



Galactic Chemical Evolution

Using NuPyCEE and JINAPyCEE to connect stellar yields to astronomical data

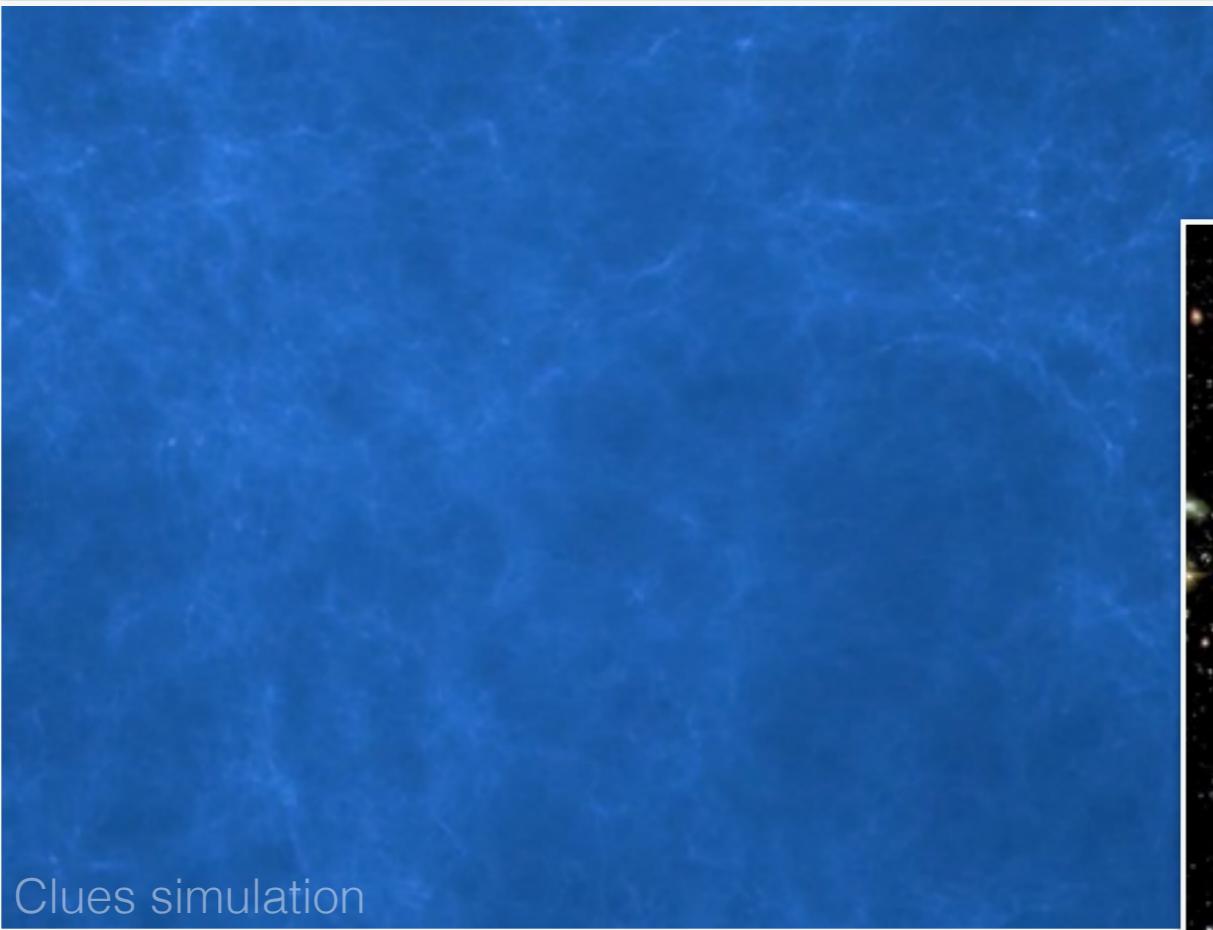
Benoit Côté
Postdoctoral Fellow

Software Tools for Simulations in Nuclear Astrophysics
Hull University, UK
September 19th 2018

ORIGIN OF THE ELEMENTS

Early universe (Big Bang nucleosynthesis)

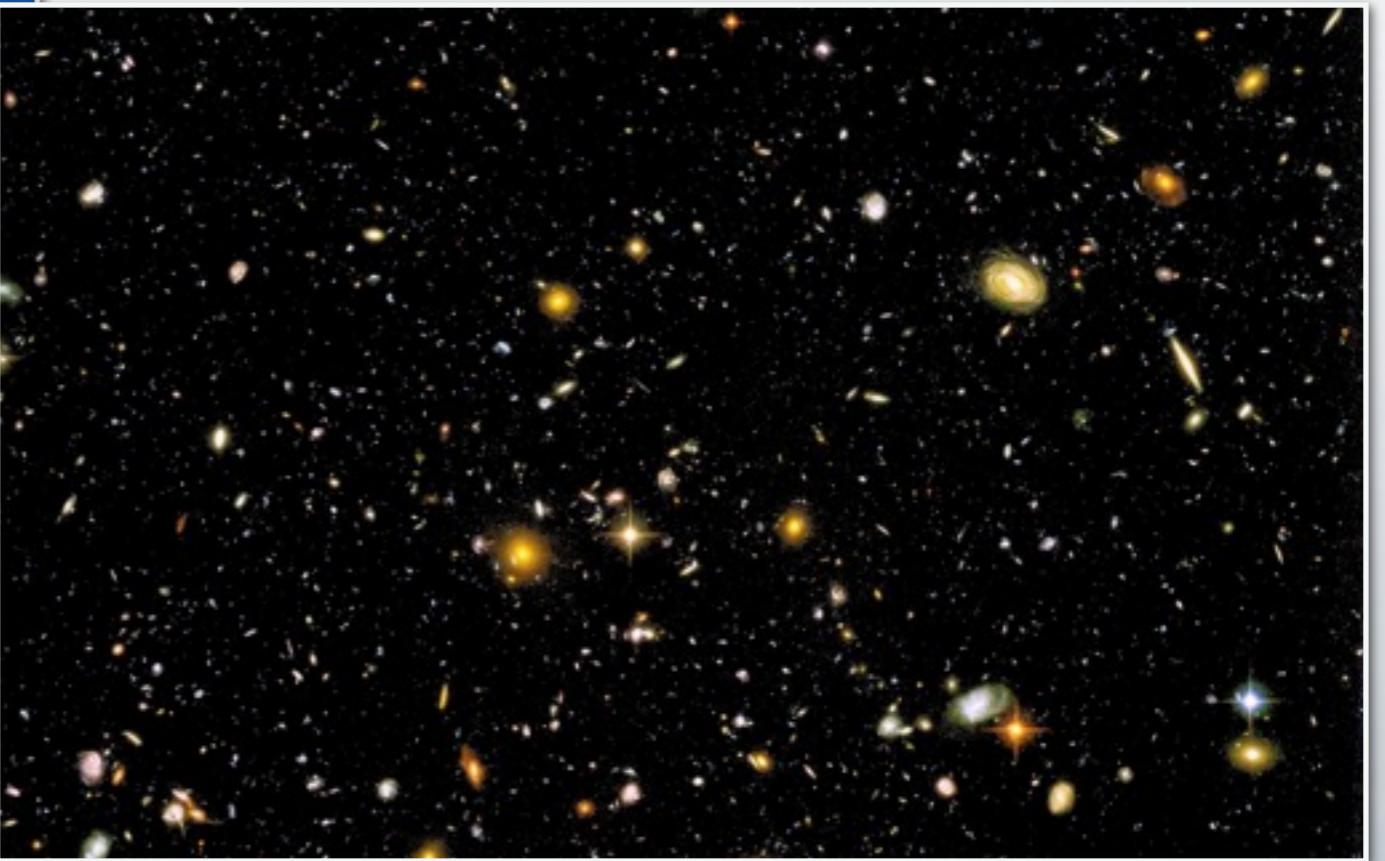
H, He, Li



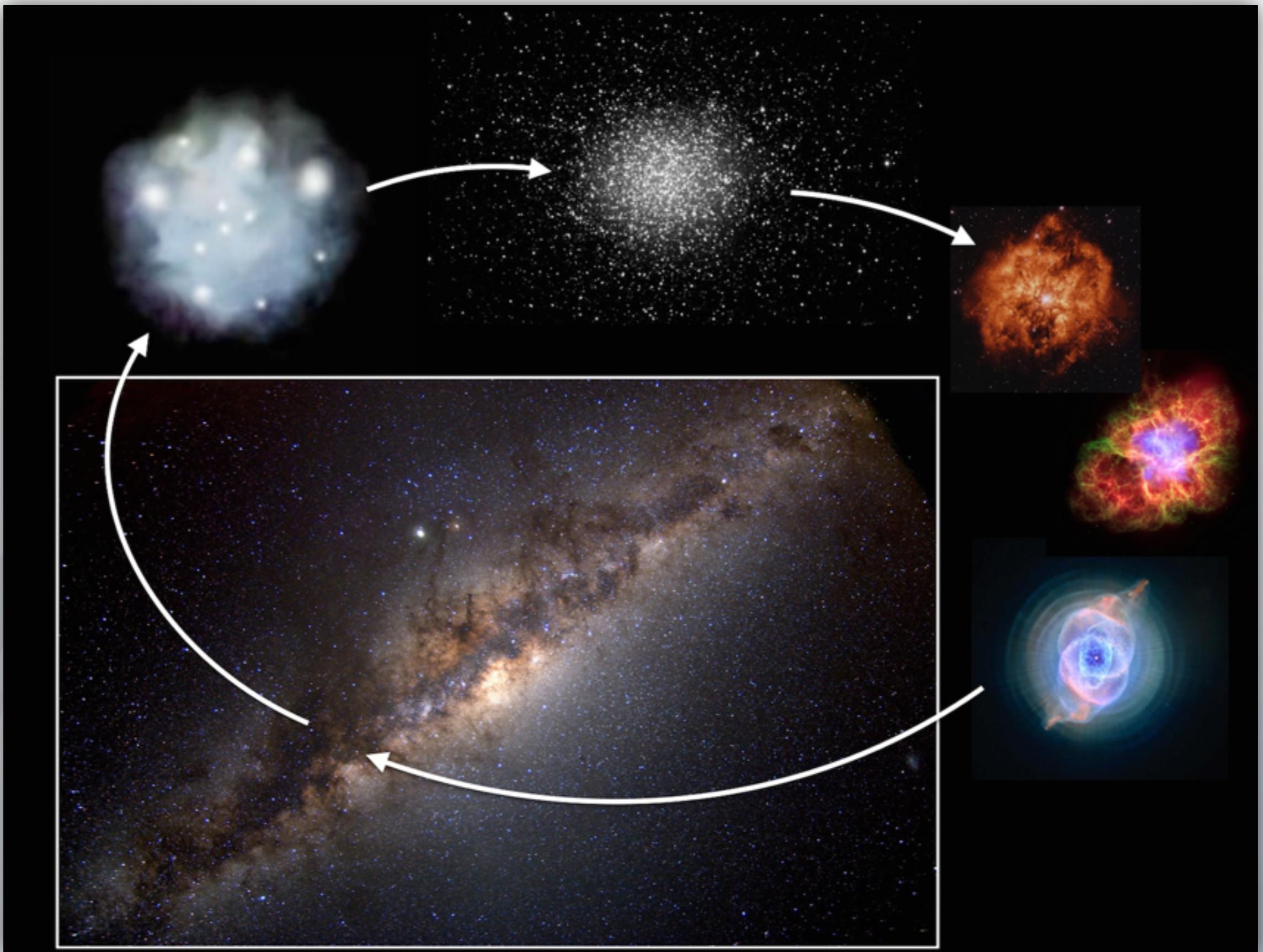
Clues simulation

Current universe (~13 Gyr later)

H, He, Li, C, N, O, Fe, Ni, Sr, Y, Ba, Eu, Ir, Hf, ...



LIFE CYCLE OF STARS

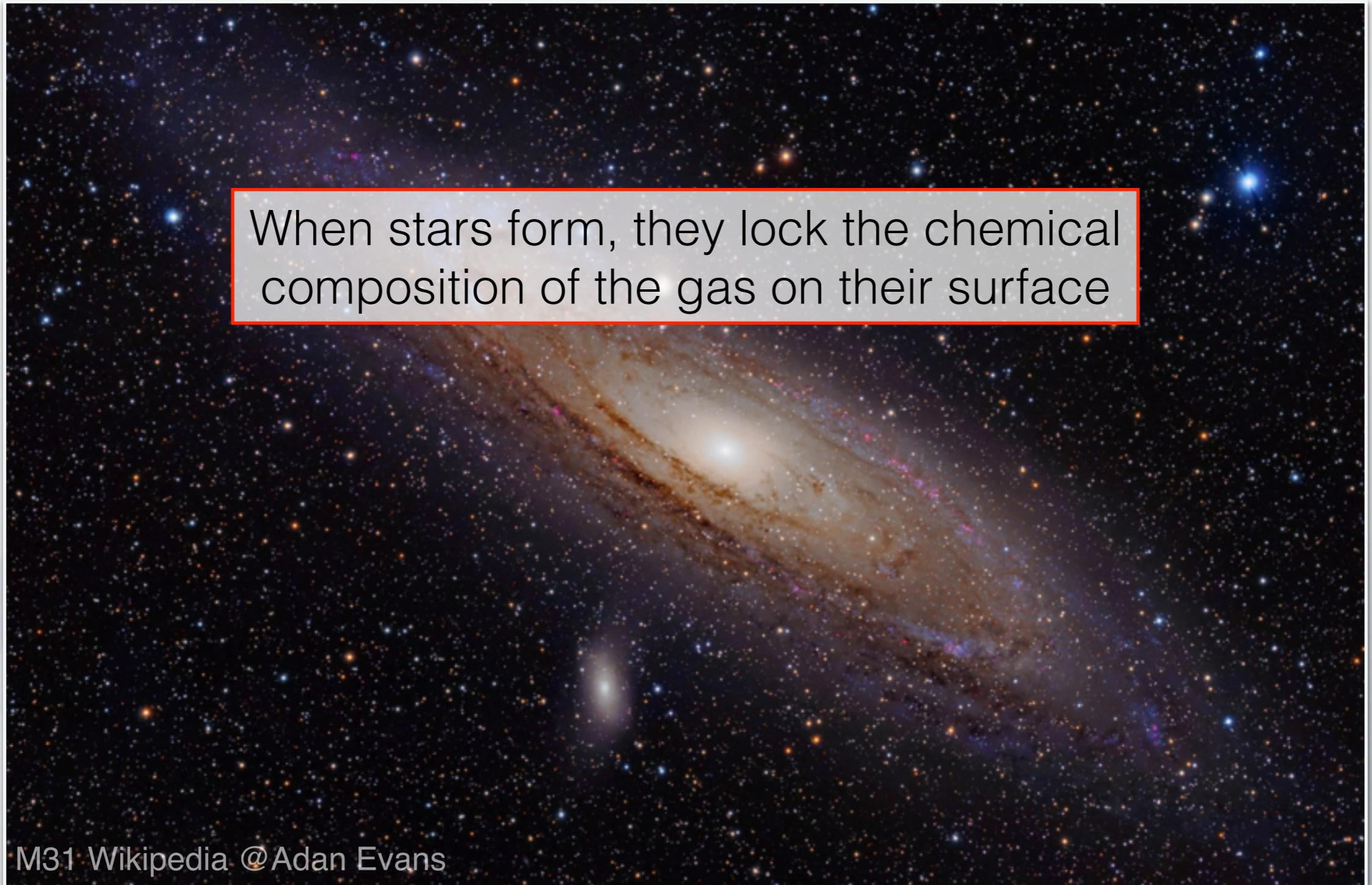


OBSERVING CHEMICAL EVOLUTION



M31 Wikipedia @Adan Evans

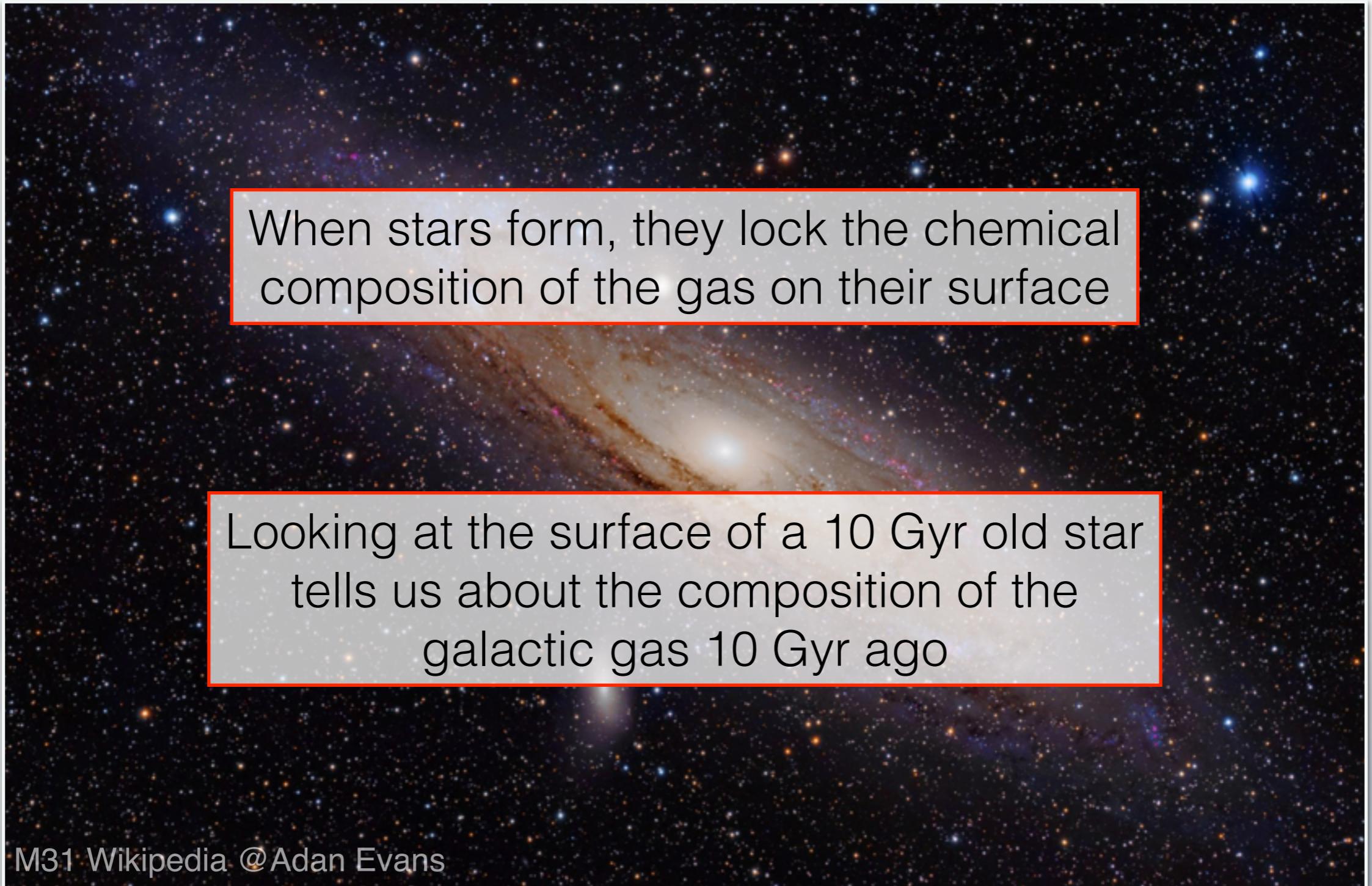
OBSERVING CHEMICAL EVOLUTION



When stars form, they lock the chemical composition of the gas on their surface

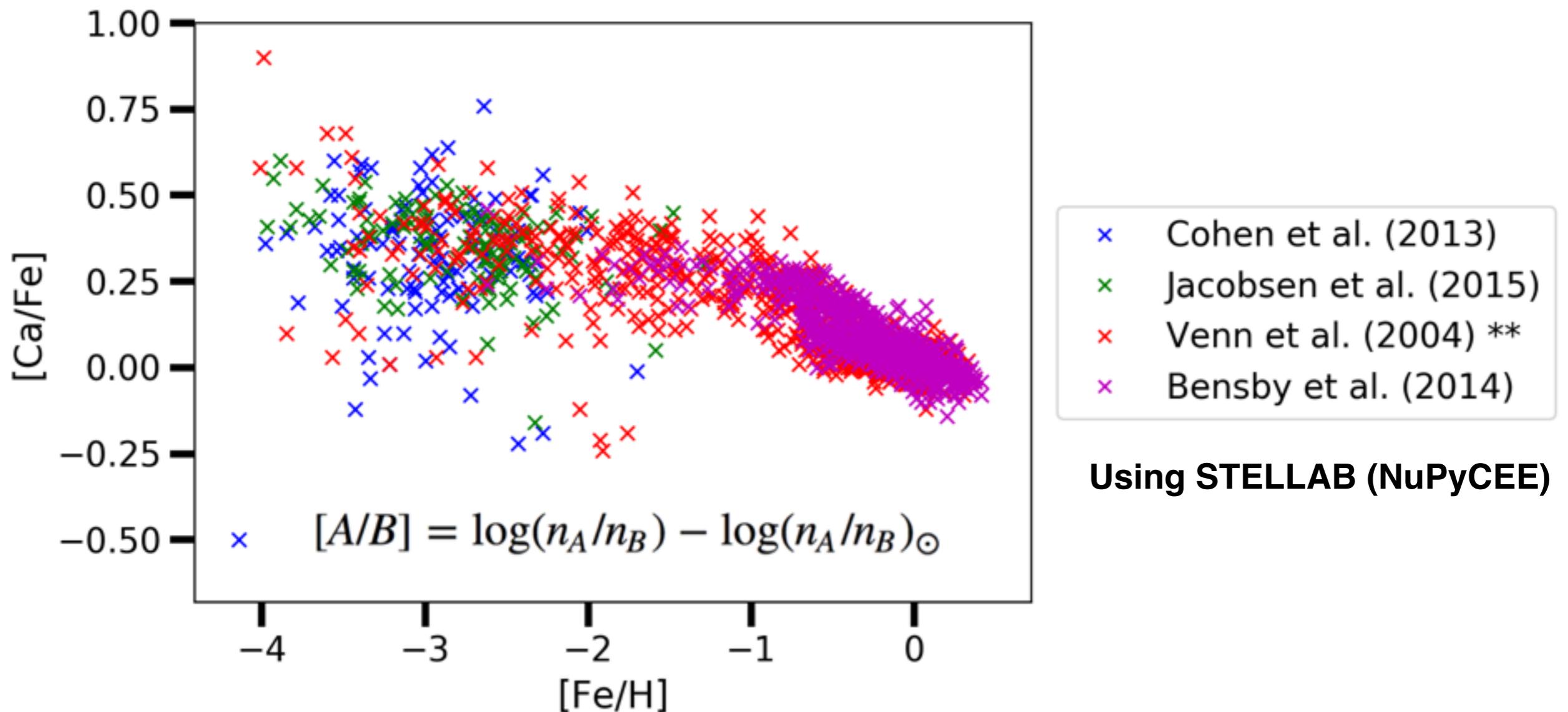
M31 Wikipedia @Adan Evans

OBSERVING CHEMICAL EVOLUTION

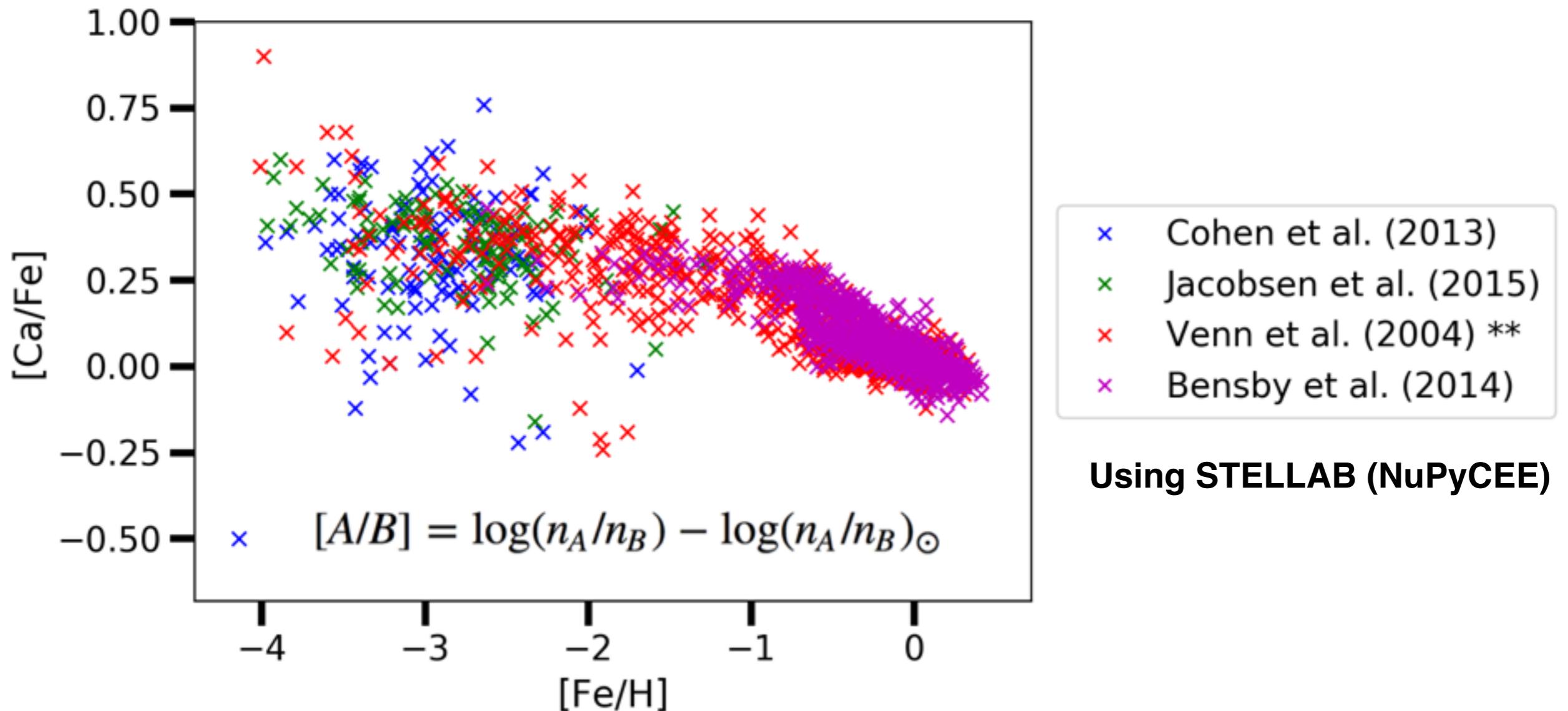


M31 Wikipedia @Adan Evans

STELLAR ABUNDANCES



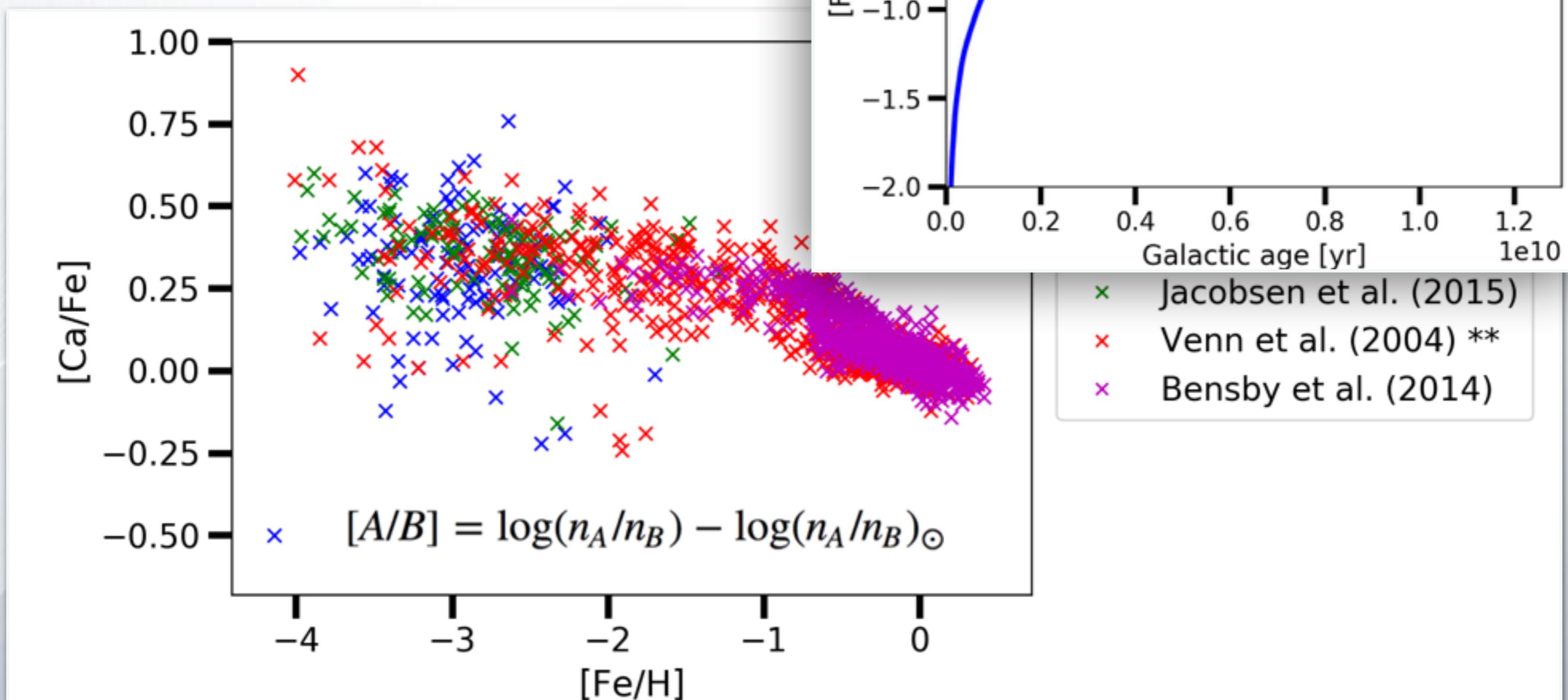
STELLAR ABUNDANCES



Past

Present

STELLAR ABUNDANCES

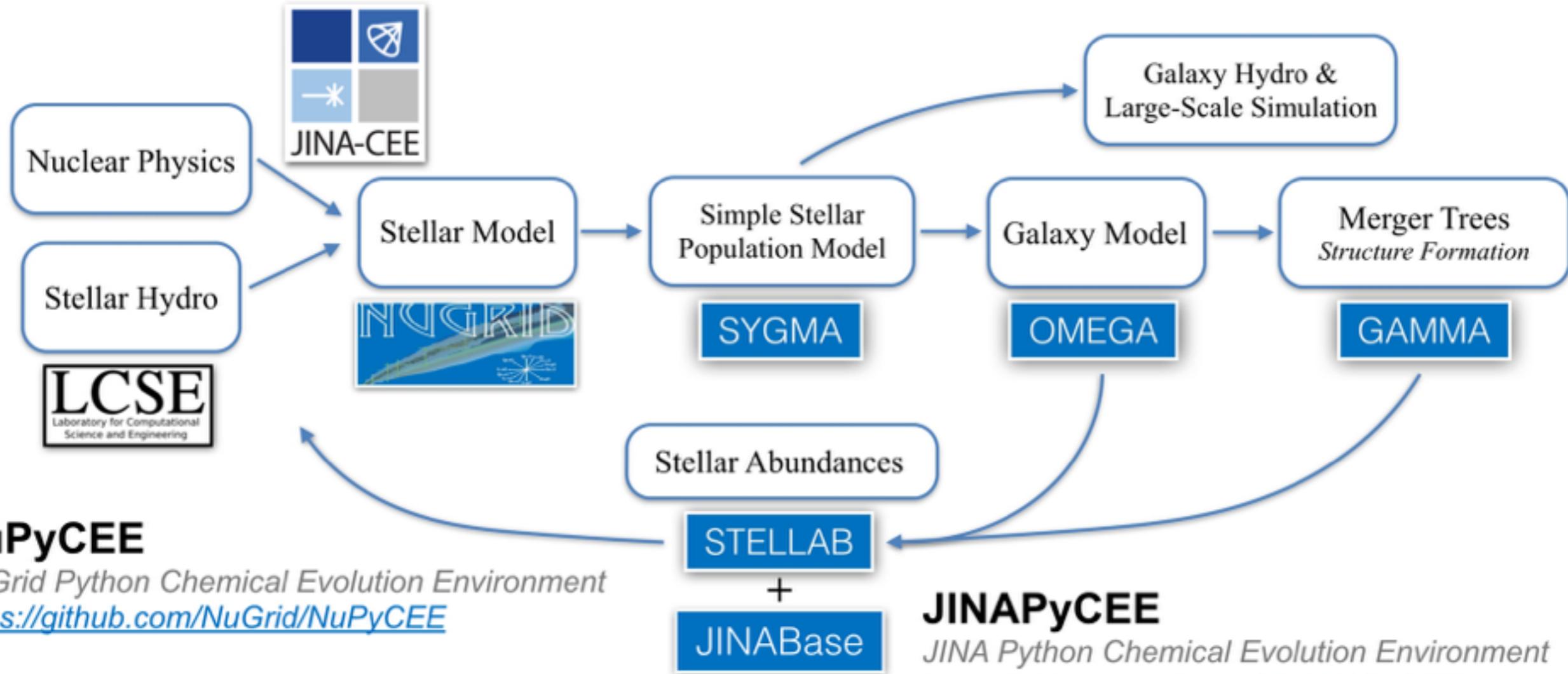


Past

Present

JINA-NUGRID CHEMICAL EVOLUTION PIPELINE

Côté, Ritter, Herwig, et al. (2017)



NuPyCEE

NuGrid Python Chemical Evolution Environment
<https://github.com/NuGrid/NuPyCEE>

SYGMA (Ritter, Côté, Herwig, et al. 2018)
Stellar Yields for Galactic Modeling Applications

OMEGA (Côté, O'Shea, Ritter, et al. 2017)
One-zone Model for the Evolution of Galaxies

STELLAB for high-Z (Côté & Ritter 2016)

JINABase for low-Z (Abohalima & Frebel, 2017, submitted)
<http://jinabase.pythonanywhere.com/plot>

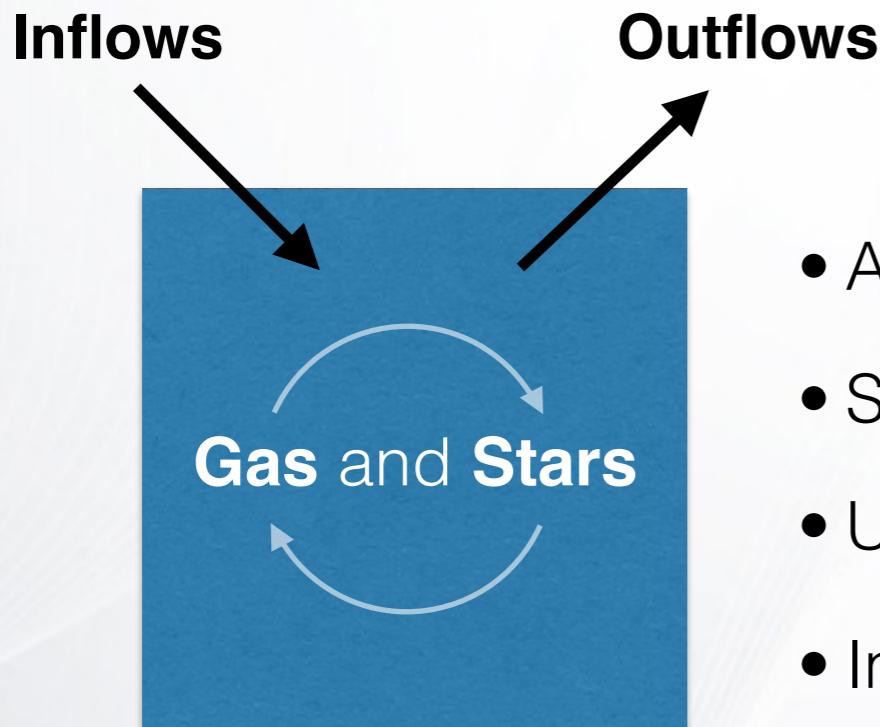
JINAPyCEE

JINA Python Chemical Evolution Environment
<https://github.com/becot85/JINAPyCEE>

OMEGA+ (Côté, Silvia, O'Shea, et al. 2018)
Two-zone model based on OMEGA

GAMMA (Côté, Silvia, O'Shea, et al. 2018)
Galaxy Assembly with Merger-trees for Modeling Abundances, based on OMEGA+

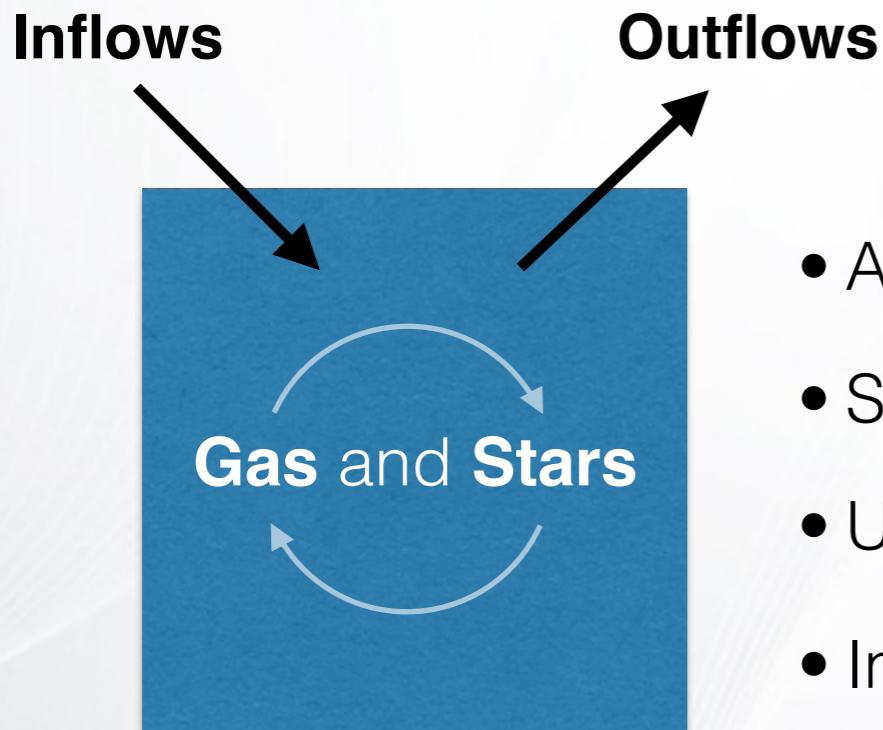
ONE-ZONE MODEL



OMEGA

- A fraction of gas is converted into stars
- Stars evolve, die, and return metals in the gas
- Uniformly mixed
- Interactions with the surrounding

ONE-ZONE MODEL

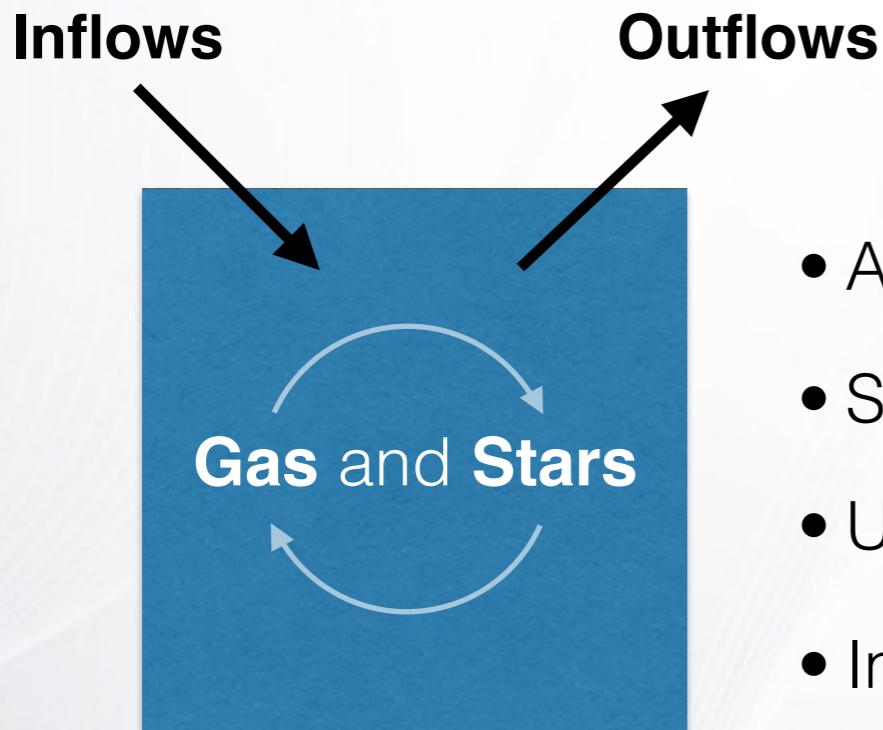


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ONE-ZONE MODEL



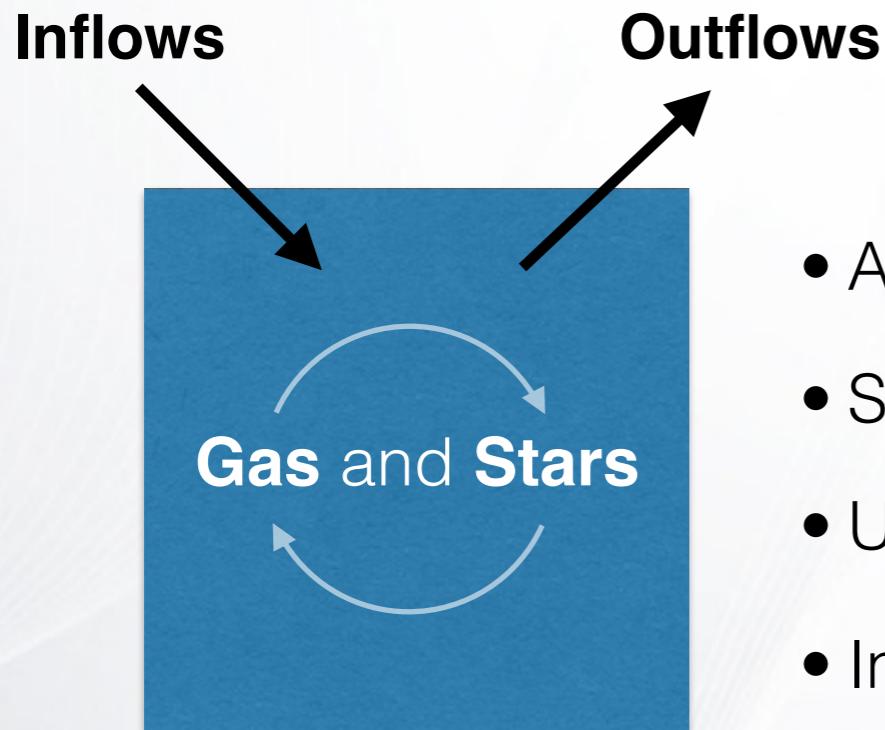
OMEGA

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Fast to compute!

Easy to use for learning the basics of chemical evolution.

ONE-ZONE MODEL



OMEGA

- A fraction of gas is converted into stars
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- Uniformly mixed
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Fast to compute!

Easy to use for learning the basics of chemical evolution.

Capture the essential to efficiently connect nuclear astrophysics to astronomical data (stellar abundances).

A group of stars that form *simultaneously*

A group of stars that form *simultaneously*

Input parameters

- Total stellar mass
- Stellar yields

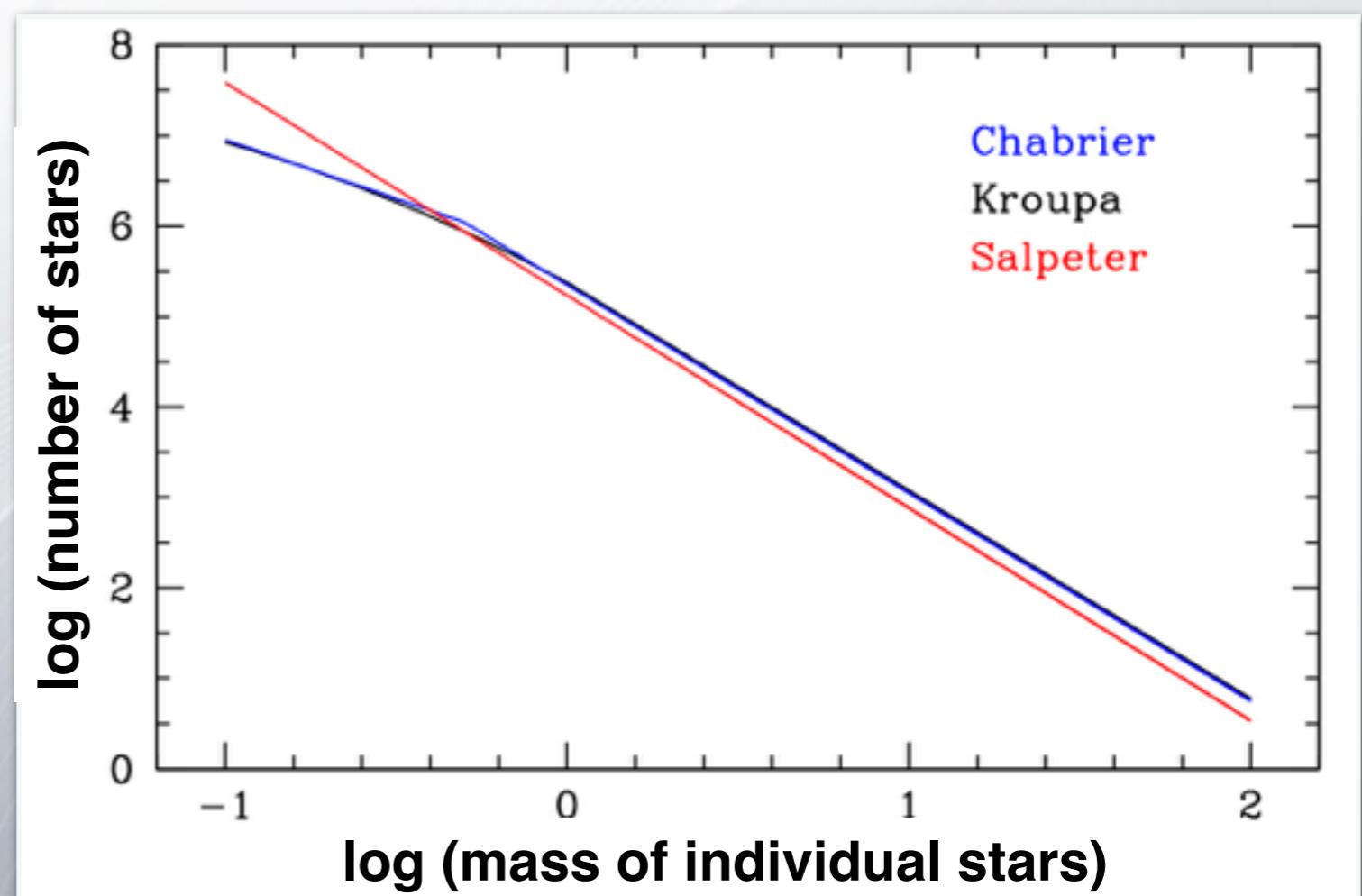
Mass and composition ejected by stars as a function of
stellar initial mass and **initial composition (metallicity)**

A group of stars that form *simultaneously*

Input parameters

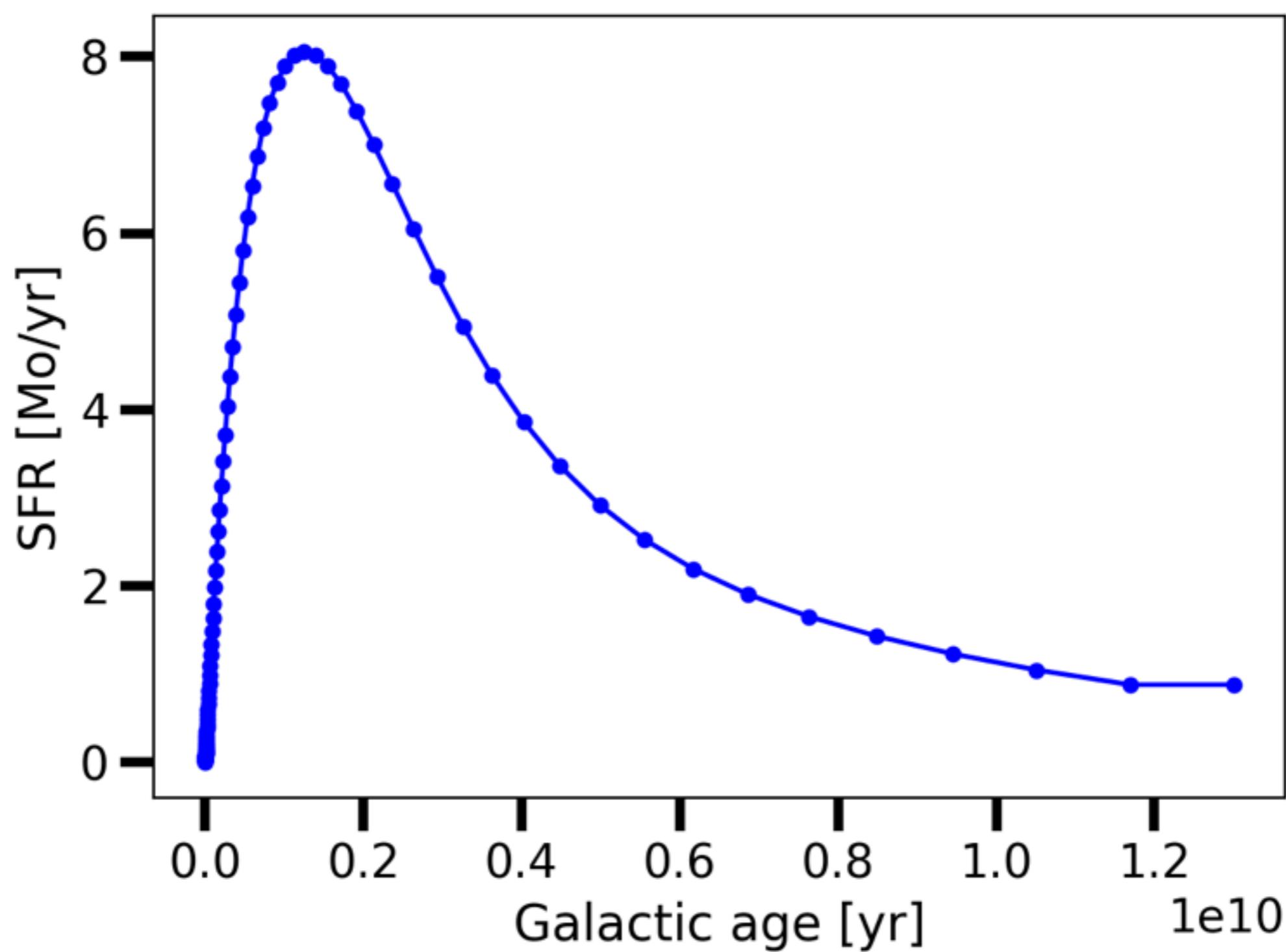
- Total stellar mass
- Stellar yields
- Initial mass function (IMF)

Mass and composition ejected by stars as a function of
stellar initial mass and **initial composition (metallicity)**



STAR FORMATION HISTORY

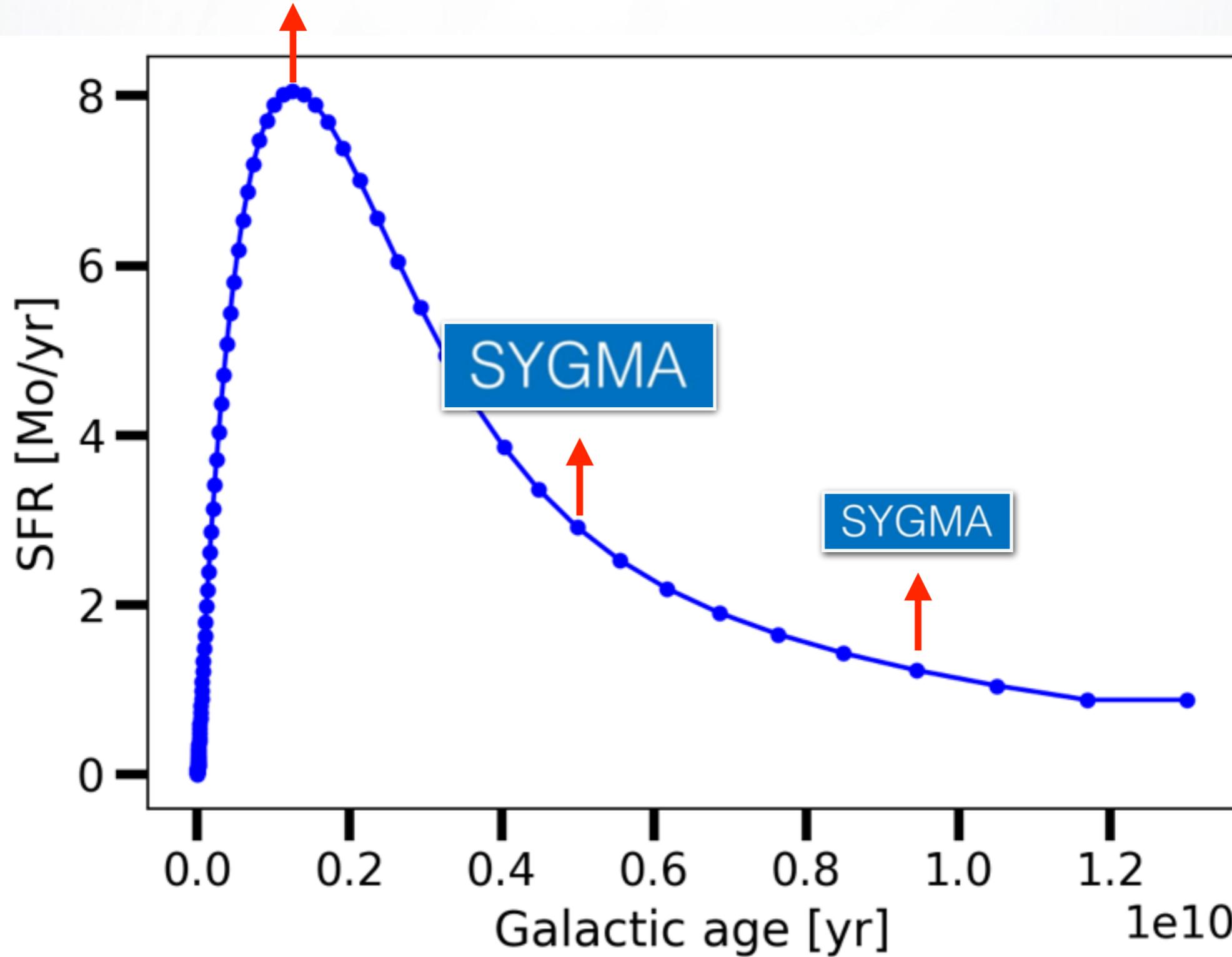
OMEGA



STAR FORMATION HISTORY

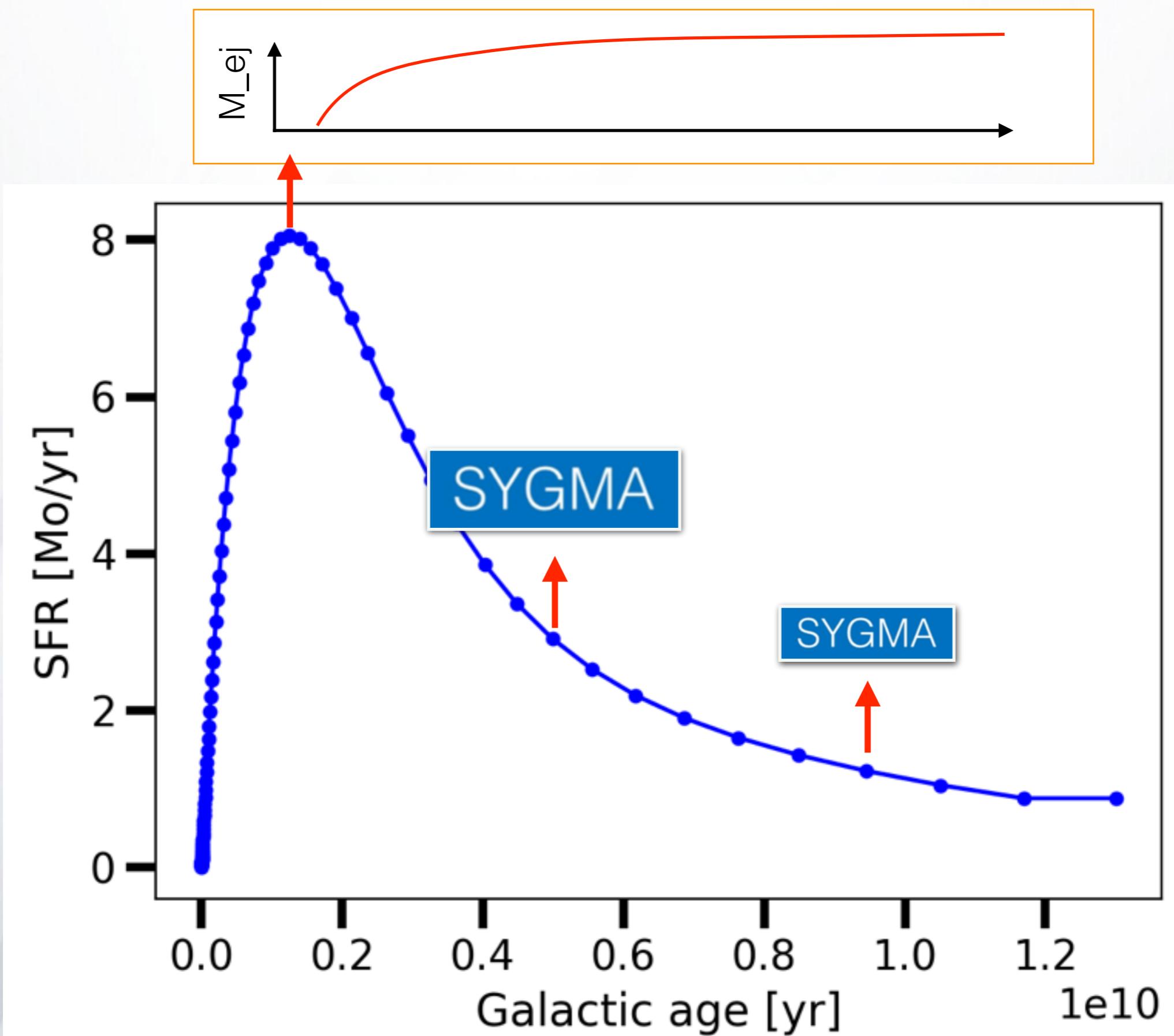
OMEGA

SYGMA



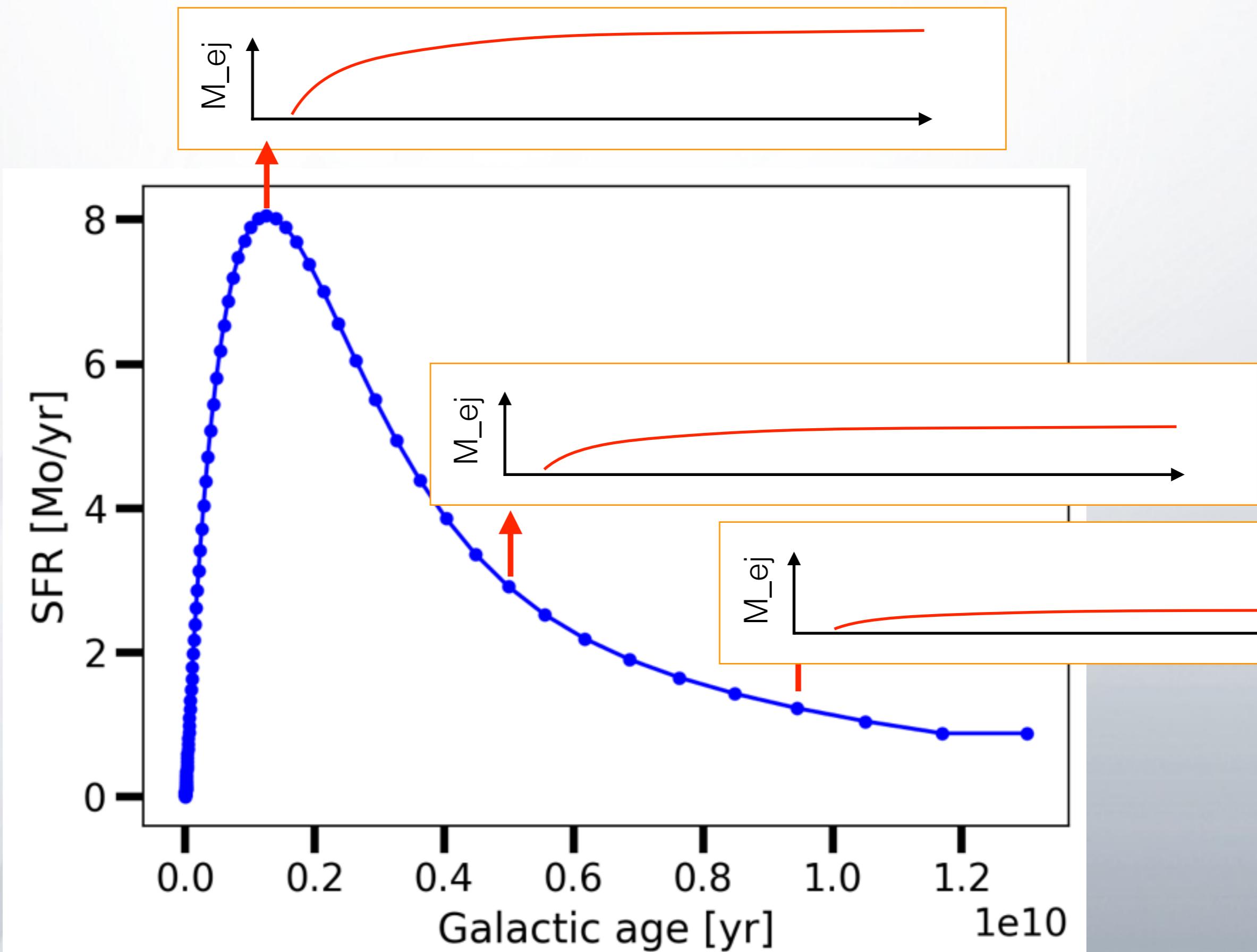
STAR FORMATION HISTORY

OMEGA



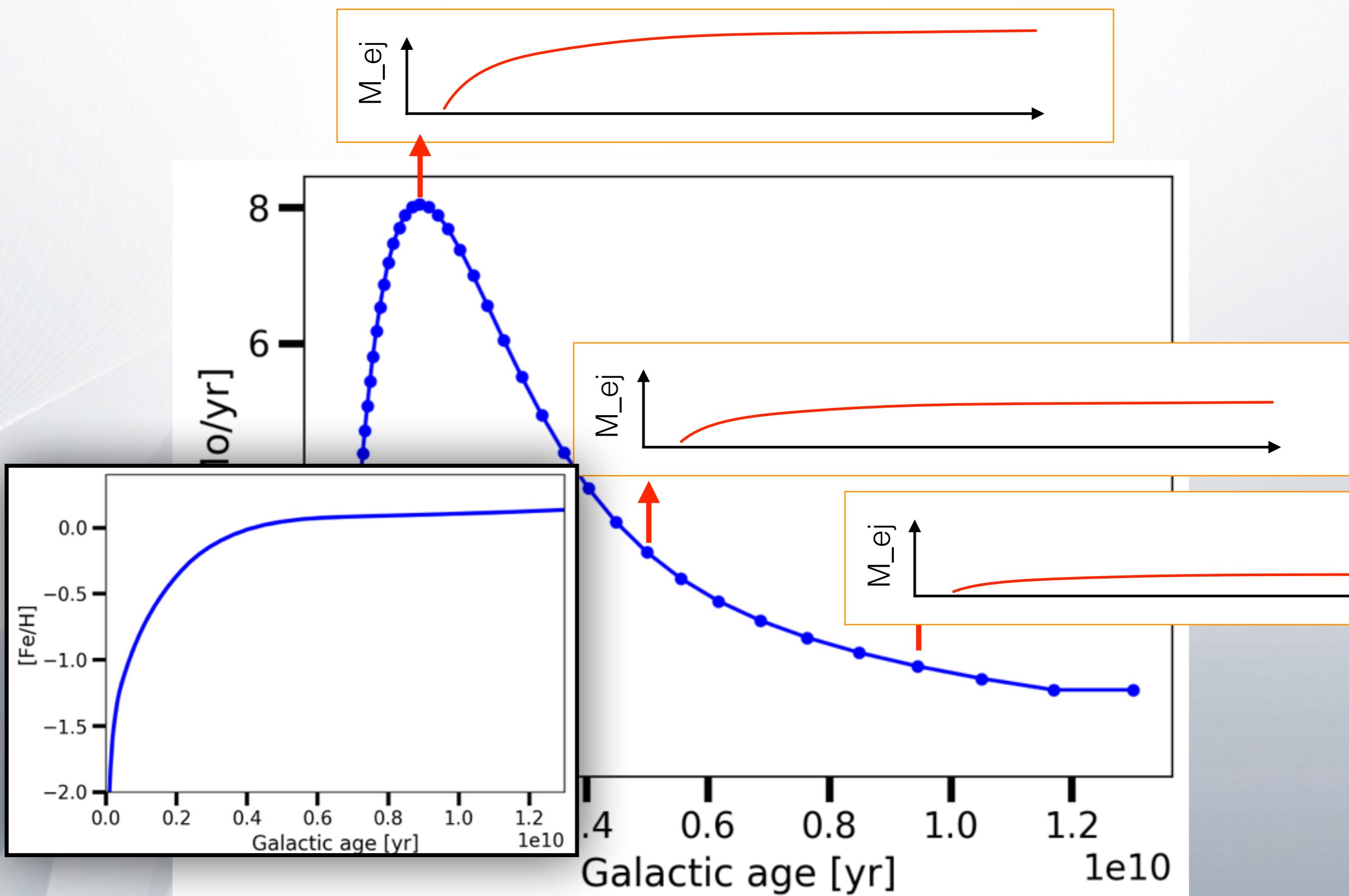
STAR FORMATION HISTORY

OMEGA



STAR FORMATION HISTORY

OMEGA

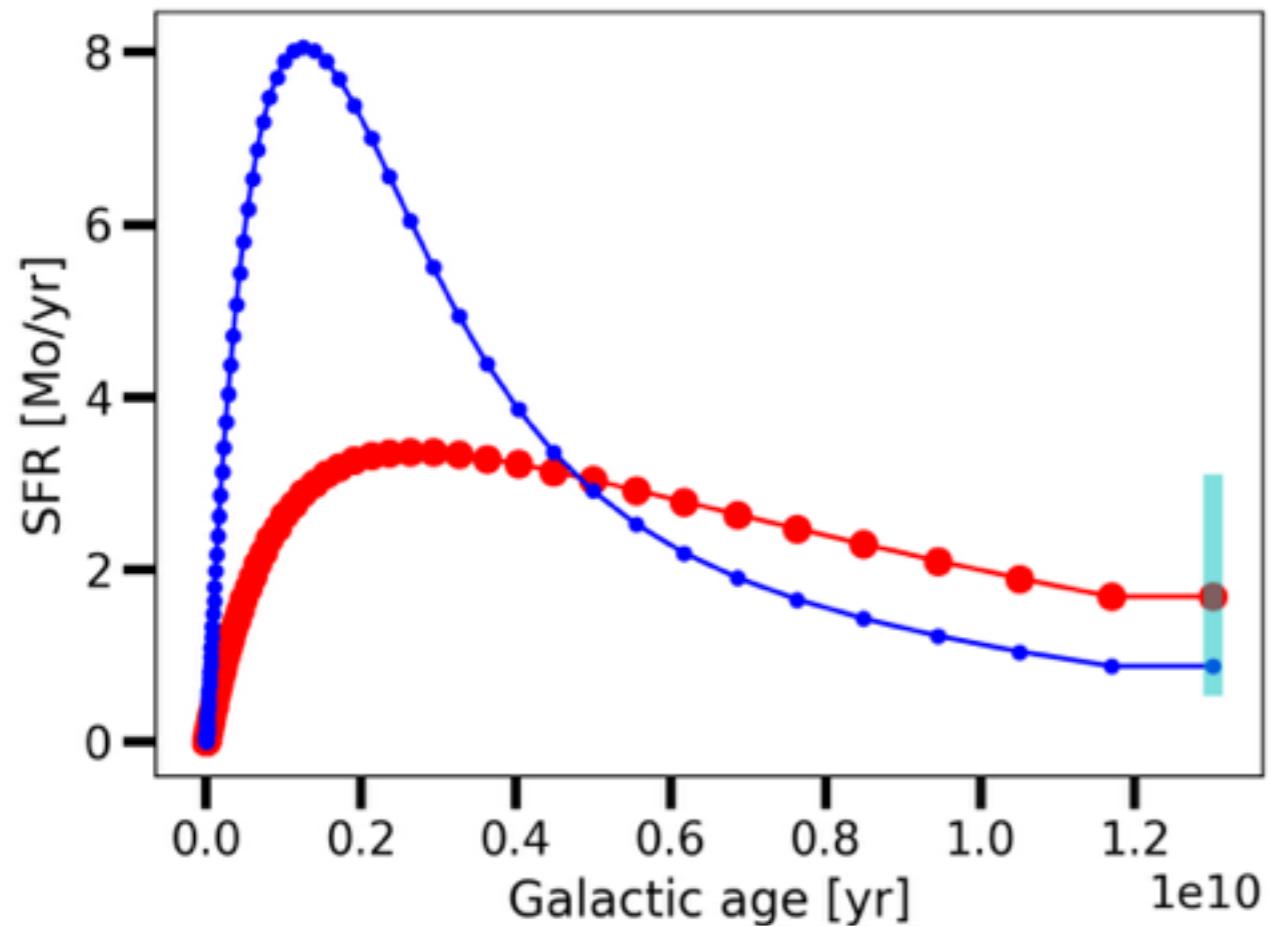


THE ACTIVITIES

-  [HS_GCE_Step_1_Constrain_MW_model.ipynb](#)
-  [HS_GCE_Step_2_Evolution_of_the_elements.ipynb](#)
-  [HS_GCE_Step_3_Stellar_abundances.ipynb](#)
-  [HS_GCE_Step_4_Chemical_evolution_trends.ipynb](#)
-  [HS_GCE_Step_5_Solar_composition.ipynb](#)

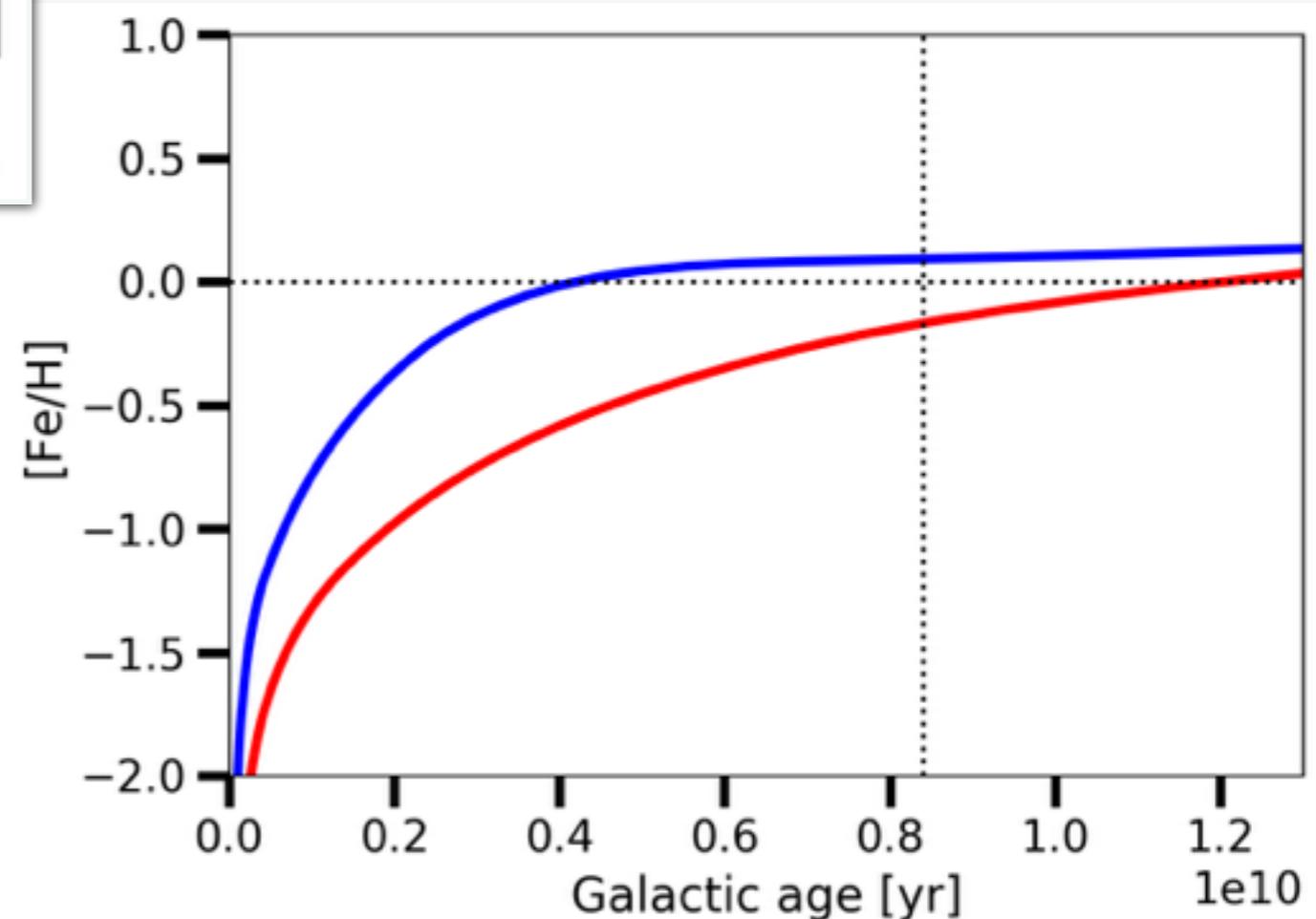
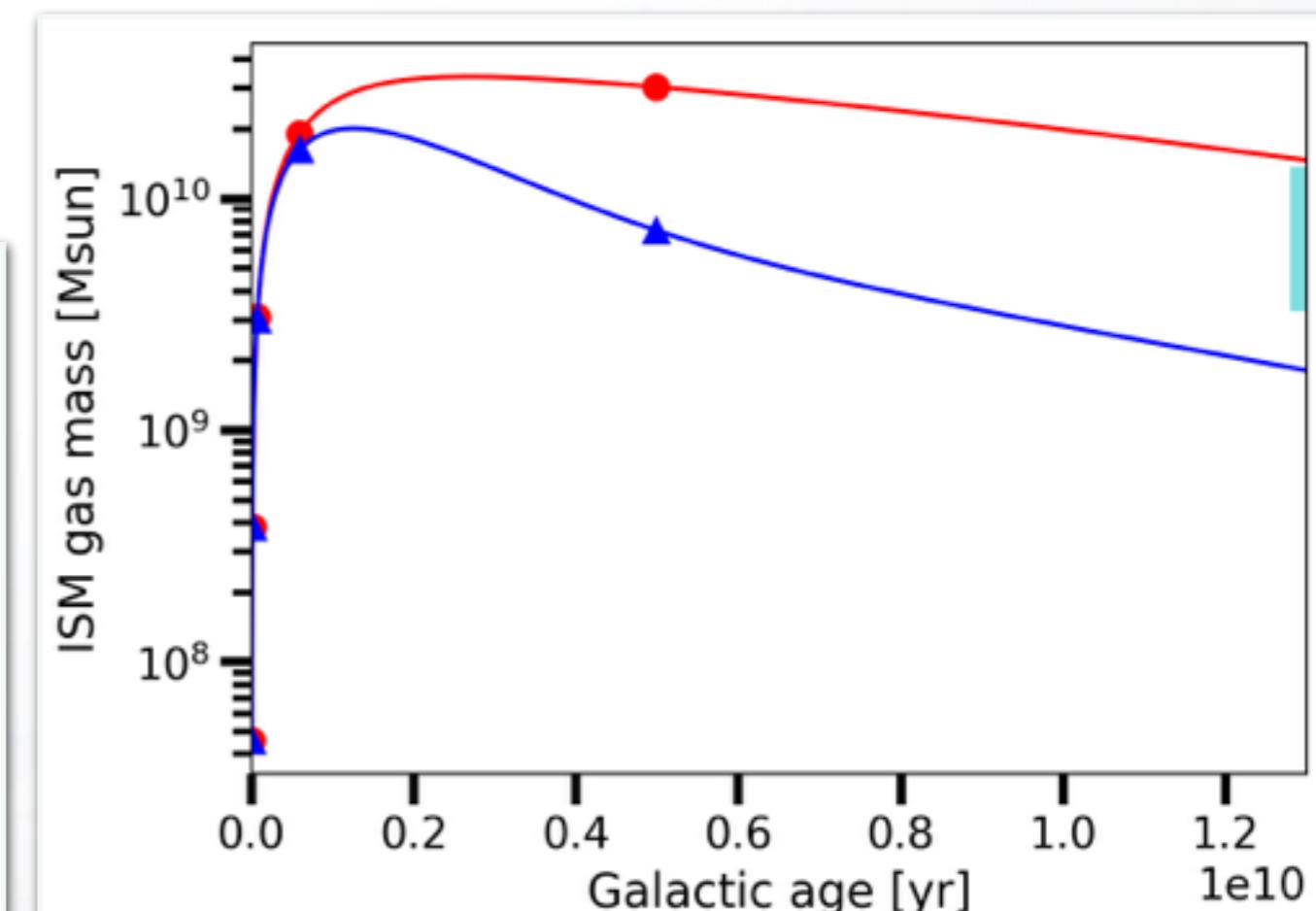
STEP I

OMEGA



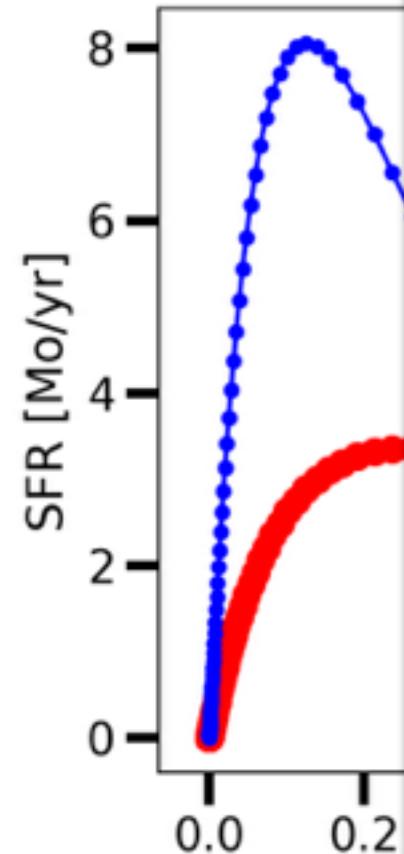
```
# Star formation efficiency ( $f_{\text{star}}$ ) -->
sfe = 0.01
```

```
# Galactic inflow rate
# Magnitude (strength) of the inflow rate
in_mag = 1.0
```



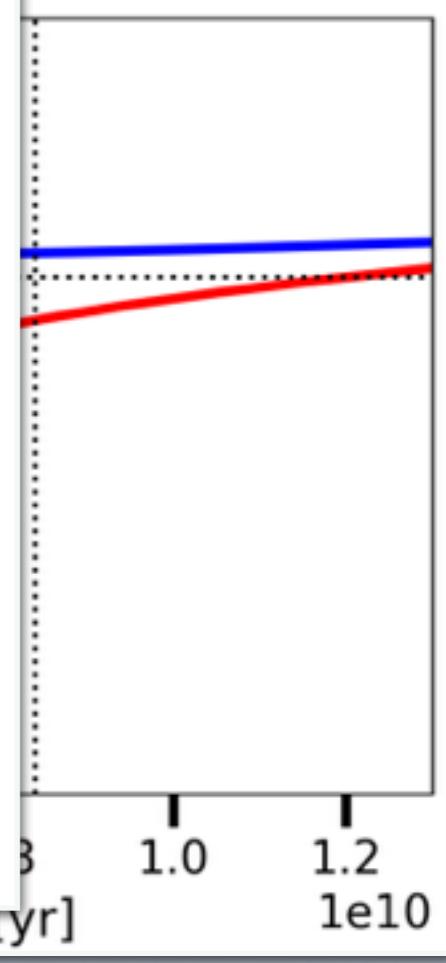
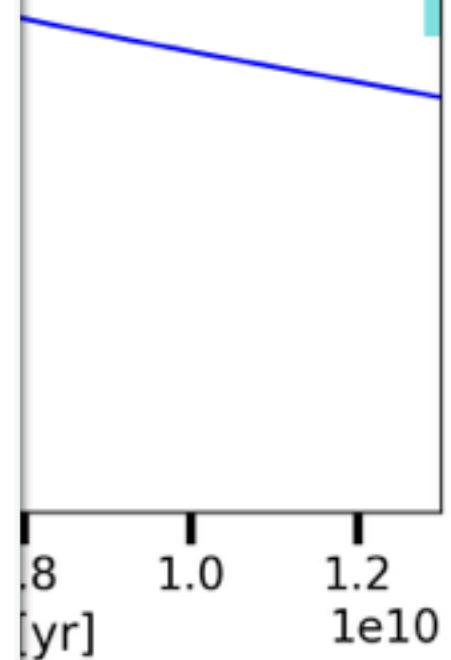
STEP I

OMEGA

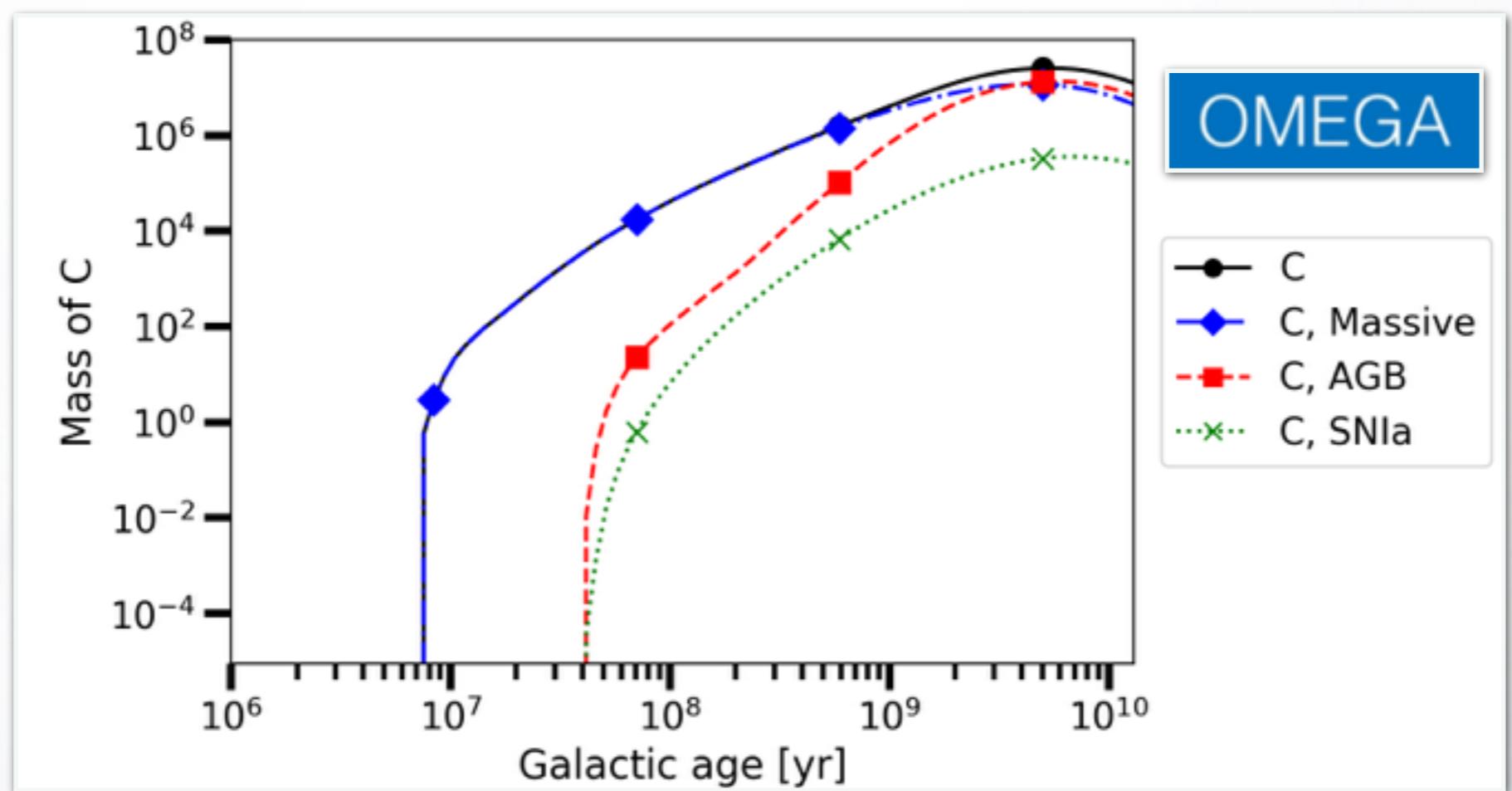


```
# Star formation rate  
sfe = 0.01
```

```
# Galactic information  
# Magnitude (in mag)  
in_mag = 1.0
```

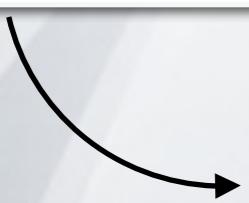


STEP 2

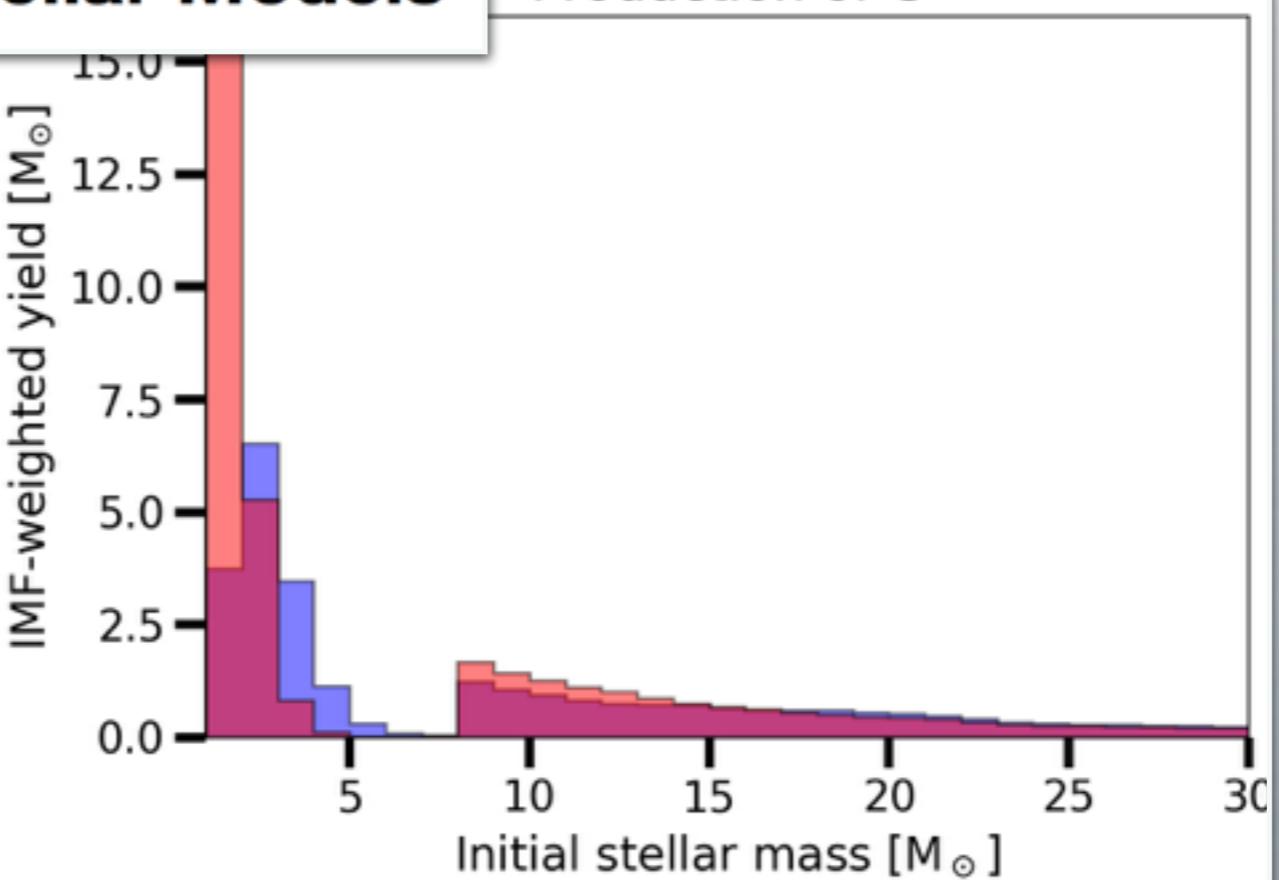


Identify the Important Stellar Models

Production of C



SYGMA



THE ACTIVITIES

-  [HS_GCE_Step_1_Constrain_MW_model.ipynb](#)
-  [HS_GCE_Step_2_Evolution_of_the_elements.ipynb](#)
-  [HS_GCE_Step_3_Stellar_abundances.ipynb](#)
-  [HS_GCE_Step_4_Chemical_evolution_trends.ipynb](#)
-  [HS_GCE_Step_5_Solar_composition.ipynb](#)

THE ACTIVITIES

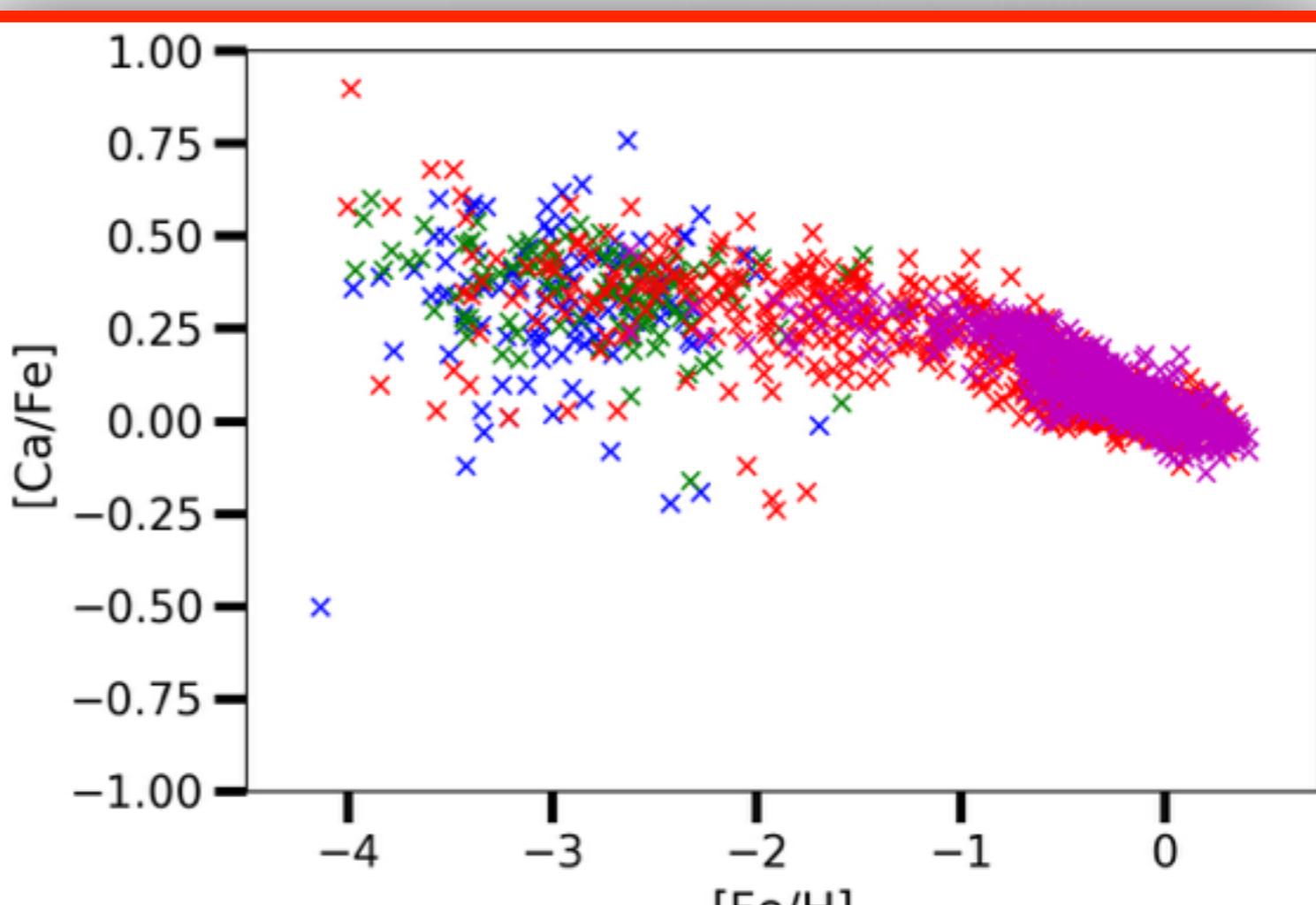
 HS_GCE_Step_1.ipynb

 HS_GCE_Step_2.ipynb

 HS_GCE_Step_3.ipynb

 HS_GCE_Step_4.ipynb

 HS_GCE_Step_5_Solar_composition.ipynb



chemical_evolution_trends.ipynb

THE ACTIVITIES

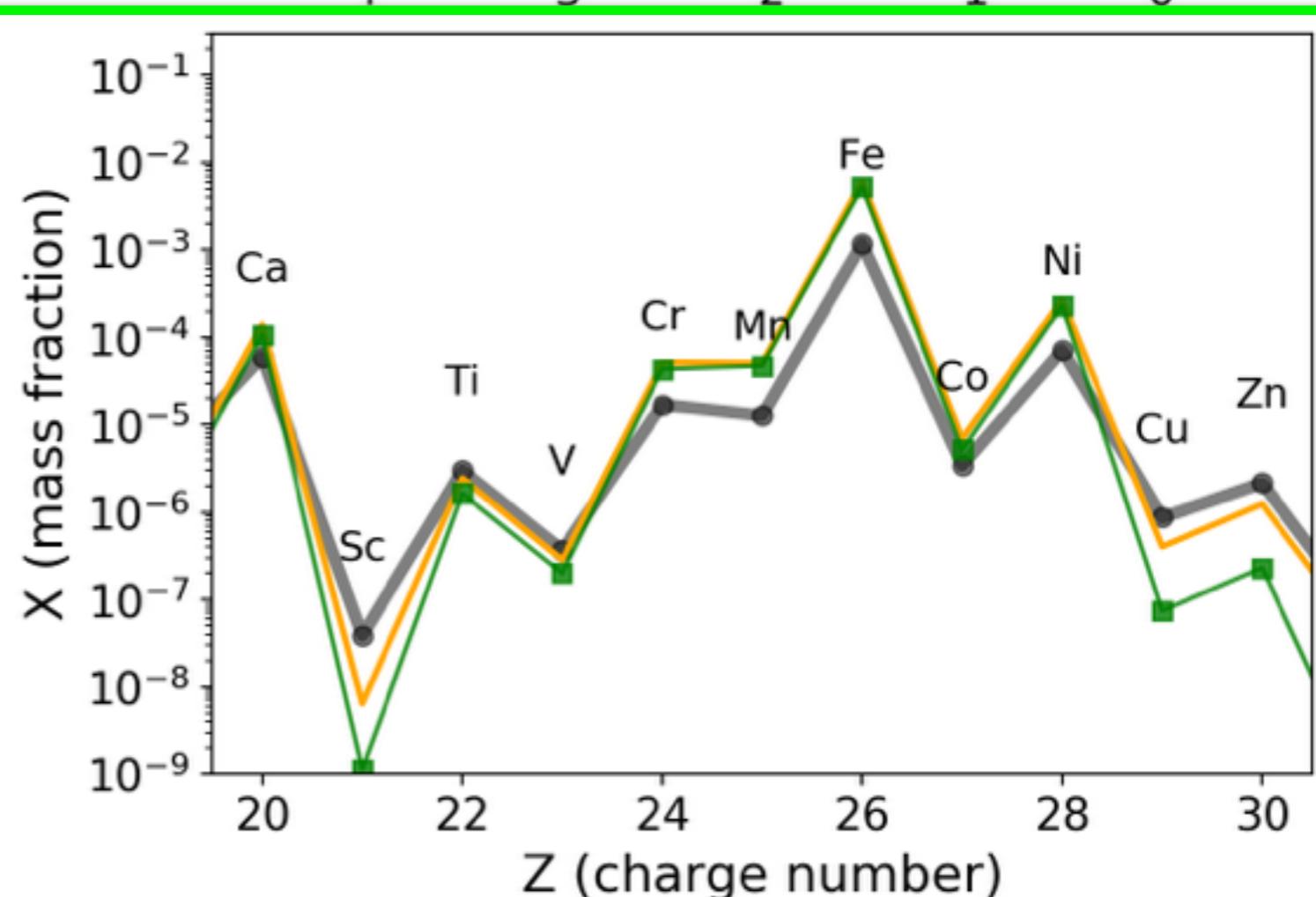
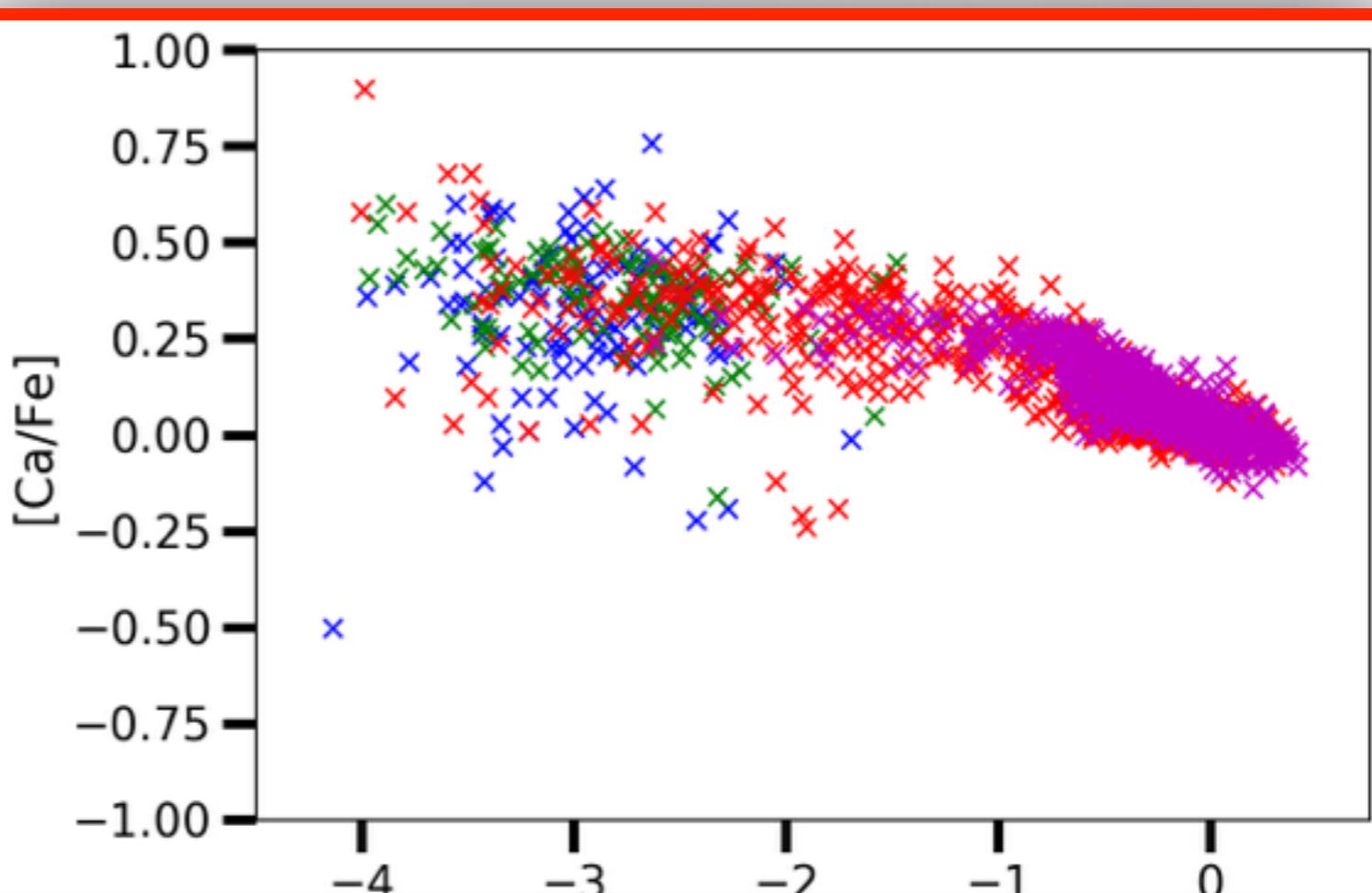
 HS_GCE_Step_1

 HS_GCE_Step_2

 HS_GCE_Step_3

 HS_GCE_Step_4

 HS_GCE_Step_5



GET STARTED

<http://wendi.nugridstars.org/>

Click on **WENDI 1**

WENDI

▲ Aller au niveau supérieur

The Web Exploration of NuGrid Datasets: Interactive (WENDI) project enables the form of iPython notebooks.

 [Wendi System About and Registration](#)



[WENDI 1](#)

Status: up and running



[WENDI 2](#)

Status: testing



[WENDI 3](#)

Access limited, for NuGrid members and associates.



[AstroHub.Phys.Uvic.ca](#)

Status: backup for wendi at NuGrid School

GET STARTED

This screenshot shows a Jupyter Lab interface. At the top right, there are two buttons: "Logout" and "Control Panel", with "Control Panel" circled in red. Below the header is a navigation bar with tabs: "Files" (selected), "Running", "Clusters", and "Nbextensions". A message "Select items to perform actions on them." is displayed above a file browser. The file browser shows a directory structure with four entries: "One-zone Model for the Evolution of Galaxies (OMEGA)", "Stellar evolution and nucleosynthesis data", "Stellar Yields for Galactic Modeling Applications (SYGMA)", and "wendieexamples". Each entry includes a checkbox, a folder icon, a name, and a timestamp ("il y a 14 heures"). To the right of the file browser are sorting options: "Name", "Last Modified", and "File size". Below the file browser are two large buttons: a red "Stop My Server" button and a green "My Server" button.

Spawner options

Jupyter Lab is still experimental, terminal works great though ...

This screenshot shows the "Spawner options" section. It features a dropdown menu set to "Jupyter Notebook". Below it is a dropdown menu labeled "Choose an application hub image ..." with "AlphaGamma" selected, also circled in red. At the bottom is a large orange "Spawn" button.

GET STARTED

Spawner options

Jupyter Lab is still experimental, terminal works great though ...

Jupyter Notebook

Choose an application hub image ...

AlphaGamma

Spawn

Folder to the 5 notebooks

 / **wendieexamples** / **Galactic_chemical_evolution_school**

EXTRA MATERIAL



GAS CIRCULATION AND RECYCLING

Tumlinson, Peeples & Werk (2017)

