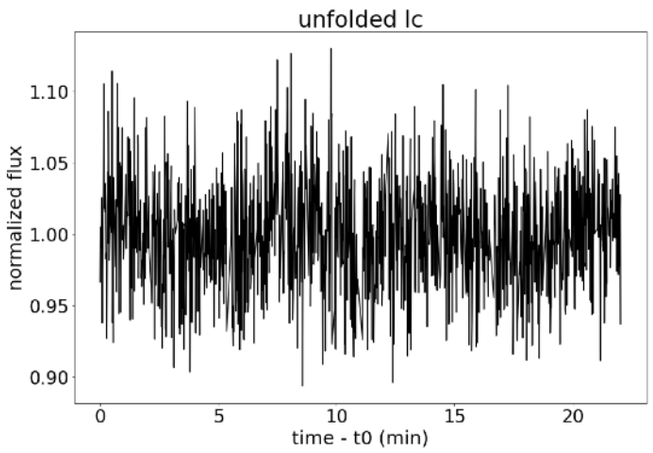
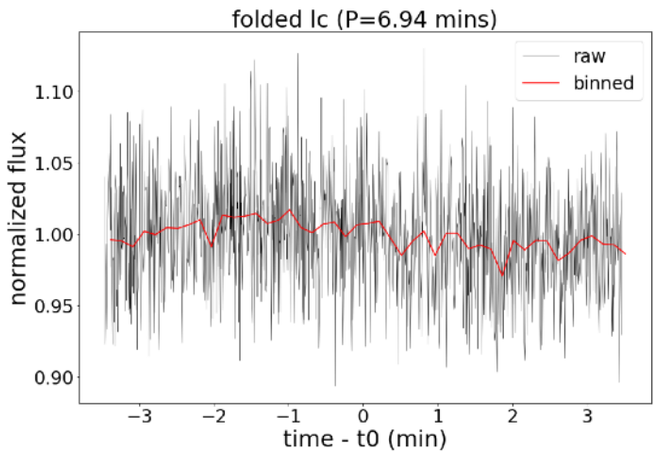
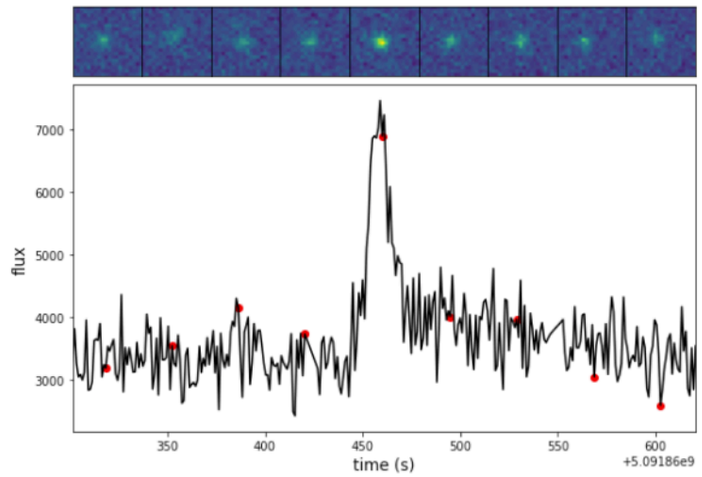
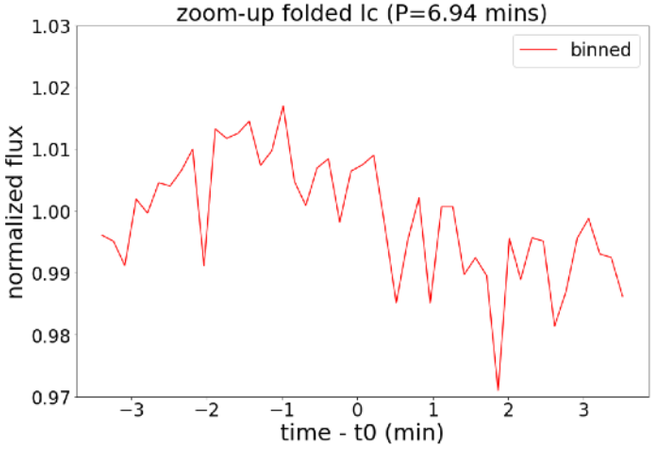
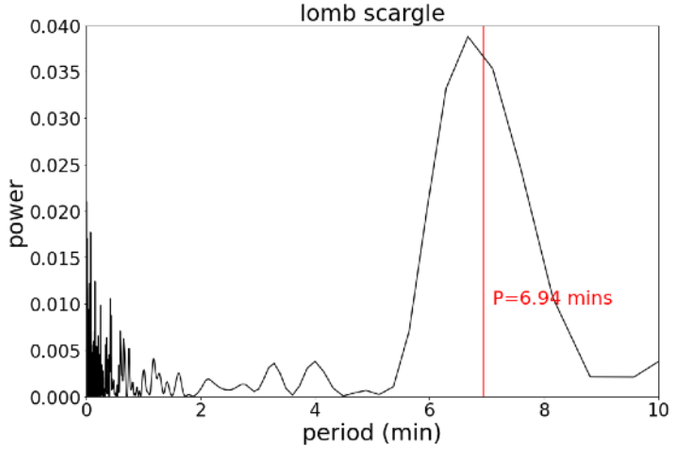
HeSO survey: search for sub-min variability of white dwarfs and M dwarfs

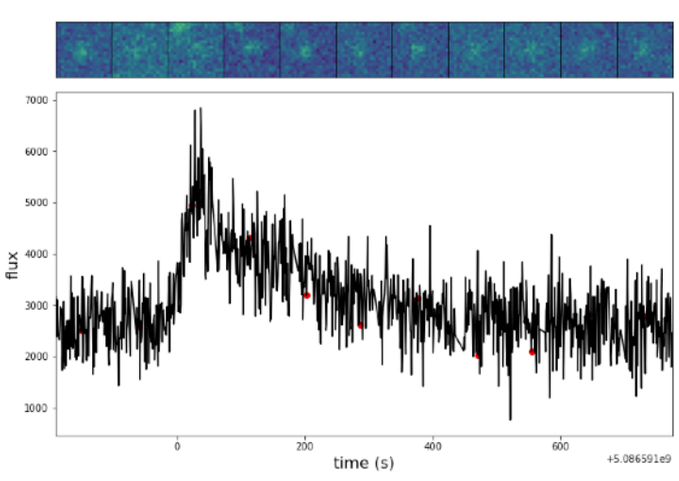












逢澤正嵩 (Tsung-Dao Lee PD fellow), 樫山和己 (東大), 川名好史朗 (東大->卒業), 河原創 (東大), 田尻智行 (東大->卒業), 大澤亮, 有馬 宣明, 酒向重行 (東大)

HeSO & Tomo-e gozen collaboration

@木曽シュミットシンポジウム2021

1. What is HeSO? Pipeline & Current Status

2. Science Cases & Results

What is HeSO = Hertz Spinning Object?

- Background

We formed HeSO in 2018 summer @ U Tokyo.

We have different backgrounds (e.g. planet, high energy, data science)

- 樫山, 逢澤 (須藤研D2 -> PD@TDLI), 川名 (吉田研D1 ->就職),
  河原, 田尻 (生駒研M2 ->就職)

- Purpose

- Discover unknown phenomena with sub-min time scales

- Data

- lightcurve data in fixed field (~ a few hours)
- As of now, we have observed for several nights
  - Data from other project (e.g. 地球影データ: PI 有馬さん) are also used

- Pipeline

- SExtractor+PCA cotrending

Possible science cases

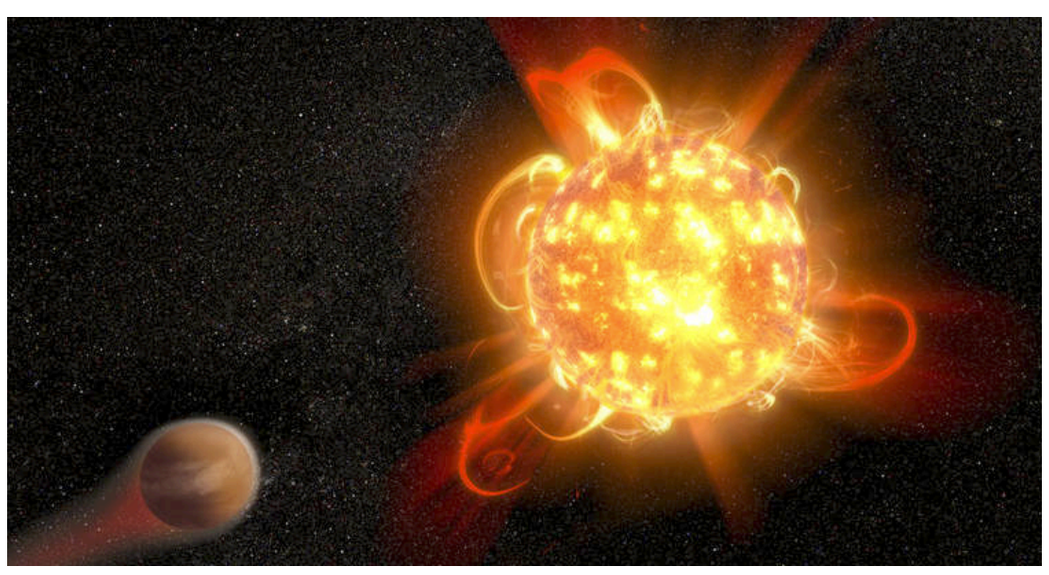
- New sub-min variability
  using Tomo-e gozen

Rapidly rotating white dwarf

- Variability from surface inhomgenity
- “a few secs <” + “1%~ a few%”

Planet (debris) around WD

- Transit by planetary object
- “1min<” + “1~100%”



Very fast flaring

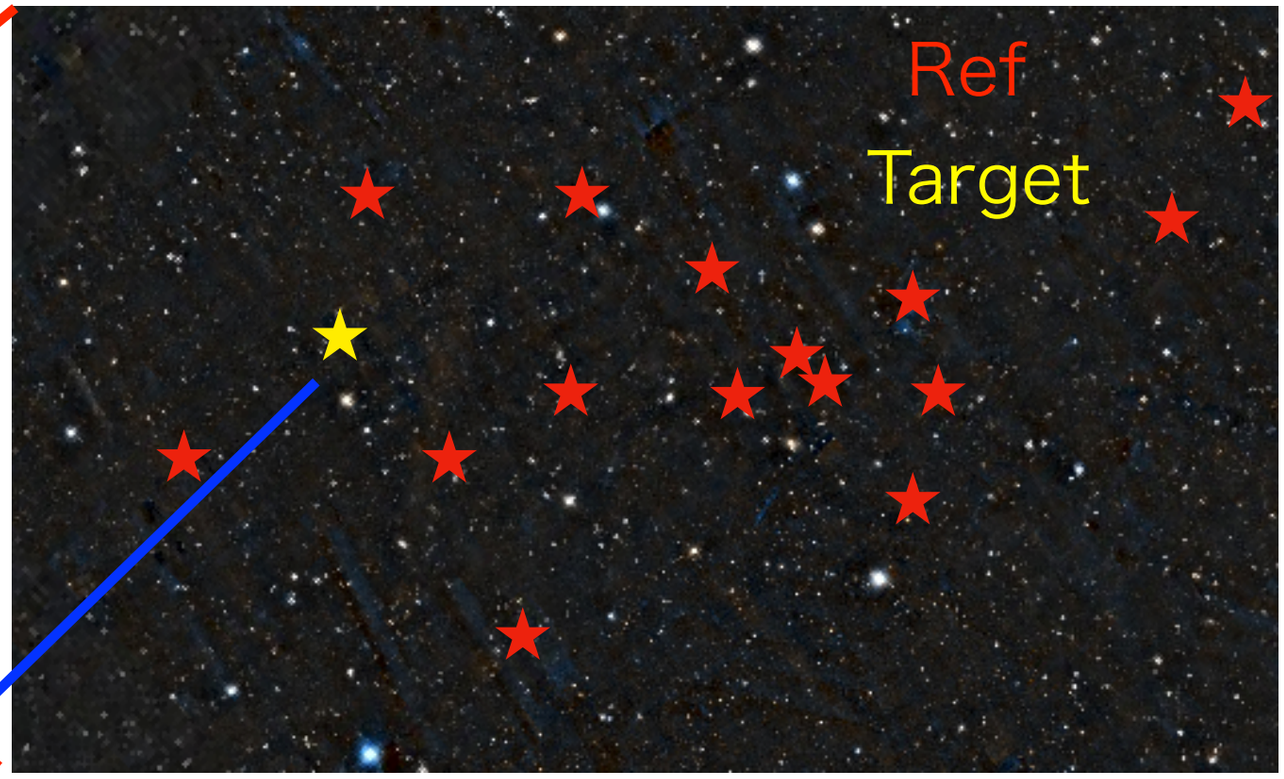
- flaring events from stars
- “a few secs <” + “1%~ 10000%?”

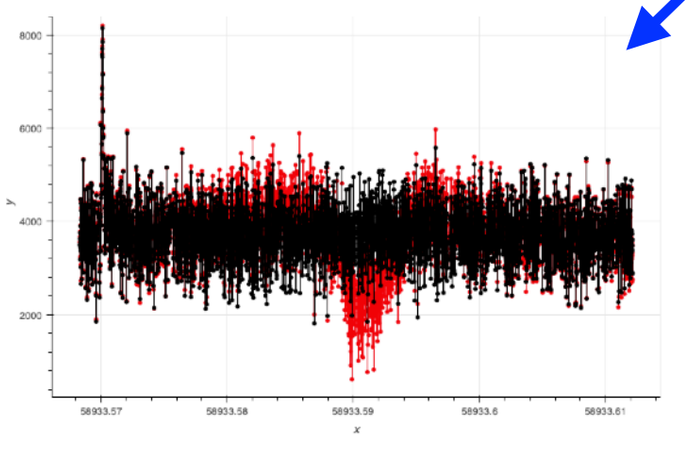
Overview of observation & analysis

(a)Subtraction of background, (b) Catalog matching,

(c)Aperture photometry (d) PCA cotrending

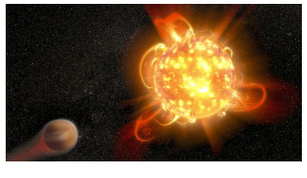
FOV (84 sensors)





HeSO catalog

- **References** (200-300/Sensor)
- **Targets** (WD, MD)
  - 2-4/Sensor (~0.02 for WD)



川名パイプラインの全体像

川名氏スライド改変

fits_header_20200518.hdf5

前準備

カタログ:
参照星 + ターゲット (WD etc)

for FITS files

FITS files

open FITS & read header

for time in FITS times

FITSイメージ内の参照星+ターゲットの抽出

background検出 (引き算 & RMSの抽出)　sep/SExtractor

source 検出 (w/ bkg RMS) ~500-5000個　sep/SExtractor
=> RA, Dec, flux_iso, flux_auto, flag_overlap

cross match　astropy
=> カタログ天体に対応するsourceを紐付け

カタログ天体の　astropy photutils
(RA, Dec) で画像切り出し

detected_sources_TMQ001.hdf5

light_curve_gaia001.hdf5, ...

movie_gaia001.hdf5

grouping

- 同じセンサーにいた天体をグループ分け

PCA cotrending

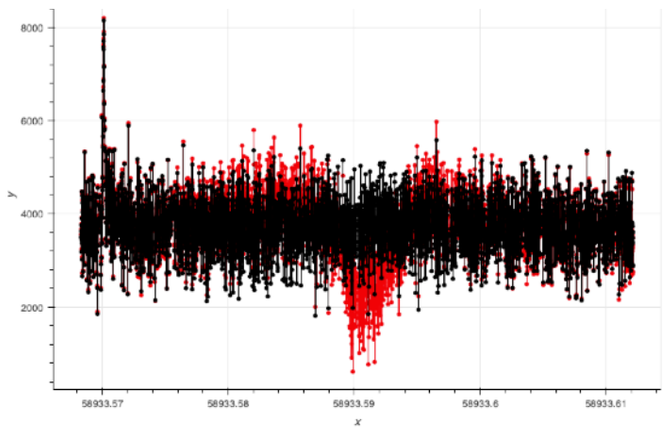
- 共通の変動成分を引き、ターゲット天体のlcをdetrend

プロダクトへ

PCA based cotrending

- PCA for lightcurves of references stars efficiently identify common trends
  - Same algorithm as Kepler pipeline (Smith+2012)
  - Variable and fixed aperture (5, 7, 10, 14pix) is used
    - fixed aperture looks better

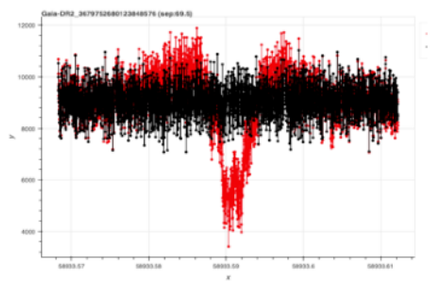
Target

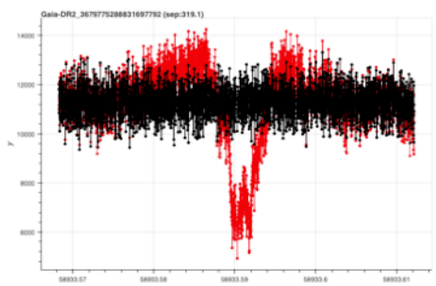


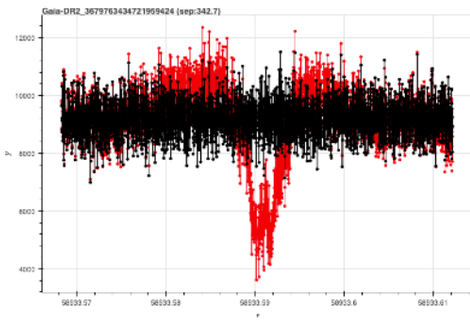
raw data

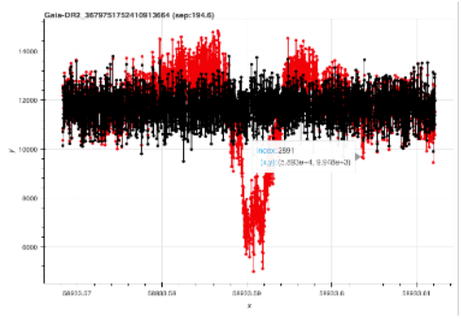
detrended

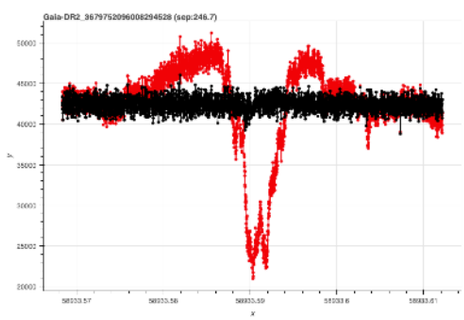
Reference

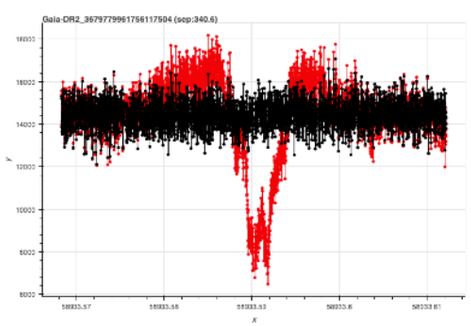




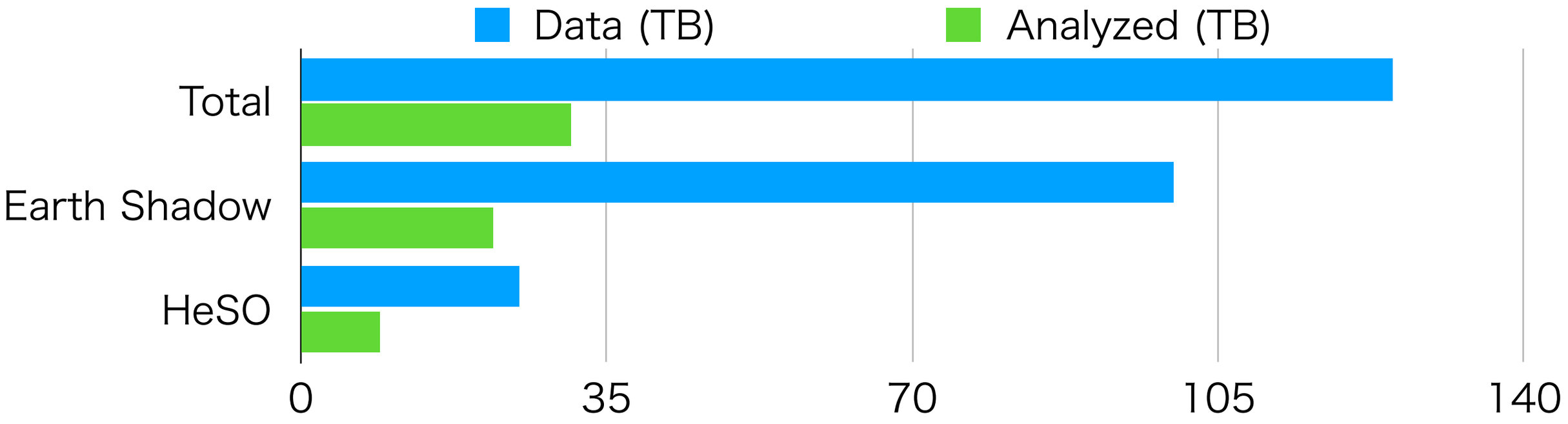








Current status of data and analyses



- In total, we have 125TB data

- Currently, we have analyzed ~30TB

- Assume 1hr=3TB (1Hz), this corresponds to 10 hrs data

- This year, we plan to take 50 fields×20mins (~50TB)

- Due to bad weather, we have completed only 4 fields since July..

More detail of analysis

- Computational time & resource

- 2 servers @本郷 (16 & 80 cores) 1 server @木曽 (8 cores)

- Using 16 cores, we spend 4-5 hrs to analyze 1hr data,
  if we avoid Galactic center or globular cluster, etc

- Output

- Lightcurves and movies of all reference and target stars

- 3.0TB raw data is reduced to 100GB

- Saved in HDD for product data @本郷

- Targets & Reference stars

~10^8 reference stars based on Gaia DR2 catalog

~10^6 target stars MD&WD brighter than 17 mag

- We can add target stars easily

1. What is HeSO? Pipeline & Current Status

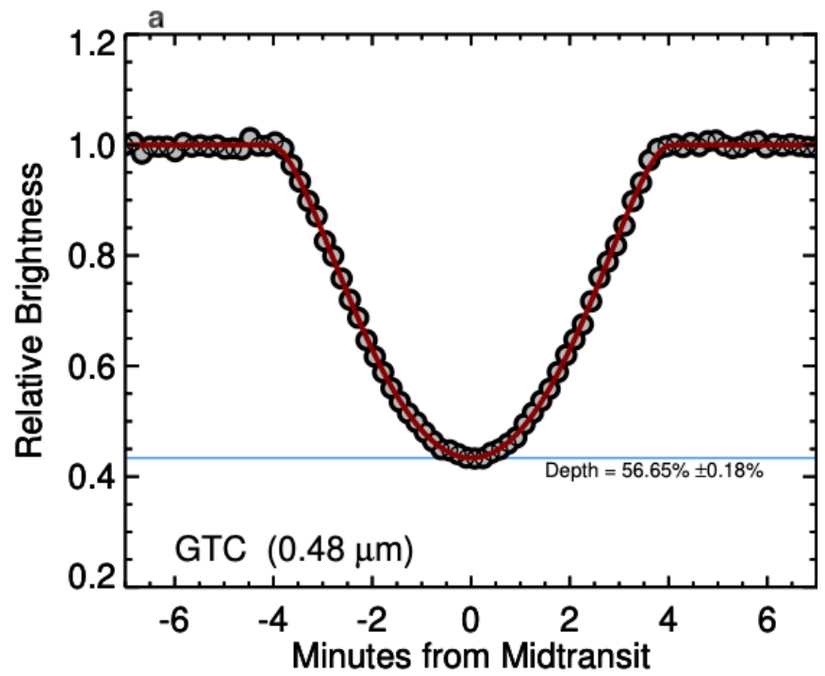
2. Science Cases & Results

Science Case I: Planet around WD

- TESS detection of planetary transit around WD

- 8 mins transit duration (2.8 days period)

- How do they form or survive after RGB?



Vanderburg+2020

- Tomo-e is power instrument to search for such short-duration transits

- 10-20 WDs are in Tomo-e FOV

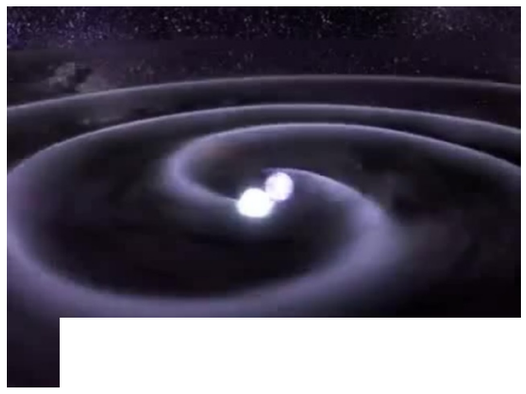
- we can search for such events in fixed-field observations

Science Case II: Rapidly rotating WD

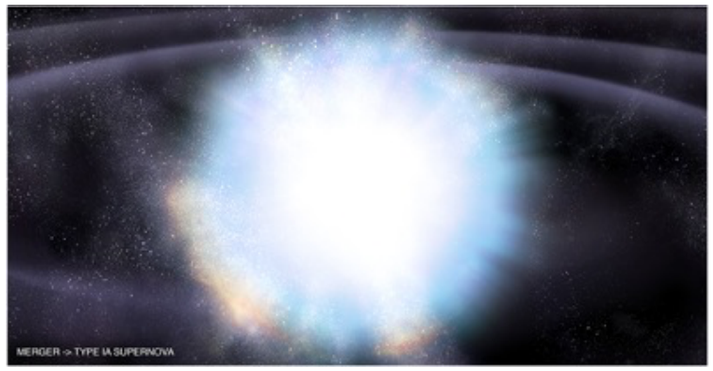
- Double WD merger can make high spin WD

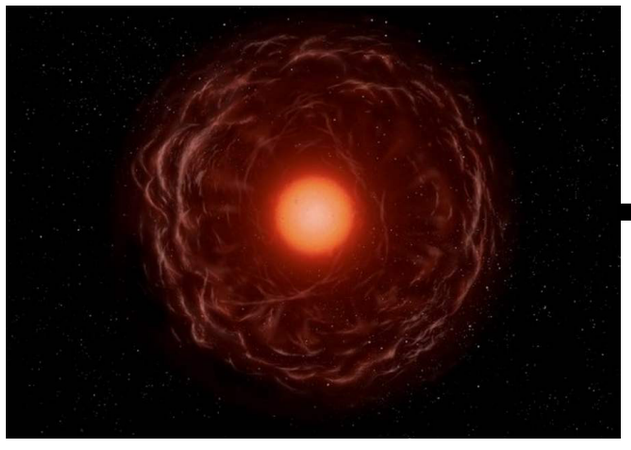
- They can rotate even at “1-10” secs

Double WD merger



Ia SNe?





Debris expansion
(R Coronae Borealis variables?)

樫山氏スライド改変

Not found

Fast-spinning WD?
if @ mass shedding limit

- Double WD merger is one of possible channels for FRB, so search for their remnant is very interesting

Article | Published: 30 June 2021

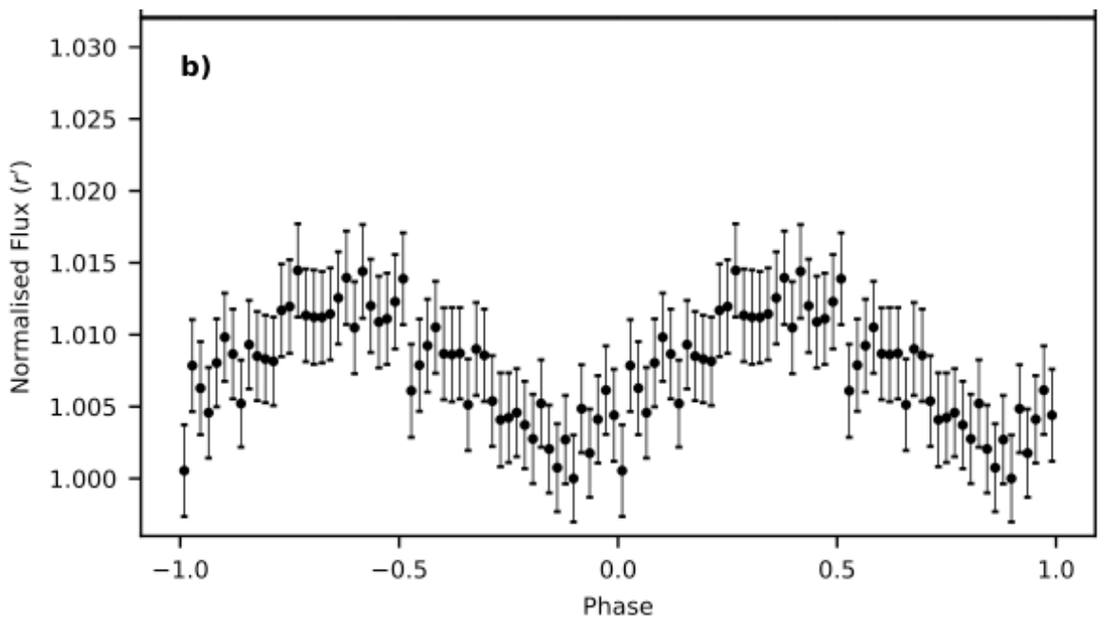
A highly magnetized and rapidly rotating white dwarf as small as the Moon

Ilaria Caiazzo ✉, Kevin B. Burdge, James Fuller, Jeremy Heyl, S. R. Kulkarni, Thomas A. Prince, Harvey B. Richer, Josiah Schwab, Igor Andreoni, Eric C. Bellm, Andrew Drake, Dmitry A. Duev, Matthew J. Graham, George Helou, Ashish A. Mahabal, Frank J. Masci, Roger Smith & Maayane T. Soumagnac

Nature **595**, 39–42 (2021) | Cite this article

- Detection of possible merger remnant WD by ZTF

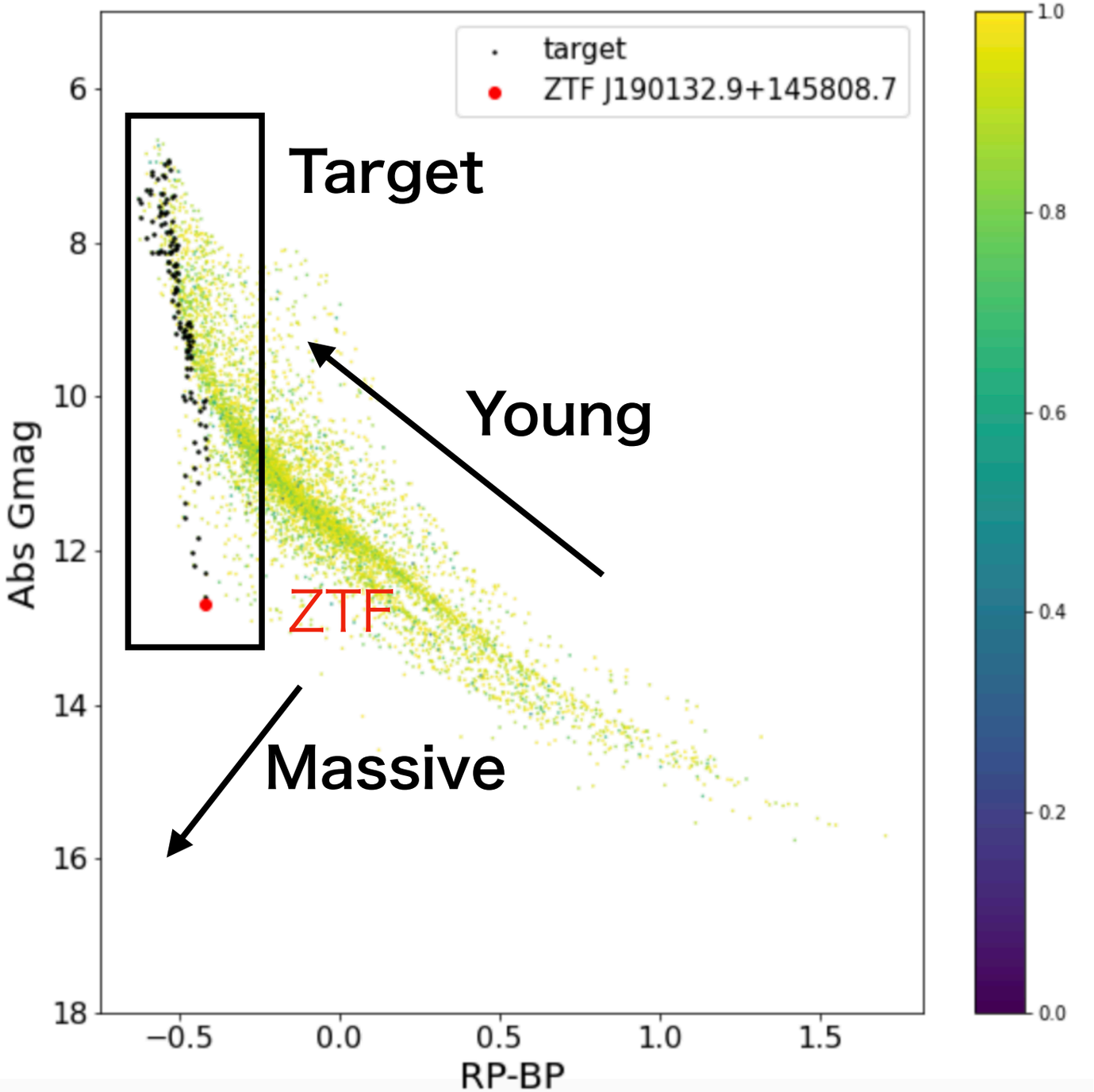
- M = 1.3Msun - P = 6.94 mins - Age = 10-100Myr



-> Interesting to unveil population of **faster rotators**

Search for rapidly rotating WD

WD brighter than 16 Gmag



- We select ~50 WD targets in black box

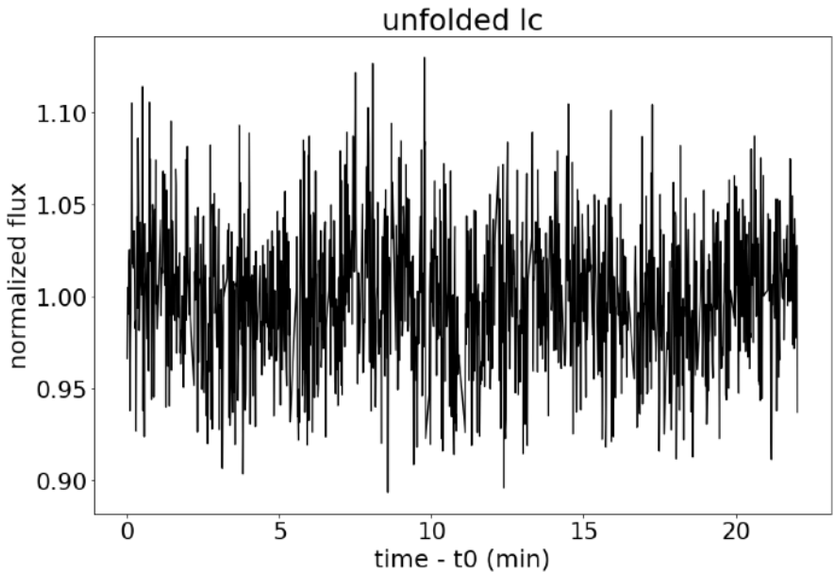
- Double degenerate WD should be massive
- Fast rotation WD should be young

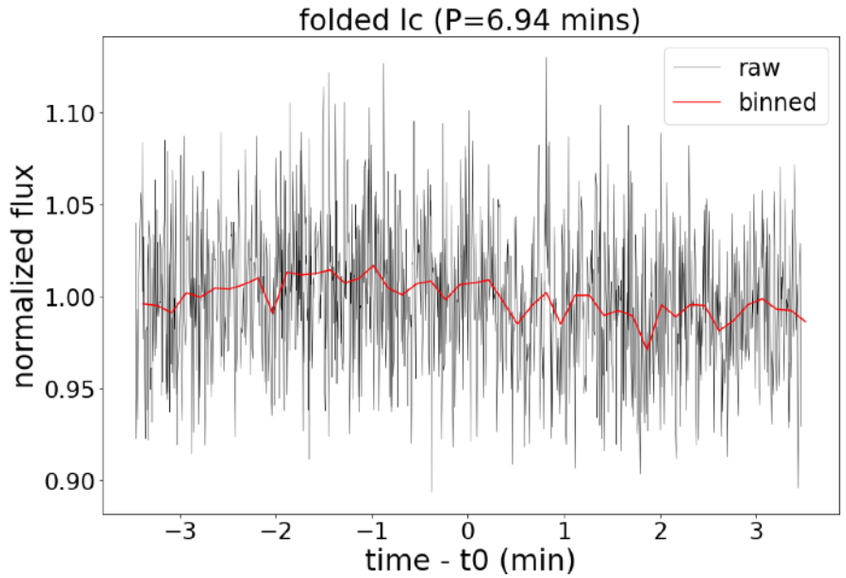
- We started campaign to study all of these stars

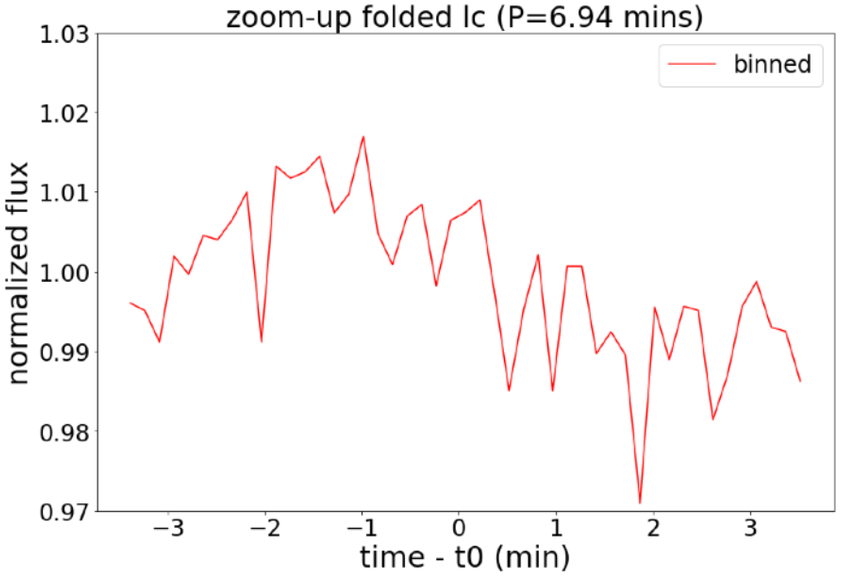
-50 targets (fields)×20mins

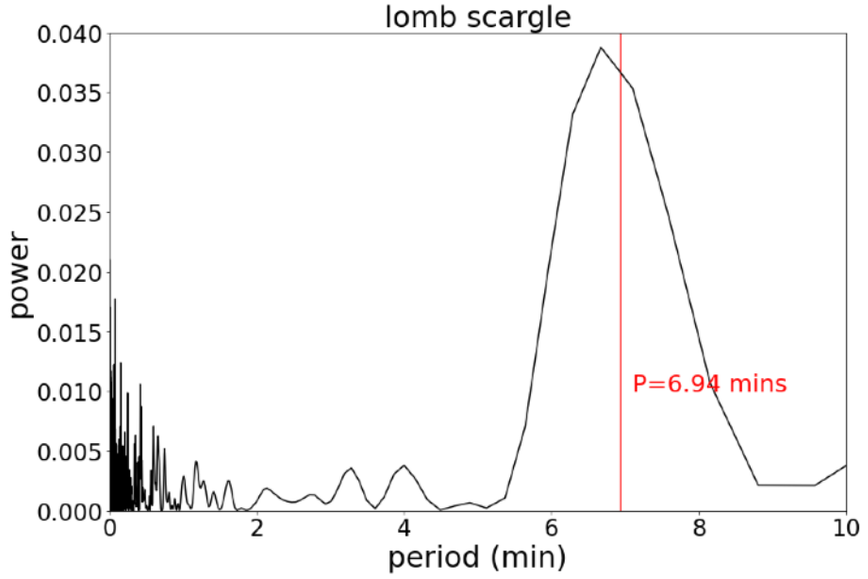
Follow-up of ZTF J1901+1458 by Tomo-e

- 20 mins observation on 2021/7/31





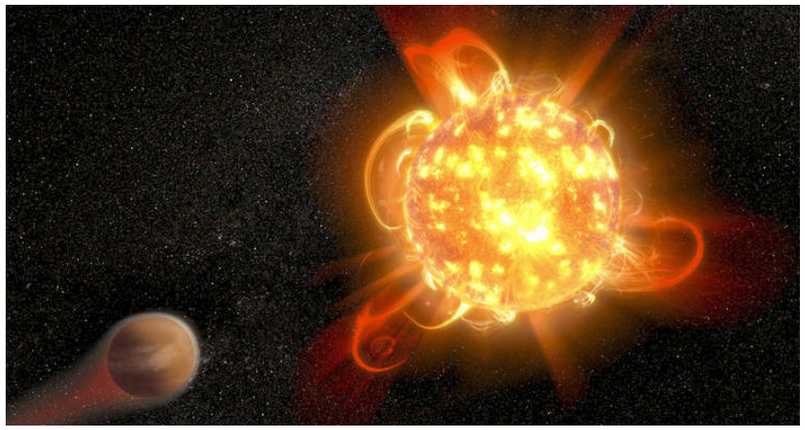




- Identify 1% variation from data
- We plan to continue to observe our targets
  - TriCCS is also good for follow-up of these targets

Science Case III: Very fast flaring from M dwarfs

- Stellar activities/flares are important for considering habitability around M dwarfs



- Very fast & luminous flares from Proxima Cen

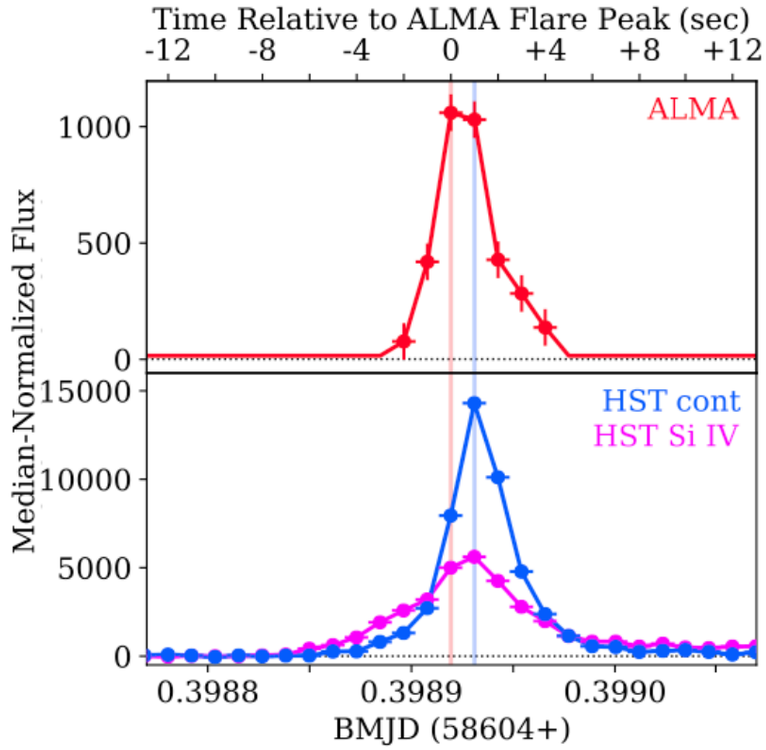
- 40hrs monitoring by HST, ALMA, TESS

- Few sec brighting by **10^4 (FUV)**

- 0.9% brighting in TESS (2 mins)

- Origin is mysterious.

  Similar to X-ray outburst in Sun (10-20s)



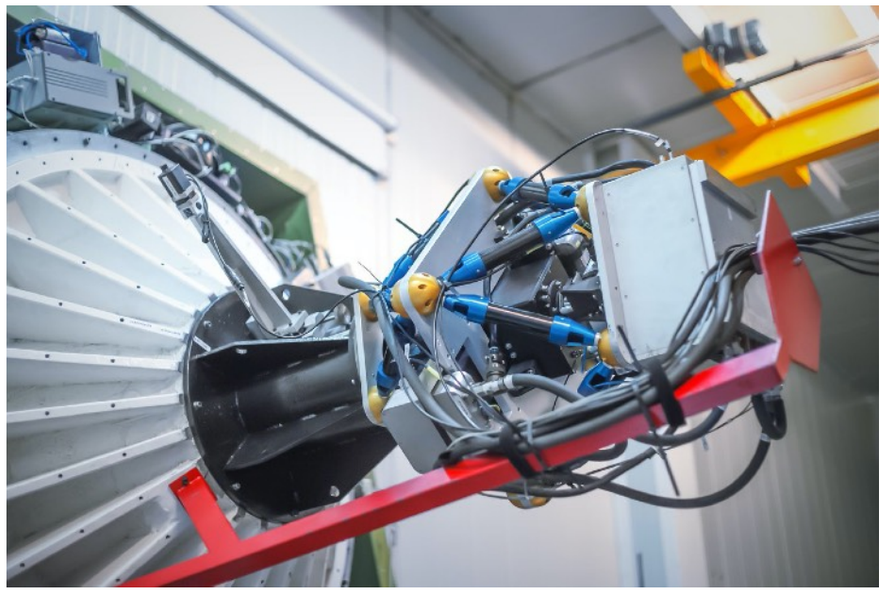
(MacGregor+2021)

Comparison of different instruments

	Δt	Aperture size	FOV
TESS	2-30mins	0.1m	2400deg^2
DES	30-50s	4m	3deg^2
Kepler	1-30mins	0.95m	115 deg^2
ZTF	30s-	1.2m	47 deg^2
NGTS	**11s**	0.2m	96 deg^2
Ultracam/VLT	**1s-**	4.2/8.2m	5arcmin^2
Tomo-e	**1s**	1.05m	**20.8 deg^2**

-> Tomo-e can search for such short-duration flares

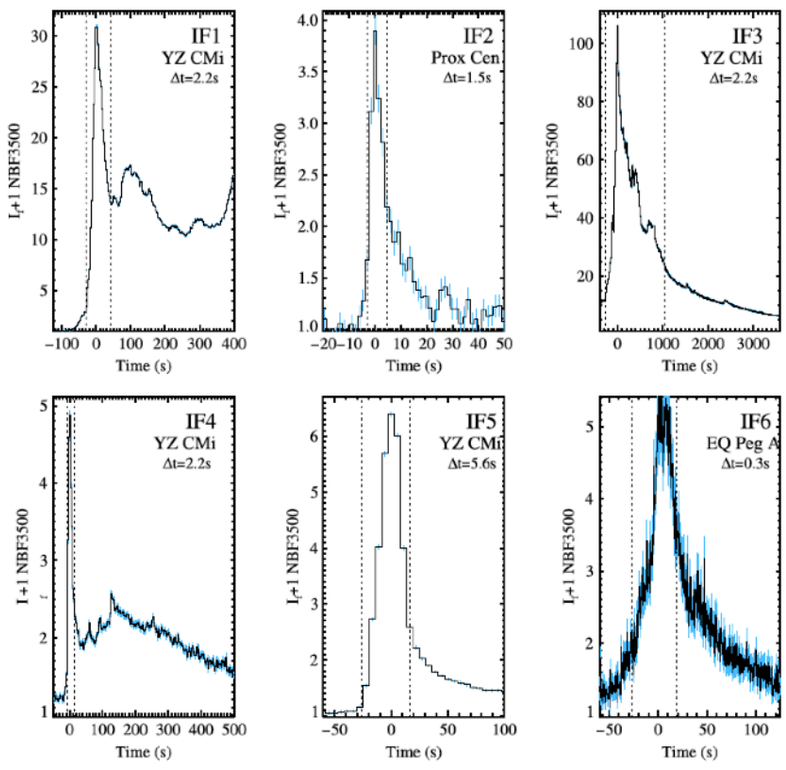
Ultracam

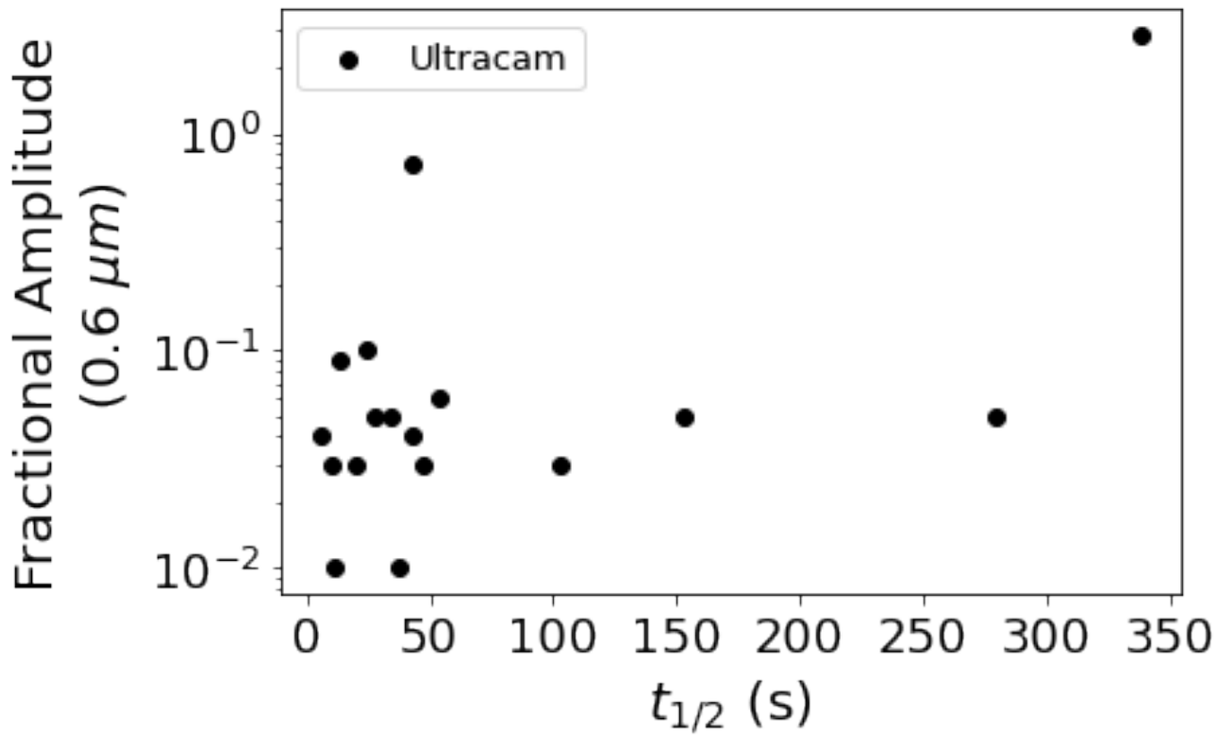


- Search for M dwarf flares at 1s
for 5 targets (e.g. Prox Cen, YZ CMi)

Kowalski+2016

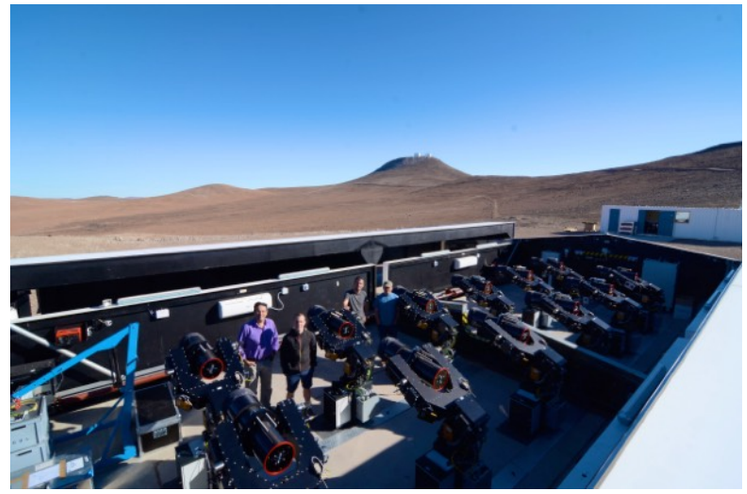
- Narrow band (0.35, 0.417, 0.601 um)
- Detection of >20 flares
- ~40 hrs in total





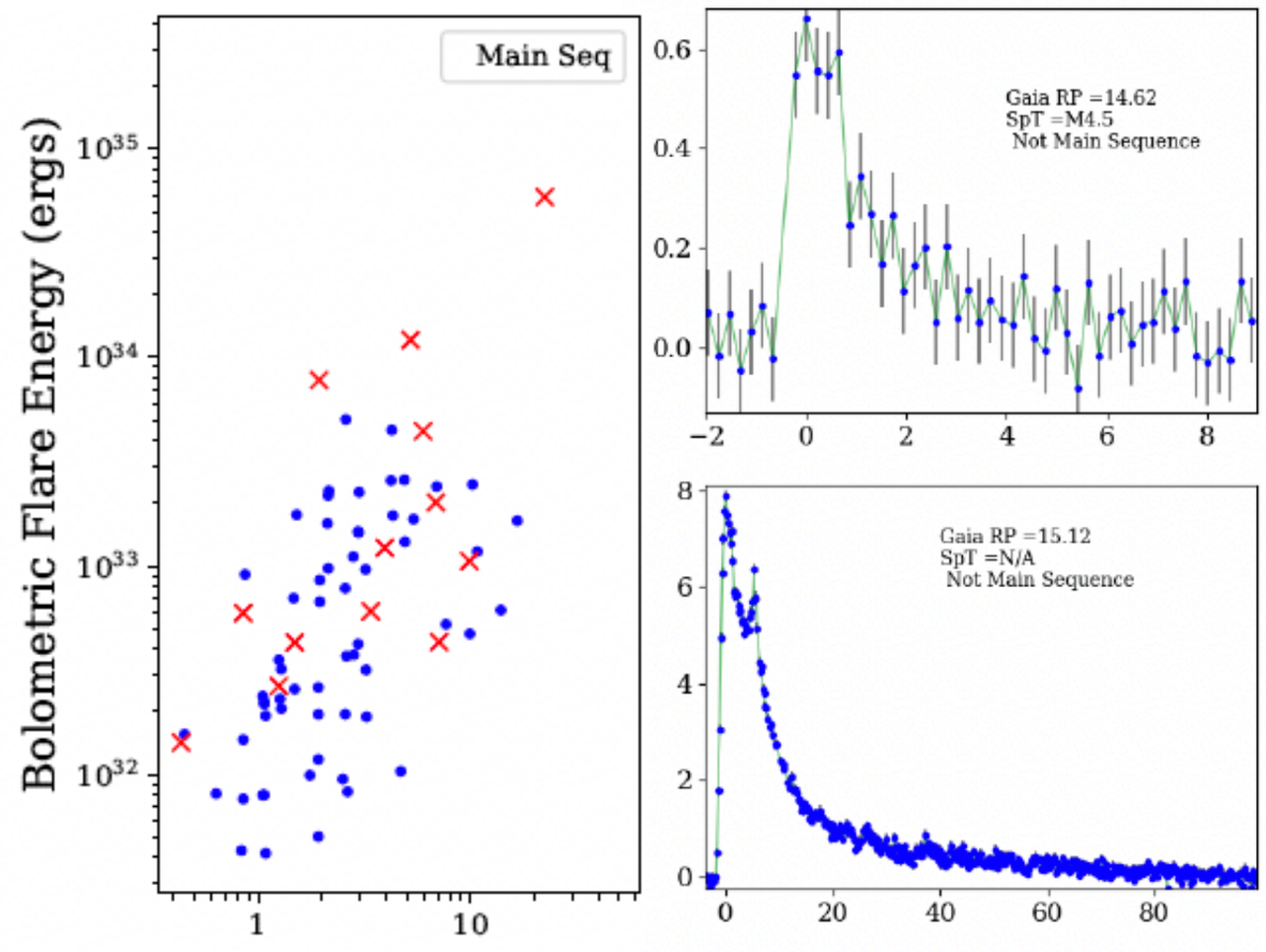
NGTS (next generation transit survey)

- 20cm aperture, 96deg^2
- 11sec (integration)



- Flare search (Jackman+2021)

- +200 nights
  - 626 M3-5V stars in total
    - <u>91flares</u>

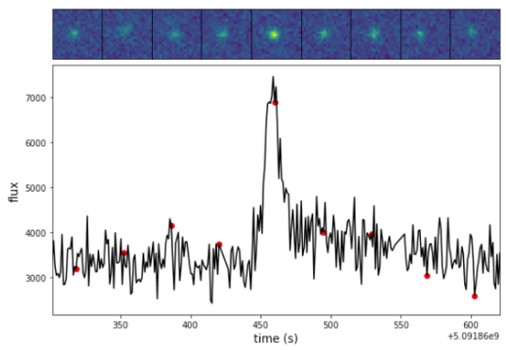


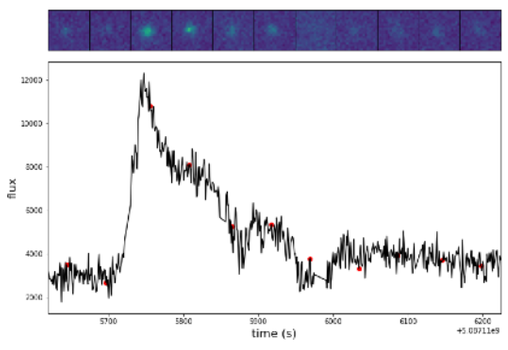
$t_{1/2}$ (min)
(Duration for half maximum)

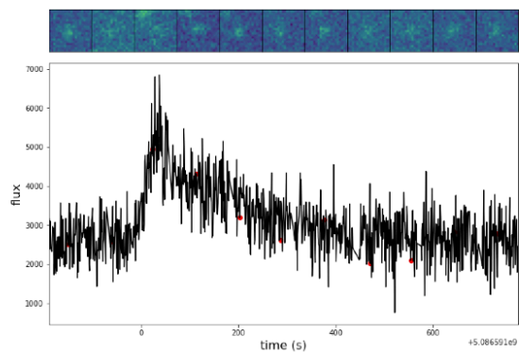
Current summary of our search

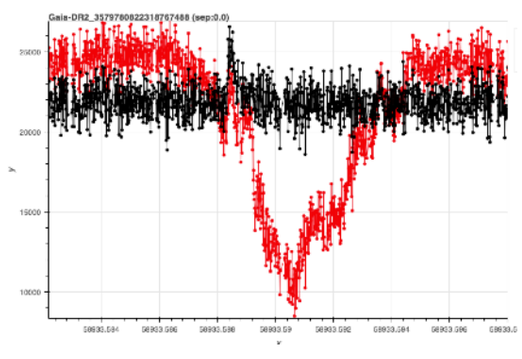
- We have analyzed 30 TB data (10 hrs data) so far
    - We made lightcurves & visually inspect individual data
        (CNN technique is also tested with 吉田研 in UTAP)
    - 200-300 M dwarfs/region × 10hrs = **~6 MD years**

- We identified 3-4 significant flares among data



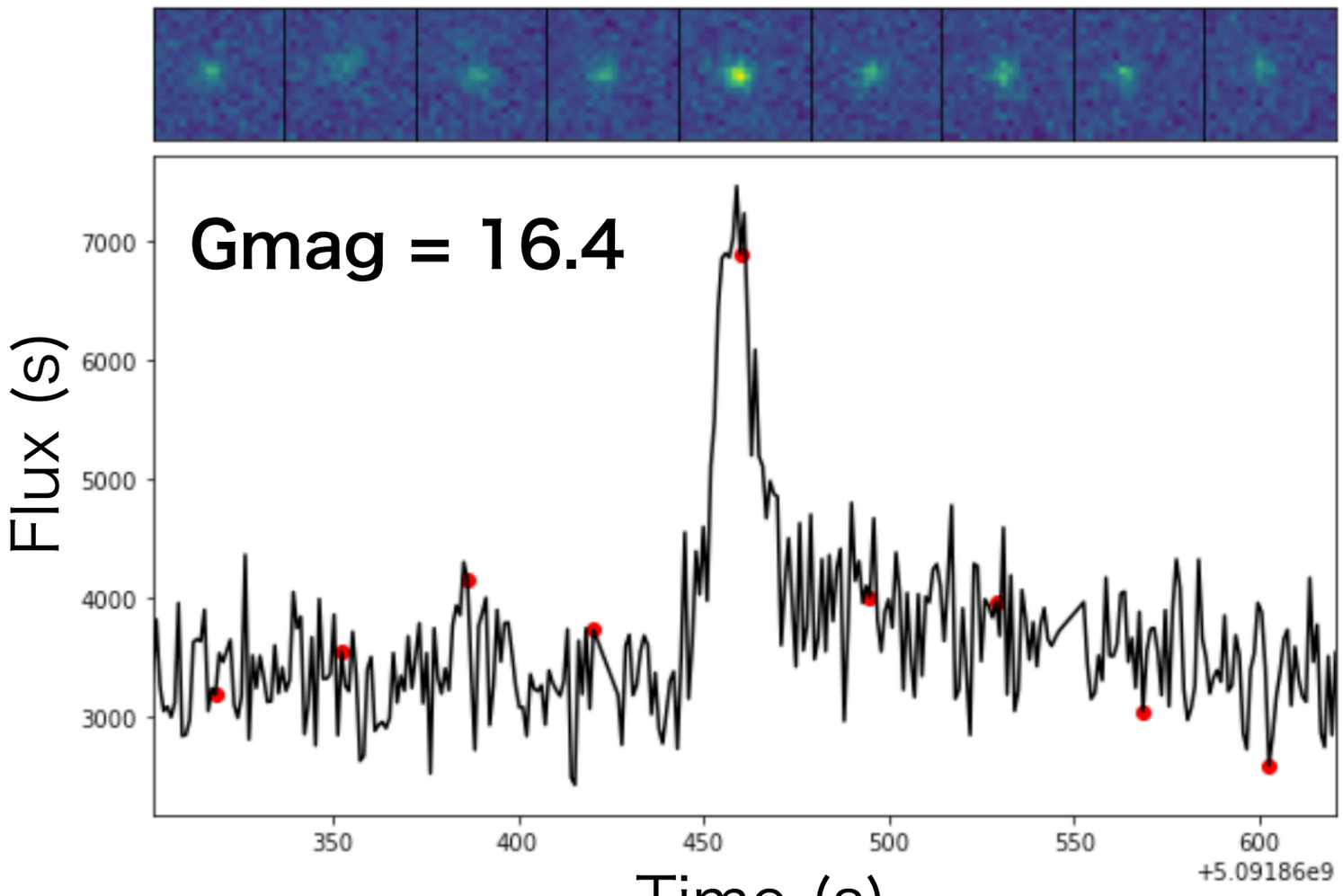


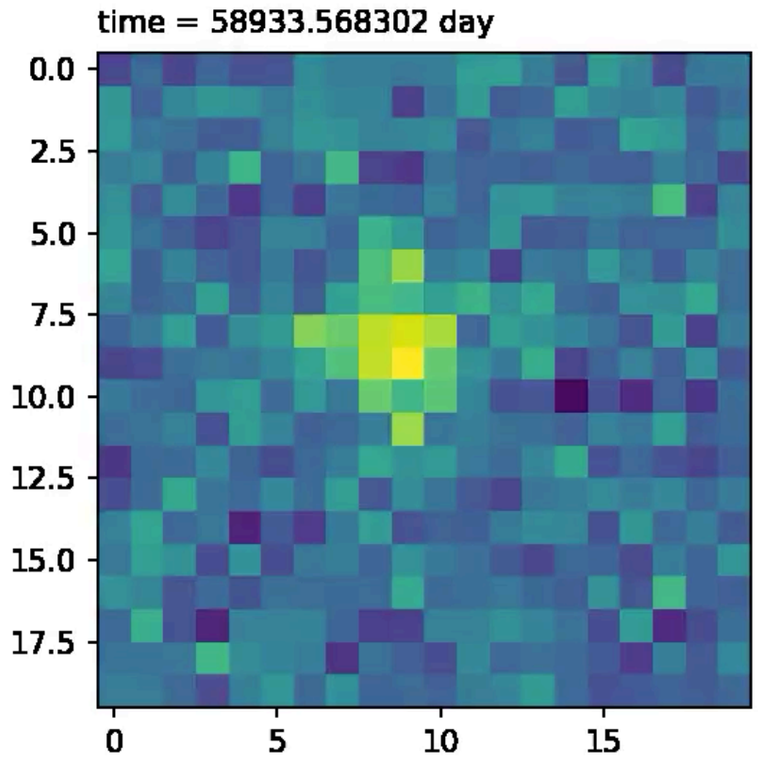




- This study: 3-4 flares for 200 deg^2 hr
    (c.f. NGTS: 81 flares for 20000 deg^2 hr)

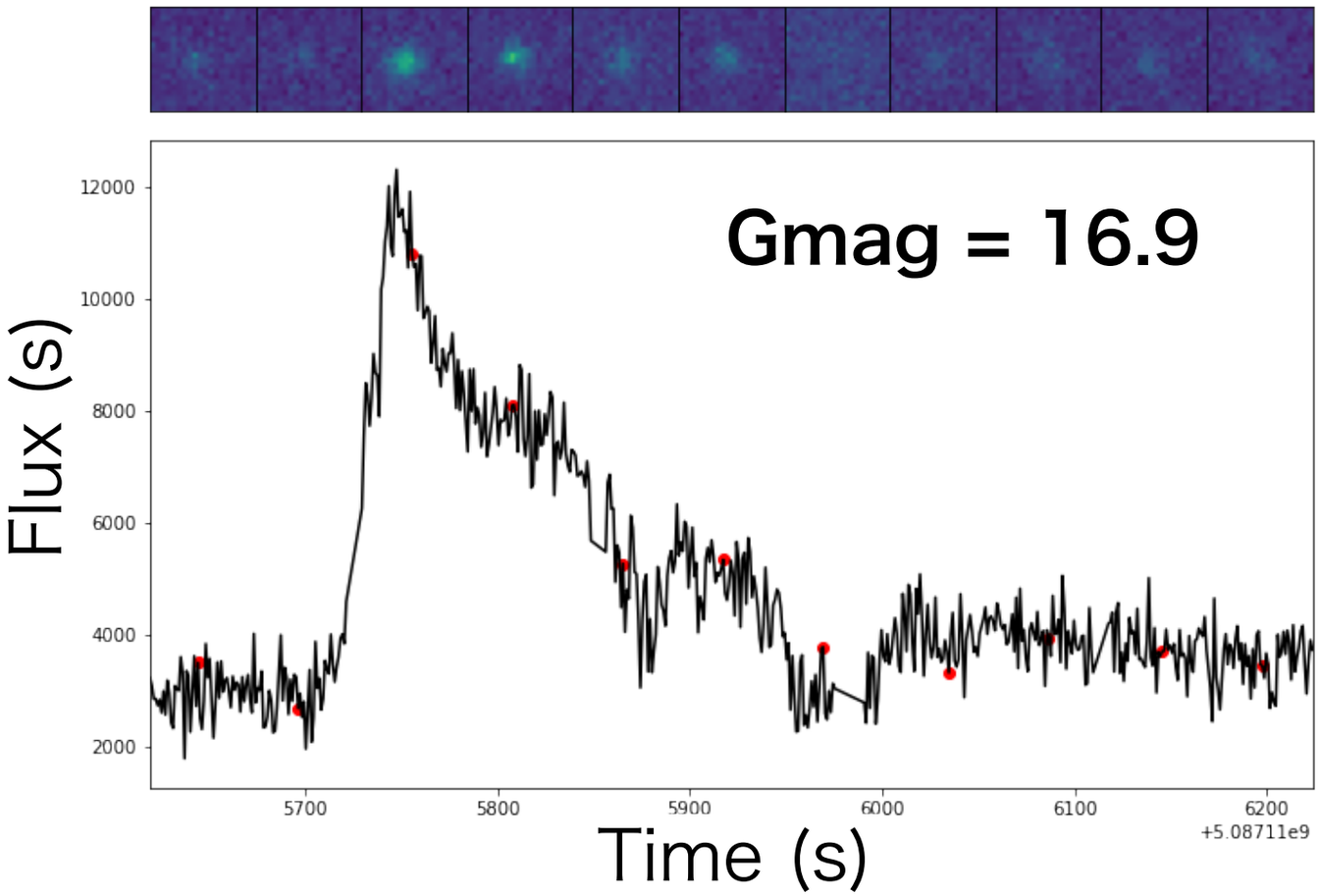
Short-duration flare (10s) from M5V star (0.16Msun)

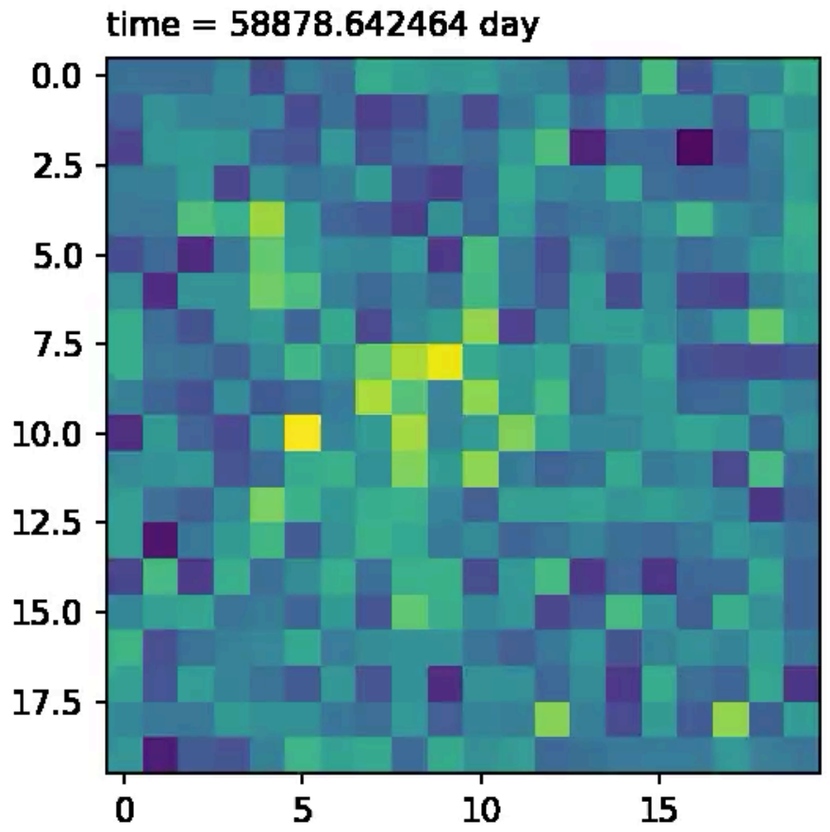




- 100% brighting at maximum
- Rise (10s) -> Half Width at Half Maximum (3s)
    - Corresponding to event at Proxima Cen?

Large flare from M3V star (0.38Msun)

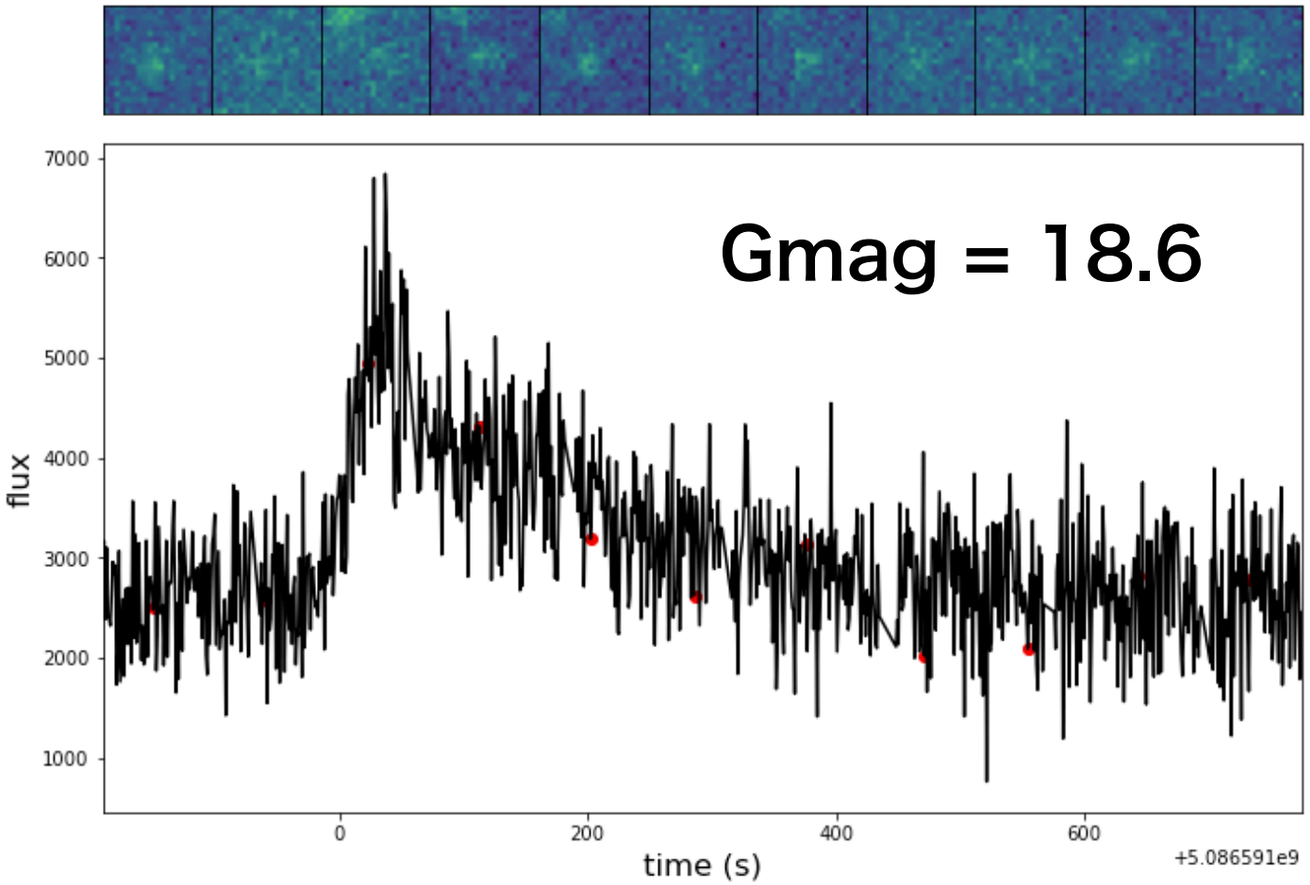


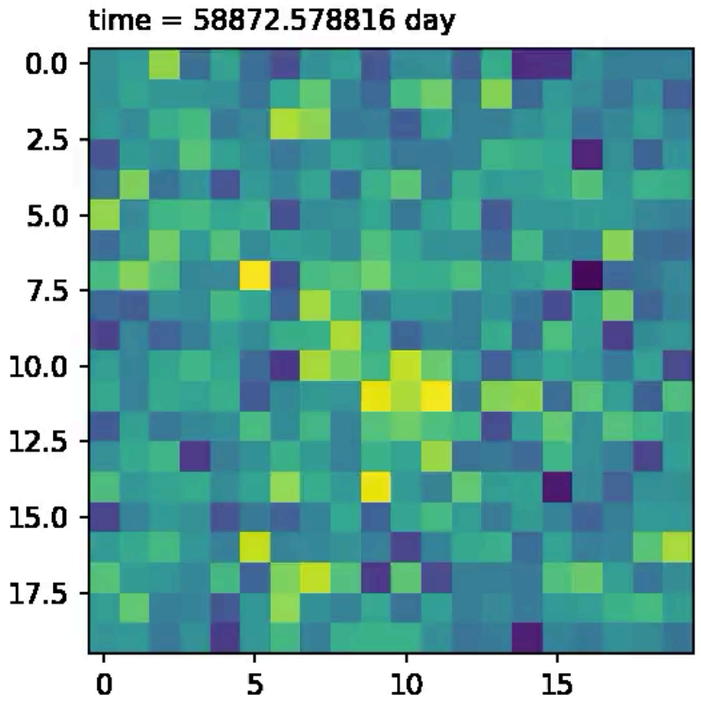


- 300% brighting at maximum
- Rise (25s) -> HWHM (100s)

Giant flare from M5V star (0.18Msun)

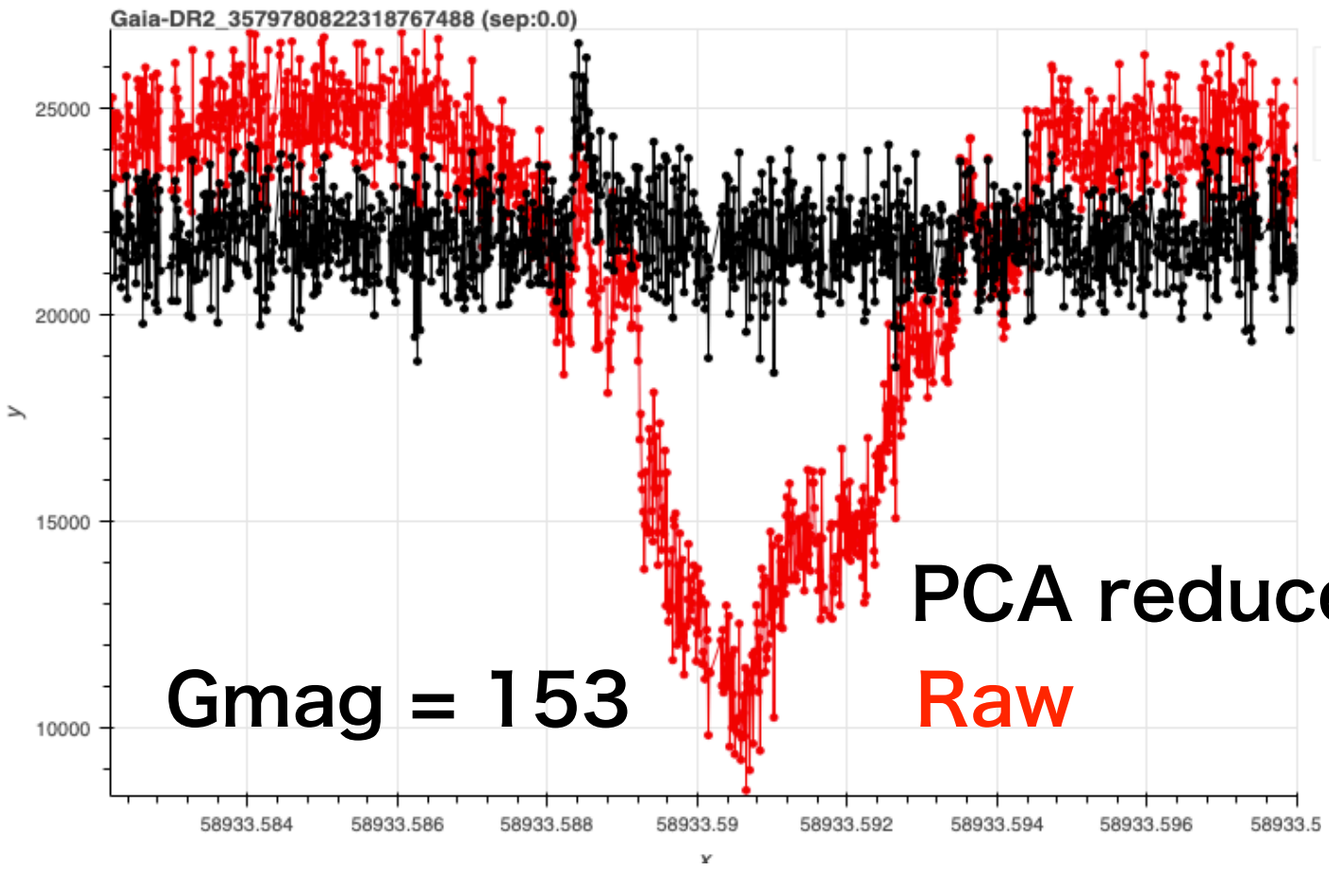
- **Flaring from Faint MD (Gmag:18.6)** near to target (Gmag:16.2)

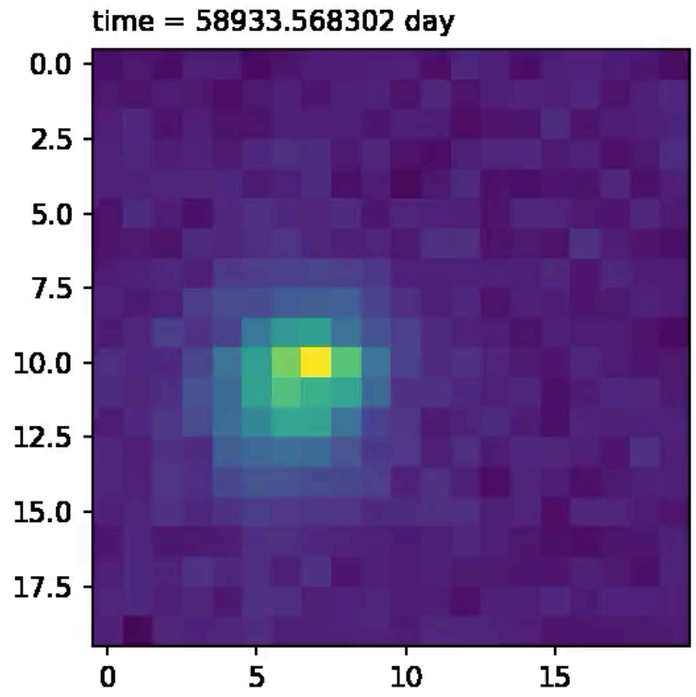




- 5000% brighting at maximum
- Rise (40s) -> HWHM (60s)
  - Good to included faint stars?

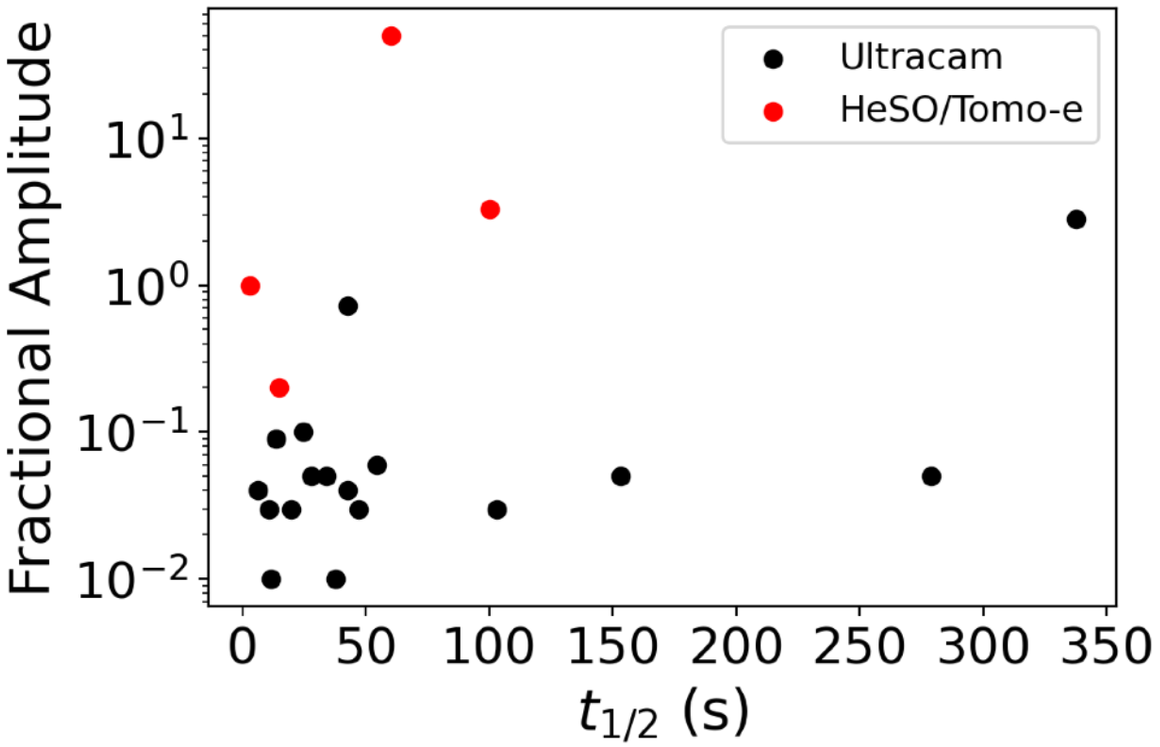
Giant flare from M4V star (0.24Msun)

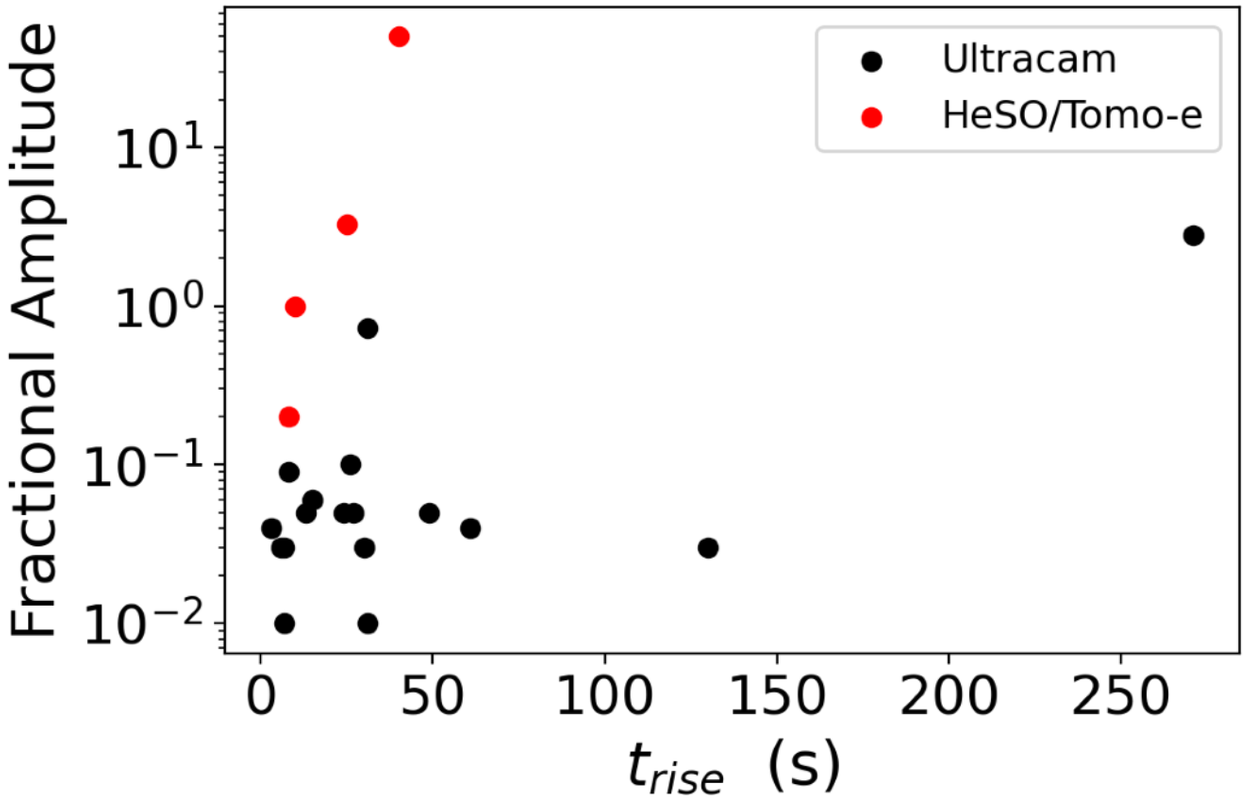


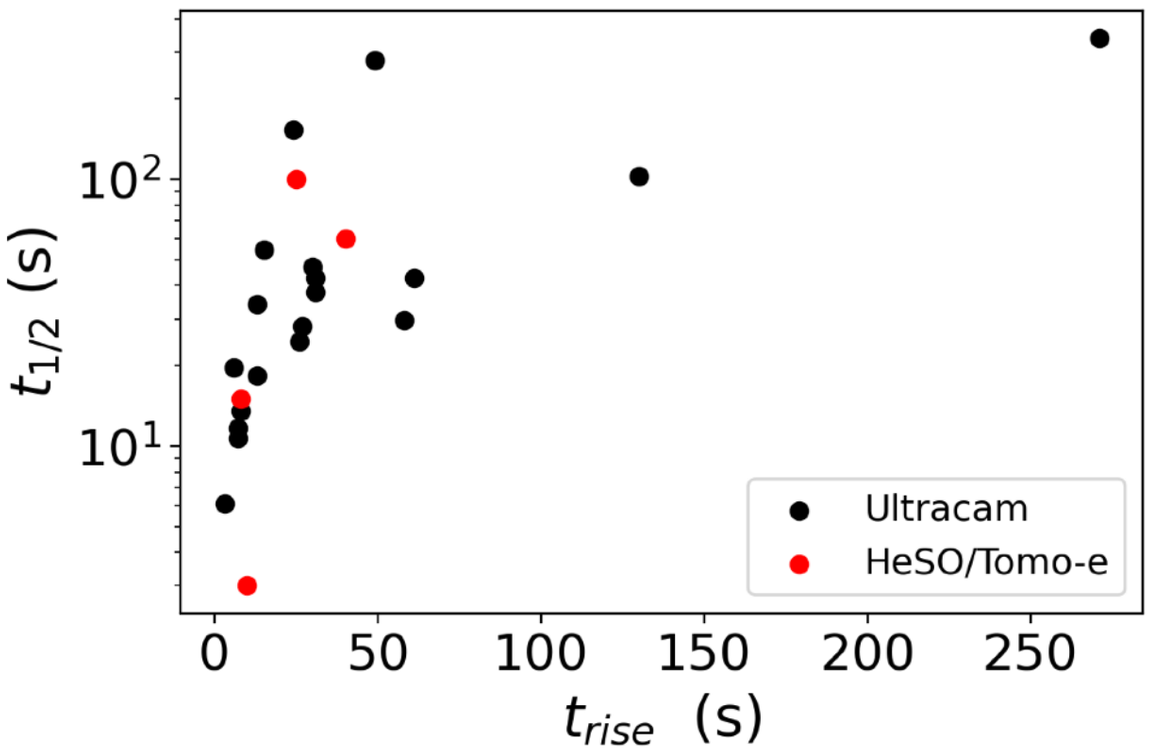


- 20% brighting at maximum
- Rise (20s) -> HWHM (15s)
    - Although systematic is significant, brighting is uniquely shown for this target

Comparison with Ultracam







- Tomo-e really detected very fast giant flares!!!

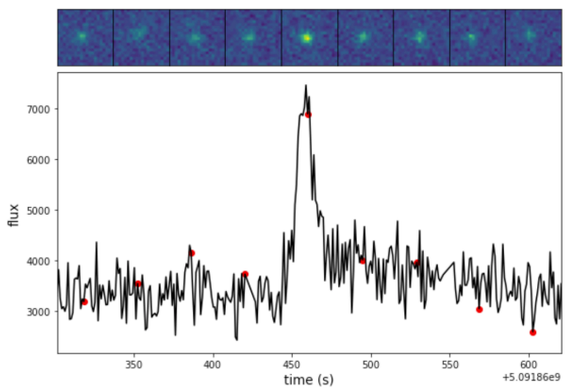
Summary

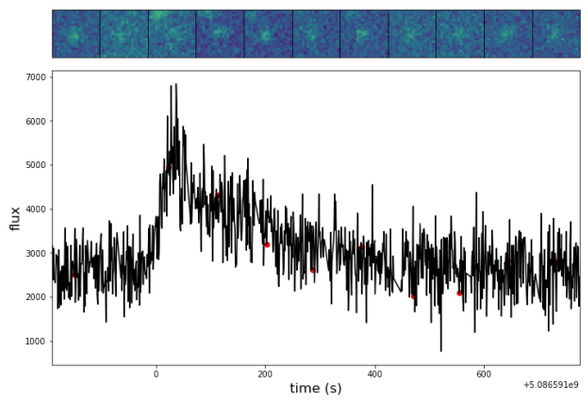
- We develop pipelines for making lightcurves from movie data

- We can add targets to HeSO catalog in any time.
  if you are interested, please contact anyone in HeSO team

- We confirmed/discovered sub-min variabilities

- We have identified unique flares from M dwarfs





- We also confirmed variability from ZTF J1901+1458

  -> We plan to take more data this year