Thermal-viscous instabilities in large accretion discs

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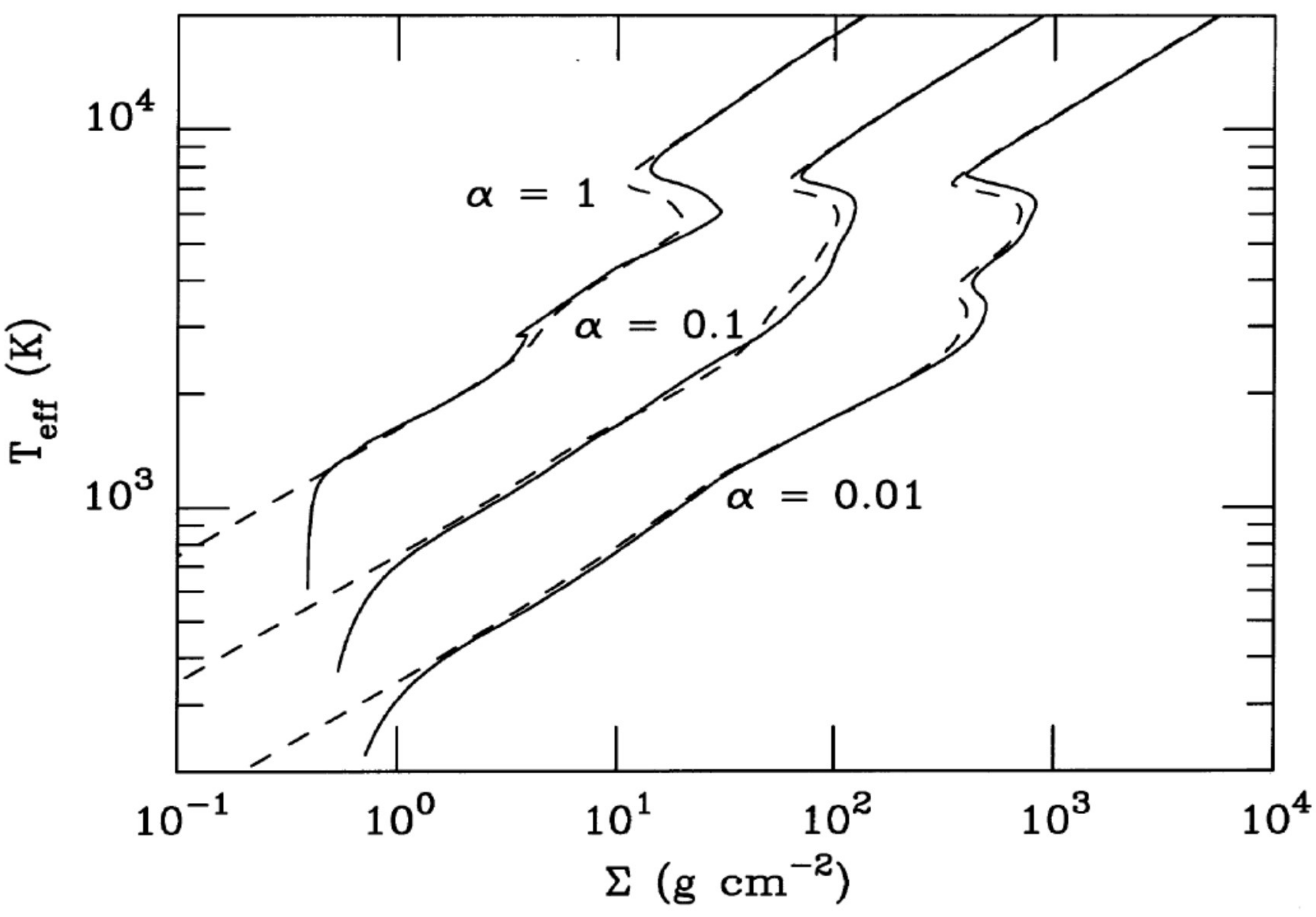
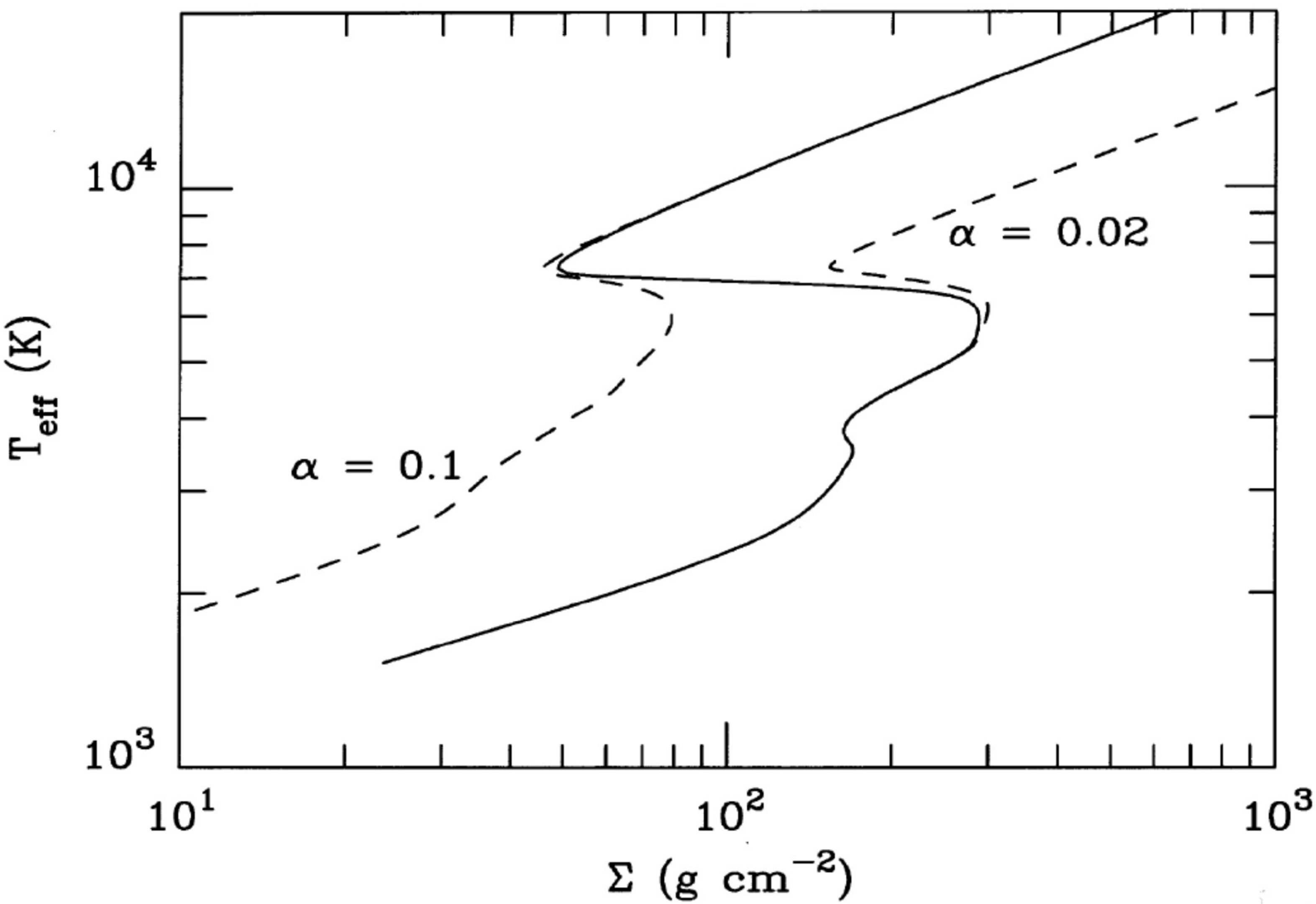
DIM basic hypotheses

- Alpha viscosity most often assumed
- Thin disk approximation:
  - Keplerian motion
  - Radial gradients small as compared to vertical gradients (but transition fronts, inner edge)
  - Vertical structure decouples from radial structure
- Vertical structure
  - Hydrostatic and thermal equilibrium assumed, with an effective alpha different from the actual one
  - Time-dependent terms in the vertical thermal equation are proportional to heat dissipation in steady state, i.e. to P

    => effective α, different from actual α
  - $T_{eff} = T_{eff}(\Sigma, T_c, r)$
    $\nu = \nu(\Sigma, T_c, r)$
- If thermal equilibrium, $T_c = T_c(\alpha, \Sigma, r)$ => S curves
- α different on the hot and cold branches: $\alpha = \alpha(T_c, \ldots)$



10^4
10^3
T_{eff} (K)
α = 1
α = 0.1
α = 0.01
10^{-1}
10^0
10^1
10^2
10^3
10^4
Σ (g cm^{-2})



10^4
10^3
T_{eff} (K)
α = 0.02
α = 0.1
10^1
10^2
10^3
Σ (g cm^{-2})

Additional ingredients

- Tidal torques:
  - Angular momentum conservation equation
  - Heating term
  - $T_{tid} \sim (r/a)^5$ or $\exp((r-r_{tid})/\delta r)$
- Hot spot
- Inner disc truncation by e.g. magnetic field
- Irradiation by the primary (hot white dwarf) or self irradiation ($F_{irr} = C\ \frac{GM_1\dot{M}}{r} r^{-2}$, with $C \sim 10^{-2}\ 10^{-3}$, Dubus et al. 1999)
- Mass transfer fluctuations
- Chemical composition (He secondaries)

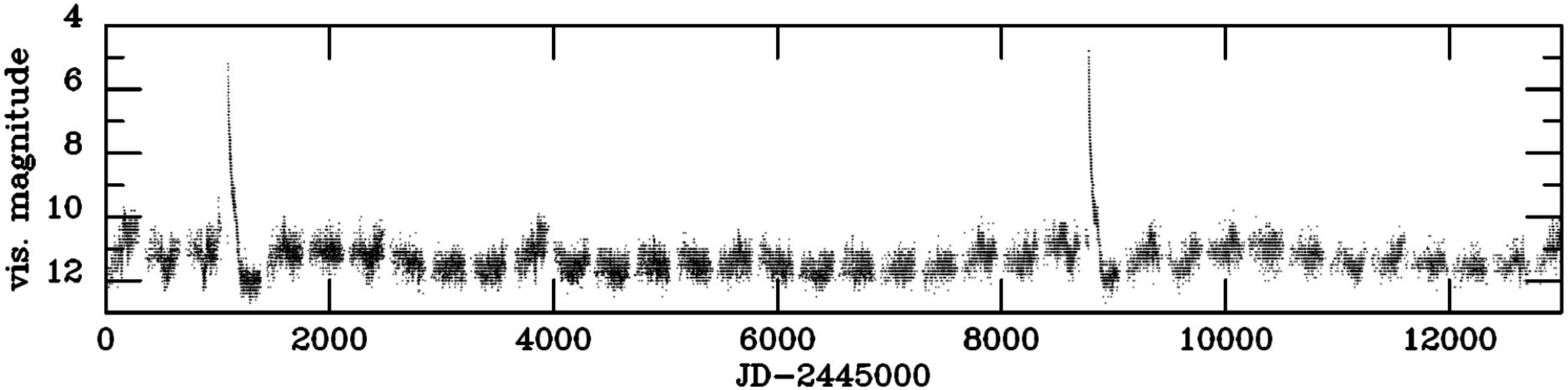
Reproduces reasonably well DN and SXT outbursts

Large discs

- Found in long period systems with evolved secondaries
  - Symbiotic stars
  - SXTs such as V 404 Cyg (P_{orb} = 6.5 d)
- No observational constraint on the effect of irradiation, in contrast with systems with short P_{orb}
- The outer disc radius is not well determined if the companion does not fill its Roche lobe (wind fed accretion)
- The disc cannot be stable unless $\dot{M} > 1.25\ 10^{-7} M_2^{0.89}\ P_d^{1.79} \mathrm{M}_\odot$ yr^{-1} (unirradiated case)
- Large outbursts are possible in principle

  $$\dot{M}_{max} = 3.6\ 10^{-7}\ P_d^{1.79} \mathrm{M}_\odot \text{ yr}^{-1}$$
- But in these systems the heating front might not reach the outer disc edge
- Numerical simulations needed

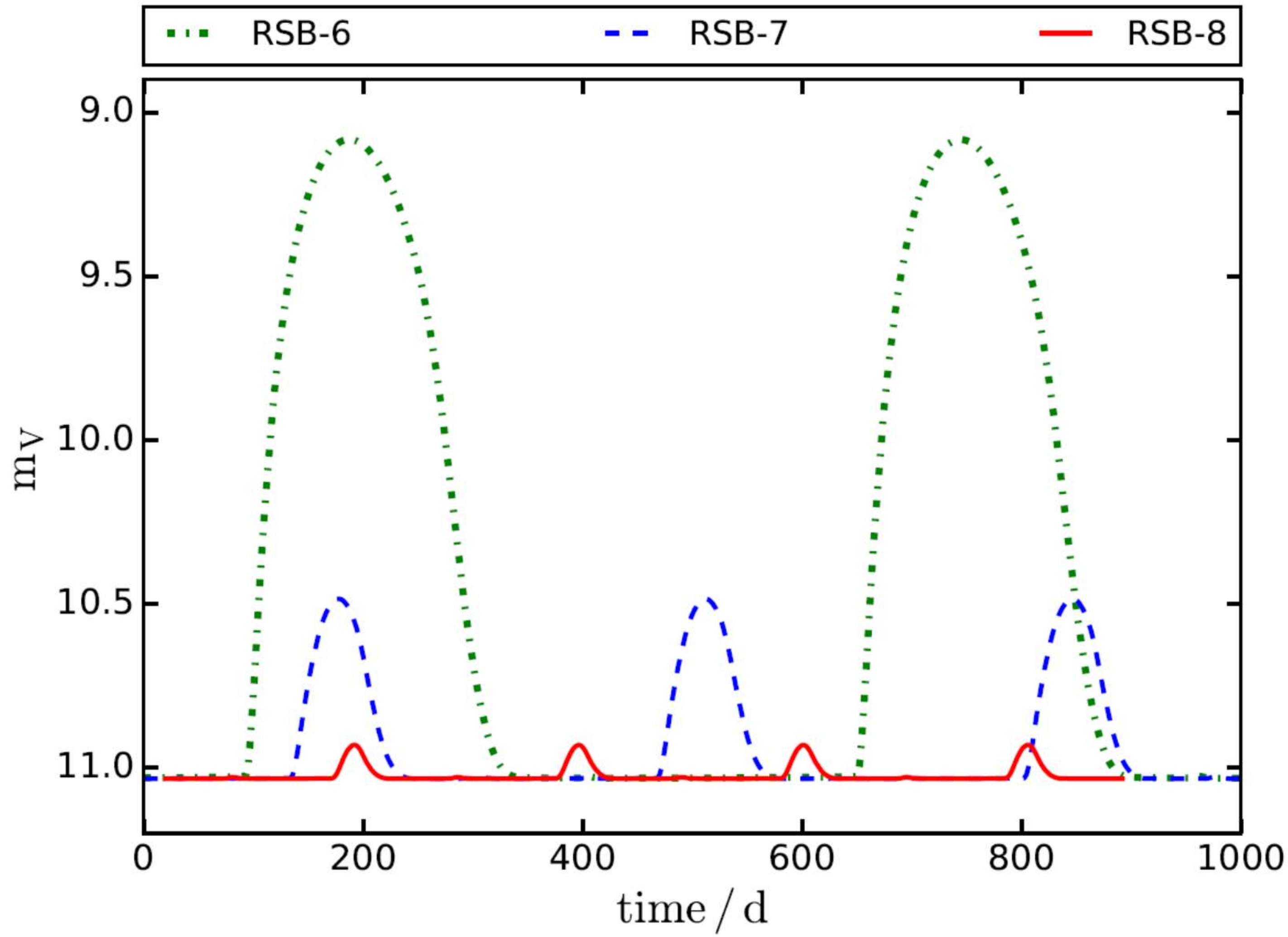
RS Ophiuci



- Recurrent nova, $\tau_{rec} = 20$ yr, $P_{orb} = 454$d, d = 2.3 kpc
- $M_1 = 1.35\ M_{\odot}$;
- $\dot{M} = 10^{-8} - 10^{-6}\ M_{\odot}yr^{-1}$; but values as low as $10^{-12} - 10^{-11}\ M_{\odot}yr^{-1}$ deduced from X-rays in quiescence
- Suggestion (Alexander et al. 2011) that outbursts might be DN outbursts

$\dot{M}$ ($M_\odot yr^{-1}$)	Δm_v	ΔM ($M_\odot$)	t_{rec} (yr)	$\dot{M}_{peak}$	$\dot{M}_{quiesc}$
10^{-6}	2	10^{-6}	1.5	$4.1\ 10^{-6}$	$3.8\ 10^{-12}$
10^{-7}	0.5	$7\ 10^{-8}$	0.9	$6.3\ 10^{-7}$	$3.8\ 10^{-12}$
10^{-8}	0.1	$4.5\ 10^{-9}$	0.5	$9.3\ 10^{-8}$	$3.8\ 10^{-12}$

- High $\dot{M}$: ΔM > $\Delta M_{ign} \sim 4\ 10^{-7} M_\odot$ for triggering a nova outburst;
  $\dot{M}_{peak}$ larger than both the limit for stable burning ($\dot{M}_{stable}$ ~ 6 10^{-8} $M_\odot$ yr^{-1}) and the limit (3 $\dot{M}_{stable}$) for burning hydrogen as quickly as it is accreted
  Recurrence time far too short
- Low $\dot{M}$: ΔM small; hydrogen accumulates until a nova eruption is triggered;
  ΔM_{ign} reached after 5 – 50 DN outbursts. DN outbursts undetectable in optical but could be observed in X-rays

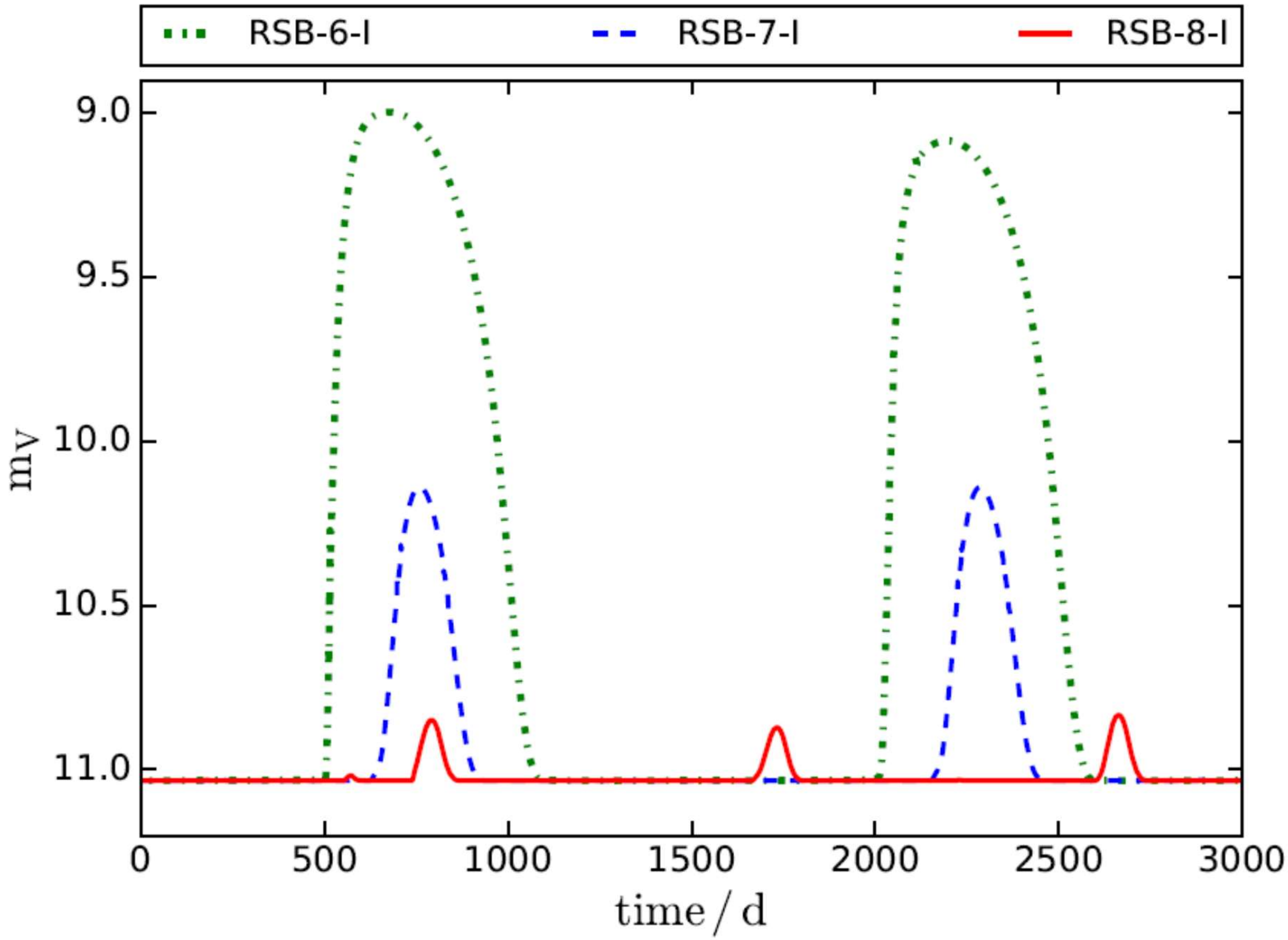


RSB-6
RSB-7
RSB-8
9.0
9.5
10.0
10.5
11.0
m_V
0
200
400
600
800
1000
time / d

Model with self-irradiation

$\dot{M}$ ($M_\odot yr^{-1}$)	Δm_v	ΔM ($M_\odot$)	t_{rec} (yr)	$\dot{M}_{peak}$	$\dot{M}_{quiesc}$
10^{-6}	2	$5\ 10^{-6}$	3.7	$4.1\ 10^{-6}$	$3.8\ 10^{-12}$
10^{-7}	0.9	$4\ 10^{-7}$	4.2	$6.3\ 10^{-7}$	$3.8\ 10^{-12}$
10^{-8}	0.2	$1.5 – 4\ 10^{-8}$	2.6 – 3.7	$9.3\ 10^{-8}$	$3.8\ 10^{-12}$

- Same conclusions as in the unirradiated case; longer recurrence time and larger ΔM, thus smaller number of DN outbursts between nova eruptions

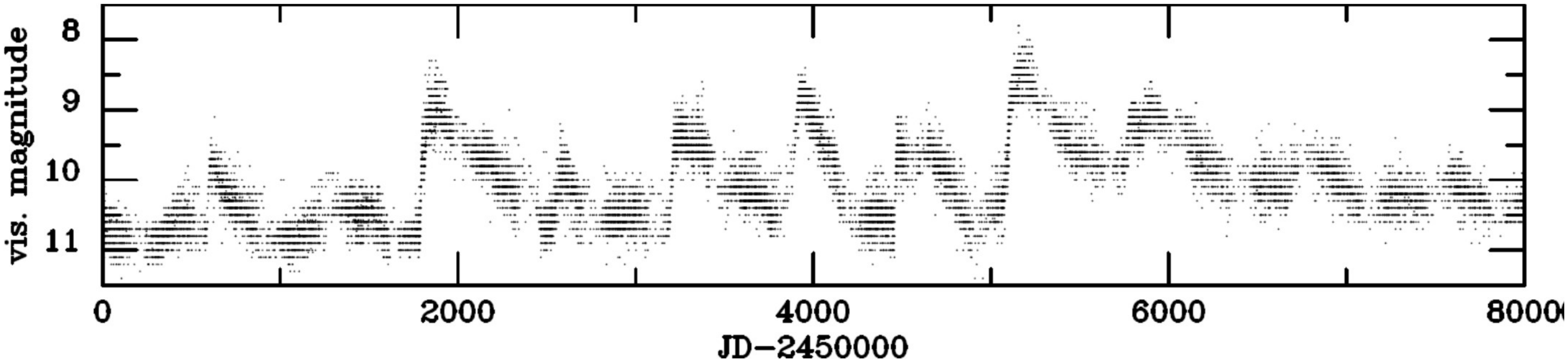


RSB-6-I
RSB-7-I
RSB-8-I
9.0
9.5
10.0
10.5
11.0
m_V
0
500
1000
1500
2000
2500
3000
time / d

Conclusions for RS Oph

- The mass transfer rate in RS Oph is $10^{-8} - 10^{-7}\,\mathrm{M}_{\odot}\,\mathrm{yr}^{-1}$
- The disc is unstable and DN outbursts occur every few years.
    - They are undectable in optical, but could be detected in X-rays
    - Account for the low quiescent rate
- RS Oph outbursts are thermonuclear outbursts that occur during the decline of a DN outburst

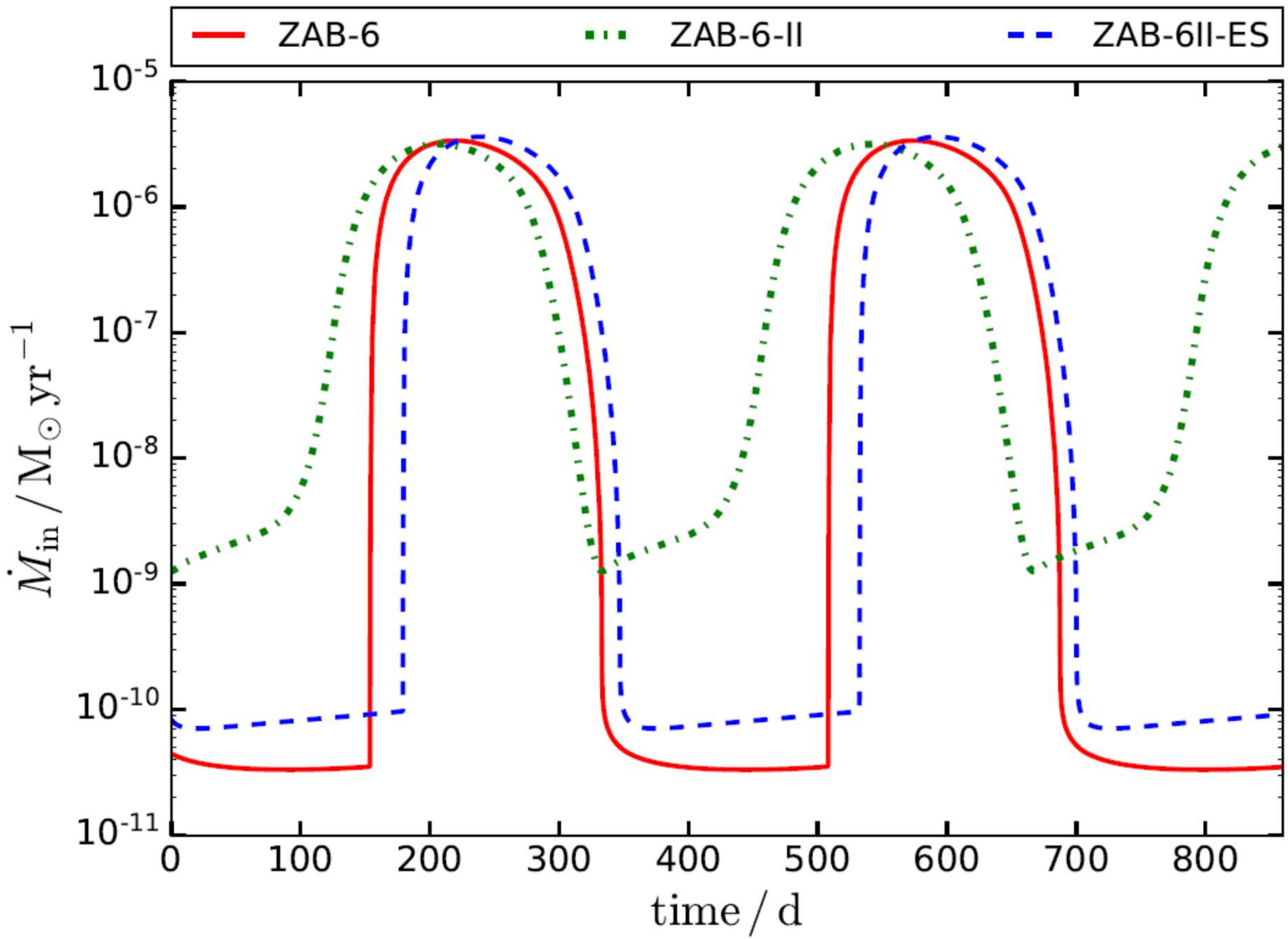
Z Andromedae



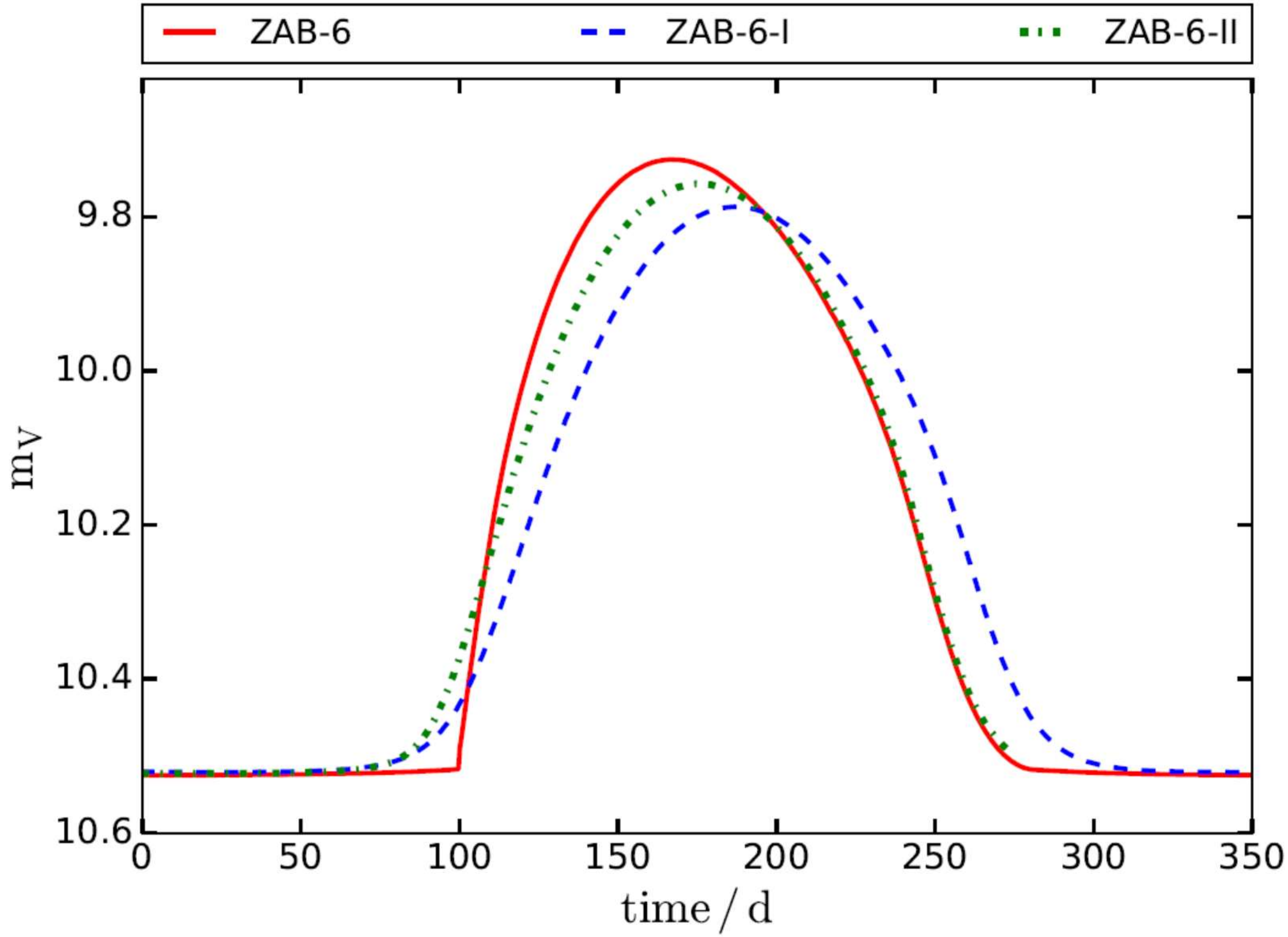
- P_{orb} = 759 d, d = 2.0 kpc
- $M_1 = 0.65$ $M_\odot$; $M_2/M_1 \sim 2$. The secondary does not fill its Roche lobe
- $B_{wd} \sim 10^4 - 10^6$ G (optical pulsations)
- Large WD constant luminosity $L_2 \sim 10^3$ $L_\odot$
- Suggestion (Sokoloski et al. 2006) that 1st outburst is a DN outburst and the 2nd a combination outburst

Results

- DN outbursts are significant for high $\dot{M}$ ($\sim 10^{-6}\ \mathrm{M_\odot}$ yr^{-1}) only;
- Their properties in optical depend only weakly on the assumptions made on irradiation
    - No irradiation
    - Irradiation of the inner parts of the disc only
    - Full disc irradiation
- Enhanced thermonuclear burning at the WD surface will occur for these high $\dot{M}$
- But such large values of $\dot{M}$ are two orders of magnitude larger than what is expected for the secular mean
- Mass transfer fluctuations in a system in which mass transfer is due to the secondary wind are much more natural

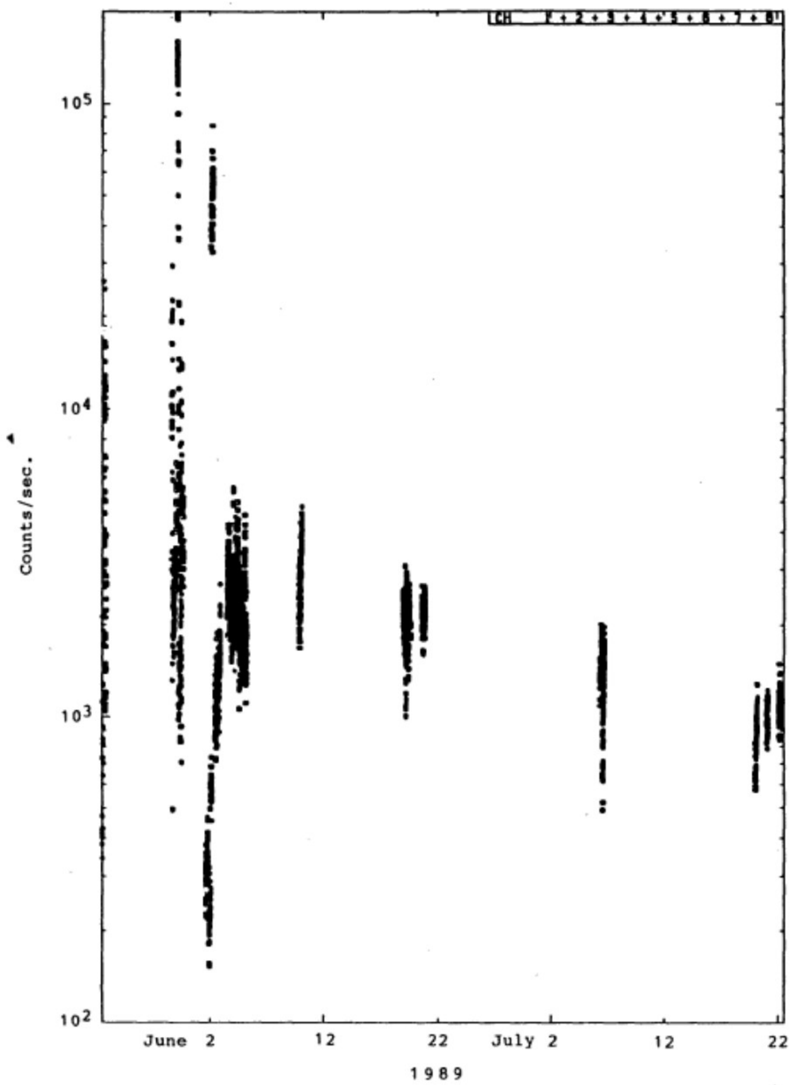


ZAB-6
ZAB-6-II
ZAB-6II-ES
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
$\dot{M}_{\rm in}\,/\,{\rm M_\odot\,yr^{-1}}$
0
100
200
300
400
500
600
700
800
time / d

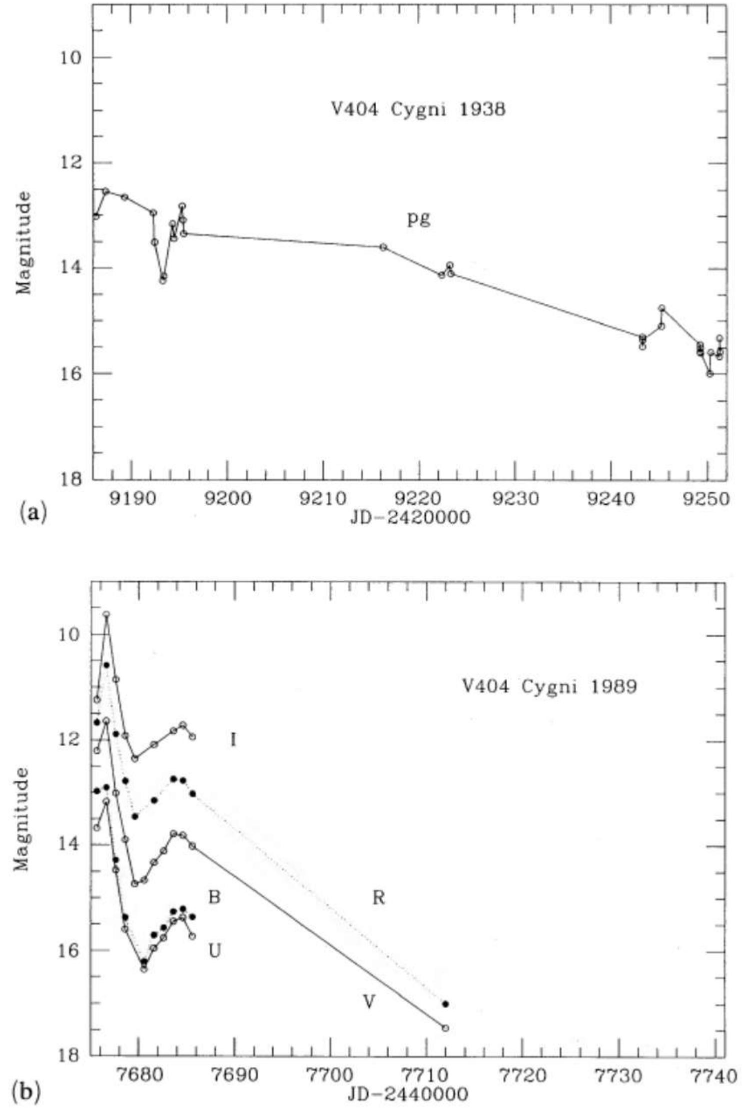


ZAB-6
ZAB-6-I
ZAB-6-II
9.8
10.0
10.2
10.4
10.6
m_V
0
50
100
150
200
250
300
350
time / d

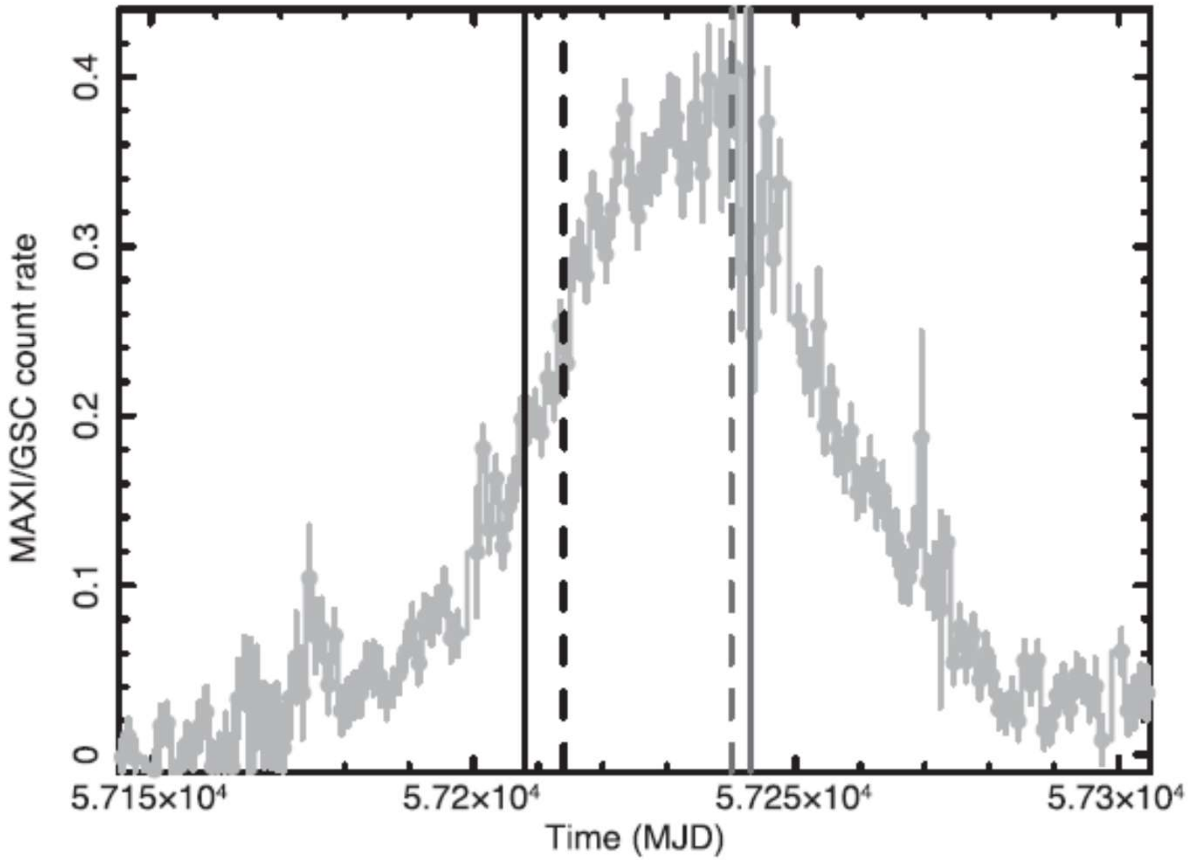
V404 Cyg



Tanaka 1989



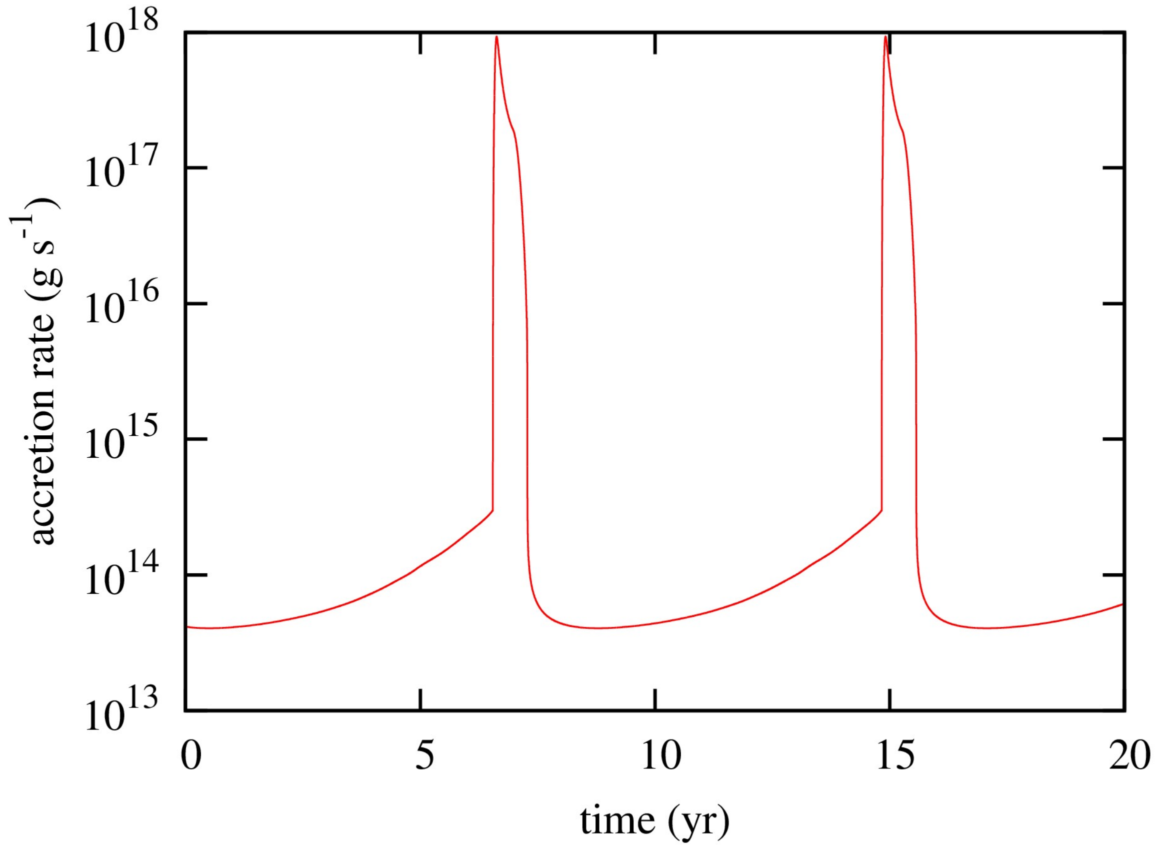
Casares et al. 1991



Outburst duration:
about 200 d

A better (?) behaved SXT: GS 1354-64

P_{orb} = 2.54d



$M_1 = 7\ \mathrm{M}_\odot$

$M_2 = 0.8\ \mathrm{M}_\odot$

$P_{\mathrm{orb}} = 155$ hr

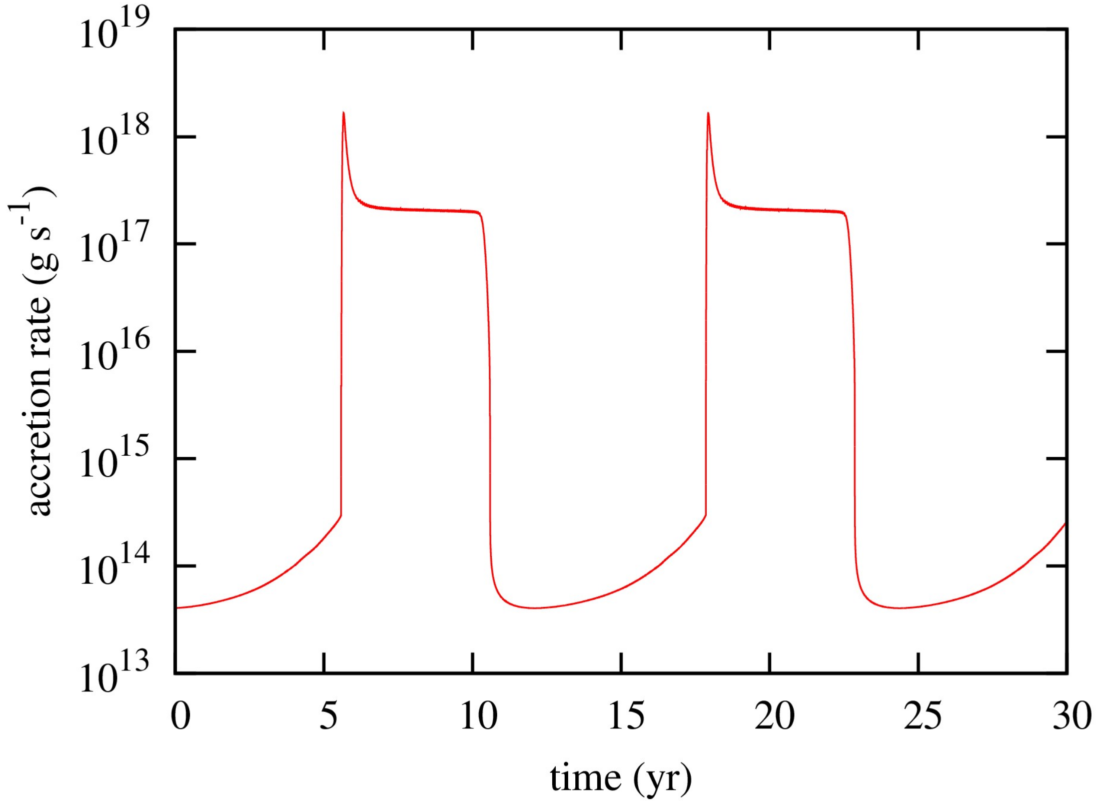
$\dot{M} = 2.5\ 10^{16}$ g s^{-1}

$\alpha_c = 0.04$

$\alpha_h = 0.20$

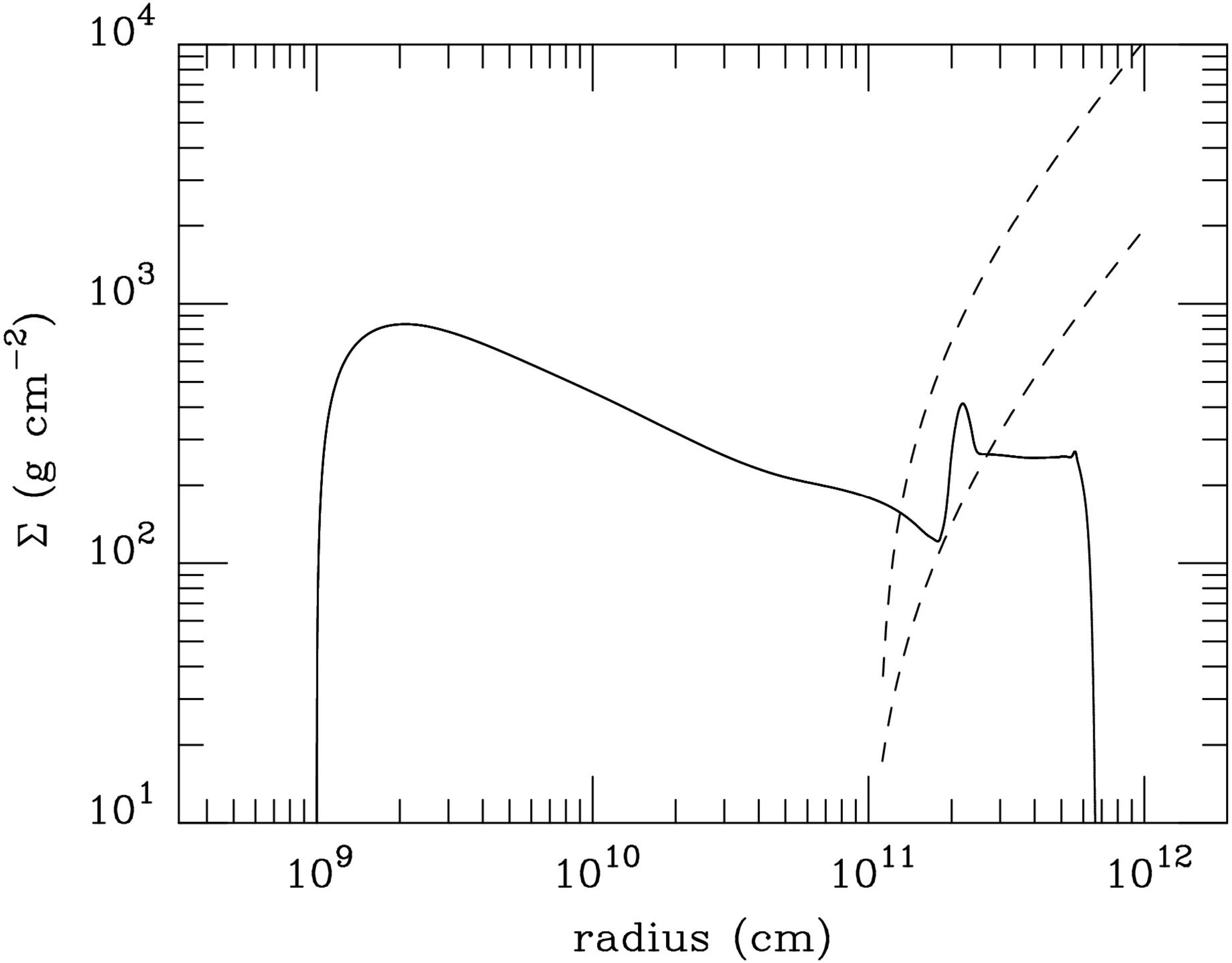
$f_{ill} = 5\ 10^{-3}$

The heating front never reaches the outer disc edge

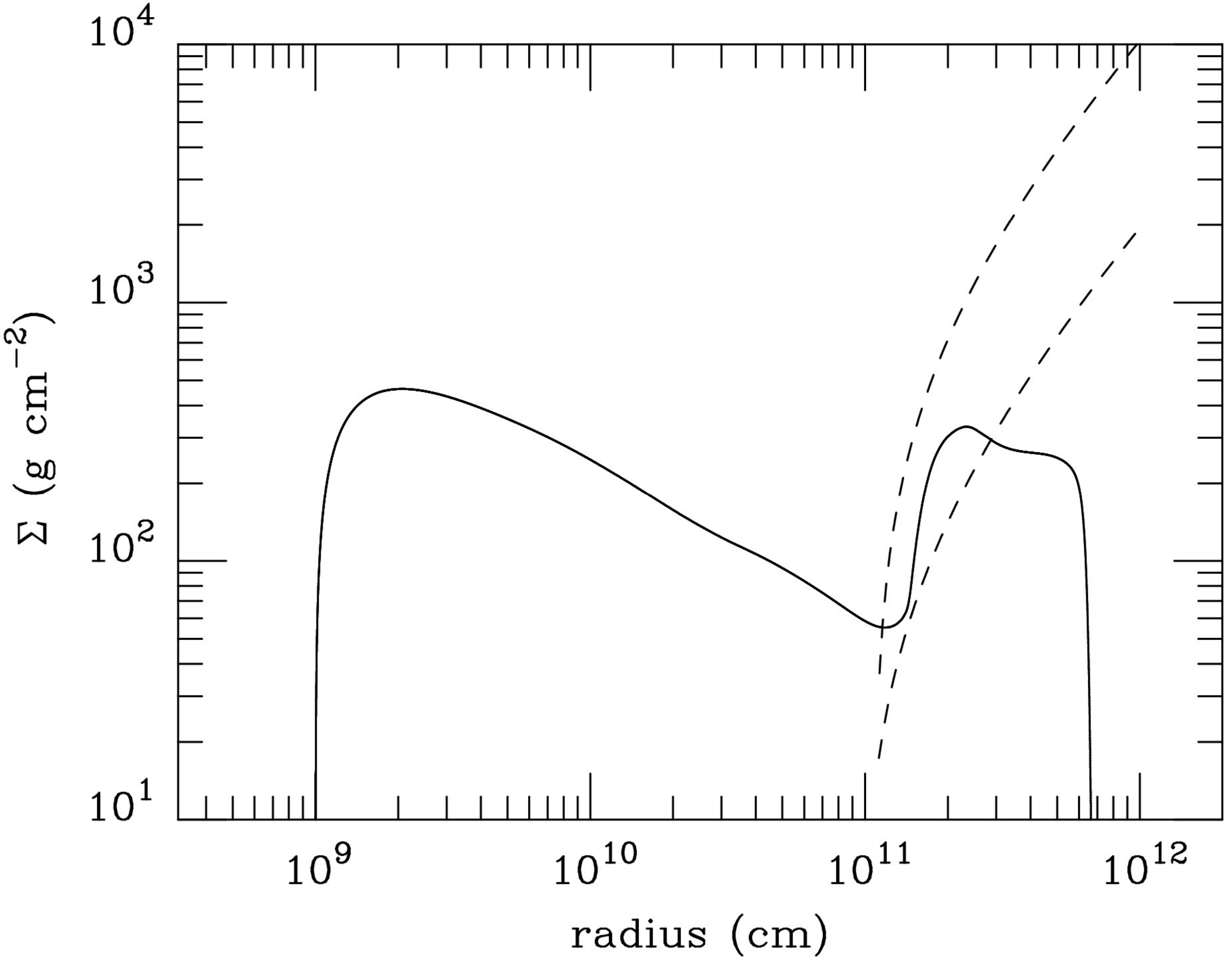


Same parameters as before, except $\dot{M} = 10^{17}\ \mathrm{gs}^{-1}$

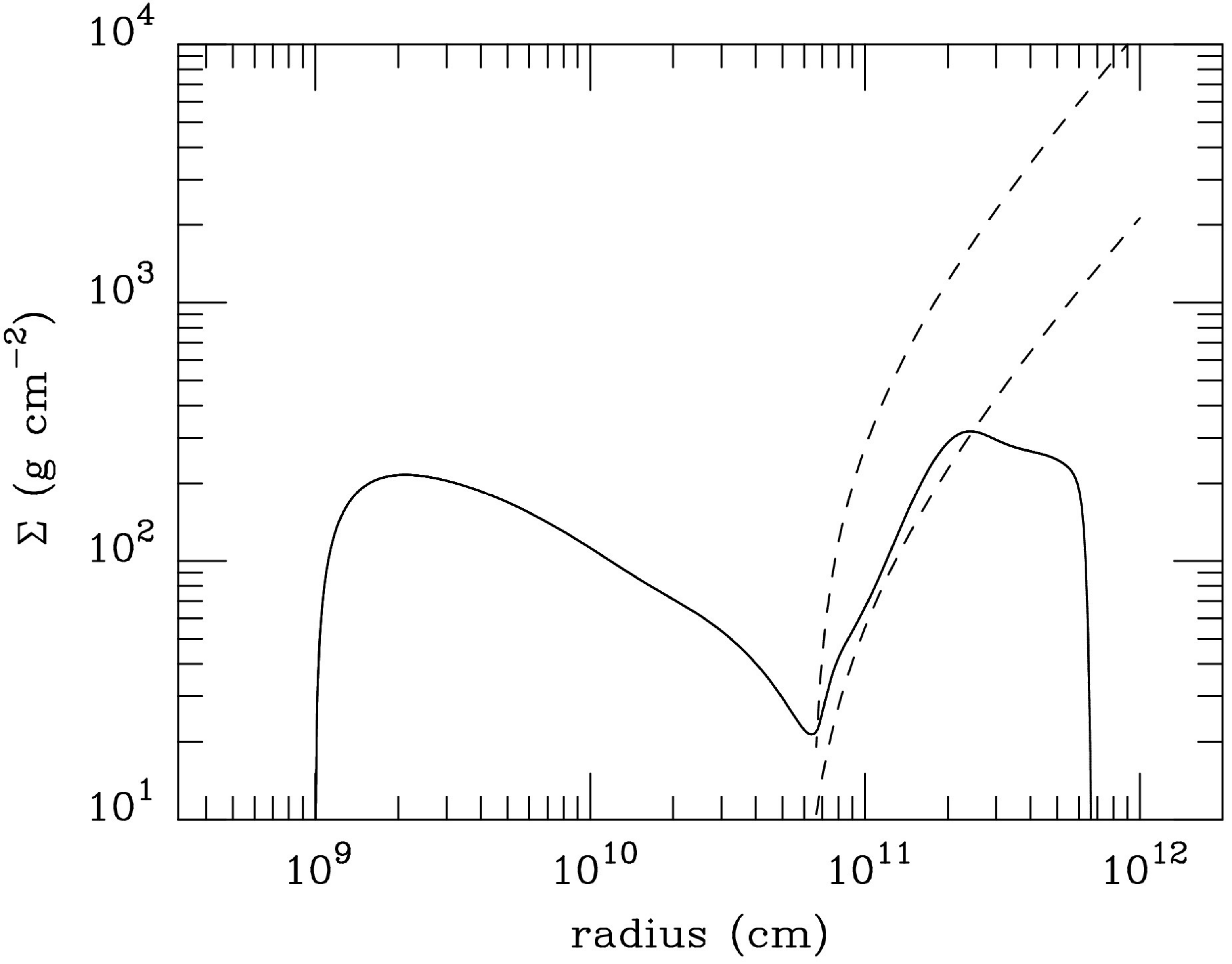
- The cooling front is stuck at a radius of about 1.5 10^{11} cm
- This is the reason for the plateau at 10^{17} g s^{-1}.



10^4
10^3
10^2
10^1
Σ (g cm^{-2})
10^9
10^{10}
10^{11}
10^{12}
radius (cm)

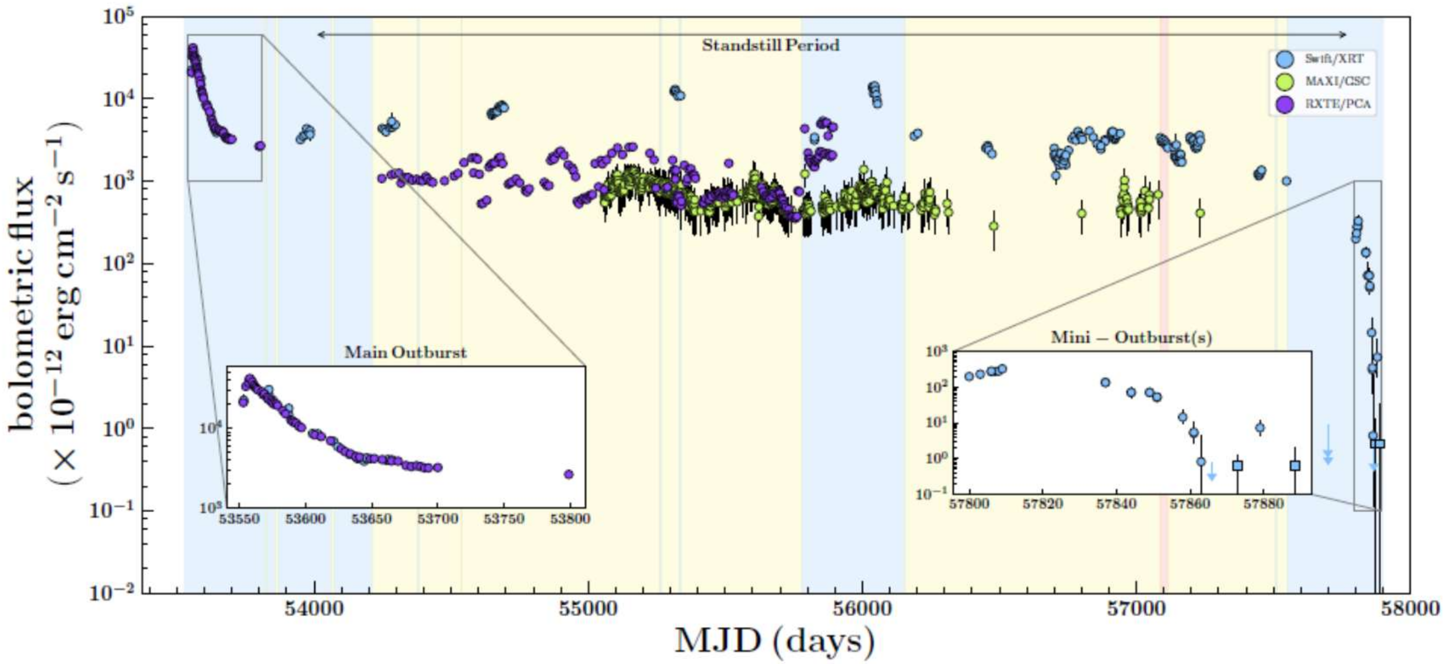


10^4
10^3
10^2
10^1
Σ (g cm^{-2})
10^9
10^{10}
10^{11}
10^{12}
radius (cm)



10^4
10^3
10^2
10^1
Σ (g cm^{-2})
10^9
10^{10}
10^{11}
10^{12}
radius (cm)

(preliminary) conclusions



- Light curves with long plateau can be obtained; these are similar to Z Cam systems, but the mechanism is very different
  - See e.g. Swift J1753.5-0127 (Shaw et al. 2018), but this source has a short orbital period; as the period is photometric only, is it the true orbital period (actually, it is interpreted as the superhump period) ?
- Eddington luminosities not simple to obtain; reduce α on the cold branch (or increase it on the hot branch)?
- Mass loss to be included