THE UNIVERSITY OF CHICAGO
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THE 82ND ARTHUR H. COMPTON LECTURE SERIES

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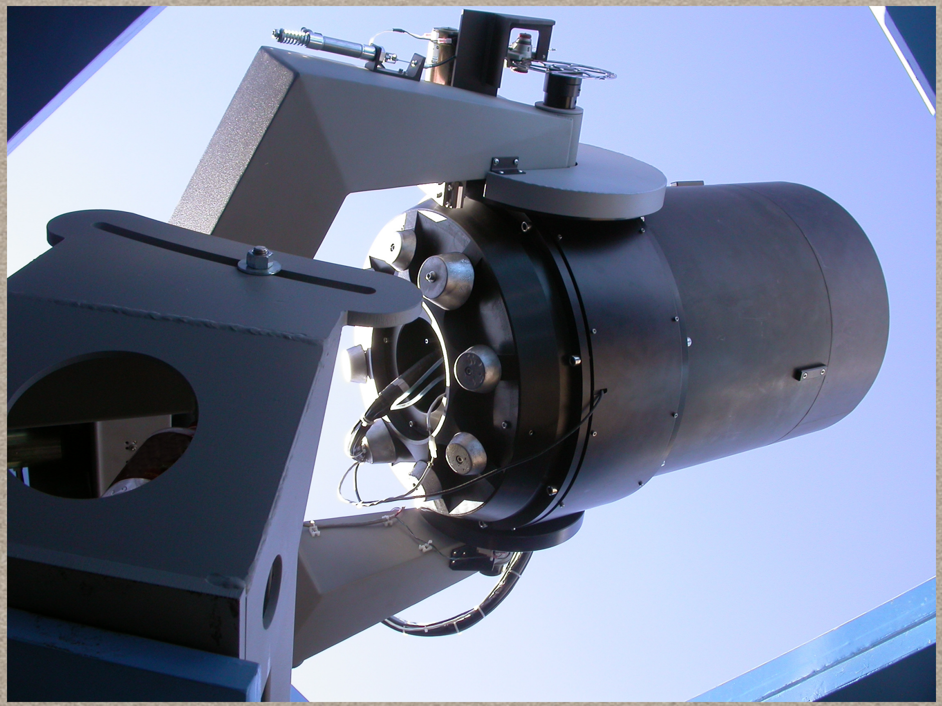


LECTURE 9

WHERE DO WE GO FROM HERE? THE FUTURE OF SUPERNOVA RESEARCH

12/12/2015

THE ROLE OF AMATEUR ASTRONOMERS

Non-professional star-gazers around the world have significantly contributed to the discovery of new supernovae!

SN 1987A is a prime example, discovered independently by New Zealand amateur astronomer Albert Jones.

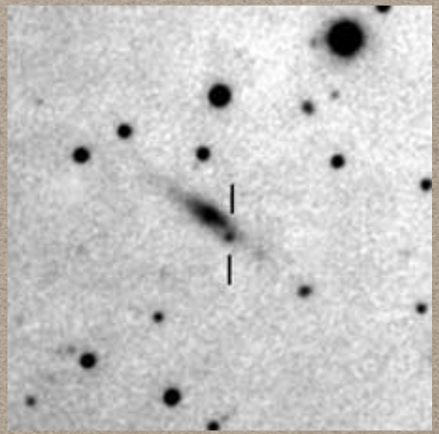
Amateurs sometimes organize and crowdsource their equipment devoting significant time to the discovery of supernovae. Example is the POSS (Puckett Observatory Supernova Search) project that has discovered 54 SNe.

Internet and social media have helped amateur supernova lovers connect around the world creating global independent networks such as the World Supernova Search.

Discovered new class of SN! Type Iax

Discovered more than > 300 SN to date!

Tim Puckett and his telescope



SN 2001eo

A STEP FORWARD: AUTOMATION

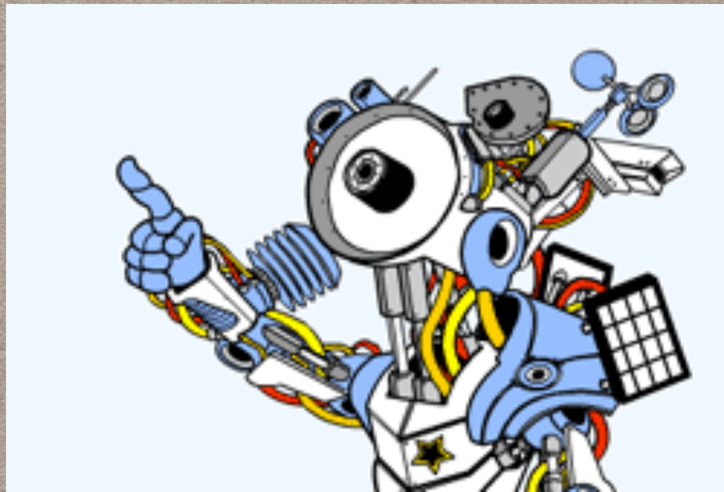
The key in discovering new transients is continuously revisiting large portions of the sky to look for “lights” that were not there during the previous scan.

Automation and AI have significantly helped that effort. Robotic telescopes now scan the sky taking pictures and automatically comparing them to pictures from the previous scan to look for new transients.

Once a transient is seen, an automatic alert is sent via e-mail to astronomers who look closer and take spectra using other telescopes in order to classify the transient.

Let to a revolution in supernova discovery with tens of thousands of events discovered daily!

Fast cadence also allows to study supernovae during the very early stages of their evolution.



THE ROTSE TELESCOPE NETWORK

The RObotic Optical Transient Source Experiment (ROTSE)

History - Robotic telescope program run by Dr. Carl Akerlof, University of Michigan, designed to discover, monitor optical transients associated with Gamma-Ray Bursts.

ROTSE III - system of four robotic telescopes, 18-inch aperture, limit ~19th mag
1.85 degree square field of view (sun ~0.5 deg), spotted around the world, all sky, all time coverage. Most rapid response on the planet - 6 seconds from email receipt.

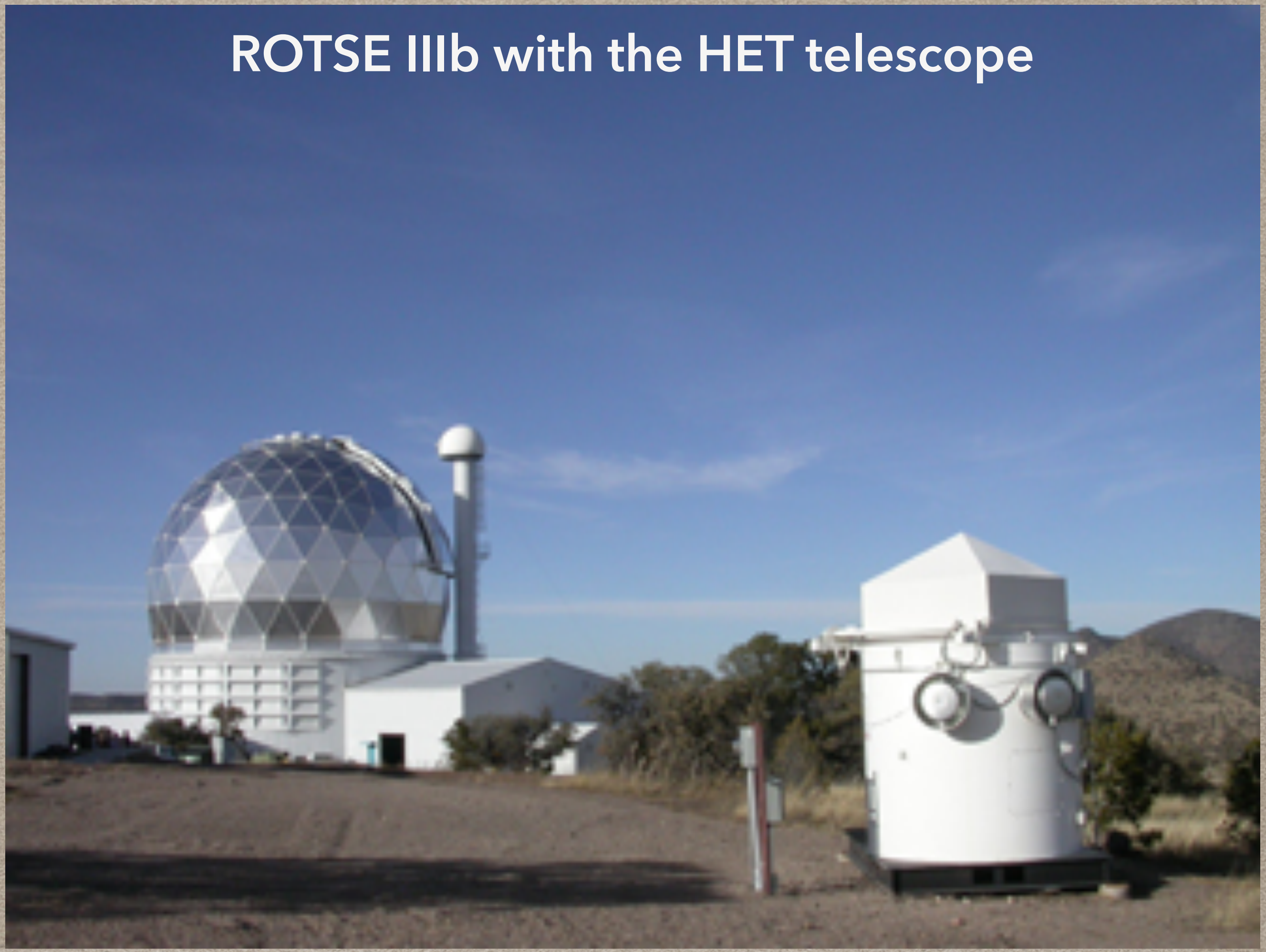
THE RSVP

ROTSE can point and shoot **within 6 secs** of electronic satellite notification, take **automatic snapshots** every 1, 5, 20, 60 secs.

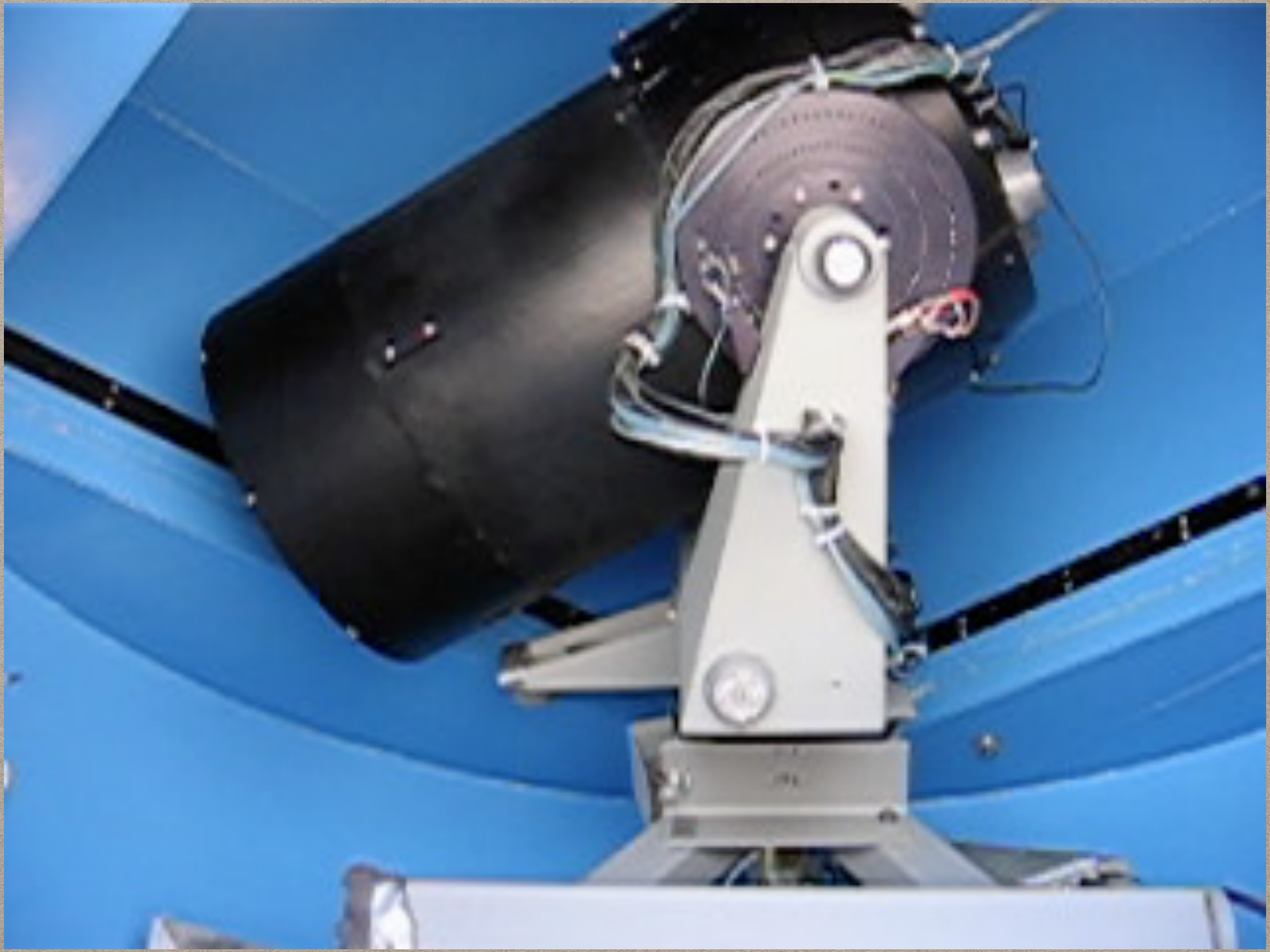
ROTSE joined UT Austin for the **TSS** project (Texas Supernova Search) evolved into the **ROTSE Supernova Verification Project** (RSVP).

ROTSE has:

- Discovered the optical transient during the 30 second gamma-ray burst;
- Followed the light in unprecedented detail;
- Relayed the discovery and coordinates to the HET for spectroscopic follow up.
- Discovered the first super luminous supernova, SN 2005ap and a lot more of the same category!
- Discovered one of the first tidal-disruption events! (“Dougie”)



ROTSE IIIB IN ACTION!



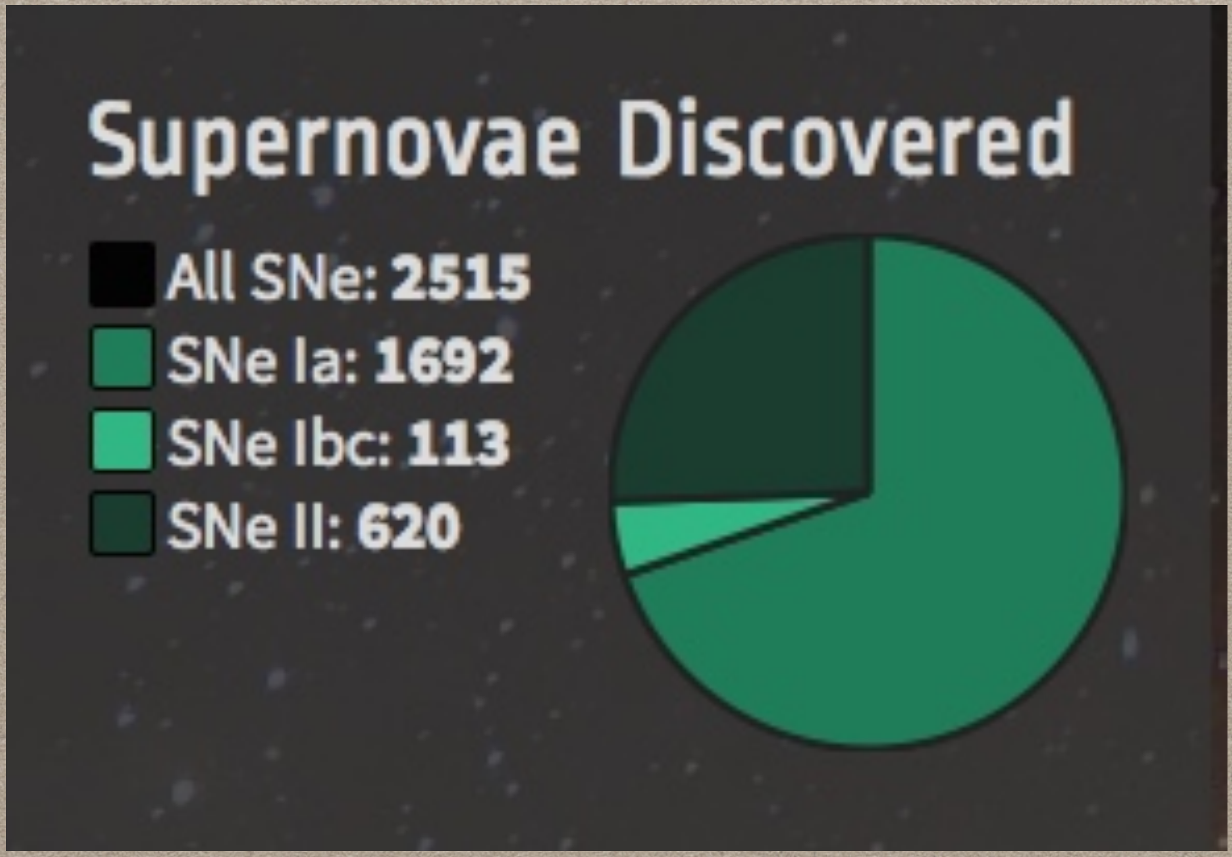
THE PANSTARRS PROJECT

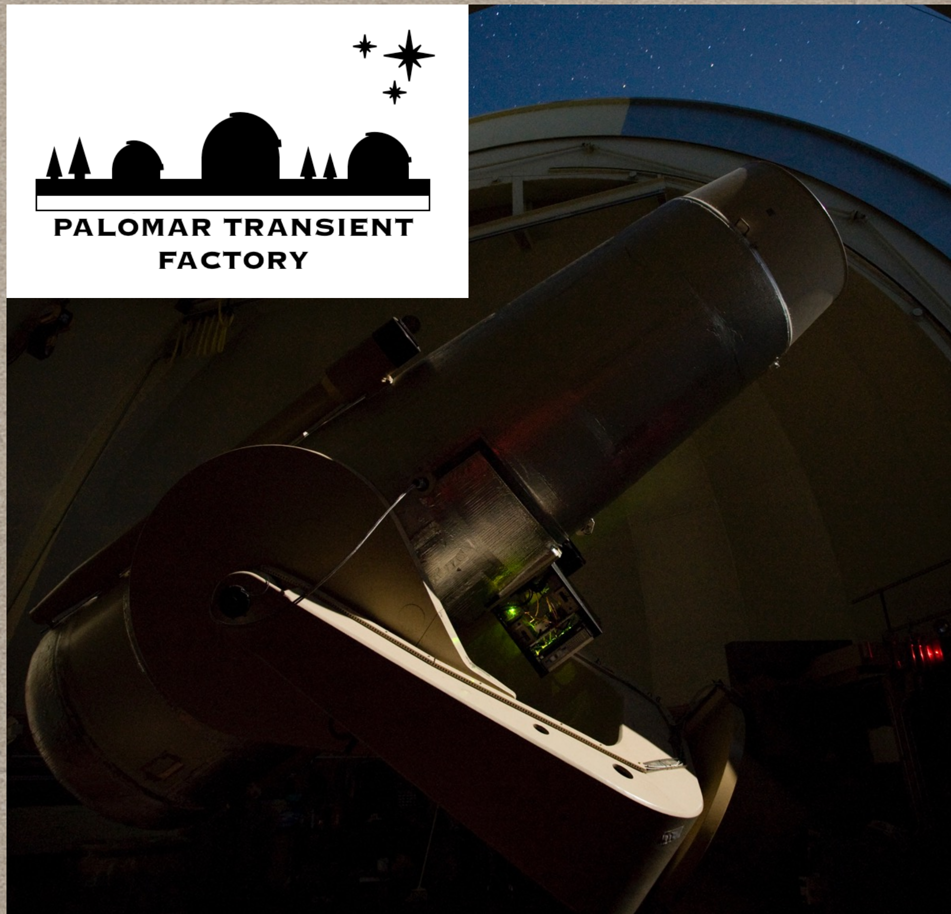
The Panoramic Survey Telescope & Rapid Response System

- PS1 telescope now located in Hawaii's mount Haleakala.
- Four individual optics systems of 1.8-meter diameter each fixed at same direction of sky simultaneously.
- 3-degree field of view (6 times size of sun) - CCD (digital) camera - 1.4 billion pixels (200 times better than your iphone's camera)!
- Designed to also look for NEOs (Near Earth Objects) but great for transient astronomy!
- Discovered thousands of Type Ia SN and many SLSNe as well as GRBs (Harvard CfA researchers).

THE PALOMAR TRANSIENT FACTORY (PTF)

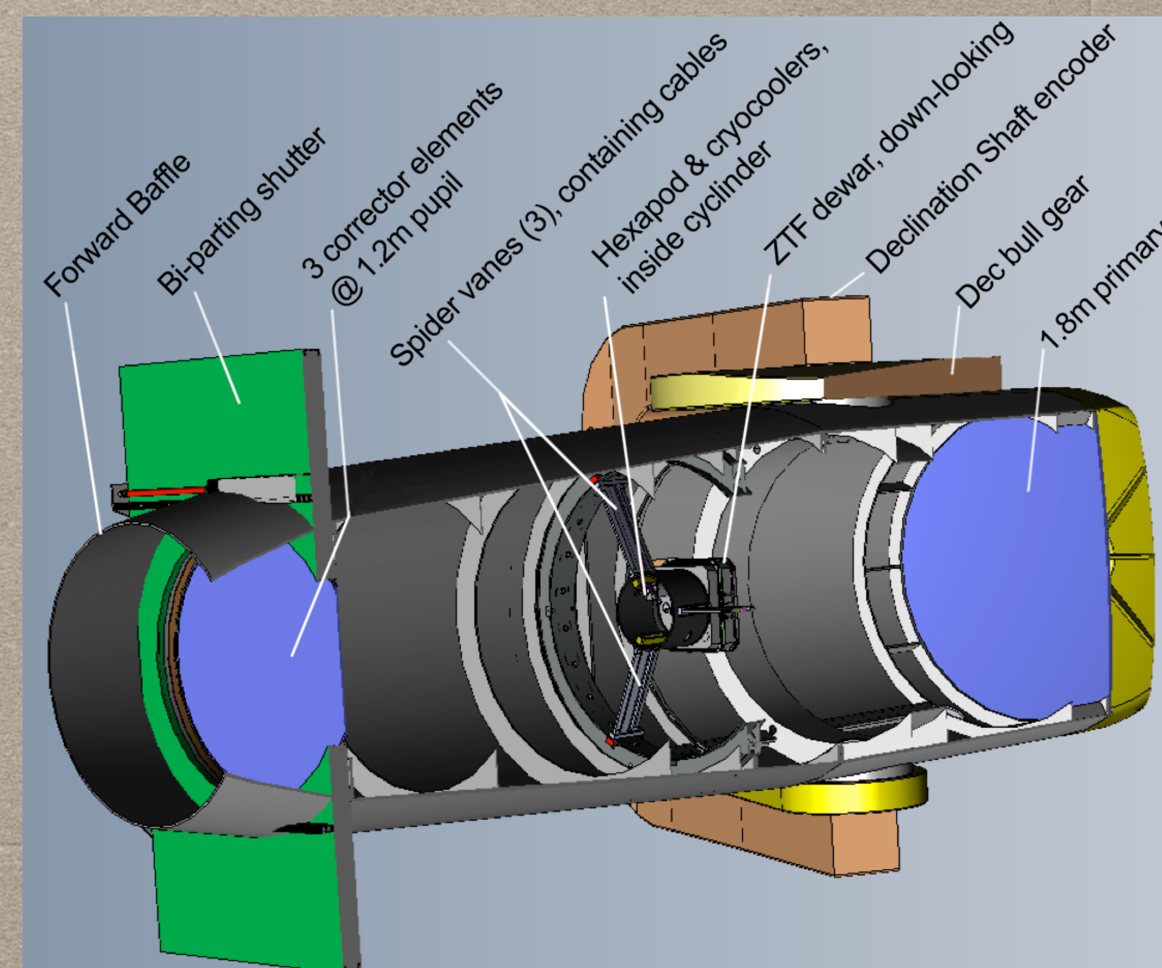
- A Caltech-led effort that begun in 2009. Using the historic California's Palomar observatory; the 7.26-square degree CFHT12k mosaic on the Palomar Samuel Oschin 48-inch Schmidt Telescope.
- High cadence - fast response - automatic classification!
- Discovered SN 2011fe, the youngest SN ever observed.
- In 2012 transition to iPTF (intermediate PTF). New filters, revamping and 11 new, active 2048x4096 pixel CCDs.
- Discovery of many SLSNe and peculiar Carbon-rich transients! Lot's of weirdos!
- Observations made in optical R-band. Real time AI data processing at the Infrared Processing and Analysis Center and the Lawrence Berkeley Lab (LBL)





ONTO THE FUTURE: THE ZTF PROJECT

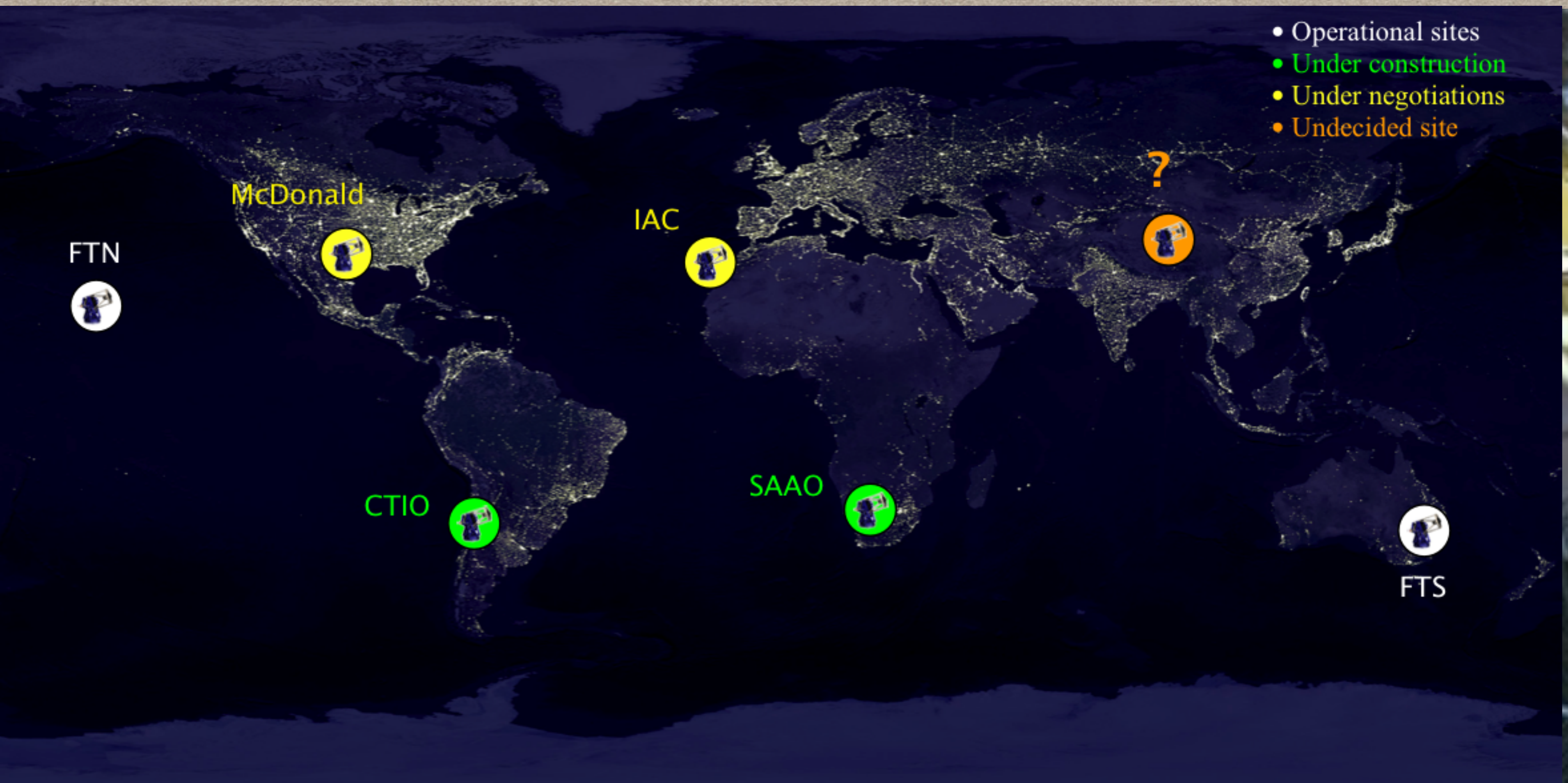
- First light in 2017, the Zwicky Transient Facility is the successor to the iPTF project, named in honor of astronomer Fritz Zwicky.
- Significant upgrades: new camera with 47 square degree field of view.
- Ability to scan 3750 square degrees an hour!
- Increased sensitivity - can capture really dim transients (down to 21 mag - 6.5 million times dimmer than sirius).
- Has the potential to discover young SN just 24 hours after its explosion as well as other exotic and yet unknown transient events.
- Also ideal for studies of binaries, Active Galactic Nuclei, variable stars and asteroids.



THE LCOGT NETWORK

Las Cumbres Observatory Global Telescope Network

- ★ Headquartered in Santa Barbara, CA. Seed funding private.
- ★ Integrated set of 2-meter diameter robotic telescopes scattered around the world: Hawaii, Australia, Chile, Texas, South Africa, Canary islands.
- ★ Purpose for transient astronomy research but also education.
- ★ Low-resolution spectrographs installed in all telescopes for rapid contemporaneous collection of transient spectra and classification.
- ★ Also used for exoplanet search.

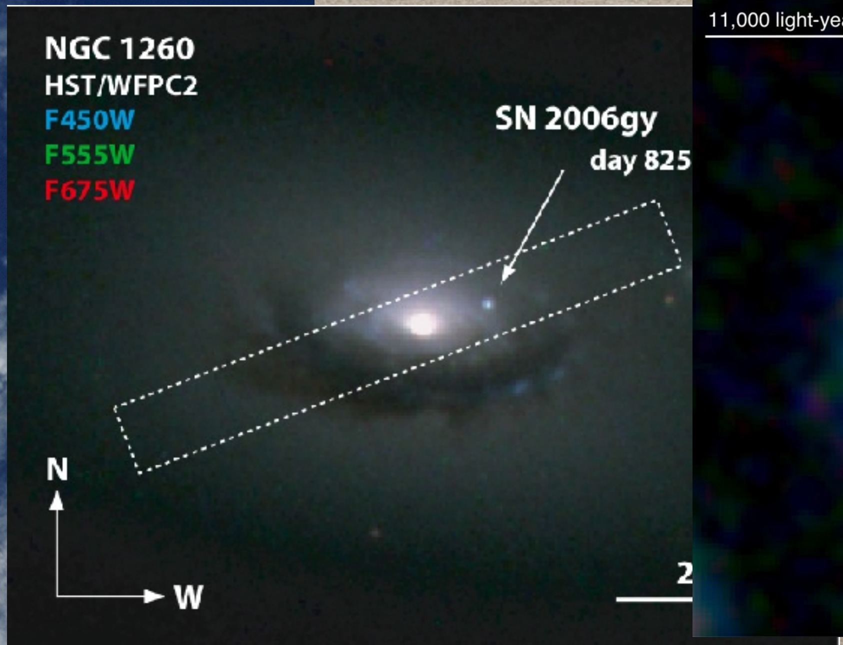


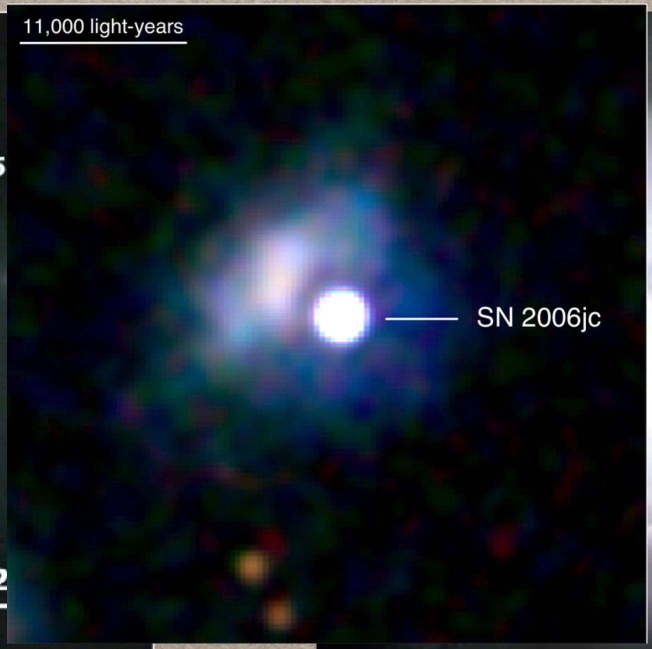
TARGET OF OPPORTUNITY OBSERVATIONS: HST AND SWIFT

It is of great importance to observe supernova both with high temporal frequency but also across different wavelengths. So, once a SN is discovered astronomers request for “special treatment” on satellite cutting-edge telescopes like HST and Swift.

HST has taken accurate images of many SN, including SLSN 2006gy and Swift has discovered a large number of GRBs but also obtained many UV and X-ray observations of young SNe.

Important to capture the SN during the rise: accurate knowledge of explosion date can constrain light curve - deduced physical properties of the explosion.





UNDERSTANDING NATURE VIA PARALLEL SUPERCOMPUTING

But how do we study Supernova right here on Earth?

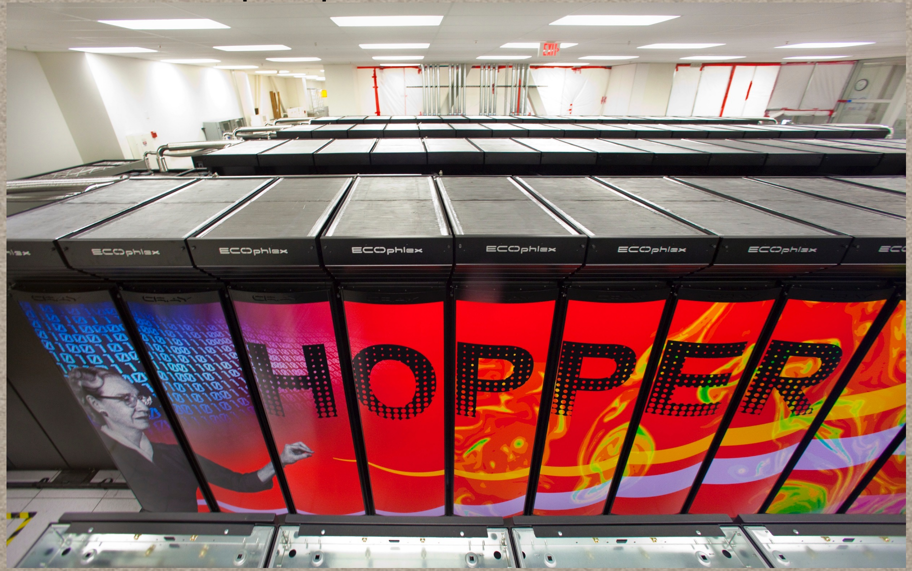
We run simulations of explosions on Supercomputers like Mira. Mira can do one simulation in less than a day while your personal computer would need thousands of years…

In the comfort of our office!

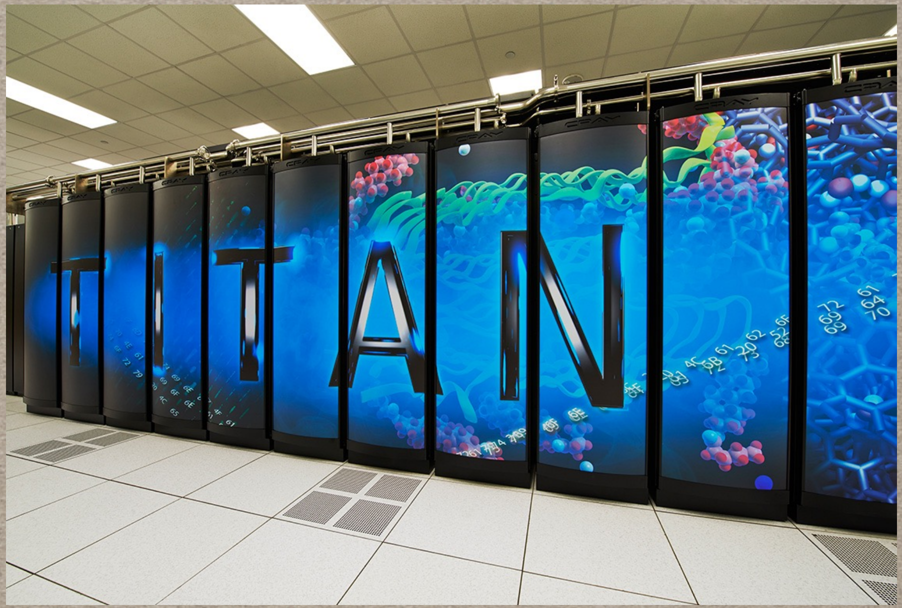
SN RESEARCH IN THE “PENTAFLOP” ERA

Mira: Argonne (ALCF). IBM system. 10 pentaflops. 786,432 processors.
1 day of Mira = 20 days of your modern laptop.

Stampede: UT Austin (TACC). Dell system. 9.6 pentaflops. 522,080 processors.



Hopper: NERSC. Cray XE6 system. 1.28 pentaflops. 152,216 processors.



Titan: Oak Ridge (OLCF). NVIDIA/Cray system. 20 pentaflops. 299,008 processors.

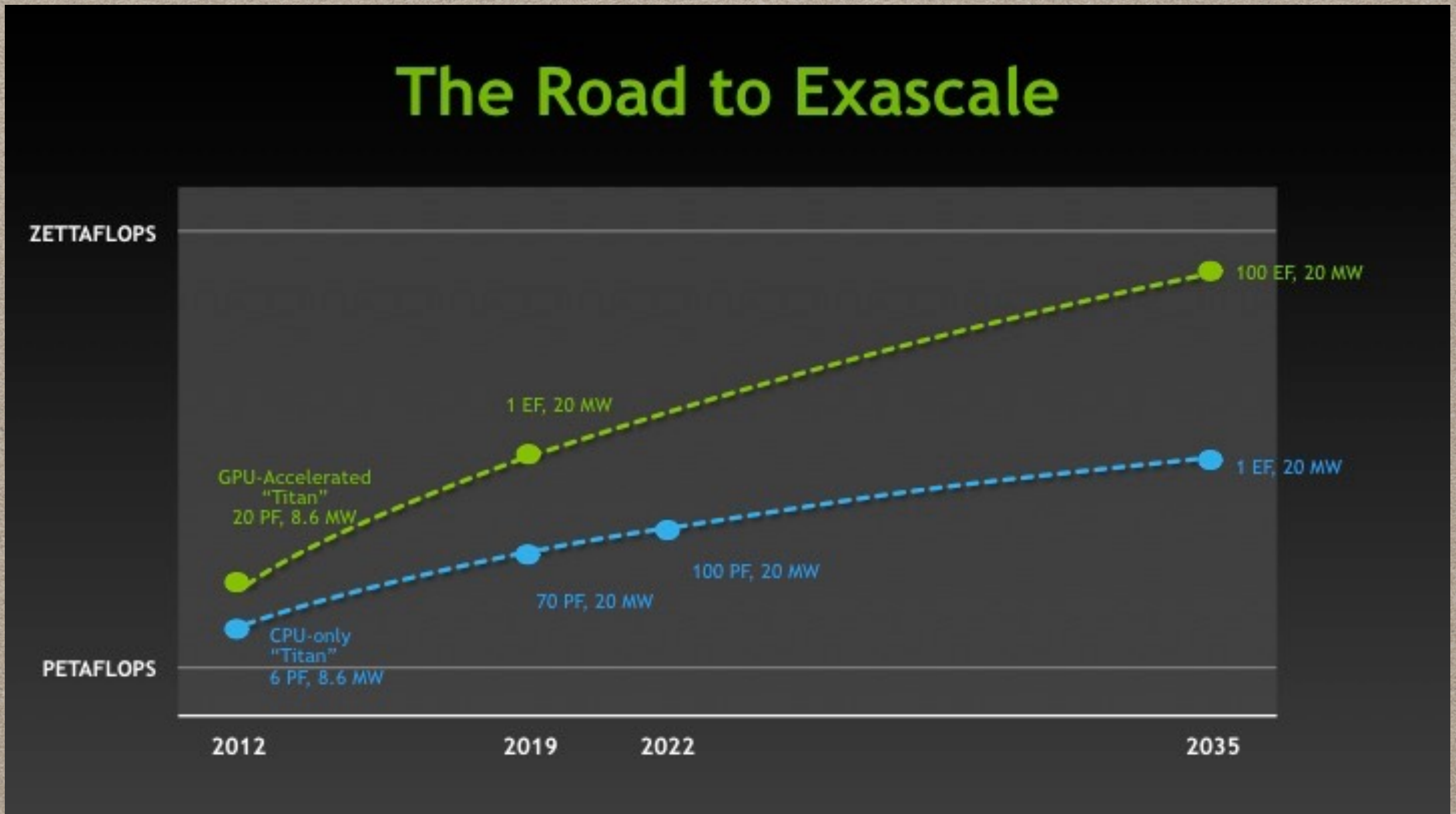
THE FUTURE: EXASCALE COMPUTING

Billions of public and private dollars are invested towards the next era of scientific supercomputing: the era of Exascale computing (10^18 flops per second…).

Practical challenges: Energy required to power them (electric bill ~ $3.5 million/year!).

Transition from CPUs to GPUs: While CPUs are comprised of a handful of cores optimized for linear tasks, GPUs are comprised of many cores optimized for parallel computing and are dramatically more energy efficient.

When we get there there will be revolutionary discoveries in the field of theoretical astrophysics and supernovae in particular. Also in stellar evolution (first 3D stellar evolution calculations!).



QUANTUM COMPUTING?

Google's new quantum co... ×

www.telegraph.co.uk/technology/news/12042781/Google-D-Wave-quantum-computer-is-100-million-times-faster-than-your-PC.html

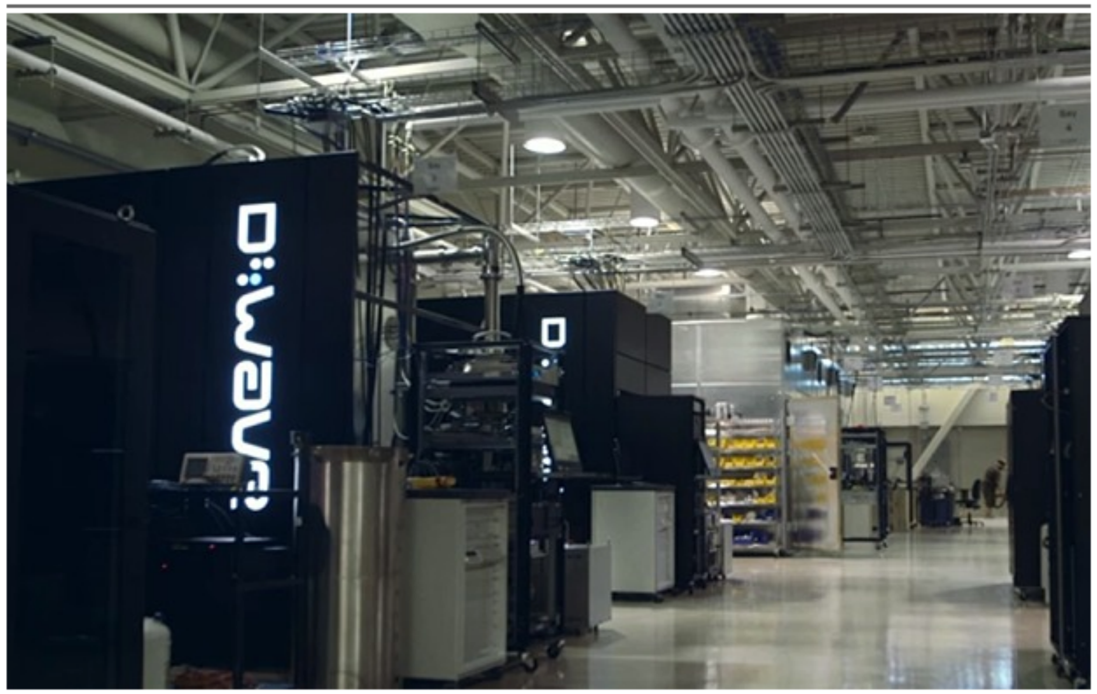
dwave quantum computer

Most Visited · Getting Started

Google's new quantum computer is '100 million times faster than your PC'

Google and Nasa have been working on a lightning-fast quantum computer that is 3,600 times faster than a supercomputer at solving complex problems

4K · 4 · 278 · 4K · Email



Google's D-Wave quantum computer is pretty fast Photo: YouTube

By Mark Molloy

9:32PM GMT 09 Dec 2015

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Has **Google** won the race to build the world's first commercial **quantum** computer?

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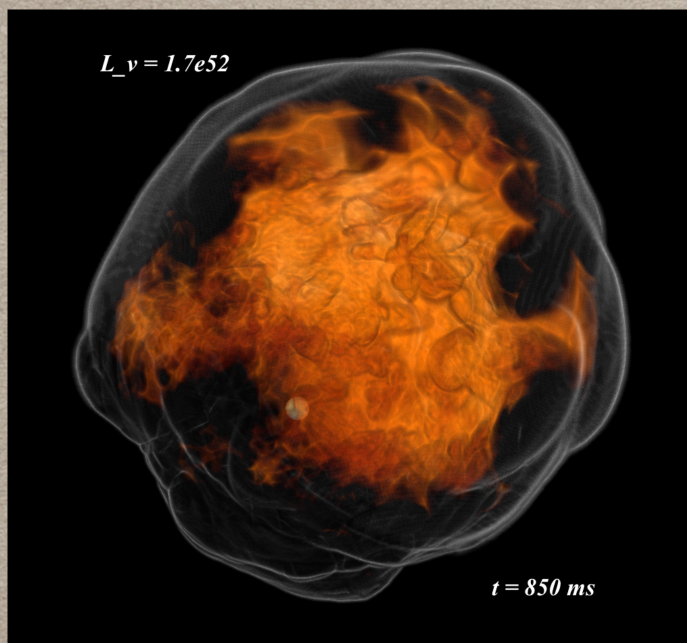
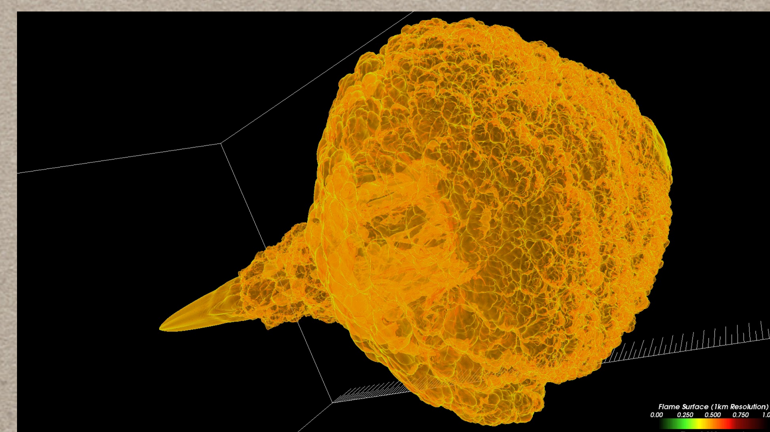
OUR OWN CHILD: THE FLASH CODE

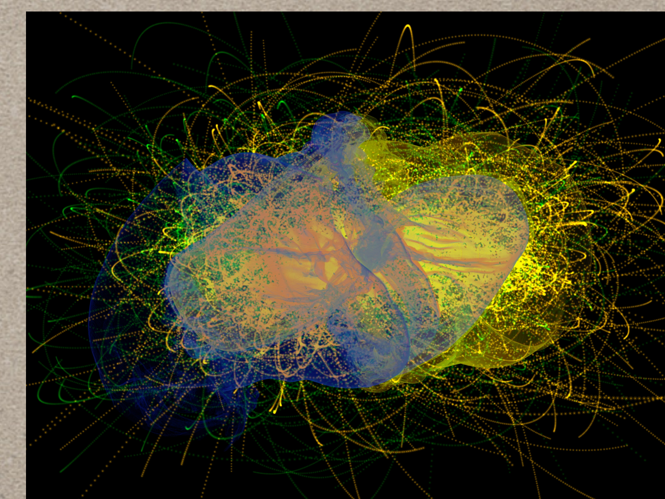
The FLASH code developed at the FLASH Center of Computational Science at the University of Chicago is a sophisticated multi-dimensional, multi-physics code consisting of ~1.5 million lines. Can be used to simulate variety of high energy-density physics phenomena from laser experiments, thermonuclear and core-collapse supernovae, galaxy mergers and even cosmology.



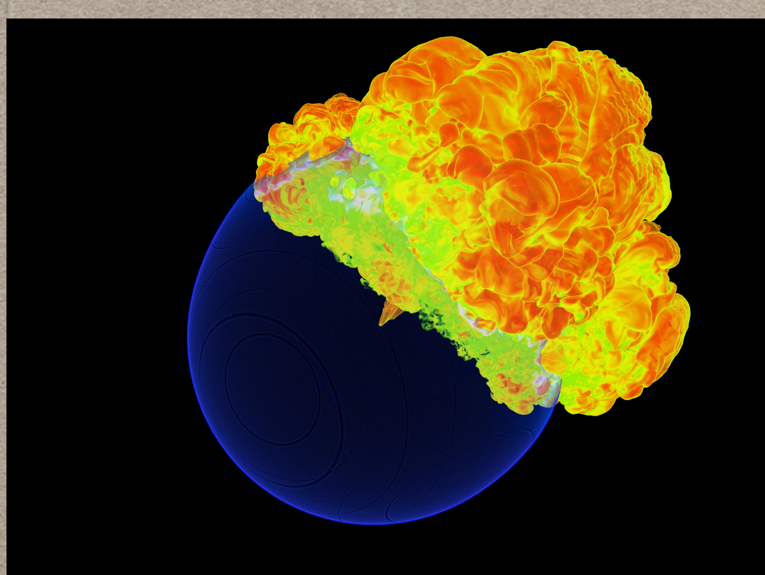
Core-Collapse Supernovae



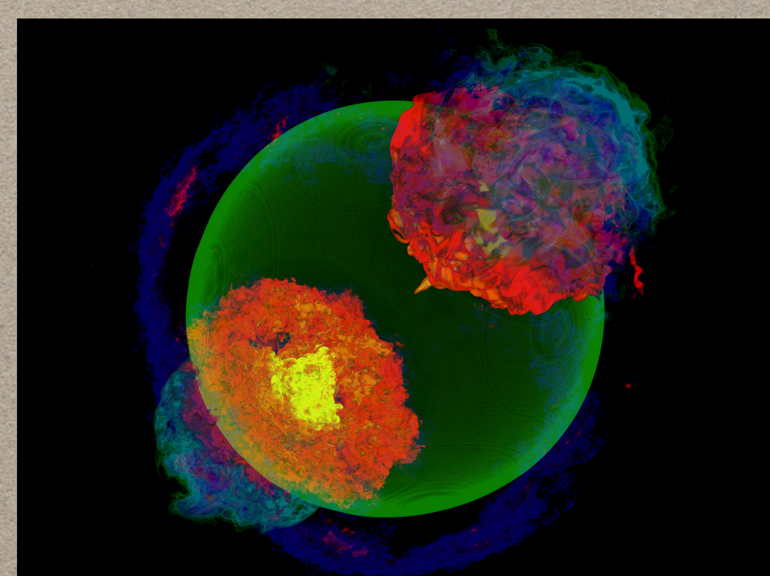
Turbulent flame propagation



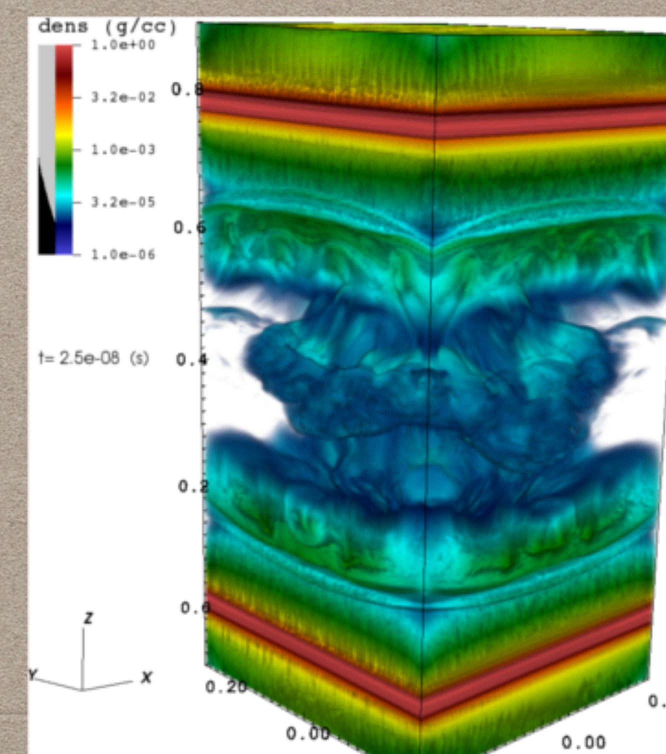
Galactic mergers



Exploding white-dwarfs



Type Ia supernovae



Lasers and HEDP

http://www.flash.uchicago.edu/site/

KEY GOAL: COMBINING CUTTING EDGE OBSERVATIONS AND SIMULATIONS

The path to understanding supernovae

The scientific method: gather high-quality data, assess accuracy and errors, interpret results. Test theories against observations. Iterate.

For supernovae we need **large number of events of all types** also discovered **early on**. New generation fast-cadence robotic surveys that are accompanied by fast spectroscopic observations and early classification a must.

$$$ - Need to hire graduate students, postdocs, scientists to look at all this wealth of **data!**

Perform realistic **multidimensional simulations** using supercomputers and use state of the art **radiation transport codes** to predict spectra and LCs. Must succeed at matching observed and model spectra at contemporaneous epochs to validate a model -> Insight. *Light is all we have…*

Success lays at the intersection between modern, fast cadence and deep SN observations across the entire spectrum and multi-dimensional radiation transport supercomputer simulations

SUMMARY

- Amateur astronomers have contributed significantly to the discovery of new supernovae.
- Key to constraining the properties of supernovae is early discovery after explosion. Automation of wide-field telescopes is a key advancement toward this goal.
- A number of fully-robotic autonomous integrated transient search projects is active around the world and the U.S. is leading the pack. Projects like iPTF, PanSTARRS, TSS, LCOGT and others are discovering supernovae by the thousands in a daily basis.
- Smart numerical algorithms are used to automatically classify supernovae if observed early on. Early SN spectra is key!
- The Zwicky Transient Facility (ZTF) is the next generation transient search project to revolutionize our understanding of SN being able to discover them just within one day after explosion.
- Supercomputing simulations are crucial in our understanding of the physical properties of supernovae given the complexity of physics involved in these phenomena.
- Modern supercomputers allow us to perform multi-dimensional simulations of supernovae in reasonable time. The upcoming Exascale era of supercomputing will lead to revolutions in our understanding of cosmic catastrophes.
- Combination of simulations and radiation transport model light curves and spectra with multi-wavelength observations of supernovae is the best way to constrain their nature.

TAKEAWAY POINTS

- Most stars have masses similar to that of the sun but a smaller number of them are significantly massive and evolve in quite a different way (> 8 Msun).

- Massive stars are the progenitors of core-collapse (Type II) supernovae. Core-collapse supernovae occur from the collapse of the iron core of the star formed during the last few moments of stellar evolution.

- White dwarfs are the progenitors of thermonuclear (Type Ia) supernovae. The progenitors of SN Ia remain under debate but the two competing scenarios are the single-degenerate and the double-degenerate channel. In both cases the cause of the explosion is mass transfer from a companion leading the white dwarf mass above the prohibitive Chandrasekhar limit of 1.4 Msun.

- Supernovae are spectroscopically divided into classes: Type II supernovae show signs of hydrogen in their spectrum while Type I events do not.

- Core-collapse SN events are either of Type IIP (plateau), or Type Ib/c. Type Ib SN do not show sings of hydrogen while Type Ic SN do not show sings of either hydrogen or helium. These are also called "stripped-envelope" SNe.

- Other types of SN are Type-IIL events (have hydrogen but show "linear" decline in late time LC) and Type IIn events (show strong emission lines of hydrogen indicative of circumstellar interaction).

TAKEAWAY POINTS (CONTD.)

- The observed light curves (LCs) and spectra of SN yield a lot of information about the nature of the explosion as well as the progenitor star. The duration of a LC is characteristic to the SN ejecta mass while it's peak luminosity and late-time decline rate characteristic of the energy input mechanism that keeps it shining.

- Most SNe are powered via the radioactive decays of nickel-56 and cobalt-56 formed after the explosion.

- Over the last decade the new spectacular class of super luminous supernovae (SLSN) was discovered with events that are 10-1000 times brighter than regular supernovae.

- The nature of SLSNe is still debated but models of strong circumstellar interaction or newly-born magnetar spin-down energy input are considered to be the explanation.

- Supernovae are important for two main reasons: A) they enrich the Universe with the heavy elements required for life to form and B) they are so bright (specifically, Type Ia SN) that can be observed at large, cosmological distances helping us probe the nature of space time and the fate of our Cosmos.

- Advancements in robotics, AI and supercomputing have led to a revolution of our understanding of supernovae as well as the discovery of new, exotic explosions.

- The ultimate goal of supernova science is to match the modern observations from across the spectrum to predictions of our models computed using sophisticated hydrodynamics and radiation transport codes.


It is clear to everyone that astronomy at all events compels the soul to look upwards, and draws it from the things of this world to the other.
-Plato
THANK YOU FOR YOUR ATTENTION!