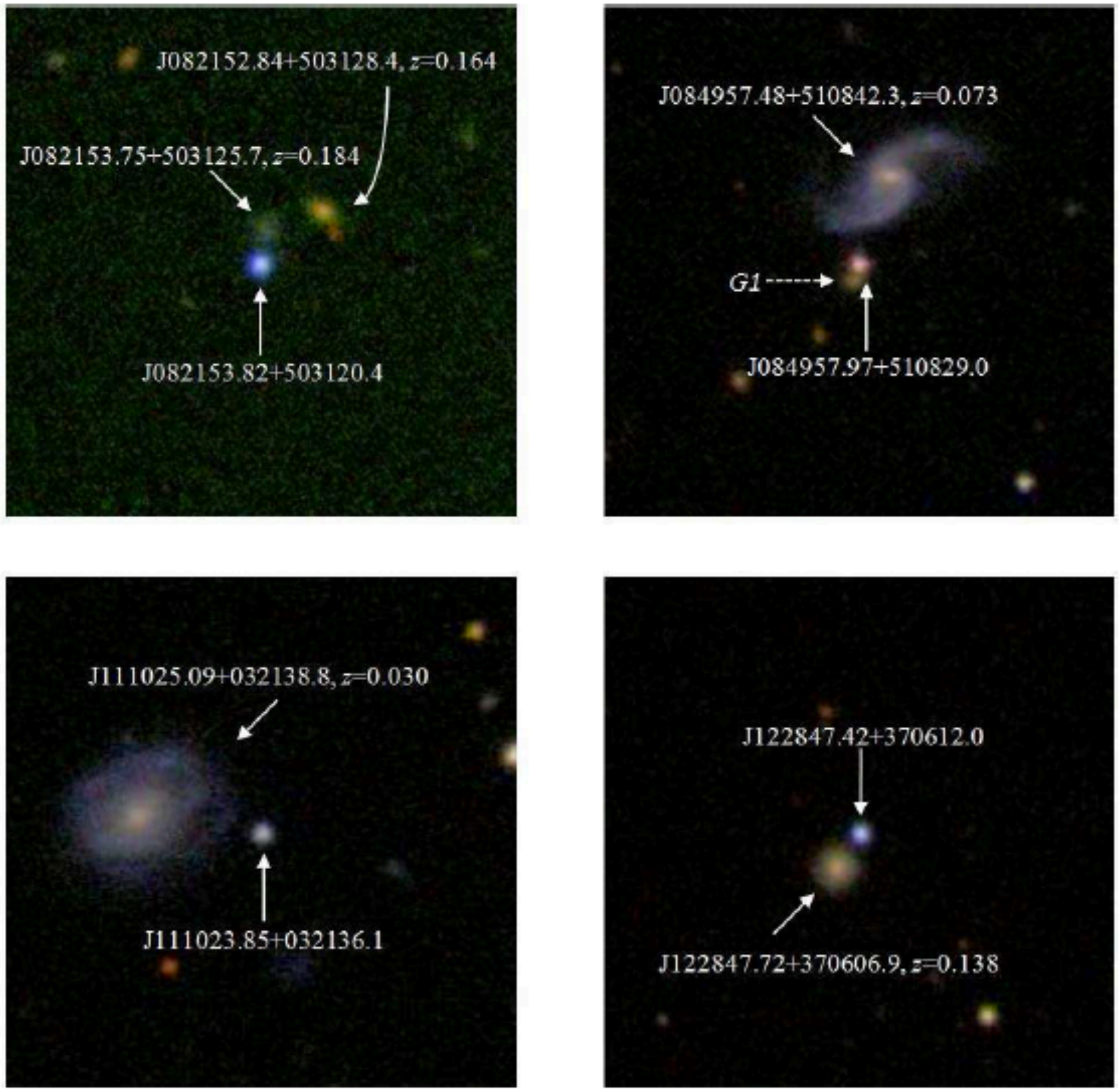
From 21cm and metal absorption lines:

$$\frac{\Delta x}{x} = -(1.7 \pm 1.7) \times 10^{-6}$$

$$\frac{\Delta\mu}{\mu} = -(1.7 \pm 1.7) \times 10^{-6} \quad \text{or} \quad \frac{\Delta\alpha}{\alpha} = -(0.85 \pm 0.85) \times 10^{-6}$$

Srianand et al. 2010, MNRAS, 405, 1888

GMRT+WSRT survey of quasar galaxy pairs (z<0.3)



- Sample of 40 pairs at b<30 kpc covering a wide range of morphologies, environments.

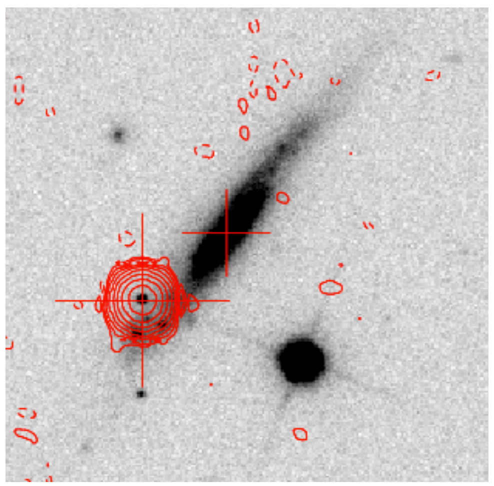
- Measure the 21-cm absorbing gas covering fraction, connection between metallicity, dust, and the star formation rate.

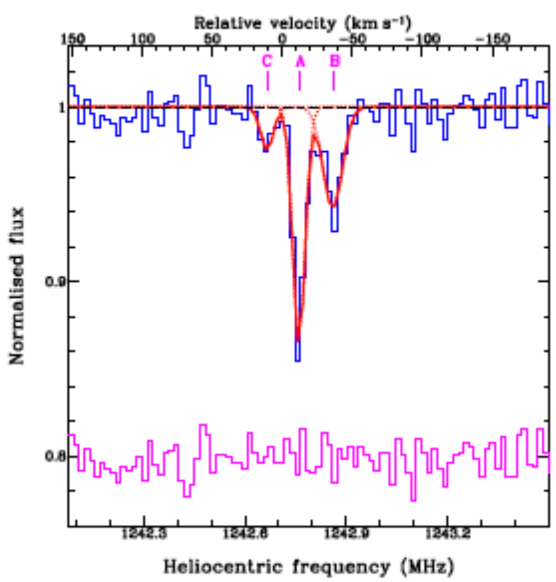
Connection between the galaxies and the nature of 21-cm absorbers.

GMRT+WSRT survey of quasar galaxy pairs (z<0.3)

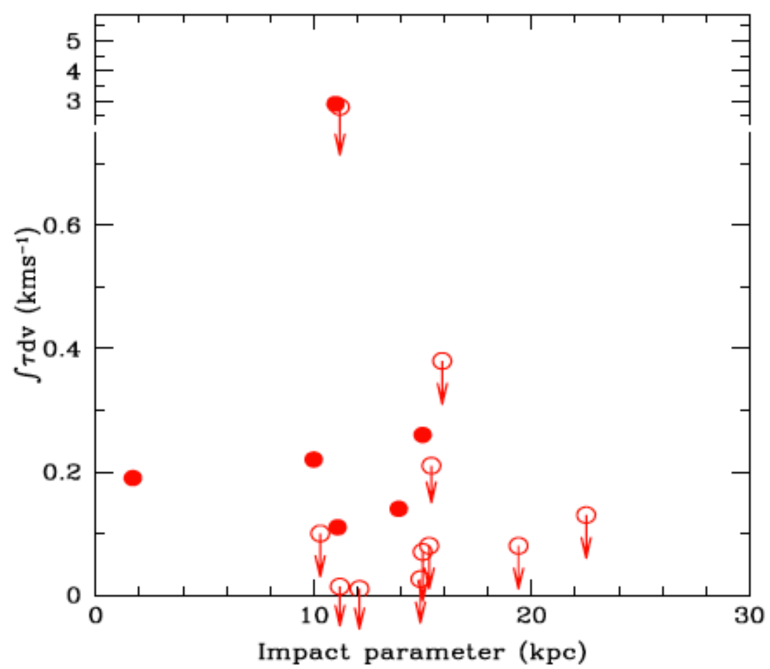
Preliminary results:

- Observations of 10 pairs completed.
  3 new detections.

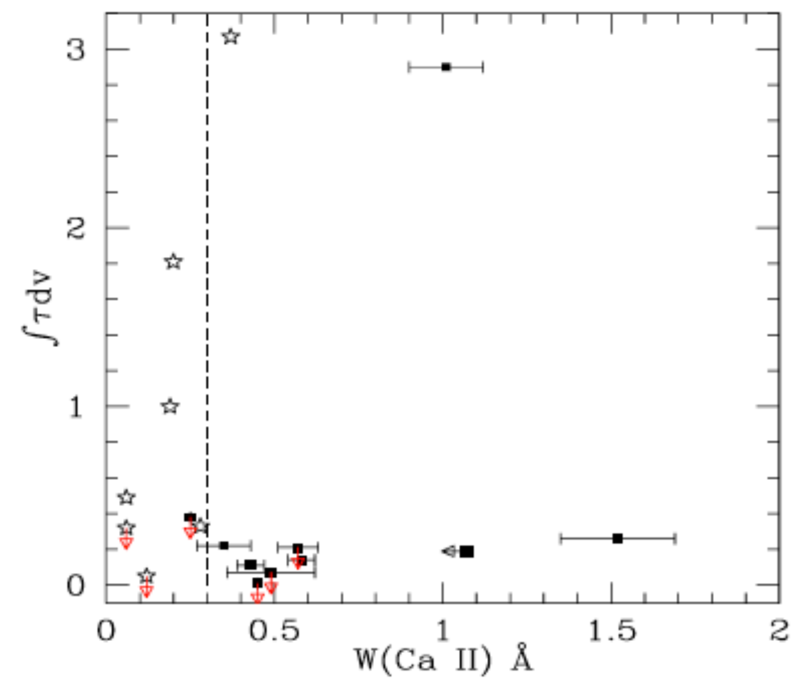




- 50% probability of detecting 21-cm absorption at b< 20 kpc.

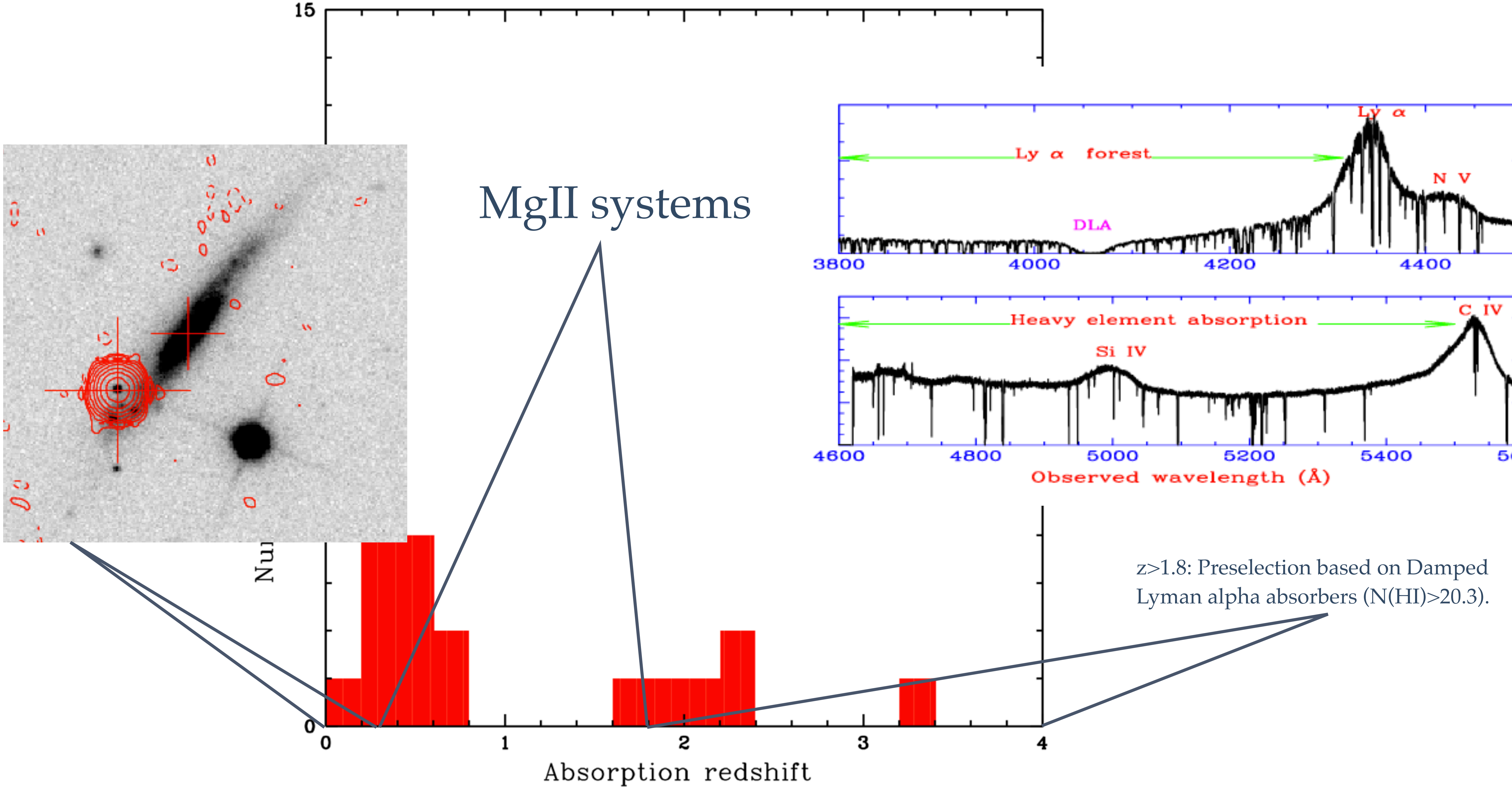


- z<1 DLAs have lower CaII widths despite having smaller impact parameters and higher 21-cm optical depths.



(Gupta et al. 2010)

Need more .....


MgII systems
z>1.8: Preselection based on Damped Lyman alpha absorbers (N(HI)>20.3).
15
0
Nu
0
1
2
3
4
Absorption redshift
Ly α
Ly α forest
N V
DLA
3800
4000
4200
4400
Heavy element absorption
C IV
Si IV
4600
4800
5000
5200
5400
5600
Observed wavelength (Å)

Need more .....

Need more .....

Blind searches of 21cm absorption

(no pre-selection and no dust bias)

Absorption line: survey speed

Driven by:

redshift coverage

$$\text{SurveySpeed}(\tau < \tau_o) \propto (A_e / T_{sys})^2 \times \Delta z \times N_t$$

sensitivity

number of targets

Absorption line: survey speed

Driven by:

redshift coverage

$$\mathrm{SurveySpeed}(\tau < \tau_o) \propto (A_e / T_{sys})^2 \times \Delta z \times N_t$$

sensitivity

number of targets

	APERTIF	ASKAP	EVLA	MeerKAT Phase-1	MeerKAT Phase-2
Frequency coverage (GHz)	1.0-1.7	0.7-1.8	1.0-50	1-1.75	0.58-1.75
Redshift coverage (21-cm)	0-0.42	0-1.03	0-0.51	0-0.42	0-1.45
Bandwidth (GHz)	0.3	0.3	8	0.75	2
Field of view (deg^2; $f = 1.4$ GHz)	8	30	$0.5/f^2$	$1/f^2$	$1/f^2$
RMS (mJy; 5 km/s† in 1 hr)	2.5	4.0	1.6‡	1.0	1.0
A_e/T_{sys} (m^2/K)	103	65	214	220	220
Δz_{max}	0.3	0.6	0.4	0.4	1.5(1.0)
$SS(\tau < \tau_o)/N_t$	0.16	0.12	0.90	1	3.6(2.3)

† 23.5 kHz at 1.4 GHz; At 1200 MHz as estimated from EVLA exposure calculator.

split receivers

MeerKAT Absorption Line Survey

4000 hrs to search for 21cm and OH absorbers at z<1.8.

Principal Investigators

Neeraj Gupta (ASTRON, NL), Raghunathan Srianand (IUCAA, INDIA)

Co-Investigators (19)

Europe: F. Combes (Observatoire de Paris), W. Baan, R. Morganti, T. Oosterloo (ASTRON), P. Petitjean (IAP), T. van der Hulst (Kapteyn)
Chile: C. Ledoux (ESO), P. Noterdaeme (Universidad de Chile)
India: D. Bhattacharya, A. Kembhavi (IUCAA)
S. Africa: C. Cress, M. Jarvis (Univ. of Western Cape), K. Moodley (Univ. of KwaZulu Natal)
USA: A. Baker (Rutgers), S. Bhatnagar, C. Carilli, E. Momjian (NRAO)
UK: R. Beswick (Univ. of Manchester), H. Klockner (Univ. of Oxford)

Image credit: E. de Blok (http://www.ast.uct.ac.za)

MALS: Observing plan

	MeerKAT-I	MeerKAT-II
Frequency range (GHz):	1-1.75	0.58-1
Bandwidth (GHz):	0.75	0.42
Pointings (hrs):	1000	1000
Hours/Pointing:	2	2
(centered at S(1.4GHz)>400mJy)		
	(2000 hrs)	(2000 hrs)

KAT-7 — 2011

MeerKAT-I — 2016

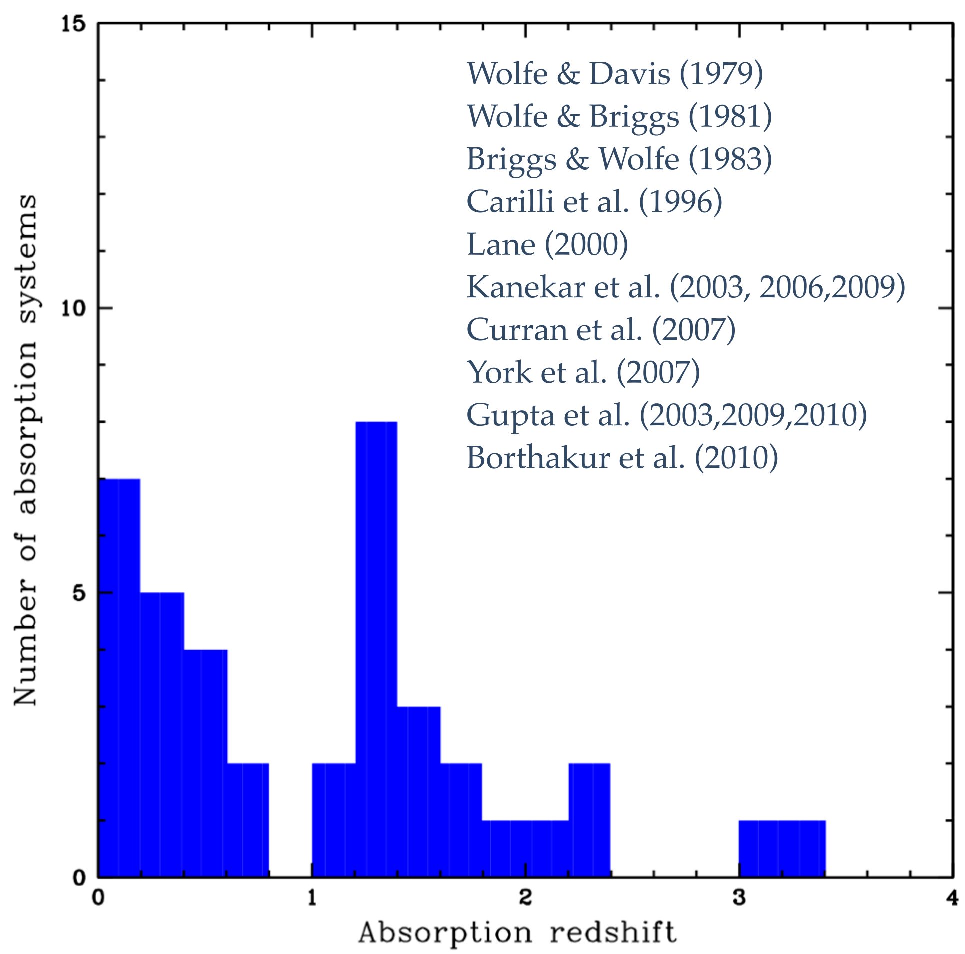
MeerKAT-II — 2018

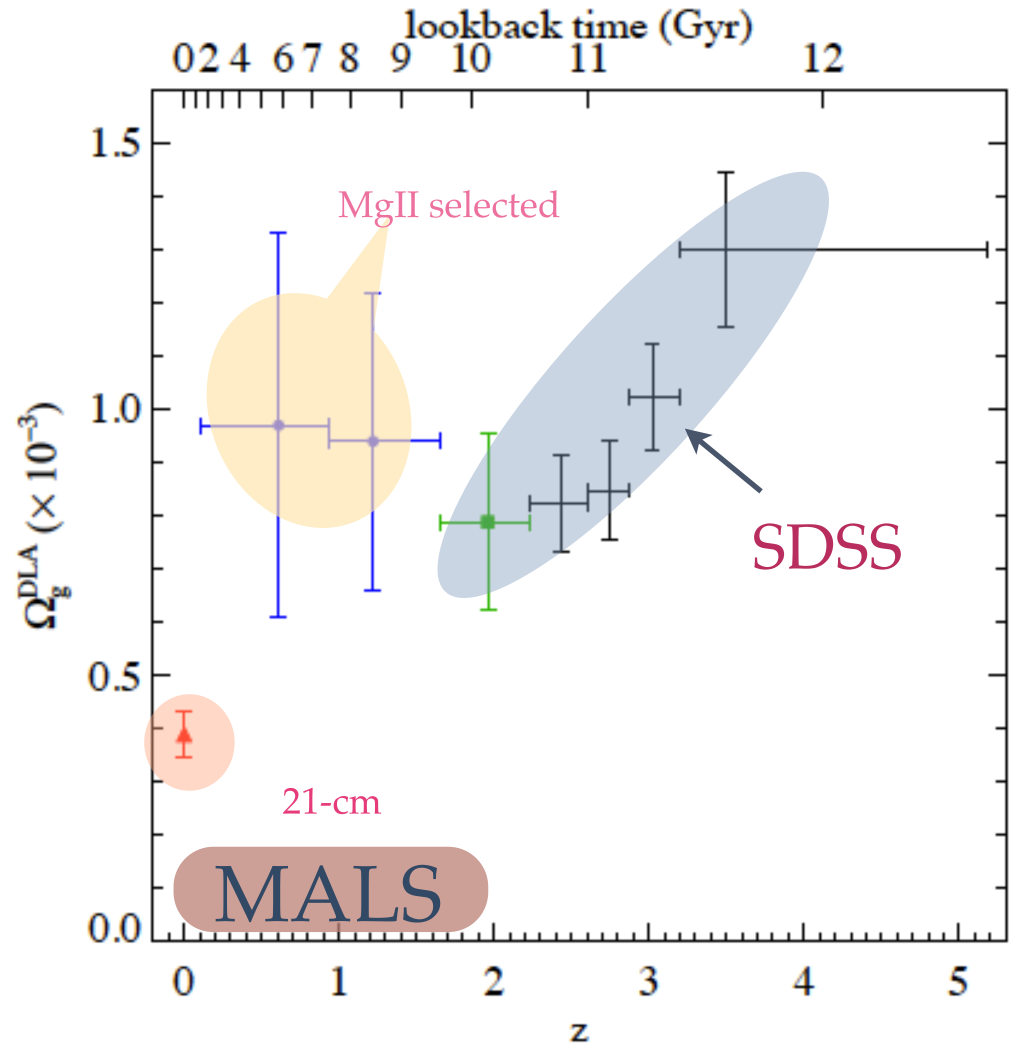
MALS: Specifications

Channel separation (kHz):	36 (18)
Spectral rms (mJy):	0.7
Line-to-continuum DR (dB):	60
Spatial resolution (@ 1GHz):	~10″

KAT-7	MeerKAT-I (2000 hrs)	MeerKAT-II (2000 hrs)
2011	2016	2018

Intervening 21-cm absorbers from MALS





39 absorbers known till date.
Only 12 at z<0.4.

Finally, only 5 molecular absorbers known at z>0.1.

Comparable to SDSS DR7-DLA survey in redshift path.

MALS detects > 600 intervening 21-cm absorbers @ z< 1.8

ASTRON

Wed, Jun 29, 2011

MALS: Goals

1) Blind search for 21cm and OH absorbers at z<1.8:
   using 580- 1750 MHz frequency band(s).
2) Detect more than ~600 intervening 21-cm absorbers:
   20 times the number of absorbers known.
3) Measure the evolution of cold atomic and molecular gas at z<1.8:
   the z-range where most of the evolution in SFRD takes place.
4) Time variation of the fundamental constants of physics:
   using OH lines, and 21-cm and optical/UV absorption lines (SALT + VLT + ALMA).
5) Probe the magnetic field in absorbing galaxies:
   using rotation measure and Zeeman splitting.
6) Synergy with ALMA, EVLA, SALT, VLBA and VLT.

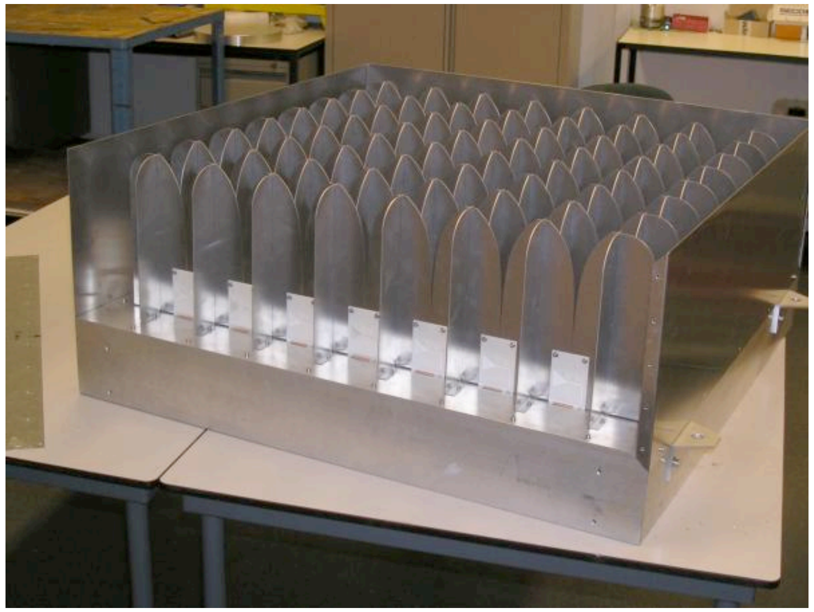
.... all the data will be public.

Blind searches of 21cm absorption

http://www.astron.nl/general/apertif/apertif

APERTIF

Increase the WSRT FOV by factor ~25.
8 square degrees !



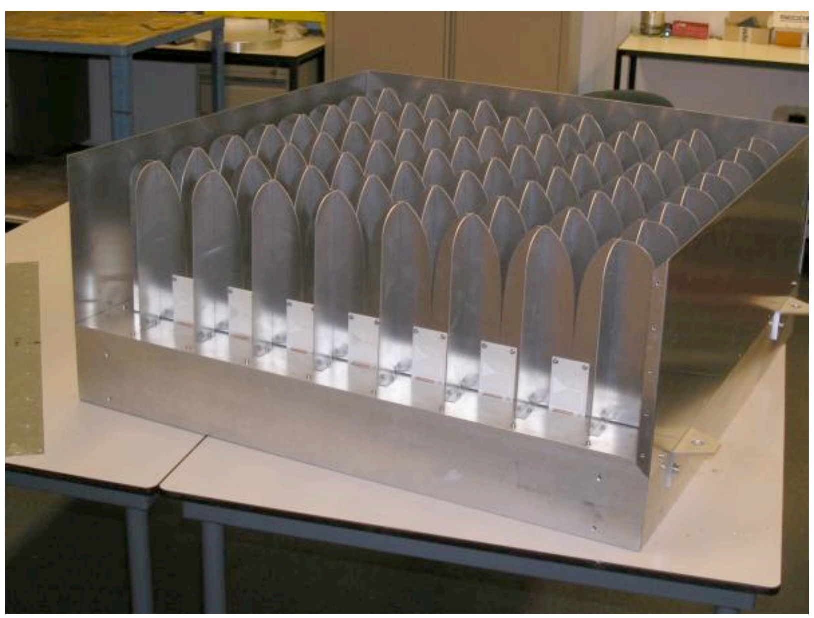
Blind searches of 21cm absorption

http://www.astron.nl/general/apertif/apertif

APERTIF

Increase the WSRT FOV by factor ~25.
8 square degrees !

ASKAP FOV~ 30 square degrees



Similary ASKAP in southern hemisphere!

http://www.atnf.csiro.au/projects/askap/

MALS: Goals

1) Blind search for 21cm and OH absorbers at z<1.8.
2) Detect more than ~600 intervening 21-cm absorbers.
3) Measure the evolution of cold atomic and molecular gas at z<1.8.
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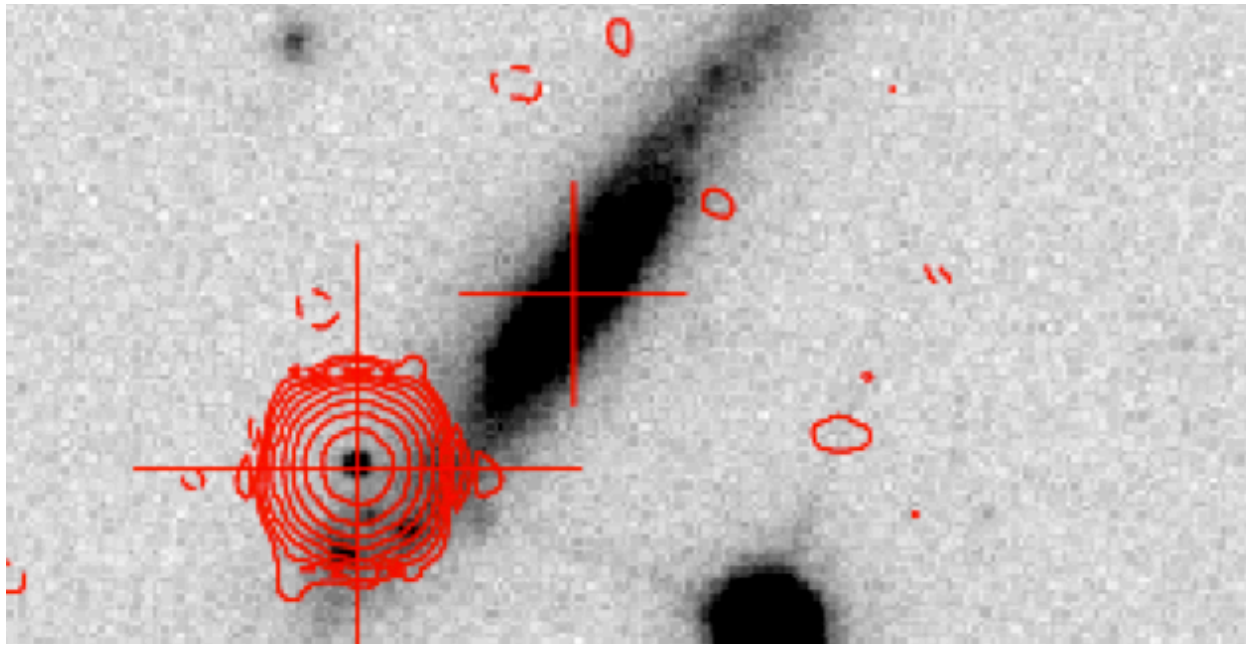

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http://www.astron.nl/

Thank you