Chandra Fellows Symposium

The Giant X-Ray Flare of NGC 5905: Tidal Disruption of a Star, a Brown Dwarf, or a Planet?

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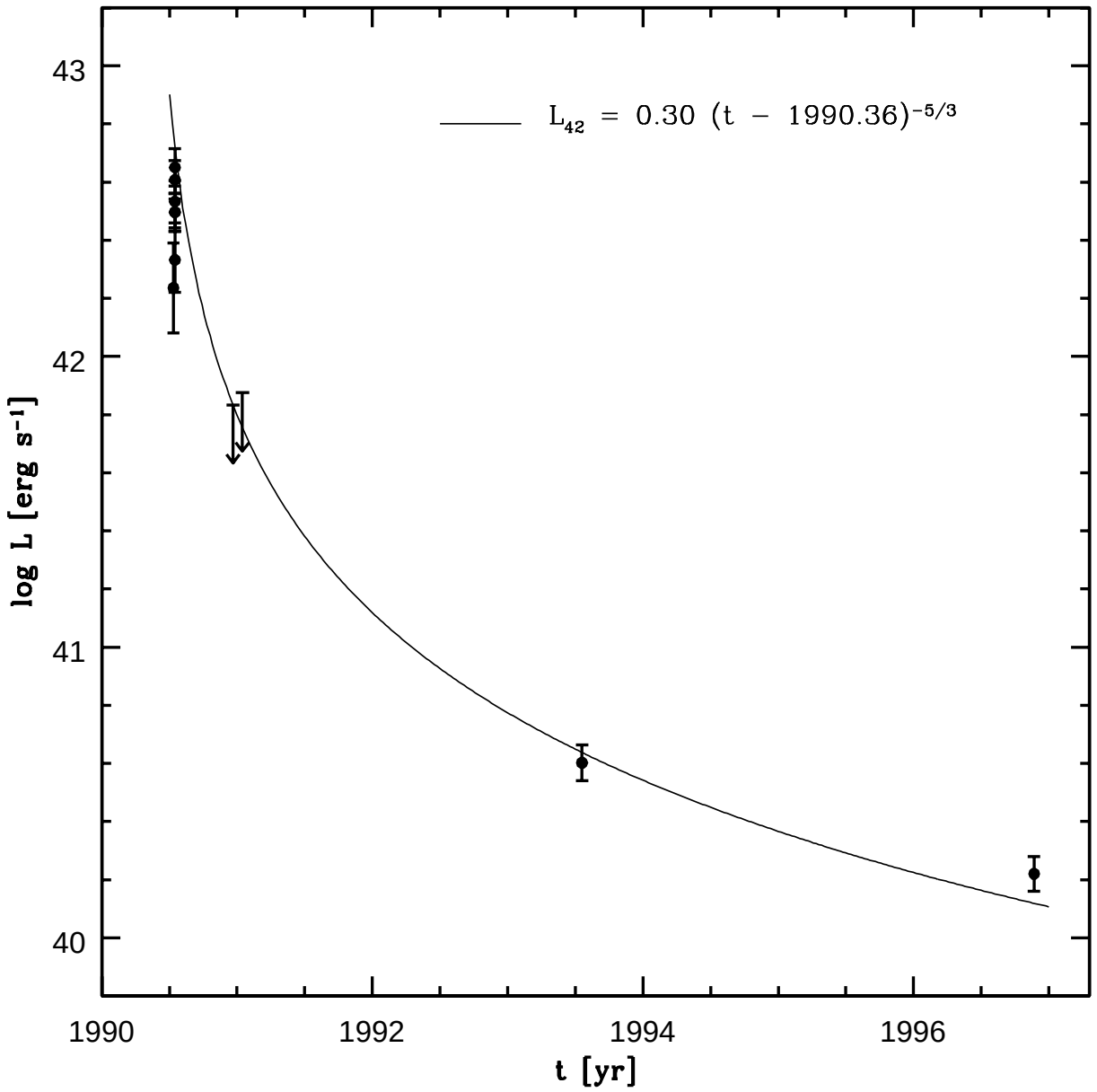
I. Introduction

- Tidal disruption: $M_H < 10^8 M_\odot$, for a solar type star.
- Disruption rate: 10^{-4} per galaxy per year, for main sequence stars.
- Two stages: (1) Fallback stage, $\dot{M} \sim t^{-5/3}$; (2) Accretion stage, $\dot{M} \sim t^{-1.2}$.
- Energy range: UV to X-ray.
- Detection (Komossa 2001): (1) Short duration; (2) Very luminous (up to $L_{\rm max} \sim 10^{45}$ erg s^{-1}); (3) Non-active galaxies.
- Known candidates:
  NGC 5905, RXJ1242-1119, RXJ1624+7554, RXJ1420+5334, (possible) RXJ1331-3243 (X-ray, *ROSAT*); NGC 4552 (UV).

II. Giant X-Ray Flare of NGC 5905



$$L_X = (0.30 \pm 0.03) \times 10^{42}\,\mathrm{erg\,s^{-1}} \left[\frac{t - (1990.36 \pm 0.02)\,\mathrm{yr}}{1\,\mathrm{yr}}\right]^{-5/3}$$

ROSAT Data on the NGC 5905 Flare

TIME[a]	CR[b]	ERR[c]	LUMX[d]	ERR_LUMX[e]
1990.53	2.2981E−1	8.1771E−2	1.72	0.61
1990.54	2.8713E−1	7.3284E−2	2.15	0.55
1990.54	4.1855E−1	6.2263E−2	3.14	0.47
1990.54	4.5519E−1	7.5933E−2	3.41	0.57
1990.54	4.1786E−1	6.2403E−2	3.13	0.47
1990.54	5.9612E−1	8.7399E−2	4.47	0.66
1990.54	5.4012E−1	8.2004E−2	4.05	0.62
1990.97	<0.09	——	<0.68	——
1991.04	<0.10	——	<0.75	——
1993.55	7.0000E−3	1.0000E−3	4.00E−2	5.71E−3
1996.89	2.9000E−3	4.0000E−4	1.66E−2	2.29E−3

[a]Time of measurement in years.

[b]Count rate in cts s^{-1}.

[c]Error in the count rate.

[d]X-ray luminosity in units of 10^{42} erg s^{-1}.

[e]Error in the X-ray luminosity.

- Total energy released:

$$\Delta E_X \approx (4.5 \pm 0.9) \times 10^{49}\,\mathrm{erg}$$

- Spectrum $(0.1 - 2.4$ keV):

$$k_B T_{\mathrm{bb}} \approx 0.06\,\mathrm{keV}$$

- Total mass associated with the released energy:

$$\Delta M \approx \frac{\Delta E_X}{\epsilon c^2} \approx (2.5 \pm 0.5) \times 10^{-4}\,M_\odot \left(\frac{\epsilon}{0.1}\right)^{-1}$$

- Radius of X-ray emitting region:

$$R_X \approx 2.4 \times 10^{12}\,\mathrm{cm} \left(\frac{f_c}{3}\right)^2 , \qquad f_c \equiv \frac{T_{\mathrm{bb}}}{T_{\mathrm{eff}}}$$

III. Fitting the Flare with Tidal Disruption

§3.1. Theoretical Models

- The flare begins when the most bound material, with specific energy $-\Delta E$, returns. The time between this and tidal disruption is:

$$\begin{aligned}\Delta t_1 &= 2\pi G M_H (2\Delta E)^{-3/2} \\ &\approx 0.068\,\mathrm{yr}\left(\frac{M_H}{10^7 M_\odot}\right)^{1/2}\left(\frac{M_\star}{M_\odot}\right)^{-1}\left(\frac{R_\star}{R_\odot}\right)^{3/2}\end{aligned}$$

- Assuming specific energy is uniformly distributed between $-\Delta E$ and ΔE. The, mass falls back at the rate:

$$\dot{M} = \frac{2 f M_\star}{3\Delta t_1}\left(\frac{t - t_D}{\Delta t_1}\right)^{-5/3}$$

- The luminosity in the fallback stage:

$$L = \dot{M} \times \frac{GM_\star}{4R_\star}\left(\frac{M_H}{M_\star}\right)^{2/3} \approx$$

$$1.55 \times 10^{43}\,\mathrm{erg\ s^{-1}} \left(\frac{f}{0.1}\right)\left(\frac{M_H}{10^7 M_\odot}\right)\left(\frac{M_\star}{M_\odot}\right)^{2/3}\left(\frac{t-t_D}{1\mathrm{yr}}\right)^{-5/3}$$

- Stellar mass-radius relation:

  (1) Low mass stars (LMS, $0.08M_\odot < M_\star < 1M_\odot$)

$$R_\star = R_\odot(M_\star/M_\odot)$$

  (2) Substellar objects (SSOs, including brown dwarfs and planets, $0.01M_\odot < M_\star < 0.08M_\odot$)

$$R_\star = 0.06R_\odot(M_\star/M_\odot)^{-1/8}$$

§3.2. Comparison with the Flare in NGC 5905

- The fitting in Fig. 1 gives a constraint on Δt_1

$$0.15\,\mathrm{yr} < \Delta t_1 < 0.23\,\mathrm{yr}$$

Using the mass-radius relation, this provides a restriction on M_H and $M_\star$.

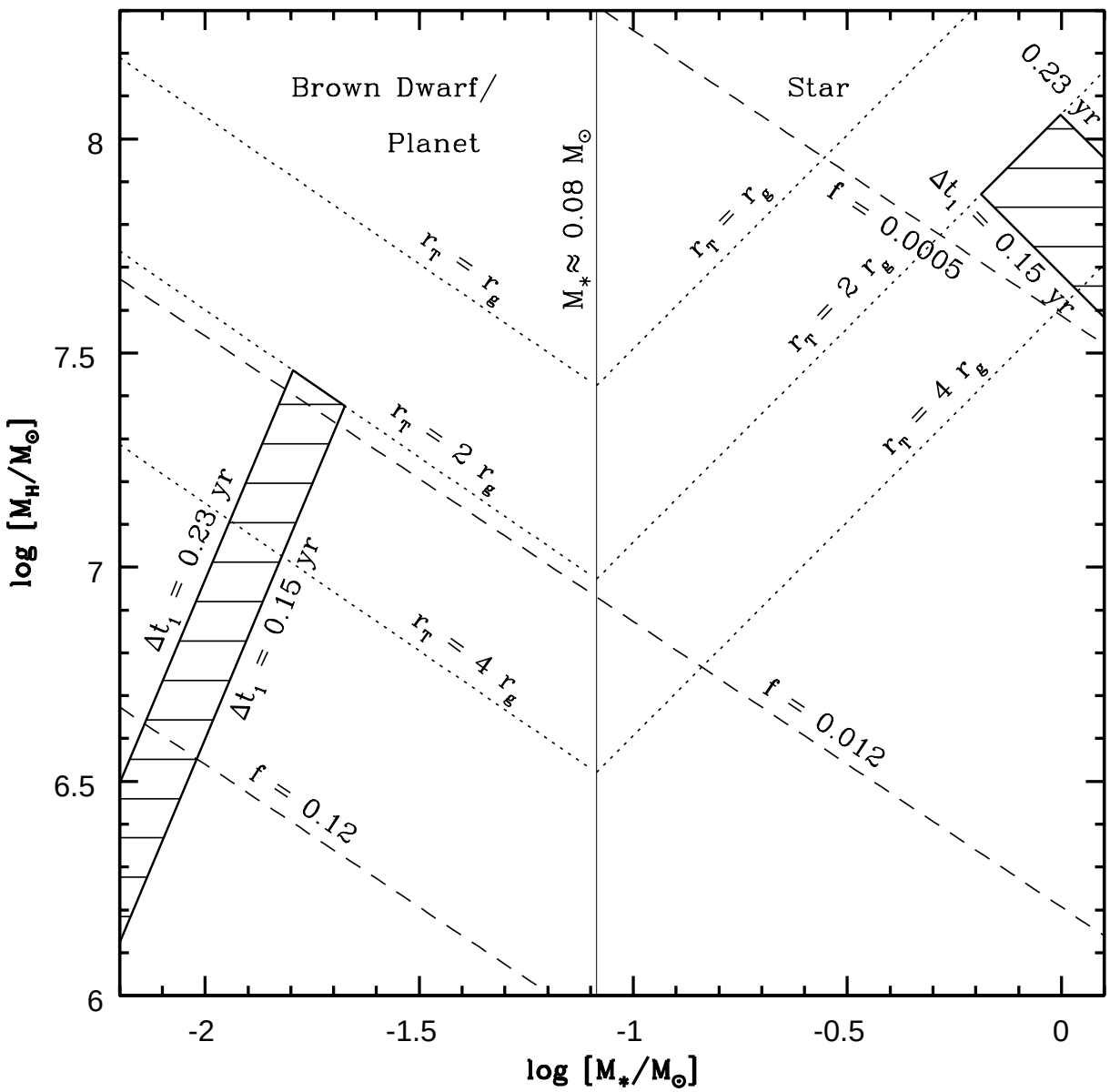
- The disruption must happen outside the black hole horizon:

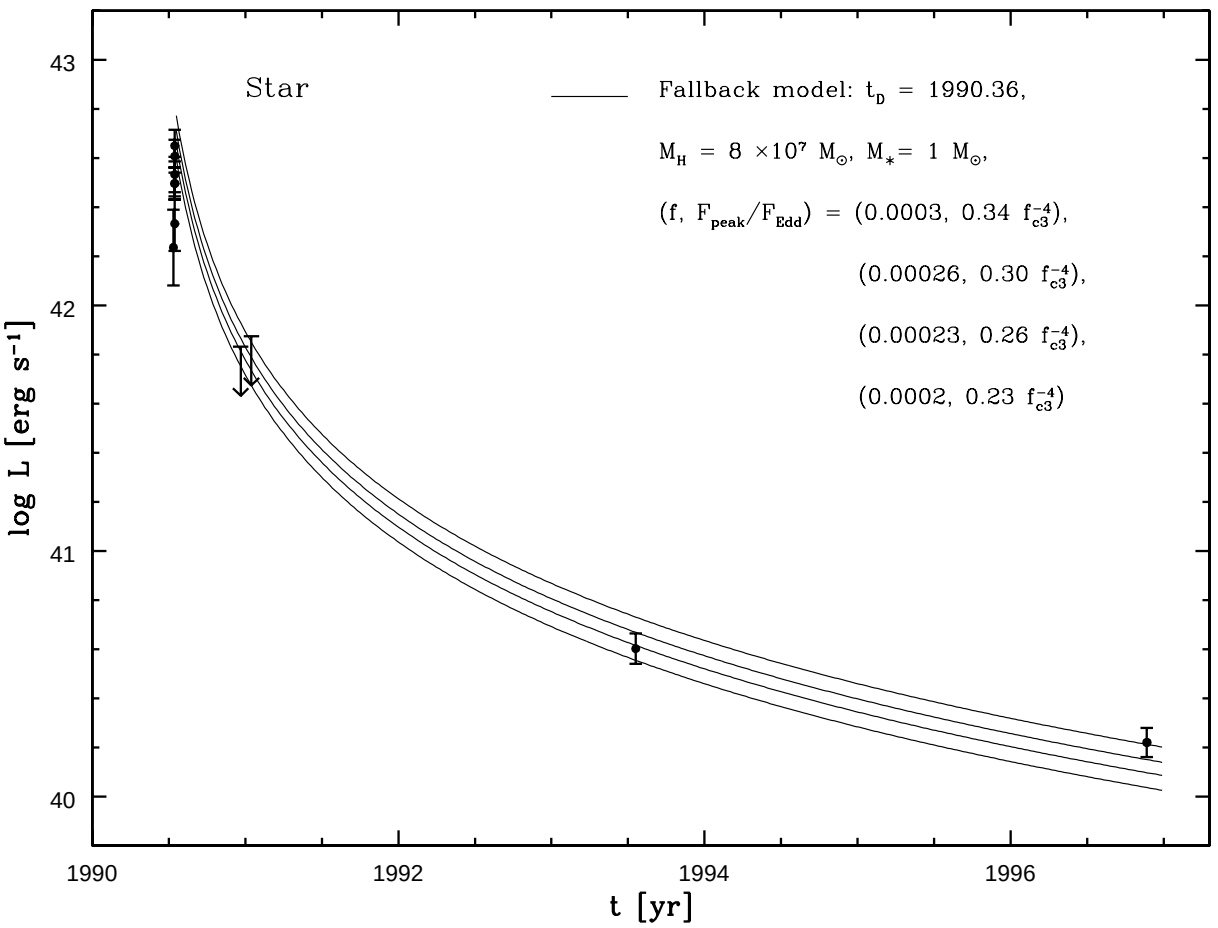
$$\frac{r_T}{r_H} = 5.08 \left(\frac{M_H}{10^7 M_\odot}\right)^{-2/3} \left(\frac{M_\star}{M_\odot}\right)^{-1/3} \left(\frac{R_\star}{R_\odot}\right) > 1$$

Then, the allowed values of M_H and $M_\star$ are shown in Fig. 2.

- Compare the theoretical luminosity to the fitting observation

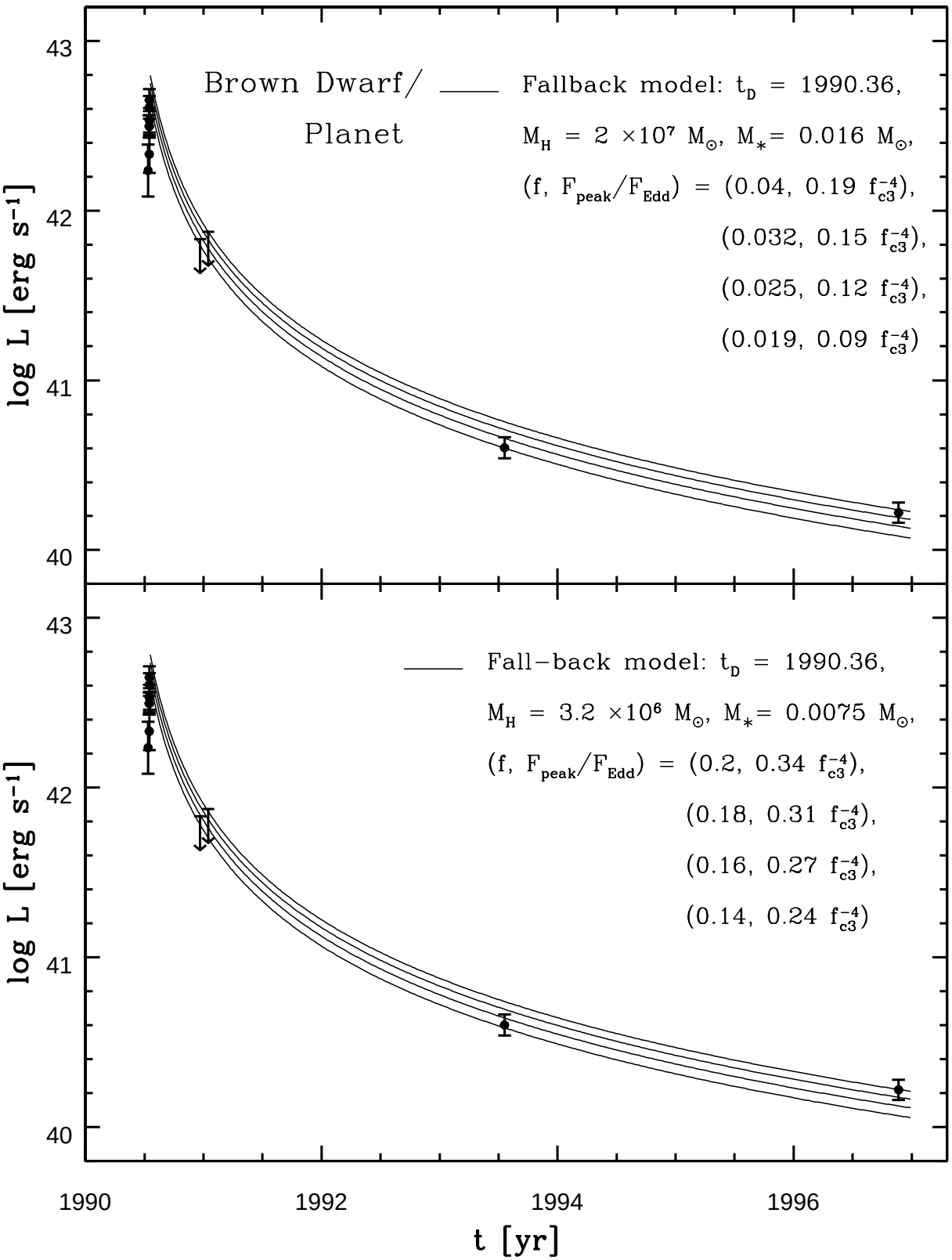
$$\frac{M_H}{10^7 M_\odot} \left(\frac{M_\star}{M_\odot}\right)^{2/3} = \frac{0.0019}{f}$$


Brown Dwarf/
Planet
Star
M* ≈ 0.08 M⊙
log [MH/M⊙]
log [M*/M⊙]
8
7.5
7
6.5
6
-2
-1.5
-1
-0.5
0
rT = rg
rT = 2 rg
rT = 4 rg
Δt1 = 0.23 yr
Δt1 = 0.15 yr
f = 0.12
f = 0.012
f = 0.0005



$$F_{\rm peak} \equiv L_{\rm peak}/\pi R_X^2$$

$$F_{\rm Edd} \equiv L_{\rm Edd}/4\pi r_T^2$$


Brown Dwarf/
Planet
Fallback model: t_D = 1990.36,
M_H = 2 ×10⁷ $M_\odot$, M_*= 0.016 $M_\odot$,
(f, F_{peak}/F_{Edd}) = (0.04, 0.19 f_{c3}^{-4}),
(0.032, 0.15 f_{c3}^{-4}),
(0.025, 0.12 f_{c3}^{-4}),
(0.019, 0.09 f_{c3}^{-4})
Fall−back model: t_D = 1990.36,
M_H = 3.2 ×10⁶ $M_\odot$, M_*= 0.0075 $M_\odot$,
(f, F_{peak}/F_{Edd}) = (0.2, 0.34 f_{c3}^{-4}),
(0.18, 0.31 f_{c3}^{-4}),
(0.16, 0.27 f_{c3}^{-4}),
(0.14, 0.24 f_{c3}^{-4})
log L [erg s⁻¹]
43
42
41
40
1990
1992
1994
1996
t [yr]

IV. Summary

- The X-ray lightcurve of the flare in NGC 5905 agrees with the $t^{-5/3}$ law predicted for fall-back of debris after tidal disruption of a star by a supermassive black hole.
- The data are consistent with two distinct solution branches: one corresponds to a relatively massive black hole disrupting a star with $M_\star \sim M_\odot$, the other consists of a lower mass black hole disrupting a brown dwarf or a giant planet with $M_\star \leq 0.02 M_\odot$.
- An unusually small f is required to explain the data: $f < 0.0003$ if the disrupted star is an LMS, $f < 0.04$ if the disrupted star is an SSO, unless the black hole has an unusually low mass ($< 10^{6.5} M_\odot$).

- The peak radiative flux is close to the Eddington flux, though the peak luminosity of the source ($\sim 4.5 \times 10^{42}$ erg s^{-1}) is much below the Eddington luminosity

$$L_{\rm Edd} \sim 10^{45} \left(\frac{M_H}{10^7 M_\odot} \right) {\rm erg\ s}^{-1}$$

V. Future Prospects

- Most tidal disruption events might be visible in soft X-rays. $F \approx F_{\rm Edd}$ ensures that the blackbody temperature of the radiation will be ≥ 50 eV for a $10^7 M_\odot$ black hole.
- Soft X-ray surveys should be well-suited for an investigation of both the frequency of tidal disruption events and the amount of mass accreted in each event.

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The journal version of this talk:

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