Revealing the Physics and Evolution of Galaxies and Galaxy Clusters with SKA Continuum Surveys*

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on behalf of the SKA Continuum Extragalactic Science WG

*based on the ***Continuum Science Chapters of new SKA Science Book***

[see chapter index at arXiv:1412.6942] + breakout sessions

SKA Radio Continuum Extragalactic Surveys Science Drivers

Not key science projects but Science Drivers!

- **Star formation history of the Universe**
- **The role of BH in galaxy evolution**
- **Non-Thermal components in galaxy clusters**
- **Detailed astrophysics of star-formation and accretion processes**
- **Dark matter and high-z with strong lensing**

Legacy, rare sources and serendipity

Agenda

Breakout session on each science driver:

1) review the scientific case: open questions and main goal
2) discuss missing important concepts
3) discuss on survey strategy
4) commensality
5) work on science use cases

Joint sessions with:

- Extragalactic molecular spectroscopy
- Cosmology+EoR
- HI Galaxy Science
- Magnetism

Star Formation History

A top SKA1 Priority Science Objective

Key questions:

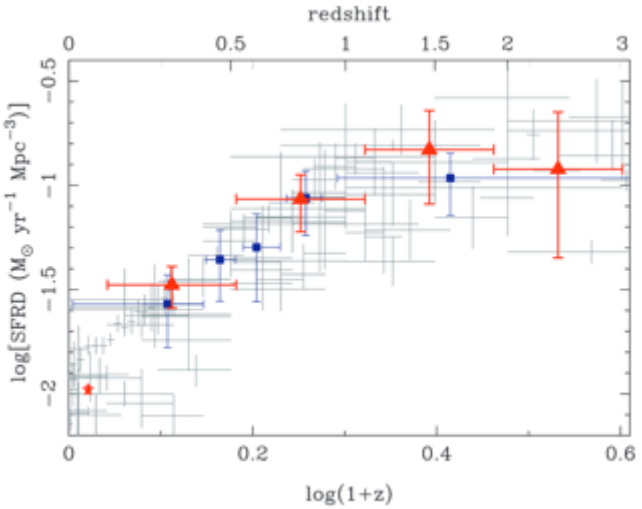
- When does SF occur?
- What dominates SFRD at each z?

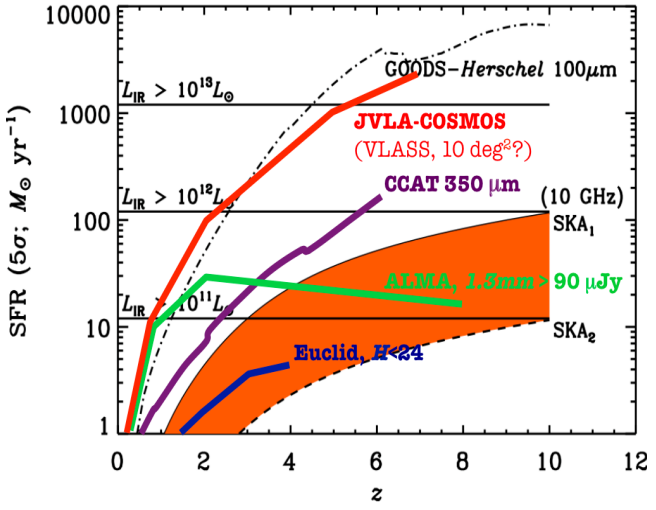
SFH vs gal type
SFH vs gal mass
SFH vs environment

Deep and wide
- sub-μJy to get low SFR/low mass systems at high redshift (10^9 Msun at z ~ 2, 10^{10} Msun at z ~ 4)
- wide to sample enough high mass systems in nearby (z < 1) universe (1000s sq deg)

* 3 tier survey in Bands 1/2 for non-thermal processes.
* 2 tier survey in Band 5 for thermal SF processes, resolving SF

Seymour et al. 2008





Murphy, Sargent et al 2015

Star Formation History

A top SKA1 Priority Science Objective

Science Drivers	Freq.	Tier	Rms (full BW)	Area	Res.
SFHU Non-thermal (gal/AGN co-evol.)	~1 GHz Band 1/2	Ultra Deep	50 nJy	1 deg2	~0.5”
		Deep	200 nJy	10-30 deg2	~0.5”
		Wide	1 uJy	1000 deg2	~0.5”
SFHU Thermal (gal/AGN co-evol.)	~10 GHz Band 5	Ultra Deep	40 nJy	0.008 deg2	~0.1”
		Deep	300 nJy	1 deg2	~0.1”

* 3 tier survey in Bands 1/2 for non-thermal processes.
* 2 tier survey in Band 5 for thermal SF processes, resolving SF

The role of BH in galaxy evolution

AGN feedback is essential ingredient in galaxy formation and evolution models

Radio/Hot Mode (Low Excitation Radio Galaxies)
jet-driven mechanical feedback

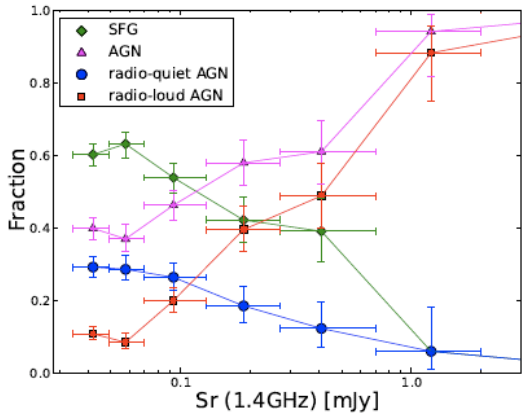
QSO/Cold Mode (High Excitation Radio Galaxies)
radiation-driven feedback (winds)

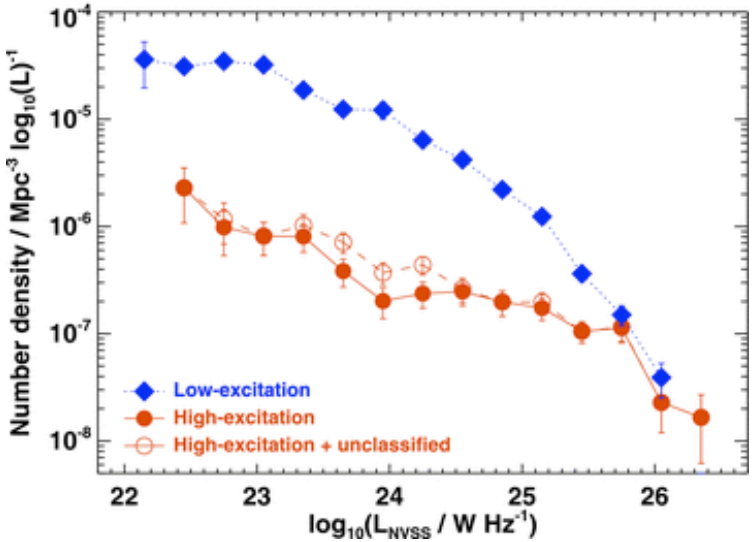
Key Aims:

- Complete census of AGN and their evolution
- Understand the physical cause of the Radio Loud vs Radio Quiet dichotomy
- Separate SF and AGN activity in radio quiet AGN
- Physics and life-cycle of radio-loud AGN

Mainly use same tiered surveys as SF History case.

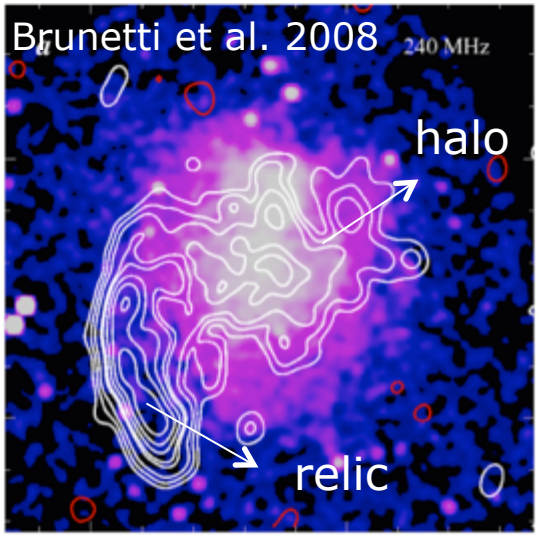
Adapted from Bonzini+2013





Best and Heckman 2012

Non-Thermal components in galaxy clusters



Diffuse Mpc-scale synchrotron radiation from the ICM of *merging* clusters => GeV relativistic e^- and μG magnetic fields on Mpc-scale

Key questions:
- Origin of non-thermal components?
- Impact on the microphysics of the ICM and on the process of formation of galaxy cluster

Main Goals:
- Study the bulk of halos and relics in the Universe (z ~ 1)
- Discovery of ~2500 radio halos, 1000 with ultra-steep spectrum ($\alpha > 1.5, S \propto \nu^{-\alpha}$)
- Discovery of "off-state" hadronic halos in "relaxed" clusters
- Fraction of clusters with halos and relics as a function of cluster M and u
- Study the radio power - cluster mass correlation (scatter, evol. with z)

→ test of theoretical models ←

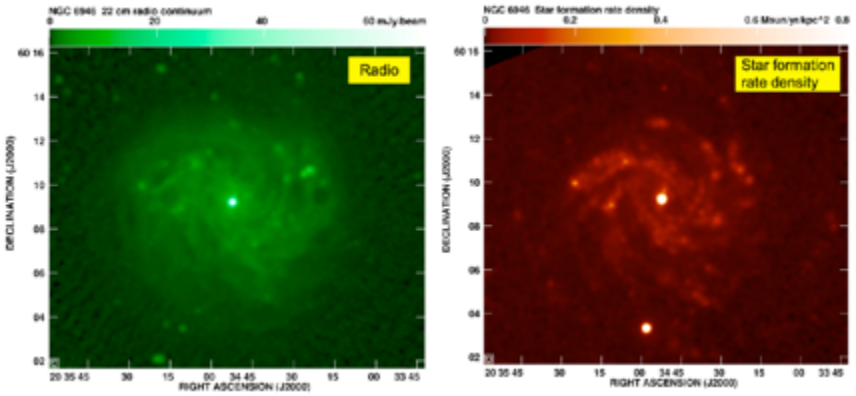
Detailed astrophysics of star-formation and accretion processes

Resolved studies of *local* galaxies.

From dwarfs to more massive galaxies, including early type galaxies.

Both isolated and merging systems, up to 100 Mpc distance, to probe all environments.

Beswick et al 2015



Key Aims:

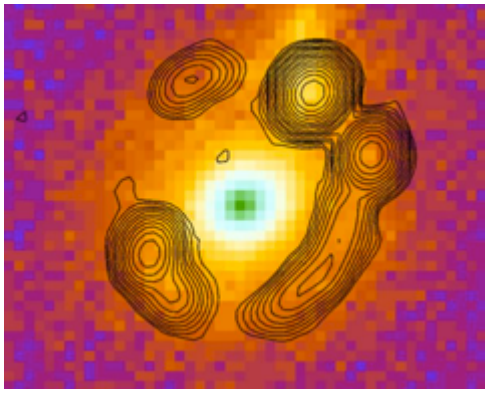
- Resolved studies of star formation as a function of galaxy type and environment
- Calibrate thermal and non-thermal radio tracers of star formation
- Understand radio emission from RQ AGN (ADAF or ADIOS, thermal emission from XRay corona, star formation)

Targeted observations using Band 2 and 5
Maximise commensality with magnetism, HI, transients, ex gal spectral line, etc.

Dark matter and high-z with strong lensing

Strong gravitational lenses provide a way to measure masses in distant universe

McKean et al. 2015



Key Aims:

- Test predicted dark matter halo profiles and dark matter halo mass function
- Use the lens to study emission from distant universe – e.g. high redshift CO

Lenses are intrinsically rare (only 100s known, 10% radio loud)

Cover Euclid field (5000 sq deg) with Band 2 to 6 μJy rms, 0.3-0.5 arcsec resolution, would yield >1000 lenses.

Followup with VLBI for lens sub-structure and Band 5 for high redshift CO (and water masers)

Explore sub-arraying of SKA1-Mid: use outer array when Pulsar observations use core?

Continuum SKA1 Reference Surveys

based on *Prandoni & Seymour 2015* + *breakout sessions*

Revisited after rebaselining (March 2015)

Science Drivers	Freq.	Tier	Rms (full BW)	Area	Res.	Science/ Commensality
SFHU Non-thermal (gal/AGN co-evol.)	~1 GHz Band 1/2	Ultra Deep	50 nJy	1 deg2	~0.5”	AGN/gal co-evol., **HI**
		Deep	200 nJy	10-30 deg2	~0.5”	AGN/gal co-evol. **High-z, Magnetism** HI deep field (B1)
		Wide	1 uJy	1000 deg2	~0.5”	Weak/Strong Lensing
SFHU Thermal (gal/AGN co-evol.)	~10 GHz Band 5	Ultra Deep	40 nJy	0.008 deg2	~0.1”	AGN/gal co-evol., **extraga. molecular. spectr.**
		Deep	300 nJy	1 deg2	~0.1”	AGN/gal co-evol.
Legacy Strong Lensing (clusters)	~1 GHz Band 2	All-sky (5000 deg2)	4 uJy	31000 deg2 (5000 deg2)	~2” 0.5”	**Magnetism + Cosmology Transients** + **(HI absor.) surveys**
Clusters (RL AGNs)	~150 MHz	All-sky	20 uJy (confusion)	31000 deg2	8-10”	**EoR**

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Joint sessions with:

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- Cosmology+EoR
- HI Galaxy Science
- Magnetism

Joint Session: Extragalactic molecular spectroscopy

Main areas of overlap:

1) Local sources

- OH in Band 2, new molecular lines in Band 5

2) High z universe

- redshifted CO, CS

3) Extragalactic Masers

- OH, methanol and redshifted water 22.2 GHz

4) Lensed sources

- Molecular gas in distant universe

Commensal Surveys:

- Targeted observations of local galaxies
- Deep Band 5 observations

Joint Session: Cosmology+EOR

Main areas of overlap:

1) All sky SKA1-Low for EOR foregrounds

- Point source subtraction: EOR want visibilities as data product. Point source subtraction is also an issue for cluster science.

2) Weak lensing surveys

- All Sky at Band 2
- Deeper tier 1000-5000 sq deg, Band 2
- Deepest tier 10-30 sq deg, Band 2
- WL requires high resolution, and good time and bandpass sampling to reduce bandwidth and time smearing

3) Matter dipole, integrated Sachs-Wolfe effect, HI intensity mapping

- 10,000s sq deg Band 1 and 2

Commensal Surveys

All Sky SKA1-Low

Tiered Band 1/2 Survey (10 and 1000 sq deg)

All Sky Band 2

Joint Session: HI Galaxy Science

Main areas of overlap:

1) Tiered survey for HI masses and kinematics to z ~ 0.8
   - 400 sq deg in band 2
   - 10 sq deg in band 2
   - 1 sq deg in band 1 (450 – 825 MHz)
2) Local galaxies (targeted, band 2)
3) HI absorption at the highest redshifts (band 1)

Commensal Surveys:

3 tiers similar to ours.

But need to check if our deep tier can be moved to Band 1 (confusion)

Joint Session: Magnetism

Main areas of overlap:

1) All sky survey for rotation measures (Band 2)
2) Deep polarization field (Band 2)

Magnetism (and cluster work) requires less resolution.
Question of whether high resolution images can be convolved.

Close science interests (clusters and AGN):

- more coordination agreed upon.
- appoint cross-SWG contacts.

Commensal Surveys:

All Sky Band 2
Deep Tier Band 1/2

General Comments on KSP and Data Policy

Continuum team is very diverse

- prefer to see a KSP model that it is science driven rather than survey driven
- keep SWG core/associate membership and core provide expertise needed

Who owns data that can be used for multiple KSPs?

- our view surveys should be owned by the office and data should be provided to KSP based on their scientific goal

Commensality requires parallel multiple pipelines.

Can the same UV data be processed with multiple pipelines?

- E.g. different resolutions, different sub-bands and spectral resolutions, point source subtraction

Several (~10) use cases drafted, more expected.