Diffuse X-ray emission in M51: a hierarchical Bayesian spatially-resolved spectral analysis

Luan Luan & Q. Daniel Wang

Department of Astronomy,University of Massachusetts, Amherst MA 01003-9305, USA

Abstract

We use the extremely deep chandra observations of M51 to extract spectra at different spiral arm phases and perform joint fitting. Using new spectral fitting methods and new galaxy structure models, the temperature distribution of hot gas and the distribution of absorbing media were analyzed. The mechanisms of star formation feedback implied by this are discussed.

Introduction

Ionized hot gas is widely thought to act as an agent of stellar feedback: formed from supernova explosions and stellar winds, and affecting the collapse of cold gas. Despite this, there are still many fundamental issues that remain unresolved in the mechanism of hot gas achieving stellar feedback, Therefore, we explore in the following aspects:

Most hot gas studies study the global properties of hot gas in the entire galaxy, or divide it into two or three regions, which cannot quantitatively describe the distribution and gradient of hot gas properties.

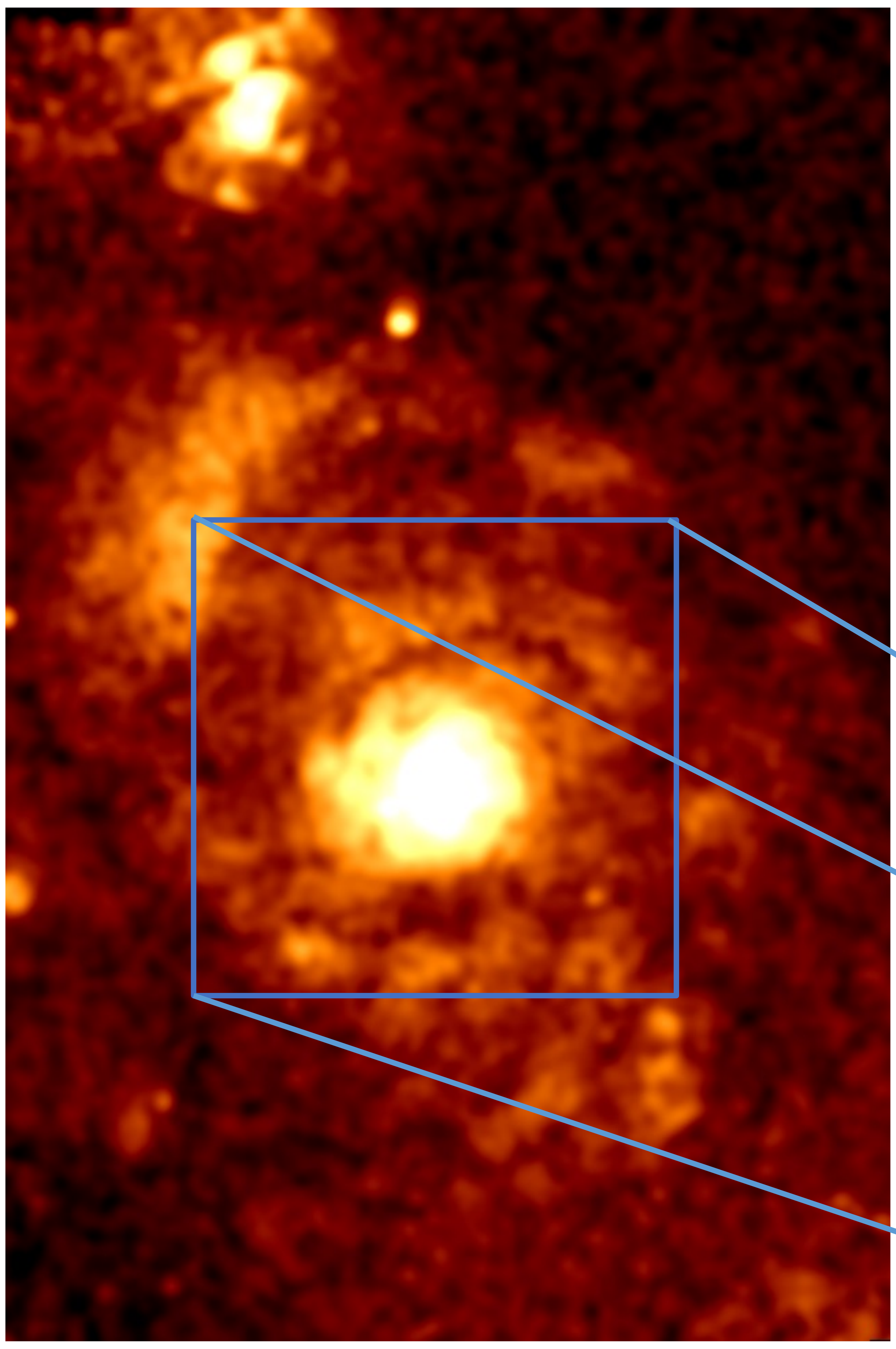
Current X-ray spectrum fitting has a strong degree of degeneracy. When multiple spectra are jointly fitted, setting parameters as linked or free will greatly affect the fitting results.

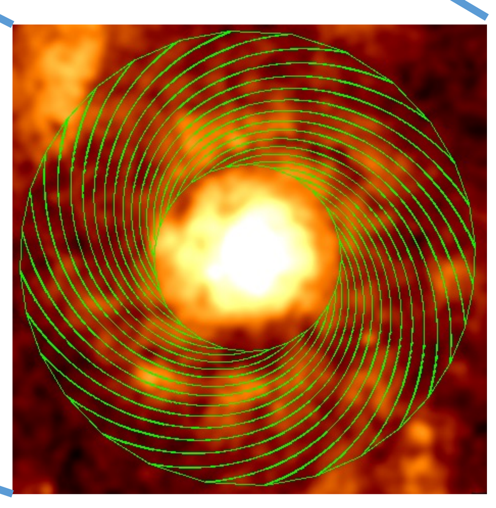
Treating absorption as a foreground screen is a typical choice, but it is not physical enough.

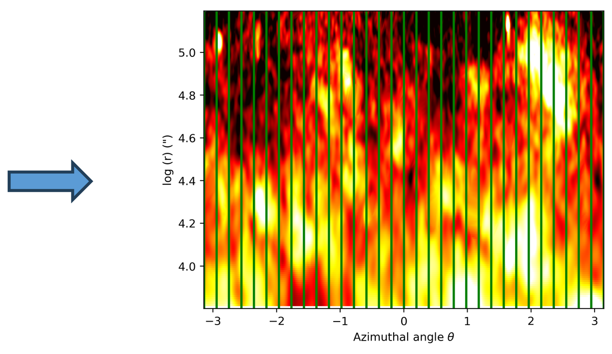
Our new methodology

Our model

M51 diffused emission from Chandra





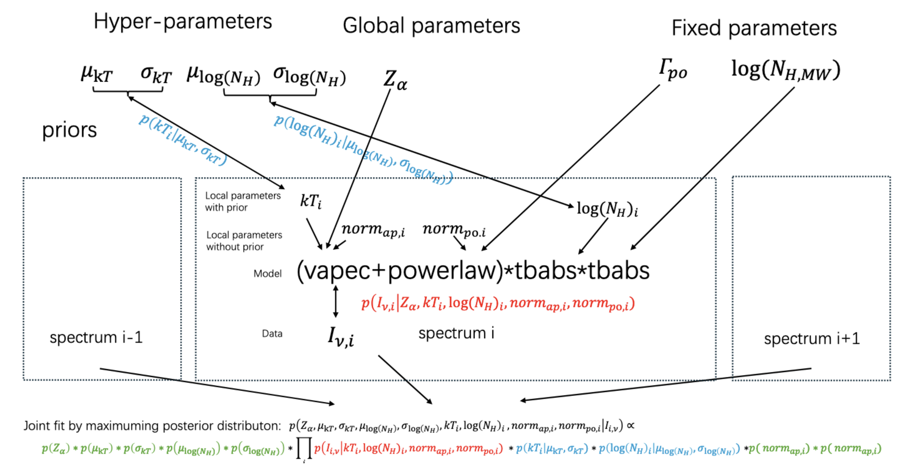


We define a coordinate system using curves along the spiral arm. The green lines in the two images represent the same position before and after the coordinate system transformation. The region between two green lines can be used to extract a spectrum to analyze the properties of the hot gas at different distances relative to the spiral arm.

Data and Methodology

Over the past 20 years, Chandra has accumulated more than 1.2Ms of observations of M51, making it almost the best sample for studying hot gas in a face-on galaxy.

- We define a curvilinear coordinate system along the spiral arms to divide the entire galaxy into dozens of regions.
- We designed models in the vertical direction. Their treatment of absorption and temperature distribution is more physical without increasing the degree of freedom.
- We design a new spectral fitting method that uses hierarchical Bayesian analysis. Thus, when jointly fitting many spectra with similar but not identical properties, a distribution is set for them as a prior function to achieve a balance between complete freedom and linked



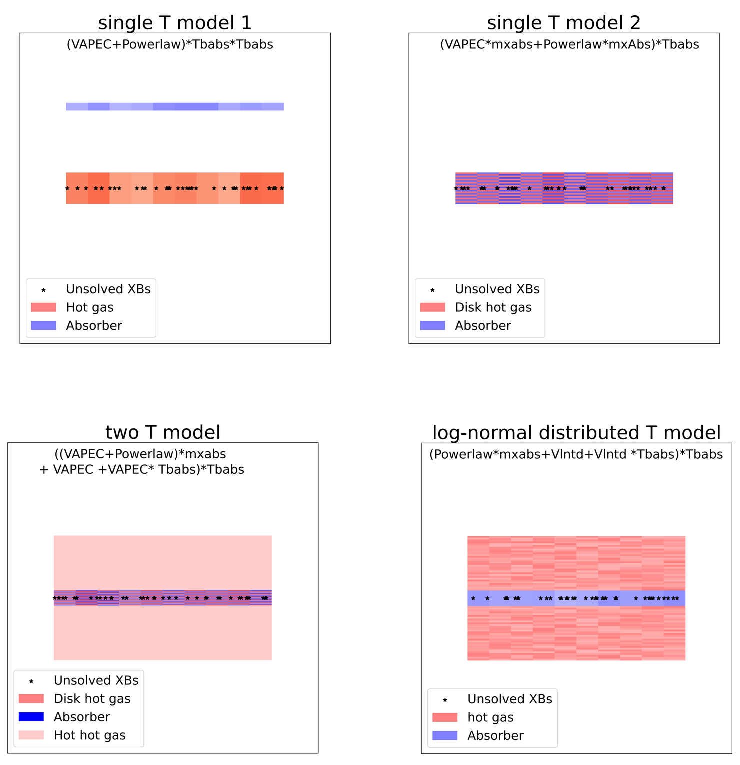
Fitting results

Table 2. Global spectal model parameters of the spectra from HIE MCMC

Model[a]		A	B	C	D
Name		Disk	Disk/$N_H$mixed	Corora+Disk/$N_H$mixed	log-T Corora+Disk/$N_H$mixed
Component	Parameter Name				
Disk	$\mu_{kT_d}(keV)$	$0.146^{+0.002}_{-0.002}$	$0.296^{+0.005}_{-0.005}$	$0.79^{+0.02}_{-0.02}$	$0.10^{+0.03}_{-0.05}$[b]
	$\sigma_{kT_d}(keV)$	$0.005^{+0.001}_{-0.001}$	$0.019^{+0.005}_{-0.004}$	$0.05^{+0.02}_{-0.01}$	-
	μ_{s_d}[c]	-	-	-	$0.53^{+0.09}_{-0.09}$
	σ_{s_d}[c]	-	-	-	$0.10^{+0.07}_{-0.04}$
	$Z_{\alpha,d}(solar)$	$0.049^{+0.006}_{-0.006}$	$1.15^{+0.04}_{-0.04}$	$1.79^{+0.22}_{-0.22}$	$0.97^{+0.34}_{-0.32}$
Corora	kT_c (keV)	-	-	$0.179^{+0.004}_{-0.003}$	$0.08^{+0.02}_{-0.01}$
	s_c[c]	-	-	-	$1.25^{+0.10}_{-0.10}$
	$Z_{\alpha,c}(solar)$	-	-	$0.14^{+0.03}_{-0.03}$	$1.40^{+0.14}_{-0.17}$
Absorbing gas (M51)	$\mu_{log(N_H)}$[d]	$21.69^{+0.02}_{-0.02}$	$21.68^{+0.11}_{-0.18}$	$21.15^{+0.11}_{-0.13}$	$21.46^{+0.09}_{-0.09}$
	$\sigma_{log(N_H)}$[d]	$0.06^{+0.02}_{-0.01}$	$0.34^{+0.07}_{-0.06}$	$0.25^{+0.07}_{-0.05}$	$0.11^{+0.05}_{-0.04}$
	χ^2/d.o.f.[e]	1261/1009	1430/1008	987/1006	941/1004

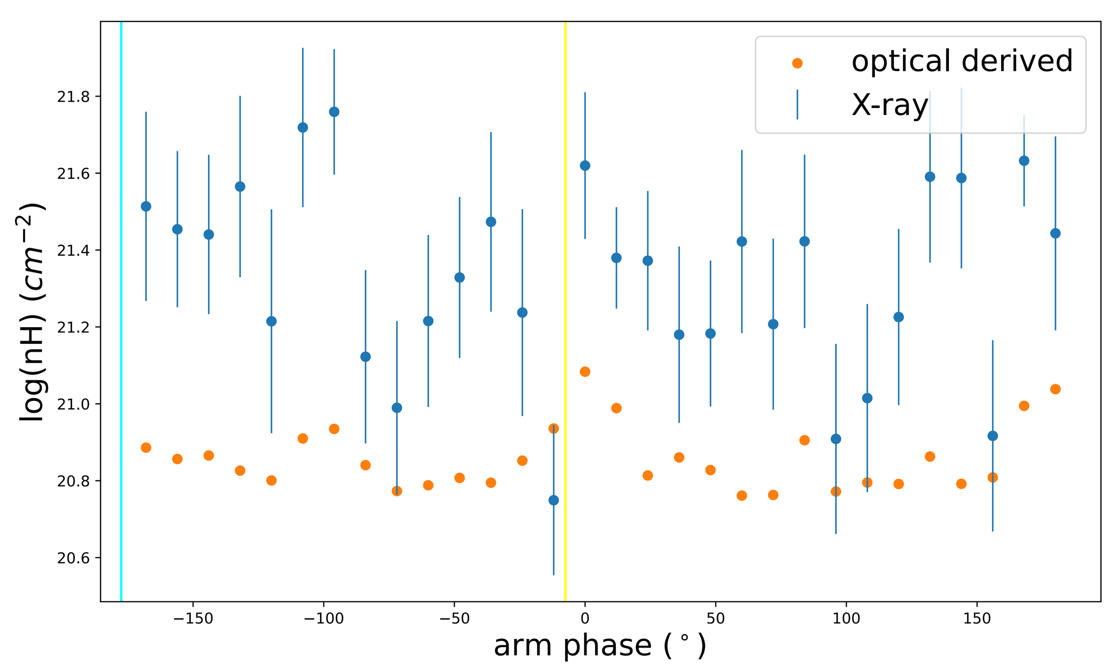
lognormal distributed T model with so many terms sound too complex?
Don't worry, it has similar freedom as the simple and typical choice of just one absorber and two temperature gases.

Face-on image Looks amazing, but what about its vertical structure? We can try to build model and verify with spectra



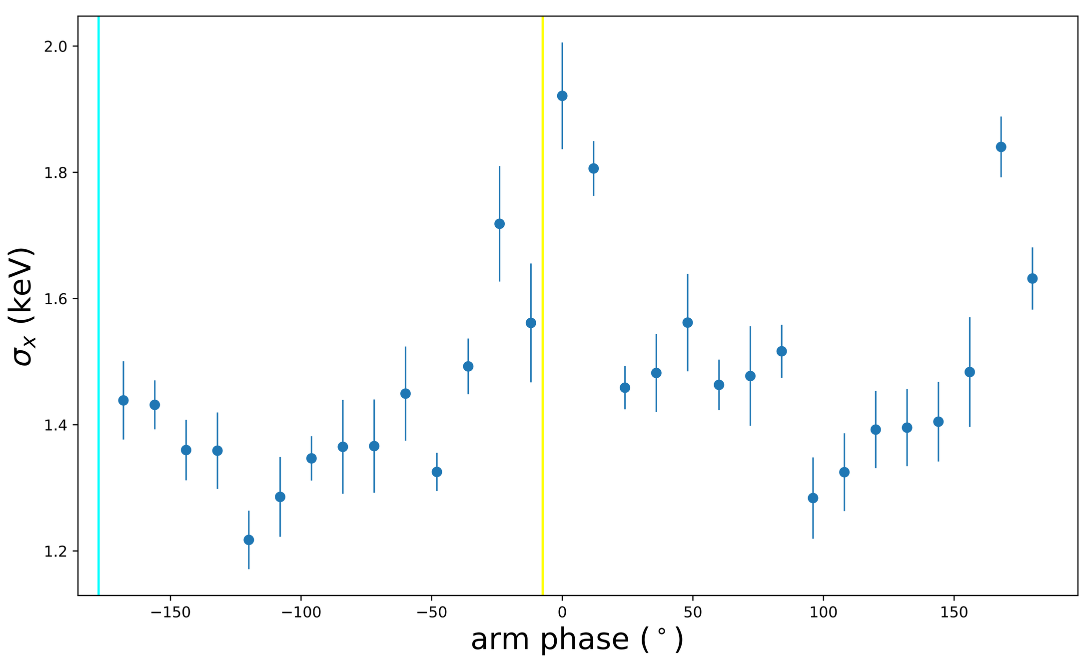
Imagine that we, as observers, are above these diagram. How is the hot gas distributed, and how much absorption medium does radiation pass through?

Properties at different arm phase



The absorbing medium inferred from the X-ray spectrum is approximately twice that inferred from the optical image? Good!

Because our model includes gas on the backside of the disk, their radiation passes through the entire disk of cold gas, while the star's light only passes through half of it.



The two vertical lines mark where the spiral arms are, so we have higher temperature dispersion at the spiral arms. Makes sense, since that's where the star formation feedback is strong.

Conclusion

1. We have developed a set of X-ray spectrum fitting methods based on hierarchical Bayesian analysis, which can fit a sample with similar but not identical physical properties. During fitting, certain parameters are set to follow a distribution, rather than a single value or complete free for each object. This can avoid overestimating or underestimating errors caused by artificial selection of degrees of freedom during spectral fitting, thus making the conclusion more reliable.

2.Even taking into account various absorptions and metallicities, a single-temperature model is insufficient to describe the diffuse hot gas in M51. The two-temperature model is a statistically viable option, but it introduces too low metallicity (0.14 solar metallcity) in the lower-temperature component and the difference between the two temperatures is large (0.18keV and 0.79keV). Model with a lognormal distributed T is a better choice, both statistically and physically.

3. The lognormal distribution model implies the existence of a large amount of gas around $10^{5.5}$K, The radiation is primarily in EUV, which would be largely absorbed by the ISM in the galaxy and cannot be observed directly in any way, let alone X-ray telescopes. However, its radiation dominates the cooling of the hot gas.

3. We find obvious differences in the spectra between the spiral arm region and the inter-spiral arm region. In the lognormal distributed T model, this difference is due to broader temperature distribution, or a greater proportion of high-temperature gas.

4. Our model analysis reasonably shows that the X-ray emission from the far side of the galactic disk is subject to more than twice the absorption as would be inferred from the optical extinction.