A Census of NUV M-Dwarf Flares Using Archival GALEX Data and the gPhoton2 Pipeline

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NUV FLARES OF M-DWARFS

A SURVEY WITH GALEX (& XMM-)

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INTRODUCTION

- M-dwarfs flare very frequently in the UV.
  - Superflares reach energies > 10^{34} ergs; >5 mag brighter.
- Paucity of UV observations lead to large uncertainties in frequencies of these flares.
- M-Dwarfs are of high interest as exoplanet hosts.
  - High prevalence (>70% of all stars); Long-lived; Favorable for exoplanet detection and spectroscopy
- Large UV flares can impact habitability
  - Atmospheric chemistry: O3 erosion, O2 false positives and more..
  - Abiogenesis: Necessary energy source for prebiotic chemistry
- Source of noise for all transient events
  - Processing pipeline should be able to distinguish flares events
- False positives for Kilonovae

M-DWARF SAMPLE

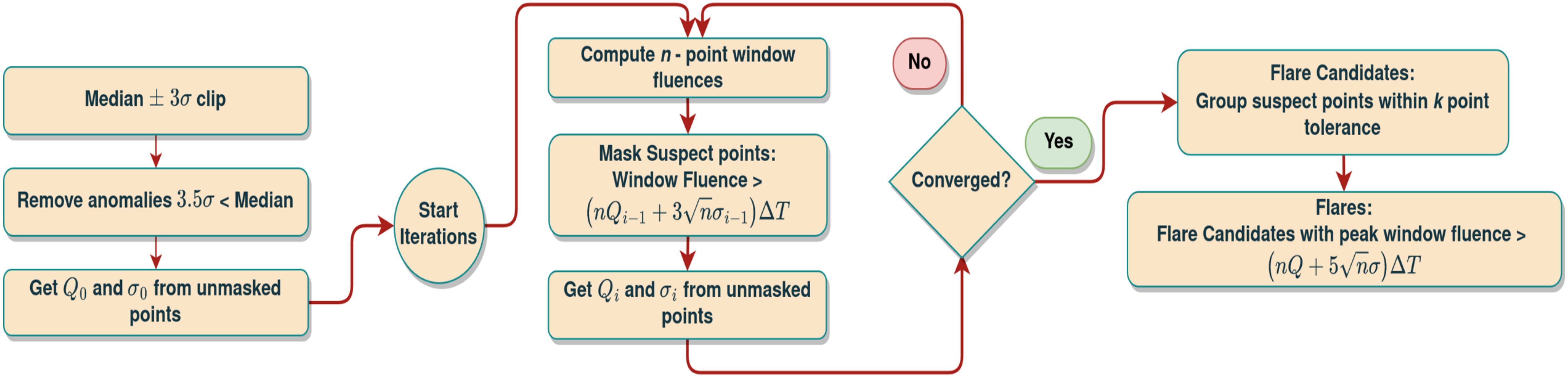
- Targets selected from the TESS Input Catalog:
  - Stars with T < 3900 K and 'DWARF' categorization.
- Filtered for Main-sequence stars:
  - Based on Gaia DR3 color-magnitude diagram
- Matched to GALEX and XMM observations after proper-motion propagation.

SpT	N_{stars}	Exposure (days)	N_{flares}	$N_{stars}^{flaring}$
GALEX				
M0-M2	2590	109.4	171	103
M3-M6	1586	59.8	357	286
XMM-OM				
M0-M5	18	4.6	20	4

GALEX LIGHTCURVES

- GALEX data obtained using `gPhoton2` and `photutils.segmentation`
- Lightcurves binned at SNR=3 or better; minimum bin size=10s.
- Max exposure duration: 1800s; orbit duration: 5900s
  - Biased against detection of highly energetic flares

FLARE IDENTIFICATION



Also, all Flares are visually inspected

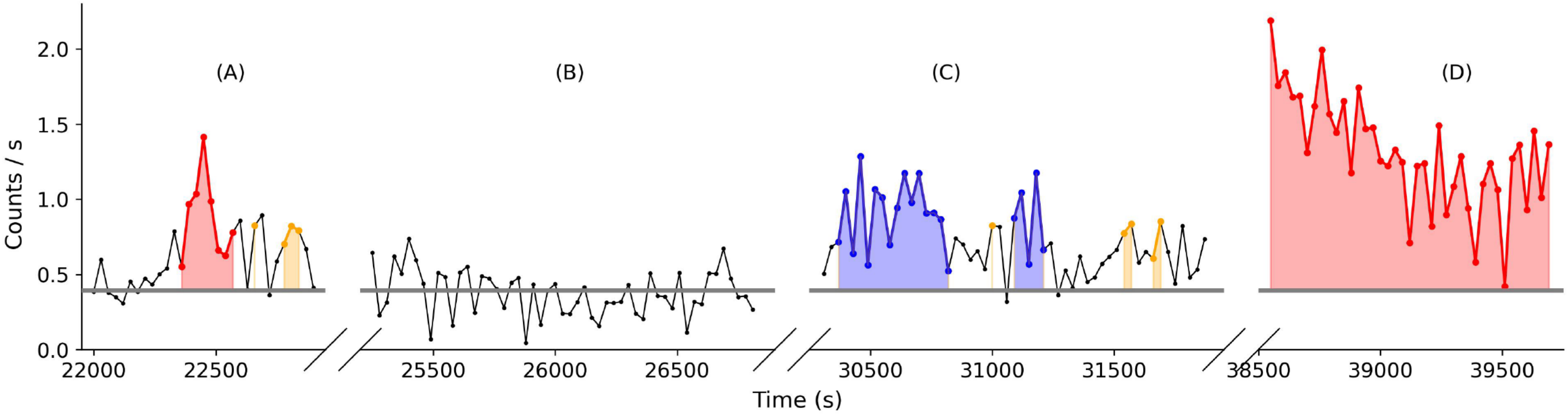


Figure 8. Example of visually rejected flares in GALEX data (blue). The red highlights show visually accepted flares and the yellow highlights denote suspect regions that the algorithm did not qualify as flares (see Figure 5). The gray line denotes the estimated quiescent level. Light curves are artificially concatenated over exposure gaps for clarity. (A) shows a small flare with a clear impulse and decay, (B) is a typical 'quiet' lightcurve segment, both blue regions in (C) are rejected for not having impulse or decay phases and being less than 3 times the quiescent and (D) is accepted as a flare for showing a decay phase.

FLARE METRICS

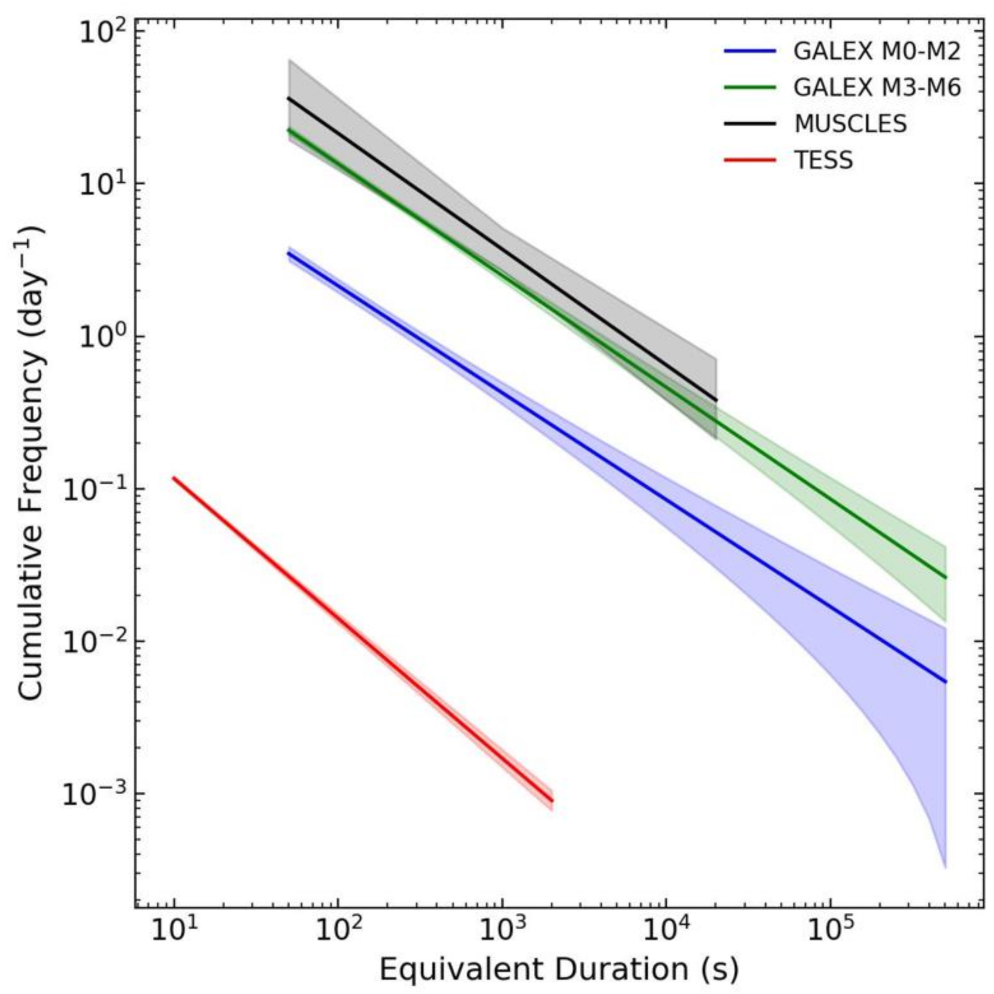
- Equivalent Duration (δ)
  - $\delta = \int_{flare} \frac{(F - F_q)}{F_q} dt$
  - Measure of flare strength relative to quiescent luminosity.
  - Ideal for comparing and aggregating flare statistics in a inhomogeneous dataset.
- Absolute Energy
  - $E = 4\pi d^2 \Delta\lambda_F \int_{flare} (F - F_q) dt$
- Relative Amplitude
  - Relative amplitude = $\mathbf{E}\left(\frac{\Delta F}{F_q}\right) = \frac{\delta}{\text{Flare Length}}$

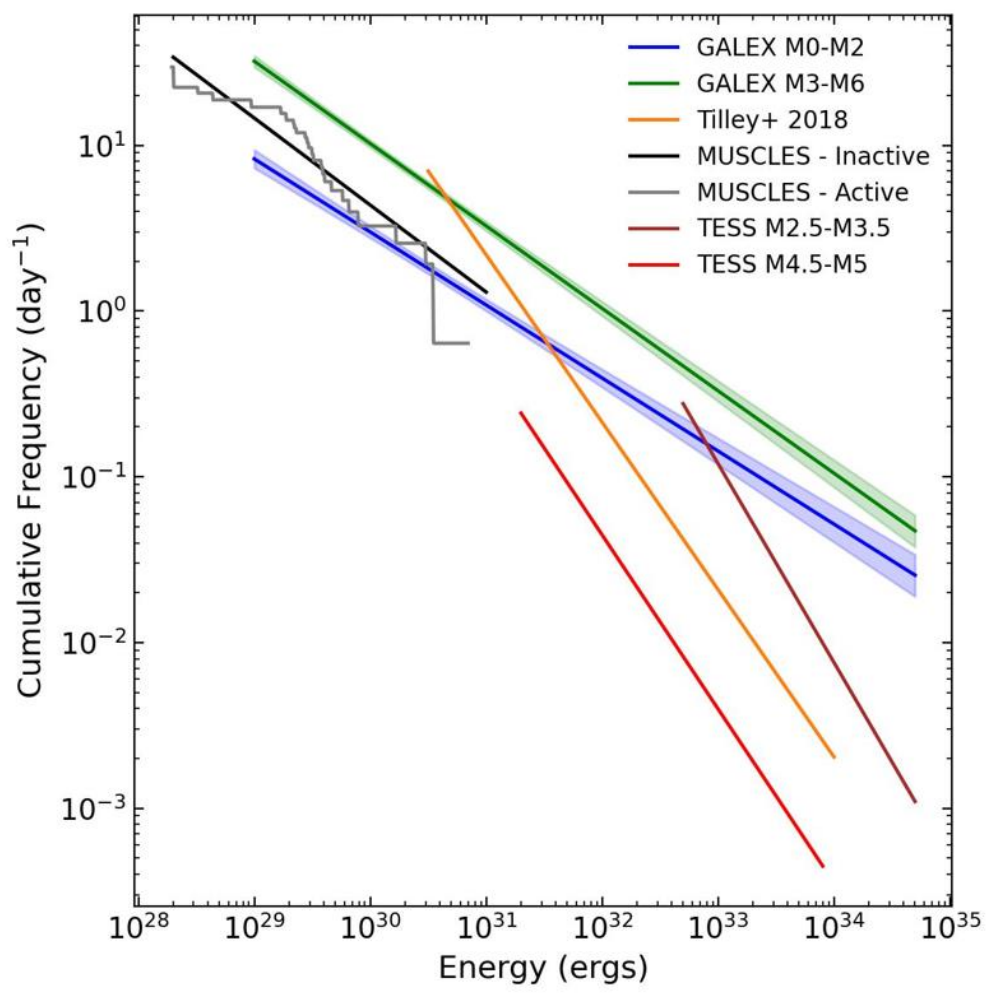
FLARE FREQUENCY DISTRIBUTIONS

- Flare rates follow a power-law distribution both as a function of energy and equivalent duration:
  - $\nu = C\delta^{-\alpha}$; $\nu = CE^{-\alpha}$, where ν is the cumulative flare frequency.

- FFDs constrained in the NUV up to ~ 10^5 s in δ and ~ 10^{34} ergs in energy for spectral groups M0-M2 and M3-M6 using MCMC fitting.

CUMULATIVE FFDs AND COMPARISONS

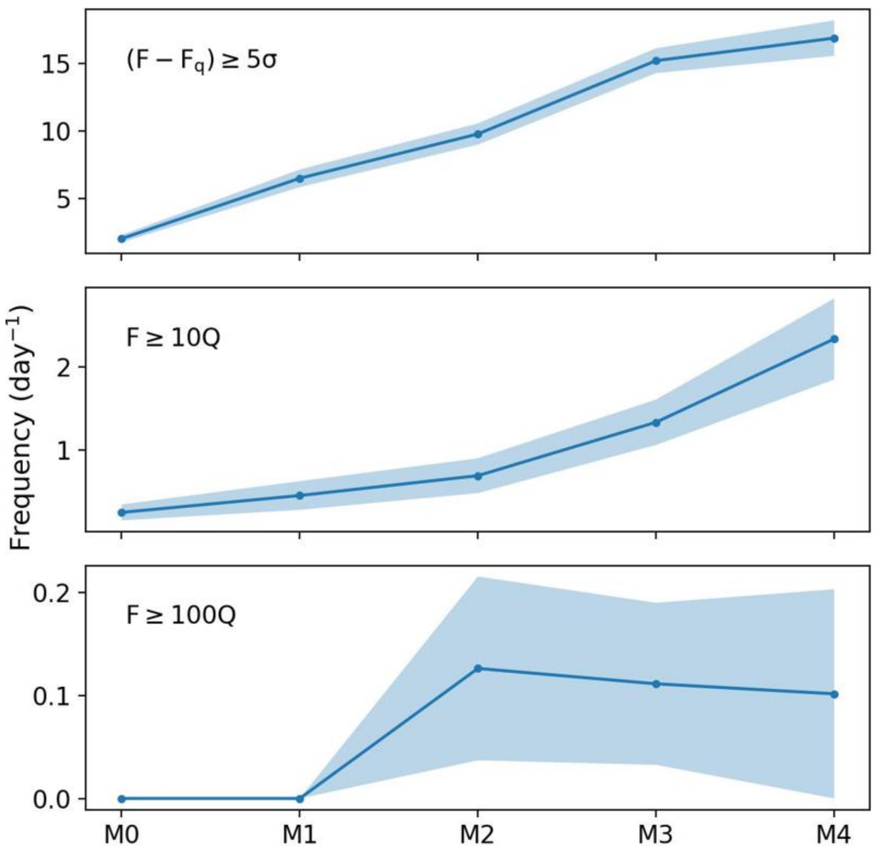


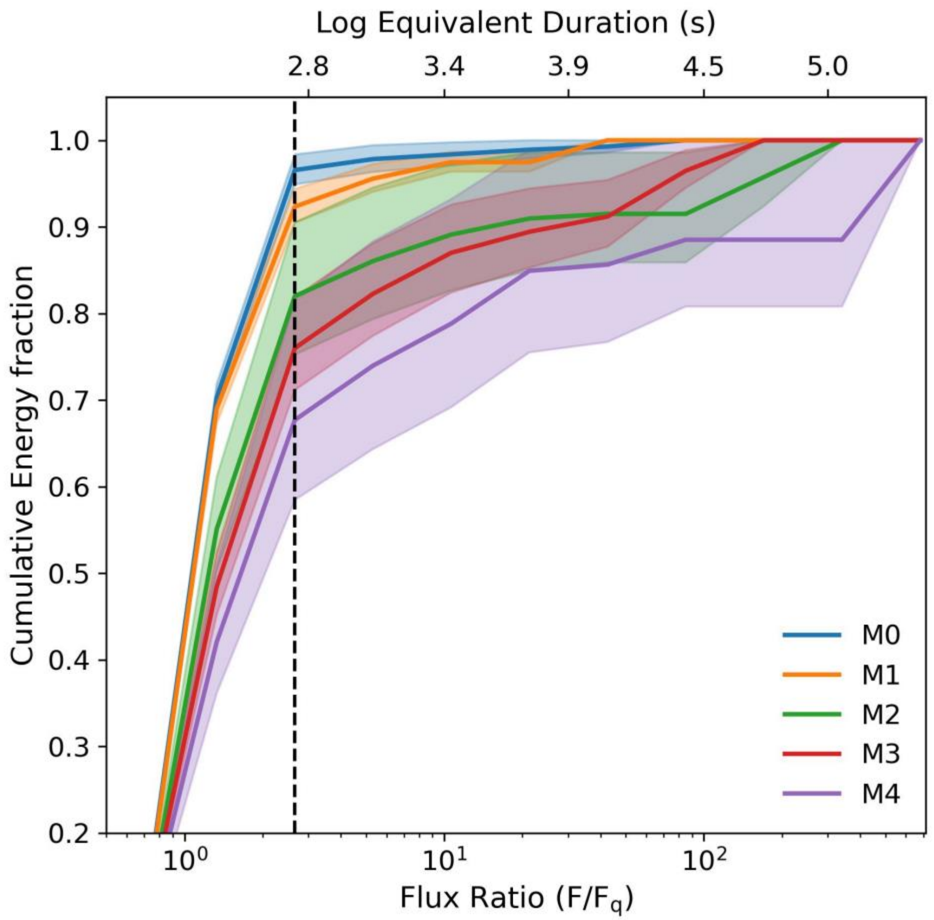


LONG BASELINE ACTIVITY

- Holistic study by aggregating data for stars of each spectral type.
  - Unrestricted by exposure gaps.
  - Does not require identification of flares
- Relevant to ULTRASAT data
- We bin counts in 300s. Then normalize bin fluxes by the quiescent flux and aggregate.
- Flare rates increase by ~ 2 OOM from M0 to M6.
- Fraction of stellar emission attributed to flares increases from ~5% for M0 to ~ 33% at M4.

LONG BASELINE ACTIVITY STUDY





IMPACT ON HZ EXOPLANETS

We compare the GALEX data to previous studies:

Abiogenesis:

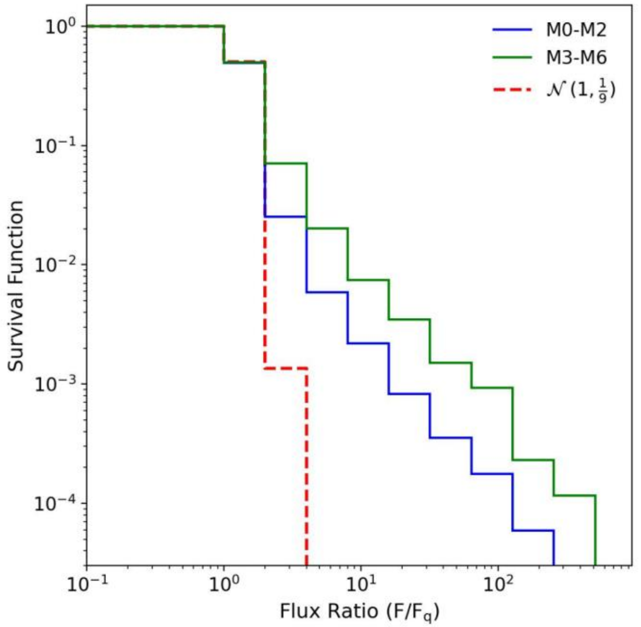
- Ranjan et al. (2017): Stars later than M2 may support abiogenesis.
- Rimmer et al. (2018): All M-Dwarfs may support abiogenesis

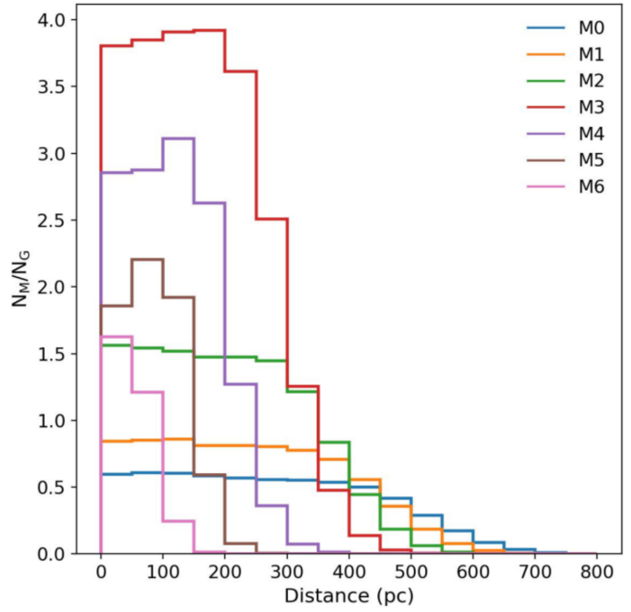
Ozone Depletion: Tilley et al (2019):

- Coronal mass ejections (CMEs) accompanying flares deplete atmospheric ozone.
- We estimate Kepler data used by Tilley underrepresent CME fluxes by more than 3 OOM → No ozone layers for habitable zone exoplanets

PROJECTIONS FOR ULTRASAT

- Need better constraints on rate of high energy flares (> 10^{34} ergs) → provided by ULTRASAT
- We obtain empirical distribution of local to quiescent flux ratios for M-Dwarfs in 300s exposure bins.
- Distribution highly deviates from a normal distribution for a SNR=3 source beyond flux ratio of 2
  → considered flaring regime.
- We assume M-Dwarf density is tied to G star density in the solar neighbourhood, hence obtain M-Dwarf number distribution out to 800 pc.
- Simulations find ~150 flares in each 300s ULTRASAT exposure, almost all occurring on M-dwarfs not visible in quiescence.

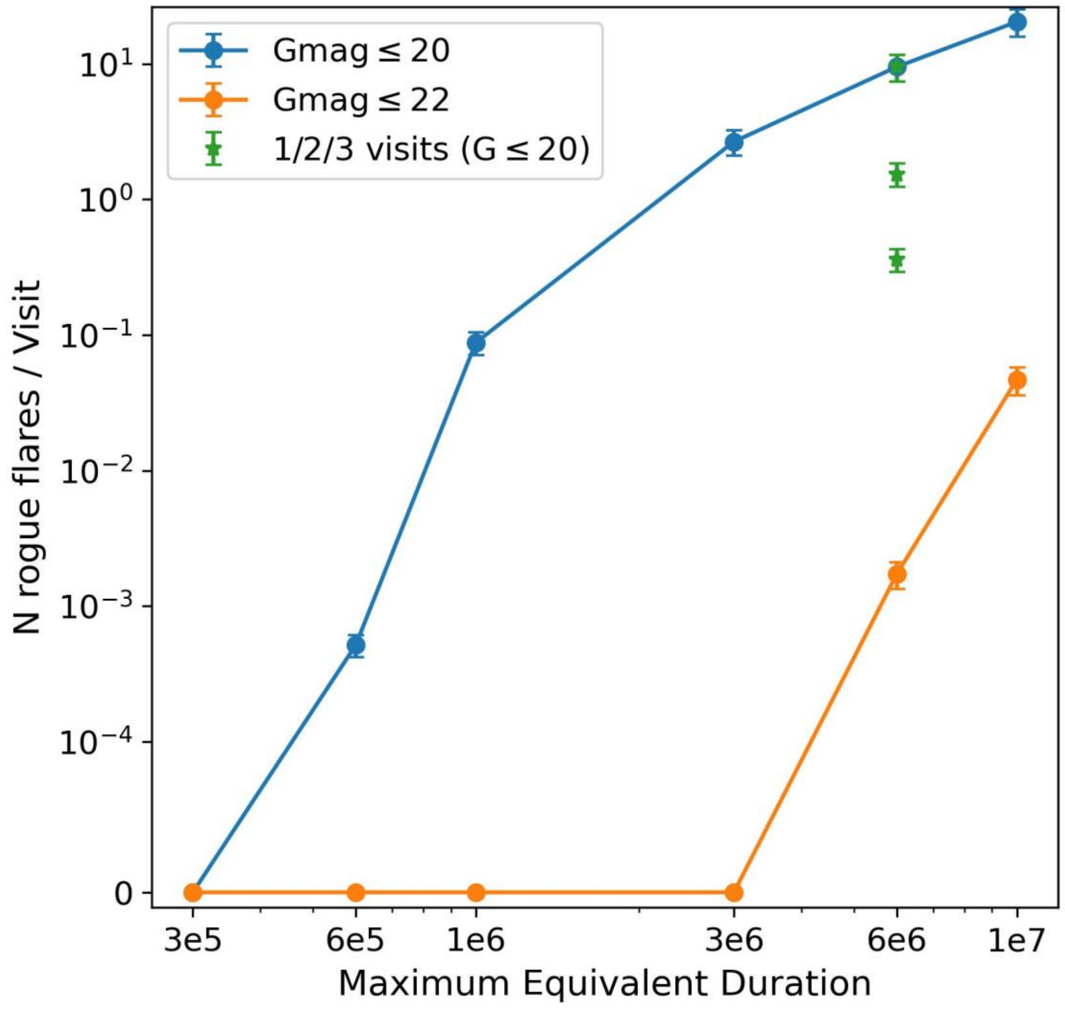




ULTRASAT: FALSE POSITIVES FOR KILONOVAE

- We want to know the no. of flares on unknown host stars possibly confused for kilonovae.
- We define kilonovae-like (rogue) flares defined as flares with $\Delta m<0.1$ across the 3 exposures
- We conduct flare injection simulations for 3/6/9 x300 visits
- Simulations conducted with range of max δ values beyond GALEX's limit constrained by its single exposure duration.
- Point-like source completeness (Gaia G mag):
  - Gaia: G ~ 20 mag
  - LSST: G ~ 25 mag
  - Gaia G – ULTRASAT NUV $\cong 7$ mag for M-Dwarfs

ULTRASAT: FALSE POSITIVES FOR KILONOVAE



THANK YOU