Project: Nearby galaxies - Birth & death of stars in the local Universe
Sub-project: LeMMINGs – Legacy e-MERLIN multi-band imaging of nearby galaxies

Abstract:
Obtaining information about the details of star-formation and activity in nearby galaxies is critical to wide range of important astrophysical issues: star-formation throughout the history of individual galaxies, provide near-Universe analogies of sources in the high-redshift Universe, exploration of the physics of high-energy sources within extreme environments, the causes and consequences of star-formation, and provide a cornerstone in our understanding of galaxy formation and evolution.

This legacy programme will produce the definitive parsec-scale, microJy sensitivity radio images of a large sample of well-known galaxies in the nearby Universe. As such this project will not only address numerous key science questions regarding star-formation and activity in galaxies but also provide a lasting Legacy data set for the wider community.

PIs	**Co-Is**
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Time Required: 60 days total	**Survey area or number of targets:** (a) e-MERLIN 1.4 & 5GHz imaging of 50 Nearby Galaxies (b) Piggy-Back spectral line observations of HI, OH, H_2CO etc in all targets

Project description:

Core Science themes:

- Understanding star-formation processes throughout the Universe
  - Provide a detailed understanding of nearby analogies of high-z galaxies
  - Placing Galactic star-formation processes in context of other galaxies
  - Charting the star-formation histories of individual galaxies
  - Providing a census of unobscured star-formation products & tracers
  - Mechanisms of triggering and fuelling star-formation
- Physics extreme sources in extreme environments
  - Evolution supernovae & their influence on the inner workings of galaxies
  - Accretion and jet physics from intermediate to supermassive black-holes
  - Role of AGN in the evolution of galaxies

Introduction

Obtaining information about the details of star-formation and activity in nearby galaxies is critical to wide range of important astrophysical issues: star-formation throughout the history of individual galaxies, provide near-Universe analogies of sources in the high-redshift Universe, exploration of the physics of high-energy sources within extreme environments, the causes and consequences of star-formation, and provide a cornerstone in our understanding of galaxy formation and evolution.

In order for these questions to be addressed high quality, multi-wavelength observations of a wide range of galaxy types in the local Universe is needed. Crucial to our understanding of the key processes underway within galaxies are high resolution radio observations. Within galaxies both thermal and non-thermal radio emission is produced by a variety of physical mechanisms, originating in the formation, evolution and death of stars, as well as via accretion onto compact objects such as intermediate and supermassive black-holes. For example, in an analogous manner to galactic X-ray binaries, AGN appear to exist in both low and high states of activity. At present only the most active AGN can be observed in detail, this will change with e-MERLIN which will have the sensitivity to probe this 'low' state for the first time. Radio observations uniquely allow these diverse physical processes to be investigated, and by virtue of not being obscured by intervening material importantly allows the very centres of galaxies to be viewed in an unbiased and systematic way. Additionally, at radio wavelengths several key neutral and molecular spectral lines transitions exist (e.g. HI, OH, H_2 CO etc). By studying these transitions via either absorption or maser emission, radio observations can trace the cool gas which fuels both star-formation and accretion.

Proposal:

In total this project will observe a sample of 50 nearby (D<30Mpc) galaxies spanning the entire range of galaxy types within the local neighbourhood. This sample will be selected to encompass all types of galaxies and maximise the cross wavelength coverage with existing data from other legacy programmes such as SINGS. Each source will be observed for ~12 hours in both of the primary observing bands of e-MERLIN (1.3-1.7GHz and 4-8GHz) providing high fidelity radio images. The images obtained will have sensitivities approach 5 and 2μJy/beam with an angular resolution of 150 and 40mas at 1.4 & 5GHz respectively. This unparalleled sensitivity will result in a surface brightness sensitivity of ~70K at 5GHz and ~200K at 1.4GHz making these observations sensitive to thermal and synchrotron radio emission originating from a diverse range objects, such as HII regions, super-star clusters, PNe, supernovae, supernovae remnants, Low luminosity AGN, extragalactic X-ray Binaries, Ultra-luminous X-ray sources (ULXs) etc, and

hence will address a diverse range of science questions (see below).

In parallel to understanding the ongoing processes resulting from the birth and death of stars and accretion, it is crucial that we understand the environment which each of these sources is embedded. Radio, along with millimetre (ALMA) and infrared observations provide a unique means by which the physics of the cold ISM in nearby galaxies can be studied. This cold ISM in the form of neutral and molecular gas, and dust is the fuel for ongoing star-formation and accretion.

The built-in flexibility of the new e-MERLIN array means that it is possible to simultaneously observe several radio spectral lines alongside deep continuum observations. Using this facility, this programme will obtain deep, high velocity resolution observations of important neutral and molecular tracers (HI, OH, H_2CO, etc), via absorption and maser emission, 'piggy-backing' on the rest of the programme.

This proposal will make the *definitive* parsec-scale centimetric images of a large, and diverse, sample of galaxies within the local Universe. The ~30-fold increase in sensitivity of e-MERLIN and its milliarcescond angular resolution make it the only instrument capable of achieving this goal. In effect, this 'Legacy' proposal will produce both high profile science results and importantly provide a major data resource for the community which will **not** be superseded by any current or future instrument.

Decomposition of Sources within individual galaxies:
Whilst this survey will observe a moderately large, well-defined sample of individual galaxies, covering a wide variety of Hubble types, SFRs, and metallicities allowing us to probe a vast area of parameter space. One of the great strengths of these extremely sensitive, high resolution radio observations is that they will decompose the each galaxy into constituent parts of which there will be many tens to hundreds in each target galaxy.

Within each galaxy e-MERLIN will detect a variety of objects, each of which will be residing within range of physical environments. These source include:

- Supernovae and Supernovae remnants
- Super star clusters
- Planetary Nebulae
- Low luminosity AGN/jets
- ULX & X-ray binaries
- HII regions
- Cold neutral and molecular Gas (via spectral line tracers such as HI, OH etc)

Crucially many of the individual components that will be detected (HII regions, supernovae, X-ray binaries, superstar clusters etc) can be thought of as proxies for star-formation at different epochs within the lifetime of an individual galaxy, and hence can be used to trace the unobscured star-formation history of each individual galaxy.

The Team:
Due to the wide diversity and *importance* of scientific results which these observations will impinge upon a large multi-national team of scientists with a wide range of expertise have assembled. All of the team listed as Co-Is have either contributed directly to this document or have to earlier discussion of this project.

Synergies with other e-MERLIN legacy areas:
This programme has direct links, both in terms of science drivers and personal, with several other proposed e-MERLIN legacy areas. In particular, one of the primary science drivers for this programme is to understand star-formation and AGN activity within the local Universe. This provides a vital local anchor point to the high-redshift studies of AGN and star-formation by studying analogous processes on pc-scales. The detailed observations of both the birth and death of stars in nearby galaxies also naturally link with investigations of stellar processes within our own Galaxy and hence bridge the gap between Galactic star-formation processes and the distant Universe.

Ancillary data:
Whilst these proposed radio will provide a unique and crucial resource addressing many important questions they do not stand in isolation. In modern astrophysics few fundamental questions can be answered using a single waveband. This survey is specifically designed to utilise both future and existing multi-wavelength data. The sample of sources being proposed closely matches samples of nearby galaxies studied as part of several related Legacy programmes, notably the Spitzer Nearby Galaxies Survey (SINGS PI: Kennicutt) and The HI Nearby Galaxy Survey (THINGS, PIs: Walter, Brinks) which share collaborators with this project. The combination of data from these surveys with e-MERLIN observations significantly enhances the scientific impact of each of these projects.

Existing associated projects providing complimentary multiwavelength data:

1) SINGS (PI Kennicutt)
2) THINGS (PI Walter; de Blok; Brinks)
3) GALEX Nearby Galaxies Survey (PI Bianchi)

Planned coordinated programmes:

1) Combined e-MERLIN+VLBI follow-up observations of selected compact sources
2) Combined EVLA +MERLIN observations of large diffuse source within the sample
3) Longer Wavelength observations of sample using the GMRT
4) LOFAR observations as part of the LOFAR Surveys-KSP (Beswick, Conway are members of this KSP).

Official Support from other teams:

1) **SINGS & THINGS**: An official letter of support of this Legacy programme from the PIs of the THINGS and SINGS collaboration is attached to this case as supporting documentation.