GROWTH:

Global Relay of Observatories Watching Transients Happen

Mansi M. Kasliwal
California Institute of Technology

GROWTH
Global Relay of Observatories Watching Transients Happen

Thank you

NSF

PIRE

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE · FOUNDED 1932 ·

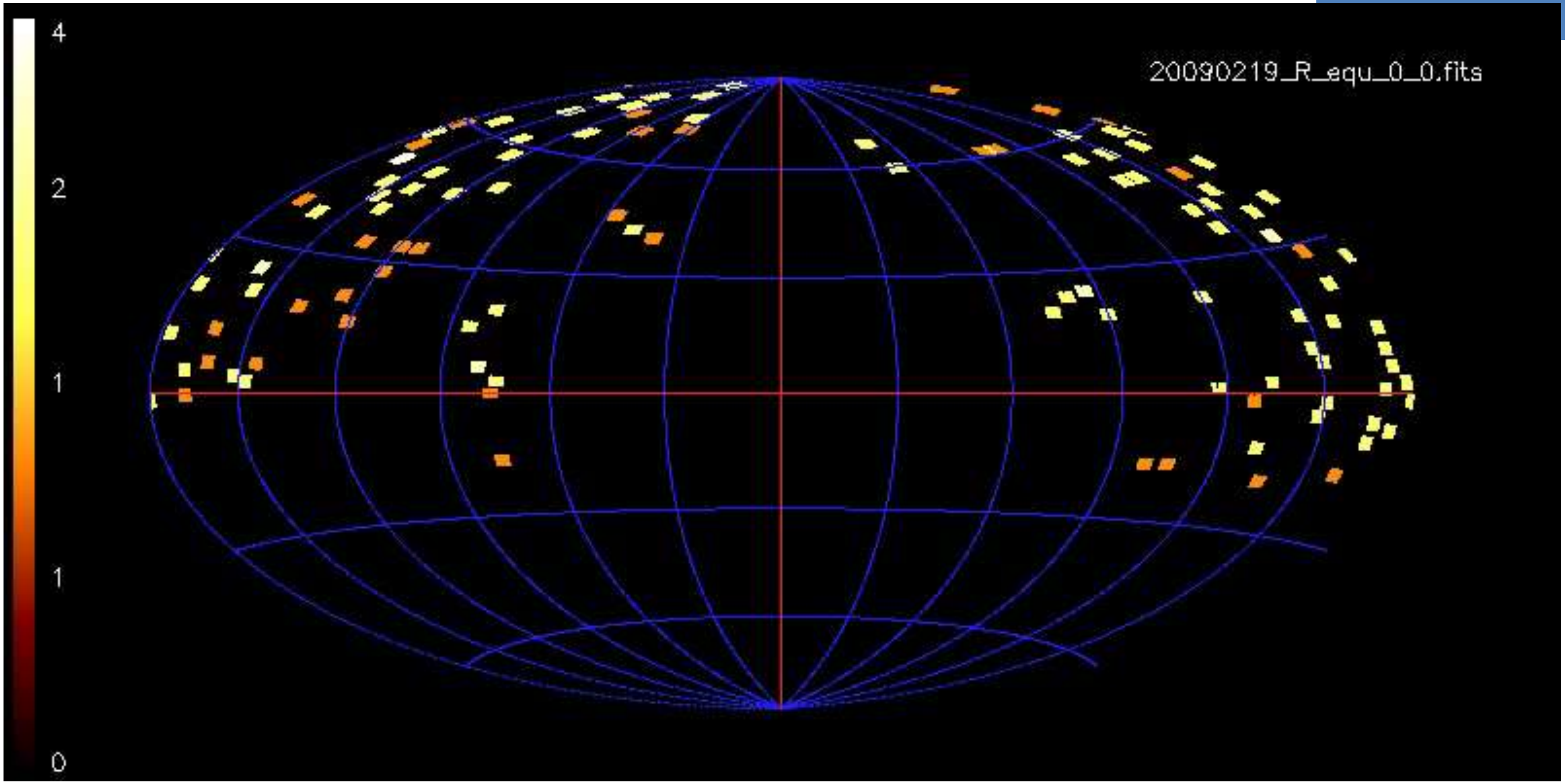
Ministry of Science and Technilogy

सत्यमेव जयते
Department of Science and Technology
Ministry of Science and Technology
Government of India

+ Independent Support for Sweden, Israel and Germany

Caltech · UNIVERSITY OF MARYLAND · Pomona College · San Diego State University · Weizmann Institute of Science · 東京工業大学 · UWM Milwaukee · Stockholm University · DESY · Los Alamos NATIONAL LABORATORY

A Renaissance in Time Domain Astronomy



Imagine: ZTF will be 12x Faster! LSST will be 16x Deeper!

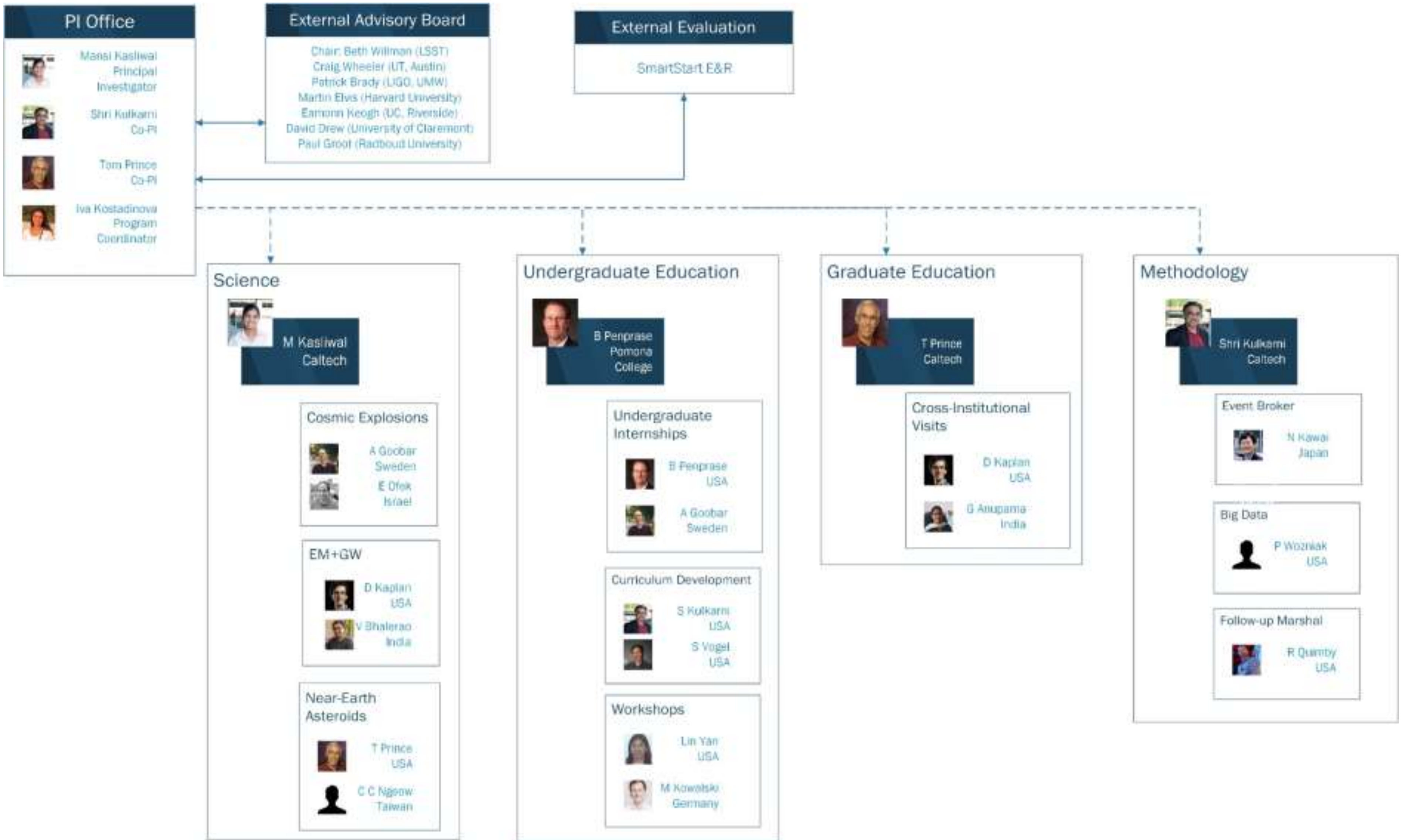
TDA in the LSST era

PTF: 4×10^4 events/night
ZTF: 3×10^5 events/night
LSST: 2×10^6 events/night

Technical	develop algorithms & software for detection & classification
Scientific	discover new transient & variable phenomena
Organizational	organize collaborations and followup strategies with real data

GROWTH builds a global community ready to contribute LSST time-domain science!

Organizational Chart



Beating Sunrise

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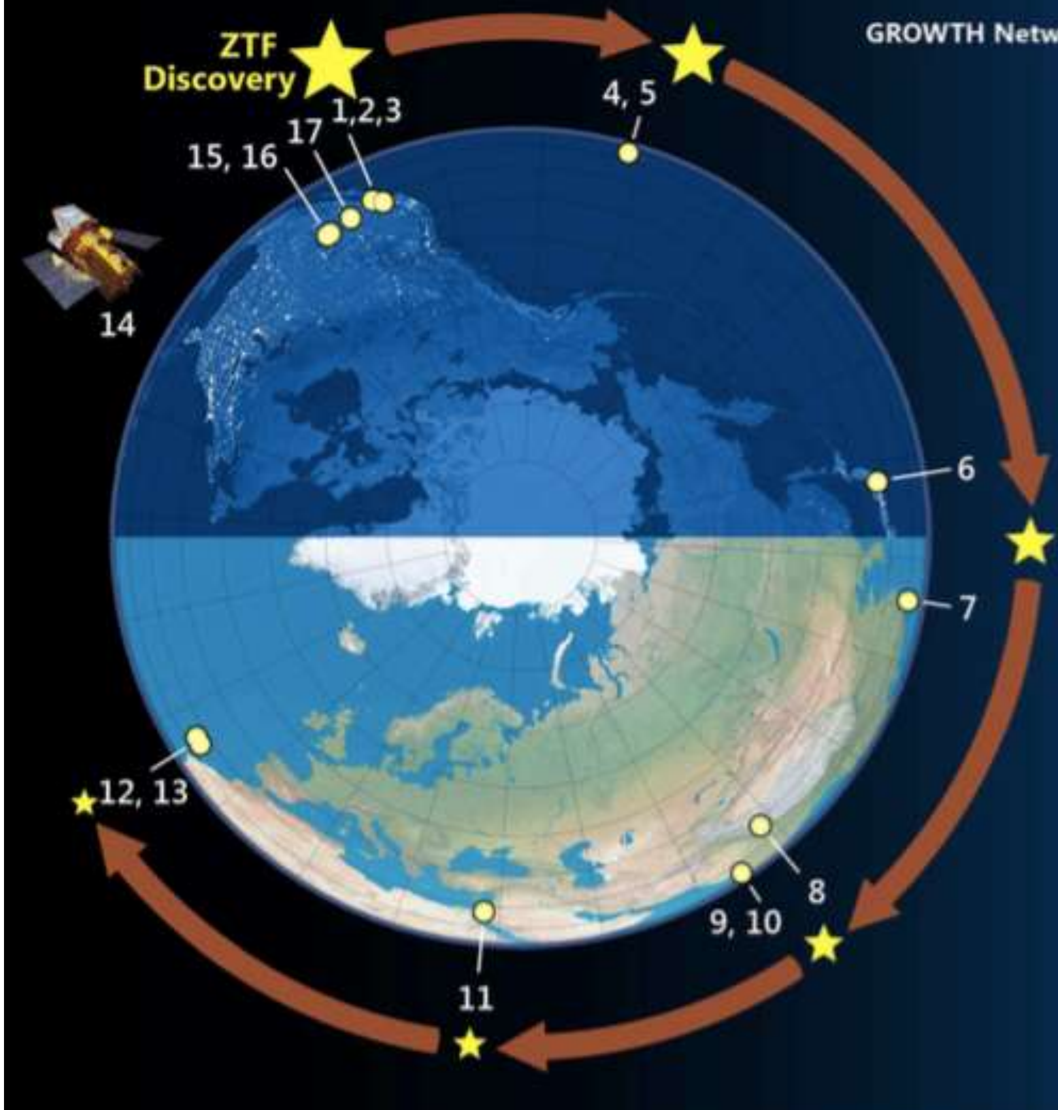

GROWTH Network:
1. **Palomar Observatory**
   Caltech (USA)
2. **Table Mountain Observatory**
   Pomona College (USA)
3. **Mount Laguna Observatory**
   San Diego State University (USA)
4. **Gemini North Observatory**
   NOAO (USA) - Mauna Kea
5. **W. M. Keck Observatory**
   Caltech (USA)
6. **Murikabushi Observatory**
   Tokyo Tech University (Japan)
7. **Lulin One-meter Telescope**
   National Central University (Taiwan)
8. **Himalayan Chandra Telescope**
   Indian Institute of Astrophysics (India)
9. **Giant Metrewave Radio Telescope**
   NCRA (India)
10. **IUCAA Girawali Observatory**
    IUCAA (India)
11. **WISE Observatory**
    Weizmann Institute (Israel)
12. **Stella Observatory**
    Humboldt University (Germany)
13. **Nordic Optical Telescope**
    Oskar Klein Centre (Sweden)
14. **Swift Satellite (Ultraviolet and X-ray)**
    NASA (USA)
15. **Expanded Very Large Array (Radio)**
    NRAO (USA)
16. **Fenton Hill Observatory**
    Los Alamos National Laboratory (USA)
17. **Discovery Channel Telescope**
    University of Maryland/JSI (USA)

\+ **University of Wisconsin-Milwaukee**

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Team Never Sleeps!

+ Przemek Wozniak

New Partner: UK

WELCOME

Dan Perley
Matt Darnley
Paolo Mazzali
Iain Steele

GROWTH is growing!

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Powerhouse: Young Researchers

Postdoctoral Fellows

Name	Home Institutions
Ragnhild Lunnan	Caltech, USA
Eric Bellm	Caltech, USA
Carrie Nugent	Caltech, USA
Nadia Blagorodnova	Caltech, USA
David Cook	Caltech, USA
Thomas Kupfer	Caltech, USA
Quanzhi Ye	Caltech, USA
Scott Adams	Caltech, USA
Angie van Sistine	UWM, USA
Branimir Sesar	MPIA, Germany
Roy Rupak	University of Stockholm, Sweden
Ulrich Feindt	University of Stockholm, Sweden
Rahman Amanullah	University of Stockholm, Sweden
Hidekazu Hanayama	Ishigakijma Observatory, NAOJ, Japan
Yoshihiko Saito	Tokyo Institute of Technology, Japan
Ryosuke Itoh	Tokyo Institute of Technology, Japan
Leo Singer	NASA, USA

PhD Students

Name	Home Institution
Yi Cao	Caltech, USA
Anna Ho	Caltech, USA
Hong Qi	UWM, USA
Javed Jana	IUCAA, India
Francesco Taddia	University of Stockholm, Sweden
Anders Nyholm	University of Stockholm, Sweden
Emir K	University of Stockholm, Sweden
Tanja Petrushevska	University of Stockholm, Sweden
Semeli Papadogiannakis	University of Stockholm, Sweden
Laura Hangard	University of Stockholm, Sweden
Raphael Ferretti	University of Stockholm, Sweden
Yutaro Tachibana	Tokyo Institute of Technology, Japan
Taketoshi Yoshii	Tokyo Institute of Technology, Japan
Taichi Fujiwara	Tokyo Institute of Technology, Japan
Shohei Harita	Tokyo Institute of Technology, Japan
Yutaro Muraki	Tokyo Institute of Technology, Japan
Barak Zackay	Weizmann Institute of Science, Israel
Guy Nir	Weizmann Institute of Science, Israel
Tiara Hung	University of Maryland, USA
Vicki Toy	University of Maryland, USA

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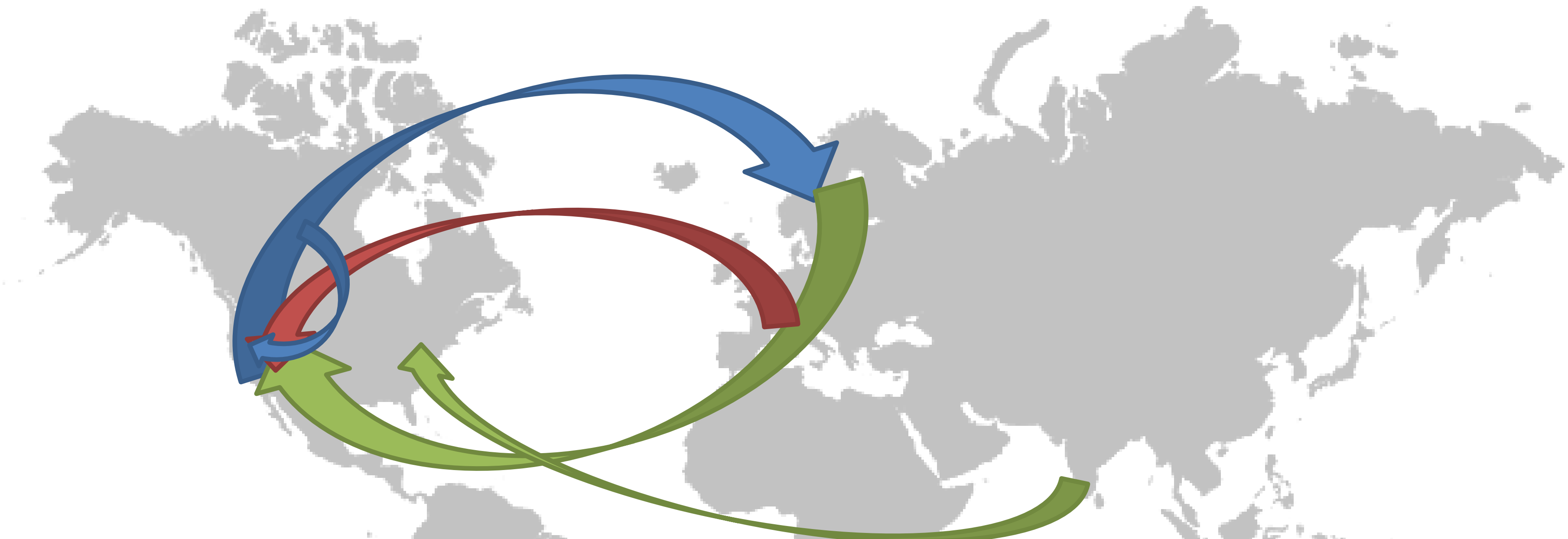
Grad/Postdoc Internships



5 graduate/postdoc internships

Ragnhild Lunnan (Caltech) → Oskar Klein Center, Sweden
Christopher Fleming (Sweden) → Caltech, USA
Monika Soraisam (Germany) → Caltech, USA
Javed Rana (India) → Caltech & Univ. of Maryland, USA
Jessica Sutter (University of Wyoming) → Caltech

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Graduate/Postdoc Internships

Nov,2015

Monica Soraisam

Caltech

iPTF M31 transient detection

Ragnhild Lunnan

Caltech → Stockholm University

Nebular Spectroscopy of Superluminous Supernovae

Christoffer Fleming

Stockholm University → Caltech

Spectral Analysis of stripped envelope supernovae discovered by PTF and iPTF

Jessica Sutter

University of Wyoming → Caltech

Follow-up spectroscopy for Census of the Local Universe (CLU) galaxy survey

Javed Rana

University of Maryland

Caltech

Observational scheduling for optical EMGW follow up & Estimation of GW counterparts from premerger of binary neutron stars

Aug,2016

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Undergrad Internships

5 undergraduate summer internships awarded in 2016

Melanie Olaes (SDSU) → Eran Ofek (Weizmann Institute of Science, Israel
Gabrielle Mehta (Pomona College) → Varun Bhalerao (IUCAA, India) + Bryan Penprase (Pomona College)
Shreya Anand (Univ of Maryland) → Wen-Ping Chen (National Central University, Taiwan)
Kit Chinnetti (Caltech) → Matt Darnley (Liverpool John Moores University, UK
Atharva Patil (IUCAA, India) → Chow-Choong Ngeow (National Central University, Taiwan)

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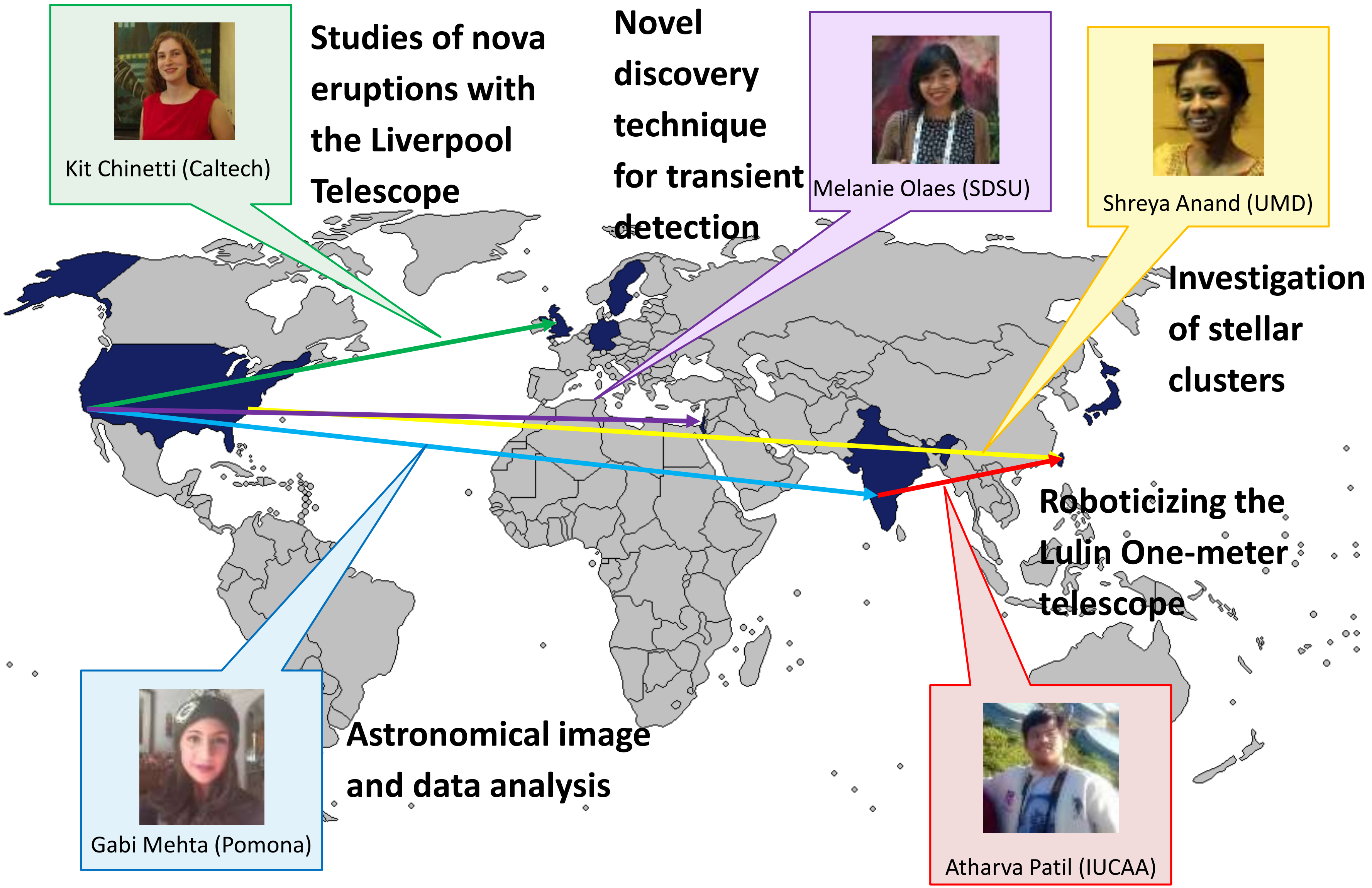
Undergraduate Internships 2016



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Undergraduate Internships 2016

I found a nova! iPTF16bqy is my first little contribution to transient discoveries.

[Previous | Next]

Independent discovery and spectroscopic classification of iPTF16bqy (ASASSN-16hf) as a Classical Nova in M31

ATel #9248; *K. Chinetti (Caltech), M. J. Darnley (LJMU), M. M. Kasliwal (Caltech), P. Mazzali (LJMU), J. D. Neill (Caltech), S. C. Williams (Lancaster)*
on ***15 Jul 2016; 18:59 UT***
Credential Certification: Matt Darnley (M.J.Darnley@ljmu.ac.uk)

Subjects: Optical, Nova, Transient

Tweet | Recommend 6

We report the independent discovery of nova candidate iPTF16bqy (ASASSN-16hf; ATel #9245) on 2016 July 12.44 UT with the intermediate Palomar Transient Factory. iPTF16bqy is located at RA 00:44:41.05, DEC +40:08:35.9 (J2000.0; consistent with the ASASSN position), and was not detected in images taken 2016 July 10.47 and earlier. Photometry of the transient with the Samuel Oschin 48-inch telescope is summarized in the table below:

Date (UT)	Filter	Magnitude
2016 July 12.44	r	18.76 ± 0.05
2016 July 13.47	r	17.03 ± 0.06
2016 July 14.44	r	16.32 ± 0.06
2016 July 15.43	r	16.71 ± 0.07

We also obtained a pair of spectra with the SPRAT spectrograph (Piascik et al. 2014) on the 2m Liverpool Telescope (Steele et al. 2004) on 2016 July 14.12 and 15.07 UT. An additional spectrum was obtained with the SEDM spectrograph on the Palomar 60-in telescope on 2016 July 14. The spectra show Balmer (Hα-δ) P Cygni profiles, consistent with the early optically thick phase of a classical nova eruption (the 'fireball'). The Hα P Cygni profiles indicate ejection velocities of 2300 ± 100 km/s. The spectra also show Fe II (multiplets 42, 73, 74), Na I (5892 Å), and O I (7713 Å) emission lines, with hints of blue shifted absorption components. Clear evolution of the P Cygni profiles is evident between the spectra with the absorption features weakening and the emission strengthening as the ejecta expands. As such we conclude that iPTF16bqy is the early stage of an eruption of a classical nova in M31 and belongs to the Fe II taxonomic class.

Finally, we comment that the large distance of this nova from the center of M31 (4053" South and 1338" East of the center of M31; ATel #9245) is in itself noteworthy. The emission line centers and the luminosity of this nova are however, consistent with the nova belonging to M31.

This work is part of an international undergraduate internship supported by the NSF PIRE GROWTH program.

Courses

COMPLETED
Ay 3: Automating Discovering the Universe
Offered at Caltech, Winter 2015

UPCOMING
Undergraduate major course
To be offered at Univ of Maryland, Univ. of Wisconsin Milwaukee and Pomona College

Goal: Ramp up to six co-ordinated courses per semester by Year 5. Publish curriculum.

Lead: Bryan Penprase

Educators Workshop to co-develop curriculum

ACTIVE LEARNING	FLIPPED	LABORATORY	PROJECT-based and RESEARCH
In Class Activities and Peer Learning Exercises Conceptual Questions Projects Using GROWTH data	Online Tutorials for Common Topics	Observational Astronomy Exercises Laboratory Experiments	Shared Journal Article "case studies" Student Developed Reports and Research

Parallel Global Observational Astronomy Course - Possible Weekly Schedule

Week 1	Week 2	Week 3	Week 4	Weeks 5+6	Week 7
Telescope Design, CCD detectors, Astronomical Coordinates	Astrometry Exercise (parallax or orbit determination)	Basic Photometry (measurement of HR diagram)	Time-Domain Photometry - light curve + periodogram	Submit Proposals for student projects + conduct observing	Presentations and writeups of student work
Begin Project (semester or quarter)	Students at multiple campuses share data	Professors share tutorials, and students pool data for photometry	Multiple student groups can provide 24-hour coverage of time-variable sources	Global student research community can share data analysis tips and telescope time	

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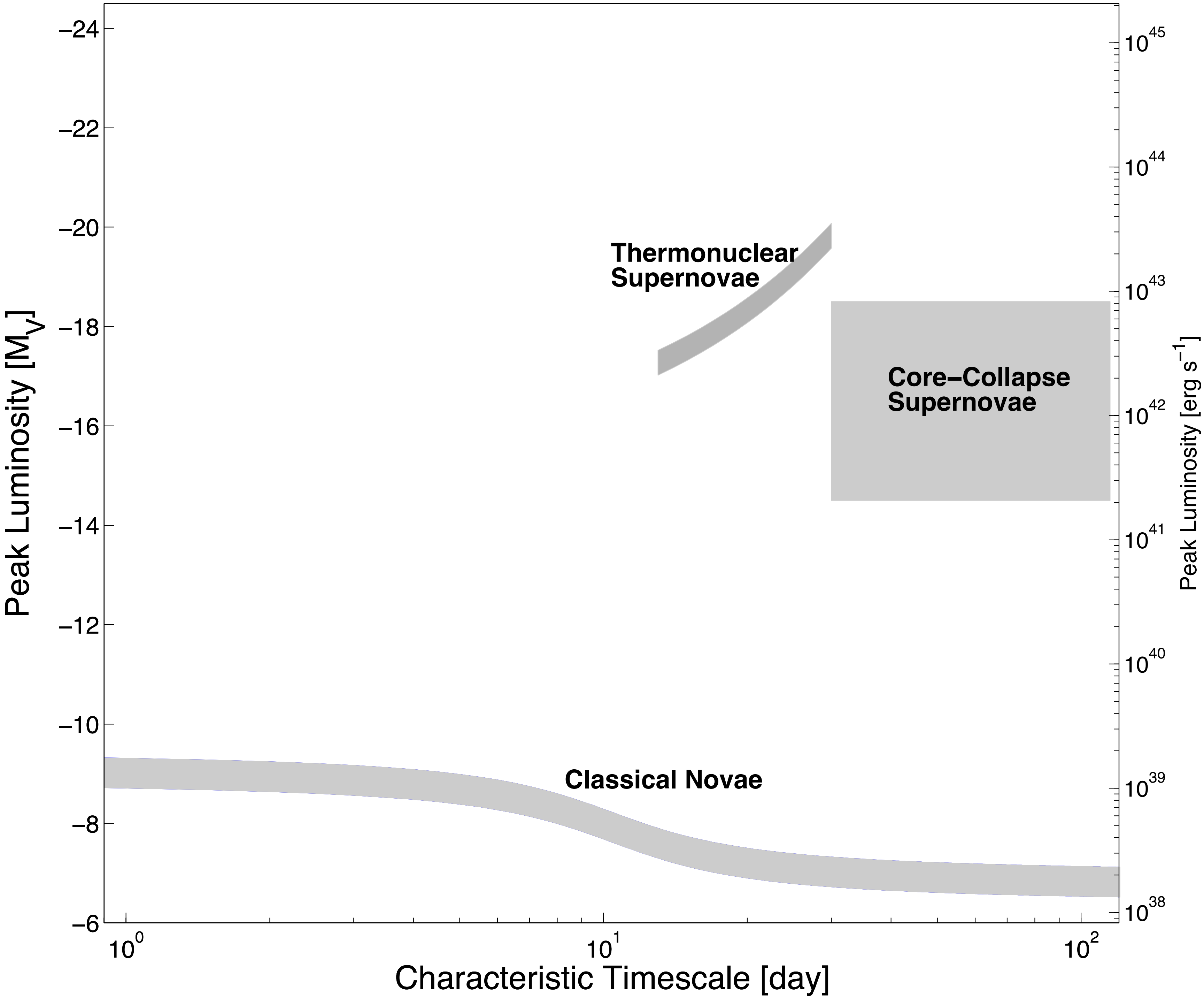
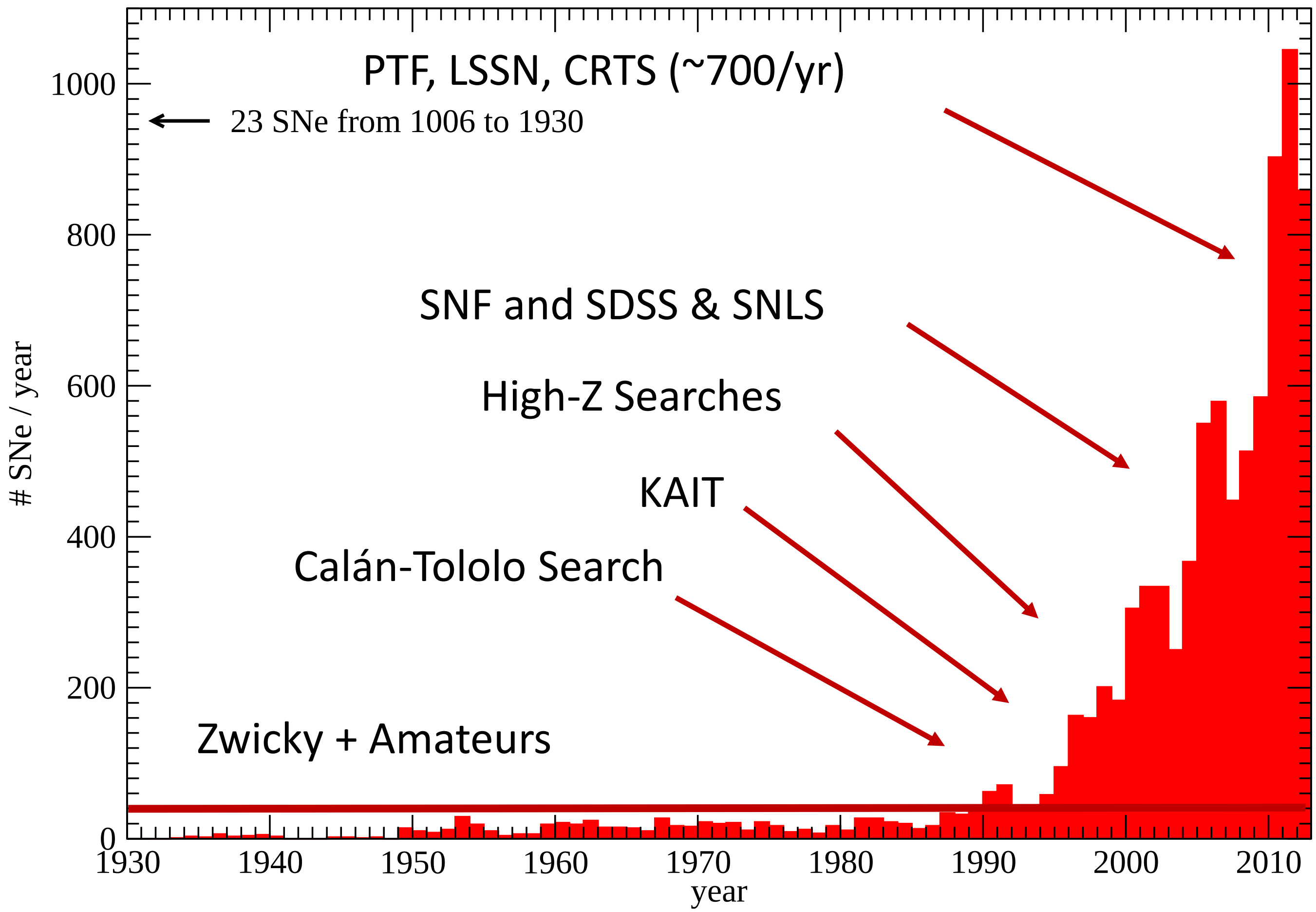
Publications

#	Bibcode / Authors	Score / Title	Date	List of Links / Access Control Help
1	2016arXiv160605655C Cao, Yi; Kulkarni, S. R.; Gal-Yam, Avishay; Papadogiannakis, S.; Nugent, P. E.; Masci, Frank J.; Bue, Brian D.	1.000 SN2002es-like Supernovae From Different Viewing Angles	06/2016	A X R U
2	2016ApJ...824L..24K Kasliwal, M. M.; Cenko, S. B.; Singer, L. P.; Corsi, A.; Cao, Y.; Barlow, T.; Bhalerao, V.; Bellm, E.; Cook, D.; Duggan, G. E.; and 21 coauthors	1.000 iPTF Search for an Optical Counterpart to Gravitational-wave Transient GW150914	06/2016	A E F X R C S U
3	2016ApJ...824....6O Ofek, E. O.; Cenko, S. B.; Shaviv, N. J.; Duggan, G.; Strotjohann, N.-L.; Rubin, A.; Kulkarni, S. R.; Gal-Yam, A.; Sullivan, M.; Cao, Y.; and 8 coauthors	1.000 PTF13efv — An Outburst 500 Days Prior to the SNHunt 275 Explosion and Its Radiative Efficiency	06/2016	A E F X R C S U
4	2016ApJ...823..147C Cao, Yi; Johansson, J.; Nugent, Peter E.; Goobar, A.; Nordin, Jakob; Kulkarni, S. R.; Cenko, S. Bradley; Fox, Ori D.; Kasliwal, Mansi M.; Fremling, C.; and 7 coauthors	1.000 Absence of Fast-moving Iron in an Intermediate Type Ia Supernova between Normal and Super-Chandrasekhar	06/2016	A E F X R C S U
5	2016MNRAS.458.2973P Prentice, S. J.; Mazzali, P. A.; Pian, E.; Gal-Yam, A.; Kulkarni, S. R.; Rubin, A.; Corsi, A.; Fremling, C.; Sollerman, J.; Yaron, O.; and 7 coauthors	1.000 The bolometric light curves and physical parameters of stripped-envelope supernovae	05/2016	A E F X R C U
6	2016arXiv160505235L Lunnan, R.; Chornock, R.; Berger, E.; Milisavljevic, D.; Jones, D. O.; Rest, A.; Fong, W.; Fransson, C.; Margutti, R.; Drout, M. R.; and 20 coauthors	1.000 PS1-14bj: A Hydrogen-Poor Superluminous Supernova With a Long Rise and Slow Decay	05/2016	A X R C U
7	2016arXiv160502491T Taddia, F.; Fremling, C.; Sollerman, J.; Corsi, A.; Gal-Yam, A.; Karamehmetoglu, E.; Lunnan, R.; Bue, B.; Ergon, M.; Kasliwal, M.; and 2 coauthors	1.000 iPTF15dtg: a double-peaked Type Ic Supernova from a massive progenitor	05/2016	A X C U
8	2016arXiv160307333S Singer, L. P.; Chen, H.-Y.; Holz, D. E.; Farr, W. M.; Price, L. R.; Raymond, V.; Cenko, S. B.; Gehrels, N.; Cannizzo, J.; Kasliwal, M. M.; and 10 coauthors	1.000 Going the Distance: Mapping Host Galaxies of LIGO and Virgo Sources in Three Dimensions Using Local Cosmography and Targeted Follow-up	03/2016	A X R C U
9	2016ApJ...820...33R Rubin, Adam; Gal-Yam, Avishay; De Cia, Annalisa; Horesh, Assaf; Khazov, Danny; Ofek, Eran O.; Kulkarni, S. R.; Arcavi, Iair; Manulis, Ilan; Yaron, Ofer; and 30 coauthors	1.000 Type II Supernova Energetics and Comparison of Light Curves to Shock-cooling Models	03/2016	A E F X D R C S O U
10	2016ascl.soft02002B Bellm, Eric C.; Sesar, Branimir	1.000 pyraf-dbsp: Reduction pipeline for the Palomar Double Beam Spectrograph	02/2016	A E O U
11	2016arXiv160208492A Abbott, B. P.; Abbott, R.; Abbott, T. D.; Abernathy, M. R.; Acernese, F.; Ackley, K.; Adams, C.; Adams, T.; Addesso, P.; Adhikari, R. X.; and 1537 coauthors	1.000 Localization and broadband follow-up of the gravitational-wave transient GW150914	02/2016	A X R C U
12	2016ApJ...818....3K Khazov, D.; Yaron, O.; Gal-Yam, A.; Manulis, I.; Rubin, A.; Kulkarni, S. R.; Arcavi, I.; Kasliwal, M. M.; Ofek, E. O.; Cao, Y.; and 17 coauthors	1.000 Flash Spectroscopy: Emission Lines from the Ionized Circumstellar Material around <10-day-old Type II Supernovae	02/2016	A E F X R C S U
13	2016arXiv160107368T Taddia, F.; Sollerman, J.; Fremling, C.; Migotto, K.; Gal-Yam, A.; Armen, S.; Duggan, G.; Ergon, M.; Filippenko, A. V.; Fransson, C.; and 10 coauthors	1.000 Long-rising Type II supernovae from PTF and CCCP	01/2016	A X R U
14	2015arXiv151201303C Corsi, A.; Gal-Yam, A.; Kulkarni, S. R.; Frail, D. A.; Mazzali, P. A.; Cenko, S. B.; Kasliwal, M. M.; Cao, Y.; Horesh, A.; Palliyaguru, N.; and 8 coauthors	1.000 Radio observations of a sample of broad-lined type Ic supernovae discovered by PTF/iPTF: A search for relativistic explosions	12/2015	A X R U
15	2015ApJ...814..108Y Yan, Lin; Quimby, R.; Ofek, E.; Gal-Yam, A.; Mazzali, P.; Perley, D.; Vreeswijk, P. M.; Leloudas, G.; De Cia, A.; Masci, F.; and 7 coauthors	1.000 Detection of Broad Hα Emission Lines in the Late-time Spectra of a Hydrogen-poor Superluminous Supernova	12/2015	A E F X D R C S N U



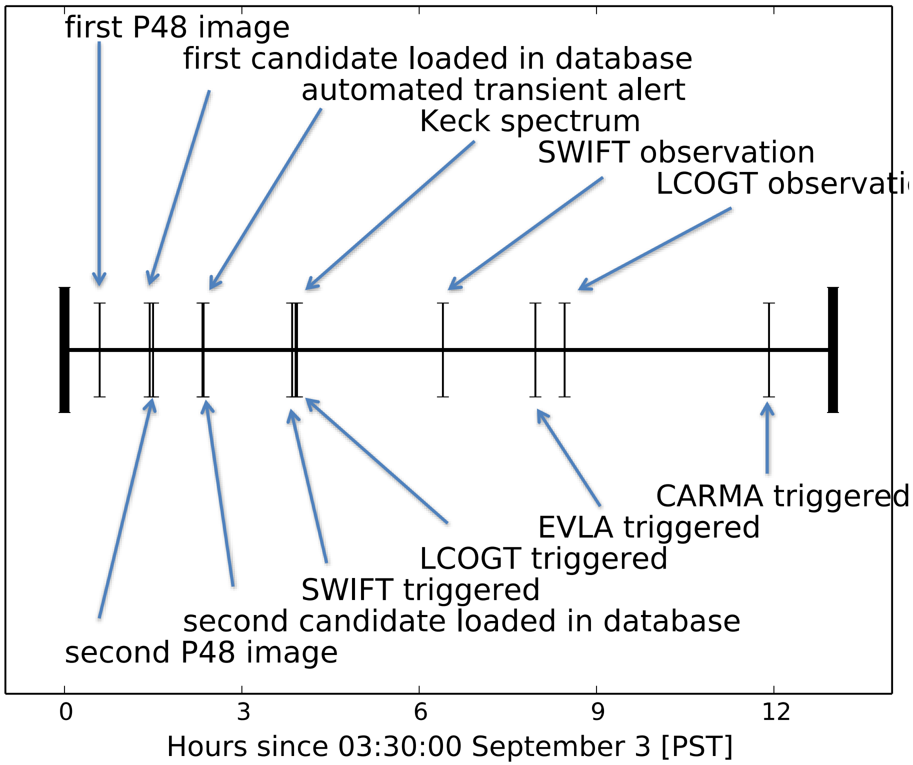
Updated from Kasliwal 2011 (PhDT)

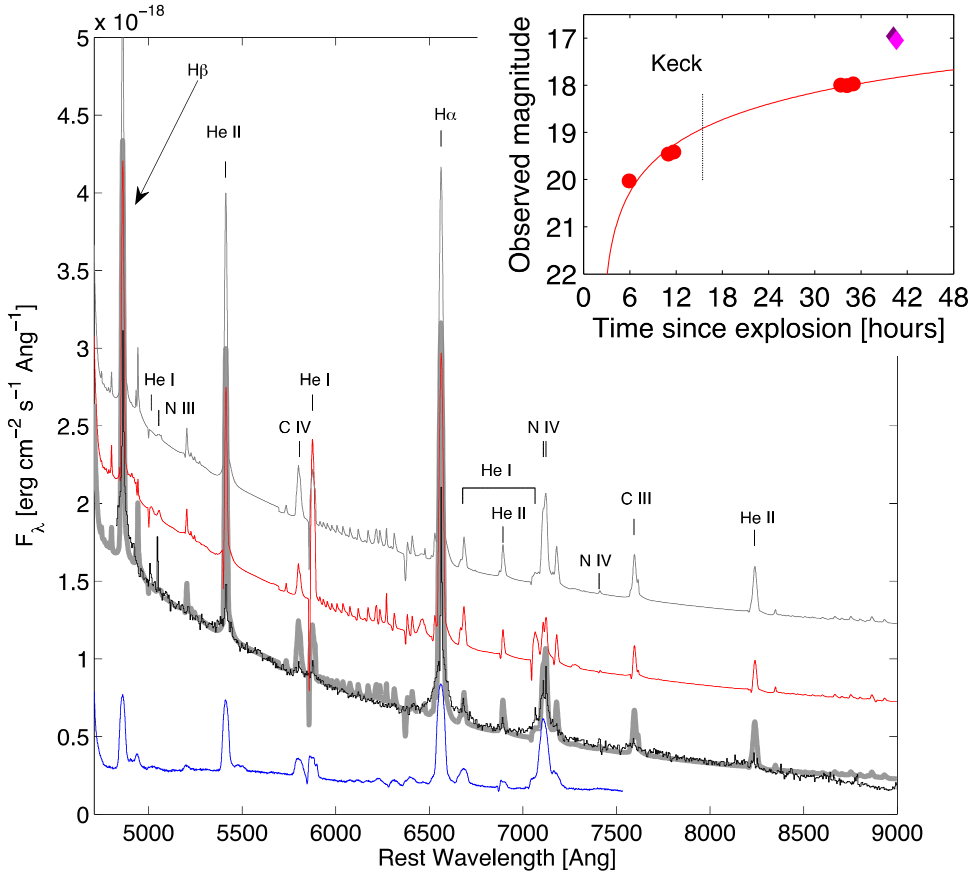
Supernova Discoveries



I. Infant Supernovae

Connecting the type of star to its explosion

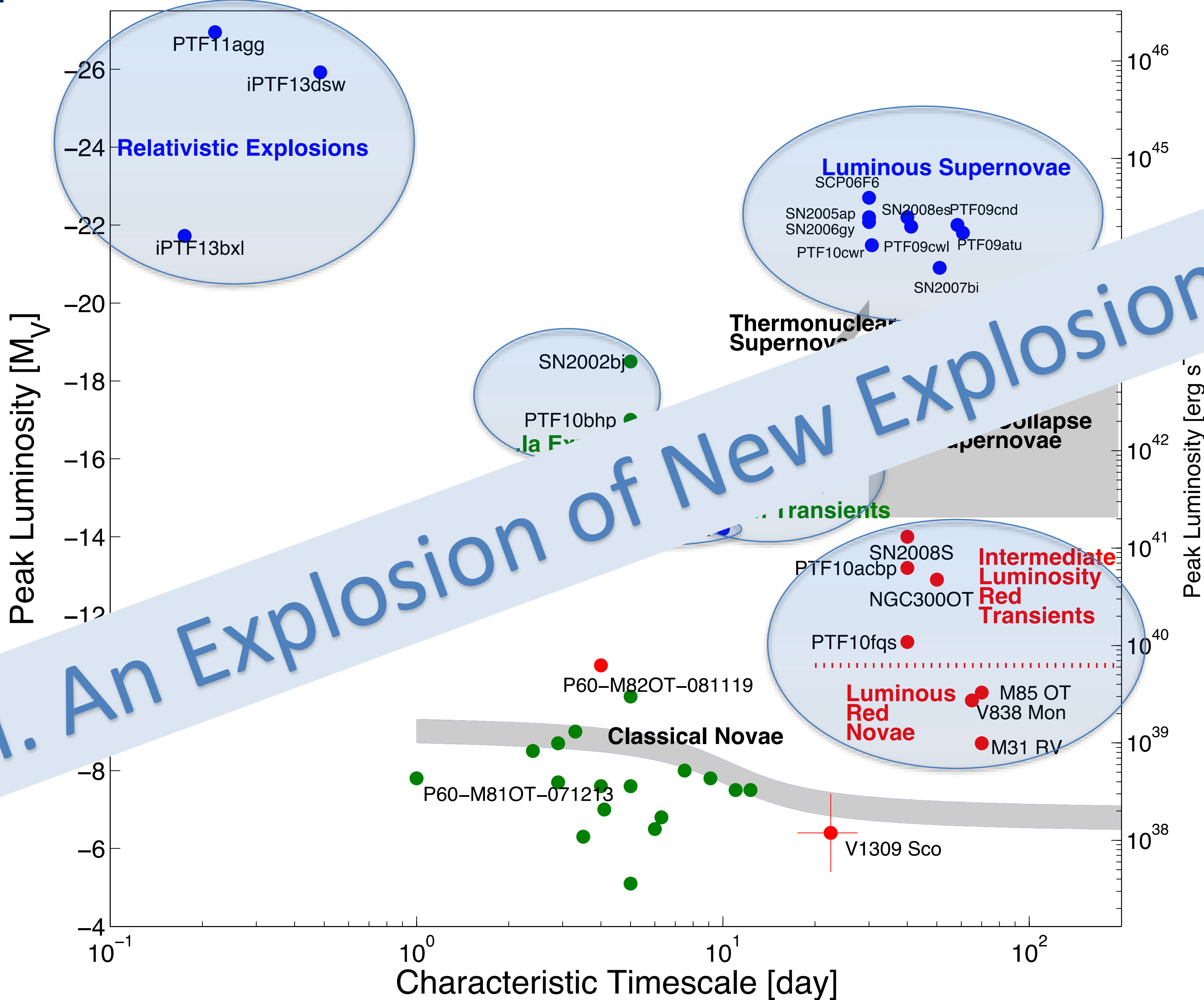




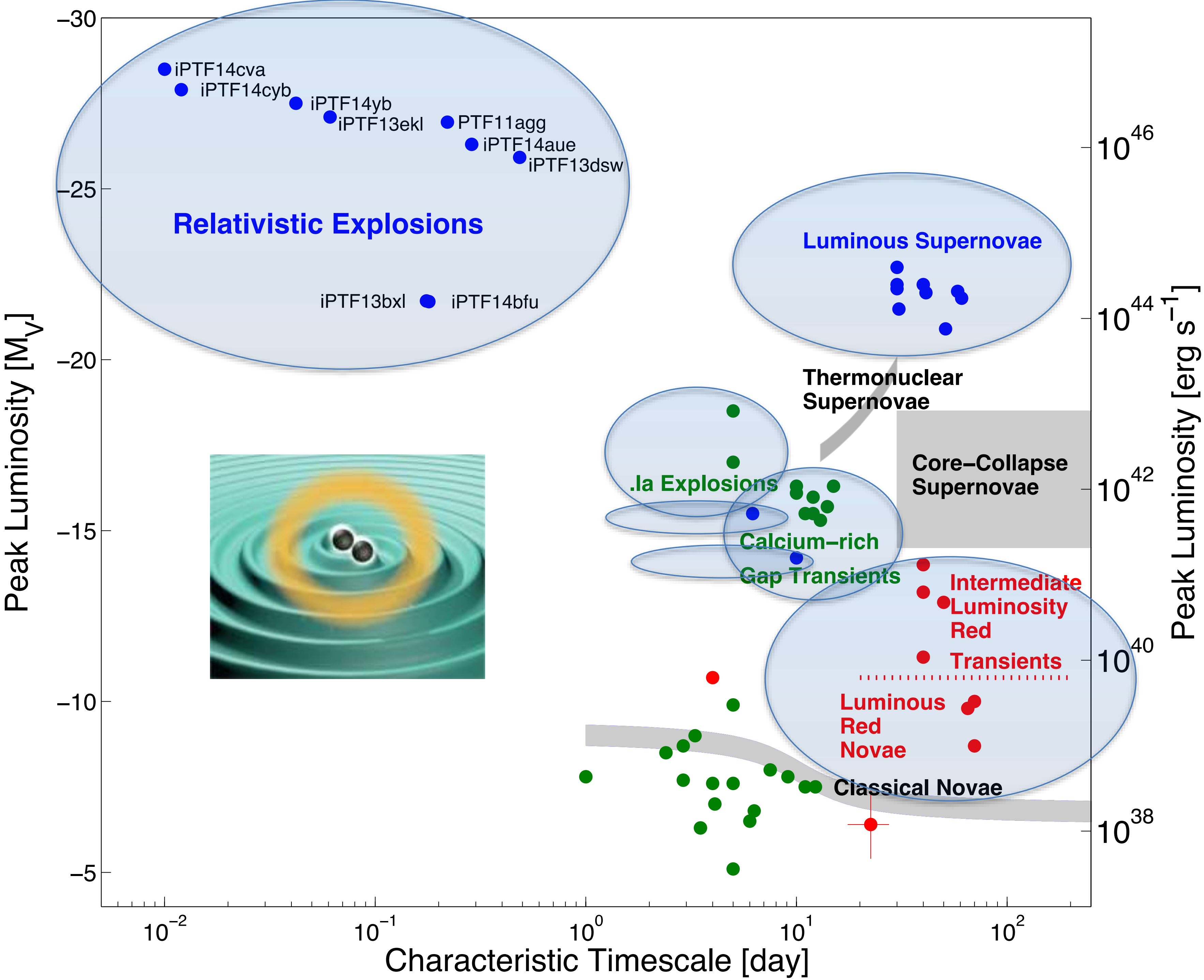
Gal-Yam et al. 2014, Nature

Young Type I: Yi Cao (PhDT)
Young Type II: Adam Rubin (PhDT)

II. An Explosion of New Explosions

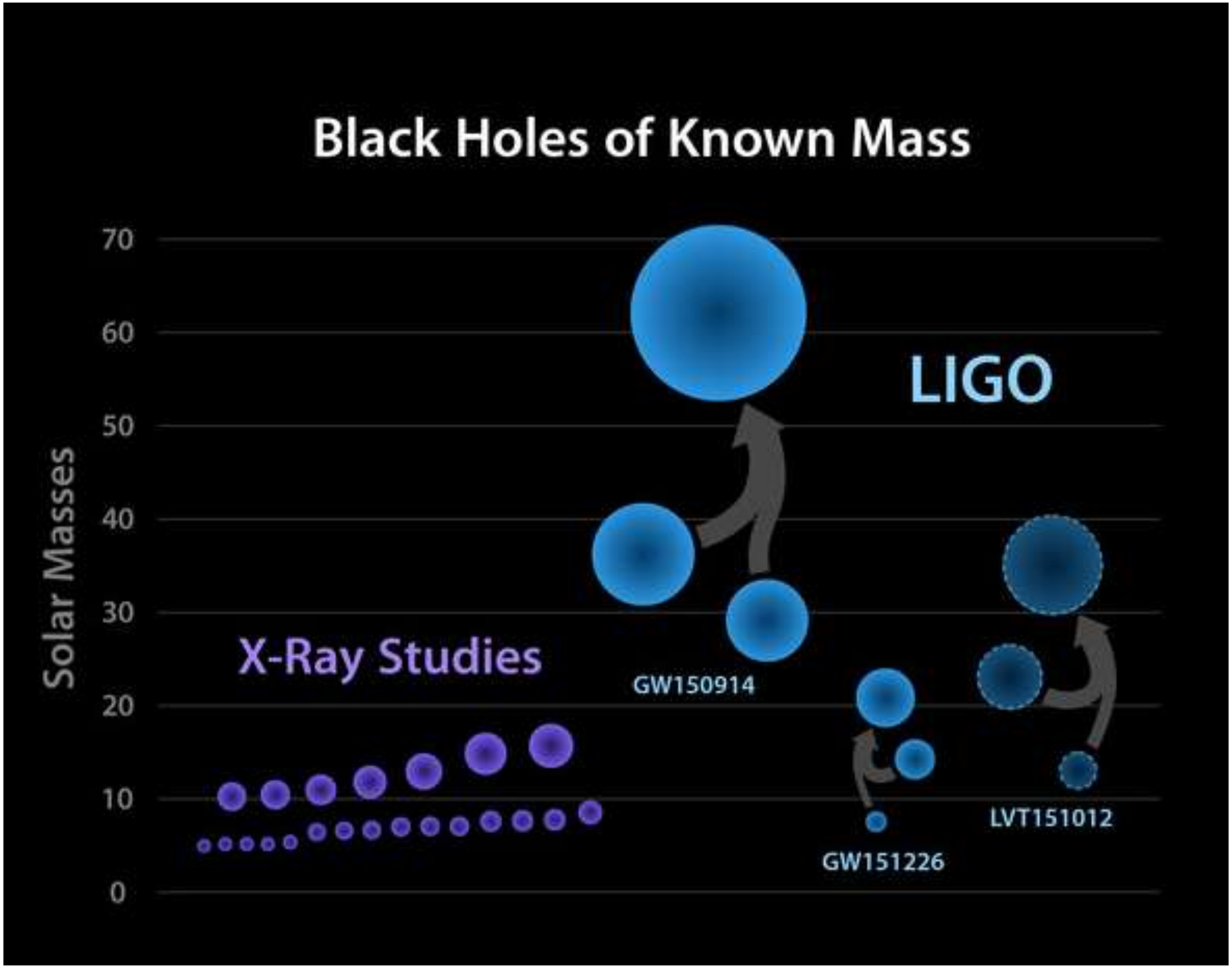


Updated from Kasliwal 2011 (PhDT)

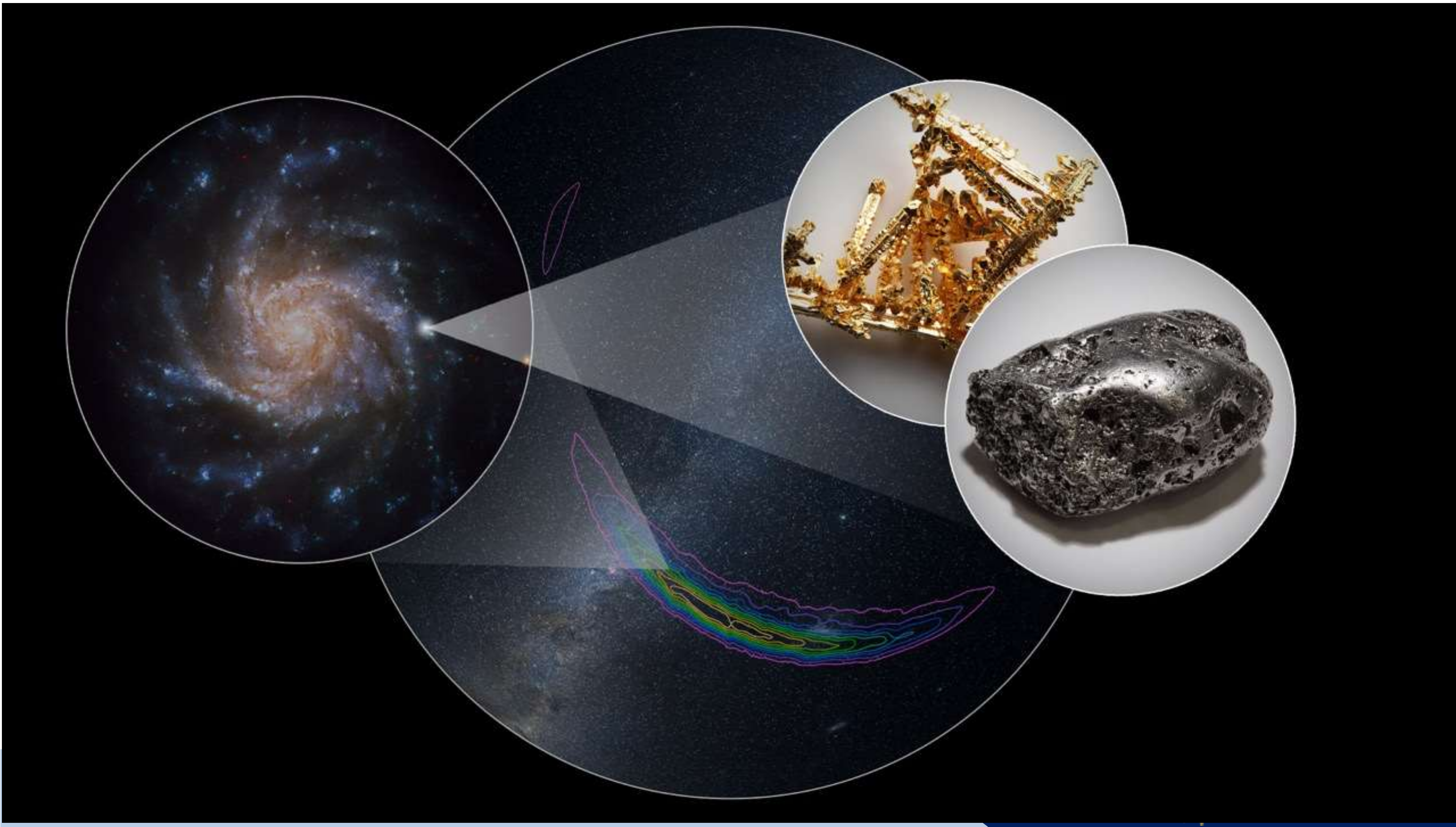


Updated from Kasliwal 2011 (PhDT)

III. Dawn of Gravitational Wave Astronomy



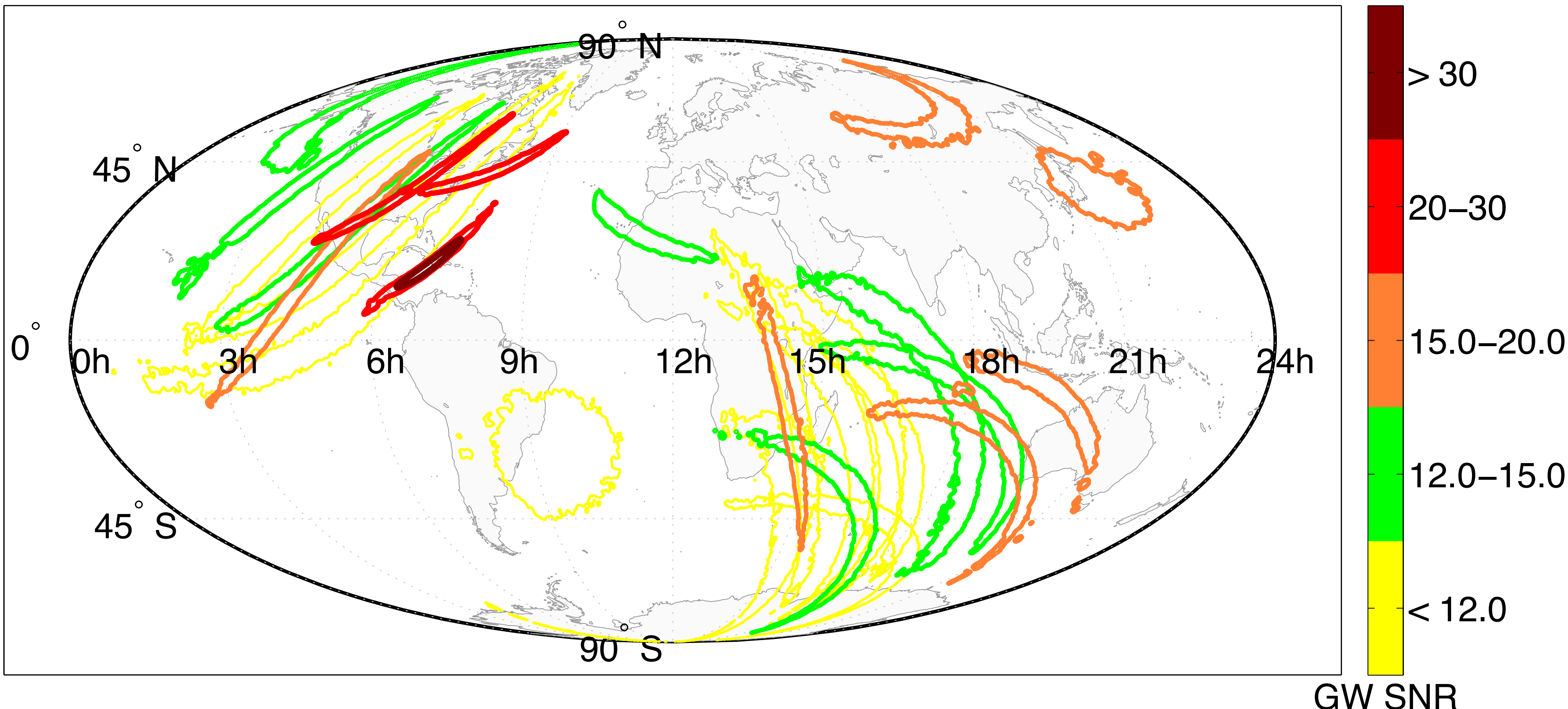
The Gold Rush: Light from Gravitational Waves



Blue Emission:
SPEED

Speed of Response
Speed of Software
Speed of Follow-Up

Coarse GW Localizations



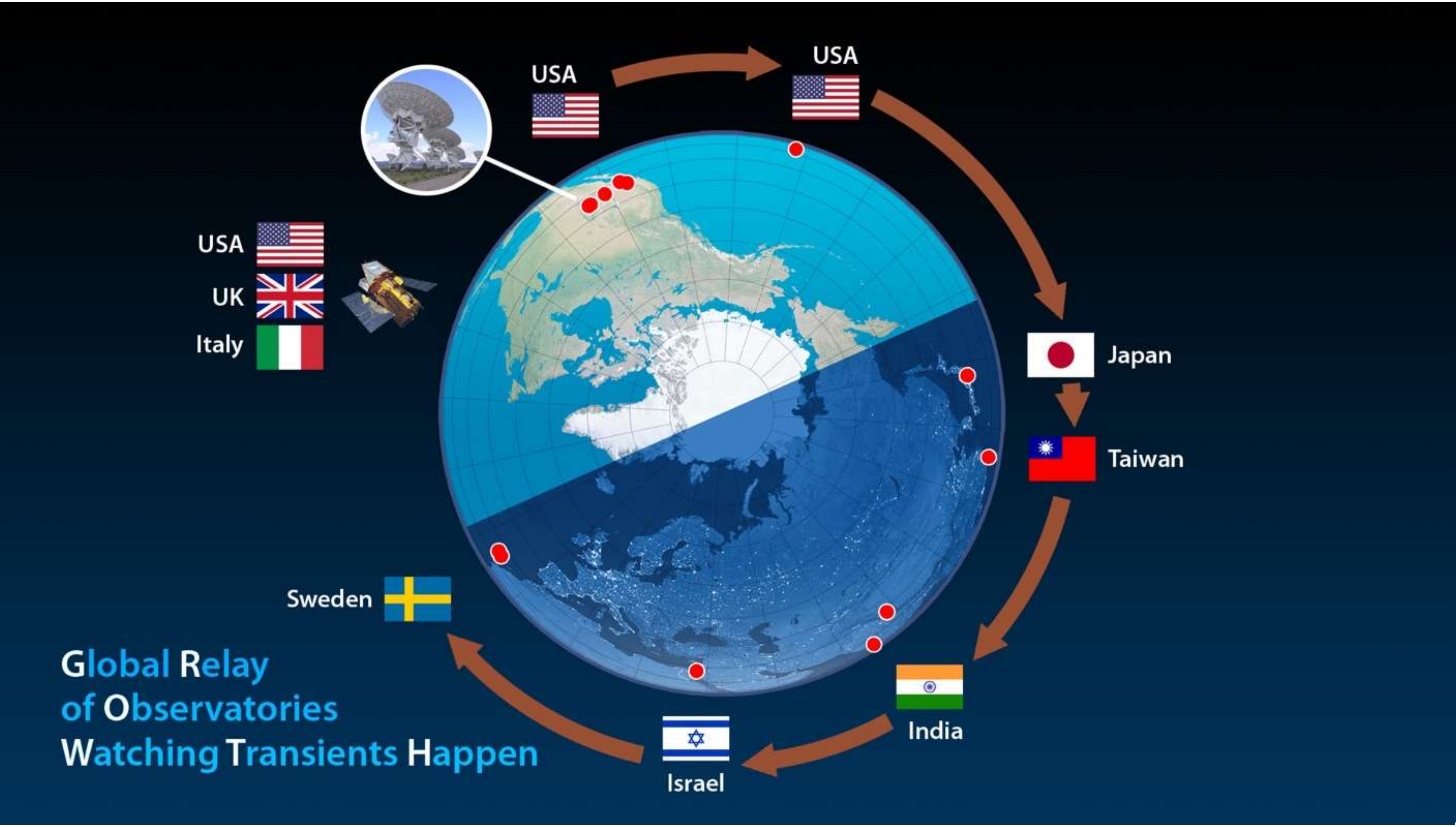
e.g. Kasliwal & Nissanke 2014, Singer et al. 2014

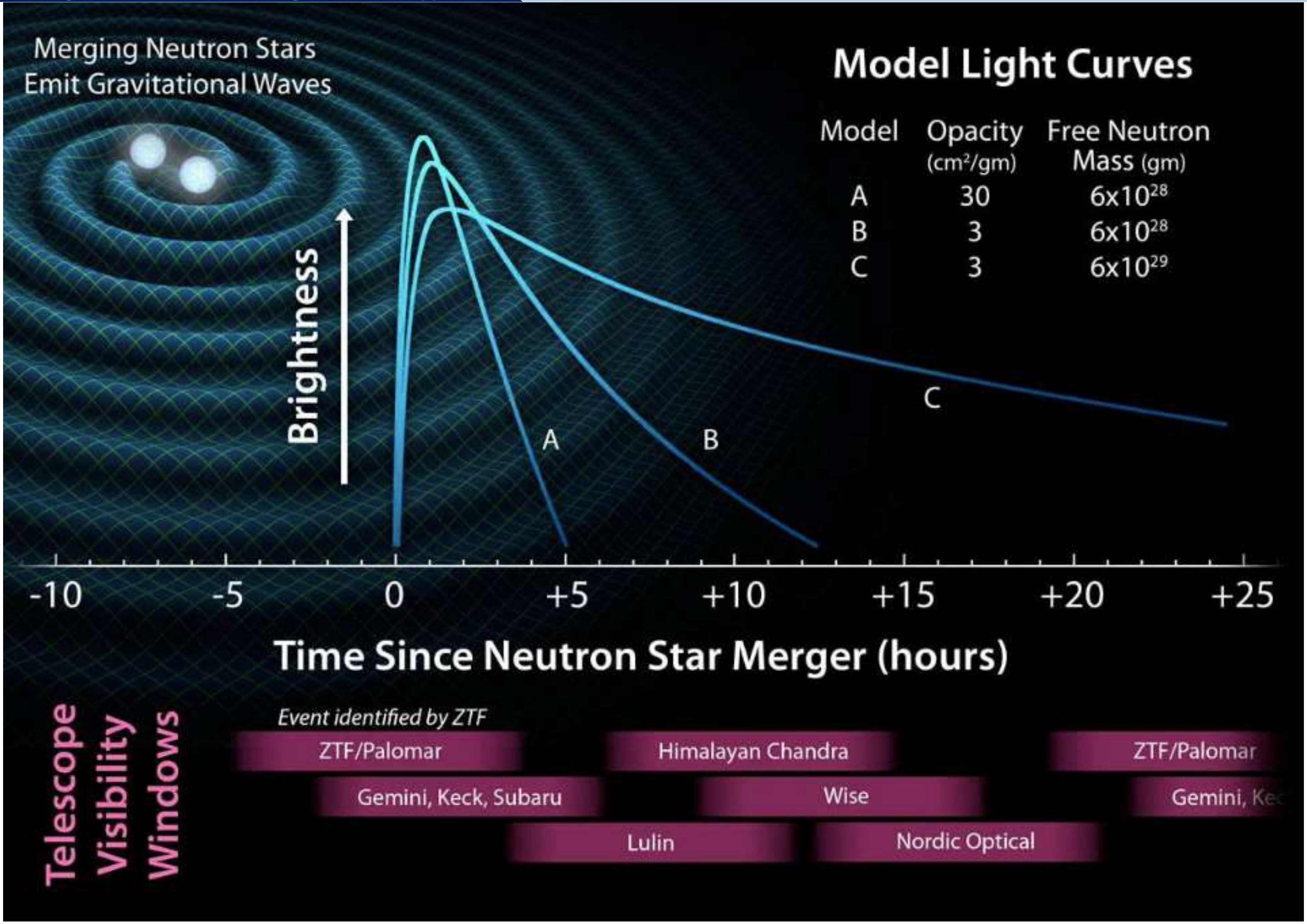
Palomar *(Zwicky)* Transient Factory

Oschin 48″ Telescope

Mayer 60″ Telescope

Hale 200″ Telescope


USA
USA
USA
UK
Italy
Japan
Taiwan
Sweden
India
Israel
Global Relay
of Observatories
Watching Transients Happen


Merging Neutron Stars
Emit Gravitational Waves
Model Light Curves
Model
Opacity (cm²/gm)
Free Neutron Mass (gm)
A 30 6x10^28
B 3 6x10^28
C 3 6x10^29
Brightness
A
B
C
-10
-5
0
+5
+10
+15
+20
+25
Time Since Neutron Star Merger (hours)
Telescope Visibility Windows
Event identified by ZTF
ZTF/Palomar
Himalayan Chandra
ZTF/Palomar
Gemini, Keck, Subaru
Wise
Lulin
Nordic Optical

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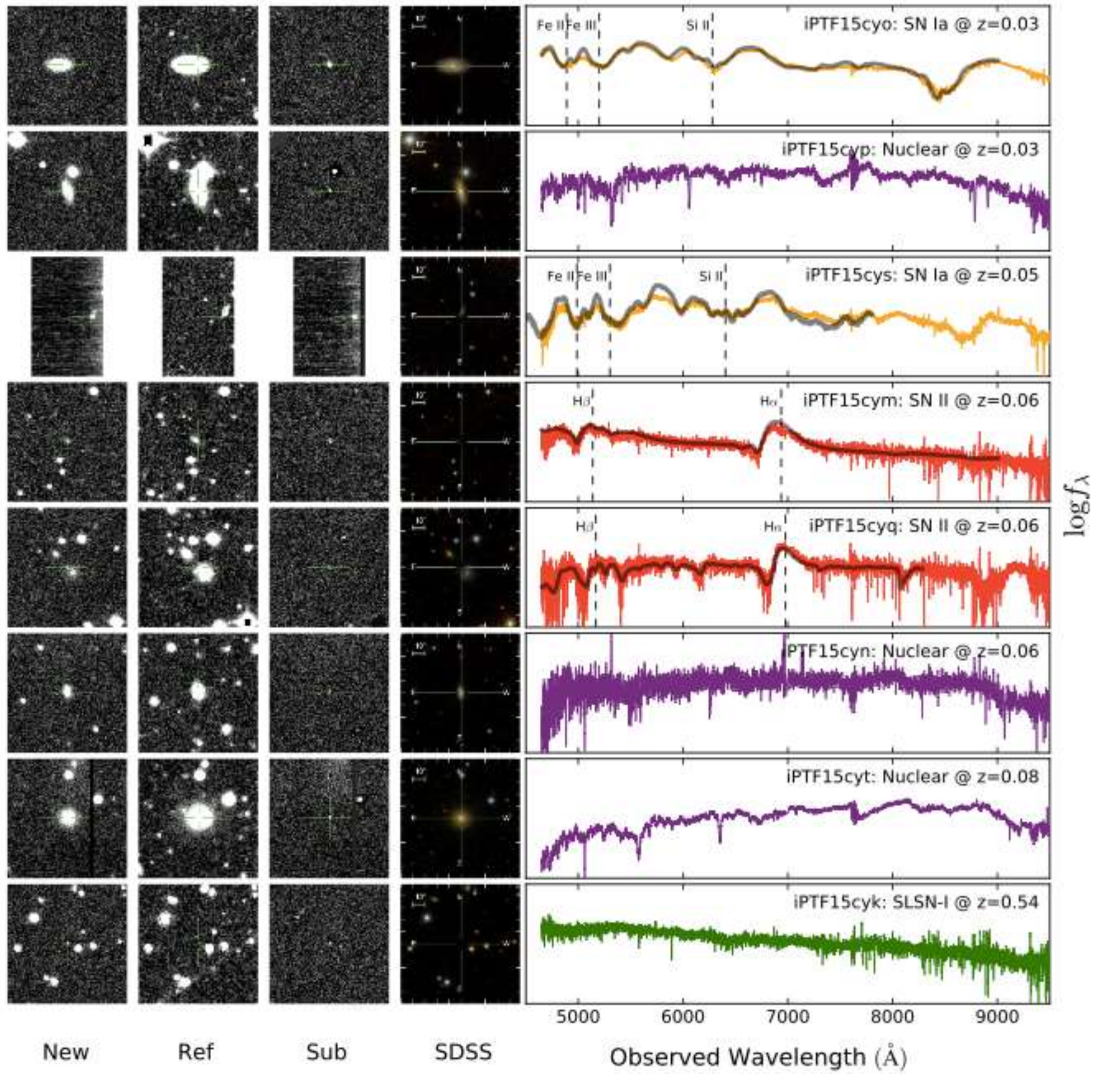
GW150914: All candidates classified in 2 hours!



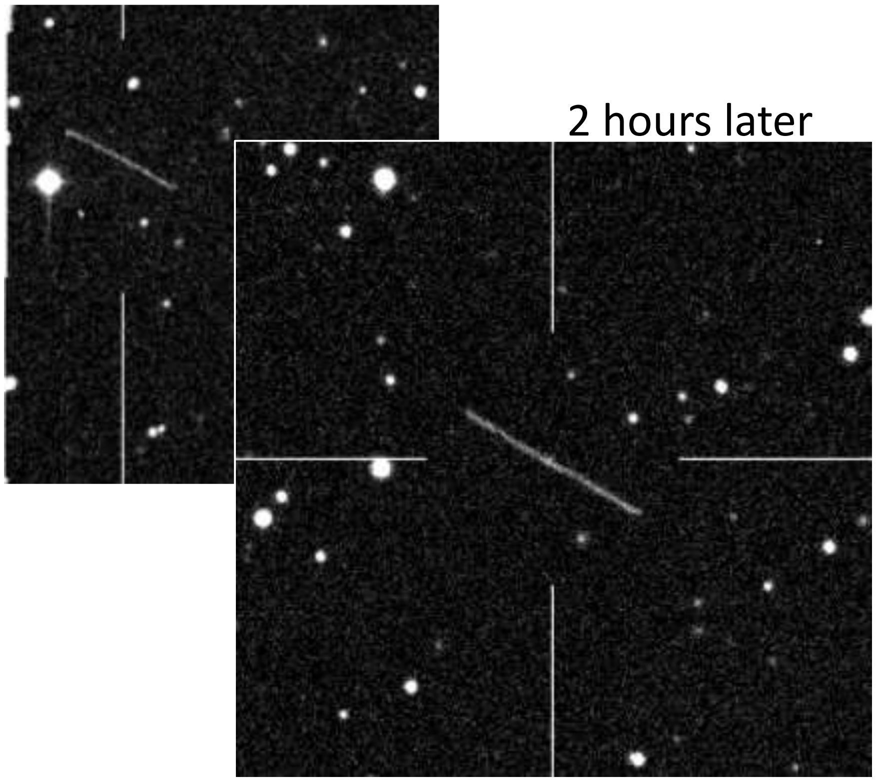
Kasliwal et al. 2016a

IV. Asteroids

iPTF discovery of NEA 2014 JG55

PhDT: A. Waszczak

2 hours later



- *Rapid response of fast-moving asteroids before they are lost*
- *Improve orbit solutions of possible impactors*
- *Fast characterization of compositional properties*
- *Monitoring mass loss events (i.e. active asteroids)*
- *Search for binaries, tumblers and erratic rotators (super-fast/slow)*

This 10m asteroid came within ¼ of the earth-moon distance!
The streak became brighter by 1 mag and faster by 50% in 2 hours.

ZTF should be 20x better. GROWTH follow-up is key.

Thank you

+ Independent Support for Sweden, Israel and Germany

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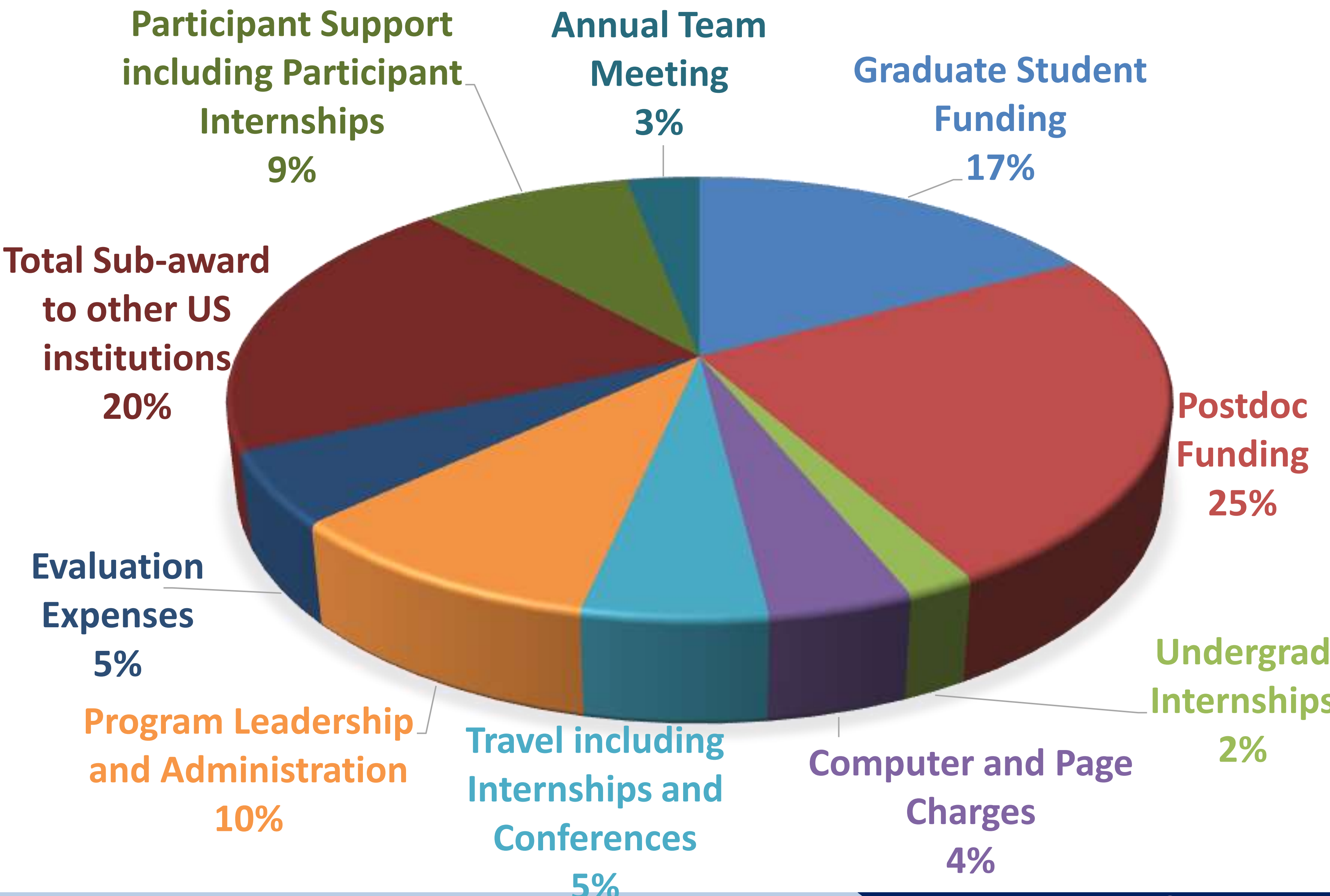

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GROWTH Team

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Brad Cenko

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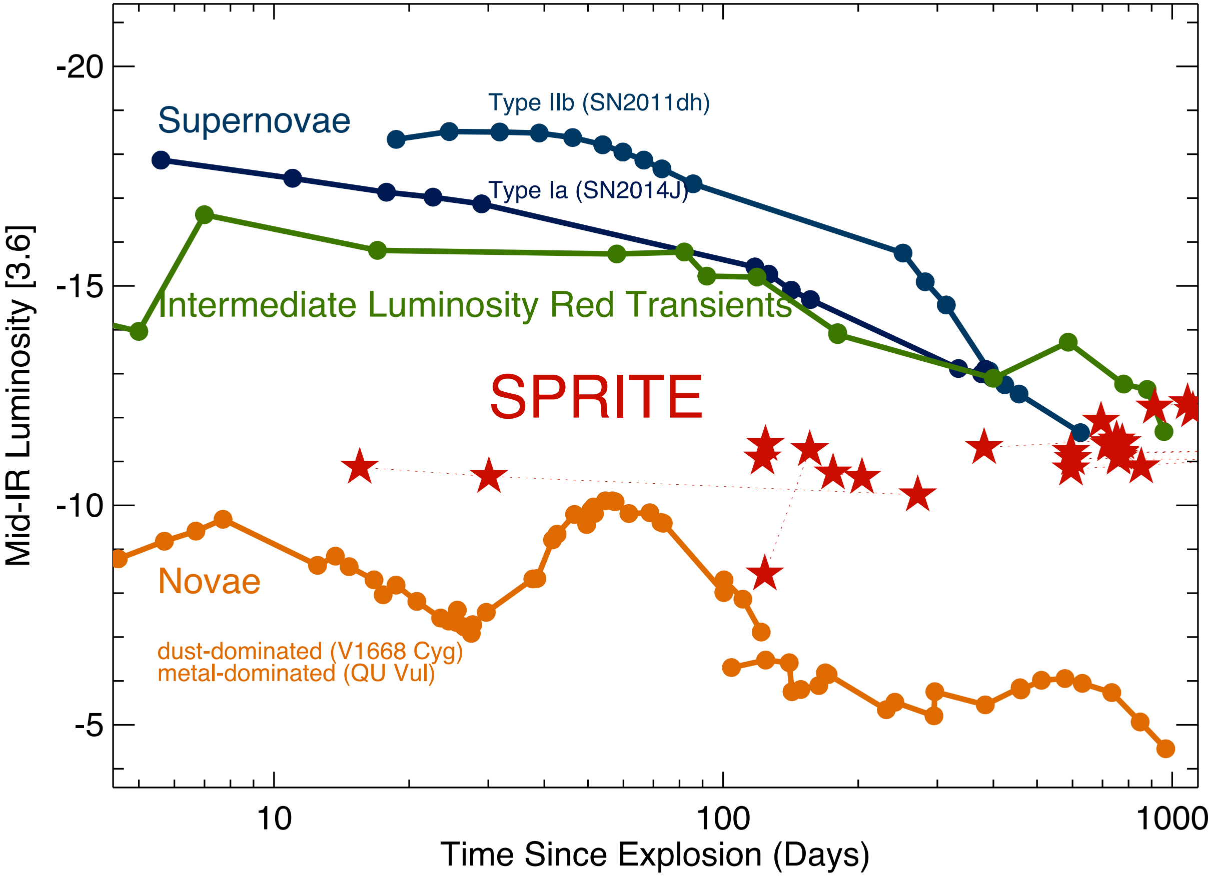
SPIRITS:

SPitzer InfraRed Intensive Transients Survey



Kasliwal et al. 2016b, ApJ, submitted

Cycles 10-12
1130 hours of Spitzer mid-IR
190 Galaxies x 10 epochs
(PI Kasliwal)

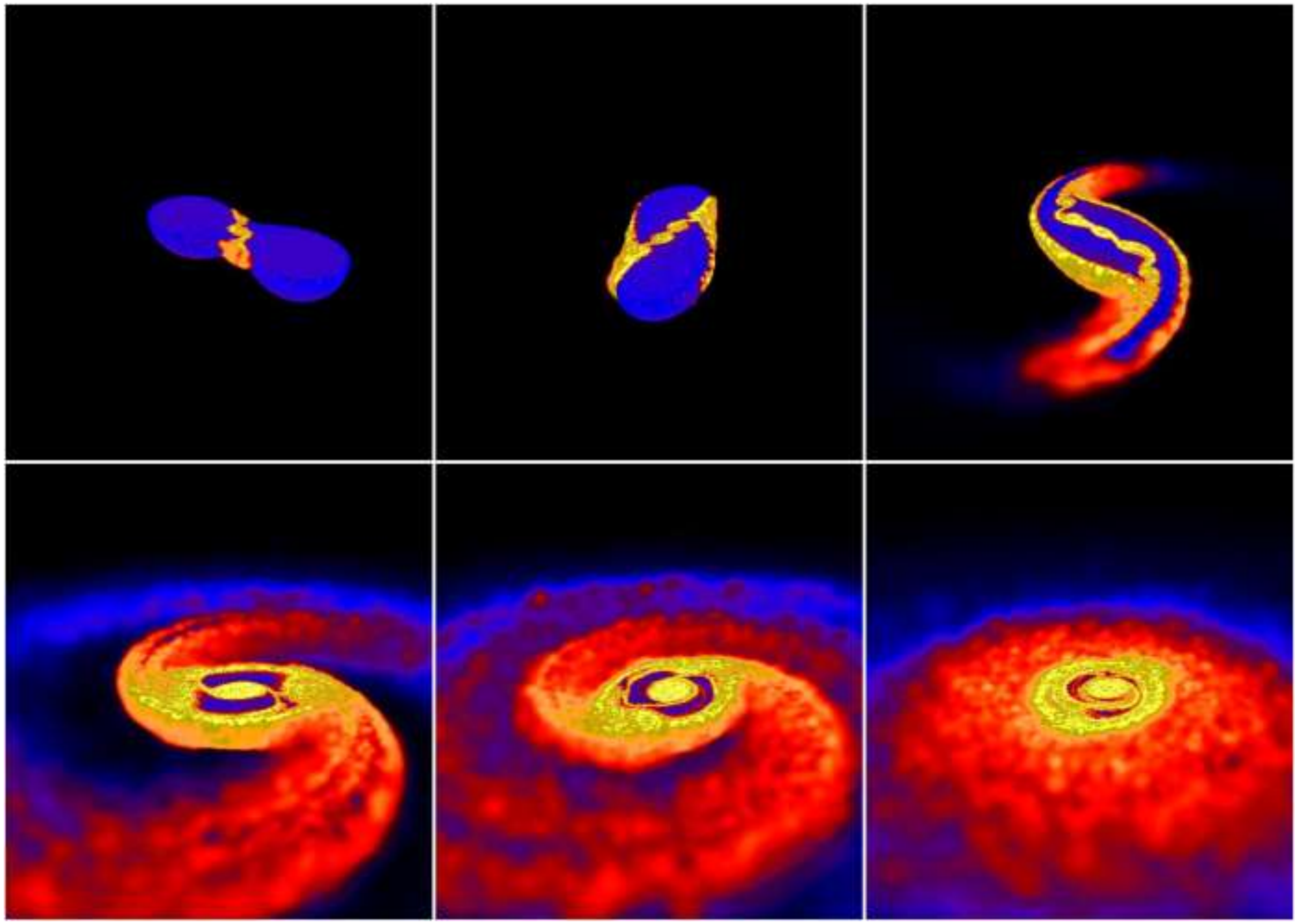
Every Year:
110 nights of near-IR imaging
66 nights of optical imaging
33 nights of spectroscopy

147 transients (35 SPRITEs)
1948 variables/year

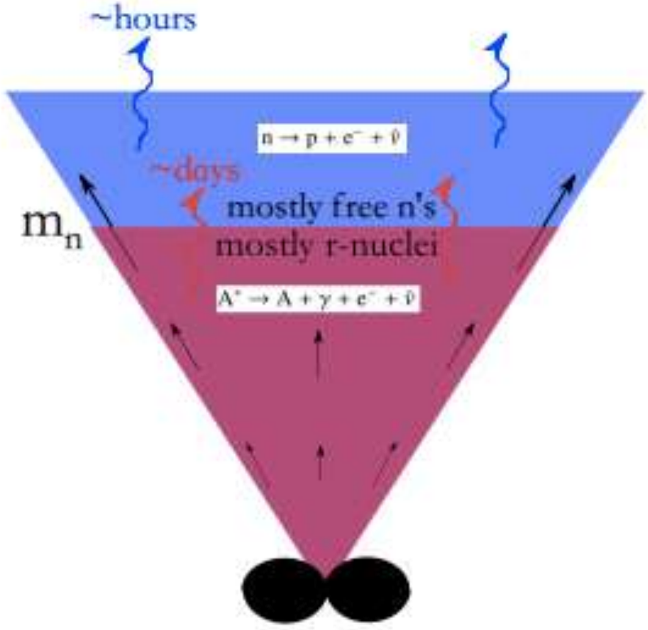
A New Infrared Discovery Engine?

Neutron Star + Black Hole

and then there is light!



Blue Flash (~hours) & Red Transient (~days)



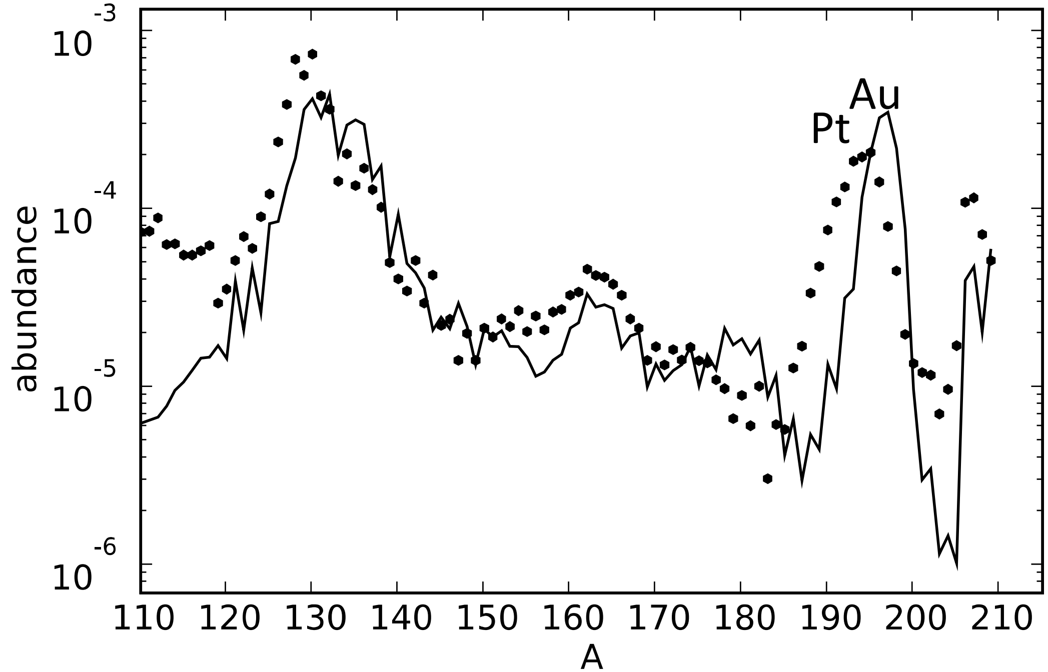
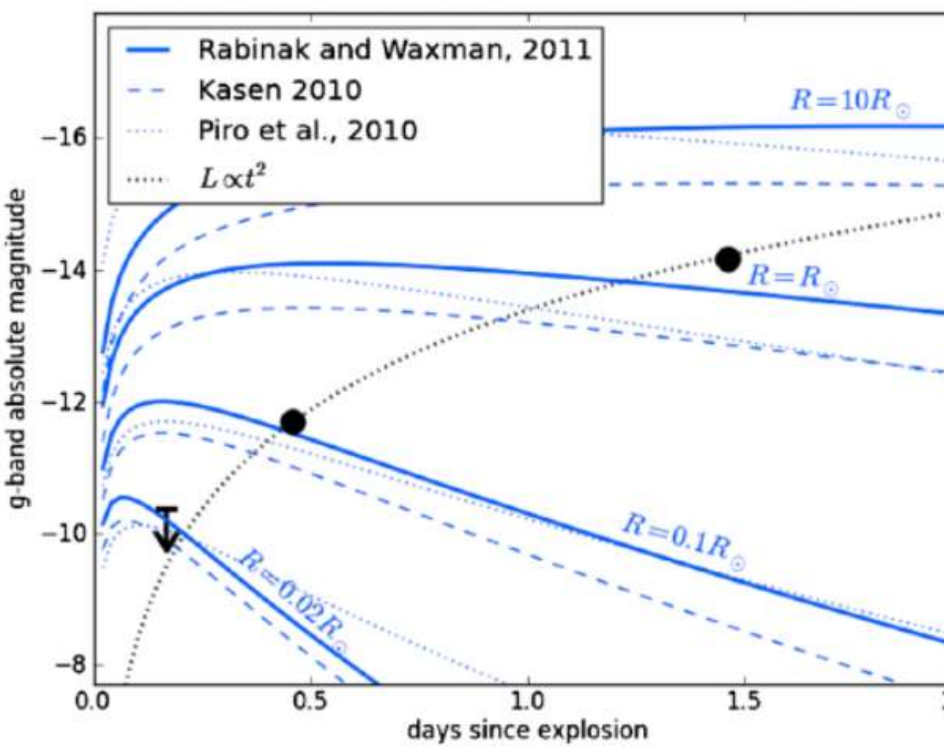
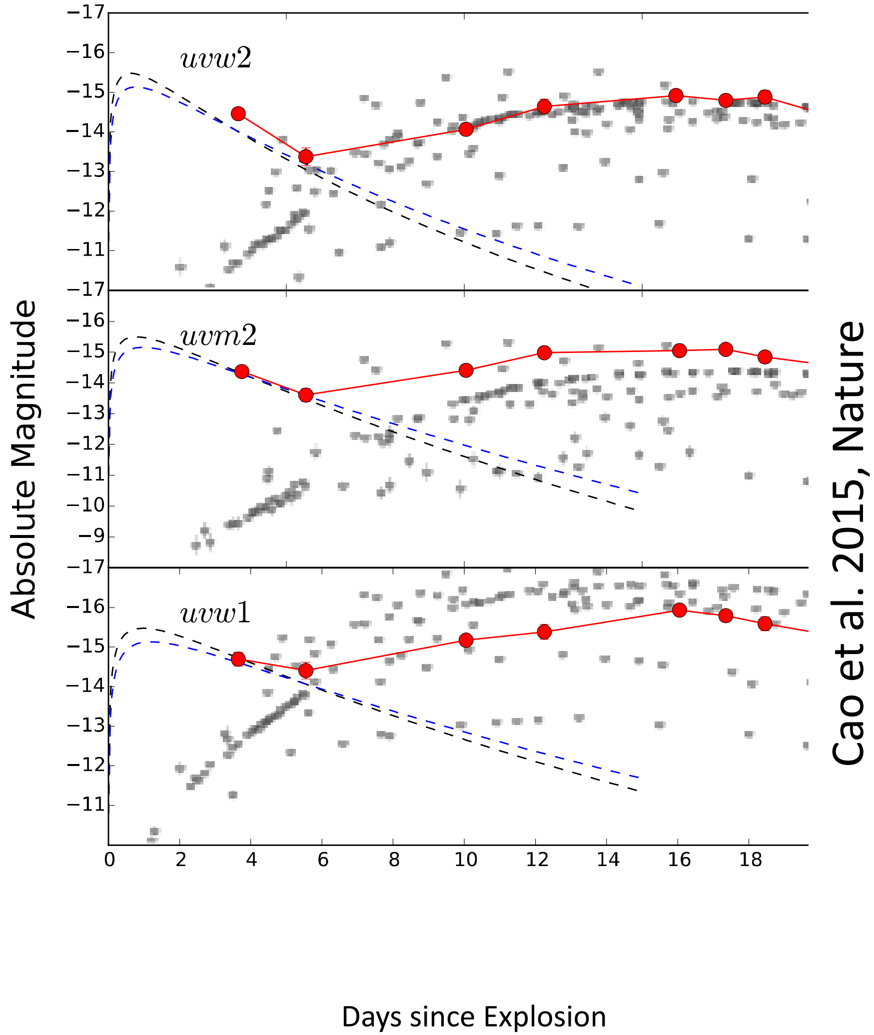


Figure from Metzger et al. 2010, 2014

e.g. Li & Paczynski 1998, Kulkarni 2005, Roberts et al. 2011, Nakar & Piran 2011, Barnes et al. 2013, Kasen 2013, Grossman et al. 2013

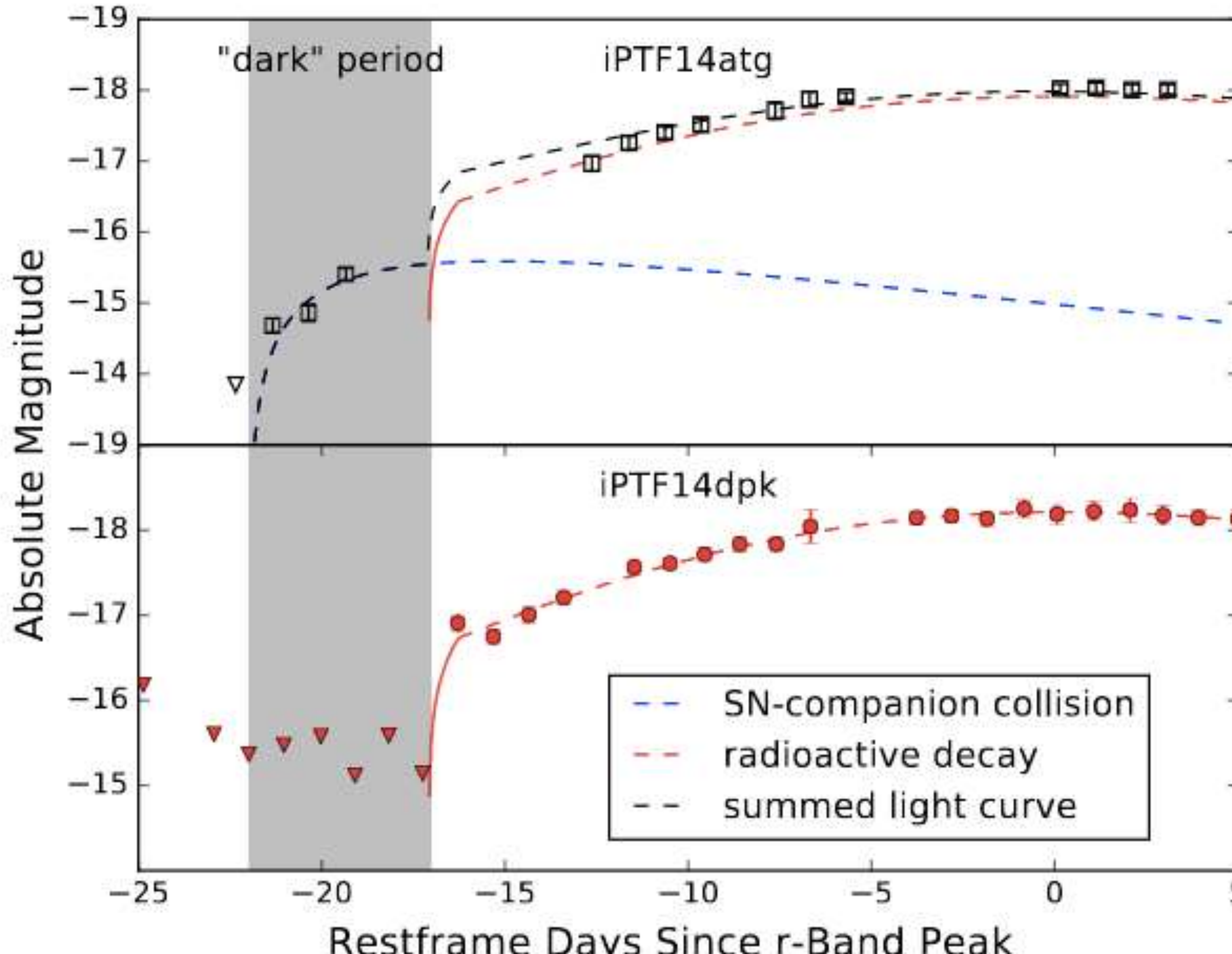
II. Infant Type Ia SNe





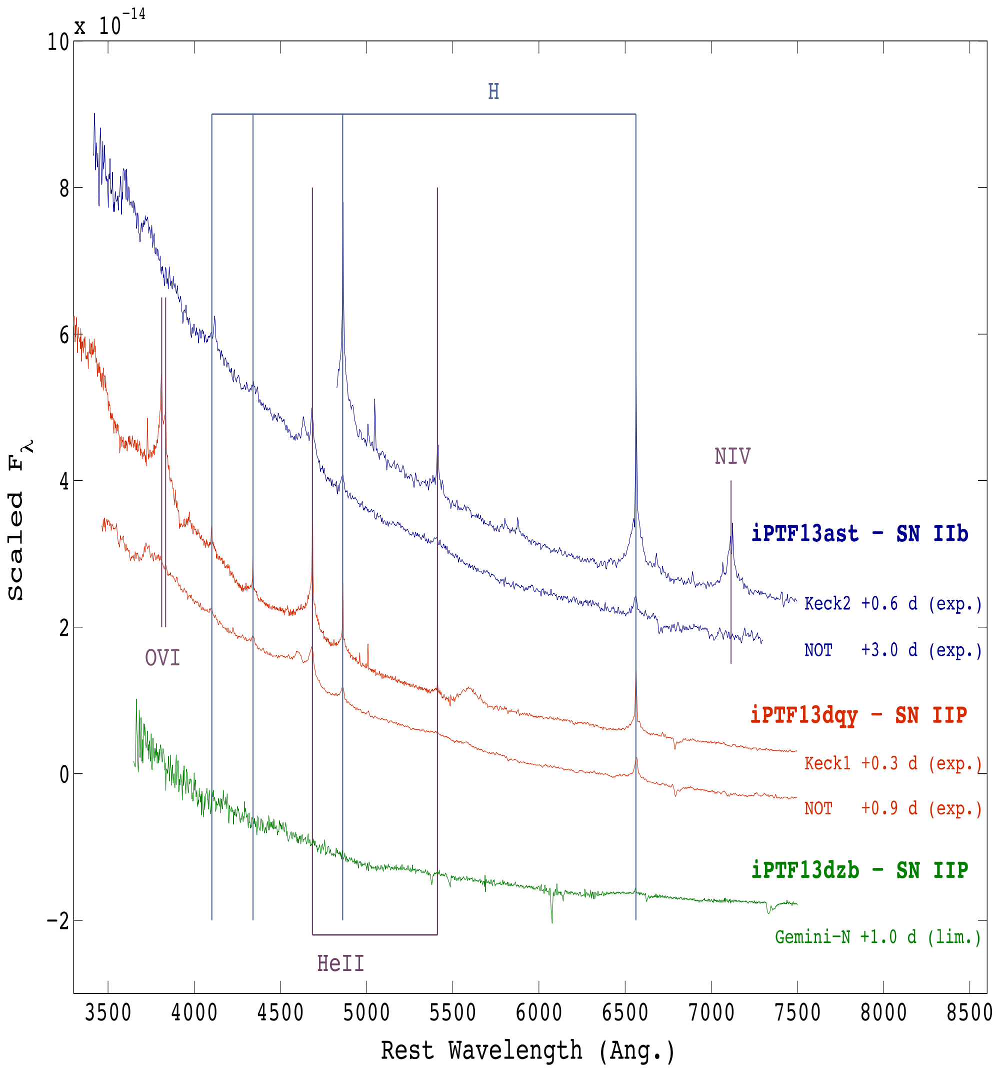
Nugent et al. 2011, Li et al. 2011,
Horesh et al. 2011, Bloom et al. 2011
+ 122 more papers

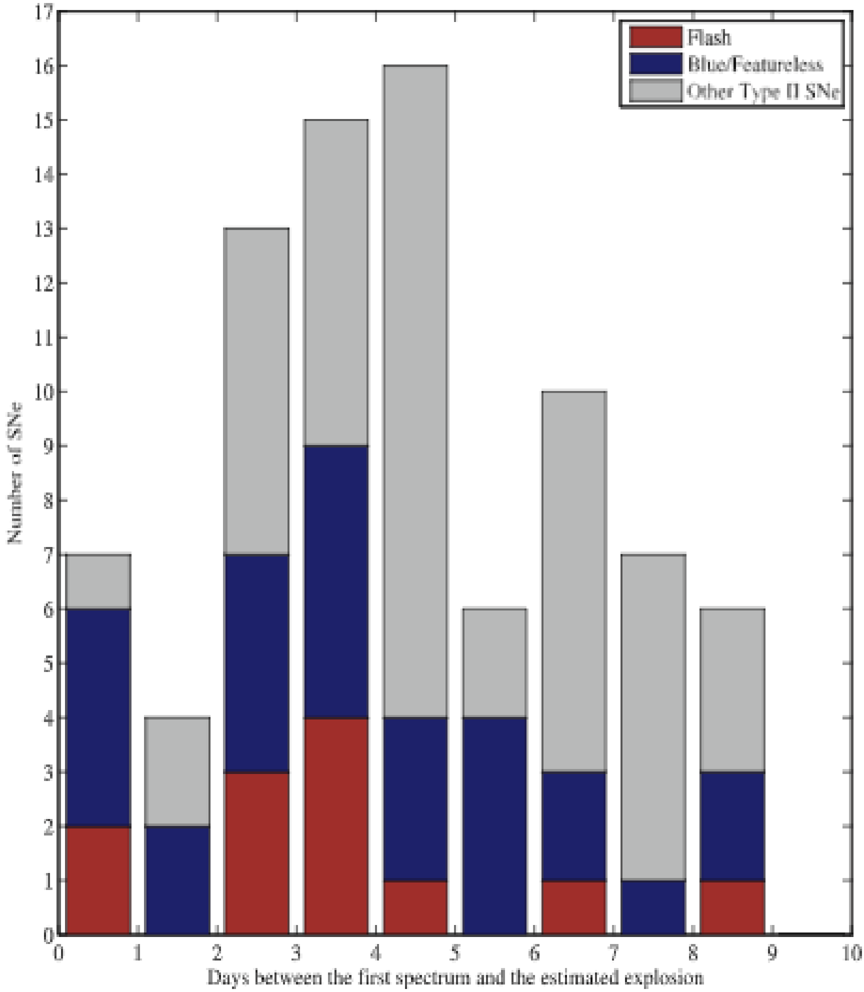
Statistics



Cao et al. 2016b

Statistics





Khazov et al. 2016, Rubin et al. 2016