The Origin of the X-Ray Polarization in the Circinus (Tanimoto+23)

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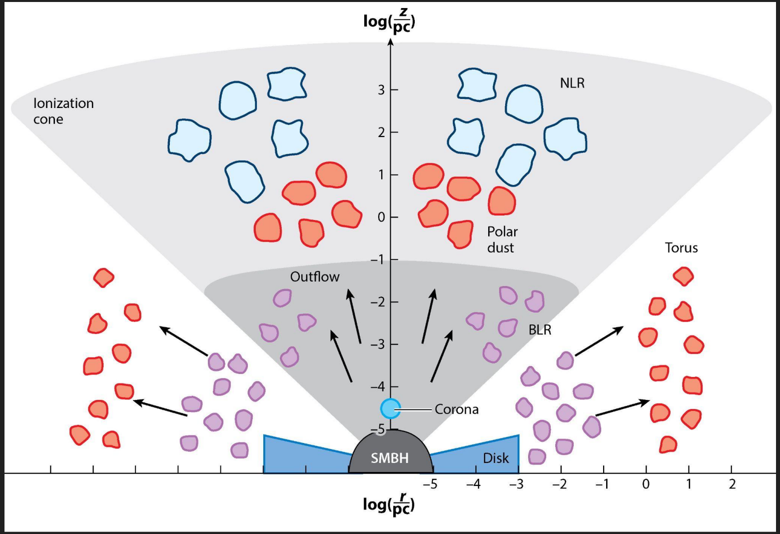
Introduction: Structure of Active Galactic Nucleus



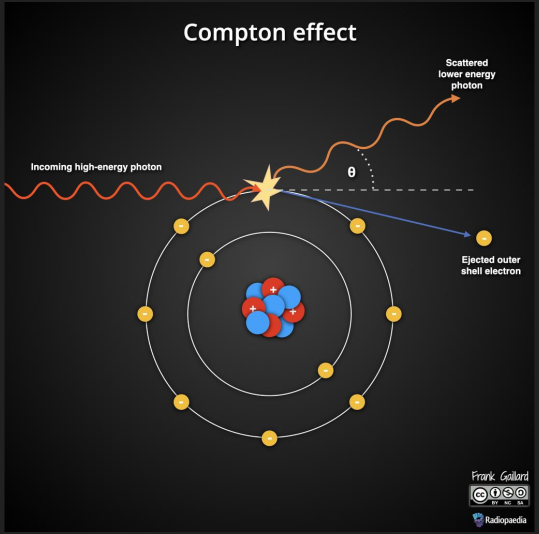
Hickox+18

Figure shows the structure of an active galactic nucleus.

Recently, ALMA have enabled direct imaging of 1-10 pc scale structures.

However, the structure of the sub-parsec-scale gases are still unclear.

Introduction: X-Ray Polarization by Compton Scat

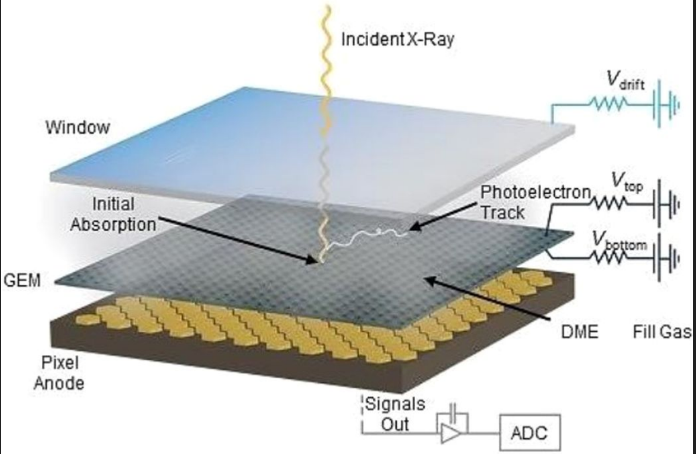


To study the structure, one of the most powerful tools are X-ray polarization.

This is because the degree of polarization depends strongly on the structure.

However, no X-ray polarization satellite had been launched since 1980s.

Introduction: Imaging X-ray Polarimetry Explorer



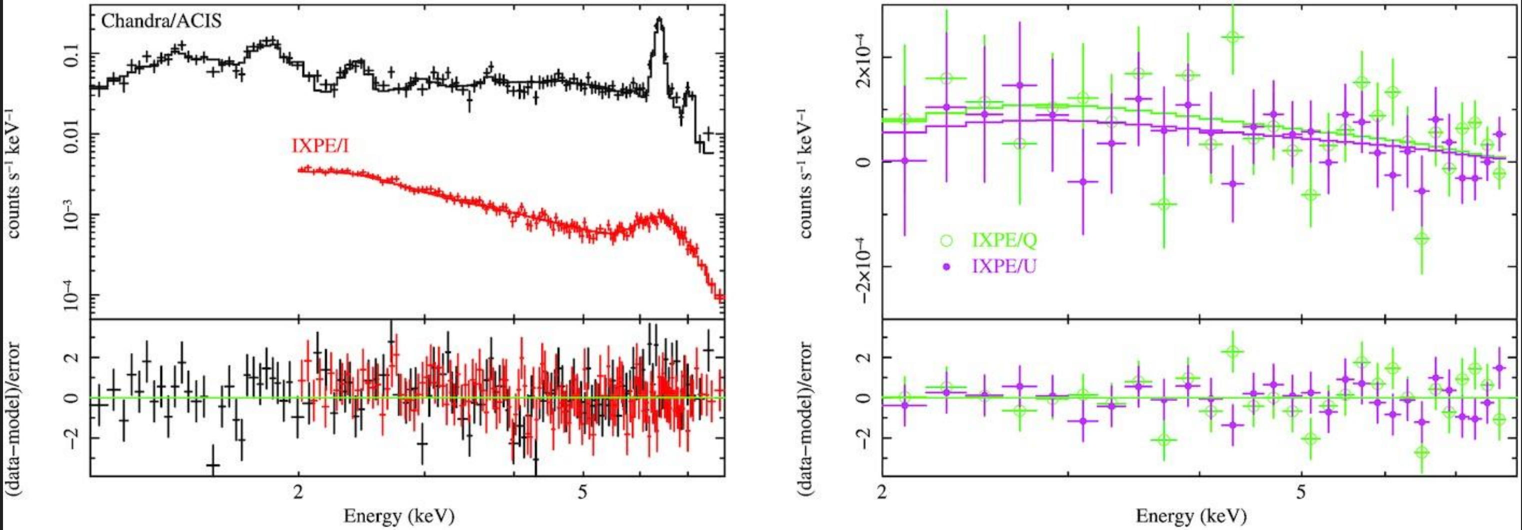
Weisskopf+22

The Imaging X-ray Polarimetry Explorer (IXPE) was launched in 2021 December.

IXPE carries three Gas Pixel Detectors to detect the 2-8 keV X-ray polarization.

Improving polarization sensitivity by two orders of magnitude over OSO-8.

Introduction: Observation of Circinus Galaxy by IXPE

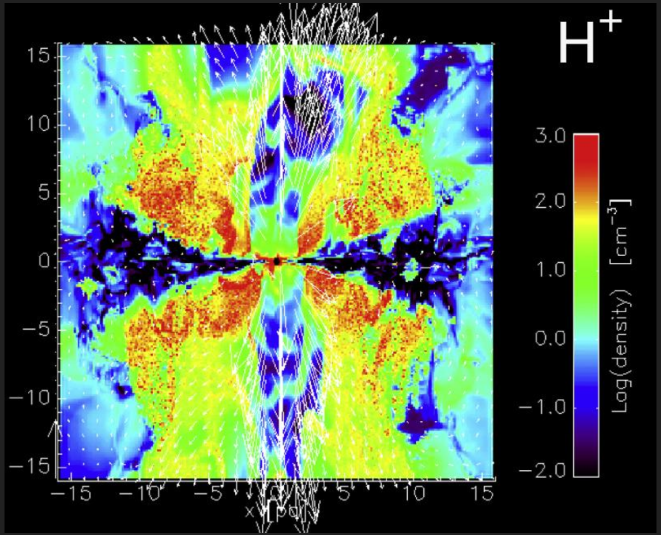


IXPE observed the Circinus galaxy at 800 ksec in 2022 August.

IXPE detected the X-ray polarization of the Circinus galaxy for the first time.

Ursini+23 indicated that the degree of polarization was 28±7%.

Method: Radiation-driven Fountain Model



Wada+16

To reproduce IXPE results, we compute polarization degree based on RHD model.

Here we used two radiation-driven fountain models (Wada+16, Kudoh+23).

We studied whether these models could reproduce the IXPE observational result.

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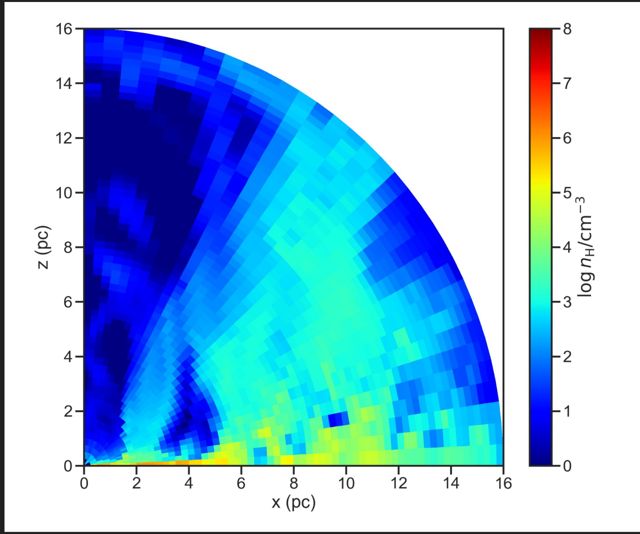
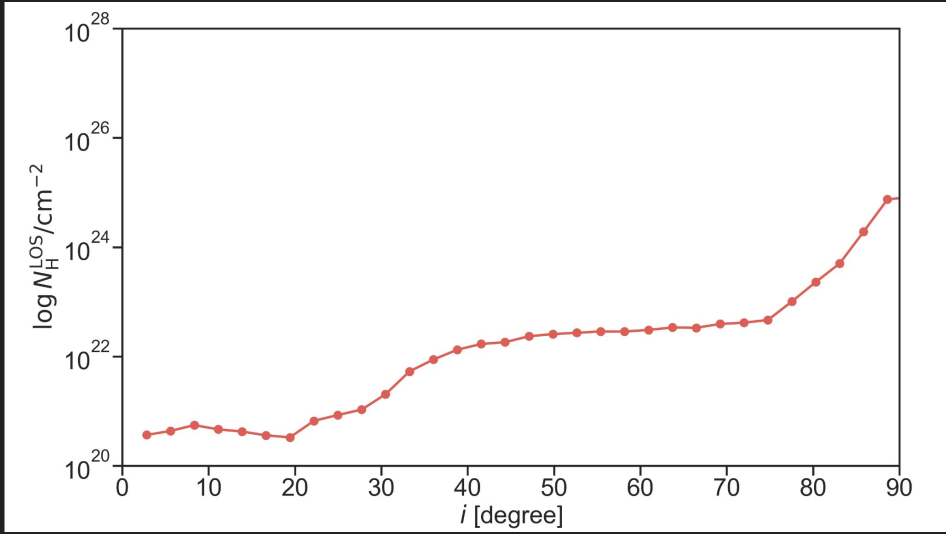
Results1: Parsec-scale Radiation-driven Fountain



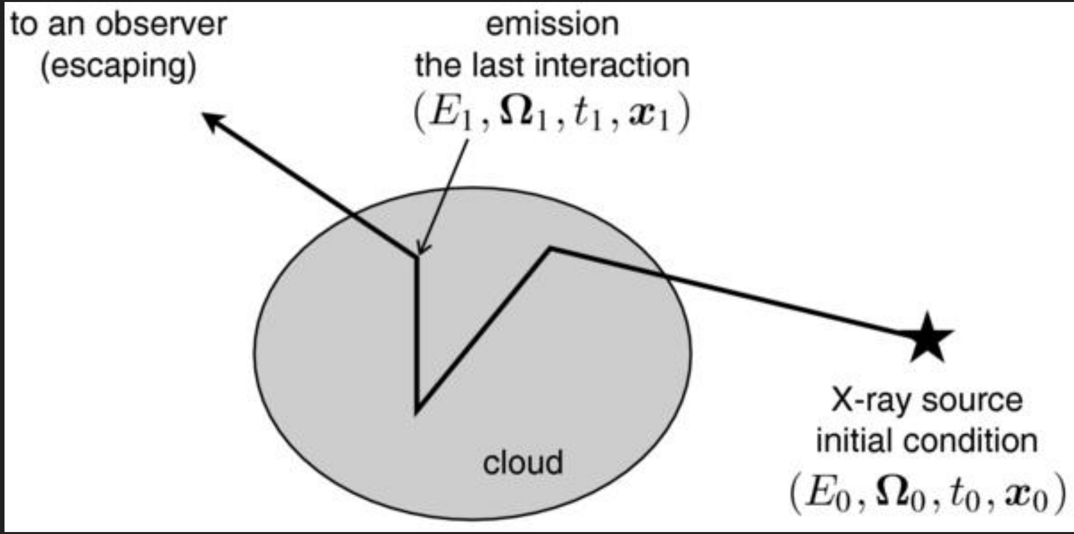


We first compute P based on the parsec-scale radiation-driven fountain model.

Figure shows the distribution of the hydrogen number density.

The black hole mass is 2.0 x 10^6 solar mass and the Eddington ratio is 20%.

Results1: Monte Carlo Radiative Transfer

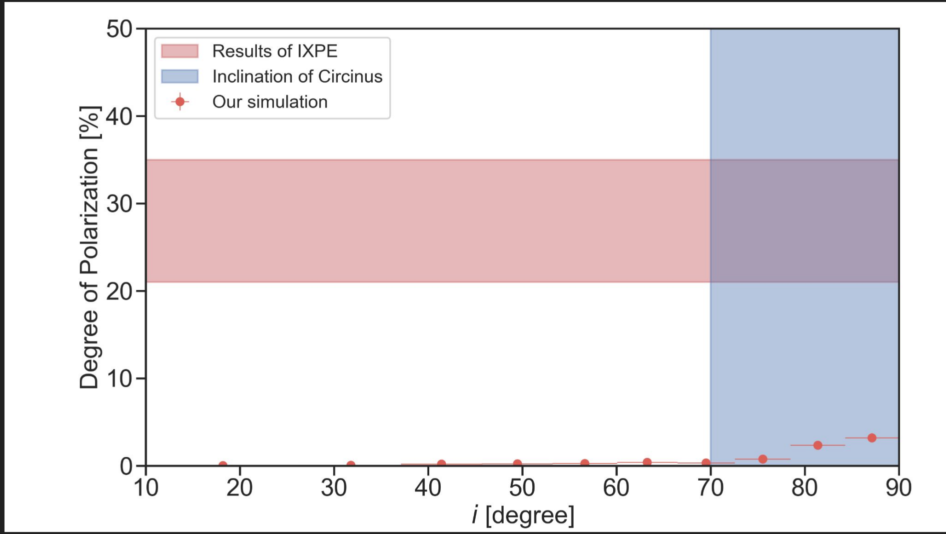


Odaka+16

To compute the degree of polarization based on RHD simulation,
we use Monte Carlo simulations for astrophysics and cosmology (MONACO) code.

We have implemented the function to compute X-ray polarization in MONACO.

Results1: Comparison of Degree of Polarization

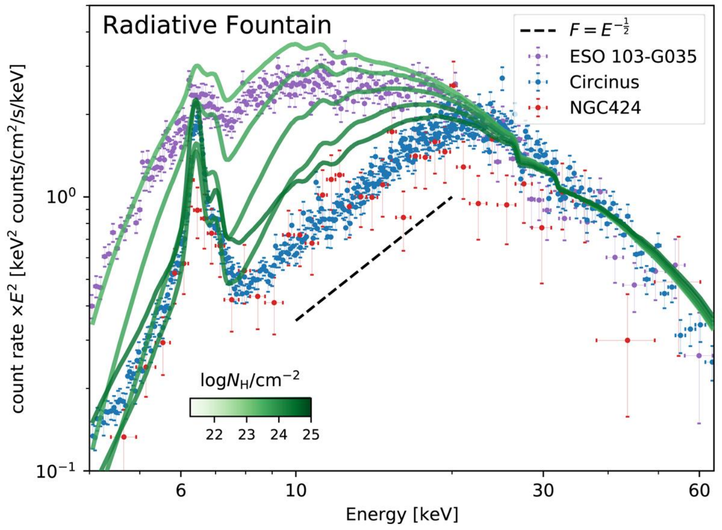


We compare P based on our simulation with that obtained from IXPE.

Figure shows the dependence of degree of polarization on the inclination angle.

The degree of polarization is smaller than that obtained from IXPE.

Results1: Parsec-scale Radiation-driven Fountain



Buchner+21

This is because the density in this model is too small to produce the polarization.

Figure compares X-ray spectrum based on this model with observation.

Buchner+21 also suggested that a compact Compton-thick material is required.

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Results2: Basic Equations

$$\frac{\partial}{\partial t}(\rho) + \nabla \cdot (\rho v) = 0$$

$$\frac{\partial}{\partial t}(\rho v) + \nabla \cdot (\rho v v^T + PI) = f_{\rm rad} + f_{\rm grav} + f_{\rm vis}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot [(\rho E + P)v] = -\rho \mathcal{L} + v \cdot f_{\rm rad} + v \cdot f_{\rm grav} + W_{\rm vis}$$

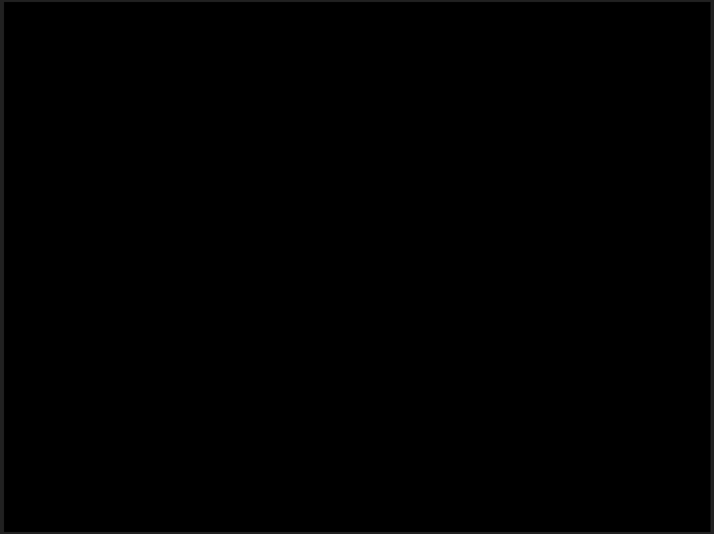
Kudoh+23

We perform 2D radiative hydrodynamic simulation with CANS+ (Matsumoto+19).

The figure shows the basic equations of our computation.

Here we consider the dust and gas and the radiation pressure.

Results2: Sub-parsec-scale Radiation-driven Fountain

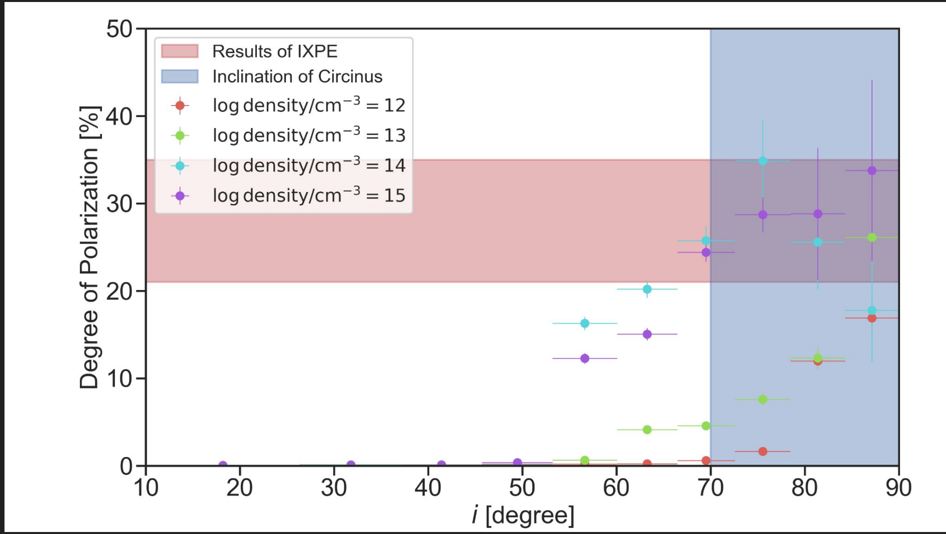


We perform 2D radiative hydrodynamic simulation with CANS+ (Matsumoto+19).

The animation shows the time variability of the hydrogen number density.

We study four cases of the hydrogen number densities of the disk.

Results2: Comparison of Degree of Polarization

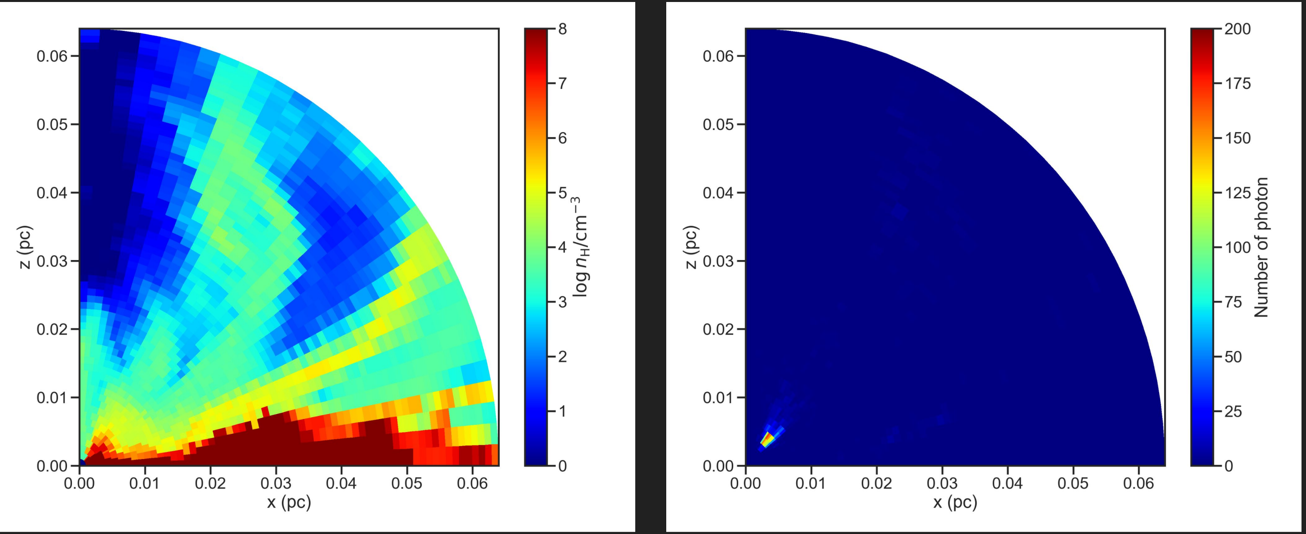


We compare P based on our simulation with that obtained from the IXPE.

Figure compares P from our simulation with P from the IXPE.

The degree of polarization is consistent with that obtained from the IXPE.

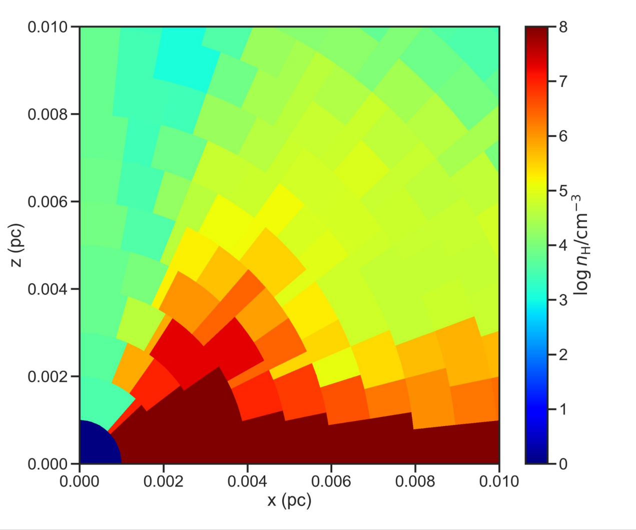
Discussion: The Origin of the X-Ray Polarization

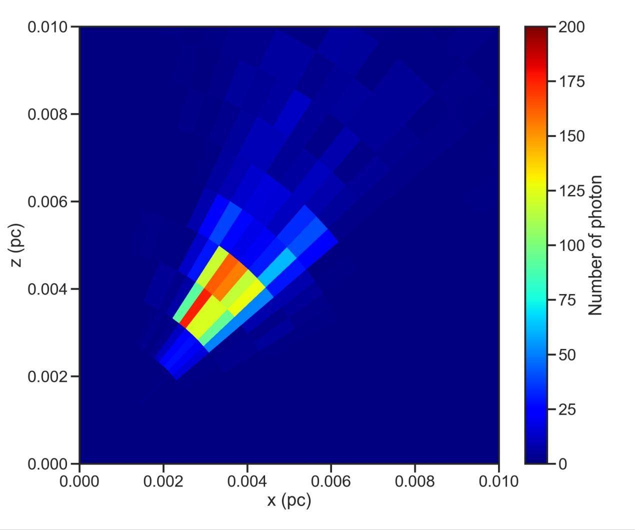


To determine the origin of the X-ray polarization in the Circinus galaxy, we investigated where the photons were Compton scattered.

This implies that the origin of X-ray polarization is a sub-parsec-scale outflow.

Discussion: The Origin of the X-Ray Polarization





To determine the origin of the X-ray polarization in the Circinus galaxy, we investigated where the photons were Compton scattered.

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Summary

It is important to understand the sub-parsec scale structure around the AGN.

X-ray polarized observation is a powerful tool for studying the structure.

The sub-parsec-scale model can explain the observed value. This implies that the origin of X-ray polarization is a sub-parsec-scale radiation-driven outflow.