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The e-MERLIN Legacy project : LeMMINGs

(a. k. a :
Legacy **e-M**ERLIN **M**ulti-band **I**maging of **N**earby **G**alaxie**s**)

Rob Beswick (JBCA/e-MERLIN)

Ian McHardy (Southampton)

Plus the LeMMINGs

e-MERLIN Legacy team

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The team of LeMMINGs

The LeMMINGs' Team

Rob Beswick *(University of Manchester)* - Co-PI

Ian McHardy *(University of Southampton)* - Co-PI

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

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LeMMINGs Science

- Basic observational aim of survey is to
  - Image a complete sample of nearby galaxies, encompassing all galaxy types, at sub-arcsecond (few pc) angular resolution and microJansky sensitivity. Multi-λ follow-up. Provide a public legacy data-set.
- Built around three Core science themes:
  1. Measure **star-formation** activity.
  2. Make a complete census of **AGN** activity and jet structures in galaxies of all types
     - measure radio LF for different galaxy types
     - properly define $L_R/L_X/M$ 'fundamental plane'
  3. A serendipitous parsec-scale imaging survey of the **cold ISM** via atomic and molecular absorption/maser emission.
- 2-tiered approach to image ~300 galaxies. Majority via snapshot imaging plus a smaller deep sample.

e-MERLIN

Sample and observing depths

- 'Shallow' = **Palomar bright galaxy sample** (Ho et al 1995) selecting Dec >20deg (290 gals)
  - Optically flux selected sample (no radio bias)
  - Sample B_T < 12.5 mag, Median Distance = 20Mpc
  - Strong multi-wavelength coverage
    - Overlap with existing major surveys such as, **SINGS, KINGFISH, THINGS,** Galex etc
    - Ongoing LeMMINGs-led campaign to complete multi-λ coverage.
- 'Deep' survey is a **sub-sample** of shallow picking 'interesting' nearby objects with best multi-λ coverage.

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LeMMINGs Sample

- Total project allocation is 810hrs of e-MERLIN time split in to 2-tiers
  - **Shallow snapshot tier** → ~290 galaxies (on-source time ~48min/band/source)
  - Median distance = 20Mpc
  - **Deep tier** → 6 Targets observed (sub-set of shallow tier) ~5hrs/band/source

	Number of targets	Sensitivity μJy/bm	Luminosity (at median D)	Approx. On-source time
Shallow (L-band) res ~120mas	290	38	$1.8 * 10^{18}$ W/Hz	48min
Shallow (C-band) Res ~ 35mas	290	15	$7.2 * 10^{17}$ W/Hz	48min
Deep (L-band) with LT	6	8	$7.5 * 10^{16}$ W/Hz	4.8hr
Deep (C-band) with LT	6	3	$2.8 * 10^{16}$ W/Hz	4.8hr

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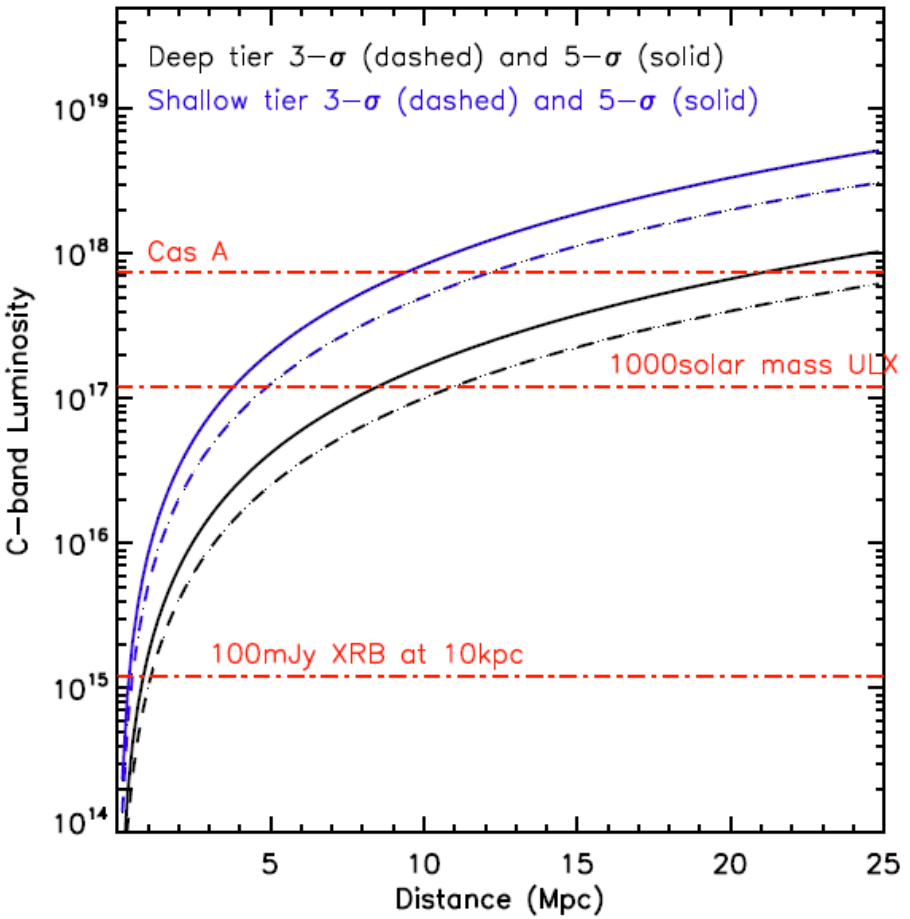
LeMMINGs Science
1. Star formation

- Shallow-tier will detect and resolve RSNe/SNRs at moderate distance
  - hence provide a complete census of Star-formation products.
- Deep tier will also detect radio emission from PNe/HII regions/super star cluster (SSC).
- Hence calibrate SFR in nearby galaxies on the basis of compact radio source populations, independent of obscuration
- New populations of radio transients?
- Measure LOCAL SFR around SNe Ia with good lightcurves from Palomar Transient Factory. Hence calibrate SN peak luminosity for SFR variation – important cosmologically



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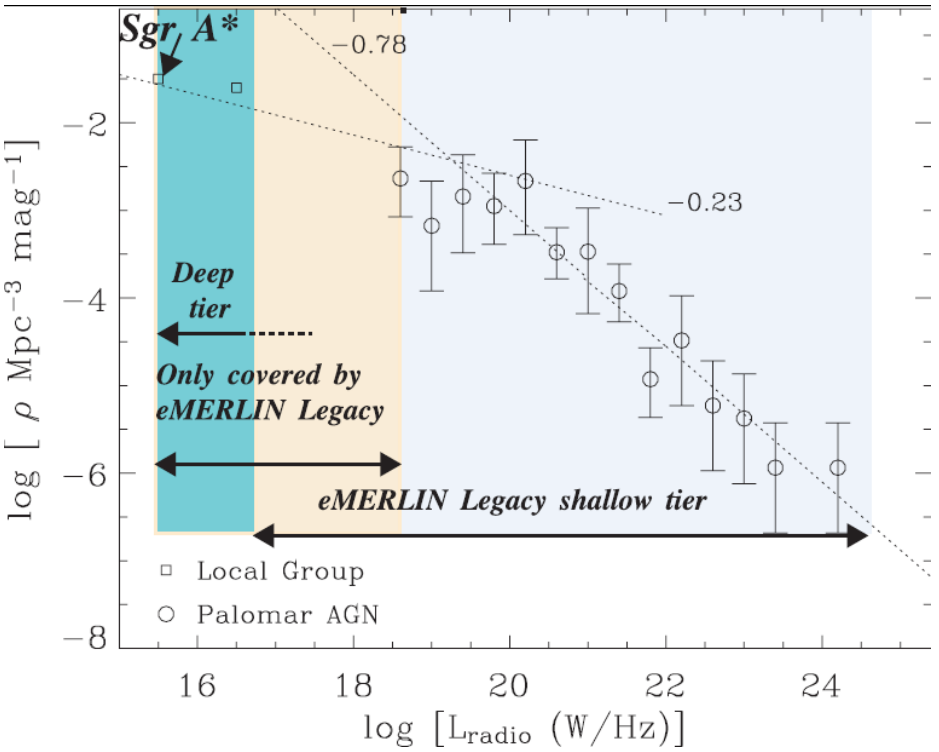
LeMMINGs Science
2a: Accretion and Low Luminosity AGN

- The shallow survey will provide a complete census of AGN activity and jet structures in local galaxies of **ALL** types, including starburst, LINER, quiescent as well as known AGN.

- We will probe several orders of magnitude lower in radio power than previous surveys with sufficient resolution (few pc) to separate star-formation and AGN/jet activity.

- Do AGN or SN produce more energy 'feedback' to their environment?

Radio luminosity function



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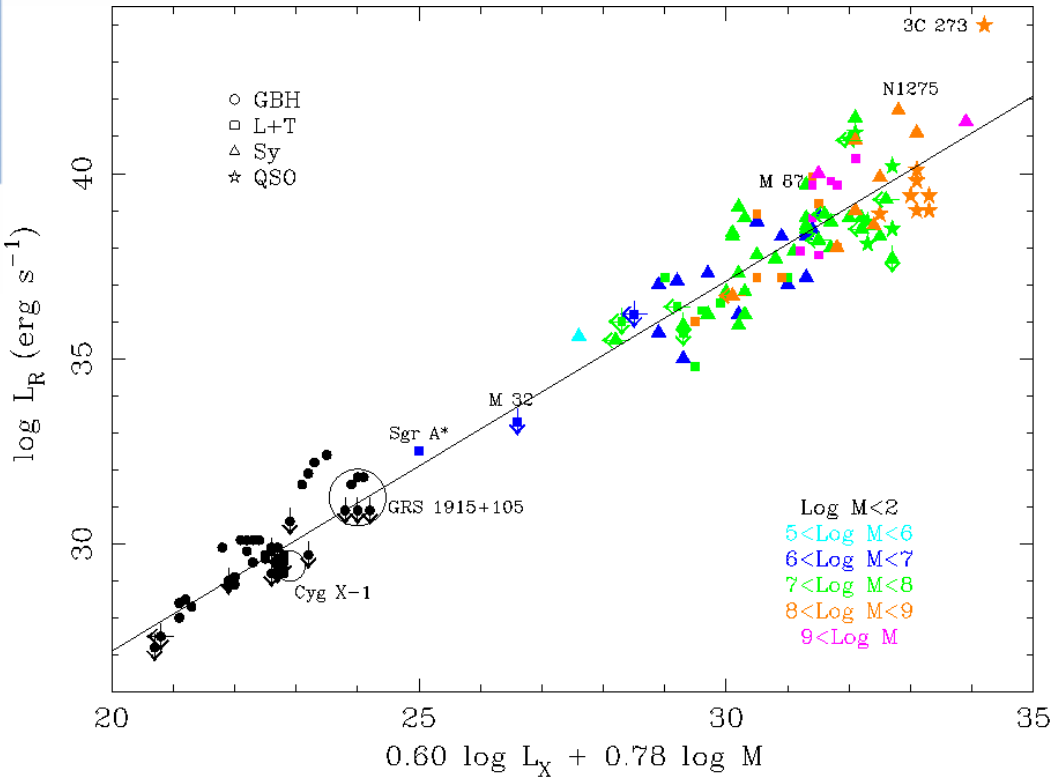
LeMMINGS Science
2b: The radio 'Fundamental Plane'



(Merloni et al 2003; cf Falcke et al 2004; Koerding et al 2006)

Jet models predict a relationship between L_X, L_R, M.

If well defined, relationship would constrain models.

Observed relationship has great scatter, largely due to poor radio resolution including non-AGN emission.

Do LINERS follow same track as Seyferts or non-AGN galaxies?

eMERLIN will greatly improve.

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LeMMINGS Science
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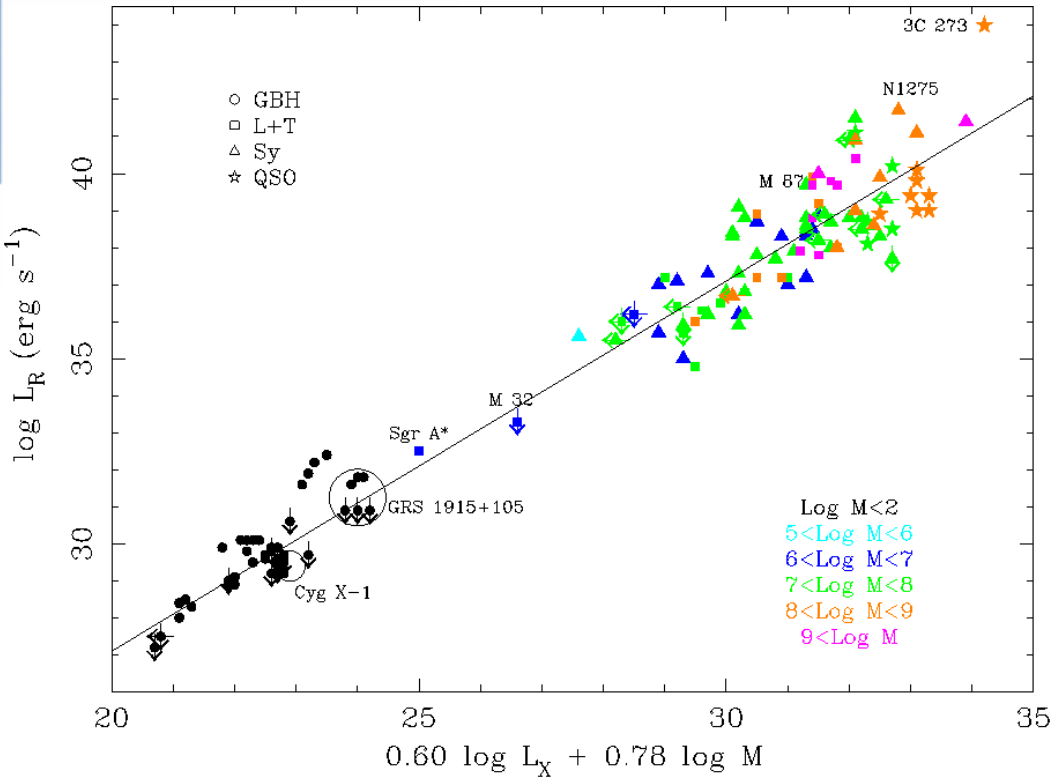

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(Balmaverdi + Capetti – are galaxies with flat optical core surface brightnesses more radio loud?)

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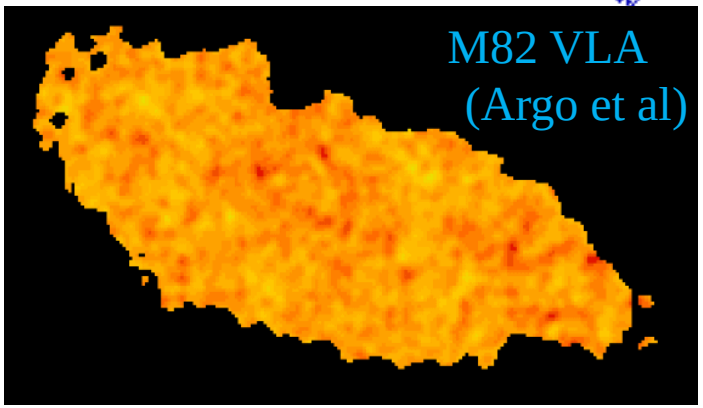
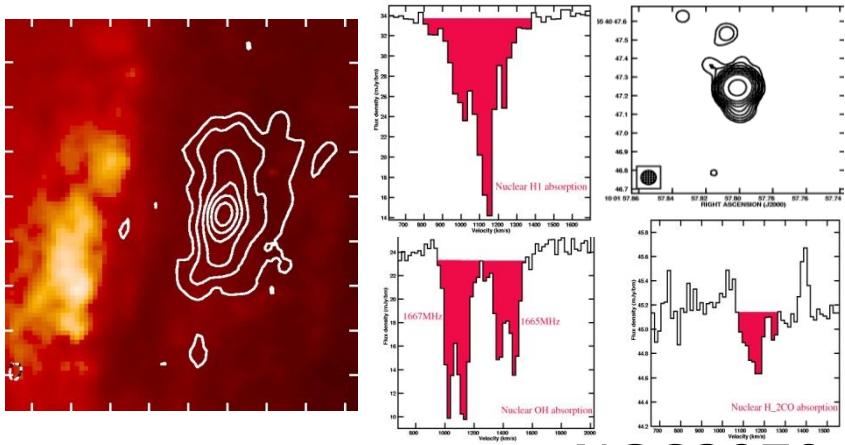
LeMMINGs Science
3. Neutral Gas



- All e-MERLIN data will be taken in spectral line mode, providing simultaneous line observations (H1, OH (1612,1665, 1667, 1720MHz) + H_2CO, excited OH, HCN?) to search and image absorption and maser emission
- - relevant for deep tier observations only which will have good spectral sensitivity.
- - First sub-arcsecond, simultaneous multi-line survey of its kind.



NGC3079
– H1, OH and H_2CO absorption (Beswick et al)

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Update

- Selection of initial deep observations now made:
  - Primary initial goals:
    - Initial deep tier observations of few selected targets – (primarily at L-band where full bandwidth is available)
    - Targets selected with complex morphology and early science potential
    - Technical aim to investigate image fidelity of snapshot survey vs deep survey

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Initial deep observations made to date

- M82 – nearby 'prototypical' starburst galaxy
- IC10 complex nearby dwarf star-forming galaxy (see talk by Elias Brinks & poster Jonathon Westcott, Herts)
- IC342 nearby dwarf
- NGC2146 – local starburst

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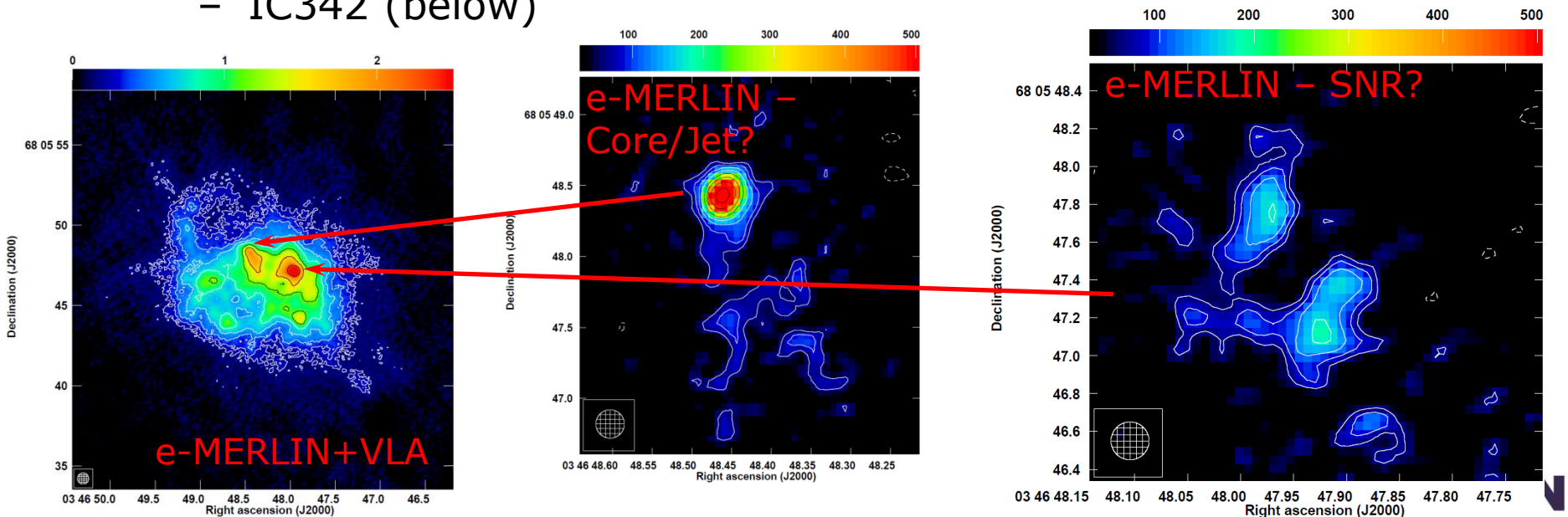
LeMMINGs : Nearby Dwarf galaxies IC10 & IC342

- Part of larger LeMMINGs sample
  - Preliminary results:
  - Two moderately deep observations of nearby irregular dwarf galaxies
  - IC10 (Jonathon Westcott /Elias Brinks (Herts) - see talk and poster)
    - Post-starburst dwarf irregular galaxy
    - Distance 1Mpc ➔ eMERLIN beam (0.18") = ~1pc
  - IC342 (below)



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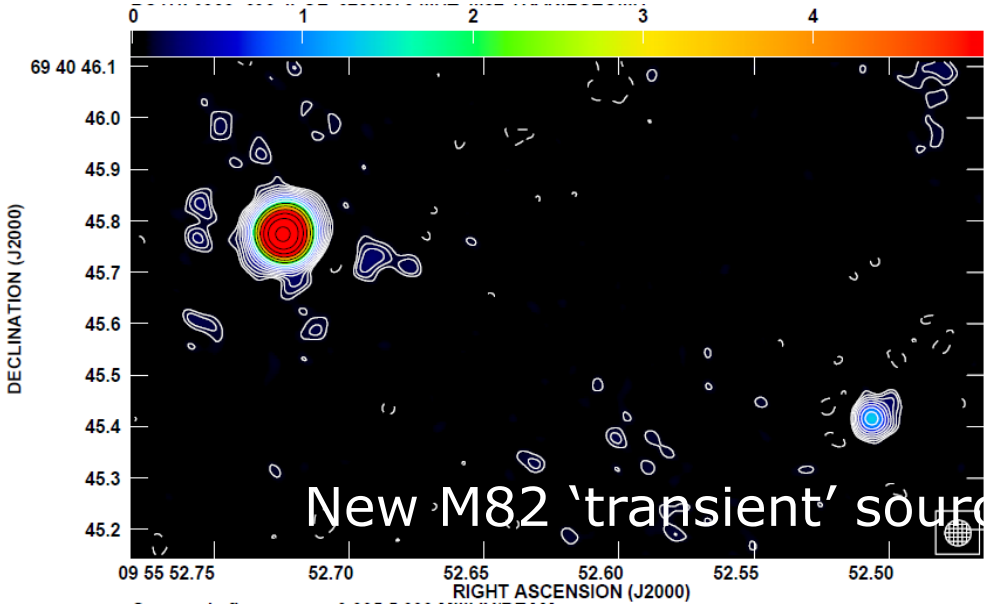
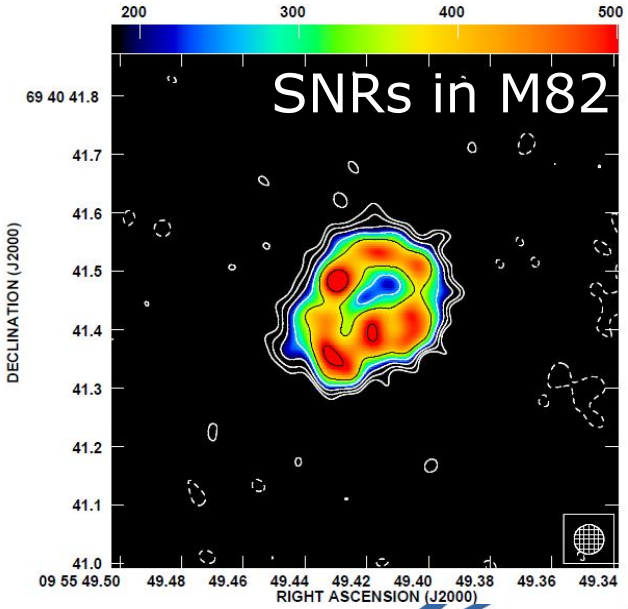
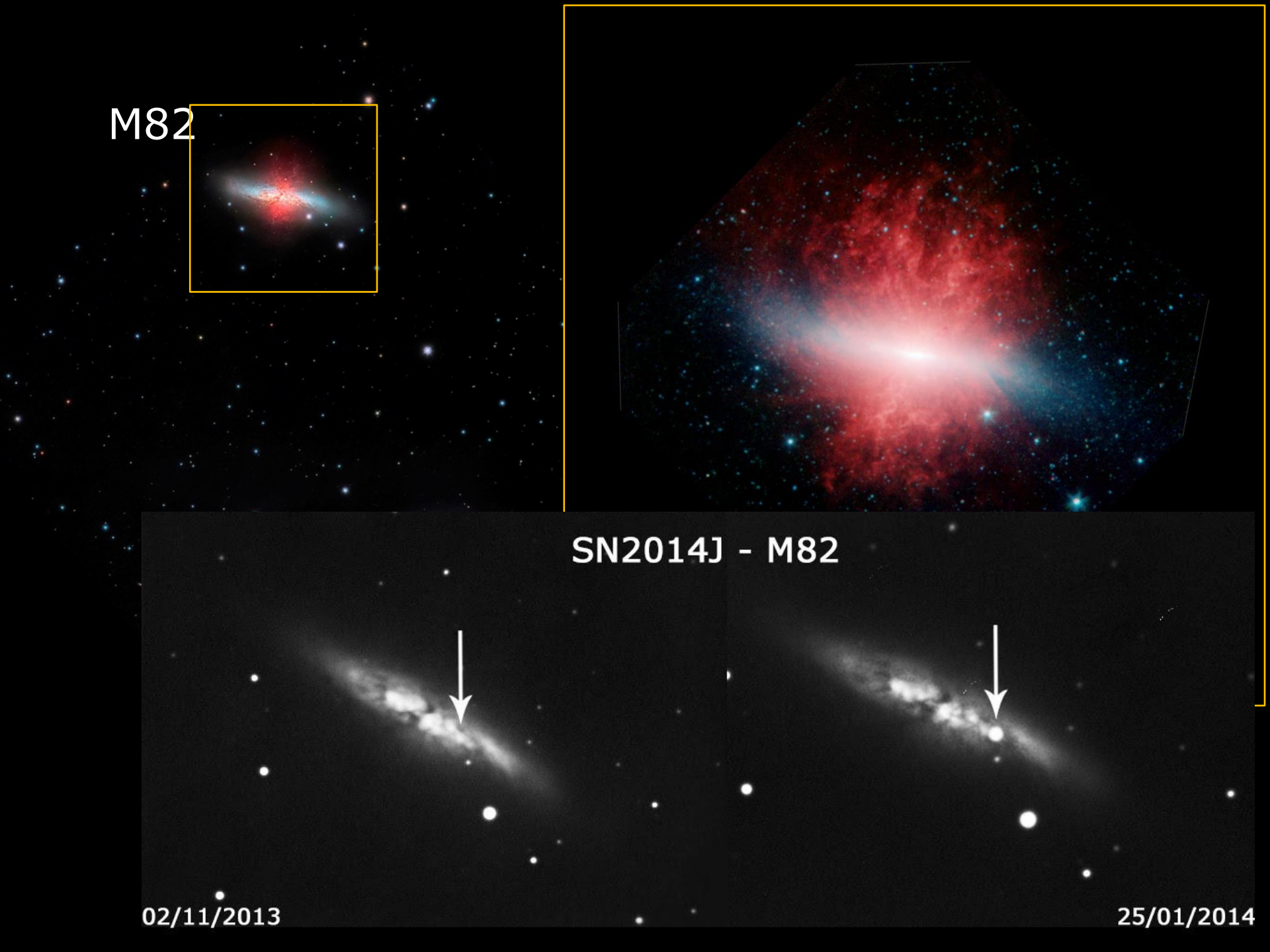
LeMMINGs: M82 – a nearby SNR laboratory

- Part of long term MERLIN+e-MERLIN campaign (Gendre et al 2013 MNRAS) – & LeMMINGs legacy project
- High fidelity e-MERLIN images of individual SNR shells
  - Tracking the evolution of new M82 Transient source (Discovered by Muxlow et al 2010)
- New Deep C and L-band imaging – Coincide with search for radio emission from SN2014J



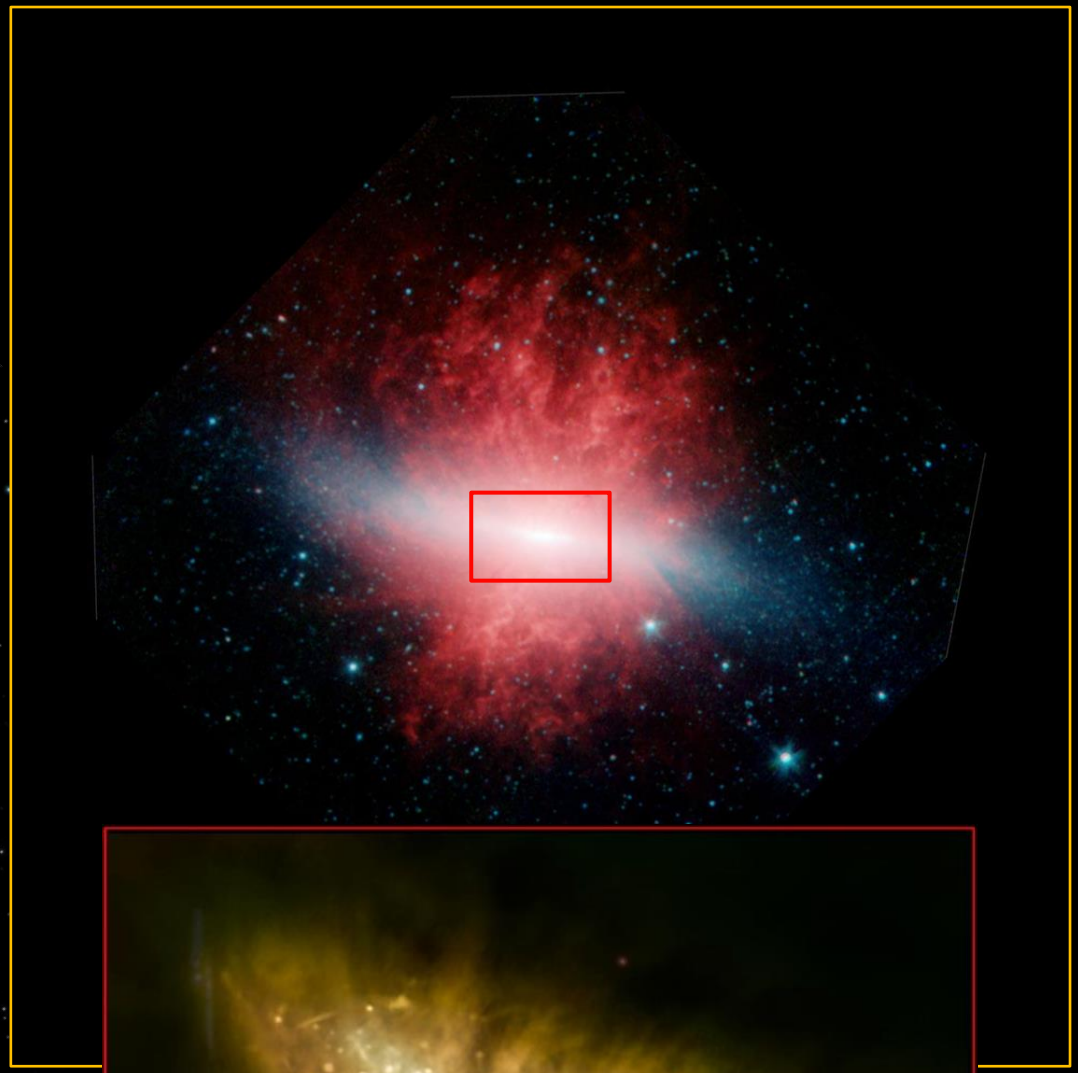


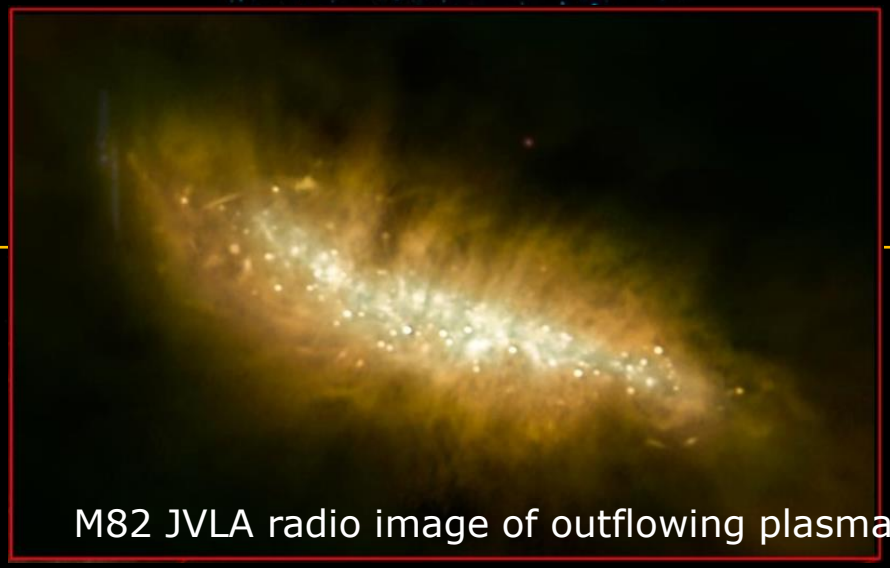
MERLIN


M82
SN2014J - M82
02/11/2013
25/01/2014

M82

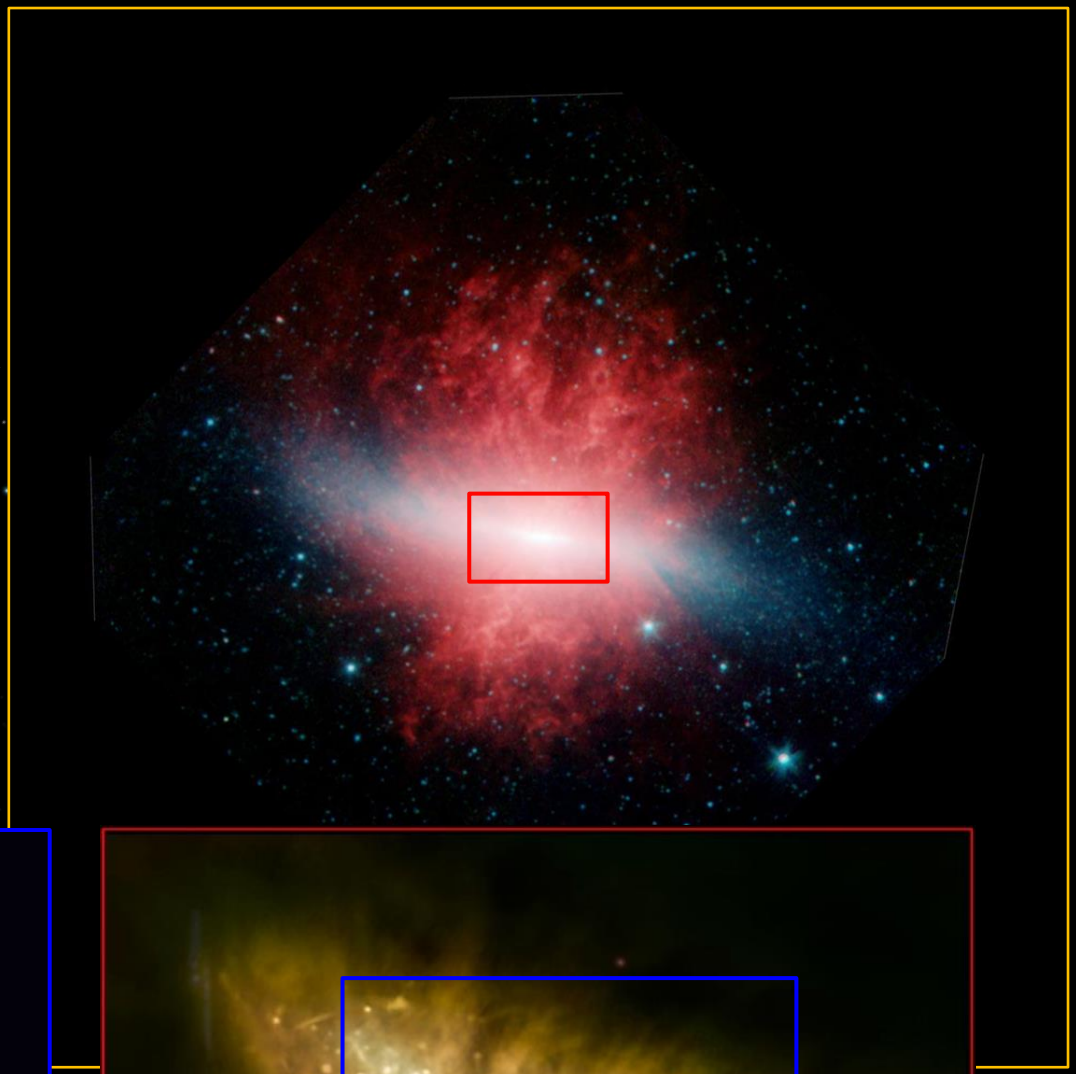
M81

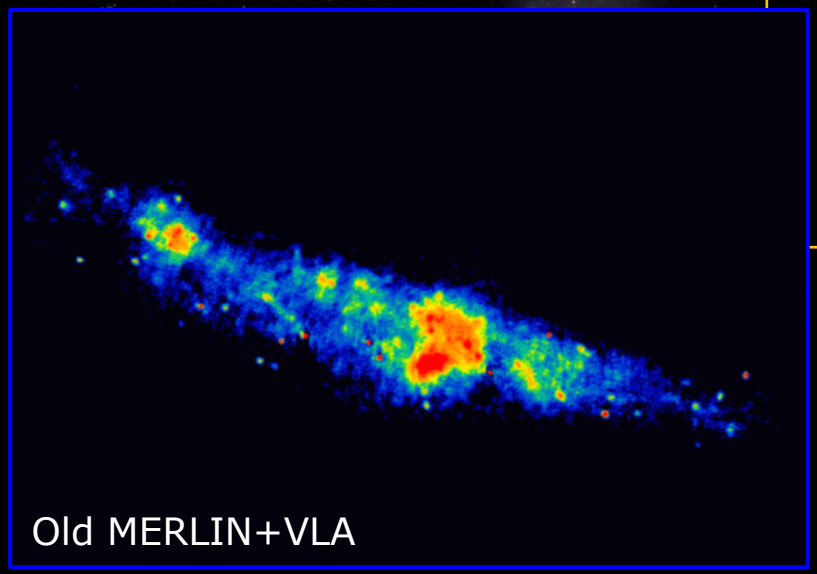




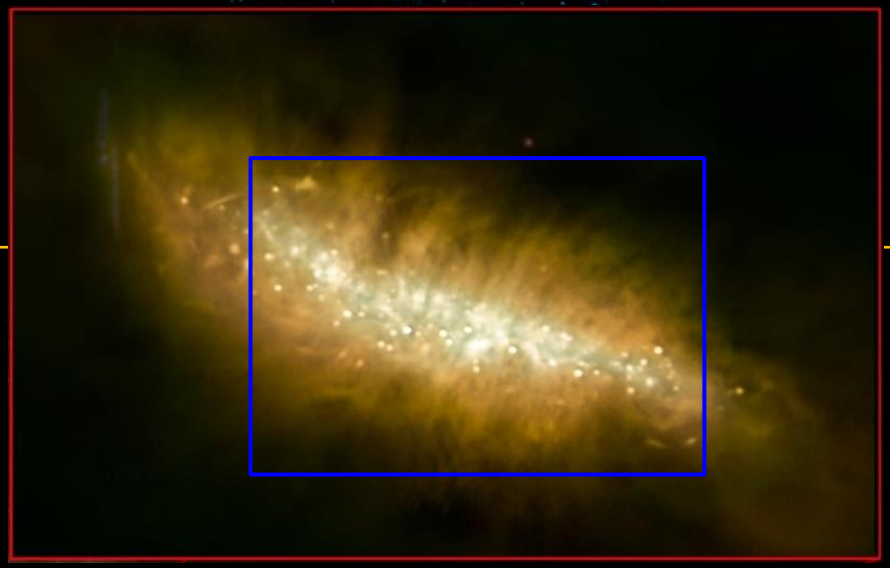
M82 JVLA radio image of outflowing plasma

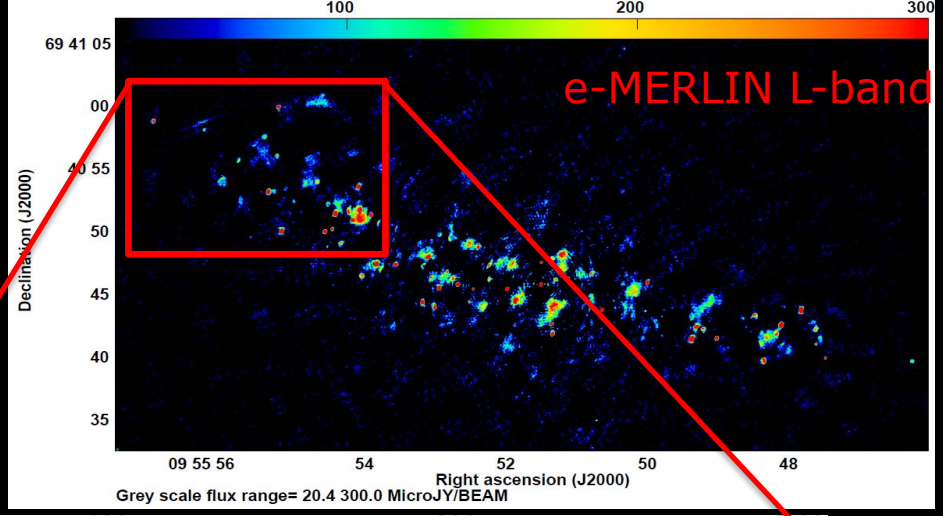
e-MERLIN radio telescope - size 220 kms

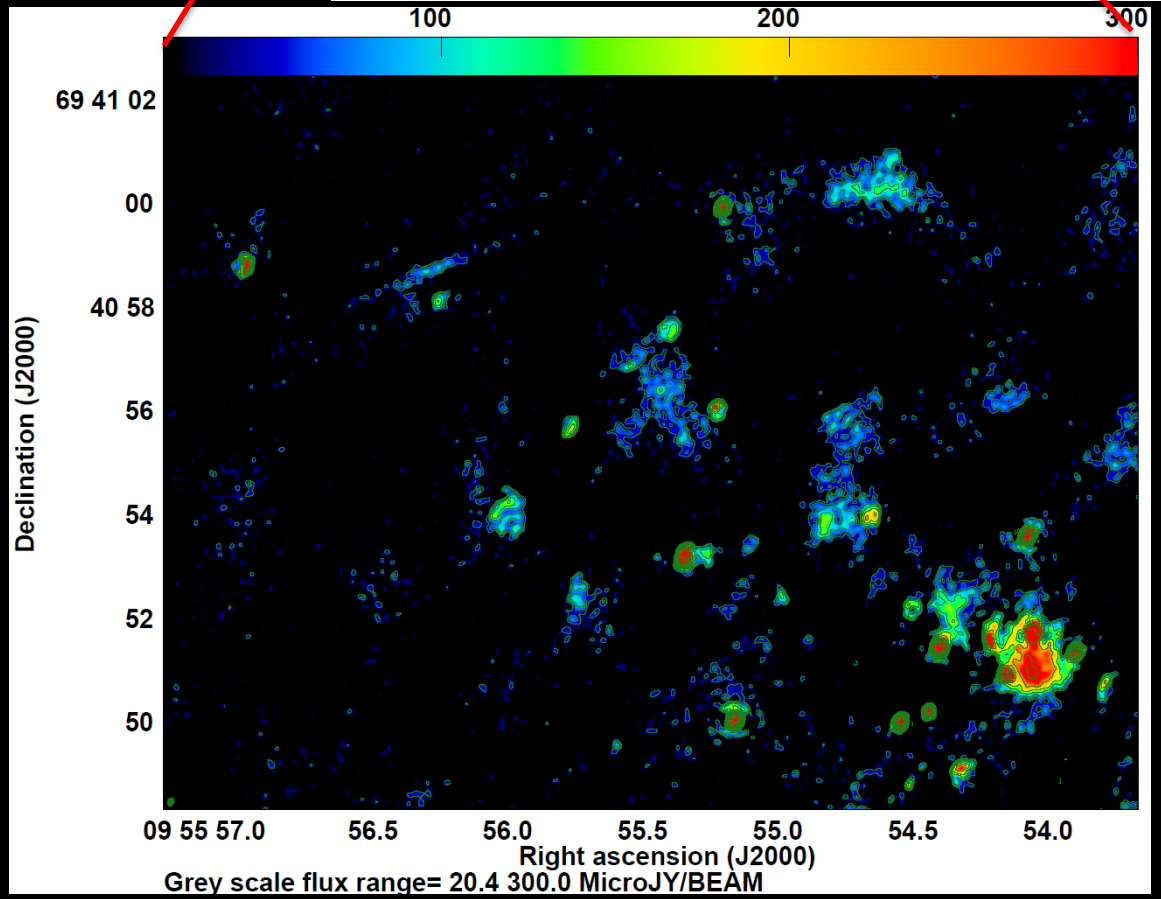




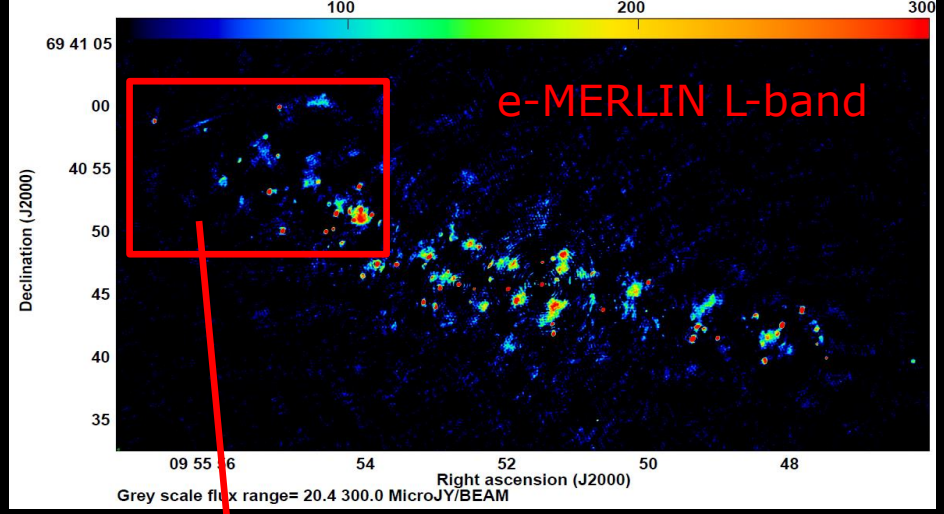
Old MERLIN+VLA

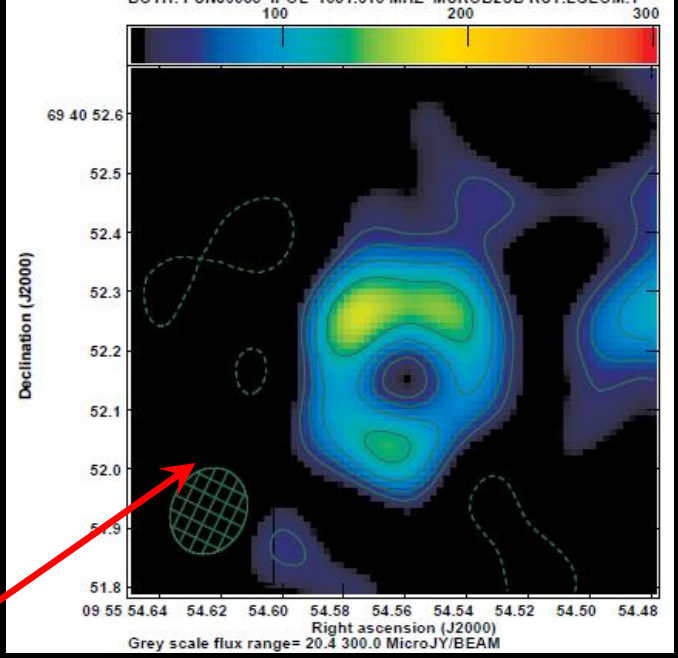




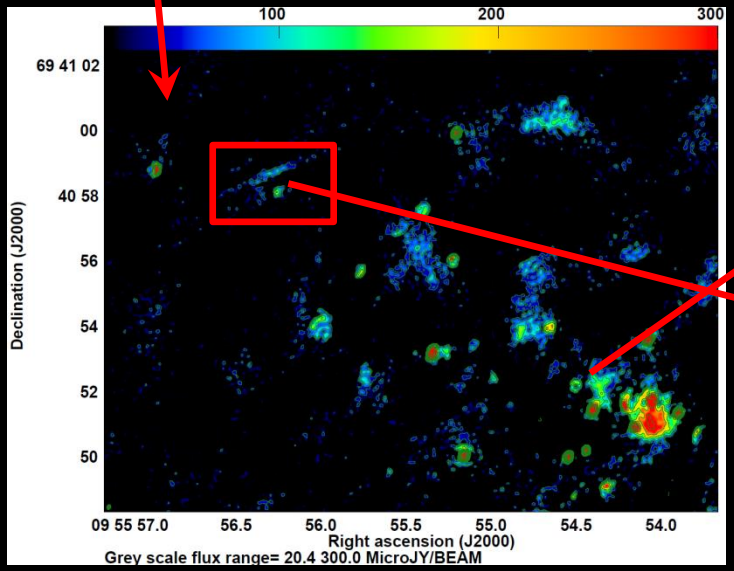


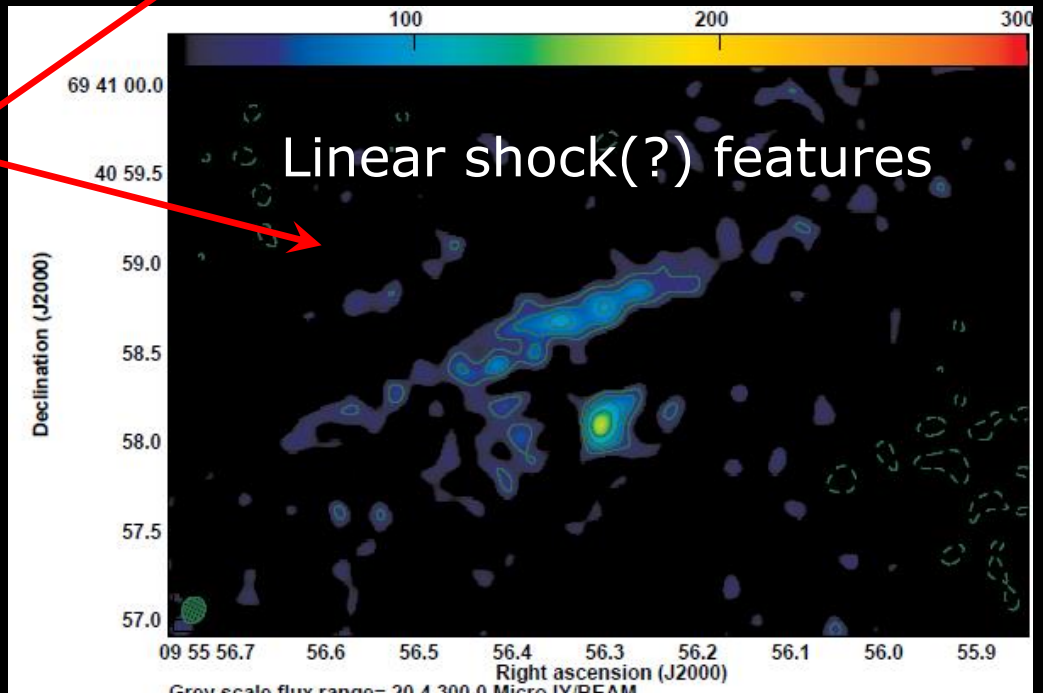
Short spacing imaging problems remain – combined e-MERLIN with JVLA still in progress





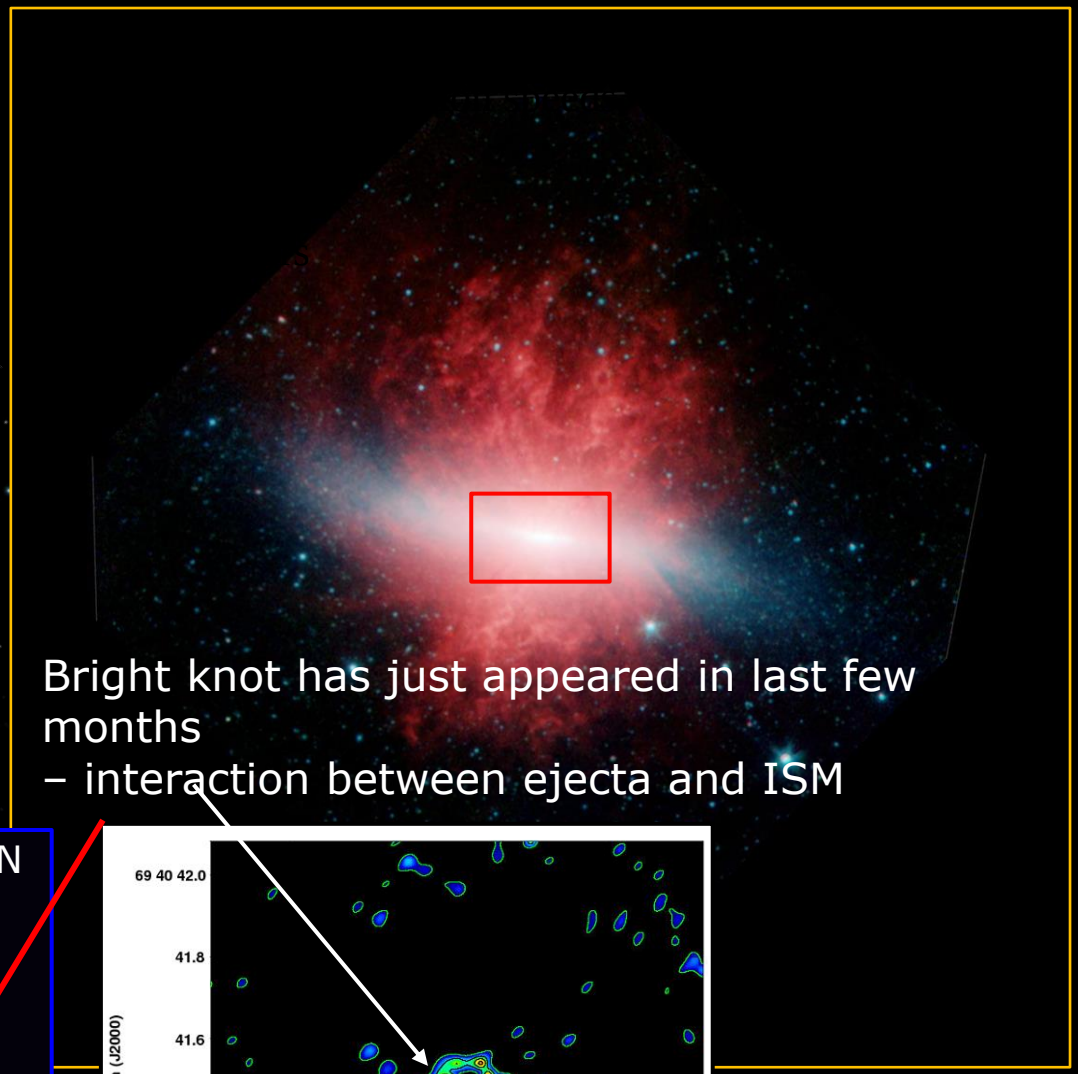
Multiple New faint 'old' RSNe





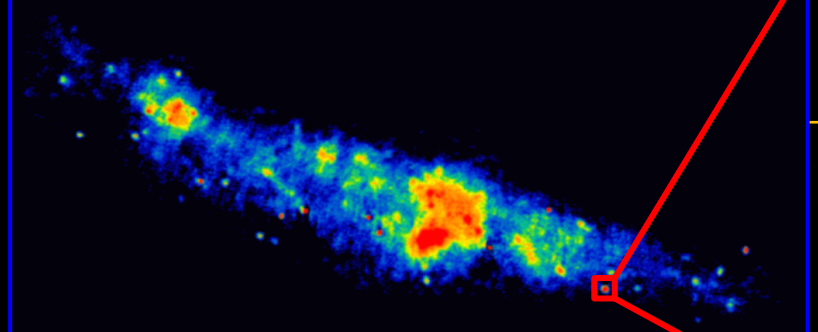
1.25-1.7GHz
Rms ~ 16uJy/bm,
150mas resolution

e-MERLIN radio telescope - size 220 kms

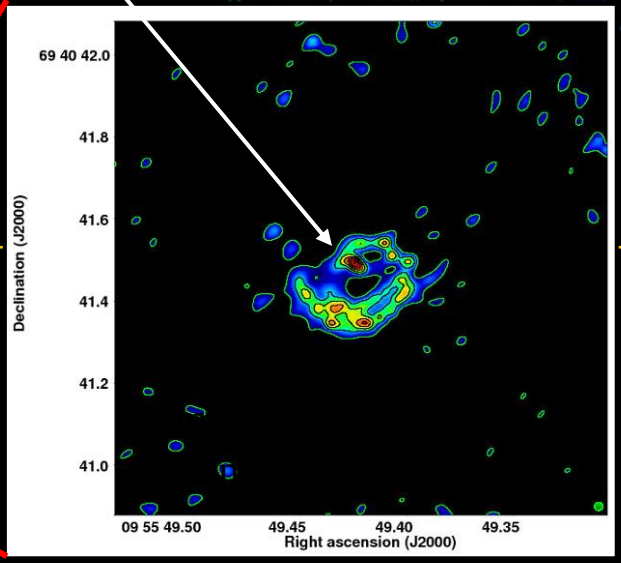


Bright knot has just appeared in last few months
– interaction between ejecta and ISM

Ultra-high resolution imaging *e*-MERLIN



– Measure expansion and deceleration



C-band,
13 uJy/bm
rms

Extend to deep imaging studies of starburst galaxies 1000 times distant

Narrow ultra-deep survey of thousands of star-forming galaxies

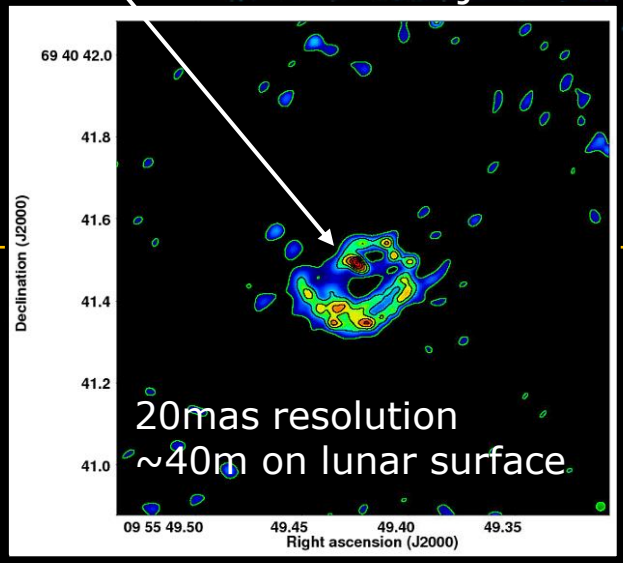
→ Measure the star-formation history of the Universe across cosmic time

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 last few months
– interaction between ejecta and ISM

Ultra-high resolution imaging *e*-MERLIN

– Measure expansion and deceleration



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Summary

- Initial observations underway
  - First deep studies, evaluating imaging fidelity
  - Snapshot imaging survey starting now(2014 Q2)
  - Image testing/scheduling and pipeline preparations ongoing.
  - First science starting to flow
  - Wide range of ancillary multi-wavelength data (eg HST, Chandra, Spitzer, Herschel) being collected.
  - Feasibility of large science survey aims and legacy value demonstrated
  - Initial postgrad projects started

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