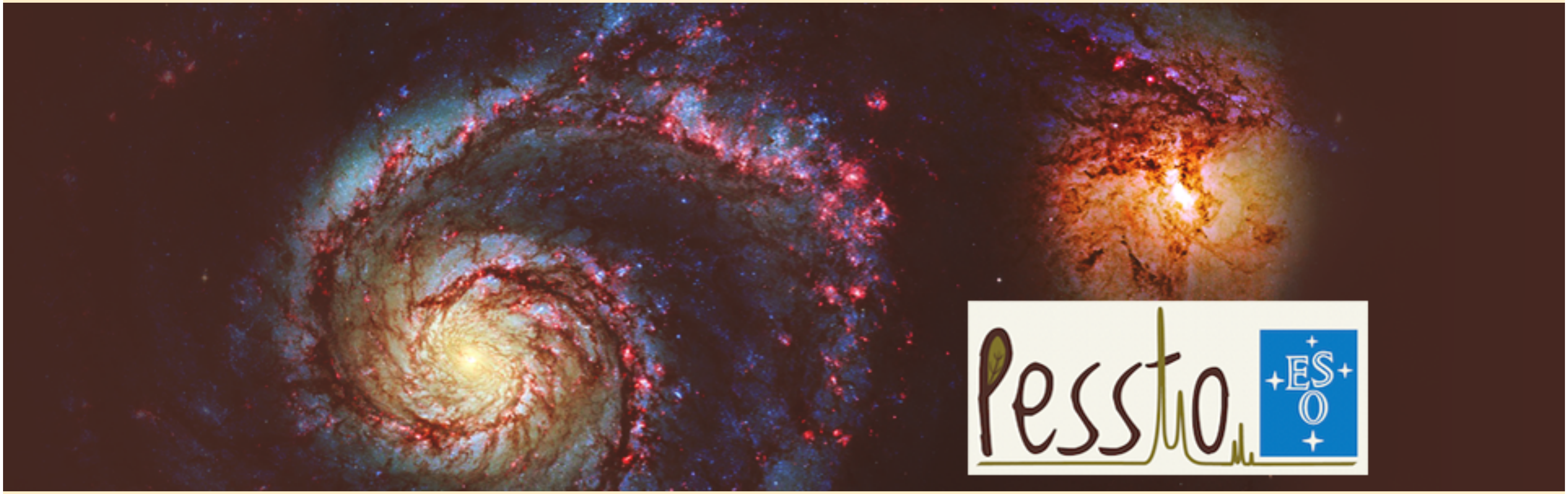
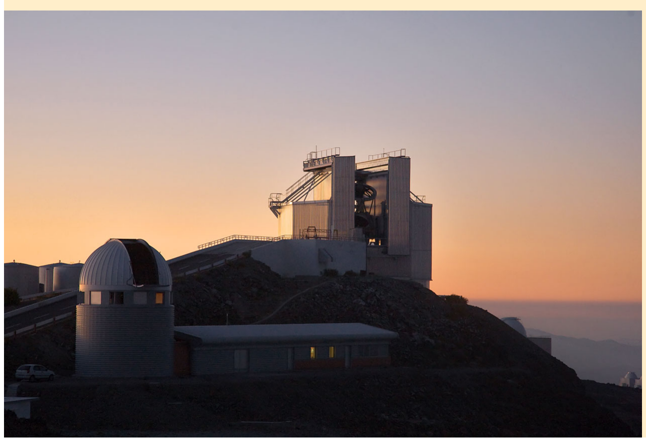


Public ESO Spectroscopic Survey of Transient Objects

www.pessto.org



Stephen Smartt
PI and Survey Director
Queen's University
Belfast

European Research Council erc

PESSTO: the survey in context

- The survey landscape and context for PESSTO
- Status of PESSTO data and science
- Science examples – results from PESSTO
- The case for extension to 2017 : large samples, science impact
- Long term science opportunities for the NTT

PESSTO Scientists : 185

Institutes : 43

PESSTO: The Public ESO Spectroscopic Survey of Transient Objects

Stephen J. Smartt[1]
Stefano Valenti[2,3,4]
Morgan Fraser[1,5]
Cosimo Inserra[1]
David R. Young[1]
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Stefano Benetti[2]
Avishay Gal-Yam[7]
Cristina Knapic[8]
Marco Molinaro[8]
Andrea Pastorello[2]
Riccardo Smareglia[8]
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Netw
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PESSTO, which began in April 2012 as one of two ESO public spectroscopic surveys, uses the EFOSC2 and SOFI instruments on the New Technology Telescope during ten nights a month for nine months of the year. Transients for PESSTO follow-up are provided by dedicated large-field 1–2-metre telescope imaging surveys. In its first year PESSTO classified 263 optical transients, publicly released the reduced spectra within 12 hours of the end of the night and identified 33 supernovae (SNe) for dedicated follow-up campaigns. Nine papers have been pub-

hemisphere surveys that have survey strategies that produce large numbers of young targets in PESSTO's sensitivity range (mag < 20.5). The La Silla QUEST survey searches for supernovae over 1000 square degrees on a 1–2 day cadence, providing PESSTO with 5–10 supernova candidates per night for classification. The rapid cadence allows for young objects to be identified for immediate follow-up and this has been the major feeder survey for PESSTO to date. The SkyMapper telescope is another powerful survey which has just started sky survey operations in earnest in September 2013 and promises a harvest of targets, and accompanying multi-colour light curves. The PESSTO science teams also scour the Catalina Sky Survey public discoveries, and, recently, the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS1) survey discoveries for appropriate targets. PESSTO also welcomes early alerts

A&A 579, A40 (2015)
DOI: 10.1051/0004-6361/201425237

Astronomy & Astrophysics

PESSTO: survey description and products from the first data release by the Public ESO Spectroscopic Survey of Transient Objects⋆,⋆⋆

S. J. Smartt[1], S. Valenti[2,3], M. Fraser[4], C. Inserra[1], D. R. Young[1], M. Sullivan[5], A. Pastorello[6], S. Benetti[6], A. Gal-Yam[7], C. Knapic[8], M. Molinaro[8], R. Smareglia[8], K. W. Smith[1], S. Taubenberger[9], O. Yaron[7], J. P. Anderson[10], C. Ashall[18], C. Balland[11], C. Baltay[12], C. Barbarino[13,14], F. E. Bauer[15,16,17], S. Baumont[11], D. Bersier[18], N. Blagorodnova[4], S. Bongard[11], M. T. Botticella[13], F. Bufano[19], M. Bulla[1], E. Cappellaro[6], H. Campbell[4], F. Cellier-Holzem[11], T.-W. Chen[1], M. J. Childress[20,32], A. Clocchiatti[15,16], C. Contreras[43,44], M. Dall'Ora[13], J. Danziger[8], T. de Jaeger[23,37], A. De Cia[7], M. Della Valle[13], M. Dennefeld[21], N. Elias-Rosa[6,22], N. Elman[12], U. Feindt[39,40], M. Fleury[11], E. Gall[1], S. Gonzalez-Gaitan[23,37], L. Galbany[23,37], A. Morales Garoffolo[22], L. Greggio[6], L. L. Guillou[11], S. Hachinger[33,34,6], E. Hadjiyska[12], P. E. Hage[11], W. Hillebrandt[9], S. Hodgkin[4], E. Y. Hsiao[44,43], P. A. James[18], A. Jerkstrand[1], T. Kangas[36], E. Kankare[1], R. Kotak[1], M. Kromer[26], H. Kuncarayakti[23,37], G. Leloudas[25,7], P. Lundqvist[26], J. D. Lyman[45], I. M. Hook[27,28], K. Maguire[29], I. Manulis[7], S. J. Margheim[30], S. Mattila[24], J. R. Maund[1], P. A. Mazzali[18], M. McCrum[1], R. McKinnon[12], M. E. Moreno-Raya[42], M. Nicholl[1], P. Nugent[31,41], R. Pain[11], G. Pignata[19,16], M. M. Phillips[43], J. Polshaw[1], M. L. Pumo[6], D. Rabinowitz[12], E. Reilly[1], C. Romero-Cañizales[15,16], R. Scalzo[20], B. Schmidt[20], S. Schulze[15,16], S. Sim[1], J. Sollerman[26], F. Taddia[26], L. Tartaglia[6,38], G. Terreran[1,6], L. Tomasella[6], M. Turatto[6], E. Walker[12], N. A. Walton[4], L. Wyrzykowski[35,4], F. Yuan[20,32], and L. Zampieri[6]

(Affiliations can be found after the references)

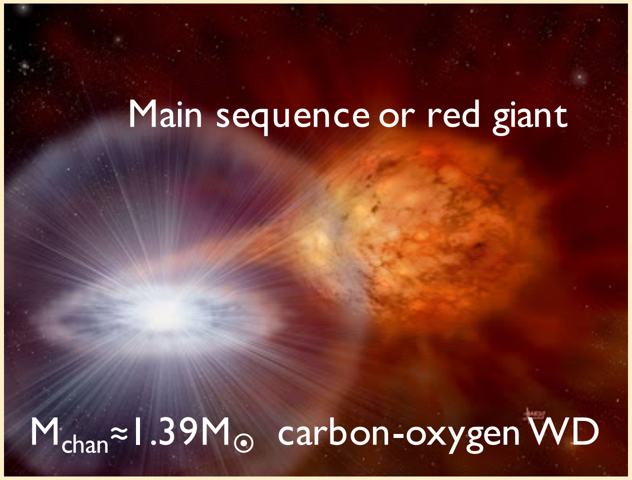
Received 29 October 2014 / Accepted 17 April 2015

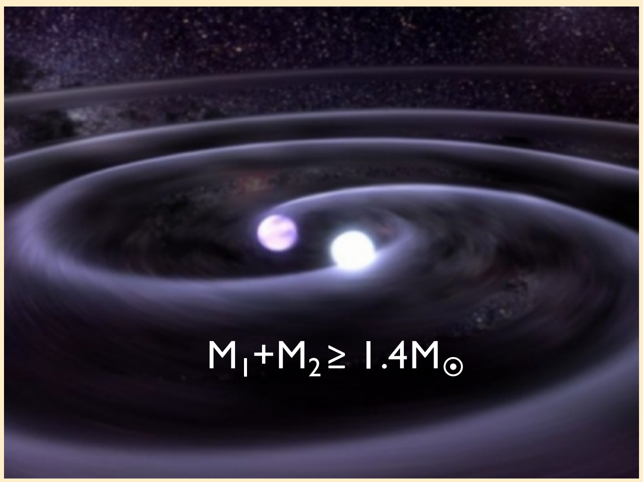
Smartt et al. 2015

2012, MPA Garching (2^{nd} meeting)

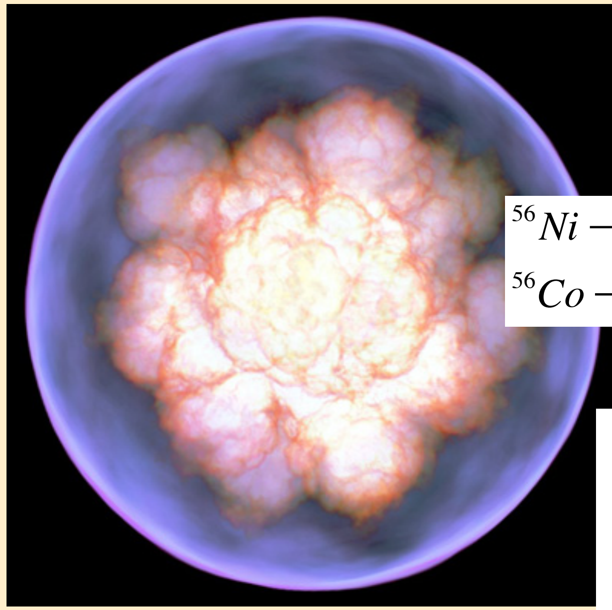
9 “young researchers”

Type Ia : thermonuclear





$$^{12}_{6}C,\ ^{16}_{8}O \rightarrow\ ^{24}_{12}Mg,\ ^{28}_{14}Si,\ ^{32}_{16}S,\ ^{40}_{20}Ca$$
$$+\ ^{56}_{28}Ni\ (0.7\mathrm{M}_{Sol})$$



$$^{56}Ni \rightarrow\ ^{56}Co + e^{+} + \nu_e + \gamma \qquad (\tau_{1/2} = 6 \text{ days})$$
$$^{56}Co \rightarrow\ ^{56}Fe + e^{+} + \nu_e + \gamma \qquad (\tau_{1/2} = 77.1 \text{ days})$$

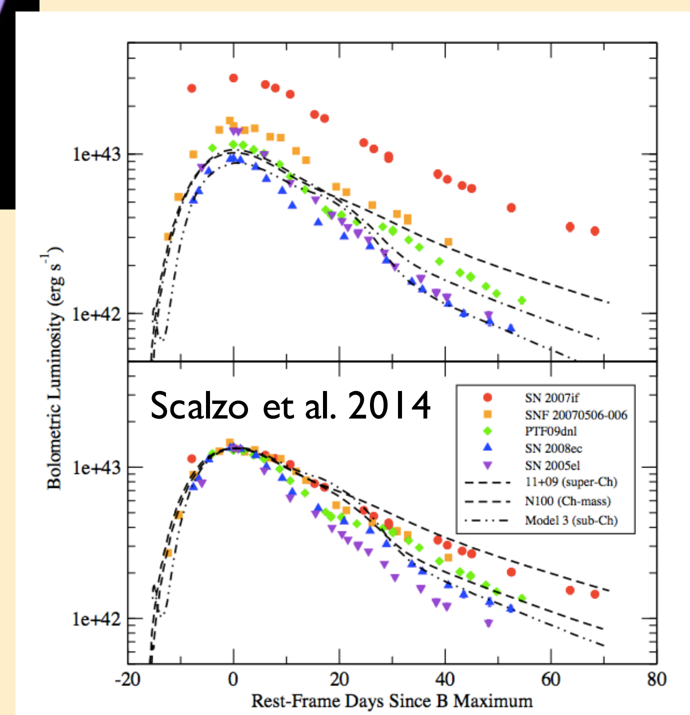
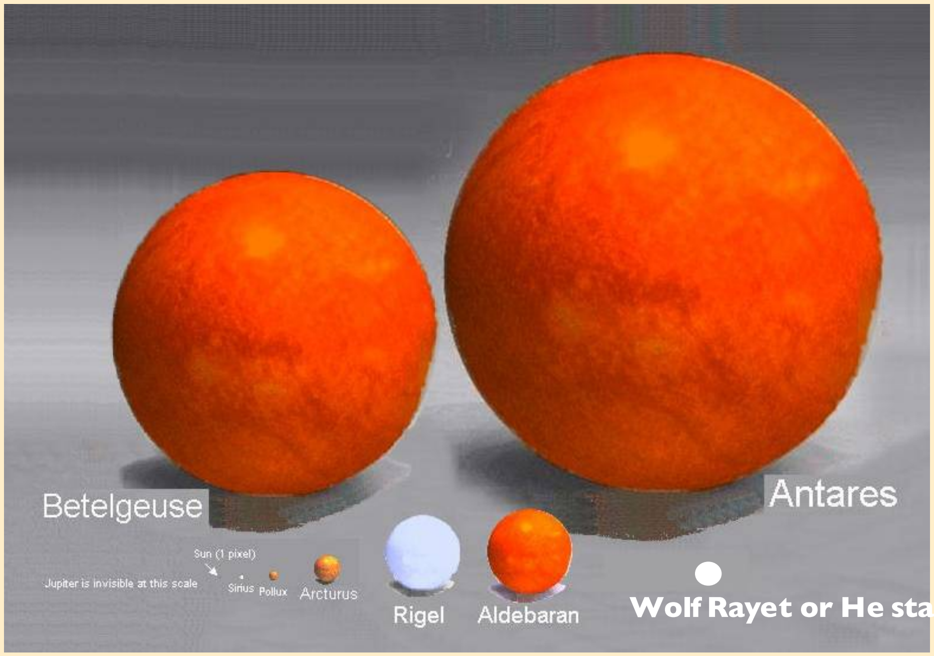
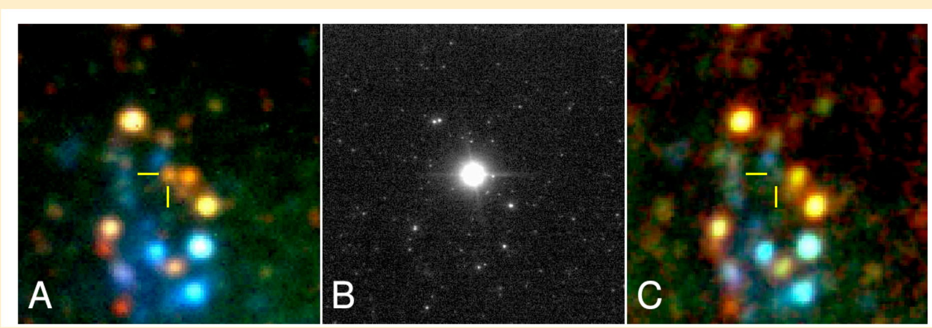


Image Credits : D. Hardy, GSFC/D. Berry/F. Ropke

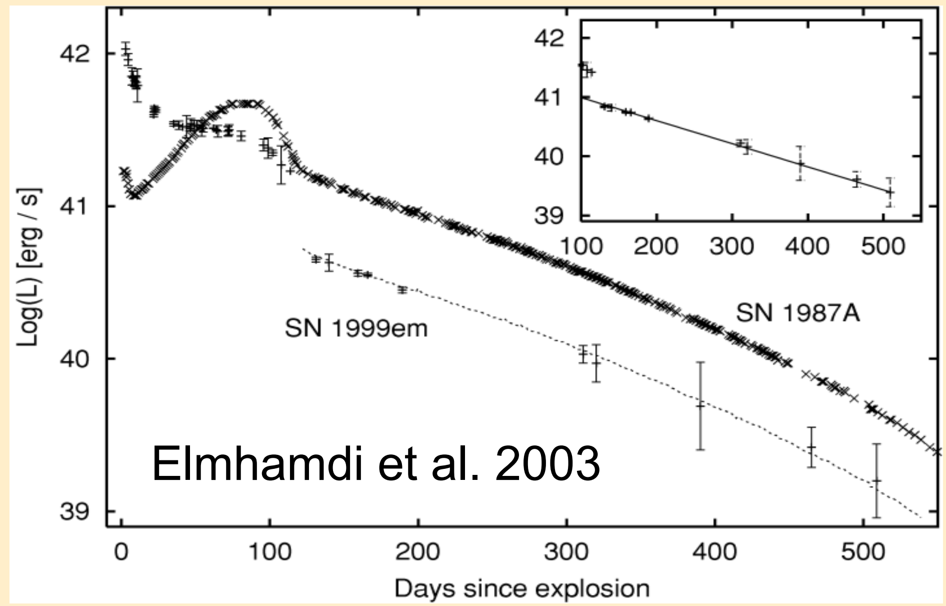
Type II, Ib, Ic : core-collapse





Picture credit : S. Mattilla
Maund & Smartt 2009, Science,
Maund et al. 2013, arXiv 1308.4393
Smartt 2009, ARAA

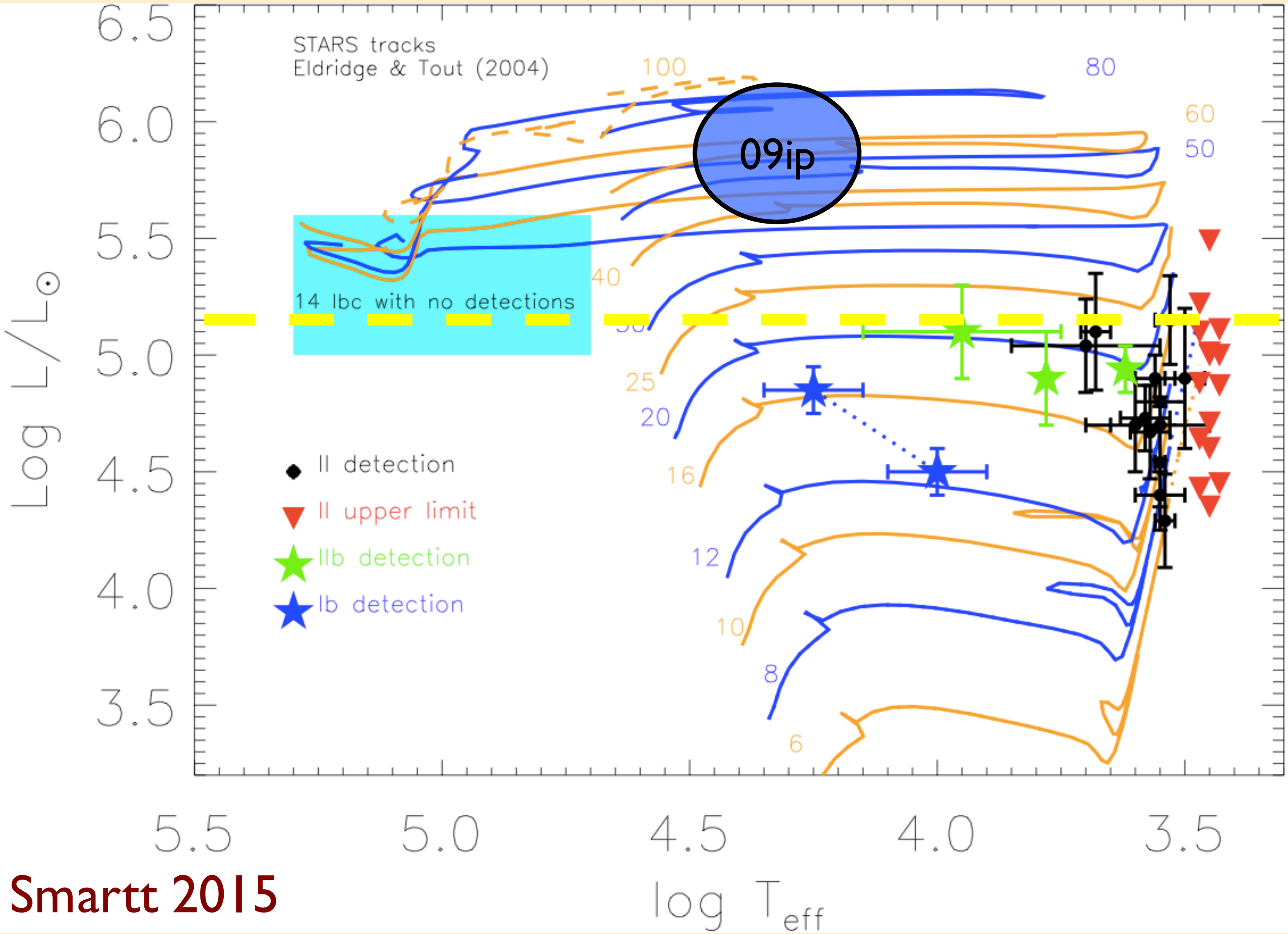
- $1.4M_{\odot}$ Fe core reaches Chandrasekhar degeneracy limit
- 10^{53} ergs of gravitational potential energy
- 1% of neutrino energy is captured
- Explosions with $E_{tot} \sim 10^{51}$ ergs



$$^{56}Ni \rightarrow {}^{56}Co + e^{+} + \nu_e + \gamma \quad (\tau_{1/2} = 6 \text{ days})$$

$$^{56}Co \rightarrow {}^{56}Fe + e^{+} + \nu_e + \gamma \quad (\tau_{1/2} = 77.1 \text{ days})$$

HRD for progenitors : missing high mass stars



Smartt 2015

- Results 1998 – 2013 ; within 28 Mpc
- 45 objects in total
- Apparent upper luminosity limit : **Log $L/L_\odot \approx$ 5.1**

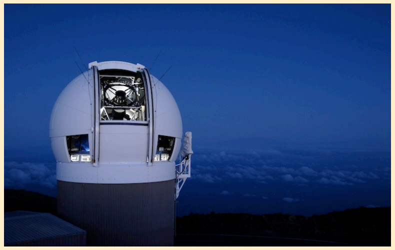
For Salpeter IMF : 75% of 8-100$M_\odot$ stars are 8-20$M_\odot$

14 high mass progenitors are “missing”

Wide-field synoptic surveys : game changer

10 square degree cameras + 1-2m telescopes

PTF – low-z SNe (“factory” follow-up built in)



PS1 – high-z SNe (dedicated 4-8m follow-up)

+

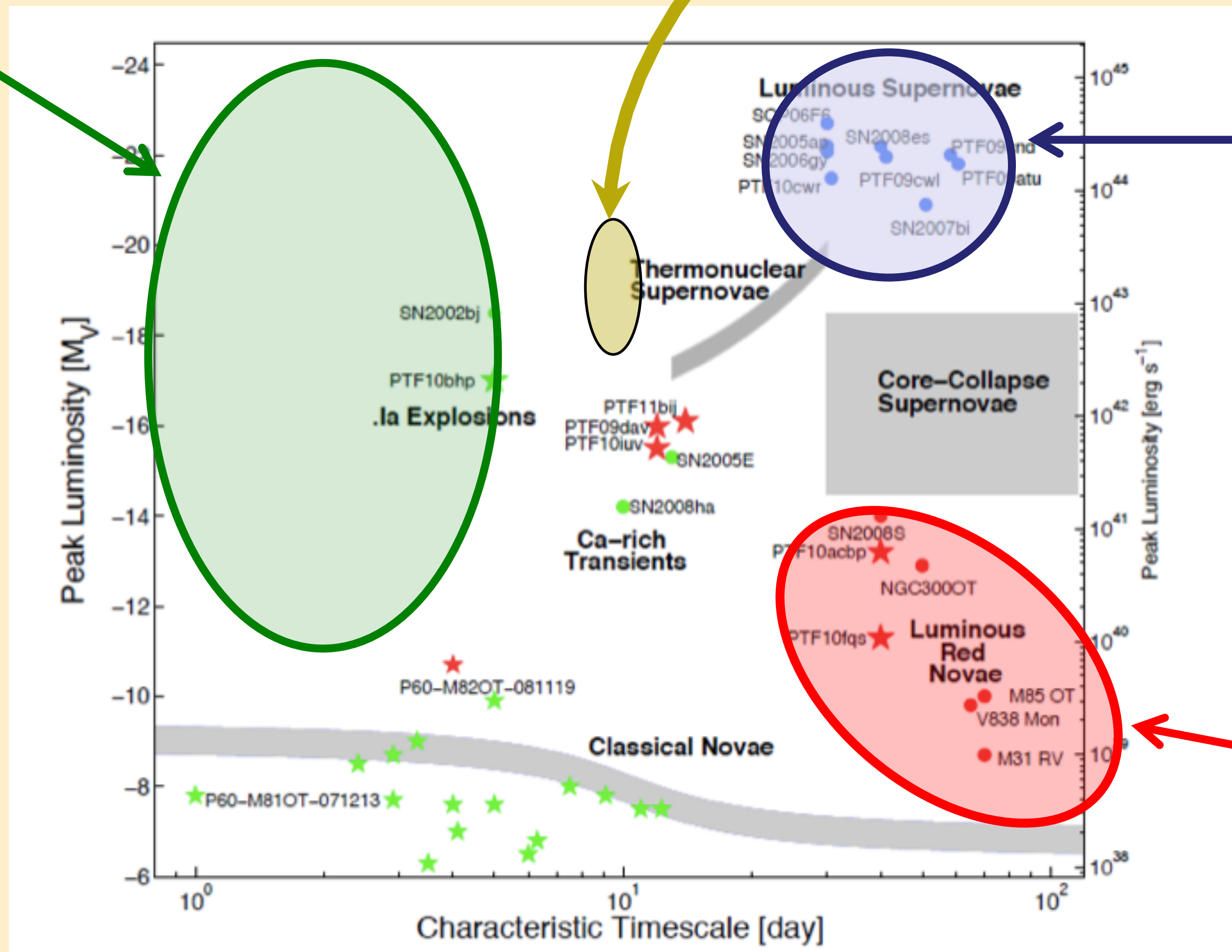
La Silla QUEST + SkyMapper

Optical Transients

the unknown

the bright

the faint

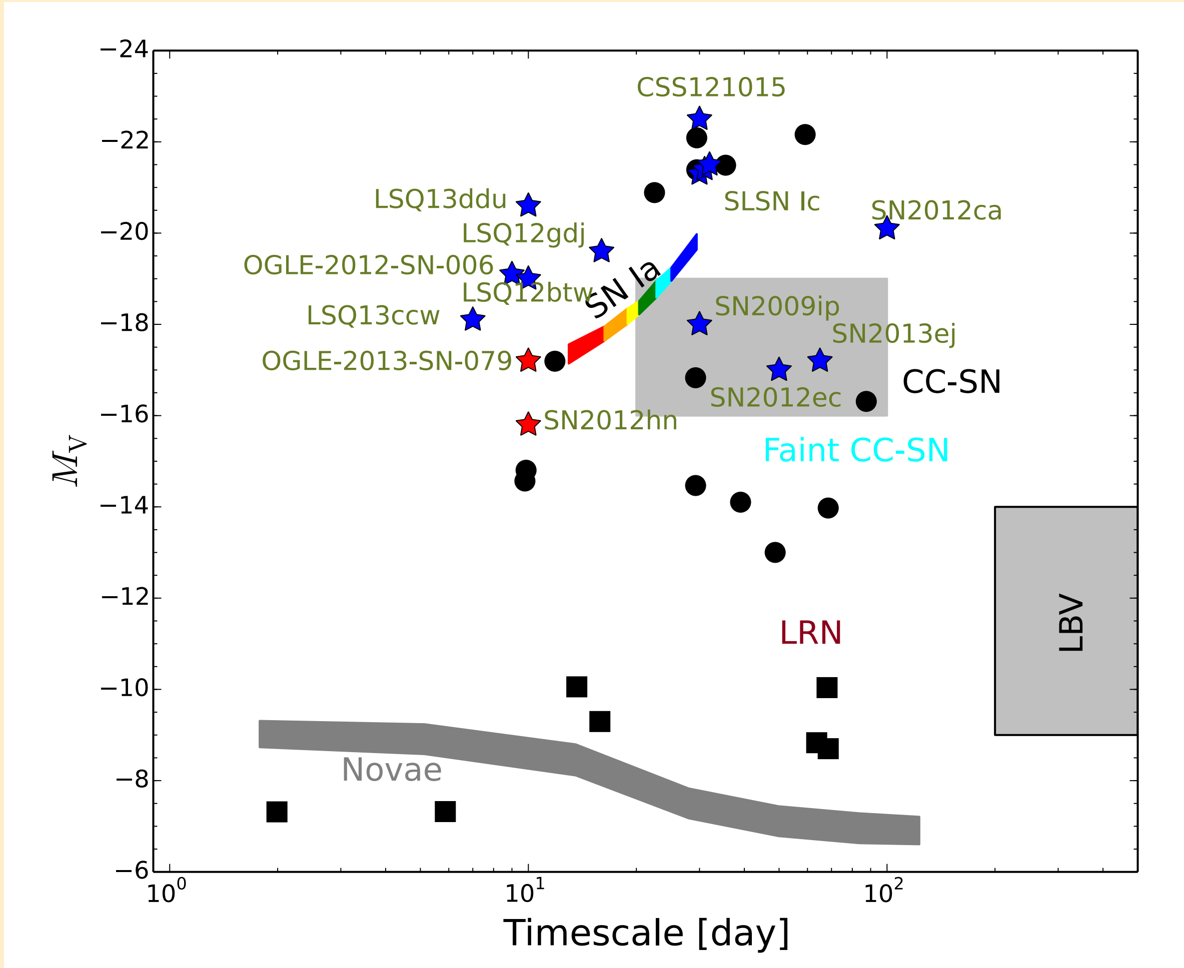


What are the limits of physical explosions and transients ?

Image credit : Shri Kulkarni, Mansi Kasiiwal

Transients : current science

Smartt et al. 2015: Survey description and products from the first data release by PESSTO,



What are the limits of physical explosions and transients ?

Image credit : Shri Kulkarni, Mansi Kasliwal, C. Inserra

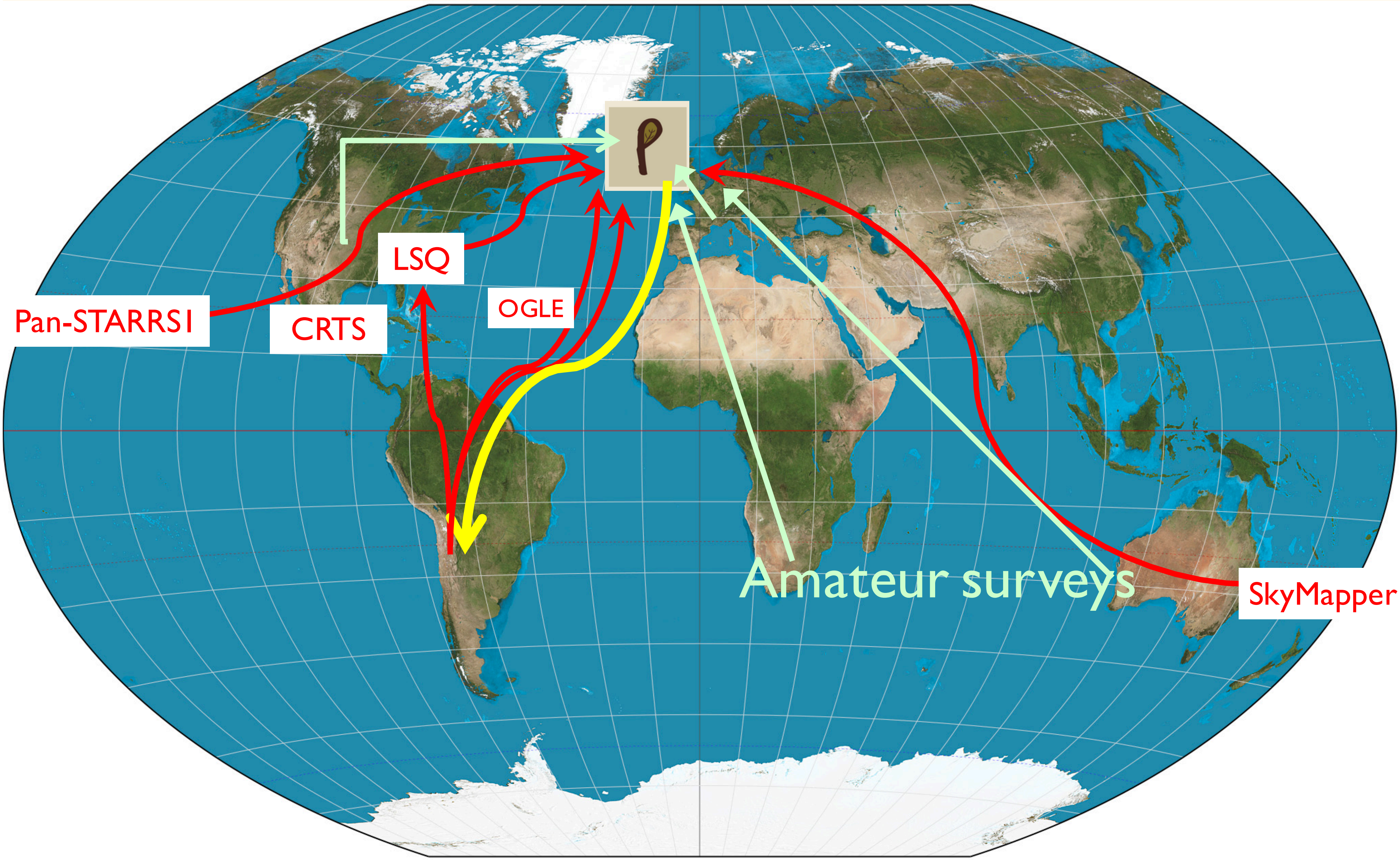
PESSTO in a Nutshell

- 90n per year : 9 months, 10n per month
- 4 yrs (2012-2016), with 1yr more pending formal NTT review (3.3 years now done)
- Aim to classify ~2000 (708) SNe – all spectra reduced, classified and released within 24hrs
- Will follow approx 150 (140) with full spectroscopic and photometric time series coverage
- Goal of 100 papers within 2 yrs of survey end (PESSTO + archive): 30 published or under review, 5 complete to be submitted

(current status in red)

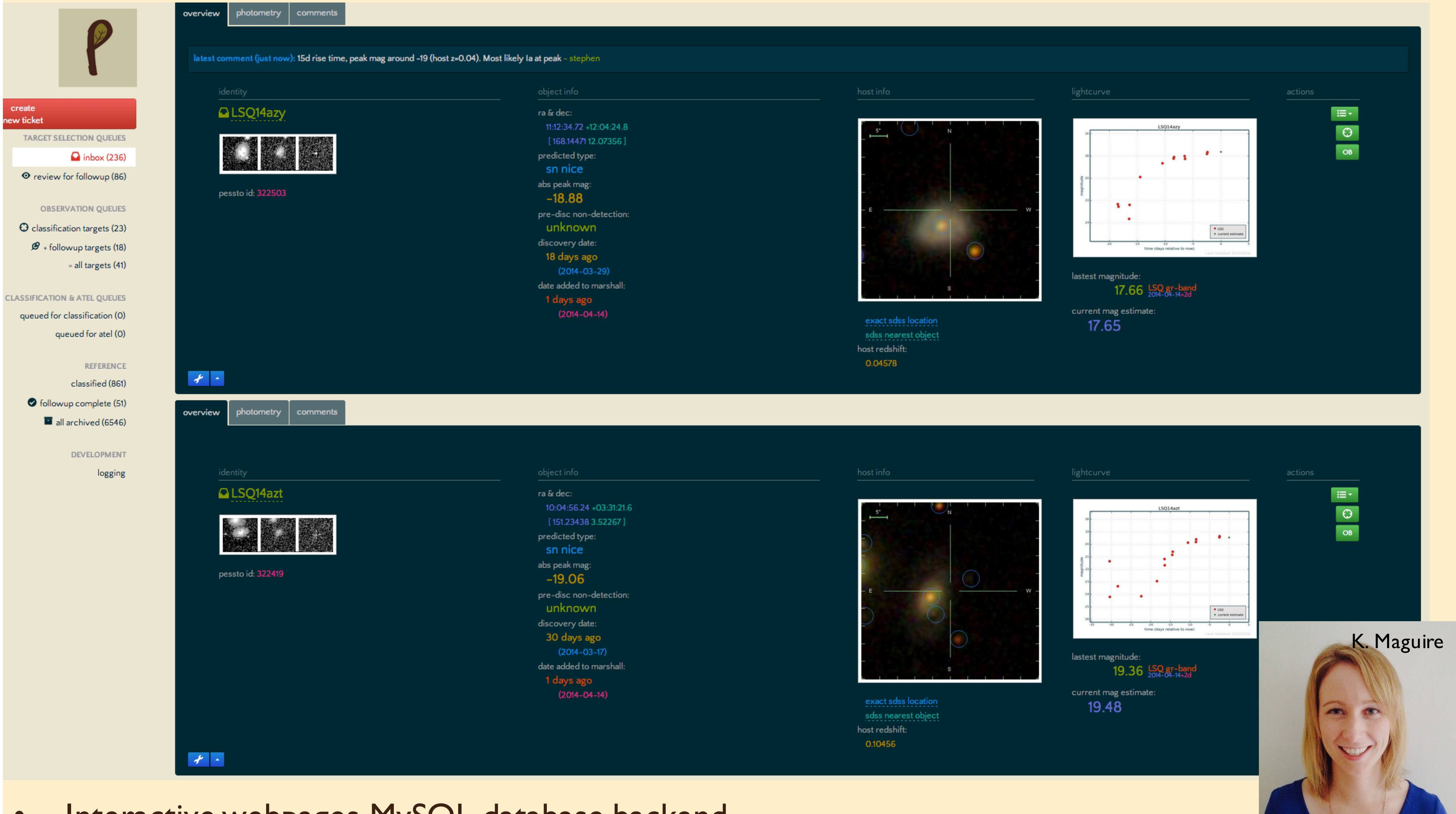
PESSTO operations

How we work and what's novel – communication, target selection, dissemination through the PESSTO marshall



LSQ
OGLE
Pan-STARRS1
CRTS
Amateur surveys
SkyMapper

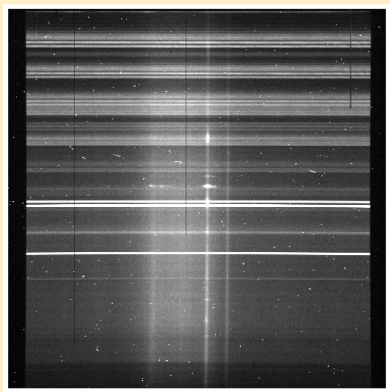
PESSTO marshall

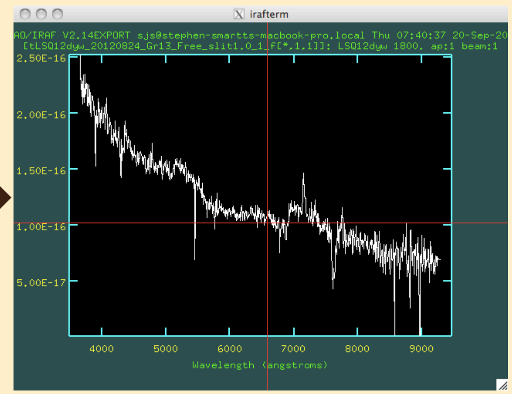


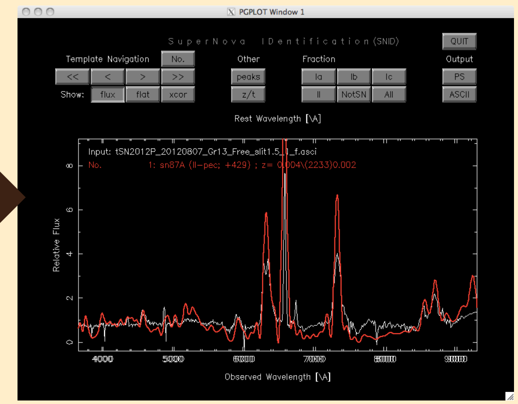
- Interactive webpages, MySQL database backend
- Communication and scheduling tool – allows full consortium to share information and direct observers
- Developed by D. Young (concept and initial software from PTF/Pan-STARRS)

12hr turnaround : NTT to public data

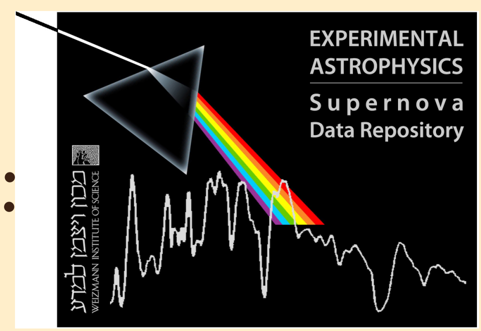
Observers (La Silla):



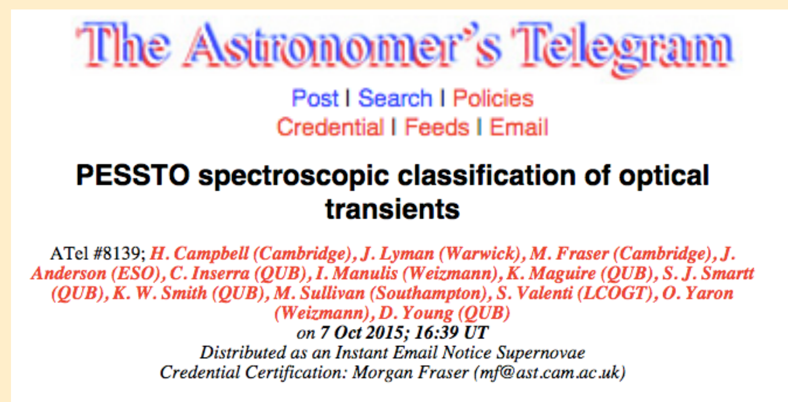




Data Team (Europe/Chile):



http://wiserep.weizmann.ac.il/



The Astronomer's Telegram

Post | Search | Policies
Credential | Feeds | Email

PESSTO spectroscopic classification of optical transients

ATel #8139; *H. Campbell (Cambridge), J. Lyman (Warwick), M. Fraser (Cambridge), J. Anderson (ESO), C. Inserra (QUB), I. Manulis (Weizmann), K. Maguire (QUB), S. J. Smartt (QUB), K. W. Smith (QUB), M. Sullivan (Southampton), S. Valenti (LCOGT), O. Yaron (Weizmann), D. Young (QUB)*
on 7 Oct 2015; 16:39 UT
Distributed as an Instant Email Notice Supernovae
Credential Certification: Morgan Fraser (mf@ast.cam.ac.uk)

Subjects: Optical, Supernovae, Transient

Public data products now at ESO SAF

SSDR1

Table 4: Total number of science files released in the various formats described here.

File type	Format	Number of files	Data Volume
EFOSC2 1D spectra	Binary Table format	814	36Mb
EFOSC2 2D spectral images	FITS image	814	2.6Gb
EFOSC2 images (of which ACQ)	FITS image	2550 (1041)	10.6Gb (4.0Gb)
SOFI 1D spectra	Binary Table format	95	4.2Mb
SOFI 2D spectral images	FITS image	95	298Mb
SOFI image weights	FITS image	234	1.69Gb
SOFI images	FITS image	234	1.69Gb
TOTAL		**4836**	**16.9GB**

SSDR2

Table 4: Total number of science files released in the various formats described here.

File type	Format	Number of files	Data Volume
EFOSC2 1D spectra	Binary Table format	798	38.4Mb
EFOSC2 2D spectral images	FITS image	798	2.61Gb
SOFI 1D spectra	Binary Table format	22	1.0Mb
SOFI 2D spectral images	FITS image	22	69.5Mb
SOFI image weights	FITS image	158	1.21Gb
SOFI images	FITS image	158	1.21Gb
TOTAL		**1956**	**5.14GB**

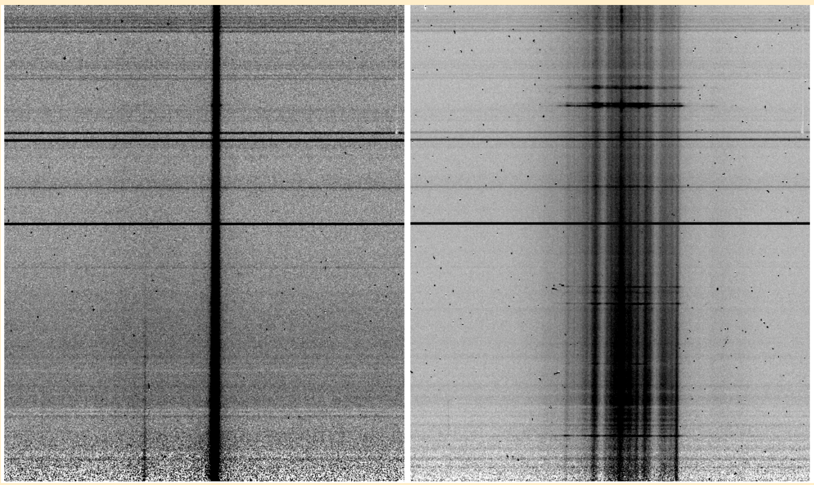
www.pessto.org

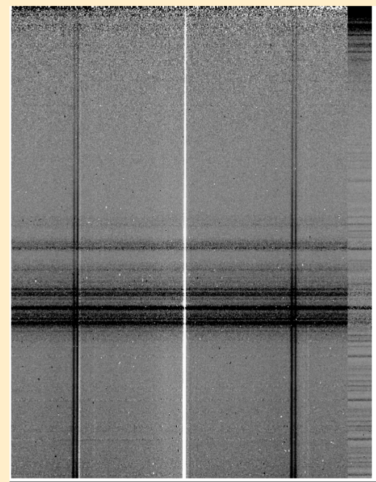
- SSDR1 : Data from April 2012 – April 2013
- SSDR2 : Data from April 2013 – April 2014
- Extra data produces – calibrated 2D spectra images, catalogues, lightcurve tables (of objects published)

Thanks to Alberto Micol (ESO), Dave Young

Cosimo Inserra, Morgan Fraser, Erkki Kankare, Stefano Valenti

Extra Data products : 2D





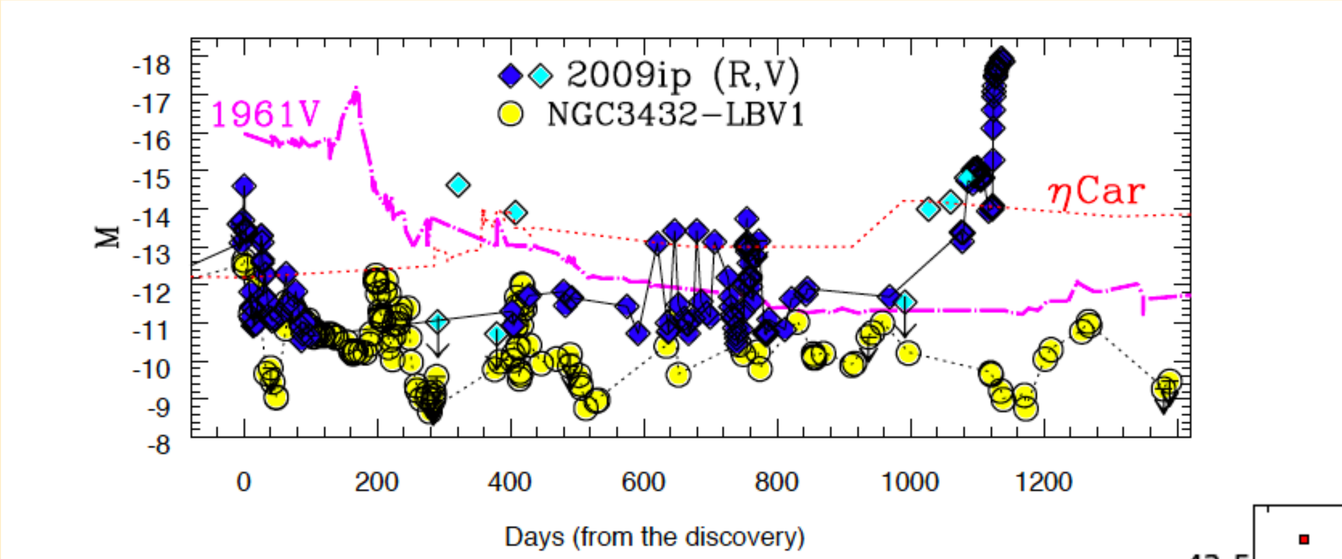
- 2D spectra frames – flux calibrated, wavelength calibrated for all targets
- User can re-extract, flux calibrated spectrum
- Imaging – small fields make photometric Phase 3 uniformity challenging. Still working on this (acquisition images provide useful "uber-calibration")

PESSTO Science

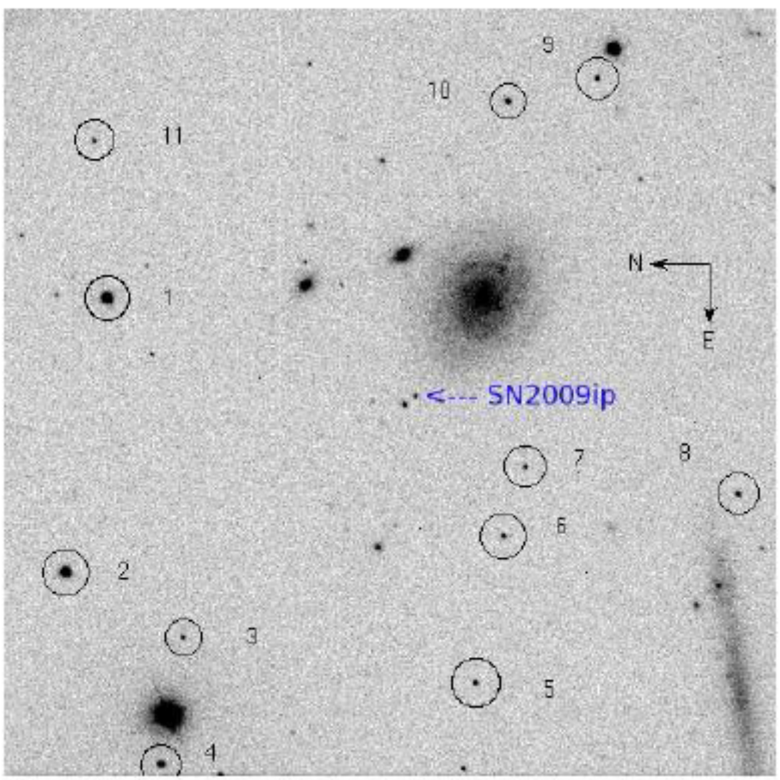
1. Detailed, legacy data sets for individual supernovae

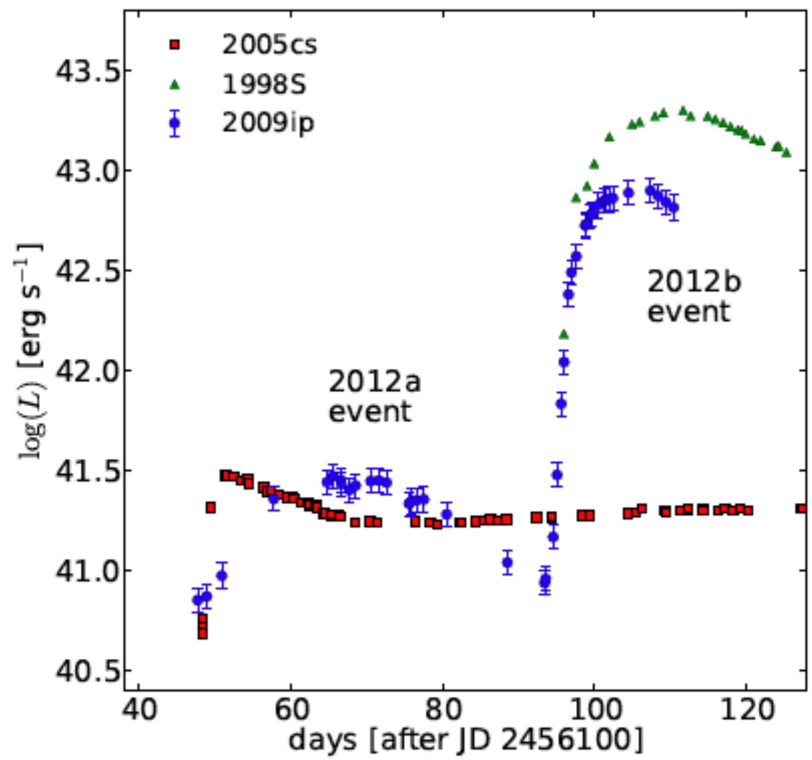
www.pesto.org : 30 refereed papers published or on arXiv, about 20 in preparation, 17 PhD theses, 222 Astronomer's Telegrams (all within ~12hrs)

SN2009ip : pulsational pair instability SN ?



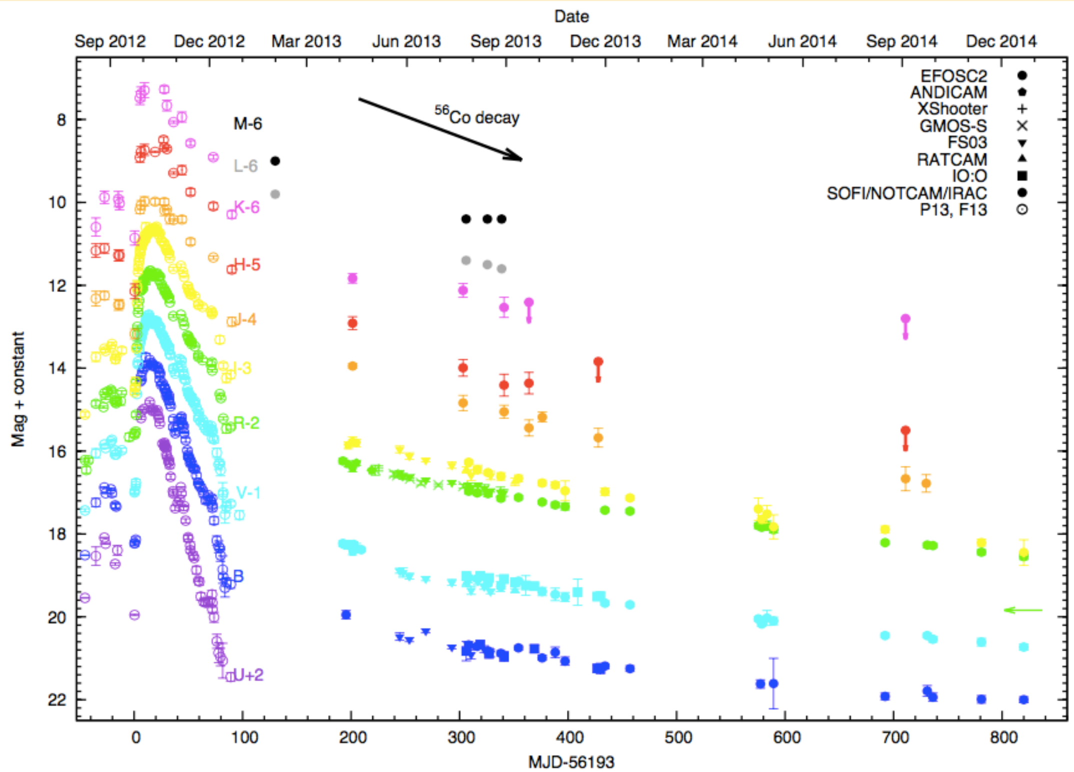
Pastorello et al., ApJ (2013) followed with Benetti et al. ESO LP "Supernovae and Nucleosynthesis"

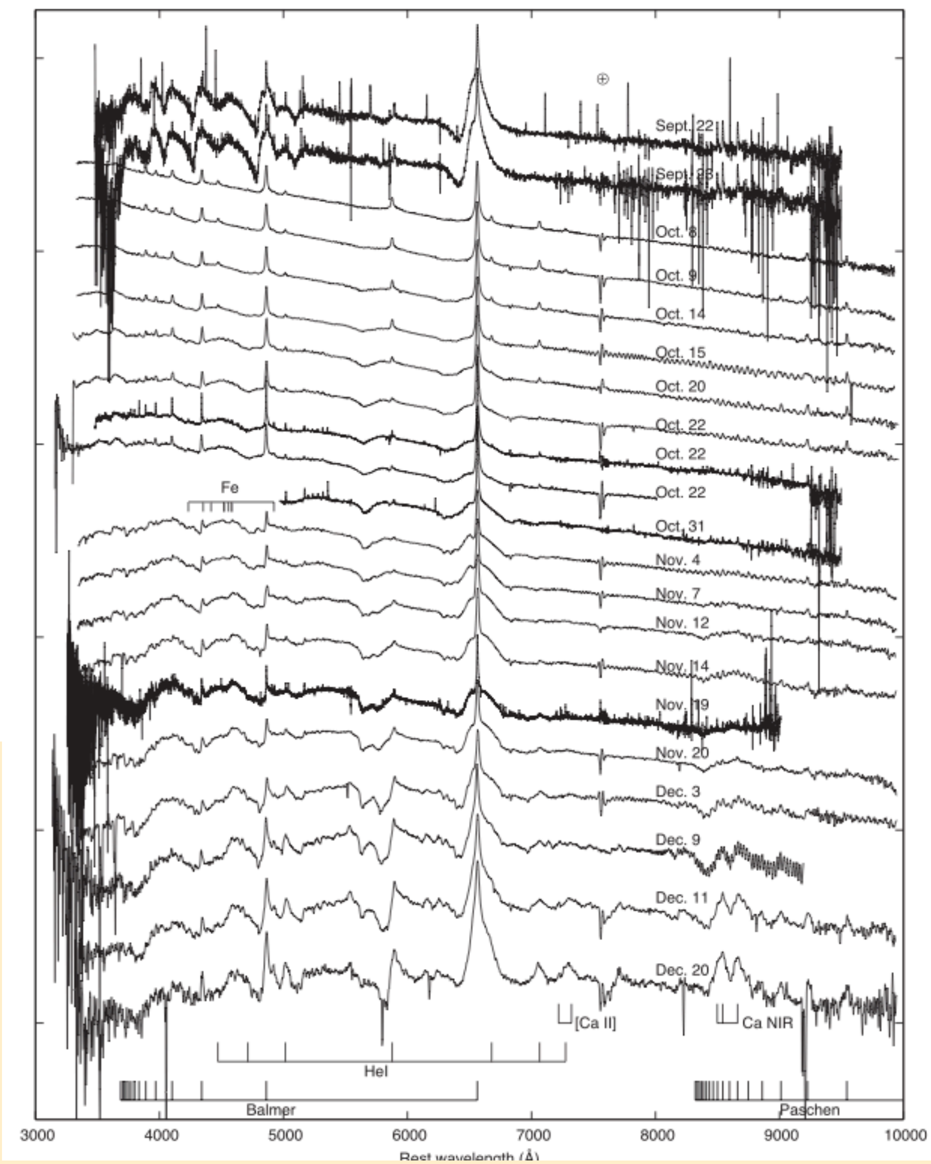




Also See Mauerhan et al. Prieto et al. ++

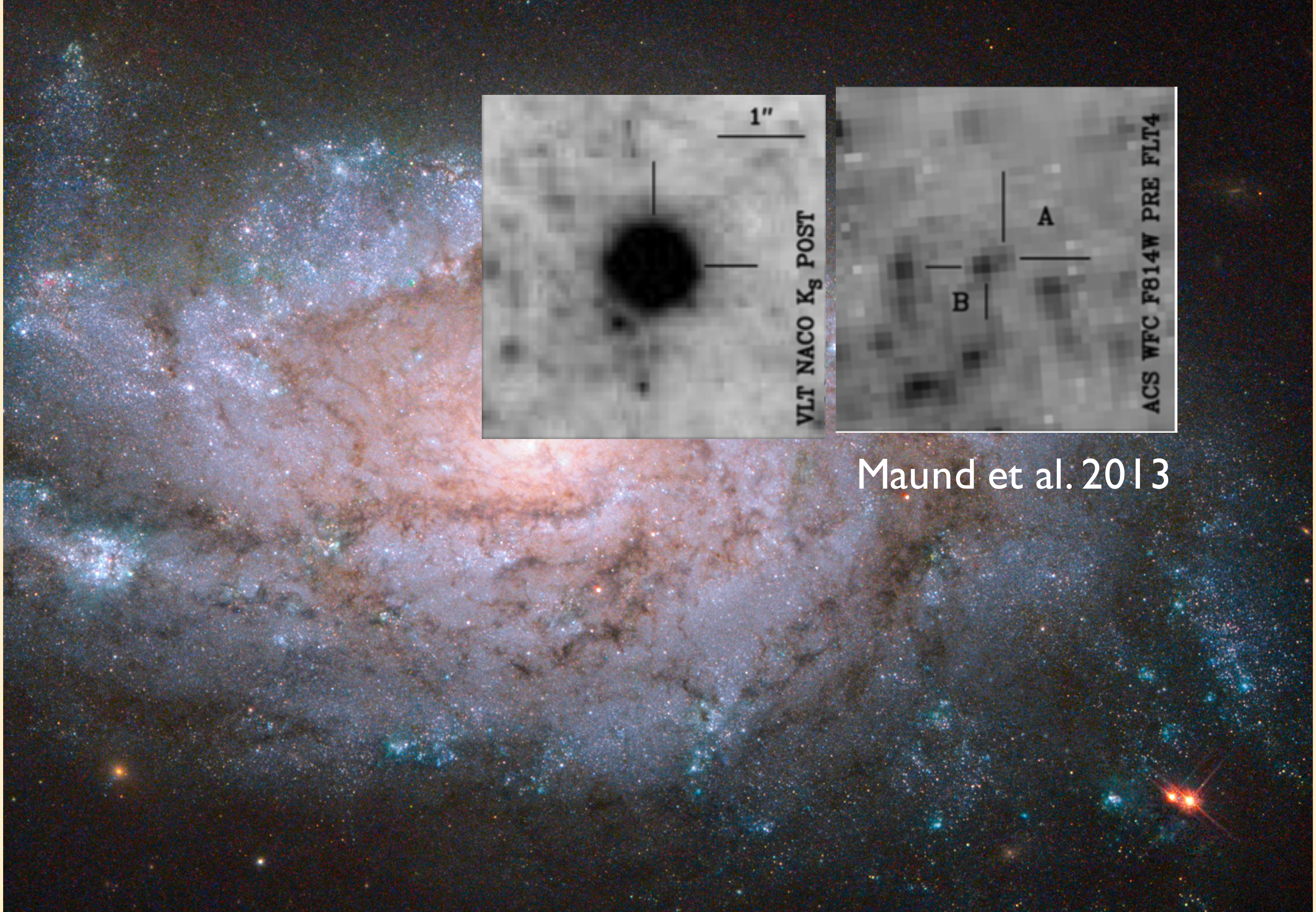
2009ip á la PESSTO





- **Fraser et al. 2013** (1st season)
- **Fraser et al. 2014** (2nd season)
- Origin still not clear : core-collapse or pulsational ?
- Excellent, legacy data set for theory and modelling

NGC1068 hosts supernova SN2012ec

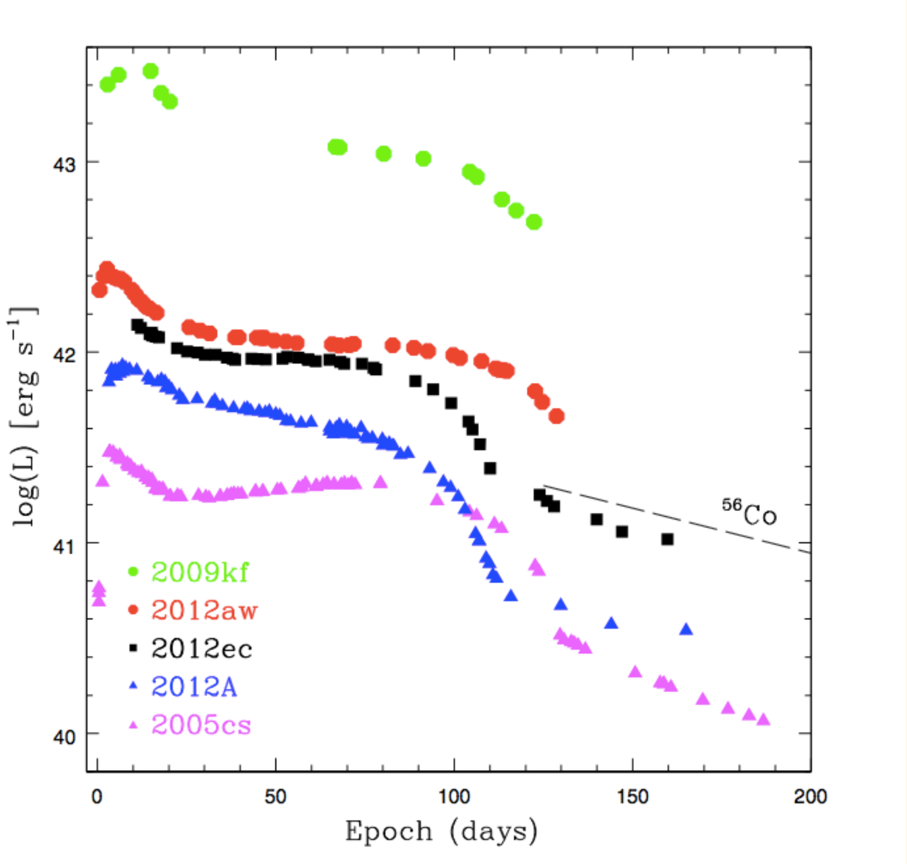


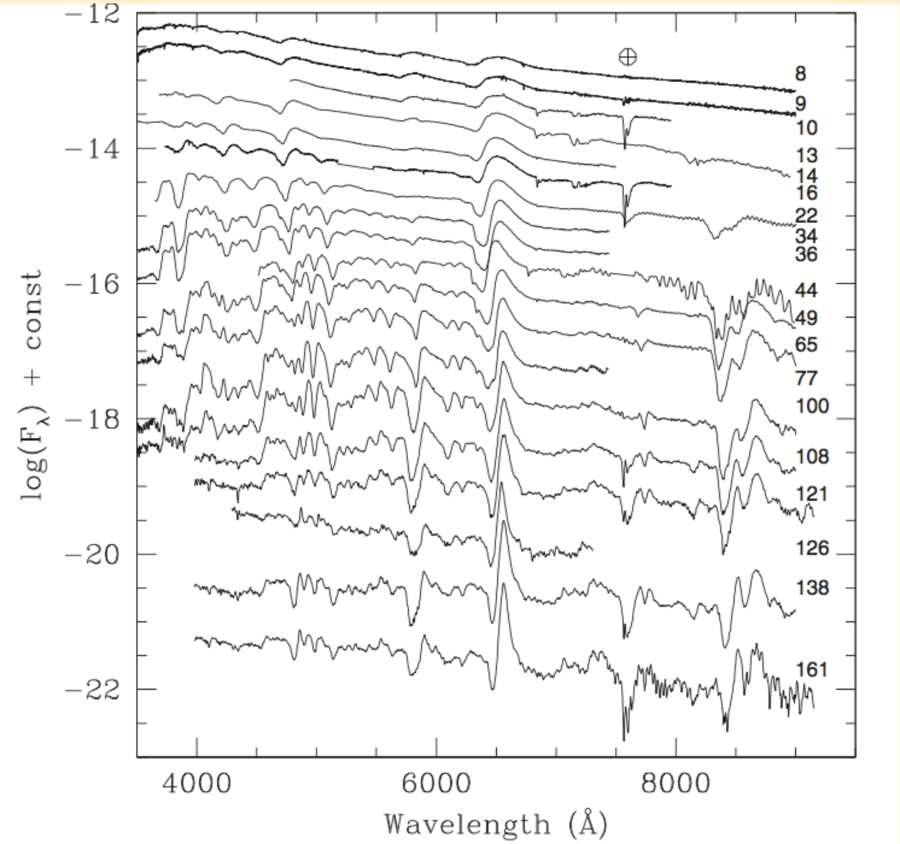
Maund et al. 2013

15M$_\odot$ Red supergiant ➔ Supernovae ➔enrichment

NASA/ESA, B. Campbell, S. Smartt

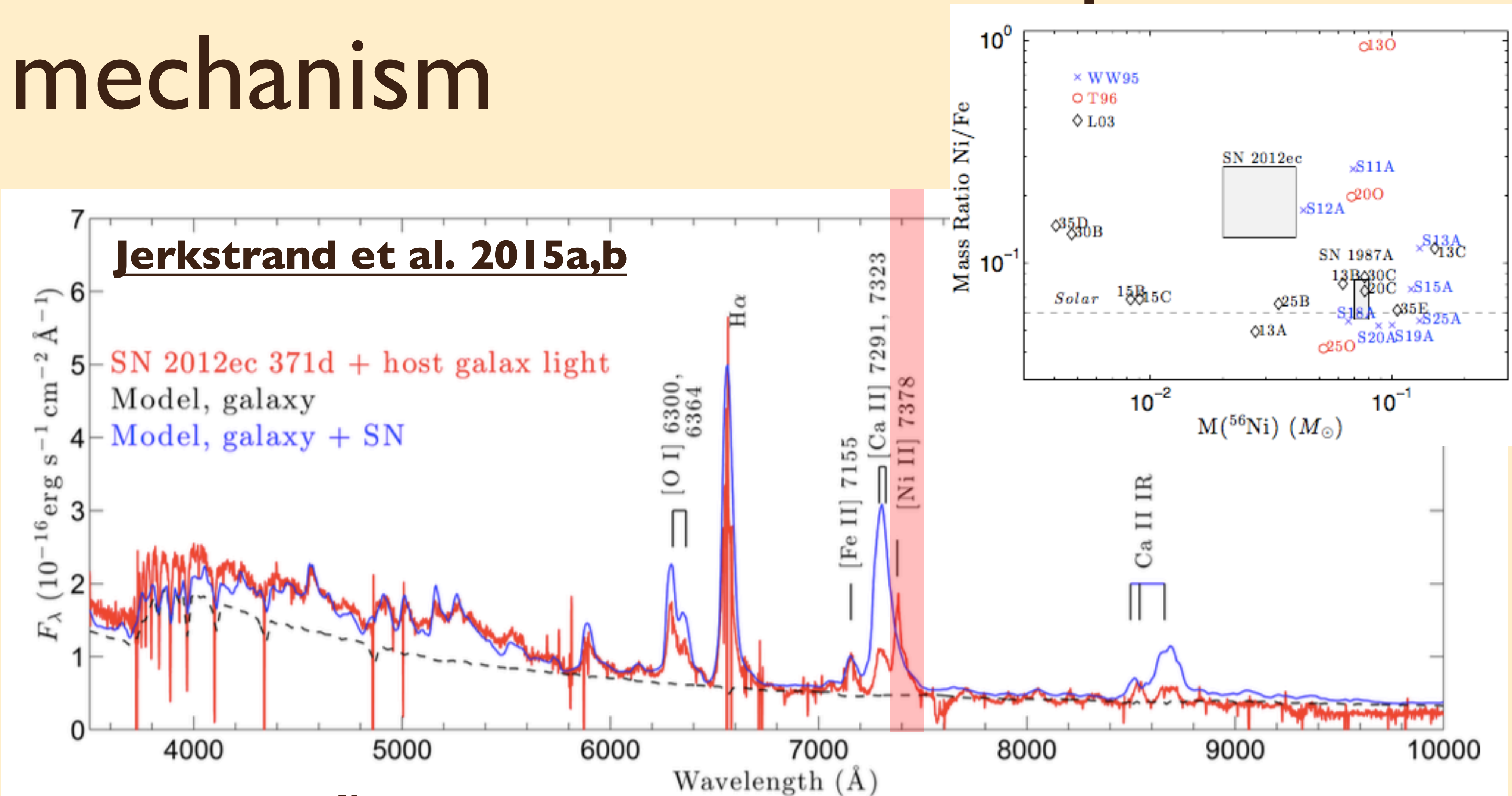
SN2012ec with PESSTO





- **Barbarino et al. 2015, Maund et al. 2012**
- Excellent data set – lightcurves, spectra
- Hydrodynamic models imply M = 13M$_\odot$ and E_k=1.2 x 10^{51} ergs
- Mass of ^{56}Ni from tail phase M = 0.04 ± 0.02 M$_\odot$

Direct constraints on explosion mechanism

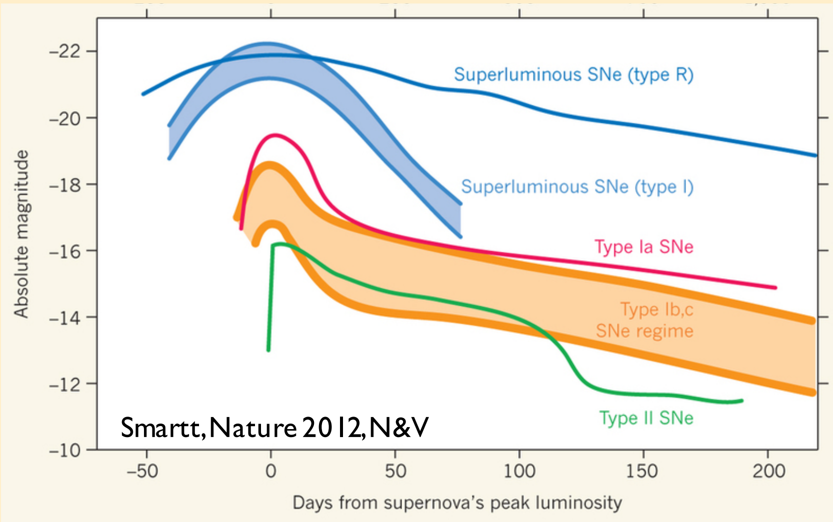


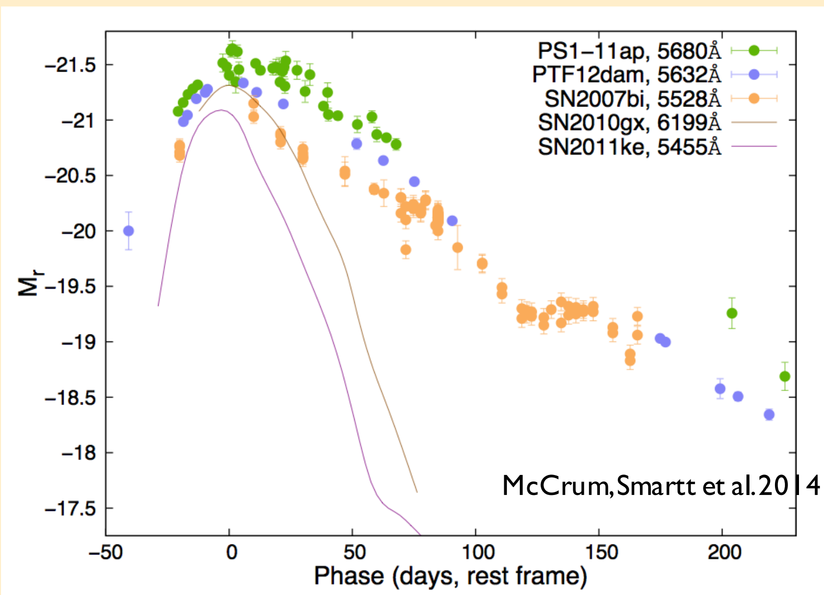
- This is <u>stable</u> ^{58}Ni
- Can only produce this through burning fuel (Si, O) with a neutron excess
- **<u>Jerkstrand, Timmes et al. 2015b</u>** : can only be in Si layer, which constrains explosion
- Potential for systematic use and probe core-collapse with Ni/Fe ratios

PESSTO Science

II. Samples of unusual and rare supernovae

Superluminous stellar explosions





What are they : stellar Explosions in dwarf galaxies – 100 times more luminous than core-collapse SNe.
Luminosity source unknown.
No hydrogen and helium seen in spectra
What is the physics powering this extreme luminosity ?

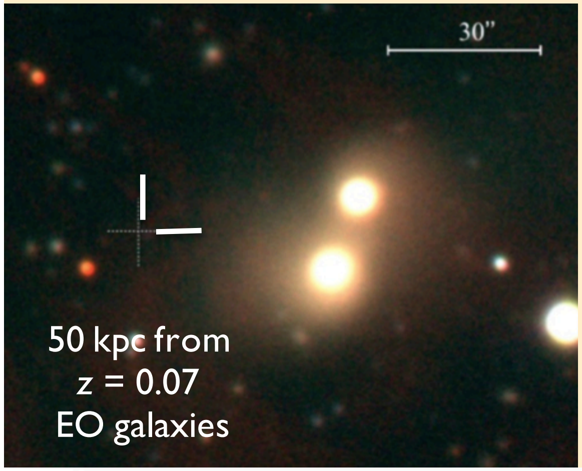
z = 0.1 – 0.3 in PTF, PS1, LSQ surveys
z = 0.5 – 4.0 in the PS1, SNLS surveys

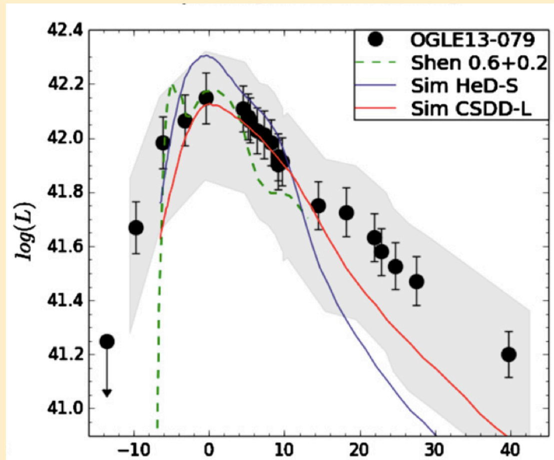
Goal with PESSTO is large sample, theory and analysis

See talk by Cosimo Inserra, poster by Janet Chen

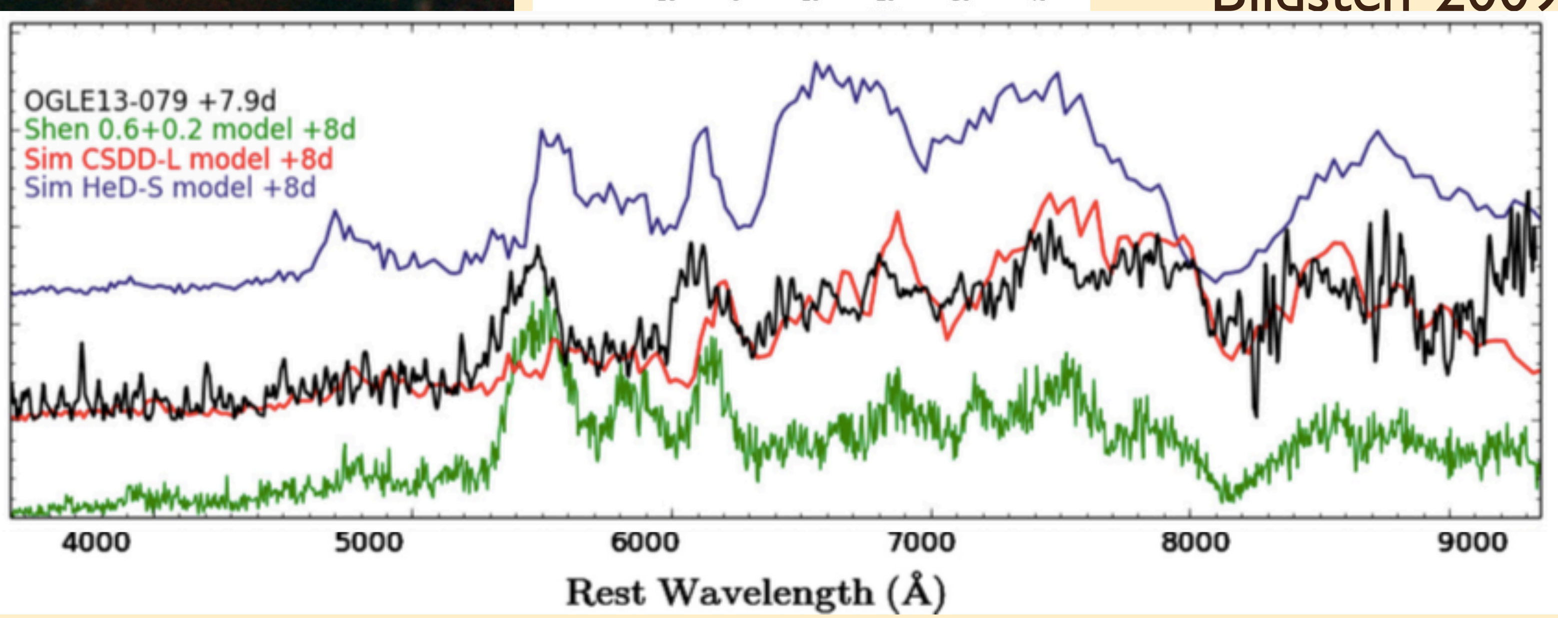
Quimby *et al. Nature* 2011
Chomiuk et al. 2011, Berger et al. 2012, Inserra et al. 2013, Nicholl et al. 2013,
Lunnan et al. 2013, Chornock et al. 2013, Cooke et al. 2012, Howell et al. 2013

OGLE13-79 : faint and fast fading



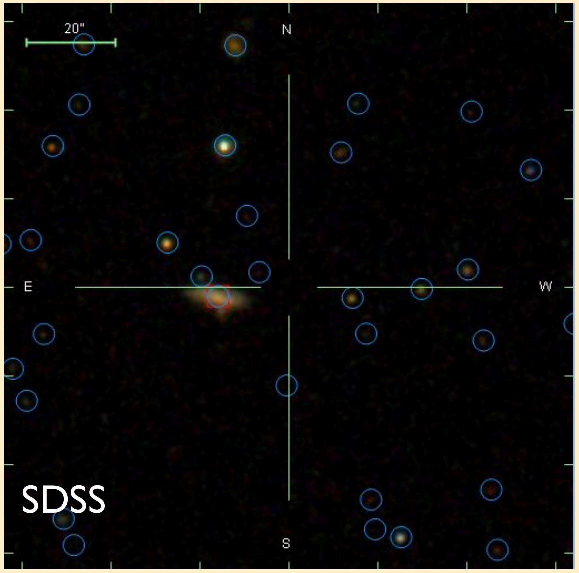


- Fainter than type Ia SNe
- Faster declining (factor 3) than SNe Ia
- ".Ia" = a tenth of a SN Ia (Bildsten et al. 2007, Shen & Bildsten 2009)

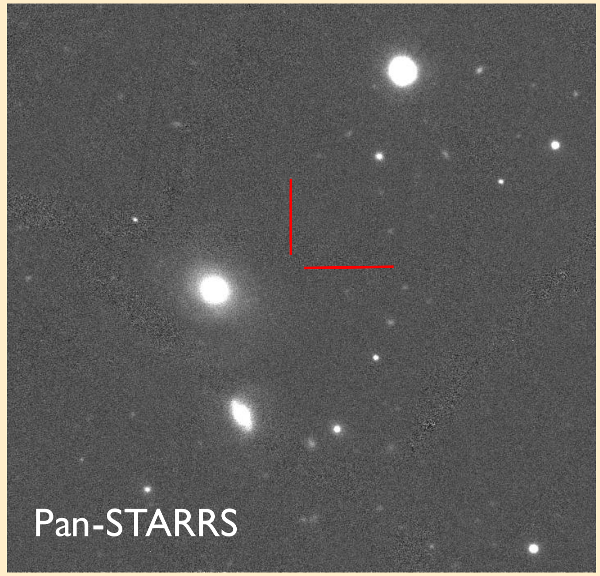


- He shell detonation on a low-mass WD
- Ti and Ca are expected burning products
- **<u>Inserra et al. 2015 ApJL</u>**

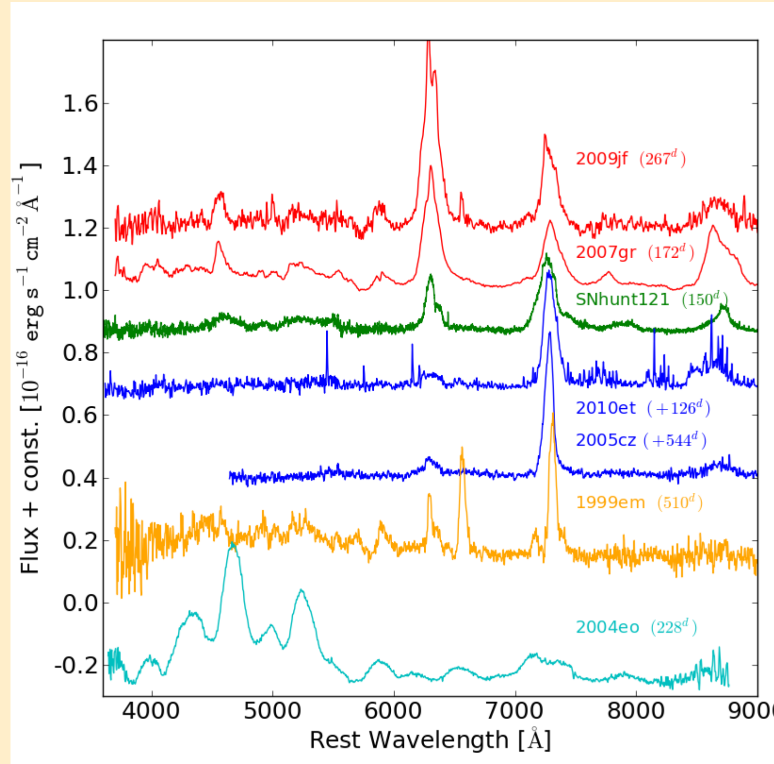
PESSTO Sample



- 20kpc from host
- Host + SN at z=0.07
- Peculiar, faint "type Ia"

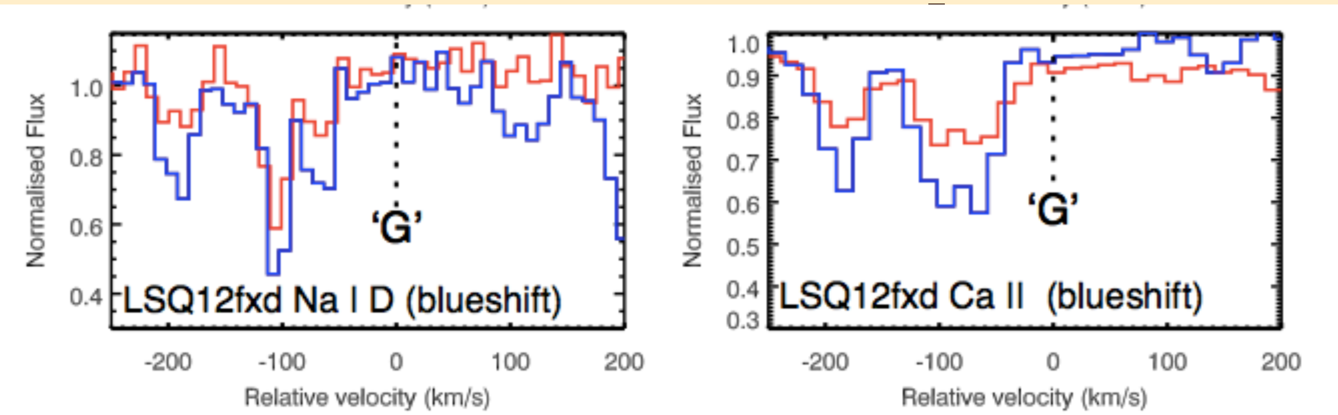


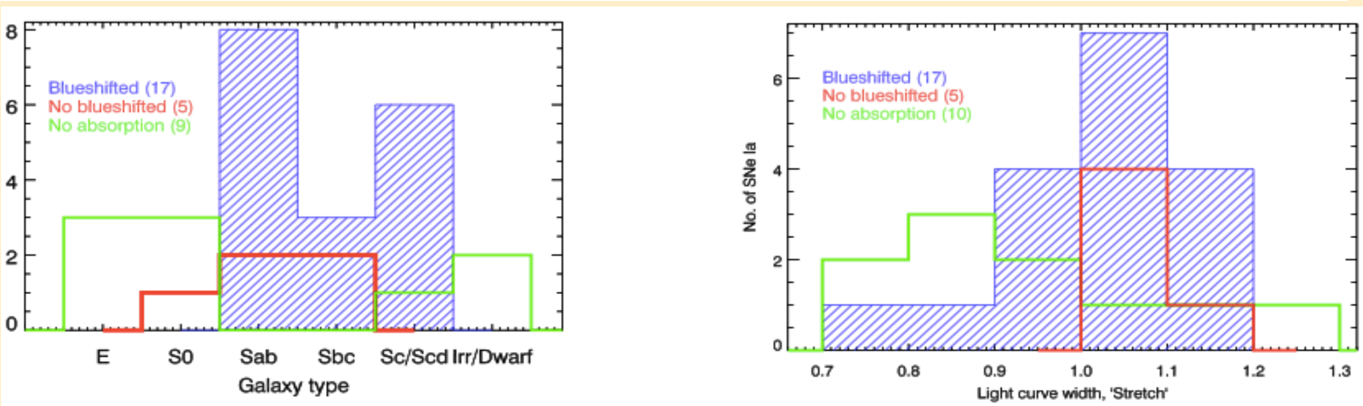
- 30kpc from host
- Host + SN at z=0.08
- Spectra -7d before max



- 10-15 PESSTO SNe followed in "remote locations" Science lead : Kate Maguire.
- How many SNe are found outside galaxies or no host ?
- Almost certainly <20% (likely ~15 ± 5%)

CSM absorption in SNe Ia

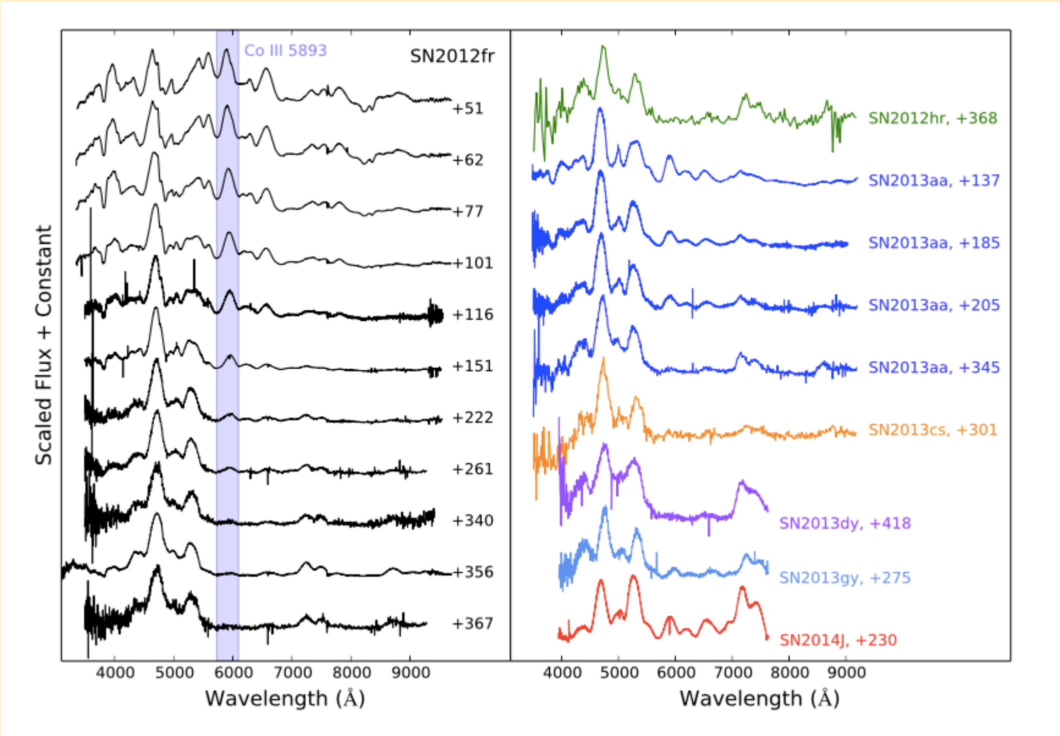


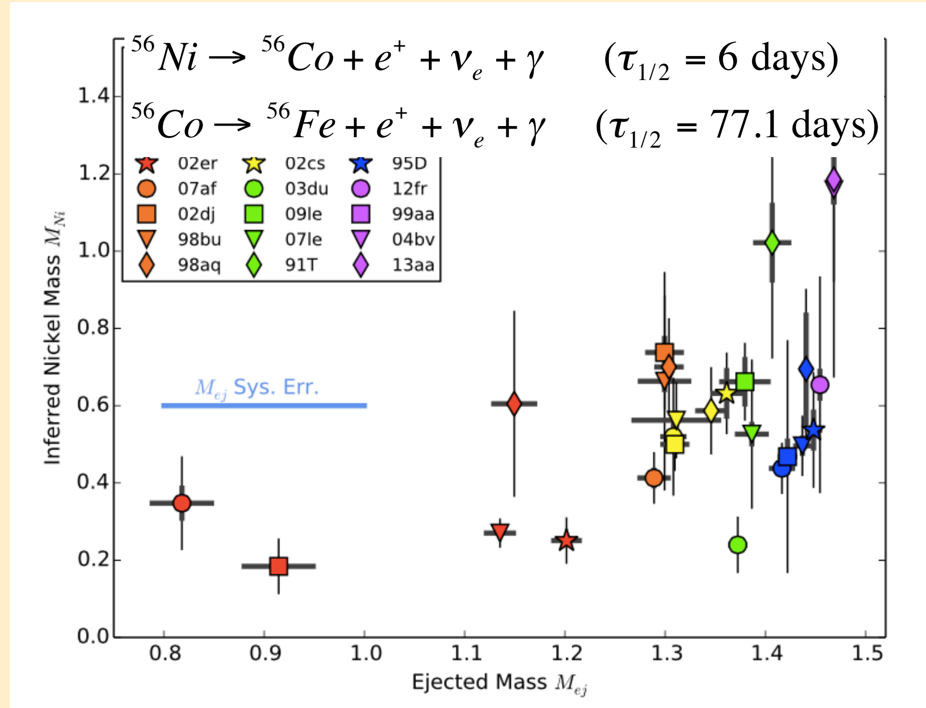


- 17 type Ia Sne
- Largest **sample** so far for this experiment
- PESSTO + xshooter
- Interstellar (circumstellar lines) toward type Ia SNe
- Classifications and spectra from PESSTO

- **Maguire et al. (2013)**
- Excess of SNe with blue shifted components (20%)
- They are more common in late type galaxies, and are broader, brighter lightcurves
- Implies *two distinct populations* of cosmologically useful SNe Ia

Cobalt in type Ia





- **<u>Childress et al. 2015</u>**
- Measurement of [Co III] λ5893 line fluxes
- New technique to determine mass of Co and Ni produced in explosion
- Two distinct explosions types :
  1. M_{Ch} and $0.7M_{\odot}$ of ^{56}Ni
  2. Sub-Chandra mass WDs and low ^{56}Ni
- All made possible with LARGE, uniform spectroscopic samples

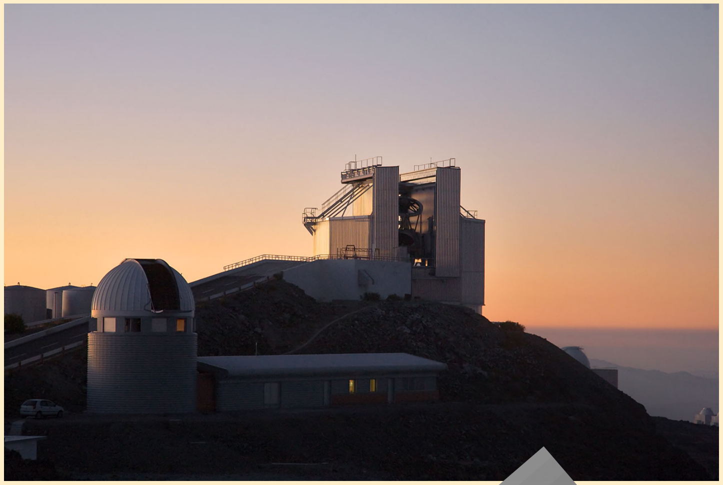
PESSTO 2016+

- On track for our target of about 150 targets by end of April 2016. And for finalised public data releases by 2016

- But major reasons to continue 2016-17 (for 5th year)
  - Link-up with GAIA Alerts
  - Faster turn around with our feeder surveys : ATLAS (Tonry et al) can survey all-sky twice per night. OGLE , ASASSN and Pan-STARRS2 major additions
  - ALIGO/VIRGO : gravitational wave transient sources. Formal MoU with PESSTO
  - New multi-wavelength triggering based on PESSTO : Swift, Chandra, ATCA, VLA, WRST and IRAM
  - VLT used efficiently : PESSTO filter for focused triggers
  - Large numbers of students trained at NTT – observing, but also decision making, target selection, efficient night planning
  - What would we do without PESSTO on NTT … apply for *n* number of incoherent proposals

2019+ : SOXS – “Son Of XShooter”

- PI Sergio Campana (Italy, UK, Chile, Denmark, Finland, Spain, Australia)
- Dedicated spectroscopic machine for the transient sky @ NTT
- 0.32 – 1.77 micron in one shot
- R ~ 4000
- Replaces EFOSC2 and SOFI
- Operations : á la PESSTO
- Follow-up of
  - SVOM, CTA : gamma ray bursts
  - LIGO/VIRGO : GW sources
  - Radio bursts
  - LSST (bright end)
  - Fast optical transients
  - X-ray binaries
  - Asteroids



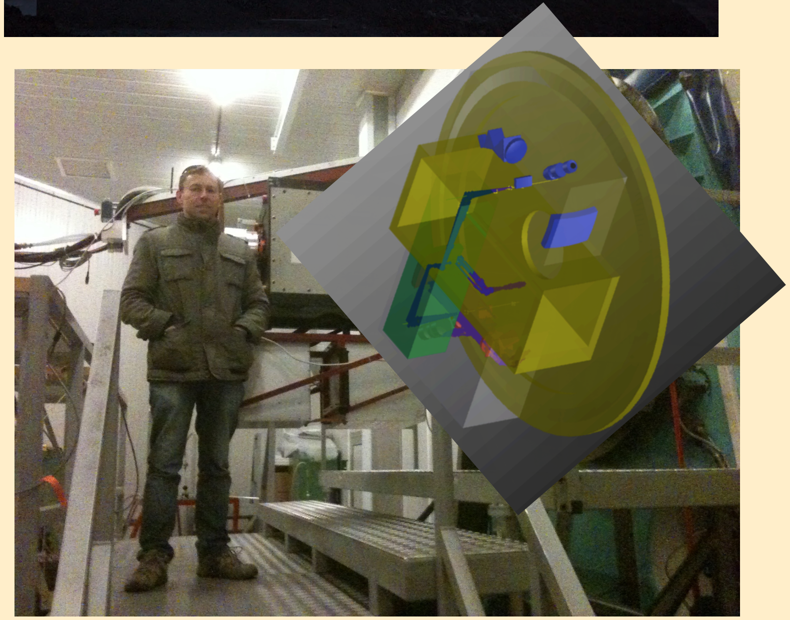


Image credit : S. Campana et al.

Long term future of NTT is transients and time domain

Backup slides

Optical Data Products

- EFOSC2 optical spectra
  - "C" (Classification setting) Gr13 : 3685-9315A, 1:00" slit produces 17.7 Å FWHM
  - "B" (Blue Setting) Gr11: 3380-7520A, 1:00" slit produces 13Å FWHM
  - "R" (Red Setting) Gr16 : 6015-10320A, 1:00" slit produces 13Å FWHM
  - Classification target range : $r < 19.5^m$ *(S/N in continuum > 20)*

Exp. Time	Mag	Continuum S/N (C)
1200s	19.5	18

1200s exposure means 1800s OB

NIR Data Products

- SOFI imaging : *JHK* for selected targets
- SOFI spectra for selected targets :
  - Blue Grism : 0.93-1.67μm
  - Red Grism : 1.50-2.50μm
  - Target range : $14 < H < 17$ (50 > *S/N in continuum > 20)*

- NIR for approximately half the targets (maybe less), with half the half the frequency
- 18% of PESSTO for SOFI means 1.5N during a lunation
- Cadence of 15 days (± 5d)

10 optical spectra for ~150 transients, cadence of 1-10d
NIR for half, half the frequency