Cosmic Forensics:
A Study of the Pulsar Wind Nebula G359.23-0.82, The “Mouse”

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Case Background
  - Pulsars, Pulsar Wind Nebulae and The Mouse

Fingerprinting: Collecting the Evidence
  - Reduction of Data from The Very Large Array (VLA)

Ballistics: Where is the Mouse Going?
  - Derivative Maps and Kinematics

Recreating the Scene of the Crime
  - Origin of the Mouse? Future?

Closing Arguments
Case Background

The Galactic Center

Mouse

Associated Supernova Remnant?

Pulsars are magnetised rotating neutron stars

\[ \dot{E} = \frac{d}{dt} \left( \frac{1}{2} I \omega \right) = I \omega \dot{\omega} \]

Get pulsar wind nebula (PWN) from interaction of shocked ambient particles with magnetised wind

Crab Nebula (Hester et al. 2002)
• Natal kicks from supernova (SN) explosion

\[ V_{\text{birth}} \approx 300 \text{–} 1000 \text{ km/s} \]

Guitar Nebula (Chatterjee & Cordes 2002)

3D hydrodynamic simulation (Vigelius, Gaensler et al. 2007)
- First radio observation in 1987 (Yusef-Zadeh & Bally 1987)
- X-ray detection in 1994 (Predehl & Kulkarni 1995)
- Pulsar J1747-2958 discovered in 2002 (Camilo et al. 2002)

**pulsar in “snout”**

\[ P = 98.8 \text{ ms} \]

\[ \dot{P} = 6.14 \times 10^{-14} \text{ s/s} \]

\[ \tau_c = \frac{P}{2\dot{P}} = 25.5 \text{ kyr} \]

\[ \dot{E} = 2.5 \times 10^{36} \text{ ergs/s} \]

\[ B = 2.5 \times 10^{12} \text{ G} \]
The Arraignment

- Where is the Mouse going?
- Can we learn about the ISM?
- Can we get an independent age estimate?
- Associated with nearby SNR?

The Mouse:
Radio $\rightarrow$ X-Ray/Radio $\rightarrow$ X-Ray

FINGERPRINTING:
COLLECTING THE EVIDENCE
Similar observations using hybrid BnA configuration at 1993, 1999 and 2005 epochs

Observing frequency of 8.5 GHz

Raw data edited, calibrated, imaged, and smoothed to uniform resolution

The Very Large Array (VLA)
http://www.vla.nrao.edu/
Comparison of Epochs

- Morphology evolution
- 1999 Epoch has poor spatial frequency coverage along direction of interest
- Only consider 1993 and 2005 epochs
BALLISTICS:
WHERE IS THE MOUSE GOING?
Morphology Evolution

[Images of galaxy evolution graphs]
Derivative Maps

1993

abs(X-Deriv)

Total Deriv

2005
\( \mu = 12.9 \pm 3.2 \text{ mas yr}^{-1} \)

For \( d = 5 \text{ kpc} \):

\( V_\perp = 305 \pm 75 \text{ km s}^{-1} \)

*Compares well with NS velocity distribution*
RECREATING THE SCENE OF THE CRIME
In Situ ISM Density

- Ram pressure balance with pulsar wind:
  \[
  \frac{\dot{E}}{4\pi(r)^2c} = \rho V^2 = 1.37n_0m_HM^2c_s^2
  \]
- Combine to estimate proper motion:
  \[
  V = \frac{1525}{\sqrt{n_0d}} \text{ km/s} \quad \mu = \frac{V}{d} = \frac{13}{\sqrt{n_0d^2}} \text{ mas/yr}
  \]
- Using detected proper motion and \(4 \leq d \leq 6\) kpc:
  \[
  0.5 \leq n_0(=1.0) \leq 2.5 \text{ cm}^{-3} \quad M \approx 60
  \]
Lower bound from distance travelled along tail: \( \sim 50 \text{ kyr} \)

\[ t > \tau_c = 25.5 \text{ kyr} \]
● Consider SNR evolution near the Mouse

● Using previous density and distance: \( \sim 90 \text{ kyr} \) to cross SNR shell

● Total age of pulsar
  \( \approx 50 + 90 = 140 \text{ kyr} \)

● But do not see SNR of correct size (too small)

Will the Mouse become an exotic magnetar?

B increasing

Similarity to Vela

Will the Mouse become an exotic magnetar?

Using data from:
• Velocity consistent with neutron star population
  ▪ First time a proper motion has been calculated for this object

• In situ measurement of ISM density from 16 kly away!

• Unlikely association with SNR G359.1-0.5

• Lower limit on age: \( t \geq 140 \text{ kyr} \approx 5\tau_c \)

• Magnetic field growing
  ▪ Mouse evolving into a magnetar?

• Results to be published later this year
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<th>Epoch 1</th>
<th>Epoch 2</th>
<th>Epoch 3</th>
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