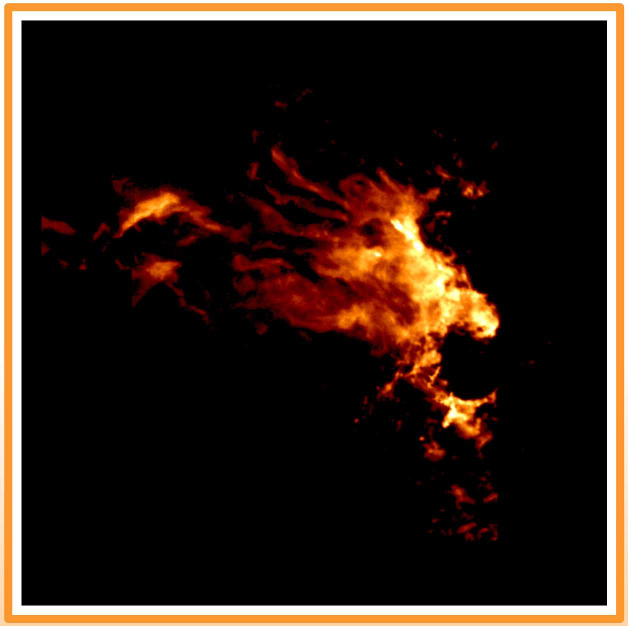


The multiscale interstellar medium

from massive molecular clouds to cold cores

Emma Mannfors

Lectio Praecursoria

30.1.2026

Add QR code/tinyurl link to thesis
Add QR code/tinyurl link to English translation of lektio

https://github.com/EmmaMannfors/Mannfors_PhD

Contents

- A story (of baby stars)
- The ISM
  - Properties
  - How they affect the rest of astronomy
- The Galaxy
- Observations
  - The wavelengths
  - Telescopes
  - How signals travel in space
- Summary of my work

Units

- 1 parsec (pc)

  = 3.26 lightyears

  = 3.09 x 10^{16} m

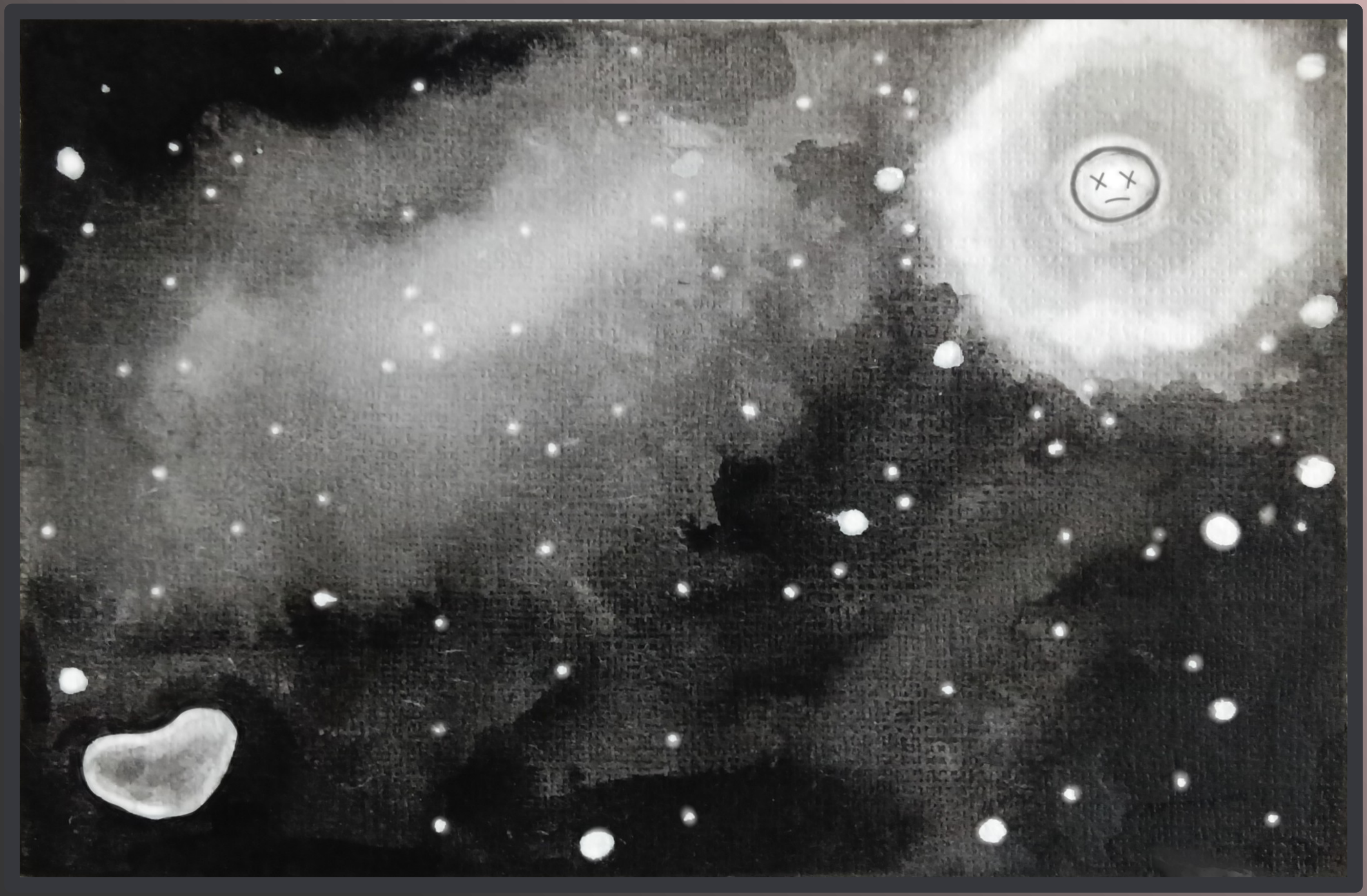
  (1 billion = 10^9)
- 0 K = -273.15 °C

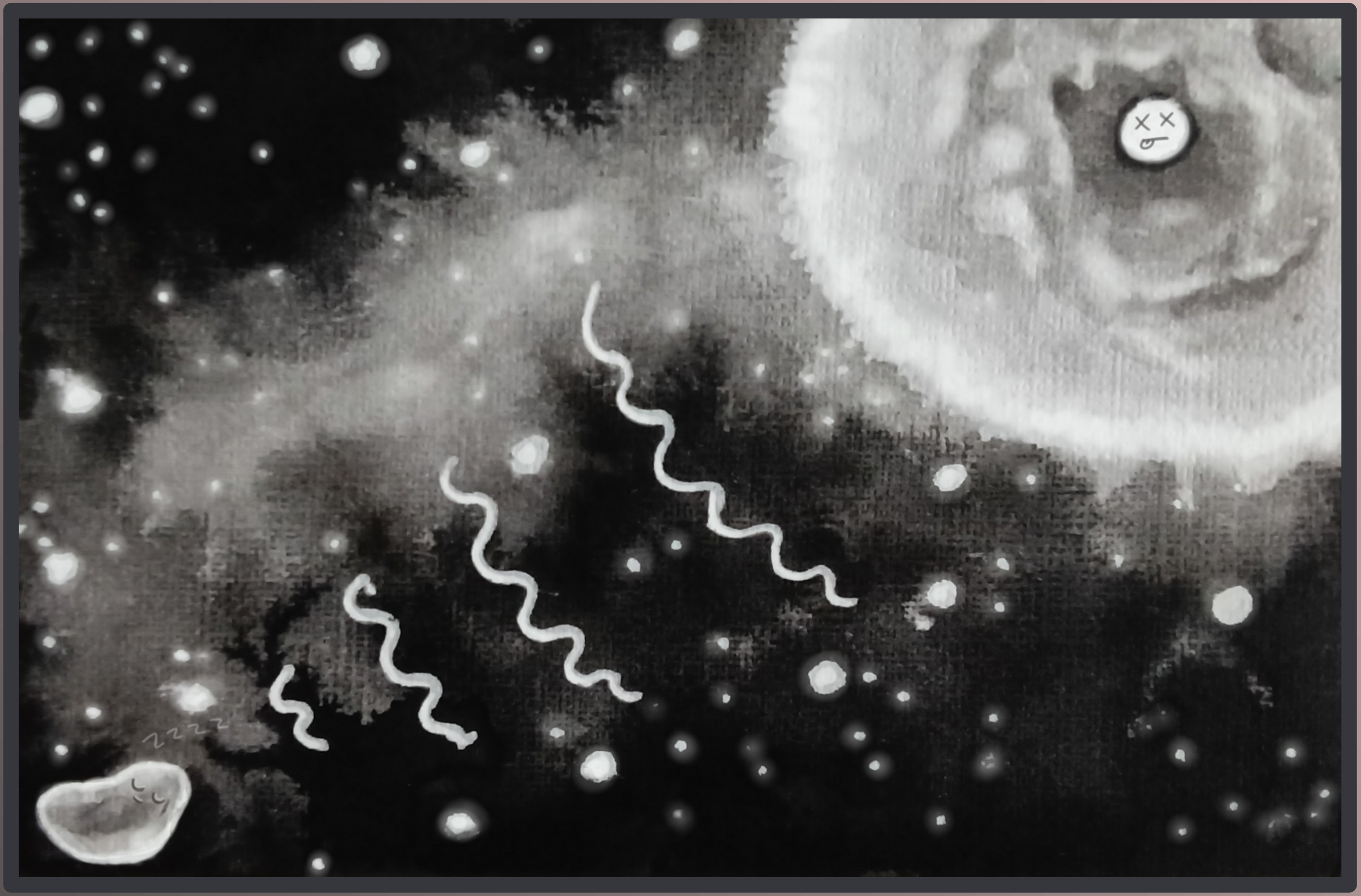
= Interstellar medium

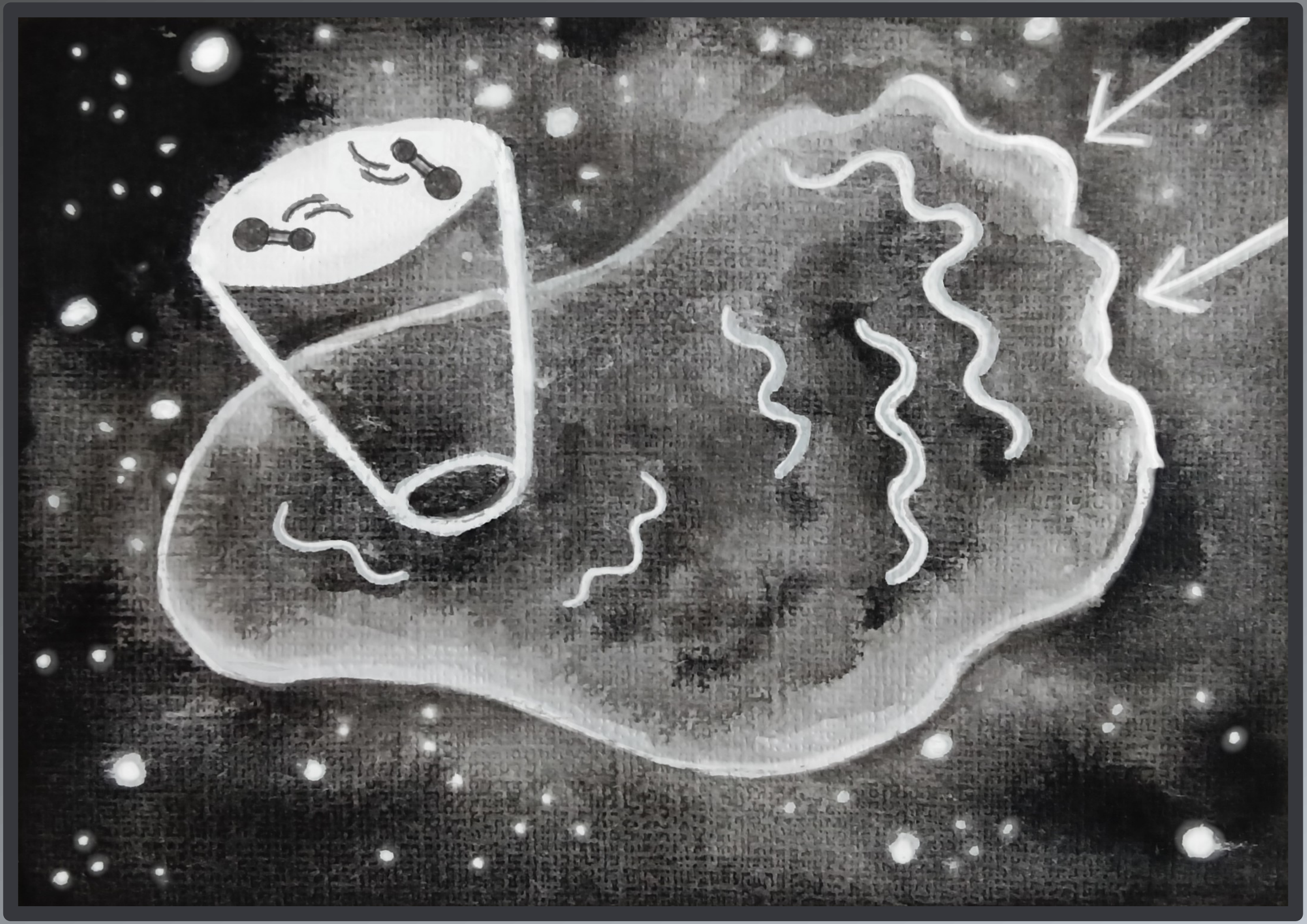
ISM = Tähtienvälinen aine

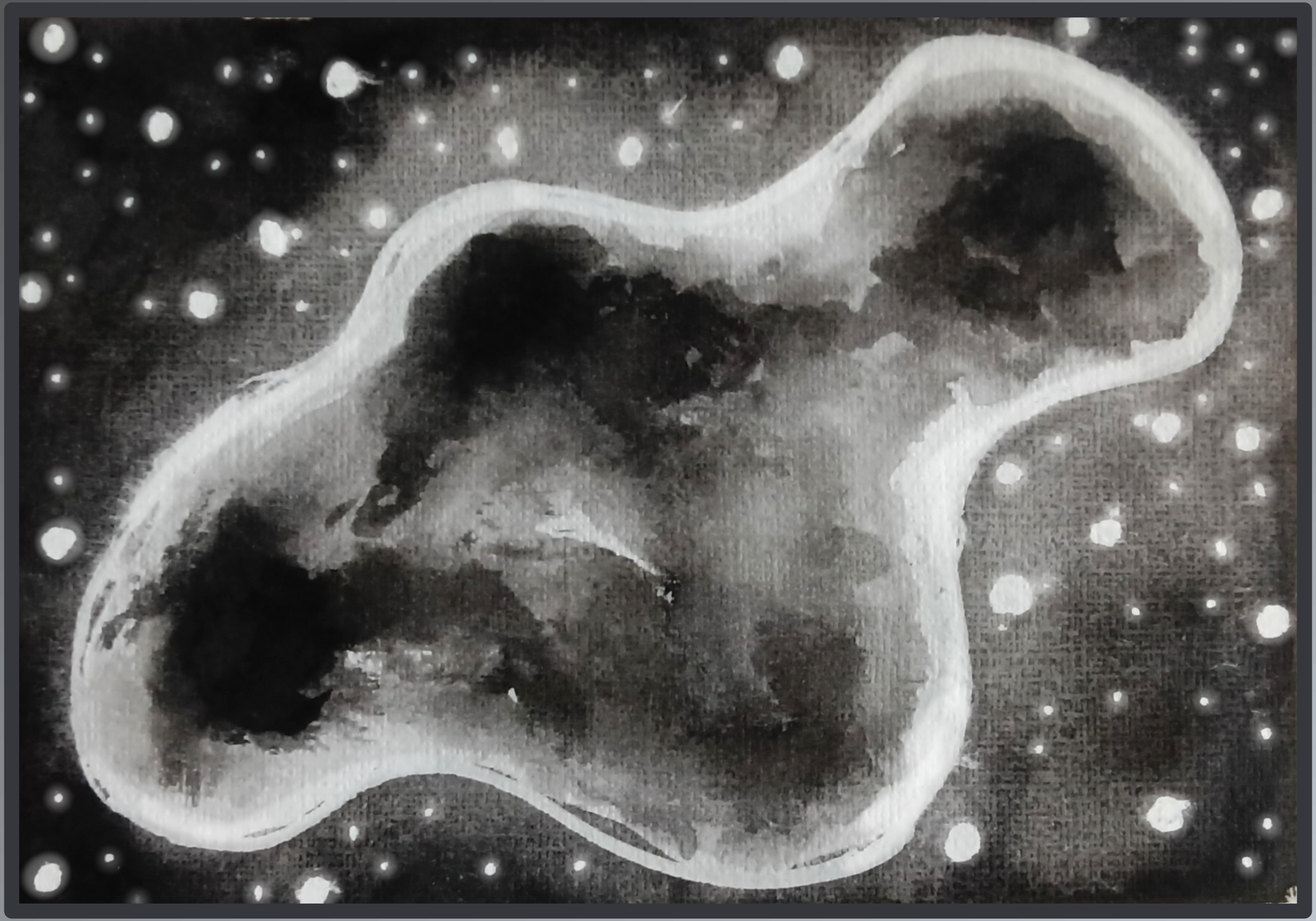
(= space clouds)

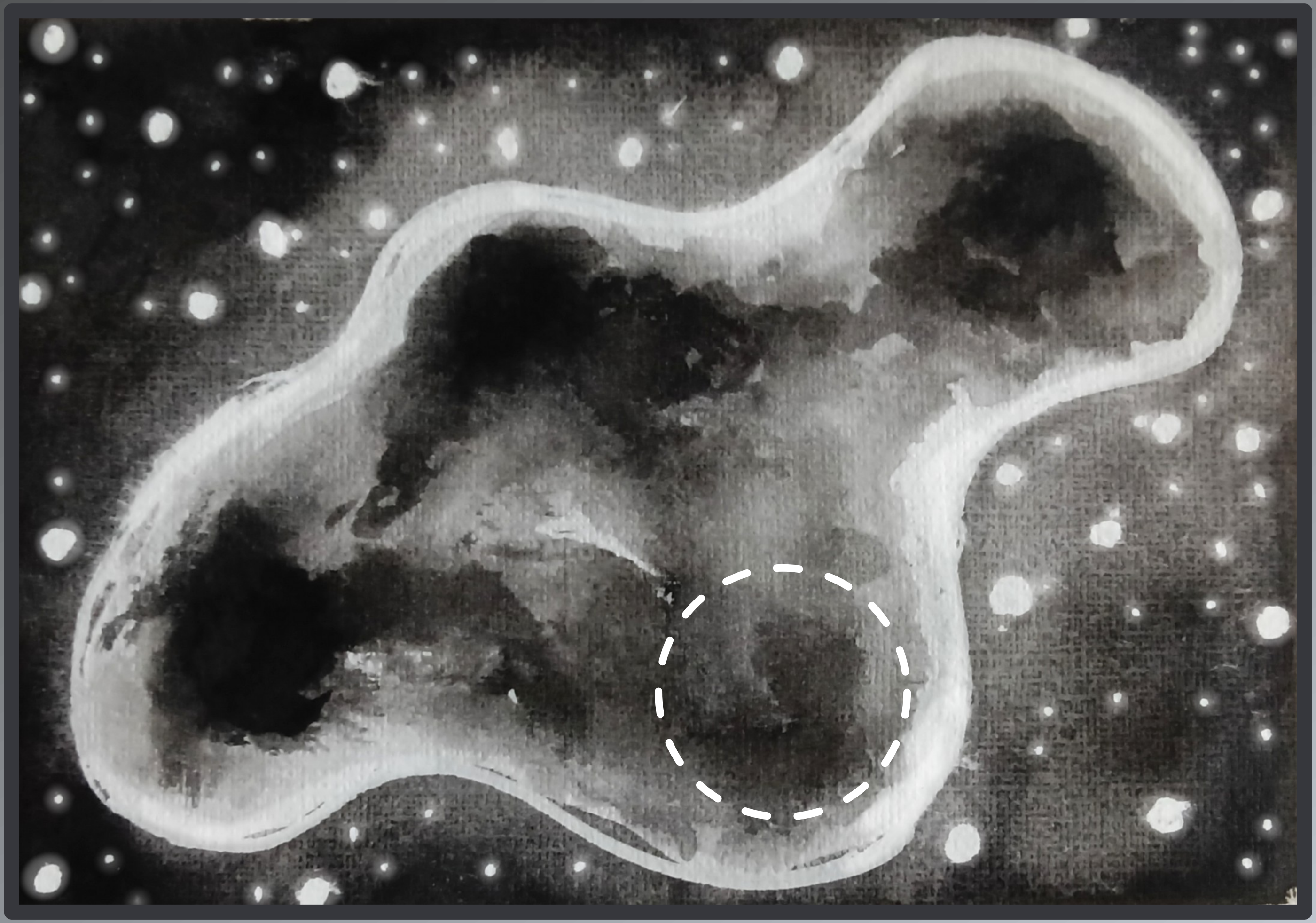
Illustrations: E. Mannfors

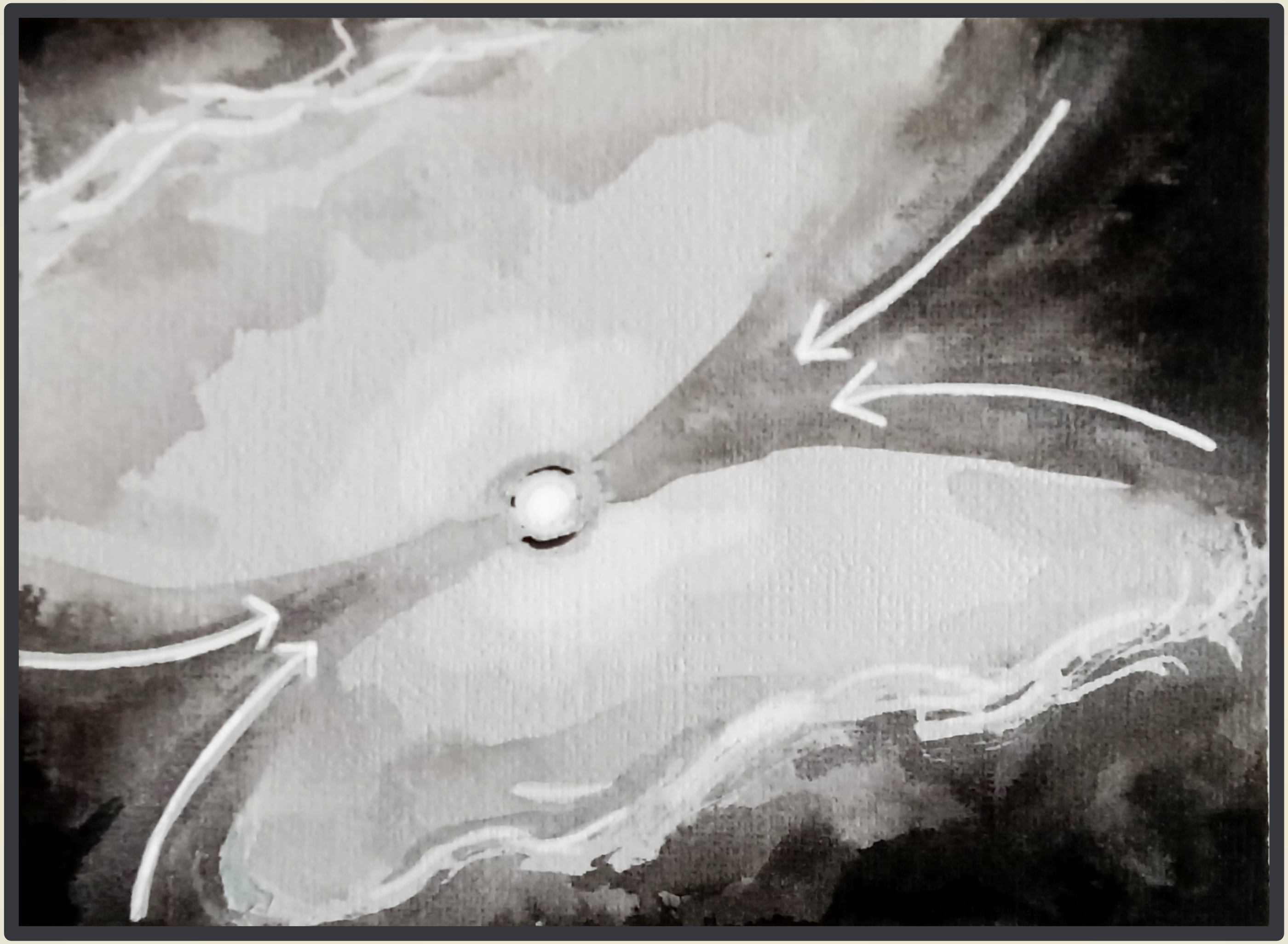


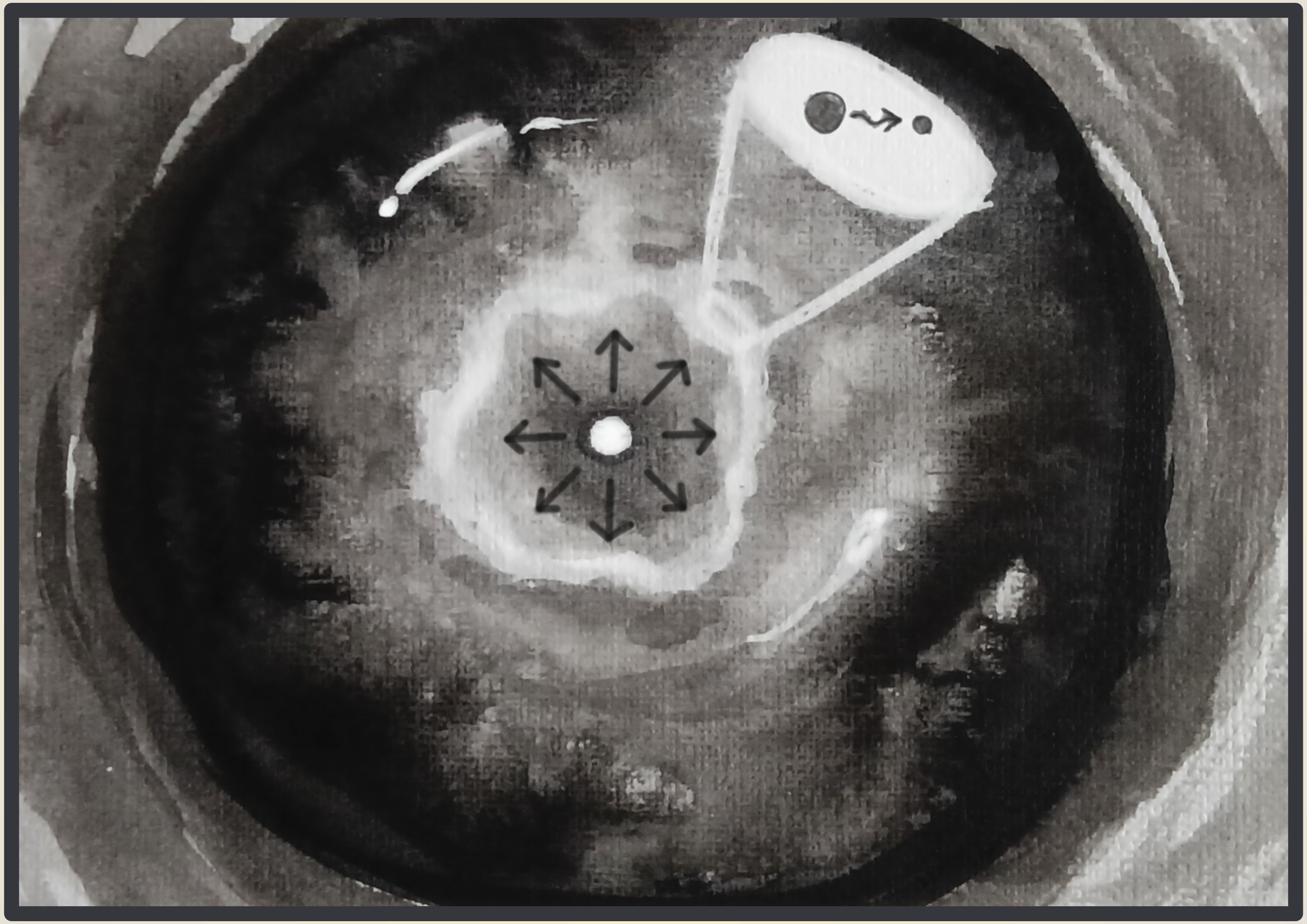


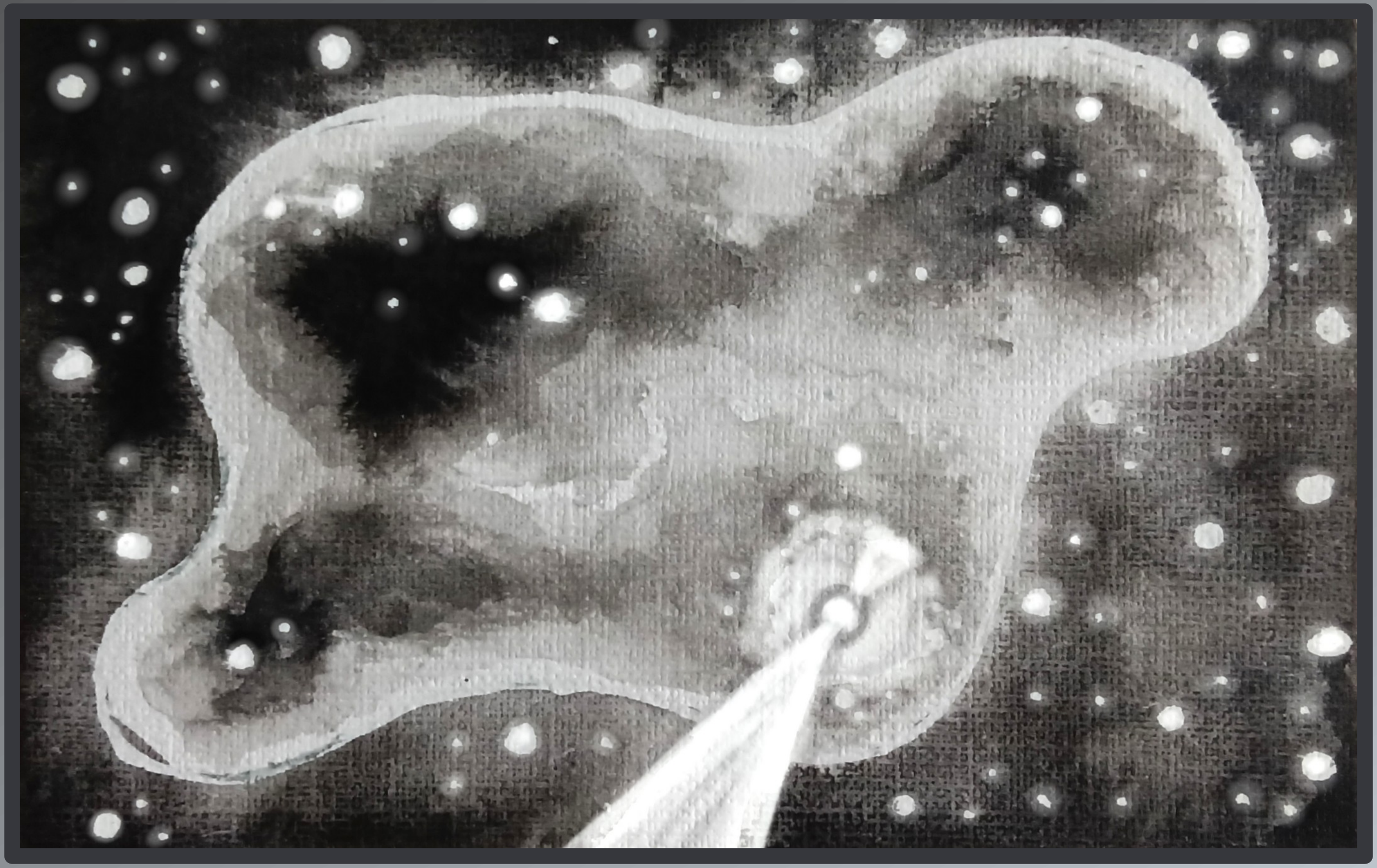




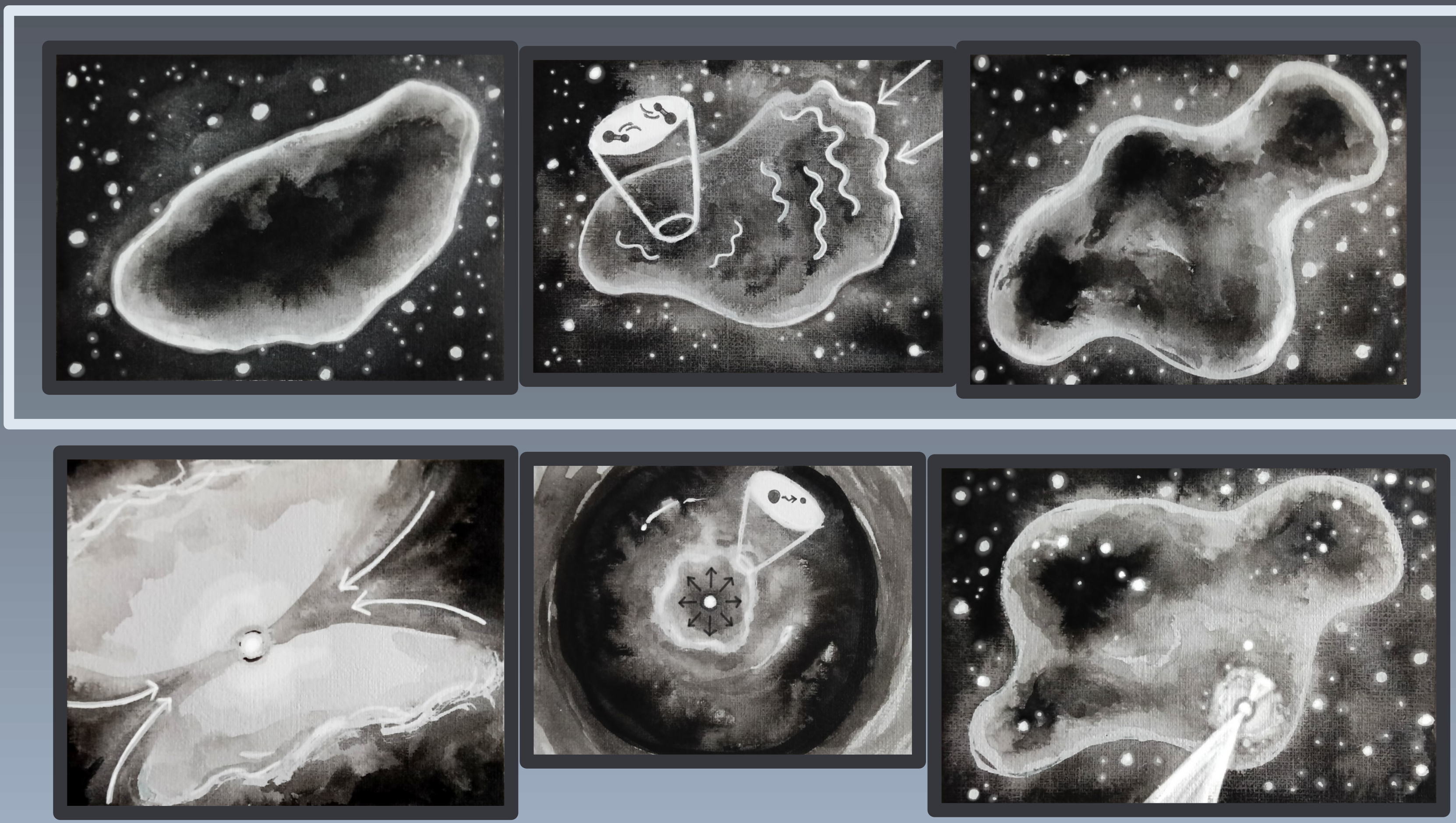






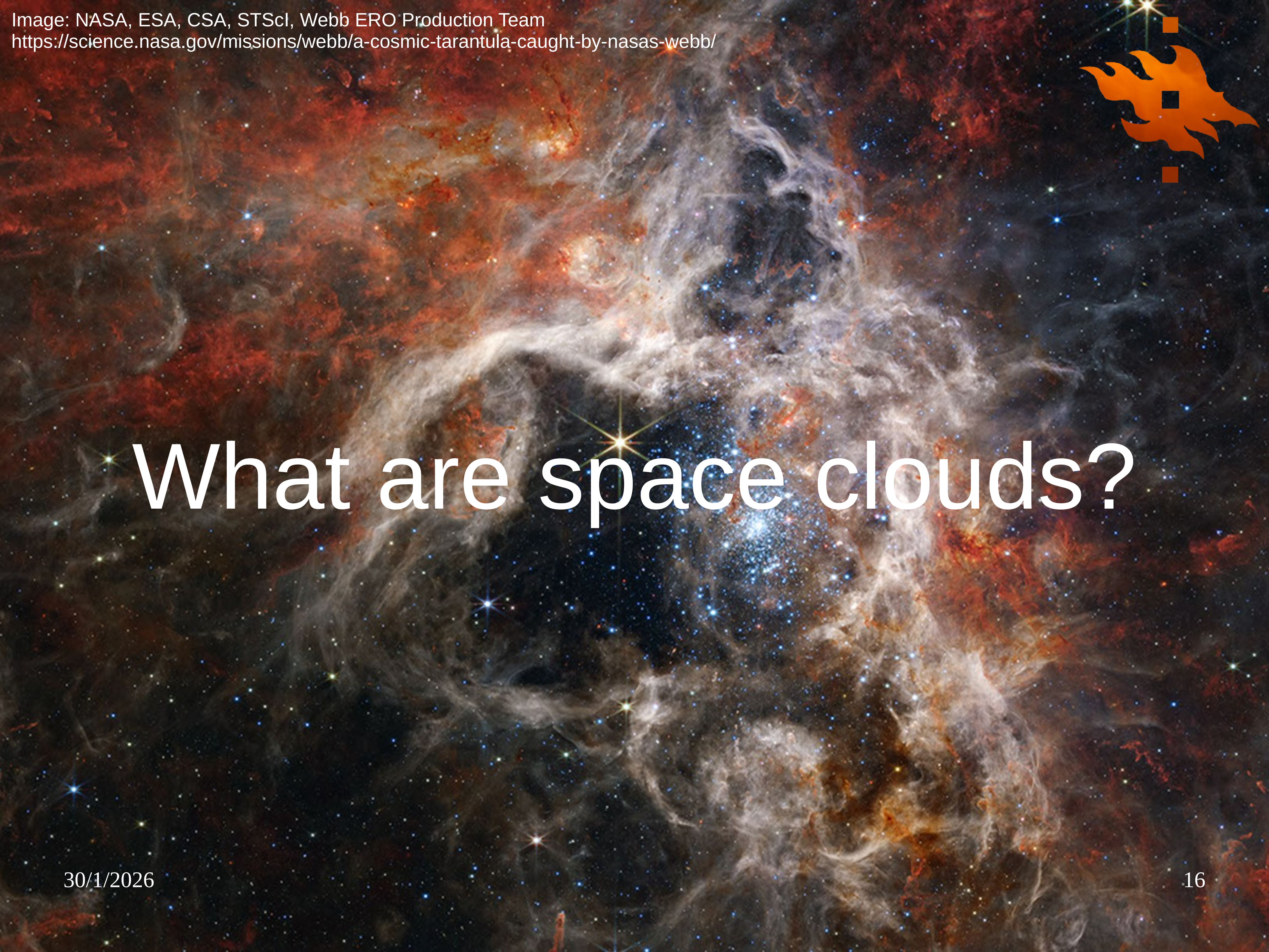


My thesis



Illustrations: E. Mannfors

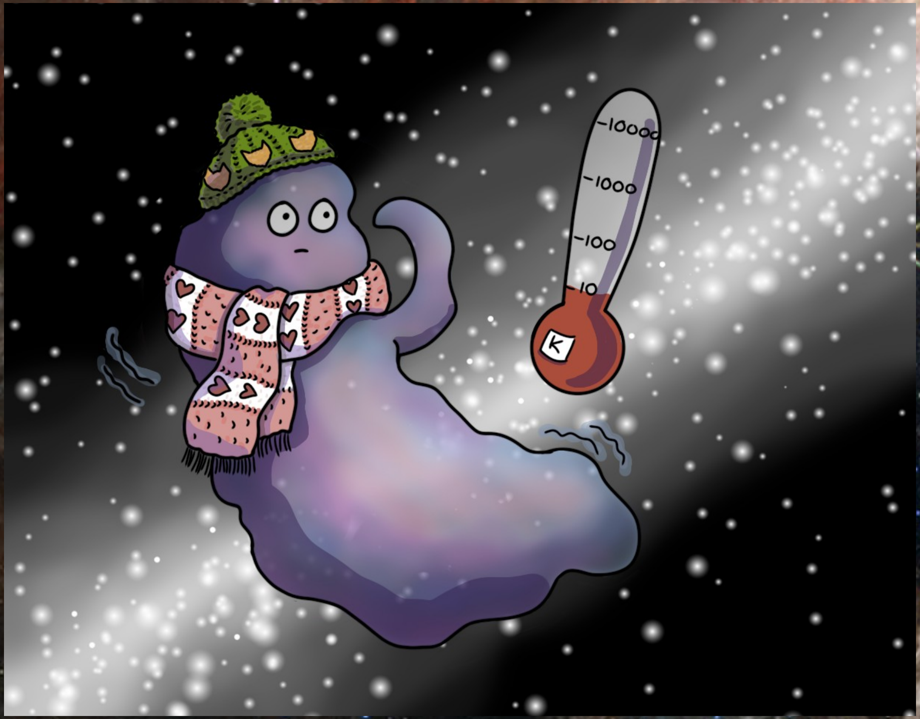
Image: NASA, ESA, CSA, STScI, Webb ERO Production Team
https://science.nasa.gov/missions/webb/a-cosmic-tarantula-caught-by-nasas-webb/



What are space clouds?

Image: NASA, ESA, CSA, STScI, Webb ERO Production Team
https://science.nasa.gov/missions/webb/a-cosmic-tarantula-caught-by-nasas-webb/

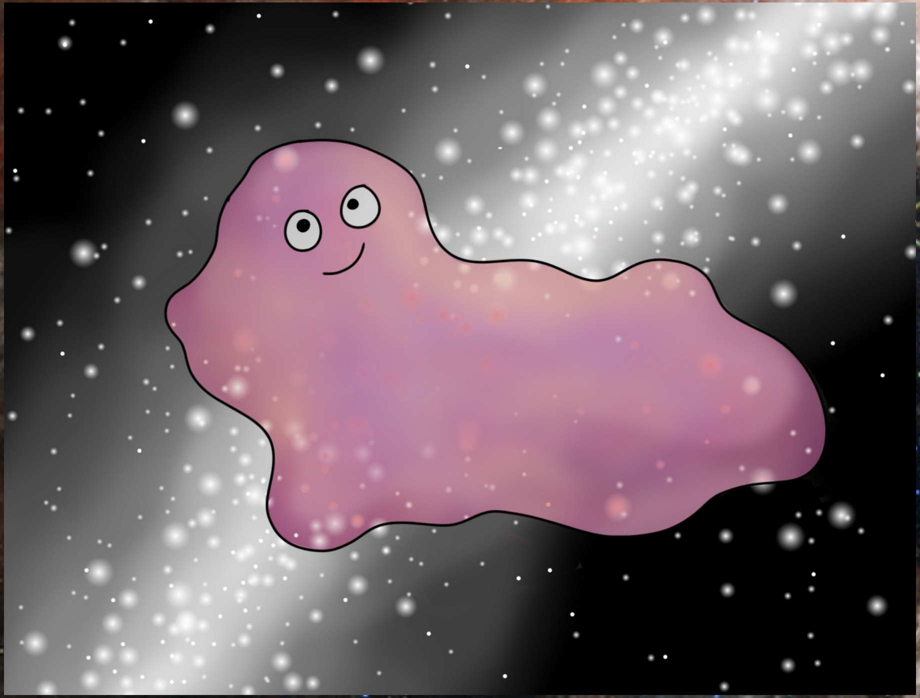
Basics of the (COLD) ISM



- Cold [10 - 100 K (-260 to -160°C)]

Image: NASA, ESA, CSA, STScI, Webb ERO Production Team
https://science.nasa.gov/missions/webb/a-cosmic-tarantula-caught-by-nasas-webb/

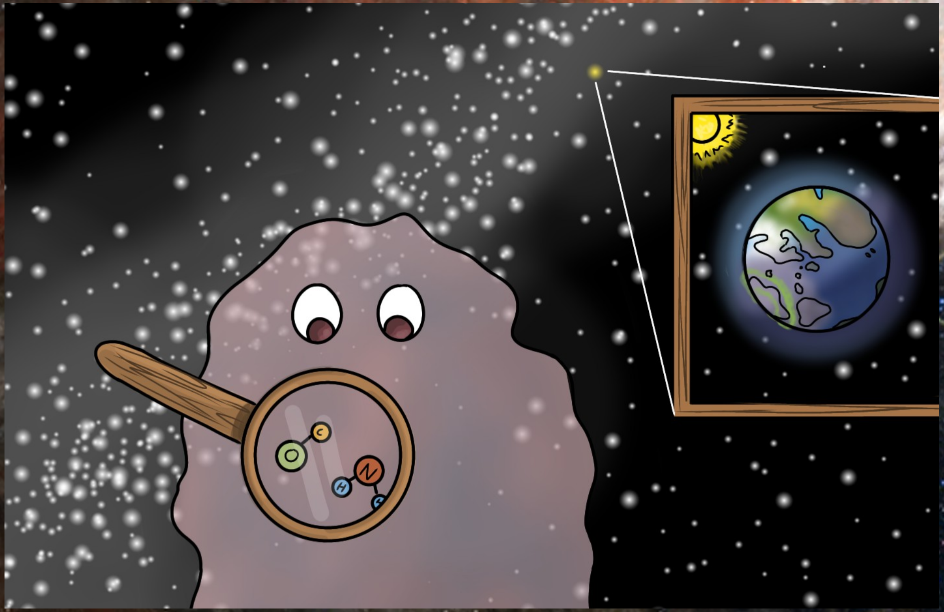
Basics of the (COLD) ISM



- Cold [10 - 100 K (-260 to -160°C)]
- Dense (for space)
  - 10^3 - 10^6 atoms / cm^2
  - Earth: ~10^{22} H atoms / cm^2
    - (T = 0°C, P = 100 kPa)

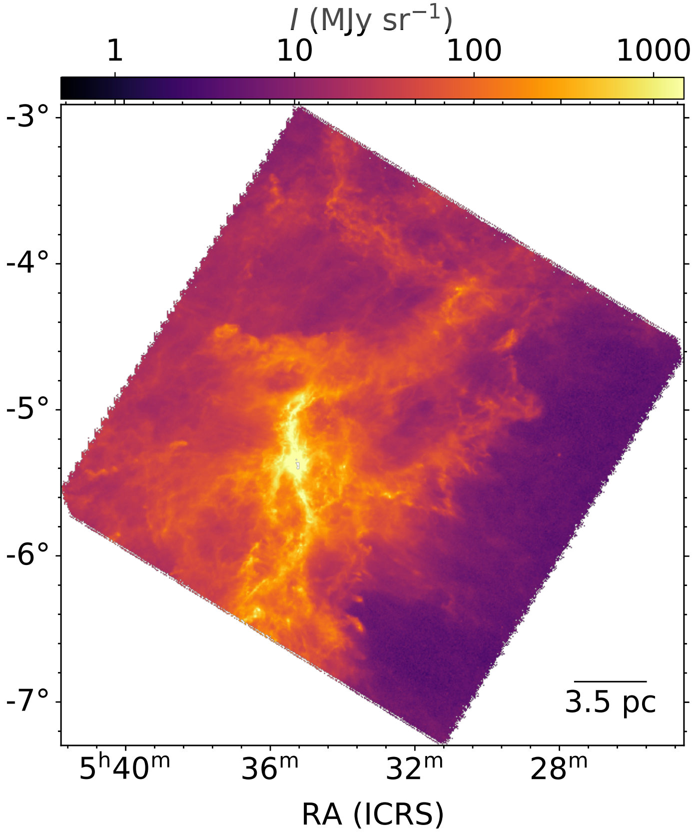
Image: NASA, ESA, CSA, STScI, Webb ERO Production Team
https://science.nasa.gov/missions/webb/a-cosmic-tarantula-caught-by-nasas-webb/

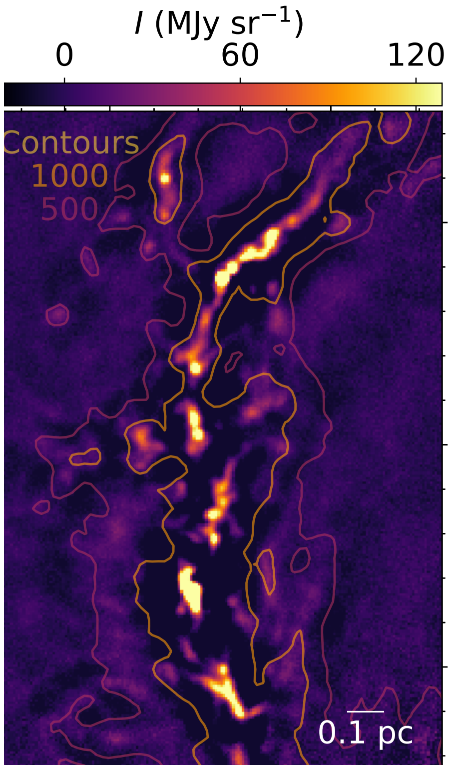
Basics of the (COLD) ISM



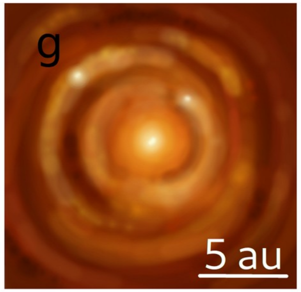
- Cold [10 - 100 K (-260 to -160°C)]
- Dense (for space)
  - 10^3 - 10^6 atoms / cm^2
  - Earth: ~10^{22} H atoms / cm^2
    - (T = 0°C, P = 100 kPa)
- Components:
  - Gas
    - Atoms: H, He, metals
    - Molecules: > 100 species
      - H^2, CO
  - Dust
    - ~1% by mass
    - Ice around silicate core
-

Scales and structure



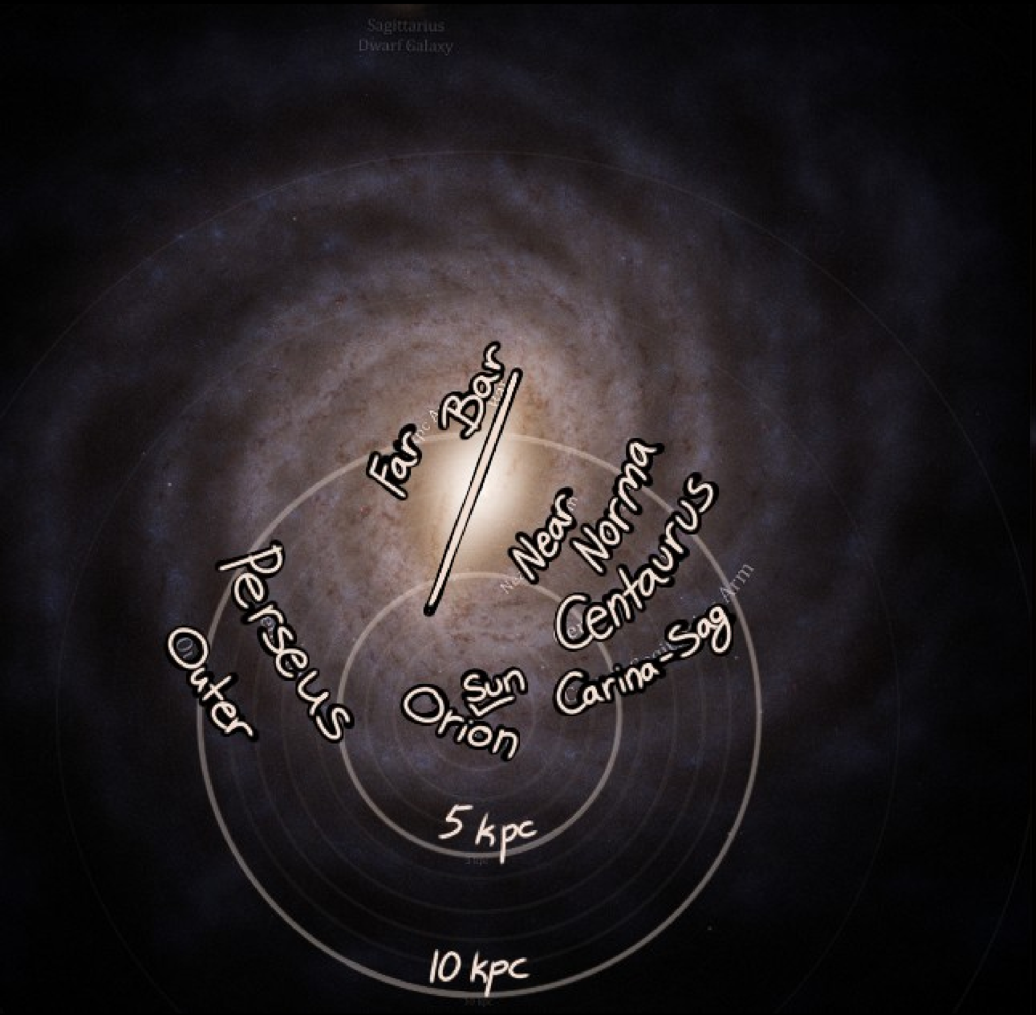


- Filaments:
  - Long, thin clouds
- Clumps & Cores:
  - Spherical, <1 pc in size

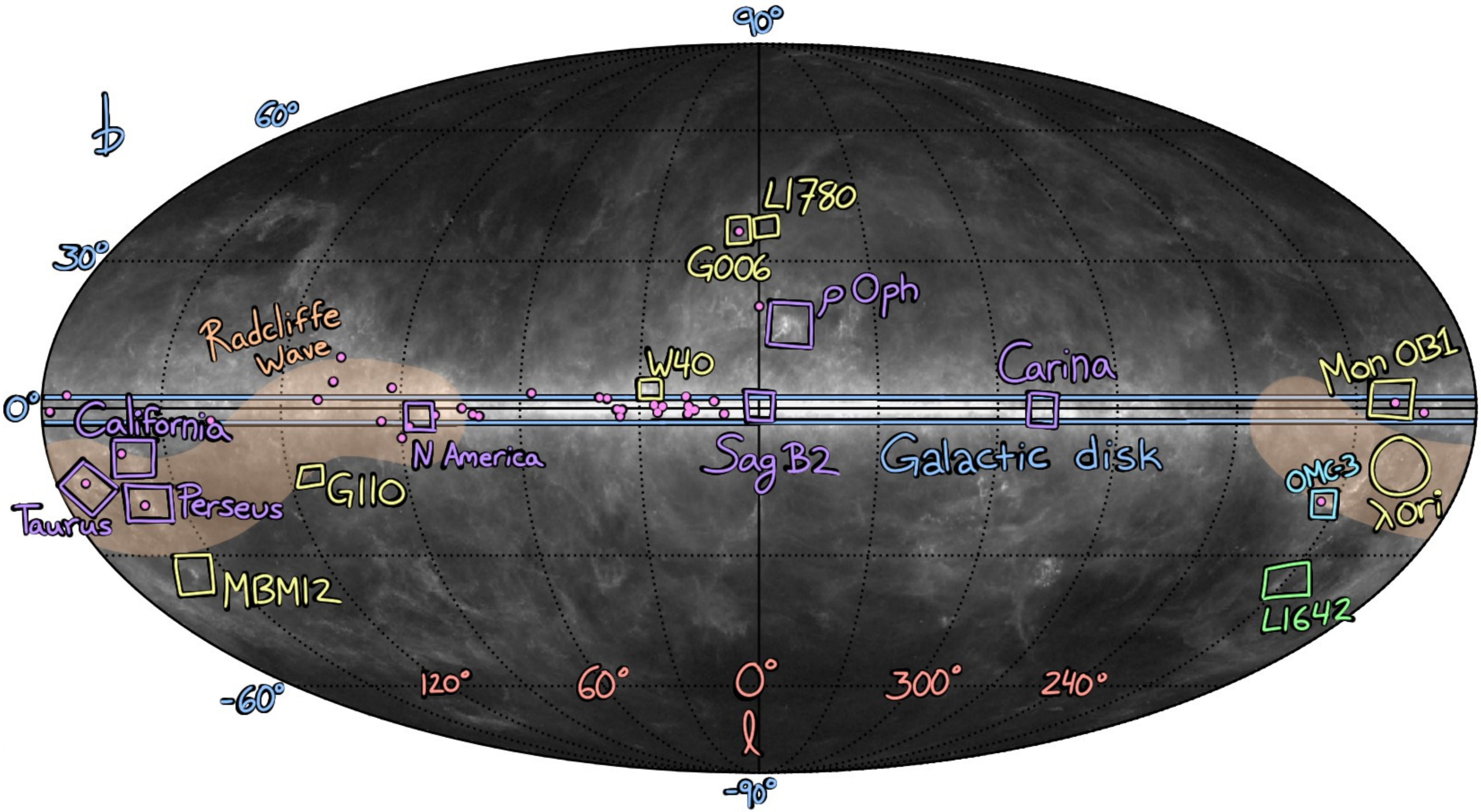


Credit: ESO/S. Brunier
https://www.eso.org/public/images/eso0932a/

Our galaxy


Sagittarius
Dwarf Galaxy
Far
Bar
Near
Norma
Centaurus
Perseus
Outer
Orion
Sun
Carina-Sag
5 kpc
10 kpc

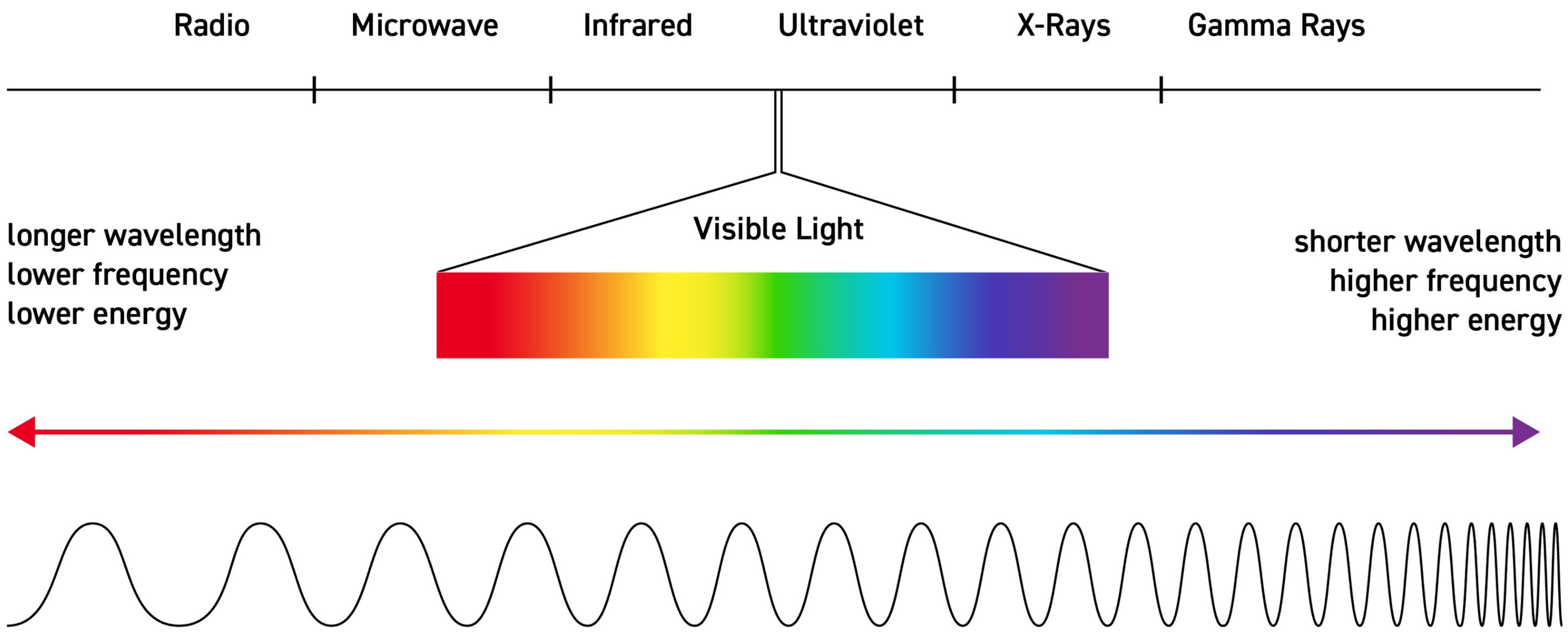

~ 20 kpc


90°
60°
30°
0°
-60°
-90°
b
L1780
G006
ρ Oph
Radcliffe Wave
W40
Carina
Mon OB1
California
N America
Sag B2
Galactic disk
OMC-3
λ Ori
Taurus
Perseus
G110
MBM12
L1642
120°
60°
0°
300°
240°
l

Observing

Credit: ESO/S. Guisard https://www.eso.org/public/images/potw1217a/

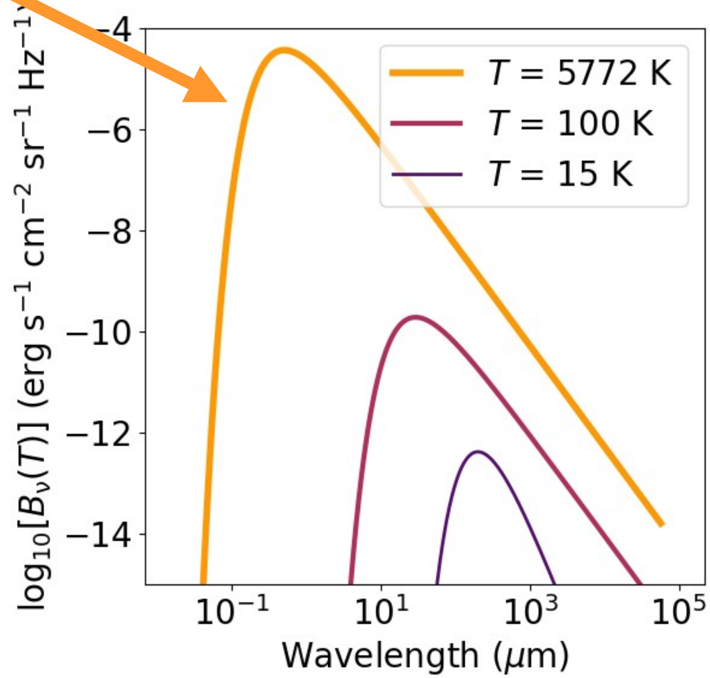
Wavelengths



https://www.nist.gov/sites/default/files/images/2025/03/28/Wavelength-spectroscopy.png

Blackbody spectrum

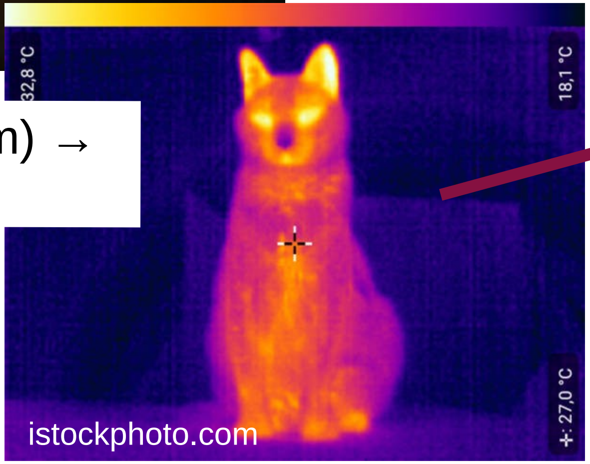
← Optical wavelengths (λ_{cen} ~ 500 nm)
T ~ 5500°C

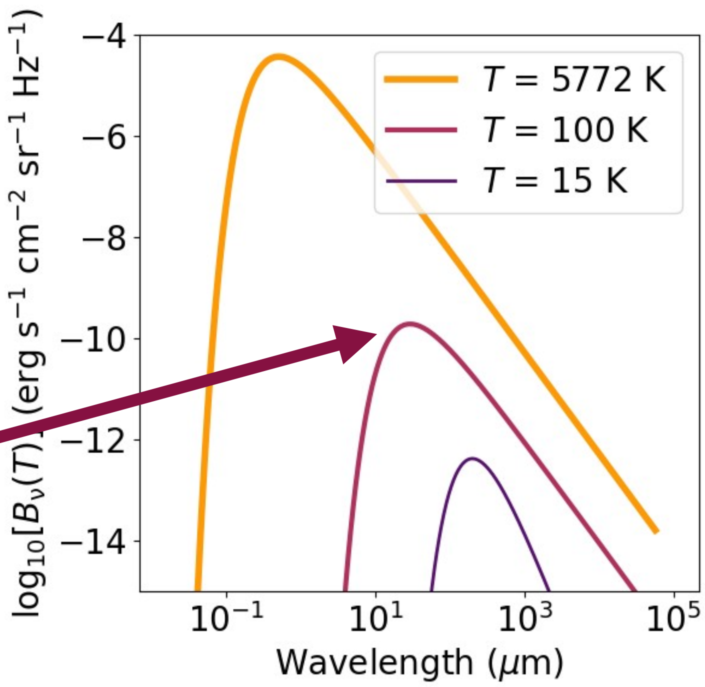


λ = wavelength; T = temperature

Blackbody spectrum

IR wavelengths (λ_{cen} ~ 10 μm) →
T ~ 30°C ~ 300 K

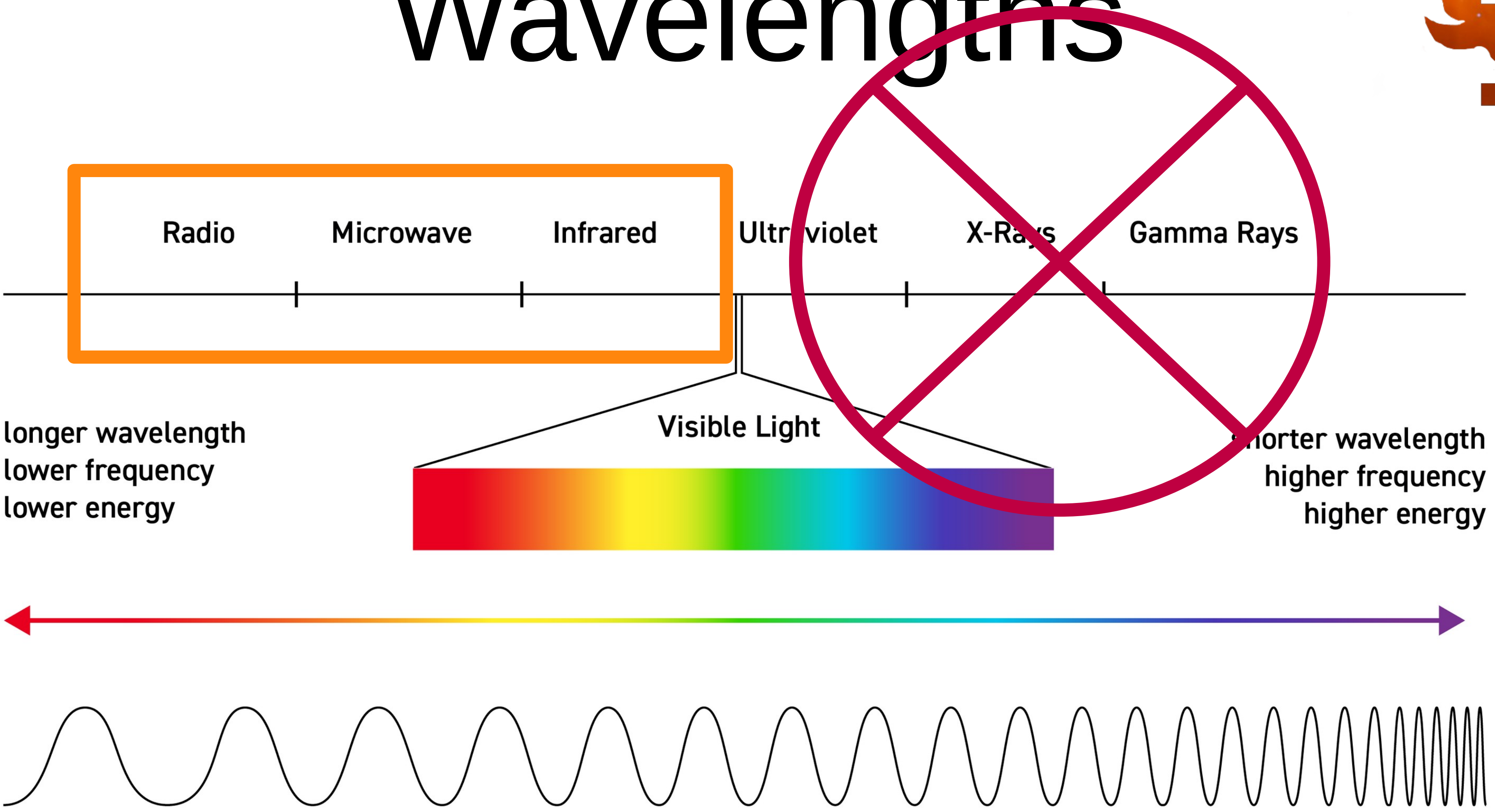




λ = wavelength; T = temperature

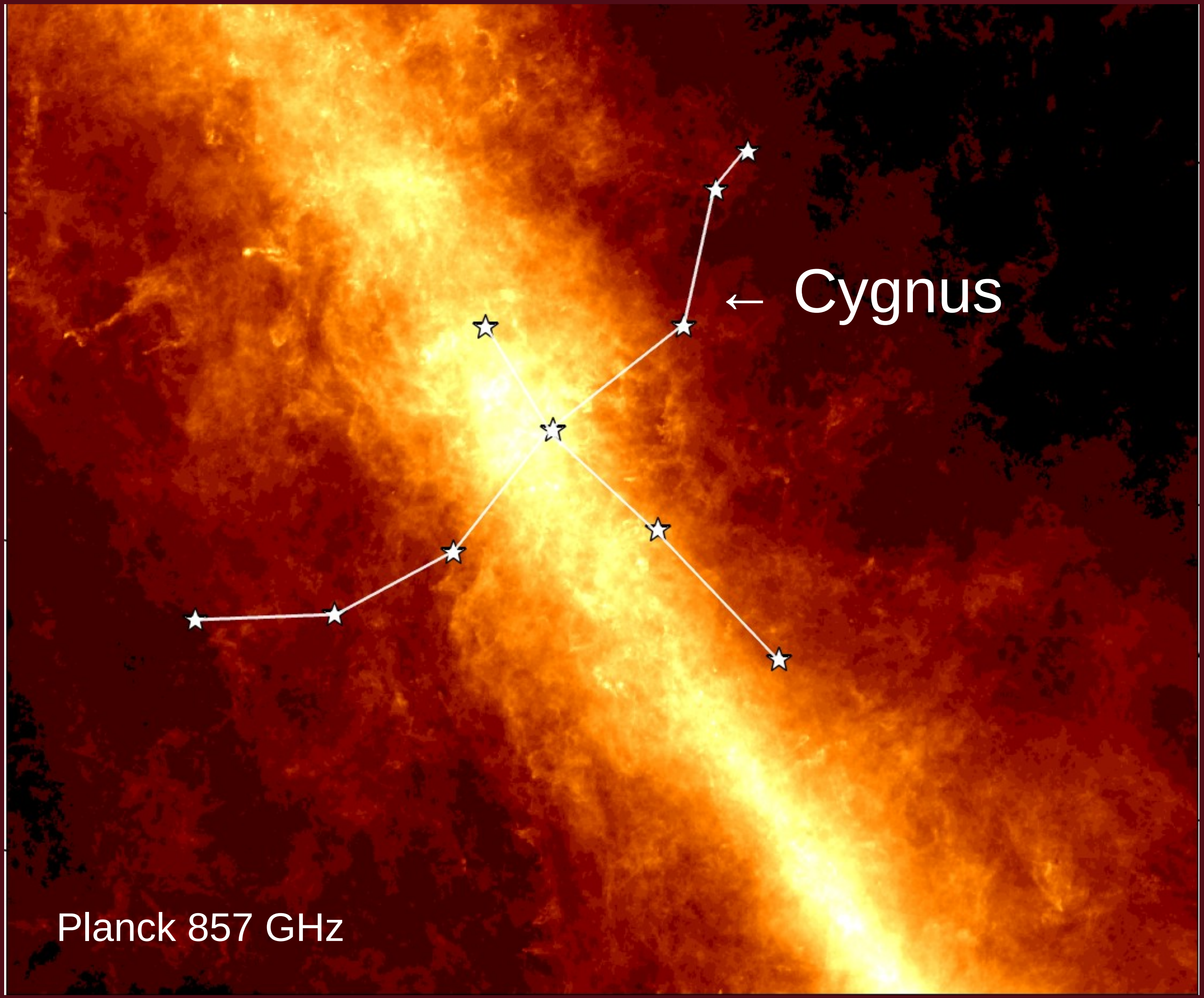
Image URL:
https://media.istockphoto.com/photos/thermovisioninfrared-thermal-image-of-a-cat-during-homeoffice-with-picture-id1339906054?k=20&m=1339906054&s=612x612&w=0&h=rpPUAs4sFwk0vBLLRIUMeT_wOxclsZgYAyrtnDuqOl0=

Wavelengths

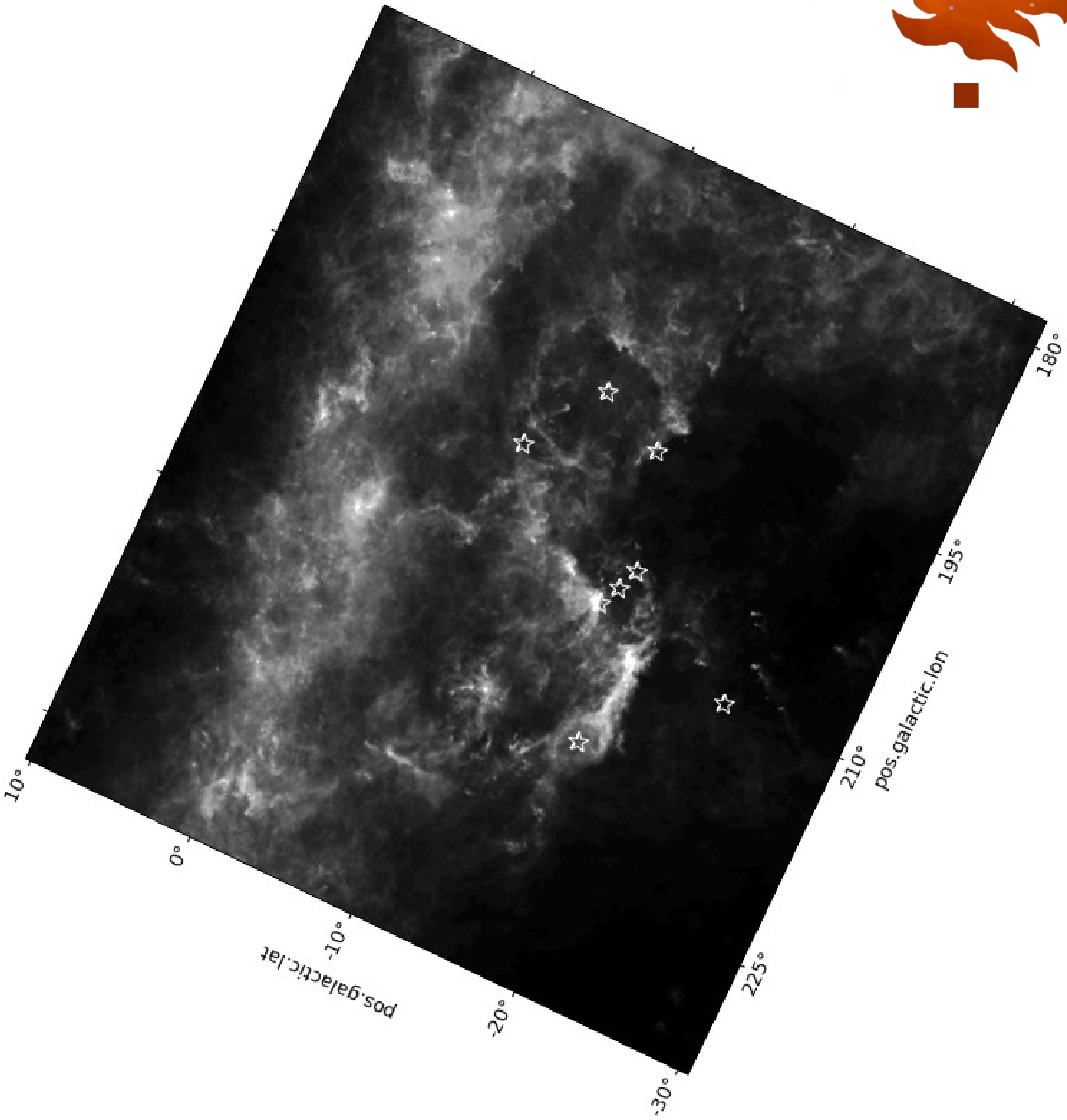


https://www.nist.gov/sites/default/files/images/2025/03/28/Wavelength-spectroscopy.png

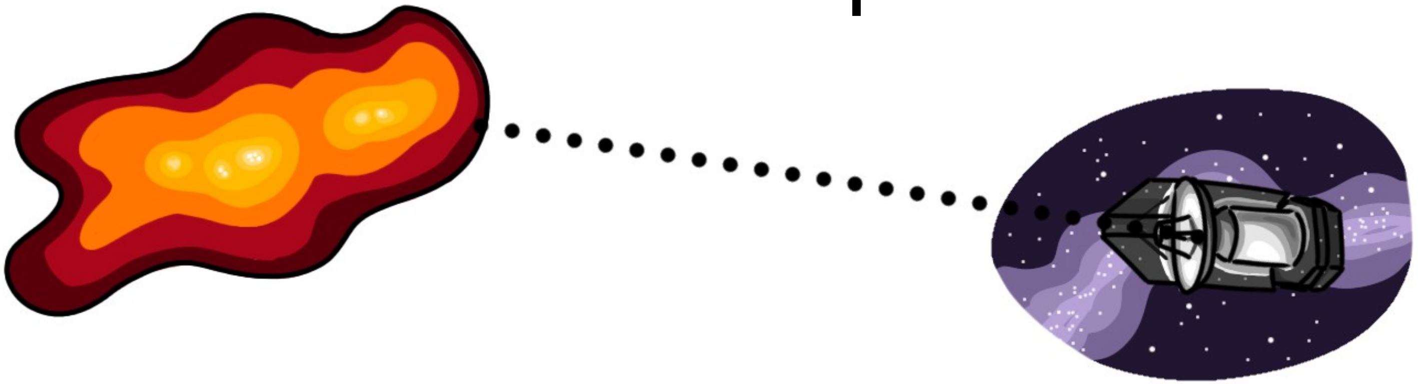

← Lyra
← Cygnus
← Aquila
Longyearbyen, Svalbard
Dec. 26, 2019
~12:00 noon
Exp: 15 sec
F/5.0
24.0 mm
ISO 1600
Photo: EM
← Berit


← Cygnus
Planck 857 GHz


Betelgeuse
Orion
Bellatrix
Rigel
Stellarium


180°
195°
210°
225°
pos.galactic.lon
10°
0°
-10°
-20°
-30°
pos.galactic.lat

Telescopes



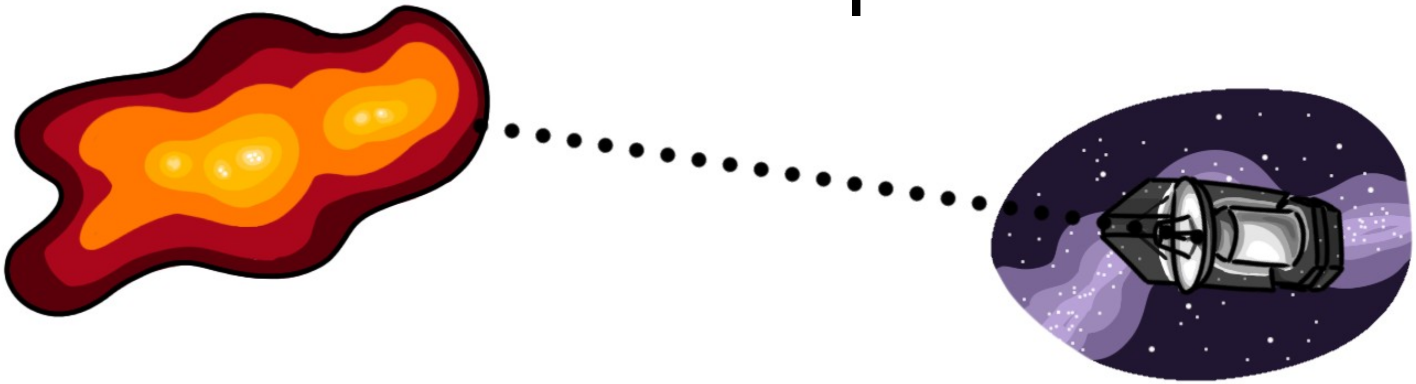
Resolution → $\theta = \frac{\lambda}{D}$ ← Wavelength / Diameter of dish

Longer wavelength
=> lower resolution

Larger dish
=> higher resolution

Illustrations: E.M.

Telescopes



Space based:
+ No atmosphere
+ Less light pollution

- Expensive
- High-risk & difficult or impossible repairs
- High environmental impact of launches
- Space weather, micrometeorites, etc.
- Size limit

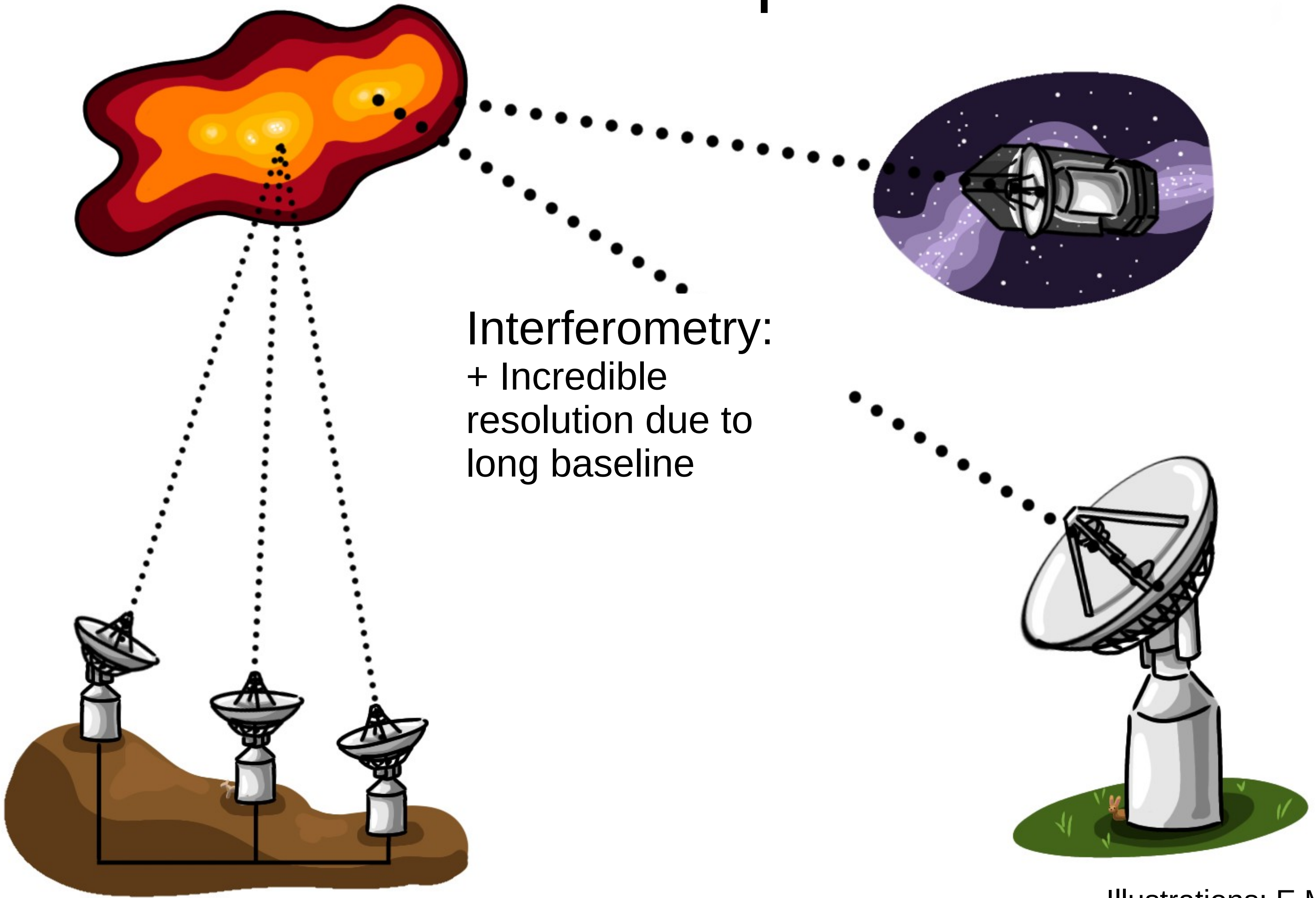
Telescopes

Ground based:

+ Easier to build, (can have) lower cost
+ Greater availability, easier access

- Atmosphere
- High environmental impact
- Good places to build telescopes tend to be sacred places (e.x. Mauna Kea in Hawai'i)

Telescopes



Interferometry:
+ Incredible resolution due to long baseline

Illustrations: E.M.

How does radiation travel through space?

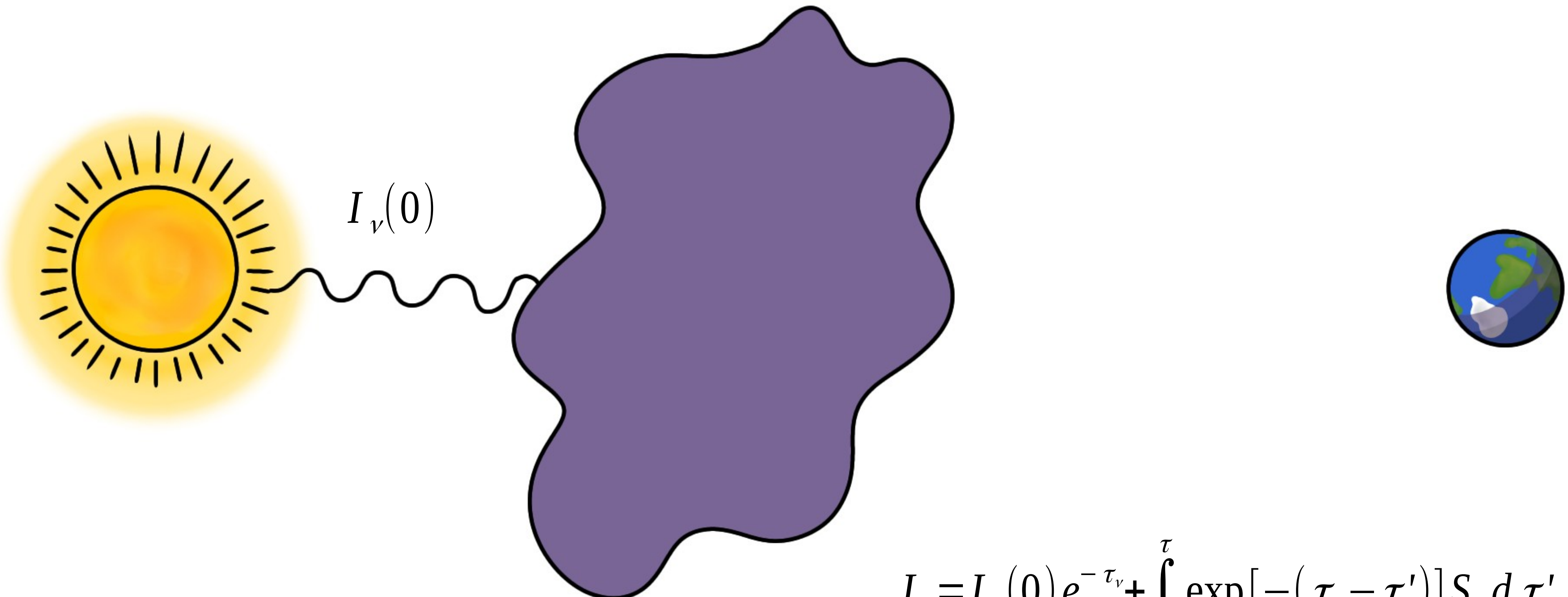
$$I_\nu = I_\nu(0)\, e^{-\tau_\nu} + \int_0^{\tau} \exp[-(\tau_\nu - \tau')]\, S_\nu\, d\tau'$$

Radiative transfer

$$I_\nu = I_\nu(0)\, e^{-\tau_\nu} + \int_0^{\tau} \exp[-(\tau_\nu - \tau')]\, S_\nu\, d\tau'$$

Illustrations: E.M.

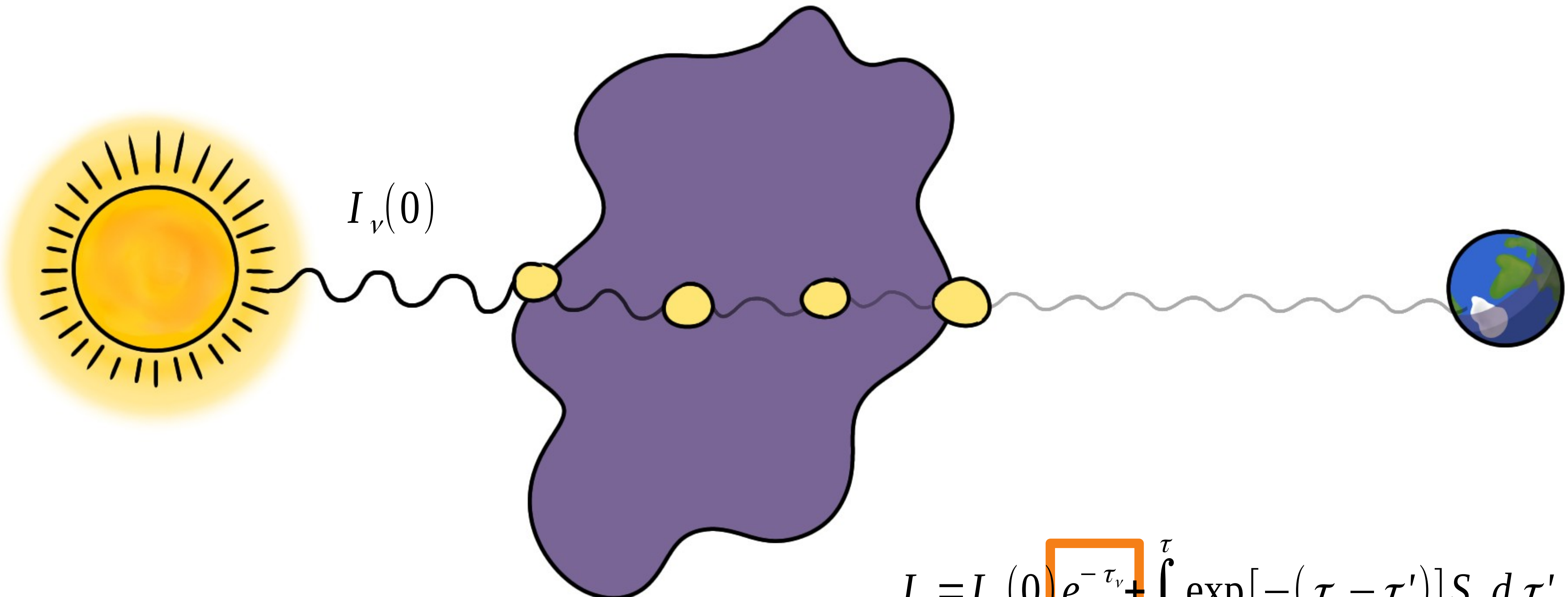
Radiative transfer



$$I_\nu = I_\nu(0)\, e^{-\tau_\nu} + \int_0^{\tau} \exp[-(\tau_\nu - \tau')]\, S_\nu\, d\tau'$$

Illustrations: E.M.

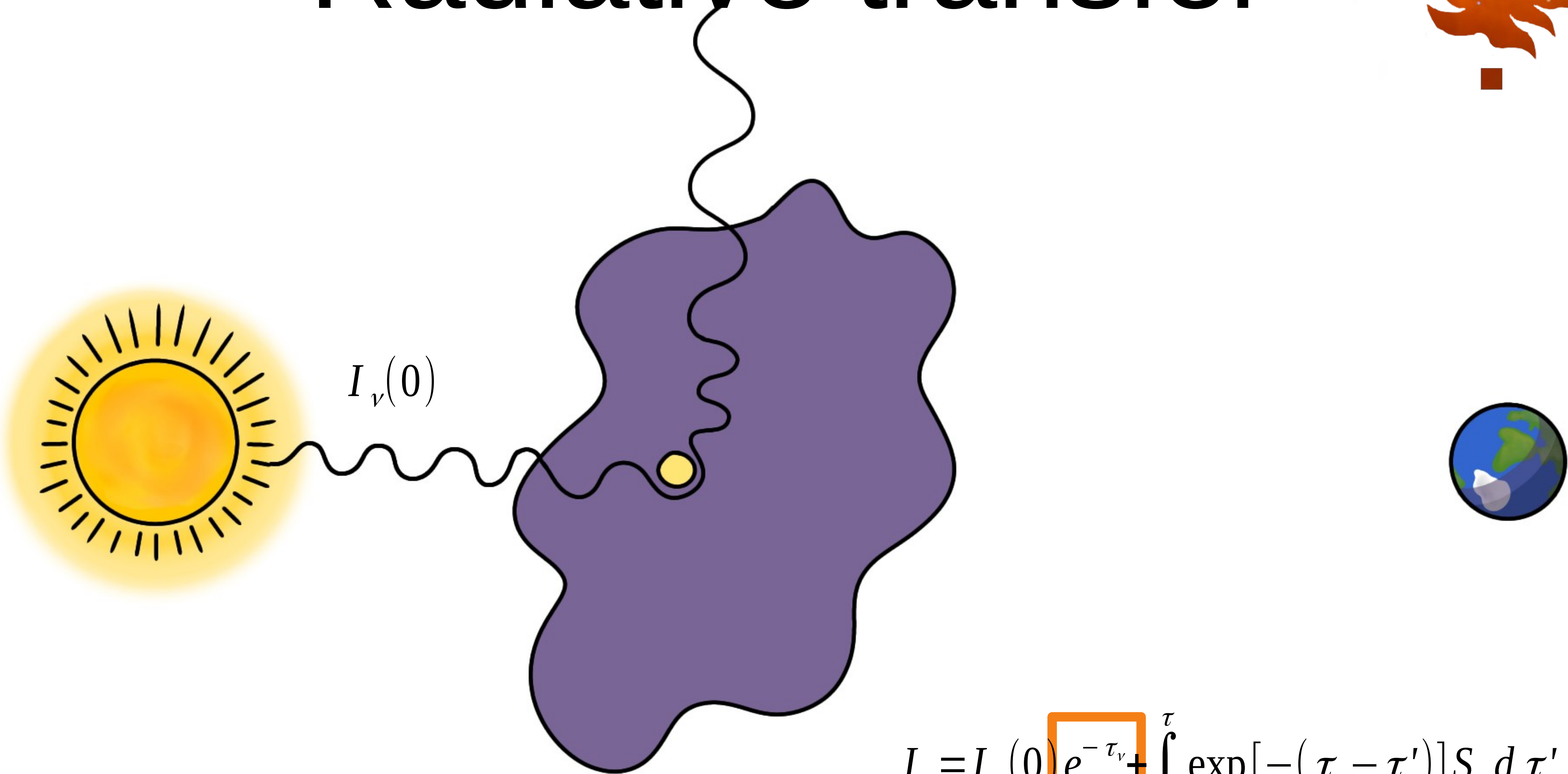
Radiative transfer



$$I_\nu = I_\nu(0)\boxed{e^{-\tau_\nu}} + \int_0^{\tau} \exp[-(\tau_\nu - \tau')] S_\nu d\tau'$$

Illustrations: E.M.

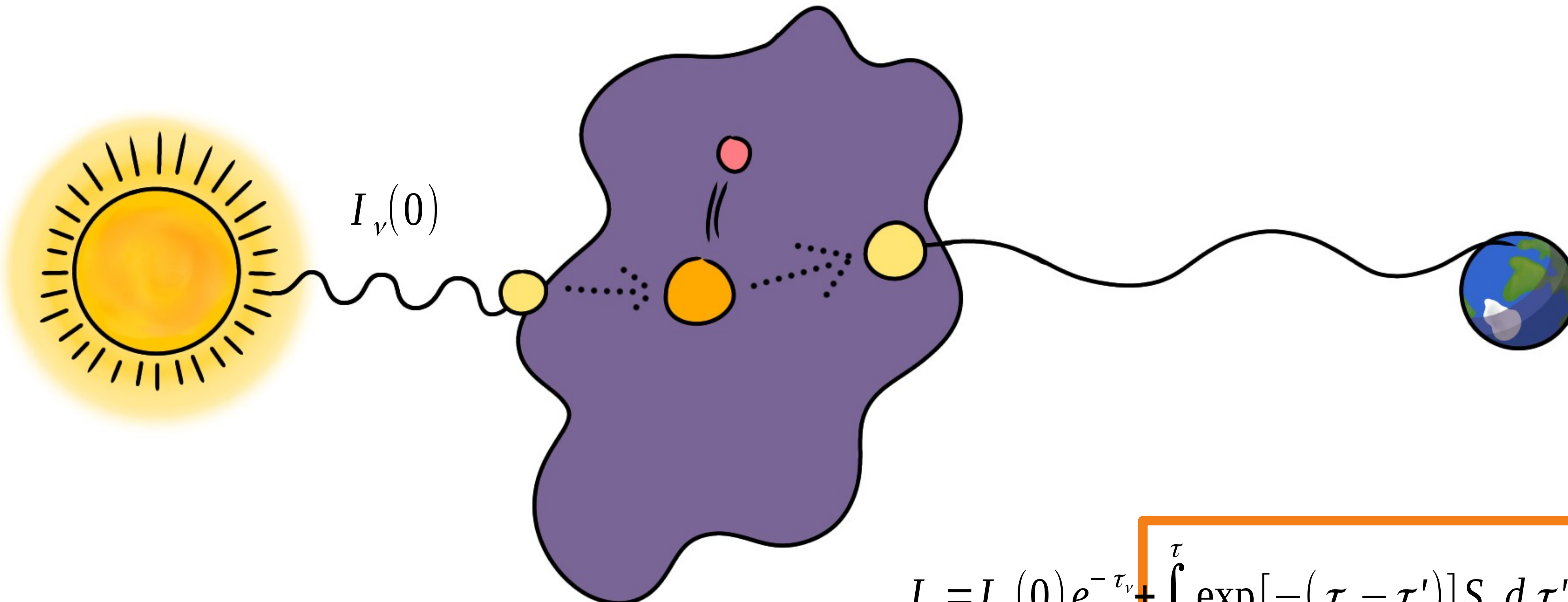
Radiative transfer



$$I_\nu = I_\nu(0)\,\boxed{e^{-\tau_\nu}} + \int_0^{\tau} \exp[-(\tau_\nu - \tau')]\,S_\nu\,d\tau'$$

Illustrations: E.M.

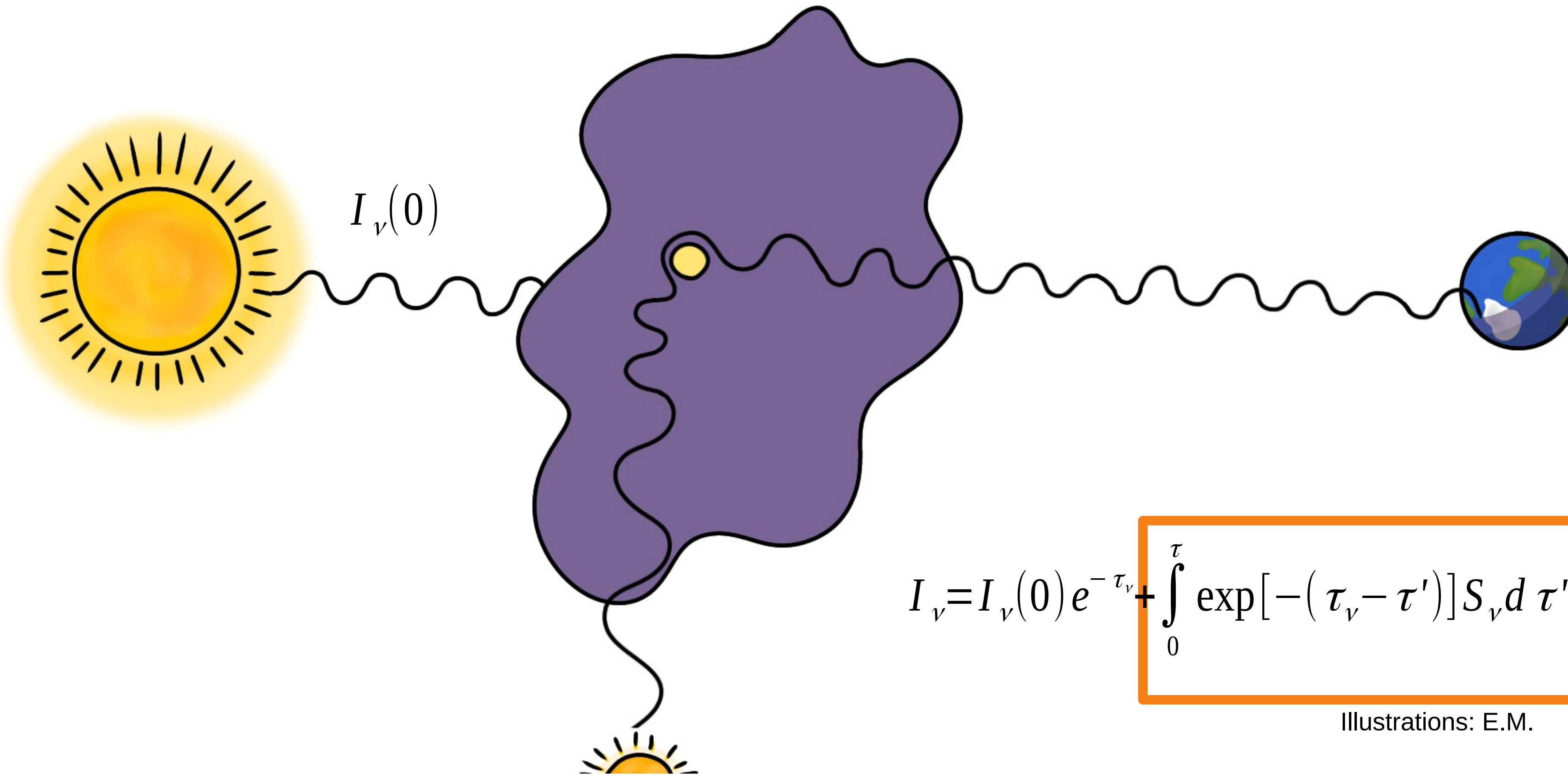
Radiative transfer



$$I_\nu = I_\nu(0)\, e^{-\tau_\nu} + \boxed{\int_0^{\tau} \exp[-(\tau_\nu - \tau')]\, S_\nu\, d\tau'}$$

Illustrations: E.M.

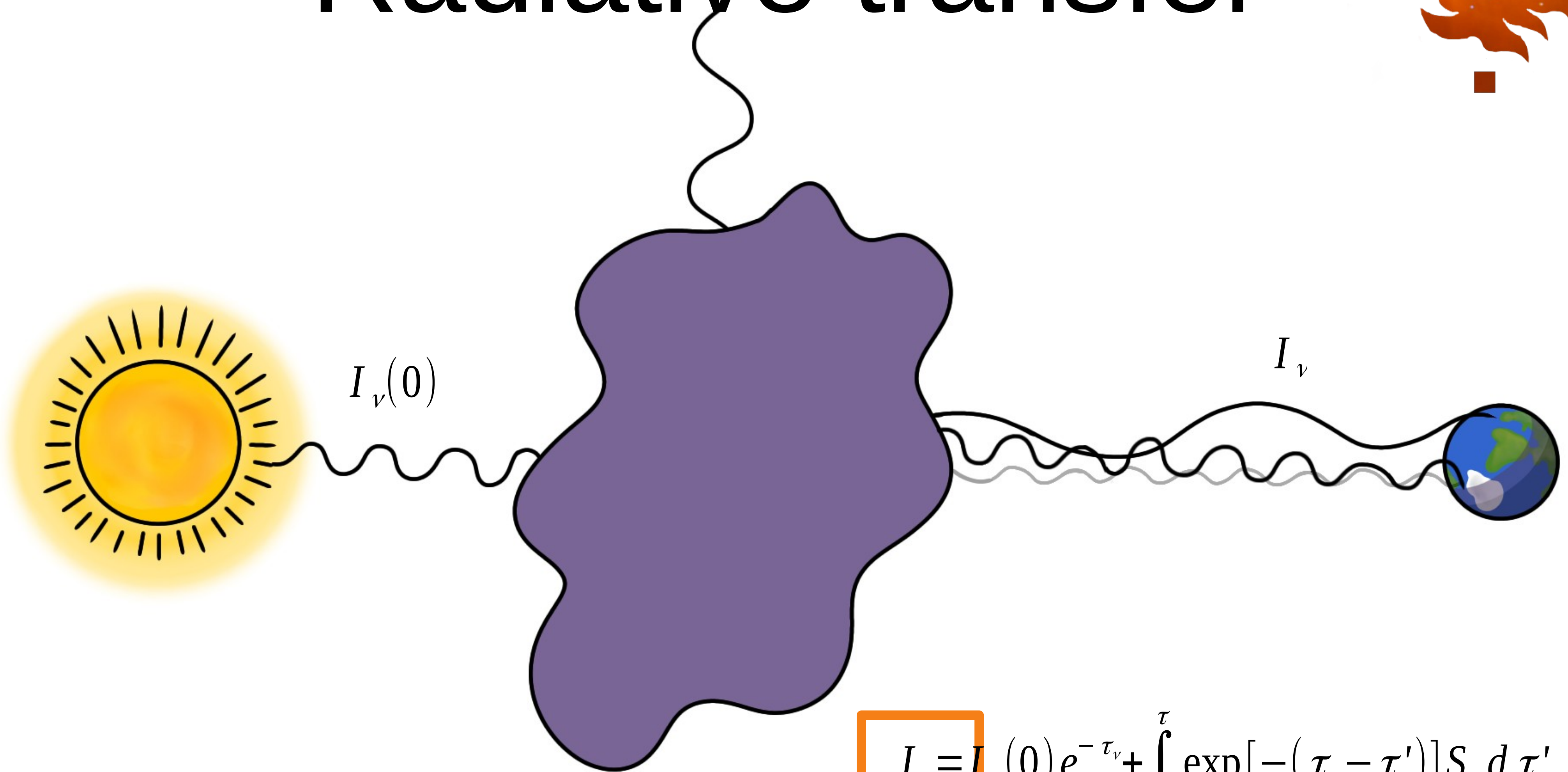
Radiative transfer



$$I_\nu = I_\nu(0)\, e^{-\tau_\nu} + \boxed{\int_0^{\tau} \exp[-(\tau_\nu - \tau')]\, S_\nu\, d\tau'}$$

Illustrations: E.M.

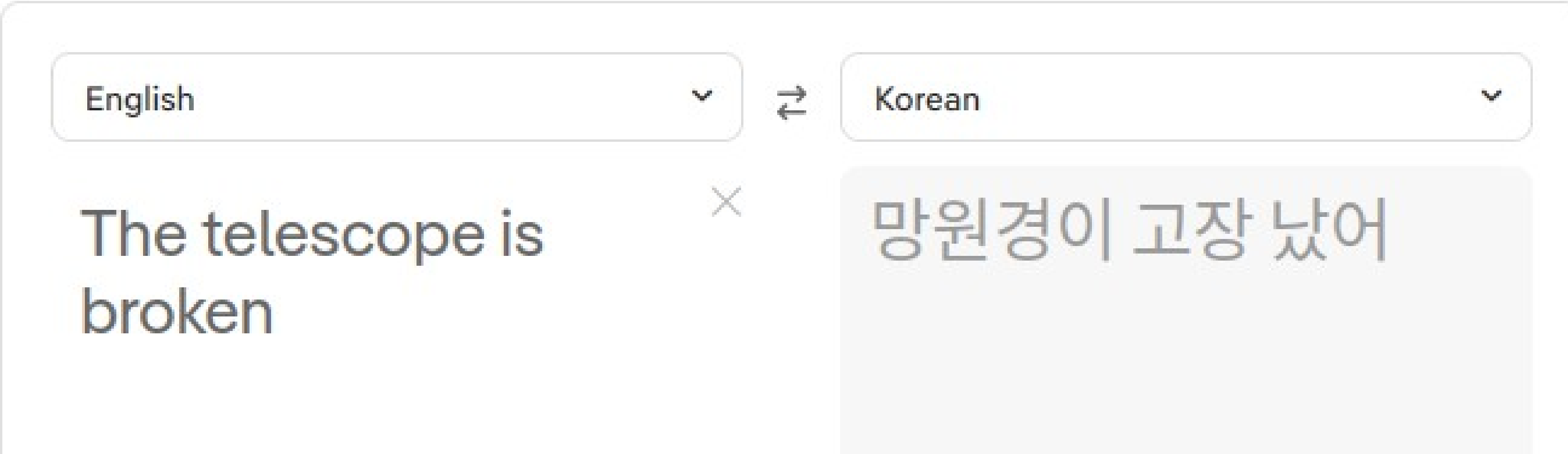
Radiative transfer



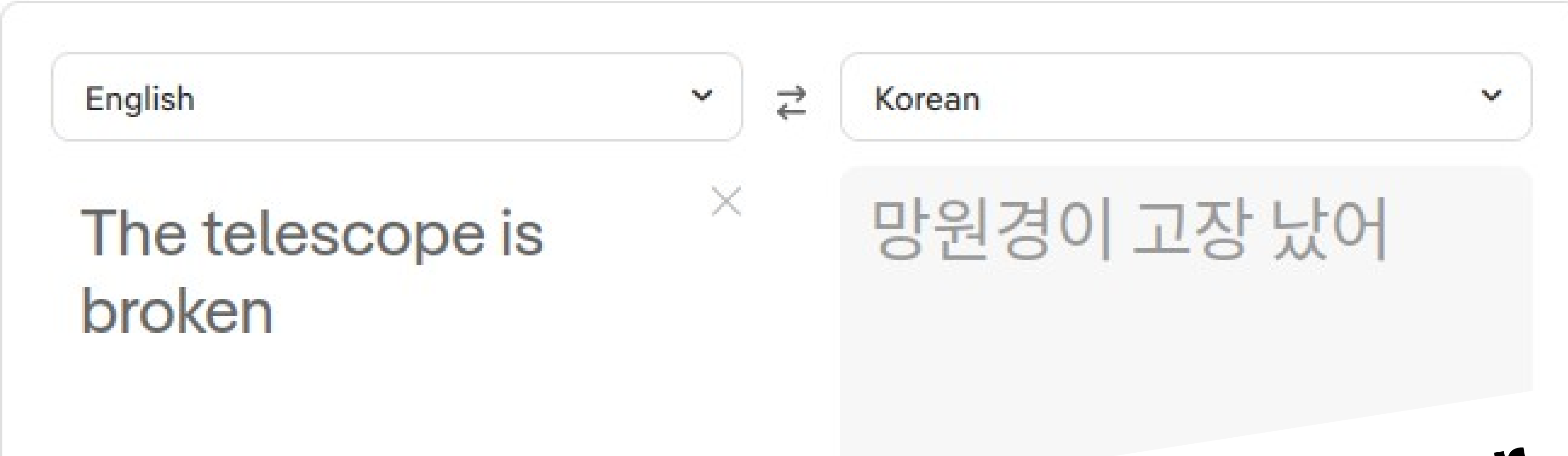
$$\boxed{I_\nu}=I_\nu(0)\,e^{-\tau_\nu}+\int_0^{\tau}\exp[-(\tau_\nu-\tau')]\,S_\nu\,d\tau'$$

Illustrations: E.M.

Astronomy is easy and our observations are great



Astronomy is easy and our observations are great

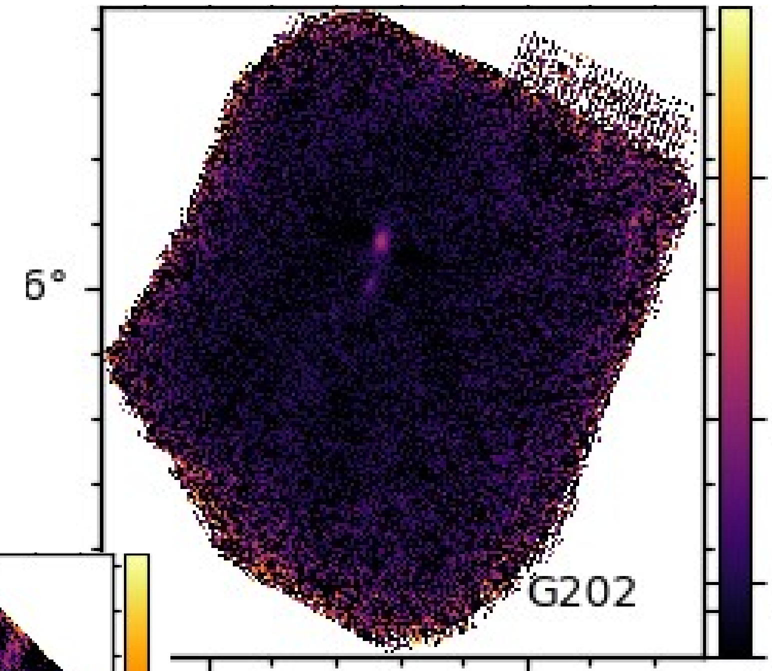


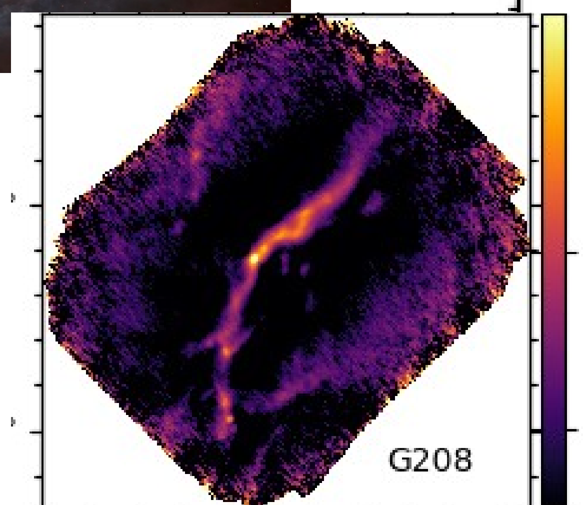
(Some) causes of error in our observations

Publication image

Normal data :')

Credit: ESO/G. Beccari
Orion nebula and cluster with the VLT
https://www.eso.org/public/images/eso1723a/



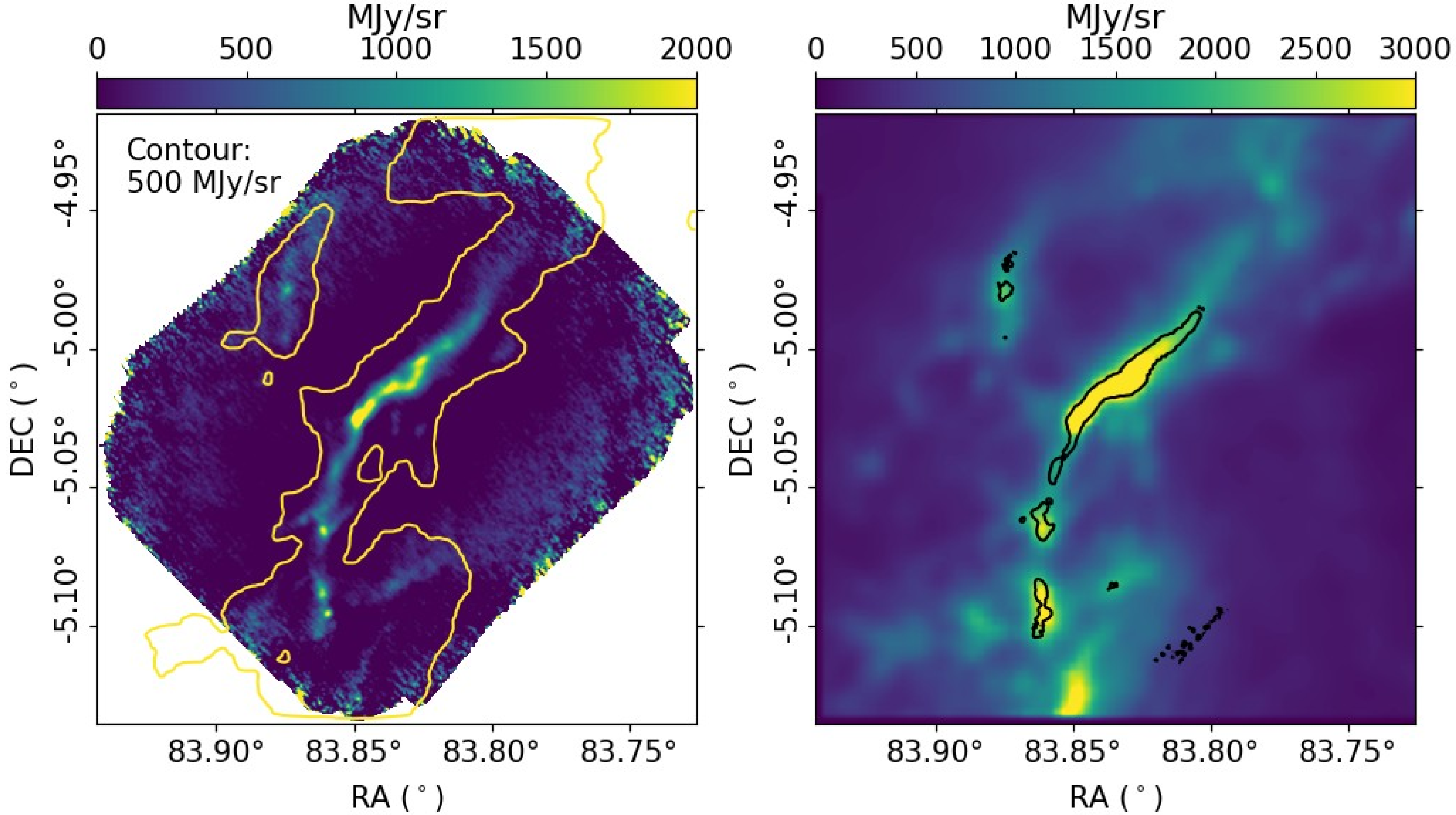


PAPER-II

Some issues

I. Noise
  I. Atmosphere
  II. Instrumental noise
II. Resolution
III. Line-of-sight confusion
IV. ~~(The telescope broke)~~
  Instrumental errors
V. Modeling, astrochemistry, other physical errors
VI.

Removal of atmospheric noise



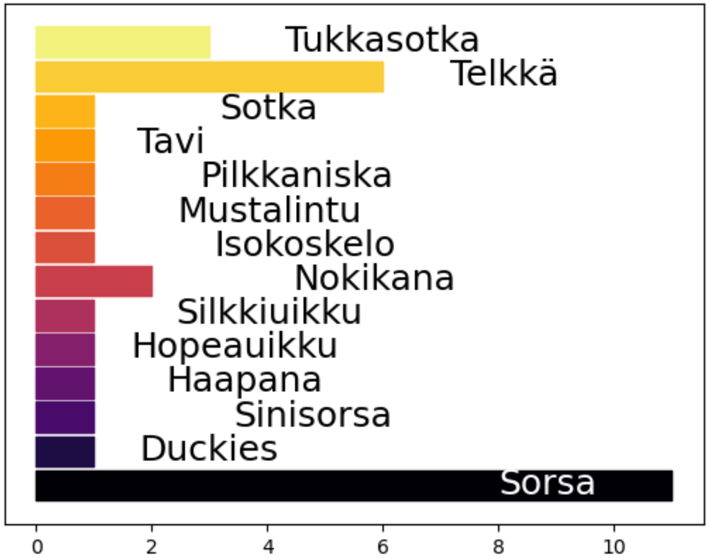
especially PAPER-II, PAPER-V

Low

High

Resolution

Crab nebula
d = 6000 light years



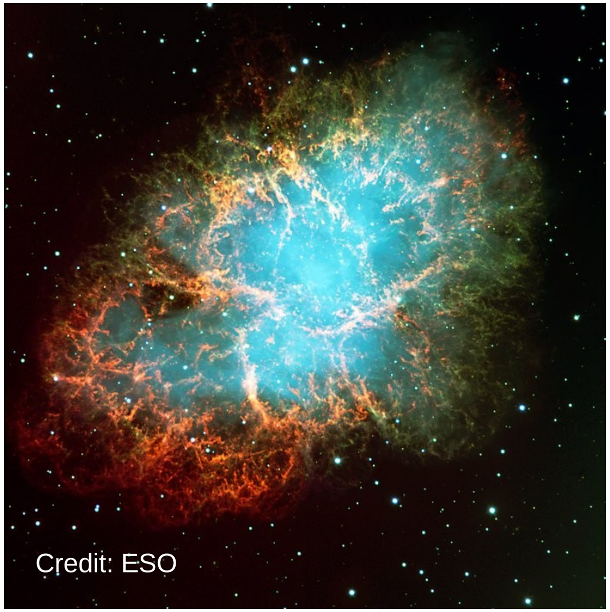
Low

High

Resolution

Credit: CONCERTO team/A. Beelen, ESO
https://www.eso.org/public/images/ann21010d/

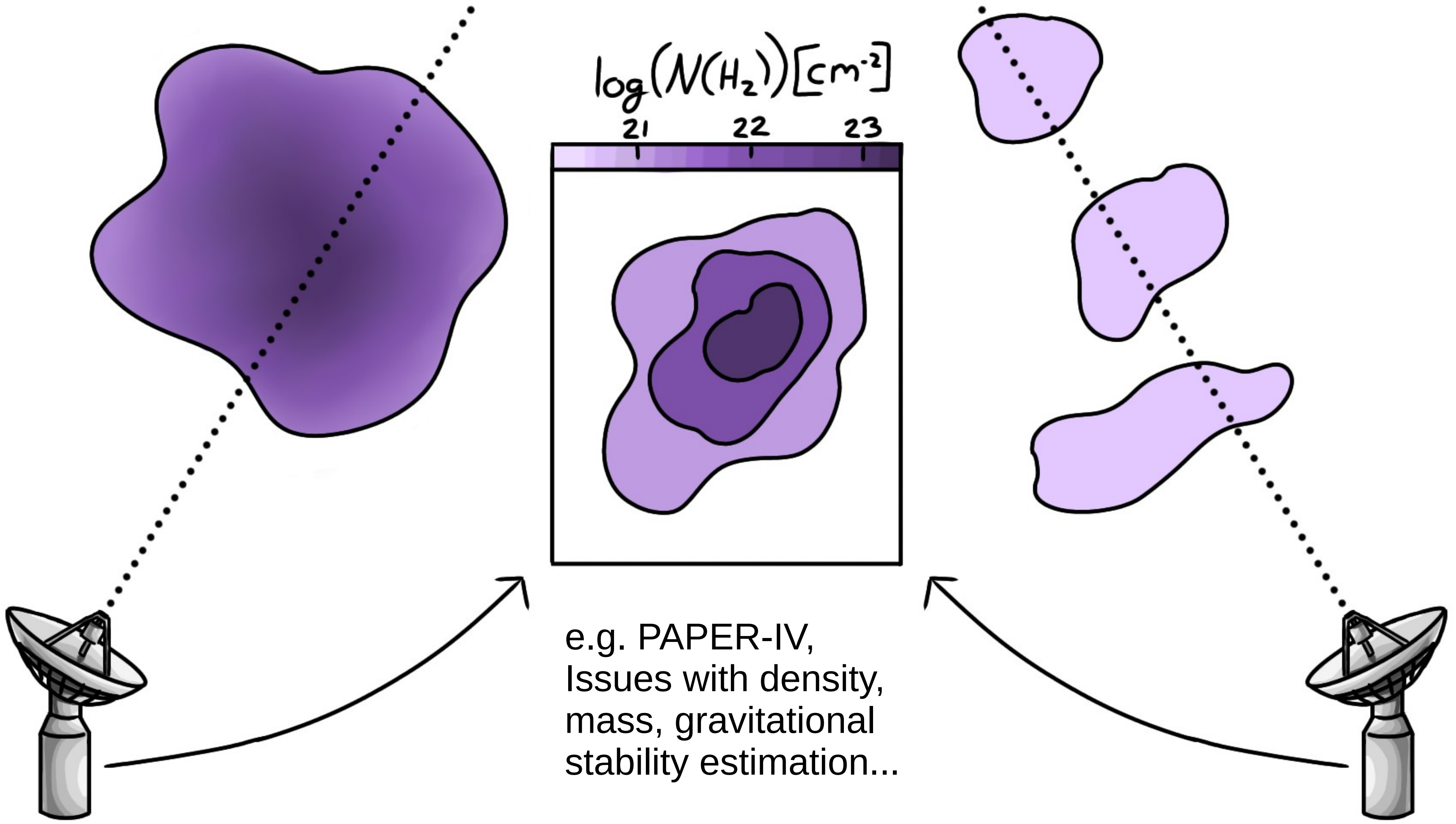
Crab nebula
d = 6000 light years



Credit: ESO

Tukkasotka !→
(3+1 correct)

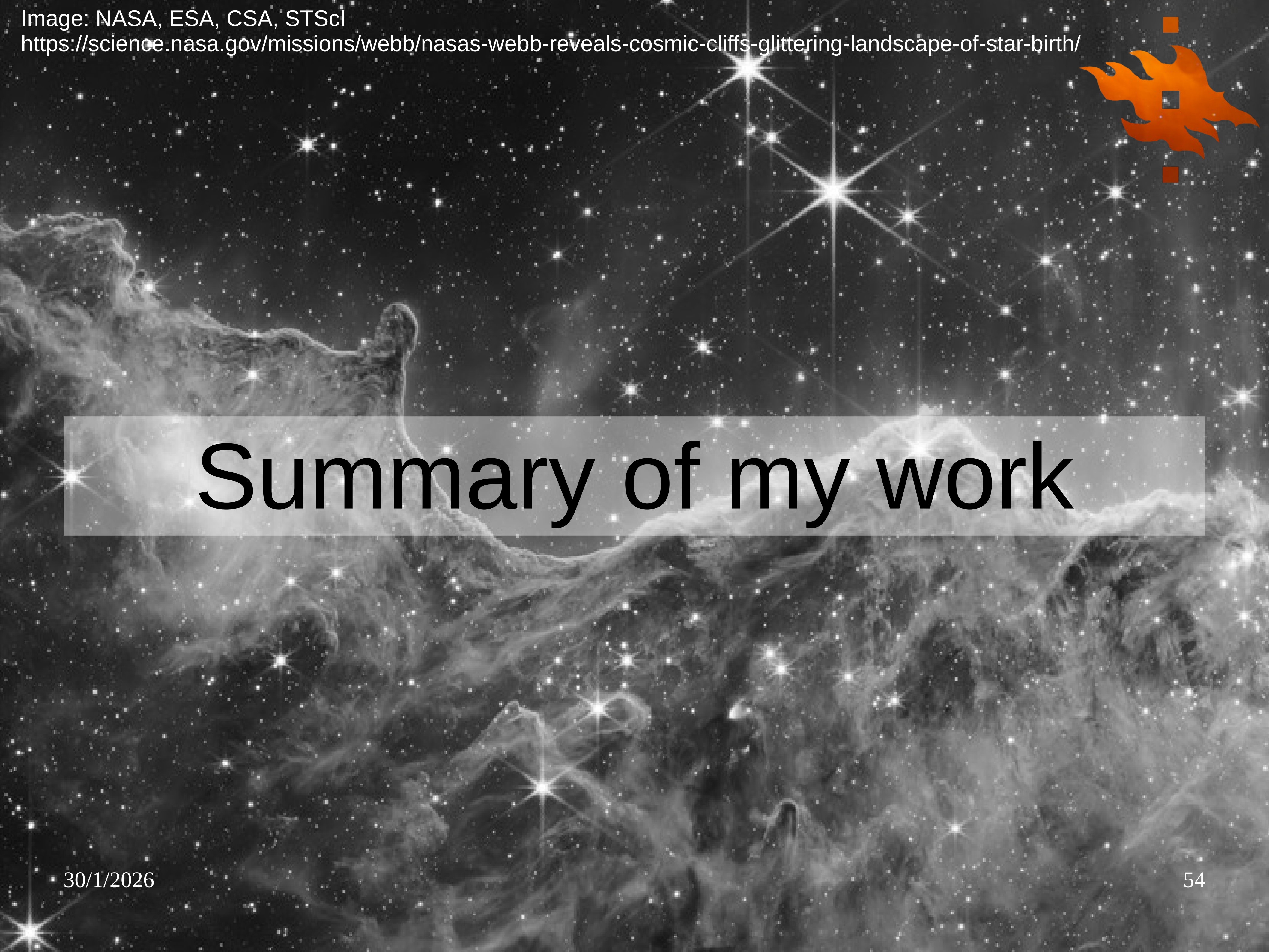
Line-of-sight



e.g. PAPER-IV,
Issues with density,
mass, gravitational
stability estimation...

Illustrations: E.M.

Image: NASA, ESA, CSA, STScI
https://science.nasa.gov/missions/webb/nasas-webb-reveals-cosmic-cliffs-glittering-landscape-of-star-birth/



Summary of my work

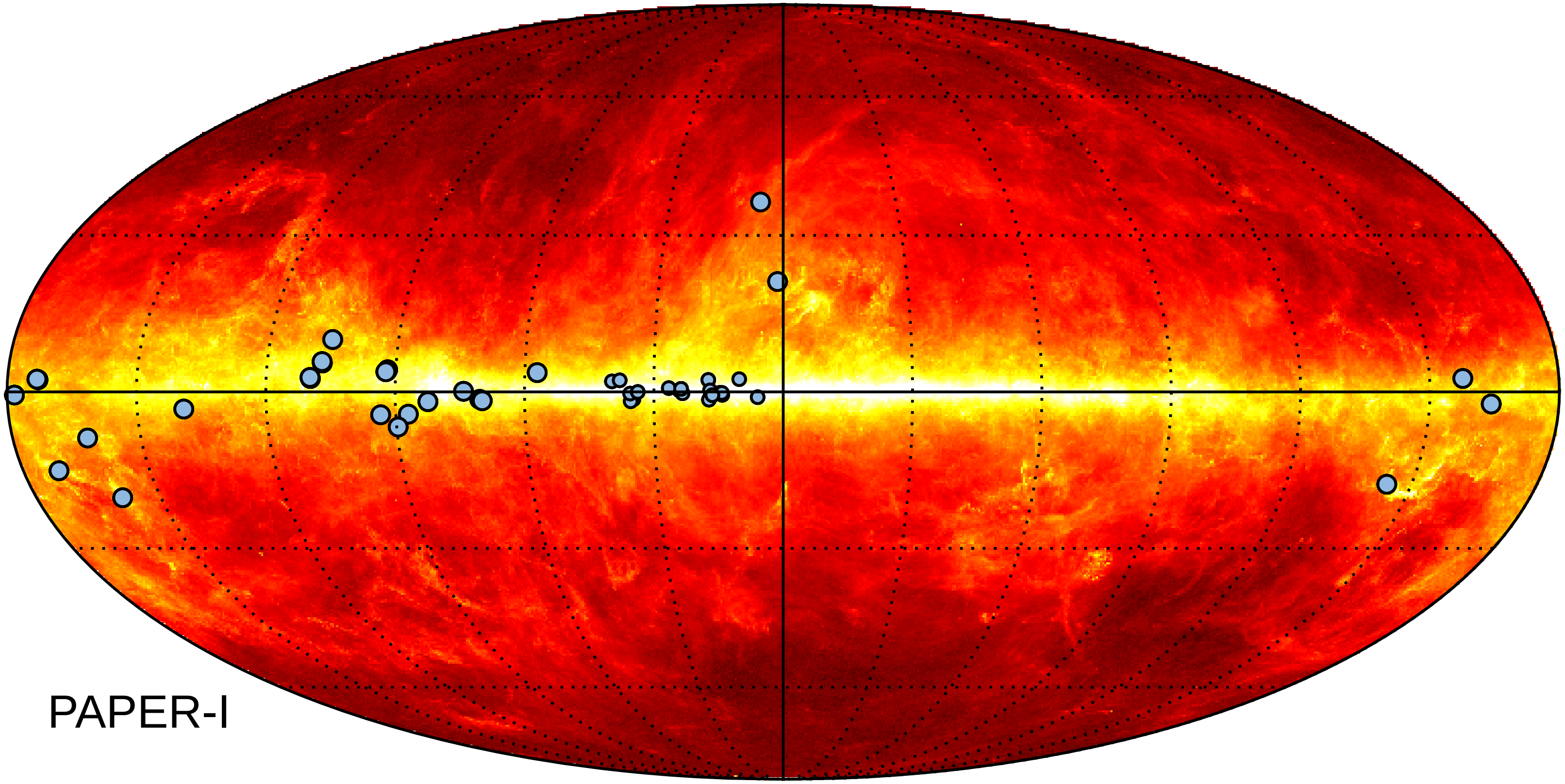
Summary of papers

PAPER-I	PAPER-II	PAPER-III	PAPER-IV	PAPER-V
- Catalog of cores in 52 dense MCs - Do properties show correlation with e.g. SF status, location in the Galaxy, etc?	- Study of the main filament in OMC-3 with *Herschel* and ArTeMiS - Determine properties of this filament. - Do the properties change based on observing method?	- Three dense clouds in the LOri bubble observed in 12CO & 13CO - How does the cloud evolve in a high-feedback environment?	- Simulated observations of high-mass filament - How does the proposed ngVLA telescope recover properties of the filament?	- Dense filament segments in OMC-3, including MIR Spitzer data. - How do properties of this filament change based on observing method?

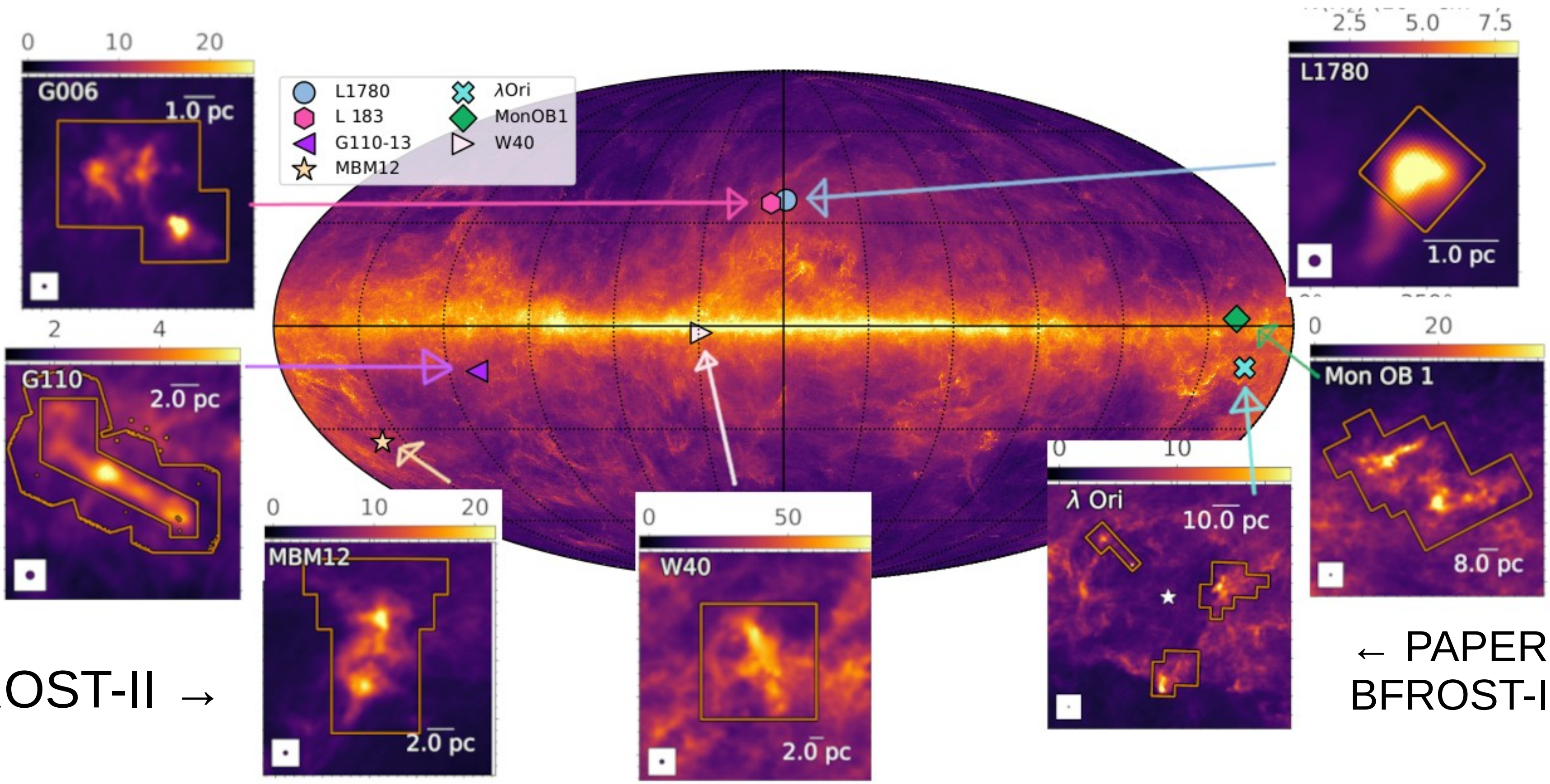
Main results

1. Creation of catalogs usable by the astronomical community

Creation of catalogs usable by the astronomical community – GCC



Creation of catalogs usable by the astronomical community – BFROST

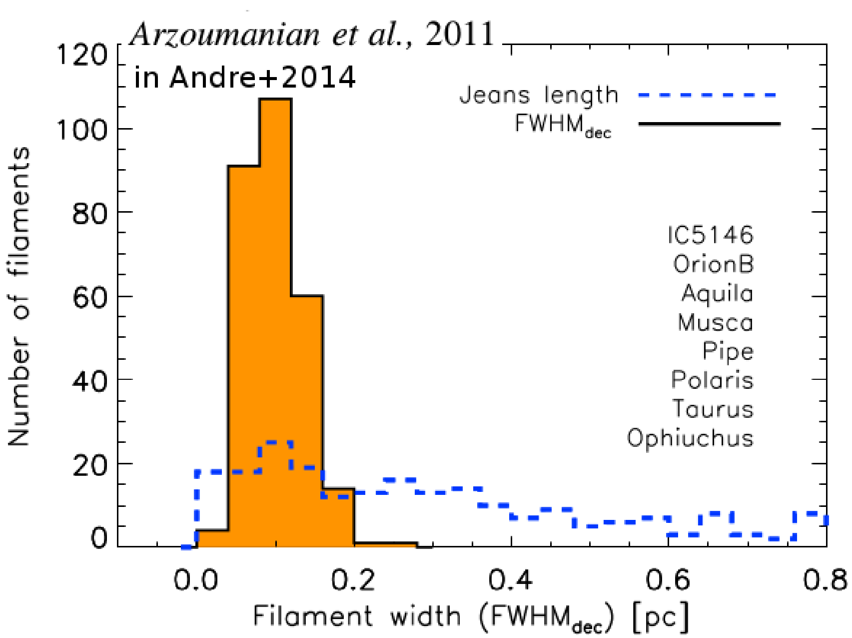


BFROST-II →

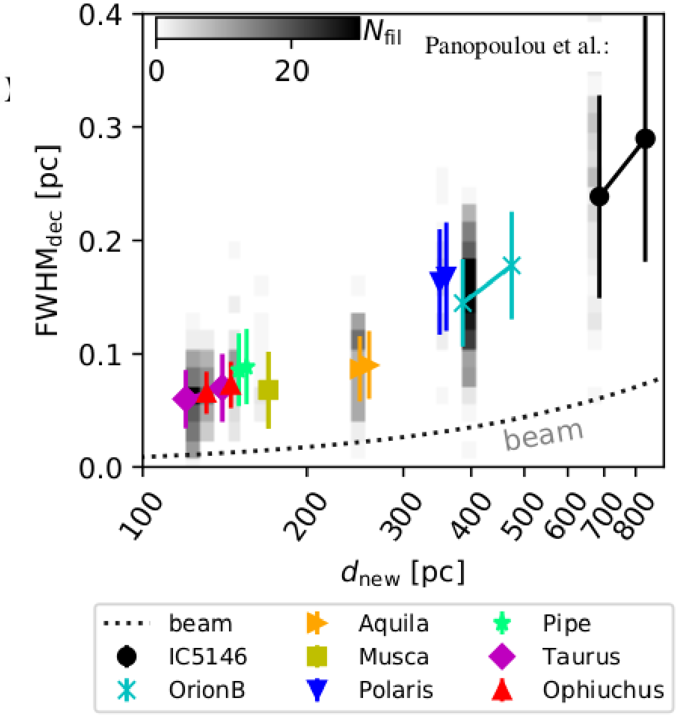
← PAPER-III
BFROST-I

2. Observational parameters affect our results

Observational parameters affect our results – 0.1 pc filament width

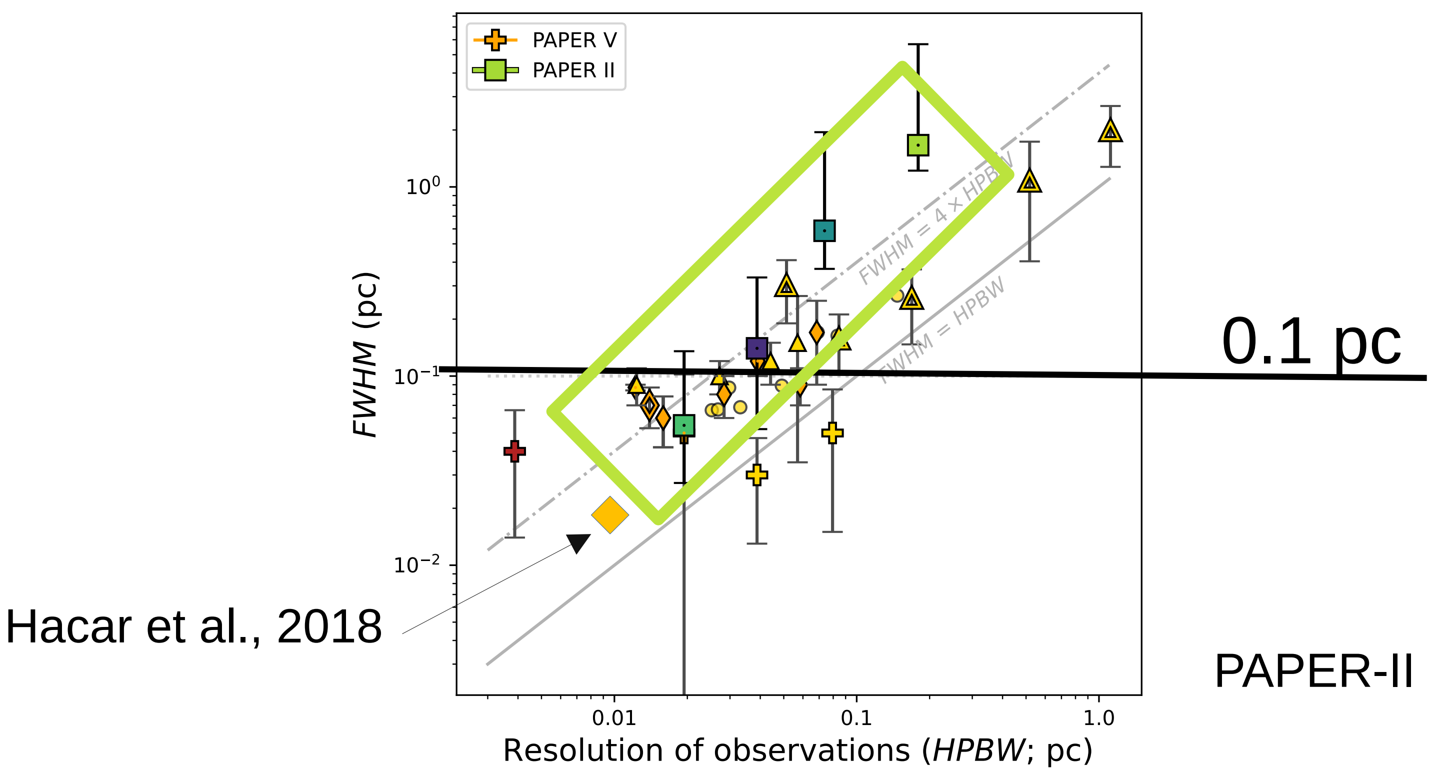


Arzoumanian et al., 2011

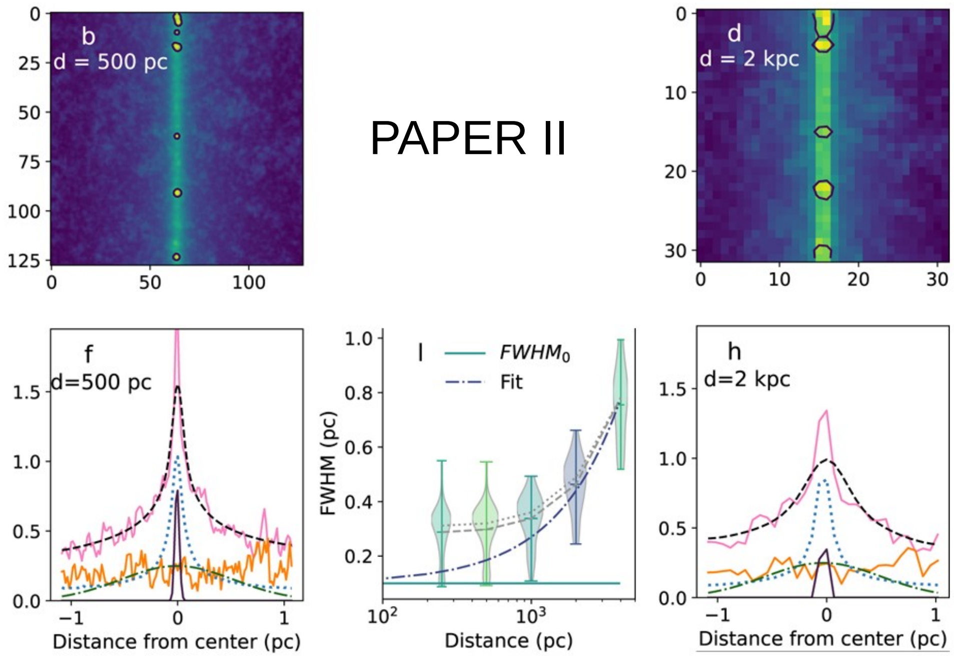


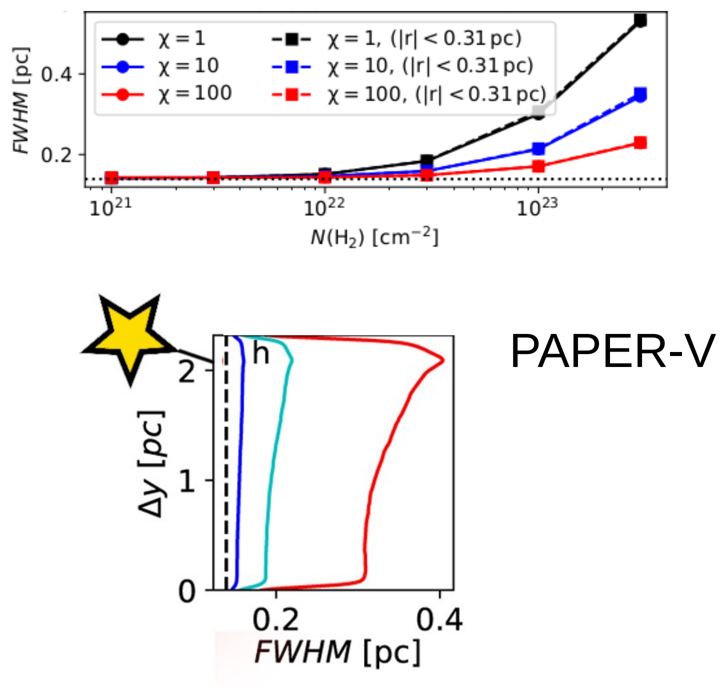
Panopoulou et al., 2021

Observational parameters affect our results – 0.1 pc filament width

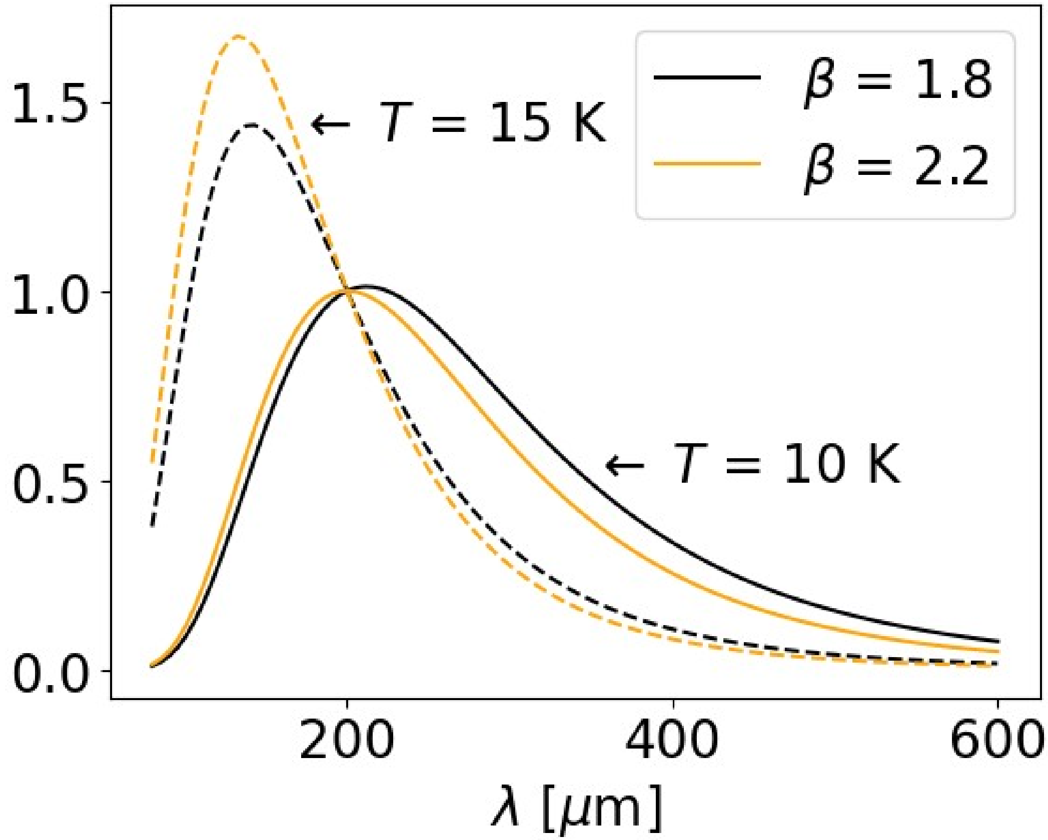


Observational parameters affect our results – 0.1 pc filament width

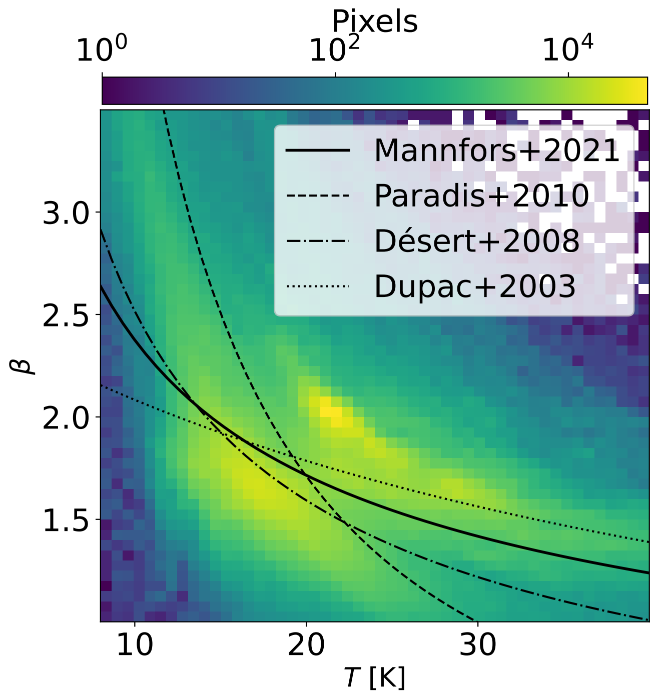




Observational parameters affect our results – T-β anticorrelation

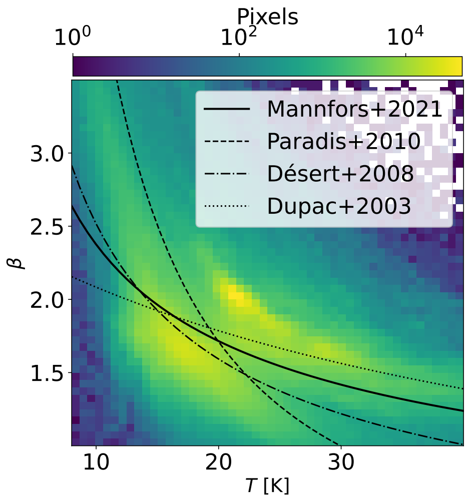


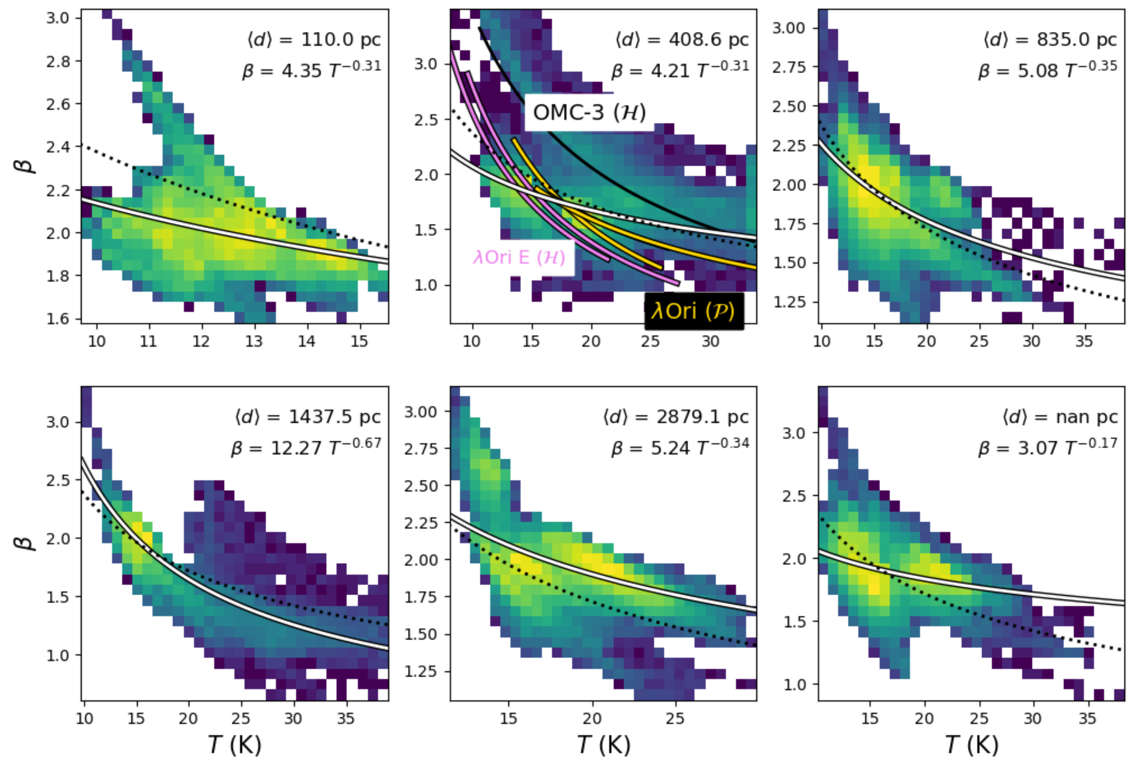
Observational parameters affect our results – T-β anticorrelation



← PAPER I

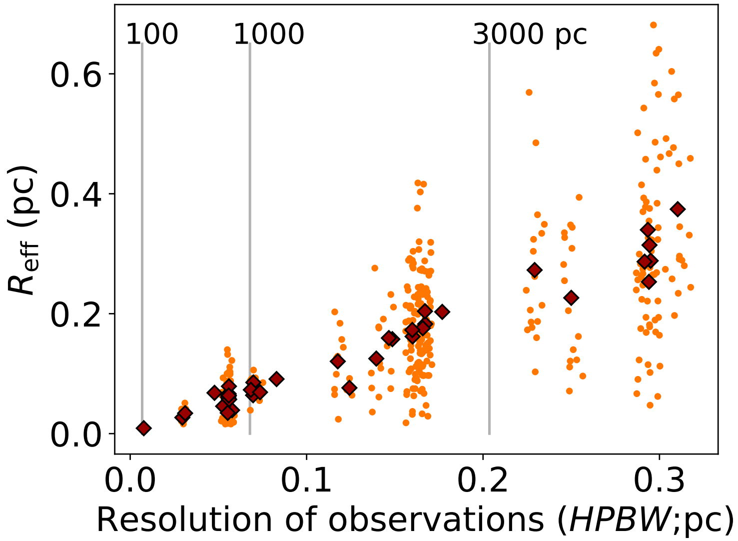
Observational parameters affect our results – T-β anticorrelation

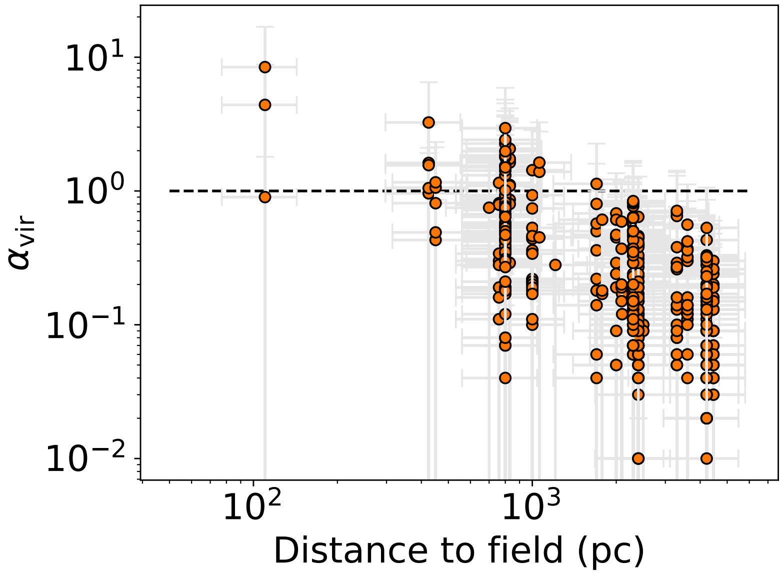




PAPERS I-III

Observational parameters affect our results – Distance dependence

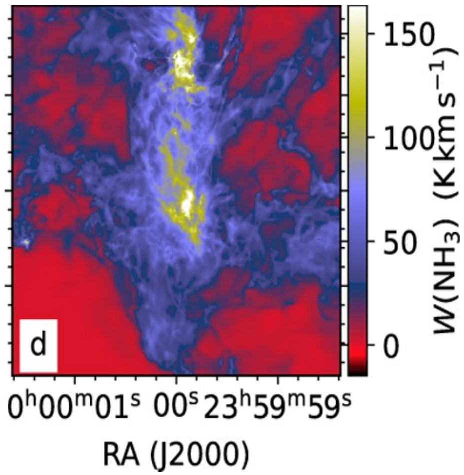




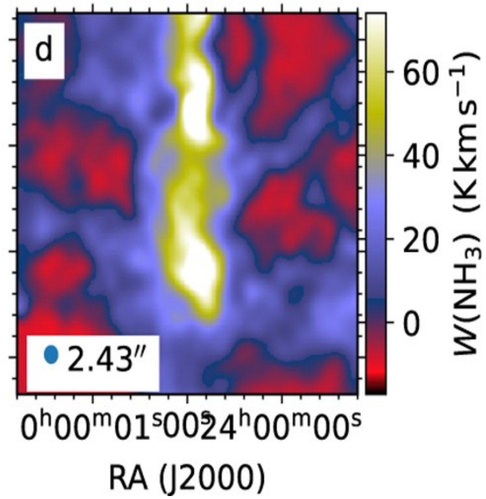
PAPER I

Observational parameters affect our results – ngVLA study

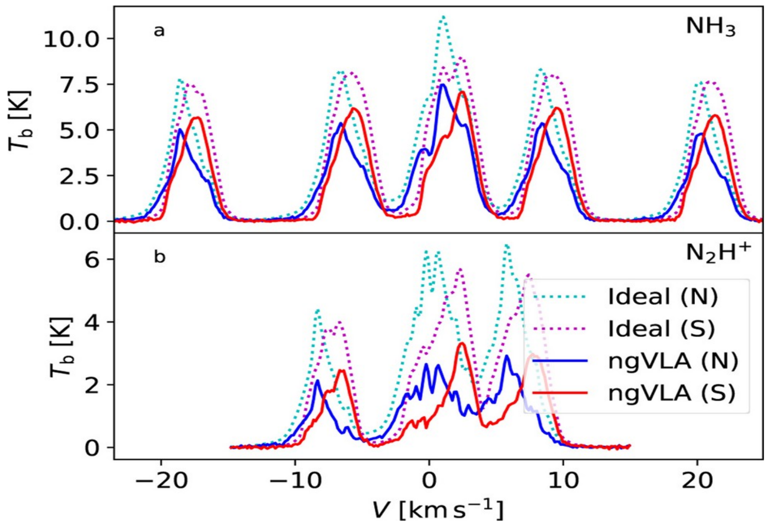
“Ideal” map



Simulated observation



Paper-IV



Future prospects

- JWST and ALMA imaging of clouds
  - Same cloud at multiple resolutions
  - Deep study of one cloud
- More sophisticated modeling of clouds
  - e.g. multi-temperature components of MBB fitting
  - Multi-dust-species
- A greater understanding of *what* causes error & our assumptions

Credit: ESO/G. Beccari
https://www.eso.org/public/images/eso1723a/