The long-duration neutron star X-ray transient KS 1731–260 in quiescence: Too cold a neutron star?

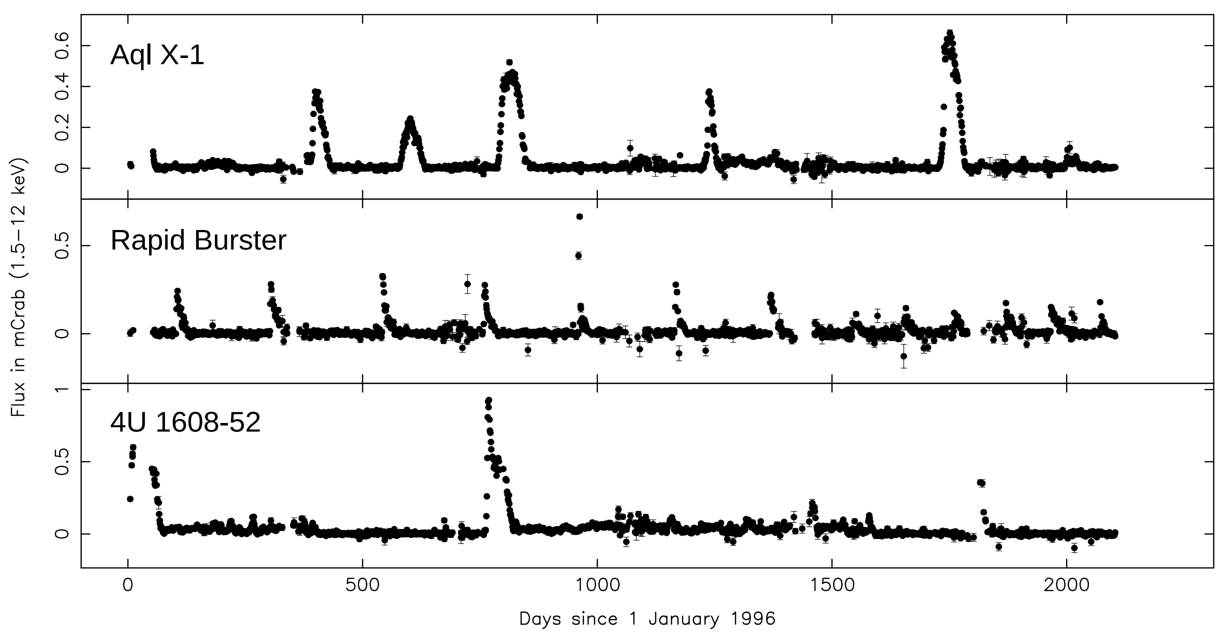
Rudy Wijnands

Center for Space Research
Massachusetts Institute of Technology

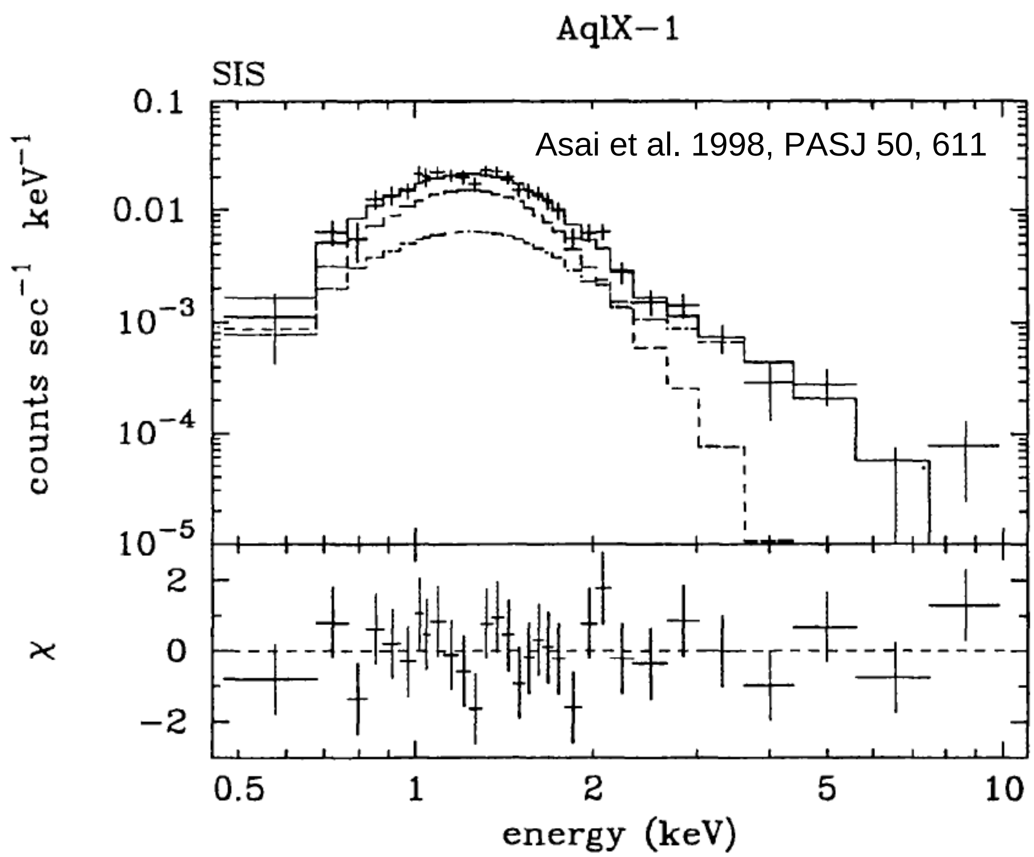
Chandra Fellows Symposium
Harvard-Smithsonian Center for Astrophysics
October 15, 2000

Neutron star X-ray transients

- Neutron-star X-ray transients in outburst
  - High luminosity: $10^{36} - 10^{37}$ erg s^{-1}
  - Active for weeks to a few months
  - Quiescent for months to decades



- Neutron-star X-ray transients in quiescence
  - Low luminosity: $10^{32} - 10^{34}$ ergs s^{-1}
  - Hard component above 2 keV: power-law like with photon index of 1–2
  - Soft spectrum: black-body like



The neutron-star cooling model

- The soft component is due to the cooling of the neutron star in between outburst
  - Van Paradijs et al. 1987, A&A 182, 47
    Verbunt et al. 1994, A&A 285, 903
    Asai et al. 1996, PASJ 48, L27

- Main problem: black-body fits to quiescent spectra give a radius for the emitting area of a few kilometers $<$ theoretical expected neutron-star radii

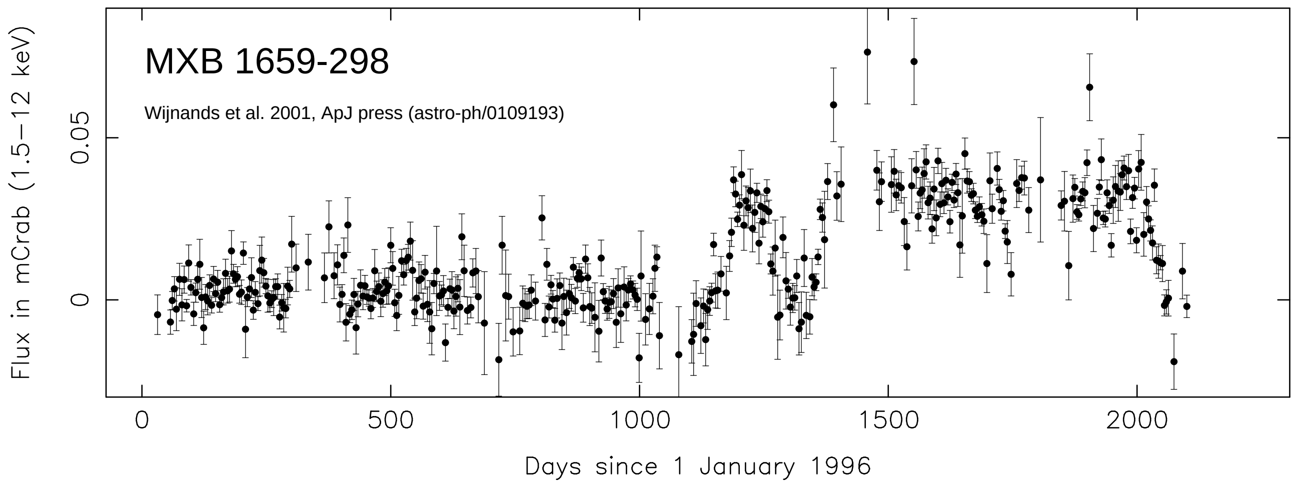
- Solution: Brown et al. (1998, ApJ 504, L95) pointed out that the spectra are more realistically fit with hydrogen atmosphere models
  - Fit data well, although many models fit data well
  - Radii of order 10 kilometers (e.g., Rutledge et al. 1999, ApJ 514, 945)

- Prediction of model: the exact quiescent luminosity depends on the time-averaged accretion history
  - Quiescent luminosities of detected sources agree with the predicted ones (e.g., Rutledge et al. 1999, ApJ 514, 945)
  - Predicted the low quiescent luminosity of SAX J1808.4–3658 based on its low time-averaged accretion rate. Dotani, Asai, & Wijnands (2000, ApJ 543, L145) detected such low quiescent luminosity

- Model successful, but more testing is needed

Long-duration X-ray transients

- Like "normal" transients they suddenly become active, but instead of disappearing after a few weeks to months they stay active for years to decades



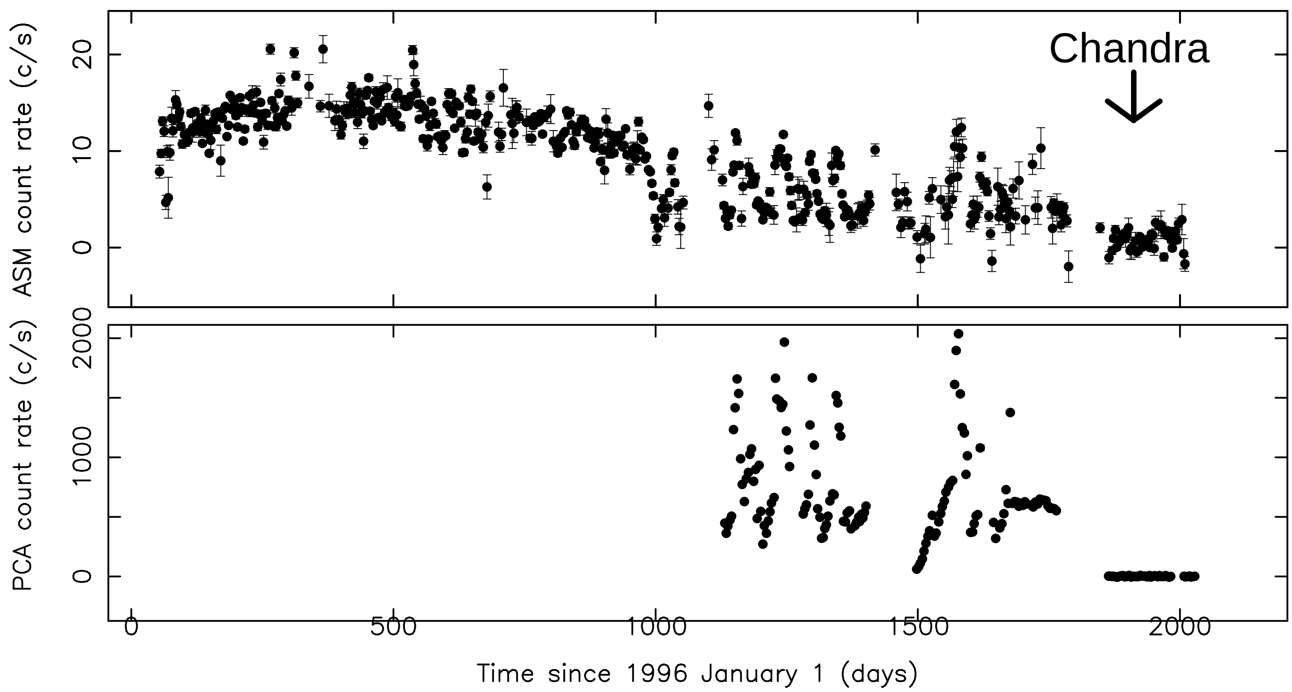
- The turn-off of such a source is an excellent opportunity to study the effects of a very long episode of accretion on the quiescent properties of a neutron star transient

- If Brown et al. model is correct, then the neutron star in such systems should be heated up to very high temperatures
  - If the quiescent periods of such systems are similar to the normal transients
  - And if such long outbursts are typical for those sources
  - And if standard cooling occurs in all neutron star systems

- But the quiescent properties could be dominated by the crust for several years. However, then the measured temperature from the X-ray spectrum is an upper limit on the temperature of the core!

KS 1731–260

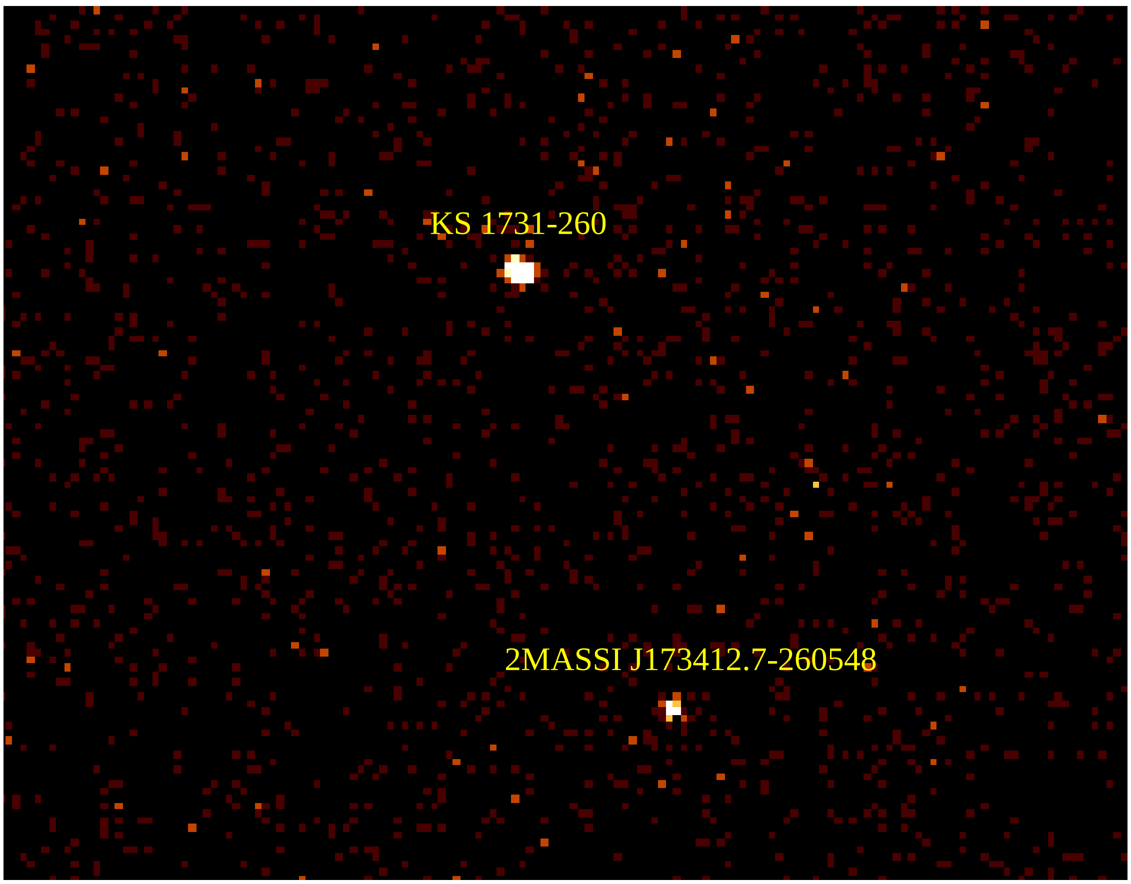
- Turned on in mid-1988 (Sunyaev 1989, IAUC 4839)
- X-ray burster $\Rightarrow$ neutron-star system
- Stayed on until end of 2000



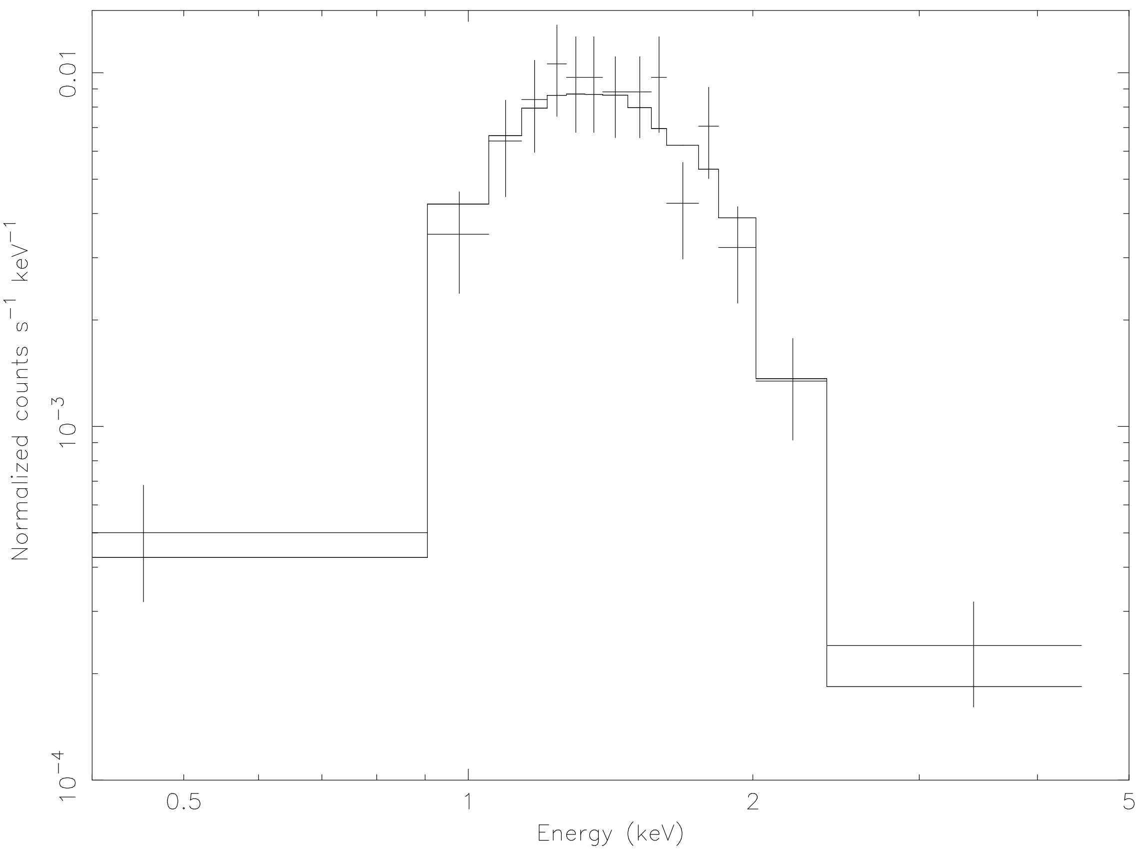
- We requested a *Chandra* DDT observation
  - Harvey Tananbaum approved; observed on 27 March 2001

The Chandra results

- Two point sources detected; one is KS 1731–260



- X-ray spectral analysis



  - Bolometric luminosity of $\sim 2 \times 10^{33}$ erg s^{-1}
  - Temperature of $\sim$0.1 keV

Conclusions and consequences

- Temperature and luminosity of KS 1731–260 are very similar to other quiescent neutron-star systems!

  – Such similarity predicted by models other than the cooling neutron-star model (e.g., residual accretion models; see Wijnands 2001, astro-ph/0107600 for discussion)

  – Unexpected in the cooling neutron-star model! As explained before, the neutron-star temperature was expected to be much hotter.

- Most likely the crust has not yet relaxed and the measured temperature is that of the crust $\Rightarrow$ the core temperature should be even lower!

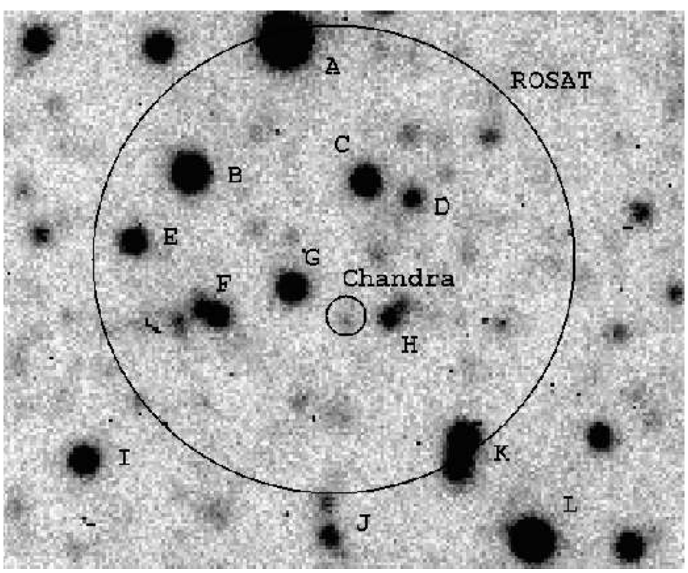
- Too cold a neutron star?

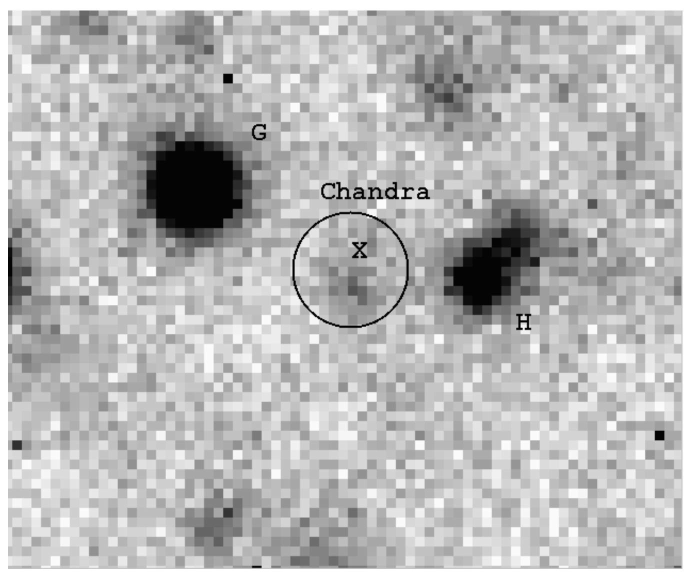
Possible reasons why the neutron star is so cold

- Enhanced neutrino cooling in the core (e.g., Colpi et al. 2001, ApJ 548, L175
  - Heavy (>1.7 $M_\odot$) neutron star
- KS 1731−260 is in quiescence in between outbursts for >1000 years in order for the neutron star to cool down
  - New type of X-ray transient?
  - Several hundreds present in our Galaxy
  - Important for population statistics
- Cooling neutron-star model is incorrect
  - But other models are even less successful

Future work

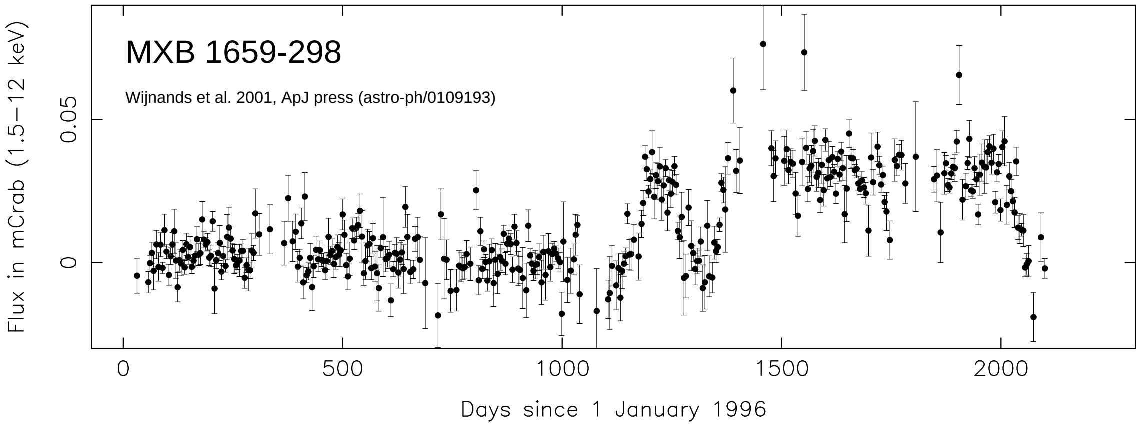
- Further observations of KS 1731–260
  - To study the relaxation of the crust
  - Rutledge et al. (2001, ApJ submitted astro-ph/0108125) presented cooling curves of the crust
  - XMM-Newton observation performed 12–13 Sep. 2001
- The optical/infra-red counterpart of KS 1731–260 (Groot et al. 2001, in preparation)





- MXB 1659–298

  – MXB 1659–298 turned off after 2.5 years!



  – Chandra observation scheduled for today!

  – Good knowledge of the outburst history

  – Very good upper limit (1–4 $\times 10^{32}$ erg s^{-1}) on the quiescent luminosity before the last outburst

    * Allows detailed comparison of quiescent luminosity before and after outburst ⇒ detailed determination of the effects of the 2.5 years of accretion on the crust!

    * The temperature of the core is very low ⇒ detailed study of the cooling curve of the crust (need follow up observations!)