Into the heart of the M82 starburst – high resolution radio studies

- an update on a long running programme…

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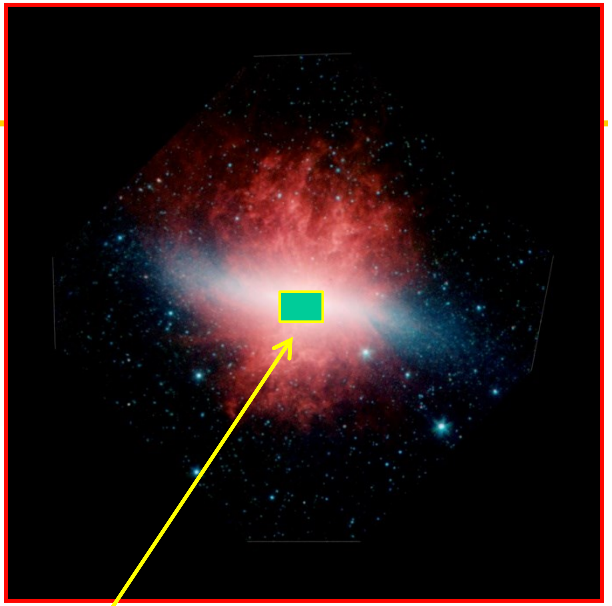
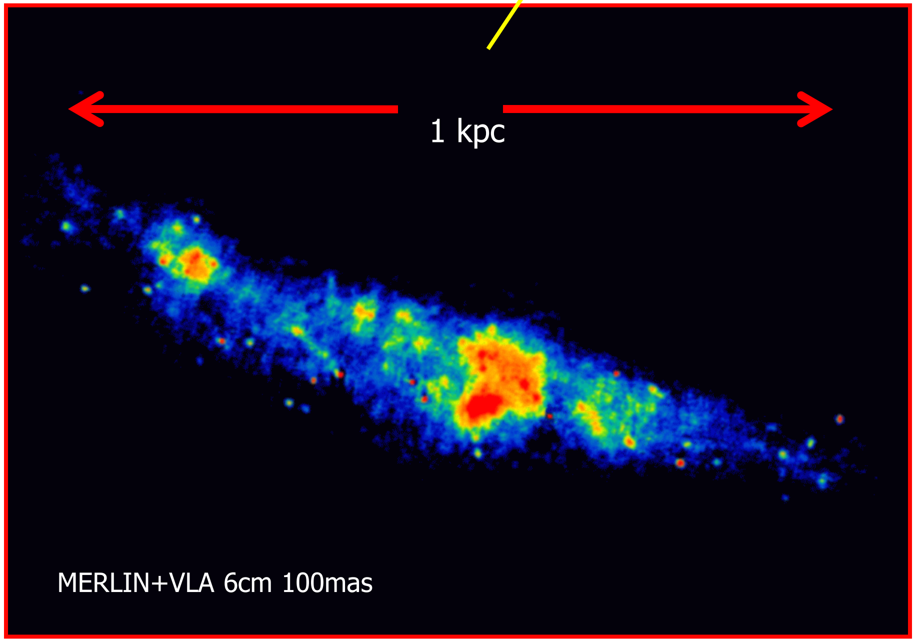
Radio Observations and monitoring of the Starburst in M82





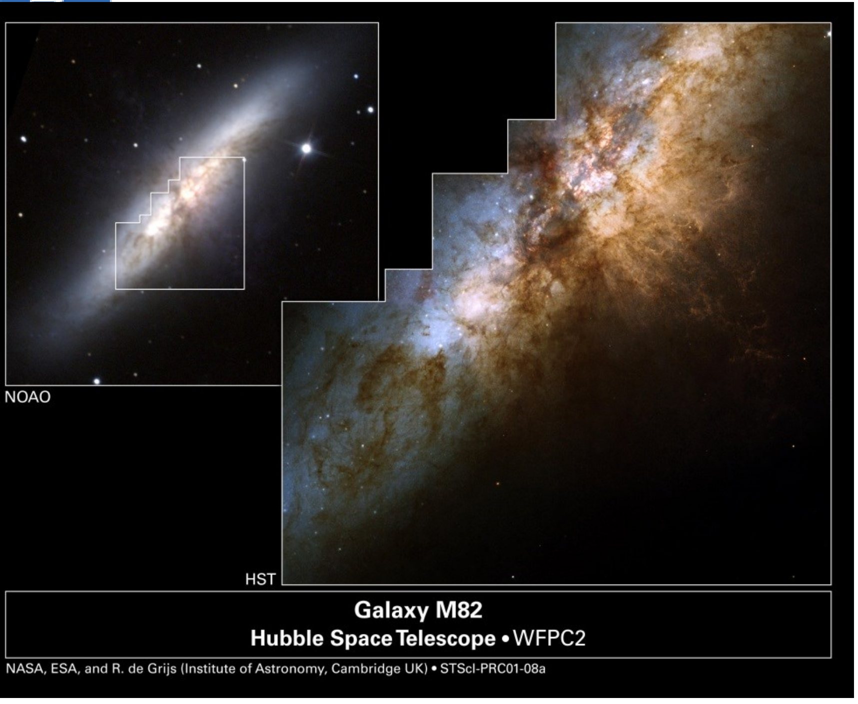
Starburst activity in external galaxies is often associated with merging or interacting systems

In the M81 / M82 system (d=3.6Mpc) M82 is interacting with neutral gas surrounding M81
– triggering a massive burst of nuclear star-formation

Radio emission from the last few million years of SNe – lies within the central 1 kpc of M82

Current starburst:

- has existed for at least 50 x 10^6 years
- heavily obscured optically ~ 20-30 M_v



Tidal interaction has channelled large amounts of gas into the central region of M82 inducing a burst of star-formation

Current supernova rate ~ 0.1-0.05 yr^{-1}
Considered archetypal local starburst galaxy

- High SFR – SNe every ~10 - 30 years
- Large number of by-products
- (Type II SNe/SNR, HII regions)

Current star-formation rate

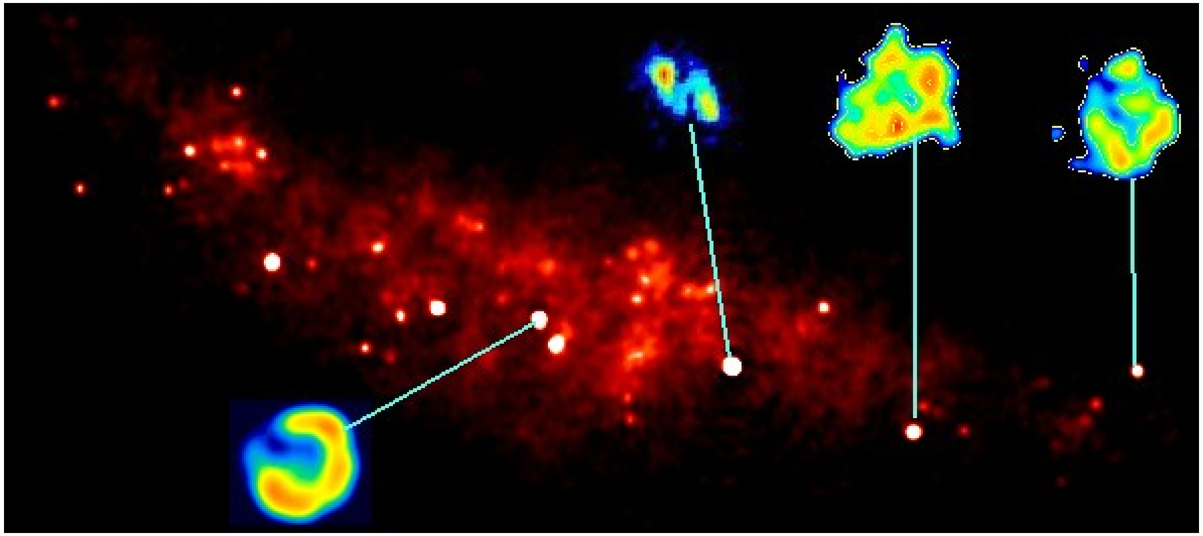
(for M > 5 $M_\odot$) ~ 2 $M_\odot yr^{-1}$

Ideal for detailed studies of the SF products

- All at ~the same distance → direct comparison
- But nucleus is heavily obscured optically… radio is a unique probe

Compact radio sources

- O & B stars are tracers recent star-formation
  - Typically these become supernovae after ~ 10^7 years
  - →SNR trace out star-formation sites ~10^7 years old
- 50-100 (deeper observations continue to reveal more) compact sources discovered in M82
  - All resolved with MERLIN+VLBI
  - Most are SNR
  - Plus number of compact HII regions



Compact radio sources

Highlight a few most compact (youngest) SNR

Radio study – no extinction + high resolution

- EVN + VLBA (few mas scales)
- eMERLIN+EVN (10s mas scales) – increased spatial scale coverage
- E-MERLIN long term monitoring (200-30mas scales)

Multi-epoch observations

- High resolution began in 1980s with brightest source

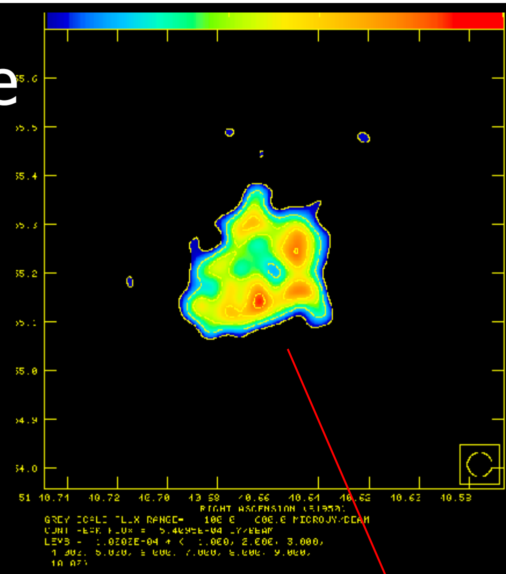
Bartel et al. 1987, Wilkinson & de Bruyn 1990, Pedlar et al 1999, McDonald et al 2001, Beswick et al. 2006, Fenech et al 2010

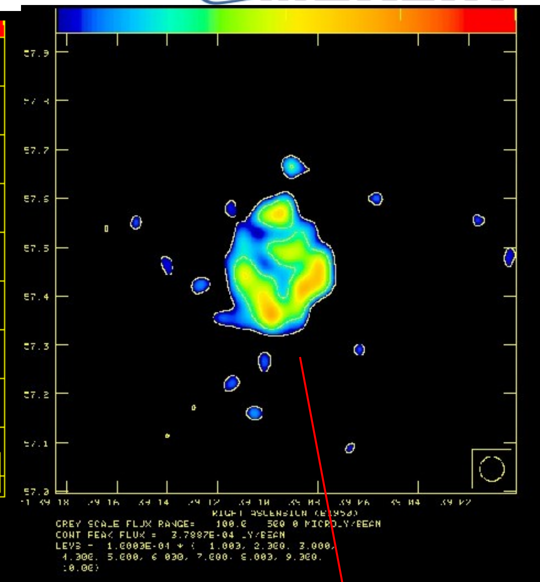
- Number of sources monitored is growing
- Better imaging / more telescopes / more sensitivity

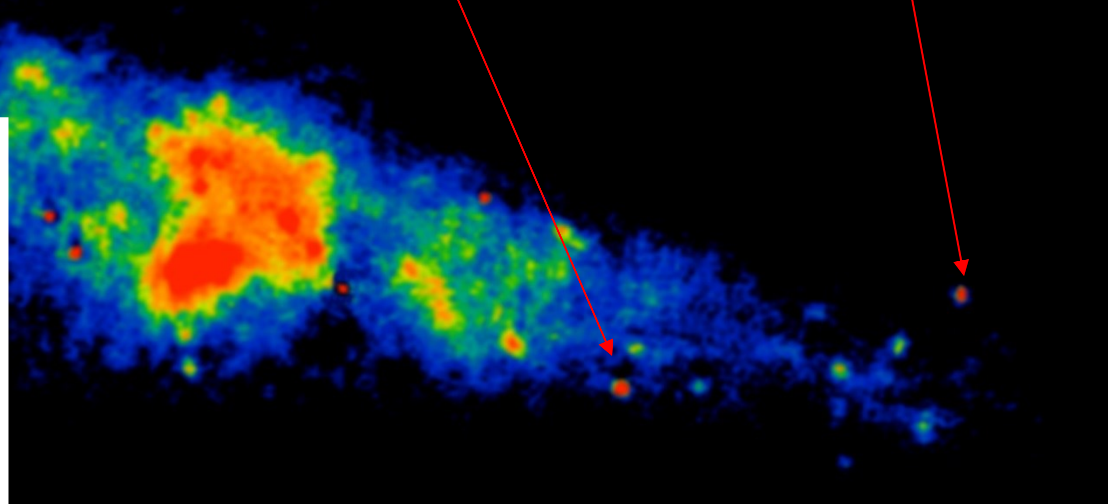
M82 SNR – How old are they?

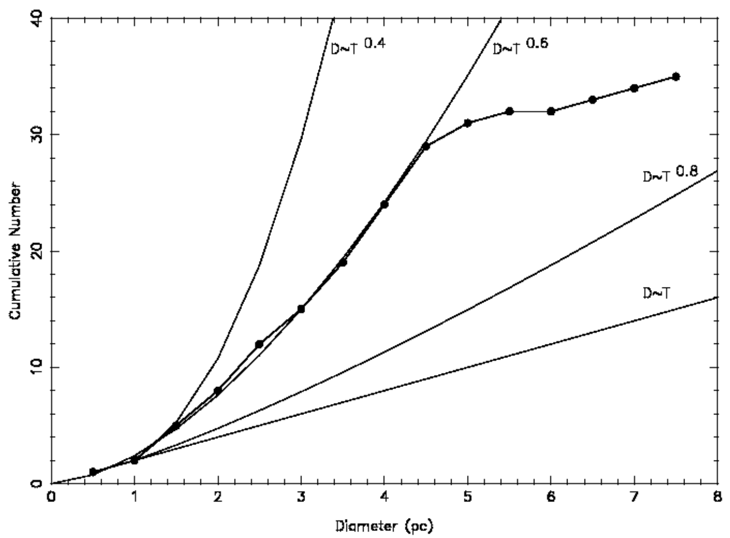
e-MERLIN/VLBI resolves all the SNR visible in M82 – derive size distribution

Assuming an initial expansion rate ~ 5000km/s → ages ~1000 yr with a SNR appearing every ~ 20-40 yr







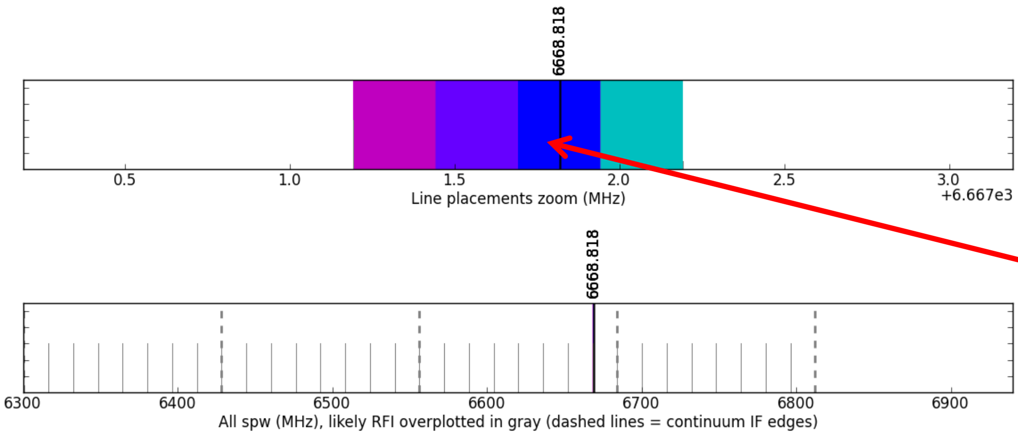


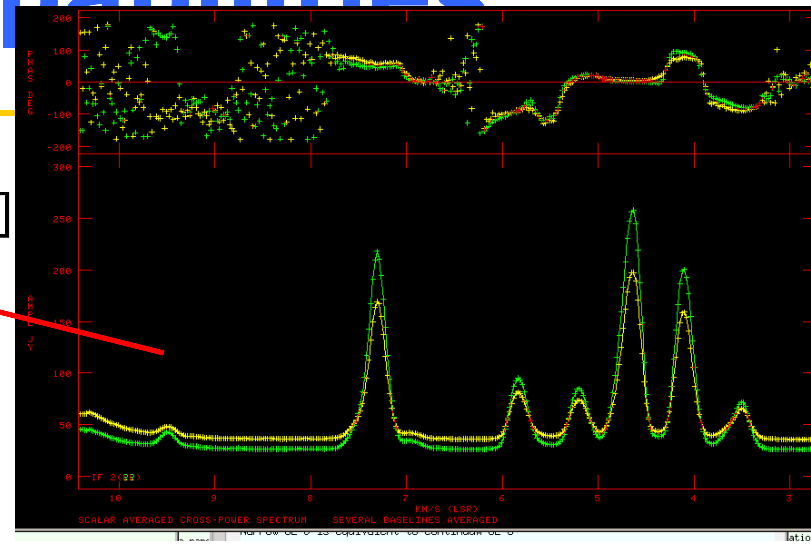
Typical expansion velocities of ~5-10,000km/s are detected by MERLIN and VLBI

e-MERLIN’s view of M82

The University of Manchester
Jodrell Bank Observatory

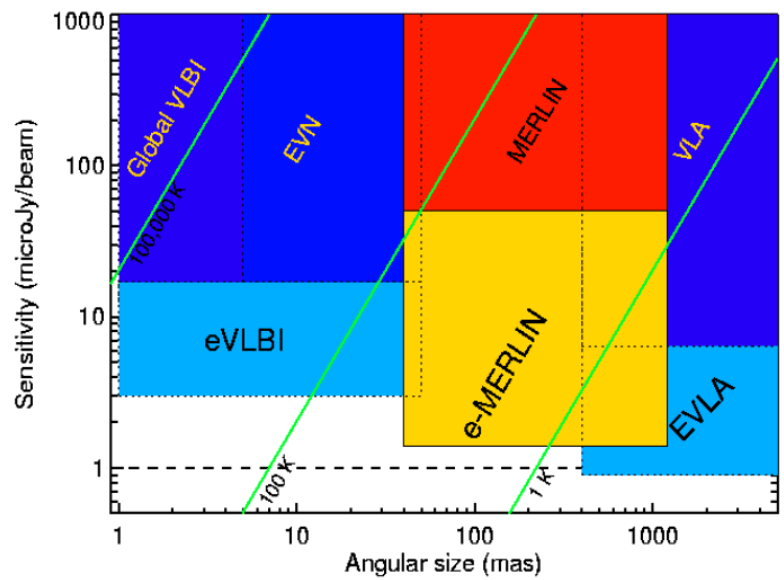
e-MERLIN Capabilities

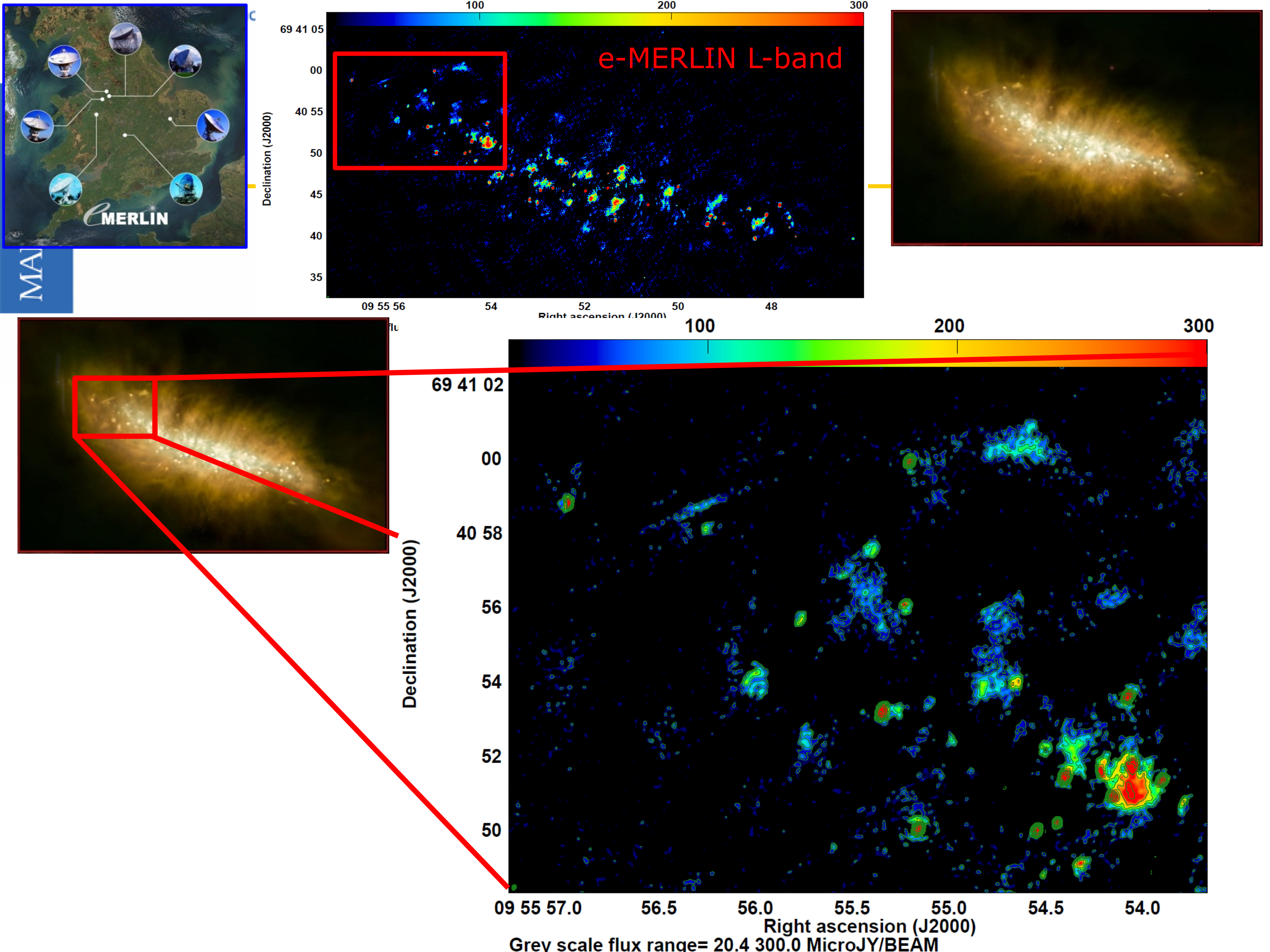




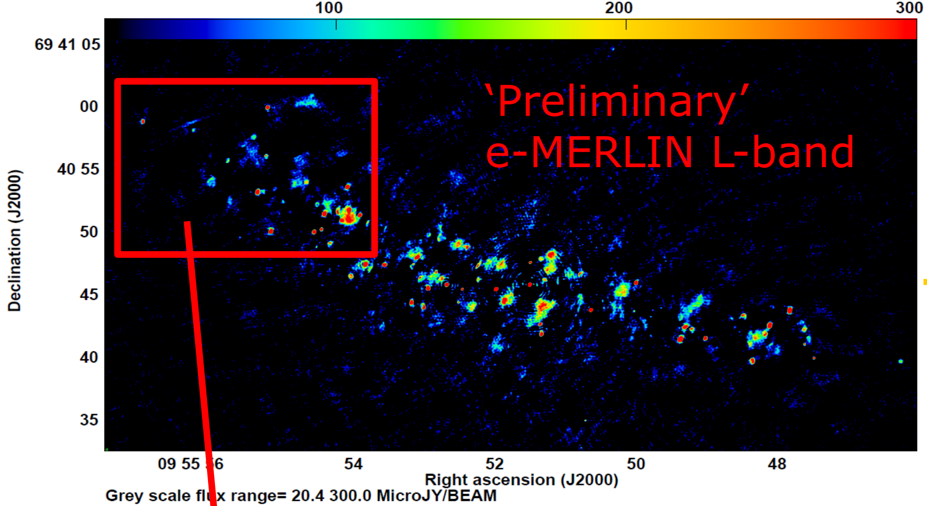
 – Out to HPBW of 25-m [7,27 arcmin]

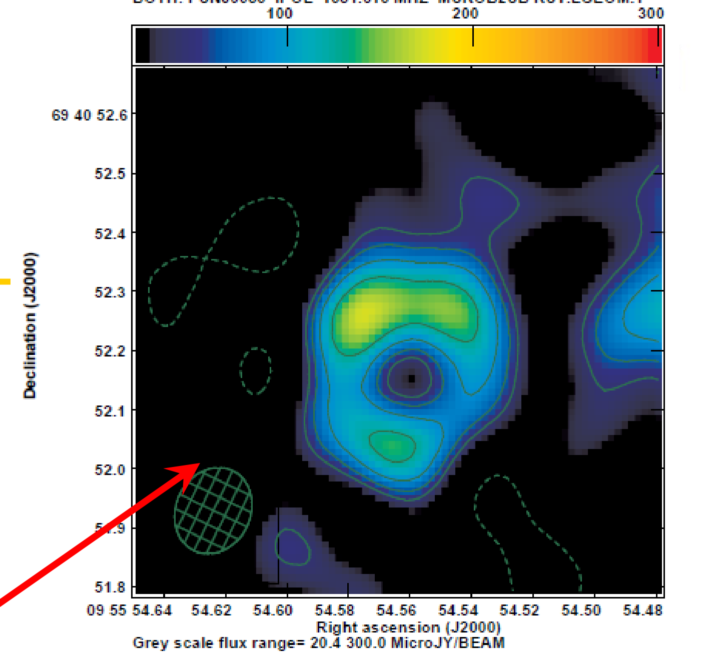
- Spectroscopy
  - Up to 16 placeable sub-bands;>512 channels/pol; recirculation
  - Can mix/trade bandwidths; no. of channels, polarisations
- Much improved aperture coverage
  - Via frequency coverage
  - May help snapshots too
- Spectral mapping
  - 1.3-1.7; 5-7/4-8 GHz
- Polarization (L,R → IQUV)
- Astrometry
  - Goal is < 1 mas wrt ICRF:
    using GPS measurements of
    troposphere delay
    (5cm error -> 5mm); closer calibrators



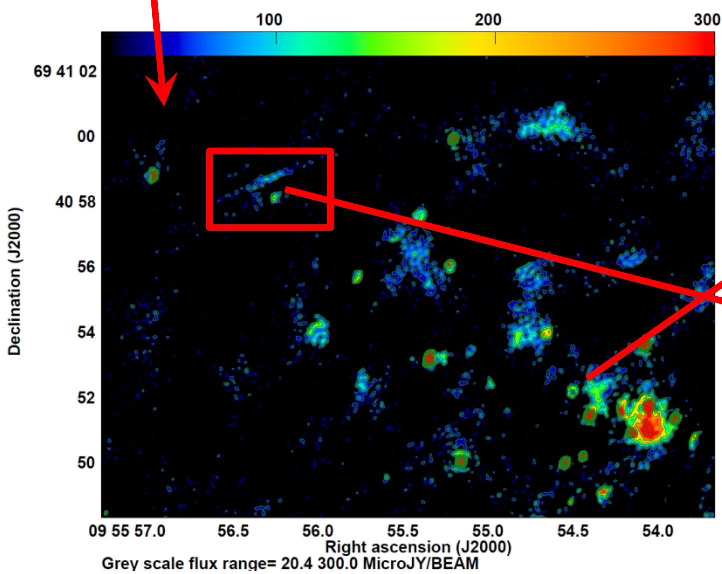


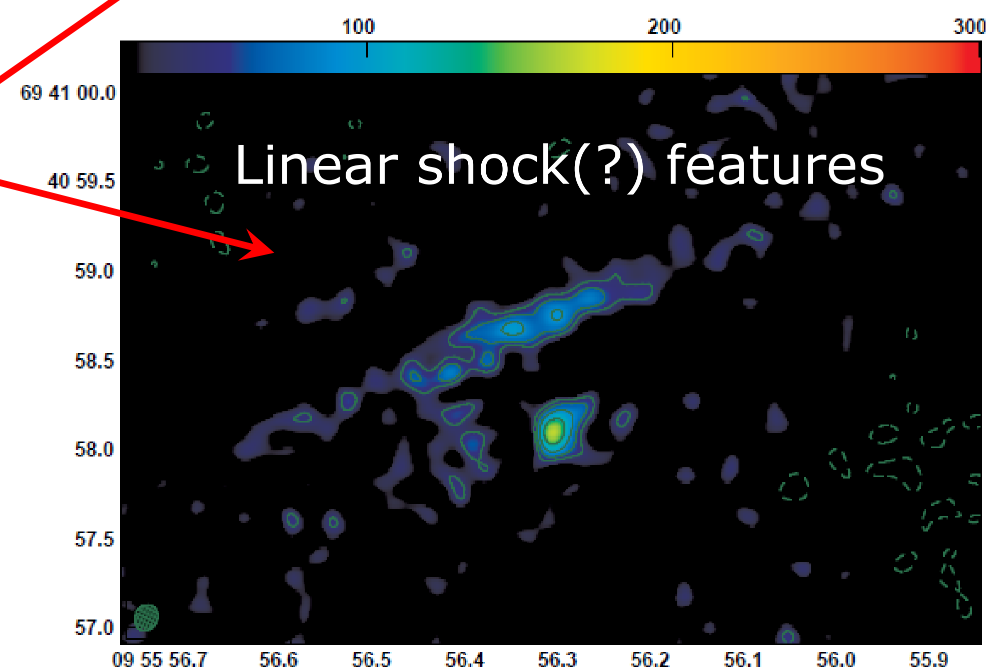
eMERLIN
e-MERLIN L-band
100
200
300
69 41 05
00
40 55
50
45
40
35
Declination (J2000)
09 55 56
54
52
50
48
100
200
300
69 41 02
00
40 58
56
54
52
50
Declination (J2000)
09 55 57.0
56.5
56.0
55.5
55.0
54.5
54.0
Right ascension (J2000)
Grey scale flux range= 20.4 300.0 MicroJY/BEAM



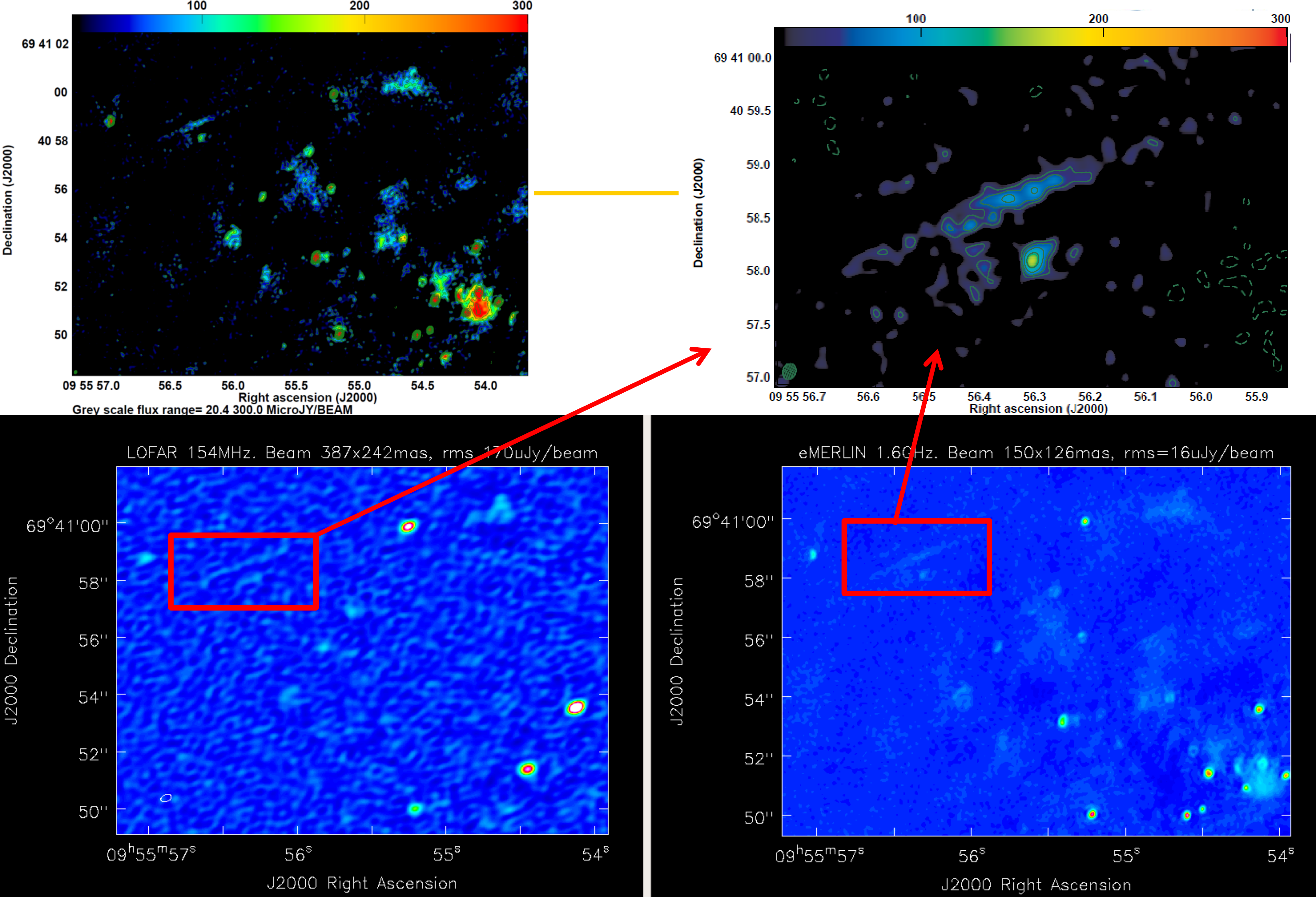


Multiple New faint 'old' RSNe



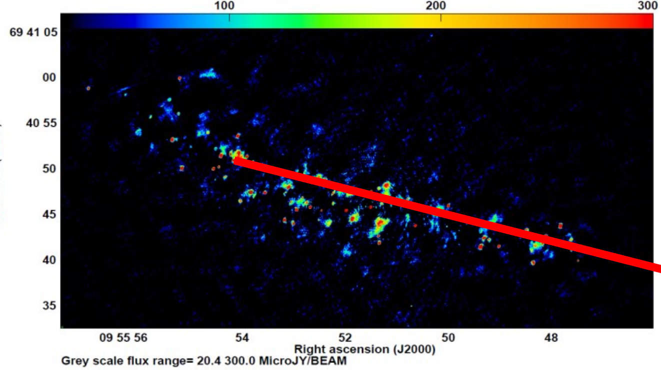


1.25-1.7GHz
rms ~ 16μJy/bm (imaging limited by ill-constrained extended flux)
150mas resolution

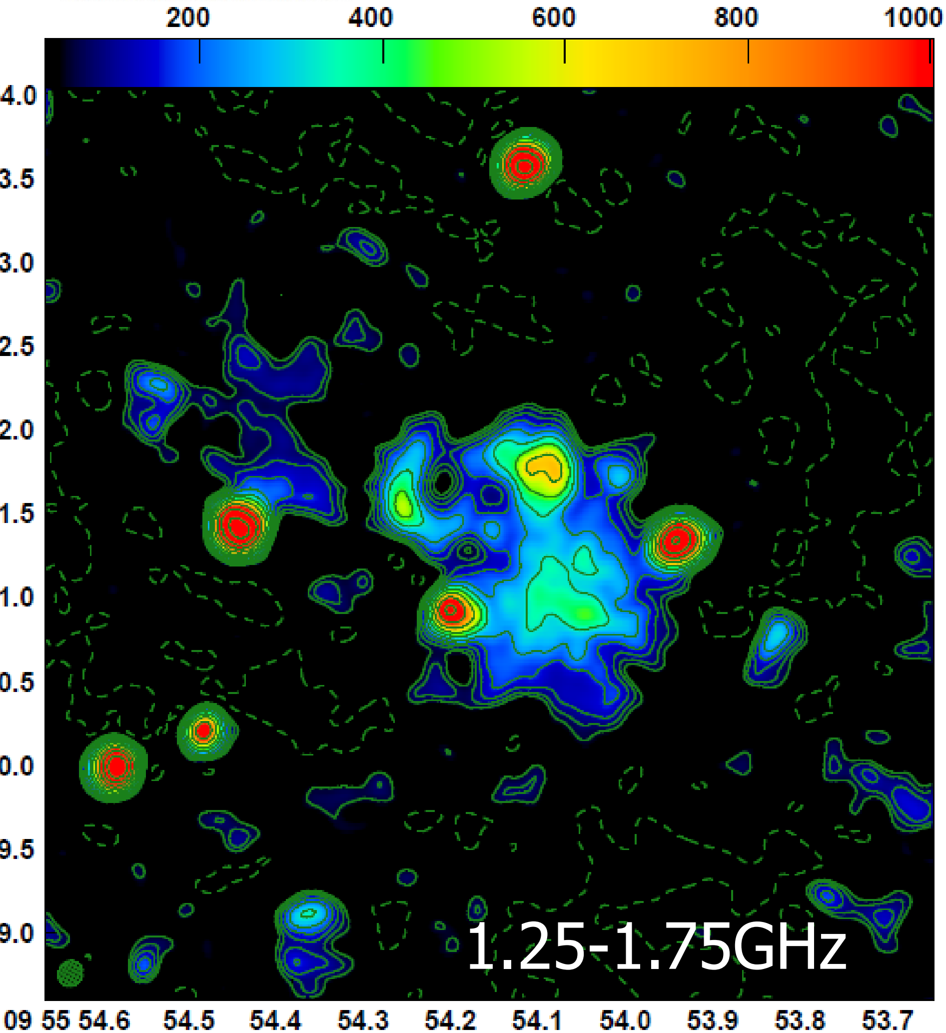


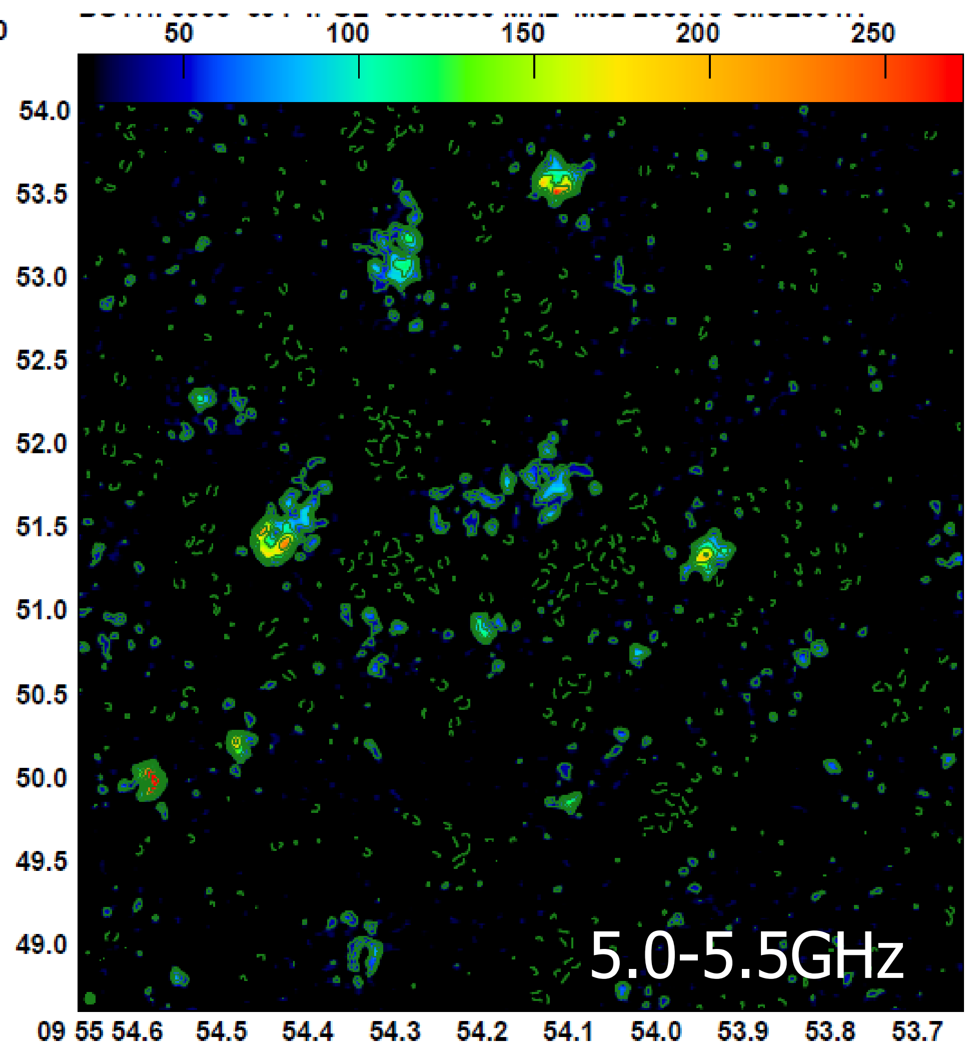
European LOFAR @ 151MHz
Varenus et al 2014

e-MERLIN @ 1.6GHz
Perez-Torres et al 2014,Beswick et al. in prep



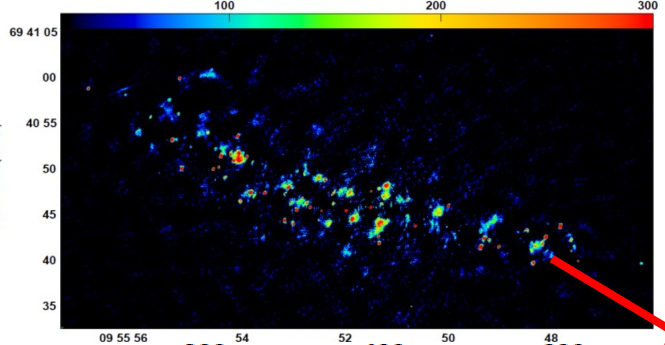
New SNR + Higher fraction of HII regions
- Multiple SNR break-outs

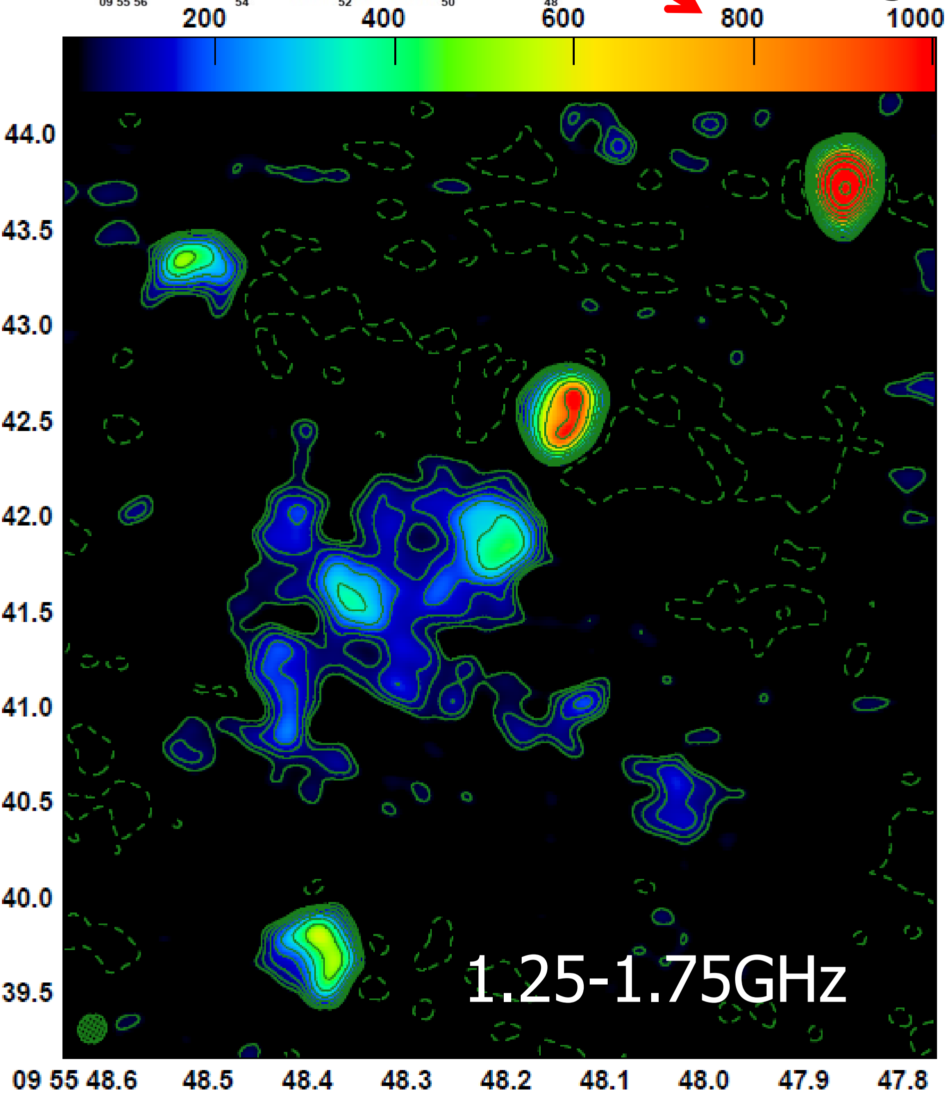


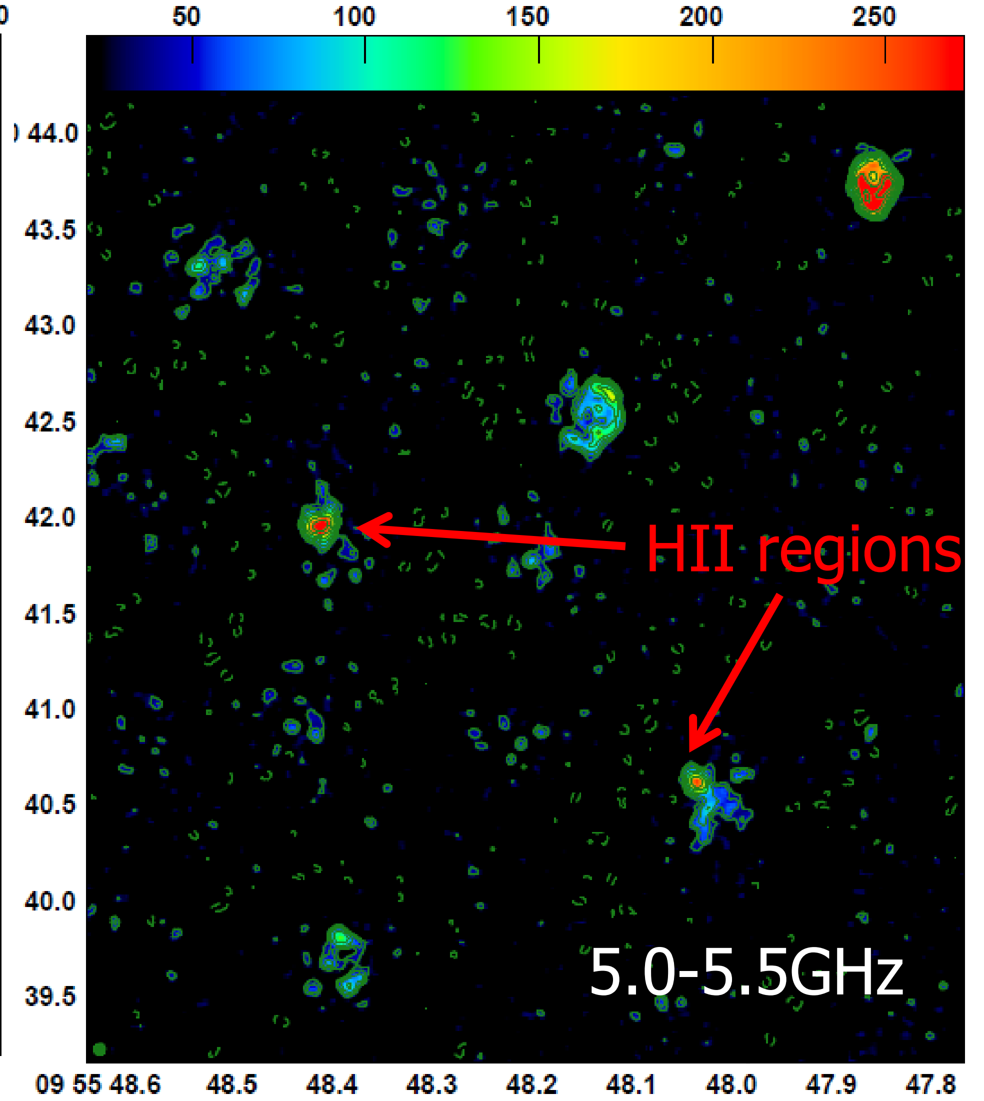


New SNR + Higher fraction of compact HII regions

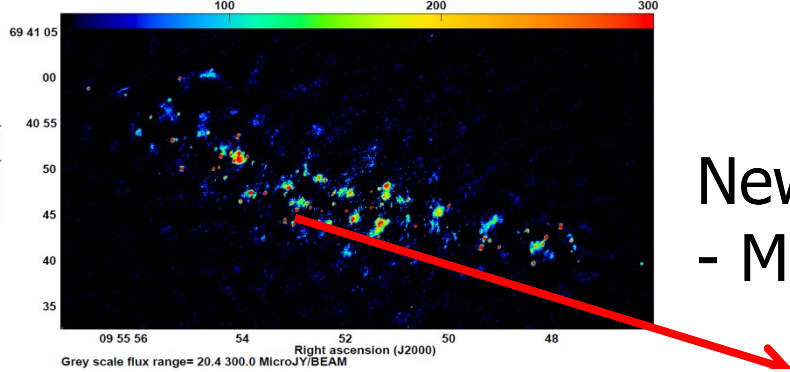
- Multiple SNR break-outs – expansion into highly inhomogeneous ISM

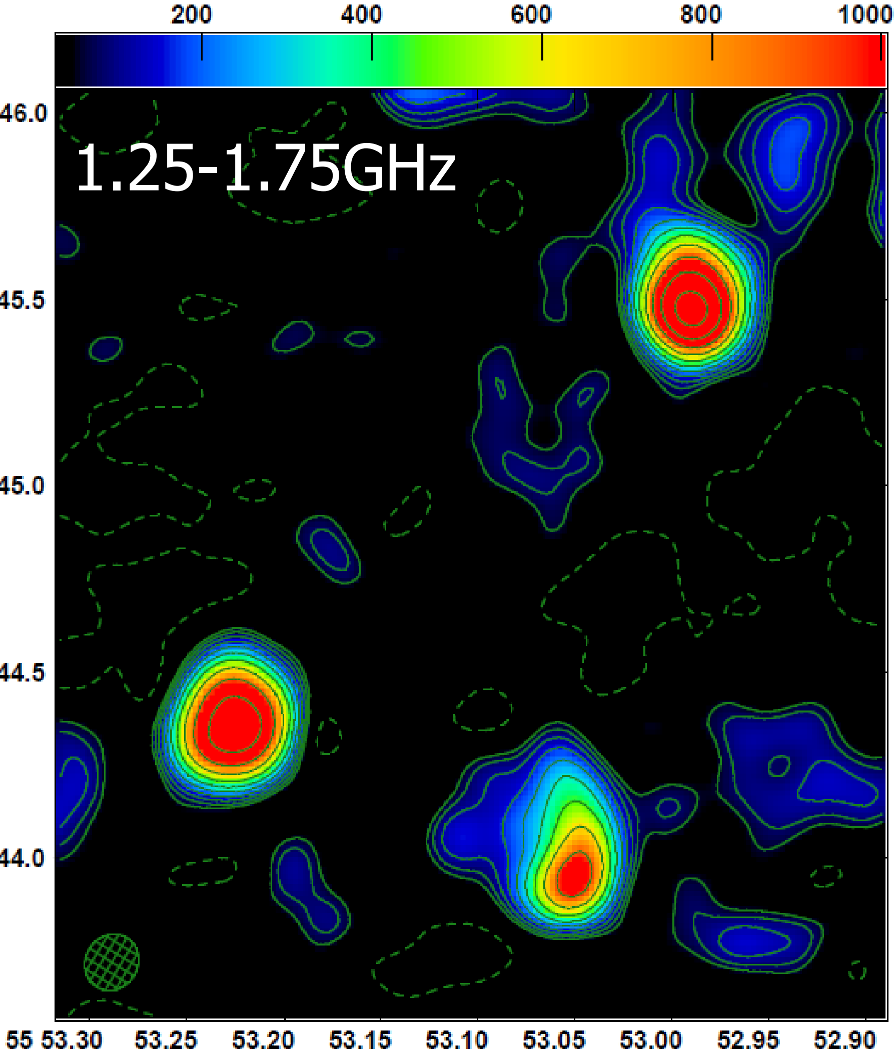


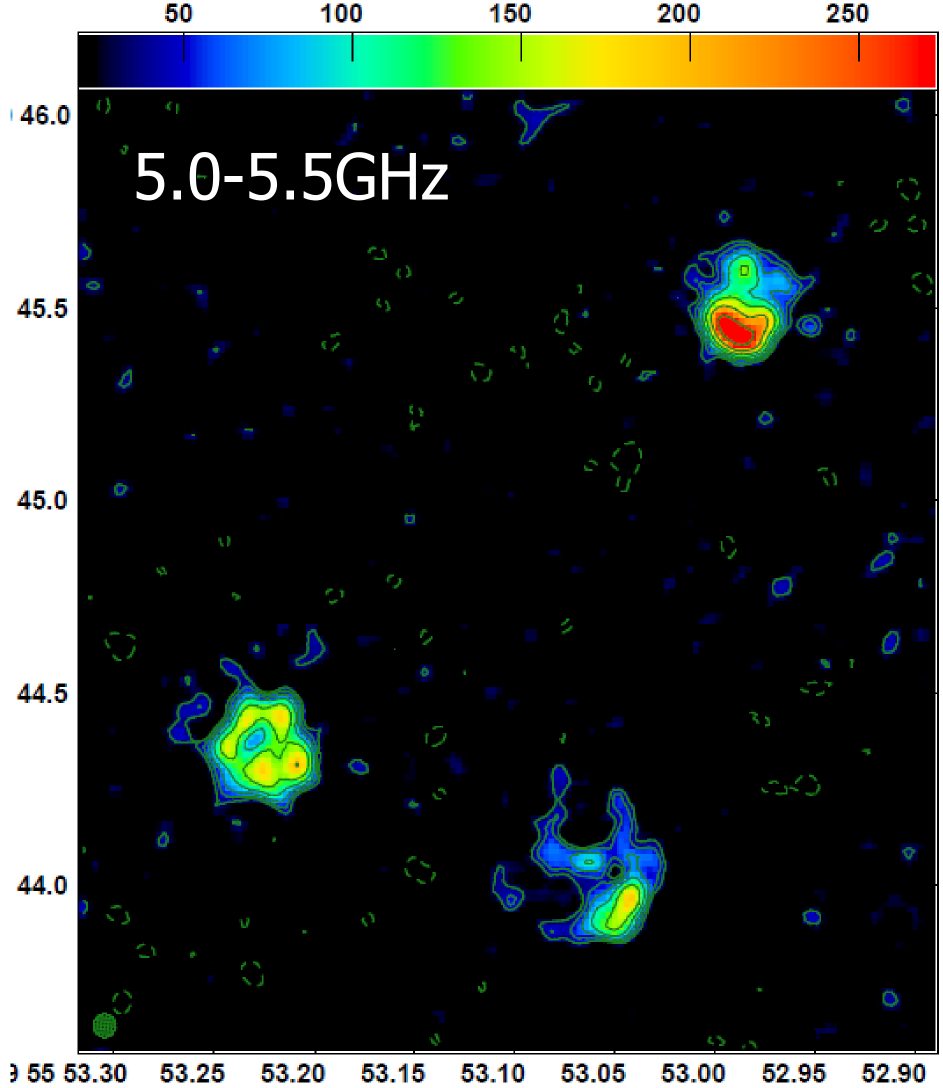




New SNR + Higher fraction of HII regions
- Multiple SNR break-outs

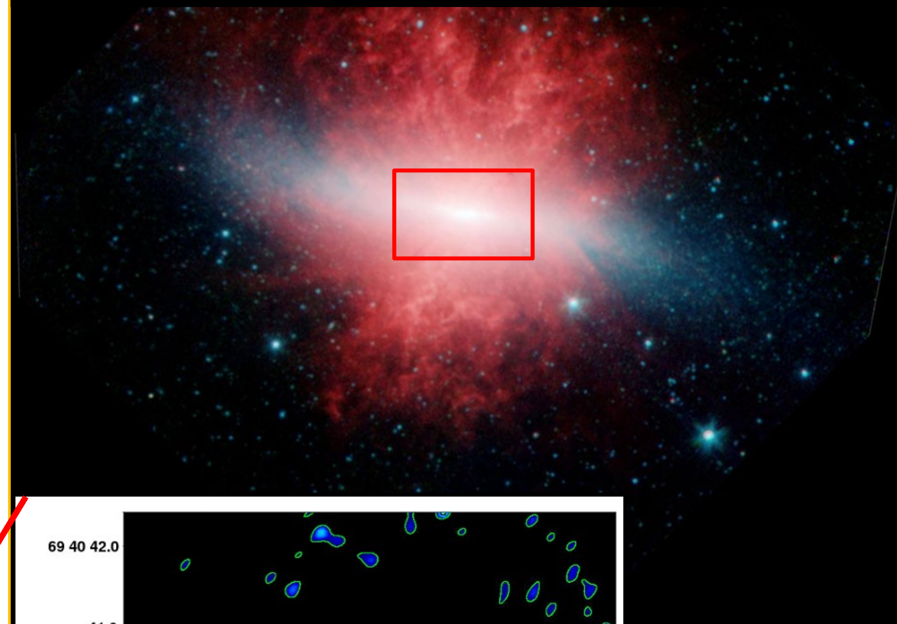


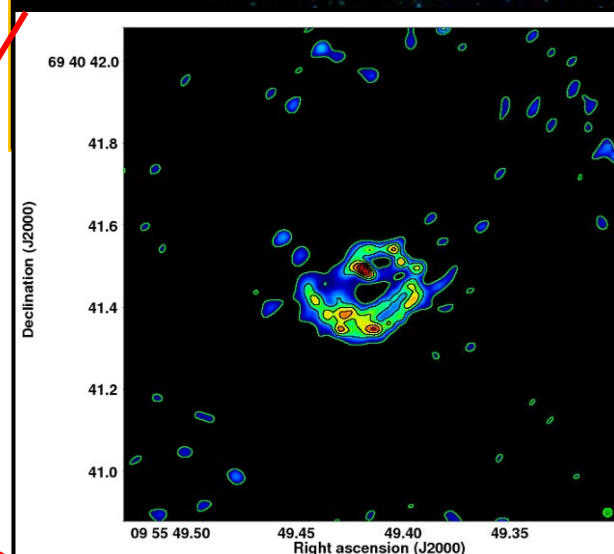




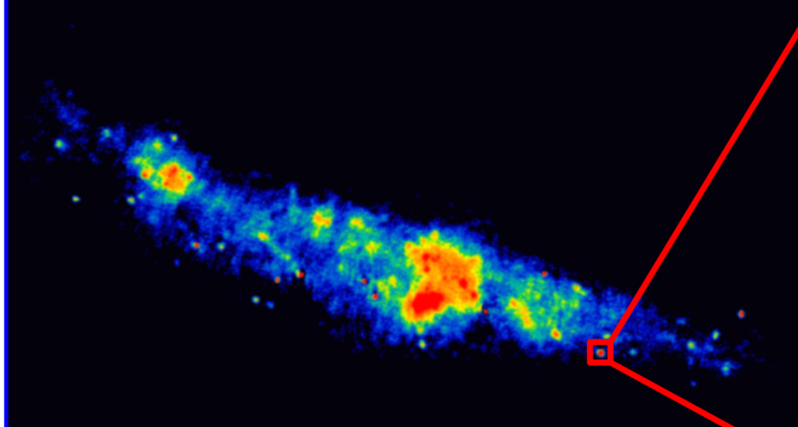
e-MERLIN radio telescope - size 220 kms

e-MERLIN monitoring of individual expanding Supernova remnants.
Expansion speeds ~10,000 km/sec
SNR 40.67+55.1
– size~10ly
– age~150 years





Ultra-high resolution imaging *e*-MERLIN



– Measure expansion and deceleration

C-band, 13 μJy/bm rms, 20mas res.

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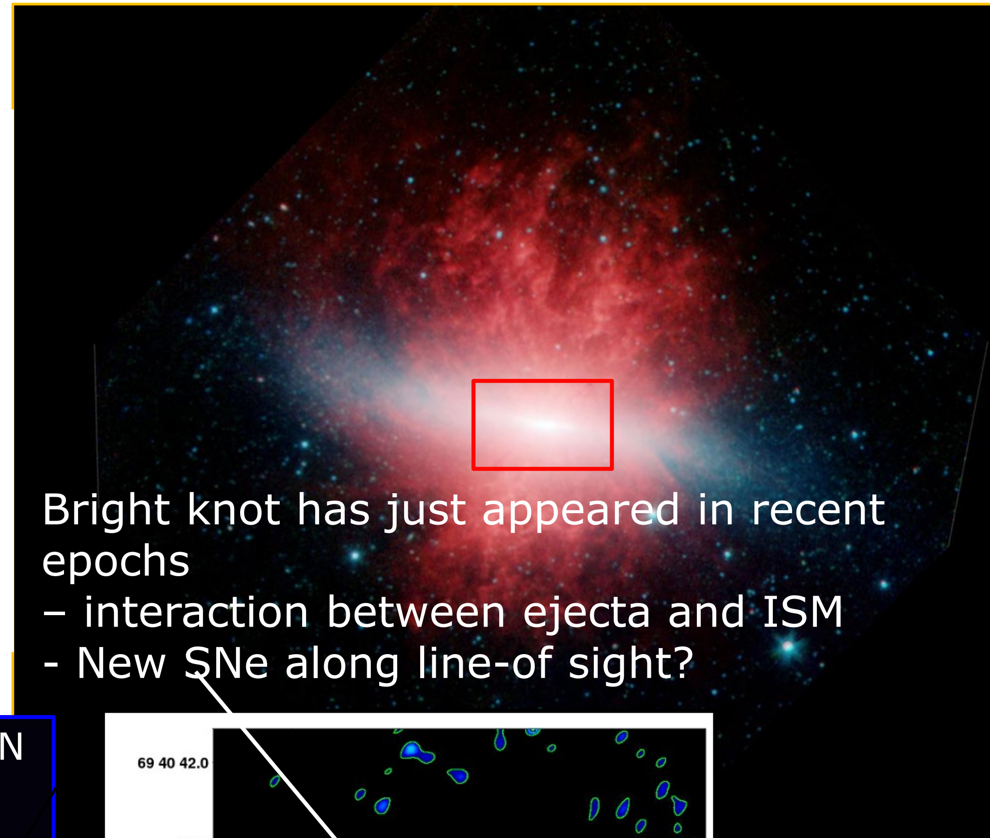
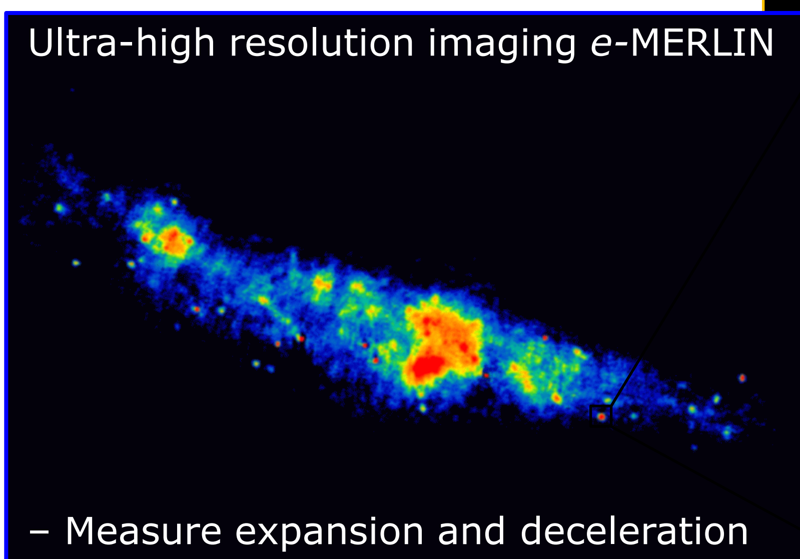
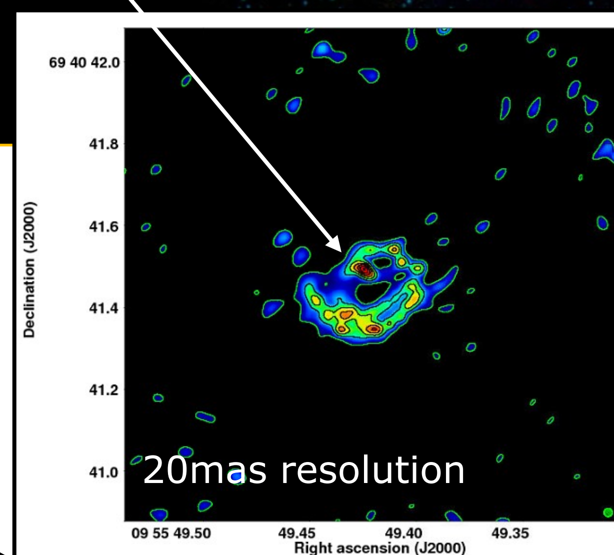
e-MERLIN ultra-high resolution imaging used to calibrate models of star-formation in nearby starburst galaxies like M82

→Directly measure SN (0.05/yr) & star-formation rate



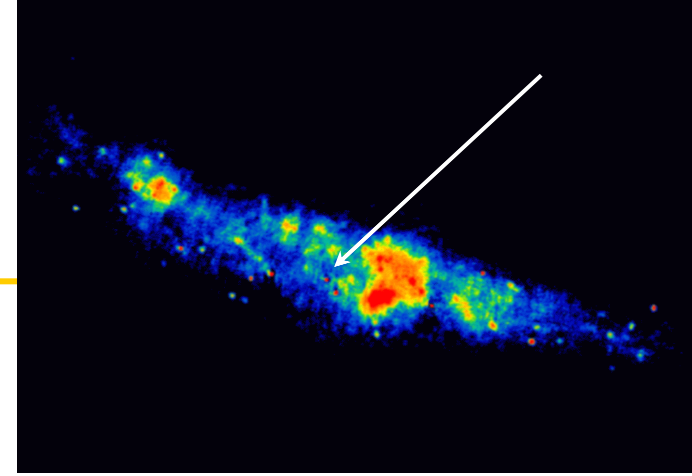
Bright knot has just appeared in recent epochs
– interaction between ejecta and ISM
- New SNe along line-of sight?





Most compact sources at the highest resolutions

43.31+5

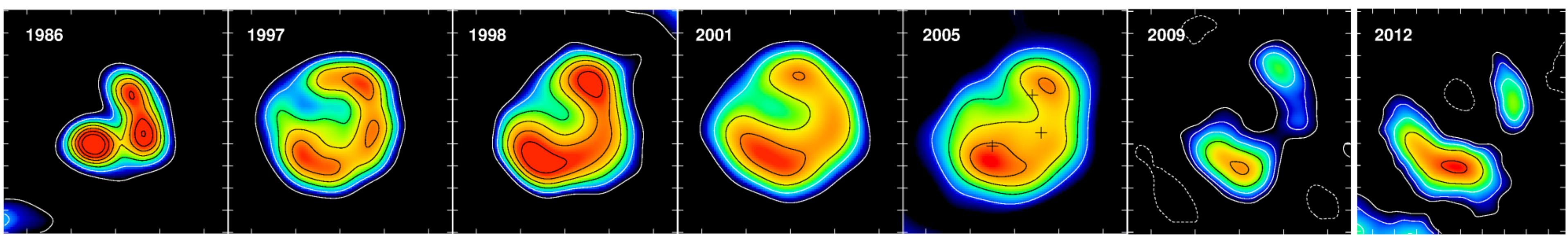


'Typical' shell-like SNR

First detected in 1972 (earlier imaging at low angular resolution)

Expansion monitored over last 30 years

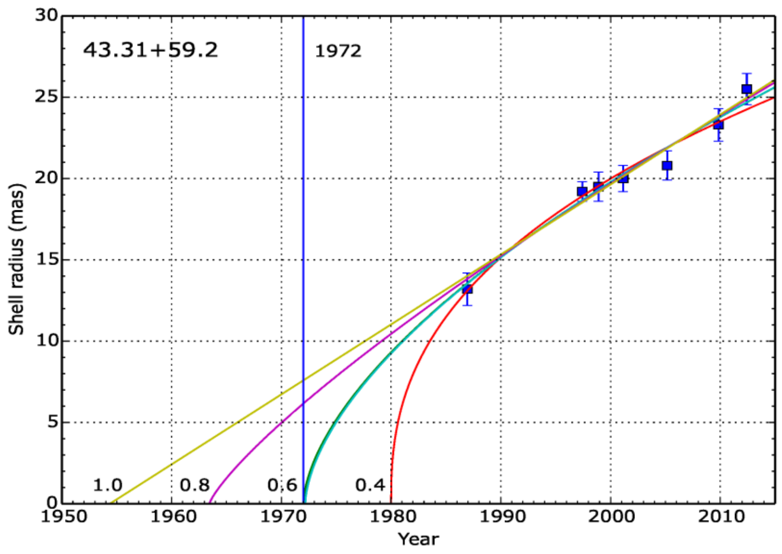
15 mas resolution imaging (EVN/ global VLBI)



- Expansion velocity ~ 7500-9000 kms^{-1}

43.31+59.2

Monitor expansion



Expansion of SNR: $D = kt^m$

m = deceleration parameter

- Lower-limit 0.60±0.06

ISM properties?

Not yet entered Sedov phase of evolution (m=0.45)

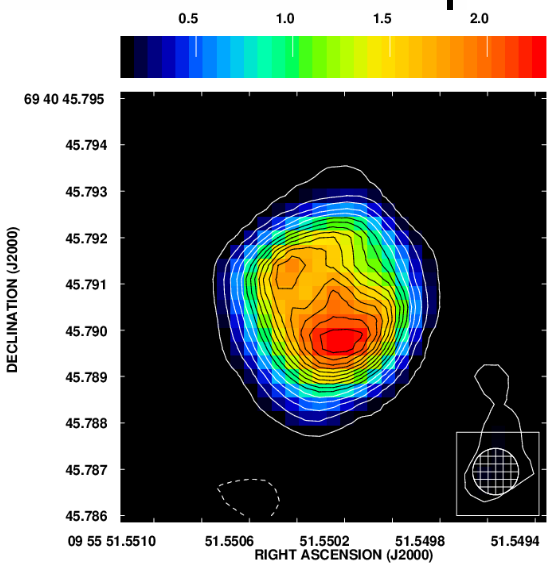
- Can use to constrain surrounding density
  - $r_s \cong 4.1(M_{ej}/n_0)^{1/3}$
  - For $M_{ej} = 0.5\ (10M_\odot)$ → $n_0 \leq 250\ cm^{-3}$ .....Low for M82 !!

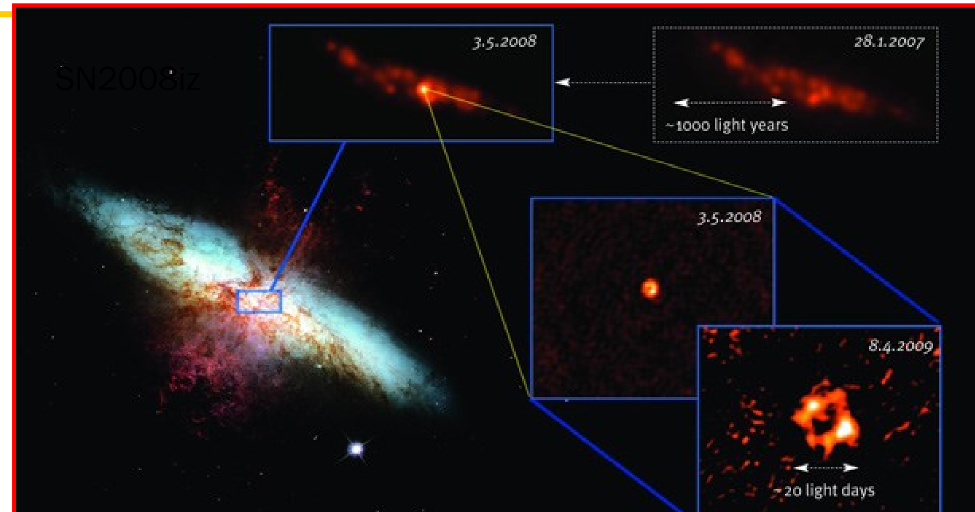
Ionised gas? Molecular clouds? Wind-blown bubble?

SN2008iz

New radio supernova

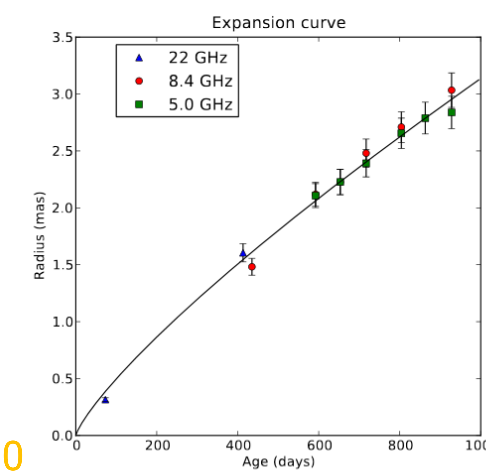
Not visible in optical bands





Bruntheler et al. 2009

5GHz global VLBI observations 2009



Shell-like SN expansion velocity ~21000km/s
Evidence for deceleration in 100 days (m=0.89)

→ Short free-expansion phase in high-pressure environment typical of M82

Brunthaler et al. 2010

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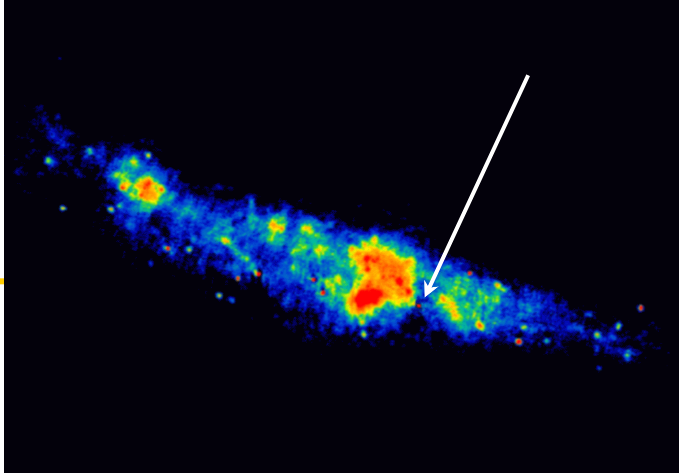
41.95+57.5



A brief history:

- Discovered in radio observations of M82 in 1965 (Bash 1968)
- Was most compact supernova-type object in M82 (SN2008iz now takes the title but is still expanding)
- Not typical behaviour of Type II SNR
- Monitored with global VLBI 1986 → (Bartel et al. 1987)

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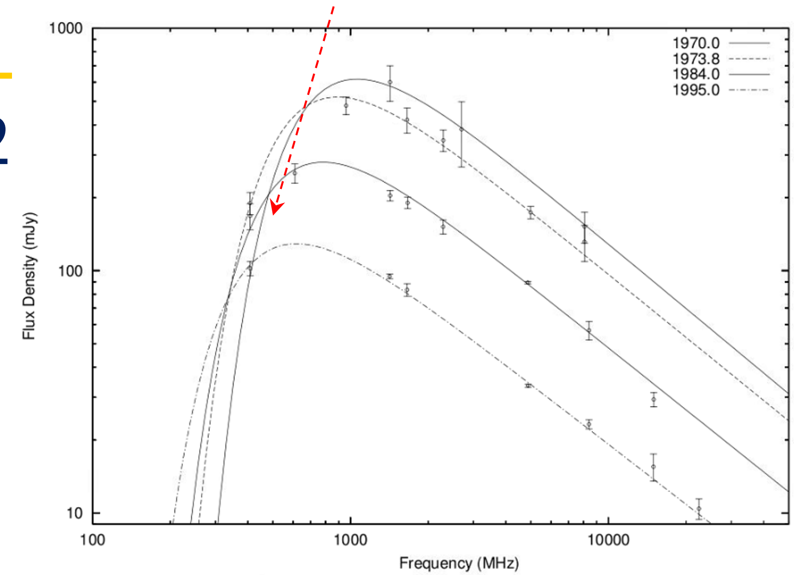
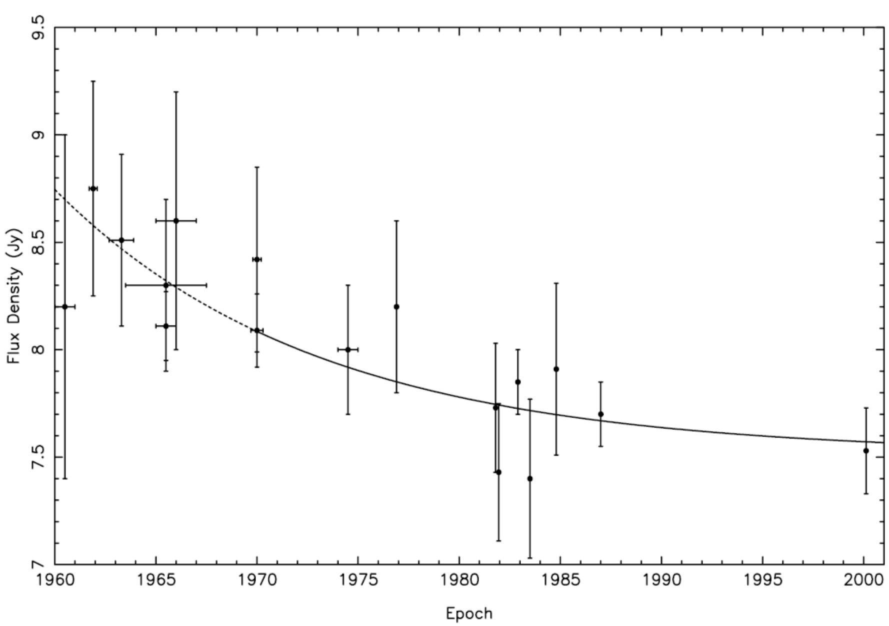
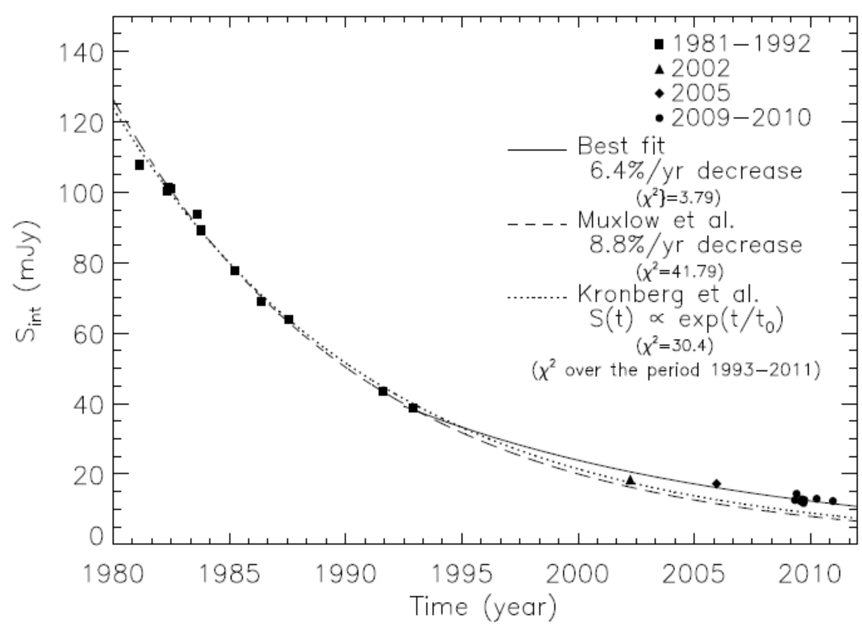
Flux density evolution



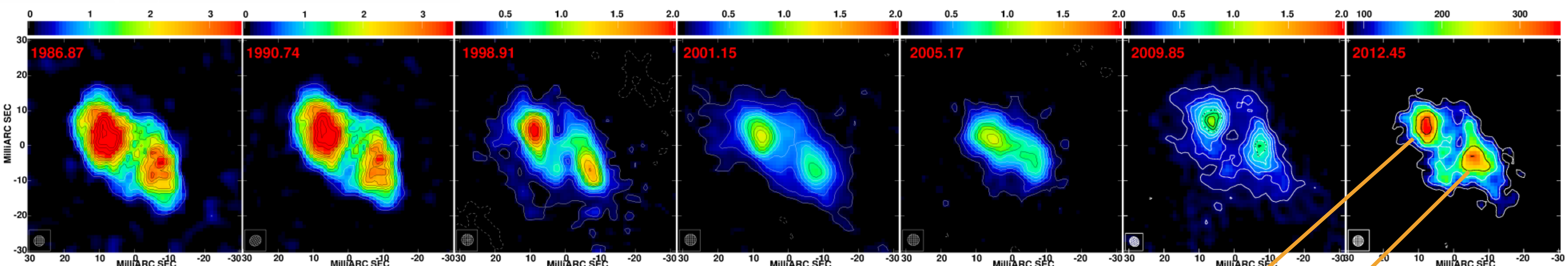
- Dominated total flux density of M82 through early radio observations
- Decaying by ~8.5%/yr from discovery
  - Now appears to be ~ 6.4%/yr



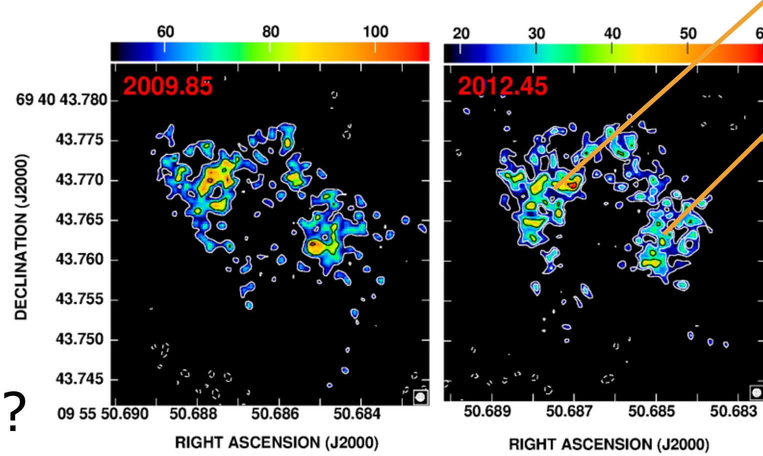


Structural Evolution

Bipolar expanding and evolving plasmons, moving apart at speeds of 1500 – 2000 km/s – but recent epochs show outer structure fading rapidly → velocity estimates problematical



Appears to have internal shell-like structure on smaller scale than bipolar emission
– change in external medium?
– emerging thermal nebula?



5 GHz 1 mas resolution

41.95+57.5 – a possible GRB

Expansion velocity measured between peaks of emission at 1.4 GHz ~ 1500-2000 kms^{-1} (Epochs 1980 - 2005)

Assuming free expansion - age ~ 100 yrs

- At least 60-65 yrs old from M82 flux measurements

Extrapolate decay rate back implies at birth 5 GHz flux ~30 Jy

Implies 5 GHz peak luminosity ~ $2x10^{30}$ ergs s^{-1} Hz^{-1}

Much brighter than brightest known Type II SN
e.g. SN1986J, SN1988Z, SN2000ft

Approaching long-duration gamma-ray burst luminosities
e.g. GRB 990506

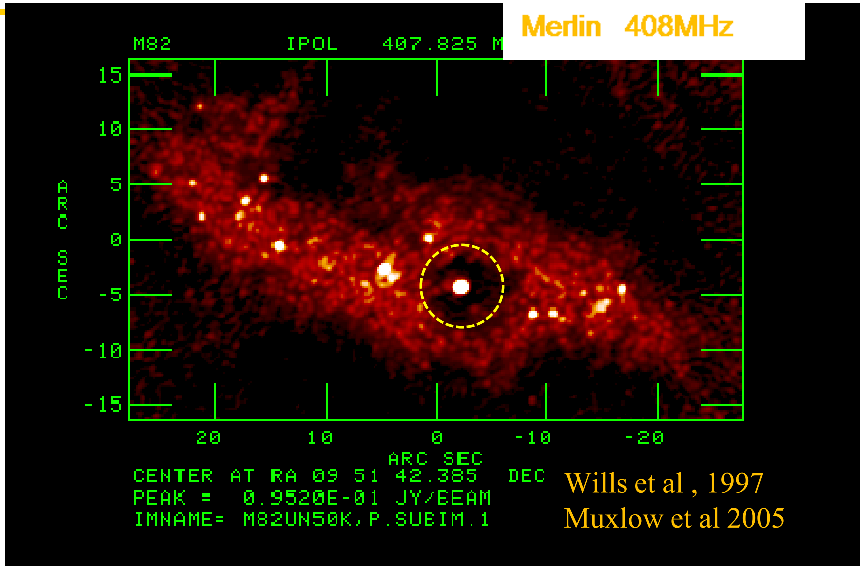
41.95+57.5 – a possible GRB

At centre of ~100pc diameter HII region

Free-free absorption seen at 408MHz

→ Emission measure ~8x10^5 pc cm^{-6}

GRB/CCSNe associated with high mass member of central star cluster?



Current GRB observations suggest ejecta in form of oppositely directed jets

Could explain morphology and evolution of 41.95+57.5

Open question - what does a 60 -100 yr old GRB look-like? 41.95+57.5?

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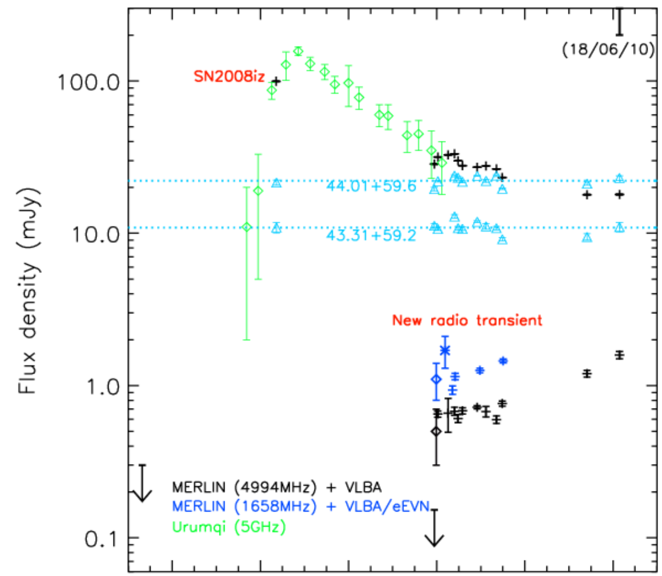
eMERLIN

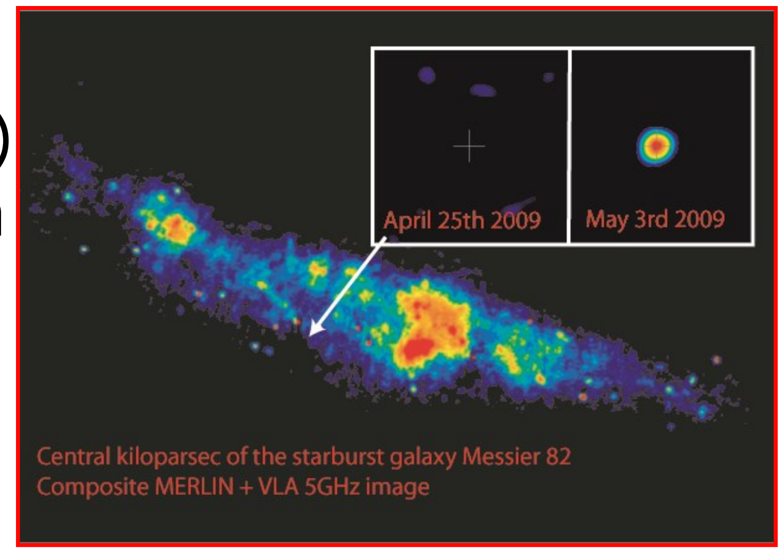
Another unusual Source

- Appeared in early 2009
  - Non-detection 1 week earlier
  - ➢ Flux density ~ 0.7 mJy
  - ➢ Increased by ~50%, now declining

- Properties include
  - ➢ Rapid turn-on
  - ➢ Steep spectral index (at turn-on)
  - ➢ Detection of superluminal motion during first 50days in MERLIN observations 10±5mas → 4.2c

→ Accretion onto a collapsed object

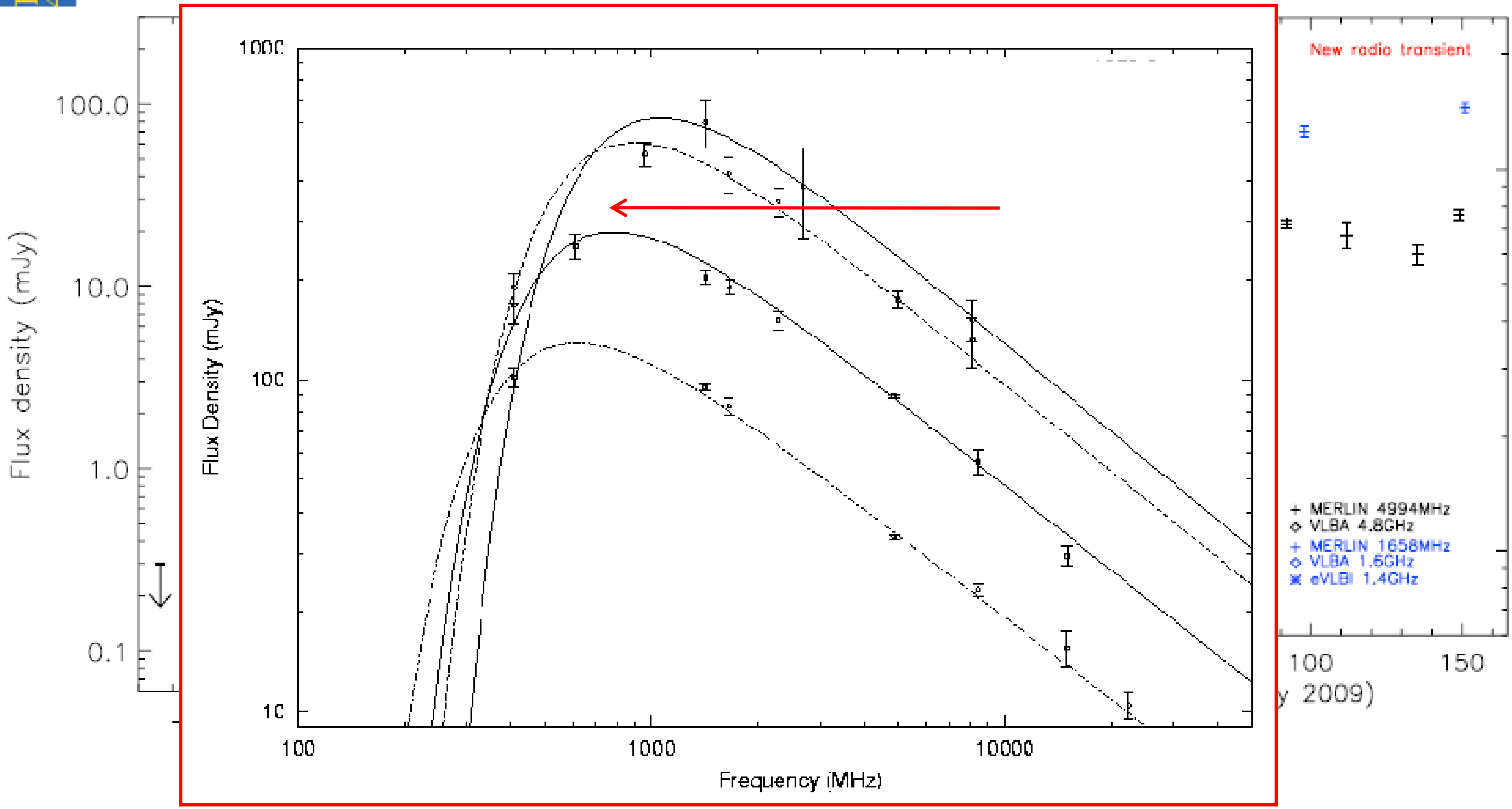




Central kiloparsec of the starburst galaxy Messier 82
Composite MERLIN + VLA 5GHz image

Muxlow et al 2010

Light curve



Source has steep spectral index α~0.7 ($S \propto \nu^{-\alpha}$) – even at turn-on!!
Very rapid turn on (within few days) - Long lived (still there now
No spectral evolution seen

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eMERLIN

New source

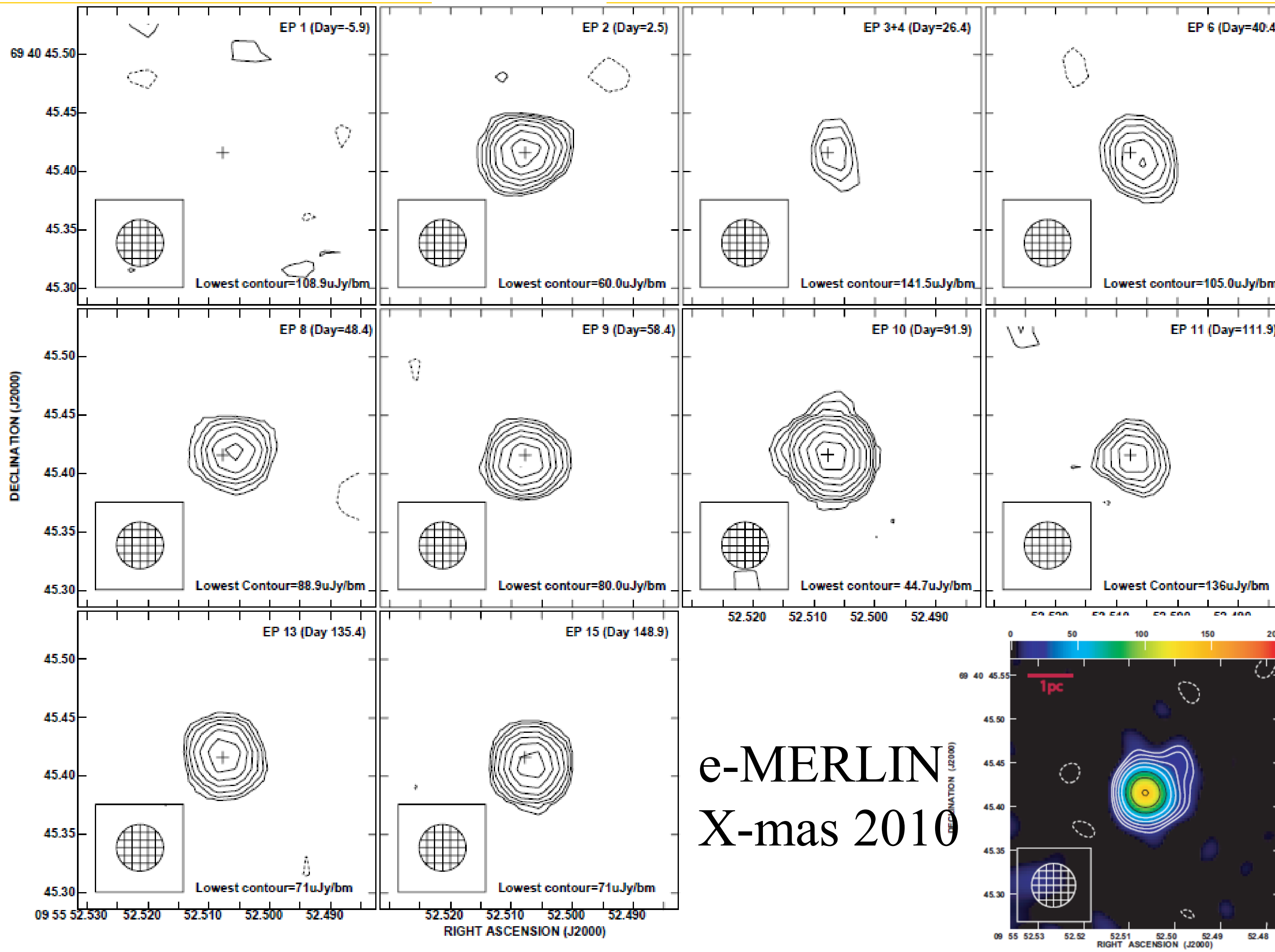
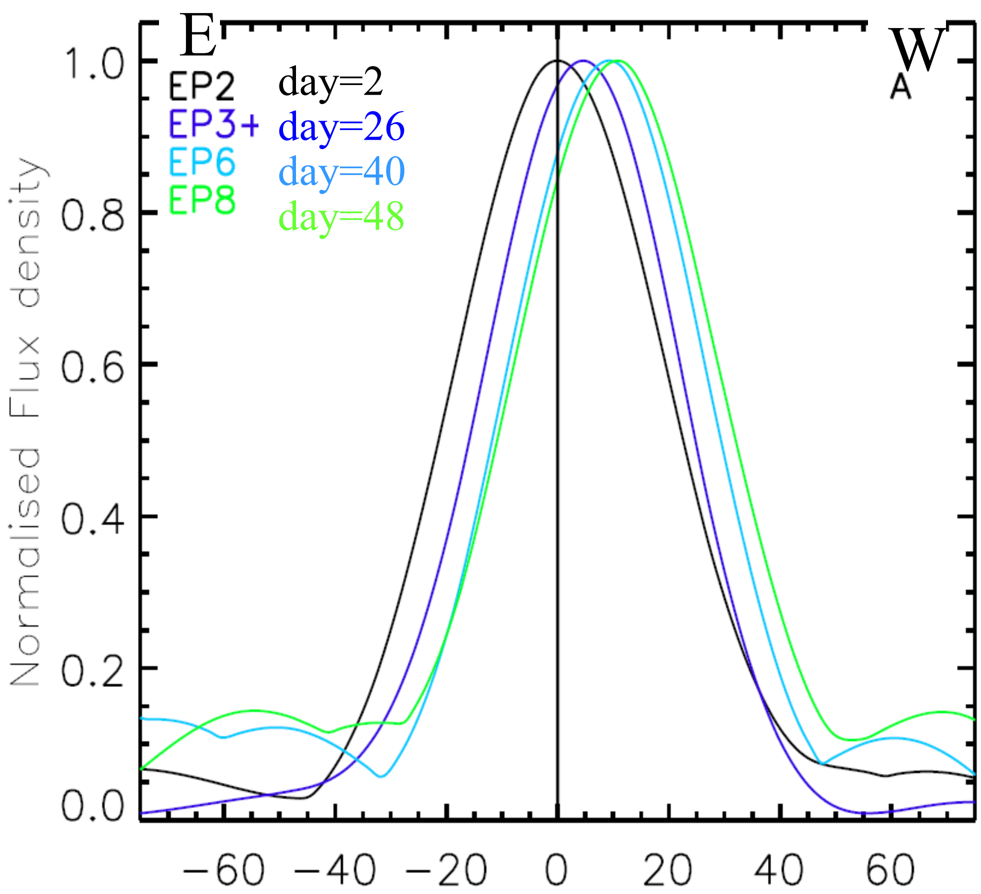


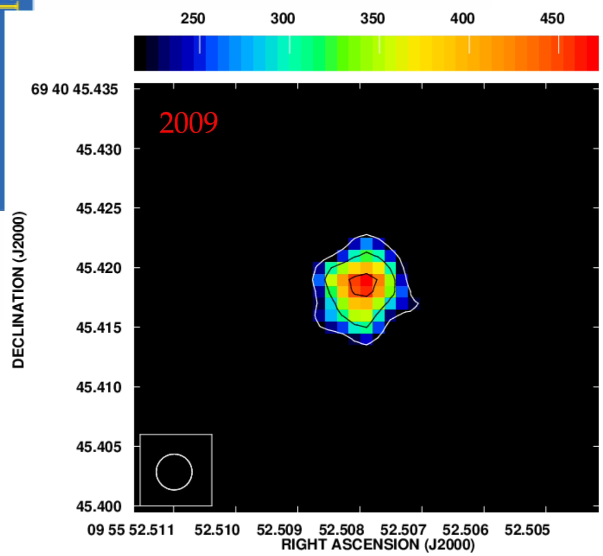
Image slices

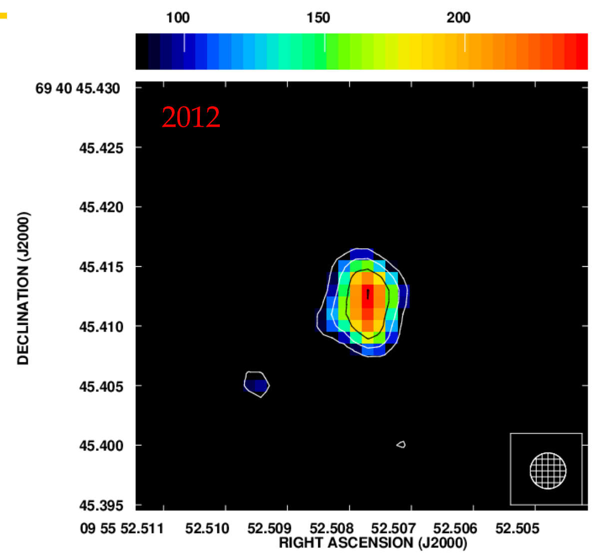


In first 50 days E→W proper motion detected relative to other sources in compact M82

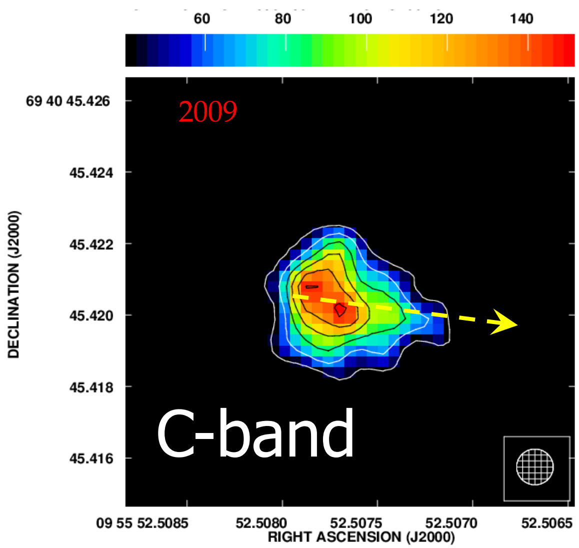
Tentative detection of apparent superluminal motion (10+/-5mas→~4c)[!!!]

Unusual Source





1.4 GHz global VLBI
~3 mas resolution



VLBI ~1 mas resolution

Extension matches p.a. of superluminal motion

SNR? ✗ (radio-spectrum & structure)

Micro-quasar? ✗ (radio-spectrum & variability τ)

AGN? ✗ (unlikely background)
(offset from dynamical centre)

IMBH accretion event ?

The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

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Summary

- M82 excellent study-ground for understanding SNR
- Size & structure evolution direct probe of ISM structure
- SNR (inc age)/SNe rate ➔ SF → calculate SFR
- Multiple 'Normal' SNR e.g. 43.31+59.2 with symmetric ring structure → homogenous ISM regions
- Many shells with ‘break-out’ regions
- Potential GRB remnant? 41.95+57.5
- \+ other interesting objects - transients….
- High resolution radio – vital tool.