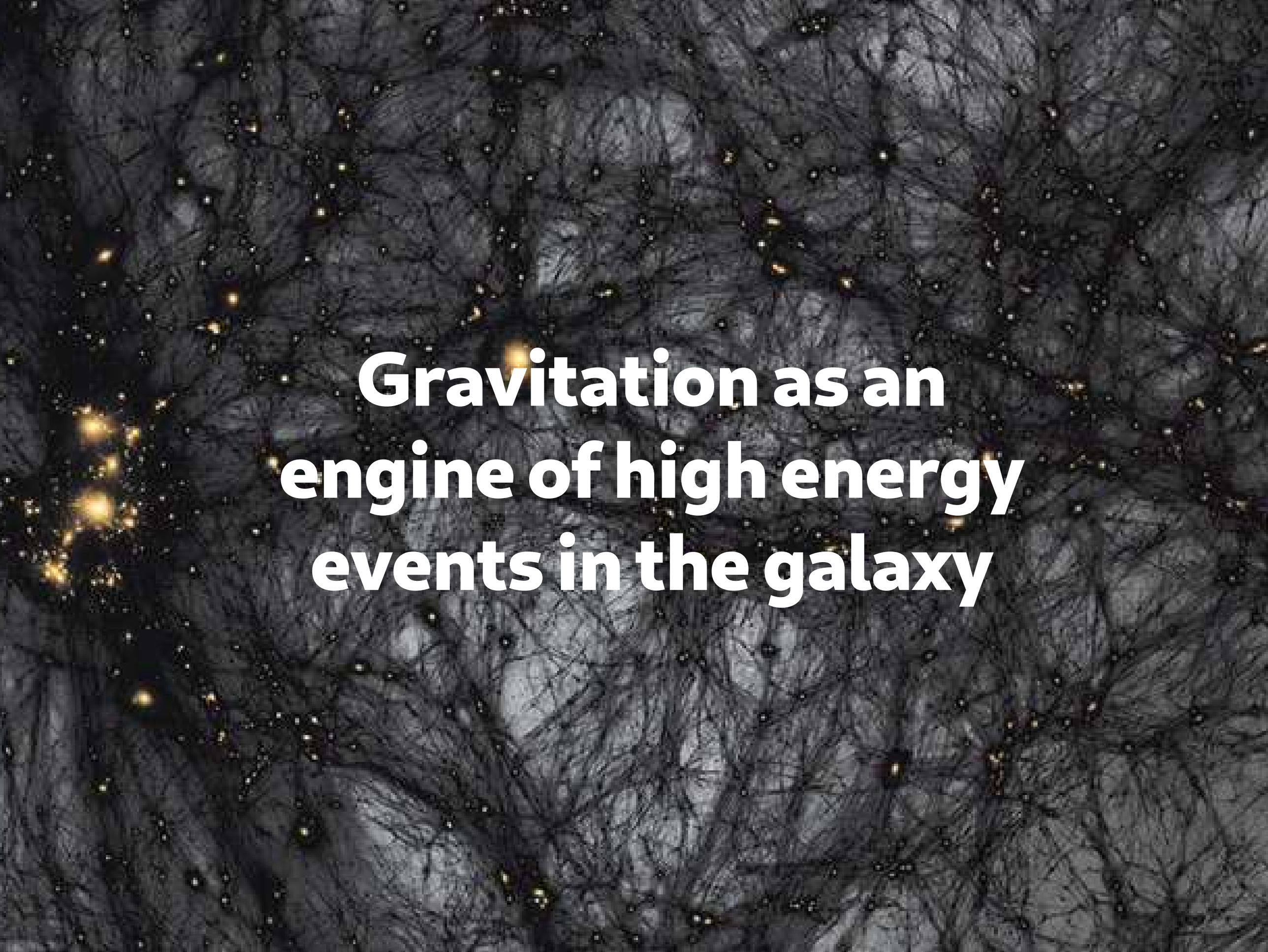
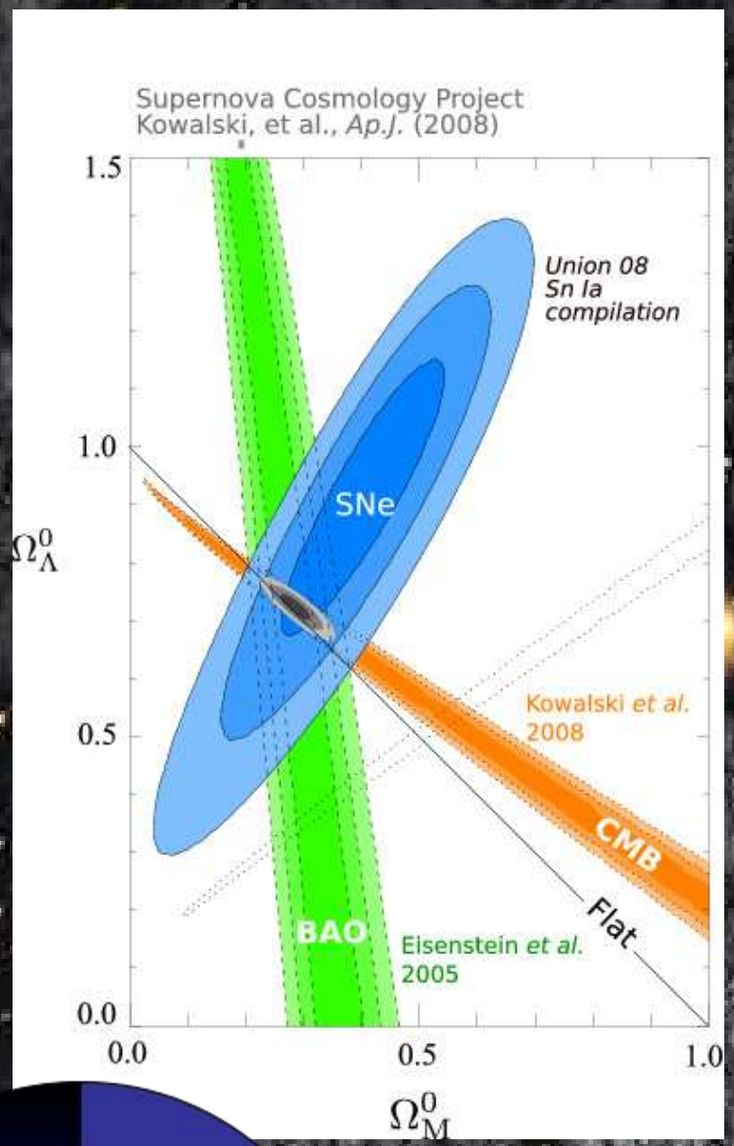
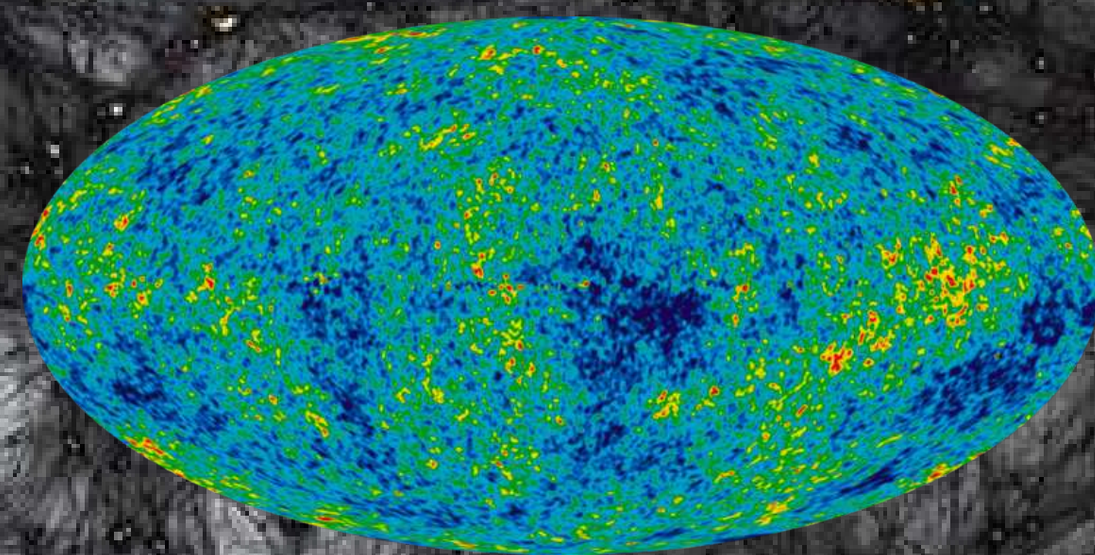
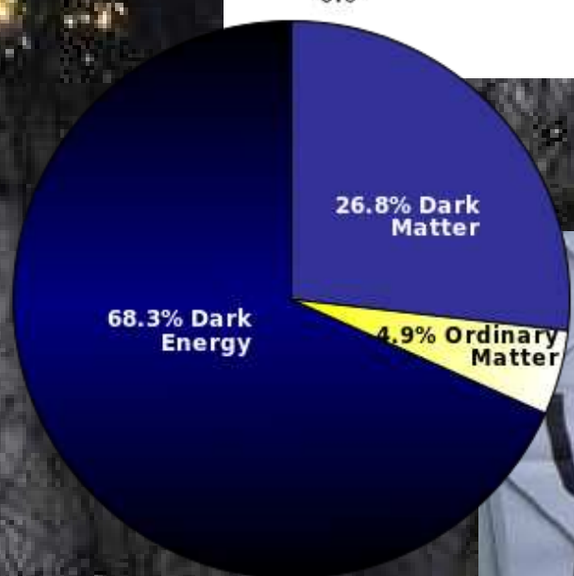


Gravitation as an engine of high energy events in the galaxy



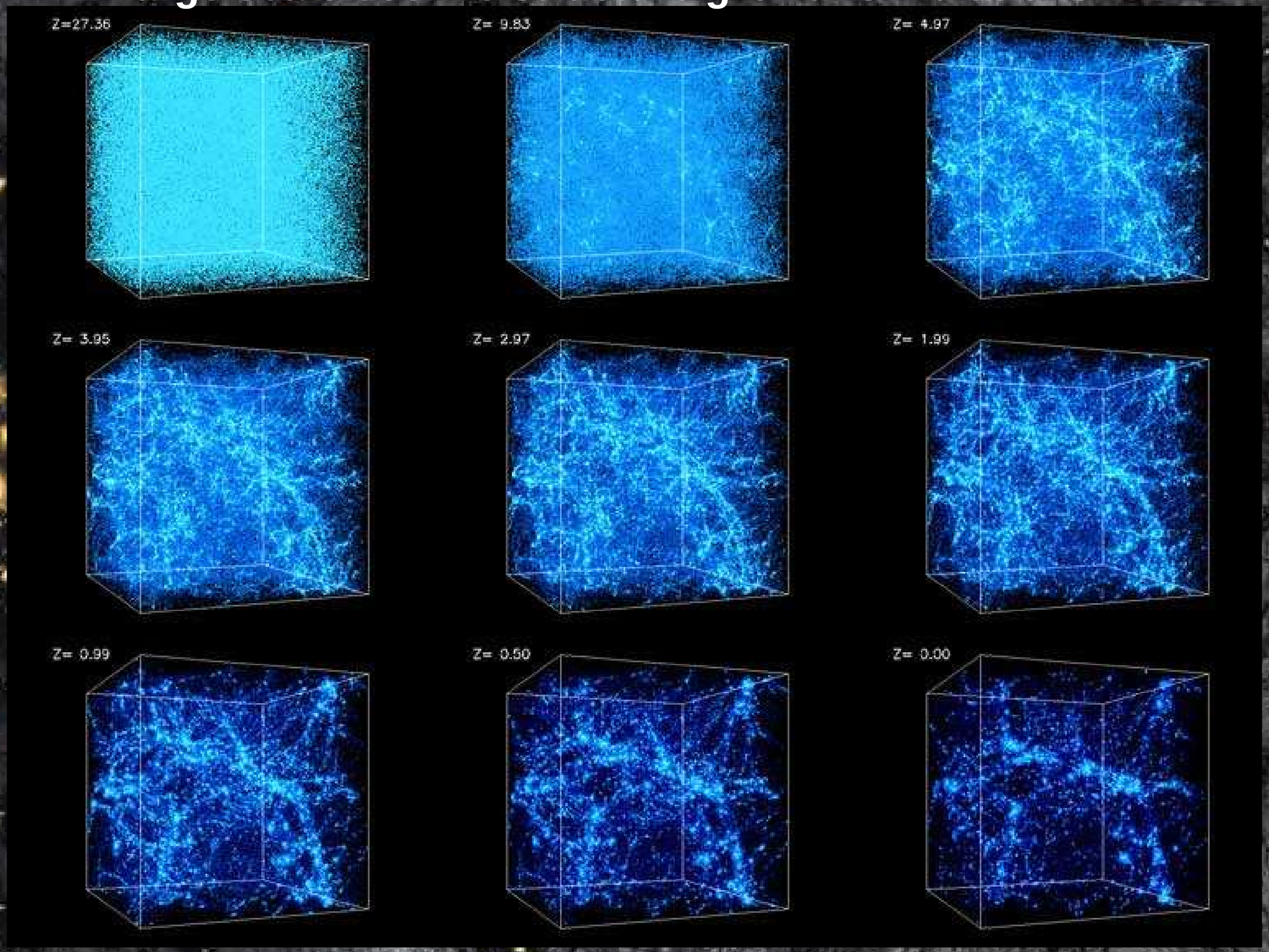
Dark matter relic density
$\Omega_{CDM}h^2 = 0.1186 \pm 0.0020$
Non-baryonic particle → cold, stable, electrically neutral, colorless





Privileged class of DM candidate: WIMPs (Weakly Interactive Massive Particles) → WIMPs miracle

Large scale cosmic structure growth simulations

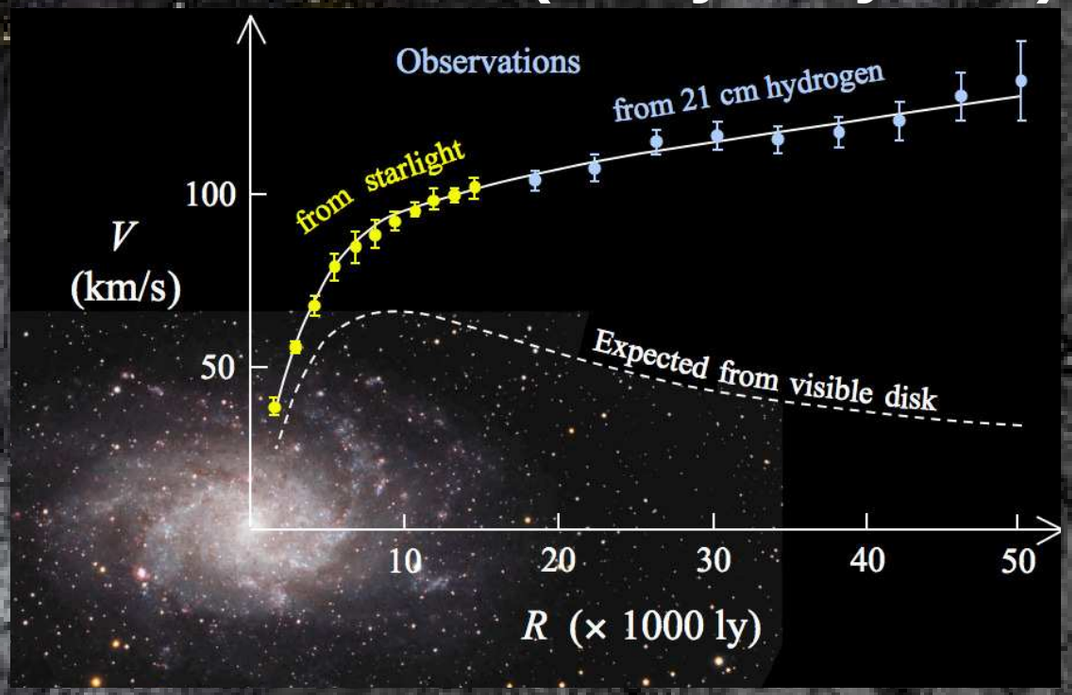


In the local Universe

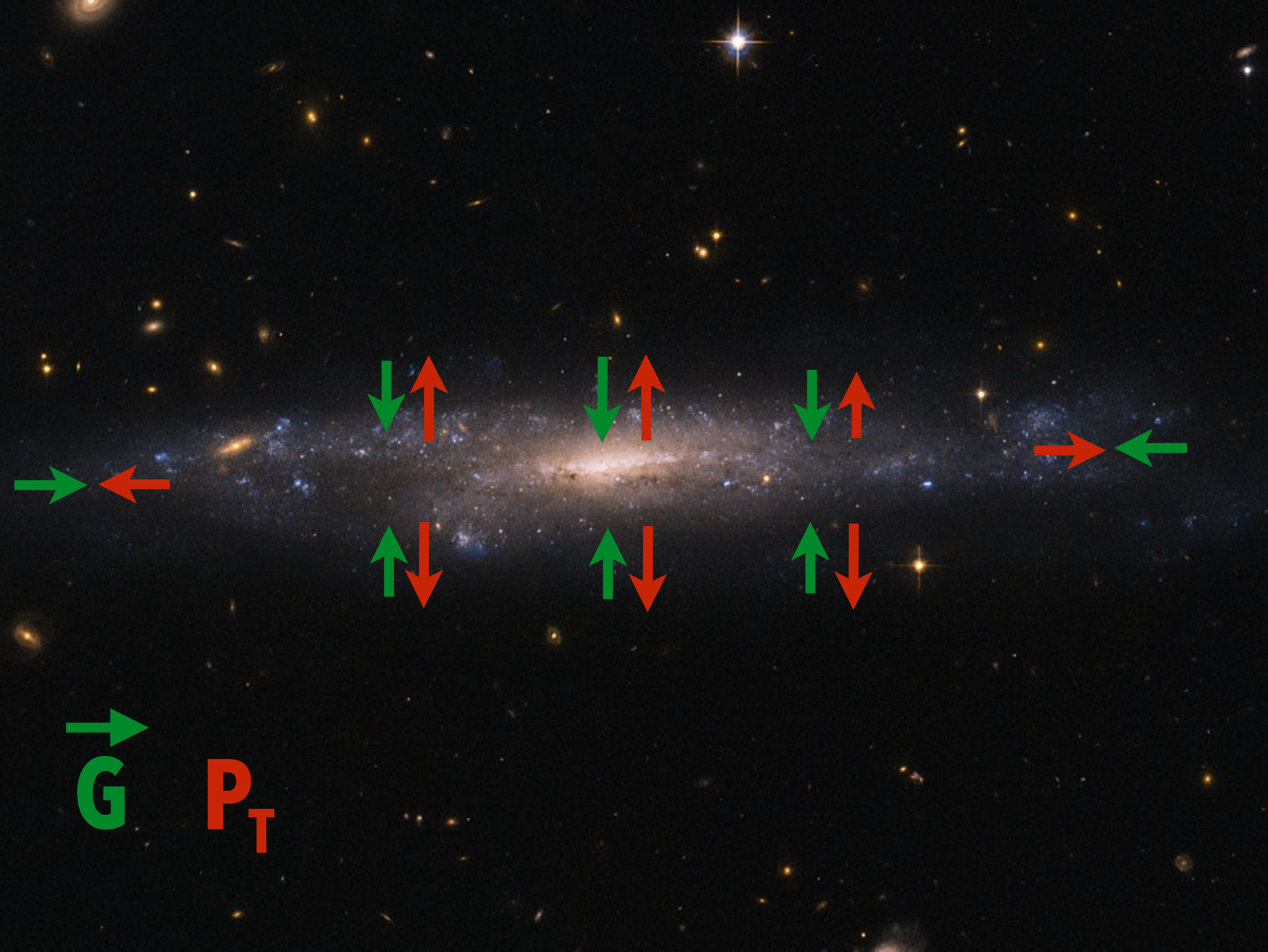
Gravitational lensing

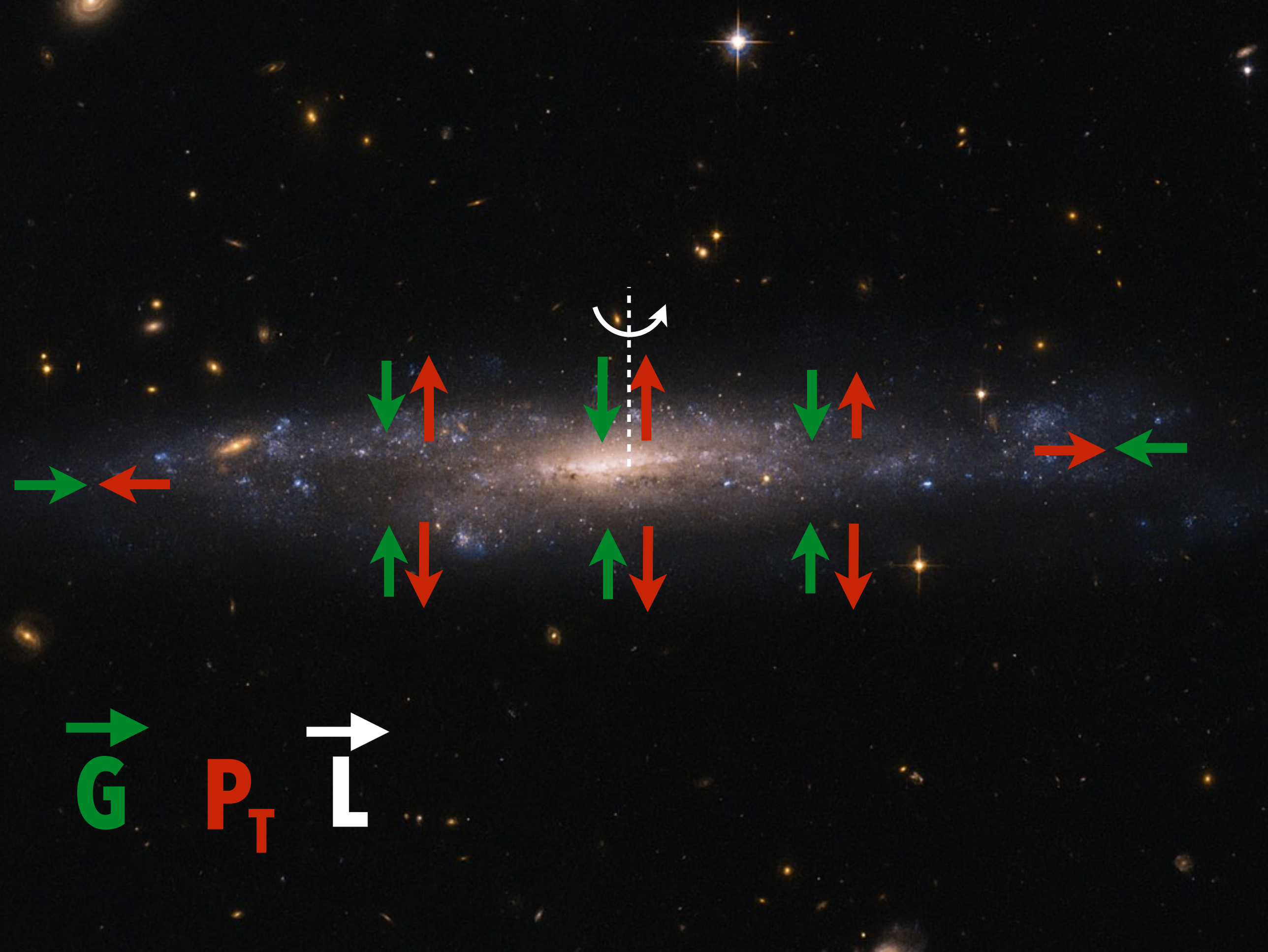
Bullet cluster

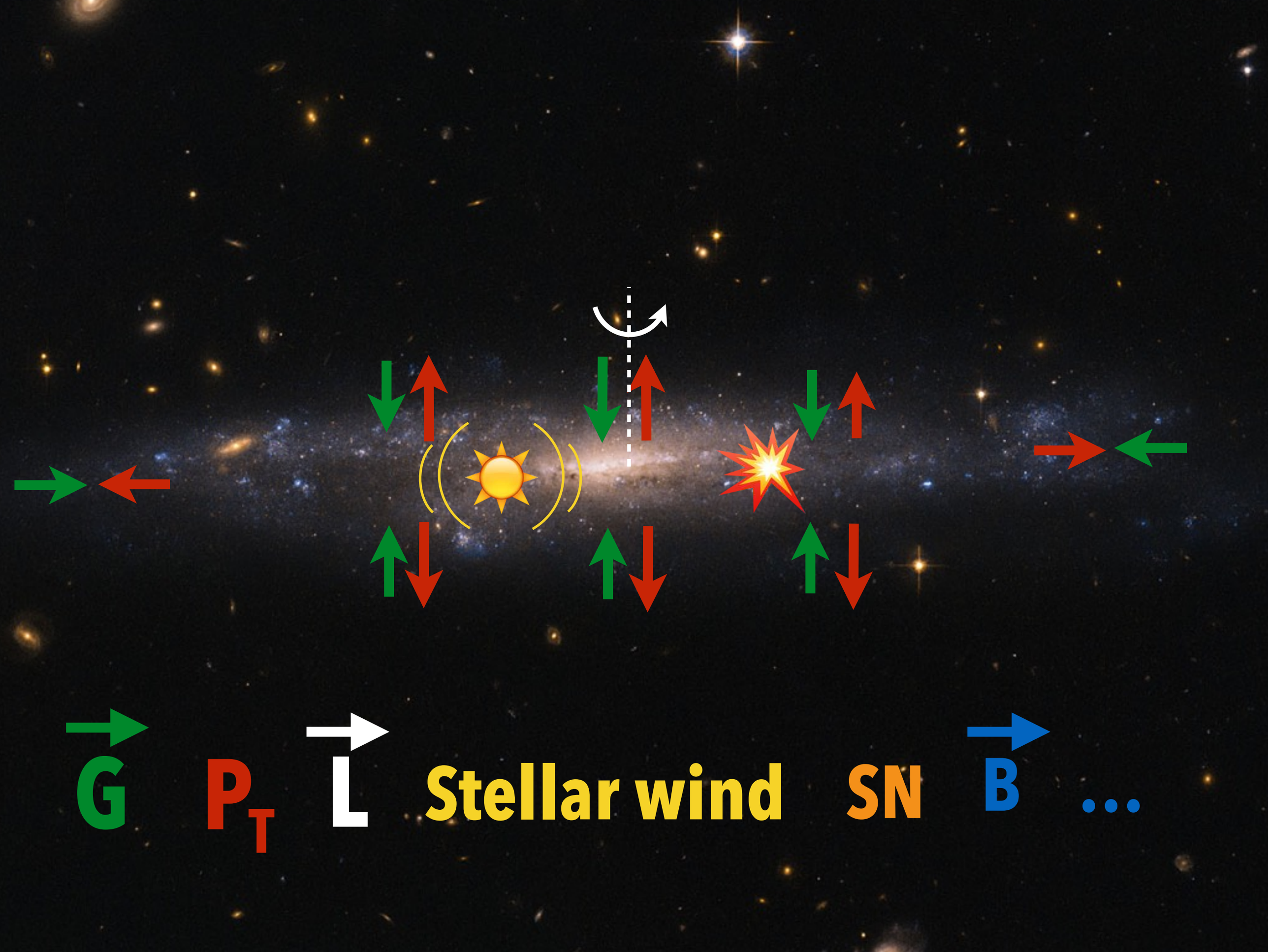
Rotation curve (Milky Way-like)

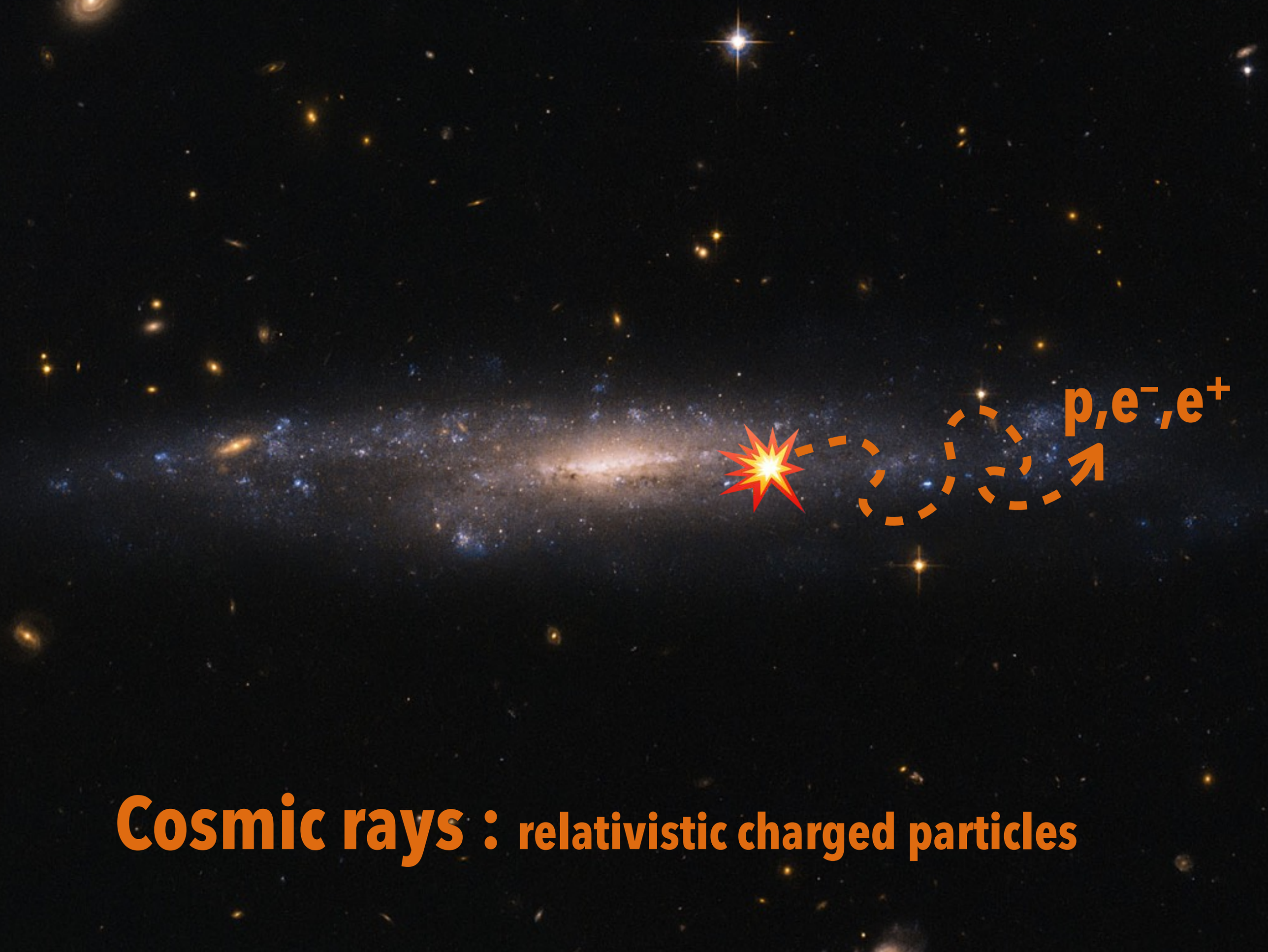



$\vec{G}$


$\vec{G}$
P_T


$\vec{G}$
P_T
$\vec{L}$


$\vec{G}$
P_T
$\vec{L}$
Stellar wind
SN
$\vec{B}$
...

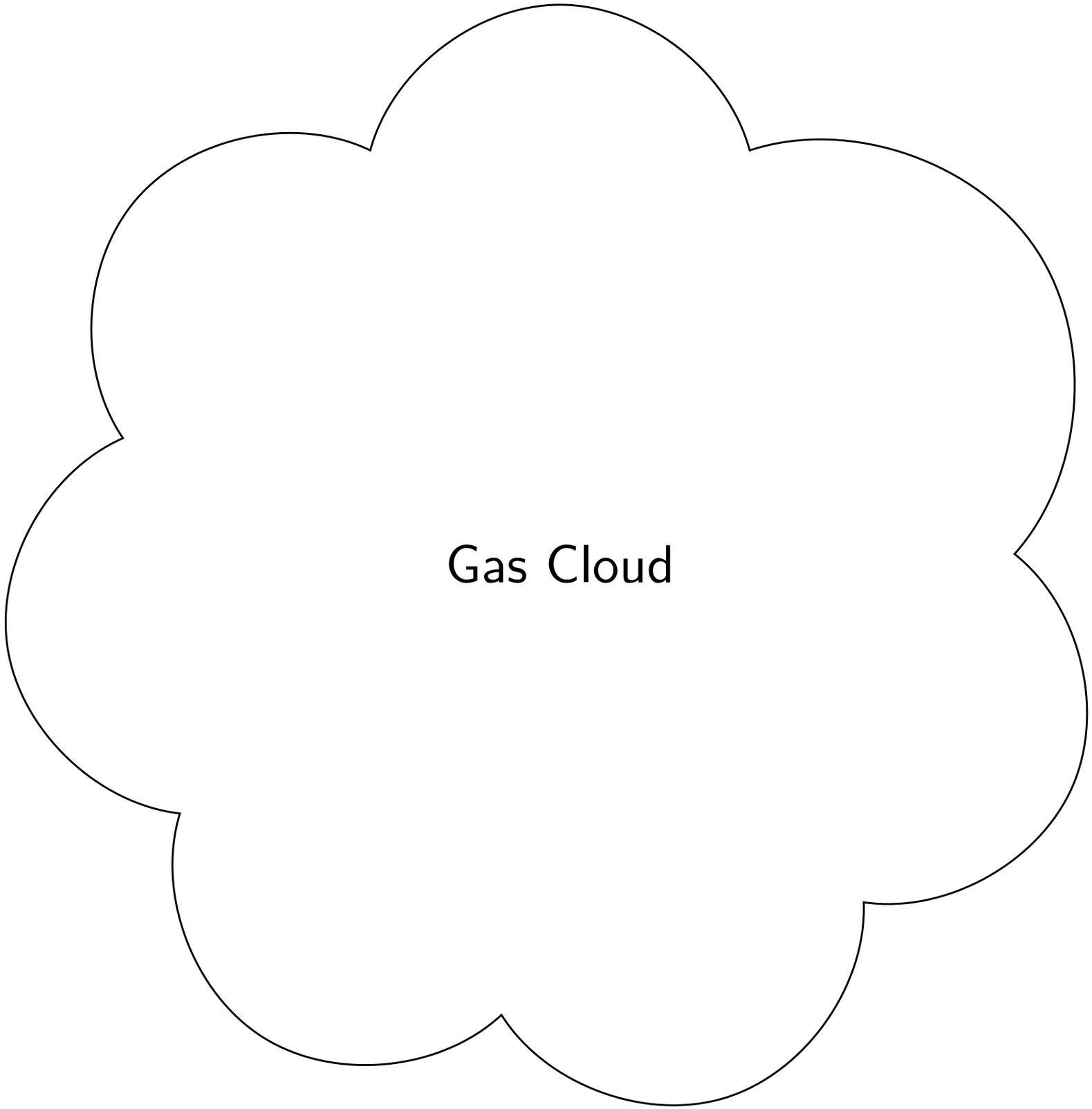


Cosmic rays : relativistic charged particles

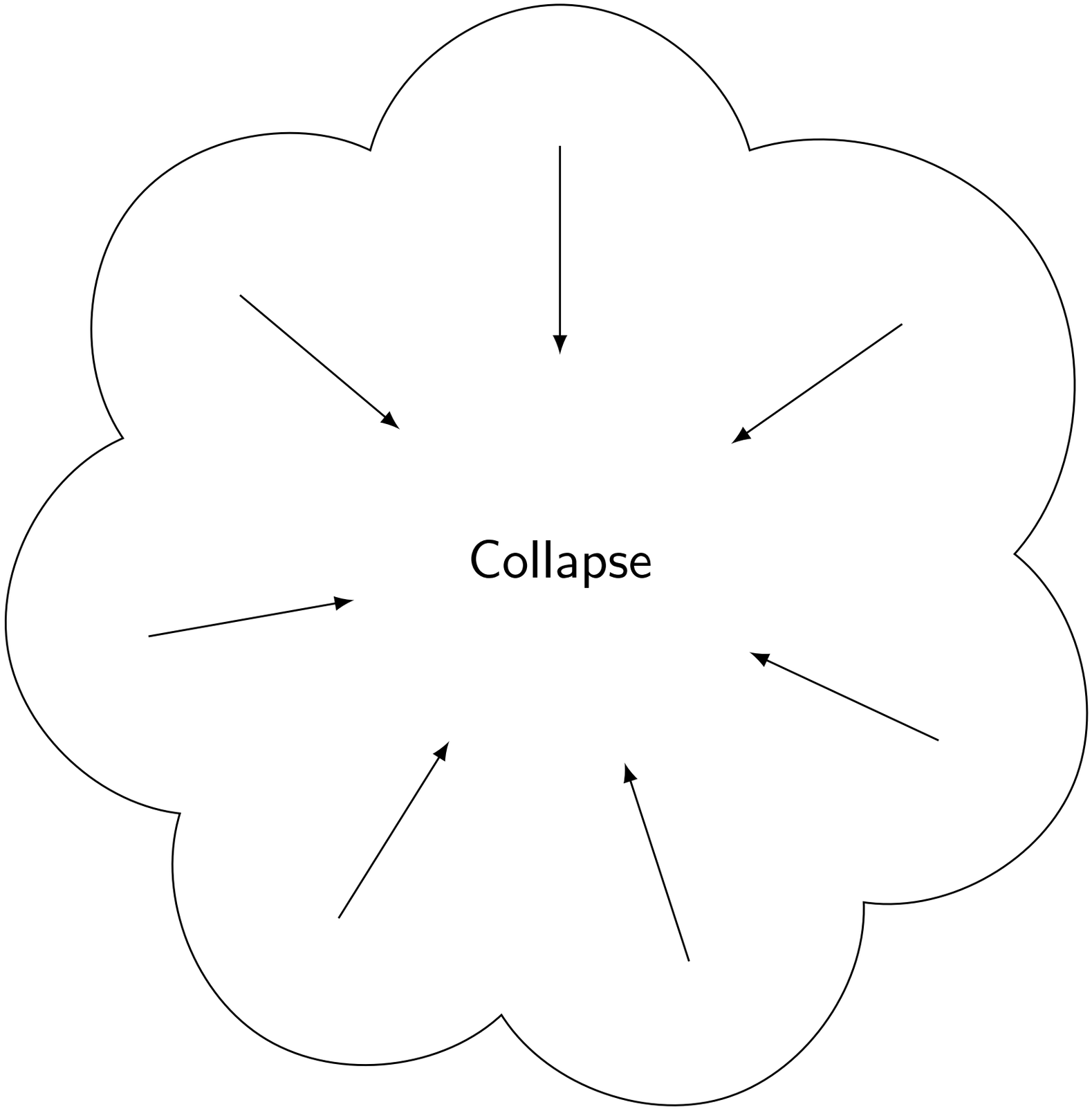
Galactic wind

Cosmic rays : relativistic charged particles

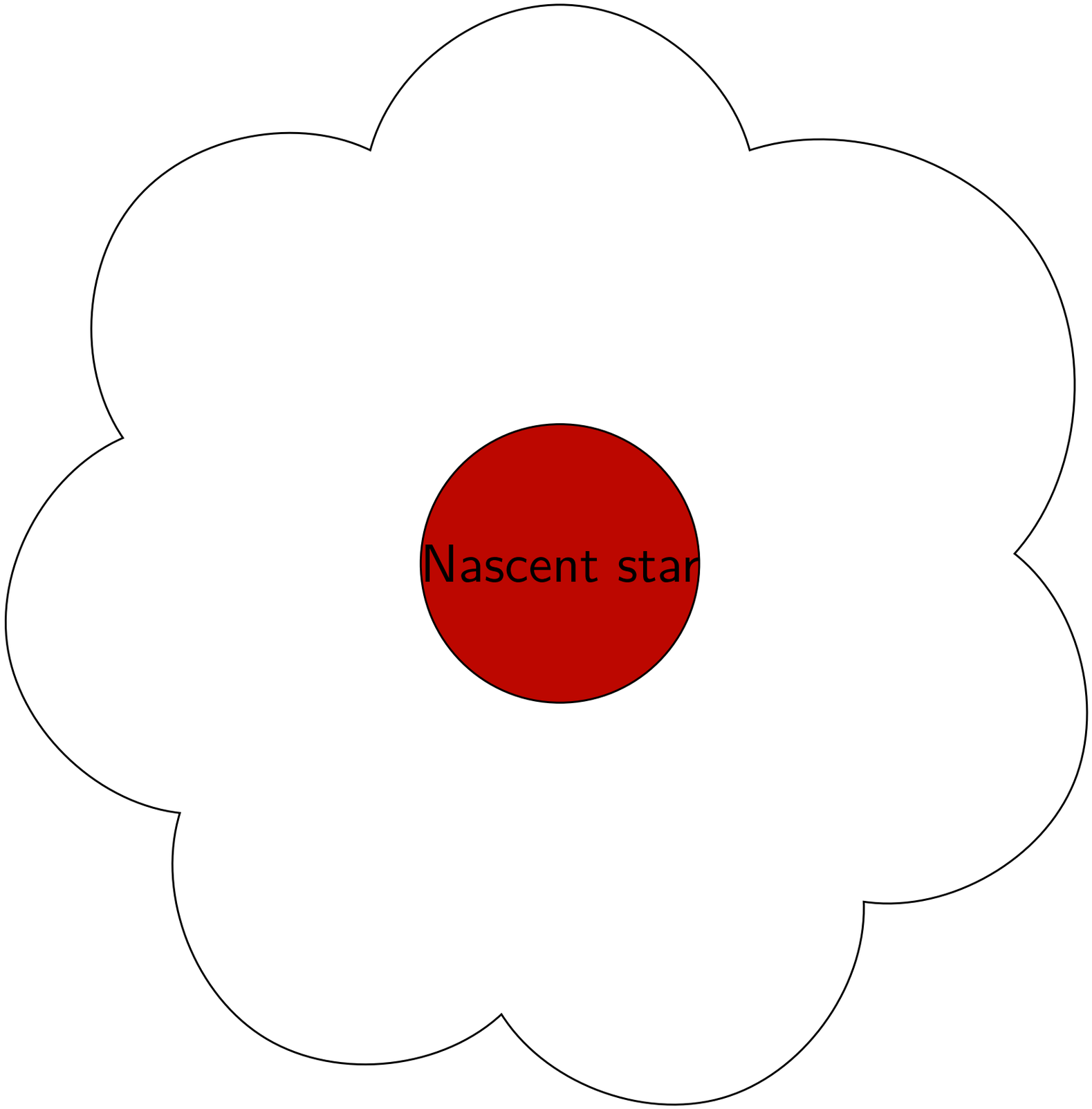
Star formation (very schematically)



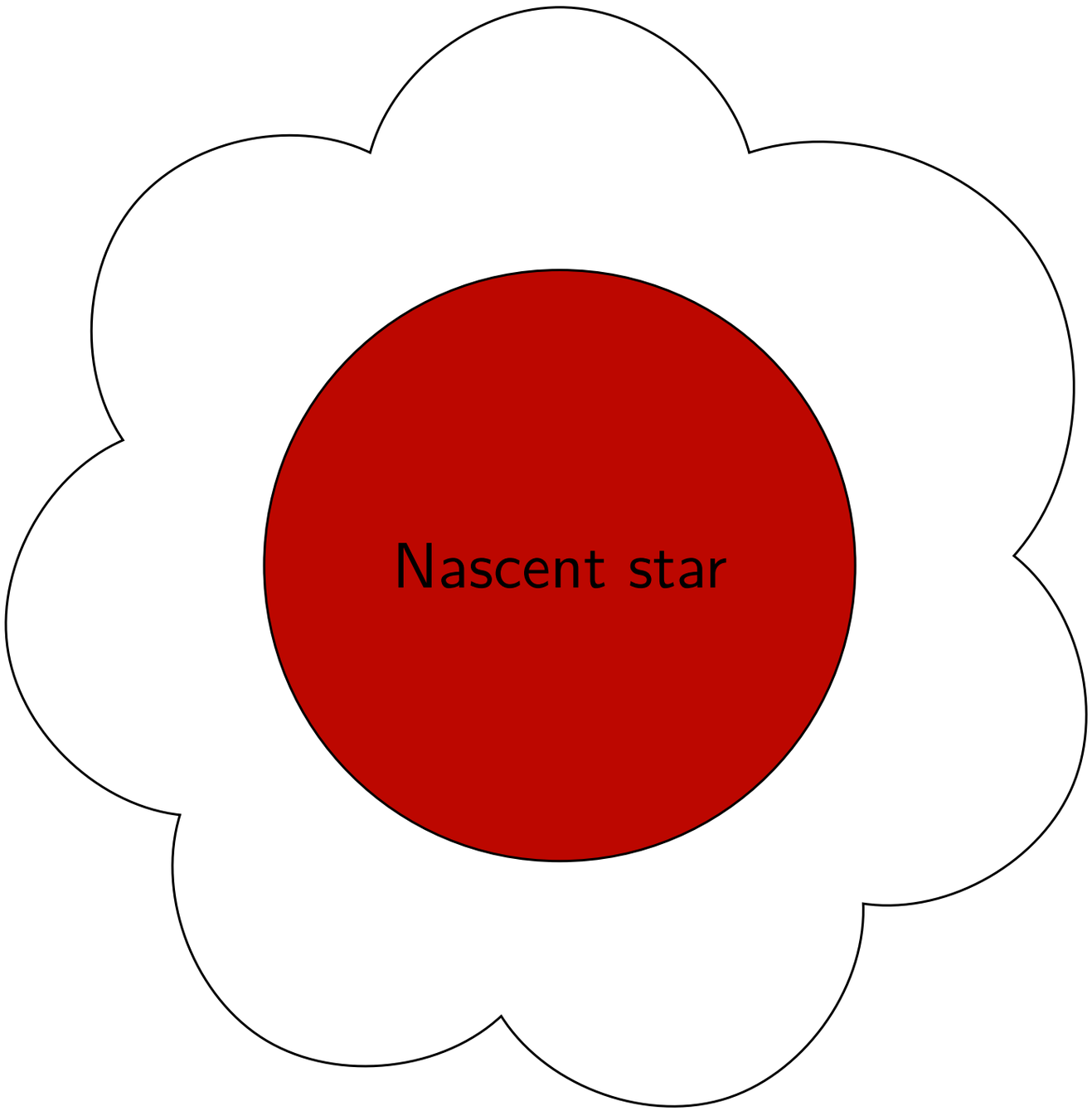
Star formation (very schematically)



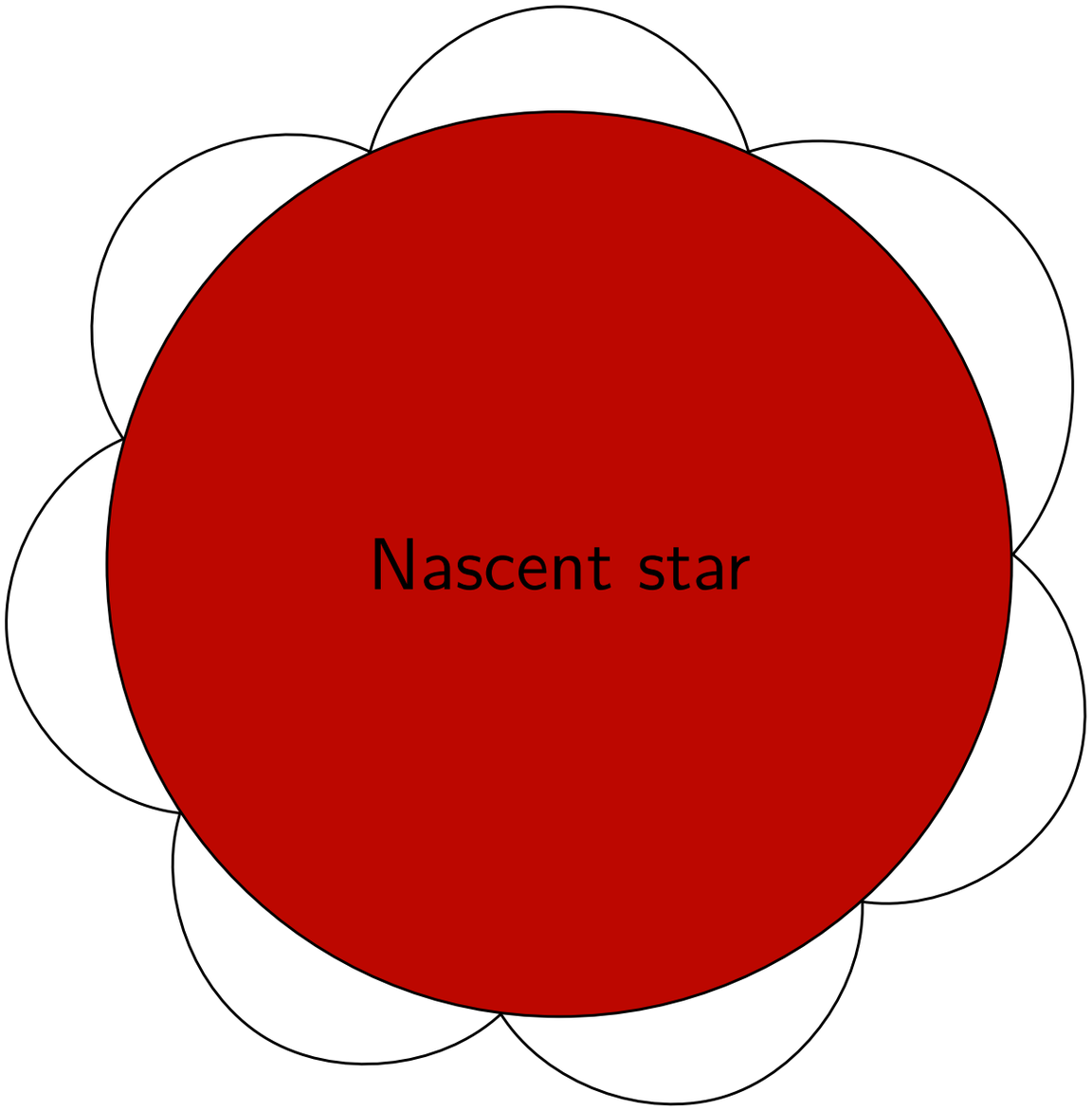
Star formation (very schematically)



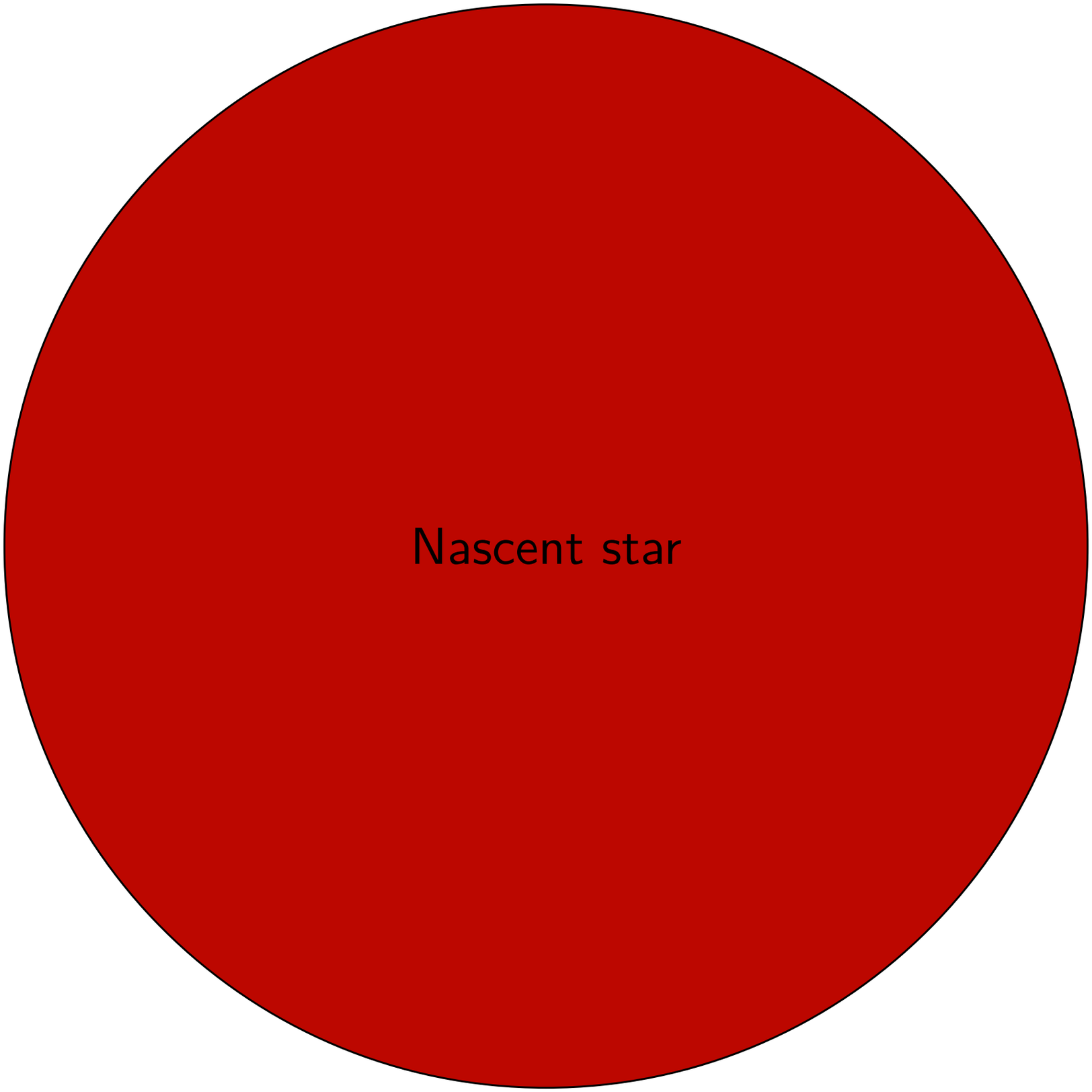
Star formation (very schematically)



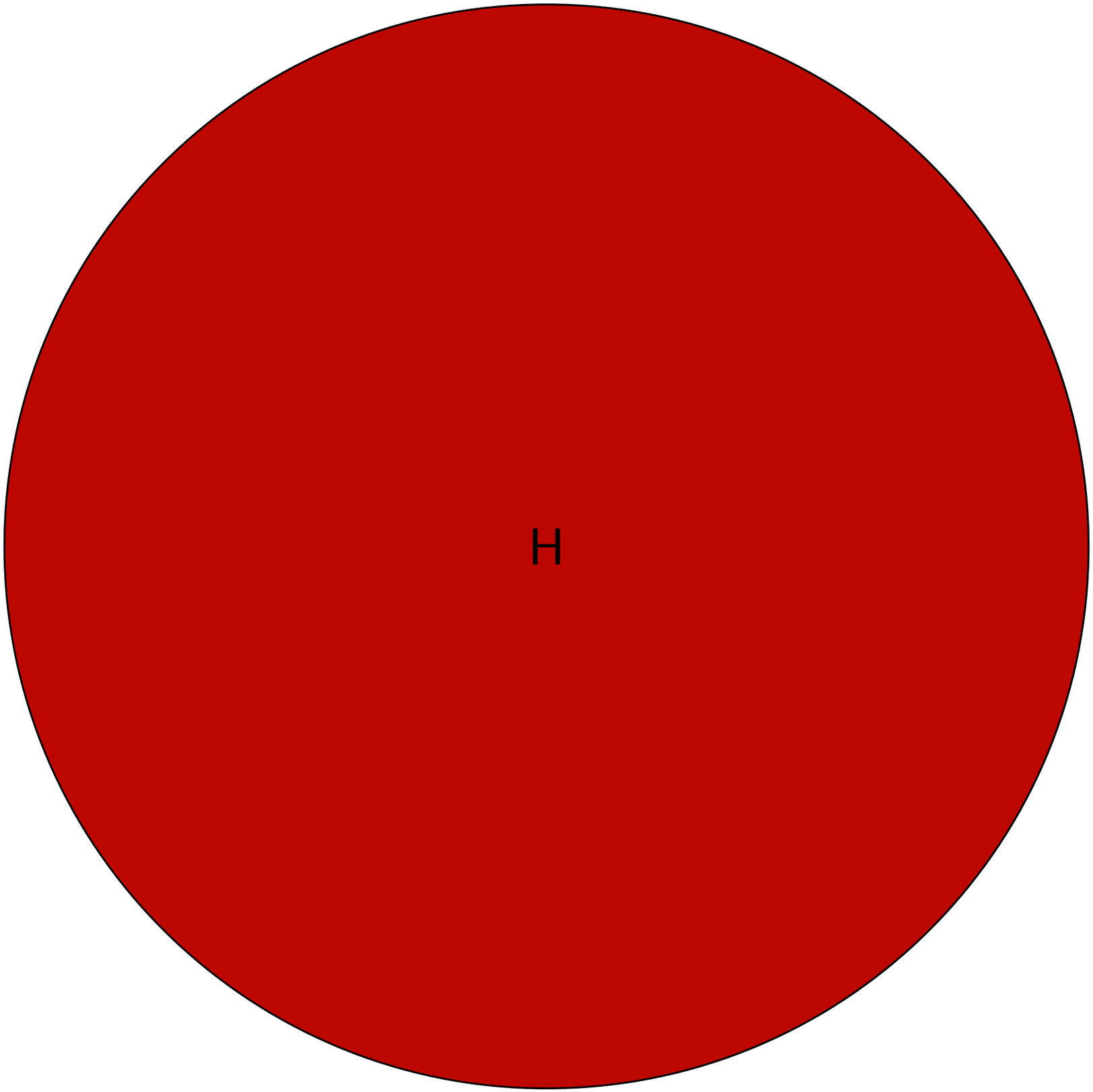
Star formation (very schematically)



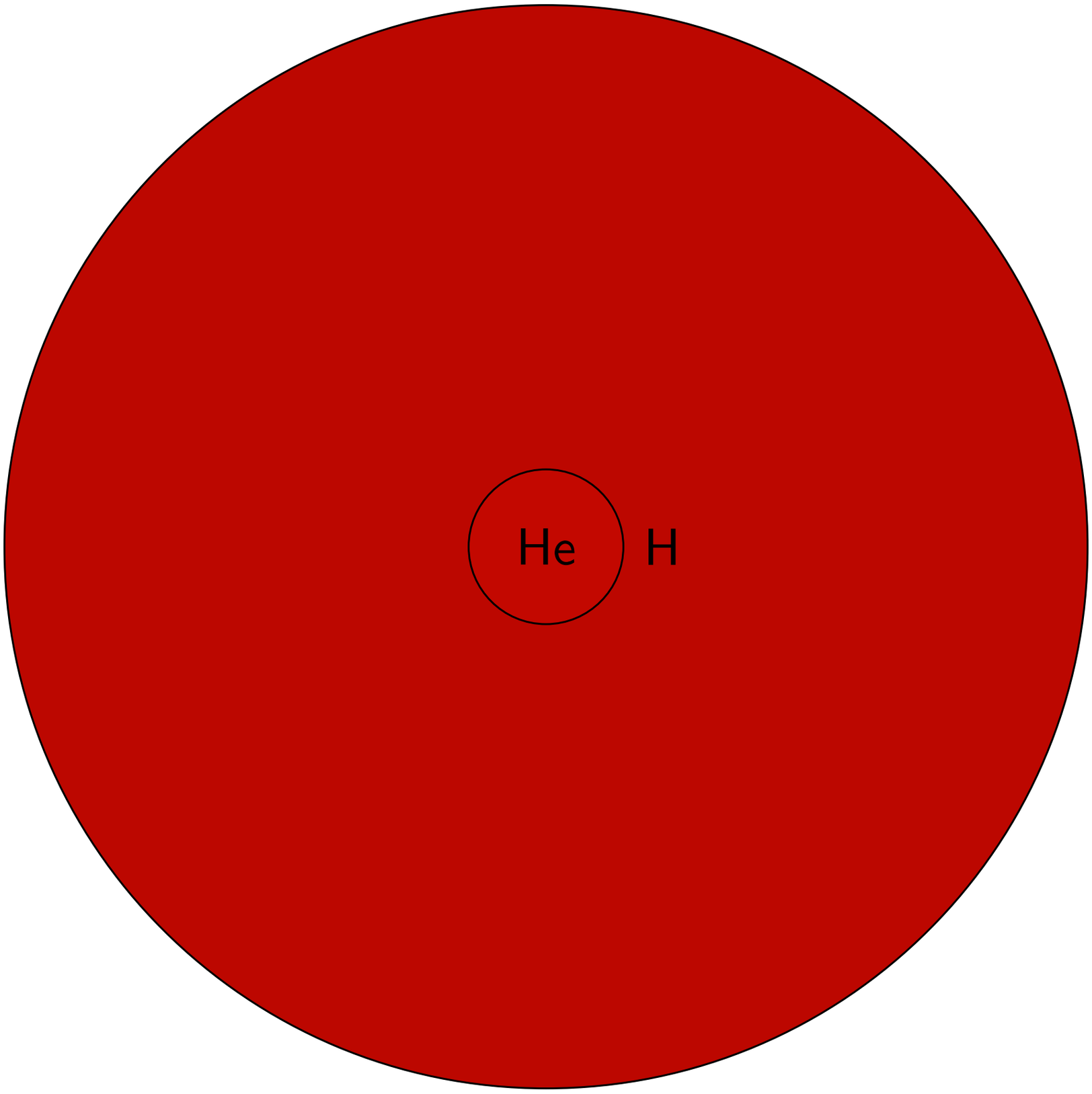
Star formation (very schematically)



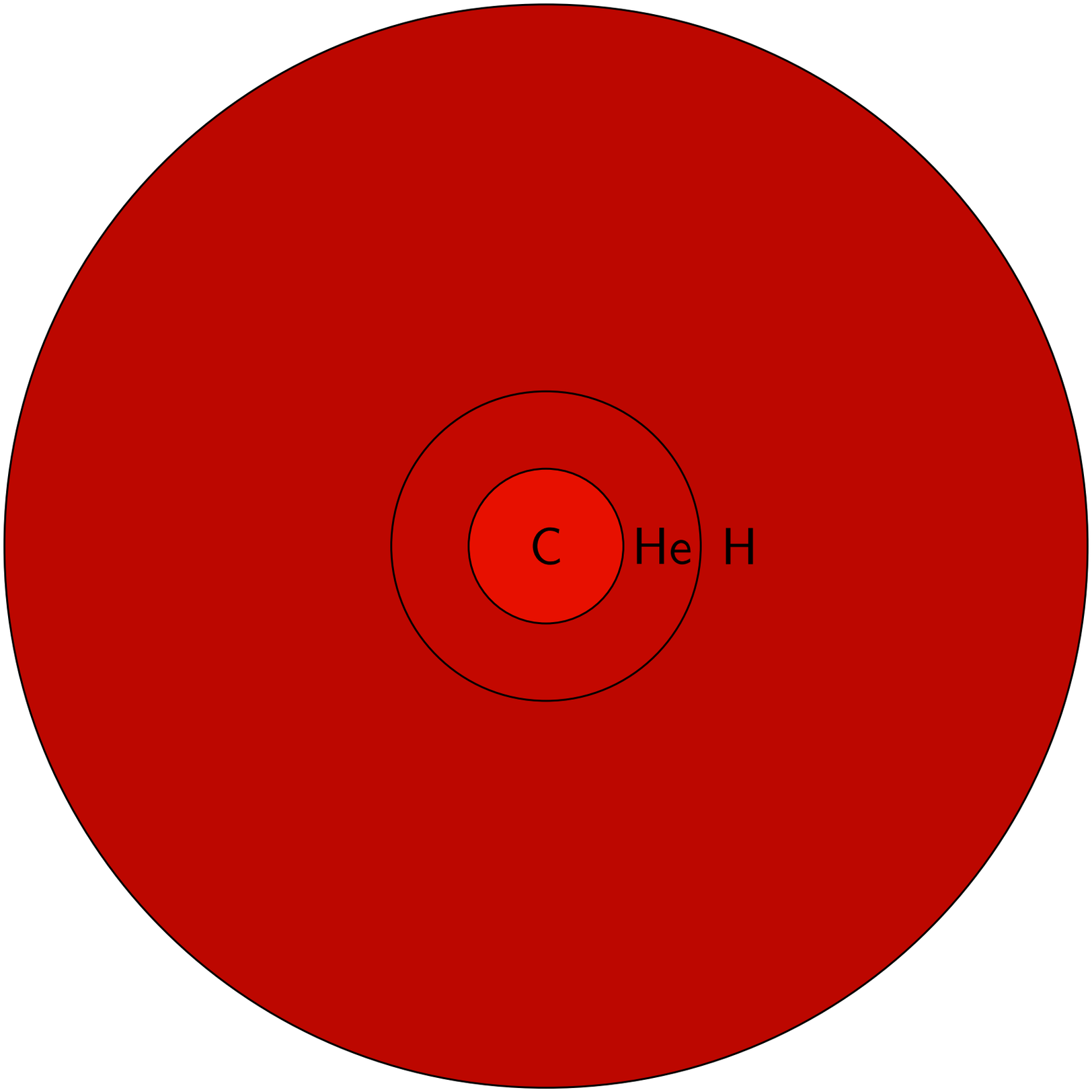
Life of a massive star



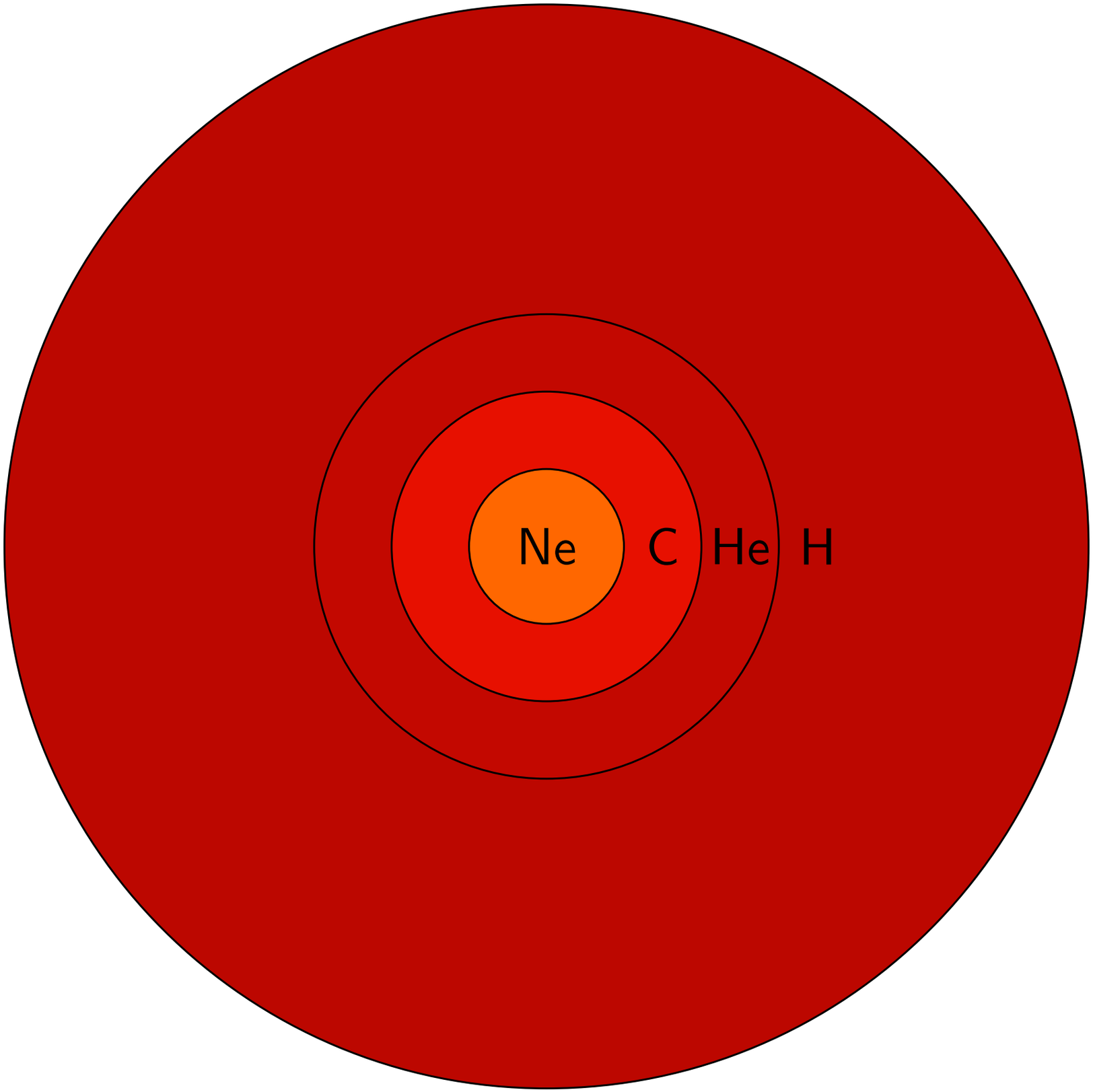
Life of a massive star



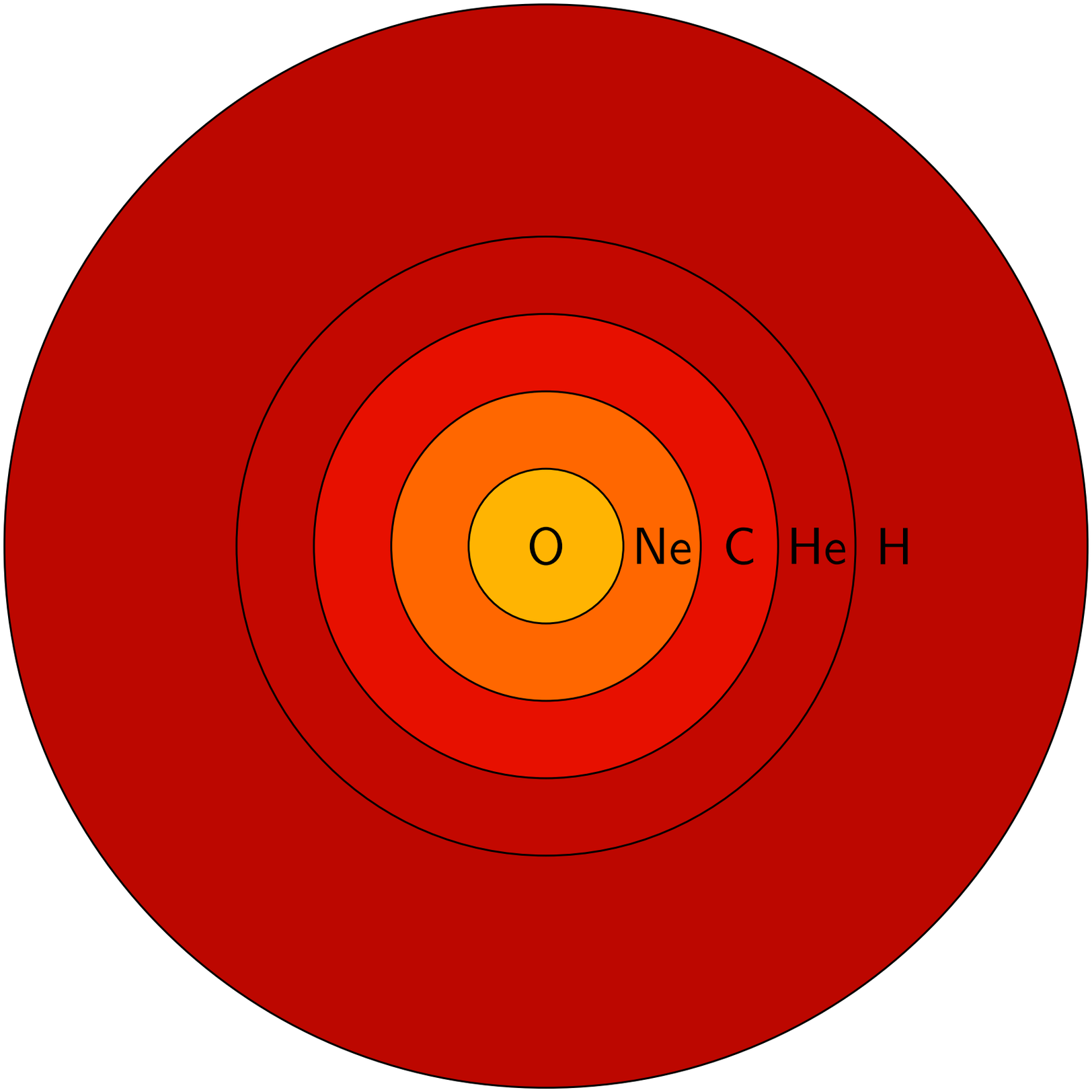
Life of a massive star



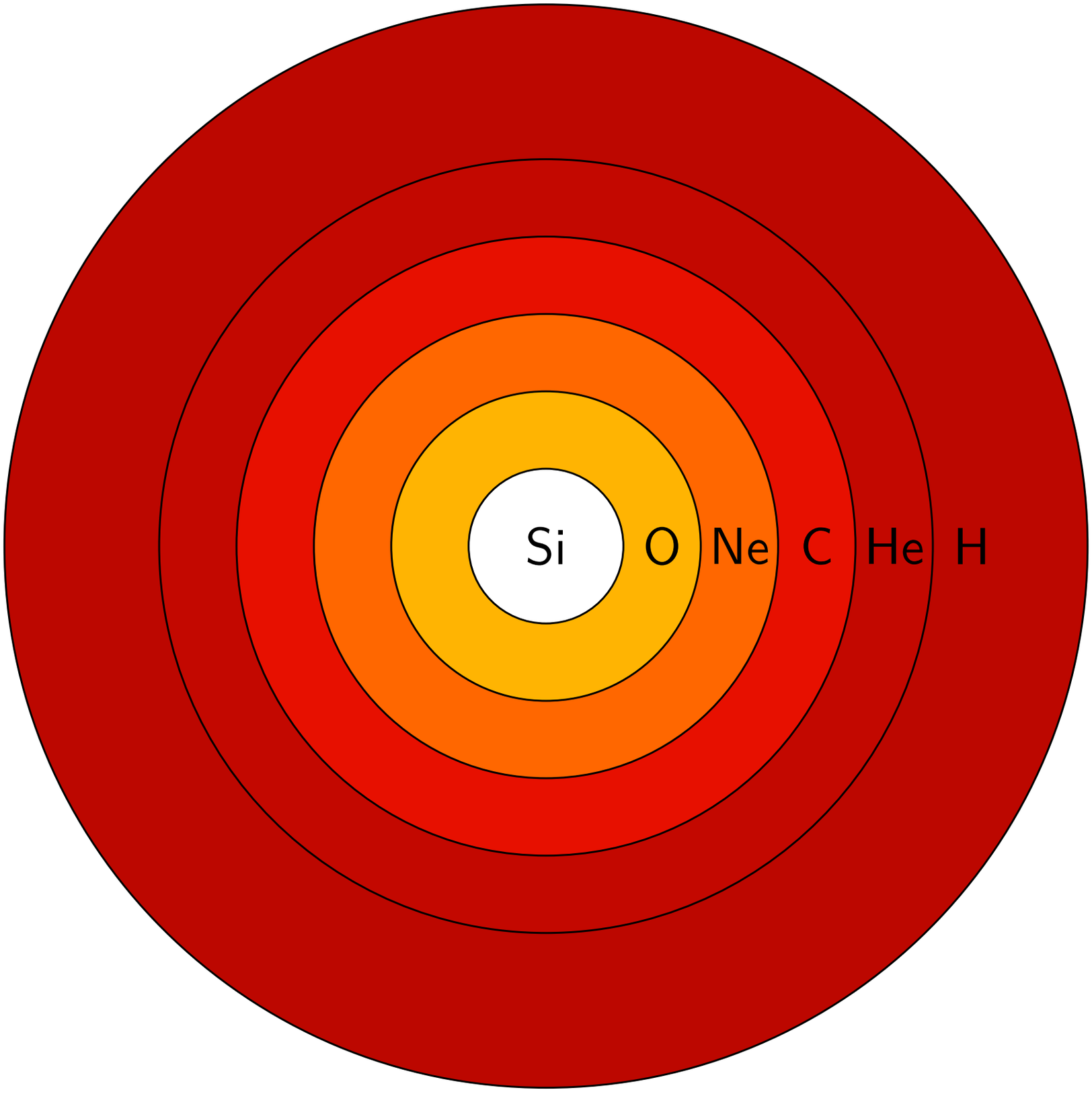
Life of a massive star



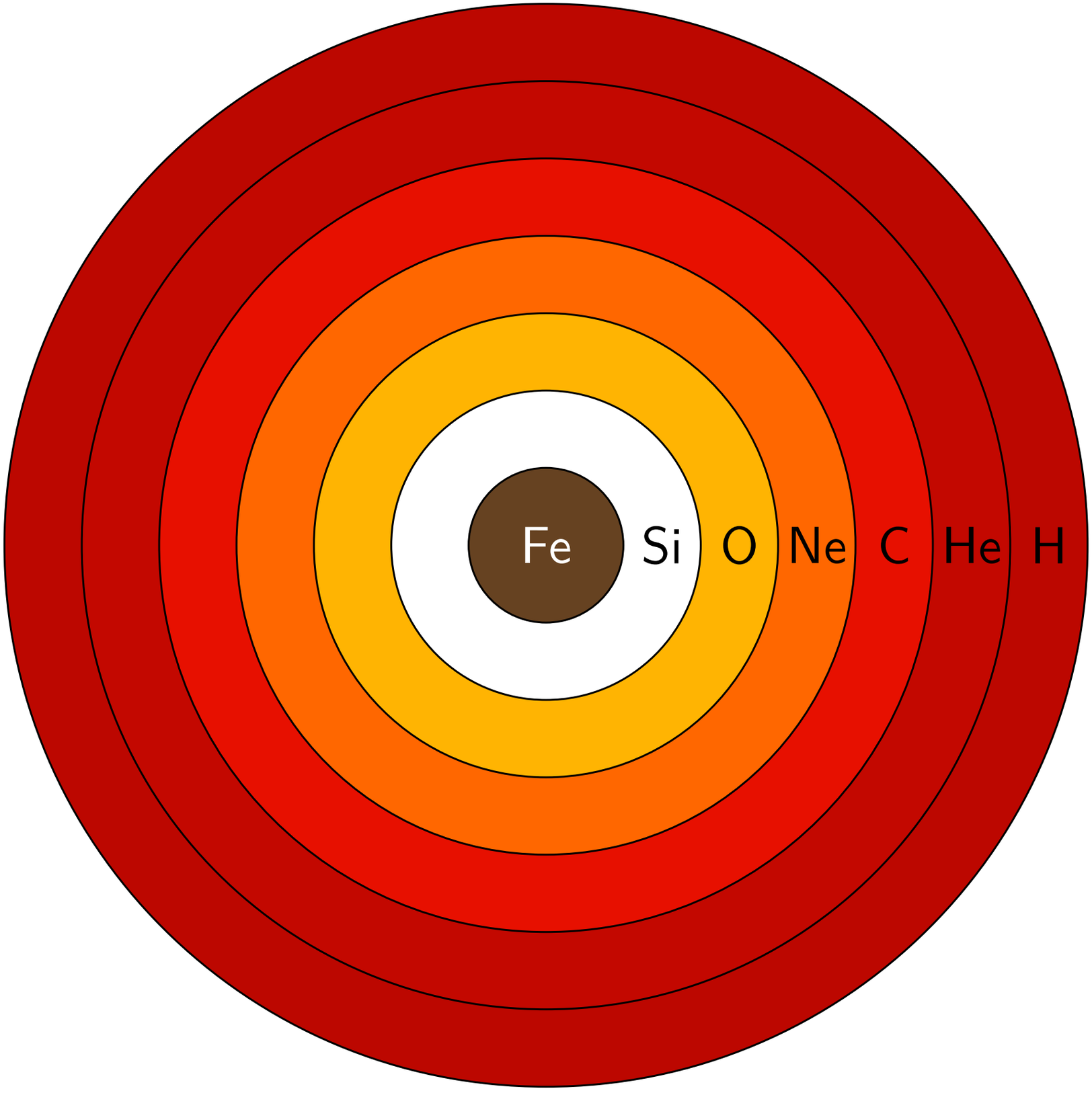
Life of a massive star



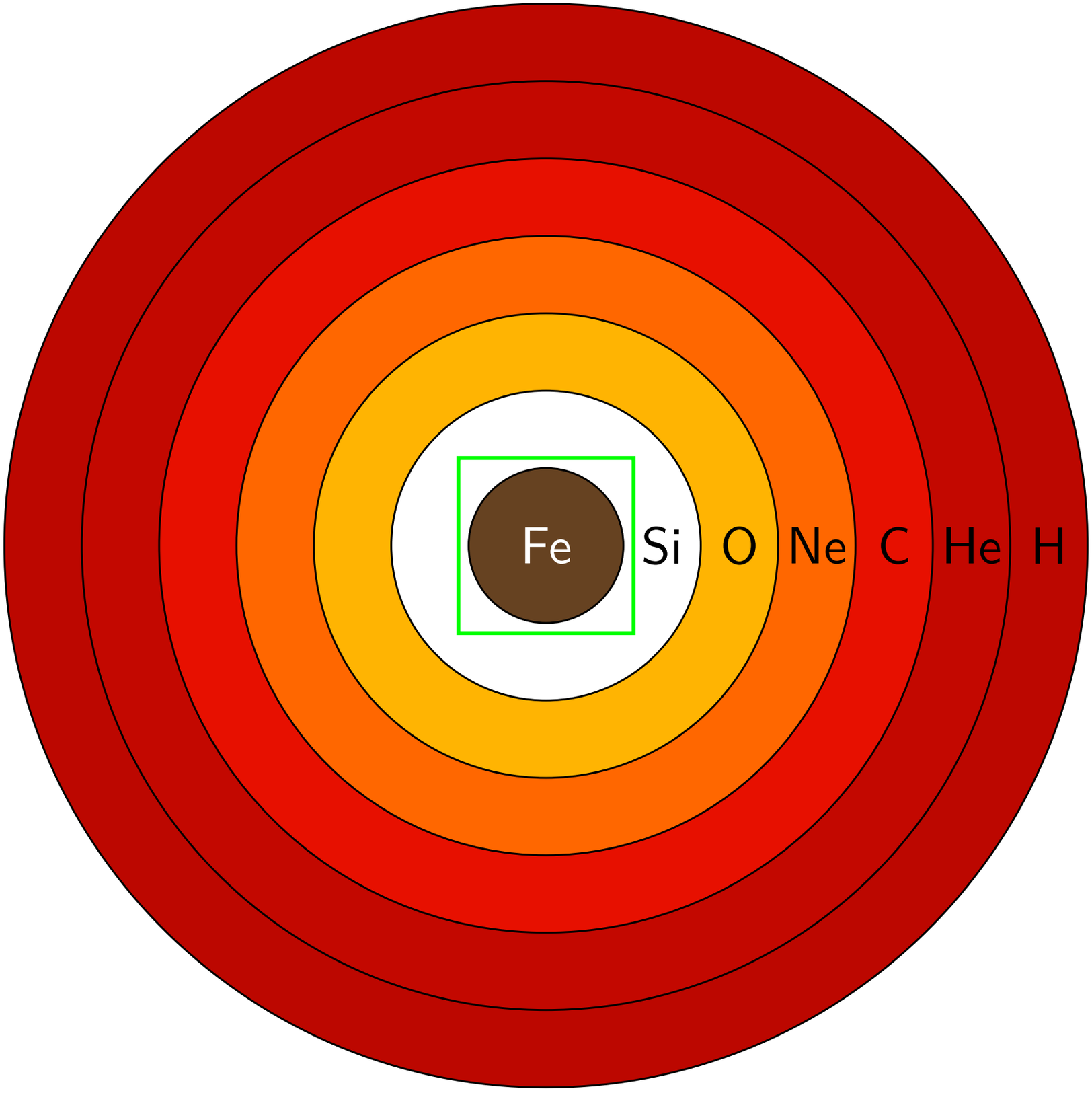
Life of a massive star



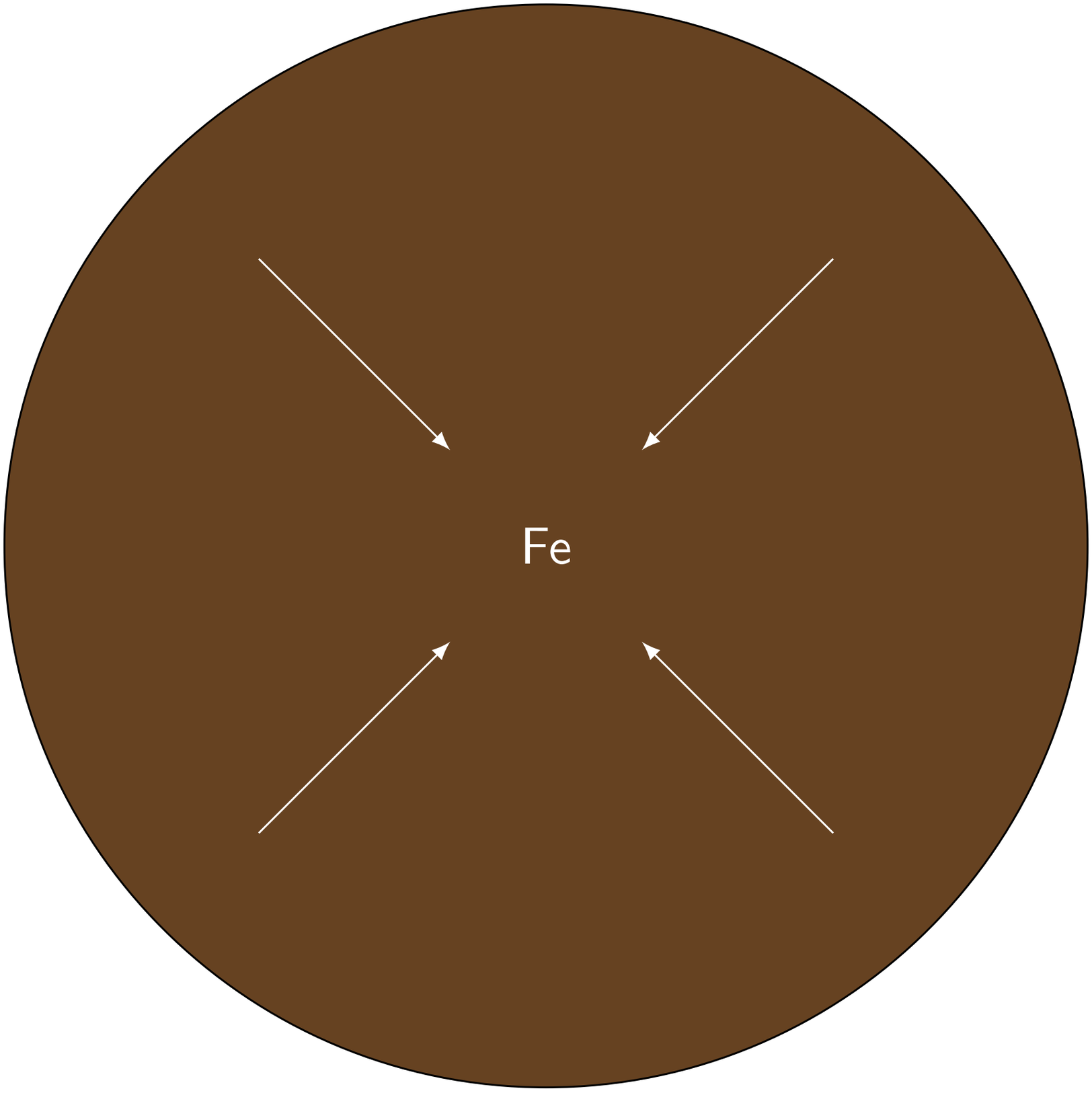
Life of a massive star



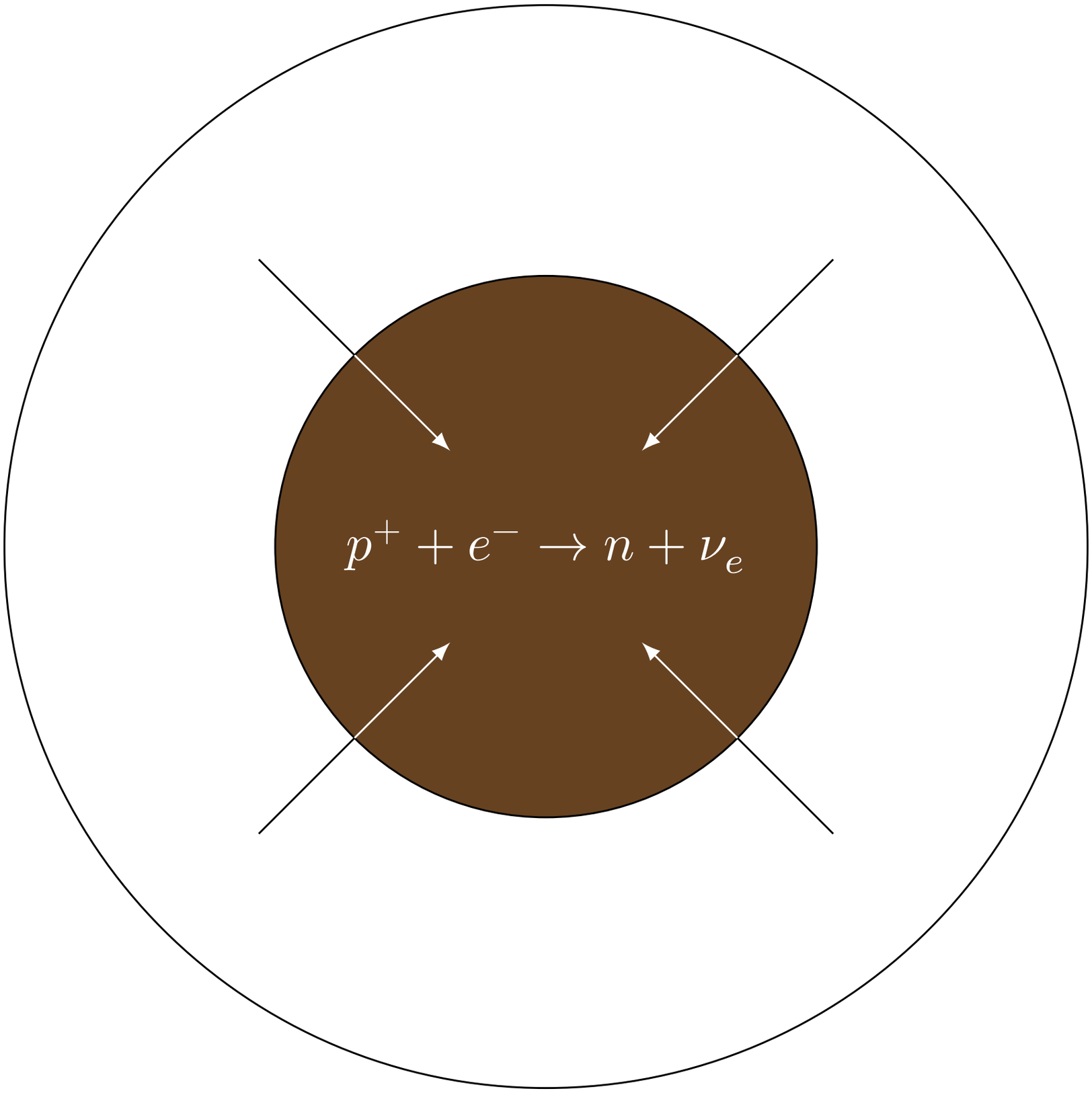
Life of a massive star



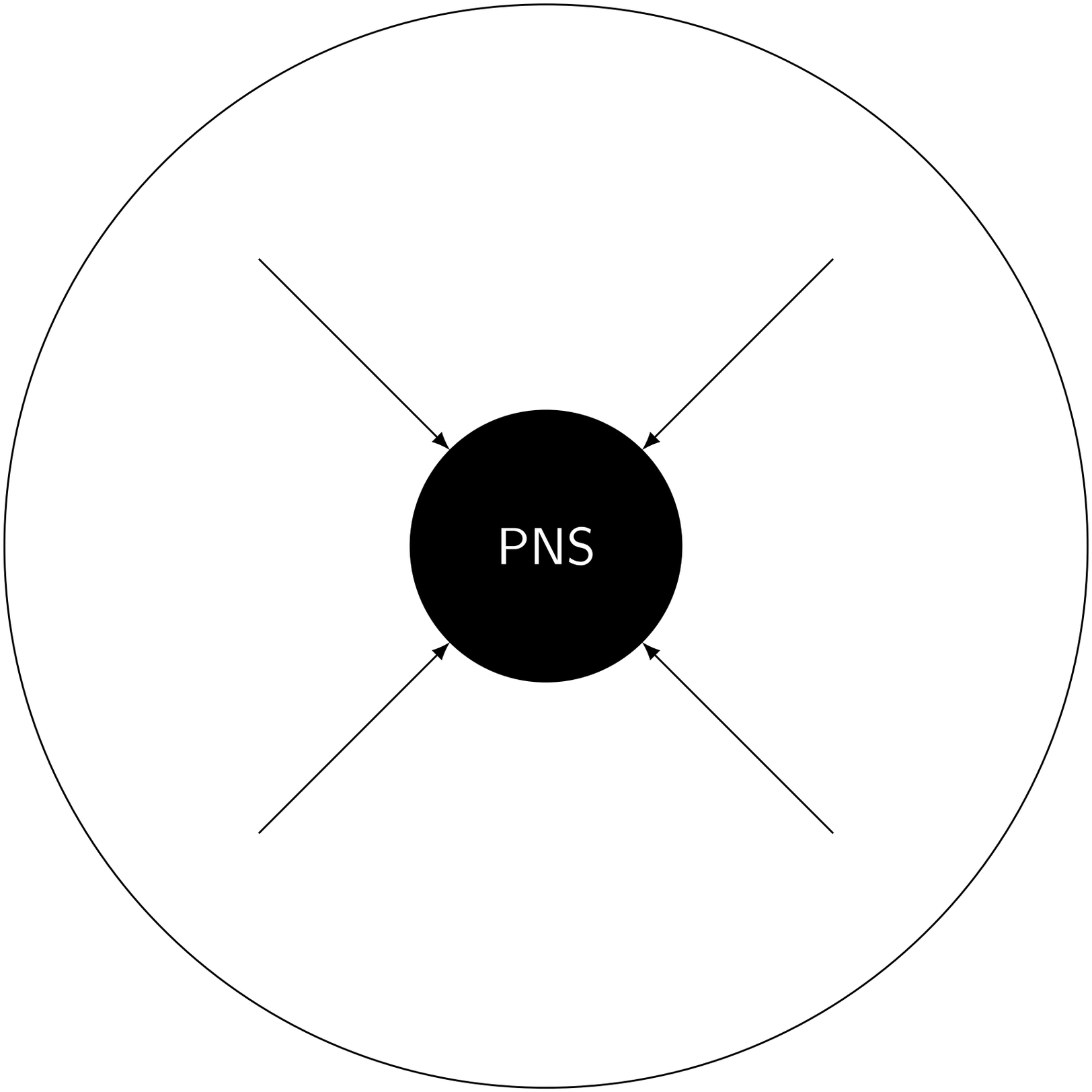
Death of a massive star



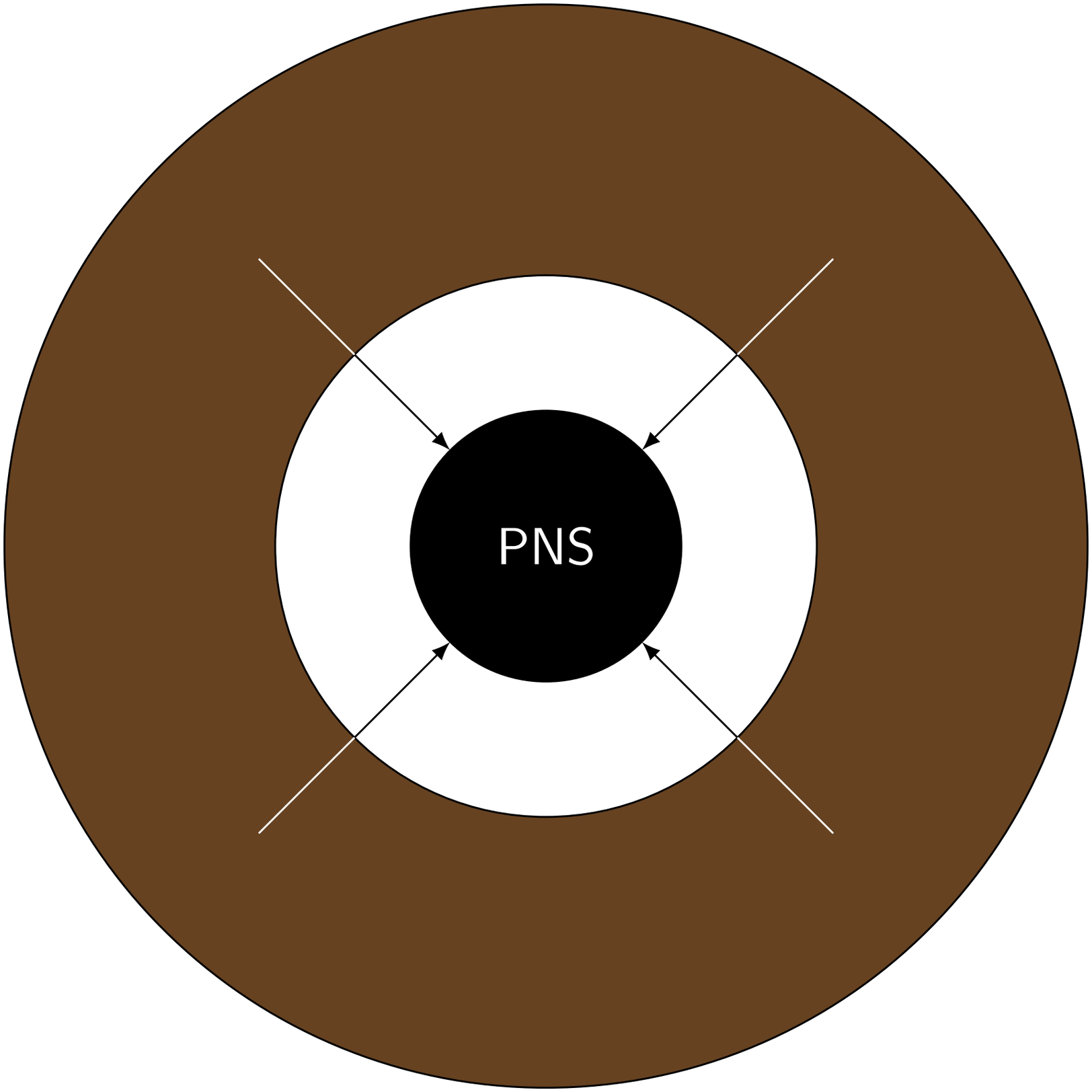
Death of a massive star



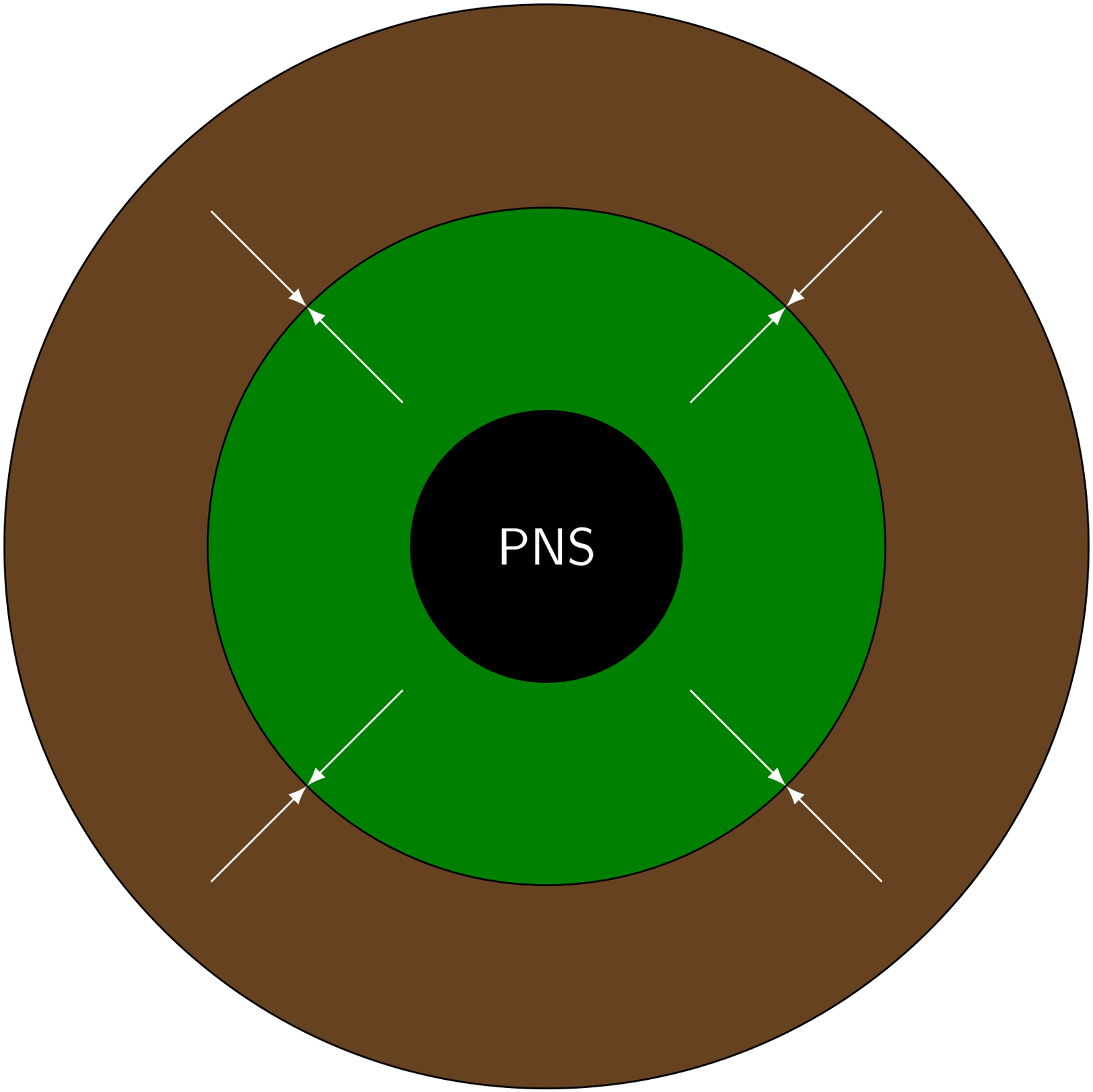
Death of a massive star



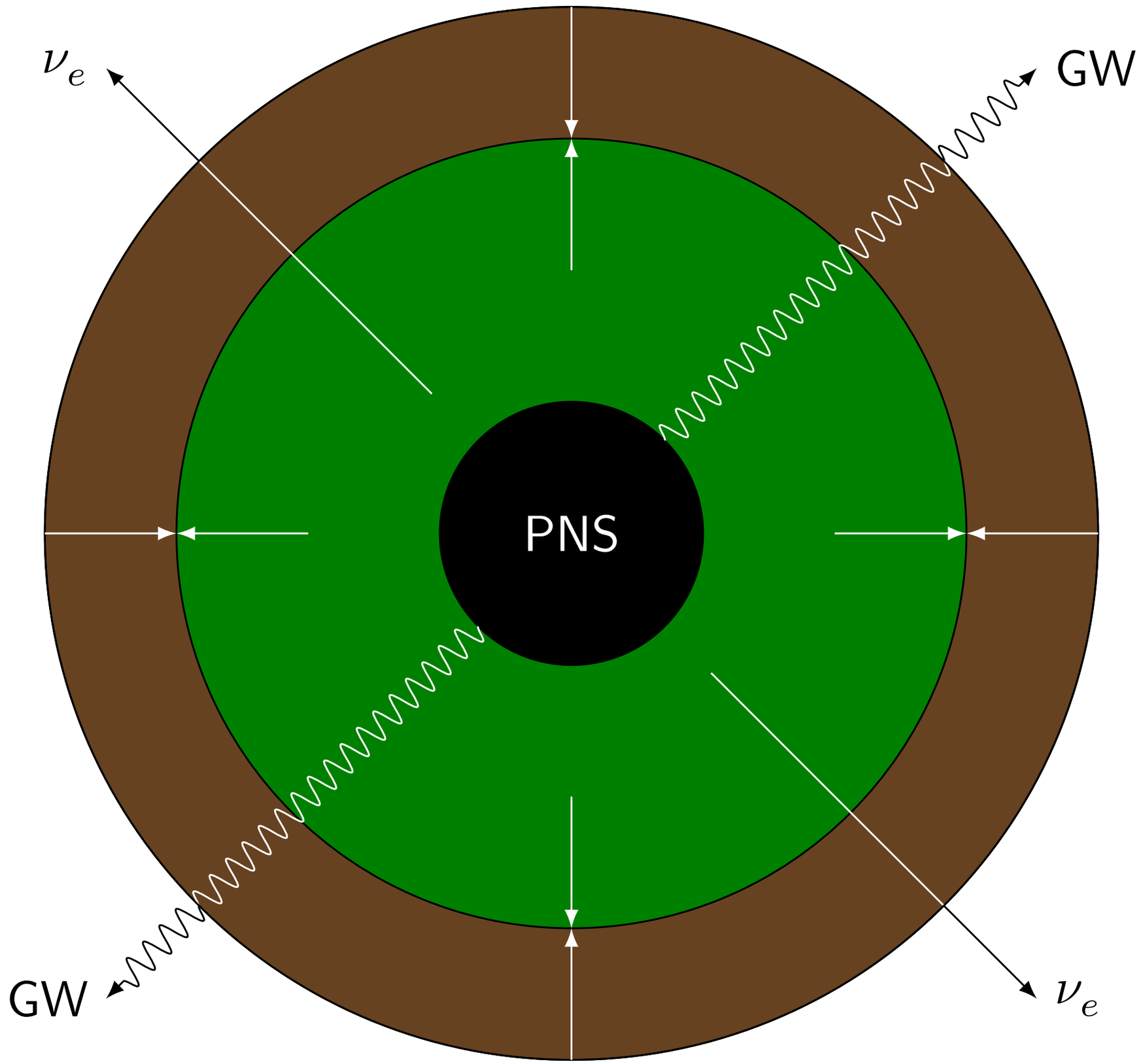
Death of a massive star



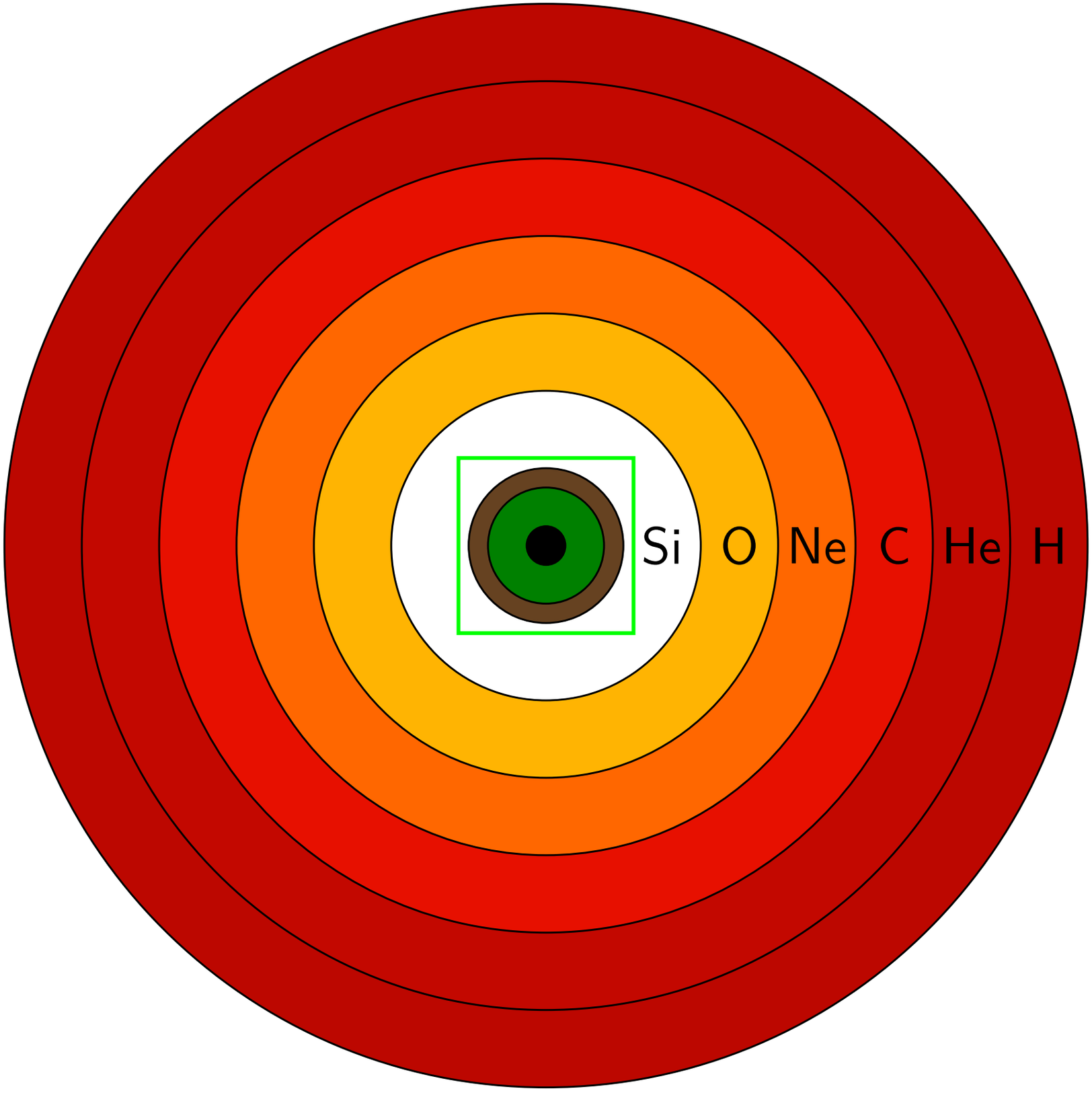
Death of a massive star



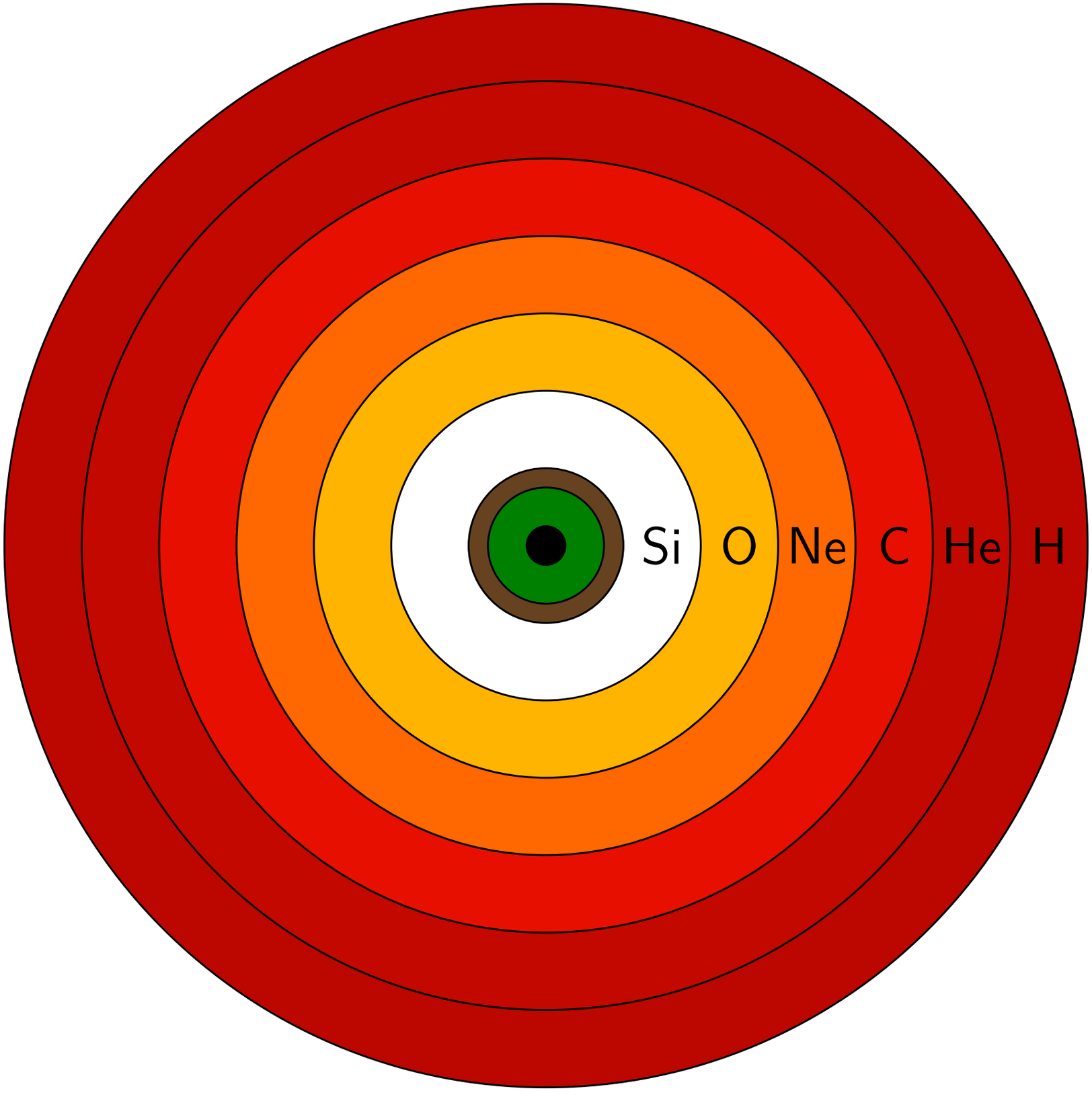
Emissions (part I)



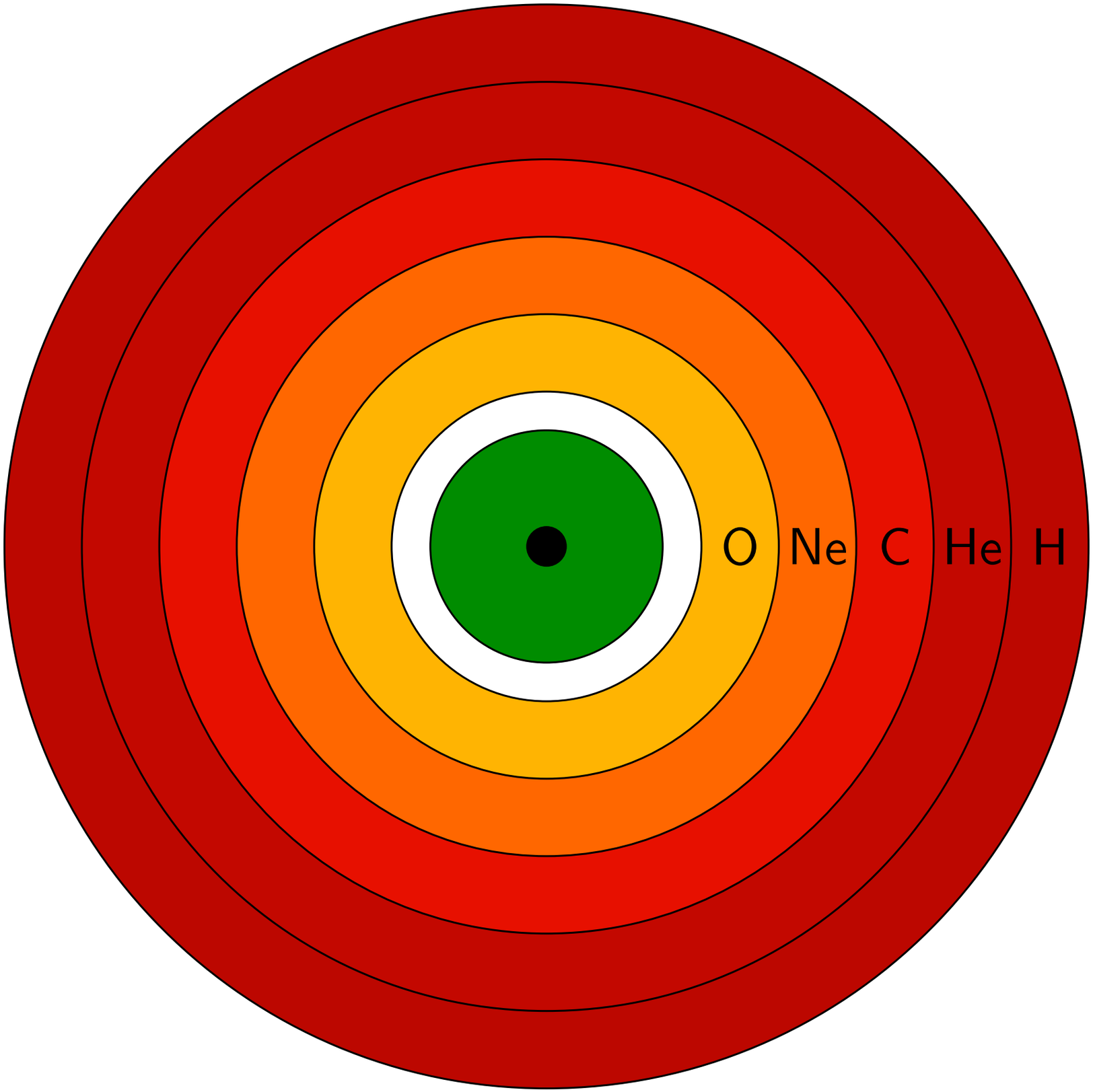
Emissions (part II)



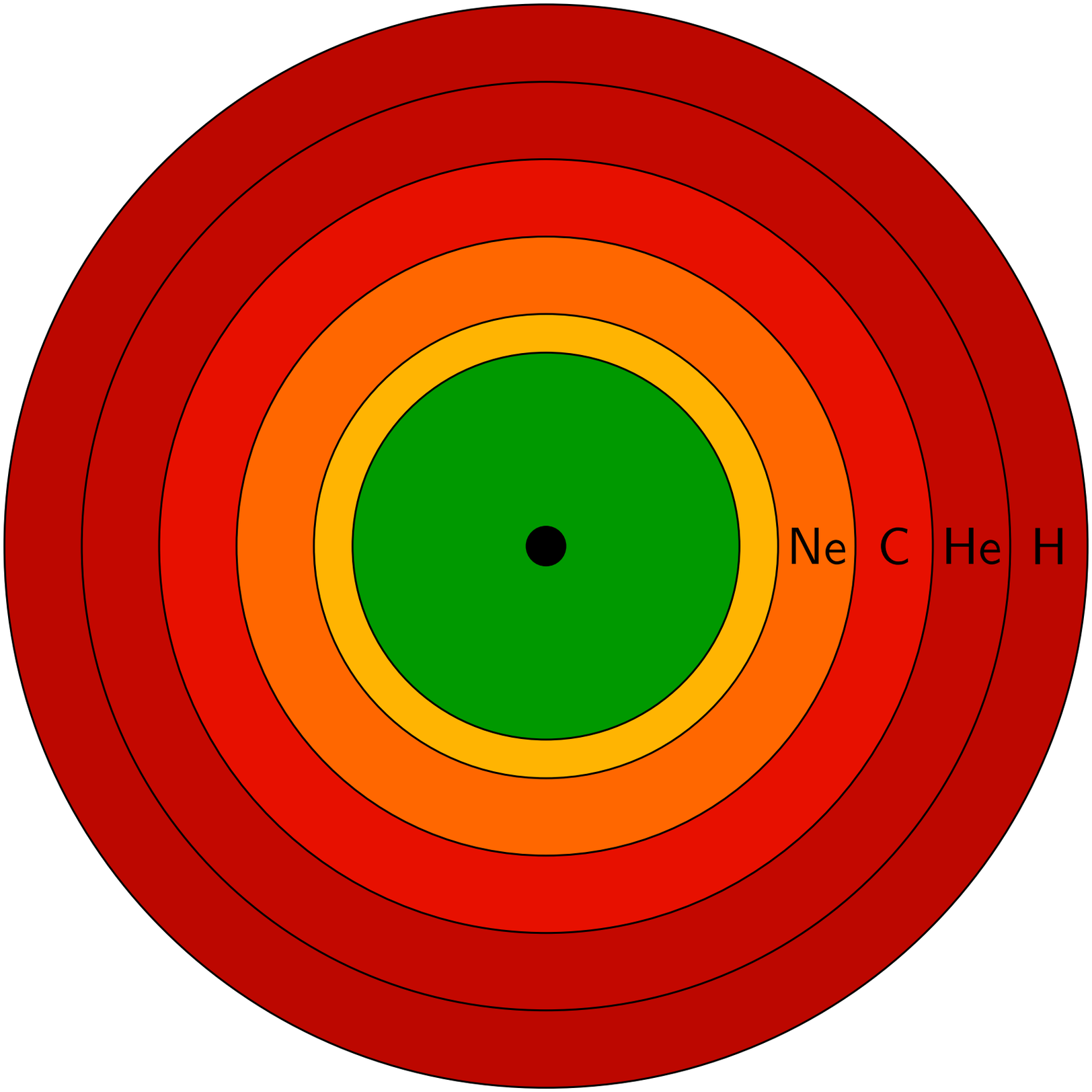
Emissions (part II)



Emissions (part II)



Emissions (part II)



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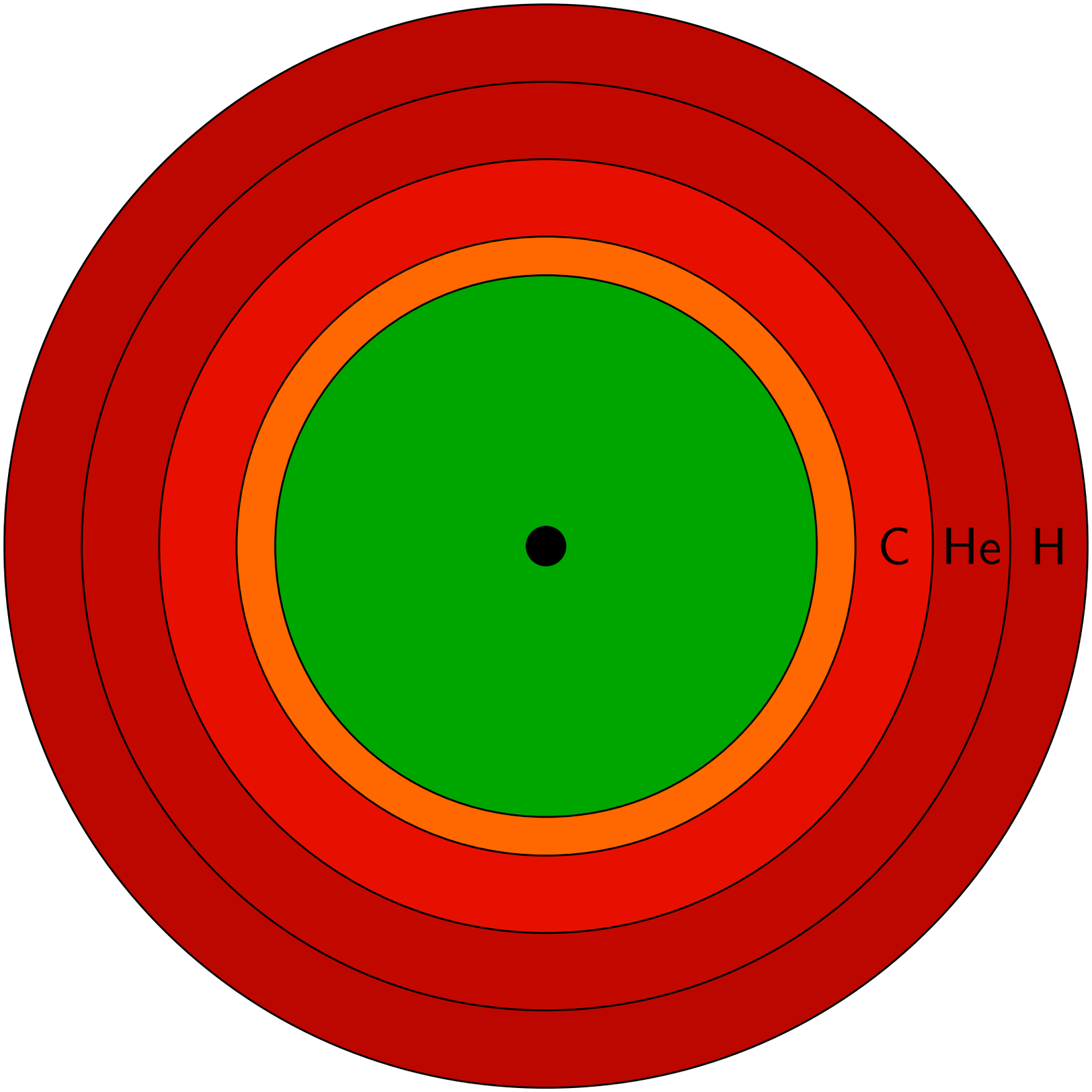
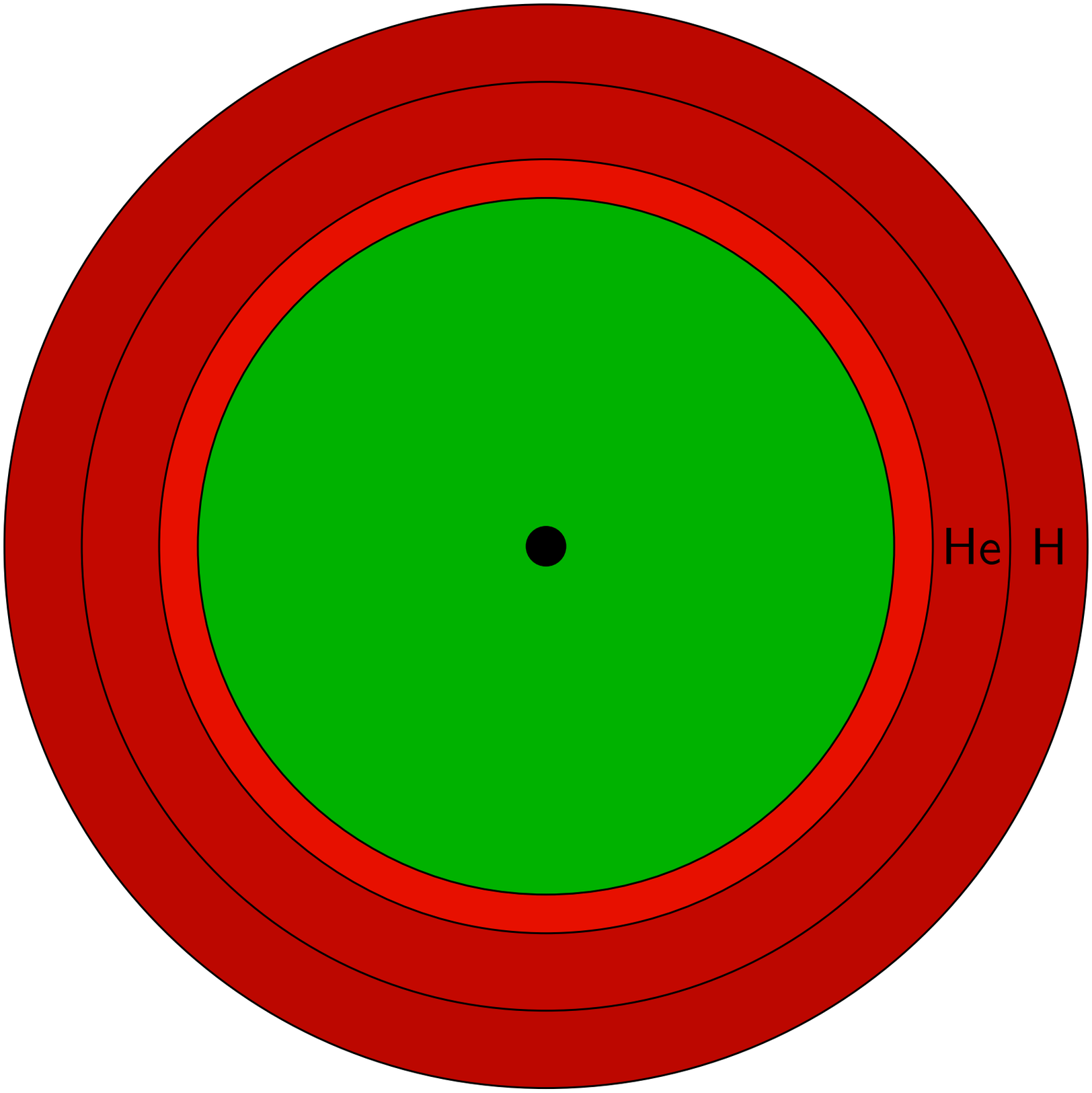


Emissions (part II)



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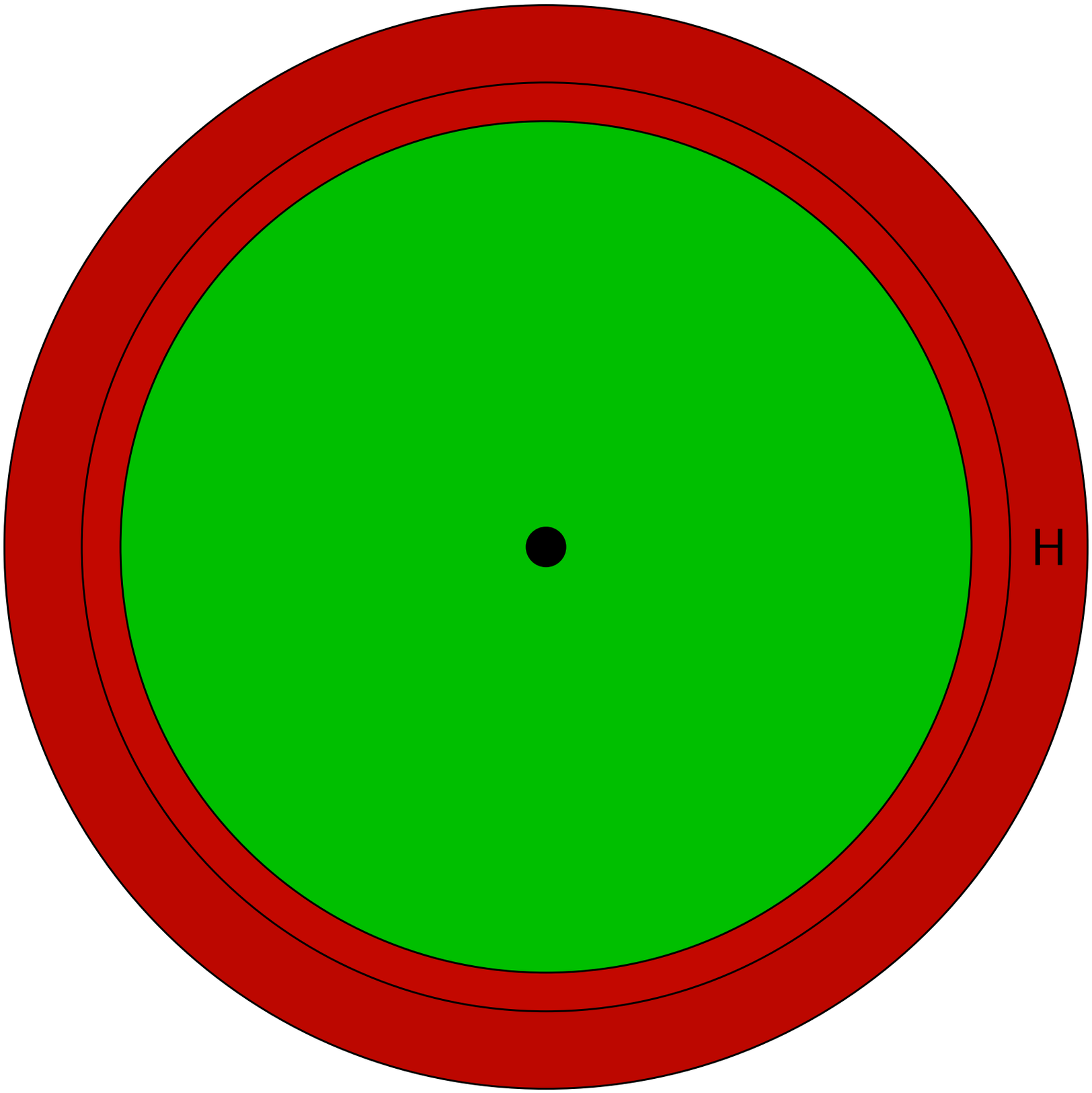

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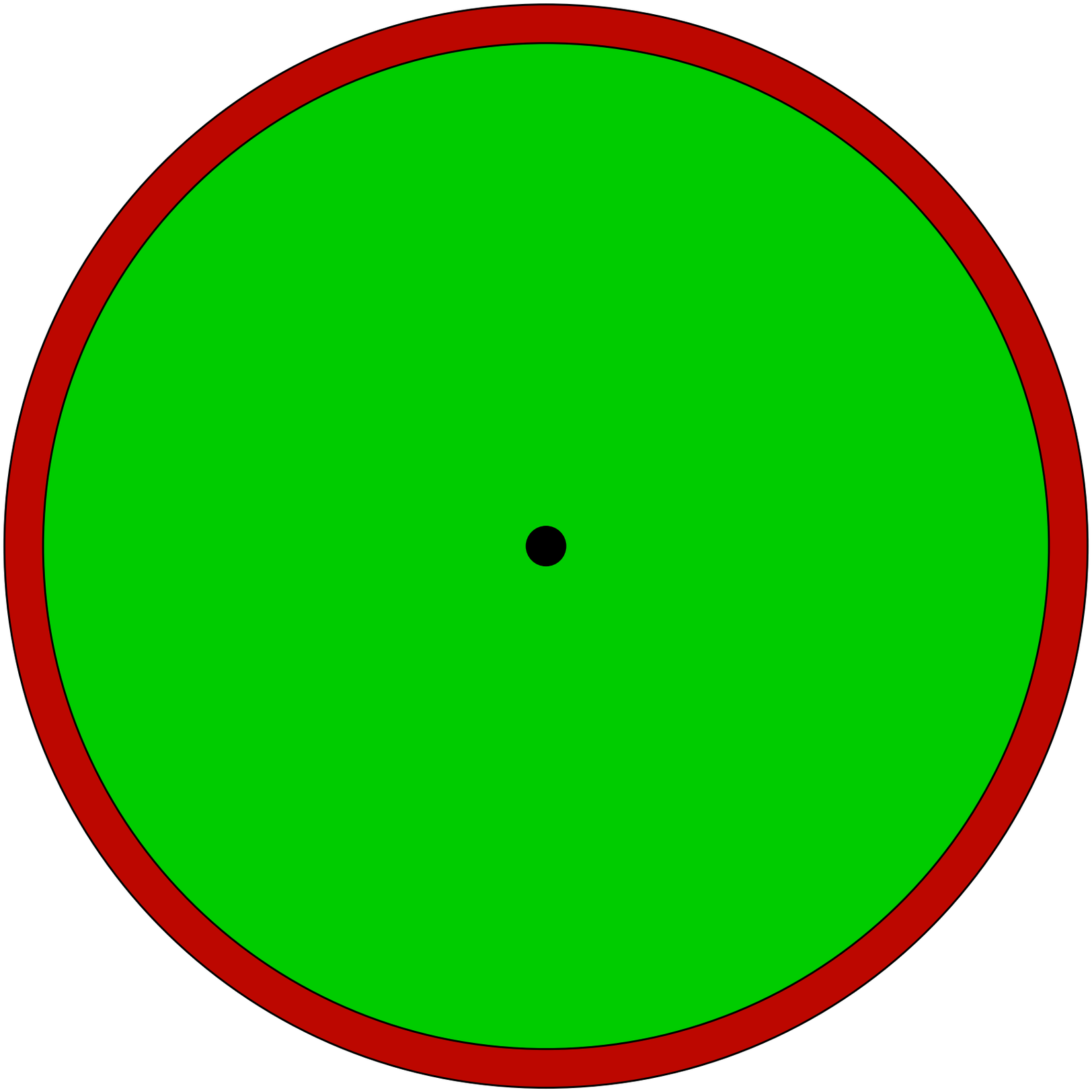

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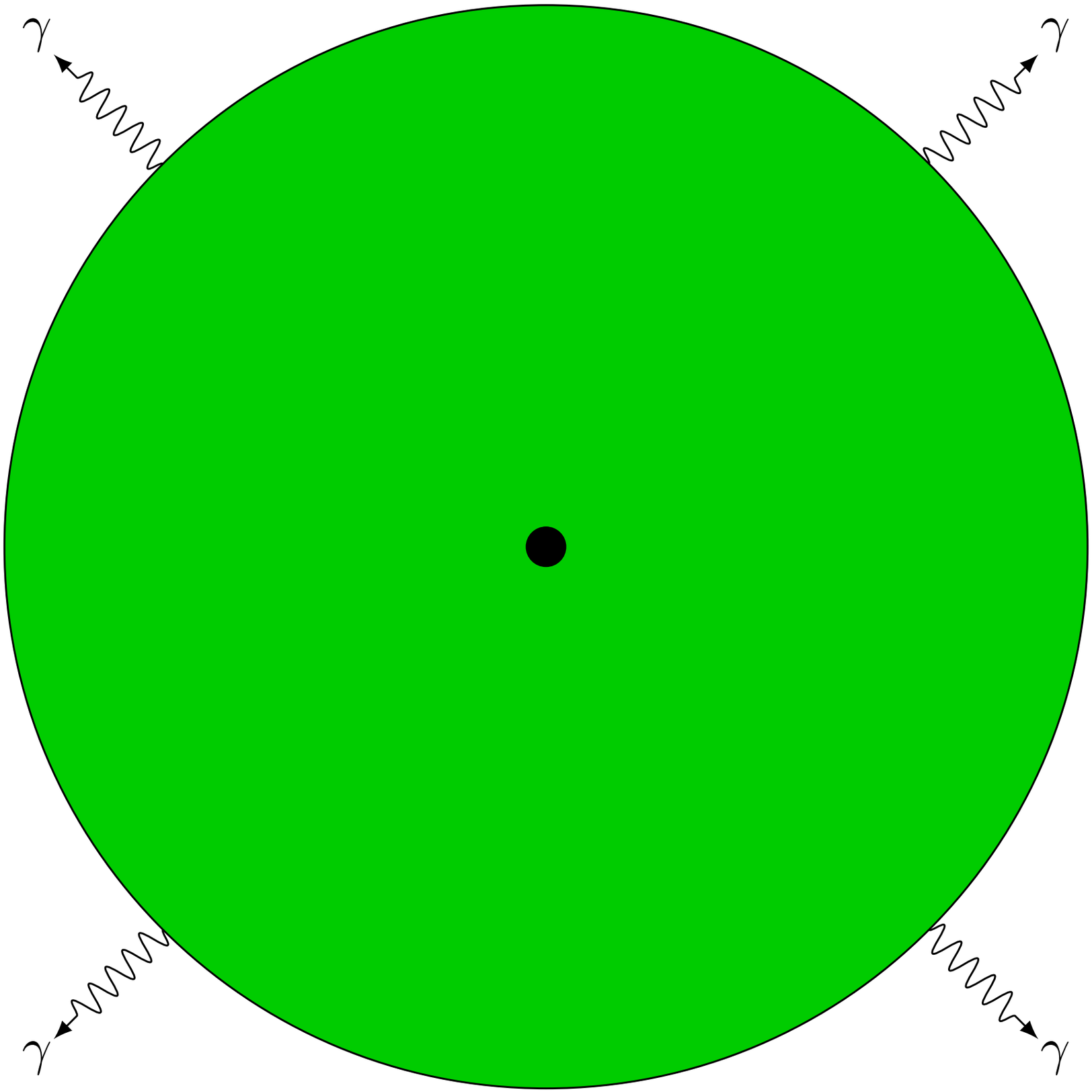
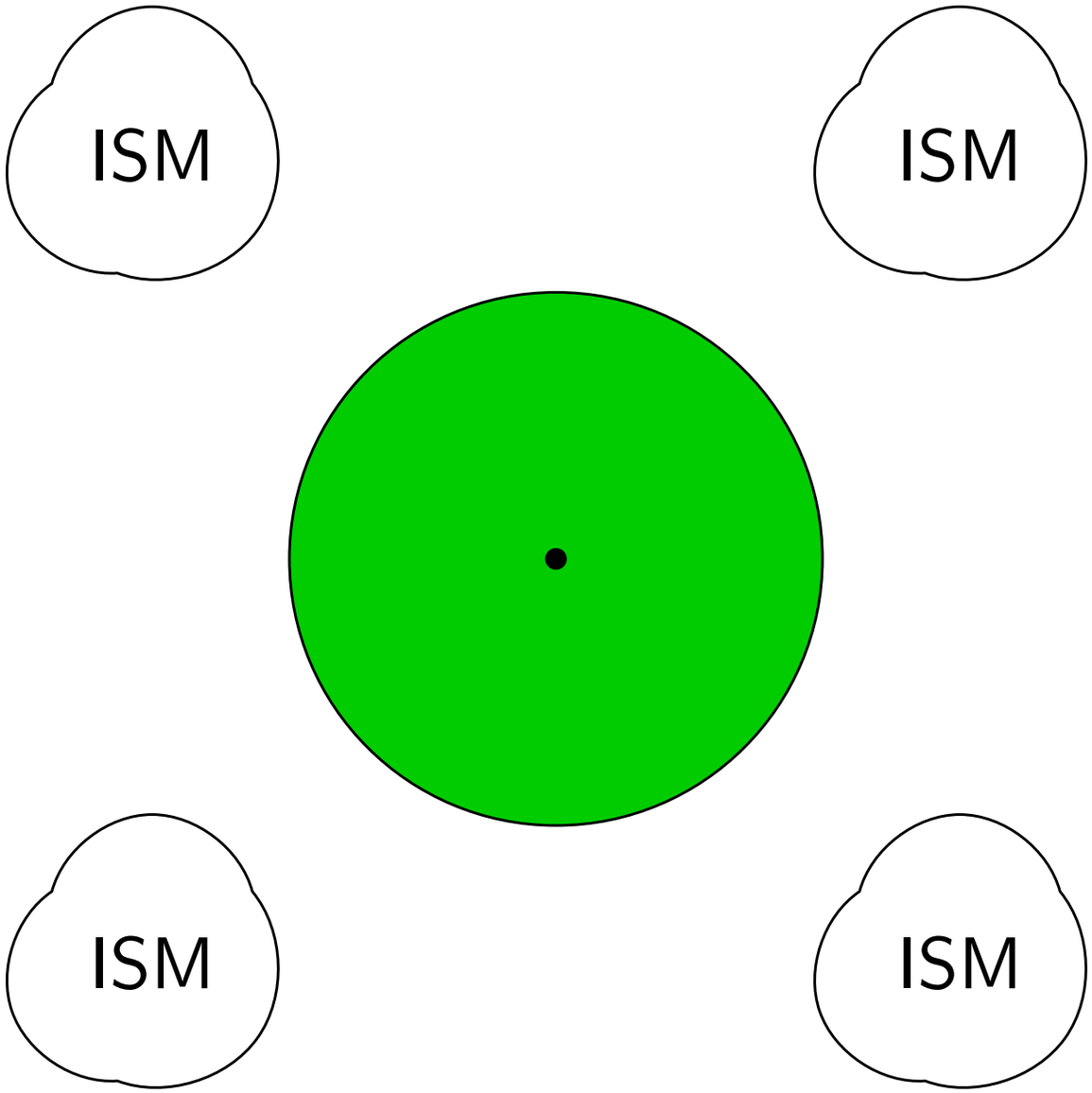
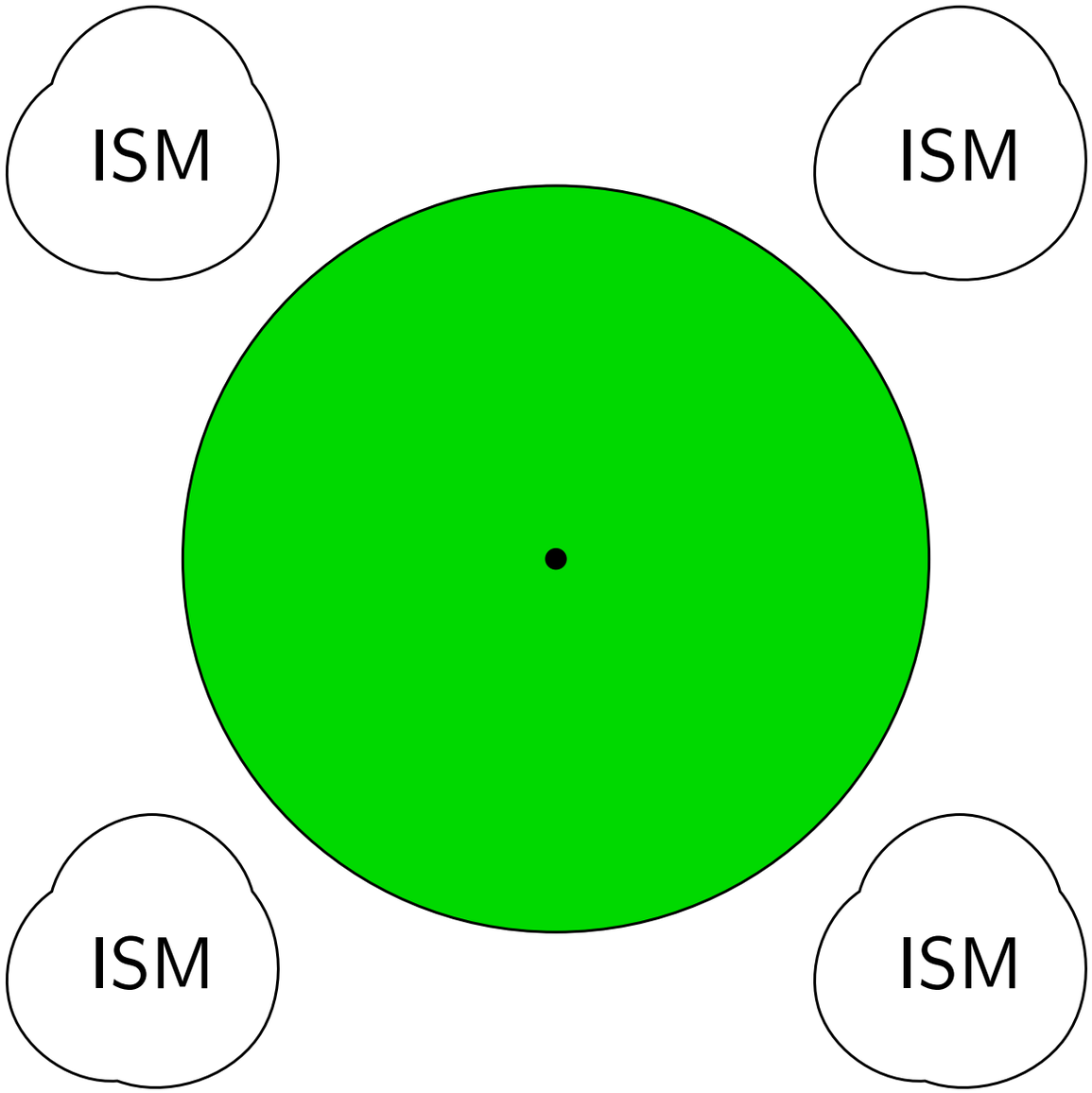


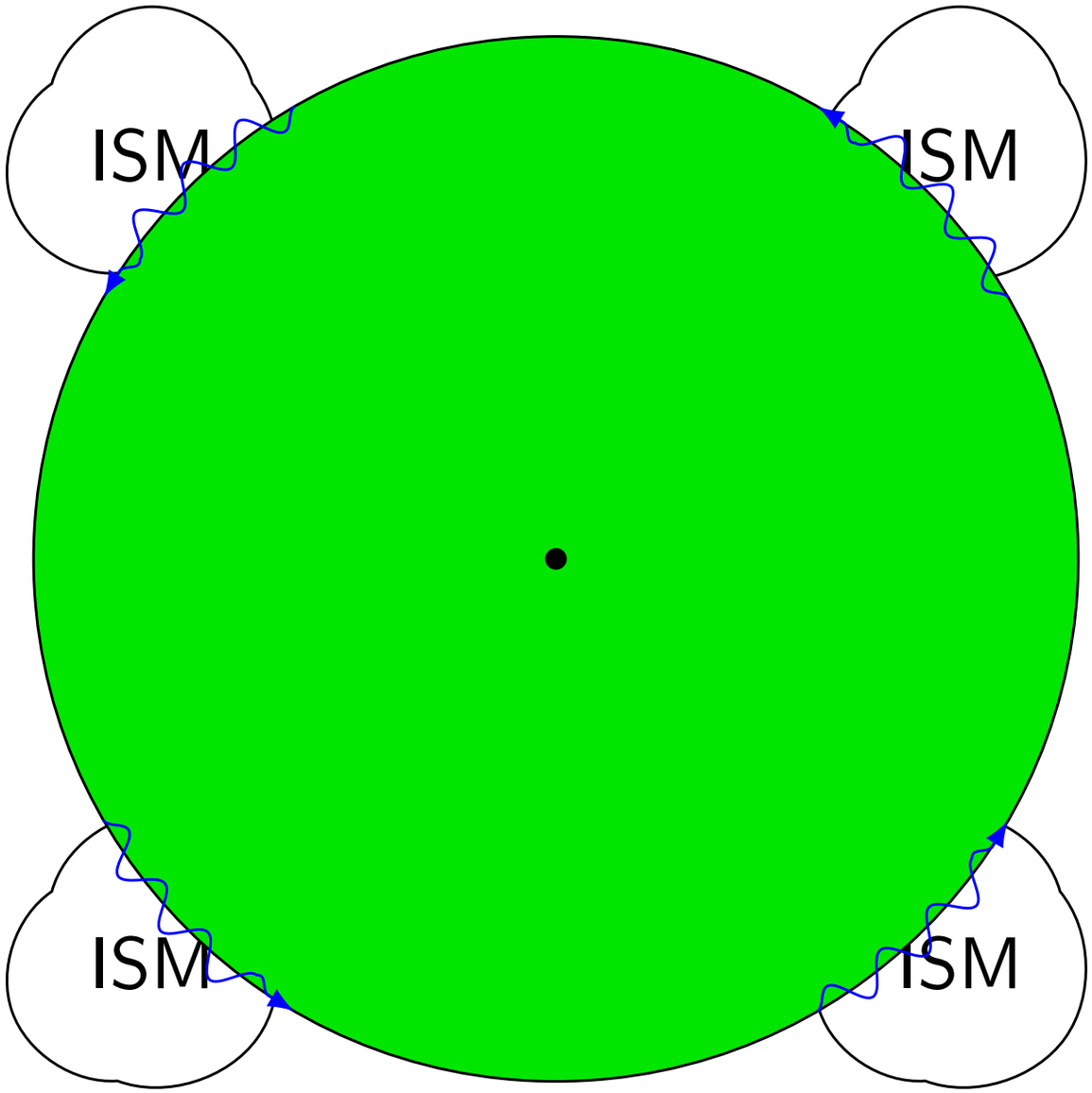
Emissions (part III)



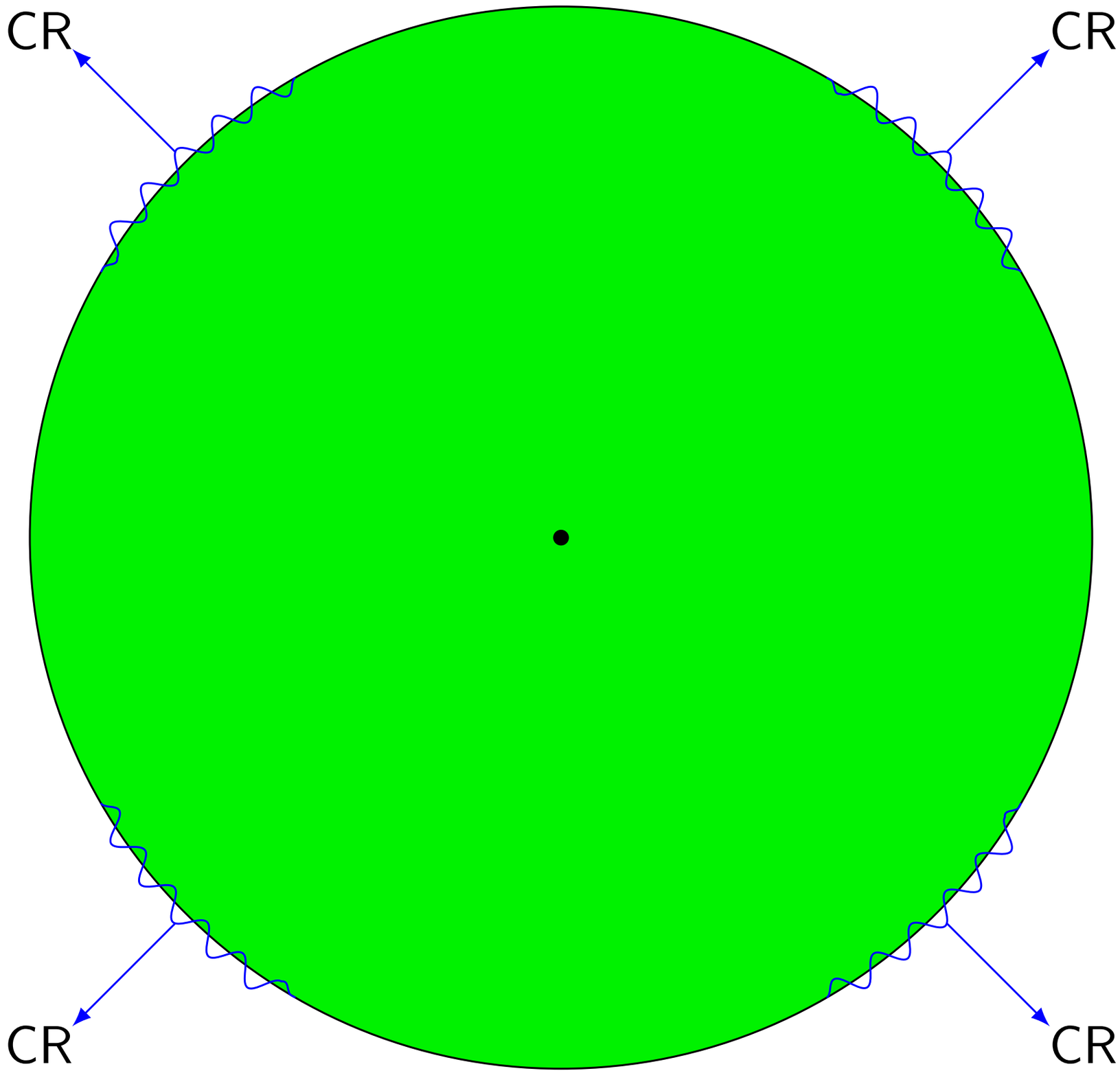
Emissions (part III)

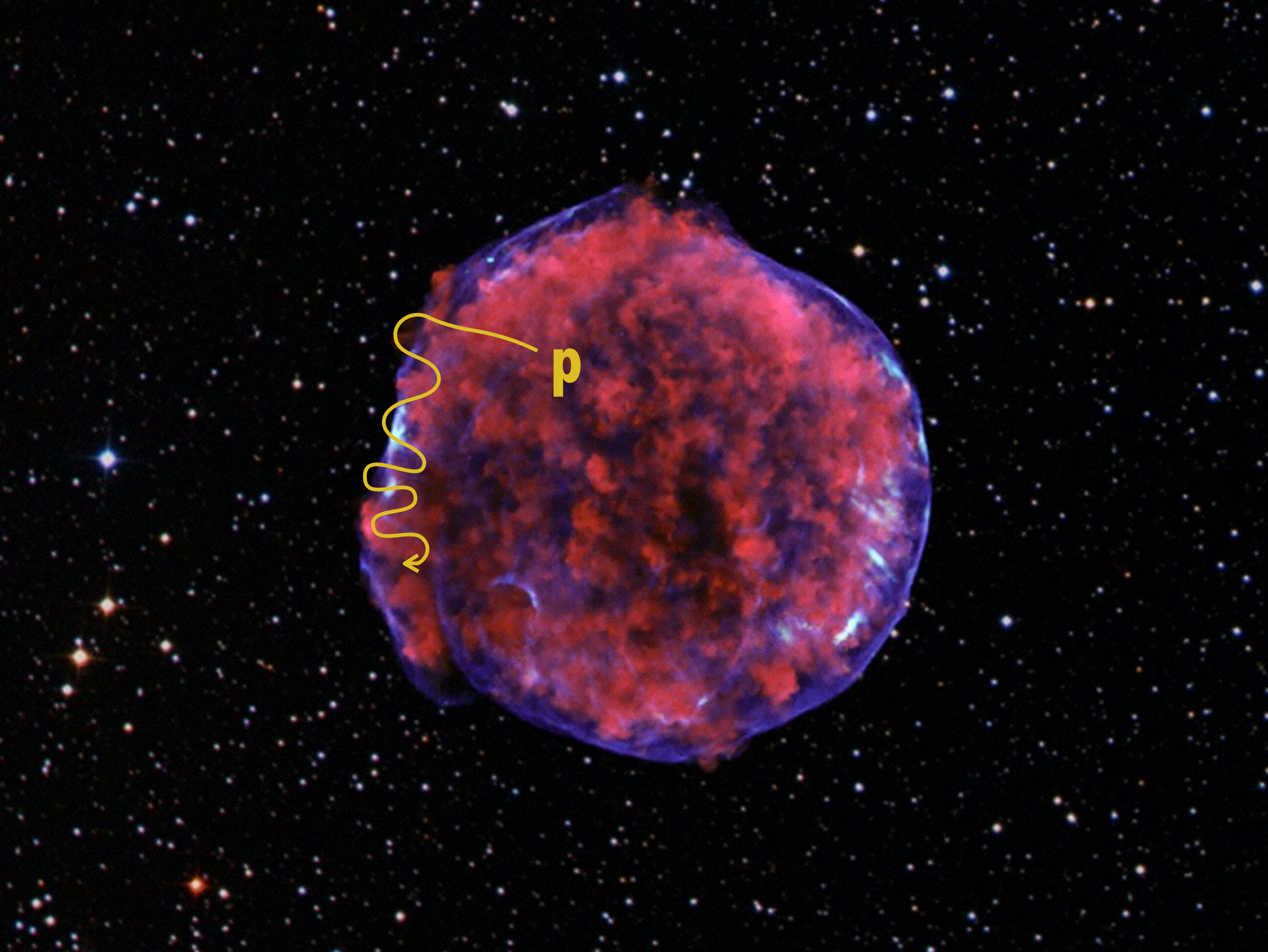


Emissions (part III)



Emissions (part III)

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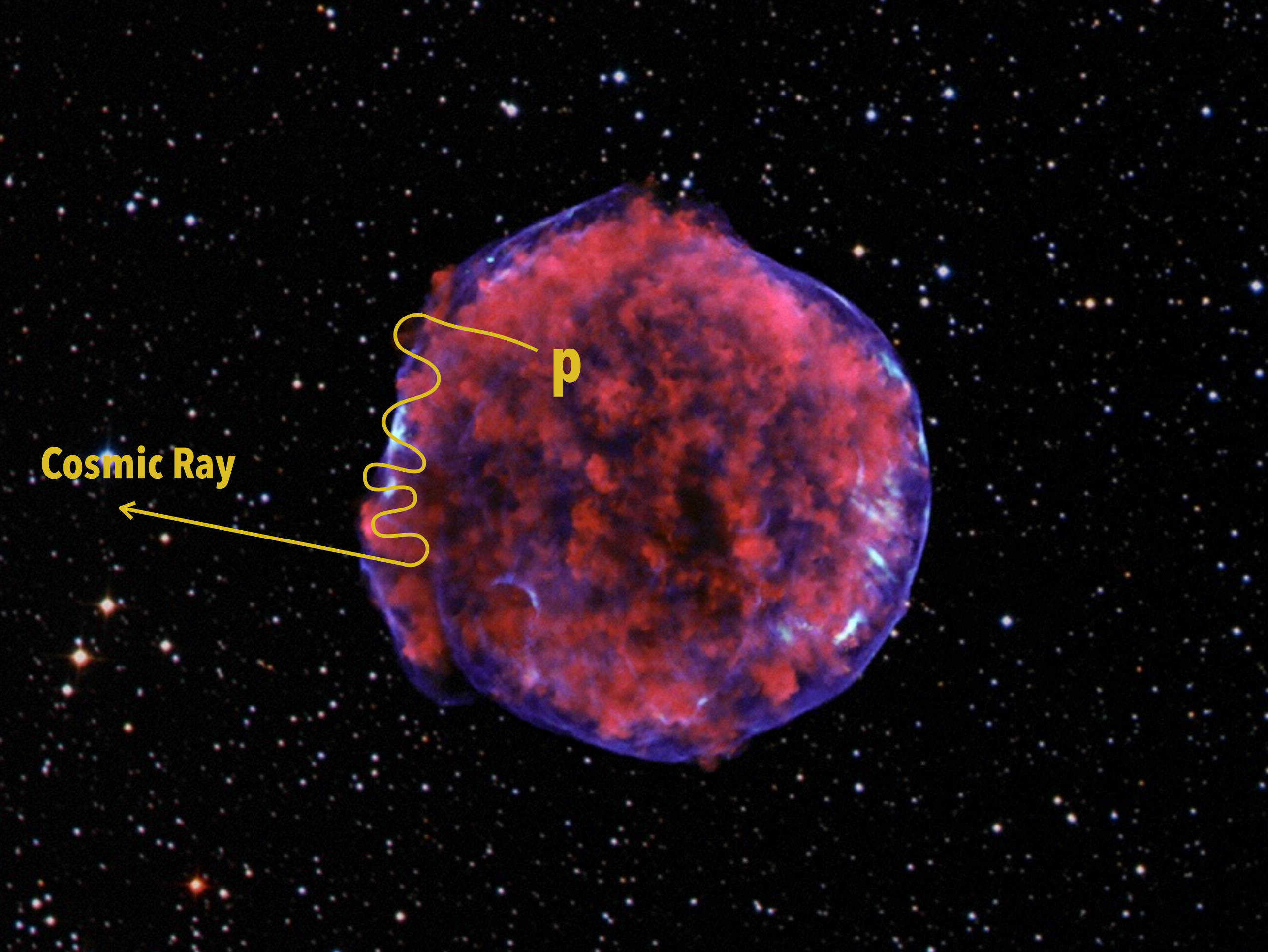
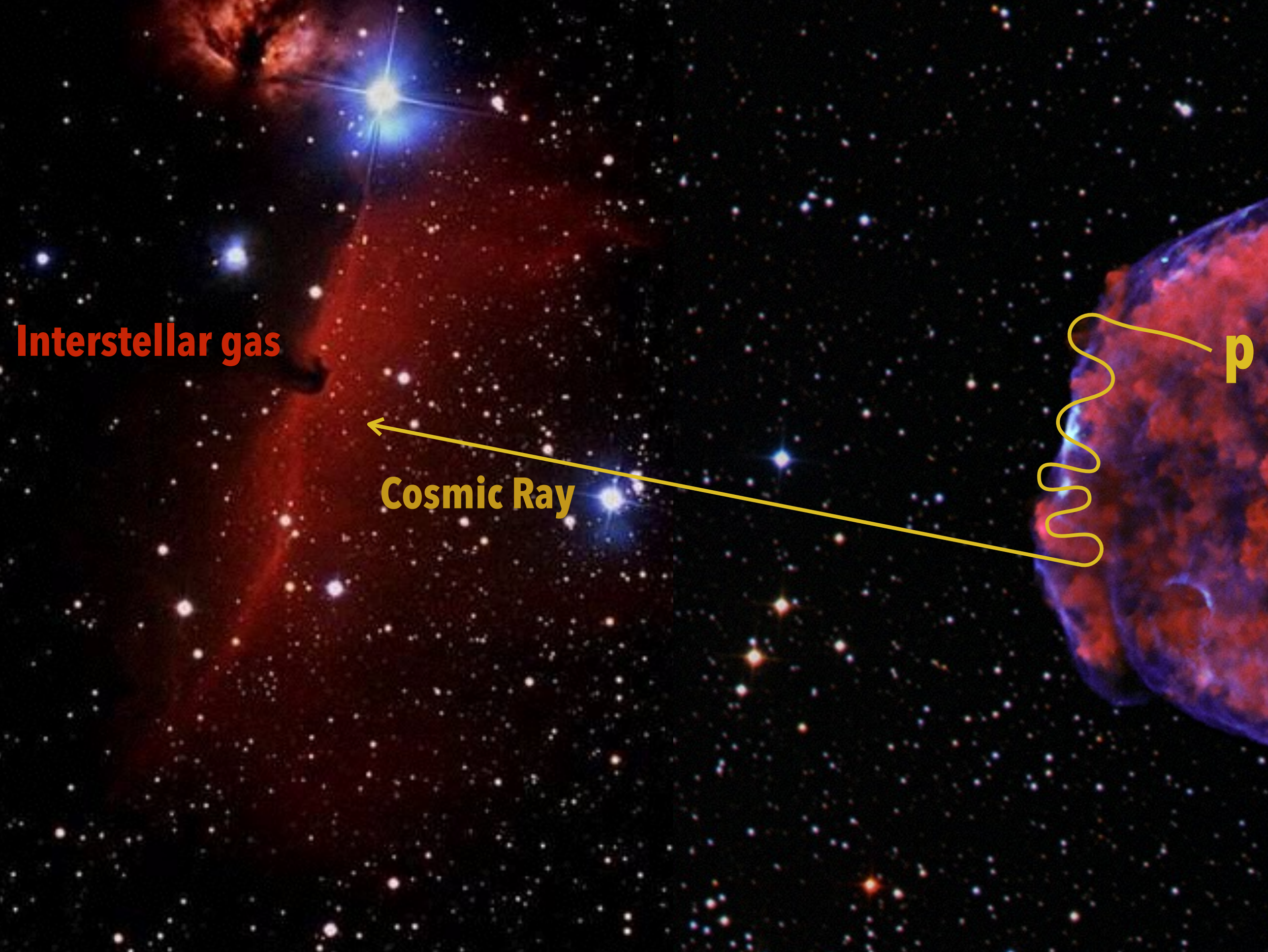
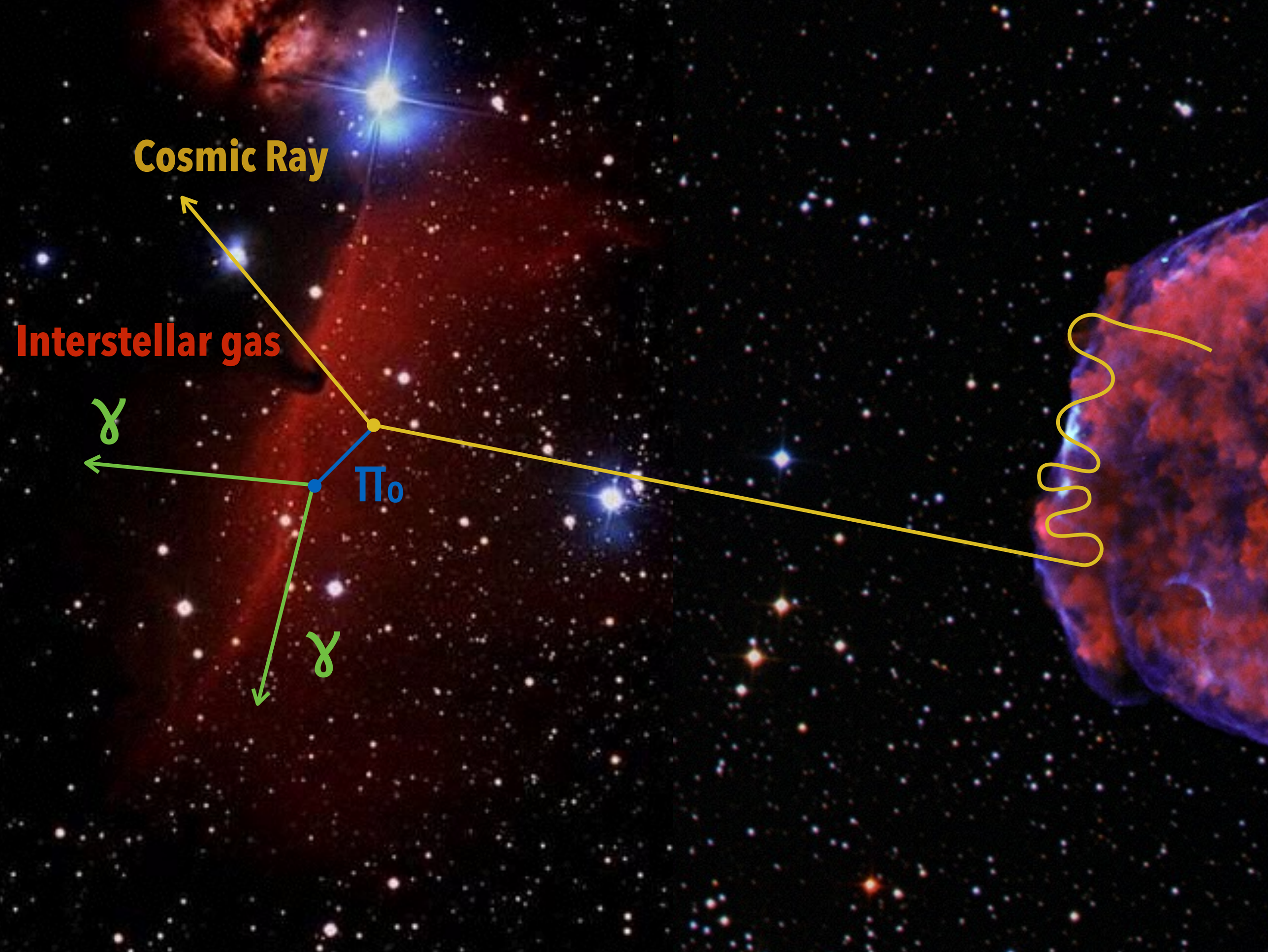
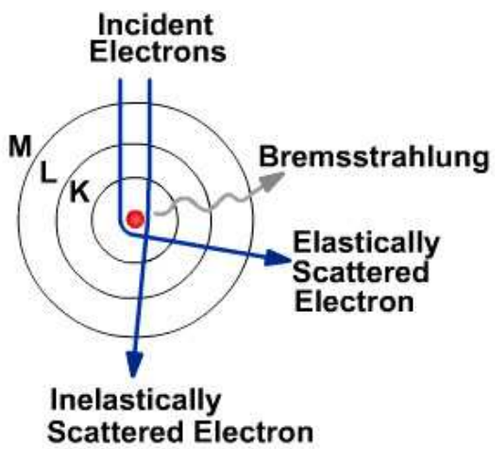
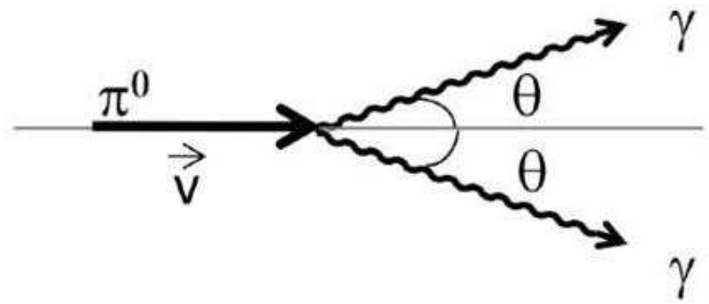

p
Cosmic Ray

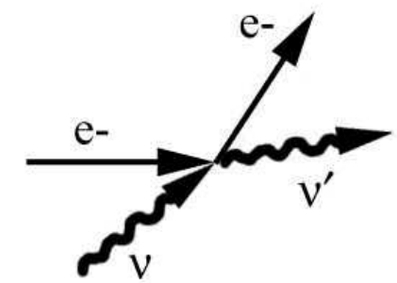

Interstellar gas
Cosmic Ray
p


Cosmic Ray
Interstellar gas
γ
π0
γ

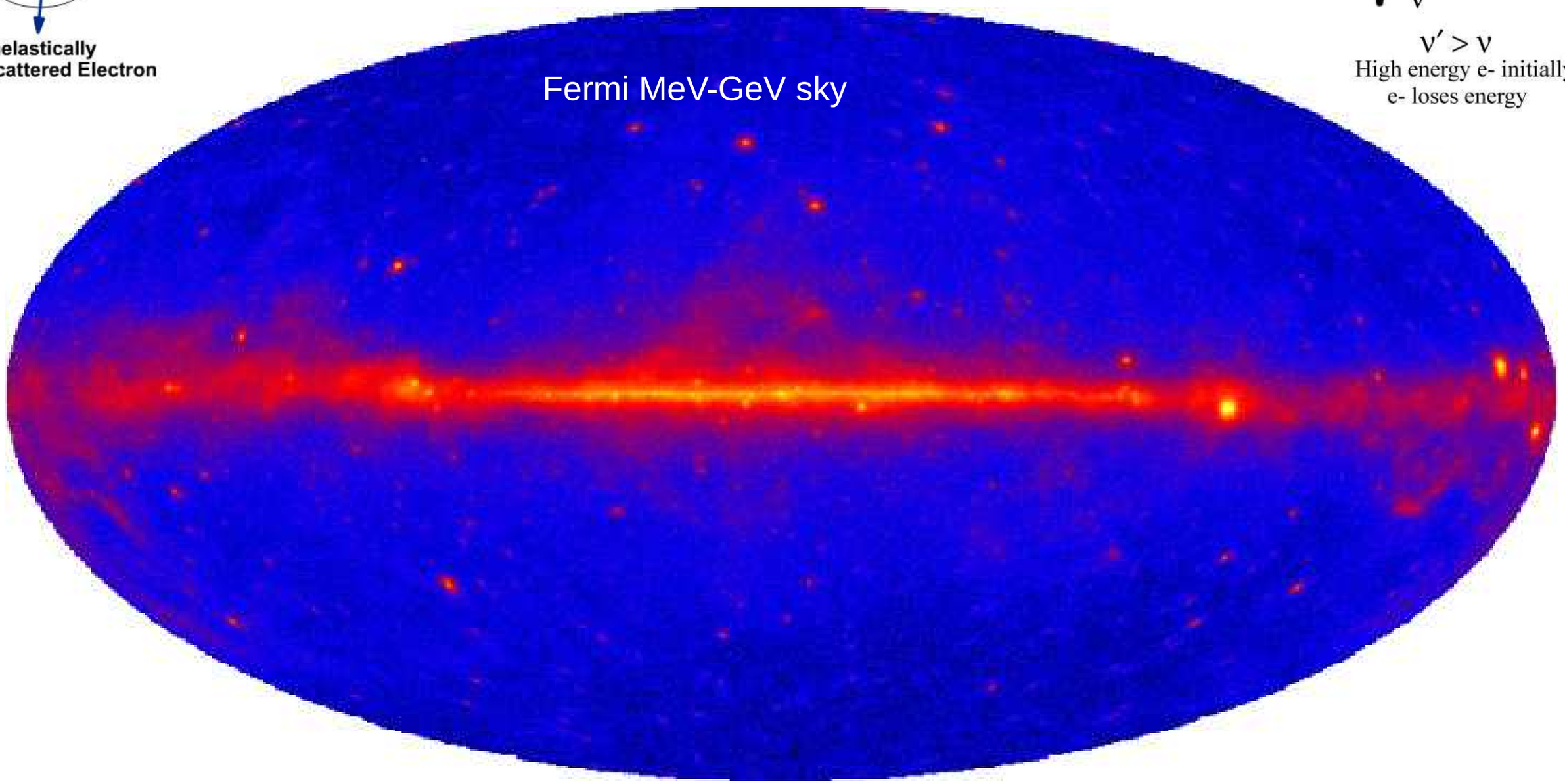




Inverse Compton scattering



$\nu' > \nu$
High energy e- initially
e- loses energy

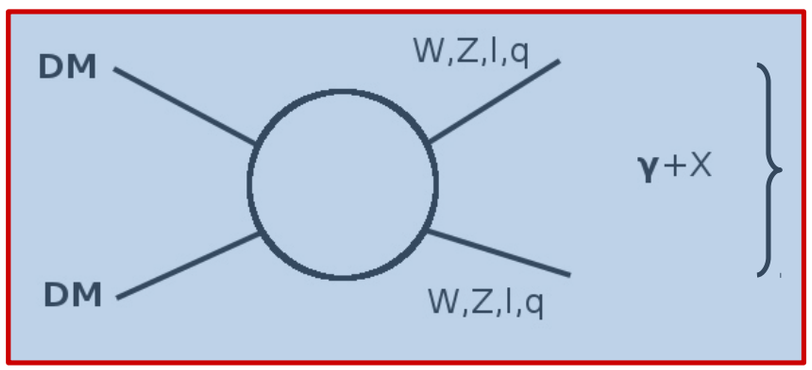


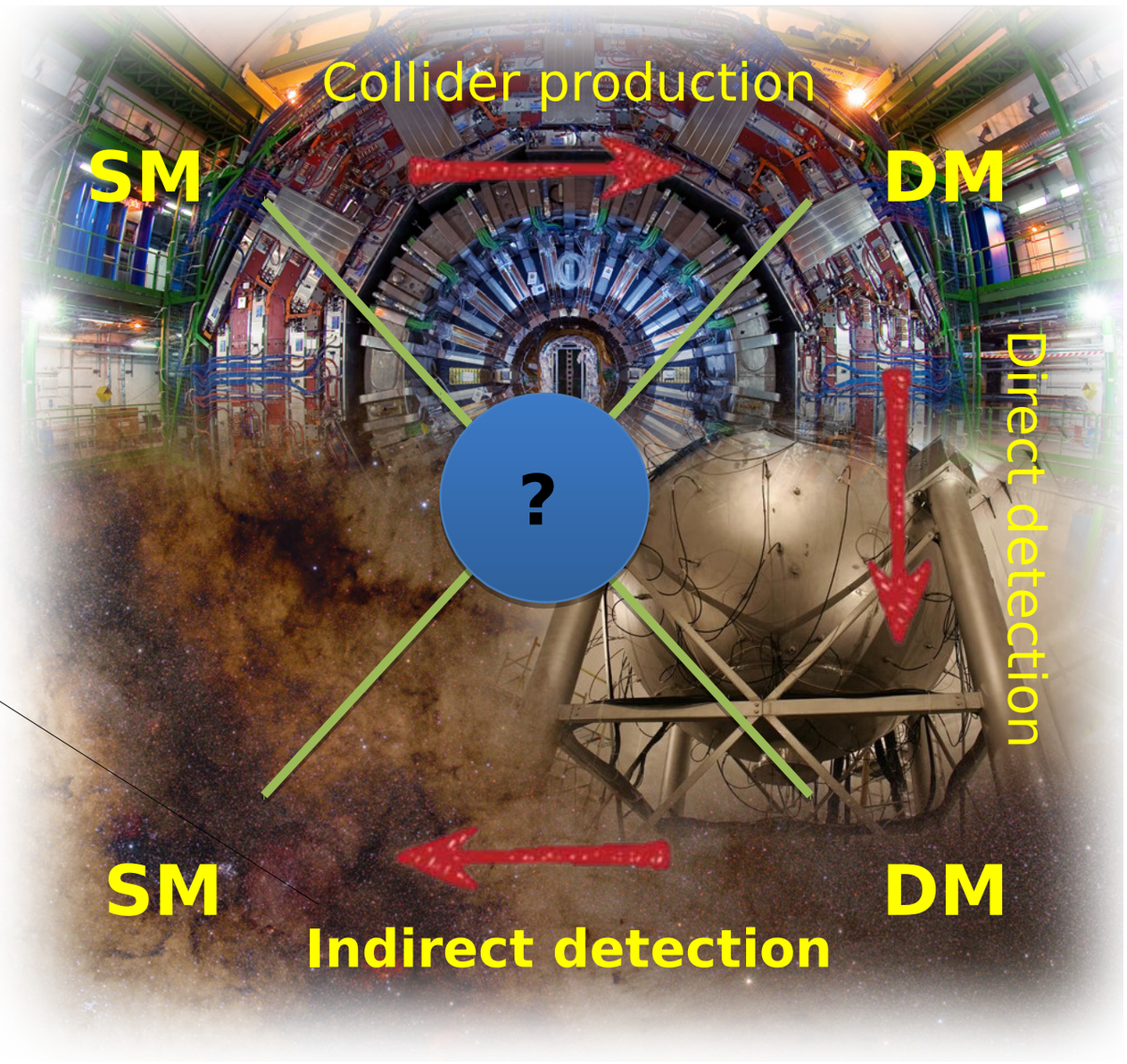
Targets:
CMB, IR, optical photons field
Matter distribution in the ISM

→ high energy (HE) and very high energy (VHE) gamma rays

Dark matter indirect detection

Dark matter (DM) can be detected indirectly through the detection of the final products of its self-annihilation



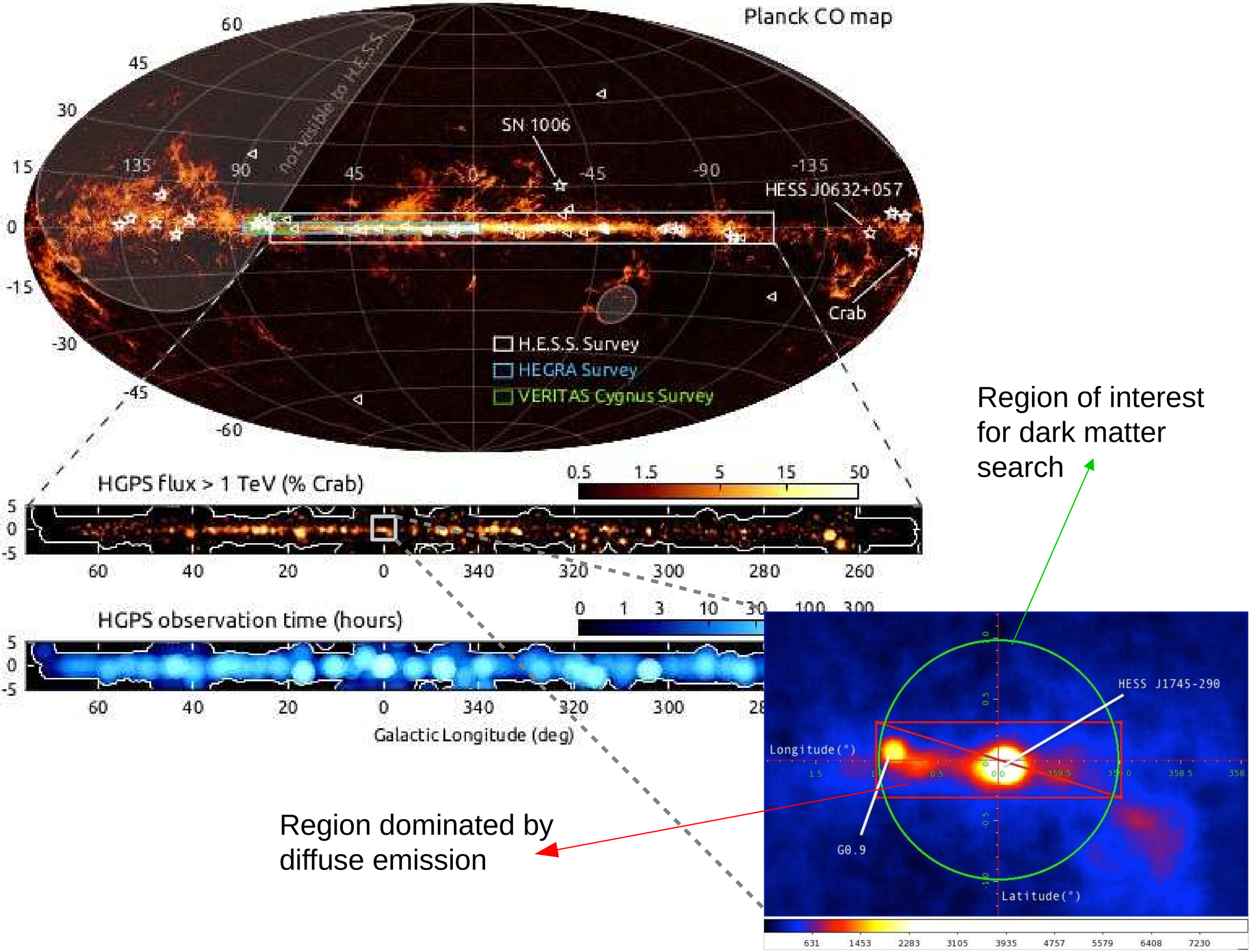


Ground-based Cherenkov telescopes are promising tools to detect WIMPs through very-high-energy (VHE, >100 GeV) gamma-rays

Targets for DM search in VHE gamma rays

H.E.S.S. observational strategy:

- Deep observations of the **Galactic Center** region
- Observations of the most promising **dwarf galaxies**


Planck CO map
not visible to H.E.S.S.
SN 1006
HESS J0632+057
Crab
H.E.S.S. Survey
HEGRA Survey
VERITAS Cygnus Survey
HGPS flux > 1 TeV (% Crab)
HGPS observation time (hours)
Galactic Longitude (deg)
HESS J1745-290
G0.9
Longitude(°)
Latitude(°)
Region of interest for dark matter search
Region dominated by diffuse emission

Following presentations

- Do we really understand **how core-collapse supernovae explode?**
- How do **cosmic-rays interactions with the interstellar medium** affect their propagation?
- Do we know the **nature of dark matter?**

Core-collapse supernovæ asymmetries

IRFU DDays

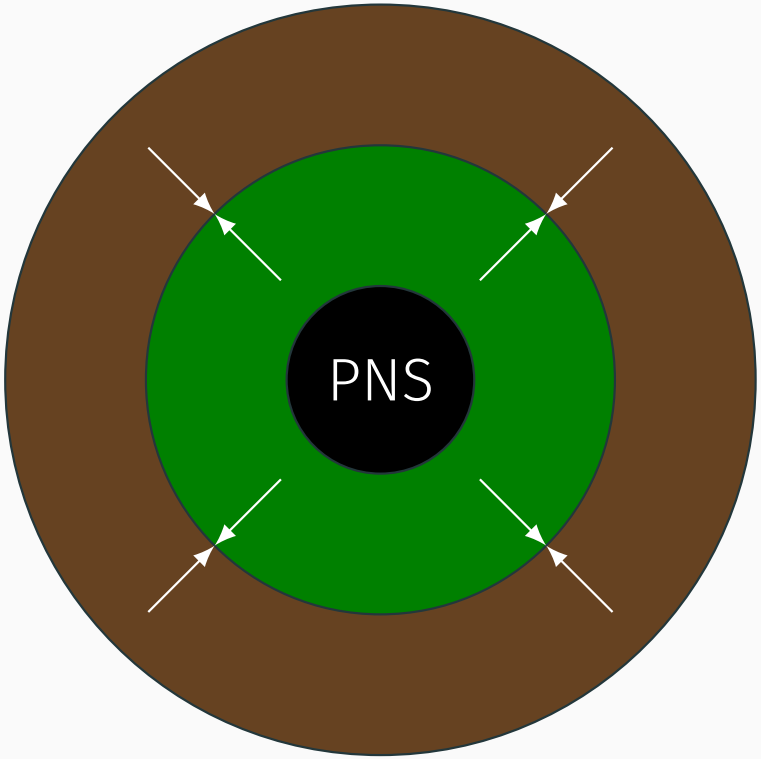
Bruno Pagani

July 10th, 2018

CEA/DRF/IRFU/DAp/LMPA – UMR 7158 AIM

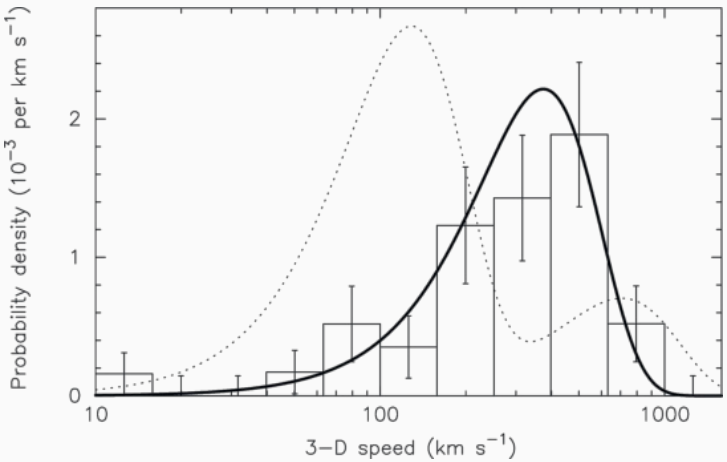
Context presentation

Restarting from the shock

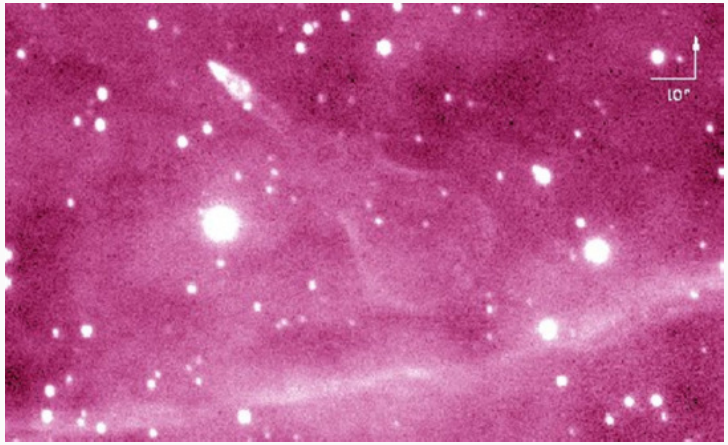


In most *numerical simulations*, the **shock actually stalls**. But *we do see exploding stars* in the Universe, so what is the trick?

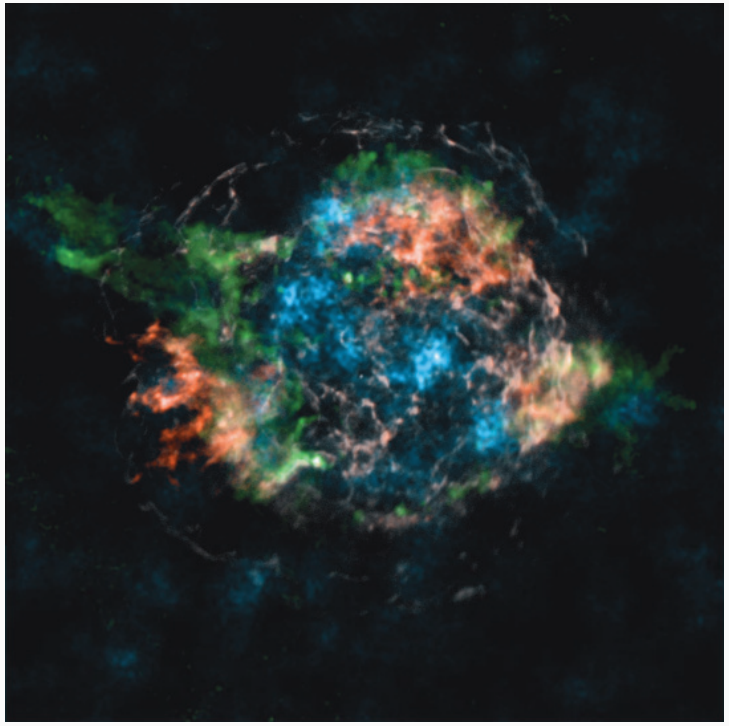
What do we observe?



Pulsar kicks – Hobbs & al., 2005



Guitar nebula's pulsar – Chatterjee & Cordes, 2003



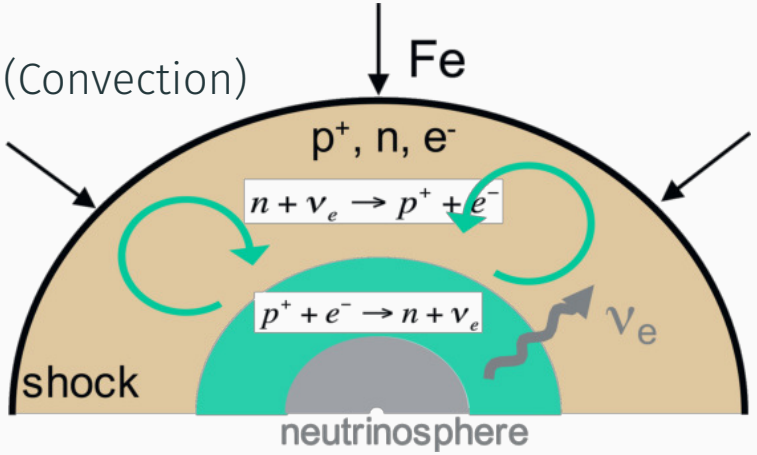
Nuclear matter spreads in supernovæ remnants (Ti, Si & Fe) – Grefenstette & al., 2014

Pulsar rotation speeds (*e.g.* Kazeroni+16,+17)

So how do we blow out those stars?

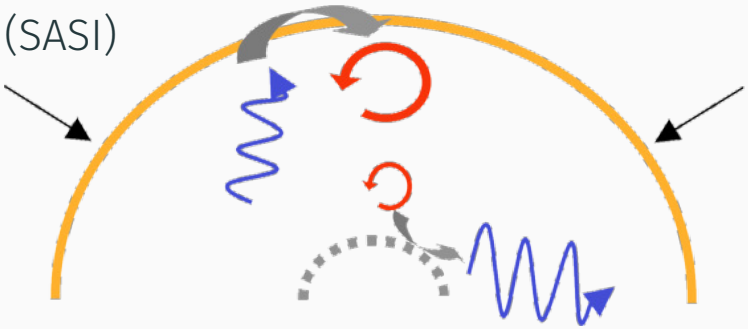
Some ideas:

- Energy deposition by **neutrinos** emitted in the core Bethe & Wilson, 1985;
- Instabilities: • MRI ?
  - **Convection** ;
  - **SASI** Blondin+03;
  - **"Low T/W"**, as known in :
    - differentially rotating neutrons stars Shibata+02; Watts+05 ;
    - accretion disks Papaloizou & Pringle, 1984 ; Goldreich & Narayan, 1985.



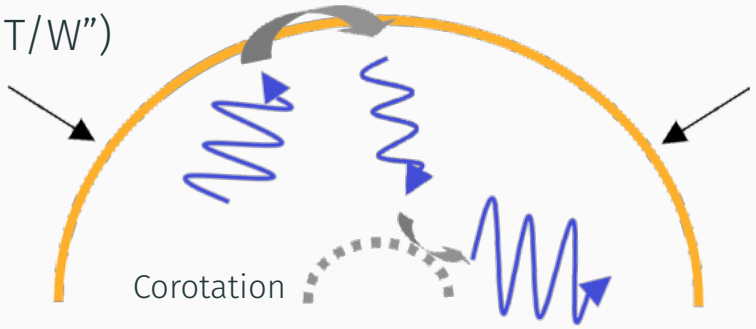
Advective-acoustic cycle

(SASI)



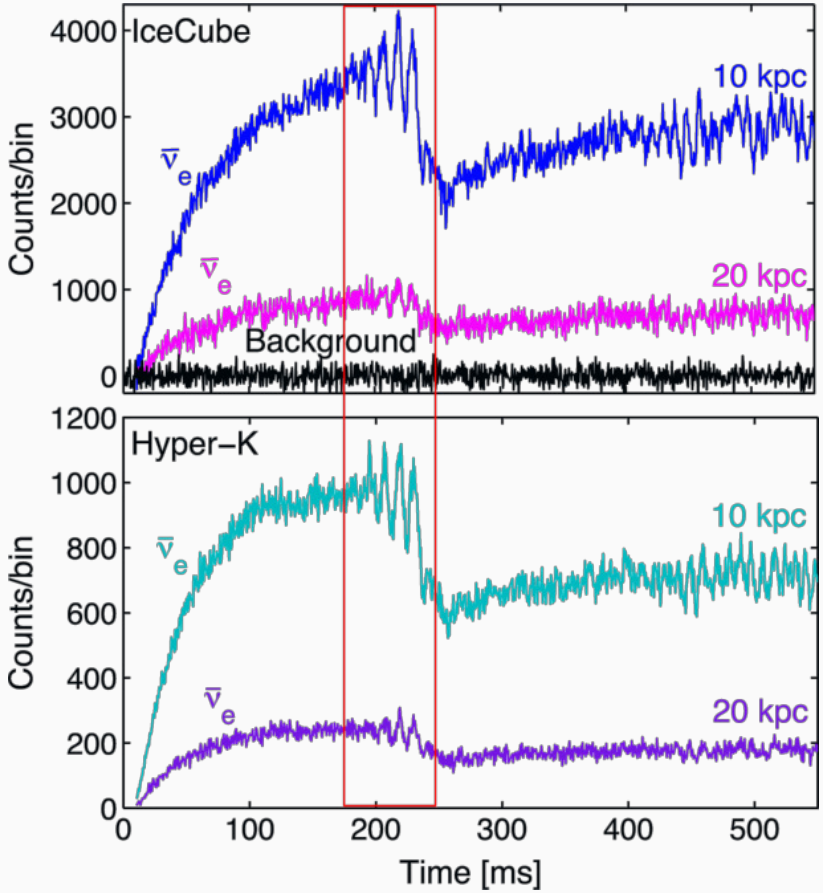
Purely acoustic mechanism

("Low T/W")

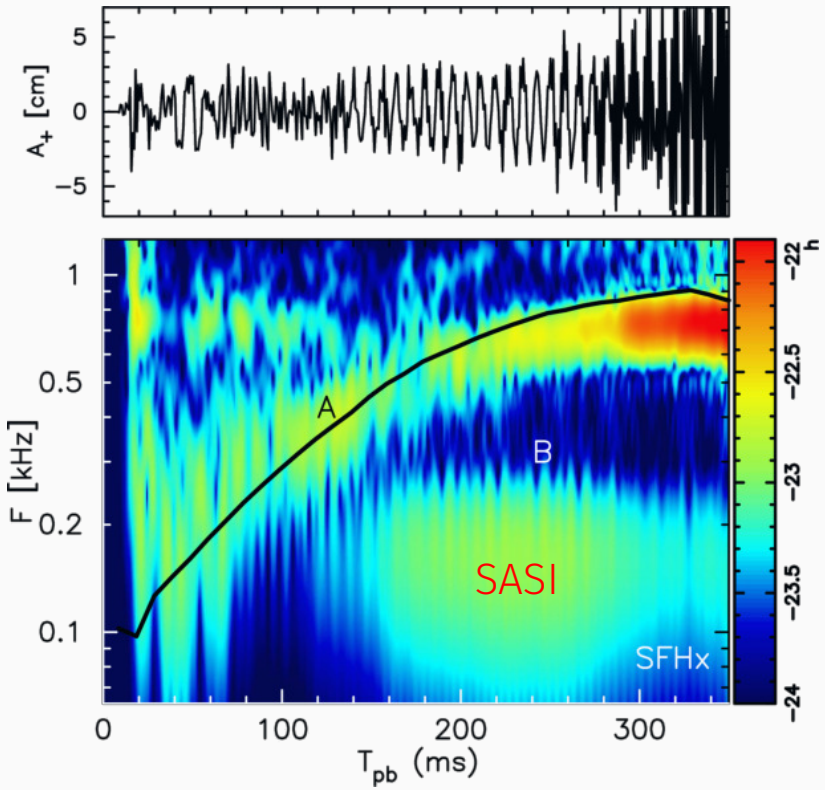


Corotation has been observed in the supernovæ fountain and simulations Takiwaki+16.

Future observations?



Neutrinos flux modulation by SASI – Tamborra & al., 2013



Gravitational waves emission, showing SASI and convections signatures – Kuroda & al., 2016

Objectives

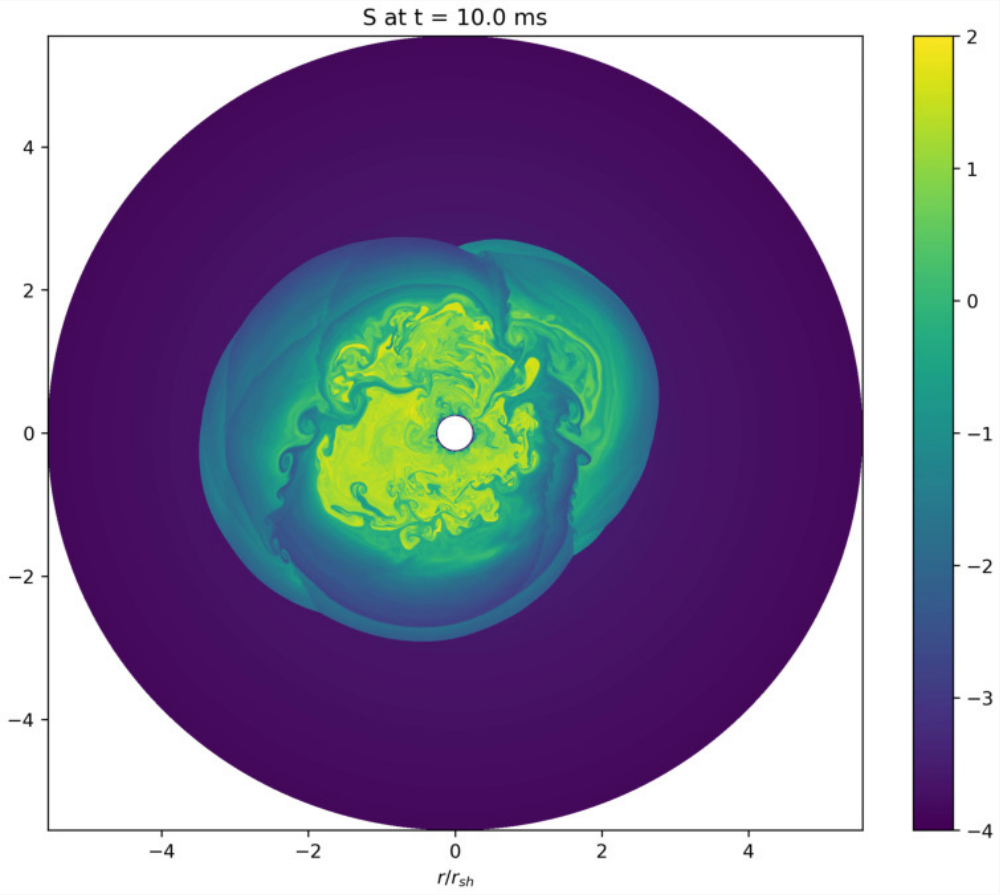
A multitude of physics questions:

- Which **instabilities** are dominating the dynamic?
- What are their **mechanisms**?
- What is the **impact** of several parameters: **rotation, heating,** magnetism...?
- **Consequences** for **explosions** and links to the **properties** of the produced **neutrons stars**?

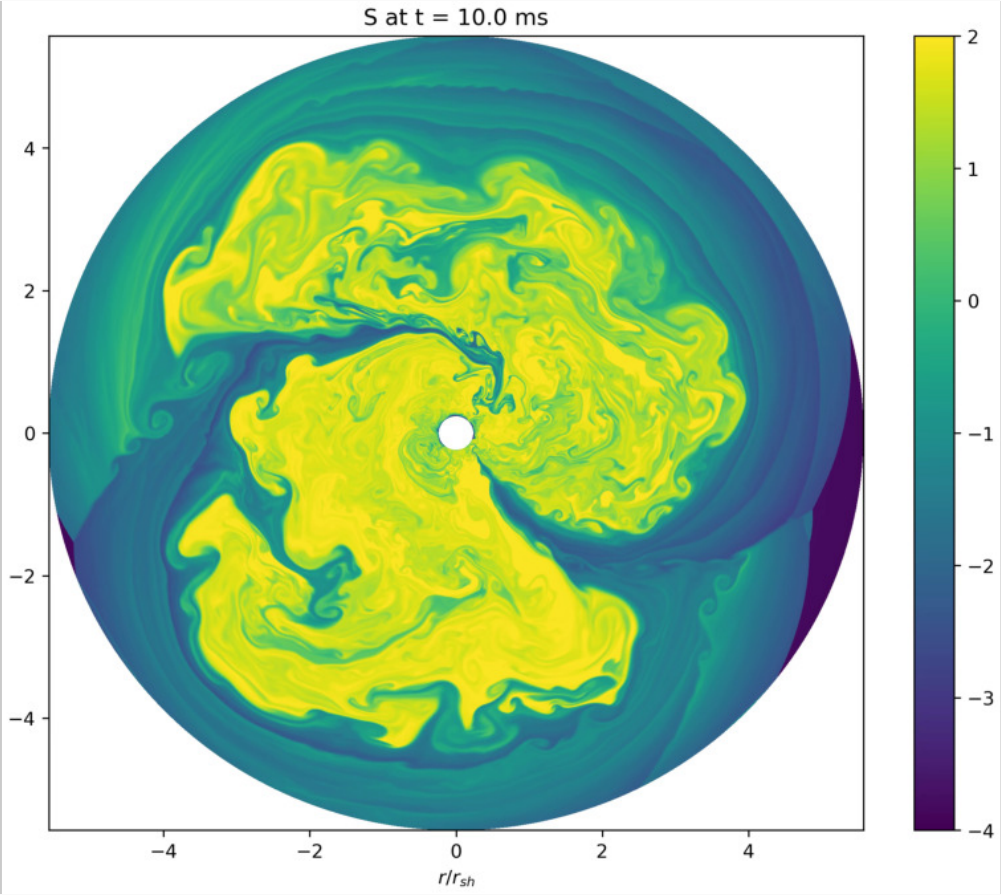
Some preliminary results

Visual comparison, with and without rotation

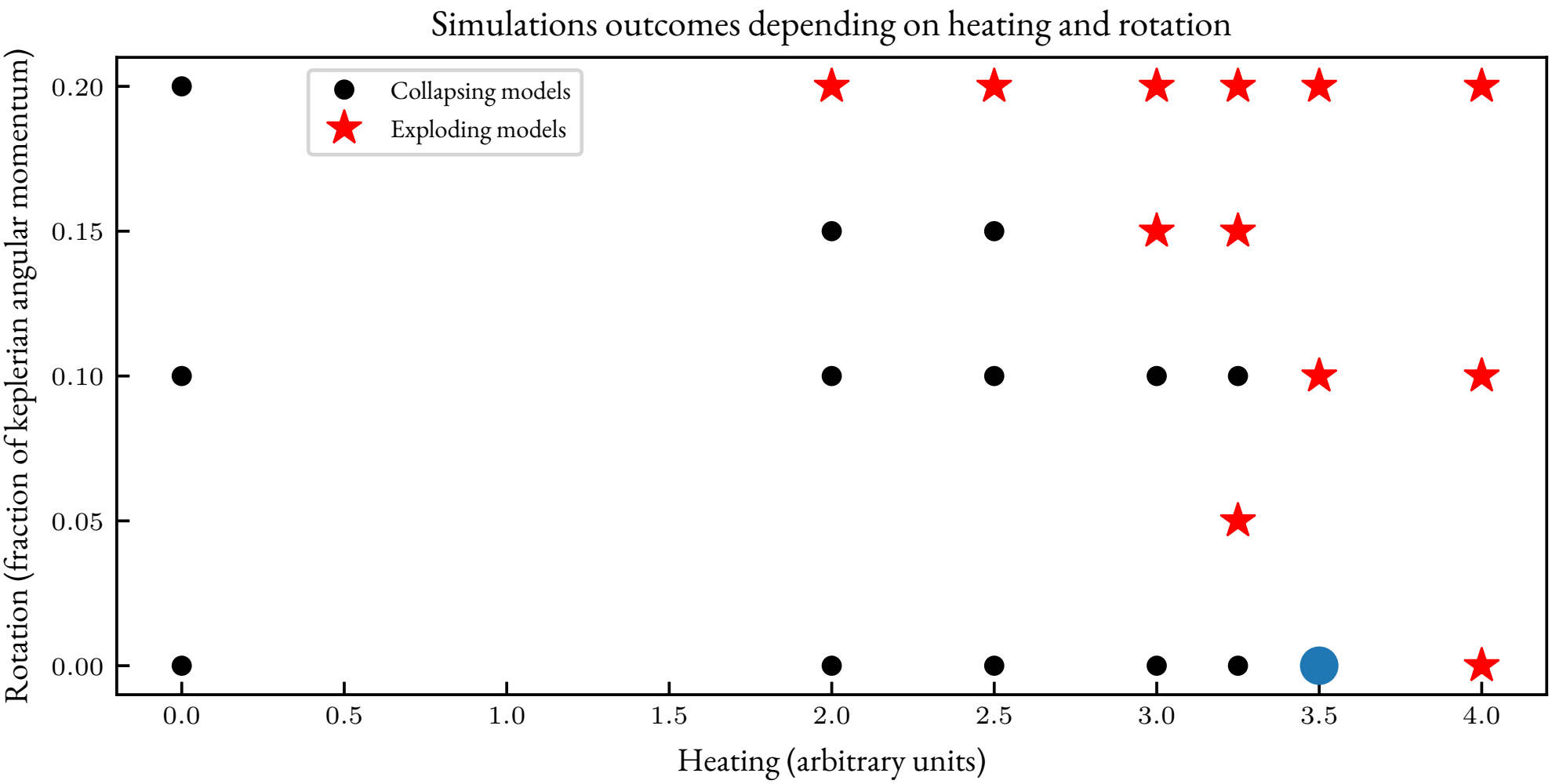
Without rotation



With rotation (20% keplerian)



Models grid


Simulations outcomes depending on heating and rotation
Collapsing models
Exploding models
Rotation (fraction of keplerian angular momentum)
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Heating (arbitrary units)

Current conclusion and perspectives

Preliminary results

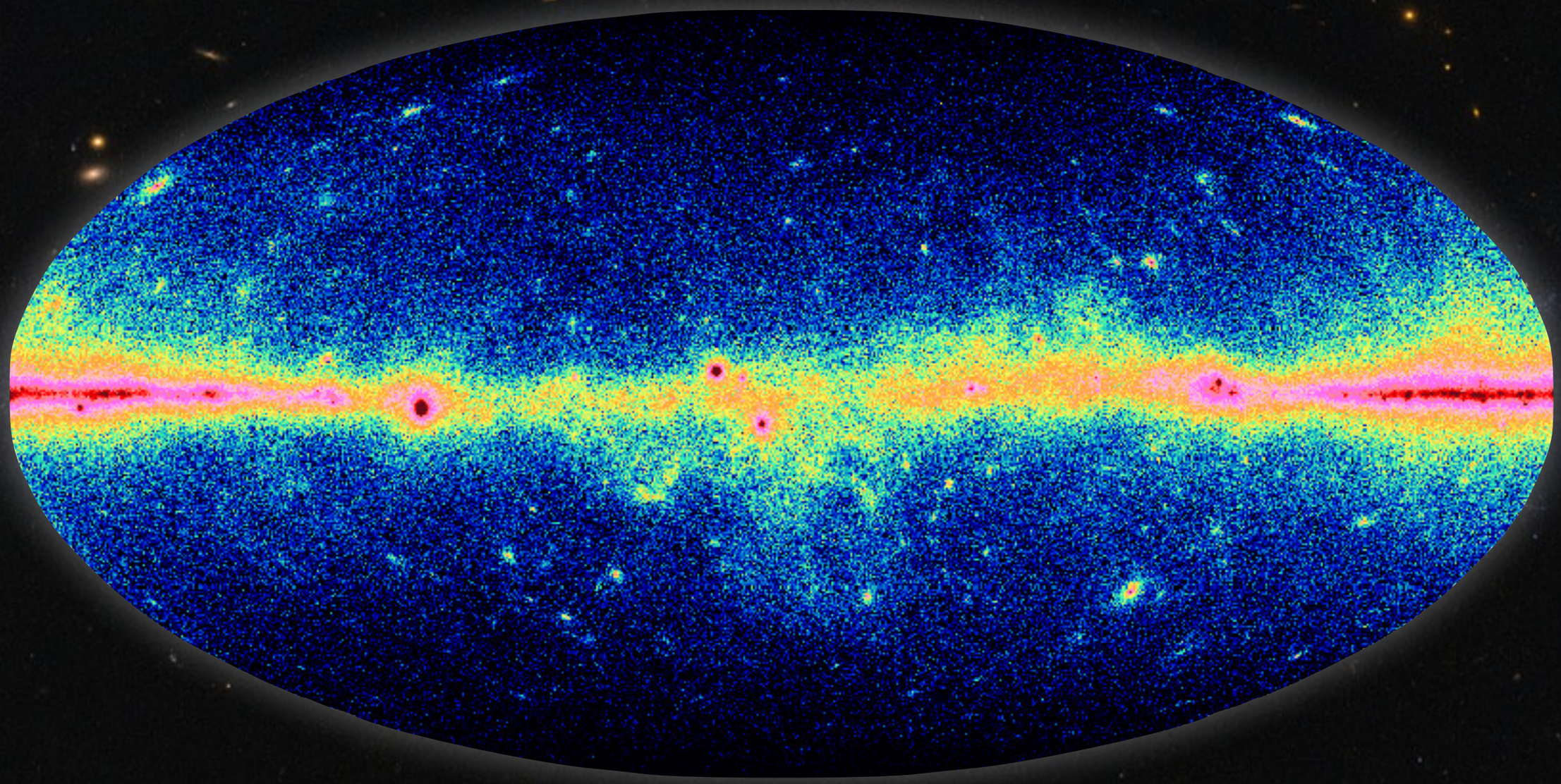
- Rotation and heating both help toward successful explosions.
- There seems to be a threshold in this parameters space between exploding and non-exploding cases.

Prospects

- Refining the boundary/robustness of the results?
- Mechanism(s) at play in those models?
- Studying some other parameters (accretion rate?).
- Some other projects I could not speak about in 5 minutes.

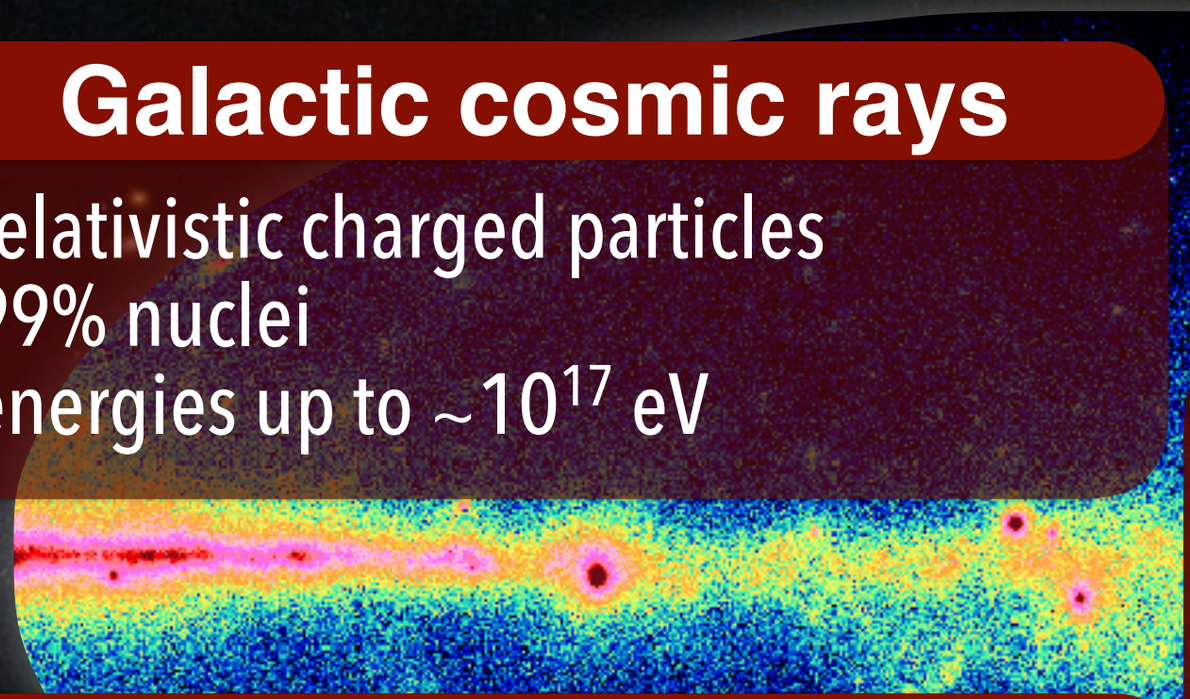
Thank you for your attention.
And now, please fasten your seat belts!

Cosmic rays in the Orion-Eridanus superbubble



Théo Joubaud,
with Isabelle Grenier and Jean-Marc Casandjian

Cosmic rays



Galactic cosmic rays

- relativistic charged particles
- 99% nuclei
- energies up to ~10^{17} eV

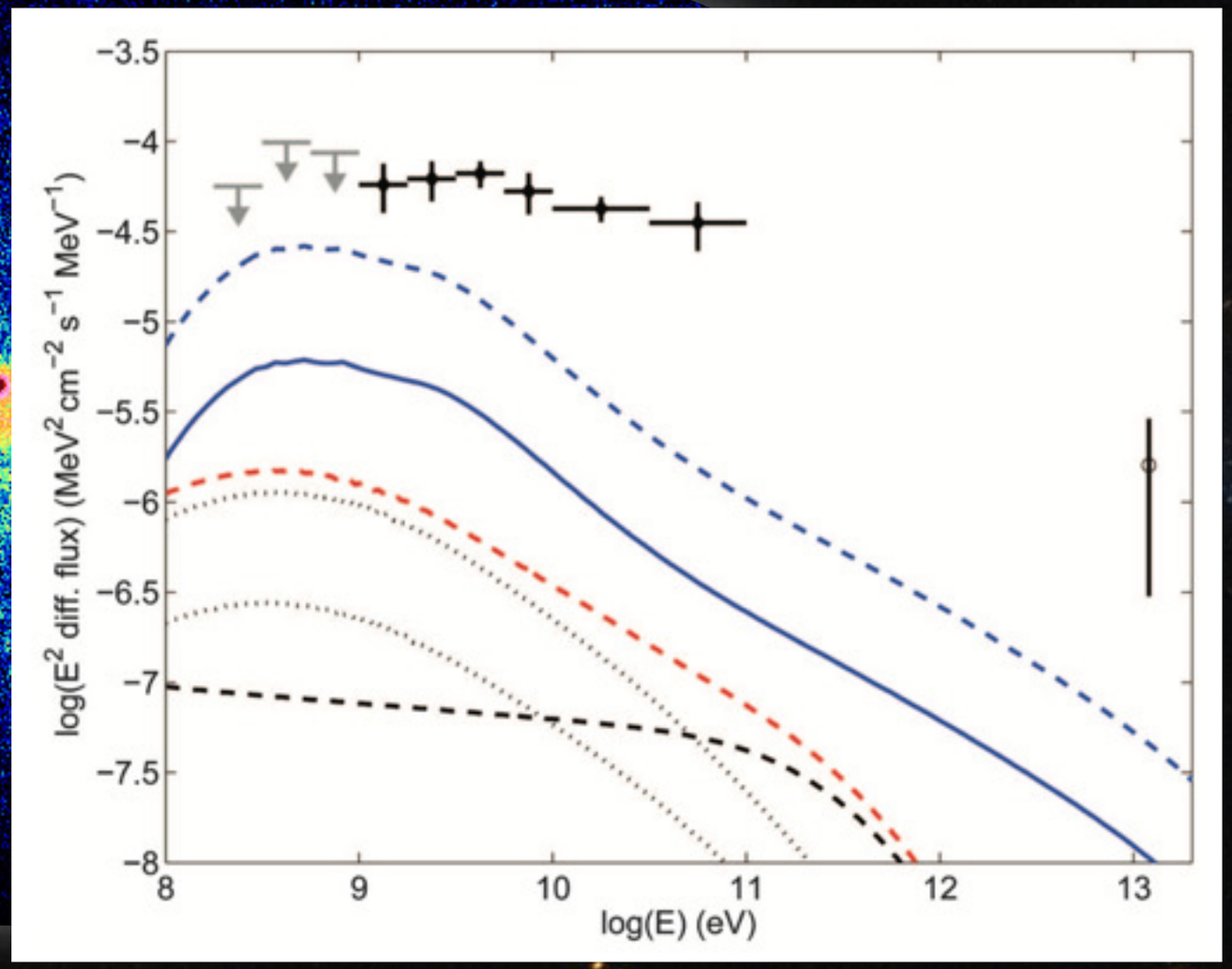
Origin(s) ?

- Shock waves of supernova remnants
- Superbubbles
- Pulsars ? …

Multi-task particles

- ionization & heating of the molecular clouds
- Galactic wind driving
- Magnetic field amplification
- Total gas tracers

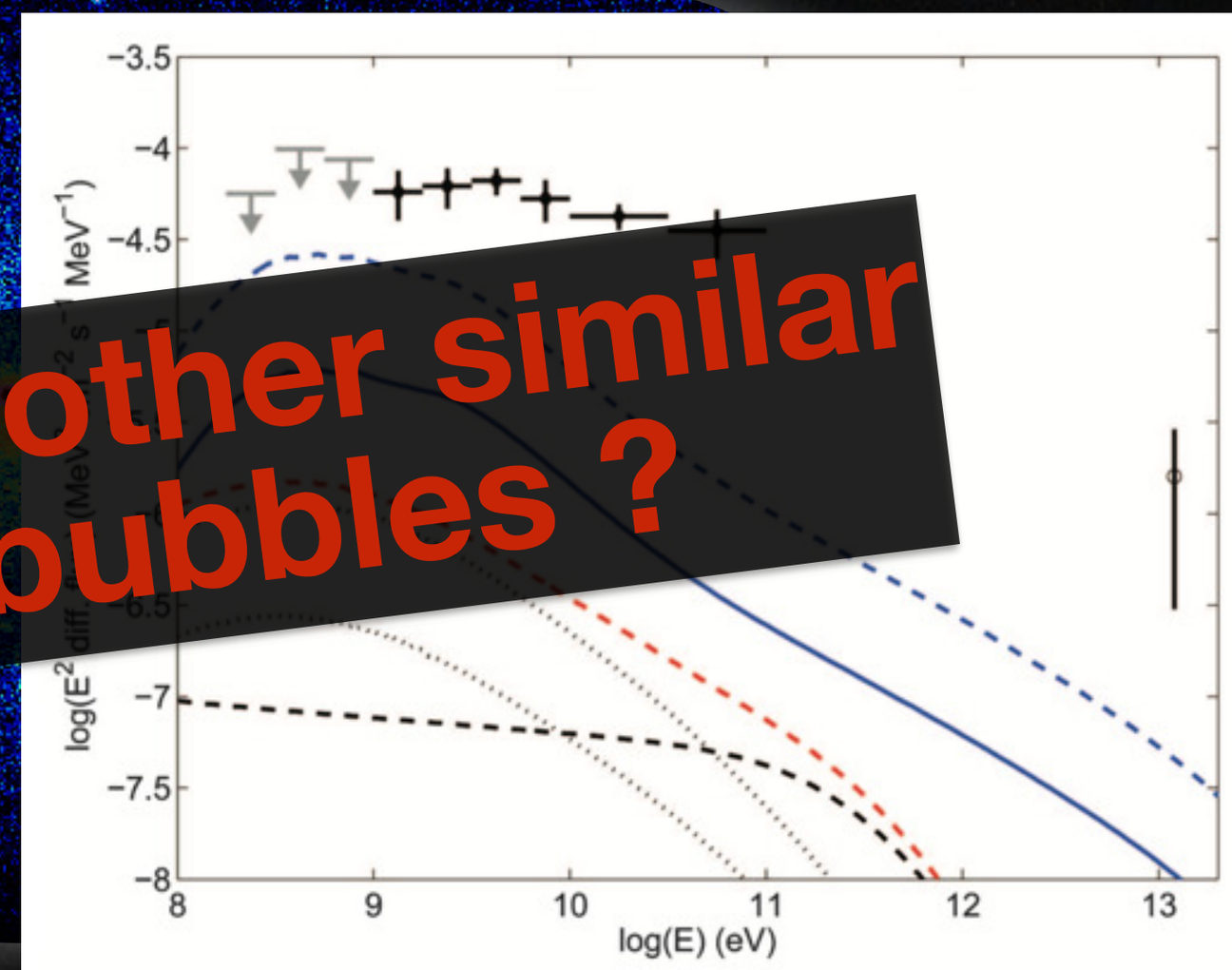
Cosmic rays & superbubbles : the Cygnus cocoon



radio, infrared, Fermi

Ackermann et al, 2011

Cosmic rays & superbubbles : the Cygnus cocoon

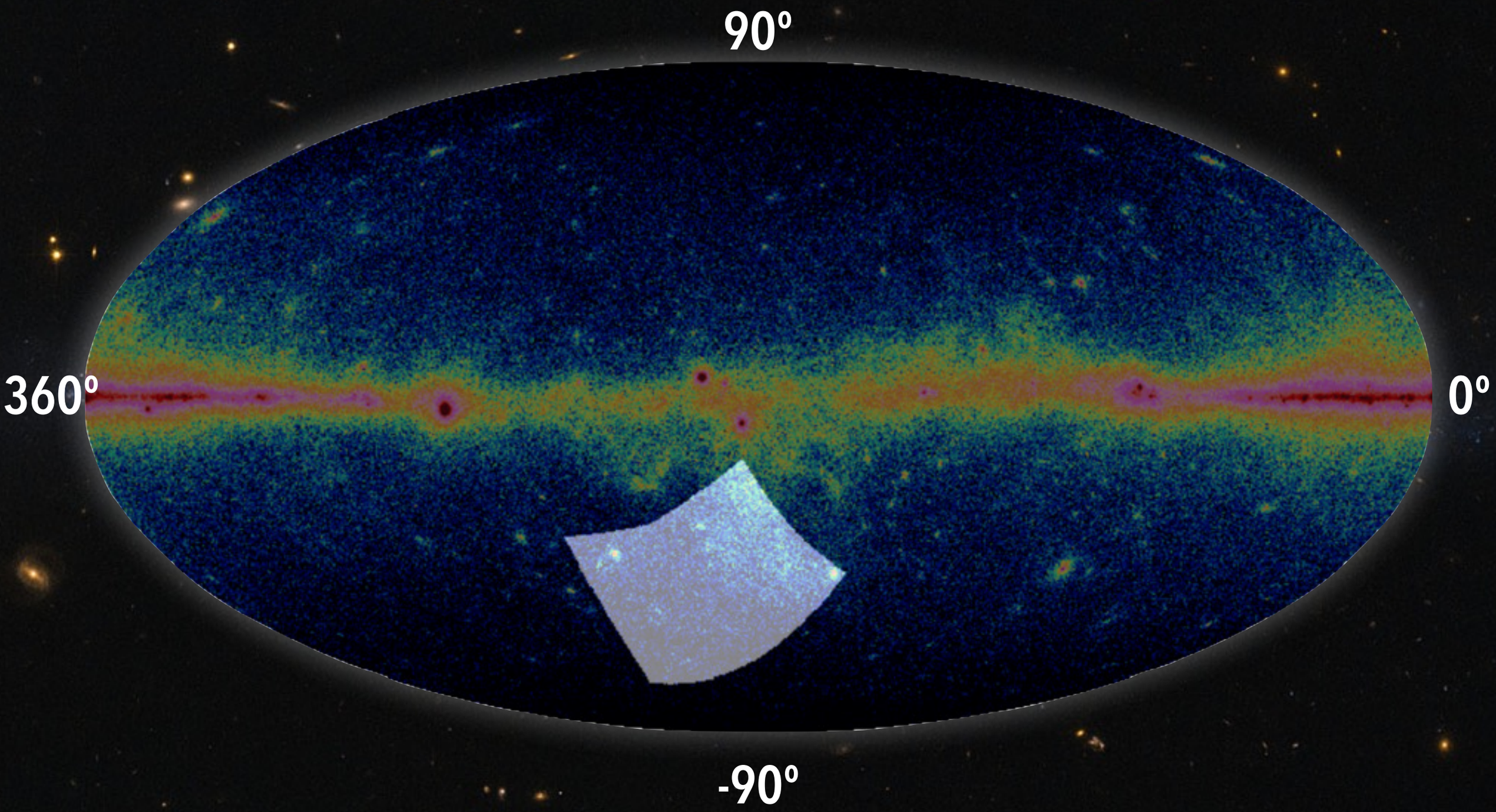


Are there other similar superbubbles ?

radio, infrared, Fermi

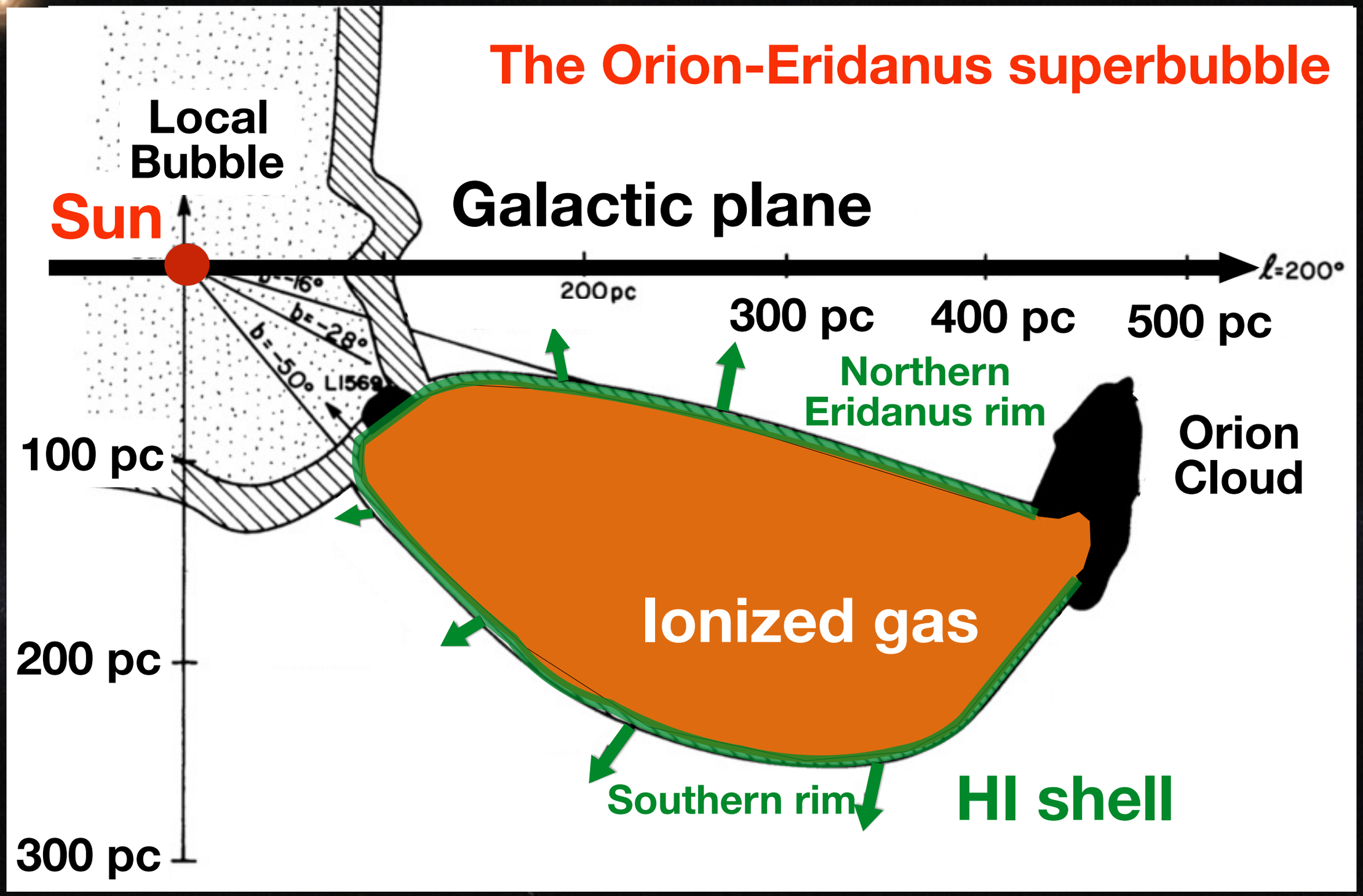
Ackermann et al, 2011

The Orion-Eridanus superbubble



γ rays > 250 MeV

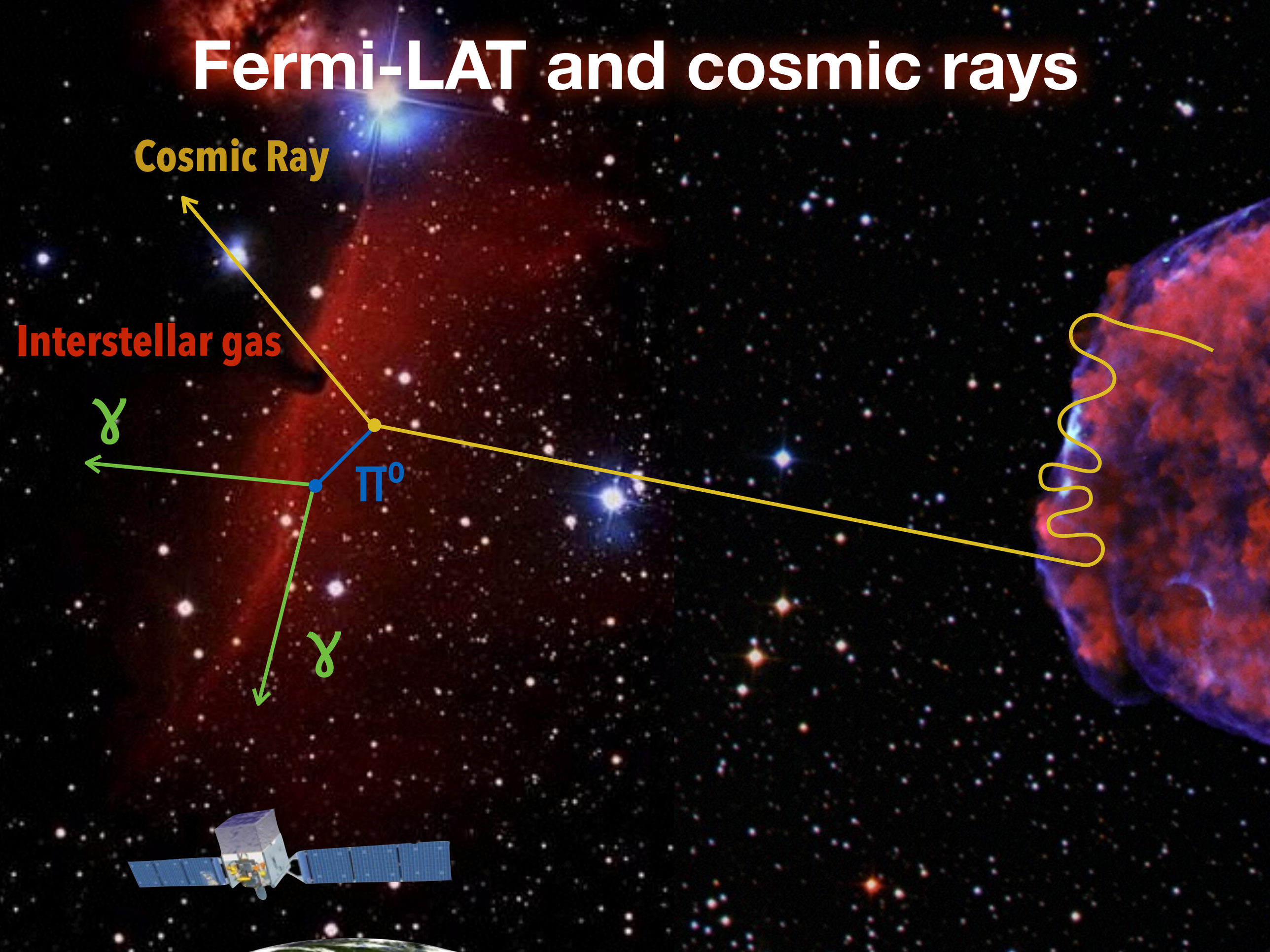
The Orion-Eridanus superbubble



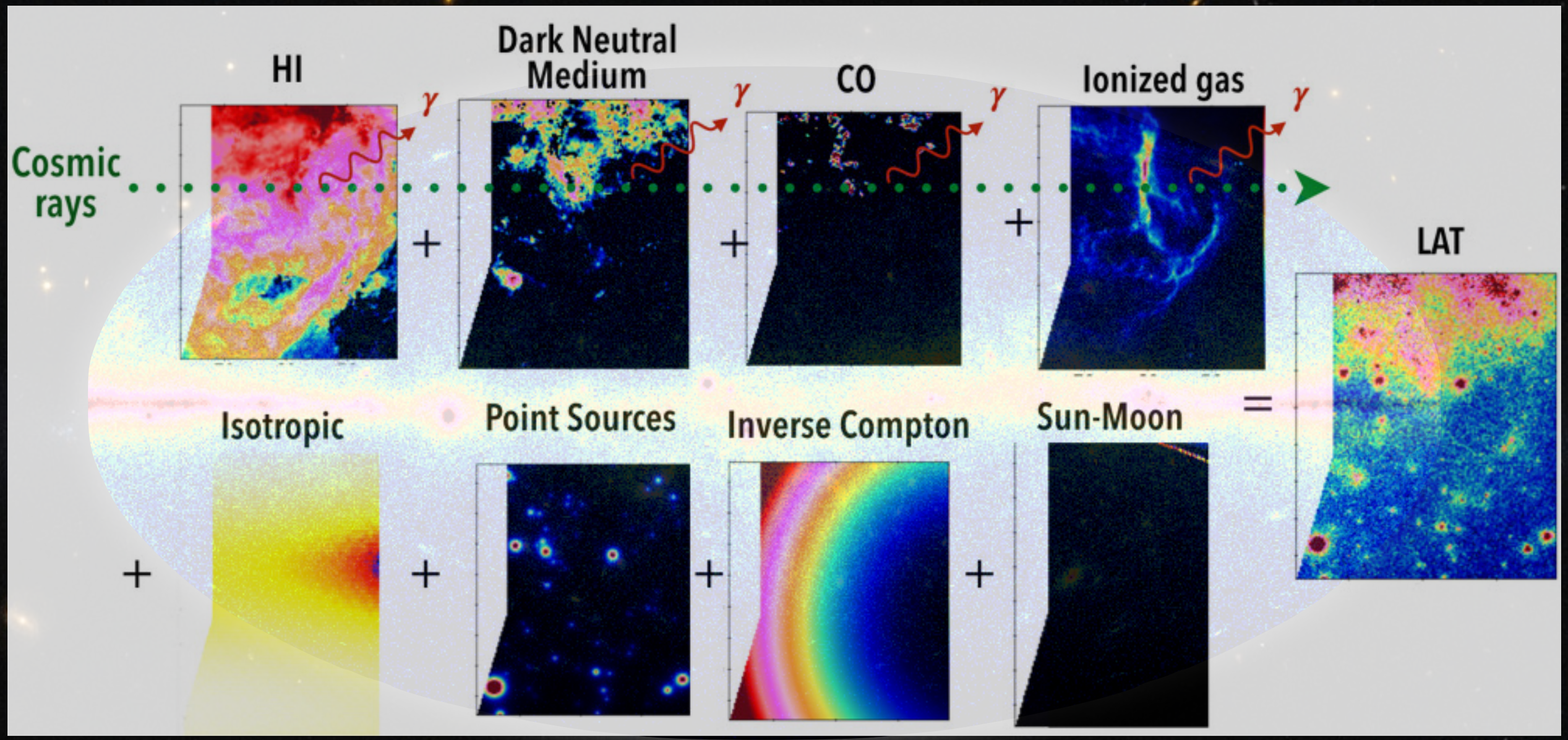
Characteristics

- 300 pc in diameter
- d ~ 180-400 pc
- last 12 Myr : 10-20 Supernovae
- last 12 Myr : 30–100 formed stars with $M \geq 8\ M_\odot$

Fermi-LAT and cosmic rays

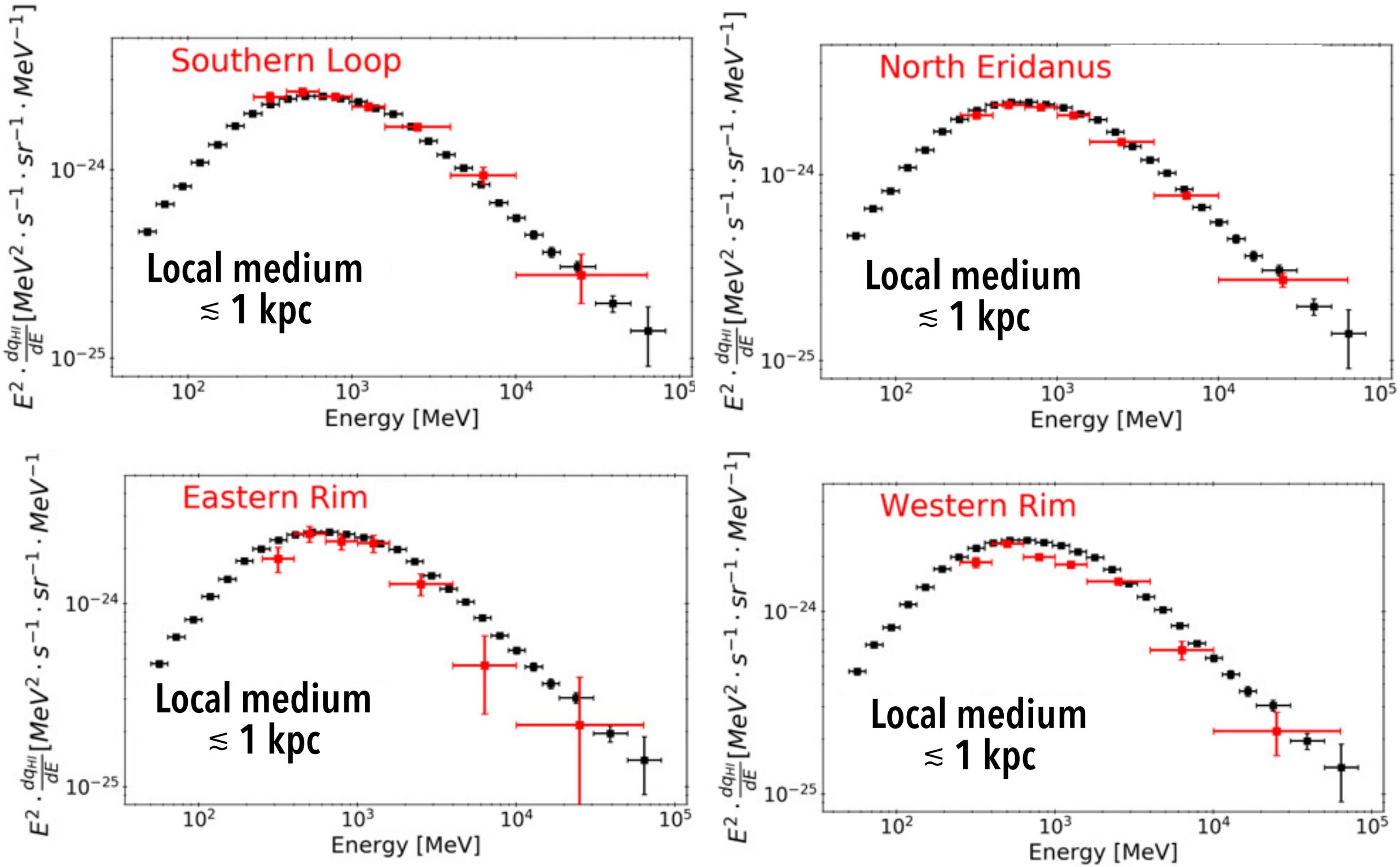


Model of the γ-ray emission

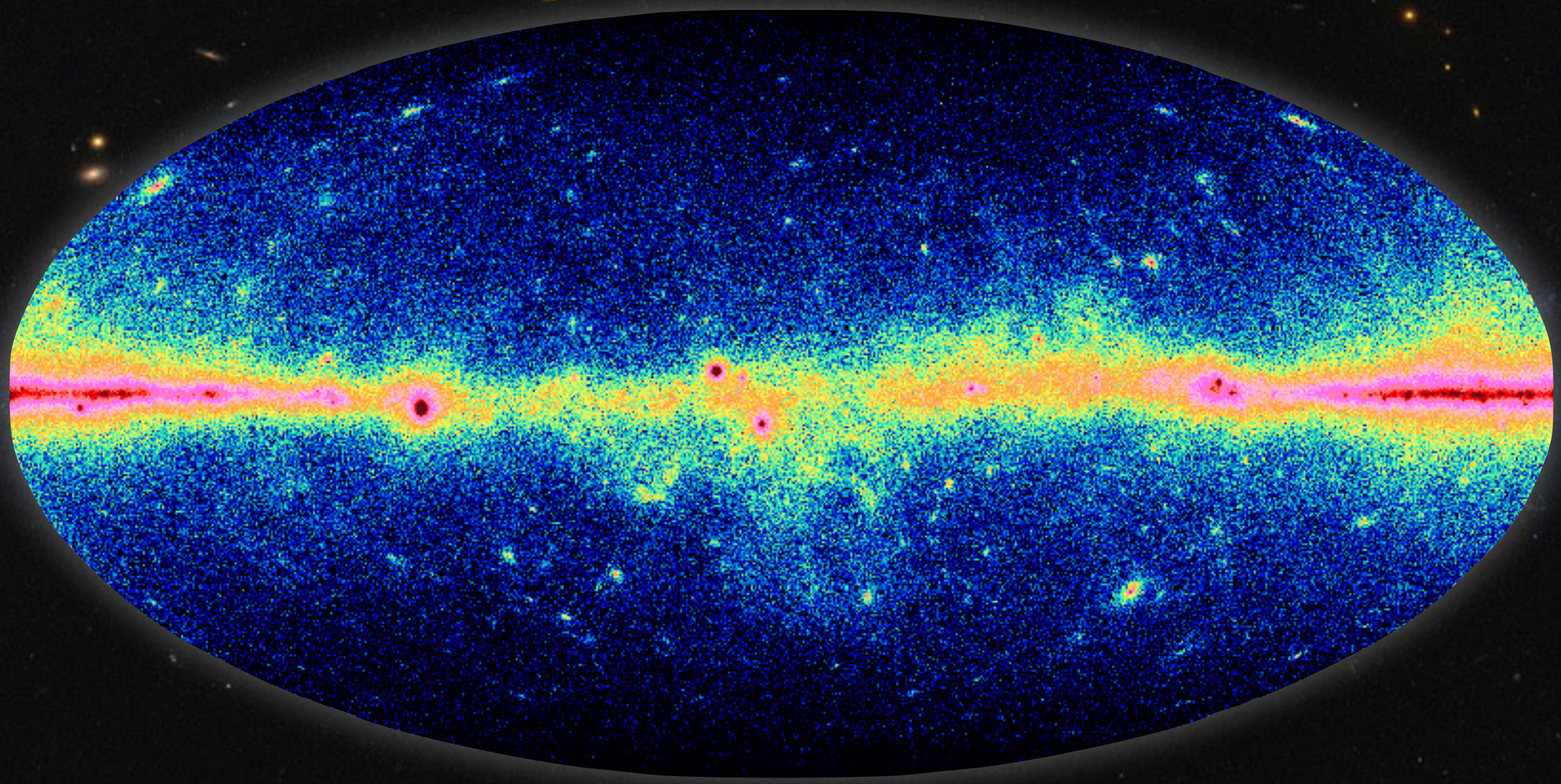


Emissivity [$\gamma.\mathrm{nuc}^{-1}.s^{-1}.\mathrm{sr}^{-1}$]

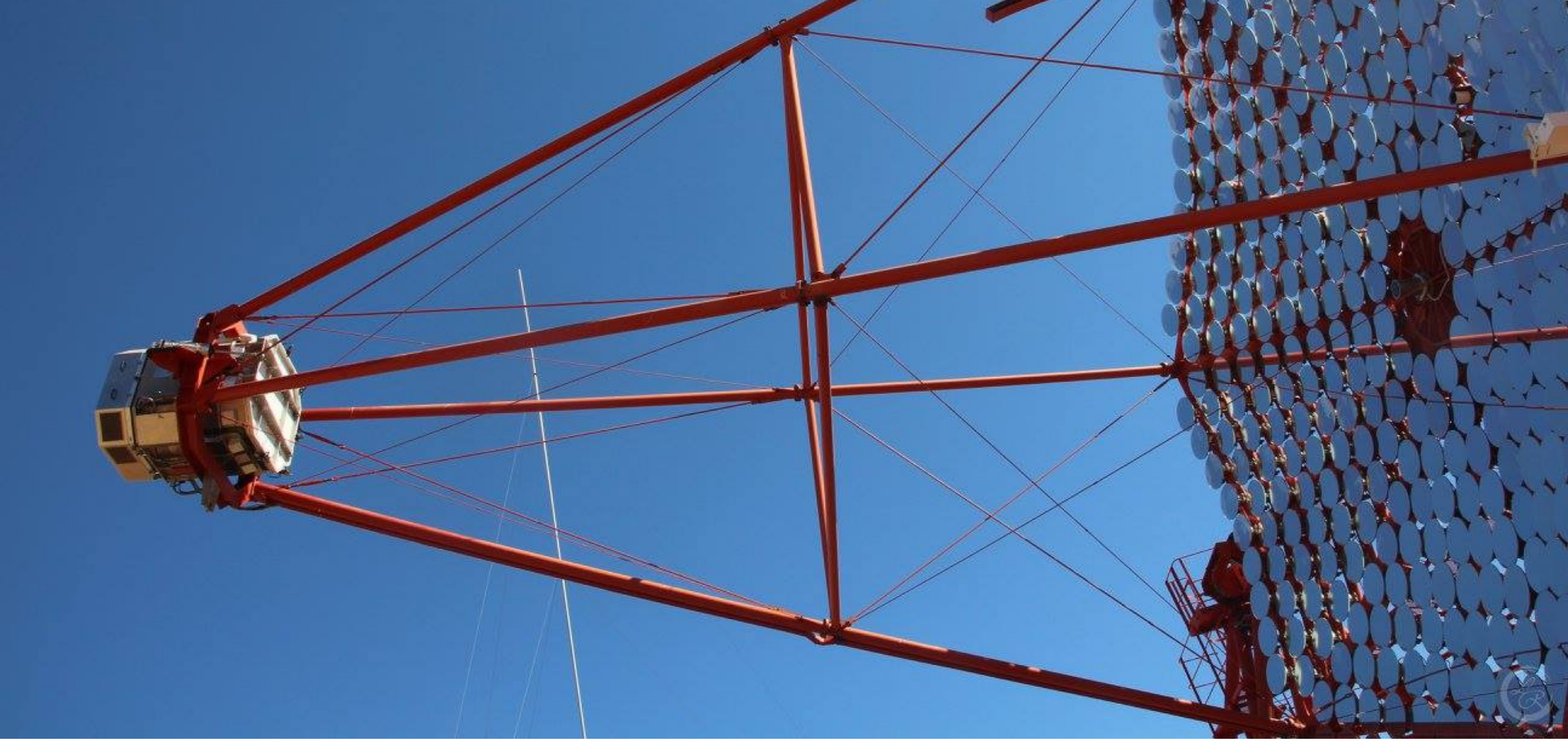
No hints of (re-)acceleration



Thank you for your attention…



…and let’s jump to higher energies !



Study of the Galactic Center region and dark matter search with H.E.S.S.

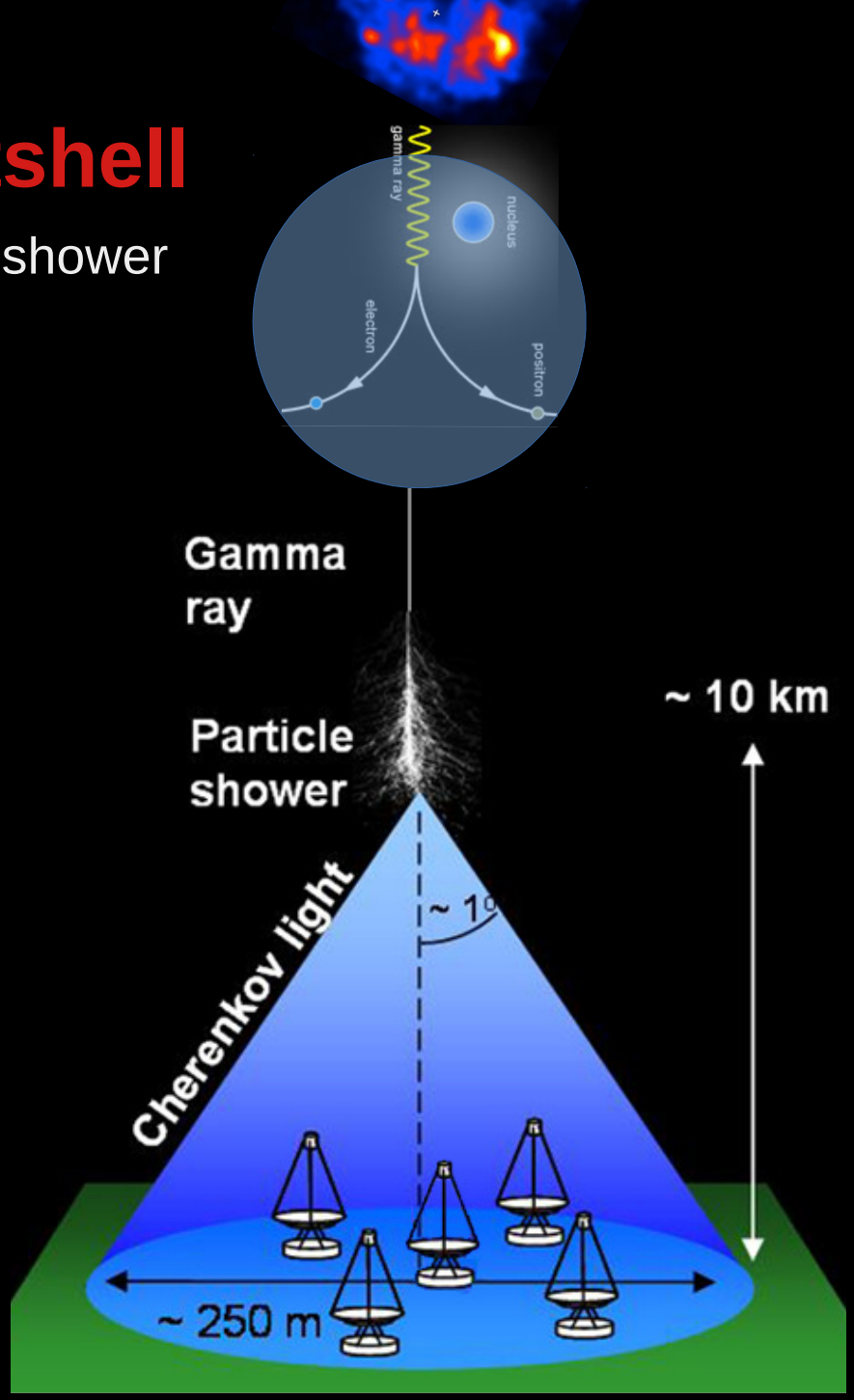
Lucia Rinchiuso

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

Detection principle in a nutshell

- The atmosphere acts like a calorimeter → shower
- Electrons produce Cherenkov light
- The telescopes fall in the cone

- H.E.S.S. (since 2003)
  - 5 telescopes (since 2014, 4 before)
  - FoV 5 deg
  - Energy resolution 10%E
  - Angular resolution <1%
  - Energy range 50 GeV-70 TeV



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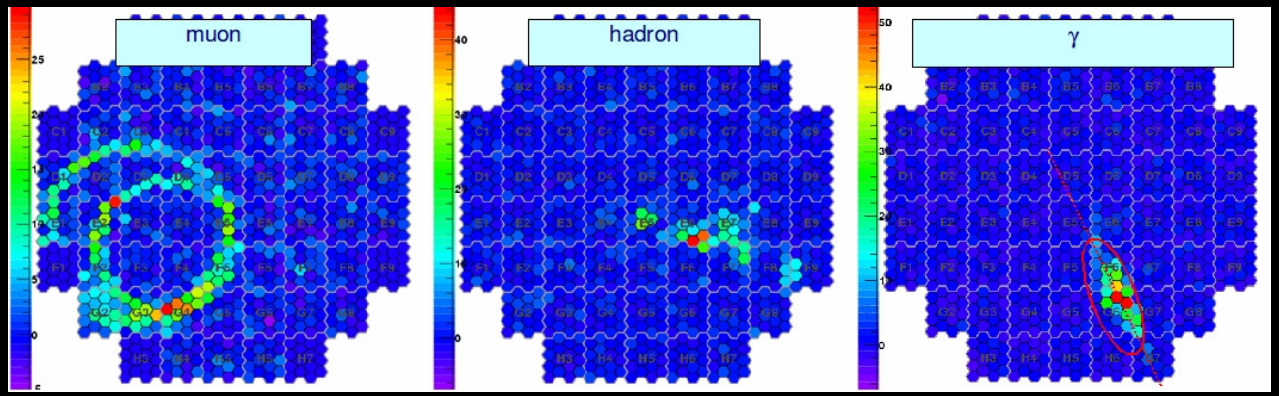
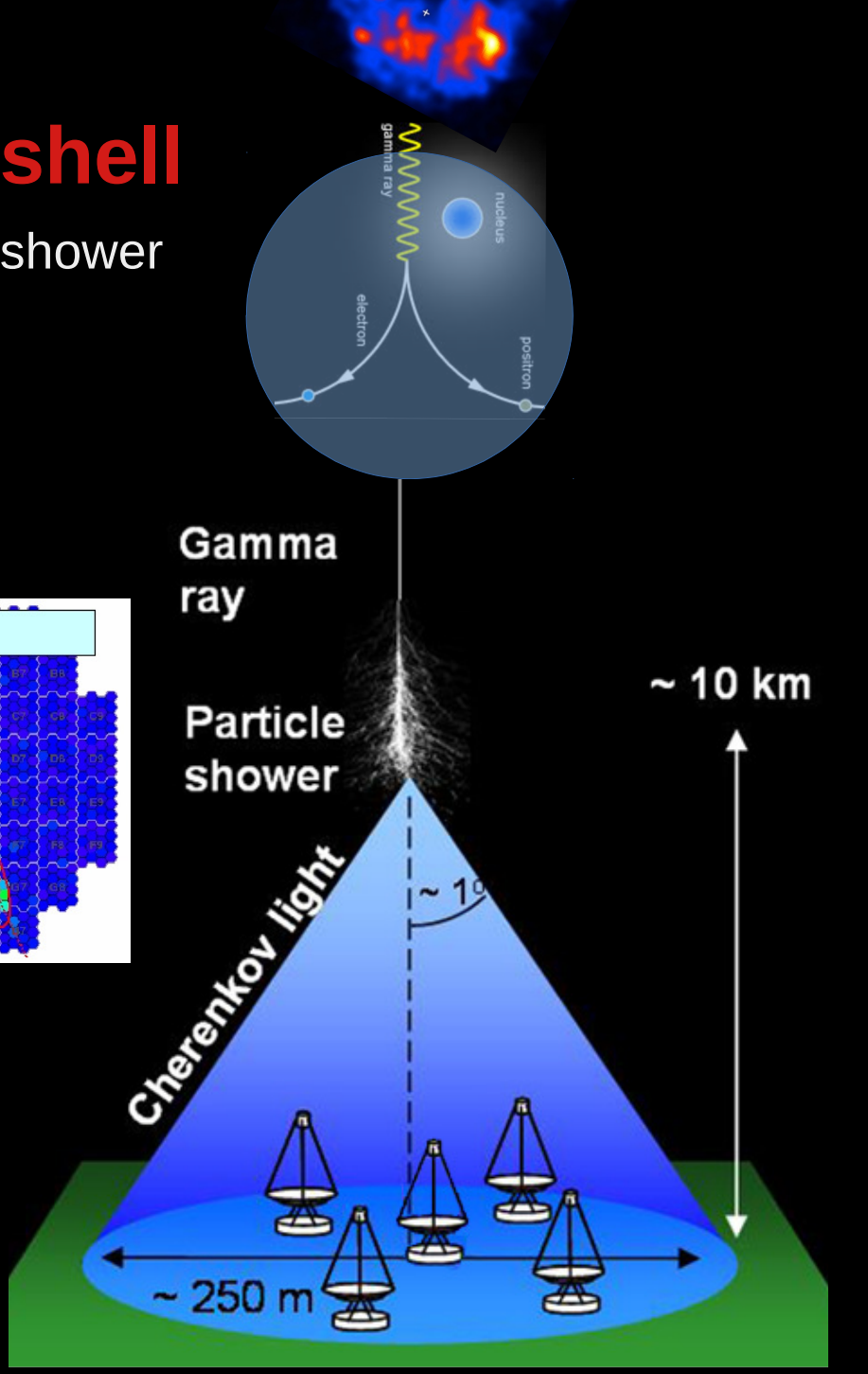
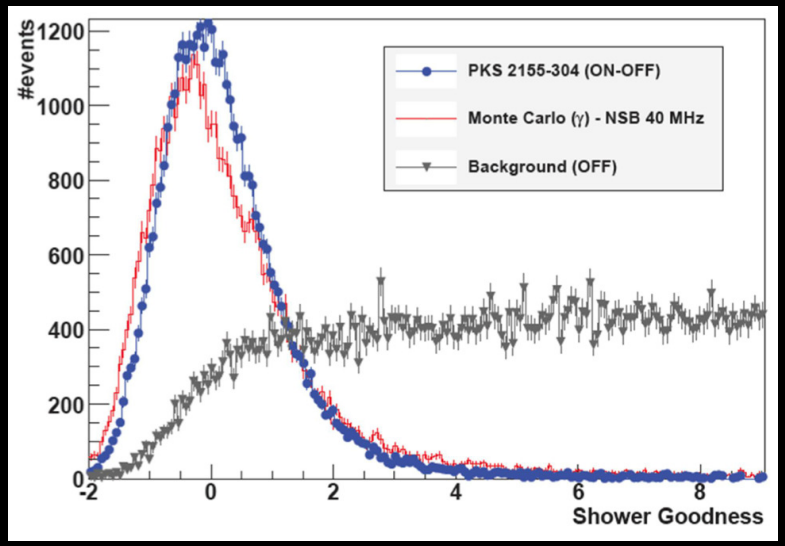


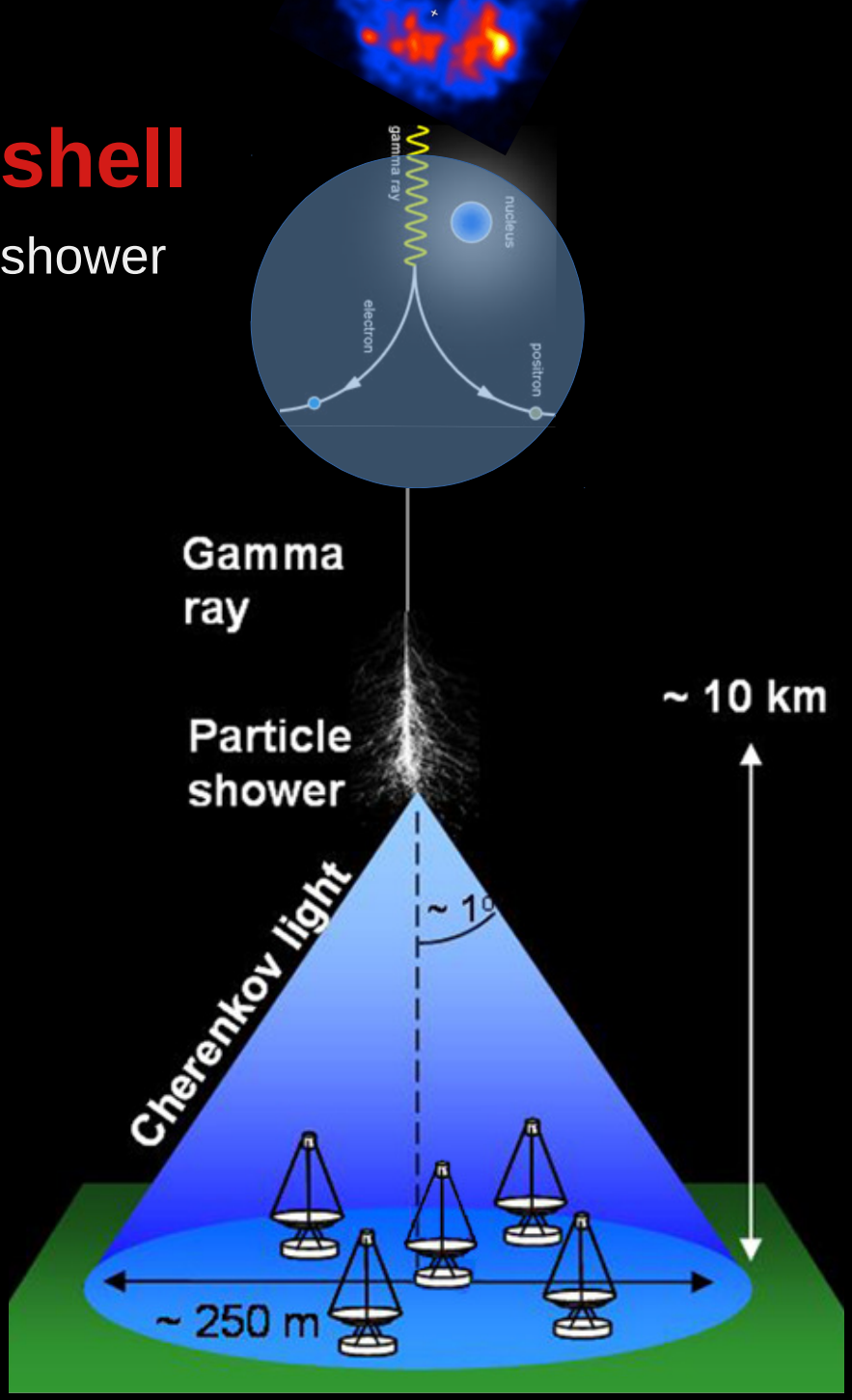


Detection principle in a nutshell

- The atmosphere acts like a calorimeter → shower
- Electrons produce Cherenkov light
- The telescopes fall in the cone
- Background discrimination:
  - stereoscopy
  - triggers
  - shape discrimination

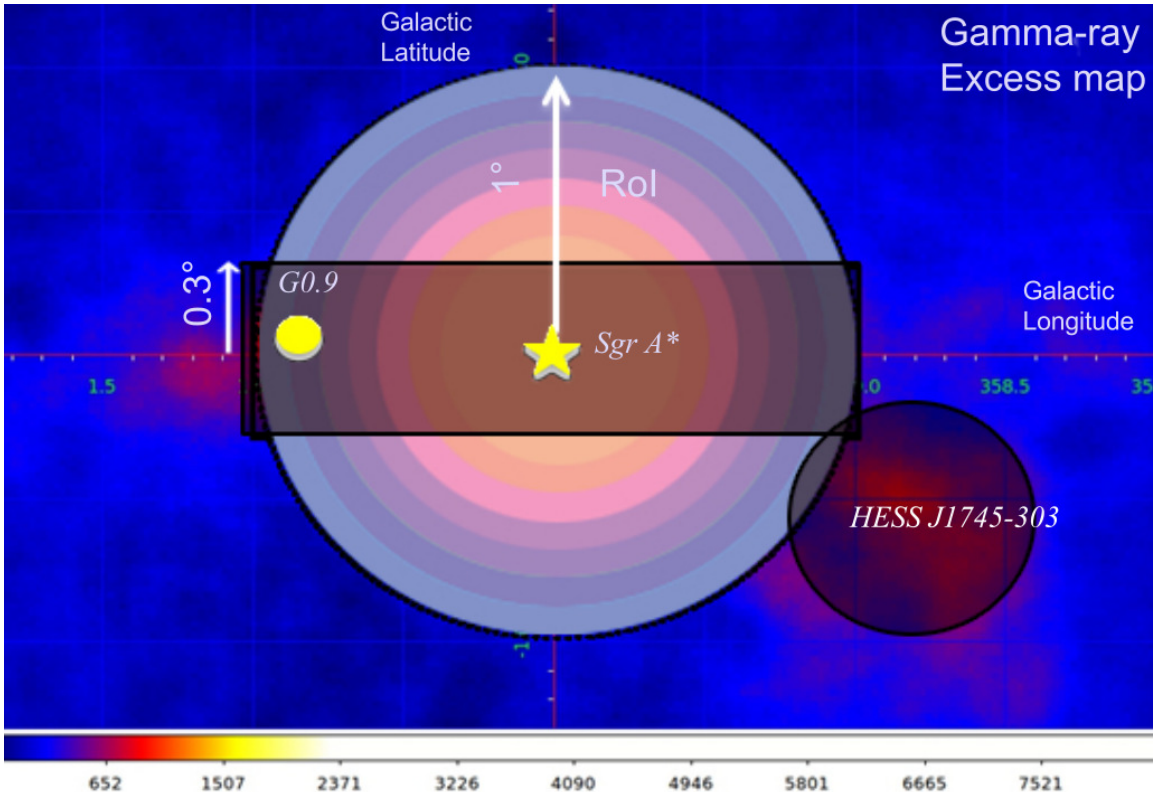


The mis-identified hadrons are the **residual background**



Observations of the GC with H.E.S.S.

- H.E.S.S. is in an ideal location to observe the Galactic Center (GC)
- **GC is a very crowded region in VHE**: TeV diffuse emission, SNR HESS J1745-303, PWN G09+01, HESS J1745-290 coincident with Sgr A*
  - A *Pevatron* has been detected in this region



254 live hours of observations with H.E.S.S. I (2004-2014) toward the GC:

- Region of interest: circle of 1° radius around GC (split in 7 sub-regions)
- Excluded regions: Galactic plane and HESS J1745-303
- Background measured in the same field of view of the signal

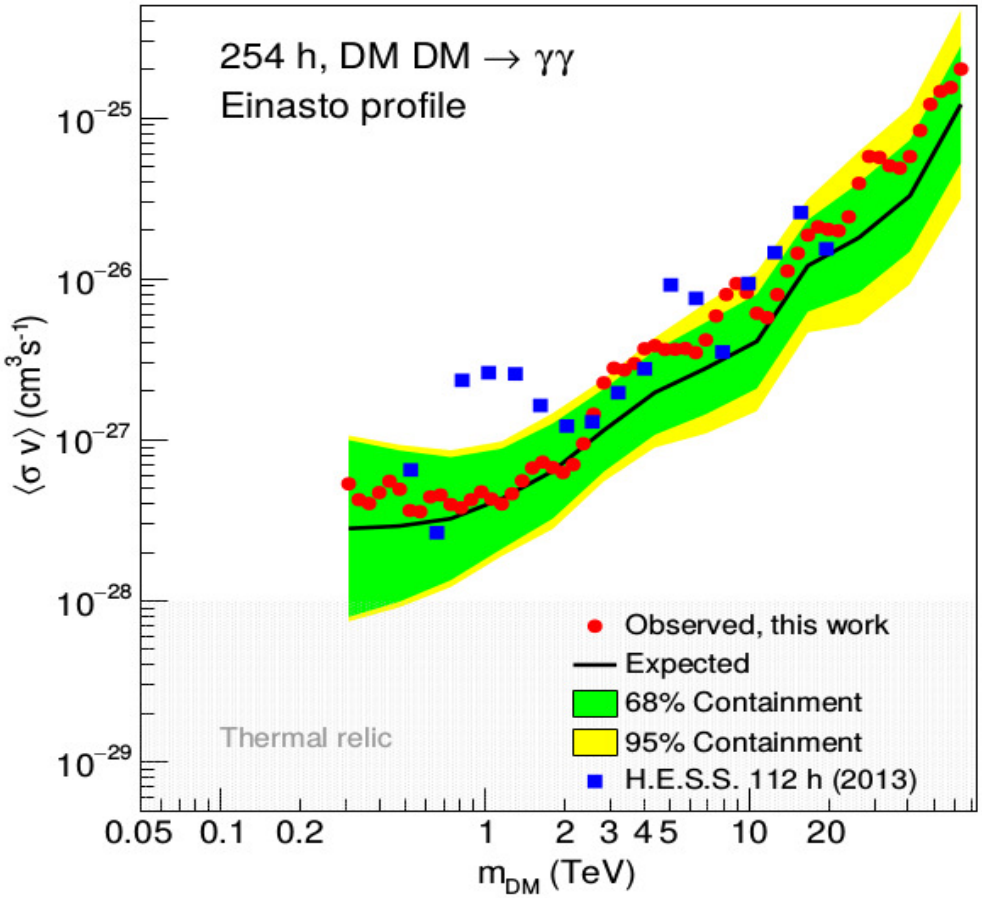
Search for DM toward the GC

Phys. Rev. Lett. 120, 201101 (2018)

- No significant signal observed in any of the RoI
  - Constraints on the annihilation cross section
  - 2D-binned likelihood ratio test statistic

- Search for mono-energetic gamma lines
  - From 300 GeV-70 TeV

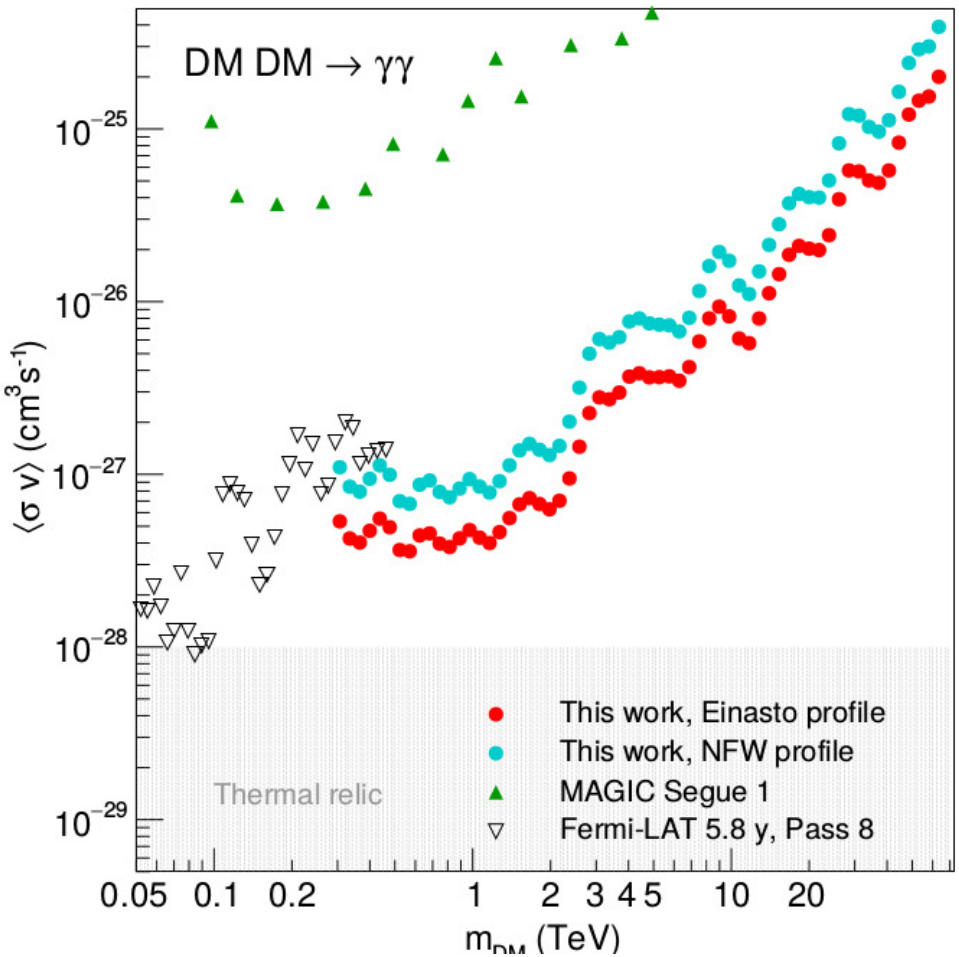
- **Most stringent limits in the TeV DM mass range so far**



Search for DM toward the GC

Phys. Rev. Lett. 120, 201101 (2018)

- Most stringent limits in the TeV DM mass range so far
- **Well complement Fermi-LAT limits obtained at lower masses**
- Explore relevant velocity-averaged cross sections **close to the thermal relic cross section**

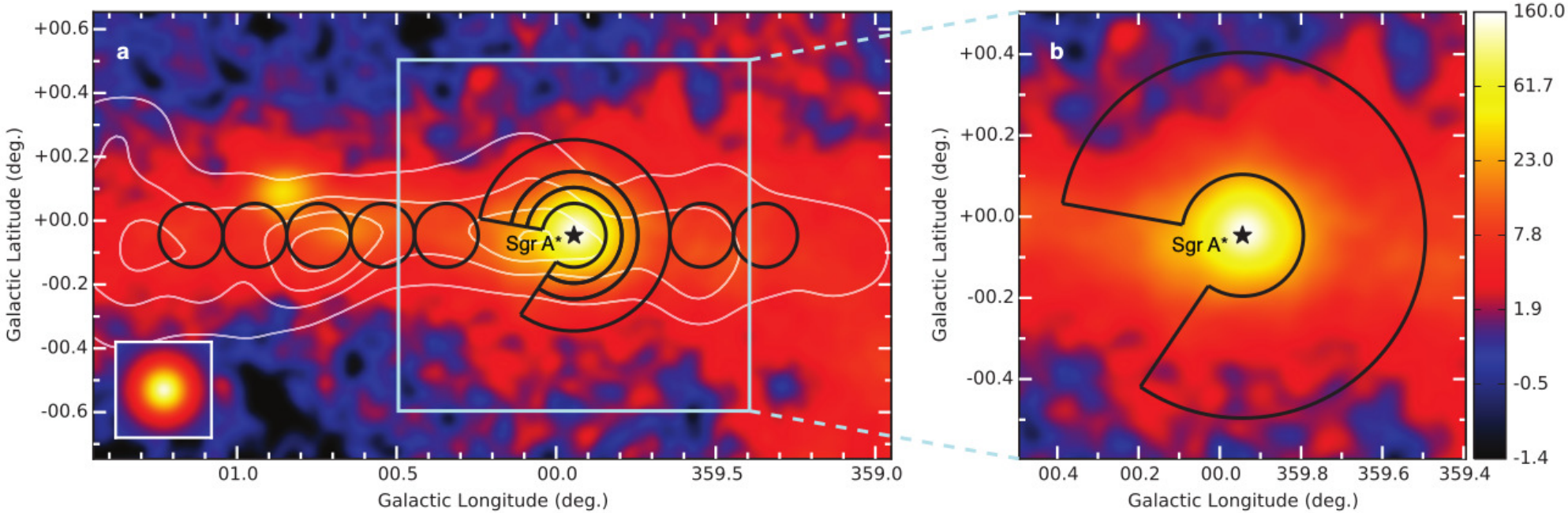


Ongoing long-term survey of the region around the GC with H.E.S.S. II

- Improved sensitivity to DM annihilation toward the GC
- Searched for GC outflows

TeV diffuse emission in the GC

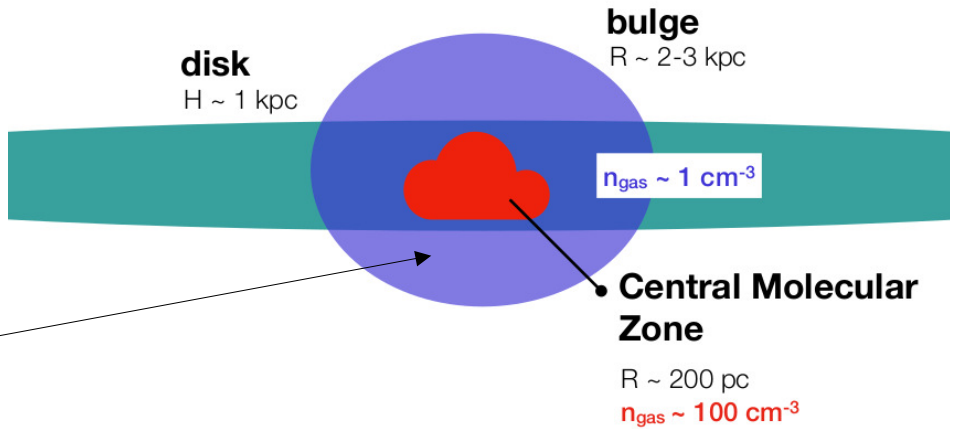
See: Nature 531, 476 (2016)

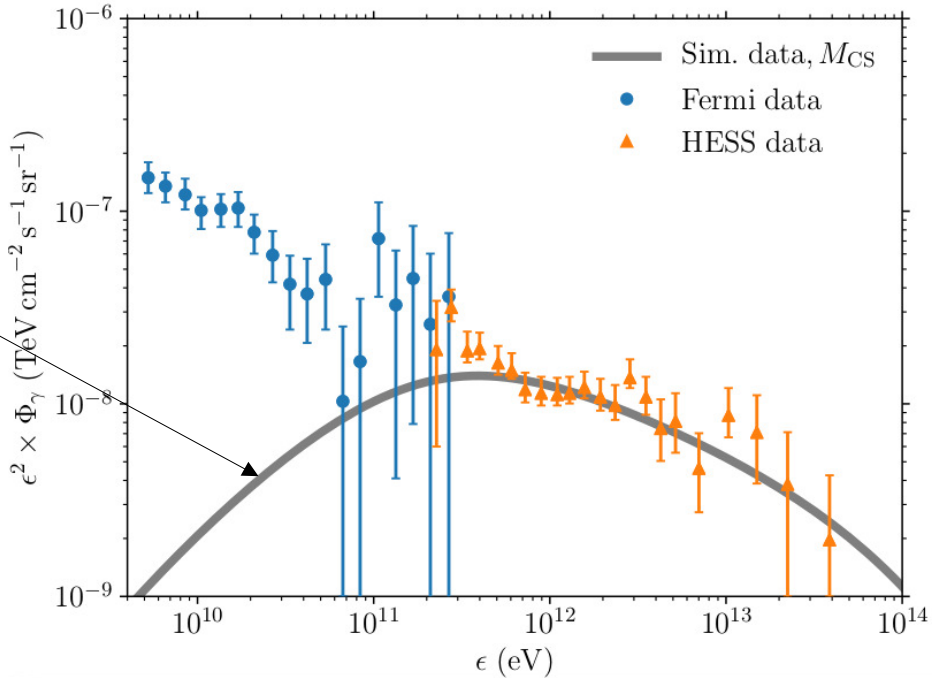


- **Diffuse emission observed at VHE by H.E.S.S.**
  - Correlated with central molecular cloud
  - Hints for protons acceleration at GC: Pevatron
  - The ratio of the TeV flux to the gas density provides the CR density

TeV diffuse emission in the GC

- Hints for protons acceleration at GC: Pevatron
- *GC excess* seen by Fermi-LAT
  - ➔ unresolved sources population: millisecond pulsars (MSP)
- Could the **TeV emission** be **explained by** such an **unresolved population of MSP**?
  - Bulge population of 10^5-10^6 pulsars can do it
- Improved H.E.S.S. measurement at higher latitudes/energies would help to constrain the MSP population





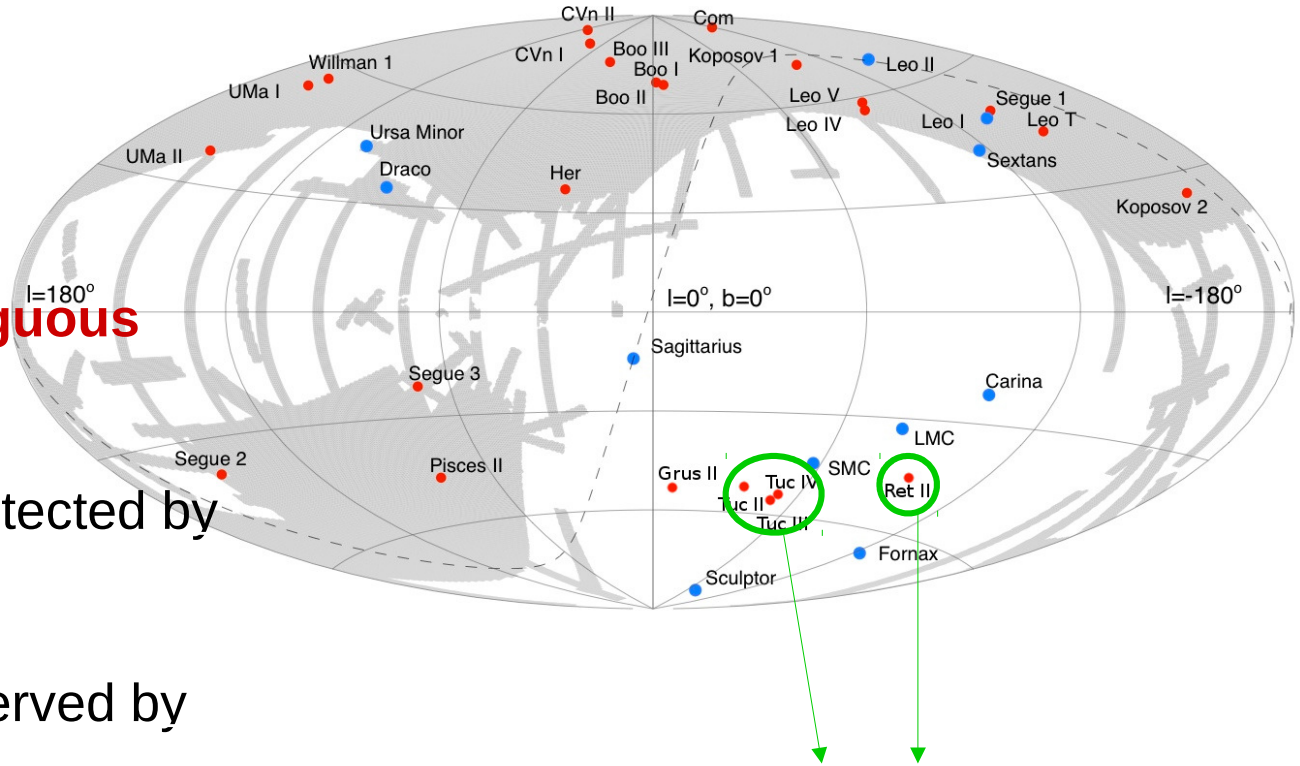
Arxiv 1806.03307, accepted by JCAP 2018

DM search toward dwarf galaxies

No recent star formation
Very low gas amount:
"clean" in VHE γ-rays
they **could give unambiguous detection**

Very recently ultra-faint detected by DES

- those in the Southern hemisphere can be observed by H.E.S.S.
- we **observed Reticulum II, Tucana II and Tucana III**



Observed by H.E.S.S. in 2017

Paper in preparation

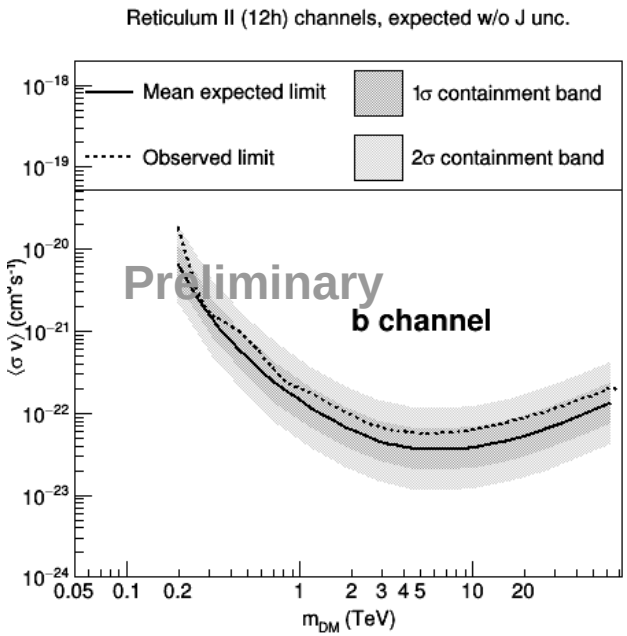
DM search toward dwarf galaxies

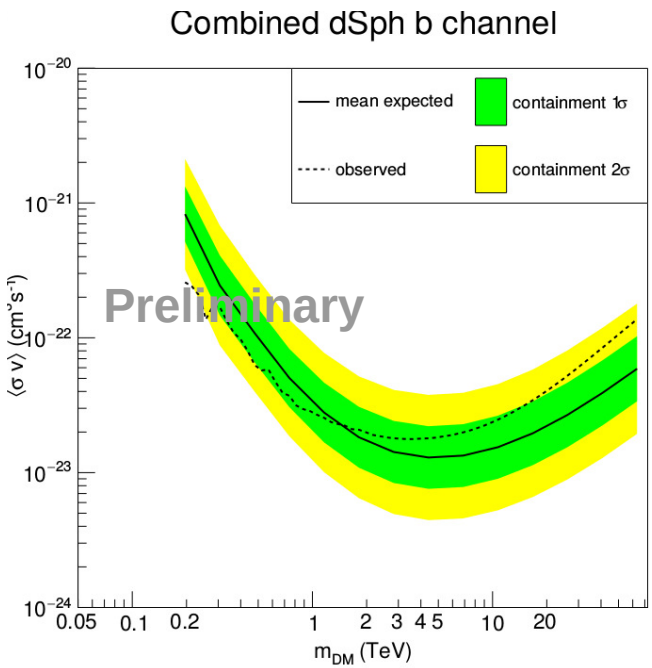
Very recently ultra-faint detected by DES

- those in the Southern hemisphere can be observed by H.E.S.S.
- we **observed Reticulum II, Tucana II and Tucana III**

Set limits complementary to other DM searches and other telescopes observations

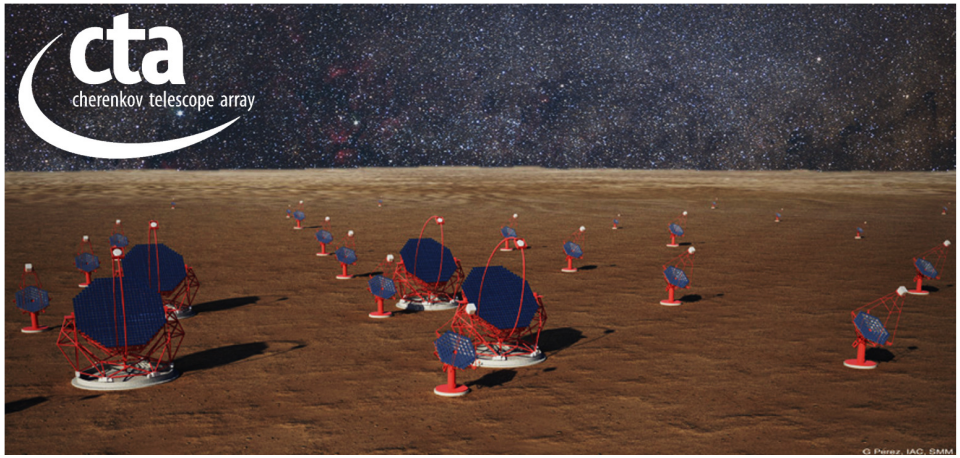
- Several annihilation channels considered
- **Combination of the data set** of the three galaxies
- Well complement Fermi-LAT limits

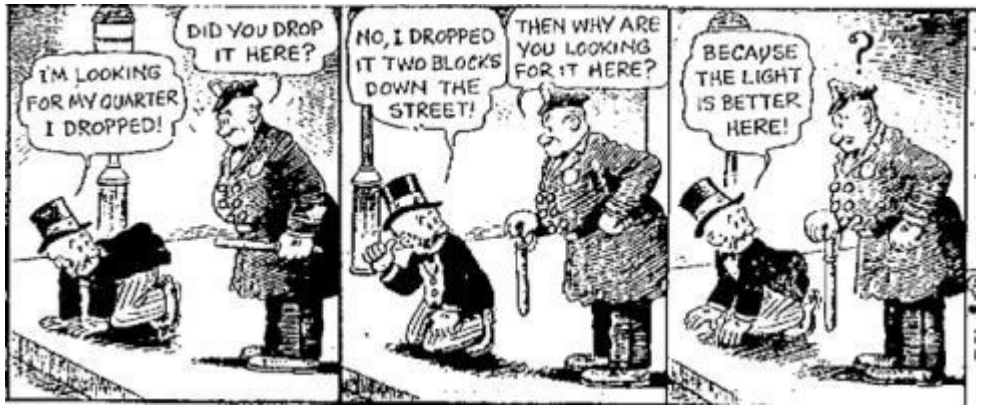




Nature of DM: still an open question

- No detection of DM so far with any technique
- Constraints are becoming more and more stringent and relevant
- Future experiments could shed light on DM → CTA era is approaching!





If WIMPs are ruled out...

- Warm DM: keV sterile neutrino, gravitino…
- Axions and axion-like particles
- Baryonic DM, e.g. PBH $O(10M_{\odot})$...
- Modified GR