Opportunities with VLBI

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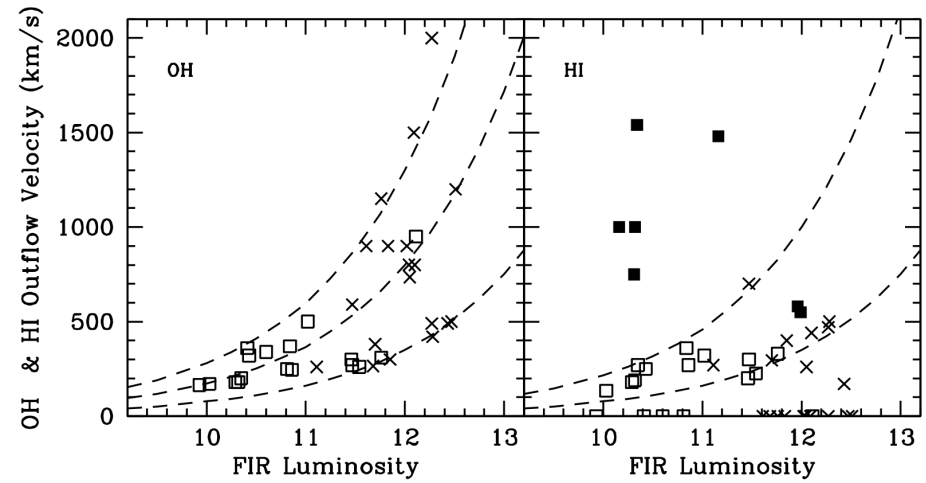
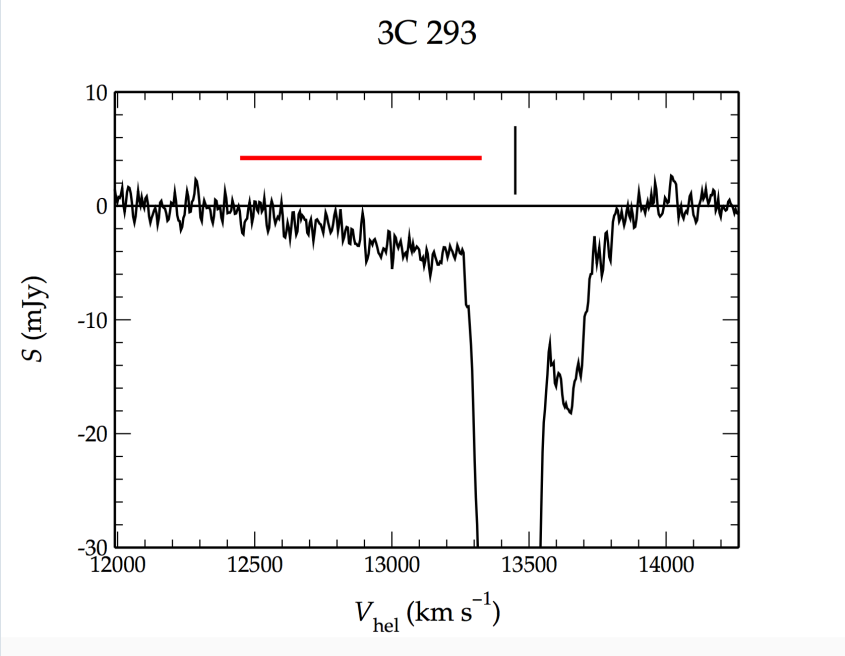
Motivation

- **The ISM around AGN or nuclear SF regions provide a unique probe of the physical conditions and processes**
- **HI and OH in absorption against strong cores reveal**
  - Narrow and deep (typically τ>0.01) absorption (e.g. from circumnuclear discs)
  - Broad, blueshifted and shallow (τ~<0.001) absorption systems
- **The terminal velocities of these scale with nuclear L_{FIR}**





- **In some galaxies evidence for massive outflows**
- **Broad, blueshifted absorbers jet-ISM interactions?**

EVN 2015 vision document

Morganti et al. (2005)
Baan (2007)

European VLBI Network (EVN)

- Three observing sessions per year

Proposal deadlines: 1 Feb, 1 June, 1 Oct

- The most sensitive standalone VLBI array
- Where data rates do not help, large dishes will: particularly well suited for HI absorption on parsec scales!
- High redshifts (below ~1300 MHz) partial coverage though, and RFI can be annoying

- Central Processor: JIVE, Dwingeloo, NL

21cm EVN status

(#) TABLE IIIA 21/18cm FREQUENCY RANGE + AGILITY

SITE	SCHED CONTR	LOCAL CMDS	Frequency range	COMMENTS
Eb/Ef	yes	no	1270-1450, 1580-1725	New system (2009) (see note ^^)
Jb1/2	yes	yes	1250-1500, 1550-1730	30s switch time
Cm	yes	yes	1370-1430, 1550-1730	30s switch time
Wb	no	yes	1150 - 1800	rephase after agility (5 min)
Mc	yes	yes	1350-1450, 1595-1715	21 and 18: diff. pointing models
Nt	yes	no	1400 - 1705	Continuous band (no delay)
Sr	no	no	1350-1450, 1625-1715	commands from the operator
On85	yes	yes	1200-1450, 1594-1720	Changes in PRC file
Tr	yes	no	1350 - 1725	
Ur	yes	no*	1400 - 1735	mixed patch: VC1-4 low, 5-8 high
Ar	?	?	1150 - 1730	
Hh	-		1580-1750	
Sh	-		1600-1740	
Tm65	-		1250 - 1750	
Sv	-	-	1380 - 1720	
Zc	-	-	1380 - 1720	
Bd	-	-	1380 - 1720	

(*) Mk4 systems:use ifadjust after switch 21/18cm to get levels OK.
(^^) The firstLO for the Ef L-band system is tunable, but the total
available IF width is limited to the range 80-240 MHz from the firstLO.
SCHED CONTR=switch 21/18 automatically from schedule.
LOCAL CMDS=extra local commands must be inserted in schedule.

http://www.evlbi.org/user_guide/EVNstatus.txt

Data and pipeline products in the EVN Archive

EVN Data Archive at JIVE

Availability of standard plots, pipeline and fitsfiles.

Select Sort order: Experiment Observation period: 2016 - 2017 Submit Query

Experiment	Stnd	Pipe	Fits	P.Investigator	Stations	Obs. Date	Distr. Date	Publ. Date	Support Scientist
EA057B	x		x	Anderson	JbWbEfO8McTrSvZcSr	160305	160905	170905	Campbell
EA058A	x	x	x	Argo	JbWbMcO8UrTrSvZcBdCmDaKnTaEfRo	161028	170407	180407	Burns
EB059	x	x	x	Blanchard	JbWbEfMcNtO8TrYsT6HhAr	160921	161208	171208	Blanchard
EB060A				Bach	JbEfMcNtO6TrYsSvZcBdHhMhKtKyKu	170309			
EB061	x	x	x	Burns	JbWbMcNtO8TrArT6Hh	170510	170515	180515	Burns
EC052F	x	x	x	Cseh	EfHhJbMcO8TrWbT6	160112	160113	170113	Paragi
EC054C	x	x	x	Cao	EfHhJbMcO8TrWbT6	160113	160114	170211	Paragi/Marcote
EC054D	x	x	x	Cao	EfJbMcNtO8TrYsWbHhT6Ox	160203	160211	170211	Marcote
EC057A	x	x	x	Cutini	EfJbMcNtO6TrYsUrSvZcBdSrMhKtKyKu	160614	161202	171202	Blanchard
EC057B				Cutini	EfJbMcNtO6UrTrYsSvZcBdMhKtKyKuRo	170308			
ED040A	x	x	x	Deane	JbEfO8HhNtMcT6TrYsWbUrSvZcBdIr	161026	170331	180331	Marcote
ED040B				Deane	JbEfO8HhMcT6TrWbUrSvZcBdIr	161101			Marcote
EG078D	x	x	x	Garrett	T6WbO8McNtTrSvBdZcUrEfJbRo	160306	161026	171028	Campbell
EG078E	x	x	x	Garrett	T6WbO8McNtTrSvBdZcUrEfJb	160308	161028	171028	Campbell
EG082G	x	x	x	Gawronski	EfJbMcNtO8TrYsWbHhT6Ox	160202	160210	170704	Marcote
EG082H	x	x	x	Gawronski	EfJbMcNtO8TrYsWbHhT6	160316	160323	170704	Marcote
EG082I	x	x	x	Gawronski	EfJbMcNtO8TrYsWbHhSh	160510	160512	170704	Paragi/Marcote
EG082J	x	x	x	Gawronski	EfJbMcNtO8TrYsShWbHhSvZcBd	160621	160704	170704	Marcote
EG088	x	x	x	Giroletti	MpHoAtKyKuKtUrBdZcSvJbMcNtSrO6TrMhEfYsHh	160614	170322	180322	Blanchard
EG089C				Gurvits	JbEfMcNtO8T6UrTrYsSvZcBdIrPu	160224			
EG089D				Gurvits	JbEfMcO8UrTrSvZcBdIrGtShT6RoPu	160304			
EG091A	x	x	x	Ghirlanda	EfJbMcNtO8TrYsWbHhT6	160315	160321	180221	Marcote
EG091B	x	x	x	Ghirlanda	EfJbMcNtO8TrYsWbHhT6	170214	170221	180221	Marcote
EG092A	x	x	x	Guirado	JbWbEfMcNtO8T6UrTrZcHhSrRo	160304	160802	180315	Marcote
EG092B	x	x	x	Guirado	JbWbEfMcO8T6UrTrZcHhSrIrRo	160527	161213	180315	Marcote
EG092C	x	x	x	Guirado	JbWbEfMcO8T6UrTrZcHhRoIr	161102	170315	180315	Marcote
EG094A				Gurvits	AtPaMpHoCdTiKsWwT6UrShBdSvZcJbEfWbMcO8TrHhIrRa	160920			

http://archive.jive.nl/scripts/listarch.php

EVN Data Reduction Guide

EVN Data Reduction "Quick Start" Guide

Congratulations on getting EVN data! What now?

JIVE correlates all EVN observations and performs a preliminary reduction using the EVN pipeline. At this point you would have received an email from your friendly support scientist with details on how to access your data. You should also have had a look at the results from the pipeline analysis. In general the pipeline results are to be used as a guide and should not be considered the final science product. We generally recommend using the amplitude calibration table from the pipeline, and fringe-fitting, bandpass calibrating, and imaging by hand.

We recommend using AIPS to reduce EVN data as, to-date, other packages do not have the ability to fringe fit data, which is integral for non-connected element arrays. This guide is written for the simple case of a phase-referenced continuum experiment.

1. Obtain data

Download the fits files from the EVN data archive (under the 'Fitsfiles' tab), as well as the *EXP*.tasav.FITS file (Click the 'Pipeline' tab and then right click "AIPS calibration tables"). This file contains the extension tables that have been applied to your data, a summary of which may be found in *EXP*.tasav.txt.

Set up the environment variable `MYDIR` to avoid having to type long paths. In the directory where your data are type

(for tcsh)

```
setenv MYDIR `pwd`
```

(for bash)

```
export MYDIR=`pwd`
```

2. Start AIPS

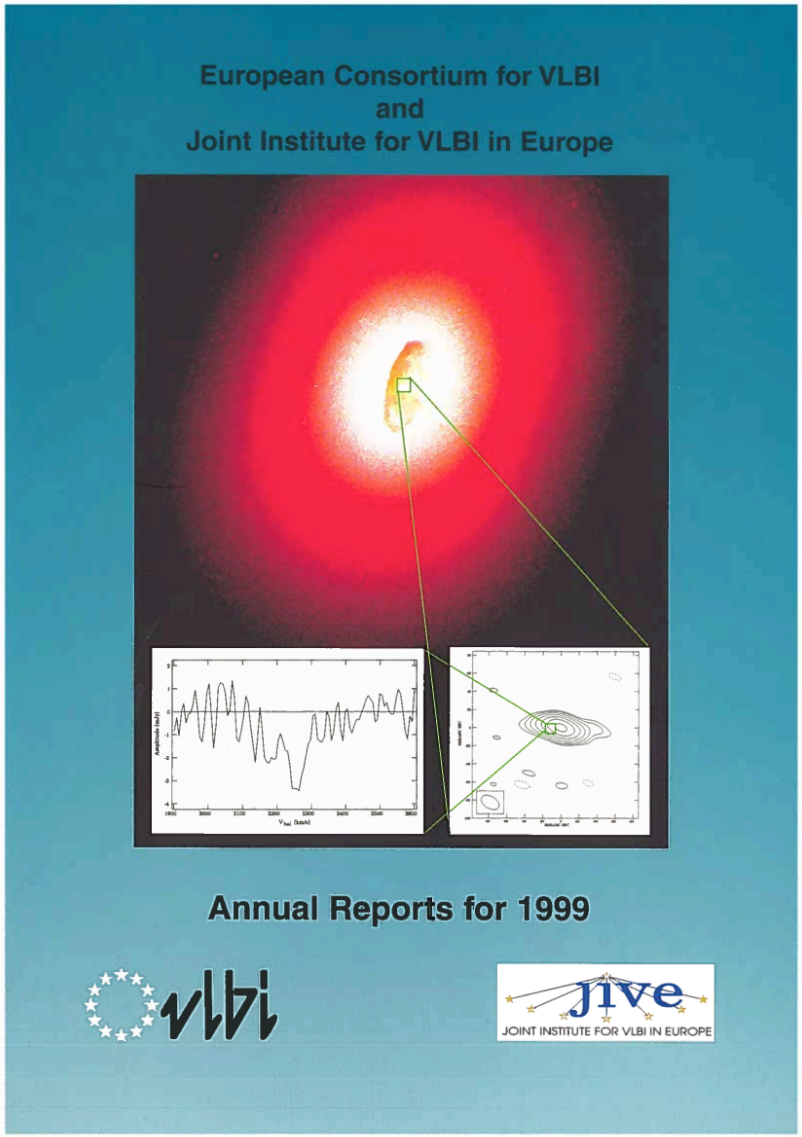
http://www.evlbi.org/user_guide/evn_datareduc.html

Science Support

- **Dedicated "black-belt" support scientists**

Support from proposing and scheduling to data reduction (at JIVE if you like)

A science driver for the EVN



- **First EVN MkIV Data Processor science result**
- **NGC4251 HI absorption against the nucleus**

  van Langevelde et al. (2000), A&A 354, L45
- **5th EVN Symposium 2000, Onsala**

  Five HI absorption papers, different authors
- **13th EVN Symposium 2016, St. Petersburg**

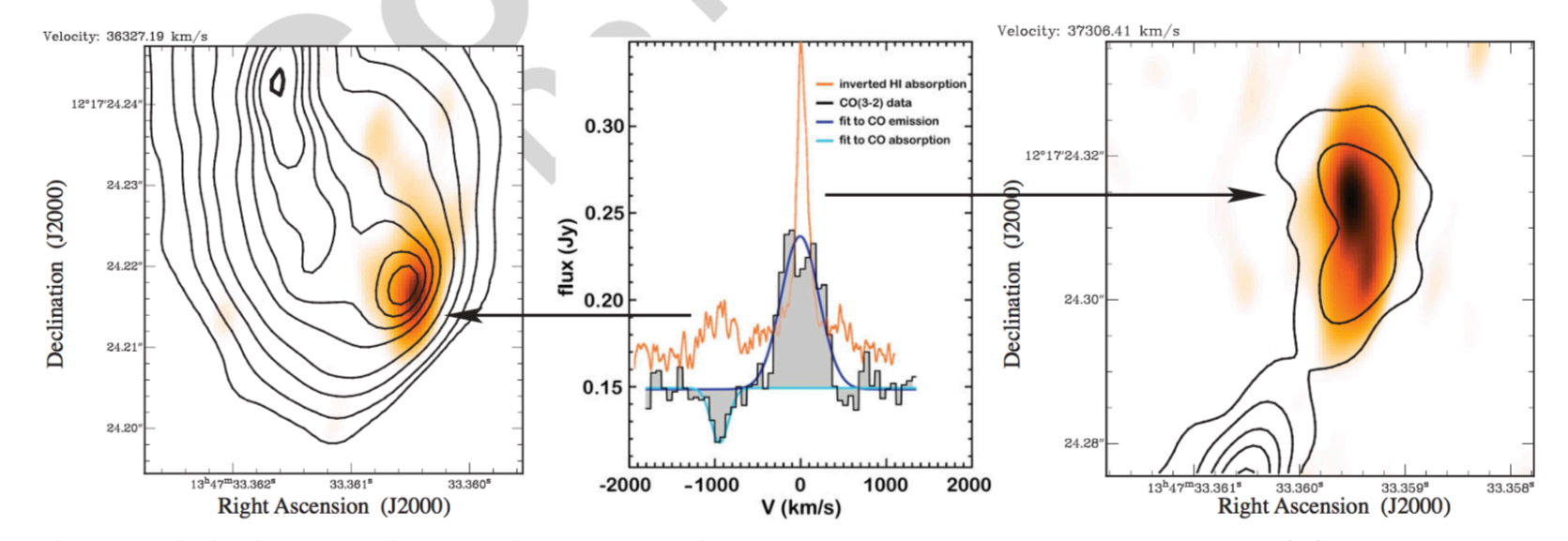
  None – need to shake up the community?
- **MkIV correlator retired ➔ SFXC**

  New features include Hanning, Hamming smoothing filterbank mode and spectral zooming

  Keimpema et al. (2015)

Recent results I. AGN jets & large scale outflows

4C 12.50 global VLBI



Young radio source in an ULIRG at z=0.1217

Morganti et al., Science, 341, 1082, 2013

- **Radio jet driving large scale outflow of atomic and molecular gas**

Recent results II. The ISM on tens of pc scales

- **ISM small scale structure: how cold gas is converted to stars?**

  The structure and turbulence of the neutral medium determines the size distribution of molecular clouds and therefore the stellar initial mass function. *(Paduan & Nordlund 2002)*

- **Galactic HI studies: ISM as "blobby sheets"?**

  Cold an warm neutral media has sheet-like structures with embedded cloudlets. *(Heiles & Troland 2003)*

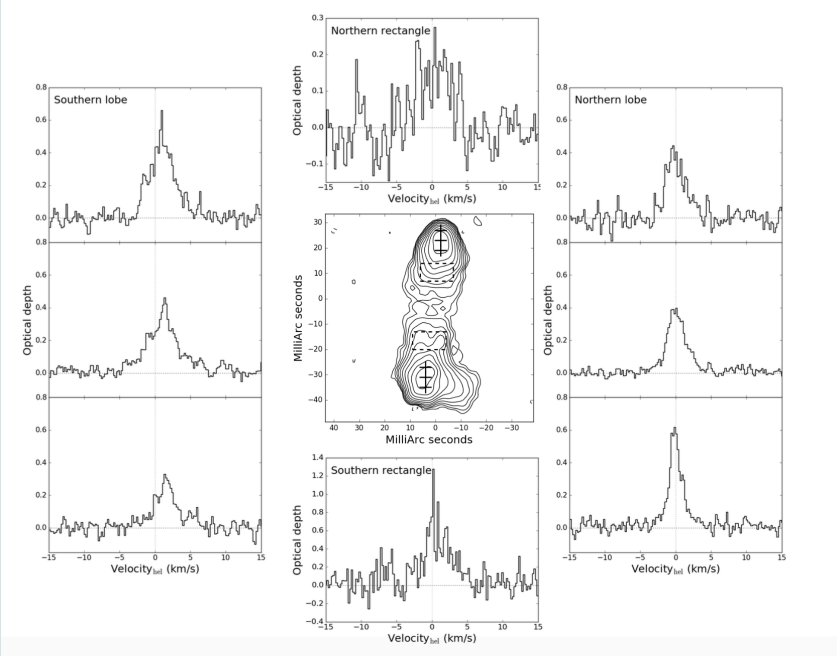
- **Use background radio-AGN to study nearby galaxies?**

  With VLBI one can probe ISM scales of tens of pc (these spatial scales cannot be studied with other methods)

- **A background CSO – nearby dwarf galaxy pair**

  J0855+5751 at z=0.54
  SDSS J085519.05+575140.7 at z=0.0026

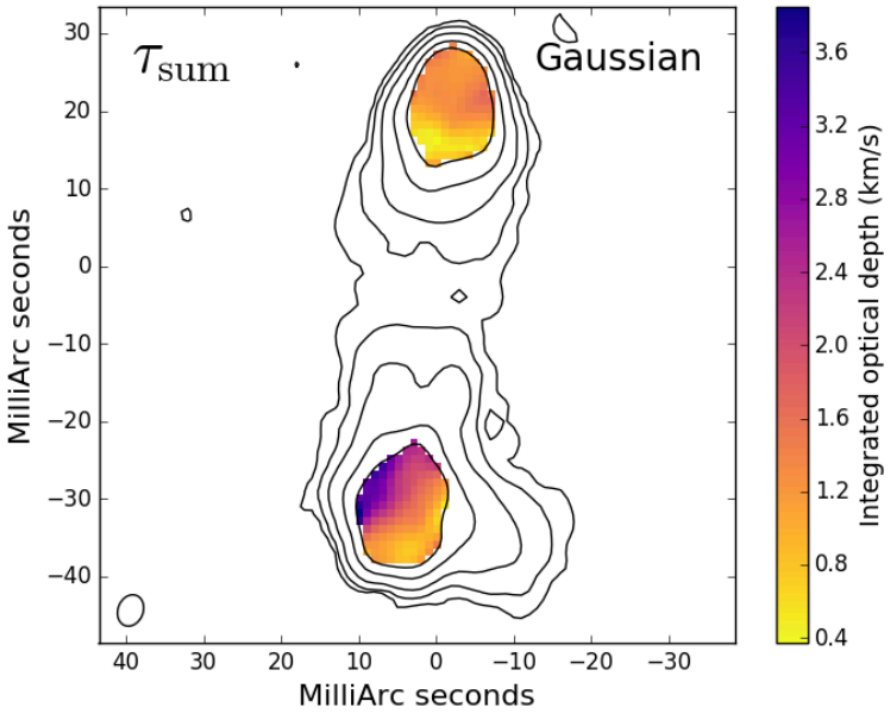
J0855+5751

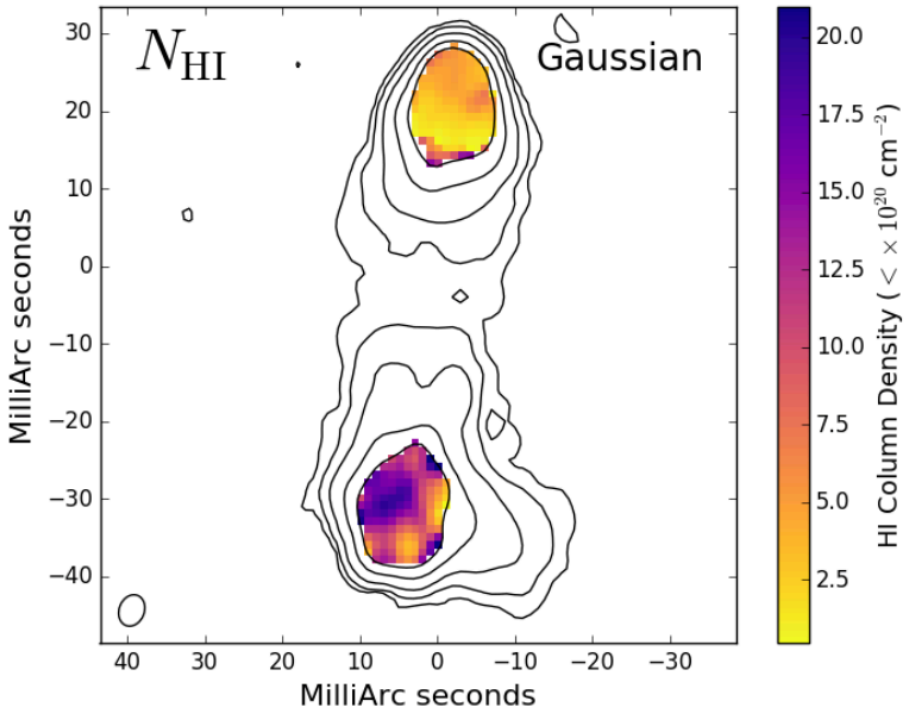


Biggs et al. (2016)

Recent results II. The ISM on tens of pc scales

J0855+5751 global VLBI





- **Observed x5 change in optical depth over 6 pc**
  Supports the blobby sheet model of the ISM

Biggs et al. (2016)

HI line detection limits for EVN

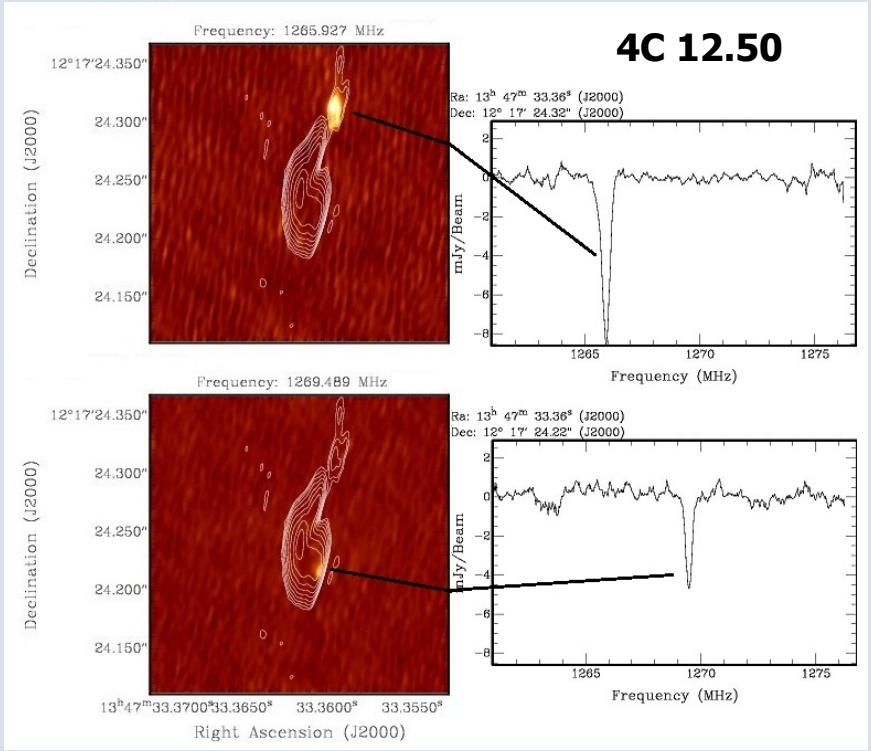
When we target HI absorption on tens of pc scales, e.g. to image blue-shifted swept-up gas in front of weak continuum, we are typically in the mJy regime – challenging!

Full EVN, 10hr integration, 0.5 MHz channel (~100 km/s):
~64 μJy/beam rms noise (EVN only)
~25 μJy/beam rms noise (adding SKA1-MID or FAST!)

Additional issues:

- ❑ Current EVN redshift-limited to $z \sim 0.12$
- ❑ Bandpass calibration is critical
- ❑ Lots of RFI at and below 1.4 GHz
- ❑ Not all cases show absorption clearly distinct from systemic velocity
- ❑ Expect velocity spread over ~1000 km/s

But it worked in 4C 12.50 ➔
Northern jet: HI absorption by nuclear gas at systemic velocity
Southern jet termination shock: blue-shifted HI

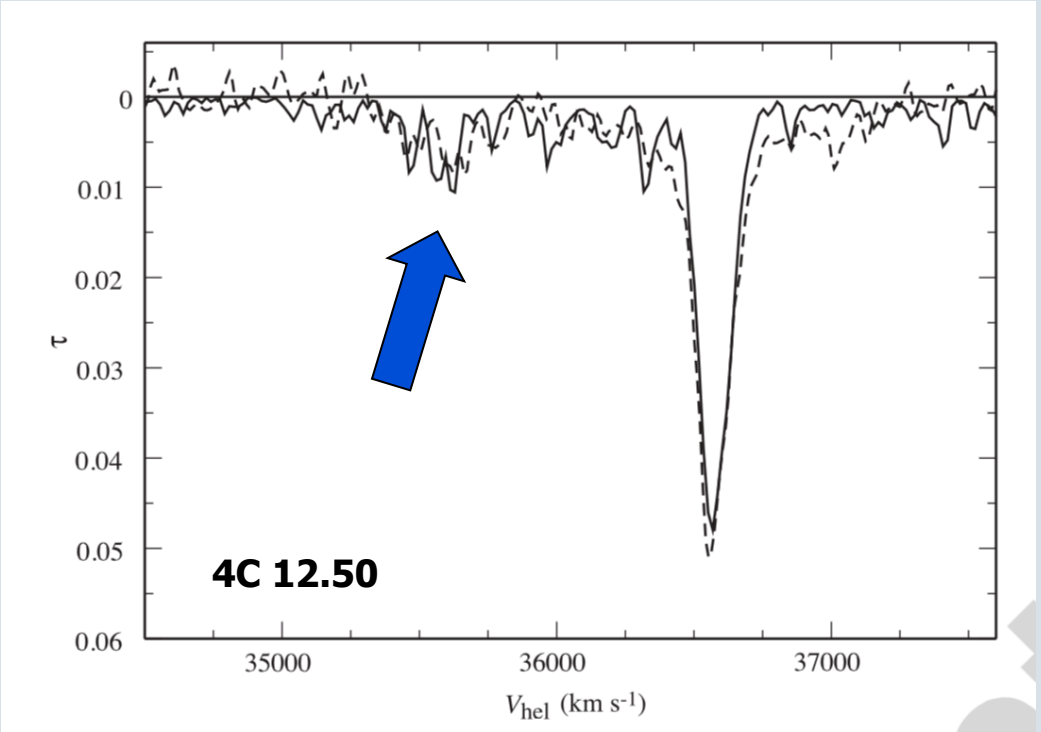


Minimum optical depth

Detectable opacity for 10 mJy continuum, 7σ:
$\tau_{\text{min, peak}}$ = 0.05 (EVN only); 0.02 (SKA-VLBI)

For comparison, 4C 12.50 again:

(Note here $\tau \sim S_{\text{line}}/S_{\text{cont}}$ is from WSRT data, assuming all unresolved continuum emission; true opacities are significantly higher – these can be better estimated with VLBI resolution)



Dashed line: WSRT spectrum; black line: global VLBI

HI column density

$N_{HI} = 1.8\times10^{18}\ T_{spin}\ \tau_{peak}\ FWHM_{line}$

(100 K; 0.02-0.05; 100 km/s)

➔ few 10^{20} – 10^{21} cm^{-2}

(4.6×10^{21} cm^{-2} in 4C 12.50)

Will need additional sensitive elements in the VLBI network, like SKA1-MID and FAST, to push these limits further!

Looking forward…

- **e-MERLIN – EVN integration on the way**

  Short spacings on few 100 km
  Fringes just detected in SFXC for e-MERLIN telescopes

- **New large telescopes coming online**

  Besides Tm65 and Sardinia, FAST, e.g. the 110m QiTai Radio Telescope

- **SKA-VLBI becoming a reality in a few years**

  "Band 2" remains largely unaffected by CCP
  Initiate a SKA-VLBI Key Science Project for HI ?

- **"The EVN future" process has started**

  Will need input from the community to define key science areas