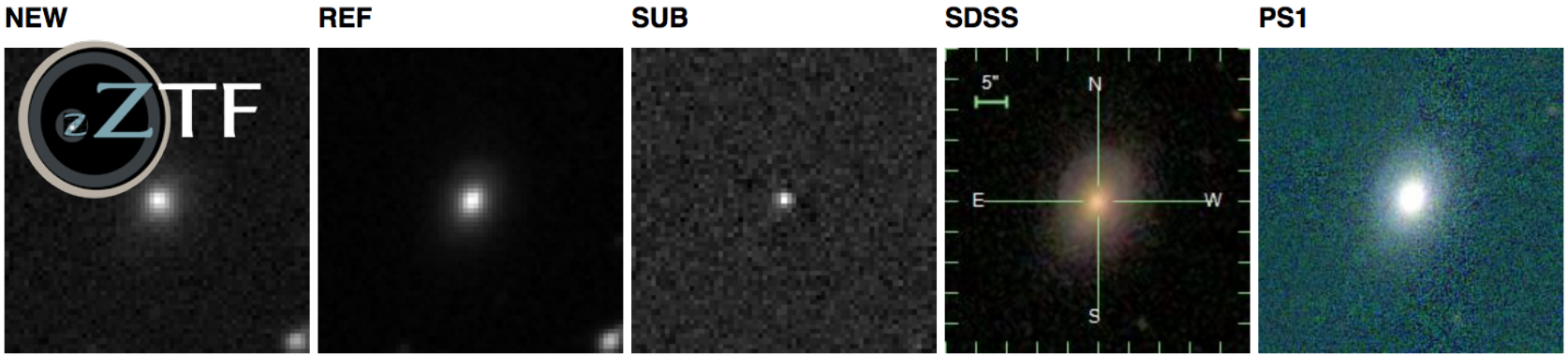


XMM-Newton Follow-up of Tidal Disruption Events from ZTF

Suvi Gezari

UNIVERSITY OF MARYLAND

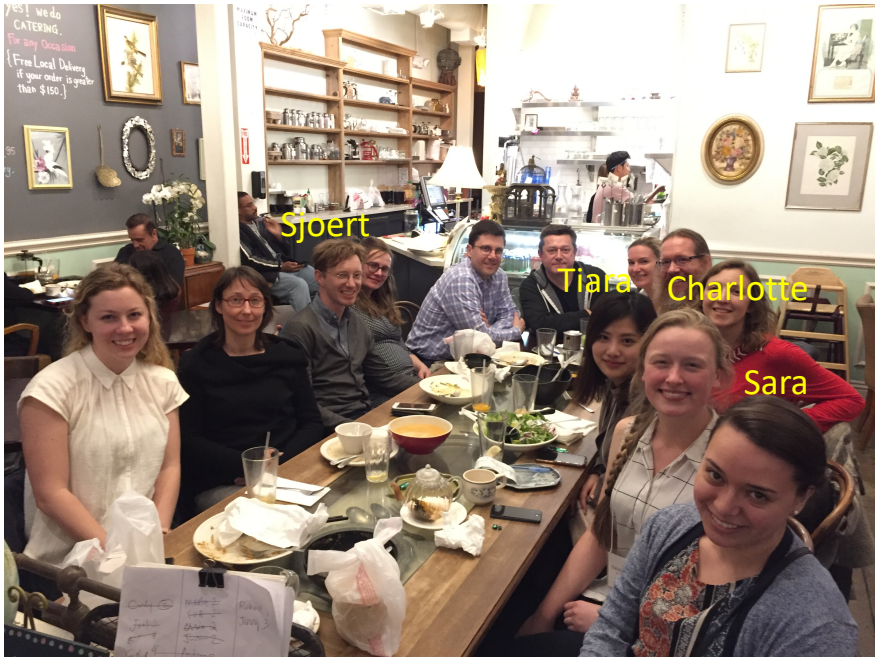
NASA/Goddard – October 21, 2019

ZTFbh: AGN and TDE SWG

Who are we?

Suvi Gezari, UMd (coordinator), Matthew Graham, Caltech (deputy coordinator)

Sara Frederick, UMd (current grad student)
Charlotte Ward, UMd (current grad student)
Erica Hammerstein, UMd (current grad student)
Sjoert van Velzen, UMd/NYU (postdoc)
Tiara Hung, UCSC (former grad student)
Brad Cenko, GSFC
Shri Kulkarni, Caltech
Peter Nugent, LBNL
Tom Barlow, Caltech
Lin Yan, Caltech
Po-Chieh Yu, NCU
Zeljko Ivezic, UW
Robert Stein, DESY
David Shupe, Caltech/IPAC
Nathaniel Roth, UMd and GSFC
Daniel Stern, Caltech/JPL
Scott Anderson UW
Nadia Blagorodnova, Radboud



ZTFbh SWG Dinner @ Daisy Mint
March 19, 2018

ZTFbh: AGN and TDE SWG

What are we doing?

We are conducting a systematic study of extragalactic nuclear transients.

What are we interested in?

<u>Nuclear Transients (< 0.5 arcsec from host galaxy center)</u>:

- variable active galactic nuclei
- changing-look quasars (CLAGN)
- tidal disruption events (TDEs)
- supermassive black holes (binary, recoiling, intermediate-mass)

What tools do we use?

GROWTH

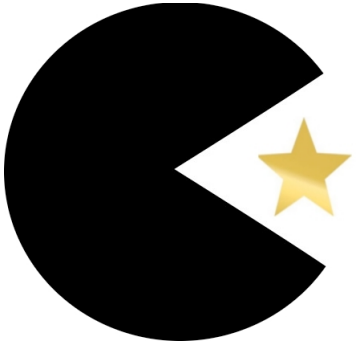
Global Relay of Observatories Watching Transients Happen

PI: Mansi Kaslilwal

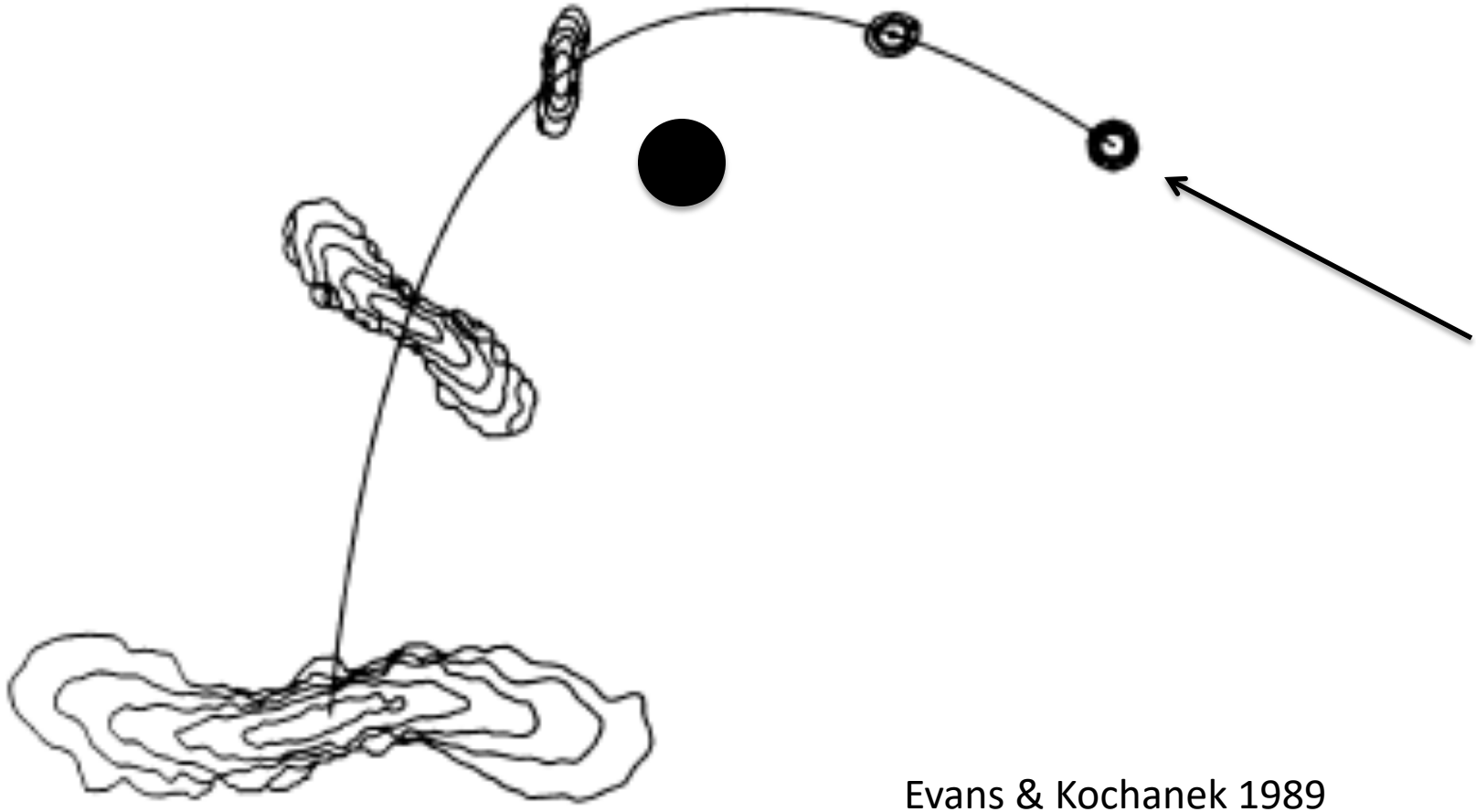
AMPEL

(DESY)

Tidal Disruption of a Star



What happens when a star ventures too close to a black hole?



Evans & Kochanek 1989

It gets ripped apart!

Tidal Disruption of a Star

The star is ripped apart when tidal forces overcome the self gravity of the star:

$$\frac{GMR_\star}{r^3} = \frac{Gm_\star}{R_\star^2}$$

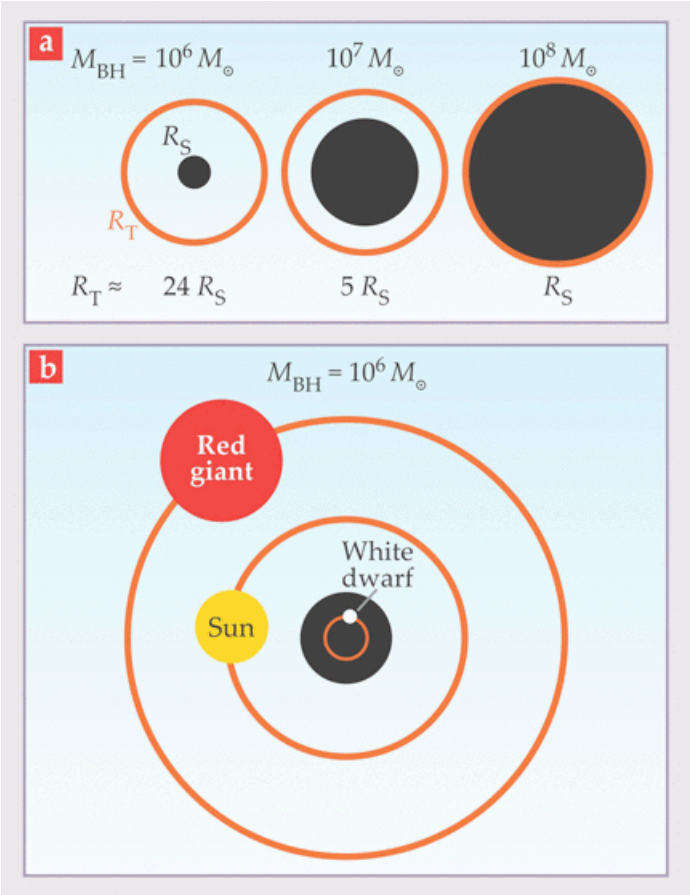
Tidal Force

Self-Gravity

$$r_{\rm T} \approx R_\star (M_{\rm BH}/m_\star)^{1/3}$$

Tidal Disruption Radius

How close do you have to get?

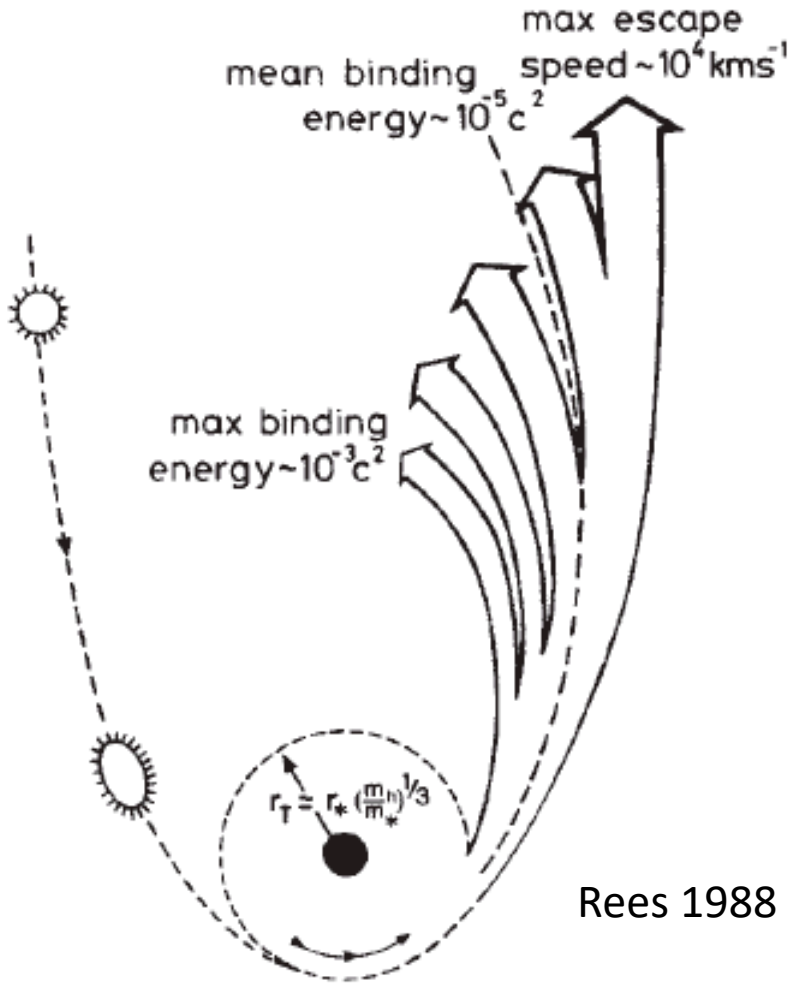


$r_S = 2GM_{BH}/c^2$

Event Horizon

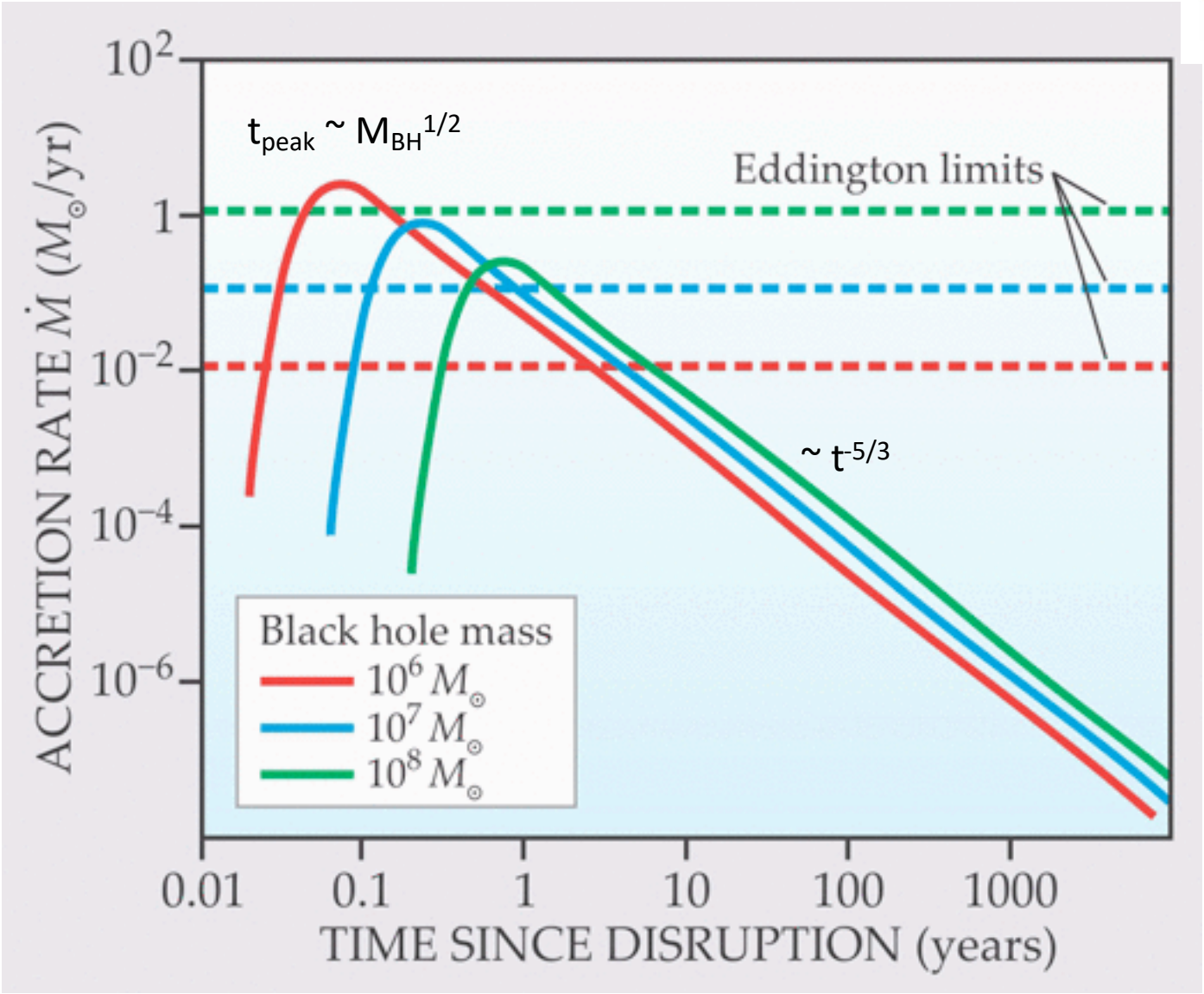
It depends on the type of star and the mass of the black hole!

Tidal Disruption of a Star



Rees 1988

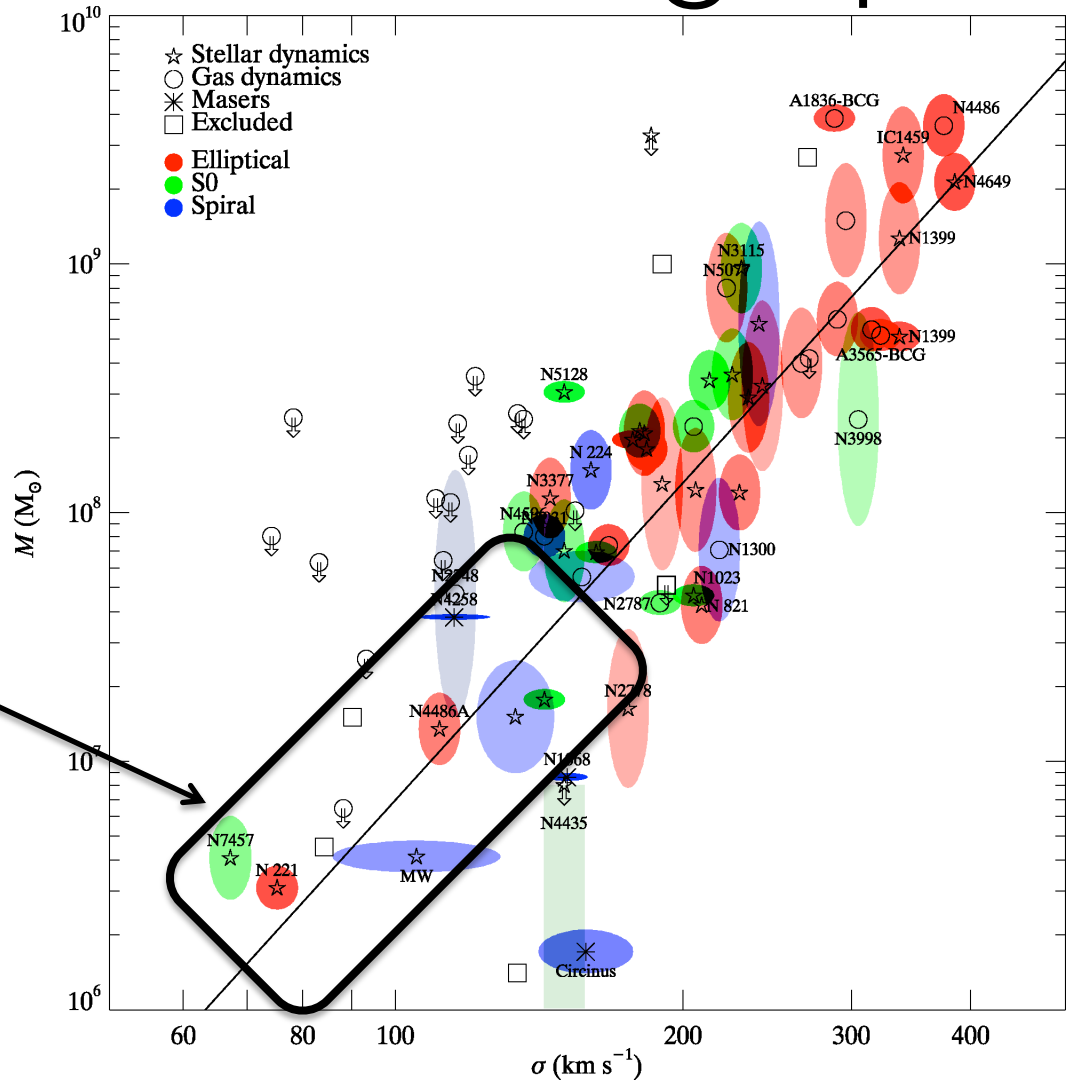
Probing Black Hole Mass



Gezari 2014, Adapted from De Colle+ 2012

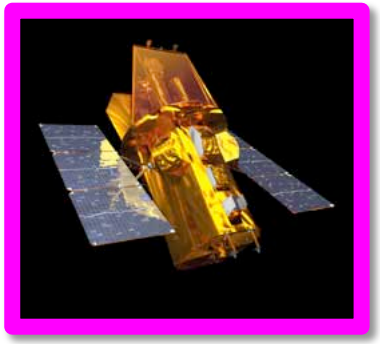
Probing SMBH Demographics

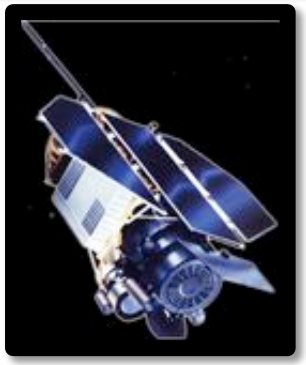
Probe BH mass range where even local scaling relations are poorly constrained.

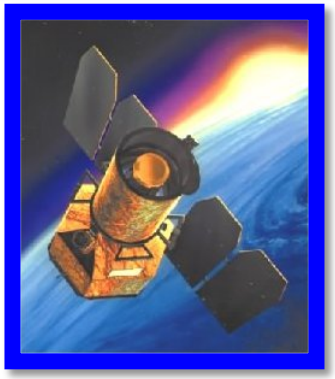


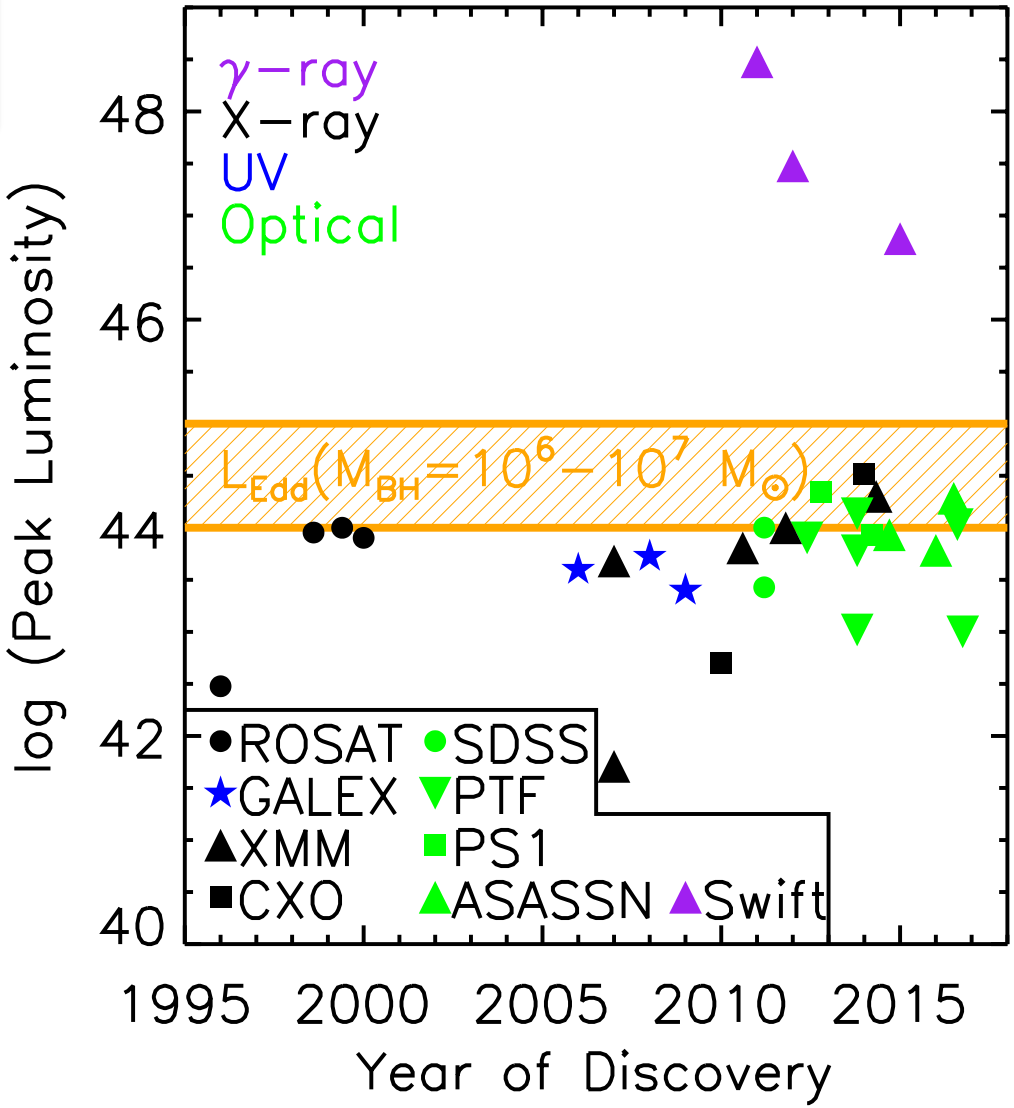
Gultekin+ 2009

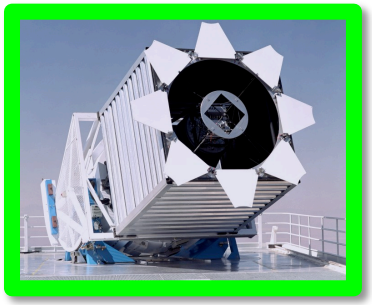
Multi-λ Searches





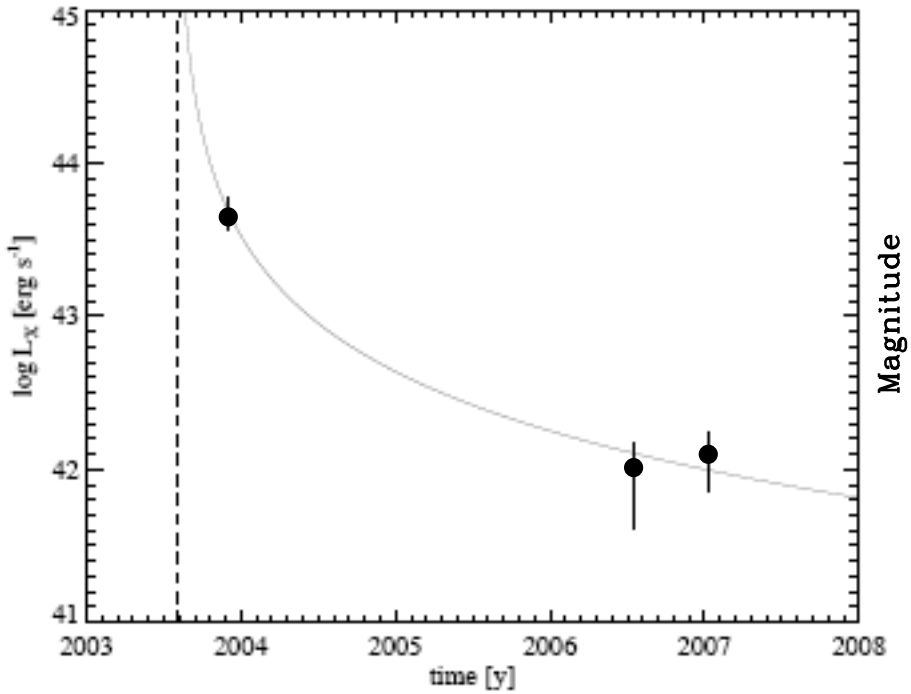






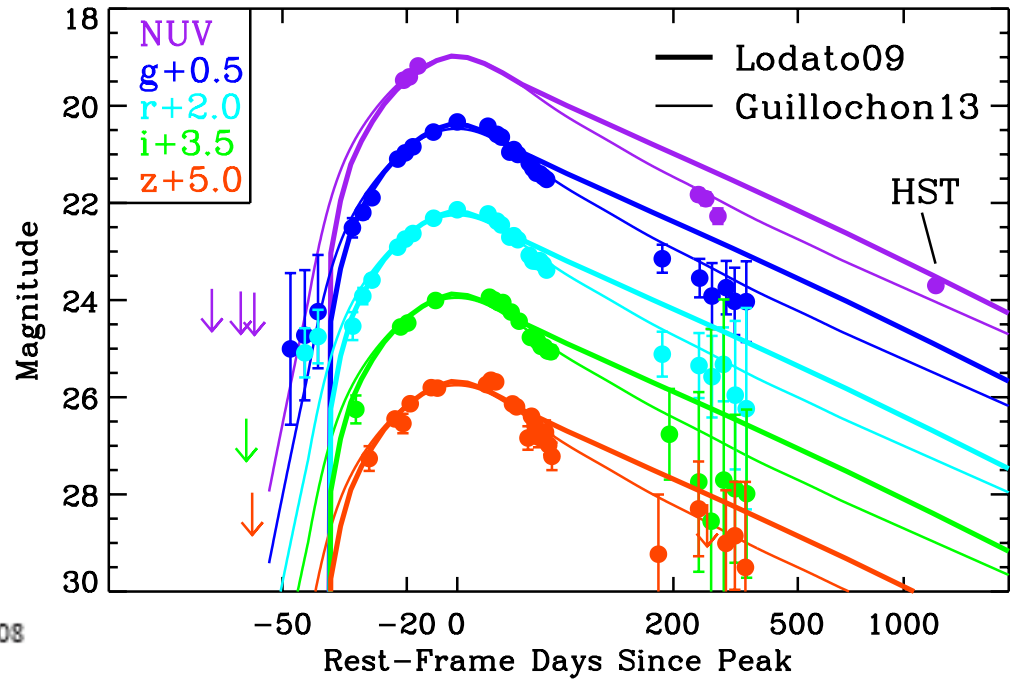
We've Come a Long Way…

X-ray Searches…



Esquej+ 2008

Ultraviolet/Optical Searches…



Gezari+ 2015

Some Basic Predictions Have Held True…

Rees 1988

The most obvious consequence of a 10^6–10^8 $M_\odot$ black hole would be transient flares whenever bound debris from a star was swallowed. The rate is given by equation (2) with $r_{min} = r_T$, the luminosities being as high as $L_E = 10^{44}$ M_6 erg s^{-1}.

Some Basic Predictions Have Held True…

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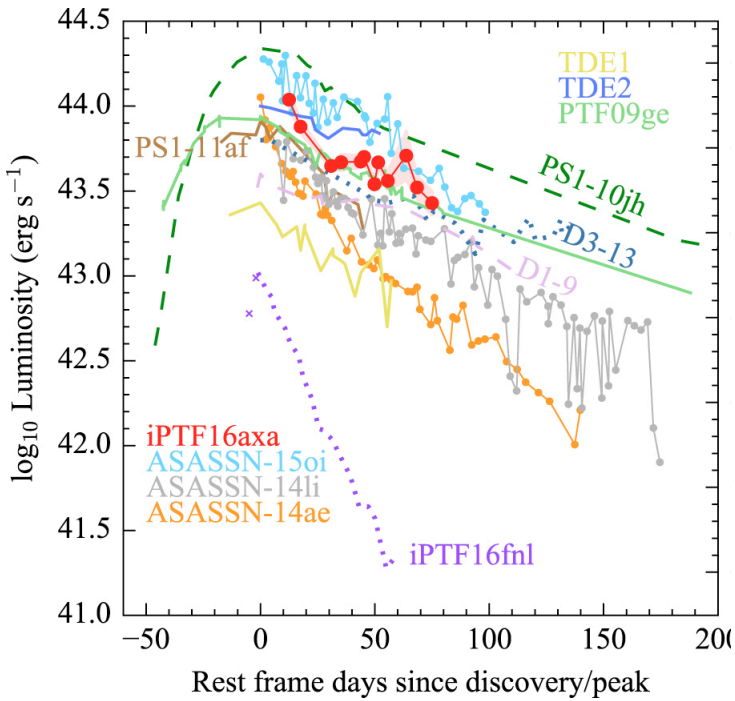
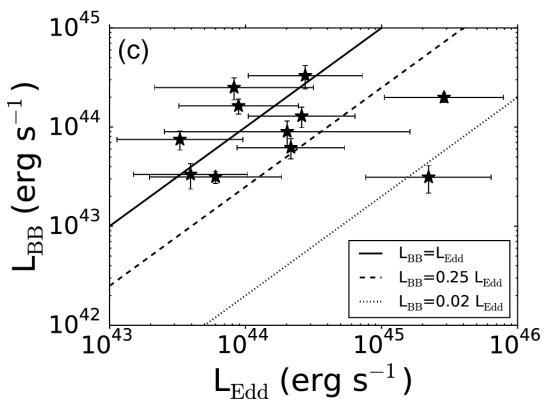
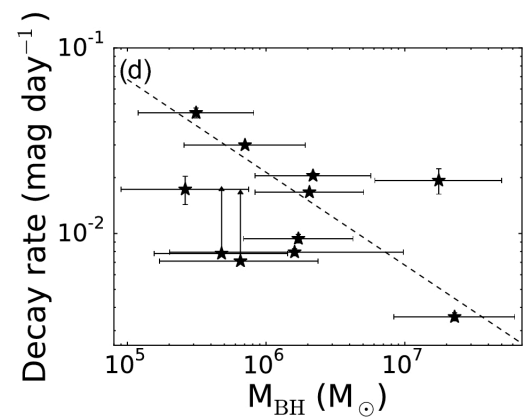
Observations



Hung, Gezari+ 2017





Wevers+ 2017

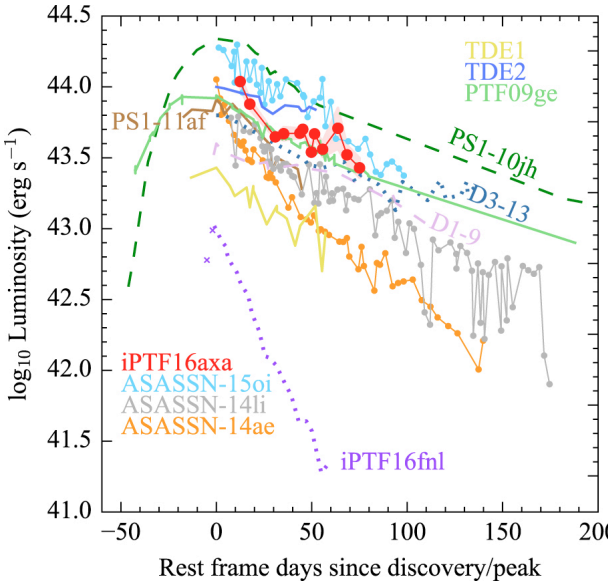
Surprises Along the Way

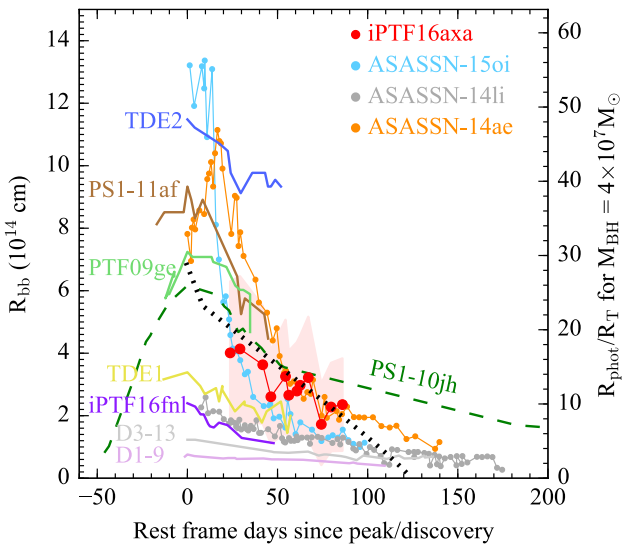
We are finding common characteristics…

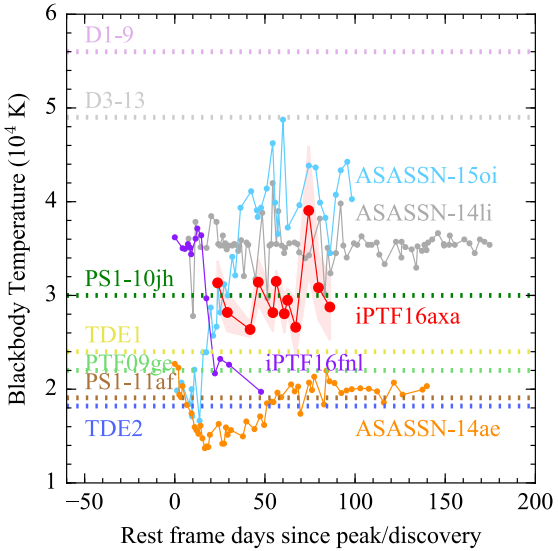
$t^{-5/3}$ decline

large radii: 10-100 R_T

constant temperature







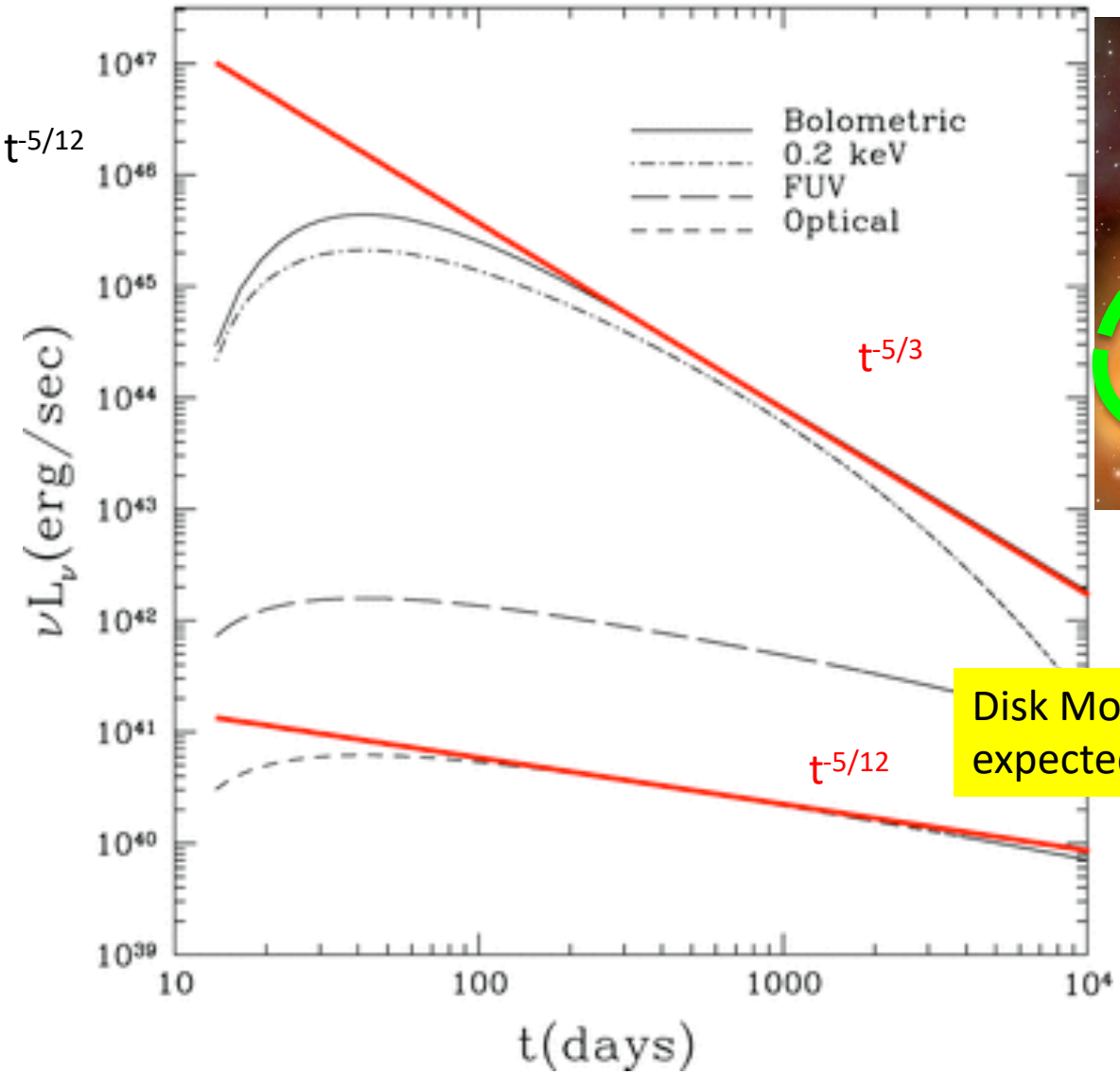
Hung, Gezari+ 2017

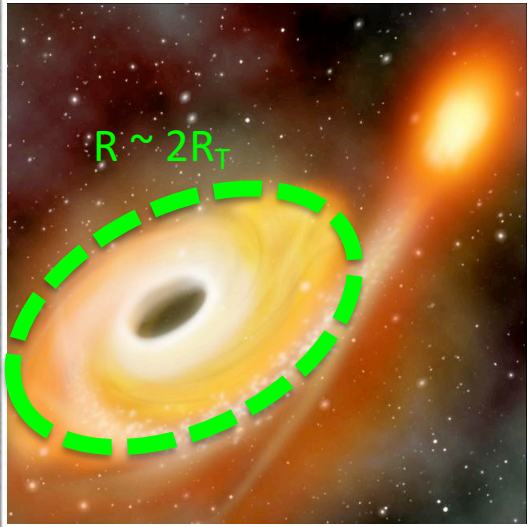
that are in tension with theoretical predictions…

$L \sim t^{-5/3}$

$L \sim T^4 R^2$

$L_{RJ} \sim T \sim t^{-5/12}$



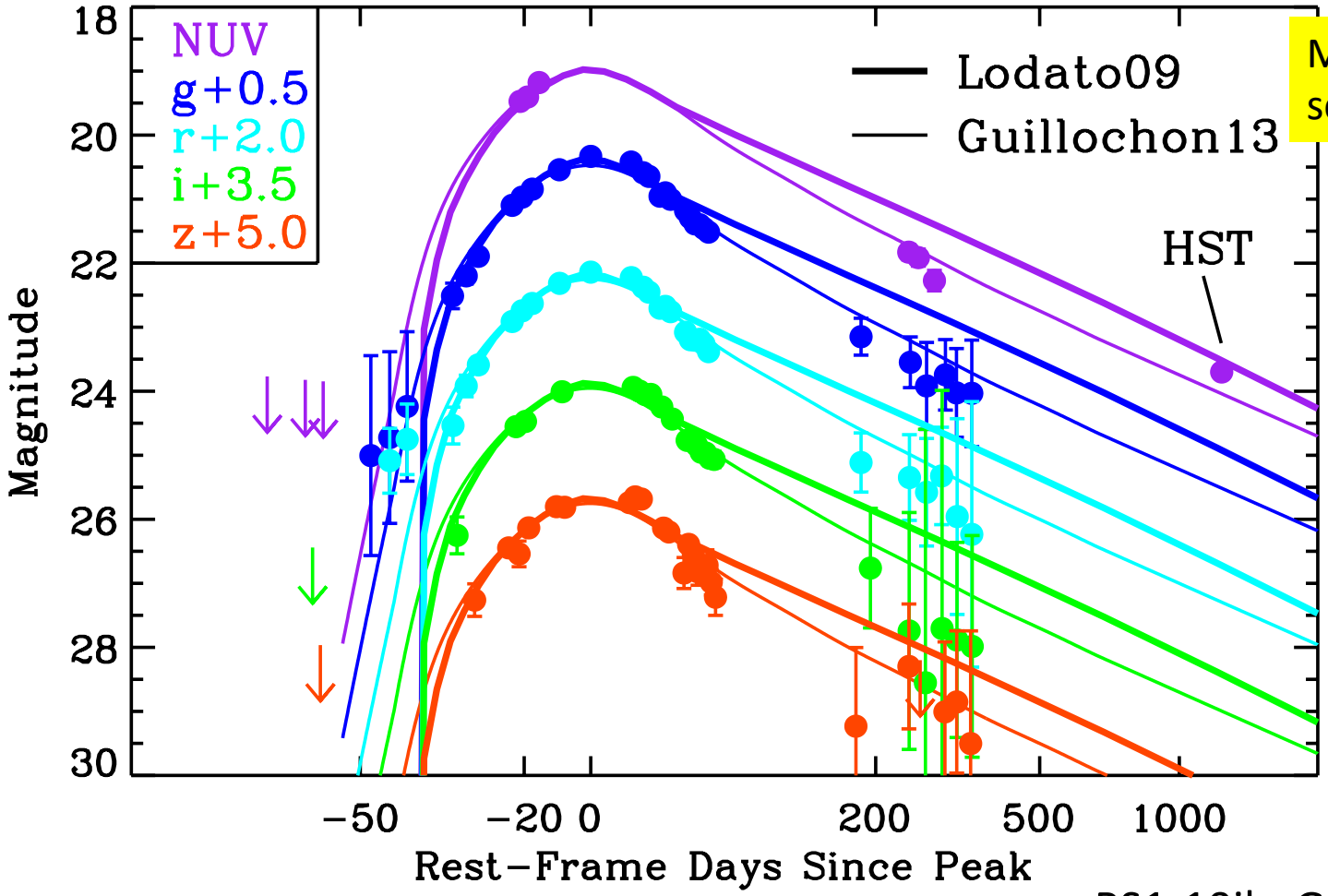


$T(R_T) \sim 10^5$ K

Disk Model: $t^{-5/12}$ decline expected in UV and optical

Lodato+ 2011

UV/Optical Light Curve Follows Fallback Rate



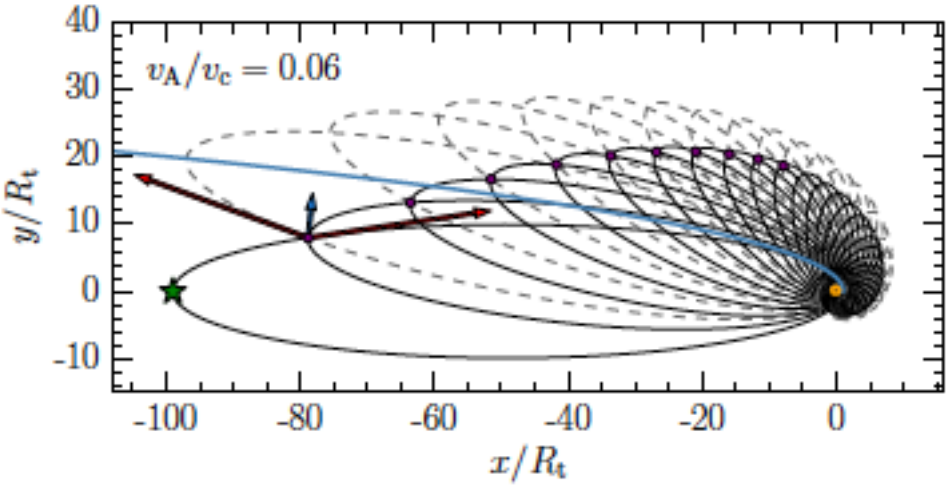
Models for dM/dt, scaled to light curve.

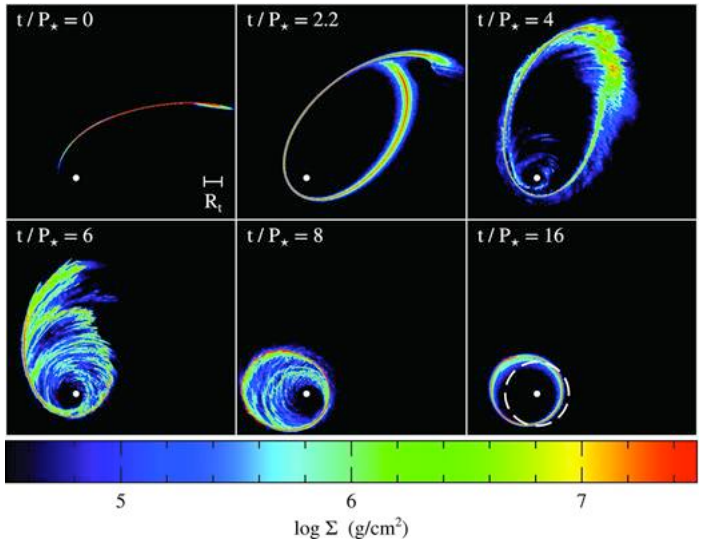
PS1-10jh: Gezari+ 2012, 2015

Why is this a Surprise?

The Great Circularization Debate of 2015:
Hayasaki, Stone & Loeb 2015
Guillochon & Ramirez-Ruiz 2015
Shiokawa+ 2015
Piran+ 2015
Bonnerot+ 2016

Bonnerot+ 2016

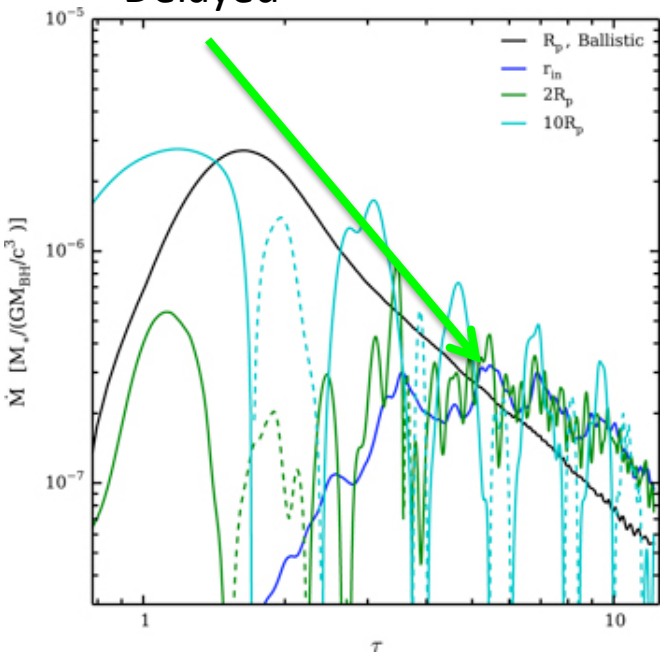




Why is this a Surprise?

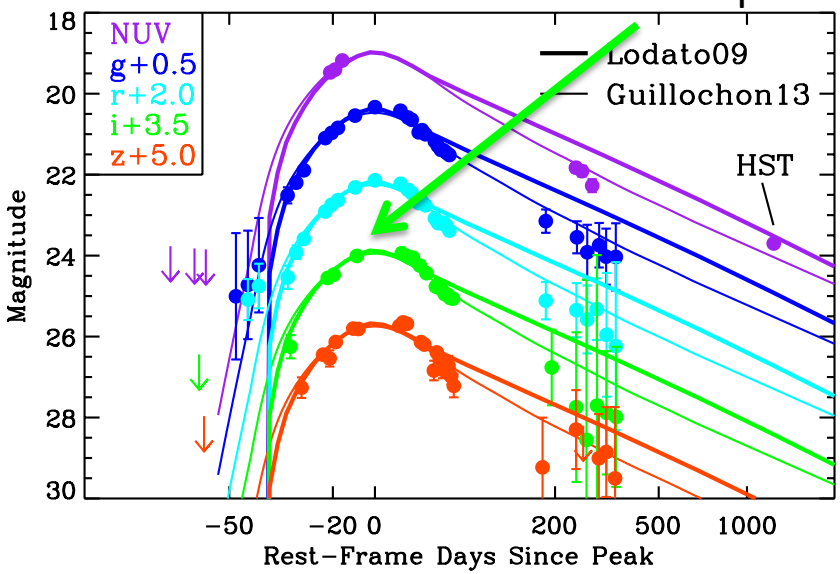
Theory vs. Observations

Delayed



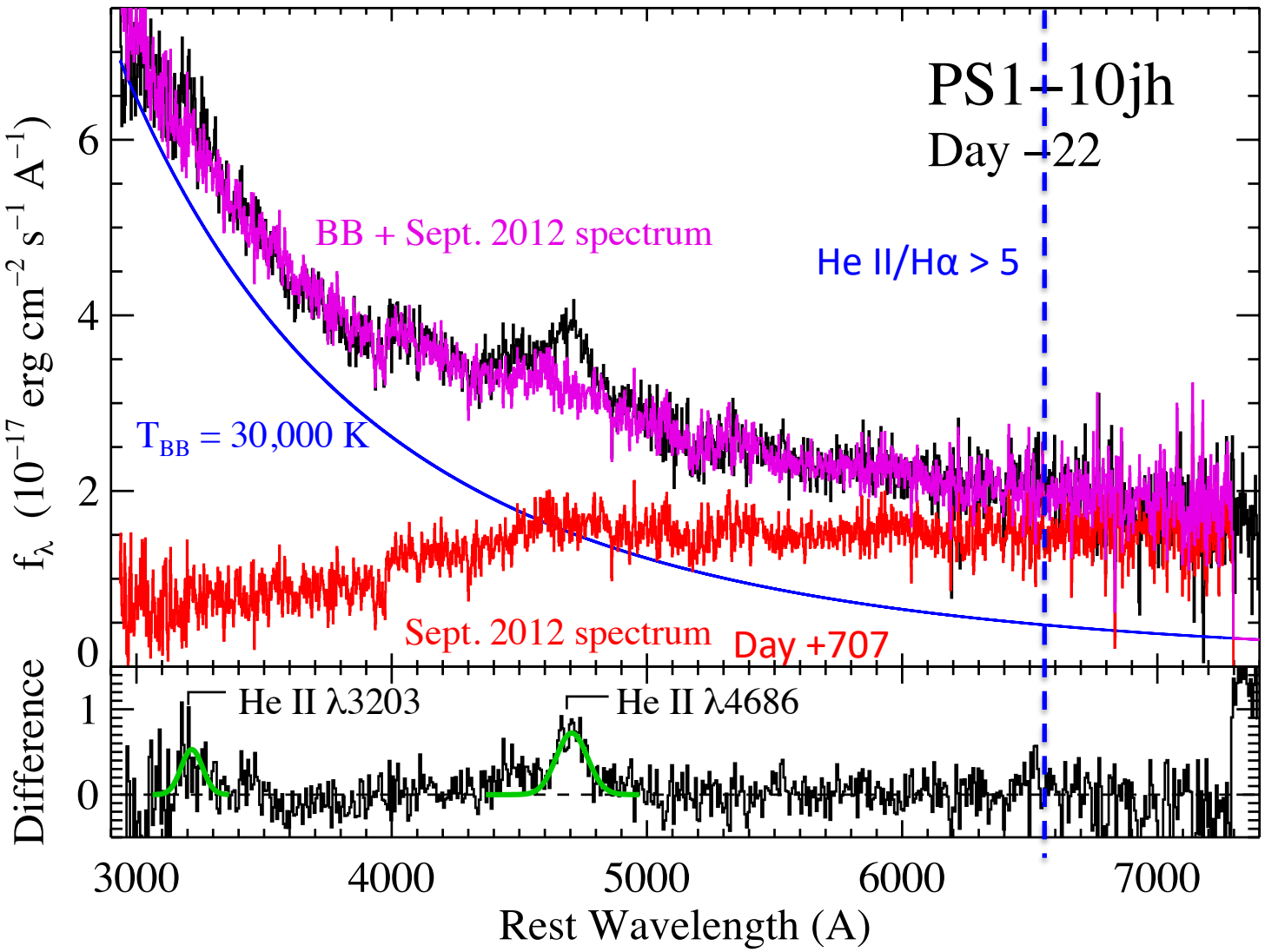
Shiokawa+ 2015

Prompt



Gezari+ 2015

Helium-Only Spectra

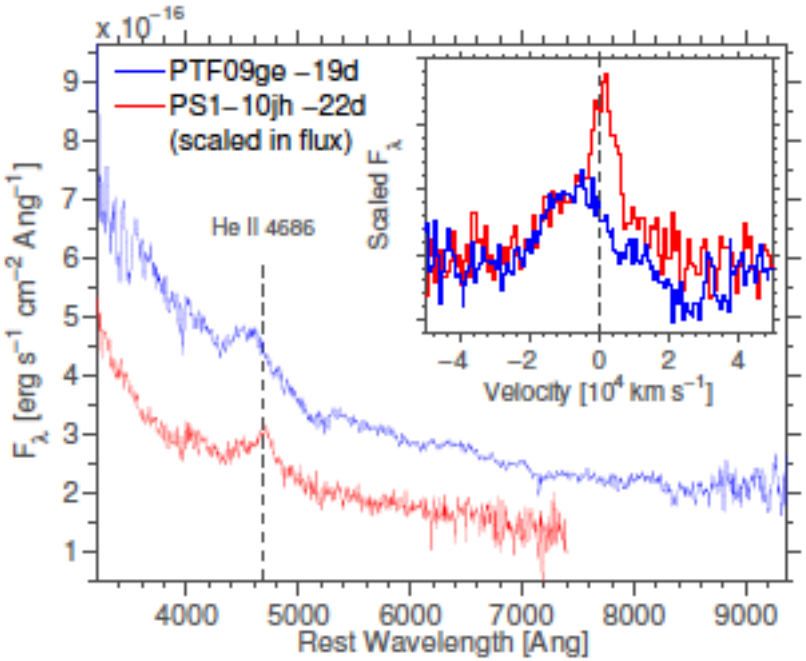


Can put strong constraints on Hα.

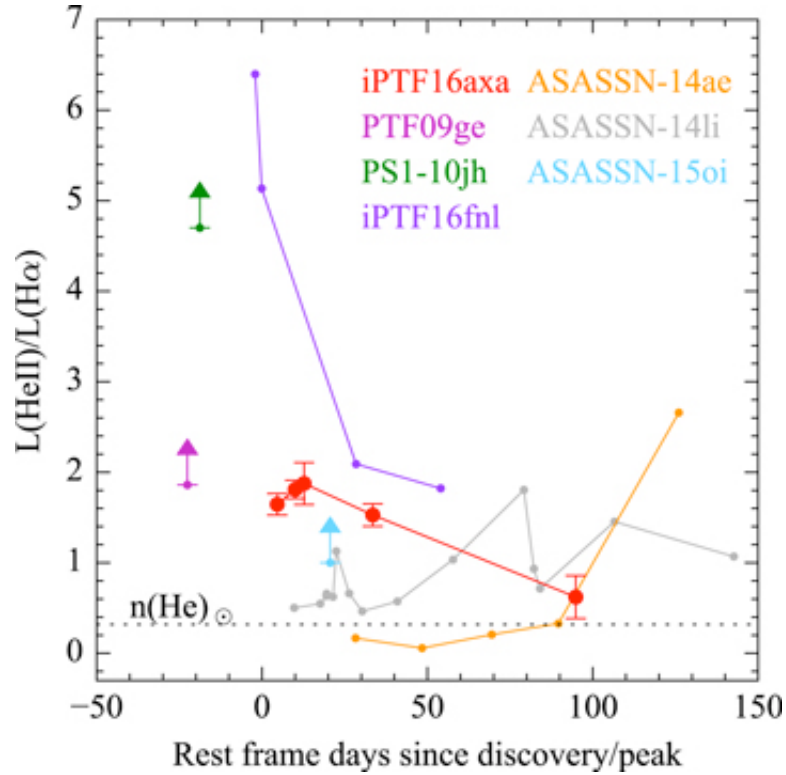
CAUTION: Telluric line

Gezari+ 2015

Enhanced He to Hα Ratios



Gezari+ 2012, Arcavi+ 2014

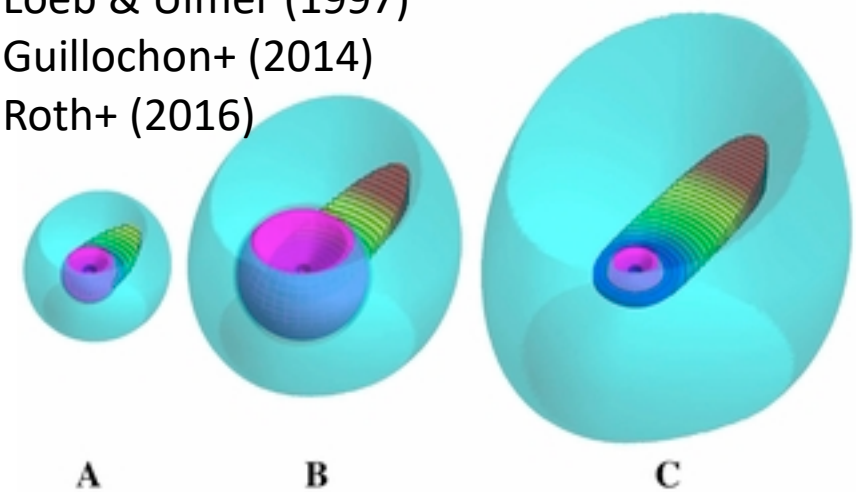


Hung, Gezari+ 2017

How to Get Large Radii

Reprocessing Envelope

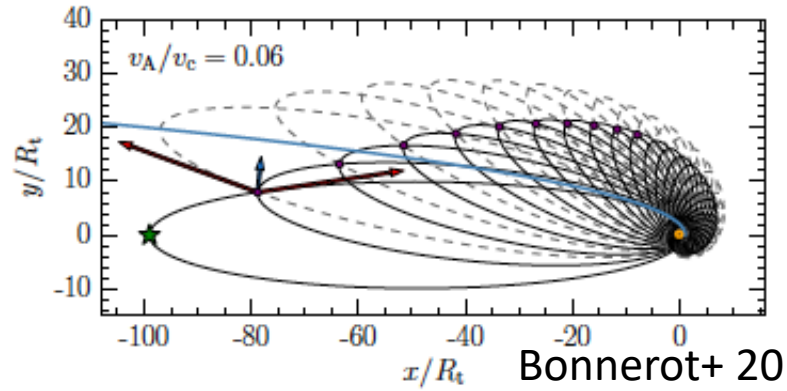
Loeb & Ulmer (1997)
Guillochon+ (2014)
Roth+ (2016)



Guillochon+ 2014

Circularization of Debris

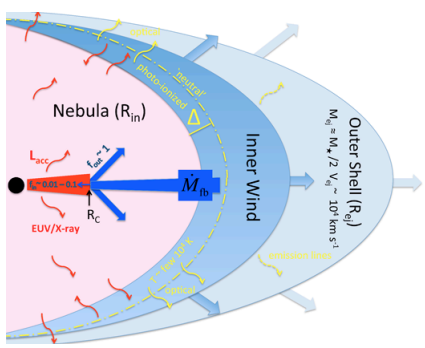
Piran+ (2015)
Jiang,Guillochon, & Loeb (2016)
Svirski, Piran, & Krolik (2017)
Bonnerot, Rossi, & Lodato (2017)



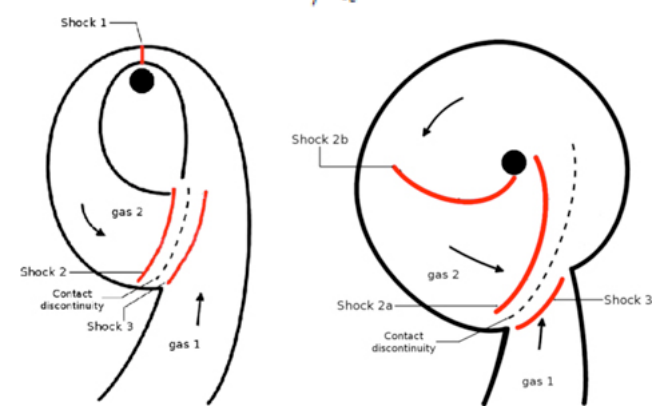
Bonnerot+ 2017

Radiatively Driven Wind

Miller (2015)
Metzger & Stone (2016)



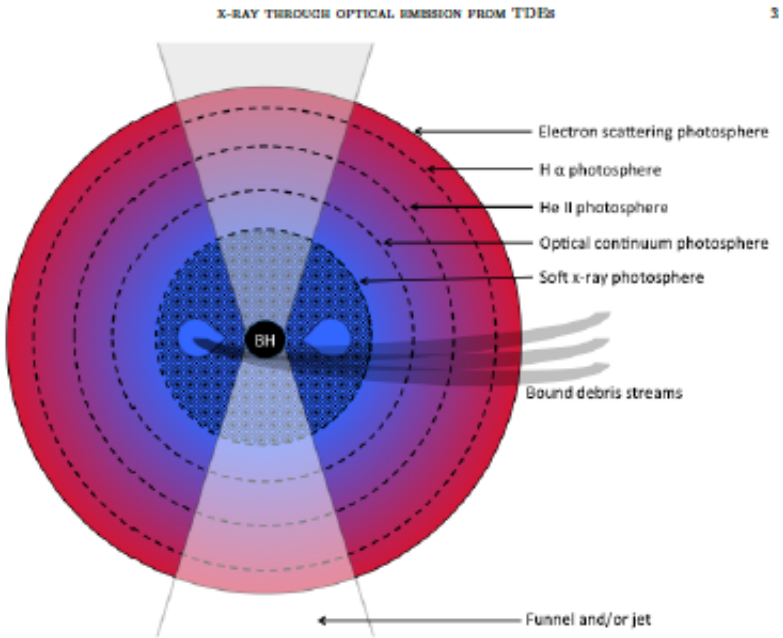
Metzger & Stone 2016

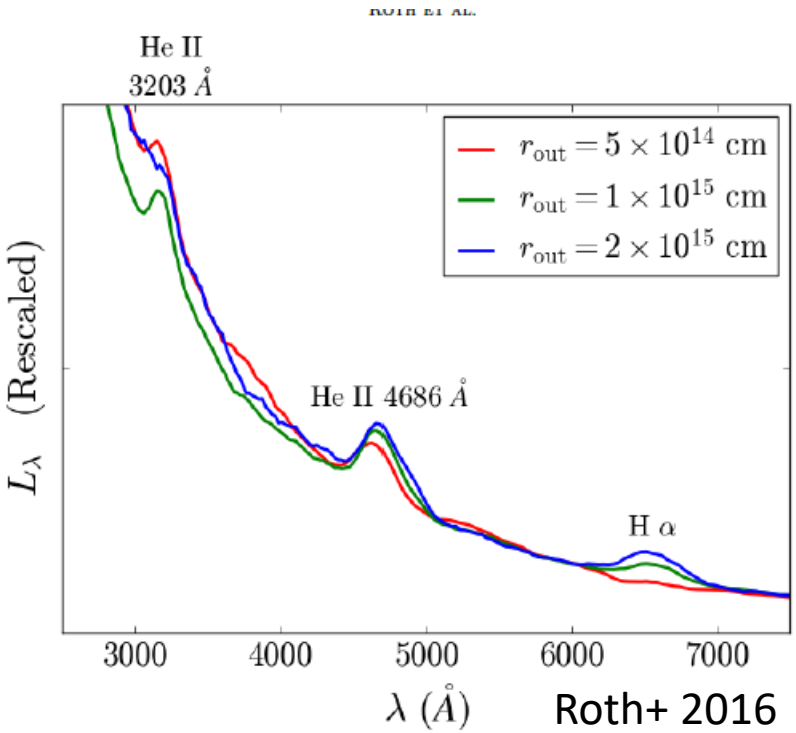


Piran+ 2015

How To Get High He-to-Hα Ratios

Reprocessing Envelope



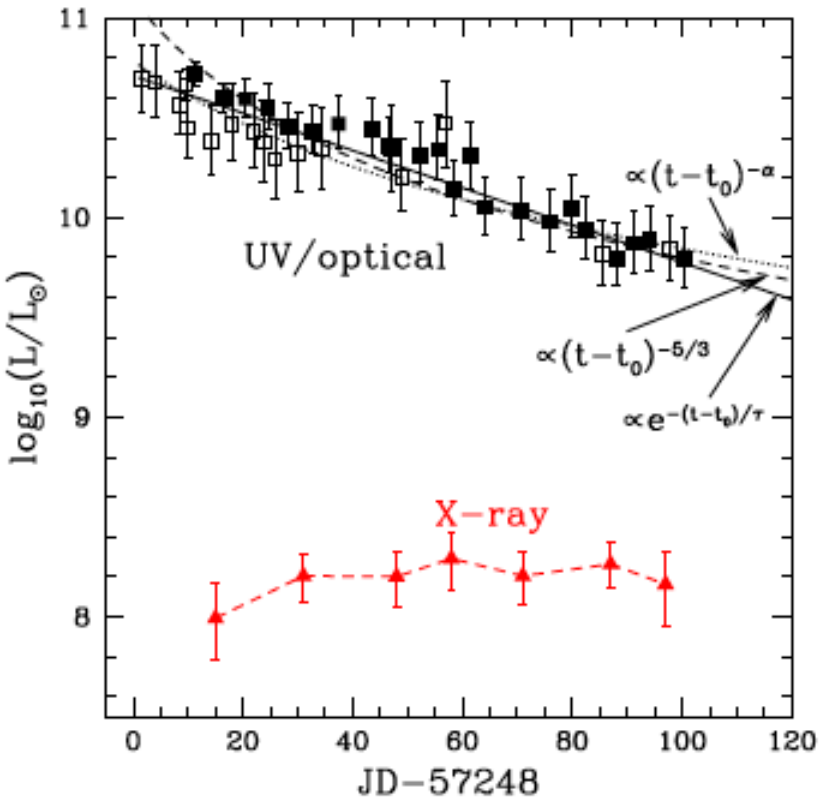


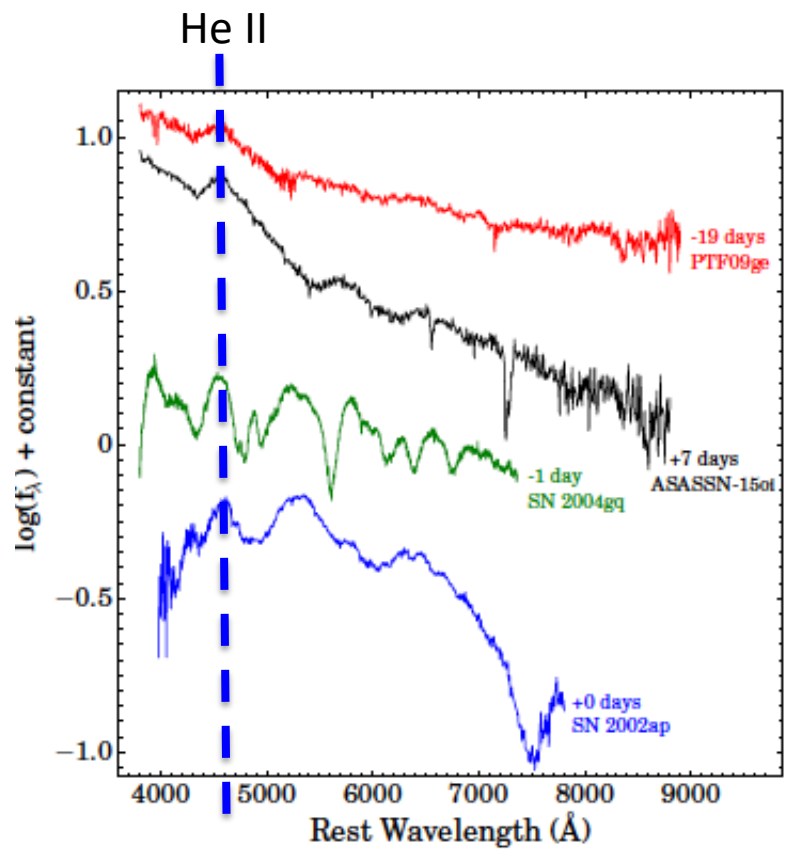
Roth+ 2016

Chemical Composition of the Star

Gezari+ (2012)
Strubbe & Murray (2015)
Kochanek (2016)
Law-Smith+ (2017)

New Insights from TDE ASASSN-15oi

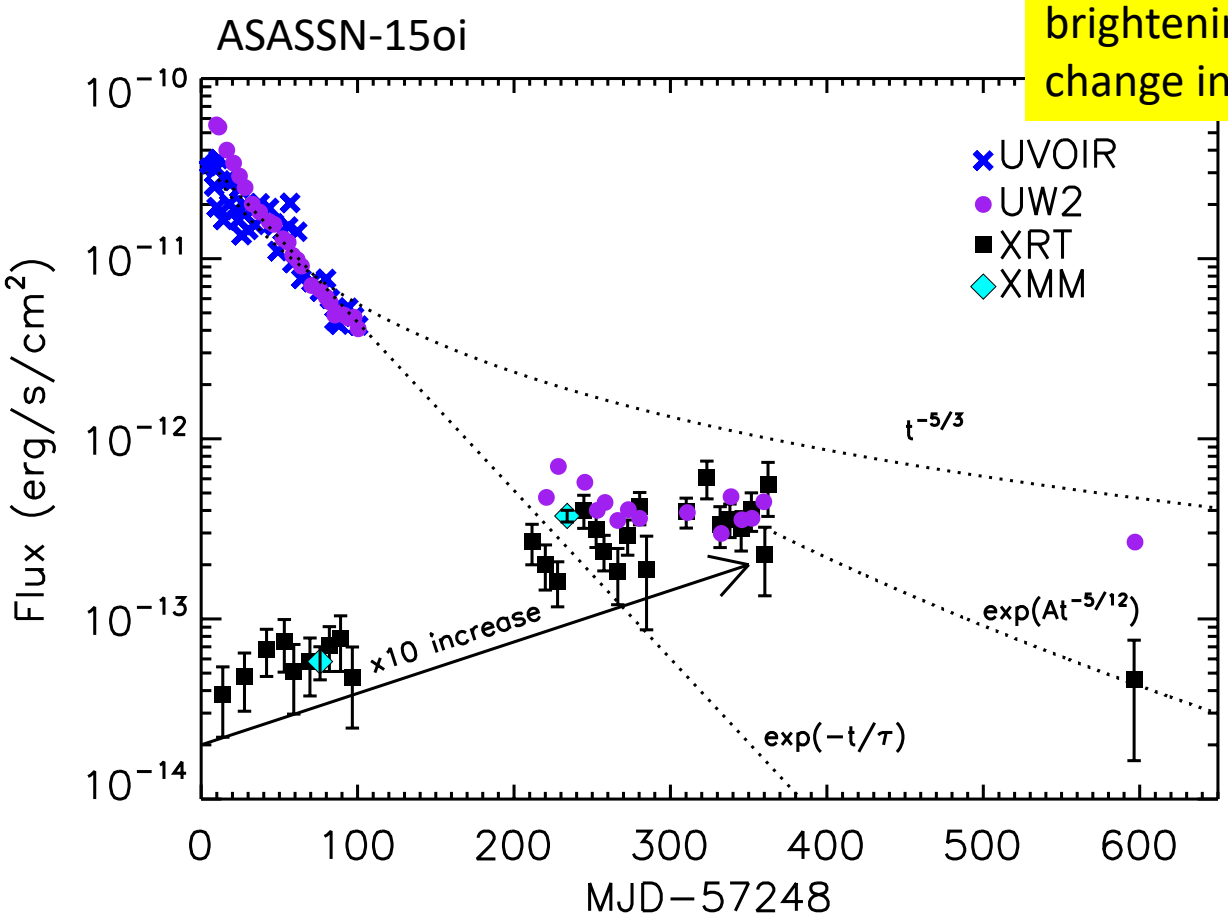




Holoien+ 2016

New Clues from Delayed X-ray Emission in ASASSN-15oi

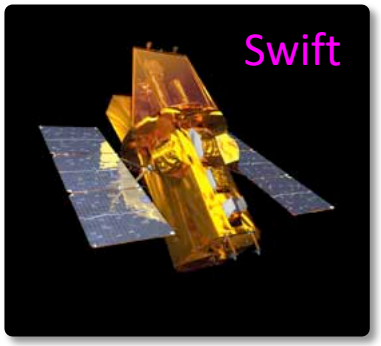
XMM and Swift measure x10 brightening of soft X-rays, with little change in spectral shape (kT_{BB} ~ 45 eV)



Viewing angle? ✗

Variable obscuration? ✗

Circularization delay? ✓



Gezari, Cenko & Arcavi (2017)

Spectral Evolution Probed by XMM

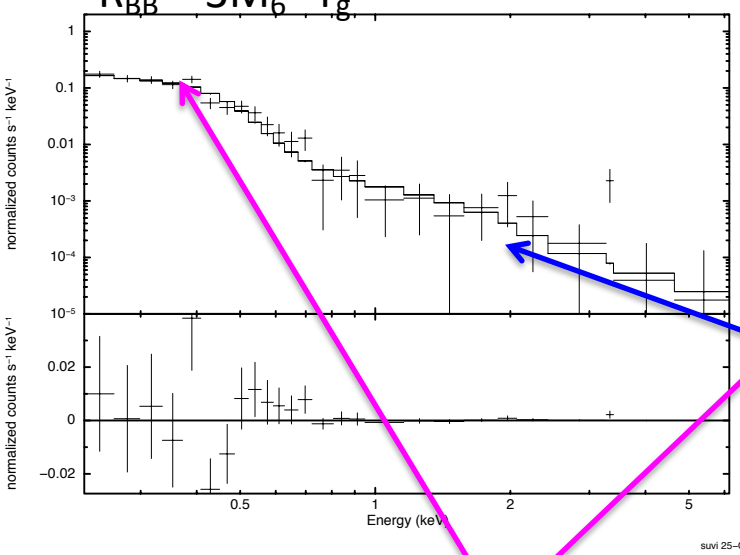
No evolution in soft blackbody temperature during factor of 10 increase in X-ray flux!

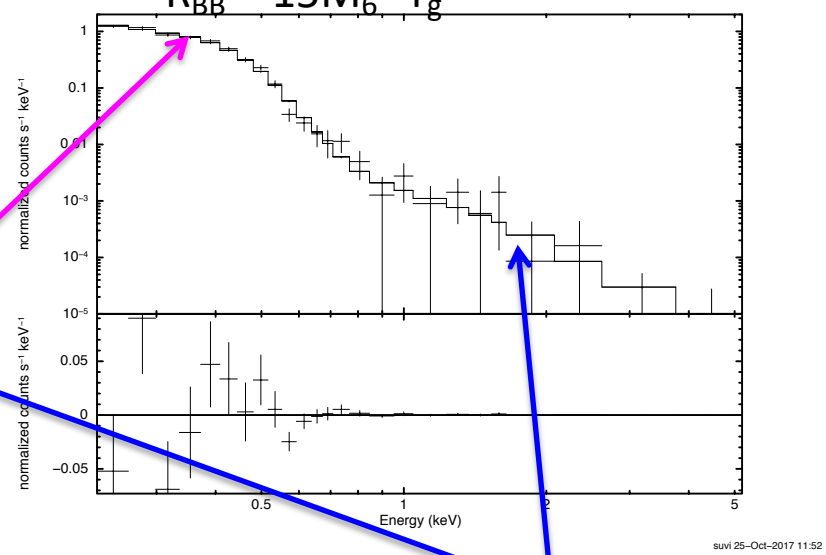
Blackbody radii consistent with inner radii of accretion disk around 10^6 M_{sun} black hole.

Gezari, Cenko & Arcavi 2017

$L_{BB} = 9\times10^{41}$ erg/s → $L_{BB} = 1\times10^{43}$ erg/s

$R_{BB} = 3M_6^{-1}\, r_g$ → $R_{BB} = 15M_6^{-1}\, r_g$



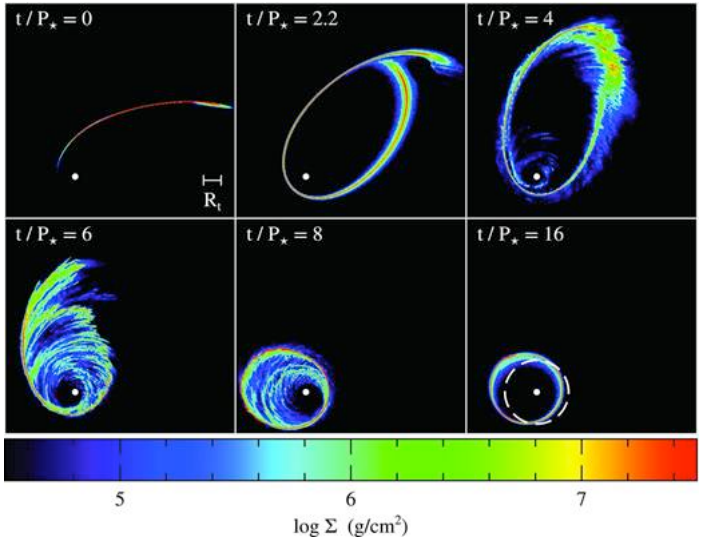


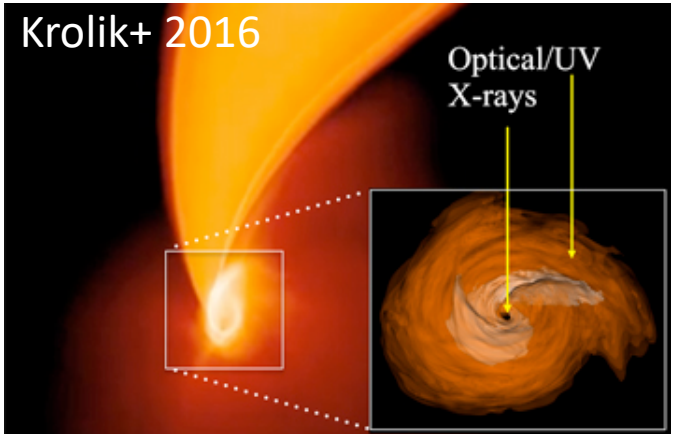
Soft blackbody (kT = 45 eV) component increases by a factor of 12.

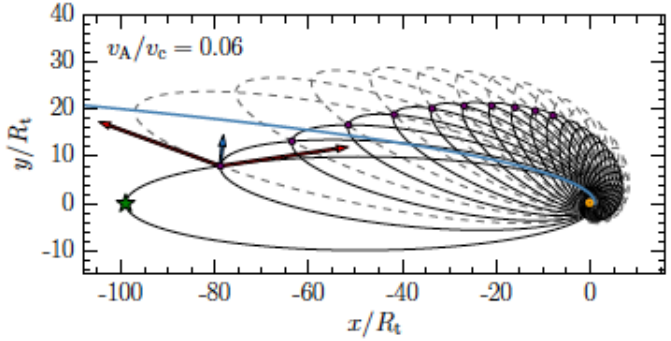
Power-law (Gamma=2.5) component remains constant.

***Delayed* X-ray Emission** due to Circularization Delay?

***Prompt* UV/Optical Emission** from Stream-Stream Collisions?





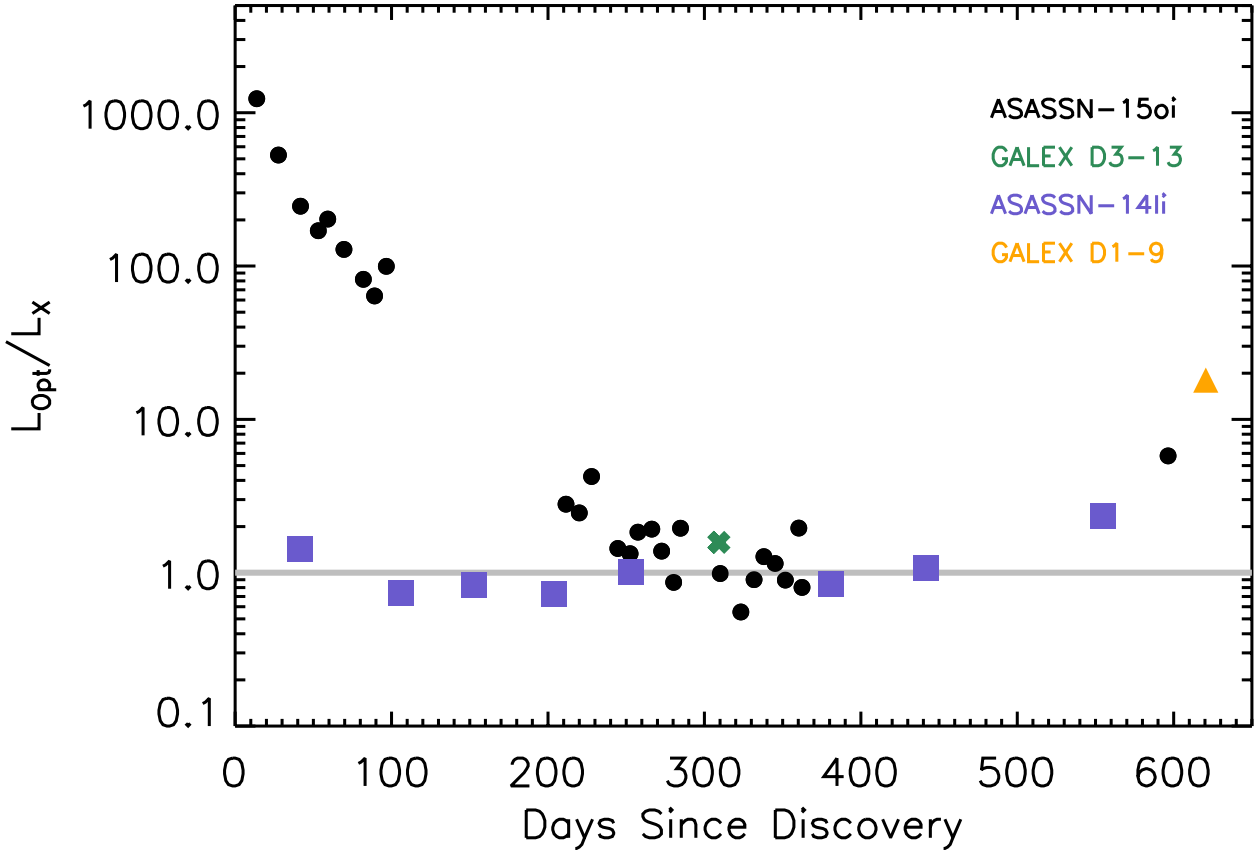


Bonnerot+ 2016

Observations consistent with Piran+ 2015 Model:

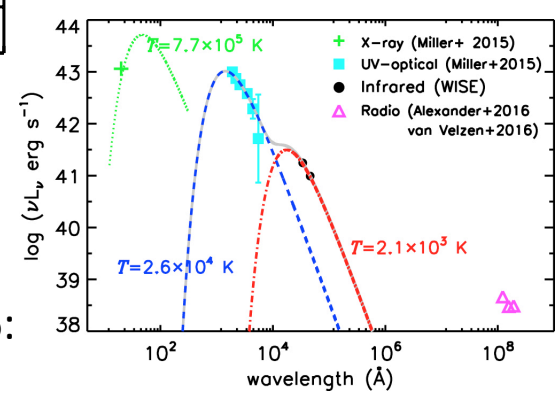
- Prompt UV/Optical component from circularization process!
- Delayed soft X-ray emission from accretion in nascent disk!

Strong Evolution in L_{Opt}/L_X



$L_{Opt}/L_X \sim 1$ characteristic of most optical+X-ray TDEs?

SED of ASASSN-14li from Jiang+ 2016:



Accretion Timescales

The characteristic timescale for a TDE is set by the orbital period of the most tightly bound debris, known as the fallback time ($t_{\rm fb}$), which for a solar-type star is:

$$\boxed{t_{\rm fb} = 41 \text{ d } M_6^{1/2}.}$$

The circularization timescale ($t_{\rm circ}$) driven by relativistic apisidal precession of the debris streams depends on the black hole mass as

$$\boxed{t_{\rm circ} = 8.3 t_{\rm fb}\ M_6^{-5/3} \beta^{-3}}$$

where $\beta = R_{\rm T}/R_{\rm p}$ Bonnerot et al. (2016). Meanwhile, the viscous inflow time scale for a standard α-disk model (Shakura & Sunyaev 1973) is

$$\boxed{t_{\rm visc} = \alpha^{-1}(h/r)^{-2} P_{\rm out} \sim 0.1 t_{\rm fb} (\alpha/0.1)^{-1} (h/r)^{-2}}$$

where α is the standard viscous parameter, h is the scale-height of the disk, and $P_{\rm out}$ is the orbital period of the outer edge of the disk.

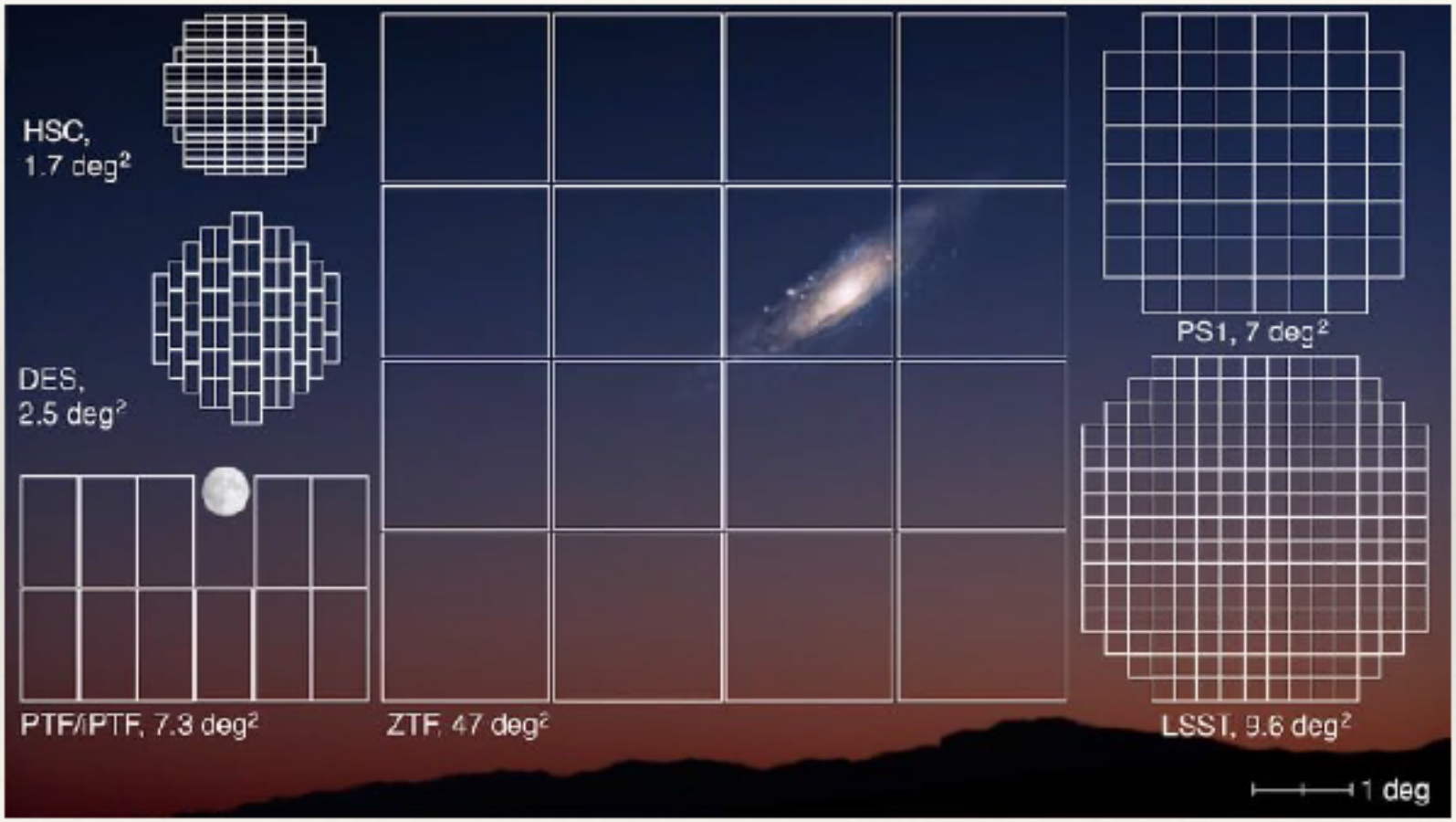
1 yr rise time of X-ray to peak is tantalizingly close to the circularization timescale of a 10^6 M_{sun} TDE!

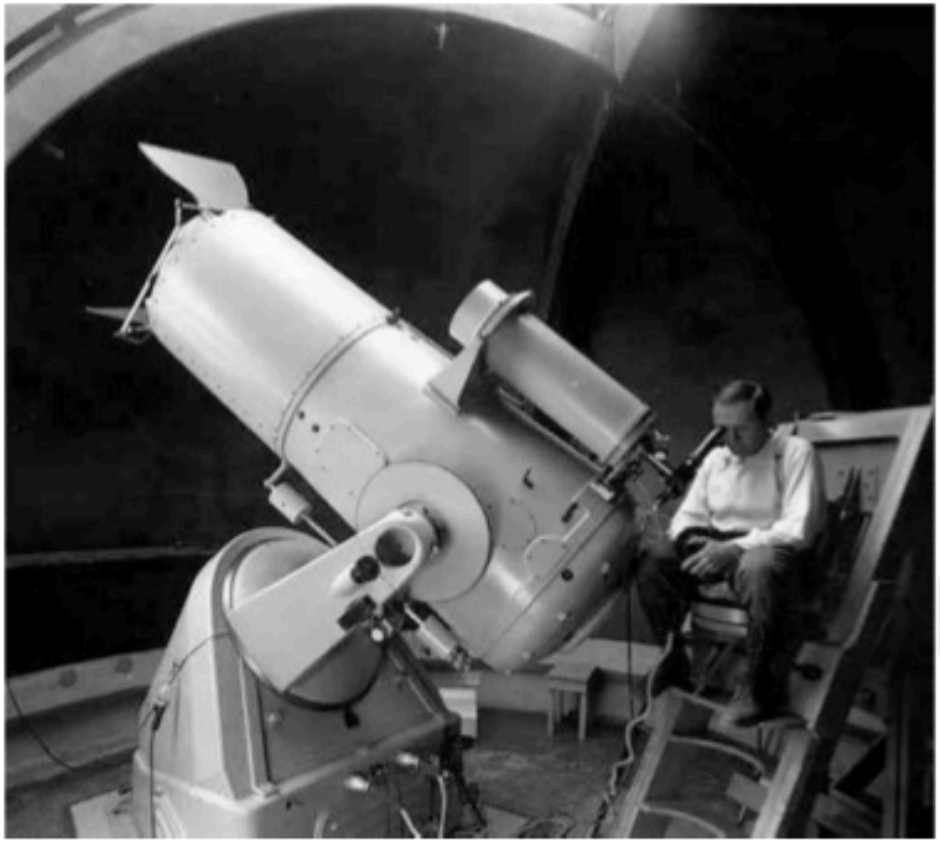
Where do we go from here…

Where do we go from here…

More events…

The Golden Age of Wide-Field Optical Surveys





The Zwicky Transient Facility (ZTF)

Started in March 2018

UMd is a member of the ZTF collaboration, along with:

ipac Caltech DESY Los Alamos NATIONAL LABORATORY Oskar Klein centre

UWM מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE W UST

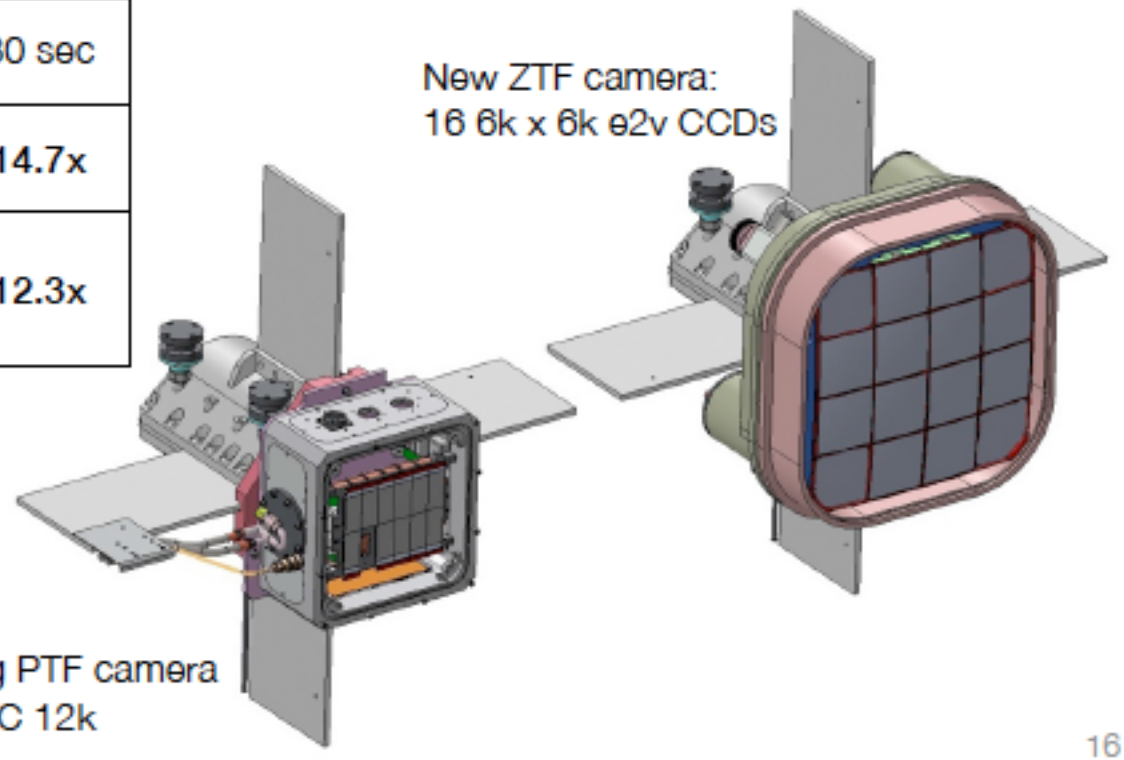
ZTF will survey an order of magnitude faster than PTF.

	PTF	ZTF
Active Area	7.26 deg^2	47 deg^2
Readout Time	36 sec	10 sec
Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	**14.7x**
Relative Volumetric Survey Rate	1x	**12.3x**

3800 deg^2/hour

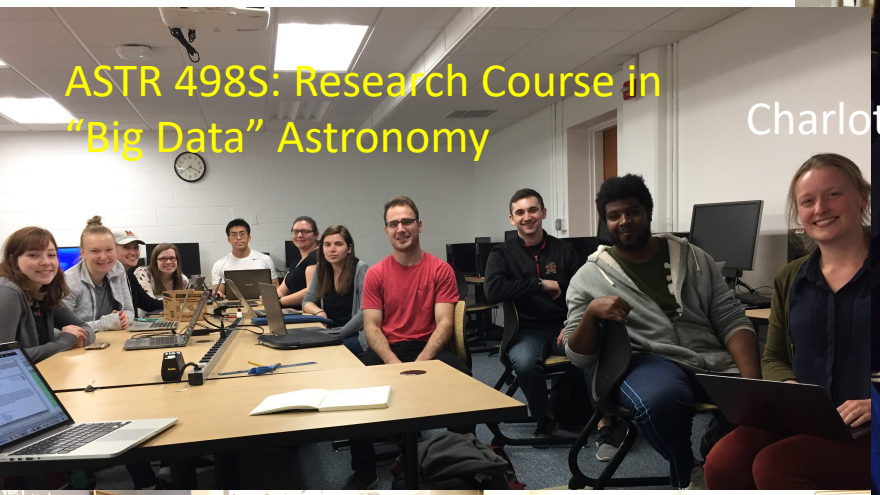
⇒ 3π survey in 8 hours,

> 250 observations/field/year

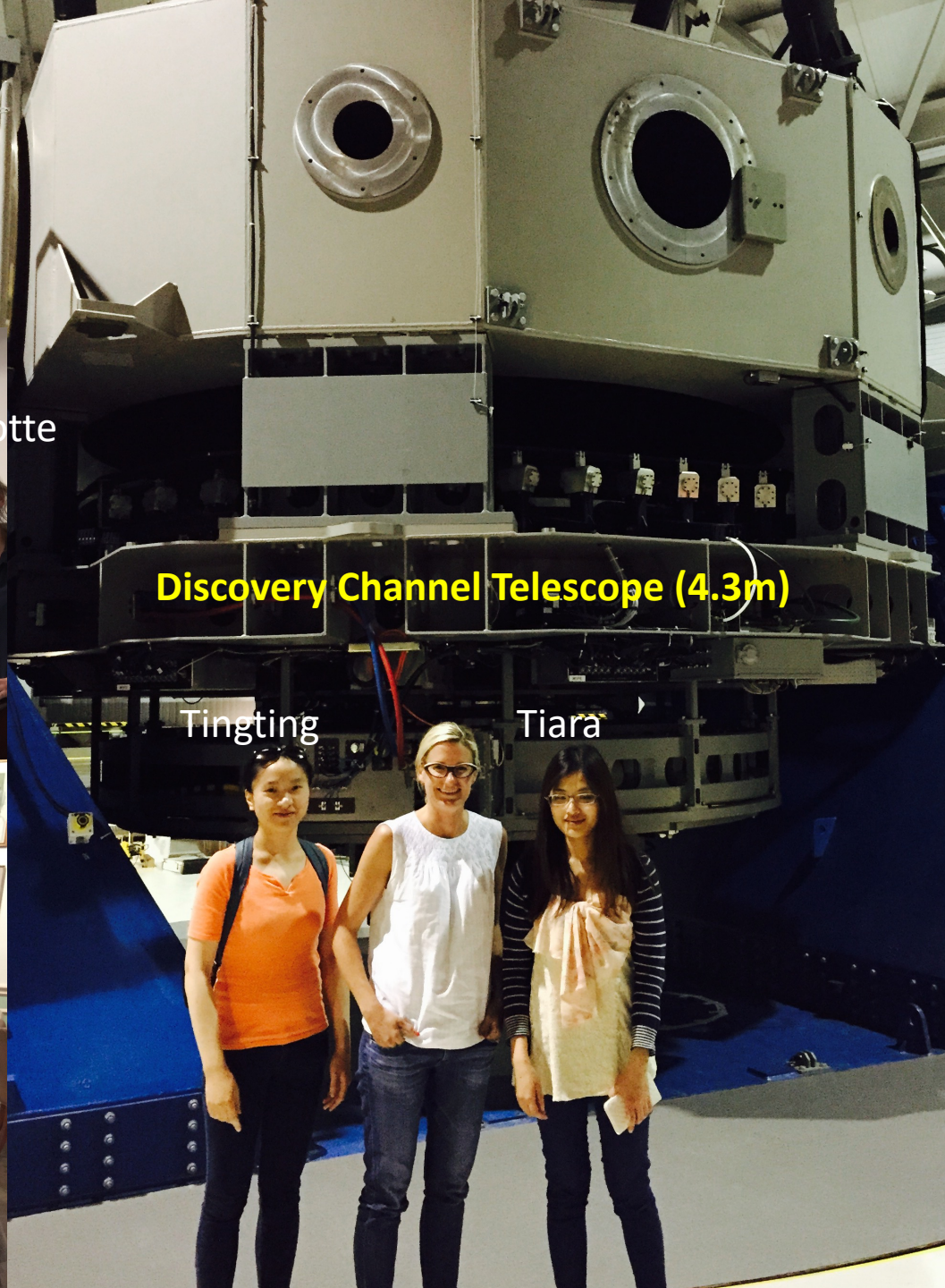


We discovered two TDEs in 4 months with iPTF…expect 1-2 TDEs per month with ZTF!

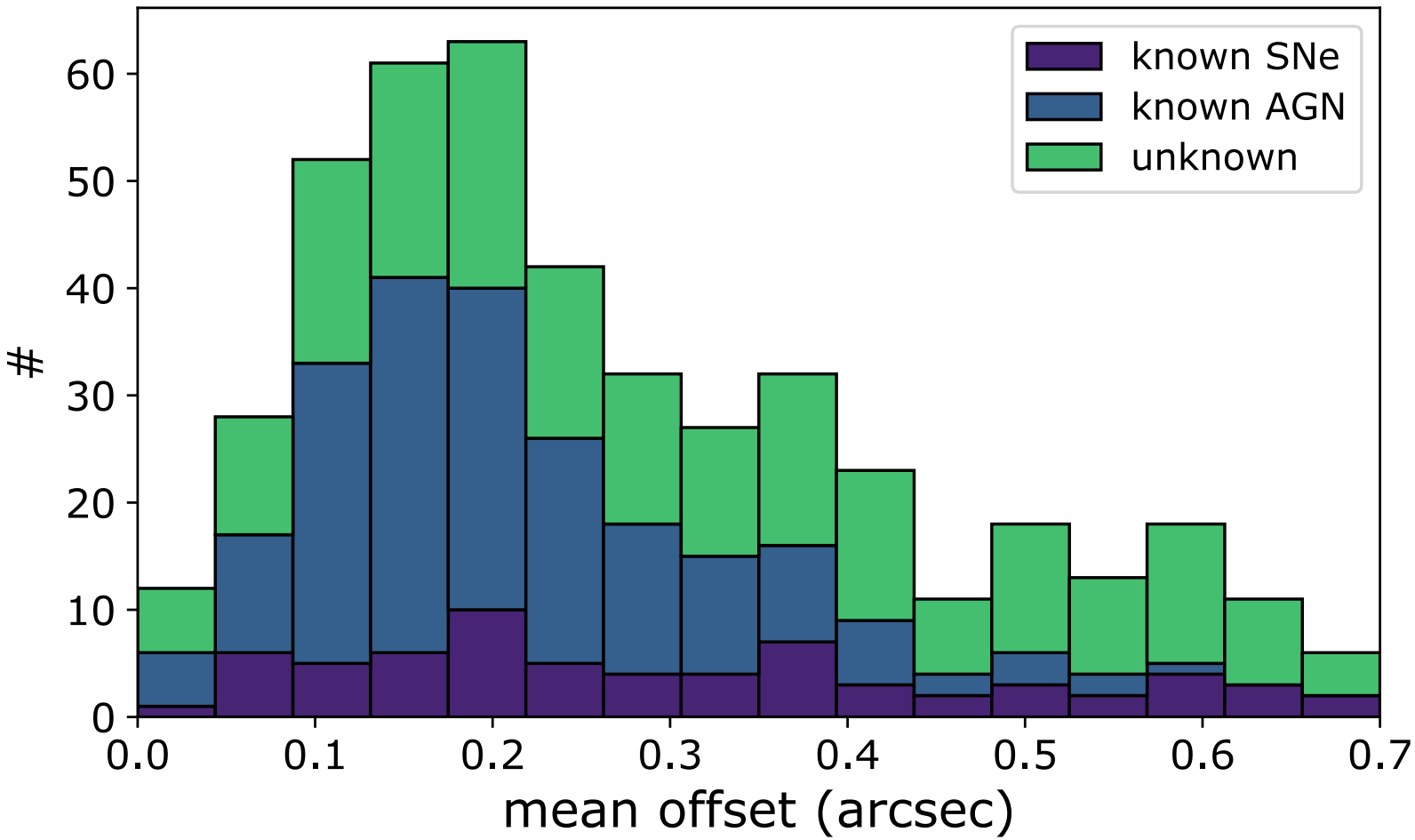
ZTF@UMd


ASTR 498S: Research Course in
"Big Data" Astronomy
Charlotte

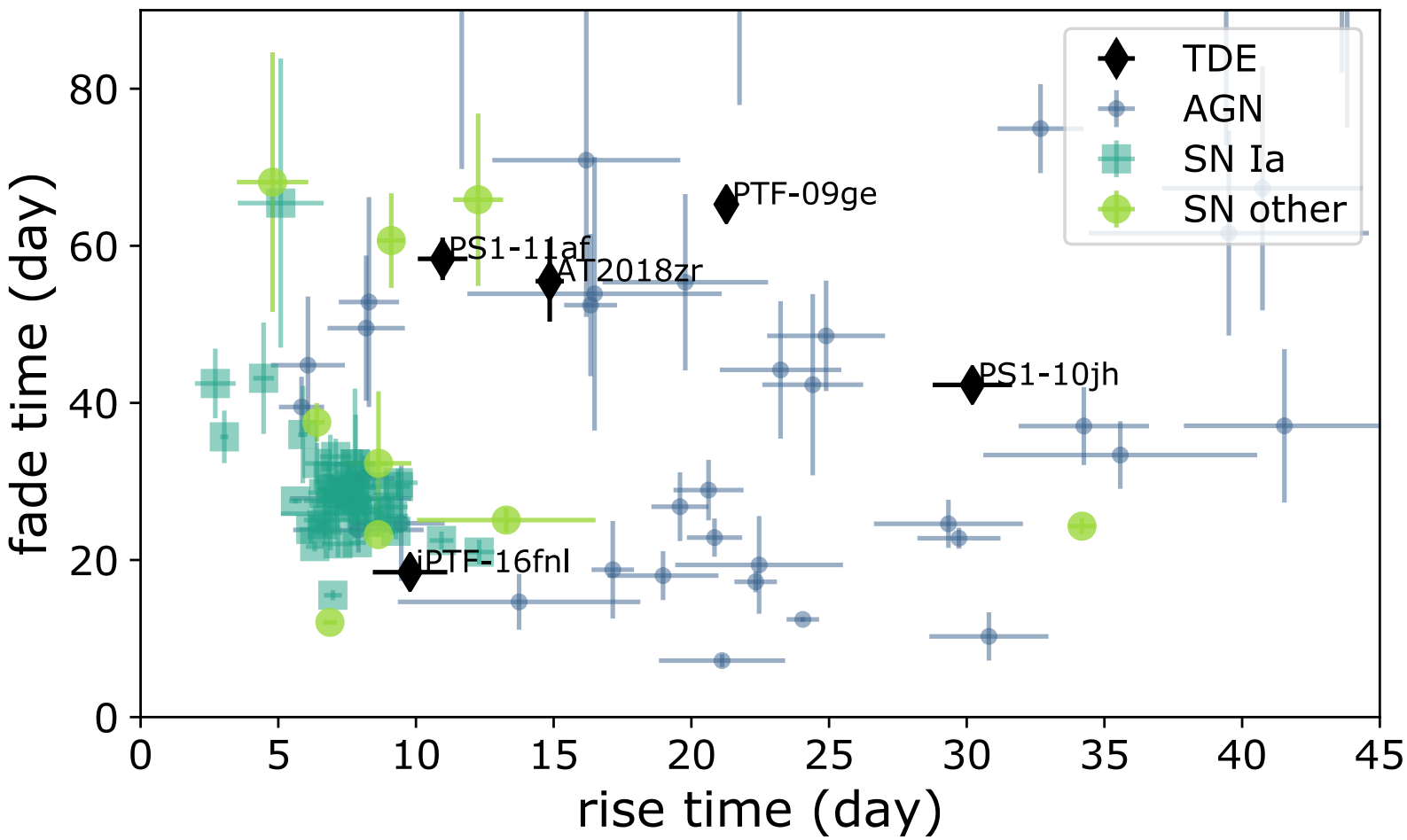
Sjoert
Sara


Discovery Channel Telescope (4.3m)
Tingting
Tiara

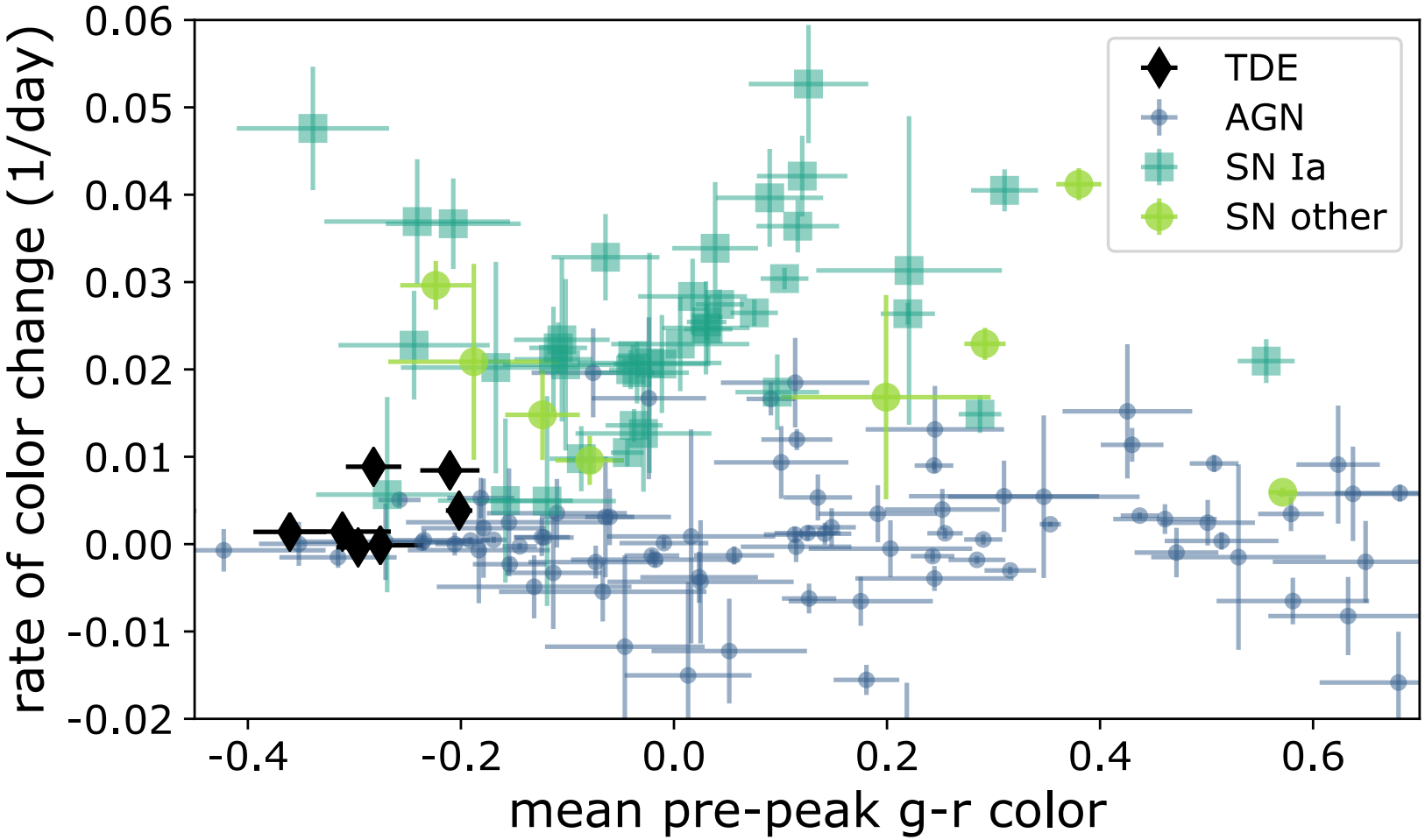
Offset Distribution



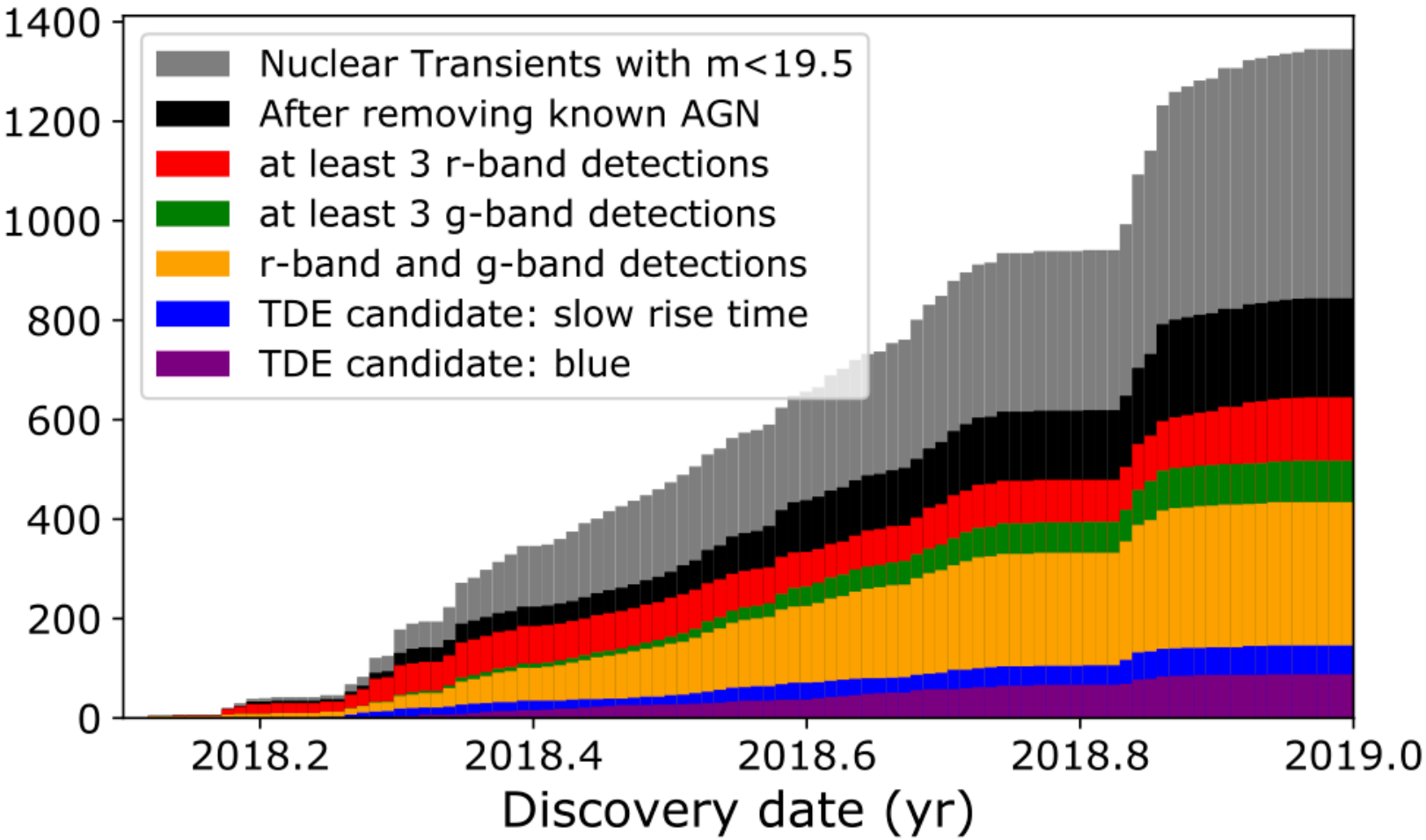
Filtering Out Pesky SNe



Filtering Out Pesky SNe



ZTF Nuclear Transient Alert Stream



WINTER
IS
COMING

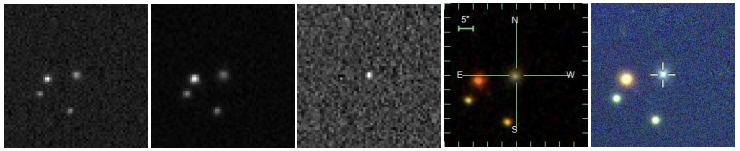
GOT Nicknames

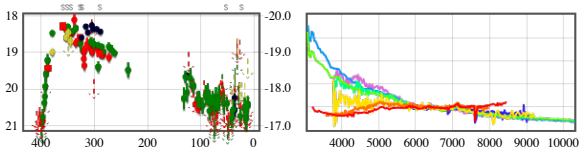
ZTF18abxftqm TDE 01:07:33.61 +23:28:34.4
16.890057 +23.476219

View another

OVERVIEW PHOTOMETRY SPECTROSCOPY OBSERVABILITY EXAMINE FINDING CHART

NEW REF SUB SDSS PS1





g = 20.4 (12.2 d) | Upload New Photometry

z = 0.088 | Upload New Spectroscopy
DM (approximate) = 38.00

First saved in public data.

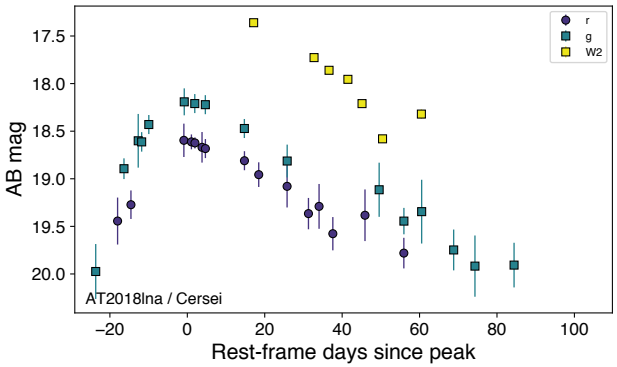
ADDITIONAL INFO

NED | TNS | SNEx | SIMBAD | VizieR | HEASARC | SkyView | MPChecker | Extinction
CFHT | IPAC | DSS | WISE | Subaru | VLT | FIRST | CRTS - ADS
iPTF Marshal | LegacySurvey | Avro Packets

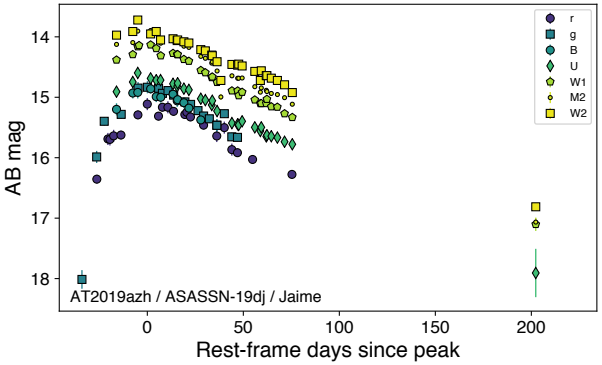
AUTO ANNOTATIONS
2019 Aug 05 AMPELBOT [saved_by_id]: AmpelTNS
2019 Jan 25 sjoert [Reference]: 2018-06-11 10:48:15 to 2018-09-12 09:08:02
2018 Nov 15 sjoert [saved_by_id]: ZTFBH Nuclear
2018 Nov 06 jnordin [saved_by_id]: AMPEL Test
2018 Nov 04 ysharma [Saved_date]: 2018-11-03 RCF
2018 Nov 03 fremling [passed_filter]: Redshift Completeness Factor
2018 Oct 22 fremling [IAU name]: AT2018hco
2018 Sep 28 suvi [passed_filter]: Nuclear Transients
2018 Sep 27 jesper [SDSS_photz_auto]: 0.109 +- 0.0376 (0.276", [reference])
2018 Sep 27 jesper [passed_filter]: ZTF Science Validation
Auto Annotation Submission Form
COMMENTS
2019 Sep 11 ekhammer [comment]: telluric corrections applied
2019 Sep 11 ekhammer [comment]: issues with blue end flux calibration
2019 Jan 09 suvi [info]: host galaxy not detected in GALEX AIS in NUV
2019 Jan 03 rsw [comment]: pysedm_report [view attachment]
2018 Dec 05 jesper [info]: ATEL #12263 Title: Classification of AT2018hco/ZTF18abxftqm as a tidal disruption flare
2018 Dec 03 suvi [redshift]: 0.088
2018 Dec 01 suvi [classification]: TDE
2018 Nov 27 suvi [info]: Sansa Stark (ZTFbh SWG Name)
2018 Nov 27 rsw [comment]: pysedm_report [view attachment]
2018 Nov 15 suvi [info]: triggered Swift
2018 Nov 15 suvi [info]: revised redshift based on Ca H,K in APO spectrum
2018 Nov 10 kde [classification]: TDE?
2018 Nov 10 kde [redshift]: 0.09
2018 Nov 04 mlgraham [comment]: APO+DIS spectrum 18-11-03: dewar contamination lead to poor quality spectra, flux calibration not trustworthy

ZTF+Swift Light Curves

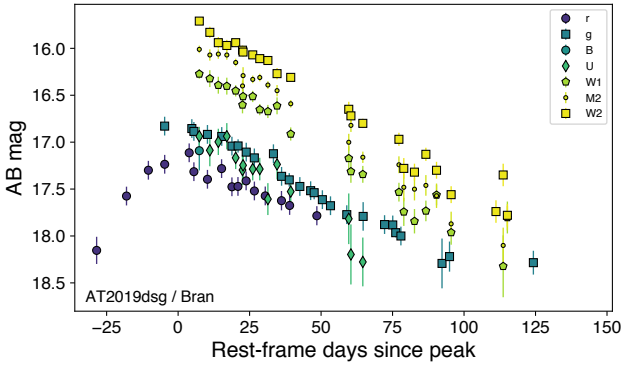
Cersei



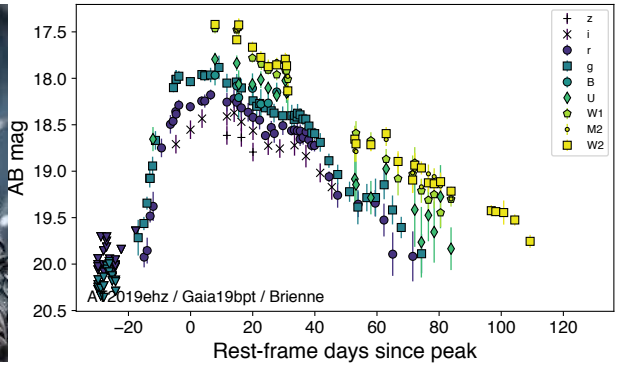
Jaime



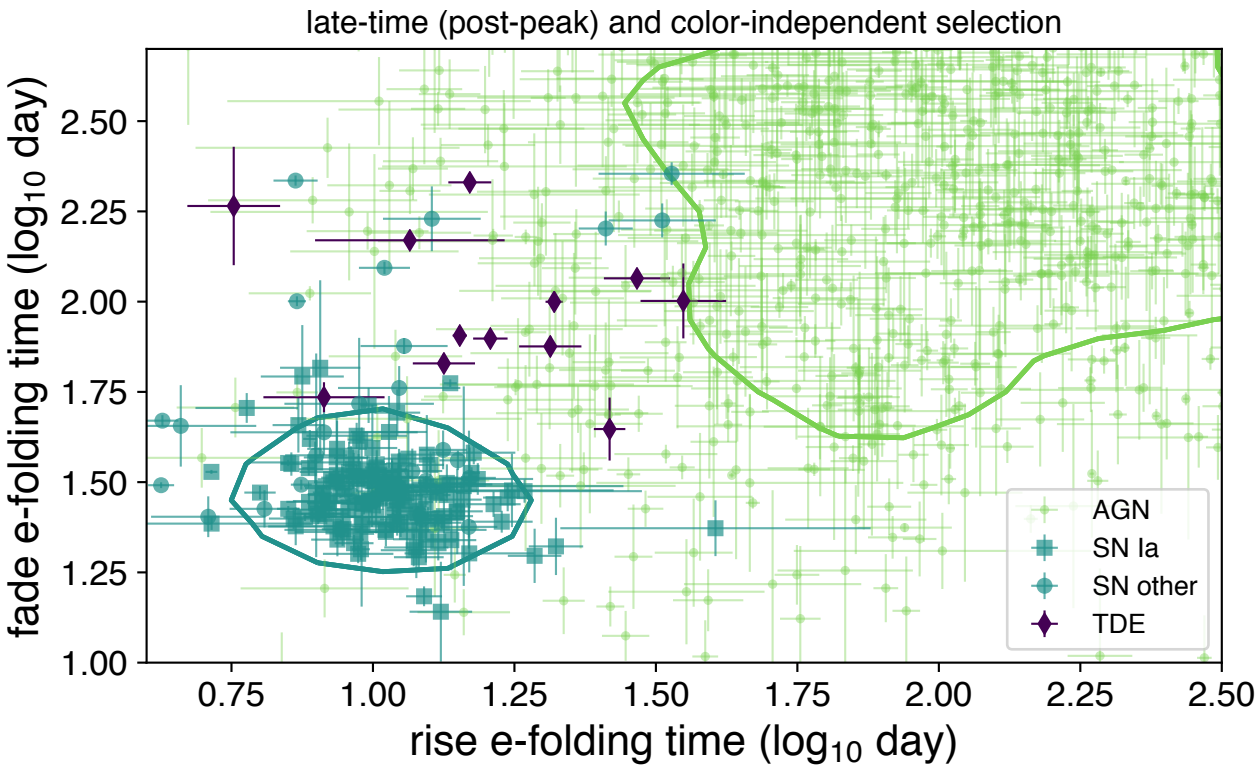
Bran



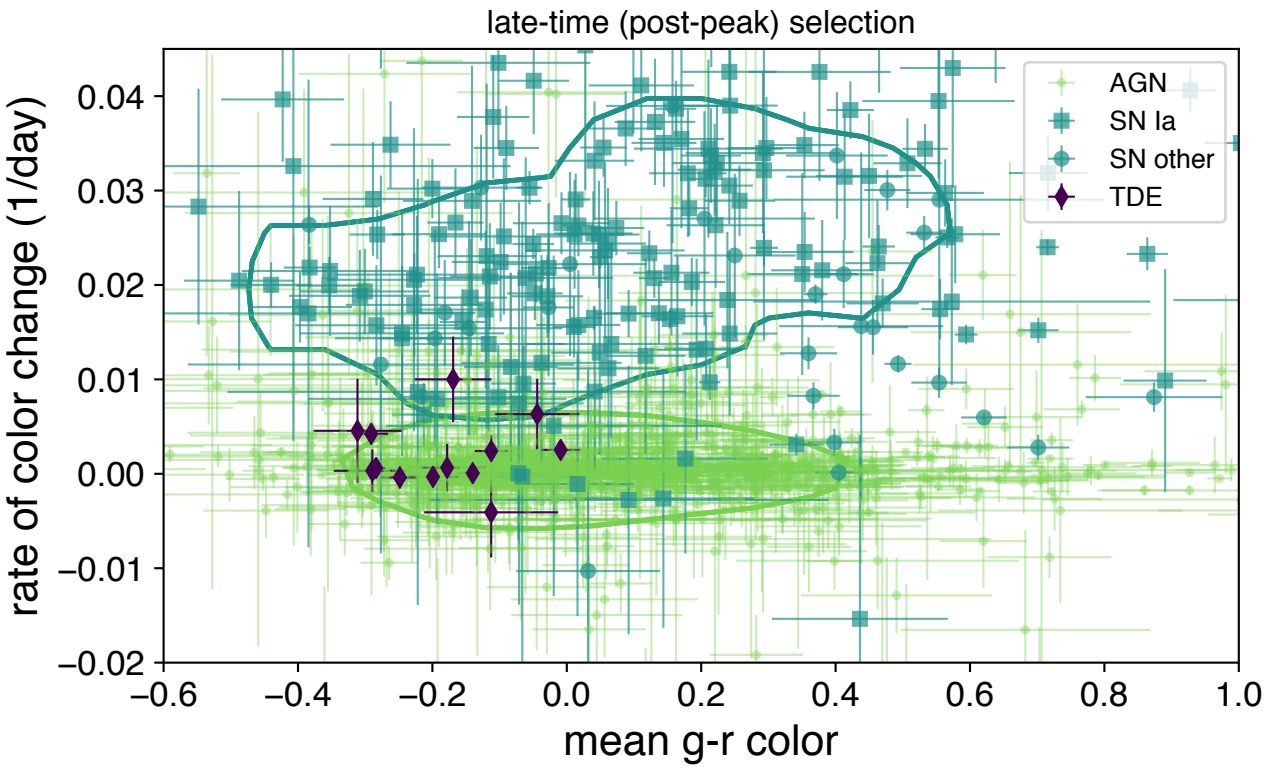
Brienne



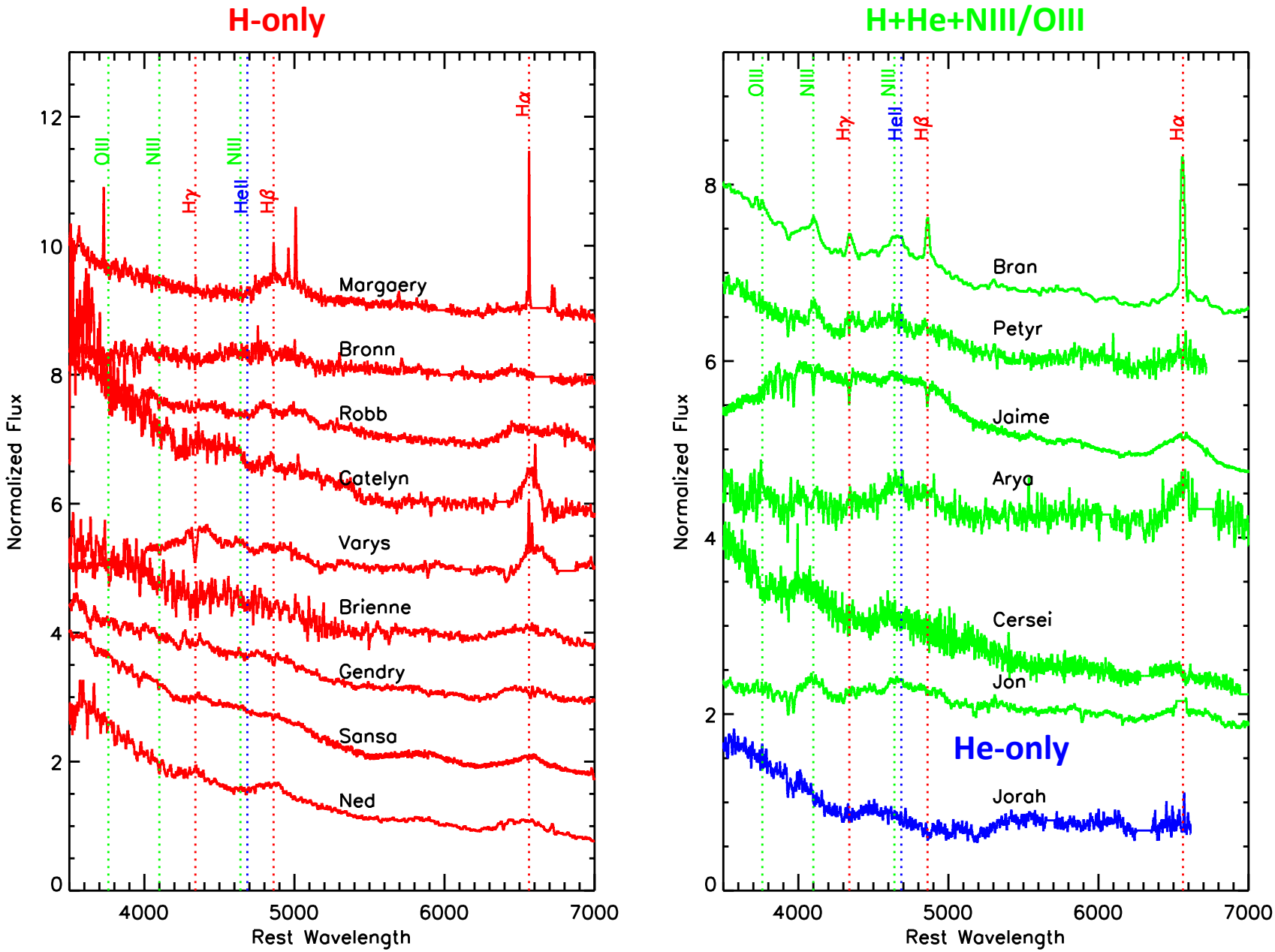
Slow Rise and Fade Times



Blue with No Color Evolution

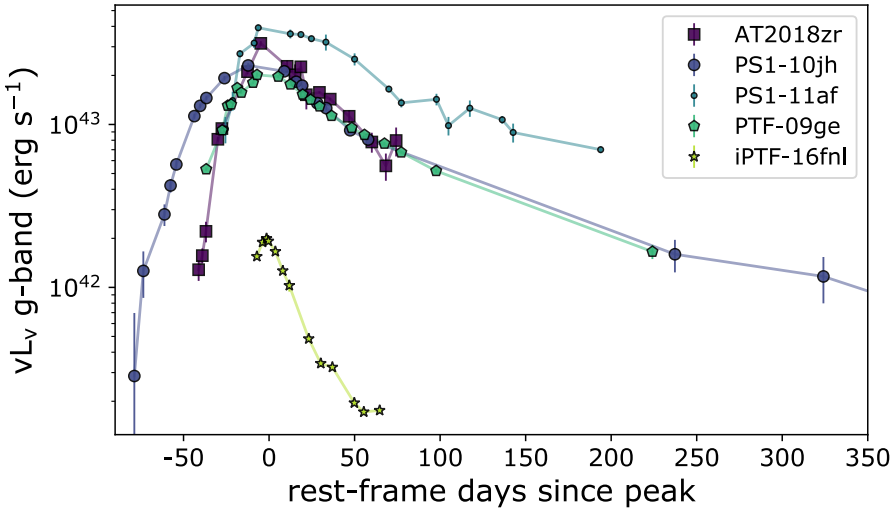


Spectral Types



Pre-Peak Light Curves

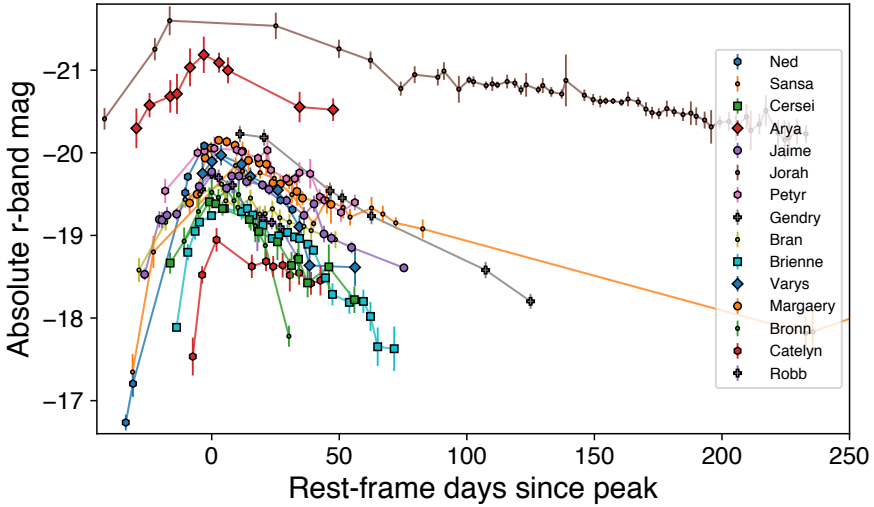
Before ZTF



van Velzen, Gezari, et al. 2018

*AT2018zr was one of only 5 TDEs discovered **before** peak!*

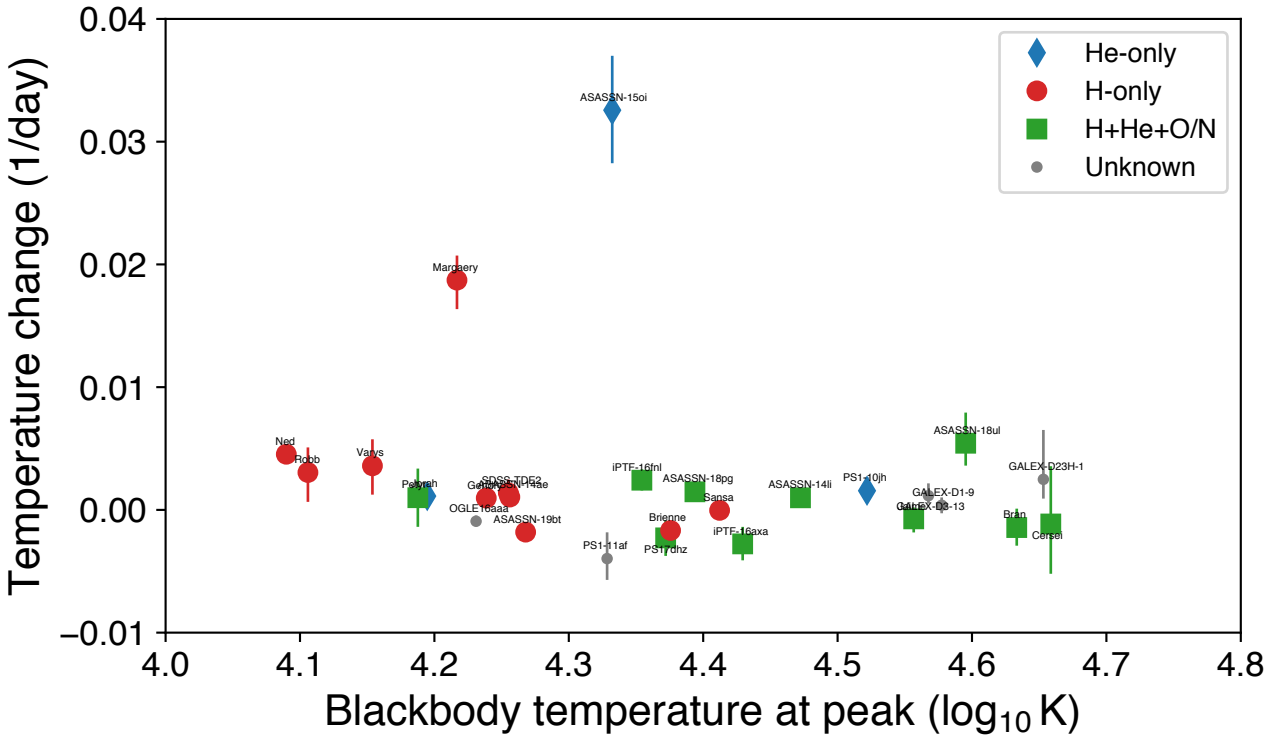
After ZTF



van Velzen, Gezari, et al. in prep.

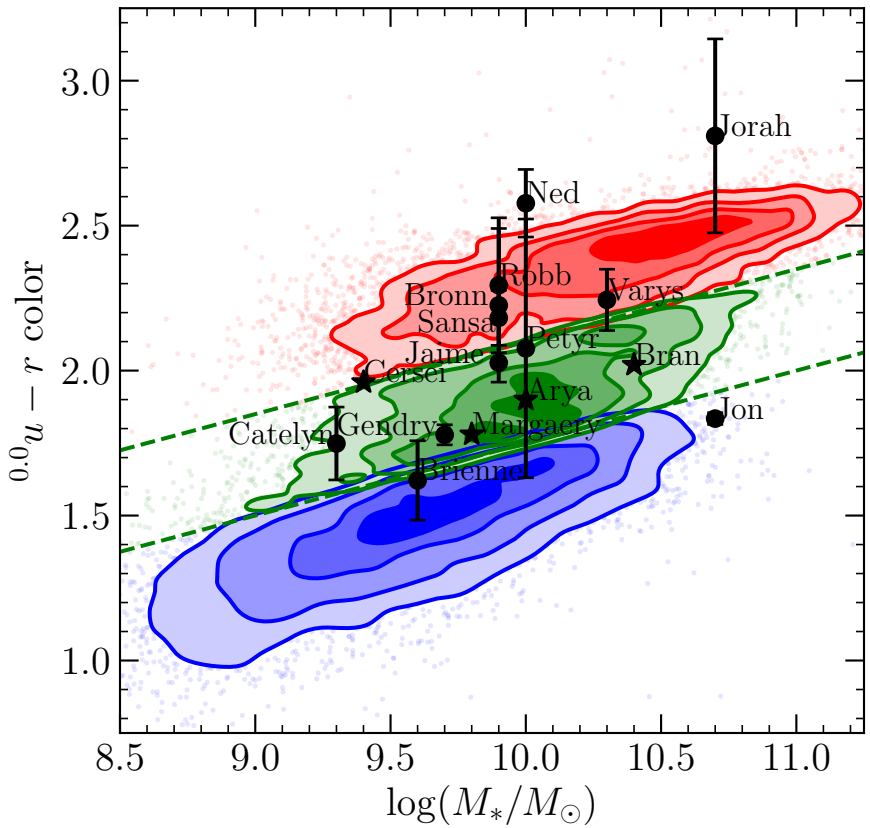
In the first 1.5yr of ZTF survey operations, we have detected 14 more!

UV-Bright BB Temperature



van Velzen, Gezari+ in prep.

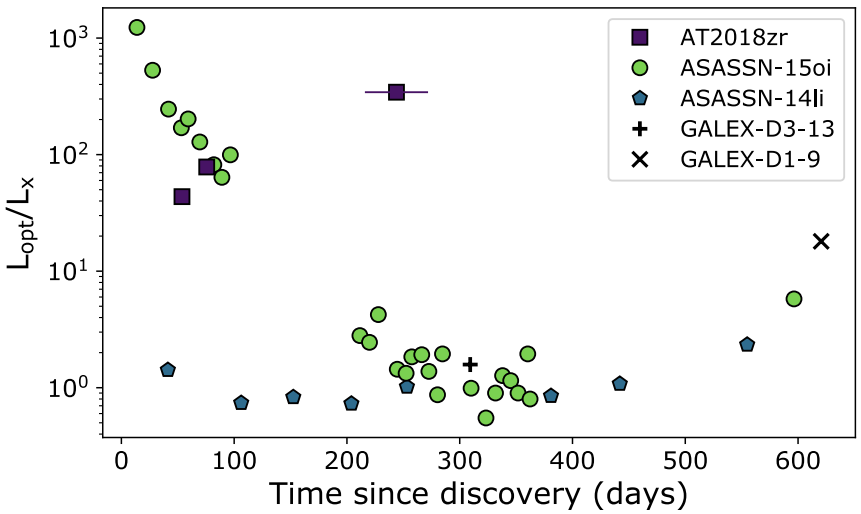
Red Galaxy Hosts



van Velzen, Gezari+ in prep.

New Landscape of Optical+X-ray TDEs

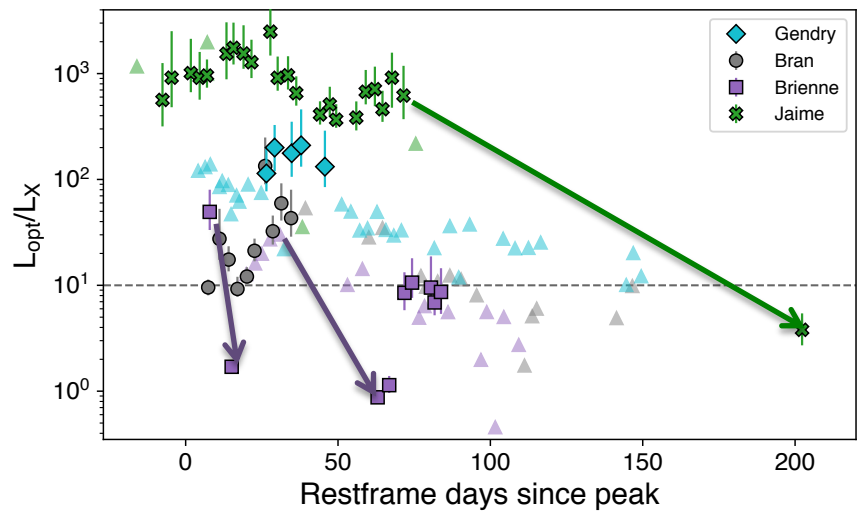
Before ZTF



van Velzen, Gezari, et al. 2018

*AT2018zr was one of only 5 TDEs with an optical **and** X-ray detection!*

After ZTF

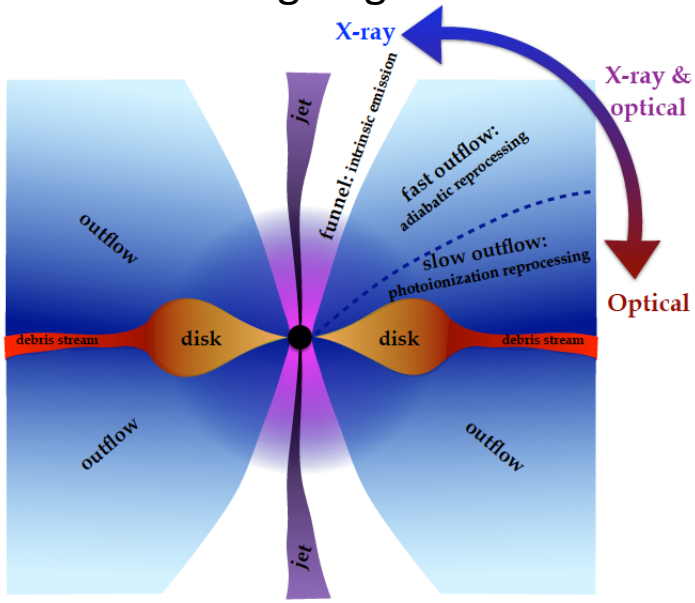


van Velzen, Gezari, et al. in prep.

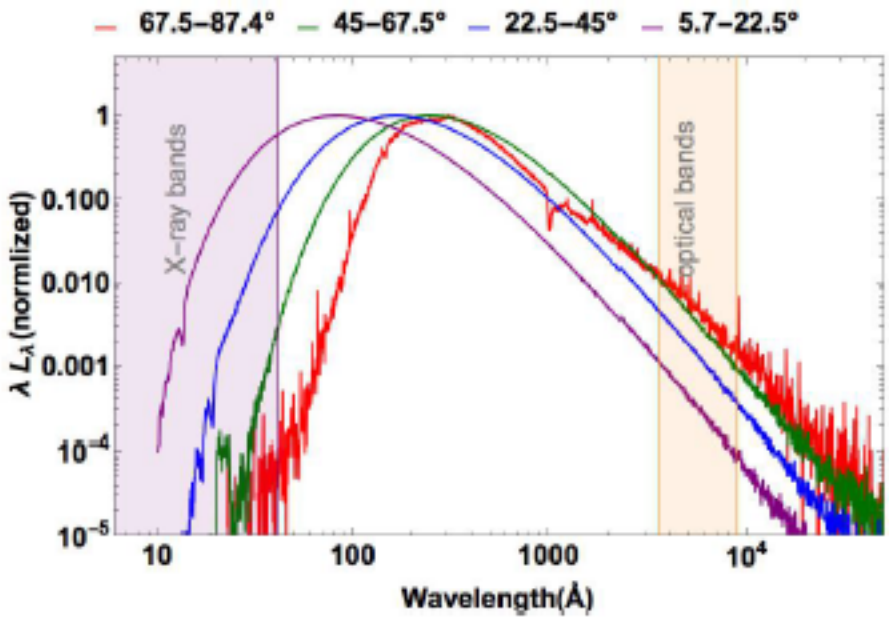
In the first 1.5yr of ZTF survey operations, we now have detected 3 more TDEs in the soft X-rays, and with dramatic variability!

What is driving changes in Lopt/Lx?

Viewing Angle?

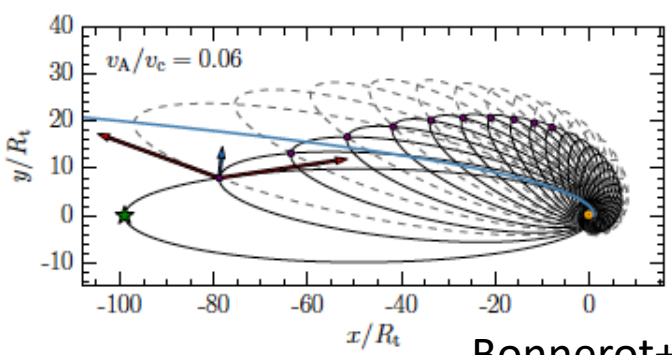


Reprocessing?



Dai et al. 2018

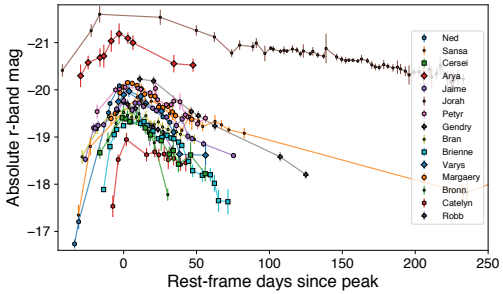
Circularization?

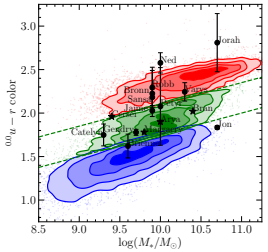


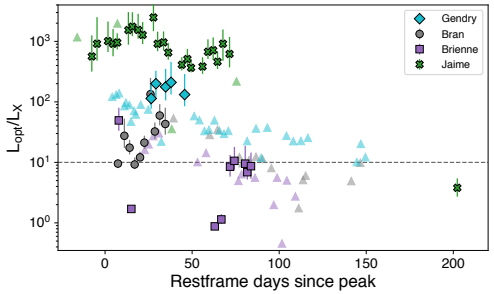
Bonnerot+ 2016

Conclusions

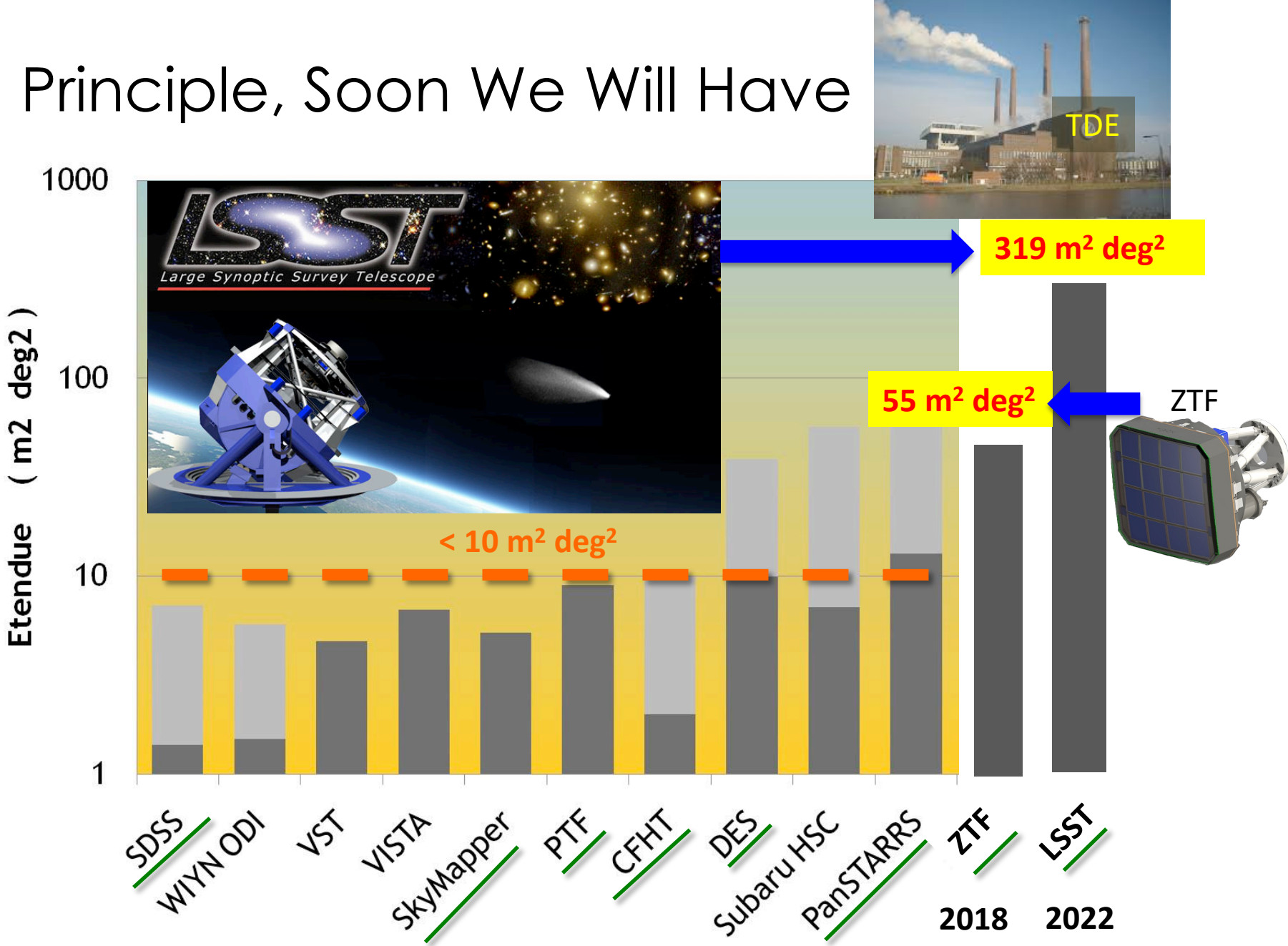
- ZTF is on track to be the first survey to produce a **statistically significant, systematically selected** TDE sample
- Will enable **population studies** of TDEs and their host galaxies and central black holes
- **Swift and XMM-Newton** follow-up have been critical for probing the UV and X-ray components
- **Soft X-ray evolution** may hold the key for unlocking the nature of the UV/optical component, and for probing the real-time formation of the accretion disk







In Principle, Soon We Will Have



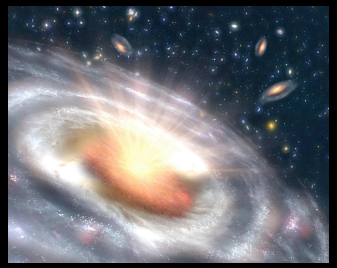
Surveys with time domain component.

LSST's Bread & Butter
Transients & Variables

(known knowns)

✧2 million variable quasars

(Sesar+ 2007)

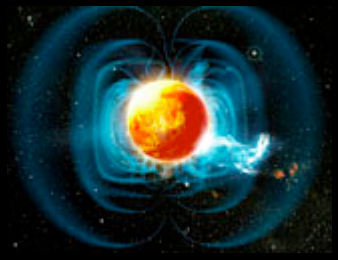


✧10 million supernovae

(LSST Science Book)

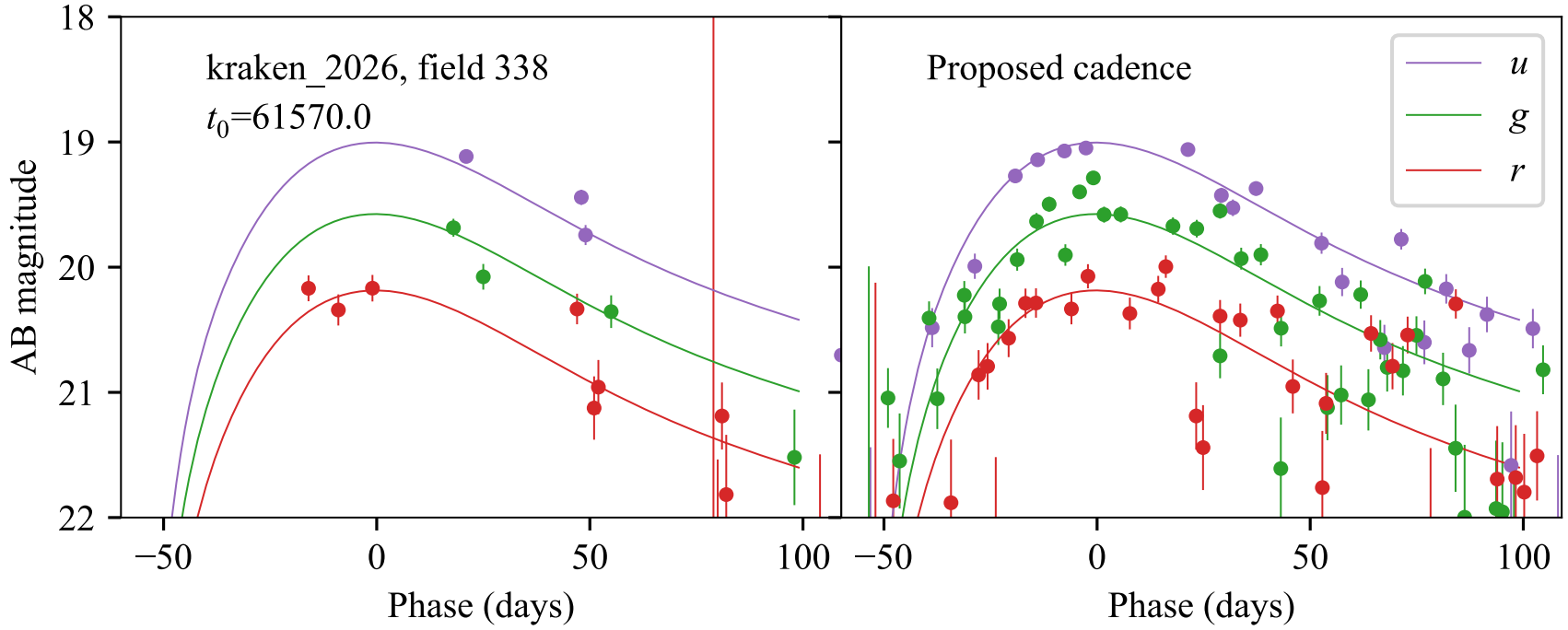
✧50 million variable stars

(Sesar+ 2007)



A Smart & Colorful Rolling Cadence Proposal for LSST Wide-Fast Deep Survey

LSST has the capability to discover 200 TDEs yr^{-1} per 1000 deg^2…but changes to the baseline LSST Wide-Fast Deep Survey cadence are required for early detection, photometric classification, and light-curve characterization.



Gezari+ 2018, LSST Cadence White Paper