The Origin of Type Ia Supernovae

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Outline

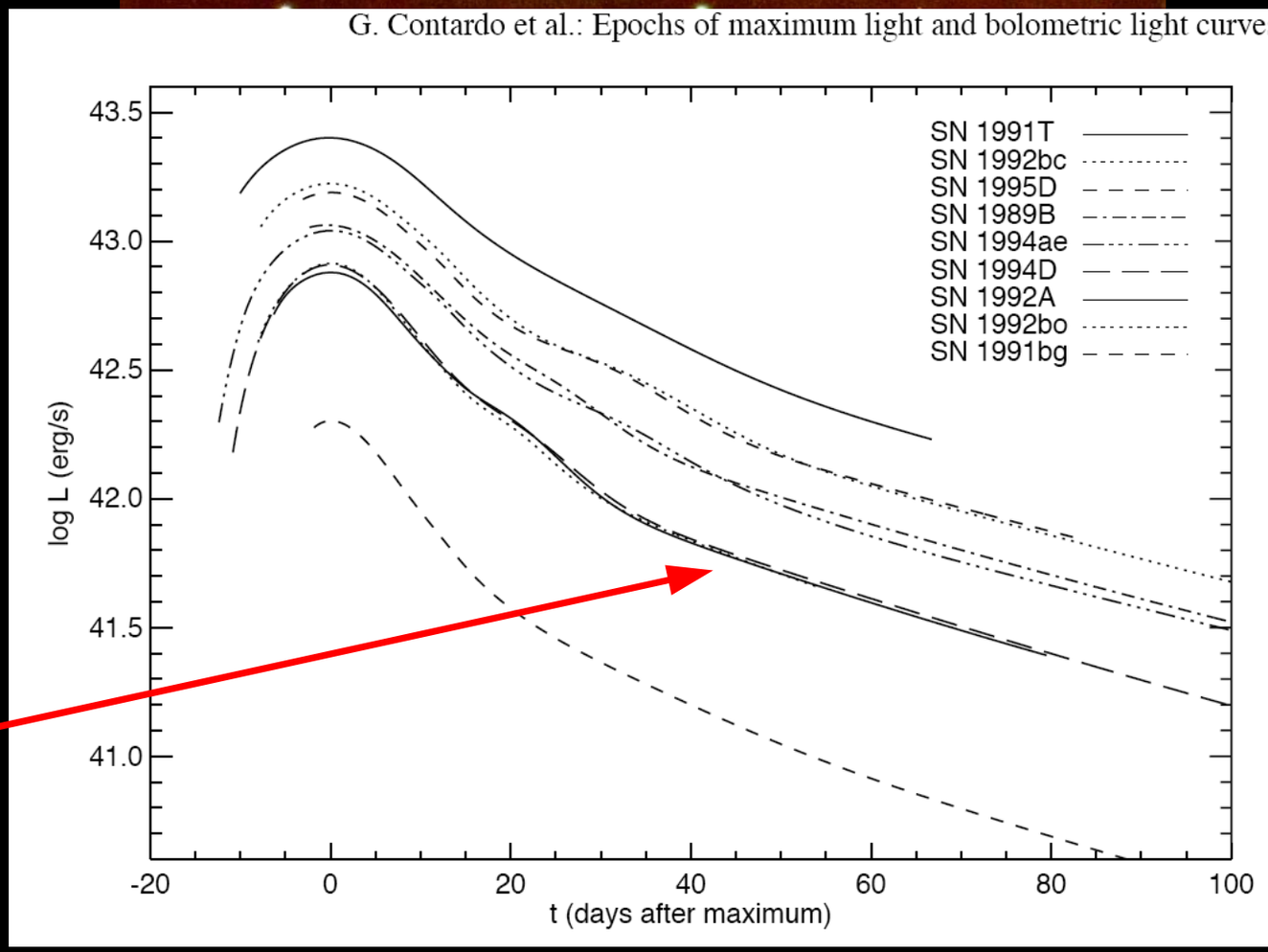
- Introduction: supernovae
- Relevance Type Ia supernovae
  - Nucleosynthesis and galaxy evolution
  - Distance measurements
- The question: what is their origin?
  - Type Ia: white dwarf binaries, but what type?
- Our approach
  - Population studies of progenitor type
  - X-ray studies of progenitors
- A little note on gravitational waves and LISA
- Conclusion and Outlook

Supernovae

- Extreme brightening
- Important historically
- Baade & Zwicky 1934 (read!)
- 20th century:
  Energy >10^{51} erg
- Order of typical binding energy WD or Fe core massive star
- Fe core: no more fusion → collapse to NS
- C/O white dwarf: at high density C burning → thermonuclear explosion

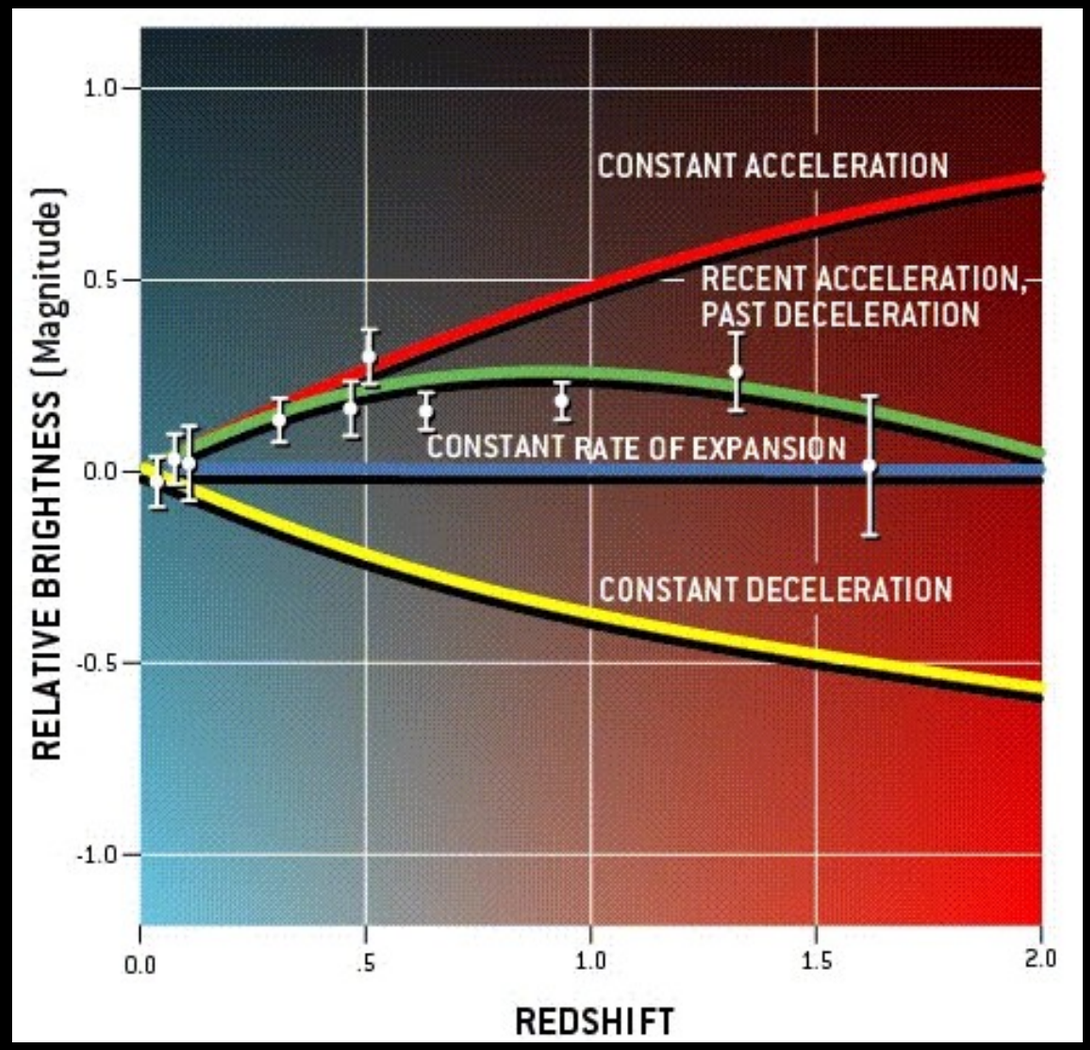
Supernovae

- Spectral types:
  - Type I (no H; Ia Si, Ib He)
  - Type II (H)
- Type II: association with massive stars
- Crab nebula and pulsar at position of SN1054
- SN type Ia in young and old populations
- Type Ia: spectra + light curve → Themonuclear explosion of C/O WD (production of Ni that decays + intermediate elements)



Relevance

- Understanding massive star evolution (Which stars become NS, which BH?)
- Galactic evolution: enrichment ISM via SN → how much of what element?
- Type Ia SN can be used for distance – redshift measurement → discovery accelerated expansion Universe

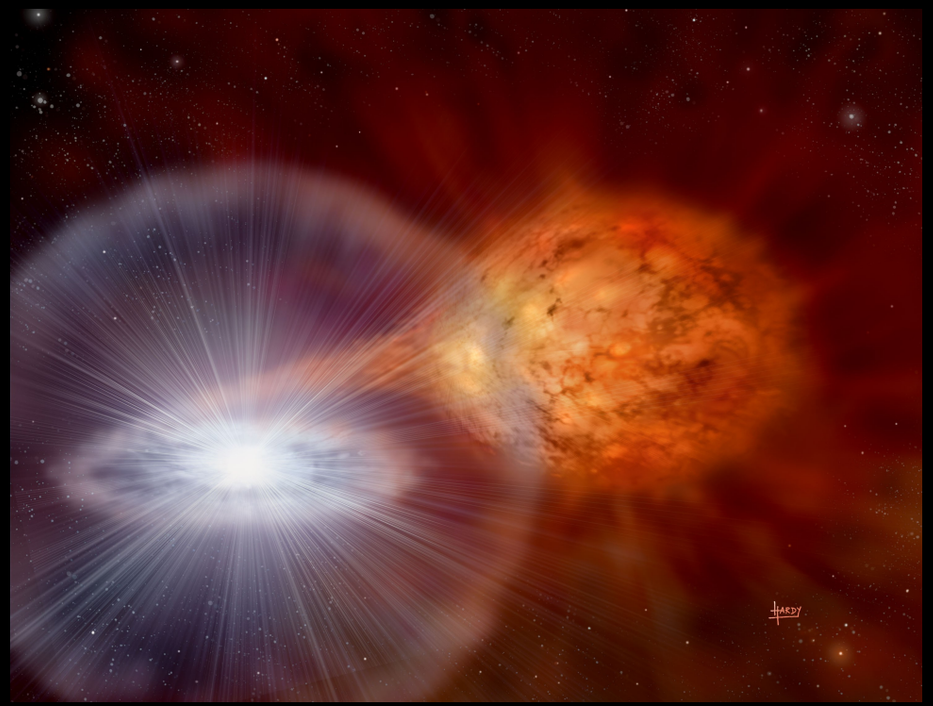


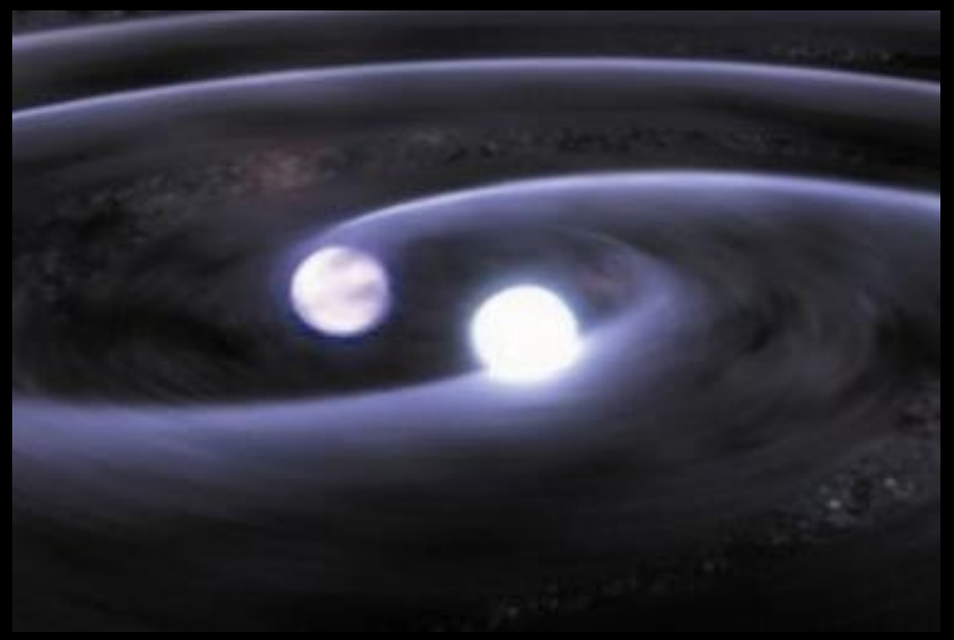
The question: what is their origin?

Lack of understanding hampers their use as Cosmological probes

Type Ia supernovae

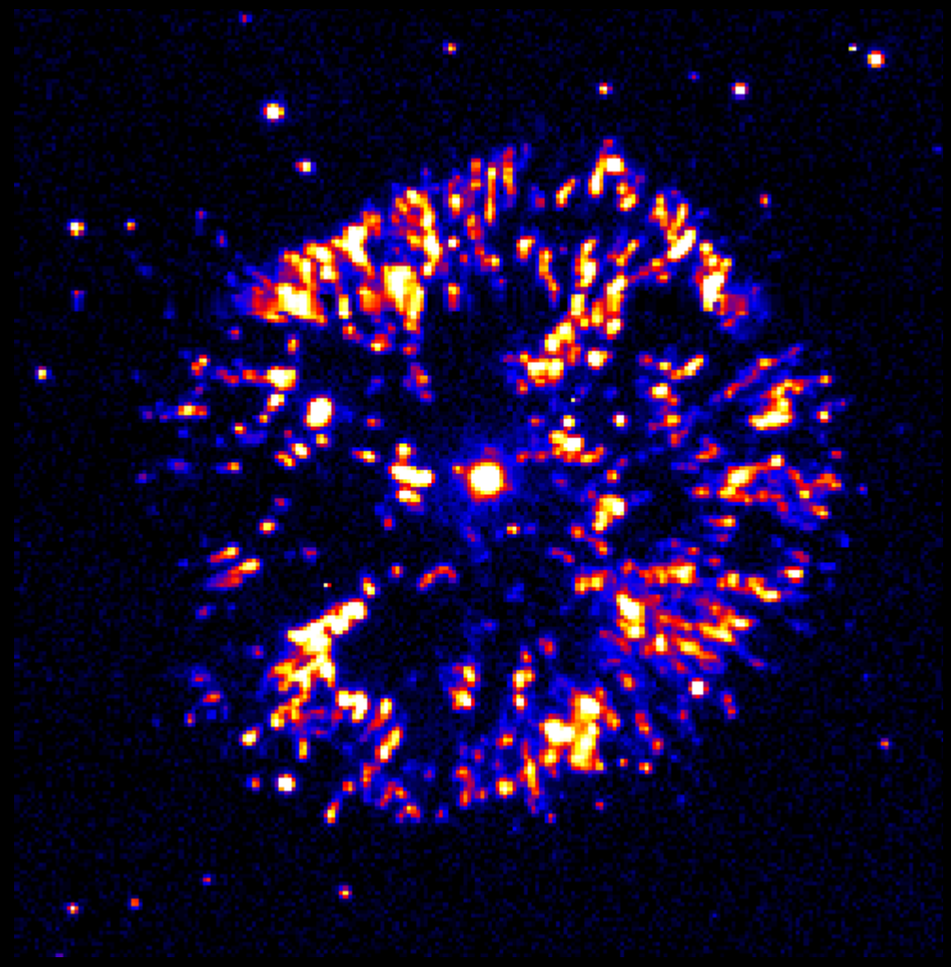
- Thermonuclear explosion in WD, but how come?
- Different models
- Single degenerate
  - WD accretes from companion
  - Supersoft source
- Double degenerate
  - Merging double WD
  - GWR sources
- Each has problems!





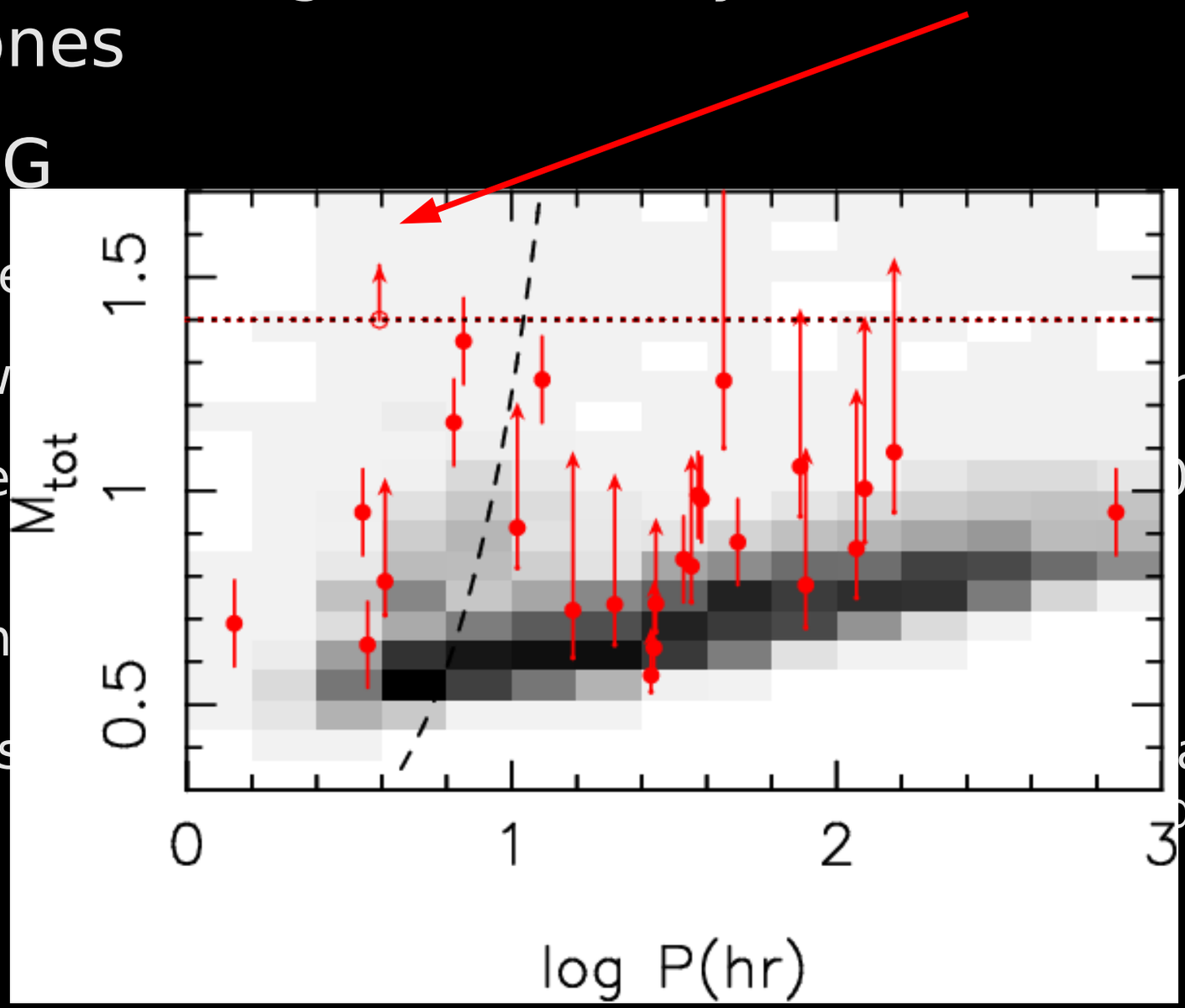
Single degenerate and supersoft sources

- Relatively young population (and SNIa also in old ones)
- Unclear if accreting WD grow in mass (novae)
- Problem: no H observed in spectra!
- Some potential progenitors know in our Galaxy



Double white dwarf mergers

- Short as well as long delays
- Rapid accretion more likely to produce AIC and NS?
- No real convincing case seen yet (V458 Vul?), few “close” ones
- WARNING
  - Should be … progenitors
  - Double w… ~ 1 kpc!
  - Single de…), d max > 1 Mpc!
  - (recurren…
  - Possible s… ae … ds check)



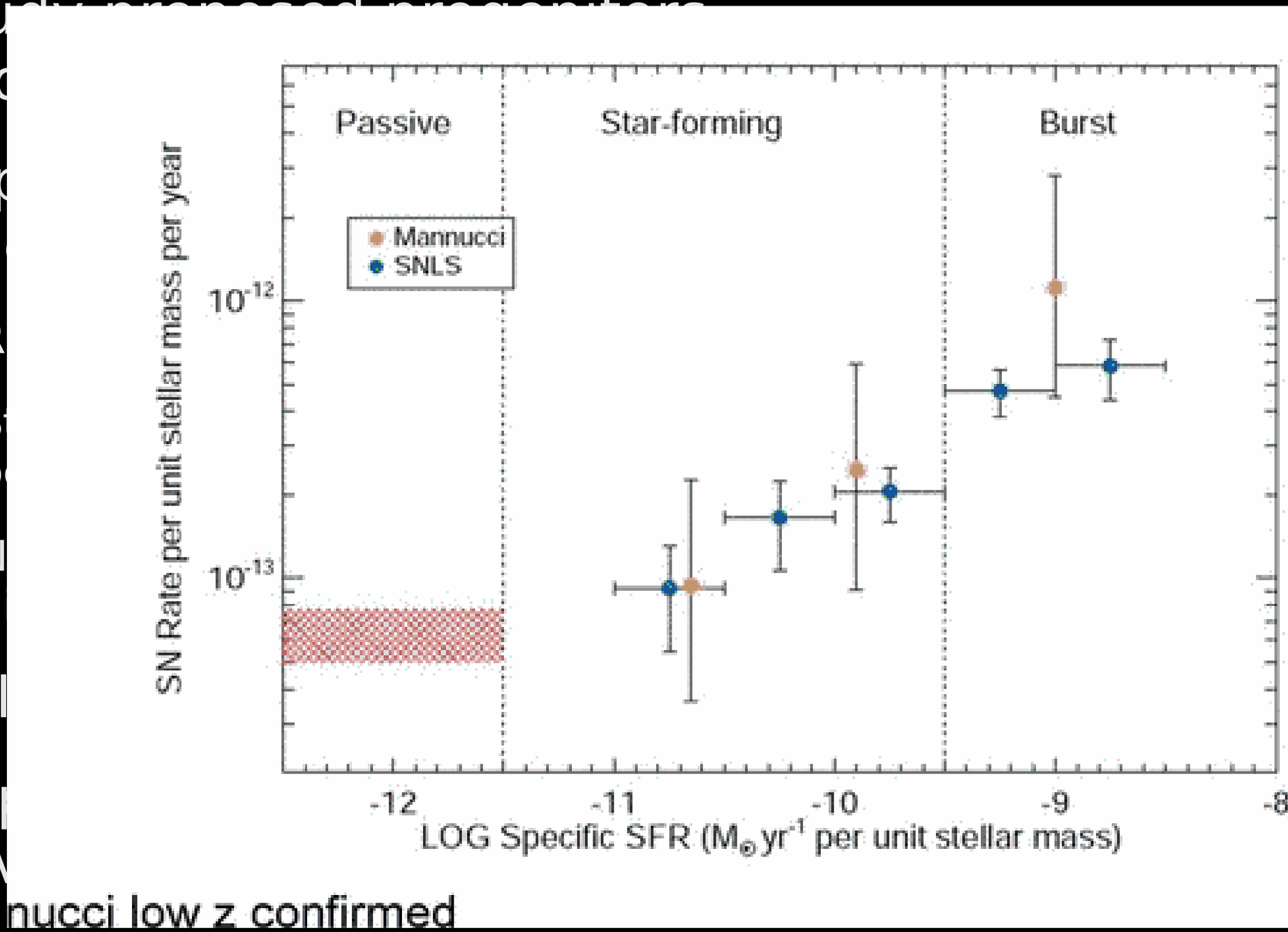
Nelemans et al. 2001, 2005

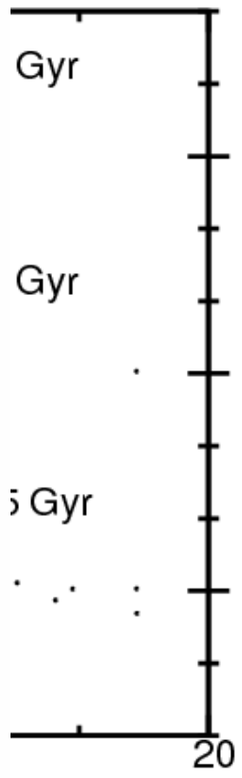
Our approach:

- Population studies of progenitors (local and global)
- X-ray studies of progenitors

Population studies

- Stu
in c
- Pop
cal
  - R
  - S
p
  - N
h
- Cal
- App
env

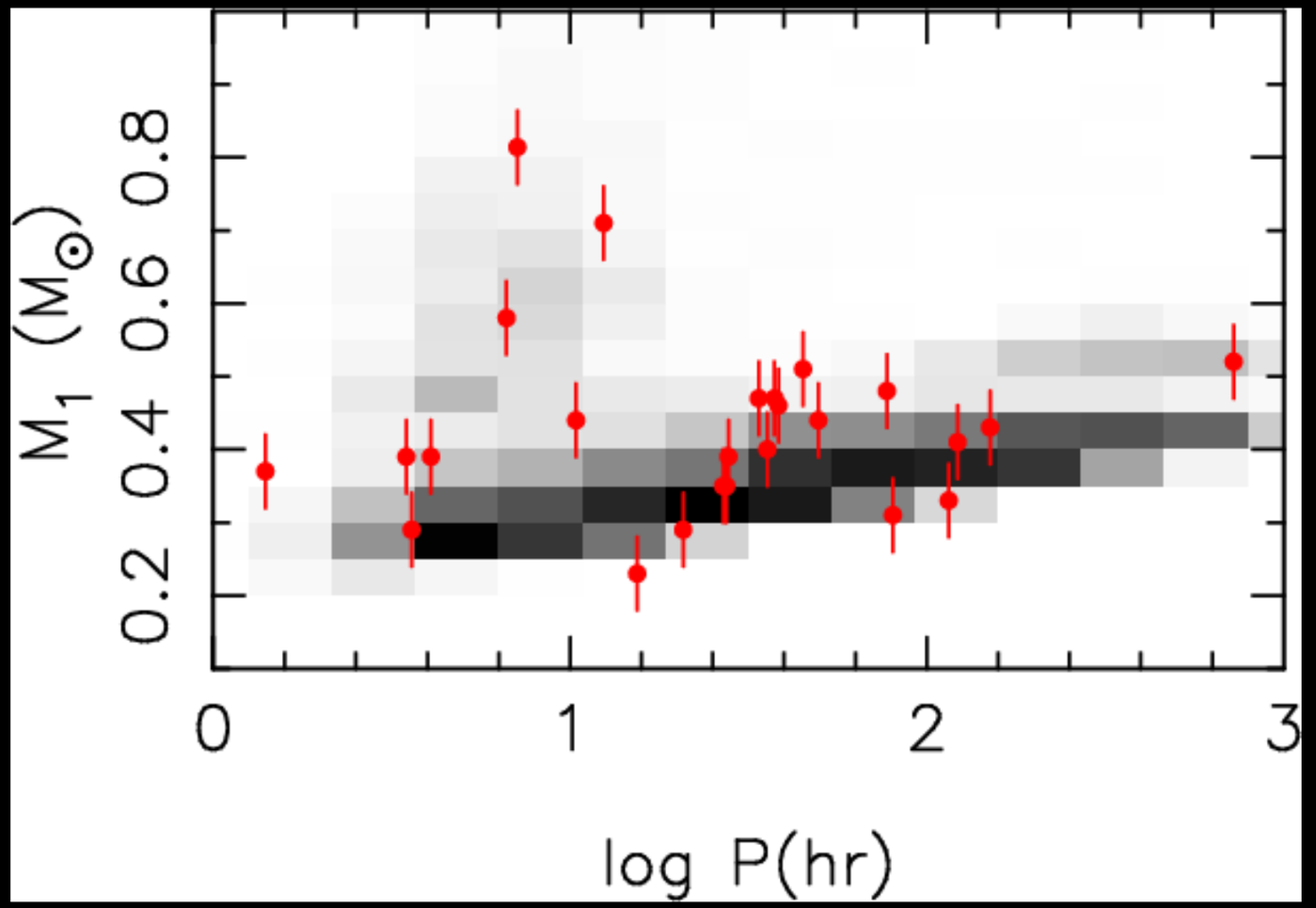




nucci low z confirmed

Calibrate on local populations

- Double WD
- Total number:
  100 million
- Birth rate:
  1/50 years
- Merger rate:
  1/125 years



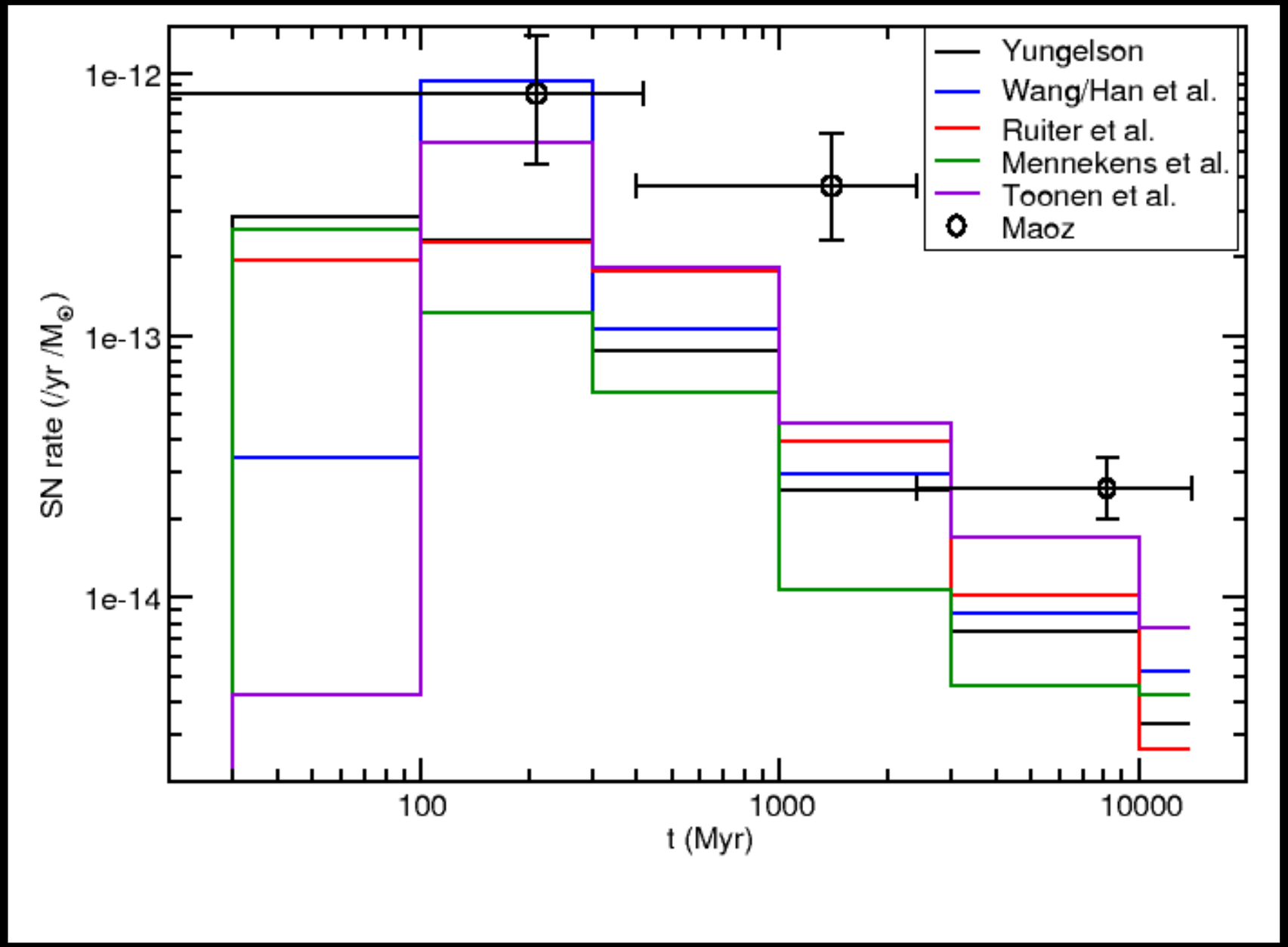
- Including selection effects
- Reasonable agreement
  (most recent object not
  yet in picture)

Nelemans et al. 2001a,b, 2005

Comparison of different groups

- Expresses in Delay Time Distribution (rate as function of time since star formation burst)

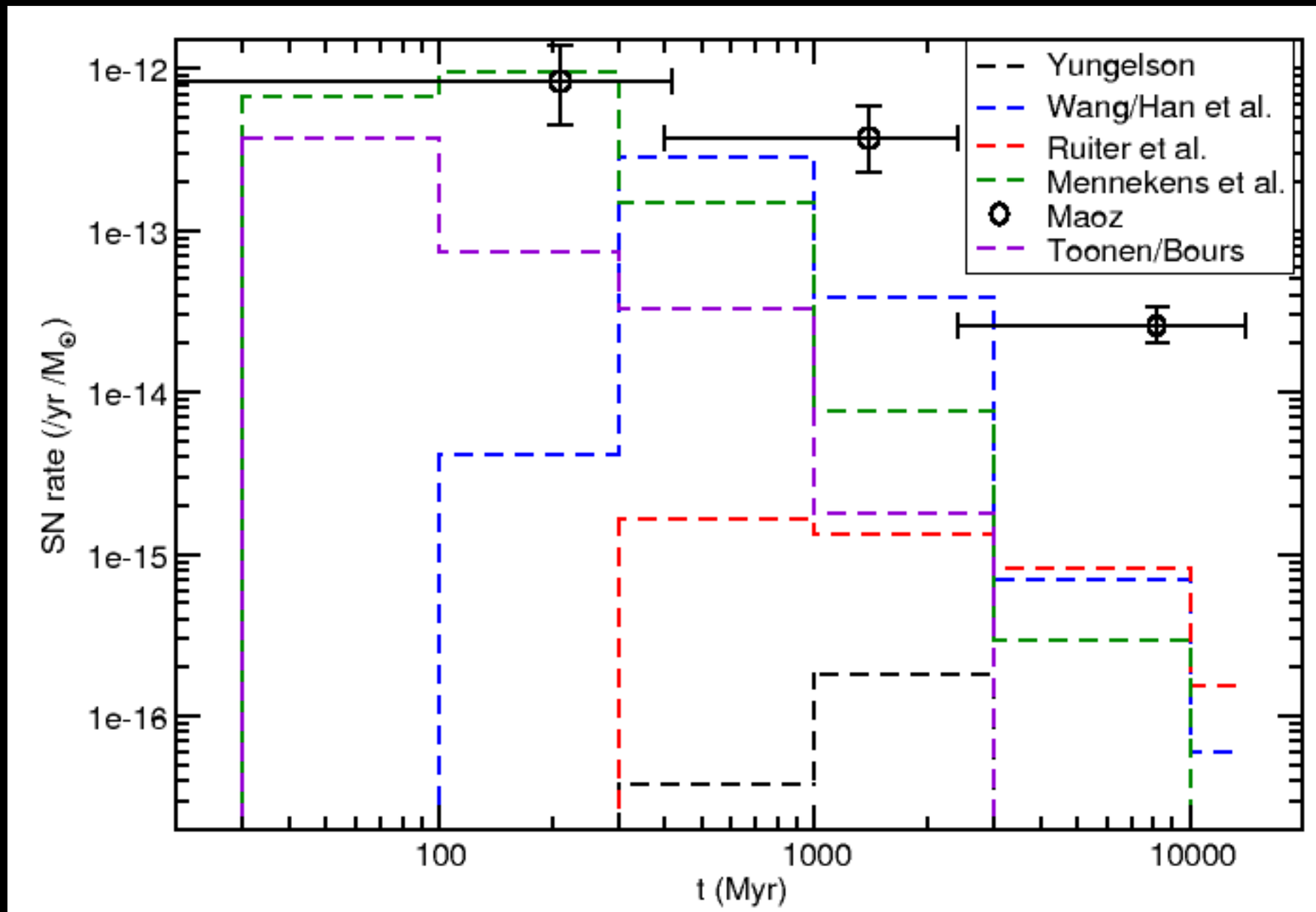
- Double degenerate reasonable agreement



Comparison of different groups

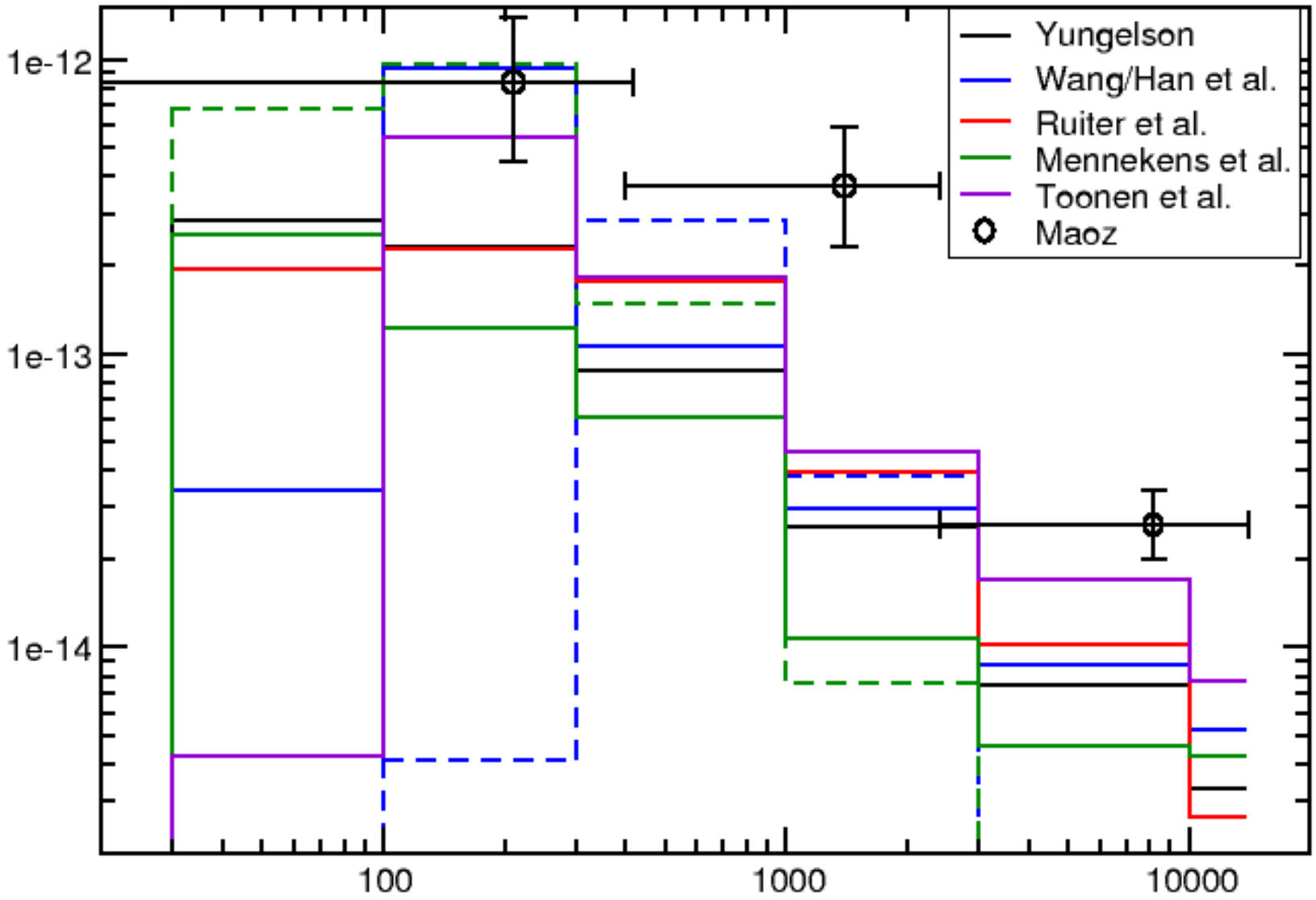
- Expresses in Delay Time Distribution (rate as function of time since star formation burst)

- Single degenerate needs work to understand differences! (Madelon Bours)



Comparison with observed rates

- Rescaled normalisation tot Kroupa IMF and 50% binaries



Integrated rates:
(10^{-4} /Msun)

DD	SD
2.4	0.006
4.4	2.8
5.7	0.17
2.2	3.7
7.5	

Maoz:
23 observed

X-ray studies of progenitors

- Type Ia supernova progenitos may be accreting WD, supersoft X-ray sources (Lx upto 10^{39} erg/s)
- Study population in externa, galaxies
- Direct search for individual progenitors
- Chandra: d_{max} for Lx 10^{39} erg/s = 50 Mpc

Missing progenitors?

- Count X-ray sources and compare to SN rate

Di Stefano, 2010, ApJ 712, 728

Table 1
Soft Sources in External Galaxies

Galaxy	SSSs	QSSs	Other Sources
M101	42	21	24
M83	28	26	74
M51	15	21	56
M104	5	17	100
NGC4472	5	22	184
NGC4697	4	15	72

Gilfanov & Bogdan, 2010, Nature, 463, 924

Name	L_K [$L_{K,\odot}$]	N_{WD}	L_X [erg/s]	
	observed	predicted	observed	predicted
M32	$8.5 \cdot 10^8$	25	$1.5 \cdot 10^{36}$	$7.1 \cdot 10^{37}$
NGC3377	$2.0 \cdot 10^{10}$	$5.8 \cdot 10^2$	$4.7 \cdot 10^{37}$	$2.7 \cdot 10^{39}$
M31 bulge	$3.7 \cdot 10^{10}$	$1.1 \cdot 10^3$	$6.3 \cdot 10^{37}$	$2.3 \cdot 10^{39}$
M105	$4.1 \cdot 10^{10}$	$1.2 \cdot 10^3$	$8.3 \cdot 10^{37}$	$5.5 \cdot 10^{39}$
NGC4278	$5.5 \cdot 10^{10}$	$1.6 \cdot 10^3$	$1.5 \cdot 10^{38}$	$7.6 \cdot 10^{39}$
NGC3585	$1.5 \cdot 10^{11}$	$4.4 \cdot 10^3$	$3.8 \cdot 10^{38}$	$1.4 \cdot 10^{40}$

<10% of expected number

Missing progenitors? Obscuration (M. Nielsen)

Can absorption hide them?

External(Milky Way and host galaxy)

Internal (winds)

Missing progenitors? Obscuration (M. Nielsen)

Can absorption hide them?

External(Milky Way and host galaxy)

No way

Internal (winds)

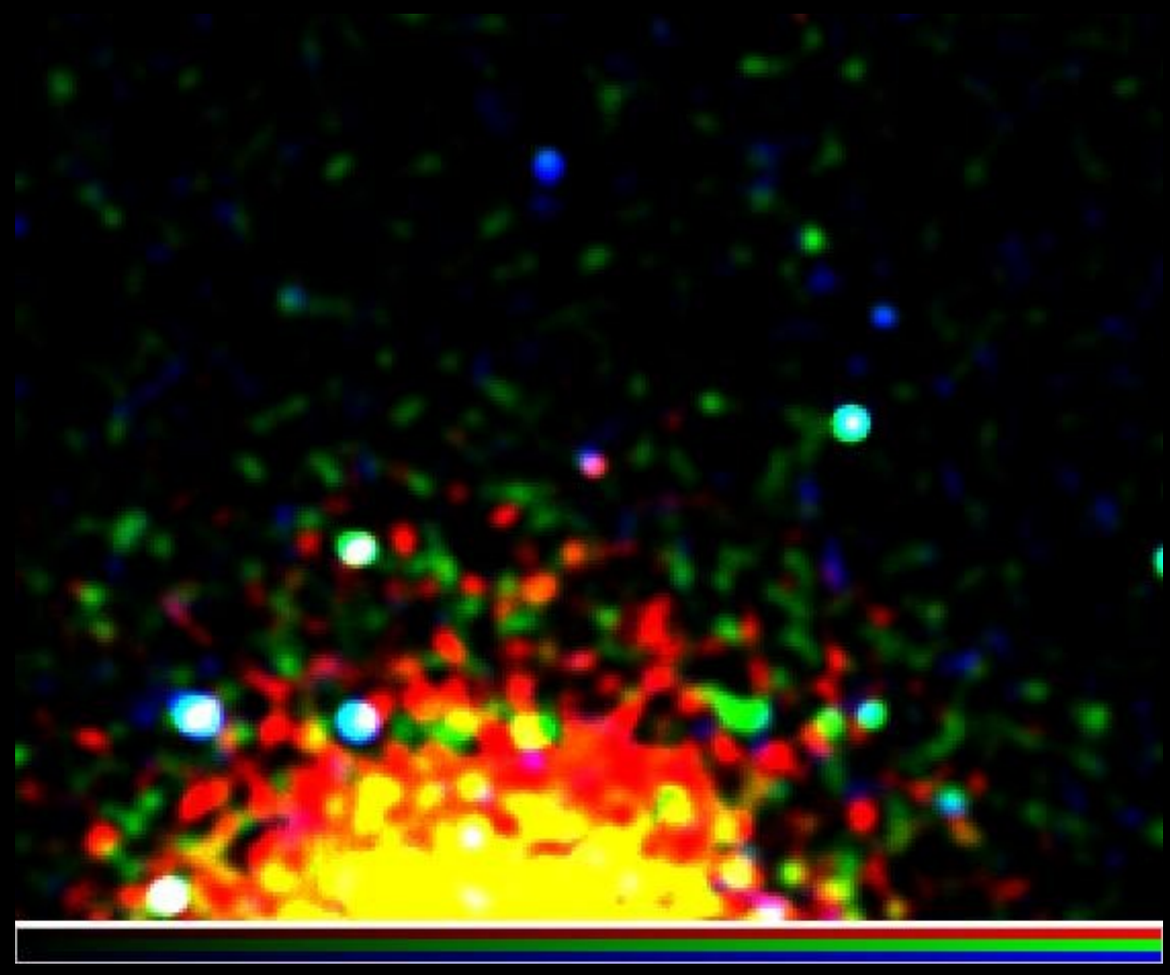
Possibly

>few times 10^{-6} M_o/year

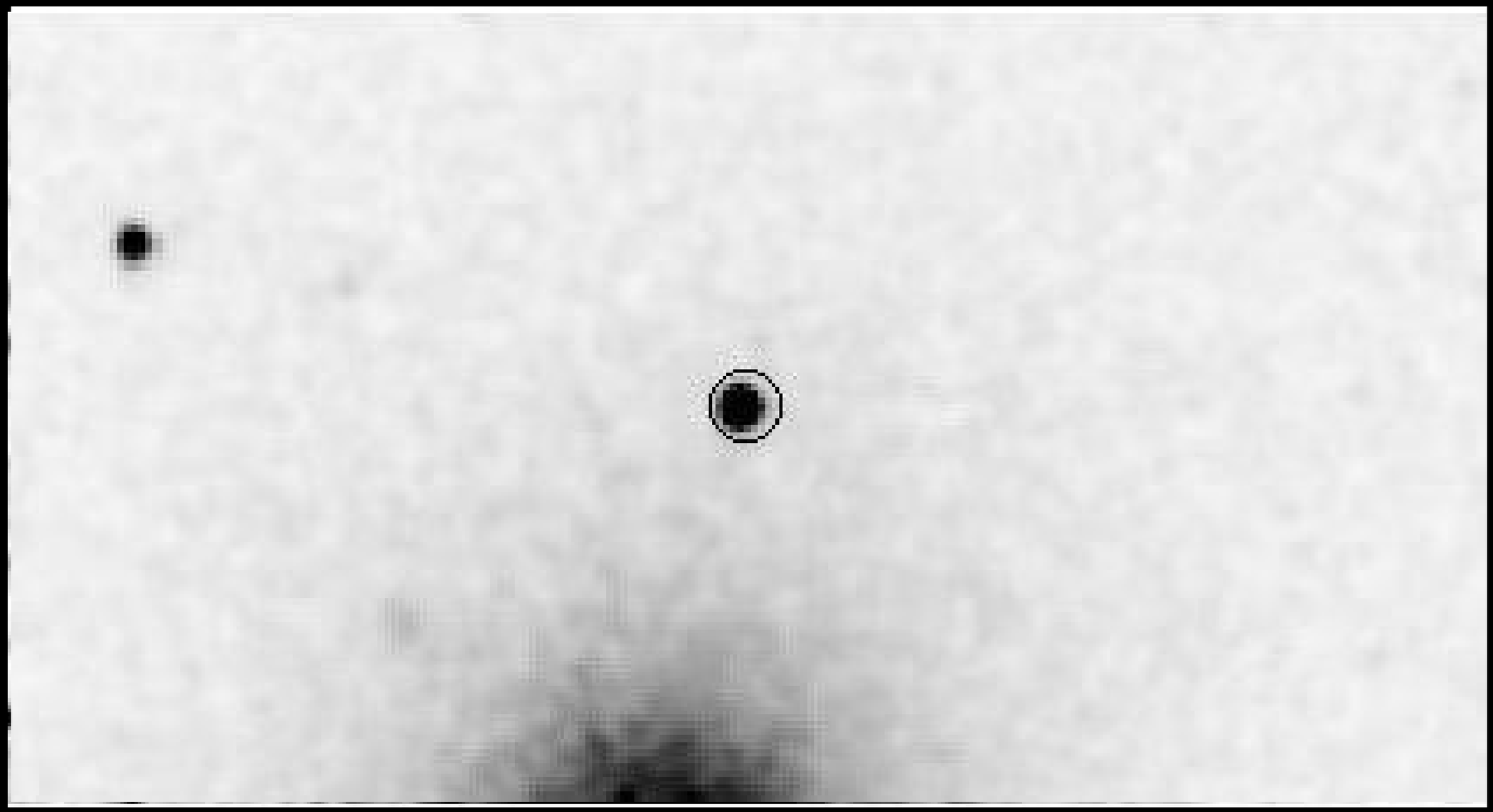
Nielsen et al in prep.

Direct detection of individual SN

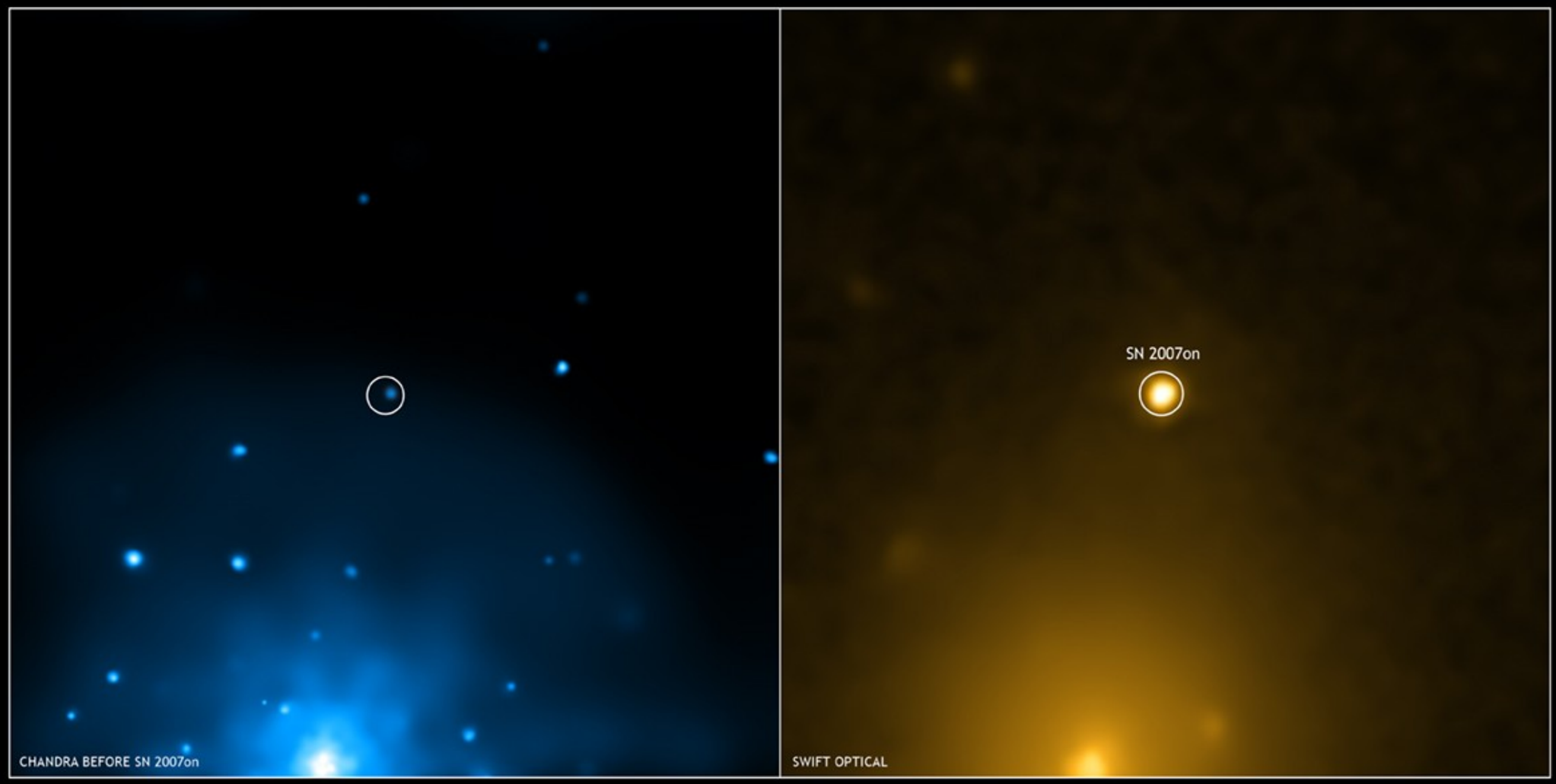
- Systematic search in 2007: upper limits only for 3 sources
- Then Fall 2007: action!
- SN2007on with possible progenitor
- SN2007sr with interesting upper limits
- Since then not much has happened....



SN2007on Swift image → pre-SN Chandra (2004)



Type Ia supernovae: SN2007on



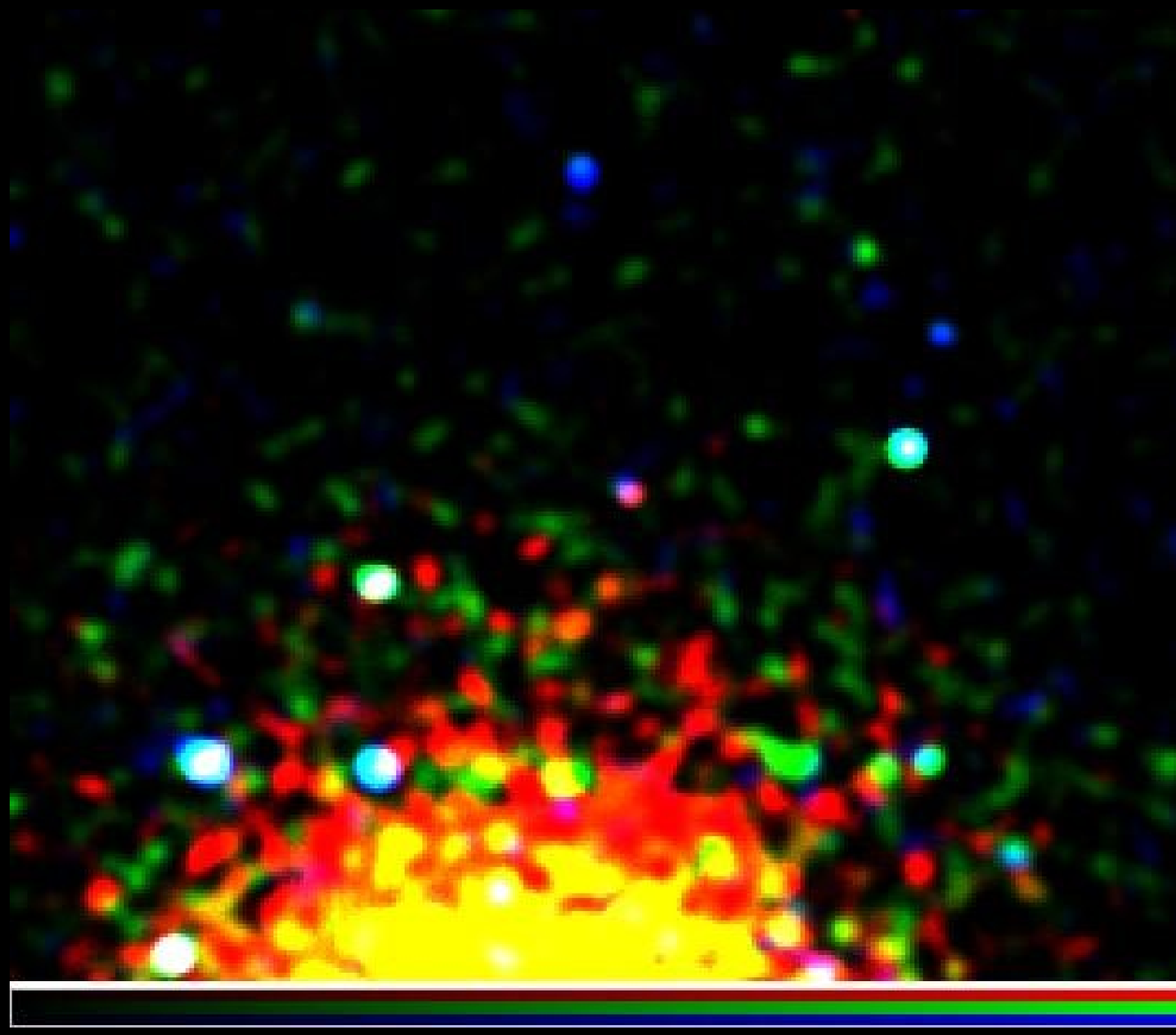
X-ray source
4 years earlier

SN November 2007
(optical)

Voss & Nelemans, 2008, Nature

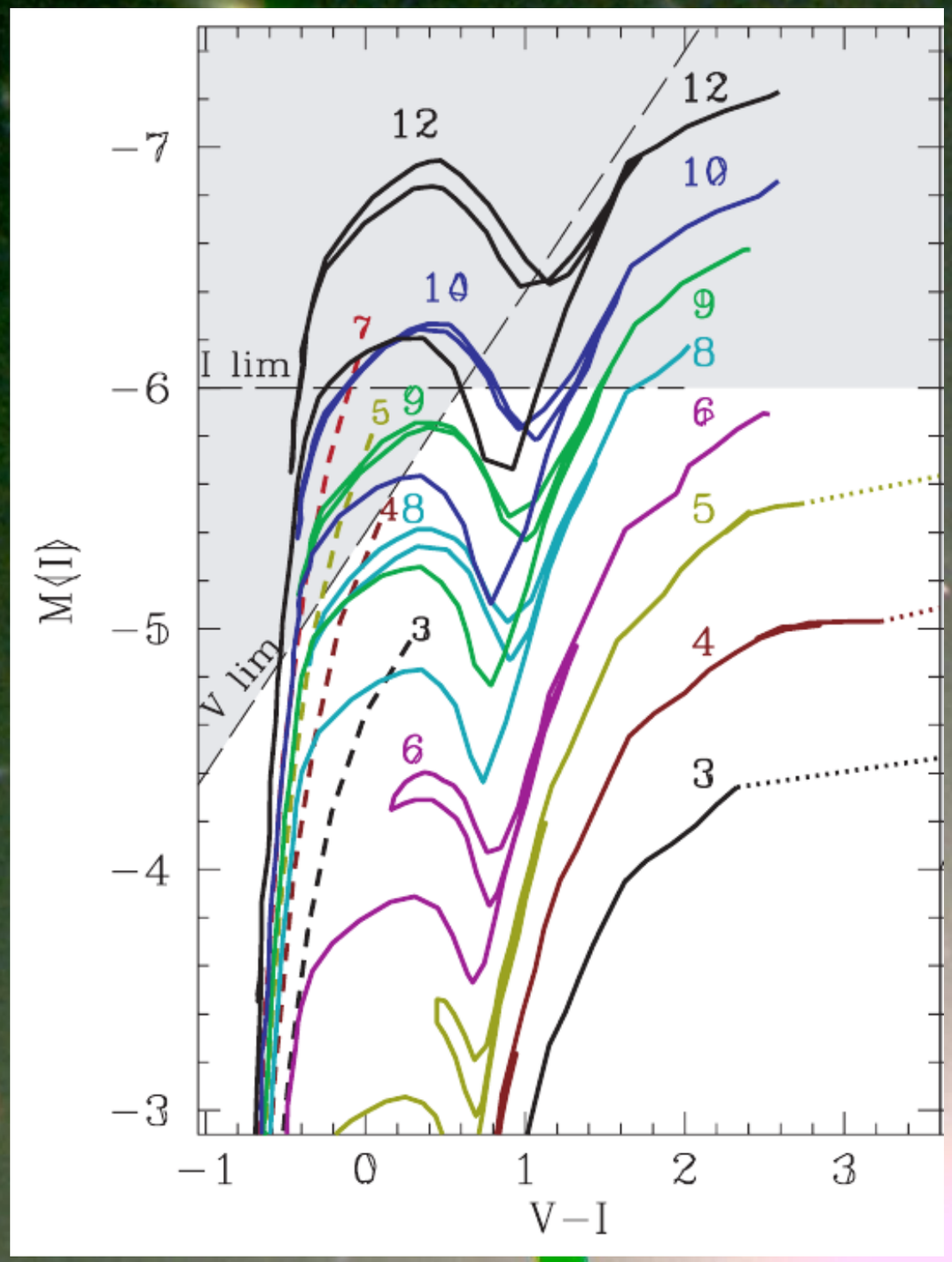
Properties X-ray source

- Rather soft source, but not as soft as SSSs!
- Looks more like single degenerate
- Lx = 6 10^{37} erg/s
- Host elliptical
- Age 6-9 Gyr
- d = 8kpc from host



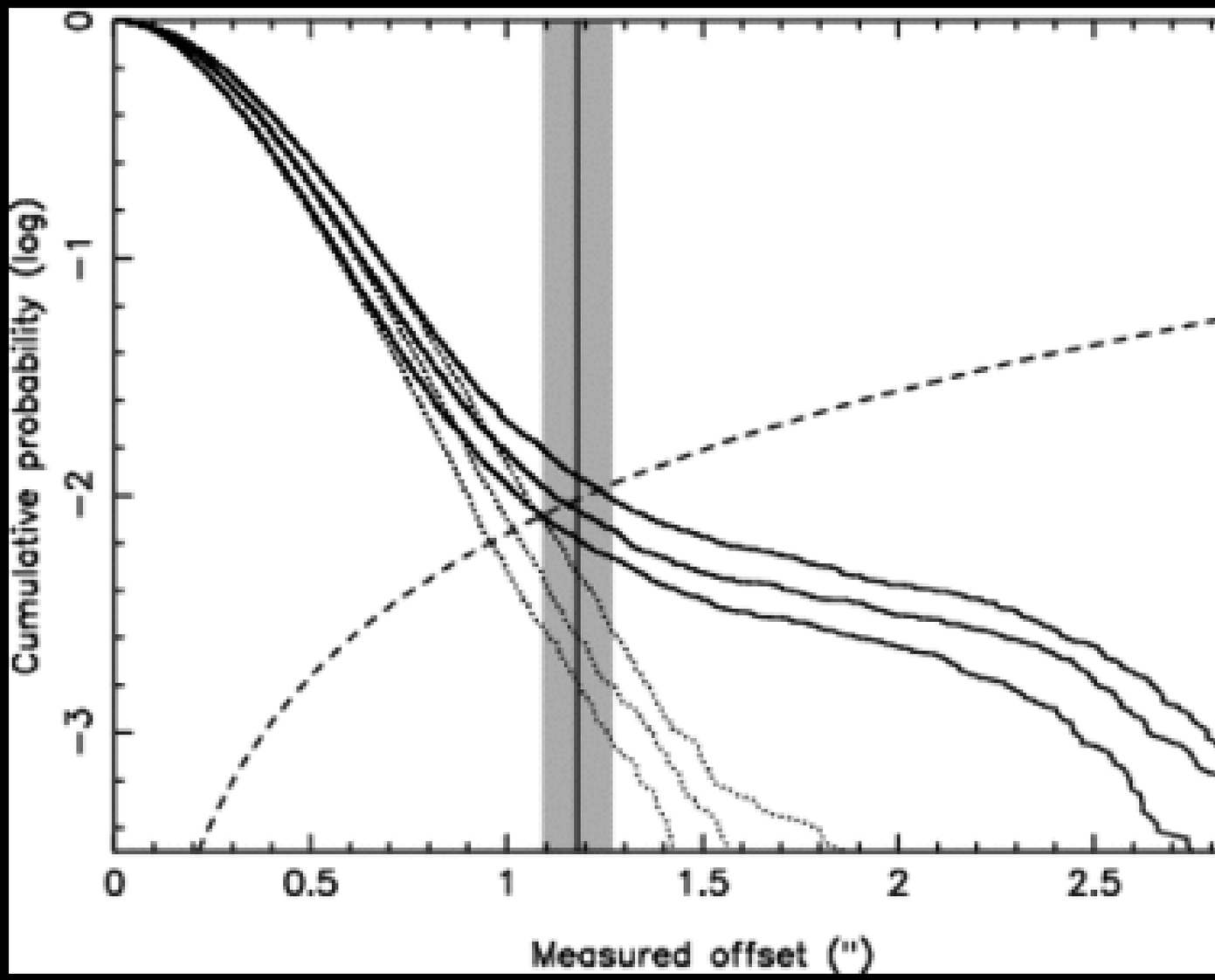
Voss & Nelemans, Nature

HST pre-SN: no object (Mv > -4.5)



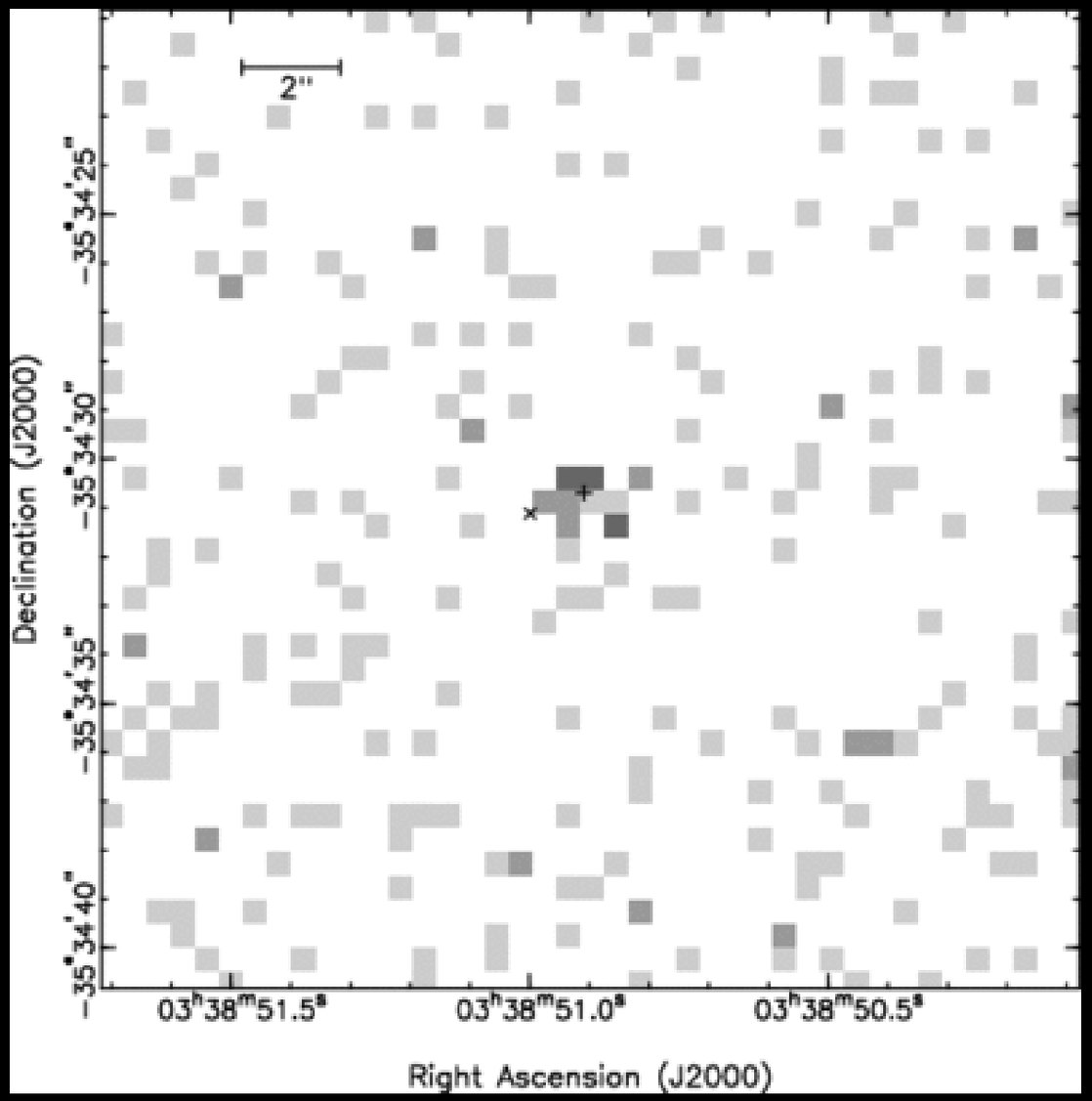
Progenitor of 2007on or not?

- New data indicate *possible* offset between X-ray source and supernova
- Chances about 50/50
- However, some “circumstantial” evidence for it being progenitor:
  - X-ray source seems gone
  - X-ray source in galaxy (no optical counterpart)
  - X-ray source rare kind (but right for progenitor!)

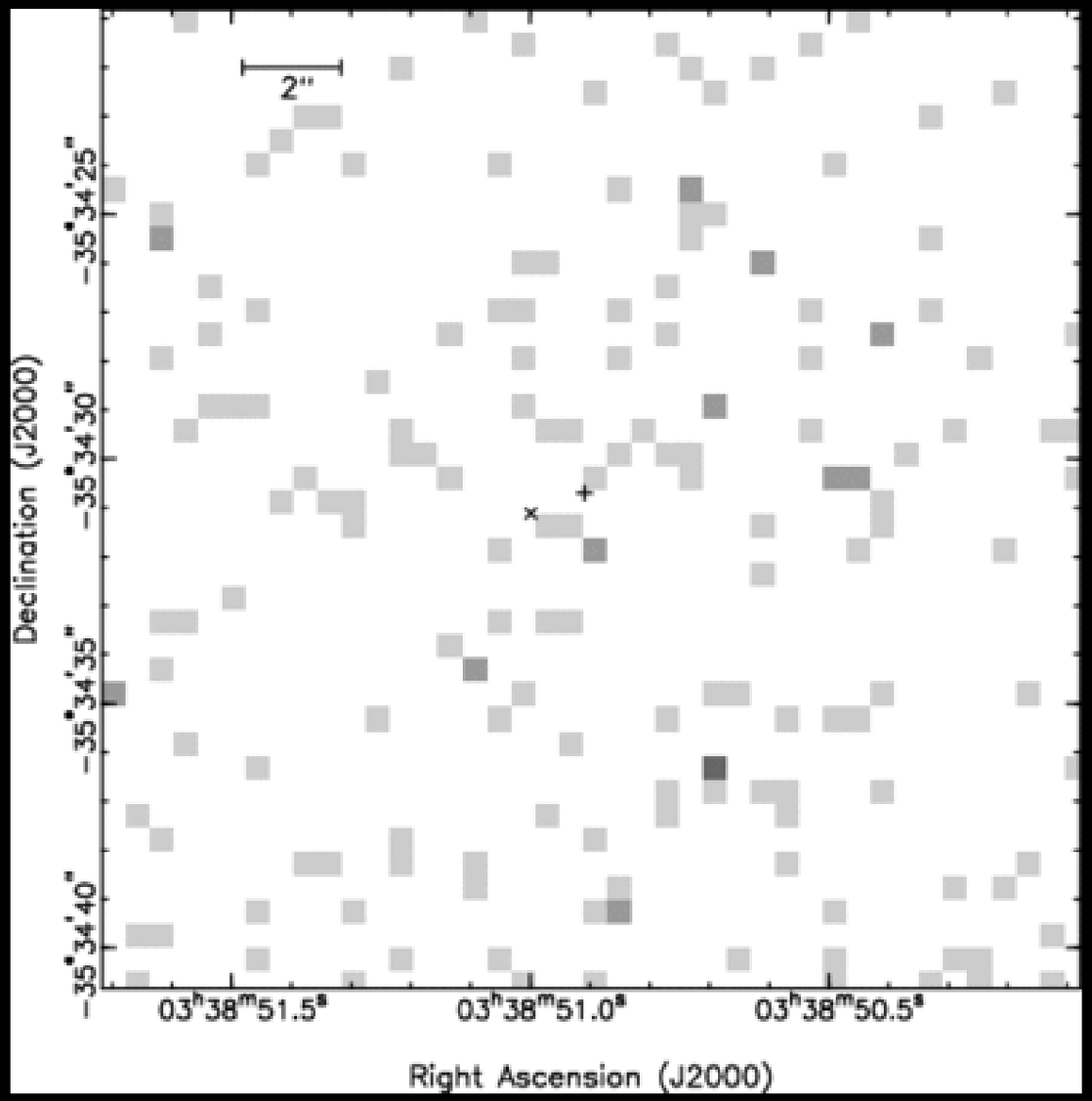


Roelofs et al.2008

Progenitor of 2007on or not?



Before



After (DDT ~0.6 sensitivity)

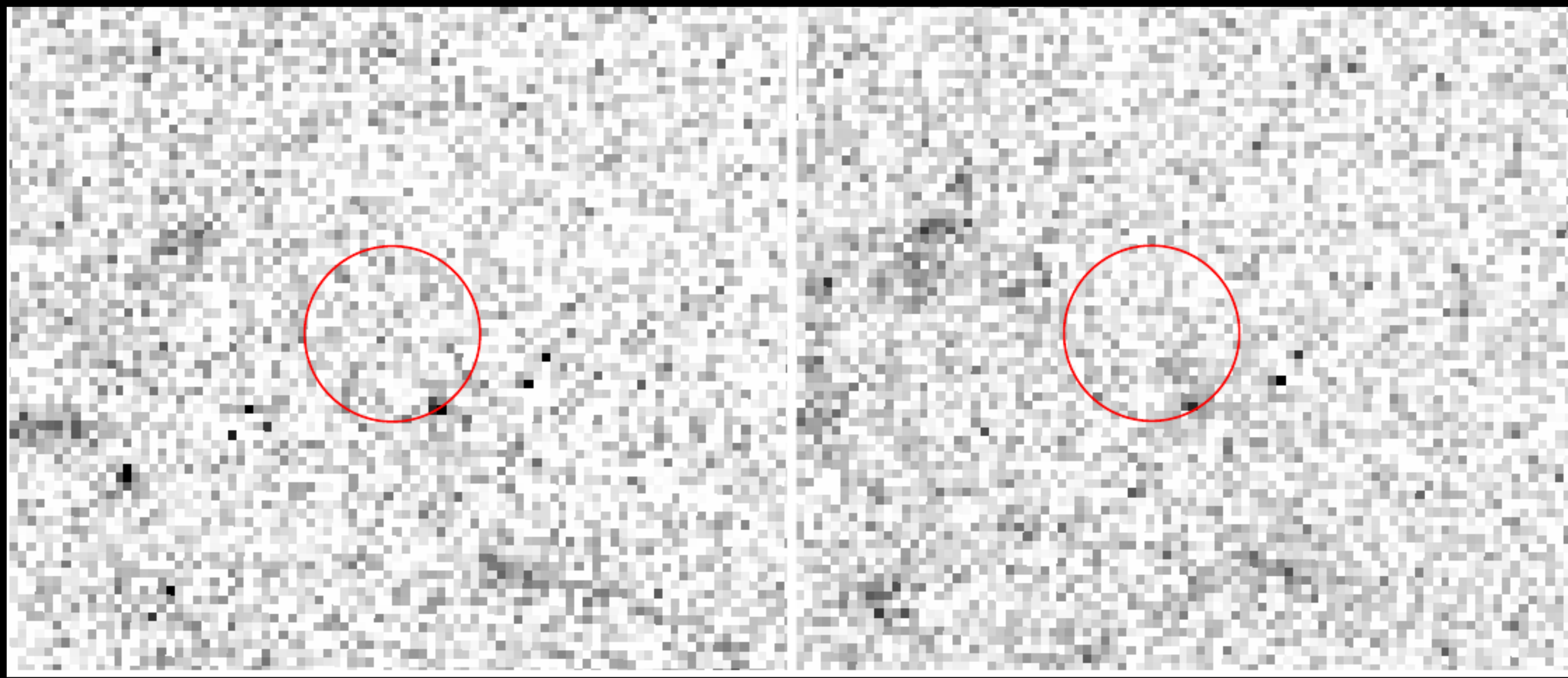
Roelofs et al.2008

SN2007sr in Antennae

Optical transient in NGC 4038 2007, December 19.42
Average of 5 exposures, 60 seconds each, through filters B, V & R
Takahashi Epsilon, D=0.25m, f/3.4 reflector + SBIG ST10 XME
Remotely near Mayhill (NM)
E. Guido and G. Sostero (http://www.afamweb.com)

~120"
N
E

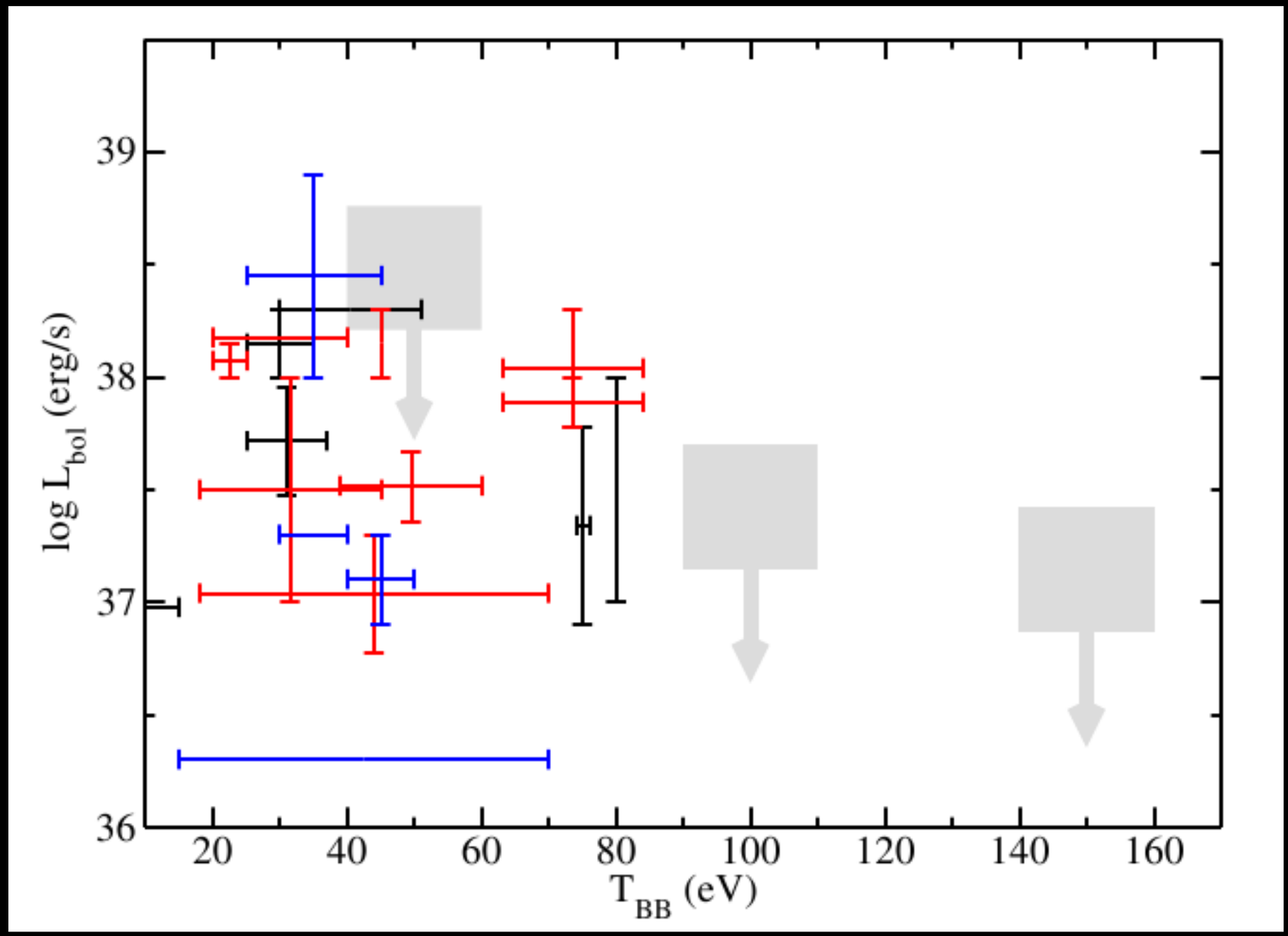
SN2007sr



- Lx < 10^{38} erg/s
  (or lower)
- Different progenitor?

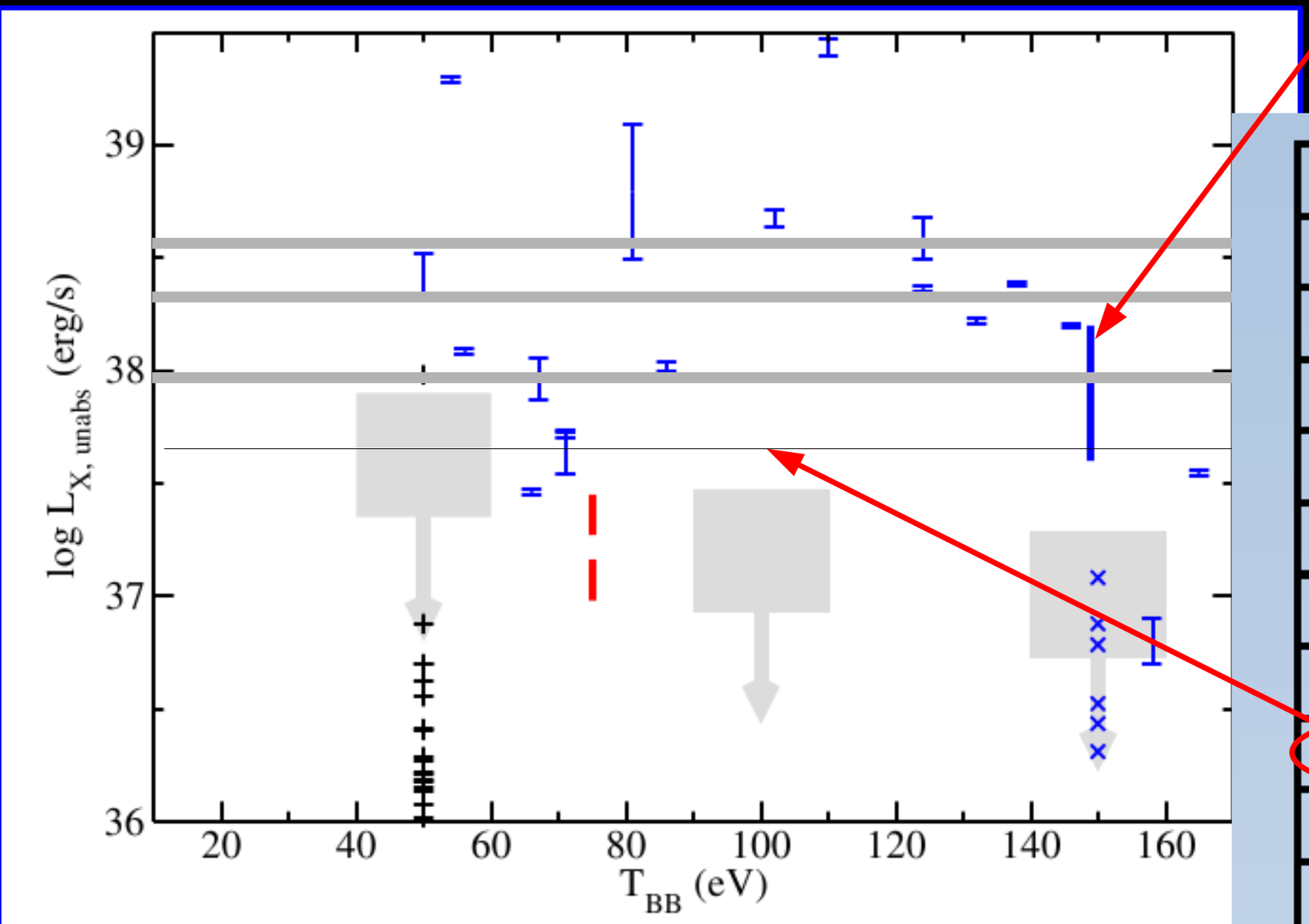
Nelemans et al.2008

Comparison with possible progenitor systems



Galactic supersoft sources

Comparison with possible progenitor systems



SN2007on

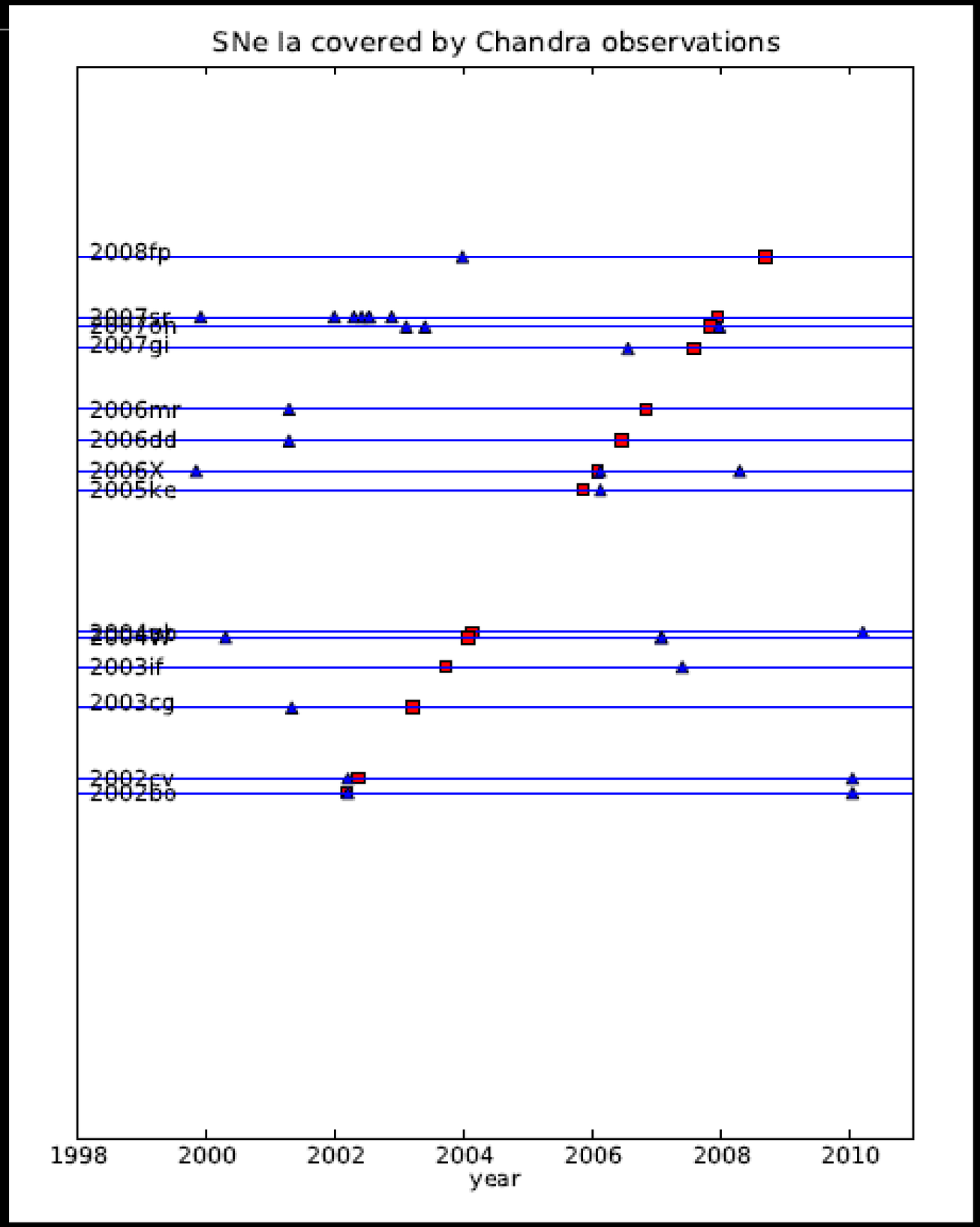
SN	L_x
2008fp	$1.5 \cdot 10^{38}$ erg/s
2007sr	$1.9 \cdot 10^{37}$ erg/s
2007on	$5.1 \cdot 10^{38}$ erg/s
2007gi	$3.6 \cdot 10^{38}$ erg/s
2006mr	$3.7 \cdot 10^{38}$ erg/s
2006dd	$3.1 \cdot 10^{38}$ erg/s
2006X	$2.5 \cdot 10^{39}$ erg/s
2004W	$4.0 \cdot 10^{37}$ erg/s
2003cg	$1.6 \cdot 10^{39}$ erg/s
2002cv	$1.9 \cdot 10^{38}$ erg/s

Extragalactic “soft” X-ray sources

Nielsen et al in prep.

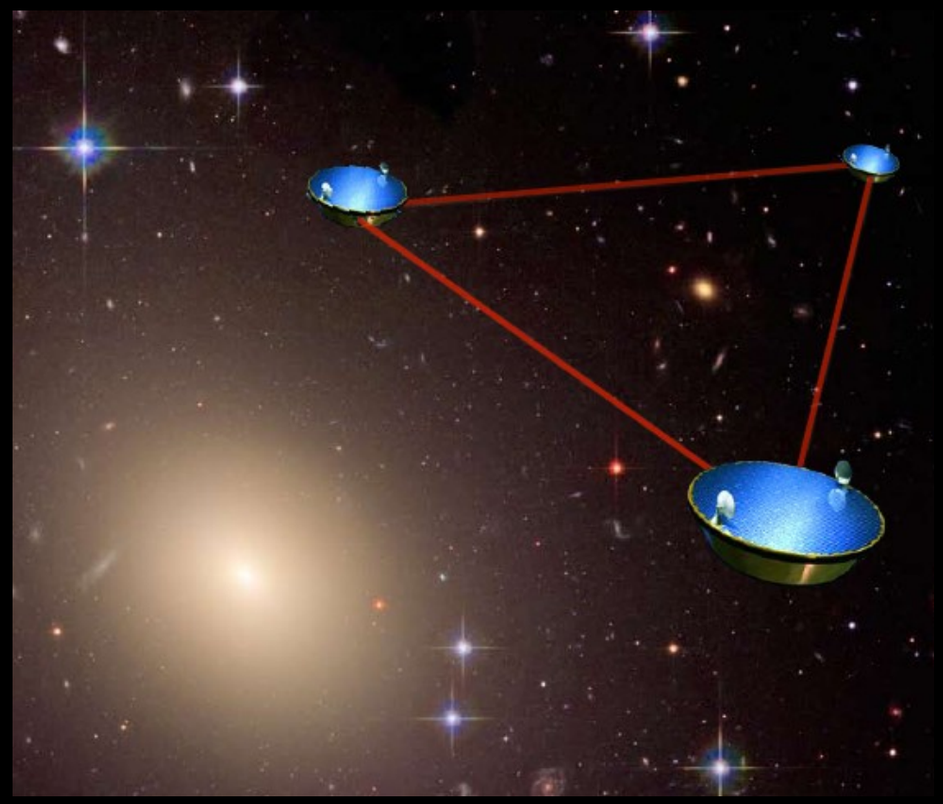
Outlook: next SN?

- Number of type Ia SN in local universe 2-3 10^{-5} /yr/Mpc^3
- Expected number within 25 Mpc ~2 per year
- Too many?
- Large fluctuations
- Some 30% have Chandra data.



A short note on LISA

- Low-frequency gravitational wave mission
- Very exciting science (test GR, follow structure formation etc)
- One ESA L1 mission candidates (down selection 2011)
- NASA: no money for any L1 mission.....
- Rapid definition team for ESA-led mission
- For LISA looks very promising: LISA is certainly not dead!



Conclusions

- Supernovae relevant for many aspects of Astrophysics/Cosmology
- Progenitors important when assessing importance of SN
- Population studies promising, but not yet constraining
  - Need local calibration!
- X-ray studies crucial
  - Single degenerate populations, but need to understand obscuration
  - Direct detection possible → One possible detection, many upper limts
- Type Ia SN have different progenitors (2007on vs upper limits)?
- New SN will make this (more) clear