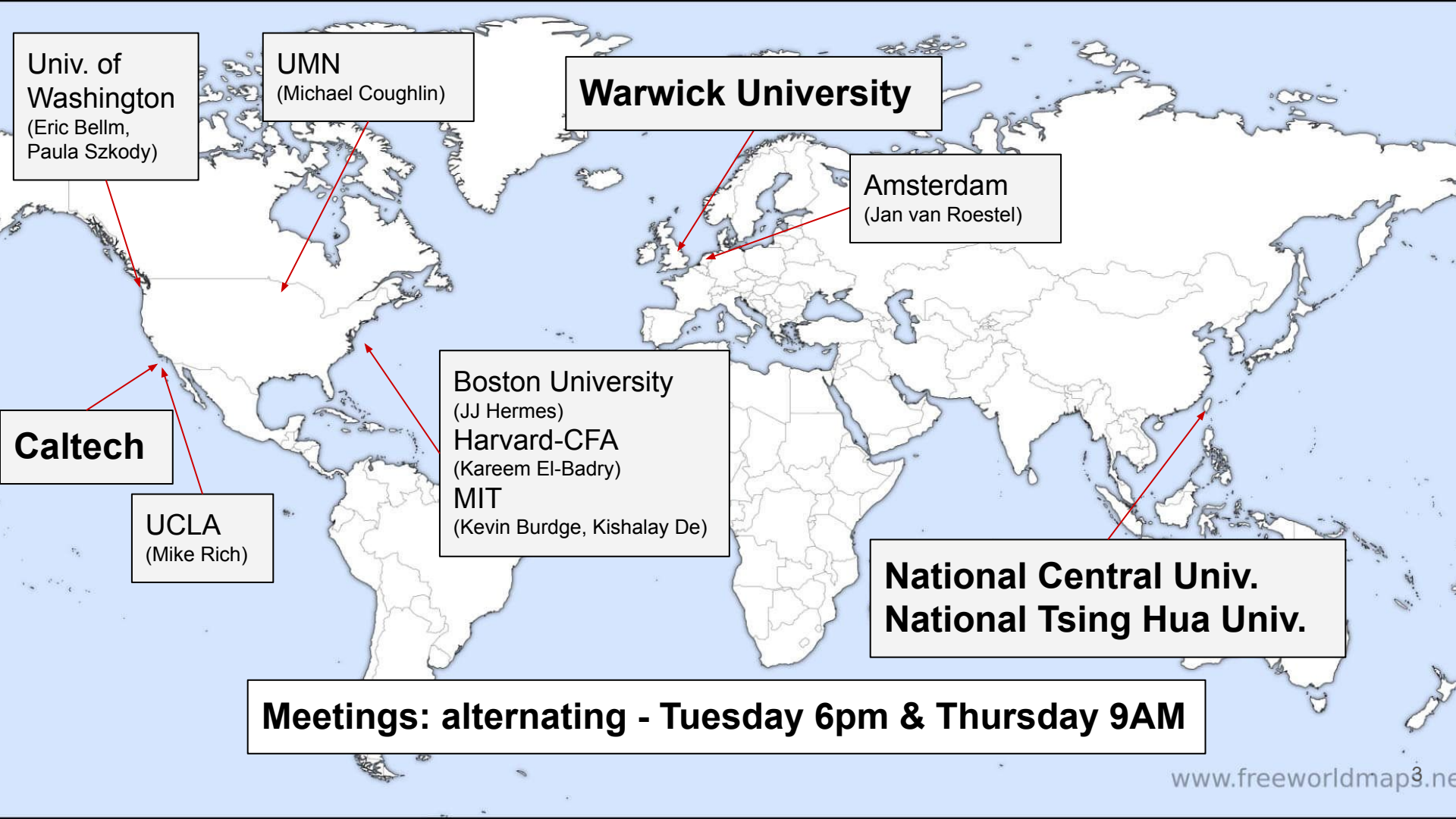
ZTF Galactic Science working group update

ZTF team meeting, May 2023, DESY

Zach Vanderbosch
On behalf of the WG

The ZTF Galactic Science Team

Paula Szkody (**co-Lead**)
Zach Vanderbosch (**co-lead**)
Eric Bellm
Kevin Burdge
Ilaria Caiazzo
Judy Cohen
Michael Coughlin
Kishalay De
Andrew Drake
Kareem El-Badry (Fall 2023)
Boris Gaensicke
Matthew Graham
J.J. Hermes
Lynne Hillenbrand
Keith Inight
Rocio Kiman
Albert Kong
Shri Kulkarni
Ashish Mahabal
Pranav Nagarajan
Chow-Choong Ngeow
Tom Prince
Mike Rich
Tony Rodriguez
Jan van Roestel
Ben Roulston
David Wang
Natsuko Yamaguchi


Univ. of Washington
(Eric Bellm, Paula Szkody)
UMN
(Michael Coughlin)
Warwick University
Amsterdam
(Jan van Roestel)
Boston University
(JJ Hermes)
Harvard-CFA
(Kareem El-Badry)
MIT
(Kevin Burdge, Kishalay De)
Caltech
UCLA
(Mike Rich)
National Central Univ.
National Tsing Hua Univ.
Meetings: alternating - Tuesday 6pm & Thursday 9AM
www.freeworldmaps.net

Why and how do we use ZTF?

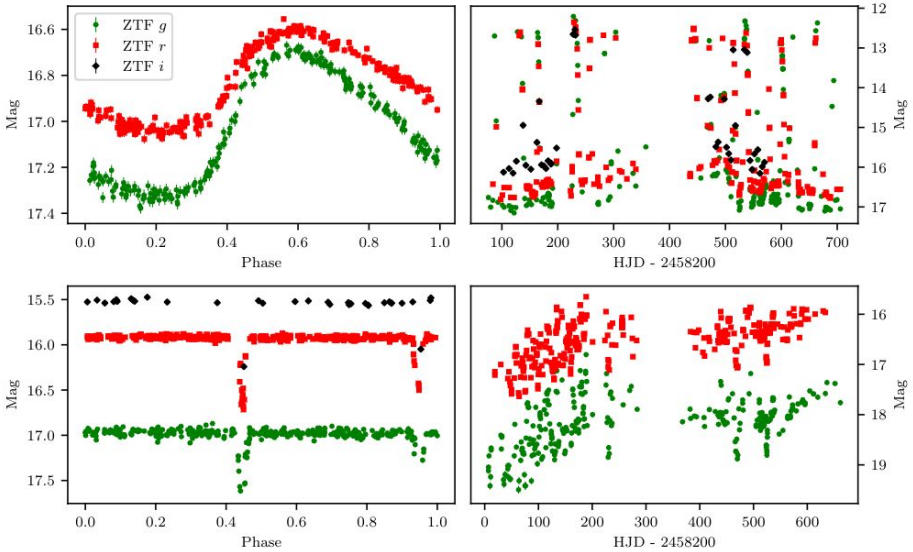
1. Stellar remnants
2. Binary star physics and evolution
3. Accretion processes
4. High energy astrophysics
5. Stellar structure
6. Extrasolar asteroids/comets
7. Age/luminosity/period relations

Single Object

and

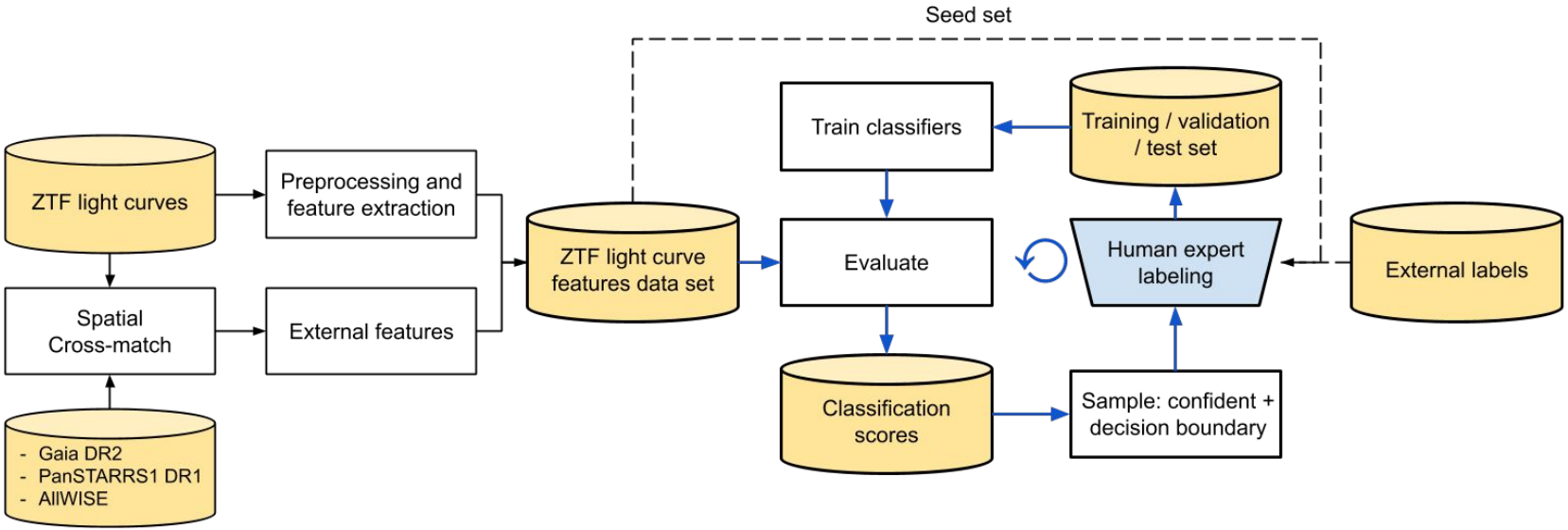
Population Studies

1. Mostly **archival photometry** searches for (periodic) variability
   a. Orbital periods
   b. Rotations periods
   c. Pulsations periods
   d. Irregular dips/transits/eclipses
2. **Real-time (alert)** searches for outbursting stars



Our big challenge:
identify objects of interest from the 2 Billion sources

- **External catalogues** (Gaia, PS1, SRG, Fermi, SDSS-V, etc)
- ZTF **alerts** (positive *and* negative)
- Period searches & other **ZTF variability metrics**
- ZTF-SCoPe - machine learning classification of persistent point sources



The Quarter Century Sky (QCS) Project

Matthew Graham, Tom Prince, George Djorgovski, Andrew Drake,
Shinn Taniya, Zach Vanderbosch, Ashish Mahabal, Kareem El-Badry

Developing a database of light curves for persistent sources covering a baseline of around 25 years

CRTS + PTF + ZTF (and potentially more)

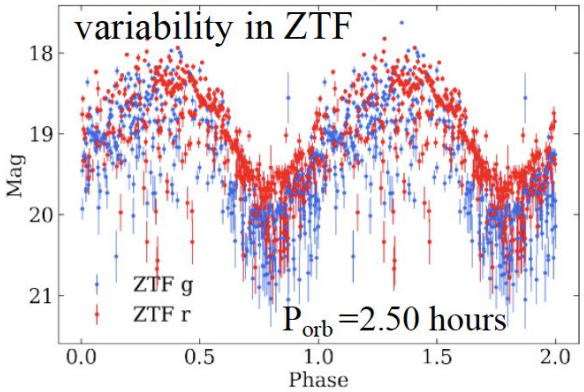
Source Catalog	Forced Photometry	Database, Frontend, API	Derived Data
Pan-STARRS1 or **Gaia** ~2 billion sources	**Difference Images** - Pipeline developed by Przemek Mroz, Kevin Burdge, Zach Vanderbosch **Science Images** - Pipeline developed by Andrew Drake	**Shinn Taniya** (Schmidt Scholar) Database prototyping and testing, pipeline comparisons, frontend and API development	**Light curve statistics,** similar to SCOPE **Period searches** **Cross matches** with sources in other catalogs

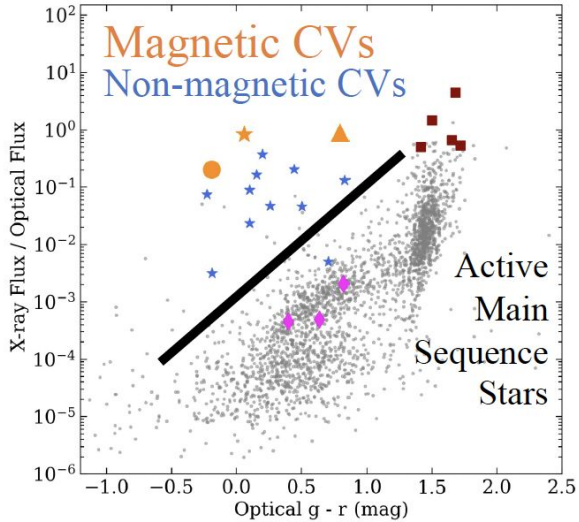
Science Snapshots from the ZTF Galactic Science Group

Discovery of Polars from SRG/eROSITA + ZTF

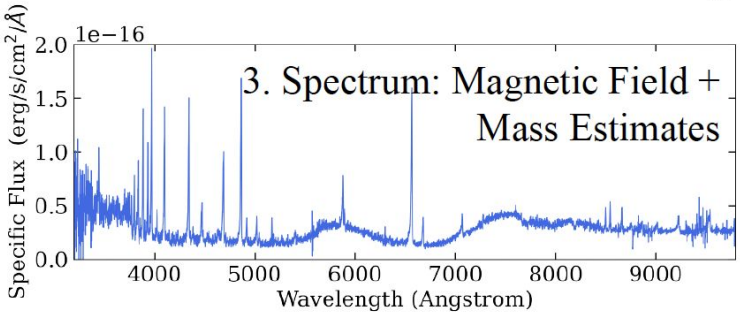
- ~120 polars known
- ~200—300 in eRASS1
- Questions to answer:
  - X-ray luminosity function
  - Mean mass of WD
  - Orbital period distribution

1. High amplitude periodic variability in ZTF





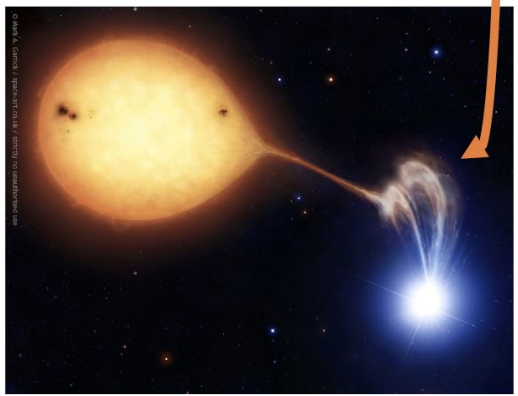
2. X-ray/Optical Flux Ratio Indicates Accretion



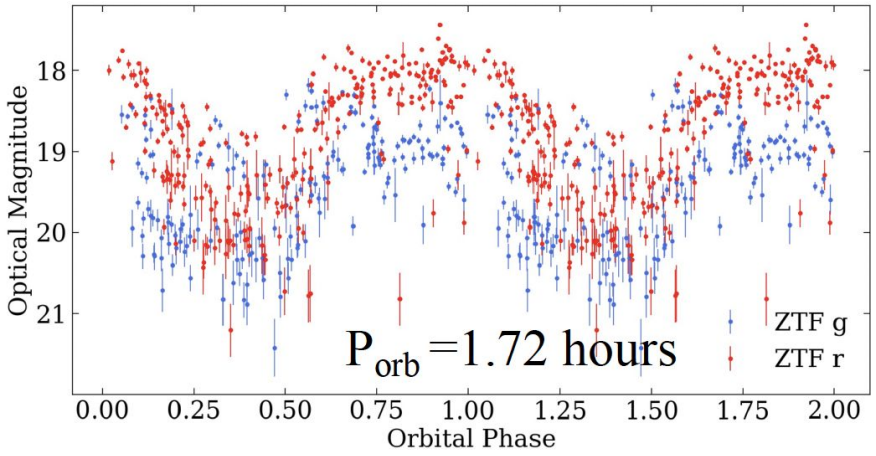
Tony Rodríguez (Caltech)

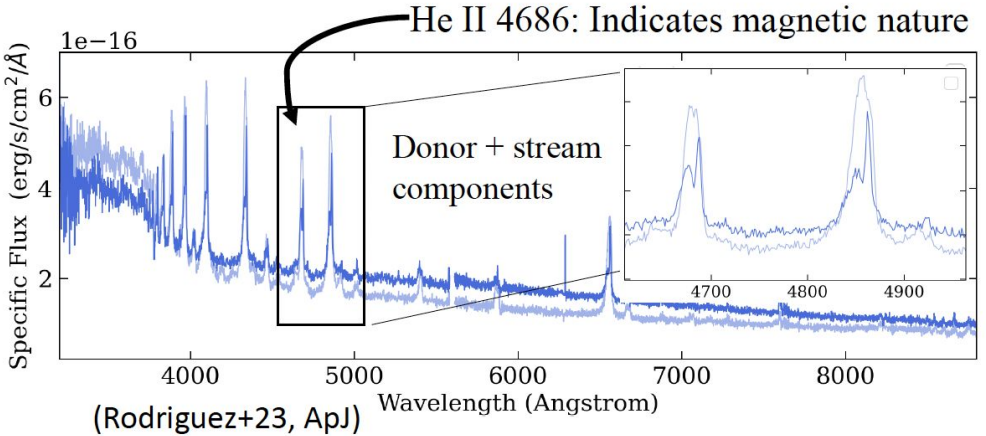
eFEDS/ZTFJ0850+0443

- One of 8 polars showing pre-eclipse absorption from accretion stream.
- M_{WD} = 0.81 ± 0.08 M_{sun}



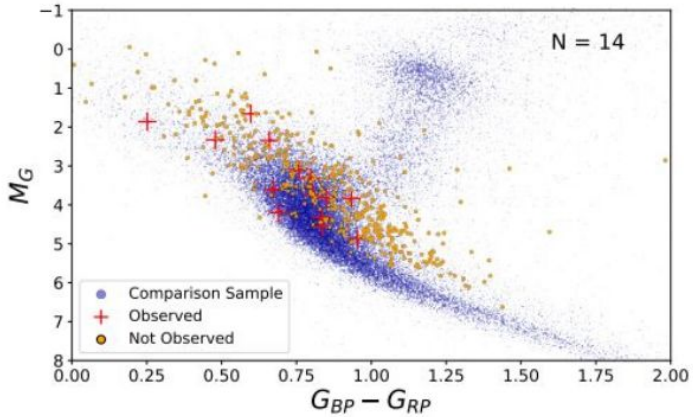
Artist rendition, used with permission of M. Garlick

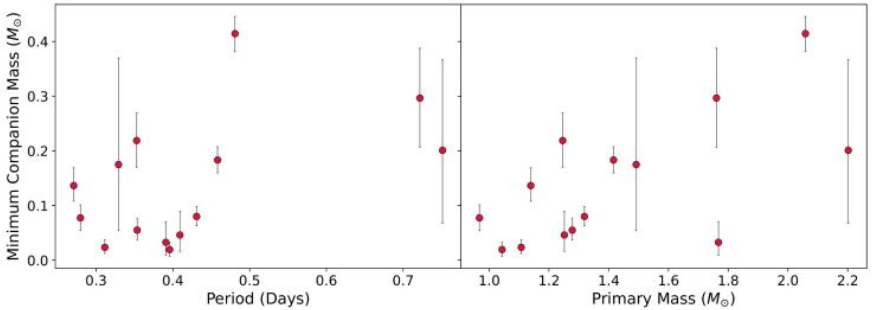




Spectroscopic Follow-up of NS and BH Candidates in Gaia DR3

Pranav Nagarajan,
Kareem El-Badry, et al.

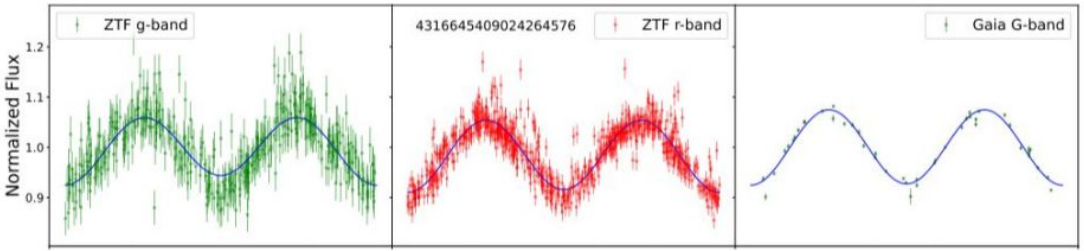


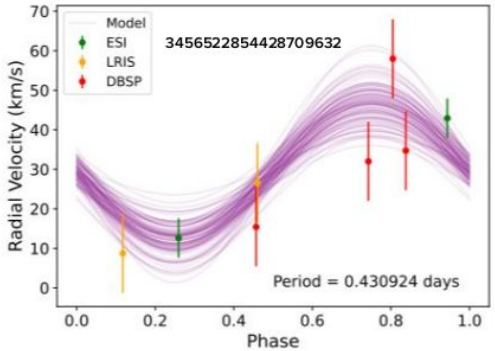


But observe small RV semi-amplitudes! Median inferred companion mass around 0.15 $M_\odot$. PHOEBE modeling suggests (spotted) contact binaries are primary contaminant.

Sample selection of promising targets from Gomel et al. (2022)

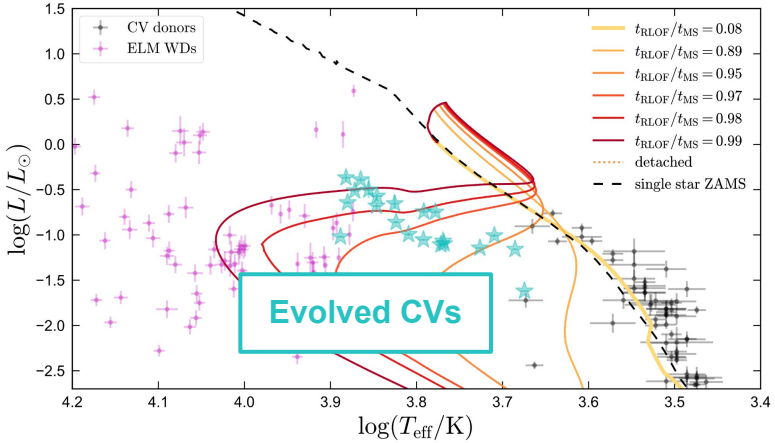
Prioritize based on large LC ellipsoidal variability amplitudes...



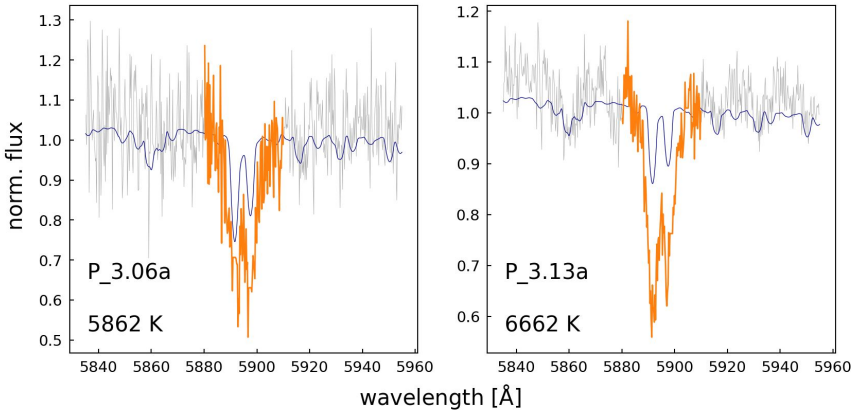


Sodium enhancement in Evolved Cataclysmic Variables

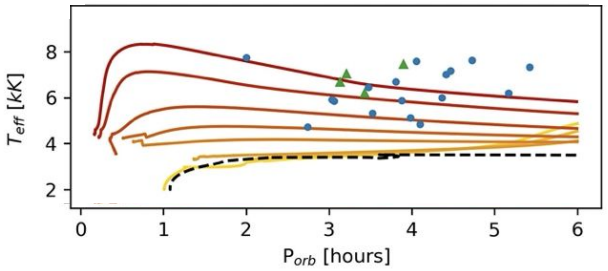
Natsuko Yamaguchi, Kareem El-Badry, Antonio C. Rodriguez, Maude Gull, Benjamin R. Roulston

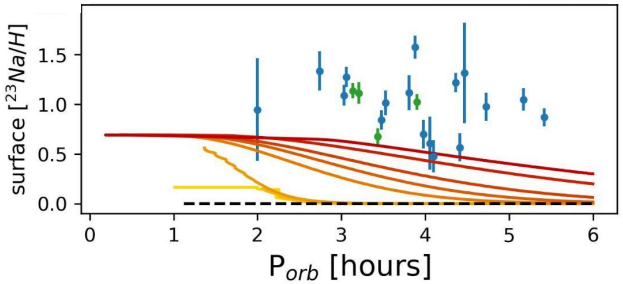


1) 21 evolved CVs found by the Birth of the ELMs survey, with the use of ZTF light curves.



2) Carried out follow-up high resolution spectroscopy and measured Na abundances using the 5900 AA doublet.
→ find significant enhancements:
[Na/H] = 0.3 - 1.5 dex, with a median of 0.956 dex



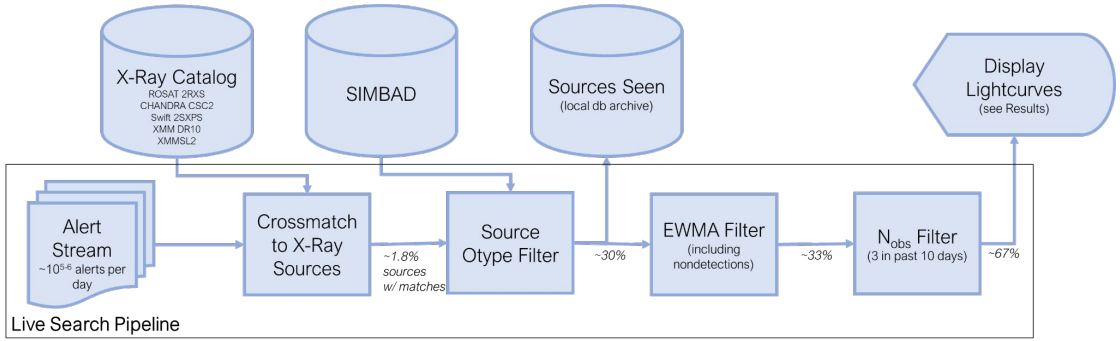


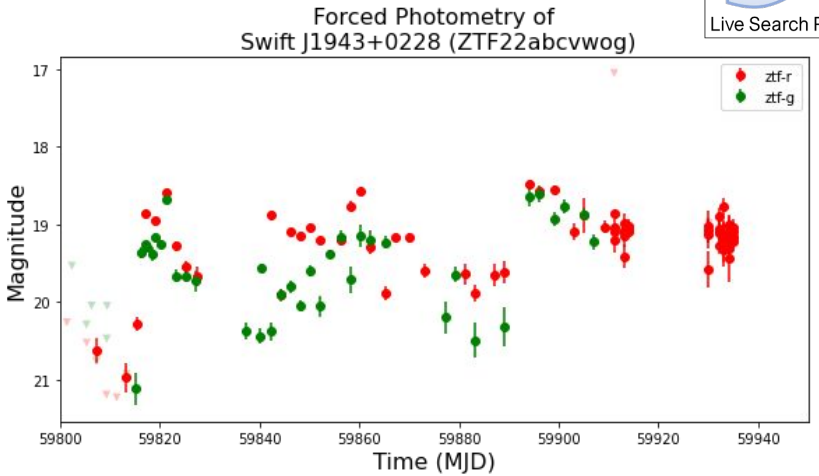
3) Ran MESA models of evolved CVs
→ **predict significant Na enhancement *not seen in normal CVs* but underpredict them** compared to observations

X-ray Binaries in the ZTF alert stream

David Wang, Eric Bellm, 2023 in prep

Goal: Find new XRBs by looking for optical outbursting in ZTF at positions of known X-ray sources. Pipeline →





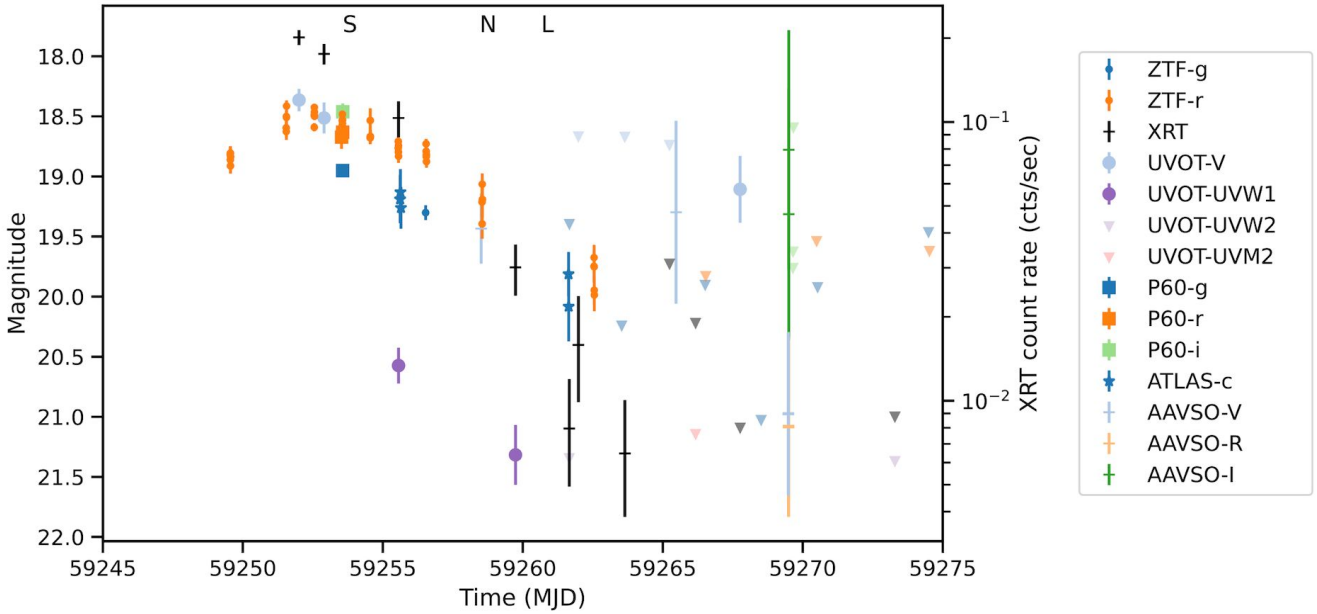
Faint detection of hard x-rays by Swift indicates this could be a hard-only failed outburst.

Optical surveys are a good pathway for finding these low luminosity outbursts, which may otherwise be too faint for all-sky x-ray monitors

Candidate XRB found in the pipeline, first outburst in 10 years

ZTF discovered a failed transition outburst from the black hole X-ray binary XTE J1859+226

Eric Bellm + friends (2023 in prep)



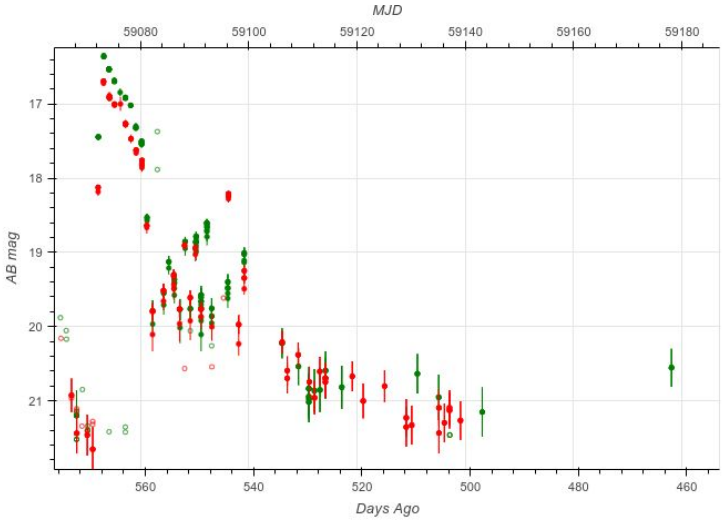
- Automated watchlist provided early warning of first outburst since 1999

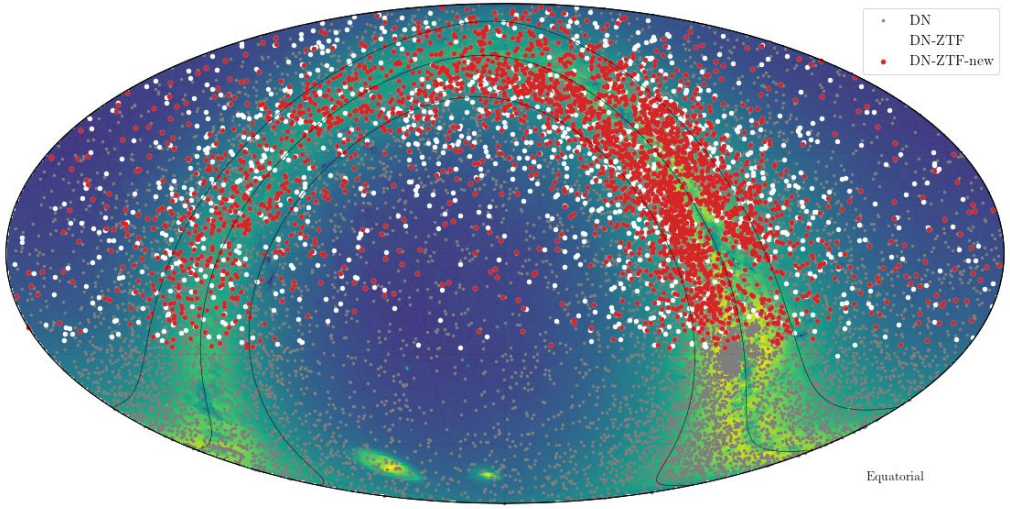
- X-ray luminosity was too low (~10^{35} erg/s) to trigger all-sky monitors and to irradiate the entire disk ⇒ short, fast-evolving outburst that stayed in the low/hard state

- OIR synoptic surveys provide a good way to search for these events!

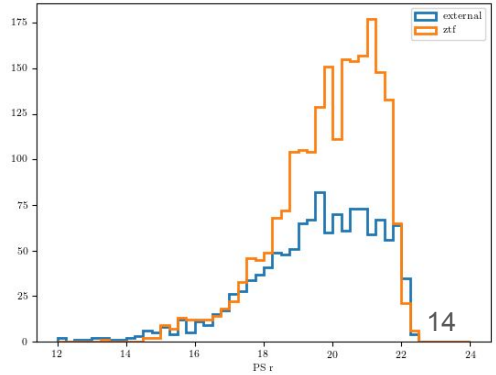
Dwarf novae and other Cataclysmic Variables

Paula Szkody & Jan van Roestel





Previously: GROWTH filter based on rise time
Now: Fritz filter for outbursts of blue stars



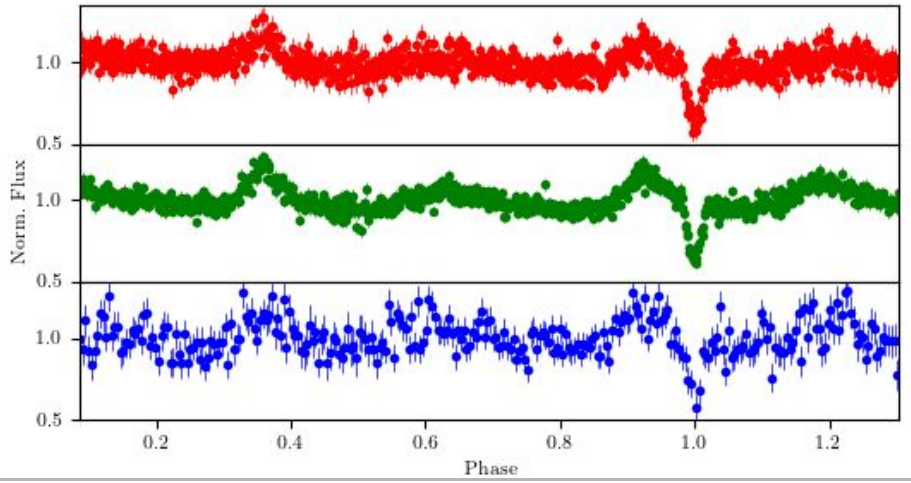
CVs found with ZTF: 3206 (Paris) ➡ **4282 (Now)**
Includes 2608 previously known, but not complete

Compact binary stars with extra physics

Jan van Roestel

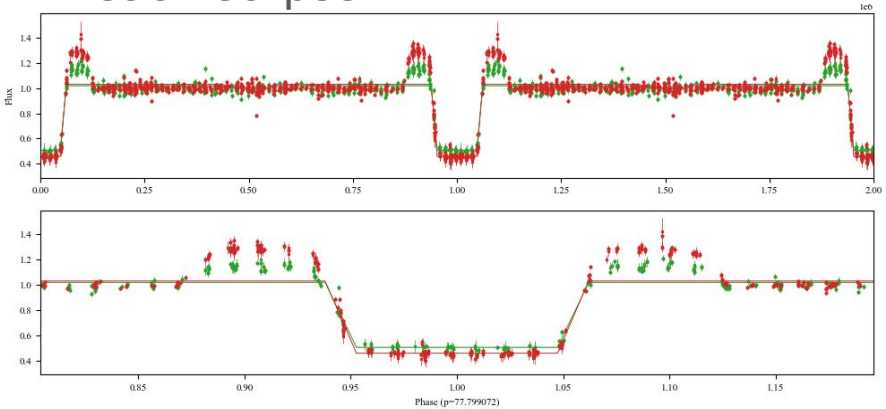
ZTFJ0836+2258

- **Eclipses**: **66** minute period
- **Pulsations(?)**: **~19** minute period



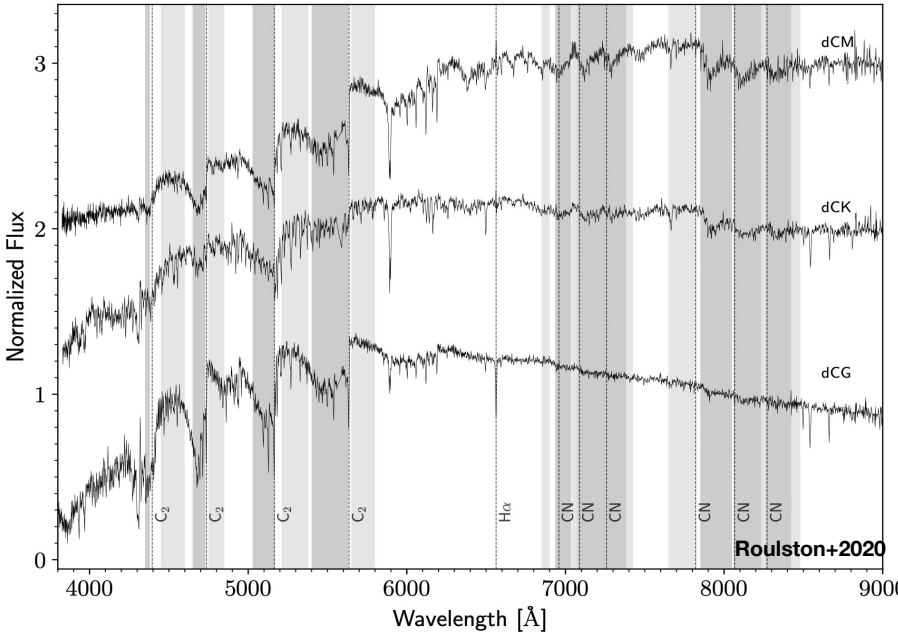
ZTFJ1743+1113

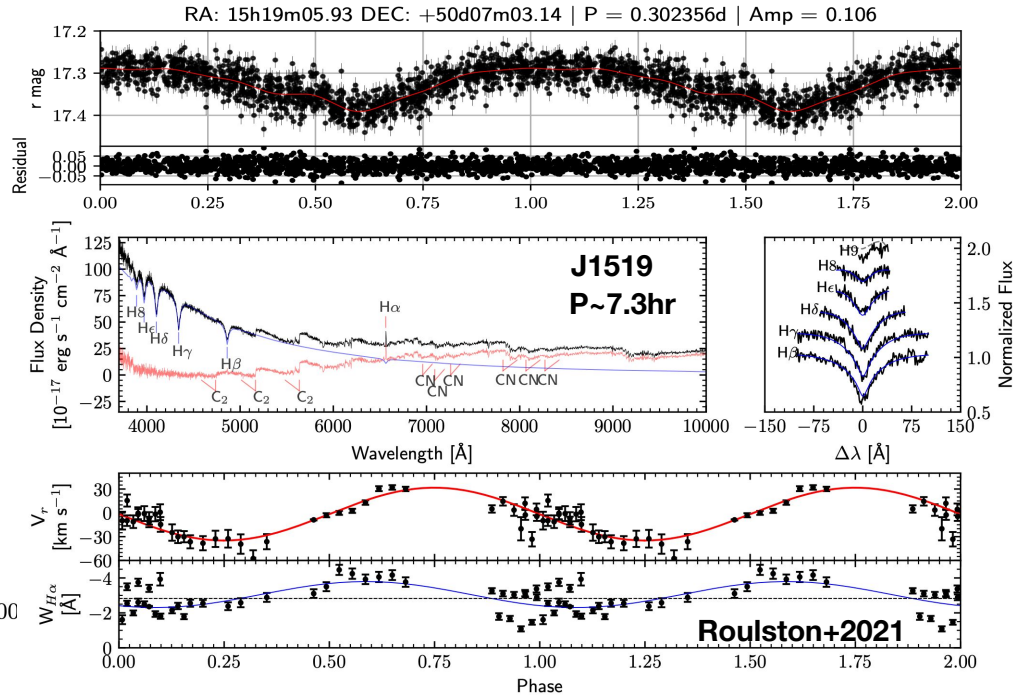
- F-type star + hot compact source
- 77 day(!) orbit
- Unknown brightening before and after each eclipse



Probing Common-Envelope Evolution with ***Dwarf*** Carbon stars

Ben Roulston (Caltech)

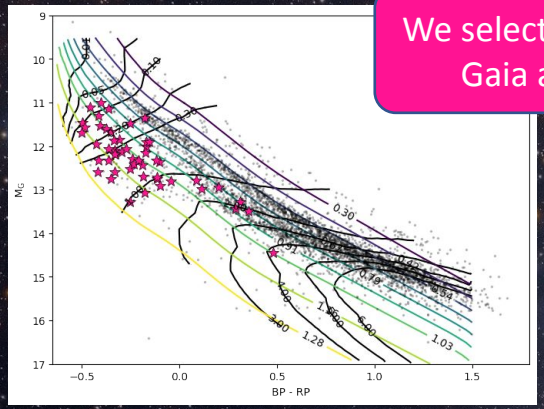




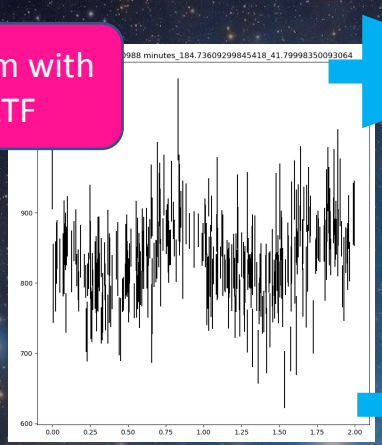
- Main-Sequence stars with C/O>1, enhanced by a binary companion. Show strong carbon molecular bands in optical spectra
- 34 periodic dCs in ZTF with P<2d (down to P~2hrs) —> Post common-envelope binaries
- Would like to expand sample of known dCs using Gaia+? (SEDMv2?) then search for periods in ZTF

Exotic rotating white dwarfs

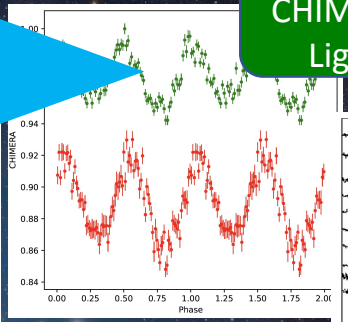
We select them with Gaia and ZTF

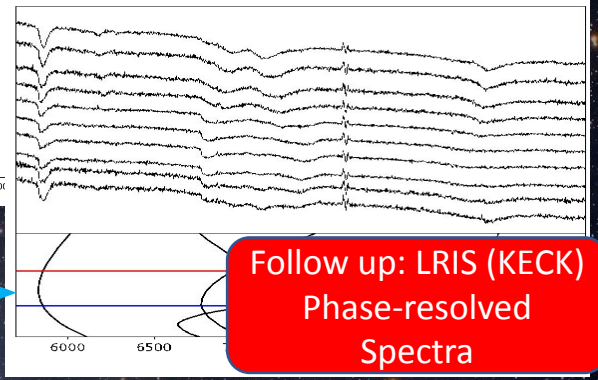


+



Follow up: CHIMERA (HALE) Light curves





Follow up: LRIS (KECK) Phase-resolved Spectra

Finding a population of rapidly rotating and highly magnetized WDs

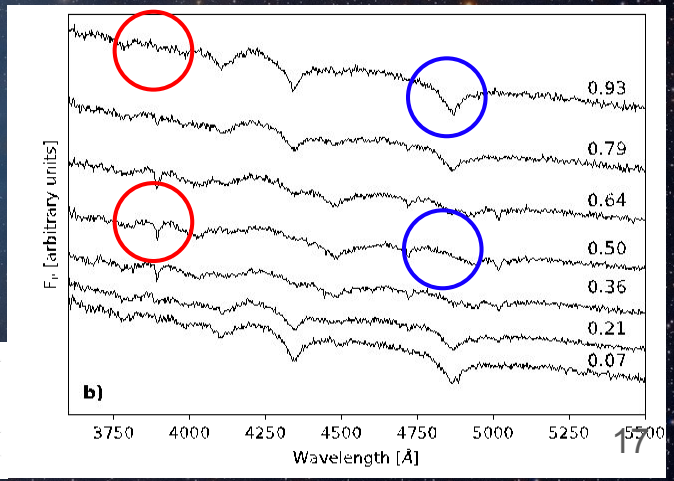
- Candidates **double white dwarf mergers**
- Reveal the characteristics of mergers and constrain merger rates
- Allow to study magnetic WDs

Finding exotic white dwarfs

- Janus: **double-faced white dwarf**

Article

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



ZTF and Globular Clusters

Chow-Choong Ngeow (NCU-Taiwan), et al.

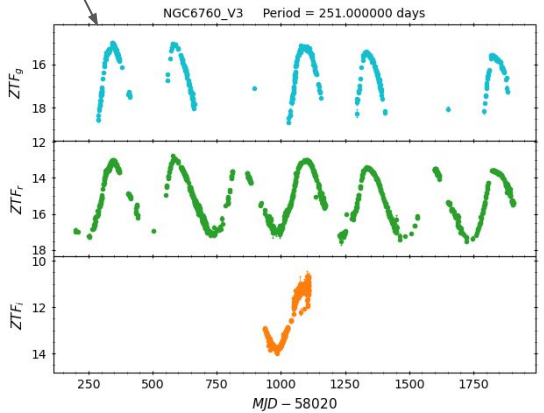
- Goal: calibrate various old population distance indicators in gr(i)-band, most of them for the *first time* → can be applied in, e.g. **LSST**, HSC-SSP, etc surveys observed with gri filters
- Why G.C.? Good → well-determined (and homogeneous) distance, most with low or vanished extinction, some rich in variable stars; Bad → blending (need PSF photometry + small pixel scale)
- Why ZTF? ZTF out-number PS1 in terms of number of observations!

Table 1. Comparison of optical time-domain surveys in the northern sky.

Best ⇨

Survey[a]	Filters[b]	Pixel Scale[c]	Photometry[d]	Depth
ZTF	*gri*	1.01	PSF & AP	$r \sim 20.6$
PS1 3π	*grizy*	0.258	PSF & AP	$r \sim 21.8$
ATLAS	*oc*	1.86	PSF	$m \sim 19.5$
ASAS-SN	*gV*	8.0	AP	$V \sim 17$
CSS	—	1.5	AP	$V \sim 19.5$
LINEAR	—	2.25	AP	$m \sim 18$
SuperWASP	—	13.7	AP	$V \sim 15$

Distance Indicators	Publication	ZTF Data
Contact binaries	AJ 162:63 (2021)	DR 3 + private
RR Lyrae	AJ 163:239 (2022)	DR 7 + private
Type II Cepheids	AJ 164:154 (2022)	DR 10 + private
Yellow Post-AGB stars	AJ 164:166 (2022)	DR 10 + private
Anomalous Cepheids	AJ 164:191 (2022)	DR 11 + private
SX Phoenicis	AJ 165:190 (2023)	DR 13 + private
Miras	Work in-progress	DR16 + private

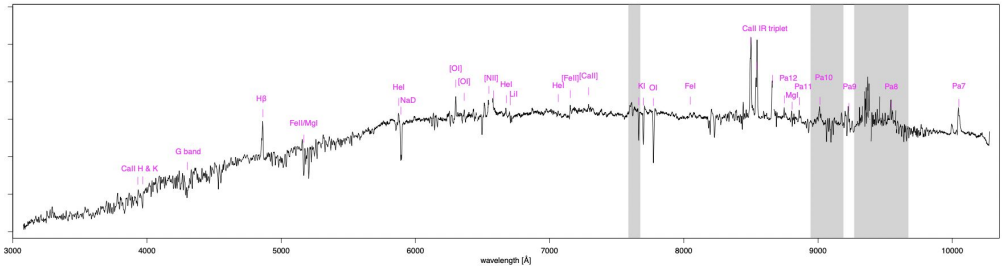


ZTF II/III wish-list:

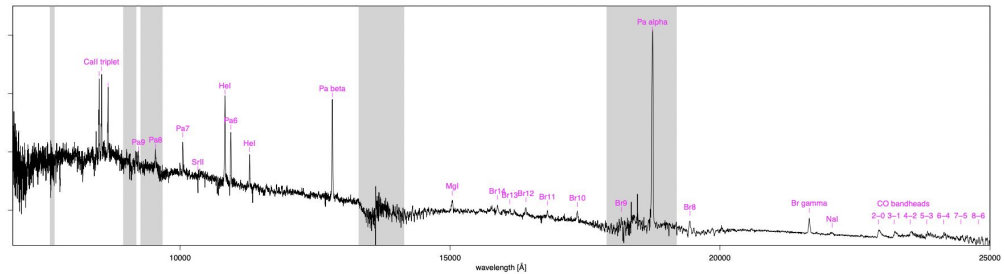
← more i-band data

More Outbursting Young Stars!

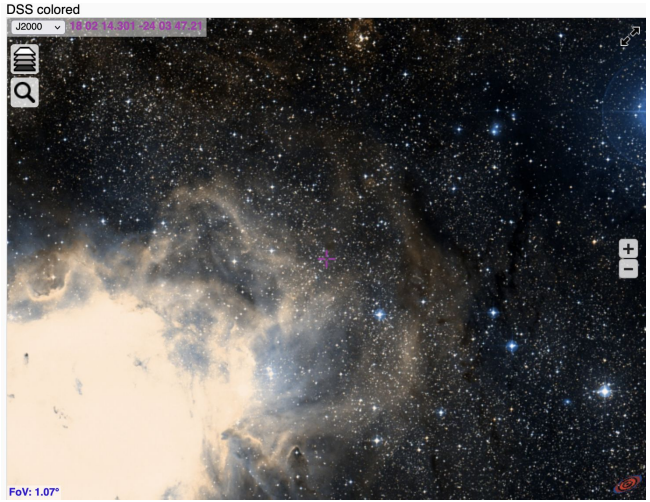
Michael Kuhn & Lynne Hillenbrand

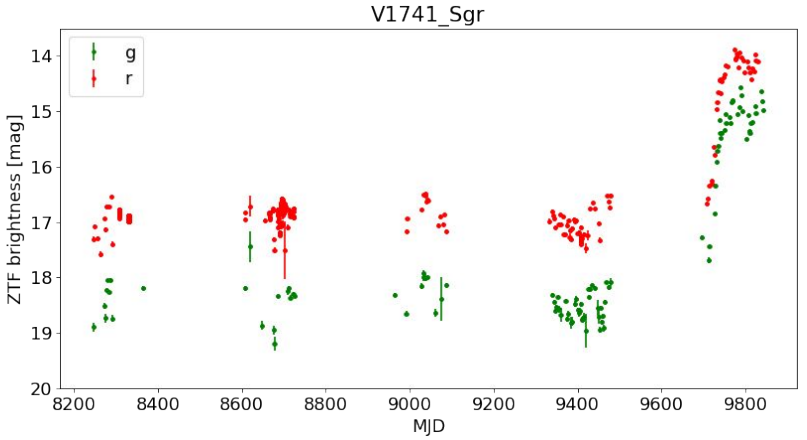


ıre 4. Keck/LRIS spectrum of V1741 Sgr during outburst. Regions affected by strong atmospheric absorption are colored gray. Prominent features are :ated.



ıre 5. IRTF/SpeX spectrum of V1741 Sgr during outburst. Regions affected by strong atmospheric absorption are colored gray. The spectrum has been



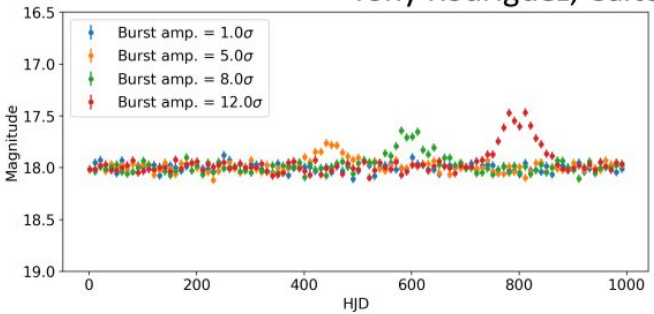


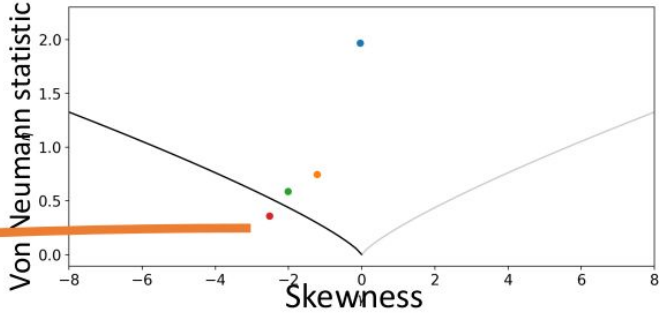
https://www.astronomerstelegram.org/?read=15721 and MNRAS paper in preparation

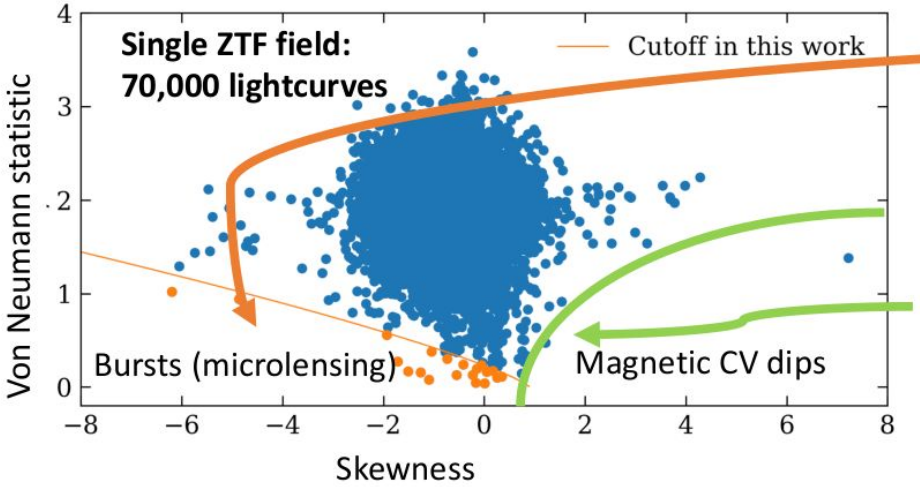
Tony Rodríguez, Caltech

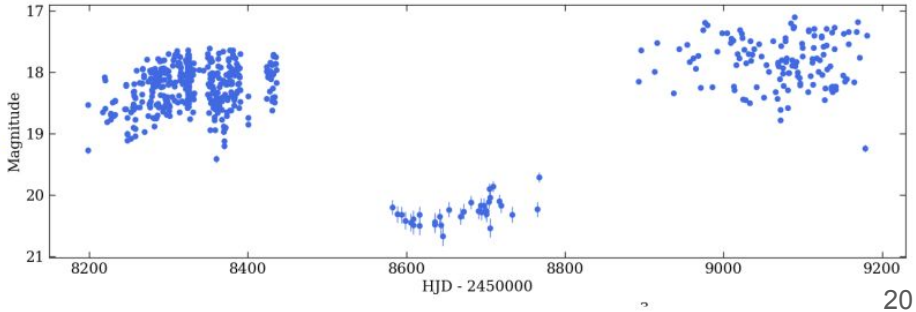
A Simple Statistic for Discovery

- The von Neumann statistic (η) is a way to **make discoveries in a data-saturated field**.
- Quantifies long-duration, statistically significant outbursts or dips.





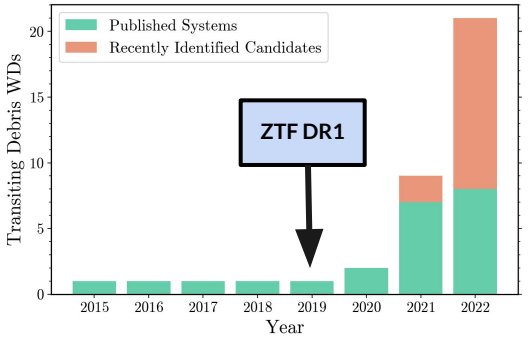




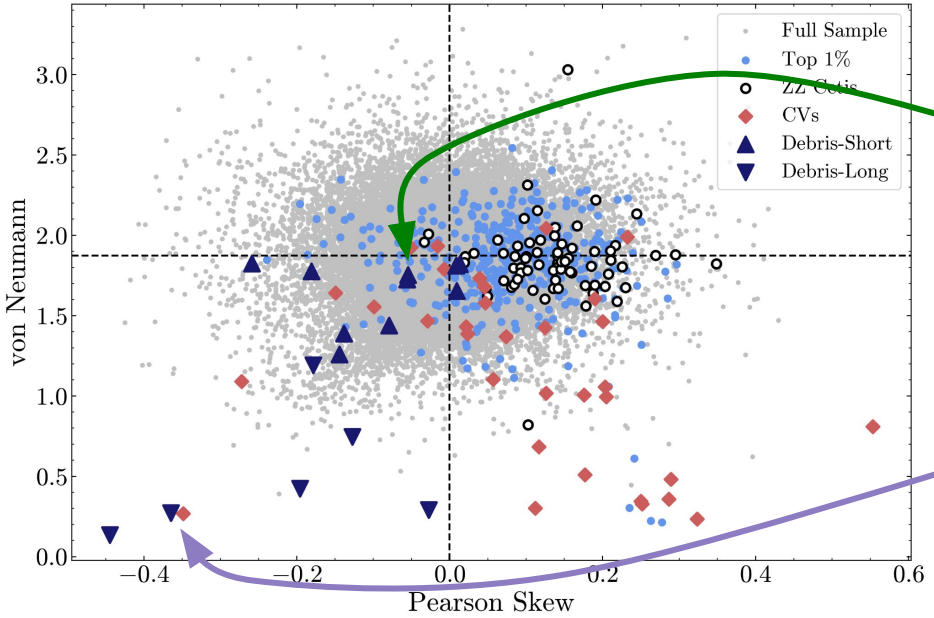
White Dwarfs with Transiting Planetary Debris:

Z. Vanderbosch, J.J. Hermes, Soumyadeep Bhattacharjee, Joseph Guidry

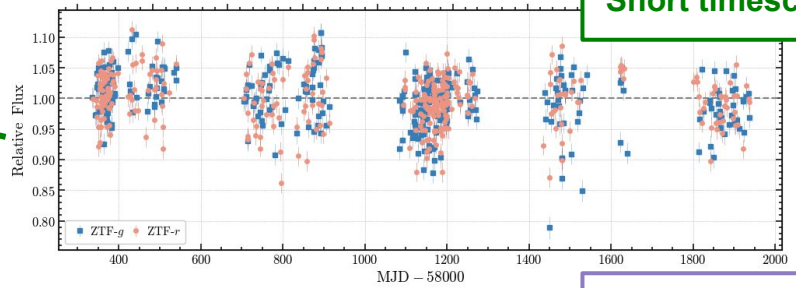
Using variability metrics best suited to **non-periodic, irregular** variables, ZTF has enabled a rapid increase in sample size



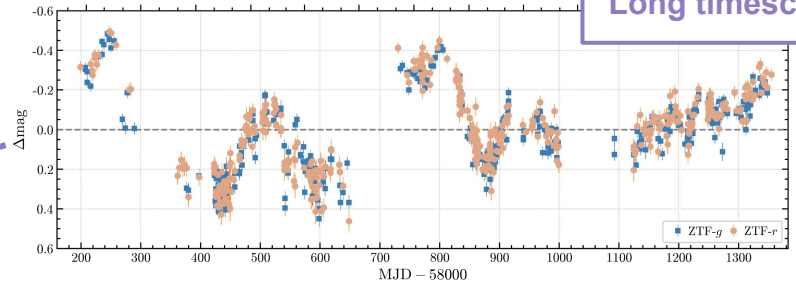
Bhattacharjee et al. 2023, in prep



Short timescale



Long timescale



White Dwarfs with Transiting Planetary Debris:

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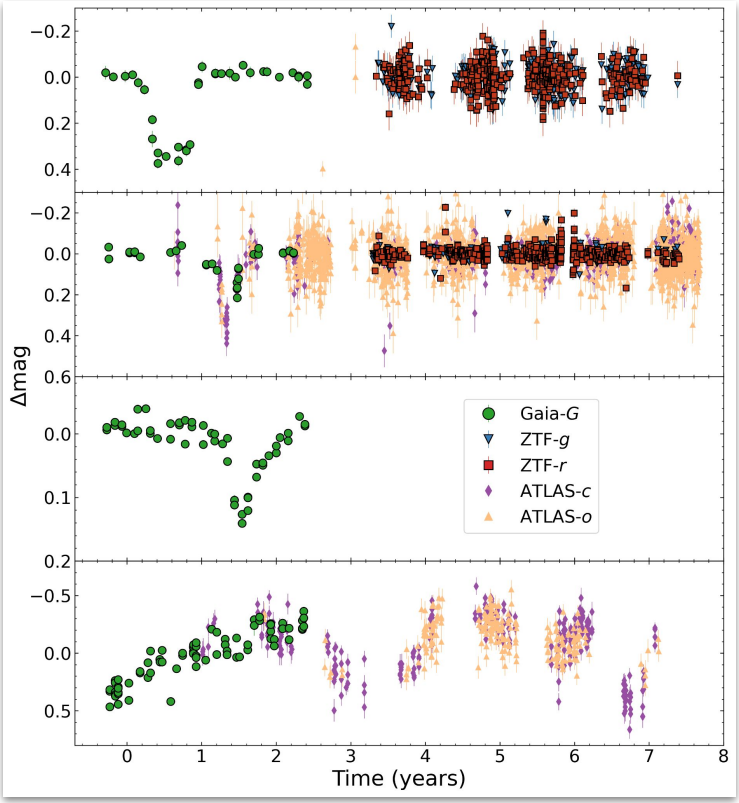
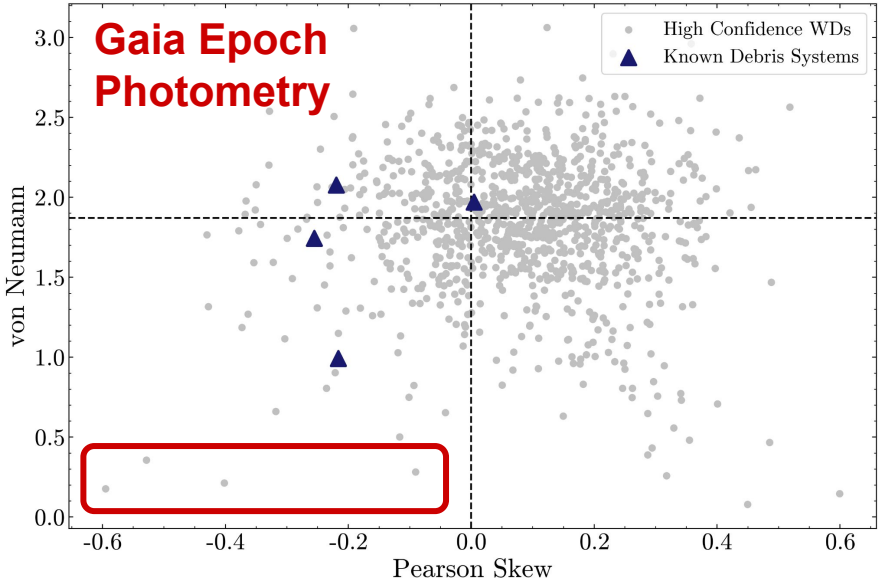
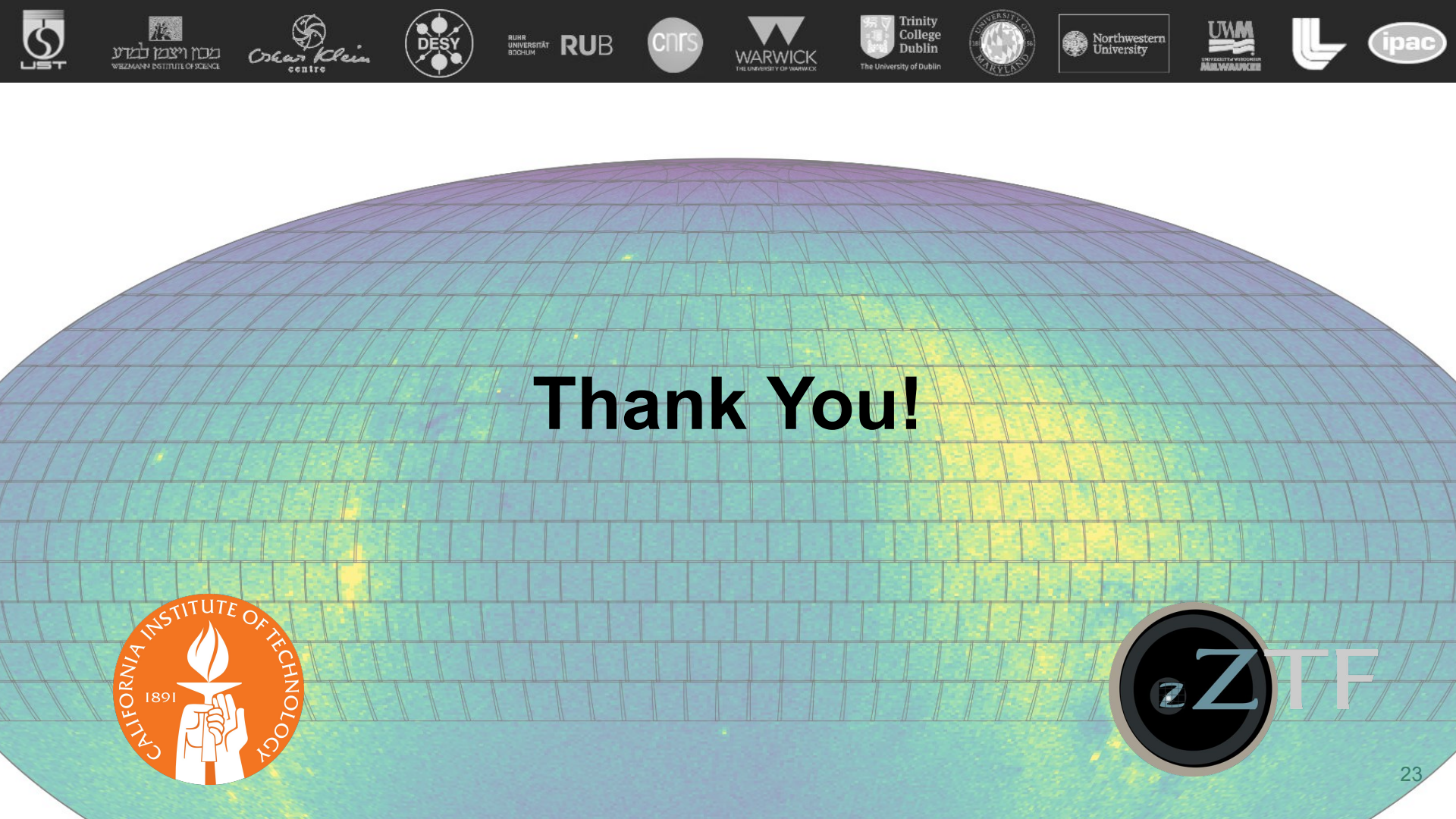
Vanderbosch et al. 2023, in prep



Applying same metrics tested on ZTF data to other surveys reveals new candidates.

Need longer-baselines (e.g. QCS)




Thank You!