Recent observations of Sakurai's Object

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Outline

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- Evolutionary models of Sakurai's Object.
- Recent radio and optical observations of Sakurai's object.
- Interpretation of the data, including a new Cloudy model.
- The evolution of the dust in Sakurai's Object.
- Conclusions.
- CK Vul has been covered by Stefan Kimeswenger. Also look out for Hajduk et al., 2007, MNRAS, in press.

Evolutionary Models

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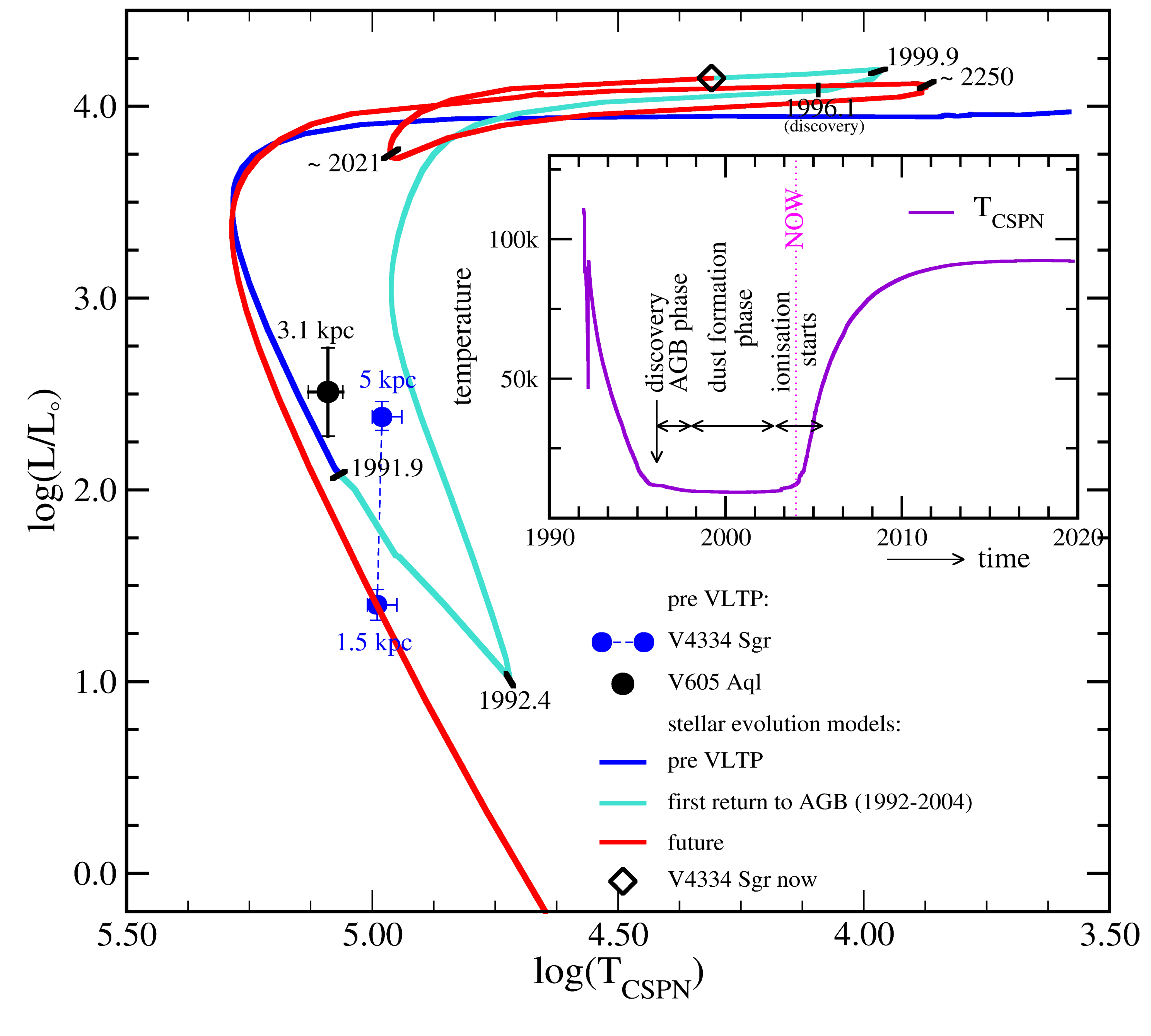
- Sakurai's object baffled the scientific community with its very fast evolution, must faster than pre-discovery models predicted.
- Three evoluitionary models have been proposed to explain the fast evolution, all focusing on the hydrogen ingestion flash in the helium burning shell.
- Herwig (2001, ApJ, 554, L71) and Lawlor & MacDonald (2003, ApJ, 583, 913) assume that the efficiency of the hydrogen ingestion is reduced by buoyancy effects, causing the burning to occur closer to the surface.
- Lawlor & MacDonald (2003) were the first to predict the double-loop evolution in the HR diagram, later confirmed by Herwig's model in Hajduk et al. (2005, Science, 308, 231).
- Miller Bertolami et al. (2006, A&A, 449, 313) claim that they can reproduce very fast evolution by using very small time steps, but without changing the mixing physics. This raises doubts about the accuracy of other calculations.

Hajduk et al., 2005, Science, 308, 231



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VLA Observations

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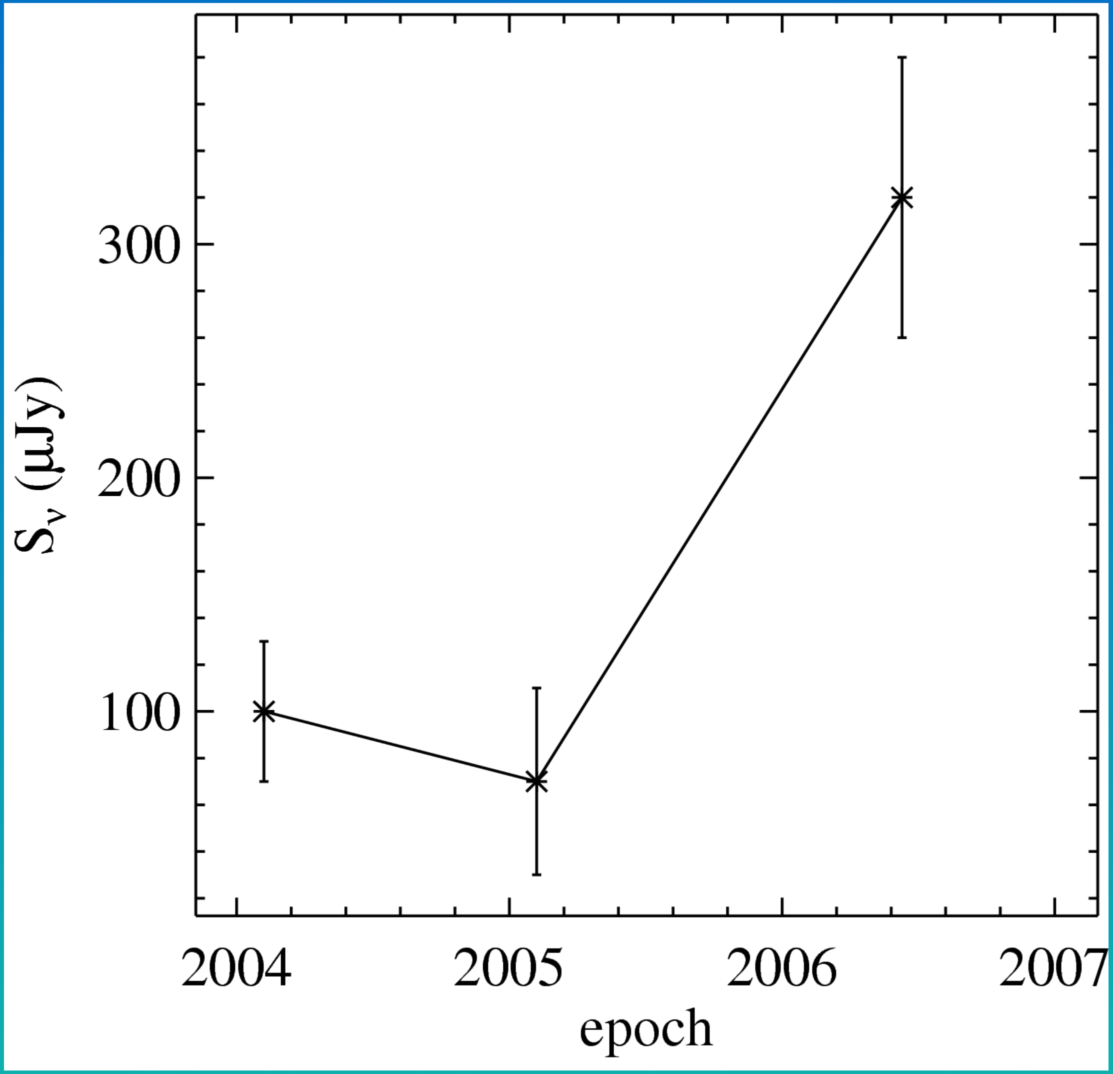
- 2004: BnC configuration:
  8 GHz 100 ± 30 μJy
- 2005: AnB configuration:
  8 GHz 70 ± 40 μJy
  5 GHz < 90 μJy
- 2006: AnB configuration:
  8 GHz 280 ± 50 μJy
  5 GHz 320 ± 60 μJy
- The sudden increase in 2006 is ascribed to the starting photoionization of carbon.
- T_{eff} must be lower than assumed in Hajduk et al. (2005).



Optical Observations

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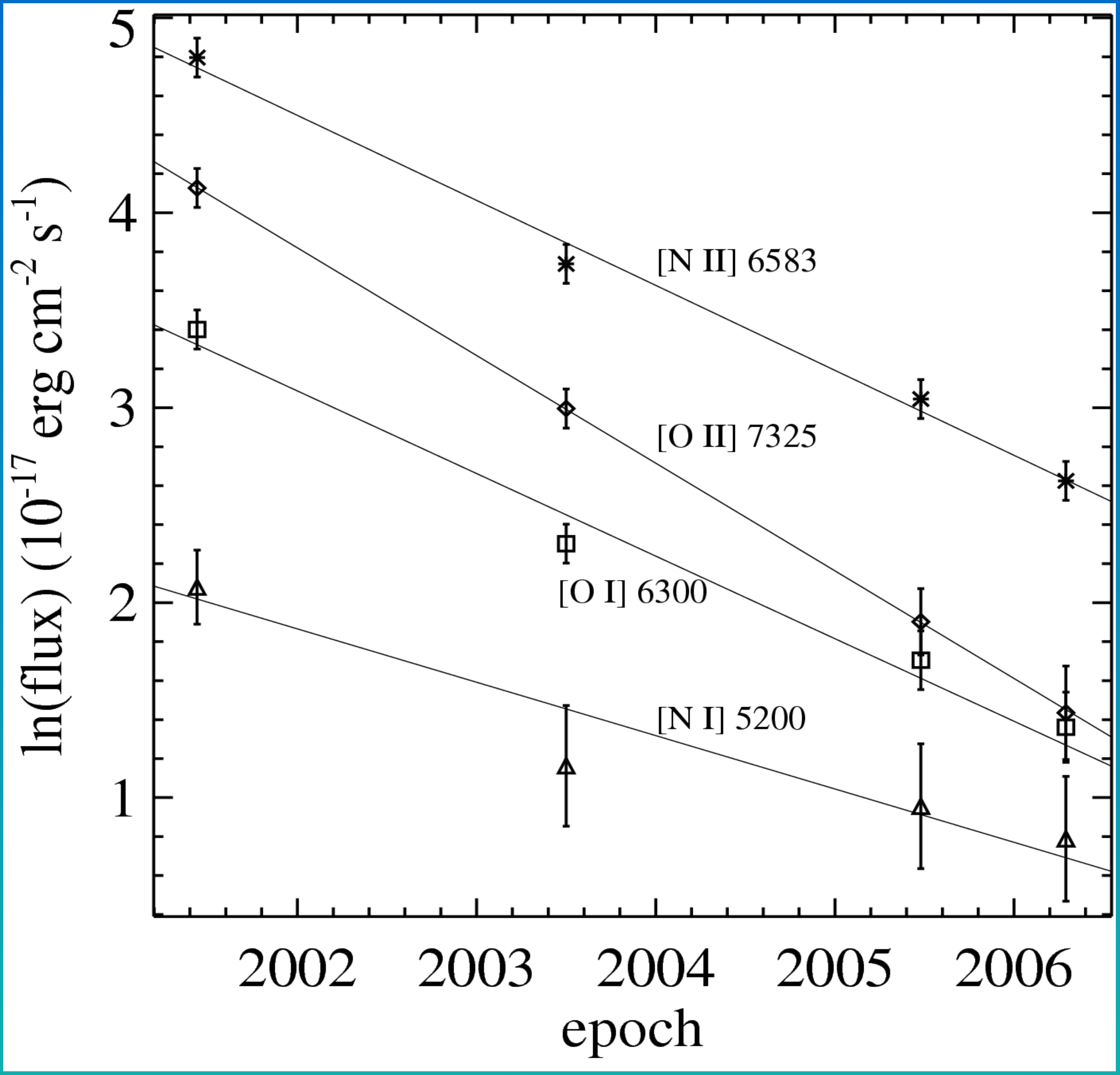
- We have been monitoring the evolution of the optical emission line spectrum since 2001. Its evolution is different from the radio flux.
- The optical lines show an exponential decline in intensity, and also a decreasing level of excitation. This trend continues even in 2006.
- This rules out photoionization as the cause of the optical emission, contrary to our claim in Hajduk et al. (2005).
- The optical spectrum is consistent with a shock that occurred somewhere before 2001 and is currently cooling and recombining. The low T_e derived from the [N II] lines in 2001 (3200 – 5500 K) and the [C I] lines in 2003 (2300 – 4300 K) is consistent with this.
- The earliest evidence for this shock is the detection of the He I 10830 Å recombination line in 1998 (Eyres et al. 1999, MNRAS, 307, L11). This line was absent in 1997. The shock must have occurred around 1998 and must have stopped soon after, leaving cooling and recombining gas in its wake.

van Hoof et al., 2007, A&A letters, in press



Cloudy Modeling

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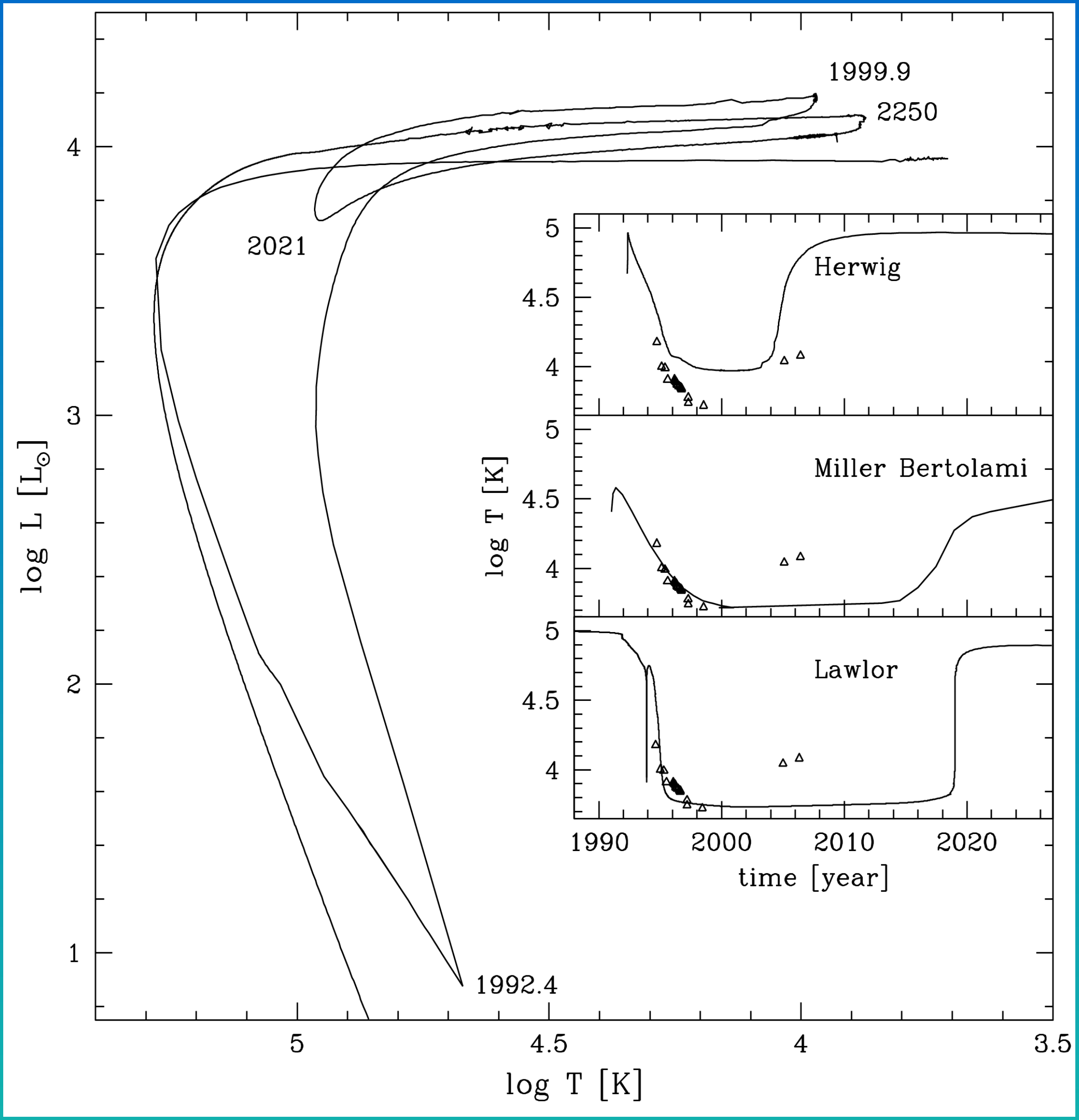
- We created new Cloudy models with various new assumptions:
- We used a preferred distance of 4 kpc (possible range 1.8 – 5 kpc).
- We used a diameter of 0.3 to 0.5 arcsec.
- We allowed the medium to be clumpy, and have a $1/r^2$ density distribution.
- We used a fixed dust mass in all the models, based on the 25 µm flux in the Spitzer IRS spectrum (Evans et al. 2006, MNRAS, 373, L75).
- We assumed the radio flux in 2004/5 to come from the shock, but the flux in 2006 was largely due to photoionization of carbon.
- We varied the density. The best-fit models are consistent with $T_{eff} \leq 11$ kK in 2005 and ≈ 12 kK in 2006. So the heating rate is around 1 kK/yr or more.
- The shell mass is between $6\ 10^{-4}$ Msol (f=0.01) and $6\ 10^{-3}$ Msol (f=1) using d=4 kpc. Removing $5\ 10^{-3}$ Msol would expose the intershell region leaving a star with [WC] or PG 1159 abundances.

van Hoof et al., 2007, A&A letters, in press



Dust Formation

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- Based on the 25 µm flux in the April 2005 Spitzer IRS spectrum (Evans et al. 2006, MNRAS, 373, L75) we determined a total dust mass of 8.7 10^{-6} Msol at 4 kpc using graphite opacities.
- Comparing this to a total dust mass of 1.6 10^{-6} Msol in June 2003 (Evans et al. 2004, MNRAS, 353, L41), it is clear that dust formation is still ongoing, despite the fact that we don't see hot dust. It is not clear whether new grains are forming beyond the sublimation radius, or existing grains are growing in mass.
- That shows that dust formation is slow in Sakurai's Object and makes converting dust growth rates into mass loss rates questionable. The current Cloudy models indicate a gas/dust mass ratio of 870 $\sqrt{f}$.
- Dust formation started around the same time as the shock occurred. The UV radiation from the shock may have accelerated dust formation elsewhere.
- In this view the shock may have occurred in a bipolar outflow, while the dust formation is taking place in an EDE / circumstellar disk.

Conclusions

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- Photoionization of carbon in the ejecta of Sakurai's Object has started around 2005.
- Simultaneously the optical spectrum shows a continuing decline, both in intensity and excitation. This is likely the result of a shock that occurred around 1998 and stopped shortly after.
- Using new Cloudy models we determined that $T_{eff} \approx 12$ kK in 2006 and rising by about 1 kK/yr or more. This confirms that the object is reheating fast.
- The shell mass is between 10^{-4} and 10^{-2} Msol, considering the full range for the distance and the filling factor of the outflow.
- The D/G mass ratio may be lower than hitherto assumed, showing that dust formation is slow and still ongoing.