



ZWICKY TRANSIENT FACILITY (ZTF) & THE LARGE SYNOPTIC SURVEY TELESCOPE (LSST)

ZTF

&

LSST



1.5m-class Telescope

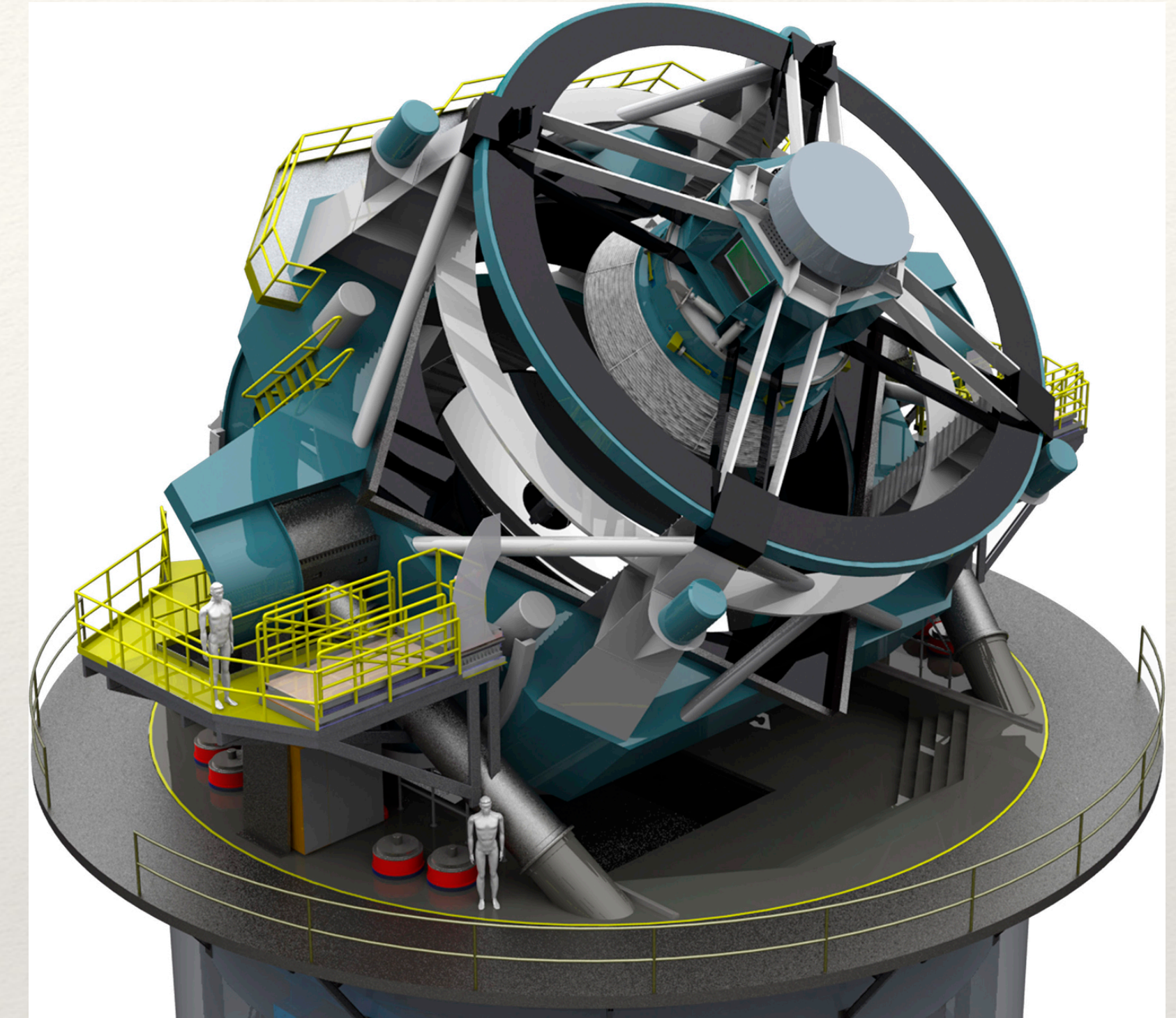
2018 — 2021(3)

Depth of 20 mag in 30s

North (California)

3 filters (g, r, i)

“Revisit at least every days”



8m-class Telescope

2022 — 2032

Depth of 24 mag in 30s

South (Chile)

5+1 filters (g,r,i,z,y + u)

“Revisit every 3 days ≠ band”

ZTF | Fast (30s exp.) & Large (full visible sky) [Not Deep]

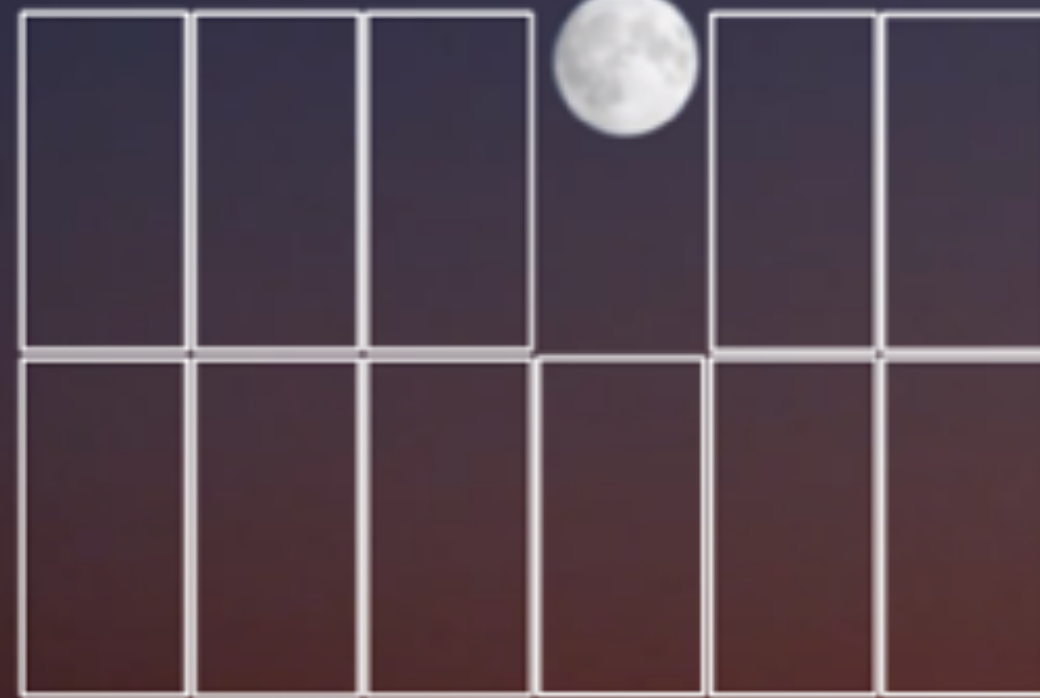
HSC,
1.7 deg²



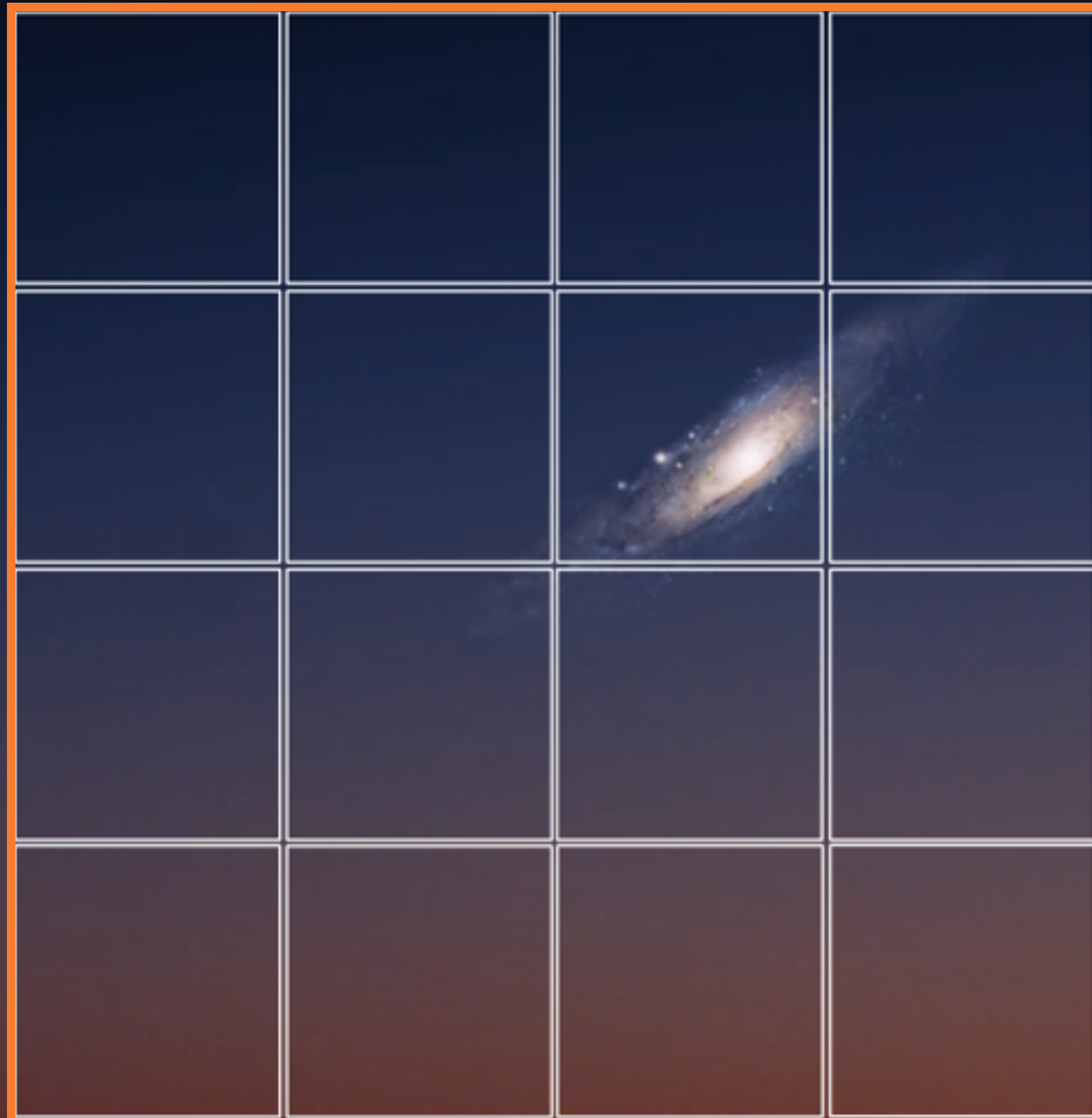
MegaCam,
1.0 deg²



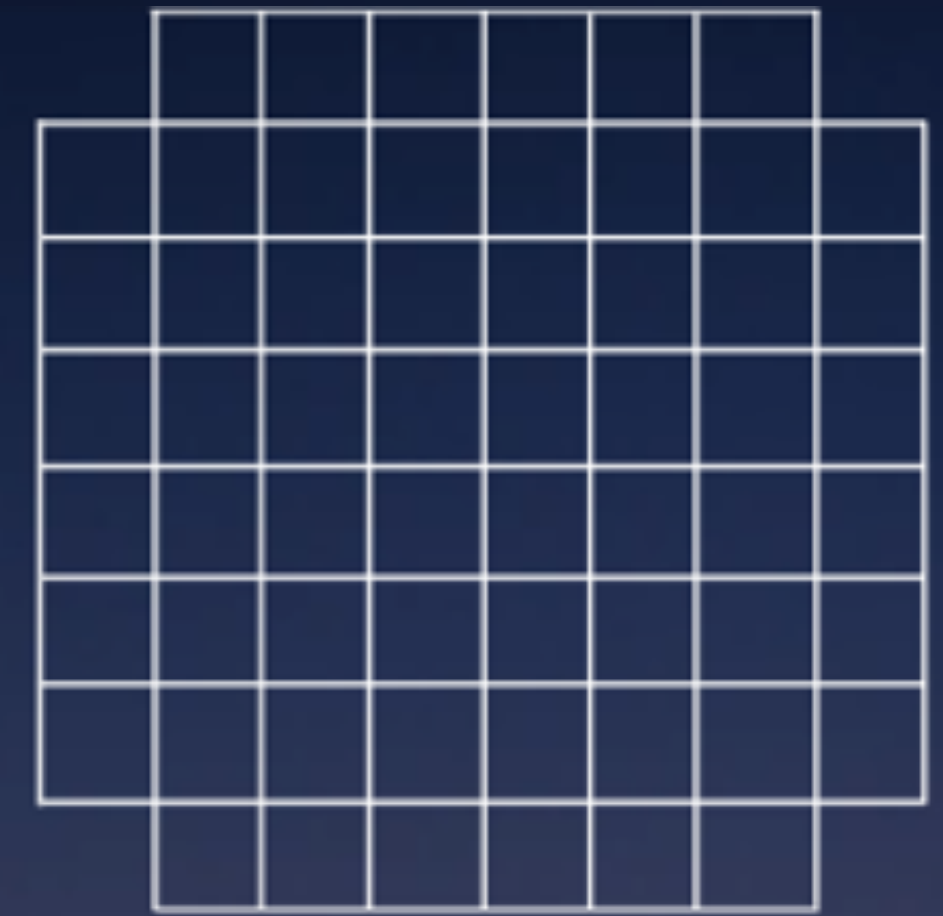
DES,
2.5 deg²



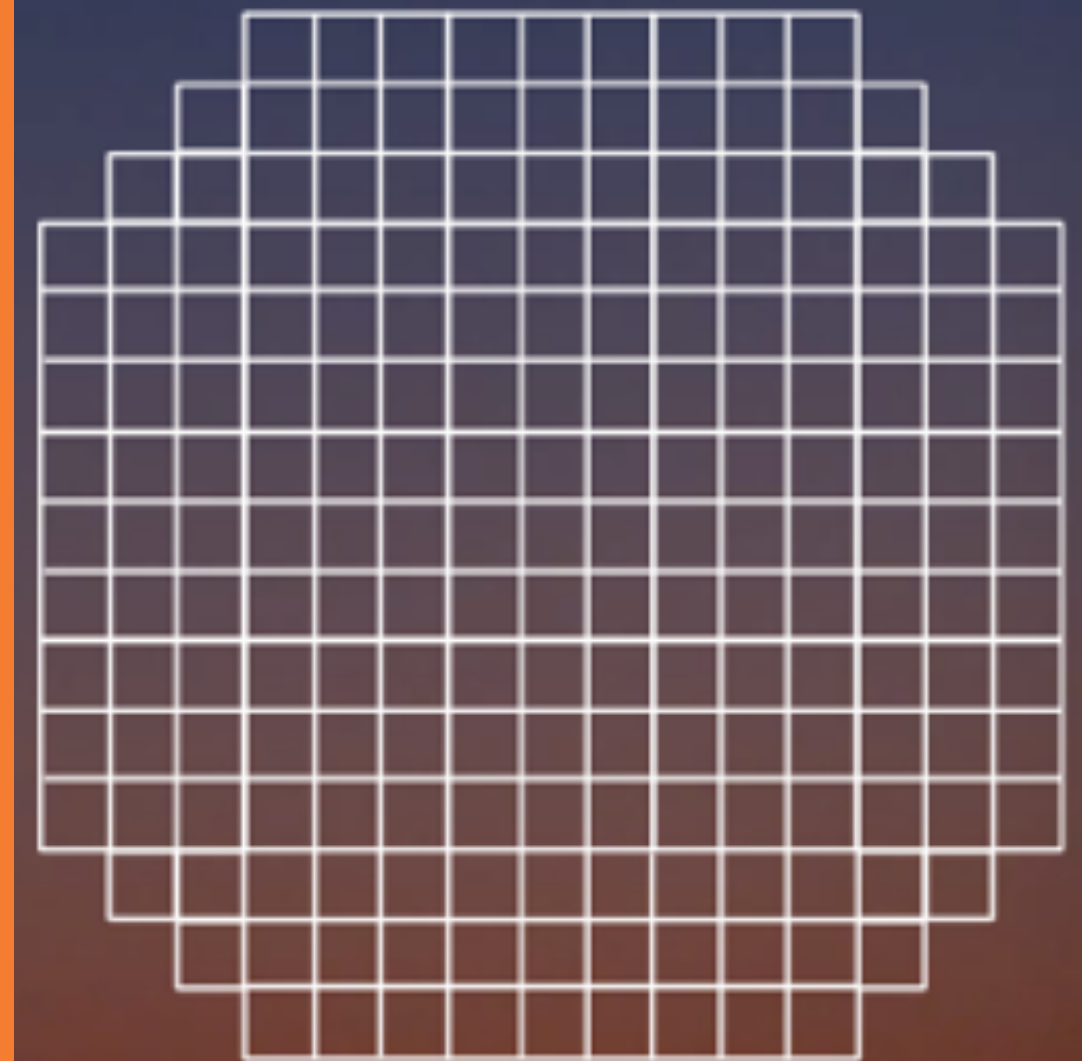
PTF/iPTF, 7.3 deg²



ZTF, 47 deg²



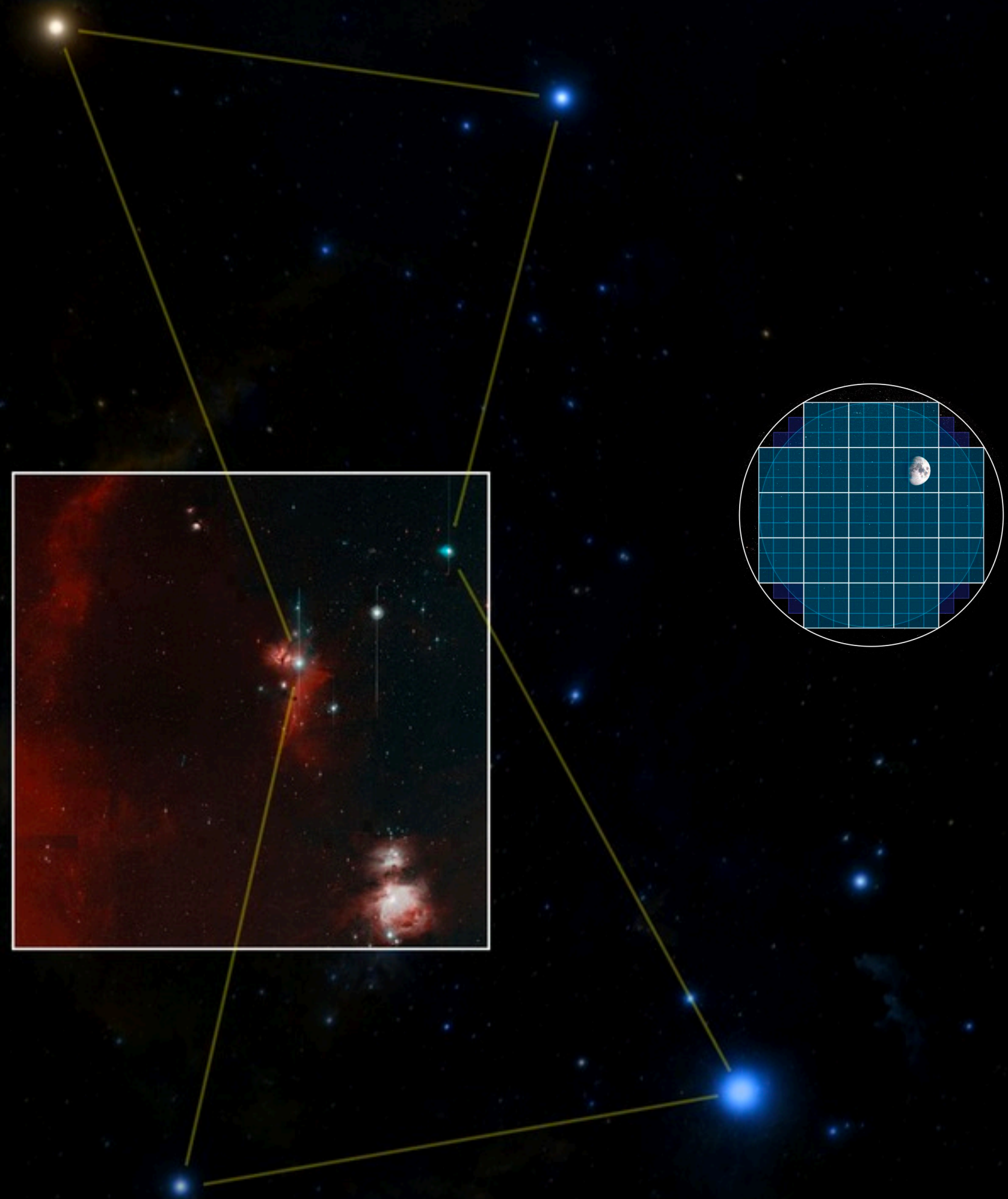
PS1, 7 deg²



LSST, 9.6 deg²

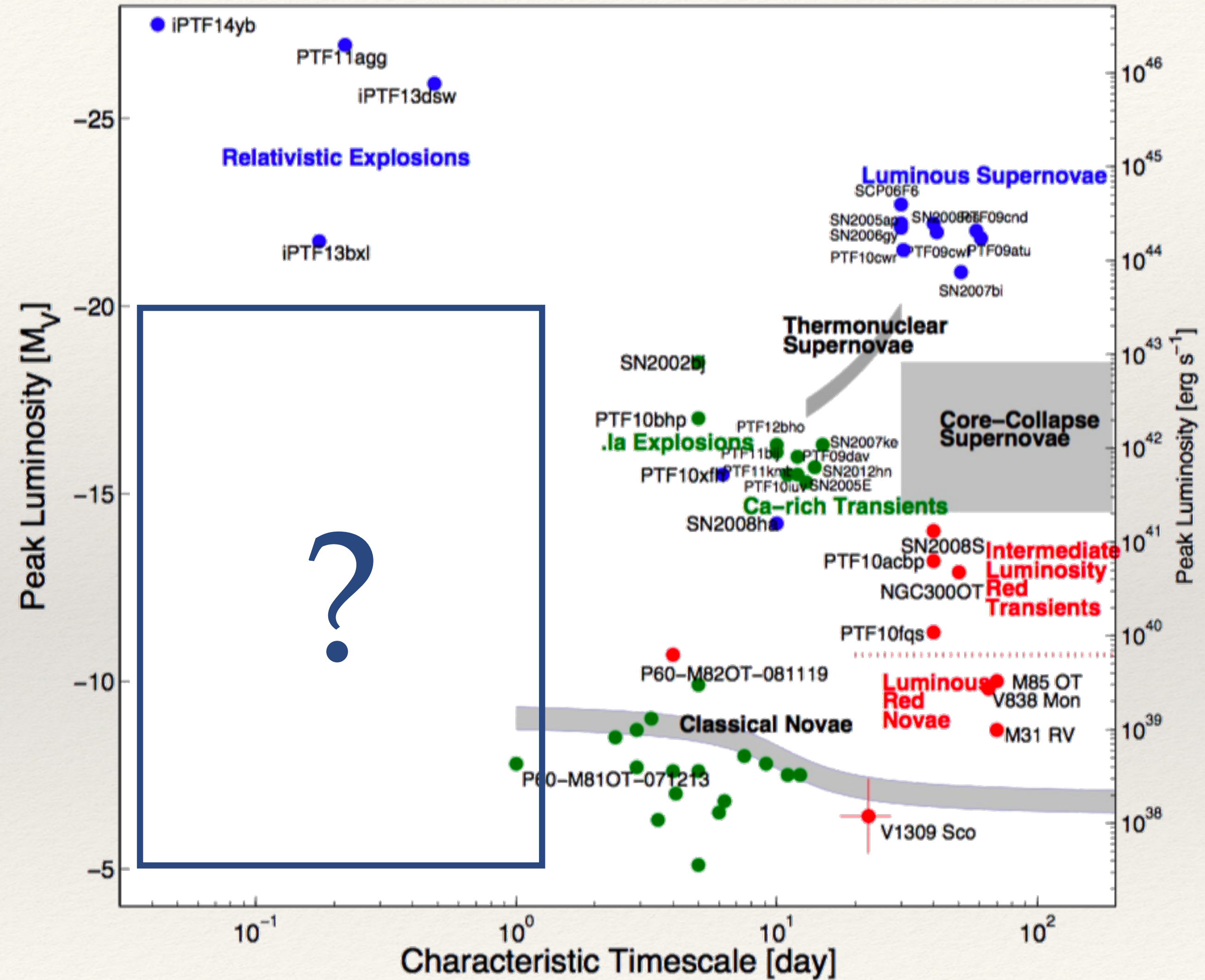
1 deg

We have about 10^5 events/night ; 10% of LSST



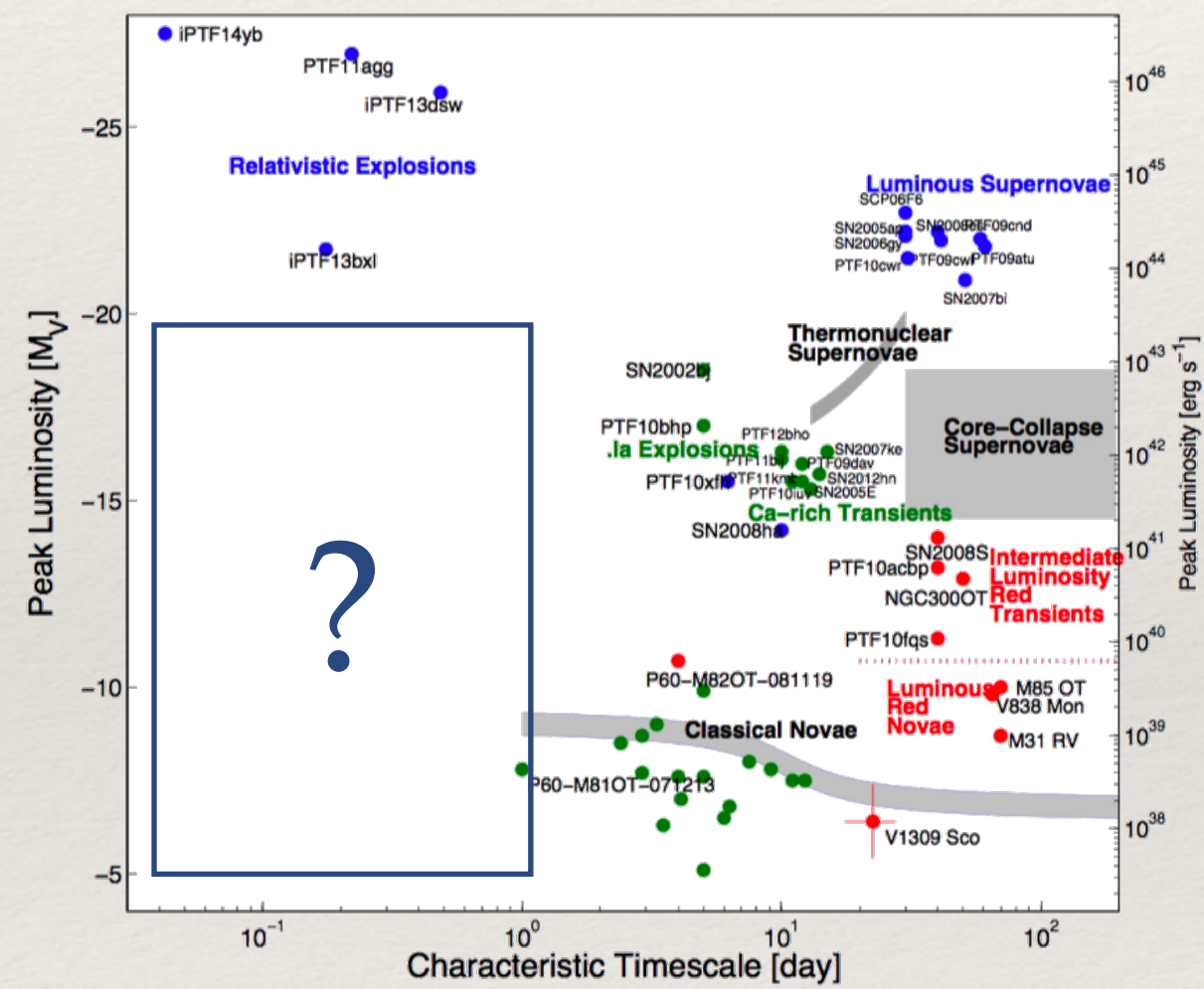
Some ZTF Science Cases

Transients Astro.
Flash Spectroscopy



Some ZTF Science Cases

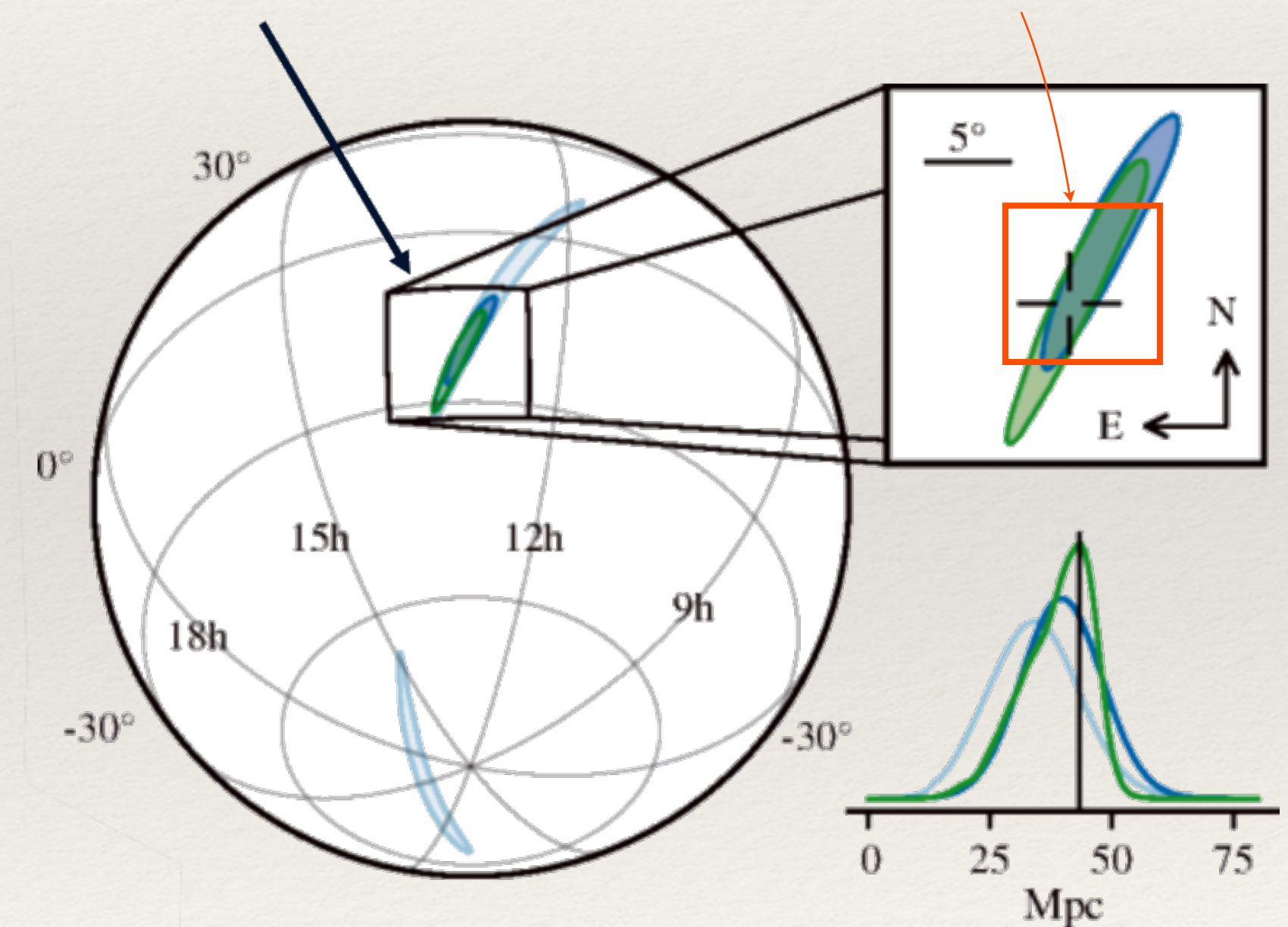
Transients Astro. Flash Spectroscopy



Multi-Messengers GW & Neutrinos

Localization of GW170817 was smaller than ZTF FoV

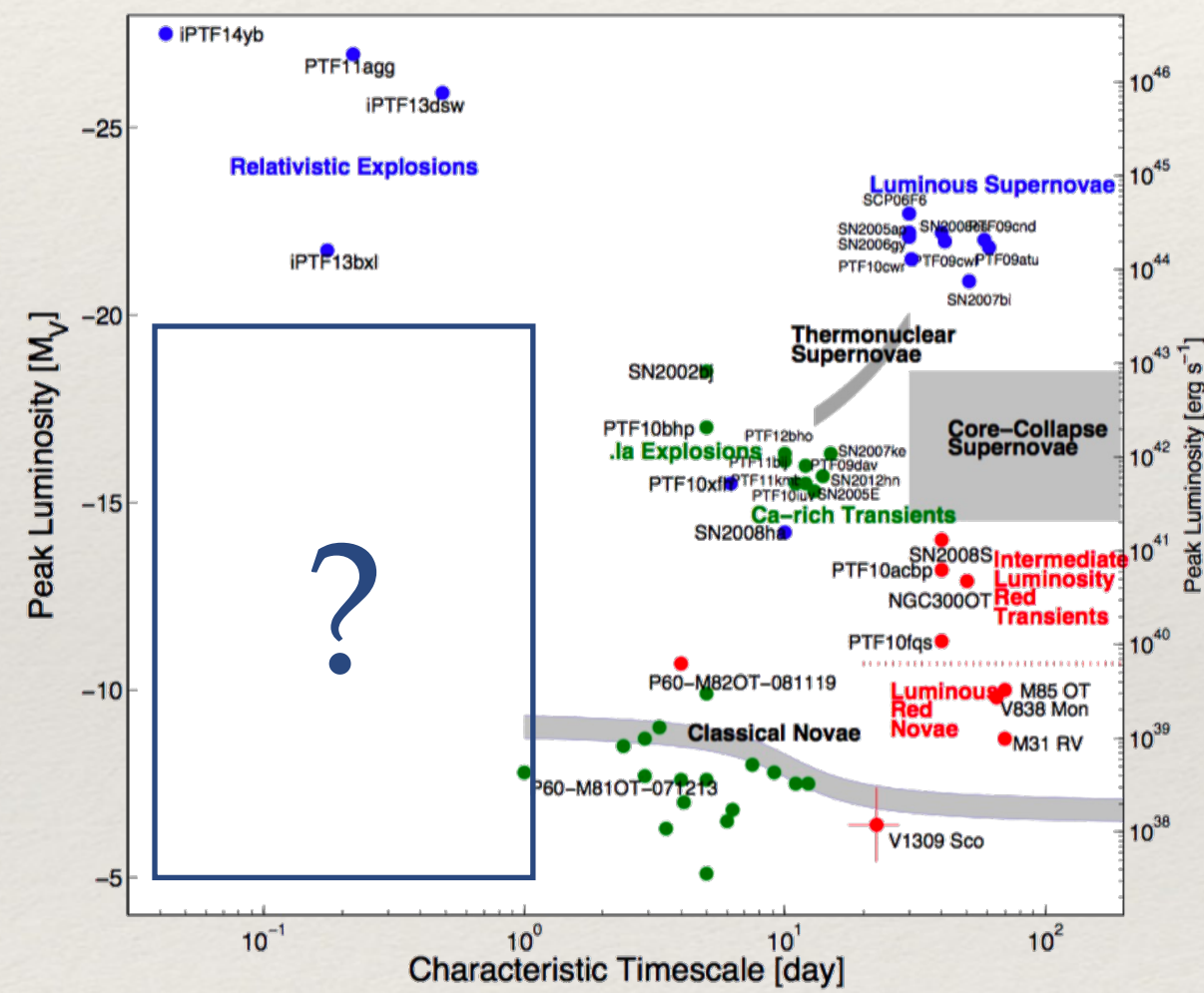
ZTF



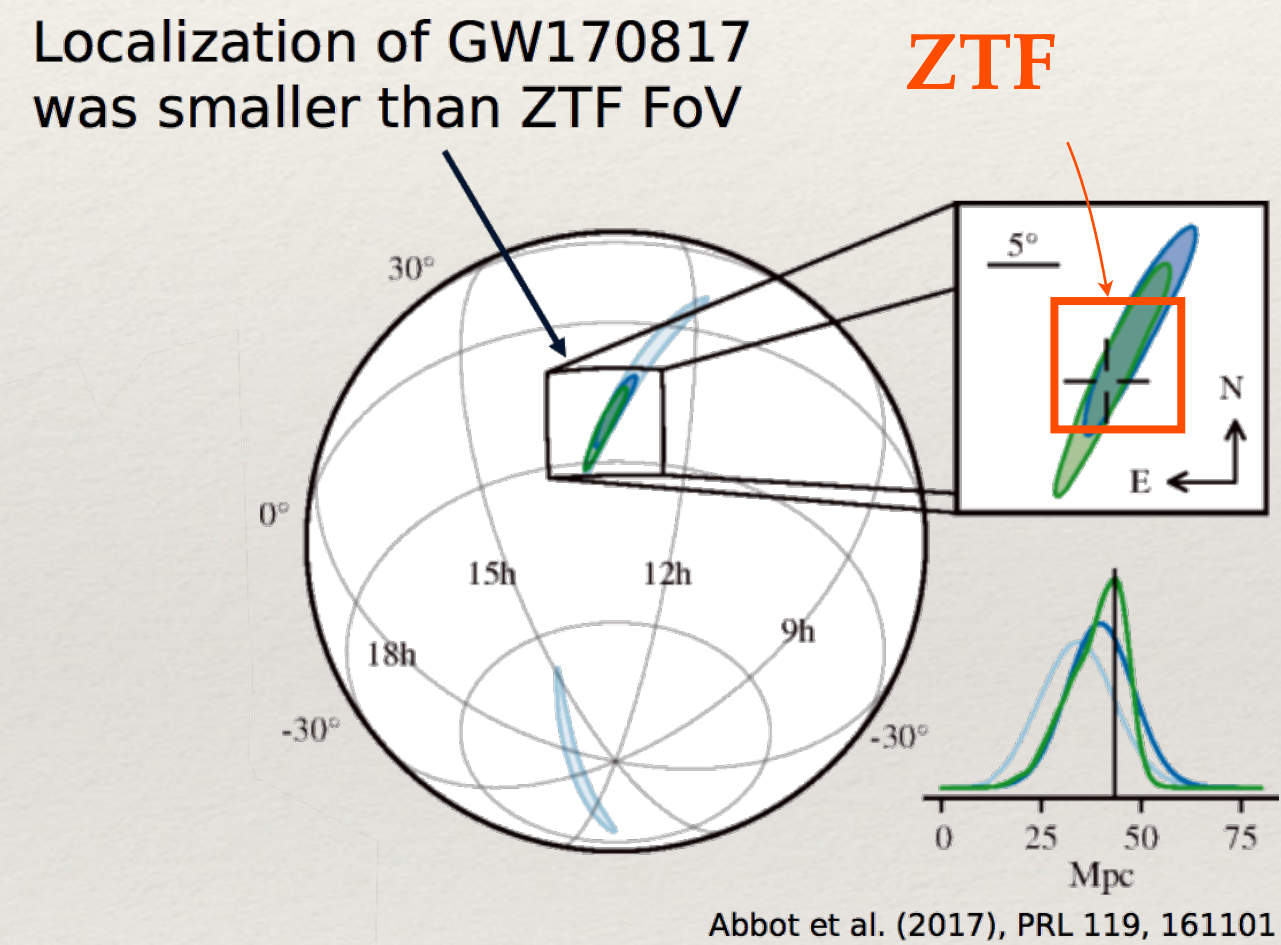
Abbot et al. (2017), PRL 119, 161101

Some ZTF Science Cases

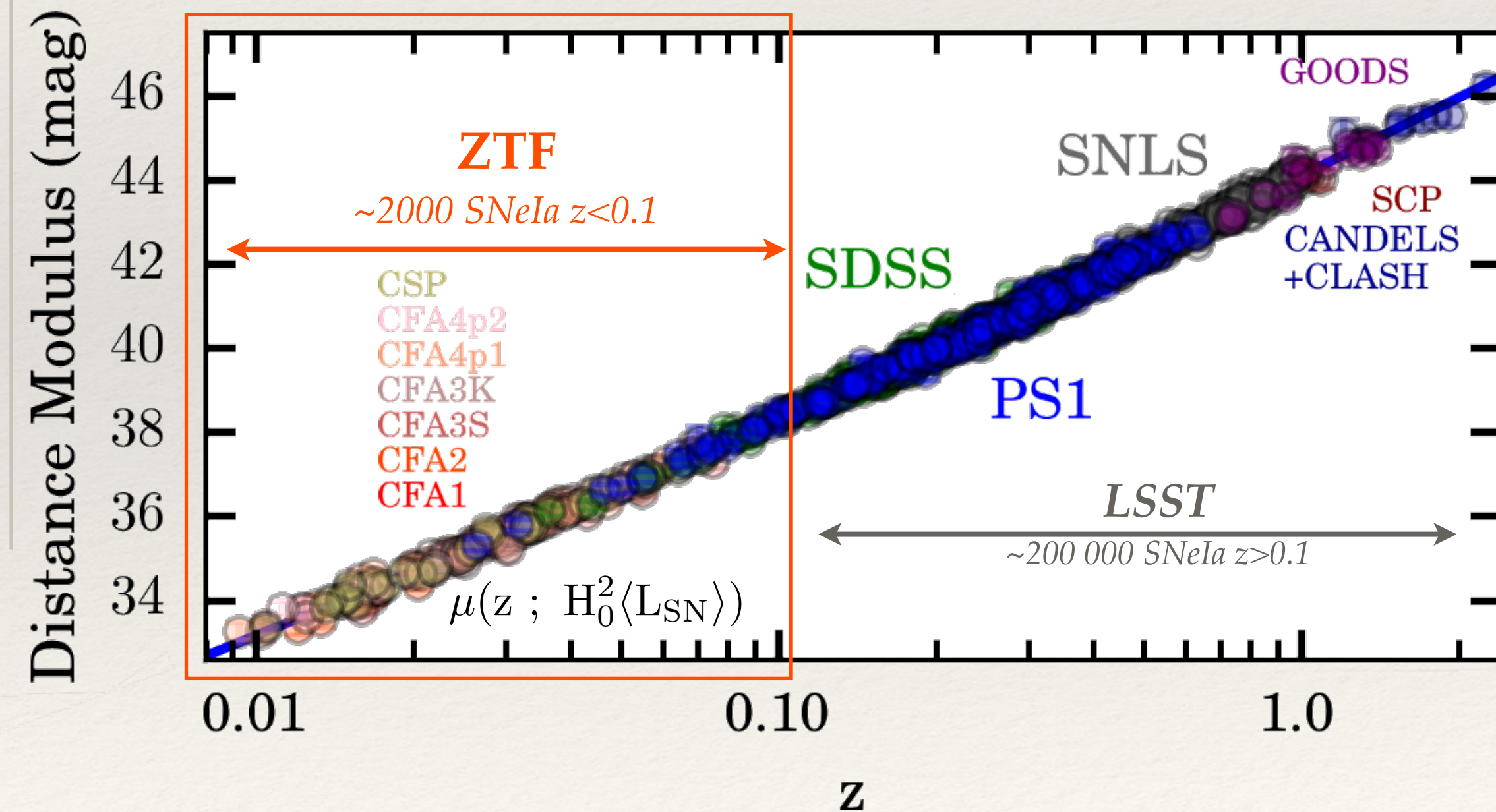
Transients Astro. Flash Spectroscopy



Multi-Messengers GW & Neutrinos

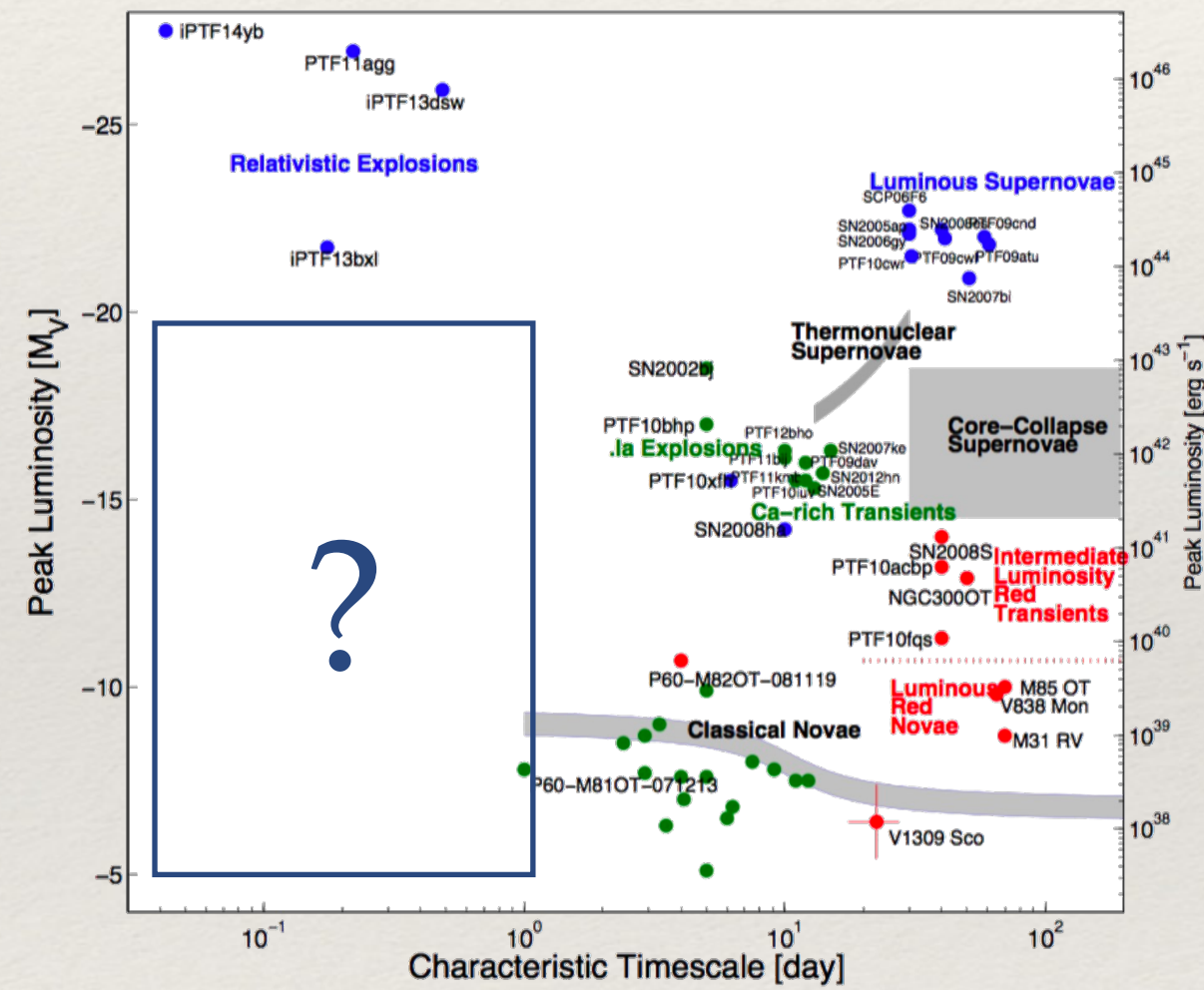


Supernova Cosmology Incl. Strongly lensed SNeIa

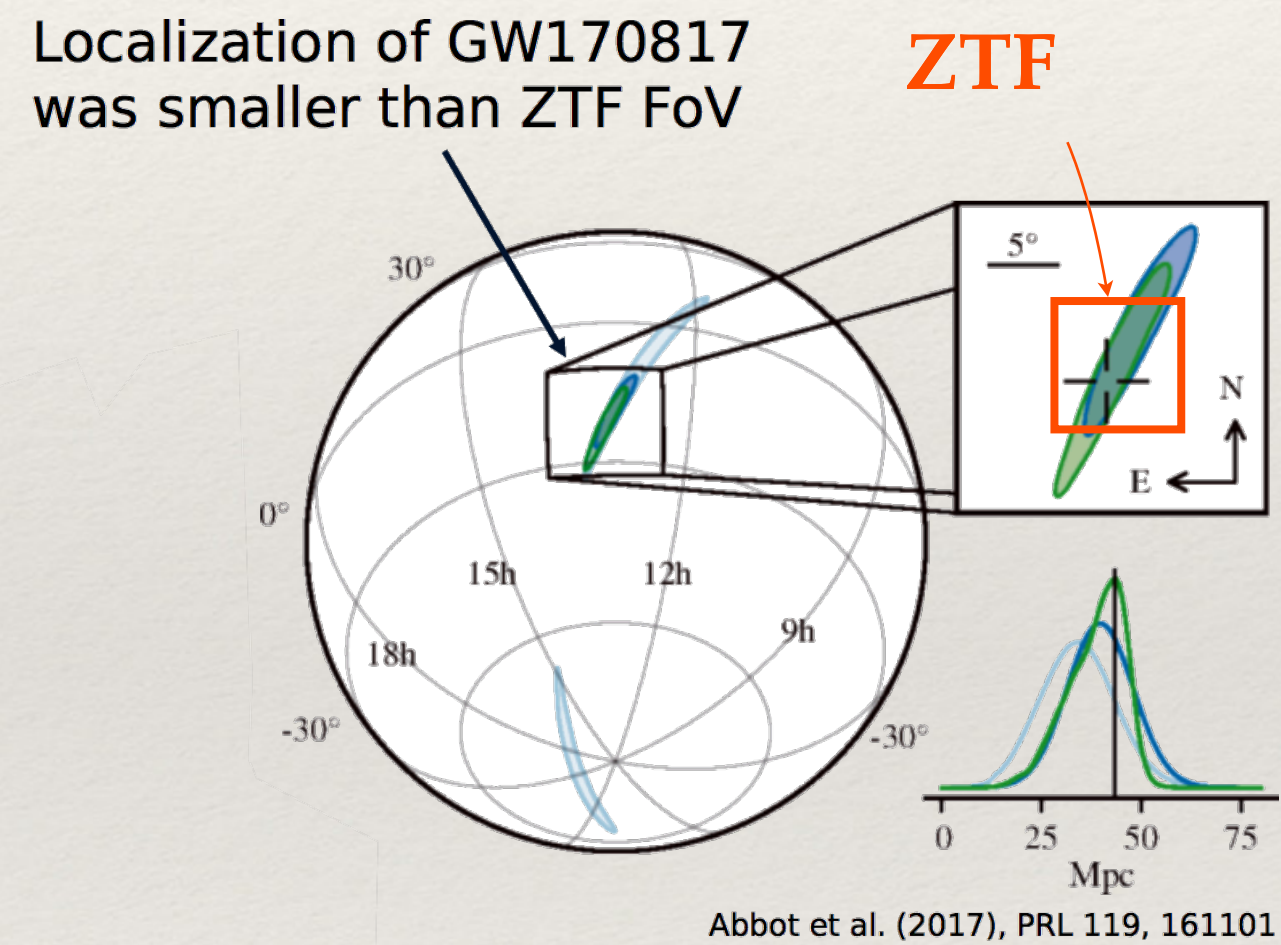


ZTF Science Cases ~ LSST Science Cases

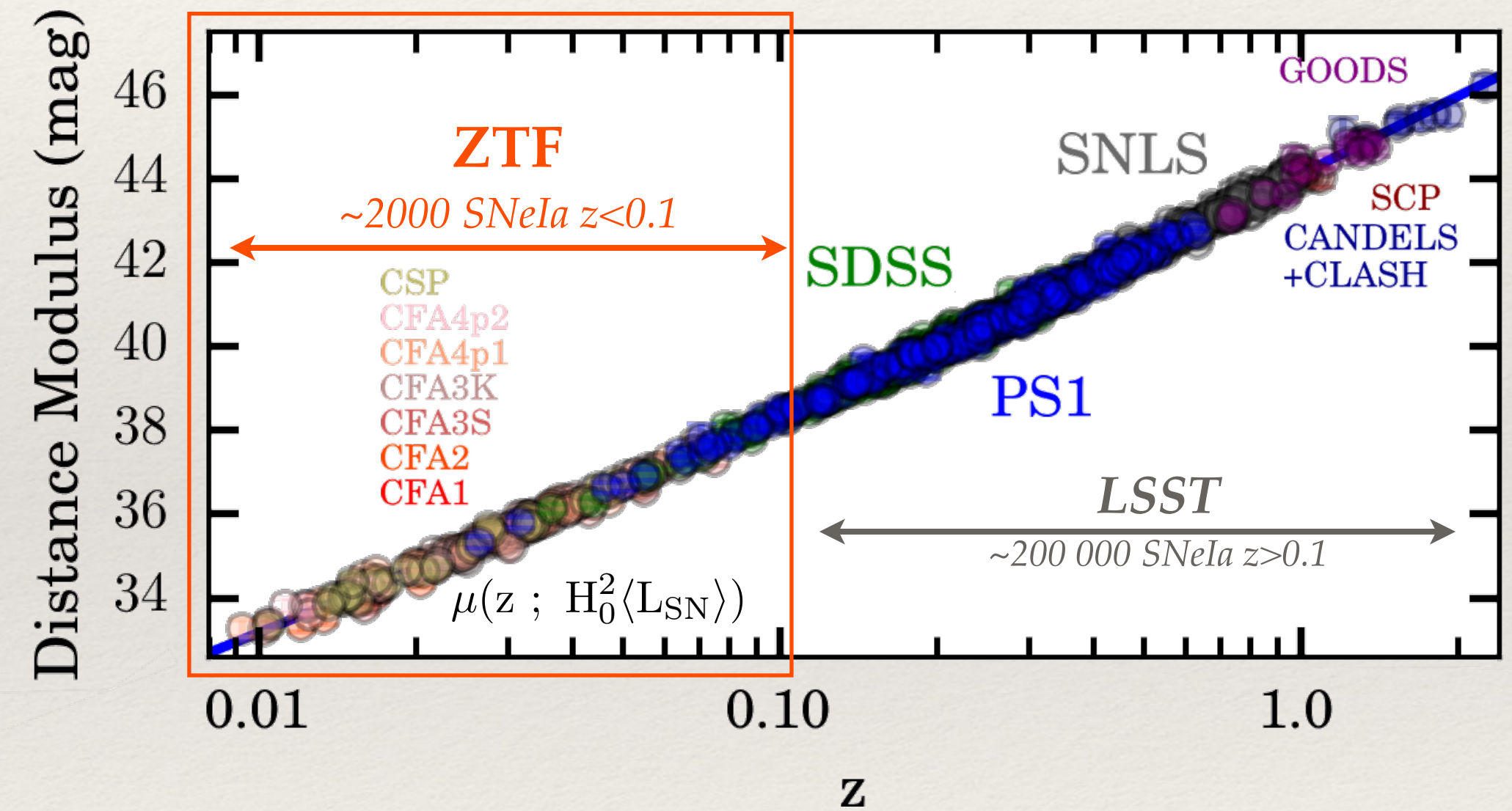
Transients Astro. Flash Spectroscopy



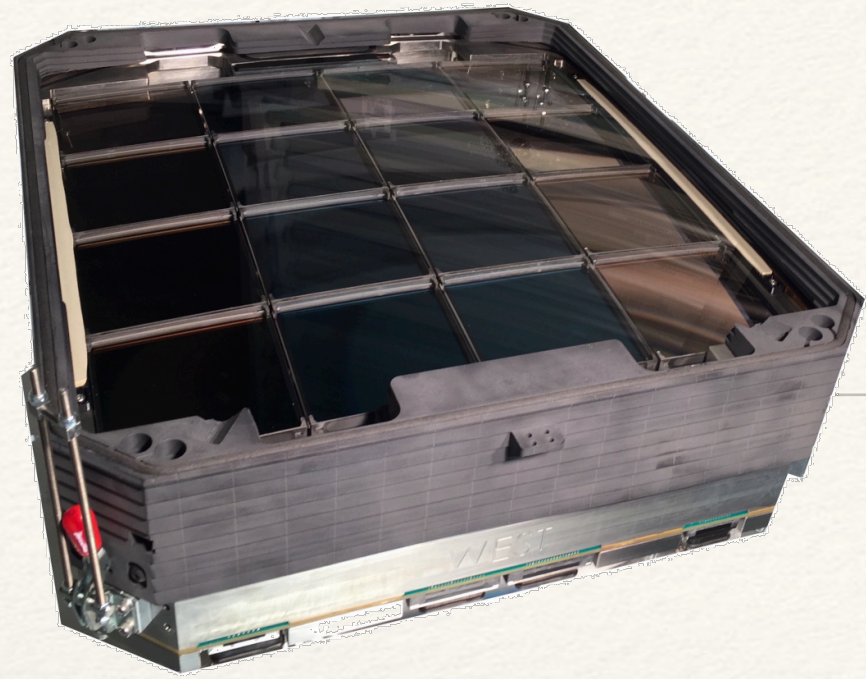
Multi-Messengers GW & Neutrinos



Supernova Cosmology Incl. Strongly lensed SNeIa



Tidal Disruption Events | Stellar Astrophysics | Solar System Bodies | ...



The Camera

KEY INFORMATION

47 square degree field
(on 2 grids ; 1 main + extra)

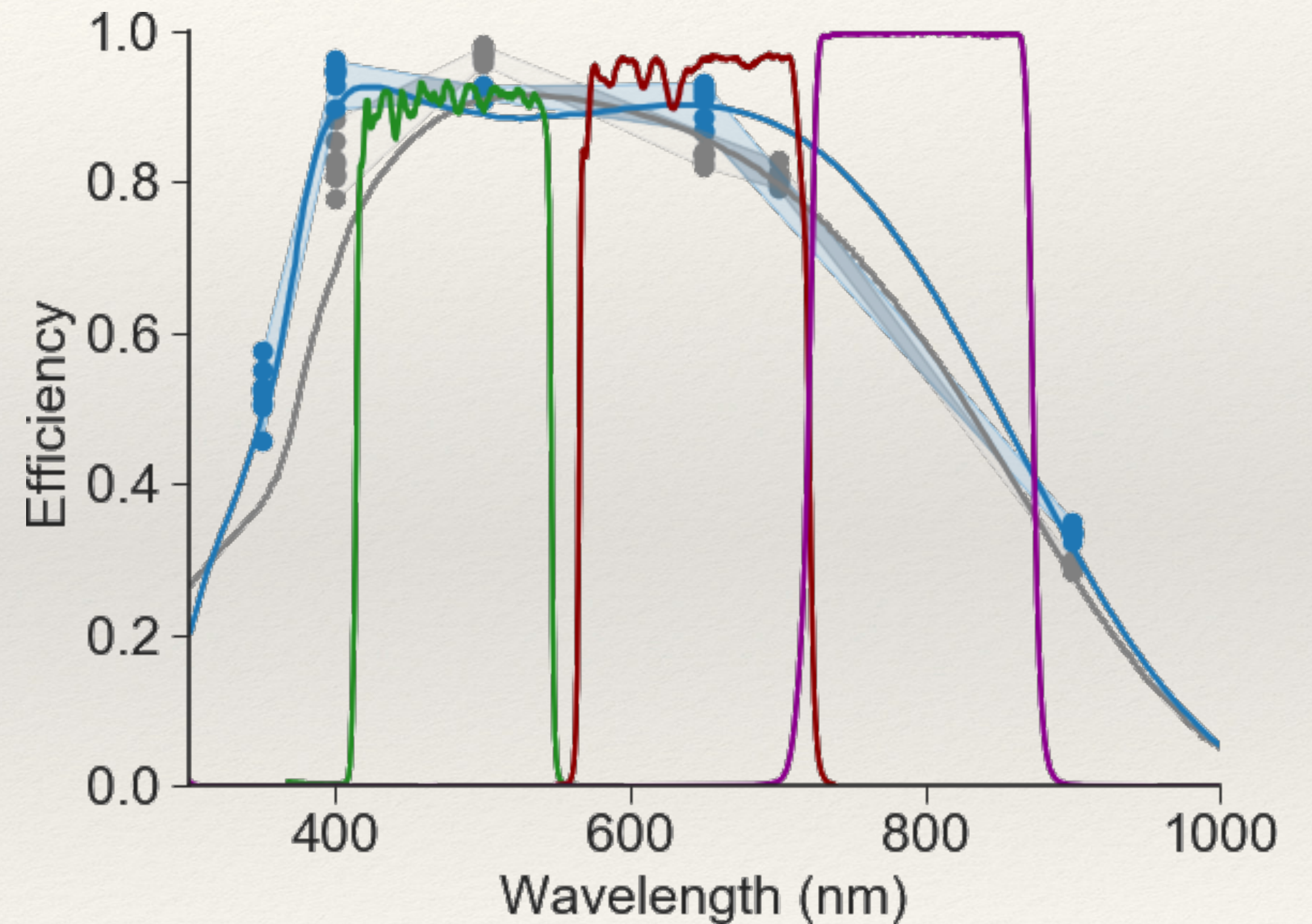
16 E2V 6k x 6k CCDs
(2 different coatings)

1 Pixel ~ 1 arcsec
(typical seeing ~2arcsec)

30s exposure + 15s slew

~20.5 mag (5σ) per exposure
(slightly better in R)

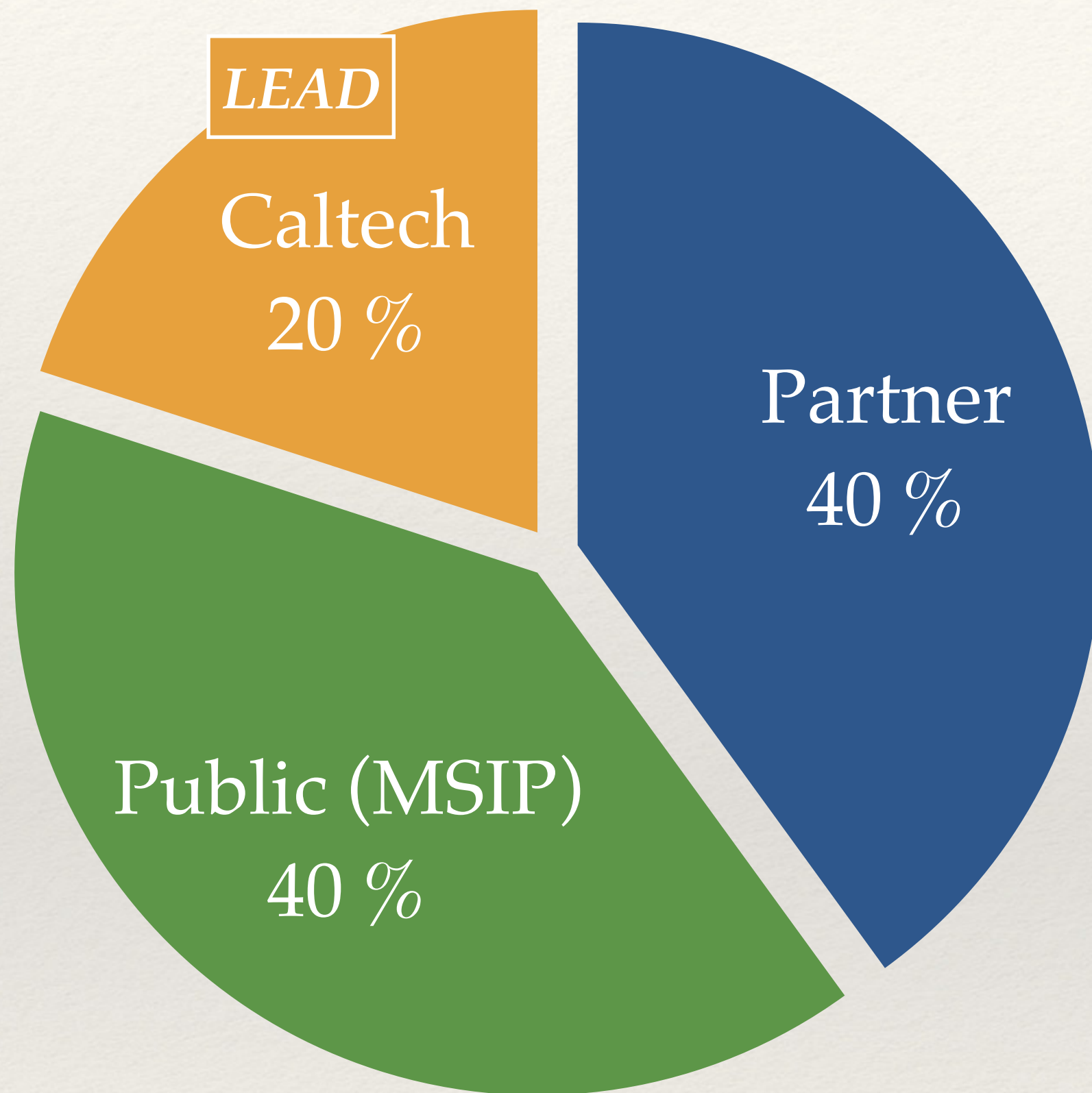
3 FILTERS | G, R, I



ZTF = 3 750 square degrees/hour

ZTF Survey Time Allocation

ZTF = 3750 square degrees/hour



PUBLIC SURVEY "MSIP"

2 Filters (g, r)

6400 sqdeg every 3 days
(in both bands!)

Alerts public right away
(all transients discovered within MSIP)

+ Galactic plane
(August mainly)

PARTNERSHIP & CALTECH

High cadence fields (g,r)
(4x the same field every night)

Third filter mapping MSIP
(4 days cadence ; For Cosmology mainly)

ToO | GW, Neutrino, GRB

Galactic Plane + M31
(Mainly August)

Data Access |

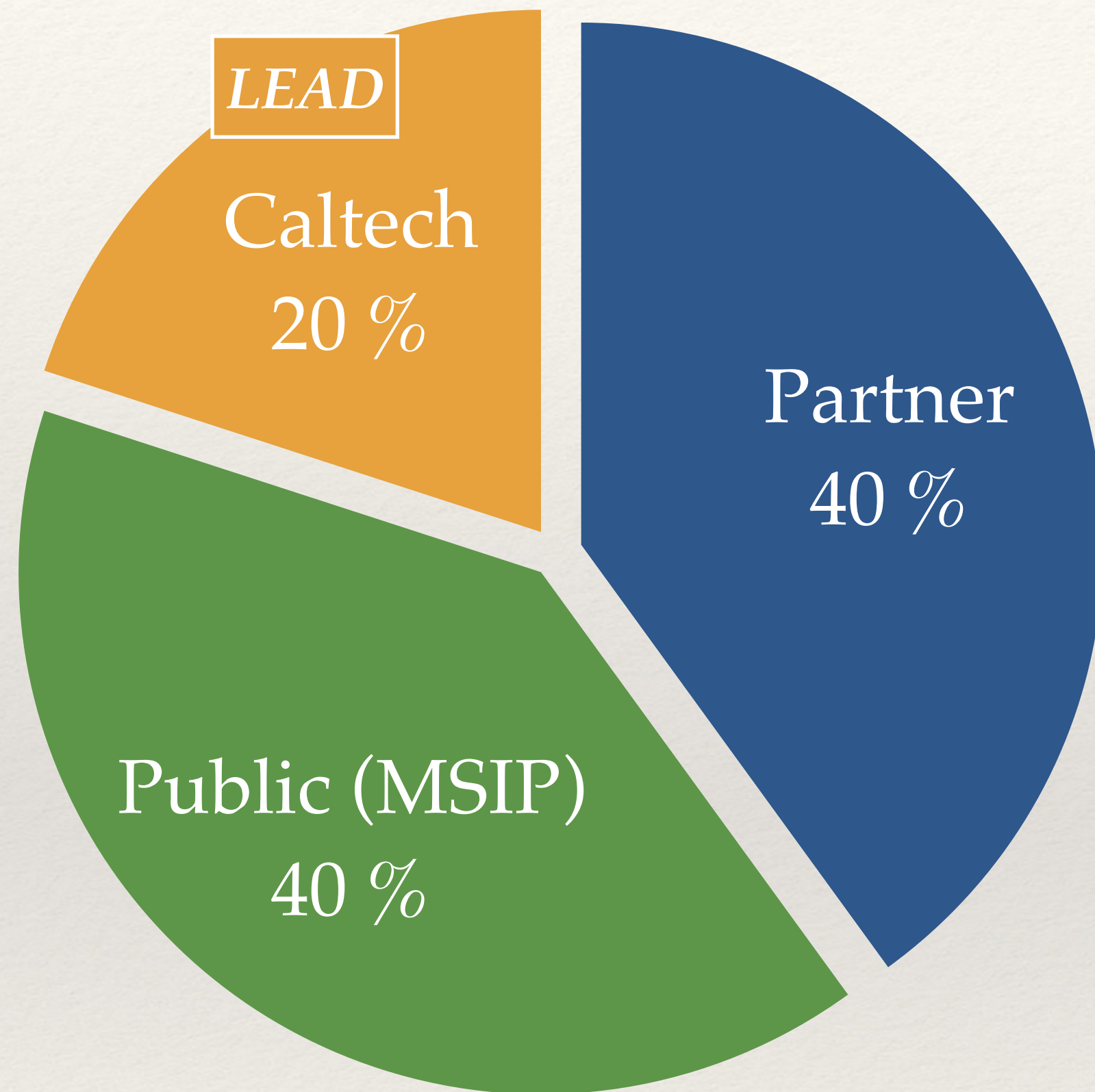
- MSIP: Alert, public right away | Pixels 6 month embargo
- Partner+: Alert, not public | Pixels 18 month embargo

Alert |

Kafka stream hosted by UW
i.e. the LSST stream

ZTF Survey Time Allocation

ZTF = 3 750 square degrees/hour



PUBLIC SURVEY "MSIP"

2 Filters (g, r)

6400 sqdeg every 3 days
(in both bands!)

Alerts public right away
(all transients discovered within MSIP)

+ Galactic plane
(August mainly)

PARTNERSHIP & CALTECH

High cadence fields (g,r)
(4x the same field every night)

Third filter mapping MSIP
(4 days cadence ; For Cosmology mainly)

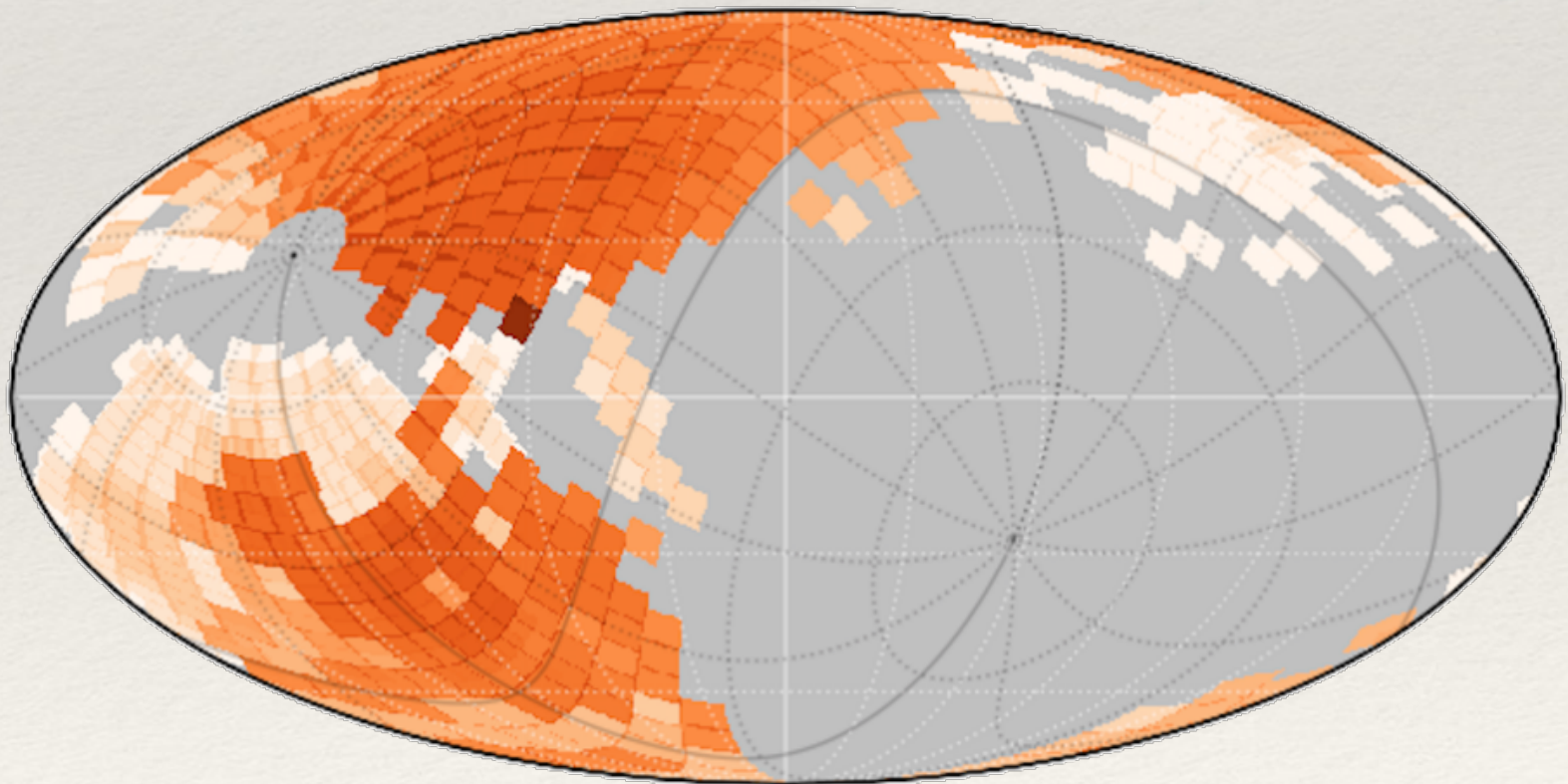
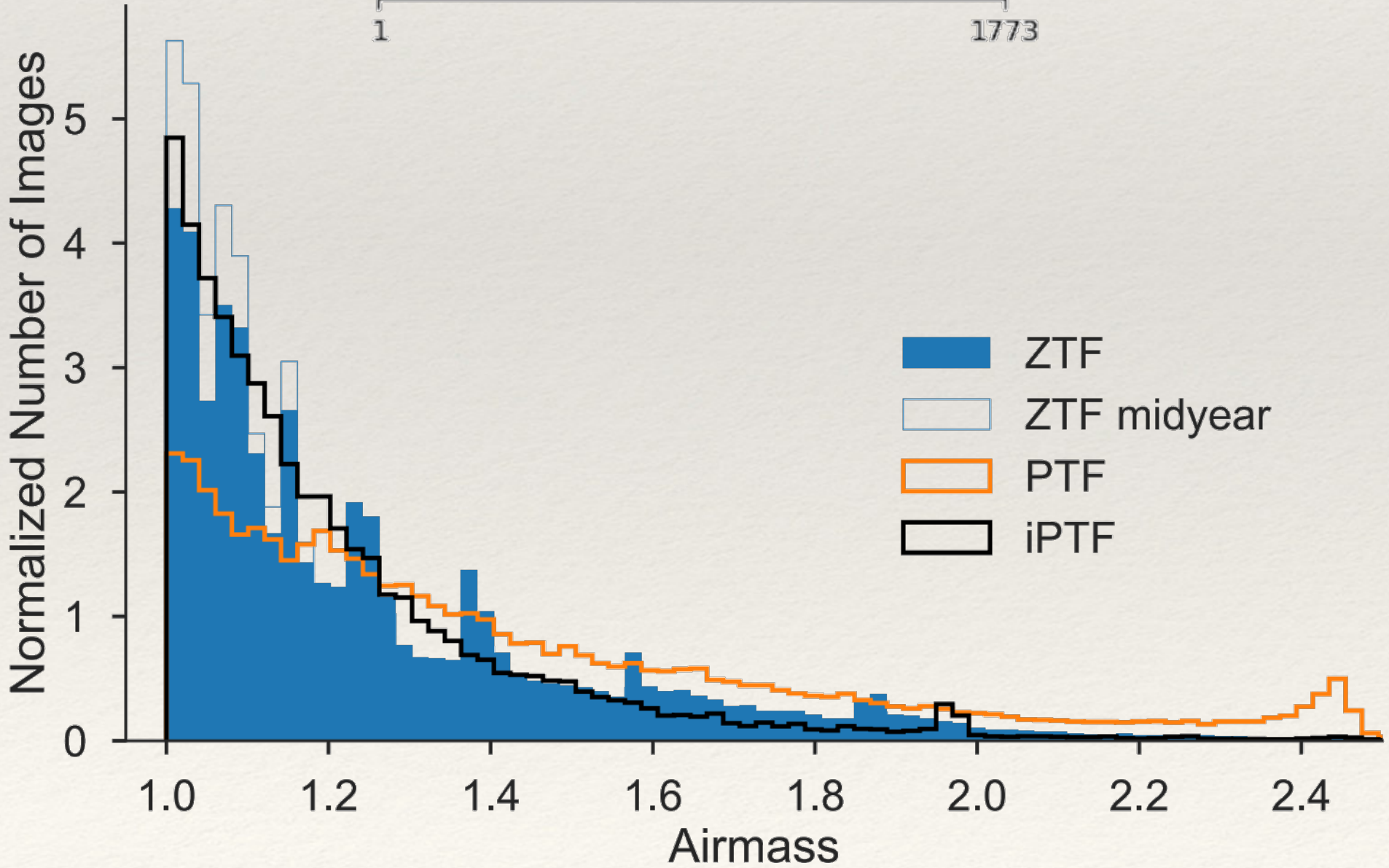
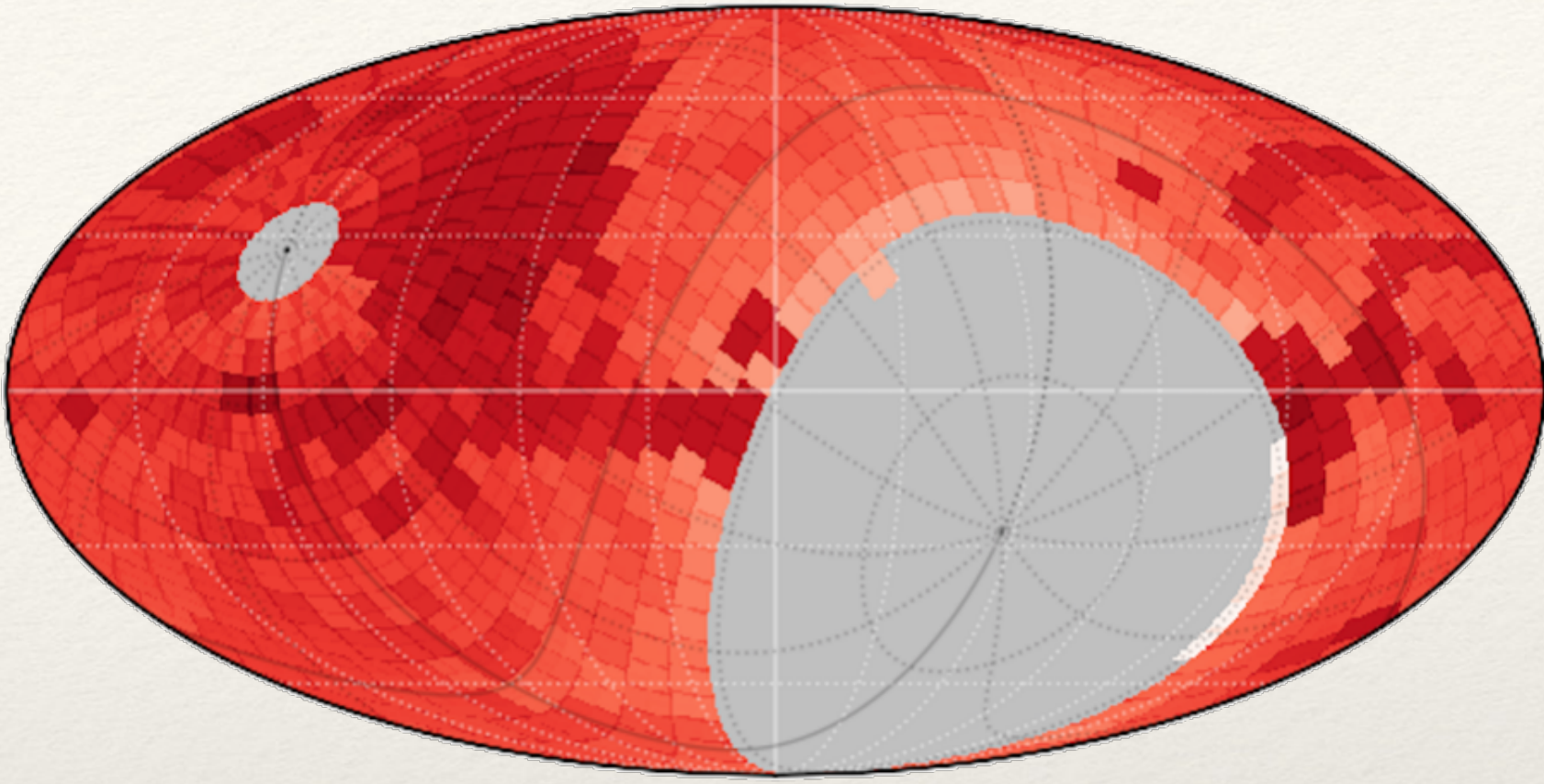
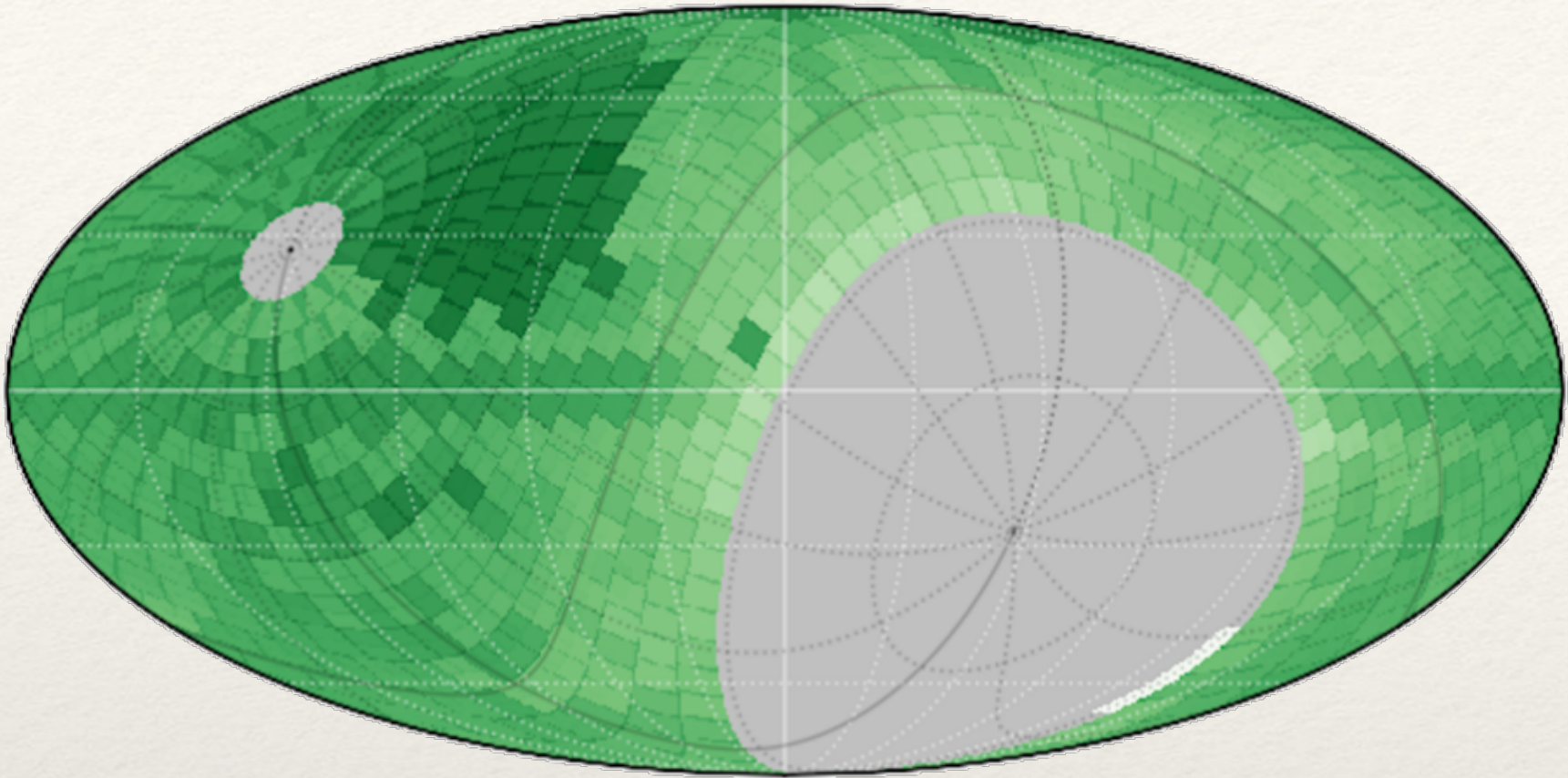
ToO | GW, Neutrino, GRB

Galactic Plane + M31
(Mainly August)

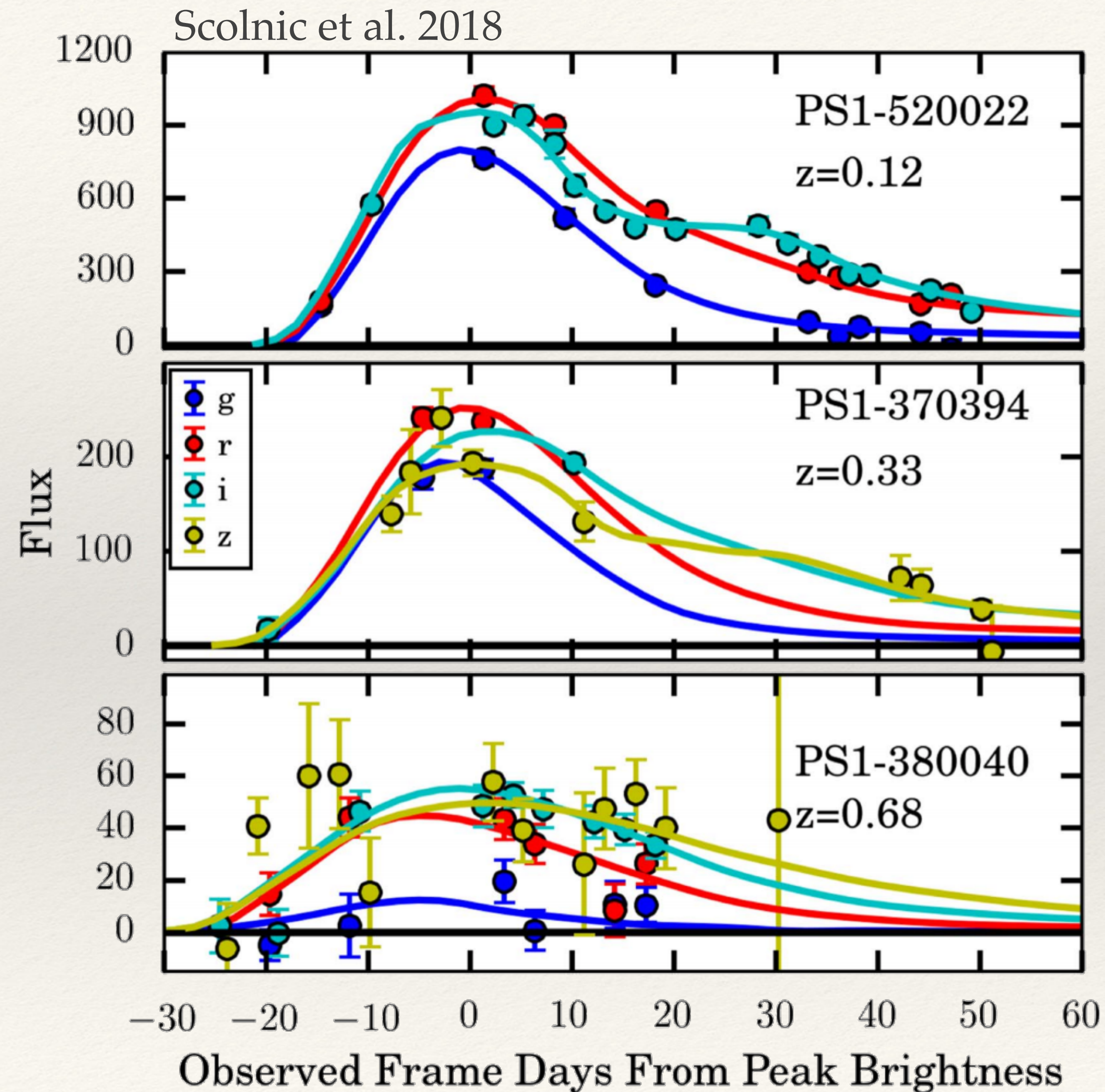
2018+2019A data MSIP images public & 2018A of private data | DR2 11/12/19

6.5 Millions images | 1 Millions light curves ($N_{\text{obs}} > 20$)

ZTF Year 1

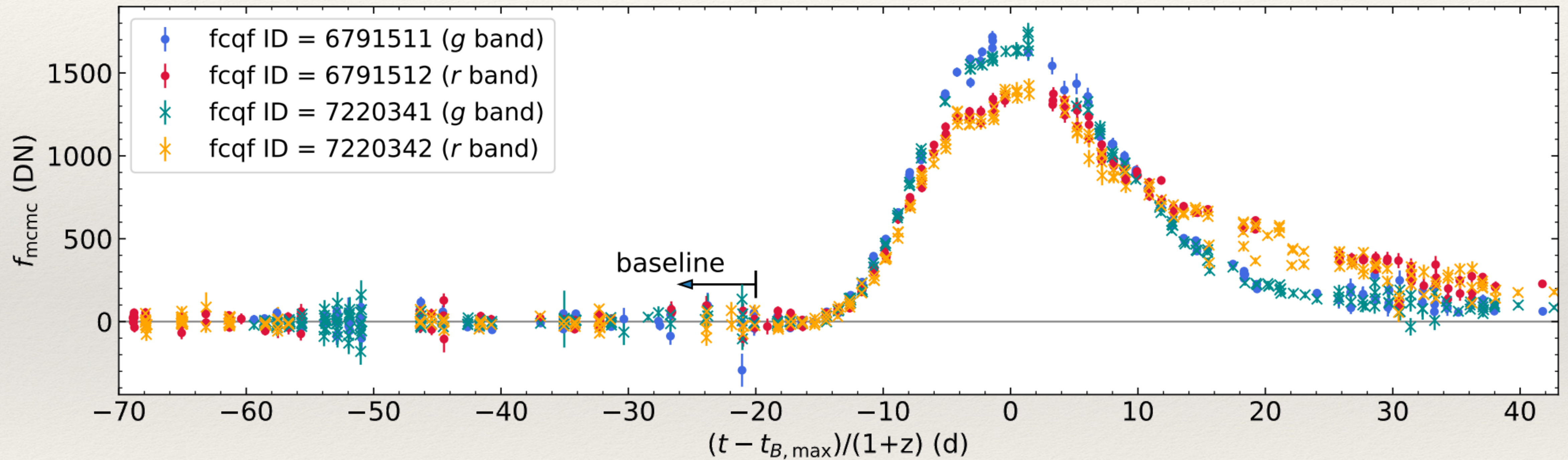


Typical SNeIa with current survey



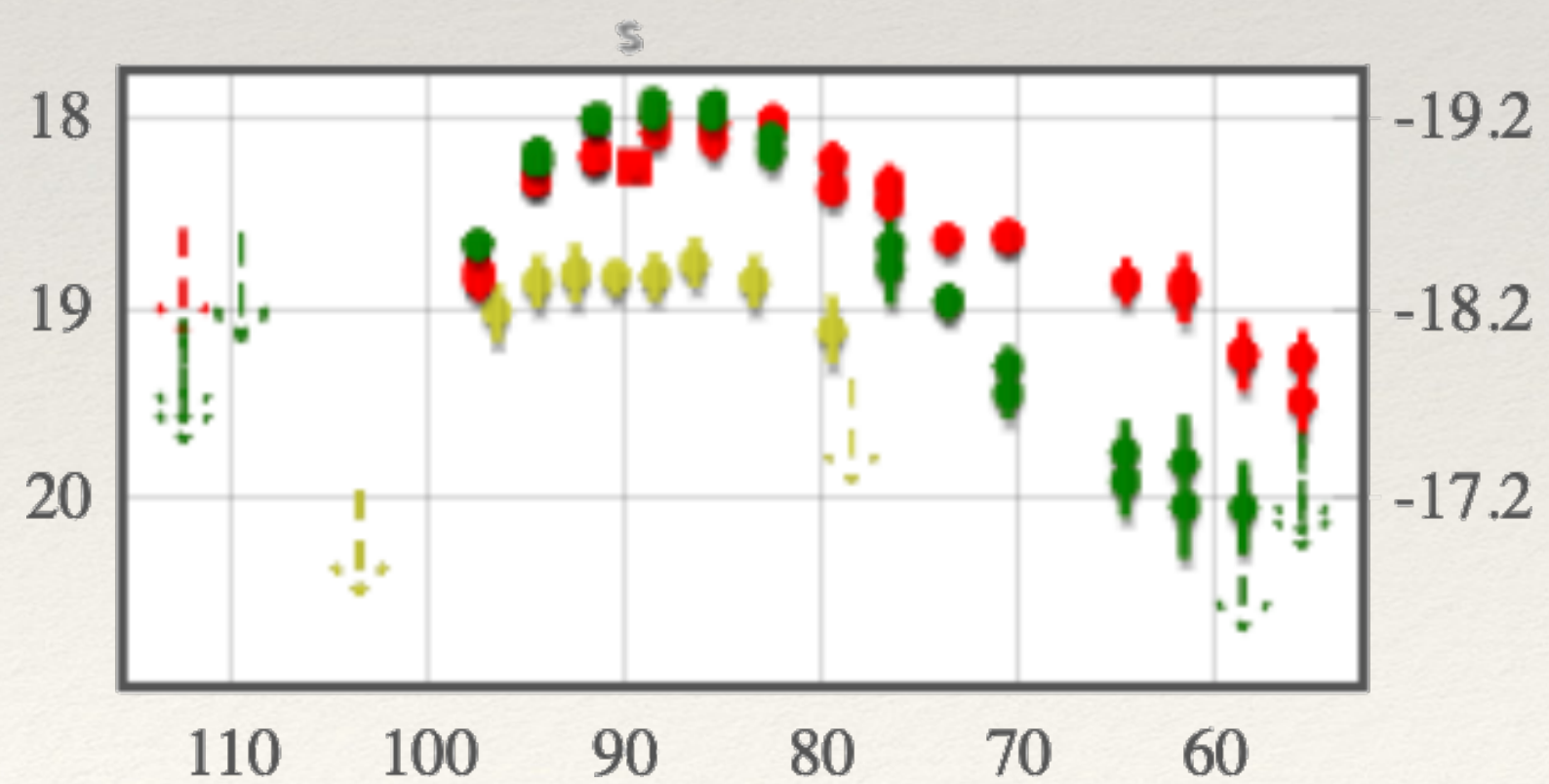
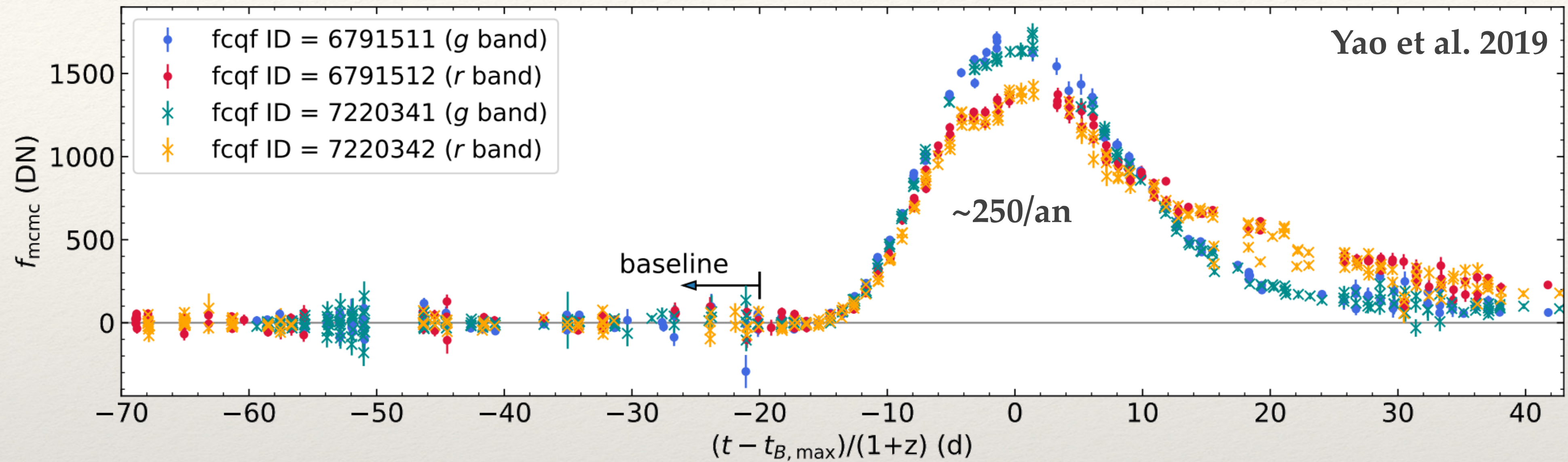
High cadence fields

Yao et al. 2019

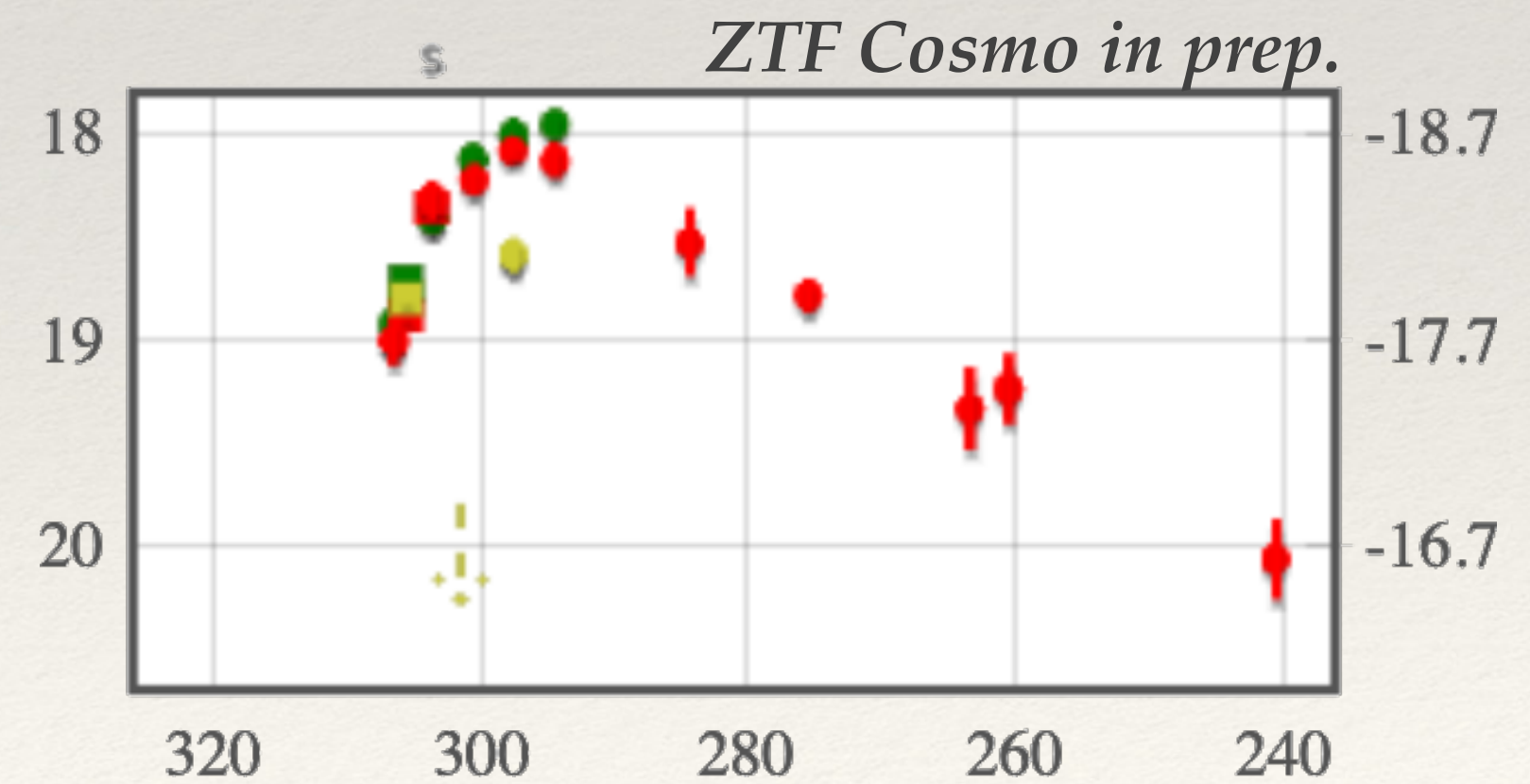


— 127 SNeIa High-Cadence SNeIa in 6 months —

ZTF Type Ia Supernovae LightCurves



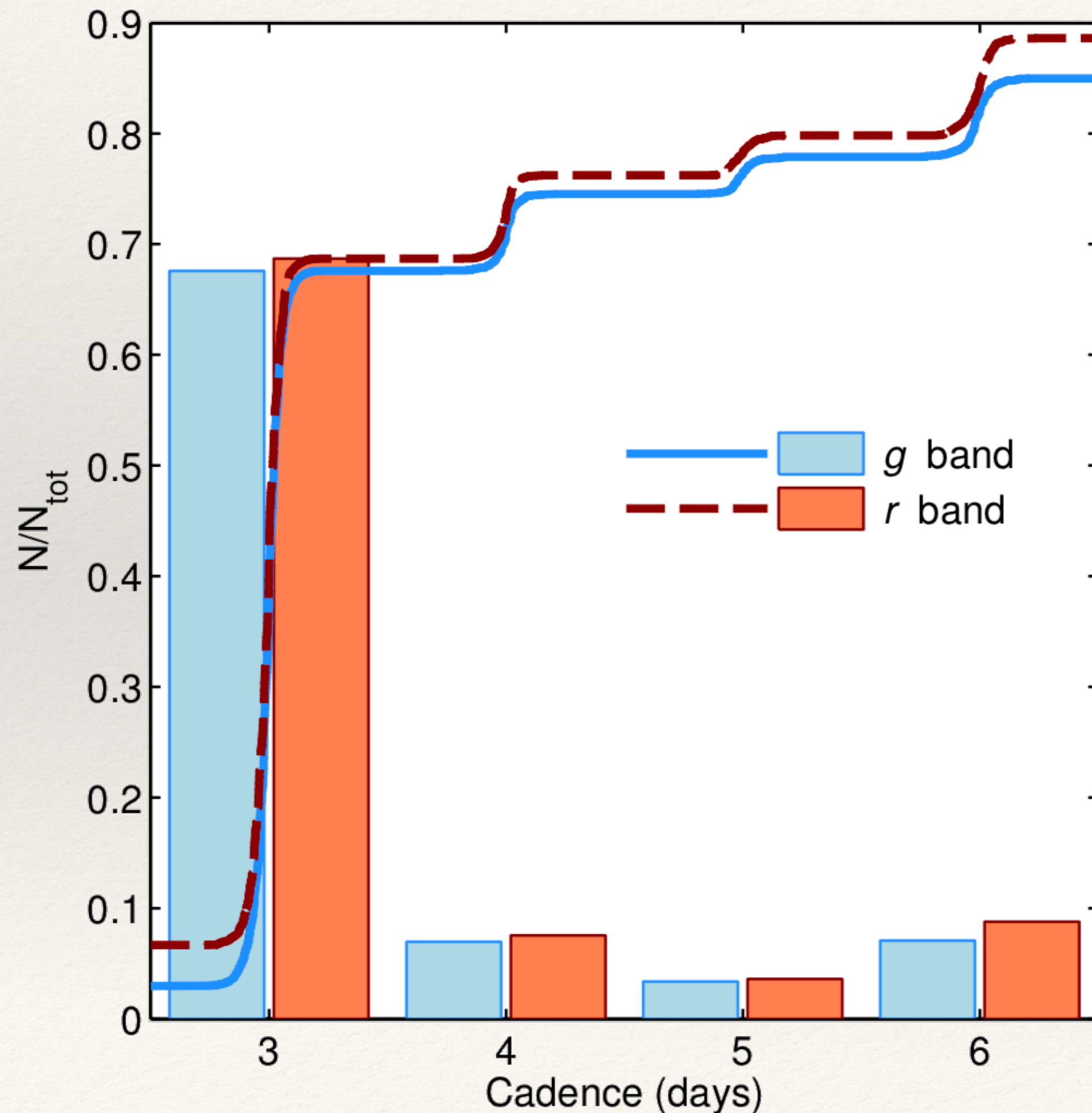
$\sim 400/\text{an}$



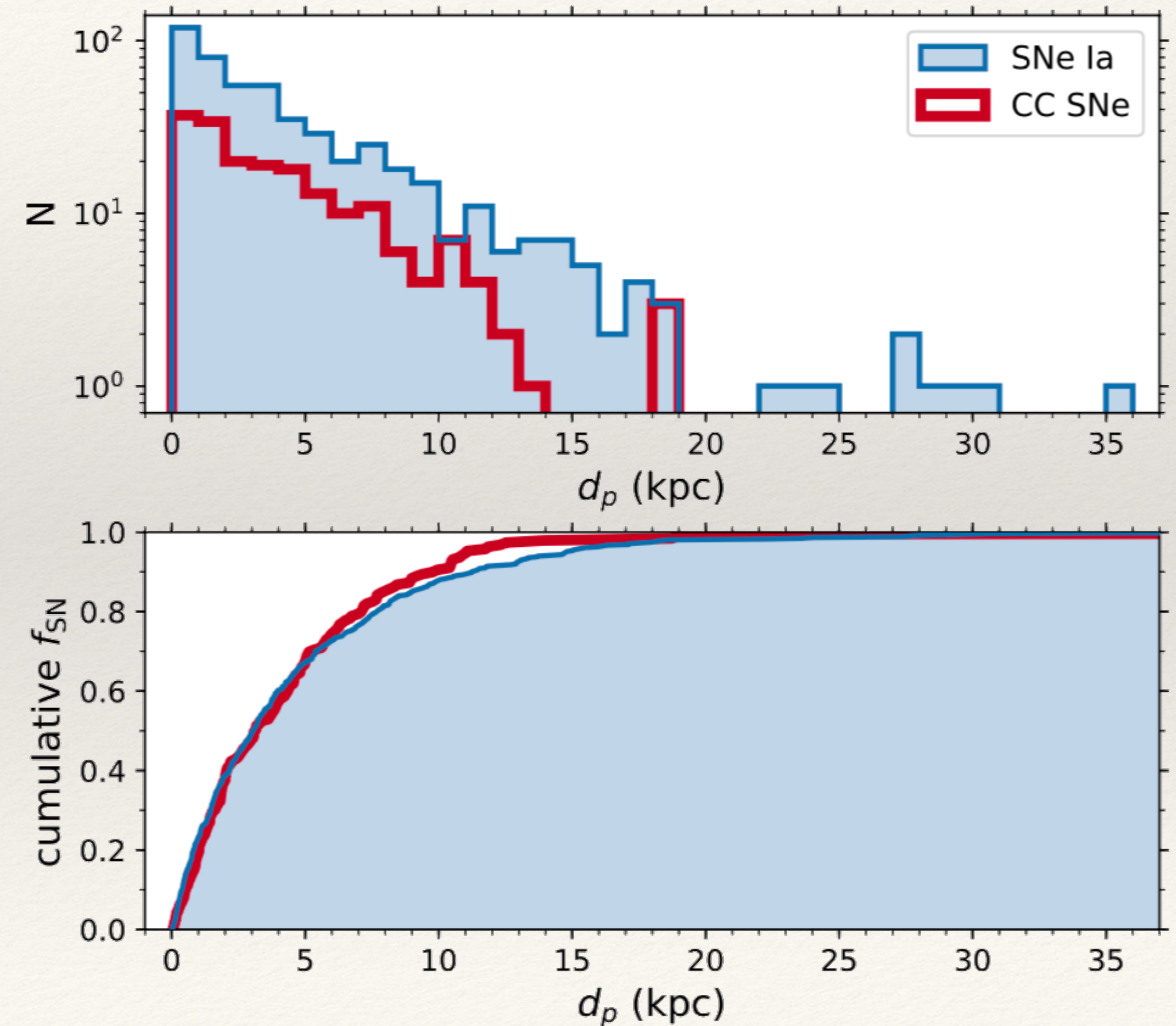
ZTF MSIP public data | *g & r every 3 days*

Fremling et al. 2019

70% revisit in same band in 3 days
(90% within 6)

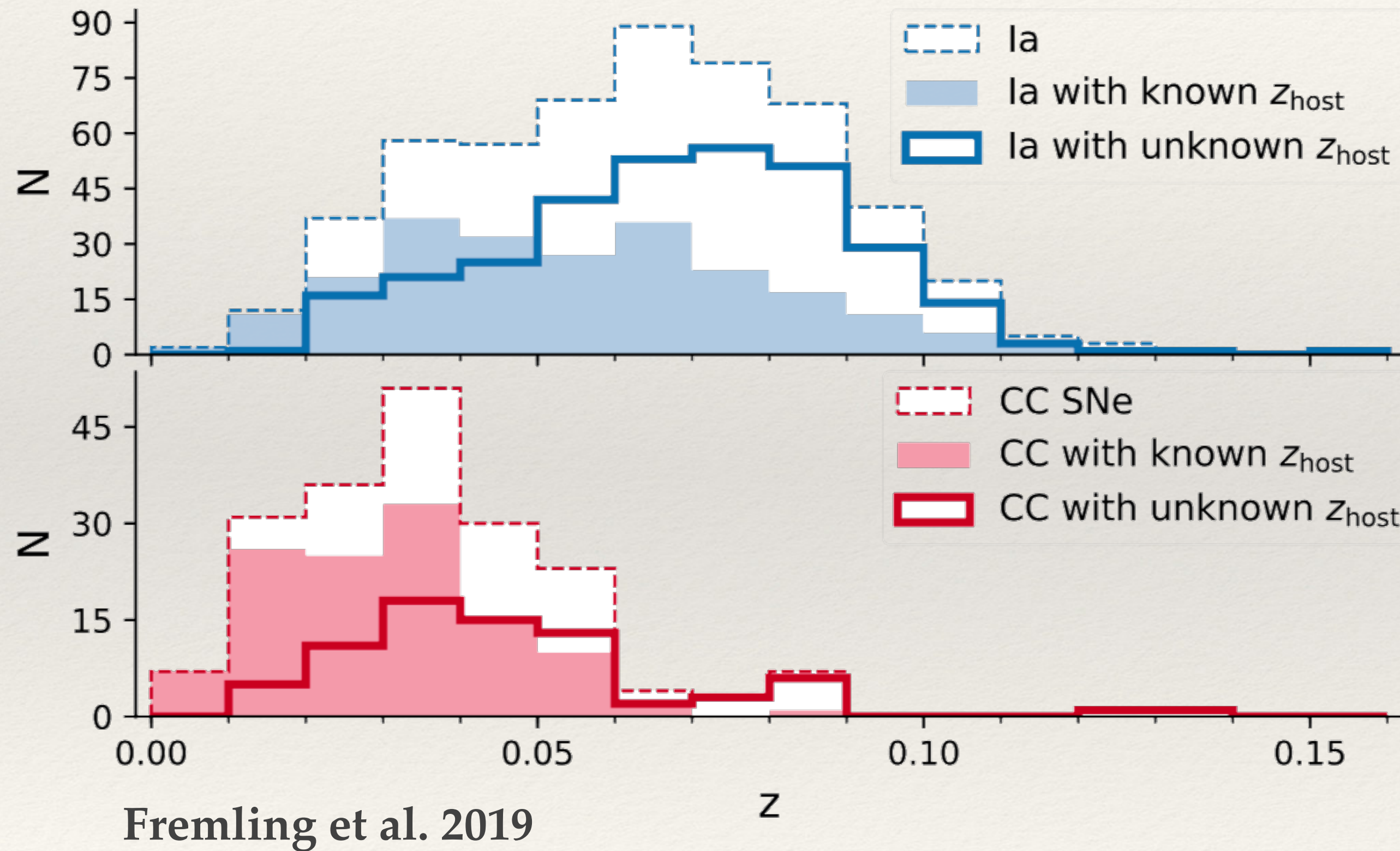


Accurate detection
no background brightness issue

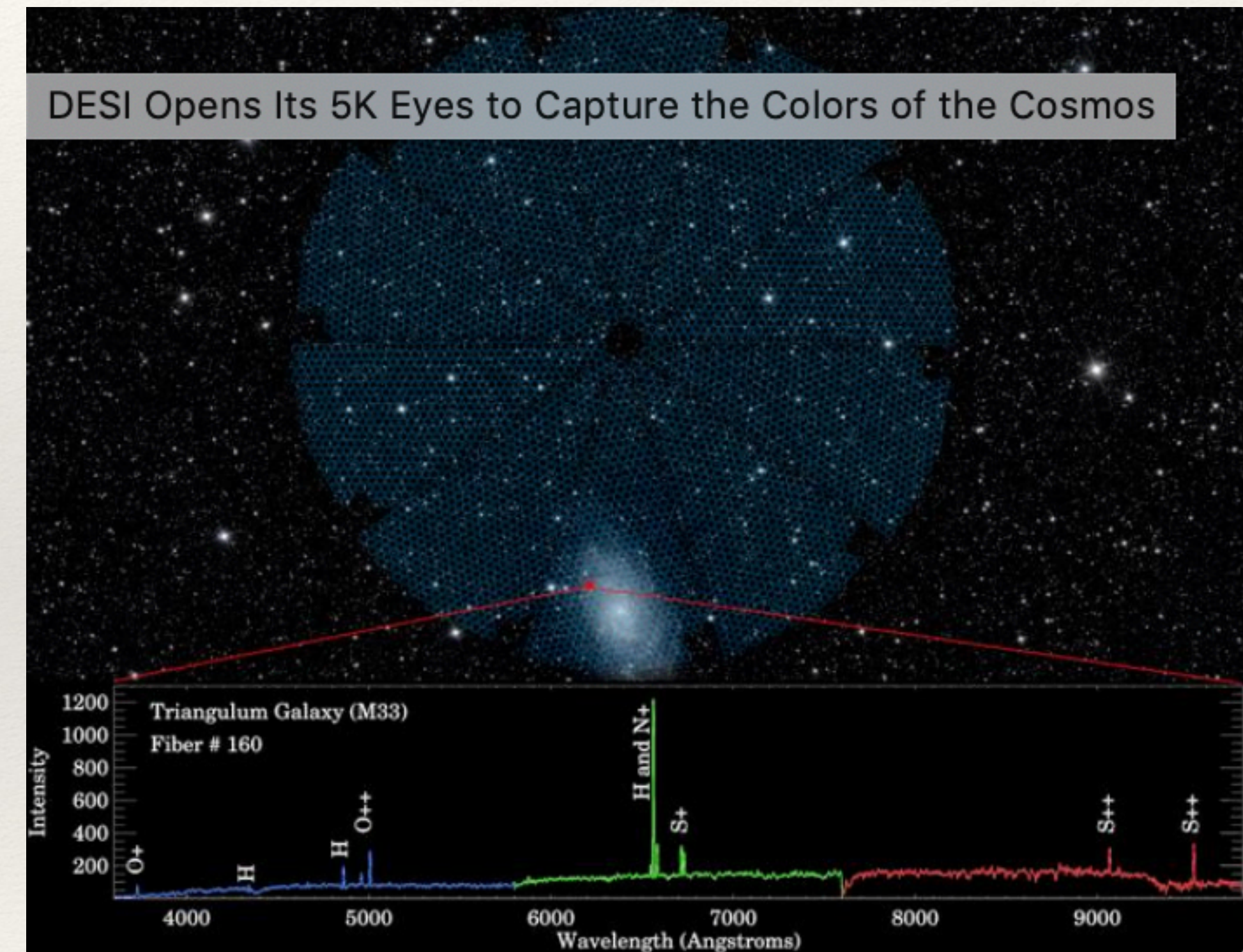


Getting Redshifts

44% of SNeIa already have host redshift | Rest will come from DESI



ZTF — DESI agreement



All transients are spectroscopically typed

— Game changer for photo-typing that are craving for non-Ia spectra —

The SED machine



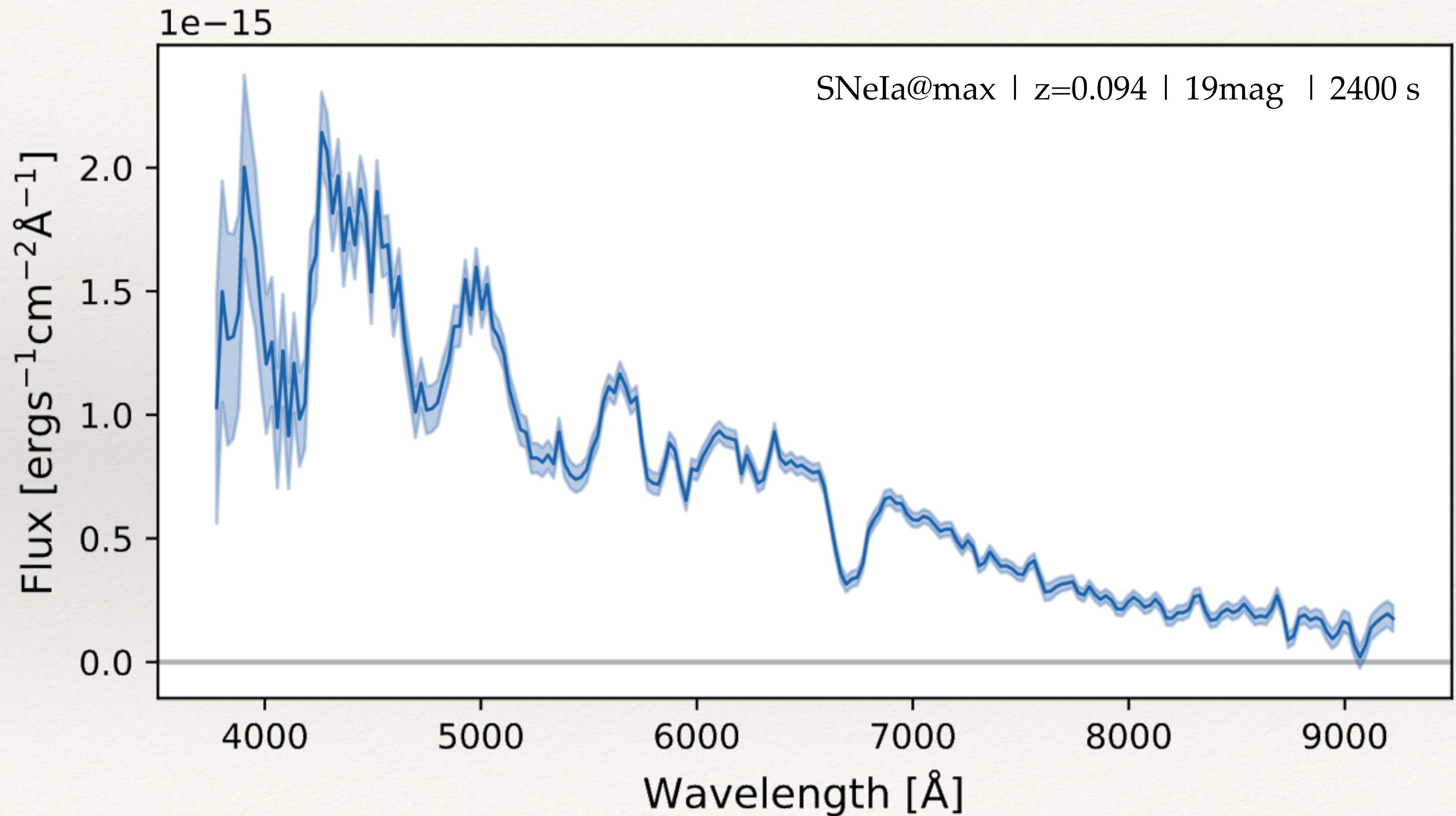
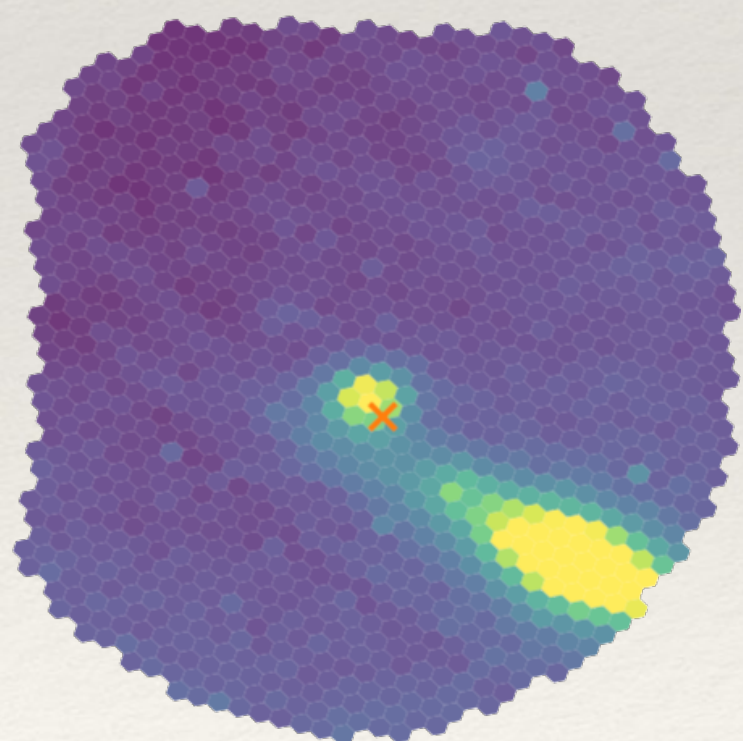
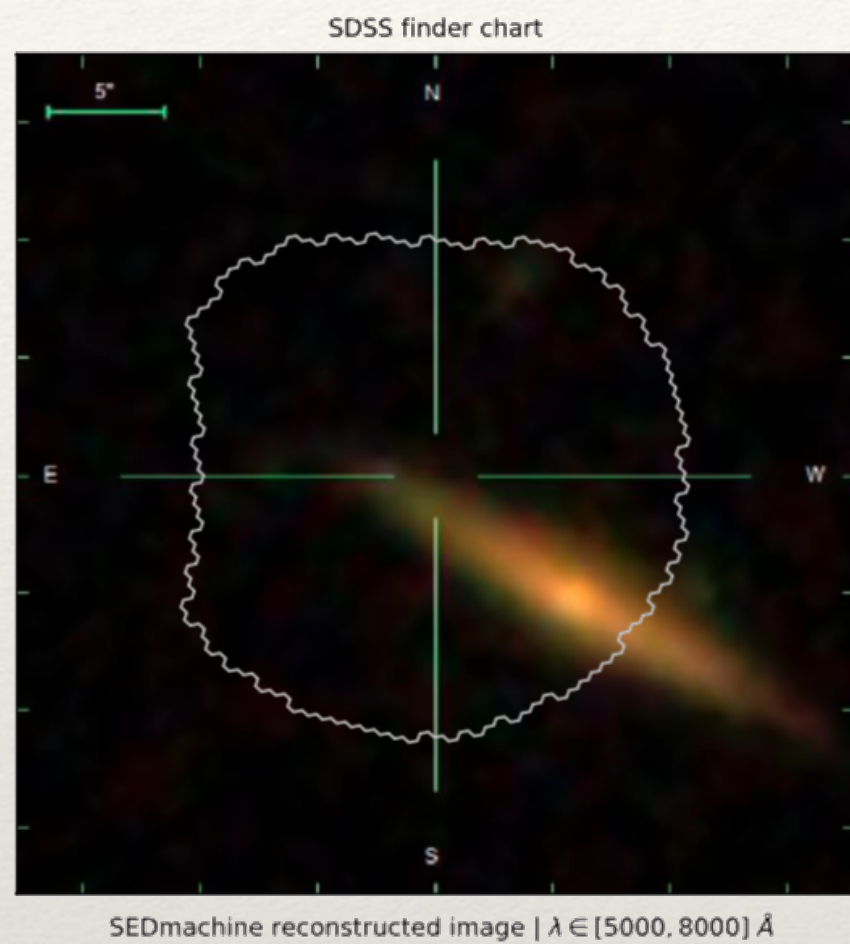
ZTF Camera

SEDMachine

P200 (*spectro*)

Very Low resolution Spectrograph

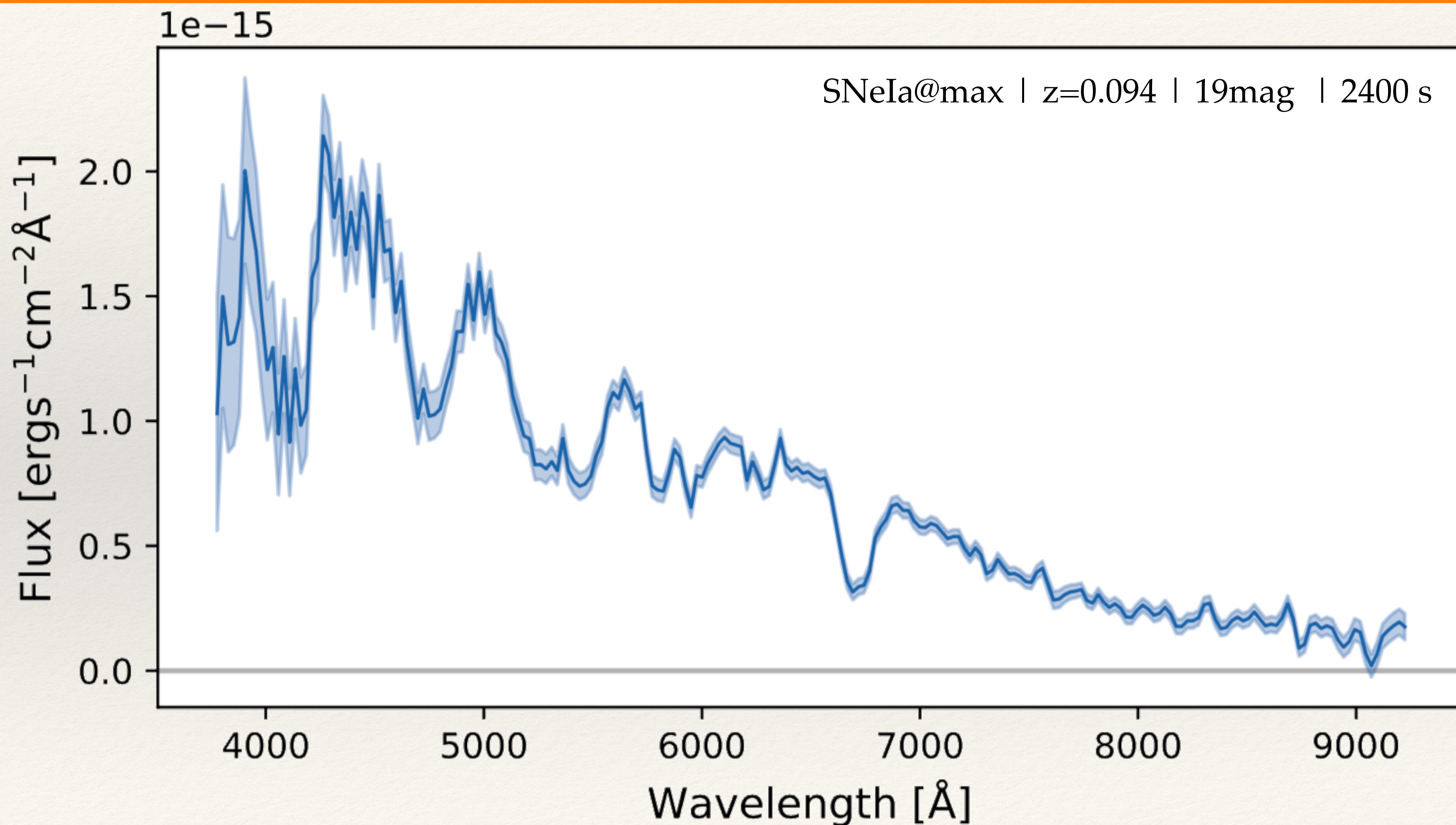
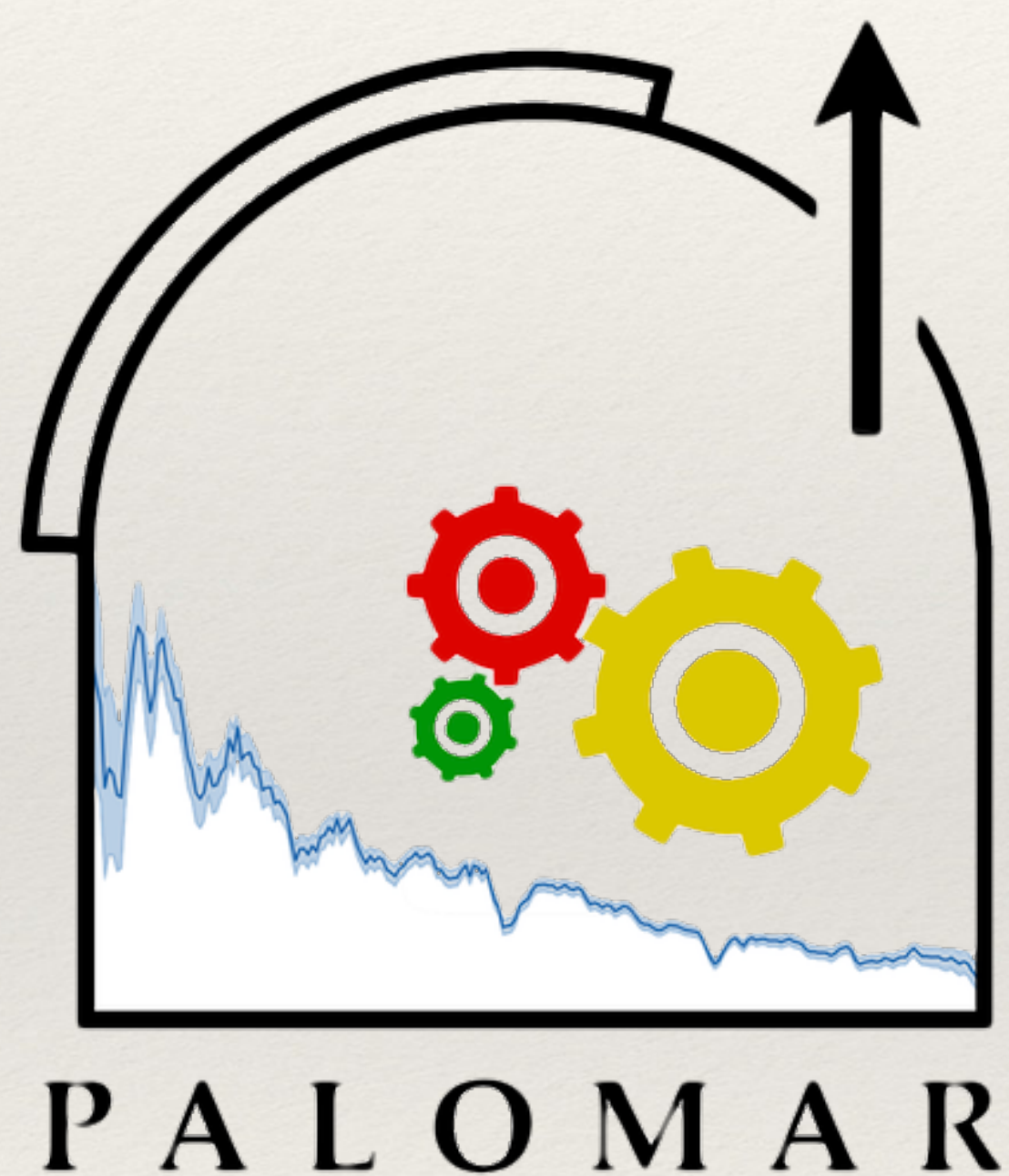
Rigault et al. 2019



pysedm | *a fully automated pipeline*

Rigault et al. 2019

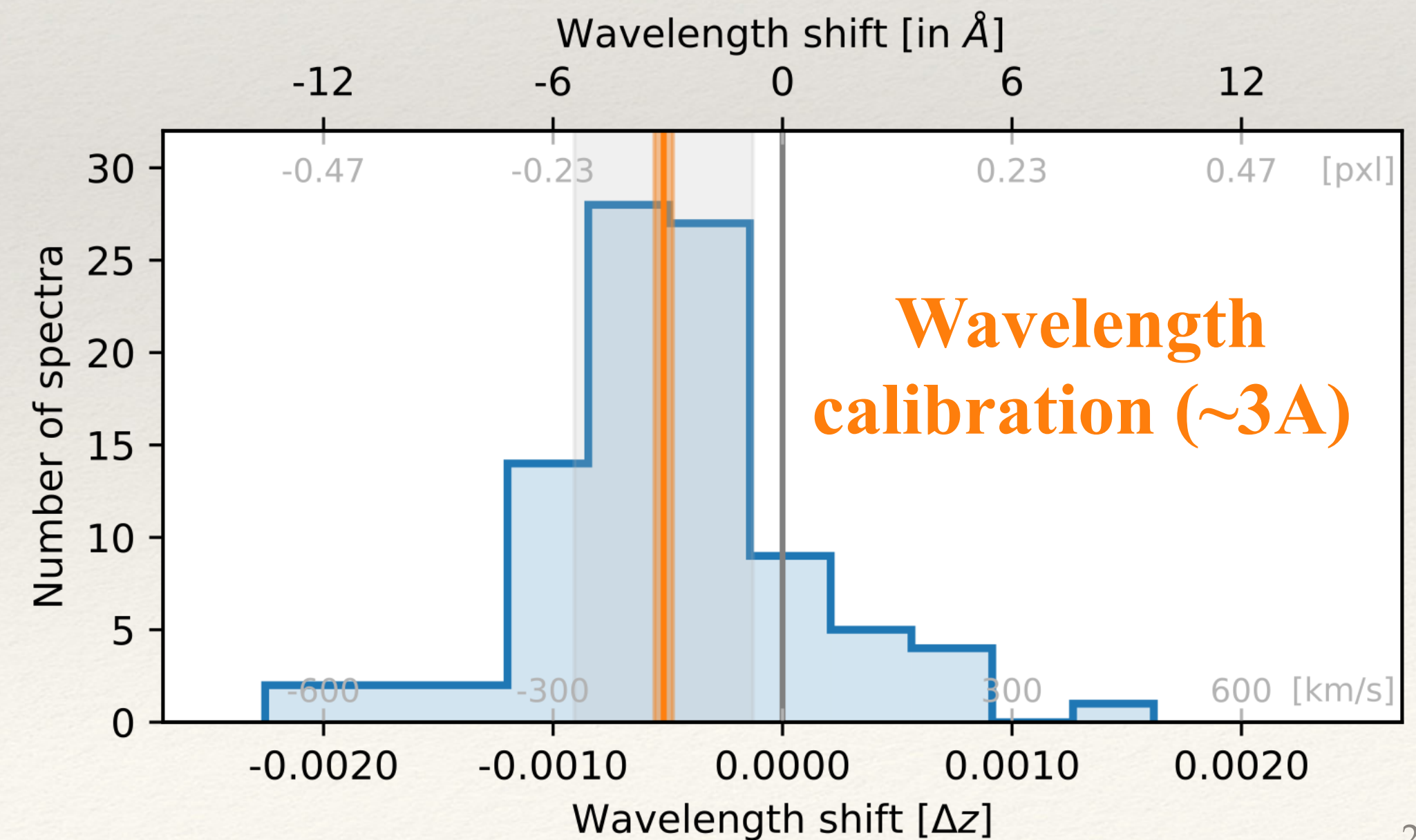
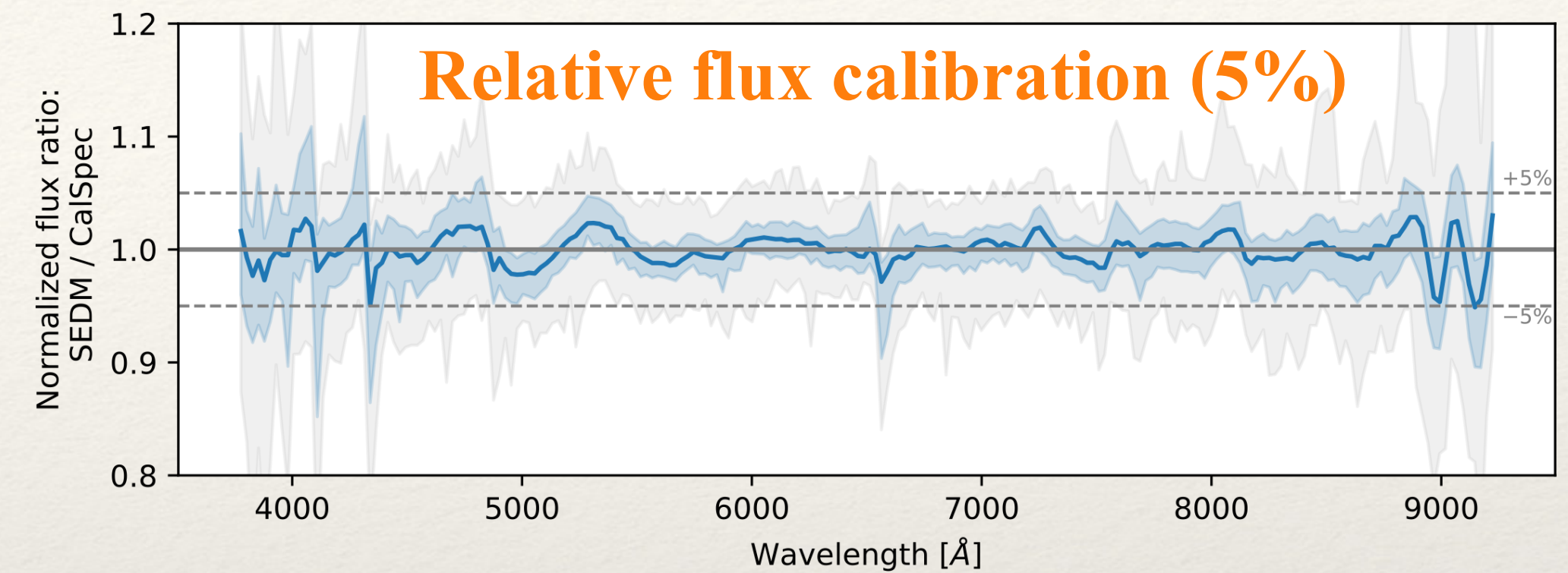
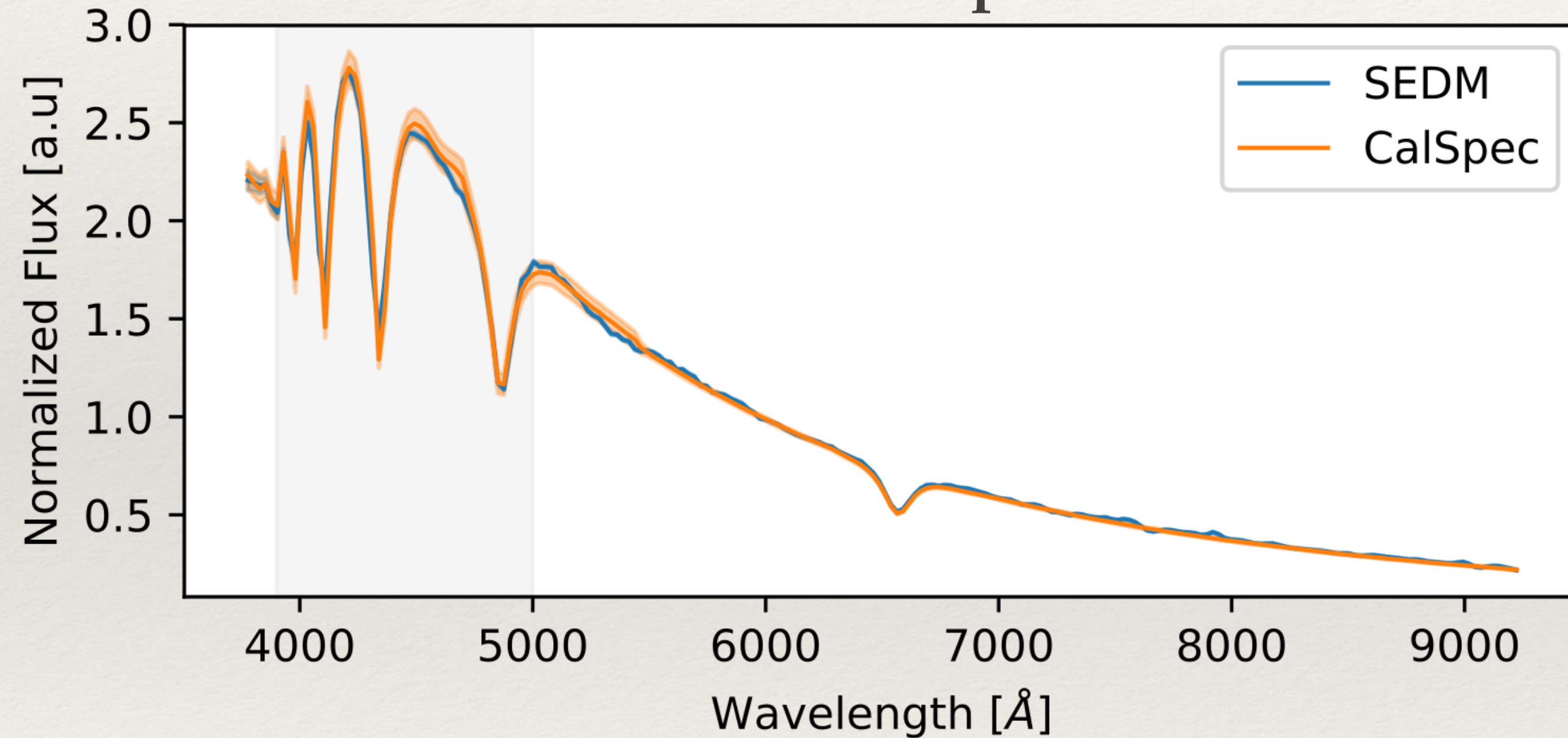
Flux calibrated spectrum & automatic typing available ~5min after end of exposure



SEDm | Precision and Accuracy

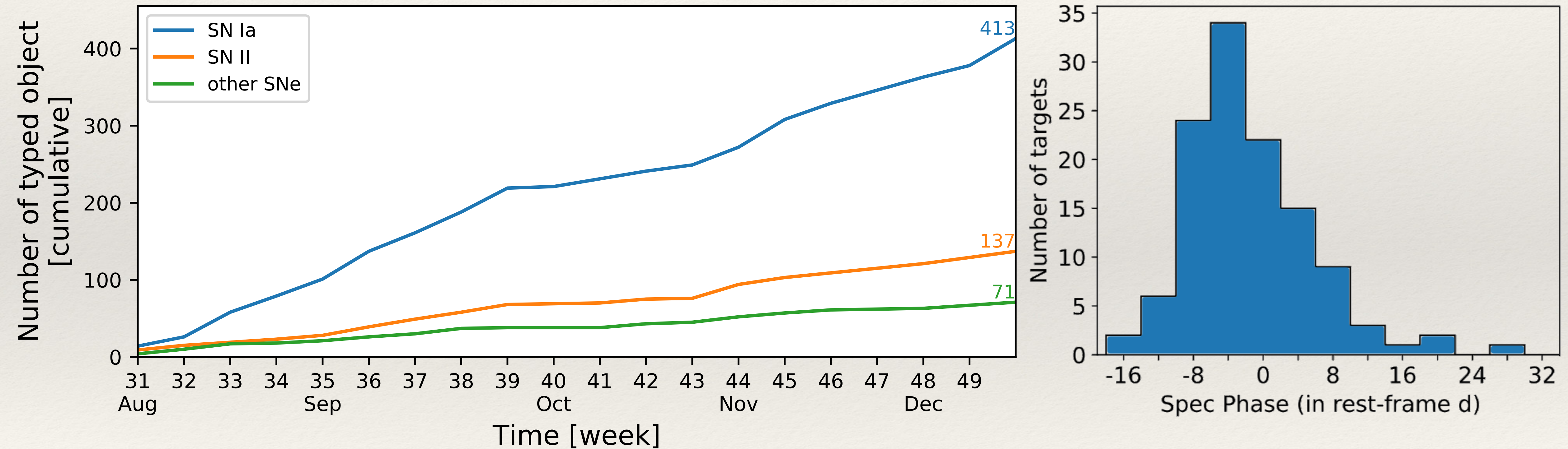
Rigault et al. 2019

Standard star spectra:
SEDm vs. CalSpec



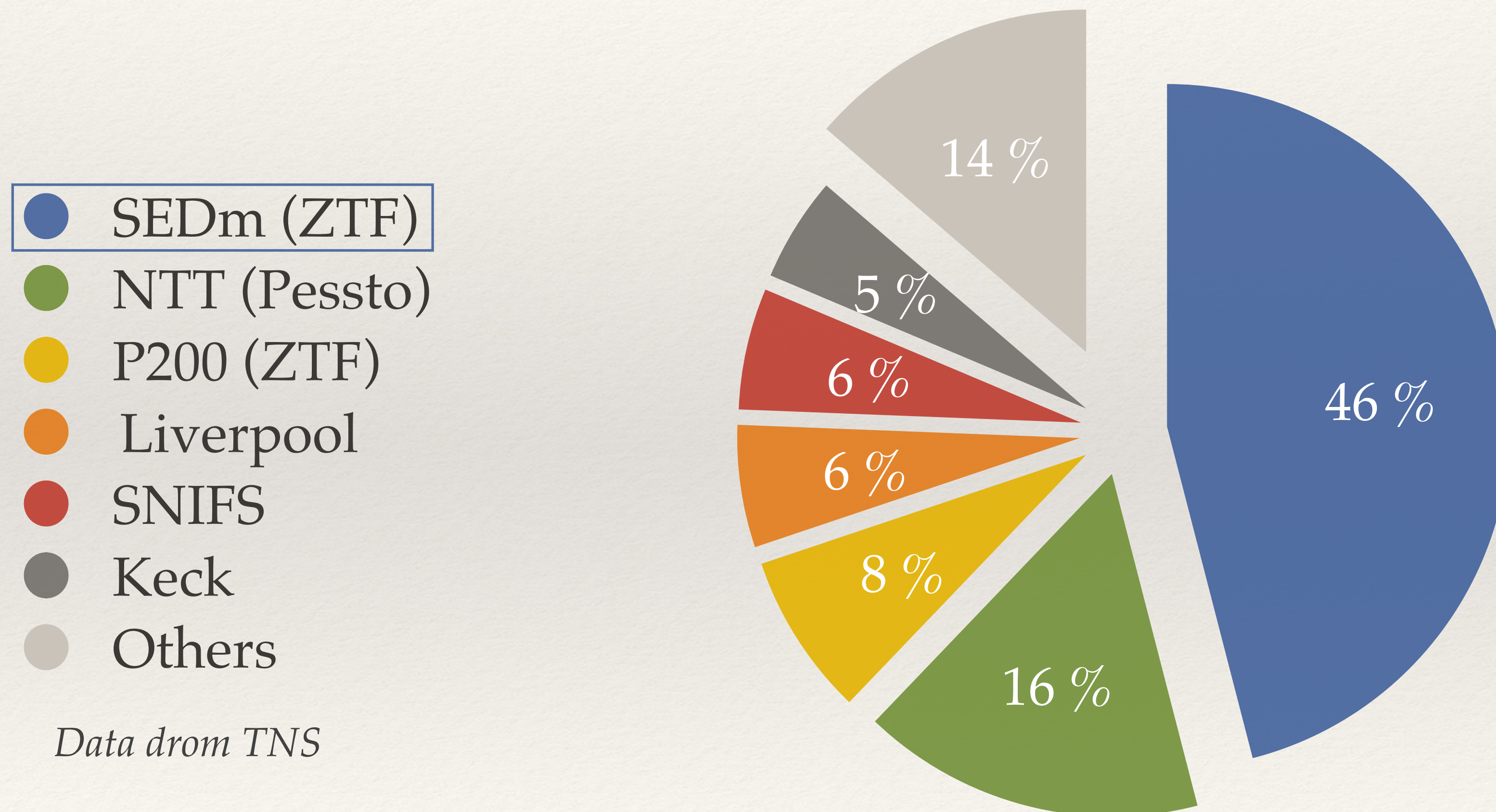
SEDM Typing from August 1st to December 2018

Rigault et al. 2019 ; Yao et al. 2019



Transient typing since March 2018

By far the greater transient typer (3x PESSTO)



Data from TNS

Triggering & Sample Selection



>80 exposures/h
47 deg² each
~350 Mb/s



CalTech, Los Angeles

20 detections/s
~2 Mb/s



U. Washington, Seattle

Stream of Alerts

Which alerts are likely to match your interest?

Converts alerts into a transient

What do you want to know about the transient?

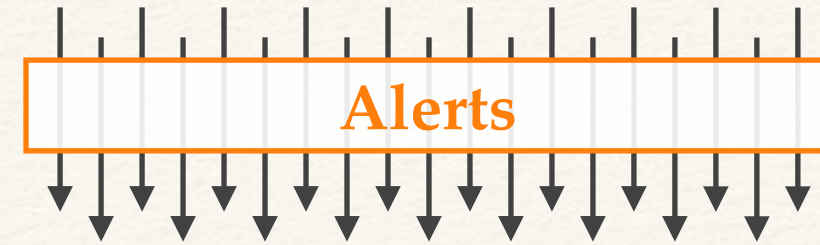
What do you want to do about it ?



AMPEL | Process Flow

Nordin et al. 2019

$O(10^5)$ per day !



T0

FILTER

Which alerts are likely to match your interest?

T1

DB MANAGEMENT

Converts alerts into a transient

T2

SCIENCE ADDED VALUES

What do you want to know about the transient?

T3

DECISION MAKING

What do you want to do about it ?



AMPEL | Process Flow

*Examples
Flash Spectro*

Nordin et al. 2019



FILTER

T0

All that have at least 2 rising points in 2 bands
no detection yesterday & off the core & nearby

T1

DB MANAGEMENT

Converts alerts into a transient (already exist?)

T2

SCIENCE ADDED VALUES

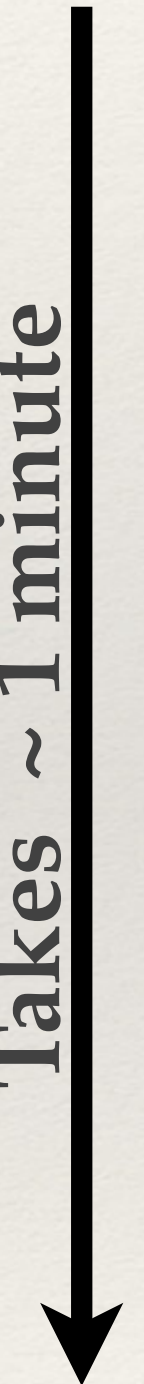
None

T3

DECISION MAKING

Trigger spectrograph right away | send emails arounds

Takes ~ 1 minute





AMPEL | Process Flow

*Examples
GW*



FILTER

**Rewind the stream by 12h &
give anything within an area of the sky**

DB MANAGEMENT

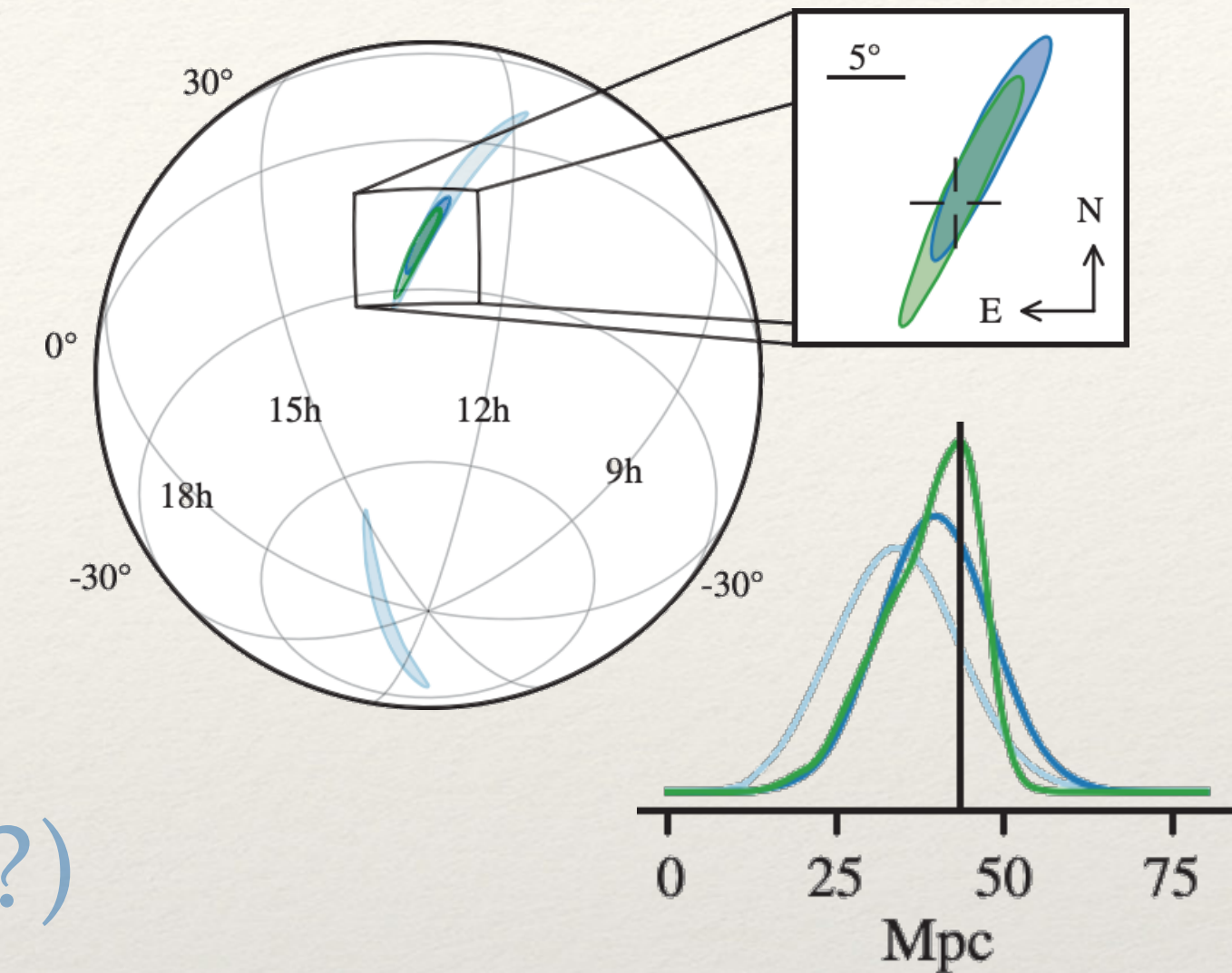
Converts alerts into a transient (already exist?)

SCIENCE ADDED VALUES

Host Properties (z) | Could it be a real transient ?

DECISION MAKING

If real, trigger spectrograph & Photometric follow up
email everyone | Push to slack | **Publish a GCN/LVS Notice**



T0

T1

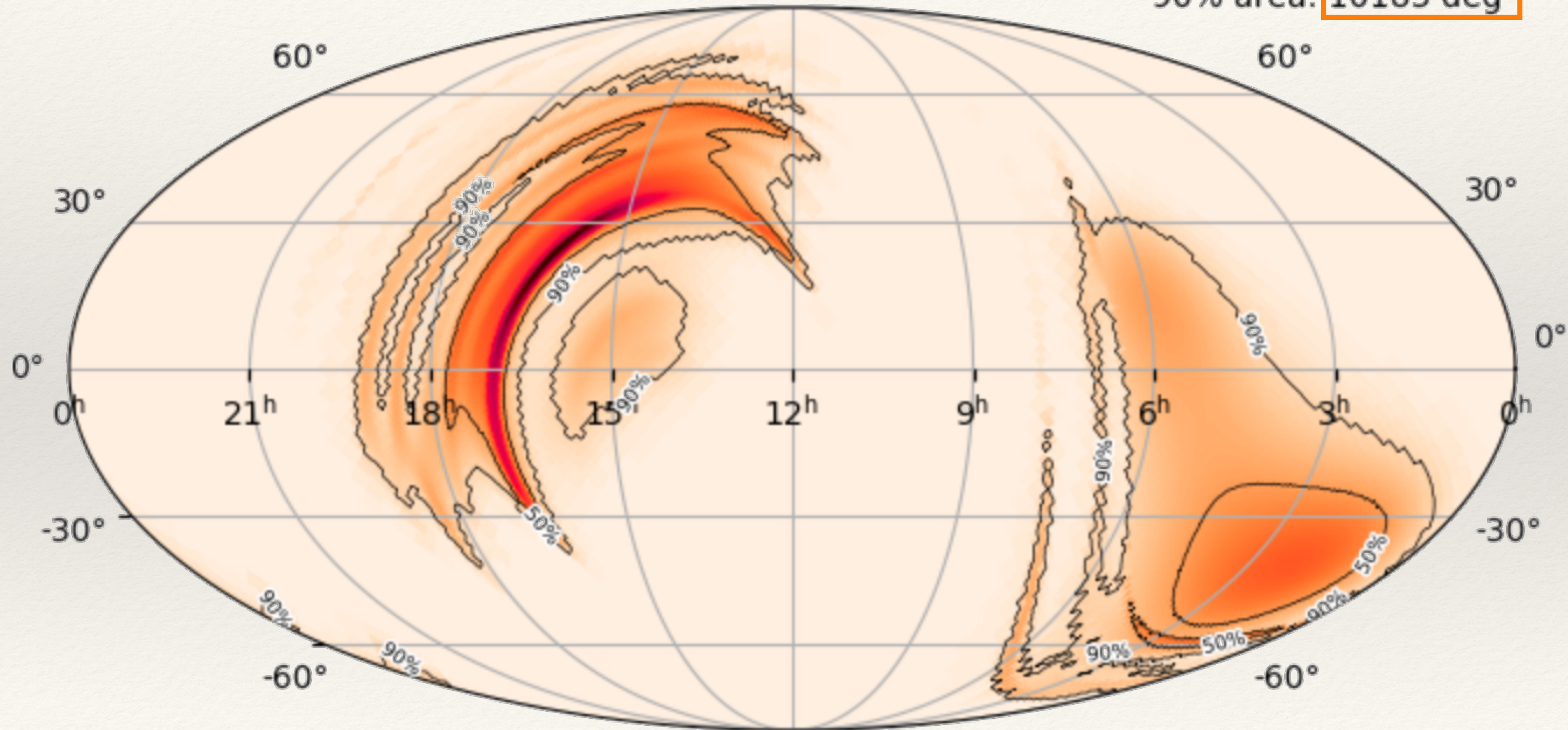
T2

T3

Binary Neutron Star Event | *GW190425z*

single detector event

event ID: G330561
50% area: 2806 deg²
90% area: 10183 deg²



GW search with AMPEL | BNS

— Looking at a potential candidat —

Found 22 output matching the criteria



too APPLI 11 h 24
Summary: 2019-09-07

```

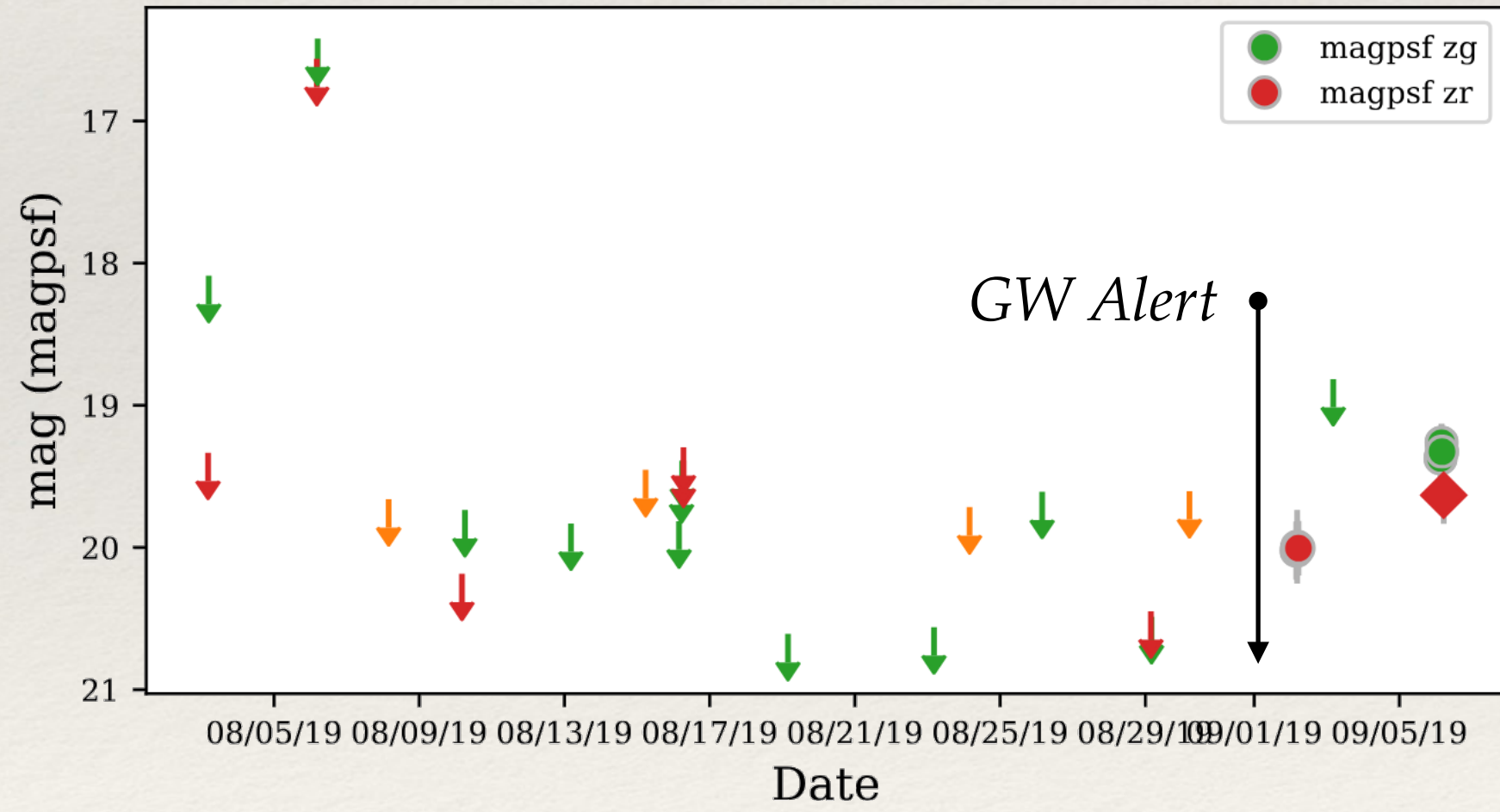
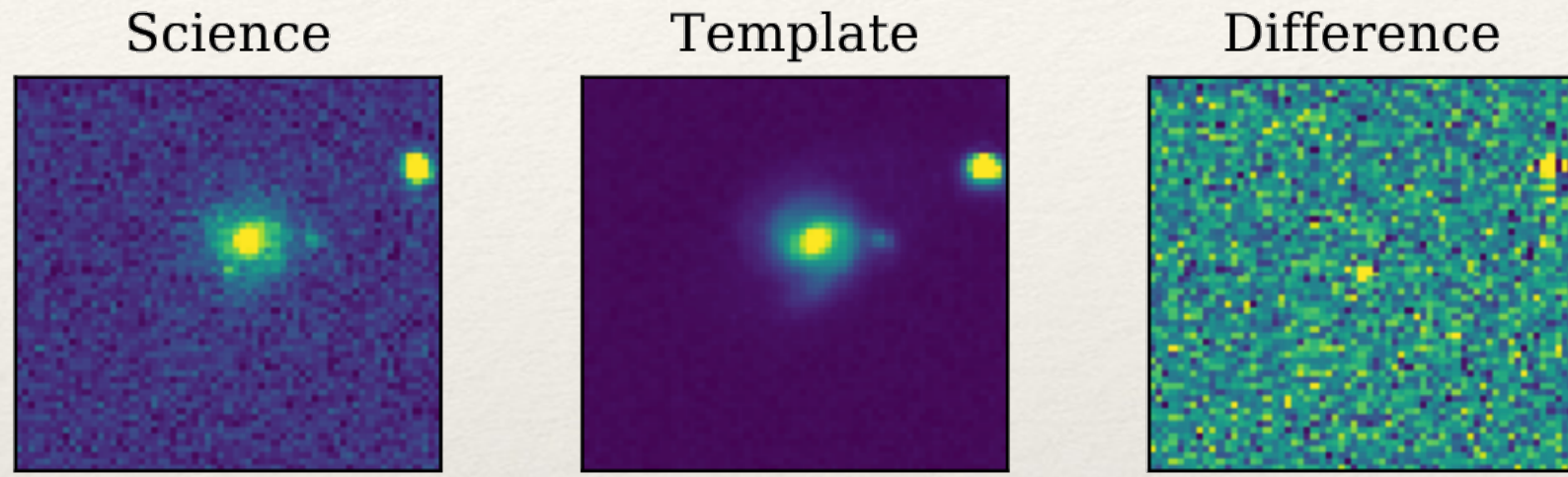
1 ,ztf_name,ra,dec,magpsf,sgscore1,rb,first_detection,most_recent_detection,n_detections,distnr,distpsnr1,isdiffpos
  ,_id,DESY_T00_TEST
2 0,ZTF18abolwbb,344.7107927,8.2407861,19.883899688720703,MISSING,0.6666669845581055,2458469.6286921,2458733.815601
  9,35,0.2626110017299652,MISSING,t,715128695315015000,True
3 0,ZTF19abaeiub,342.7762513,7.9168824,18.1737766265869,0.876688003540039,0.46000000834465,2458653.9415972,2458653.
  9415972,1,4.65612077713013,15.0120964050293,t,899441595715015001,True
4 0,ZTF19abaejff,343.2315487,8.1177775,18.5571346282959,1.0,0.381428569555283,2458653.9420486,2458653.9420486,1,12.
  5434093475342,12.6535234451294,t,899442040215015007,True
5 0,ZTF19abaejgs,340.5133117,10.8542407,18.3296947479248,0.00166666996665299,0.392857134342194,2458653.9420486,2458
  653.9420486,1,4.49421834945679,16.6980838775635,t,899442042415015005,True
  
```

Full Photometry: 2019-09-07

```

1 ,_id,aimage,aimagerat,alFlags,bimage,bimagerat,chinr,chipsf,classtar,clrcoeff,clrcounc,clrmed,clrrms,dec,decrn,di
  ffmaglim,distnr,distpsnr1,distpsnr2,distpsnr3,drb,drbversion,dsdiff,dsnrms,elong,exptime,fid,field,fwhm,isdiffpos
  ,jd,jdendhist,jdendref,jdstarhist,jdstartref,magap,magapbig,magdiff,magfromlim,maggaia,maggaibright,magnr,magps
  f,magzpsci,magzpsci rms,magzpsciunc, mindtoedge,nbad,ncovhist,ndethist,neargaia,neargaibright,nframesref,nid,nmatc
  hes,nmtchps,nneg,objectidps1,objectidps2,objectidps3,pdiffimfilename,pid,programid,ra,ranr,rb,rbversion,rcid,rfid
  ,sccorr,seeratio,sgmag1,sgmag2,sgmag3,sgscore1,sgscore2,sgscore3,sharpnr,sigmatap,sigmatapbig,sigmagnr,sigmatpsf,si
  mag1,simag2,simag3,sky,srmag1,srmag2,srmag3,ssdistnr,ssmagnr,ssnamenr,ssnrms,sumrat,szmag1,szmag2,szmag3,tblid,to
  oflag,tranId,xpos,ypos,zpclrcof,zpmed,ztf_name,most_recent_detection,first_detection,n_detections,DESY_T00_TEST
2 0,715128695315015000,0.9819999933242798,0.41965800523757935,"[1, 2, 19,
  23]",0.6800000071525574,0.2905980050563812,0.4909...
  
```

alert: ID: 978220762815015009 (RA: 220.34974 | Dec: 54.15111 | Filter: zr)



rb : 0.869
fwhm : 2.270
nbad : 0.000
elong : 1.176
isdiffpos : t
objectidps1 : 172982203482633712
objectidps2 : 172982203465482689
objectidps3 : 172982203437013557
sgscore1 : 0.0811963975429535
sgscore2 : 0.401762008666992
sgscore3 : 0.5
distpsnr1 : 5.93016958236694
distpsnr2 : 7.15922927856445
distpsnr3 : 13.6035718917847
srmag1 : 18.1639003753662
srmag2 : -999.0
srmag3 : 19.6291999816895

Robert Stein (DESY), Harsh Kumar (IITB), Michael Coughlin (Caltech), Varun Bhalerao (IITB), Shreya Anand (Caltech), Igor Andreoni (Caltech), Maitreya Khandagale (IITB), Kunal Deshmukh (IITB), Pradip Gatkine (UMD), Viraj Karambelkar (Caltech), Yashvi Sharma (Caltech), Mansi Kasliwal (Caltech), Tomas Ahumada (UMD), Leo P. Singer (NASA GSFC), Eric Bellm (UW):

On behalf of the Zwicky Transient Facility (ZTF) and Global Relay of Observatories Watching Transients Happen (GROWTH) collaborations:

We have continued observing the localization region of the gravitational wave trigger S190910d (LVC et al. GCN 25707) with the Palomar 48-inch telescope equipped with the 47 square degree ZTF camera (Bellm et al. 2019, Graham et al. 2019). In addition to the target-of opportunity observations beginning at UT 2019-09-04 10:18 UT which were already reported by us (Ananad et al. GCN 25706), we have continued serendipitous observations of the localisation region. Each exposure was 30s, with a typical median depth of 20.6 mag. In total, we have now observed 34.6% of the enclosed probability map at least twice since merger, accounting for chip gaps.

The images were processed in real-time through the ZTF reduction and image subtraction pipelines at IPAC to search for potential counterparts (Masci et al. 2019). **AMPEL (Nordin et al. 2019) was used to search the alerts database for candidates.** We rejected stellar sources (Tachibana and Miller 2018) and moving objects, applied machine learning algorithms (Mahabal et al. 2019), and removed candidates with history of variability prior to the merger time. Four additional candidates were found by our pipeline, lying within the 95% probability region.

ZTF Name		IAU Name		RA (deg)		DEC (deg)		Filter		Mag		Magerr
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GW search with AMPEL | BNS



Found 22 output matching the criteria

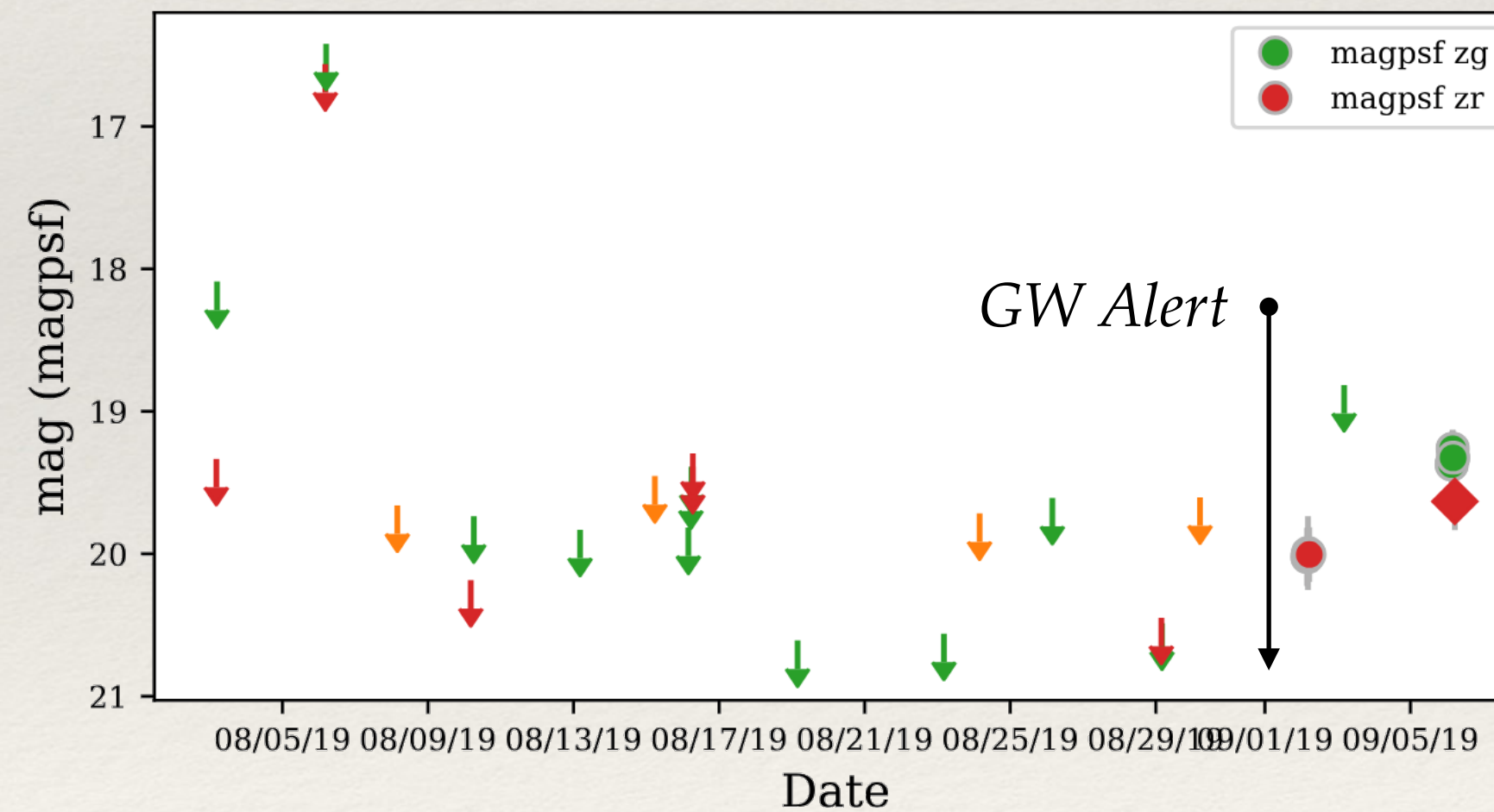
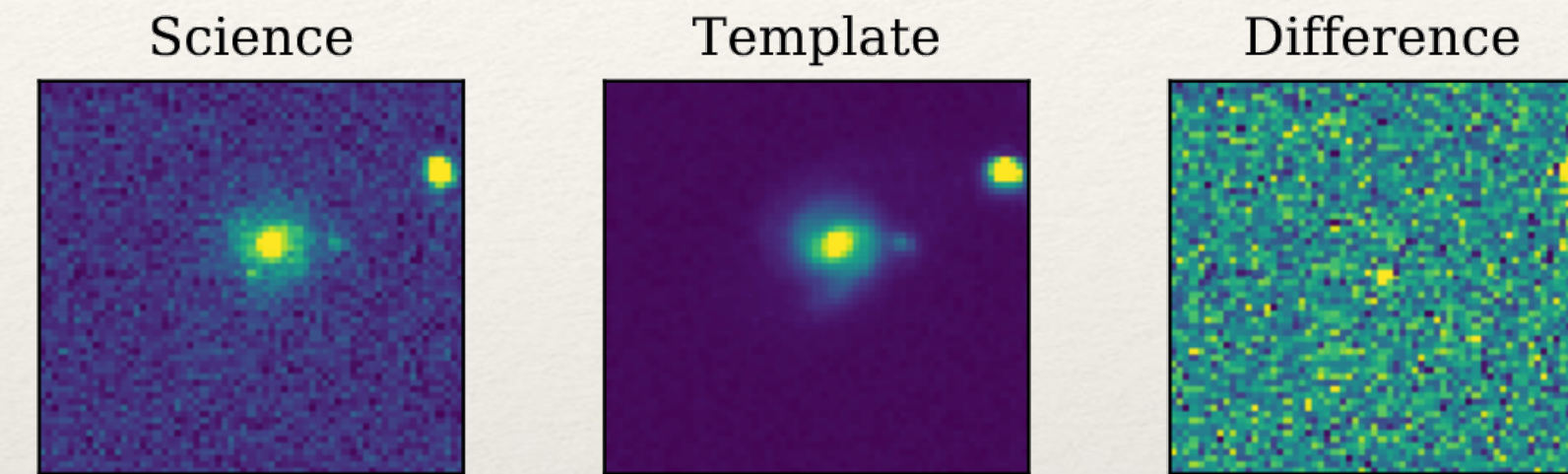
— Looking at potential candidate —

```

too APPLI 11 h 24
Summary: 2019-09-07
1 ,ztf_name,ra,dec,magpsf,sgscore1,rb,first_detection,most_recent_detection,n_detections,distnr,distpsnr1,isdifffpos
  ,_id,DESY_T00_TEST
2 0,ZTF18abolwbb,344.7107927,8.2407861,19.883899688720703,MISSING,0.6666669845581055,2458469.6286921,2458733.815601
  9,35,0.2626110017299652,MISSING,t,715128695315015000,True
3 0,ZTF19abaeiub,342.7762513,7.9168824,18.1737766265869,0.876688003540039,0.4600000834465,2458653.9415972,2458653.
  9415972,1,4.65612077713013,15.0120964050293,t,899441595715015001,True
4 0,ZTF19abaejff,343.2315487,8.1177775,18.5571346282959,1.0,0.38142856955283,2458653.9420486,2458653.9420486,1,12.
  5434093475342,12.6535234451294,t,899442040215015007,True
5 0,ZTF19abaejgs,340.5133117,10.8542407,18.3296947479248,0.00166666996665299,0.392857134342194,2458653.9420486,2458
  653.9420486,1,4.49421834945679,16.6980838775635,t,899442042415015005,True

Full Photometry: 2019-09-07
1 ,_id,aimage,aimagerat,alFlags,bimage,bimagerat,chinr,chipsf,classtar,clrcoeff,clrcounc,clrmed,clrrms,dec,decr,di
  fffmaglim,distnr,distpsnr1,distpsnr2,distpsnr3,drb,drbversion,dsdiff,dsnrms,elong,exptime,fid,field,fwhm,isdifffpos
  ,jd,jdendhist,jdendref,jdstarthist,jdstartref,magap,magapbig,magdiff,magfromlim,maggaia,maggaibrightr,magnr,magps
  f,magzpsc,imzpsc,imzpscirms,magzpscunc,mindtoedge,nbad,ncovhist,ndethist,neargaia,neargaibrightr,nframesref,nid,nmatc
  hes,nmtchps,nneg,objectidps1,objectidps2,objectidps3,pdiffimfilename,pid,programid,ra,ranr,rb,rbversion,rcid,rfid
  ,scorr,seeratio,sgmag1,sgmag2,sgmag3,sgscore1,sgscore2,sgscore3,sharpnr,sigmatap,sigmatapbig,sigmagnr,sigmatpsf,si
  mag1,simag2,simag3,sky,srmag1,srmag2,srmag3,ssdistnr,ssmagnr,ssnamenr,ssnrms,sumrat,szmag1,szmag2,szmag3,tblid,to
  oflag,tranId,xpos,ypos,zpclr cov,zpmed,ztf_name,most_recent_detection,first_detection,n_detections,DESY_T00_TEST
2 0,715128695315015000,0.9819999933242798,0.41965800523757935,"[1, 2, 19,
  23]",0.6800000071525574,0.2905980050563812,0.4909...
    
```

alert: ID: 978220762815015009 (RA: 220.34974 | Dec: 54.15111 | Filter: zr)



rb : 0.869
 fwhm : 2.270
 nbad : 0.000
 elong : 1.176
 isdifffpos : t
 objectidps1 : 172982203482633712
 objectidps2 : 172982203465482689
 objectidps3 : 172982203437013557
 sgscore1 : 0.0811963975429535
 sgscore2 : 0.401762008666992
 sgscore3 : 0.5
 distpsnr1 : 5.93016958236694
 distpsnr2 : 7.15922927856445
 distpsnr3 : 13.6035718917847
 srmag1 : 18.1639003753662
 srmag2 : -999.0
 srmag3 : 19.6291999816895

4h later....

ZTF19abwvals has been classified as Ia btw:
<https://gcn.gsfc.nasa.gov/gcn3/25675.gcn3>

robertstein 15 h 56
 Yes, I saw 😞

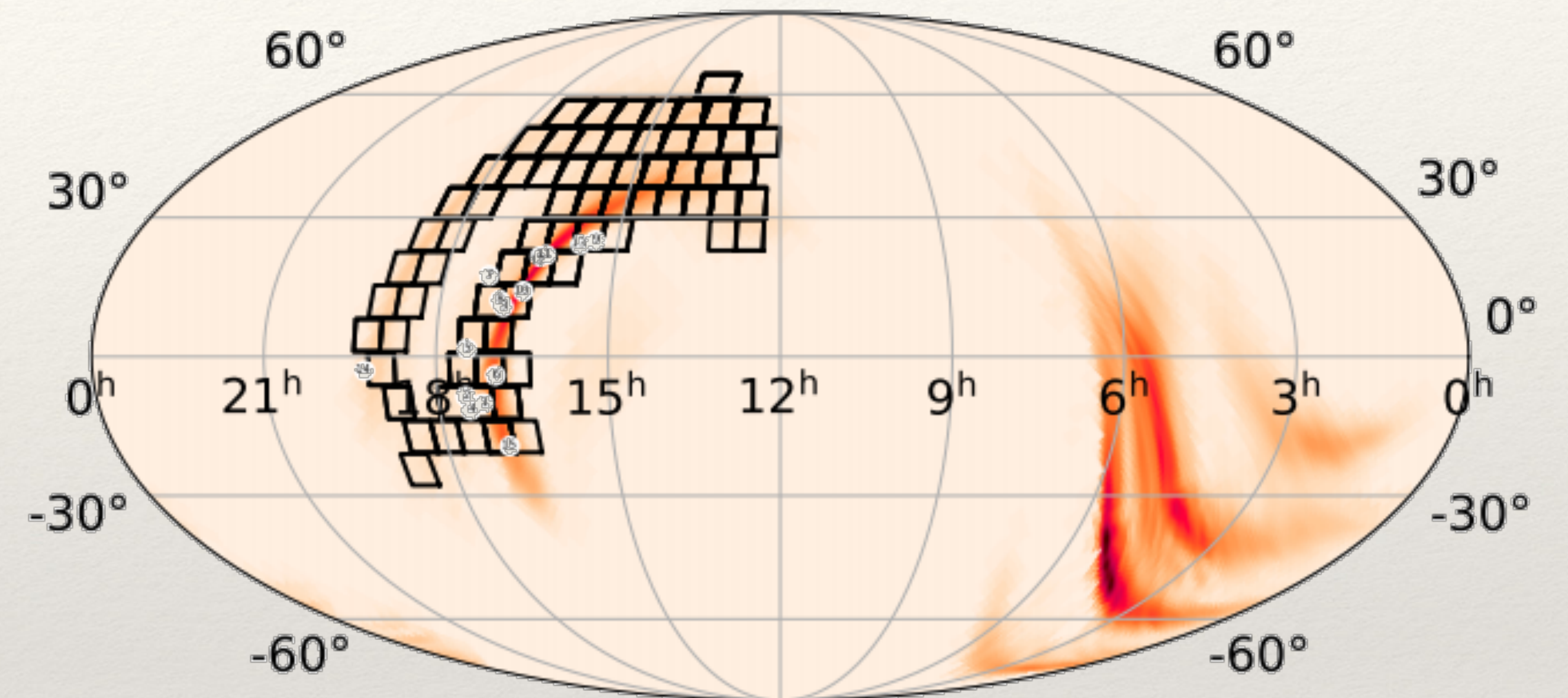
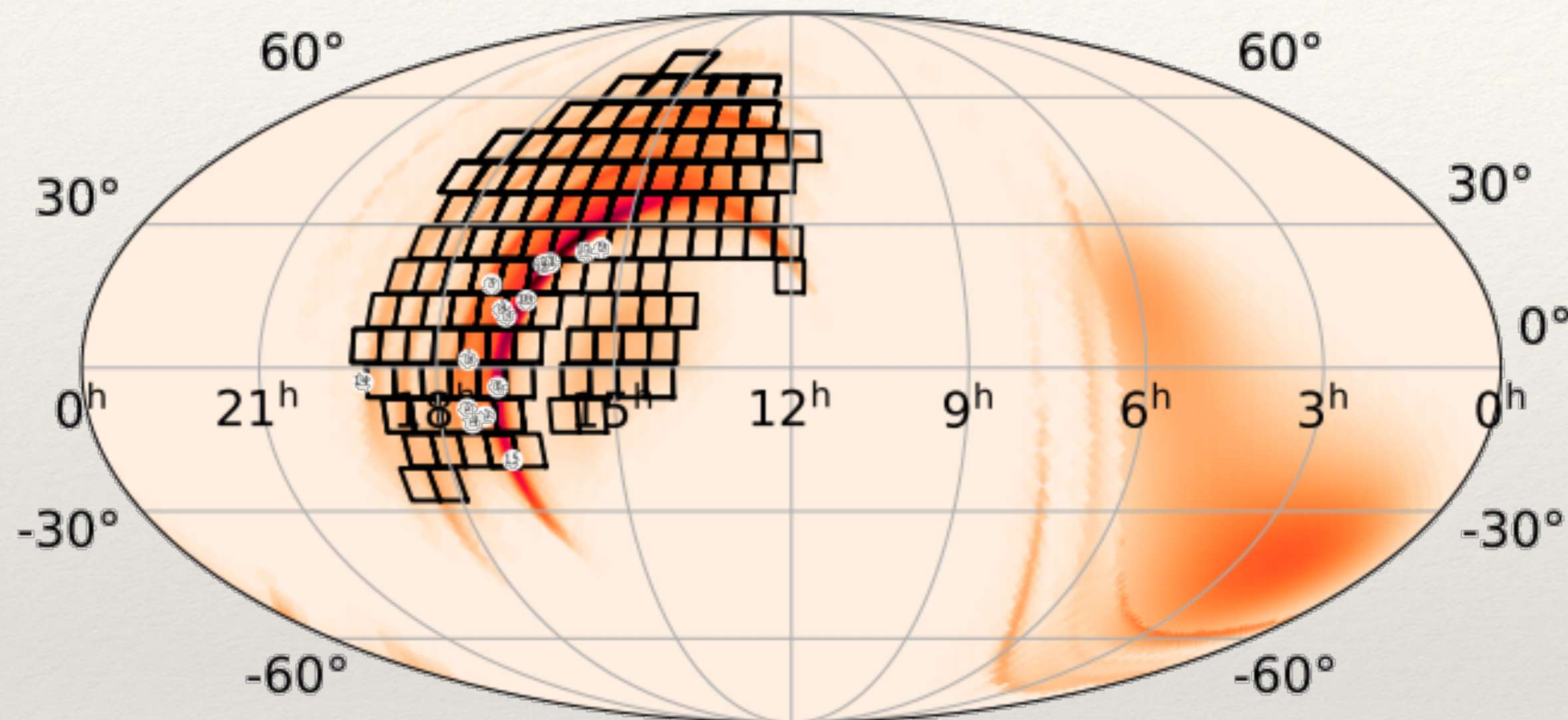
ZTF follow-up GW | *GW190425z*

Coughlin et al. 2019

single detector event

Quick pipeline contours | 8000 deg²

Final contours



ZTF scanned 46% of confidence area in 3 hours in 2 bands (25% observing time used)

338 646 alerts

15 candidates counterparts

2 particularly interesting

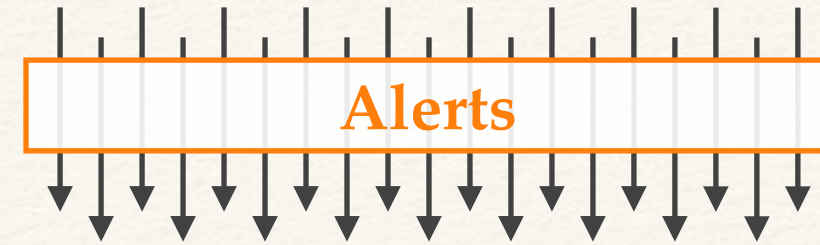
All Supernovae...



AMPEL | Process Flow

*Examples
SNeIa*

Nordin et al. 2019



FILTER

T0

All that have at least 2 rising points in 2 bands

DB MANAGEMENT

T1

Converts alerts into a transient (already exist?)

SCIENCE ADDED VALUES

T2

SALT2 parameters | Host Properties (z) | Probability to be a « Ia »

DECISION MAKING

T3

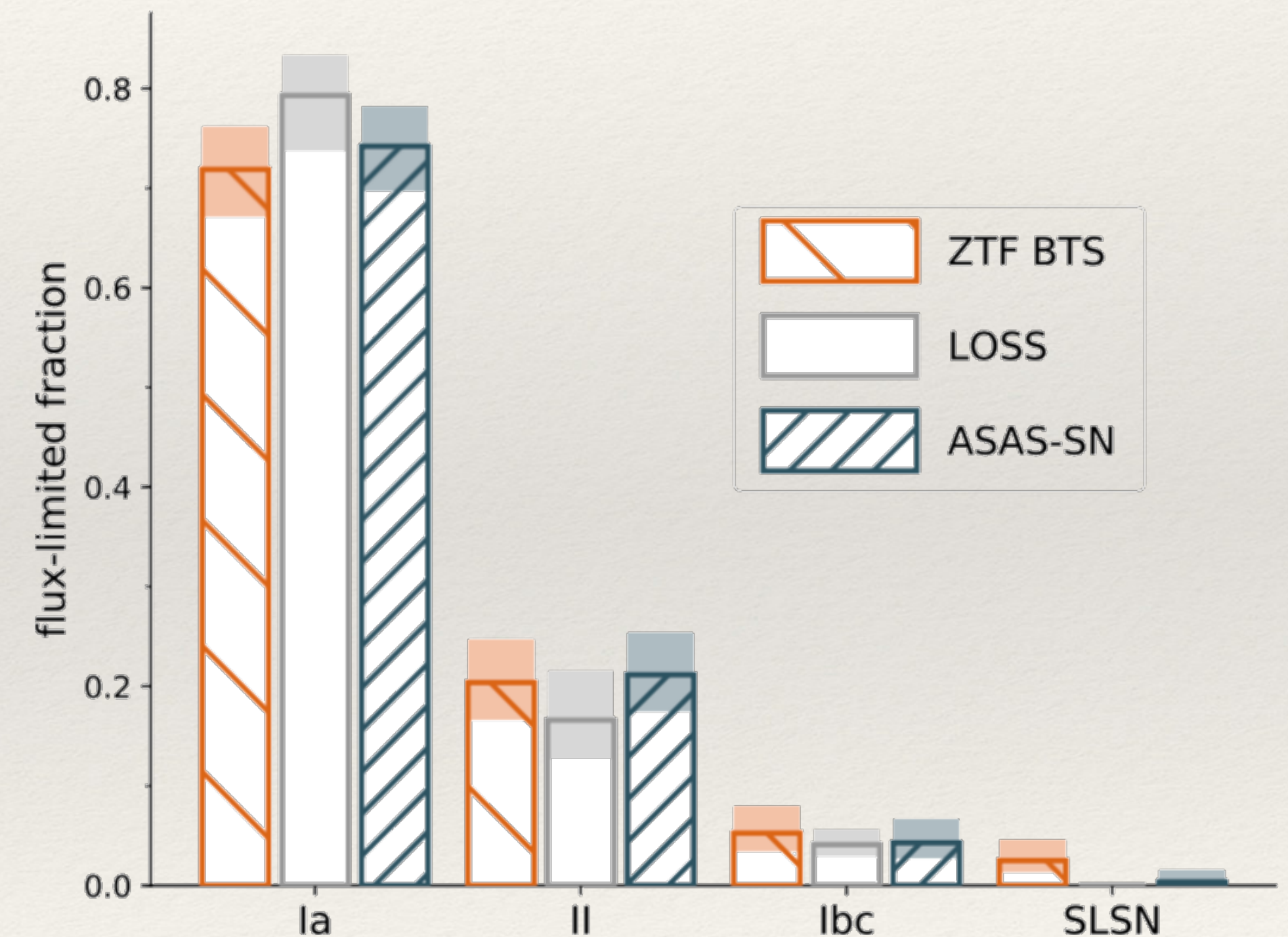
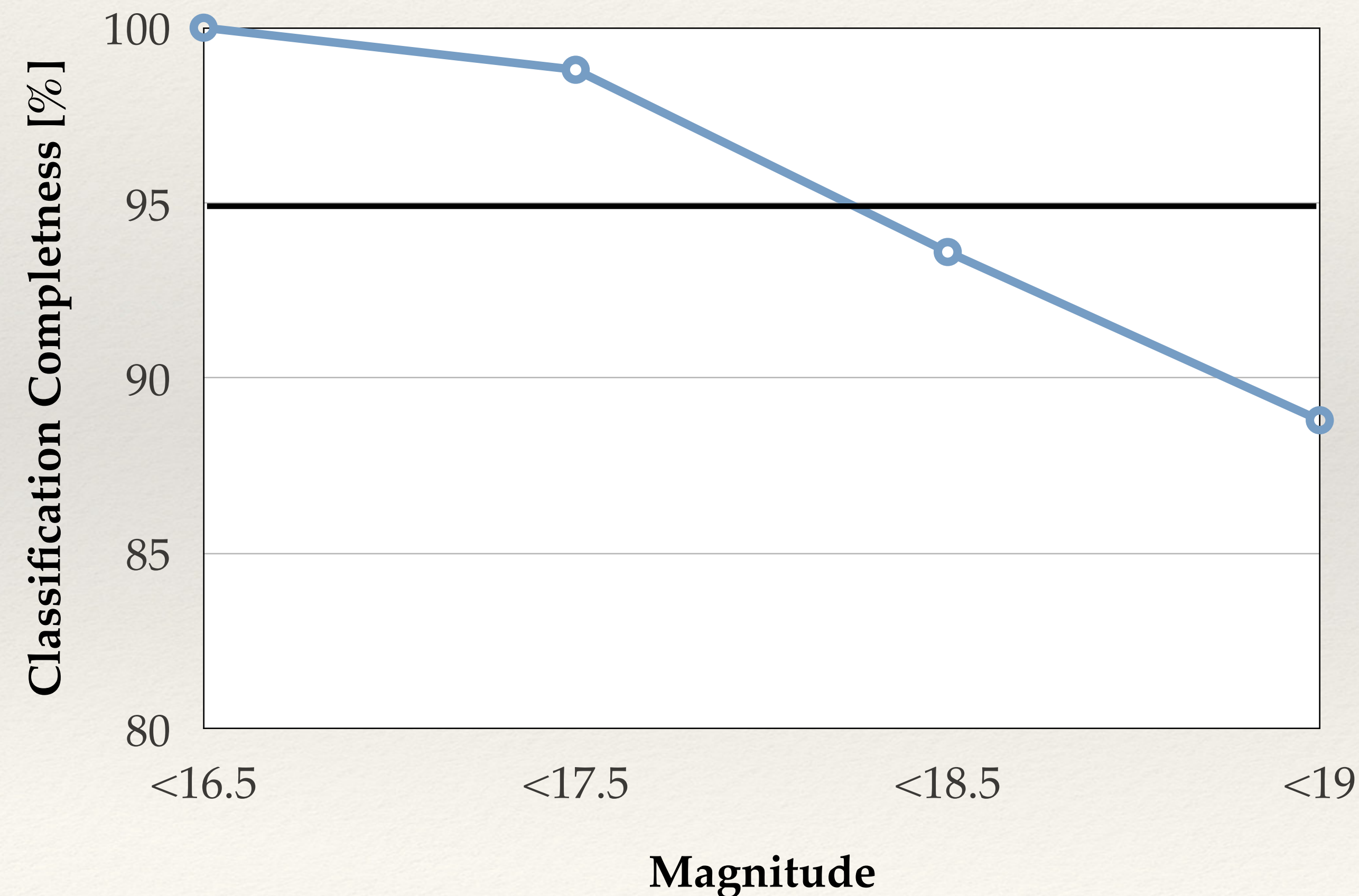
If at max, trigger spectrograph | if odd, trigger spectrograph
push LC on Slack | Publish on TNS

Bright Transient Survey

Fremling et al. 2019

“Trigger spectroscopy for any SN-like objects with mag<18.5”

We have all SNeIa nature provides in the northern sky with $z < 0.08$ (~800/an)



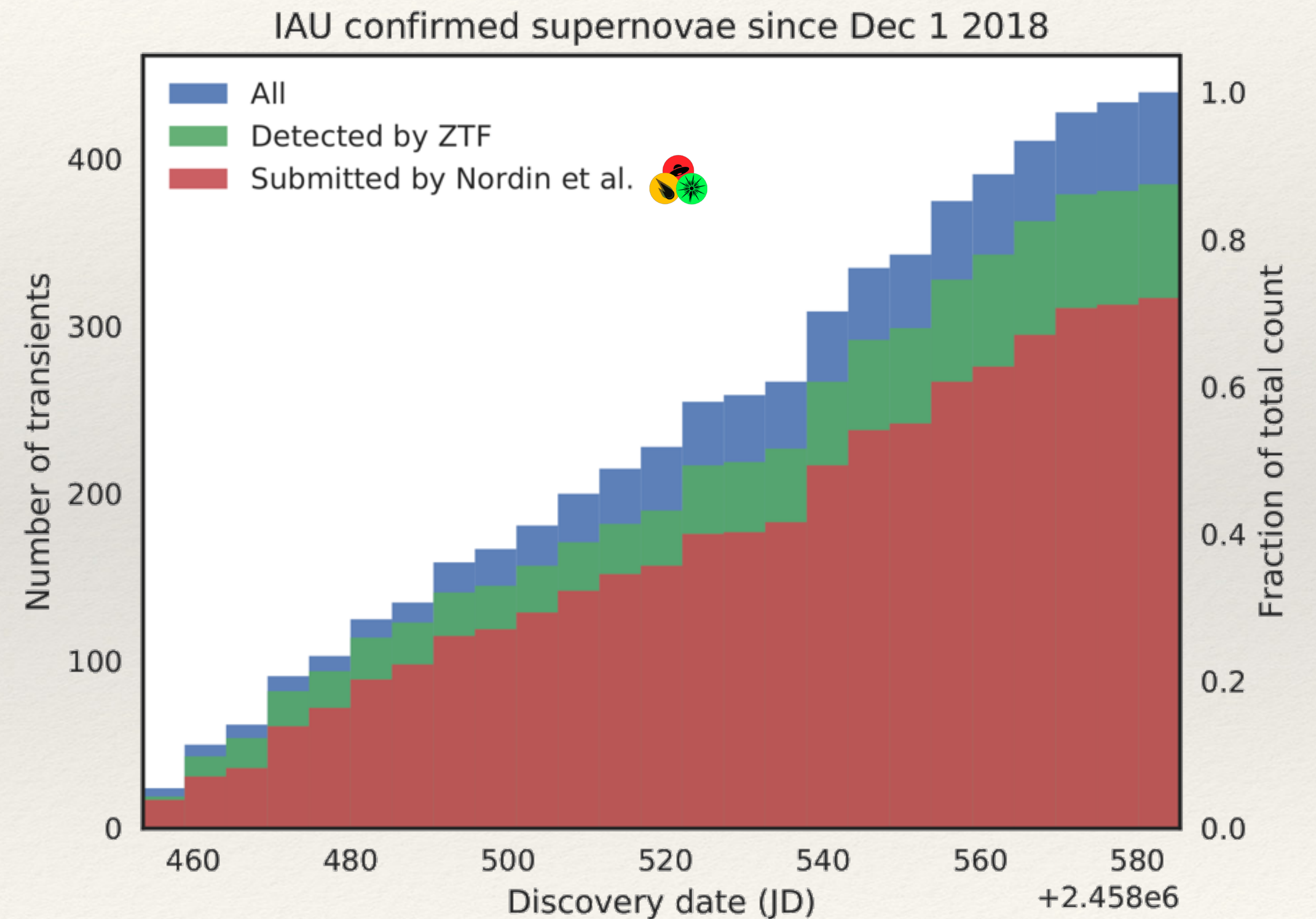


AMPEL | *Some* Facts & Numbers

Nordin et al. 2019

*Already the largest
Supernova reporter*

*80% of the reported transients
end up being extragalactic variables
&
less than 5 days old when reported*





AMPEL | *Some* Facts & Numbers

Nordin et al. 2019

Able to rerun the entire stream while changing any of your AMPEL configurations
-> *Understand your selection fonction* | *looking for missed events*

Can process ~1250 alerts per second (T0) ~3x more than what LSST will provide
AMPEL is already LSST ready!

T0 (filters) and T2 (science) can use more than 24 already available catalogs (SDSS/Gaia/PS)

Currently 12 parallel science cases running
— *Including the ZTF GW search* —

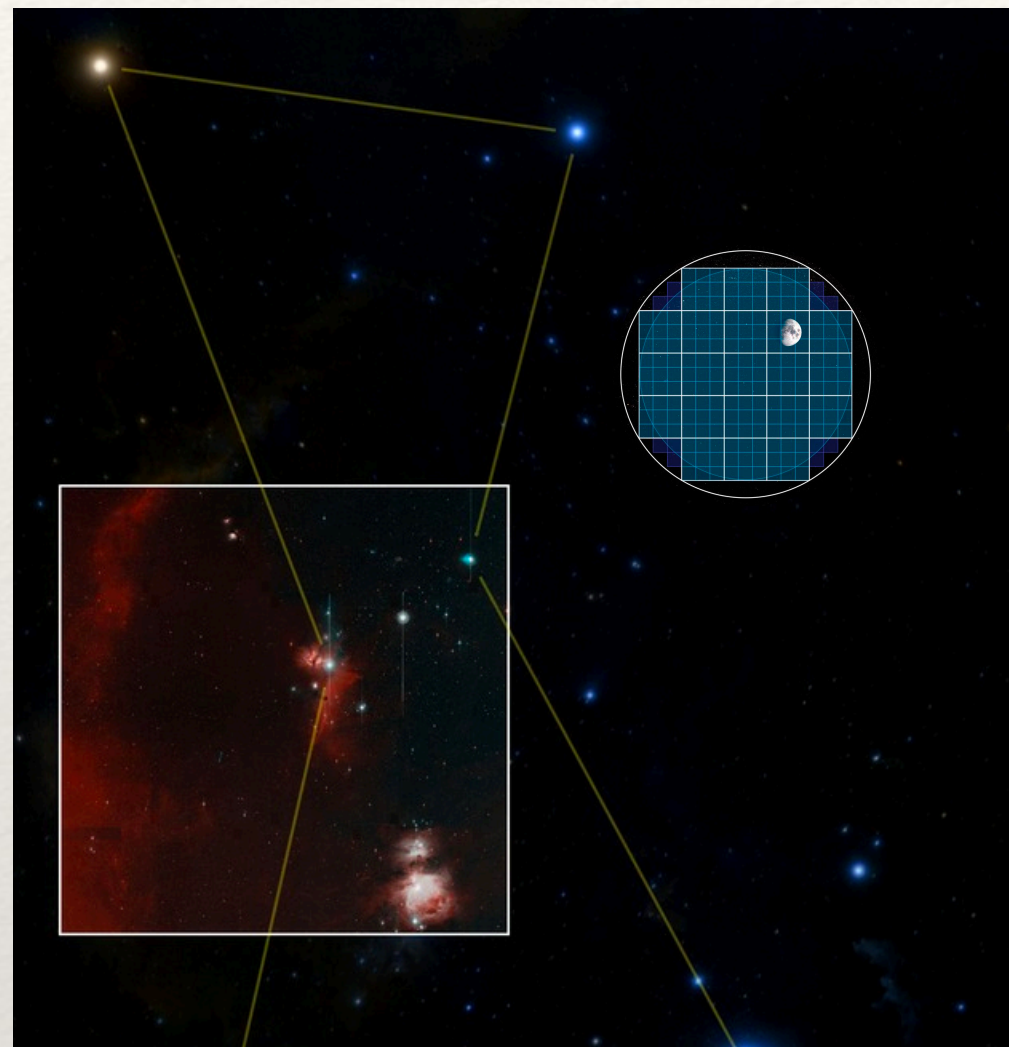
AMPEL can automatically trigger instruments (*e.g. ZTF spectro*)

Start instructions at:
<https://github.com/AmpelProject/Ampel-contrib-sample>

Join us

Contact us:
J. Nordin (PI, jnordin@hu-berlin.de) or myself

Conclusion



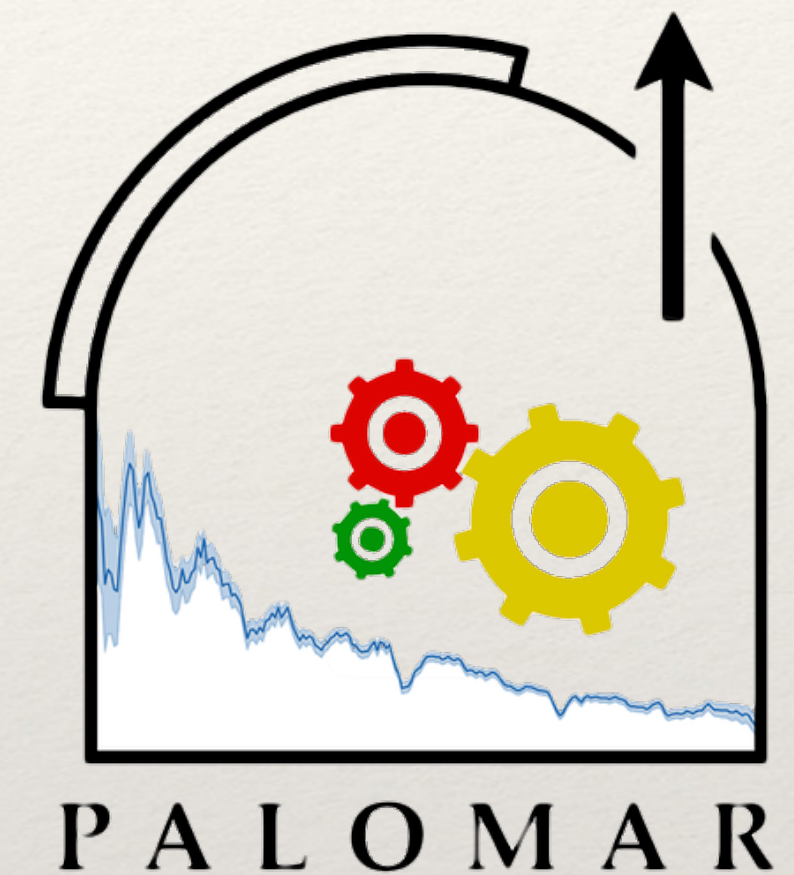
ZTF → LSST

**The Optical Transient Sky
Alerts & Counterpart**



AMPEL

**Combine & Follow alerts
Core of the Multi-messenger quest**



SEDmachine

**Type Transient &
Get early spectra**