The role of nova systems in the ^{26}Al abundance: constraints from INTEGRAL

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Outline

Introduction

- INTEGRAL data on ^{26}Al
- Scientific motivation

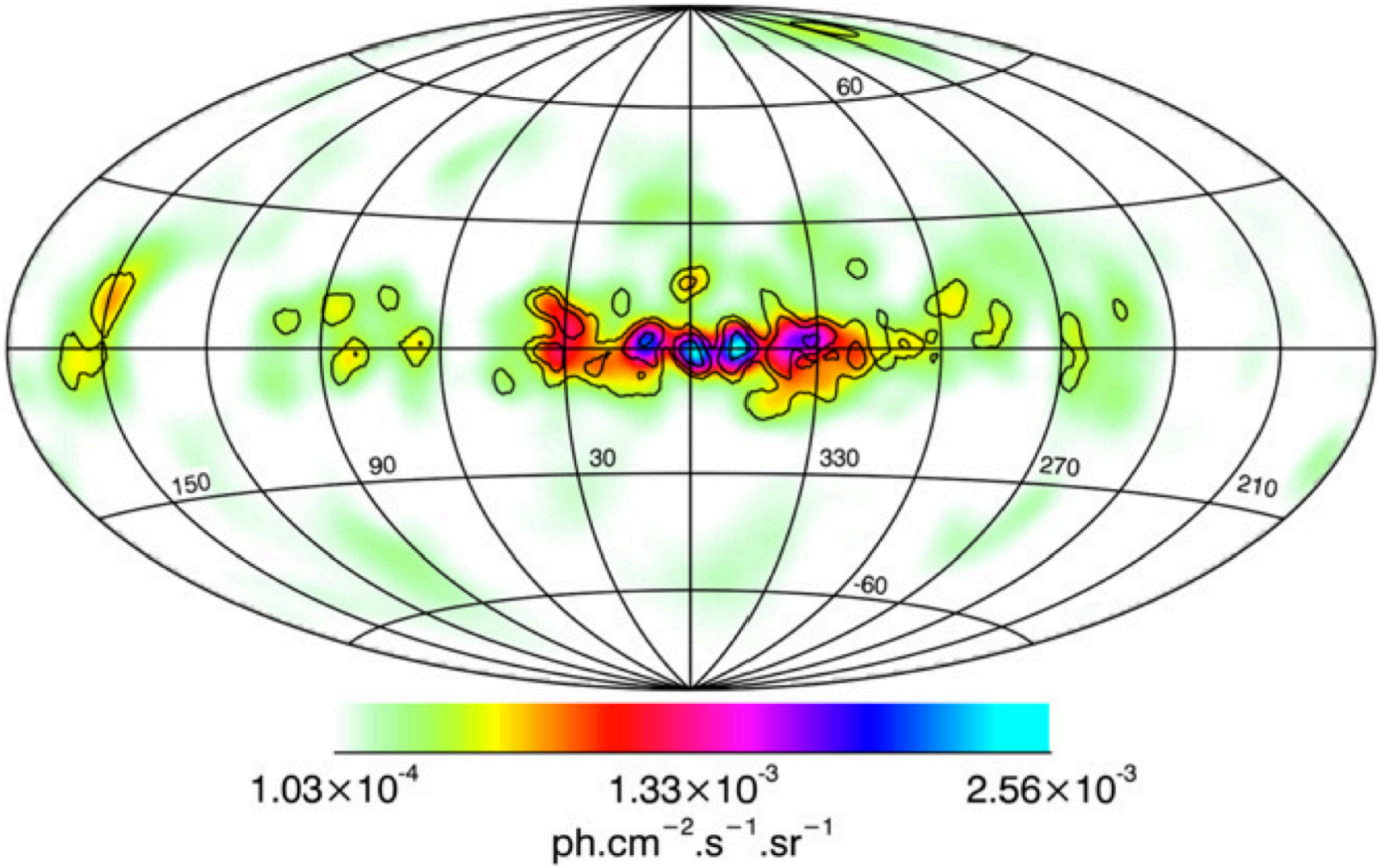
Chemical Evolution of ^{26}Al

- What is Chemical Evolution
- *Vasini+2022:* novae as ^{26}Al producers
- *Vasini+2024:* SFR tracing and bulge nova population

Conclusions

- Summary and future perspectives

INTEGRAL ^{26}Al map



Bouchet+15

1.809 MeV map of the Milky Way

decay of ^{26}Al:

$$^{26}\text{Al} \xrightarrow{\tau_{26al} = 1.035\ Myr} {}^{26}\text{Mg} + \gamma$$

Characteristics:

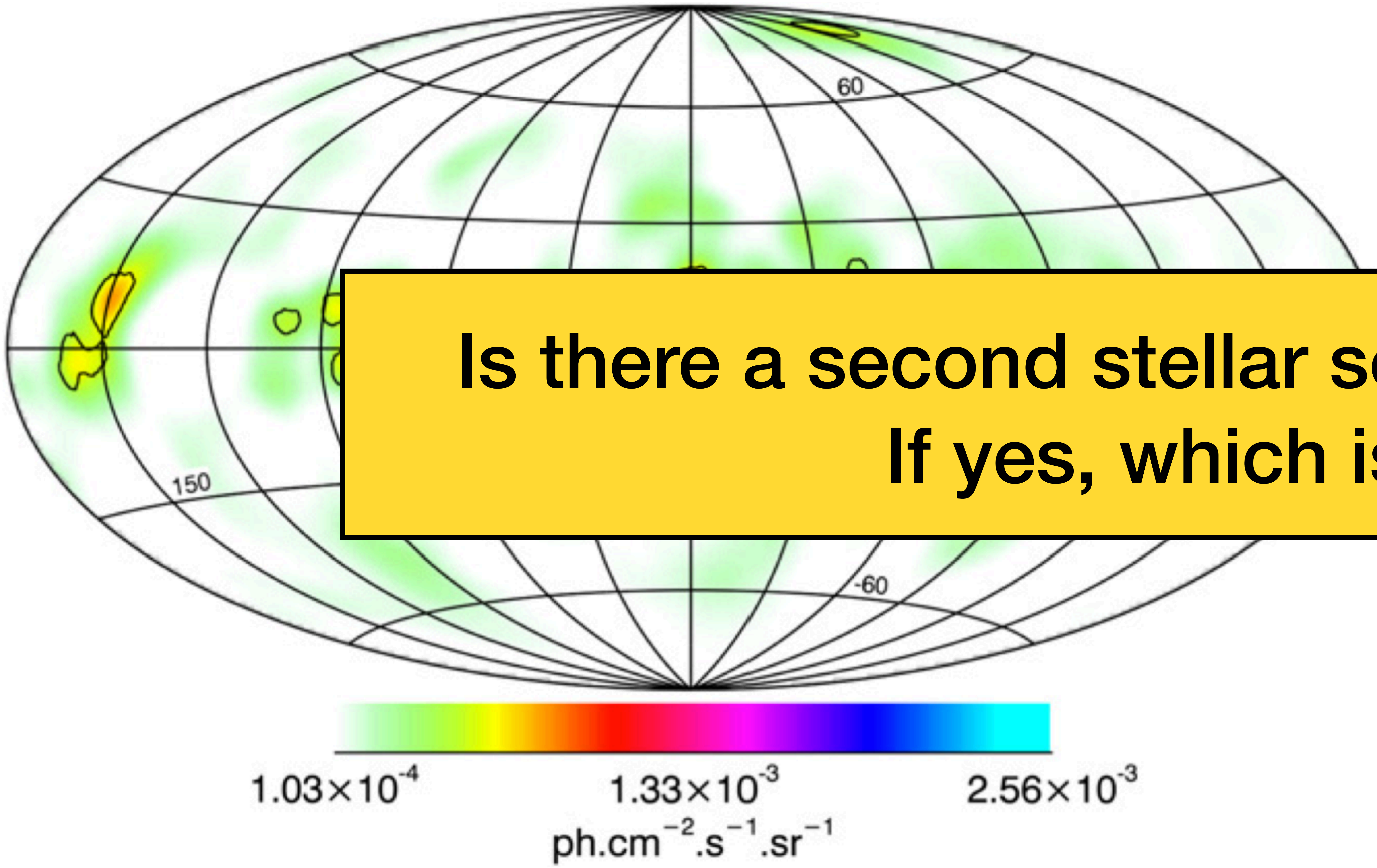
Distributed mainly on the Galactic plane

Not too smooth, not too clumpy

Concentrated in the direction of the bulge (bulge, something in the foreground…?)

⟶ **Massive stars + ??**

INTEGRAL ^{26}Al map



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decay of ^{26}Al:

$$^{26}Al \xrightarrow{\tau_{26al} = 1.035\ Myr} {}^{26}Mg + \gamma$$

Is there a second stellar source for ^{26}Al?
If yes, which is?

Distributed mainly on the Galactic plane

Not too smooth, not too clumpy

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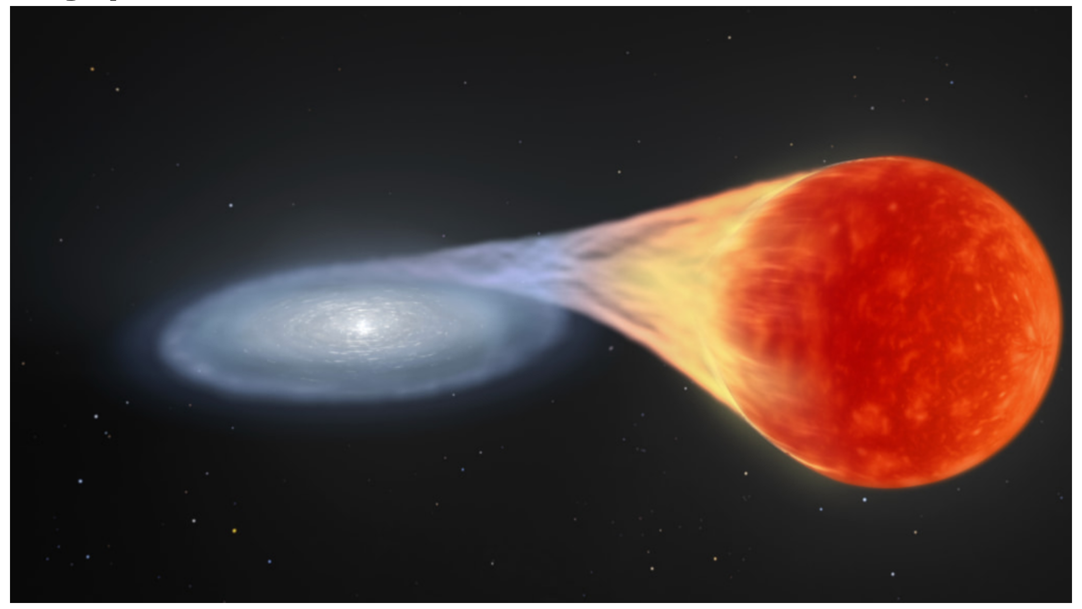
⟶ **Massive stars + ??**

Why do we care?

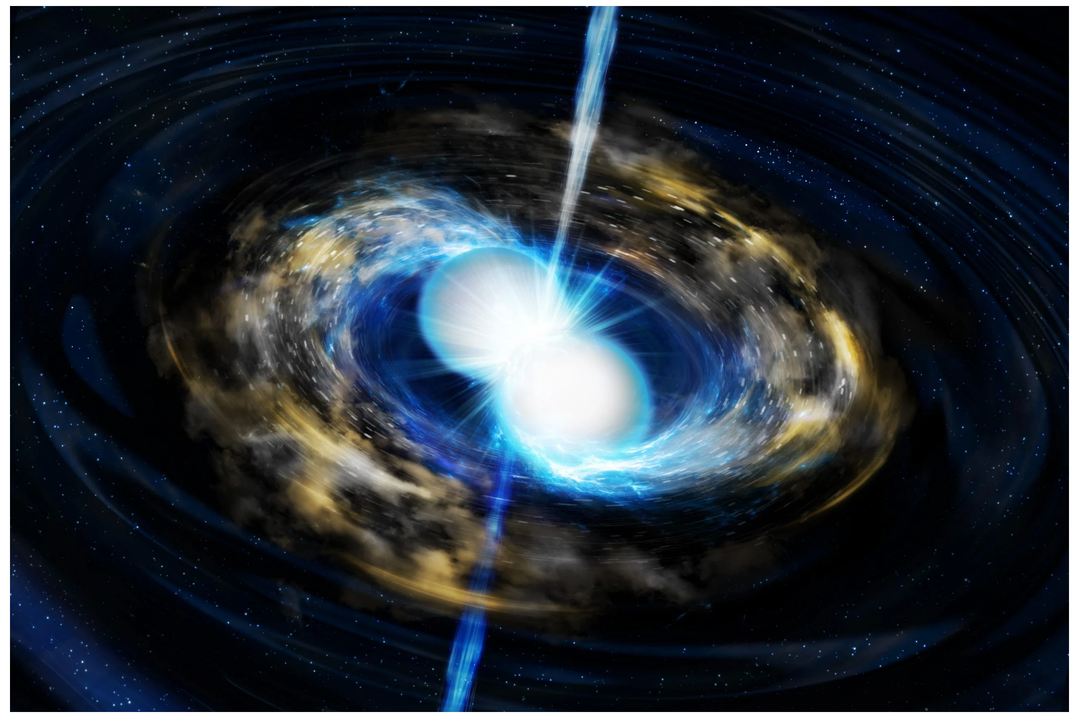
Nucleosynthesis:
which star produces which element

α-elements (O, Mg, Ca, Si, Ti,…) → Massive stars

Fe-peak (Fe, Mn,…) → Type Ia SNe

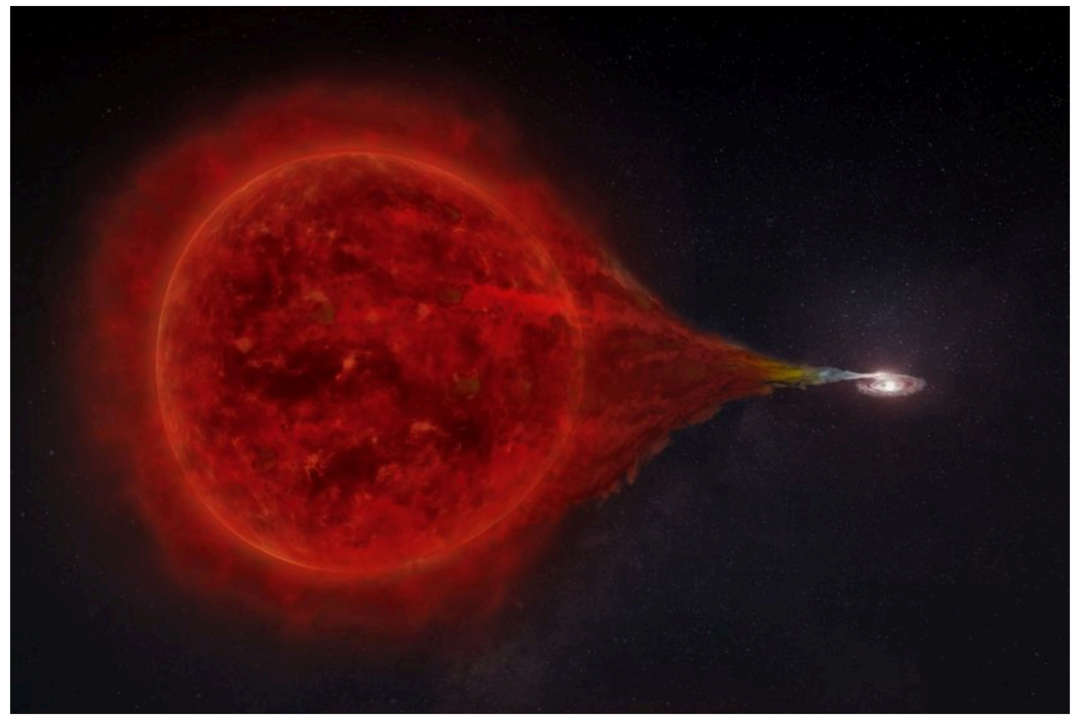


Neutron-capture elements (Eu, Ba, Y, Zr, La, Ce, Mo, Nd, Pr,…): → Merging neutron stars



Long-lived radioisotopes (^{232}Th, ^{238}U,…)

Lithium: → Nove



Short-lived radioisotopes (^{26}Al, ^{60}Fe, ^{244}Pu,…)

Why do we care?

Massive stars

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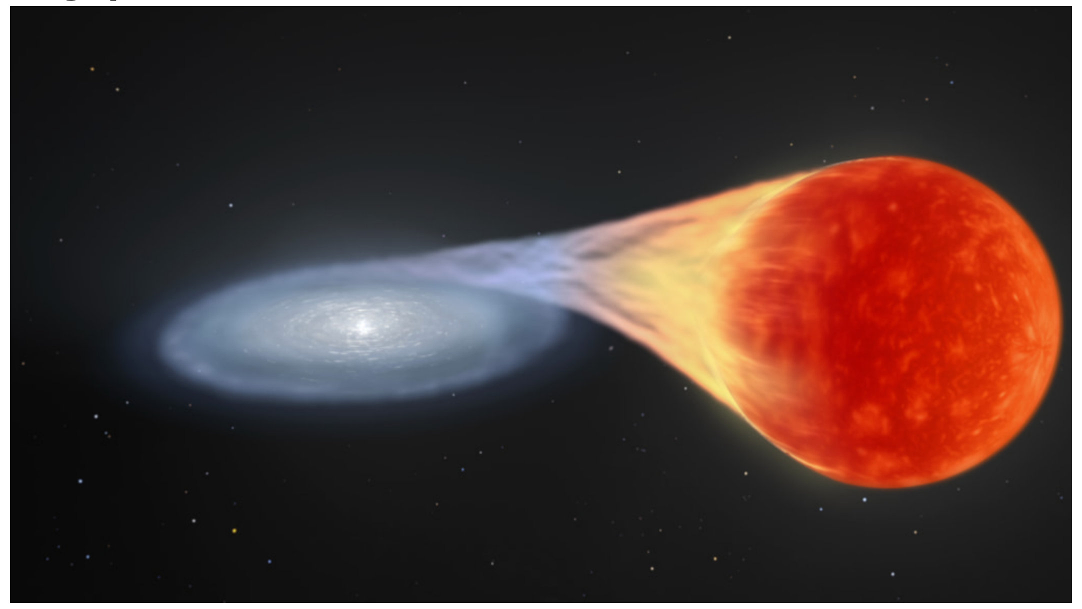

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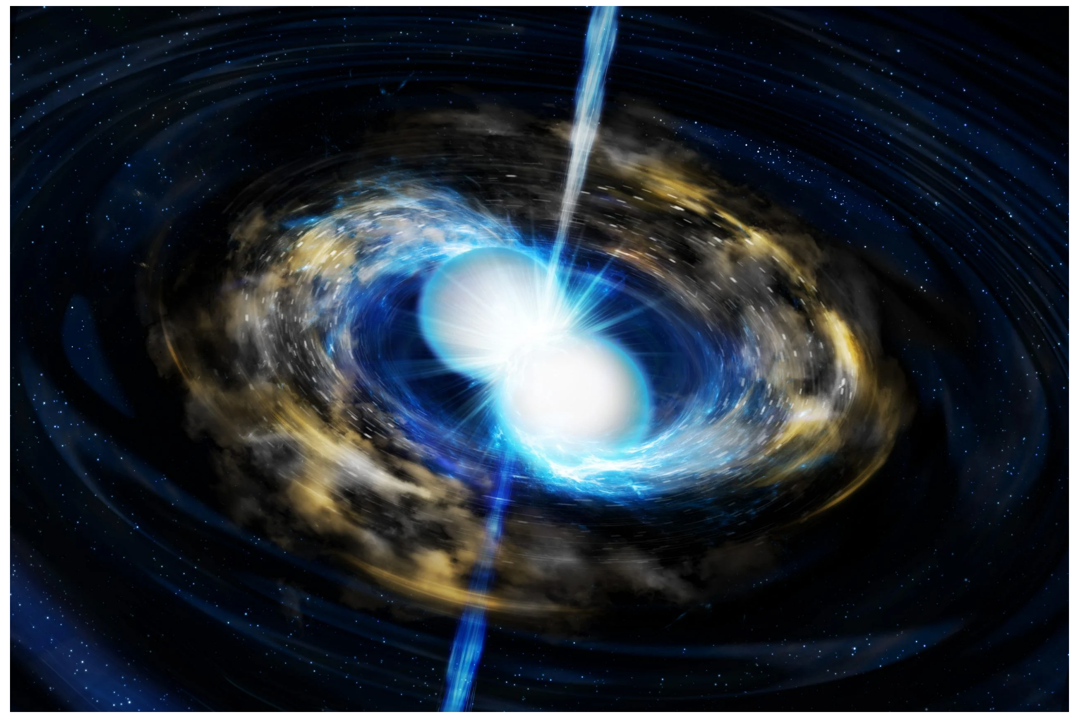

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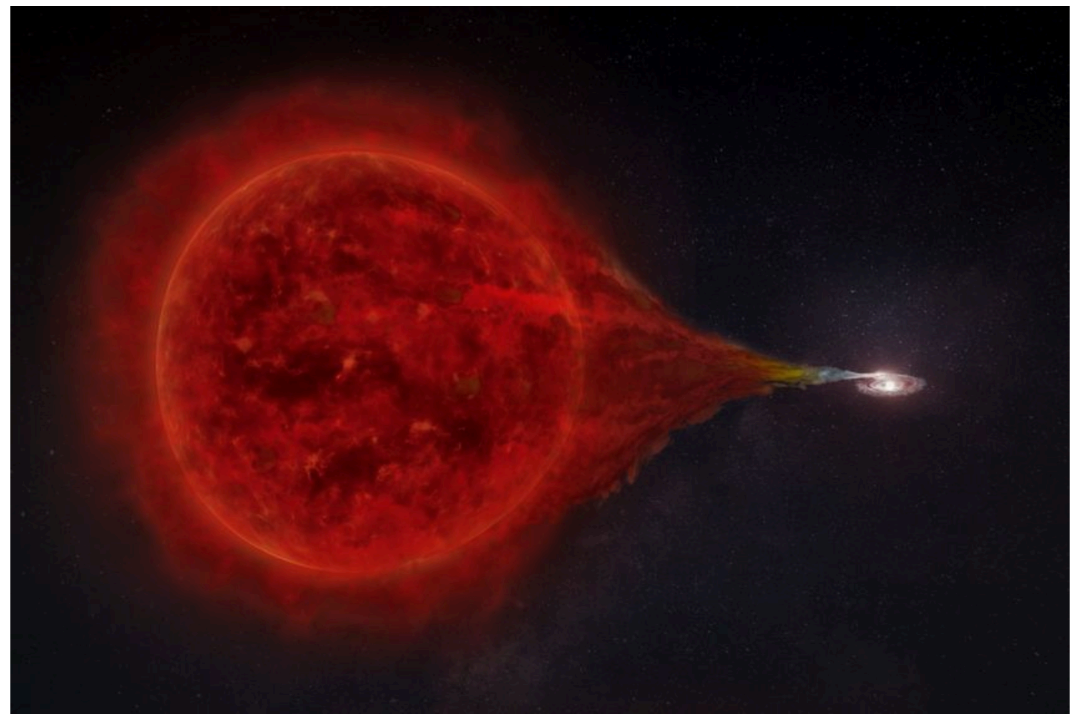
Long-lived radioisotopes (^{232}Th, ^{238}U,…) → stellar ages

Nove



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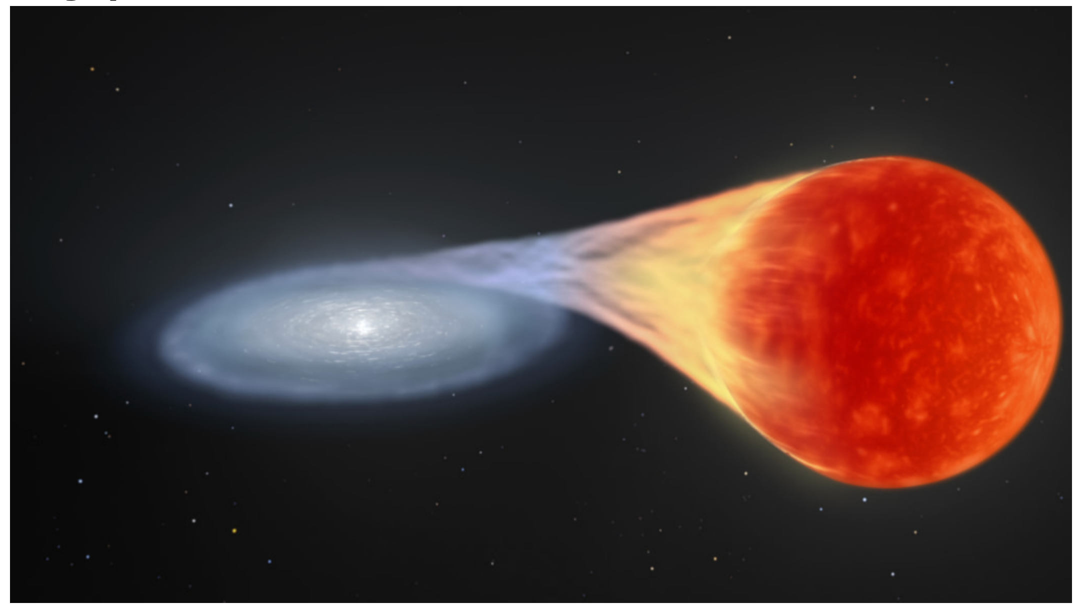

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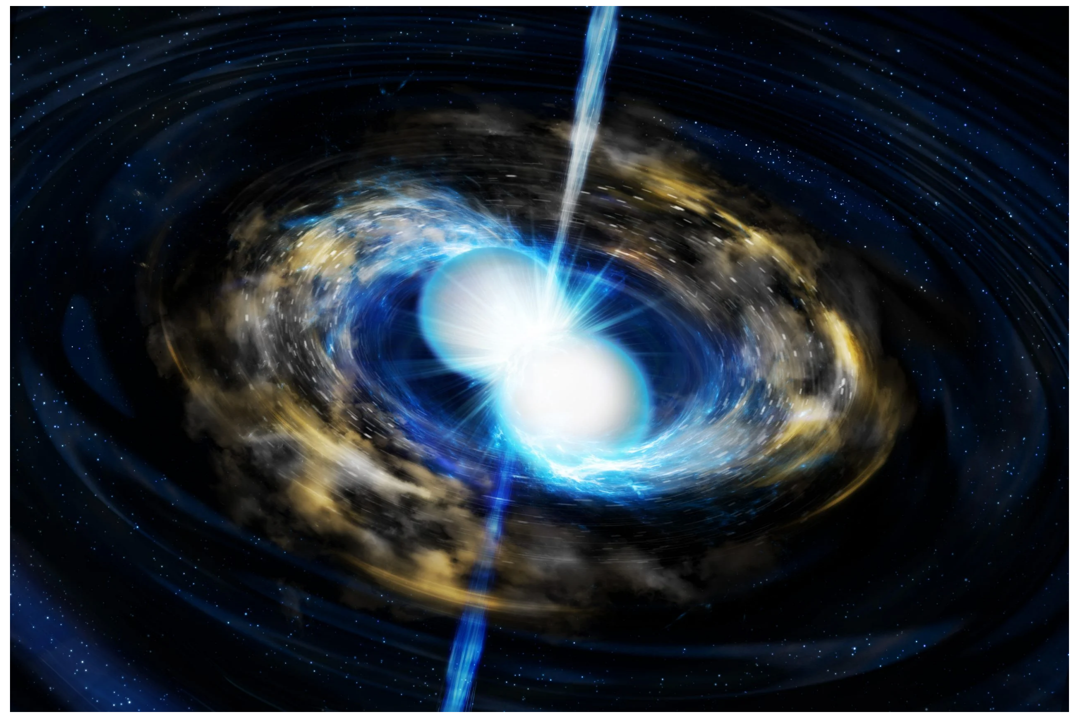

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Lithium: → Nove

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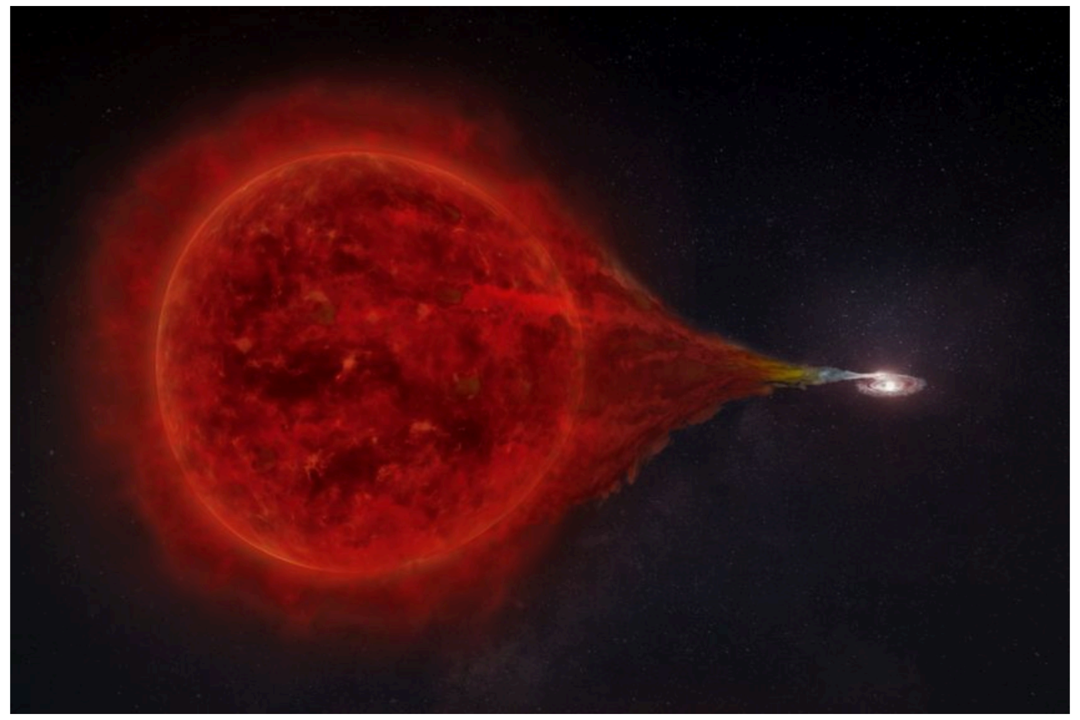
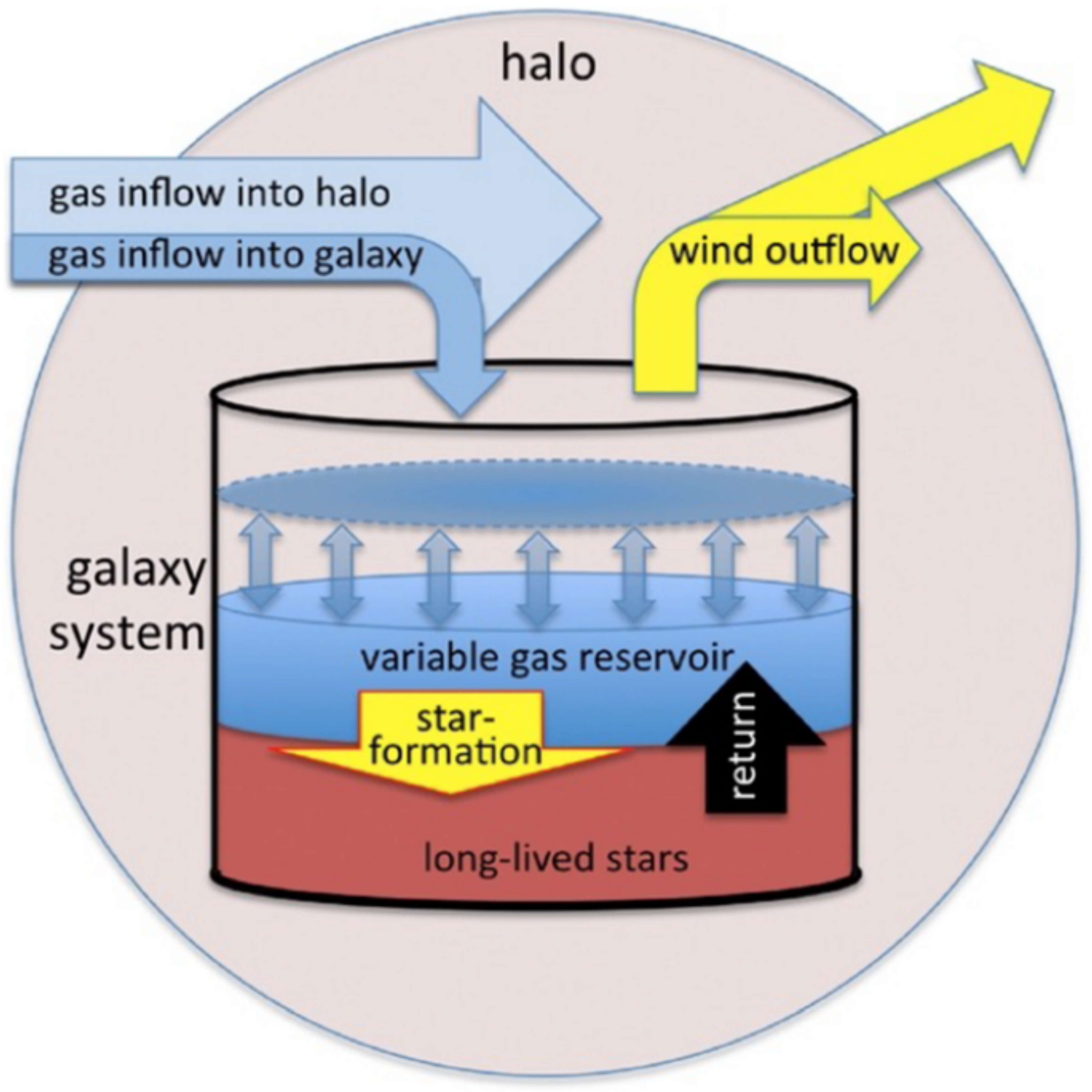


Short-lived radioisotopes (^{26}Al, ^{60}Fe, ^{244}Pu,…)
→ **SFR tracer**

Chemical evolution of galaxies



Main ingredients

- **open**/closed box
- Initial composition (**primordial**)
- gas flows
- **SFR + IMF** ⟶ populate the galaxy
- **stellar yields** ⟶ pollute the galaxy

Chemical evolution of galaxies

The prescriptions are used to solve the Chemical Evolution Equation

$$\dot{M}_{\mathrm{gas},i}(\mathbf{r},t) = -\psi(\mathbf{r},t)X_i(\mathbf{r},t) + \dot{R}_i(\mathbf{r},t) + X_{i,A}A(\mathbf{r},t) - X_i(\mathbf{r},t)W(\mathbf{r},t) - \frac{1}{\tau_i}X_i(\mathbf{r},t)e^{-t/\tau_i}$$

SFR

pollution

infall

outflow

radioactive decay

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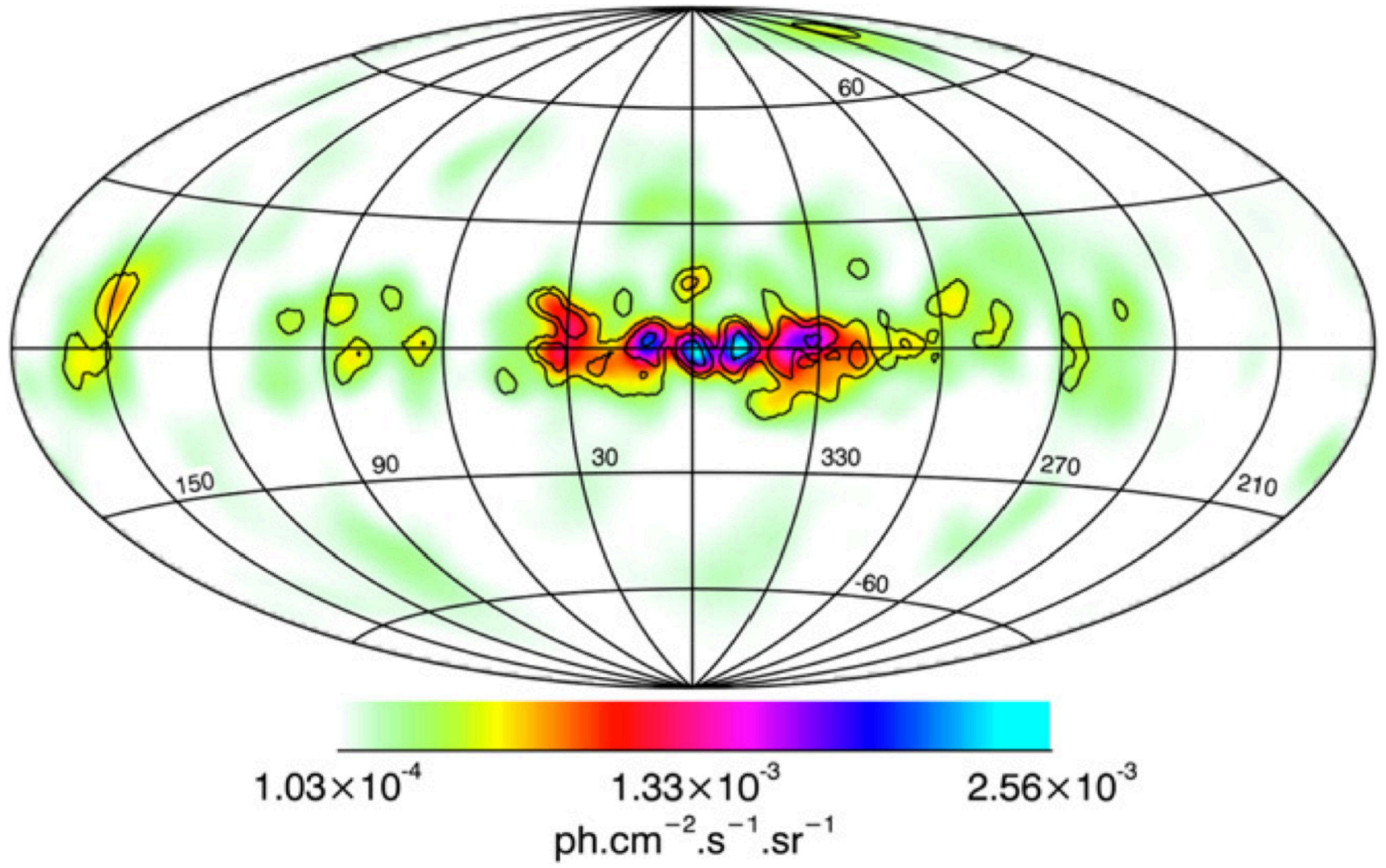

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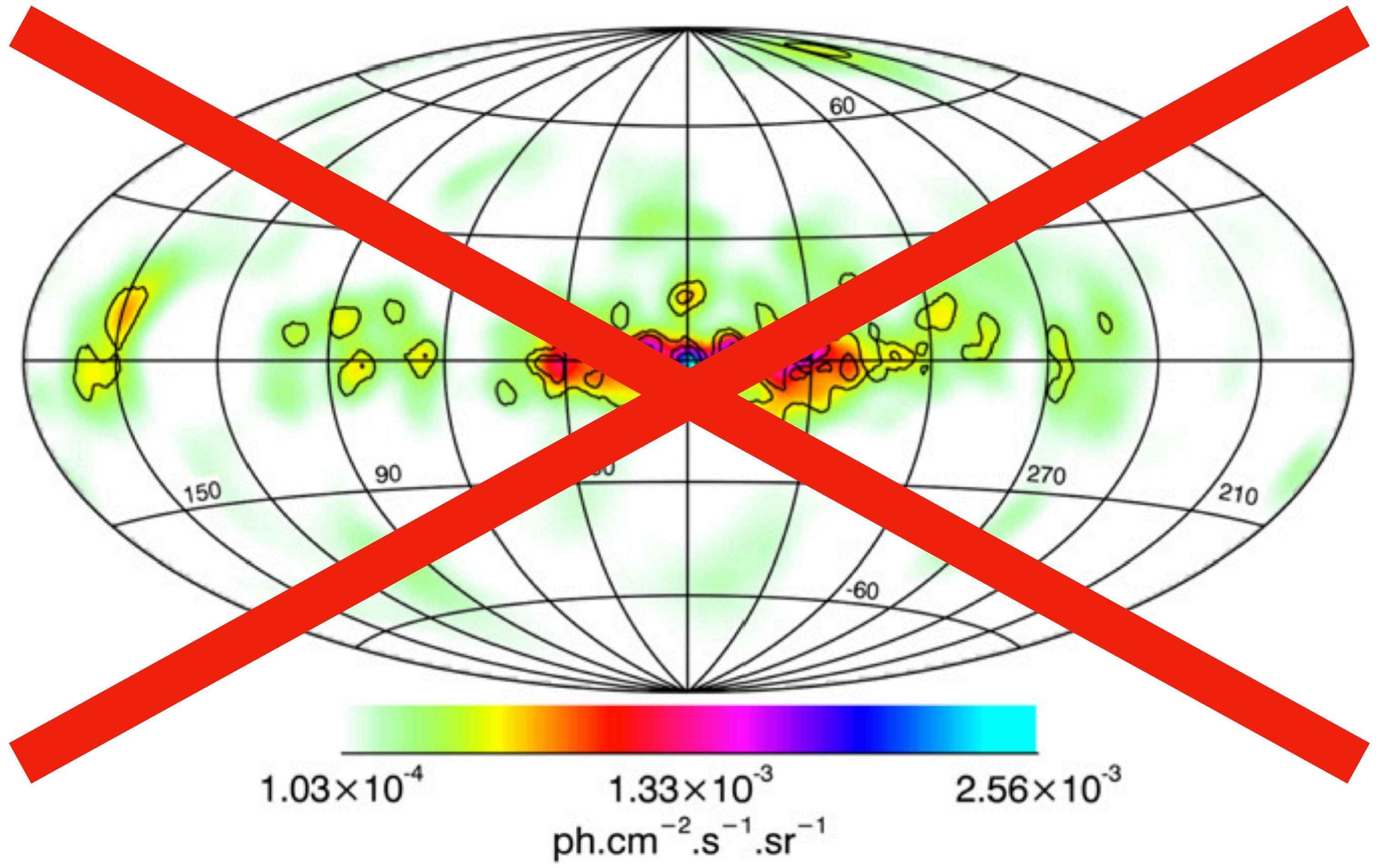

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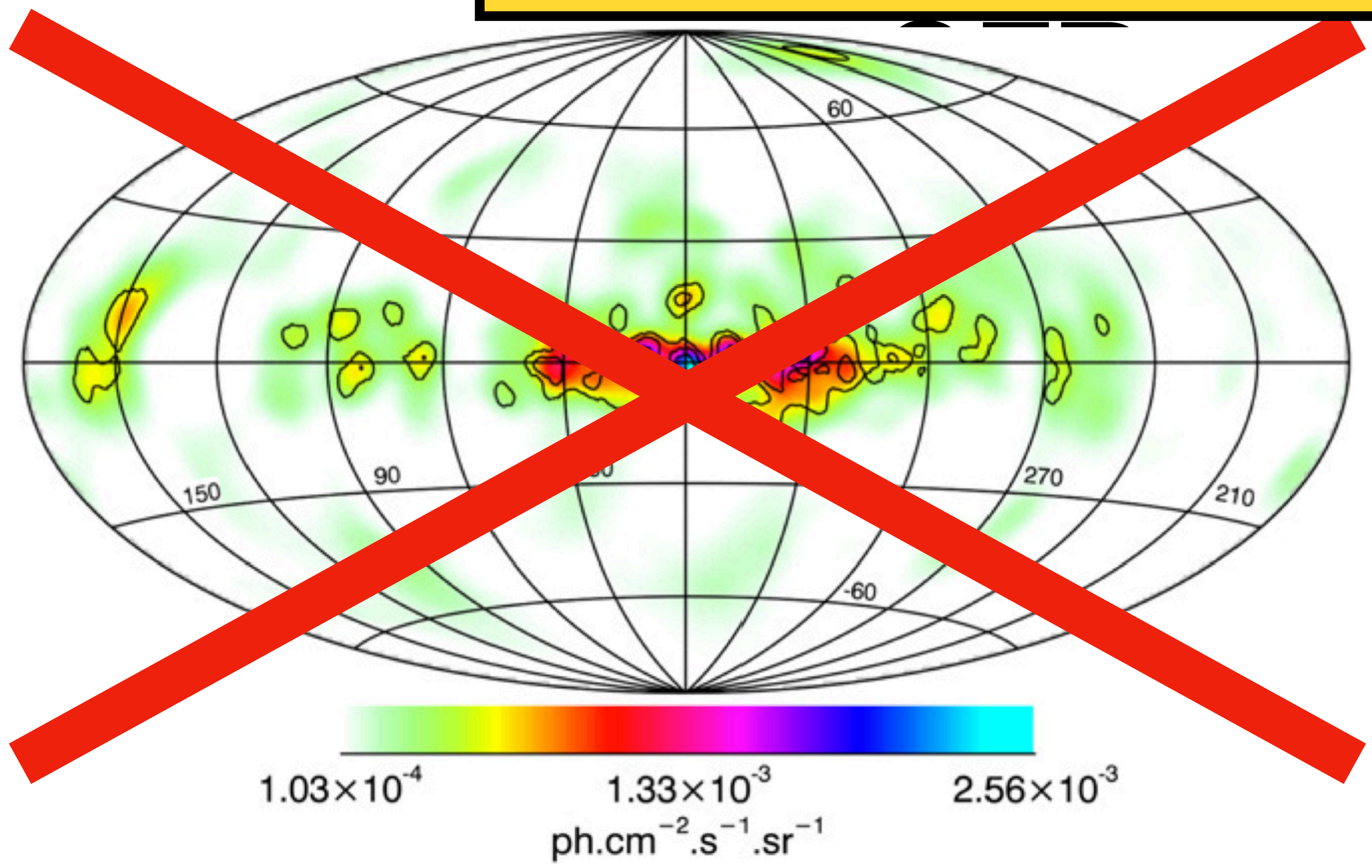
comparison with the ^{26}Al integrated mass

$\sim 2\ M_\odot$

infall

outflow

radioactive decay

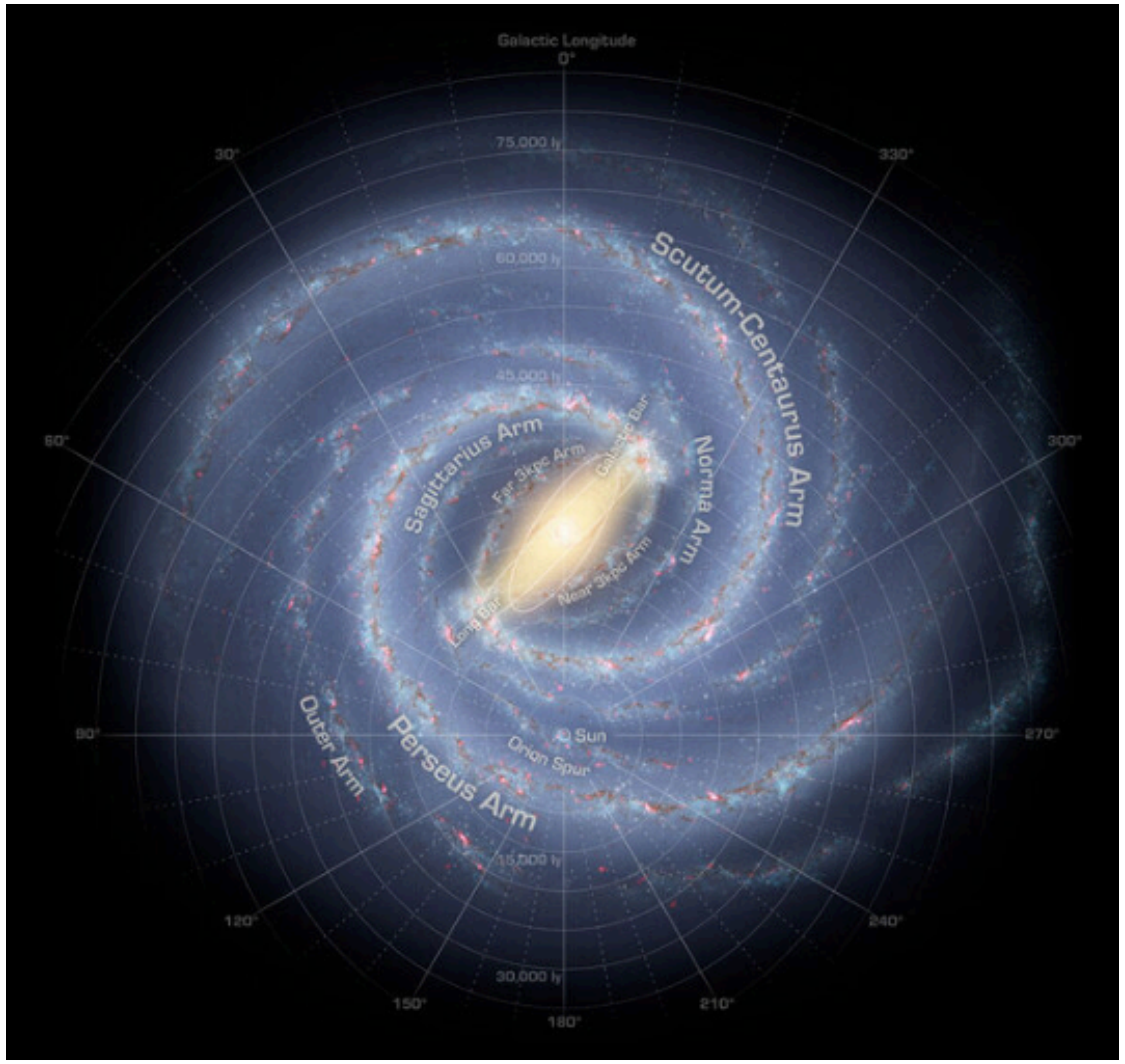


Chemical evolution of galaxies: ^{26}Al in 1D MW

Vasini, Matteucci & Spitoni 2022

How do we picture the galaxy?

→ 1D scenario (radial coordinate)



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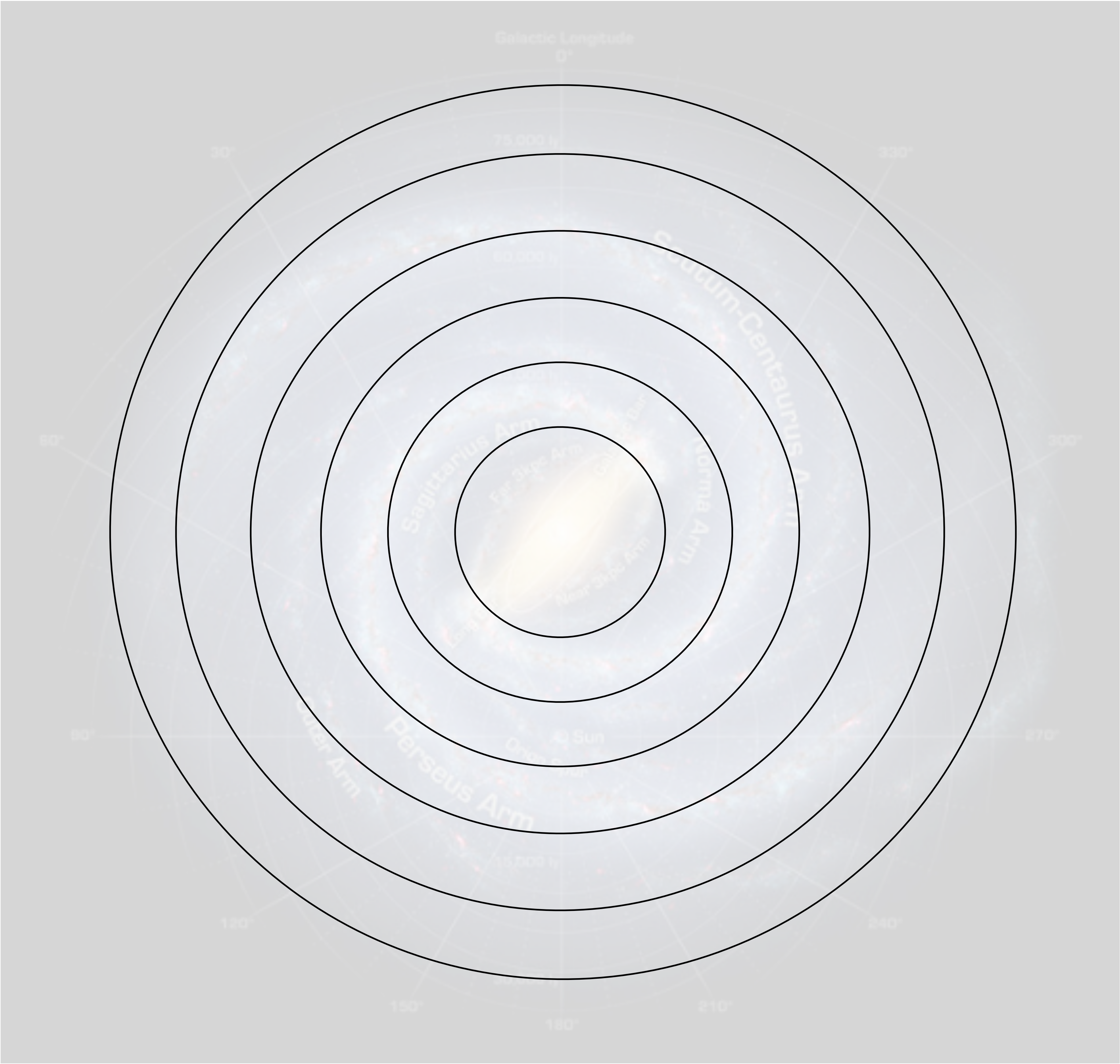

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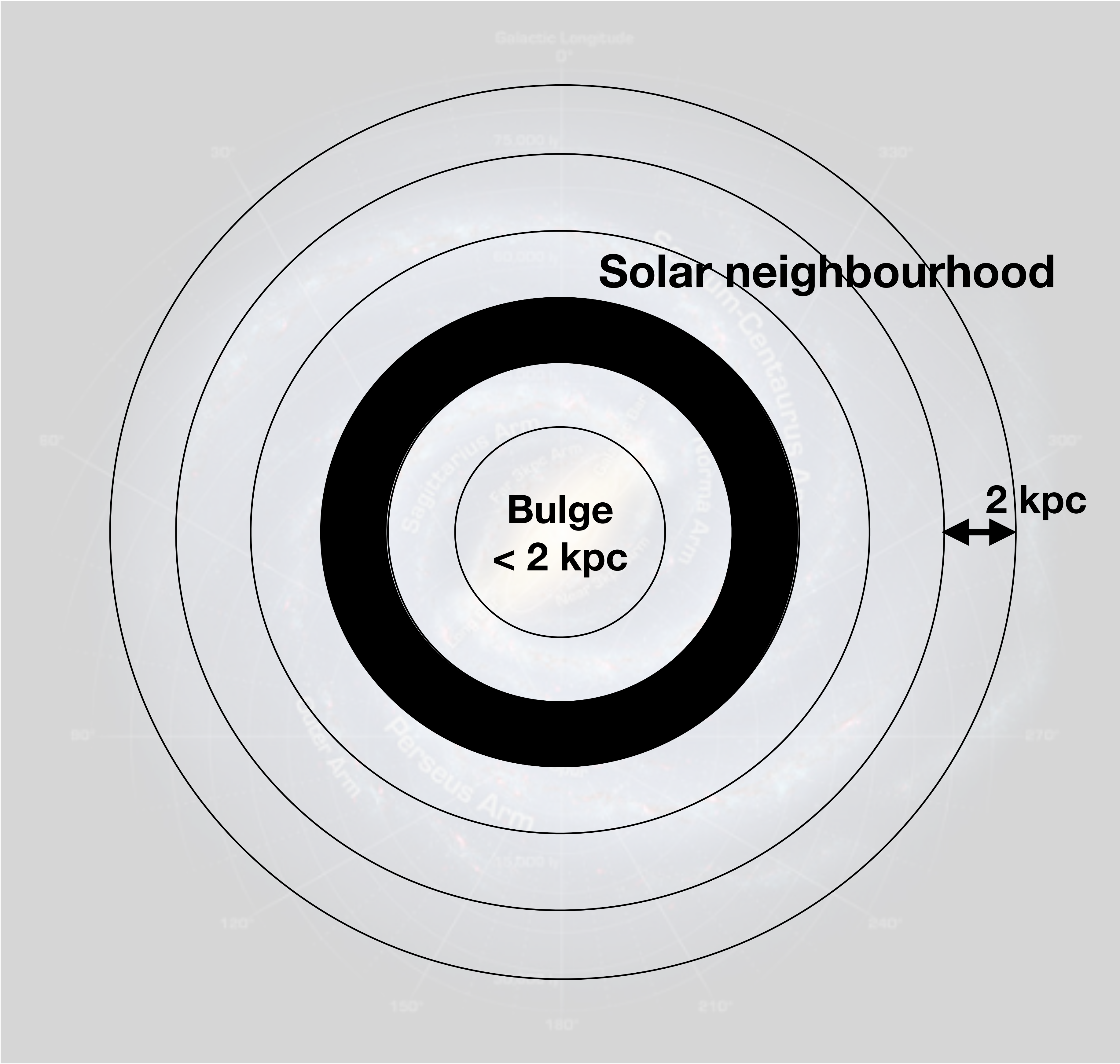

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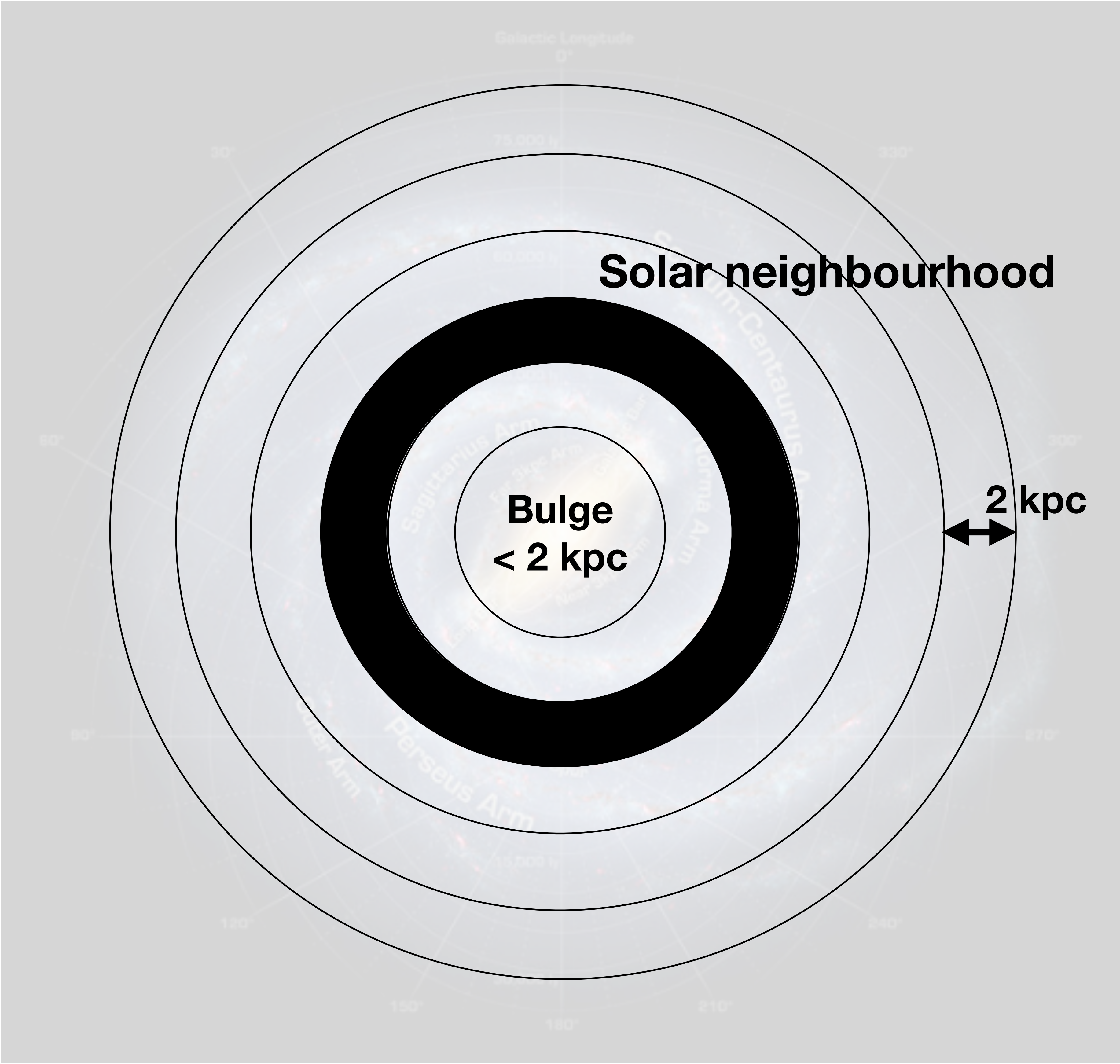


Approximations:

- No dependence on the azimuth
- Each ring is isolated from the others
- **Homogeneous mixing** within each ring

Chemical evolution of galaxies: ^{26}Al in 1D MW

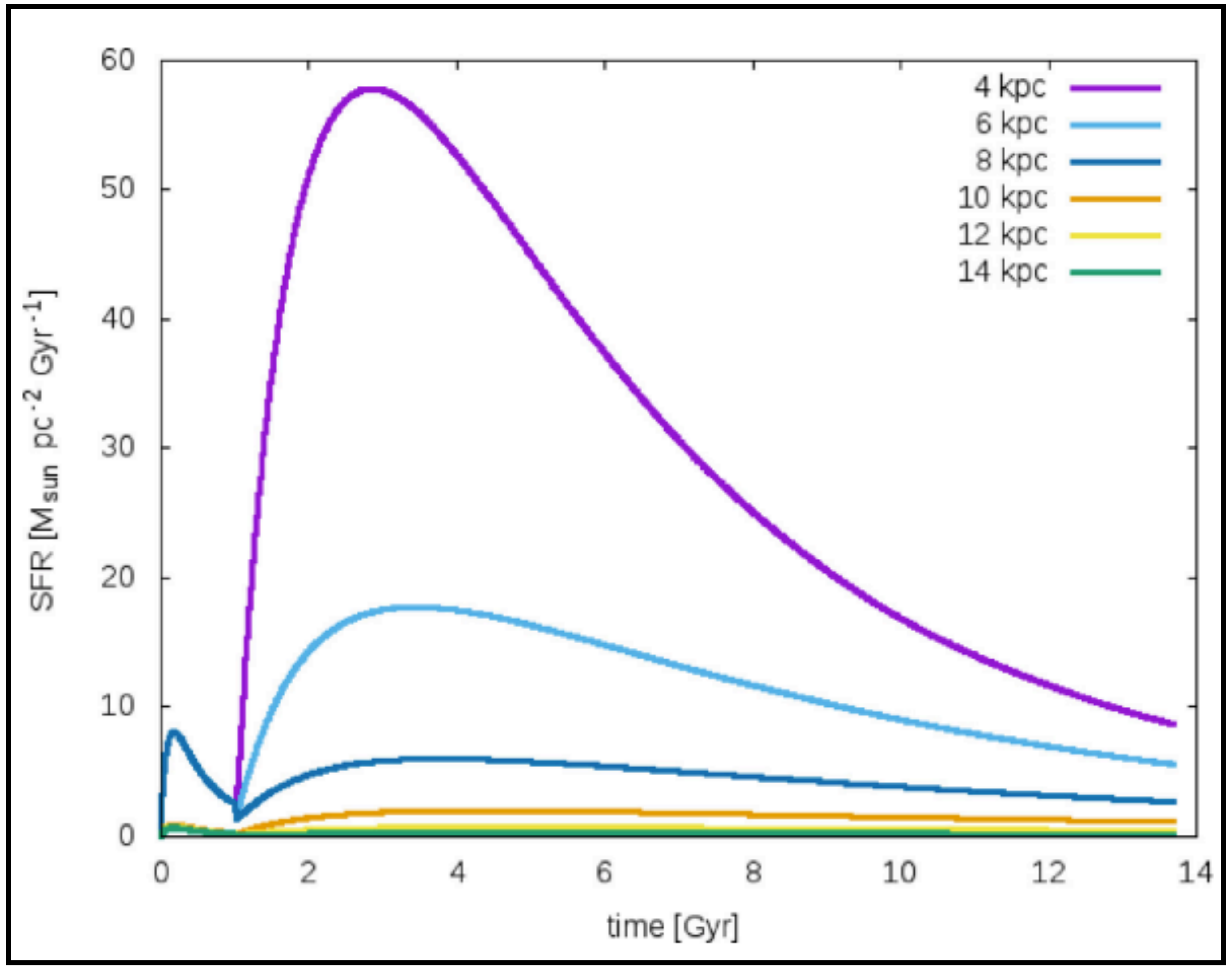
Vasini, Matteucci & Spitoni 2022

SFR →

- Double infall (thick and thin discs)
- Schmidt-Kennicutt (1998) relation:

$$\psi(t) = \nu \sigma_{gas}^{k}$$

Grisoni+18



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SFR →
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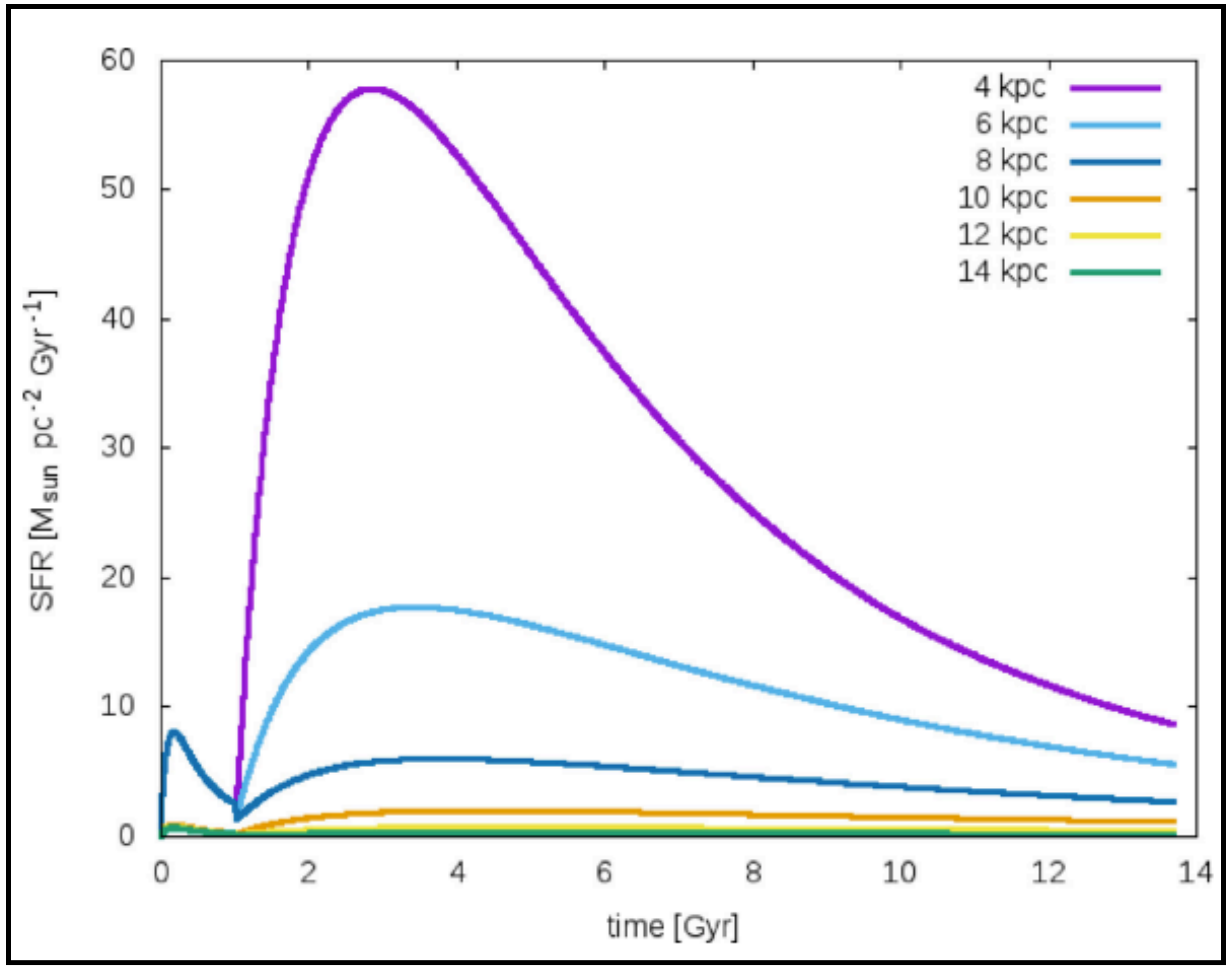
IMF → Mass spectrum of the stars formed:

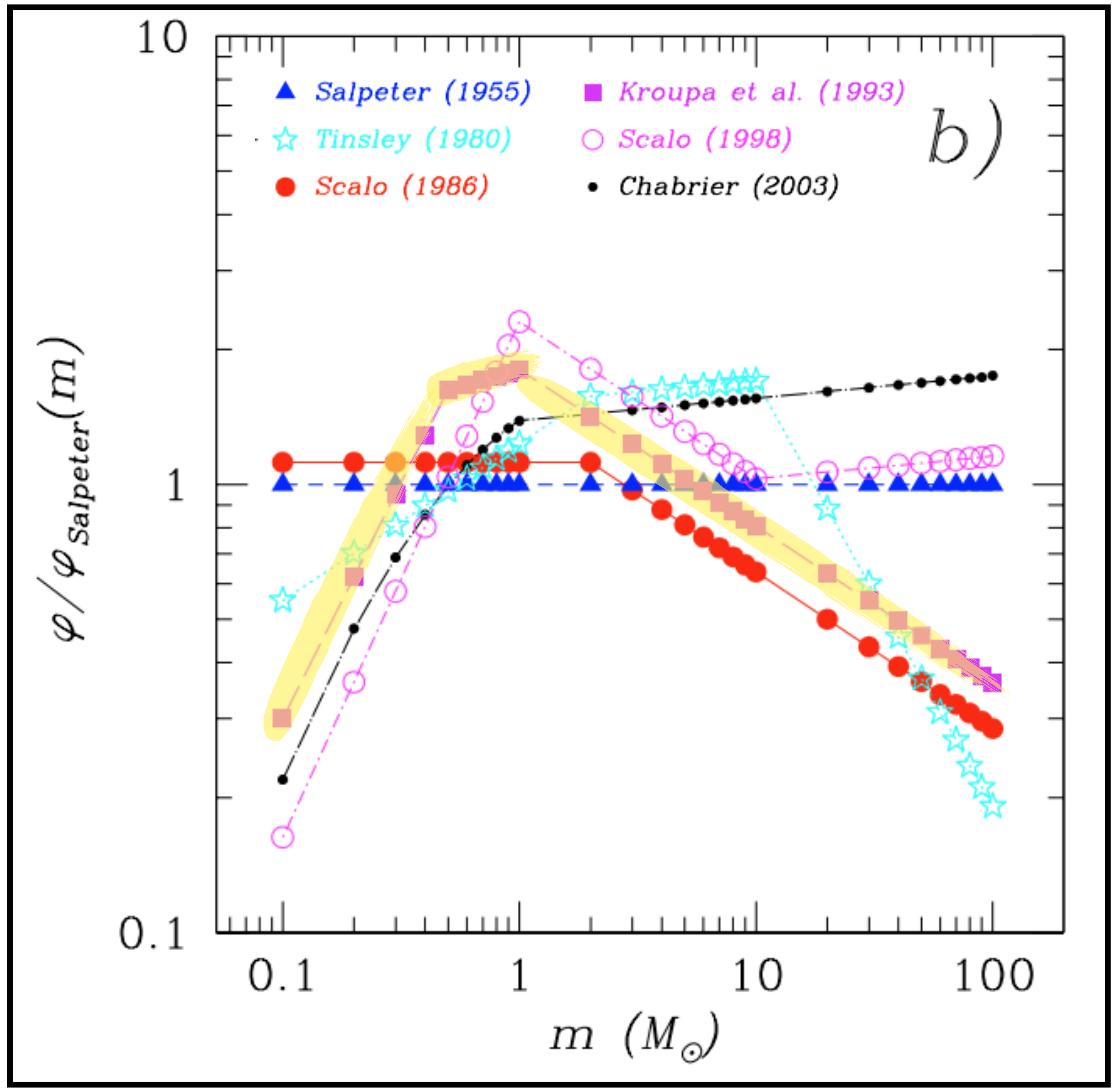
$$\varphi(m) \propto m^{-\alpha}$$

- Kroupa+93: $\alpha = 1.3,\ 2.2,\ 2.7$

Grisoni+18



Romano+05



Chemical evolution of galaxies: ^{26}Al in 1D MW

Vasini, Matteucci & Spitoni 2022

^{26}Al stellar producers (Stellar yields)

- **Massive stars**: major contribution - 4 yields tested
- Type Ia SNe: minor contribution (NTY1984)
- AGBs: minor contribution (Karakas+10)
- **Novae**: 3 cases tested
- Minor contributions (VMSs, binaries…): excluded

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Massive stars

- Woosley & Weaver 1995 (Z dependent)
- Woosely & Weaver 1995 ($Z_{\odot}$ only)
- Limongi & Chieffi 2006
- Limongi & Chieffi 2018

X

Nova systems

- no production
- Josè & Hernanz 1998
- Josè & Hernanz 2007

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Vasini, Matteucci & Spitoni 2022

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X

stems

uction
Hernanz 1998
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^{26}Al theoretical mass

vs.

^{26}Al observed mass

($\sim 2\ M_\odot$)

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Woosley & Weaver 1995 (Z dep)
+
Josè & Hernanz 2007
2.12 $M_{\odot}$ of ^{26}Al
the nova contribution is necessary

Massive stars

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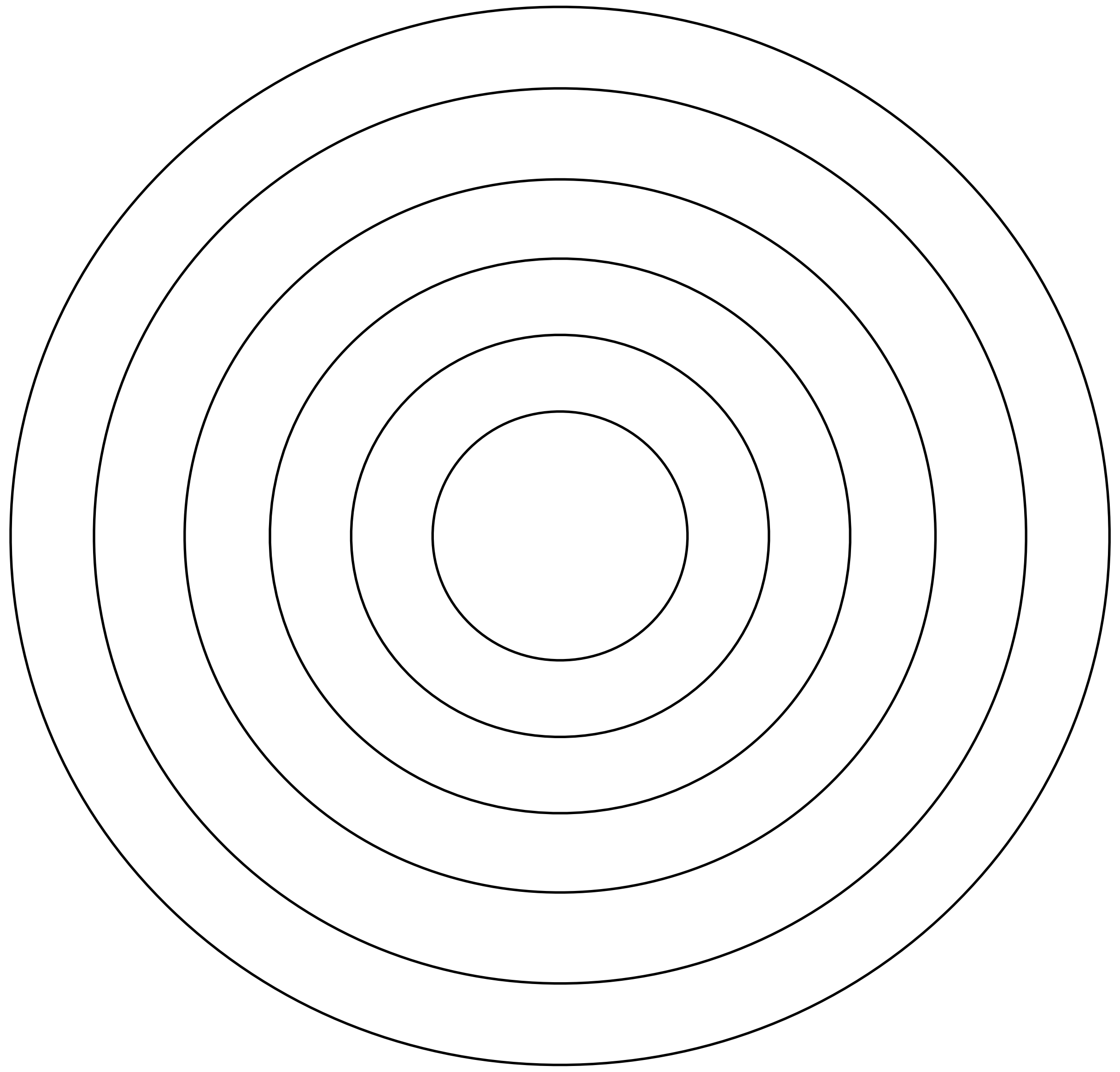
1D model limitations

Chemical Evolution model with 1D approximation → The scenario is too simplistic for ^{26}Al



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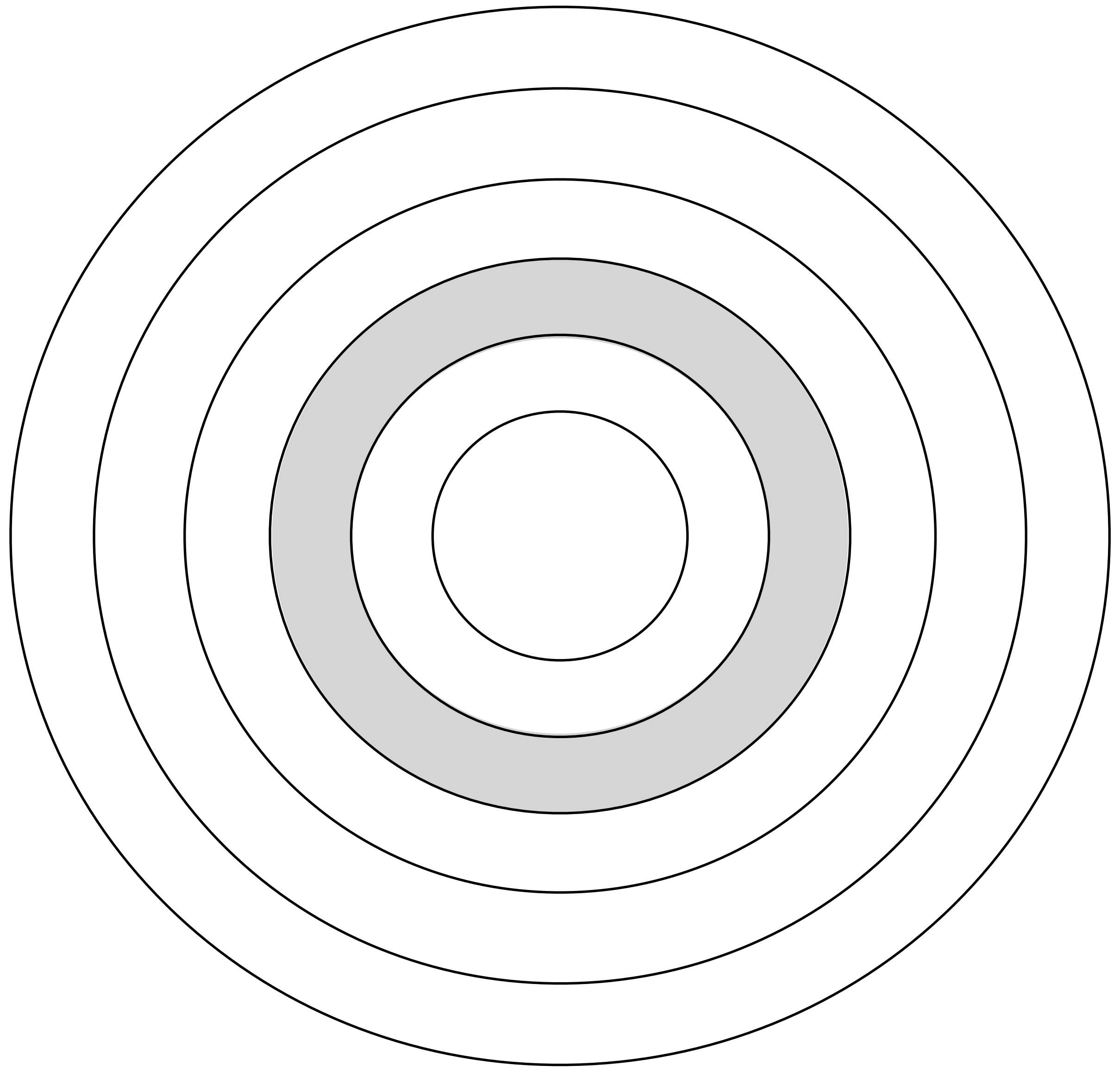

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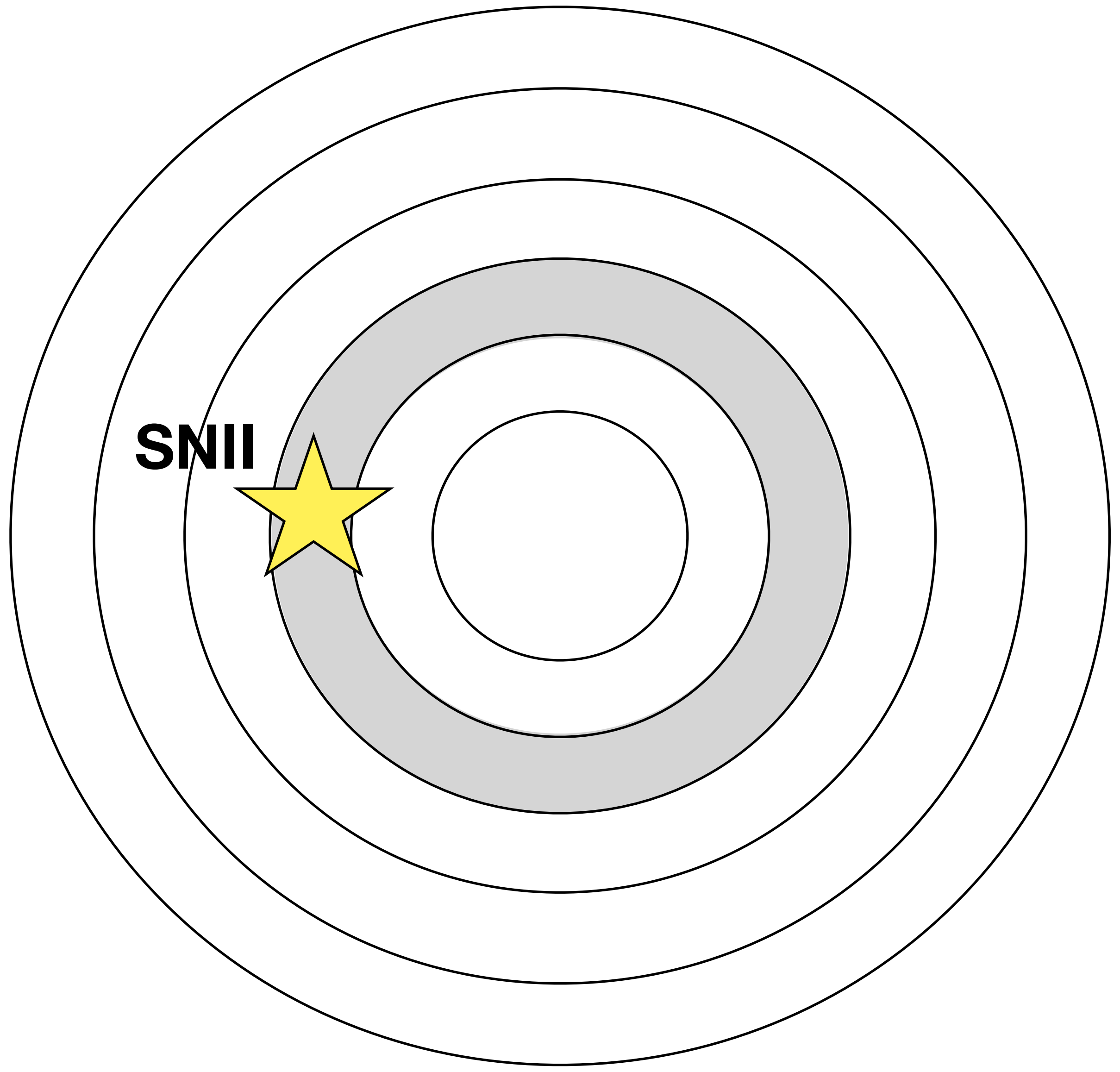

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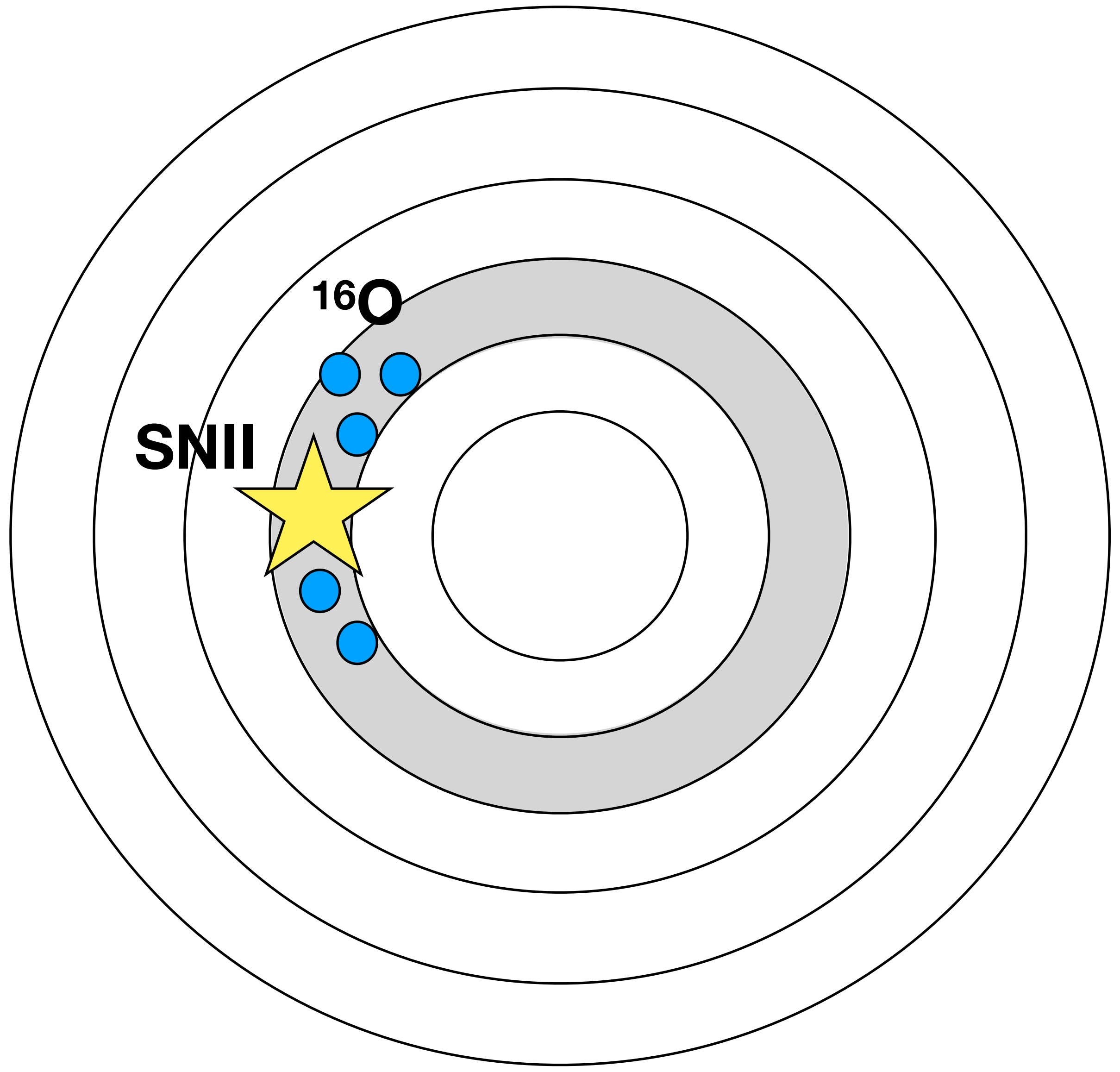

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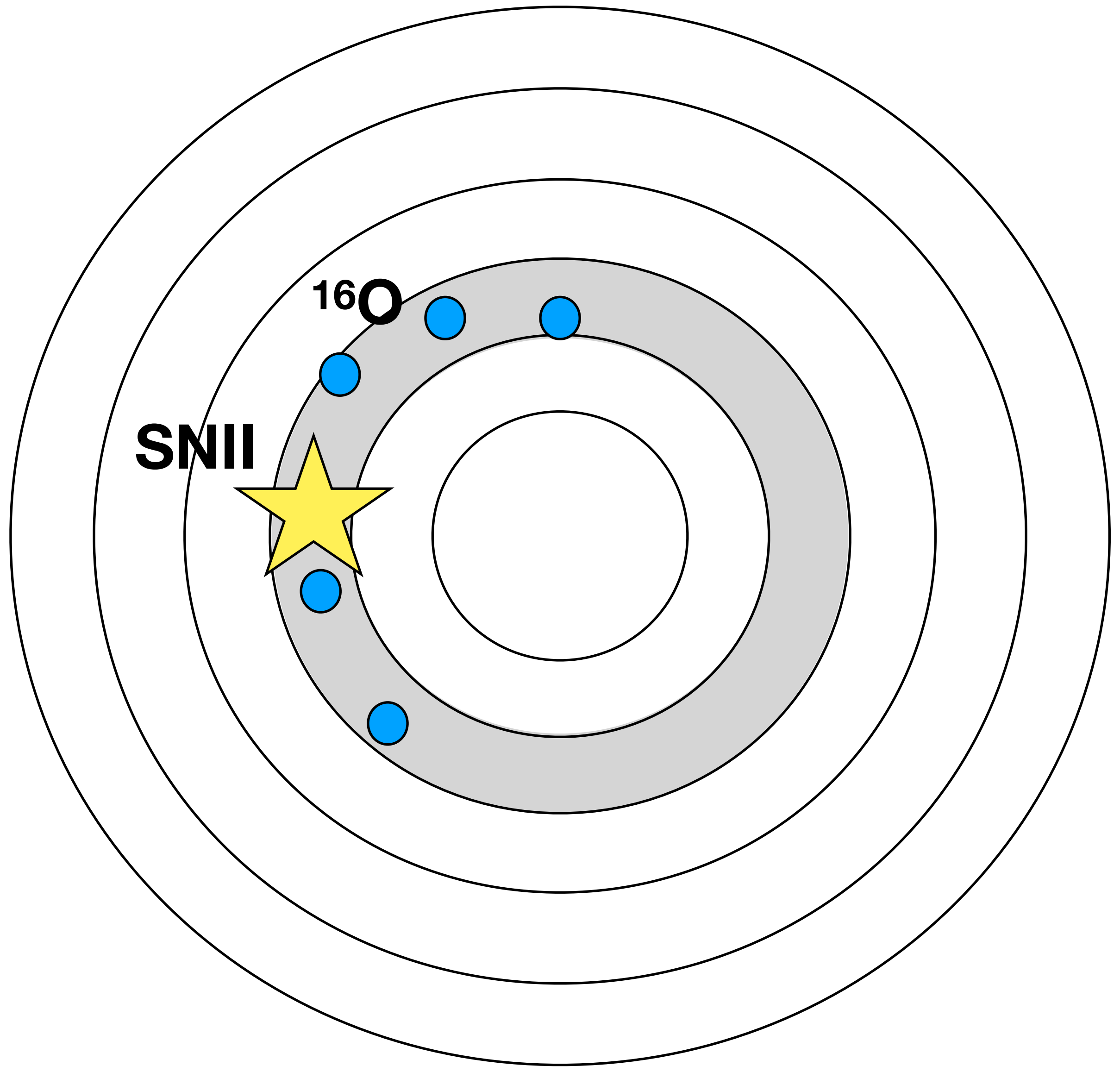

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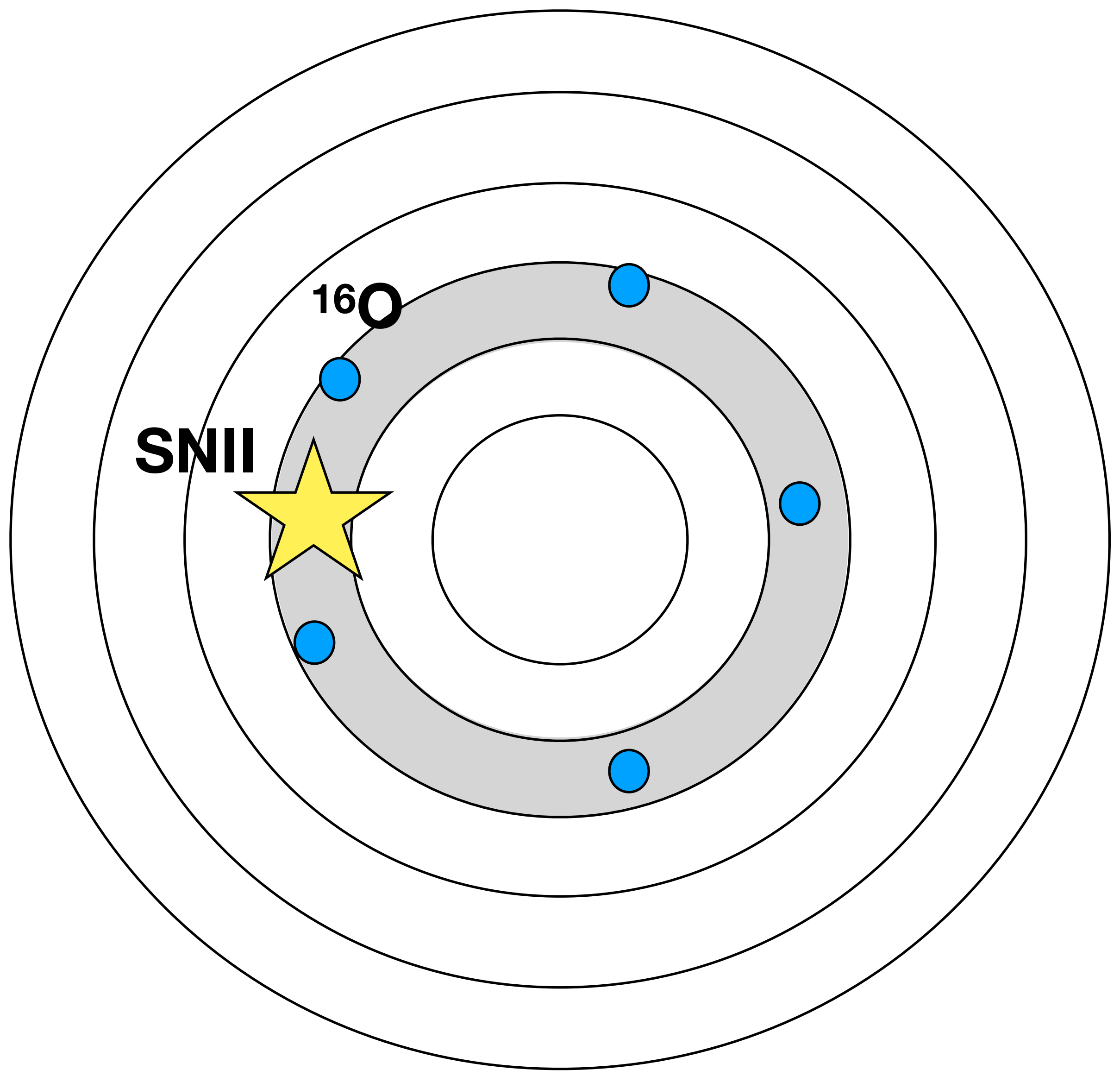

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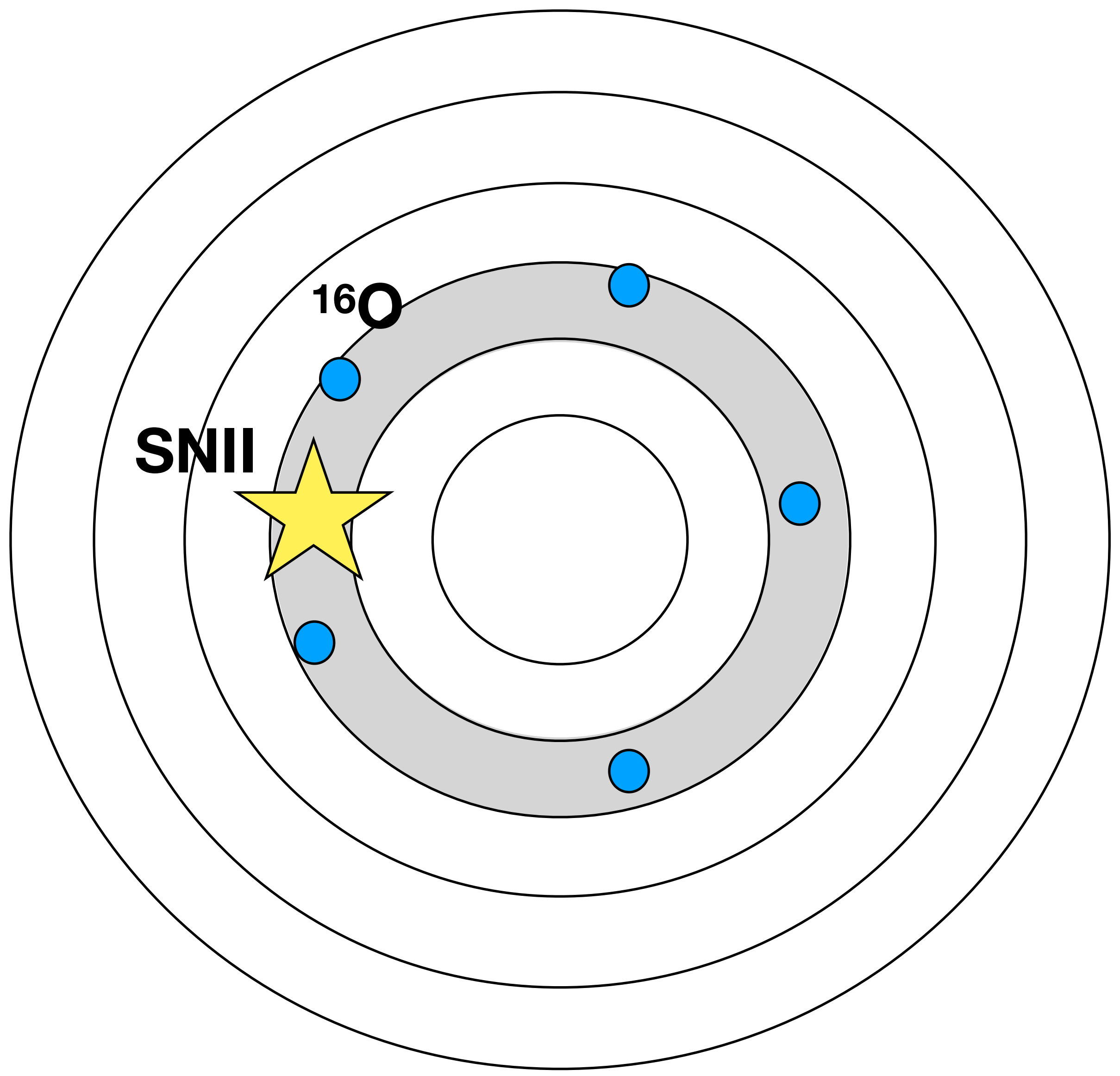

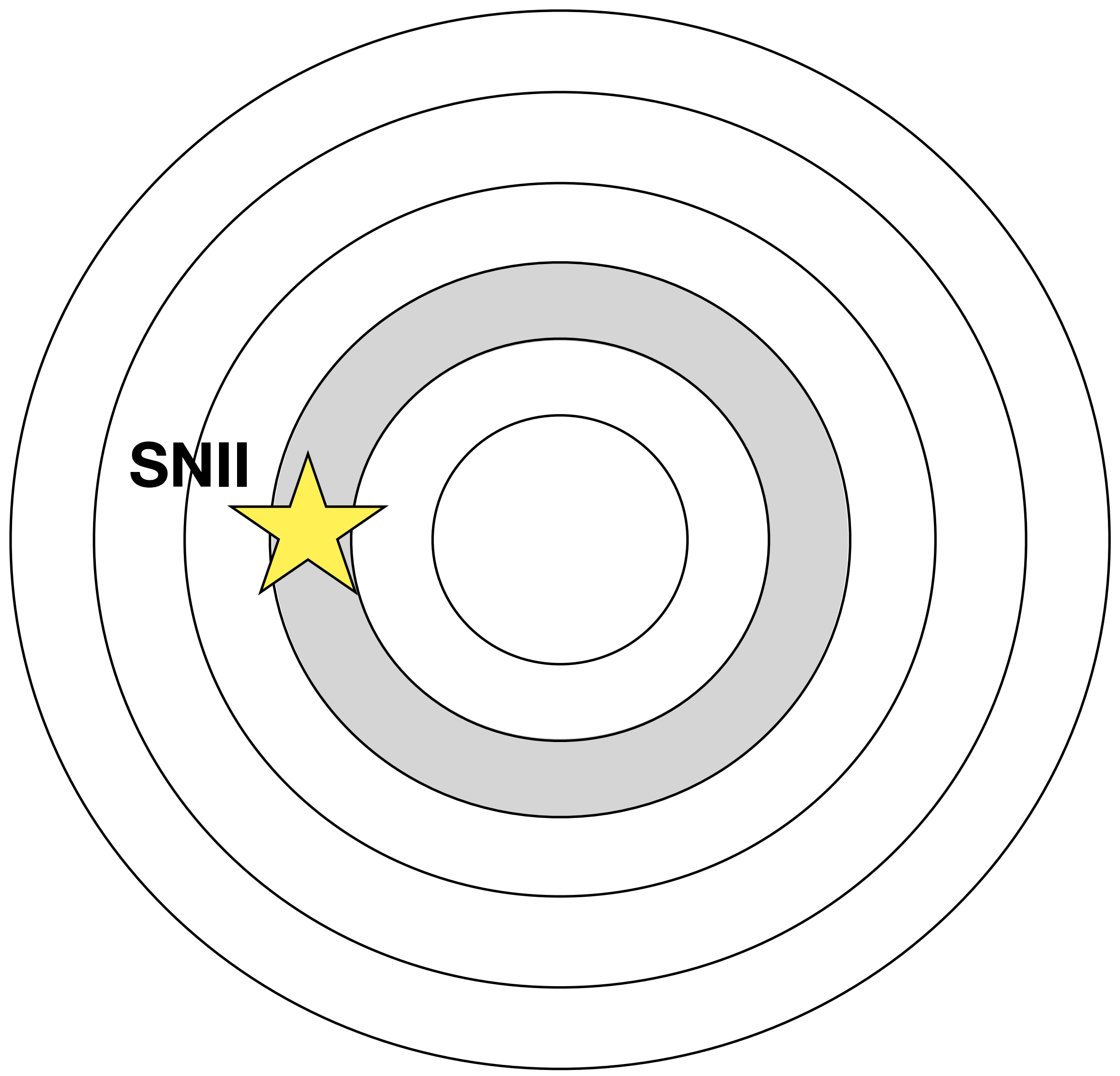

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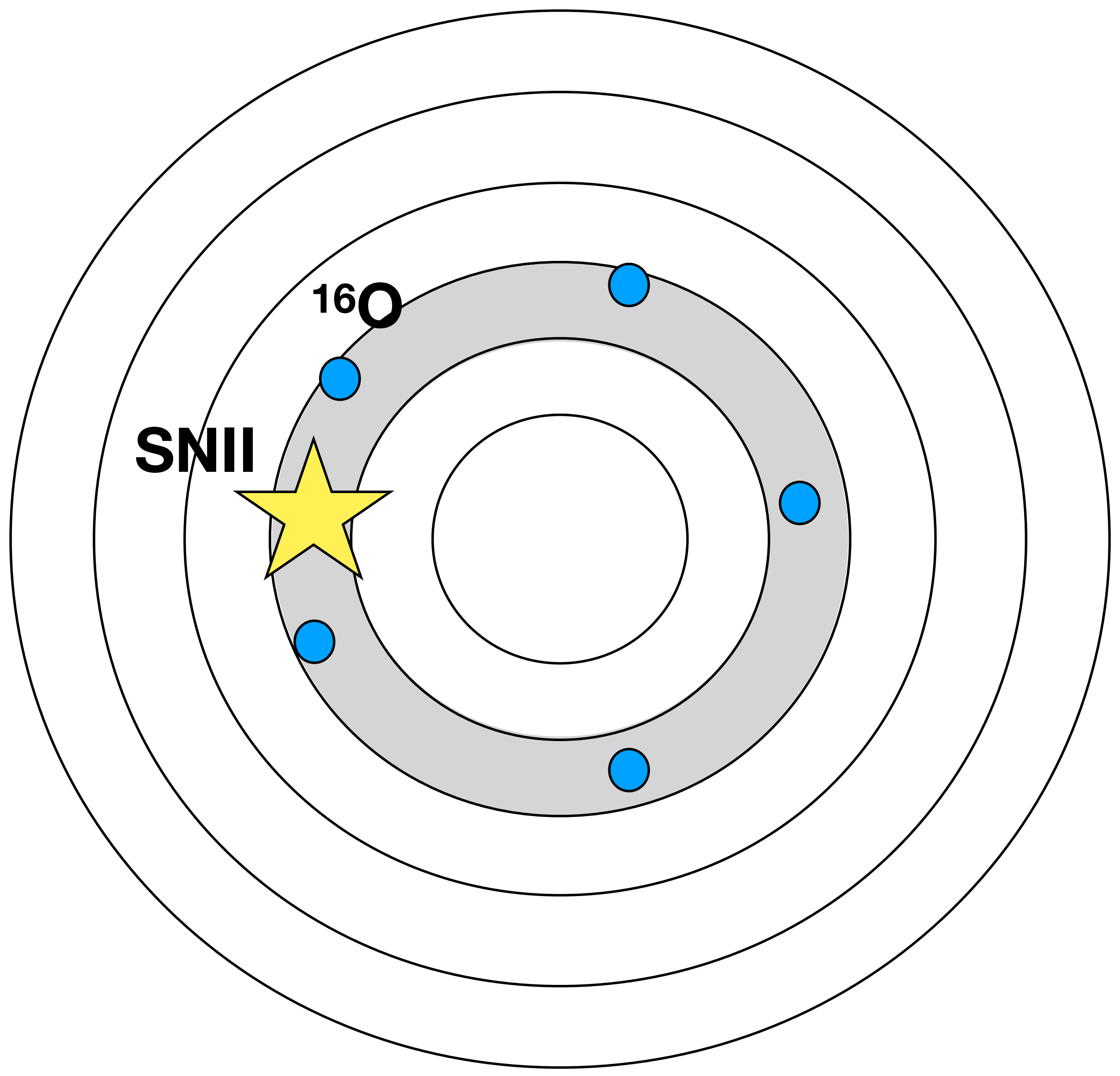

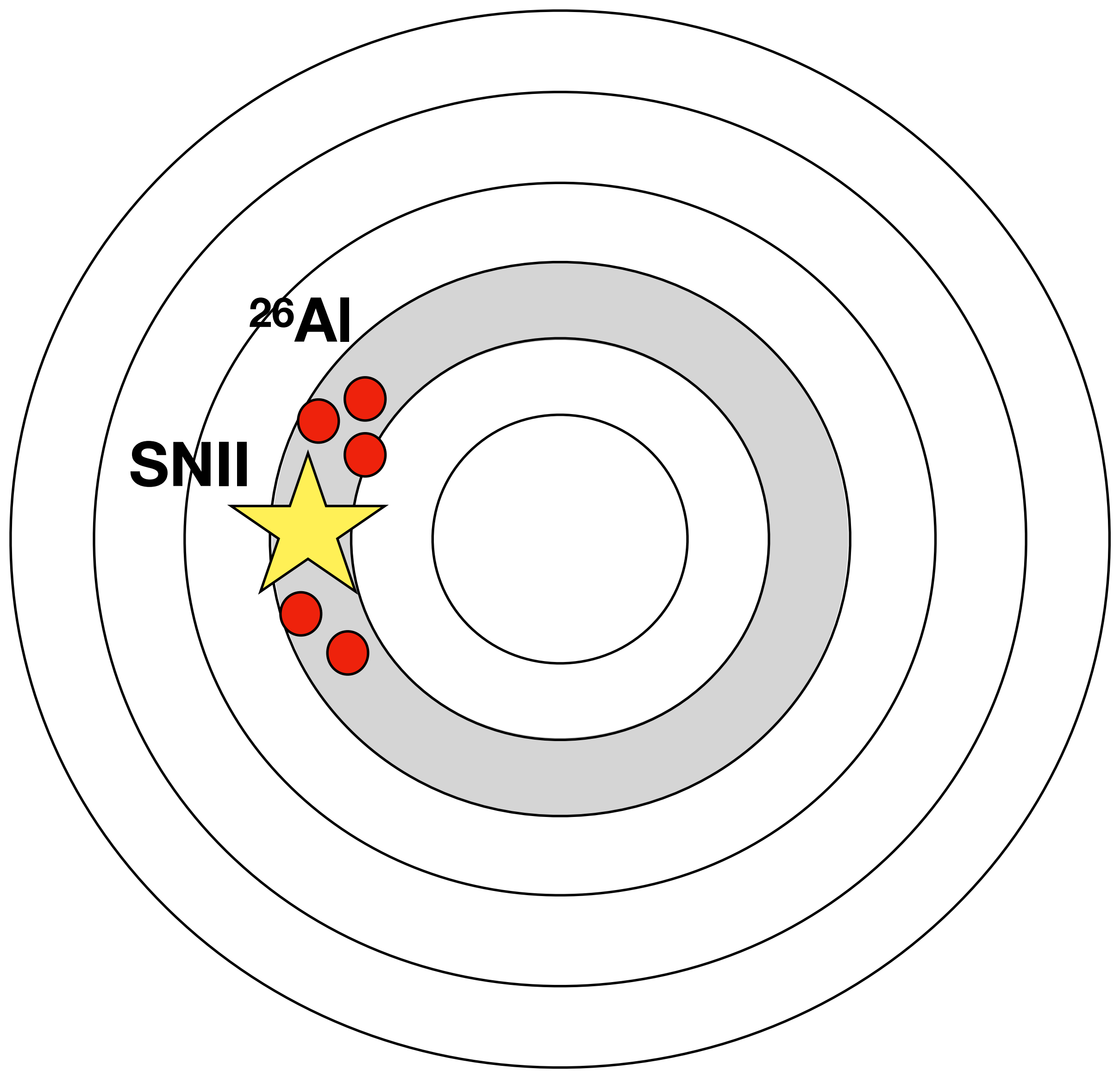

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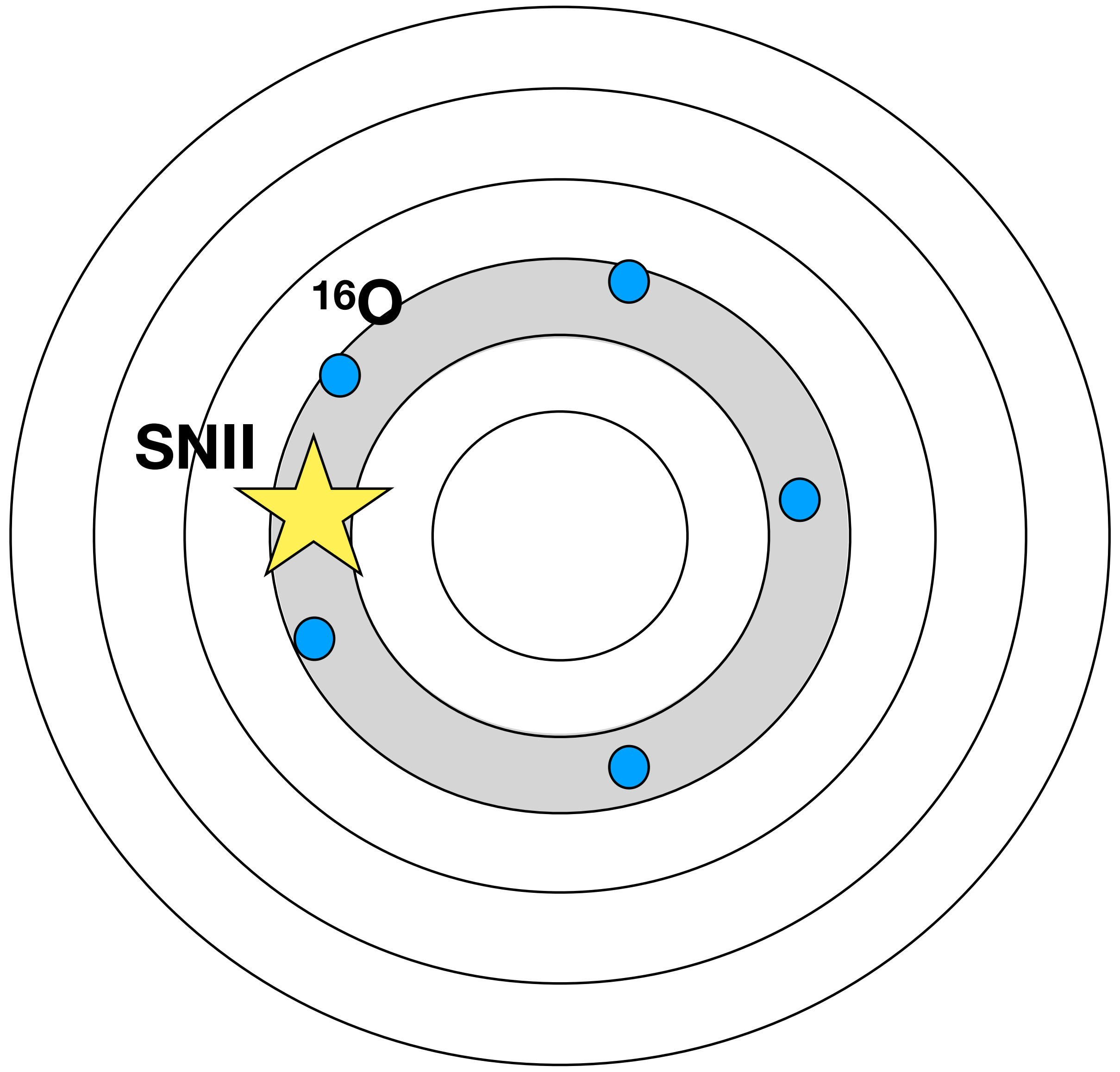

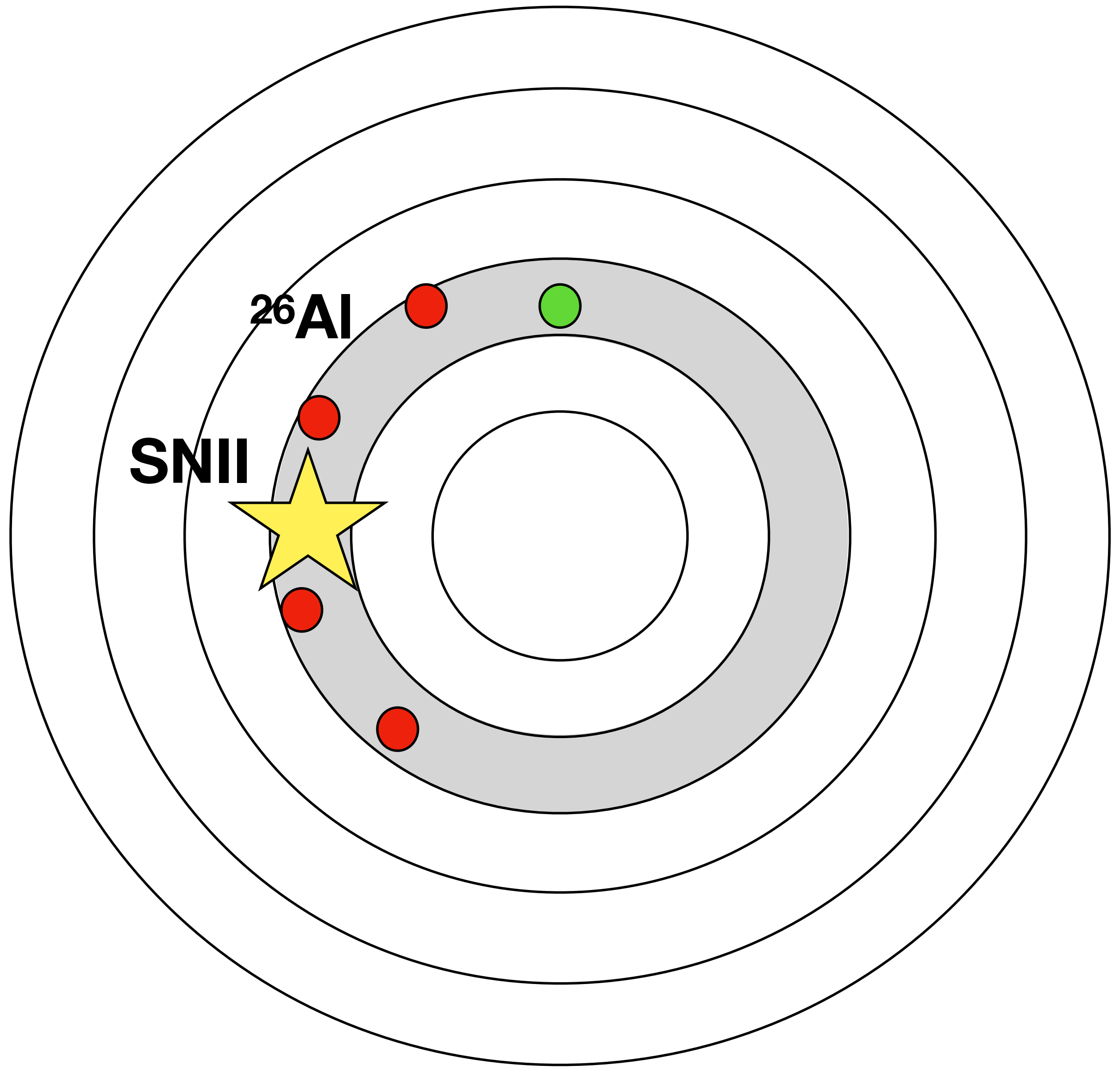

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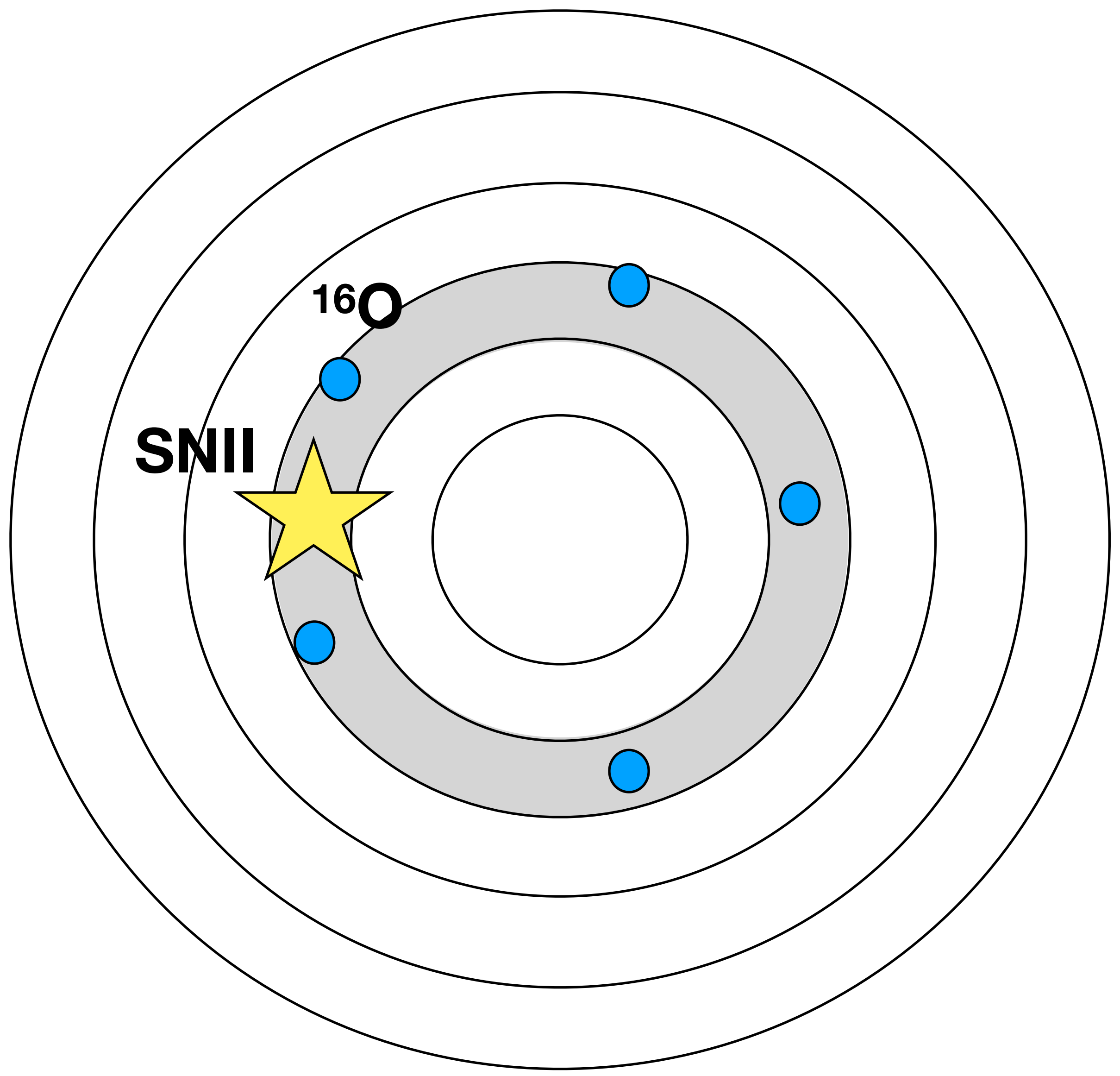

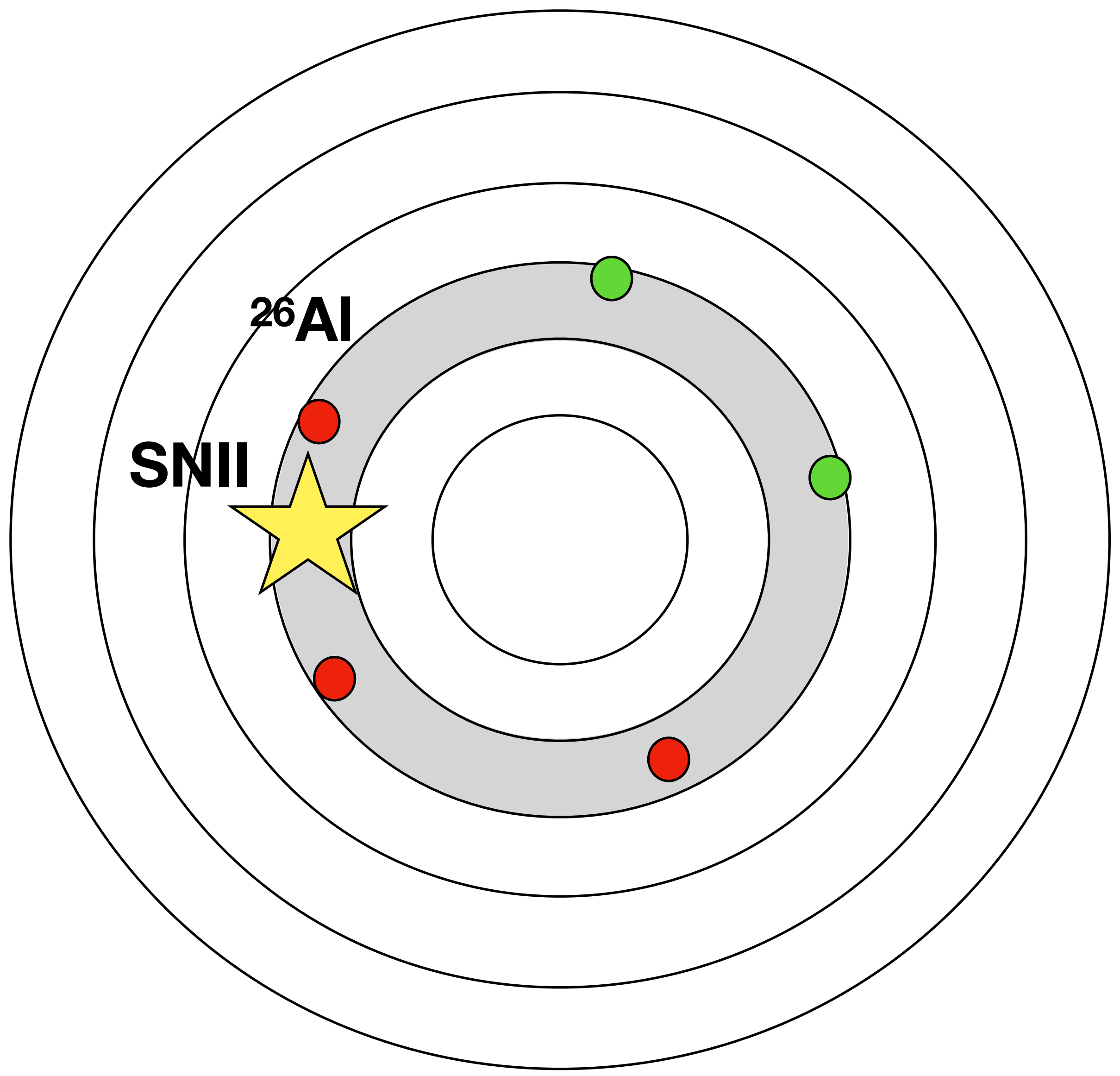

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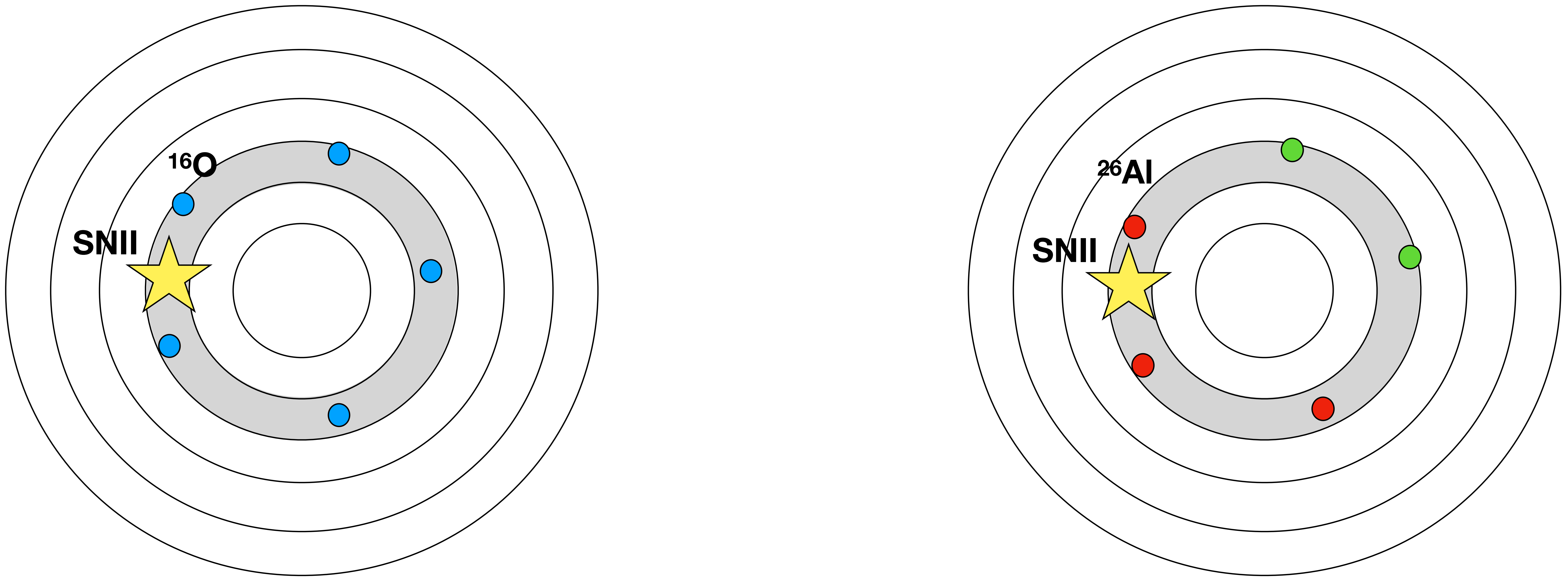


→ homogeneous mixing does not hold for Short Lived Radioisotopes: 2D model needed

1D model limitations

→ **How much the previous results about ^{26}Al are affected by the choice of 1D over 2D model?**

Massive stars are not the only astronomical production site of ^{26}Al

Nova systems contribute too:
- delay for the formation of the white dwarf
- delay for the cooling time

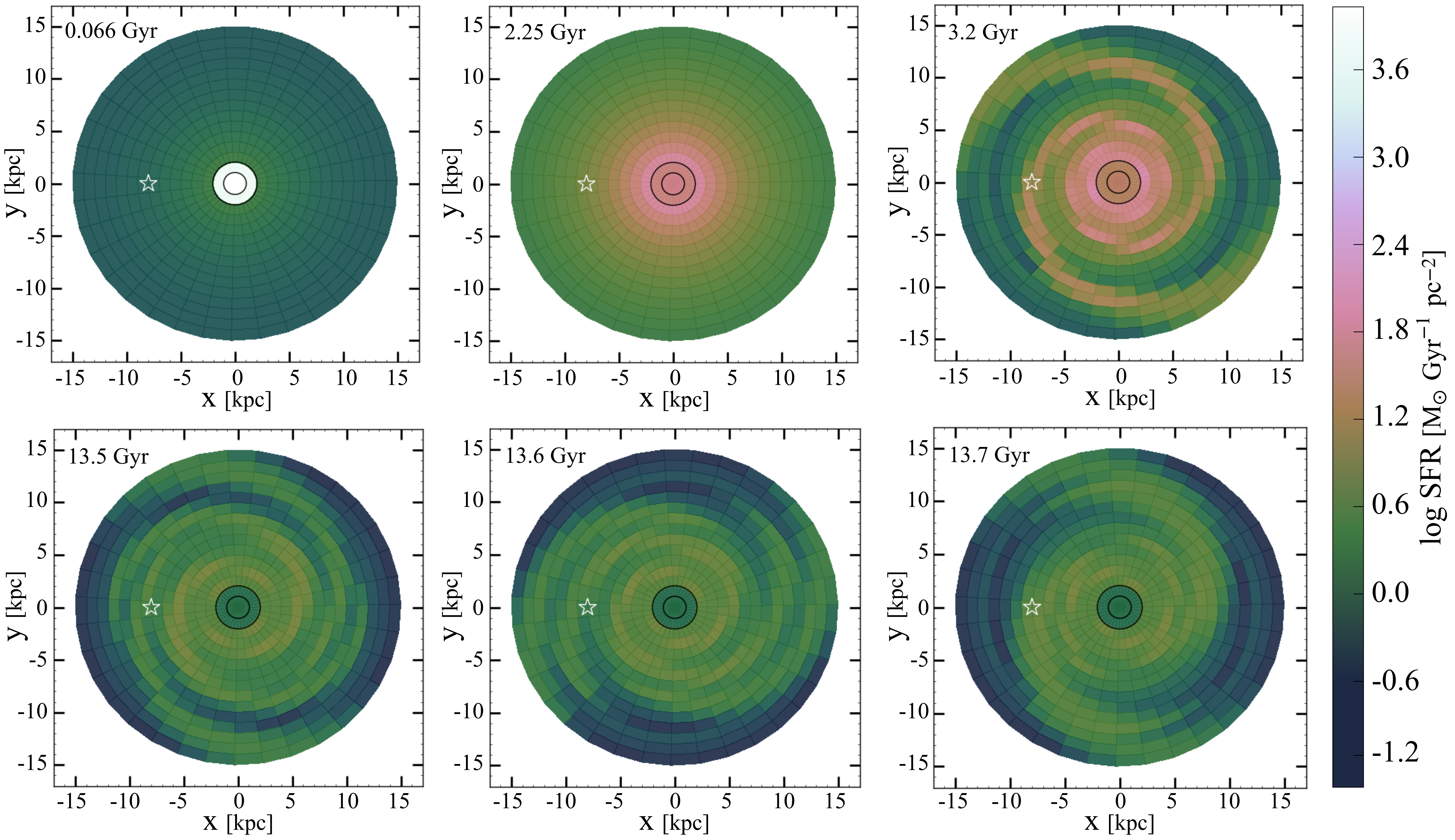
→ Nova systems do not trace the SFR

→ **How much the nova contribution affect the precision of the ^{26}Al SFR tracing?**

Chemical evolution of galaxies: ^{26}Al in 2D MW

Vasini, Spitoni, Matteucci, Cescutti & Della Valle 2024

SFR from
2D model
by *Spitoni+19,+23*:



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massive stars + nove

^{26}Al producers:
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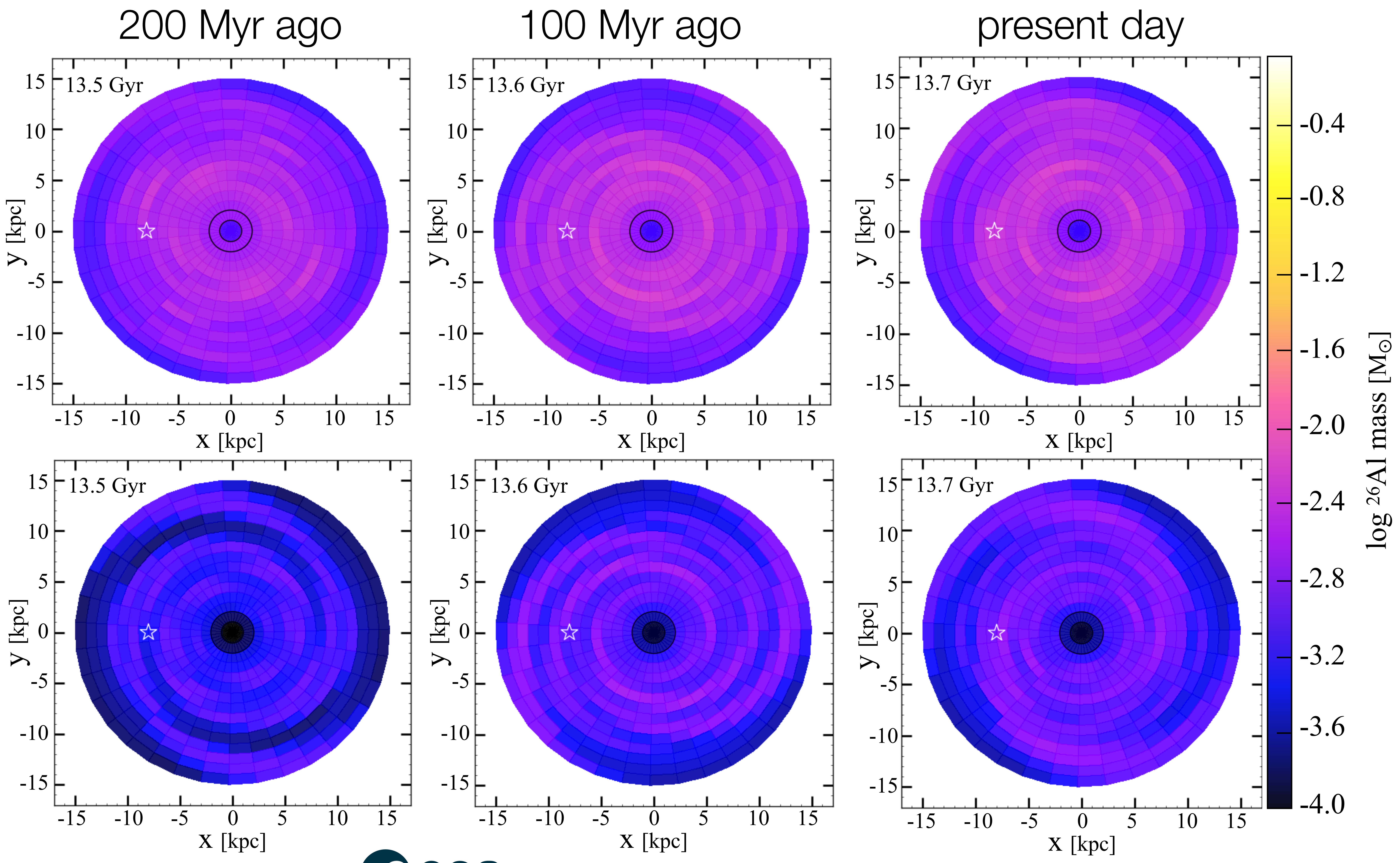

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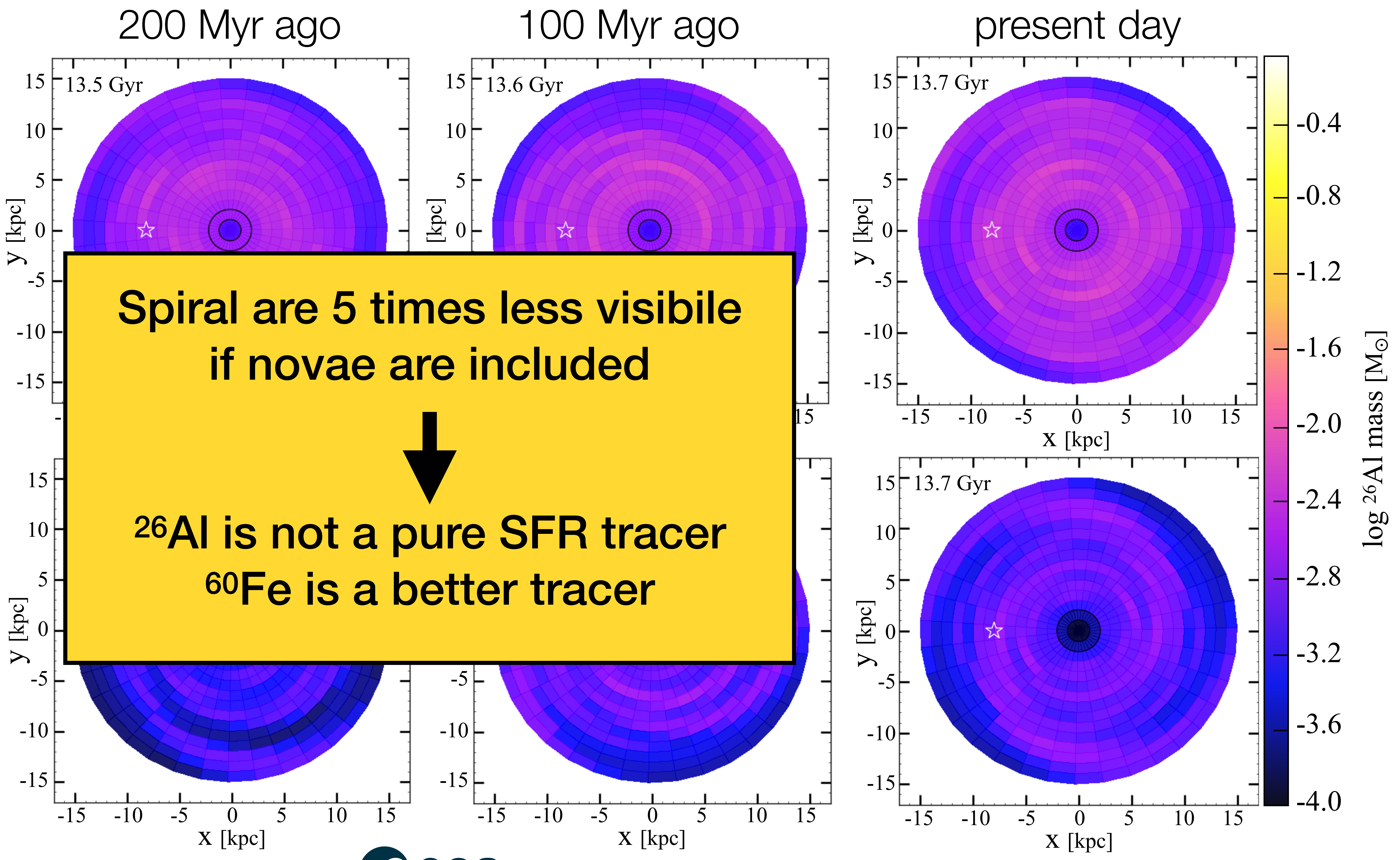

Spiral are 5 times less visibile if novae are included

^{26}Al is not a pure SFR tracer
^{60}Fe is a better tracer

Chemical evolution of galaxies: ^{26}Al in 2D MW

Vasini, Spitoni, Matteucci, Cescutti & Della Valle 2024

^{26}Al producers:
massive stars + nove → 1.028 $M_\odot$

^{26}Al producers:
massive stars → 0.265 $M_\odot$

vs 2 $M_\odot$ observed

↓

theoretical ^{26}Al is too low

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vs $2\ M_\odot$ observed

↓

theoretical ^{26}Al is too low

two different nova populations:

disc novae
(regular novae)

bulge novae
(Enhanced nucleosynthesis
x10 disc novae)

↓

$2.88\ M_\odot$

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^{26}Al producers:
massive stars + nove → $1.028\ M_\odot$

^{26}Al producers:
massive stars → 0.2

vs $2\ M_\odot$

theoretical ^{26}Al is too low

two different nova populations:

bulge novae
(Enhanced nucleosynthesis
x10 disc novae)

↓

$2.88\ M_\odot$

If bulge novae eject up to x10 more matter than a disc nova

↓

we reproduce the observations

Conclusions

Chemical evolution + INTEGRAL data → **constraints on the ^{26}Al production**

Milky Way 1D (Vasini+22):

- Only by including production from novae we can reproduce the observations → **novae are ^{26}Al sources**

Milky Way 2D (Vasini+24):

- 1D models have limitations → we developed a 2D model
- novae smooth out the spiral arm pattern → **^{26}Al is not a pure SFR tracers, ^{60}Fe traces it better**
- we cannot reproduce the observations → **increased production by bulge novae** (already observed)