Long term monitoring of the SNR in M82

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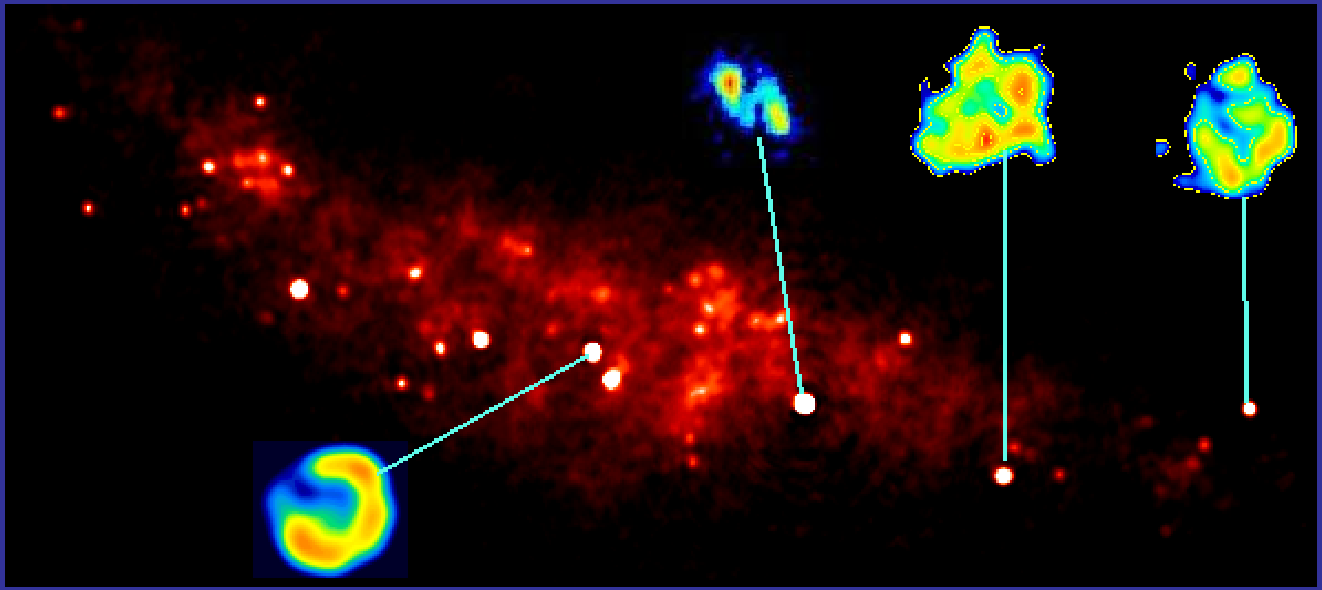
Outline

- Introduction
  - The compact radio source population in M82
- Ten years of MERLIN monitoring at 5GHz
  - Resolving tens of SNR and HII regions
  - Measured sizes and velocities
- VLBI imaging
  - Global VLBI monitoring since 1980s of the most compact SNR.
- e-MERLIN
  - Impact of proposed legacy projects on SNR imaging
  - The LeMMINGs project
- Summary

M82 Supernova remnants

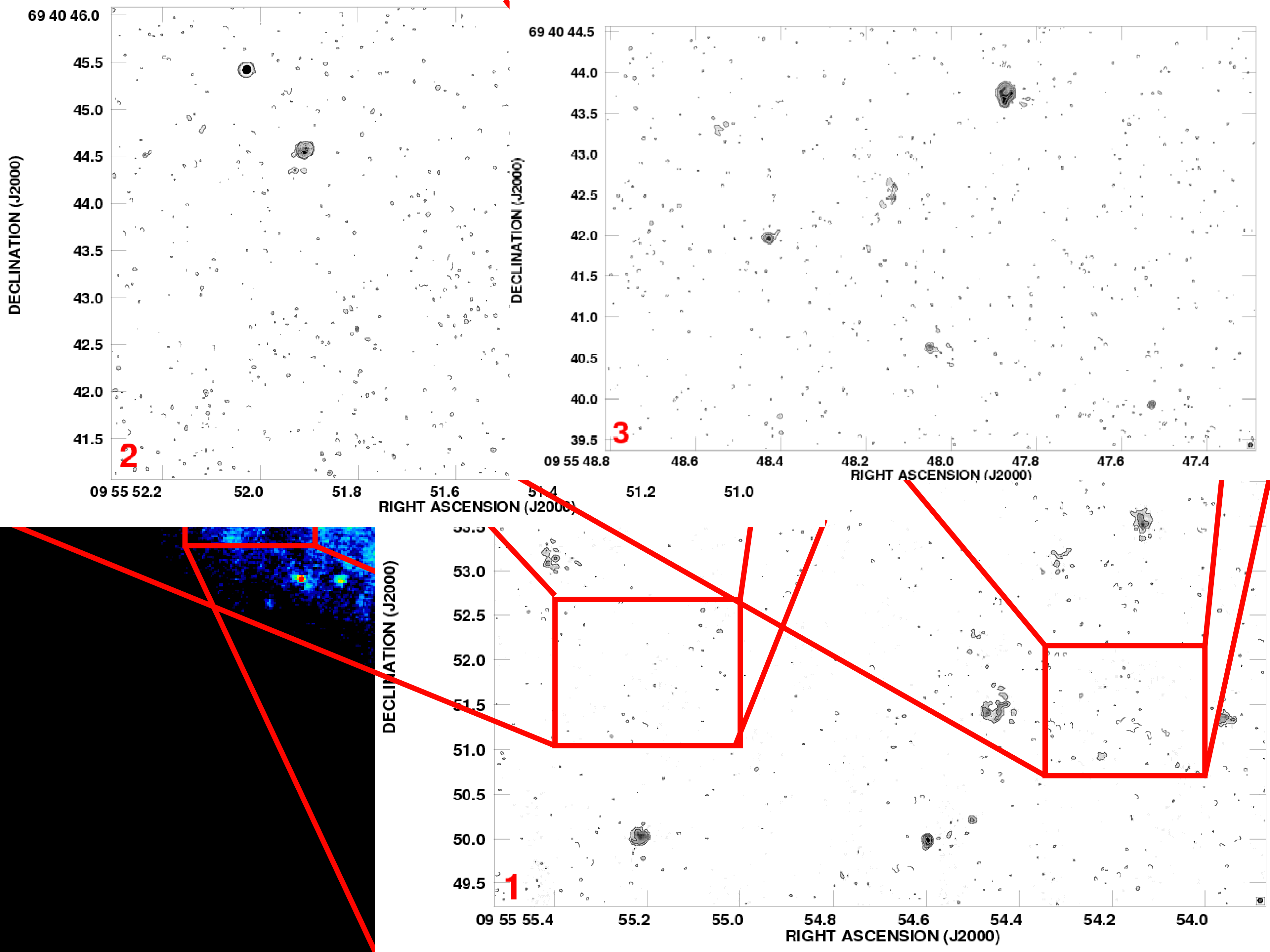
- >50 compact sources discovered in M82
  - All resolved with MERLIN &/or VLBI
  - Most are SNR- although ~13 are HII regions



Latest deep MERLIN 5GHz M82 observations (Fenech et al '08)

- MERLIN observations in 2002 (Fenech et al. '08)
  - 8 day deep integration (total observing time)
    - ~175 hours on-source
    - Image rms ~ 17 μJy beam^{-1}
    - >50 discrete sources detected
- MERLIN Observations in 1992 (Muxlow et al. '94)
  - 37 hr deep observation
    - Image rms ~46 μJy beam^{-1}
    - >40 discrete sources detected

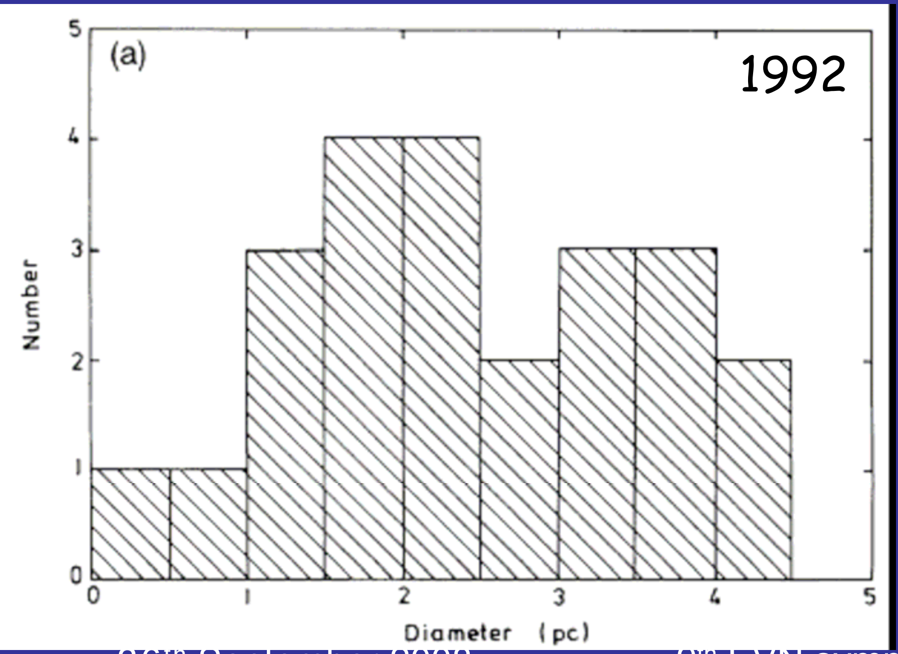
- 2002 data are the most sensitive observations of M82 to date!
  - 10 year baseline when compared with 1992 data
  - Compare 1992-vs-2002 epochs
    - Expansion velocities for ten remnants
      - Between 2200 → 10500km/s

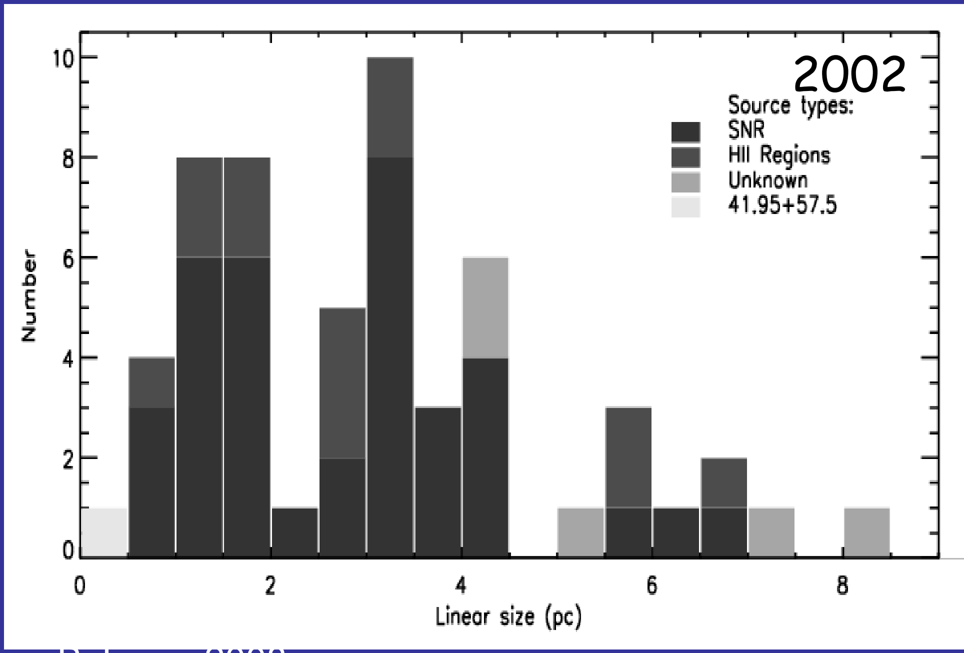


DECLINATION (J2000)
RIGHT ASCENSION (J2000)
69 40 46.0
45.5
45.0
44.5
44.0
43.5
43.0
42.5
42.0
41.5
09 55 52.2
52.0
51.8
51.6
51.4
51.2
51.0
2
69 40 44.5
44.0
43.5
43.0
42.5
42.0
41.5
41.0
40.5
40.0
39.5
09 55 48.8
48.6
48.4
48.2
48.0
47.8
47.6
47.4
3
53.0
52.5
52.0
51.5
51.0
50.5
50.0
49.5
09 55 55.4
55.2
55.0
54.8
54.6
54.4
54.2
54.0
1

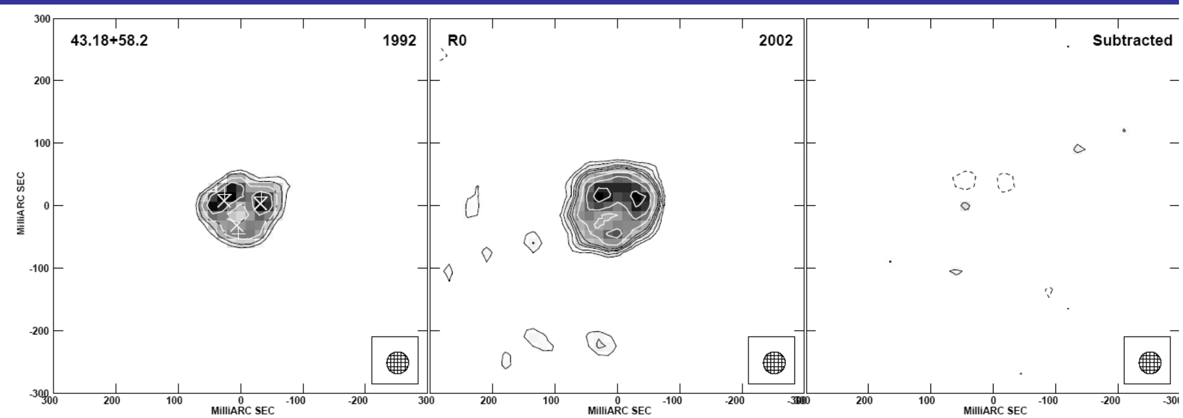
Compact sources in M82 - 5GHz results

- 2002 data - 55 sources in total – 37 SNR, 13 HII regions and 5 as yet unidentified.
- Size distribution up to an LAS ~9pc

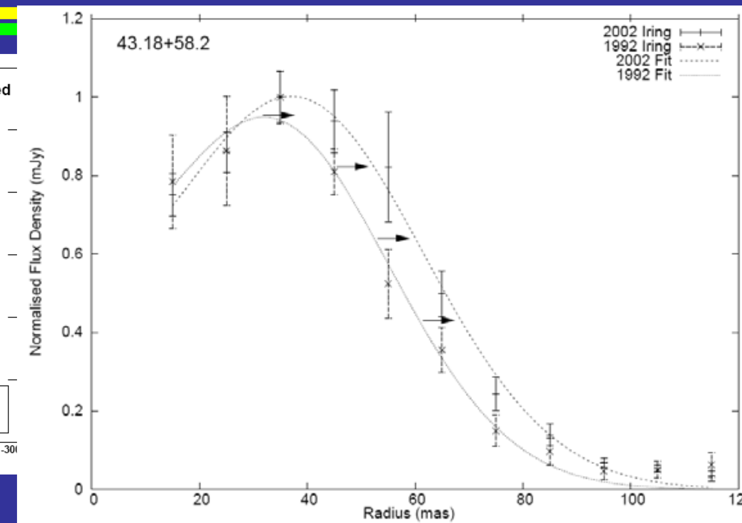




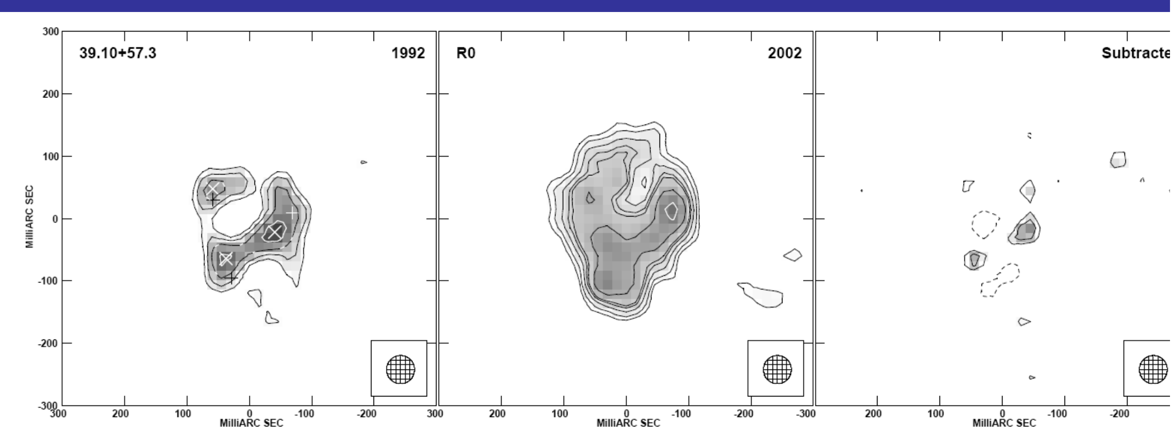
1992-vs-2002



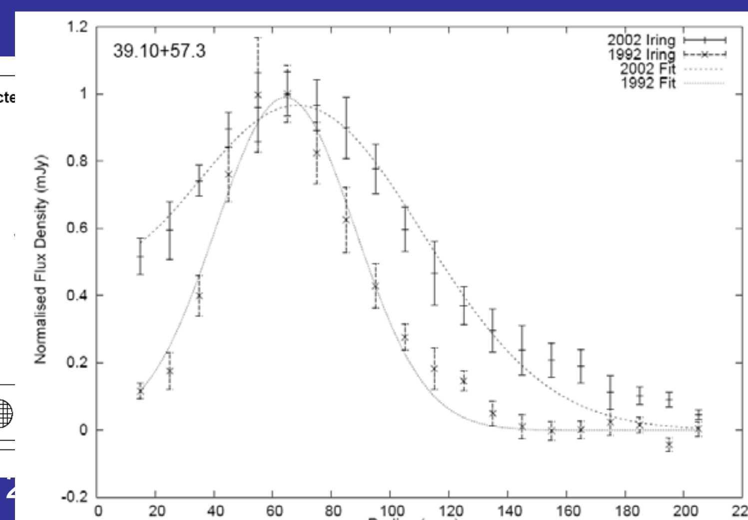
43.18+58.2
1992
R0
2002
Subtracted
MilliARC SEC



43.18+58.2
2002 Iring
1992 Iring
2002 Fit
1992 Fit
Normalised Flux Density (mJy)
Radius (mas)



39.10+57.3
1992
R0
2002
Subtracte
MilliARC SEC



39.10+57.3
2002 Iring
1992 Iring
2002 Fit
1992 Fit
Normalised Flux Density (mJy)
Radius (mas)

Expansion velocities

- Ten supernova remnants in total
  - Range of velocities from 2200 – 10500 kms^{-1}
  - Good agreement with VLBI estimates for 41.95+57.5 and 43.31+59.2
  - Predictions of expansion velocities made by Chevalier & Fransson (2001) ~ 500 kms^{-1} given pressures of $10^7 cm^{-3}K$ and densities of 10^3 cm^{-3}
  - Free expansion radio peak $D \approx 8.2(M_1/n_0)^{1\backslash 3}$ implies densities < 10^3 cm^{-3} for observed population.

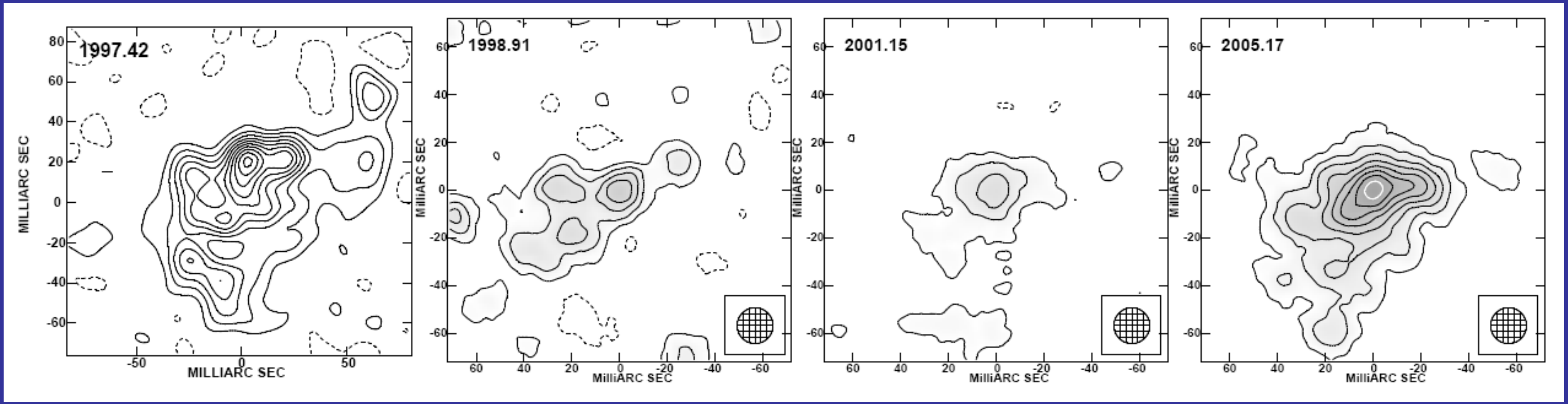
Long term Global VLBI monitoring

- Compact sources within M82 monitored since 1980's using VLBI
- Epochs in 1986 (EVN), 1997 (EVN), 1998 (gVLBI), 2001 (gVLBI) & 2005 (gVLBI+MER) @ 1.4-1.6GHz
- VLBI observations have concentrated on four most compact sources – 41.95+57.5, 43.31+59.2, 44.01+59.6 and 45.17+61.2.
  - These sources remain relatively unresolved in MERLIN observations.

Pedlar et al. 1999, McDonald et al. 2001, Beswick et al. 2006, Fenech 2007 PhD

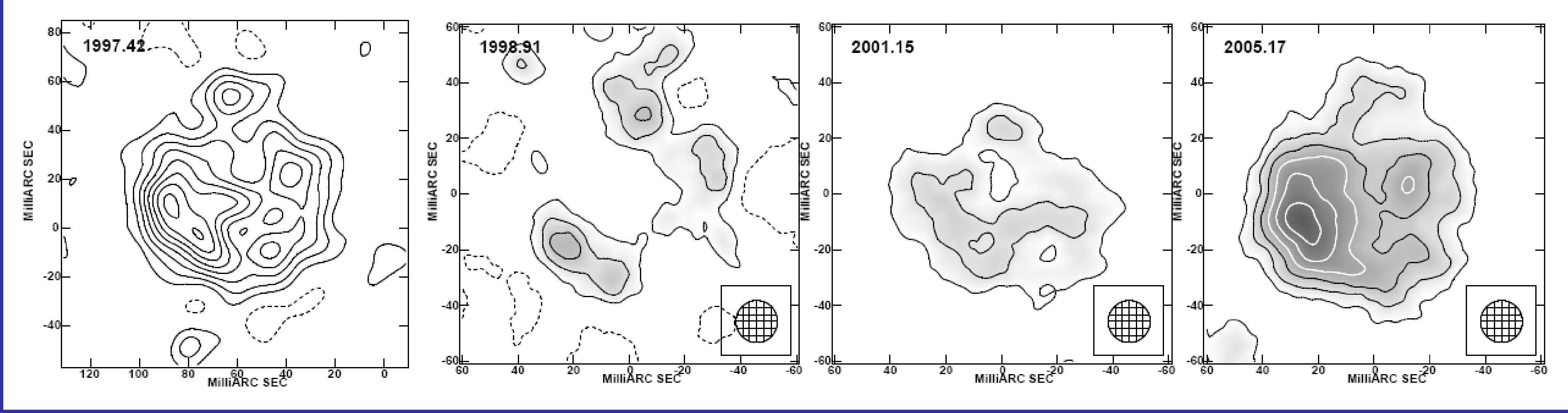
45.17+61.2

- Believed to be a possible partial shell due to elongated structure.
- Difficult trace source evolution and expansion.



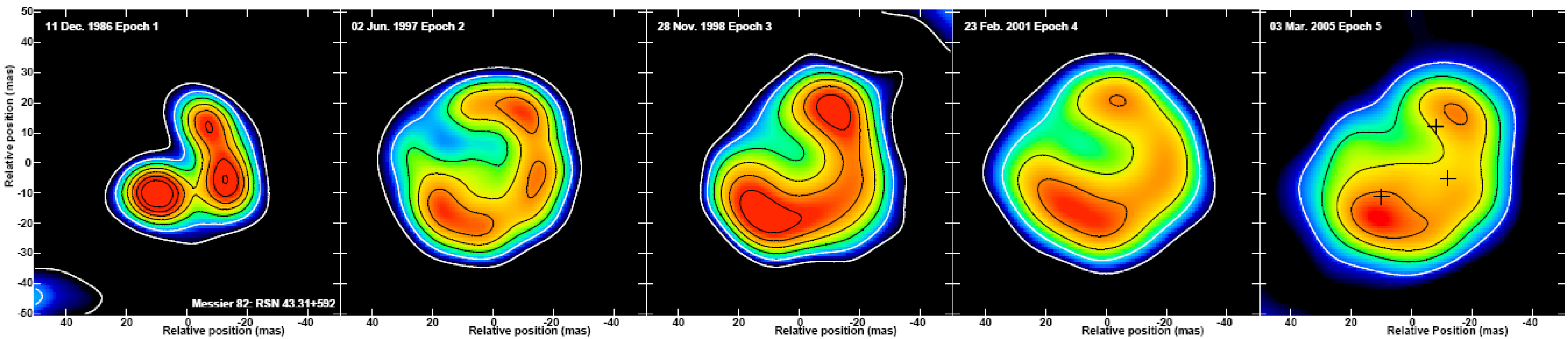
44.01+59.6

- Compact shell structure
- Little success using previous epochs to try to determine any expansion



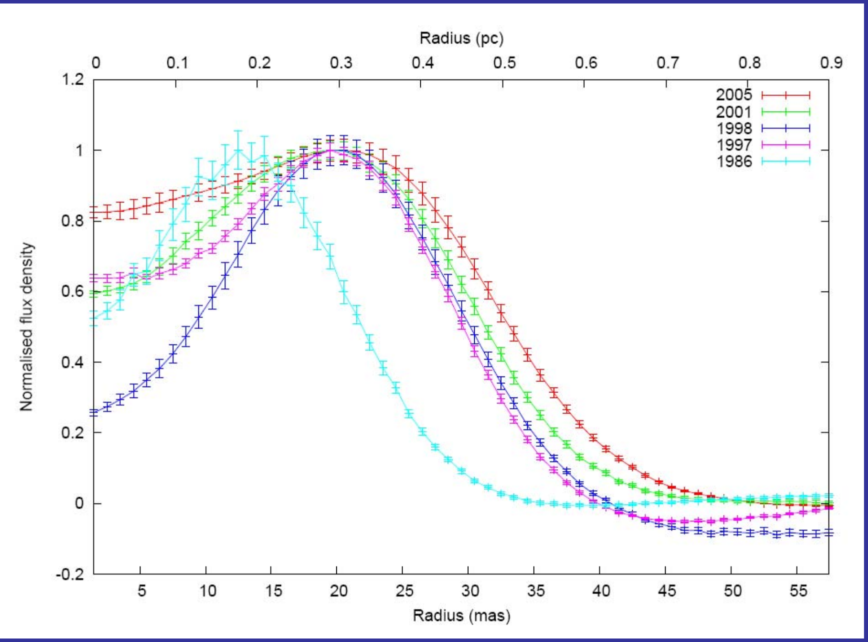
43.31+59.2

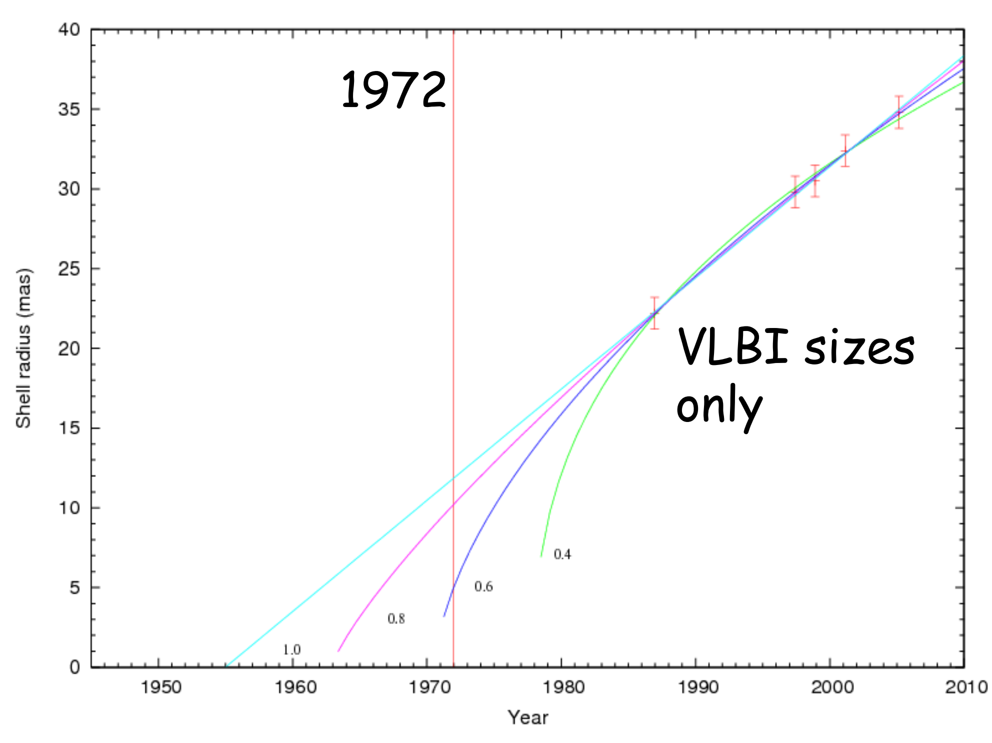
- Youngest remnant in M82, first observed in 1972 (Kronberg & Wilkinson 1975)
- Almost complete shell structure.



43.31+59.2

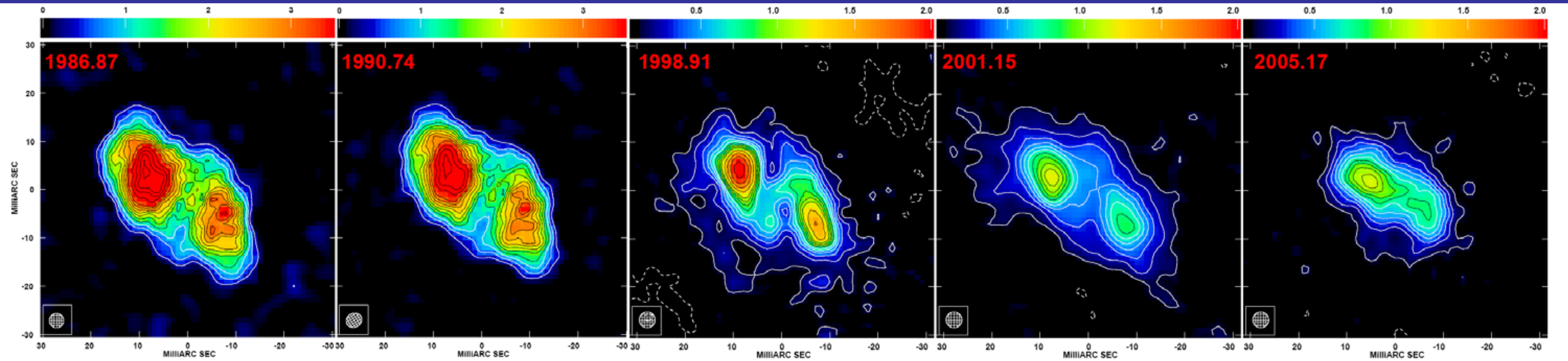
- Can use integrated the source annular profiles to determine expansion of provides velocity 7600±1200 kms^{-1}





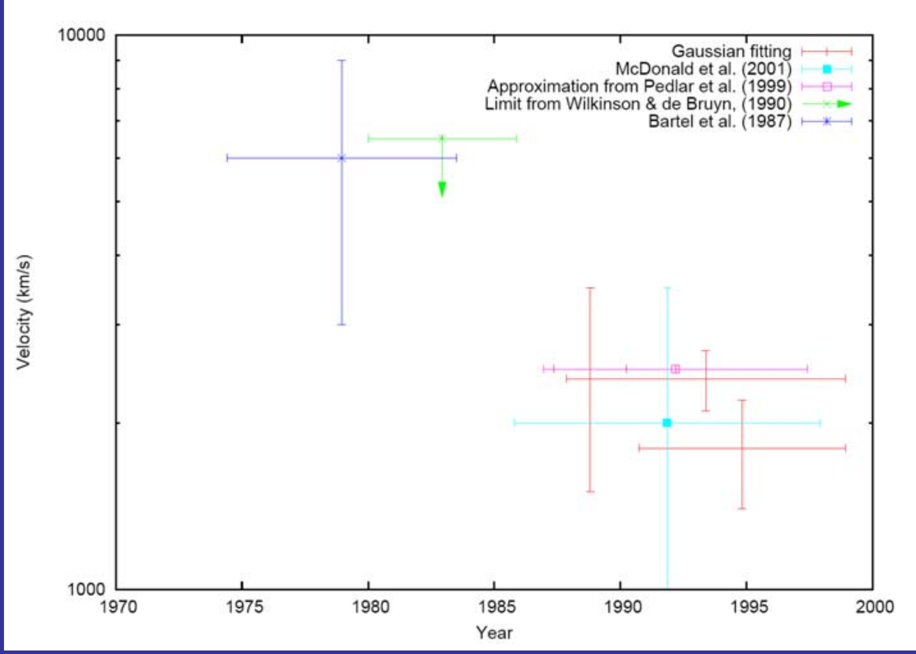
41.95+57.5

- Most compact source in M82
- Was the brightest until ~2005
- Bi-polar structure not typical of SNR



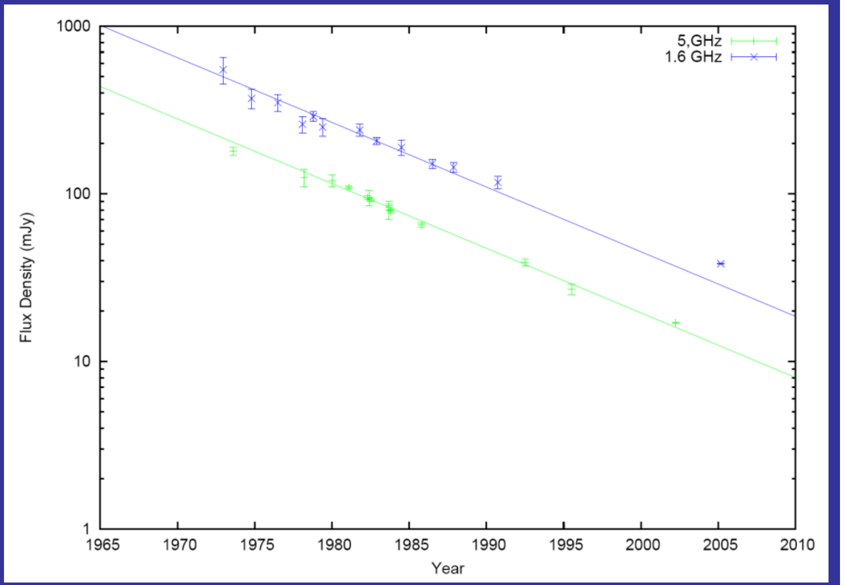
41.95+57.5

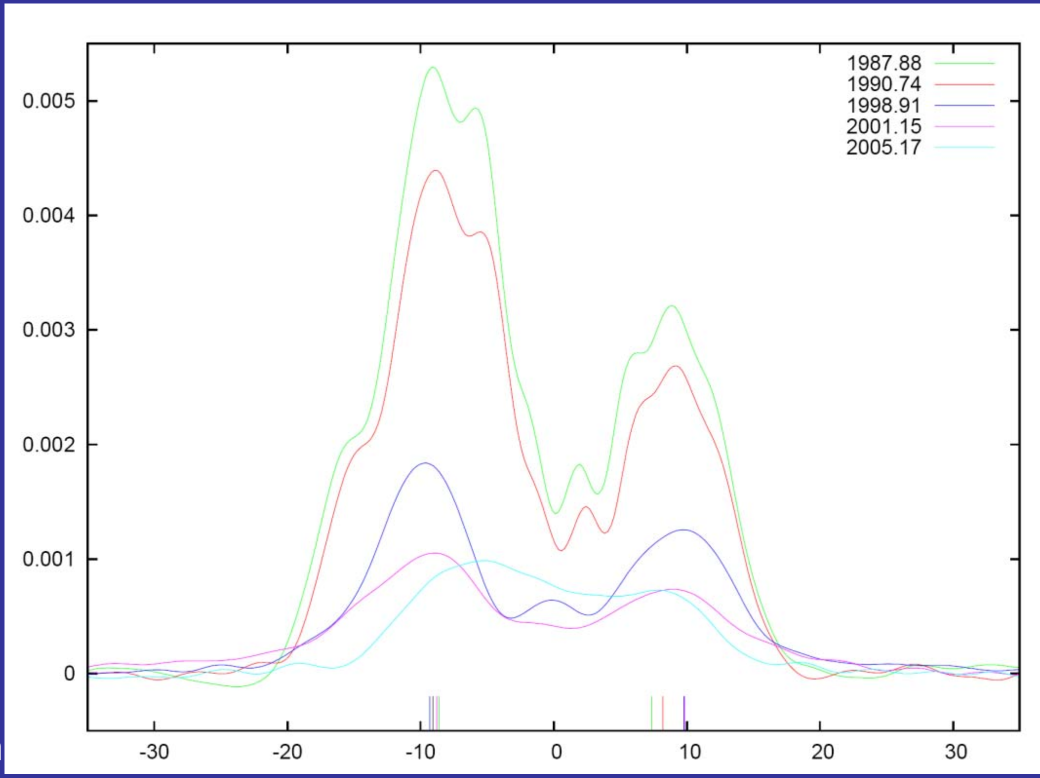
- First epochs show expansion between peaks equivalent to ~ 2000kms^{-1}
- But latest two epochs show distance between apparent peaks is shrinking
- Possibly explained by flux density changes



41.95+57.5

- Decaying at 8.5%/yr
- Originally dominated the flux density of whole galaxy.





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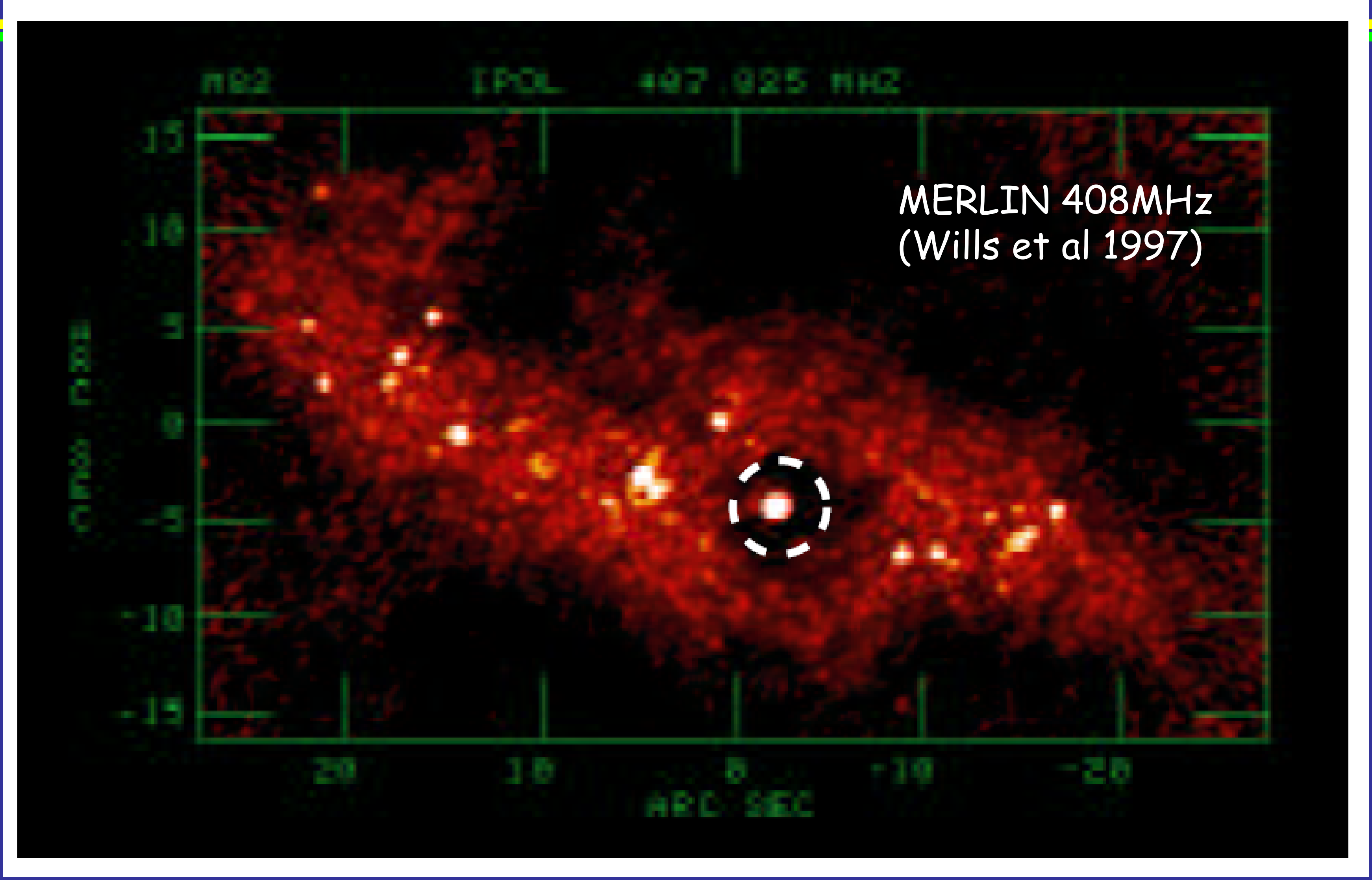
What is 41.95+57.5?



Combined MERLIN+gVLBI

- Simultaneous observations of M82 at 1.6GHz using MERLIN & gVLBI on 3rd March 2005.
- Combined datasets used produce images with angular resolutions from ~5-100 mas
- Images comparable to MERLIN deep integration observations at 5GHz with angular resolution 35mas.
- Study size and structure of ~35 sources at 1.6GHz

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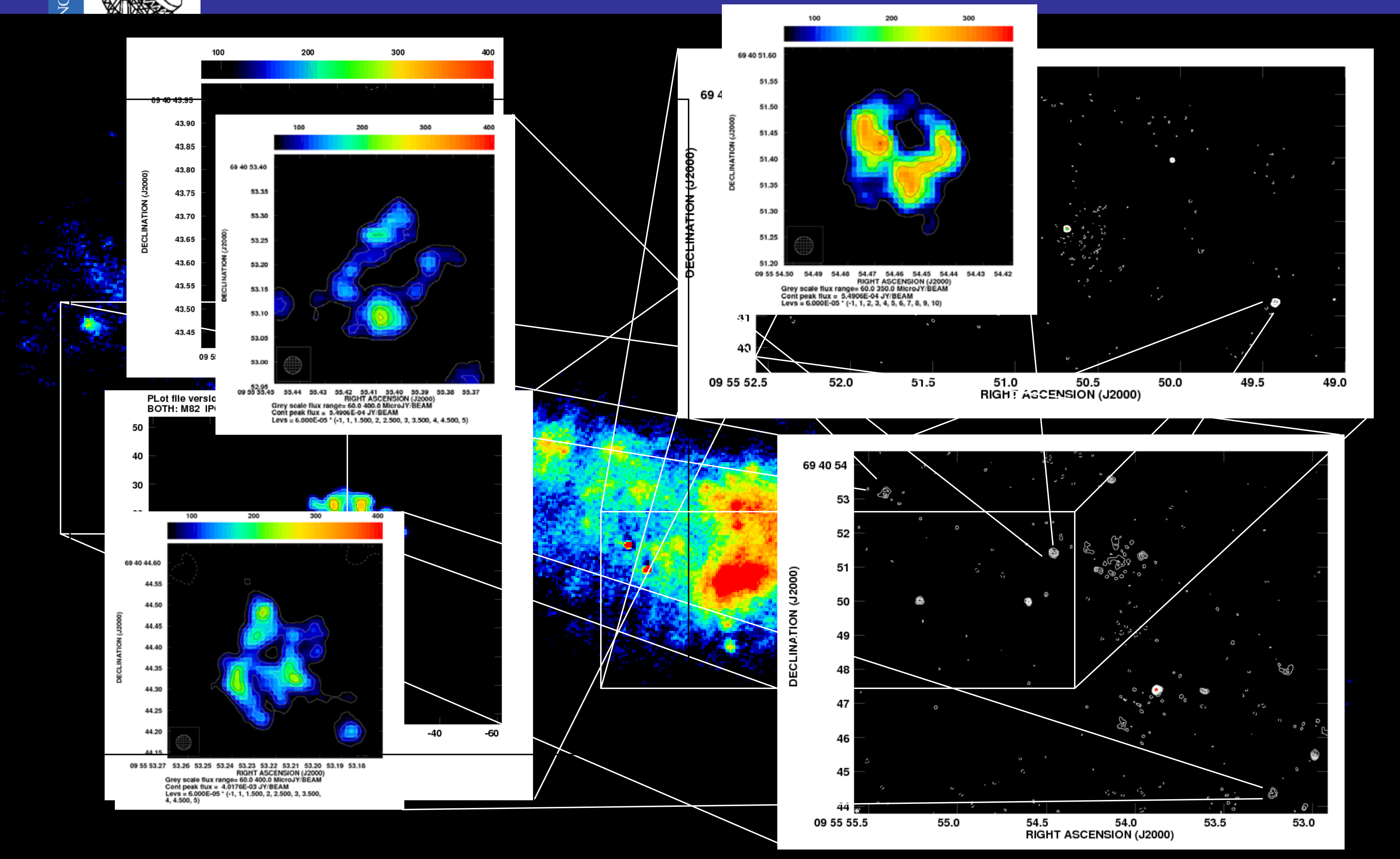
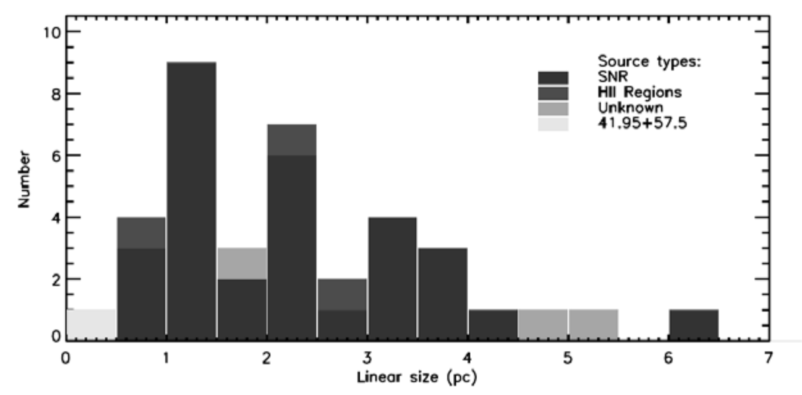


Combined data



- Source distribution less complete than 5GHz -37 in total
- 3 HII regions, 32 SNR
- 2 new sources – 8 and 10σ detections
- SNR steep spectrum would expect more.
- Less sensitive than 5GHz MERLIN

  (rms~ 30 μJy beam^{-1})
- Low frequency turnover – free-free absorption by intermediary ionised gas

Summary

- ~20 years of VLBI monitoring of M82 SNR
  - VLBI alone detects and resolves 4 sources
    - Tracking the velocities of 43.31 → beginning to determine deceleration?
    - Complex faint part-shells of 44.01 & 45.17
    - Structural and flux evolution of 41.95 seems inconsistent with typical shell-like SNR
  - New combines gVLBI+MERLIN resolves and detects many more SNR → start to trace the structural evolution of many SNR, start to relate their expansion behaviour with the ISM they are embedded & make direct comparisons to MERLIN (& future e-MERLIN) observations.

e-MERLIN studies of nearby Galaxies

- Currently sensitivity limits the number of sources that can be studied in detail..
  - Sensitivity of *e*-MERLIN will revolutionise this.

- Two legacy proposals to address this by studying moderately large samples of nearby galaxies at sub-arcsec resolution and microJy sensitivities (LIRGI, PI: Conway/Perez-Torres & LeMMINGs, PI: Beswick/McHardy).

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Legacy e-MERLIN Multi-band Imaging of Nearby Galaxy Sample (LeMMINGs)

- Proposal submitted for ~1140hrs of e-MERLIN time over 5 semesters
- 45 Co-Is (PIs: Beswick & McHardy)
- Two depth tier project
  - 48min 'multi-cut, snapshot' survey of the complete Palomar BGS (Dec>20deg)
    - 250 Galaxies
    - rms~40 & 15μJy/bm @ L & C respectively
  - Deep, nearby 5hr survey
    - Superb multi-wave coverage SINGS/KINGFISH/THINGS ++++
    - 41 Galaxies of all types (inc. M82 etc)
    - rms ~ 8 & 3μJy/bm @ L & C respectively

If approved, will provide a systematic radio census of star-formation products and AGN activity in the local Universe.

Legacy e-MERLIN Multi-band Imaging of a complete Nearby Galaxy Sample (LeMMINGS)

Coordinators:
R. J. Beswick (Robert.Beswick@manchester.ac.uk) & I. McHardy(imh@astro.soton.ac.uk)
Addresses:
R. J. Beswick, Jodrell Bank Centre for Astrophysics, The University of Manchester, M13 9PL, UK
I. McHardy, School of Physics & Astronomy, University of Southampton, SO17 1BJ, UK

Abstract: The two processes which dominate the appearance of our universe are star-formation and accretion. Star-formation (SF) is fundamental to the formation and evolution of galaxies whilst accretion provides a major power source in the universe, dominating the emission from distant quasars as well as from nearby X-ray binary systems. The feedback between these two processes is also crucial, e.g. in reconciling the observed galaxy luminosity function with the predictions from the standard hierarchical clustering models. Radio observations provide by far the best single diagnostic of these two processes, providing a direct view of SF even in dusty environments and allowing detection of AGN and measurement of their accretion rate at bolometric luminosities far below anything detectable at higher energies. A large, statistically complete, sample of galaxies such as we propose here, provides the perfect laboratory to study for the first time not only these two processes, but also to quantify how they interact in different types of galaxies. e-MERLIN is perfectly tuned to such studies as, even at low frequencies, its pc-scale resolution, coupled with spectral information, allows almost unambiguous discrimination of even faint AGN inside large SF regions. Specifically here we will carry out a complete census of SF and AGN activity as a function of galaxy mass, morphology and spectral type, black hole mass and luminosity. We will thus calibrate other SF indicators, e.g. IR and Hα luminosity, and constrain patterns in jet strength compared to merger histories. Additionally, we will determine whether ultra-luminous X-ray sources may come from intermediate mass black holes.

The broad philosophy of this legacy programme will be to provide the definitive parsec-scale, μJy sensitivity radio images of a large sample of well-known galaxies in the nearby universe. As such this project will both address numerous key science questions regarding SF and activity in galaxies and is specifically designed to be a lasting Legacy data-set for the wider community, with the sample selected to maximize multi-wavelength coverage and consequently the amount of future legacy science achievable.

Full list of team members:

Susanne Aalto *(Onsala Space Observatory, Sweden)*,
Paul Alexander *(Cambridge)*,
Willem Baan *(ASTRON, The Netherlands)*,
Elias Brinks *(Hertfordshire)*,
Stephane Corbel *(CEA Saclay, France)*,
Tom Dwelly *(Southampton)*,
Danielle Fenech *(UCL)*,
Jack Gallimore *(Bucknell, USA)*,
Melvin Hoare *(Leeds)*,
Rob Kennicutt *(Cambridge)*,
Johan Knapen *(IAC, Tenerife, Spain)*,
Elmar Körding *(Southampton/Saclay, France)*,
Tom Maccarone *(Southampton)*,
Sera Markoff *(Amsterdam, The Netherlands)*,
Carole Mundell *(LJMU)*,
Alison Peck *(ALMA, Chile)*,
Miguel Perez-Torres *(IAA, Spain)*,
D. J. Saikia *(NCRA, India)*,
Ralph Spencer *(JBCA, Manchester)*,
Ian Stewart *(JBCA, Manchester)*,
Philip Uttley *(Southampton)*,
Martin Ward *(Durham)*,
Antxon Alberdi *(IAA, Spain)*
Megan Argo *(Curtin, Australia)*
Rob Beswick *(JBCA, Manchester)*
John Conway *(Onsala Space Observatory, Sweden)*
Phil Diamond *(JBCA, Manchester)*
Janine van Eymeren *(JBCA, Manchester)*
Jay Gallagher *(Wisconsin, USA)*
Dave Green *(Cambridge)*
Sebastian Jester *(MPIA Heidelberg, Germany)*
Hans-Rainer Klöckner *(Oxford)*
Christian Knigge *(Southampton)*
Ian McHardy*(Southampton)*
Jon Marcaide *(Valencia, Spain)*
Ivan Marti-Vidal *(Valencia, Spain)*
Tom Muxlow *(JBCA, Manchester)*
Alan Pedlar *(JBCA, Manchester)*
Cristina Romero-Canizales *(IAA, Spain)*
Eva Schinnerer *(MPIA Heidelberg, Germany)*
Ian Stevens *(Birmingham)*
Michele Thornley *(Bucknell, USA)*
Fabian Walter *(MPIA Heidelberg, Germany)*
Jeremy Yates *(UCL)*

LeMMINGs objectives

Some of the specific science objectives

1. To measure levels of SF activity in galaxies of all morphological, luminosity and spectral population mix. These measurements, and in particular the resulting systematic and unbiased census of individual SF products (RSNe, SNR, HII regions and alike), will be used as a direct extinction-free tracer of SF, and hence be used to help calibrate commonly used SFR indicators such as IR and H.

2. A complete census of AGN activity and jet structures in galaxies of all optical types, including LINERs and absorption line galaxies as well as broad line AGN, which will be cross-correlated against levels of ongoing SF.

3. A serendipitous parsec-scale imaging survey of the cold ISM using its HI absorption and maser emission. This survey will constrain the content and composition of cold gas present in the immediate nuclear region of galaxies as well as its kinematics. Both of which are basically unknown on these size scales and can be addressed with e-MERLIN well before ALMA or the SKA are fully operational.