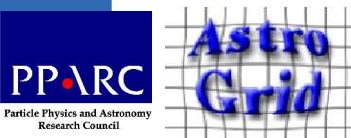# Radio data access:
on-demand interferometry imaging

Anita Richards and members of MERLIN, RadioNet and AstroGrid teams.

- **'Old' radio archive access**
  - Source lists, fixed images or visibility data
  - Most maps only inner few arcsec, fixed resol^n
- **MERLIN archive on-demand imaging**
  - via AstroGrid, using ParselTongue
- **Next-generation interferometry**
  - Archive development strategies
  - VO requirements
- ***Enable all astronomers to use multi-λ data***
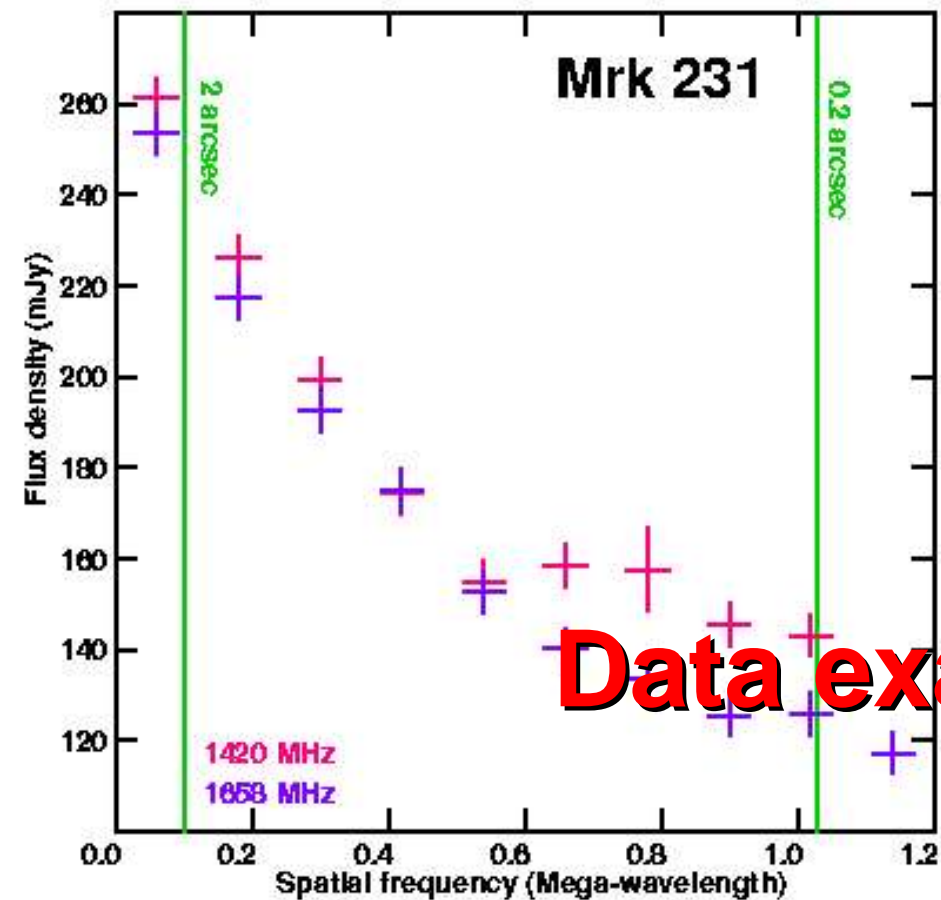
Interferometry data

* GB – TB raw data per experiment (mins - weeks)

  ✳ Visibility data

  ⭐ Cal sources. antennas etc.

  ✳ Domain-specific software

* No unique product

  ✳ Resolution v. sensitivity tradeoff by baseline weighting

  ✳ 3D/polarisation cubes, spectra, time series...

* Field of view e.g. 8', image pixels 10 mas

  ✳ Map out regions of interest, usually not all 10^9 pixels

  ✳ Most PI results too varied to archive

* Pipeline data for VOs

  ✳ Quick Look static images

  ✳ Flexible products to order

  ✳ Raw data option rarely wanted if alternatives!
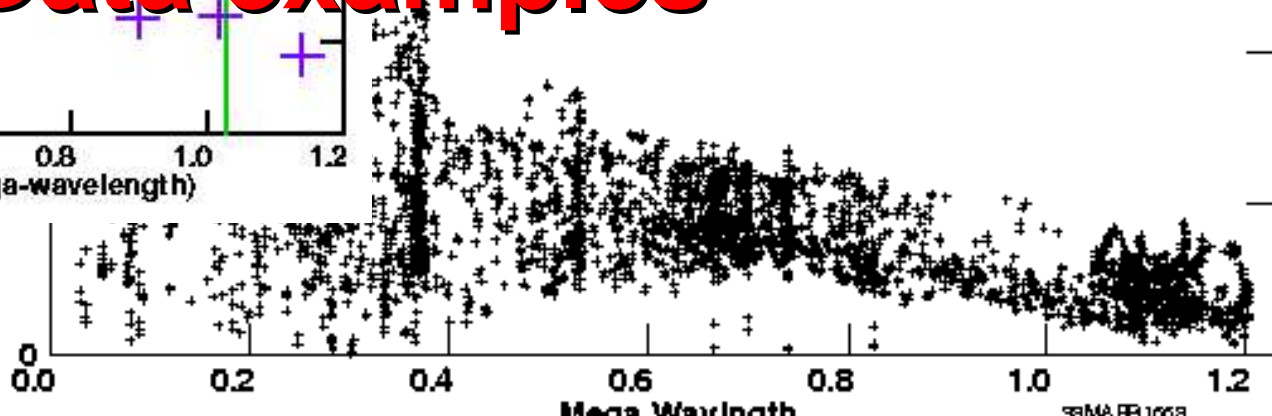
Calibrated,
binned visibility
amplitudes

Interferometry
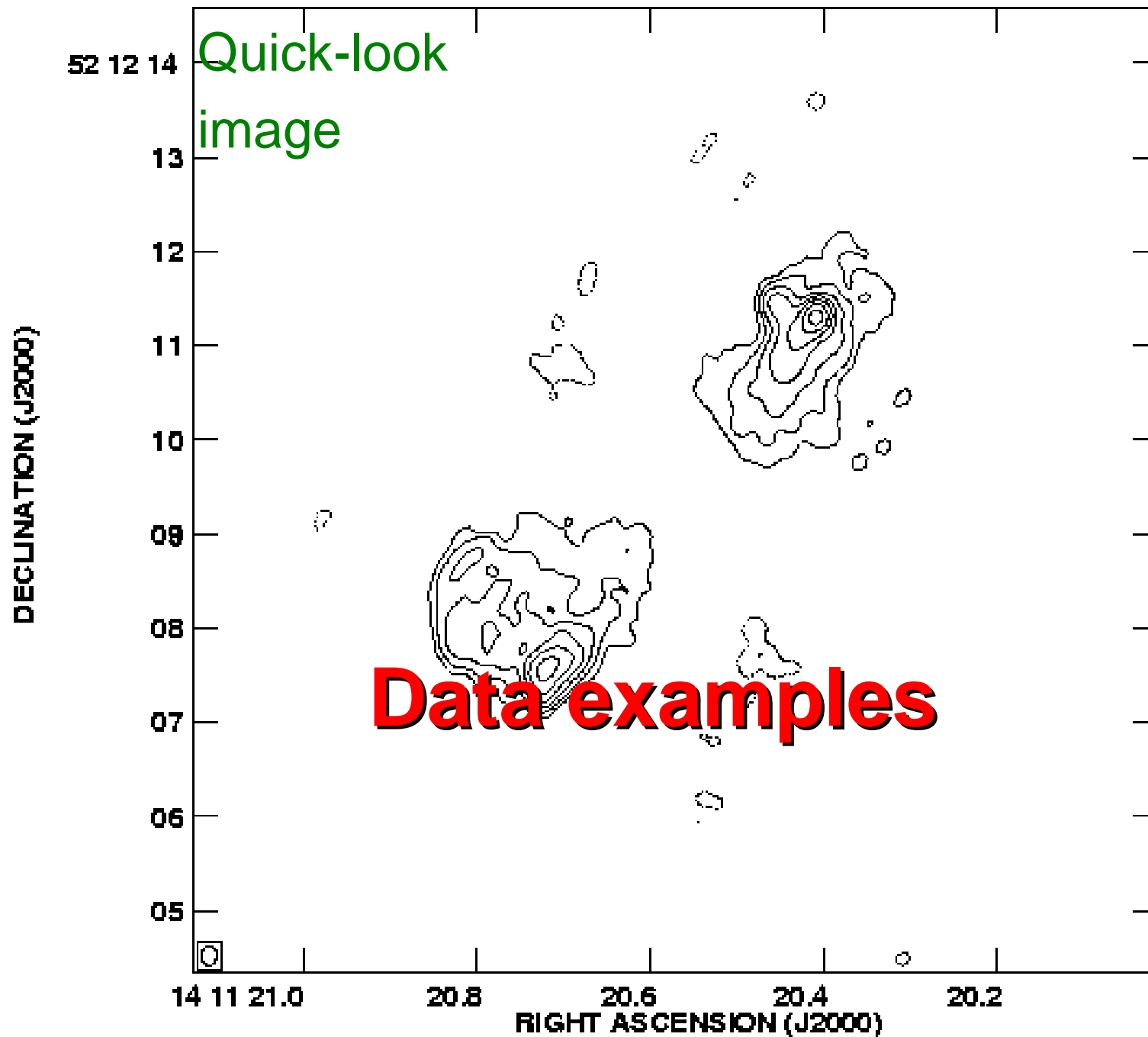visibility
amplitude v.
baseline length

3C295   MERLIN 1658 MHz Mar B 1998 1   created 30-APR-2001 19:54:38
Amplitude vs UV dist for 3C295.UVSRT.1   Source:3C295
Ants * - *   Stokes I IF# 1 Chan# 1

16

Mrk 231

2 arcsec

0.2 arcsec

260

240

220

200

180

160

140

120

Flux density (mJy)

1420 MHz
1658 MHz

0.0   0.2   0.4   0.6   0.8   1.0   1.2
Spatial frequency (Mega-wavelength)

Data examples

0

0.0   0.2   0.4   0.6   0.8   1.0   1.2
Mega Wavlngth

3C295 MERLIN 1658 MHz Mar B 1986 1 created 21-MAY-2001 20:32:14
3C295 IPOL 1658.000 MHZ 3C295.ICL001.4

Quick-look image

Data examples

DECLINATION (J2000)

RIGHT ASCENSION (J2000)

Data cube

First Moment

Data examples

Janskys

MilliARC SEC

1596.117 MHZ

1596.742 MHZ 1596.867 MHZ 1596.992 MHZ 1597.117 MHZ 1597.242 MHZ

1597.617 MHZ 1597.742 MHZ 1597.867 MHZ 1597.992 MHZ 1598.117 MHZ

1598.492 MHZ 1598.617 MHZ 1598.742 MHZ 1598.867 MHZ 1598.992 MHZ

1599.367 MHZ 1599.492 MHZ 1599.617 MHZ 1599.742 MHZ 1599.867 MHZ

1600.242 MHZ 1600.367 MHZ 1600.492 MHZ 1600.617 MHZ 1600.742 MHZ

1601.117 MHZ 1601.242 MHZ 1601.367 MHZ 1601.492 MHZ 1601.617 MHZ

1601.992 MHZ 1602.117 MHZ 1602.242 MHZ 1602.367 MHZ 1602.492 MHZ

km/s 11800   12000   12200   12400

Milli-arcsec offset

Milli-arcsec offset

200 150 100 50 0 -50 -100 -150 -200
Milli-arcsec offset

VOSPEC

Spectra Extraction Tool

•eesa

Target **IC418** Ra **81.8675156** D

- Non-expert access pre-2006
  - Ready-made FITS images
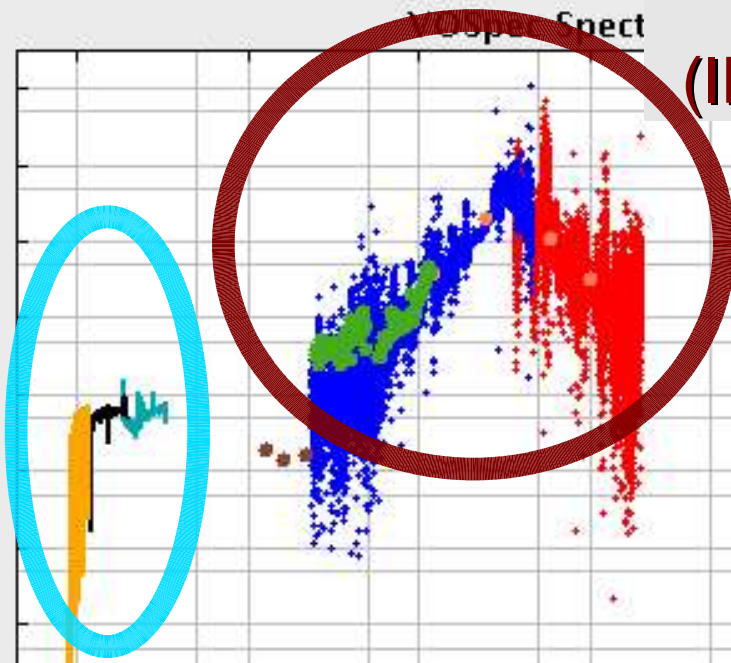 - Aladin
  - Catalogues:
  - SpecFind

IR from warm dust in remnant AGB shell (IRAS, ISO, 2MASS)

Hot stellar emission FUSE, IUE

Non-thermal nebular radiocontinuum (various - Vollmer catalogue)

Wave Length micron

	Server	Title	Ra	Dec	Format	Select	Status
	Far Ultravi...	IC418 FUSE (IAP)	81.87	-12.6967	spectrum...	✔	compl...
	Local File	Radio data: IC 418			spectrum...	✔	compl...
	Local File	IRAS Photometry Data: IC ...			spectrum...	✔	compl...
	Local File	ISO PHT IC 418			spectrum...	✔	compl...

Lines	▼	
Dots	▼	
Dots	▼	
Dots	▼	
Dots	▼	

View

VLBI data – then and now

C20:
Search list by experiment code

NAME	ON		ID	RA1950			DEC1950			PI	AFFL	EVNPN	USPN	WL
0004+139			Q	0	4	23.500	13	59	12.000	Gurvits	Arecibo	GG14		6
0004+139			Q	0	4	23.500	13	59	12.000	Gurvits	Arecibo	GG14		6
0008+106	IIIZw2		G	0	8	0.000	10	42	0.000	de Waard	Leiden	83-09		6
0008+260				0	8	0.851	26	1	35.420	Lestrade	JPL	90-19G	L49G	6
0010+775				0	10	22.260	77	32	5.690	Polatidis	NRAL	GP7		18
0010+775				0	10	22.260	77	32	5.690	Polatidis	NRAL	GP7		18
0010+405			Q	0	10	54.200	40	35	1.000	Readhead	CIT	89-74G	R51G	6
0010+405			Q	0	10	54.200	40	35	1.000	Readhead	CIT	89-74G	R51G	6
0010+405			Q	0	10	54.300	40	34	55.810	Akujor	MPIfR	89-07G	A25G	6
0010+405			Q	0	10	54.300	40	34	55.810	Akujor	MPIfR	89-07G	A25G	6
0010+405			Q	0	10	54.342	40	34	56.310	Readhead	CIT	89-74G	R51G	18
0010+405			Q	0	10	54.342	40	34	56.310	Readhead	CIT	89-74G	R51G	18
0014+813				0	14	4.100	81	18	28.400	Kuehr	MPIfR	83-29G	K15G	6
0014+813			Q	0	14	4.460	81	18	28.500	Wehrle	CIT	90-18G	W59G	18
0014+813			Q	0	14	4.460	81	18	28.500	Wehrle	CIT	90-18G	W59G	18
0014+813			Q	0	14	4.462	81	18	28.680	Wilkinson	NRAL	GW7		6
0014+813				0	14	4.462	81	18	28.680	Vermeulen	CIT	GV014		6
0014+813				0	14	4.462	81	18	28.680	Wilkinson	NRAL	GW7		6
0017+257	4C25.01		Q	0	17	3.415	25	46	13.500	Kapahi	JPL	89-21G	K25G	18
0017+257	4C25.01		Q	0	17	3.415	25	46	13.500	Kapahi	JPL	89-21G	K25G	18
0016+731			Q	0	16	54.100	73	10	52.000	Schalinsky	MPIfR	87-15G	S71G	6
0016+731			Q	0	16	54.100	73	10	52.000	Schalinsky	MPIfR	87-15G	S71G	6

EVN
Catalogues
Info

Working
Directory
evn

Select

Select by
center

EUROPEAN

http://db.ira.inaf.it/evn/

VLBI data – then and now

JIVE

JOINT INSTITUTE FOR VLBI IN EUROPE

EVN Data Archive at JIVE

C21:

Friendly search

Pipeline products

VO links

The EVN Data Archive at JIVE contains correlated data assembled and processed at JIVE. The archive includes a growing database as data entered the public domain.

In addition, the archive makes available various correlator and pipeline products. In a number of cases, preliminary images of sources are also available. The archive allows these to be combined resources in a natural way.

Select EVN experiment. Select a source/position from EVN experiment

Ra	Dec	Source	Image	Image
250.7450	39.8103	3C345	sdss	evn
291.7001	11.3546	IRC10420		
293.3409	15.0796	J1933+1504		evn
343.4906	16.1482	3C454.3		evn

Access to EVN archive

- Show experiment RAH2
- Show catalo... exper...
- Searc... archiv... sourc... or pos...
- The E... archiv... EVN obser...

Access to VO archives

- Aladin Sky Atlas (EVN image add...
- Sloan Digital Sky Survey (Image is...

Aladin v3.6 multiview

| Load... | Save... | Tools... | Print... | Help. |

Position J2000   Pixel 8 bits

DSS2J:POSSII 16:43:10 16:43 16:42:50

+39:50
+39:48
+39:46

1'   6.13' x 7.05'

http:..arc 16:42:58.81

+39:48:37

0.05"   0.244" x 0.281"

select rsamp, dist, cont, draw, zoom, tag, mglss, text, hist, filter, prop, rgb, del, blink

multiview

Done

NAME   **ON**

0004+139
0004+139
0008+106   IIIZw2
0008+260
0010+775
0010+775
0010+405
0010+405
0010+405
0010+405
0010+405
0010+405
0010+405
0014+813
0014+813
0014+813
0014+813
0014+813
0014+813
0017+257   4C25.01
0017+257   4C25.01
0016+731
0016+731

EVN Catalogues Info

Working Directory

evn

Select

Select by center

EUROPEAN

http://db.ira.inaf.it/evn/

Back   Forward   Reload   Stop

Done

MERLIN 2005
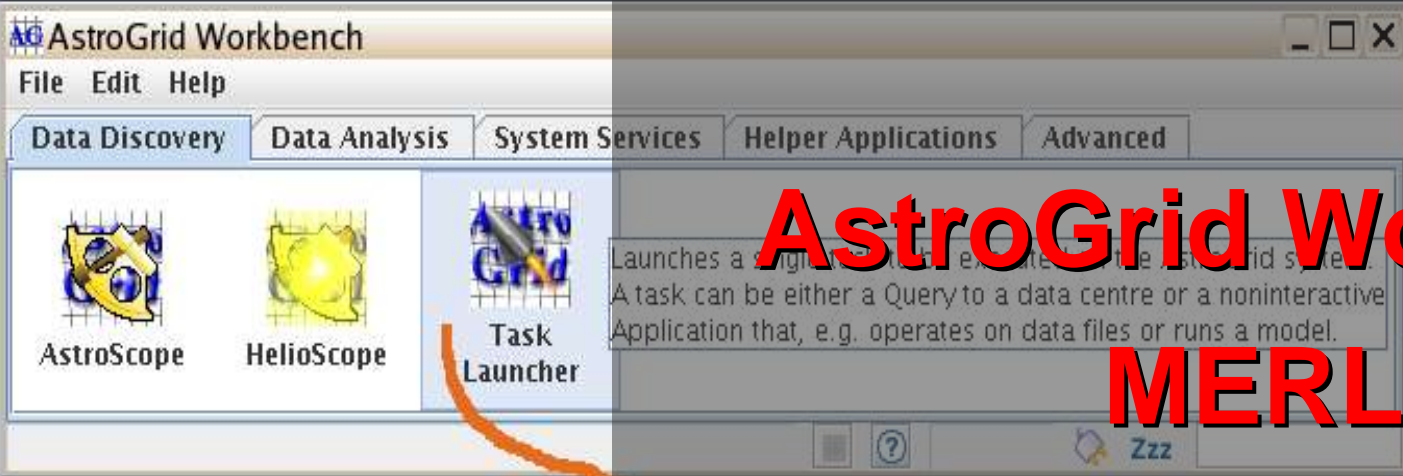**Web forms: static images**
Calibrated visibility data

* Visibilities live on disc, calibrated
* Sample products
* User version of pipeline
  * Still need AIPS

What's wrong with that?

✴ Dedicated web site fine for PIs of major projects

    ✪ Able to use domain-specific projects

    ✪ For simple observations, even PIs use pipeline images!

  ✷ Not really friendly for non-experts

  ✷ Not convenient for multi-wavelength

  ✷ Can't be used easily in workflows

✴ Need VO access

  ✷ Databases of observations and metadata

  ✷ Static quick-look products

  ✷ Flexible data products

✴ 2003-4 ATCA/CSIRO prototype imager using VO interferometry data model

User

Download

Aladin, TopCat

AstroGrid Workbench

MySpace

Task Launcher

MERLINImager

Registry

Position, size,
ν, resol^n, date

2006

CEA

AstroGrid Task

JBO server

RadioNet package

Python (perl/dbi)

ParselTongue

SIAP VOTable

MERLINImager

Select AIPS data

Image best 5
(calibration, fov)

FITS images,
logs, to public
HTML area

Interoperability (Plastic)

* Matching resolution

☀ Spectral index image

18 cm   6 cm

Steep spectrum – SE not AGN

Hunt-the-AGN in Markarian 273
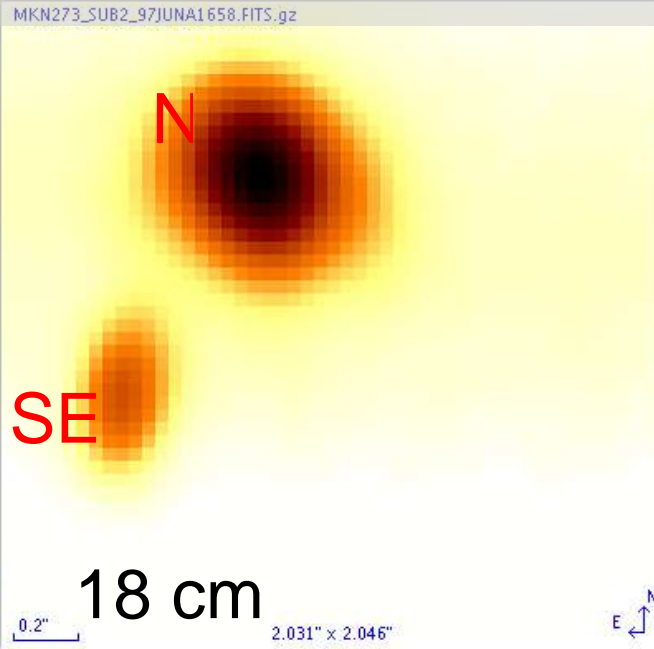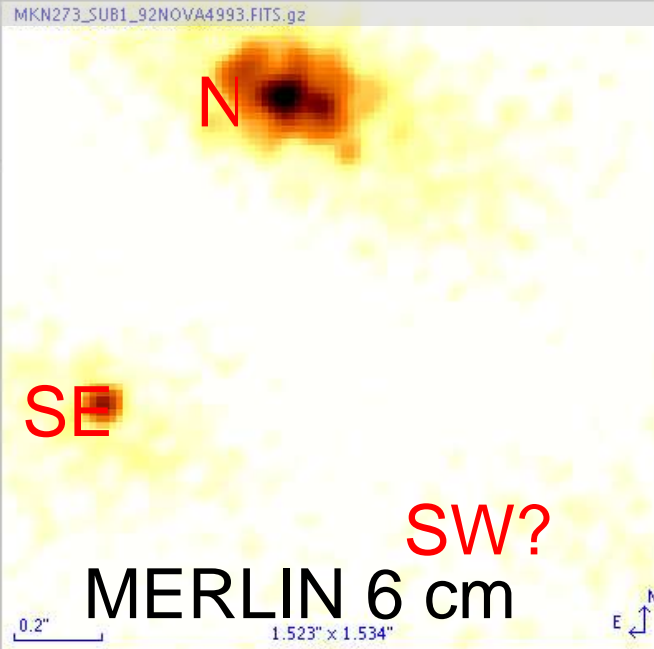
Compare:

old static

fixed

resolution

images

MKN273_SUB1_92NOVA4993.FITS.gz

N

SE

SW?

MERLIN 6 cm

0.2"   1.523" x 1.534"

MKN273_SUB2_97JUNA1658.FITS.gz

N

SE

18 cm

0.2"   2.031" x 2.046"

RGB img

N

SE?

SW

HST 110, 160, 220

0.5"

Server selector

Choose an image server or a data server
and fill in the associated form drawn below

Image servers:

Aladin server

SSS...

SkyView

SDSS

VLA...

MAST

Others...

Missions in VizieR

Specify a target and a mission to get the point so
Select them in the view window to get the associa

Target Markarin 273   Grab coord   Get all

Mission MERLIN   Radius 0.5   column

For your help, you can pick up mission names fro

FUSE – Log of FUSE (Far-UV Spectroscopic Explorer) –
HST – Hubble Space Telescope Archives – 384Krow
HUT – Log of Hopkins Ultraviolet Telescope – 1Krow
INT – The Isaac Newton Telescope observation log – 8
ISO – Log of ISO validated data – 23Krow
IUE – IUE Ultraviolet Spectra – 109Krow
MERLIN – The MERLIN interferometer at Jodrell Bank

Simbad

NED

Others..

SDSS.

AGN

Starburst with AGN core

Starburst

Starburst
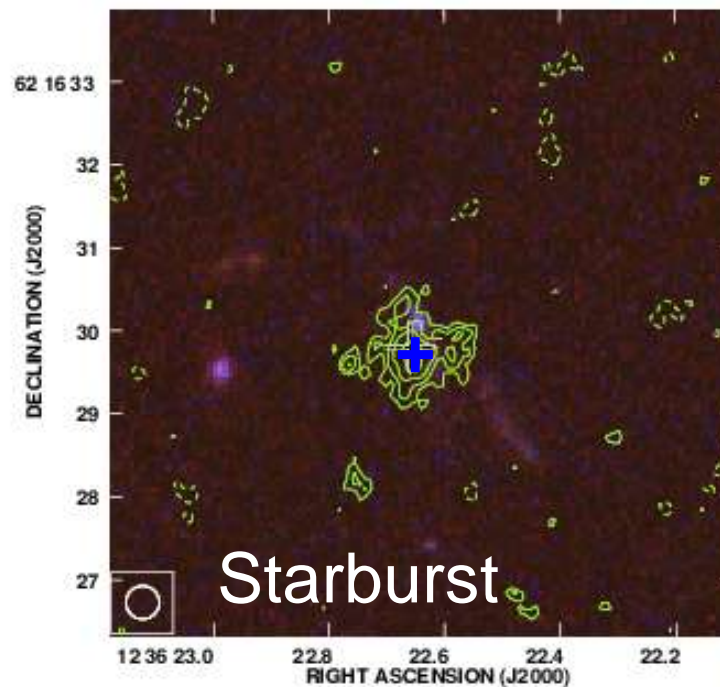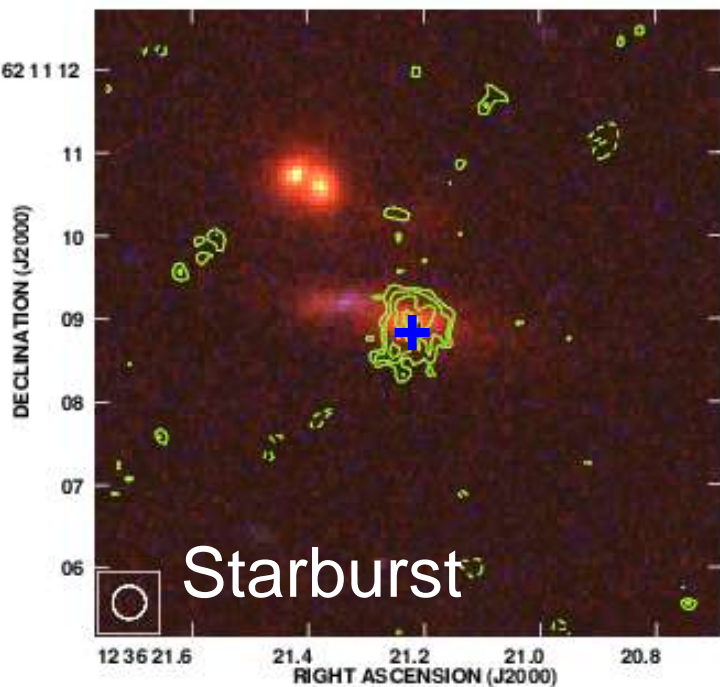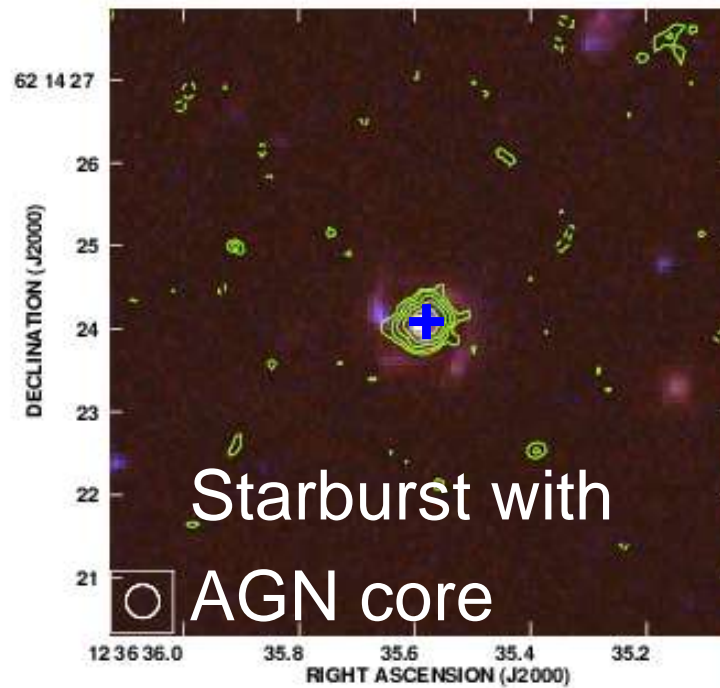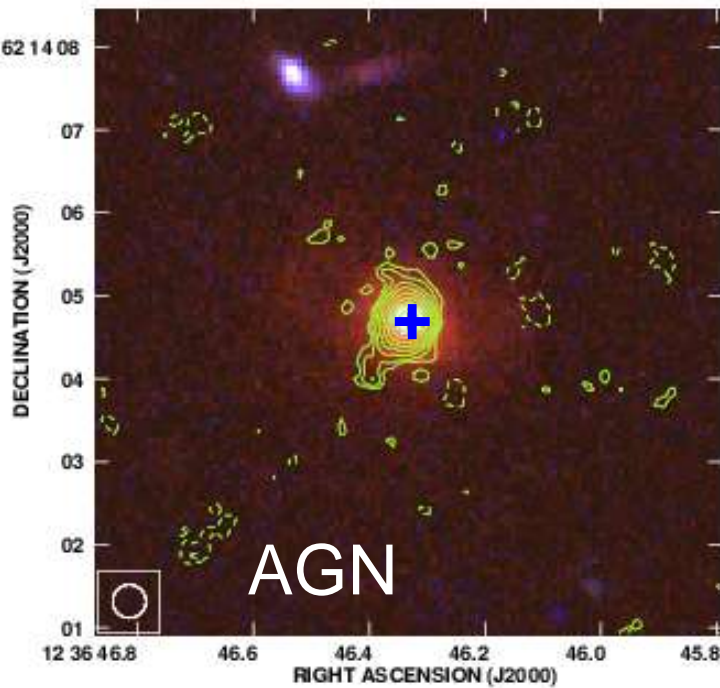
Coming soon: M+VLA HDF(N) cutouts

1"

10 μJy contours

+ X-ray selected AGN2

1 < z < 2.5

High-z radio starbursts host obscured X-ray AGN

R. Beswick, S.T. Garrington, A.J. Holloway, T.W.B. Muxlow, **A.M.S. Richards**, H. Thrall, N. Winstanley (JBO);
M.A. Garrett, M. Kettenis, H.J. van Langevelde (JIVE); E. Gonzalez-Solarez, N.A. Walton (IoA)
P.A. Harrison, P. Padovani, P. Rosati (ESO); M.G. Allen (CDS)

1   Introduction and Data

We use Virtual Observatory methods to investigate the strong association between the presence of radio and X-ray emission at high redshifts.

A region of 100 arcmin^2 around the Hubble Deep Field North (HDFN 10-arcmin field) was observed by the UK radio interferometer MERLIN and the USA VLA [13]. 92 sources brighter than 40 μJy were found in the combined images, which reach a noise level of $< 4\mu$Jy using beam sizes of $0.''2 - 2''$. These are the only observations apart from the HST images (this background shows the UDF) to resolve almost all the objects detected. There is a close relationship between radio and FIR emission of starburst origin which exends to $z \sim 3$ [10, 12]. Many of the higher-redshift radio sources have sub-mm SCUBA counterparts (e.g. [16, 7, 8]), corresponding to the rest-frame FIR peak. 55 of the radio sources are among the 100 X-ray sources detected by *Chandra* in the 10-arcmin field[4]. 18 of these are among the obscured AGN identified by [14]; the radio emission is starburst dominated in at least 11 cases.

We employed data access, crossmatching and manipulation tools now available via the AstroGrid Workbench[1] and the EuroVO[2]. These include the Vizier and Aladin services, TopCat and a cut-out extractor for radio images which uses the parselTongue scripting interface developed by RadioNet[3]. We compare the radio data with the *Chandra* CDF(N) source list and other GOODS [11] HDFN observations to investigate the properties of active galaxies at $z \gg 1$:

1. Can radio emission originate from a process different from the X-ray source in the same galaxy? If so, how much radiation has a common origin and how much is separate?

2. Are high-redshift starbursts just analogues of local ULIRGs or are they a distinct phenomenon only seen in the early universe?

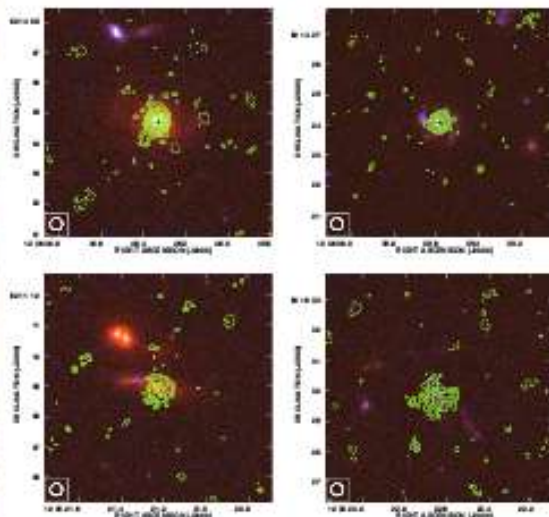## 2   Classification of radio+X-ray sources

Fig. 1 Radio contours at $(-1, 1, 1.4, 2...) \times 10\mu$Jy/beam overlying astrometrically aligned ACS images in the HDFN. Black crosses show the *Chandra* source positions; all are X-ray type-2 AGN.

Fig. 1. illustrates the radio classification criteria developed by [13]. J123646+621404 ($z = 0.96$) is a bright AGN with a compact core overlying the optical peak and lobes extending outside the host. J123635+621424 ($z = 2.01$) shows a radio AGN core within an ex-

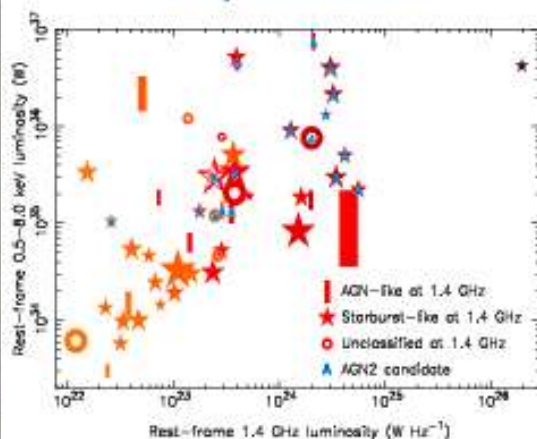## 3   High-redshift radio starbursts host X-ray-selected AGN

Fig. 3 Resolved radio-X-ray sources in the HDFN. Symbol height is proportional to the radio source largest angular size which ranges from $0''.3$–$12''$. Symbol shade from orange to dark red represents the redshift range 0.2–4.4.

Fig. 3. shows the classifications and luminosities of 1.4-GHz radio sources in the HDF(N) with X-ray counterparts and measured redshifts. 3 out of every 4 μJy sources are starbursts, including those with X-ray counterparts. Over half of these X-ray sources have $L_X > 10^{35}$ W (the unshaded area in Fig. 4.), indicating an AGN, 17 of which are classed as type-2 AGN. [14]. These are shown by a blue A in Figs. 3., 4. and 5.

5   A distinct population of high-z starburst AGN hosts

At $z < 1.1$, under 1/3 X-ray sources in the HDFN have radio counterparts. This rises to over 1/2 at higher redshift and in most of these the high X-ray luminosity indicates the presence of an AGN. The $L_X - L_R$ relationship for starbursts at $z < 1.3$ [6] shown by the green line in Fig. 4 breaks down at higher z where we see a dramatic increase in the scatter. This is the case even if only the soft-band or the de-absorbed hard-band X-ray luminosity is considered.

The mean angular size of the radio sources in the HDFN is $1''.3$ (Fig. 3), corresponding to a typical extent of 8-10 kpc for starbursts, all of which are larger than 2 kpc. The inferred star-formation rates are 1-2000 M$_\odot$ yr^{-1} for the higher-redshift sources. In contrast, local ULIRGs, with FIR luminosities $\geq 10^{12}$ W m^{-2}, have star-formation rates typically 50–200 M$_\odot$ yr^{-1}, concentrated inside the inner kpc of the galaxy. The near and far starbursts do have one feature in common; their optical counterparts very frequently show signs of severe disturbance and merger.
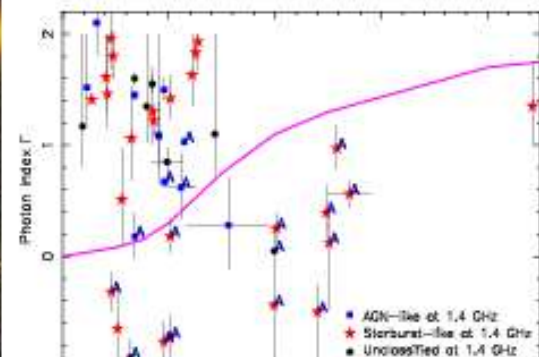
Next Generation Interferometers

* *e*-MERLIN, eVBLI, EVLA ATCA/LBA, LOFAR, GMRT, ALMA, SKA etc
  * Committed to VO access
  * Software development
    * RadioNet – ParselTongue (Python over e.g. AIPS)
    * NRAO – CASA (aips++ based, Python scripting).
    * ESO – XML binary and metadata storage

* 'B2E' obs-to-archive integrated data path
  * Metadata retrieval
  * Flexible remote processing of products

* VO components in archive management?
  * Cornish, GMRT, MMB and other surveys

Char DM Markarian 273 @ 18 cm

General	Spatial	Temporal	Spectral	Observable
frame/units	ICRF, deg	ISOstring	Mhz	Jy
Location	13.123456 +55.987654	1997-06-14 T12:00:00	1658	undef
Bounds	12.92, +55.58 13.32, +56.38	...T06:00:00 ...T18:00:00	1650 1665	0.0002 0.5
Support	13.123456 +55.987654 0.4	(on-source scan listing URL)	1650 1665	undef
Sensitivity	$f(\tau_{int}, \delta\nu, 1\text{ary beam})$	undef	(bandpass LUT URL)	? dynamic range <5E+4
Filling Factor	1	0.7	1	undef
Resolution	0".2 2".0 0".2 2".0	PT00H05M	1000 kHz	5E-5 10E-6
Sampling	0".04 0".0625 0".04 0".0625	PT16S	1000 kHz	undef

Development

* Expand/apply VO standards
  * Spatial frequencies, polarization...
  * Tools for radio data (Jy/beam, 3+D cubes...)
  * Authentication
* Expand data products/services available
  * Robustness
  * Visibility data, spectra, time series
  * Single-dish data
  * Image cutouts for Deep Fields
  * Solve queuing/overload and other problems
* Impliment at other sites/other radio datasets

AstroGrid/RadioNet workshop

- Radio data management (1400 5 Dec – 1600 8 Dec)
- Workshop for data providers/large surveys etc.
  - Data flow using archives and pipelines
    - ParselTongue, Common Proposal Tool etc.
  - Data delivery
    - Publishing data to VOs
    - Use and development of relevant VO tools
- Science use (0900 4 Dec – 1300 5 Dec)

Oxford w/c 4 December 2006

radiovo@jb.man.ac.uk   **http://wiki.astrogrid.org**