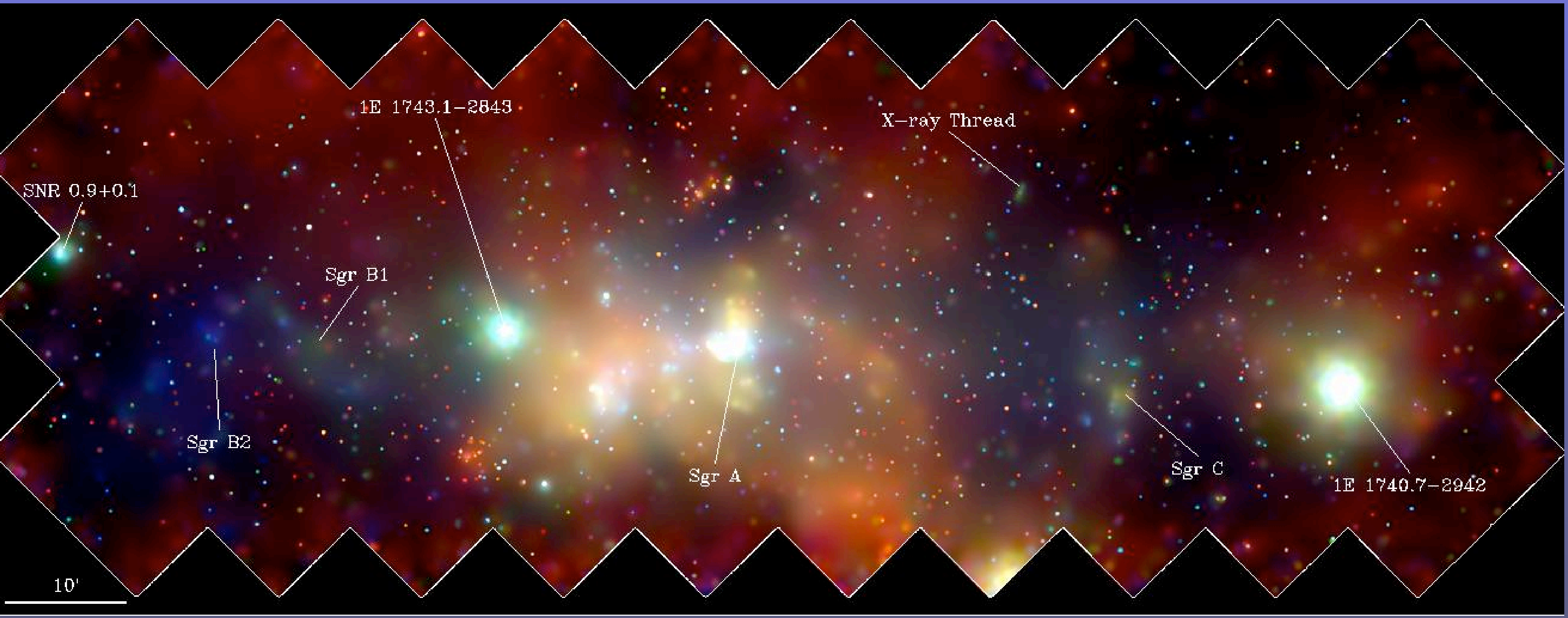
THE FAINT X-RAY SOURCE POPULATIONS IN THE GALACTIC CENTER

- Observational Overview
- Stellar Models
- Accreting Compact Objects
- Non Accreting Compact Objects
- Faint X-ray Source Population
- Summary & Future Work

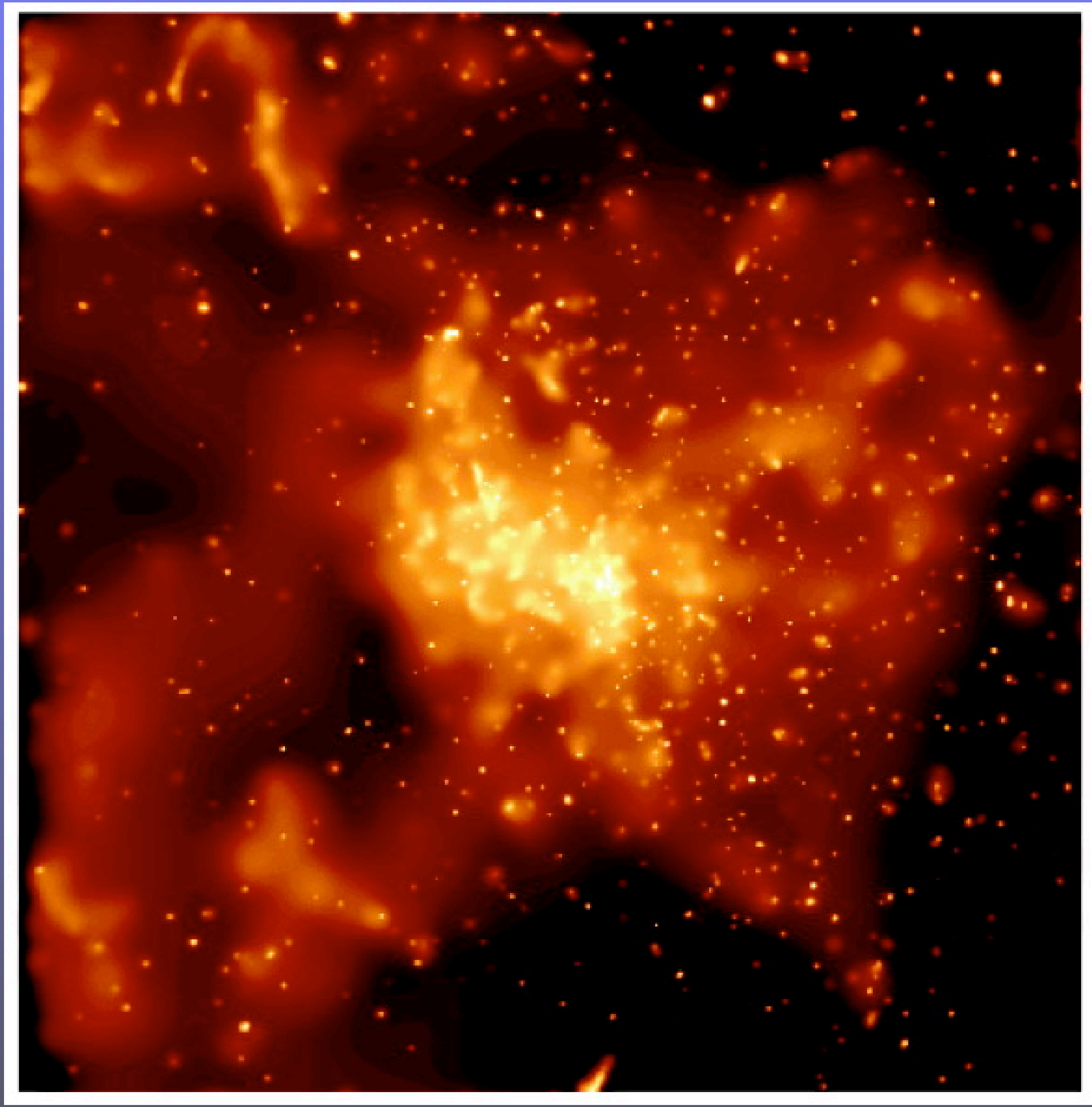
OBSERVATIONAL OVERVIEW

- Deep Imaging Surveys - Wang, Gotthelf, & Lang (2002): 2 x 0.8 square degree band; Muno et al. (2003): 17' x 17' field
- Luminosities - in the innermost field, ranges from $10^{30} - 10^{33}$ ergs/s and in the larger field to about $10^{33} - 10^{35}\mathrm{ergs/s}$
- Spectrally hard with photon power law index, $\Gamma \sim 0 - 3$

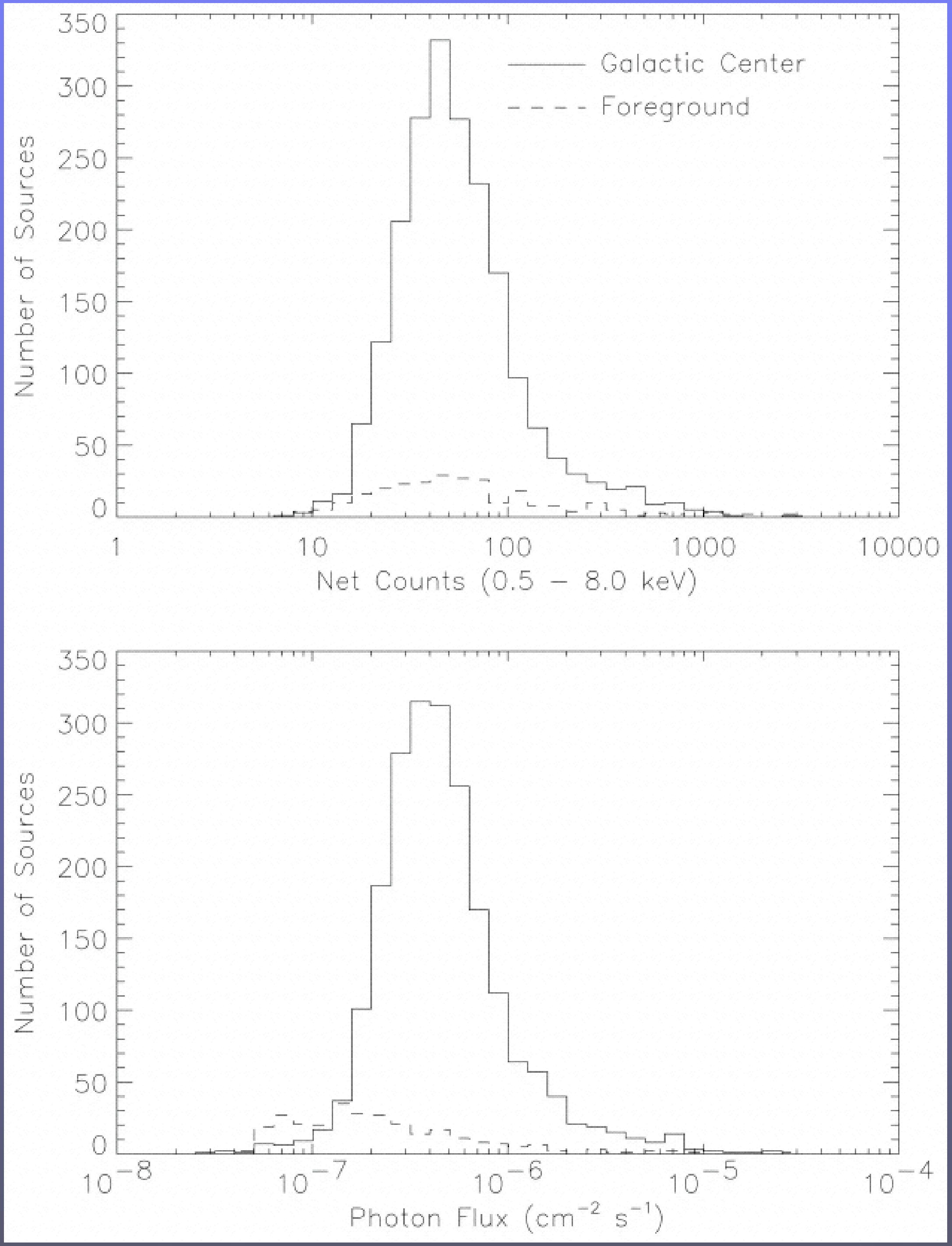
GALACTIC CENTER IN X-RAYS: WANG ET AL. (2002)



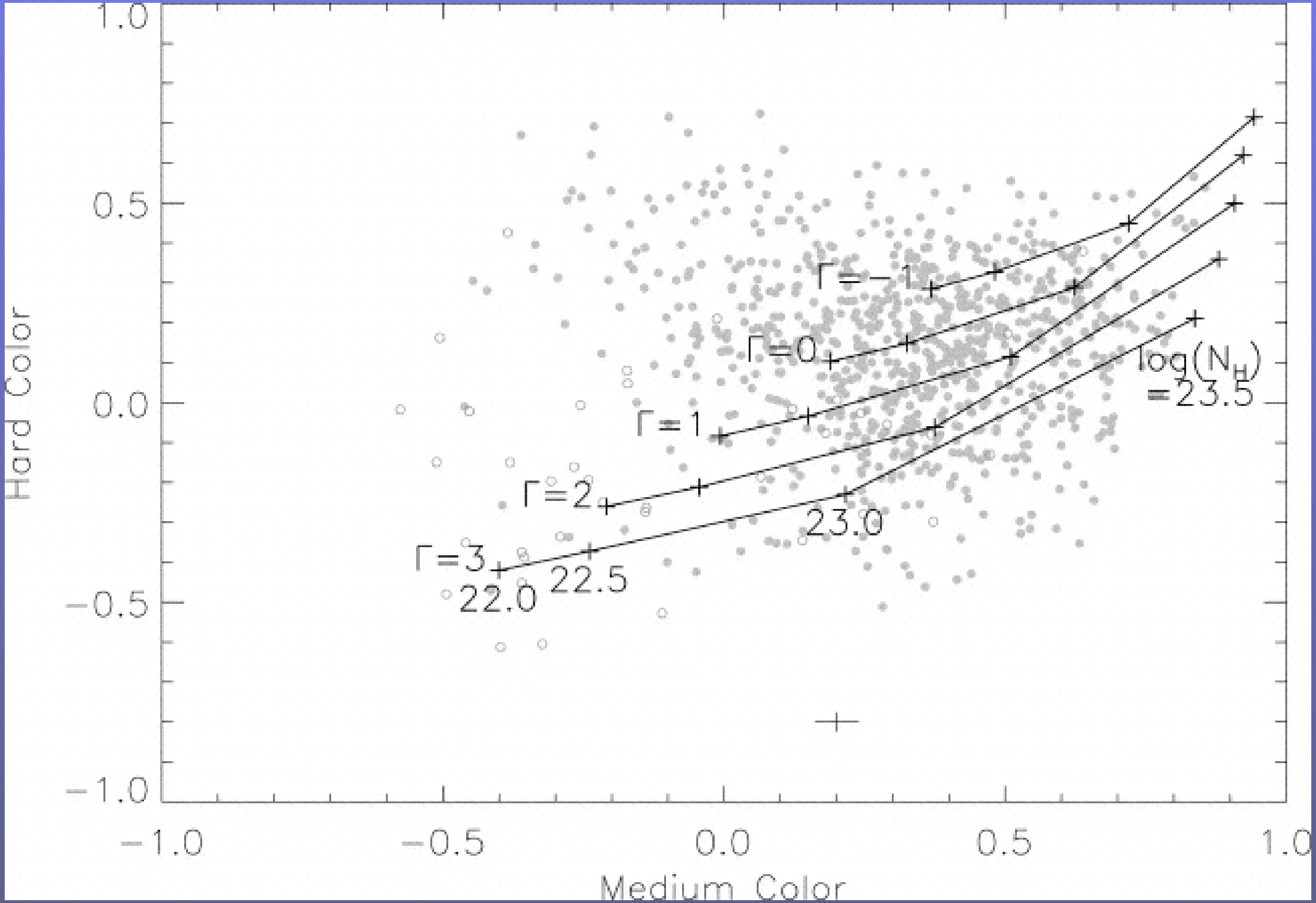
GALACTIC CENTER IN X-RAYS



Muno et al.
2003



Muno et al. (2003)



Muno et al. (2003)

FAINT X-RAY SOURCES AT GALACTIC CENTER

- What are they?

  Need ~ 2000 with $L_x \sim 10^{31} - 10^{33} \mathrm{ergs/s}$

  About 1400 sources have $\Gamma < 1$

  About 600 sources have $\Gamma > 1$

POSSIBLE STELLAR MODELS

Binary

- detached binaries (MS/MS): coronal activity
- accreting white dwarf stars (MS/WD)
- accreting neutron stars (MS/NS; WD/NS)

Isolated

- low mass stars: coronal activity
- young pulsars
- old millisecond pulsars

ACCRETING COMPACT OBJECTS

- Roche Lobe Overflow White Dwarf Models - magnetic cataclysmic variable systems (intermediate polars: MS/WD)
- Stellar Wind Fed Neutron Star Models - intermediate mass X-ray binaries (MS/NS); pre-low mass X-ray binaries (MS/NS)
- Roche Lobe Overflow Neutron Star Models - low mass X-ray binaries (MS/NS); ultracompact X-ray binaries (WD/NS)

NON ACCRETING COMPACT OBJECTS

- Rotation powered neutron stars: extraction of rotational spin energy through magnetic fields - young pulsars and old millisecond pulsars

  - point source X-ray emission from pulsar
  - extended emission from a pulsar trail or a pulsar wind nebula

INTERMEDIATE POLAR MODELS FOR GALACTIC CENTER SOURCES

- Class of systems fall in the correct X-ray luminosity range
- Class of systems is characterized by hard X-ray spectra
- On the order of 10,000 cataclysmic variables expected within 20 pc (Muno et al. 2003)
- Companions restricted to later than B0 by lack of identified IR counterparts (Laycock et al. 2005)

ACCRETING NEUTRON STARS FOR GALACTIC CENTER SOURCES

- Wind-fed accreting neutron stars with intermediate mass donors (Pfahl et al. 2002)
- Wind-fed accreting low mass pre-LMXBs (Willems & Kolb 2003)
- Quiescent LMXBs (Belczynski & Taam 2004; Liu & Li 2006)

FAINT NEUTRON STAR X-RAY BINARY POPULATION

- Wind Fed Systems
  - $\dot{M} \sim \dot{M}_{wind} R_{cap}^2 / A^2$
  - $L_x \sim G M_{ns} \dot{M} / R_{ns} \sim 10^{31} - 10^{34} \mathrm{ergs/s}$
  - Donors ~ $3 - 8 M_{\odot}$ (Pfahl et al. 2002)
  - Donors $< 2 \mathrm{M}_{\odot}$ (Willems & Kolb 2003)
  - Does the magnetic interaction at low mass capture rates, lead to accretion?

- Roche Lobe Overflow Systems
  - Low mass donors: $\mathrm{M} < 1\mathrm{M}_{\odot}$
  - Short orbital periods: P < 0.5 day
  - Transient systems: accretion disk instability

$$\dot{\mathrm{M}}_{\mathrm{crit}}(\mathrm{M}_{\mathrm{ns}}, \mathrm{P})$$

  - outburst luminosity $\sim 10^{36} - 10^{38}\mathrm{ergs/s}$
  - quiescent luminosity $\sim 10^{31} - 10^{33}\mathrm{ergs/s}$

QUIESCENT STATE EMISSION OF SOFT X-RAY TRANSIENTS

- Spectra

  - Soft component (kT ~ 0.3 keV): deep crustal heating

  - Hard power law component $(\Gamma \sim 1.5 - 2.5)$

  residual accretion; activation of the pulsar mechanism

- Luminosities

  - quiescent state emission (2 - 8 keV):

$$L_x \sim 10^{31} - 10^{32} \text{ergs/s}$$

  - relative contribution of hard component can vary from 10% - 90%

  - harder at lower luminosities $(\sim 10^{31} \text{ergs/s})$

  - harder at higher luminosities $(\sim 10^{33} \text{ergs/s})$

ROTATION POWERED NEUTRON STAR SOURCES

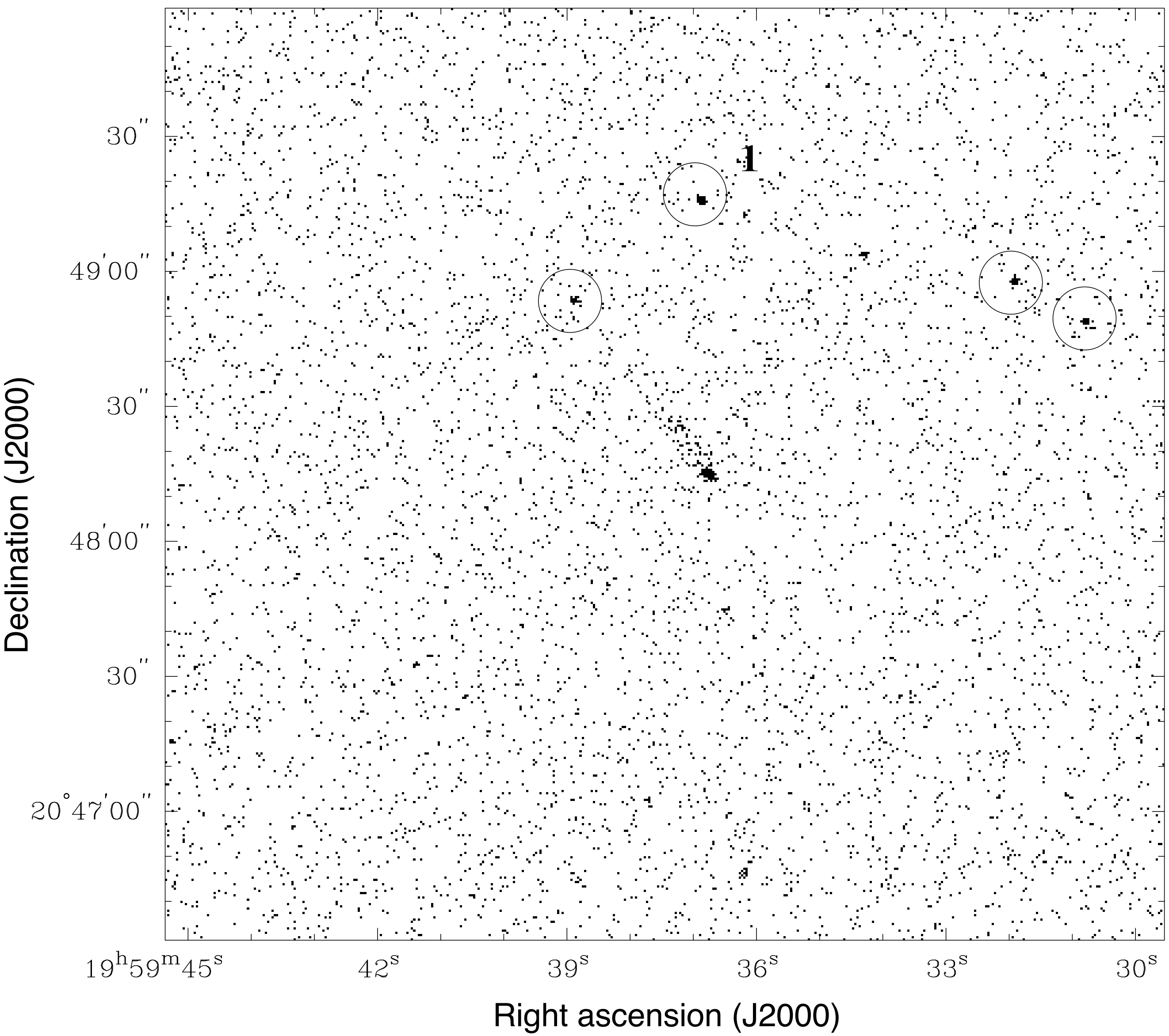
- Pulsars and their wind nebulae

$\mathrm{L_x} \sim \dot{\mathrm{E}}_{\mathrm{sd}}$ (0.1 - 2.4 keV)

$\mathrm{L_x} \sim \dot{\mathrm{E}}_{\mathrm{sd}}^{1.4}$ (2 - 8 keV)

Thermal plus power law spectra $\Gamma \sim 1 - 2.5$

PSR 1957+20 (Stappers et al. 2003)



$$L_x \sim 3 \times 10^{31} \mathrm{ergs/s}$$

$$\Gamma = 1.9 \pm 0.5$$

POPULATION SYNTHESIS

- Ingredients

  - wind mass loss

  - tidal synchronization/circularization

  - angular momentum loss (magnetic braking, gravitational radiation)

  - conservative/non-conservative mass transfer

  - common envelope evolution

  - supernova kicks

- Initial Conditions

  - primary and secondary masses
  - mass function
  - mass ratio distribution
  - orbital period distribution

FORMATION OF NEUTRON STARS

- Formation by Fe Core Collapse of Massive Stars

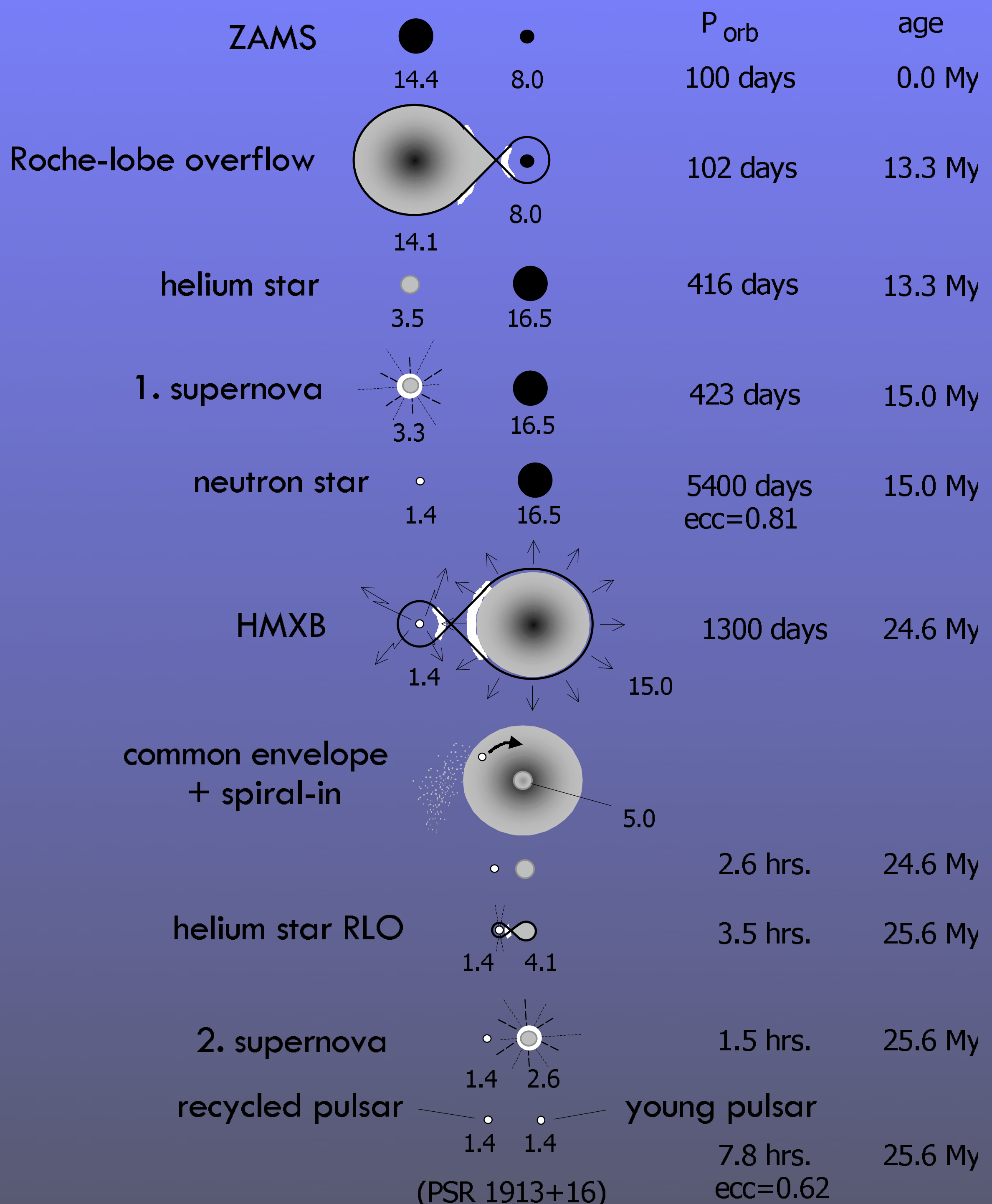
  - Single Stars: M ~ $8 - 25 M_\odot$

  - Binary Systems: M ~ $12 - 25 M_\odot$

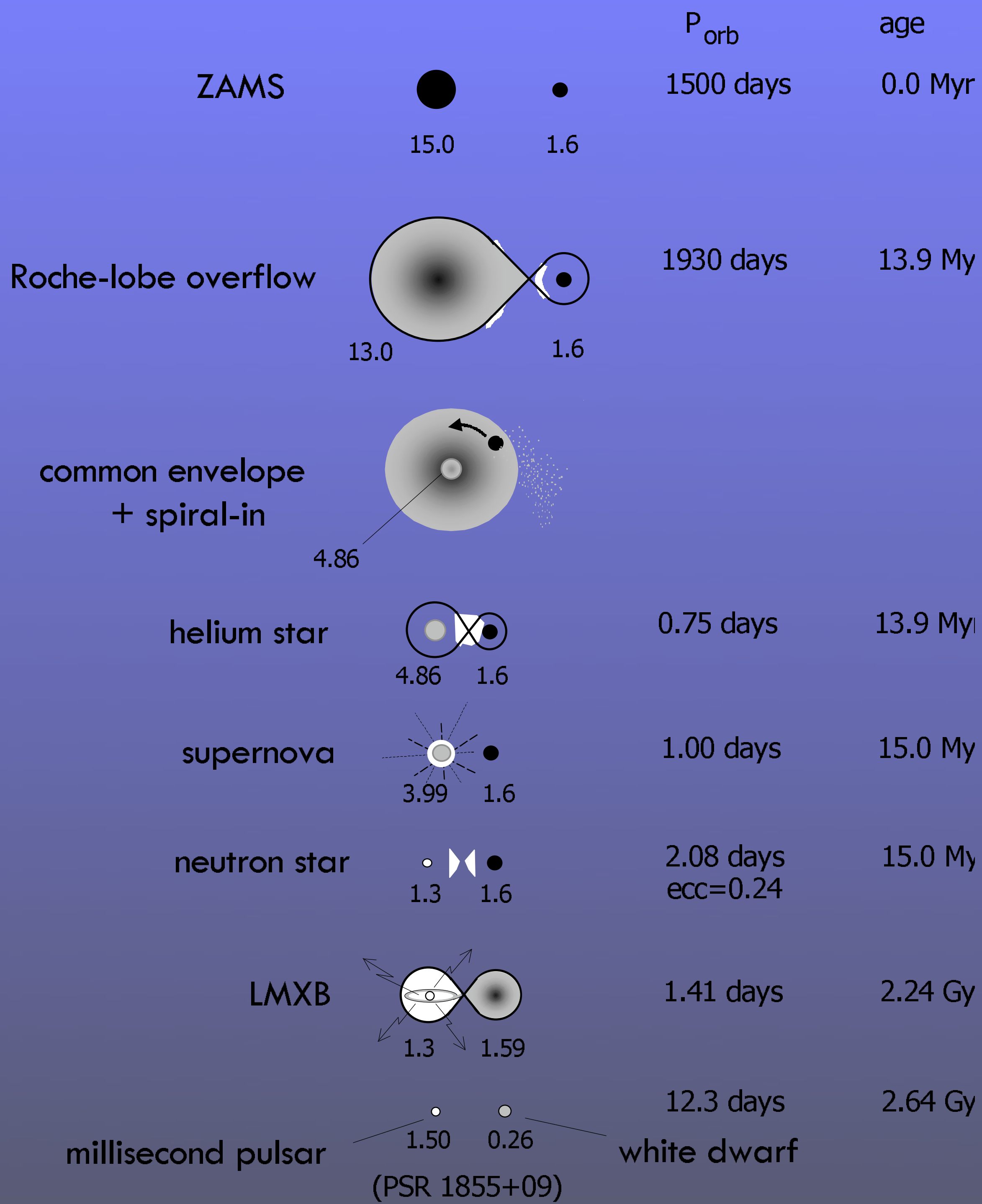
  - Evolution: MS,MS - He, MS - NS, MS

- Formation by Accretion Induced Collapse of ONeMg White Dwarf
  - Single Stars: M ~ $6 - 8 M_\odot$
  - Binary Systems: M ~ $6 - 12 M_\odot$
  - Evolution: MS, MS - WD,MS - NS,MS - NS,WD

    MS,MS - WD,MS - WD,He - NS,He - NS,WD

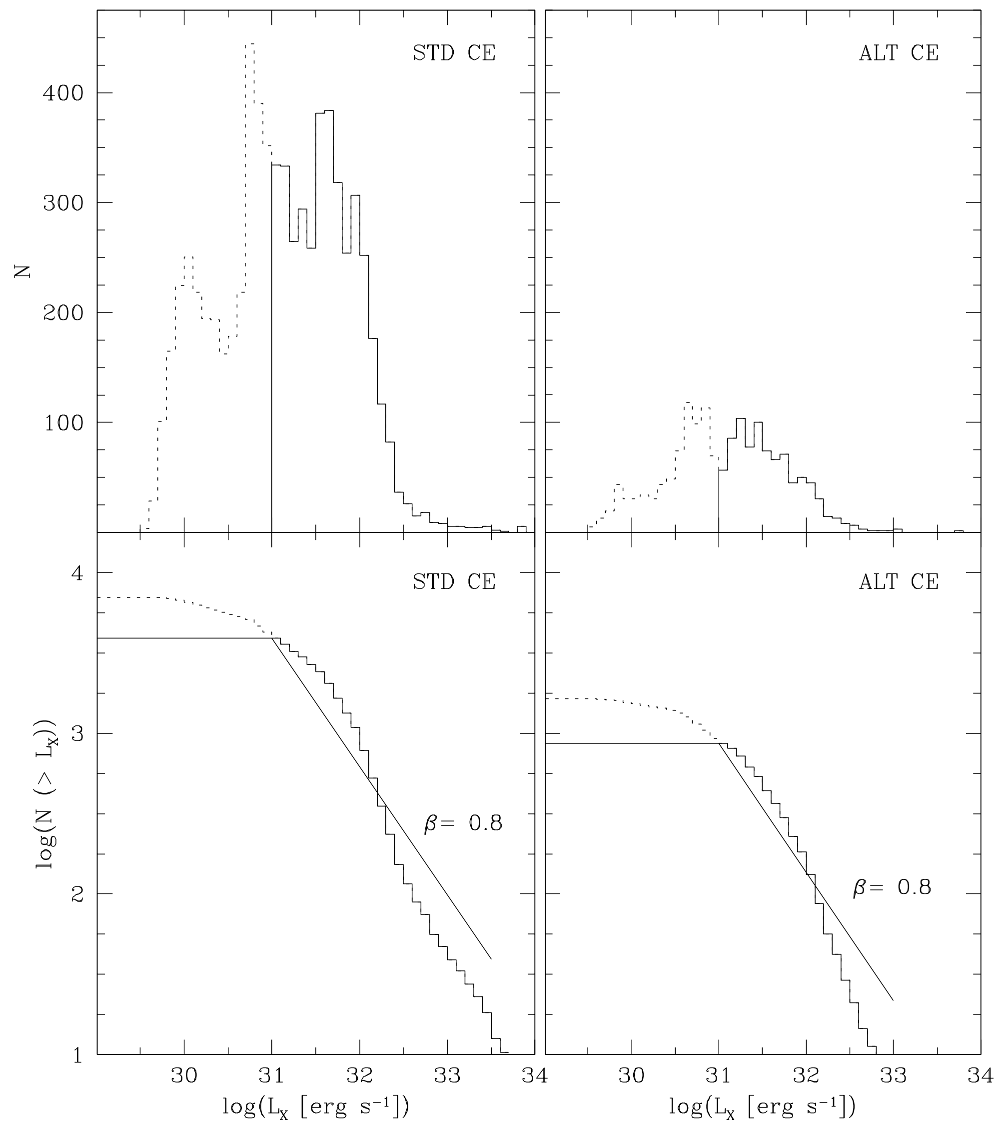


Tauris & van den Heuvel (2005)



Tauris & van den Heuvel (2005)

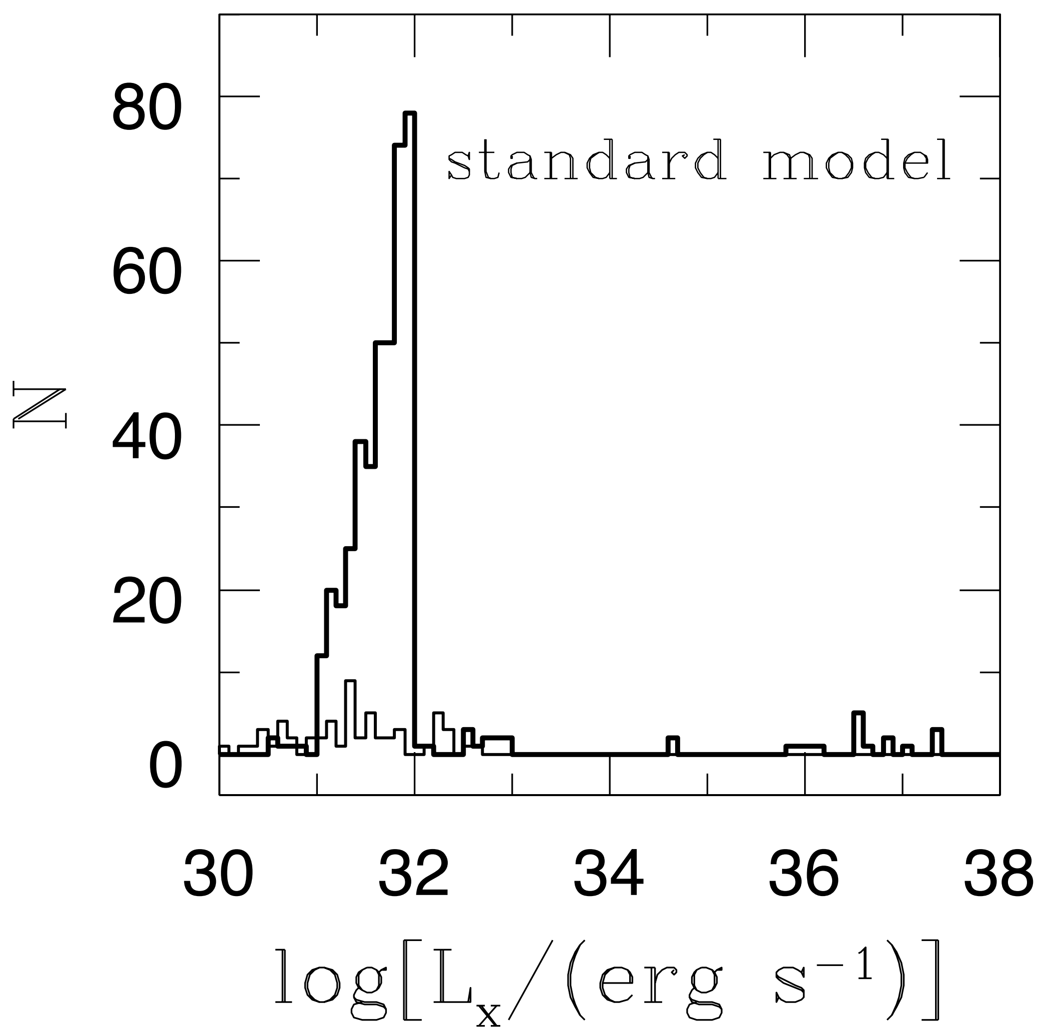
X-ray Luminosity Distribution and X-ray Luminosity Function for Intermediate Polars (Ruiter et al. 2006)



RESULTS FROM INTERMEDIATE POLAR POPULATION SYNTHESIS STUDIES

- Intermediate polar cataclysmic variable sources can be consistent in number and luminosity for hard sources (Ruiter et al. 2006) assuming that the IP fraction of CVs is several percent, however Liu & Li (2006) find that they are a minor contributor. Note, that the latter group underestimates the mass transfer rates due to their prescription for angular momentum losses.
- X-ray luminosity function, $\mathrm{N} \sim \mathrm{L_x^{-\alpha}}$ where $\alpha_{\mathrm{theory}} \sim 0.8$ and $\alpha_{\mathrm{obs}} \sim 1.3$

X-ray Luminosity Distribution for Neutron Star Sources (Belczynski & Taam 2004)



RESULTS FOR NEUTRON STAR POPULATION SYNTHESIS

- Wind fed neutron stars are insufficient to explain the faint hard X-ray sources in part because of propeller effects, by a factor of 10.
- Roche lobe overflow neutron star X-ray binaries can contribute to the faint soft source population during their quiescent state, but too few bright sources are observed suggesting a contribution of less than about 30%.
- Pulsars can also contribute to the faint soft source population. Young pulsars and millisecond pulsars contribute at the level of less than about 20%.

What are the harder Galactic Center sources?

- Harder systems are difficult to explain as there are no known class of sources which have a spectral index < 0
- Need several 100 sources in central 20 pc, so should be common in the Galaxy
- Wind-fed neutron stars are too few and there are problems with respect to accretion as a result of inhibition due to the propeller effect

SUMMARY

- Intermediate polars may contribute to the bulk of the faint hard X-ray sources
- Soft X-ray transients in quiescence can contribute to the soft, faint component
- Rotation powered neutron stars can contribute to both the point source and extended emission
- Hard X-ray sources with spectral index ~ 0 are difficult to explain.

FUTURE

- Nature of the companion star
- Detection of orbital periods
- Detection of soft X-ray component in regions of low extinction
- Can the enhanced metallicity of the Galactic Center region be responsible for the anomalously hard spectra?