A double component in the emission of GRB 090618

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Introduction

We study the emission in the fireshell model of GRB 090618, which is one of the closest (z=0.54) and the most energetic (Eiso= 2.4 x 10^{45} erg) GRBs. It has been observed by many satellites, namely Fermi, Swift, Konus-WIND, AGILE, RT-2 and Suzaku. We analyzed the emission of this GRB first identifying the P-GRB and then using different spectral models with XSPEC. The fundamental parameters to be determined in the fireshell model [1] in order to obtain the spectra are the dyadosphere energy, the baryon loading and the density and porosity of the CBM. We found that there exist two different components. The first component lasts 50 s with a spectrum showing a very clear thermal component evolving, between kT = 60 keV and T = 14 keV, and a radius increasing between ~ 9000 km and 50000 km, with an estimate mass of ~ 10 M☉. The second component is a canonical long GRB with a Lorentz gamma factor at the transparency of γ = 490, a temperature at transparency of 25.48 keV and with characteristic size of the clouds, generating the luminosity observed, of R_{cl} ~ 10^{15} cm. We confirm in this work that the second episode corresponds to a canonical GRB, while the first episode don not. Indeed, it is related to the progenitor of the collapsing bare core leading to the black hole formation: what we have defined the "proto black hole". For the first time the process of formation of the black hole is followed from the phases preceding the gravitational collapse to the formation of the black hole and the GRB emission.

Data reduction and light curve

We made use of Swift-BAT and XRT [4] data, together with the Fermi- GBM [5] and Coronas-PHOTON-RT2 [6] ones. The data reduction was done using the canonical Heasoft packages [7] for BAT and XRT, plus the Fermi-Science tools for GBM (see Fig. 1). On the other hand, the Swift-BAT light curve was obtained in the band (15- 150 keV) using the standard headas procedure.

The fireshell scenario

Whithin the fireshell scenario, all GRBs originate from an optically thick $e^{\pm}$ plasma in thermal equilibrium, as a result of a gravitational collapse to form a black hole. This plasma has total energy $E_{tot}^{e\pm}$. The annihilation of $e^{\pm}$ pairs occurs gradually and is confined in an expanding shell called "fireshell". This plasma engulfs the baryonic material (of mass M_B) left over in the process of gravitational collapse. The baryon loading is measured by the dimensionless parameter $B=M_B c^2/E_{tot}^{e\pm}$. The fireshell self-accelerates to ultra-relativistic velocities until it reaches the transparency, when all the photons are emitted in what is called the P-GRB. The remaining accelerated baryonic matter starts then to slow down due to the collisions with the CBM, of average density nCBM. This gives place to the extended afterglow.

Time Interval (s)		α	β	$E_0(keV)$	$\tilde{\chi}^2_{BAND}$	$kT(keV)$	γ	$\tilde{\chi}^2_{BB+po}$
A	0 - 50	-0.74 ± 0.10	-2.32 ± 0.16	118.99 ± 21.71	1.12	29.84 ± 1.38	1.67 ± 0.03	1.28
B	50 - 59	-1.07 ± 0.06	-3.18 ± 0.97	195.01 ± 30.94	1.23	31.22 ± 1.49	1.78 ± 0.03	1.52
C	59 - 69	-0.99 ± 0.02	-2.60 ± 0.09	321.74 ± 14.60	2.09	47.29 ± 0.68	1.67 ± 0.08	7.05
D	69 - 78	-1.04 ± 0.03	-2.42 ± 0.06	161.53 ± 11.64	1.55	29.29 ± 0.57	1.78 ± 0.01	3.05
E	78 - 105	-1.06 ± 0.03	-2.62 ± 0.09	124.51 ± 7.93	1.20	24.42 ± 0.43	1.86 ± 0.01	2.28
F	105 - 151	-2.63 ± -1	-2.06 ± 0.02	unconstrained	1.74	16.24 ± 0.84	2.23 ± 0.05	1.15

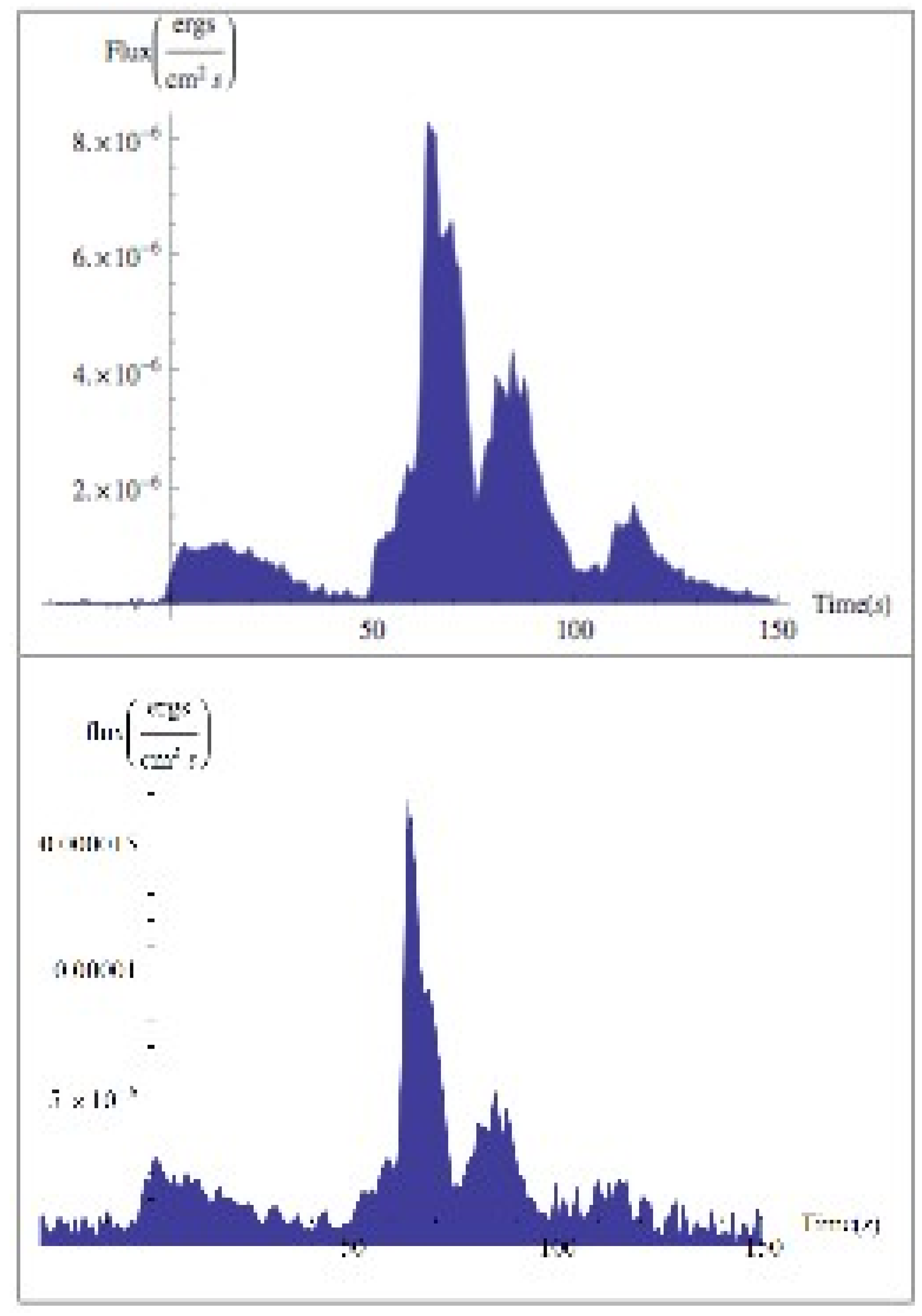

Figure 1: Fermi NaI (8-440 keV, upper panel) and BGO (260 keV- 40 MeV, lower panel) light curves.

The identification of the P-GRB emission allows to determine the value of the Baryon Loading and as it is possible to see in the figure on the right, other physical properties of the fireshell plasma, as the temperature and the Lorentz gamma factor at the transparency, as well as the lab radius when the P-GRB emission would Happen. From the observations we need the knowledge of the P-GRB energy and the temperature of the black body due to the P-GRB emission [2].

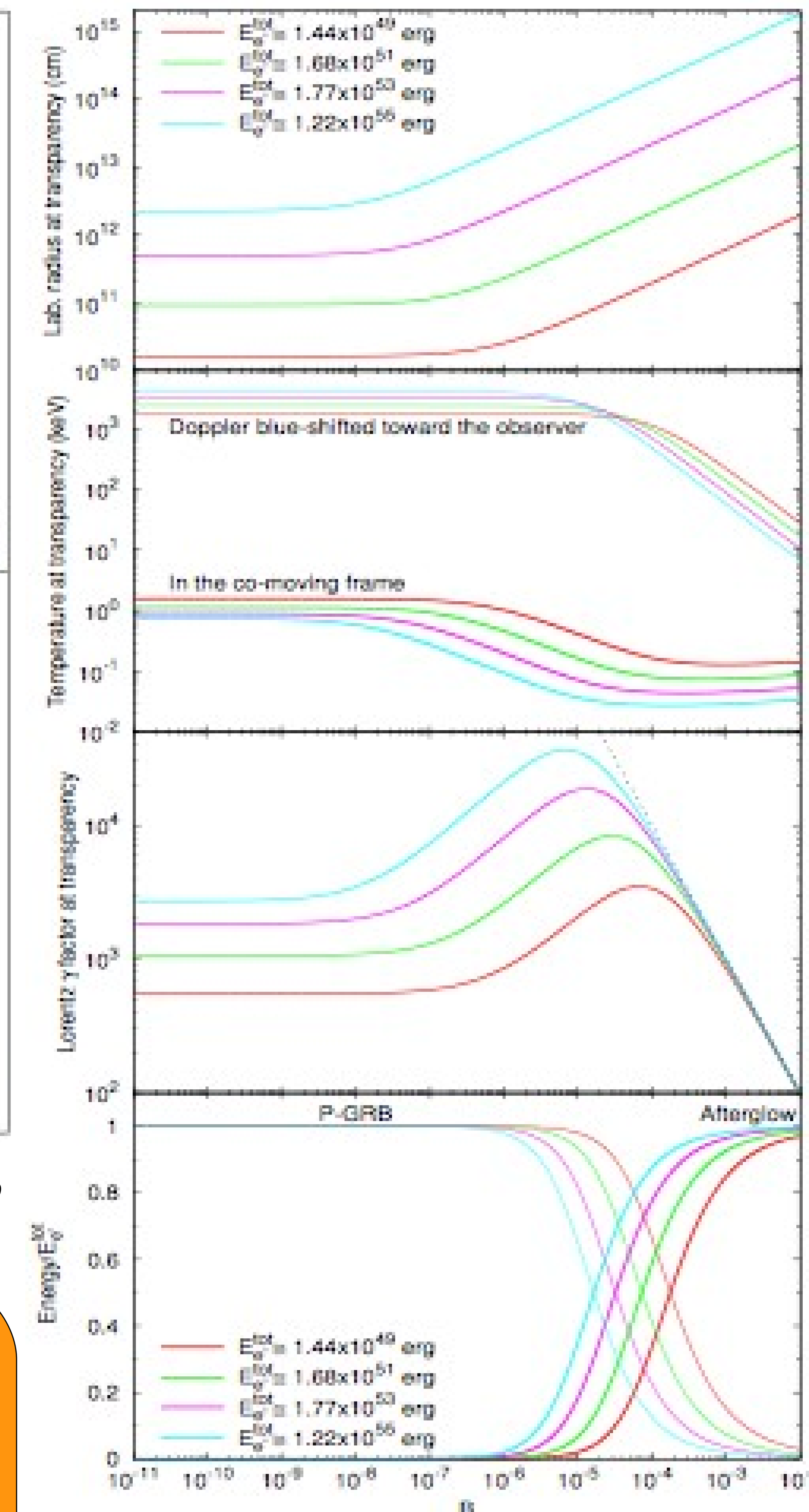

Figure 2: (first and second panels) Laboratory radius at the transparency emission and the fireshell temperature in the co-moving and observer frames. (third panel) Lorentz gamma factor at the transparency. (fourth panel) Energy radiated in the P-GRB in units of $E_{tot}^{e\pm}$, as a function of the baryon loading B, for 4 different values of the dyadosphere energy.

Spectral analysis: identification of the P-GRB

One of the crucial results of the fireshell scenario is the existence of two different phases in the GRB bolometric light curve: the P-GRB and the extended afterglow. Therefore, we first need the identification of the P-GRB in the light curve. We proceeded with the time resolved spectral analysis of GRB 090618 dividing the emission in several time intervals. We then made a data fitting procedure with XSPEC [3] using two spectral models: a Band function and black body plus a power-law component (bb+po). The results are shown in table 1.

<u>From 0 to 50s</u>: As a first attempt, we divided the emission into two main episodes, the first lasting from 0 to 50s, and the second from 50 to 150s. The first episode is well-fitted by a BB+po model of temperature kT=29.84 ± 1.38 keV (which in principle is a distinctive feature of a P-GRB) and a photon index γ=-1.67 ± 0.03. The isotropic energy of the GRB is Eiso= 2.8 x 10^{53} erg, while the energy emitted by the sole black body component in this first 50 s emission is EBB = 8.88 x 10^{51} erg (the 3.2% of the total energy emitted). This implies a baryon loading B≈10-4. From Fig 2. we derived a theoretically predicted temperature at the transparency which, corrected for the cosmological redshift of the source, gives kT= 425 keV. This value is in clear disagreement with the observed temperature, and leads us to conclude that the firs episode cannot be the P-GRB. Moreover, the duration of this episode is much longer than the typical considered, which is at most 10s.

<u>The second episode as an independent GRB:</u> We try to identify the P-GRB within the emission from 50s to 59s. A detailed analysis allowed us to consider the first 4 s as due to the P-GRB emission. The spectrum is well-fitted by a BB+po model with temperature kT= 25.48 ± 2.04 keV and a photon index γ= 1.85 ± 0.06. The integrated spectrum of the remaining part is best fitted with a Band model (see Table 1). The isotropic energy of the second episode is Eiso= 2.37 x 10^{53} erg. If we assume Eiso=Edya and a baryon loading B=2 x 10-3, we find that the P-GRB energy is the 2% of the total. From fig. 2 we obtain a Lorentz gamma factor at the transparency of γ0=490. The theoretically computed, cosmologically corrected temperature is kT=24.48 keV, in agreement with the observations.

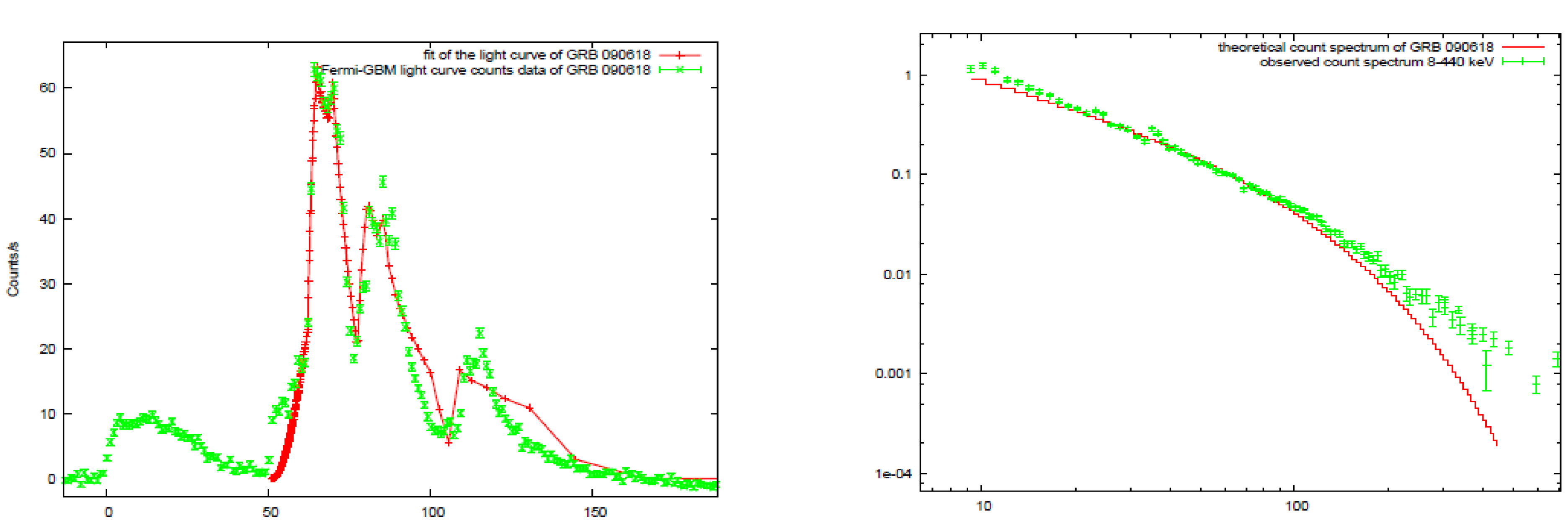

Figure 4: Simulated light curve and time integrated (t0+58, t0+150 s) spectrum (8-440 keV) of the extended afterglow of GRB 090618.

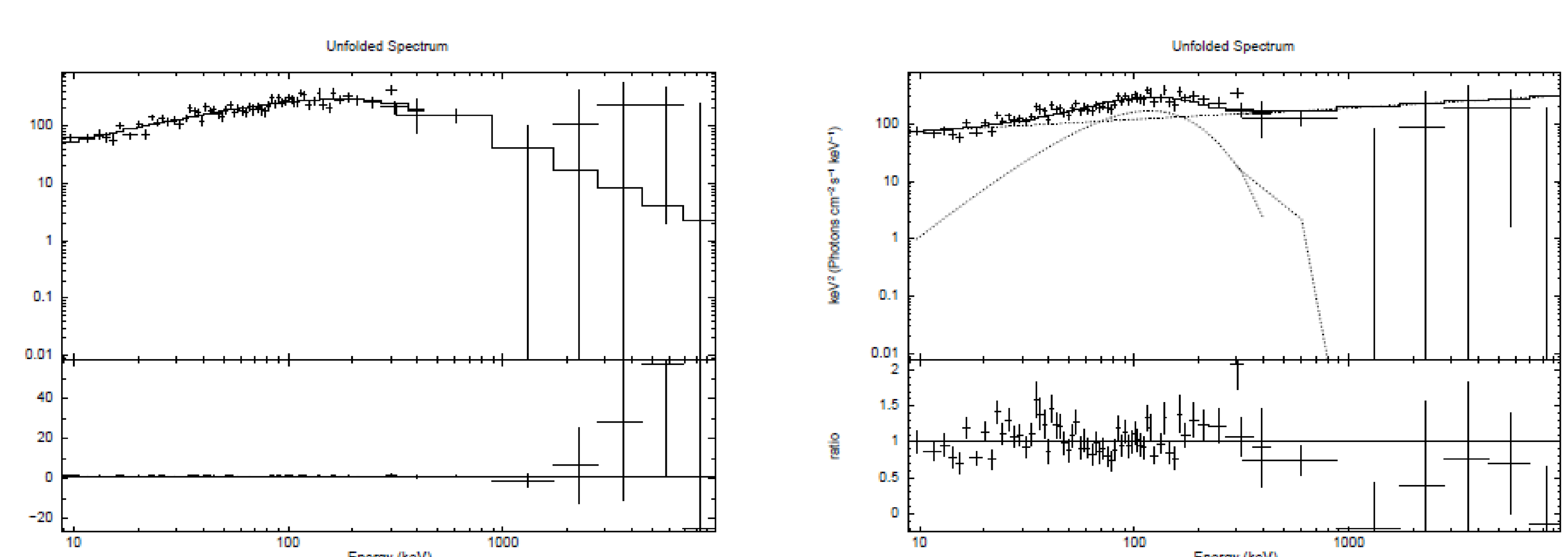

Figure 3: Time-integrated spectra for the second episode of GRB 090618 fitted with the Band (left) and blackbody plus a power-law (right) models.

<u>The first 50 s emission is not a GRB:</u> We check if the first 50s emission could be an independent GRB.We attempted a first interpretation by assuming the first 6 s as the P-GRB component, as opposed to the remaining 44 s as the extended afterglow of the GRB. A value of the fit gives Edya = 3.87 x 10^{52} ergs and B = 1.5 x 10^{-4}. This would imply a very high value for the Lorentz factor at the transparency of 5000. In turn, this value would imply a spectrum of the P-GRB peaking around 300 keV, which is in contrast with the observed temperature of 58 keV. If indeed we consider all the 50s emission as the extended afterglow, and considering a "virtual" P-GRb below the detector threshold lasting 10s, we conclude that this P-GRB should have been detected by Fermi. We can then conclude that in no way we can interpret this episode either as a P-GRB of the second episode or, as proved here, as a separate GRB.

A different emission process

A detailed spectral analysis of the first episode shows a strong spectral evolution. We have considered a blackbody plus an extra power-law component as spectral model to explain this first emission episode, and we see that the temperature varies from the initial value of 54 keV to 14 keV. The extra power-law non-thermal component is assumed to be related to the blackbody by some process which will be studied in the future. Assuming a non-relativistic expansion for this first episode, we computed the evolution of the blackbody radius from the luminosity observed.

The radius evolution allowed us to estimate the initial expansion velocity and, from the virial theorem, we obtain a strong constraints for the mass of this episode, which we have called "proto black hole".

$$M_{\rm pbh} \approx k_1 = \frac{R\overline{v^2}}{G} + \frac{3k_B}{Gm_H}R \gtrsim 2.1 M_{\odot}. \qquad \Longleftrightarrow \qquad M_{\rm pbh} \lesssim \sqrt{\frac{E_{\rm iso}R}{G}} \sim 13.4 M_{\odot}.$$

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