2FHL J0826.1-45.00: Discovery of a new VHE Galactic Accelerator

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ABSTRACT

The discovery of a very high energy (VHE) Galactic gamma-ray source was recently observed at energies above 50GeV using the Large Area Telescope (LAT) on board *Fermi*. This object, 2FHL J0826.1-4500, displays one of the hardest >50 GeV spectra (photon index~1.6) in the 2FHL sample, and a follow-up observation with XMM-*Newton* led to the discovery of diffuse, soft thermal emission at the position of the gamma ray source. A detailed analysis of the available multi-wavelength data led to the finding that this source is located on the Western edge of the Vela supernova remnant (SNR): the observations and the spectral energy distribution modeling support a scenario where 2FHL J0826.1-4500 is the byproduct of an interaction between the front shock of the SNR and a neutral Hydrogen cloud. If confirmed, this shock-cloud interaction would make 2FHL J0826.1-4500 a promising candidate for efficient particle acceleration.

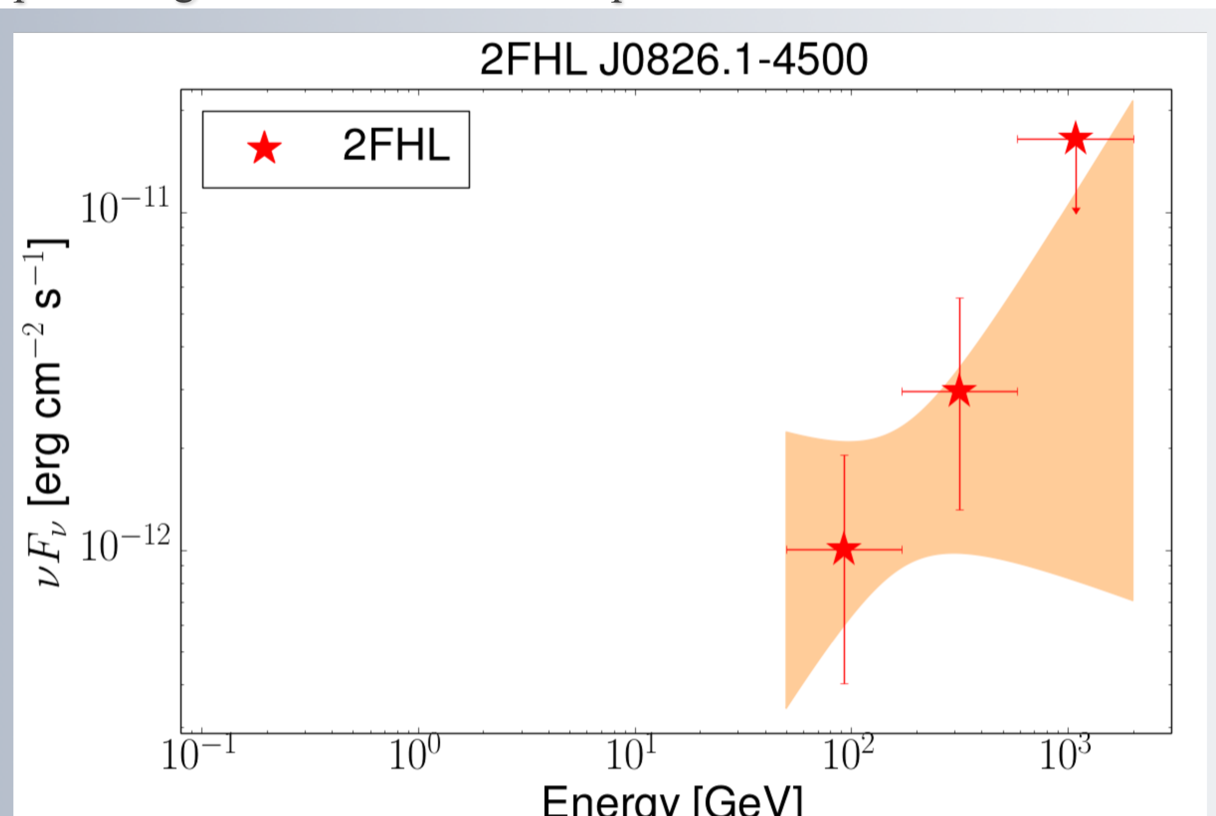

Fig 1: The gamma-ray spectrum of 2FHL J0826.1-4500. The spectrum is very hard with Γγ =1.6 ± 0.3.

MISSION

2FHL J0826.1-4500 presents a particularly hard γ-ray spectrum with photon index $\Gamma\gamma = 1.6 \pm 0.3$ and a maximum energy photon of ~412GeV detected by the LAT (see figure 1 above). The source is compact and shows no clear evidence of extended emission beyond the point spread function of the *Fermi*-LAT in this energy range. To further investigate the properties of this intriguing VHE object, we were granted a 20ks XMM-*Newton* follow-up observation. XMM-*Newton* has the largest effective area in the 0.5–10keV band among all the X-ray telescopes, therefore being the most effective instrument to detect faint, diffuse X-ray emission along the Galactic plane, like the one commonly observed in PWNe and SNRs.

REFERENCES

☼ Atwood, W., Albert, A., Baldini, L. et al. 2013a, ArXiv e-prints [1303.3514] ☼ Atwood, W. B., Baldini, L., Bregeon, J., et al. 2013b, ApJ, 774, 76 ☼ Ackermann, M., Ajello, M., Baldini, L., et al. 2017, ApJ, 843, 139 ☼ Dubner, G. M, Green, A. J., Goss, W. M., Bock, D. C.-L., & Giacani, E. 1998, AJ, 116, 813 ☼ Duncan, A. R., Stewart, R. T., Haynes, R. F., & Jones, K. L., 1996, MNRAS, 280, 252 ☼ H.E.S.S. Collaboration, Abdalla, H., Abramowski, A., et al. 2018b, A&A, 612, A1 ☼ Murphy, T., Mauch, T., Green, A., et al. 2007, MNRS, 382, 382

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SPECTRAL ANALYSIS

In the figure below (Fig 2, left panel) we show the smoothed 0.5-2keV image of 2FHL J0826.1-4500 as seen with the MOS2 camera mounted on XMM-*Newton*. Faint, diffuse X-ray emission is evident with extension of roughly 15'. X-ray emission is spatially coincident with an optical filament visible in Hα (figure 2, right panel). Analysis of X-ray emission reveals it to be soft with no significant emission detected above 2keV. Spectral fitting was performed to characterize observed emission. Due to low signal-to-noise, we chose to model both the background and source emission (rather than subtracting background emission which would lead to poor statistics with such few photon counts). Background emission was modeled taking into account both instrumental and astrophysical background. Spectral fitting was performed with the most recent update of HEASOFT software with corresponding calibration files for the XMM-*Newton* telescope.

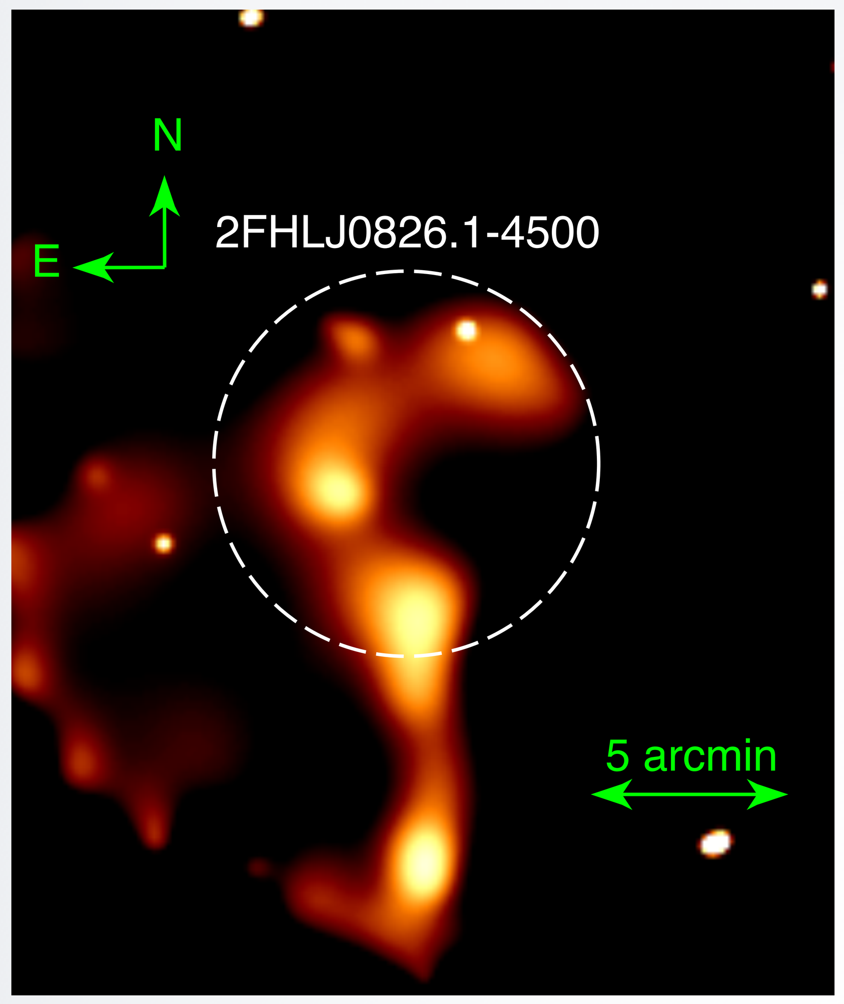
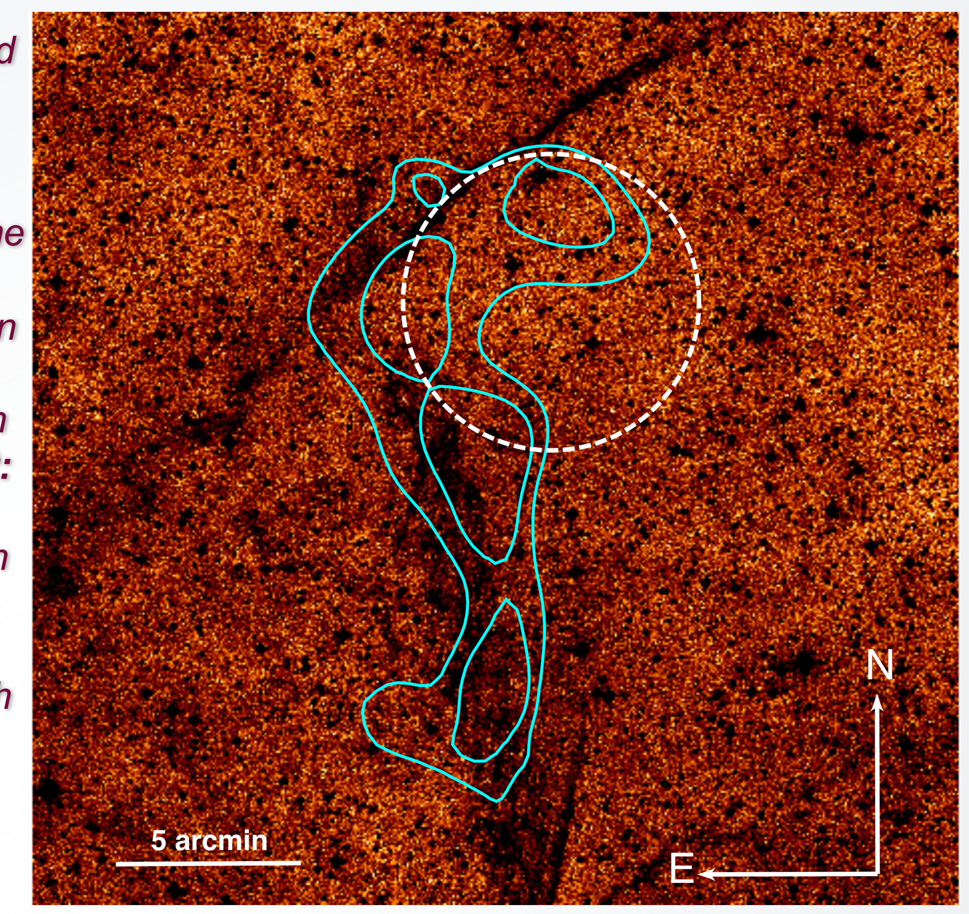
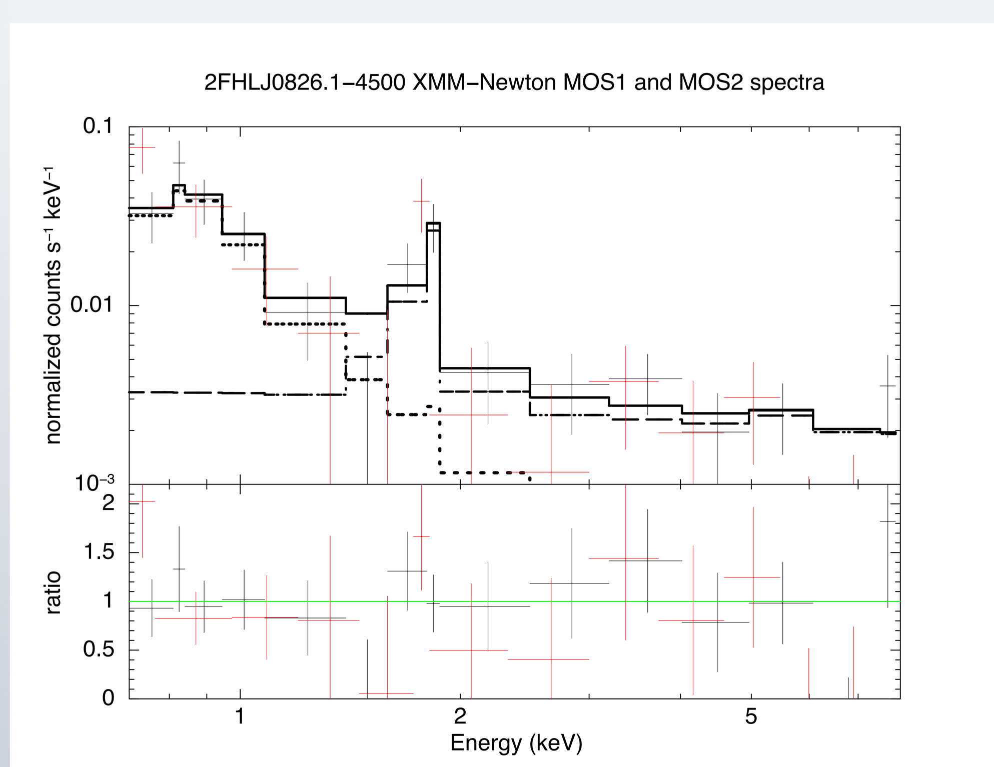


***Fig 2: Left:** Smoothed 0.5-2keV image of 2FHL J0826.1-4500 created using CIAO `csmooth` tool using the faster fourier transforms convolution method and a Gaussian convolution kernel set to 3. **Right:** X-ray emission countours overlaid on an Hα image of the region of 2FHL J0826.1-4500. In both images, the white dashed circle marks the FERMI-LAT position, r=4'.*



SPECTRAL ANALYSIS RESULTS

A thermal emission scenario was found to be statistically preferred over a non-thermal scenario (`mekal` vs. power law) with a best-fit temperature of $kT = 0.60 \pm {}^{0.11}_{0.60} keV$ that can be interpreted as an upper limit of $kT < 0.72keV$. Upon a multi-wavelength analysis, we link this source with the front shock of the Vela SNR, located on the Western edge, and is located at ~1.5° SW of the Vela Pulsar. Additionally, it is found that an HI cloud is seen to be spatially and morphologically coincident with 2FHL J0826.1-4500 (Fig 3, right panel) . A deeper investigation leads us to believe the combined gamma-ray, X-ray, optical, and radio data depicts a scenario of interaction between the Vela SNR forward shock and the HI cloud.



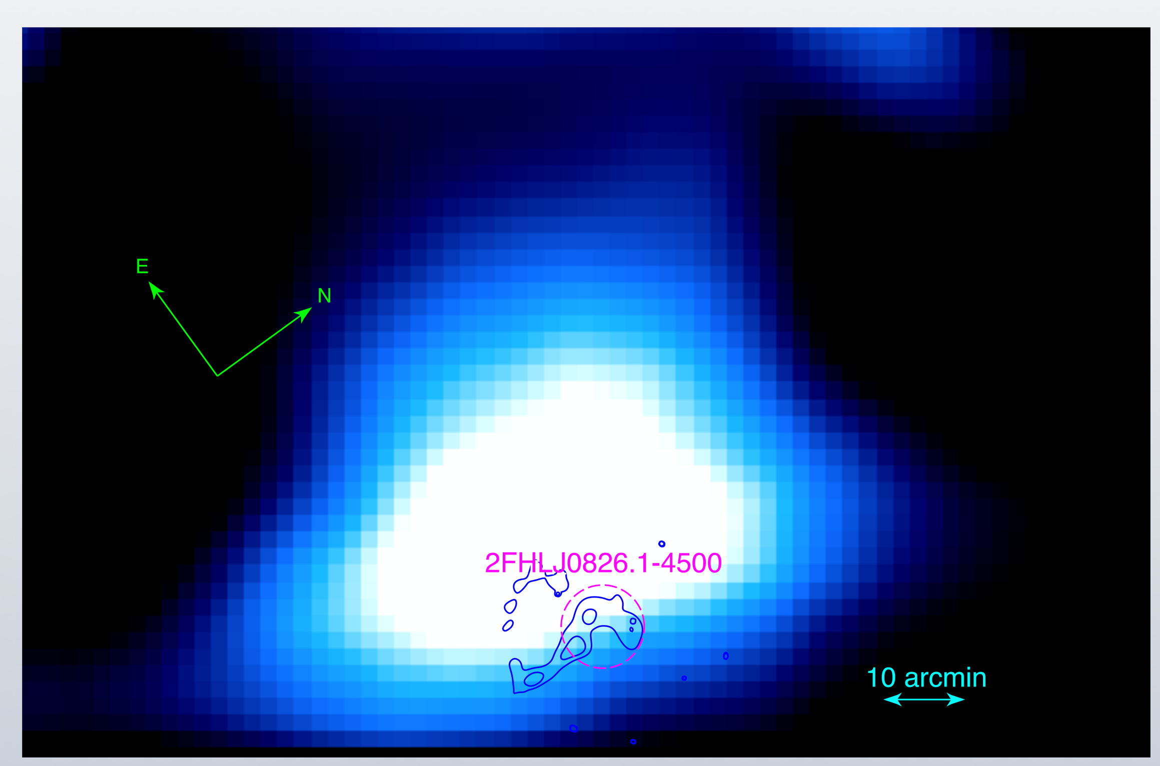


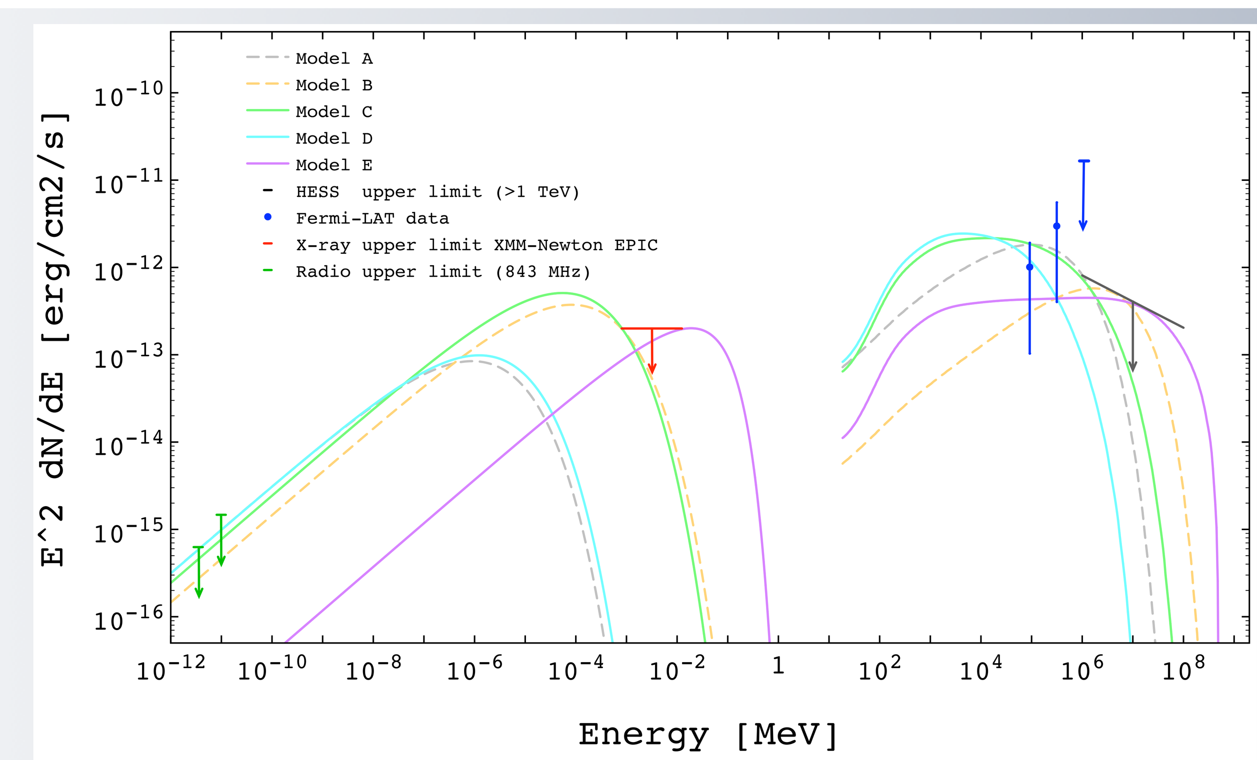
***Fig 2 (above, left)**: XMM-Newton MOS1 (black) and MOS2 (red) data of 2FHL J0826.1-4500 and the best-fit model obtained using `mekal`. The best-fit model (solid black line), the instrumental background (dashed black line) and the combination of source and astrophysical background (dotted black line) are plotted. PN data was removed for clarity. **(above, right):** HI 21cm radio map integrated between 29.7 and 35.3 $\frac{km}{s}$ indicating the location of 2FHL J0826.1-4500 with respect to the HI cloud with blue contours for reference of shock structure and location.*

SED MODELING

The multi-wavelength information available can be combined to build a picture of the broadband spectral characteristics of the region. The data are shown below with upper limits from 843MHz and 2.4GHz radio emission, soft X-ray emission, and TeV gamma-ray emission. Assuming a distribution of accelerated particles in momentum to be:

$$\frac{dN_i}{dp} = a_i p^{-\alpha_i} \exp\left(\frac{p}{p_{0,i}}\right)$$

Where i is either proton or electron population, and α_i and $p_{0,i}$ are the spectral index and the exponential cutoff momentum of the distributions, respectively. α_i is set using the total energy in relativistic particles and the electron to proton ratio as input parameters, together with the spectral shape of the distributions. For non-thermal radiation from the particle distributions we have used pion-decay emission, synchrotron and inverse Compton (IC) emission, and non-thermal bremsstrahlung emission. The model (Fig 3) establishes the range of some physical parameters that would result in the observed *Fermi*-LAT emission as well as complying with the upper-limits at other wavelengths.



		p_0 (TeV/c)	$B_{2,max}$ (μG)	$n_H \times E_{CR,p}$ (10^{48} erg/cm^3)	$E_{CR,e}$ (10^{44} erg)
Leptonic	A	5	3	–	9
	B	30	9	–	1
Hadronic	C	10	50	6	–
	D	1	50	6	–
	E	600	10	1	–

***Fig 3**: Spectral energy distribution (SED) for various scenarios constrained to upper limits of available data across the electromagnetic spectrum. Models A (gray dashed line) and B (yellow dashed line) demonstrate resultant gamma-ray spectrum of radiation from relativistic electrons. Models C (solid green), D (solid cyan), and E (solid purple) demonstrate resultant spectrum of radiation from a hadronic population. Table shown provides the input model parameters for each SED model.*

CONCLUSIONS

Data presented for 2FHL J0826.1-4500 supports a shock-cloud interaction scenario on the western edge of the Vela SNR. Multi-wavelength data suggests the FS of the SNR is interacting with a small HI cloud. This makes 2FHL J0826.1-4500 a candidate for CR acceleration. If the hadronic models prove to be most realistic in characterizing 2FHL J0826.1-4500, not only is the location a likely site of efficient particle acceleration, but also poses as a possible site of fresh CR acceleration. Future work to confirm this includes studying the physical conditions (e.g. velocity, direction, elemental composition) of the shock which will help us understand the shock's kinematics and thus can provide clues to whether 2FHL J0826.1-4500 may be a site generating fresh CRs or is instead a re-acceleration mechanism.