Outbursts of helium discs

Jean-Pierre Lasota

Based on:

Hameury, J.-M., & Lasota, J.-P., 2016 A&A, 594, A87
Kotko, I., & Lasota, J.-P., 2012 A&A, 545, A115
Kotko, I., Lasota, J.-P., Dubus, G., & Hameury, J.-M. 2012, A&A, 544, A13
Lasota, J.-P., Dubus, G., & Kruk, K. 2008, A&A, 486, 523

(see also the excellent talk by Paul Groot[meester] at the KITP conference)

Kavli Institute for Theoretical Physics
University of California, Santa Barbara

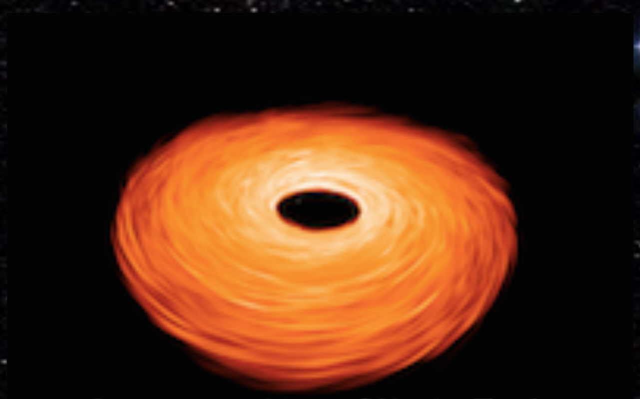
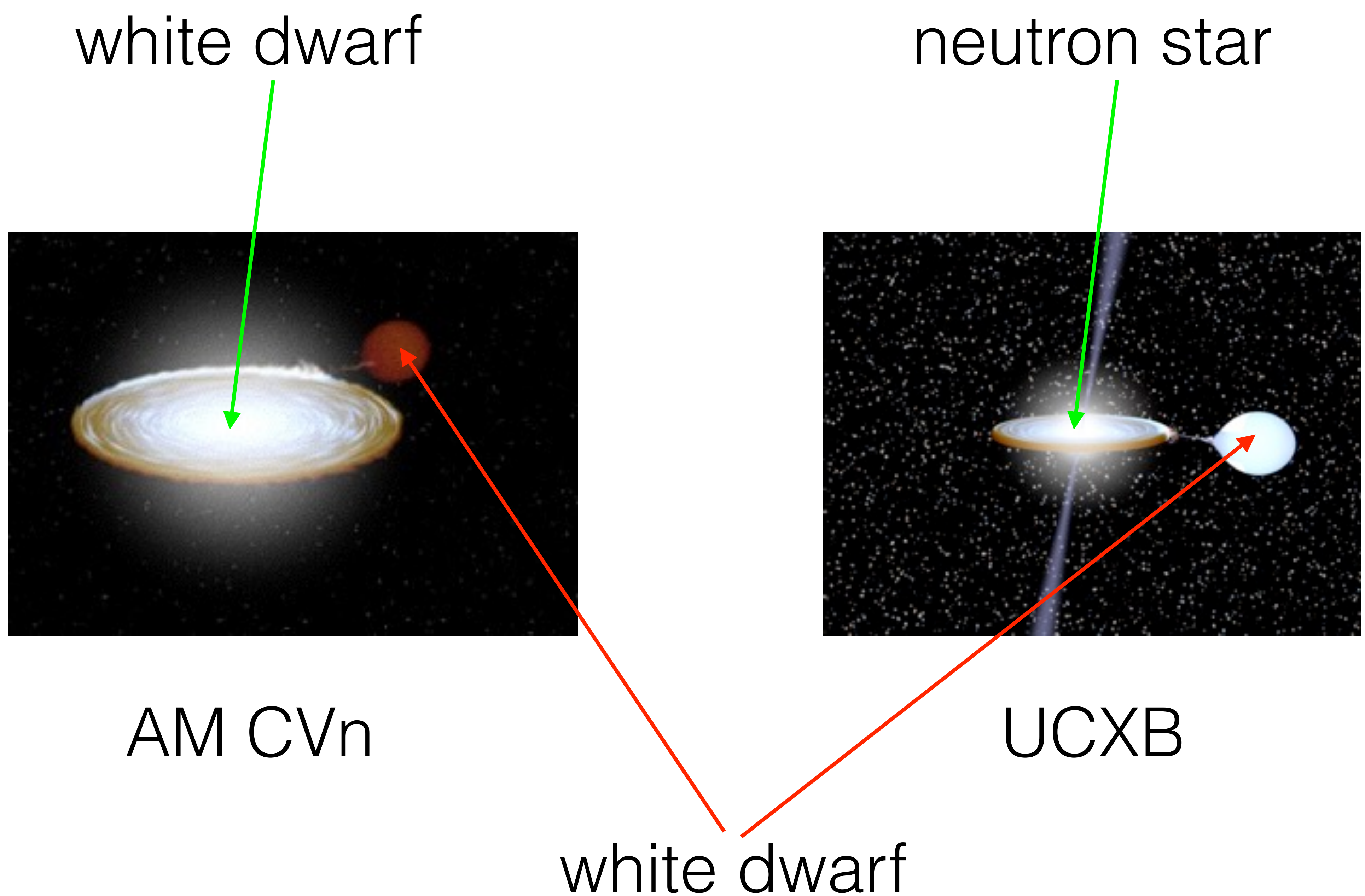
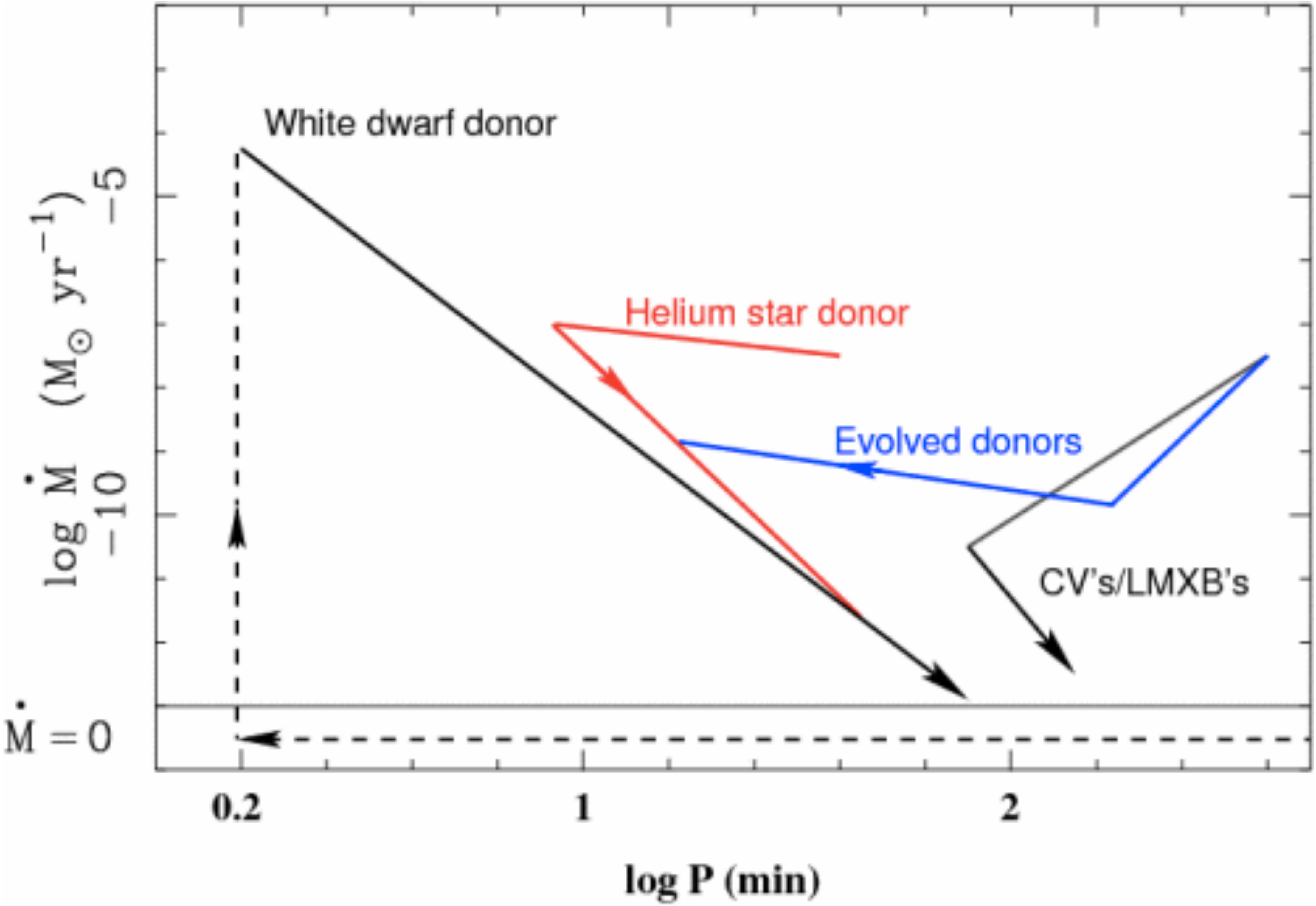


Image courtesy of Mario Flock

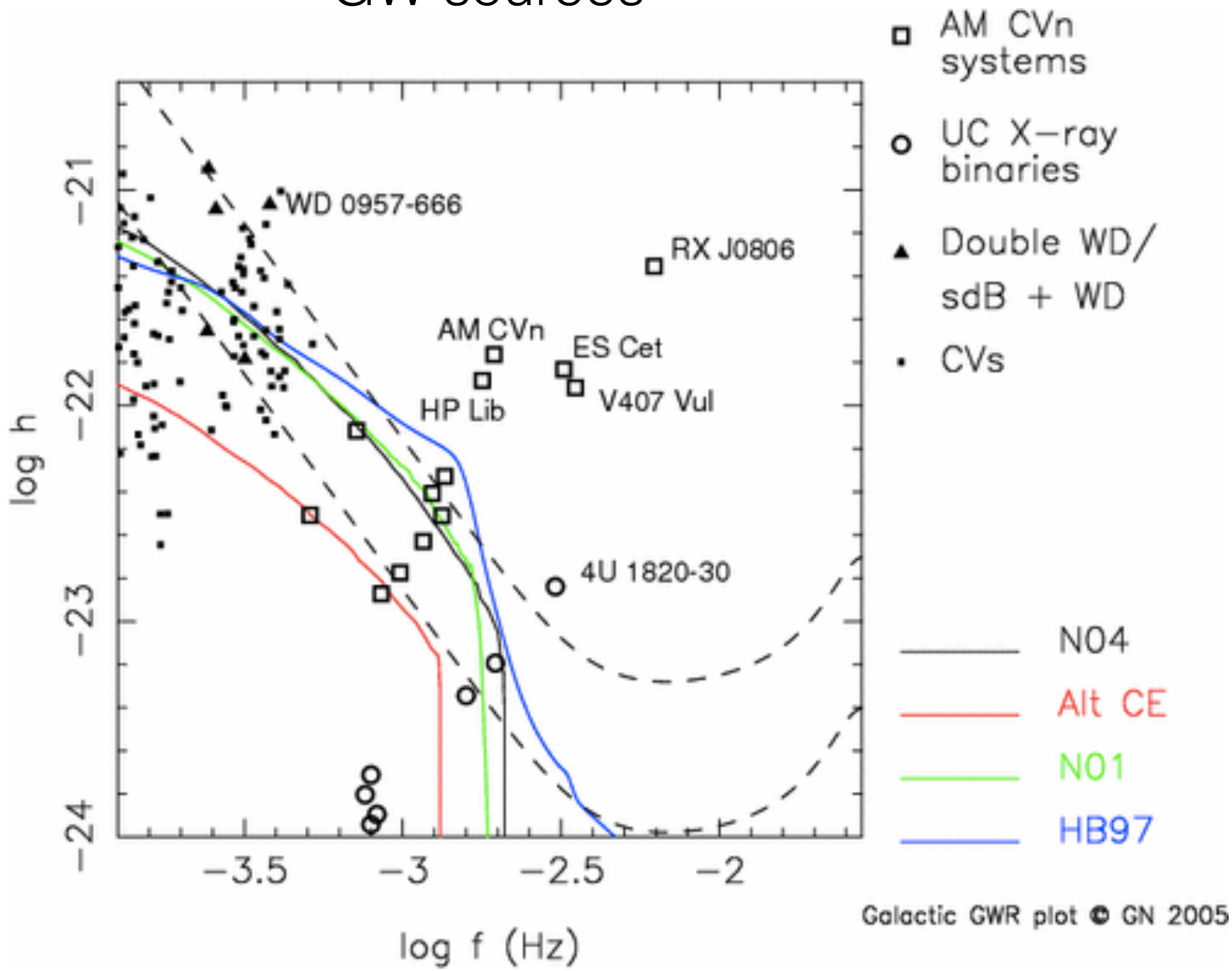


Discs in both types of systems can be subject to the DN-type instability

Three evolutionary channels

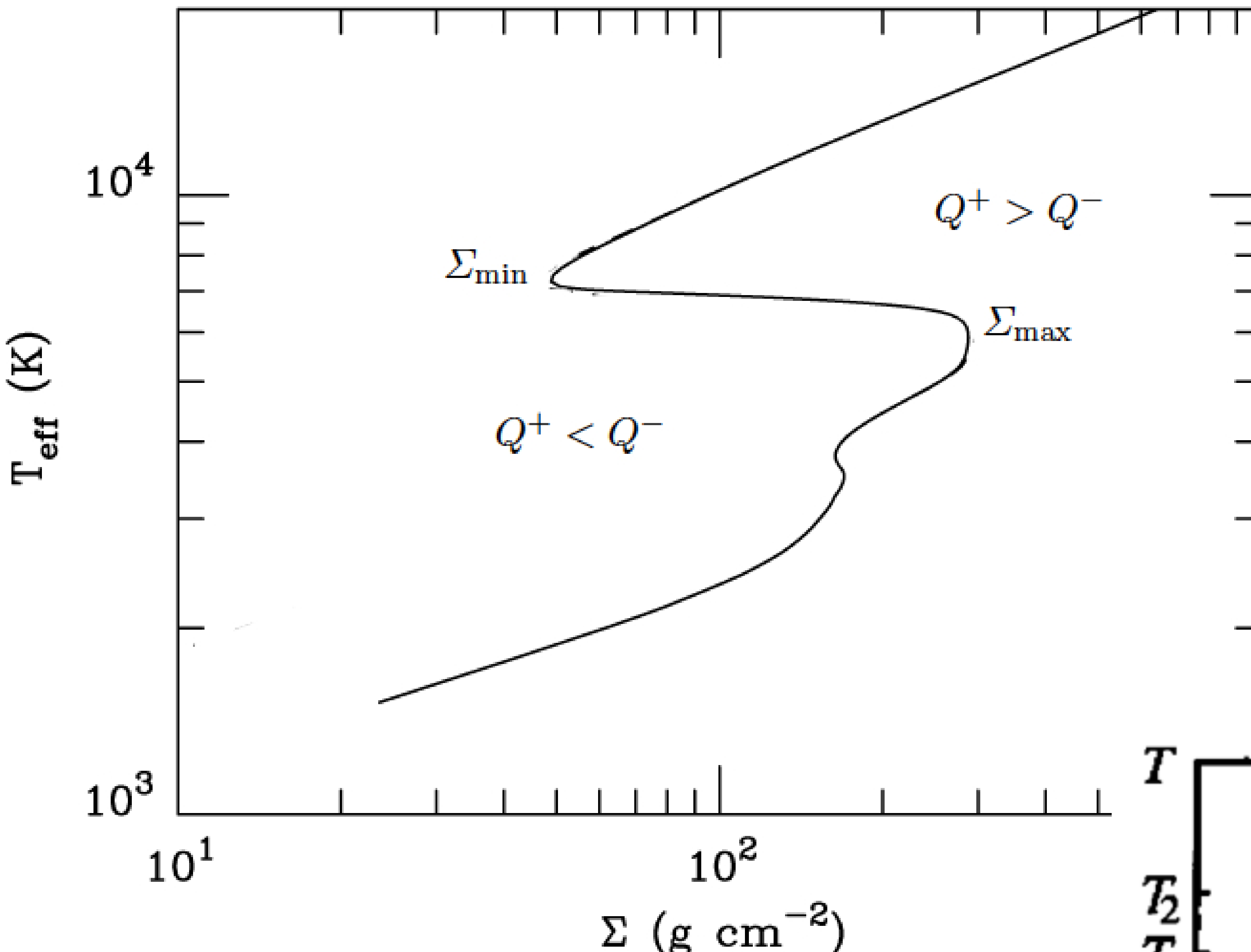


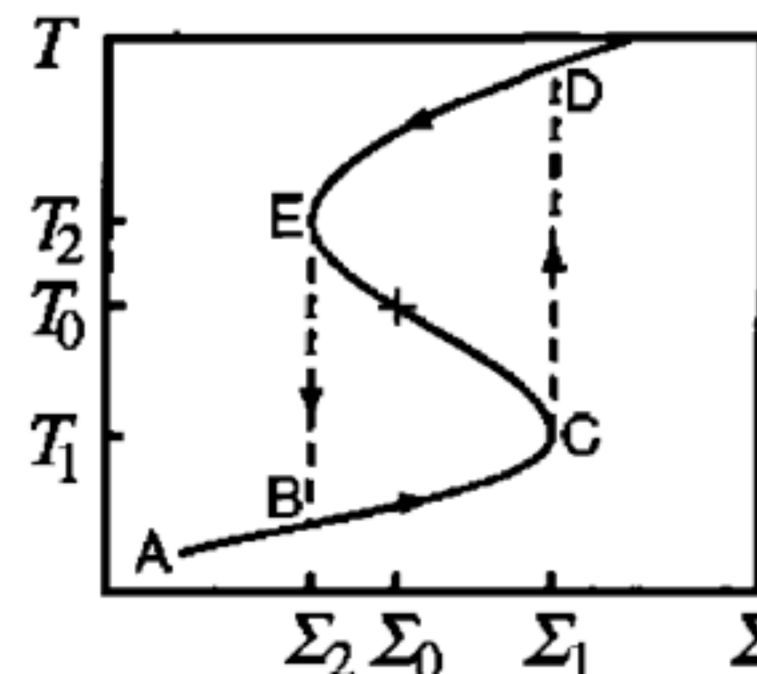
GW sources



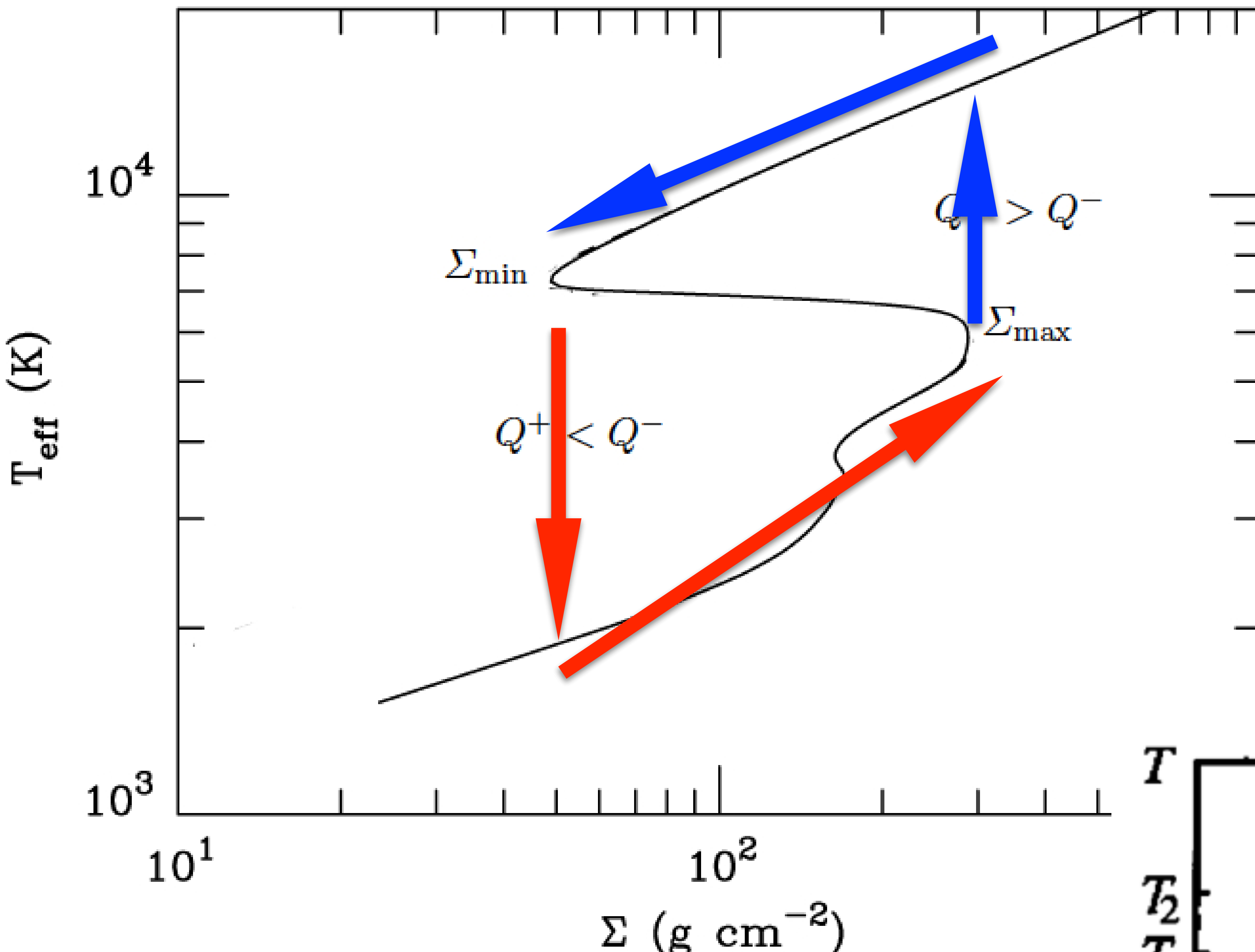
AM CVn systems
UC X−ray binaries
Double WD/ sdB + WD
CVs
WD 0957-666
RX J0806
AM CVn
ES Cet
HP Lib
V407 Vul
4U 1820-30
N04
Alt CE
N01
HB97
−21
−22
−23
−24
log h
−3.5
−3
−2.5
−2
log f (Hz)
Galactic GWR plot © GN 2005

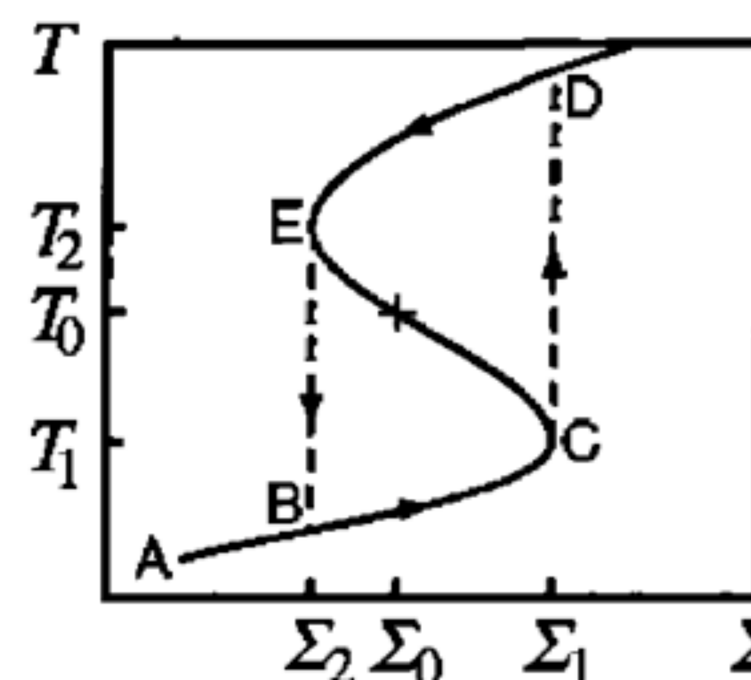
DIM (presumed) limit cycle

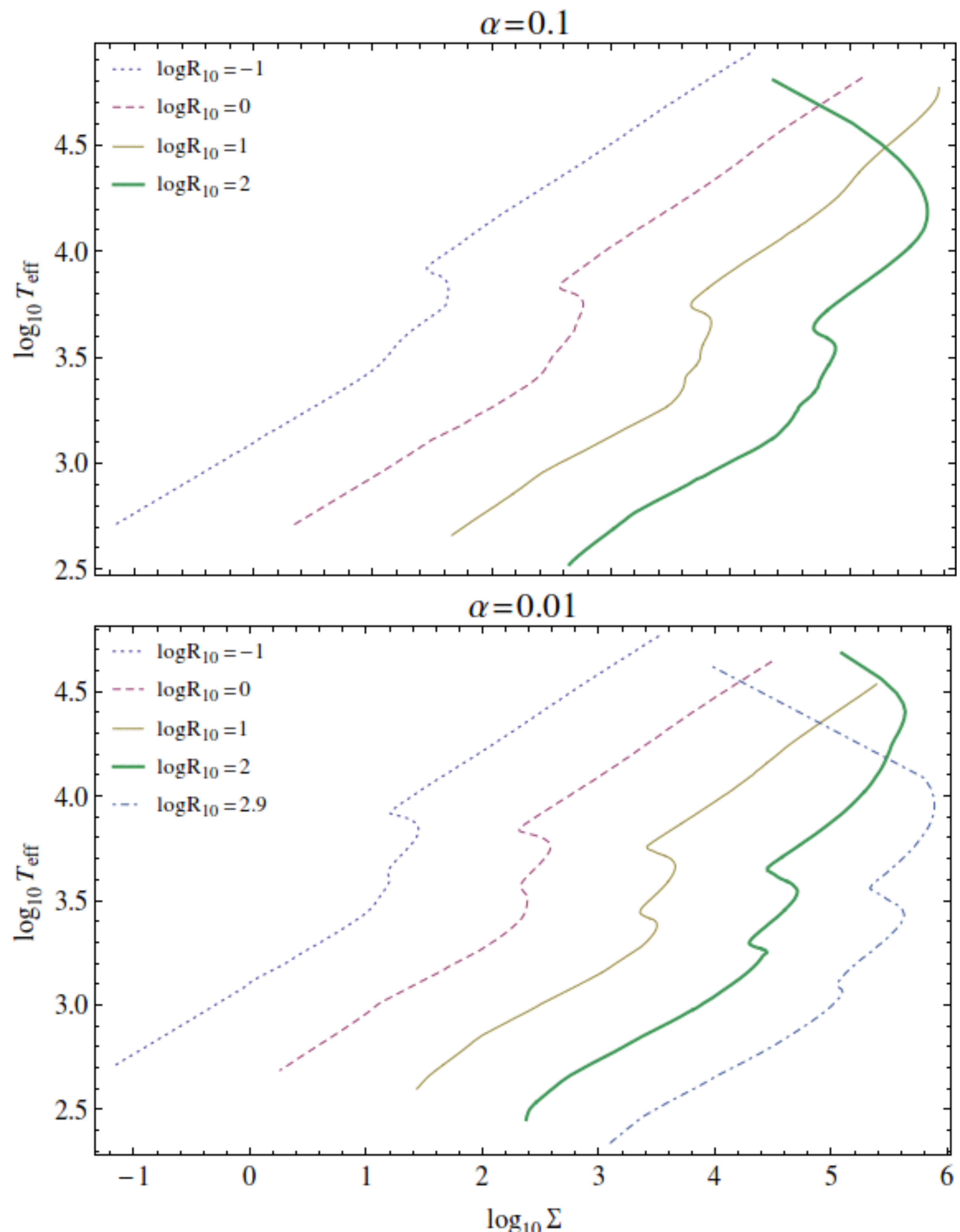




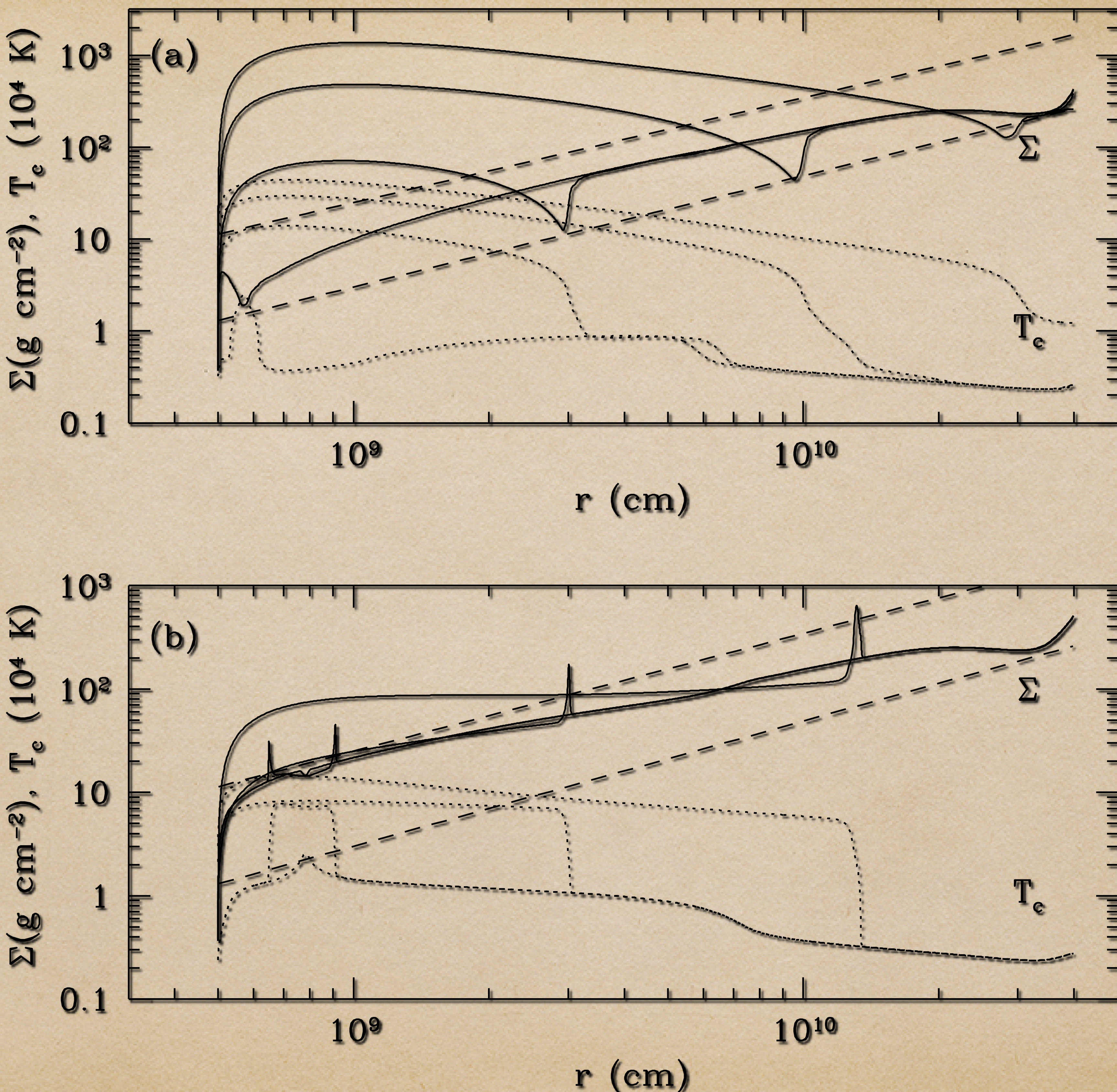
DIM (presumed) limit cycle

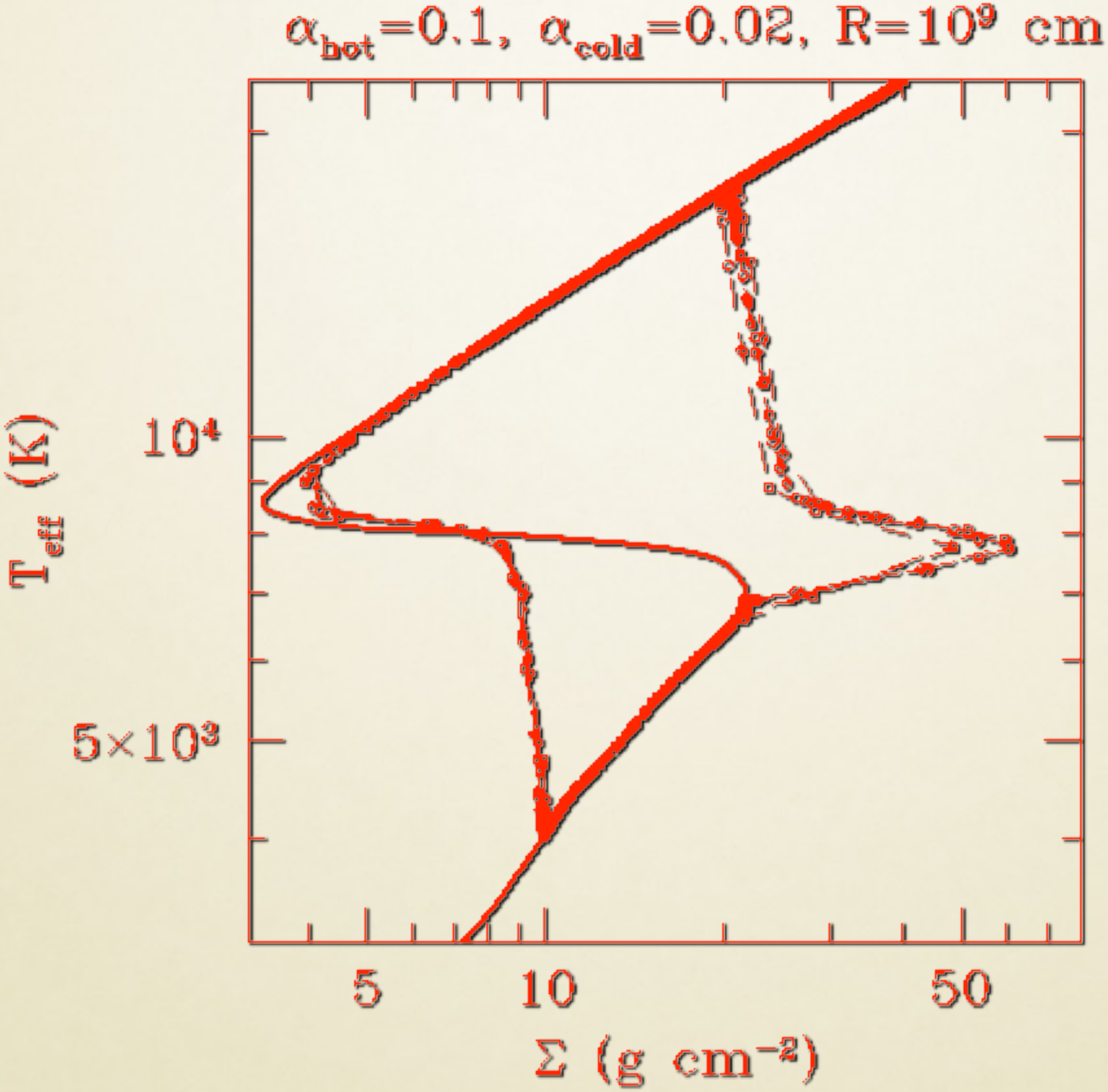




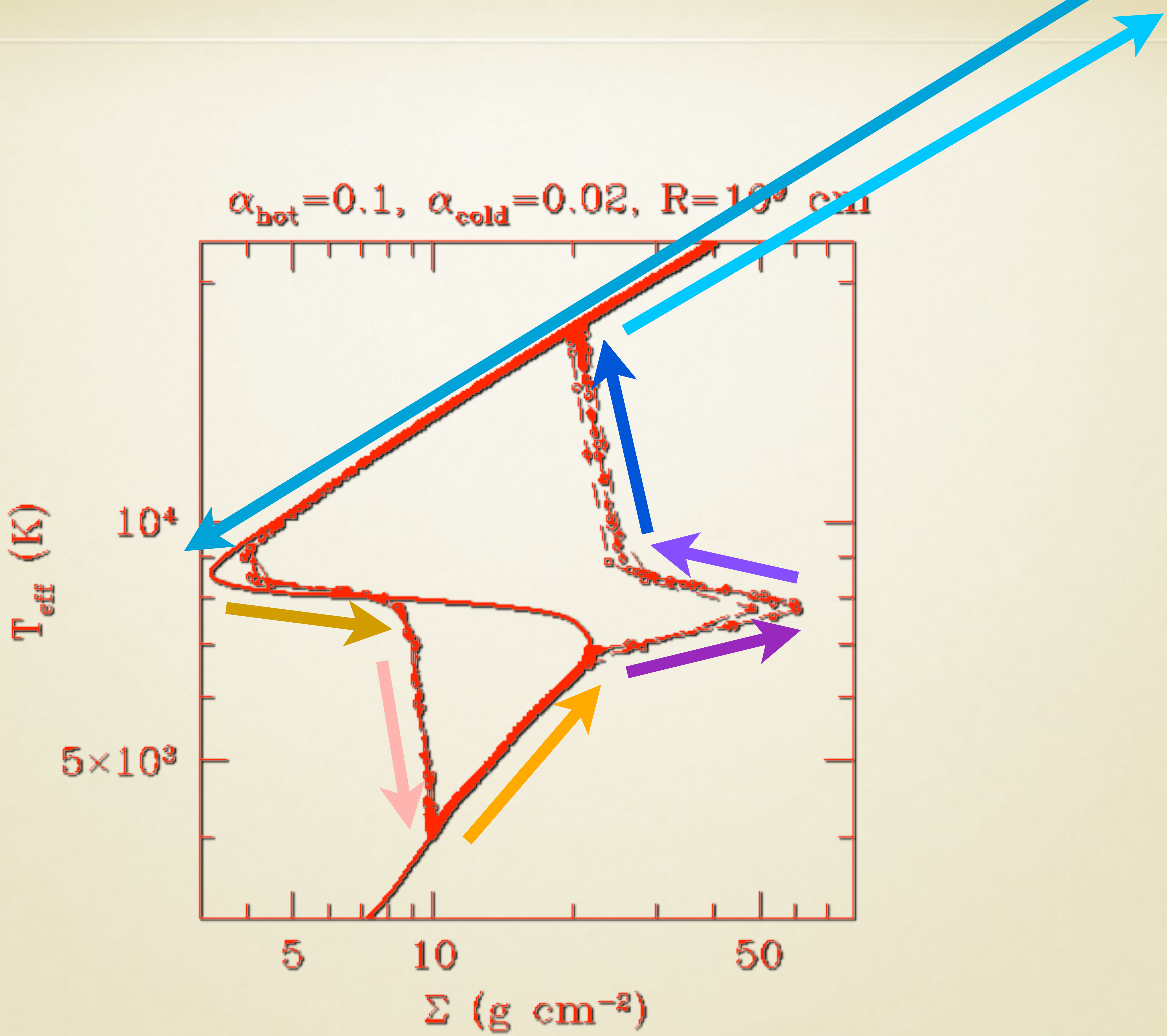


α=0.1
logR10 = −1
logR10 = 0
logR10 = 1
logR10 = 2
4.5
4.0
3.5
3.0
2.5
log10 Teff
α=0.01
logR10 = −1
logR10 = 0
logR10 = 1
logR10 = 2
logR10 = 2.9
4.5
4.0
3.5
3.0
2.5
log10 Teff
−1
0
1
2
3
4
5
6
log10 Σ


(a)
Σ(g cm^{-2}), T_c (10^4 K)
10^3
10^2
10
1
0.1
Σ
T_c
10^9
10^{10}
r (cm)
(b)
Σ(g cm^{-2}), T_c (10^4 K)
10^3
10^2
10
1
0.1
Σ
T_c
10^9
10^{10}
r (cm)



Menou, Hameury & Stehle



Menou, Hameury & Stehle

H (solar)

$$\Sigma^+_{\rm crit} = 39.9\,\alpha_{0.1}^{-0.80}\,R_{10}^{1.11}\,M_1^{-0.37}\,{\rm g\,cm^{-2}}$$

$$T^+_{\rm c} = 30000\,\alpha_{0.1}^{-0.18}\,R_{10}^{0.04}\,M_1^{-0.01}\,{\rm K}$$

$$T^+_{\rm eff} = 6890\,\alpha_{0.1}\,R_{10}^{-0.09}\,M_1^{0.03}\,{\rm K}$$

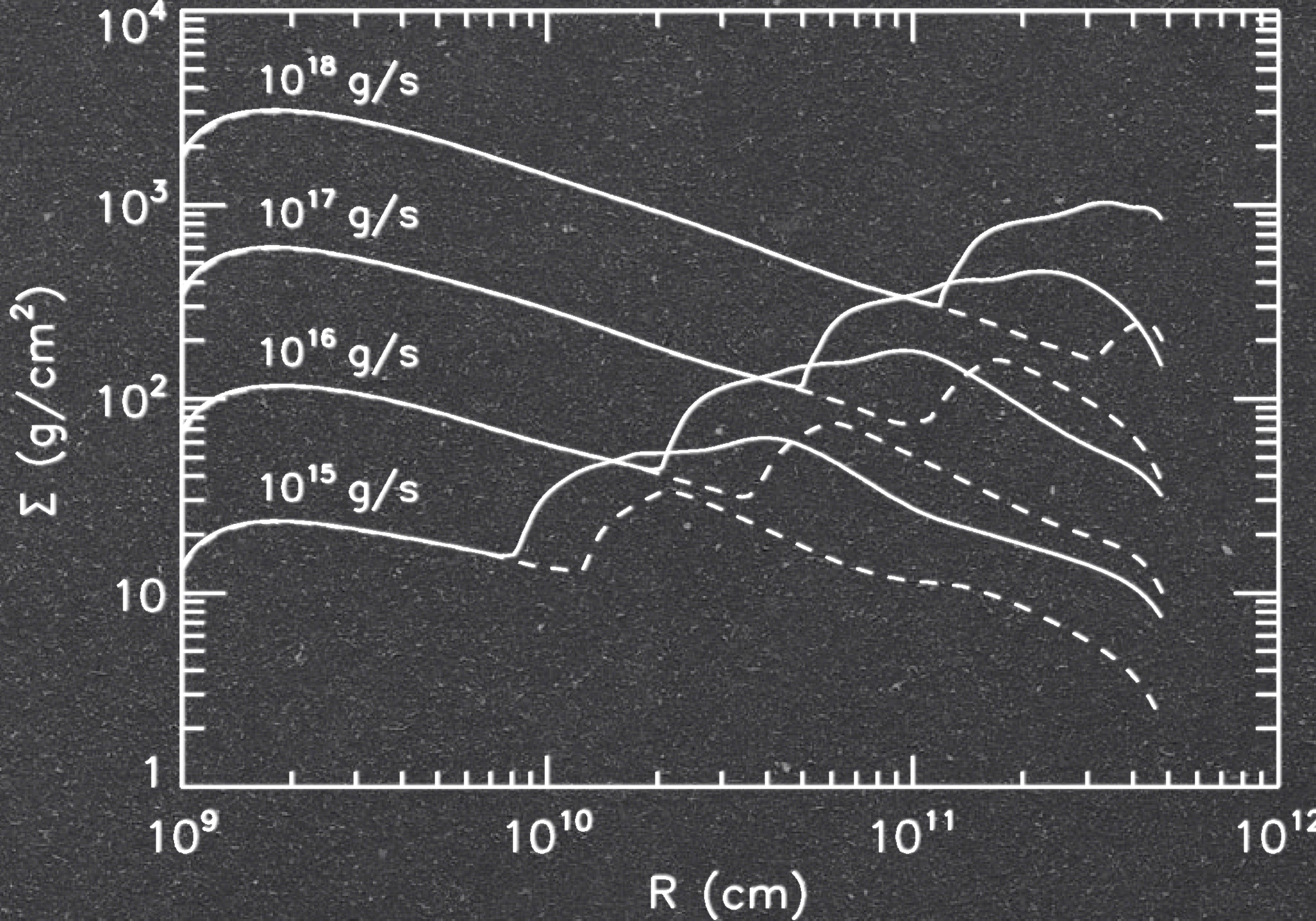
$$\dot{M}^+_{\rm crit} = 8.07\times10^{15}\,\alpha_{0.1}^{-0.01}\,R_{10}^{2.64}\,M_1^{-0.89}\,{\rm g\,s^{-1}}$$

$$\Sigma^-_{\rm crit} = 74.6\,\alpha_{0.1}^{-0.83}\,R_{10}^{1.18}\,M_1^{-0.40}\,{\rm g\,cm^{-2}}$$

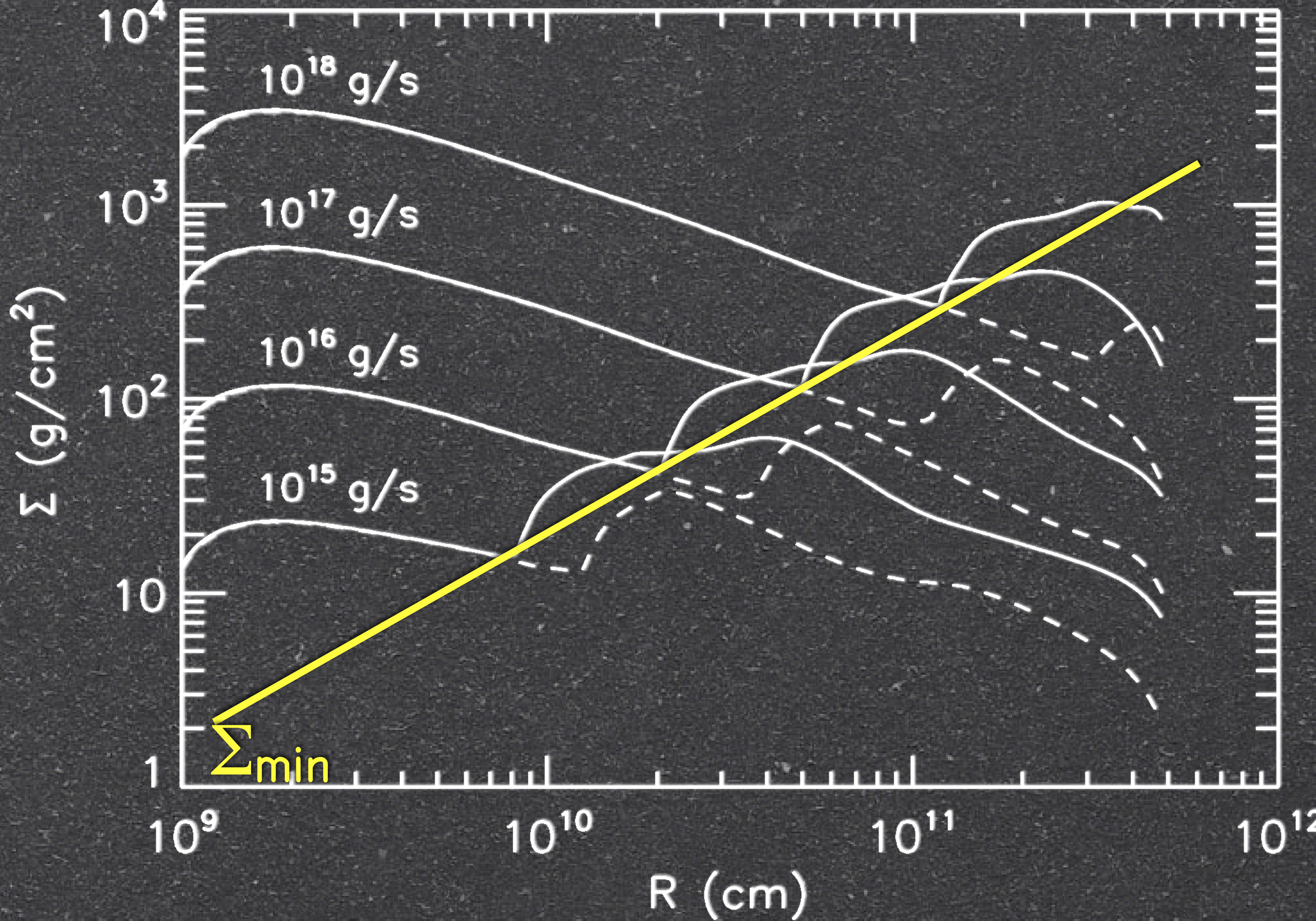
$$T^-_{\rm c} = 8240\,\alpha_{0.1}^{0.14}\,R_{10}^{-0.10}\,M_1^{0.04}\,{\rm K}$$

$$T^-_{\rm eff} = 5210\,\alpha_{0.1}\,R_{10}^{-0.10}\,M_1^{0.04}\,{\rm K}$$

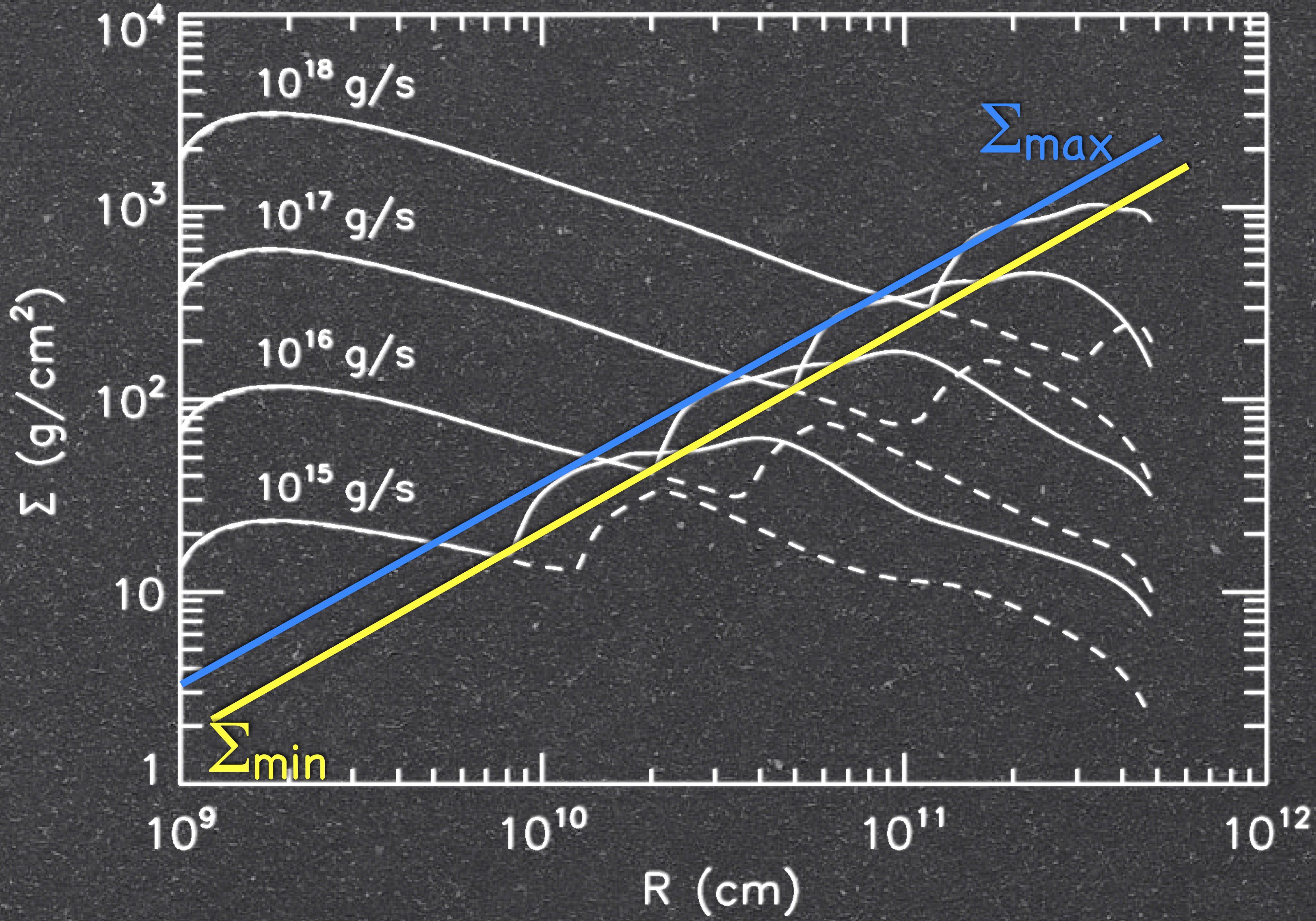
$$\dot{M}^-_{\rm crit} = 2.64\times10^{15}\,\alpha_{0.1}^{0.01}\,R_{10}^{2.58}\,M_1^{-0.85}\,{\rm g\,s^{-1}}$$



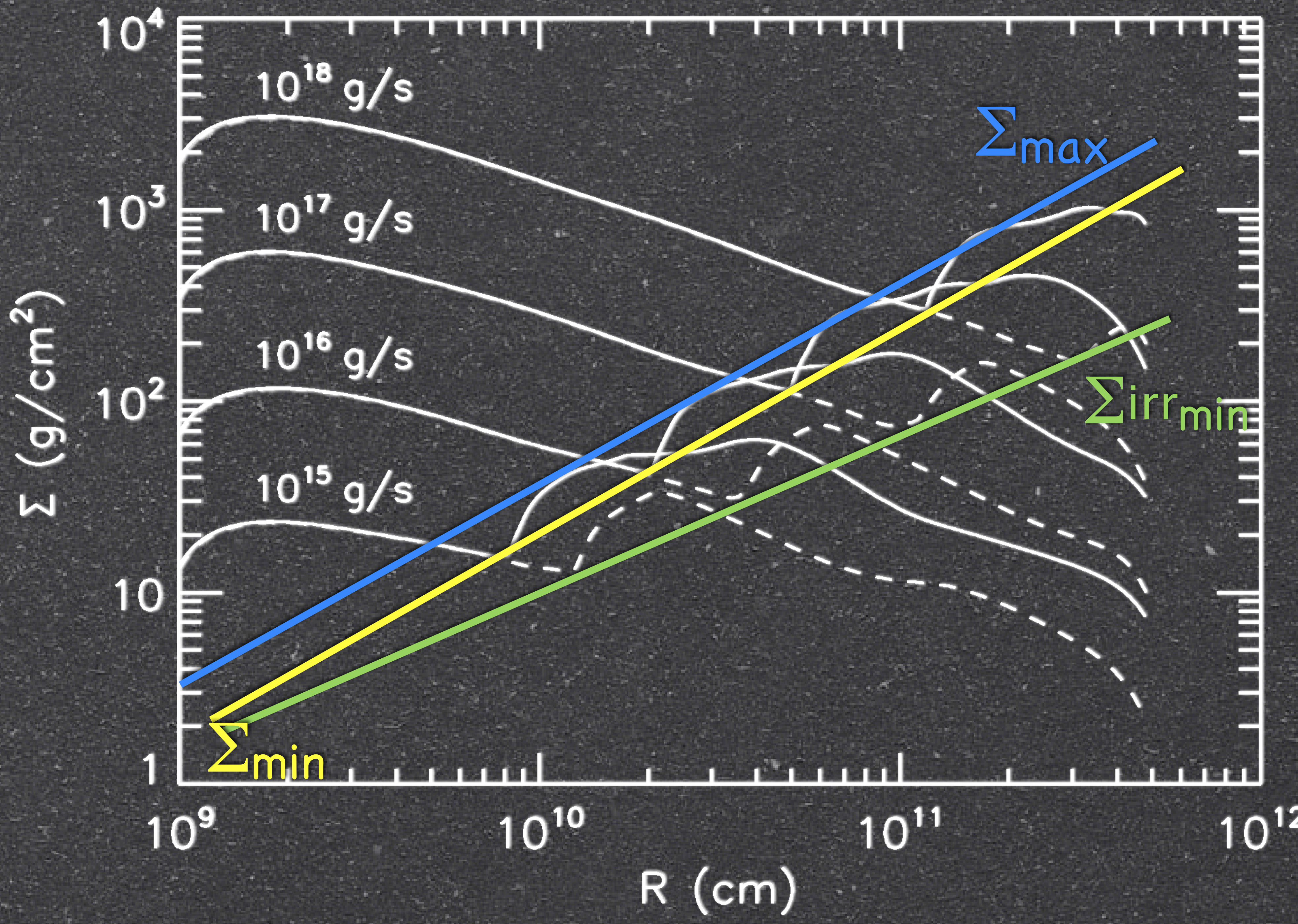
10^4
10^3
10^2
10
1
10^{18} g/s
10^{17} g/s
10^{16} g/s
10^{15} g/s
Σ (g/cm^2)
10^9
10^{10}
10^{11}
10^{12}
R (cm)



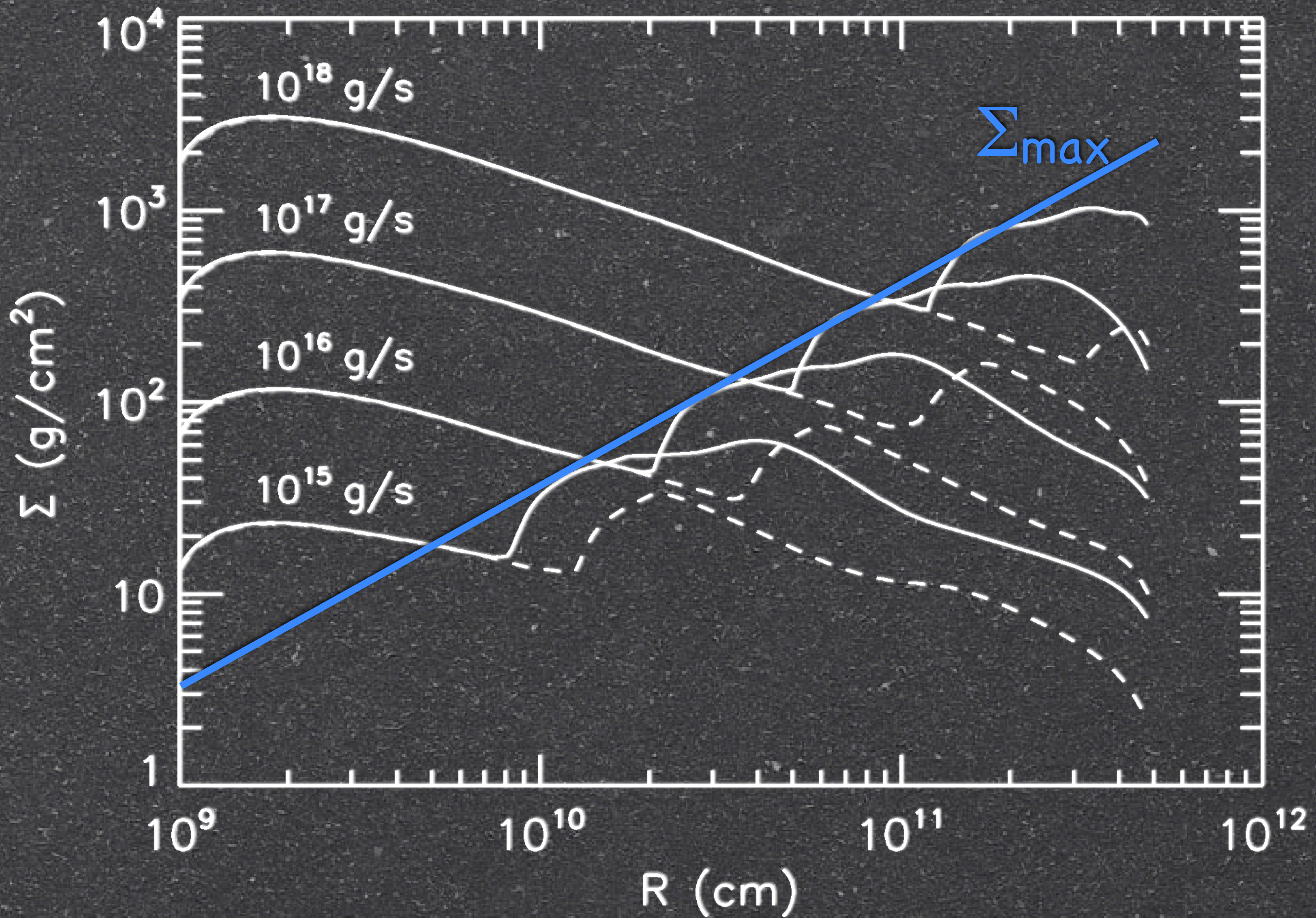
10^{18} g/s
10^{17} g/s
10^{16} g/s
10^{15} g/s
Σ_{min}
Σ (g/cm^2)
R (cm)
10^4
10^3
10^2
10
1
10^9
10^{10}
10^{11}
10^{12}

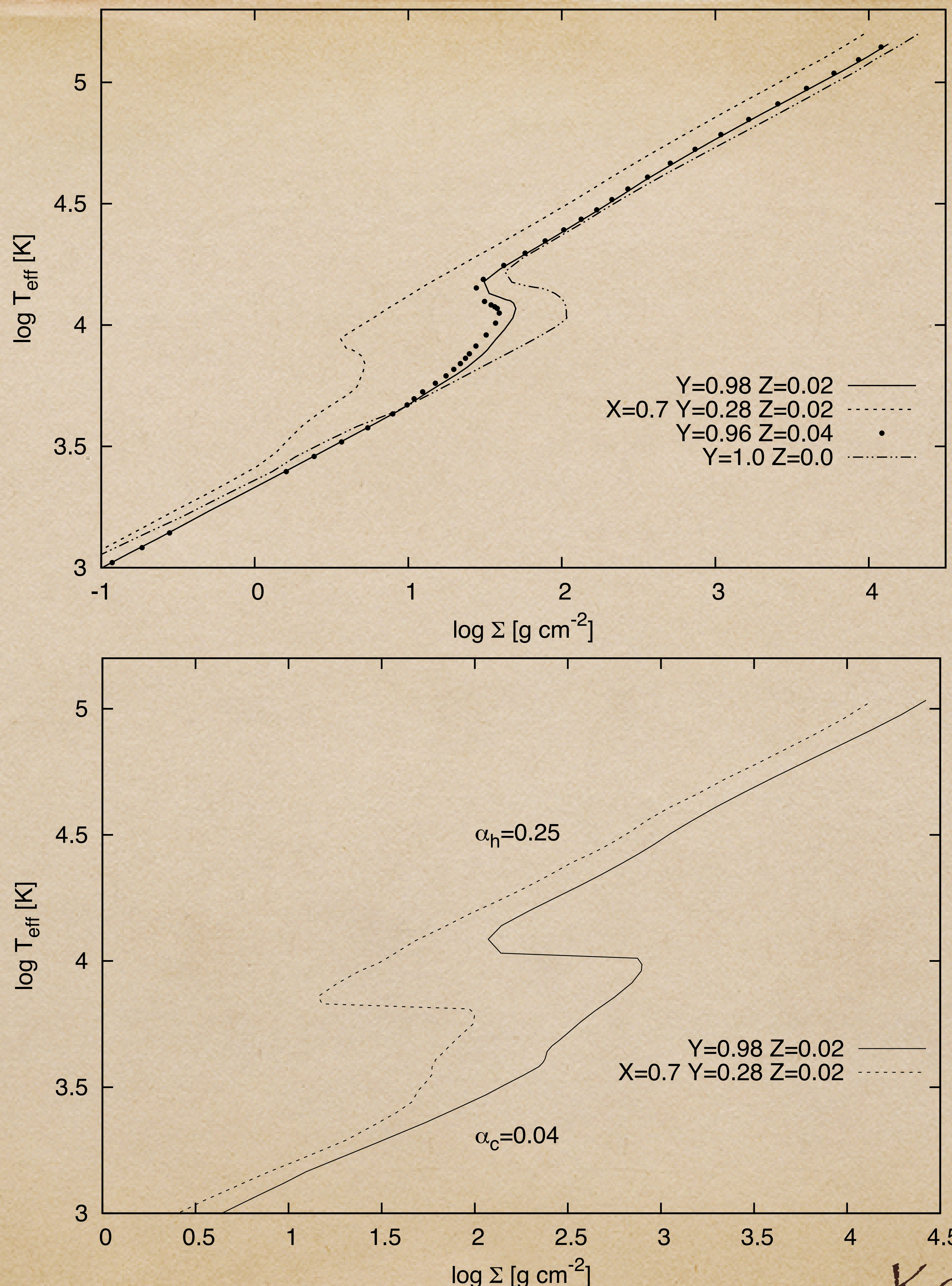


10^4
10^3
10^2
10
1
10^{18} g/s
10^{17} g/s
10^{16} g/s
10^{15} g/s
Σ_{max}
Σ_{min}
Σ (g/cm^2)
10^9
10^{10}
10^{11}
10^{12}
R (cm)



10^18 g/s
10^17 g/s
10^16 g/s
10^15 g/s
Σmax
Σirrmin
Σmin
Σ (g/cm²)
R (cm)
10^4
10^3
10^2
10
1
10^9
10^10
10^11
10^12

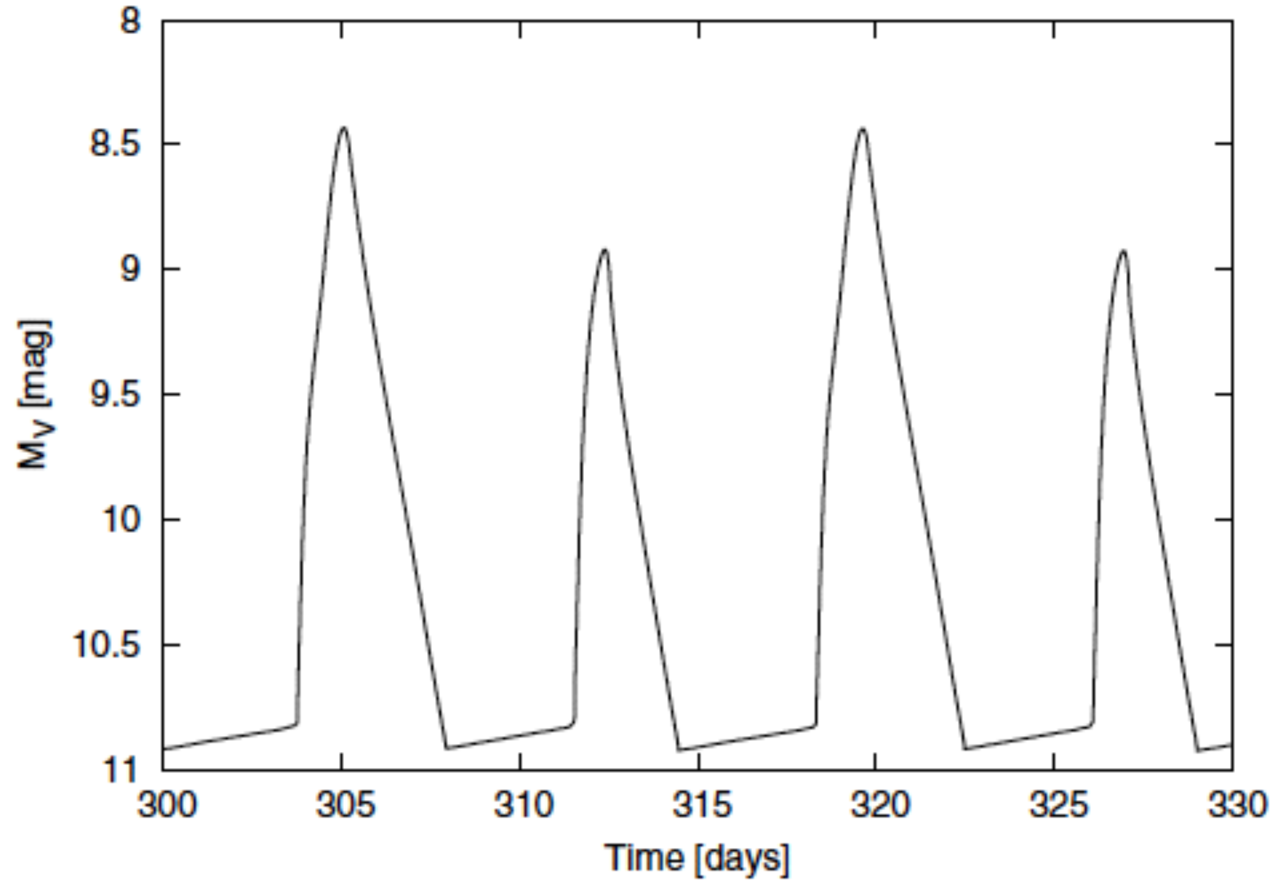

10^18 g/s
10^17 g/s
10^16 g/s
10^15 g/s
Σmax
Σ (g/cm²)
R (cm)
10^4
10^3
10^2
10
1
10^9
10^10
10^11
10^12



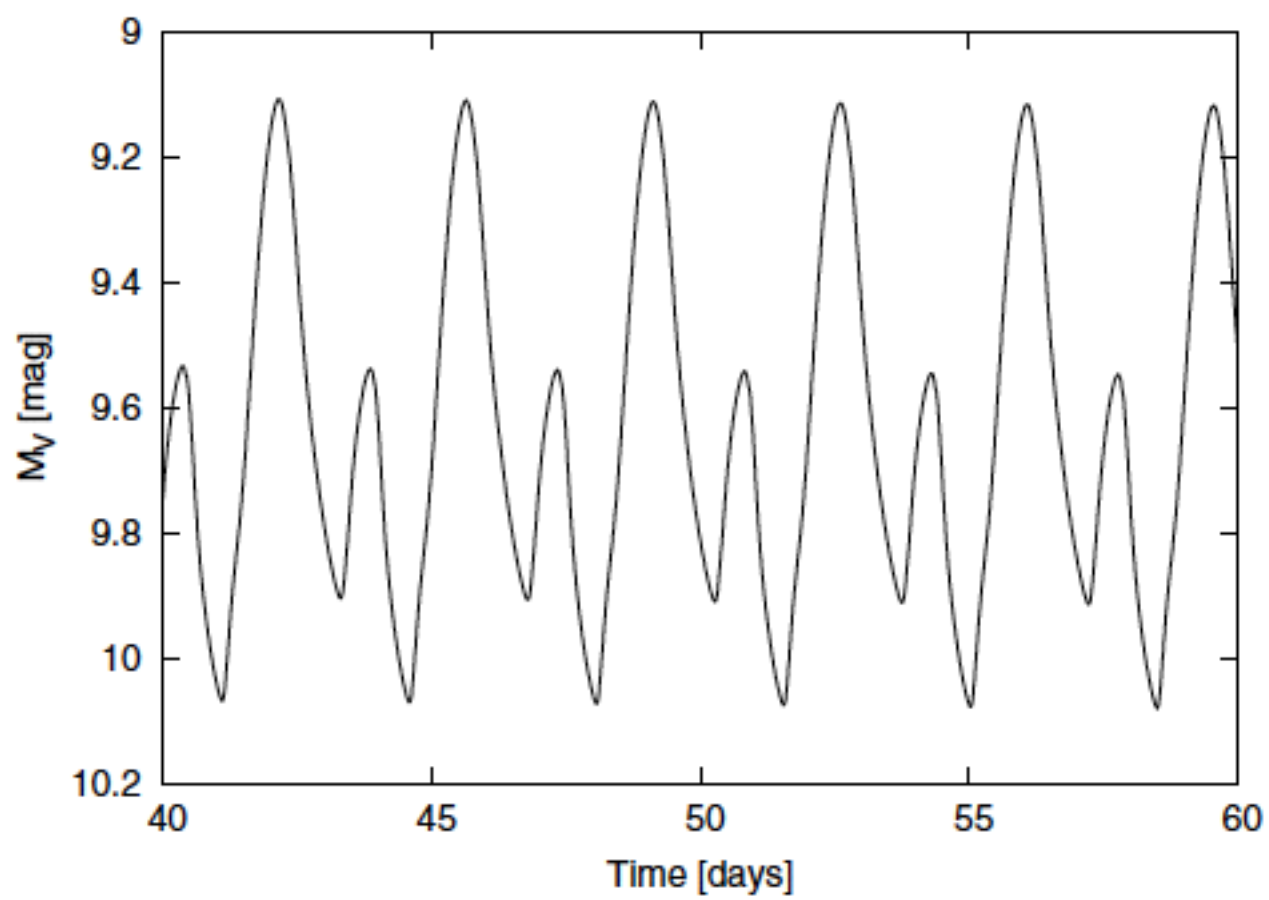
Kotko et al. 2012

$\alpha_h = \alpha_c$

Y=1



Y=0.98



Solar

$$\Sigma^+_{\rm crit} = 39.9\,\alpha_{0.1}^{-0.80}\,R_{10}^{1.11}\,M_1^{-0.37}\,{\rm g\,cm^{-2}}$$
$$T_{\rm c}^+ = 30000\,\alpha_{0.1}^{-0.18}\,R_{10}^{0.04}\,M_1^{-0.01}\,{\rm K}$$
$$T_{\rm eff}^+ = 6890\,\alpha_{0.1}\,R_{10}^{-0.09}\,M_1^{0.03}\,{\rm K}$$
$$\dot{M}^+_{\rm crit} = 8.07\times10^{15}\,\alpha_{0.1}^{-0.01}\,R_{10}^{2.64}\,M_1^{-0.89}\,{\rm g\,s^{-1}}$$
$$\Sigma^-_{\rm crit} = 74.6\,\alpha_{0.1}^{-0.83}\,R_{10}^{1.18}\,M_1^{-0.40}\,{\rm g\,cm^{-2}}$$
$$T_{\rm c}^- = 8240\,\alpha_{0.1}^{0.14}\,R_{10}^{-0.10}\,M_1^{0.04}\,{\rm K}$$
$$T_{\rm eff}^- = 5210\,\alpha_{0.1}\,R_{10}^{-0.10}\,M_1^{0.04}\,{\rm K}$$
$$\dot{M}^-_{\rm crit} = 2.64\times10^{15}\,\alpha_{0.1}^{0.01}\,R_{10}^{2.58}\,M_1^{-0.85}\,{\rm g\,s^{-1}}$$

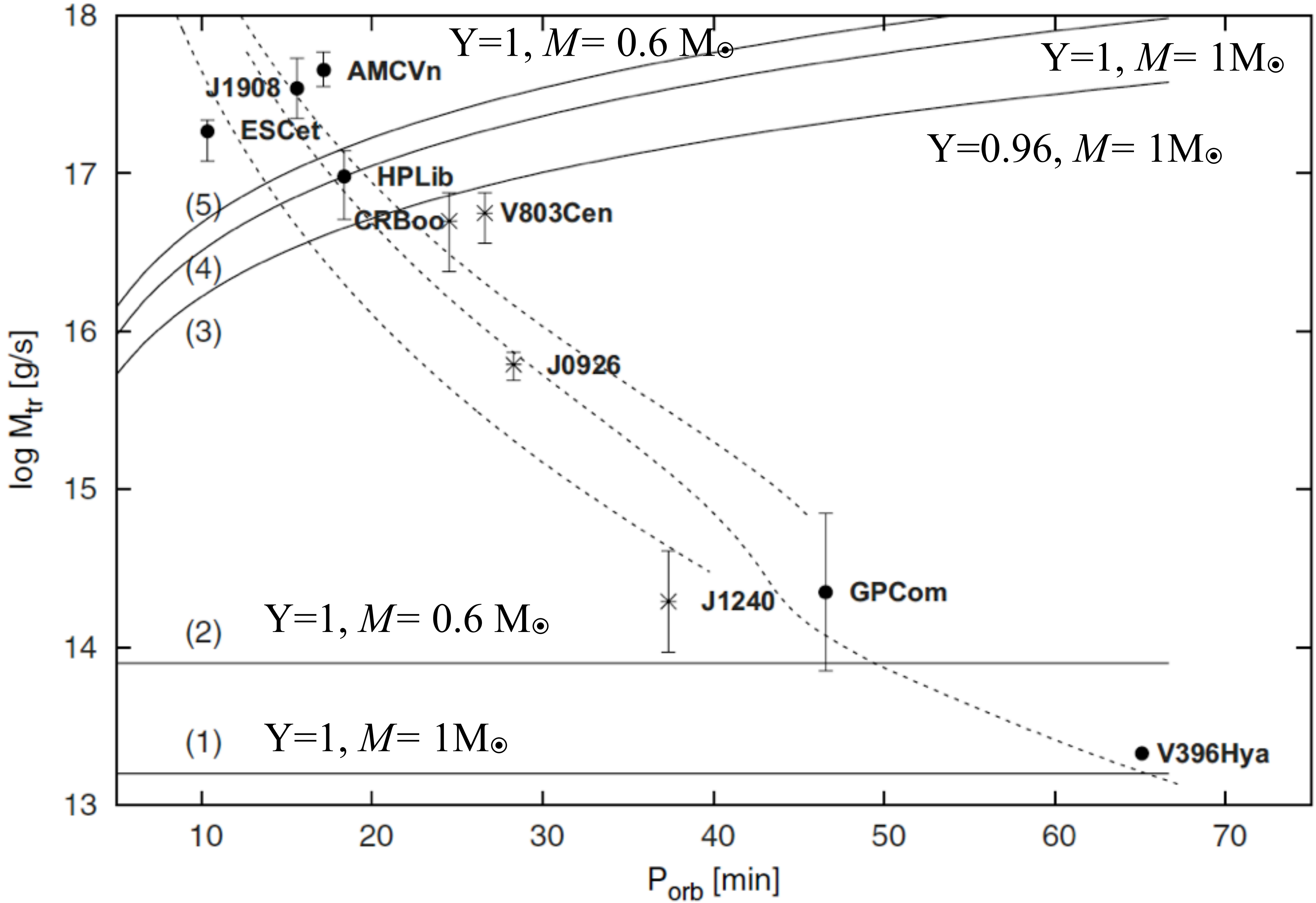
He

$$\Sigma^+ = 528\,\alpha_{0.1}^{-0.81}\,R_{10}^{1.07}\,M_1^{-0.36}\,{\rm g\,cm^{-2}}$$
$$\Sigma^- = 1620\,\alpha_{0.1}^{-0.84}\,R_{10}^{1.19}\,M_1^{-0.40}\,{\rm g\,cm^{-2}}$$
$$T_{\rm c}^+ = 77000\,\alpha_{0.1}^{-0.20}\,R_{10}^{0.08}\,M_1^{-0.03}\,{\rm K}$$
$$T_{\rm c}^- = 17800\,\alpha_{0.1}^{-0.13}\,R_{10}^{-0.03}\,M_1^{0.01}\,{\rm K}$$
$$T_{\rm eff}^+ = 13000\,\alpha_{0.1}^{-0.01}\,R_{10}^{-0.08}\,M_1^{0.03}\,{\rm K}$$
$$T_{\rm eff}^- = 9700\,\alpha_{0.1}^{-0.01}\,R_{10}^{-0.09}\,M_1^{0.03}\,{\rm K}$$
$$\dot{M}^+ = 1.01\times10^{17}\,\alpha_{0.1}^{-0.05}\,R_{10}^{2.68}\,M_1^{-0.89}\,{\rm g\,s^{-1}}$$
$$\dot{M}^- = 3.17\times10^{16}\,\alpha_{0.1}^{-0.02}\,R_{10}^{2.66}\,M_1^{-0.89}\,{\rm g\,s^{-1}}$$

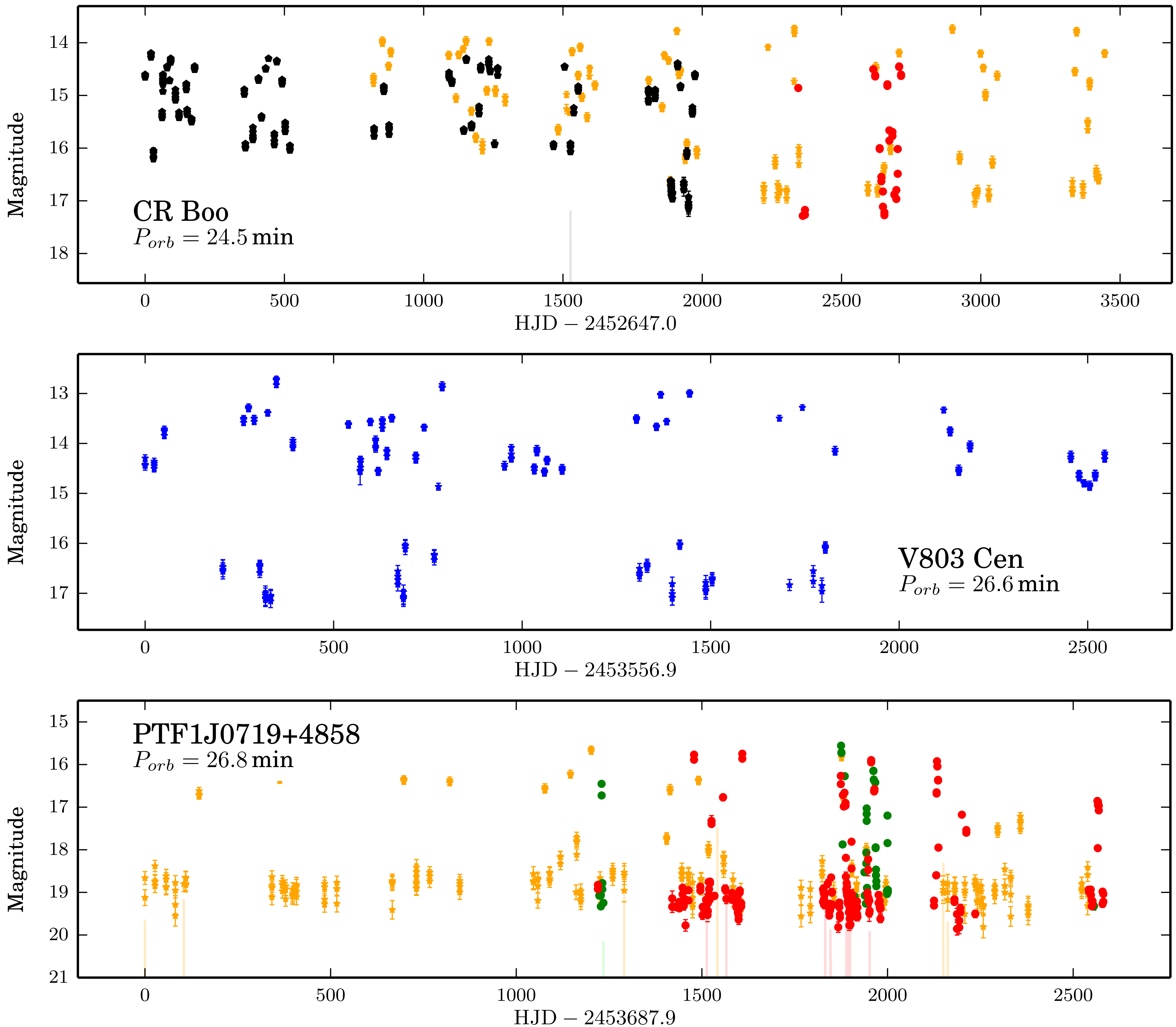
Levitan, Groot et al. 2014

Table 1. Known AM CVn Systems.

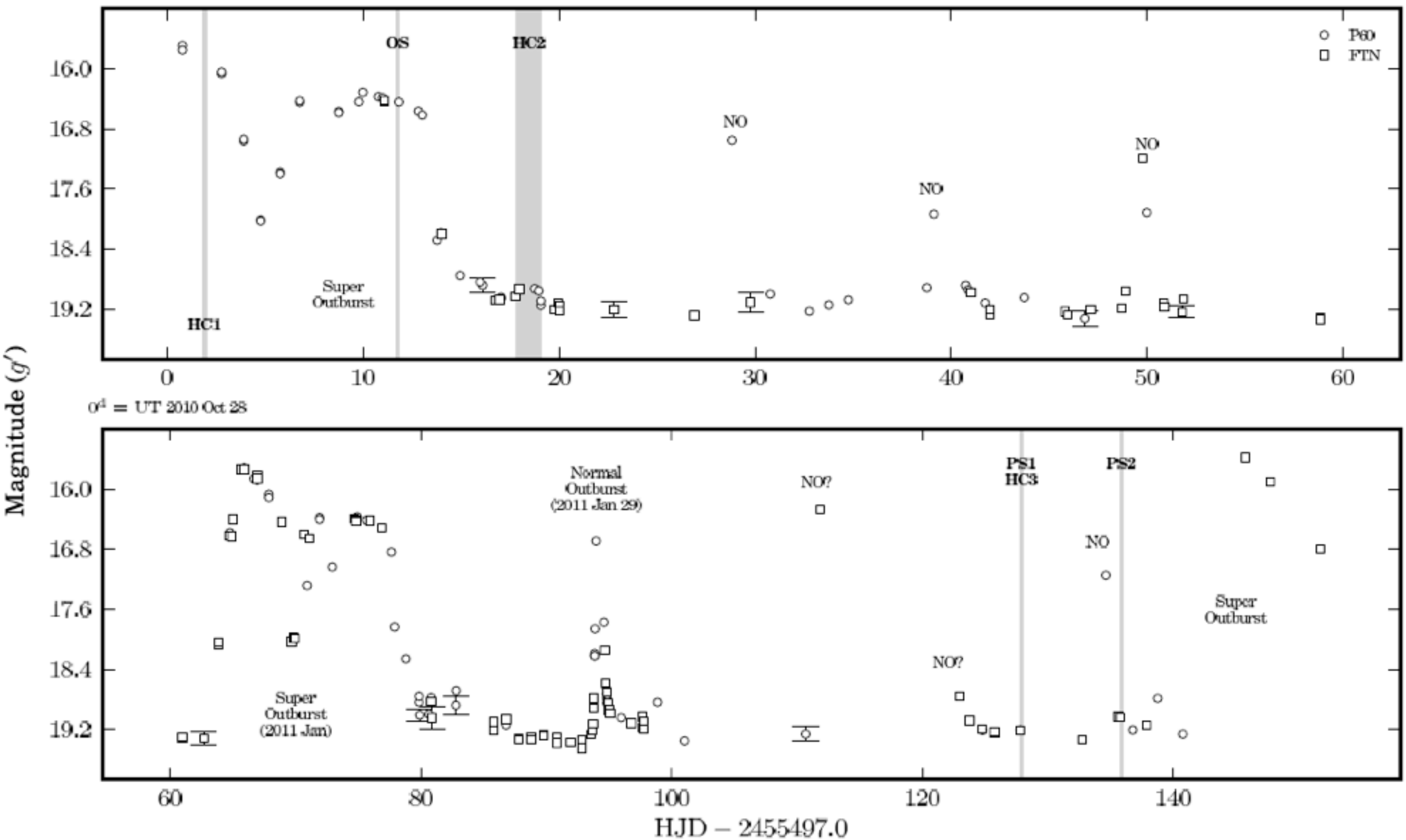
System[a]	Outbursting	Period (min)	Quiescence (g')	PTF[b]	CSS[b]	MLS/SSS[b,c]	LINEAR[b]	References
HM Cnc	N	5.36	20.7	58/59	···	···	···	1
V407 Vul	N	9.48	19.7	···	···	···	···	2
ES Ceti	N	10.3	17.1	···	164/235	···	···	3
KIC 004547333	N	15.9	16.1	117/118	31/36	···	···	4
AM CVn	N	17.1	14.2	103/104	···	···	293/293	5
HP Lib	N	18.4	13.5	···	131/134	S: 130/130	···	6
PTF1 J191905.19+481506.2	Y	22.5	21.5	22/110	···	···	···	7
CR Boo	Y	24.5	17.4	31/31	286/286	···	266/271	8, 9
KL Dra	Y	25.0	19.1	···	···	···	···	10
V803 Cen	Y	26.6	16.9	···	···	S: 231/231	···	6, 11, 12
PTF1 J071912.13+485834.0	Y	26.8	19.4	250/262	281/292	···	···	13
SDSS J092638.71+362402.4	Y	28.3	19.0	8/8	254/295	···	77/714	14, 15
CP Eri	Y	28.7	20.3	198/300	160/228	S: 35/45	···	16
PTF1 J094329.59+102957.6	Y	30.4	20.7	71/217	50/296	M: 51/53	16/1163	17
V406 Hya	Y	33.8	20.5	···	83/262	···	···	18
PTF1 J043517.73+002940.7	Y	34.3	22.3	2/213	7/319	···	···	17
SDSS J173047.59+554518.5	N	35.2	20.1	···	69/119	···	0/535	19, 20
2QZ J142701.6–012310	Y	36.6	20.3	···	62/298	···	19/493	21
SDSS J124058.03–015919.2	Y	37.4	19.7	···	224/302	M: 86/86	39/529	22
SDSS J012940.05+384210.4	Y	37.6	19.8	···	74/260	···	···	14, 23, 24
SDSS J172102.48+273301.2	Y	38.1	20.1	208/298	31/382	···	0/409	25, 26
SDSS J152509.57+360054.5	N	44.3	19.8	80/100	181/254	···	60/231	24, 25
SDSS J080449.49+161624.8	···[d]	44.5	18.2	110/112	336/358	···	···	27
SDSS J141118.31+481257.6	N	46.0	19.4	102/111	84/121	···	0/237	14
GP Com	N	46.5	15.9	11/12	315/315	···	207/450	28
CRTS J045020.8–093113	Y	47.3	20.5	31/66	21/240	···	···	29
SDSS J090221.35+381941.9	Y[e]	48.3	20.2	···	47/341	···	0/337	25, 30
SDSS J120841.96+355025.2	N	52.6	18.8	97/101	283/288	···	101/290	24, 31
SDSS J164228.06+193410.0	N	54.2	20.3	···	1/369	···	0/430	24, 25
SDSS J155252.48+320150.9	N	56.3	20.2	125/242	47/297	···	0/230	32
SDSS J113732.32+405458.3	N	59.6	19.0	72/77	300/309	···	0/539	33
V396 Hya	N	65.1	17.3	54/56	46/48	S: 235/236	···	34
SDSS J150551.58+065948.7	N	···	19.1	143/149	337/347	···	106/606	33
CRTS J084413.6–012807	Y	···	20.3	···	22/324	···	···	35
SDSS J104325.08+563258.1	Y	···	20.3	14/16	22/120	···	34/216	19
PTF1 J221910.09+313523.1	Y	···	20.6	49/72	53/111	···	···	17
CRTS J074419.7+325448	Y	···	21.1	···	103/460	M: 32/49	···	35
PTF1 J085724.27+072946.7	Y	···	21.8	15/126	50/349	···	0/791	17
PTF1 J163239.39+351107.3	Y	···	23.0	61/173	36/324	···	0/564	17
PTF1 J152310.71+184558.2	Y	···	23.5	10/28	2/325	···	0/203	17
SDSS J204739.40+000840.1	Y	···	24.0	···	0/67	···	0/591	31



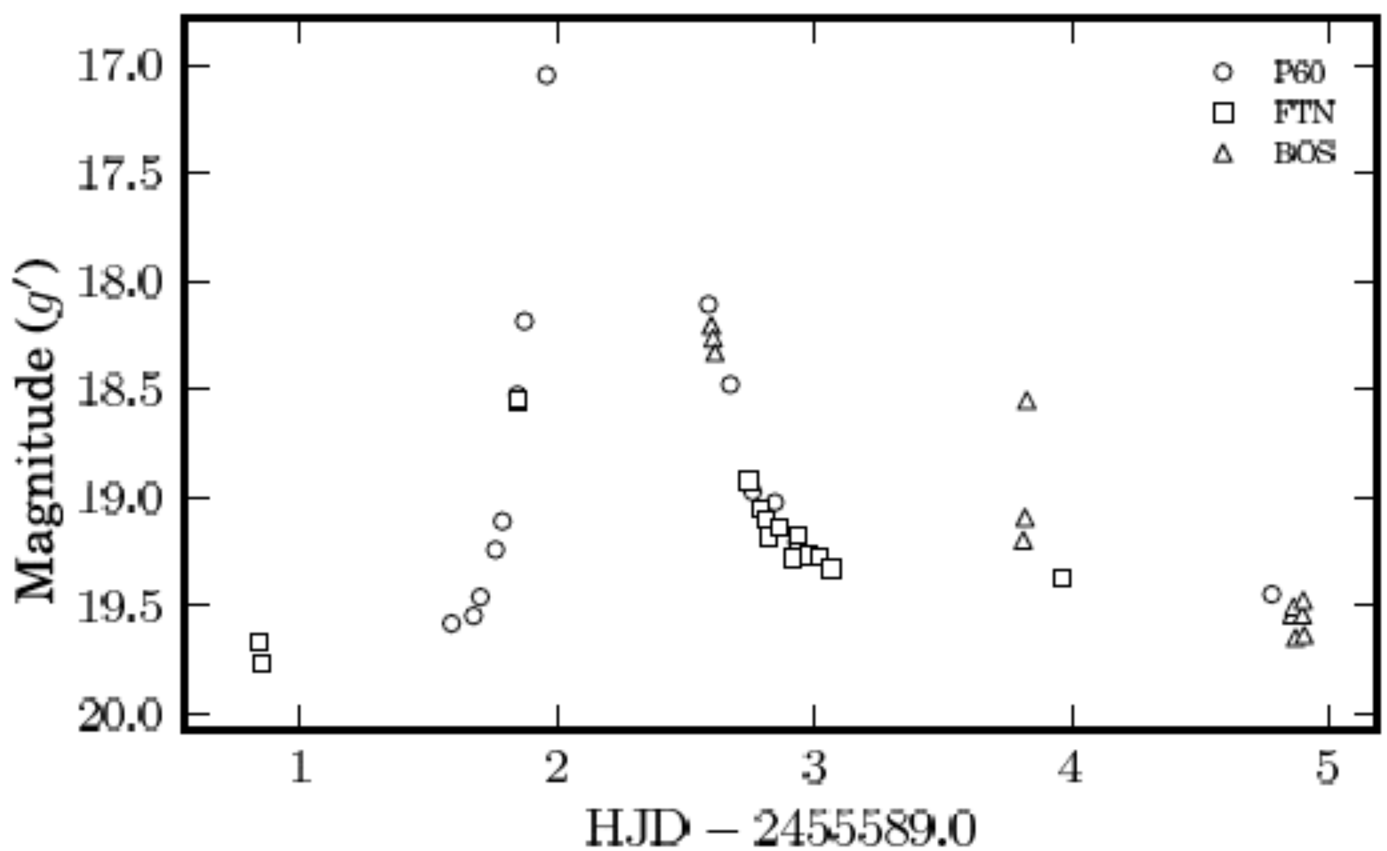
Y=1, M= 0.6 M☉
Y=1, M= 1M☉
Y=0.96, M= 1M☉
AMCVn
J1908
ESCet
HPLib
CRBoo
V803Cen
J0926
J1240
GPCom
V396Hya
(5)
(4)
(3)
(2)
(1)
Y=1, M= 0.6 M☉
Y=1, M= 1M☉
log M_tr [g/s]
P_orb [min]
18
17
16
15
14
13
10
20
30
40
50
60
70



CR Boo
$P_{orb} = 24.5\,\mathrm{min}$
Magnitude
HJD − 2452647.0
V803 Cen
$P_{orb} = 26.6\,\mathrm{min}$
Magnitude
HJD − 2453556.9
PTF1J0719+4858
$P_{orb} = 26.8\,\mathrm{min}$
Magnitude
HJD − 2453687.9

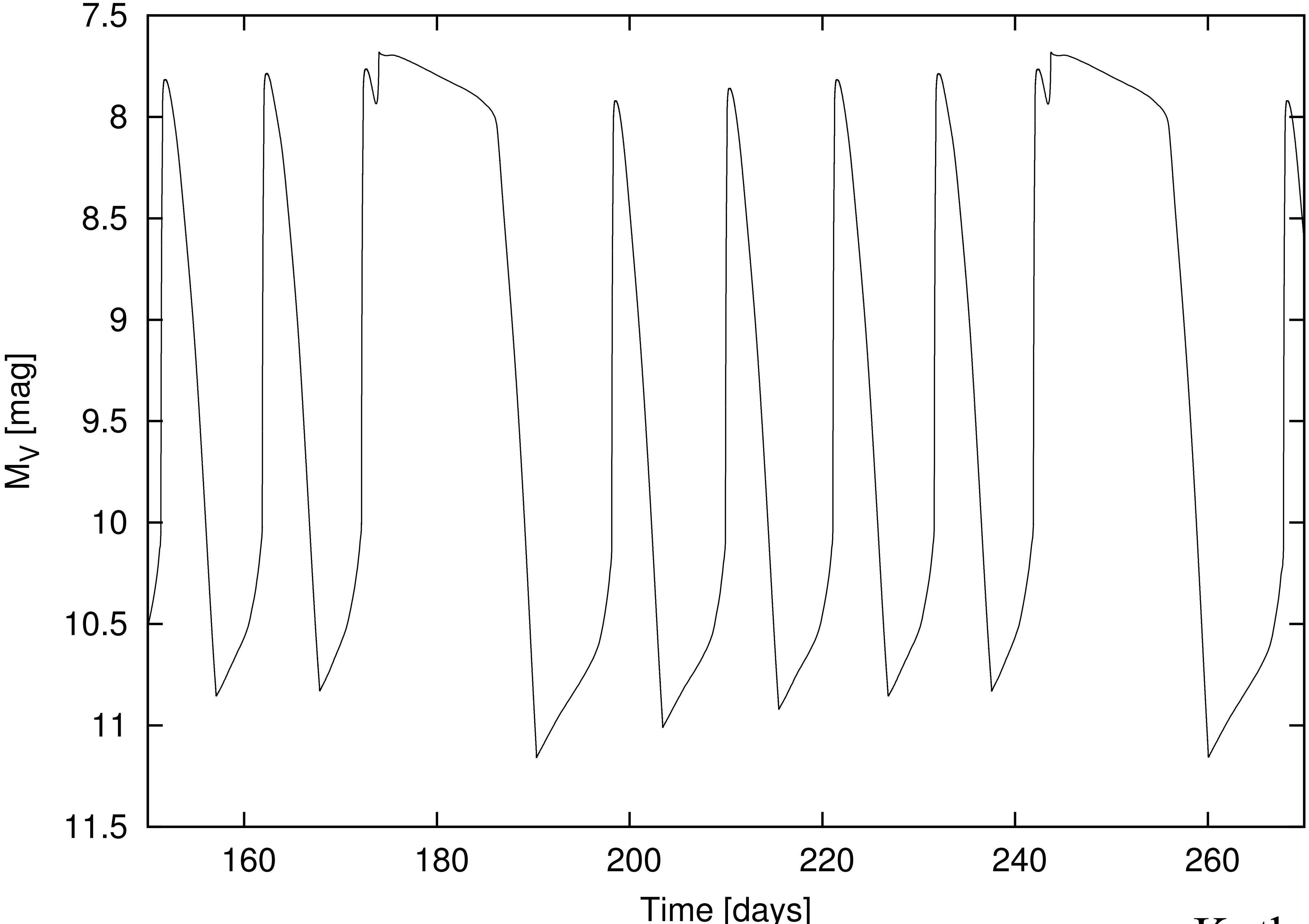


P60
FTN
OS
HC2
HC1
NO
Super Outburst
0^d = UT 2010 Oct 28
Magnitude (g')
Normal Outburst (2011 Jan 29)
NO?
PS1
HC3
PS2
Super Outburst (2011 Jan)
HJD − 2455497.0

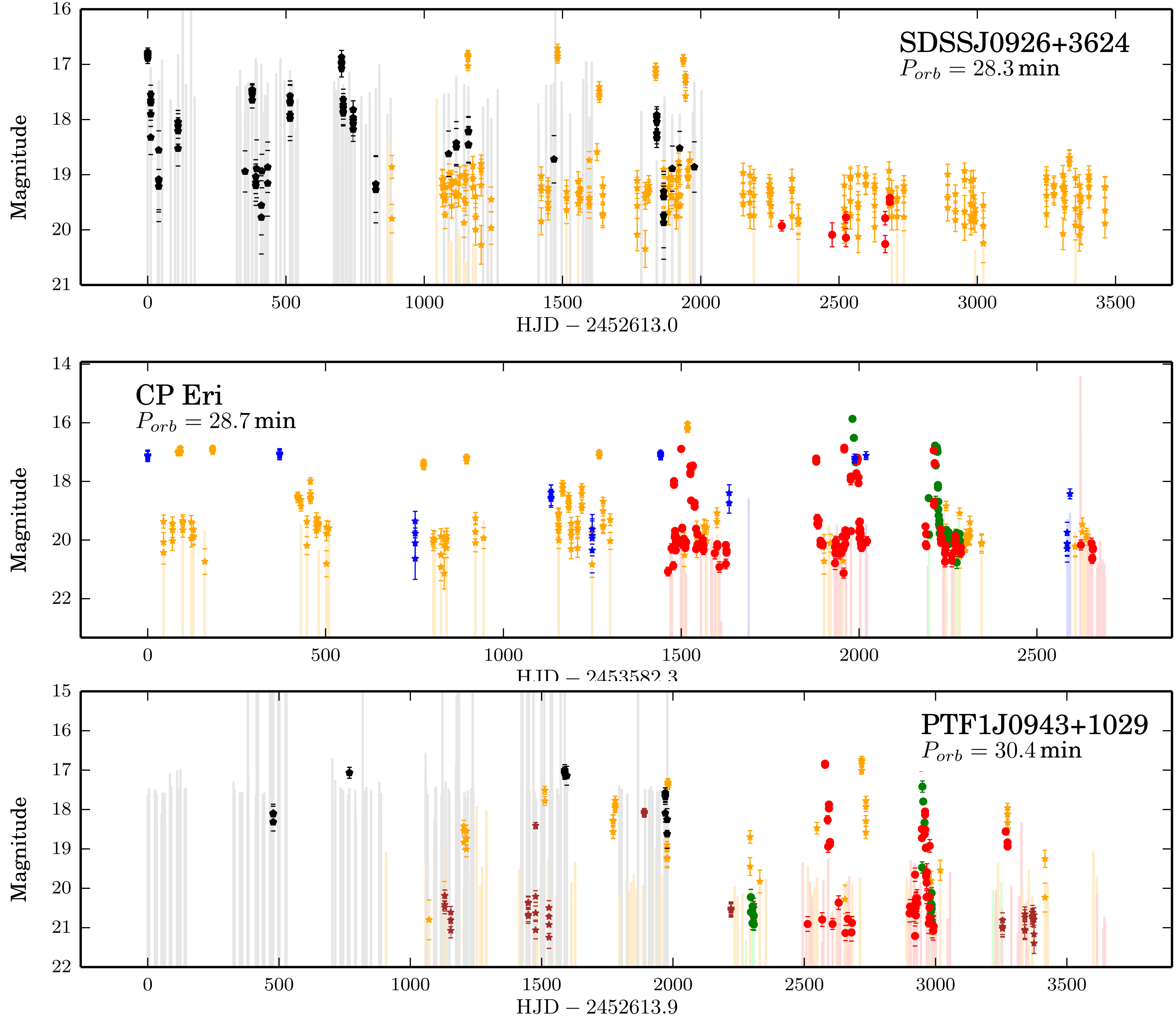


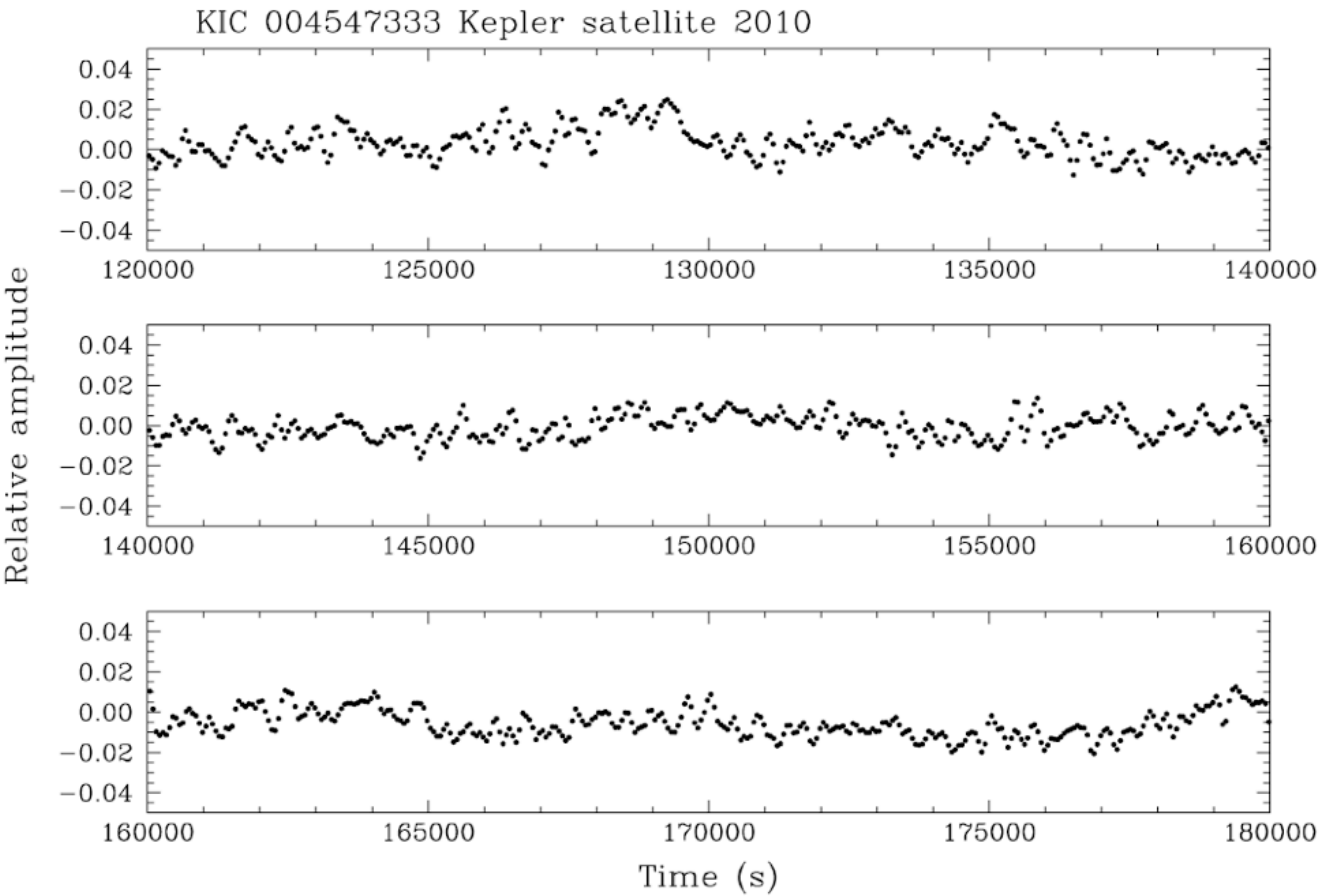
P60
FTN
BOS
Magnitude (g')
HJD − 2455589.0

“Imitation” of PTF 1J0719+4858



Kotko et al. 2012


SDSSJ0926+3624
$P_{orb} = 28.3$ min
Magnitude
HJD − 2452613.0
CP Eri
$P_{orb} = 28.7$ min
Magnitude
HJD − 2453582.3
PTF1J0943+1029
$P_{orb} = 30.4$ min
Magnitude
HJD − 2452613.9


KIC 004547333 Kepler satellite 2010
Relative amplitude
Time (s)
0.04
0.02
0.00
−0.02
−0.04
120000
125000
130000
135000
140000
145000
150000
155000
160000
165000
170000
175000
180000

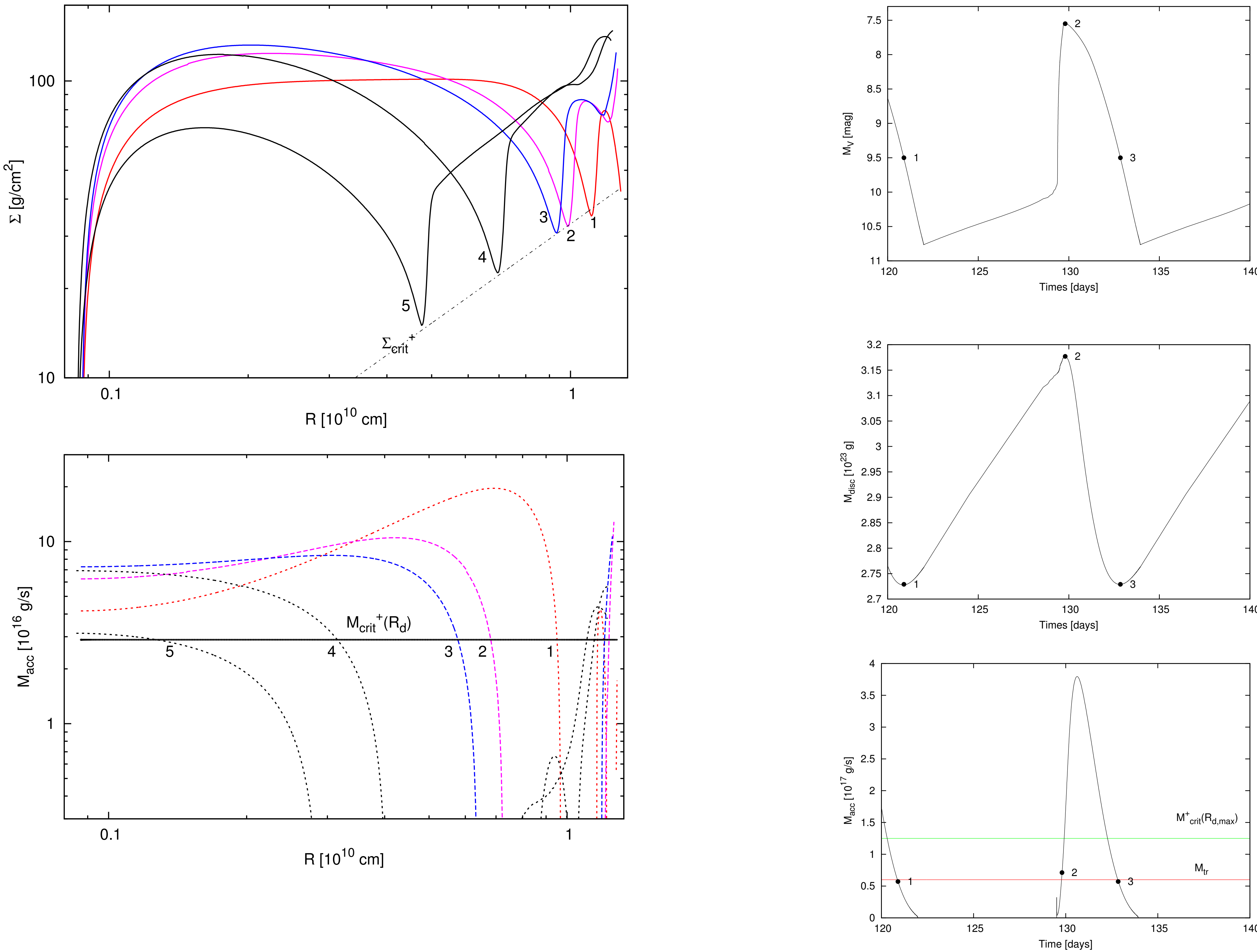
When the heating front reaches the outer disc radius

$$\dot{M}_{\rm max} \approx \dot{M}^{+}_{\rm crit} = 2.4 \times 10^{-12} f_{0.6}^{2.51} P_{\rm min}^{1.67}\, M_{\odot}\, {\rm y}^{-1}.$$

AM CVn $$L_{\rm max} \simeq 1.9 \times 10^{34} \left(\frac{P_{\rm orb}}{1{\rm h}}\right)^{1.67} {\rm erg\ s^{-1}},$$

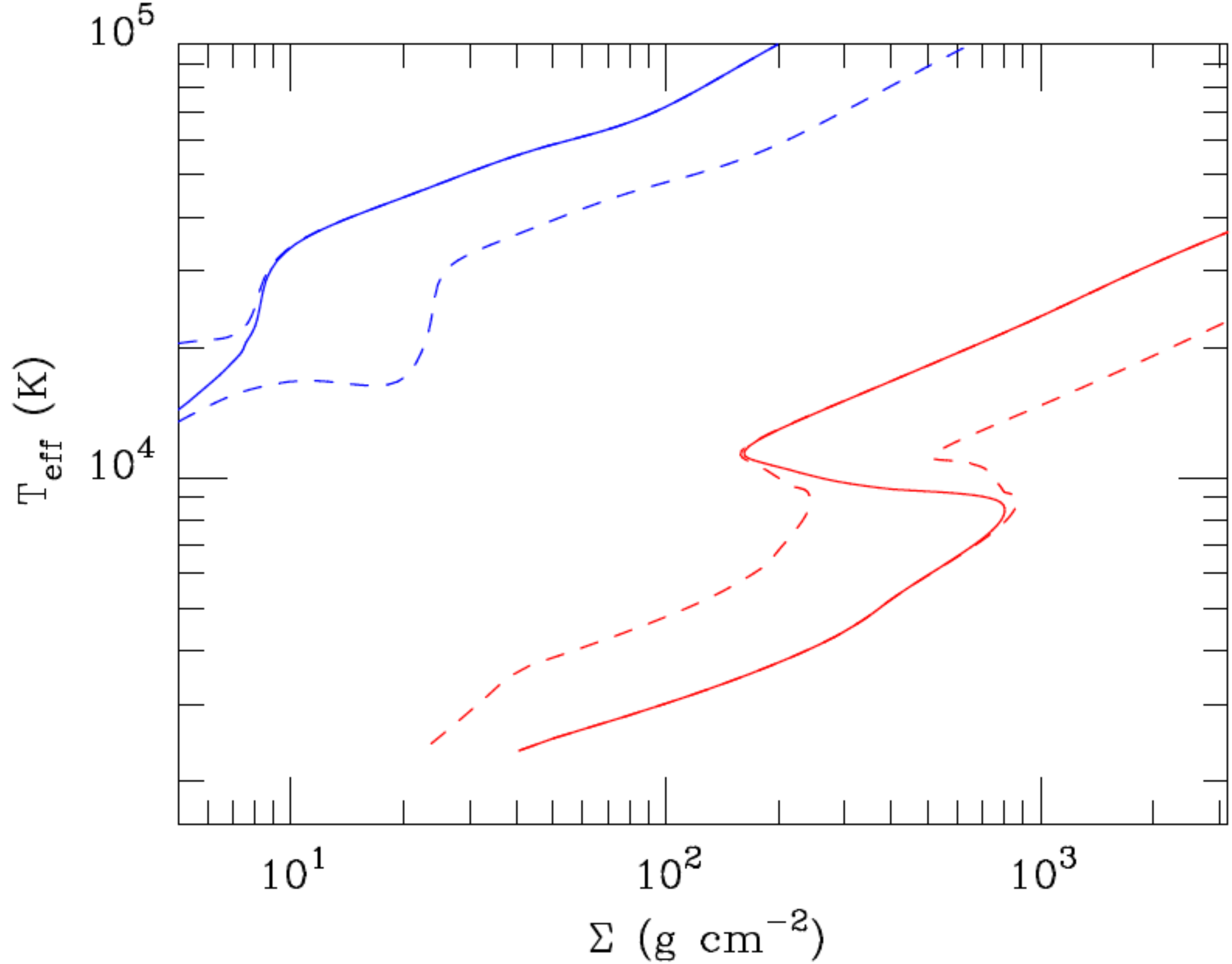
UCXBs $$L_{\rm max} \simeq 3.5 \times 10^{37} \left(\frac{P_{\rm orb}}{1{\rm h}}\right)^{1.67} {\rm erg\ s^{-1}},$$

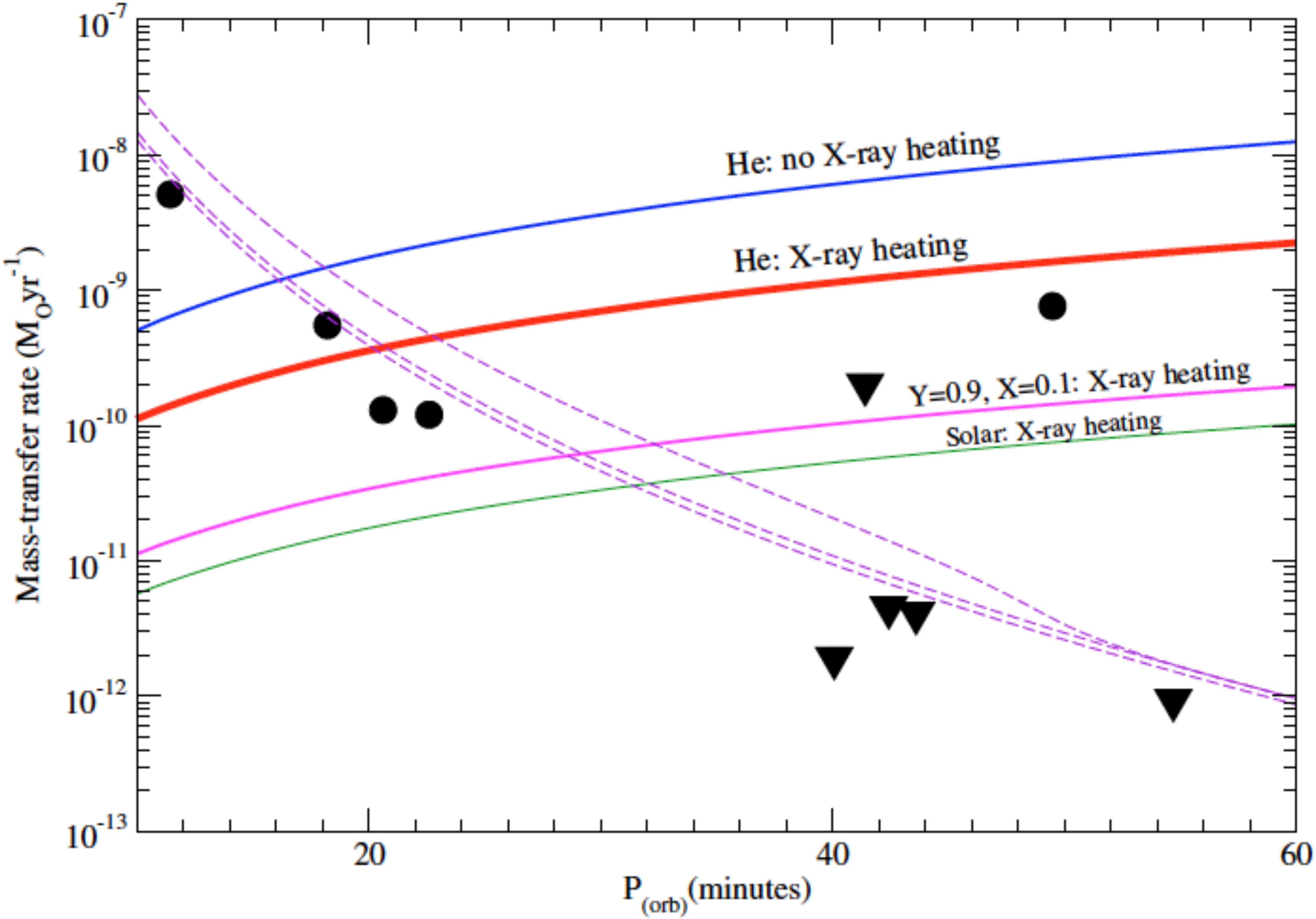
… when it does not: $L < L_{\rm max}$.



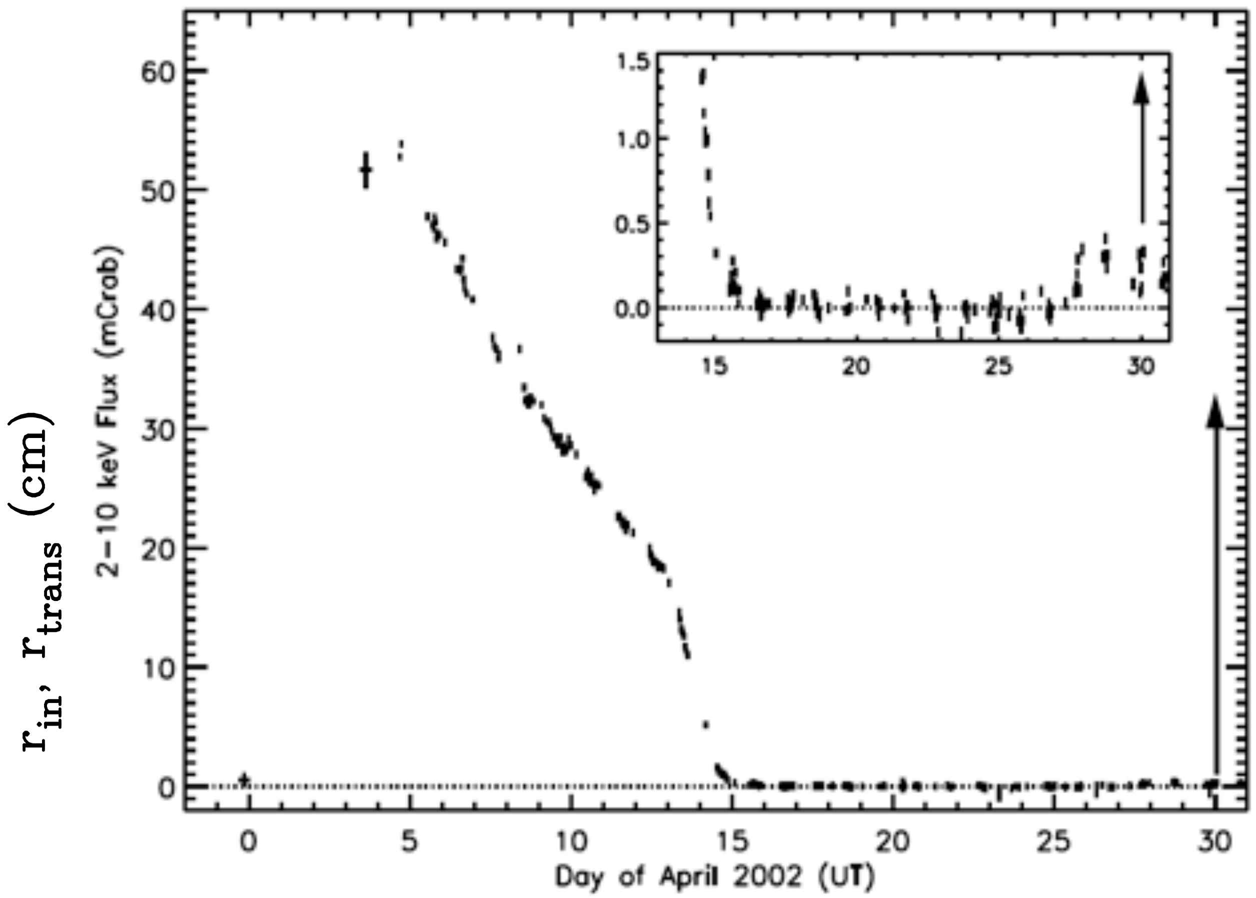
Σ [g/cm²]
R [10¹⁰ cm]
Σcrit⁺
1
2
3
4
5
100
10
0.1
1
Macc [10¹⁶ g/s]
Mcrit⁺(Rd)
R [10¹⁰ cm]
MV [mag]
Times [days]
Mdisc [10²³ g]
Times [days]
Macc [10¹⁷ g/s]
M⁺crit(Rd,max)
Mtr
Time [days]
120
125
130
135
140

UCXBs

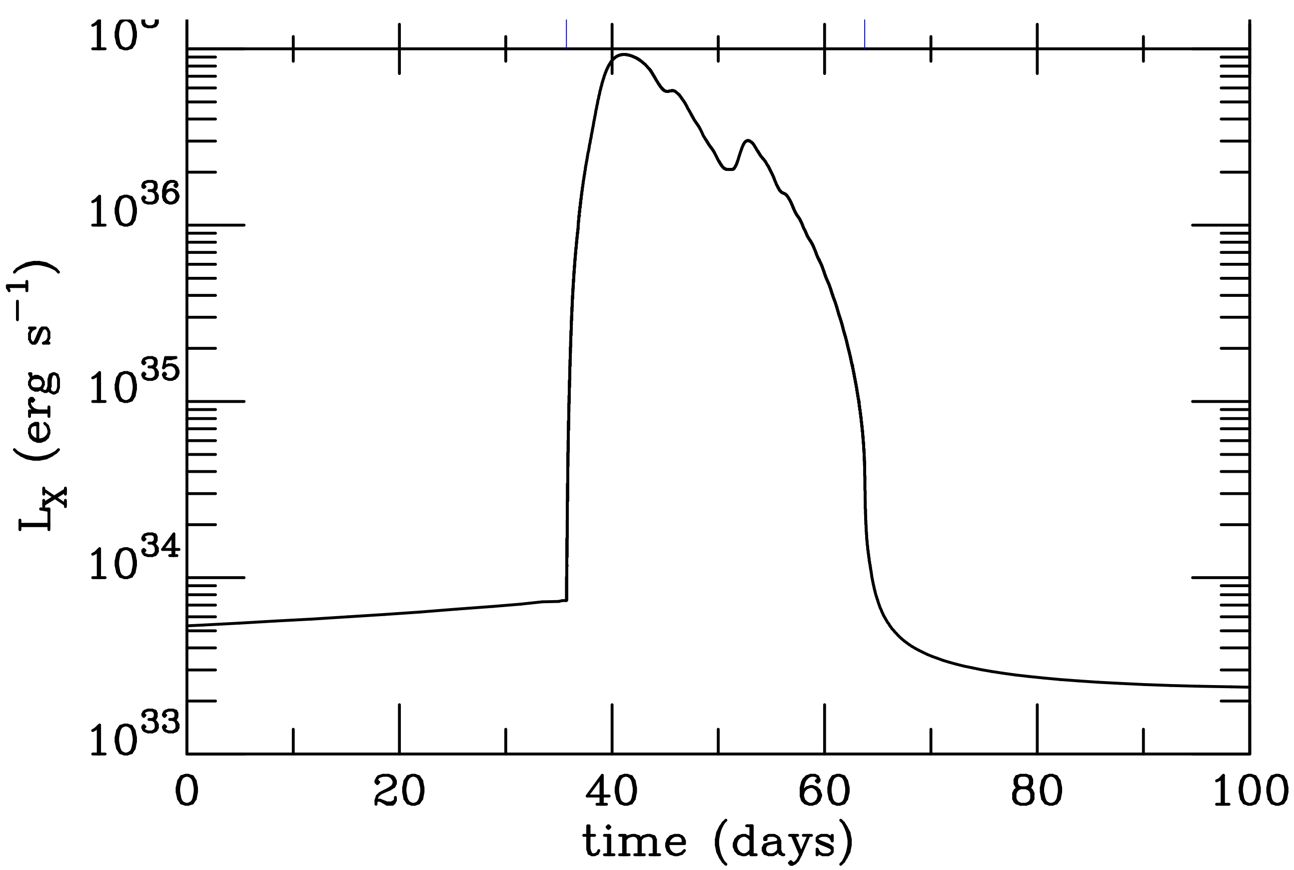




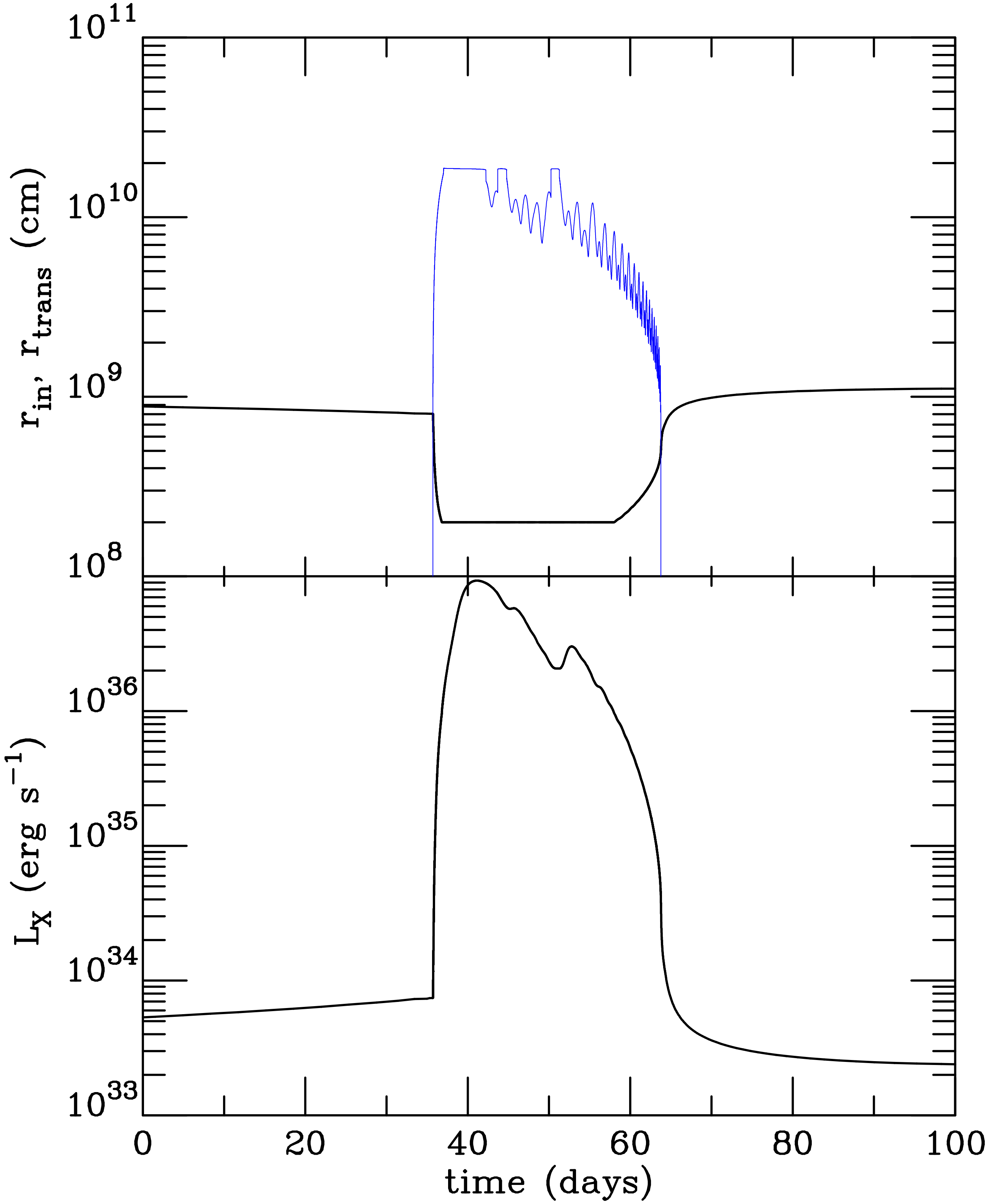
He: no X-ray heating
He: X-ray heating
Y=0.9, X=0.1: X-ray heating
Solar: X-ray heating
Mass-transfer rate ($M_{\odot} yr^{-1}$)
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
20
40
60
$P_{(orb)}$(minutes)



FXT



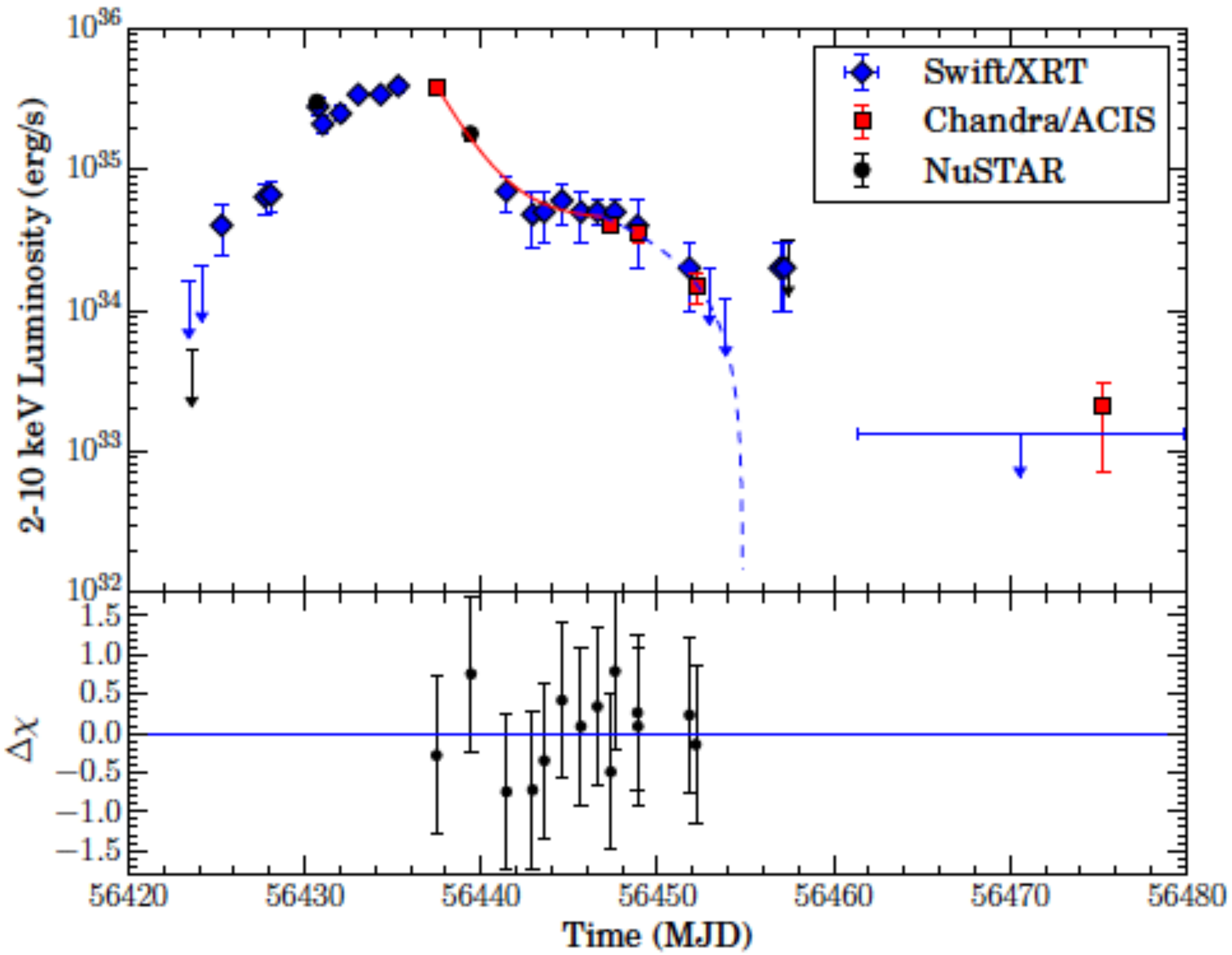
$P_{\rm orb}$=42 min, R = 1.8 × 10^{10}cm, $\dot{M}$= 3 × 10^{15} g/s

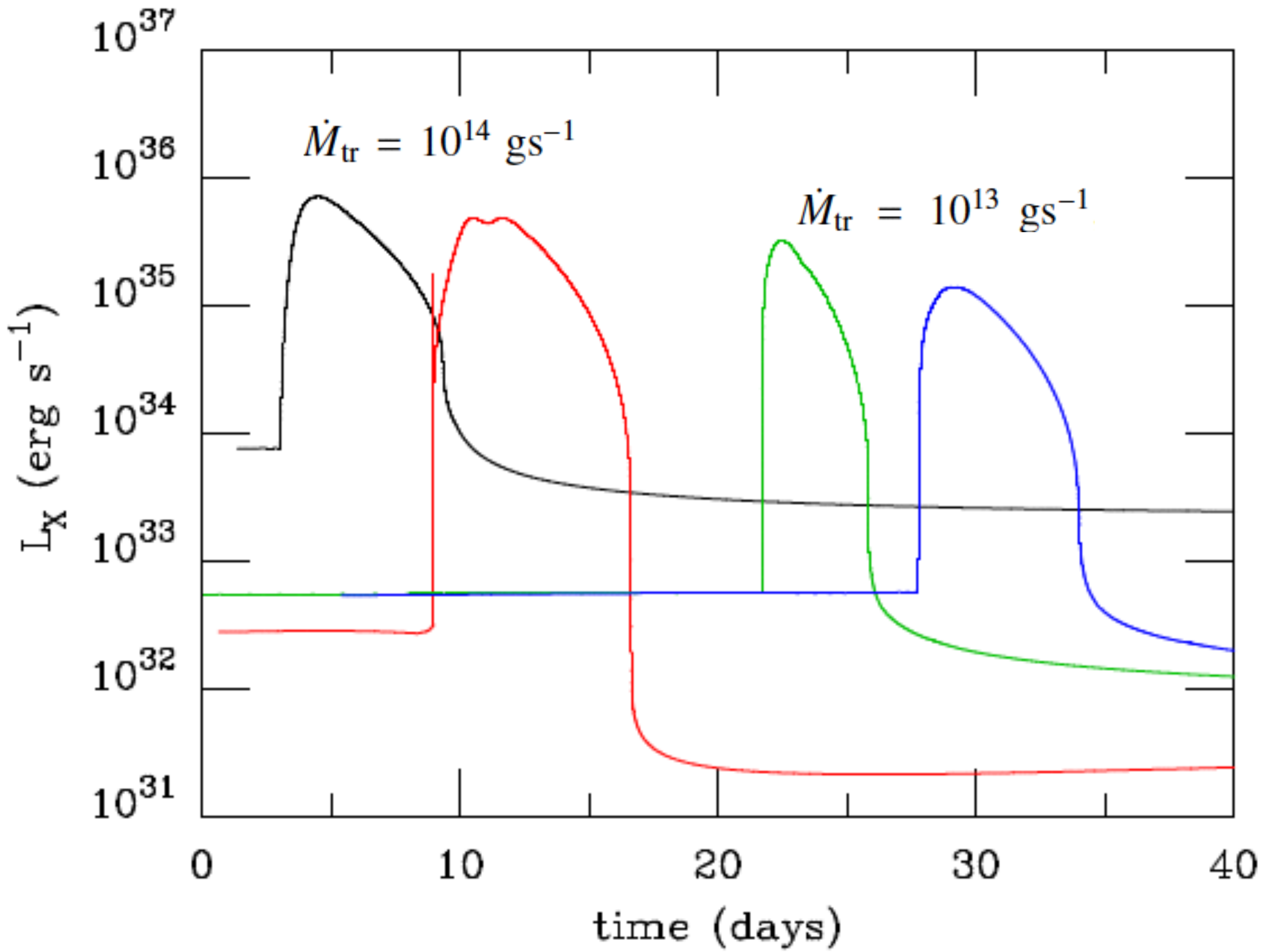


FXT

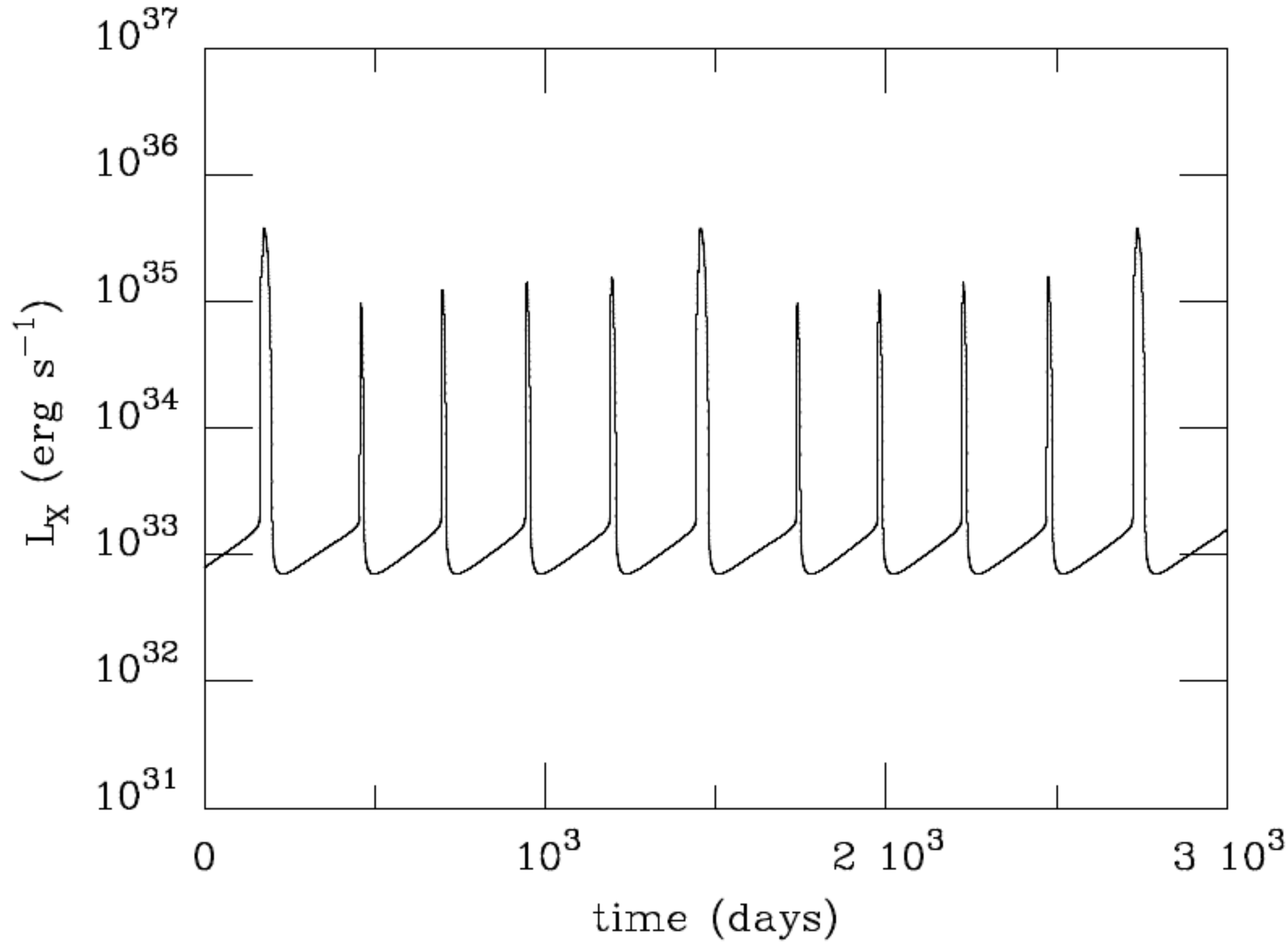
P_{orb}=42 min, R = 1.8 × 10^{10}cm, $\dot{M}$= 3 × 10^{15} g/s

VFXT


Swift/XRT
Chandra/ACIS
NuSTAR
2-10 keV Luminosity (erg/s)
10^{36}
10^{35}
10^{34}
10^{33}
10^{32}
$\Delta\chi$
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
56420
56430
56440
56450
56460
56470
56480
Time (MJD)



$\dot{M}_{tr} = 10^{14}$ gs^{-1}
$\dot{M}_{tr} = 10^{13}$ gs^{-1}
L_X (erg s^{-1})
10^{37}
10^{36}
10^{35}
10^{34}
10^{33}
10^{32}
10^{31}
0
10
20
30
40
time (days)



10^{37}
10^{36}
10^{35}
10^{34}
10^{33}
10^{32}
10^{31}
L_X (erg s^{-1})
0
10^3
2 10^3
3 10^3
time (days)

"C/O" disc