

# Signature of Charge-Exchange for identification of new GCRs accelerators

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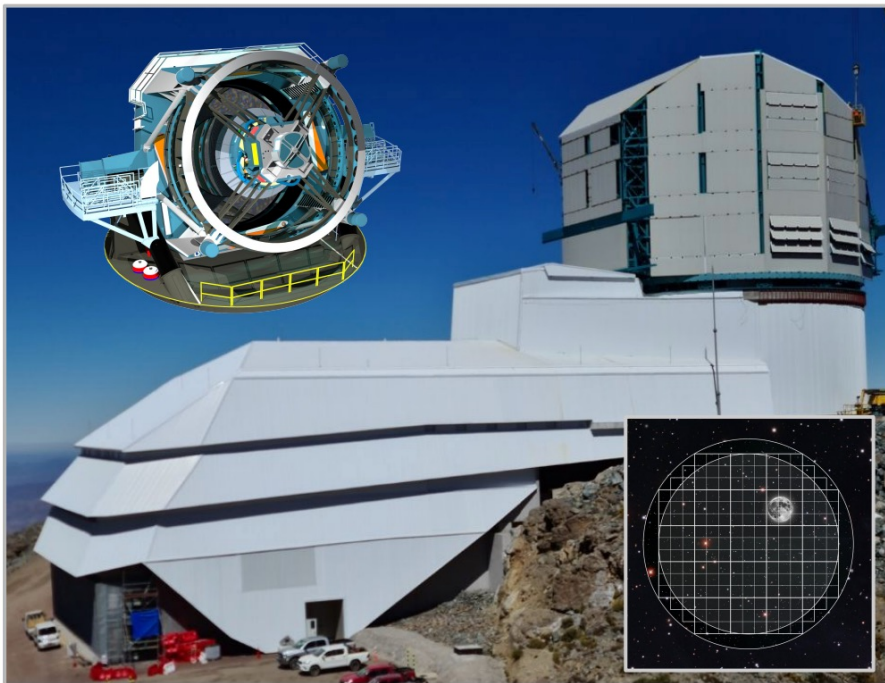
Optical and Radio group at INAF – OACT & UniCT

# Outline

**Aim:** present the scientific work we are doing with the purpose of implementing and optimizing a pipeline for the next LSST photometric survey for the automatic detection of Galactic Cosmic Rays sources based on the measurements of charge-exchange signatures, and discuss how the Radio synergy optimizes skills and outcomes.

- The Vera Rubin Legacy Survey of Space and Time (LSST)
- Charge-Exchange (CX) and observational expectation
- Photometric tool for GCRs sources detection and Radio synergy

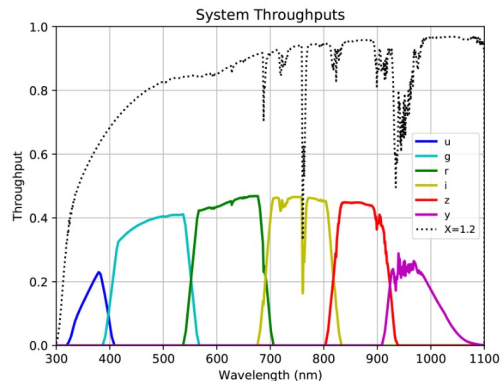
# The Vera C. Rubin Observatory



The Vera C. Rubin Observatory is located on Cerro Pachón in Chile. The Simonyi Survey Telescope's primary mirror has an 8.4 meter diameter and its camera an  $9.6 \text{ deg}^2$  field-of-view and six optical-NIR filters: *ugrizy*.

Once construction and commissioning are complete, Rubin Observatory will execute the 10-year Legacy Survey of Space and Time (LSST).

Standard visit exposures : 2 x 15 sec (cover the full sky in 5 nights)



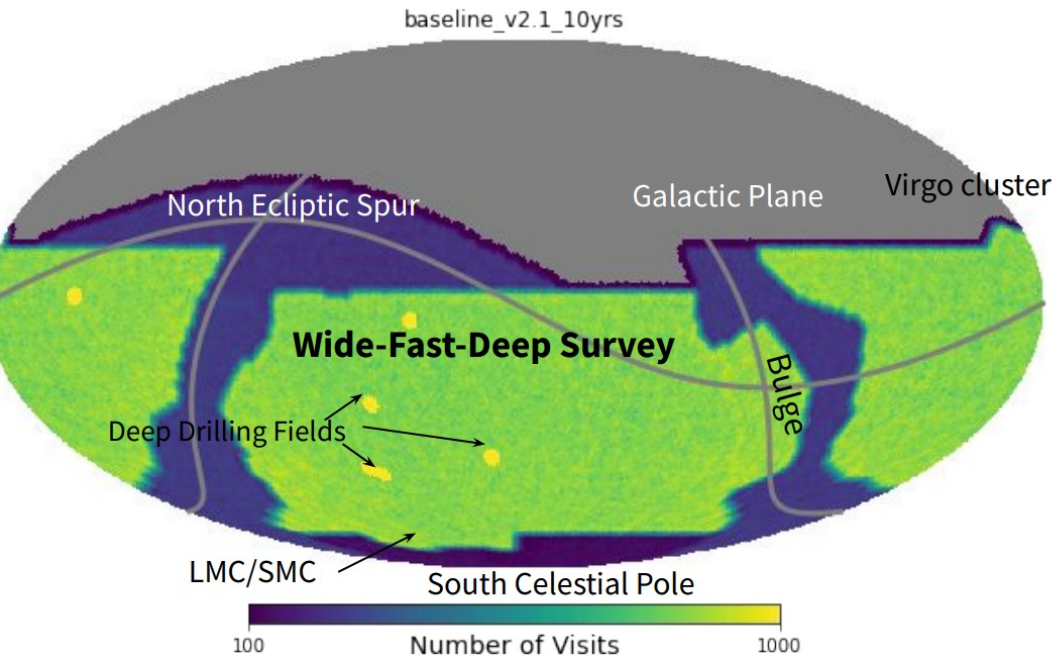
# The Legacy Survey of Space and Time (LSST)

The main wide-fast-deep survey will use about 90% of the observing time

A digital movie of the Universe !

An optical/near-IR survey of half the sky in ugrizy bands to  $r \sim 27.5$  based on  $\sim 800$  visits over a 10-year period.

With angular resolution (0,7 arcsec) and sensitivity (10 mmag) we will look the sky wide, fast, and deep, to discover transient and localized Cosmic rays sources



# LSST In-kind Program

43 teams are making in-kind contributions to Rubin Observatory and LSST Science in return for LSST data rights.

Data rights : the right to access LSST data during its 2-year proprietary period

The International Data Rights Holder list is linked at <https://www.lsst.org/scientists/international-drh-list>

**This project have been selected as in-kind contribution  
PI I. Busa**

## Why ?

SNR Paradigm Weak points (Gabici et al. 2019; Morlino 2017)

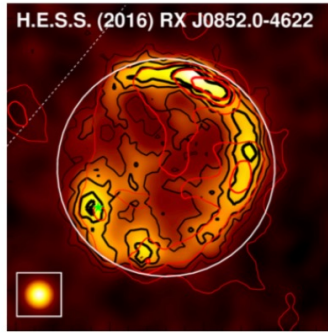
- Sharp break  $e^-$  : a stochastic model of different sources ?
- $e^-$  spectrum steeper than  $p$ : different  $e^-$ ,  $p$  accelerator sources?
- TeV  $e^-$  observed: due to short energy-loss-time,  $d < 100\text{pc}$

## Challenge

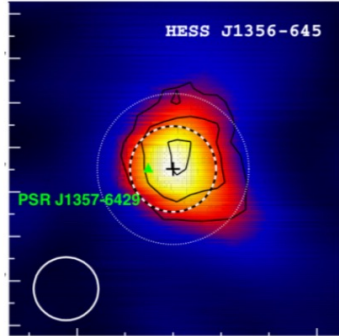
Different GCRs sources besides SNRs

# Galactic $\gamma$ -ray sources: candidates

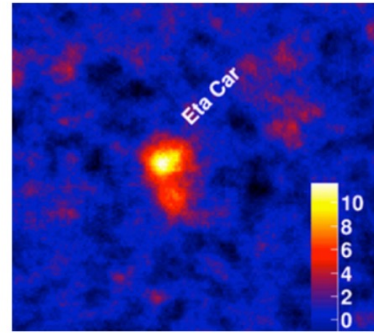
7



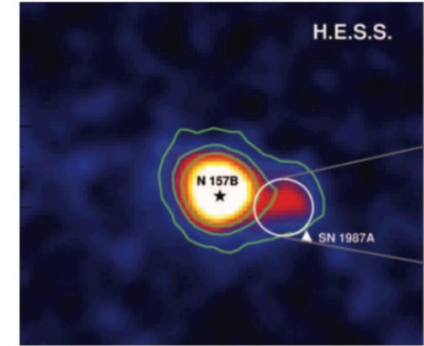
**SNRs**



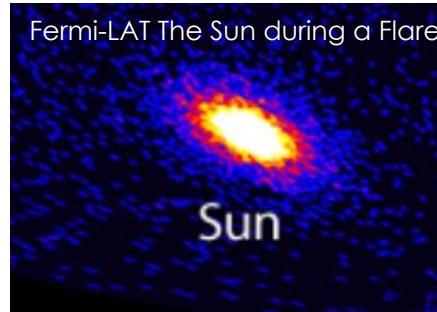
**PSRs, PWNe**



**Binaries**



**Superbubbles, SFR**



**Flare stars**

# WRs and LBVs: candidates

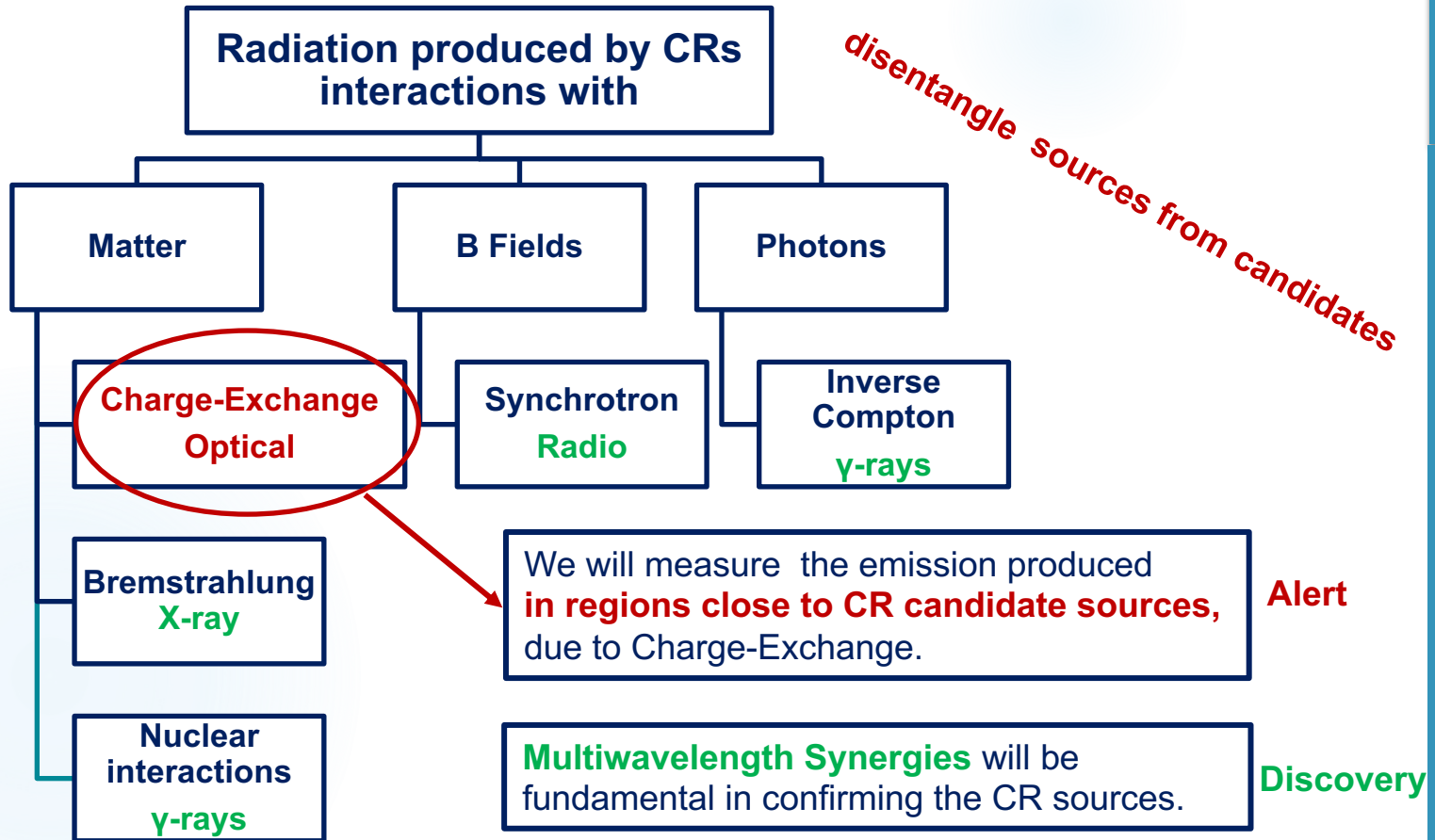


High isotopic  $^{22}\text{Ne} / ^{20}\text{Ne}$  ratio  $\approx 5.3$   
times the solar ratio in solar wind !  
(Binns et.al. 2005)

$^{22}\text{Ne}$  synthesized by the CNO cycle  
during the He burning phase

**WR stars** winds and outburst? **LBV stars** ?  
**Superbubbles** enriched in  $^{22}\text{Ne}$  from outburst of WR stars?





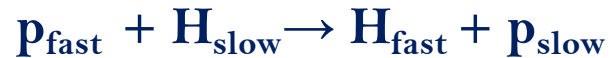
# Charge-Exchange

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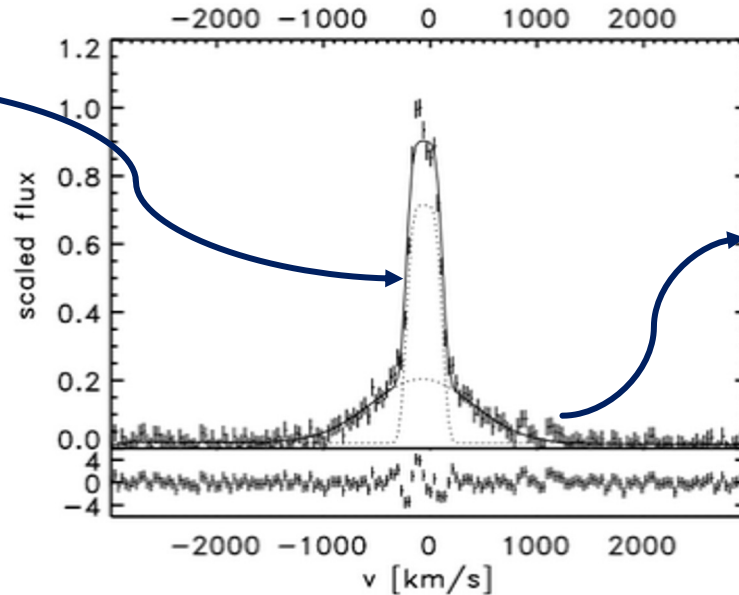
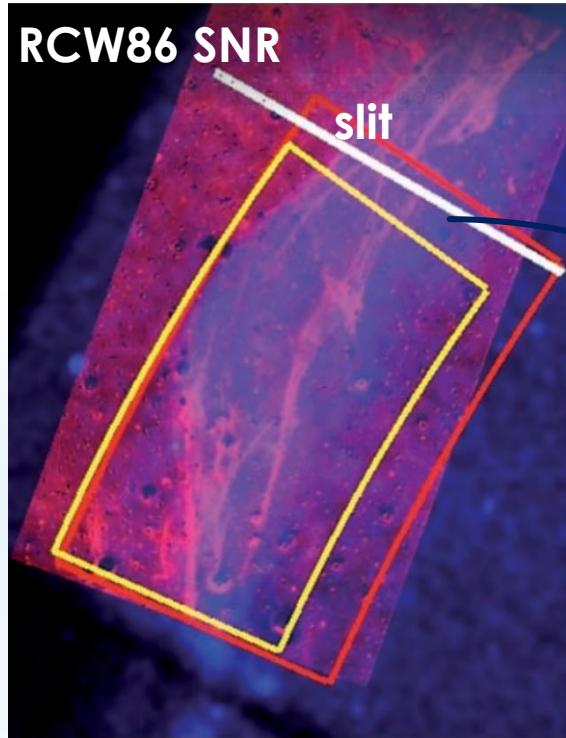
**Charge Exchange (CX)** is a collision between a fast ion and a steady neutral atom in which an electron transfers from the atom to the ion, producing a fast neutral

**In this work we are dealing with CX from protons colliding with a neutral H, we plan to extend the analysis also to heavier ions.**

Proton CX reaction



# CX observed in many SNRs Balmer-Dominated-filaments



**CX emission**  
H with velocity  
distribution  
of the post-  
shock protons

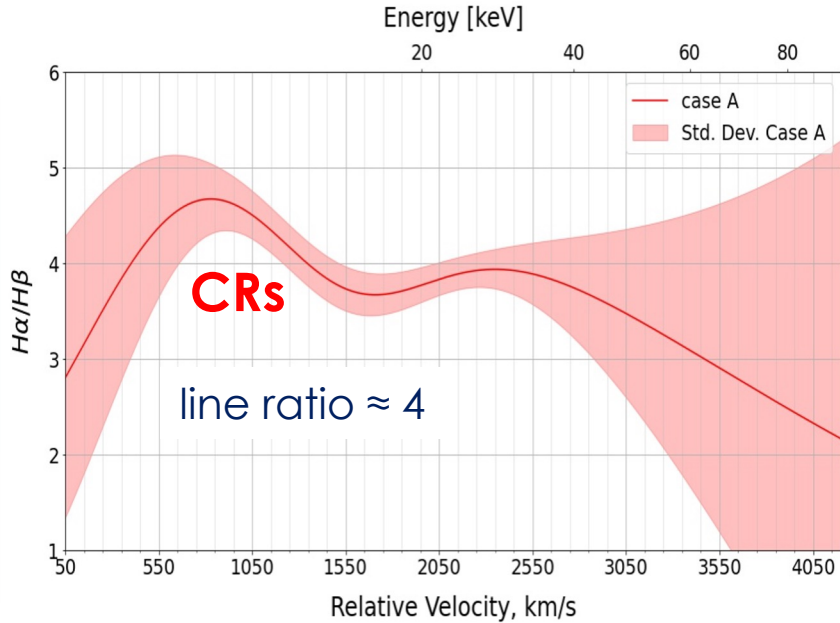
Blue: broadband keV Chandra image; red: VLT H $\alpha$  filter.

H $\alpha$  profile obtained in the slit (Helder et al. 2009)

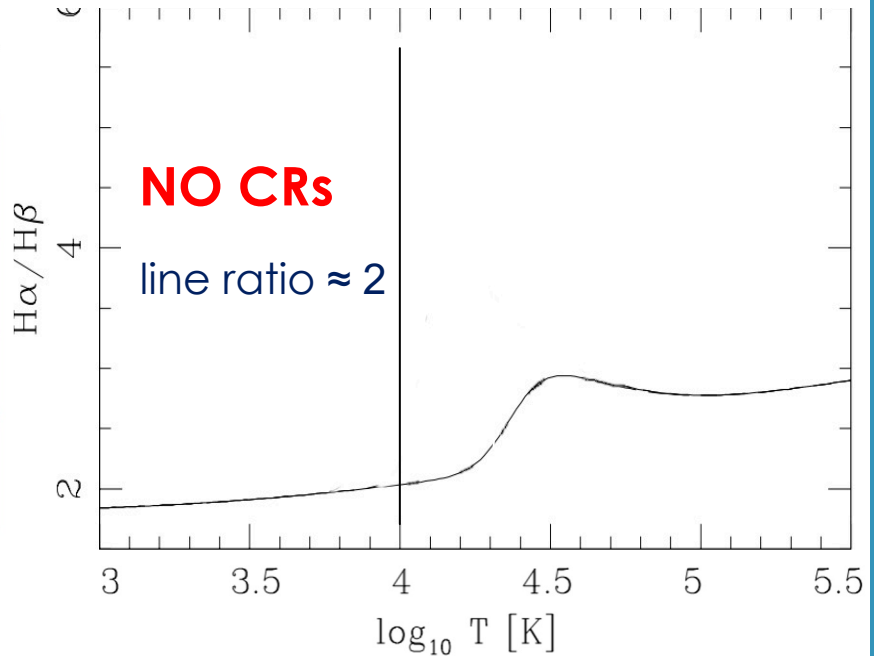
# Charge exchange double $H\alpha/H\beta$ ratio

Paper in preparation

## CHARGE-EXCHANGE: CRs sources

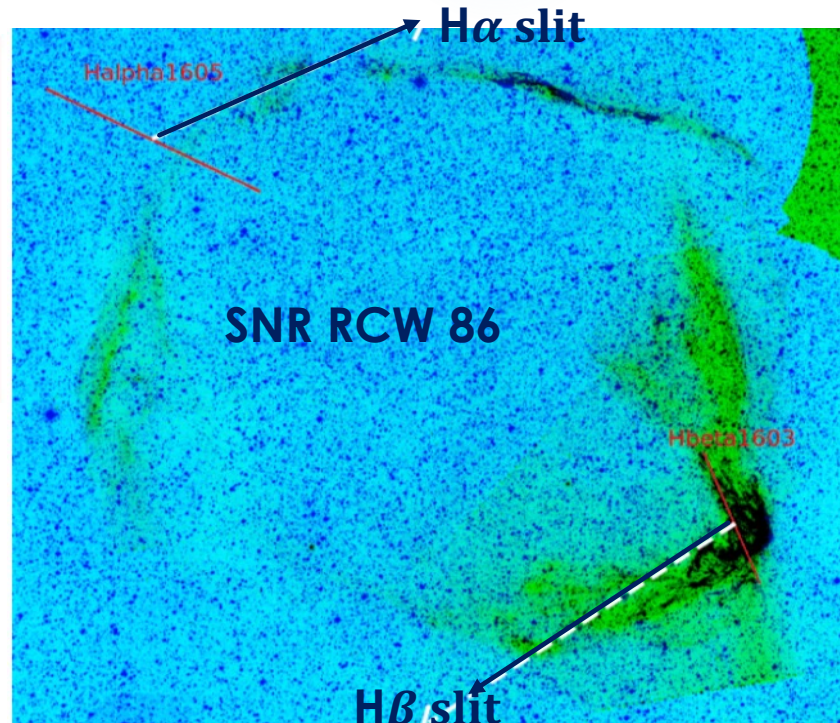
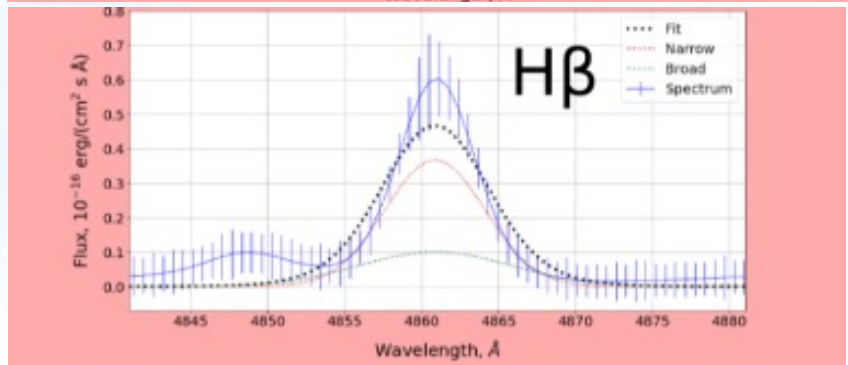
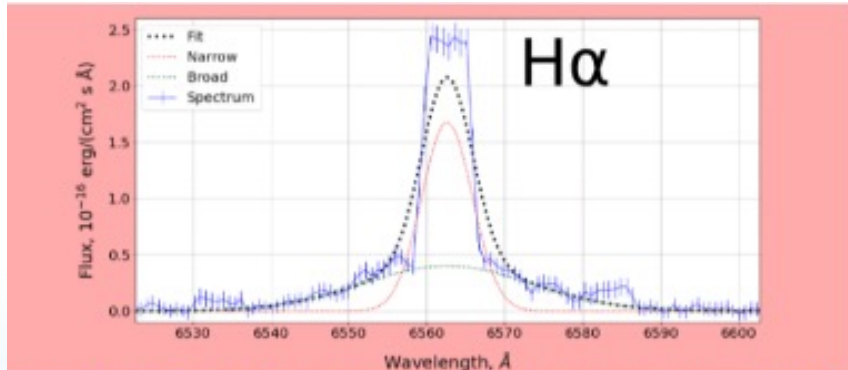


## RECOMBINATION: HII regions, PNe



# Spectroscopic test on RCW86 Balmer-Dominated filaments

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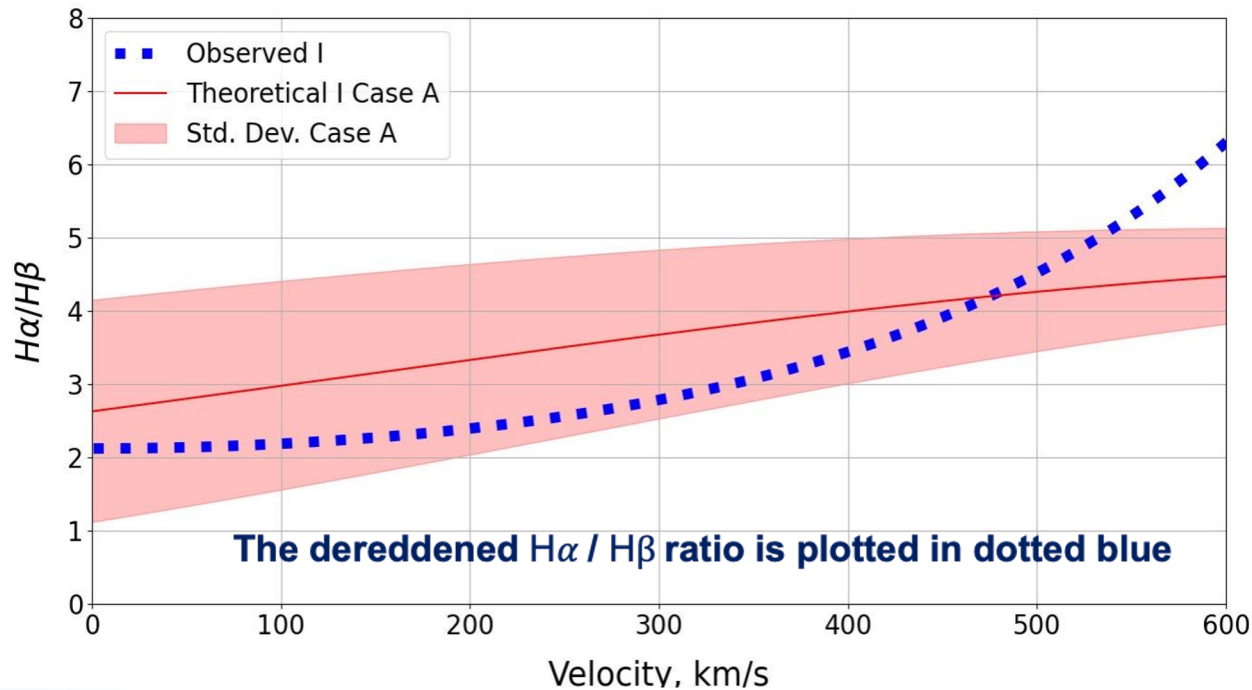
Green: 0.2-10 keV X-ray band (XMM-Newton)  
Blue: H $\alpha$  (SuperCOSMOS)

# Spectroscopic test on RCW86 Balmer-Dominated filaments

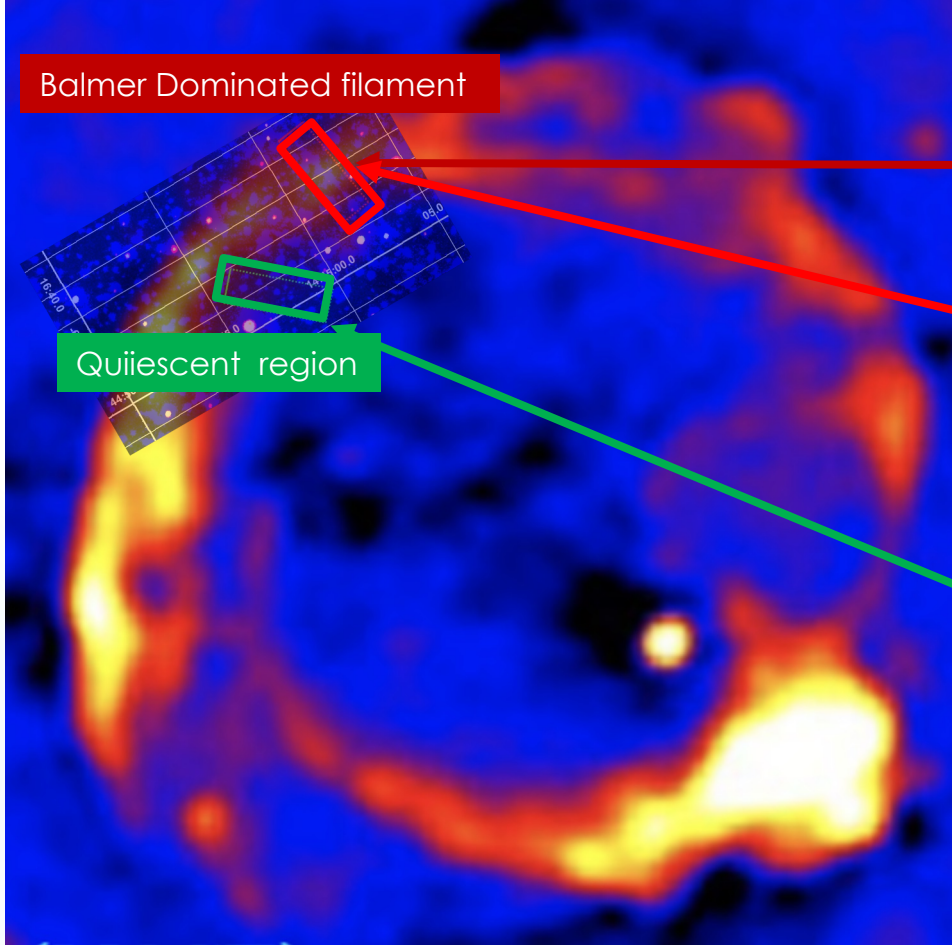


(S. Cabibbo Master Thesis)

## Charge - Exchange



Spatial correlation of Radio and CX emission is observed in the SNR RCW86



Balmer Dominated filament

Quiescent region

CX detection

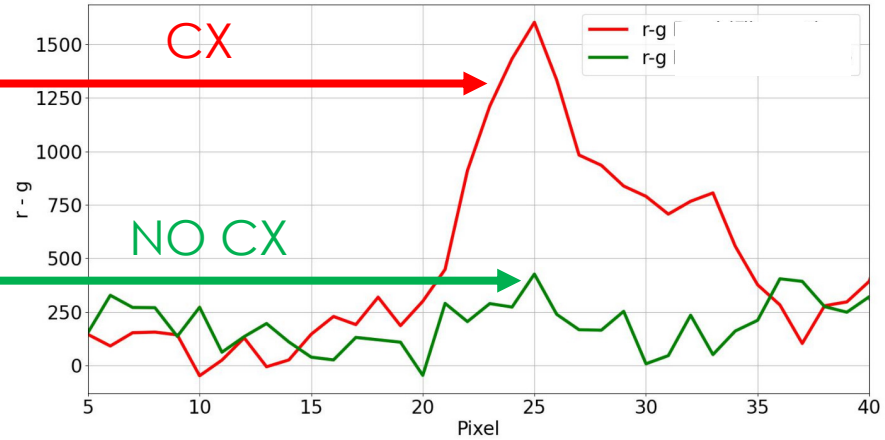
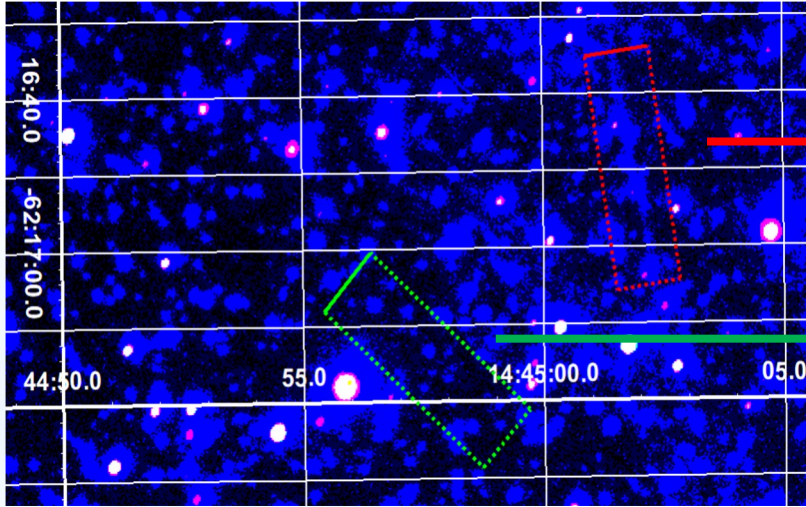
Radio detection

No Radio  
No CX  
detection

RCW 86 SNR 1.34 GHz radio, MOST

# Preliminary Photometric test on RCW86 Balmer-Dominated filaments

## SNR BD filament compared with quiescent region (r and g filters)



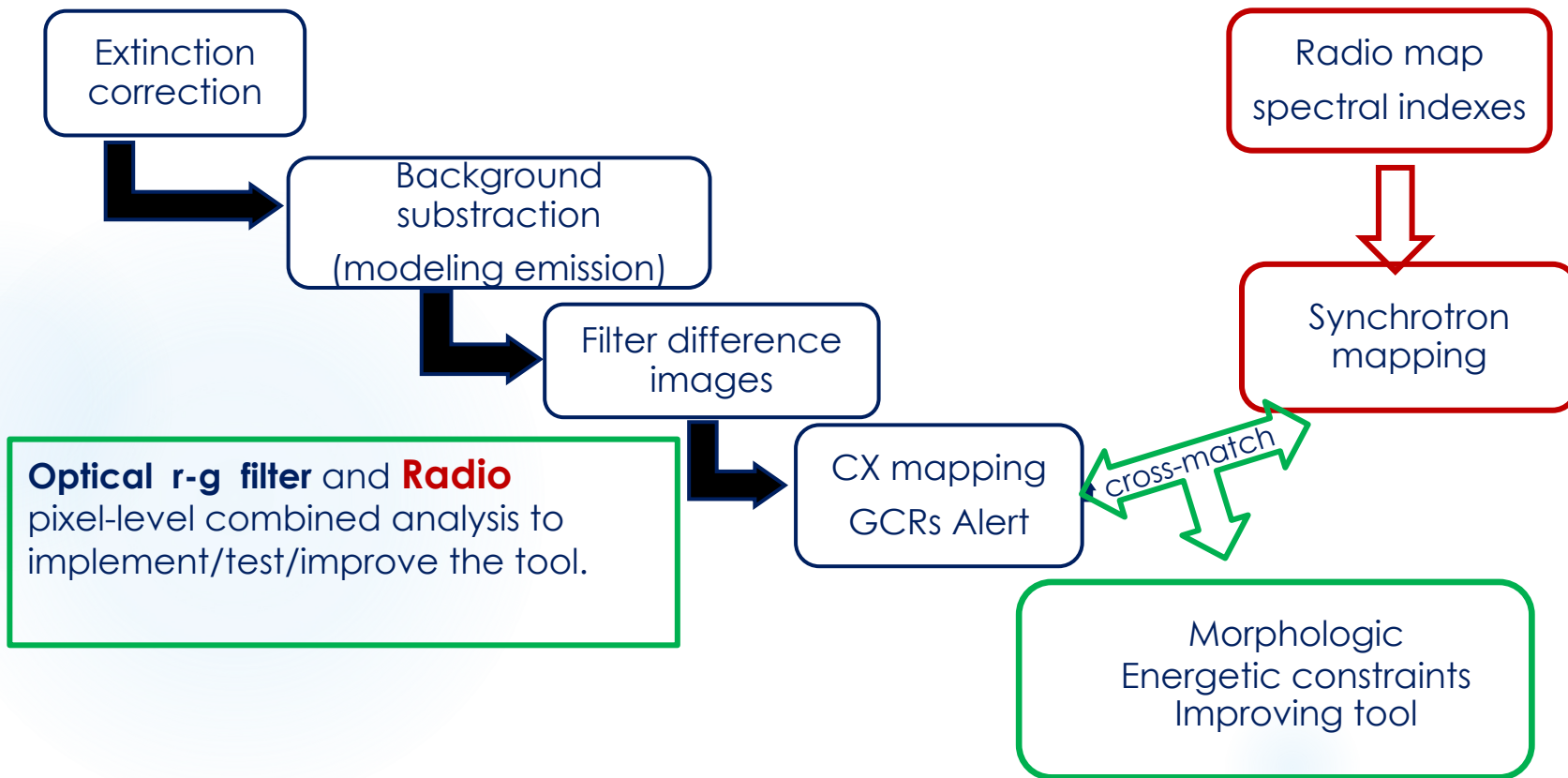
r - g color index can map CX



# Optical-Radio implementing/testing tool for mapping GCRs sources

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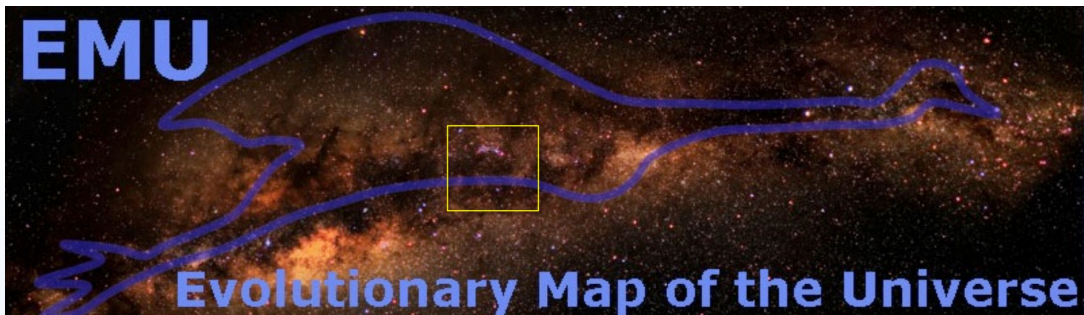
Innocenza Busa "The salt of the star formation recipe"  
Florence 8-10 November 2022



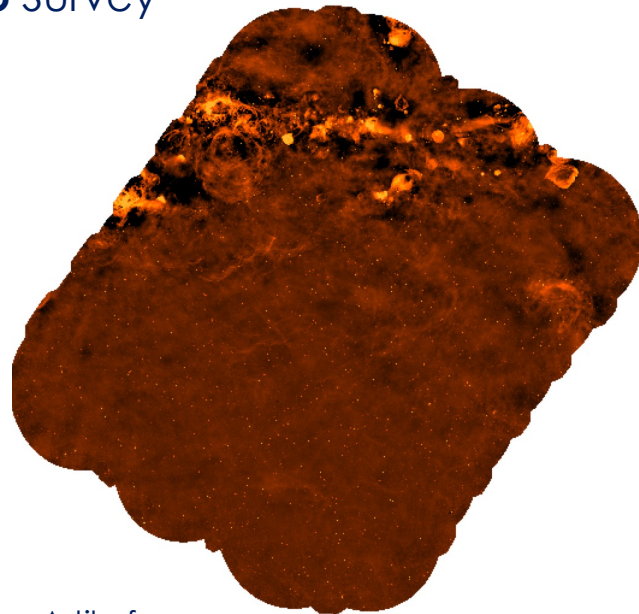
# Radio Synergy work in progress

Working on **Optical** – **Radio** surveys images testing and constraining the method

ASKAP Evolutionary Map of the Universe (EMU) **Radio** Survey  
EMU Pilot2 (36 dishes) **SCORPIO field**



- Coverage: 150 square deg
- **Frequency: 928 MHz**
- **Angular resolution ~ 10 arcsec**
- Sensitivity: 20 - 100  $\mu$ Jy/beam

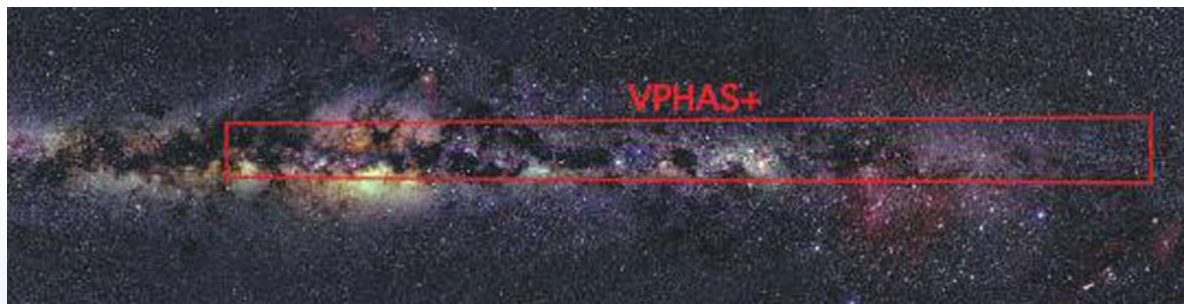


A tile from  
SCORPIO field

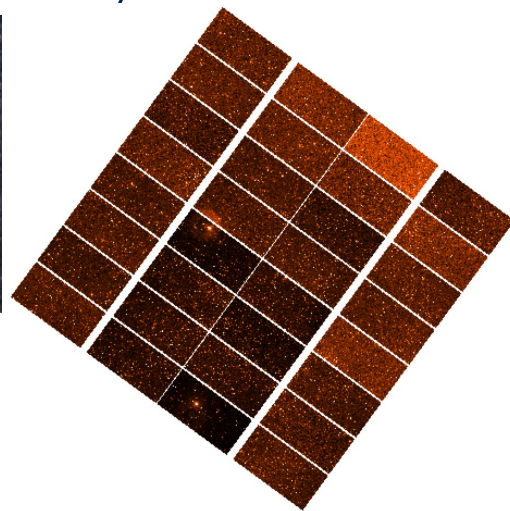
## Radio Synergy work in progress

Working on **Optical** – **Radio** surveys images testing and constraining the method

VPHAS+ (Drew et al 2014) VST **Optical** Photometric Survey



- Coverage: 1800 square deg
- **Filters: ( $H\alpha$ , u,g,r,i)**
- **Angular resolution  $\sim 1$  arcsec**
- 21-22th mag in the optical bands r and g

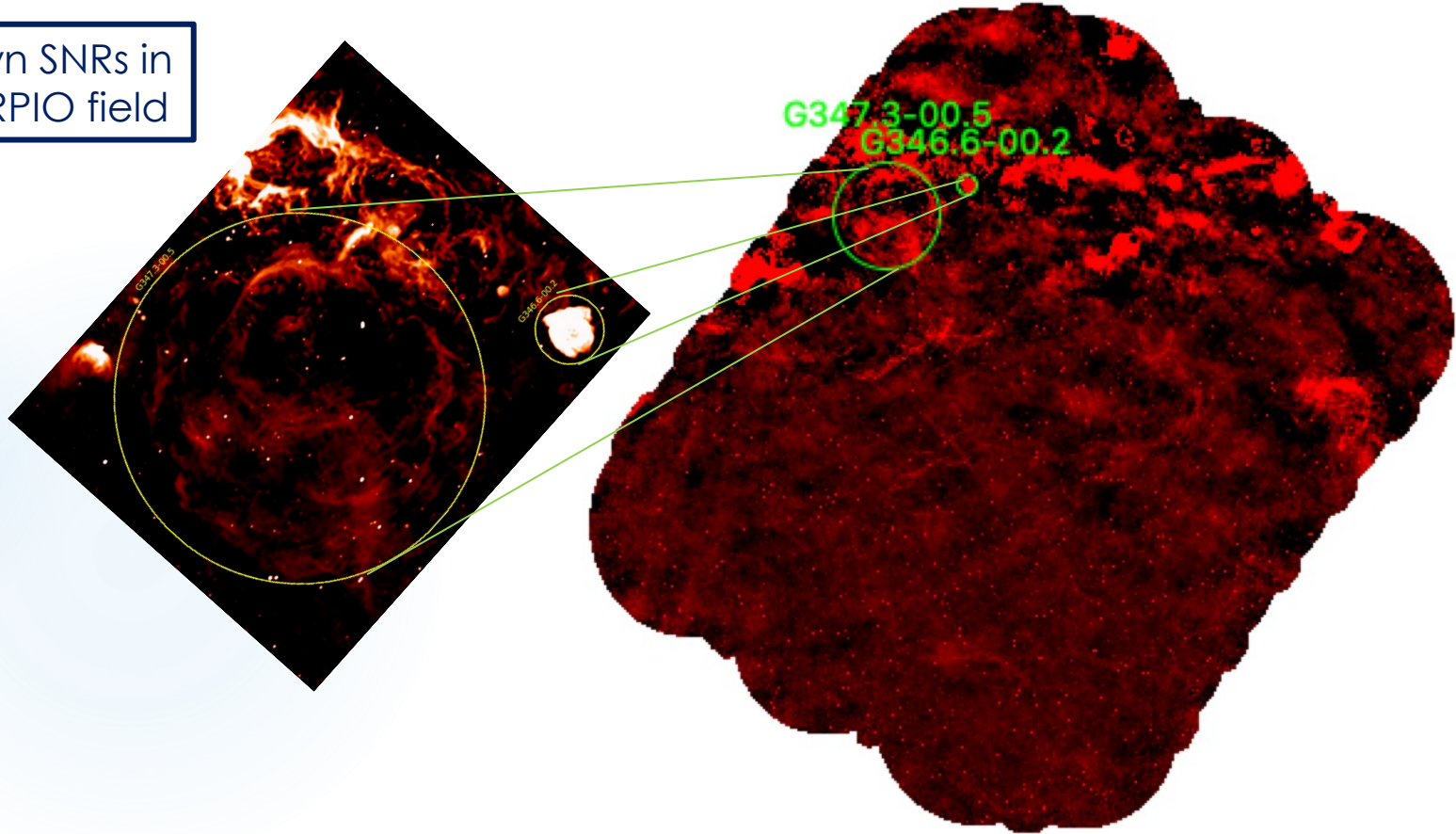


32 CCD Mosaic  
r filter in the SCORPIO field

# ASKAP Scorpio Pilot2 Radio field

Selection of regions with known CRs sources

Known SNRs in  
SCORPIO field



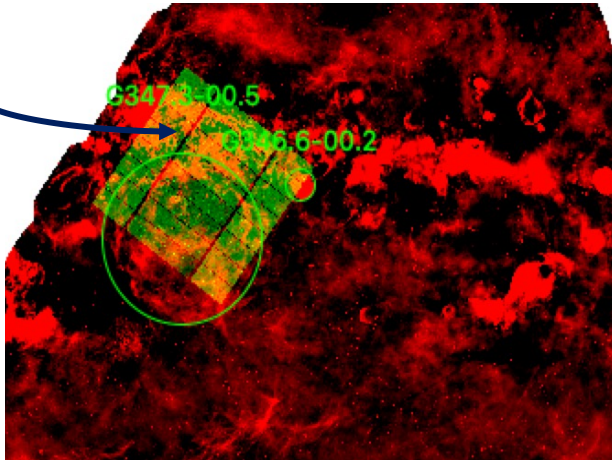
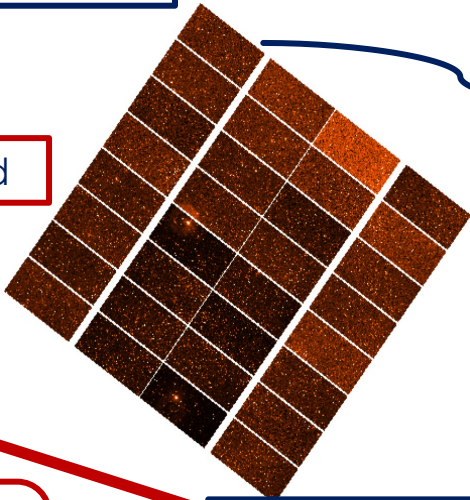
# Radio-Optical Synergy work in progress

VPHAS+ VST r,g filter  
Pixel-level Mapping CX  
around known CR sources

Spectroscopic proposal planned

**Cross-Match  
Morphologic  
energetic**

Testing and Improving the tool  
Deriving limits and constraints



Scorpio Pilot2 ASKAP radio field  
Pixel-level Mapping Synchrotron  
around known CR sources

## Working at an extended optical - radio synergy that includes:

- Extraction of extended Galactic regions  
(*LSST LSB Sinergy - Radio Meerkatplus Ska1-Mid*)
- Classification of GCRs source candidates SNR, WPN, X and  $\gamma$  rays binaries, WR, Flare, LBV stars (*LSST TVS Sinergy – Multiwavelenght Surveys*)
- Classification of GCRs source by CX mapping  
(*LSST SMWLV Sinergy - Radio Meerkatplus Ska1-Mid + CTA?*)

# To be ready for the next exciting years with LSST - MeerKATplus SKA-Mid Synergy

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Innocenza Busa "The salt of the star formation recipe"  
Florence 8-10 November 2022

MerKATplus Legacy Survey (~2027)

Band S 1750 – 3500 MHz

**Angular res 1.77 – 0.88 arcsec**

SKA-Mid (~2028)

Band1-2-5 350 MHz - 15.4 GHz

**Angular res 1.4 - 0.03 arcsec**

Rubin LegacySurveySpaceTime (~2026)

Filter: u, g, r, i, z, y

**Angular res 0.7 arcsec**



All with subarcsec angular resolution !



Thanks !