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Optical and X-ray observations of stellar flares on an active M dwarf AD Leonis

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Stellar flares are the sudden brightening on the stellar surfaces where the magnetic energy is released via the magnetic reconnection [1, 2]. Some stars such as cool M-type stars, binary stars, and young stars have much higher magnetic activity than the Sun, and sometimes show very large flares called ‘superflares’ (flare having the energy of more than 10 times the largest solar flare energy) [3]. Recently, there is an increasing interest in the properties of stellar flares both from the perspective of their impact on the exoplanet environment and from the viewpoint of a possible extreme space weather event on our Sun. So far, the stellar (super-)flare properties have been well investigated with optical photometry [2, 3]. However, multi-wavelength observations have not been enough conducted because of the low occurrence probability and the difficulty of simultaneous observations, and therefore the detailed nature of radiation/heating mechanism of stellar (super-)flares has not been understood.

Here we report on multi-wavelength monitoring observations of an M-dwarf flare star AD Leonis with the 3.8-m Seimei Telescope (Hα), SCAT (Balmer lines), and NICER (X-ray), with the collaboration of the OISTER program (optical spectroscopy/photometry). Twelve flares are detected in total, including ten Hα, four X-ray, and four optical-continuum flares; one of them is a superflare with a total energy of ~2.0×10^{33} erg (~20 times the largest solar flare energy; Figure 1 left). We found that: (1) during the superflare, the Hα emission line full width at 1/8 maximum dramatically increases to 14 Å from 8 Å in the low-resolution spectra (R ~ 2000) accompanied by large white-light flares (Figure 2 right), (2) some weak Hα/X-ray flares are not accompanied by white-light emissions, and (3) the non-flaring emissions show clear rotational modulations in X-ray and Hα intensity in the same phase [4].

To understand these observational features, one-dimensional hydrodynamic flare simulations are performed using the RADYN code. We find the simulated Hα line profiles with hard and high-energy non-thermal electron beams to be consistent with the initial phase line profiles of the superflare, while those with a softer and/or weak-energy beam are consistent with those in decay phases, indicating the changes in the energy fluxes injected to the lower atmosphere. Also, we find that the relation between the optical continuum and Hα intensity is nonlinear, which can be one cause of the non-white-light flares.

The flare energy budget is found to exhibit diversity both in the observations and models. More observations of stellar superflares are necessary for constraining the occurrence of various emissions in stellar flares.

References

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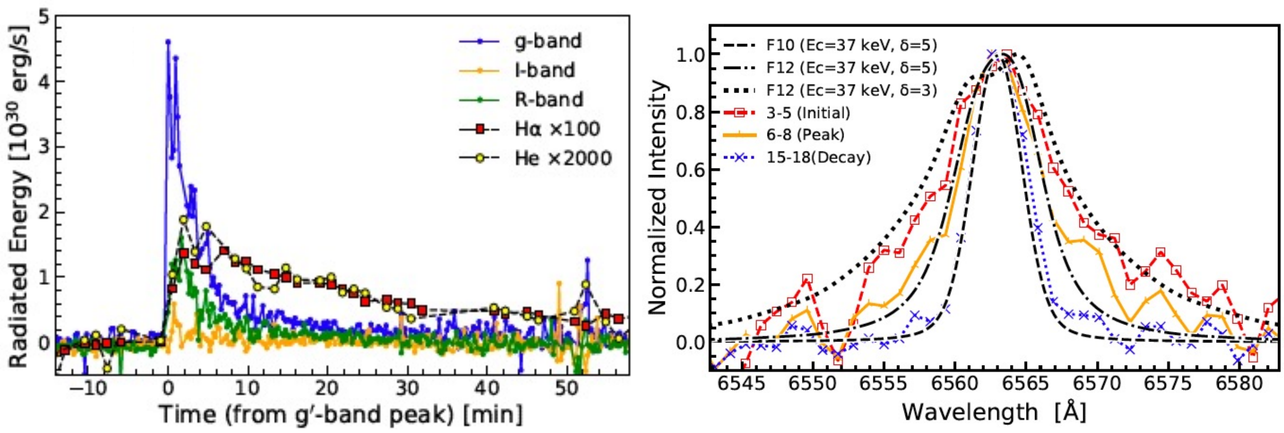

Figure 1. Light curves and Hα spectra of a stellar superflare on an M dwarf AD Leonis. (left) The light curve with Hα, He (Seimei telescope), and optical continuum (MITSuME photometry). (right) Colored lines corresponds to the observations, and black lines correspond to the numerical simulations.