The Legacy e-MERLIN Multi-Band Imaging of Nearby Galaxies Survey - results

Rob Beswick
On behalf of the LeMMINGs e-MERLIN Legacy team.
Outline

e-MERLIN (& LeMMINGs) – background & capabilities

Highlights of results

The future – what next??
e-MERLIN (SKA-pathfinder) operating at cm-λ with µJy sensitivity and ~10-220km baselines

Key/integral part of the EVN
- providing ‘short’ spacing baselines
- Now becoming fully integrated
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First science eEVN + e-MERLIN + SRT run (18/19<sup>th</sup> Sept 2018)
- 4 e-MERLIN stations (CM, KN, DE, & MK2)
**e-MERLIN Proposal deadline**

**PATT proposals** (aka PI-led proposals of all sizes)
- 6 monthly call cycle (spring/Autumn) – fully open
- Proposals accepted via Northstar proposals system
See [www.e-merlin.man.ac.uk/observe/](http://www.e-merlin.man.ac.uk/observe/)
- Online Simulator tools and exposure calculators available from e-MERLIN website
- Any use questions: e-merlin@jb.man.ac.uk

Typical oversubscription rates are
- 4-3:1 (all proposals)
- 8-5:1 (proposals requesting Lovell telescope inclusion)

**NEXT OPEN PATT DEADLINE:**
15th November 2018 – 23:59:19 UTC

See call at [www.e-merlin.ac.uk](http://www.e-merlin.ac.uk) – or speak to any e-MERLIN person here this week for info.
The e-MERLIN Legacy project: LeMMINGs

(a. k. a: Legacy e-MERLIN Multi-band Imaging of Nearby Galaxies)

Rob Beswick (JBCA/e-MERLIN)

Ian McHardy (Southampton)

Plus the whole LeMMINGs e-MERLIN Legacy team

Extra special mention to the key people that have really done the work:

Raneri Baldi, David Williams, Jonathan Westcott, Megan Argo, Bil Dullo
Original LeMMINGs Science case

• Basic premise of survey is to
  – Image a complete (representative) sample of nearby galaxies, encompassing all galaxy types, at sub-arcsecond angular resolutions and microJansky sensitivities. Multi-$\lambda$ follow-up. Provide a public legacy data-set.

• Built around three Core science themes:
  1. Measure star-formation activity and star-formation.
  2. Make a complete census of AGN activity and jet structures in galaxies
  3. A serendipitous parsec-scale imaging survey of the cold ISM via HI absorption and maser emission.

• 2-tiered approach to image $\sim$300 galaxies. Majority via snapshot imaging plus a smaller deep sample.
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Results DR1 (1/3 statistical sample), lots of single gal. results (Deep tier)!

On-going process working well - lots coming!!!

FIRST results DR1

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- coming soon
Two tier approach – Results thus far..

- Deep ‘targeted’ tier
  Multiple ‘single-source’ papers from deep tier programme + usage of data in other projects.. (incomplete selection)
  - Dullo et al 2018 MNRAS- NGC5322
  - Plus multiple papers associated or using LeMMINGs data

- Shallow ‘statistical’ tier - 280 gals sample
  - LeMMINGs Shallow paper#1 -- LEM#1 Baldi et al 2018, MNRAS (45pp!).
  - LEM#2 – Williams et al (radio, X-ray)
Samples

1) *Shallow(ish)* Sample = Palomar bright galaxy sample
   - Well selected sample of nearby galaxies (Ho ++ 1995)
   - Optical selected (NO radio bias), $B_T < 12.5$ mag
   - All galaxy types : Active (Seyfert, LINER), non-active (HII, Absorption line gals)
   - Total sample 280 galaxies, following applying a declination cut ($+>20$deg)
     - Median distance = 20Mpc
   - Strong multi-wavelength coverage ... both pre-existing and being compiled.
     - Complete HST, Spitzer and (near complete) Herschel
     - Almost complete Chandra imaging (with Associated LeMMING large programme approved to fill gaps)
     - Complete JVLA imaging (L + C-band), and selected sub-sample at 15GHz.

Project Core – e-MERLIN ‘shallow’ snapshot imaging survey of whole sample. (1.5GHz – complete, 5-7GHz pending)

2) *Deep* Sample = small number selected targets of interest at L & C-band with observations ~10 times deeper than shallow tier
LeMMINGs #1 – shallow (results Baldi et al 2018)

- Results release 1 (103 targets - snapshot)
  - image rms ~70µJy/bm @ 150mas ang res @ 1.5GHz
  - ‘Core region search only’ – inner 1arcmin only
  - 47/103 (~46%) detection rate at F>0.2mJy

Fractions by type:
1. LINER: 22/34 → 65%
2. Seyfert: 4/4 → 100%
3. HII: 16/51 → 31%
4. Absorption line gals: 5/14 → 36%
Typical core $L_{\text{core}} \sim 10^{32} - 10^{40}$ erg/s (ie. $\sim 100$ Sgr A* at L-band C-band will be $\sim 10 \times$ Sgr A*)

Survey depth $>10$ deeper than previous surveys (e.g. Nagar+, Filho+)

Optical source classification via BPT

Detection fraction follow $M_{\text{BH}}$

Jetted structures in sources $>10^6 M_\odot$
Typical images

Single core
NGC5353

Triple source
NGC4051

Double jet
NGC2681

Full resolution

Low resolution

200pc

70pc

50pc
Images

NGC0777  NGC0972  NGC2273  NGC4028  NGC2639  NGC2634
NGC2342  UGC3828  NGC2300  NGC2681  NGC2655  NGC2841
Radio – BH Mass

Detection fraction proportional to $M_{BH}$

For $M_{BH} > 10^{6.5} M_{BH}$

$L_{core} \sim M_{BH}$

Break below $10^{6.5} M_{BH}$

(Greater proportion of SF emission)

Hierarchical evolution + SF
Conclusions

- Nearby galaxy surveys with e-MERLIN are well suited to LLAGN, jets and SF on small scales.
- LeMMINGs survey first DR1 (103 gals) now available
  - Deepest survey high-res survey
  - Pc-scale radio emission to BH $\sim 10^6 M_\odot$
  - Lots more to come – Deep LeMMINGs survey producing wealth of results.
  - More shallow survey ($\sim 180$ more galaxies) C/L-band imaging

- Deep tier programme continues on smaller sample but at uJy/bm sensitivities

Next stages of data releases
  - Full sample (280 gals) including Ancillary data:
    HST imaging, Spitzer, Herschel, new Chandra imaging, new JVLA (1.5, 5 and 15GHz) ++ etc

All to be released with the complete DR1 data set from e-MERLIN..
Special thanks

**All credit to:** Wider LeMMINGs team how have done all the hard work.

But especially
- David Williams (Soton, PhD -> Now PDRA Oxford)
- Jonathan Westcott (Herts, PhD → Soon PDRA at Herts)
- Raneri Baldi, Megan Argo, Bil Dullo
- Plus all of the other LeMMINGs core team members!