Mini Grant ShaSEE
Shapley Supercluster Exploration and Exploitation

P.I. Venturi Tiziana – INAF, IRA

*Request associated with the **Scheda ShapleyS** (Merluzzi)*

Astrophysical area

- Superclusters, mass assembly in the Universe, galaxy evolution

Target

- Shapley Supercluster – Southern Hemisphere, <z>=0.048, tens of galaxy clusters, groups, filaments of the Cosmic Web

Available data

- Radio observations from the state-of-the-art facilities: MeerKAT, ASKAP, uGMRT
- Optical-Infrared observations: Spitzer, WISE, ESO/VISTA, ESO/VST, ESO 3.6m MEFOS, OPTOPUS AAOmega, WiFeS (ANU), ESO-MUSE, GALEX
- X-ray observations: XMM, Chandra, eROSITA

Codes for simulations

Participants and FTE

	2022	2023
Venturi T.	0.3	0.5
Merluzzi P.	0.6	0.6
Busarello G.	0.6	0.6
Casasola V.	0.2	0.2

Initial goals as stated in the request and current status

1. **Spectral study of the radio bridge between A3562 and SC1329-313 (ShaSS-M2)**

✓ It is now part of a PhD thesis of a South African student (K. Trehaeven) in a PhD project between INAF and South African Radio Astronomical Observatory (SARAO). First paper in progress. Expected submission early 2024

2. **Detailed spectral study of 3 more ram-pressure stripped galaxies (ShaSS-M2)**

✓ Paper ready for submission (expected at the end of November 2023, after the publication policy steps of ASKAP and POSSUM have been fulfilled)

3. **Cross-match of the optical and radio data of the whole central region of ShaS (ShaSS-M1)**

✓ In progress

4. **Detailed optical, radio ad X-ray study of the A3528 complex ShaSS-M3)**

✓ Advanced stage. Radio data reduction completed. Paper in progress. Expected submission early 2024

Future observations as in the request and current status. I.

1. **Chandra 130ks observation**
- ✓ Data analysis in progress

2. **uGMRT proposal accepted under AO42 (42_019) to perform full mosaic of the ShaS core for spectral index studies of diffuse emission and individual radio galaxies**
- ✓ Full data reduction completed. First results are presented in Merluzzi et al. to be submitted **ShaSEE-D1**), and will be part of at least two more papers (Keegan et al. in prep.) expected to be submitted in Q1-2024 and Q2-2024 (**ShaSEE-D3 & ShaSEE-D4**)

3. **MeerKAT+ Expression of Interest for an HI survey of the ShaS as part of the Legacy Survey programs (LS)**
- ✓ This EoI has been submitted to the INAF/MPIfR/SARAO panel in charge of the redesign of the LS to account for the current state of the MeerKAT+ project.

- ➢ In the context of the MeerKAT+ LS, a second EoI (not included in the mini-grant request) has been submitted (September 2023) to observe ShaS under the S-band polarimetric LS

Future observations as in the request and current status. II.

4. **AO3 MeerKAT proposal to study A3560**

✓ The proposal has been submitted and accepted. The observations were carried out in March 2023 and have already been reduced. They will be part of K. Trehaeven's PhD thesis and a publication is expected by Q3-2024 (**new deliverable**)

5. **uGMRT proposal to be submitted to complement the study of the filaments in A3562 and A3560**

➢ This has not been done, due to changes in the scientific priority. **Instead**, a MeerKAT proposal to observe the whole A3558 complex in UHF has been submitted under AO4 and has been accepted. Observations will be carried out in March 2024 and will be part of K. Trehaeven's thesis for the spectral study of the bridge between A3562 and SC1329-313 and for the study of the other features of diffuse emission in ShaS (**new deliverable**)

Further progress

Other proposals not planned at the time of the mini grant request

- A uGMRT proposal has been submitted under cycle AO43 (43_012) to complete our frequency coverage of the A3528 complex. The data reduction has been completed and the paper is in prepration (**ShaSEE-D2**, expected submission Q2-2024). Results will be presented at MeerKAT@5.

- A uGMRT proposal has been submitted and accepted under AO44 (January 2023, proposal 44_024) to observe a fourth ram pressure stripped galaxy in the ShaS, located outside the fields of the available observations. Observations took place in May 2023. Data reduction has just started. Results will be presented at MeerKAT@5 and GASPISA2024 and published in a new paper (Merluzzi et al. in prep.).

Dissemination of results
ShaSEE-D5

1. **Seminar at IRA** (2 November 2023)
- Trehaeven K. – Unveiling large scale structure formation in the nearby Universe. The spectacular case of the Shapley Concentration

2. **SARAO Postgraduate and Postdoctoral Research Conference** – Cape Town (RSA) 27 Nov – 1 Dec 2023
- Trehaeven K. – New data analyis tools for a full scientific exploitation of the Shapley Supercluster (poster)

3. **MeerKAT@5 –** Stellenbosch (RSA) 20-23 February, 2024
- Venturi T. – Radio tails of ram-pressure stripped galaxies in the harsh environment of the Shapley Supercluster – Talk
- Di Gennaro G. - Cosmic dance in the cluster complex A3582-A3532 in the Shapley Concentration Core – Poster
- Trehaeven K. – Unveiling large scale structure formation in the nearby Universe. The spectacular case of the Shapley Concentration - Poster

4. **The physical processes shaping the stellar and gaseous contents in galaxies** – Pisa, 27-31 May 2024
- Merluzzi P., Ram-pressure stripped radio tails detected in the dyamically active environment of the Shapley Supercluster (Talk requested)

Financial status

Requested 20.000 Euros – Allocated 18.000 Euros

Year	Purpose	Cost (Euros)
2023	Travels for meetings among members of the project	1204,80
	Support to K. Trehaeven for his visit at IRA	1400,00
2024	CHANCES 4MOST conference (P. Merluzzi)	4000,00
	MeerKAT5 conference (T. Venturi)	4000,00
	GASPISA2024 conference (T. Venturi, P. Merluzzi)	3000,00
	Travels for meetings among project members	2000,00

The remaining budget (2395,2 Euro) will be used both for activities not yet planned and to partially support another visit of the PhD student K. Trehaeven to Italy

General considerations

- The project is progressing very well, in line with the goals stated in the proposal, as clear from this report.
- Milestones and deliverables are being delivered timely.
- New activities are being planned as soon as the results from our new observations become available.
- Dissemination of results is flowing
- Since early 2023 a PhD student, SARAO MSc Keegan Trehaeven, is full time on this project, working under the supervision of the PI (T. Venturi) and of Prof. Oleg Smirnov, and in coordination with the other non-INAF close collaborators.

Criticalities

As a criticality, I wish to make a point related to the request of funding through the GOG grant call 2023
SPOTSS – SKA Precursors Observations Throw a new light on the Shapley Supercluster

Given the new PhD student working on the topic, a GOG request was submitted to support vistis for two years to work with our group. The request was linked to the **Scheda ShapleyS**, the same as this mini grant, which provides the background and all the details of the project. Because the PhD just started, a GOG request was submitted to ensure funding for two years.
The proposal was evaluated very positively (9, 9, 9, 8, 7.75, 8.75) but the final comment ”It is not clear if radio data alone will be enough to reach the ambitious goals of the project or if multi-band data will be also needed” most likely left it below the threshold. The associated schedule ShapleyS does however clarify the multifrequency synergy, so this statement seems not very strongly justified.
There is at present no funding to support the visits of the PhD student. Because of this, in 2023 a fraction of the budget of ShaSEE was dedicated to this purpose, and most likely this will happen again in 2024. This is a change (not negligible) in the use of our budget.

It is important to point out that a considerable effort is ongoing in the area of education and knowledge transfer between Italy and South Africa, with the final goal to ensure full scientific exploitation of the INAF/Italian investment for SKA and MeerKAT+. This is supported by the DS and INAF. It is a pity that such relevant details have not been taken into consideration in the process of funding allocation.

ShaSEE-D1

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Ram-pressure stripped radio tails detected in the dynamically active environment of the Shapley Supercluster

P. Merluzzi[1]★, T. Venturi[2,3], G. Busarello[1], G. Di Gennaro[4,2], S. Giacintucci[5], V. Casasola[2], D. Krajnović[6], E. Carretti[2], O. Smirnov[3,7], K. Trehaeven[7,3,2], G. Heald[8], T. Vernstrom[9]

[1] *INAF-Osservatorio Astronomico di Capodimonte, salita Moiariello 16, I-80131 Napoli, Italy*
[2] *INAF-Istituto di Radioastronomia, via Gobetti 101, I-40129 Bologna, Italy*
[3] *Center for Radio Astronomy Techniques and Technologies, Rhodes University,Grahamstown 6140, South Africa*
[4] *Hamburger Sternwarte, Universität Hamburg, Gojenbergsweg 112, 21029 Hamburg, Germany*
[5] *Naval research Laboratory, 4555 Overlook Avenue SW, Code 7213, Washington, DC 20375, USA*
[6] *Leibniz-Institut fr Astrophysik Potsdam (AIP), An der Sternwarte 16, 14482, Potsdam, Germany*
[7] *South African Radio Astronomy Observatory, 2 Fir Street, Black River Park, Observatory, Cape Town 7925, South Africa*
[8] *CSIRO, Space and Astronomy, PO Box 1130, Bentley, WA 6102, Australia*
[9] *ICRAR, The University of Western Australia, 35 Stirling Hwy, 6009, Crawley, Australia*

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ABSTRACT

We study the radio continuum emission of four galaxies experiencing ram pressure in four clusters of the Shapley supercluster as redshift $z \sim 0.05$. Multi-band (235-1367 MHz) radio data, complemented by integral field observations, allow us to detect and analyse in detail the non-thermal component both in the galaxy disks and the radio continuum tails. Three galaxies present radio continuum tails - 30-42 kpc in projection. By deriving the radio spectral index in the inner and outer tails and comparing our findings with the distribution of the extraplanar ionised gas and the results of N-body/hydrodynamical simulations, we demonstrate that these tails are caused by the ram pressure which, together with the ionised gas, sweeps the magnetic field form the galaxy disks. We suggest the radio continuum emission in the three tails can be differently powered by (*i*) *in situ* star formation; (*ii*) relativistic electrons stripped from the disk; (*iii*) shock excitation or a combination of them. All the ram-pressure stripped galaxies are find in enviroments where cluster-cluster interactions occurred and/or are ongoing thus strongly supporting the thesis that cluster and group collisions and mergers may locally increase the ram pressure and trigger hydrodynamical interactions between the intracluster medium and the galaxy interstellar medium.

Key words: keyword1 – keyword2 – keyword3

1 INTRODUCTION

Galaxies orbiting in the cluster environment experience the hydrodynamical interaction of their cold interstellar medium (ISM) with the hot diffuse intracluster medium (ICM). This interplay may result in the ISM evaporation (Cowie & Songalia 1977) and 'starvation' (Larson et al. 1980) or may remove the cold gas supply by means of the external pressure exerted by the ICM on the ISM (Gunn & Gott 1972). The primary strength of these processes consists of explaining the lower star formation rates (SFRs; e.g. Balogh et al. 2000) and the redder colours (e.g. Bamford et al. 2009) as well as the HI deficiency (e.g. Guiderdoni & Rocca-Volmerange 1985; Balkowski et al. 2001) seen in cluster galaxies with respect to the field population. At present, galaxy evolution studies support the ram-pressure stripping (RPS) as the dominant hydrodynamical mechanism contributing to the evolution of cluster galaxies (for a review see Boselli et al. 2022, and references therein).

In their pioneering work Gunn & Gott (1972) modelled the RPS process by means of an analytic expression where the ram pressure opposes the gravitational restoring force per unit area - a decreasing function of the disk radius. It results that in the dense environment of the cluster cores the ram pressure can effectively remove the cooler ISM in the galaxy starting from outside and thus quenching star formation in the ram-pressure stripped regions. Subsequent studies based on observations (e.g. Merluzzi et al. 2016; Brown et al. 2017; Vulcani et al. 2021; Roberts et al. 2021b) and simulations (e.g. Marcolini et al. 2003; Roediger & Hensler 2005; Bekki 2009) showed that the RPS can occur, or start at least, also in less dense environments and/or out of the cluster cores differently affecting high- and low-mass galaxies. The time-scales for RPS is about one cluster crossing time ($\sim 10^9$ yr).

The characteristic signatures of RPS are the presence of *i*) extraplanar ISM stripped form the galaxy disk in the shape of one-side tail; *ii*) distortion and ultimate truncation of the gaseous disk without corresponding distortion of the old stellar component (Boselli & Gavazzi 2006). Besides, the ISM of late-type galaxies has a multi-phase nature whose components (warm diffuse ionised hydrogen, cold and warm neutral hydrogen, dense molecular gas, interstellar dust), having different surface densities, are differently affected by the ram pressure (see Casasola et al. 2004; Corbelli et al. 2012; Boselli et al.

★ E-mail: paola.merluzzi@inaf.it