The Feuerkugel app: A co-designed mobile application for documenting fireballs

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The background

- A fireball is a very bright meteor that is visible more than 3 seconds in the Earth's atmosphere. As the meteor enters the Earth's atmosphere at very high speed, it burns up due to the friction with the air and creates a streak of light.
- Fireballs contain crucial information on the solar system.
- Reconstructed fireballs' flight paths can lead to the recovery of meteorites, which hold precious information on extra-terrestrial objects.
- Since the existing camera networks, which capture pictures of fireballs, do not cover the whole sky, we developed an mobile application that allows observers to document fireball events.

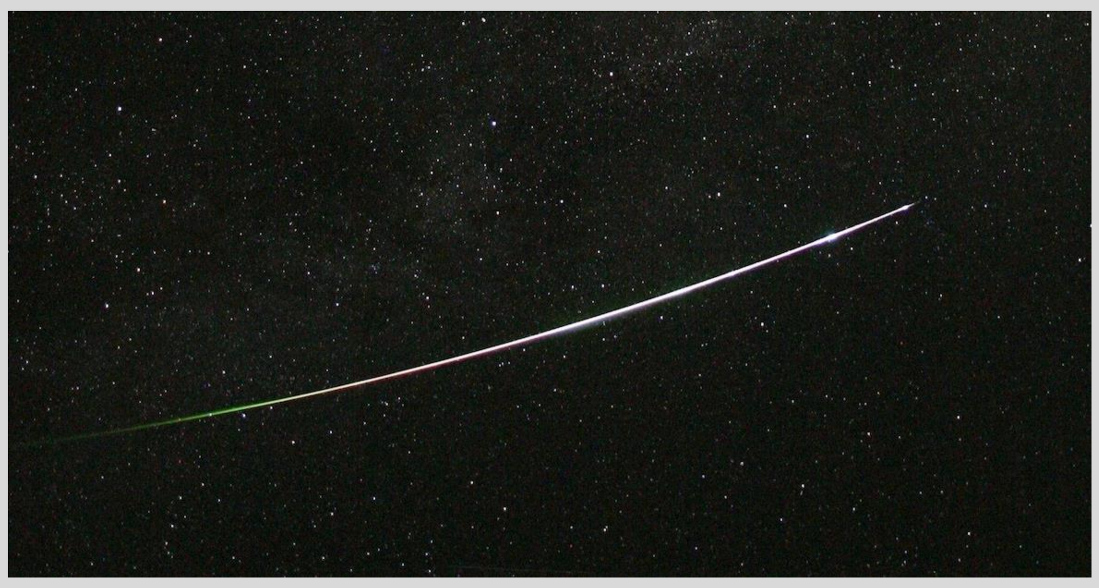
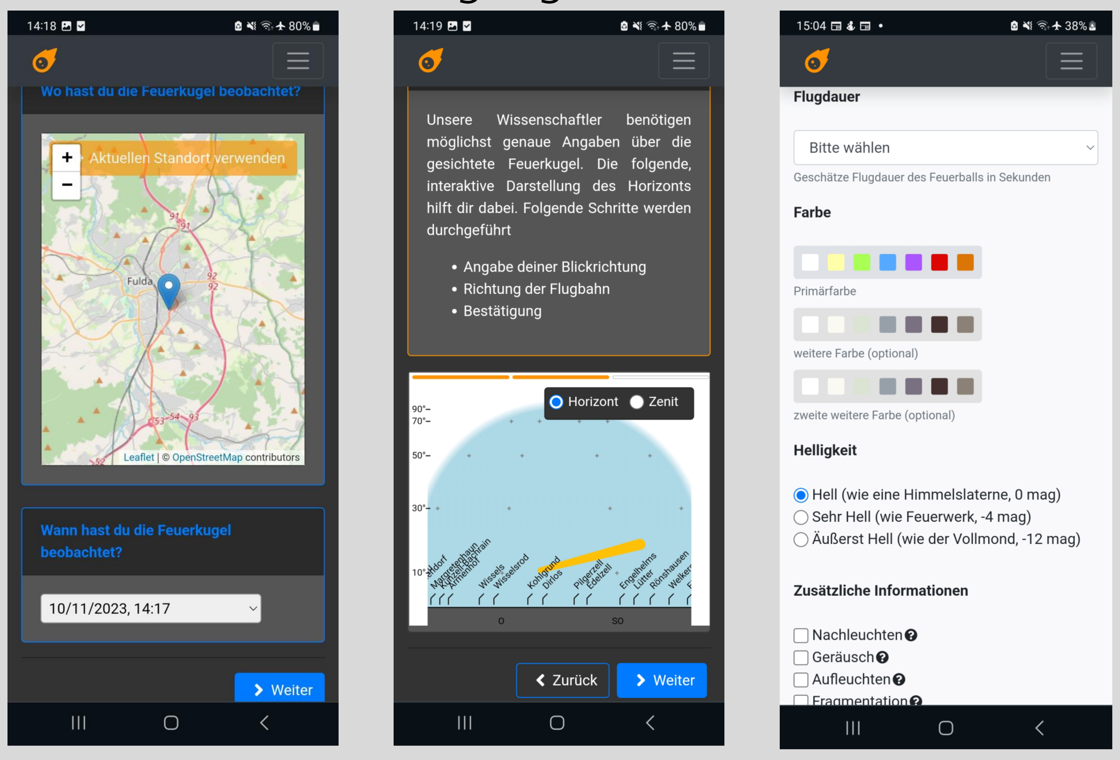


Figure 1: A fireball captured at Wettzell (Bavaria) in 2007 (photo: DLR Institute for Planetary Research)

The Feuerkugel app

- It is a web app (https://meteor.nachtlicht-buehne.de/home) designed to assist observers in documenting a fireball.
- Each observation data set consists of the observer's location, time, starting azimuth and elevation, ending azimuth and elevation, duration, color and brightness of the fireball.
- A fireball event is built upon observations with close time proximity.
- Currently the app is available in German only, but it will be extended to other languages soon.



QR code of the web app

Figure 2: Screenshots from the Feuerkugel app, showing the main steps of documenting a fireball

Data collected with the Feuerkugel app

Data collection period from 01 Jan 2022 to 25 June 2023:

- 600 fireball events based on 1715 observations
- Fireball events captured by Feuerkugel app are compared with those captured by dedicated camera networks (AllSky7 and FRIPON) during same time period.
- AllSky7 network captured 56 events with at least 1 station in Germany.
- FRIPON network captured 105 events with at least 1 station in Germany.
- 73 fireball events (from 681 observations) matched with events captured by aforementioned camera networks.

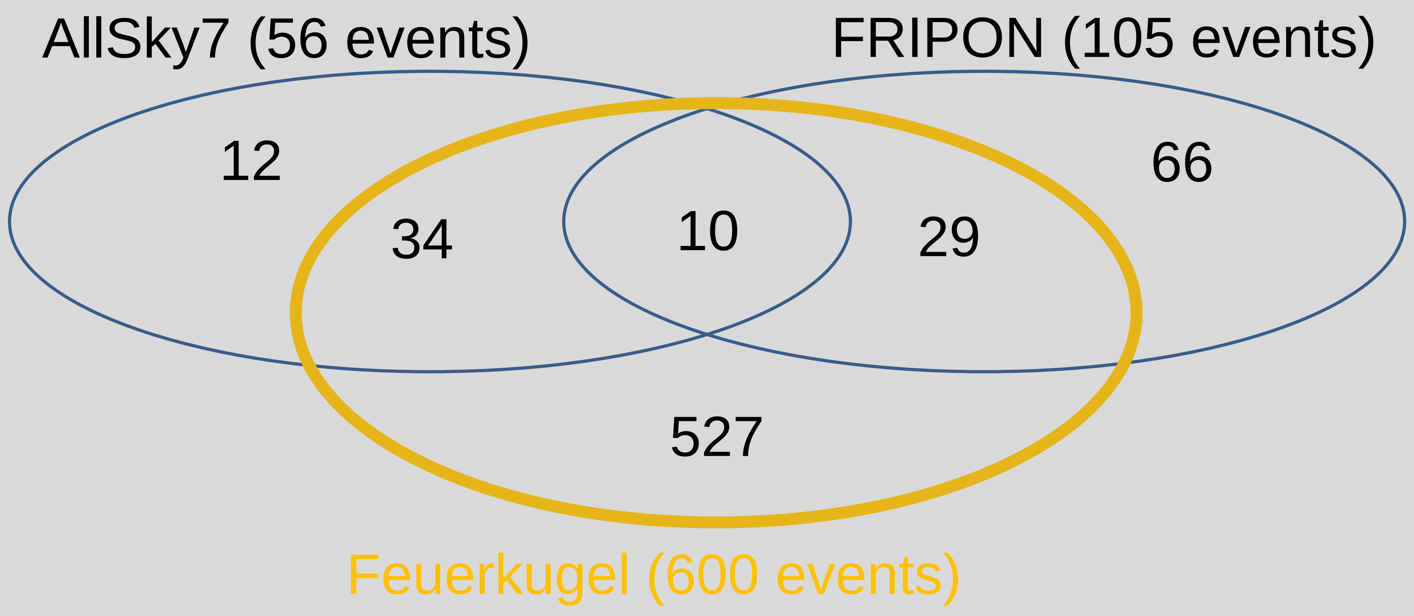
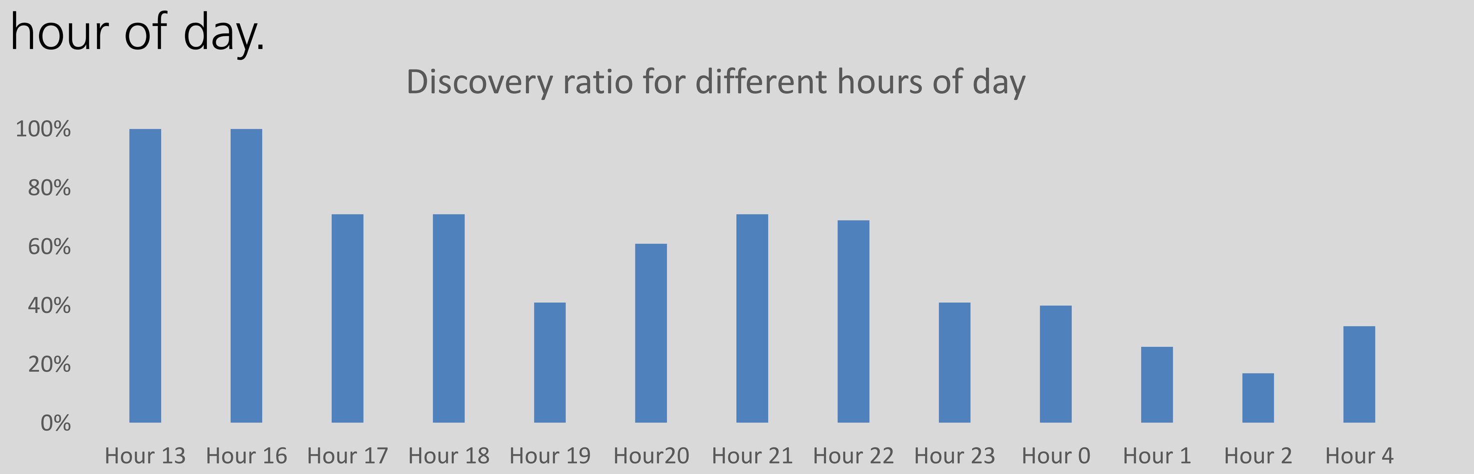


Figure 3: The overview of the events captured by Feuerkugel app and different camera networks

Analysis of the collected data

- Among the Feuerkugel events that matched with events from camera networks, the mean and median number of observation per vent is 9.29 ± 12.79 and 3.5, respectively.
- The discovery ratio is the ratio between the number of matched fireball events and the number of confirmed events within a specific hour of day.



- At observation level:
  Report delay positively correlates with observation time difference ($\varrho = 0.127$, p-value = 0.001)
- At event level:
  Number of observation negatively correlates with minimum report delay ($\varrho = -0.697$, p-value < 0.001) and minimum observation time difference ($\varrho = -0.499$, p-value < 0.001)
  Event time difference positively correlates with minimum report delay ($\varrho = 0.328$, p-value = 0.005) and median report delay ($\varrho = 0.279$, p-value = 0.018)

Evaluation of data quality

- Classification of the submitted observations into reliable and unreliable observations, which is a crucial step in the reconstruction of the fireball's flight path.
- Each point on the map has a rank, which is defined by the number of observations, which overlay that point.
- Each observation has a rank, which is the highest rank of all points covered by this observation.
- Unreliable observations have lower rank and reliable observations have higher rank.

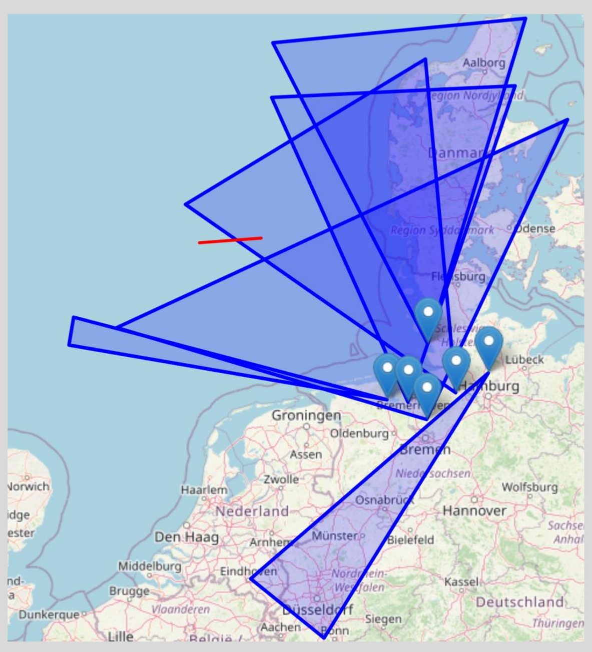


Figure 4: All observations of a fireball event captured by FRIPON and recorded by users of Feuerkugel app

Estimation of data acquisition accuracy and uncertainty

- The imaginary line between two landmarks is used to simulate the trajectory of a fireball.
- Based on known location and height of the landmarks, the errors in determining azimuth (direction) and elevation angles can be quantified.

Figure 5: The imaginary line between two high landmarks serves as a simulation of a fireball (photo: Manh Khoi Ngo)

- From a data acquisition campaign with 12 participants and 12 observation sites (each participant measured 3 times at 2 of these sites), the error in determining azimuth and elevation angle ranges from 20 to 30 degree and 10 to 20 degree, respectively. These errors are consistent across the 12 observation sites.

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The Feuerkugel app is part of the Nachtlicht-BüHNE project, which is funded by Bundesministerium für Bildung und Forschung

DLR Deutsches Zentrum für Luft- und Raumfahrt