Radio observations of star-forming regions

ICCUB Winter Meeting 2024

Image Credit: NASA,ESA, M. Robberto

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UNIVERSITAT DE BARCELONA

EXCELENCIA MARÍA DE MAEZTU 2020-2023

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Outline

Scientific context

On-going projects

Future work

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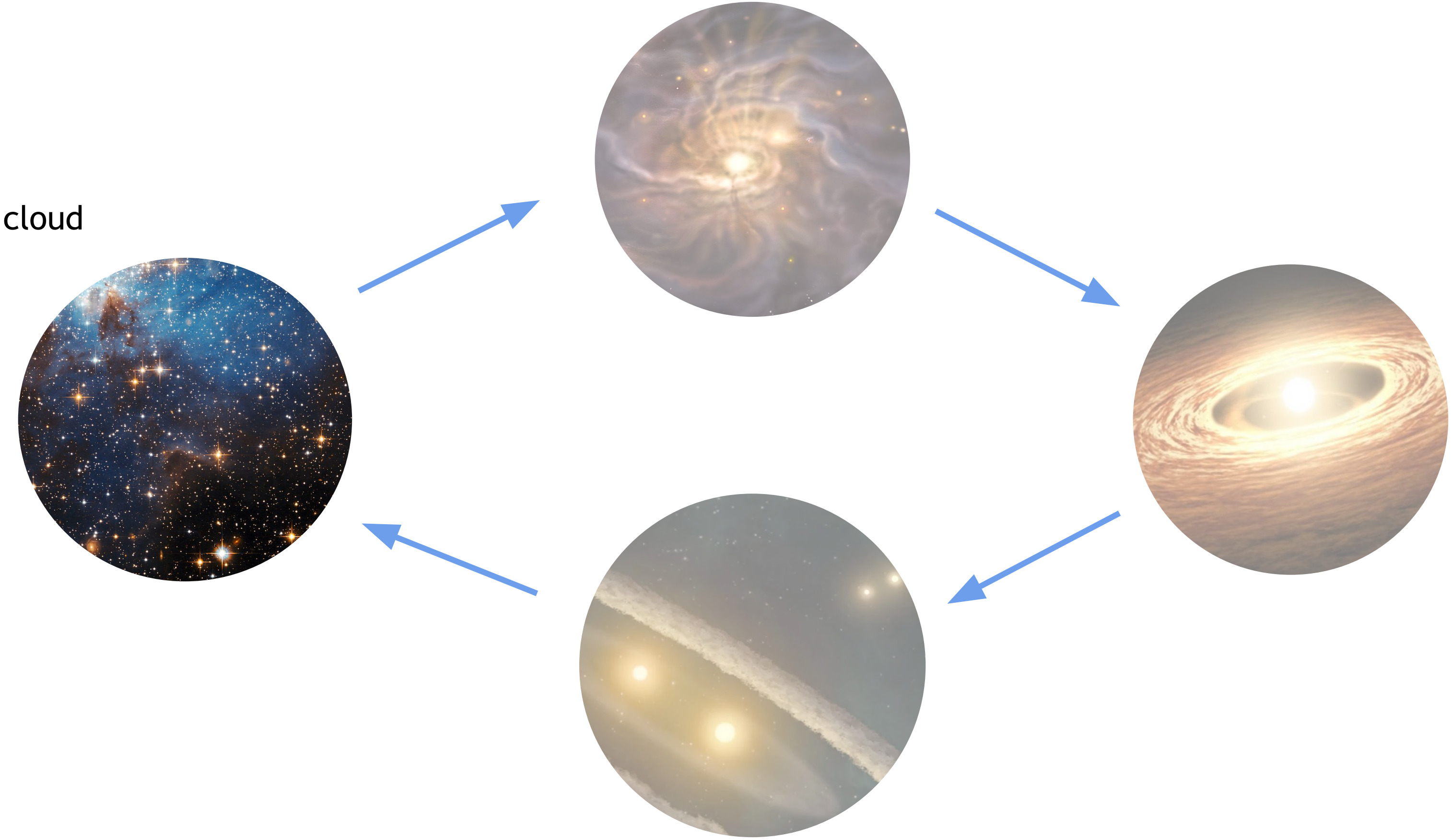
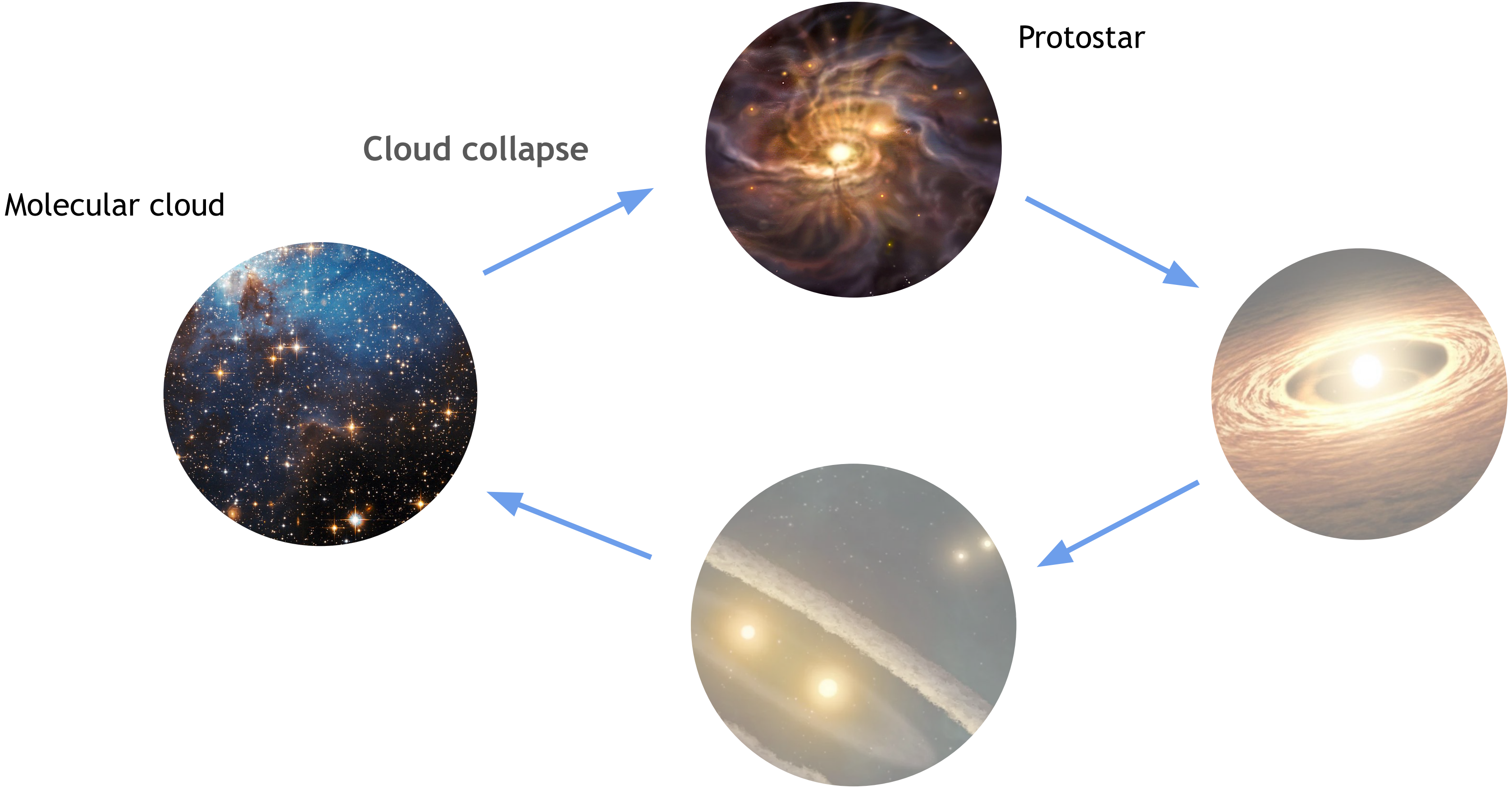
The star formation cycle

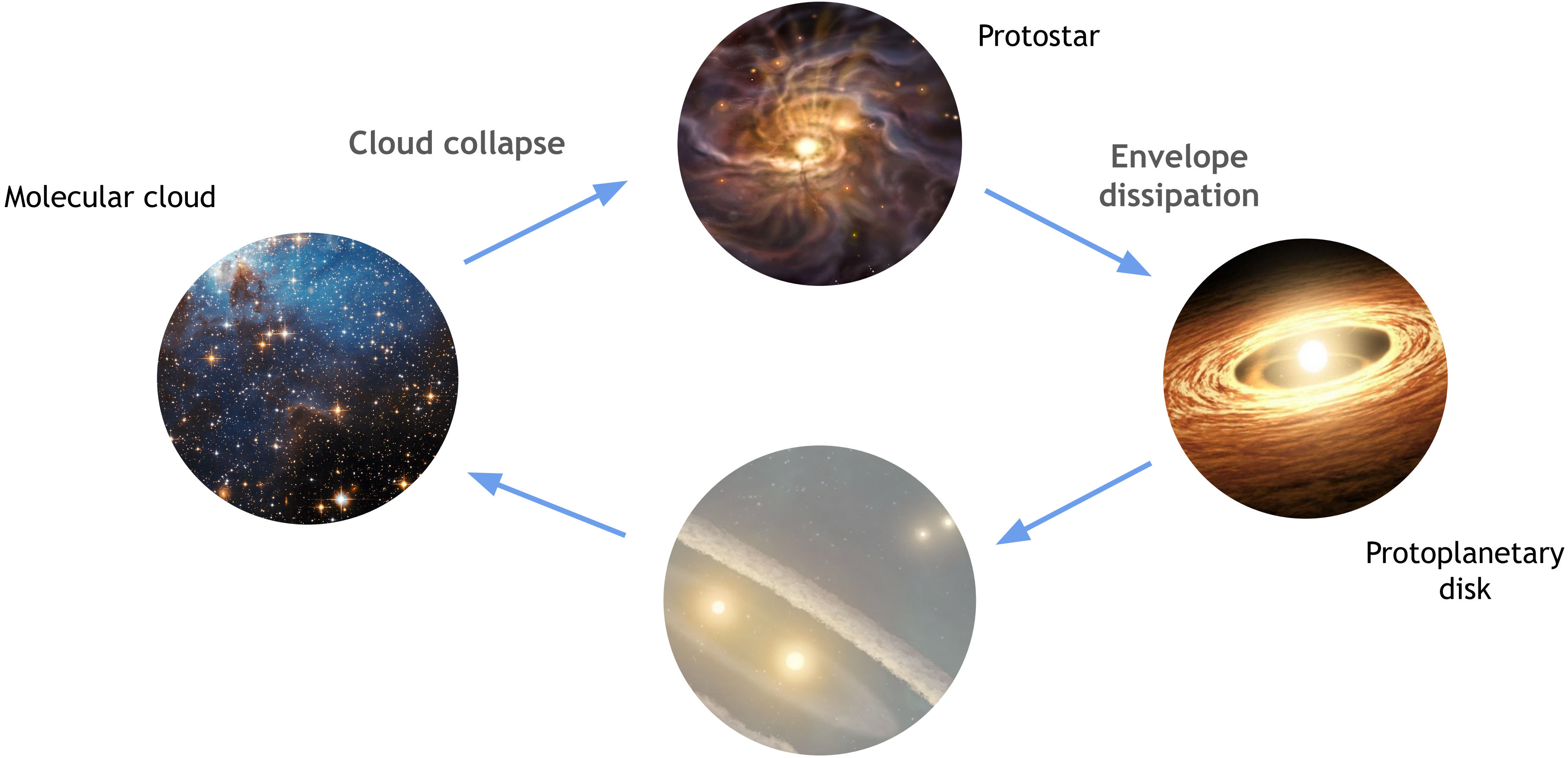
Molecular cloud



The star formation cycle



The star formation cycle



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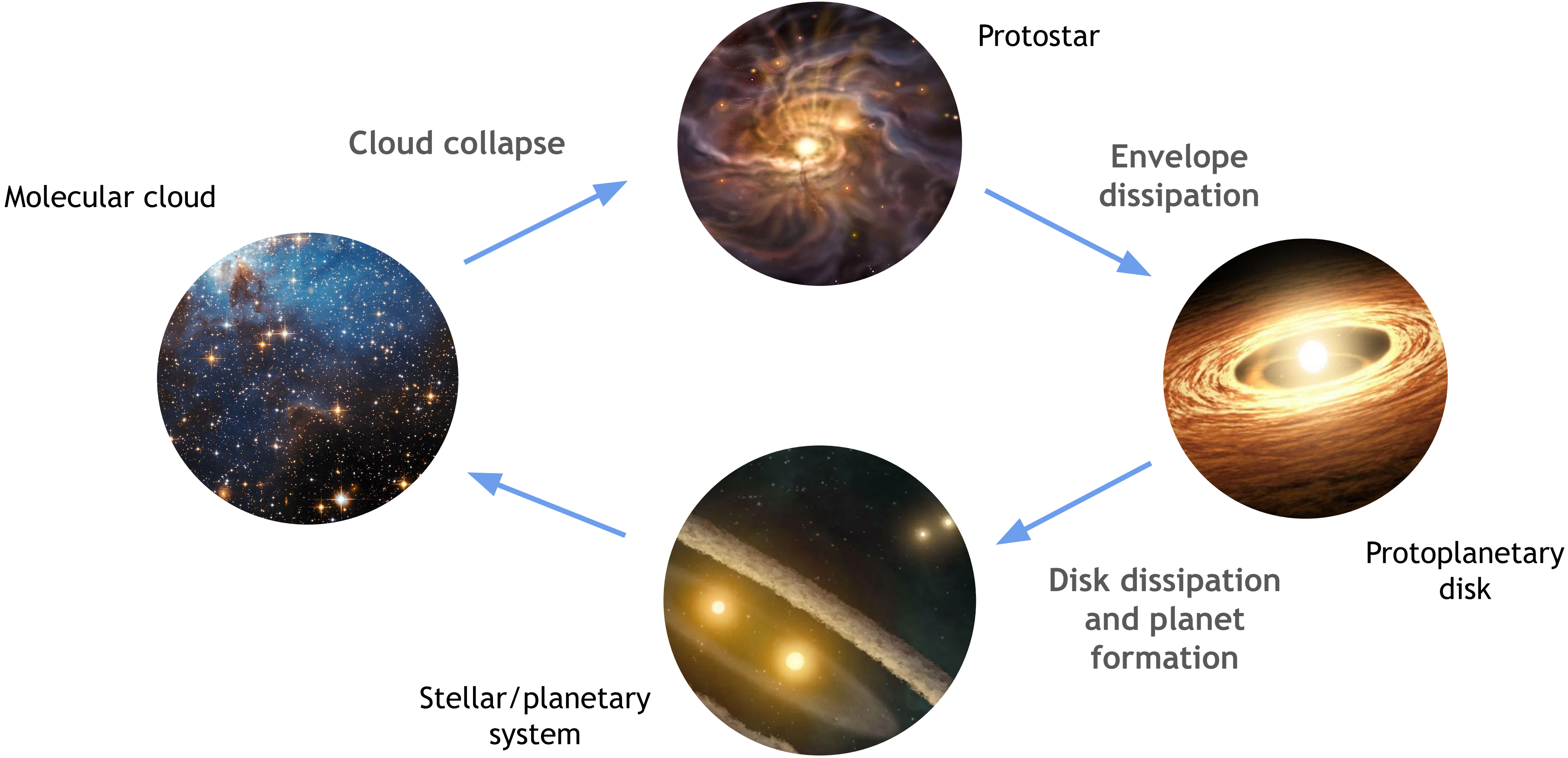

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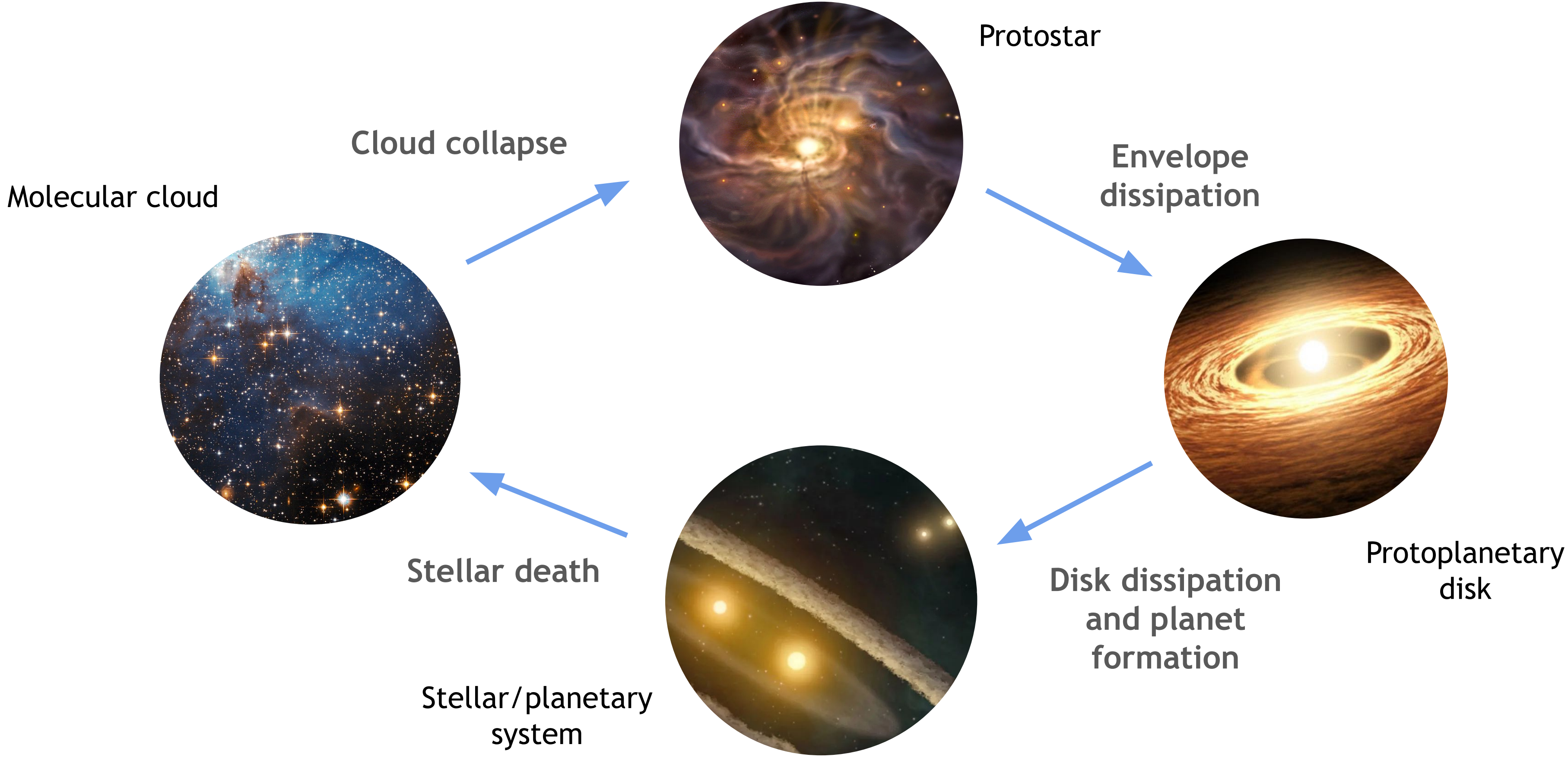
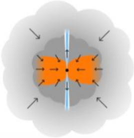
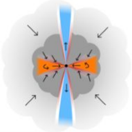
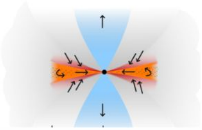
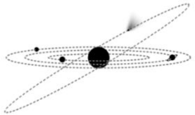
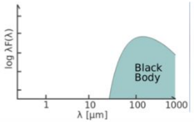
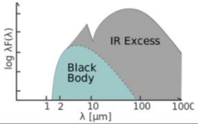
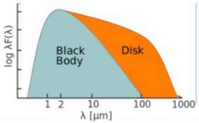
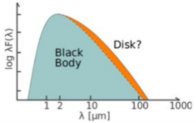


Radio emission

PROPERETIES	Infalling protostar	Evolved protostar	Classical T Tauri star	Weak T Tauri star	Main sequence star
SKETCH					
AGE (YEARS)	10^4	10^5	10^6–10^7	10^6–10^7	$>10^7$
MM/INFRARED CLASS	Class 0	Class I	Class II	Class III	(Class III)
DISK	Yes	Thick	Thick	Thin or non-existent	Planetary System
THERMAL RADIO	Yes	Yes	Yes	No?	No
NON-THERMAL RADIO	No?	Yes	No?	Yes	Yes
SED					

G. Busquet, adapted from Feigelson & Montmerle (1999)

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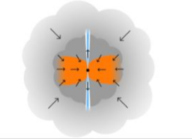
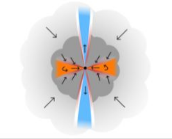
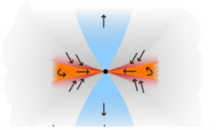
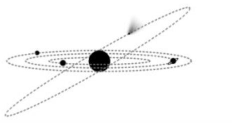
SKETCH					
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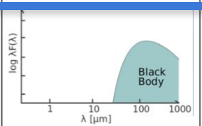
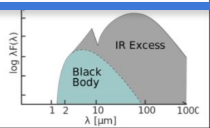
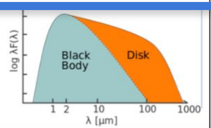
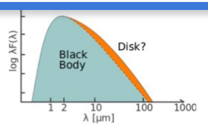
SED					

$$S_\nu \propto \nu^\alpha$$

G. Busquet, adapted from Feigelson & Montmerle (1999)

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Non-thermal emission

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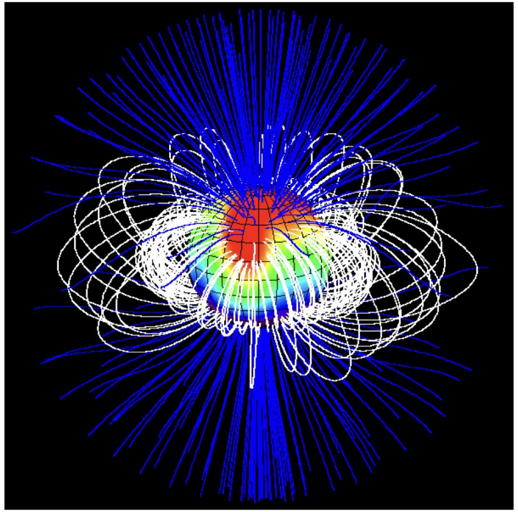

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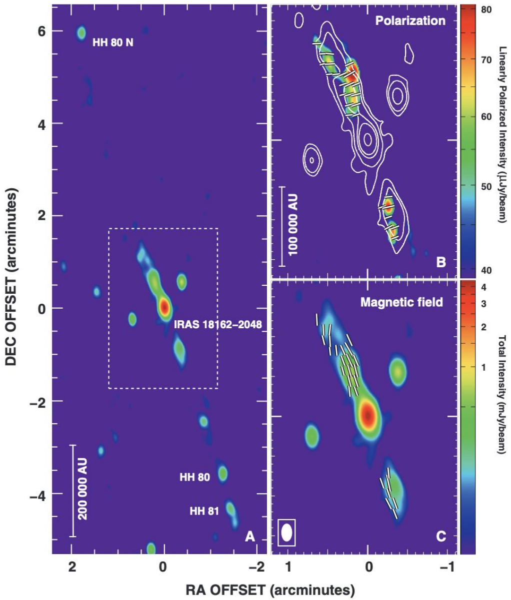
Carrasco-González et al. (2010)



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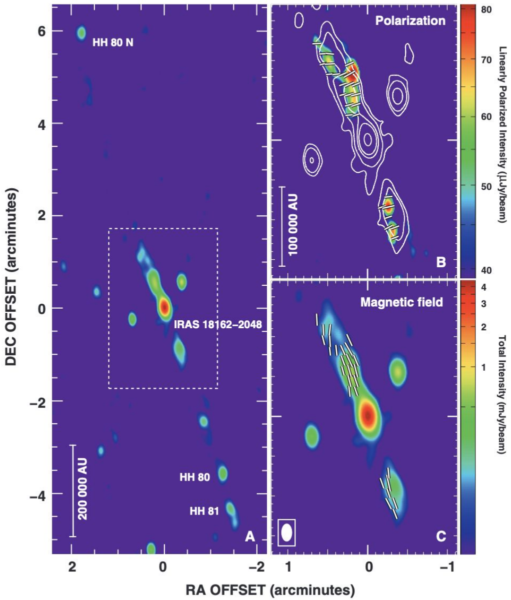
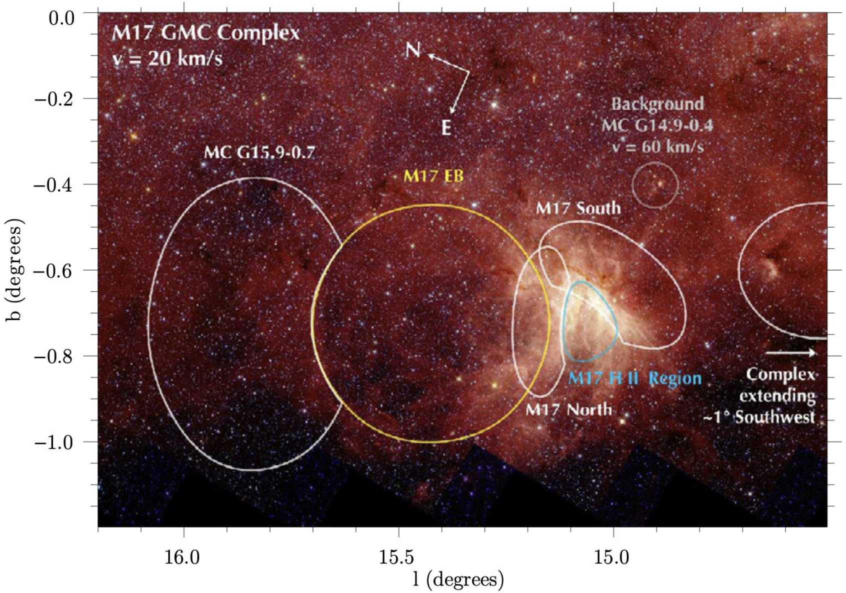
Carrasco-González et al.(2010)





Povich et al.(2009)

The nature of the cm emission

Thermal emission

- Emission from free-free electron encounters
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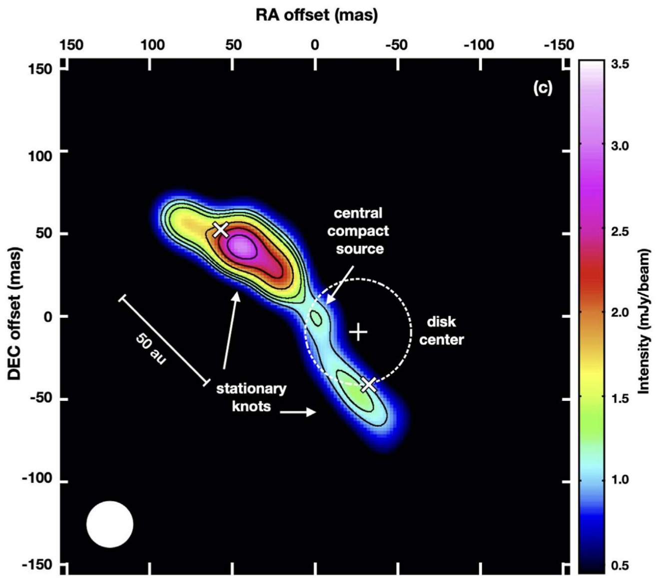
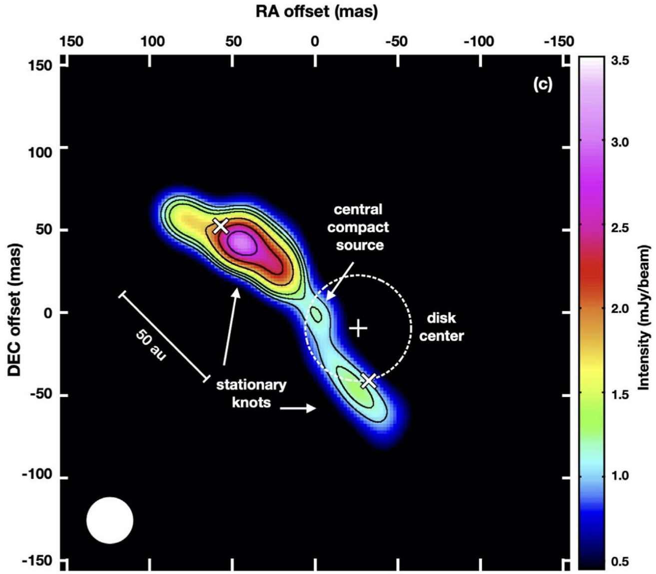


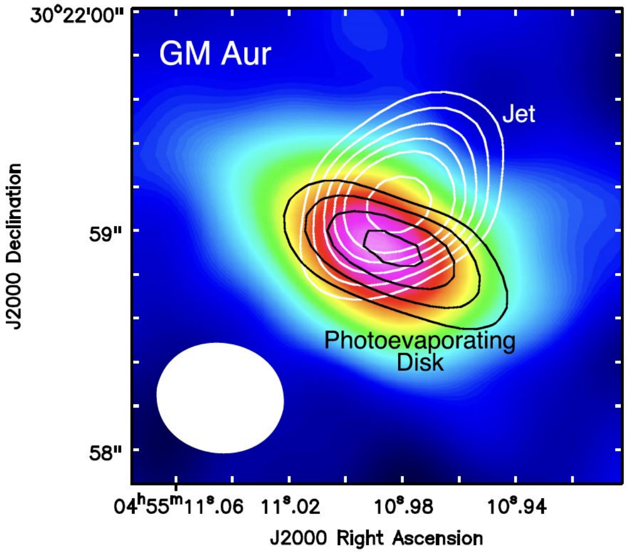
The nature of the cm emission

Thermal emission

- Emission from free-free electron encounters
- Can arise from shocks in jets powered by YSOs and also from HII regions
- Other regions, present protoplanetary disks under the influence of external photoevaporation

Carrasco-González et al. (2021)





Macías et al. (2016)

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The targets

The IRDC G14.2

The VOLS project

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The IRDC G14.2

The VOLS project

The IRDC G14.2

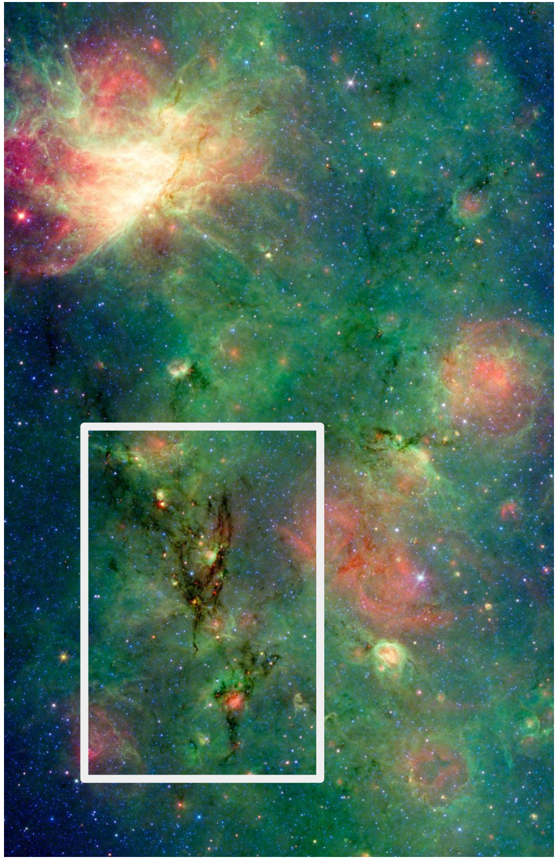


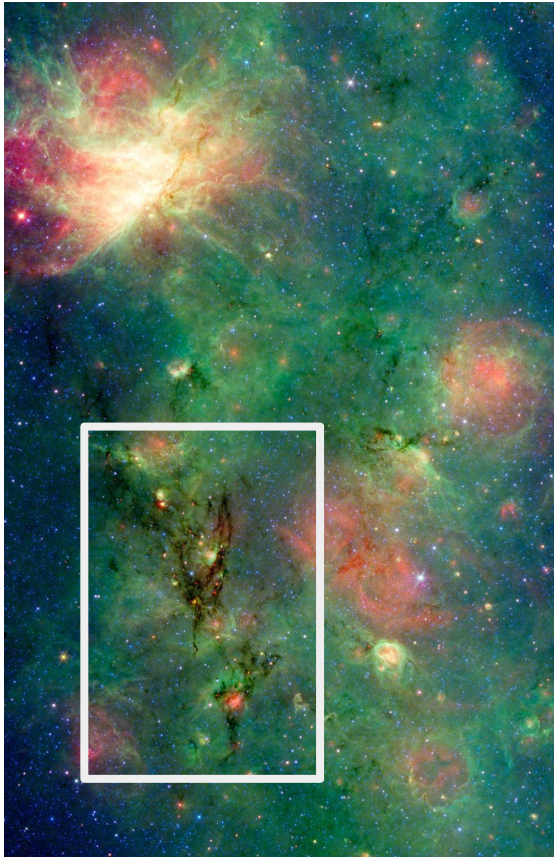
Image Credit: NASA/ JPL-Caltech/Matthew Povich (Penn State)

- Part of the extended and massive molecular cloud located at the M17 region (d=1.6 kpc) (*Zucker et al. 2020*)

- Signposts of star formation and rich population of protostars (*Wang et al. 2006, Povich & Whitney 2010, Povich et al. 2016*)

- Associated with a network of filaments, which result in two different dense hubs (*Busquet et al. 2013, Busquet et al. 2016*)

The IRDC G14.2



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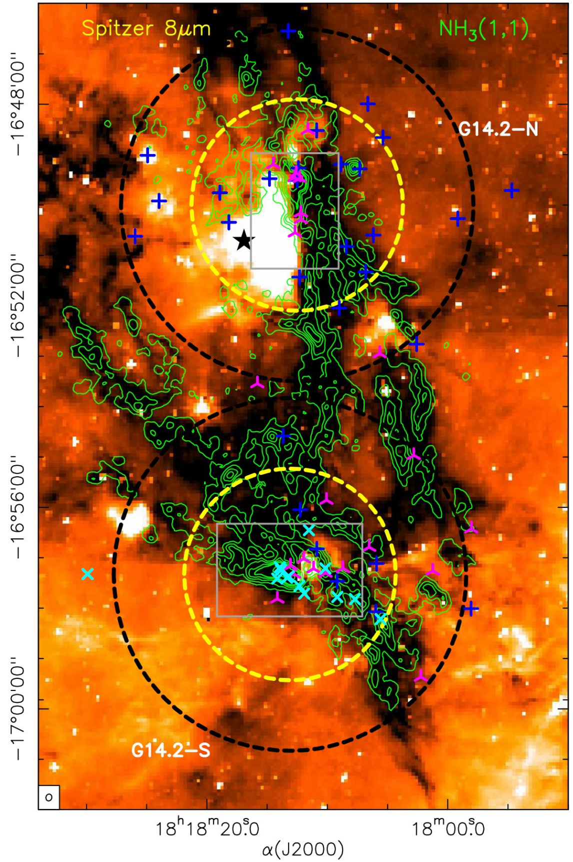
G14.2 is a complex and dynamic environment with ongoing star formation activity

The IRDC G14.2



Díaz-Márquez et al. (2024) accepted for publication in A&A*

VLA observations

- Angular resolution of ~ 0.3’’~ 480 au (most extended A configuration)
- Sensitivity of 1.5 μJy/beam at C-band (4–8 GHz; ~6 cm) and 2 μJy/beam at X-band (8–12 GHz; ~3.6 cm)
- Two pointings labelled as **G14.2-N** and **G14.2-S**

*https://ui.adsabs.harvard.edu/abs/2023arXiv231112542D/abstract

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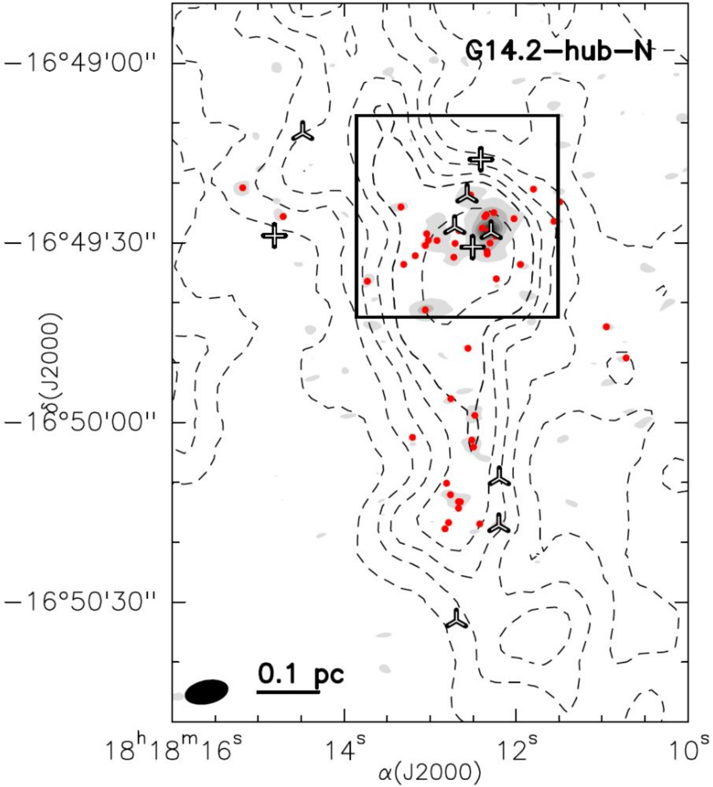

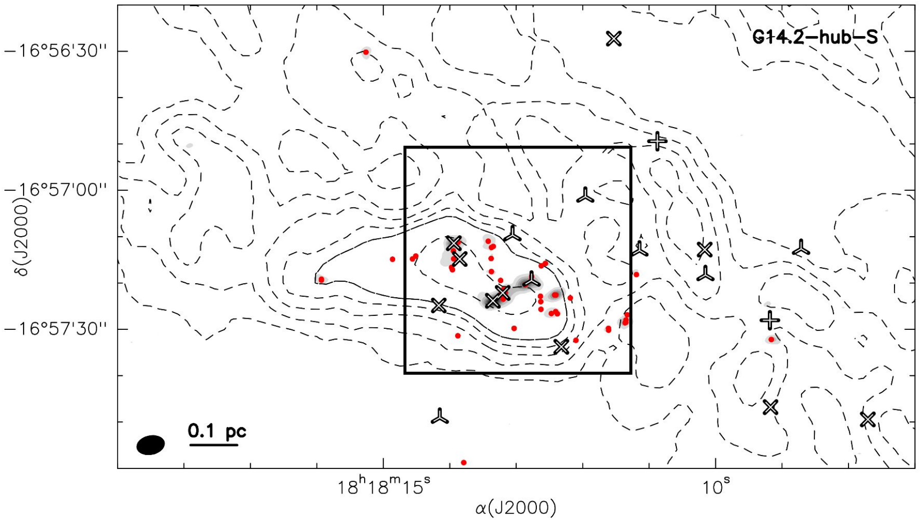

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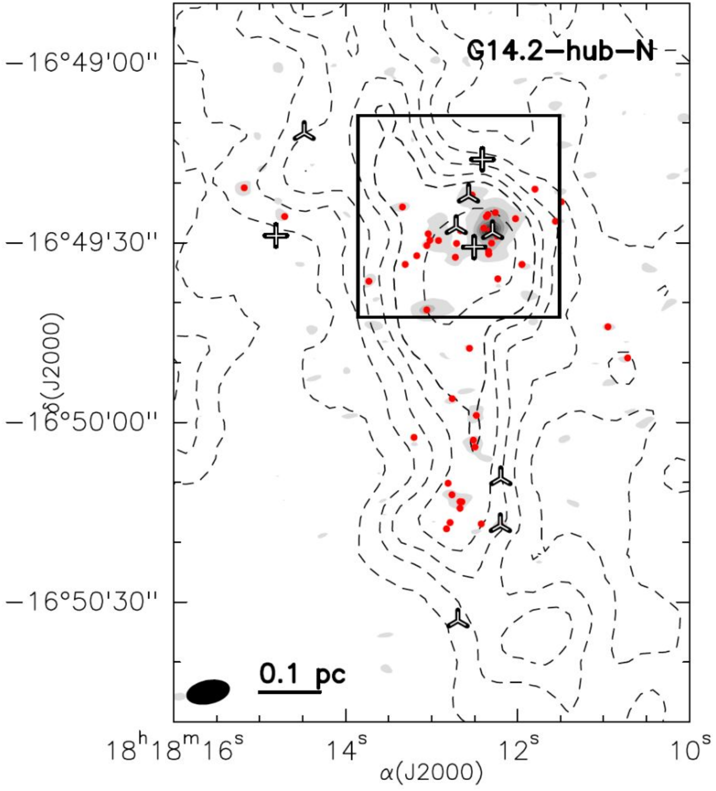
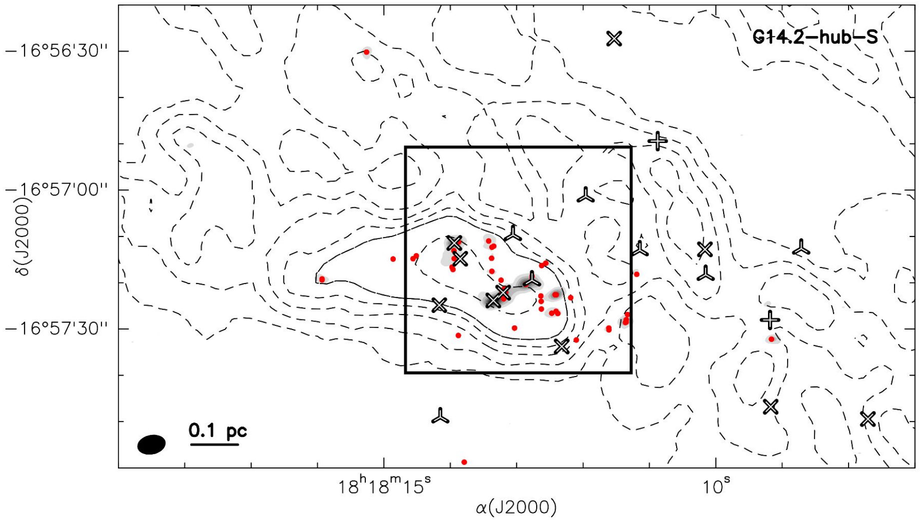


32 sources in G14.2-N

34 sources in G14.2-S



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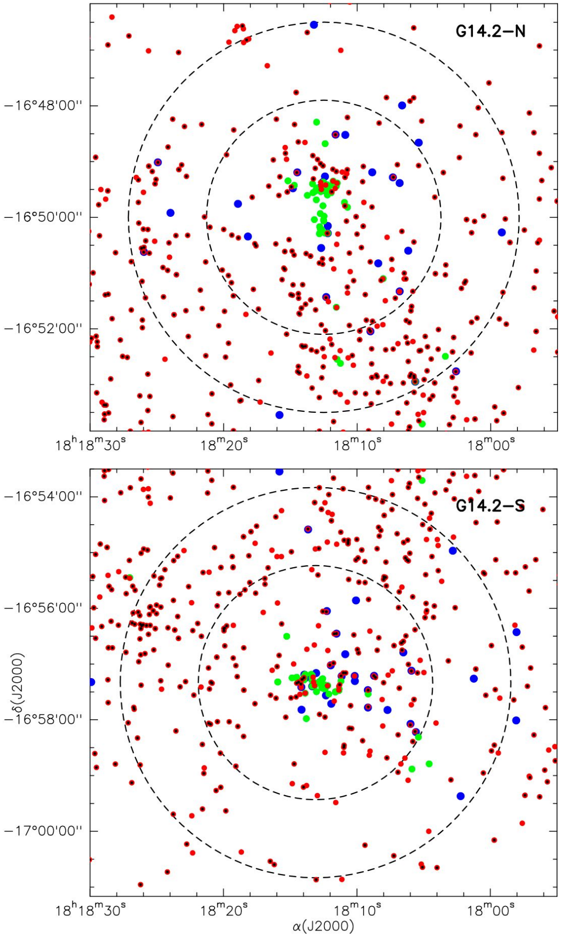
The IRDC G14.2

Stellar population in G14.2

cm sources
mm sources
IR sources
X-ray sources



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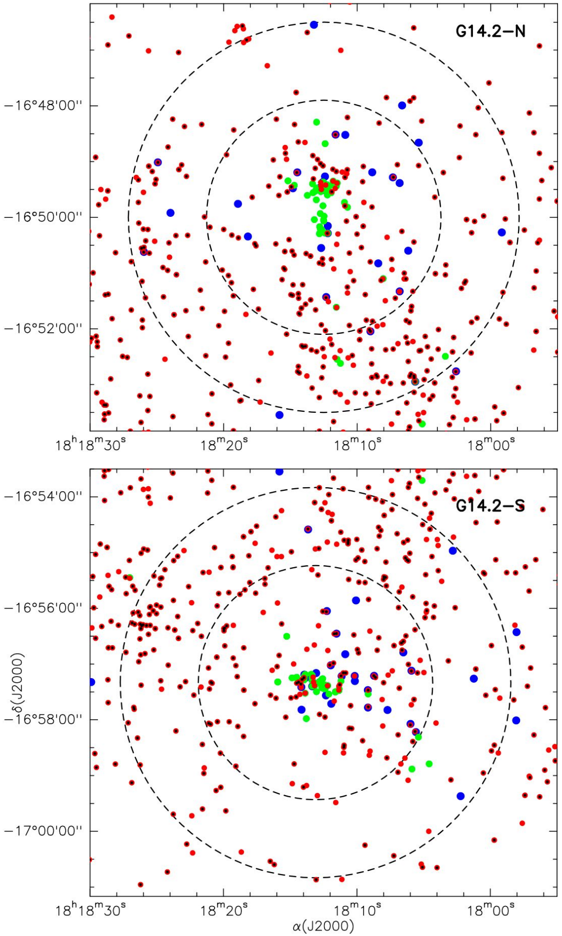


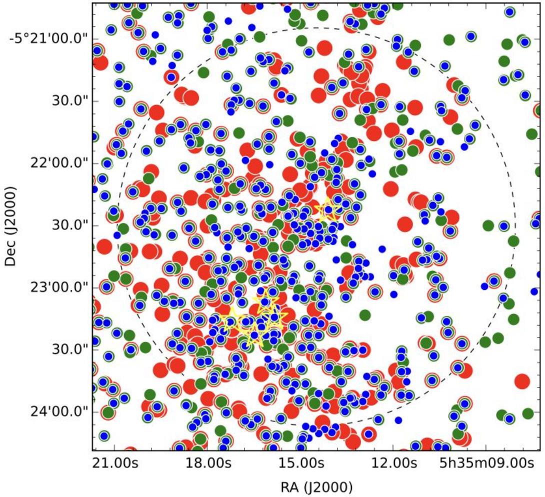
Díaz-Márquez et al.(2024), accepted

Despite the high sensitivity of VLA observations, the fraction of radio detections is low in comparison with the IR and X-ray stellar population

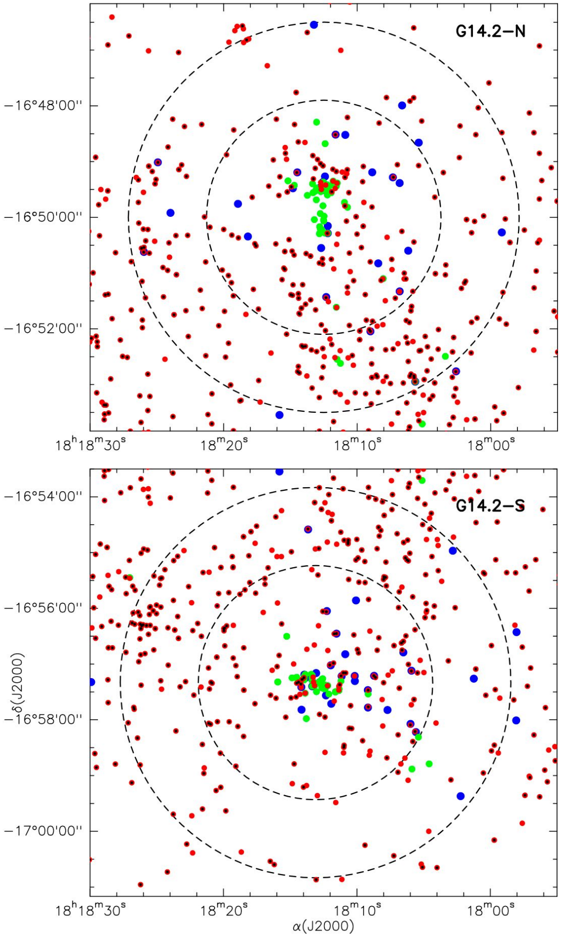
The IRDC G14.2

Stellar population in G14.2

Forbrich et al. (2016)



X-ray sources
IR sources
radio sources



Díaz-Márquez et al. (2024), accepted

In other regions such as the ONC, there also differences in the distribution of the sources

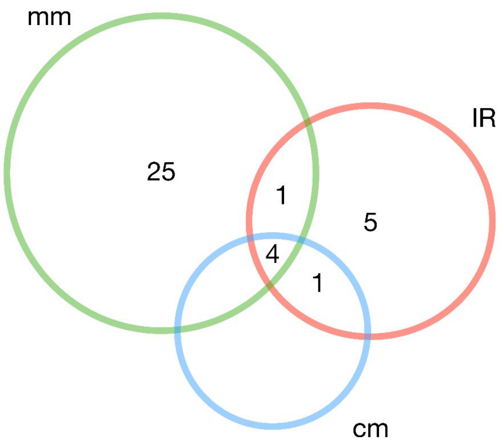
The IRDC G14.2

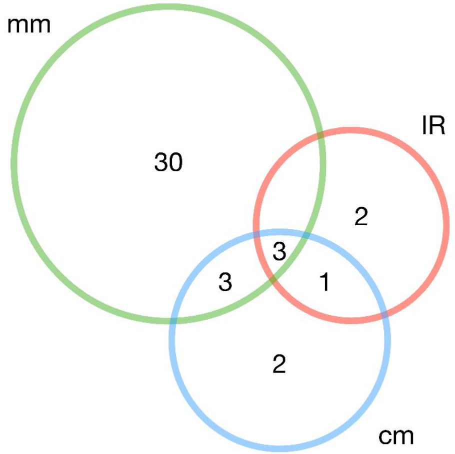
Counterparts

Hub-N

Hub-S

0.4 pc region





The number of IR sources compared to the radio sources suggests that sources is Hub-N are in a more advanced evolutionary stage

The IRDC G14.2

We already know that the hubs present differences in the levels of fragmentation (*Busquet et al., 2016*) and in the magnetic field (*Añez-López et al., 2020*)

Can we distinguish more differences between the two regions?

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G14.2-N

- Sources in a more advanced evolutionary stage
- Dominated by non-thermal emission
- Composed of more massive objects

G14.2-S

- Larger population of objects at an earlier evolutionary stage
- More thermal emitters
- Less compact sources

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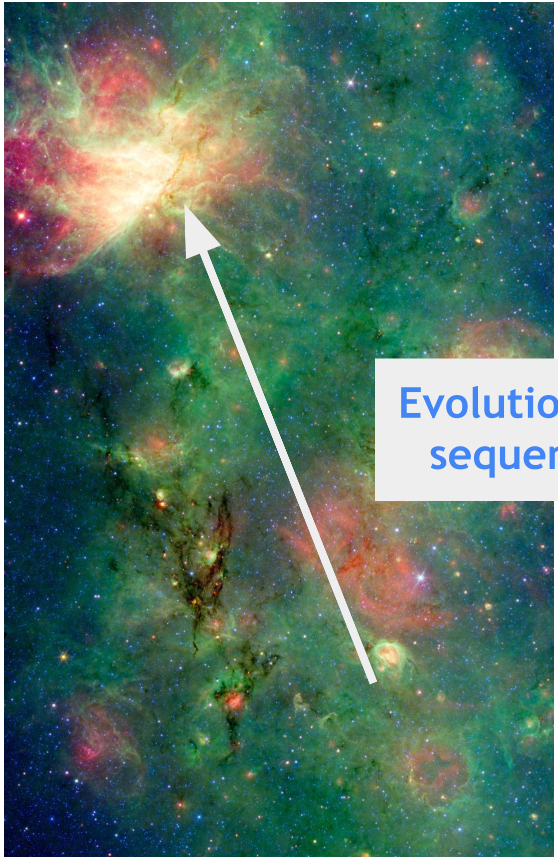
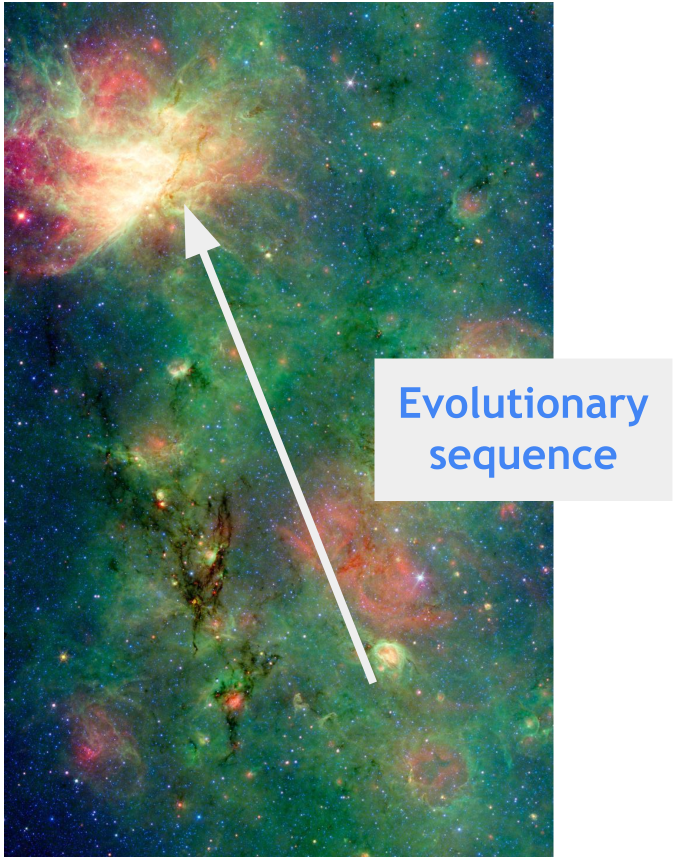
The differences in age and mass seem to be in agreement with the "filament-halo" gradient observed by *Povich et al. (2016)*

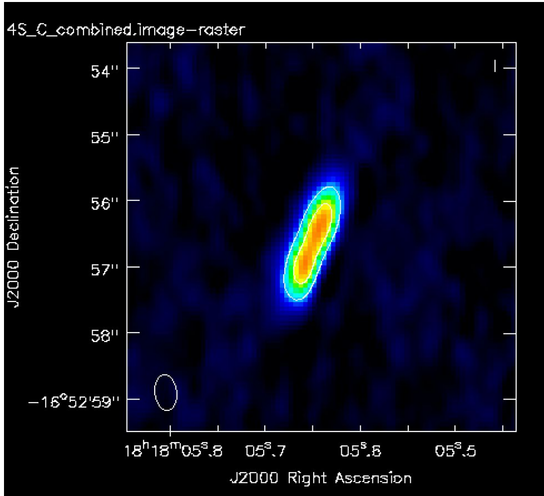
The IRDC G14.2



Evolutionary sequence

The IRDC G14.2





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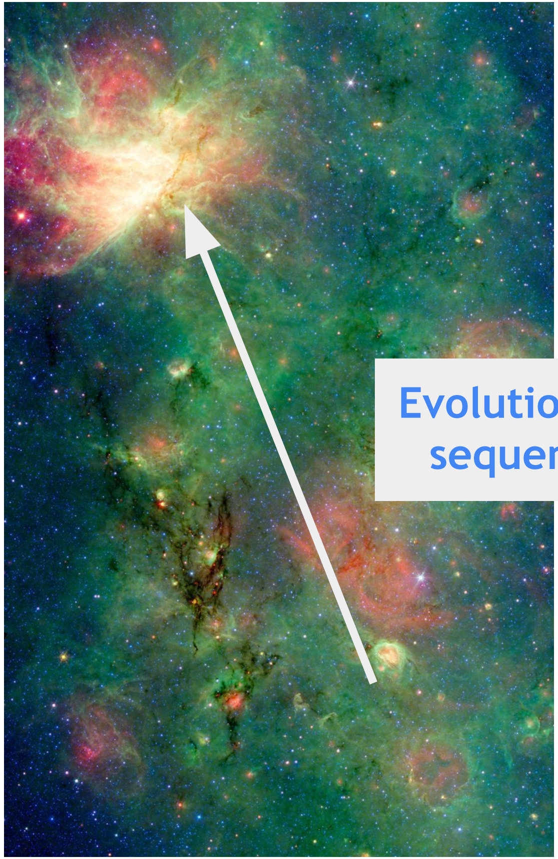

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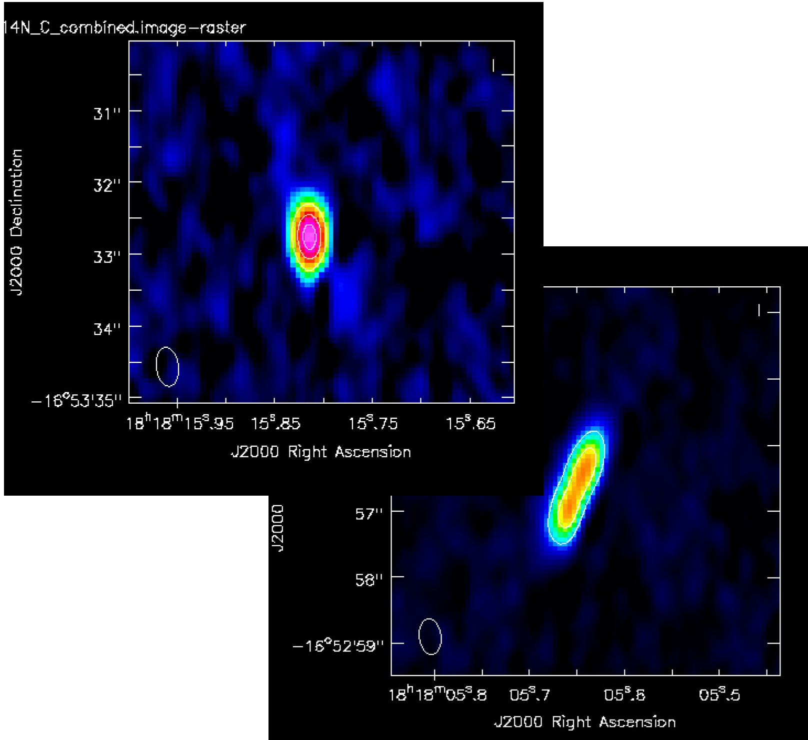

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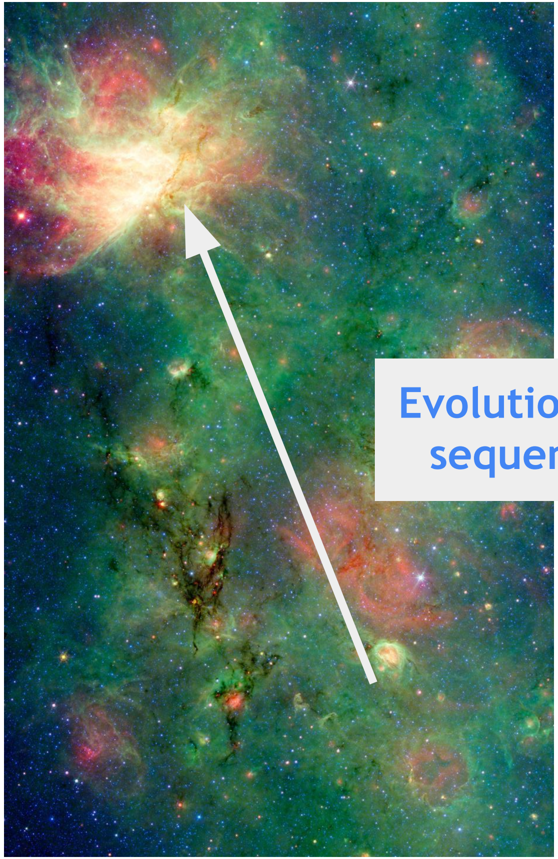

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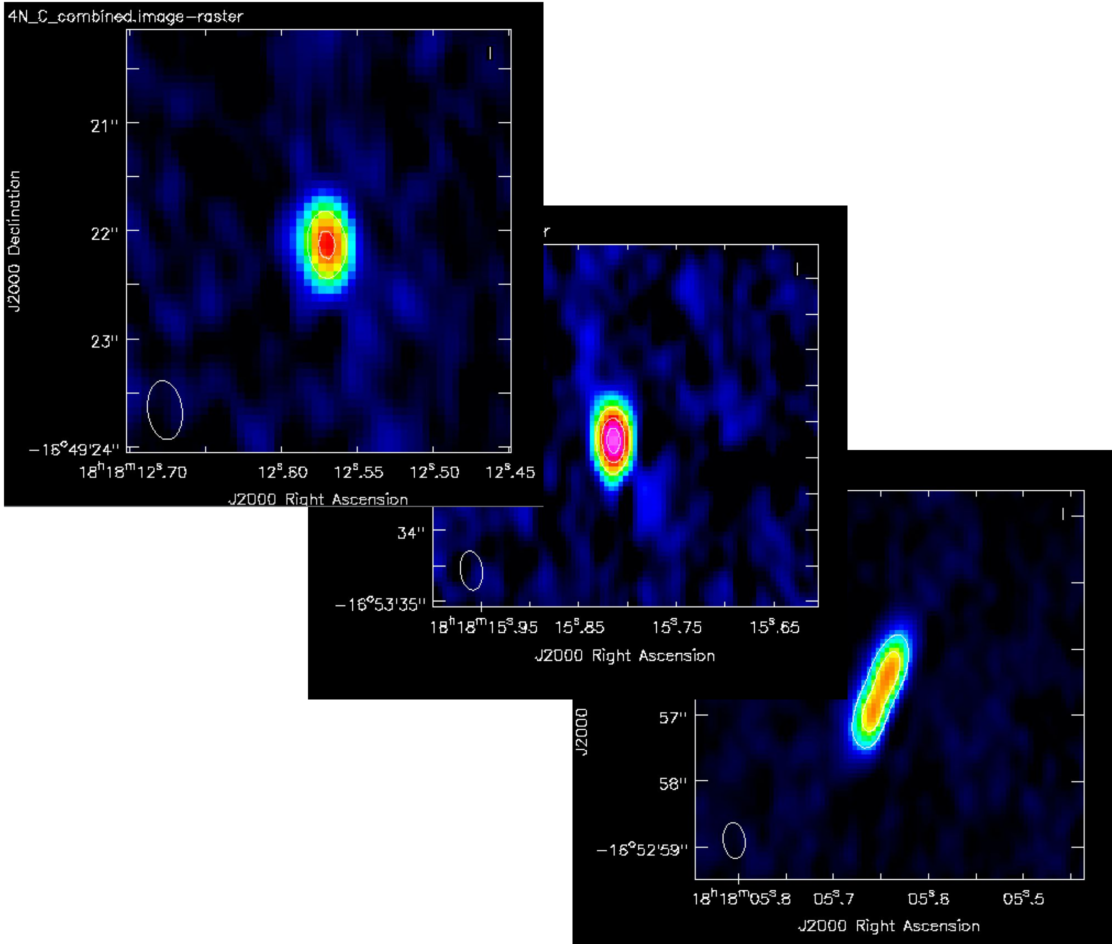


The targets

The IRDC G14.2

The VOLS project

The VOLS project*

The VLA Orion A Large Survey

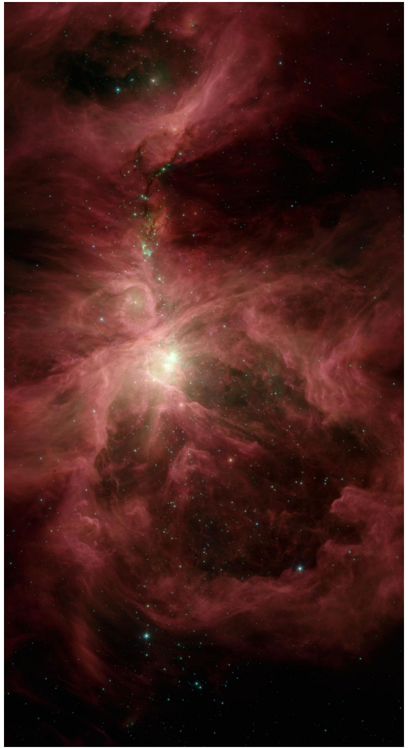


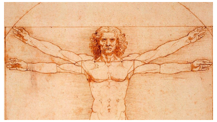
Image Credit: NASA/ JPL-Caltech/Univ. Of Toledo

Large Project for the JVLA

Global collaboration

PI: G. Busquet, co-PIs: P. Hofner (USA), M. Fernández-López (Argentina), P. Texeira (UK)

Fundación BBVA



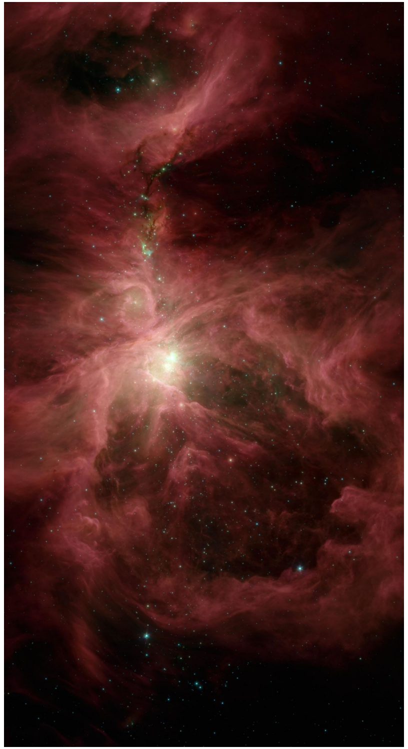
*Work produced with the support of a 2022 Leonardo Grant for Researchers in Physics, BBVA Foundation

vols

The VOLS project*

The **V**LA **O**rion A **L**arge **S**urvey

Image Credit: NASA / JPL-Caltech/Univ. Of Toledo



It is the nearest star-forming complex containing within 500 pc

Contains a broad range of environments populated by protostars and YSOs with different masses and evolutionary stages

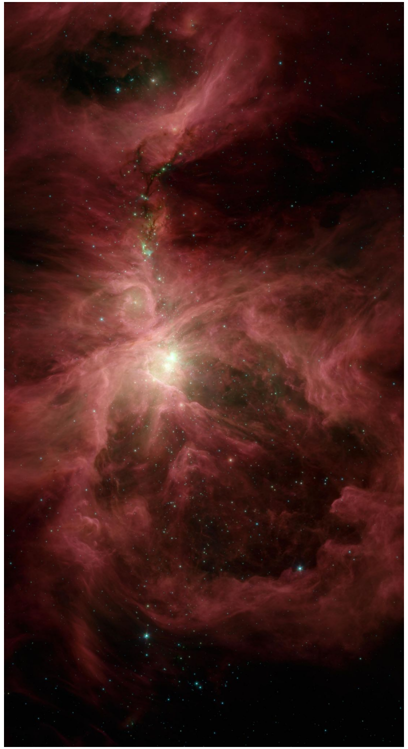
It harbors high-mass star formation and is strongly interacting with a young OB association

*https://vols.fqa.ub.edu

The VOLS project*

The **V**LA **O**rion A **L**arge **S**urvey

Image Credit: NASA / JPL-Caltech/Univ. Of Toledo



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Orion A represents a testbed for star formation theories

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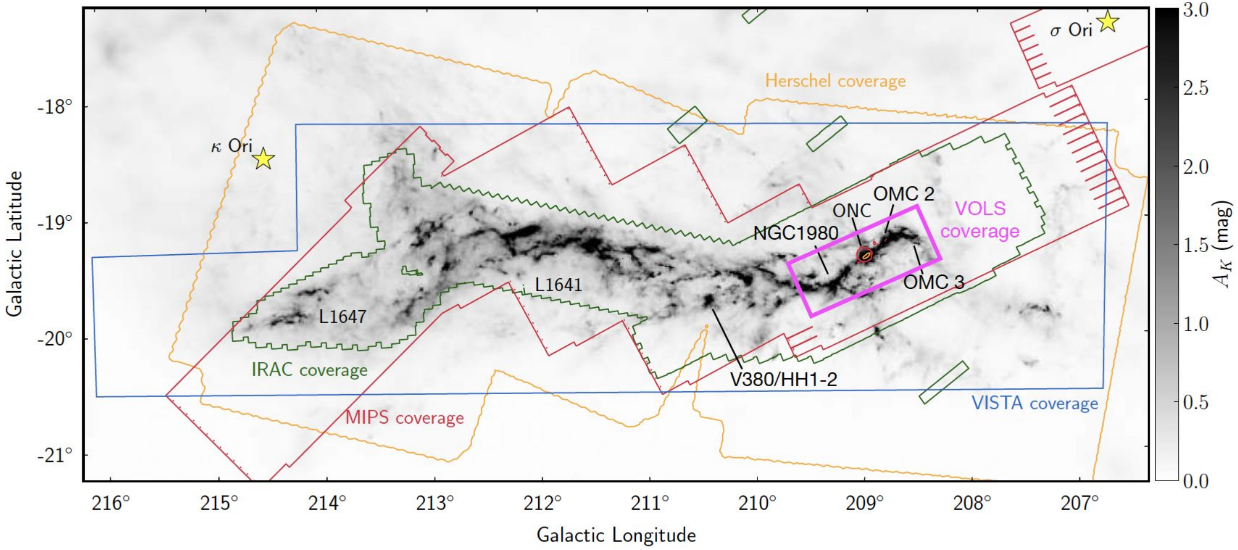
The VOLS project

Observations

- 306 hours of observing time with the VLA
- C-band (completed) and Ku-band (on-going) observations with the A and B configurations (~120 au): continuum + lines (RRL and masers emission)

- Improve the sensitivity by a factor of 20 compared to previous surveys in Orion (*Kounkel et al. 2014*)

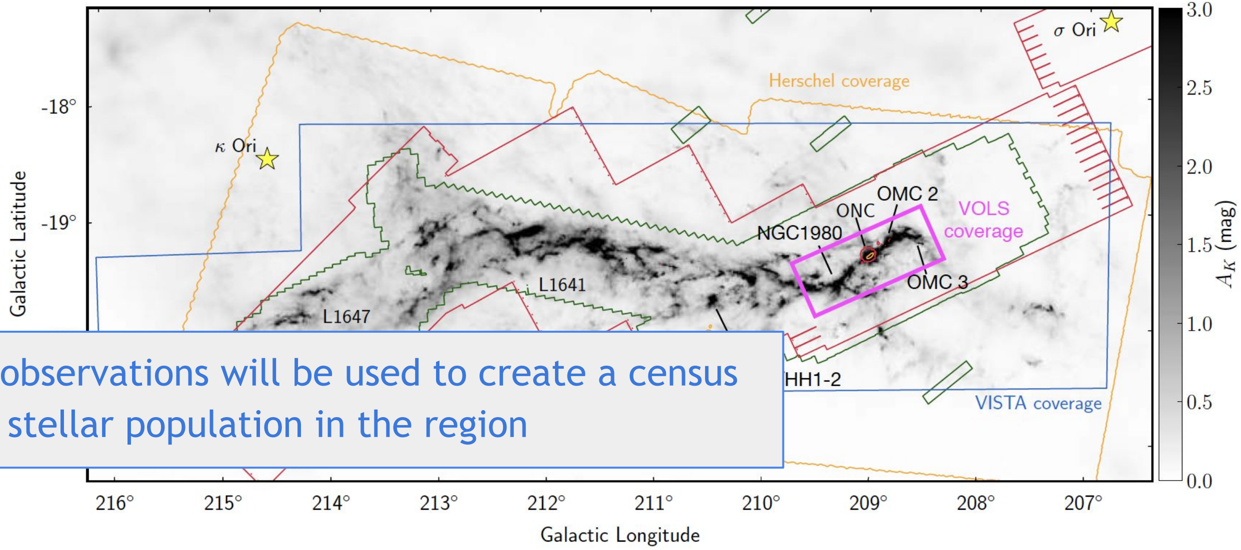


Großschedl et al. (2019)

The VOLS project

Observations

- 306 hours of observing time with the VLA
- C-band (completed) and Ku-band (on-going) observations with the A and B configurations (~120 au): continuum + lines (RRL and masers emission)
- Improve the sensitivity by a factor of 20 compared to previous surveys in Orion (*Kounkel et al. 2014*)

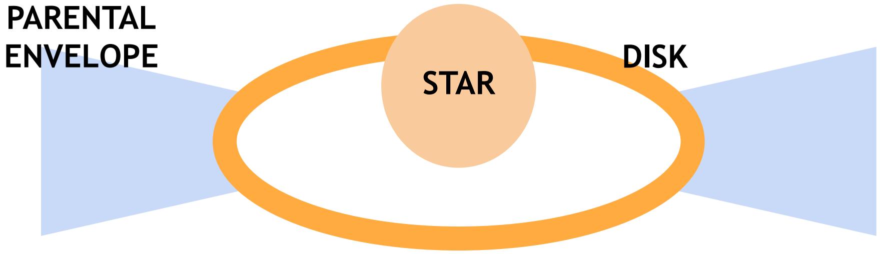


Radio observations will be used to create a census of the stellar population in the region

Großschedl et al. (2019)

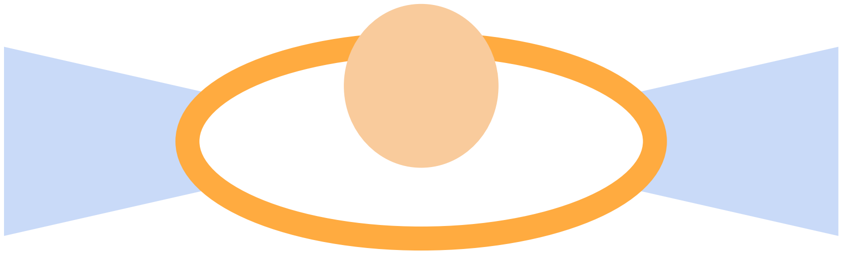
The VOLS project

The mass-accretion and mass-loss rate



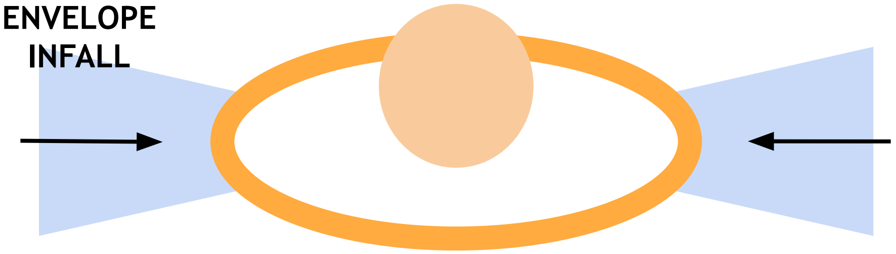
The VOLS project

The mass-accretion and mass-loss rate



The VOLS project

The mass-accretion and mass-loss rate

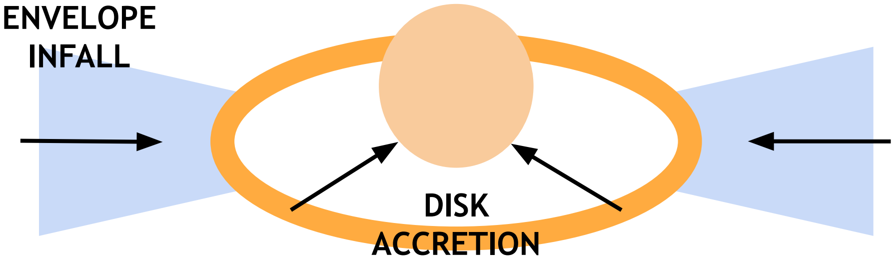


- **Infall** onto the star-disk system from the parental envelope

The VOLS project

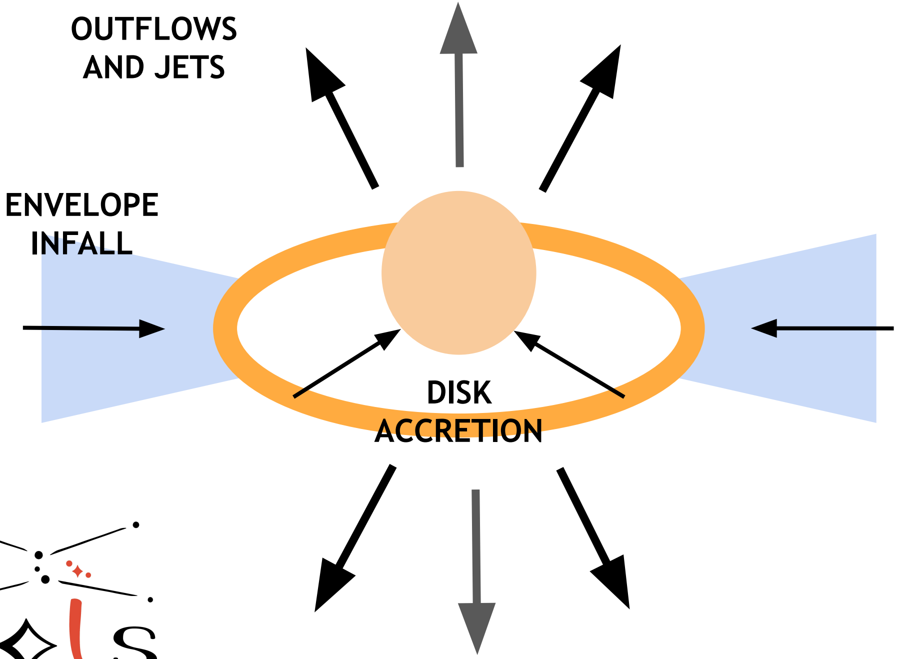
The mass-accretion and mass-loss rate

- **Infall** onto the star-disk system from the parental envelope
- **Accretion** from the disk on the star



The VOLS project

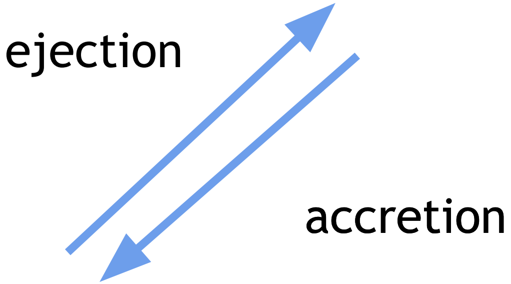
The mass-accretion and mass-loss rate



- **Infall** onto the star-disk system from the parental envelope
- **Accretion** from the disk on the star
- Energetic **outflows** and **jets** remove angular momentum

The VOLS project

The mass-accretion and mass-loss rate

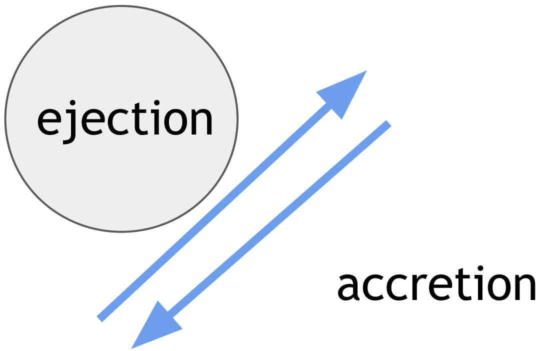


- **Infall** onto the star-disk system from the parental envelope
- **Accretion** from the disk on the star
- Energetic **outflows** and **jets** remove angular momentum

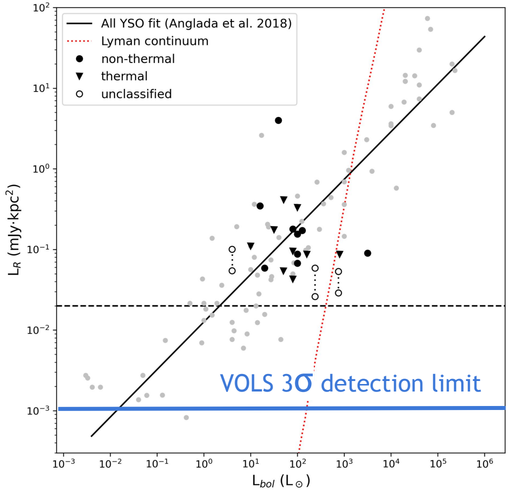
The VOLS project aims to investigate how these rates **vary with protostellar evolution** and how depend on **the environment** and on **the mass** of the central object

The VOLS project

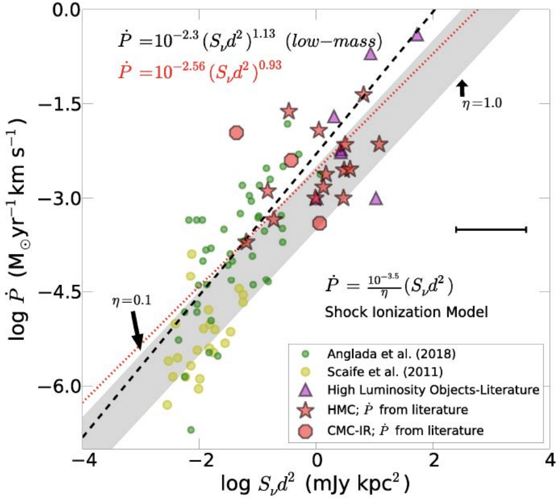
The mass-accretion and mass-loss rate



Traced by the radio luminosity



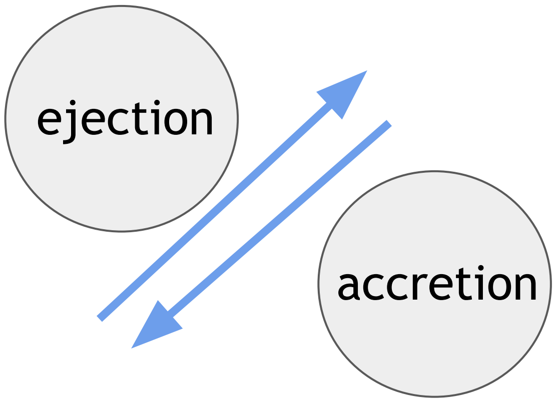
Díaz-Márquez et al. (2024), accepted



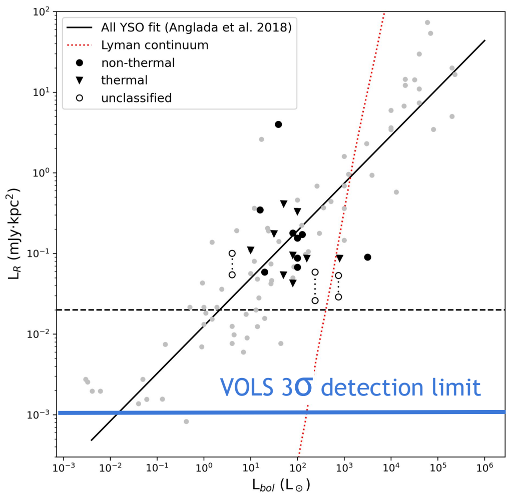
Rosero et al. (2019)

The VOLS project

The mass-accretion and mass-loss rate



Traced by the bolometric luminosity



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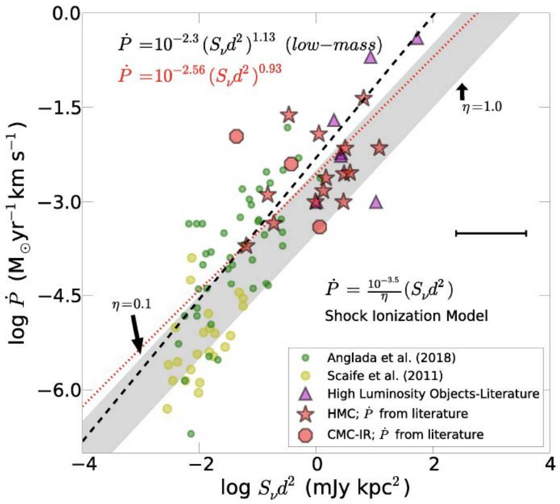
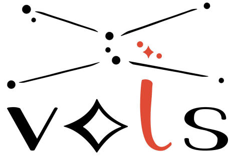
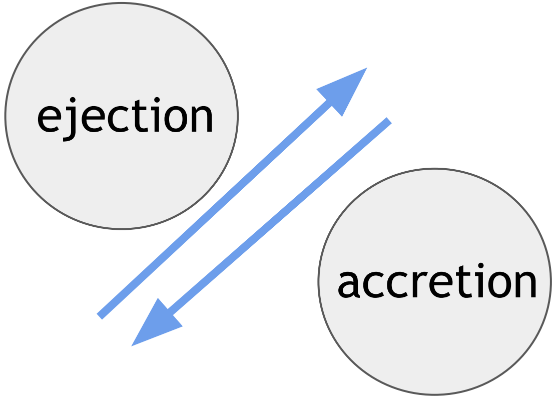


Rosero et al. (2019)



The VOLS project

The mass-accretion and mass-loss rate



Radio continuum observations are a powerful tool to investigate this connection

The VOLS project

Deep learning implementation

- Source detection and automatic classification of the emission
- Morphology classification using deep learning methods with radio continuum images
- Template for future radio interferometers

vols

Outline

Scientific context

On-going projects

Future work

Next generation of radio interferometers

SKA

Resolution of 0.08" at 6.7 GHz and 0.04" at 12.5 GHz
Sensitivity 1.3 microJy/beam at 6.7 GHz and 1.2 microJy/beam at 12.5 GHz in 1 hour of observing time

ngVLA

Resolution of 0.2 mas at 30 GHz

Sensitivity of 0.2 - 0.7 microJy/beam in 1 hour of observing time

Next generation of radio interferometers

IRDC G14.2

11 hour for a single pointing at X-band → **one hour** of observation

Systematic studies of short- and long- term **variability** in radio emissions

The vols project

These data are going to be a **crucial guide** for future observations

Template for future radio interferometers that will collect **a lot of data**

Thank you for your attention