Are Luminous Supersoft X-Ray Sources Progeniors of Type Ia Supernovae?

YES?

Or

NO?

Promises and Puzzles

- Overview, Rosanne Di Stefano
- The white dwarf, Ken Nomoto
- Binary evolution, Ed van den Heuvel
- The disk, Jean-Pierre Lasota

Are SSSs Type Ia progenitors?

Are accreting WDs Type Ia progenitors?

Are SSSs Type Ia progenitors?

Extragalactic studies indicate that not all SSSs are accreting WDs.

Are accreting WDs Type Ia progenitors?

All progenitor systems have the potential to be SSSs at some point during their evolution.

What is needed

- WD

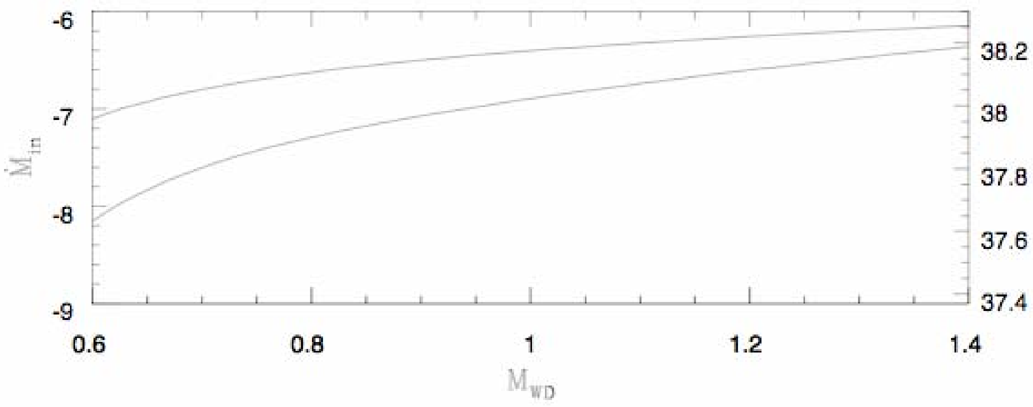
What is needed

- WD
- Source of mass--generally a companion

What is needed

- WD
- Source of mass--generally a companion
- Mass must be burned; this places limits on m_dot.

Quasisteady nuclear burning occurs in a narrow range.



What is needed

- WD
- Source of mass--generally a companion
- Mass must be burned; this places limits on m_dot.
- This places limits on donor’s mass and state of evolution.

What is needed

- WD
- Source of mass--generally a companion
- Mass must be burned; this places limits on m_dot.
- This places limits on donor's mass and state of evolution.
- It also determines L (~10^38 erg/s) and kT (tens of eV)

The Discovery of SSSs

- L and kT are in the right range.

The Discovery of SSSs

- L and kT are in the right range.
- van den Heuvel et al. developed a binary model in which a somewhat more massive, slightly evolved donor contributes rate at just the right rate for nuclear burning.

The Discovery of SSSs

- L and kT are in the right range.
- van den Heuvel et al. developed a binary model in which a somewhat more massive, slightly evolved donor contributes rate at just the right rate for nuclear burning.
- There are ~9 candidates in the Galaxy and Magellanic Clouds for the CBSS (close binary supersoft model).

Population synthesis

- How many CBSSs are predicted from first principles?
- Result: ~1000 in M31 and in the Milky Way (Rappaport et al. 1994)
- Verified by Yungelson et al. (1995), who predicted about half as many.

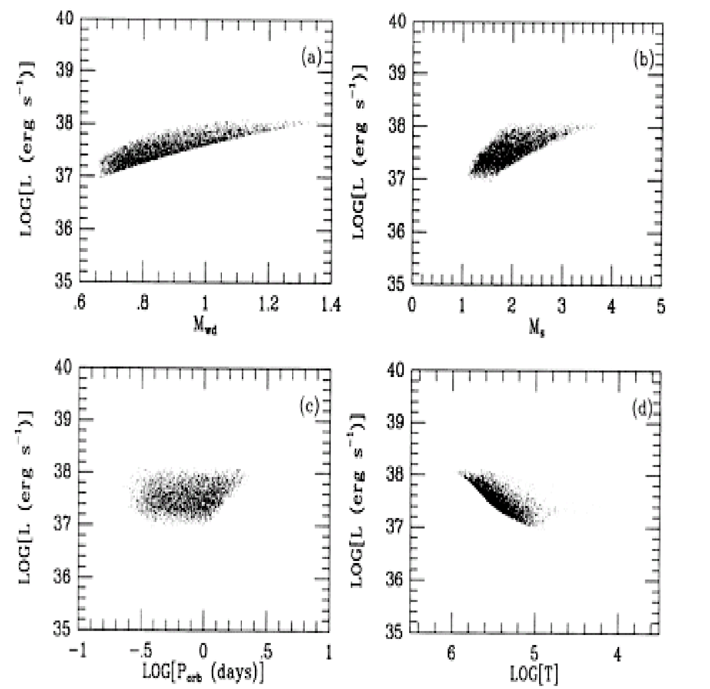


FIG. 2.—Luminosity vs. (*a*) white dwarf mass, (*b*) mass of donor star, (*c*) orbital period, and (*d*) effective temperature of simulated supersoft X-ray sources at the current epoch (standard model). Approximately 3×10^6 initial binaries were used in the simulation. Each dot represents a single supersoft system, without regard to its lifetime.

Based on observations

- Modeling galactic gas distributions; ``seeding" galaxies with SSSs from:
  (a) observations
  (b) simulations
- Result: ~1000 in M31 and in the Milky Way (Di Stefano & Rappaport 2004)
- Interstellar gas hides most SSSs--whatever their basic nature.
- Could be many more with low L and/or T.

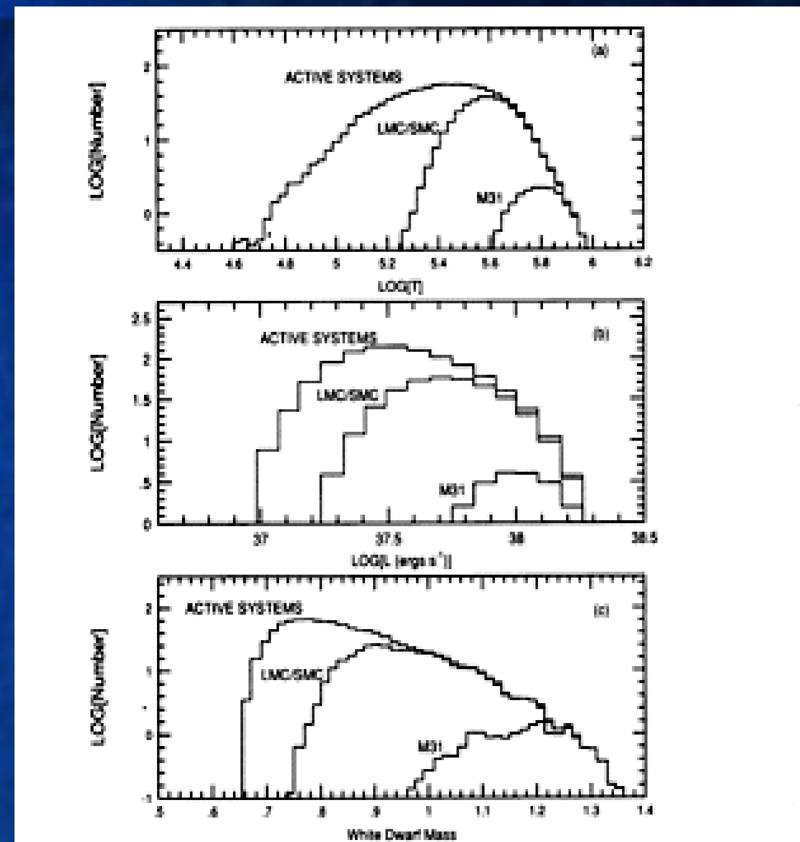


FIG. 3.—Calculated properties of supersoft X-ray sources that should be detected with *ROSAT*. In each panel the uppermost curve, which encompasses

What do NBWDs look like?

- The disks do not hide the soft radiation.
- Radiation from the disk may dominate over radiation from the donor.
- Are there winds from the the disks?
- Not all systems have disks.

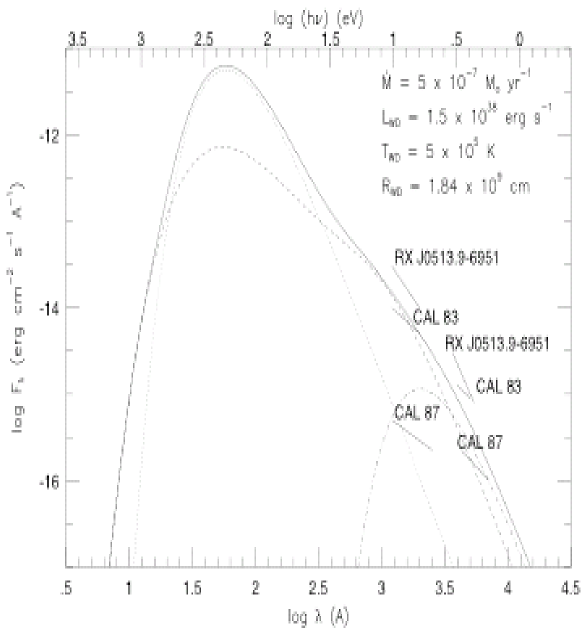
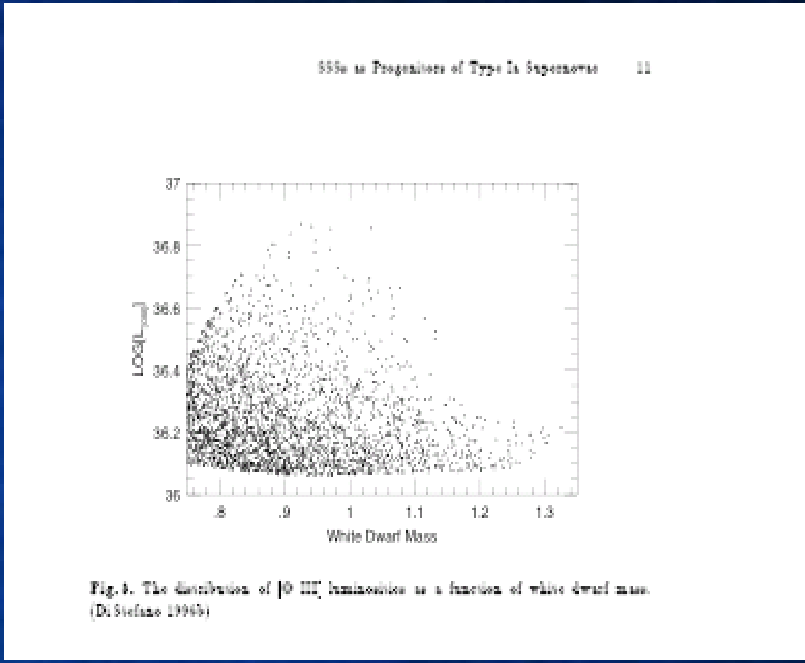


Fig. 4. Spectra for the same solution as in Fig. 3: the spectra of the white dwarf (dotted line), the disk with reprocessing and flaring (dashed line), and the donor star (dash-dotted line), and the combined spectrum of the three (solid line).

What do NBWDs look like?

- SSSs emit copious quantities of highly ionizing radiation.
- They can ionize the ISM over volumes of ~10^3 pc^3
- SSS nebulae have distinctive line ratios.
- Not very sensitive to duty cycle.
- Only CAL 83 has such a nebula.



Computing the Evolution

Conservation of Angular Momentum

$$\frac{\dot{J}}{J} = \frac{\dot{m}}{m} + \frac{\dot{M}}{M} - \frac{1}{2}\frac{\dot{M}_T}{M_T} + \frac{1}{2}\frac{\dot{a}}{a}$$

Loss of Orbital Angular Momentum

$$\frac{\dot{J}}{J} = \frac{\dot{J}_{gr}}{J} + \frac{\dot{J}_{mb}}{J} + \frac{\dot{J}_{ej}}{J}$$

Assume that the Donor Overfills its Roche Lobe

$$R_d = f(q)\ a; \quad q = m/M$$

$$\frac{\dot{a}}{a} = \frac{\dot{R}_d}{R_d} - \dot{q}\ \frac{d\ ln[f(q)]}{dq}$$

$$\frac{\dot{R}_d}{R_d} = \frac{(\dot{R}_d)_{th}}{R_d} + \frac{(\dot{R}_d)_{ad}}{R_d} + \frac{(\dot{R}_d)_{nuc}}{R_d}$$

$\dot{m}$ can be computed:

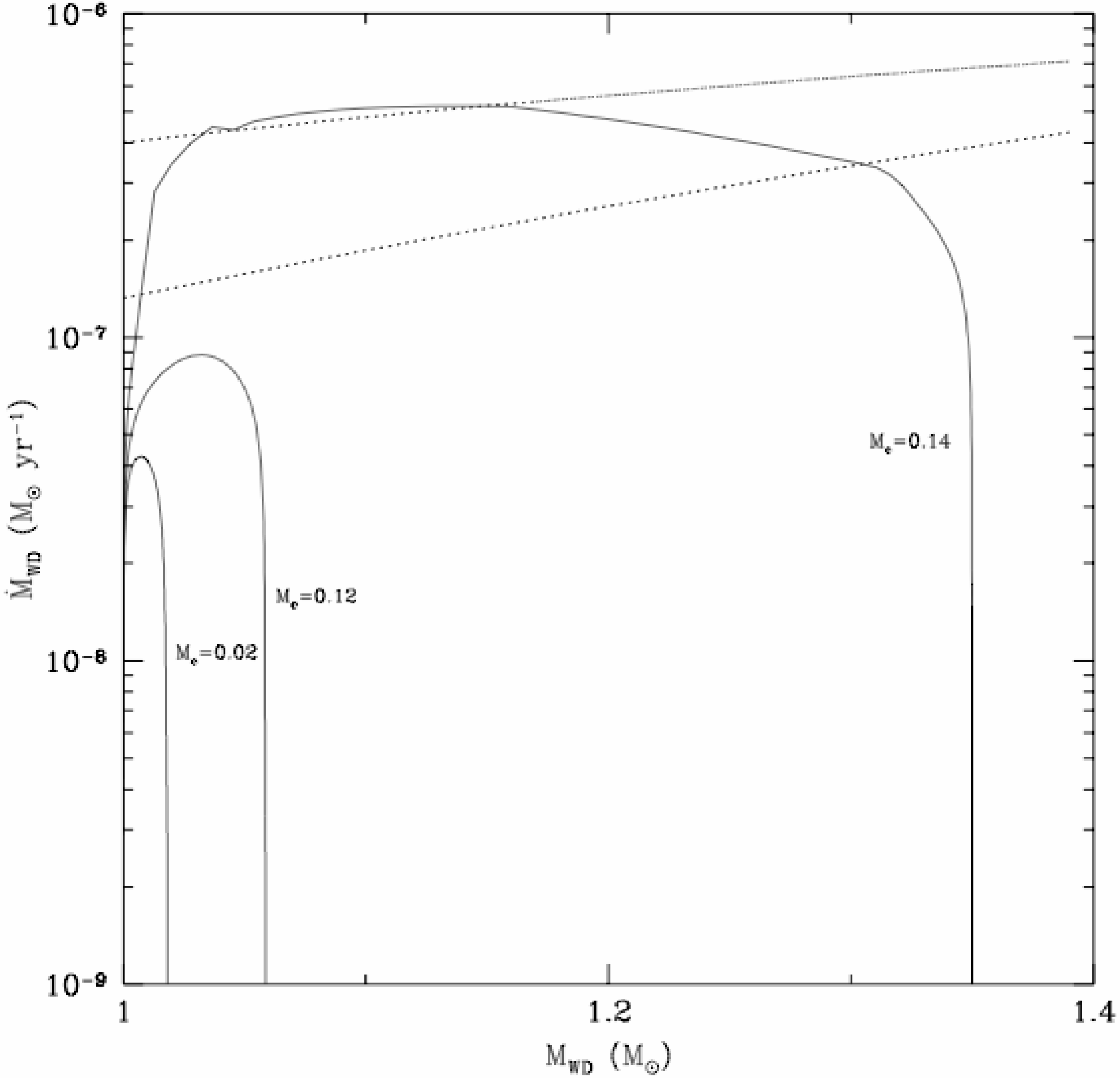
$$\frac{\dot{m}}{m} = \frac{\mathcal{N}}{\mathcal{D}}$$

$$\mathcal{N} = 2\left[\frac{\dot{J}_{gr}}{J} + \frac{\dot{J}_{mb}}{J}\right] - \left[\frac{(\dot{R}_d)_{th}}{R_d} + \frac{(\dot{R}_d)_{nuc}}{R_d}\right]$$

$$\mathcal{D} = \xi_{ad} + 2(1 - \beta\ q) - \frac{q(1-\beta)(1+2q^{\alpha-1})}{(1+q)}$$

$$-(1+\beta\ q)\frac{d\ ln[f(q)]}{d\ ln[q]}$$

Stability of mass transfer $\Longrightarrow \mathcal{D} > 0$.



10^{-6}
10^{-7}
10^{-8}
10^{-9}
$\dot{M}_{WD}$ ($M_\odot$ yr^{-1})
M_e=0.14
M_e=0.12
M_e=0.02
1
1.2
1.4
M_{WD} ($M_\odot$)

Population synthesis + Evolution

- The rates are adequate--but only if there is significant mass ejected from the system, and the mass doesn’t carry much angular momentum. (Di Stefano, Nelson, Rappaport, Wood, Lee 1995; Di Stefano & Nelson 1996; Di Stefano 1996)

The full range of binary models

- At least 17 parameters are needed to determine the stability of mass transfer and the nature of the final state.
- These encompass CBSSs, WBSSs, symbiotics and other wind driven systems, each of which is itself specified by masses, compositions, and orbital characteristics.

The full range of binary models

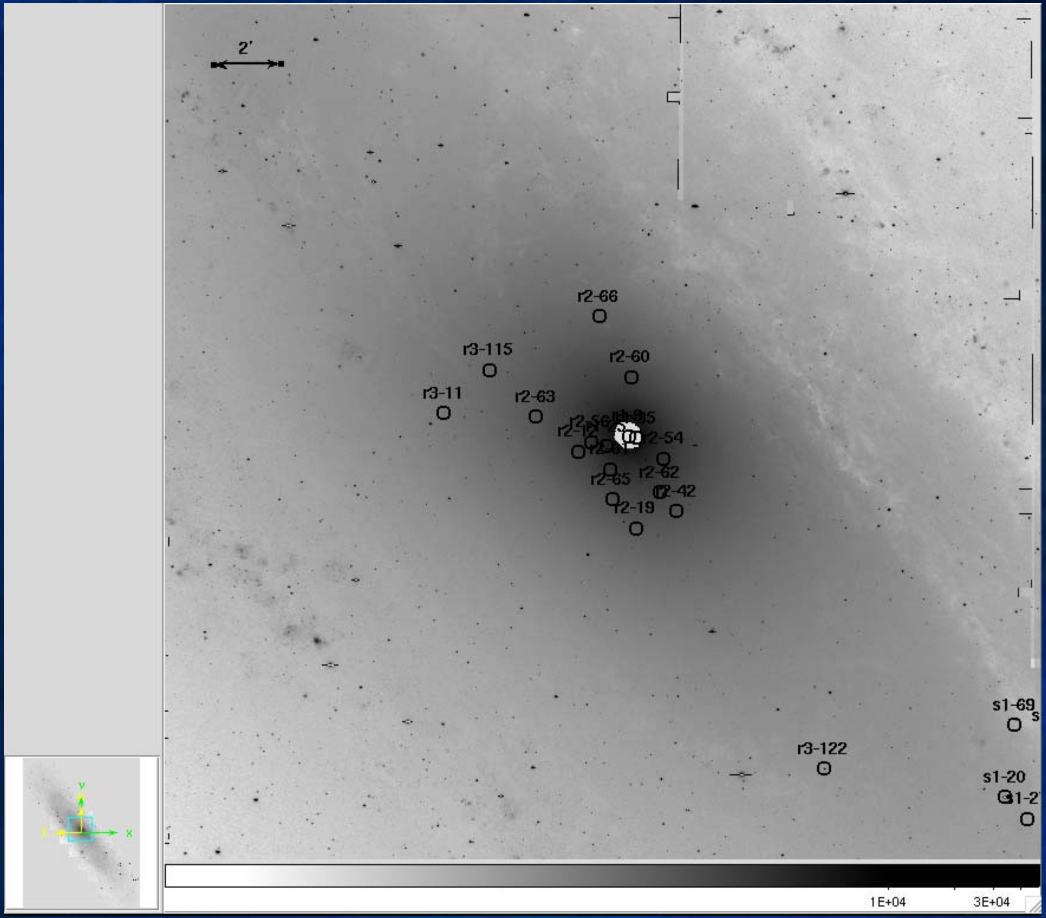
- There are many paths that, with our present understanding seem viable; the rates can be achieved.
- Physical principles can be used to predict the values of the parameters. In addition, they are not all independent. But we have a lot to understand in order to make reliable predictions.
- Failed accretion systems can become double degenerates.

The post-SN interactions are determined by the flow of mass and radiation in the progenitor systems.

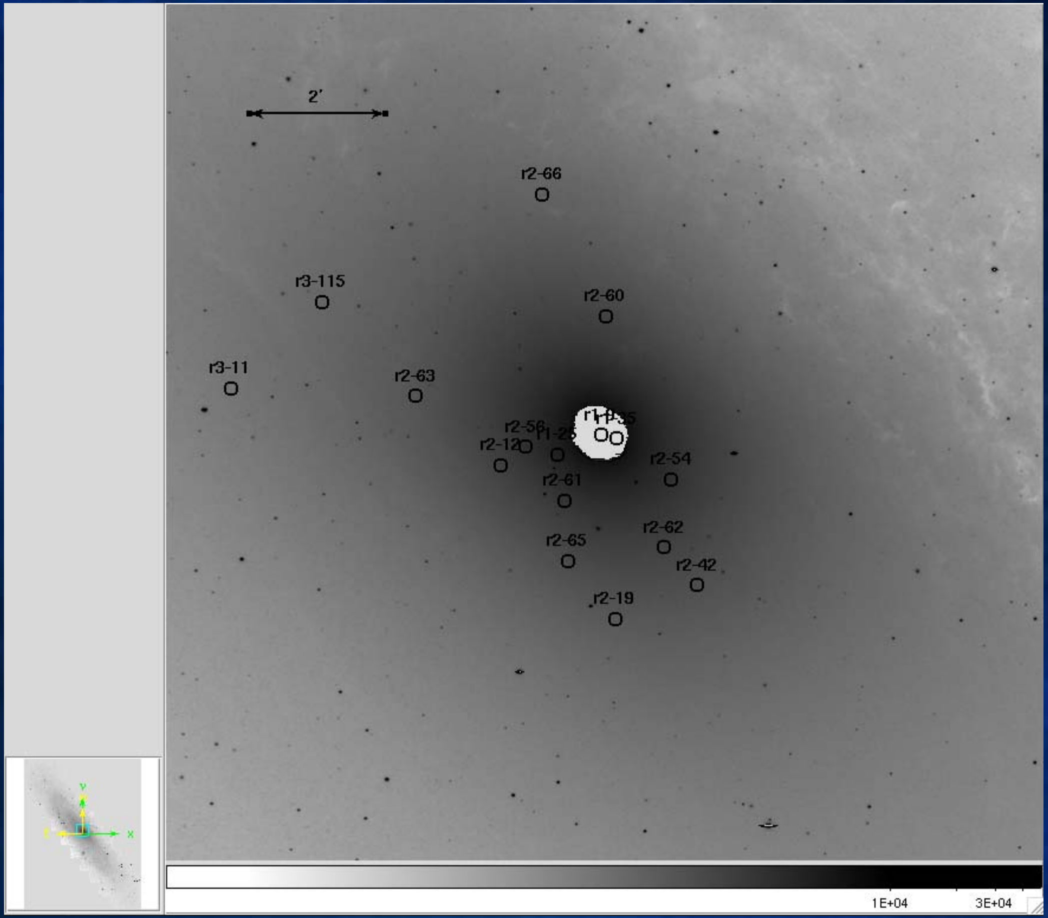
Searching for SSSs in other galaxies

- Collaborators: Albert Kong, Frank Primini, Jifeng Liu, Jochen Greiner, Pauline Barmby, Roberto Soria, Steve Murray, Mike Garcia, Brandon Patel, Sarah Scoles, Tess Russo, Shannon Curry, Ben Williams, Paul Hodge, Phil Massey, Marina Orio, Robert Friedman, Bill Harris, and others…

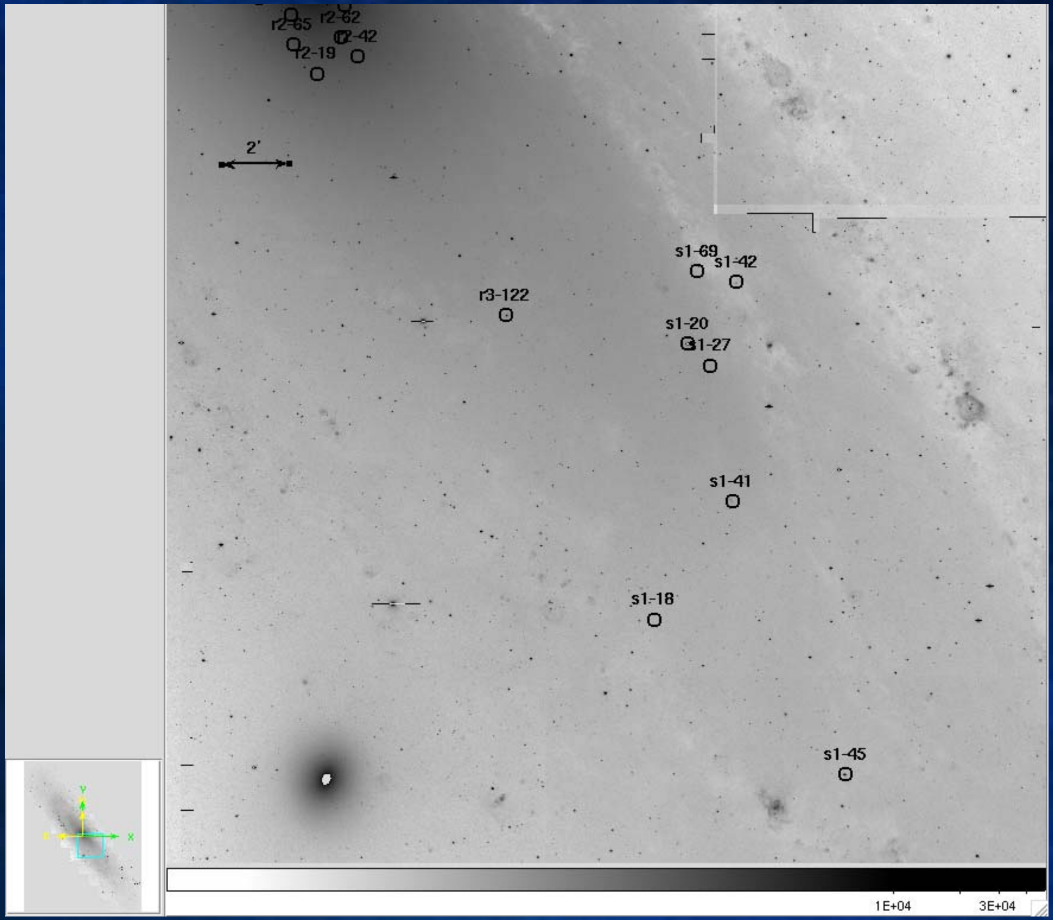
SSSs in the center of M31



SSSs in the center of M31



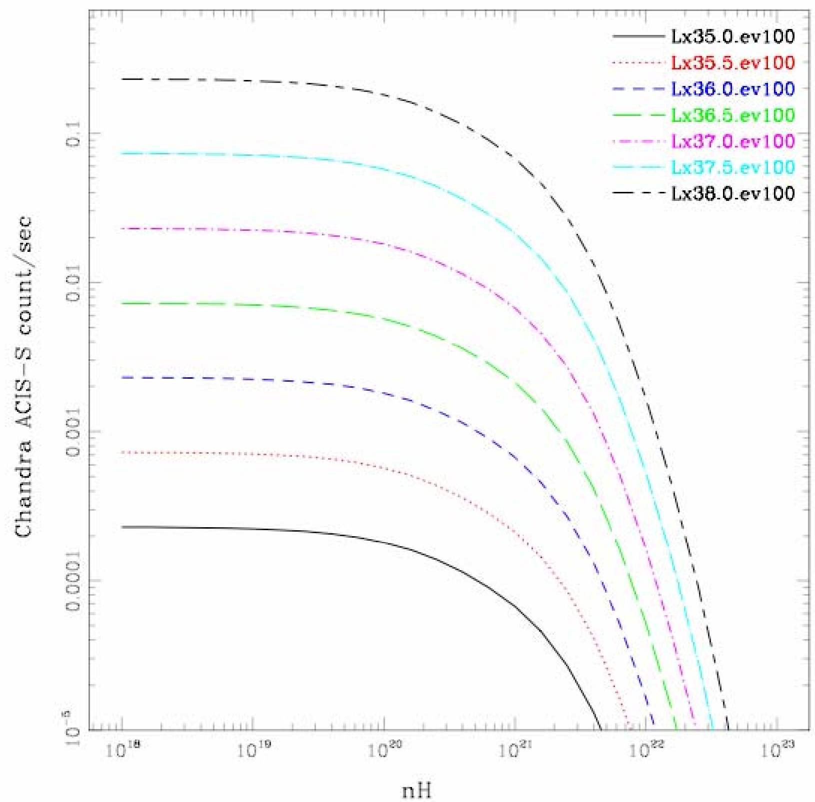
SSSs in the disk of M31



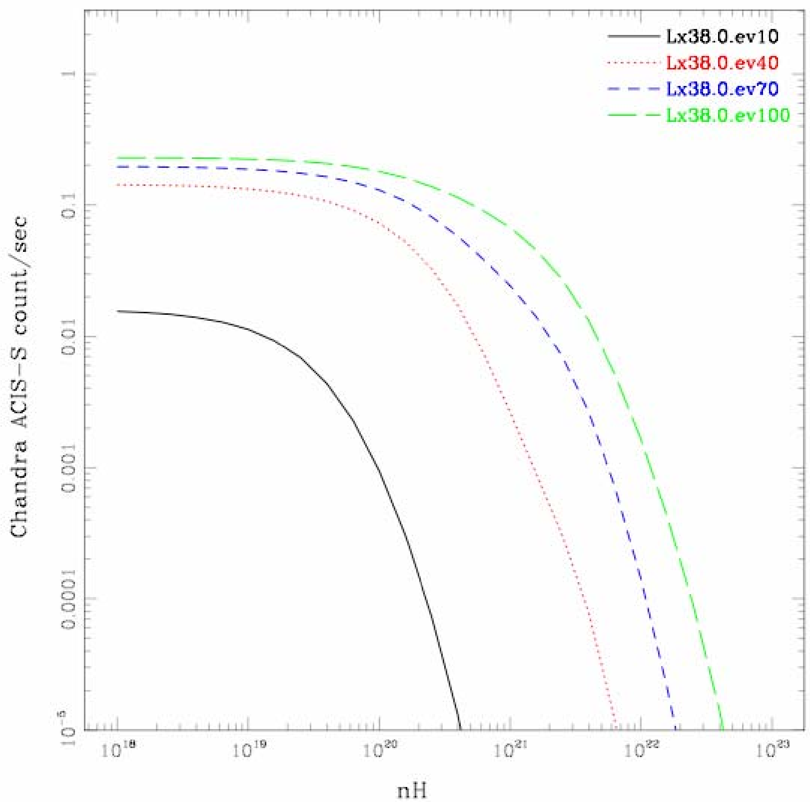
- SSSs in other galaxies: with ~18 in the Galaxy and the Magellanic Clouds, we now know of hundreds in external galaxies. (See the 10 facts of SSS life in the van den Heuvel volume.)
- Some are very close to the central BH. (Tidally stripped giants? RD et al. 2001)
- Some are good candidates for intermediate-mass black holes. (See work by Kong et al.)

Accreting, nuclear-burning WDs with $M > 1 M_{sun}$

- Their luminosities are high ($L_x \sim 10^{38}$ erg/s).
- Their temperatures are high ($kT \sim 100$ eV)
- They are not generally hidden by the ISM or their galaxy or of our Galaxy.



Lx35.0.ev100
Lx35.5.ev100
Lx36.0.ev100
Lx36.5.ev100
Lx37.0.ev100
Lx37.5.ev100
Lx38.0.ev100
Chandra ACIS-S count/sec
0.1
0.01
0.001
0.0001
10^{-5}
10^{18}
10^{19}
10^{20}
10^{21}
10^{22}
10^{23}
nH



Lx38.0.ev10
Lx38.0.ev40
Lx38.0.ev70
Lx38.0.ev100
Chandra ACIS-S count/sec
1
0.1
0.01
0.001
0.0001
10^{-5}
10^{18}
10^{19}
10^{20}
10^{21}
10^{22}
10^{23}
nH

If M_c single degenerate models are the dominant progenitor channel, we should detect hundreds of bright, hot SSSs in external galaxies like M31.

Because the most luminous systems are nuclear-burning WDs (NBWDs) with mass near M_C, we focus on systems within $0.2\,M_\odot$ of a Type Ia SN explosion. The time required to reach M_C is:

$$\tau_{acc} = \left(\frac{\Delta M}{0.2\,M_\odot}\right)\left(\frac{4 \times 10^{-7} M_\odot\, yr^{-1}}{\beta\, \dot{M}_{in}}\right) 5 \times 10^5\, yrs. \tag{1}$$

where the value of $\beta\, \dot{M}_{in}$ represents an average during the epoch when the WD's mass changes from roughly $1.2\,M_\odot$ to $1.4\,M_\odot$.

In spiral galaxies, the rate of SNe Ia is roughly 0.3 per century per $10^{10} L_\odot$ in blue luminosity. In a galaxy with blue luminosity L_B, the number, N_{acc}, of accreting progenitors within $0.2\,M_\odot$ of M_C is roughly

$$N_{acc} = 1500 \left(\frac{\Delta M}{0.2\,M_\odot}\right)\left(\frac{4 \times 10^{-7} M_\odot\, yr^{-1}}{\beta\, \dot{M}_{in}}\right)\left(\frac{L_B}{10^{10} L_\odot}\right). \tag{2}$$

For most spiral galaxies (and even for ellipticals, with a lower rate of SNe Ia), N_{acc} cannot be much smaller than several hundred, and is likely to be more than 1000.

- We typically detect ~10.
- We can rule out that the M_c accreting, nuclear-burning WD models are the dominant channel…if they must appear as SSSs when most of the mass is gained.

Obscuration?

- For example by winds?
  Winds can open up a cavity around the source, and can also set the stage for post-explosion interactions.

- Testable by studying late-time evolution and also by signatures in the remnants.

Photospheric expansion?

- Likely to produce a lot of photoionizing radiation.
- May be testable both pre-and post-explosion.

Duty cycle?

- Predicts more systems, each of which is “on” for a shorter time.

Almost all progenitors likely experience some stage of quasisteady nuclear burning.

Some may look like SSSs part of the time.

A variety of existing and future data can place limits and provide clues to the fundamental physics.