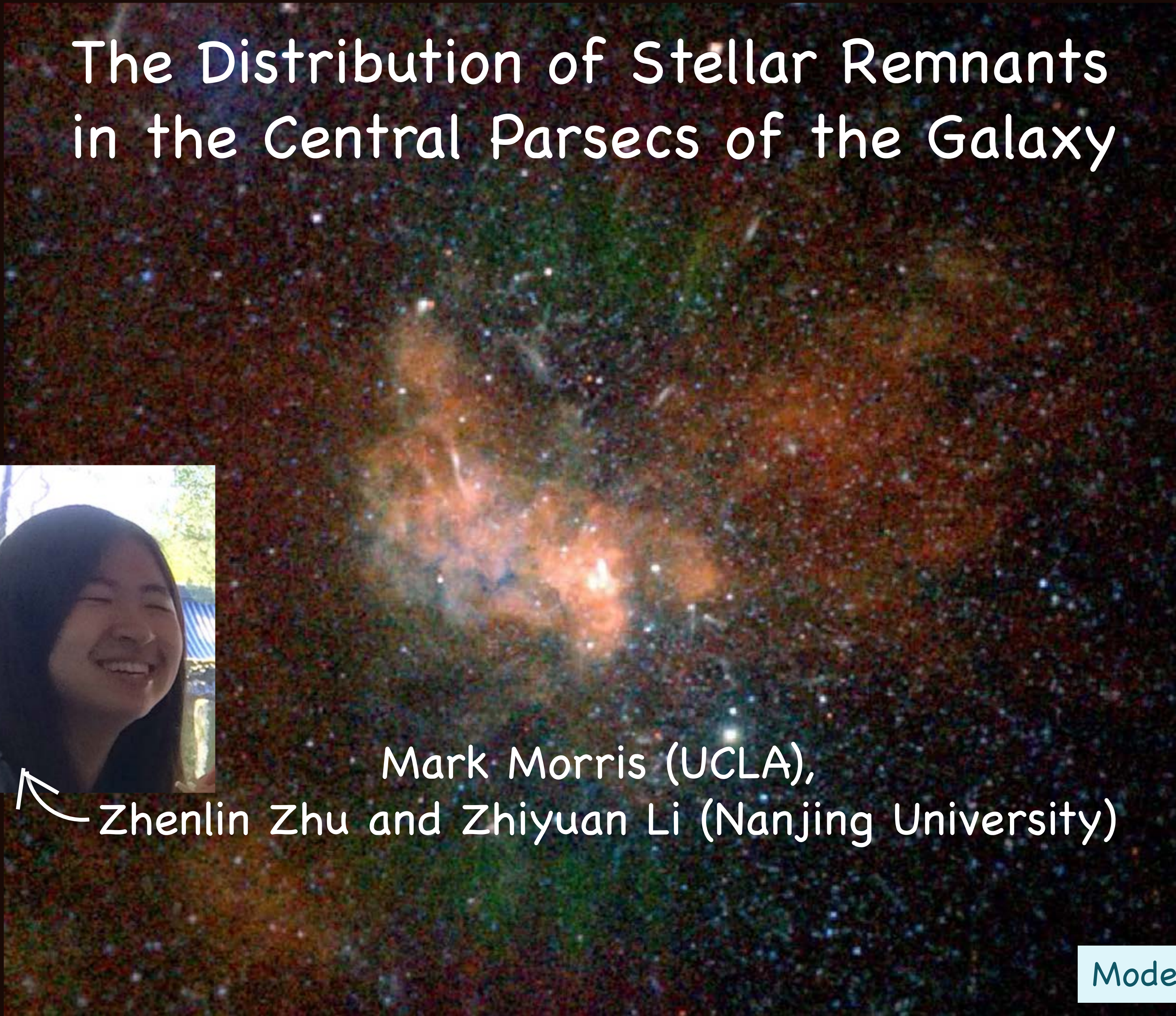

The Distribution of Stellar Remnants in the Central Parsecs of the Galaxy

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Zhenlin Zhu and Zhiyuan Li (Nanjing University)

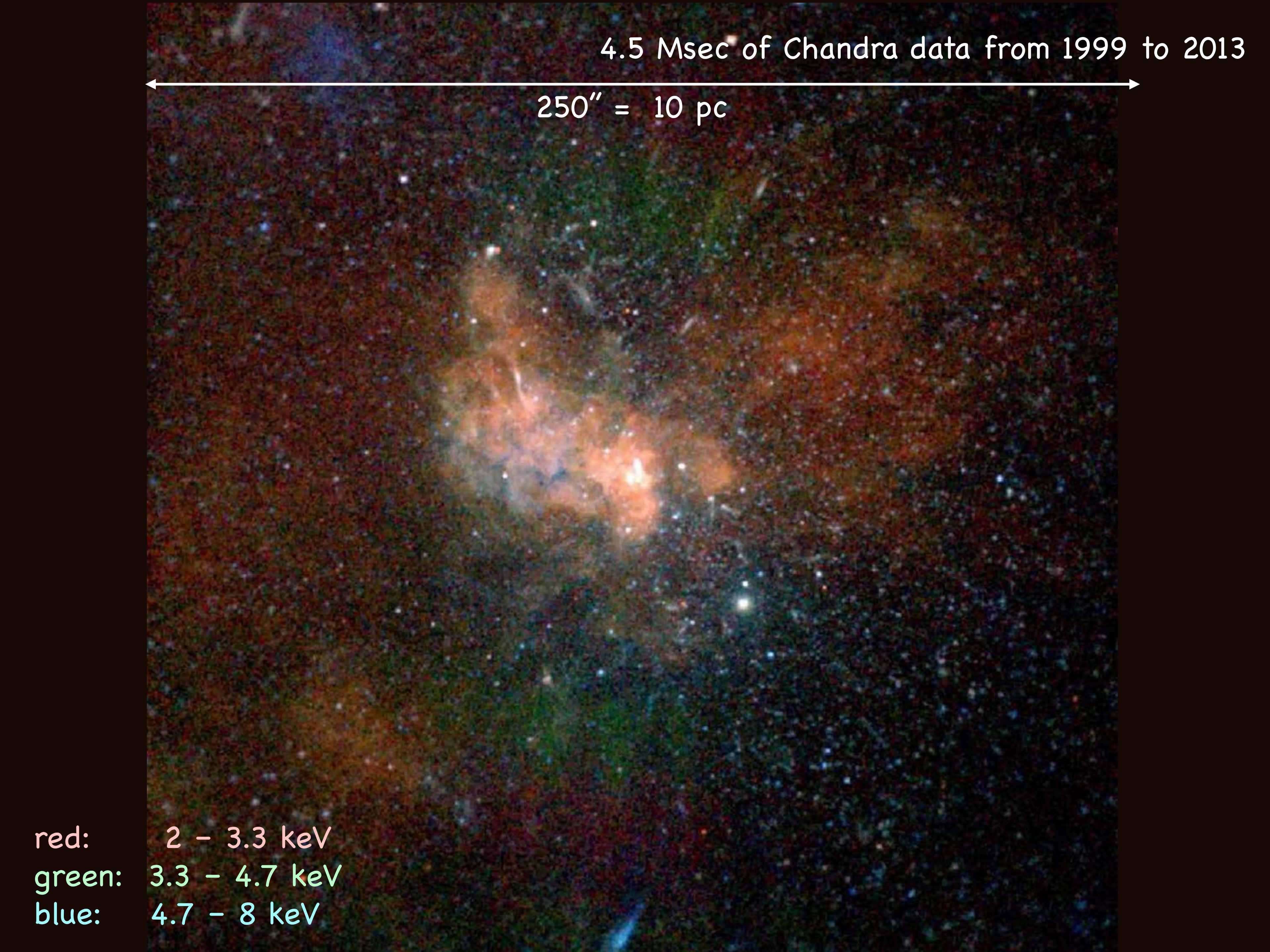
Modest-18

Observable manifestations of stellar remnants:

- White dwarfs – magnetic cataclysmic variables
  (mCVs, primarily intermediate polars – IPs,
  about 10% of all CVs)
- Neutron stars – low-mass X-ray binaries (LMXBs)
- Black holes – BH-LMXBs

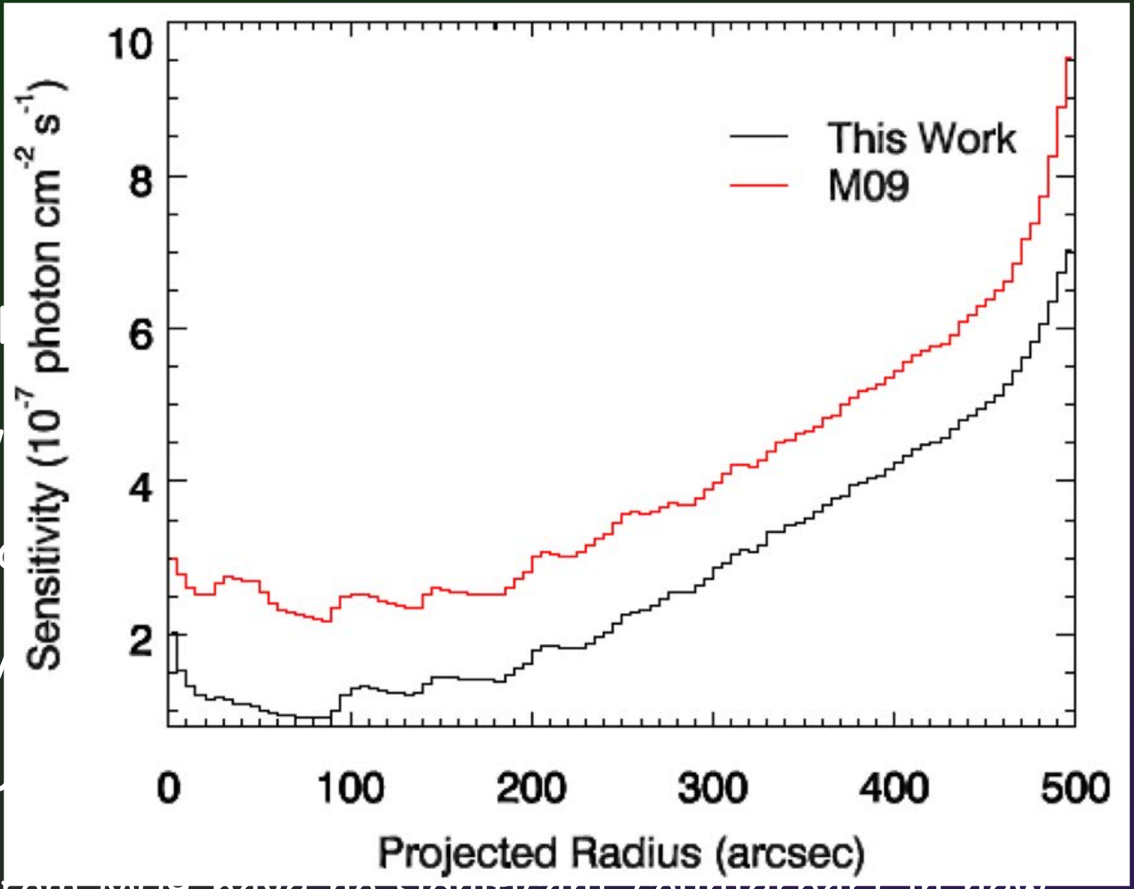
→ All binaries, and all X-ray sources

High-mass X-ray binaries? (HMXBs) →
none presently known in the Galactic center


4.5 Msec of Chandra data from 1999 to 2013
250" = 10 pc
red: 2 – 3.3 keV
green: 3.3 – 4.7 keV
blue: 4.7 – 8 keV

Catalog:

- 3619 sources in 2 – 8 k
  - → sensitivity dow
  - → ~ 3500 are pro
  - → ~ 1300 are new
  - → compare to Mu
  - → ~1100 sources from M09 have no significant counterpart in new catalog. Attribute to low significance background fluctuations
  - → GC point sources collectively account for ~ 20% of the total 2 – 8 keV flux from inner 250″ (the rest: unresolved, undetected point sources, + extended features)



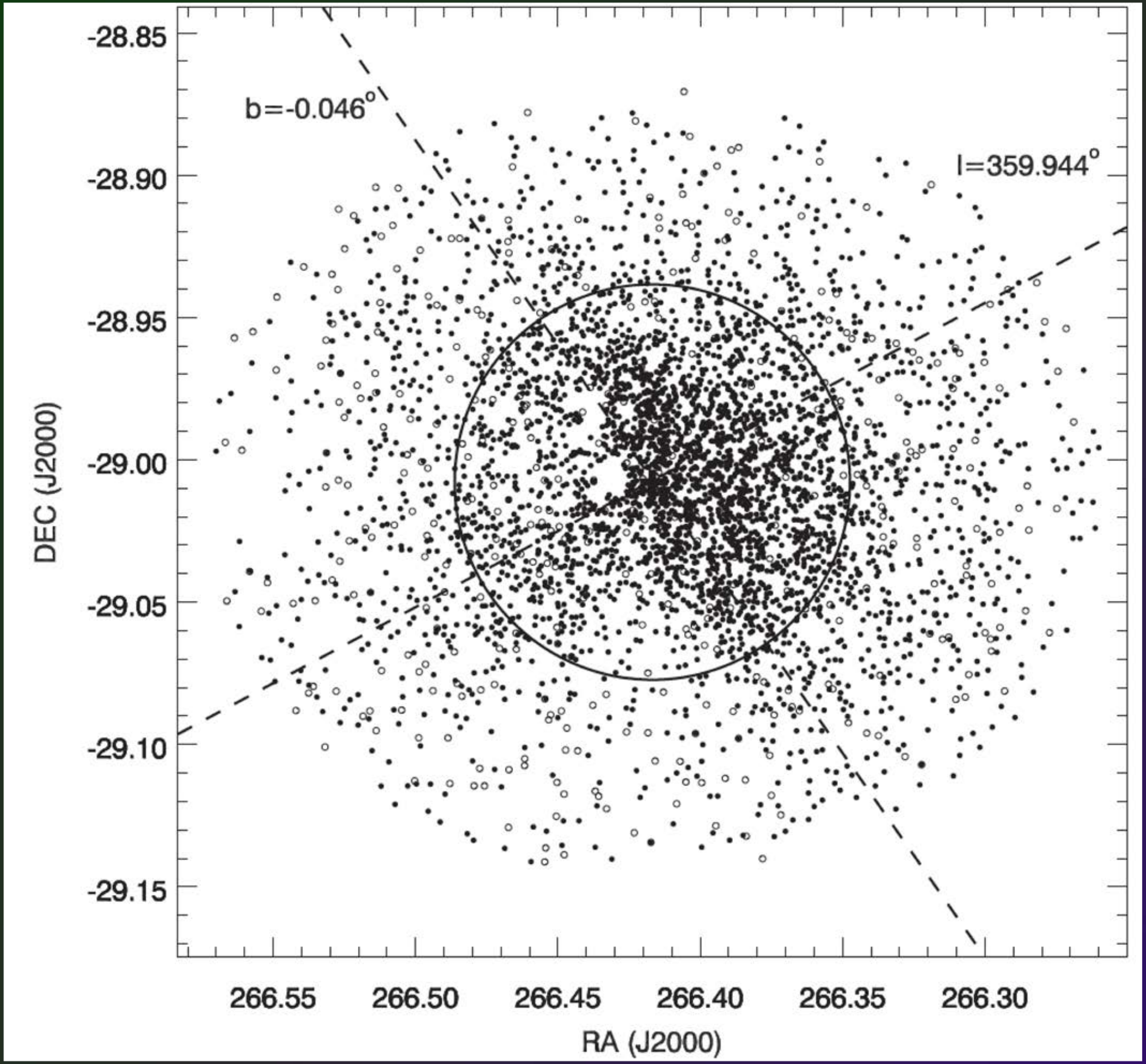
Distribution of detected sources, inner 500"

Open circles:
foreground sources (distinguished by color)

Filled circles:
GC or beyond

Inner circle covered by all 87 ACIS observations

Note regions of absorption (molecular clouds) and confusing extended background (Sgr A East SNR)



What are they?

9 massive star binaries with colliding winds (Mauerhan et al. 2010)

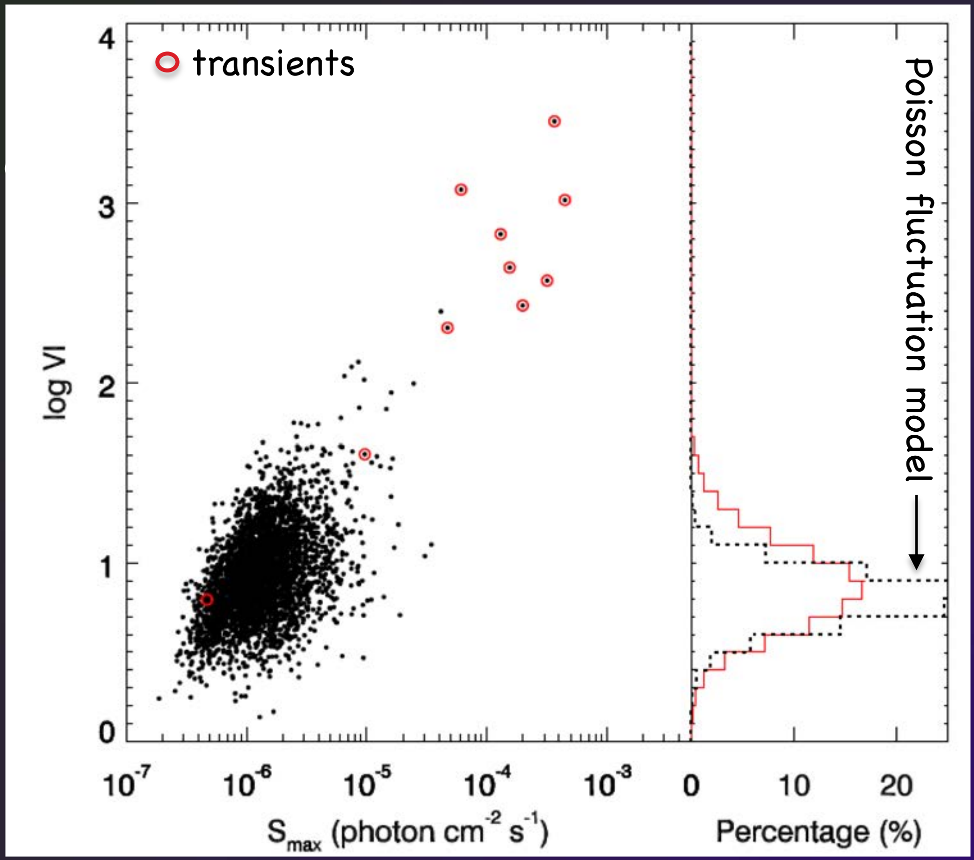
12 transients (Muno et al. 2005a,b; Degenaar et al. 2015, 2016; Ponti et al. 2016)
→ likely LMXBs

1 magnetar (Degenaar et al. 2013)

~12 BH-LMXB candidates (Hailey et

CVs — the rest

Variability index = VI = S_{max}/S_{min} →

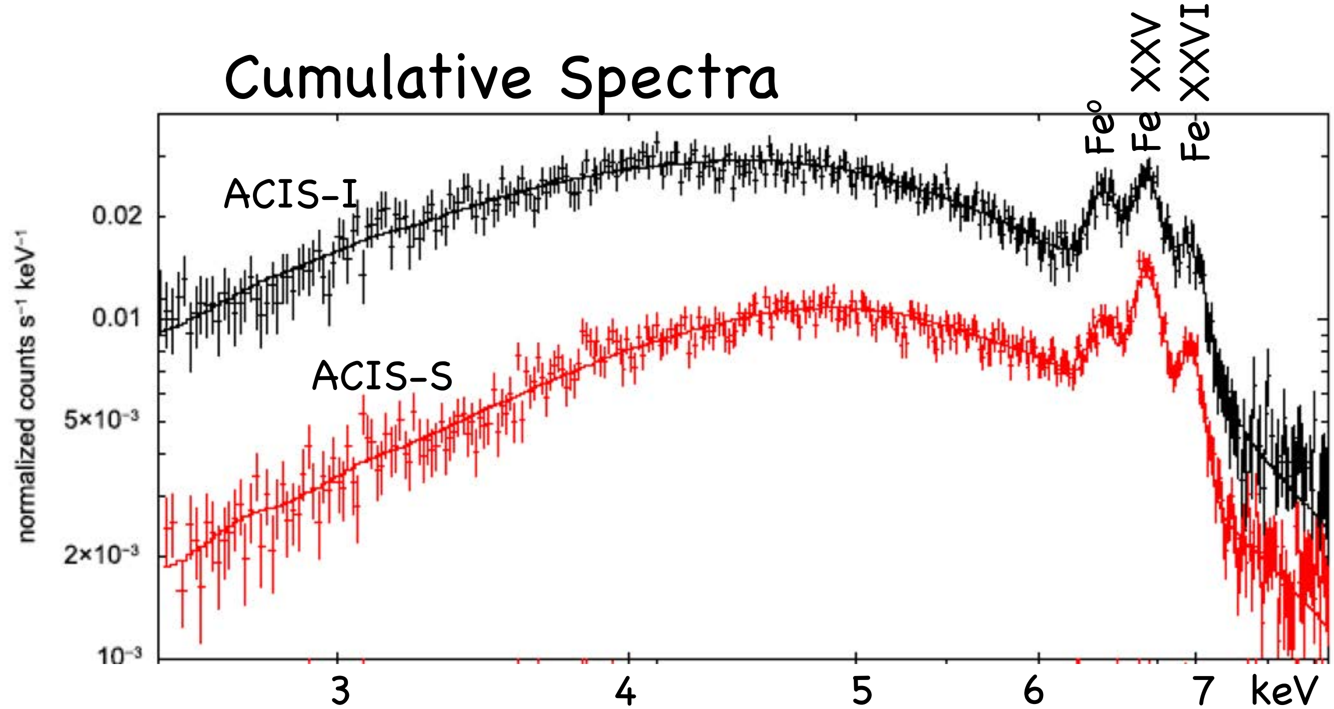


Except for the transients, most sources don't show evidence for variability ….
~ 15% appear significantly variable

Cumulative Spectra

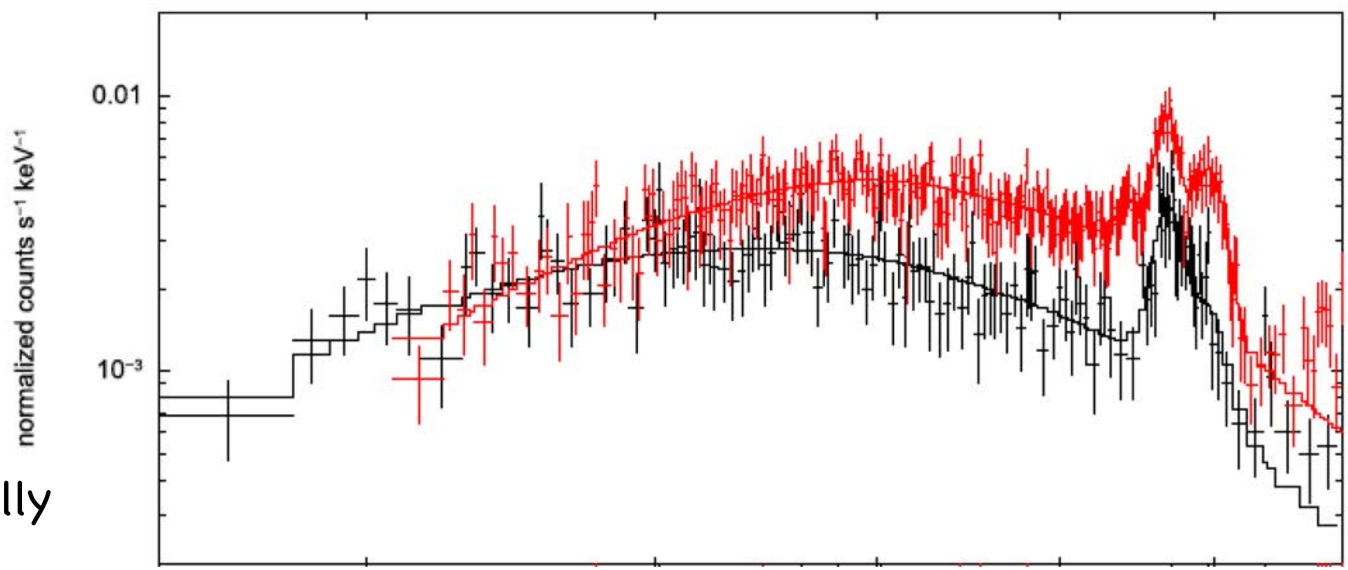
bright sources
$L_x > 6 \times 10^{31}$ ergs/s

Hard spectrum, typical of CVs



faint sources
$L_x > 6 \times 10^{31}$ ergs/s

Admixture of coronally active binaries

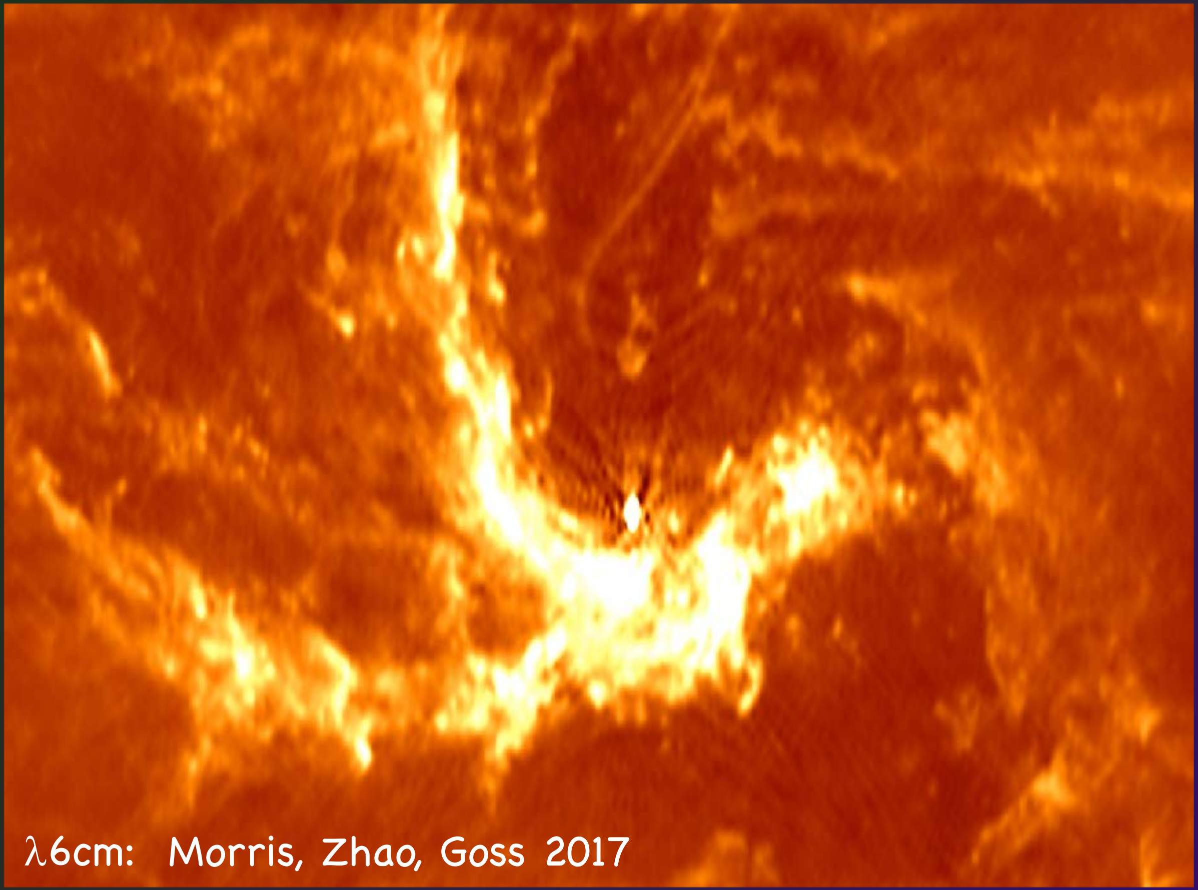


Other wavelengths?

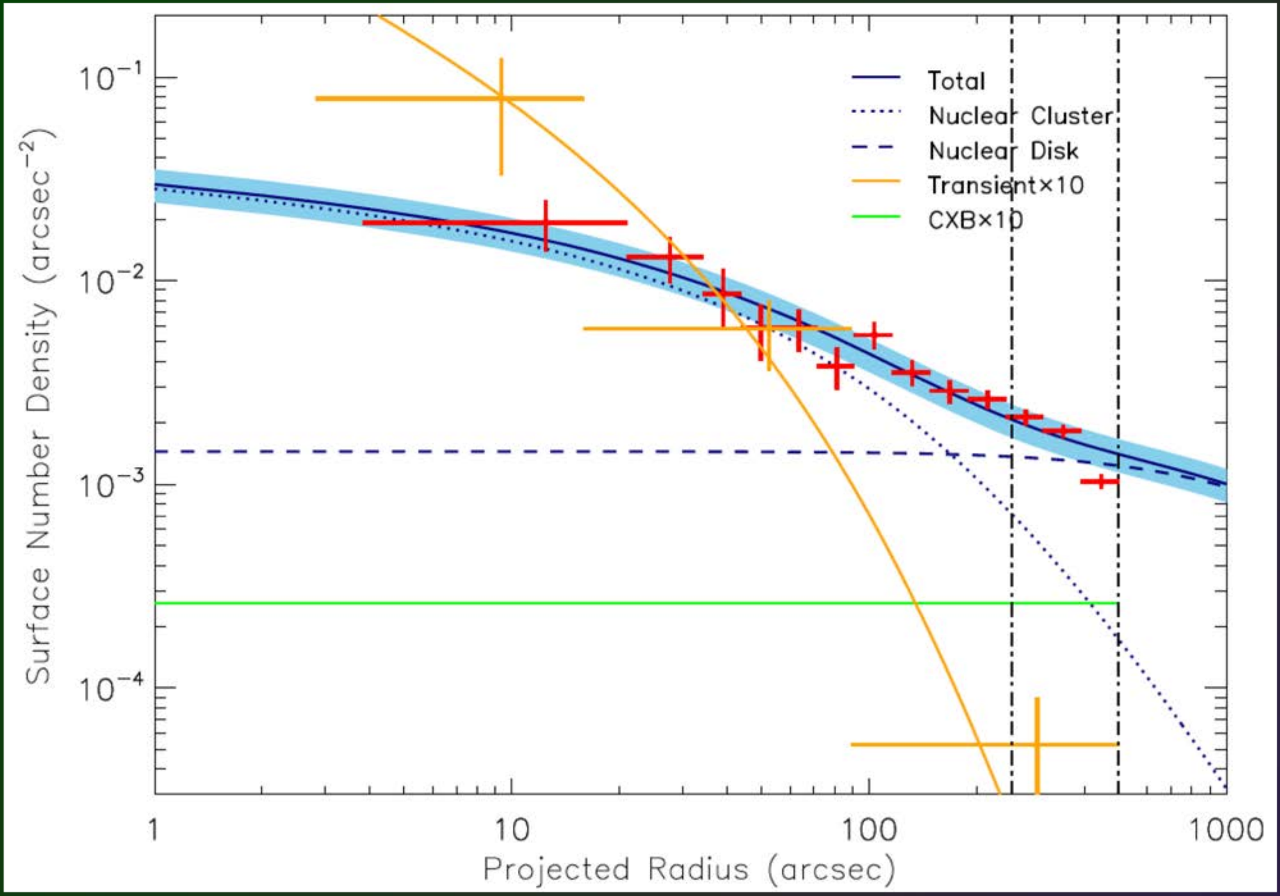
- No optical, UV ($A_V \sim 30$ magnitudes)

- IR: crowding – too many candidates. ELT/AO resolutions can help, but still limited by Chandra resolution, ~1″

- Radio
  (c.f., Bahramian talk – MAVERIC):
  dynamic range problem in the central parsec



Surface Density Profile [sources with S(2-8 keV) > 3.5 x 10^{-7} photons cm^{-2} s^{-1})



Assumed form of stellar distribution (Dehnen 1993):

$$\rho_s(r) = \frac{3-\gamma}{4\pi}\frac{L}{r^\gamma}\frac{a}{(r+a)^{4-\gamma}}$$

Two components of NSC:
(Launhardt et al. 2002)

1) inner
Nuclear stellar cluster:
γ_{in} = 0.90
L_{in} = 6.73 x 10^4 stars
a_{in} = 194″

2) outer
nuclear disk:
γ_{out} = 0
L_{out} = 7.05 x 10^6 stars
a_{out} = 3396″

(model following Fritz et al. 2016)

The CV distribution follows the stellar mass distribution !

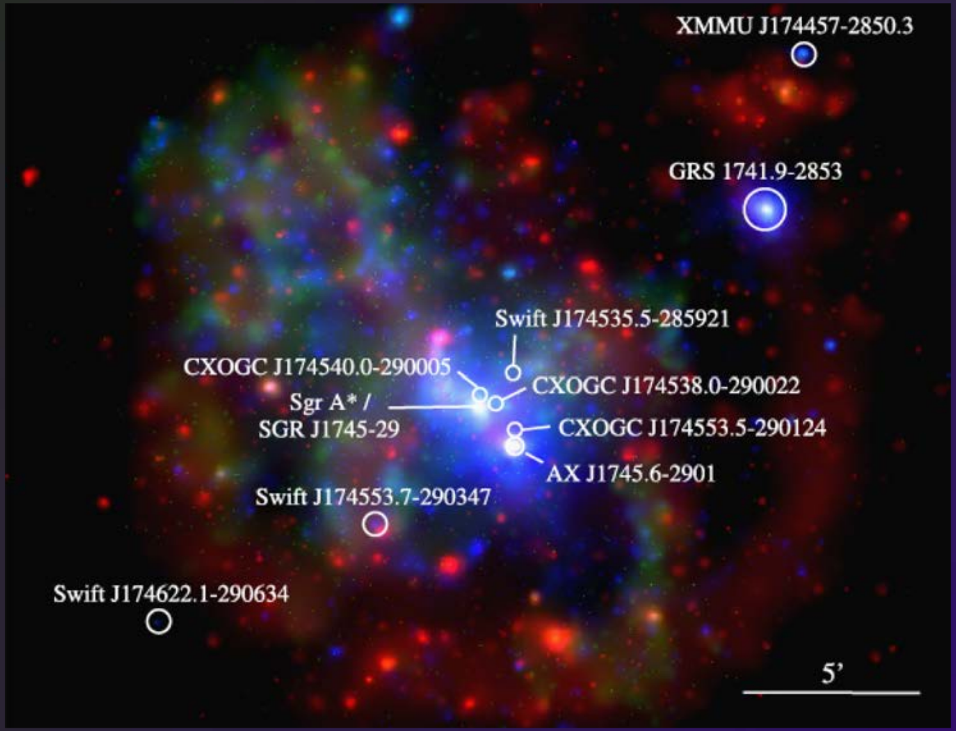
Neutron star binaries (NS-LMXBs):

- Expect neutron stars and black holes to be more concentrated toward the Galactic center than CVs because of mass segregation (Morris 1993)

- Expect also that almost all NS-LMXBs have now been seen as transients, given their short timescales for burst re-occurrence (<~ 10 years), and the persistent monitoring by SWIFT (Degenaar et al. 2015)

- → steep radial distribution of transients – ρ_s^2 – compared to mCVs, consistent with dynamical formation (tidal captures, direct collisions, binary–single exchanges)

- Relative contribution of LMXBs <~ 5% of the detected sources



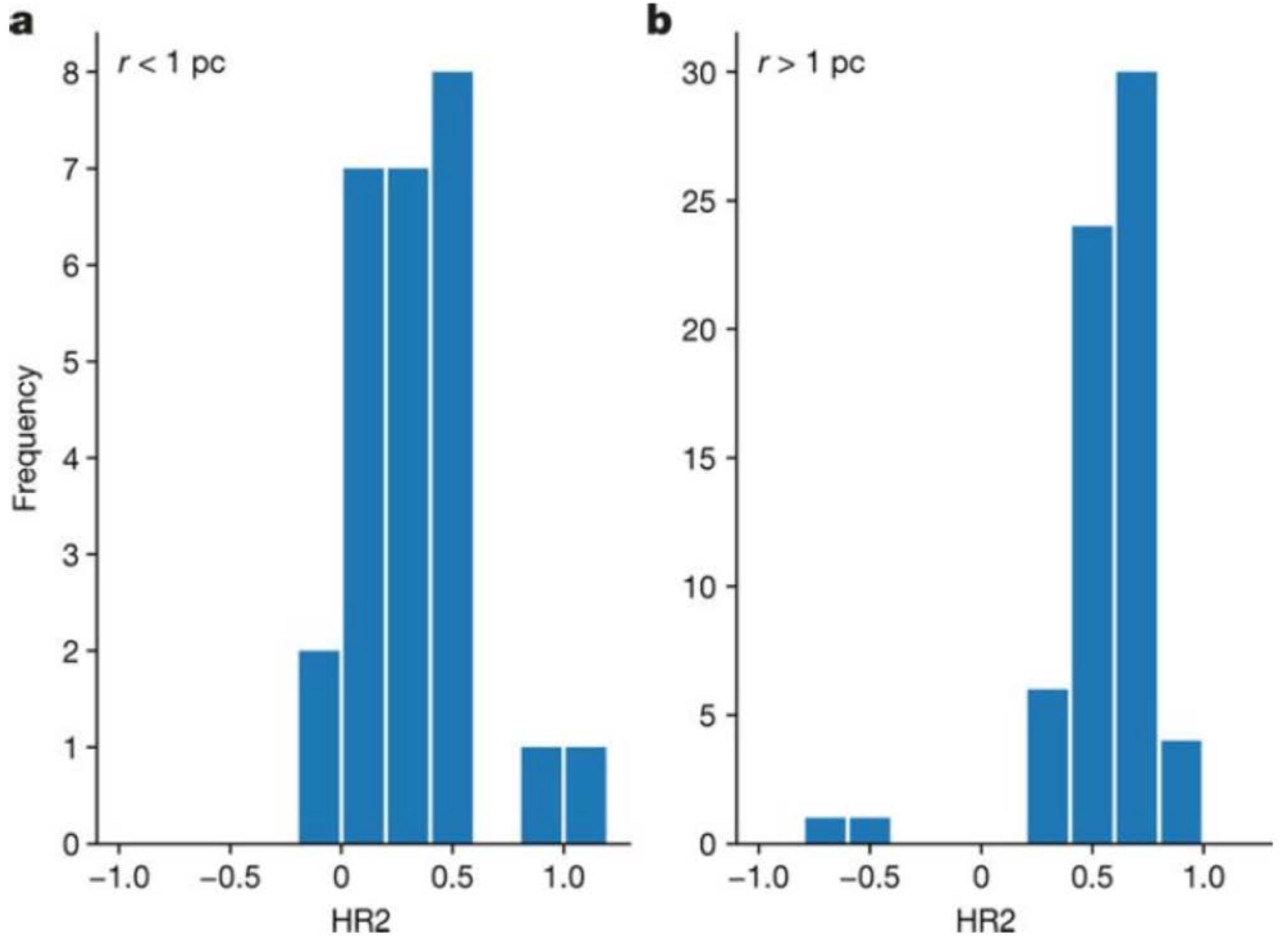
Black hole binaries (BH –LMXBs)

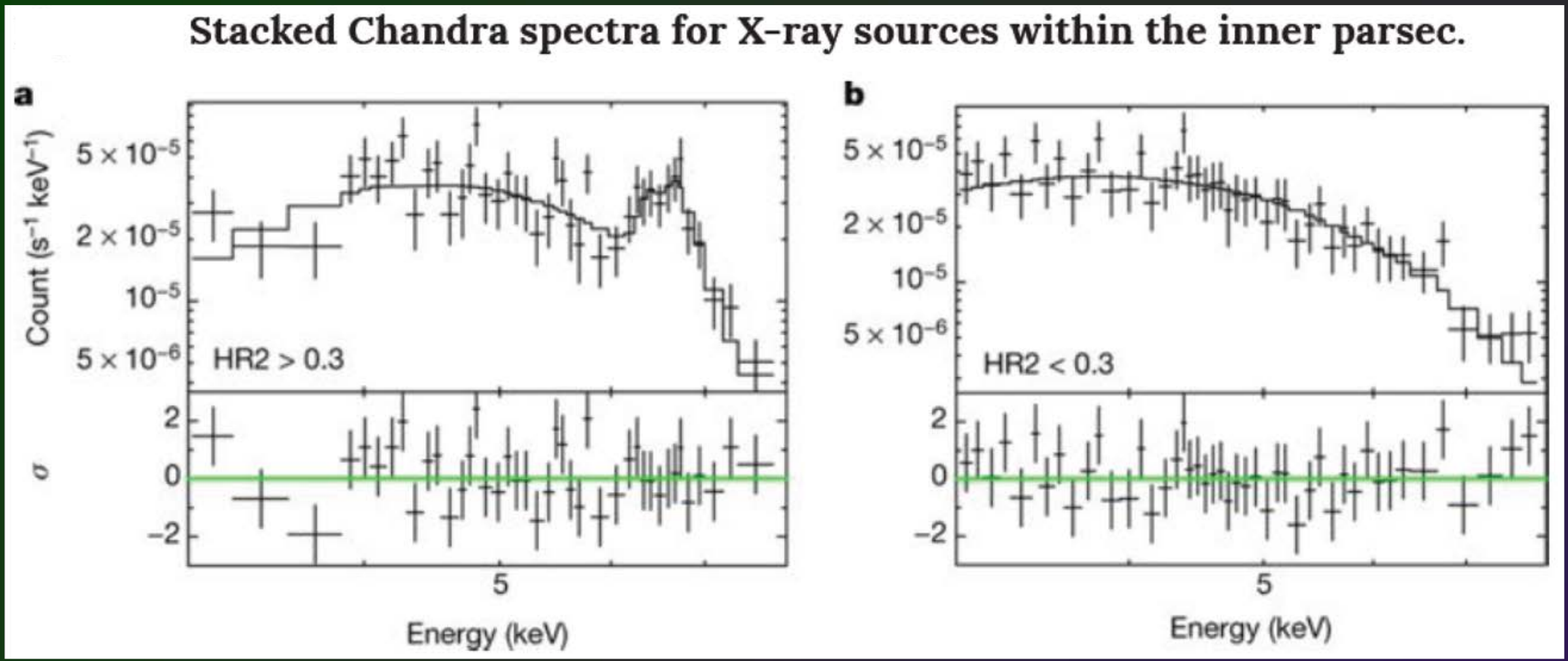
- Expect to be concentrated toward the center by mass segregation (+ possibly *in situ* formation)
  - Population/dynamical studies → up to 10^4 BHs in central parsec (Morris 1993; Miralde-Escude & Gould 2000; Freitag & Amaro-Seoane 2006; Deegan & Nayakshin 2007)
- Empirically, quiescent BH-LMXBs exhibit a power-law X-ray spectrum without significant Fe 6.7 keV line emission
  → soft nonthermal spectrum
- Dominated by jet synchrotron emission
- Much longer timescale for outburst re-occurrence (> 100 years)
- Hailey et al. (2018) define a hardness ratio:

HR2 = $(C_H - C_L)/(C_H + C_L)$, where C_L and C_H are, respectively, the net source counts in the 2–4-keV (low) and 4–8-keV (high) energy bands

Hailey et al. (2018): HR2 = 0.3 defined as the discriminant for BH-LMXBs

: Hardness ratio (HR2) distribution of X-ray point sources with net counts of C ≥ 100 at a projected radial distance from Sgr A*.





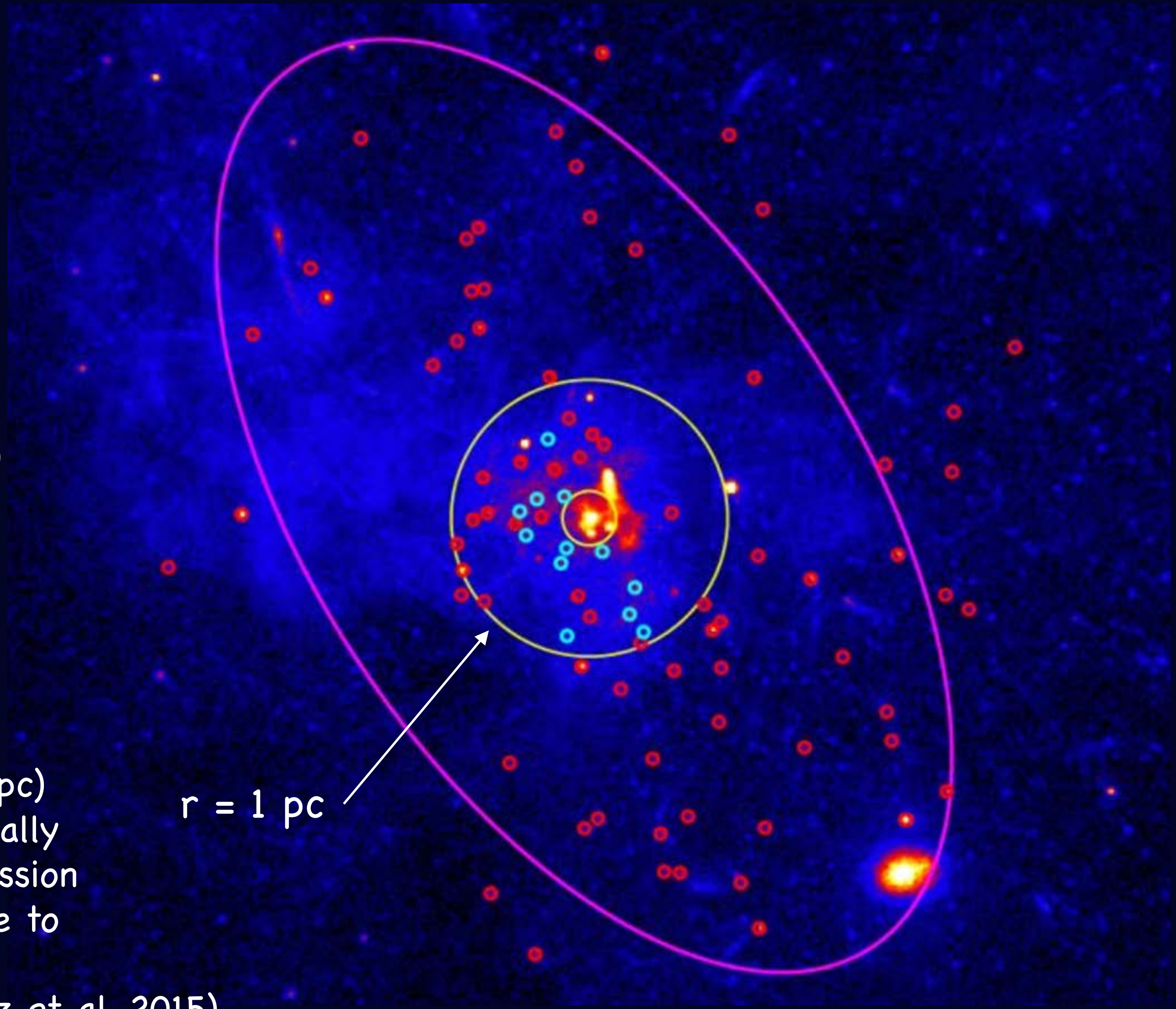
Hailey et al. (2018)

Distribution of X-ray point sources (from Muno+ 2009 catalog):

HR2 < 0.3

HR2 > 0.3

Excluded region (< 0.2 pc)

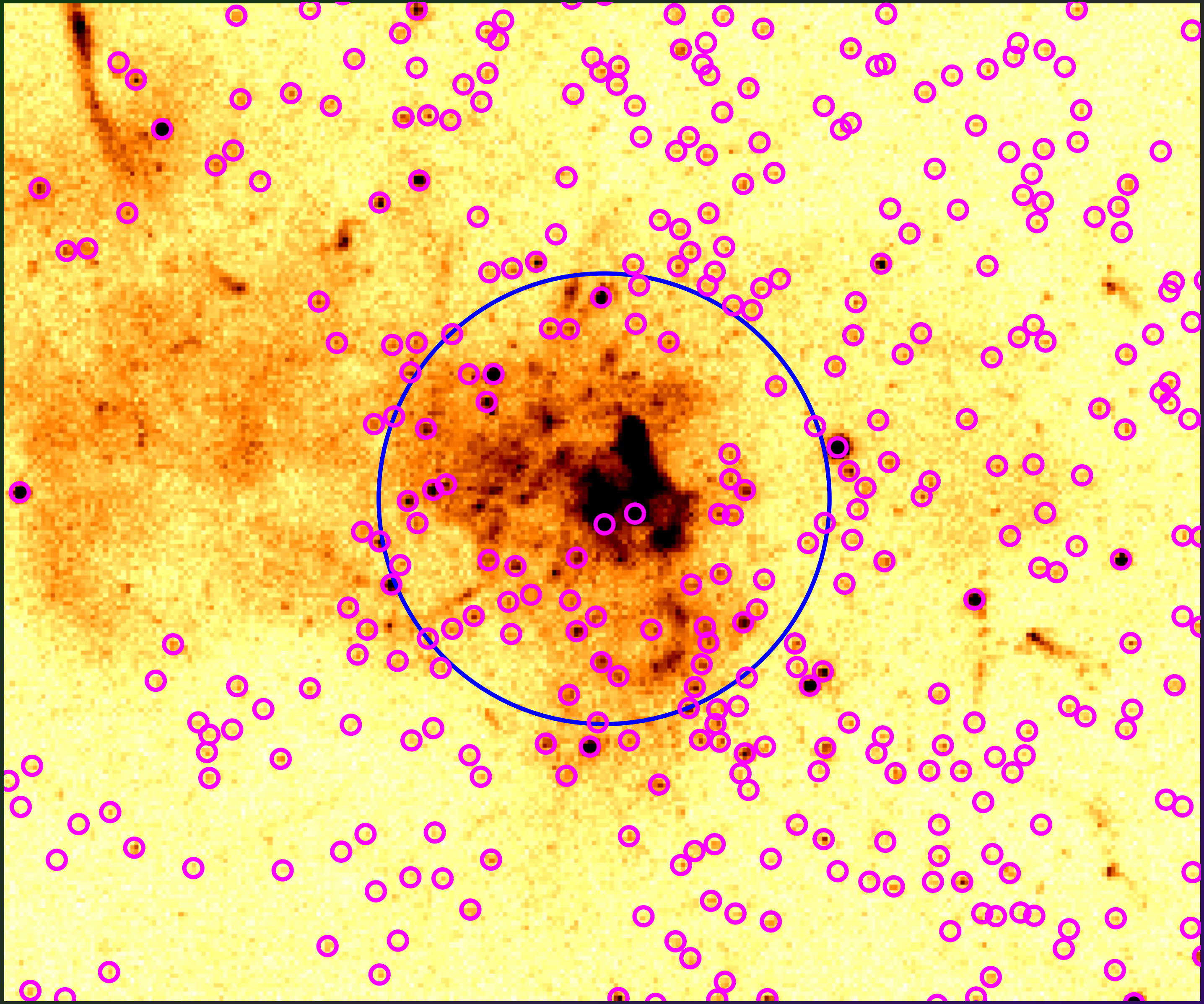


magenta ellipse (7.8 x 3.9 pc) bounds the region of spatially unresolved hard X-ray emission discovered by NuSTAR, due to thermal emission from intermediate polars (Perez et al. 2015)

Hailey et al. 2018

However, discussion remains on the significance of all the sources

Zhu et al. (2018):



Conclusions

- The mCV distribution follows the stellar mass distribution.
  → tight binary frequency not affected by stellar density up to ~10^5 stars pc^{-3}
- Neutron star binaries (traced by transients) appear to be centrally concentrated: tight binary formation rate $\propto \rho_s^2$
  plus relatively small effect of mass segregation ?
- Black holes:
  - If Hailey et al. (2018) results can be confirmed, then expectations for a large population of stellar-mass BHs in central parsec would be fulfilled
  - See next talk by Aleksey Generozov
  - Confirmation will be non-trivial: already using 16 years of Chandra data
  - Profound implications for stellar dynamics in central parsec


Thank you !

Binomial no-source probability as a function of the 2–8 keV photon flux. The dashed line marks the threshold (**P_B > 90%**) for filtering spurious detections, for example due to background fluctuations.