The Restless Universe

(the rise of time domain astronomy) (& the periodic table)

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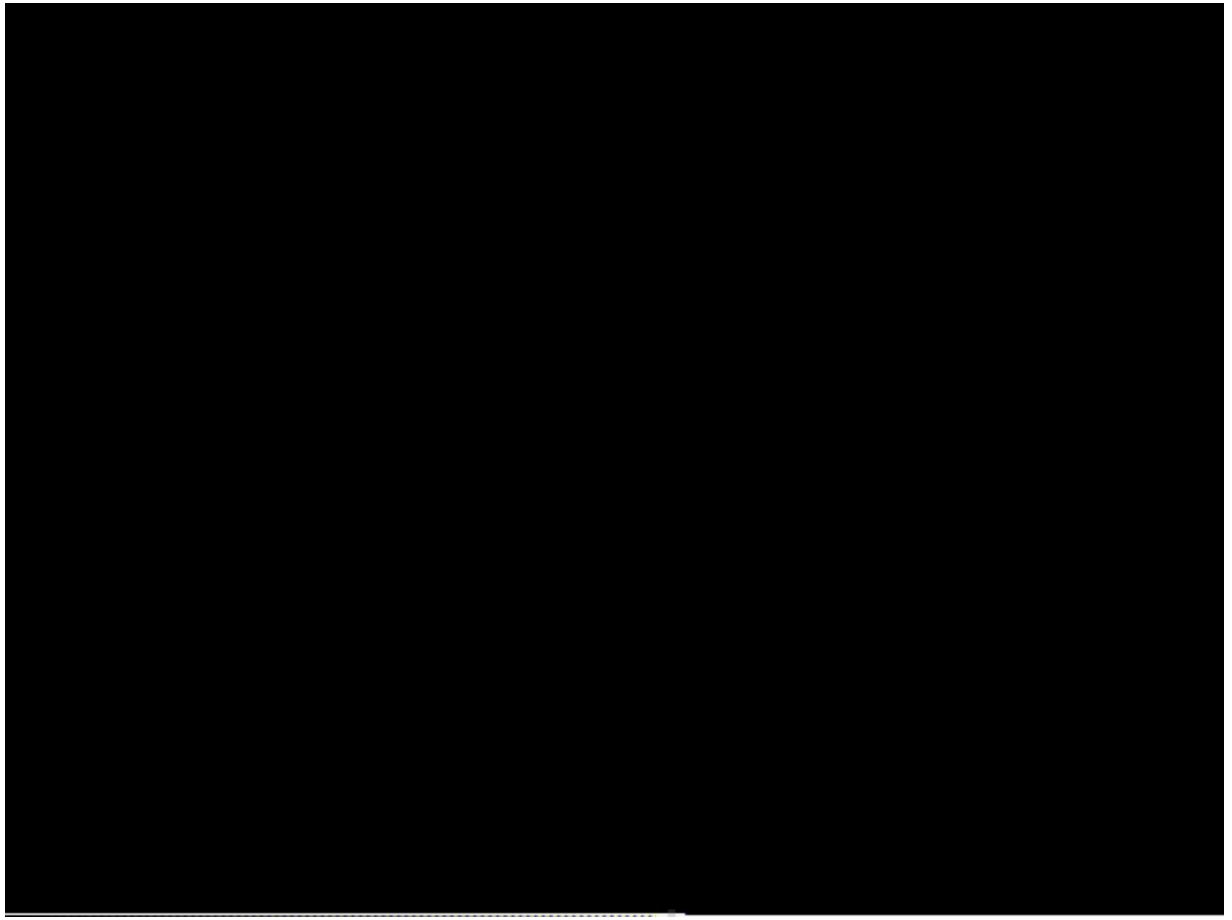
Principal Investigator, Zwicky Transient Facility

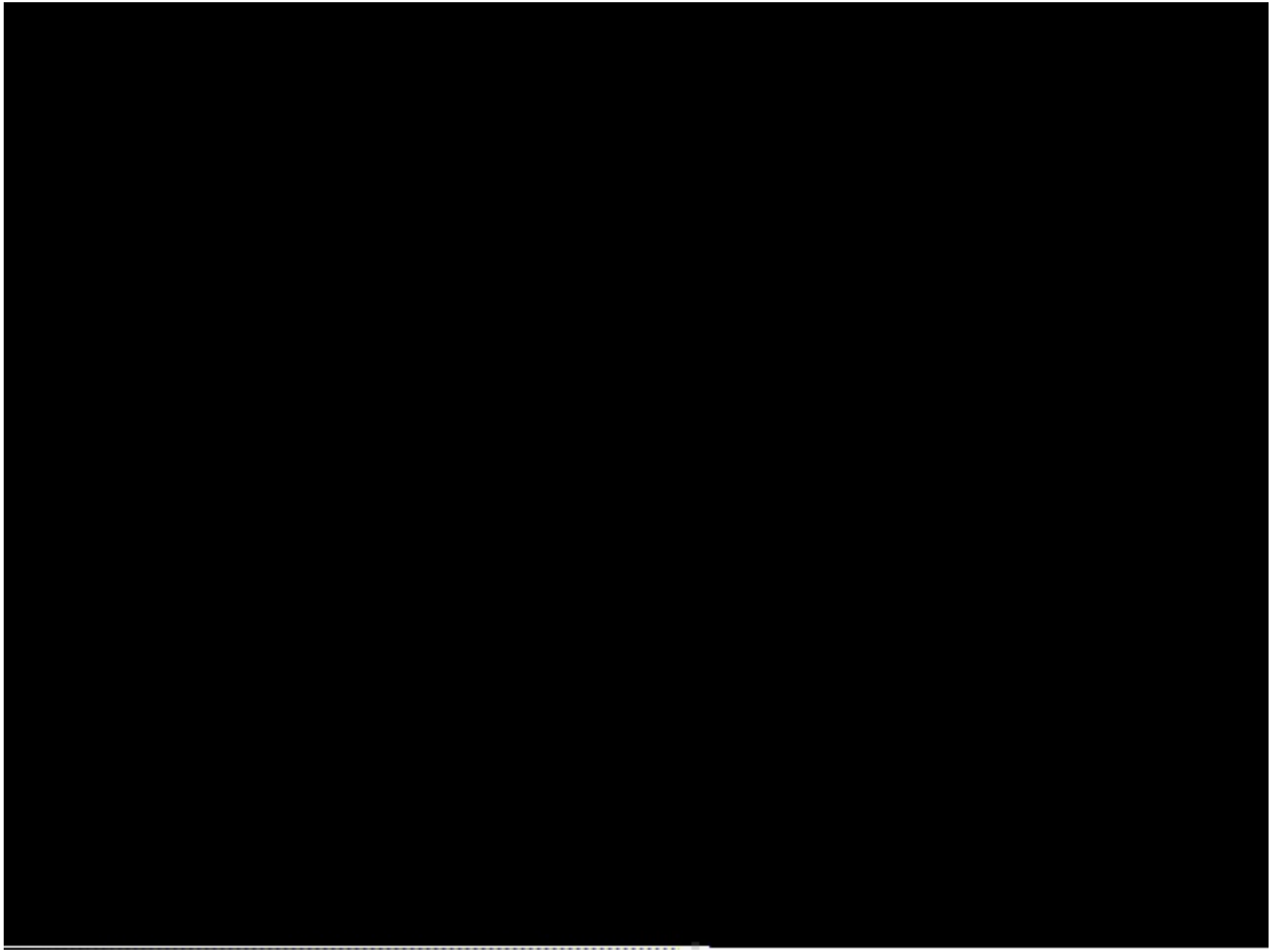
An observation

- Astronomy, like biology, geology and exo-planetology is a phenomenological subject
  - In contrast, physics is all about distilling phenomena to the ultimate essence
- Phenomenological subjects have three distinct steps
  - Discovery
  - Systematic study of phenomena: Search for patterns
  - Inference: Physical models to explain observations (and occasionally make predictions)
- Discovery is largely a function of technology

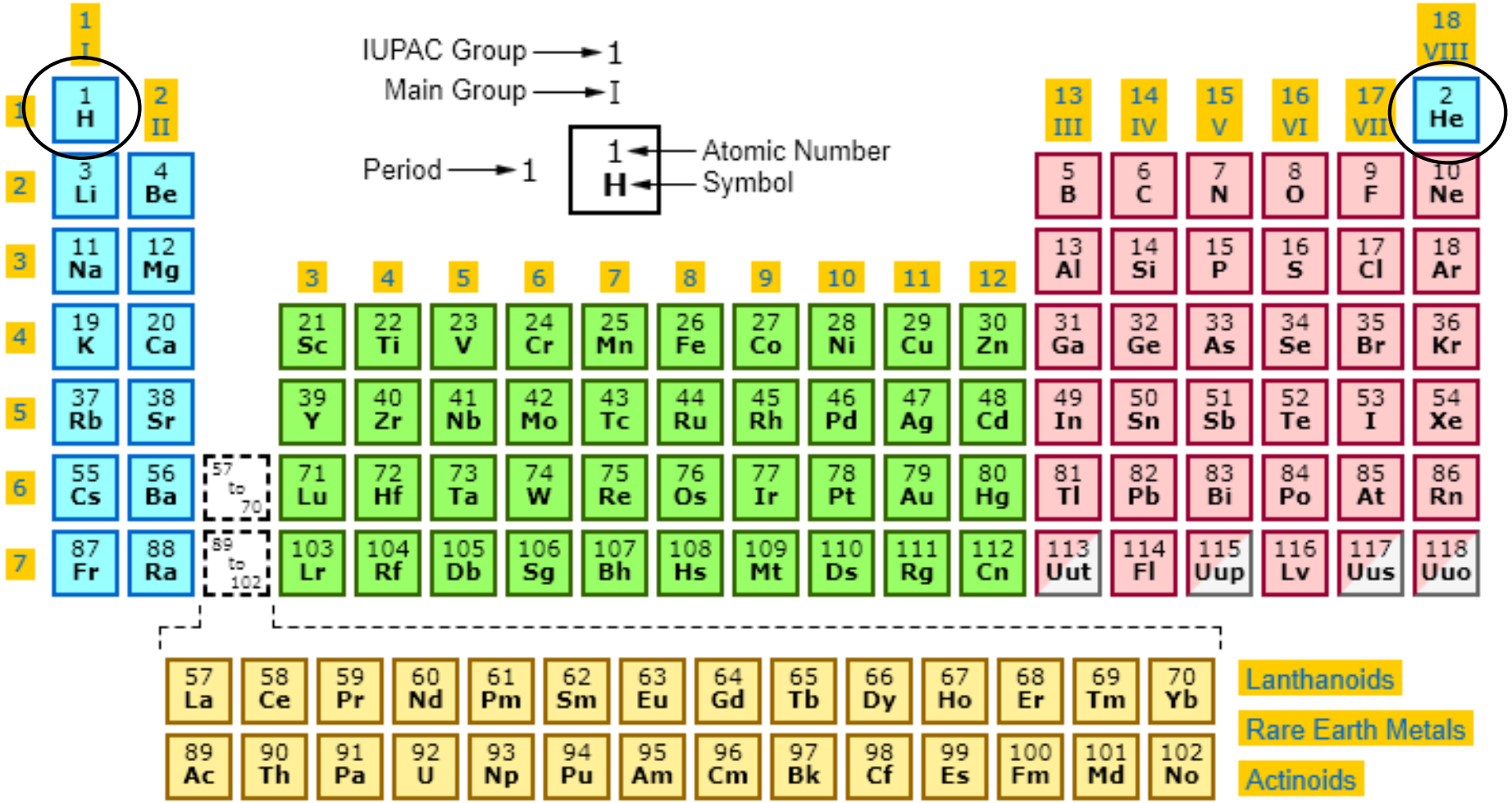
THE RISE OF TIME DOMAIN ASTRONOMY (FOCUS ON BUILD UP OF ELEMENTS)

This is how it all began

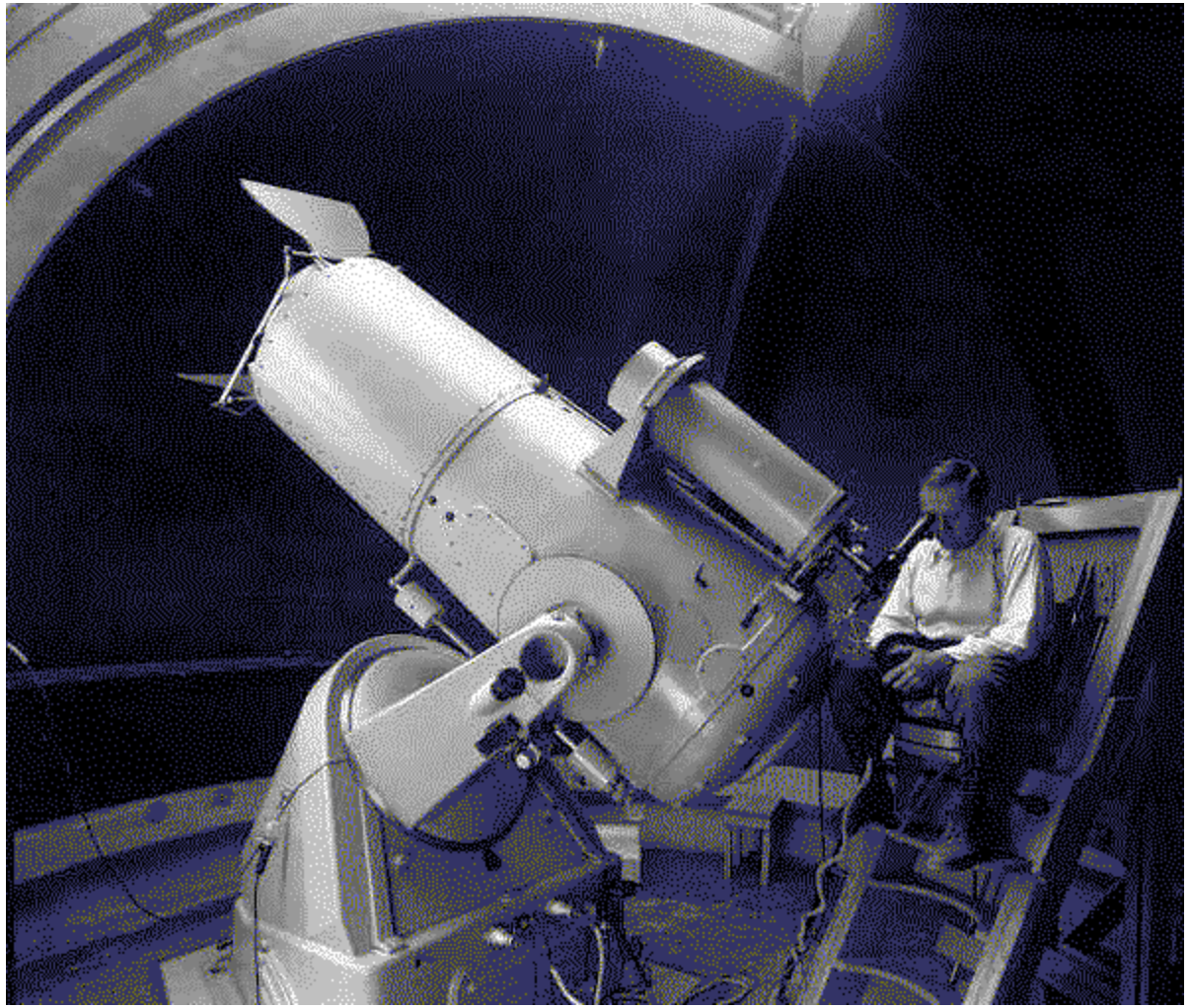




Chemistry in the young Universe was simple

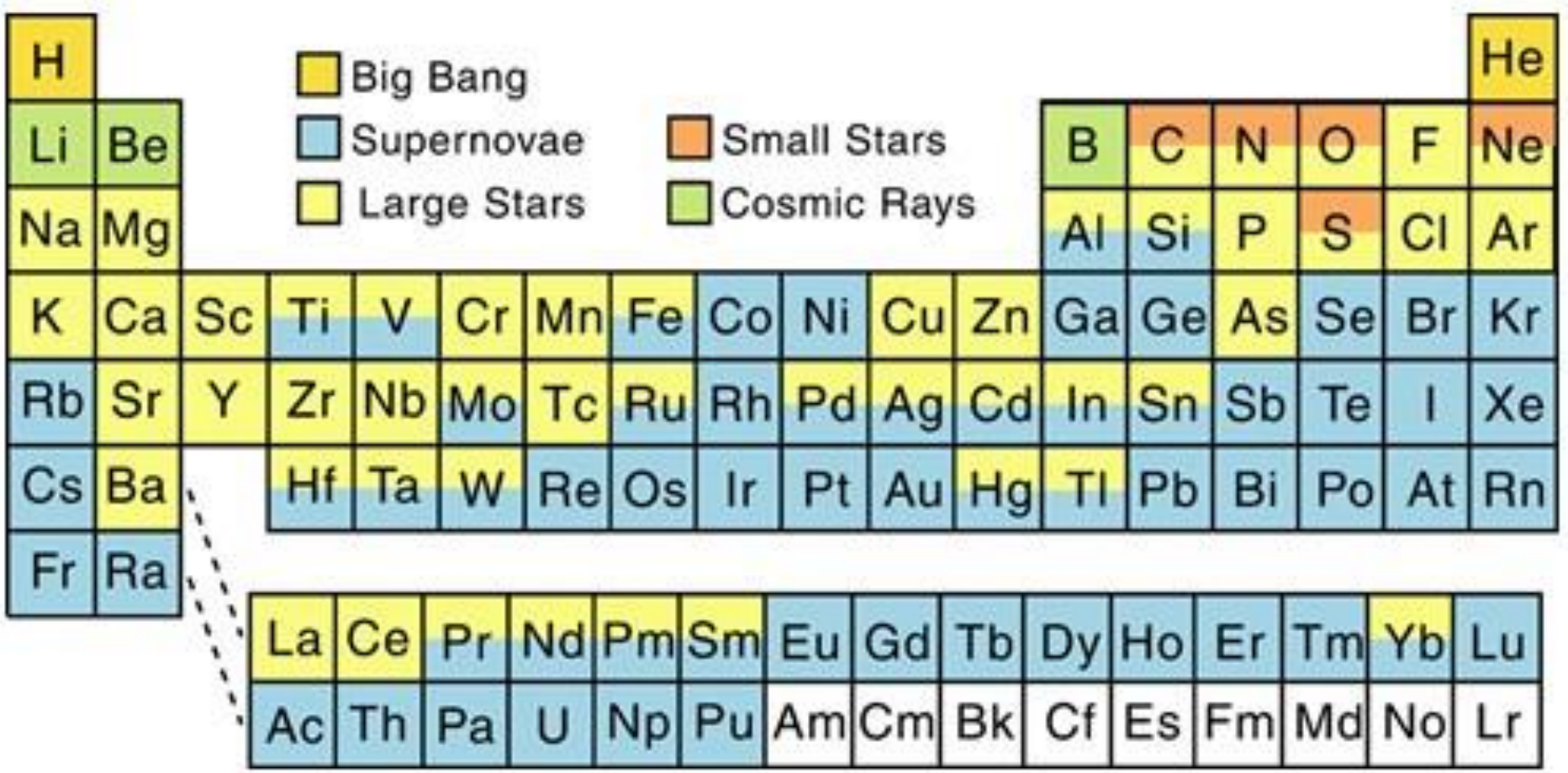


Time Domain Astronomy (Supernovae): Fritz Zwicky



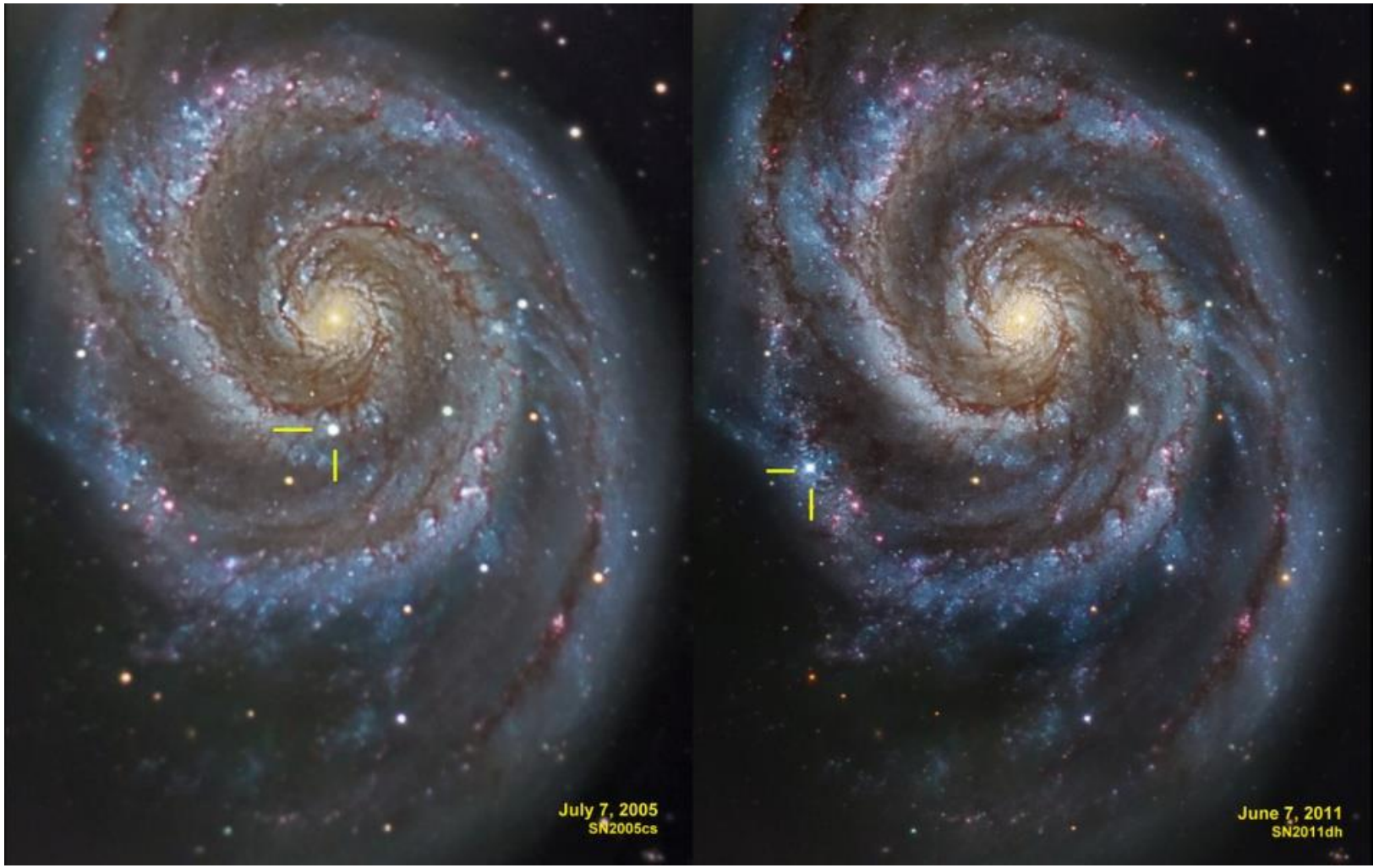
Nucleosyntheis: Burbidge, Burbidge, Fowler & Hoyle (B^2FH)

We are star dust!



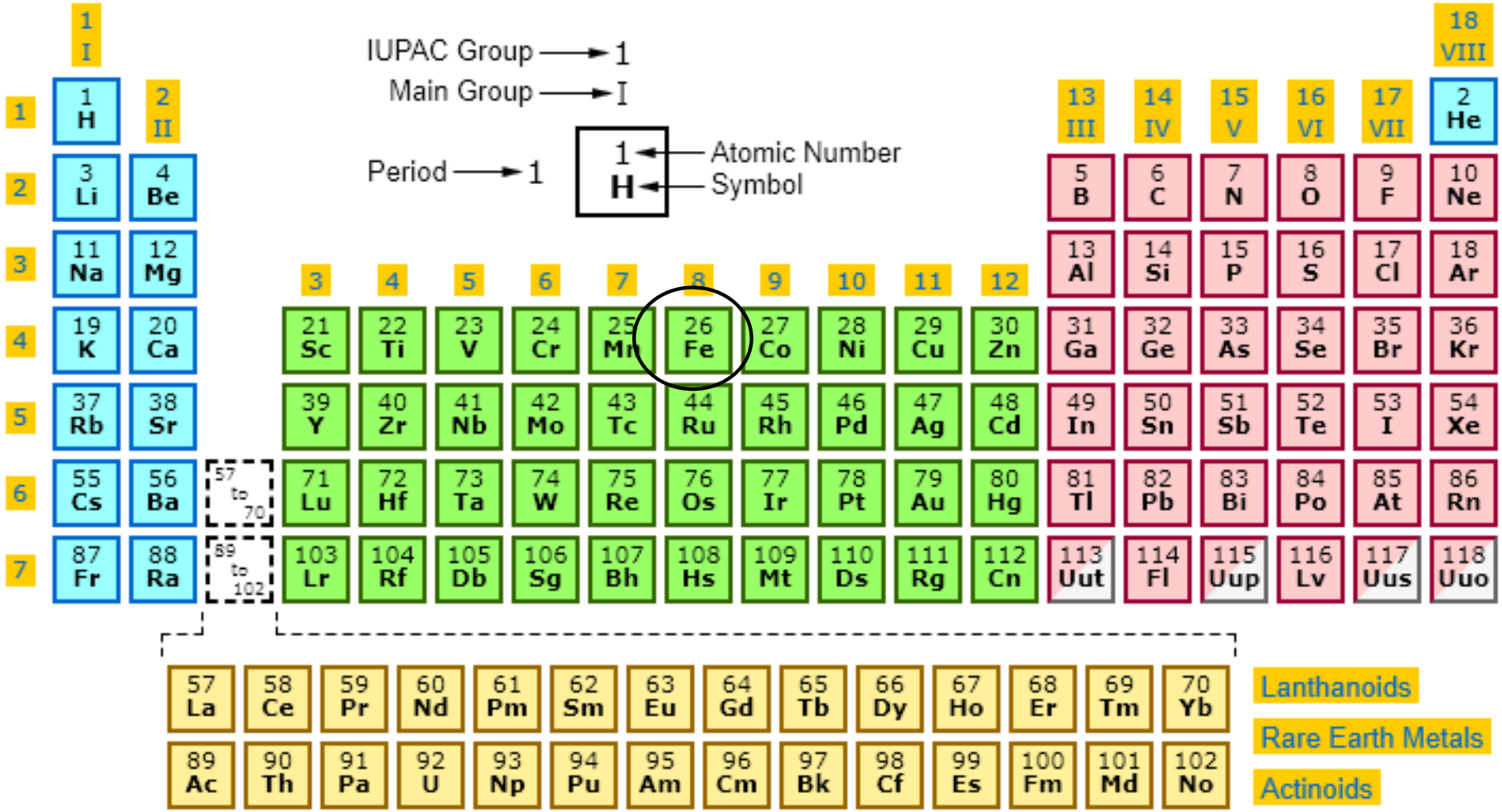
From Universetoday.com

A star dies: A supernova is born & heavy elements are made



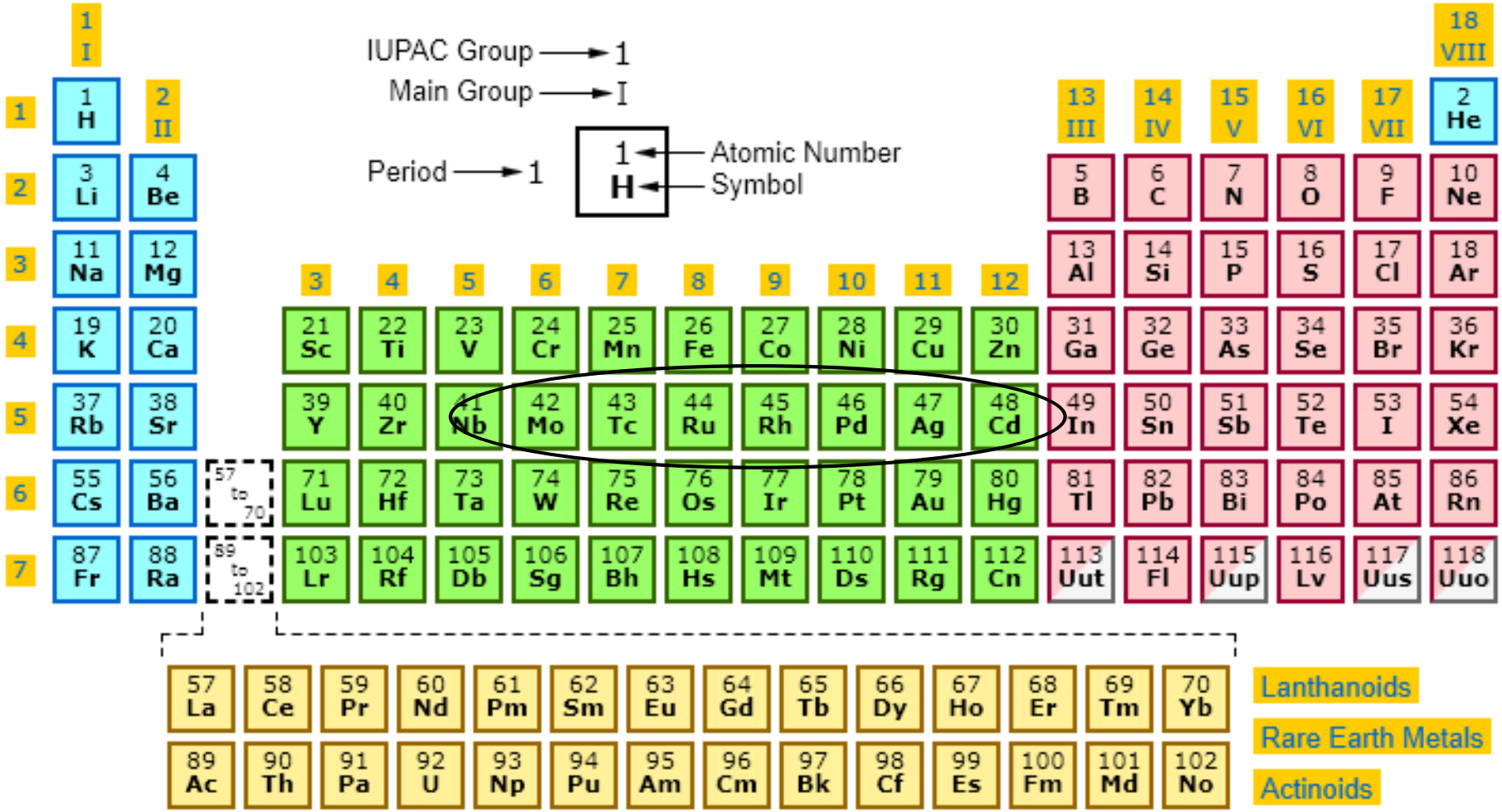
Astronomy Picture of the Day (NASA)

Iron is special



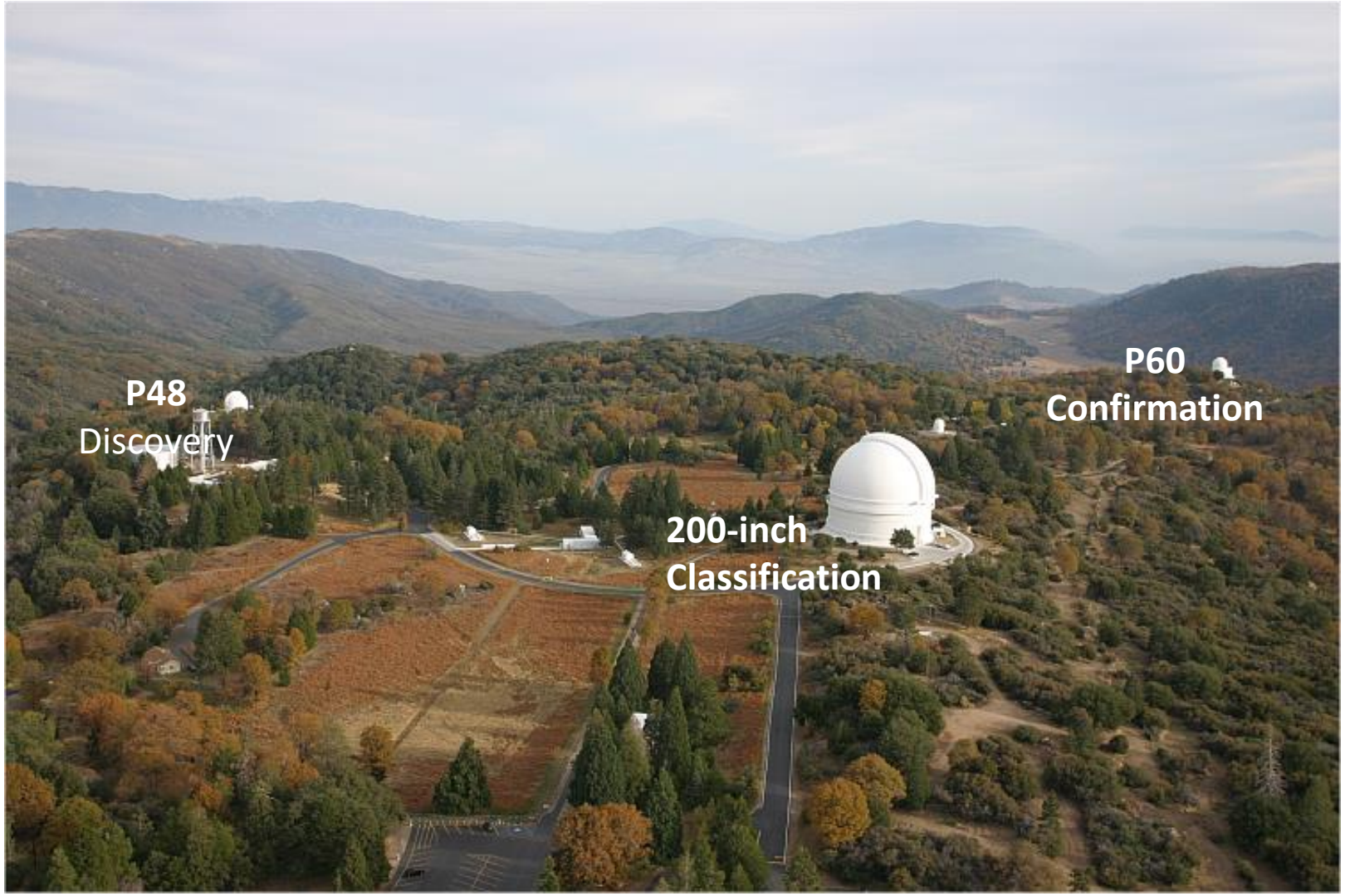
Frontier Area: Gravitational Waves

Special explosions make “precious” metals

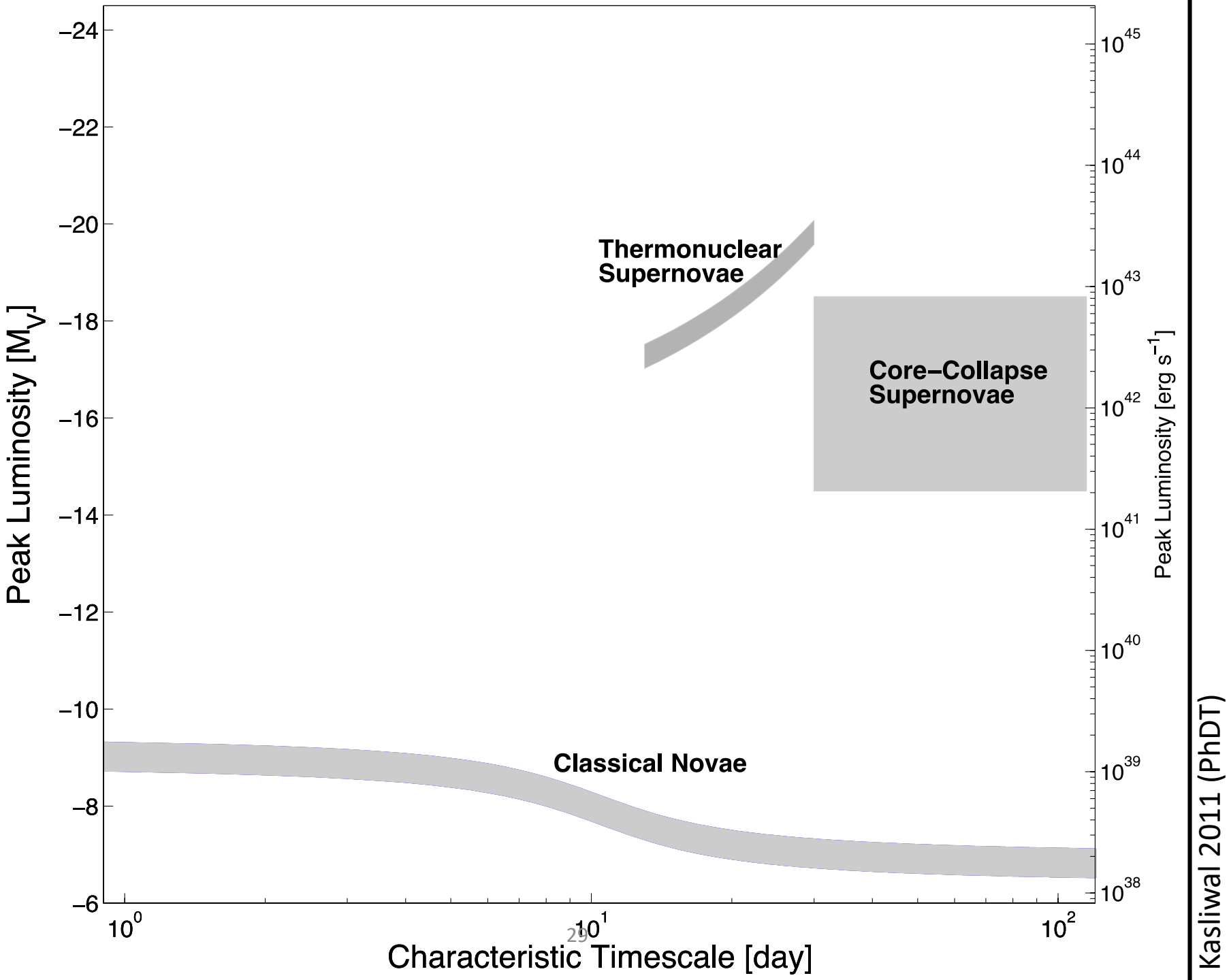


A FACTORY TO SYTSTEMAICALLY DISCOVER EXPLOSIVE TRANSIENTS

Palomar Transient *Factory*



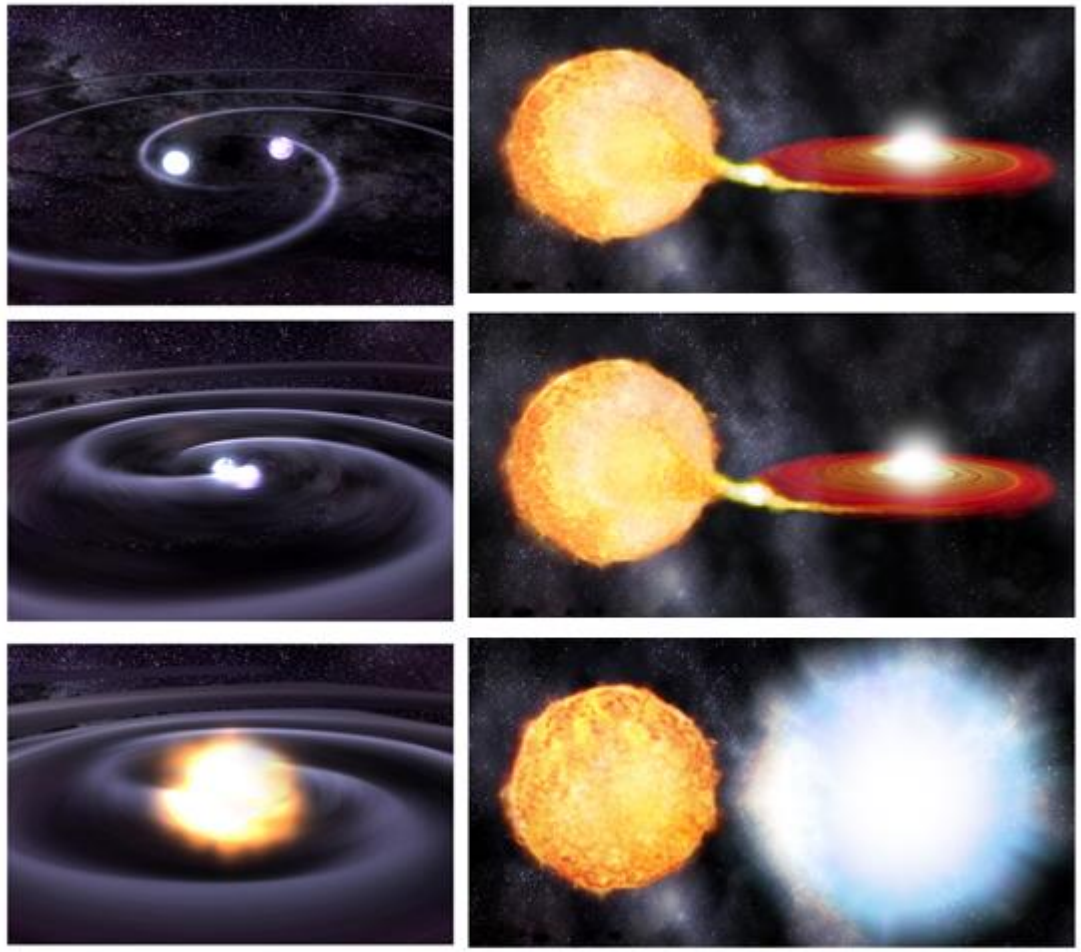
Palomar Transient Factory: Hardware, Software & *Grayware!*


Thermonuclear Supernovae
Core–Collapse Supernovae
Classical Novae
Peak Luminosity [M_V]
Peak Luminosity [erg s^{-1}]
Characteristic Timescale [day]
−24
−22
−20
−18
−16
−14
−12
−10
−8
−6
10^{45}
10^{44}
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
10^{0}
10^{1}
10^{2}
Kasliwal 2011 (PhDT)

PTF11ky: only 10 hours old!

Source: PTF Collaboration

Nature makes Type Ia SN in two ways!



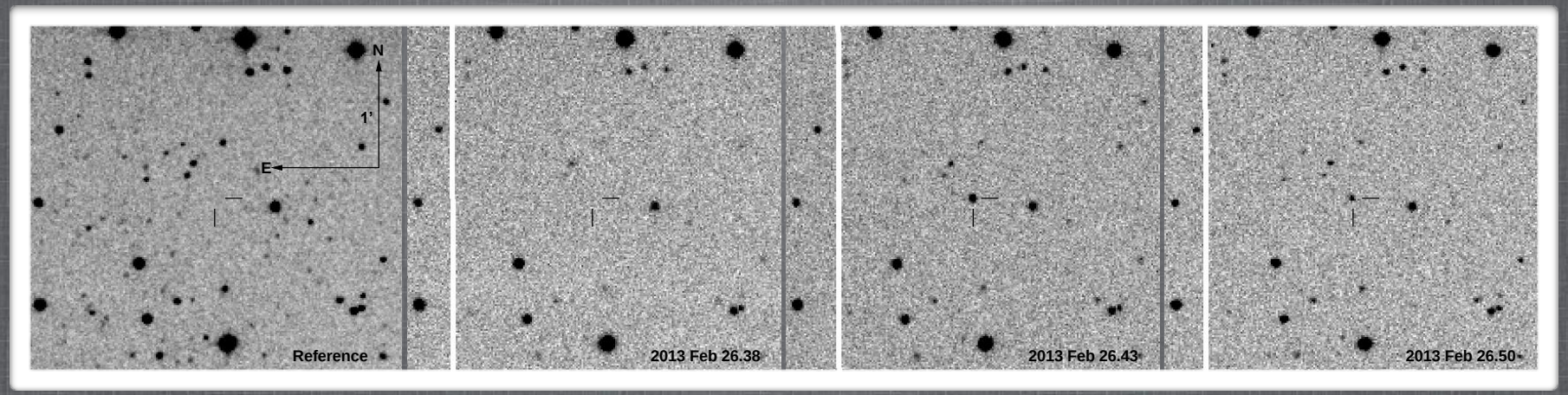
Li et al.
Nugent et al.

Yi Cao 2016 thesis

NEEDLE IN A HAYSTACK SEARCH (GETTING READY FOR LIGO)

iPTF14yb: "UNTRIGGERED" GRB

Reference | 2013 Feb 26.38 | 2013 Feb 26.43 | 2013 Feb 26.50



SBC+, in prep.

09:04 UT:!
P48 Non-detection

10:17 UT:!
P48 r = 18.16

12:01 UT:!
P48 r= 19.77

12:46 UT:!
Flagged by software

15:26 UT:!
Keck/ LRIS Spectrum

17:11 UT:!
Swift X-ray+UV

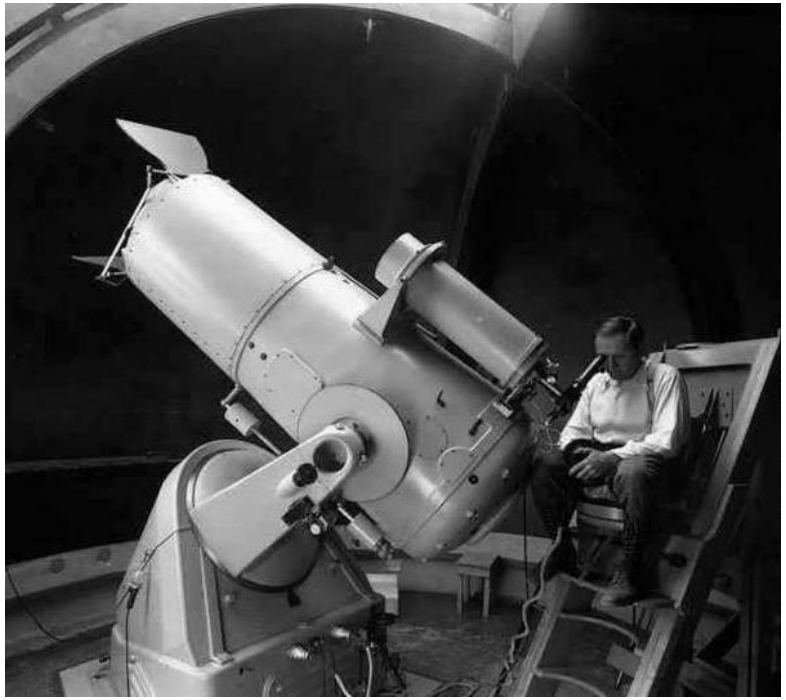
AUTOMATING THE DISCOVERY OF THE UNIVERSE

Zwicky Transient Facility

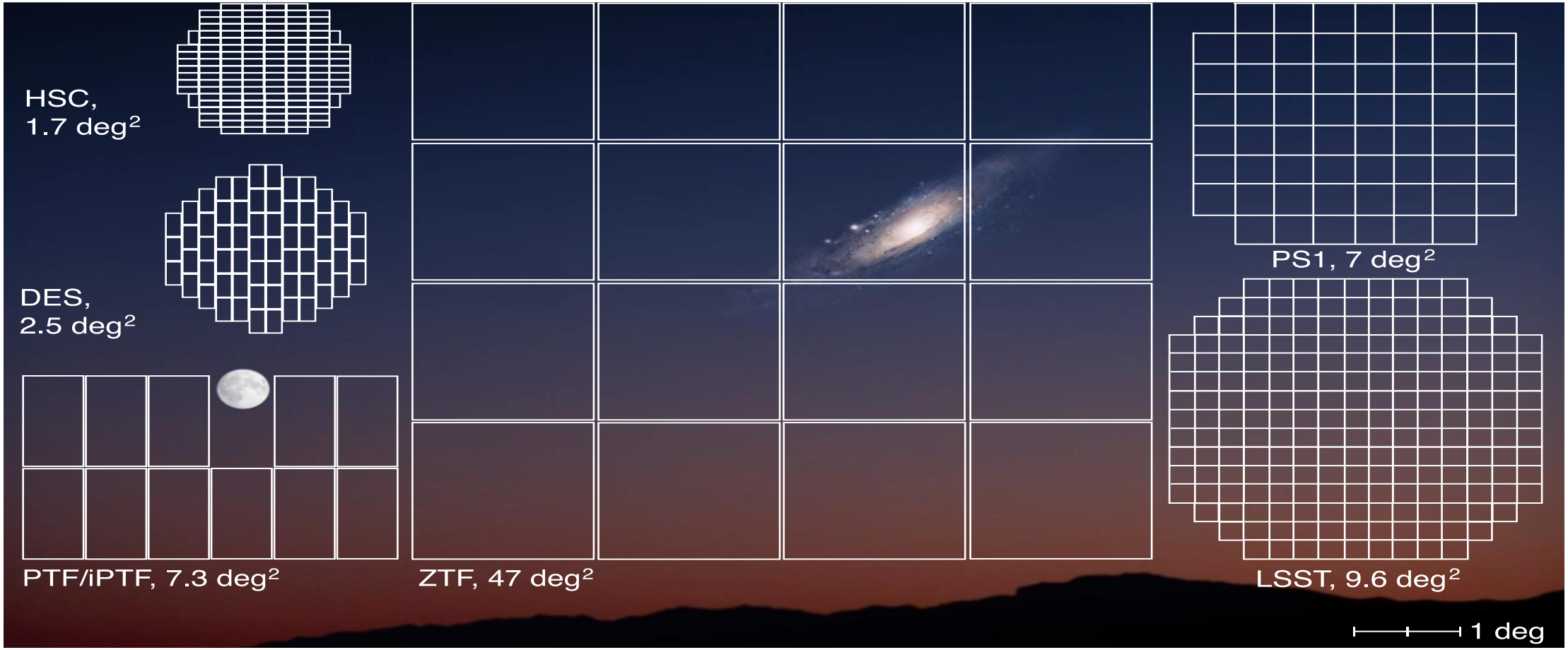
S. Kulkarni, Principal Investigator

E. Bellm. Survey Scientist

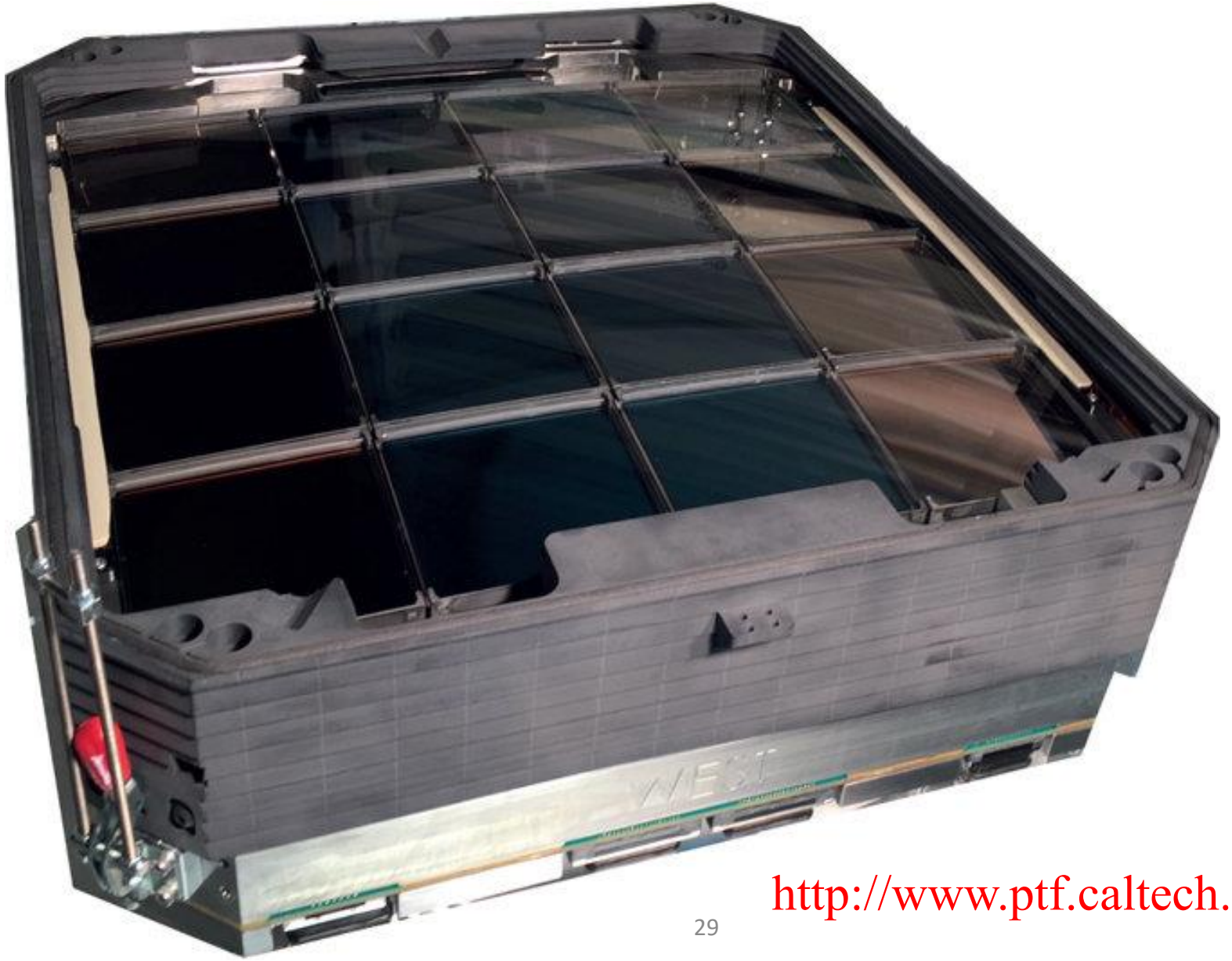
M. Graham, Project Scientist



Wide field Imagers



The 600 Mega-Pixel Camera!



http://www.ptf.caltech.edu/ztf

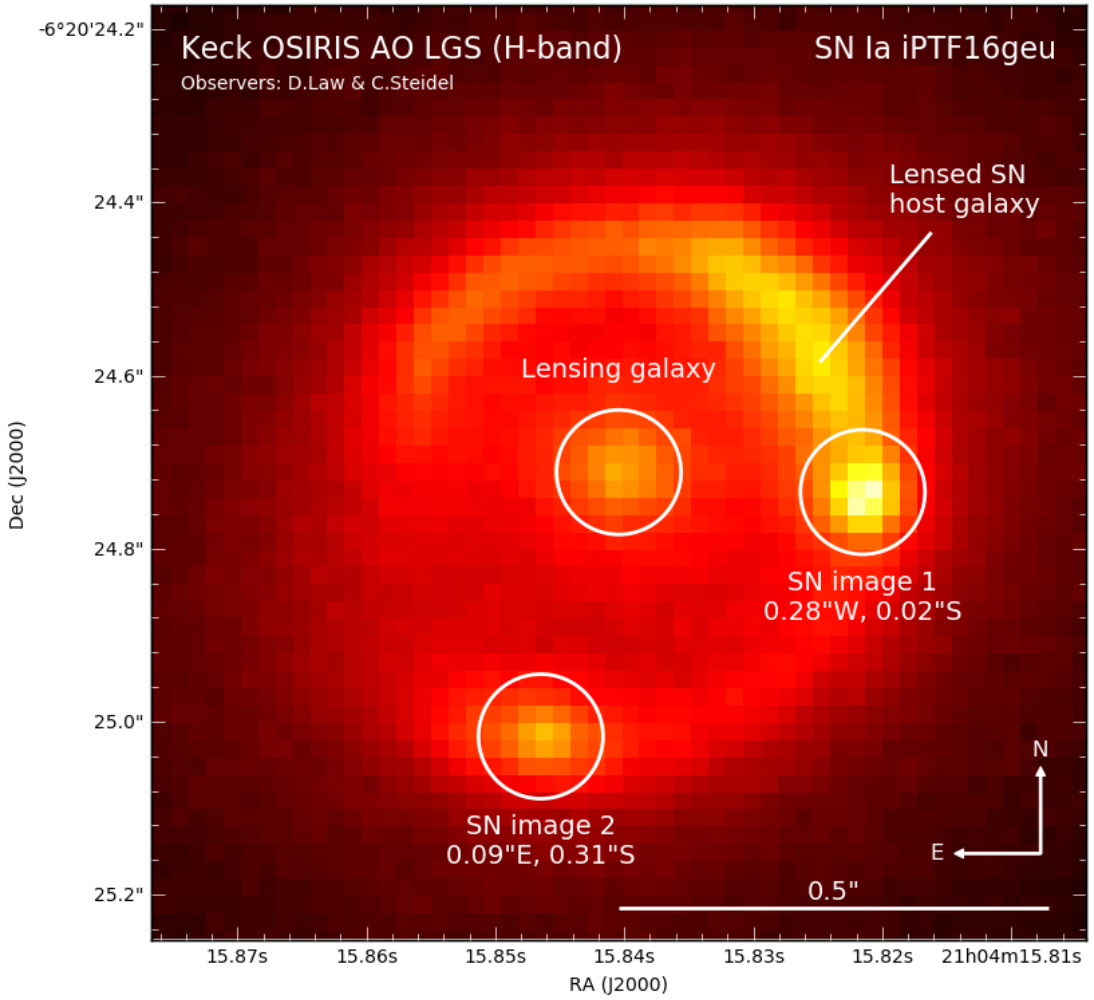
TO COMPLETE THE DISCOVERY FOLLOW UP & NEW TOOLS ARE ESSENTIAL

Followup & Tools

- Spectroscopy on demand
- Novel ultra-low resolution spectrograph aimed at rapid classification
- Mounted on Palomar 60-inch
- Already great success (highly magnified gravitational lensed supernova, nearest TDE)

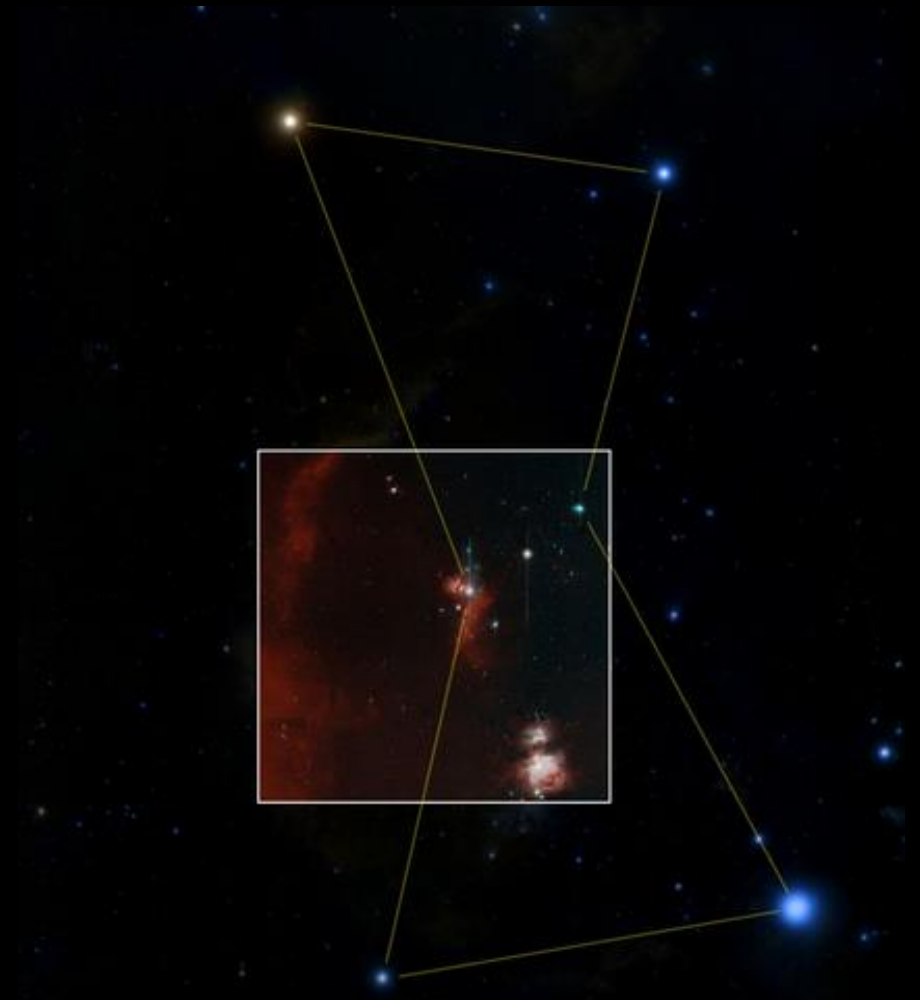
- Robo-Adaptive Optics (Robo AO)
  - Dedicated telescope (Kitt Peak 84-inch)
  - Collaboraton with IUCCA, UH
- Tool Development
  - ”Broker” services
  - ”Sentinels”

A strongly magnified supernova



Keck Adaptive Optics

Zwicky Transient Facility: First Light



FoV 47 sq deg. Survey Speed: 3750 sq deg per hour to a depth of 20.4 mag
Real-time public alert stream in LSST format this summer!

Ultimate Celestial Cinematography in 2022

(Dark) Matter bends light