RAGA

Radio Survey of the **Ga**lactic Plane

Grazia Umana

MARE

Magnetospheres and **A**uroral **R**adio **E**mission from hot stars and exoplanets

Corrado Trigilio

CIRASA

Collaborative and **I**ntegrated platform for **R**adio **A**stronomical **S**ource **A**nalysis

Simone Riggi

Understanding the **cycle of matter** between components of our Galaxy

Strengthen the Italian Galactic Radio community:

- **radio expertise + theoretical and experimental skills**
- **multi-λ approach.**

Our final goal: to achieve skills and expertise in the run-up to the development of the full SKA to be ready and competitive for leading and participating in SKA KSPs.

RAGA

The life cycle of matter in Our Galaxy

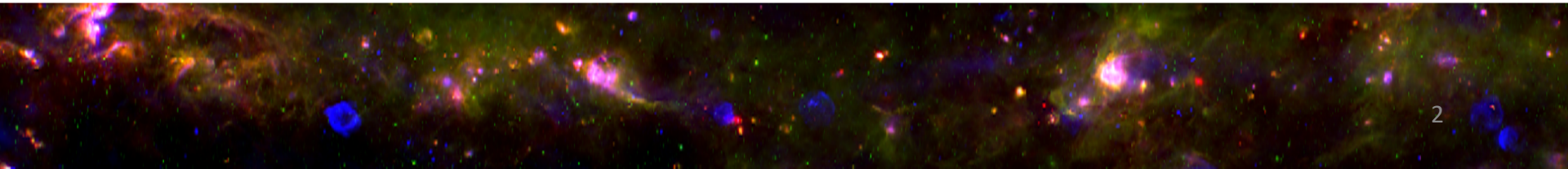
From ISM to star formation, Interaction stars-ISM/CSM, chemical enrichment of ISM by stellar ejecta. Use of state of the art Radio Surveys, not limited by extinction.

MARE

The importance of magnetic fields, from interaction between stars and CSE to Star-Planet Interaction. Magnetoactive plasmas.

CIRASA

Acquire the experience in handling data from SKA precursors that are representative of SKA. Innovative developments in data processing, archiving, analysis and visualization in next-generation facilities for radio astronomy.



RAGA MARE CIRASA

All together

Diagnostics at Radio wavelengths:

- radio continuum (bremsstrahlung, synchrotron), coherent emission
- radio recombination lines (RRL)
- maser lines (ML)

Diagnostics at other bands:

- Existent Galactic Plane surveys Near/Mid/Far-IR, Hα, high-energy

Data:

State of art radio **surveys of the Galactic plane** (GP), complemented by **targeted observations**.
Based on radio data collected in the context of the **SKA precursors**.
A fundamental role will be played by data acquired as part of large approved projects with **ASKAP**, **MeerKAT** and, in the very next future, with **MeerKAT+**.

Targeted observations with ATCA, JVLA, LOFAR, Single dish SRT and Parkes

RAGA MARE CIRASA

Team (2021-2023)

26 researcher in 7 INAF structures

G.Umana, C.Trigilio, S.Riggi,
U.Becciani, M.Benedettini, C.Bordiu, C.Buemi,
F.Bufano, I.Busà, F.Cavallaro, A.Ingallinera,
F.Leone, P.Leto, S.Leurini, S.Liu, S.Loru,
D.Magro, M.Molinaro, M.Munari, A.Pellizzoni,
I.Pillitteri, F.Schillirò, E.Sciacca, A.Traficante,
G.Tudisco, F.Vitello

19 Staff INAF
3 Associati
(UNICT, UNI CapeTown, UNI Malta)
4 TD, Assegnisti (INAF)

RAGA MARE CIRASA

Team (2021-2023)

FTE

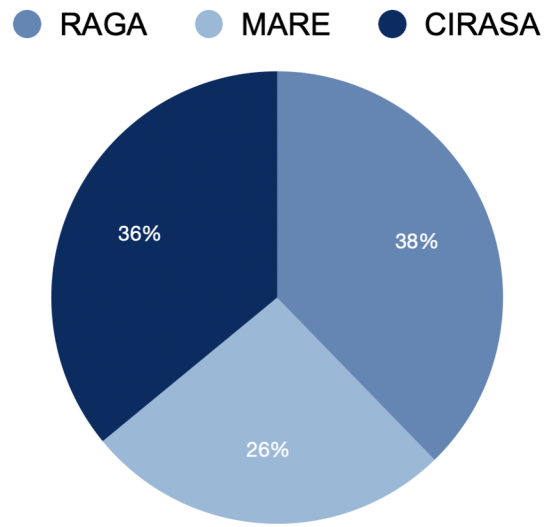
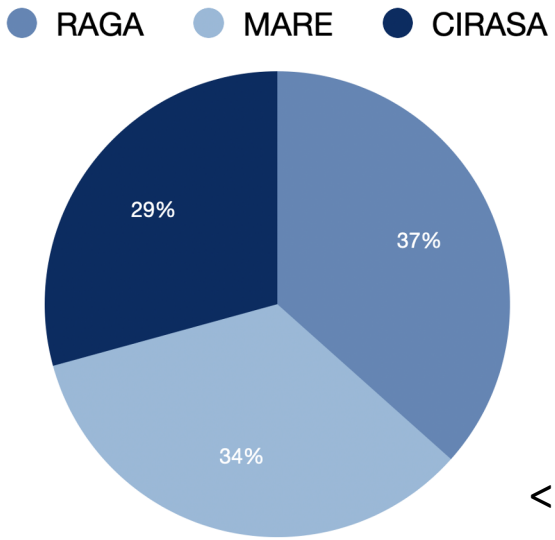


Table 1- FTE 2021-2023

	RAGA	MARE	CIRASA	FTE Tot
OA Catania	6,75	4,30	4,10	15,15
IAPS Roma	0,10		1,20	1,30
OA Cagliari	0,00		0,60	0,60
OA Palermo		0,30		0,30
IRA Bologna			0,60	0,60
OA Trieste			0,60	0,60
UNI CP Town	0,60	0,60		1,20
UNI Malta				0,00
TOTAL	7,45	5,20	7,10	19,75

People



<FTE>/yr=0,27

Table 2 Personnel 2021-2023

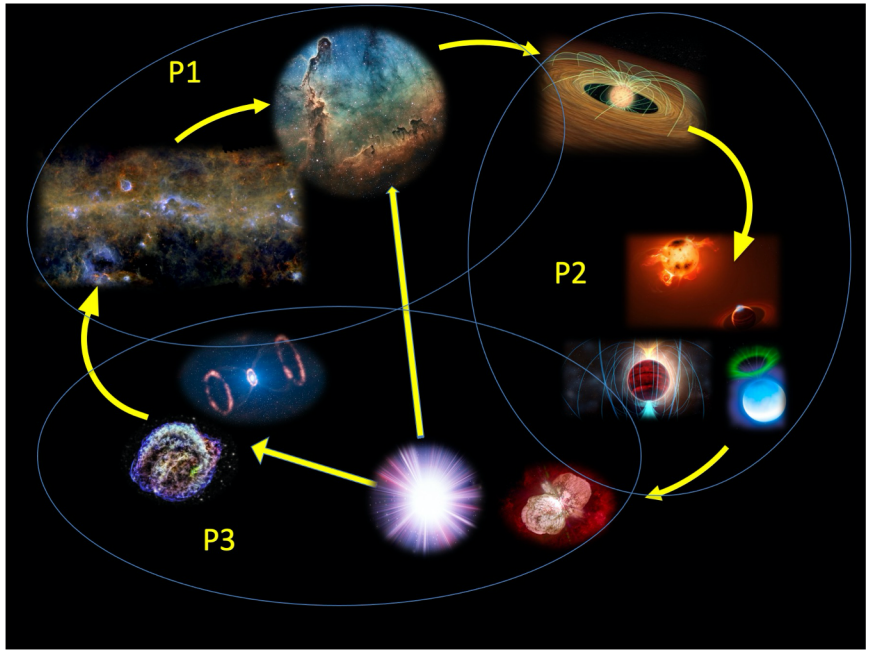
	RAGA	MARE	CIRASA
OA Catania	11	12	6
IAPS Roma	2		2
OA Cagliari	1		1
OA Palermo		1	
IRA Bologna			1
OA Trieste			1
UNI CP Town	1	1	
UNI Malta			1
TOTAL	15,0	14,0	12,0

RAGA Radio Survey of the **Ga**lactic Plane 3 Main Pillars

PILLAR 1: From ISM to Stars

Study of the ISM and SF, by using radio emission (cont+lines), far-IR databases. Understanding of our Galaxy as a star formation engine.

MW as a normal star-forming galaxy, z=0 template for the accurate determination of star formation rates in distant galaxies.



PILLAR 2: Stars and their neighbourhood:

Interaction between stars and CSE/ISM , by using radio emission, in synergy with optical, IR and X-ray observations. Better understand magnetic phenomena taking place in the outer stellar atmospheres, including star-planet systems.

PILLAR 2: From Stars to ISM:

Stellar ejecta in post MS evolution, by using radio diagnostics together with multi-λ observations. Origin and full characterization of mass-loss are important for the chemical enrichment of the ISM. Particularly relevant, the study of SNRs, in synergy with high-energy observations to assess their role as cosmic accelerators (see PROGRESS).

RAGA Radio Survey of the **Ga**lactic Plane SCORPIO, SMGPS

ASKAP: Direct involvement in EMU survey (flanked by POSSUM and GASKAP)
MeerKAT: Direct access to the ThunderKAT survey

- **SCORPIO** project (a pathfinder to EMU), obtained with ASKAP early science.
- **EMU** – including the Galactic plane
- **SMGPS** – SARAO MeerKAT Galactic plane survey

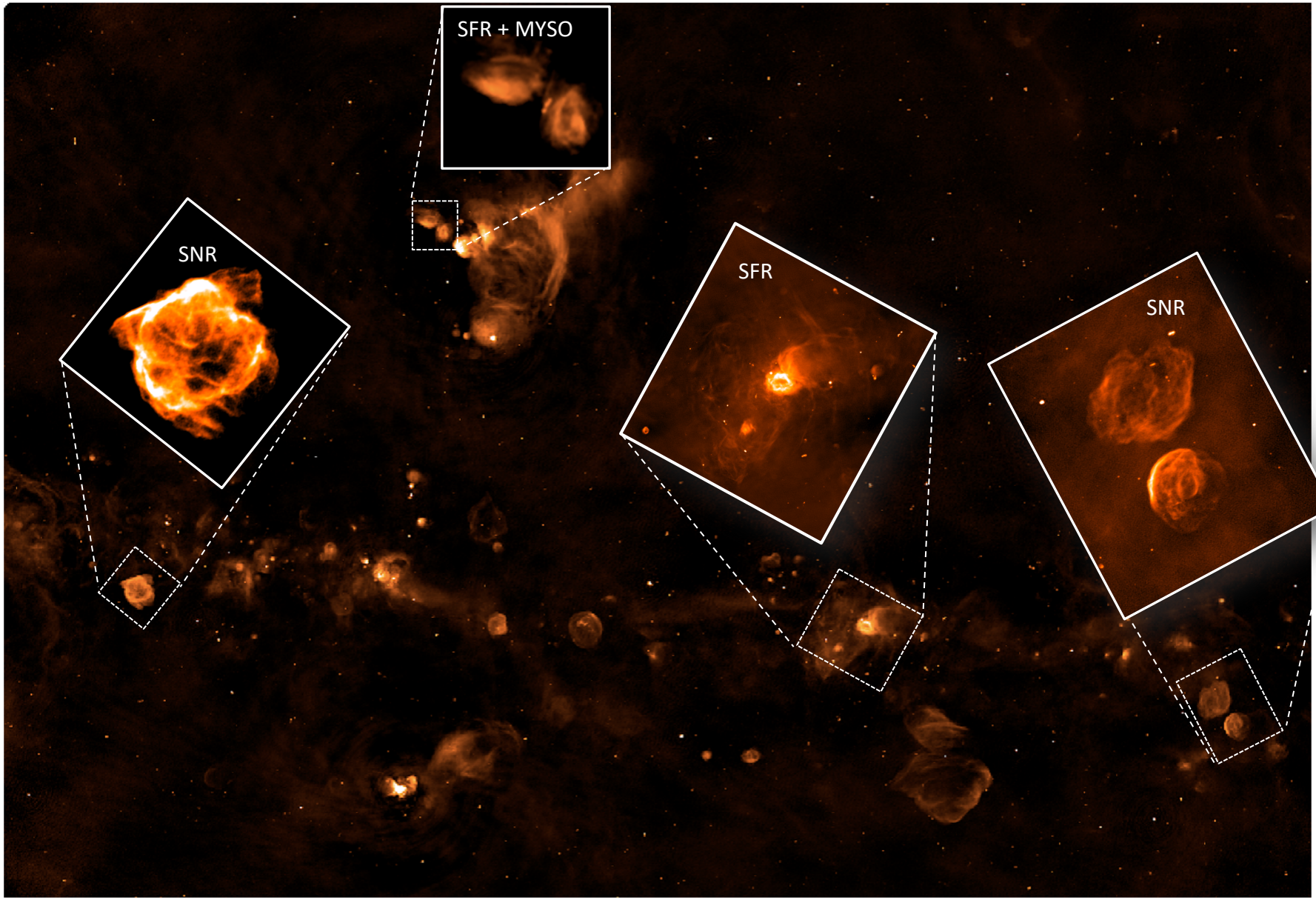
SCORPIO Field 5°x5°

- Good estimation of the potential of deep radio surveys for Galactic studies
- Forecast the scientific impact of SKA precursors on our view of the Milky Way.
- Test-bed to identify technical issues arising from the complex structure of the GP.


ASKAP and the Milky Way

RAGA

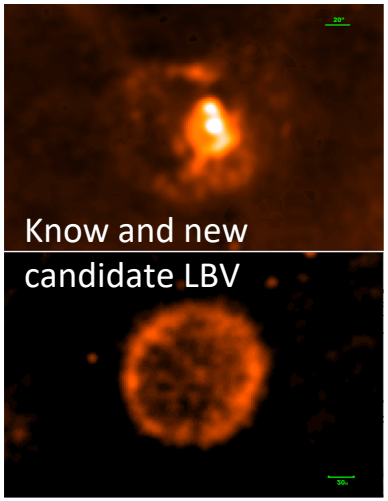
The SCORPIO field



Main results

Main results: Deep Survey, high resolution (SCORPIO)

- **3963 compact radio sources**, 250 Galactic (Riggi et al. 2021)
- **New discovery of missing population** of SNR, PNe, HII
  Umana+ 2015; Cavallaro+ 2018; Ingallinera+ 2019; Umana+ 2021

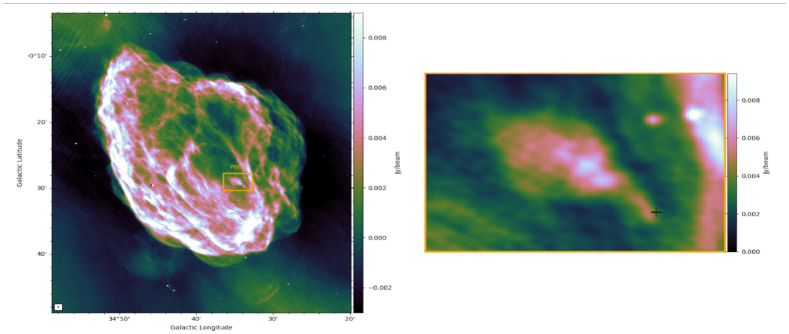


Characterisation of known populations, related observations:

- SNRs – Loru et al., 2016; 2021- SRT
- LBVs – Bordiu et al., 2021 (ALMA-Apex); Agliozzo et al, 2017a; 2017b
- (ALMA, ATCA, VISIR); Buemi et al. (ATCA, VISIR, Herschel)
- PNe – Irabor et al, 2018; Cerrigone et al, 2017 (JVLA)
- Galactic "bubbles" – Ingallinera+ 2016 (JVLA); Bufano+ 2017 (WISE, Herschel)

Papers in preparations in the framework of the SMGPS

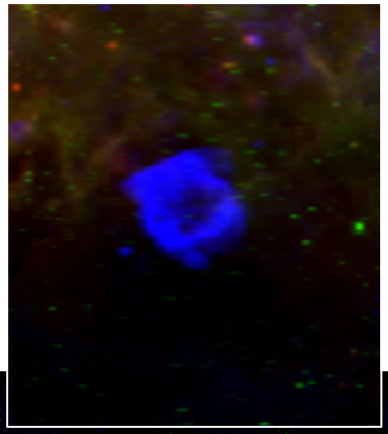
- SMGPS survey paper (Goedhart+)
- Catalogue of extended sources (Bordiu+)
- Catalogue of known SNRs and candidates (Cavallaro+)
- Characterisation of known SNRs (Loru+)
- PNe (Ingallinera+)
- LBV and WR (Umana+)

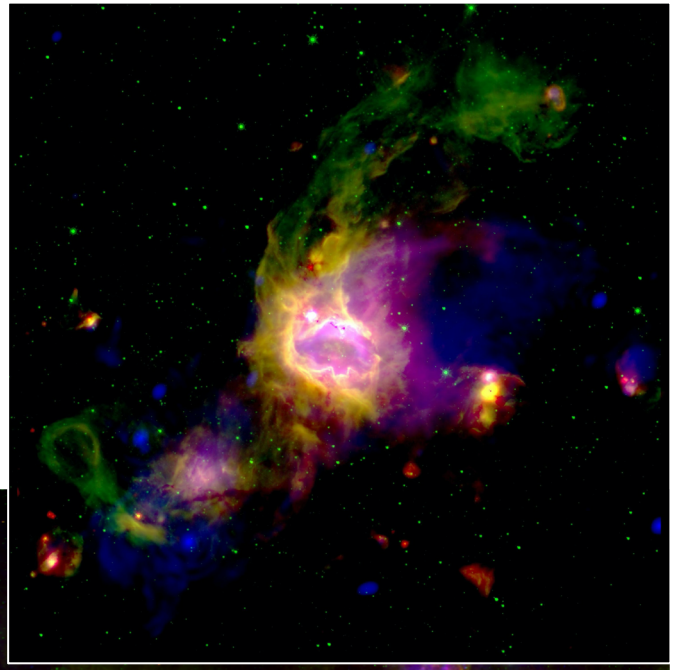


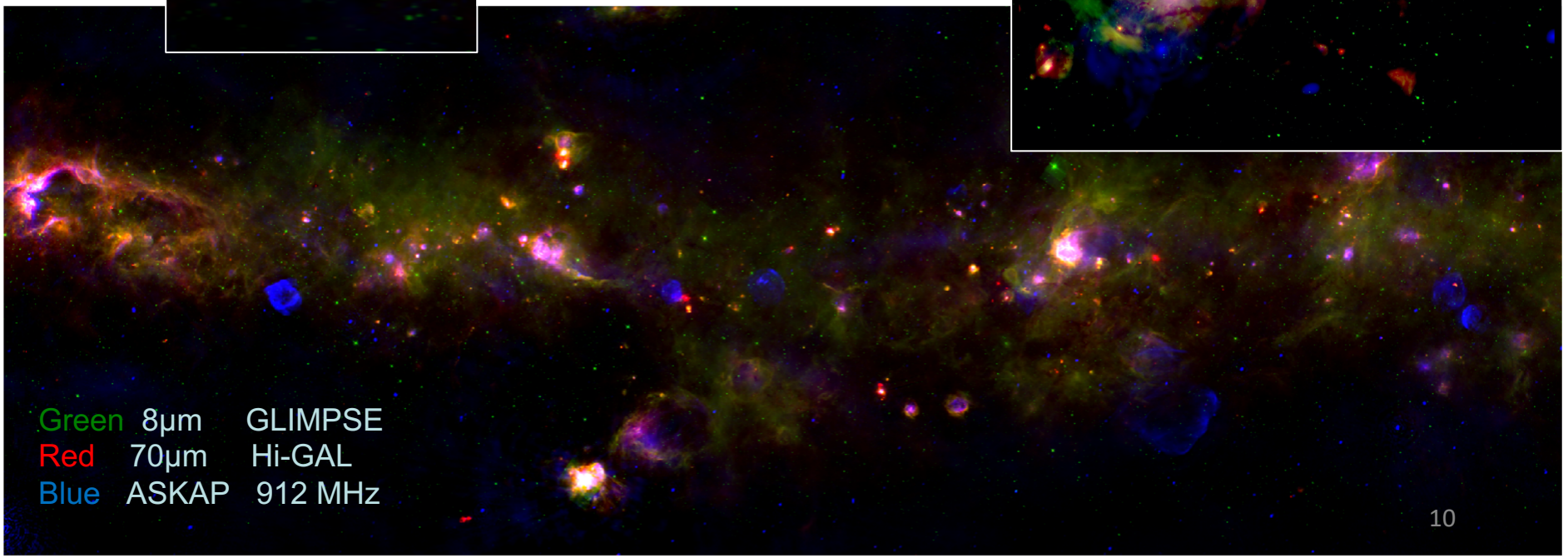
SNR and a Pulsar Wind Nebula.
Evidence of shocks and jets

Synergies with Surveys at other bands

IR/mm: Spitzer, WISE and Herschel ALMA..
Hi Energy: mini-array, CTA, MAGIC, HESS…
(scheda PROGRESS)







The RAGA team has a **consolidated and internationally recognized scientific reputation** in the field of Galactic Radio:

- capacity of **scientific** exploitation
- knowledge of **data processing** and **analysis** of **observations** in the Galactic plane.

SKA SWG "Our Galaxy": G. Umana chair with prof. M. Thompson (UK) (2014-2019).
A. Ingallinera is the actual chair of "Our Galaxy".

Our team is in an excellent position for the **EMU** and the **SMGPS** projects, **leadership** positions and participation in **numerous KSPs** and working groups:
The Galactic Plane EMU WG: G. Umana (chair)

EMU-KSP: KP13 Scorpio (PI Umana); **KP12 Galactic Plane** (RAGA team); **KP14** (WTF, Riggi and Bufano); **KP4** (Cosmic Web, Bufano)
EMU-Early Science: ESP10 (PI Trigilio); EMU-Development Project: D4 (PI Riggi); D6 (Riggi)

The **SMGPS Consortium**: Umana (coordination group member), the RAGA team (members)

Core members in **SKA Regional Centre** (SKARC) several WP (scheda SKA-3).

Expertise to be acquired:

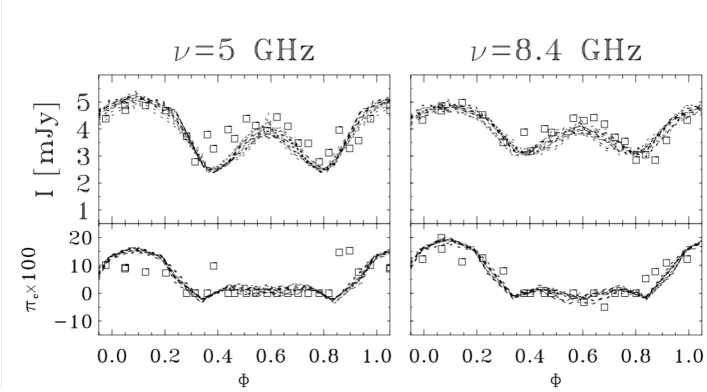
- Both **theoretical and data** handling/analysis, necessary for an efficient multi-λ approach.
- **Software skills** for processing and analysing SKA precursor data efficiently
- **Knowledge of SKA precursor pipeline** frameworks for data reprocessing scopes

Budget: Main resources so far:

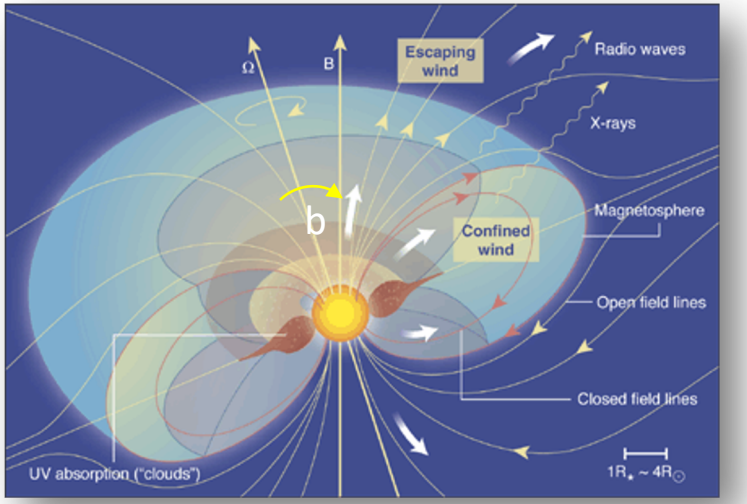
- Competitive call **INAF- Main stream**
  The SCORPIO Project as a pathway to ASKAP and to SKA (ref. Grazia Umana)
- European **FP7 ViaLactea** programme
  FP7 VIALACTEA (ref. Sergio Molinari)
- **Prin SKA_CTA**
  Probing particle acceleration and gamma ray propagation with CTA and its precursors (ref. Fabrizio Tavecchio)

Many of the funds have been already used.
At the present only “residuals” are available (see criticalities).

Observing and modelling radio emission from stable rotating magnetospheres.
MCP stars as a perfect laboratory for the study of magneto-active plasma.

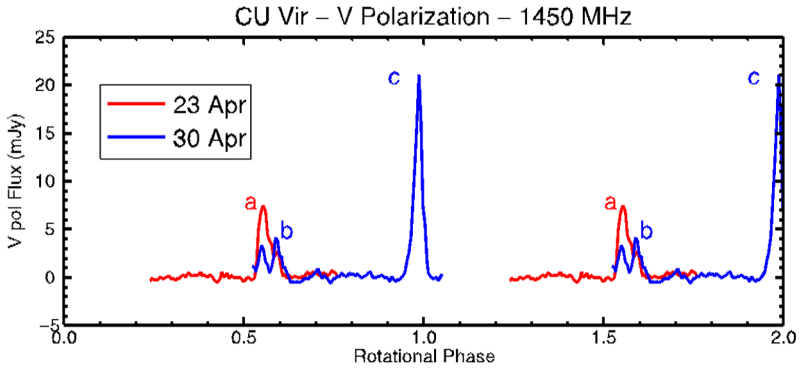


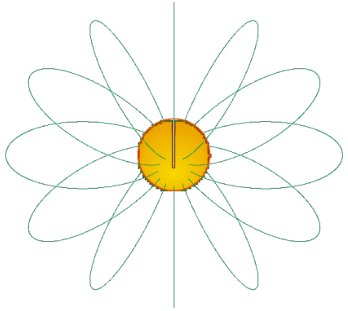
3D model for gyrosynchrotron emission.
Derivation of parameters about magnetized plasma and acceleration region.



Model for the Auroral Radio Emission

CU Vir: first star showing Radio Auroras

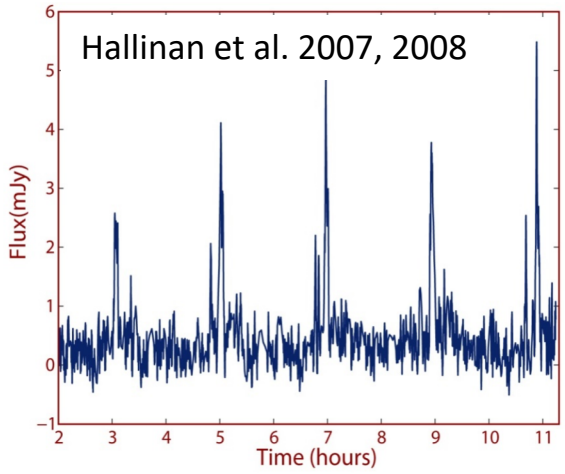




(Trigilio,C.+ 2000, 2008,2011, Leto,P.+ 2016,2017,2020)

Cool stars/planets: Auroral Radio Emission

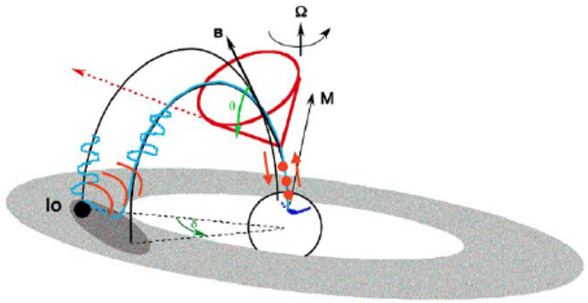
Same kind of emission observed in **Brown Dwarfs**



TVLM 513-46
M9V

M_{star}=0.07 $M_{\odot}$

Io-Jupiter interaction

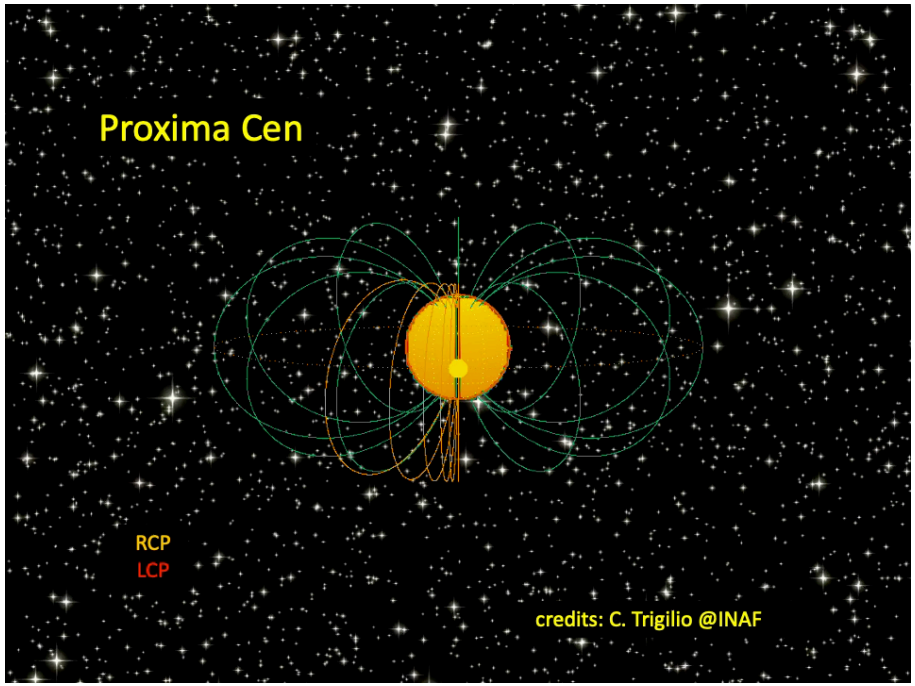


Same kind of emission observed in
all Planets of Solar System with magnetospheres

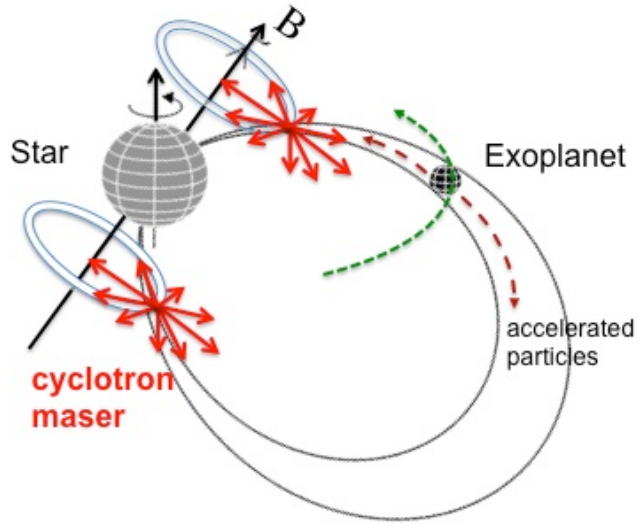
Hot Star, Cool Stars, Planets
Common ingredient?
Acceleration of particles toward the central object.
What triggers the acceleration?

Exoplanets: Auroral Radio Emission

ECME triggered by the transit of an exoplanet. Implications on the **magnetic fields of the planet**



(Leto et al in 2017)

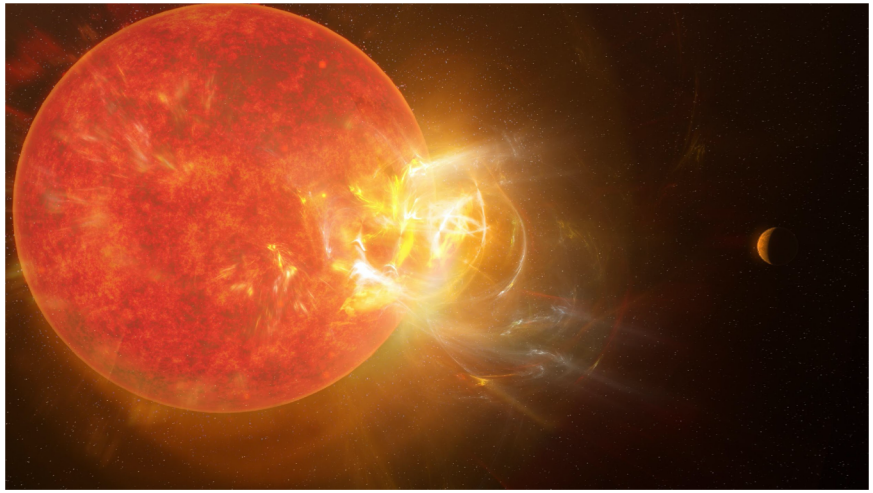


First detection of ARE for SPI from Proxima/Proxima b
(collaboration with Perez-Torres+ 2021)

Search for Auroral Radio Emission in:

- Hot stars
- Brown dwarfs
- Nearby planetary systems

as a function of rotation, orbital phase.



(eg. MacGregor+, 2021)

Active stars (late type)

- Addressing the problem of coronal heating by microflares (quiescent radio corona maintained by series of small flares)
- Long-term monitoring could uncover magnetic activity cycle
- detection of CMEs and major flares (development of live in exoplanets)

- **Leadership/collaborations**:
  Our group is in first line in this field, with consolidated leadership.
  Collaborations with researcher groups in Spain (IAA), South Africa (UNI Cape Town), ESO, UNI Potsdam, several UNI in USA…

- **Observations**:
  JVLA, ATCA, MeerKAT, ASKAP (radio), XMM, Chandra NuSTAR (X-ray), HST (vis)

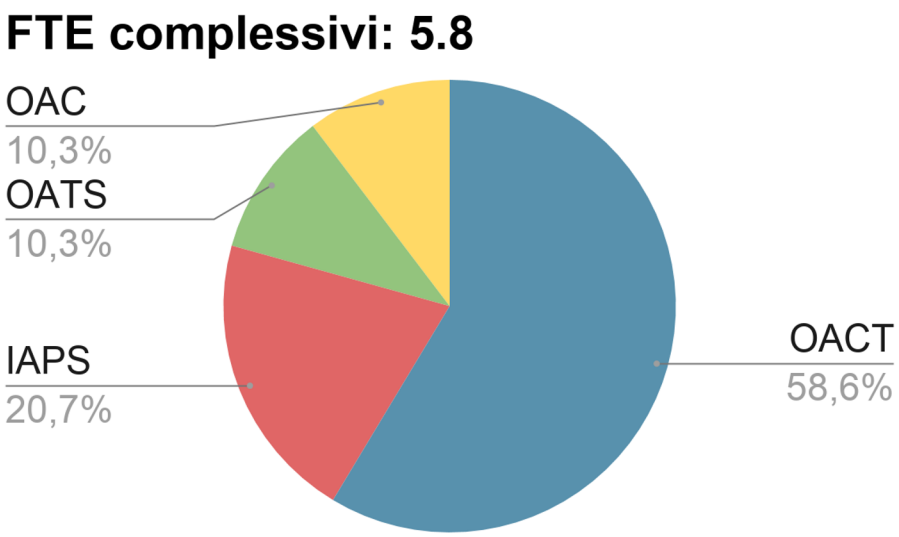
- **Modelling/data reduction**:
  internal resources (server, storage from related resources as RAGA, CIRASA)

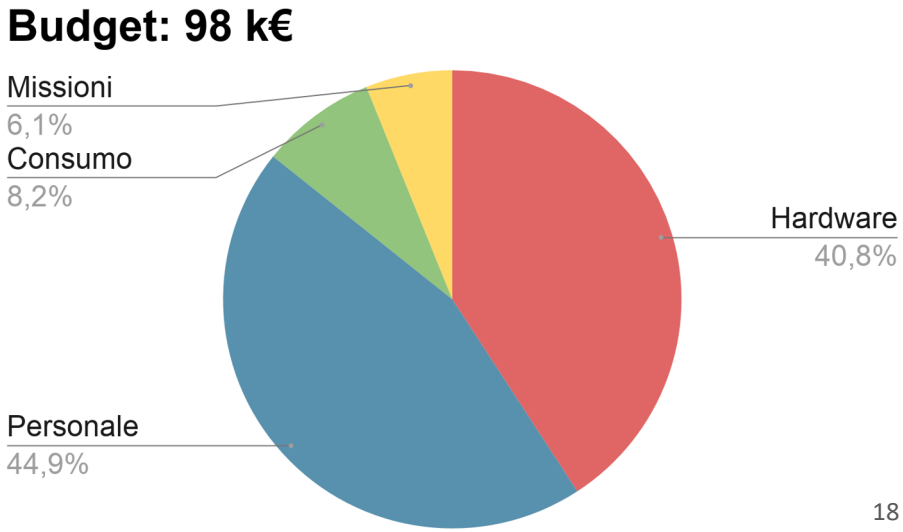
- **Personnel:**
  experience in all the important topics (observations at radio, X-ray, optical; modelling, spectro-polarimetry…)

- **Budget**:
  Not critical, if funds available from the Galactic Research (e.g. RAGA)

Project info

- **CIRASA**: **C**ollaborative and **I**ntegrated platform for **R**adio **A**stronomical **S**ource **A**nalysis
- **Grant**: INAF PRIN TEC 2019, PI: S.Riggi (INAF-OACT)
- **Duration**: Mar 2021 - Mar 2023
- **Budget**: 98 k€
- **Main scientific context**: Galactic radio surveys with SKA & precursors (not only!)
- **Objectives**: Development of a visual analytic software platform for astronomical source extraction, visualization and analysis





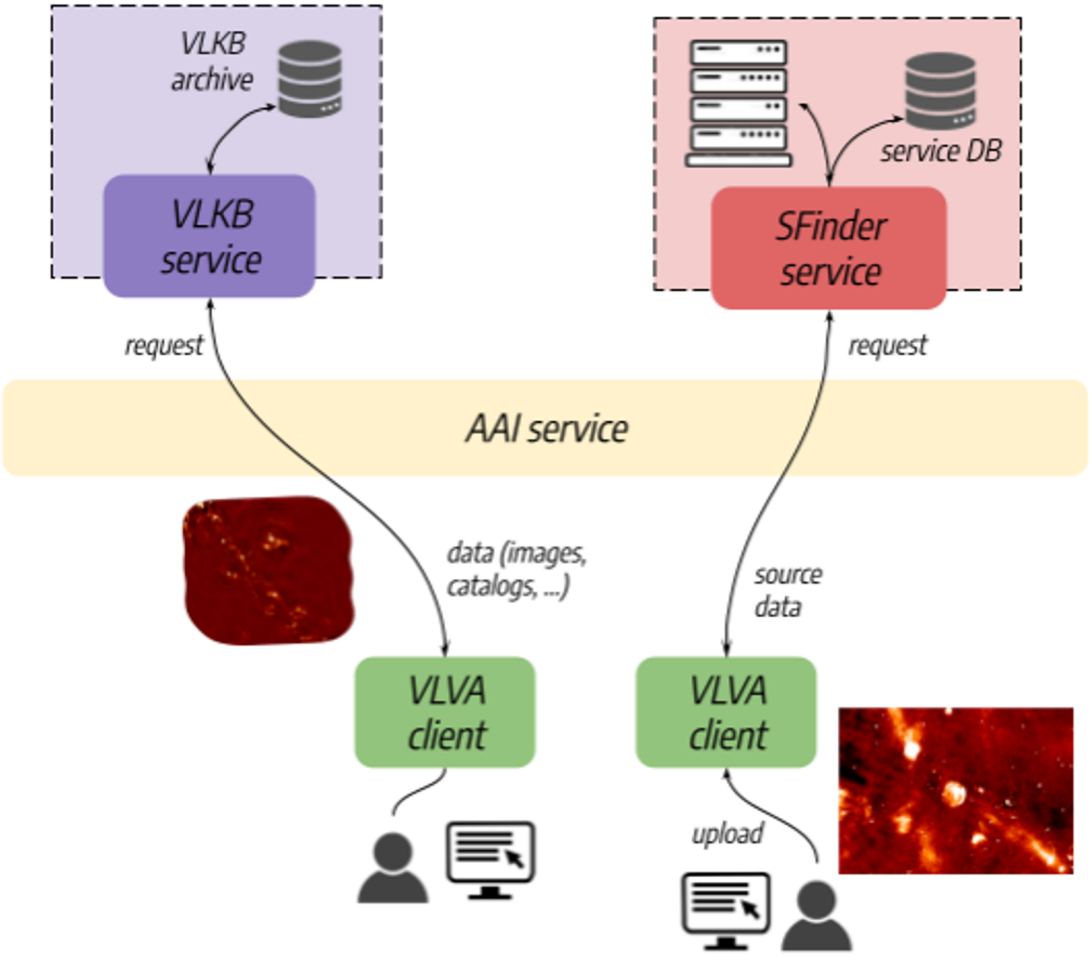
Objectives

- **Challenges when facing SKA & precursor data post-processing**
  - increased data product size and complexity introducing scalability issues
  - ability to extract scientific information in a mostly automated and reproducible way
  - traditional data visualization challenging on local viewers
  - limited source analysis functionalities in existing viewers
  - technological skill gaps in astronomers

- **CIRASA objectives**
  - Create a visual analytics platform integrating existing developed in INAF (see next slides)
  - Add new interactive source visualization and analysis features following major scientific drivers (ASKAP/MeerKAT Galactic plane survey data, additional data & inputs from project scientists)
  - Develop and integrate new ML-based source finders and classifiers

- **Potential benefits for the radio (and not only) community**
  - Speed-up the source cataloguing process for next-generation radio surveys
  - Bridging the astronomer technological gaps, leaving them more time for doing science
  - Develop SKA Regional Center solutions, scalable to larger infrastructures
  - CIRASA software usable also at different wavelengths

Components



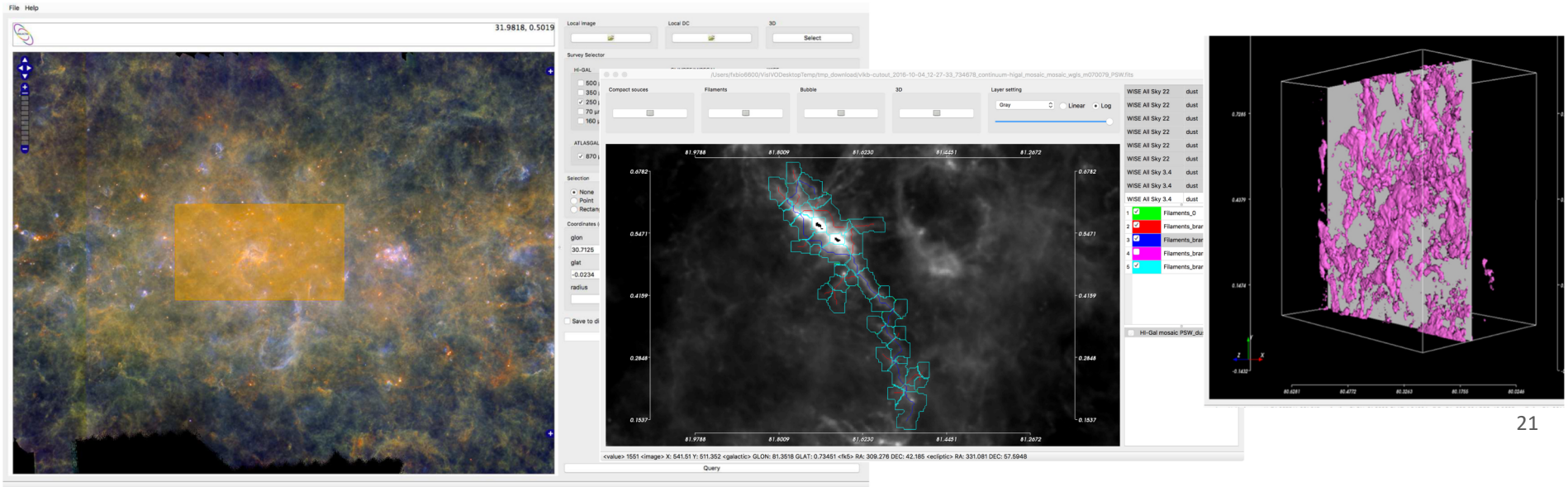
3 main components to be interfaced

- **Visual Analytic client (VLVA)**
- **Knowledge Base service (VLKB)**
- **Source finding services**
  - CAESAR
  - CUTEX & FilamentFinder
  - Finders based on deep learning models
  - others from the community

Visual analytics client (VLVA)

- **VLVA: a desktop tool for 2D/3D astronomical map visualization & analysis**
  - Developed @ OACT, main contributors: F. Vitello, G. Tudisco
  - Main technologies: QT, VTK
  - Ref: F. Vitello et al., PASP, 130, 084503 (2018), doc: https://vlva.readthedocs.io/en/latest/index.html
  - Code: https://github.com/NEANIAS-Space/ViaLacteaVisualAnalytics

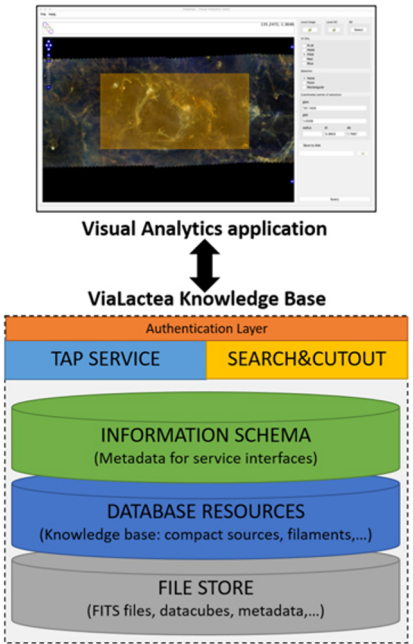
- **Main features**
  - 2D & 3D image visualizations (e.g. volume rendering, slices, isocontours)
  - Ability to load and view images & source catalogs from the VLKB archive
  - Bubble, filament & compact source visualization
  - New features to be added for this project (e.g. interface with source finders, source visualization, ...)

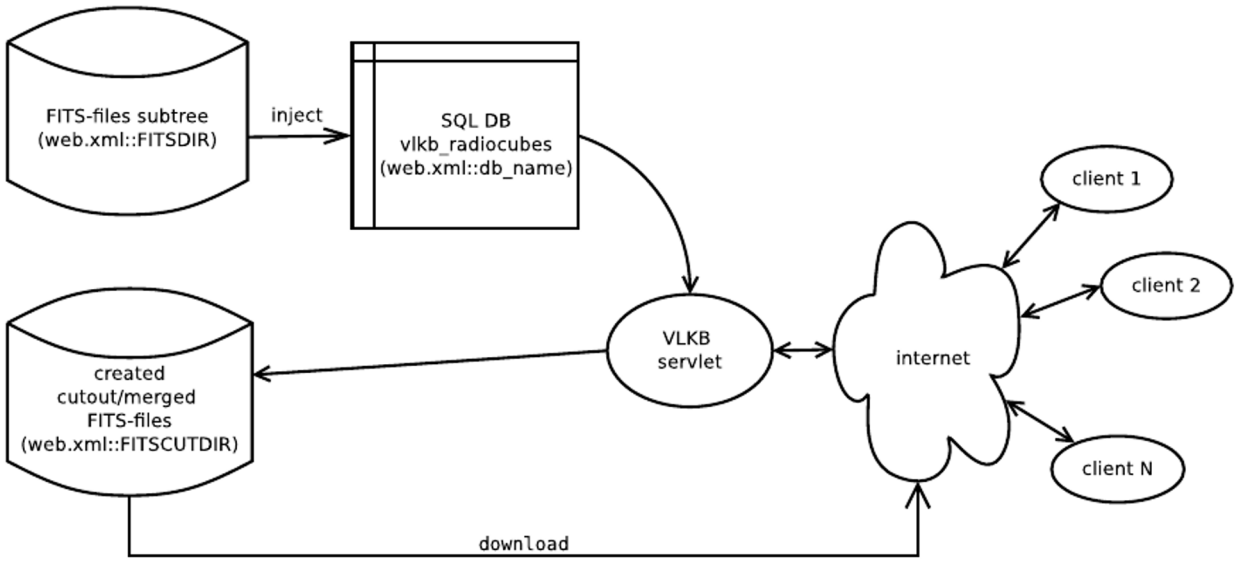


Knowledge base (VLKB)

- **VLKB: a large archive of survey data and services to retrieve them**
  - Developed @ OATS, main contributors: M. Molinaro, R. Butora
  - Ref: M. Molinaro et al., Proc. SPIE (2016), https://doi.org/10.1117/12.2231674

- **Main features**
  - 40000 cubes and 2-D images from 20 surveys (IR/radio/molecular), >1 TB data
  - Discovery, Cutout & Merge interfaces for data discovery, sub-cubes/cutout creation & merge adjacent areas on the sky if stored in separate files
  - IVOA TAP interface for matching compact sources
  - Additional survey data will be added for this project

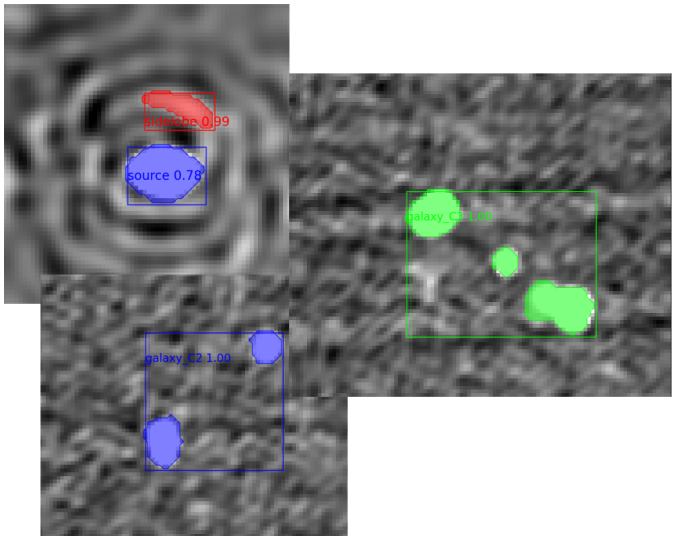




Source finding services

- **CAESAR-REST services for source extraction & classification**
  - Developed @ OACT, main contributors: S. Riggi, C. Bordiu
  - Code: https://github.com/SKA-INAF/caesar-rest
  - Including interface to mature & new source finder batch apps:
    - ➢ CAESAR (https://github.com/SKA-INAF/caesar): S. Riggi, MNRAS 2016, PASA 2018
    - ➢ Mask R-CNN (https://github.com/SKA-INAF/mrcnn): S. Riggi & D. Magro
  - Deployed on the GARR cloud (setup for the NEANIAS EOSC project) and CIRASA INAF resources
  - Additional new ML (e.g. Tiramisù) & traditional (Sofia, Aegean) source finders to be integrated

- **CUTEX & FilamentFinder services**
  - Developed @ IAPS, main contributors: E. Schisano, S.J.Liu
  - Ref: http://ia2-vialactea.oats.inaf.it/ViaLactea-VSH/vshCuTEx.html



Status

Project started very recently but many activities are ongoing ...

- **Project management**
  - Funds now available to all partners
  - Computing infrastructure for source finding services procured
  - AdR personnel for the project under recruitment

- **VLVA developments**
  - interface with AAI service completed
  - interface with VLKB services done, improvements ongoing
  - new features selected for implementation (local data and remote catalog import, sfinder interface)

- **Source finding service developments**
  - web interface for testing the service completed, interface with desktop VLVA to be done
  - scalability tests for caesar ongoing
  - logging components to be integrated
  - additional source finders to be integrated (Tiramisu, Sofia, Aegean) and added in the test UI

- **New ML algorithms**
  - Data preparation efforts needed

- **Budget**. Current **manpower is barely sufficient** to carry on ongoing activities.
- **New researchers & postdocs** (2 PhD students and 3 Post-Doc (AdR) in next 3 years). Final goals are to **guarantee and maintain the Italian competitiveness in mid/long-term**.
- Lack of **computing resources** (storage and processing nodes) to scale up the scientific analysis at the level of SKA and precursors.
- **Supercomputing time needed** for refining **data reduction and analysis** (critical). Currently limited computing resources. Planning to scale analysis using distributed **SKA Italian regional centre** resources, both at the OACT "SKA centre of competences" (see details in the Scheda BIT-ICC) and at the Bologna Tecnopolo (see details in the Scheda SKA REGIONAL CENTER, SKA-3).