A *CHANDRA* XVP PROGRAM OF A LOW-METALLICITY STAR-FORMING GALAXY: *FIRST RESULTS*

VALLIA ANTONIOU

SMITHSONIAN ASTROPHYSICAL OBSERVATORY

A. Zezas (PI; UoC/SAO)

SMC XVP Collaboration: C. Badenes; B. Blair; R. Di Stefano; J. Drake; A. Foster; T. Gaetz; F. Haberl; J. Hong; V. Kalogera; K. Kuntz; S. Laycock; T. Linden; K. Long; S. Mineo; P. Plucinsky; M. Sasaki; R. Smith; S. Snowden; R. Sturm; B. Williams; F. Winkler; N. Wright

—X-ray View of Galaxy Ecosystems, Boston, 9-11 July 2014

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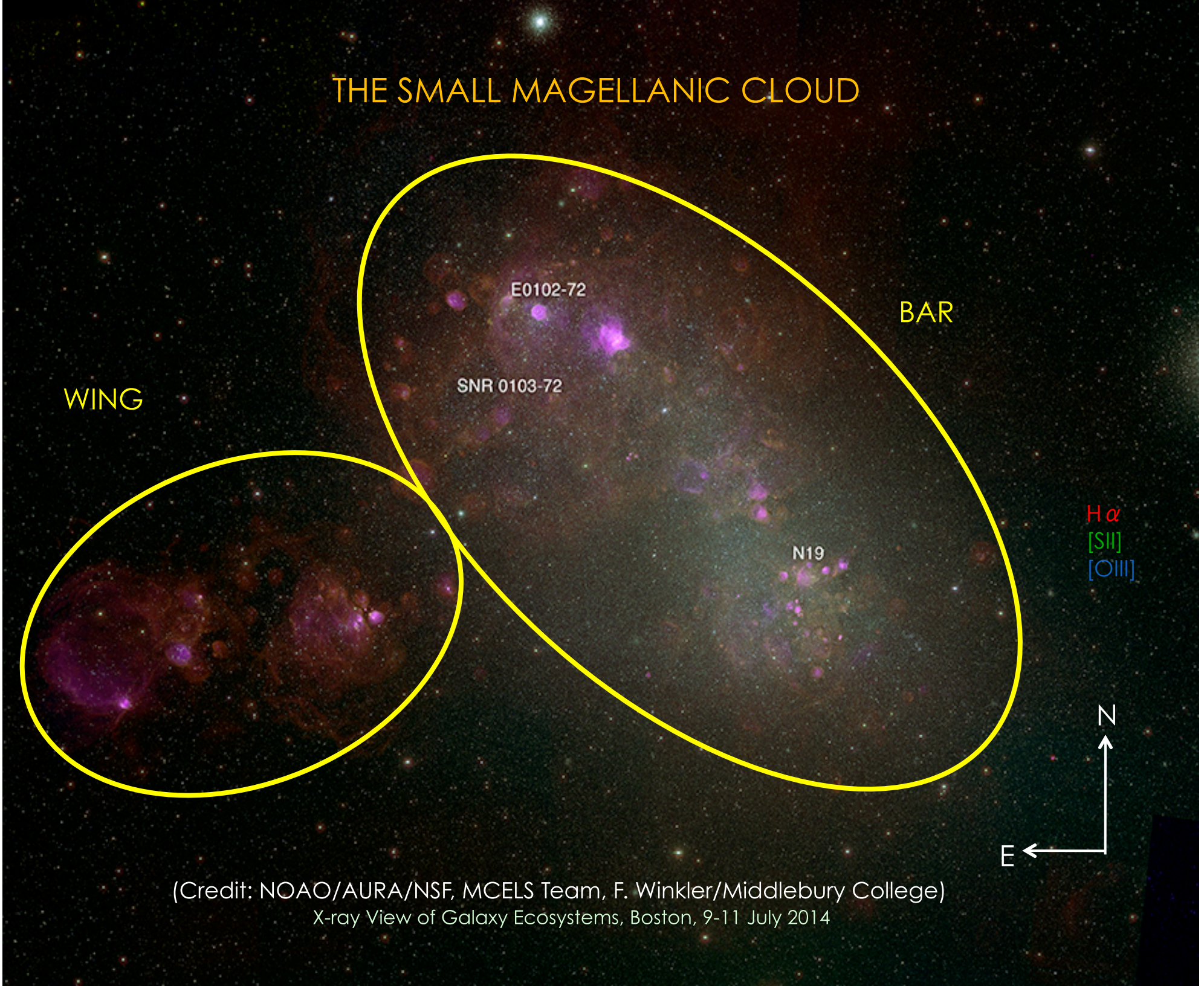
Photograph by Miloslav Druckmüller



(Credit: NOAO/AURA/NSF, MCELS Team, F. Winkler/Middlebury College)

X-ray View of Galaxy Ecosystems, Boston, 9-11 July 2014

WHY OBSERVE THE SMALL MAGELLANIC CLOUD?

* proximity (2^{nd} nearest star-forming galaxy @ ~60 kpc)

* low interstellar absorption ($N_H \sim 6 \times 10^{20}$ cm^{-2})

* resolved stellar populations (young <100 Myr, intermediate ~500 Myr, old ~ few Gyr)

* "clean" X-ray source populations (almost entirely HMXBs & SNRs)

* small angular size (compared to the Galactic Plane; 10x smaller than LMC;100x smaller than MW)

* has been extensively studied in ALL wavelengths over the years allowing us to obtain a very good picture of its properties

WHY OBSERVE THE SMALL MAGELLANIC CLOUD?

* Probe very faint populations

EARLIER SHALLOW X-RAY SURVEYS OF THE SMC

Chandra observations

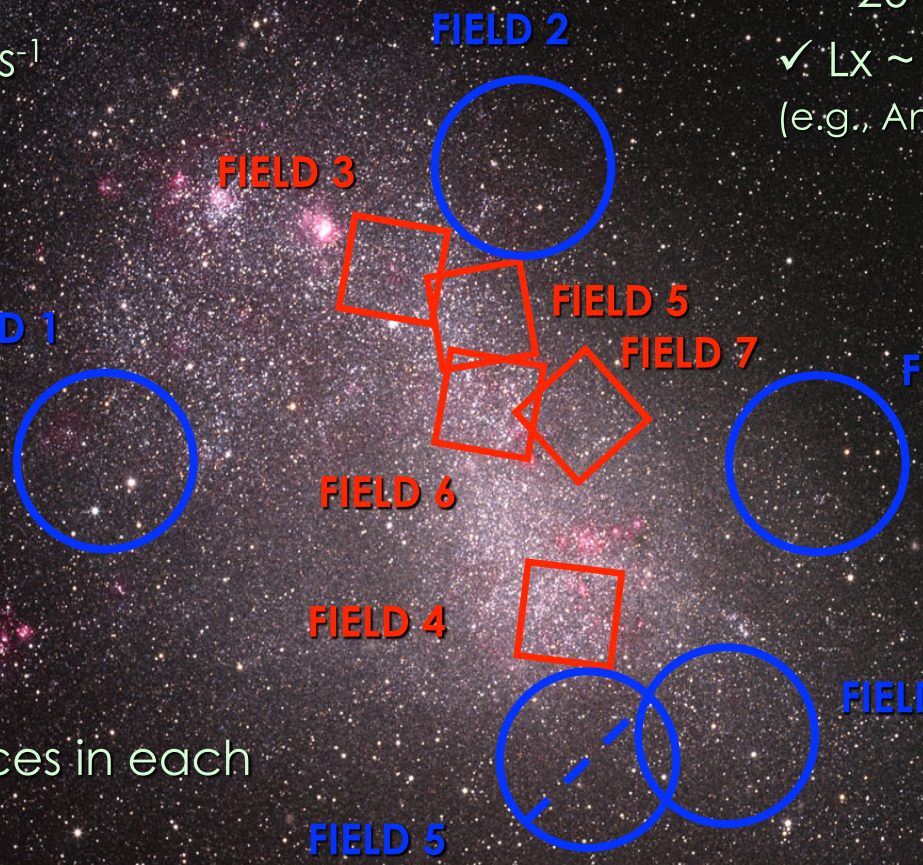
- ✓ ~10 ks each
- ✓ Lx ~ 4 x 10^{33} erg s^{-1} (0.7-10 keV)

(e.g., Antoniou+ 2009)

XMM-Newton observations

- ✓ ~20-30 ks each
- ✓ Lx ~ 10^{34} erg s^{-1} (0.5-12 keV)

(e.g., Antoniou+ 2010, Haberl+ 2012)



✓ ~150 - 200 sources in each survey

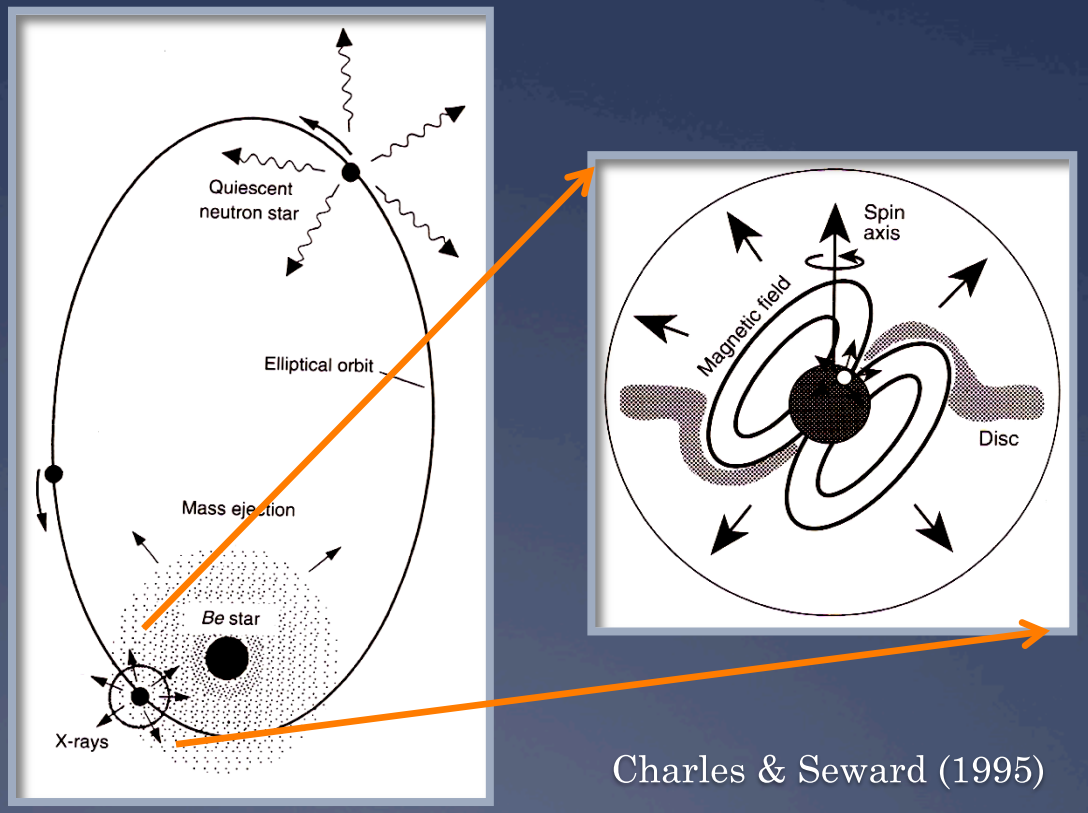
WHY OBSERVE THE SMALL MAGELLANIC CLOUD?

* Probe very faint populations

* Large populations of HMXBs

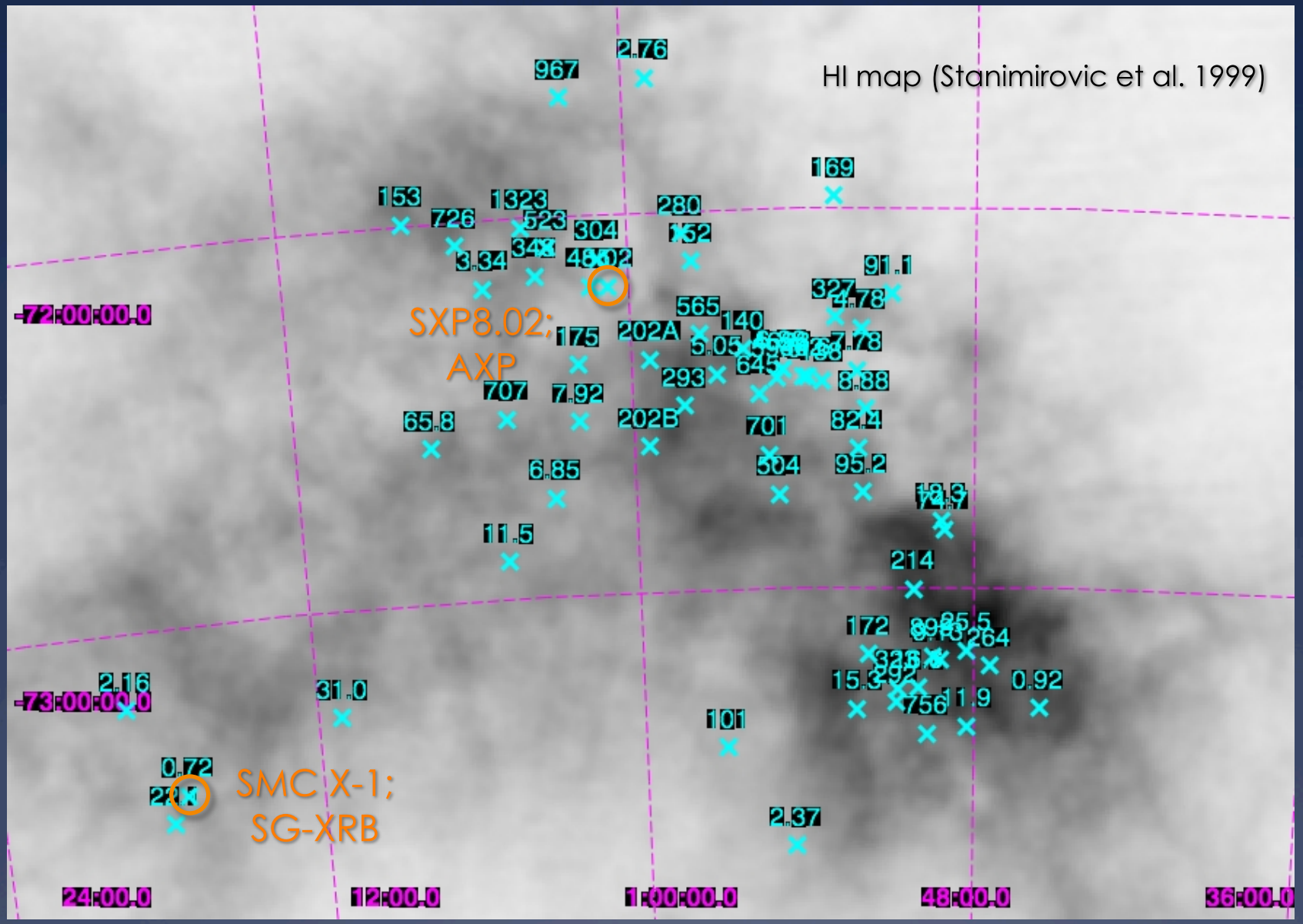
Be-XRBs: most numerous sub-class (NS + Oe/Be)

population associated with recent SF



Charles & Seward (1995)

THE X-RAY PULSAR POPULATION OF THE SMC



68 known to date …with the exception of 2 systems, all known pulsars are Be-XRBs

WHY OBSERVE THE SMALL MAGELLANIC CLOUD?

* Probe very faint populations

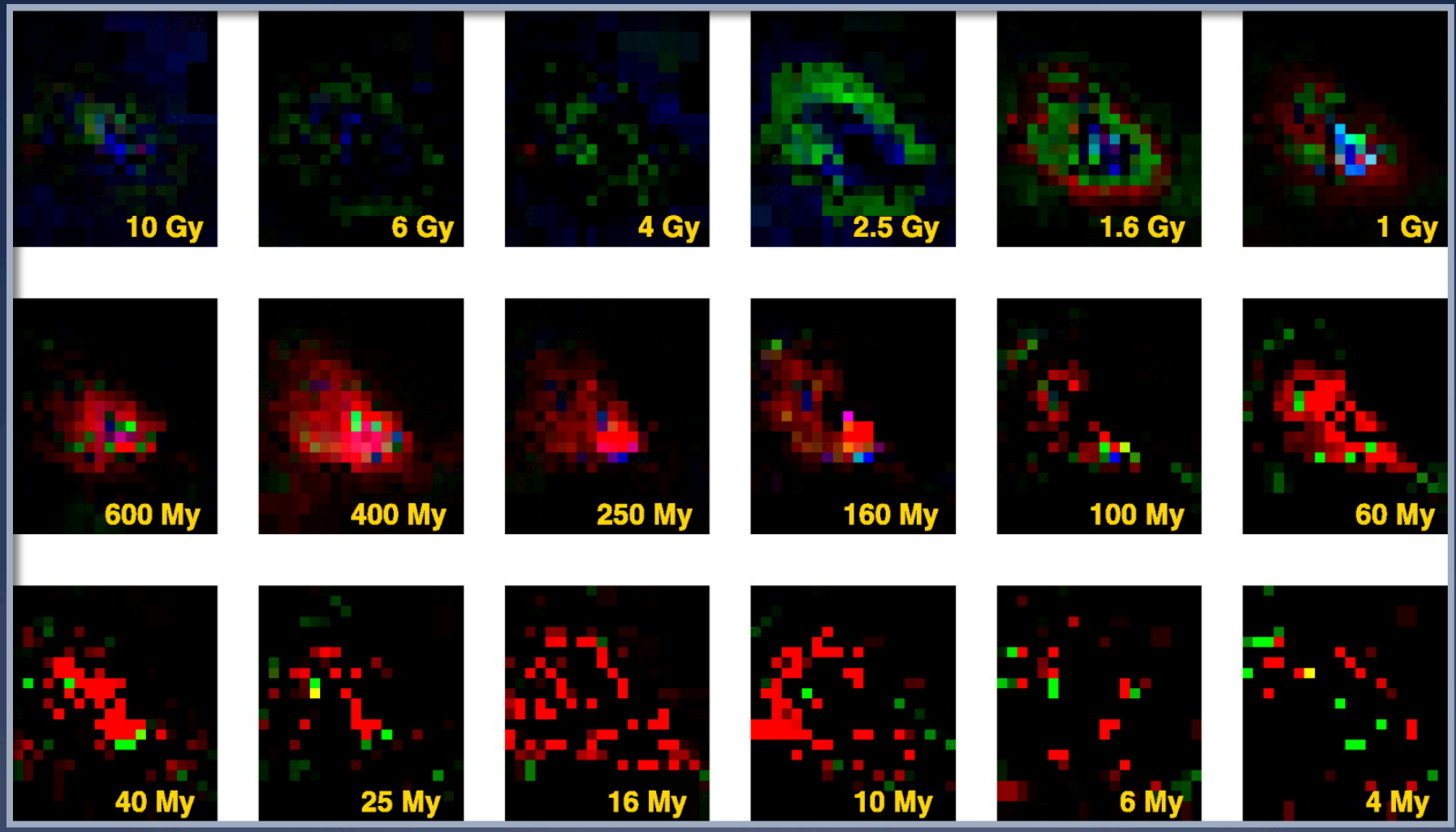
* Large populations of HMXBs

  Be-XRBs: most numerous sub-class (NS + Oe/Be)

  population associated with recent SF

* Well known SF parameters (SFR, age & duration of burst)

STAR-FORMATION HISTORY OF THE SMC



pixel intensity proportional to the SFR

Harris & Zaritsky (2004)

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* Well known SF parameters (SFR, age & duration of burst)

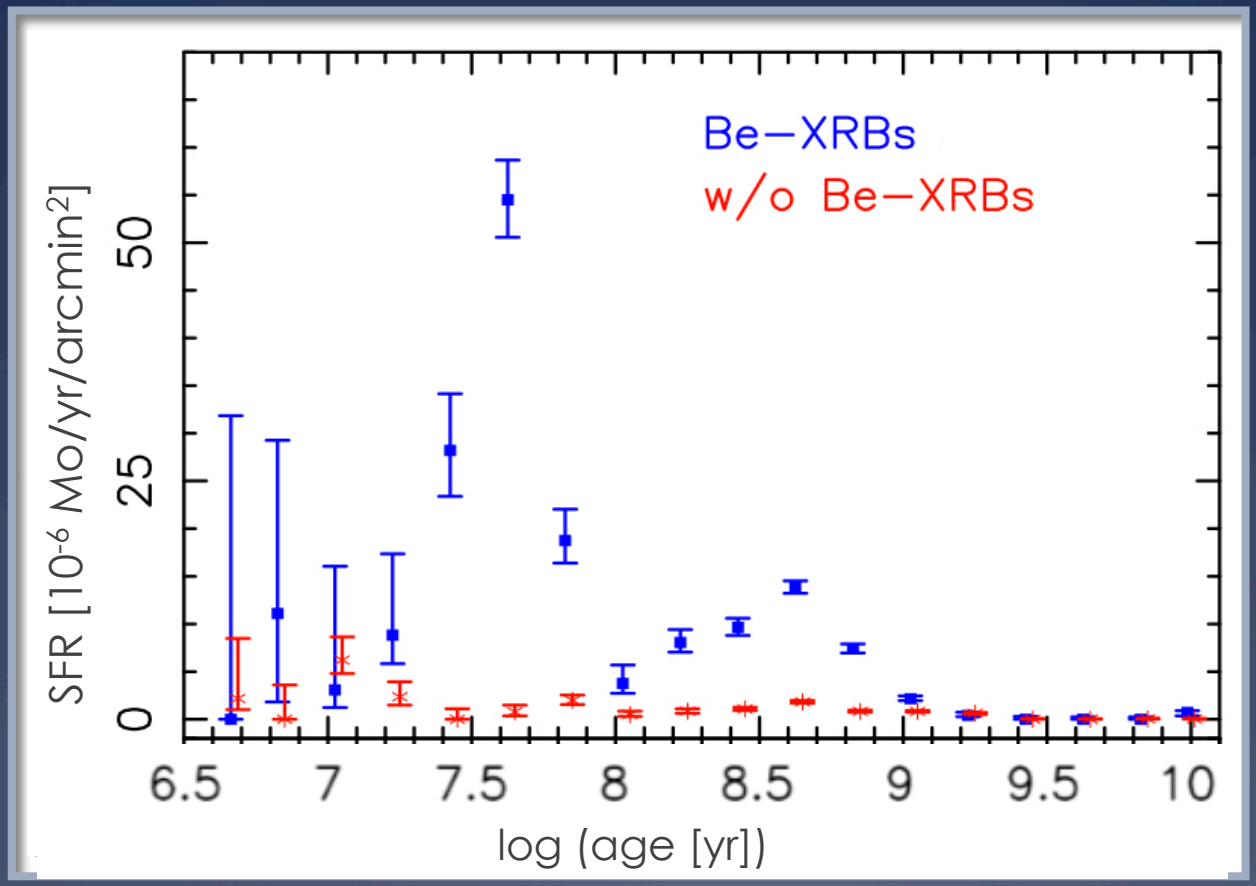
Unique laboratory to understand accreting binary evolution channels in a low metallicity environment (Z_{SMC}~1/5 $Z_{\odot}$)

- XRBs formation efficiency
- Physics of accretion
- Physical parameters affecting the formation & evolution of young XRBs

CONNECTING XRBs WITH THEIR PARENT STELLAR POPULATIONS

Average SFH of regions in the SMC w/ and w/o young XRBs

(using data from Harris & Zaritsky 2004)



Antoniou et al. (2010)

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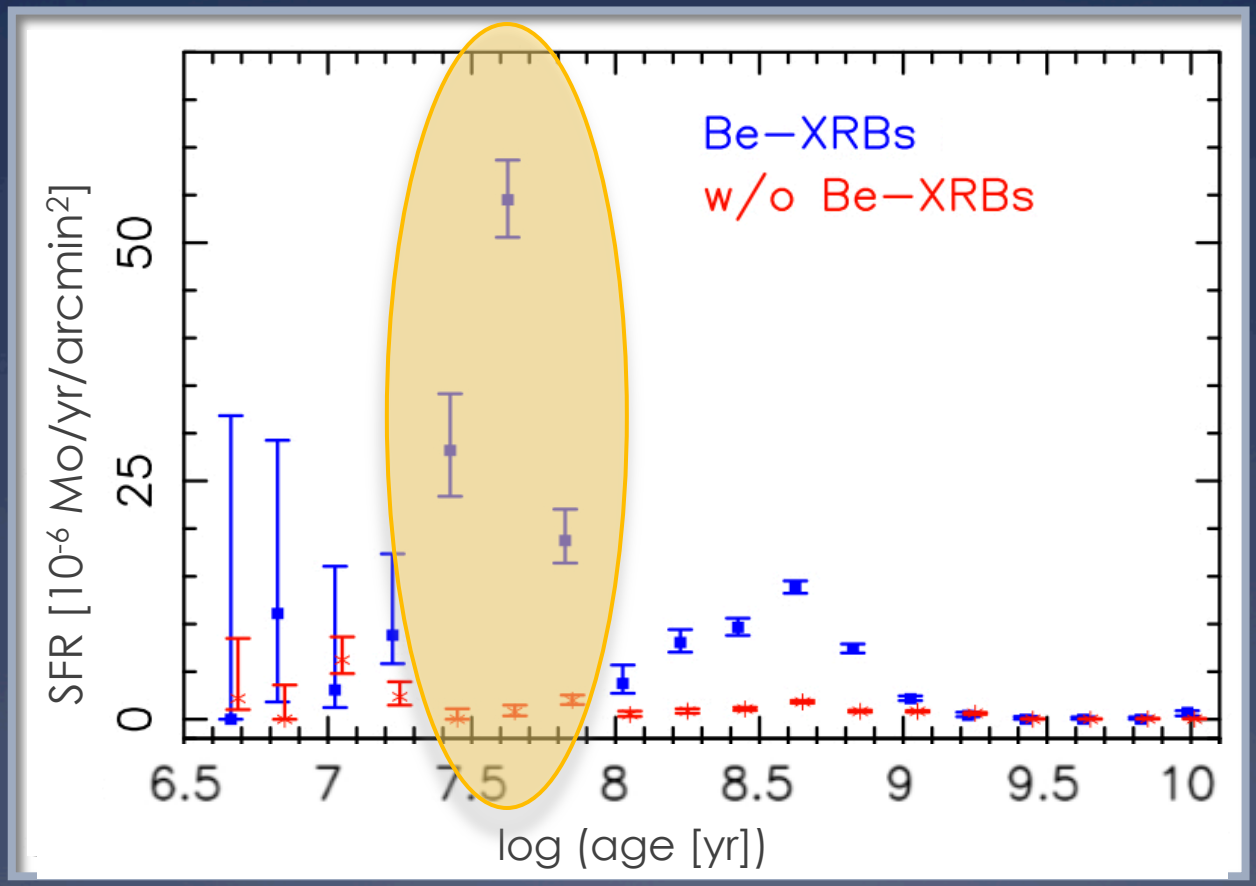
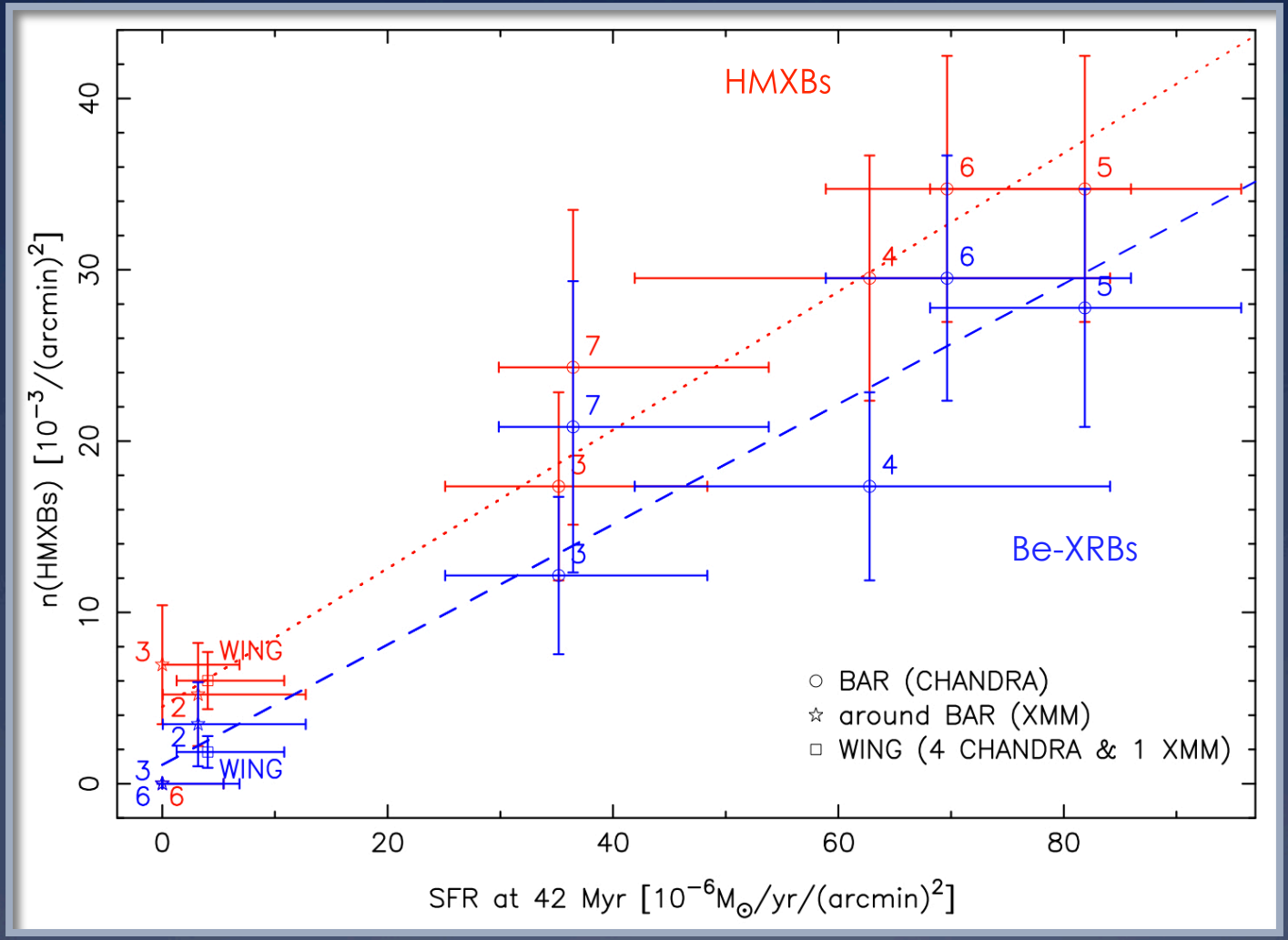


~40 Myr

Antoniou et al. (2010)

HMXB FORMATION EFFICIENCY IN THE SMC



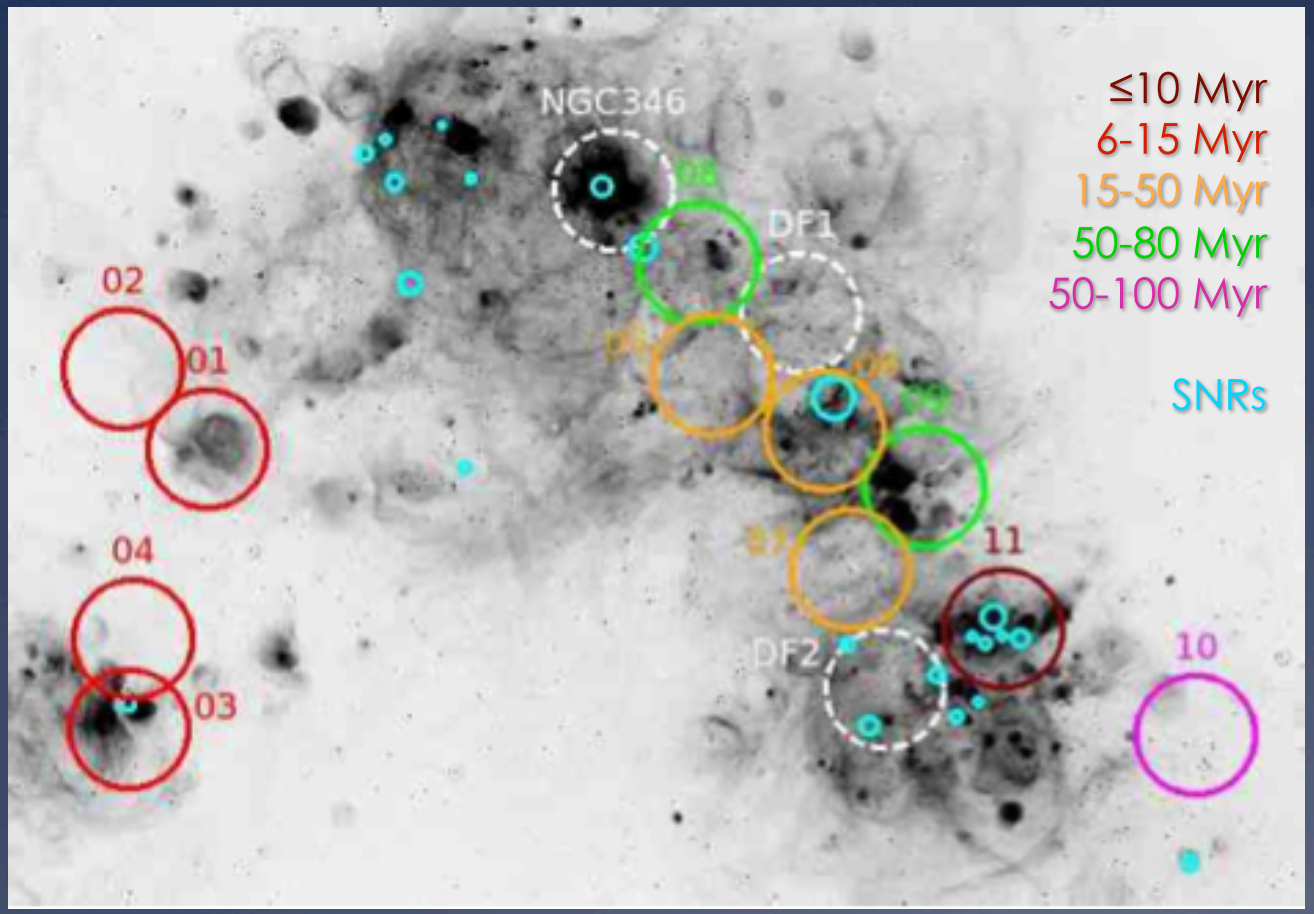
First <u>direct</u> calibration of the HMXB formation efficiency at 40 Myr: ~ 1 HMXB per 3 x 10^{-3} Mo/yr

Antoniou et al. (2010)

TOWARDS A MORE COMPLETE UNDERSTANDING OF HMXBs

Cycle 14 XVP Program (1.1 Ms)

A comprehensive survey of sources brighter than ~few x 10^{32} erg/s in 11 fields in the SMC representing young (<100 Myr) populations of different ages

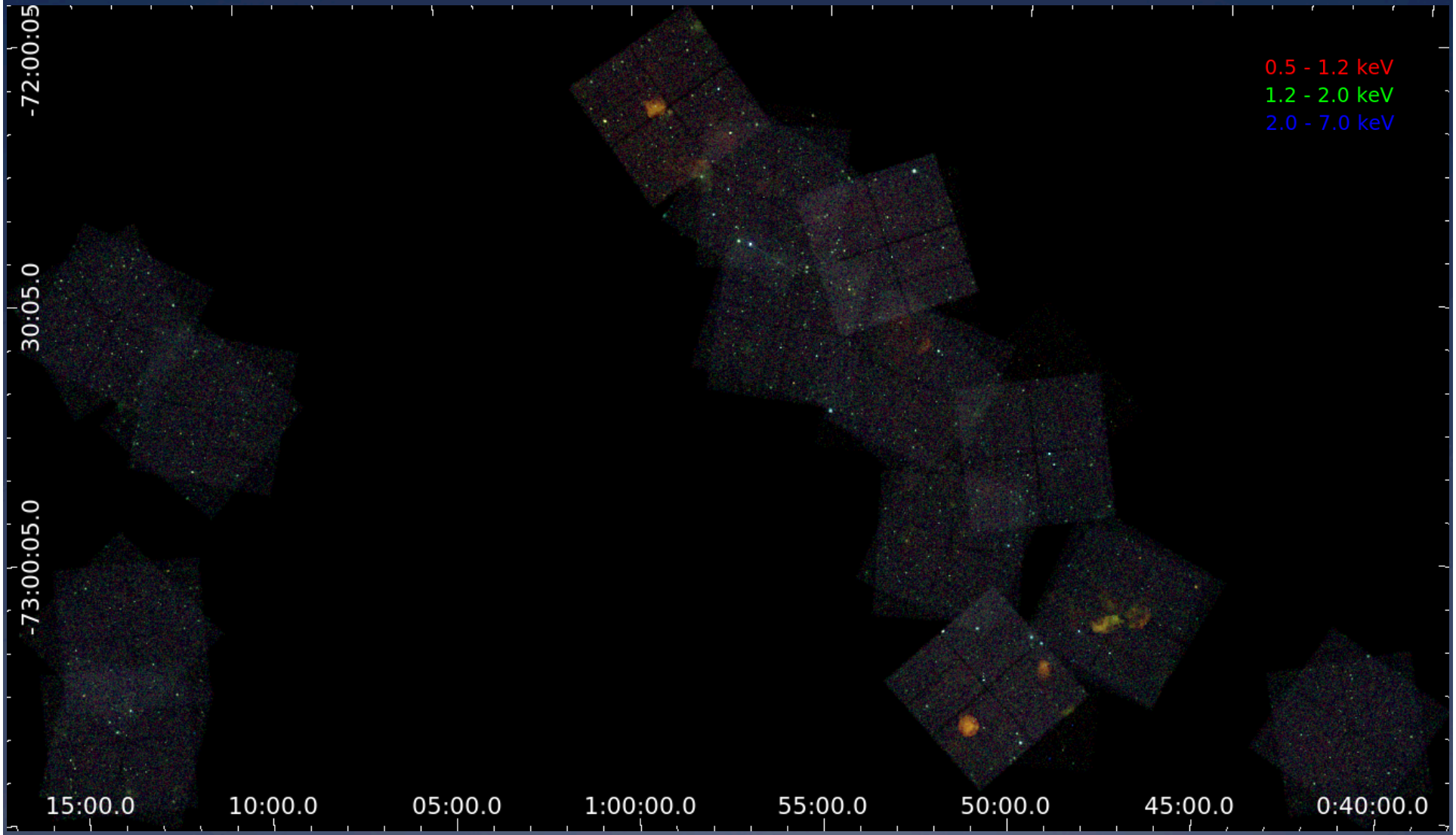


GOALS

- A deep census of accreting pulsars
- HMXB formation efficiency at different ages
- Short/long term variability of accreting binaries
- Detailed studies of SNRs
- Stars at low metallicity

THE DEEP CHANDRA SURVEY

- survey completed (Dec 2012 – Feb 2014)
- 11 fields (each 2 x 50ks) + 3 archival fields with similar exposure times



THE DEEP CHANDRA SURVEY: FIRST RESULTS

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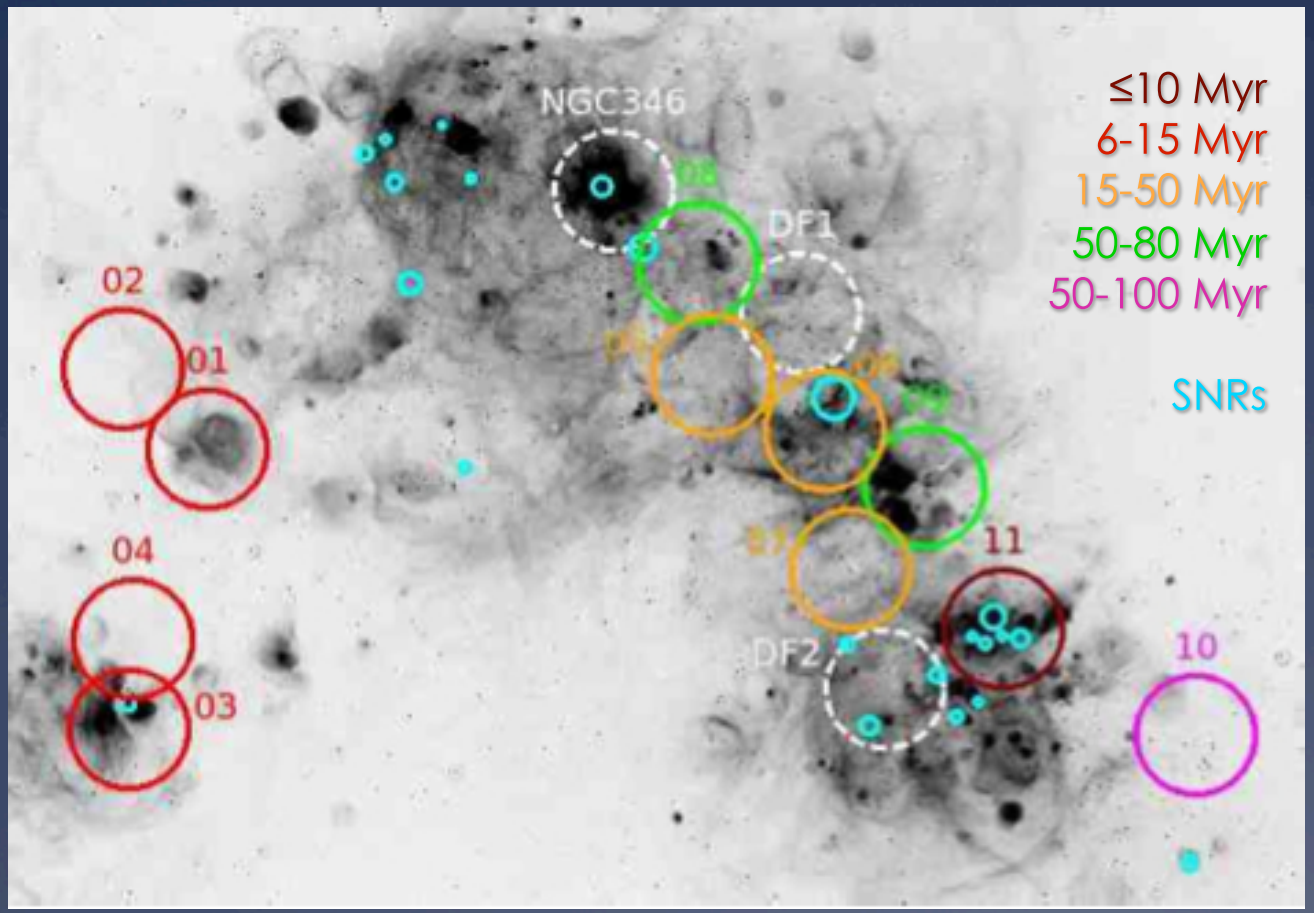

FIRST RESULTS

- 60 – 80 srcs per field
- Limiting Lx ~ 5 x 10^{32} erg/s

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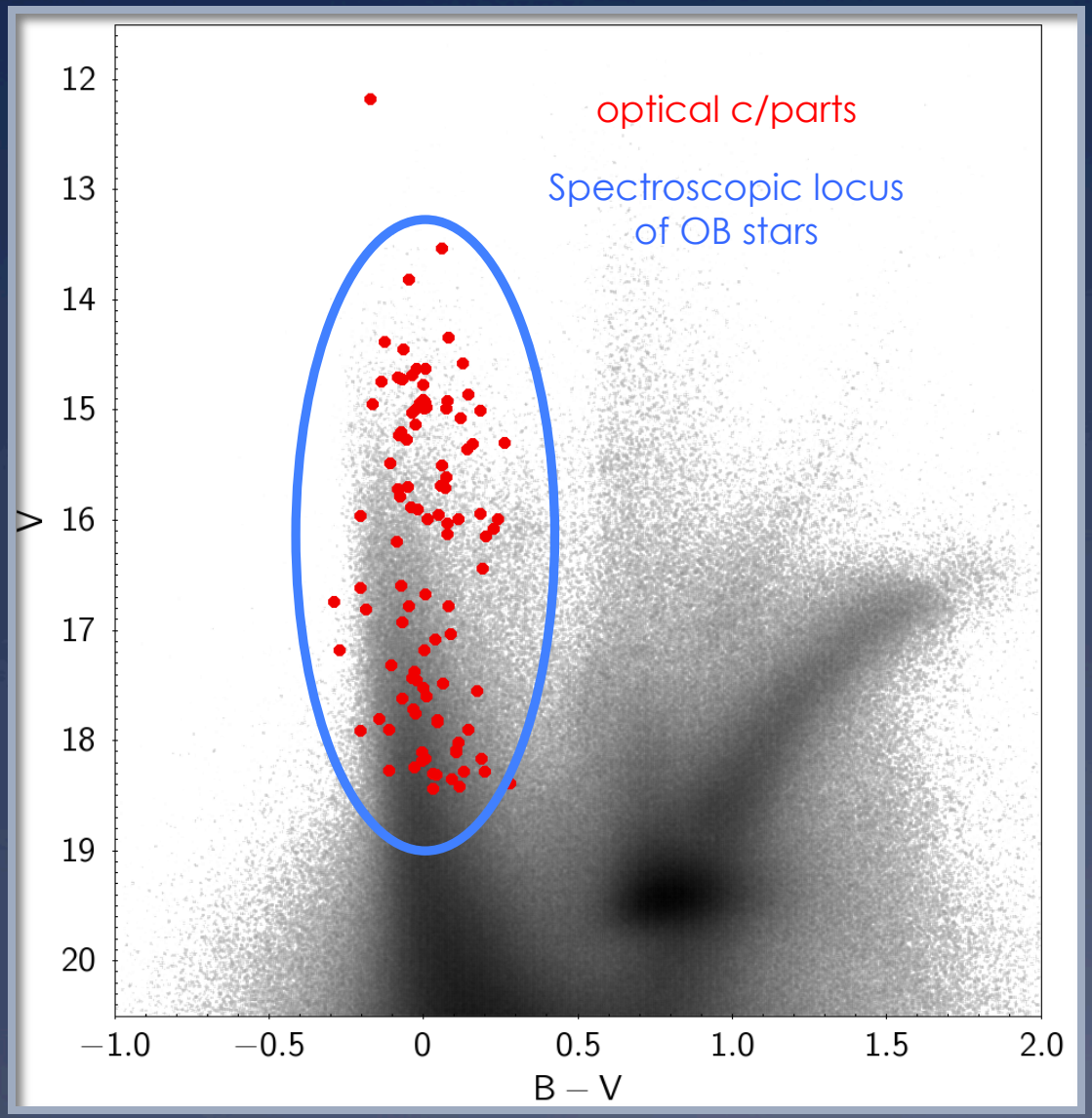

Using the MCPS optical photometric survey (Zaritsky et al. 2002):

~100 HMXBs candidates down to Lx ~ 5 x 10^{32} erg/s

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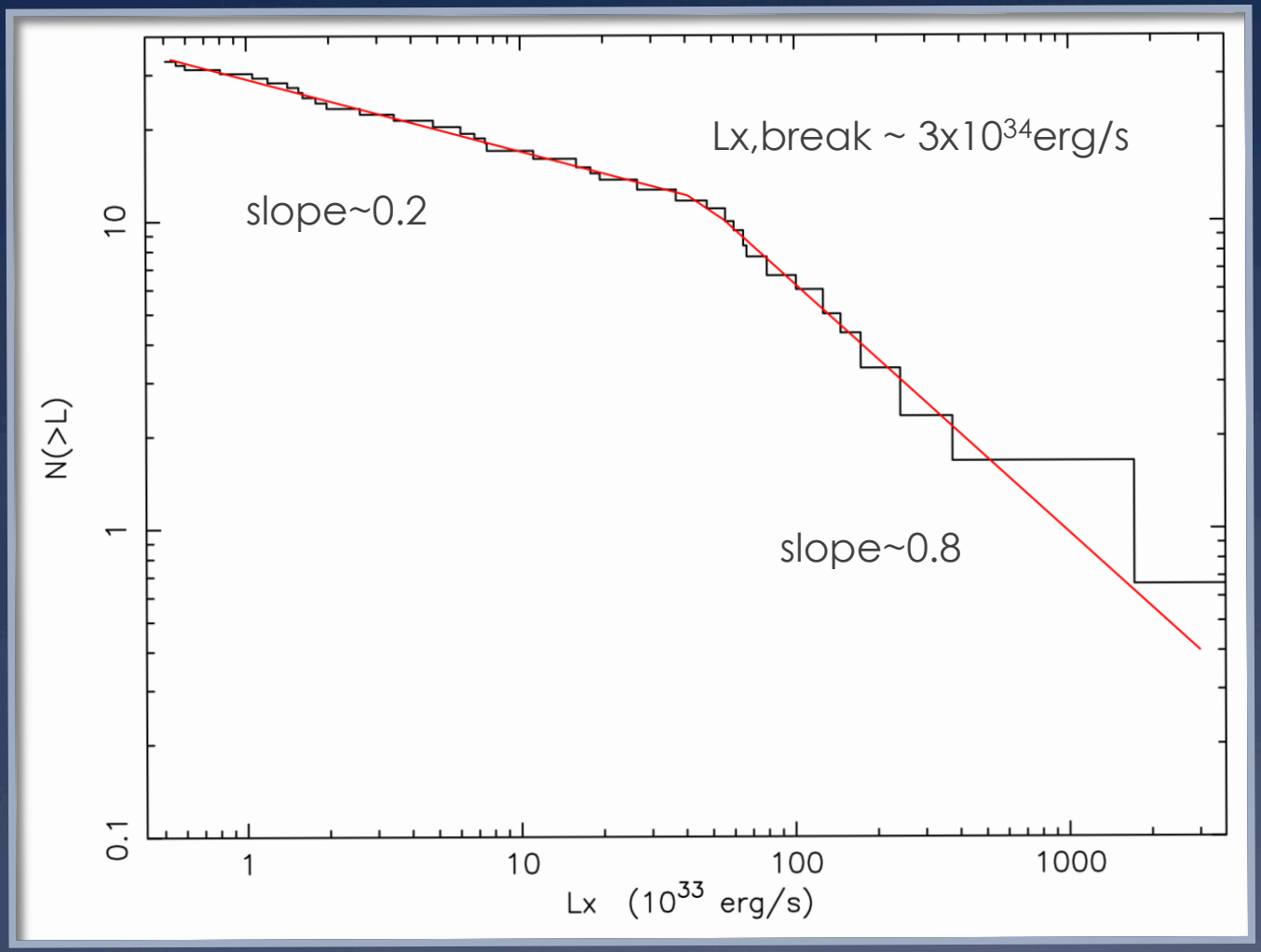

HMXBs XLF

- Flat slope: α ~0.2 / 0.8
- Evidence for break

→consistent with accretion in an inhomogeneous environment & the onset of the propeller effect (c.f. Shtykovskiy & Gilfanov 2004)

- *Deepest XLF ever recorded for a galaxy!*

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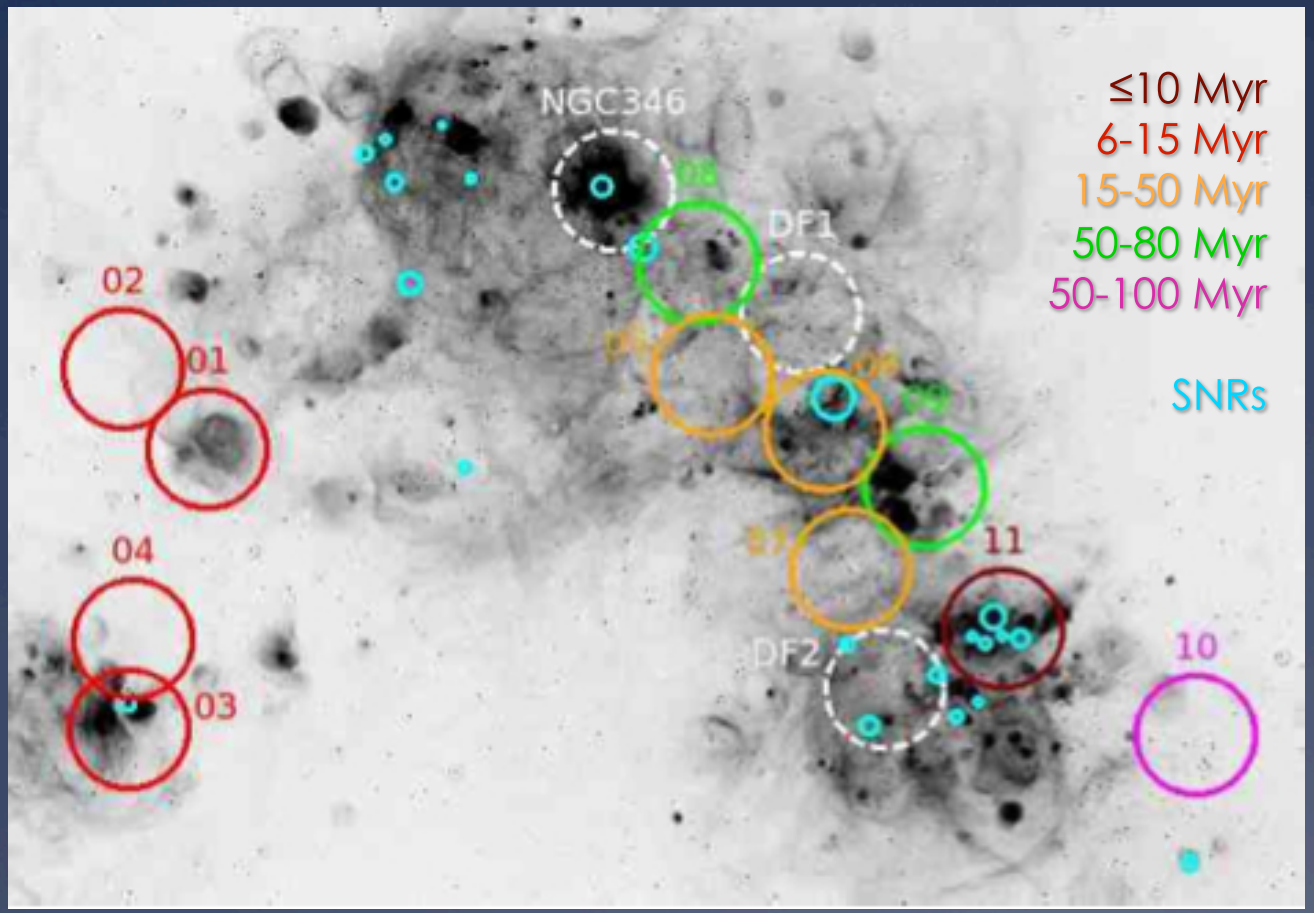

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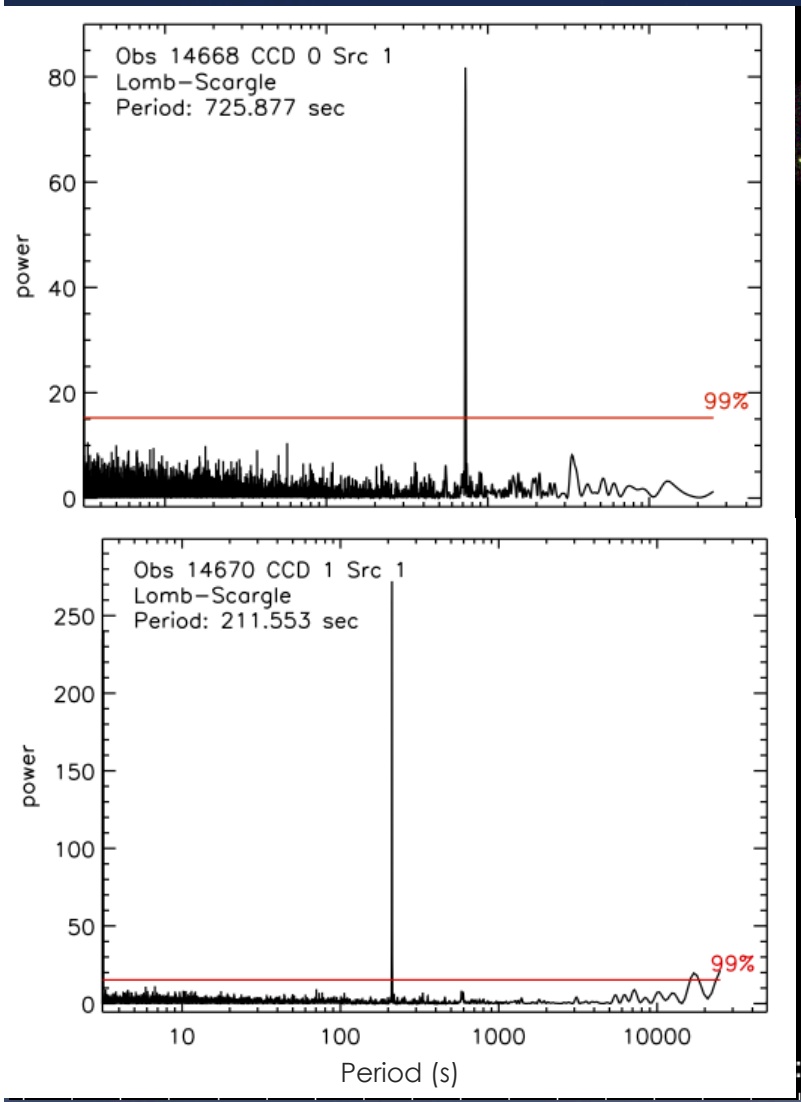

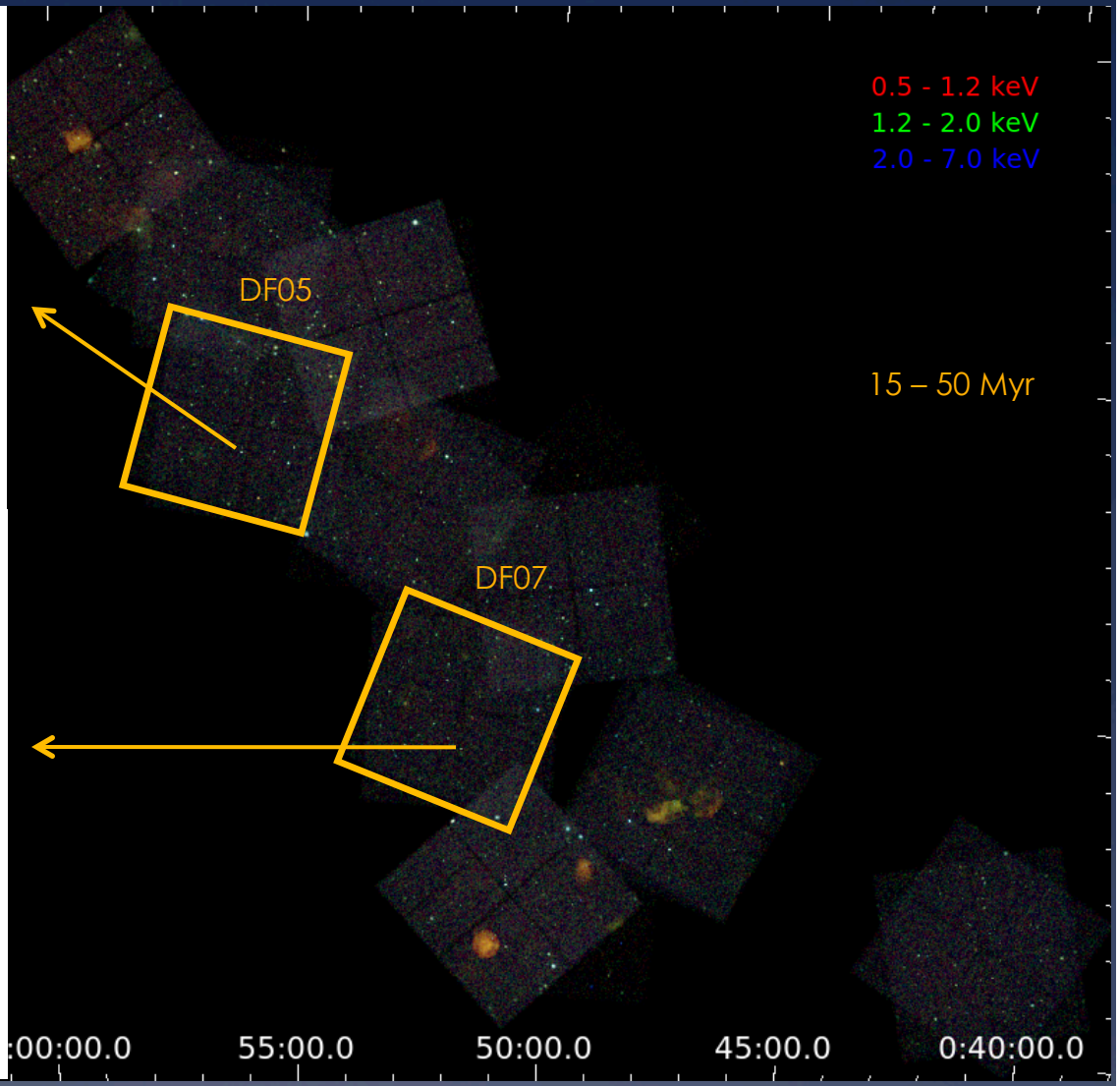

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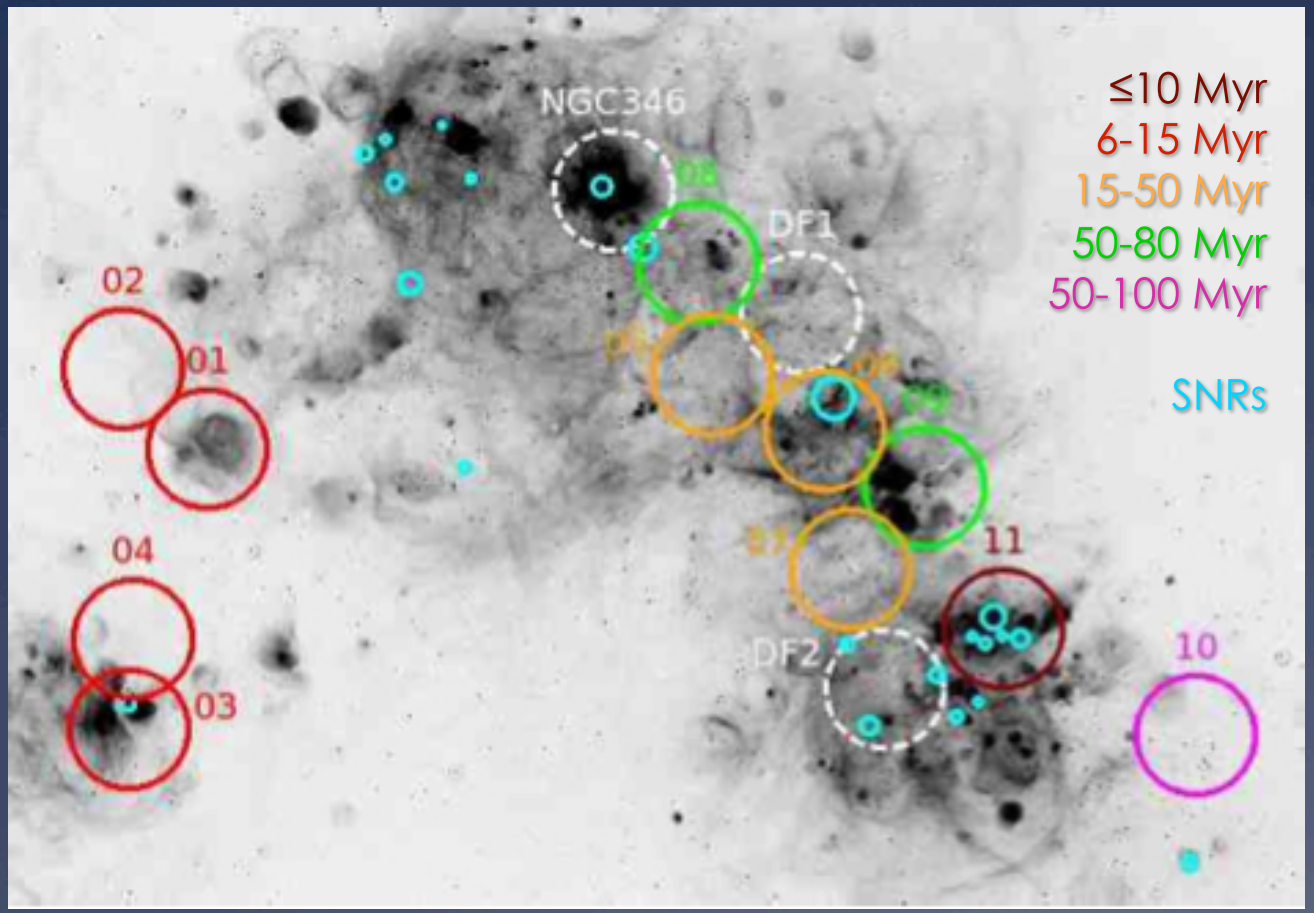

FIRST RESULTS

- 60 – 80 srcs per field
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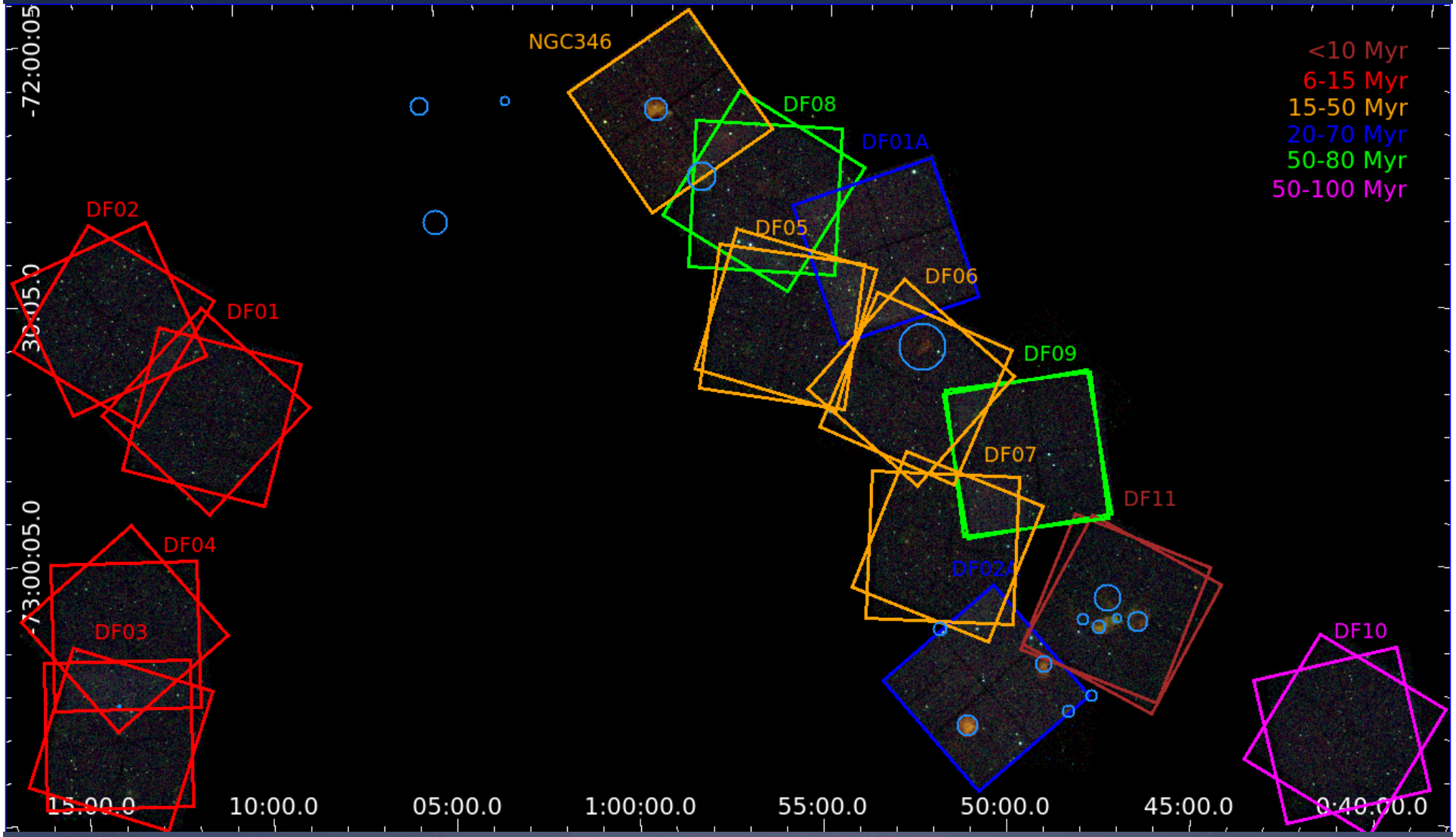
THE DEEP CHANDRA SURVEY: AN SNR GALLERY



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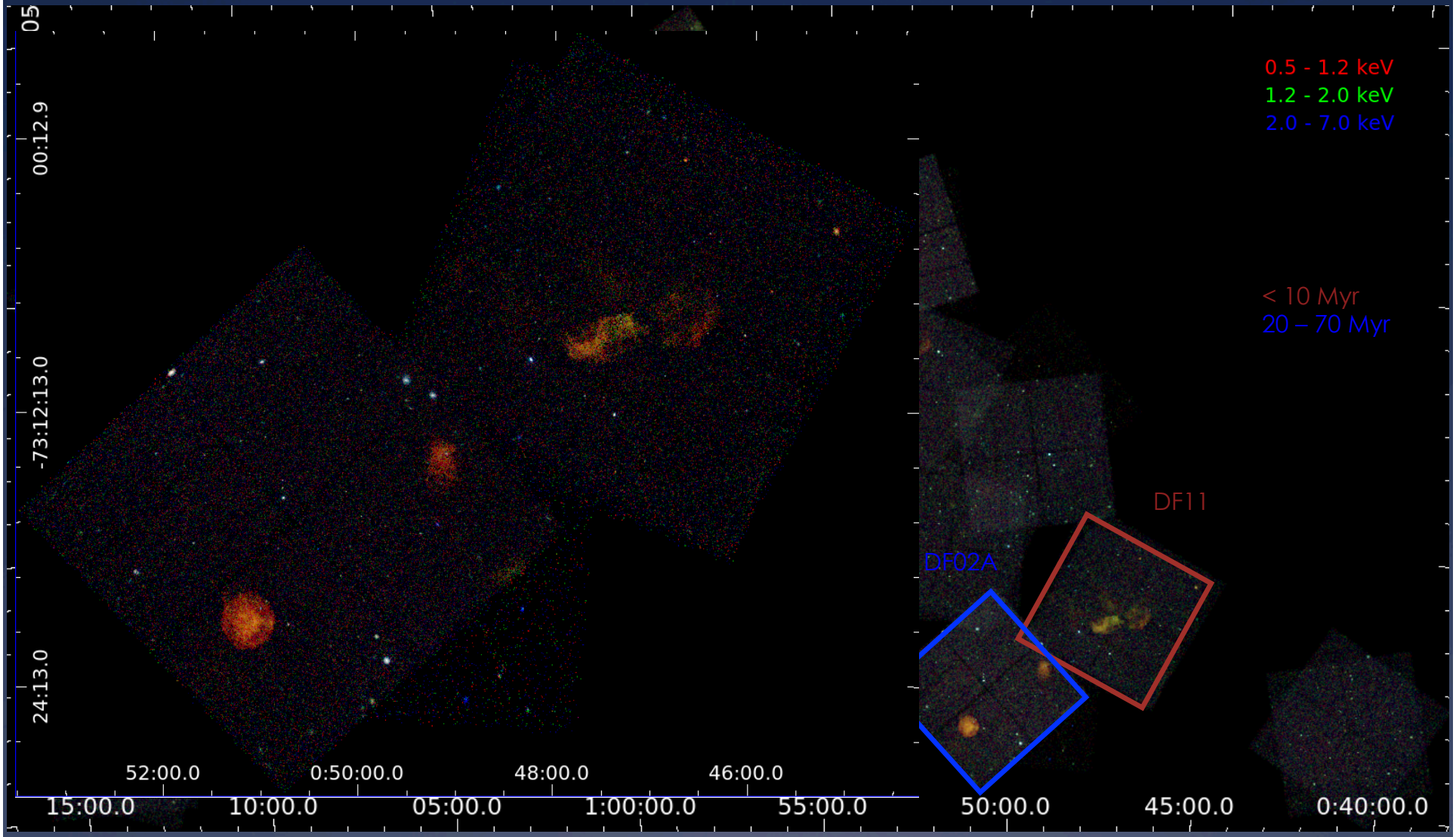

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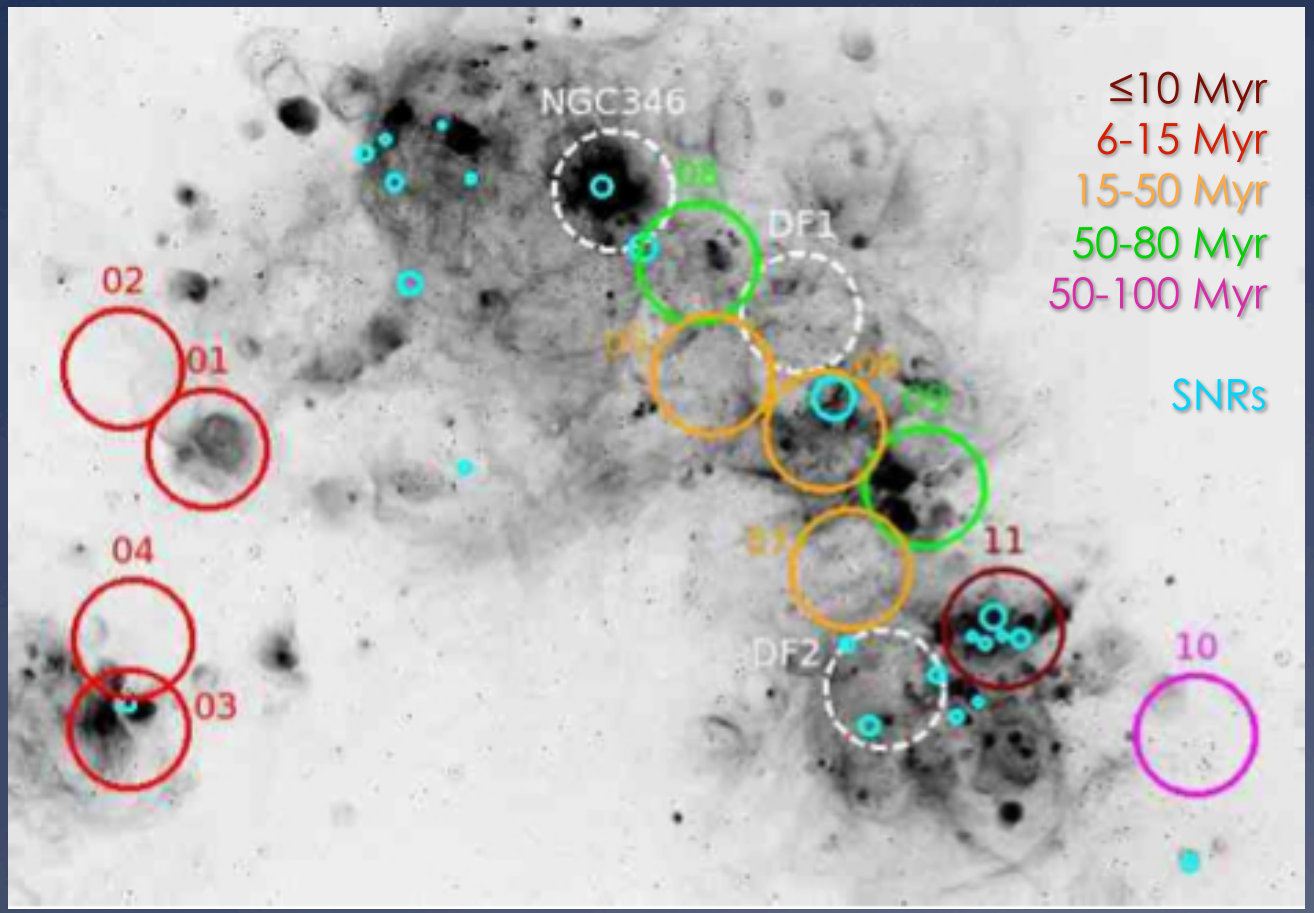

FIRST RESULTS

- 60 – 80 srcs per field
- Limiting Lx ~ 5 x 10^{32} erg/s
- 2 new pulsars (from the analysis of epoch 1 only)
- 8 SNRs
- HMXB formation efficiency

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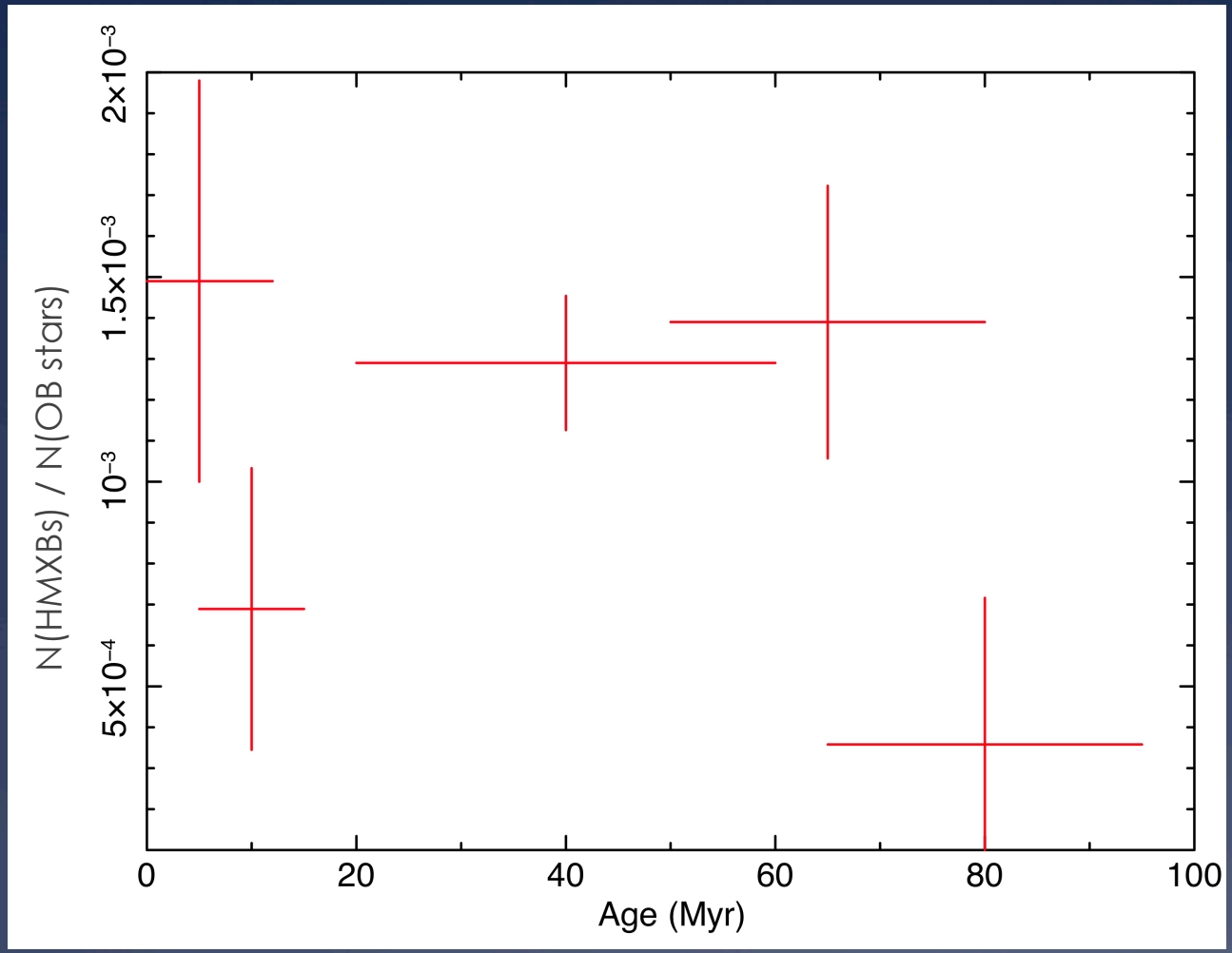

HMXB

Formation Efficiency

as a function of age

Peak at ~ 40 – 60 Myr

THE DEEP CHANDRA SURVEY: SUMMARY & FUTURE PLANS

Very promising first results

✓ Measure XLF down to Lx ~ 5 x 10^{32} erg/s

✓ Evidence for changes in formation efficiency of HMXBs with age

What's next?

✧ Follow-up spectroscopically the identified optical counterparts → Characterize the sources

✧ Investigate differences in XLFs as a function of age

✧ *Extend this work to other galaxies…*