Trinity College Dublin
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Lancaster University

The diversity in the thermonuclear SN population as observed from ZTF

April 3rd, 2025

Georgios Dimitriadis

An Extraordinary Journey Into The Transient Sky
A conference in honour of Enrico Cappellaro, Massimo Della Valle, Laura Greggio and Massimo Turatto
Palazzo della Salute, Via San Francesco 90, Padova, Italy

Progenitor/explosion scenarios

Theorist

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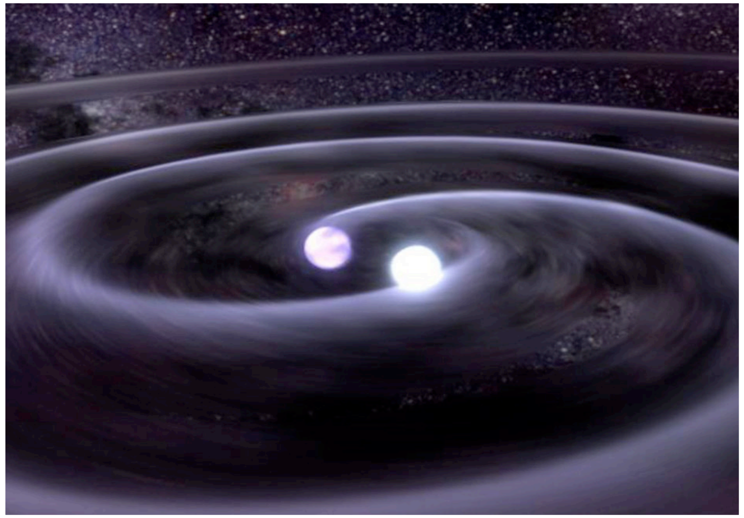

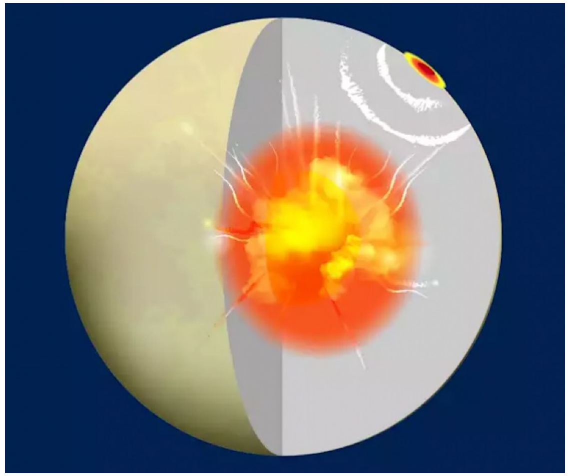

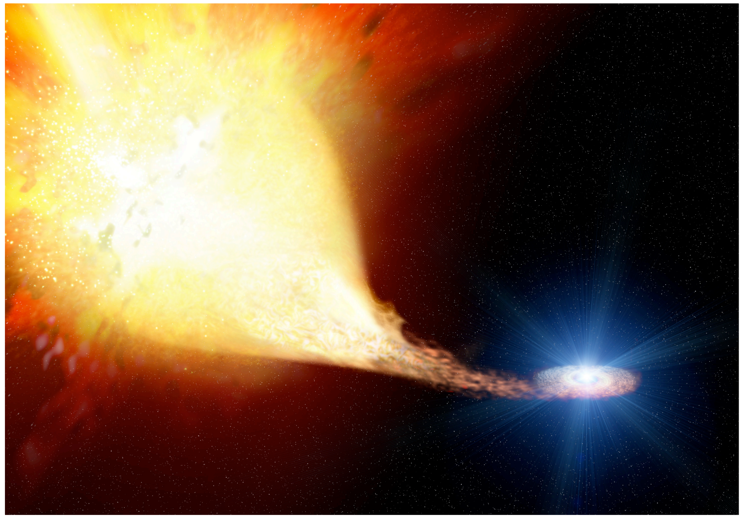

Double Degenerate (DD) Scenario:

Two CO-WDs lose angular momentum to gravitational waves and merge (violently?) to ignite carbon fusion

Double Detonation Scenario:

CO-WD accretes helium from a companion (He star or He WD), a first detonation on the helium layer produces shock-waves, compressing the core and initiating the second detonation that unbinds the WD

Single Degenerate (SD) Scenario:

CO-WD accretes hydrogen from MS or RG binary companion to approach Chandrasekhar Mass (M_{Ch})

+ variations
Core-degenerate, D6, WD collisions etch…

Thermonuclear Supernovae Family

Observer

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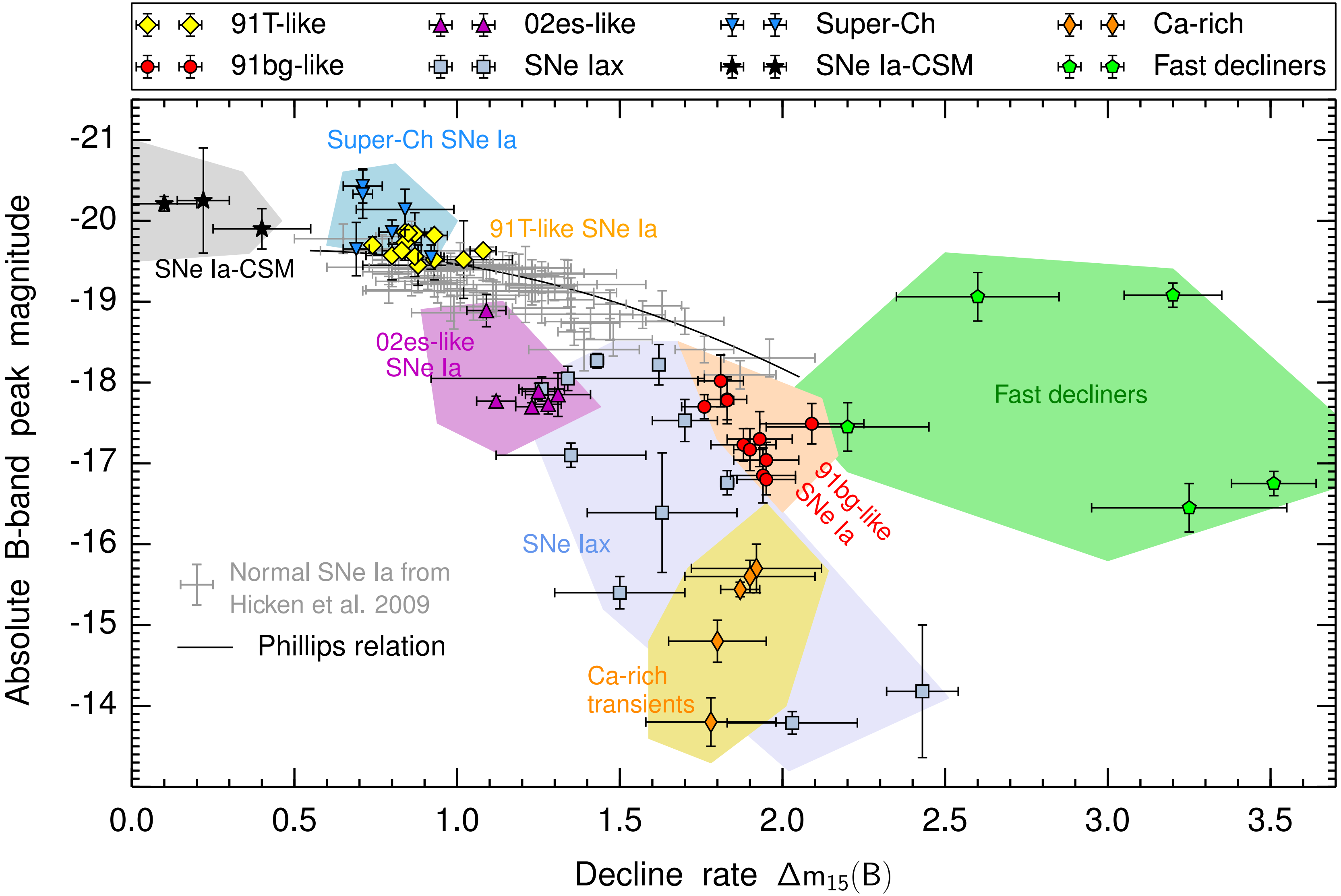
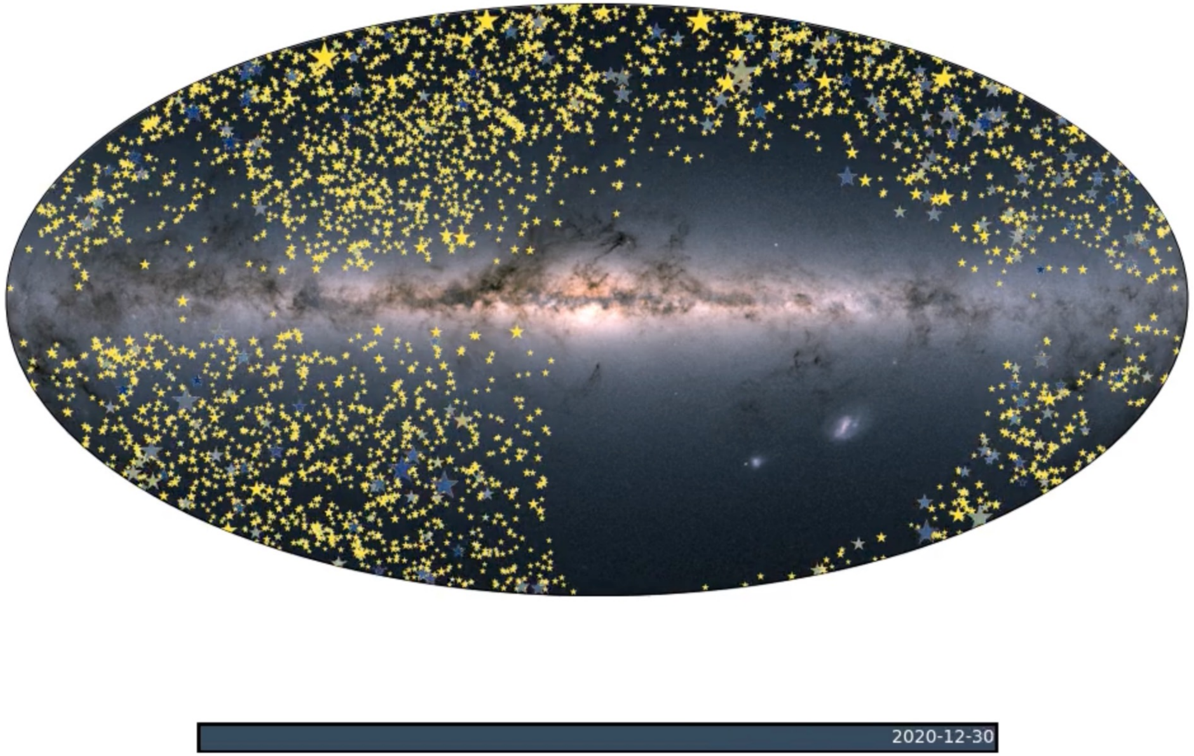


Liu+ 2023, adapted from Taubenberger 2017

Zwicky Transient Facility

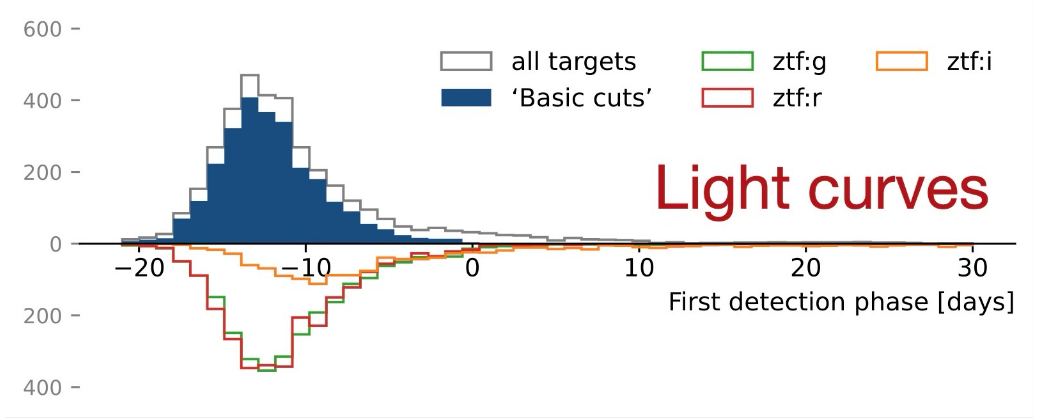


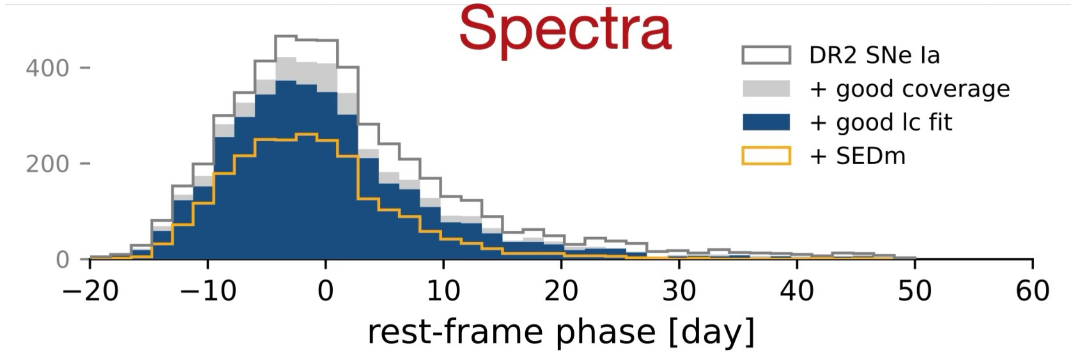
- Initiated in March 2018
- Extremely wide field-of-view (47 square degrees)
- Observations in 3 filters (g, r and i)
- High cadence (2, 1 and 5 days)
- Deep limits (20.5, 20.4 and 20.0 mags)
- Spectroscopically complete for normal SNe Ia at z~0.06

ZTF SN Ia DR2

Grab the data!!!

- 3,628 SNe Ia of all flavours, with each one having at least one spectrum (5,138 total spectra)
- 2,667 SNe Ia pass standard cosmology light curve quality cuts
- Spectroscopically complete (for normal SNe Ia) at z 0.06
- Spectroscopic follow-up within the collaboration + publicly available resources
- Photometry, spectra, classifications, redshifts, light curve fit parameters, spectral indicators, host galaxy parameters publicly available

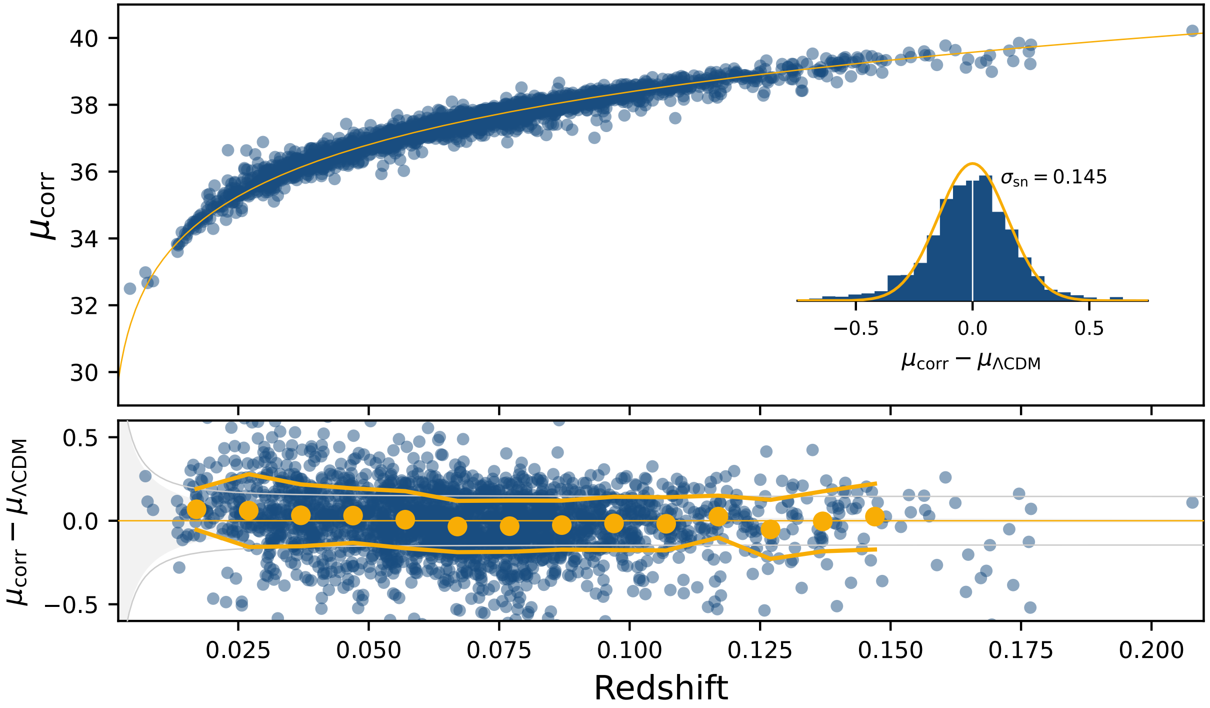


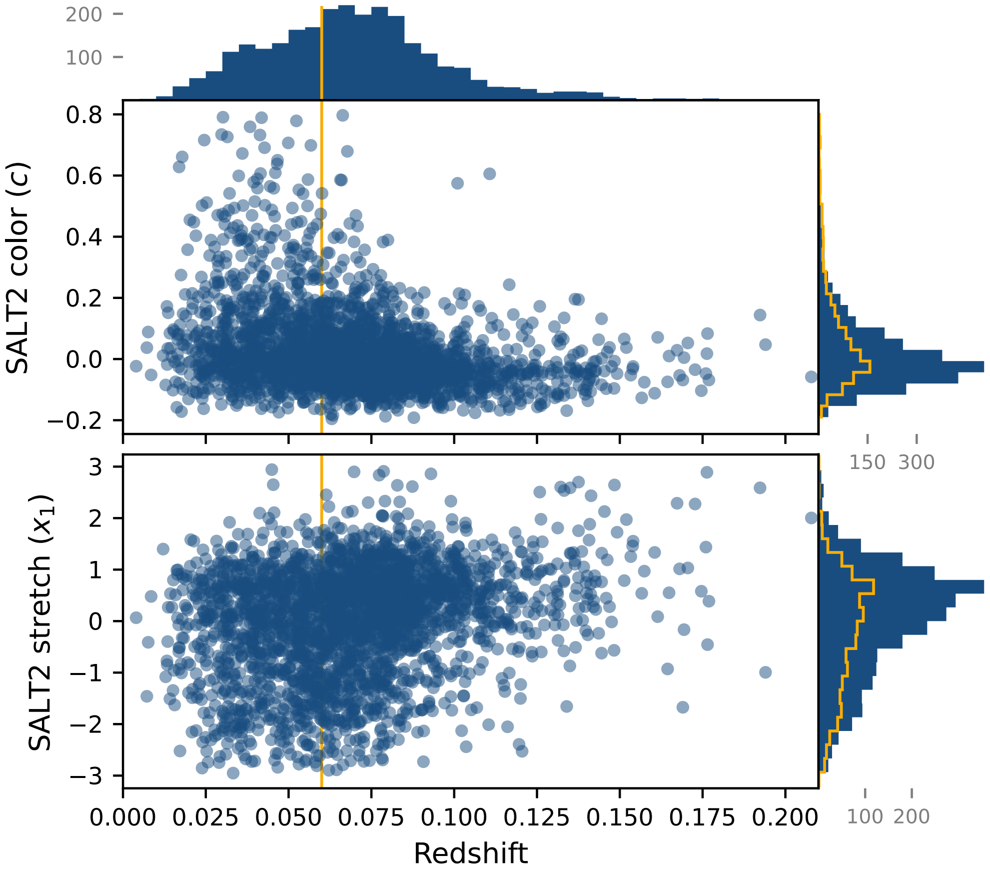


ZTF SN Ia DR2

ZTF SN Ia DR2: Overview

Rigault, M.[1,⋆], Smith, M.[1,2,⋆⋆], Goobar, A.[3], Maguire, K.[4], Dimitriadis, G.[4], Johansson, J.[3], Nordin, J.[5], Burgaz, U.[4], Dhawan, S.[6], Sollerman, J.[7], Regnault, N.[8], Kowalski, M[9,5], Nugent, P.[10,11], Andreoni, I.[12,13,14], Amenouche, M.[15], Aubert, M.[16], Barjou-Delayre, C.[16], Bautista, J.[17], Bellm, E.[18], Betoule, M.[8], Bloom, J. S.[11,10], Carreres, B.[17,19], Chen. T. X.[20], Copin, Y.[1], Deckers, M.[4], de Jaeger, T.[8], Feinstein, F.[17], Fouchez, D.[17], Fremling, C.[26], Galbany, L.[22,23] Ginolin, M.[1], Graham, M.[21], Groom, S. L.[20], Harvey, L.[4], Kasliwal, M. M.[21], Kenworthy, W. D.[3], Kim, Y.-L.[2], Kuhn, D.[8], Kulkarni, S. R.[21], Lacroix, L.[8,3], Laher, R. R.[20], Masci, F. J.[20], Müller-Bravo, T. E.,[22,23], Miller, A.[24,25], Osman, M[8], Perley, D.[27], Popovic, B.[1], Purdum, J.[26], Qin, Y-J,[21], Racine, B.[17], Reusch, S[9], Riddle, R.[26], Rosnet, P.[16], Rosselli, D.[17], Ruppin, F.[1], Senzel, R.[4], Rusholme, B.[20], Schweyer, T.[7], Terwel, J. H.[4,27], Townsend, A.[5], Tzanidakis, A.[28], Wold, A.[20], Yan, L.[26]





ZTF SN Ia DR2

Check the papers!!!

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ZTF SN Ia DR2: Environmental dependencies of stretch and luminosity of a volume limited sample of 1,000 Type Ia Supernovae

Ginolin, M.[1,⋆], Rigault, M.[1], Smith, M.[1,2], Copin, Y.[1], Ruppin, F.[1], Dimitriadis, G.[3], Goobar, A.[4],

ZTF SN Ia DR2: Cosmology-independent constraints on Type Ia supernova standardisation from supernova siblings

S. Dhawan,[1] E. Mortsell[2], J. Johansson[2] A. Goobar,[2] M. Rigault,[3], M. Smith[3,4], K. Maguire,[5] J. Nordin,[6]

ZTF SN Ia DR2: Study of Type Ia Supernova lightcurve fits

Rigault, M.[1⋆], Smith, M.[1,2], Regnault, N.[3], Kenworthy, W. D.[4], Maguire, K.[5], Goobar, A.[4], Dimitriadis

ZTF SN Ia DR2: Exploring SN Ia properties in the vicinity of under-dense environments

M. Aubert[1,⋆], P. Rosnet[1], B. Popovic[2], F. Ruppin[2], M. Smith[3], M. Rigault[2], G. Dimitriadis[4], A. Goobar[5]

ZTF SN Ia DR2: The spectral diversity of Type Ia supernovae in a volume-limited sample

U. Burgaz[1], K. Maguire[1], G. Dimitriadis[1], L. Harvey[1], R. Senzel[1], J. Sollerman[2], J. Nordin[3],

ZTF SN Ia DR2: Simulations and volume limited sample

M. Amenouche[1*], M. Smith[2**], P. Rosnet[3***], M. Rigault[4], M. Aubert[3], C. Barjou-Delayre[3], U. Burgaz[5],

ZTF SN Ia DR2: Peculiar velocities' impact on the Hubble diagram

B. Carreres[1,2,⋆], D. Rosselli[1,⋆], J. E. Bautista[1], F. Feinstein[1], D. Fouchez[1], B. Racine[1], C. Ravoux[1,3],

ZTF SN Ia DR2: High-velocity components in the Si II λ6355

L. Harvey,[1] K. Maguire,[1] U. Burgaz,[1] G. Dimitriadis,[1] J. Sollerman,[2] A. Goobar,[3] J. Johansson,[3] J. Nordin,[4] M. Rigault,[5] M. Smith,[5,6] M. Aubert,[7] R. Cartier,[8] P. Chen,[9] M. Deckers,[1] S. Dhawan,[10] L. Galbany,[11,12] M. Ginolin,[5] W. D. Kenworthy,[3] Y.-L. Kim,[6] C. Liu (刘畅),[13,14] A. A. Miller,[13,14] P. Rosnet,[7] R. Senzel,[1] J. H. Terwel,[1,15]

ZTF SN Ia DR2: Impact of the galaxy cluster environment on the stretch distribution of Type Ia supernovae

Ruppin, F.[1,⋆], Rigault, M.[1], Ginolin, M.[1], Dimitriadis, G.[2], Goobar, A.[3], Johansson, J.[3], Maguire, K.[2],

ZTF SN Ia DR2: Colour standardisation of Type Ia Supernovae and its dependence on environment

Ginolin, M.[1,⋆], Rigault, M.[1], Copin, Y.[1], Popovic, B.[1], Dimitriadis, G.[2], Goobar, A.[3], Johansson, J.[3],

ZTF SN Ia DR2: Evidence of Changing Dust Distributions With Redshift Using Type Ia Supernovae

B. Popovic[1,*], M. Rigault[1], M. Smith[1,2], M. Ginolin[1], A. Goobar[4], W. D. Kenworthy[4], C. Ganot[1], F. Ruppin[1],

ZTF SN Ia DR2: The secondary maximum in Type Ia supernovae

M. Deckers[1,⋆], K. Maguire[1], L. Shingles[2], G. Dimitriadis[1], M. Rigault[3], M. Smith[4], A. Goobar[5], J. Nordin[6], J.

ZTF SN Ia DR2: Properties of the low-mass host galaxies of Type Ia supernovae in a volume-limited sample

U. Burgaz[1,⋆], K. Maguire[1], G. Dimitriadis, M. Smith, J. Sollerman, L. Galbany[4,5], M. Rigault[6],

ZTF SN Ia DR2: The diversity and relative rates of the thermonuclear SN population

G. Dimitriadis[1,2⋆], U. Burgaz[1], M. Deckers[1], K. Maguire[1], J. Johansson[3], M. Smith[4,2], M. Rigault[4],

ZTF SN Ia DR2: An environmental study of Type Ia supernovae using host galaxy image decomposition

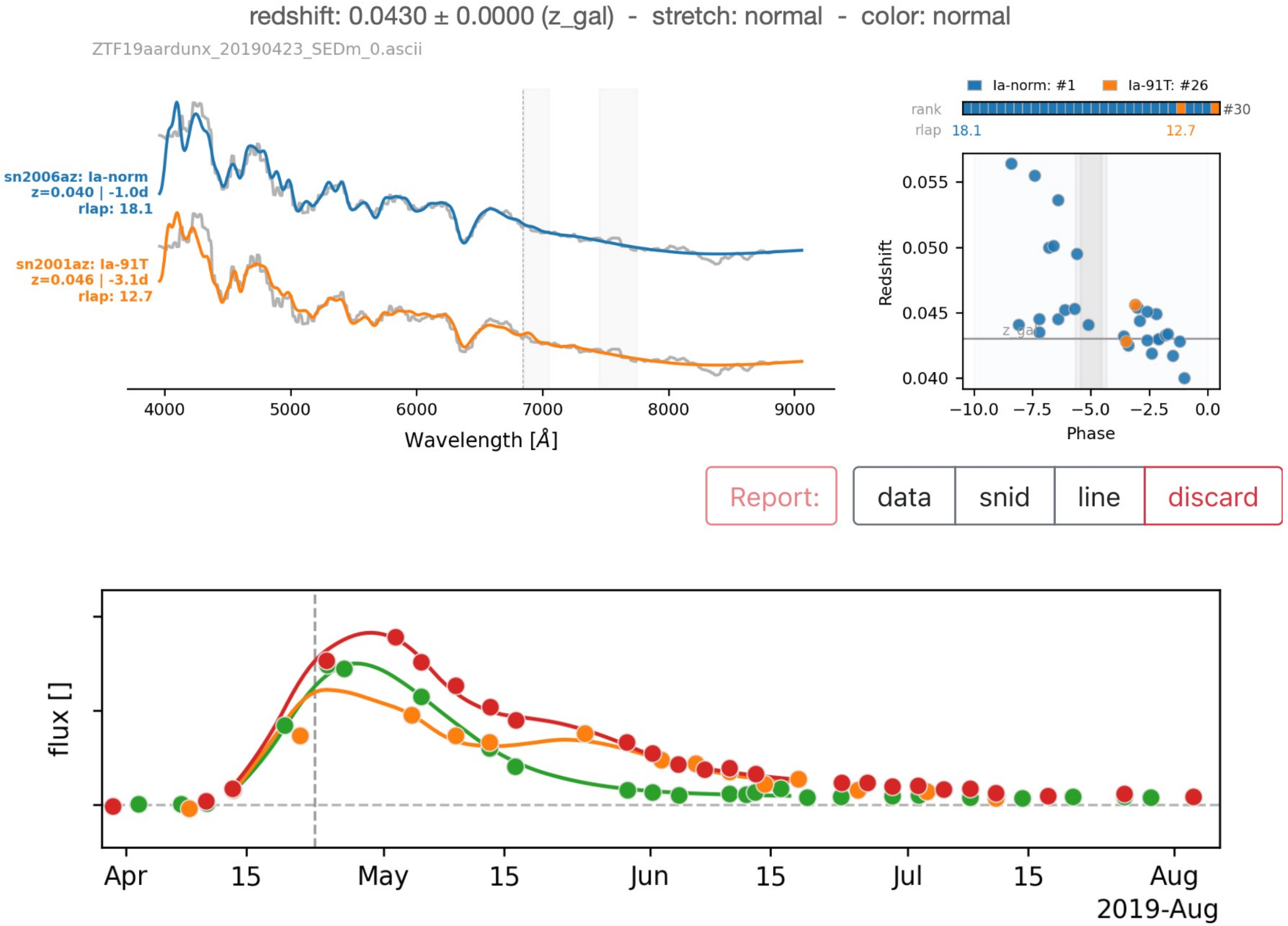
R. Senzel[1,2,⋆], K. Maguire[1], U. Burgaz[1], G. Dimitriadis[1], M. Rigault[3], A. Goobar[4], J. Johansson[4], M. Smith[5], M. Deckers[1], L. Galbany[6,7], M. Ginolin[3], L. Harvey[1], Y.-L. Kim[5], T. E. Muller-Bravo[6,7],

ZTF SN Ia DR2: Searching for late-time interaction signatures in Type Ia supernovae from the Zwicky Transient Facility

Jacco H. Terwel[1,2,⋆], Kate Maguire[1], Georgios Dimitriadis[1], Mat Smith[3,4], Simeon Reusch[5,6], Leander Lacroix[7,8], Lluís Galbany[9,10], Umut Burgaz[1], Luke Harvey[1], Steve Schulze[8], Mickael Rigault[4], Steven L. Groom[11], David Hale[12], Mansi M. Kasliwal[13], Young-Lo Kim[3], Josiah Purdum[12],

+more to come

ZTF SN Ia DR2 – How to classify 3,628 SNe Ia



- >14,000 sub-classifications by 32 users
- ~ 3.5 classifications per object (at least 2)
- "arbiter" > "expert" > "auto"
- 24% - 44% - 32%
- Mostly non-normal SNe Ia needed an "arbiter"
- Dedicated effort for all SNe with z < 0.06
- ~ 10% of SNe with z < 0.06 are not subtyped (but are SNe Ia)
- We learned a lot on (semi-) automatic classification of transients, we will apply it to future large-scale surveys

ZTF SN Ia DR2 – How to classify 3,628 SNe Ia

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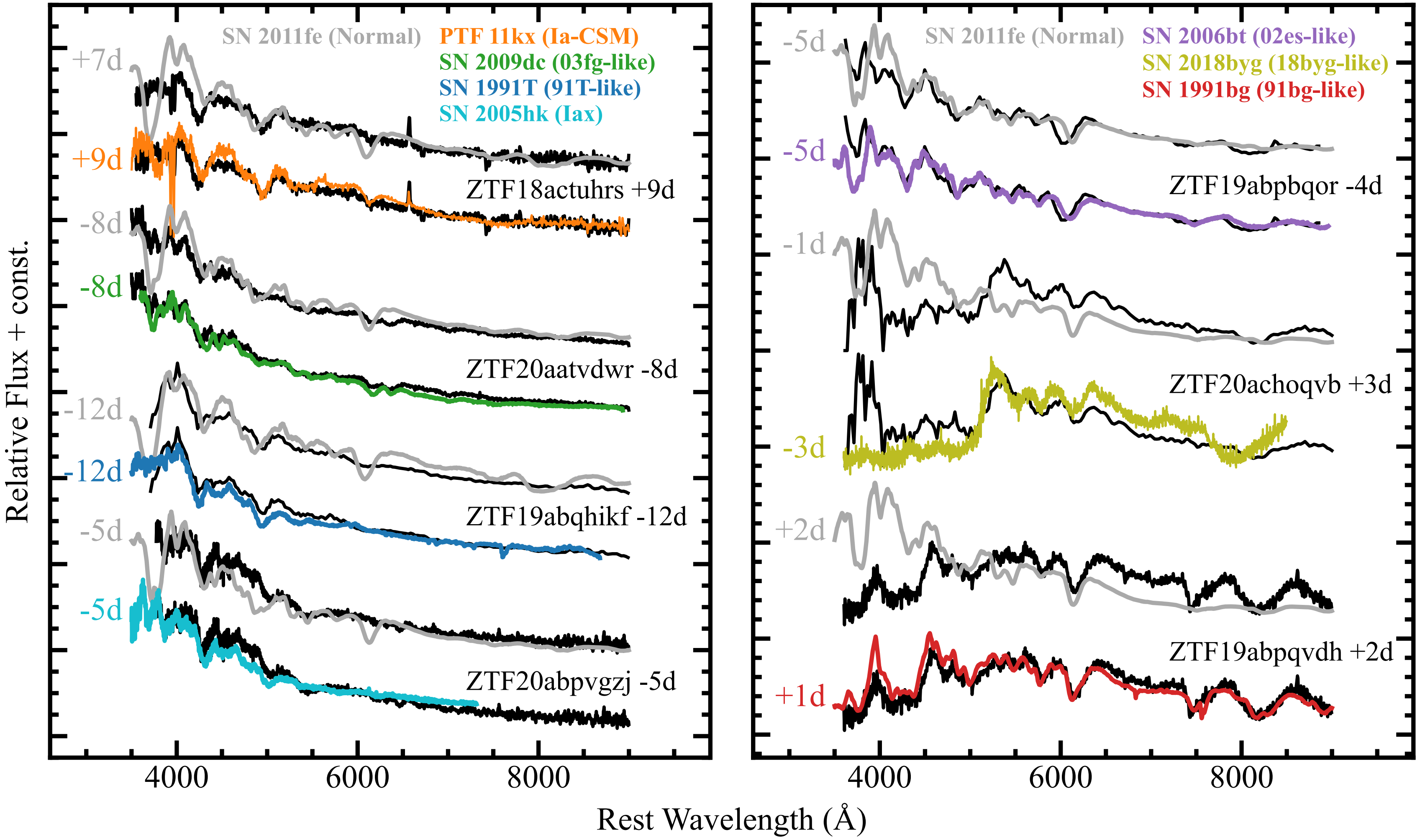
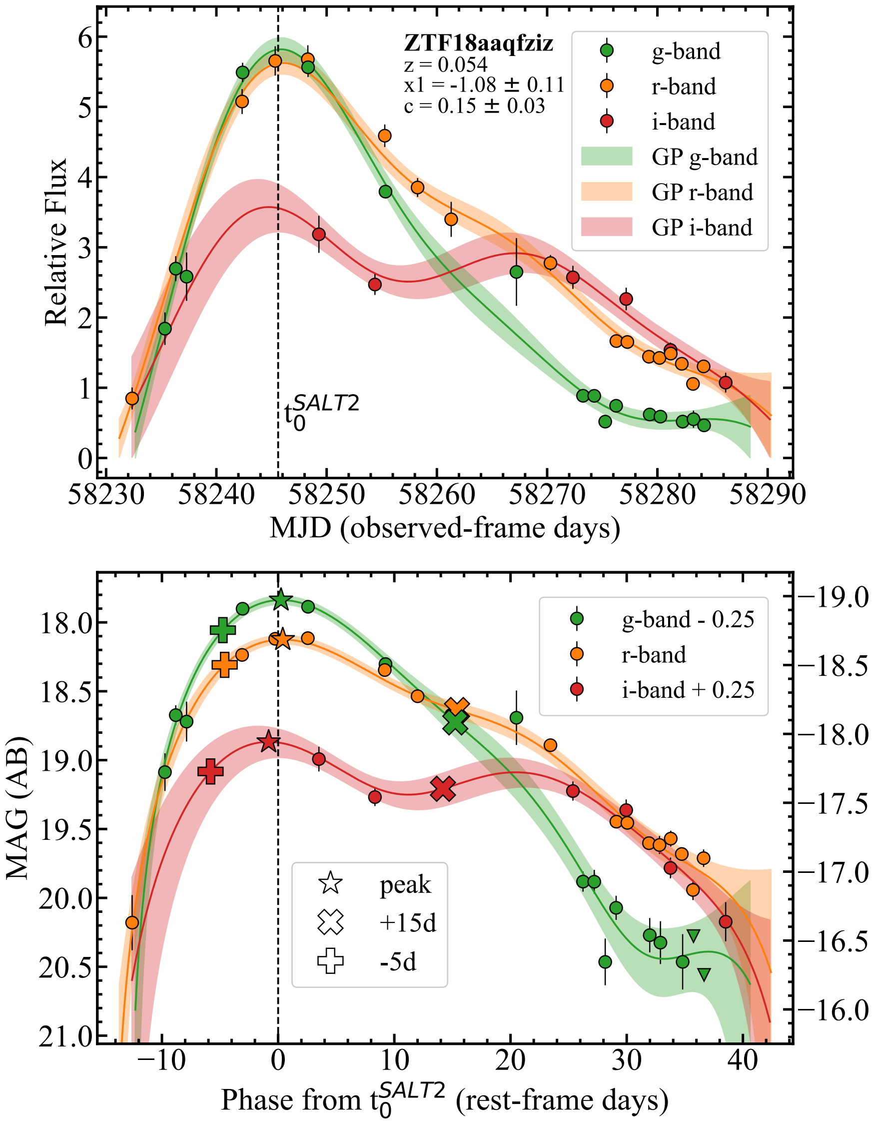
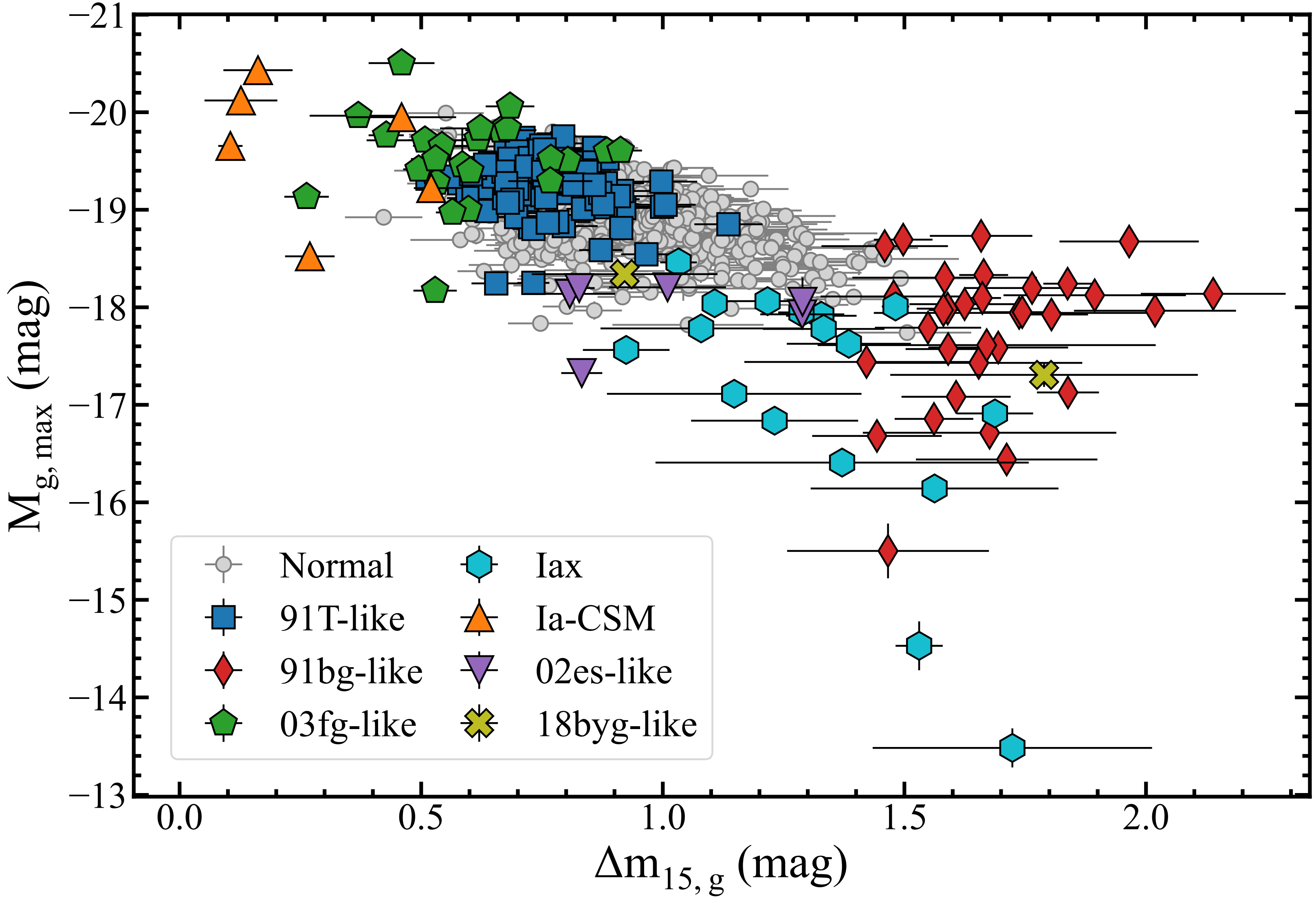


ZTF SN Ia DR2 – SN parameters

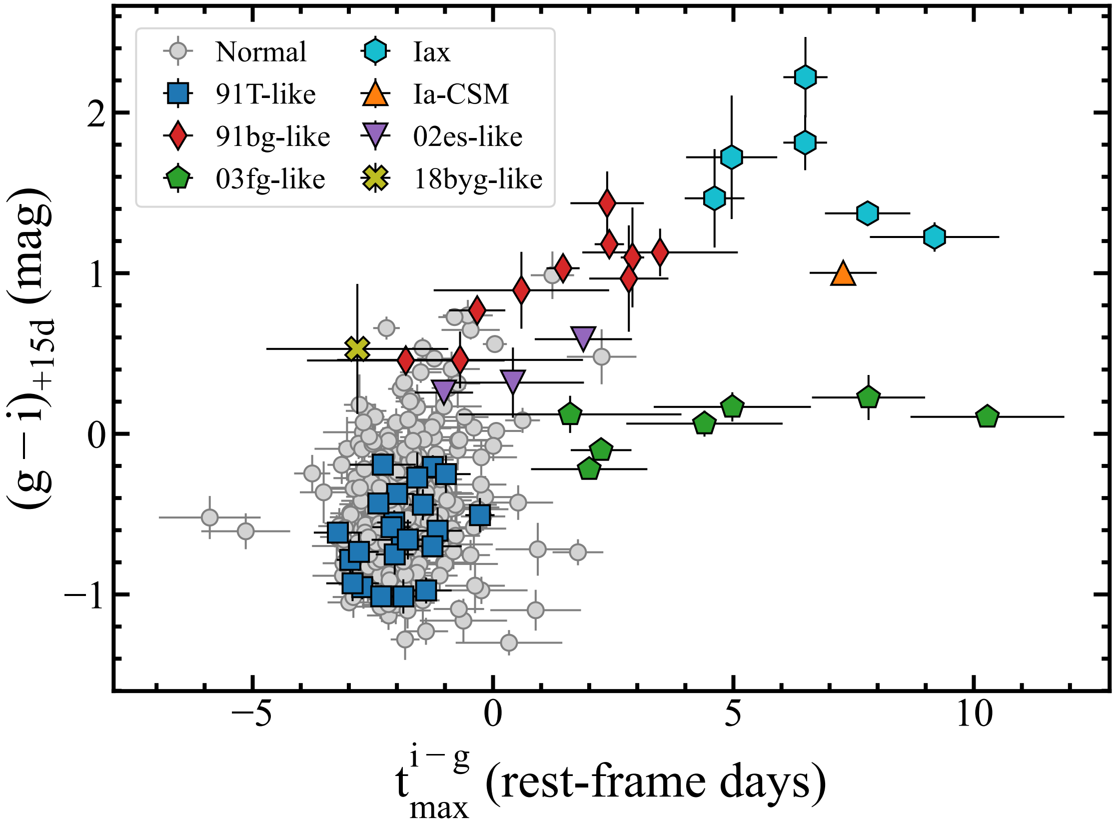
- Given a (sub-)classification and a redshift:
  - K-corrections
    - All SNe k-corrected with SALT2.4, and:
      - Normal, 91T-like → SALT2.4
      - 91bg-like, 02es-like → PLAsTiCC 91bg-like template
      - SNe Iax → PLAsTiCC SN Iax template
      - 03fg-like → SN 2009dc spectral series
      - 18byg-like → SN 2018byg spectral series
      - SNe Ia-CSM → No k-correction
  - Gaussian Processes fits
    - Both in time and in wavelength space
    - Estimation of various light curve parameters
      - Time of peak
      - Difference in times of peak per filter
      - Peak mag, colors…
      - $\Delta m_{15}{}^{g,r,I}$, colors at +15d
      - -5d …
- All parameters estimated for no-kcor, salt-kcor and template k-cor, and publicly available
- Additional metadata (x1, c, host galaxy mass, color, dDLR etch…)

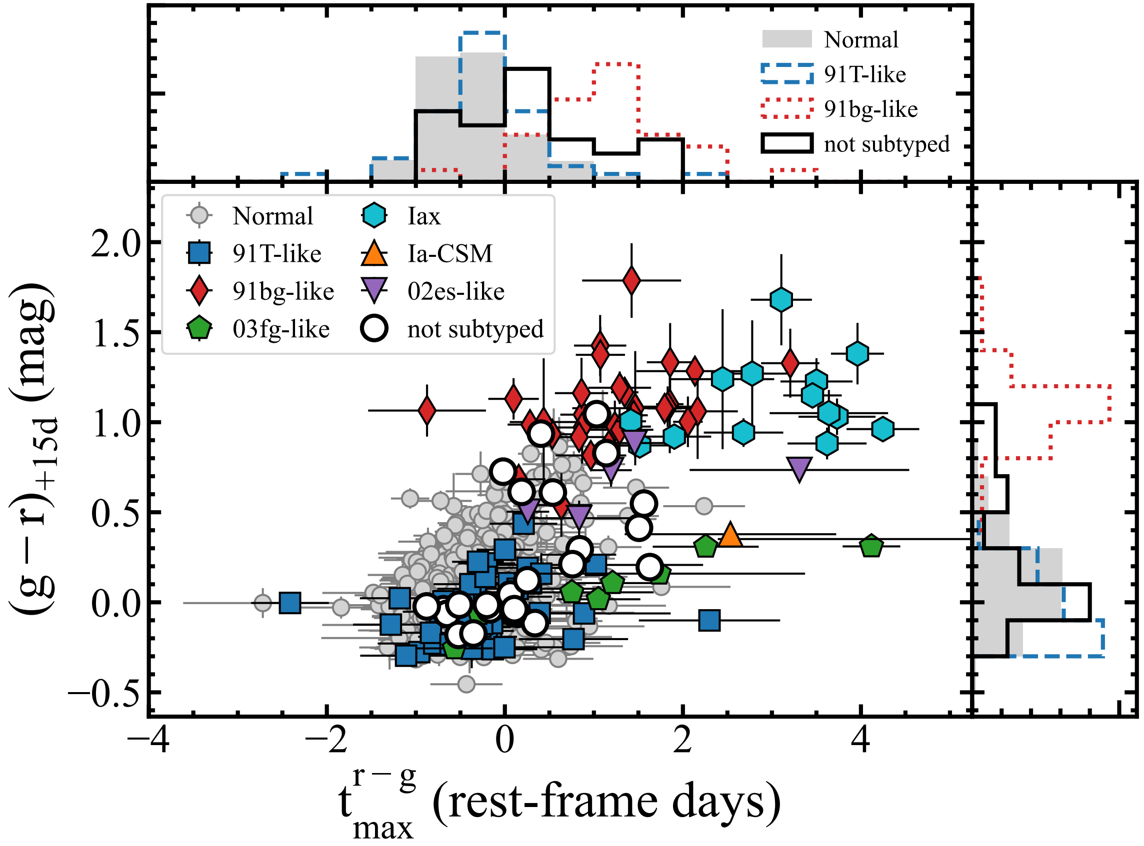


ZTF SN Ia DR2 – Photometric diversity

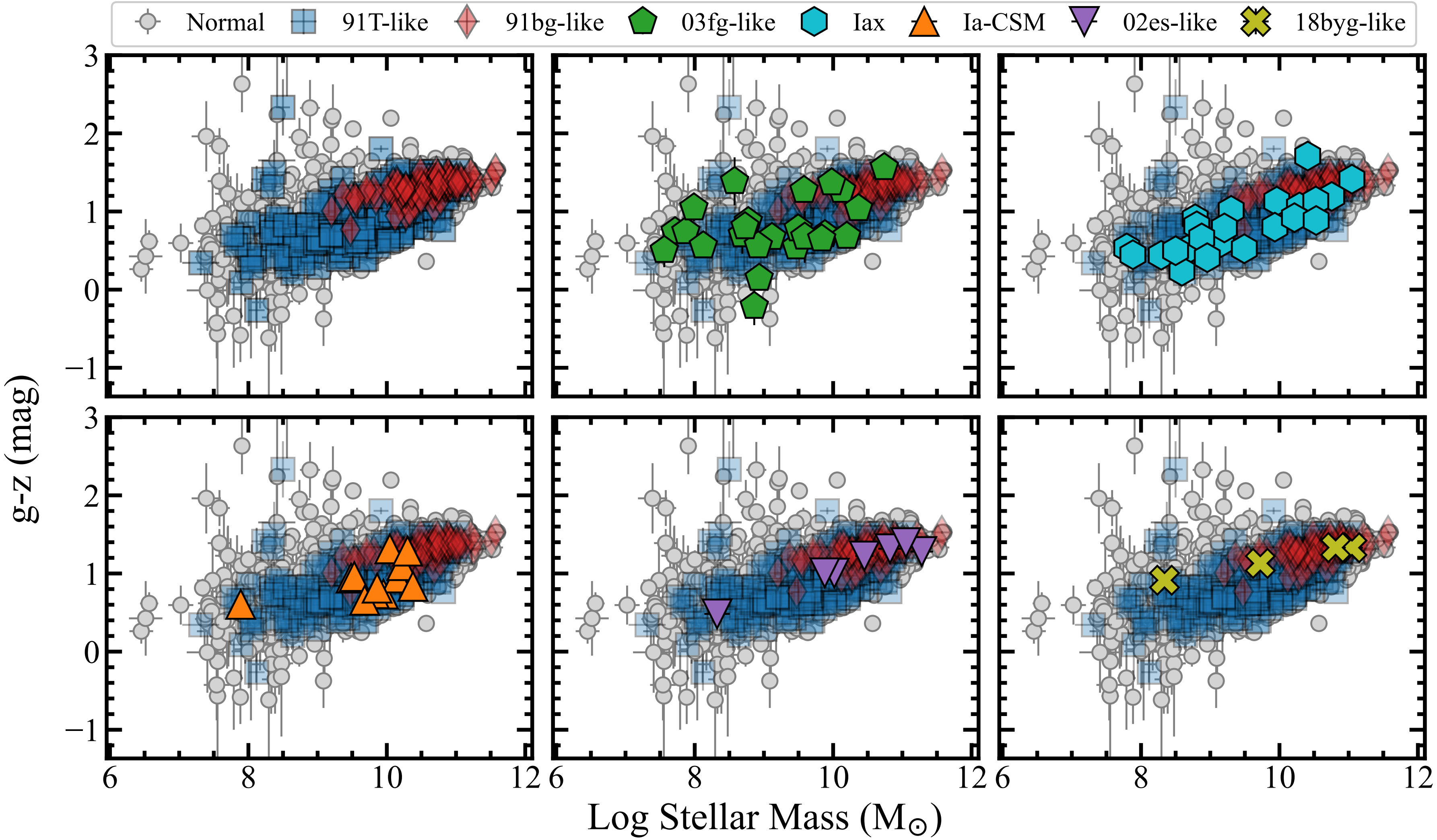


ZTF SN Ia DR2 – Photometric subtyping

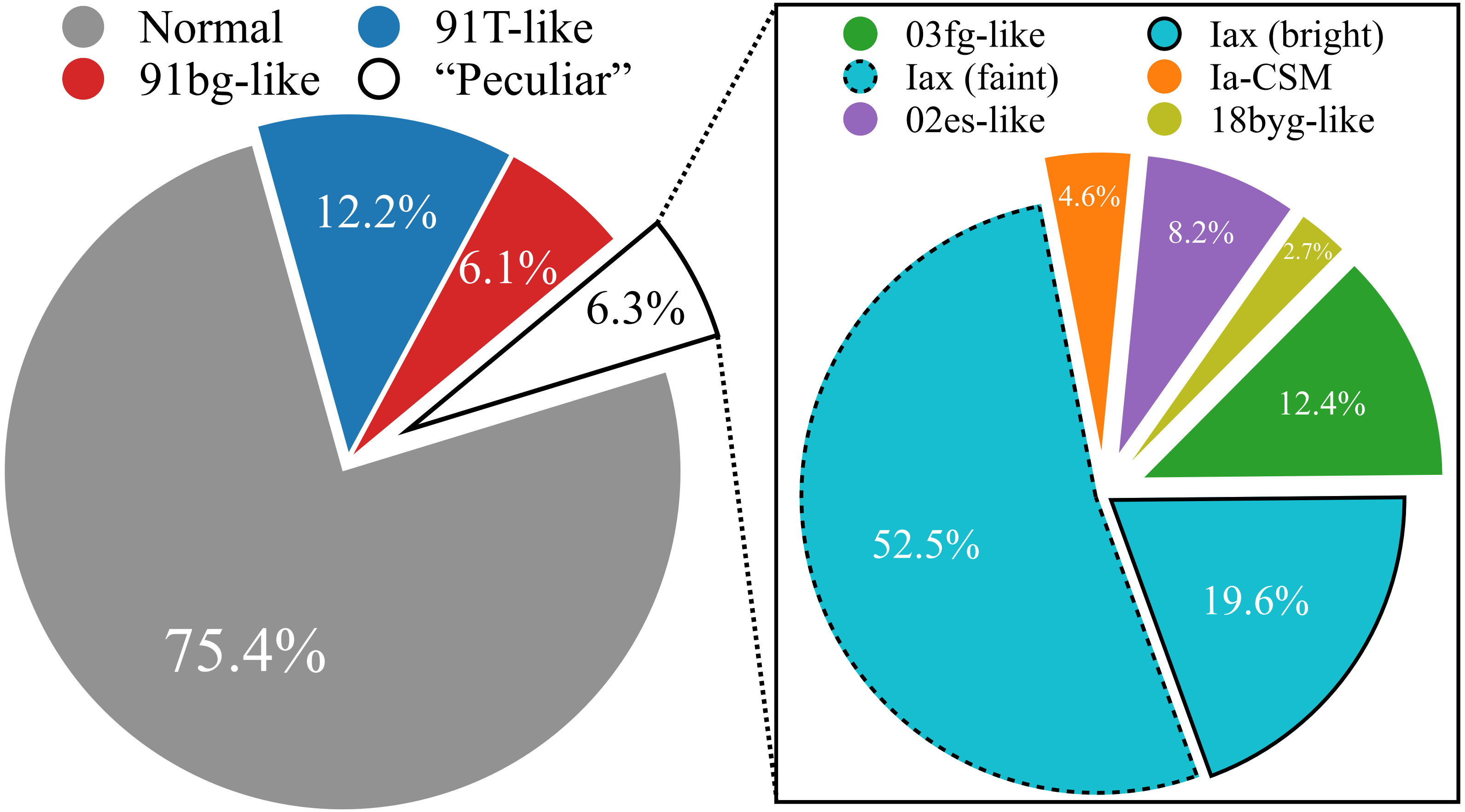




ZTF SN Ia DR2 – Host galaxies



ZTF SN Ia DR2 – Observed fractions



ZTF SN Ia DR2 – Conclusions

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- Peculiar sub-classes of the ZTF SNe Ia sample (generally) follow the previously established trends:
  - SNe Ia-CSM and 03fg-like are bright and blue
  - SNe Iax and 91bg-like are faint and fast
  - 02es-like with normal timescales but fainter
  - 18byg-like are in small numbers, but are probably fainter than normal SNe Ia
  - Exception: 91T-like have photometric properties identical to the brighter end of the normal SNe Ia population
- A method for identifying peculiar events in non-spectroscopic samples is measuring the differences of the timing of maximum of a blue and a red photometric band and the colour at +15 days from peak brightness
  - Exception: 91T-like SNe Ia
- The properties of the host galaxies of the peculiar sub-classes (generally) follow the established trends seen in the literature
  - Exception: 91T-like SNe Ia do not prefer low mass and star-forming galaxies
- The differences of the normal and the 91T-like SNe Ia are purely spectroscopic