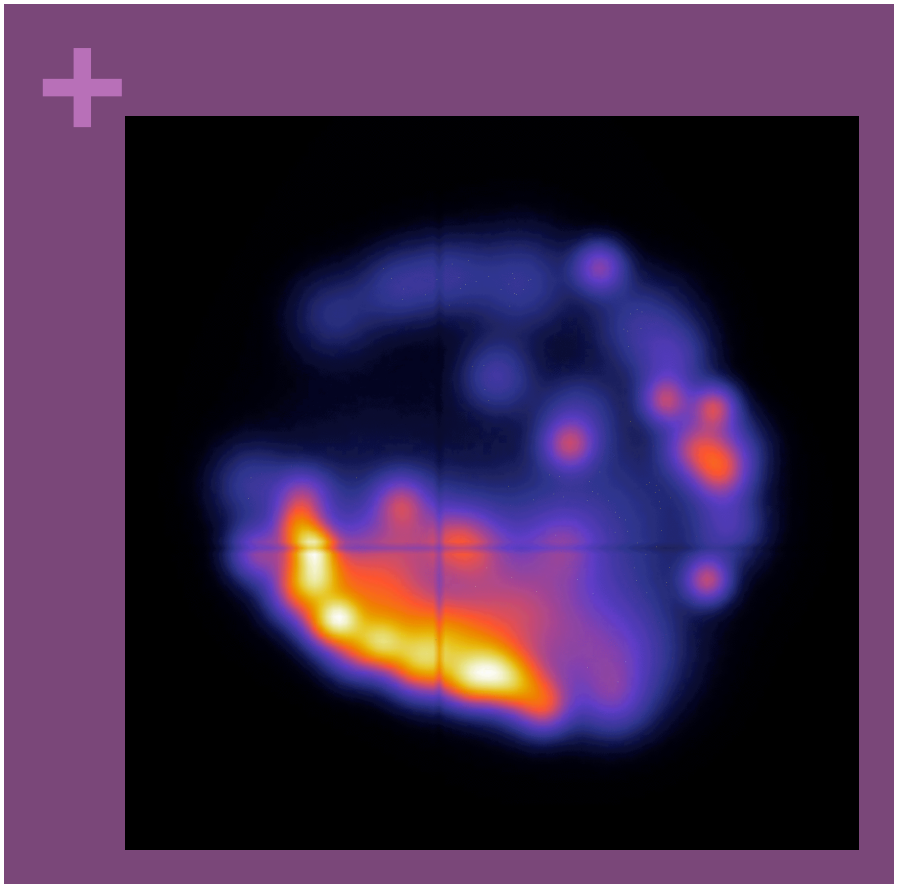
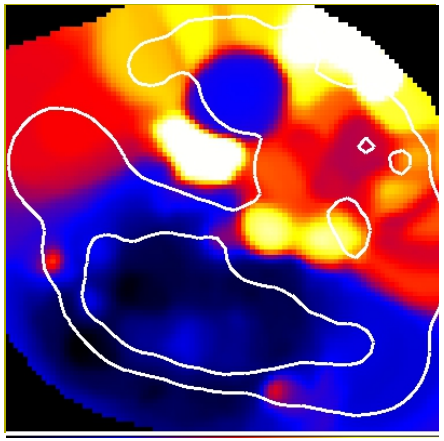
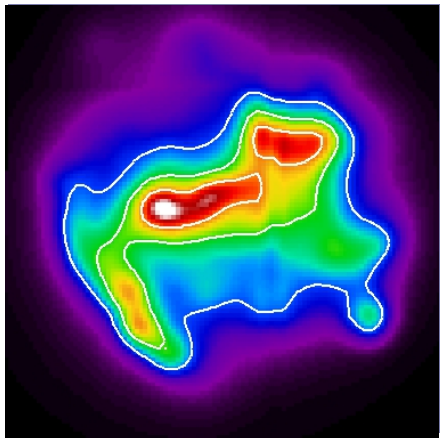
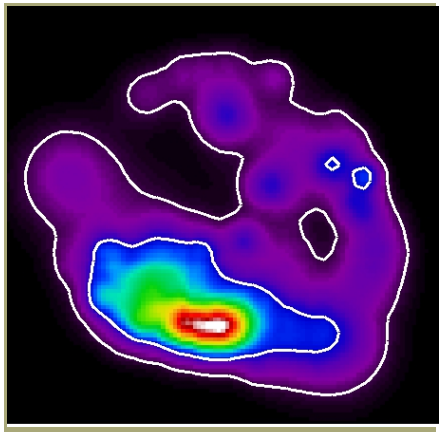
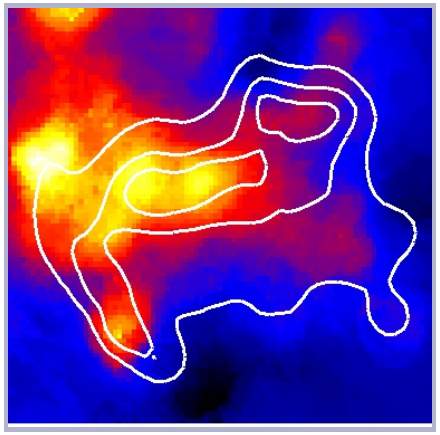










A New Approach to X-ray Analysis of SNRs

The SPIES Project

Kari A. Frank Pennsylvania State University

David Burrows Pennsylvania State University

Vikram Dwarkadas University of Chicago

Supernova Remnants

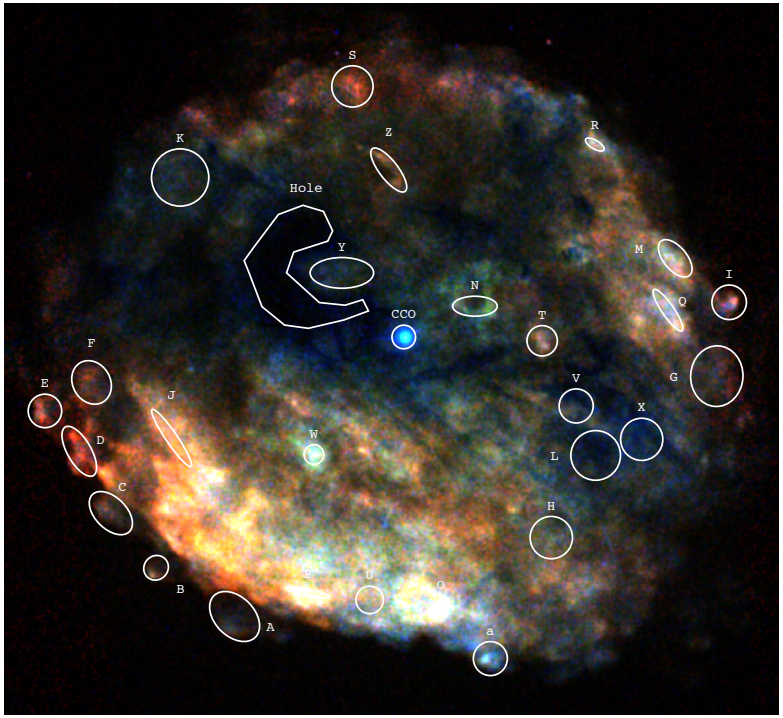
June 2016

Crete, Greece

SNRs in (thermal) X-rays

- Shocked Plasma
  - Abundances
  - Kinematics
  - Temperatures
  - …
  - => SN type, age, plasma conditions, CSM/ISM environment
- Difficult to characterize entire volume of SNR
  - Projection effects
  - Complex morphology
  - Many spectral components
  - Paucity of photons

Chandra ACIS (Frank+2015)



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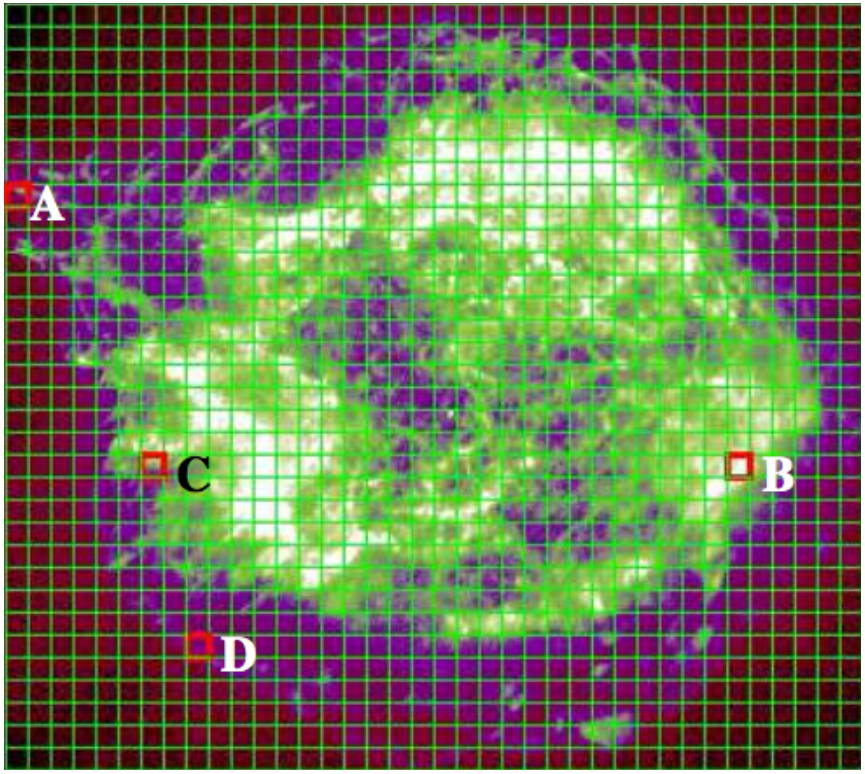


SPIES Project

Smoothed Particle Inference Exploration of SNRs

- MCMC procedure to fit the event file
  - Event positions and energies are not separated – truly spatially resolved spectroscopy
- Does not require unusually long exposure times
- Does not require strict assumptions on the spatial morphology
- Capability to model many spectral components along a line-of-sight and in the plane of the sky
- SPIES Project: Apply SPI to sample of 14 SNRs observed with XMM
  - Characterize full volume of SNR plasma
  - Variety of ages, types, and environments

Outline

Smoothed Particle Inference

Preliminary Results

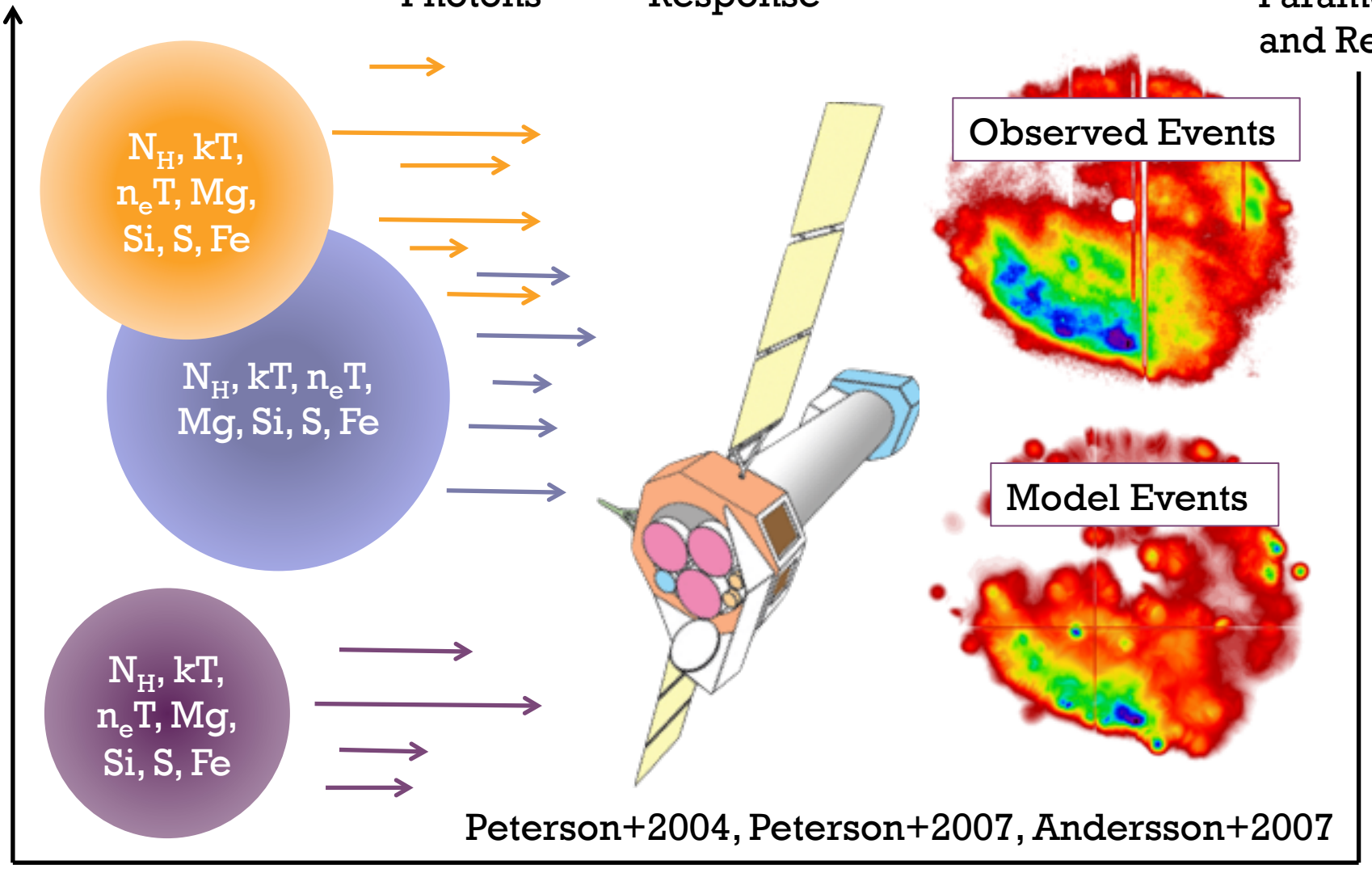
RCW103

W49B

Conclusion and What's Next

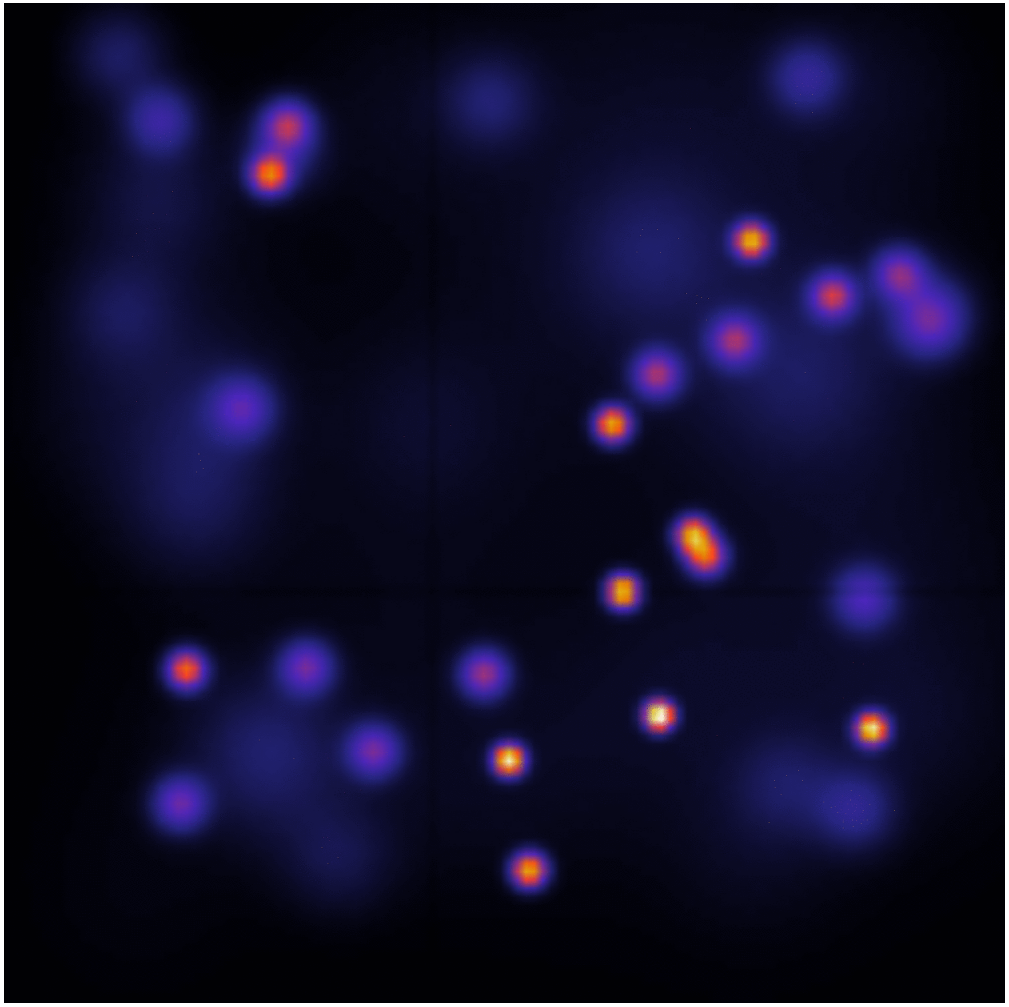
Smoothed Particle Inference

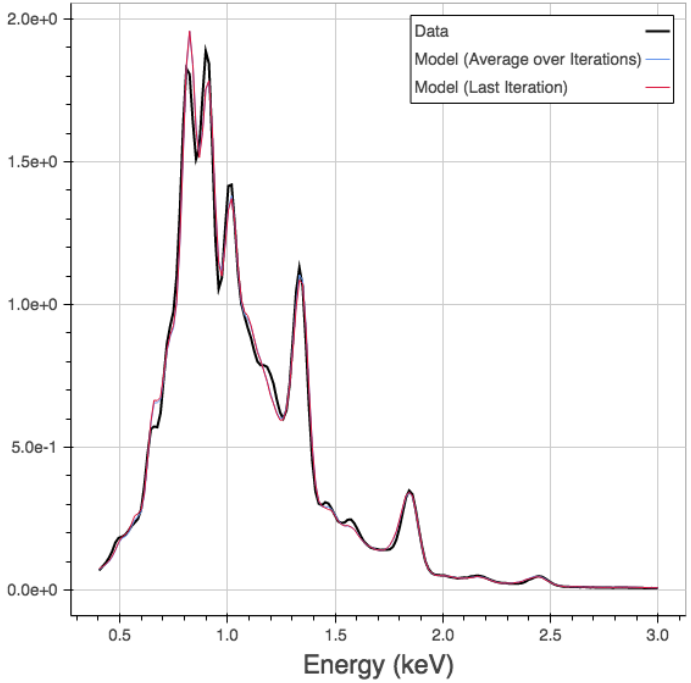
Blob Spatial +Spectral Model → Generate Model Photons → Fold Through XMM Response → Compare Events → MCMC: Choose New Parameters and Repeat

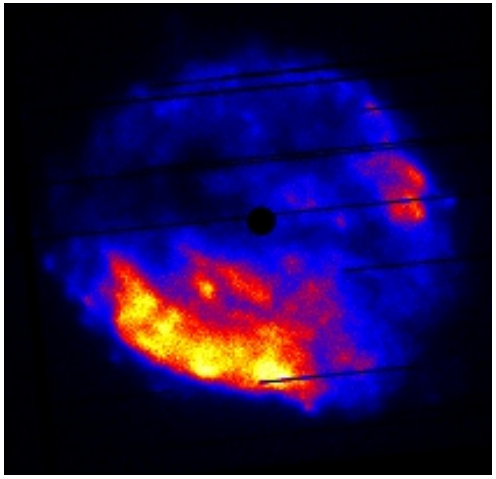


Peterson+2004, Peterson+2007, Andersson+2007

SPI Fitting in Action

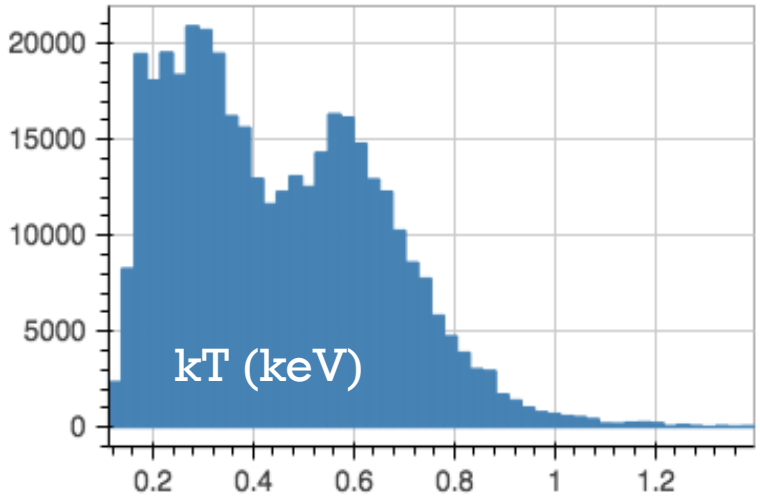






Data Products

- Set of spectral and spatial parameters for every blob for every iteration after convergence
  - Representative of the plasma conditions throughout the SNR
- Parameter Distributions
- Parameter Maps
- Can slice the data in any model dimension
  - e.g. map the abundances of the highest temperature plasma only



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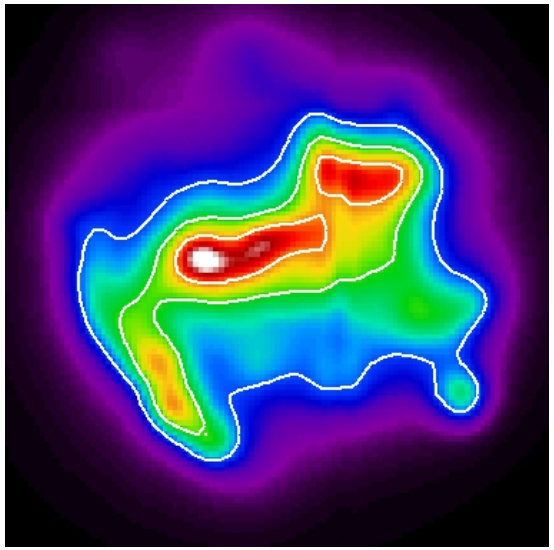
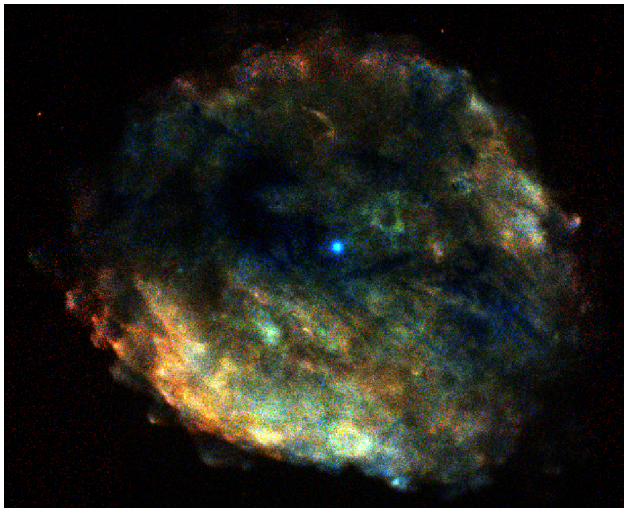


RCW 103

Preliminary Results

RCW 103



Chandra ACIS (Frank+2015)

Known Information

- Shell Morphology
- Distance ~ 3.3 kpc
- Age ~ 2000 years
- Diameter ~ 9’
- Core Collapse
  - Anomalous CCO
- X-ray Emission dominated by shocked CSM
- Frank+2015

XMM Observation

- MOS 1 and MOS 2
- Exposure = 76 ks
- ~7.4×10^6 counts
- Si, S, Mg, Fe, Ne lines
  - not uniform across SNR

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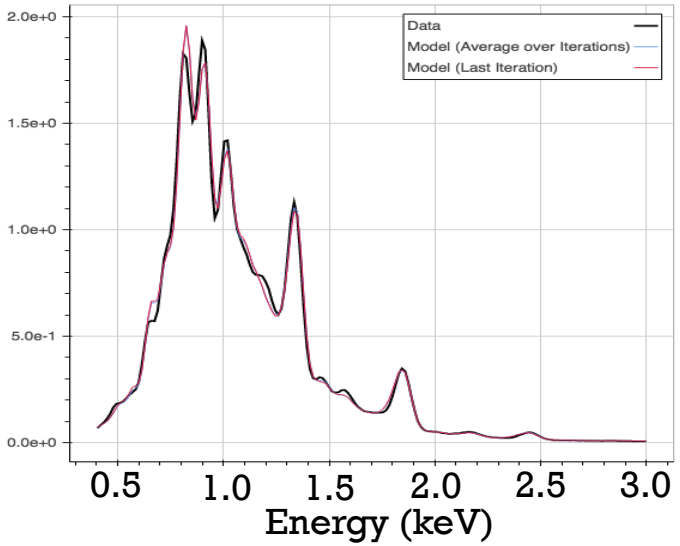

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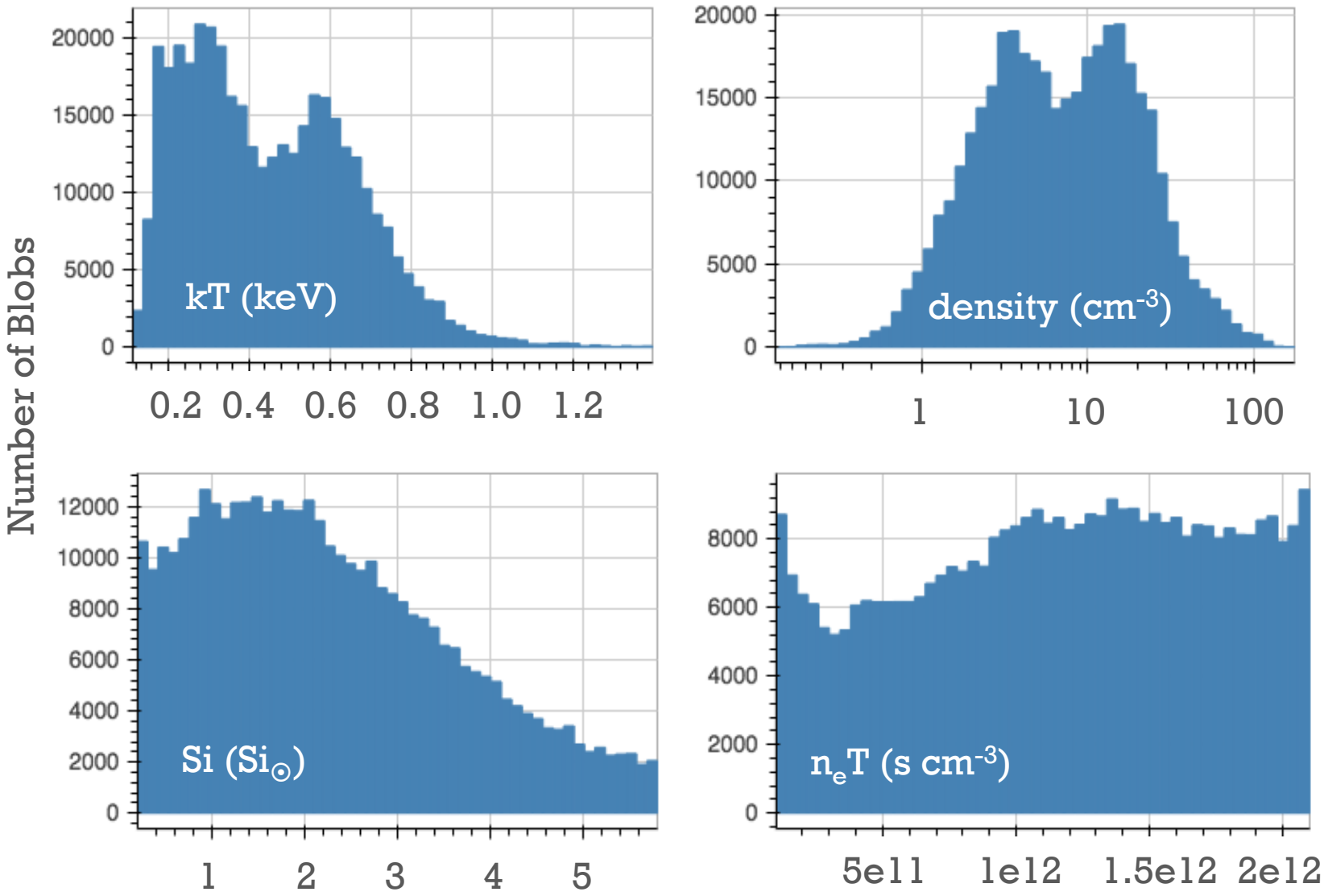
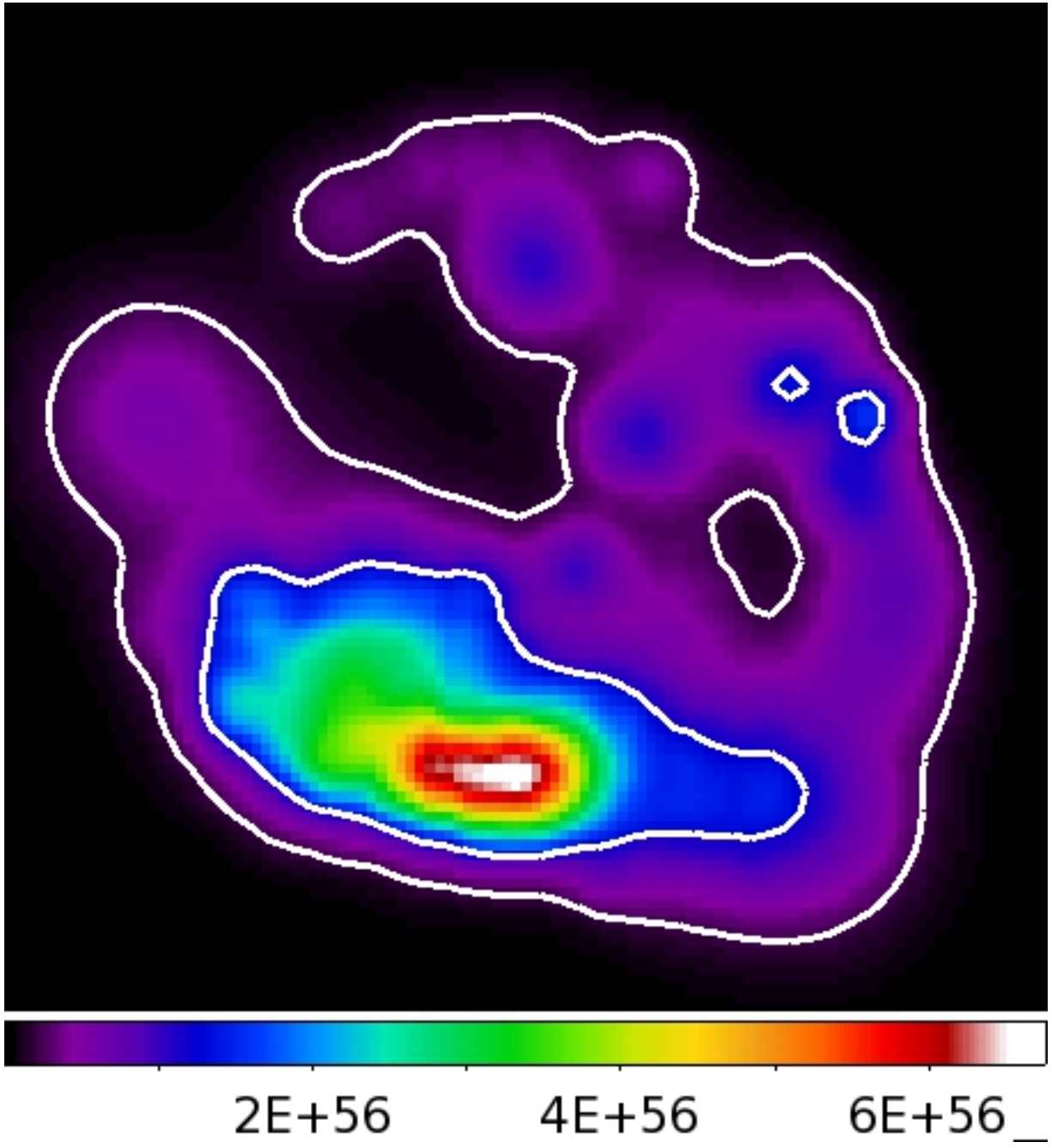
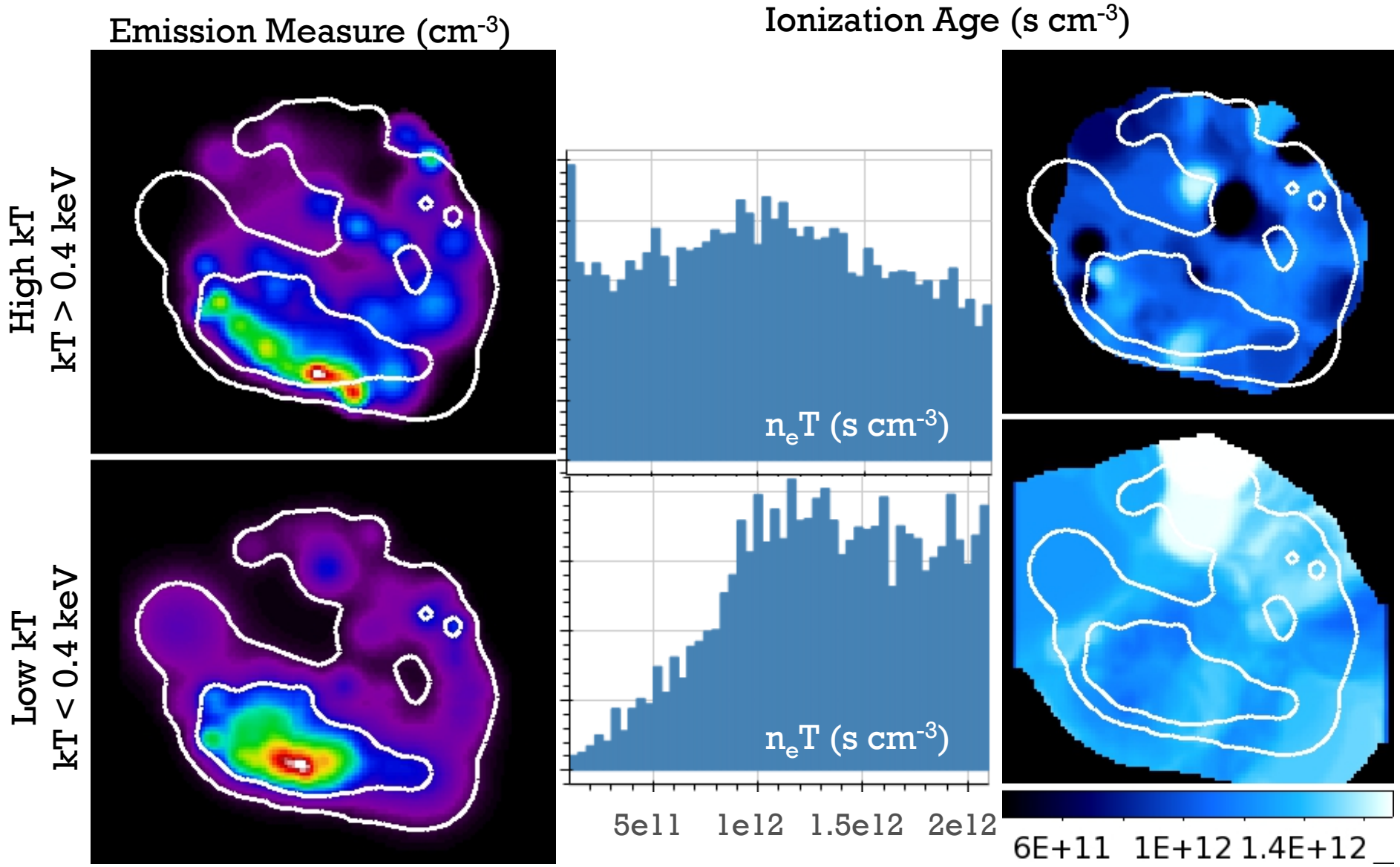


Maps

Emission Measure (cm^{-3})



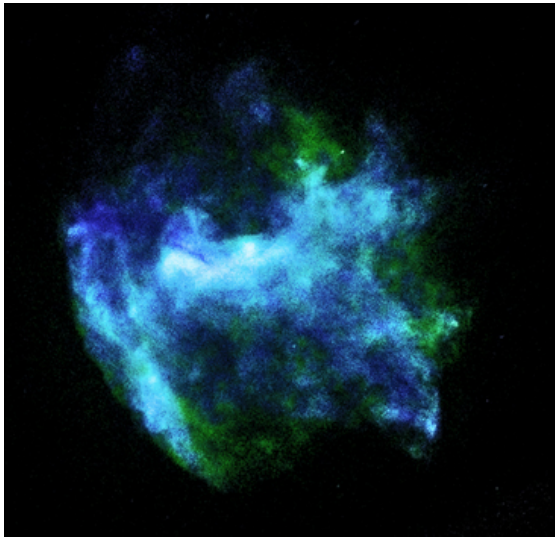
Plasma Components



W49B

Preliminary Results

W49B



Chandra ACIS (Lopez+2013)

Known Information

- Elongated Central Bar
- Distance ~ 8 kpc
- Age ~ 1000-6000 years
- Diameter ~ 5’
- Core Collapse
  - No central object
  - Possibly jet-driven SN
- X-ray Emission dominated by shocked ejecta
- Miceli+2006, Lopez+2013(a), Lopez +2013(b)

XMM Observation

- MOS 1, MOS 2, and pn
- Exposure = 18.2 ks
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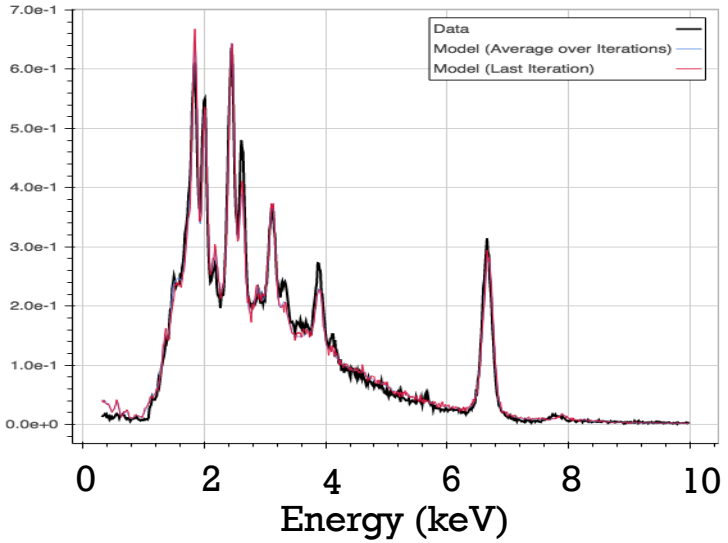

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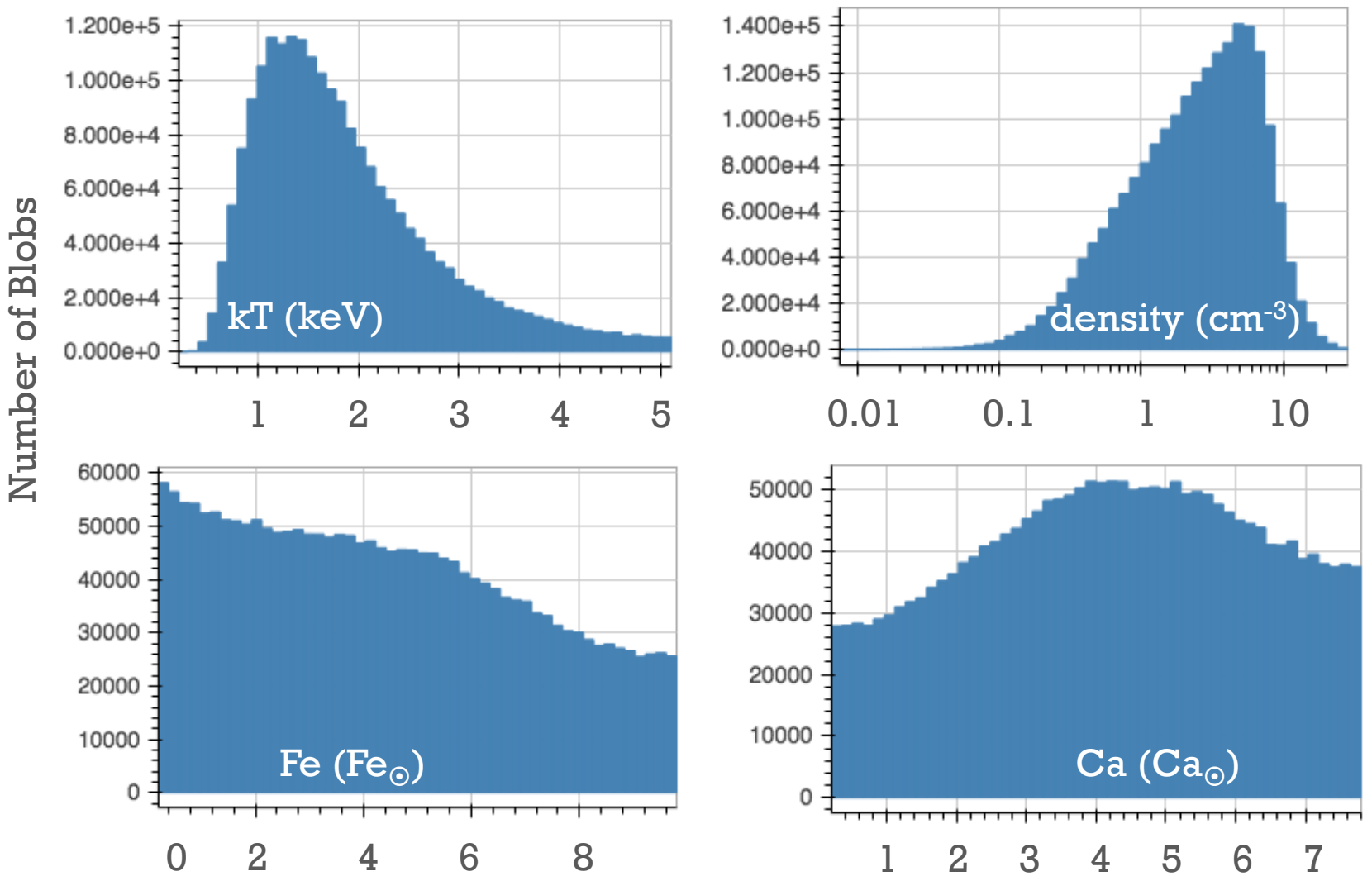
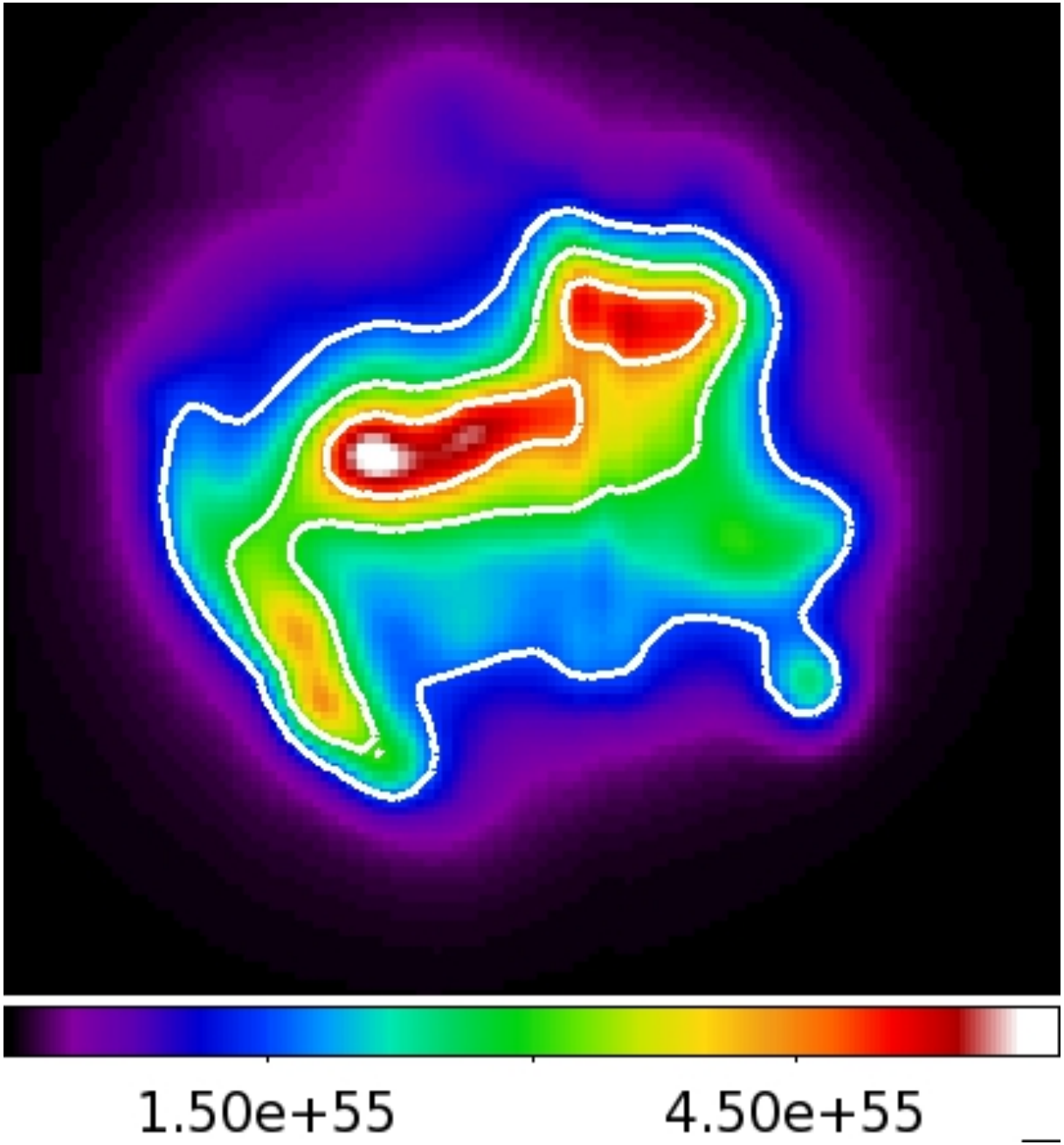


Maps



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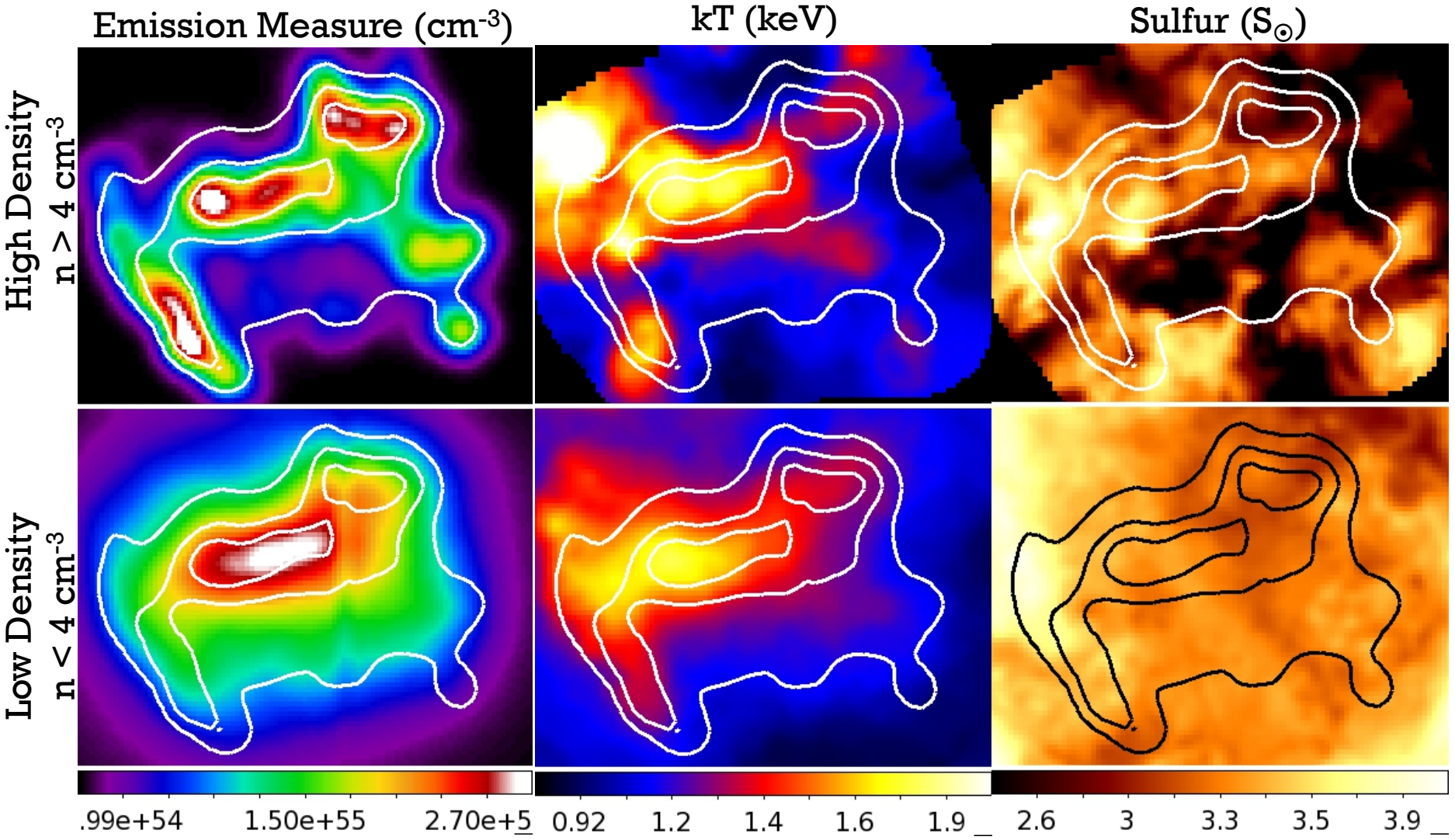
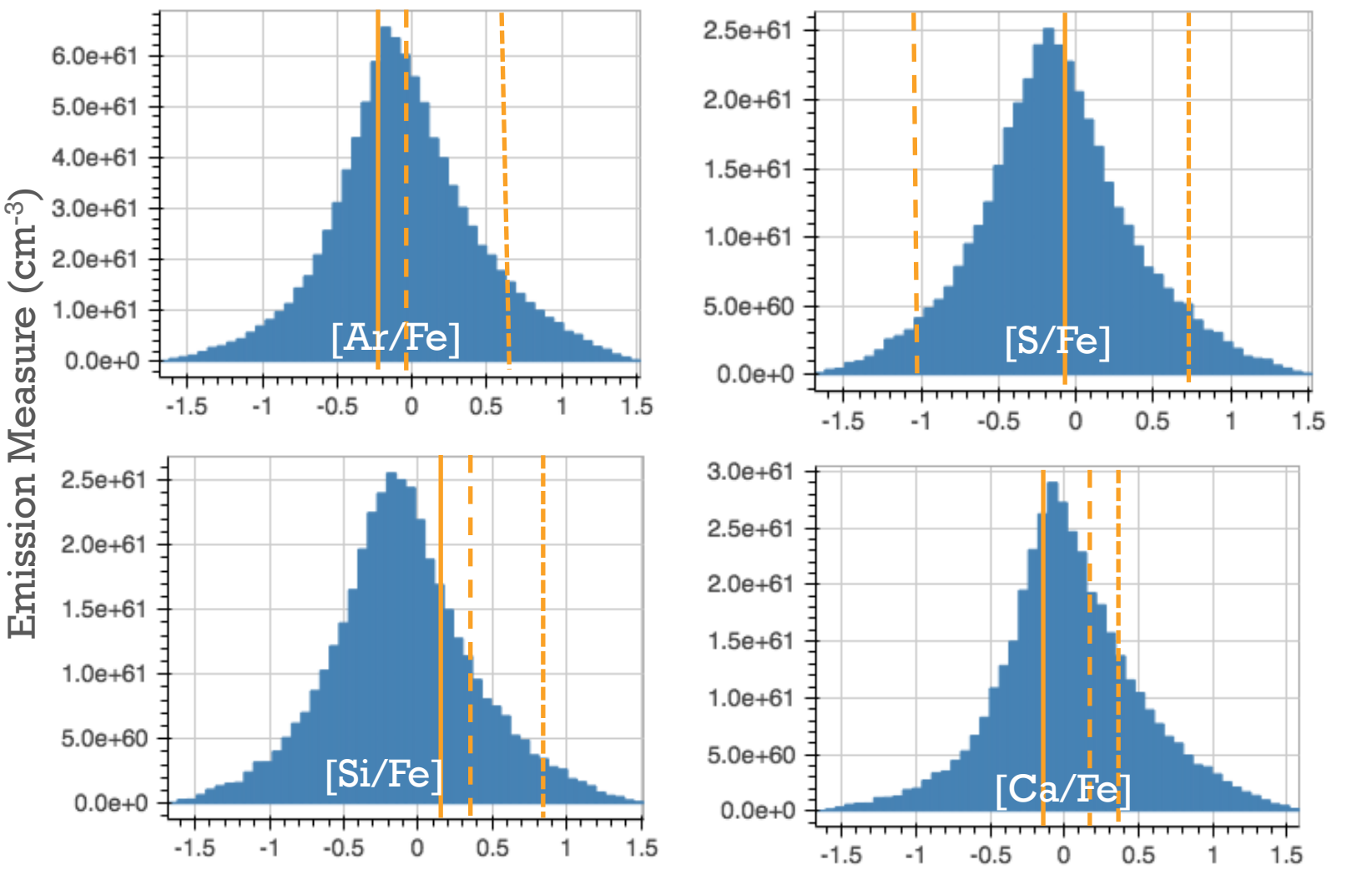
Plasma Components



Abundance Ratios

Isotropic, $M_{ZAMS}=40M_{\odot}$, $E_{51}=30$
$\theta = 45°$, $M_{ZAMS}=25M_{\odot}$, $E_{51}=0.6$
$\theta = 15°$, $M_{ZAMS}=25M_{\odot}$, $E_{51}=6.7$

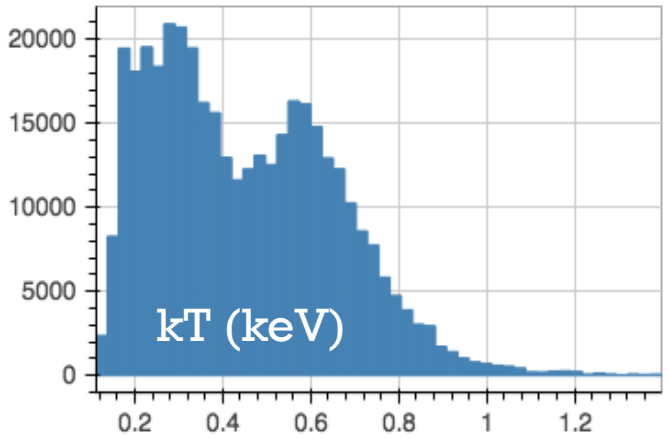


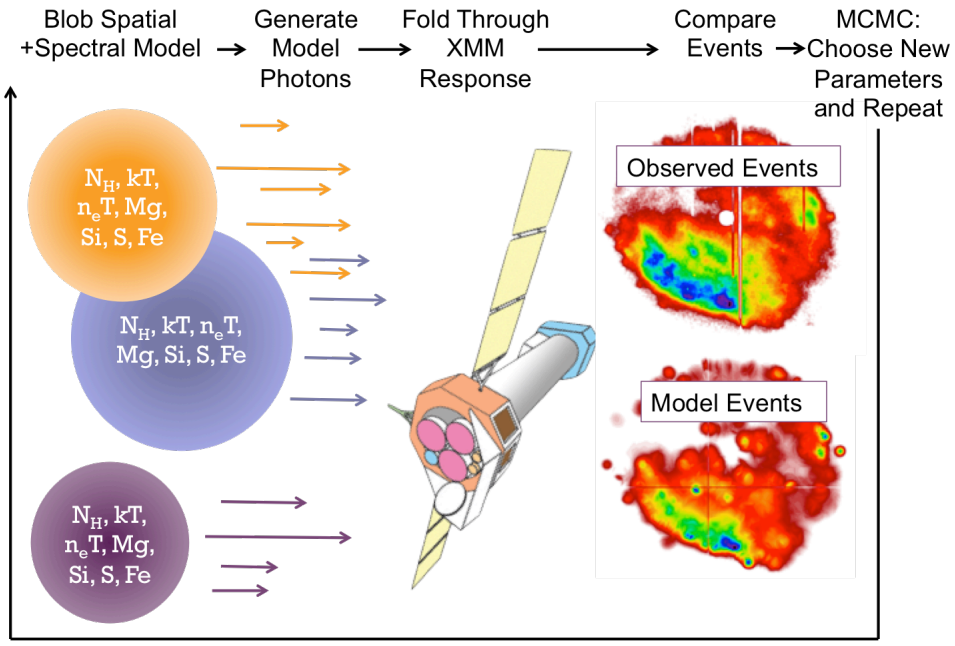
Nucleosynthesis products from Nomoto+2006 (Isotropic) and Maeda+2003 (bipolar) models

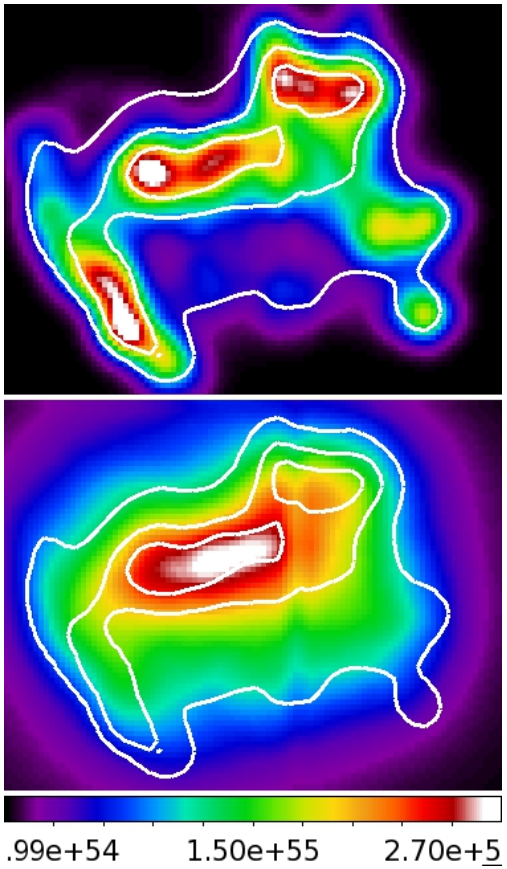
Conclusions and What's Next

Conclusions

- Smoothed Particle Inference
  - addresses many of the drawbacks of typical X-ray analysis methods
  - can characterize plasma in **full volume** of SNRs with typical X-ray exposure times
  - deeper investigation of **different plasma components**

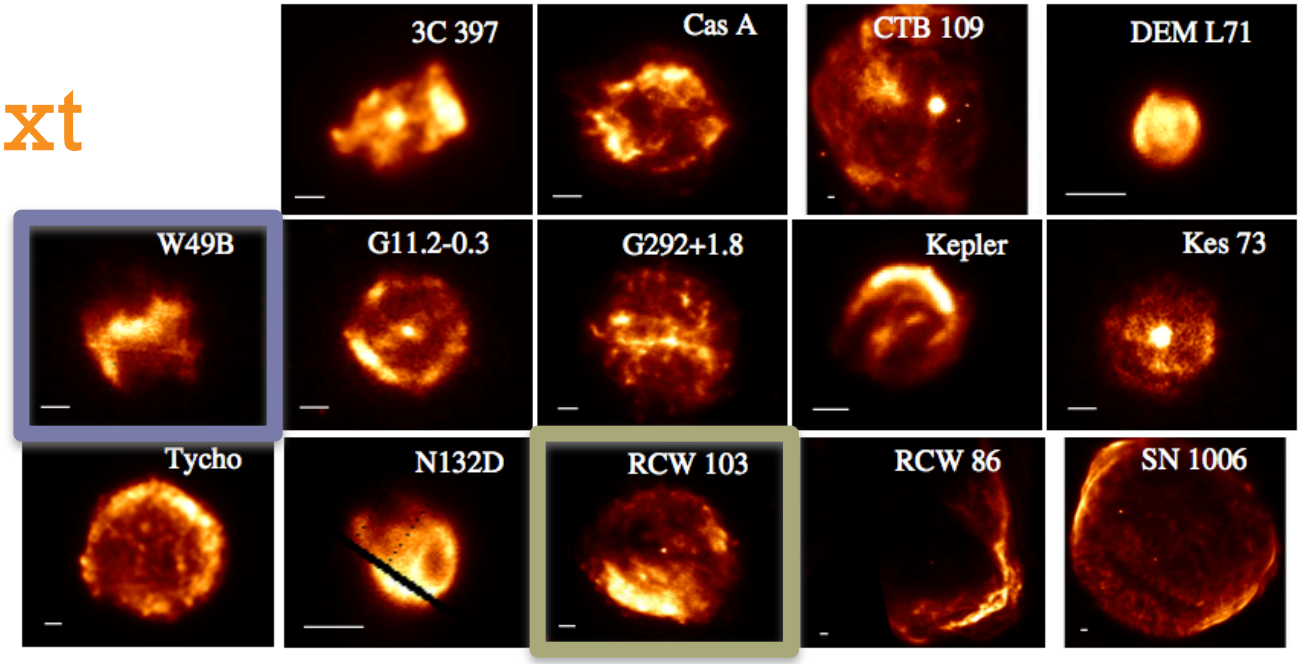






What's Next

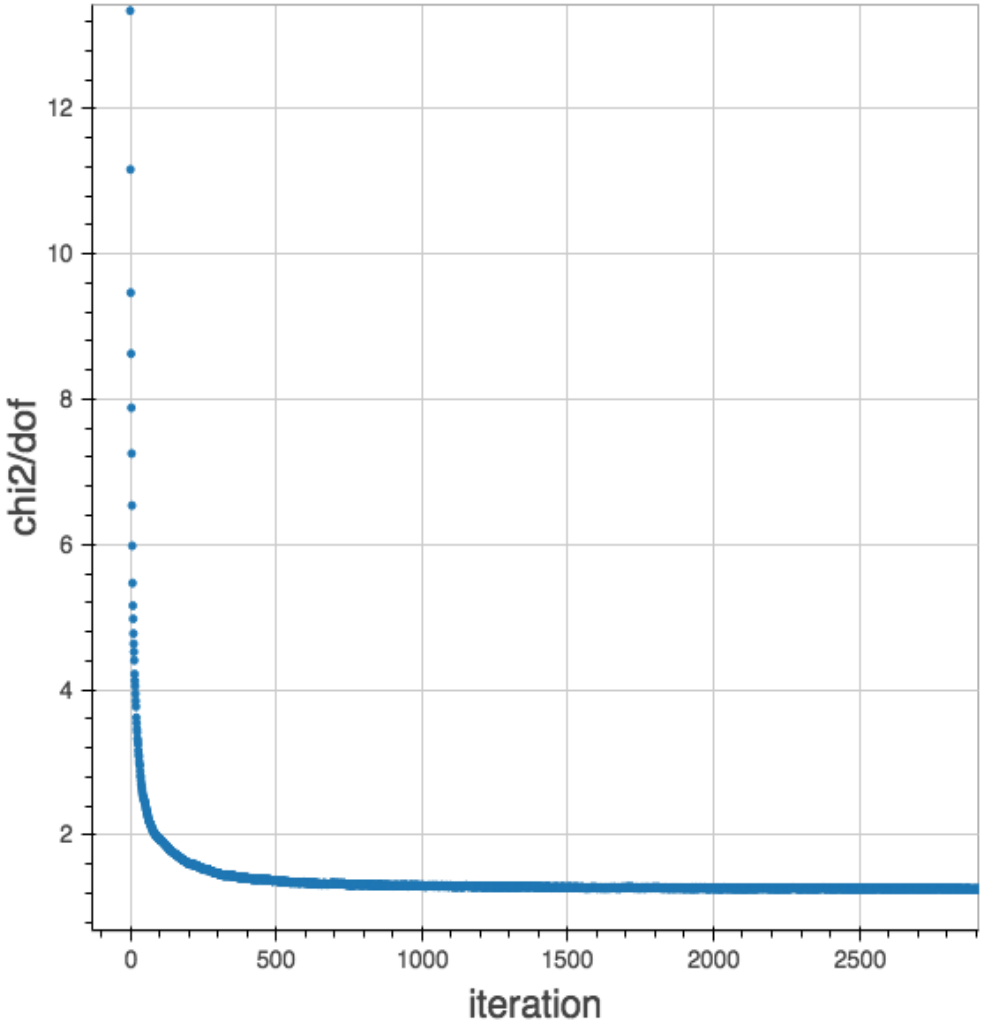
- RGS
- Non-thermal spectral components
- Expand to full 14 SNR sample
  - Ages
  - Types
  - Environments



SNR Name	Angular Size† (arcmin)	Type‡	D‡ (kpc)	Radius‡ (pc)	Age‡ (yr)	# EPIC counts
Cas A[a]	5	CC	3.4	3.8	333	5.2×10^6
W49B	4×3	CC	8.0	6.3	~ 1000	4.6×10^5
G11.2-0.3[b]	4	CC	5.0	4.2	1628	3.1×10^5
Kes 73	4	CC	8.0	6.1	$(500 - 2200)$	0.9×10^5
G292.0+1.8	12×8	CC	6.0	9.5	~ 3300	4.9×10^6
RCW 103	10	CC	3.3	5.4	~ 2000	4.7×10^6
3C 397[c]	5×3	CC?	10	7	~ 5300	3.9×10^5
CTB 109[d]	28	CC	3	16	1.4×10^4	8.0×10^5
Kepler	3	Ia	5.0	3.9	410	2.2×10^6
Tycho	8	Ia	2.4	3.7	437	8.0×10^6
SN 1006[e]	30	Ia	2.2	9.5	1007	3.7×10^6
RCW 86[f]	42	Ia	2.5	12	~ 1800	1.5×10^6
N132D	2.1×1.6	CC	50	21.5	~ 3150	1.2×10^6
DEM L71	1.2×1.4	Ia	50	11.9	~ 4360	7.3×10^5

Bonus Slides

Convergence



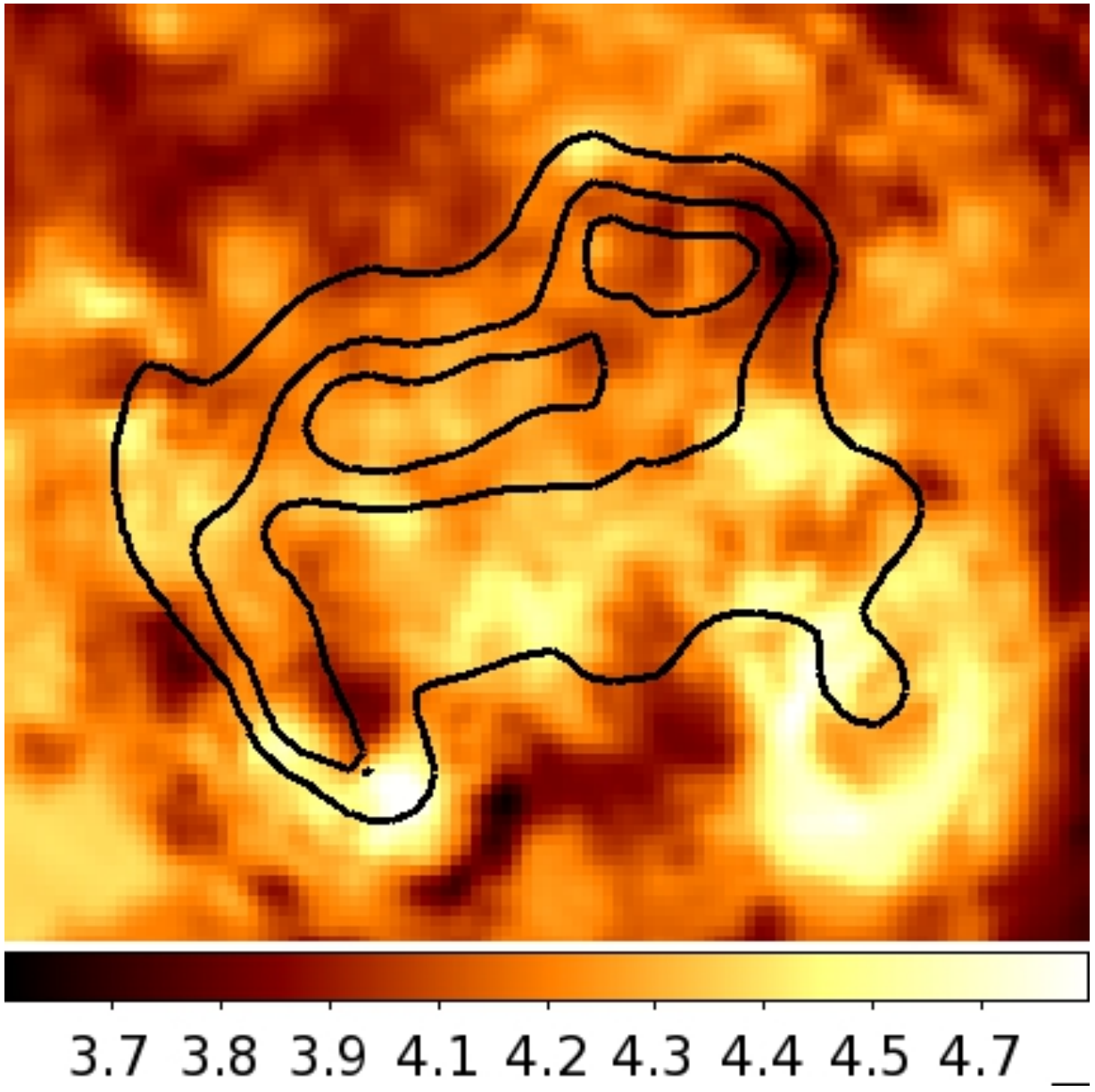
RCW 103: chi2/dof = 1.23
W49B: chi2/dof = 1.27

Definition of [X/Fe]

- $[X/Fe] = \log10(N_X/N_{Fe}) - \log10(N_X/N_{Fe})_\odot$

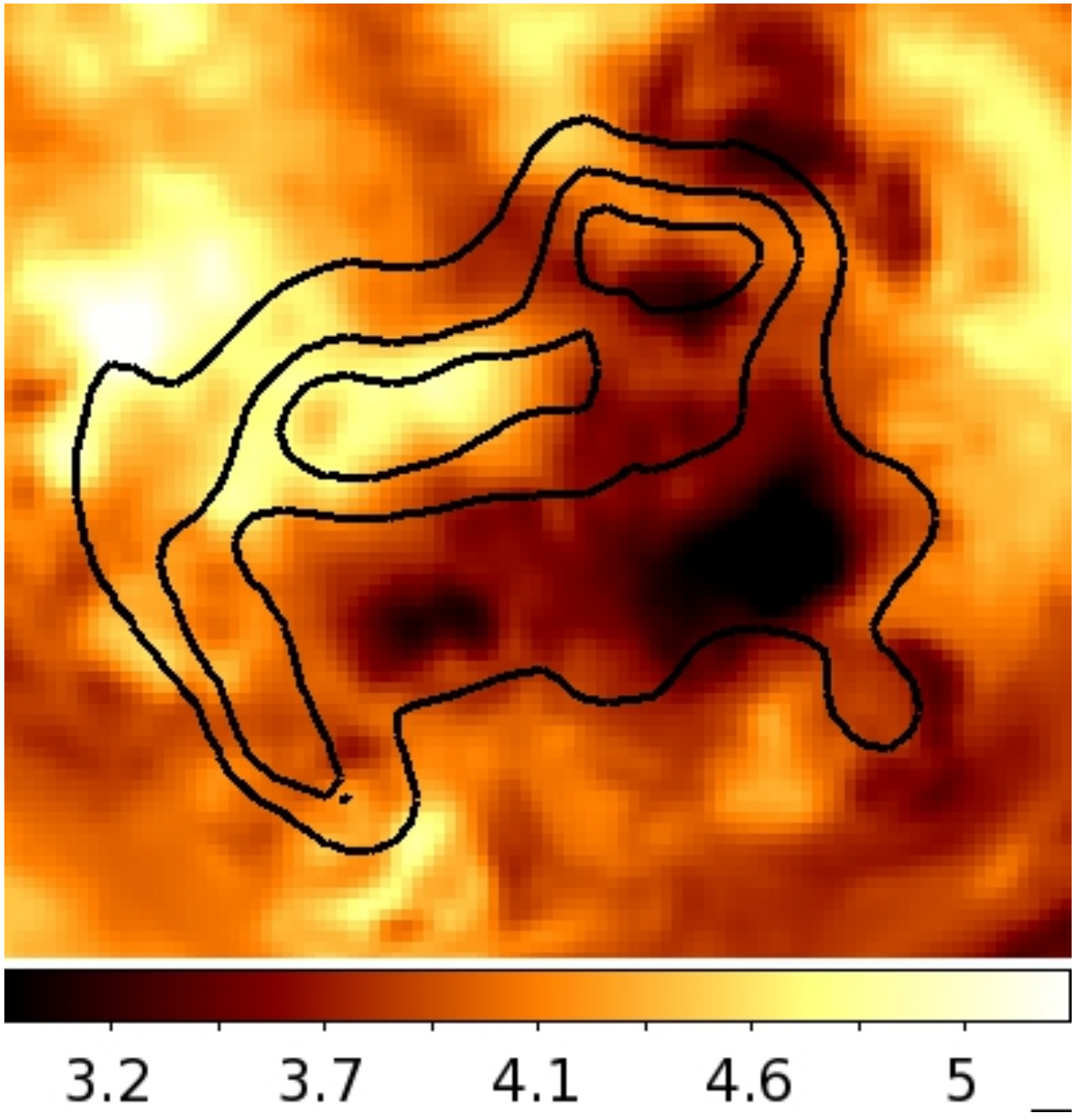
Maps

Ca ($Ca_{\odot}$)

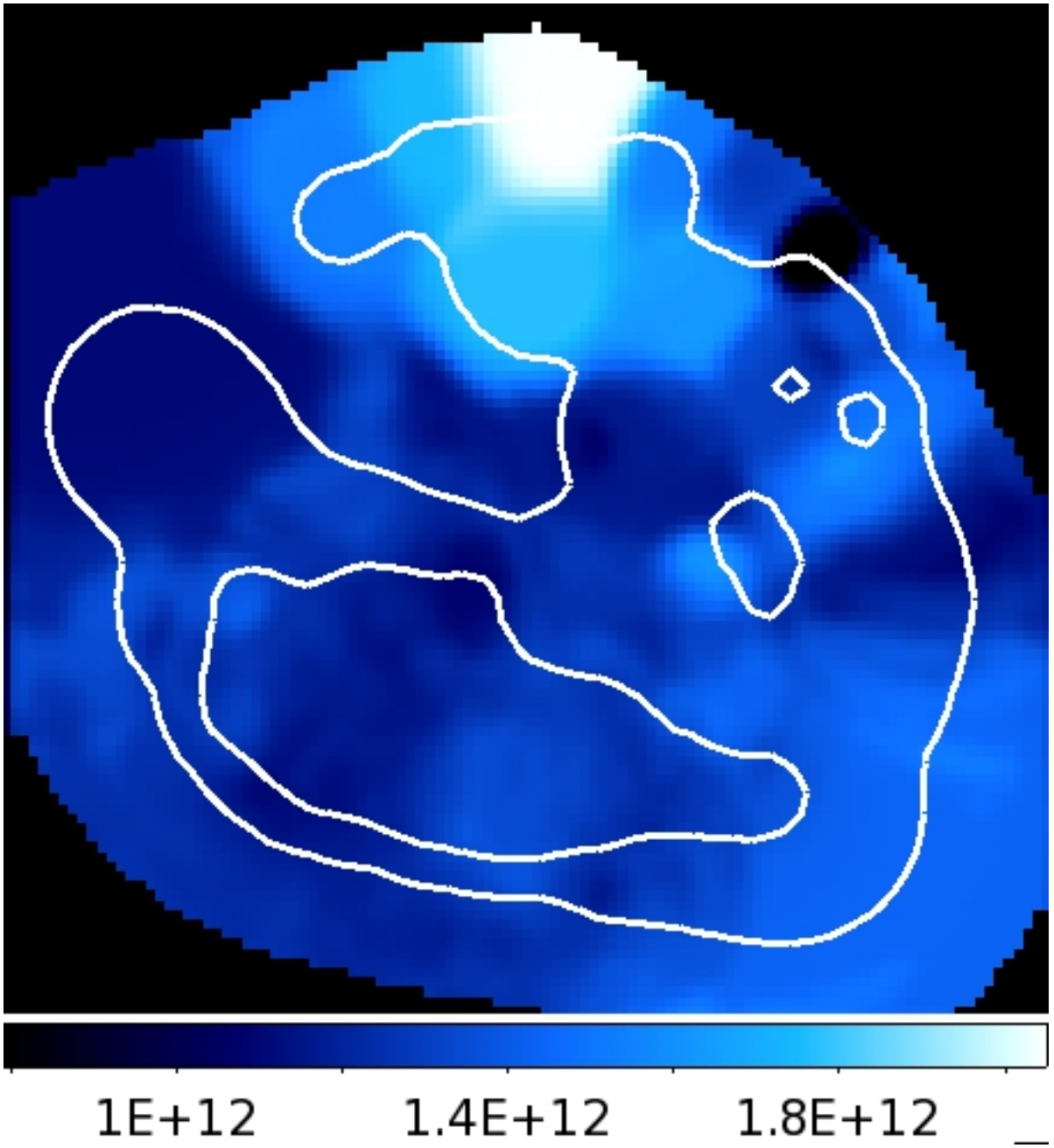


Maps

Fe ($Fe_{\odot}$)



Maps



Ionization Age ($s\ cm^{-3}$)

Maps

Si ($Si_{\odot}$)