QUB MSc Astro Analytathon Summer 2021

Classification of astronomical lightcurves

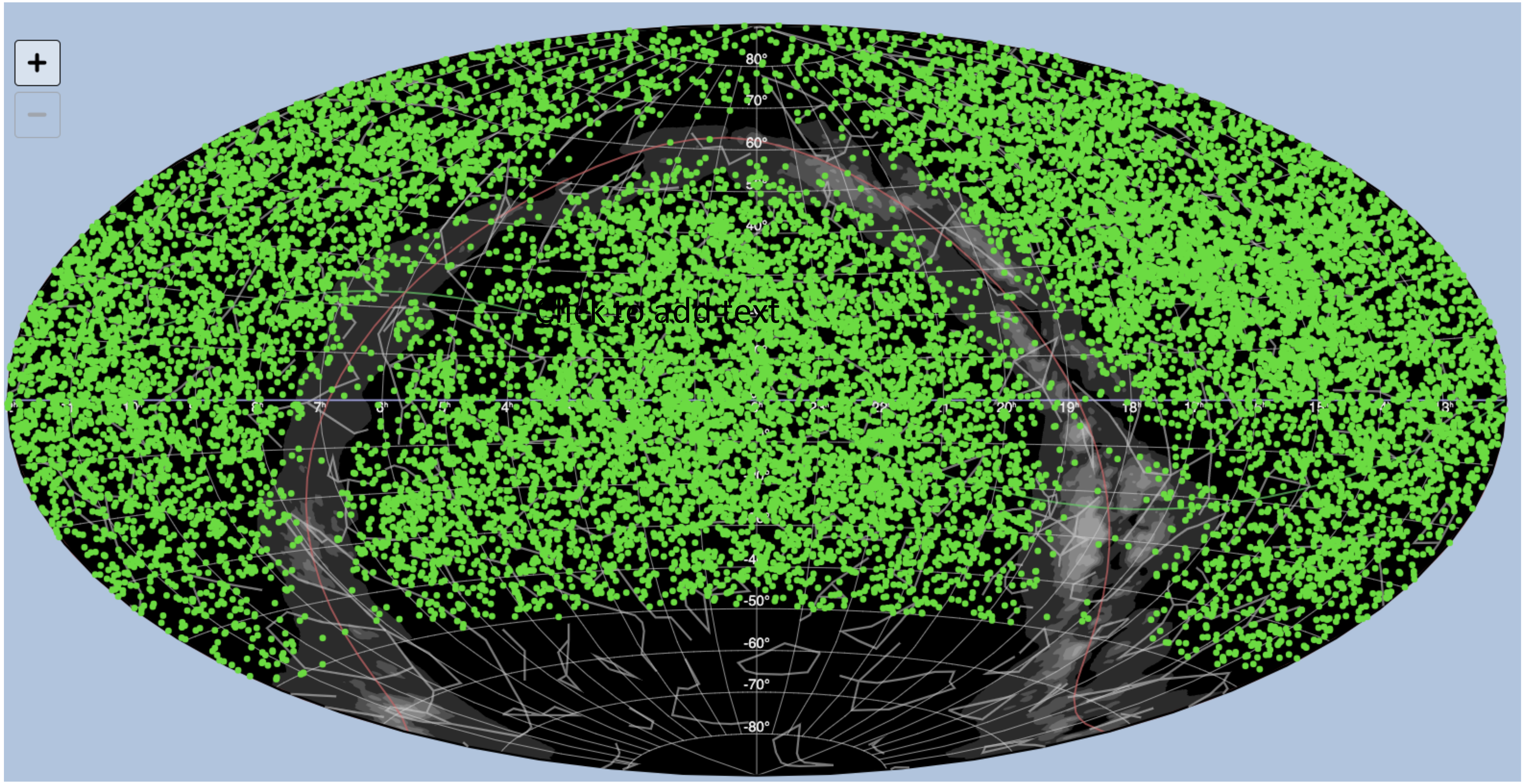
Prof Stephen Smartt, Dr Dave Young, Dr Ken Smith

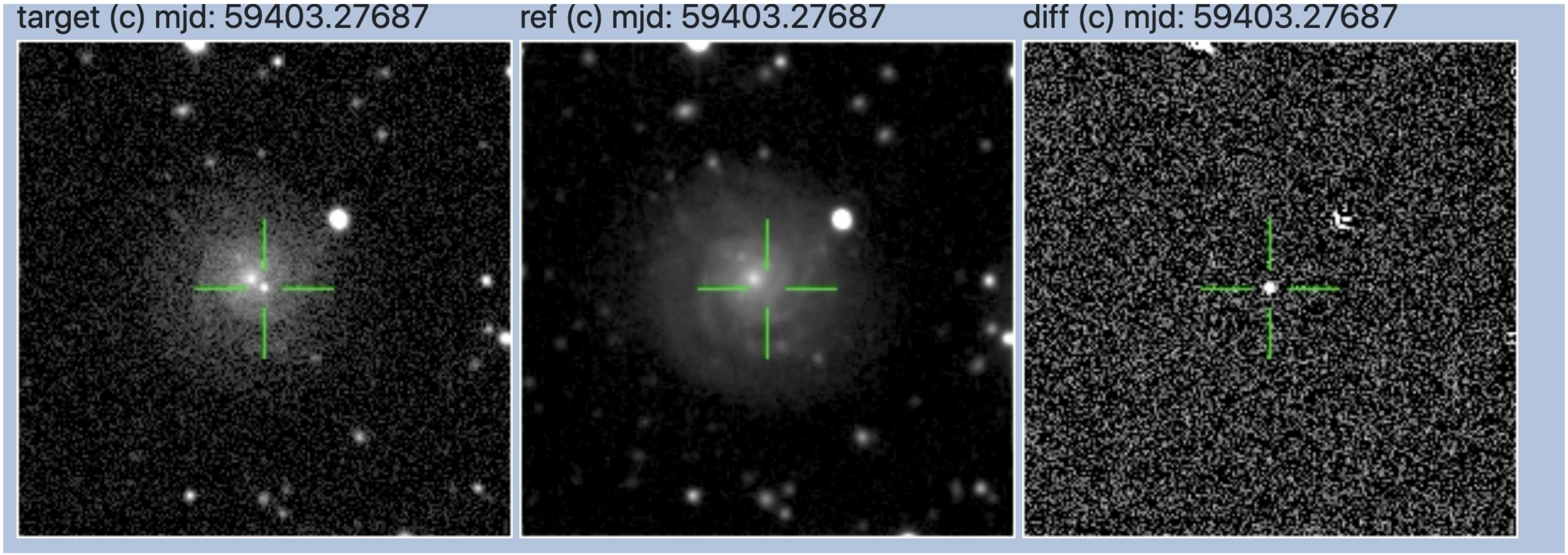
The ATLAS telescopes in Hawaii

ATLAS home page :
https://fallingstar.com

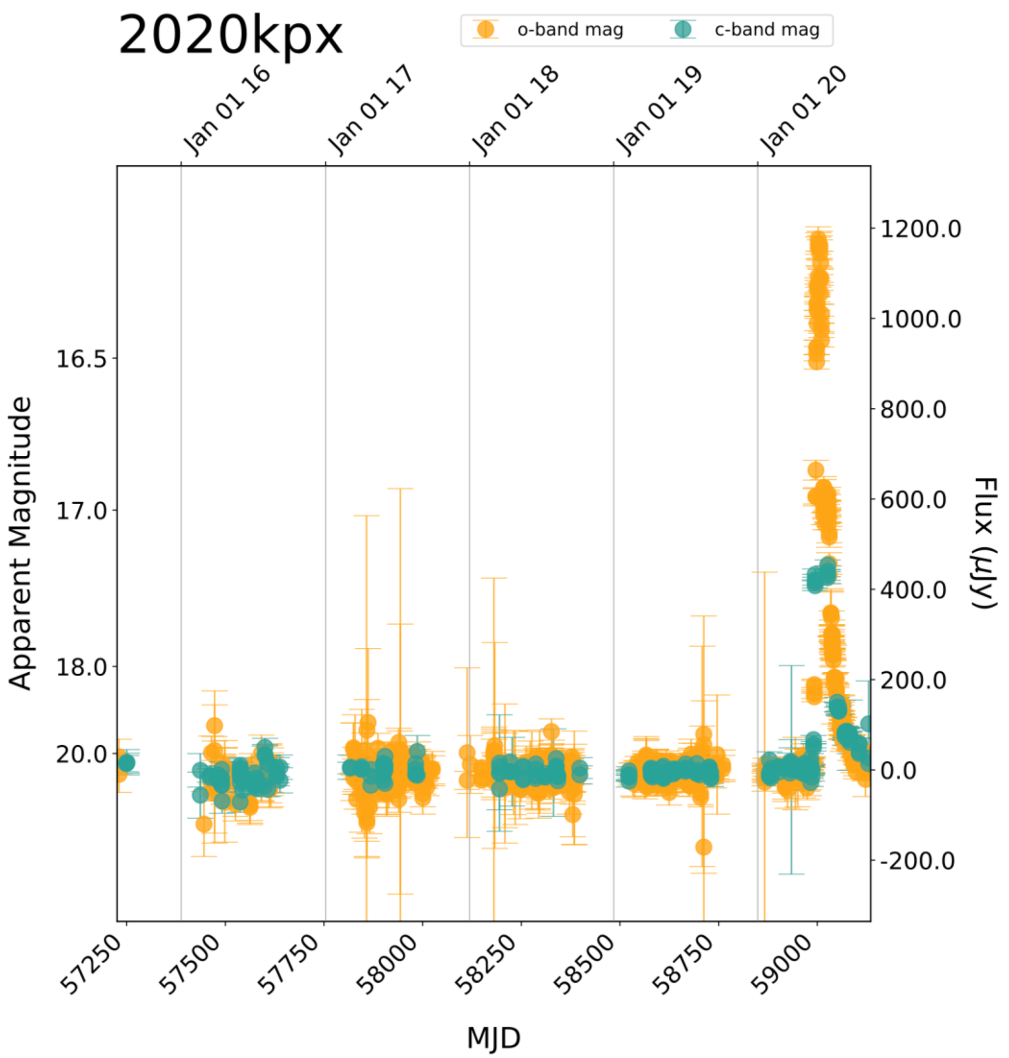
Hawaii - Ireland : perfect longitude match !

Supernovae and exploding stars – flashes in the sky




target (c) mjd: 59403.27687
ref (c) mjd: 59403.27687
diff (c) mjd: 59403.27687

Time series data = a lightcurve



X axis : modified Julian date. This is in units of days (decimal)

Y axis : Flux, which is a measurement of power, or energy per second received on earth

The flux unit is microJanskys

1 Jansky = 10^{-23} Watts m^{-2} Hz^{-1}

(where m is a metre on the earth)

1 microJansky = 10^{-6} Jansky

Orange or o-band : light measured through a filter at 690 nm

Cyan or c-band : light measured through a filter at 535 nm

The dataset

https://github.com/thespacedoctor/astro-analytathon

- 645 objects, each with a lightcurve
- Lightcurve contains measurements over about 5 years
- Most points will be at zero flux (within the errors)
- Different shapes, timescales, peak values : star exploded sometime over last 5 years
- Supernovae can be more luminous than 10^{11} Suns, or brighter than a whole galaxy
- They can last somewhere between 1 – 6 months
- ATLAS is effectively a large camera : observes 4 exposures (each 30 seconds) at each position each night
- Within the night – not much variation

The dataset

###MJD	m	dm	uJy	duJy	F	err	chi/N	RA	Dec	x	y	maj	min	phi	apfit	mag5sig	Sky	Obs
57248.473434	-18.658	0.737	-125	92	c	0	0.94	0.95507	7.46675	2526.19	5286.52	3.85	3.53	-58.7	-0.429	19.54	21.62	02a57248o0308c
57248.491712	-19.084	1.333	-84	113	c	0	1.16	0.95507	7.46675	2515.93	5290.44	3.86	3.58	-61.4	-0.462	19.52	21.63	02a57248o0331c
57248.524200	-18.044	1.632	-220	359	c	0	0.98	0.95507	7.46675	3977.22	3853.77	3.85	3.69	-55.8	-0.758	19.48	21.59	02a57248o0370c
57248.550040	18.657	6.364	125	796	c	0	1.10	0.95507	7.46675	6607.15	6745.05	3.85	3.62	-88.9	-0.620	18.83	20.85	02a57248o0404c
57313.373363	-19.717	0.411	-47	19	c	0	0.87	0.95507	7.46675	8086.04	5315.77	4.19	3.89	82.8	-0.445	19.39	21.32	02a57313o0175c
57313.396284	-21.068	1.500	-14	20	c	0	0.94	0.95507	7.46675	8078.49	5319.98	4.20	3.90	-89.8	-0.448	19.40	21.34	02a57313o0207c
57313.427114	-19.513	0.286	-57	16	c	0	1.07	0.95507	7.46675	6610.53	6764.57	4.19	3.73	-79.8	-0.445	19.37	21.31	02a57313o0250c
57313.458158	-21.480	2.182	-9	20	c	0	0.79	0.95507	7.46675	6608.58	6766.60	4.26	3.78	-75.1	-0.445	19.35	21.31	02a57313o0294c
57318.262930	-18.883	0.452	-102	46	o	0	0.73	0.95507	7.46675	2524.29	5306.71	4.14	3.35	-55.4	-0.475	18.33	19.49	02a57318o0107o
57318.284315	-18.383	0.239	-161	38	o	0	1.24	0.95507	7.46675	2522.76	5309.72	4.31	3.34	-58.3	-0.491	18.42	19.63	02a57318o0140o

Example content of object lightcurve file

Not all columns are useful for time-series analysis; but here are the definitions for those that are:

Column	**Definition**
`MJD`	Modified Julian Date. A datetime-format preferred by astronomers, with units of days.
`uJy`	The object's flux (brightness) as measured from a single telescope image.
`duJy`	The error associated with the measured flux above.
`F`	Colour-filter used during the telescope observation. `o` orange, `c` cyan.
`chi/N`	A *possible* indication of the quality of the flux measurement (unrelated to `duJy`, lower is better)

Your challenge

We think we understand the physics of most supernovae – many are very similar lightcurve shapes
We have matched many of these lightcurves to physical models and also to each other
But we bring our own bias to this.

- Treat the dataset purely from a data analytics perspective – no physics !
- Group the objects into clusters or classes by their shape – some will be incredibly similar, implying the same physical mechanism causes the energy release
- How many classes can you find ?
- How many in each class ?
- How many can't be classified comfortably into the main classes ?
- Why can they not ?
- How many are true anomalies ?

Pay close attention to errors and missing data ! See next slide ….

Data issues to look out for

- Uncertainty and noise – each flux point comes with an associated error. This is a noisy data set, pay close attention to the error bars
- Season gaps. Sometimes the lightcurve of a transient event is truncated because it either disappears behind the sun, or appears from behind the sun.
- Sudden discontinuities in the lightcurve. This probably implies that the "template" image was changed while the transient event was active (and maybe contains flux from the event).
- Random single point high flux or low flux events. This is caused by satellite trails, moon glints, bright star spikes, clouds, etc.
- A transient event might be very red or very blue, hence very different flux in each filter. You might want to treat the filters separately. Note that historically, the cyan filter is much more sparsely sampled.

Hints and tips

- Many of these lightcurves can reasonably well reproduced with simple analytic functions of the form :

  $f = \alpha\, t\, exp\, [-(t-t_0)/\beta]$

Where t is time in days, t0 is a time constant to shift the start time of the function, β sets the timescale or width of the rise and fall, and α is just an overall scaling factor.

- But not all, some will have rise and long flat phase of 80 – 100 days
- There are more complex functions that can work better – up to you to decide
- All objects are at different distances (a factor 10 difference between the nearest and furthest), which means the peak flux could differ by a factor 100
- You could choose to normalise the peak flux of all of them to 1, for example. But then you lose the information of how intrinsically bright they are
- We give you the estimated distance to each object in a file on github. If you wanted to remove distance, then pay attention to the units of flux. Since a Jansky is measured in Watts m^2 Hz^{-1}, and we define intrinsic luminosity as that emitted by the source :

  $L = 4\pi r^2 f$

then to get L in Watts Hz^{-1}, (thus removing the distance dependence) simply multiply f by $4\pi r^2$ where r is in metres

1 parsec = 3.086×10^{16} metres

1 megaparsec = 3.086×10^{22} metres