Follow-up observations of *Gaia* alerted eruptive young star candidates

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I. Variability of forming stars

–Accretion in pre-main sequence stars is inhomogeneous in space and time.
–The **accretion rate** can vary by orders of magnitude due to thermal or gravitational instabilities.
–Brightness variations in young stars can also occur due to other processes, e.g. variable **circumstellar extinction**

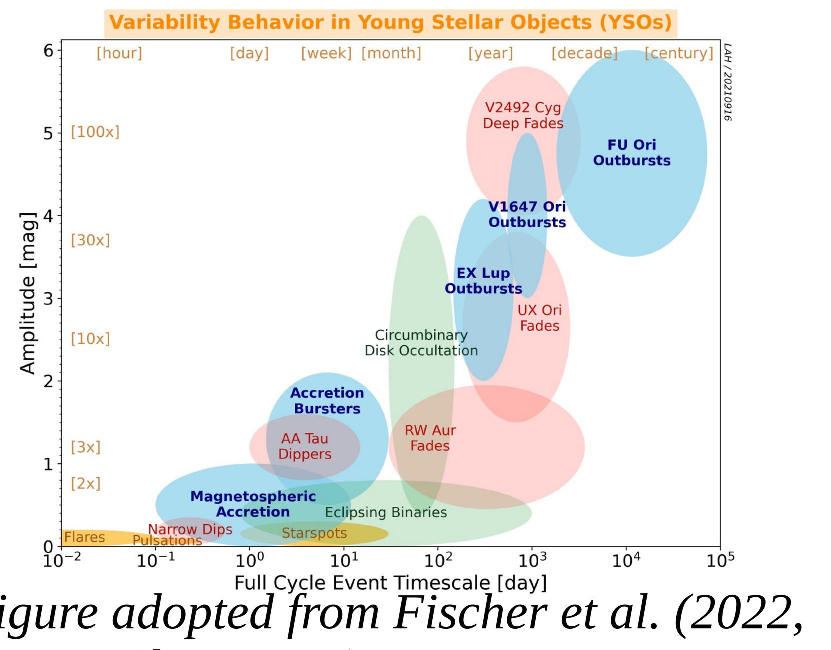
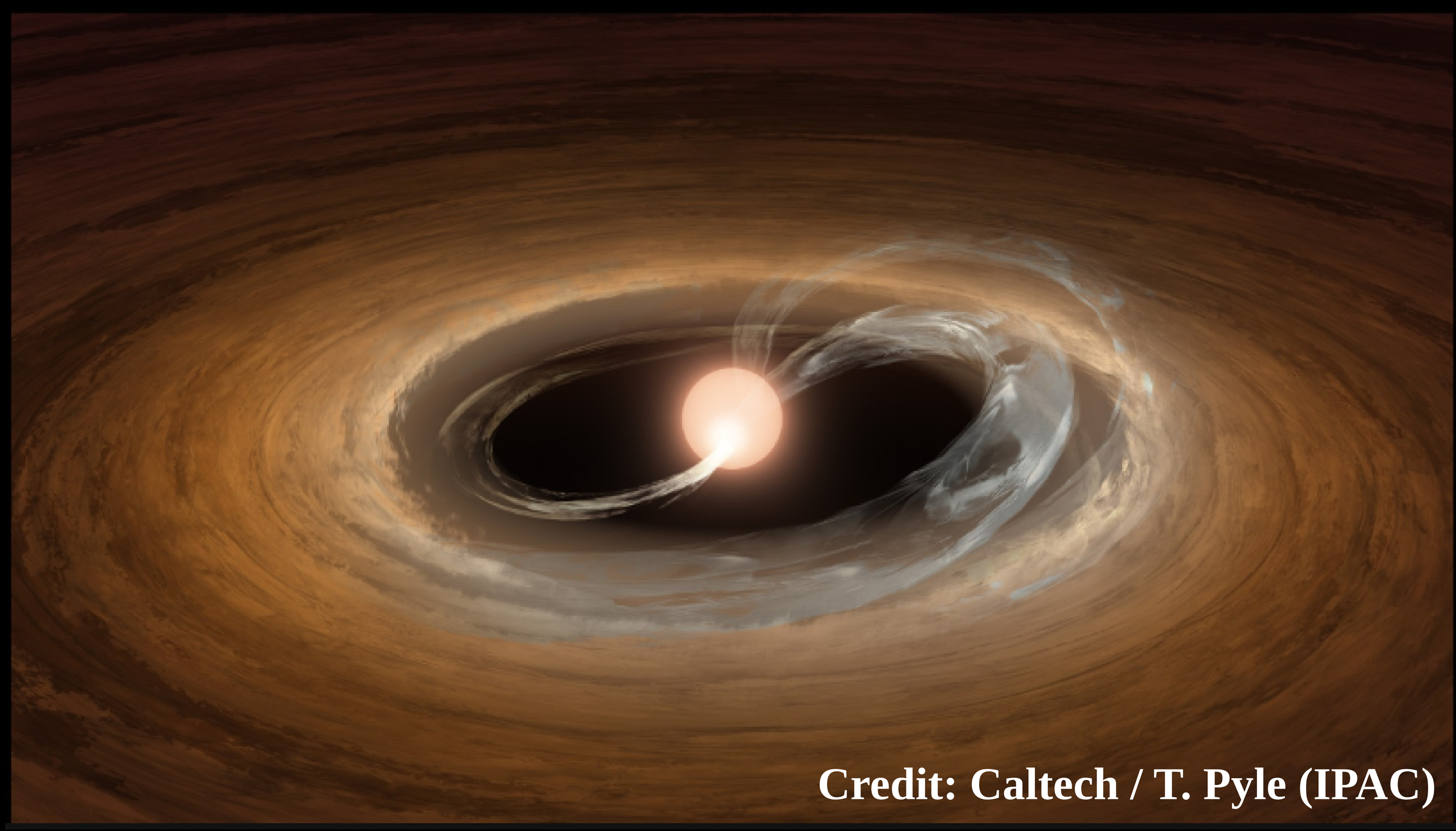


Figure adopted from Fischer et al. (2022, PPVII, Chapter 10)

–Most stars are likely to go through episodic accretion during their formation.



Credit: Caltech / T. Pyle (IPAC)

II. Eruptive young stars

–Eruptive young stars – examples of episodic accretion – have two main classes:

–**FU Orionis-type stars** (**FUors**, e.g. Audard et al. 2014, Protostars and Planets VI, 387):
- –Decades-centuries long outbursts
- –Optical burst strength: 4-6 mag
- –Absorption-line spectrum

–**EX Lupi-type stars** (**EXors**, e.g. Herbig 2008, AJ, 135, 637):
- –Months-year outburst time-scale
- –Optical burst strength: 3-5 mag
- –Emission-line spectrum

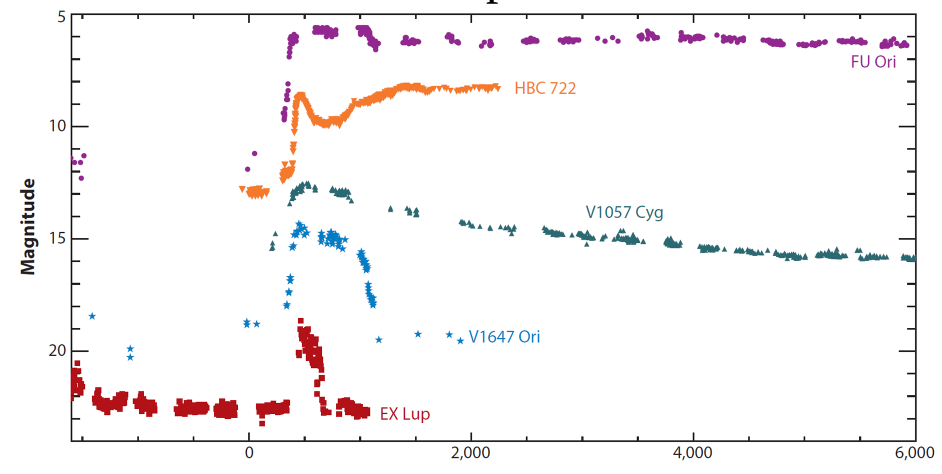


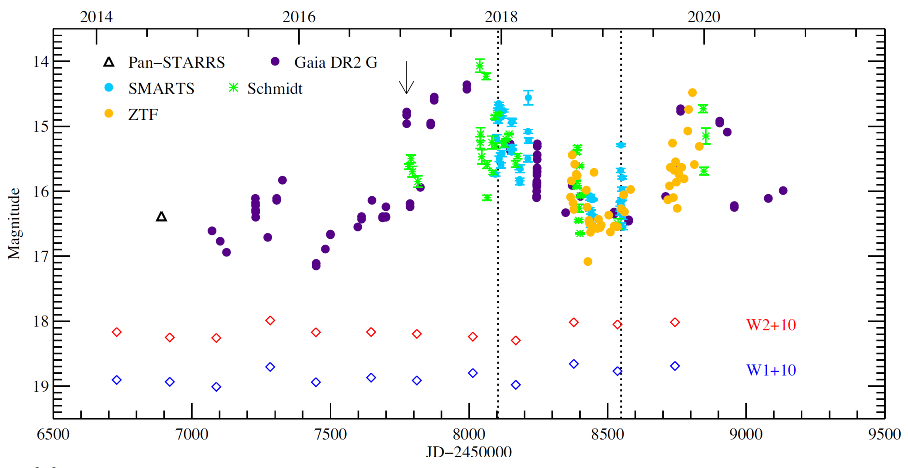
Figure adopted from Kóspál et al. (2011, A&A 527, A133)

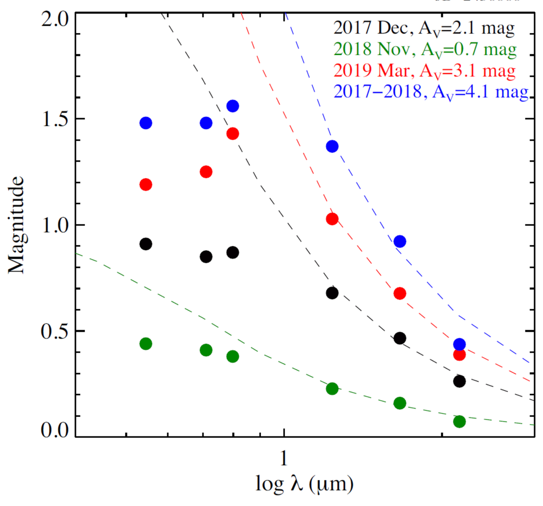
III. Finding eruptive YSOs among *Gaia* Science alerts

–Only about 50 eruptive young stellar objects (YSOs) are known – identification of new examples is important
–One of the best available tools is the *Gaia* Photometric Science Alerts System (Hodgkin et al. 2021, A&A, 652, 76)
–The alerted sources show a brightening / fading → their eruptive YSO nature is to be confirmed using follow-up photometry and spectroscopy
–What we are searching for:
- –Brightening of (candidate) YSOs → discovery of new eruptive YSOs
- –Fading of (candidate) YSOs → understand the fading of FUors

V555 Ori (Gaia17afn)

–Amplitude and time-scale similar to EXors
–Quasi-periodic variations: a period of ~5 days – consistent with AA Tau-type stars





–Long-term and short-term light variations are both due to change in extinction

Nagy et al. (2021, MNRAS, 504, 185)

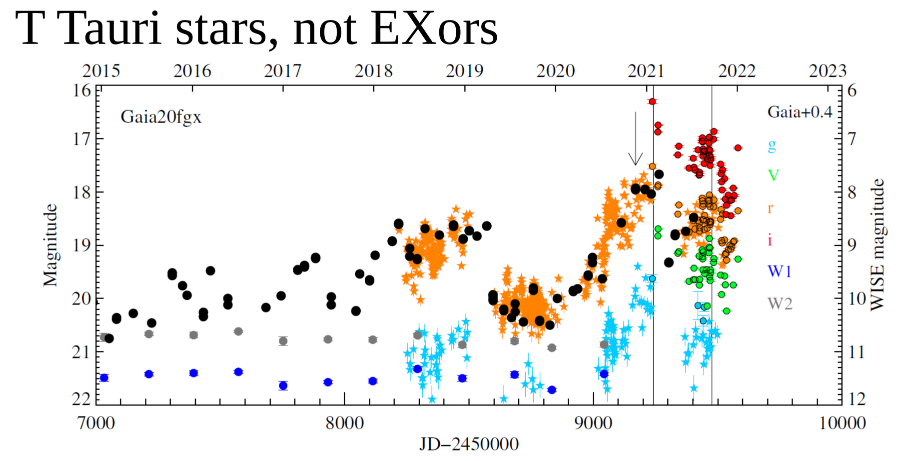
IV. Selection of candidates, follow-up observations

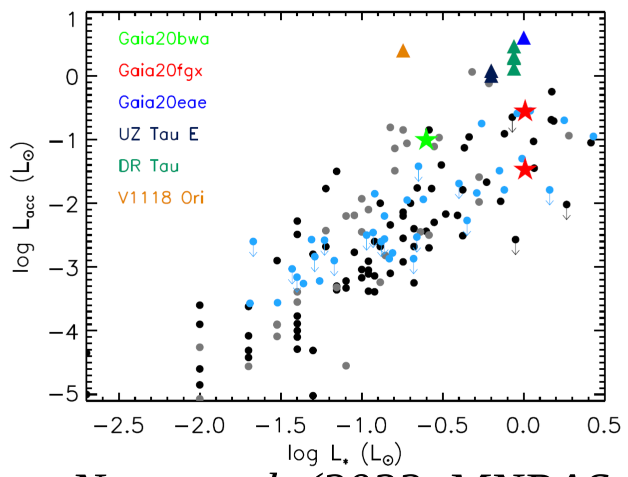
–**Selection criteria for eruptive YSO candidates**:
- –Brightening event similar to EXors/FUors, or fading of known YSO
- –Spectral energy distribution shows infrared excess
- –Is it related to a star-forming region?

–For the selected eruptive YSO candidates we obtain photometric and spectroscopic follow-up observations
–**Follow-up photometry**: 1-m class telescopes e.g. Piszkéstető (Hungary), Mount Suhora (Poland), Adiyaman Observatory (Turkey), South African Astronomical Observatory (South Africa), Rapid Eye Mount (Chile)
–**Follow-up spectroscopy**: Nordic Optical Telescope (La Palma, 2.6 m), Telescopio Nazionale Galileo (La Palma, 3.6 m), Gran Telescopio Canarias (La Palma, 10.4 m), Liverpool Telescope (Tenerife, 2.0 m), New Technology Telescope (La Silla, 3.6 m), Large Binocular Telescope (Arizona, 8.4 m), Very Large Telescope (Cerro Paranal, 8.2 m)

Gaia20fgx

–Time-scale and amplitude (2.5 mag) similar to EXors
–Accretion luminosities and rates similar to T Tauri stars, not EXors

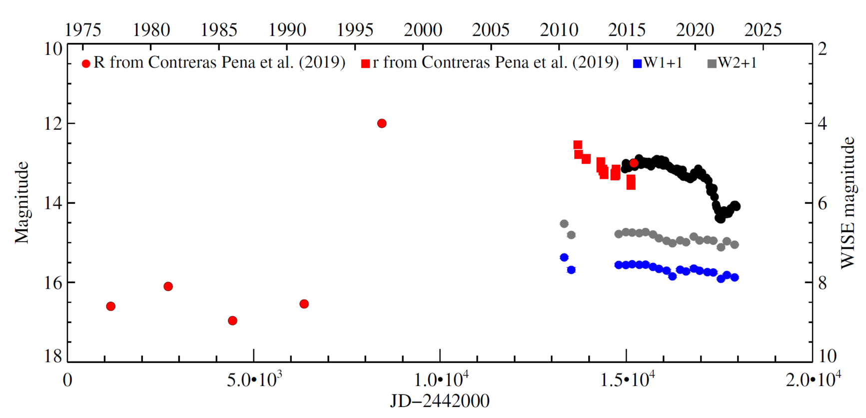


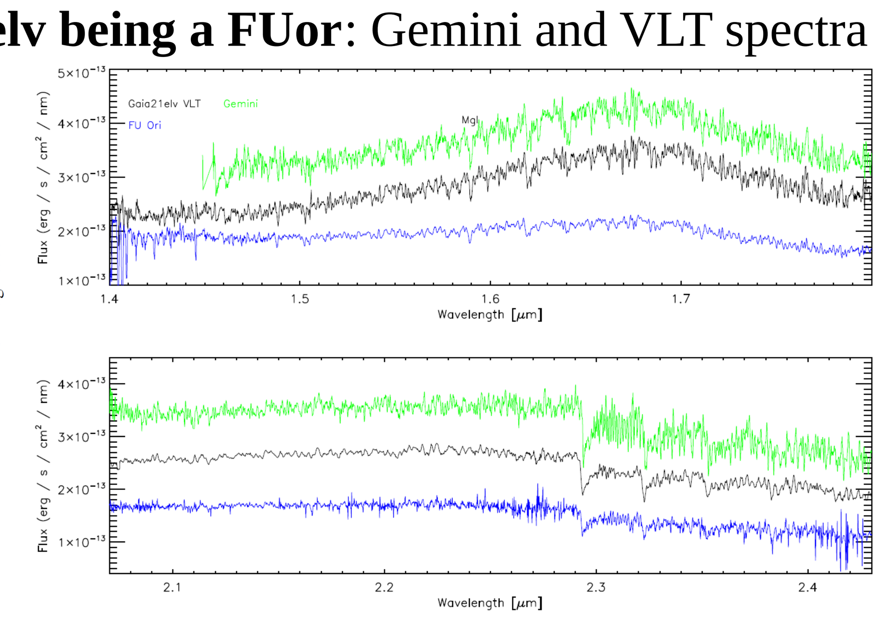


Nagy et al. (2022, MNRAS, 515, 1774)

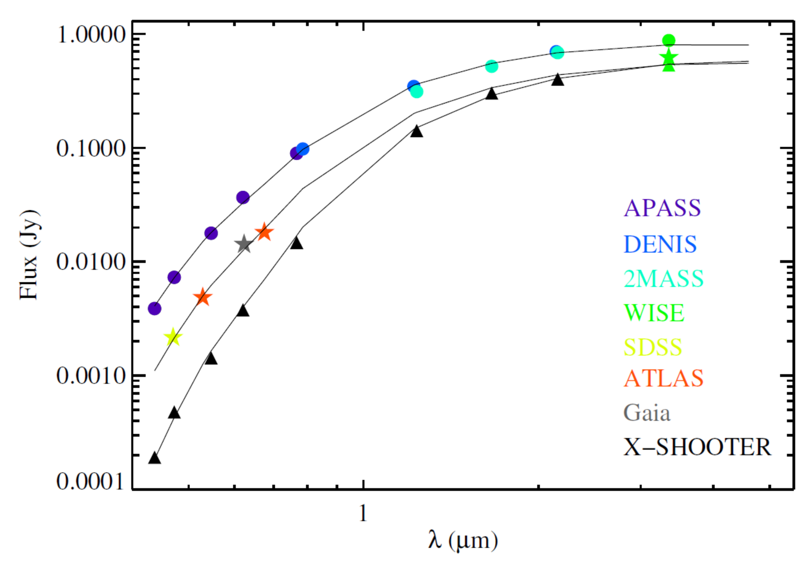
Gaia21elv

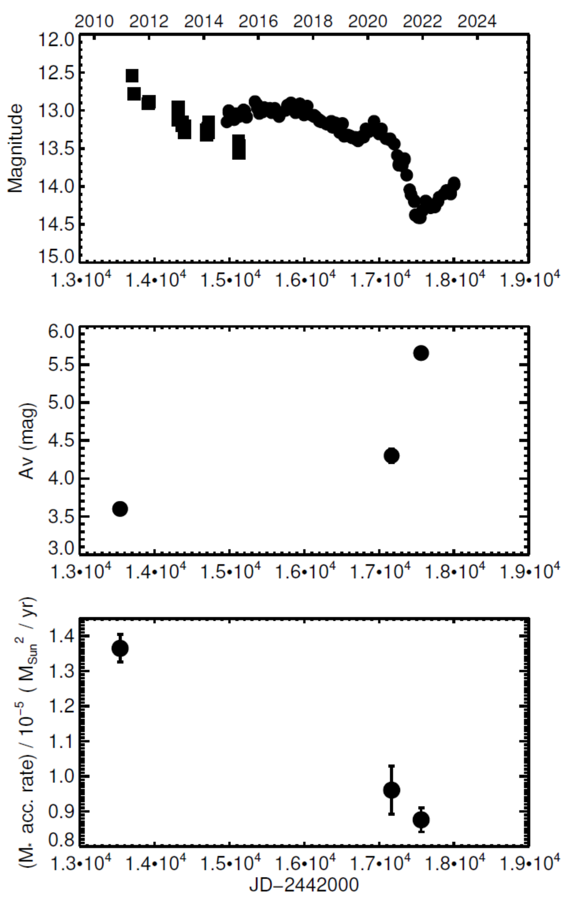
–A known young star (ESO Hα−148) showing a long-term outburst based on archival data (Contreras Peña et al. 2019, MNRAS, 486, 4590)
–*Gaia* alerted due to 1.2 mag fading over 18 months
–**Spectroscopic confirmation of Gaia21elv being a FUor**: Gemini and VLT spectra





–**Accretion disk modeling**: a steady, optically thick accretion disk, constant accretion rate in the radial direction

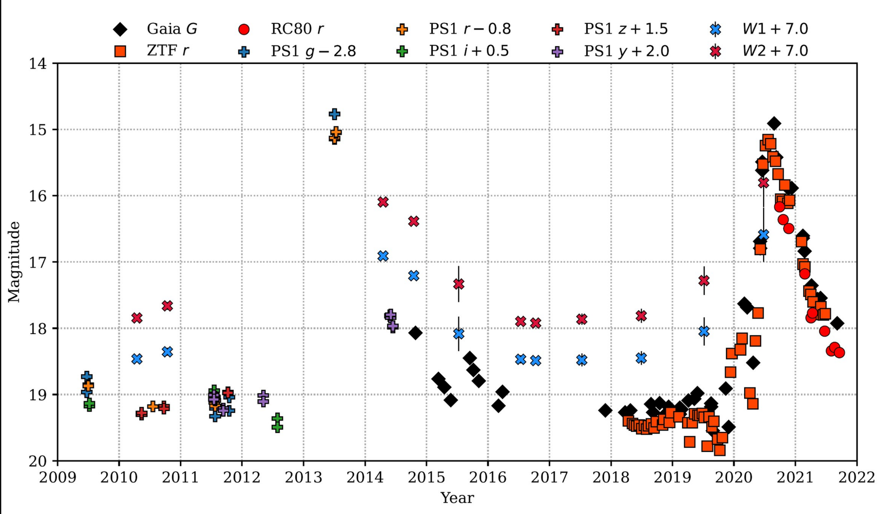


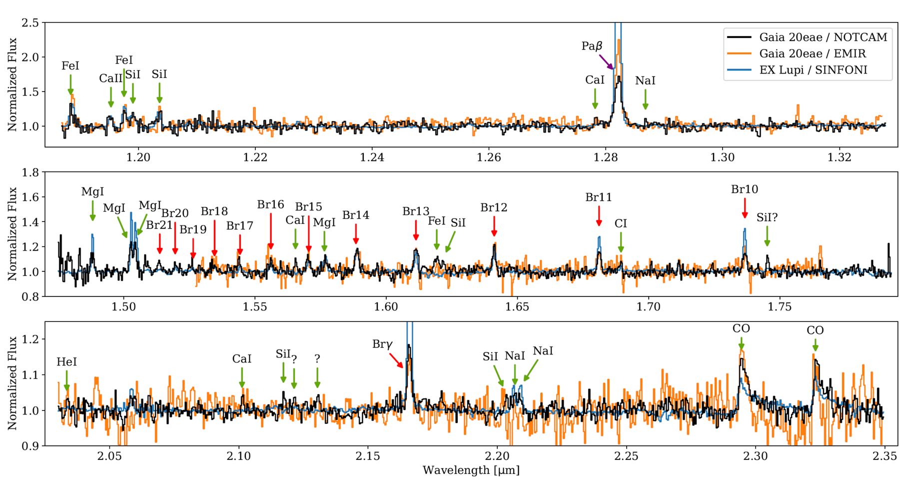


–The accretion rate decreased since the bright state
–The rapid fading that triggered the *Gaia* alert was mostly due to increasing extinction
–**This is the third FUor discovery based on Gaia alerts**

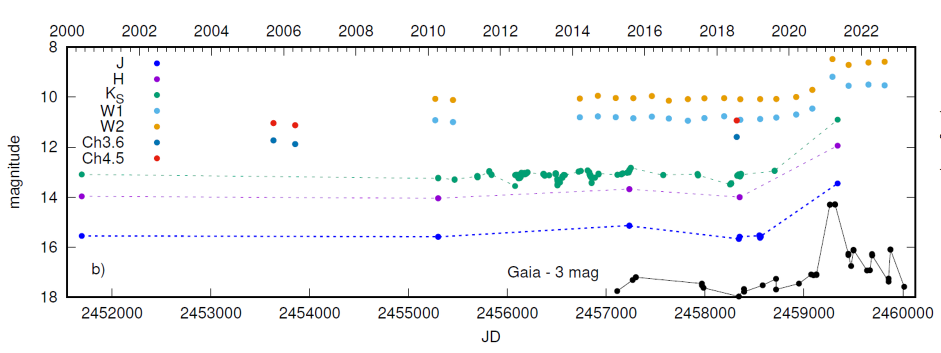
Nagy et al., submitted

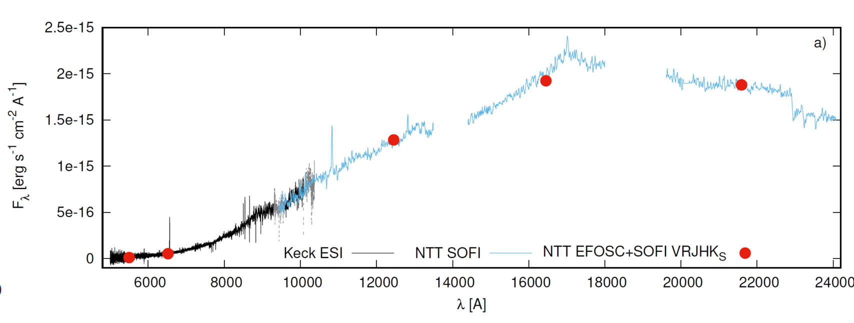
Other sources





An EXor: Gaia20eae (*Cruz-Sáenz de Miera et al. 2022, ApJ, 927, 125*)





A FUor-like star with a peculiar light-curve: **Gaia21bty** (Siwak et al., submitted)

Summary of results:

–In our systematic program at Konkoly Observatory (in collaboration with INAF Rome), we have identified more than 100 *Gaia* alerted eruptive young star candidates
–Follow-up spectroscopy for 20+ sources
–Discovery of two new FUors: **Gaia18dvy** (Szegedi-Elek et al. 2020, ApJ, 899, 130), **Gaia21elv** (Nagy et al., submitted)
–Discovery of a new EXor: **Gaia20eae** (Cruz-Sáenz de Miera et al. 2022, ApJ, 927, 125), and follow-up observations on another EXor: **Gaia19fct** (Park et al. 2022, ApJ, 941, 165)

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