AT2022dbl: A Theory Defying Tidal Disruption Event

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Background

- **What is a TDE?**
  - TDE stands for Tidal Disruption Event. It happens when a star travels too close to a supermassive black hole (SMBH) in the center of a distant galaxy and gets tidally ripped apart.
  - Theoretically, the optical/UV light curves of TDEs are expected to typically exhibit a singular flare of radiation, followed by a power-law decline.
- **What's so special about AT2022dbl?**
  - Unlike theoretical predictions, the light curve of AT2022dbl exhibits two peaks (see Figure 6) with a separation of two years (2022, 2024). It is a very rare optical/UV rebrightening TDE.
  - Our explanation: a Partial TDE (PTDE), occurs when the star lost some mass at its first encounter with the SMBH, survives, and returns for subsequent encounters.
- **Why do we study it?**
  - Probing the characteristics of dormant SMBHs that cannot be explored otherwise.
  - Studying the mechanisms of PTDEs.

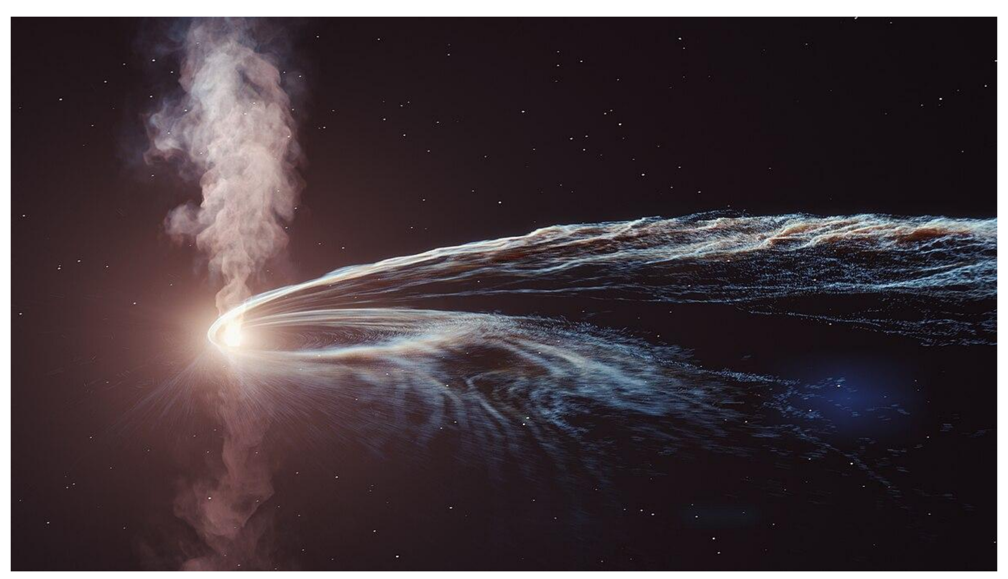

Figure 1: Tidal Disruption Event (TDE) Simulation

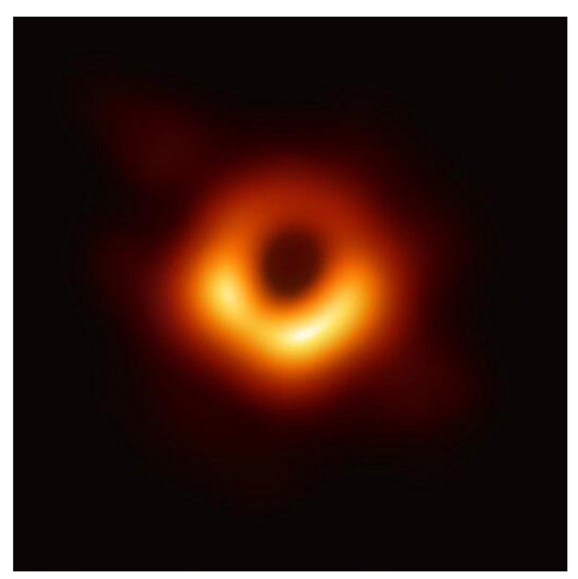

Figure 2: M87 (a SMBH)

Photometry Methods

We used imaging data (called photometry) of AT2022dbl from **Swift-UVOT**, **ZTF**, and **ATLAS**. We performed host galaxy subtraction and extinction correction on all the data. For all extinction correction, we used Fitzpatrick 1999 model with $R_V = 3.1$ and $A_V = 0.052$ mag.

- **Swift-UVOT:** Swift is a space telescope launched by NASA providing observations across optical to X-ray wavelengths. Data are downloaded from `HEASARC` and reduced by `heasoft`. We used a 10" source region for all six bands and 40" to 50" source-free background regions to extract the TDE+host galaxy emission. We subtracted the host galaxy emission using the magnitude predicted by `prospector`.
- **ZTF**: ZTF uses a wide-field camera to detect transients in the night sky. Data are obtained from ZTF Forced-Photometry Service. We corrected the baseline and binned the data in ~30 days or signal to noise ratio (S/N) > 3.
- **ATLAS**: ATLAS provides optical observations. Photometry data are obtained from the ATLAS forced photometry server. We binned the data ~5 days.

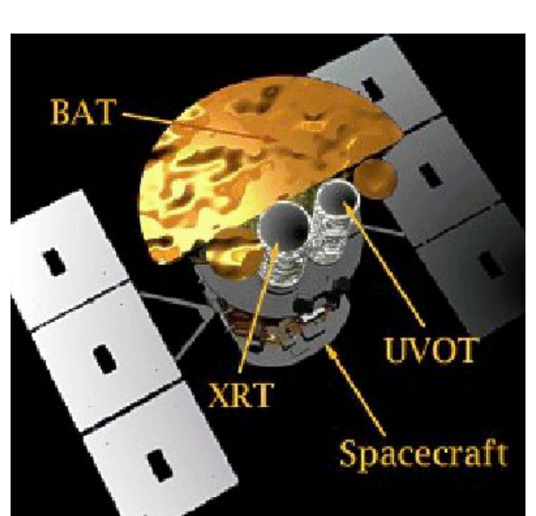

Figure 3: Swift Telescope

Figure 4: ZTF

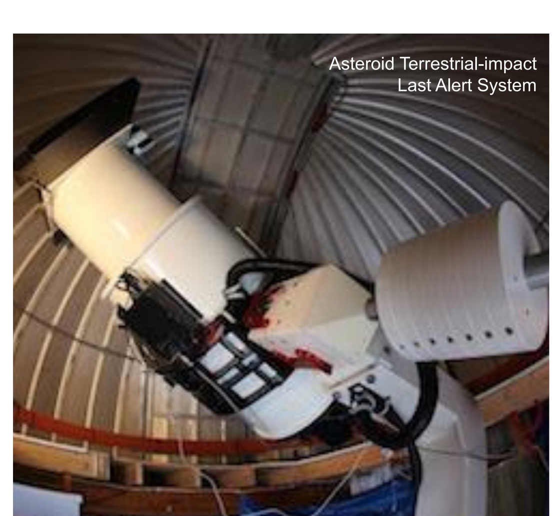

Figure 5: ATLAS

Photometry Results

After retrieving and reducing the data, we put together all the photometry data we have. ATLAS and ZTF data well-covered 4 years before the first flare, and they didn't show any prominent peak. We concluded that there were no previous outbursts similar to the two in 2022 and 2024, and the detection in 2018 is most likely a false alarm.

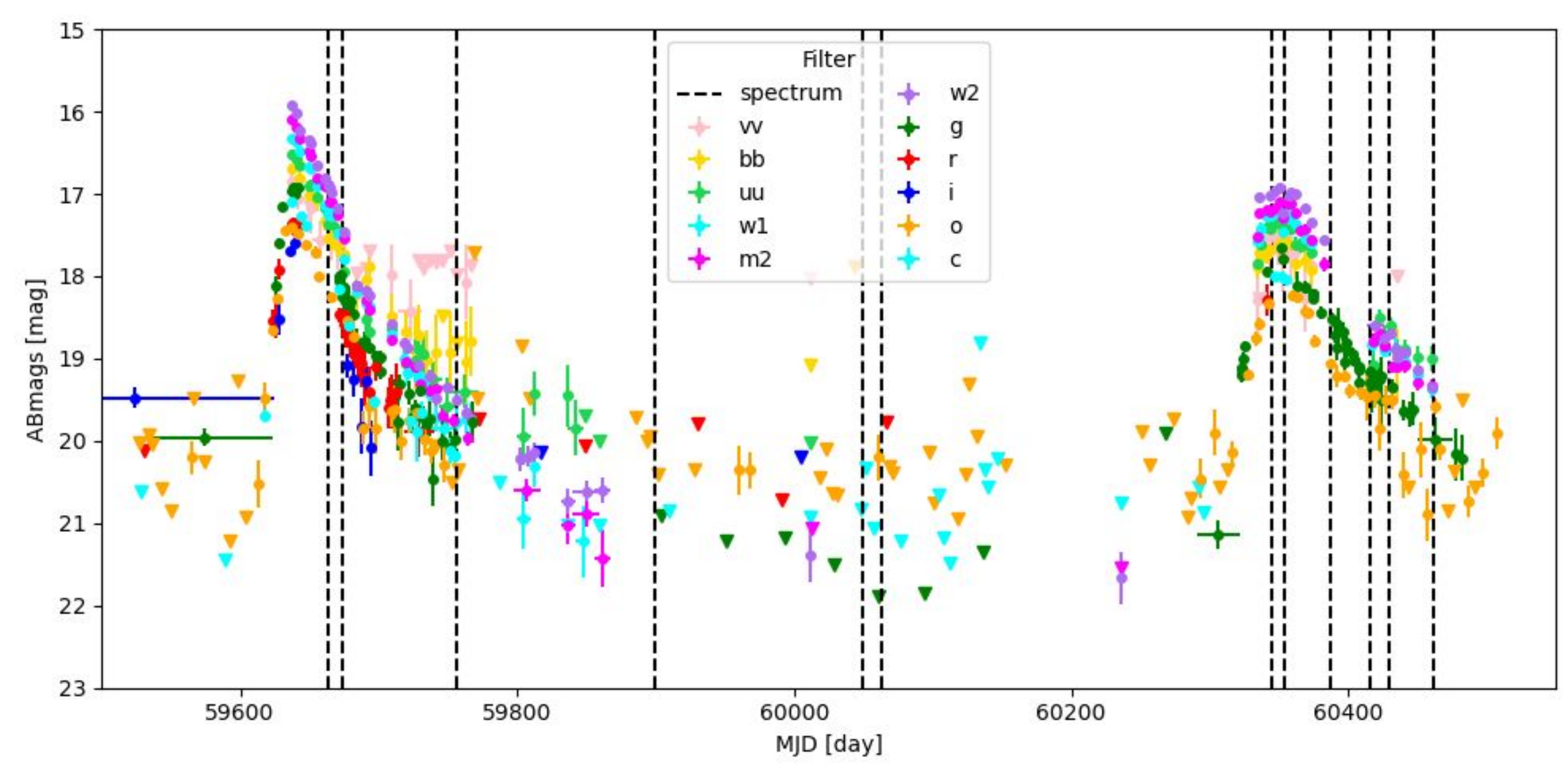

Figure 6: the two flares monitored by Swift-UVOT 6 bands (vv, bb, uu, w1, m2, and w2), ZTF 3 bands (g, r, and i), and ATLAS 2 bands (o and c) photometry of AT2022dbl with extinction correction and host galaxy subtraction. Triangles represent upper limits. Dashed vertical lines mark the time of acquisition of an optical spectrum.

Optical Spectroscopy & Host Galaxy Modeling

- The spectroscopic data are from **SDSS**, **KAST**, and **LRIS**.
- We used the SDSS spectrum taken in 2002 as the spectrum with only host galaxy emission. We used the `Prospector` library to fit for stellar population properties, model a host galaxy spectrum, and derive Swift magnitudes from both photometric and spectroscopic data.
- In addition to the SDSS spectrum, we provided GALEX, SDSS, 2MASS, and WISE photometry data as input to fit for mass, age, metallicity, dust attenuation parameter, and characteristic timescale of the star formation rate decline of the galaxy using stellar population synthesis (SPS) models.
- The best-fit parameters are $\log \frac{M}{M_\odot} = 10.22^{+0.00}_{-0.01}$, $\log \frac{zsol}{Z_\odot} = -0.64^{+0.01}_{-0.01}$, $\frac{d}{mag} = 0.00^{+0.00}_{-0.00}$, $\frac{t_{age}}{Gyr} = 6.38^{+0.25}_{-0.38}$, $\frac{\tau}{Gyr} = 0.41^{+0.08}_{-0.15}$.

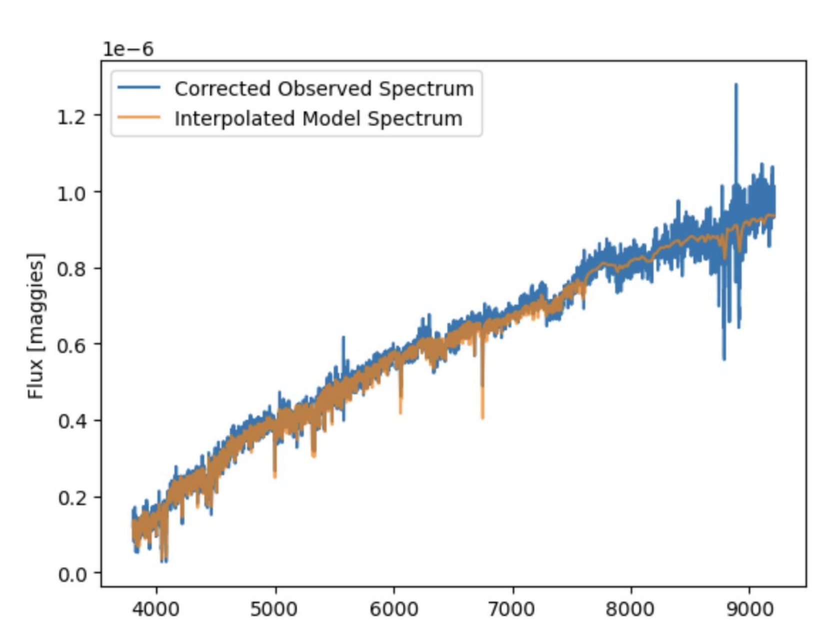

Figure 7: SDSS-observed spectrum vs. fitted model spectrum

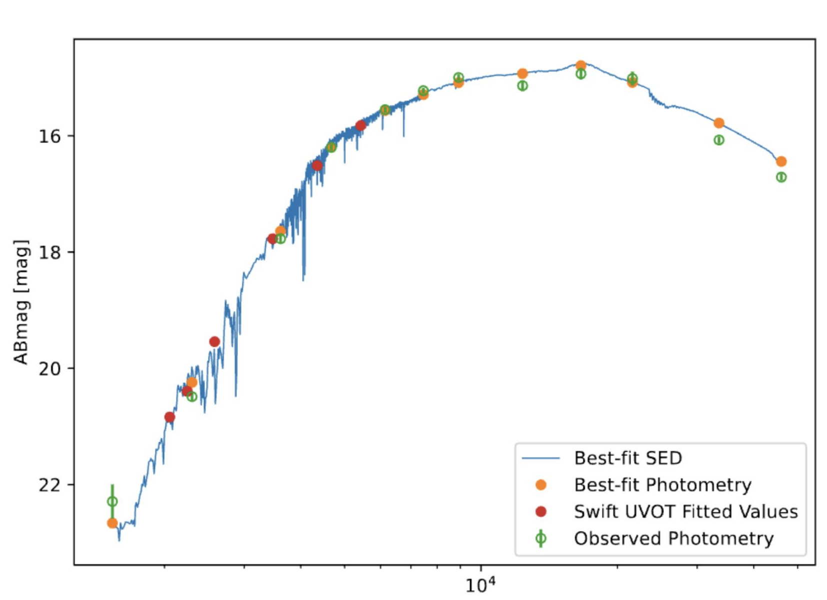

Figure 8: SED fitting result of the prospector library

Blackbody Temperature Fit

We interpolated the flux of the 6 Swift-UVOT bands. For each new epoch, we fit a blackbody model to it and obtain the blackbody temperature. Figure below shows the temperature evolution of both flares in AT2022dbl.

We can see that the TDE is the hottest at the peak with a temperature over 30,000K, and gradually cools down, consistent with the results of Lin et al.

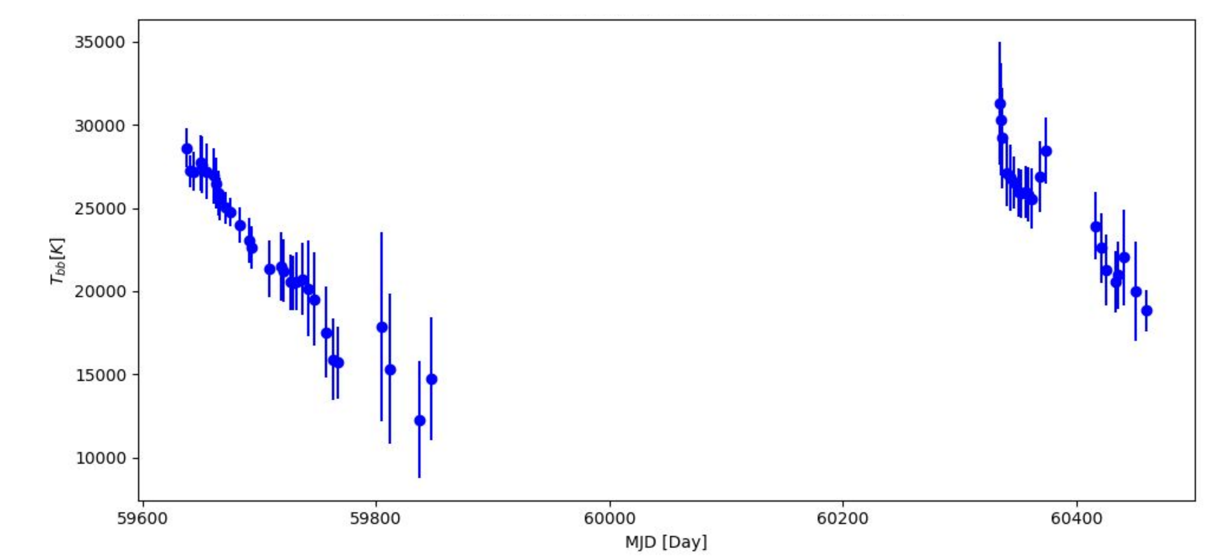

Figure 9: Blackbody Temperature Evolution for AT2022dbl

Summary

- We present a reduction of the UV-optical photometry that properly accounts for error estimation, host galaxy subtraction, and extinction correction that covers the entire evolution of AT2022dbl between 2022-03-25 and 2024-06-01. We observed that the UV light measured through the w2 filter did not return to its pre-event level, unlike the other five filters.
- We modeled the host galaxy based on its stellar population properties, which not only give us a good galaxy-only photometric estimation, but also the template for later spectroscopic analysis.
- We revealed the temperature evolution of both flares in AT2022dbl. It gradually cooled from over 30,000K to ~15,000K, consistent with the results of Lin et al.

Future Work

- In the future, we plan to subtract the host emission and blackbody continuum from the 11 spectra we have and perform a detailed analysis of the absorption and emission features of the TDE during its evolution.
- We will give an estimation of the SMBH mass and the disrupted star mass.
- Need more simulation and data to understand the mechanisms of the partial disruptions.
- If the star is not completely disrupted in the second encounterance, given its short period, we might be able to observe its third encounterance in 2026 and confirm it as a PTDE.

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