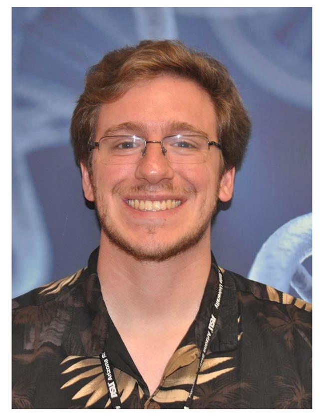


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# Titanium and Iron in the Cassiopeia A Supernova Remnant


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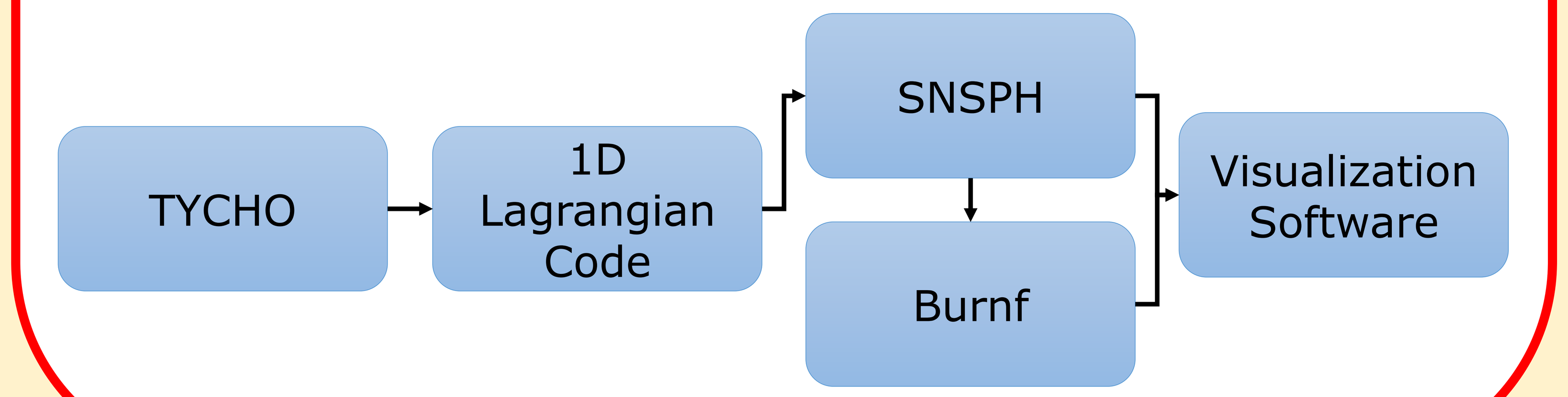
## Introduction & Motivation

- We present spatially resolved yields from a 3D supernova simulation based on the convective supernova engine.
- Our model produces a clustered, bimodal distribution of iron-to-titanium ratios, reproducing observations of Cas A.
- Comparisons using our results could help with inferring the conditions that were present in the Cas A supernova.

## Simulation Methodology

- Our stellar progenitor was evolved to the point of core collapse using the TYCHO 1D stellar evolution code [1], and a 1D Lagrangian code was used to model its collapse through core bounce [2,3].
- After the revival of the supernova shock, our model was mapped into 3D, and the SNSPH code [4] was used to follow its long-term evolution and expansion.
- To obtain accurate yields, the model was post-processed using the Burnf code [5], which employs a network of 524 isotopes up to $^{99}$Tc.




## Specifics of the cco2 Model

- Full 3D hydrodynamics simulation
- Dynamic compact object modeled
- Initial mass of star in TYCHO: 15 $M_\odot$
- Initial mass of compact object: 1.35 $M_\odot$
- Simulation duration in SNSPH: 23.908 simulated hours

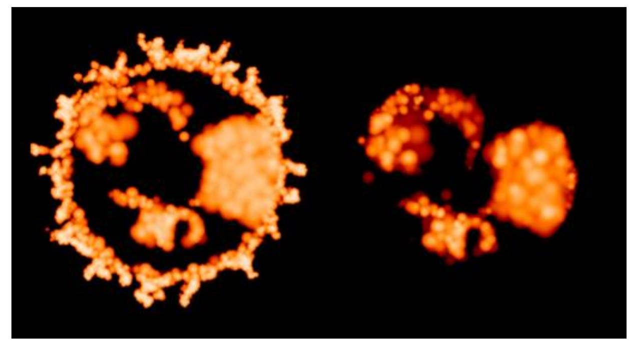


***Figure:** Cross section renders of He (left) and $^{44}$Ti (right) abundances for the cco2 model. Much of the $^{44}$Ti is located in alpha-rich regions, suggesting production in alpha-rich freezeout conditions.*

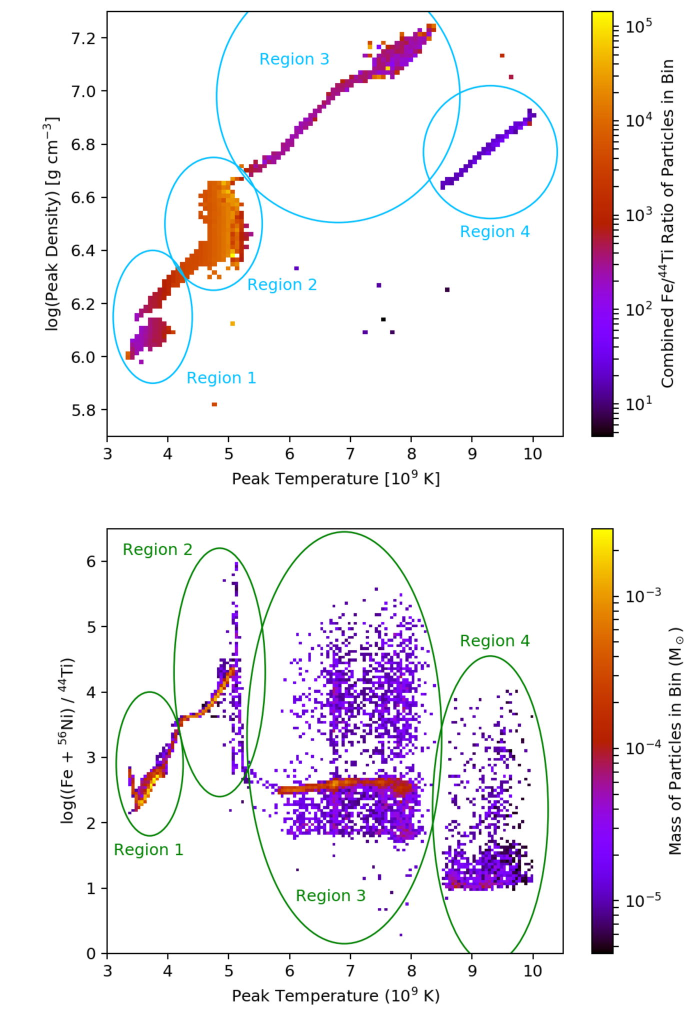
## Four Distinct Regions of Material

When material is plotted according to its peak temperature in the simulation, four regions emerge with distinct conditions. *Note: "Fe" in all ratios includes $^{56}$Ni, which decays to $^{56}$Fe.*

- **Region 1:** coolest, low Fe/$^{44}$Ti
- **Region 2:** warmer, high Fe/$^{44}$Ti
- **Region 3:** hot, low Fe/$^{44}$Ti
- **Region 4:** very hot, very low Fe/$^{44}$Ti

***Table:** Summary of the most important physical conditions for each of the four regions of particles.*

| Region | Peak Temperature ($10^9$ K) | log(Peak Density) [g/cm³] | Average log(Fe/$^{44}$Ti) |
|---|---|---|---|
| 1 | 3.3–4.2 | 5.9–6.4 | 2.6 |
| 2 | 4.2–5.3 | 6.1–6.8 | 3.9 |
| 3 | 5.3–8.4 | 6.6–7.3 | 2.8 |
| 4 | 8.4–10.1 | 6.5–7.0 | 1.6 |




***Figures:** 2D histograms showing the definitions of the four regions in terms of peak temperature and peak density, as well as the Fe/$^{44}$Ti ratios for material in each region.*

## Connections to Cassiopeia A

- *NuSTAR* X-ray observations of Cas A [6] reveal the spatial distributions of iron (including $^{56}$Fe from decayed $^{56}$Ni) and $^{44}$Ti in the remnant.
- Above peak temperatures of about $4\times10^9$ K, production of $^{56}$Ni is insensitive to changes in temperature. $^{44}$Ti production is much more sensitive to peak temperature, so it serves as a good indicator for the explosion conditions.
- Both Cas A and our cco2 model show a clustered, bimodal distribution of Fe/$^{44}$Ti ratios. Correlations between Fe/$^{44}$Ti ratios and explosion conditions seen in our model can allow for inferences about the explosion conditions that created Cas A.

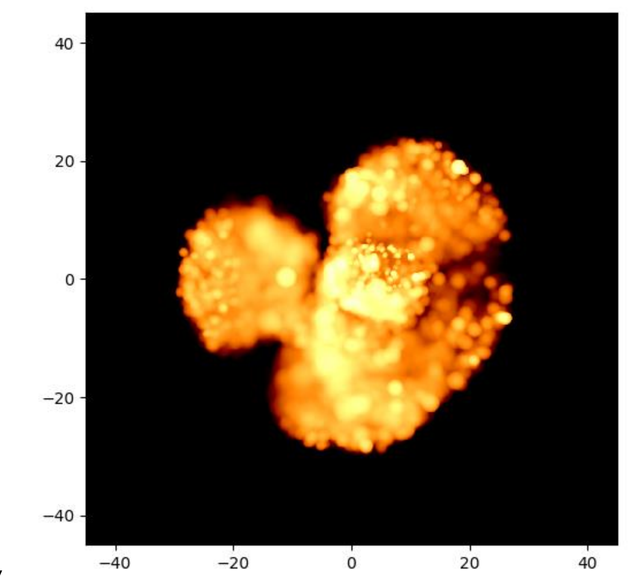


***Figure:** 3D render of our cco2 model with color brightness corresponding to the logarithm of the material's Fe/$^{44}$Ti ratio.*

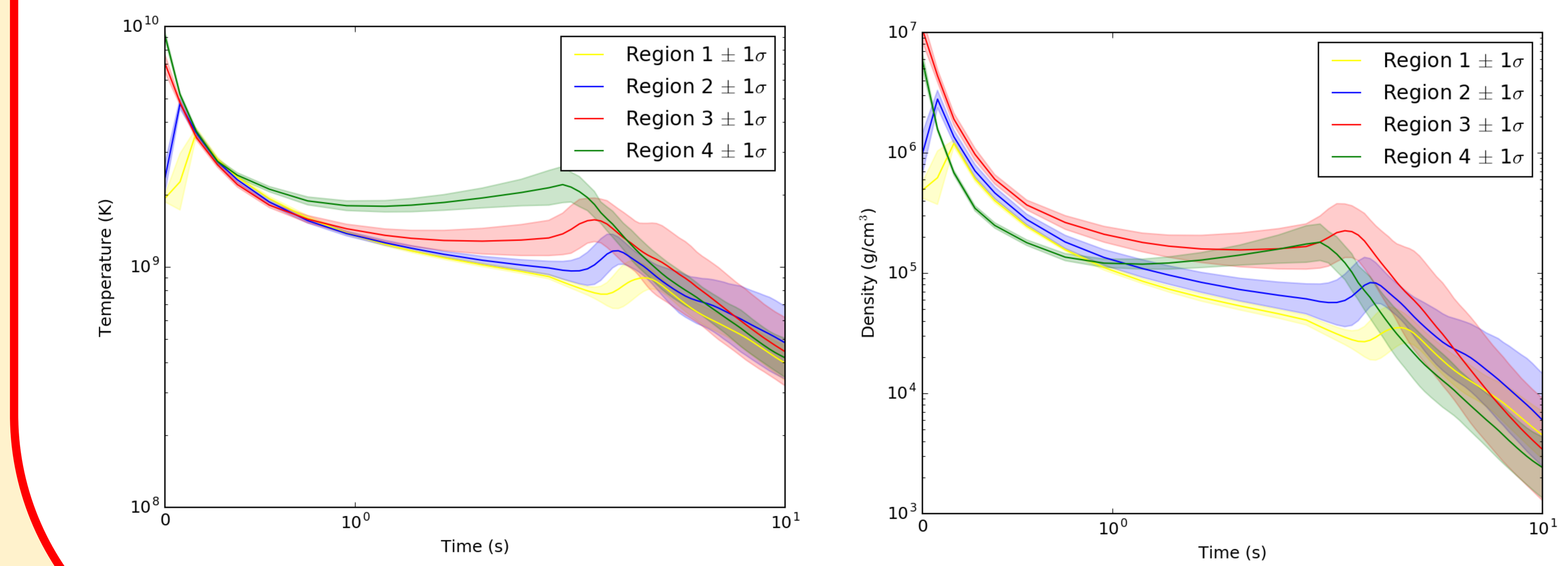
## Nucleosynthesis in the Four Regions

**Region 1:** Due to the low peak temperatures in region 1, very little production of either $^{44}$Ti or $^{56}$Ni occurs here. The low Fe/$^{44}$Ti ratio here is attributed almost entirely to the progenitor's composition.

**Region 2:** The conditions in region 2 fall within the "QSE chasm" of $^{44}$Ti production [7]. The peak temperatures are high enough for normal $^{56}$Ni production, but low production of $^{44}$Ti results in a high Fe/$^{44}$Ti ratio.

**Region 3:** With high enough peak temperatures for normal production of both $^{44}$Ti and $^{56}$Ni, region 3 has a low Fe/$^{44}$Ti ratio. The typical ratio here is comparable to that of region 1.

**Region 4:** Elevated $^{44}$Ti production at the high peak temperatures in region 4 results in an even lower typical Fe/$^{44}$Ti ratio when compared with regions 1 and 3. $^{56}$Ni production continues as normal here. Region 4 represents very little mass when compared with the other three regions.




***Figures:** Average temperature (left) and density (right) histories for material in each of the four regions over the first 10 simulated seconds of the cco2 simulation.*

## References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