



# e-MERLIN science overview

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The MERLIN logo, featuring the word "MERLIN" in a bold, white, sans-serif font. A stylized green and blue swoosh graphic is positioned to the left of the text, and a small white starburst icon is to the right.

# e-MERLIN

e-MERLIN (SKA-pathfinder)  
operating at cm- $\lambda$  with  $\mu\text{Jy}$   
sensitivity and  $\sim 10\text{-}220\text{km}$   
baselines



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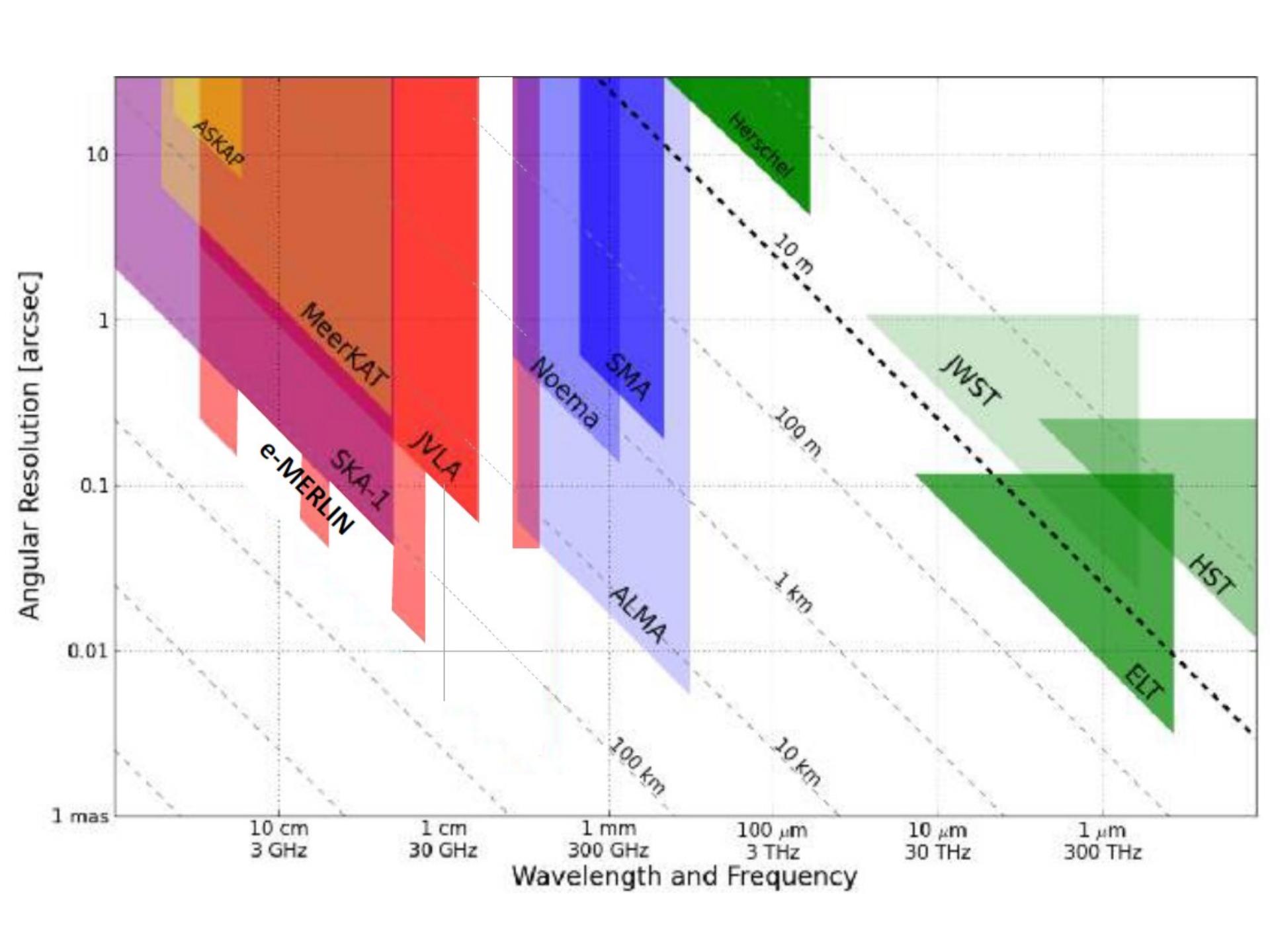
Key/integral part of the EVN  
- providing 'short' spacing baselines  
- Now becoming fully integrated

# e-MERLIN

Unique instrument covering particular resolutions scales..

Basic Capabilities - See [www.e-merlin.ac.uk](http://www.e-merlin.ac.uk) for more details

	1.5GHz (L-band)	5GHz (C-band)	22GHz (K-band)	Notes
Resolution (milliarcseconds)	150	40	12	Uniform weight at central frequency
Field of View (FoV) (arcmin)	30	7	2	FWHM of 25m dishes; reduced when the Lovell Telescope is included
Frequency range (GHz)	1.25-1.75	4-8	21-24	Tunable frequency range
Bandwidth (GHz)	0.5	2	2	Max bandwidth per polarisation; at C or K-band, 4GHz is possible using a single polarisation.
Sensitivity ( $\mu$ Jy/bm) in a full imaging run	6-7	4	15	Performance depends on usable bandwidth and observing conditions. Figures are for e-MERLIN with the Lovell telescope at L and C-band.
Surface brightness sensitivity (K)	190	~70	~530	
ICRF astrometric performance (mas)	2	~1	~2	With respect to the ICRF (assuming a typical 3° target-calibrator separation)
Astrometric repeatability (mas)	~0.5	~0.2	~1	Day-to-day repeatability using surveyed or in-beam sources, and assuming a full imaging run
Amplitude calibration (%)	2	1	10	Targets for day-to-day repeatability



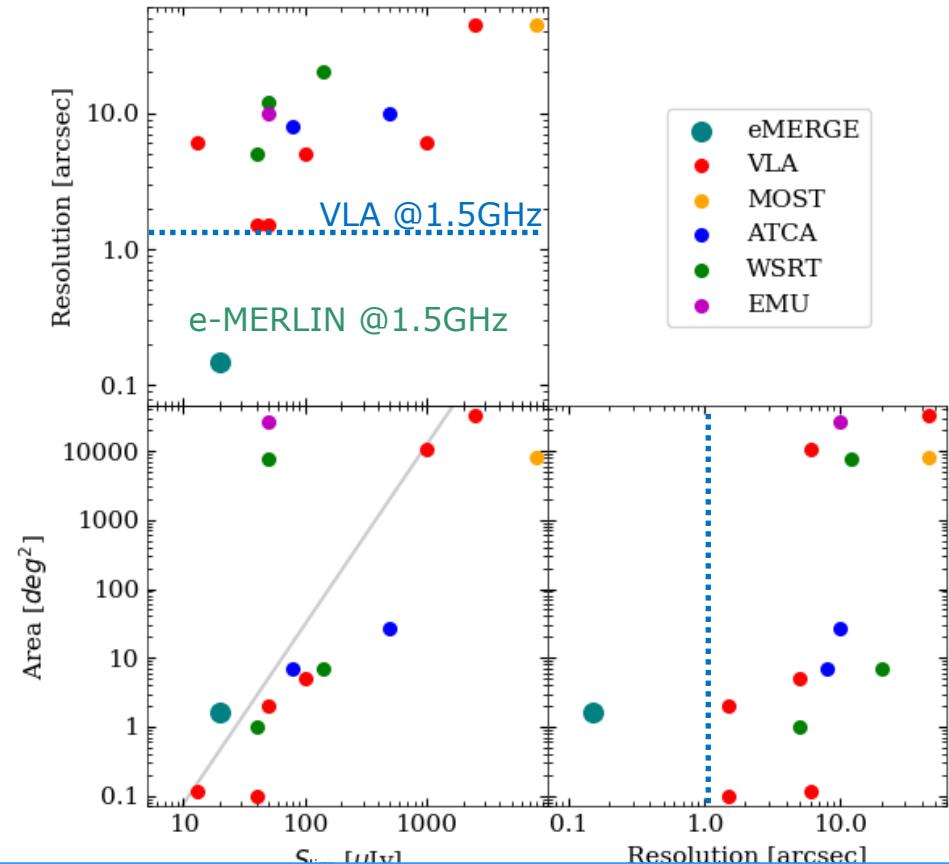
# Area/Depth/Resolution..

Traditionally e-MERLIN 'more targeted' objected based programmes.

Large legacy surveys now targeting wide areas

- eMERGE, AGATE, SuperCLASS & CoBRAS

- *Large FoV – lots of pixels/big data*
- Unique part of *resolution discovery-space*



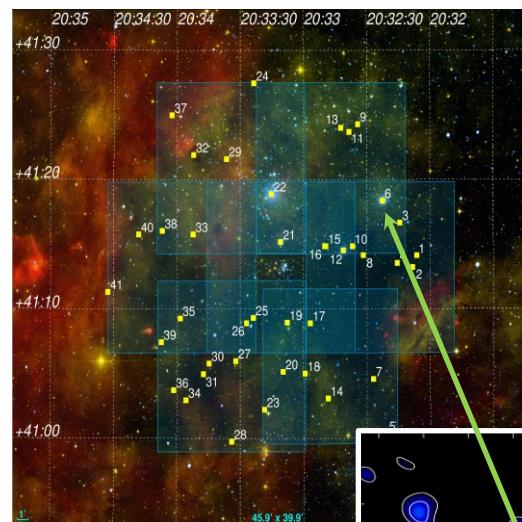
e-MERLIN resolution – actually resolve all sources!!

- spatial separation of SF/AGN at high-z
- resolve galactic source

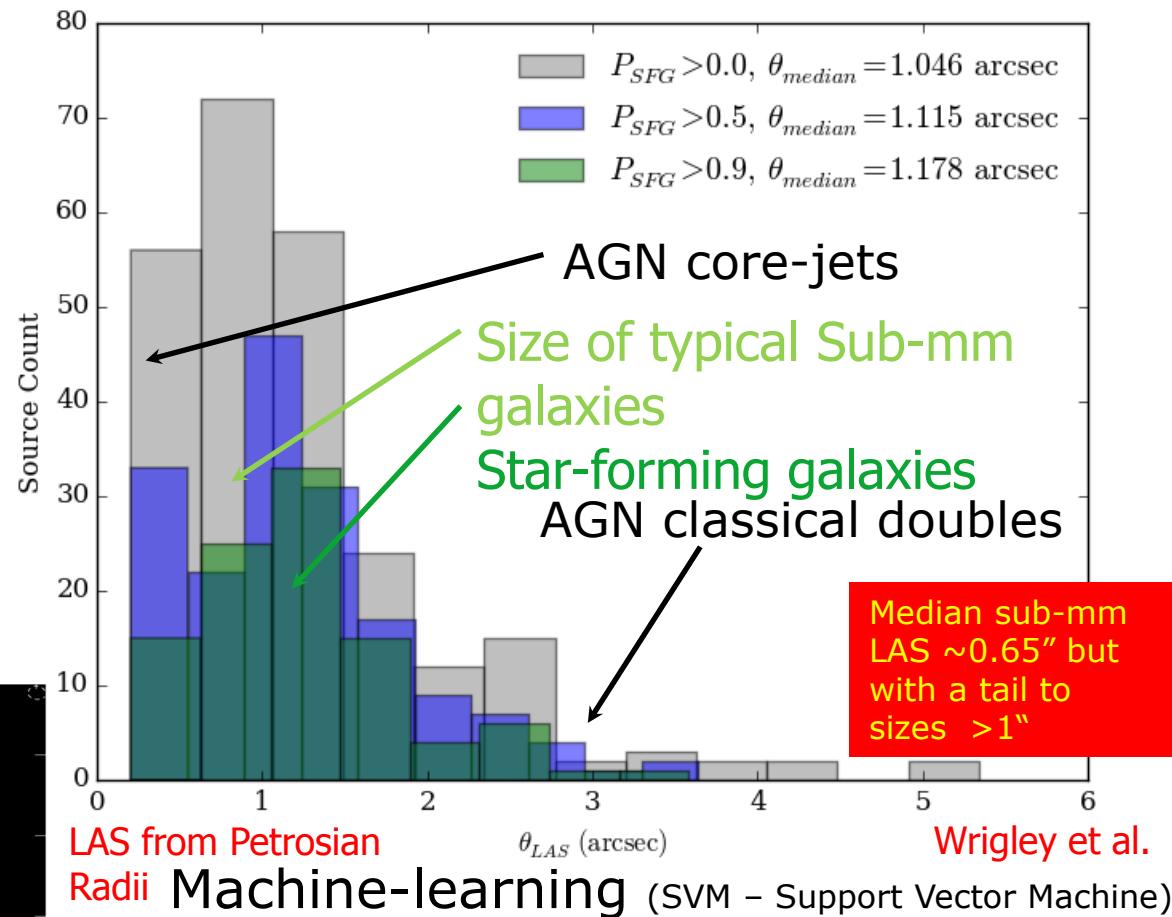
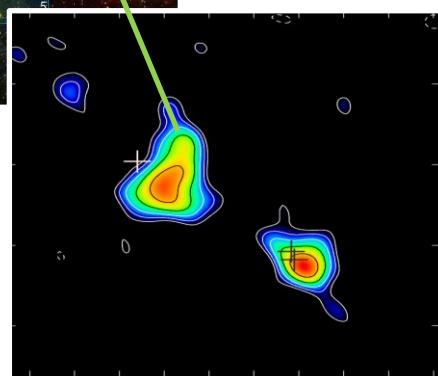
*Surveys & Detailed resolved astrophysics*

# Size of the faint radio source populations

EX-GAL : Assign probabilities of being AGN or SF from radio structures and spectral properties...



GAL : resolve stellar systems, outflows, stellar winds...



# e-MERLIN access : Proposals

**PATT proposals** (aka PI-led proposals of all sizes)

**Next deadline – call imminent – deadline : end of October**

- 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](mailto:e-merlin@jb.man.ac.uk)**

## **Existing Large Legacy projects**

- Account for ~50% of available observing time
- Competitively allocated programme - 12 large projects
- Cover all science areas – planets to cosmology
- Long-term observing status – allowing large international teams to build resources and sustain projects.
- Opportunities for new projects will be available... soon!...

## legacy programme:

### Addressing the Key science challenges..

**12 Large projects covering planet formation → cosmology**

#### **Galactic Science :**

- eΠ - Pulsar astrometry – Vlemmings/Stappers et al. 160hrs\*
- PEEBLES – planet formation - Greaves et al. 402hrs
- Feedback processes in Massive SF – Hoare/Vlemmings et al. 450hrs
- Thermal jets from low mass stars - Rodriguez et al 180hrs
- COBRaS – wide-field deep galactic survey - Prinja et al. 294hrs

#### **Extragalactic and cosmology :**

- LEMMINGS – 300 nearby gals - Beswick/McHardy et al. 810hrs
- LIRGI – LIRGs/ULIRGs - Conway/Perez-Torres et al. 353hrs
- Extragalactic Jets – Laing/Hardcastle et al 375hrs
- AGATE – cluster fields - Simpson/Smail et al 330hrs
- e-MERGE – deep field - Muxlow/Smail/McHardy et al 918hrs
- Gravitational lenses – Jackson/Serjeant et al 228hrs \*
- SuperCLASS - 1+deg<sup>2</sup> supercluster field - Battye et al 832hrs

\* Additional allocations pending on-going reviews

# e-MERLIN/VLBI Legacy Science

Pulsars, Gravity & Gravitational waves

Time-domain & Transient astrophysics

Planet & star-formation

Galaxy formation & evolution

Cosmic shear & Gravitational lensing

# e-MERLIN Science

Pulsars, Gravity &  
Gravitational waves

See talks later this afternoon -  
Weltevrede

Time-domain & Transient astrophysics

Planet & star-formation

See talks later in this meeting -  
Greaves/Drabeck-Maunder, Richards,  
Fenech, Etoka

Galaxy formation & evolution

See talks later in this meeting -  
Baldi/williams, Muxlow

Cosmic shear & Gravitational  
lensing

See talks later this meeting -  
Harrison, Hartley

# e-MERLIN Science

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# Time-Domain astrophysics

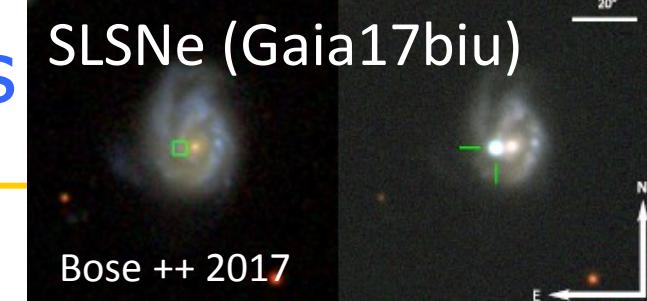
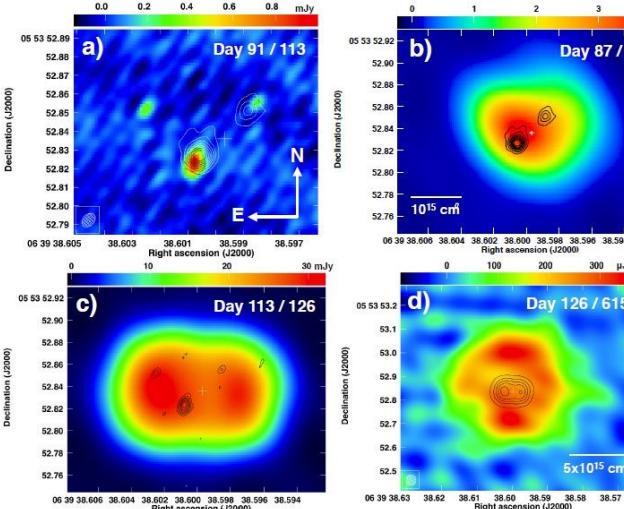
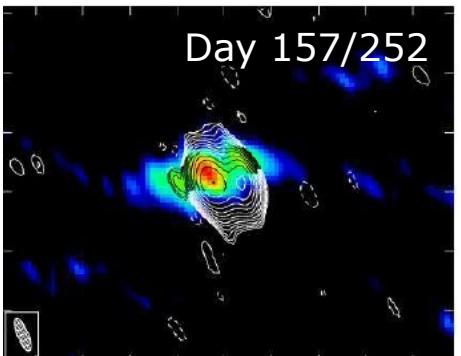
*'rapid response, sensitivity and resolution'*

e-MERLIN provides high sensitivity, temporal imaging, mas-astrometry, flux monitoring of time variable objects.

From XRB, novae to SNe, SLSNe, TDEs, GRBs, FRBs, GW-EM

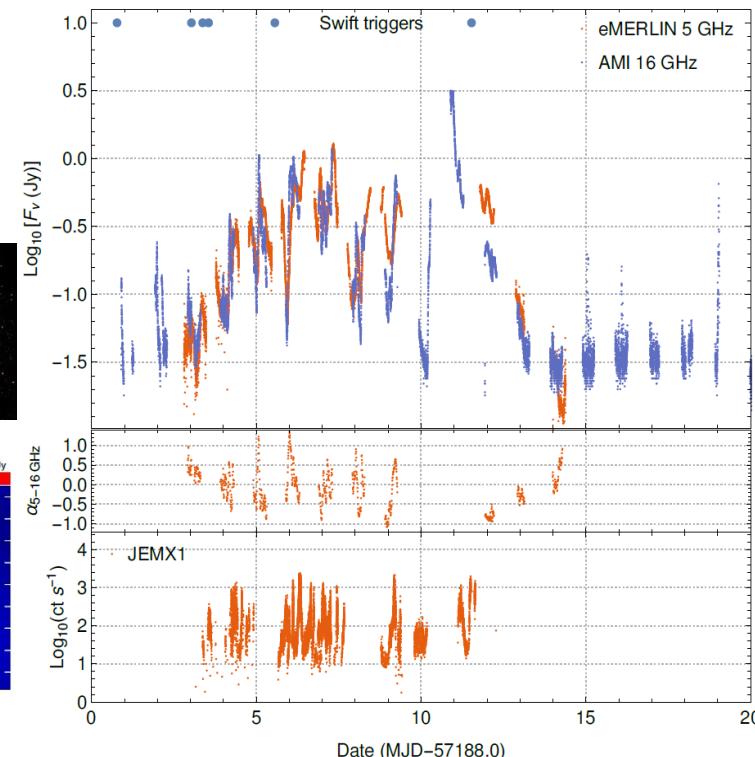
- Most energetic cosmic sources
- High energy particle accelerations
- Time-evolving structures

Evolution of the gamma ray nova (Nova mon)  
EVN+e-MERLIN, JVLA  
Chomiuk + 2014 Nature,  
Healy+ 2017 MNRAS



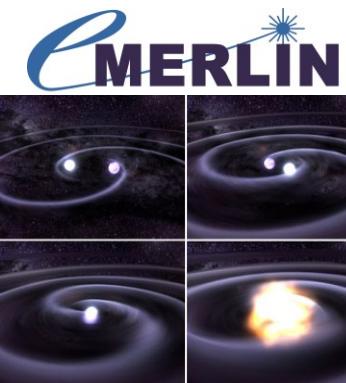
SLSNe (Gaia17biu)

Bose ++ 2017



V404cyg 2015 outburst from stellar mass Black-Hole binary

- Unprecedented coverage of particle acceleration (Fender et al., in prep)



# Time-Domain astrophysics

*'rapid response, sensitivity and resolution'*

X-ray peak

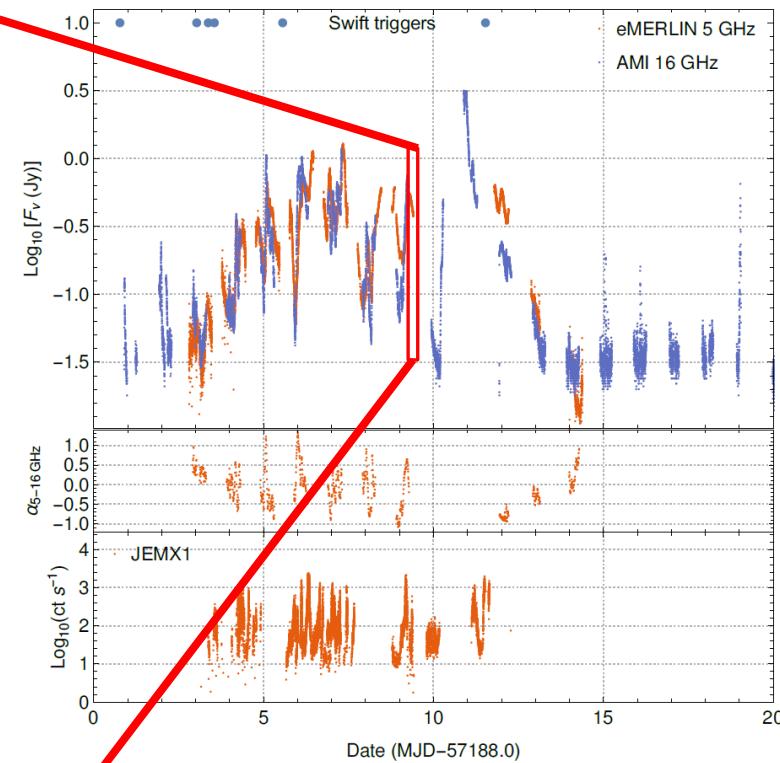
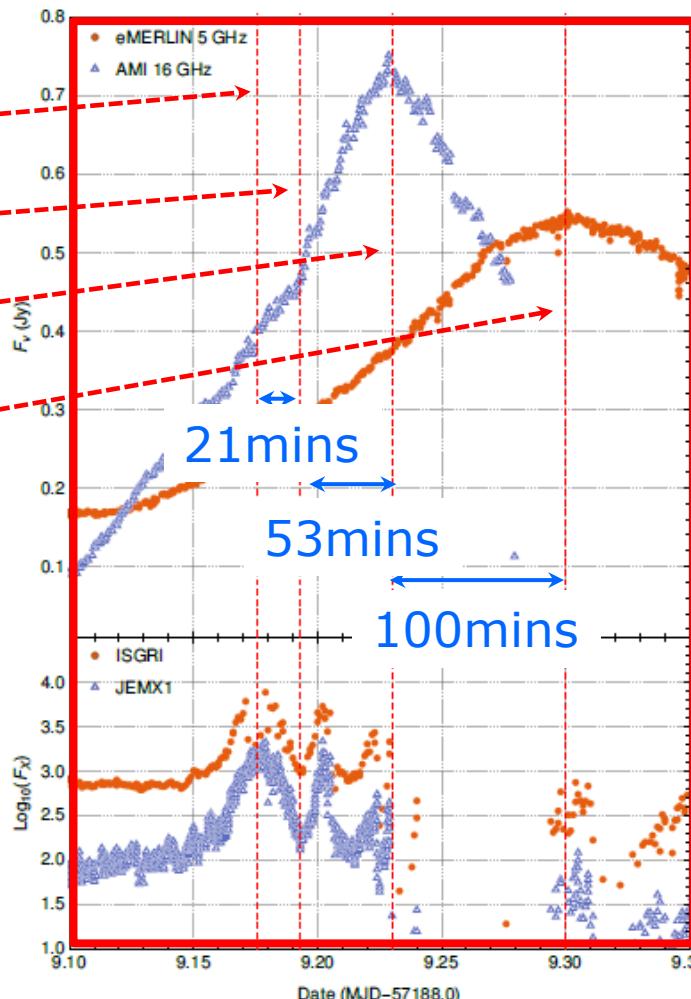
Radio spectral index change

16GHz emission peak

5GHz emission peak

e-MERLIN plus multi- $\lambda$  campaign

- Highest cadence radio observations
- No jet on e-MERLIN scales (>30mas scales)
- Mix of discrete impulsive particle acceleration injection and strong extended injection events .



V404cyg 2015 outburst from stellar mass Black-Hole binary  
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# e-MERLIN/VLBI Science

Pulsars, Gravity & Gravitational waves

Time-domain & Transient astrophysics

Planet & star-formation

See talks later in this meeting -  
Greaves/Drabeck-Maunder, Richards,  
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Galaxy formation & evolution

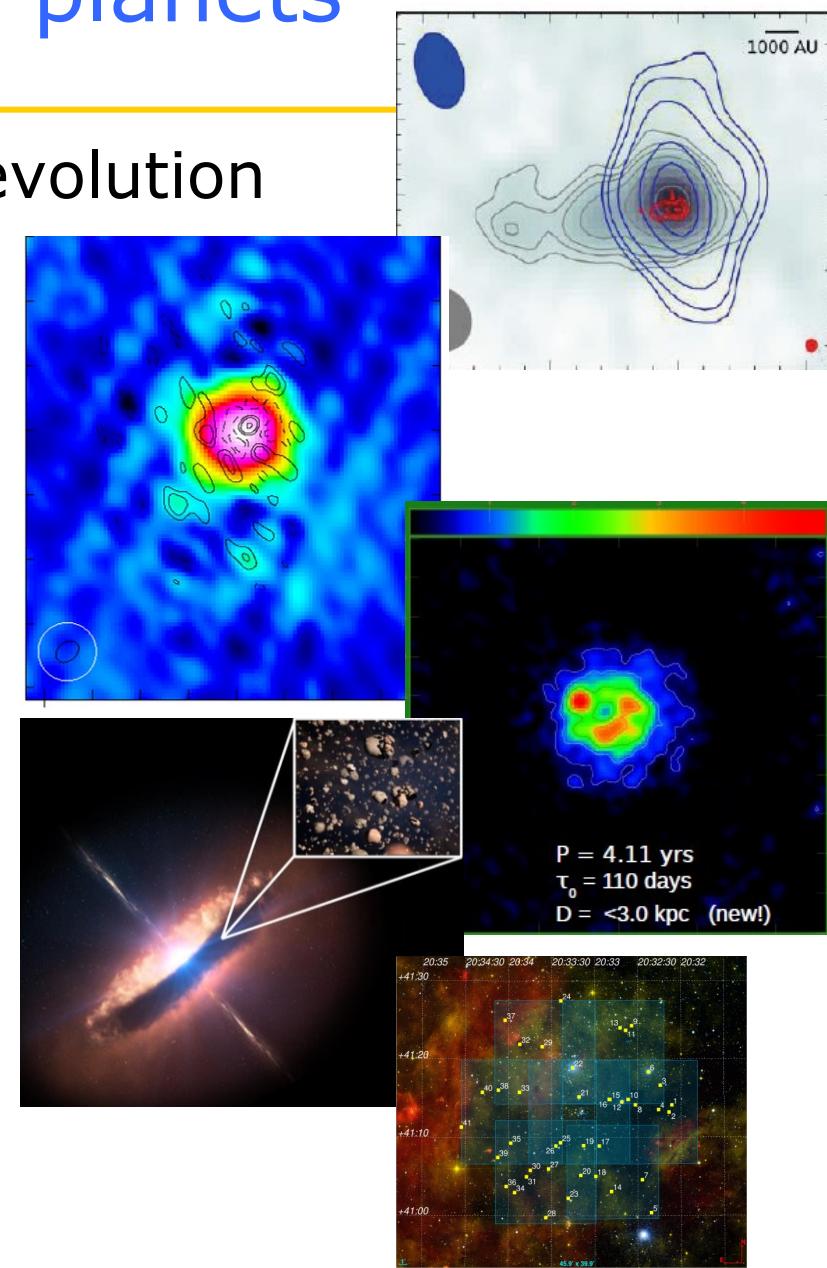
Cosmic shear & Gravitational lensing

# From stars to planets

*'sensitivity, resolution, spectral lines'*

Probing full range of stellar evolution  
and planet formation

- cm-sized grain formation in protoplanetary disks
- YSOs to evolved stars to stellar end-points
- Stellar outflows
- Stellar evolution
- Molecular astrophysics
- Magnetic fields
- Fundamental physics



Multiple legacy programmes

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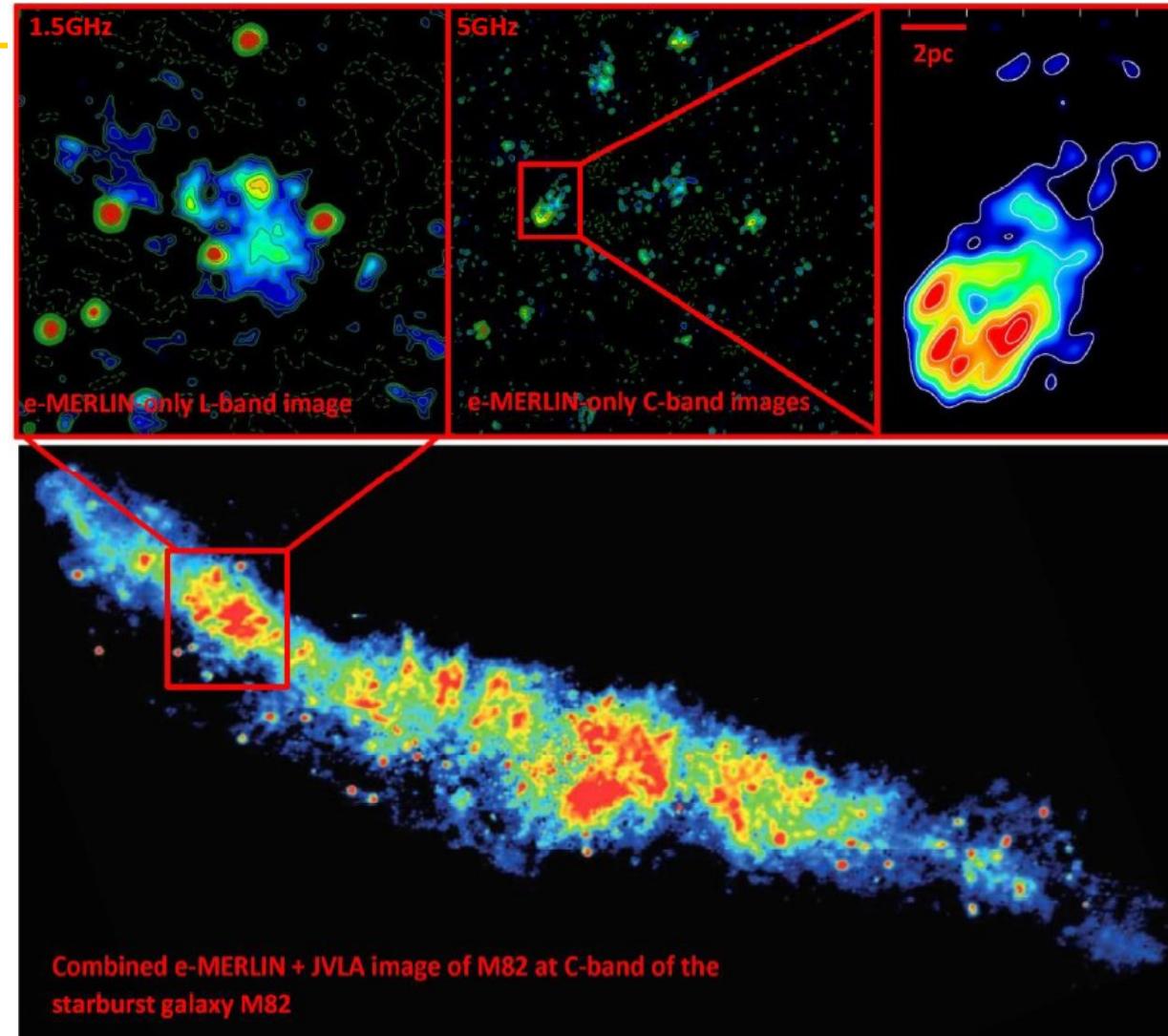
# The Local Universe

Seeing through the dust

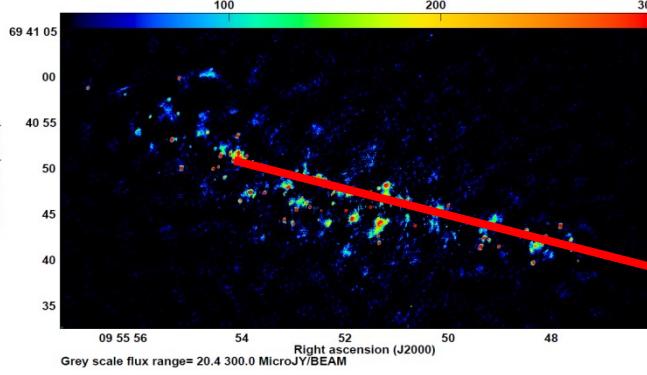
Decomposing individual galaxies into 100s of SF/accretion products – unique laboratories for galaxy evolution

Physics of SF/accretion on sub-pc scales.

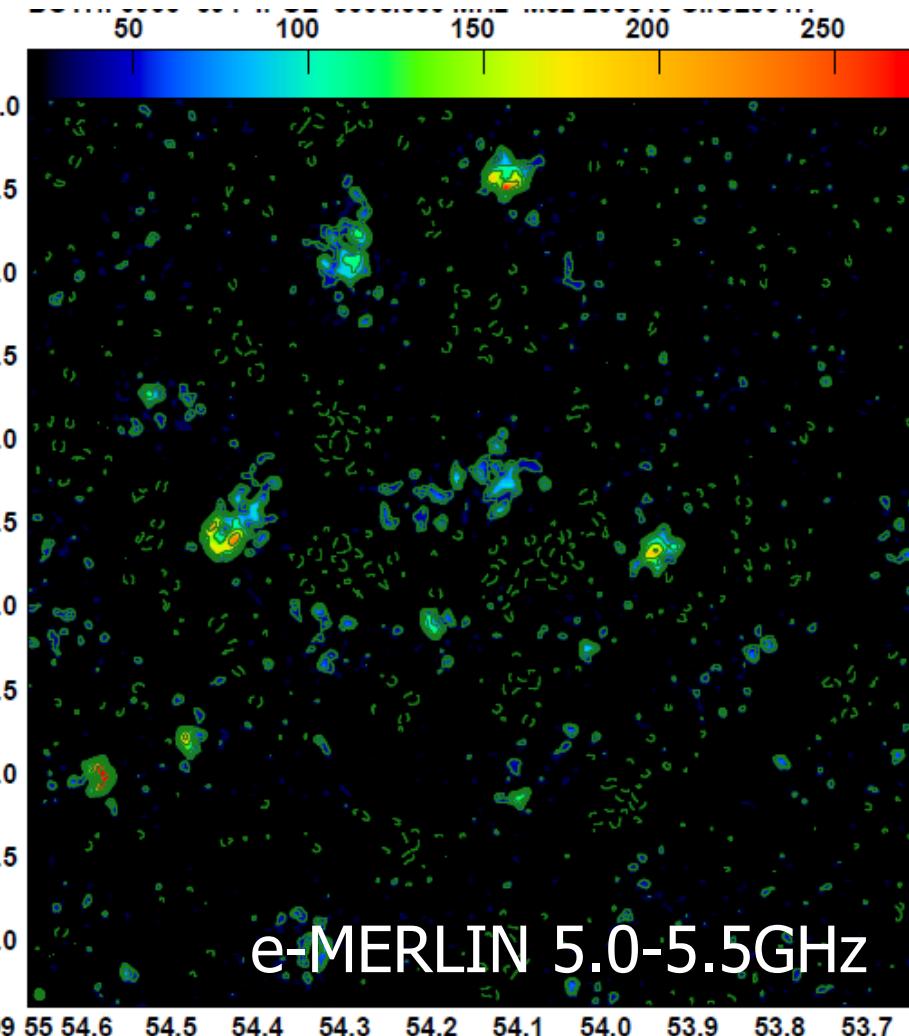
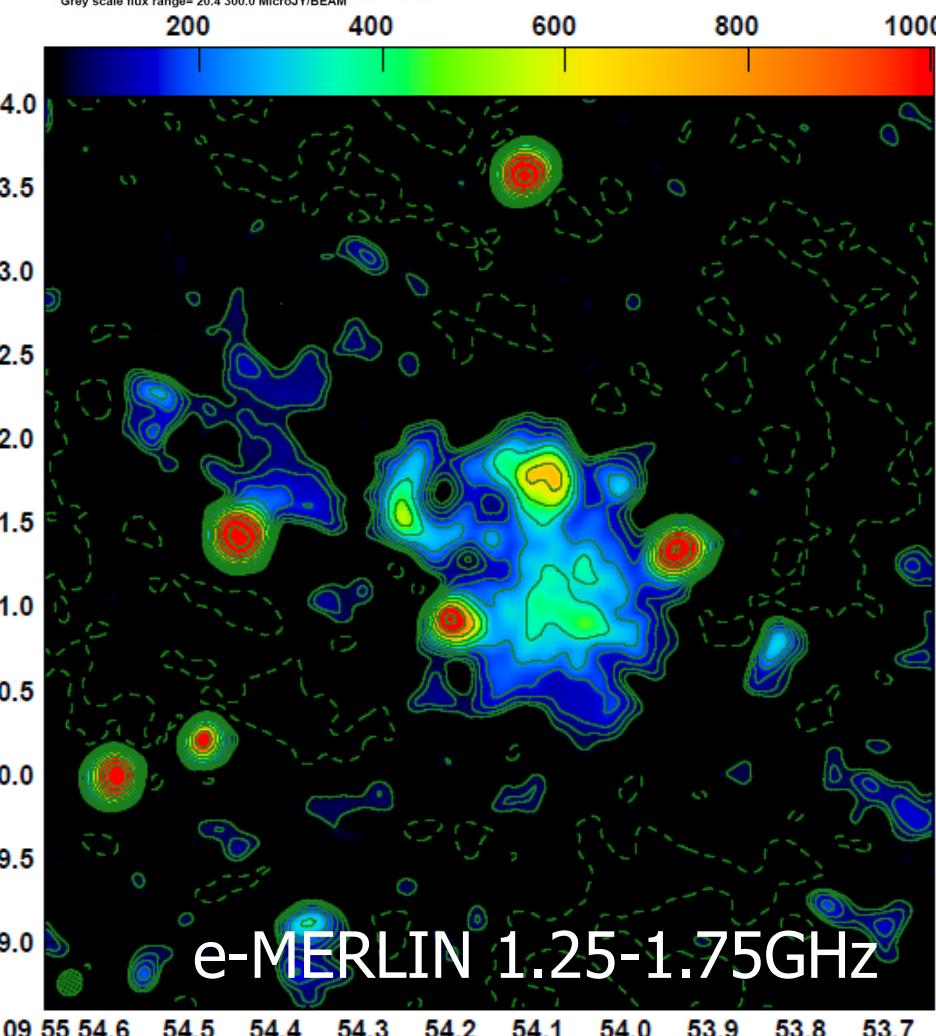
Galactic-style physics in galaxies of all environments and classifications



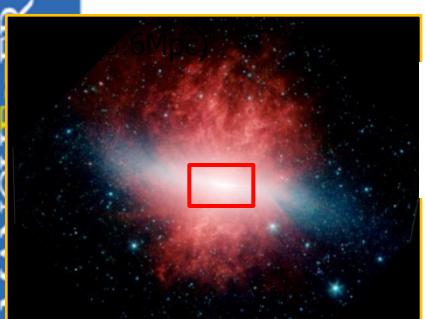
LeMMINGs legacy programme (Beswick/McHardy et al)



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



# M82 – Deep Imaging

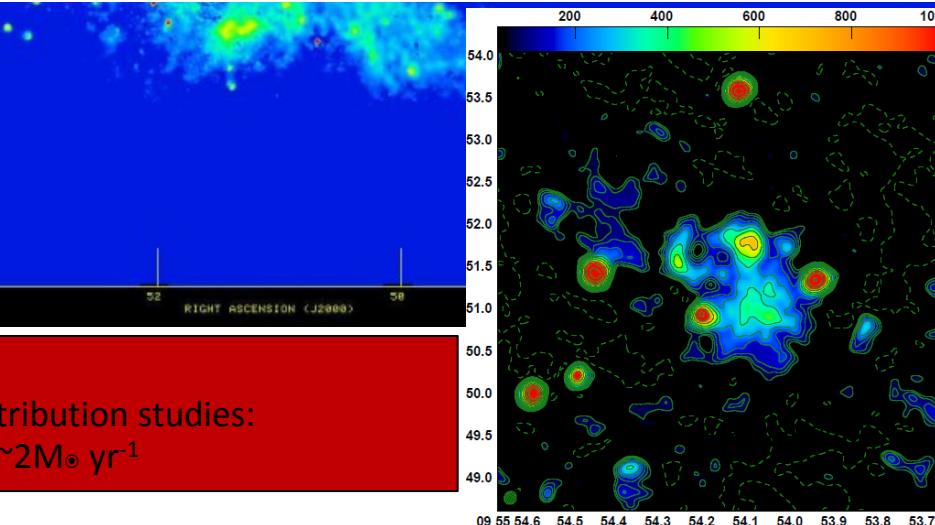
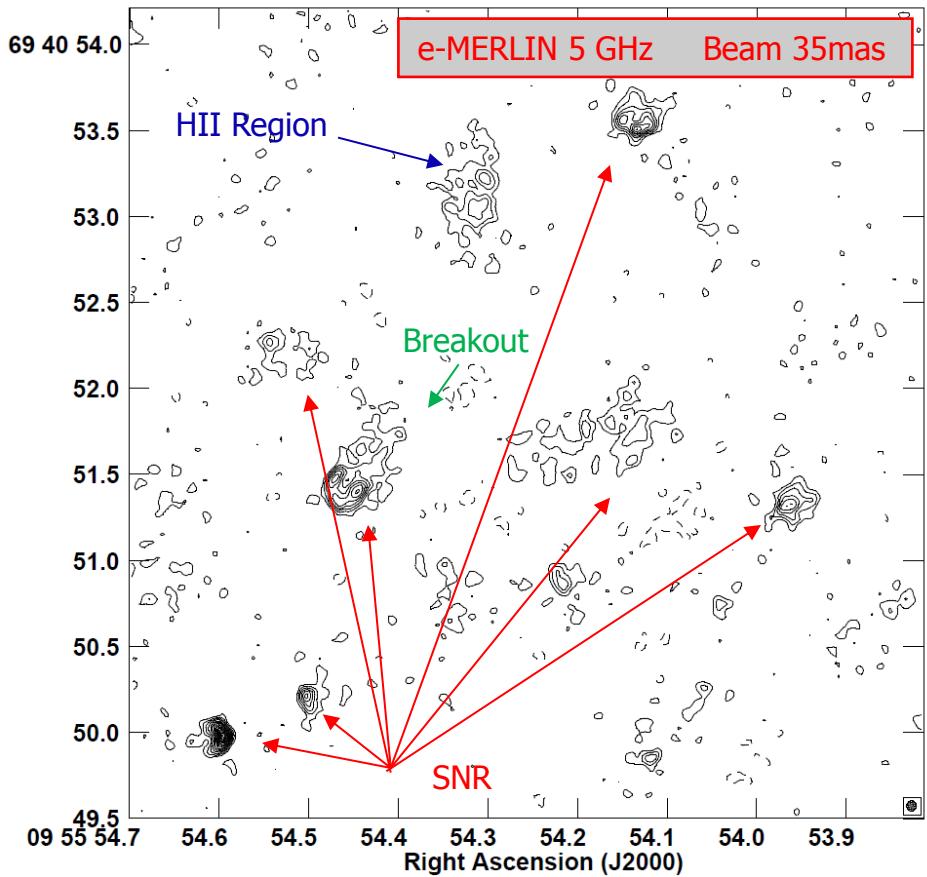
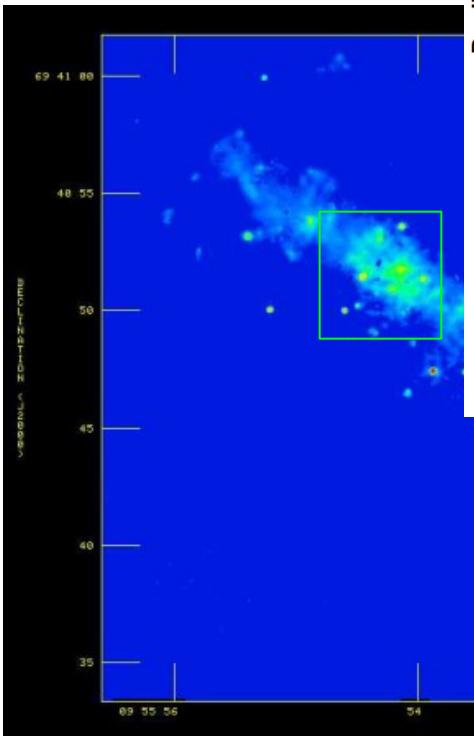


Combination e-MERLIN +JVLA 5GHz image of central  $\sim 1\text{kpc}$  in M82

Deep high angular resolution e-MERLIN 5GHz image: Beam 35mas  
 $1\sigma \sim 9\mu\text{Jy}/\text{bm}$

Spectral properties from comparison with deep e-MERLIN 1.5GHz image: Beam 220mas  
 $1\sigma \sim 15\mu\text{Jy}/\text{bm}$

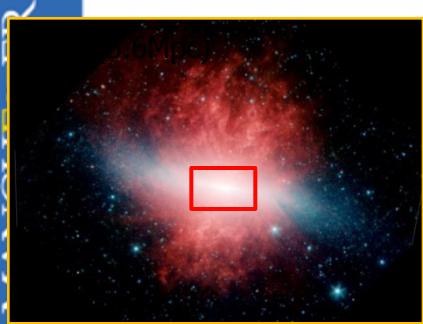
Mapping individual HII regions & SNR



81 classified compact sources: 53 SNR + 27 HII regions:

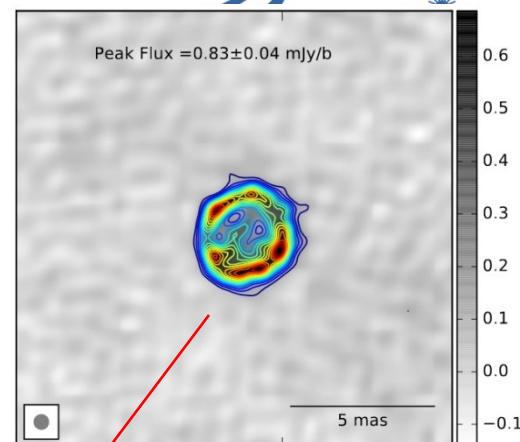
Casseopeia A luminosity comparisons + cumulative size distribution studies:  
SNe rate  $\sim 0.07 \text{ yr}^{-1}$  (1 SNe every  $\sim 15$  yrs)  $\rightarrow$  SFR ( $>5\text{M}_\odot$ )  $\sim 2\text{M}_\odot \text{ yr}^{-1}$

# Recent Type II SNe – VLBI Imaging



VLBI image of the expanding shell from SN2008iz on day 595 after the Sne explosion (Kimani et al 2016)

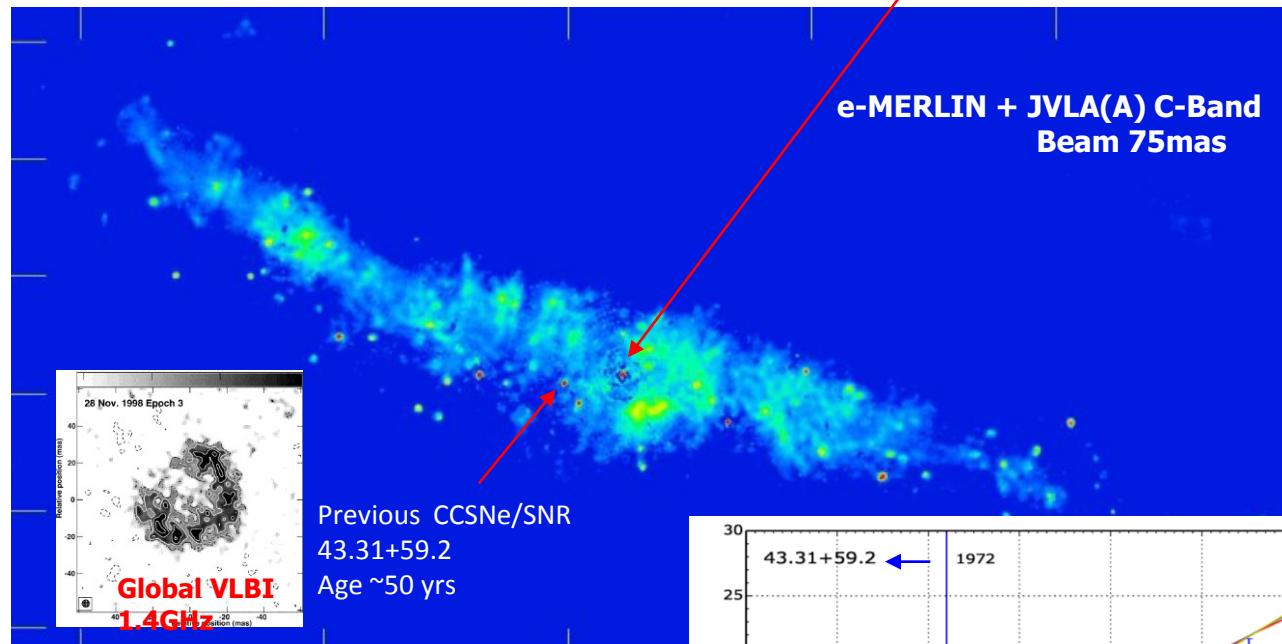
Initial expansion velocity  $\sim 21,000 \text{ km/s}$   
 $\rightarrow \sim 12,000 \text{ km/s} \text{ after } \sim 4 \text{ years } [R \sim t^{0.86}]$



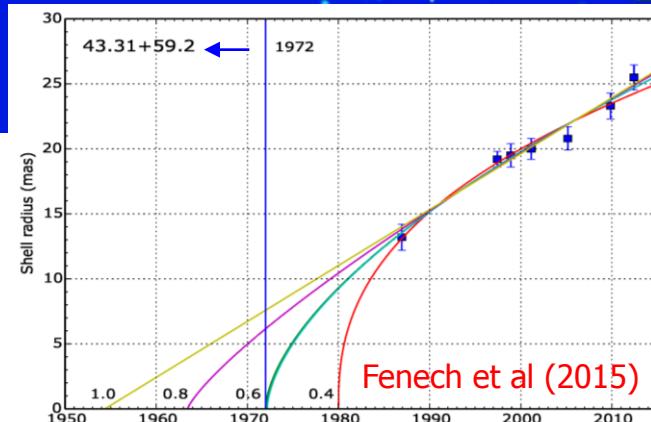
43.31+59.2:  
Evolution of SNR shows  
expansion beginning to  
slow  $[R \sim t^{0.8}]$

2<sup>nd</sup> youngest M82  
remnant – exploded in  
1960s?  
Velocity  $\sim 7200 \text{ km s}^{-1}$   
 $\rightarrow > 15,000 \text{ km s}^{-1}$  at  
birth

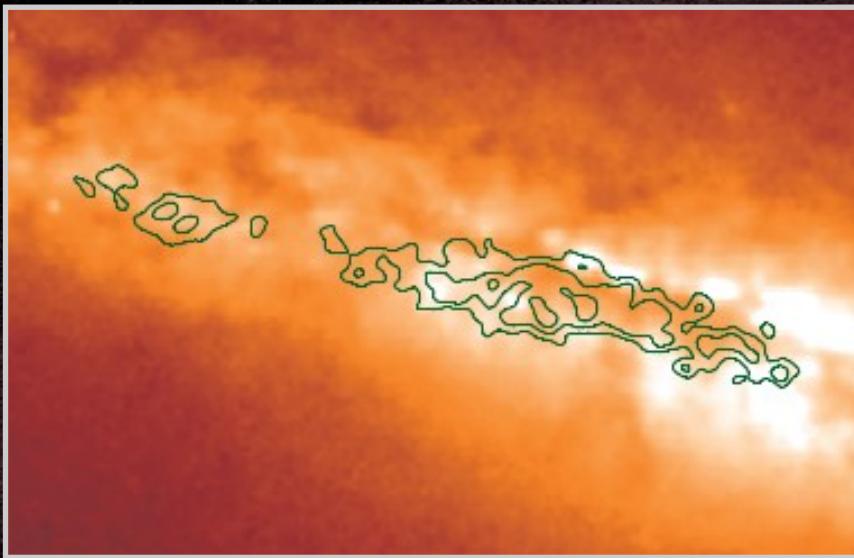
Detected by Kronberg &  
Wilkinson (1975) with  
observations taken in  
1972



3 SNe (2 type II and 1 type Ia) in  
the last  $\sim 50$  years      43.31+59.2,  
SN2008iz, SN2014j

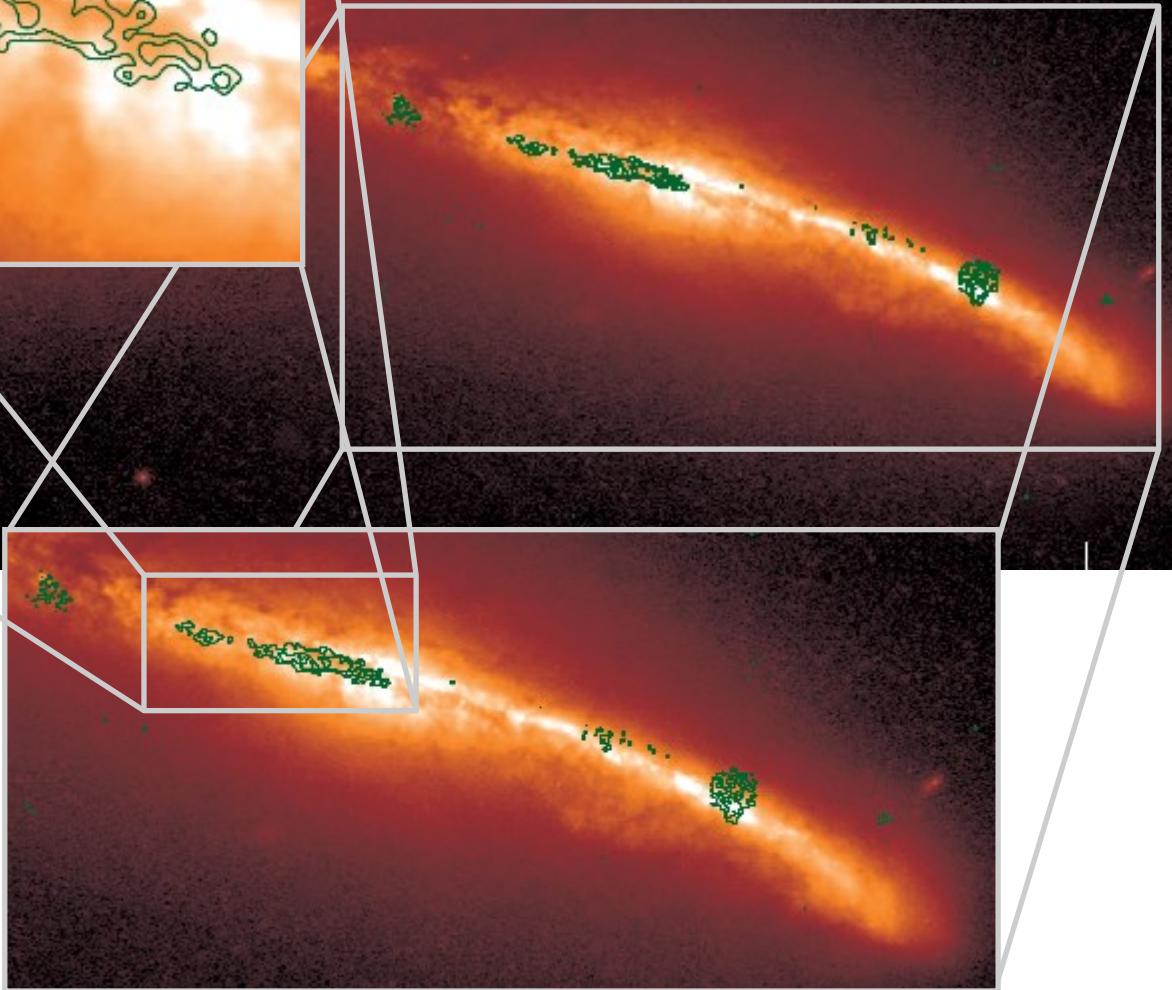


Merging LIRG NGC6670  
HST WFC3/e-MERLIN  
(Alberdi & LIRGI/GOALS projects)



Edge-on disk galaxy  
merger in early stages of  
interaction ( $D \sim 120$ Mpc)

Radio traces obscured  
nuclear starburst/SF  
along galaxy disk.



LIRGI legacy programme (Perez-Torres/Conway et al)

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# Cosmic shear : radio weak lensing

Pioneering radio weak lensing surveys -  
aiming at first radio weak lensing  
detections. Pathfinder for SKA science

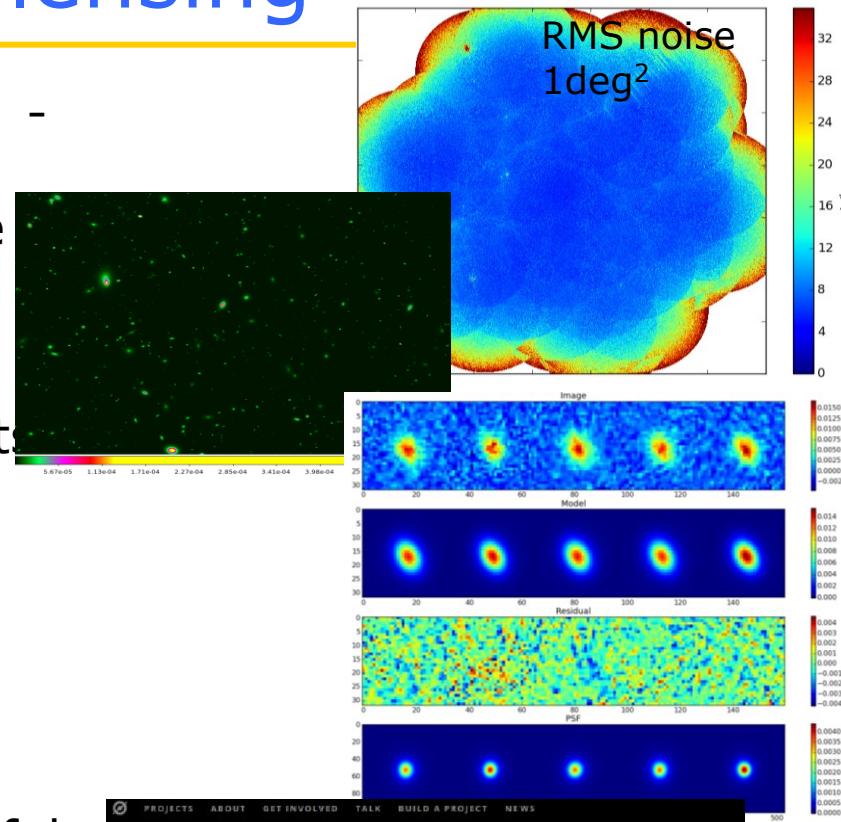
Exploiting e-MERLIN's unique  
ability to resolve high-z radio starbursts

- precisely defined, stable PSF

SuperCLASS field covering multiple  
supercluster fields

- combined Multi- $\lambda$  programme

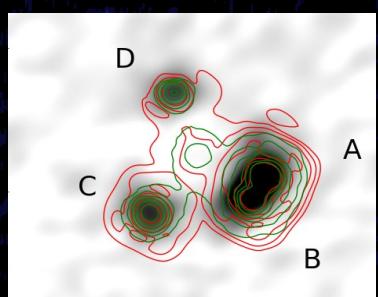
Radio + Optical weak lensing → powerful  
complementary constraints.



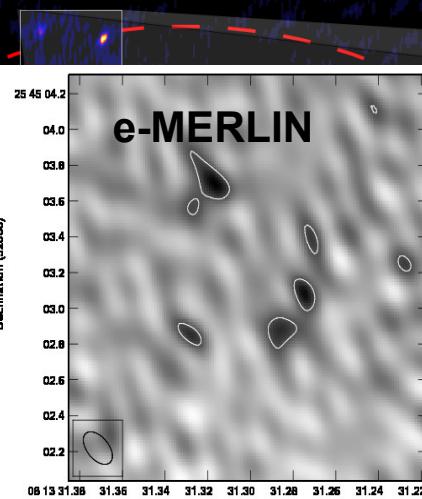
SuperCLASS legacy programme  
(Battye et al)

# Probing the faintest $3\mu\text{Jy}$ Radio-quiet quasars

Intrinsic flux density  $\sim 3\mu\text{Jy}$  (SKA SCIENCE NOW)  
r.m.s. =  $7\mu\text{Jy}/\text{beam}$

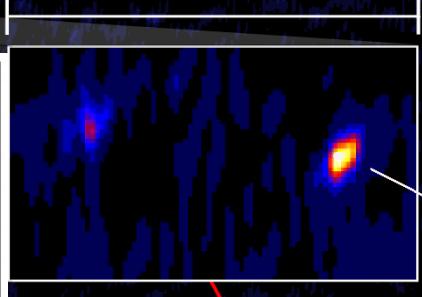


Multi-resolution  
→ nature  
of radio  
emission  
(AGN-dominated)  
& Lens models  
→ Probe galaxy  
Substructure

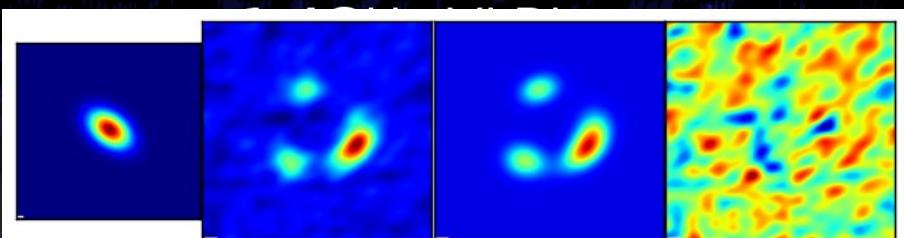


QSO J0810+2554

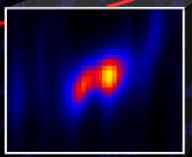
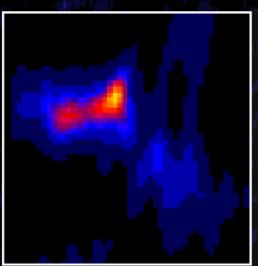
$\sim 0.1''$



$T_B \sim 10^6 \text{ K}$



LENS MODEL



# Summary

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- e-MERLIN provides a unique set of capabilities
  - Providing the frequencies and baseline lengths of SKA1-Mid now.. Perfect for (pre-SKA) science demonstration and development..
- e-MERLIN legacy programme covering a wide range of science goals
  - Current programmes first sets of results coming out now
  - New programmes will be considered in future rounds
- Exciting range of new capabilities being considered to further enhance instrument (~15M£ programme)
  - Great capabilities and complementarities
  - See Simon's talk
  - ~25% SKA1-mid..., new RXs 1-26GHz..., enhanced survey speeds etc... etc...





[www.e-merlin.ac.uk](http://www.e-merlin.ac.uk)