Demographics of the Transient Universe from Large Surveys: from ZTF to LSST

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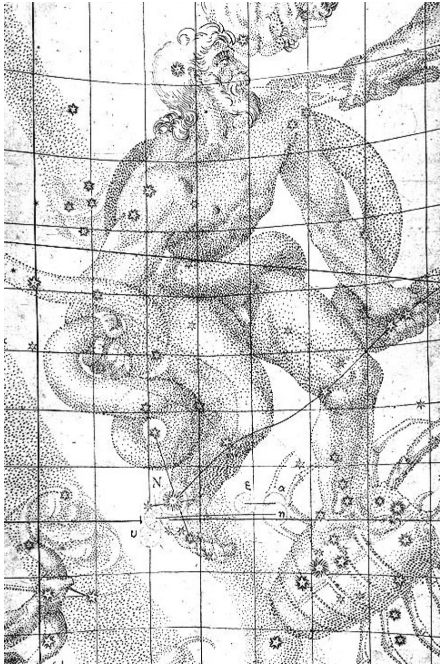
The Catastrophic Universe

- Rates per year:

	< 100 Mpc	< 300 Mpc	z < 0.15 ($V=1Gpc^3$)	z < 0.25 ($D_{cov}=1Gpc$)	z < 1
SN Ia	100	2500	2.5×10^4	1×10^5	4×10^6
CCSN	400	10^4	1×10^5	4×10^5	1×10^7
LGRBs	~1	20	200	1000	3×10^4
NS+NS	~2	50	500	2000	7×10^4
-17+DM	17	19.4	21.3	22.5	26.1

Transient Studies (sometimes)

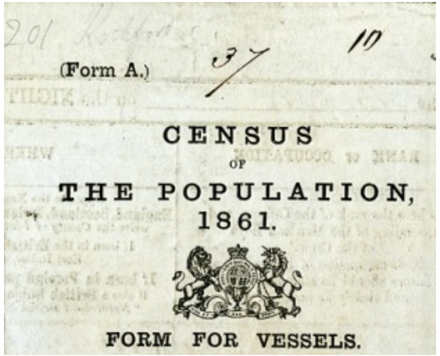
Serendipity-Driven Science



Population studies for optical transients

<u>Needed to address:</u>

- How common things are (**rates**)
- What does *not* exist (**rate limits**)
- Where things happen (host galaxies)
- How events group into **classes** ("phase space")
- Anything systematics-limited (e.g. cosmology)


(Form A.)

CENSUS

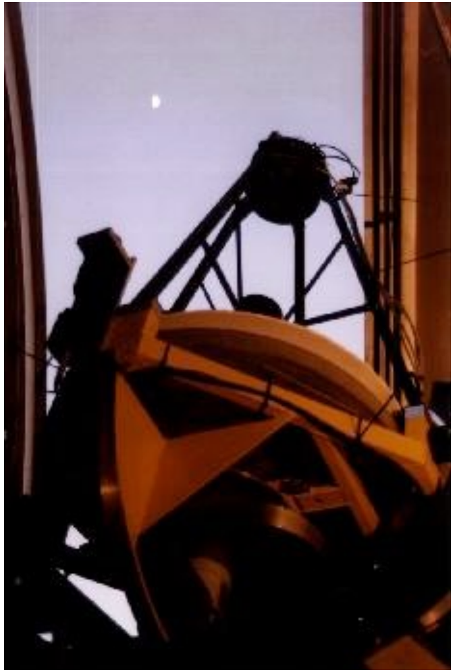
OF

THE POPULATION,

1861.

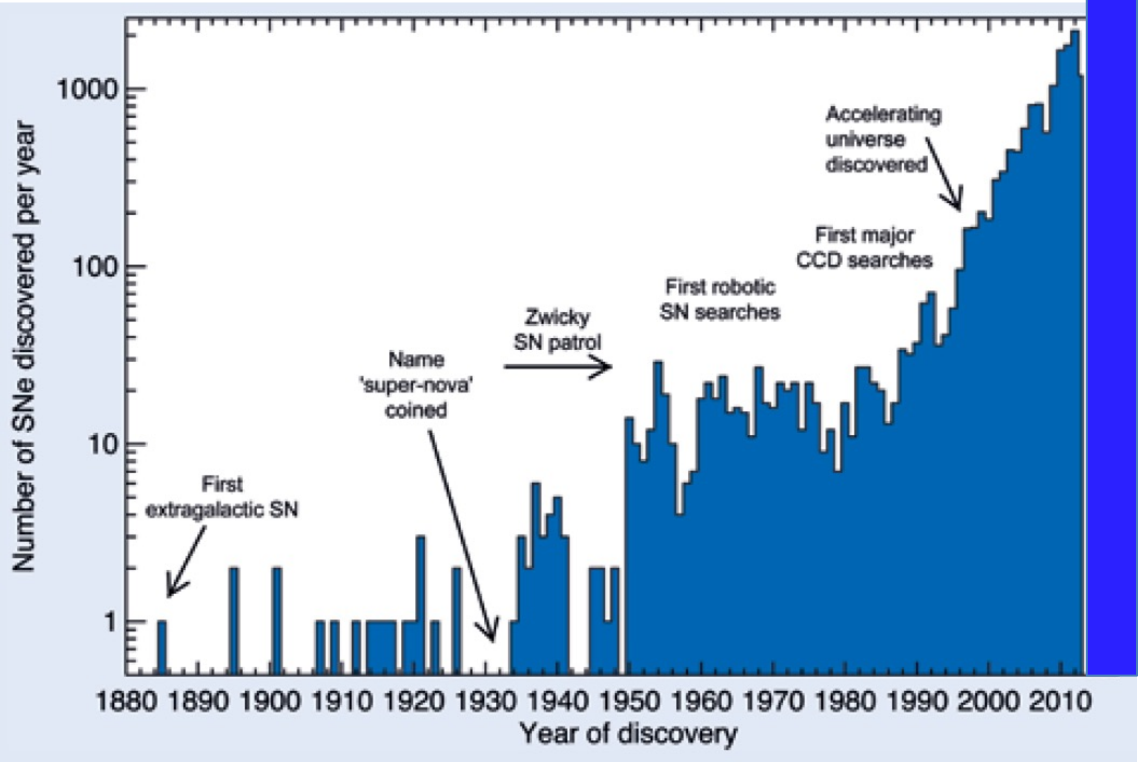
FORM FOR VESSELS.

Progress...

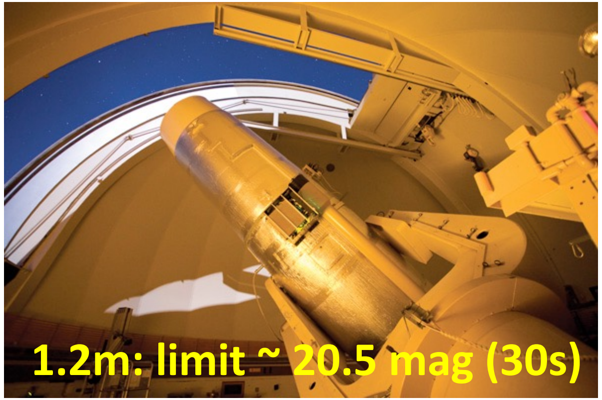


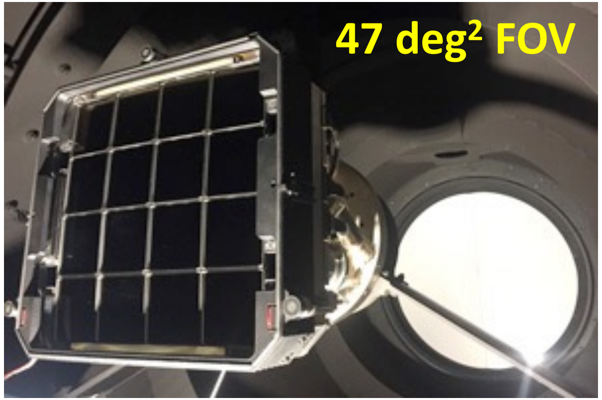
Vast Numbers of Transients

ZTF	37798
Pan-STARRS	35925
GaiaAlerts	16832
ATLAS	14544
iPTF	1642

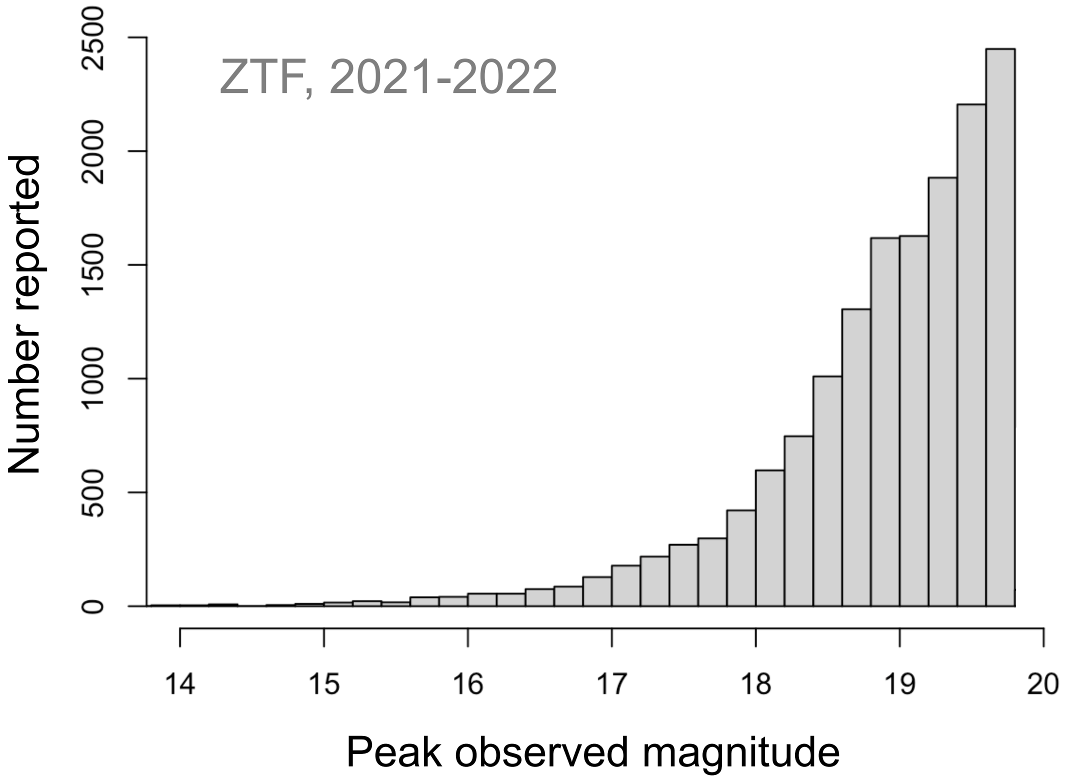


The Zwicky Transient Facility



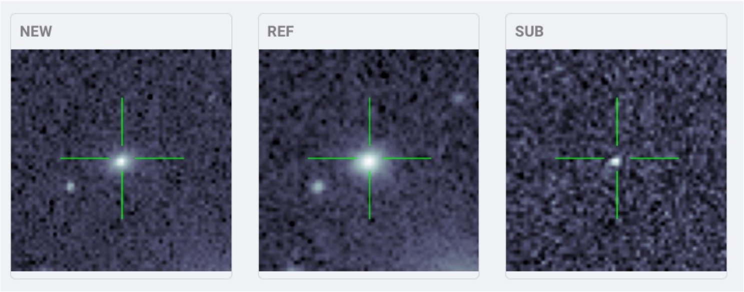


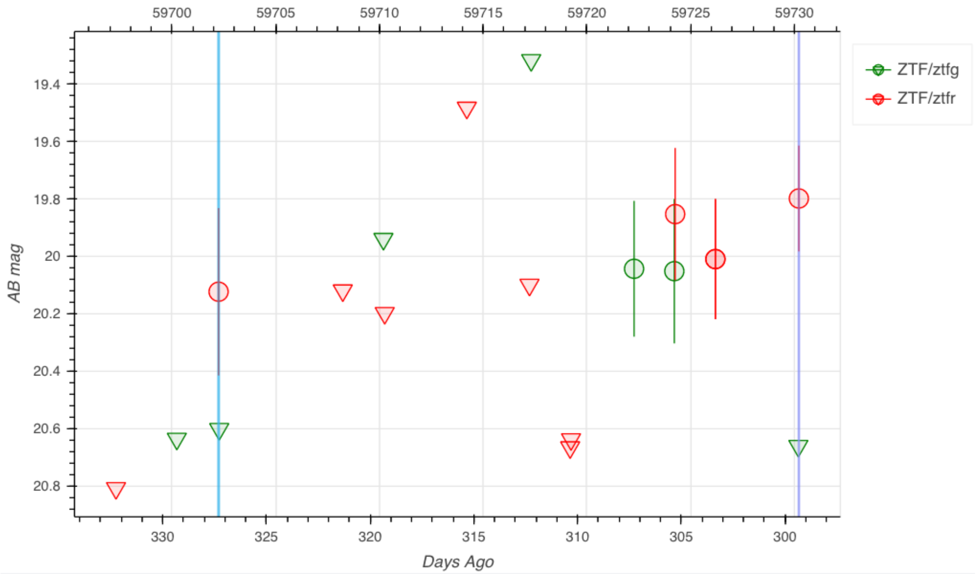
Lots of Transients



Lots of Faint Transients

Most of them look like this...





m~19.5 mag: ~1 hour 4m spectroscopy to classify (x1000+ transients each year)

Detection is Not Enough

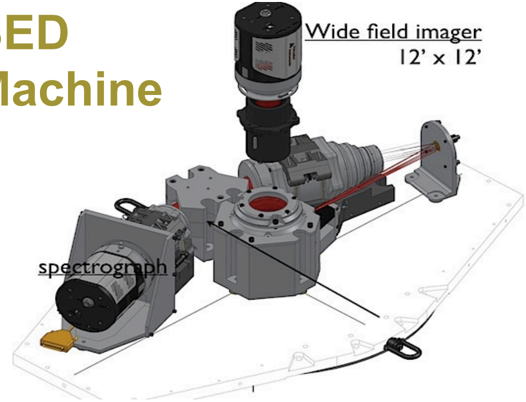
Systematic, demographic science requires:

- Redshift
- Classification

\+ Light curve, colours, spectrum, radio, X-ray, host...

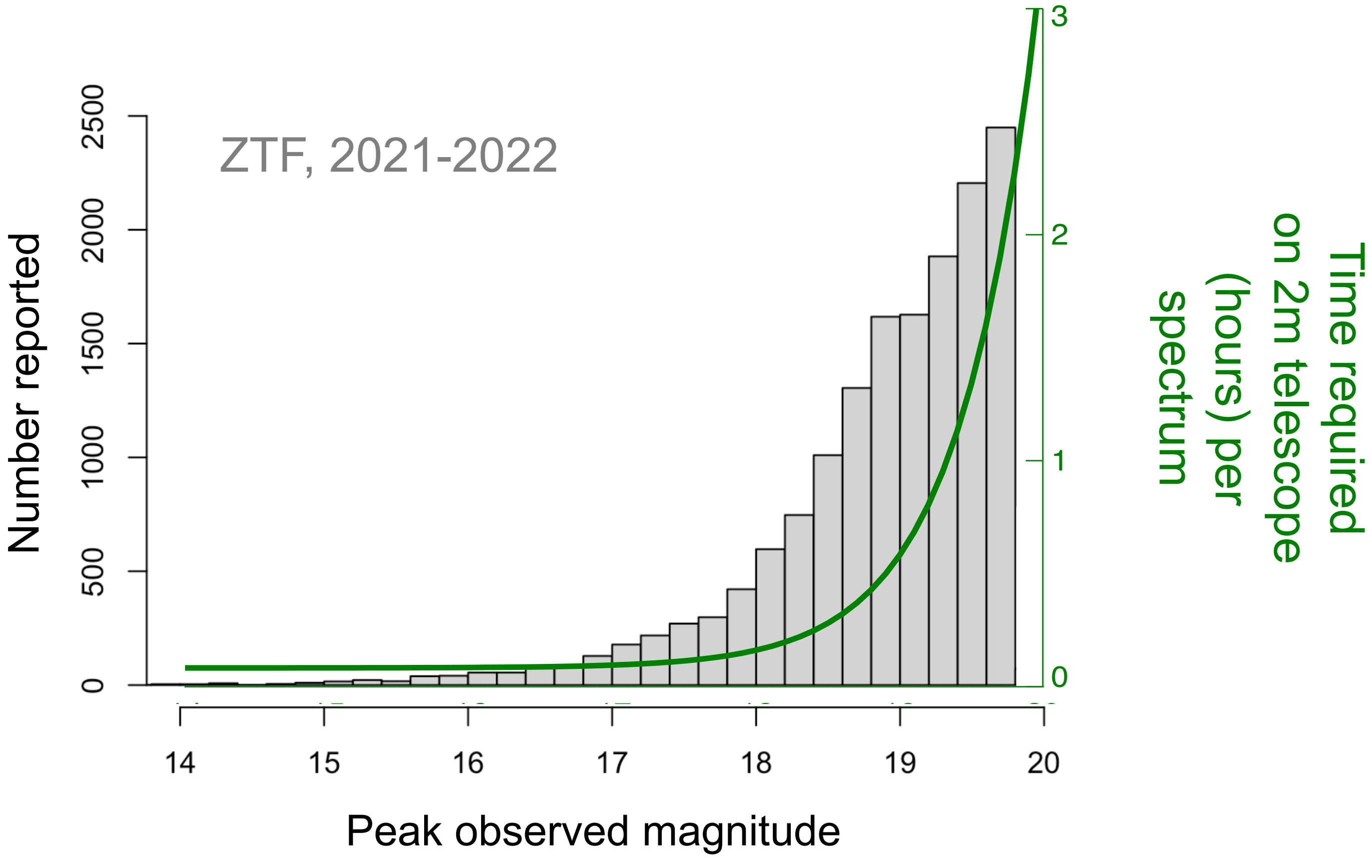
Dedicated Spectroscopic Follow-up

SED Machine



Blagorodnova+2018

Lots of Transients



BTS: ZTF's mag-limited transient survey

- **Catalog** all (public, extragalactic) ZTF transients to m < 19.8
- **Classify** all ZTF transients to **m < 18.5**

Catalogue to m=19
(deeper since 2021)

Classify to m=18.5
(deeper when possible!)

Mag limit	Predicted SNe/year
17	155
17.5	300
18	585
18.5	**1130**
19	**2220**
19.5	4370
20	8500
20.5	16500

Spectroscopically

Classified SN Count (2018-2022)

m < 19 (incomplete)

7428 supernovae

5418 Ia

incl. 20 Iax, 13 Ia-CSM

374 Ib/c

incl. 25 Ibn, 53 Ic-BL, 61 SLSN-I

1469 II

incl. 101 IIb, 193 IIn, 36 SLSN-II

+ 46 TDEs, + 39 novae

+ 21 "other" (ILRTs, FBOTs, GRBs)

+ 4231 unclassified (36%)

m < 18.5 passing cuts

3019 supernovae

2231 Ia

incl. 9 Iax, 5 Ia-CSM

163 Ib/c

incl. 14 Ibn, 31 Ic-BL, 17 SLSN-I

531 II

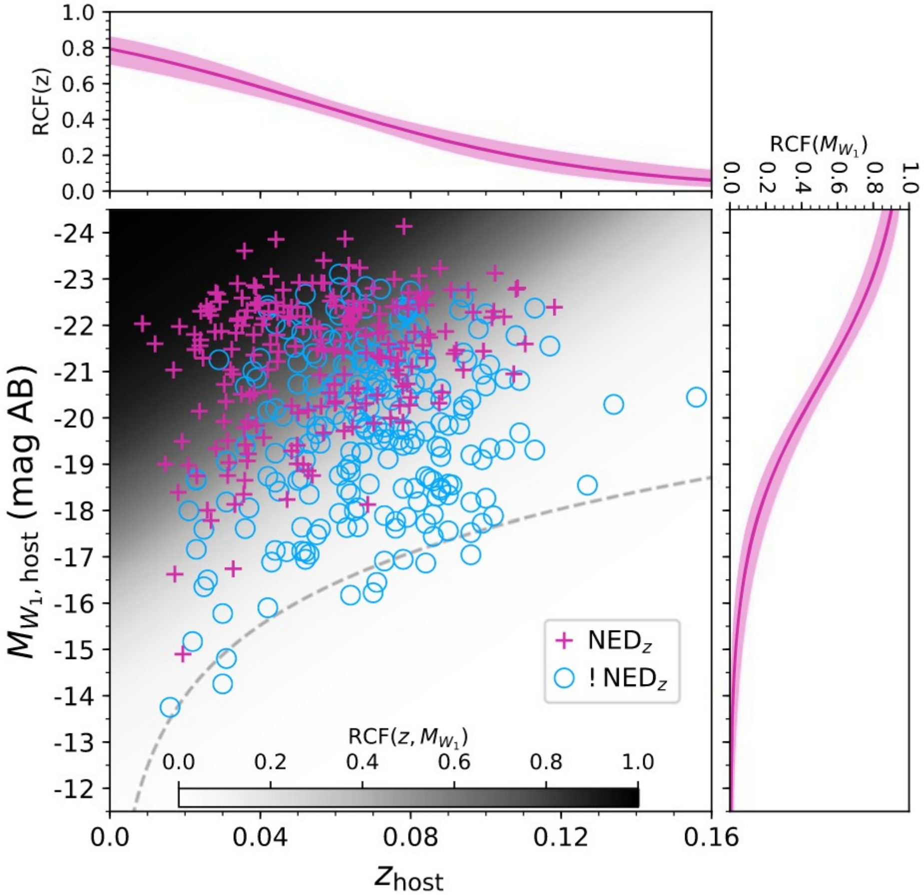
incl. 43 IIb, 85 IIn, 10 SLSN-II

+ 11 TDEs, + 22 novae

+ 7 "other"

*+ 149 unclassified **(5%)***

Redshift Completeness Factor



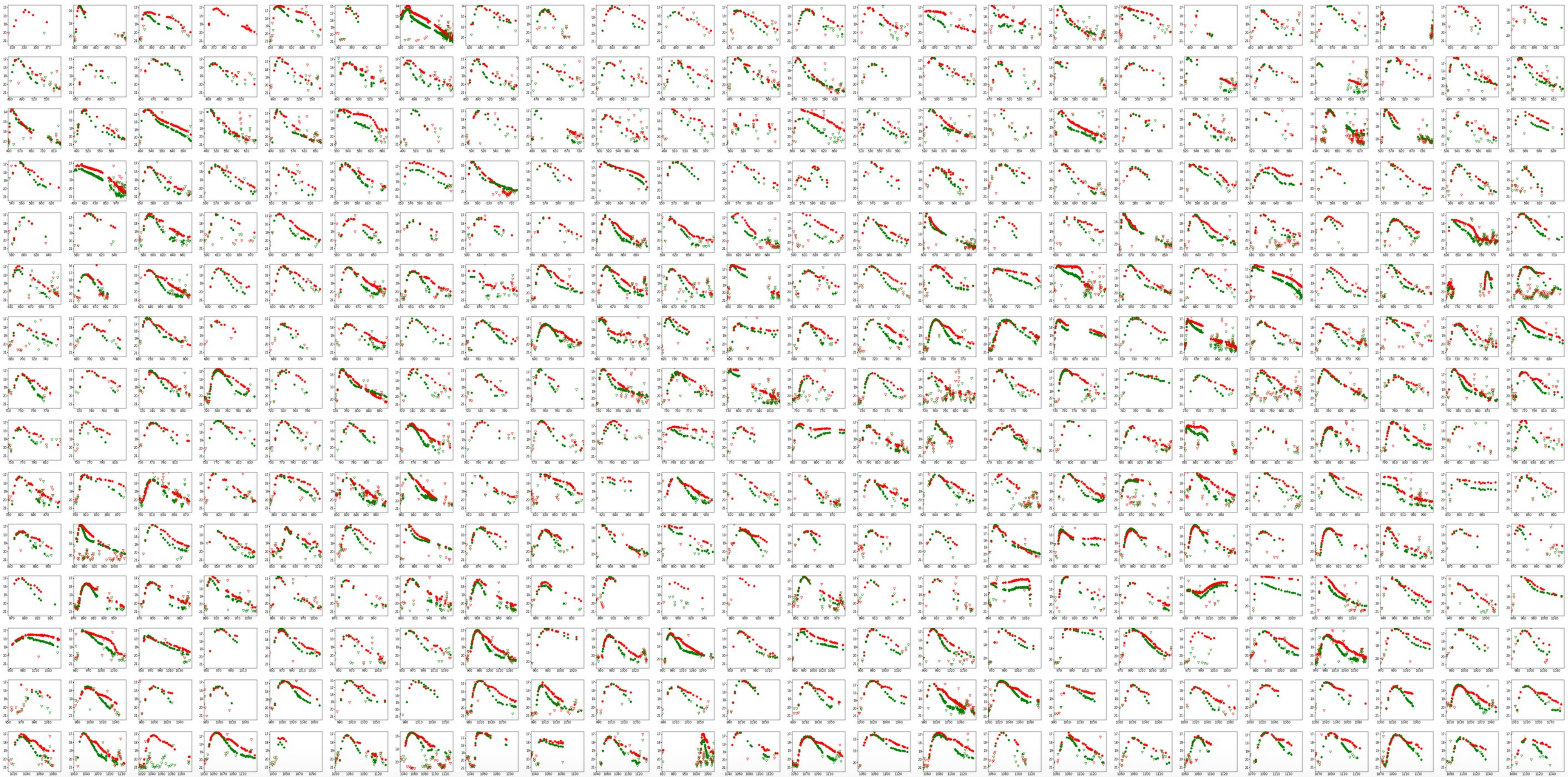
What proportion of transients are in galaxies of known redshift?

63 %

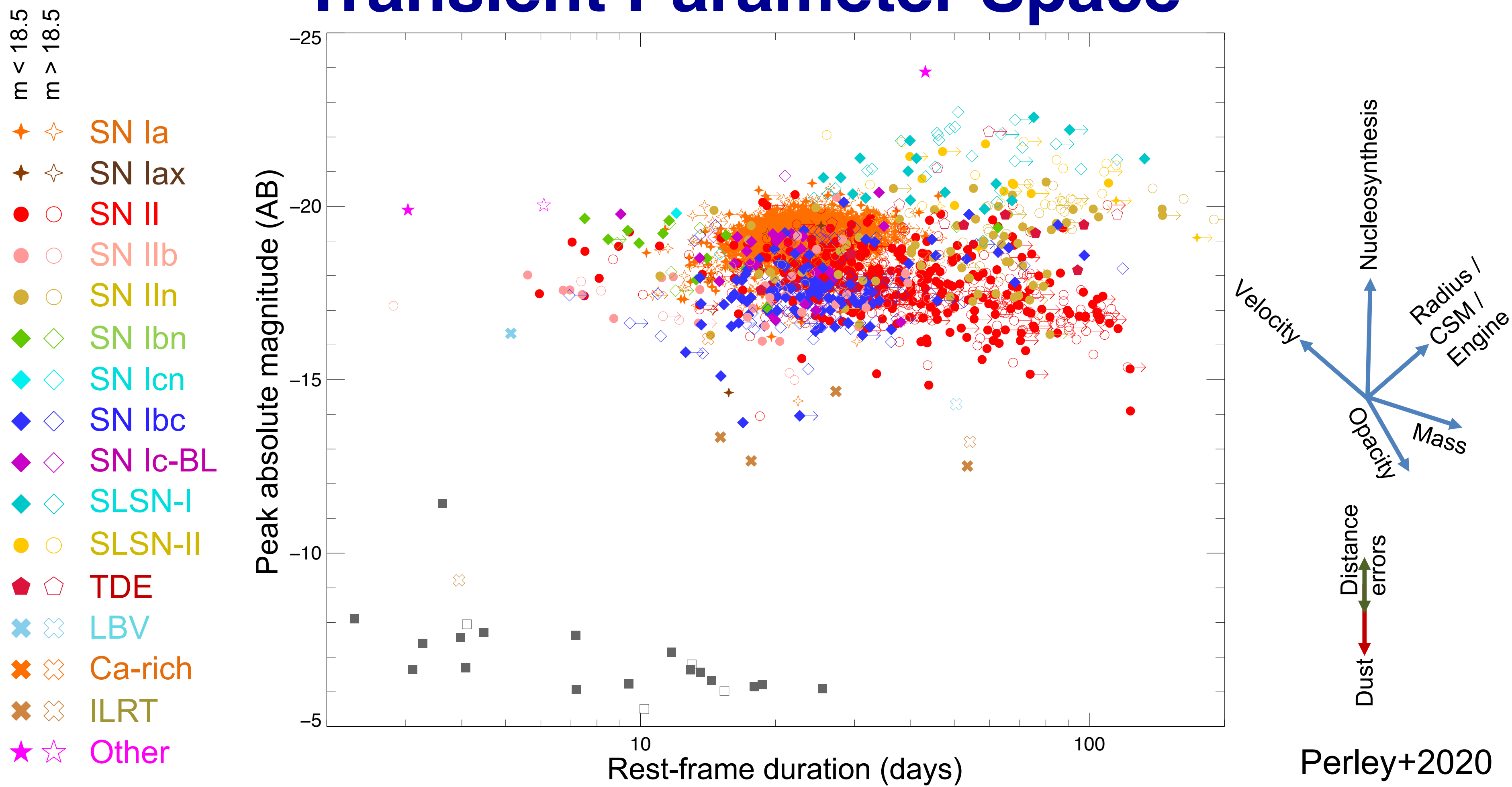
(to z=0.05 / 200 Mpc)

Fremling+2020

Continuous Coverage → Light Curves



Transient Parameter Space



Perley+2020

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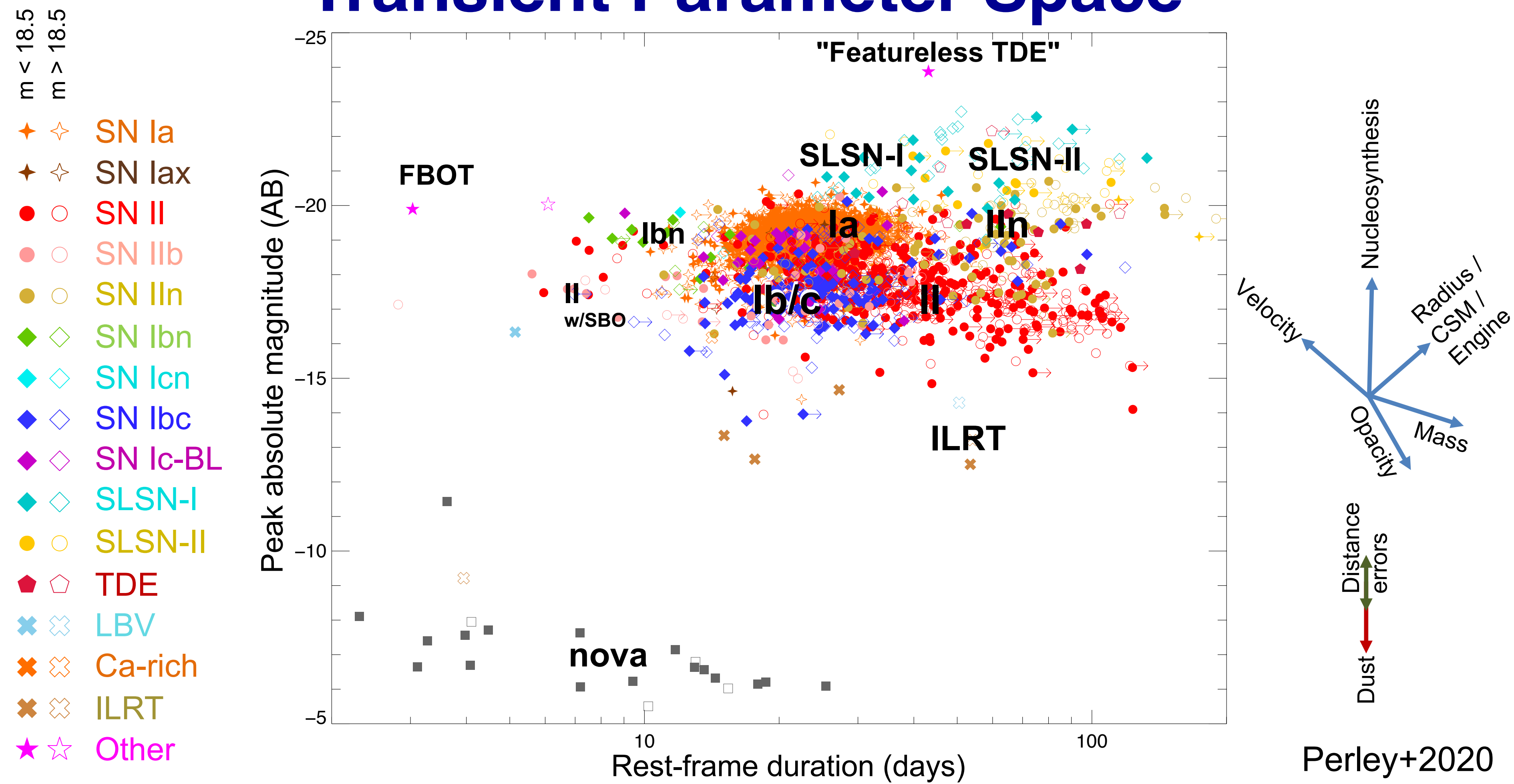
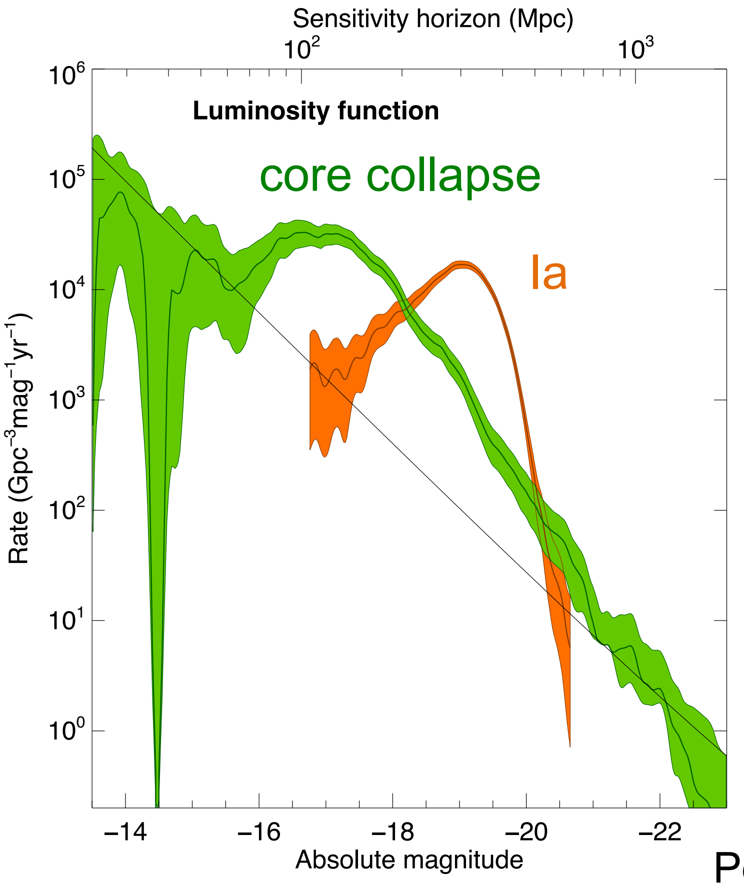


Perley+2020

Supernova Luminosity Functions



uncorrected for host extinction

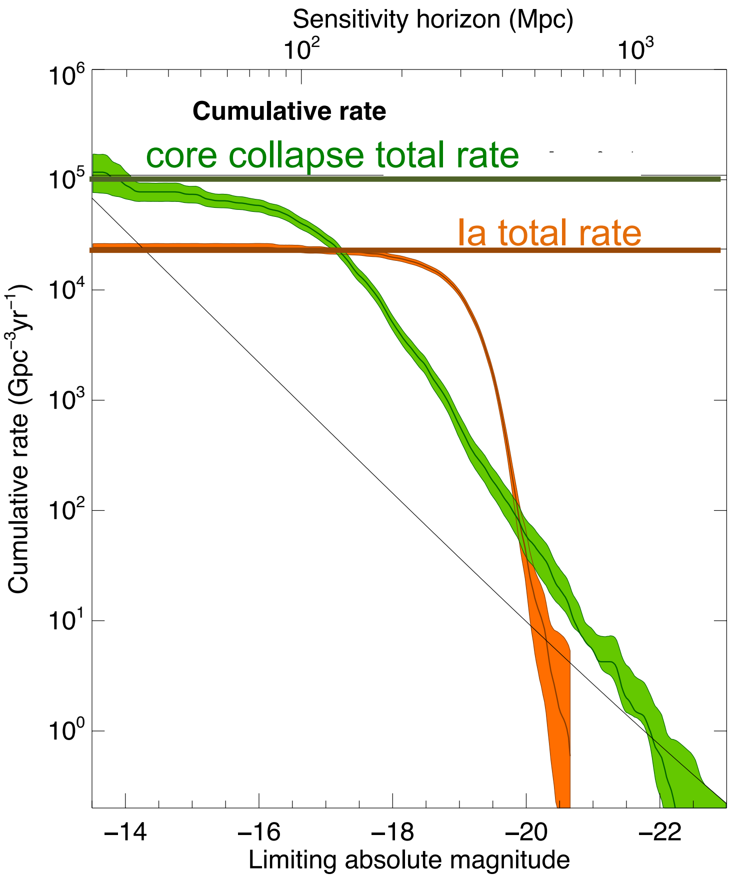
CCSN rate peaks at M ~ -16.5

SN Ia LF is unimodal
(Sharon & Kushnir 2022)

"Normal" SN Ic LF extends to -19
(Sollerman et al. 2022)

Perley+2020

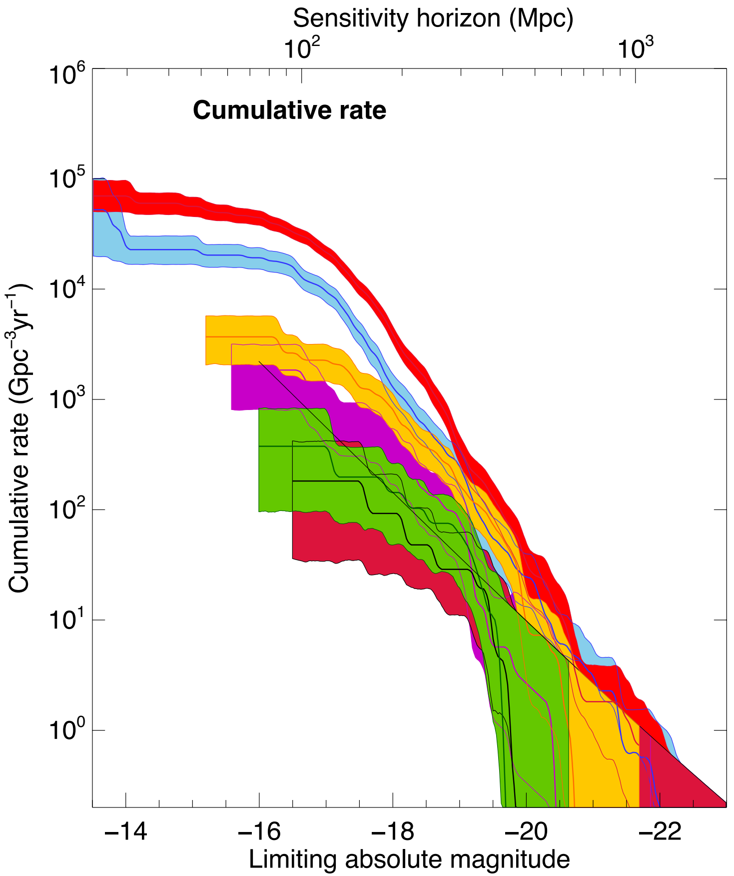
Supernova Rates



CCSN: 7.8×10^4 Gpc^{-3} yr^{-1}

Ia: 2.4×10^4 Gpc^{-3} yr^{-1}

CCSN Rates by Subtype



SN II: ~75% of CCSN rate

SN Ib/c: 22% (±6%) of CCSN rate

IIn: 2-5%

Ic-BL: 1-4% (5-20% of Ib/c)

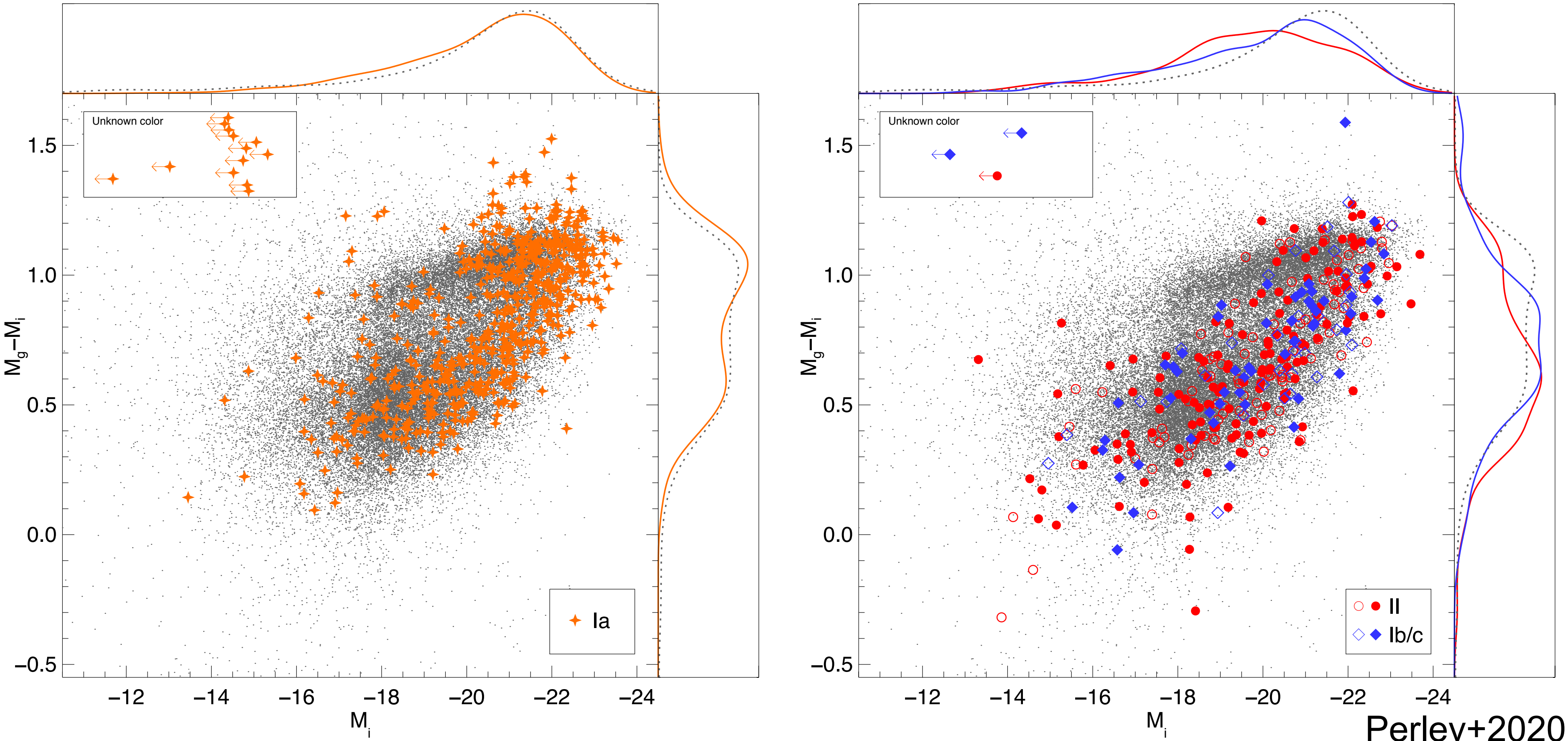
Ibn: 0.05-0.5%

SLSN I: 0.01-0.05%

SLSN II: 0.01-0.03%

Also: Ia-CSM, afterglows, FBOTs, Icn, kilonovae...

Host Galaxies



Perley+2020

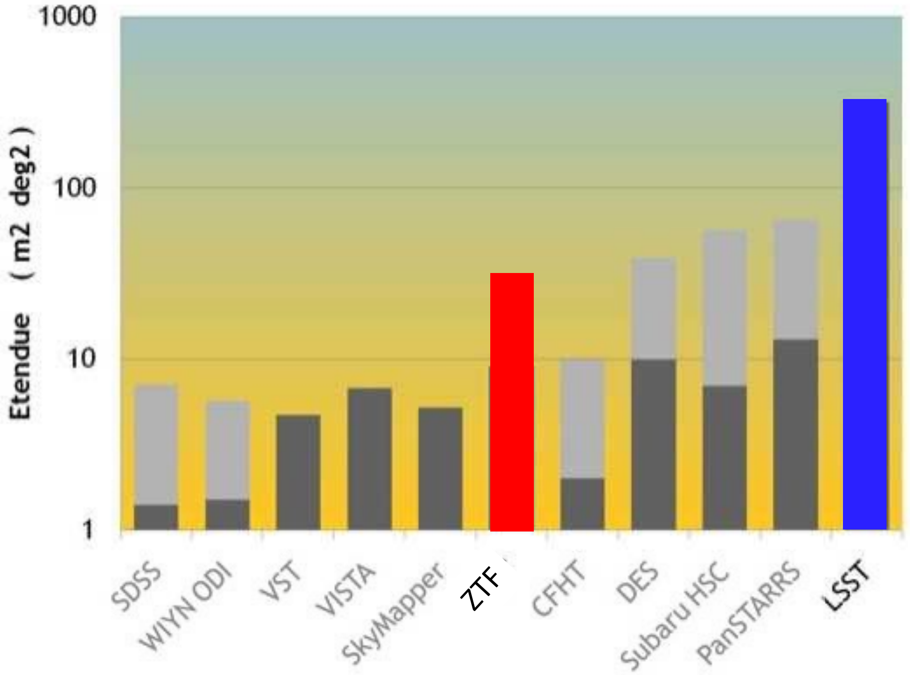
Limitations of 2m-class surveys

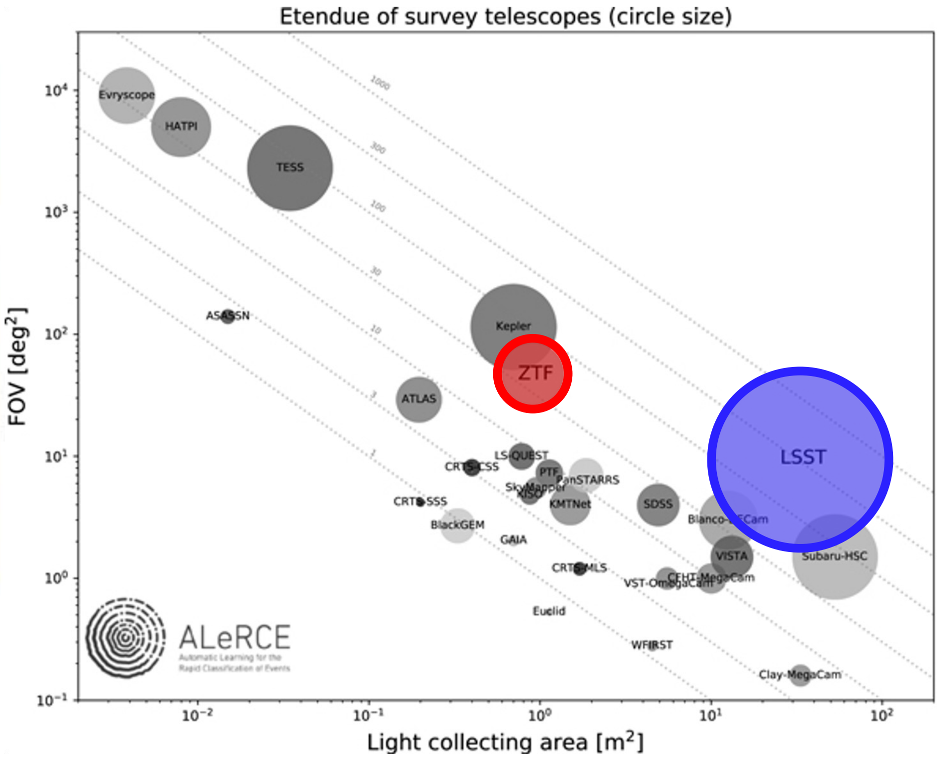
- Can probe local universe only – no possibility to search for cosmic evolution

- Rare classes are rate-starved: difficult to map out the entire population if only ~0-1 events per year (off-axis GRBs, kilonovae, 18cow-like, relativistic TDE... + the unknown)

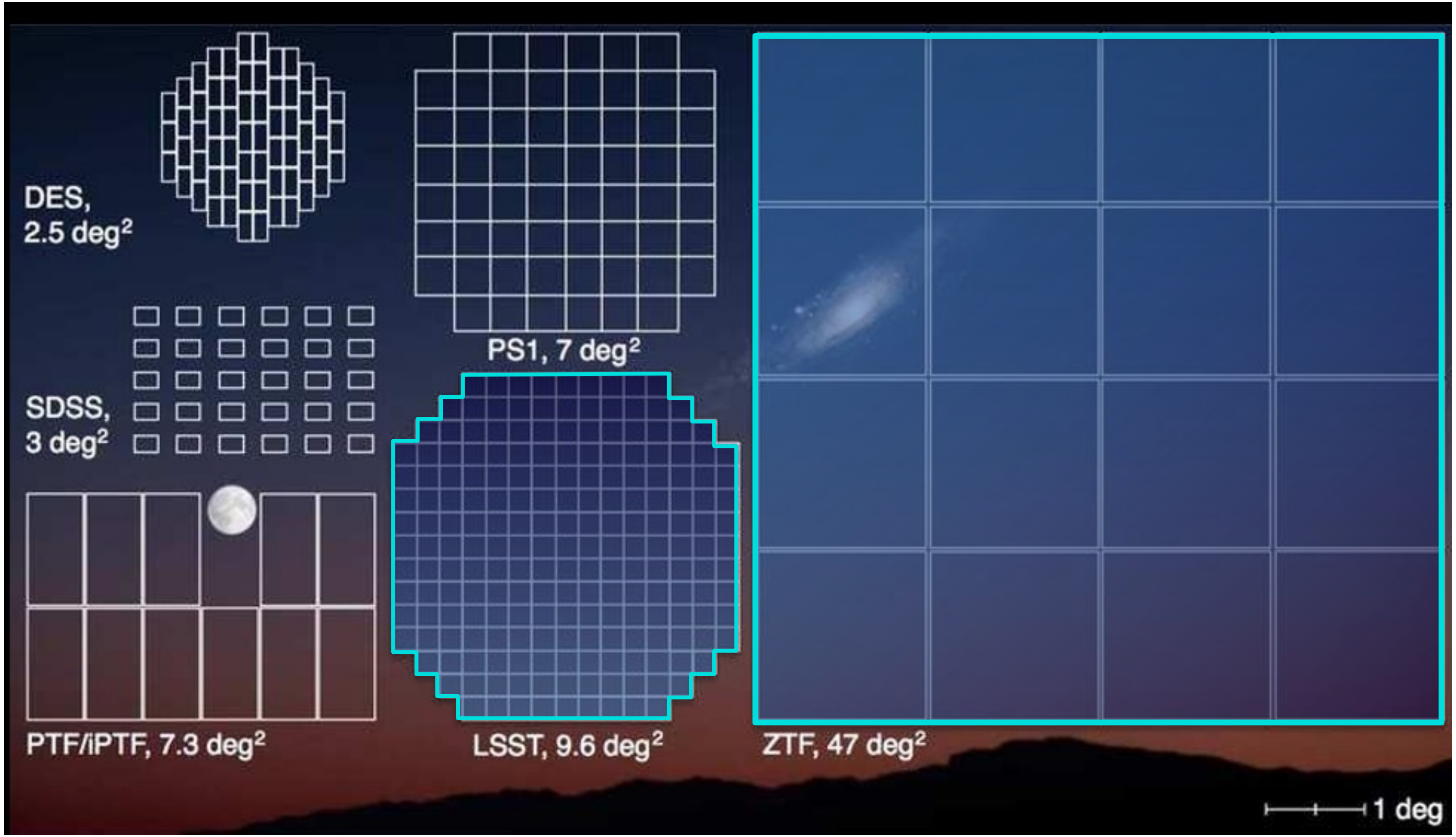
ZTF -> LSST

Increasingly Powerful Surveys

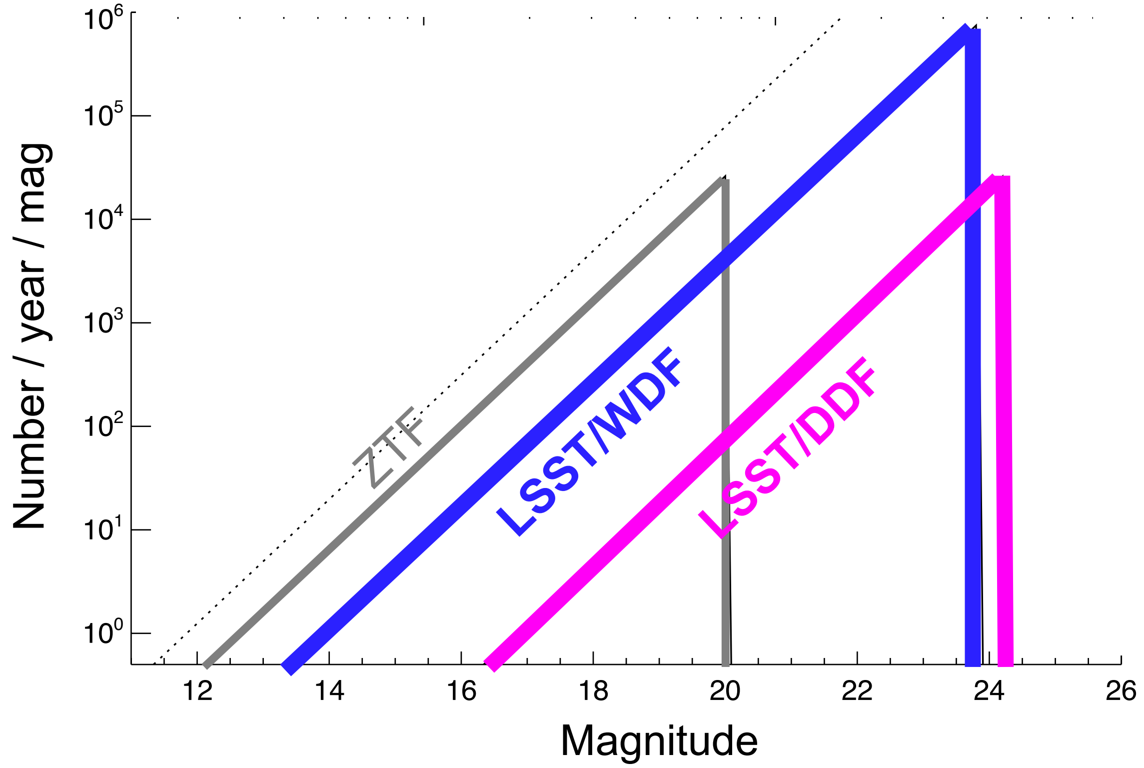




Field of View



Projected number counts



Qualitative differences

- Most transients are spectroscopically inaccessible
  → photometric classification essential – but these will be effective only on well-established types or types with very extreme behavior
  → follow-up will also be very challenging

- Cadence will be much slower, especially revisits in same filter
  → Fast transients (Cow, Icn, Ibn, on-axis AG difficult to study)
  → Slow transients (SLSNe, IIn) much less affected

- Most transients will be at cosmological redshift
  → photometric redshifts (SN or host) viable

- Bright transients are detectable for a very long time
  → Powerful constraints on precursors, radioactive tails, and progenitors

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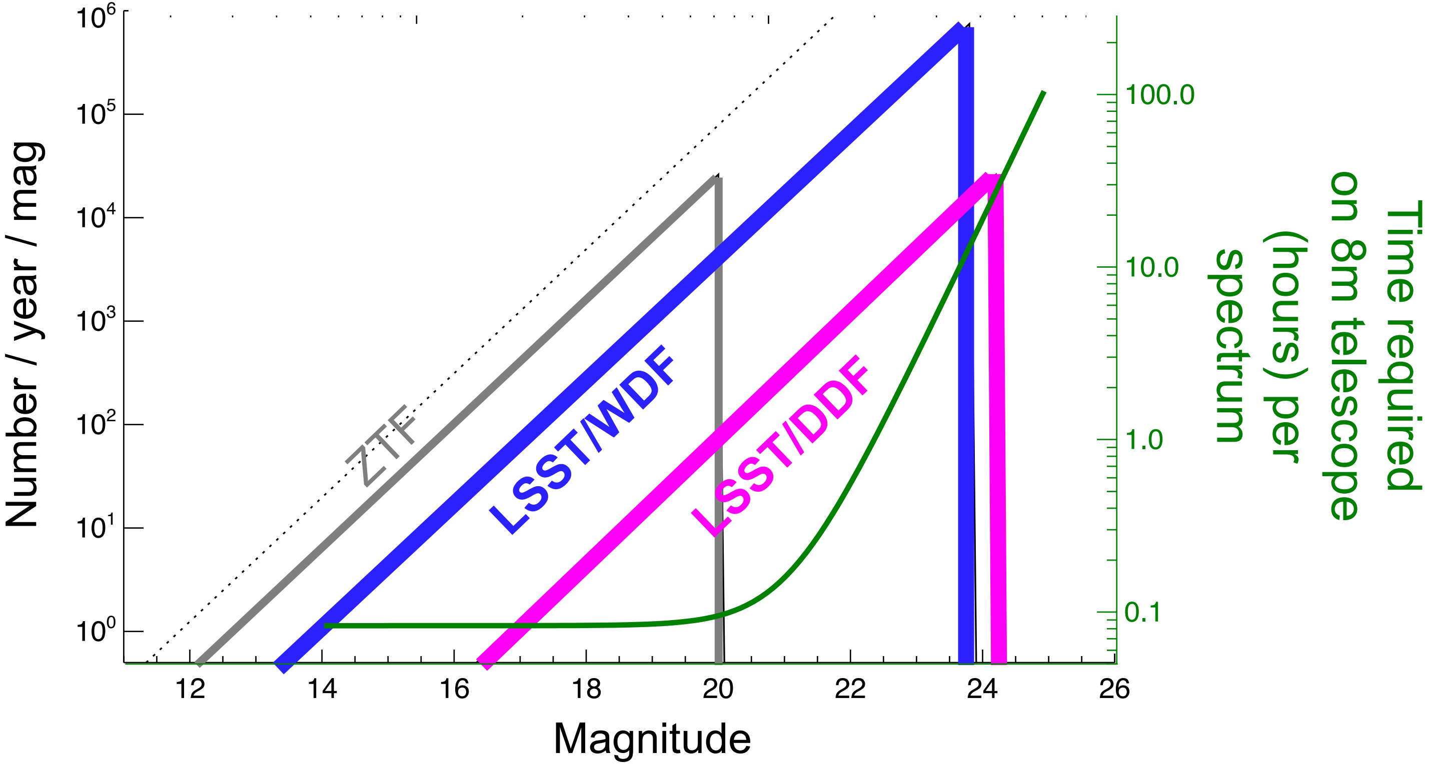
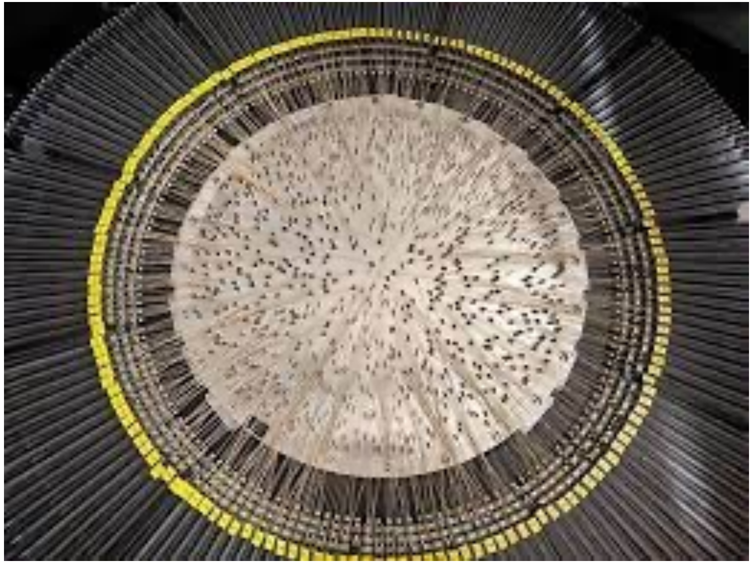
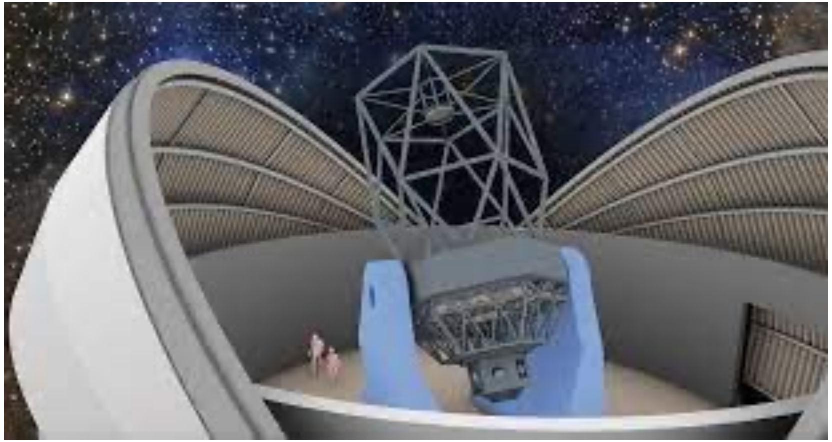


New Telescopes, Multiplexing





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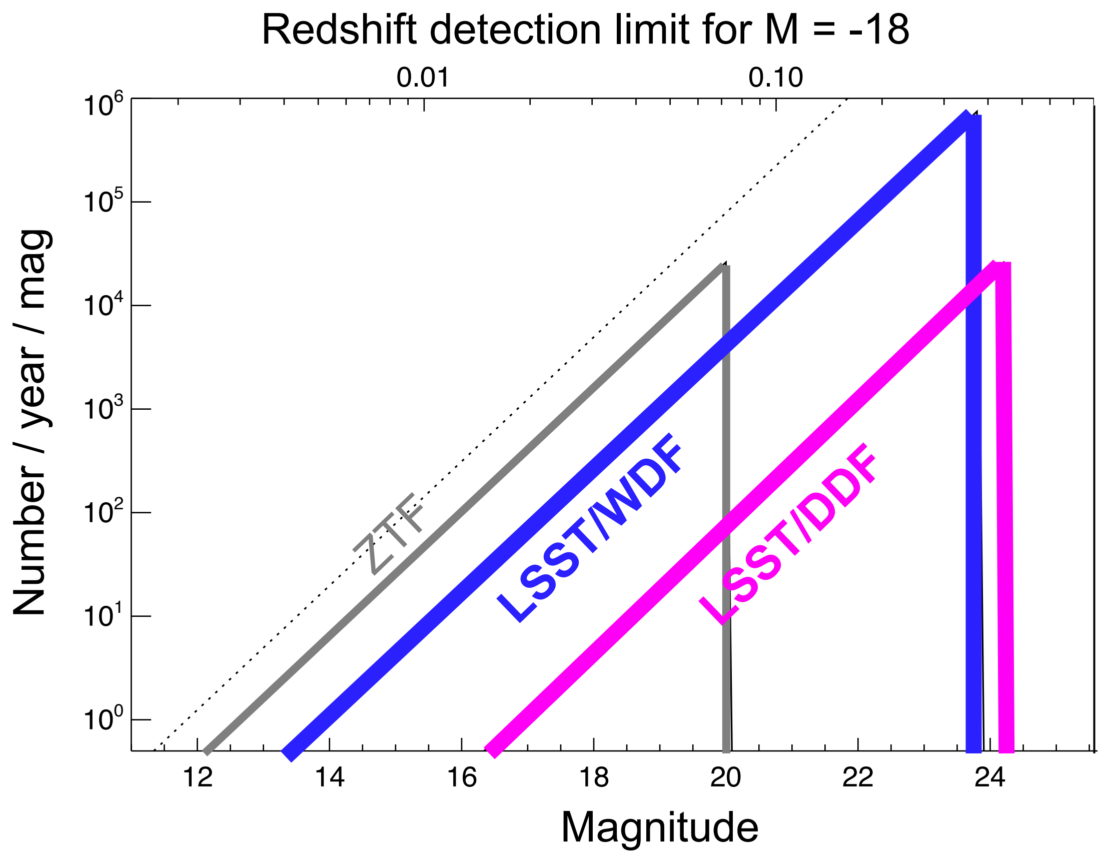

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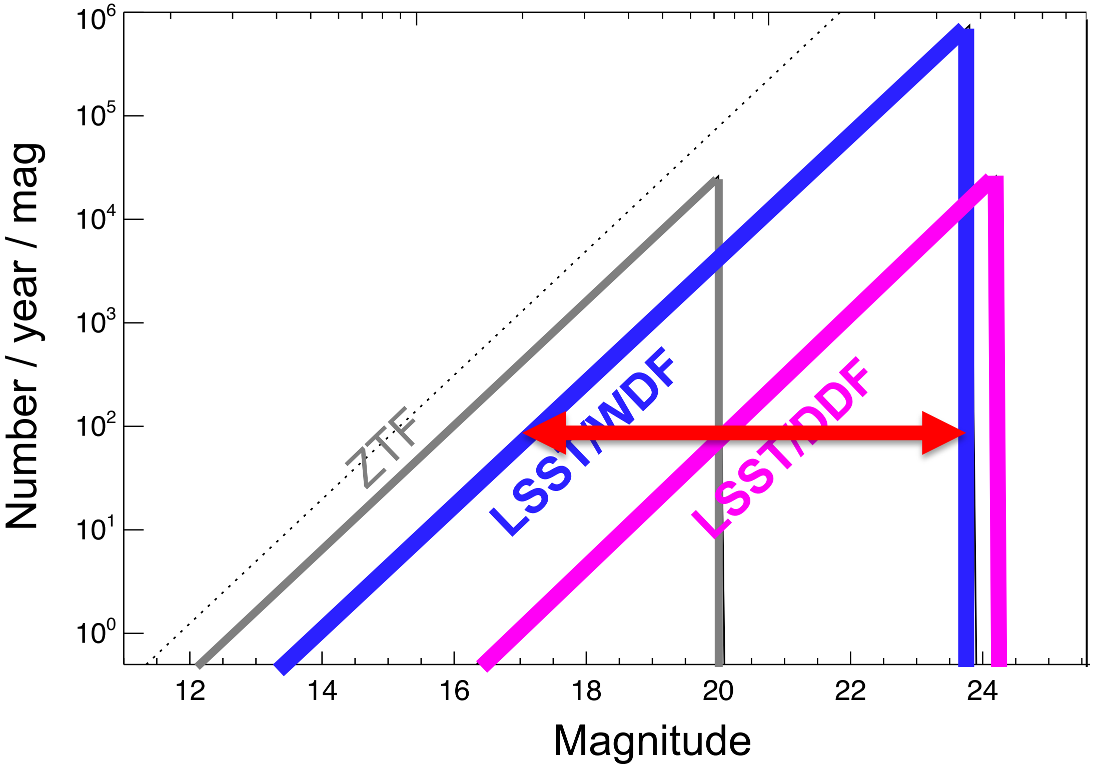

LSST Complements Wide/Bright Surveys

- Rare transients can be found in much larger numbers (10x)... But will inevitably be poorly characterized on an individual basis.

- Bright end surveys (which allow follow-up and late-time spectroscopy, X-ray, radio, etc.) are essential to fill in the physics underlying LSST's demography

LSST Complements Wide/Bright Surveys

We still need prize examples to understand the population they were drawn from!

Conclusions

- Follow-up is important
- Cadence is important
- Photo-z's are critical
- We still need bright-end surveys