Diffuse X-ray Emission from a Distributed Component of Dark Matter Surrounding Sgr A*

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Chandra Observations

X-ray source CXOGC J174540.0-290027 coincident with radio position of Sgr A* to within 0.35”

2.4 pc

- Extended in the X-band
- Reported intrinsic size ~ 1”- 2”
- X-ray luminosity ~ 2 \times 10^{33} \text{ erg s}^{-1} (2 - 10 \text{ keV})
- Spectrum well fit by absorbed power law or absorbed optically thin thermal plasma model

(Baganoff et al. 2002)
X-ray Flux Distribution
Extended Nature of Sgr A*

- FWHM on axis HRMA PSF $\sim 0.5''$
- FWHM of two nearby sources $\sim 1''$
- Broader than Chandra's PSF
- Narrower than Sgr A*
- Use them to estimate the flux distribution of the diffuse component

(Baganoff et al. 2002)
Possible Origin of X-ray Emission
Stellar vs. Massive Black Hole

- Colliding winds from WR binaries
- O binaries in the central cusp
- Young magnetically active low mass stars
- Accreting X-ray binary system

Stellar origin seems unlikely

- Accretion from stellar winds
- Bondi Hoyle - ADAF models, X-rays dominated by thermal bremsstrahlung

Cannot be ruled out with current data
Motivation for the Present Study:

- Only one model has been proposed so far (Quataert 2000)
- No studies trying to fit X-ray flux distribution (only spatial extent)
- Some room in ‘enclosed mass space’ to allow extended component
- The proposed scenario provides a different approach to study dark mass distribution surrounding MBH

Questions to be Addressed:

1) Can a cluster of NS accreting from ISM account for X-rays?
2) What conditions are necessary?
Evidence for Dark Mass Concentration and Why a Cluster Would Not Work

(Ghez et al. 1998)
Dark Cluster Surrounding Sgr A*

- $M \sim 10^6 M_\odot$ in stellar remnants in the central pc (Morris 1993)
- X-ray flux consistent with this scenario (Haller et al 1996)
- Unlikely to be in a stable cluster without a BH (Maoz 1998)
- Moderate mass BH, $M_{BH} \sim 10^3 M_\odot$ (Quinlan & Shapiro 1990)
- BH grows up to MBH over a Hubble time (Murphy et al 1991)
Dark Cluster Model

Numerical simulations:
- \( M_C \sim 10^6 M_\odot - 10^9 M_\odot \)
- Density profiles: broken power law
- Core radius: \( 10^{-1} \text{ pc} - 10^{-3} \text{ pc} \)
- Relaxation times: \( 10^8 \sim 10^9 \text{ yr} \)

Analytical model:
- \( \eta \)-model, allows BH (central cusp)
- Maxwellian velocity distribution
- Velocity dispersion \( \sigma = \sigma (r) \)
- NS cluster

(Murphy et al 1991)

\( \eta \)-model
Accretion onto the MBH

\[ \dot{M}_{\text{BH}} = \pi R_{\text{acc}}^2 \rho(\infty) v_{\text{gas}}(\infty) \quad R_{\text{acc}} = \frac{2GM_{\text{BH}}}{v^2_{\text{gas}}(\infty)} \]

This will set the density profile \( \rho(r) \) seen by stars around MBH.

Accretion onto a single NS: Bondi - Hoyle

\[ \dot{M}_g = \pi r_g^2 \rho(r) v_{\text{eff}}(r) \]

\[ r_g = \frac{2GM_{\text{ns}}}{v_{\text{eff}}^2(r)} \]

\[ \dot{M}_g \propto v_{\text{eff}}^{-3} \]

Bondi-Hoyle accretion goes DOWN with increasing velocities!
Accretion onto a single NS: Magnetic Accretion

\[ \dot{M}_m = \pi r_m^2 \rho(r) v_{\text{eff}}(r) \]

\[ r_m = \left[ \frac{B^2 R_{ns}^6}{4\pi} \rho(r) v_{\text{eff}}^2(r) \right]^{1/6} \]

\[ r_m \sim v_{\text{eff}}^{-1/3}(r) \]

\[ \dot{M}_m \propto v_{\text{eff}}^{1/3} \]

Magnetic accretion goes UP with increasing velocities!
Dominant Accretion Mechanism

\[ \frac{\dot{M}_m}{\dot{M}_g} \sim \left( \frac{v_{\text{eff}}}{100 \text{ km/s}} \right)^{10/3} \]

- Strongly magnetized NS more likely to contribute to X-rays
- Estimated to represent 10% of isolated pulsars

- Consider diluted BB spectrum
  \[ T_{\text{col}} \sim \gamma T_{\text{eff}} \quad \text{with} \quad \gamma \sim 2.6 \]

\[ L_T = 4\pi R_{\text{ns}}^2 \sigma T_{\text{eff}}^4 = \left( \frac{GM_{\text{ns}}}{R_{\text{ns}}} \right) \dot{M}_m \]
Intensity Produced by the Cluster

\[ j_\nu(r) d\nu = \delta \int_{3\nu} L_\nu^*(r, \nu) f(r, \nu) \, d^3\nu \, d\nu \]

\[ I_\nu(R) = \frac{2}{4\pi} \int_R^\infty \frac{j_\nu(r)}{\sqrt{1 - (R/r)^2}} \, dr \]
Results: Best Fit Models

\[ B \sim 10^{15} \, \text{G}: \quad M_C \sim 0.4 \times 10^6 \, \text{M}_\odot \quad r_0 \sim 0.06 \, \text{pc} \quad L_X \sim 10^{33} \, \text{erg s}^{-1} \]

\[ B \sim 10^{14} \, \text{G}: \quad M_C \sim 1.6 \times 10^6 \, \text{M}_\odot \quad r_0 \sim 0.03 \, \text{pc} \quad L_X \sim 10^{33} \, \text{erg s}^{-1} \]

(Data from Genzel et al. 1997)

Flux profile of diffuse component
Constraints from Enclosed Mass

(Data from Genzel et al. 1997)

\( B \sim 10^{15} \text{ G} \)

\( B \sim 10^{14} \text{ G} \)

\( \chi^2 \) Contour Plot

\( B \sim 10^{14} \text{ G} \)

\( B \sim 10^{15} \text{ G} \)
Conclusions

- A cluster of NS can provide acceptable overall description: luminosity, extent & flux profile
- This requires roughly 15% mass in inner pc to be in NS
- 10% of them should be magnetic accretors

Implications for Dark Mass Distribution:
• The model requires a MBH
• But $M_{\text{BH}}$ no longer necessarily $2.6 \times 10^6 \, M_\odot$ (rather $2.2 \times 10^6 \, M_\odot$)
• Agreement with independent lower limits for $M_{\text{BH}} \sim 10^6 \, M_\odot$

Refinements & Caveats:
• Cluster dynamics needs to be understood better
• Better estimates of emergent spectrum of individual NS
• 10% NS with strong magnetic fields
• WD and BH might be important dynamically