Australian-Subaru large collaborative programs

Galaxies, supernovae, and fast transients

Jeff Cooke

Collaborative large programs

My Science ***Jeff Cooke, Swinburne University***

High redshift galaxies

Lya and spectral properties and environment
Reionisation (LCGs and LyC from galaxies and supernovae)

High redshift supernovae

Surveys, detection, spectral study, PISNe, Pop III star deaths

Fast transient detection

Millisecond-to-hour durations, FRB and GW counterparts,
Multi-wavelength, simultaneous observations, rapid-response and longer-term follow-up observations
Real-time reduction, analysis and candidate identification software, human visualisation, citizen science

JWST Early Release Science Supernova Survey

First Stars:

Proposed Early Release Science with JWST

Lifan Wang[1], Jeremy Mould[2], Jeff Cooke[2], Paul Geil[3] & the SN in the dark team

[1]Texas A&M University, [2]Swinburne University of Technology, [3]University of Melbourne Email: jmould@swin.edu.au

Just as a well-publicized early goal of the Hubble Space Telescope was to measure the Hubble Constant, so a well-publicized early goal of the James Webb Space Telescope is to find and characterize the first stars in the Universe. First stars, however, is shorthand for the first galaxies, the first supermassive black holes (SMBH), and the first supernovae (SNe), and all that that entails. The scientific community is looking at four momentous astrophysics problems in the epoch between the Dark Ages and the transparent Universe: first SNe, first black holes, earliest galaxies and the large scale structure in the epoch of reionization. This ERS will enable time-domain astronomy to redshift above 6, and set strong constraints on physics of massive star and black hole formation at redshifts around 10-20.

This ERS will take two epochs of NIRCAM images of 50 contiguous fields covering about 400 square arcmin around a popular deep survey field, separated by ~3 months. Foreground exclusion is defined with rigor in this ERS. Our team will complete a 1μ Subaru HSC survey of these fields to complement the 2um and 4um filters of the JWST NIRCam imaging. We will generate a catalog of high redshift objects with a preliminary variability screening that will be of great value throughout the lifetime of JWST. JWST takes us into a discovery space of transient phenomena at AB>26 mag at 4μ of which we have no knowledge. The community needs to know what is there. This ERS can be the reference frame for all future community work on high z transients and large scale structure formation.

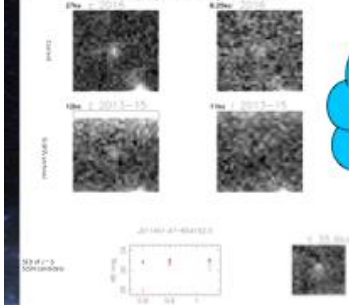
The High z Universe

An unavoidable problem in probing the high redshift Universe is the rapid rise of luminosity distance with redshift. In luminosity distance the epoch of reionization (EoR) from t = 100 Myrs extends 80 Hubble radii. We have spent the best part of the 20th century getting a passable picture of one Hubble radius. More powerful telescopes and instruments are needed for the EoR, such as:

- **JWST: [powerful, but small field, with spectroscopy paramount]**
- **DECam: [1μ and shorter, wide field (Flaugher et al 2012)]**
- **KDUST: [1μ<λ< 3μ, wide field (Yuan et al 2012)]**
- **Subaru: [Hyper Suprime Cam (HSC -- Miyazaki 2015)].**

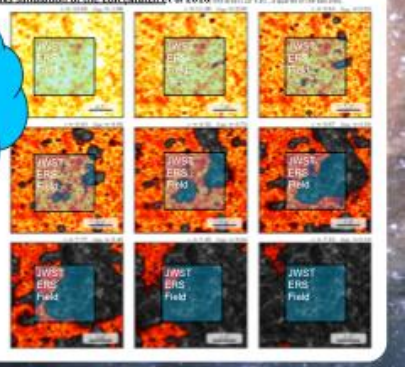
Goals of the ERS ERS program

DECamERON project: finding z ~ 6 SLSNe



A contiguous field as large as 20'X20' is needed to provide a realistic probability of discovery at z above 10. To find targets at even higher redshifts, a 1 degree field may be necessary.

DRAGONS simulation of the EoR (Mutch et al 2016



The goal of the DECamERON project is a deep-wide field high redshift photometric survey to study large scale structure (LSS) and rare events. It is not to compete with deeper narrow surveys like EGRS (Trenti et al 2010). To maximize time allocation flexibility all 3 of our chosen single DECam fields are circumpolar.

Abbott et al (2017) review four years' progress in this project, including a preliminary LSS result. The large scale structure in Hubble diagnostic agrees with HIGH CANDELS (Barone-Nugent et al.) The paper also reviews surveys and expectations for superluminous supernovae (SLSNe) and reports high z DECamERON SN candidates.

Reference

Abbott et al 2017, PASA, 34, 12

Barone-Nugent et al 2014, ApJ 793, 17

Mutch et al 2016, MNRAS, 461, 3353

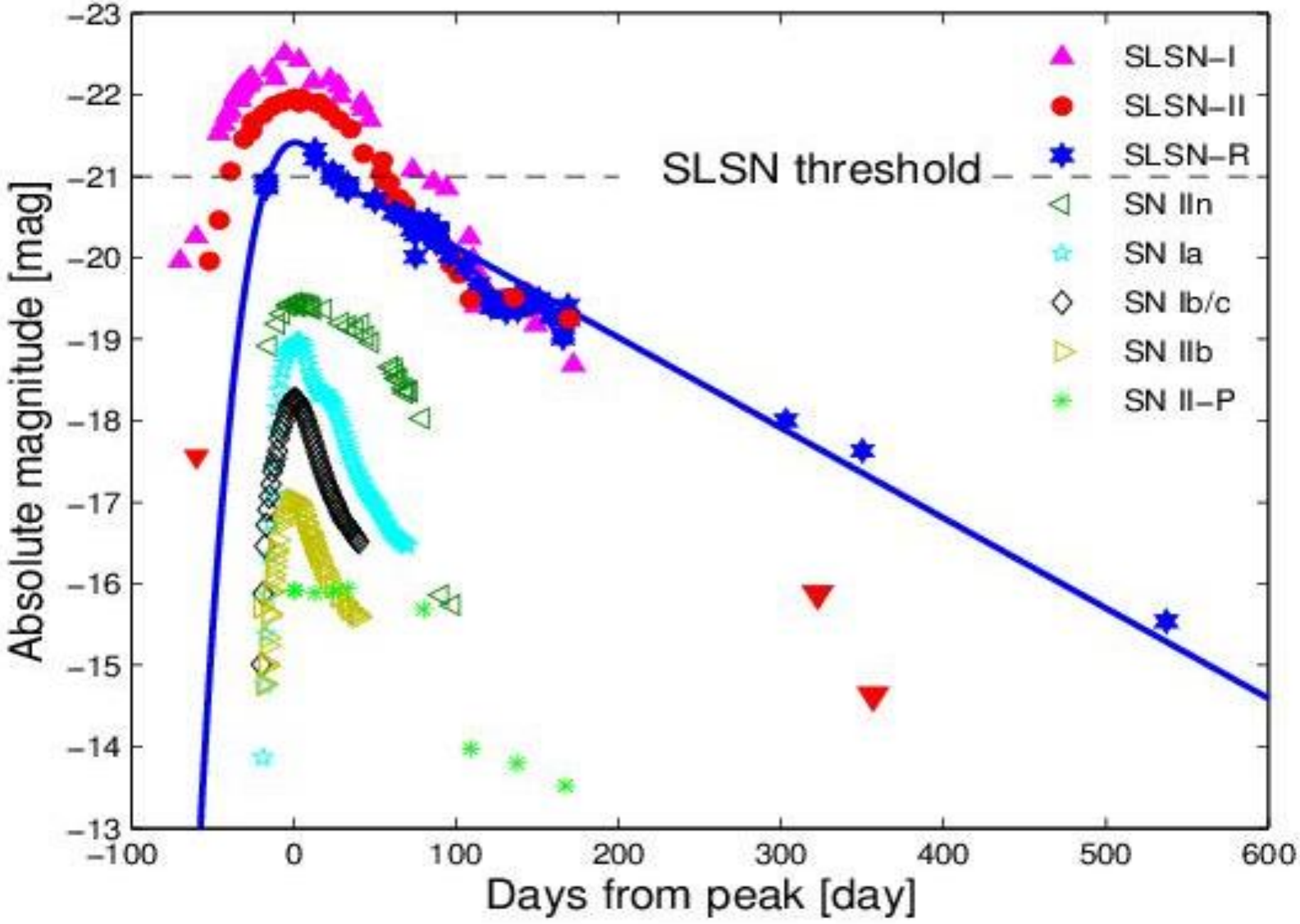
Trenti et al 2010, ApJ, 714, 202

DECam Acknowledgement

The DECamERON project used data obtained with the Dark Energy Camera, which was constructed by the Dark Energy Survey (DES) collaboration. Funding for the DES Projects has been provided by the DOE and NSF (USA), MISE (Spain), STFC (UK), HIFCE (UK), NCSA (UIUC), KICP (U. Chicago), CCAPP (Ohio State), MIFPA (Texas A&M), CNPQ, FAPERJ, FINEP (Brazil), MINECO (Spain), DFG (Germany) and the collaborating institutions in the Dark Energy Survey, which are Argonne Lab, UC Santa Cruz, University of Cambridge, CIEMAT-Madrid, University of Chicago, University College London, DES-Brazil Consortium, University of Edinburgh, ETH Zurich, Fermilab, University of Illinois, ICE (IEEC-CSIC), IFAE Barcelona, Lawrence Berkeley Lab, LMU Munchen and the associated Excellence Cluster Universe, University of Michigan, NOAO, University of Nottingham, Ohio State University, University of Pennsylvania, University of Portsmouth, SLAC National Lab, Stanford University, University of Sussex, and Texas A&M University.

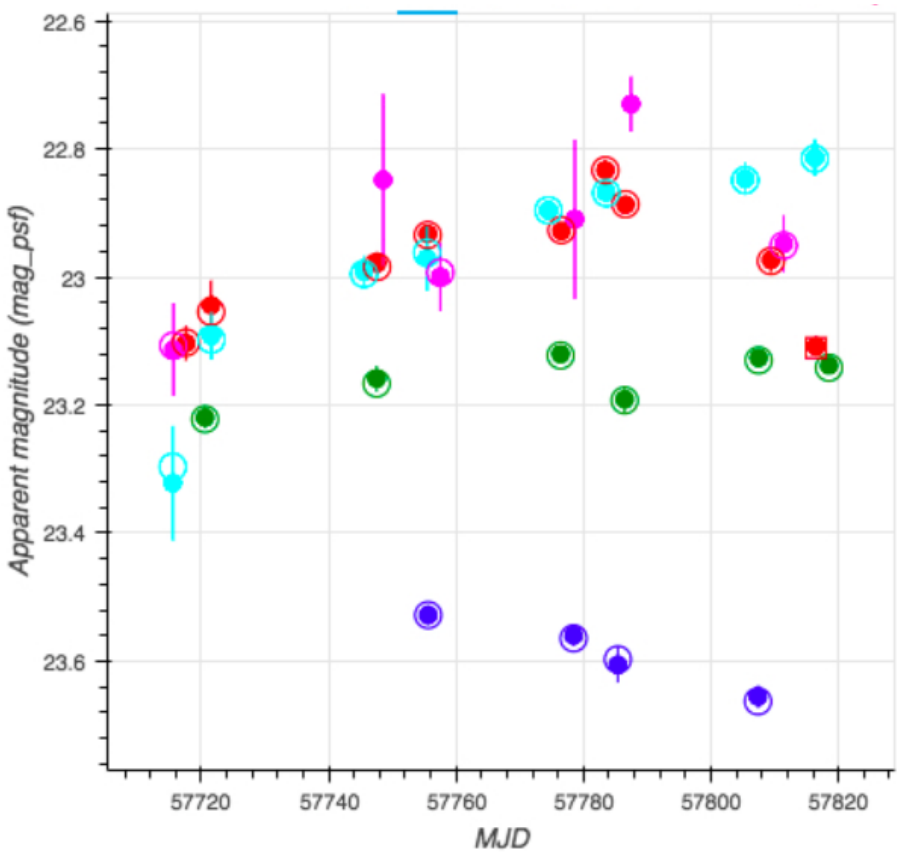
We also acknowledge CAASTRO support.

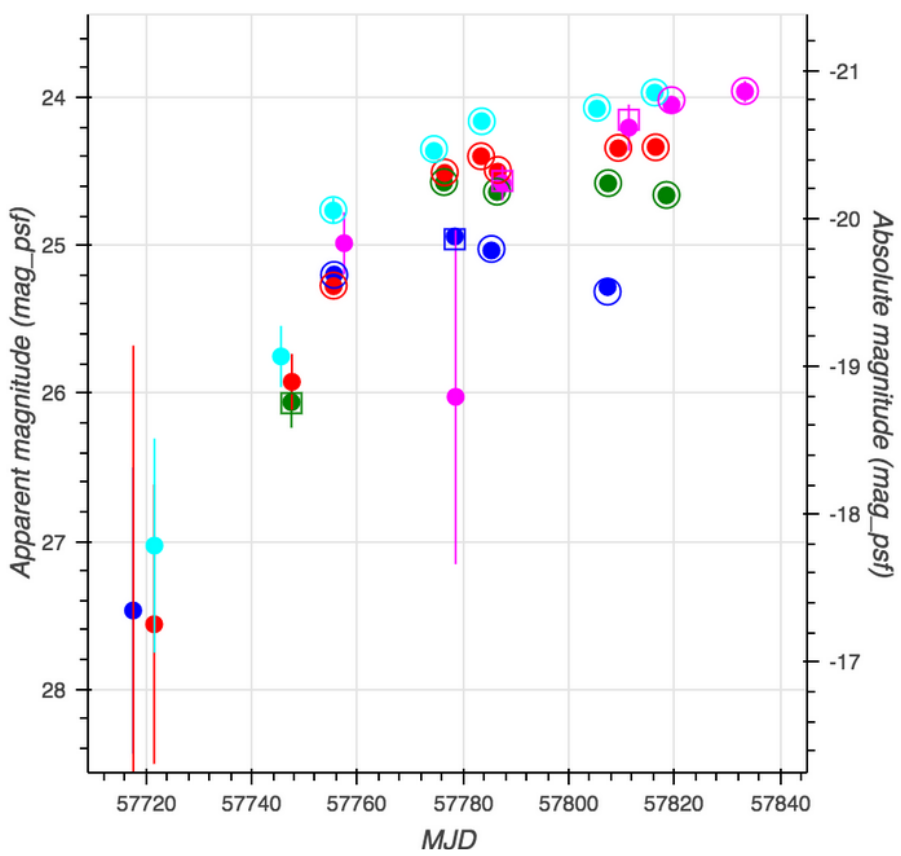
HSC-SSP Superluminous Supernovae at z ~ 2-6



HSC-SSP Superluminous Supernovae at z ~ 2-6

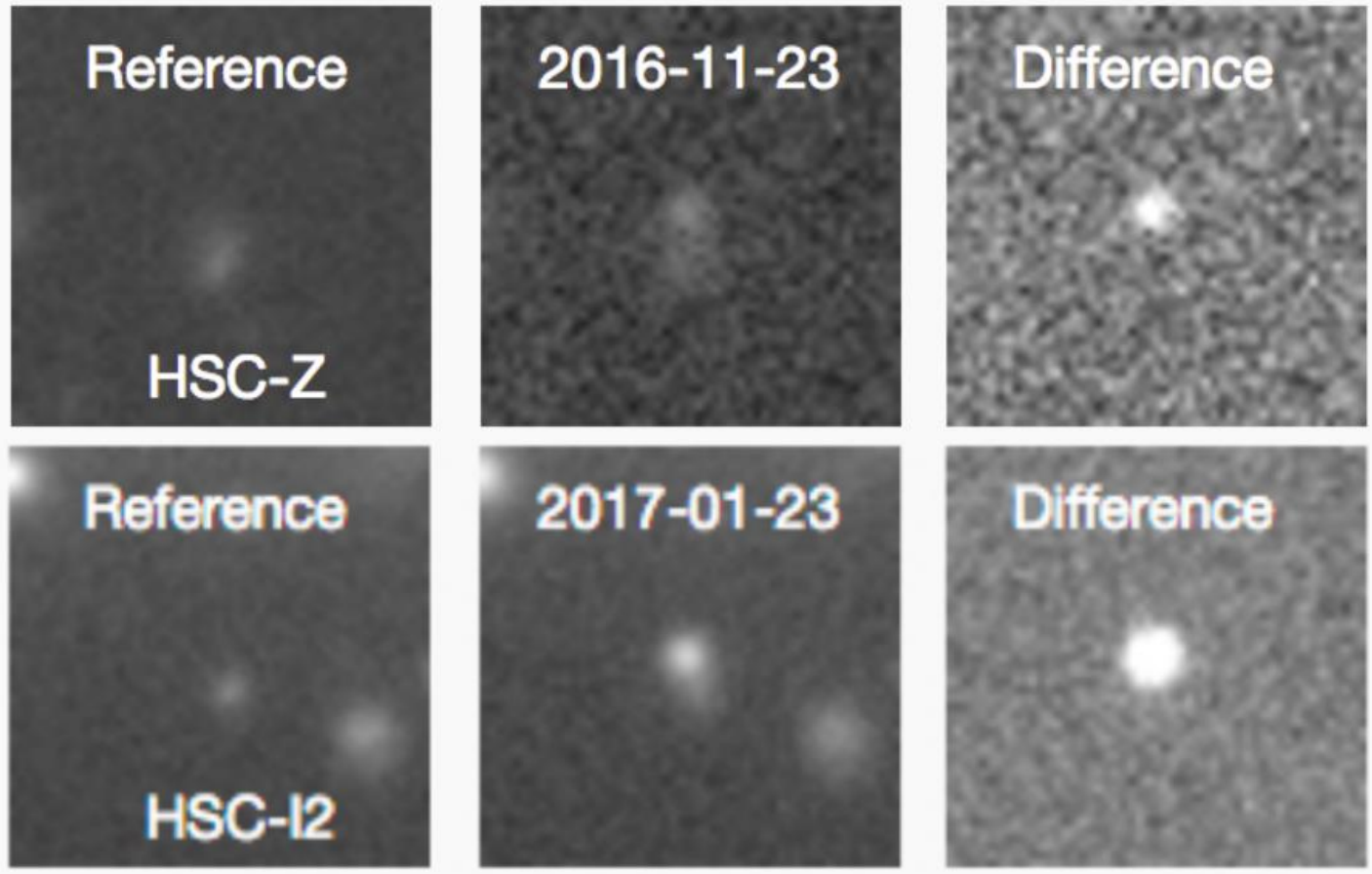
HSC-SSP g r i z Y imaging





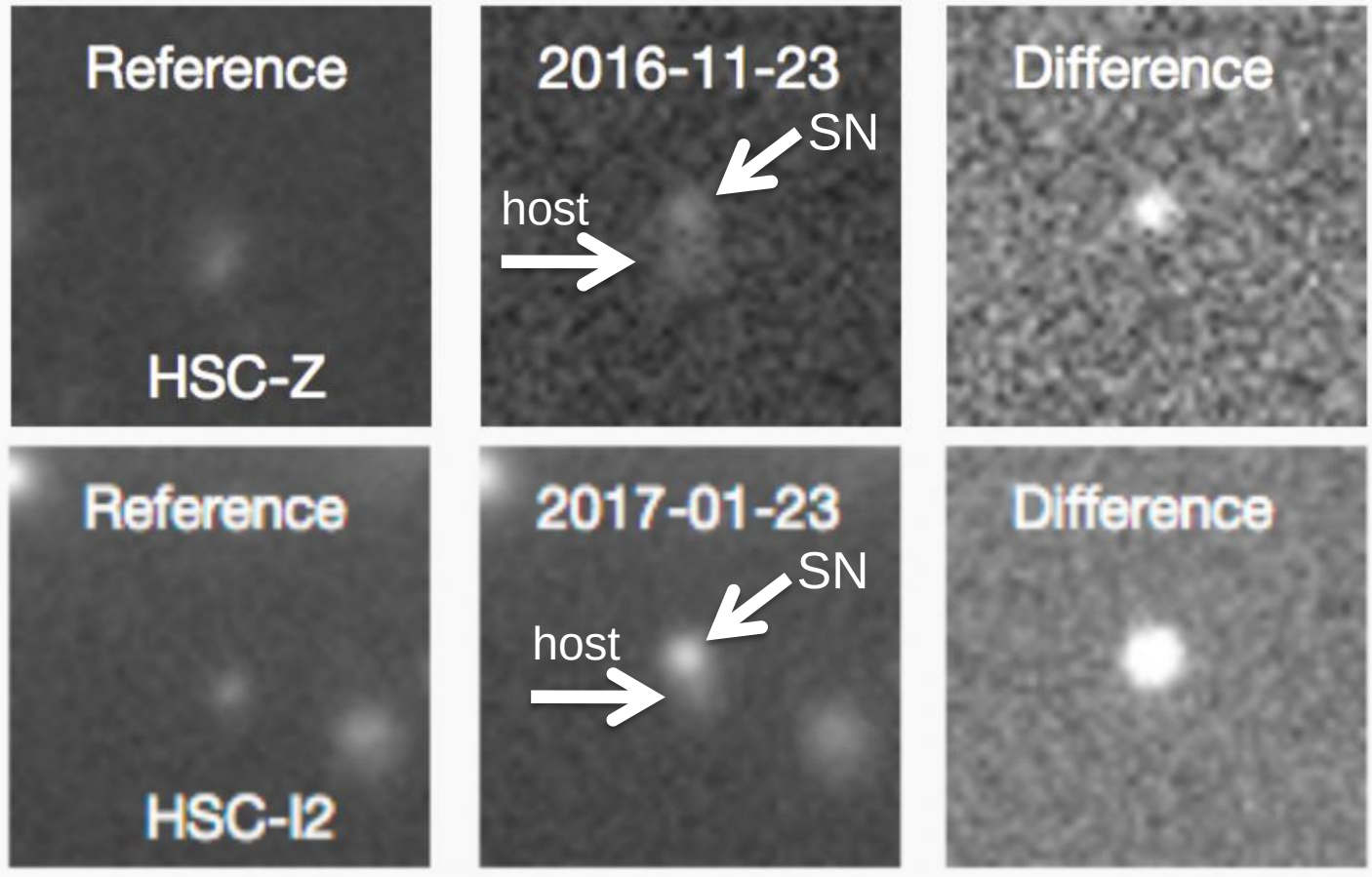
HSC-SSP Superluminous Supernovae at z ~ 2-6

HSC-SSP　g r i z Y imaging



HSC-SSP Superluminous Supernovae at z ~ 2-6

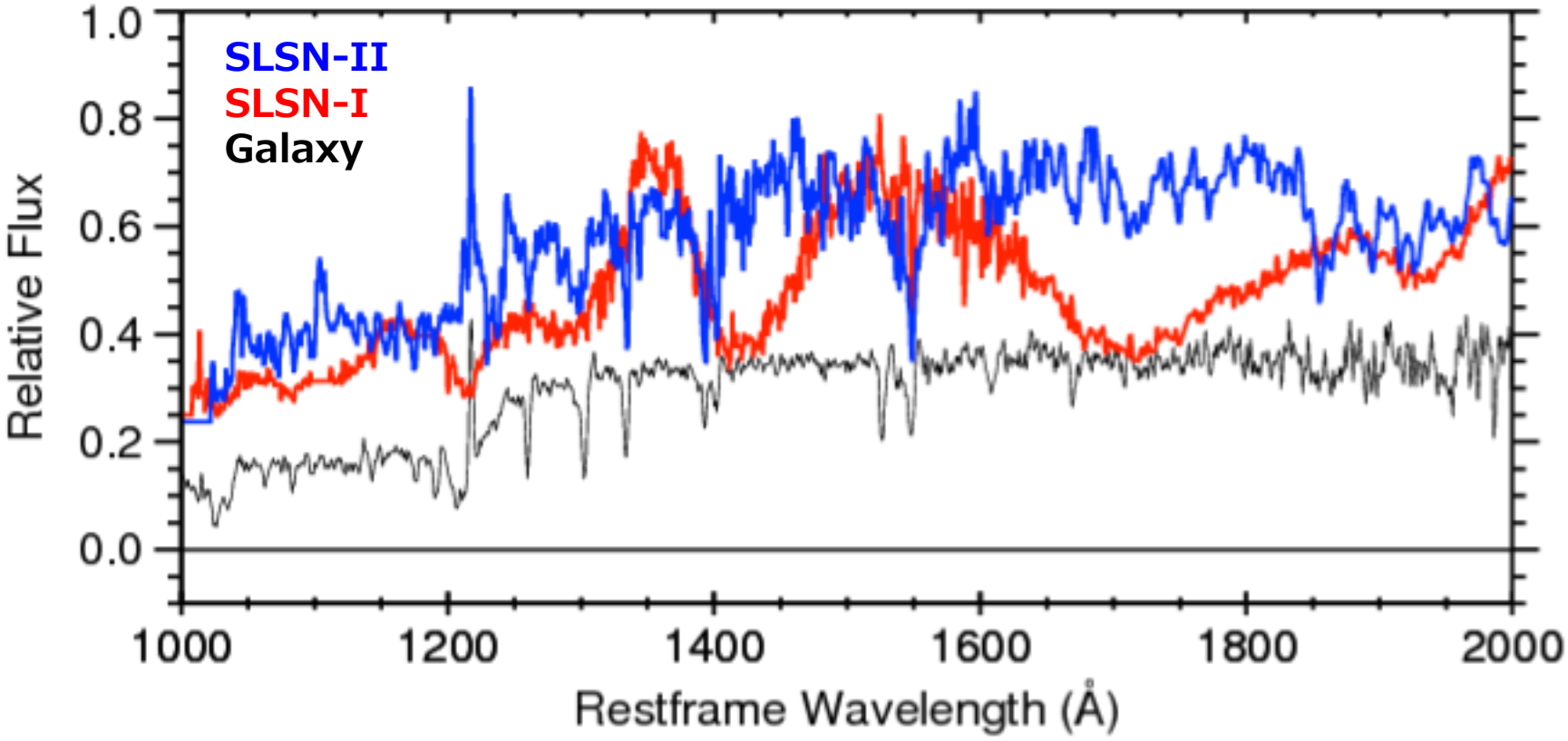
HSC-SSP　g r i z Y imaging



HSC-SSP Superluminous Supernovae at z ~ 2-6

HST far-UV spectroscopy

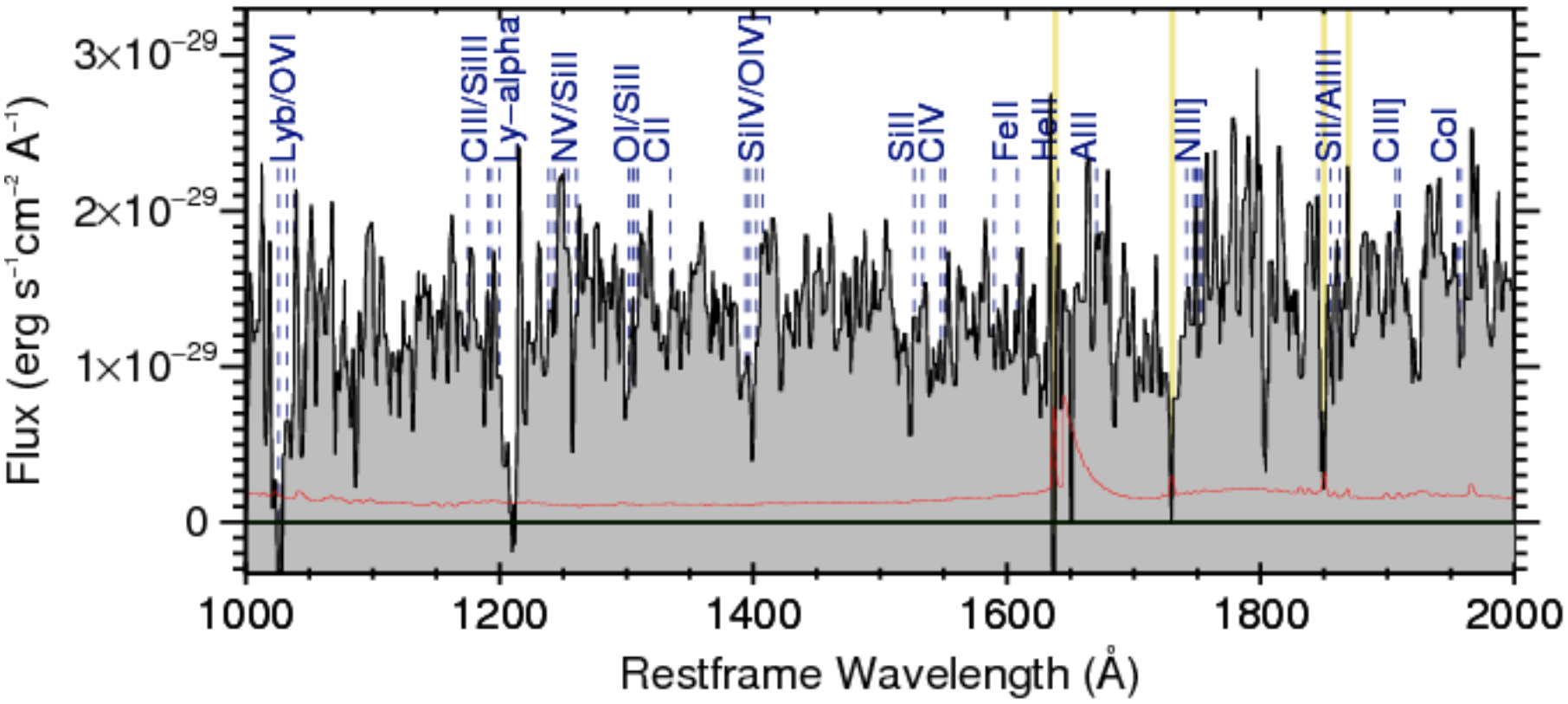
z ~ 0.1-0.2 SLSNe



HSC-SSP Superluminous Supernovae at z ~ 2-6

AU Keck spectroscopy

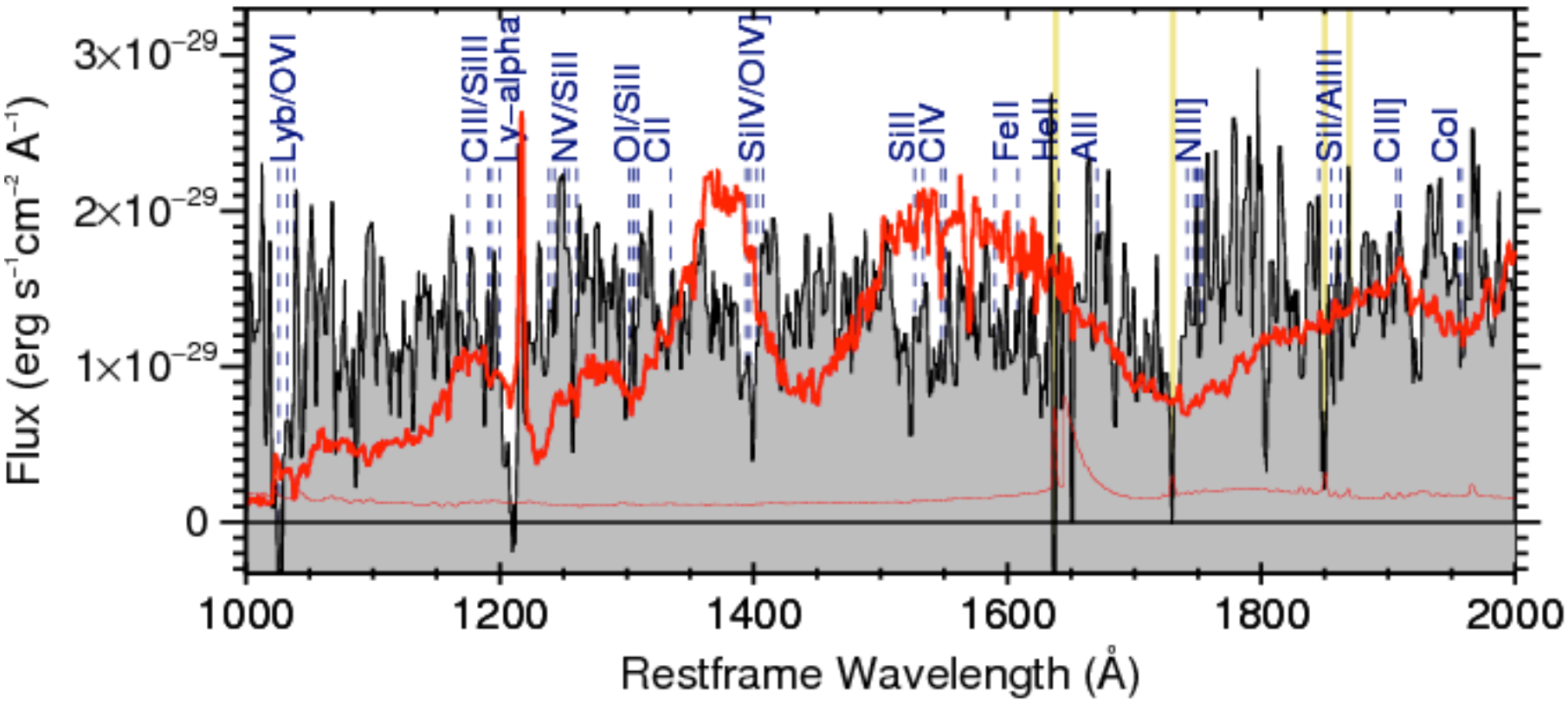
z = 2.4 SLSN?



HSC-SSP Superluminous Supernovae at z ~ 2-6

AU Keck spectroscopy

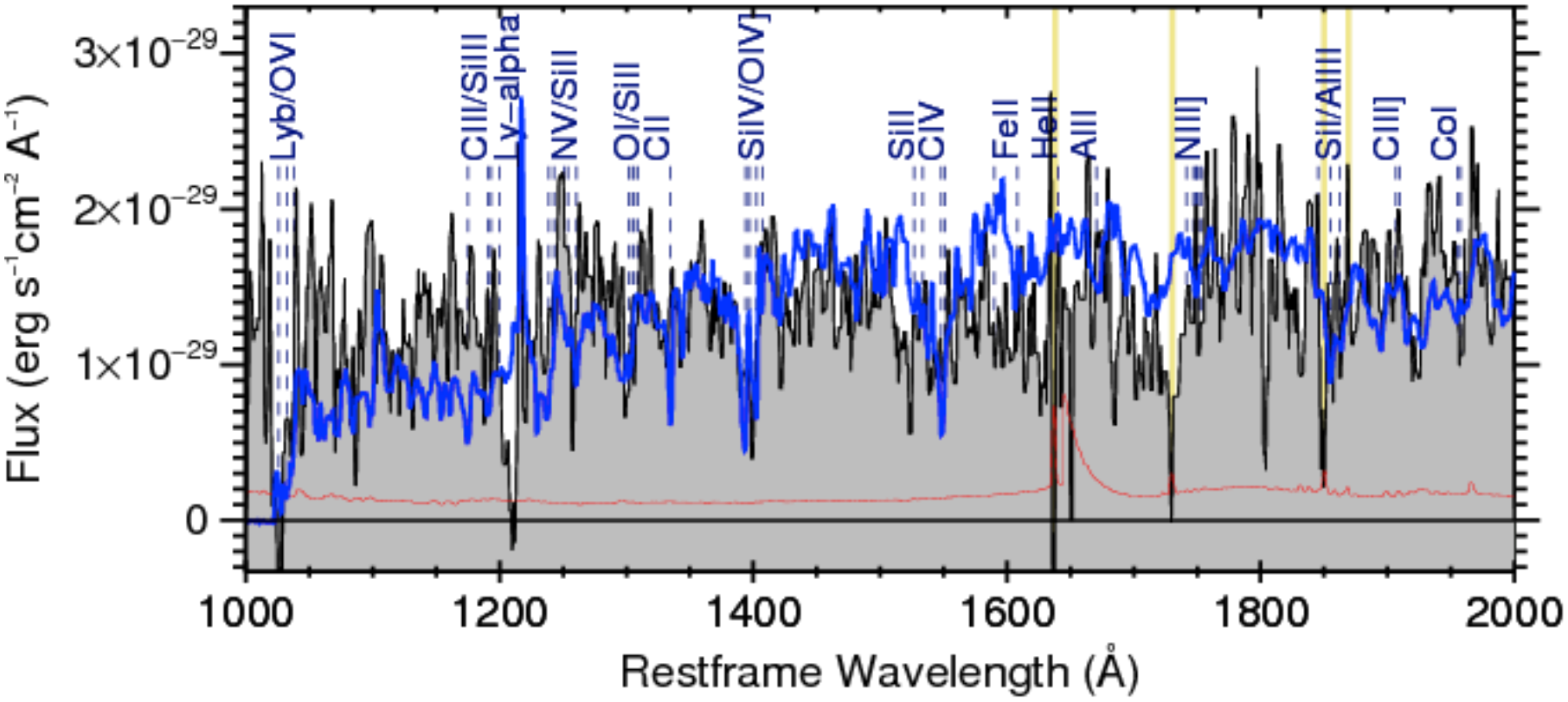
z = 2.4 SLSN-I



HSC-SSP Superluminous Supernovae at z ~ 2-6

AU Keck spectroscopy

z = 2.4 SLSN-II



HSC-SSP Superluminous Supernovae at z ~ 2-6

HSC-SSP SLSN program

Based on the success, current plan, and duration of
HSC Ultradeep survey

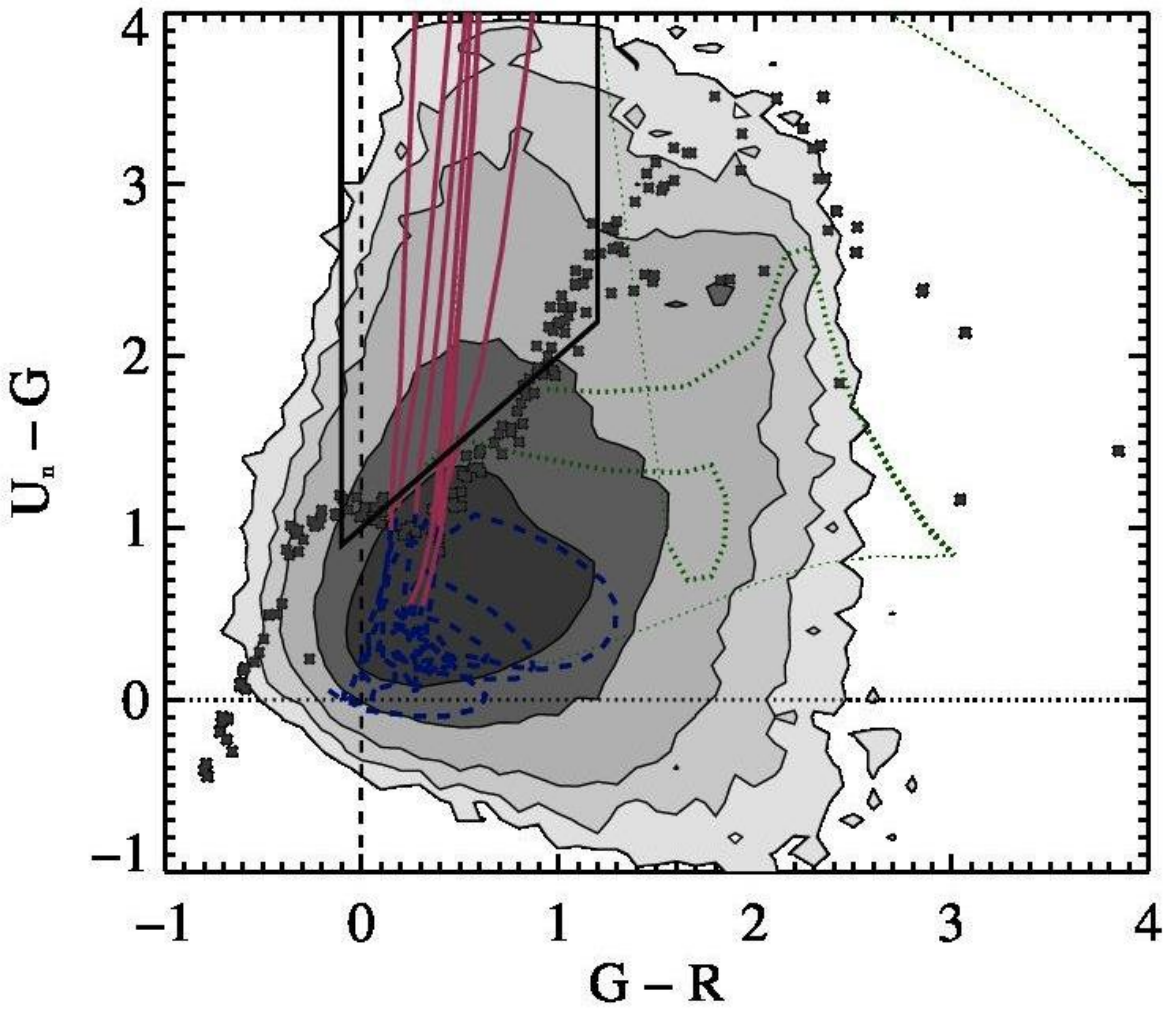
Propose complementary z and Y observations
for z ~ 5-7 SLSNe and LAE continua and Lya EWs

Keck synergy, JWST z ~ 5-7 SLSN spectra
to calibrate for FUV spectra to z ~ 20

Subaru	HSC, PFS, ULTIMATE
Keck	LRIS, MOSFIRE, NIRES, OSIRIS
TAO	SWIMS deep IR survey
JWST	Restframe FUV through optical spectra
GMT	FUV+optical spectra, IFU of hosts and SNe

HSC-SSP Lyman Continuum Galaxies at z ~ 3-4

U_nGR selected $z \sim 3$ LBGs *(e.g., Steidel et al. 2003)*



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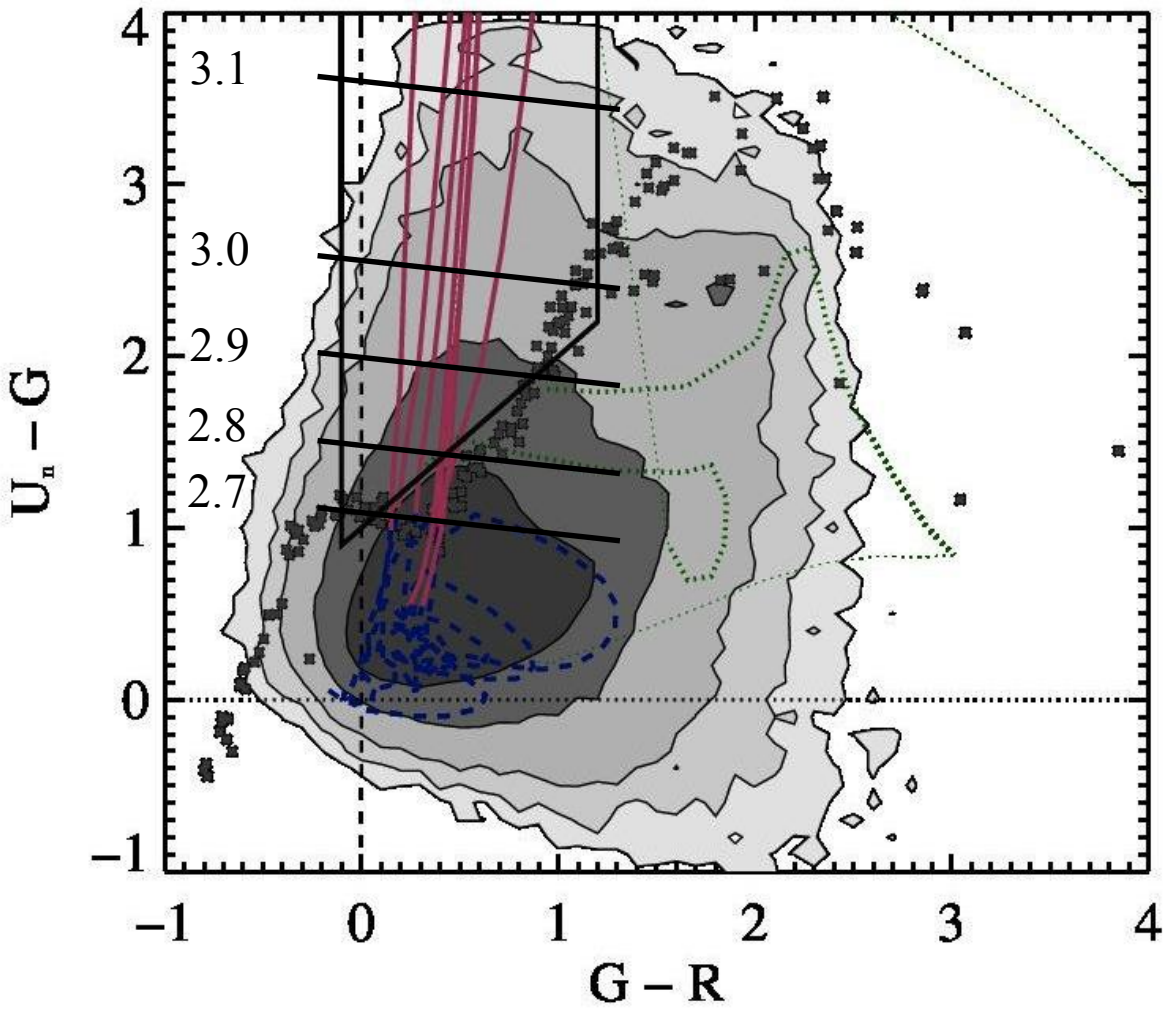

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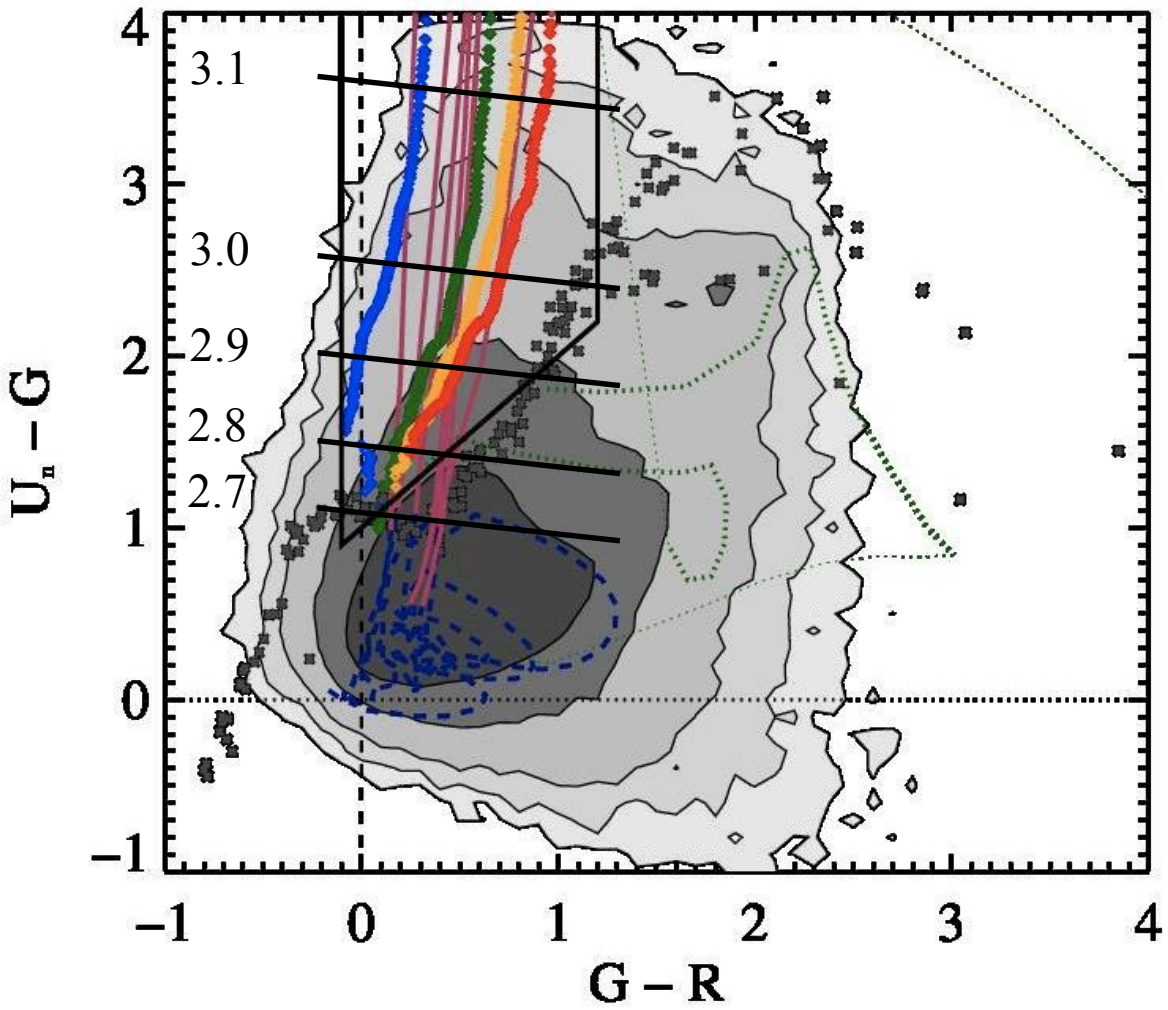

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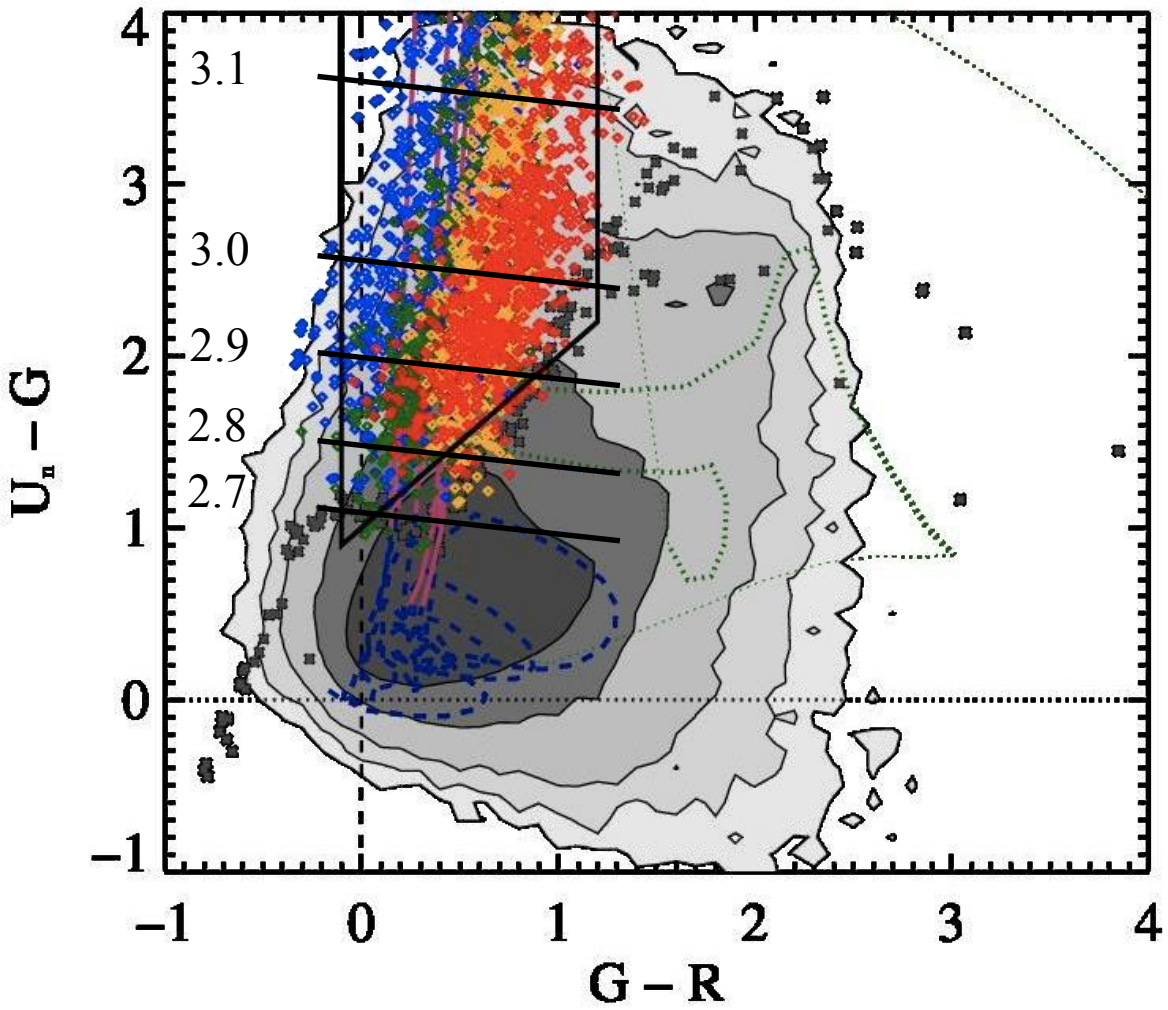

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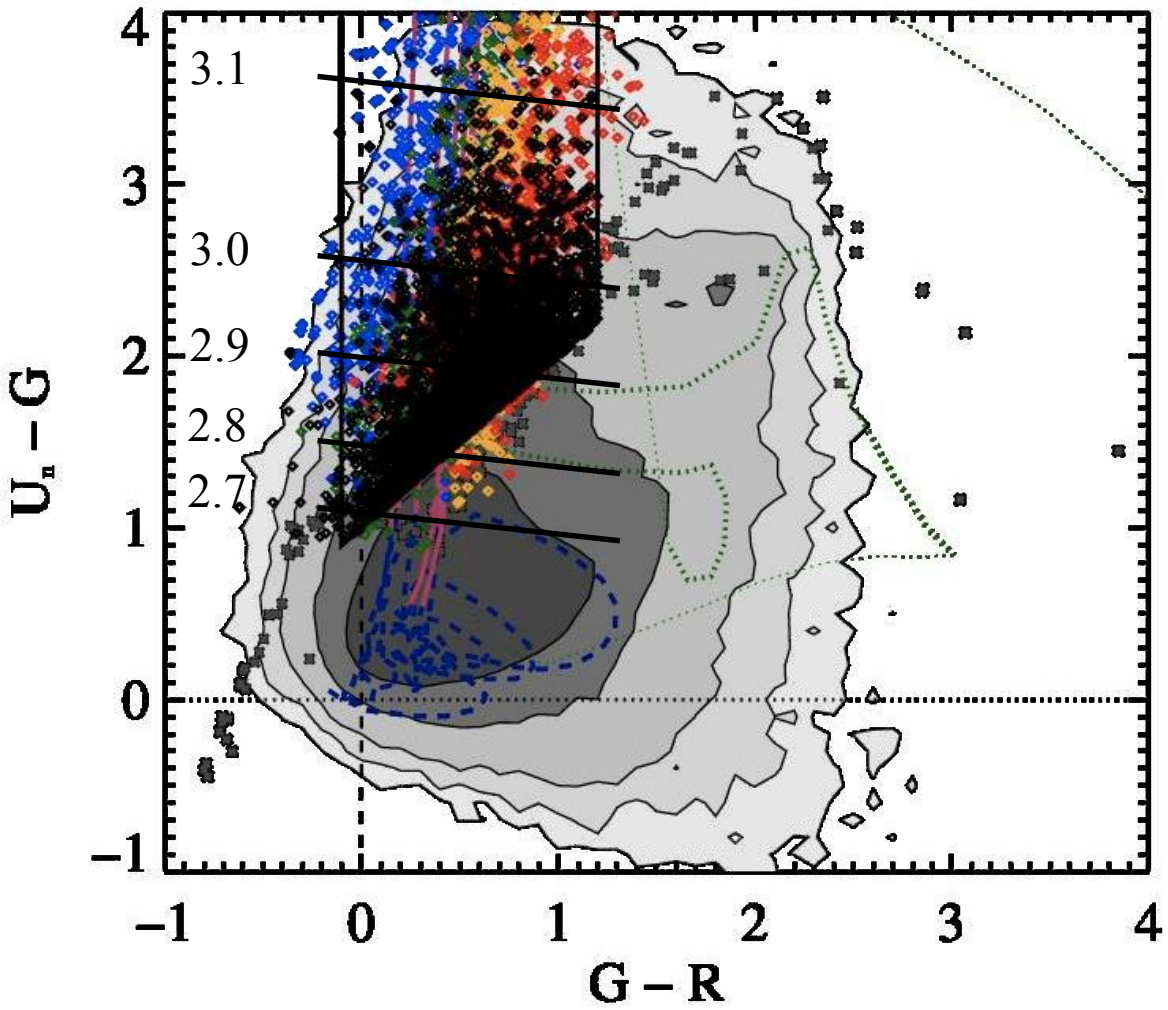

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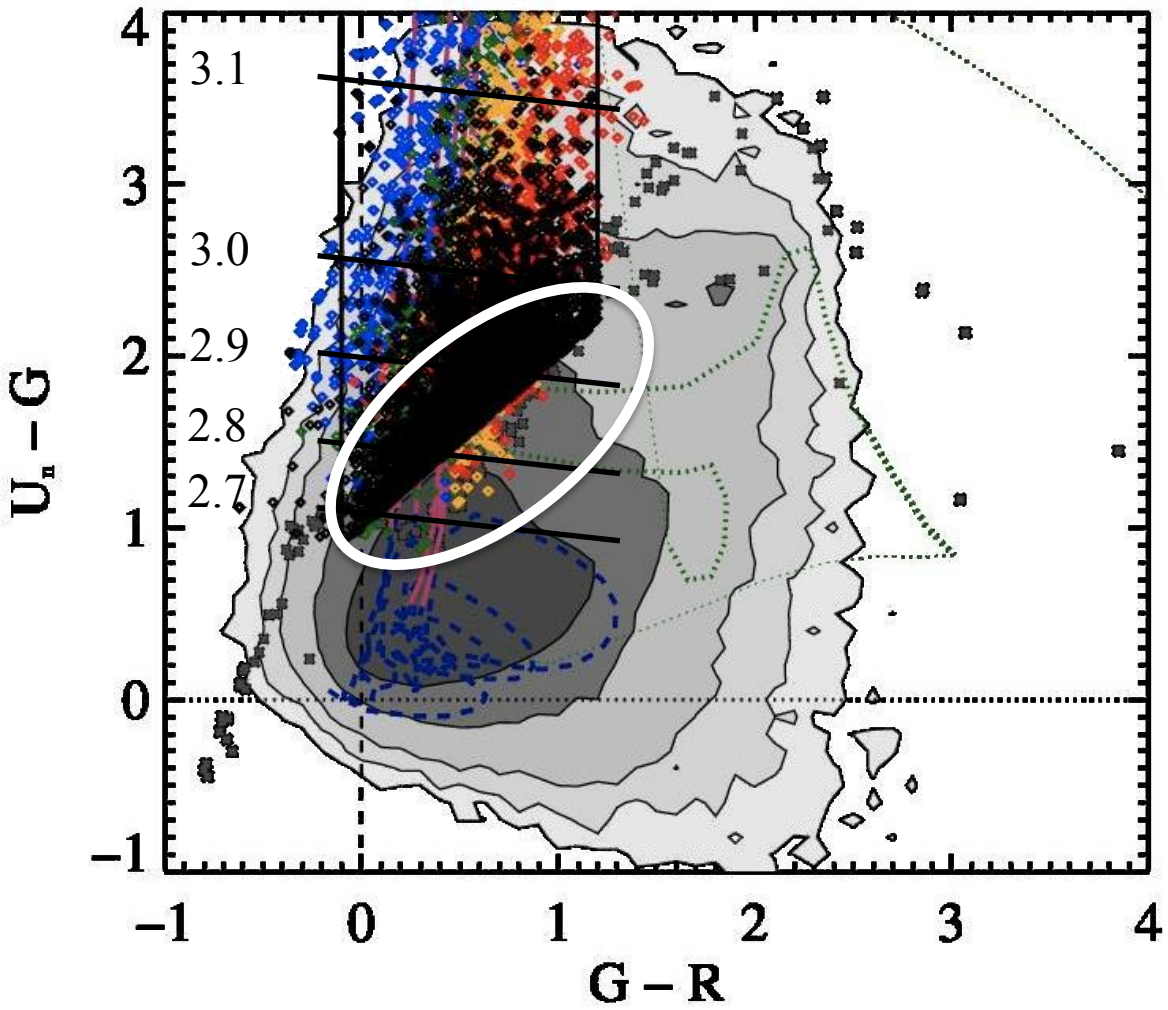
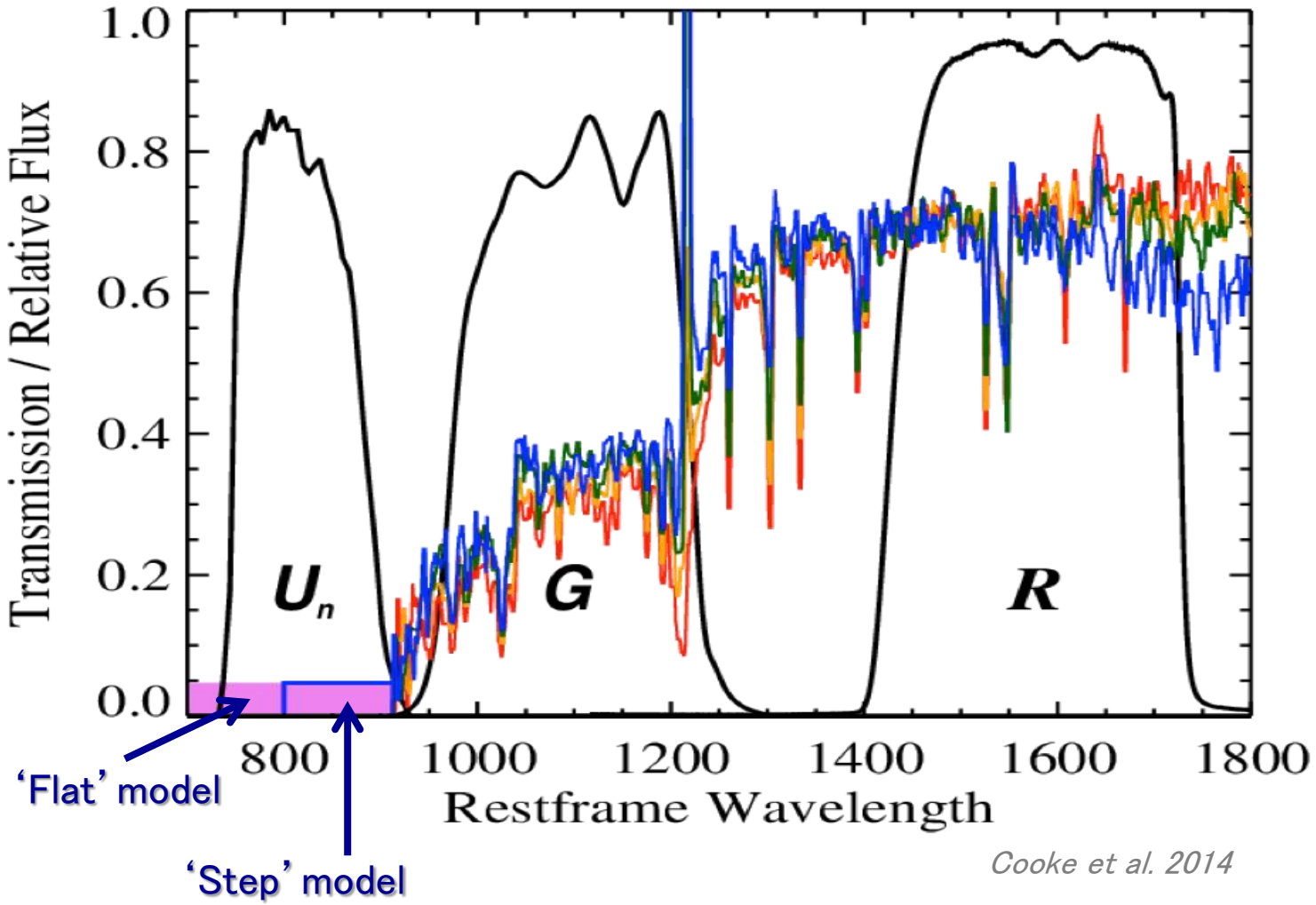


HSC-SSP Lyman Continuum Galaxies at z ~ 3-4

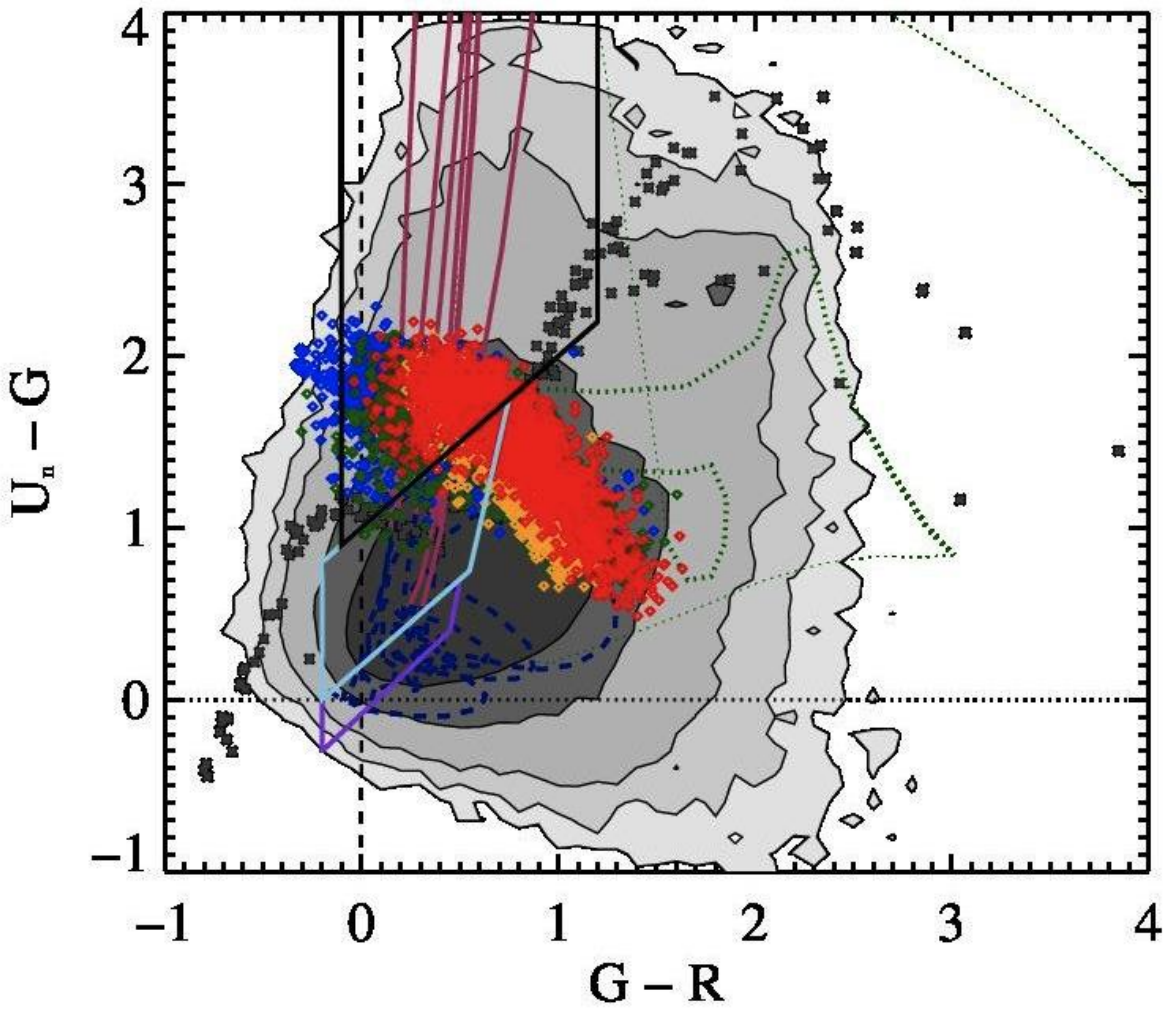
Modifying the composite spectra



Cooke et al. 2014

HSC-SSP Lyman Continuum Galaxies at z ~ 3-4

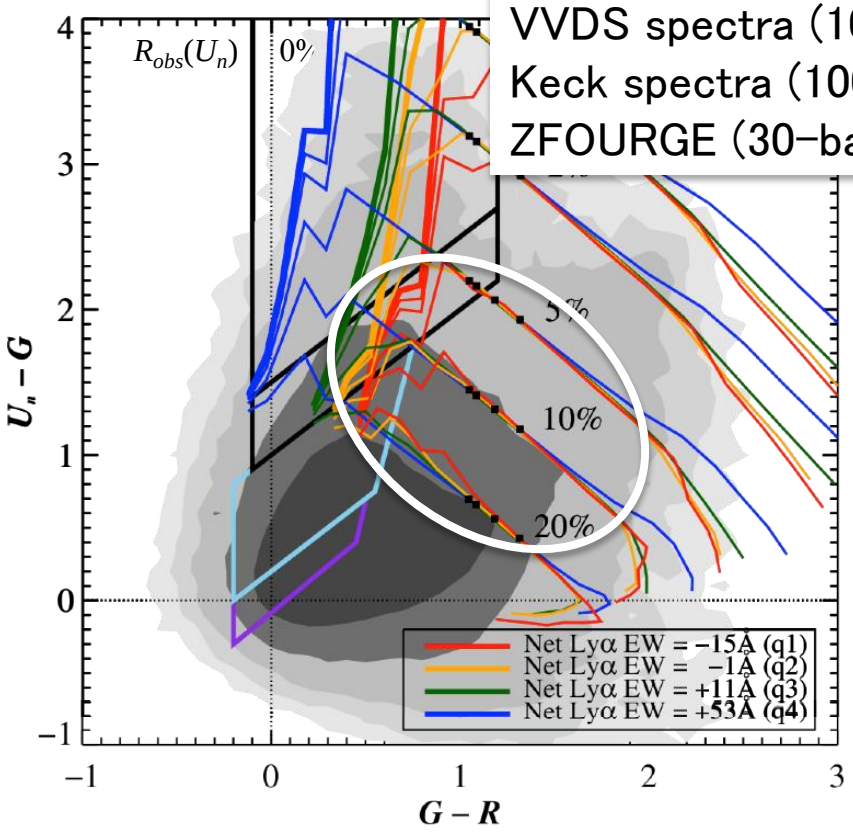
Modifying the composite spectra

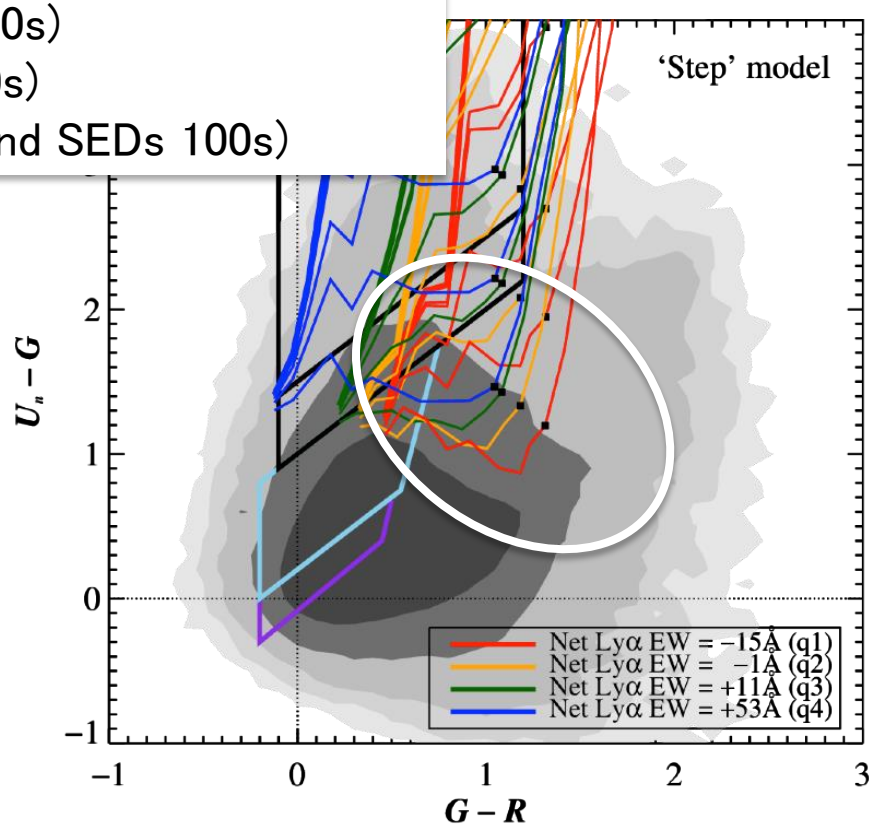


HSC-SSP Lyman Continuum Galaxies at z ~ 3-4

Modifying the composite spectra

VVDS spectra (100s)
Keck spectra (100s)
ZFOURGE (30-band SEDs 100s)

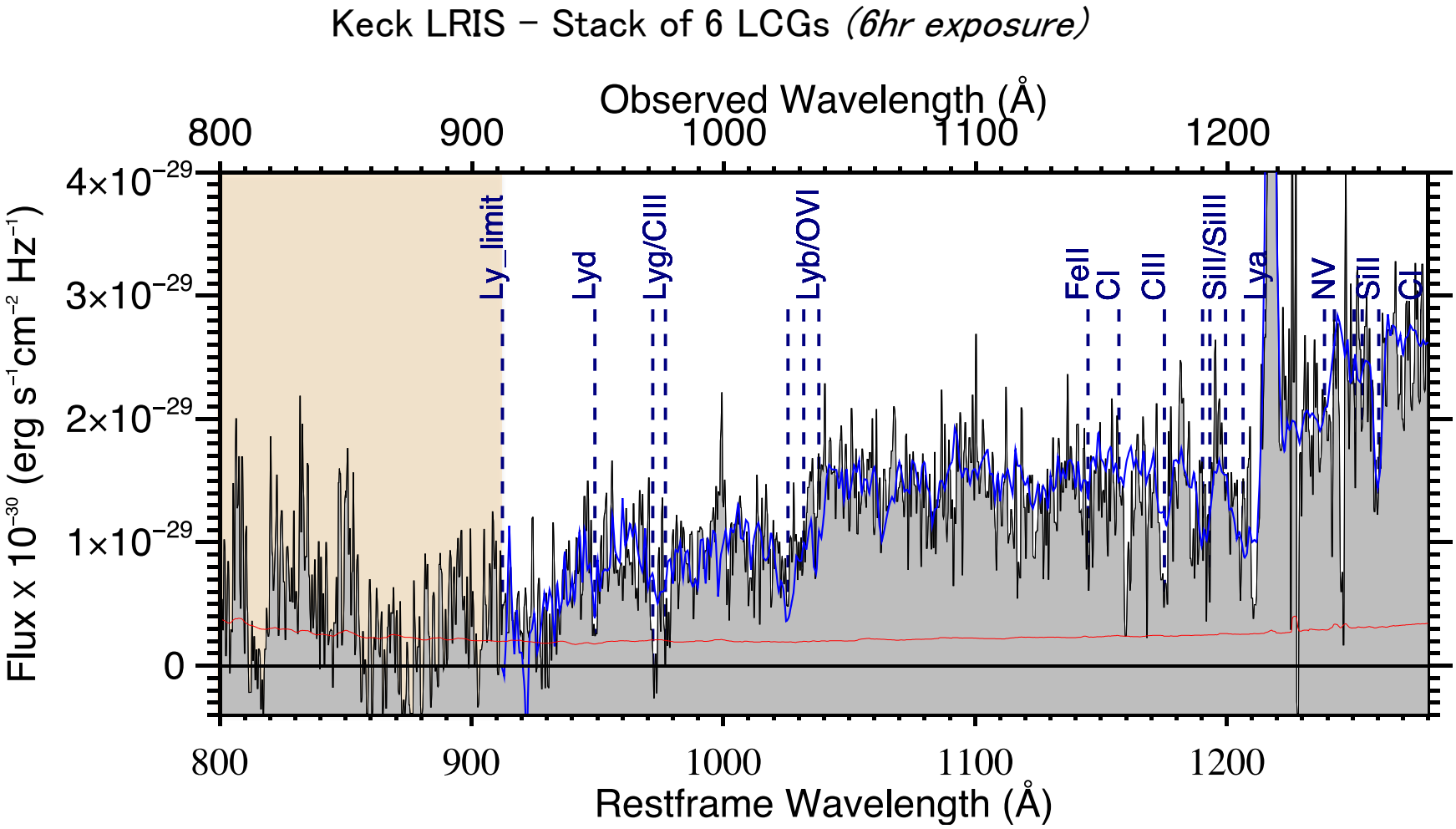




Cooke et al. 2014

$$R_{obs}(U_n) = \frac{F_{obs}^{LyC}(U_n)}{F_{obs}^{1500Å}}$$

HSC-SSP Lyman Continuum Galaxies at z ~ 3-4



HSC-SSP Lyman Continuum Galaxies at z ~ 3-4

HSC Project 212

CLAUDS – CFHT U-band survey (Sawicki+)

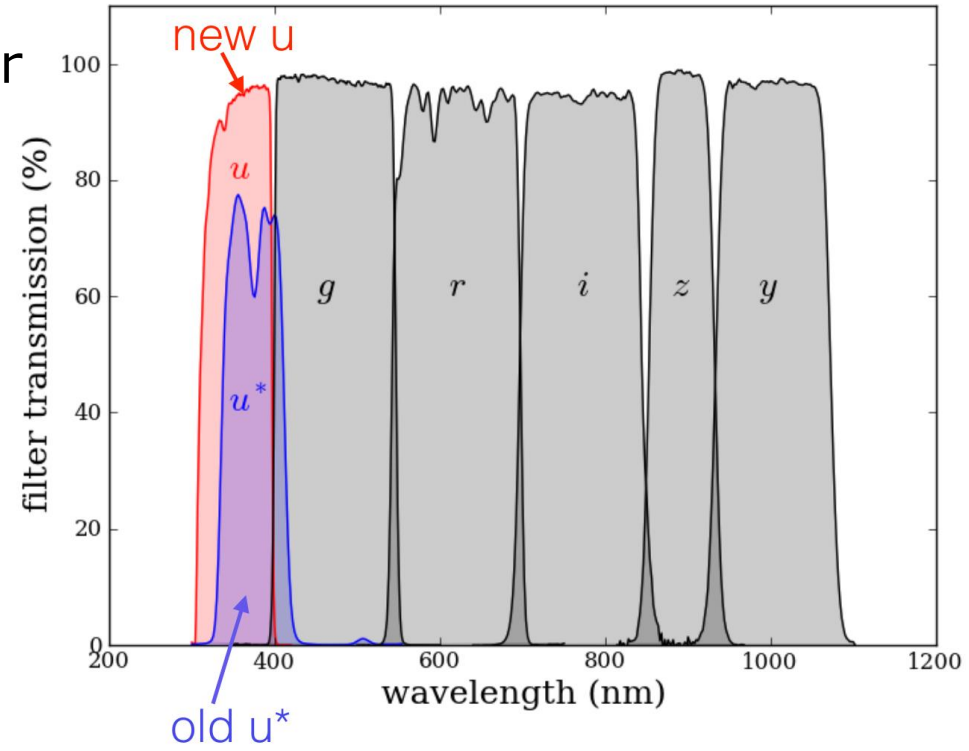
HSC SSP Deep layer, U=27AB

CLAUDS+HSC SSP

will enable 0.5 mag deeper

5x wider search of LCGs

(Iwata, Cooke, et al.)



HSC-SSP Lyman Continuum Galaxies at z ~ 3-4

HSC-SSP LCGs

LCG number density, bright candidates, quantify the contribution of galaxies to reionisation

Test merger hypothesis

Wide-field narrow band LyC emission searches potentially powerful detection technique

Subaru	HSC, PFS, ULTIMATE
Keck	LRIS, MOSFIRE, NIRES, OSIRIS
HST	Deep LyC imaging
JWST	z > 6 restframe optical nebular emission lines
GMT	z > 6 restframe optical nebular emission lines

Deeper, Wider, Faster

(as of July 2016)

PI: *Jeff Cooke* [1]

Radio: *Emily Petroff* [2], *Chris Flynn* [1], *Manisha Caleb* [1,3], *Shivani Bhandari* [1], *Evan Keane* [4], *Stuart Ryder* [5], *Wael Farah* [1], *Fabian Jankowski* [1], *Vivek Venkatraman Krishnan* [1], *Themiya Nanayakkara* [1], *Aditya Parthasarathy* [1], *Sarah Burke-Spolaor* [6], *Casey Law* [6]

Optical: *Tyler Pritchard* [1], *Tim Abbott* [7], *Chris Curtin* [1], *Stephanie Bernard* [8], *Chuck Horst* [9], *Mansi Kasliwal* [10], *David Coward* [11], *the SkyMapper team, the Zadko team, and the Gemini-South and SALT support astronomers*

UV/x-ray/gamma-ray: *Tyler Pritchard* [1], *Igor Andreoni* [1], *Amy Lien* [12], *Neil Gehrels* [13]

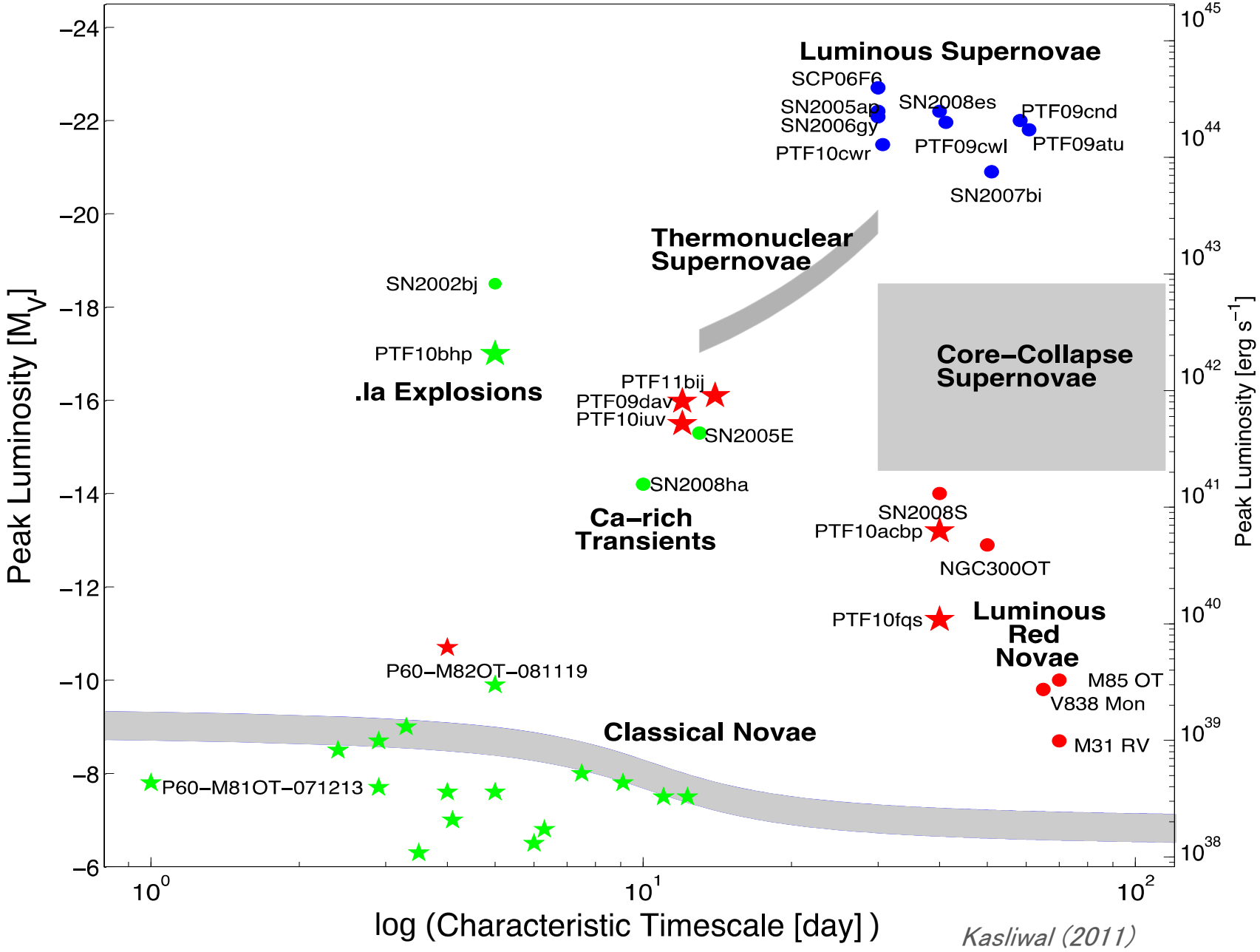
Real-time processing: *Igor Andreoni* [1], *Tyler Pritchard* [1], *Armin Rest* [12,14], *Alex Codoreanu* [1], *Phil Cowperthwaite* [14], *Chuck Horst*

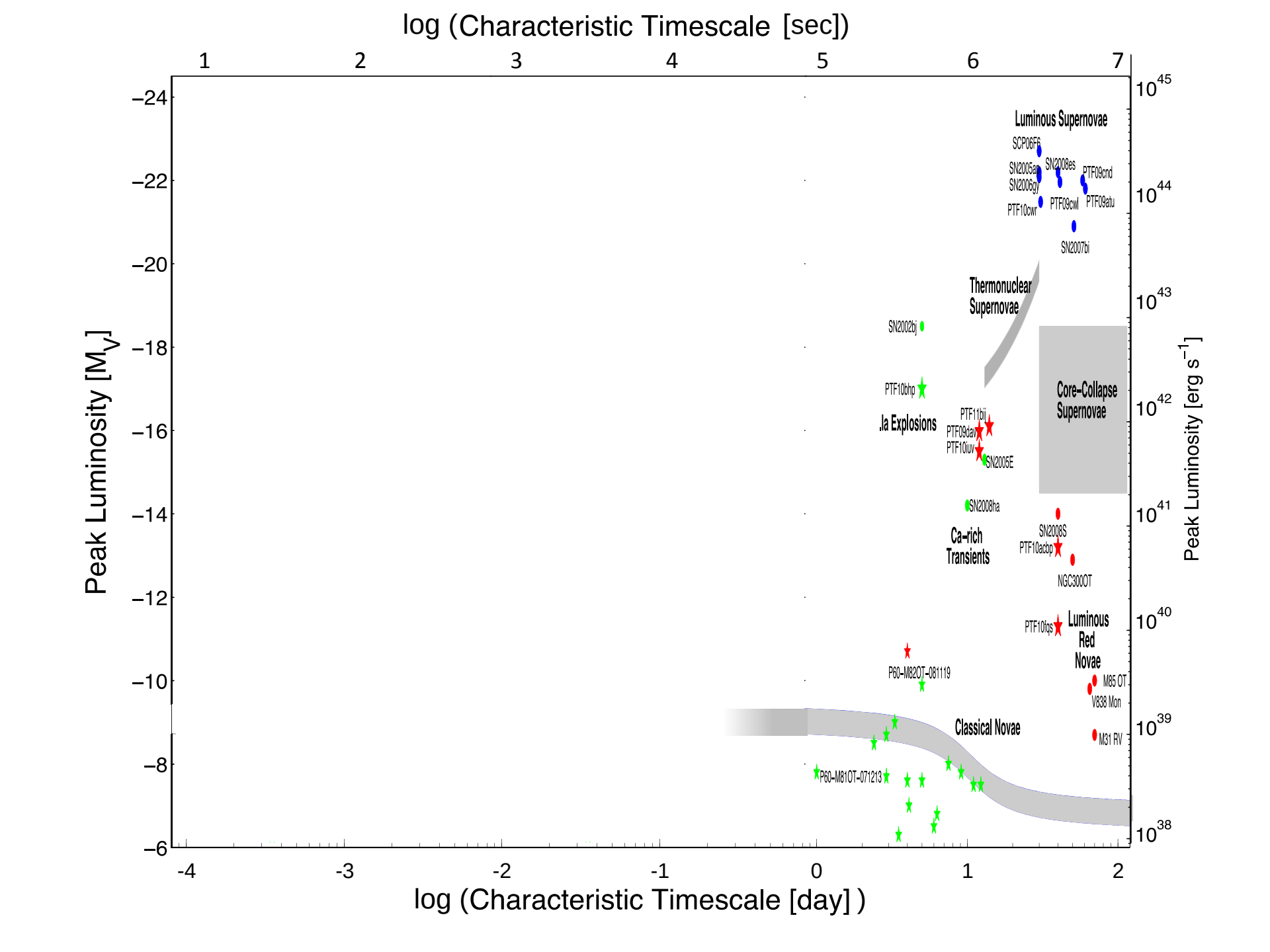
Data Science: *Dany Vohl* [1], *Colin Jacobs*[1], *Vincent Morello* [15]

Visualization: *Bernard Meade* [8], *Chris Fluke* [1], *Dany Vohl* [1], *Sarah Hegarty* [1]

Real-time data Inspection and Analysis: *Uros Mestric* [1], *Chuck Horst* [9], *Garry Foran* [1], *Stephanie Bernard* [8], *Rebecca Allen* [1], *Michael Murphy* [1], *Katie Mack* [8], *Srdan Kotus* [1] *Albany Asher* [1], *Bernard Meade* [8], *Shivani Bhandari* [1], *Chris Curtin* [1], *Wael Farah* [1], *Sarah Hegarty* [1], *Eric Howell* [11], *Colin Jacobs* [1], *Fabian Jankowski* [1], *Regina Jorgenson* [16], *Vivek Venkatraman Krishnan* [1] *Aditya Parthasarathy* [1], *Tristan Reynolds* [8], *Geoff Bryan* [1], *Frederic Robert* [1], *Themiya Nanayakkara* [1], *Fanual Rumokoy* [8], *Luciana Sinpetru* [16], *Cameron van der Veldon* [8], *Ibnul Hussaini* [8], *Pamela Bain, Dany Vohl* [1], *SAO students* [1]

[1]*Swinburne* [2]*ASTRON/NIRA* [3]*ANU* [4]*University of Manchester/SKAO* [5]*AAO* [6]*NRAO* [7]*CTIO/NOAO*
[8]*University of Melbourne* [9]*San Diego State University* [10]*Caltech* [11]*UWA* [12]*STScI* [13]*NASA/GSFC*
[14]*Harvard University* [15]*University of Bonn* [16] *Maria Mitchell Observatory* [17] *University of Edinburgh*


Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF10cwr
PTF09cwl
PTF09atu
SN2007bi
Thermonuclear Supernovae
SN2002bj
PTF10bhp
.Ia Explosions
PTF11bij
PTF09dav
PTF10iuv
SN2005E
SN2008ha
Ca–rich Transients
Core–Collapse Supernovae
SN2008S
PTF10acbp
NGC300OT
PTF10fqs
Luminous Red Novae
M85 OT
V838 Mon
M31 RV
P60–M82OT–081119
Classical Novae
P60–M81OT–071213
Peak Luminosity [M_V]
Peak Luminosity [erg s^-1]
log (Characteristic Timescale [day])
Kasliwal (2011)


log (Characteristic Timescale [sec])
1
2
3
4
5
6
7
Peak Luminosity [M_V]
−24
−22
−20
−18
−16
−14
−12
−10
−8
−6
Peak Luminosity [erg s^{-1}]
10^{45}
10^{44}
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
log (Characteristic Timescale [day])
-4
-3
-2
-1
0
1
2
Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF09cwl
PTF09atu
PTF10cwr
SN2007bi
Thermonuclear Supernovae
SN2002bj
PTF10bhp
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PTF11bij
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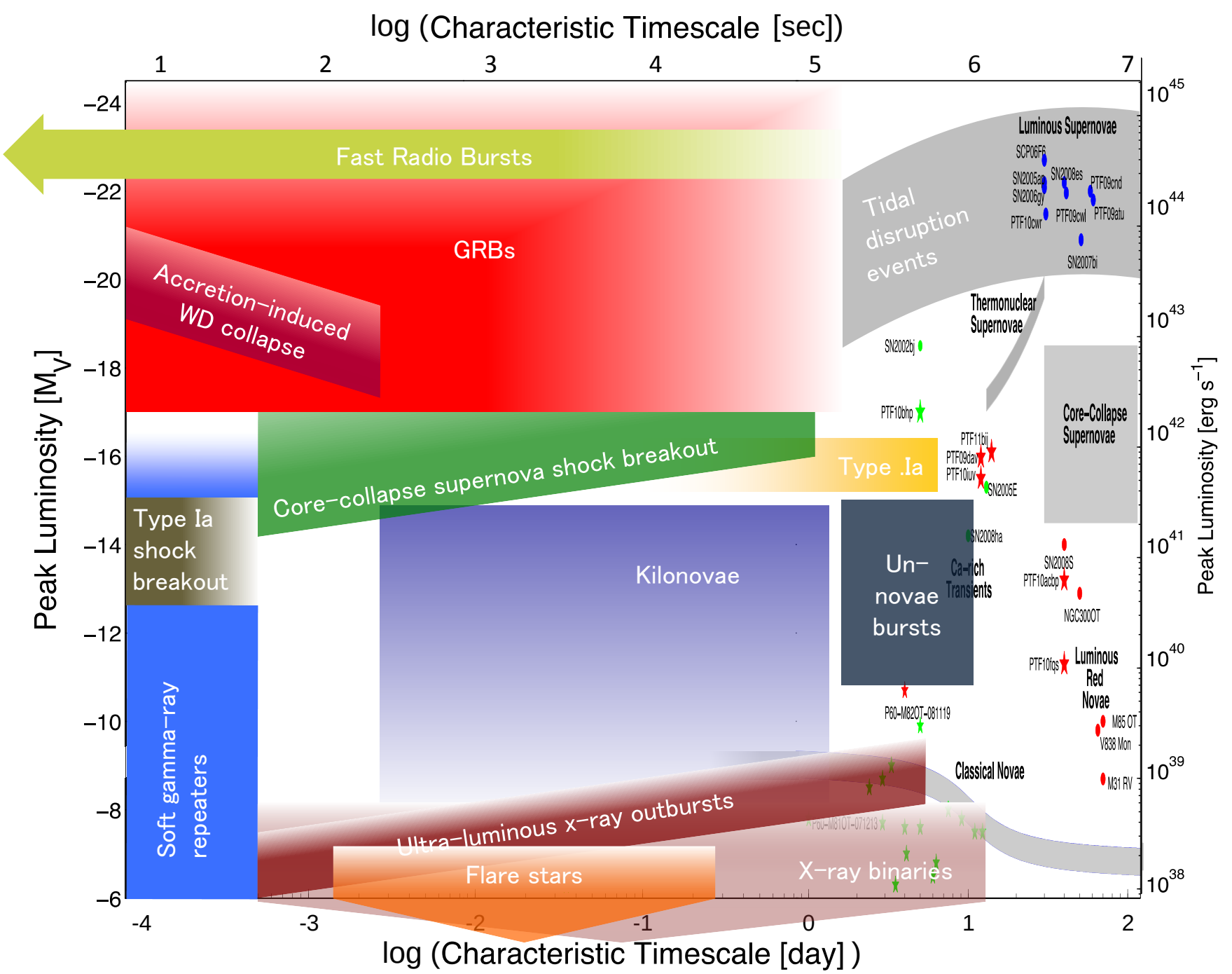
Classical Novae
P60-M81OT-071213


log (Characteristic Timescale [sec])
1
2
3
4
5
6
7
Peak Luminosity [M_V]
−24
−22
−20
−18
−16
−14
−12
−10
−8
−6
Peak Luminosity [erg s^{-1}]
10^{45}
10^{44}
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
Fast Radio Bursts
GRBs
Accretion−induced WD collapse
Tidal disruption events
Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF10cwr
PTF09cwl
PTF09atu
SN2007bi
Thermonuclear Supernovae
SN2002bj
PTF10bhp
Core−Collapse Supernovae
PTF11bij
PTF09dav
PTF10iuv
SN2005E
Core−collapse supernova shock breakout
Type .Ia
Type Ia shock breakout
Kilonovae
SN2008ha
Un−novae bursts
Ca−rich Transients
SN2008S
PTF10acbp
NGC300OT
PTF10fqs
Luminous Red Novae
M85 OT
V838 Mon
M31 RV
P60−M82OT−061119
Classical Novae
Soft gamma−ray repeaters
Ultra−luminous x−ray outbursts
P60−M81OT−071213
Flare stars
X−ray binaries
-4
-3
-2
-1
0
1
2
log (Characteristic Timescale [day])

Gravitational Wave Sources

Many sources of gravitational waves are expected to be fast transients

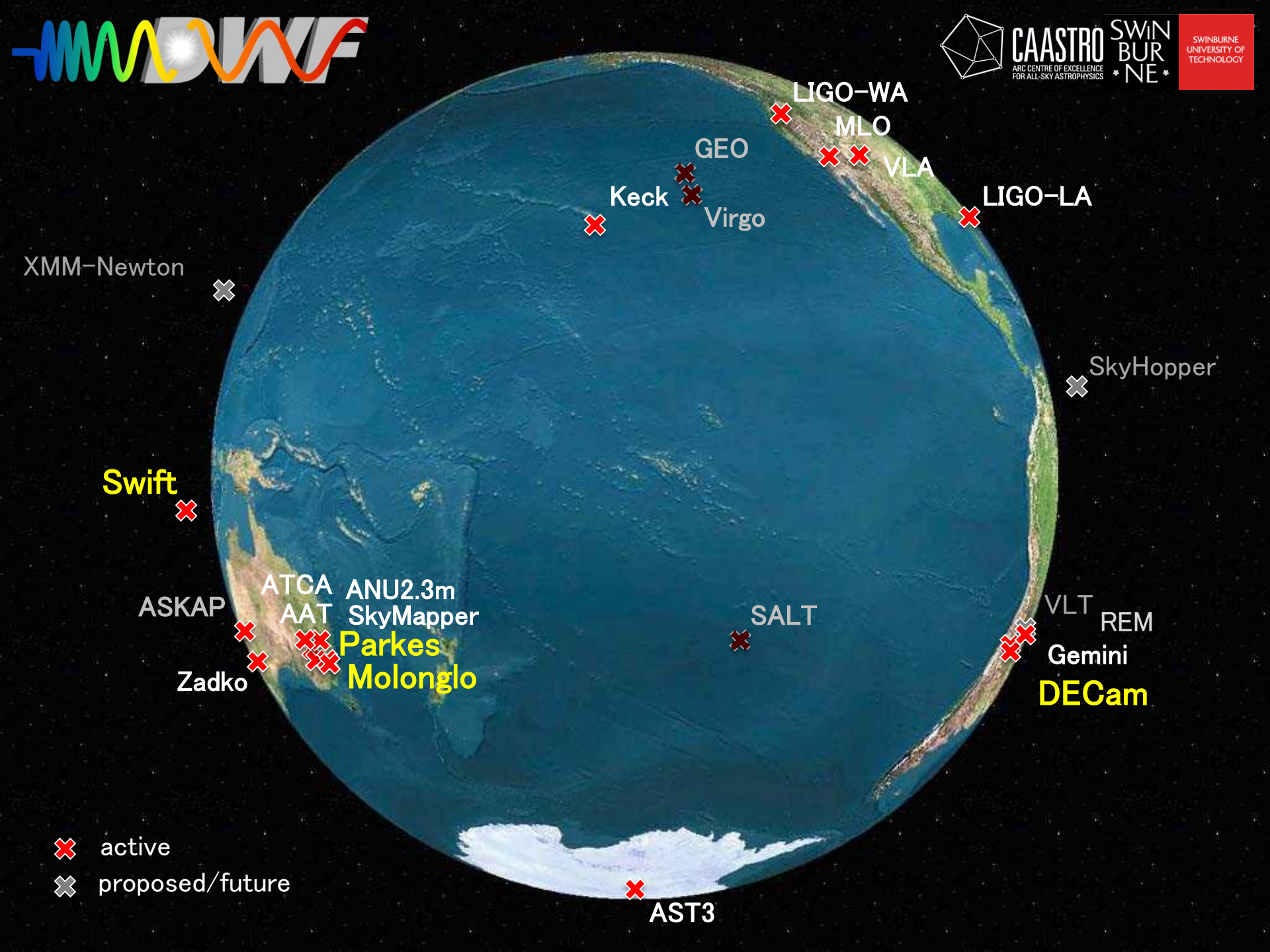
LIGO (WA, USA)

LIGO (LA, USA)

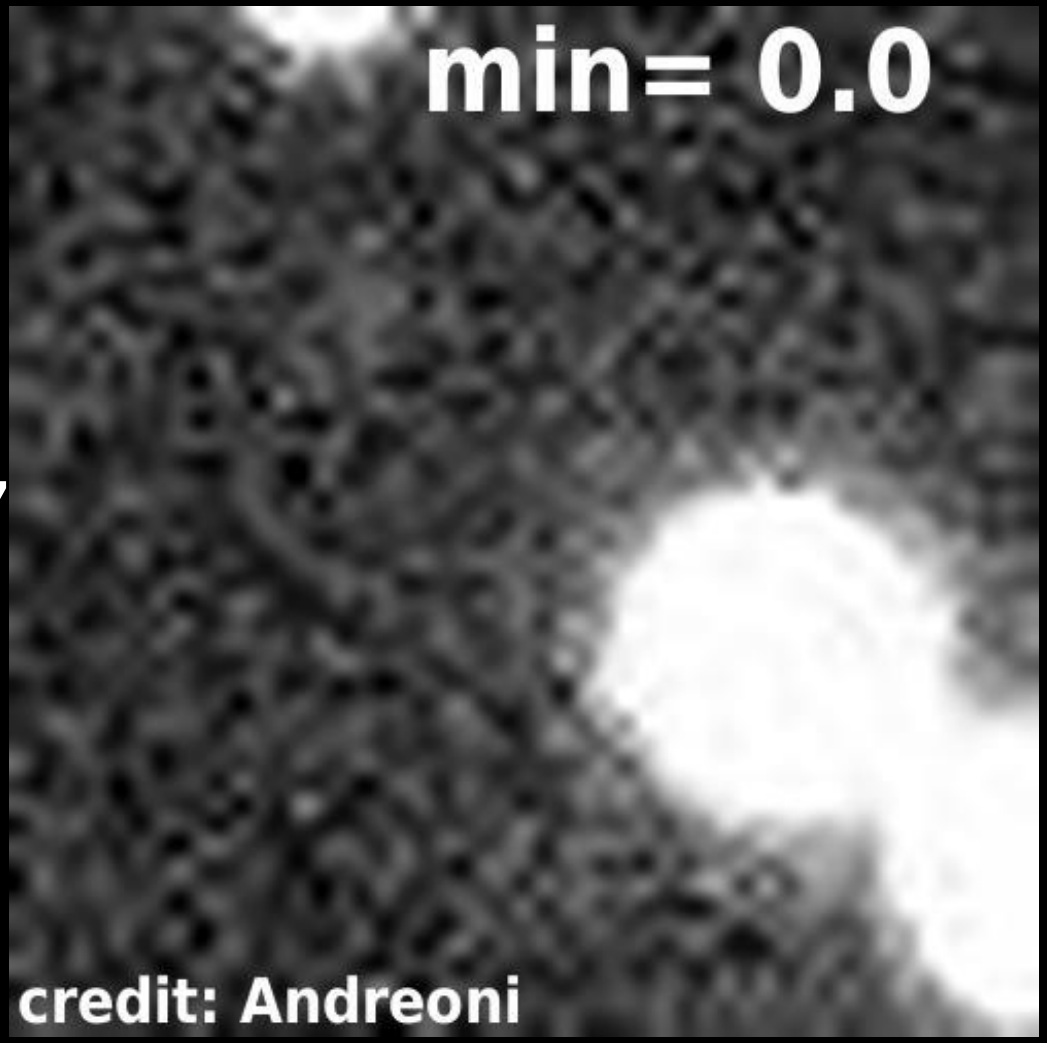
Virgo, Italy

e.g., kilonovae,
supernovae shock breakout,
gamma-ray bursts, etc.

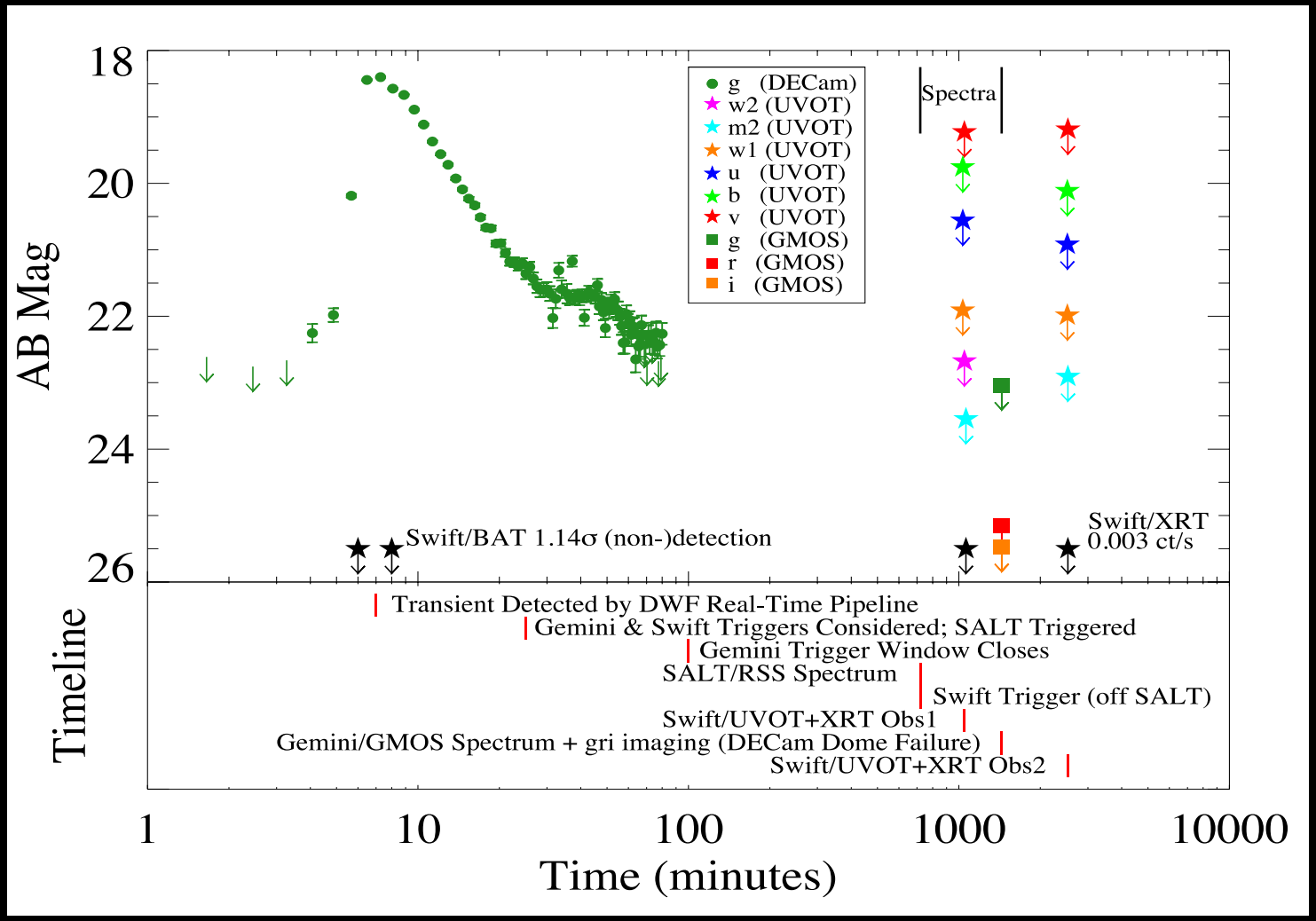
GEO, Germany


DWF
CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS
SWINBURNE UNIVERSITY OF TECHNOLOGY
LIGO-WA
MLO
GEO
VLA
Keck
LIGO-LA
Virgo
XMM-Newton
SkyHopper
Swift
ATCA
ANU2.3m
ASKAP
AAT
SkyMapper
SALT
VLT
REM
Parkes
Gemini
Zadko
Molonglo
DECam
active
proposed/future
AST3

ID = dwf9497

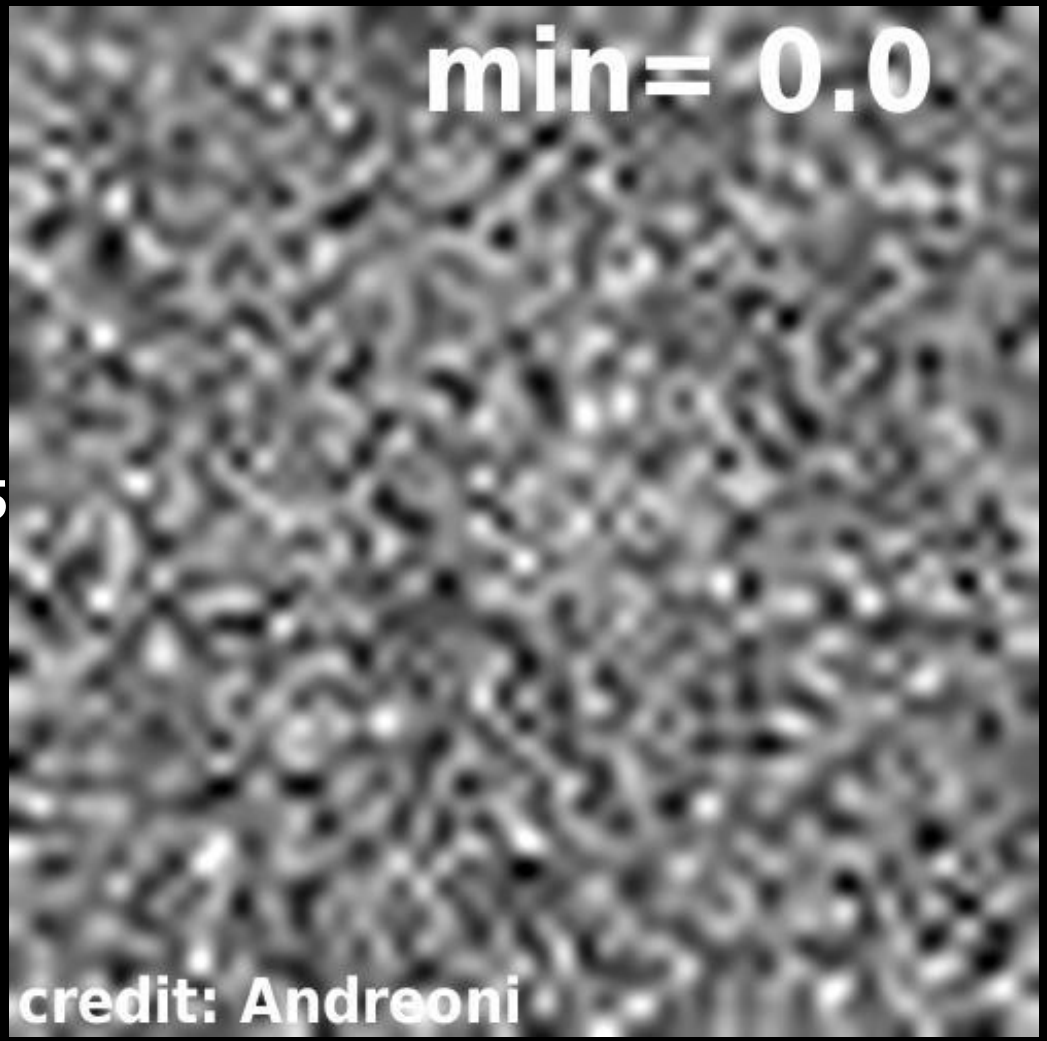


fast transient



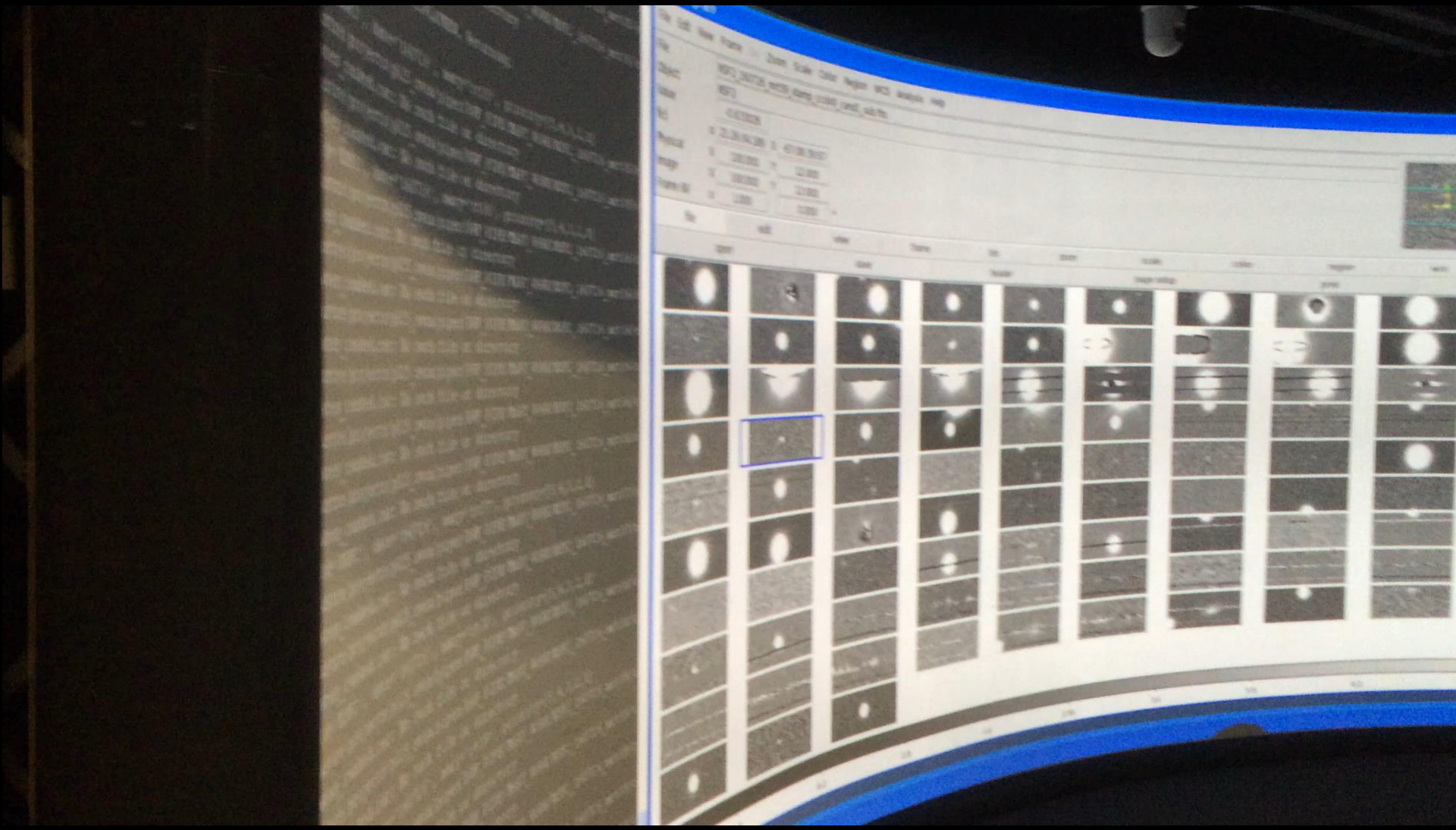
Multi-wavelength coverage

ID = dwf1675



bursty fast transient

Real-time analysis



Real-time analysis

Real-time analysis

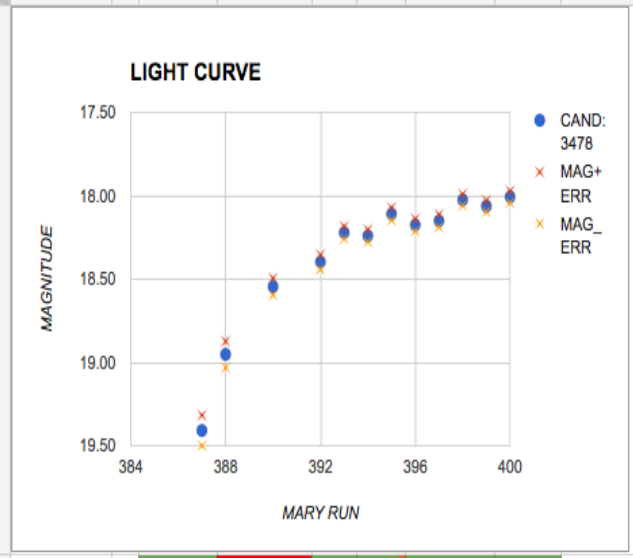
EVAL_NGC6744_CCD1-10_1607

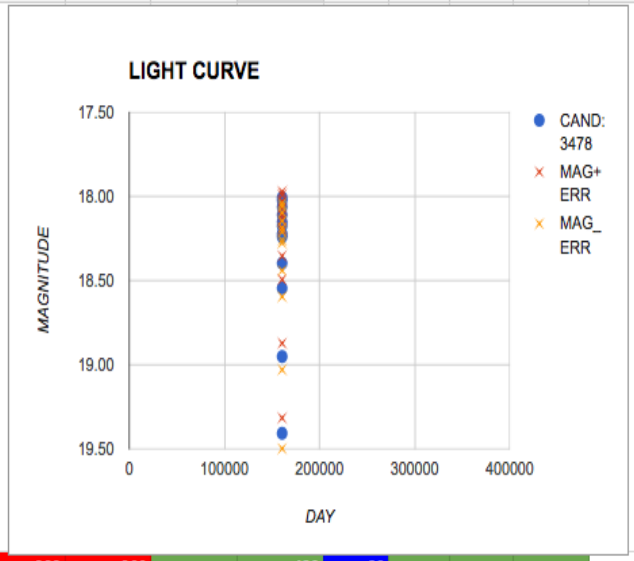
File Edit View Insert Format Data Tools Add-ons Help All changes saved in Drive

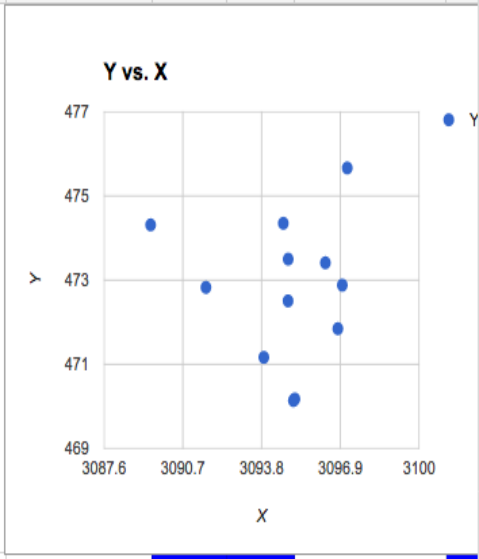
astrofizboy@gmail.com

Comments Share

fx 470

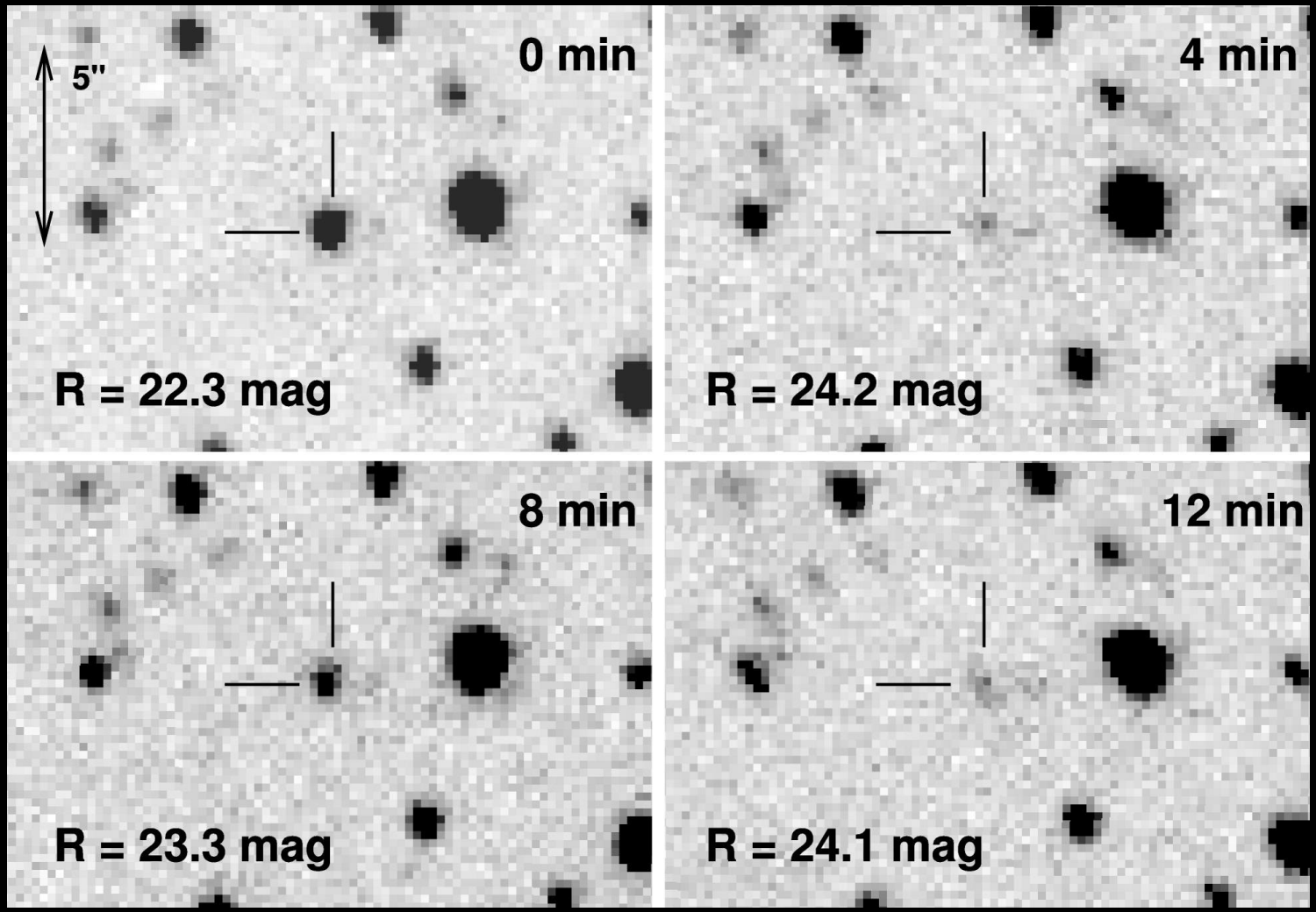




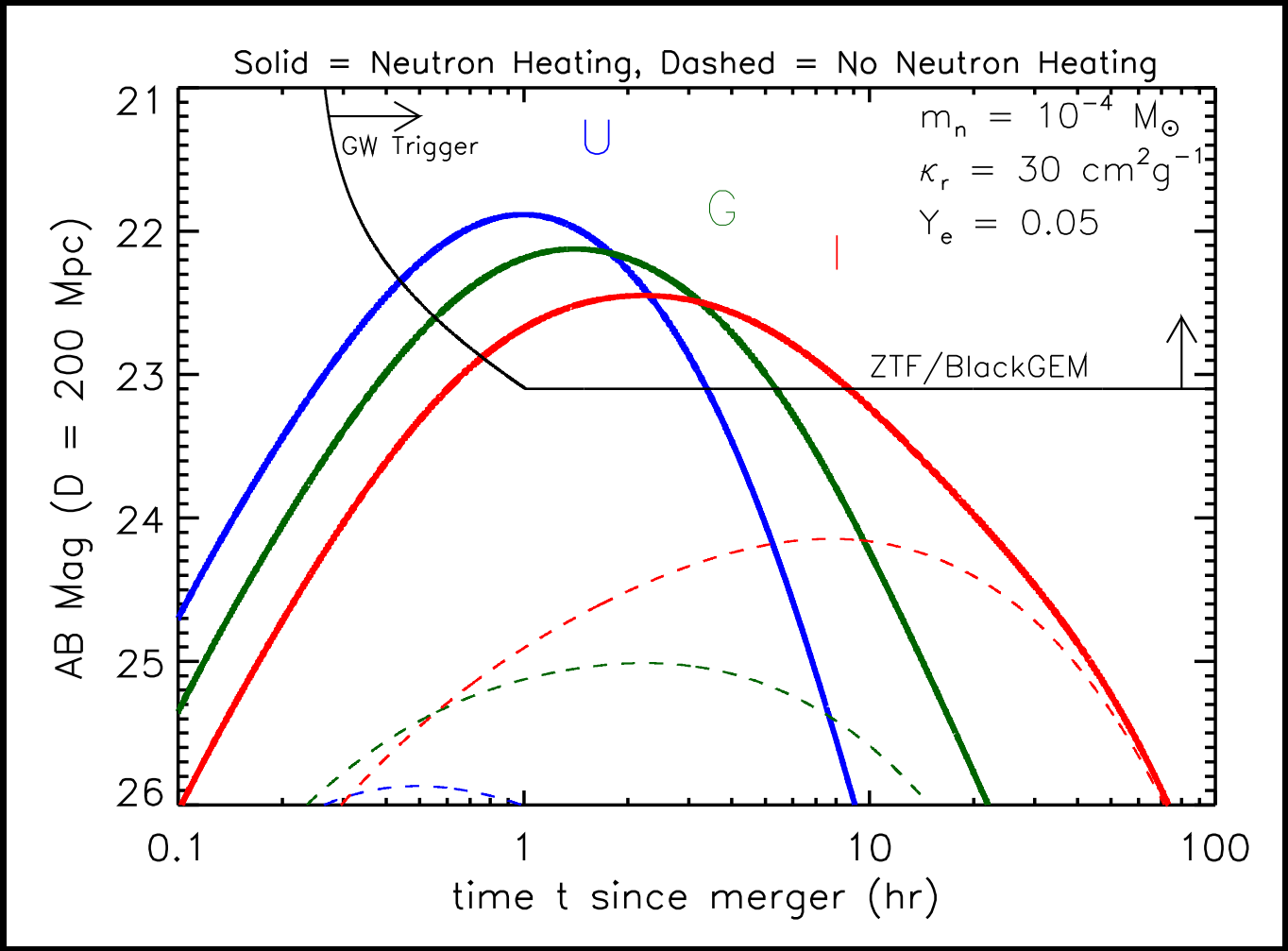


2	FILTERS:		3478	NGC6744		430				360	360		480	23						5	200			
3	SORT COL:	1	=	=		384				-360	-360		470							-1	-1			
4	SORT DIR:	0	0/1	YOUR NAME:		jeff				360/-360	360/-360		MAG RANGE:	1.40			MAG AVG:	18.36		5/-1	200/-1			5/-1
5	COLUMN #:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
6	12	CAND	FIELD	CCD	RUN	DAY	CCD CAND	UT	RA	DEC	X	Y	MAG	ERR	MARY PRI	CAT CLASS	CAT OTHER	MARY NOTES	EVAL STATUS	EVAL BY	EVAL NOTES	EVA PRI		
7	12	3478	ngc6744	8	387	160804	2				3097.1721	475.66329	19.4071	0.091	2	103	non-star 1 1995.6							
8	12	3478	ngc6744	8	388	160804	2				3095.1098	470.17449	18.9512	0.0786	2	103	non-star 1 1995.6							
9	12	3478	ngc6744	8	390	160804	4				3095.0527	470.13699	18.5452	0.0508	2	103	non-star 1 1995.6							
10	12	3478	ngc6744	8	392	160804	3				3096.8010	471.84509	18.3976	0.0432	2	103	non-star 1 1995.6							
11	12	3478	ngc6744	8	393	160804	2				3096.9772	472.87860	18.2216	0.037	2	103	non-star 1 1995.6							
12	12	3478	ngc6744	8	394	160804	3				3094.8417	472.50399	18.2407	0.0367	2	103	non-star 1 1995.6							
13	12	3478	ngc6744	8	395	160804	2				3094.6552	474.34820	18.1096	0.0379	2	103	non-star 1 1995.6							
14	12	3478	ngc6744	8	396	160804	2				3094.8471	473.49679	18.1755	0.0361	2	103	non-star 1 1995.6							

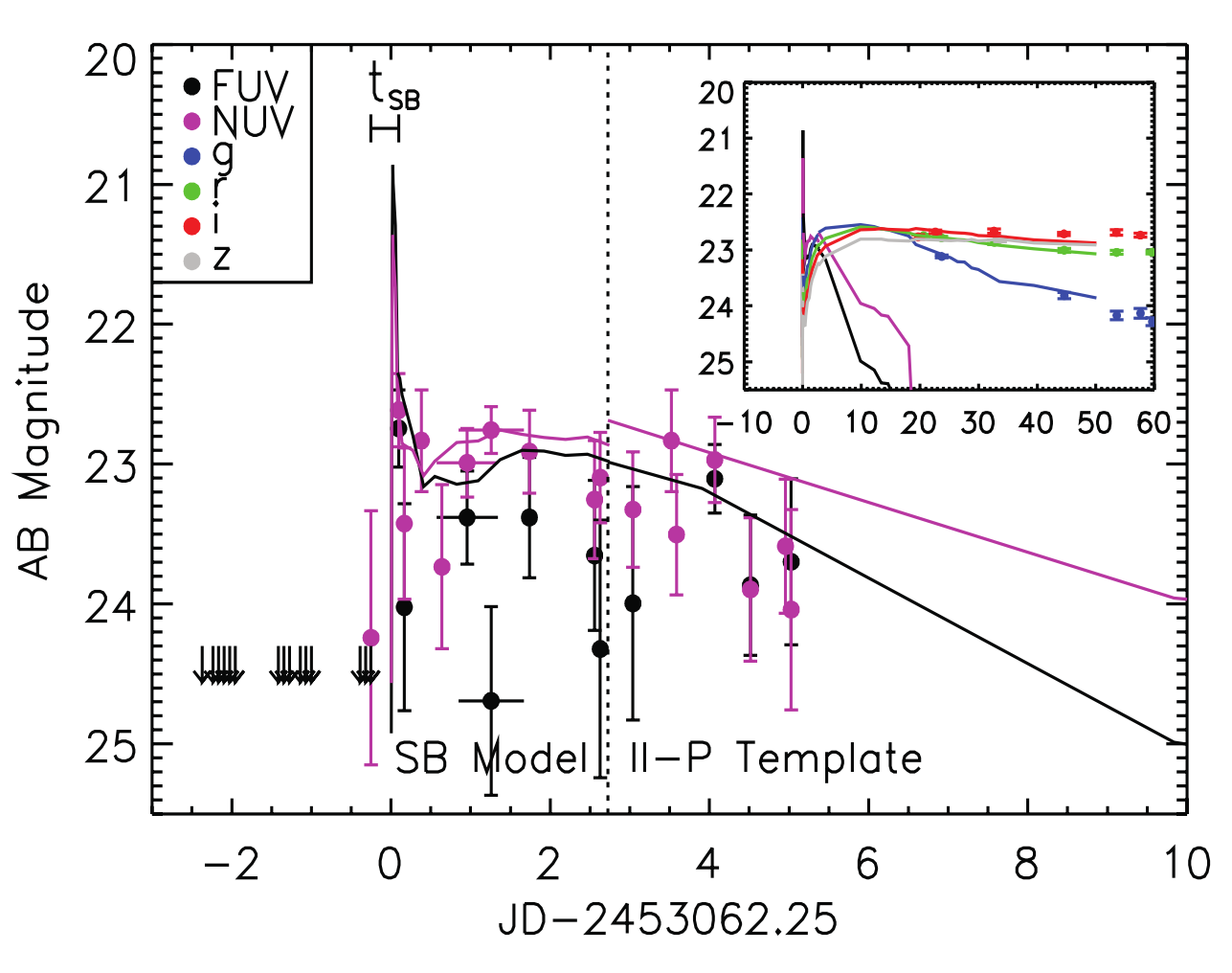
Fast transients are faint

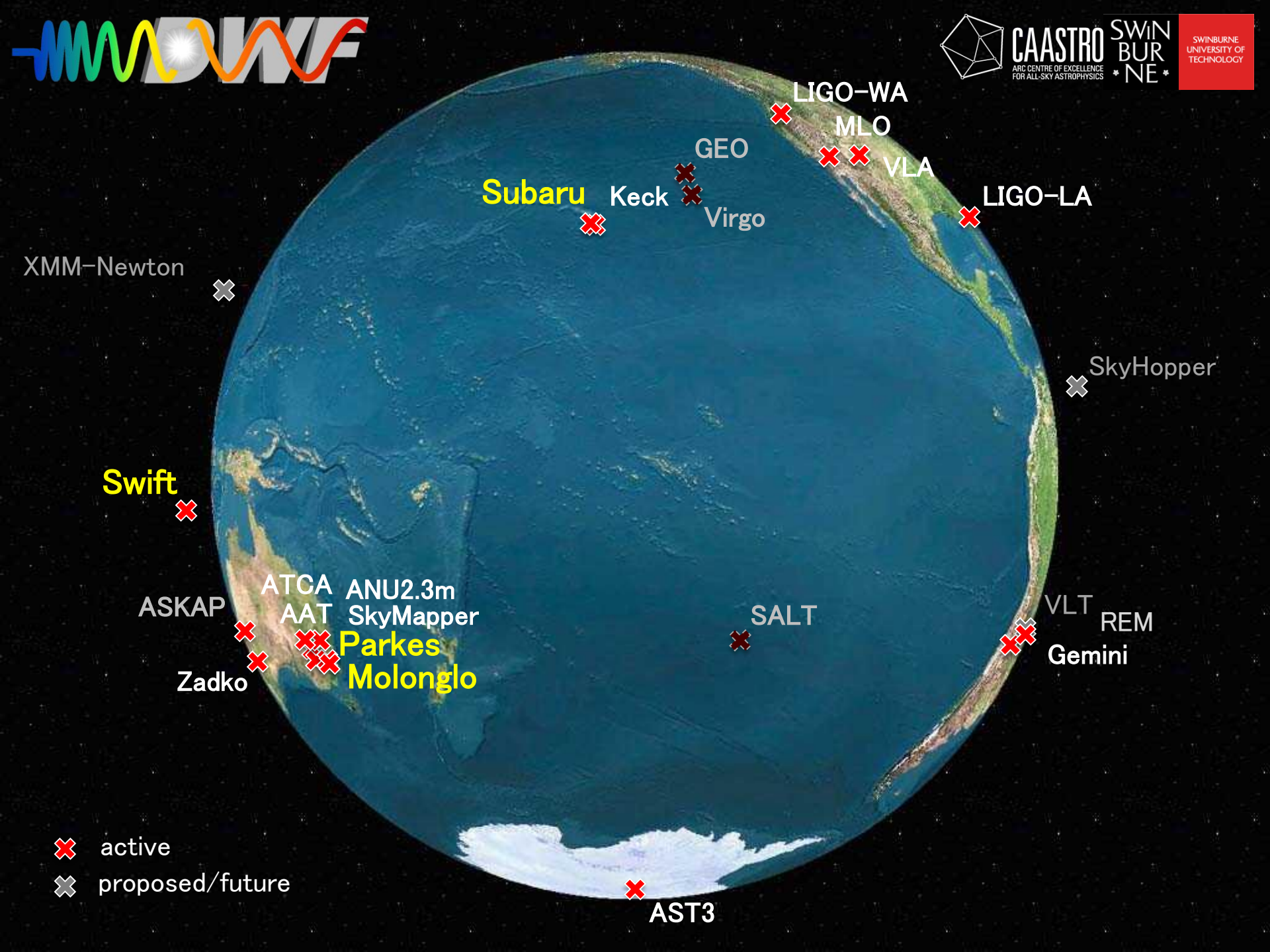


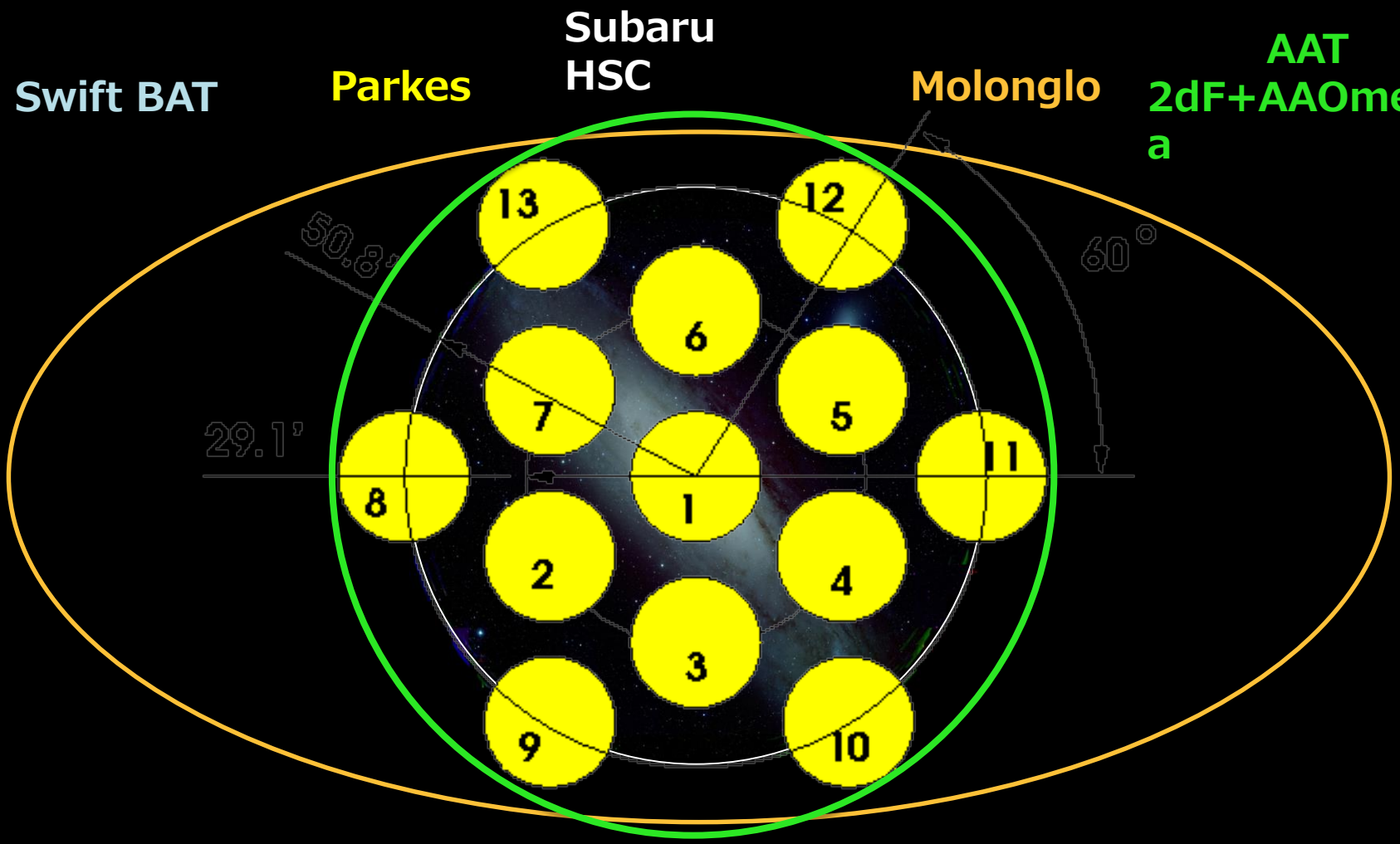
Fast transients are faint



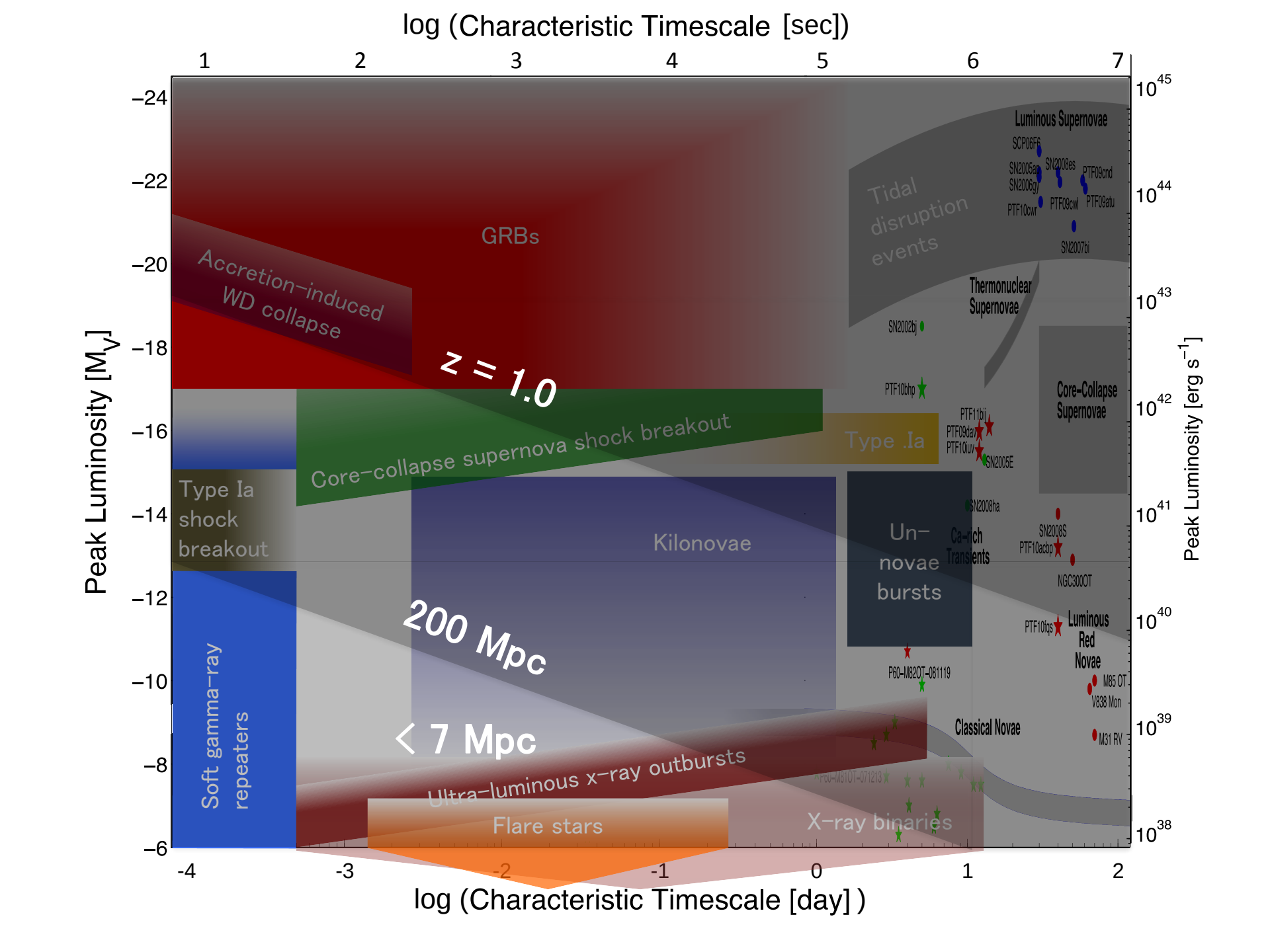
Fast transients are faint




DWF
CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS
SWINBURNE
SWINBURNE UNIVERSITY OF TECHNOLOGY
LIGO–WA
MLO
GEO
VLA
Subaru
Keck
Virgo
LIGO–LA
XMM–Newton
SkyHopper
Swift
ASKAP
ATCA
ANU2.3m
AAT
SkyMapper
Parkes
Molonglo
Zadko
SALT
VLT
REM
Gemini
AST3
active
proposed/future



Collect simultaneous data *(continuous 20s integrations)*, transfer it, process, calibrate and analyse it, and identify candidates *every ~1 minute*


log (Characteristic Timescale [sec])
1
2
3
4
5
6
7
Peak Luminosity [M_V]
−24
−22
−20
−18
−16
−14
−12
−10
−8
−6
Peak Luminosity [erg s^{-1}]
10^{45}
10^{44}
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
log (Characteristic Timescale [day])
-4
-3
-2
-1
0
1
2
GRBs
Accretion−induced WD collapse
z = 1.0
Core−collapse supernova shock breakout
Type Ia shock breakout
Kilonovae
200 Mpc
< 7 Mpc
Soft gamma−ray repeaters
Ultra−luminous x−ray outbursts
Flare stars
X−ray binaries
Tidal disruption events
Luminous Supernovae
SCP06F6
SN2005ap
SN2006gy
SN2008es
PTF09cnd
PTF10cwr
PTF09cwl
PTF09atu
SN2007bi
Thermonuclear Supernovae
SN2002bj
PTF10bhp
Type .Ia
PTF11bij
PTF09dav
PTF10iuv
SN2005E
Core−Collapse Supernovae
SN2008ha
Un−novae bursts
Ca−rich Transients
SN2008S
PTF10acbp
NGC300OT
PTF10fqs
Luminous Red Novae
P60−M82OT−061119
M85 OT
V838 Mon
Classical Novae
M31 RV
P60−M81OT−071213

DWF summary

The optical fast time domain is essentially *unexplored territory*

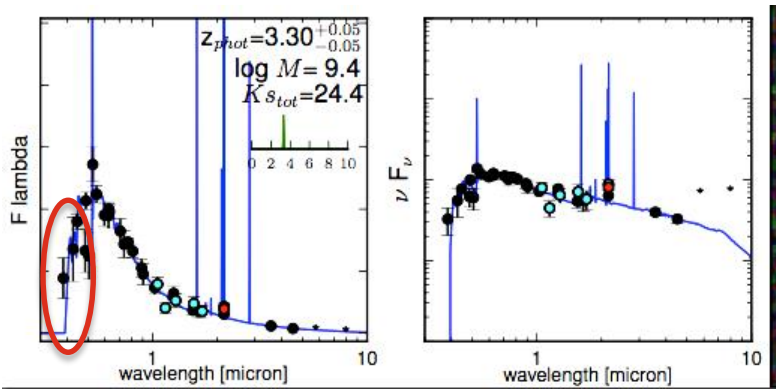
Multi-facility, multi-wavelength collaboration search for fast transients
- Simultaneous, rapid-response and follow-up observations
- Real-time reduction, analysis, and candidate identification

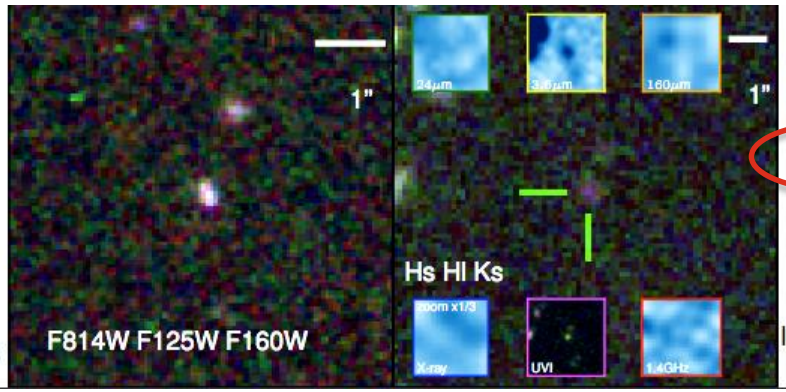
HSC will drive discovery
- Need faint detection; *KNe, SBO, off-axis GRBs, etc.*

Japan	**Subaru (HSC, PFS), TAO (SWIMS)**
Australia	**AAT, SkyMapper, ANU 2.3m, Zadko, Gattini Parkes, Molonglo, ATCA, ASKAP, MWA**
China/AU	**AST3-2, PMO, KDUST**
US	**Keck, Gemini, Palomar, ZTF, MLO, VLA, LSA**
Canada	***CFHT*, CHIME**
Chile/ESO	**Gemini, *VLT*, DECam, REM**
South Africa	**SALT**
Space	**Swift, *XMM-Newton*, SkyHopper**
Other	**IceCube, aLIGO, Virgo, KAGRA**

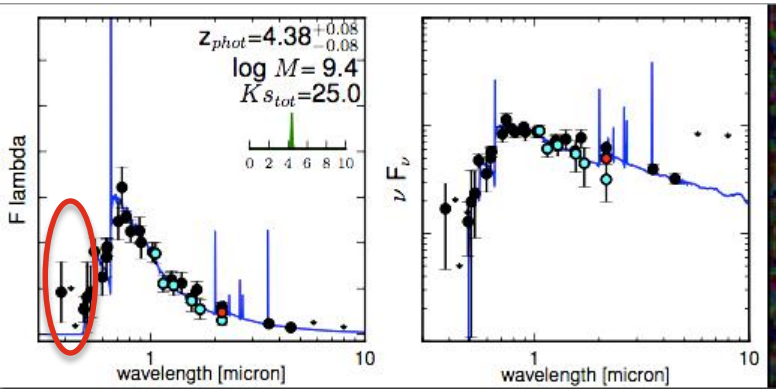
ZFOURGE
Fourstar Galaxy Evolution Survey

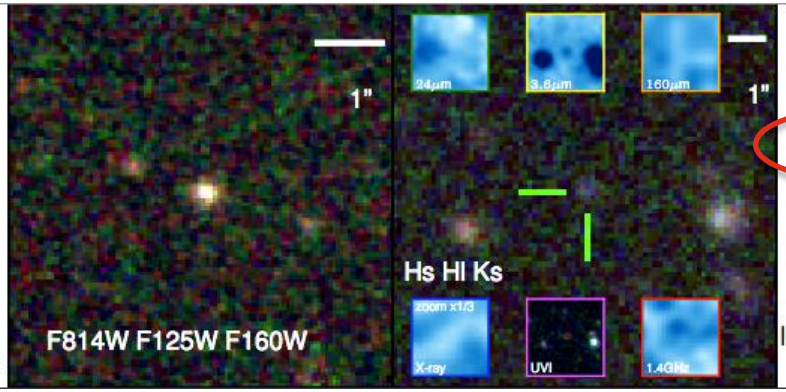
HSC-SSP Lyman Continuum Galaxies at z ~ 3-4



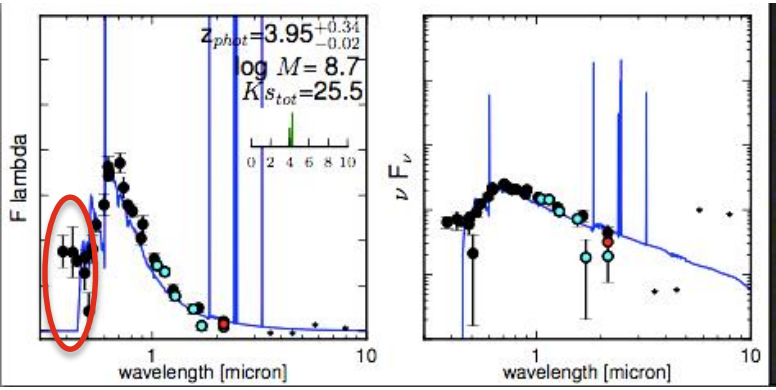


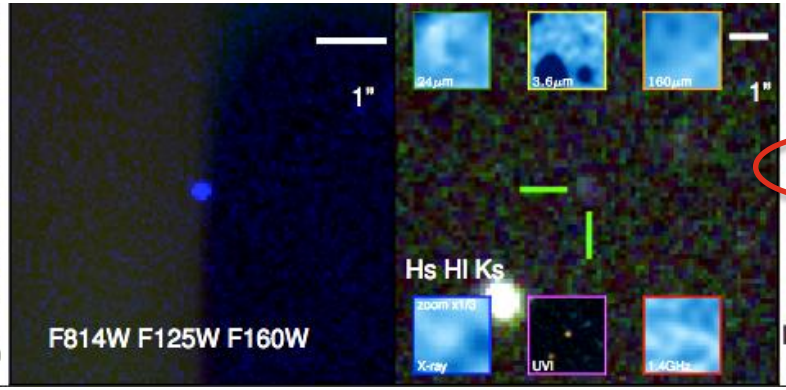
ZFOURGE USE=1
COSMOS v1.3.0 ID: 2037
z_{phot}^{peak}=3.30$^{+0.05}_{-0.05}$ chi_p = 2.46e + 01
U-V$_{z=0}$= 0.36 V-J$_{z=0}$= 0.10 SF
Ks_{tot} = 24.44 log M = 9.42
I_{tot} = 25.2
SFR$_{step}$=-99.0
log age = 8.50 A_V =0.0 τ = 8.2





ZFOURGE USE=1
COSMOS v1.3.0 ID: 8965
z_{phot}^{peak}=4.38$^{+0.08}_{-0.08}$ chi_p = 3.10e + 01
U-V$_{z=0}$= 0.15 V-J$_{z=0}$=-0.10 SF
Ks_{tot} = 24.97 log M = 9.39
I_{tot} = 25.4
SFR$_{step}$=-99.0
log age = 8.10 A_V =0.5 τ = 9.4





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z_{phot}^{peak}=3.95$^{+0.34}_{-0.02}$ chi_p = 1.70e + 02
U-V$_{z=0}$=-1.89 V-J$_{z=0}$=-0.33 SF
Ks_{tot} = 25.46 log M = 8.71
I_{tot} = 24.6
SFR$_{step}$=-99.0
log age = 7.50 A_V =0.1 τ = 11.0