Time-domain Sciences in the TMT Era

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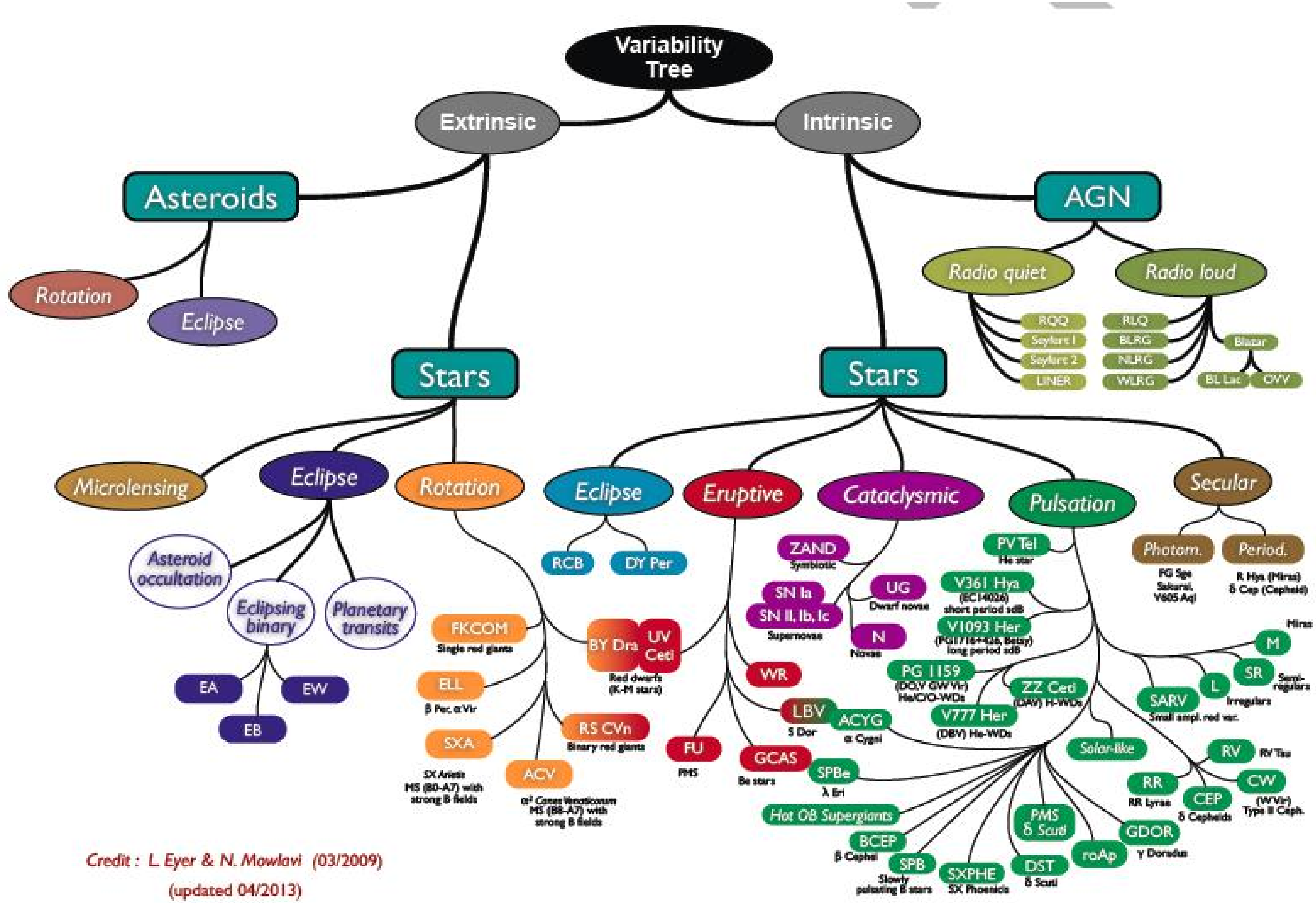
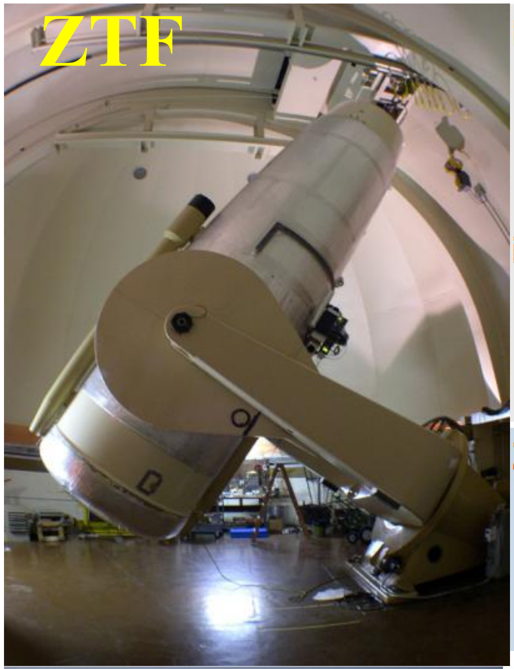
On behalf of the TMT ISDT of Time-domain Sciences

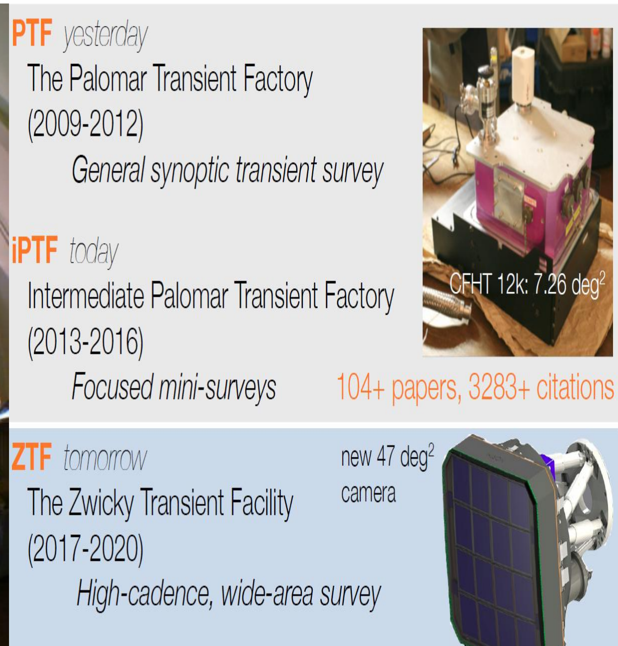
TMT Forum, Kyoto, May 25, 2016

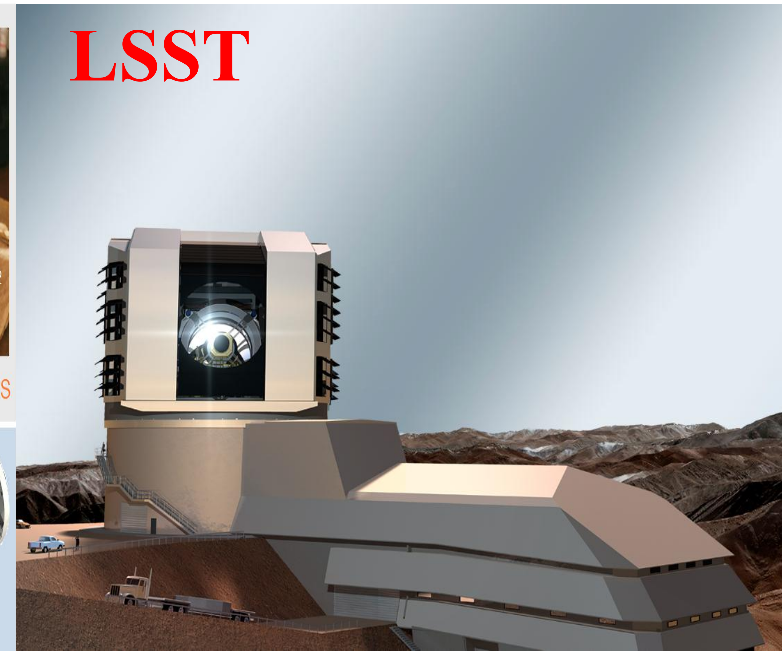
Transients in the Universe

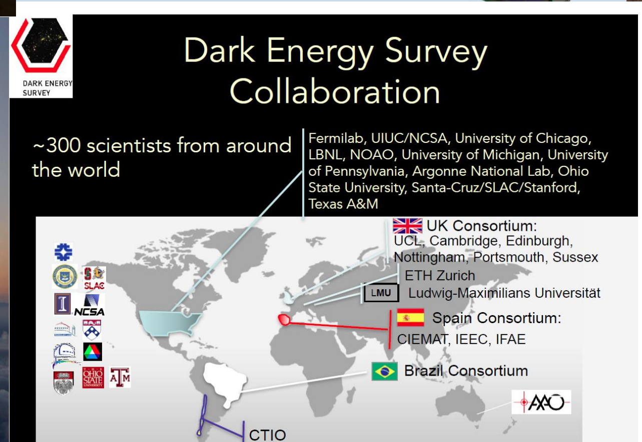


The Existing and Upcoming Transient Surveys









Transients in the Universe

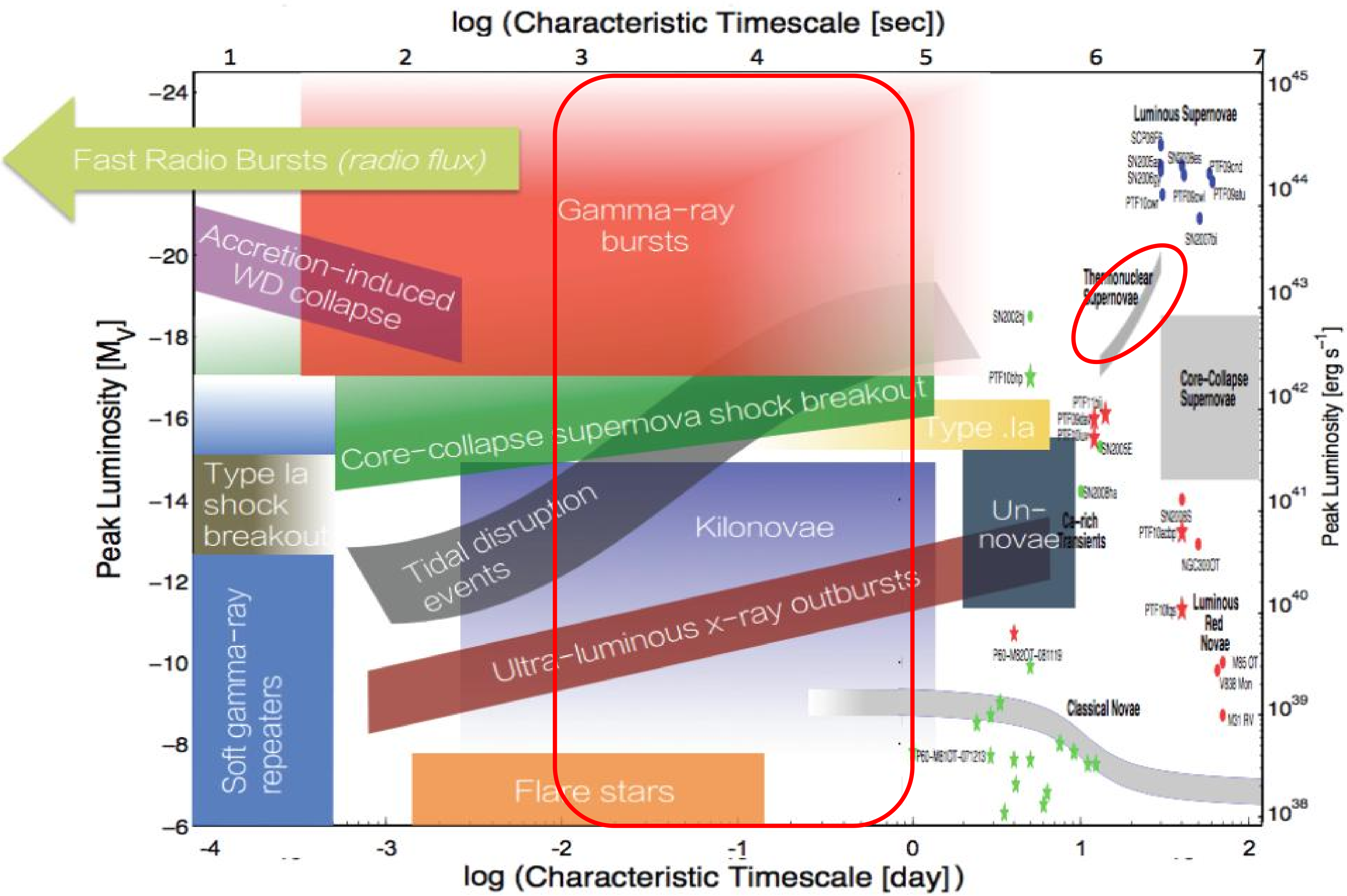
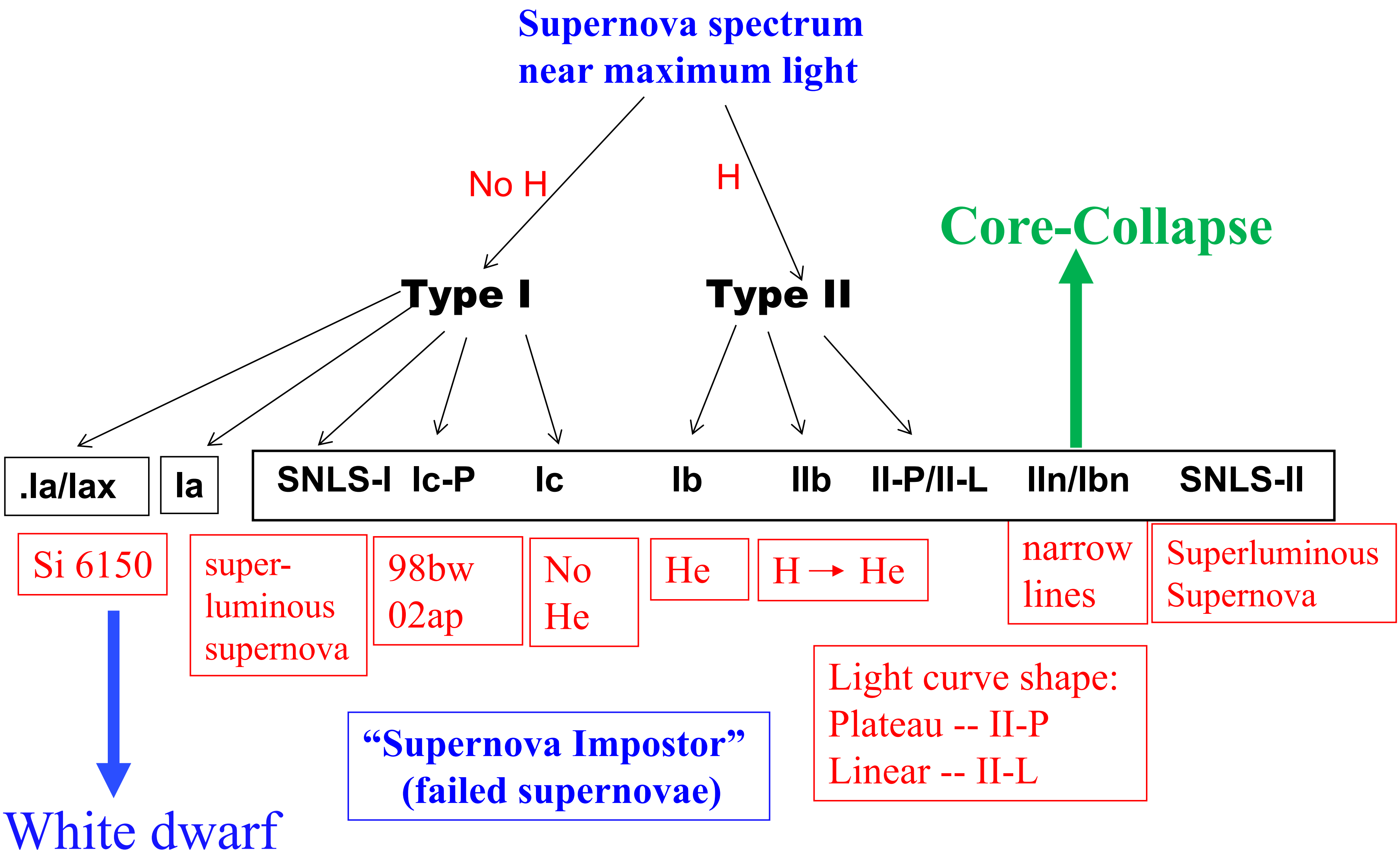


Figure credit Jeff. Cooke based on Kasliwal (2013)

Supernova Zoo



The Progenitor – SN Map

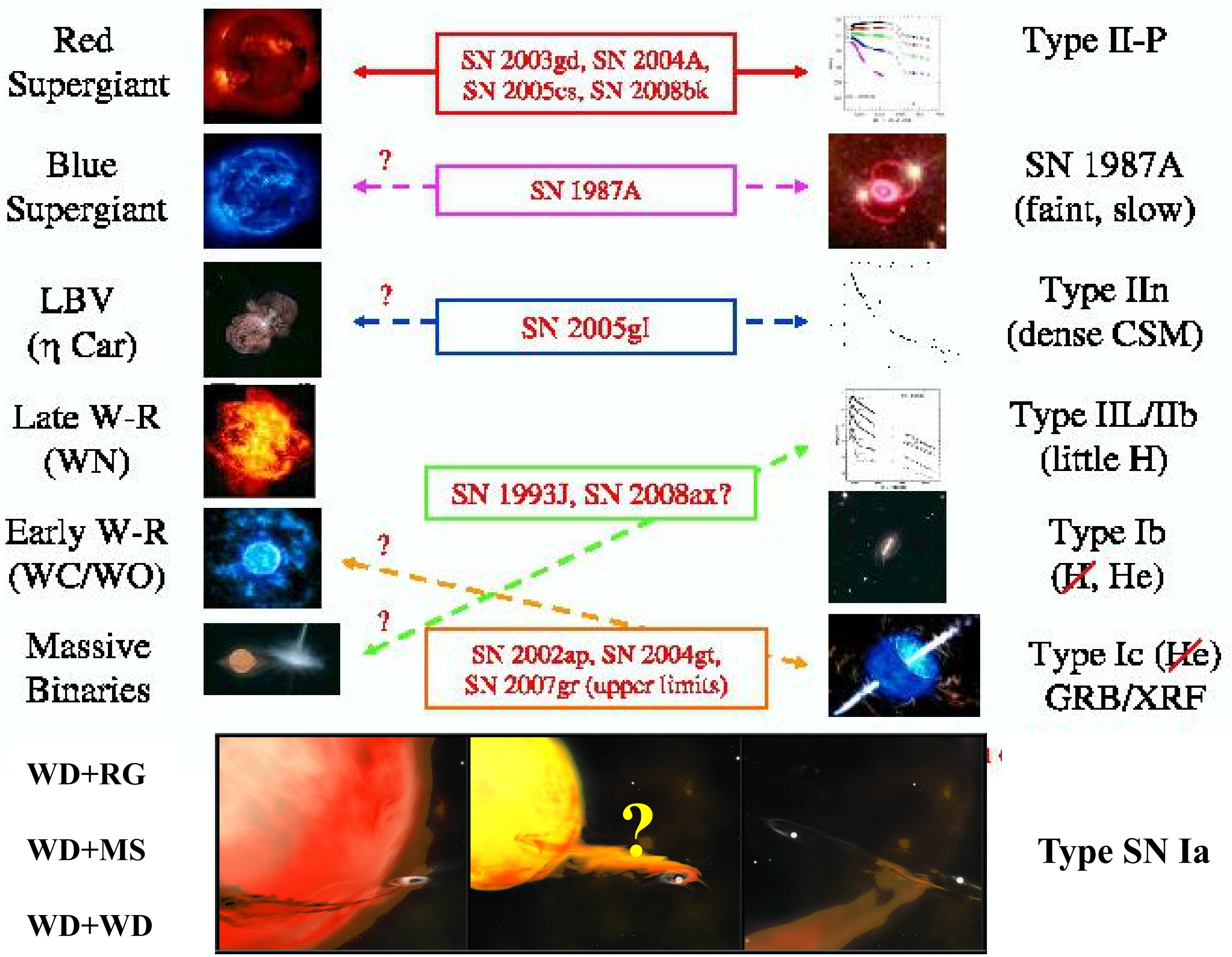
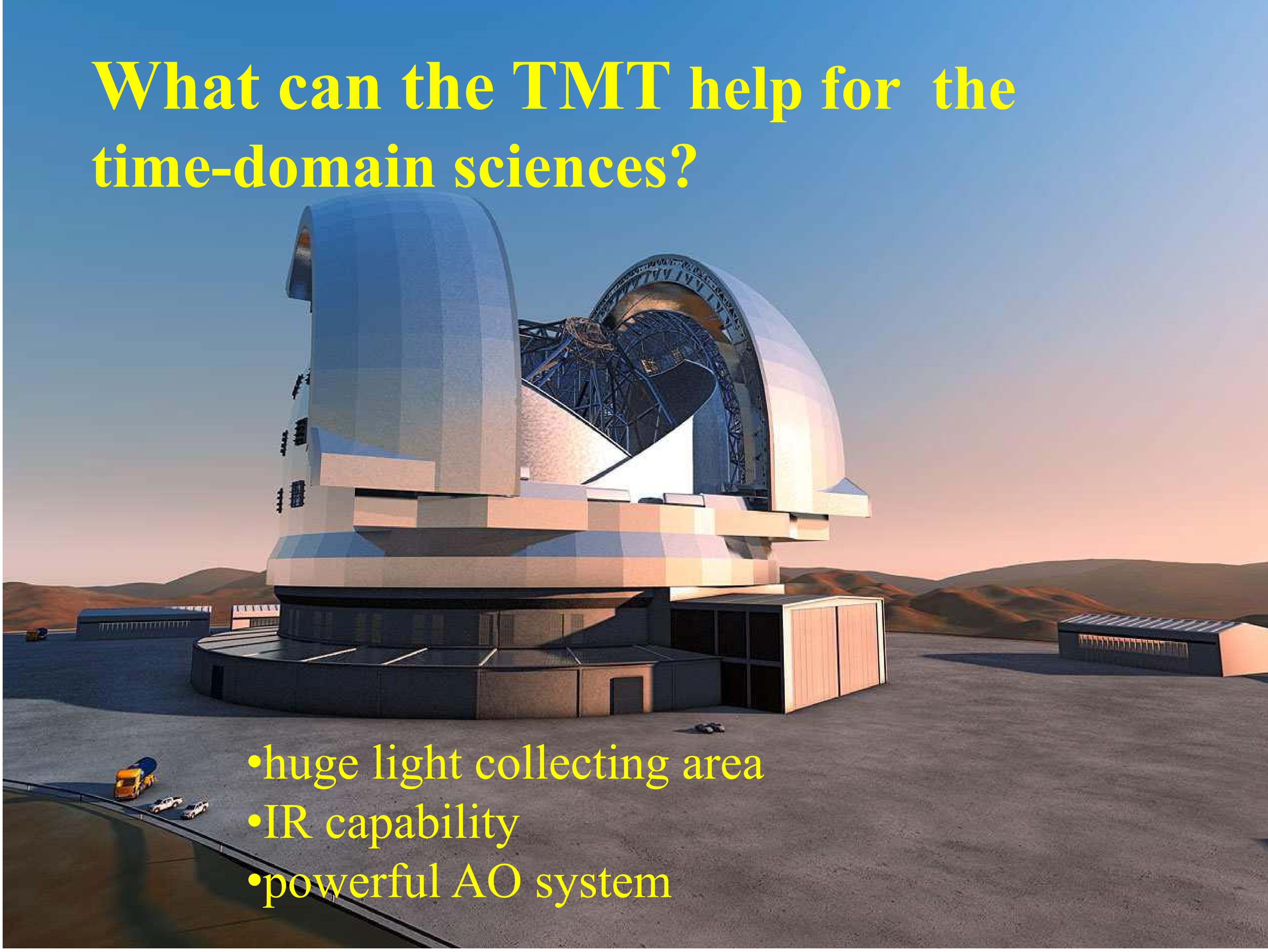


Figure credit revised from Avishay Gal-yam 2007

What can the TMT help for the time-domain sciences?



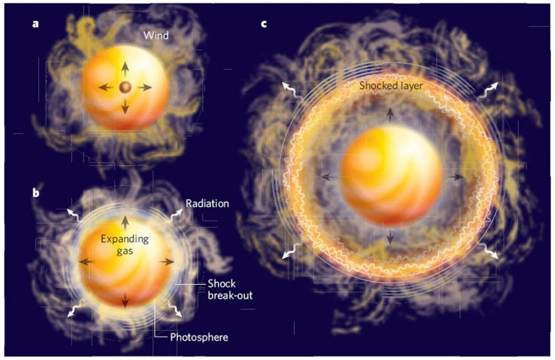
- huge light collecting area
- IR capability
- powerful AO system

Some time-domain sciences with TMT

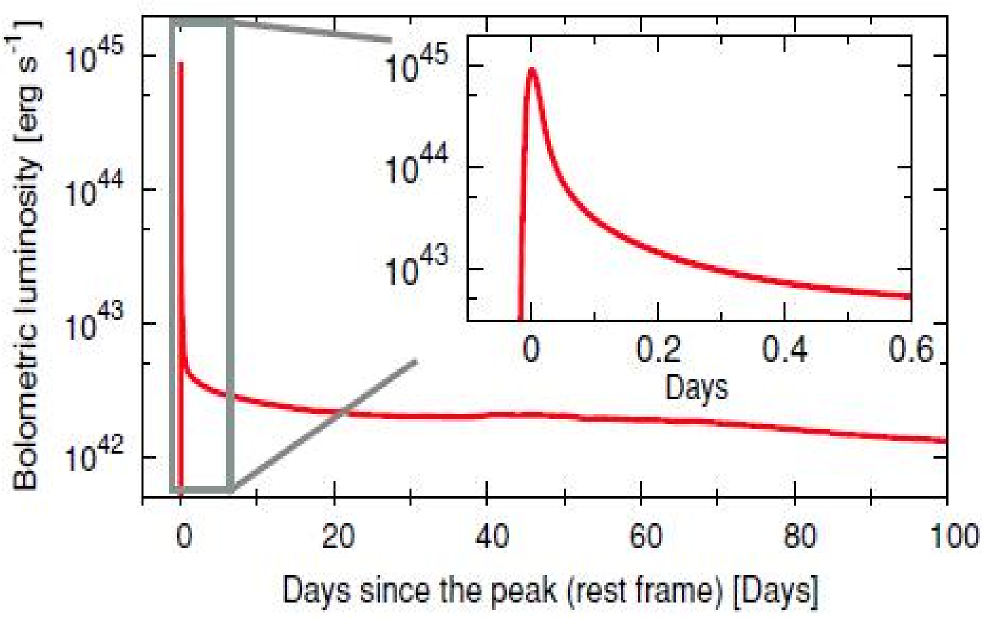
- Supernovae and supernova cosmology;
- Gamma-ray burst;
- Electromagnetic Counterparts of Gravitational-wave Sources (see Masaomi's talk);
- AGN and tidal disruption events
- Stellar phenomena;

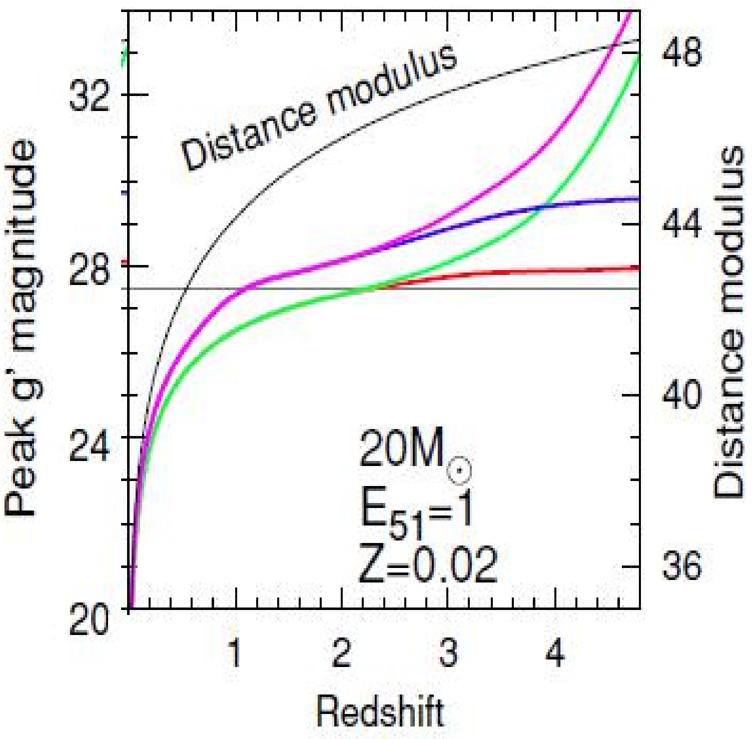
Progenitors and Explosion Physics of Supernovae

Identifying Shock Breakout of Core-collpase Supernovae



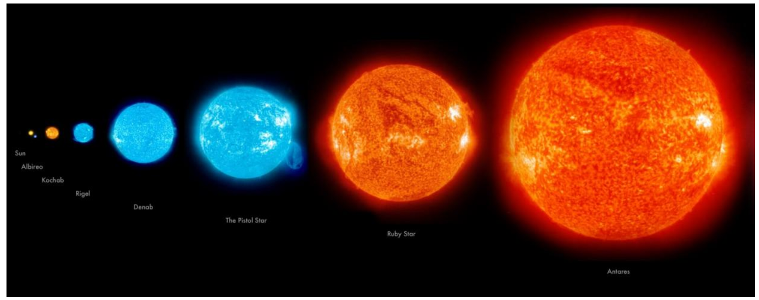
In spite of the soft X-ray/UV-peaked spectra, it is shown that shock breakouts will be most effectively detected by optical facilities such as Subaru HSC and LSST due to their deep and wide-field capabilities.

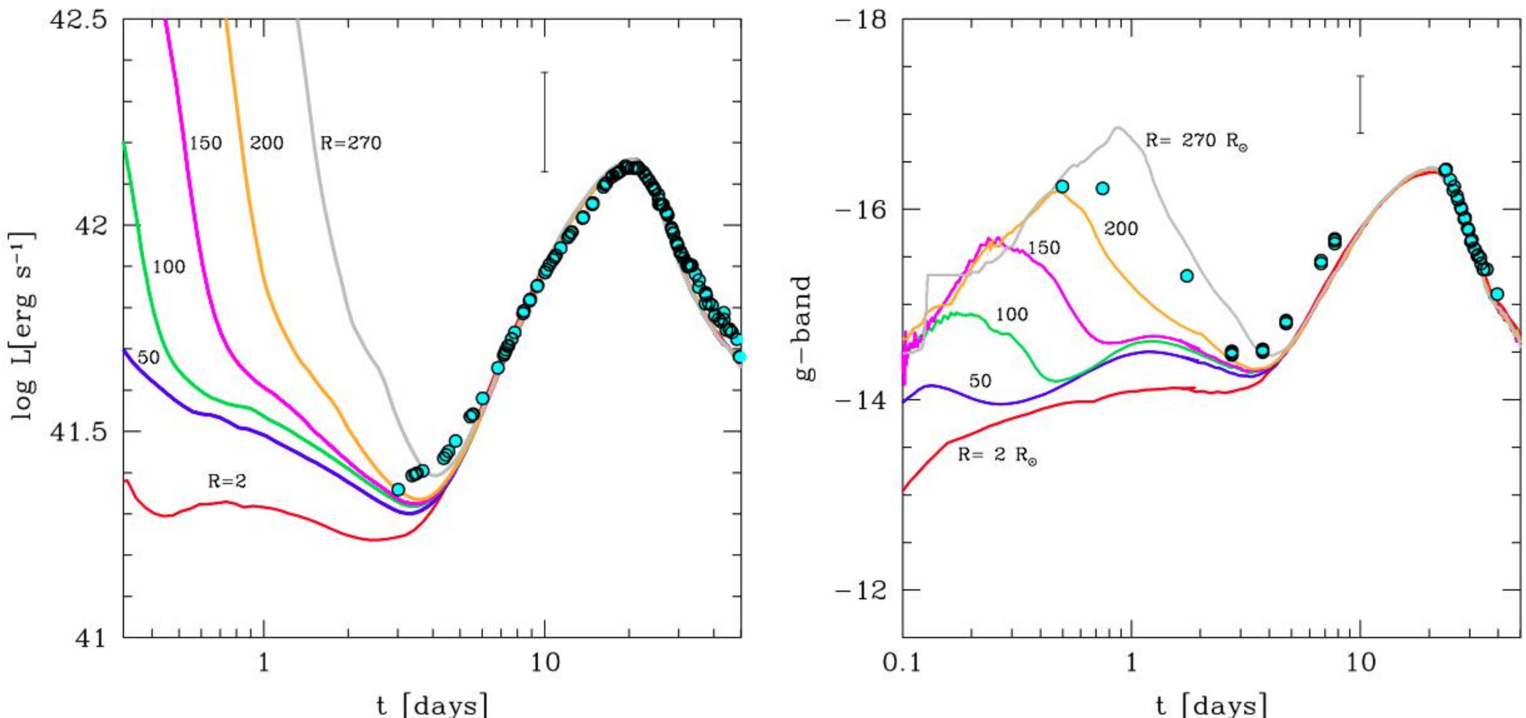




Tominaga et al. 2011

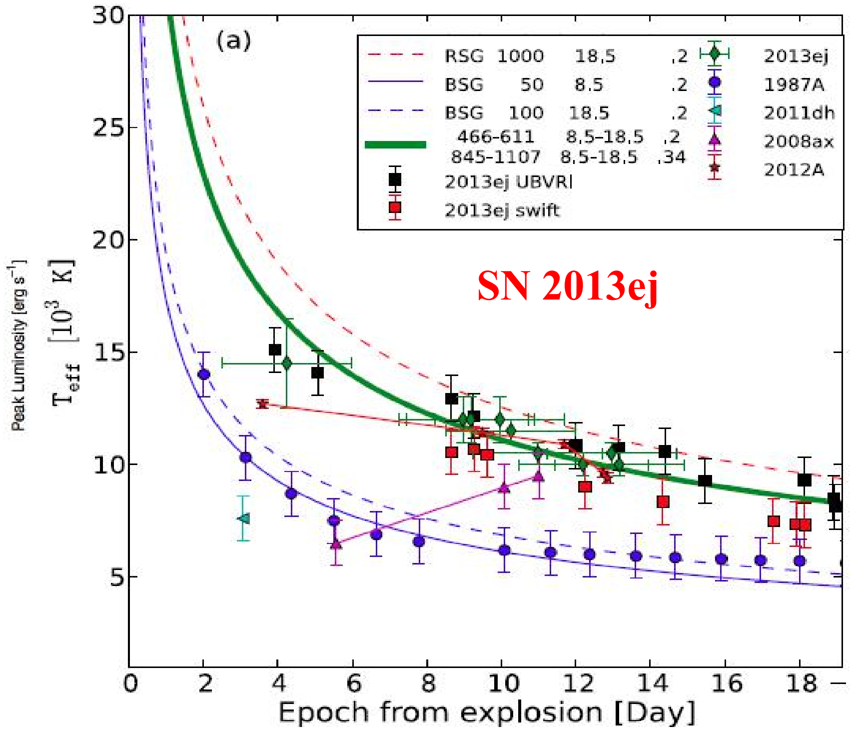
Shock breakout from core-collaspe of massive stars

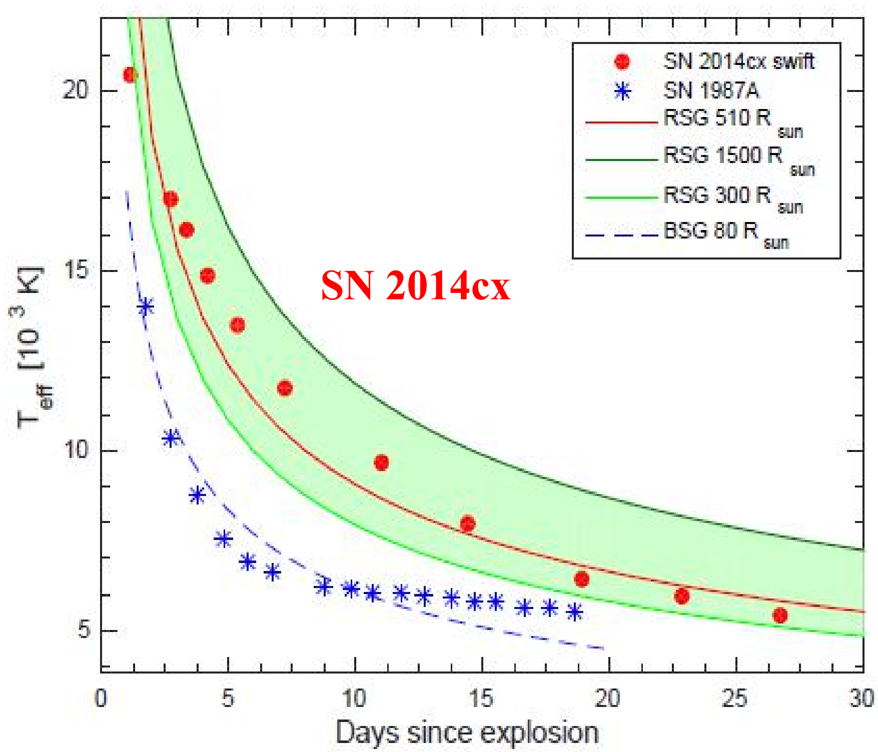




Bersten et al. 2012

Constraining Progenitor Size from Early-time Cooling Curve of Photospheric Temperature





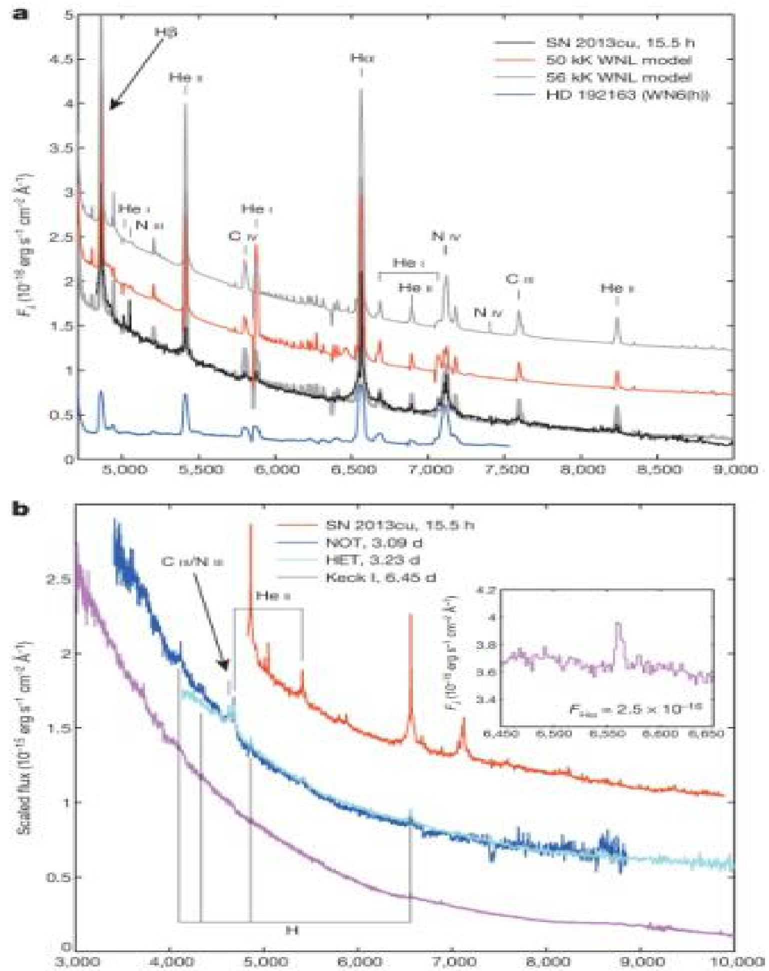
Plot showing the cooling curve of the photospheric temperature measured for the nearby type IIP SN 2013ej in M74 (Valenti et al. 2014) and SN 2014cx in NGC 337 (Huang et al. 2016).

Early-time flash spectroscopy reveals progenitor features

Flash spectroscopy: rapid spectroscopic observations of supernovae during or shortly after shock breakout.

Spectroscopy of the type IIb supernova SN 2013cu reveals transient Wolf–Rayet-like features.

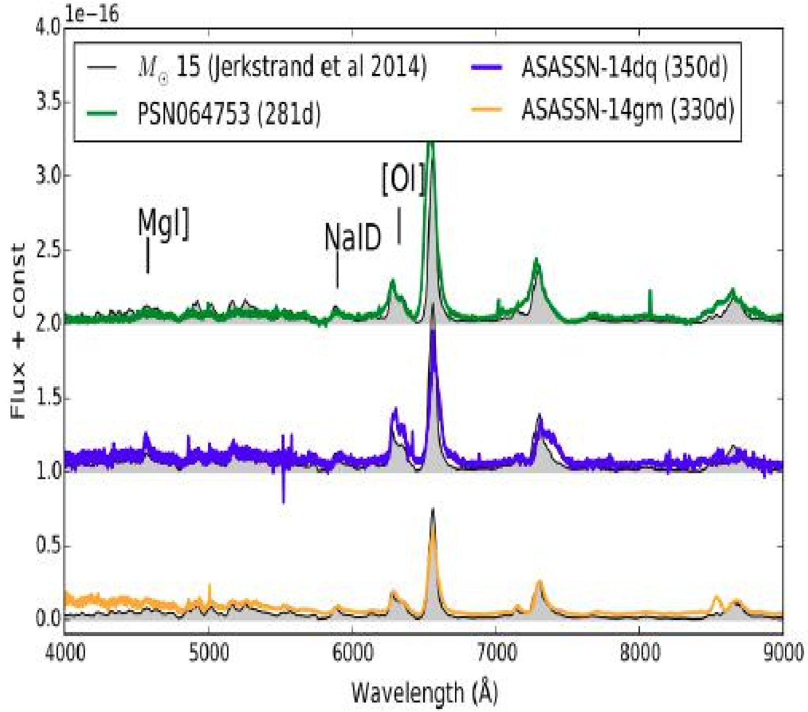
High-ionization emission lines dominate during the first few hours after explosion

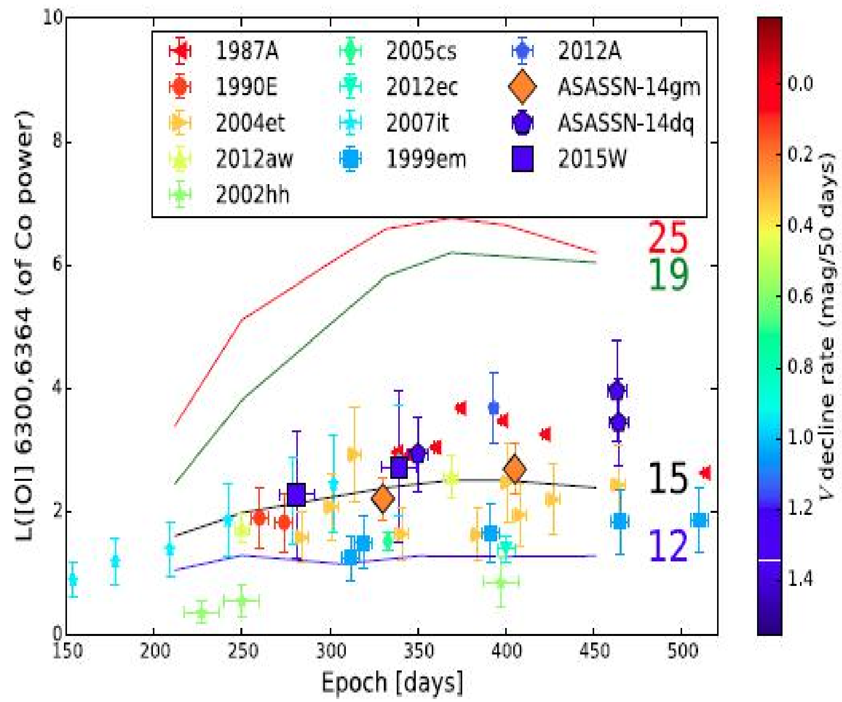


A Gal-Yam *et al.* *Nature* **509**, 471-474 (2014) doi:10.1038/nature13304

nature

Late-time spectra reveal the mass of progenitor Stars of SNe II

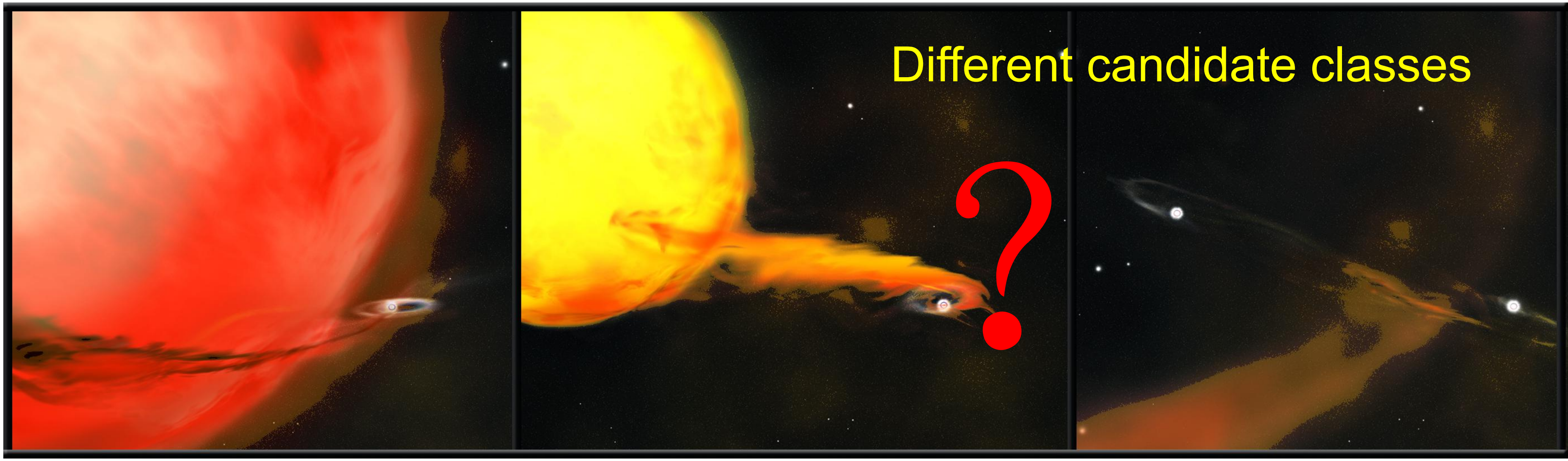




Jerkestrand et al. 2014

At late time, it has been shown that the intensity of a few, isolated lines such as O I 6300, 6364 increase with the mass of the progenitor.

Identifying Progenitors of Type Ia Supernovae



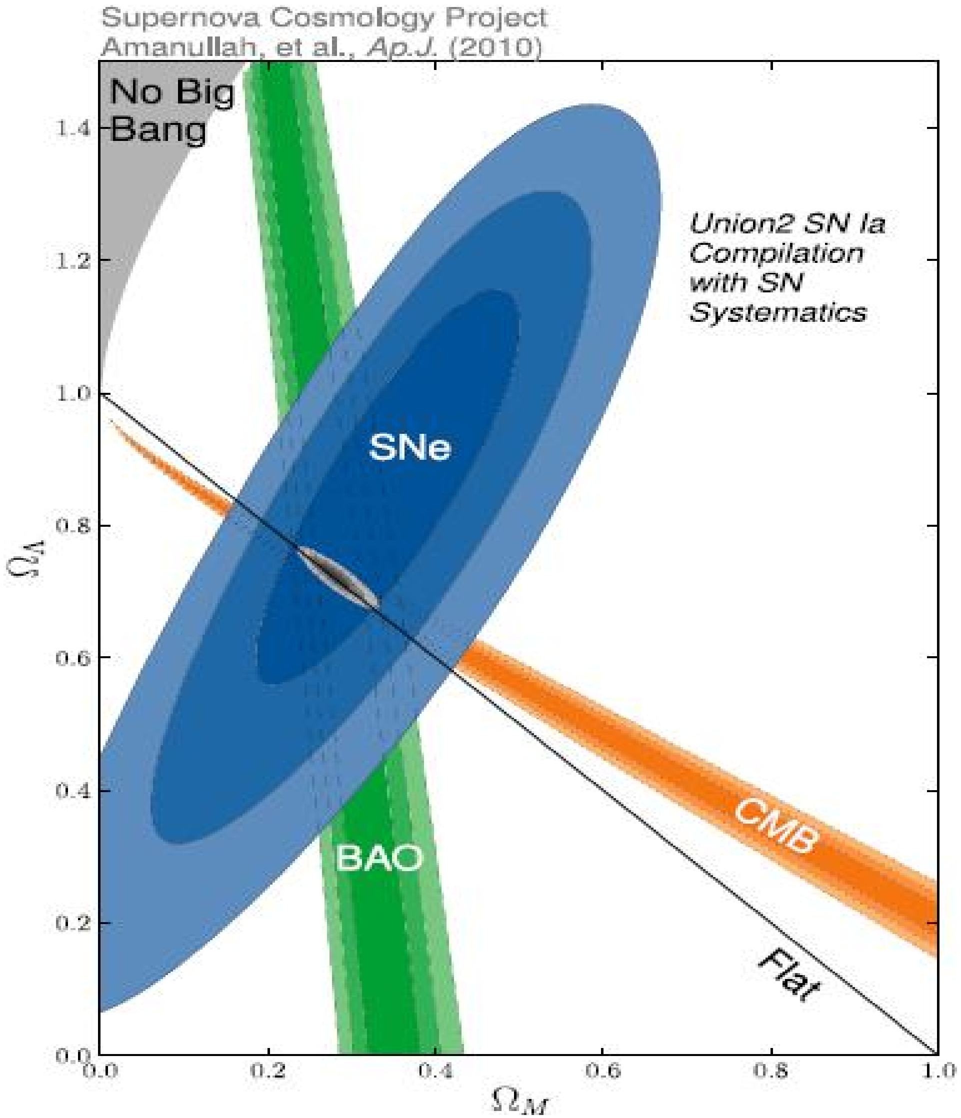
SD: Nomoto et al. 1982; 1997;

- Patat et al. 2007, Science：
- Sternberg et al. 2011, Science;
- Dilday et al. 2012, Science; PTF11kx;
- Nomoto et al. 1997, Science.

DD: Iben & Tutukov 1984; Webbink 1984

Schaefer et al. 2012, Nature;
Hernández et al. 2012, Nature;

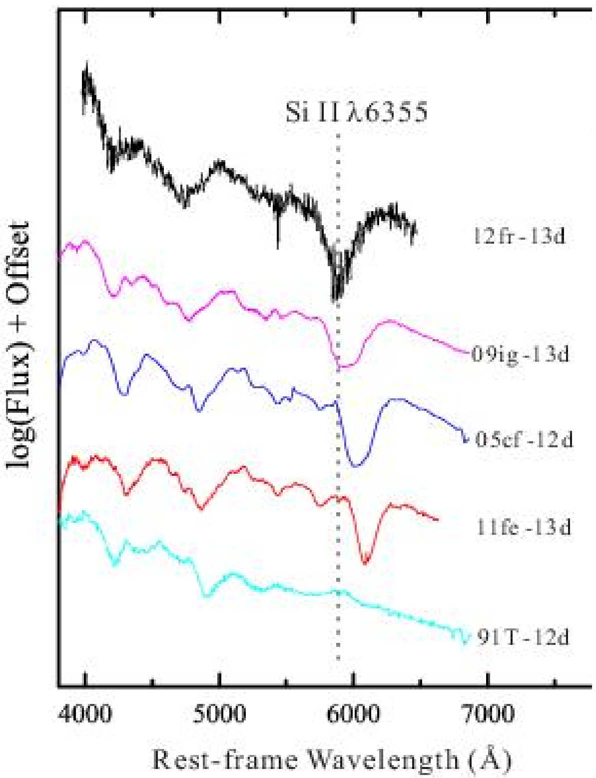
Why is identifying the progenitors of SNe Ia so important?

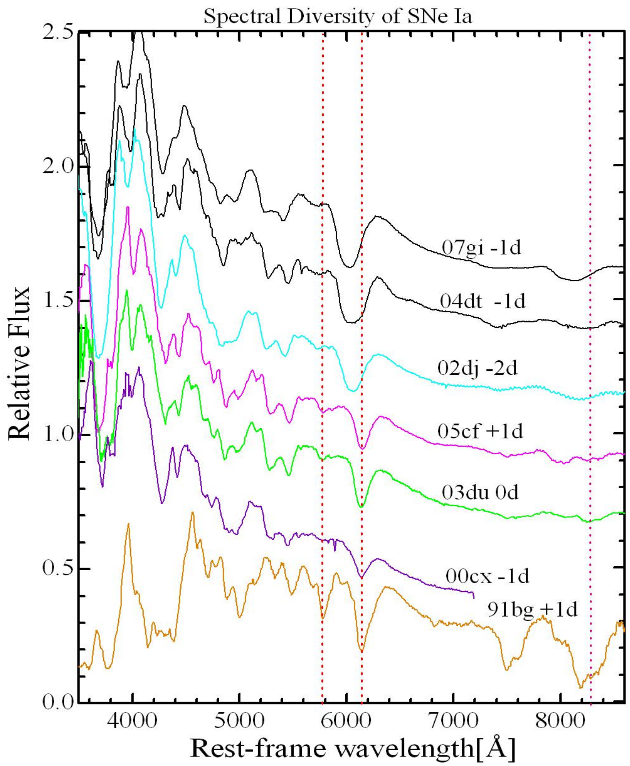


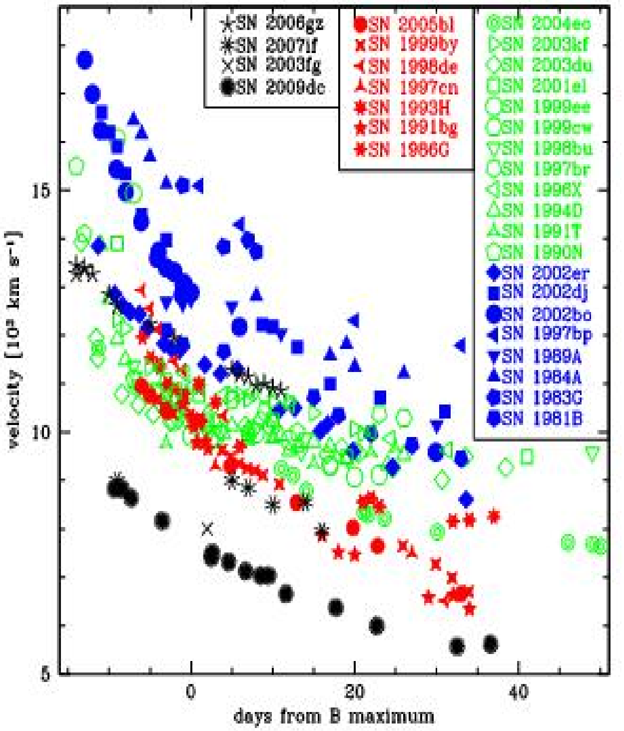
Accelerating Universe
2011 Nobel Prize in Physics!

- The fact that we still don't know the progenitors of some of the most dramatic explosions – a major embarrassment.
- For dark energy properties we need to understand the evolution of the SN Ia luminosity with cosmic time.

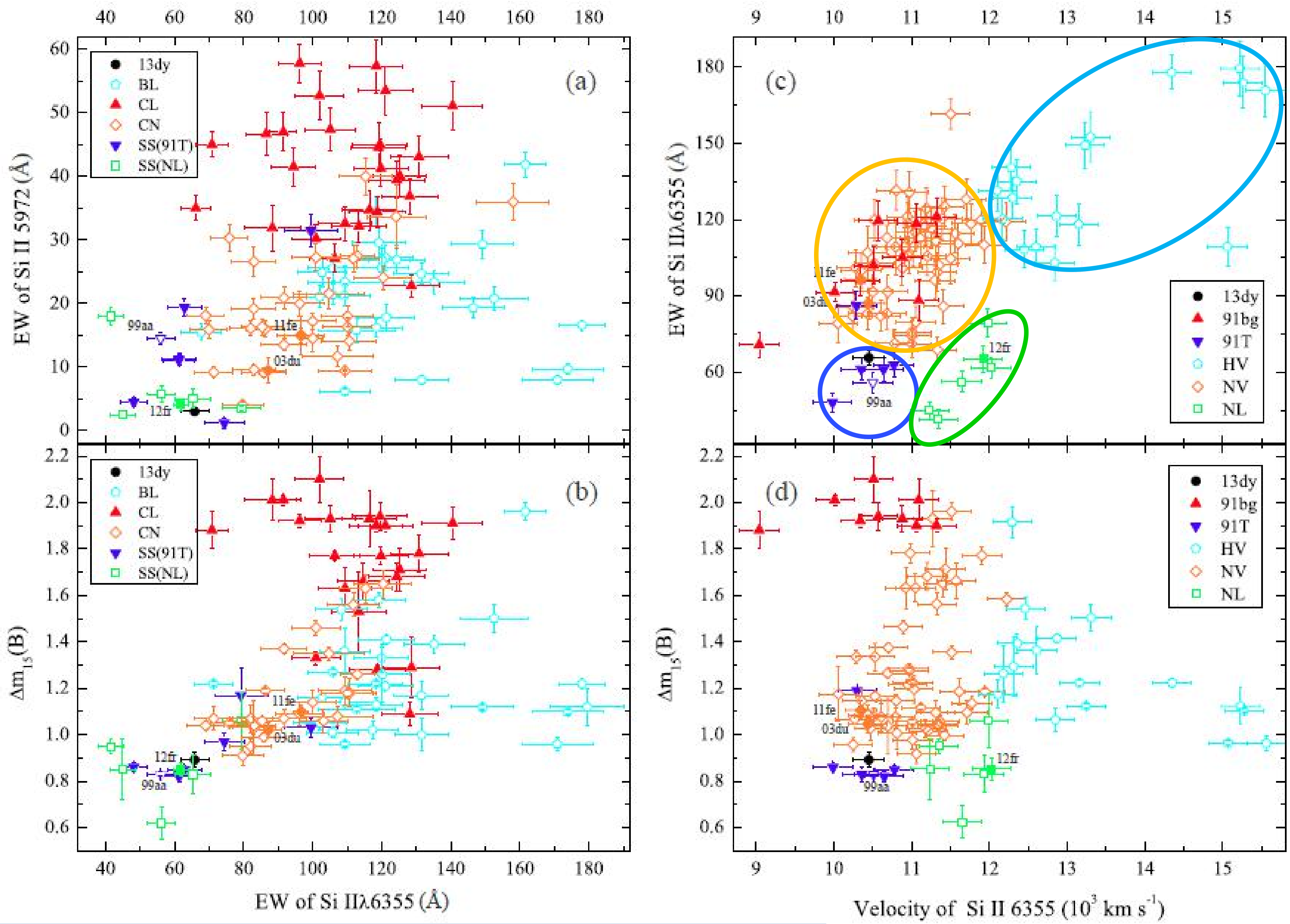
Spectroscopic Diversity of Type Ia Supernovae





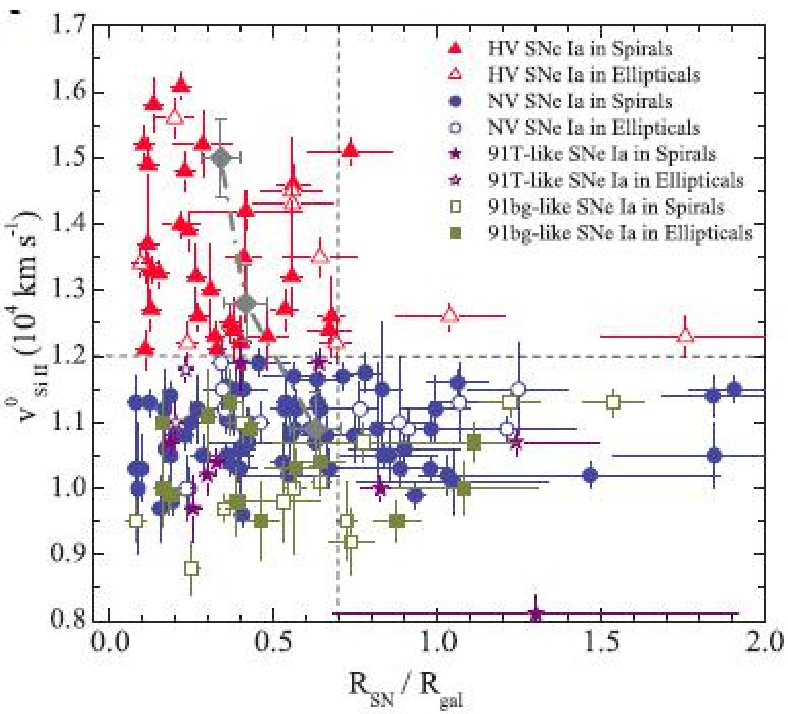


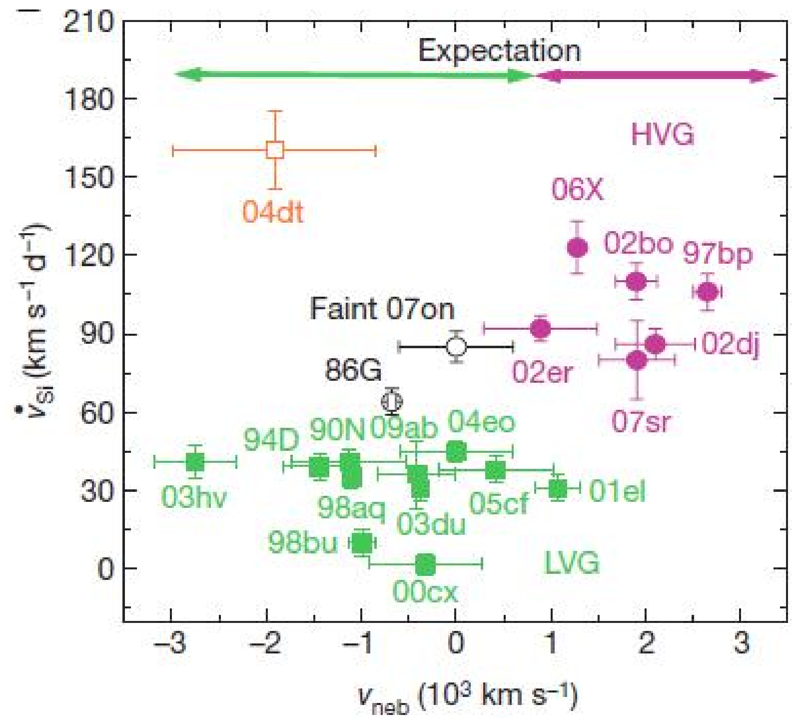
Different Spectrocopic Classifcations of SNe Ia



Zhai, Q., Zhang, J.-J., Wang, X. et al. 2016, AJ, 151,125

Origin of Spectral Diversity of SNe Ia: Environmental or Geometric Dependence?



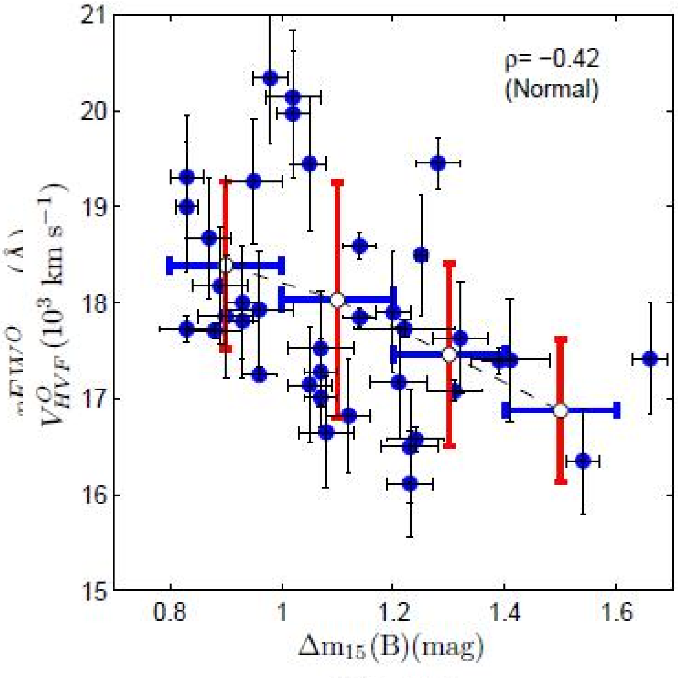


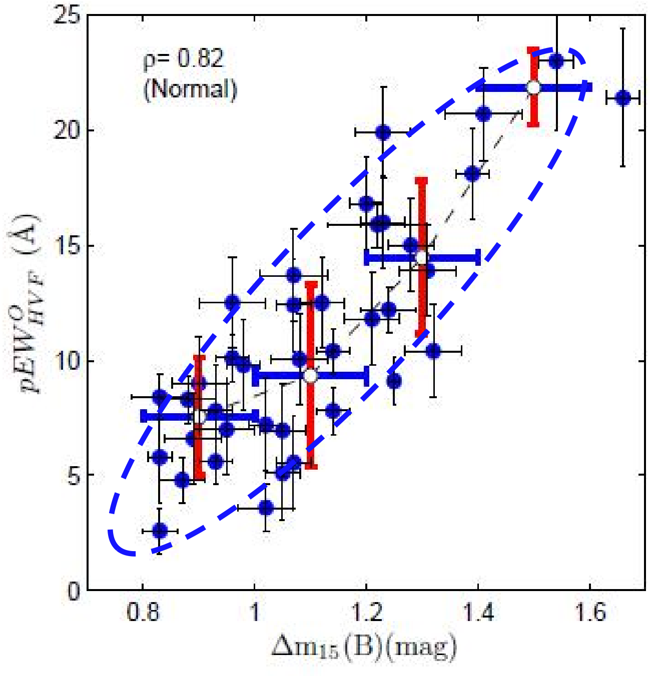
Wang, X., et al. 2013, Science

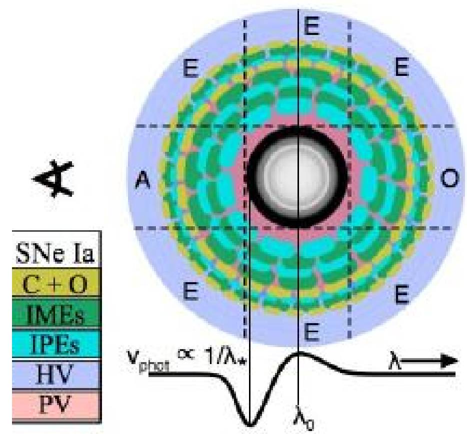
Maeda, K., et al. 2010, Nature

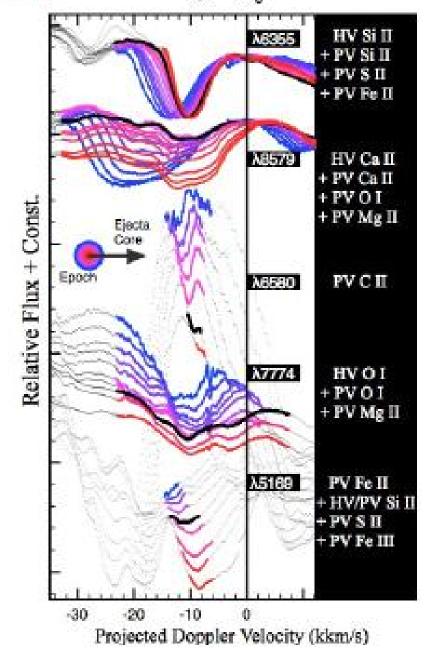
The TMT will open up a new window to study the explosion mechanism, using IRIS and WFOS for the late-time spectroscopy.

Obseved Diversity of High-Velocity Features in SNe Ia







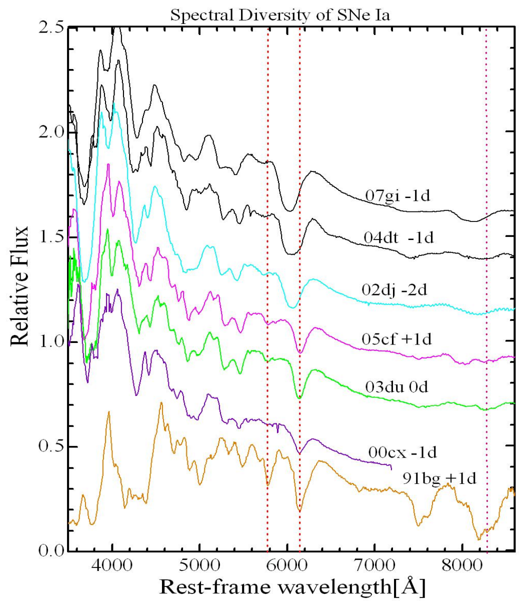


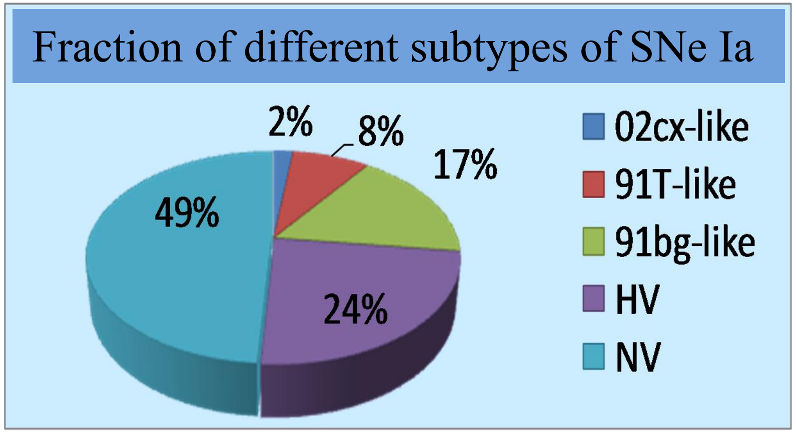
High velocity features (HVFs) of oxygen tend to be weaker and have larger velocities for more-luminous SNe Ia for the spectroscopically normal subclass. In addition to progenitor system, observed diversity is related to the degree of burning in the outer layers.

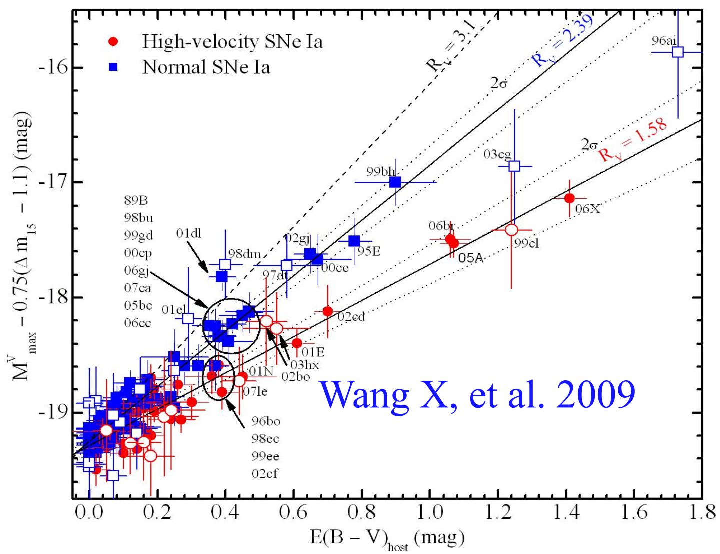
Zhao, Maeda, Wang, et al. 2016, ApJ, accepted (arXiv:1605.07781)

Searching More Uniform Subclasses of SNe Ia

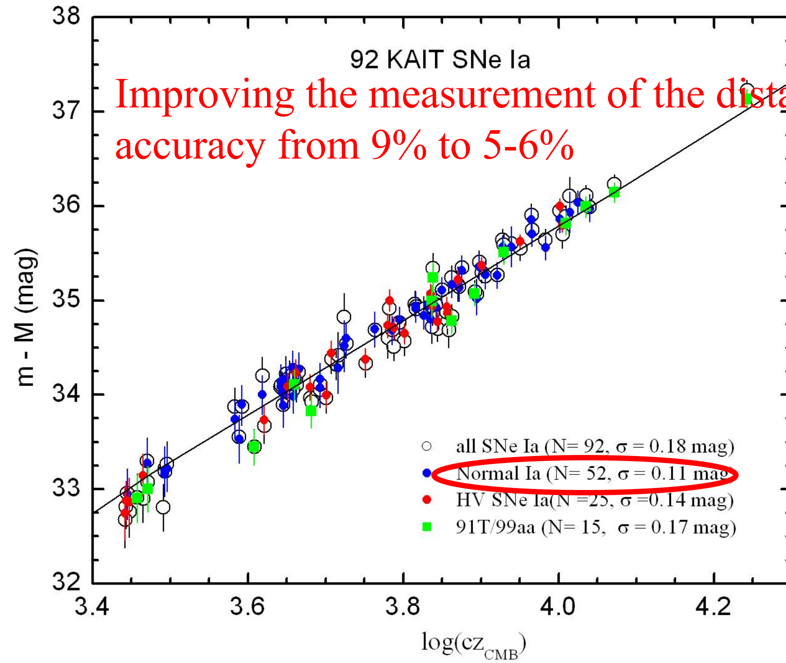
Early-time spectra are important! (TMT is needed for high-z SNe Ia)





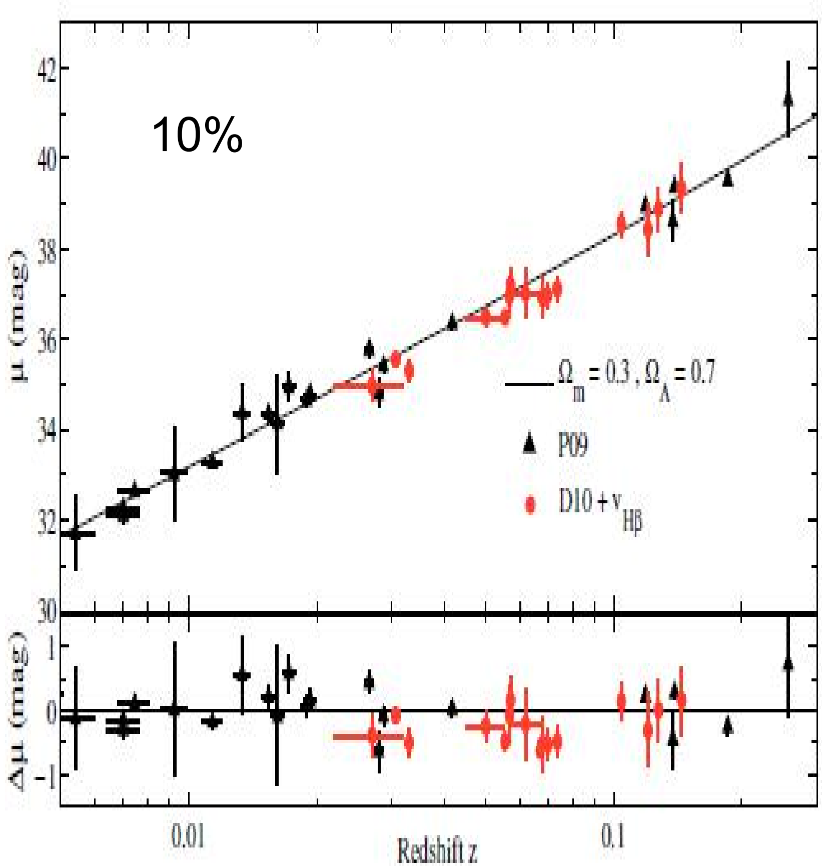


Wang X, et al. 2009



Improving the measurement of the distance accuracy from 9% to 5-6%

SN IIP Cosmology



Pozanski et al. 2010

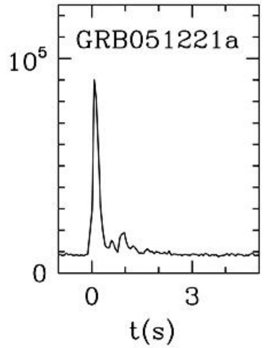
SNe IIP are simple and better understood standard candles than SNe Ia, but challegening to their relative faint brightness (Kasen & Woosley 2009) .

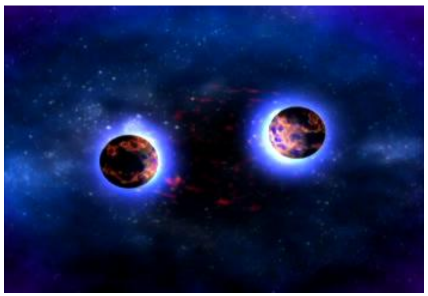
Fe II velocity near 5000A can be better measured with TMT WFOS and IRIS.

z~0.3 for Keck: < 10 SNe IIP
z~1.0 for TMT: > 100-500 SNe IIP

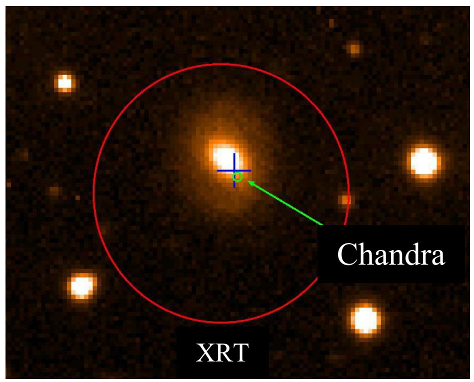
Understanding Progenitor of Gamma-ray Bursts

Short GRB

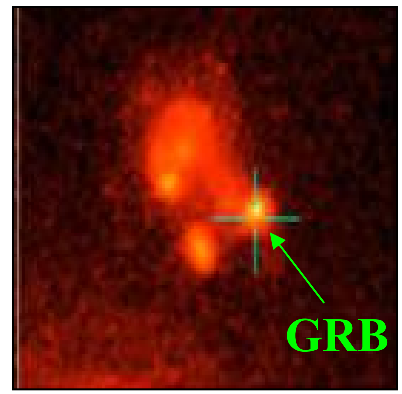




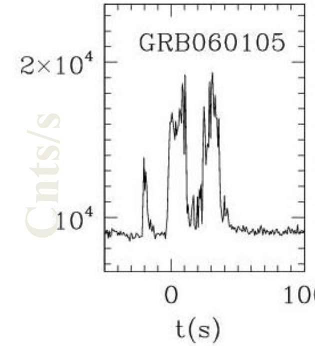
GRB 050724 - *Swift*
elliptical host

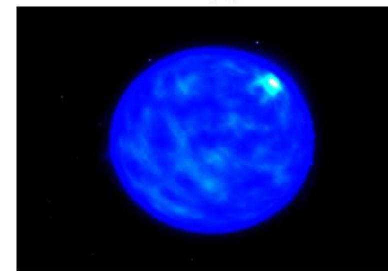


GRB 020903 - *SAX*
SF dwarf host



Long GRB

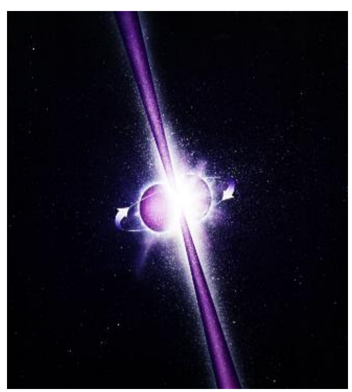


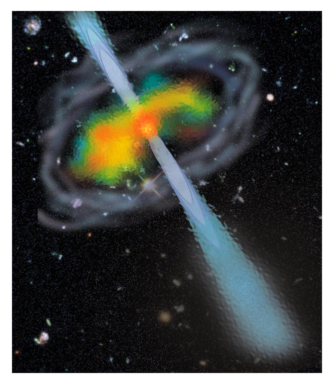


In non-SF
and SF galaxies

No SNe detected

Possible **merger** model





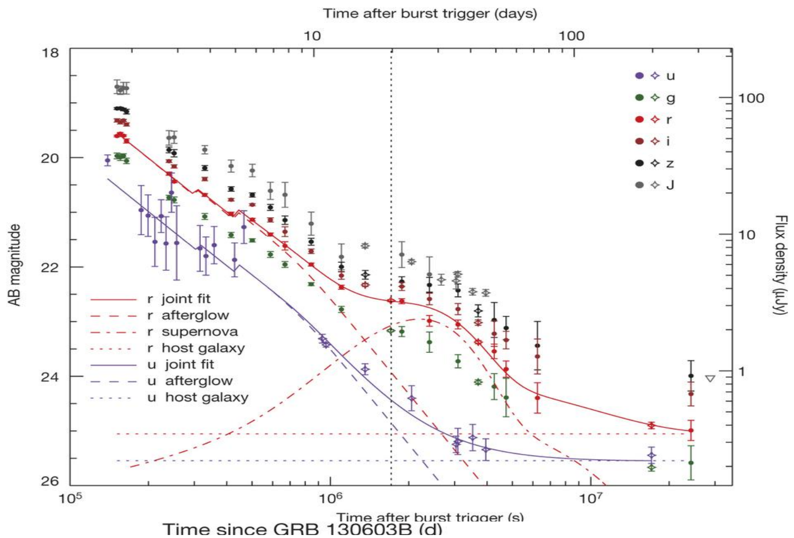
BH

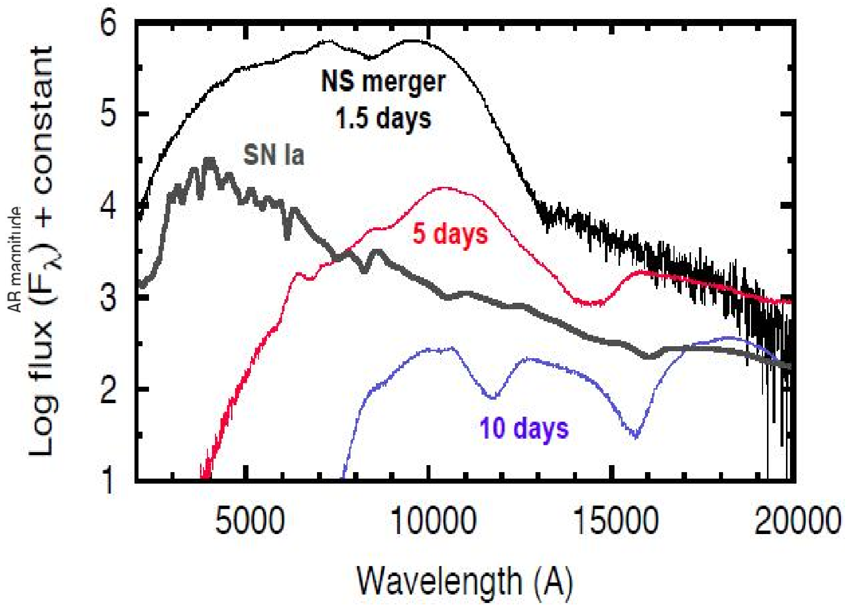
In SF
galaxies

Accompanied by SNe

Collapsar model well supported

Understanding the Progenitor of Gamma-ray Bursts

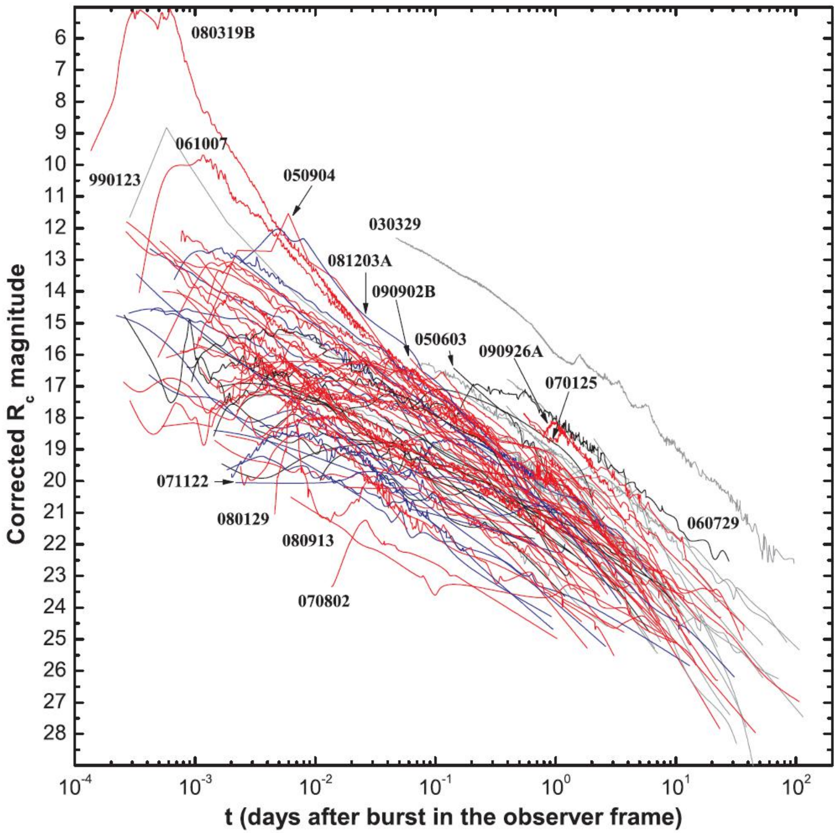


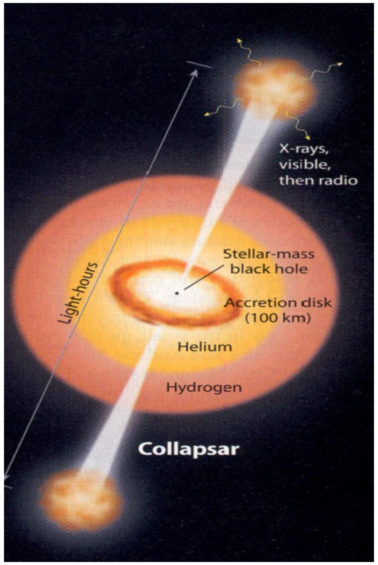


- TMT WFOS will be important to search for the missing SN component in some low redshift GRBs
- TMT IRIS will enable the spectroscopic identification of SN component at z=0.5-1.0
- TMT IRIS will be ideal instrument to perform ToO NIR spectroscopic observations of kilonova events associated with short GRBs to fully understand their progenitors.

Tanaka&Hotokezaka 2013

Probing the High-z Universe with GRBs

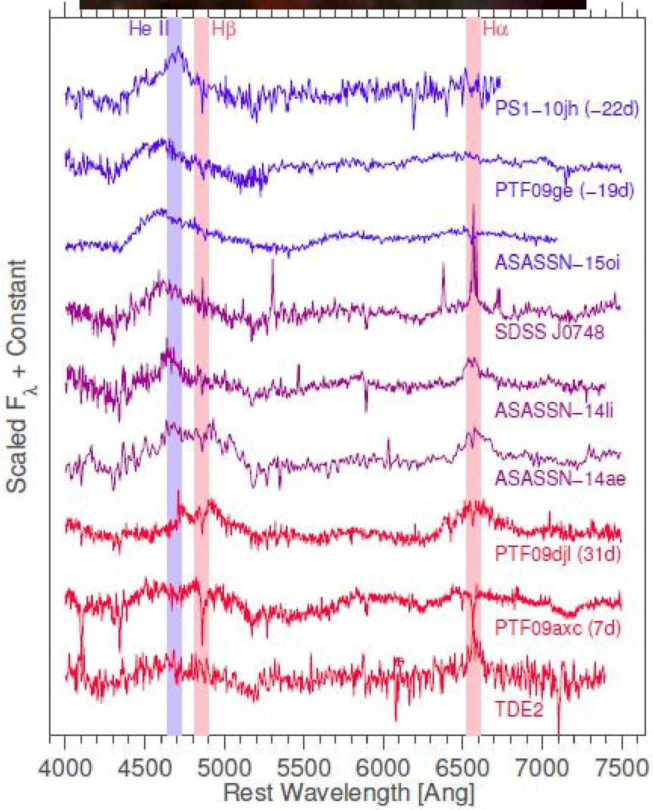




- High-z GRBs can be used to probe the early phase of star and galaxy formation;
- The optical light from afterglow of some GRBs is known to be brighter than quasars;
- Prompt NIR spectroscopic observations of high-z GRBs are essential.

Kann, et al., 2010, ApJ, 720, 1513

Understanding Physics of Tidal Disruption Events



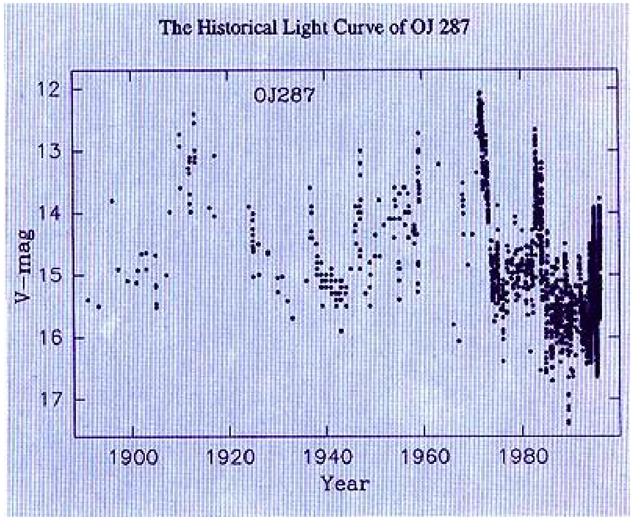
- A star passing close to a black hole can be torn apart by tidal forces in a TDE, accompanied in most cases by an observable flare (Hills 1975; Rees 1988).

- The TDE flares can be used to probe and study the inactive supermassive blackholes, physics of disruption, the subsequent accretion, and the emission mechanism.

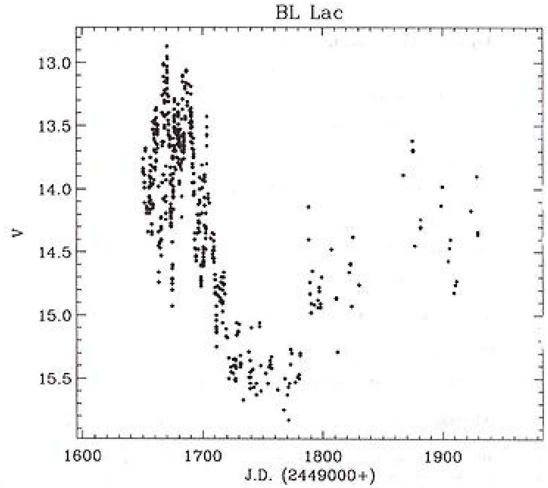
- Spectra of more events at different phases are needed to better explore the diversity, especially to late times where data currently exist for only one event (Gezari 2012).

Time-domain study of AGN

Longterm Variability

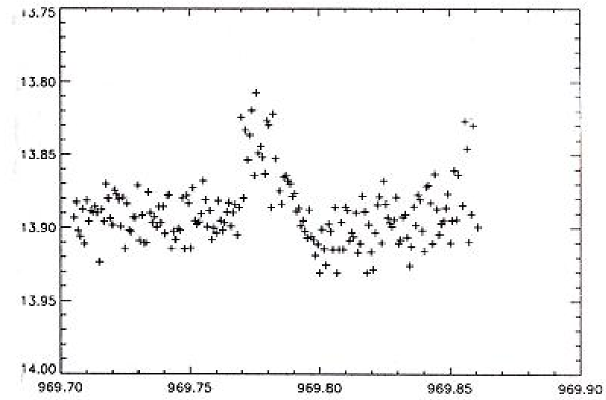


Intraday Variability

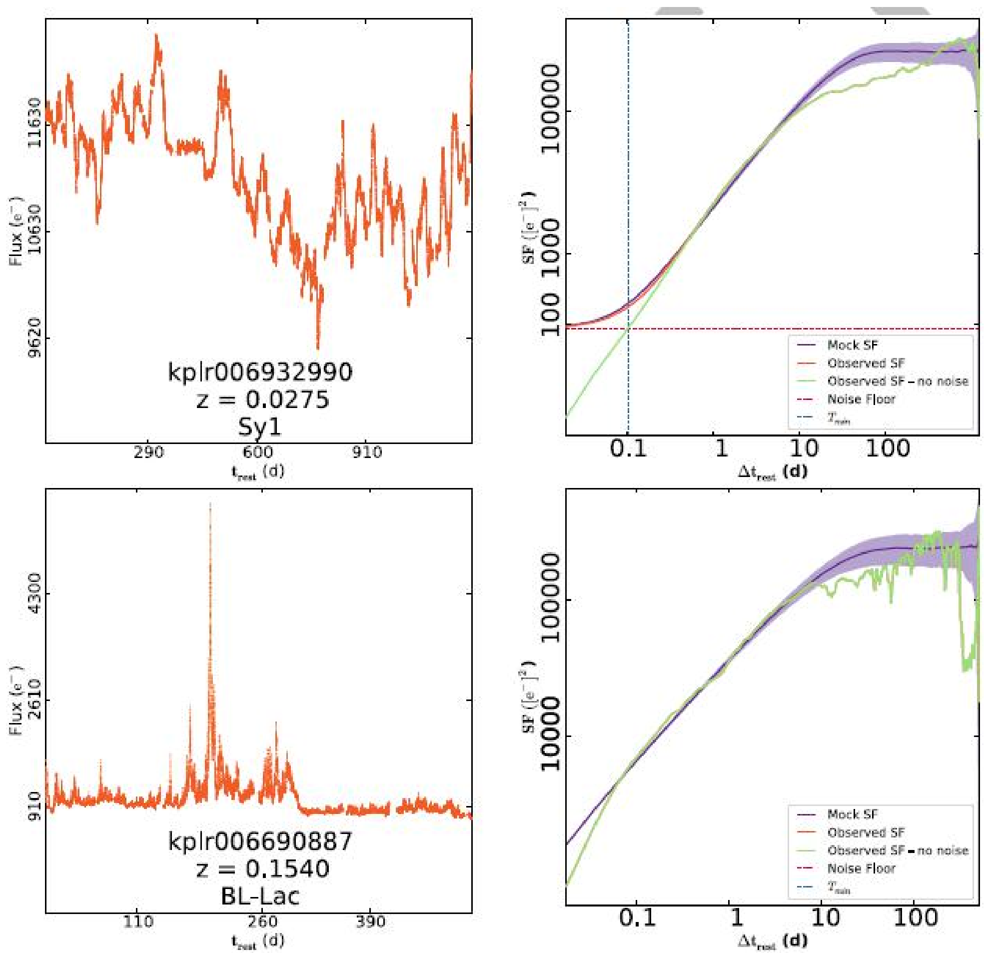


V band light curve of BL Lac during June 1997–May 1998

Microvariability



Understanding the Light Varability of AGN



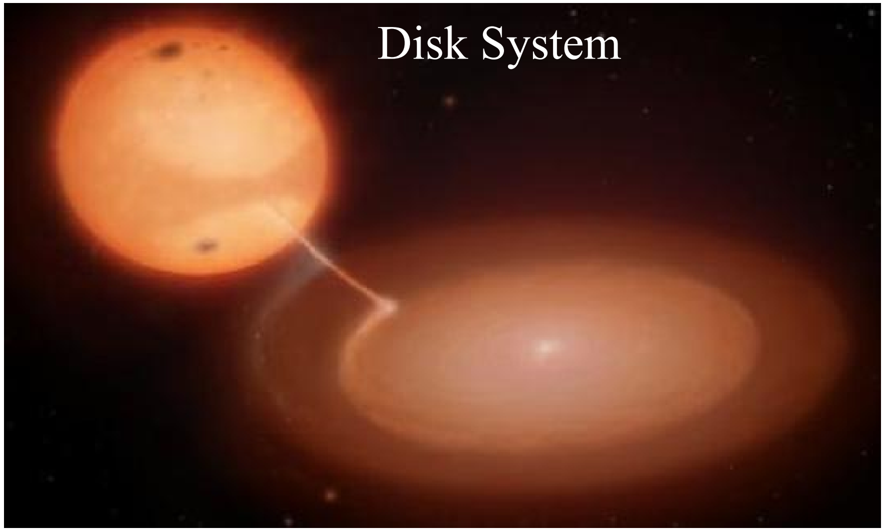
Mechanism for fast light variations: shock waves, turbulence, and magnetic reconnections (different time-varaible linear polarization).

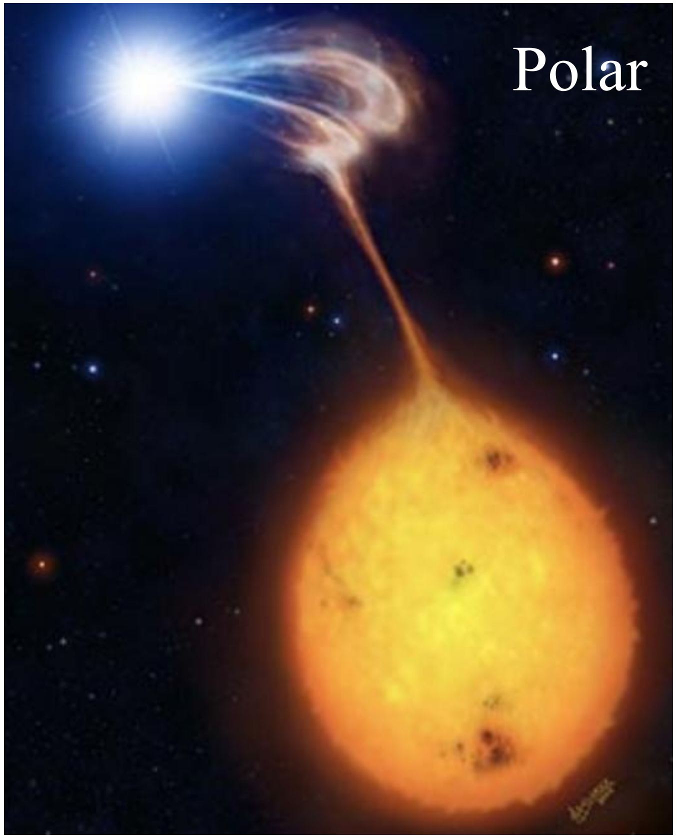
Discerning among these possibities requires precise spectro-polarimetric observations on times scales of a few minutes with the TMT.

This will detrmine the power spectrum of the fluctutions down to small size scales, testing different models of particle acceleration and blazar variability.

Kasliwal et al. 2015

Cataclysmic Variables



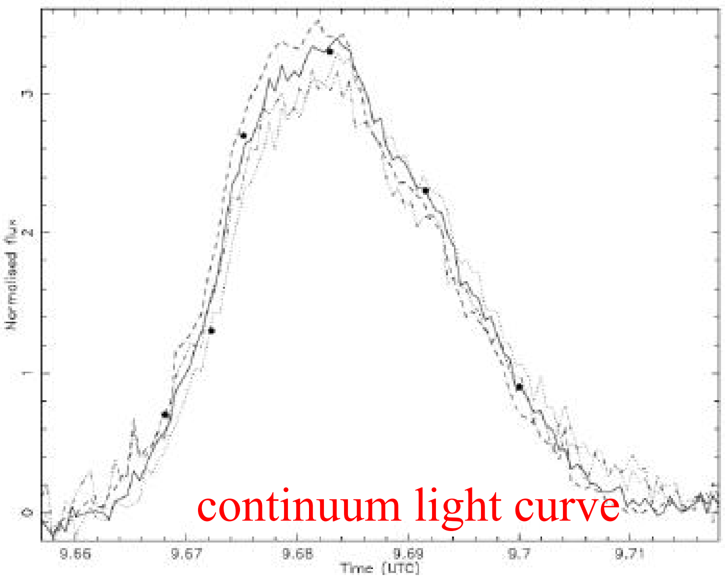


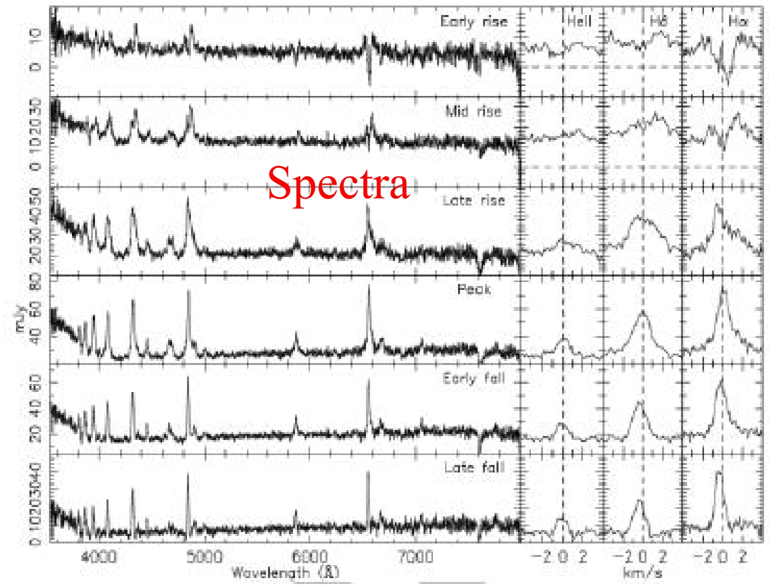
Accretion is a very common process but it is poorly understood. CV display rapid variability related to accretion process.

CV accretion disk is an ideal laboratory for studying the angular momentum dissipation mechanism and relation between dissipation, disc density, temperature, magnetic field, and radial velocity profile.

Origin of CV Flares

Dwarf Nova SS Cyg (11 mag)





The light variation of SS Cyg obtained from Keck LIRS observation is consistent with that arising in accretion disc and could be descibed with a fireball model (Skidmore et al. 2004).

Time resolved optical spectrometry with TMT WFOS with R=4000 (with t_{sample} =50 ms and duration of 20 minutes) will give S/N=1000 for a CV with Mv=15 mag (N > 100). Such a sample will allow comprehensive understanding of accretion disc physics that is impossible for the existing facilities.

Summary

- Time-domain astronomy will be an exciting area of research in the TMT era, by synergy with various surveys from upcoming facilities such as the LSST, WFIRST and Euclid, and search for the graviational wave sources.
- In the TMT era, we can have better understanding of supernova progenitors, their explosion physics, and improving their use in cosmology (SNe Ia, SNe IIP), through the early-time and late-time WFOS and IRIS spectrometry.
- Better understanding of GRB Progenitors (searching the missing signals in some low-z long GRBs, identifying the progenitor of short GRBs)
- Revealing the origin of fast variability in AGN and CVs (accretion physics).