Mansi M. Kasliwal

Professor of Astronomy

California Institute of Technology

Kasliwal Research Group

Kishalay De
(Graduated 2021)

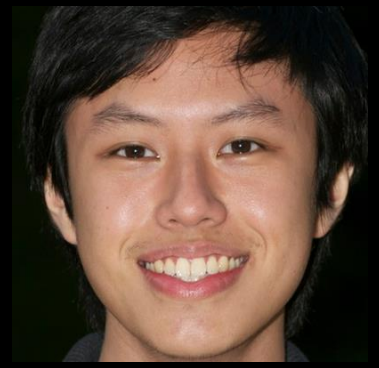
Shreya Anand
(Grad, 3rd year)

Viraj Karambelkar
(Grad, 2nd year)

Christoffer Fremling
(Postdoc)

Igor Andreoni
(Postdoc)

Jacob Jencson
(Graduated 2020)



Samaporn Tinyanont
(Graduated 2020)

Matt Hankins
(Now faculty)

Ragnhild Lunnan
(Now faculty)

Nadia Blagorodnova
(Veni Fellow)

Dave Cook
(Staff Scientist)

Ryan Lau
(ITYF Fellow)

Undergrads: Andy Tzanidakis, Gokul Srinivasaragavan, Stephanie Kwan, Lindsey Whitesides, Chris Cannella

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Outline

I. How do we DISCOVER cosmic fireworks?
II. After discovery, how do we CHARACTERIZE cosmic fireworks?
III. After characterization, what do we LEARN from cosmic fireworks?

如何發現宇宙爆發事件 —— 望遠鏡、相機、軟體
發現以後，如何述性 —— 多波段觀測、物理與的化學知識
述性以後，如何用來瞭解宇宙 —— 週期表、恆星演化

最大的200吋（5米）望遠鏡
紀念 Hale 先生，其座右銘
「不要做小事，不要作小夢」

Palomar Observatory

加州帕洛瑪天文台
配套全自動望遠鏡偵測動態的
天體變化，形同幫宇宙拍電影

Celestial Cinematography

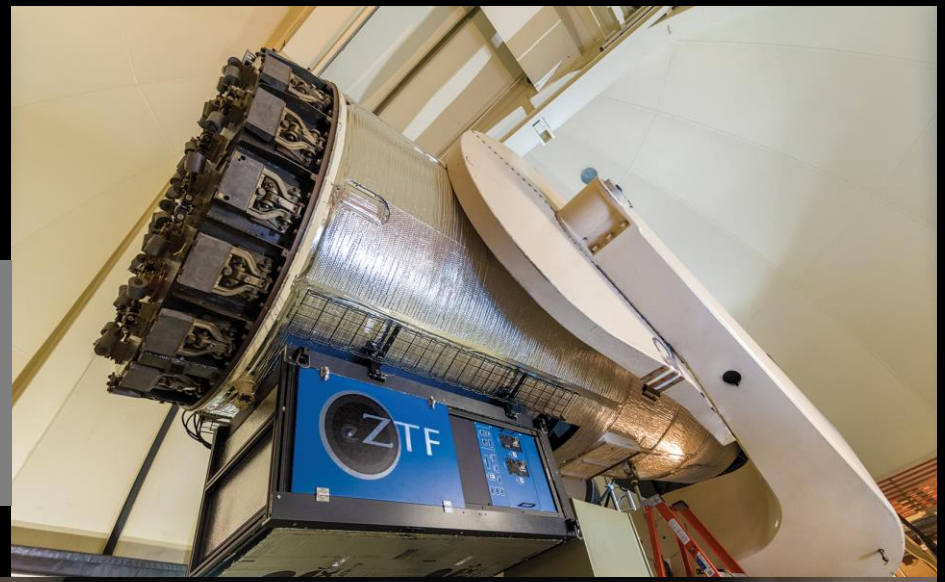
Caltech

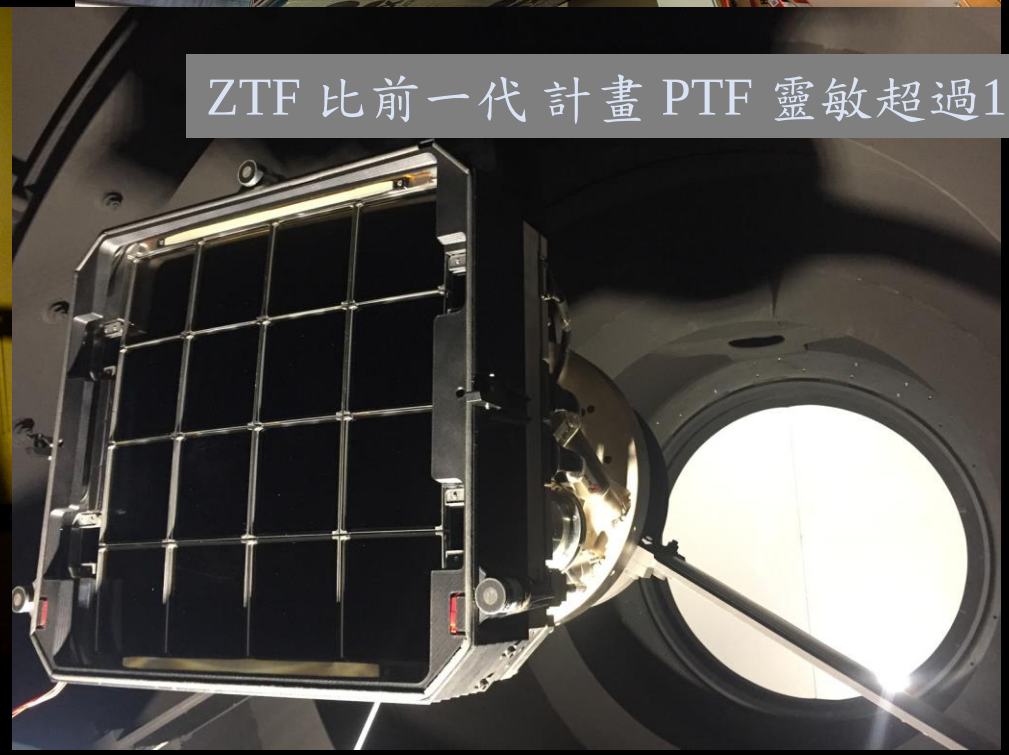
Zwicky Transient Facility
(PI Prof. Shri Kulkarni)

加州理工學院為研究天體「時變現象」先驅.

Zwicky 教授率先研究超新星

帕洛瑪天文台現行計畫 Zwicky Transient Facility (ZTF)





ZTF 比前一代 計畫 PTF 靈敏超過10倍

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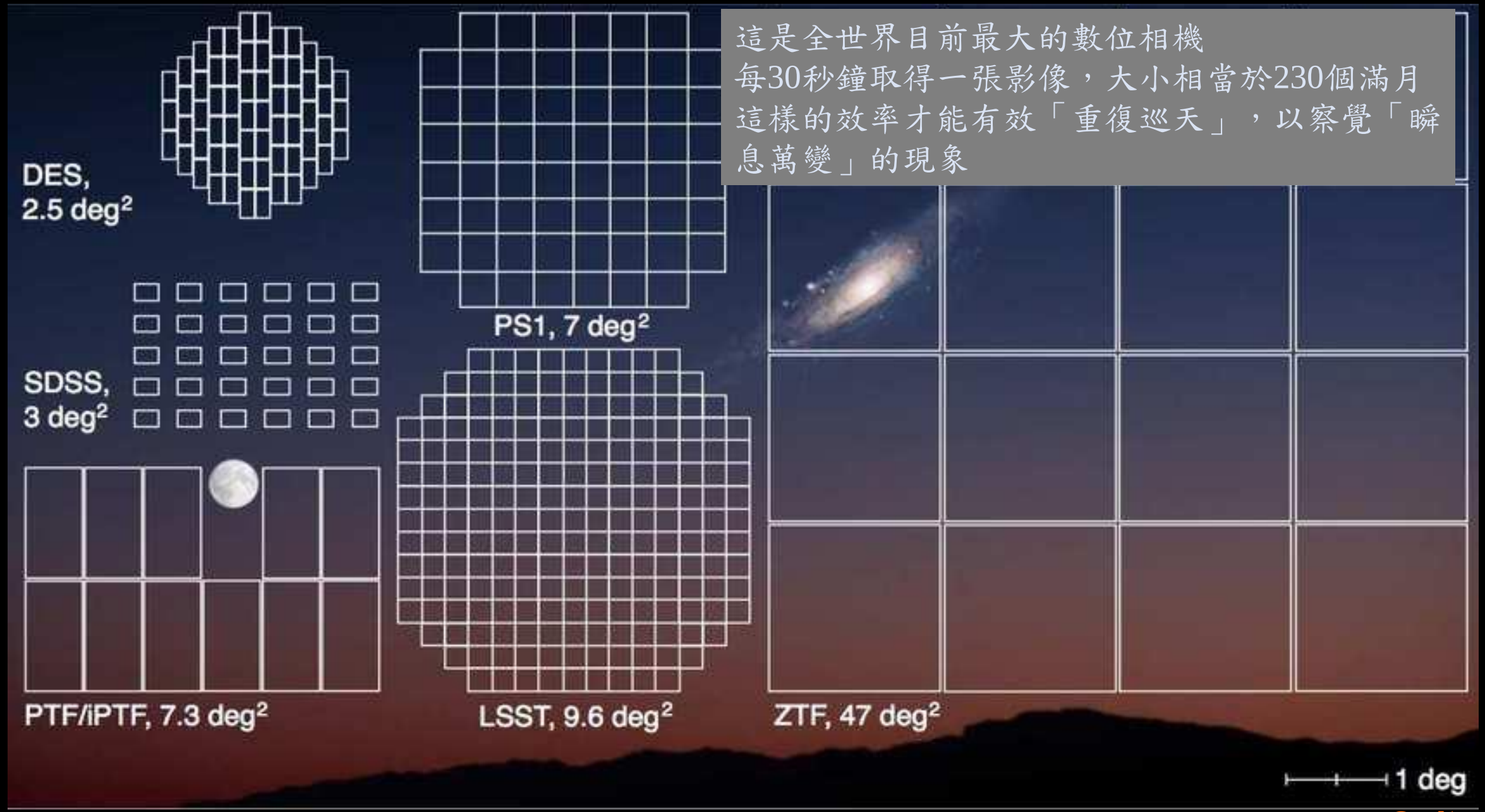
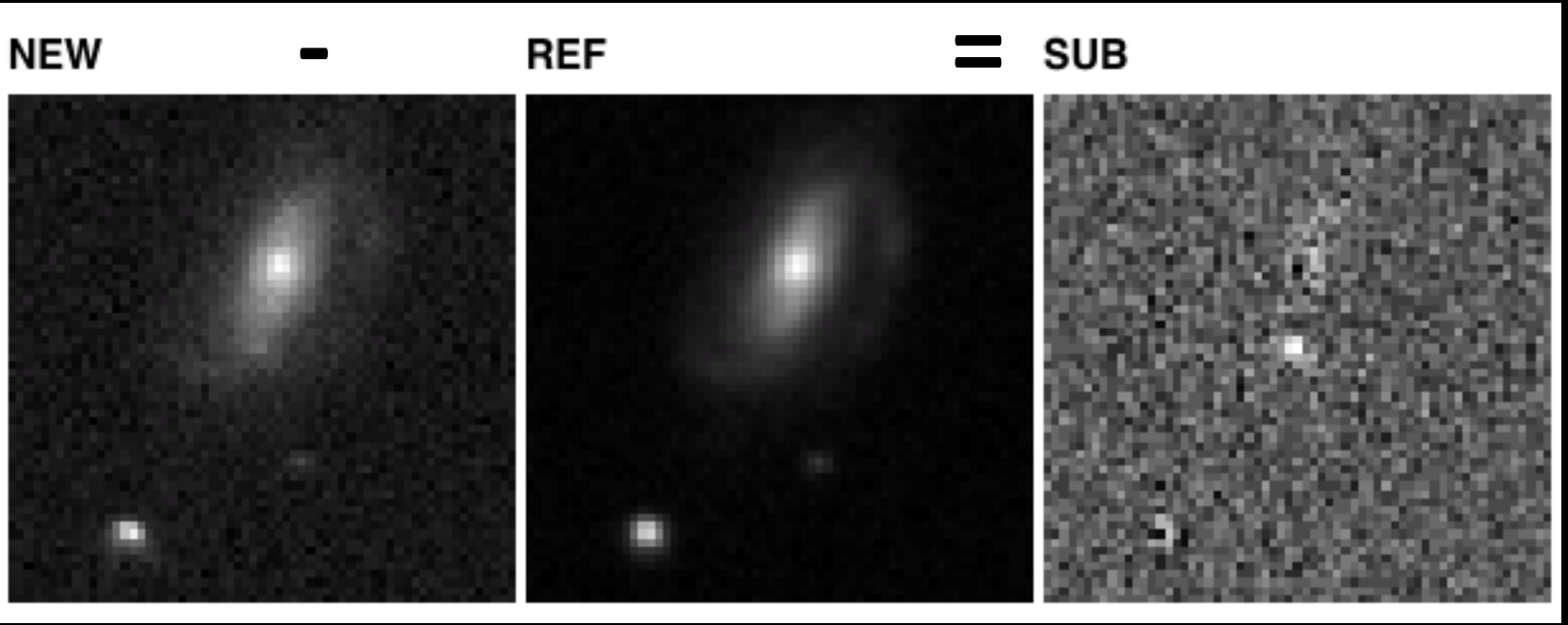

這是全世界目前最大的數位相機
每30秒鐘取得一張影像，大小相當於230個滿月
這樣的效率才能有效「重復巡天」，以察覺「瞬息萬變」的現象
DES, 2.5 deg²
PS1, 7 deg²
SDSS, 3 deg²
PTF/iPTF, 7.3 deg²
LSST, 9.6 deg²
ZTF, 47 deg²
1 deg
Adapted from Laher et al. 2017

Learning subtraction all over again



Fully automated data science challenge.

研究「瞬變現象」必須處理海量數據

重新學習「減法」——不同時間取得的影像對減，發現不同

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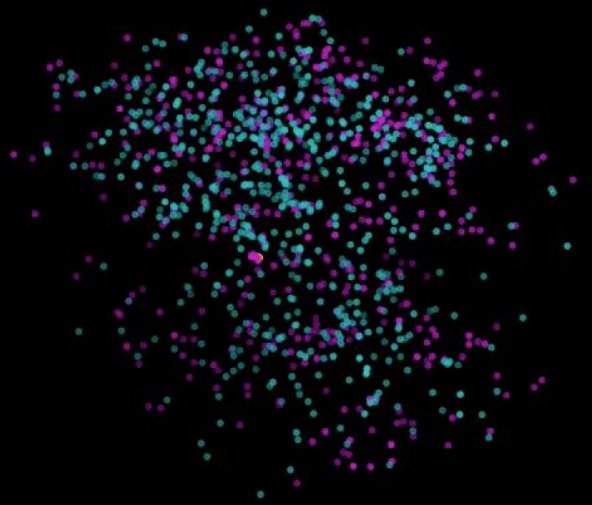
Celestial Cinematography

Christoffer Fremling

Andy Tzanidakis



目前數據處理全自動化，還加入機器學習
這展現在發現超新星的效率
影片中每個紅點代表某顆白矮星爆發成為 Ia 型超新星，每個藍點表示某顆大質量恆星爆發成為 第II 型超新星
右邊是空間分布　我們剛邁過5000顆超新星里程碑

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Unveiling the Dynamic Infrared Sky

在可見光看似暗黑的塵雲，在紅外波段觀測則可以看到剛誕生的恆星發出噴流。這不錯，但要是拍個短片怎麼樣？

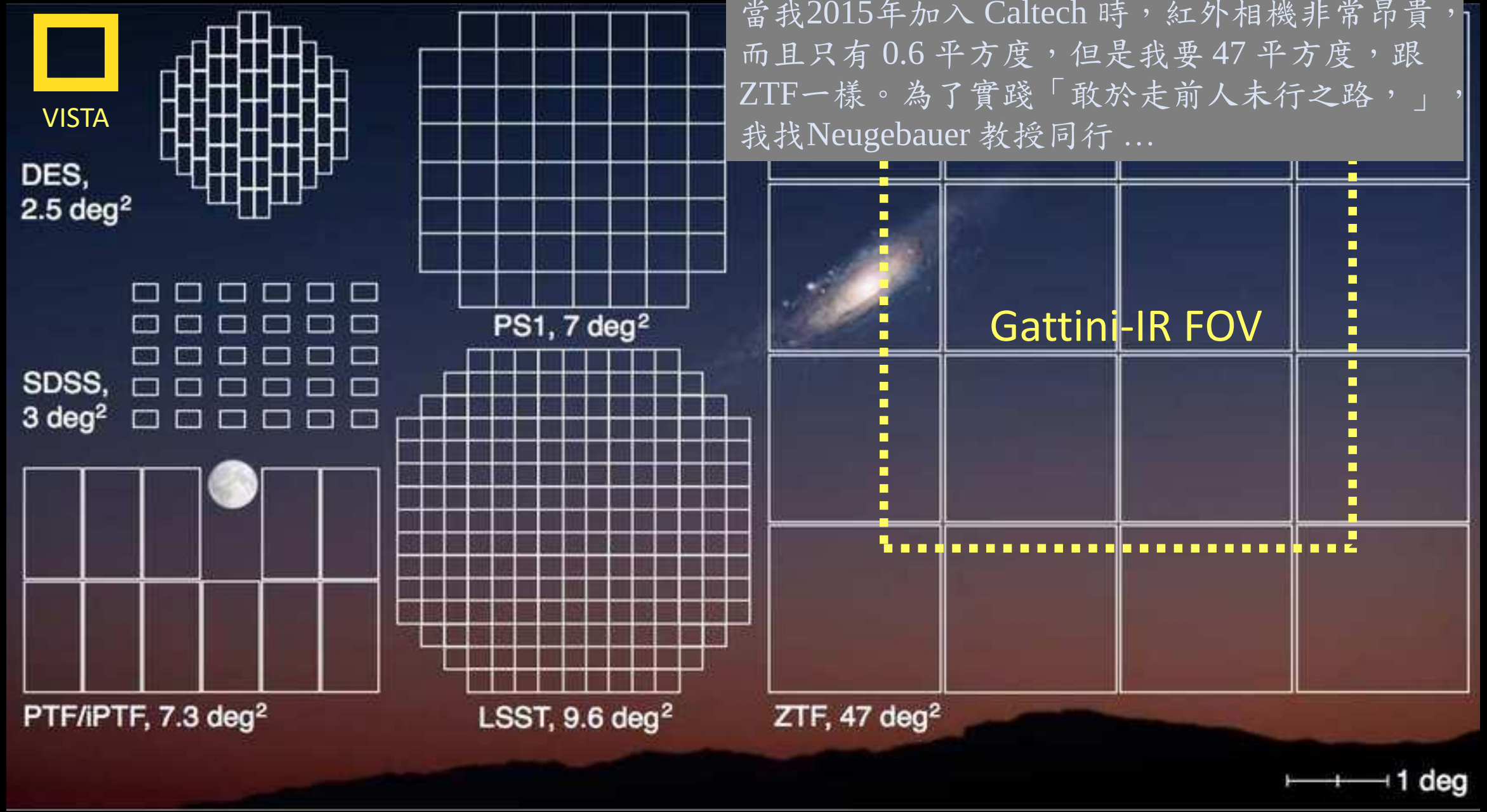
Visible Light

Infrared Light

Spitzer/NASA-JPL/T. Bourke

Caltech

當我2015年加入 Caltech 時，紅外相機非常昂貴，而且只有 0.6 平方度，但是我要 47 平方度，跟ZTF一樣。為了實踐「敢於走前人未行之路，」，我找Neugebauer 教授同行 …



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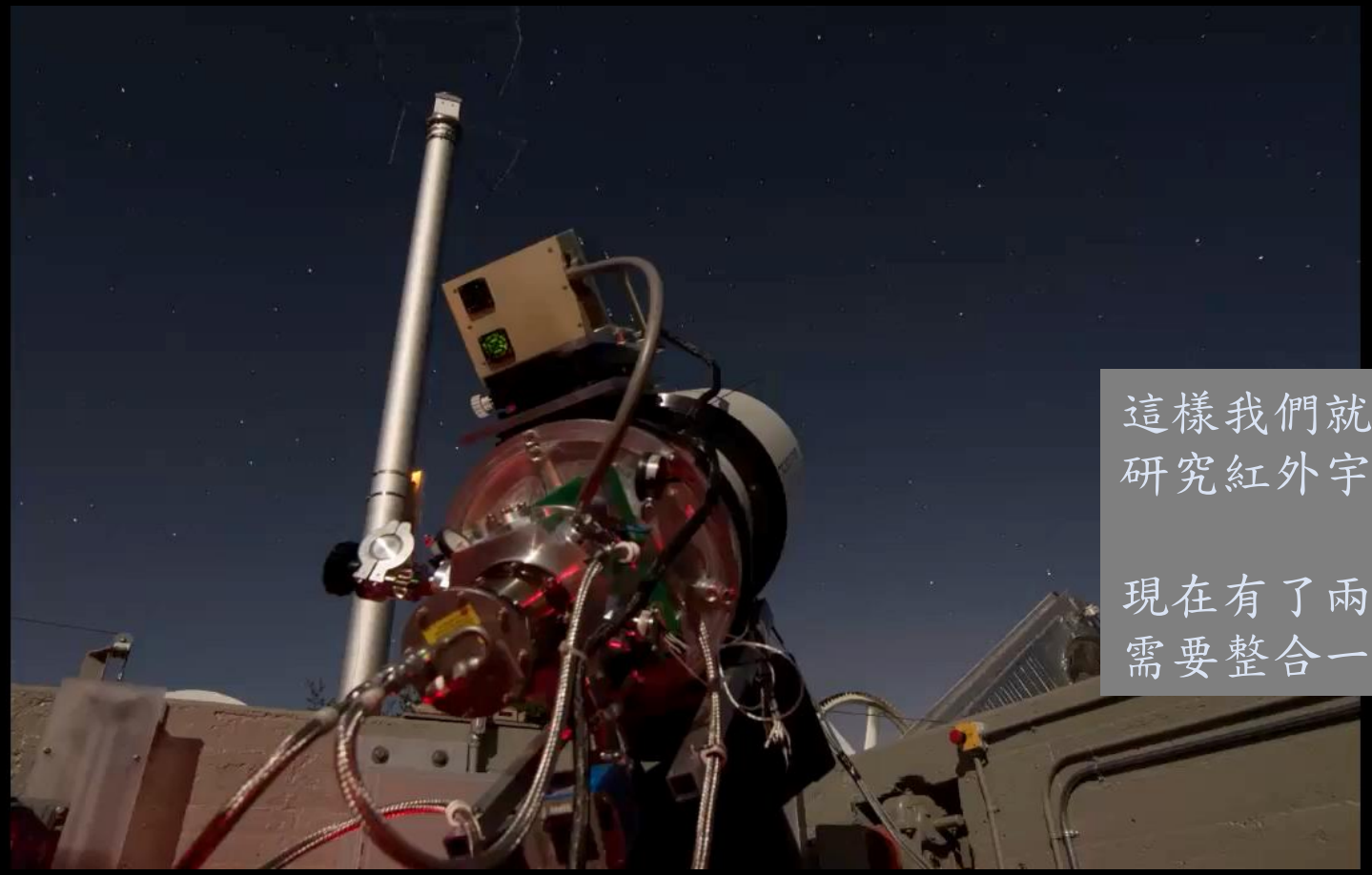
Infrared Cinematography


Scott Adams


Matt Hankins



這樣我們就能放映「紅外電影」，研究紅外宇宙的變化

現在有了兩個「電影院」，我們需要整合一下

Palomar Gattini IR maps 9,000 sq. deg. every 2 nights to J=15.7 AB mag

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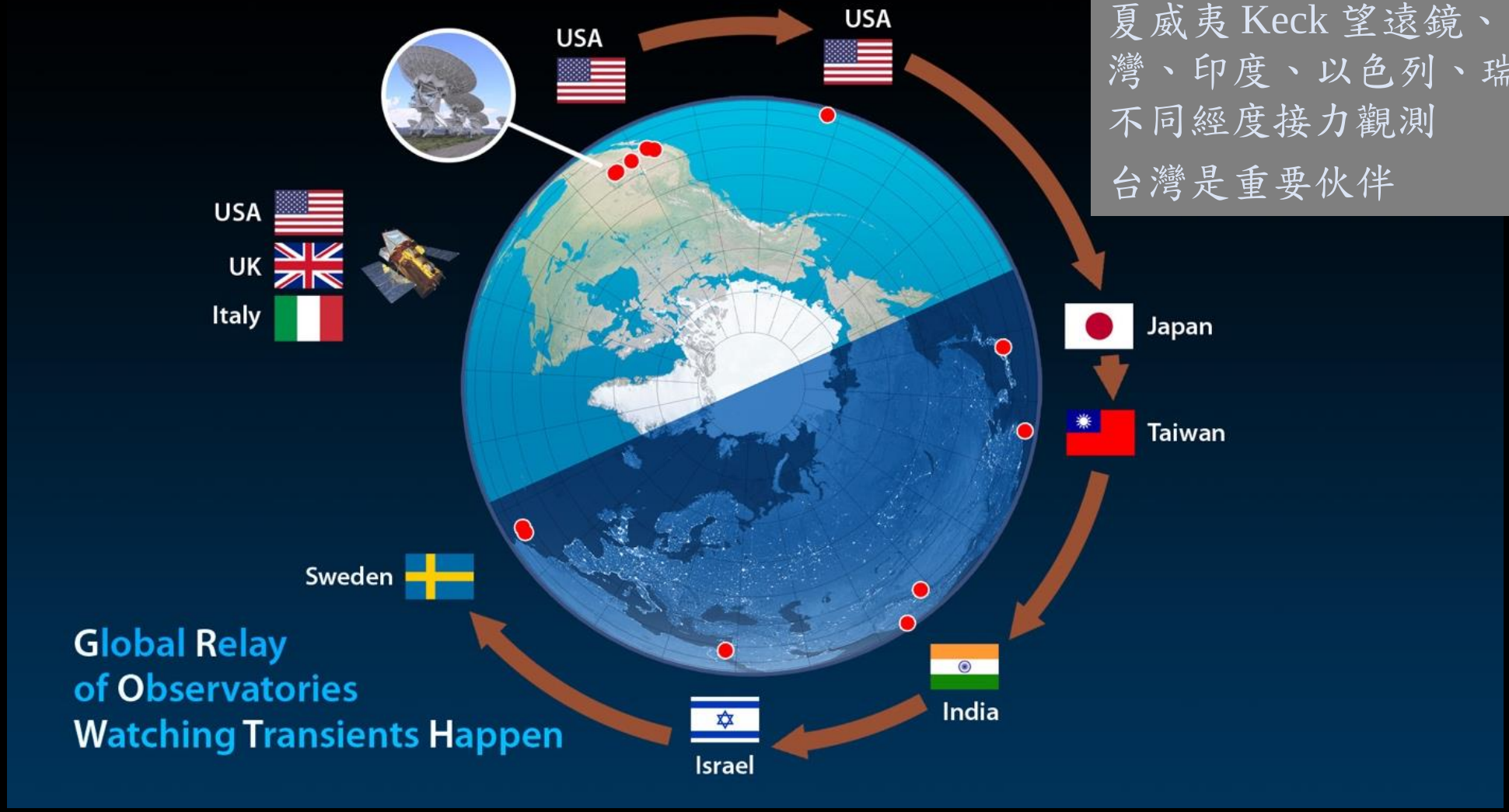
有些現象變化很快，「太陽出來就不見」，所以 GROWTH 結盟夏威夷 Keck 望遠鏡、日本、台灣、印度、以色列、瑞典 … 在不同經度接力觀測

台灣是重要伙伴



GROWTH
Global Relay of Observatories Watching Transients Happen

NSF PIRE

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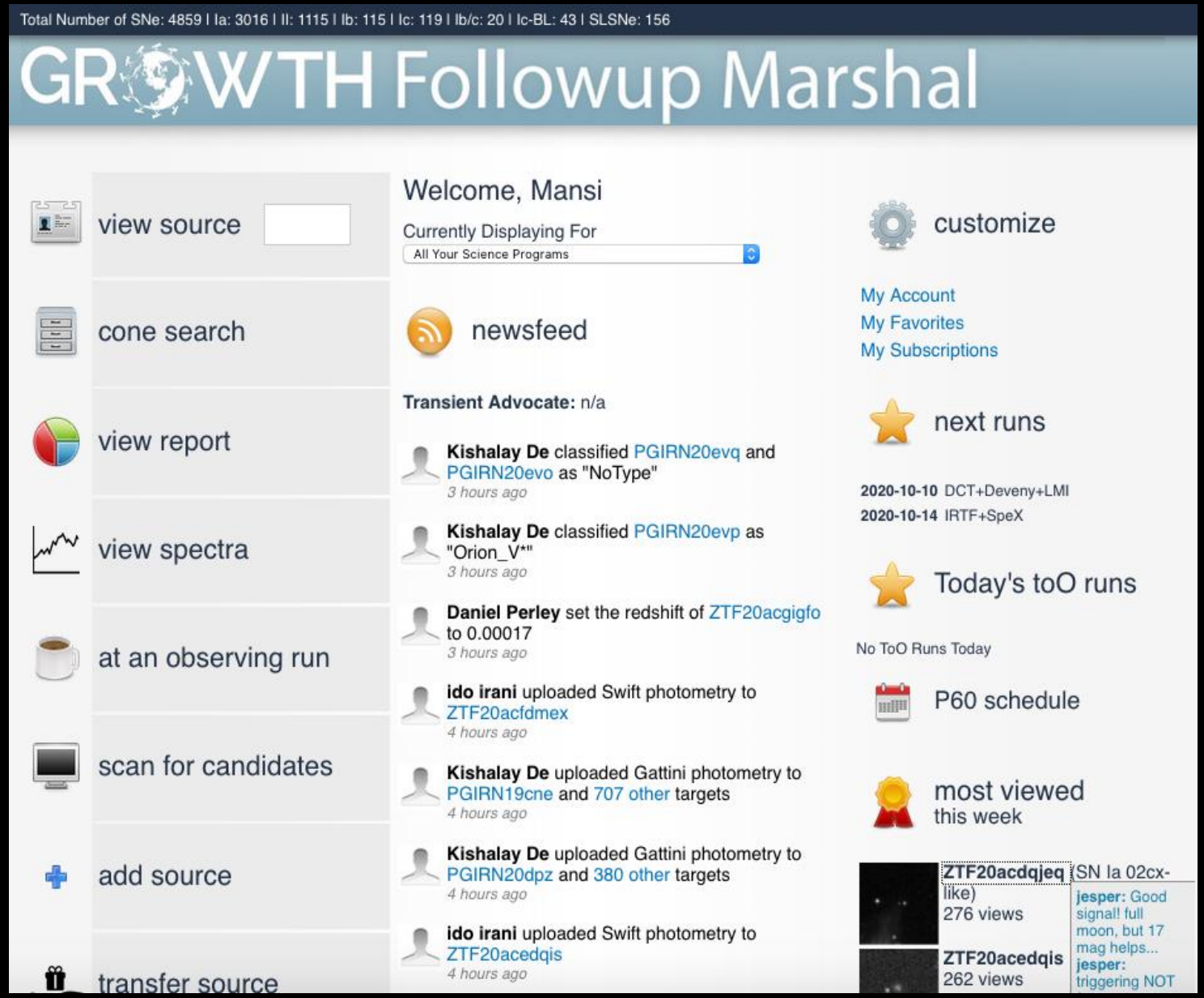
A Dynamic Collaborative Platform



Kasliwal et al. 2019a

發現了之後的後隨述性

最新一代是 Fritz

137 Scientists

37 Telescopes

38 Science Programs

100,000 events/night

5603 Supernovae to date

182 Refereed Journal Papers in 5 years

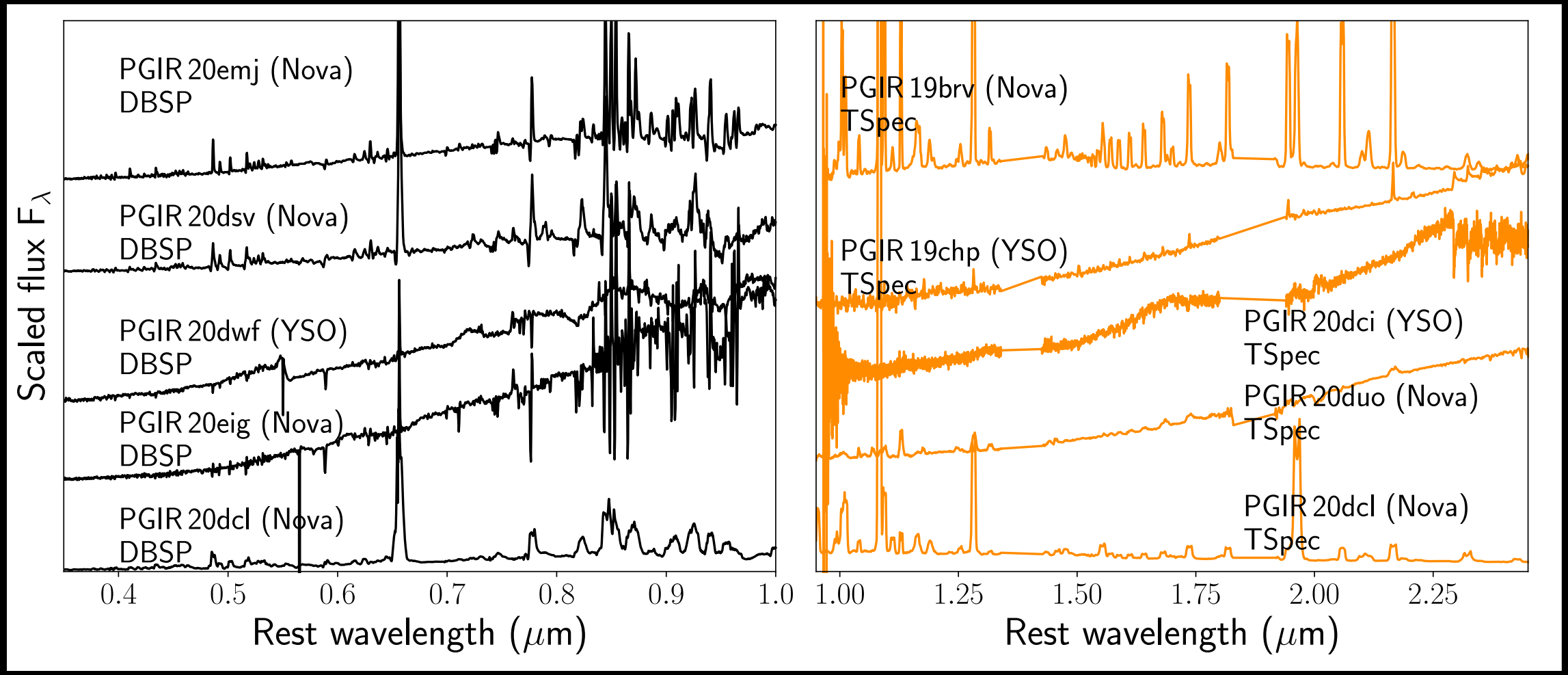
8236 citations

h-index 42

 Next generation of this system: open-source Fritz just went live

Spectrum is Truth

光譜是王道，有很多重要訊息



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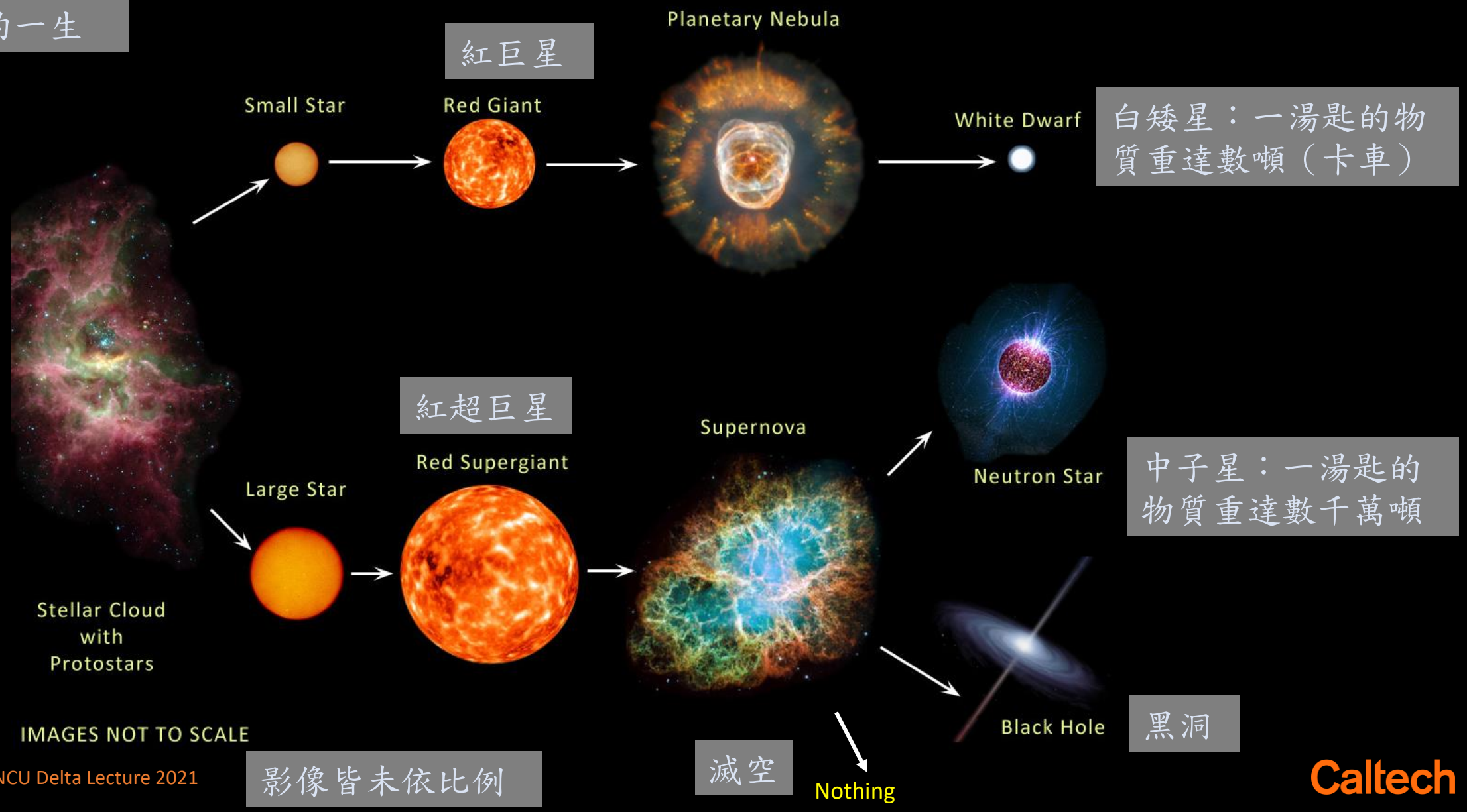
Life Cycle of a Star

恆星的一生



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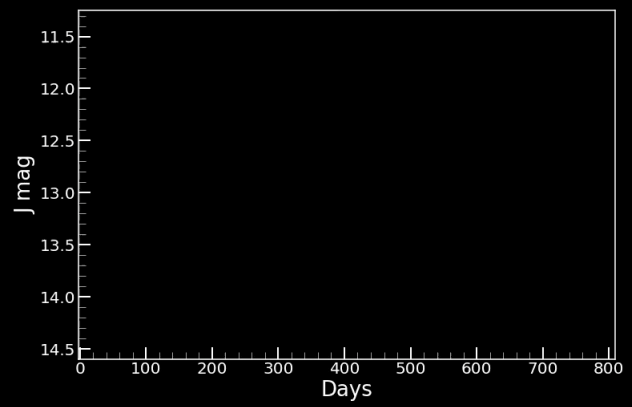
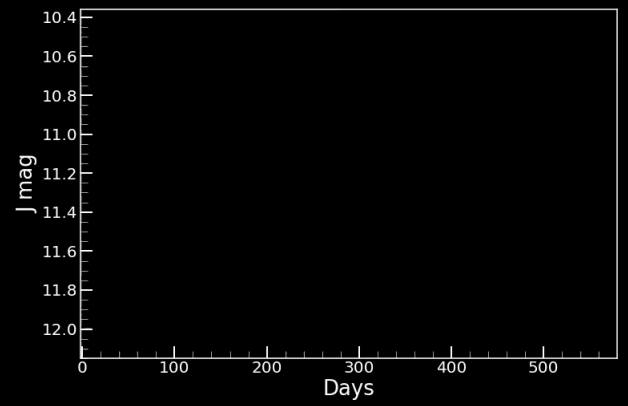
White Dwarf
Fireworks

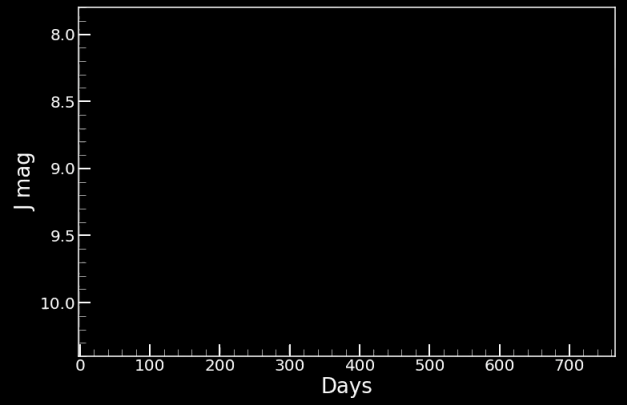
White Dwarf Merger Products

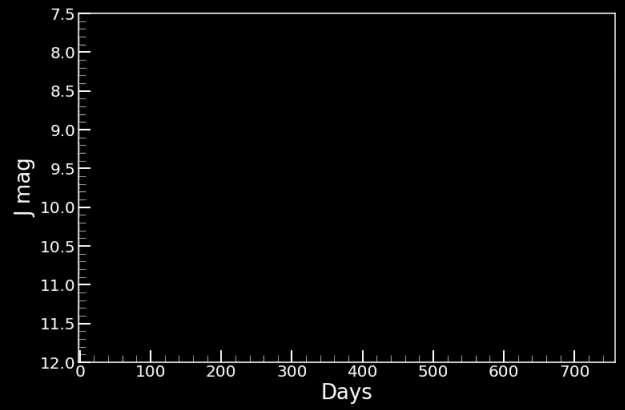
當白矮星合併

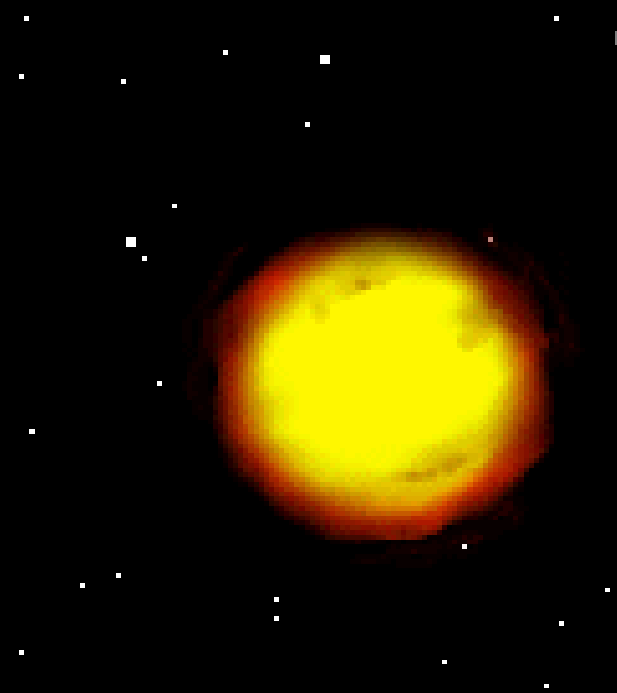
Viraj Karambelkar
(Grad, 2nd year)











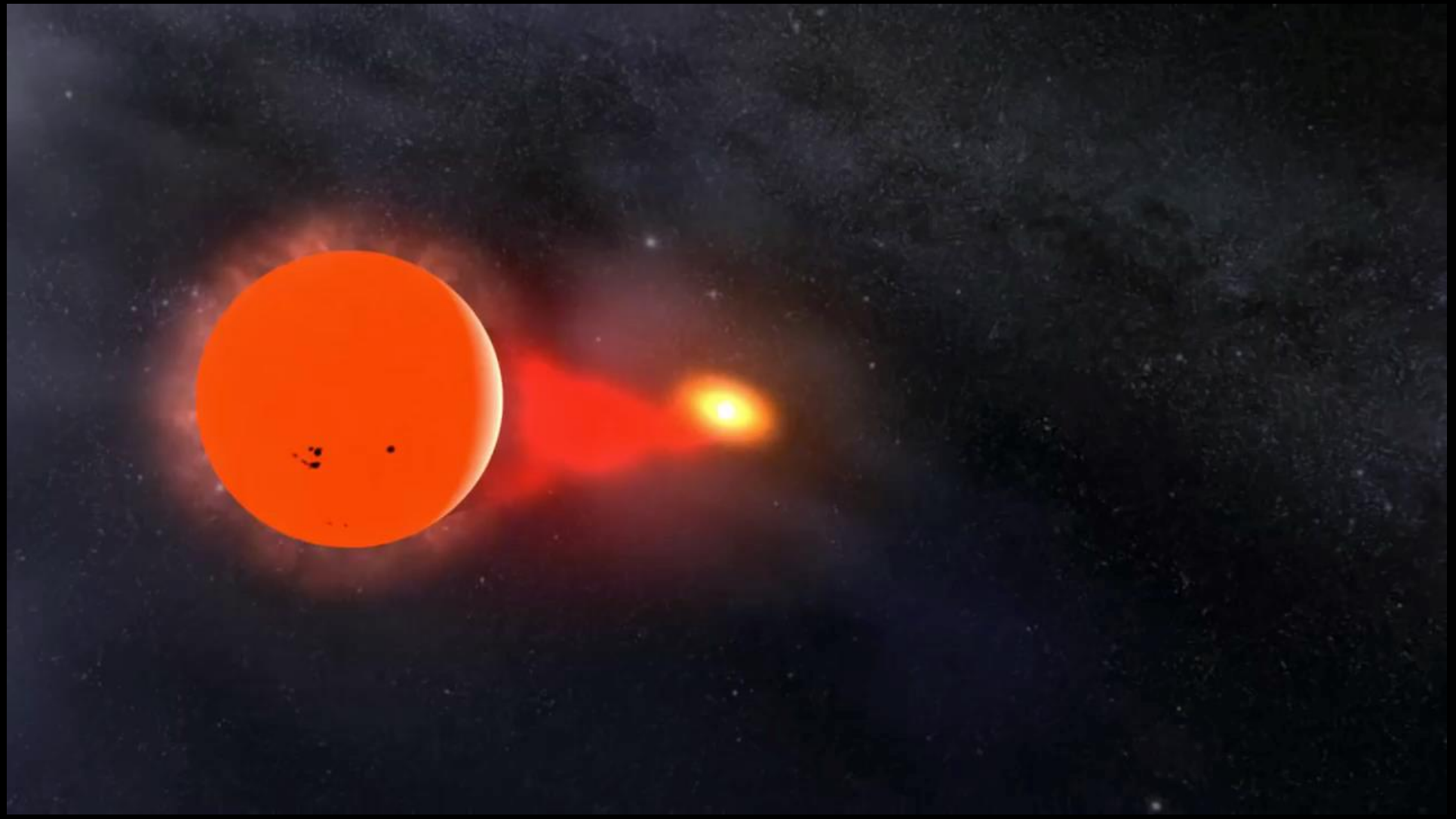
帕洛瑪 Gattini 紅外光變曲線發現了149 顆新的北冕座R型變星（不規律亮、暗）

Palomar Gattini IR light curves suggest 149 new R Cor Bor candidates

Caltech

白矮星爆發

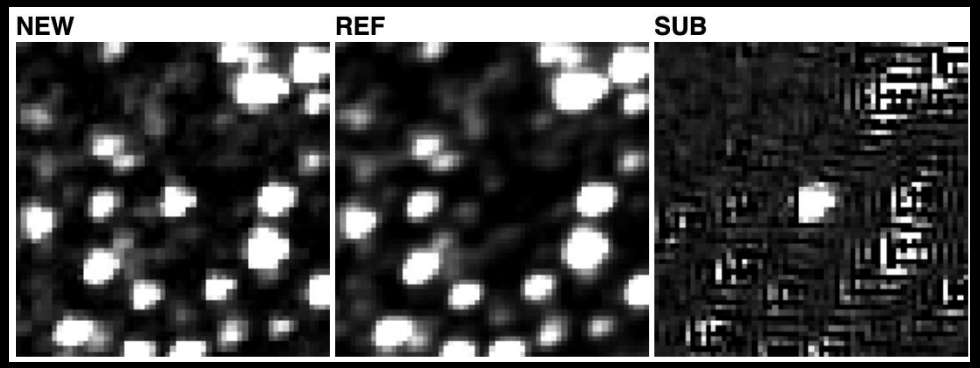
White Dwarf Explosions



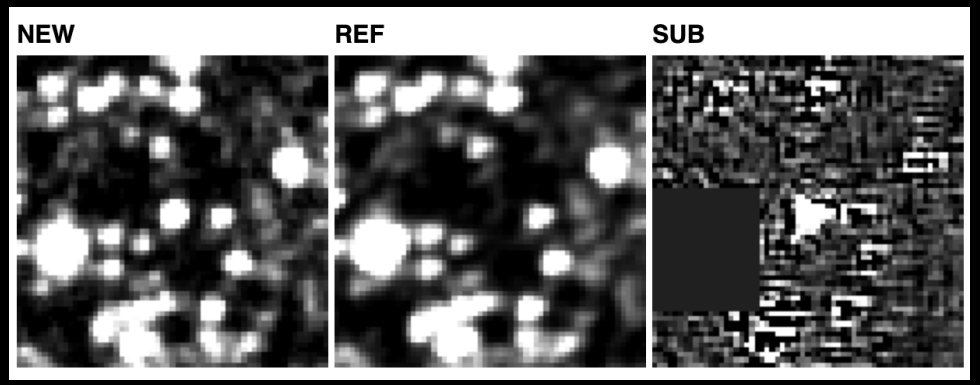
Discoveries by Palomar Gattini IR

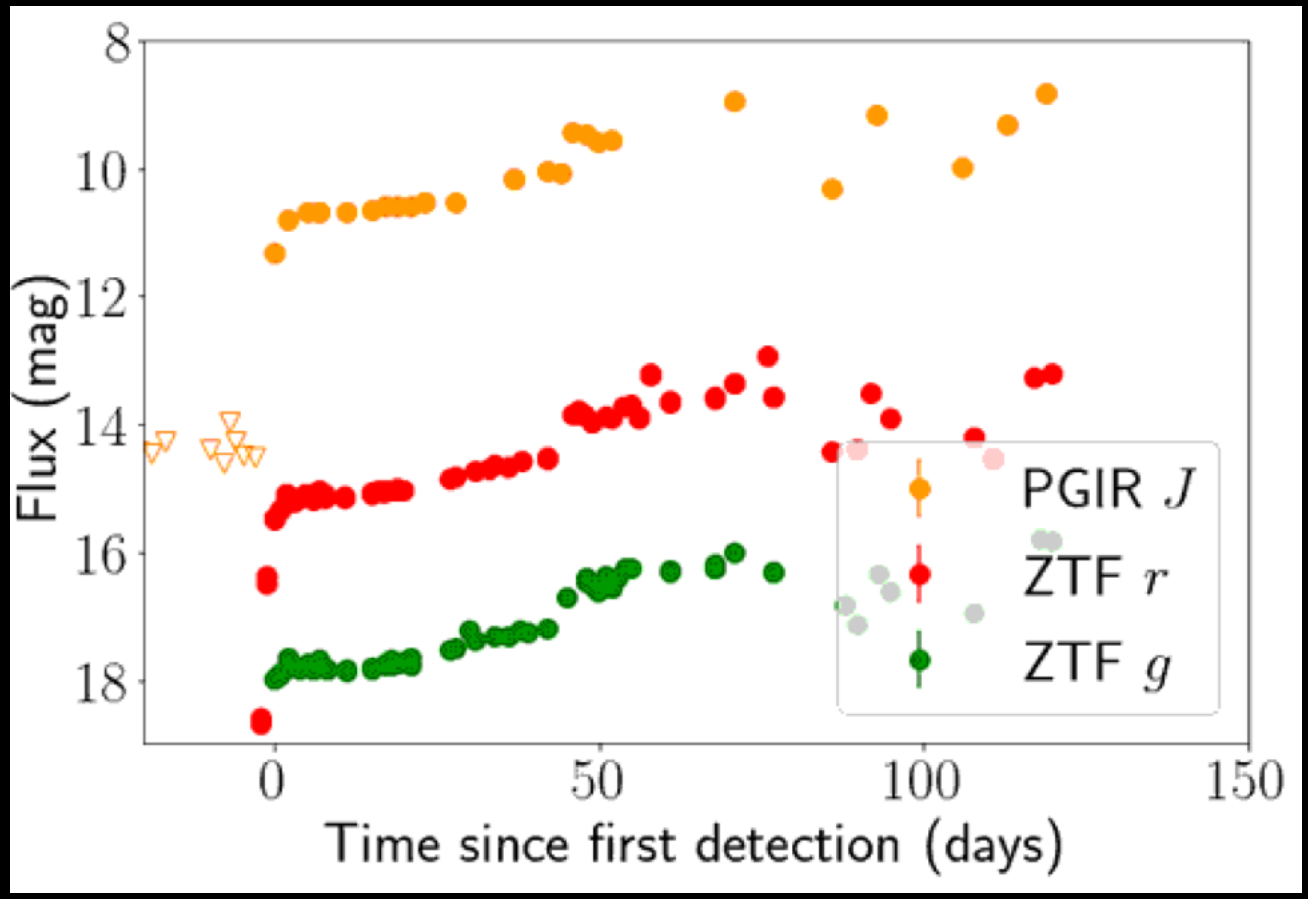
Kishalay De
(Grad, 5th Year)

PGIR19brv



PGIR20duo





PGIR has more than doubled the discovery rate of novae!

帕洛瑪 Gattini 紅外相機 (PGIR) 把發現新星的效率增加了兩倍

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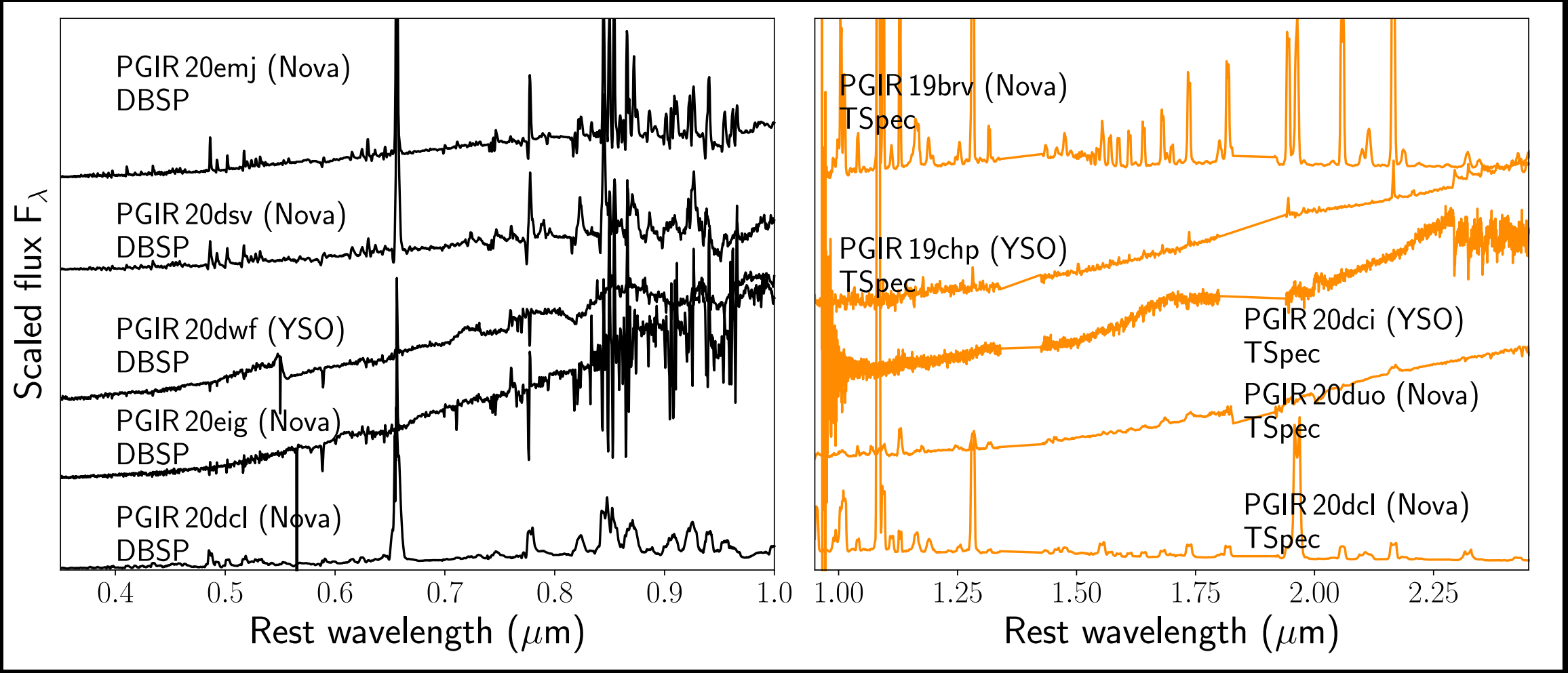
Spectrum is Truth

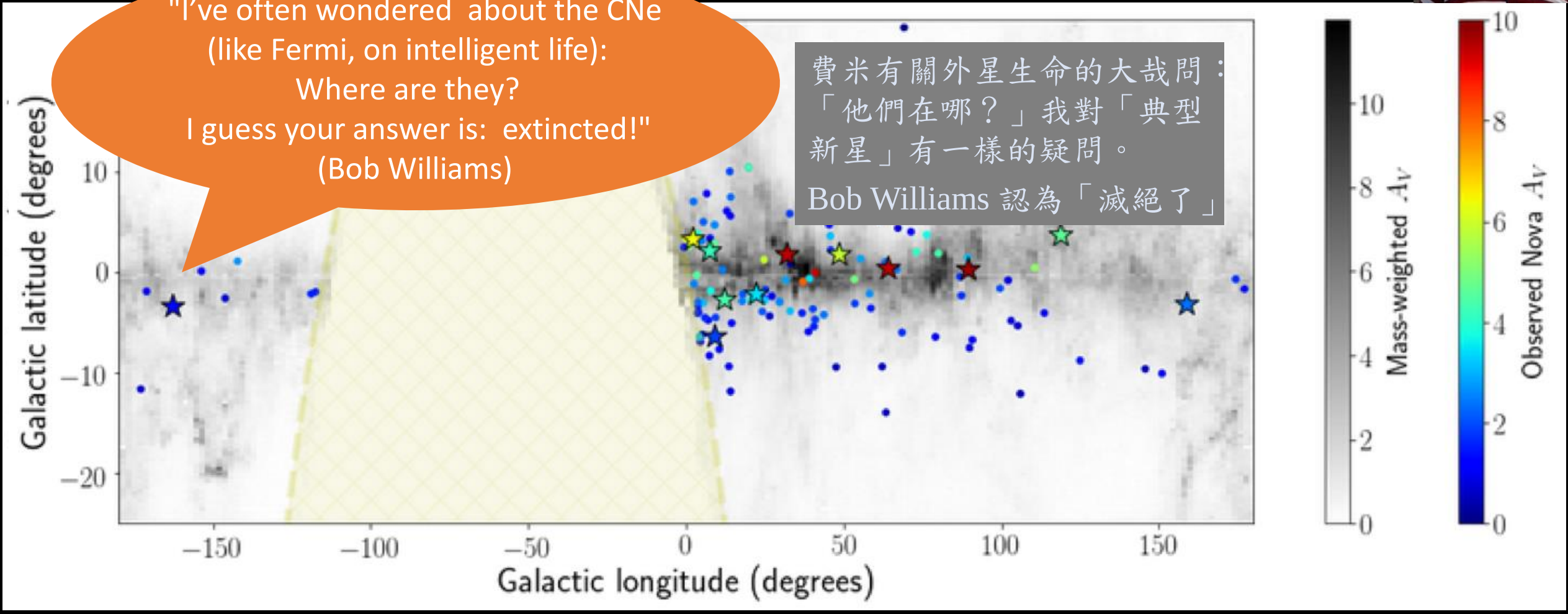


Where are the classical novae?

典型新星哪去了？

"I've often wondered about the CNe (like Fermi, on intelligent life): Where are they? I guess your answer is: extincted!" (Bob Williams)

費米有關外星生命的大哉問：「他們在哪？」我對「典型新星」有一樣的疑問。Bob Williams 認為「滅絕了」



De et al. 2021a

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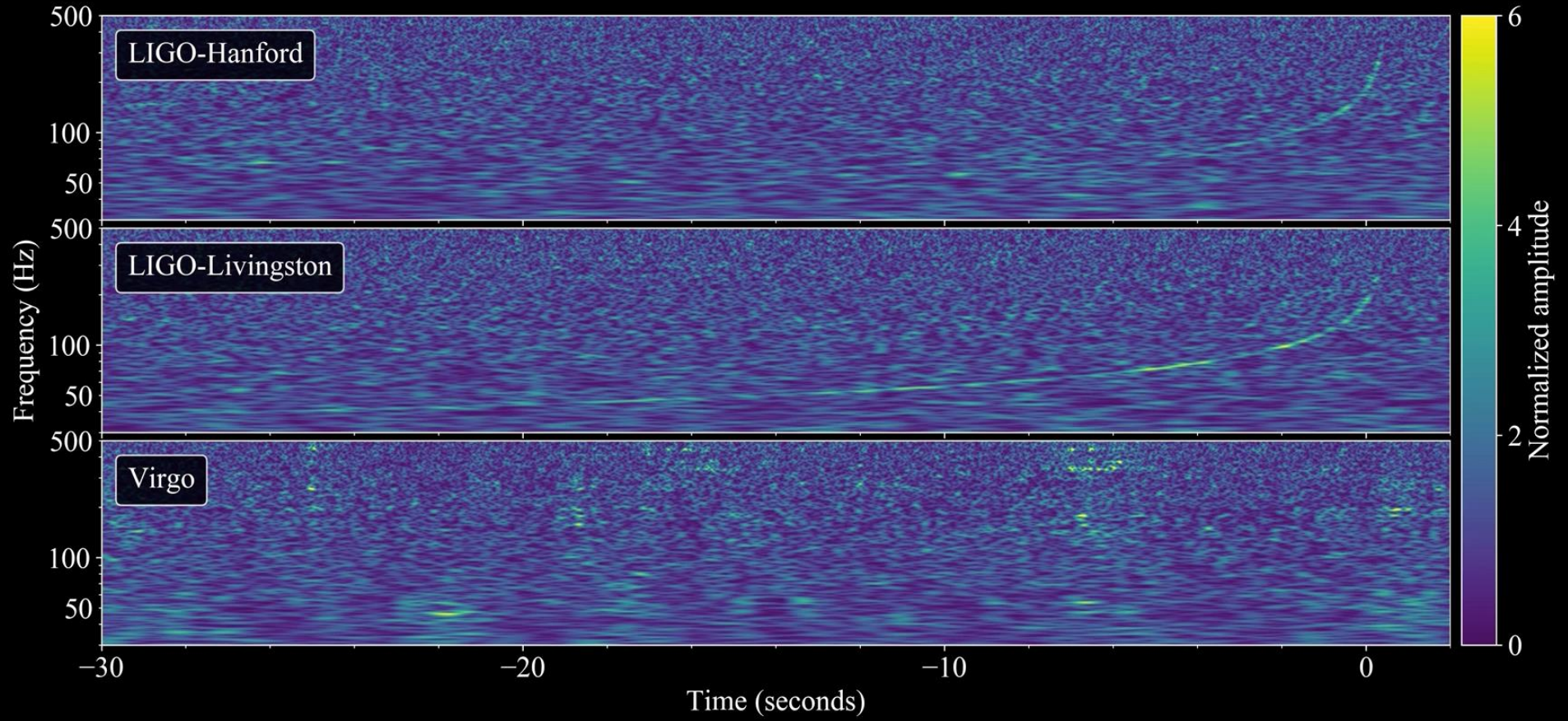
Neutron Star
Fireworks

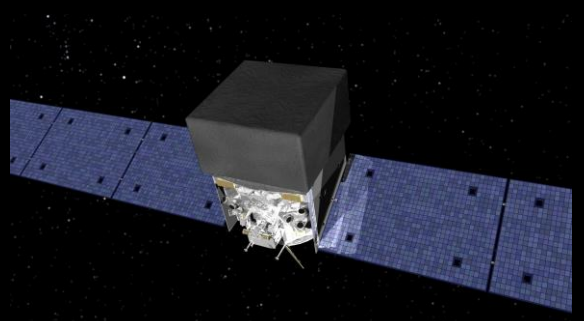
August 17, 2017, 12:41:04 UTC

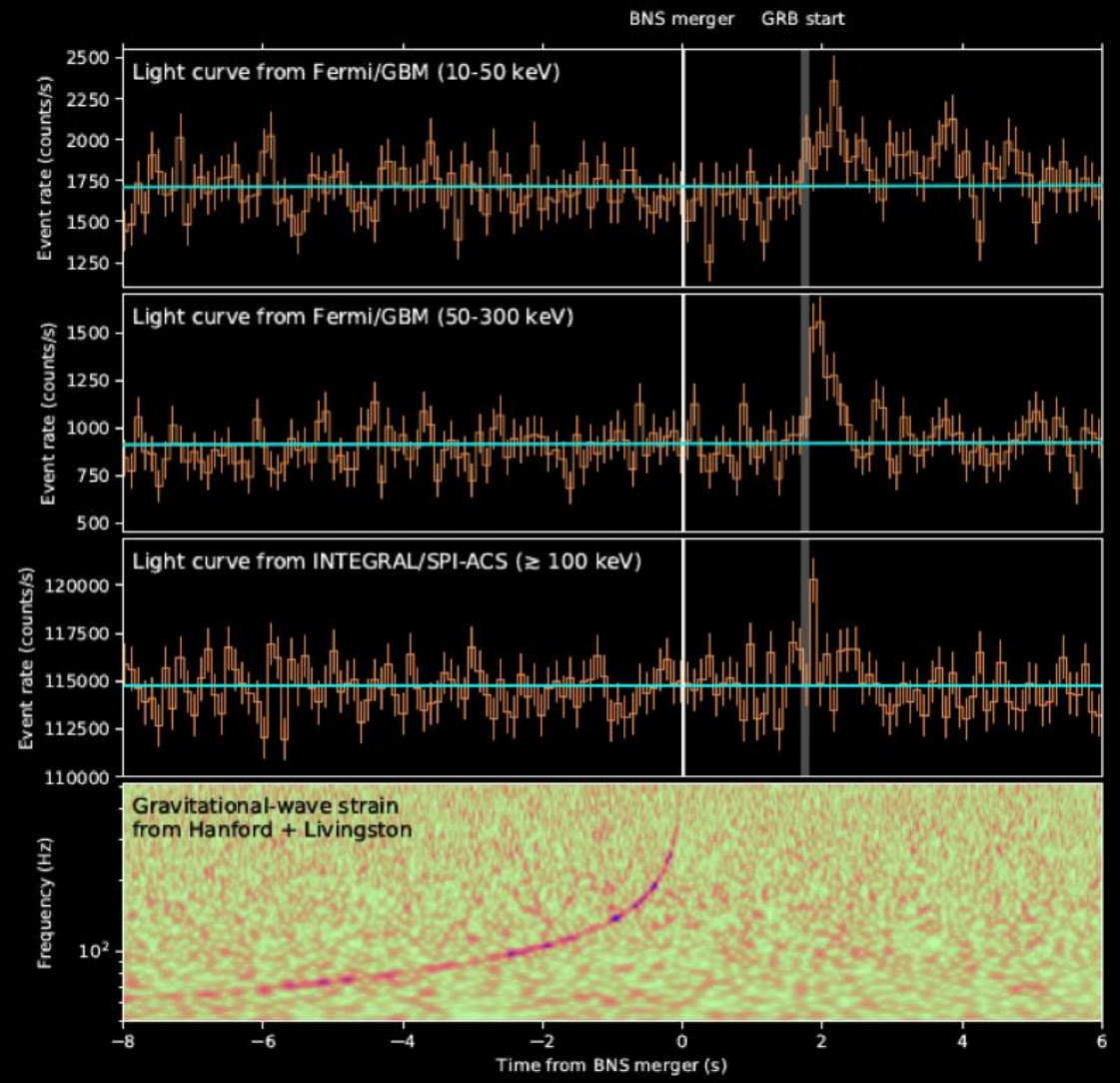


LVC, *Phys. Rev. Lett.* 119, 161101 (2017)

僅僅1.7秒之後，出現伽瑪射線

Just 1.7 seconds later, a burst of gamma rays





LVC, Fermi, Integral *Astrophys. J. Lett., 2017; Goldstein et al. 2017*

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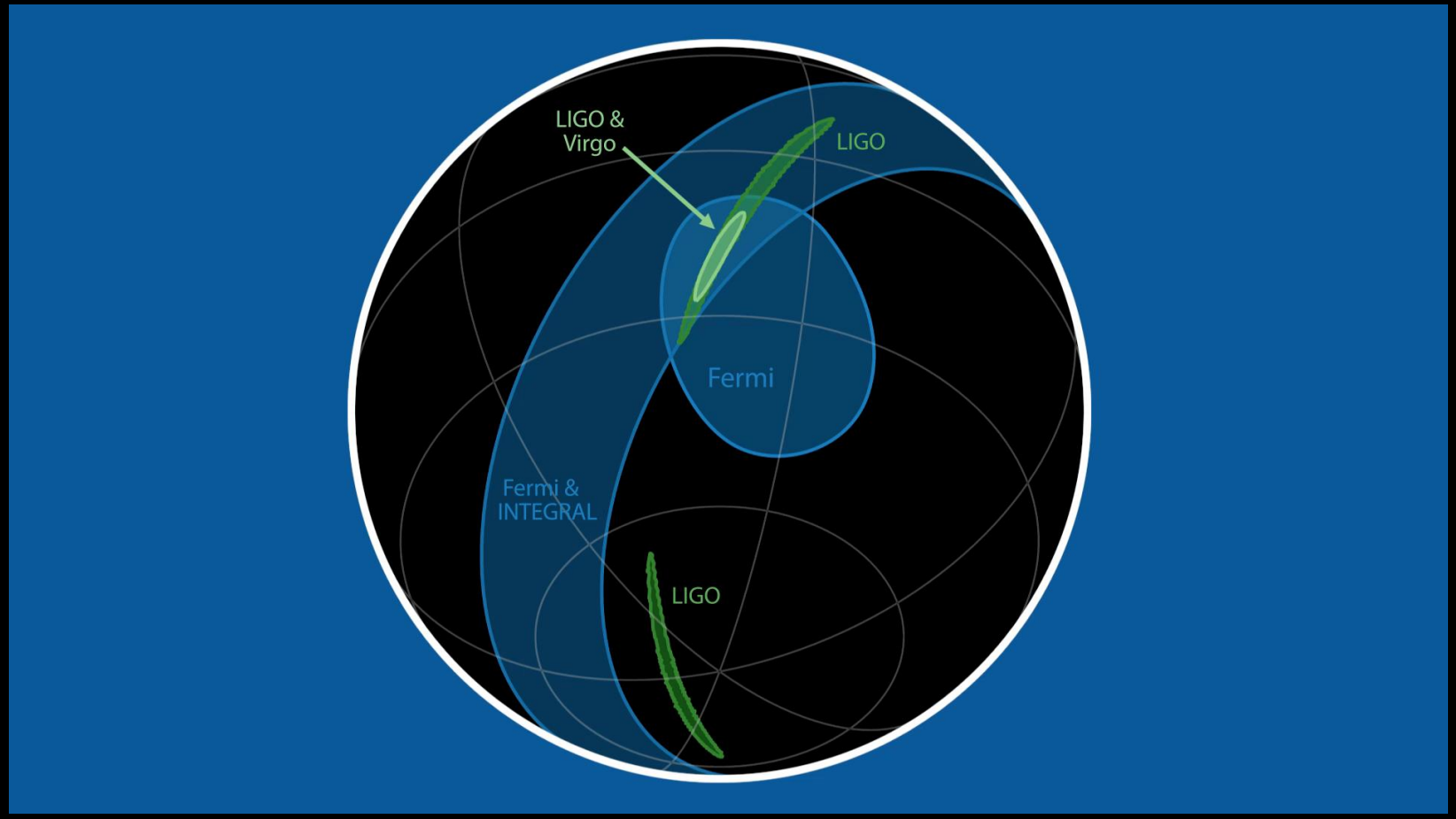
Finding Home 從哪來的呢？



Movie Credit: R. Hurt/IPAC Caltech

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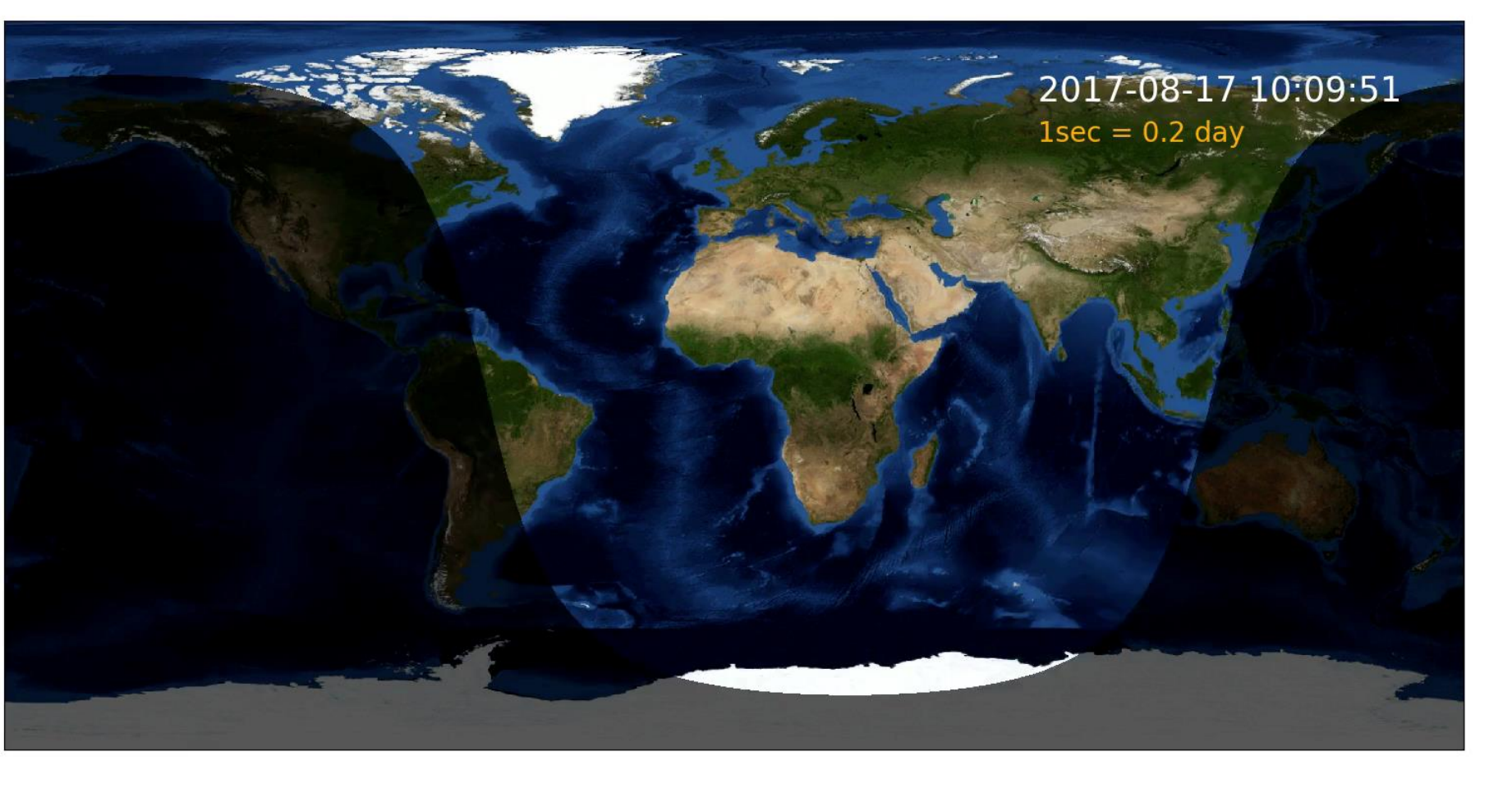
A Global Effort



Movie Credit: GROWTH co-I V. Bhalerao

GROWTH
Global Relay of Observatories Watching Transients Happen

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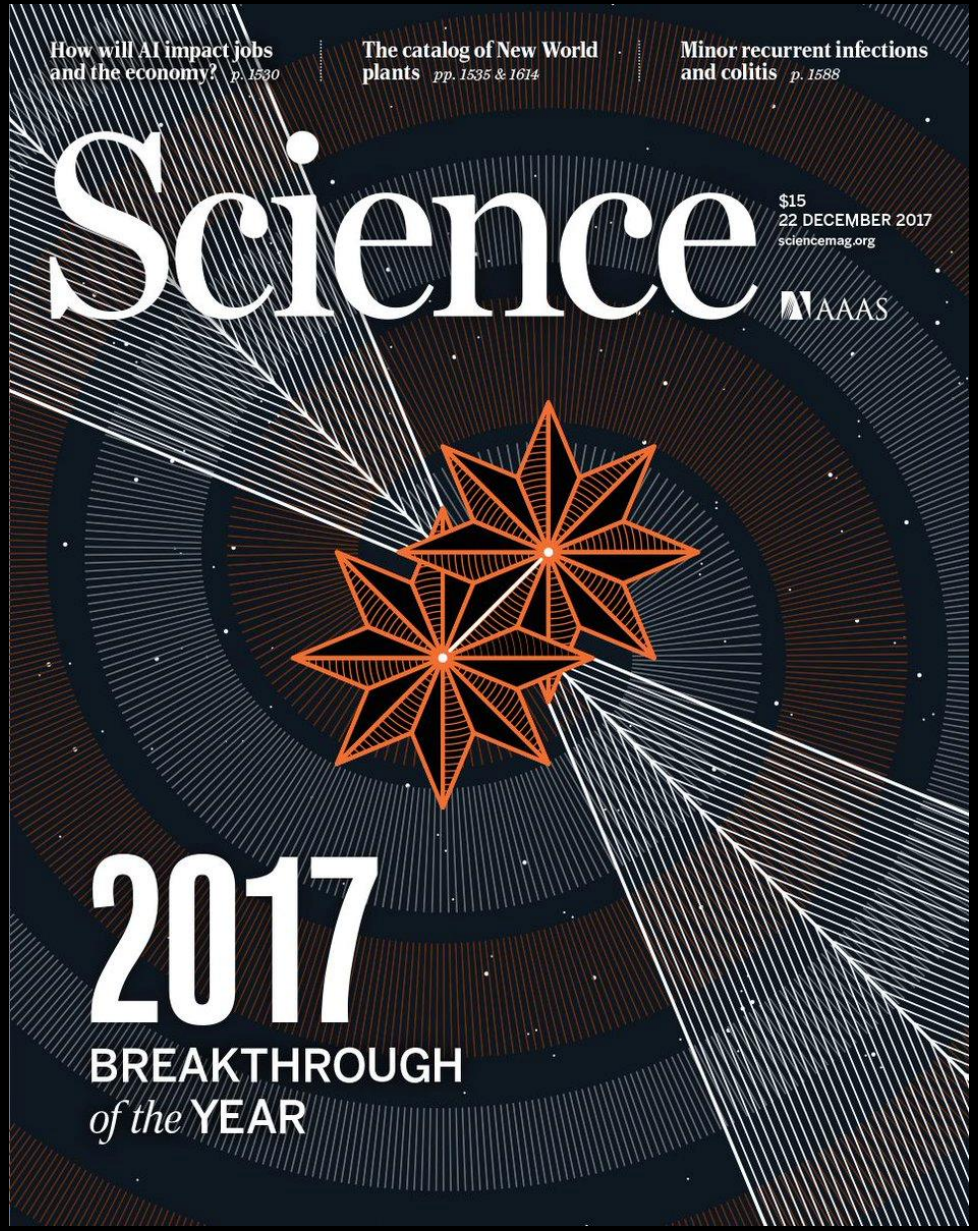

有關該事件的三篇 Science 論文，包括電波與高能觀測

Kasliwal 領銜發表了可見光與紅外的觀測結果，並統整了各波段結果的解讀

Celebrating a trio of papers in journal Science:
Evans et al. 2017, Kasliwal et al. 2017, Hallinan et al. 2017

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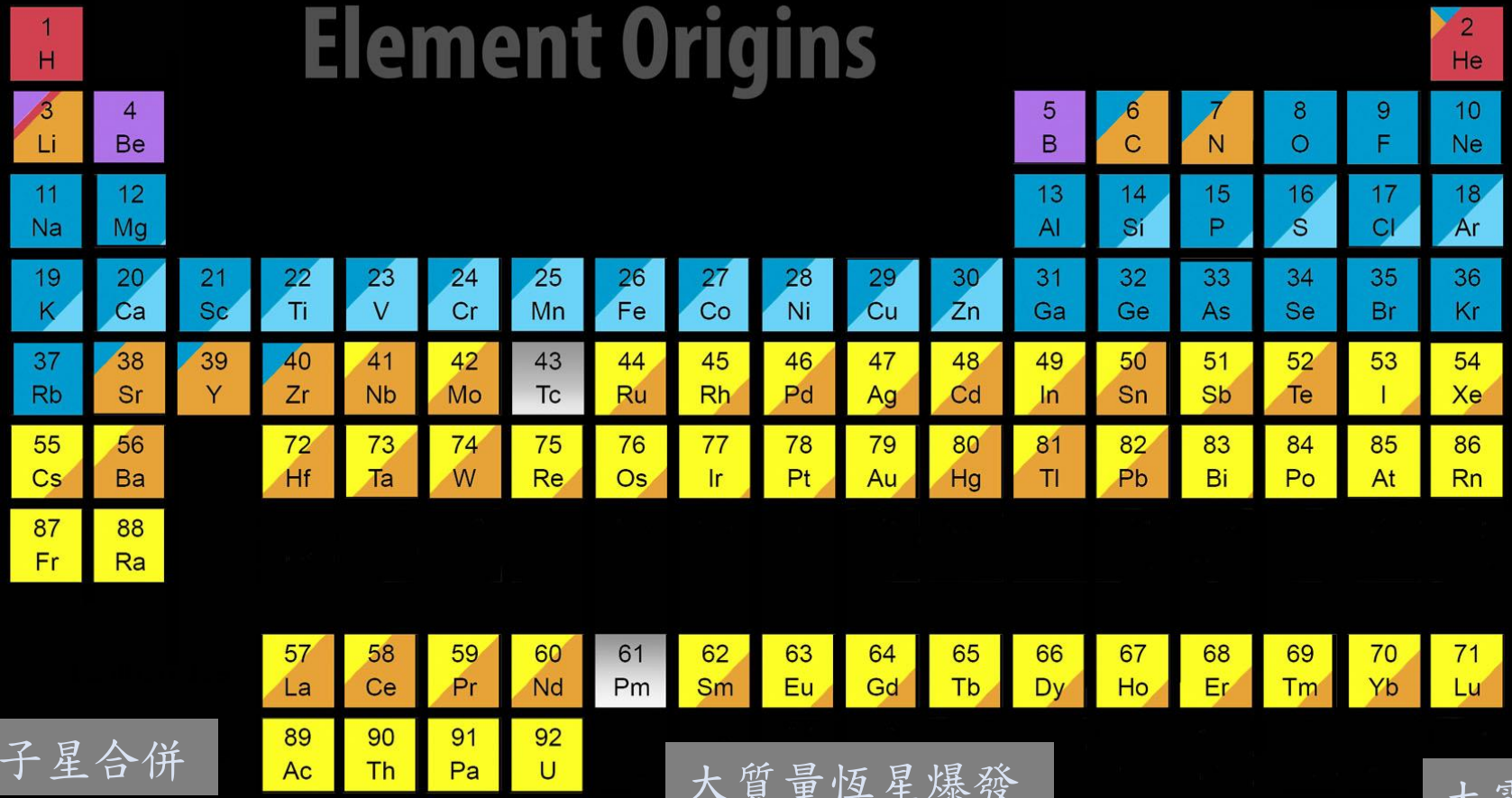
新的元素來源週期表

Element Origins



中子星合併

大質量恆星爆發

大霹靂

Merging Neutron Stars

Exploding Massive Stars

Big Bang

Dying Low Mass Stars

Exploding White Dwarfs

Cosmic Ray Fission

宇宙射線撞擊

低質量恆星死亡

白矮星爆發

Based on graphic created by Jennifer Johnson

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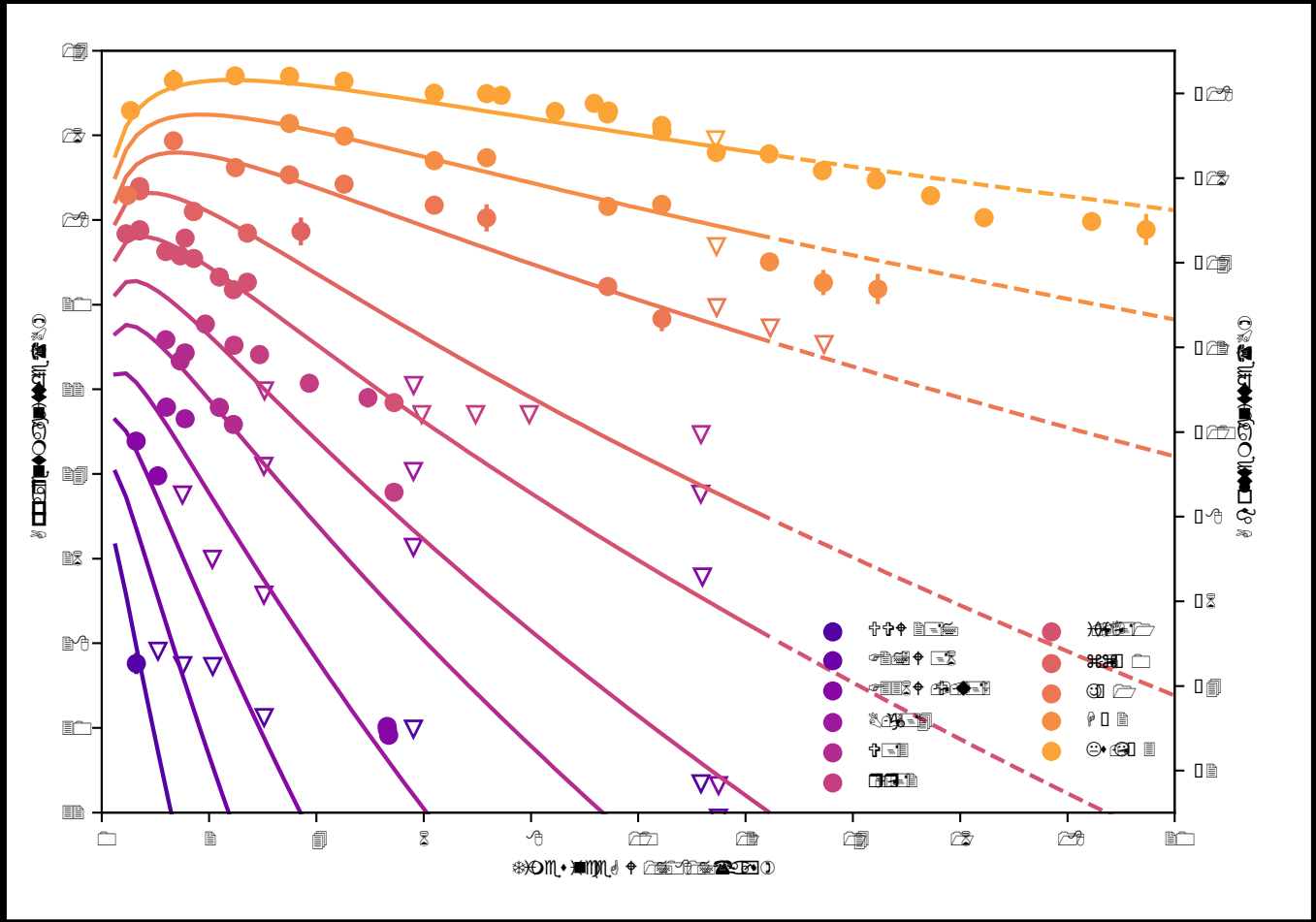
UVOIR Light Curve

低質量恆星死亡從紫外、可見光，到紅外的光變曲線



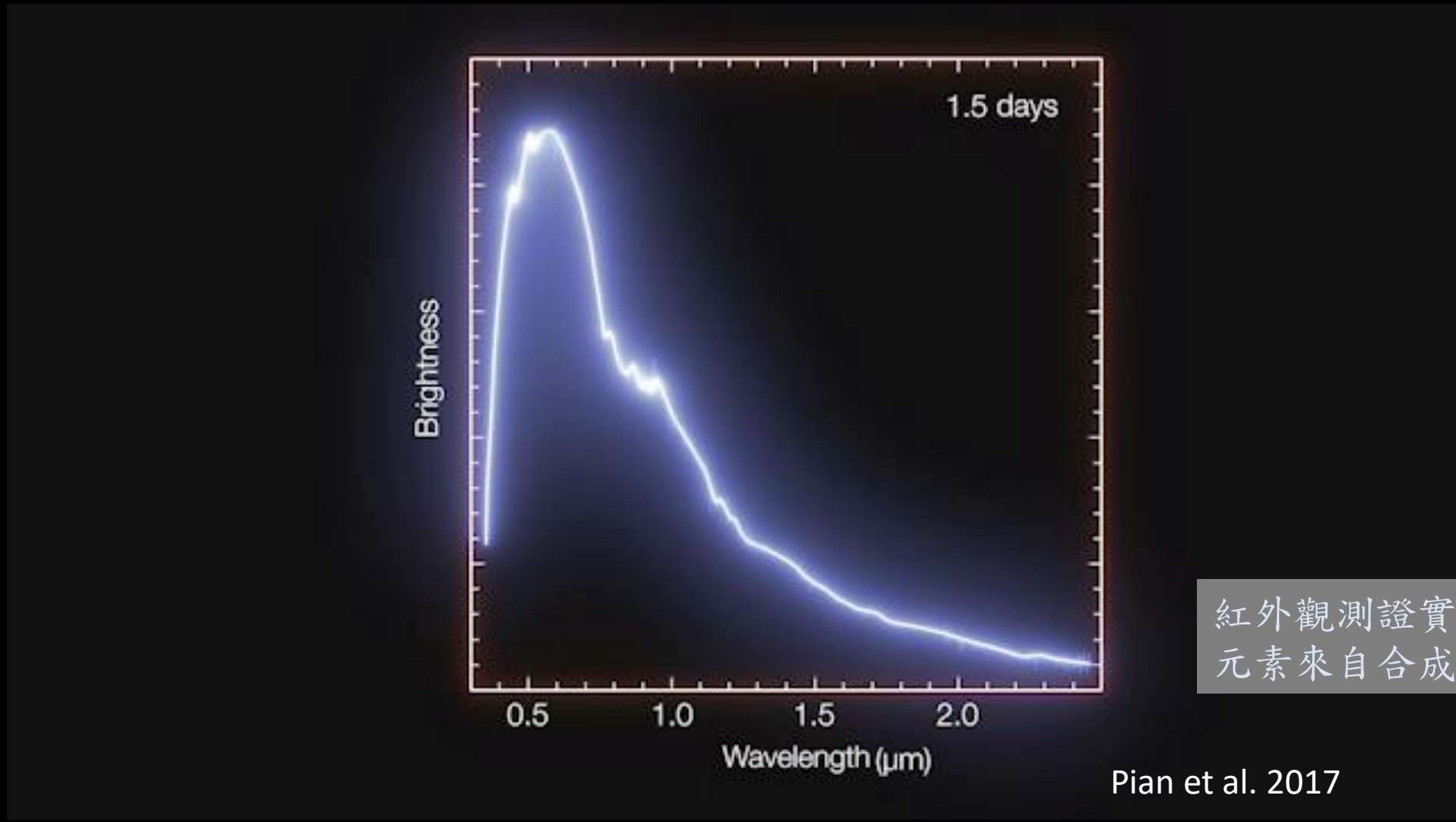
Evans et al. 2017, Kasliwal et al. 2017c

See also:
Andreoni et al. 2017
Arcavi et al. 2017
Cowperthwaite et a. 2017
Coulter et al. 2017
Drout et al. 2017
Lipunov et al. 2017
Lyman et al. 2017
Pian et al. 2017
Soares-Santos et al. 2017
Smartt et al. 2017
Tanvir et al. 2017
Utsumi et al. 2017
Villar et al. 2017

Surprise # 1: Too Bright and Blue at Early Time

意外：早期太亮，也太「藍」

Spectra are the chemical thumbprint



紅外觀測證實重元素來自合成

Pian et al. 2017

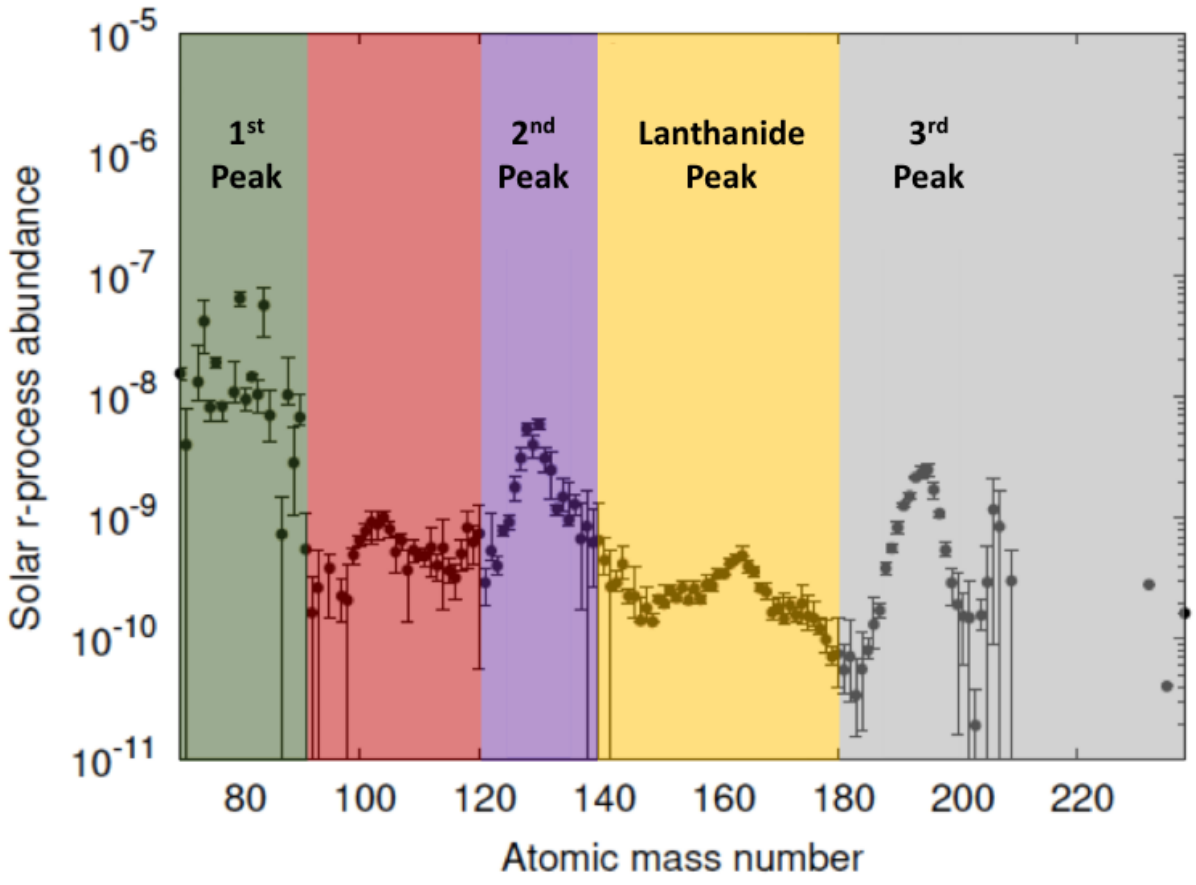
Infrared Confirms that Heavy Elements were Synthesized.

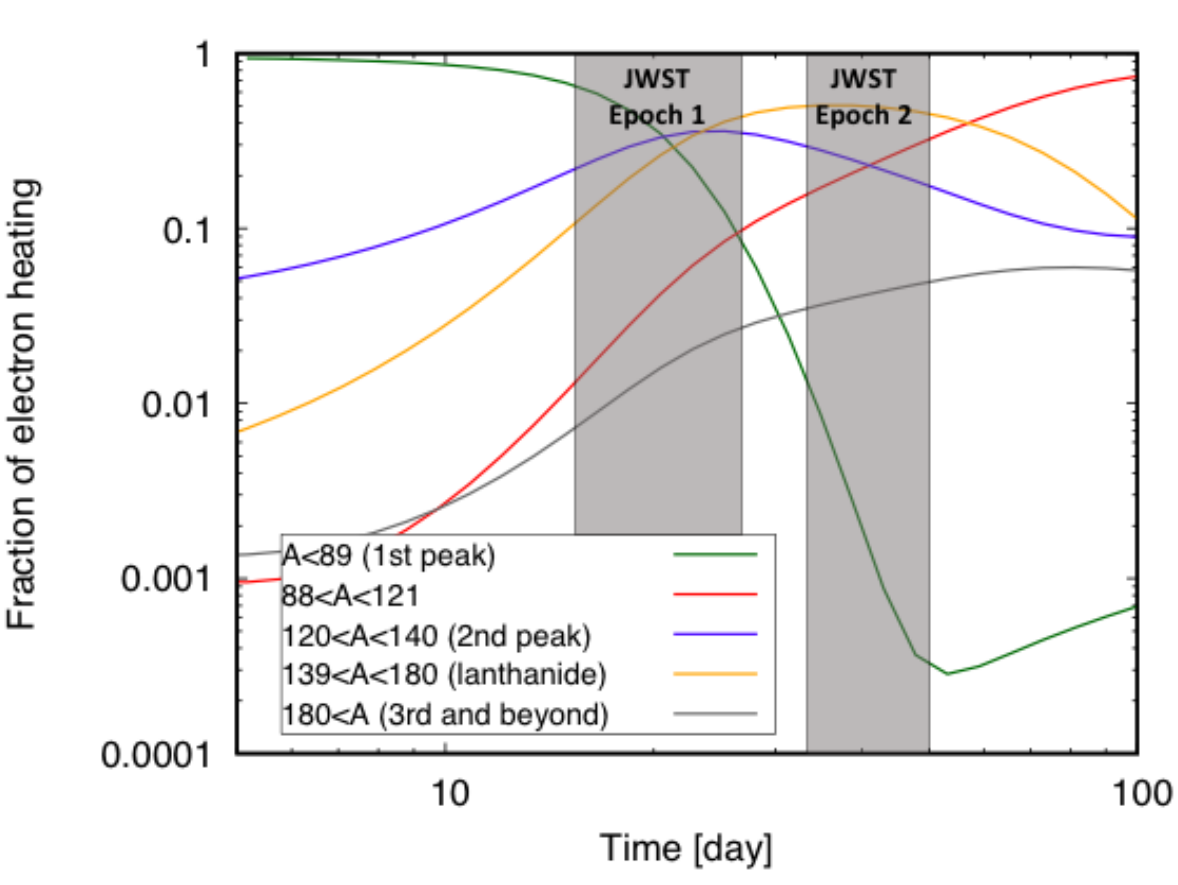
Caltech

A Site or The Site:

但是「其中之一」，還是「就是它」？
產生足夠的重元素數量嗎（例如能解釋太陽的成分）？

Was the production rate of heavy elements enough to explain the observed solar abundance?





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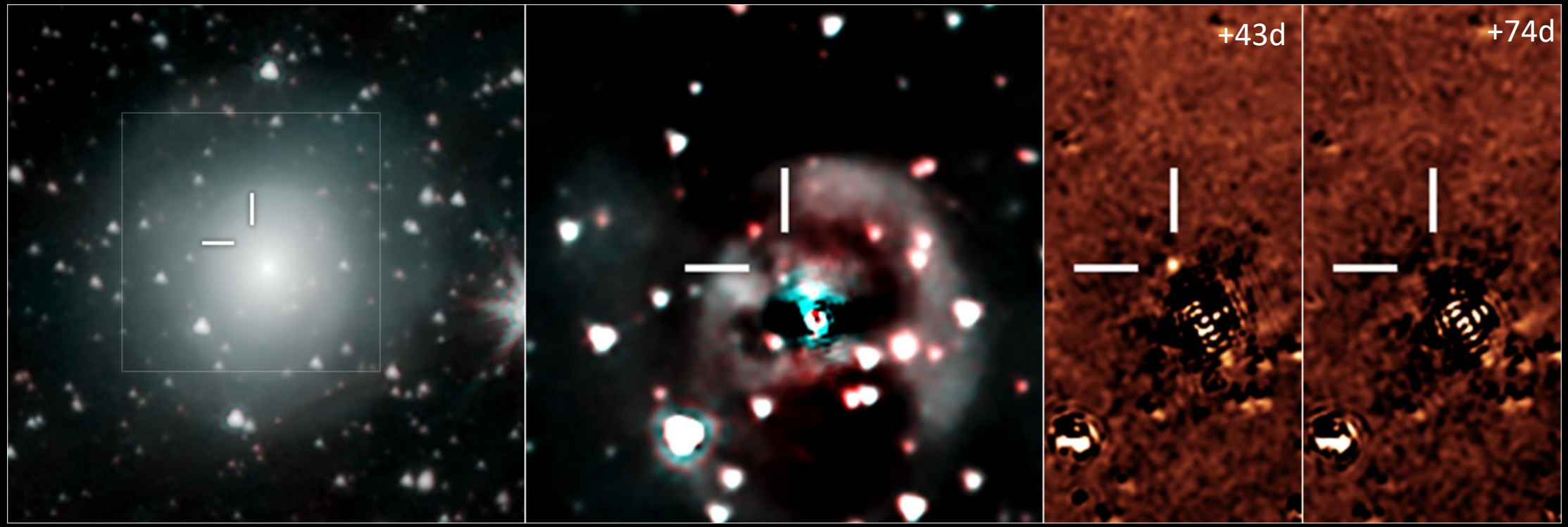
重元素來自合成的直接證據

Direct evidence that the heaviest elements were indeed synthesized!



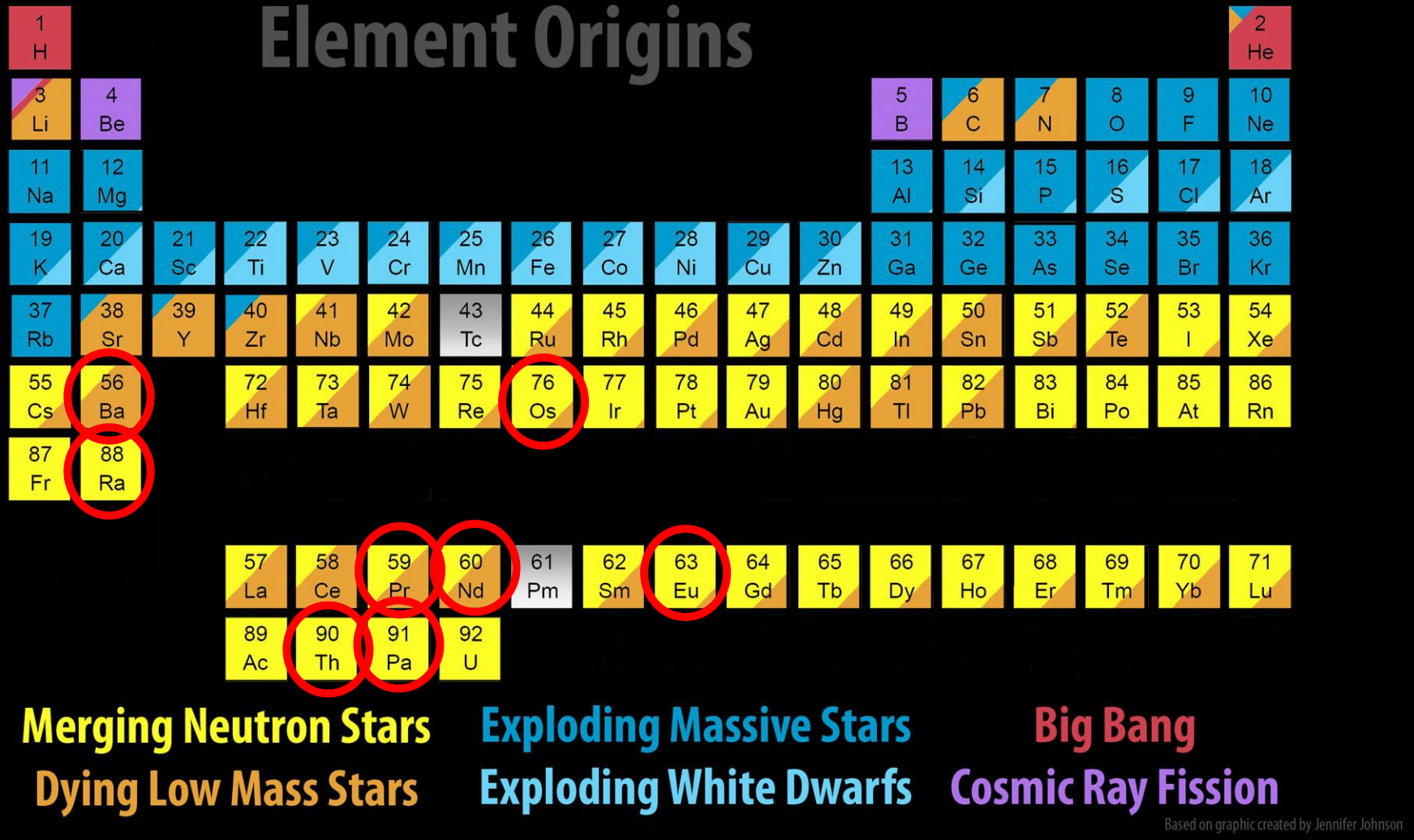
Kasliwal et al. 2019a

We did strike gold!

我們真的「挖到金礦」（得到金牌）了

Caltech

Cosmic Mines



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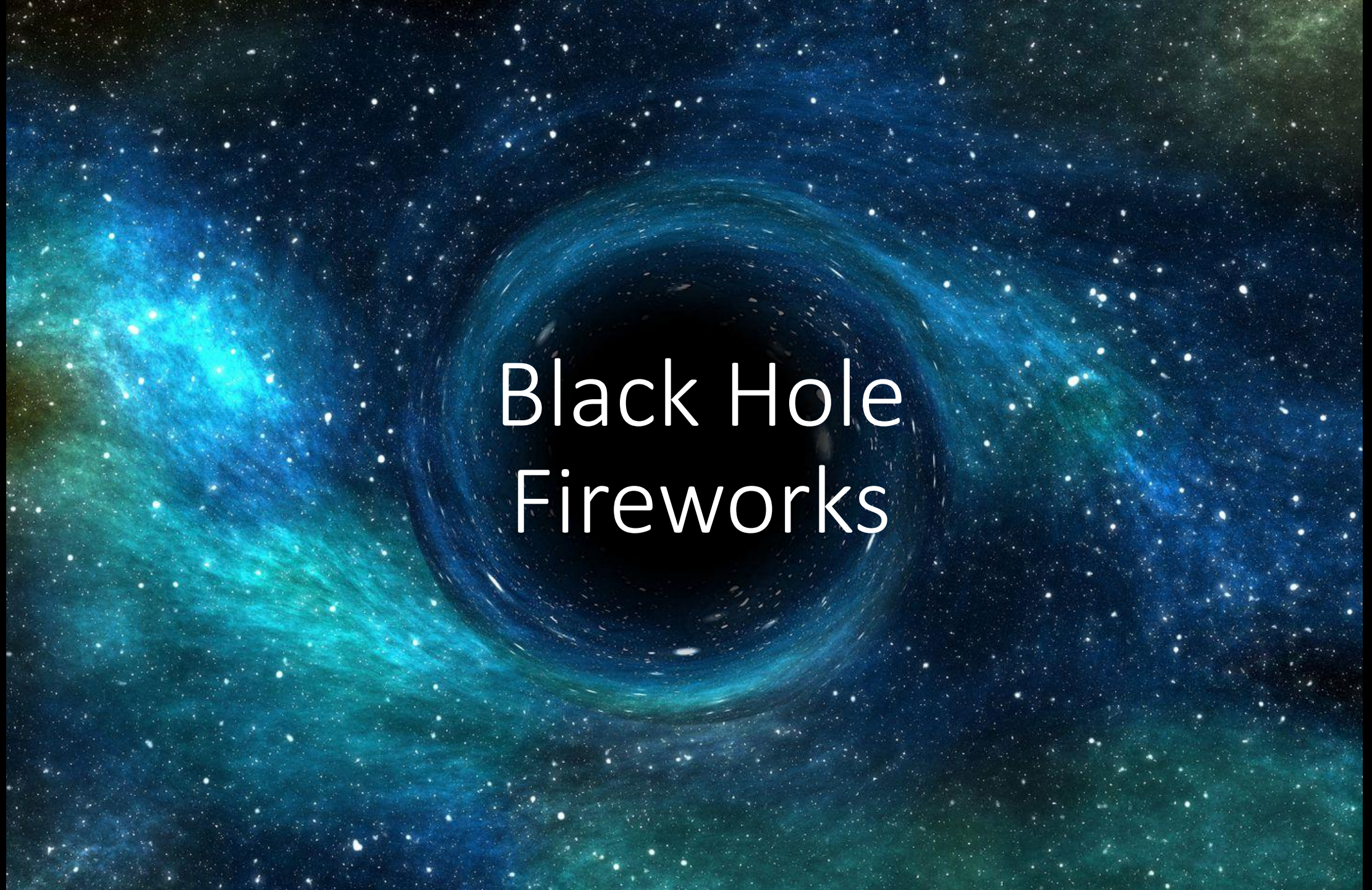
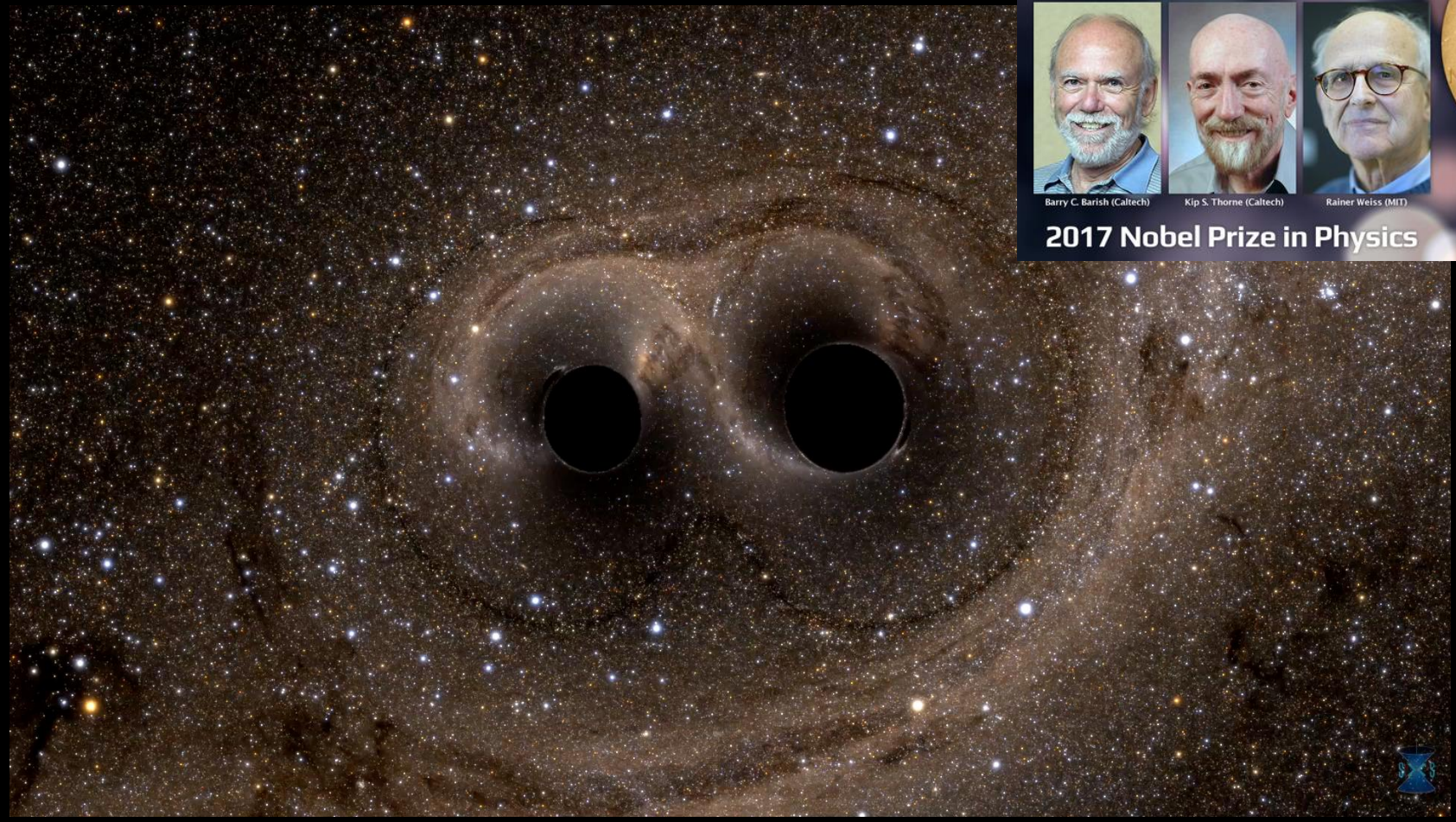

Black Hole
Fireworks

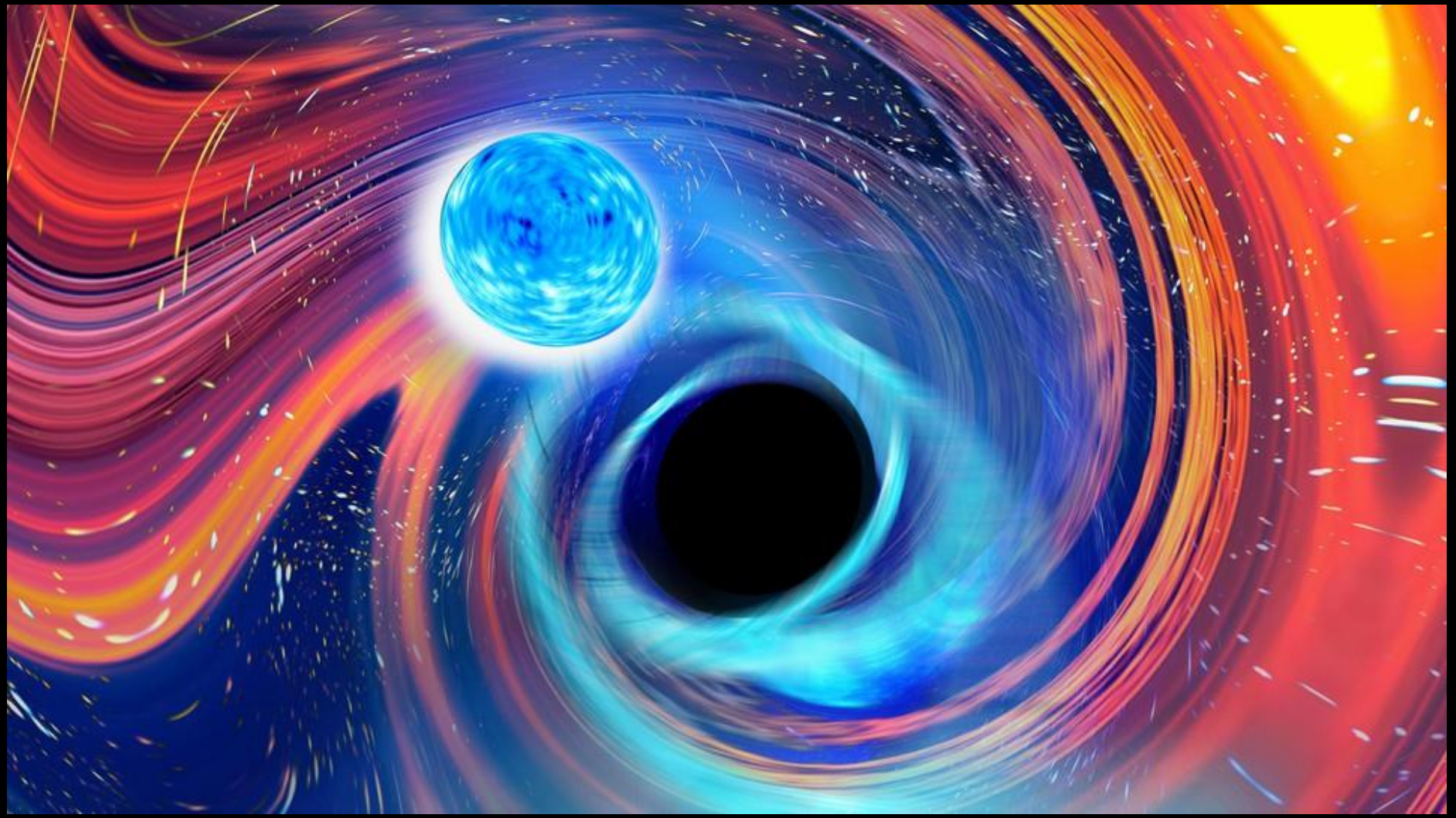
September 14, 2015

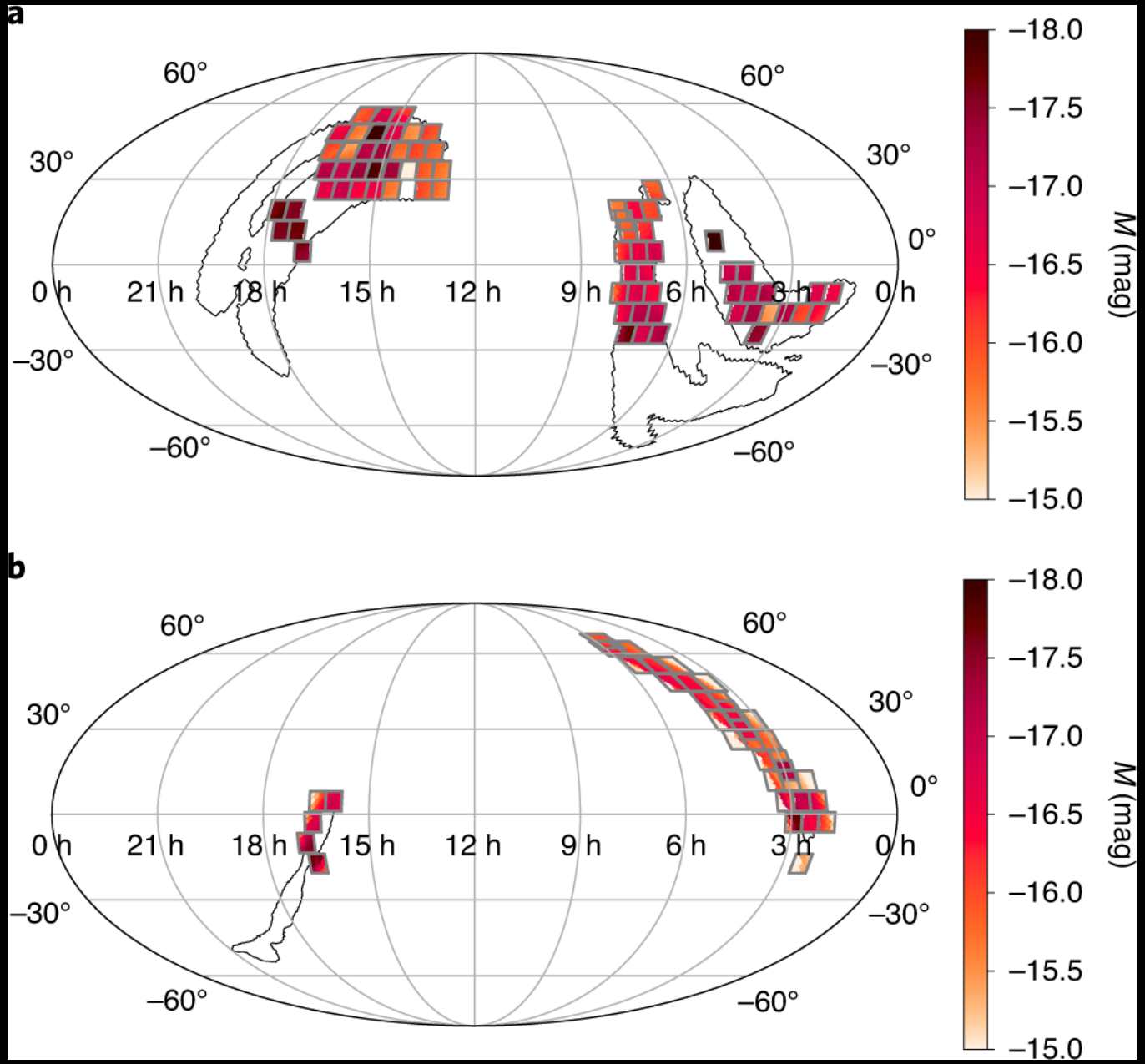


Caltech

中子星與黑洞合併

Neutron Star + Black Hole Merger





Shreya Anand
(Grad 3rd Year)

Anand, Coughlin et al. 2020

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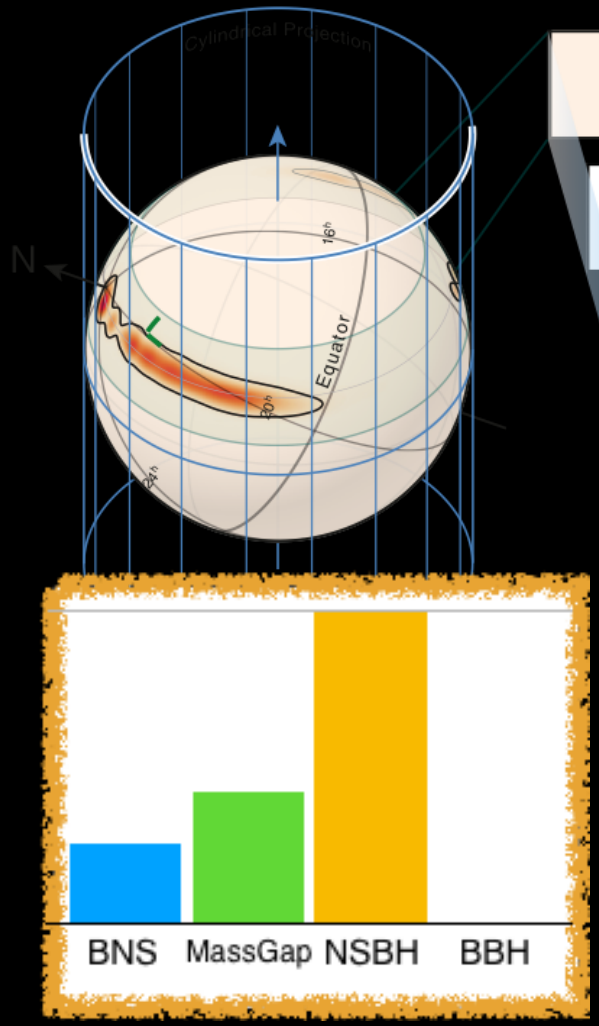
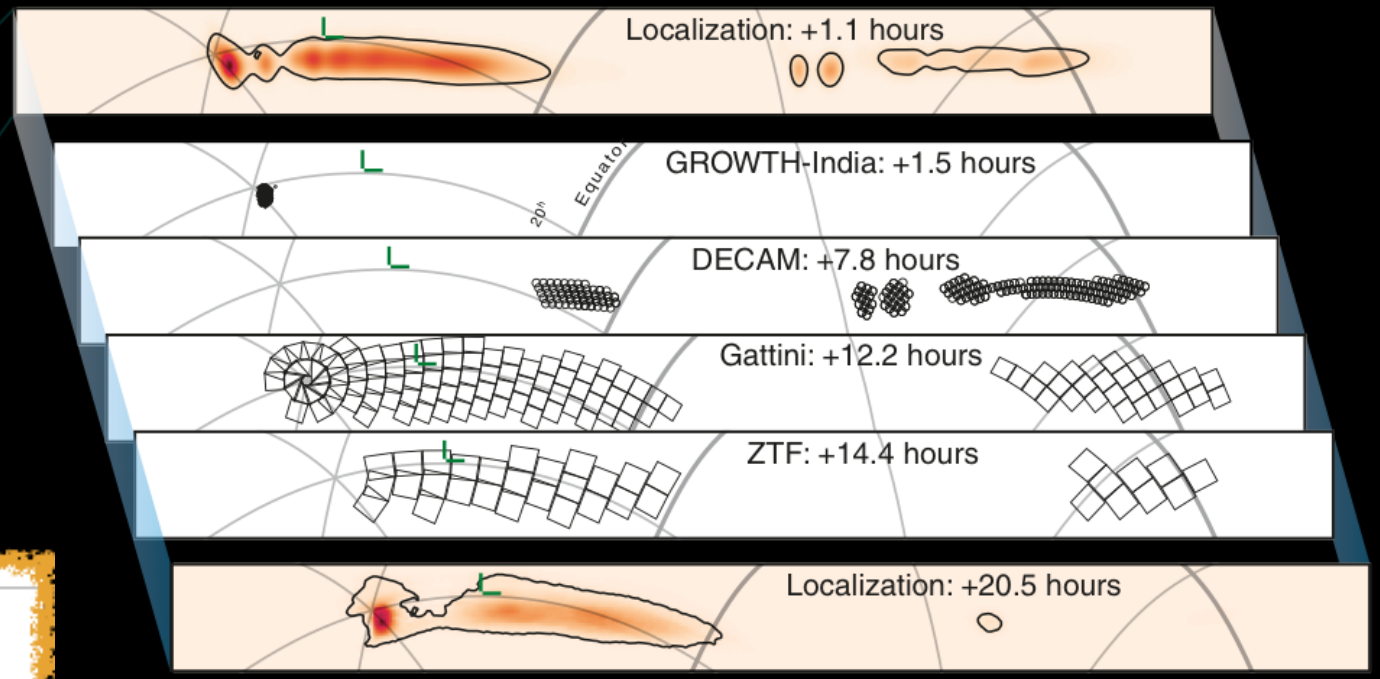
April 26, 2019

Shreya Anand
(Grad 3rd Year)





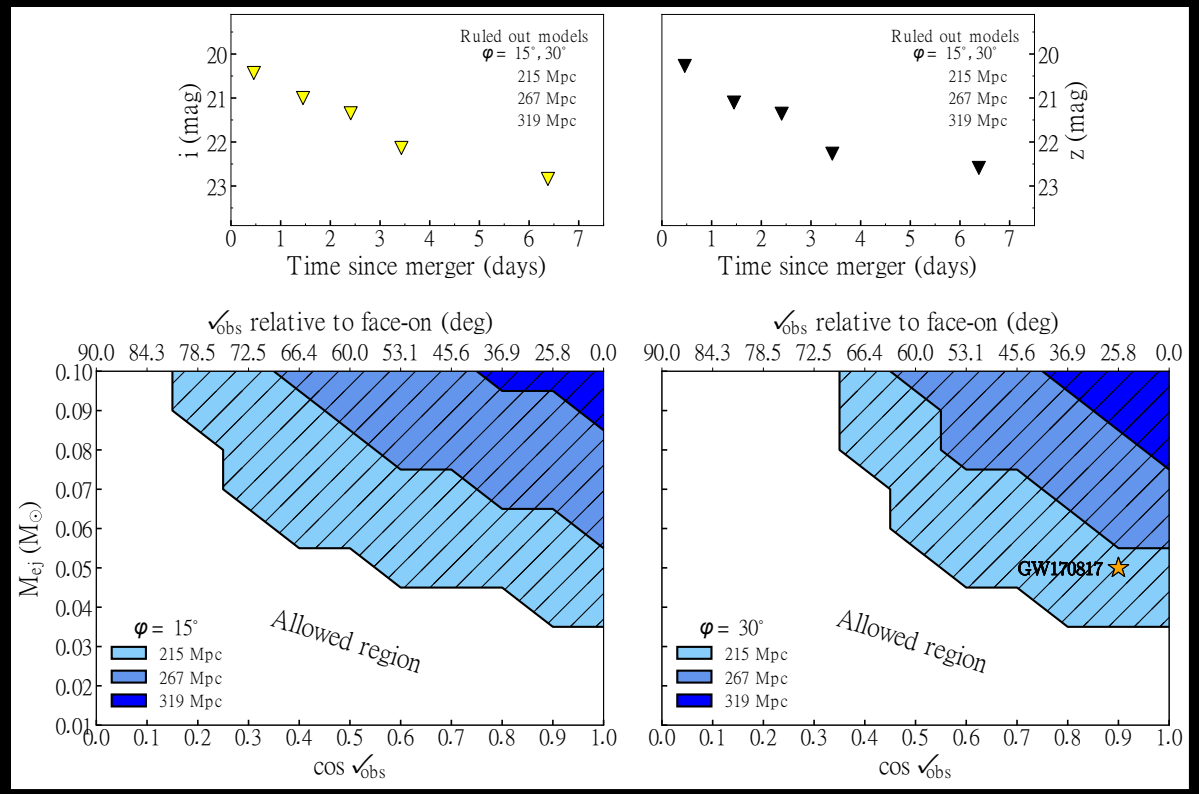
GROWTH Team undertook a co-ordinated search mapping the full area with four discovery engines worldwide.

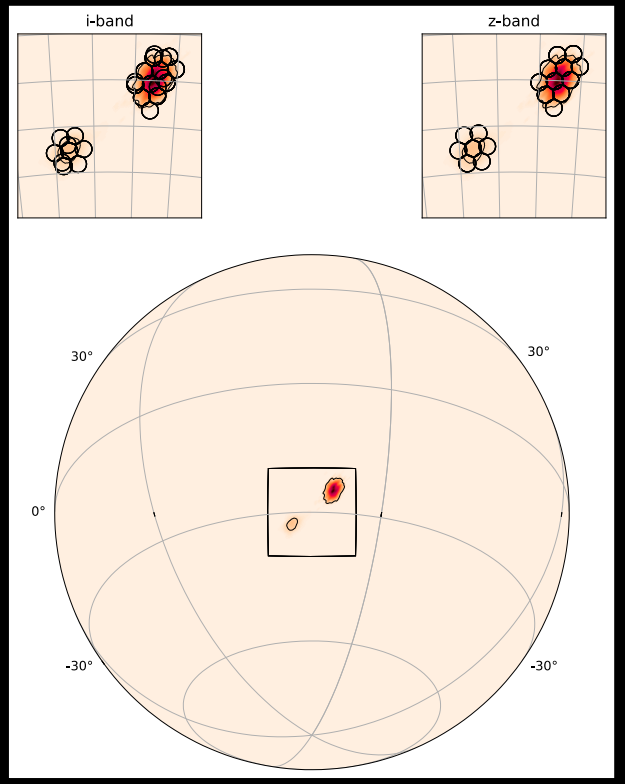
GROWTH 團隊 定位

Caltech

August 14, 2019

Igor Andreoni Danny Goldstein





NSBH	>99%
MassGap	<1%
Terrestrial	0%
BNS	0%
BBH	0%

Andreoni, Goldstein et al. 2019c

Upper limits suggest that either opacity was too high or the mass ratio was too high.
See also Morgan et al. 2020 (independent analysis by DESGW team)

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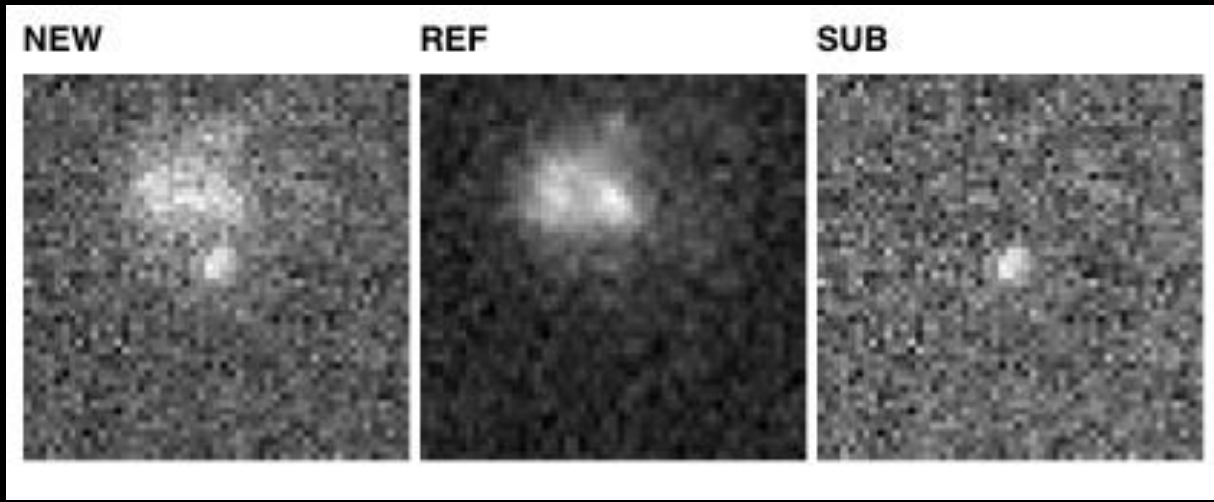
DG19wxnjc

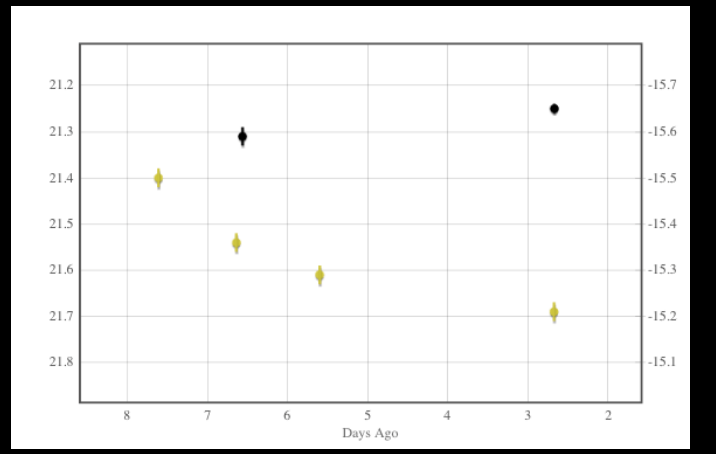
方位、時間、距離、光度、
顏色變化　似乎都對

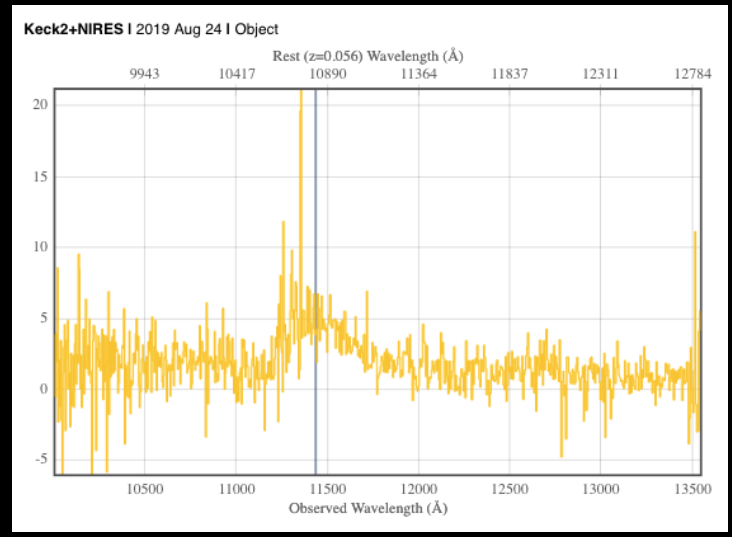


- Right Place
- Right Time
- Right Distance
- Right Luminosity
- Right Color Evolution

BUT… spectrum is truth

但光譜 …





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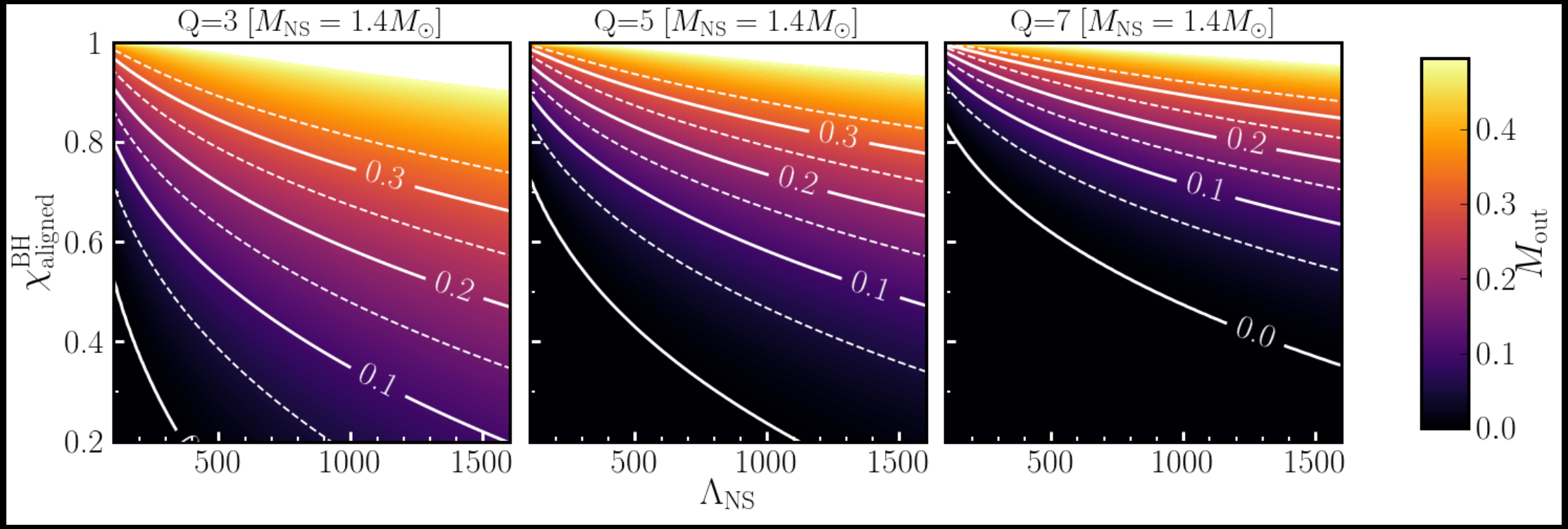
Could the neutron star be swallowed whole by the black hole?

有沒有可能中子星整個被黑洞吞掉了？

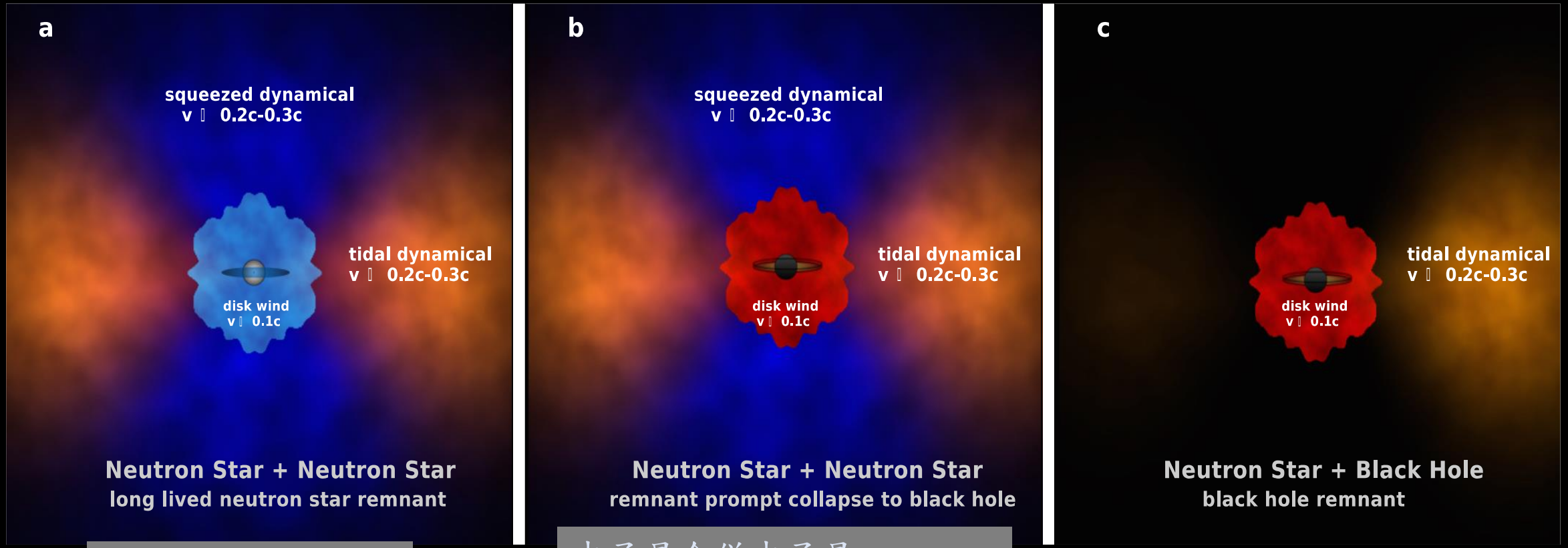


Foucart et al. 2018

The hallmark signature is a red source that rapidly reddens.

有顆紅色天體瞬間變紅了

Infrared: Ubiquitous, Luminous and Long-lived



中子星合併中子星
中子星遺骸長存

中子星合併中子星
中子星遺骸快速塌縮成黑洞

Kasen et al. 2017

中子星合併黑洞
成為黑洞遺骸

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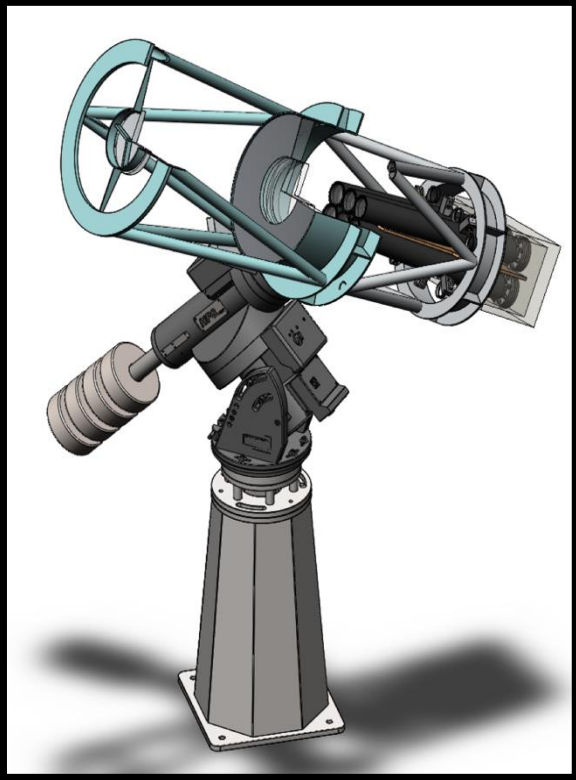
Opening up Our Dynamic Infrared Sky

Palomar Gattini IR, 25 deg^2, 30cm

WINTER, 1.1 deg^2, 100cm @ Palomar



DREAMS, 3.7 deg^2, 50cm @SSO

研究紅外動態宇宙的工具

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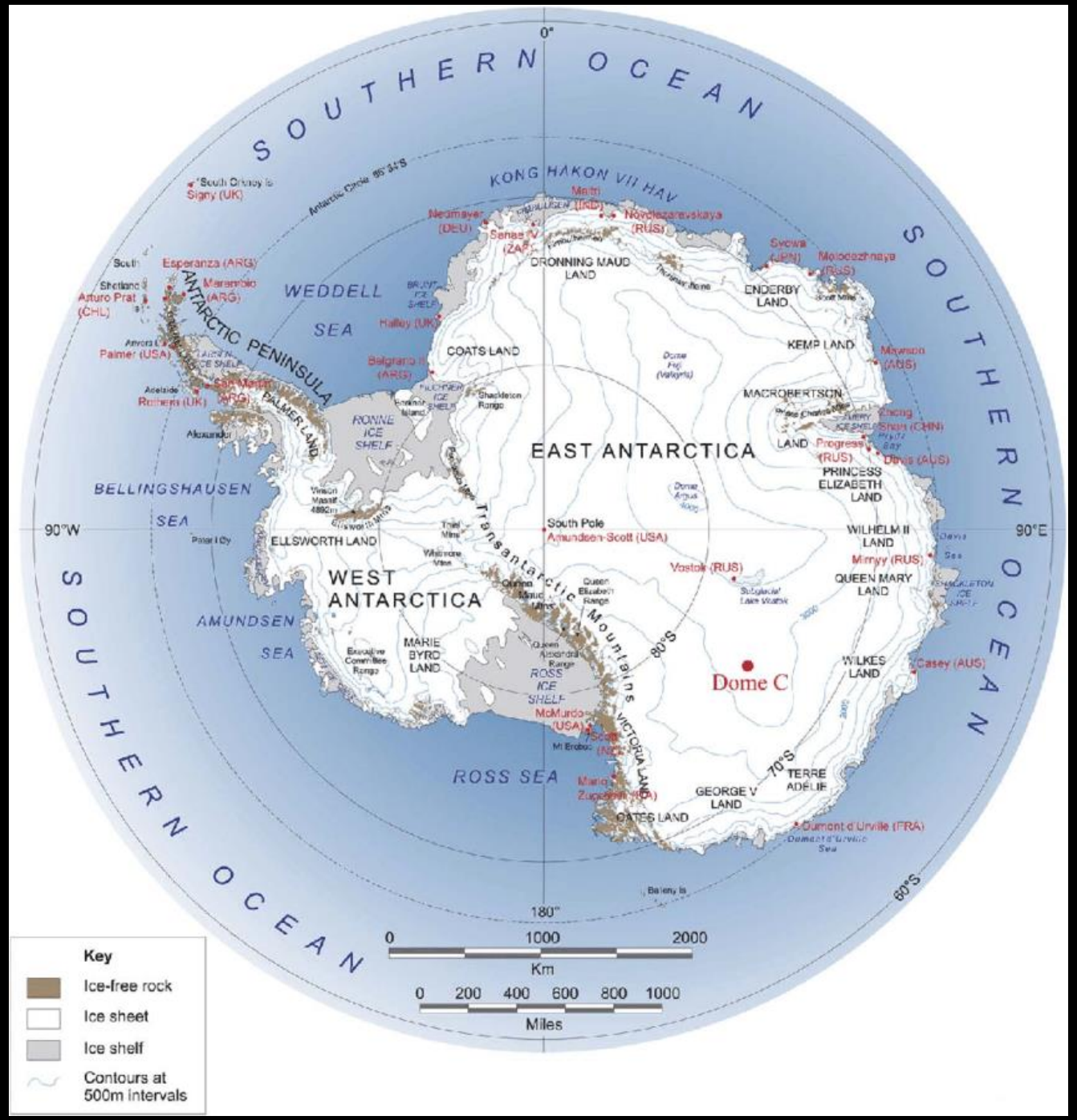
Looking ahead

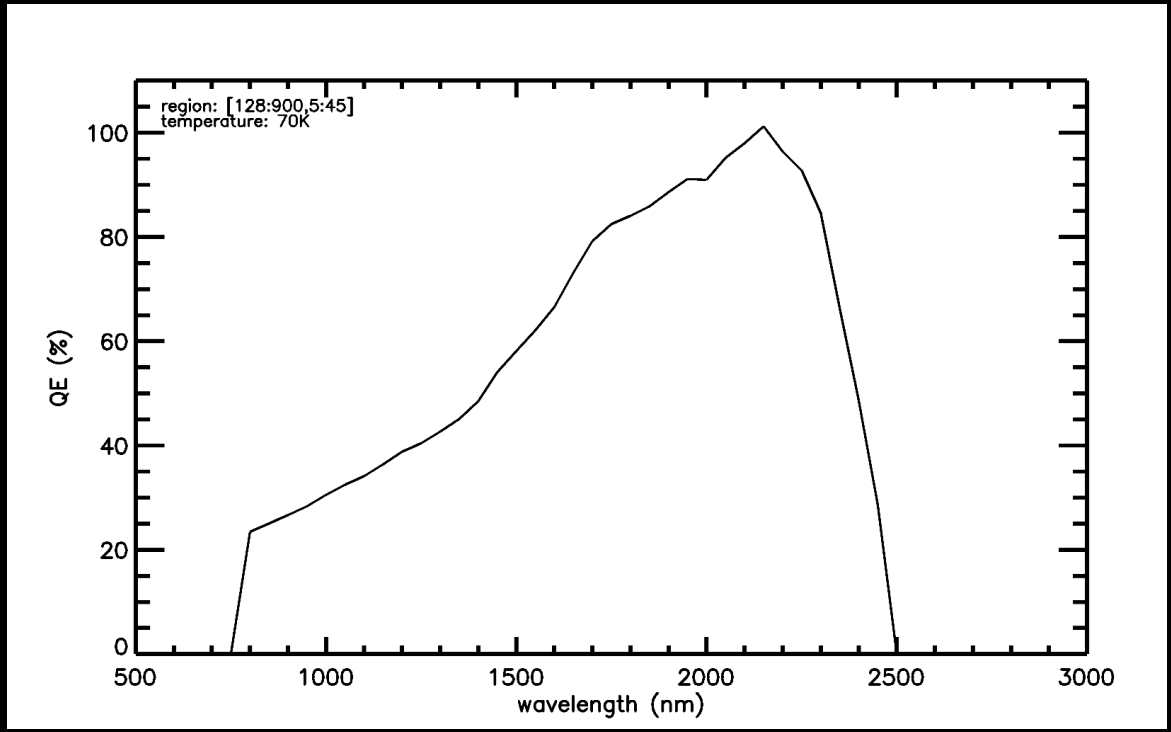
下一站：南極


SOUTHERN OCEAN
KONG HAKON VII HAV
WEDDELL SEA
ANTARCTIC PENINSULA
PALMER LAND
RONNE ICE SHELF
BELLINGSHAUSEN SEA
AMUNDSEN SEA
ROSS SEA
ROSS ICE SHELF
EAST ANTARCTICA
WEST ANTARCTICA
DRONNING MAUD LAND
ENDERBY LAND
KEMP LAND
MACROBERTSON LAND
PRINCESS ELIZABETH LAND
WILHELM II LAND
QUEEN MARY LAND
WILKES LAND
TERRE ADELIE
GEORGE V LAND
OATES LAND
COATS LAND
ELLSWORTH LAND
MARIE BYRD LAND
Transantarctic Mountains
VICTORIA LAND
South Pole
Amundsen-Scott (USA)
Vostok (RUS)
Dome C
Halley (UK)
Belgrano II (ARG)
Esperanza (ARG)
Marambio (ARG)
Palmer (USA)
Rothera (UK)
Neumayer (DEU)
Sanae IV (ZAF)
Novolazarevskaya (RUS)
Syowa (JPN)
Molodezhnaya (RUS)
Mawson (AUS)
Progress (RUS)
Davis (AUS)
Mirnyy (RUS)
Casey (AUS)
McMurdo (USA)
Scott (NZL)
Dumont d'Urville (FRA)
90°W
90°E
180°
60°S
70°S
80°S
0
1000
2000
Km
0
200
400
600
800
1000
Miles
Key
Ice-free rock
Ice sheet
Ice shelf
Contours at 500m intervals

Two Technology Innovations

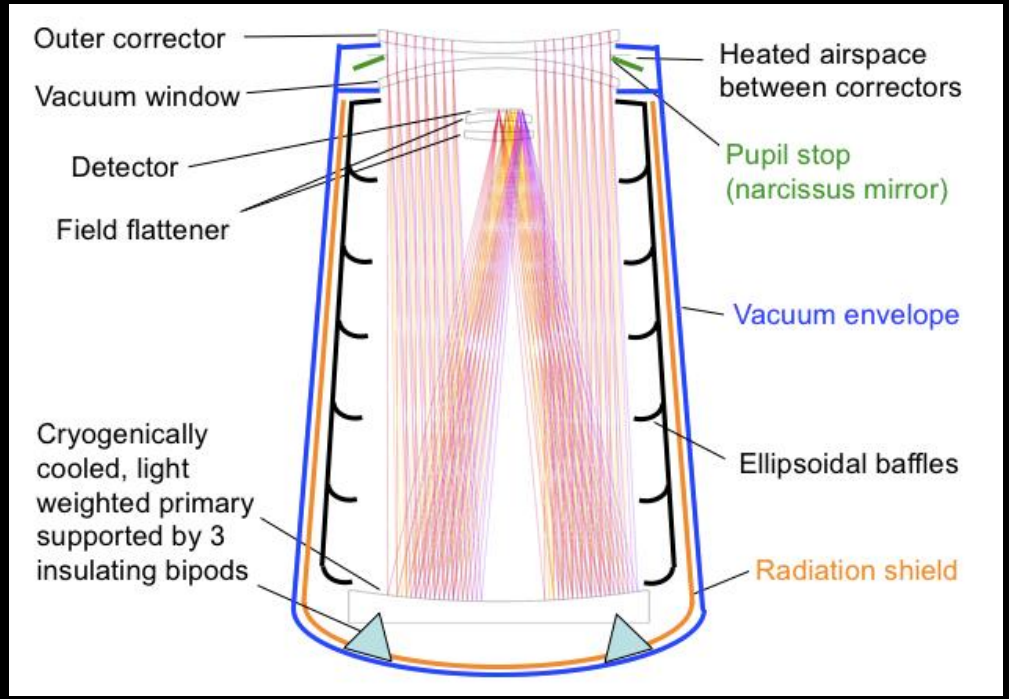
Don Figer (RIT)

Roger Smith



Challenge: Affordable Detectors
Solution: Molecular Beam Epitaxy on Silicon

挑戰一：價格



Challenge: Thermal Noise
Solution: Fully Cryogenic Telescope System

挑戰二：熱雜訊

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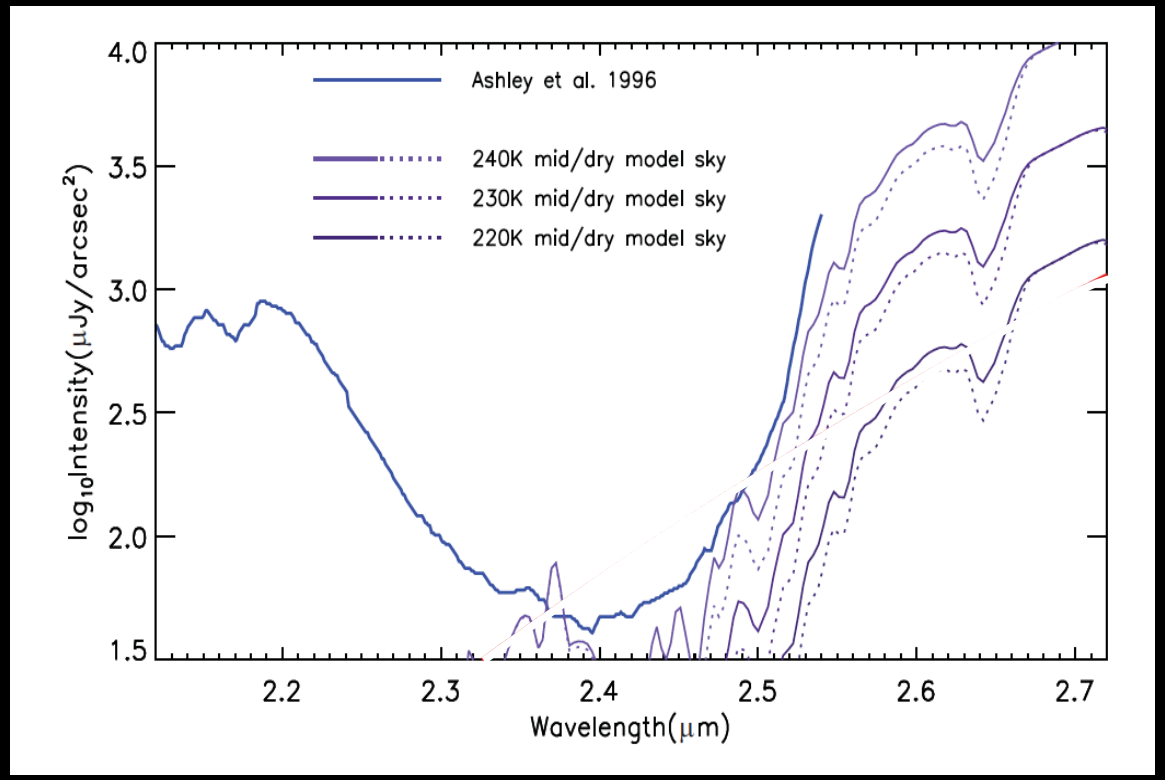
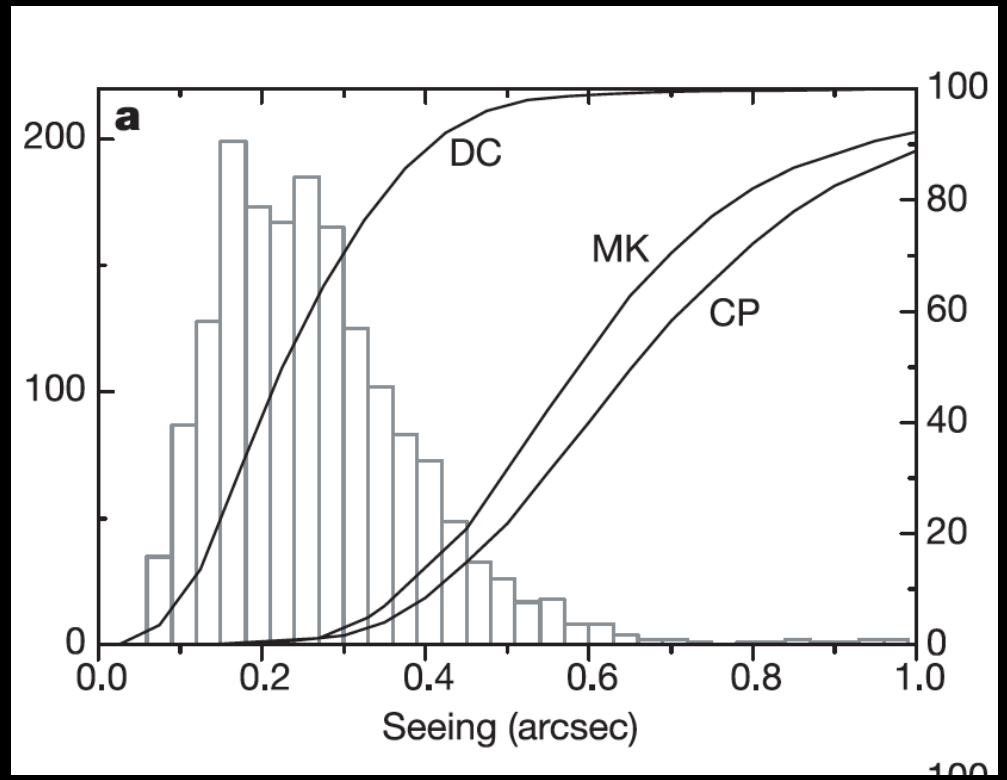
Why Antarctica?

- Sky is 40x Darker 天空暗得多



- Seeing is fantastic 影像清晰



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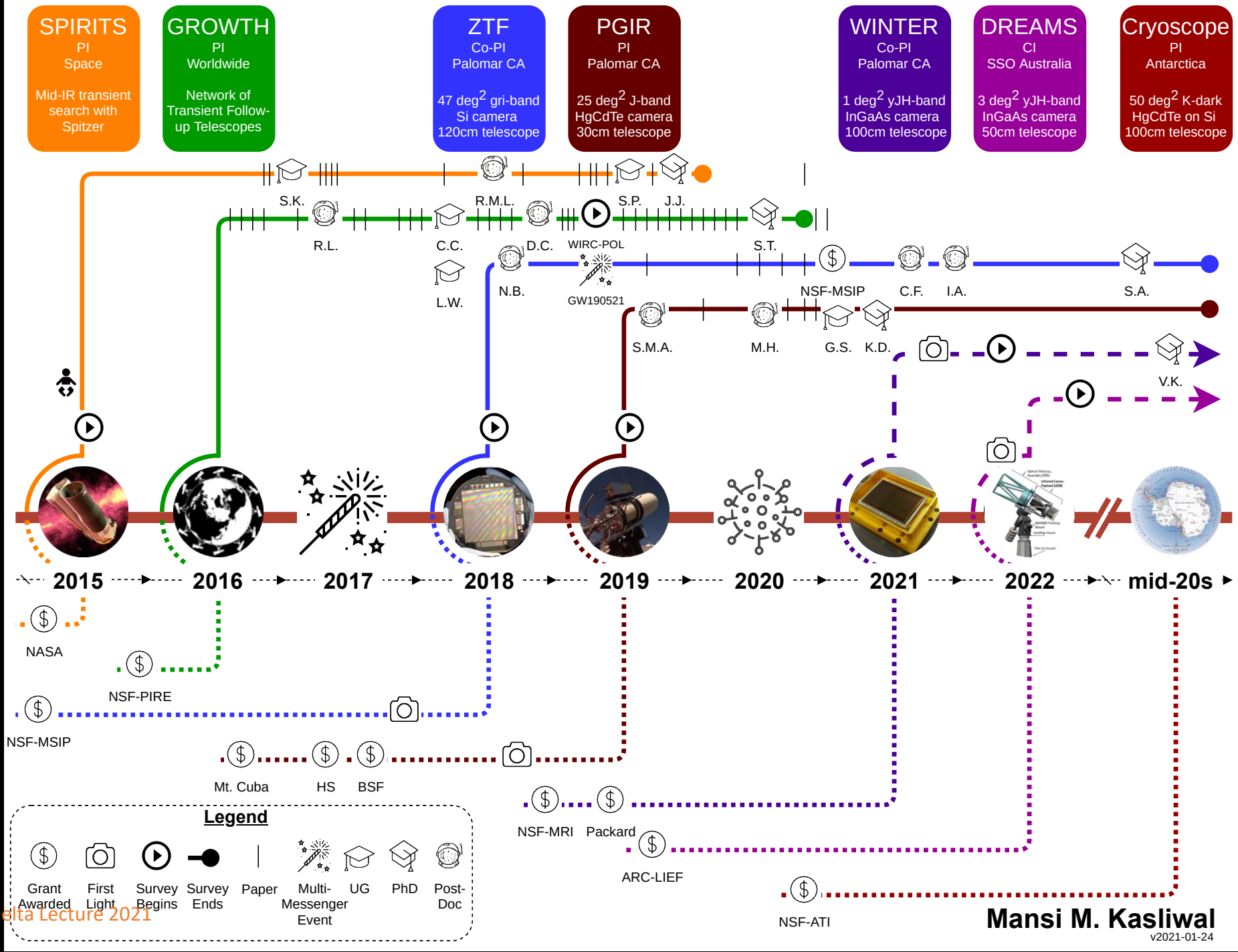
SPIRITS
PI
Space
Mid-IR transient search with Spitzer
GROWTH
PI
Worldwide
Network of Transient Follow-up Telescopes
ZTF
Co-PI
Palomar CA
47 deg2 gri-band Si camera 120cm telescope
PGIR
PI
Palomar CA
25 deg2 J-band HgCdTe camera 30cm telescope
WINTER
Co-PI
Palomar CA
1 deg2 yJH-band InGaAs camera 100cm telescope
DREAMS
CI
SSO Australia
3 deg2 yJH-band InGaAs camera 50cm telescope
Cryoscope
PI
Antarctica
50 deg2 K-dark HgCdTe on Si 100cm telescope
S.K.
R.L.
R.M.L.
C.C.
L.W.
D.C.
N.B.
WIRC-POL
GW190521
S.P.
J.J.
S.T.
NSF-MSIP
C.F.
I.A.
S.A.
S.M.A.
M.H.
G.S.
K.D.
V.K.
2015
2016
2017
2018
2019
2020
2021
2022
mid-20s
NASA
NSF-PIRE
NSF-MSIP
Mt. Cuba
HS
BSF
NSF-MRI
Packard
ARC-LIEF
NSF-ATI
Legend
Grant Awarded
First Light
Survey Begins
Survey Ends
Paper
Multi-Messenger Event
UG
PhD
Post-Doc
Mansi M. Kasliwal
v2021-01-24

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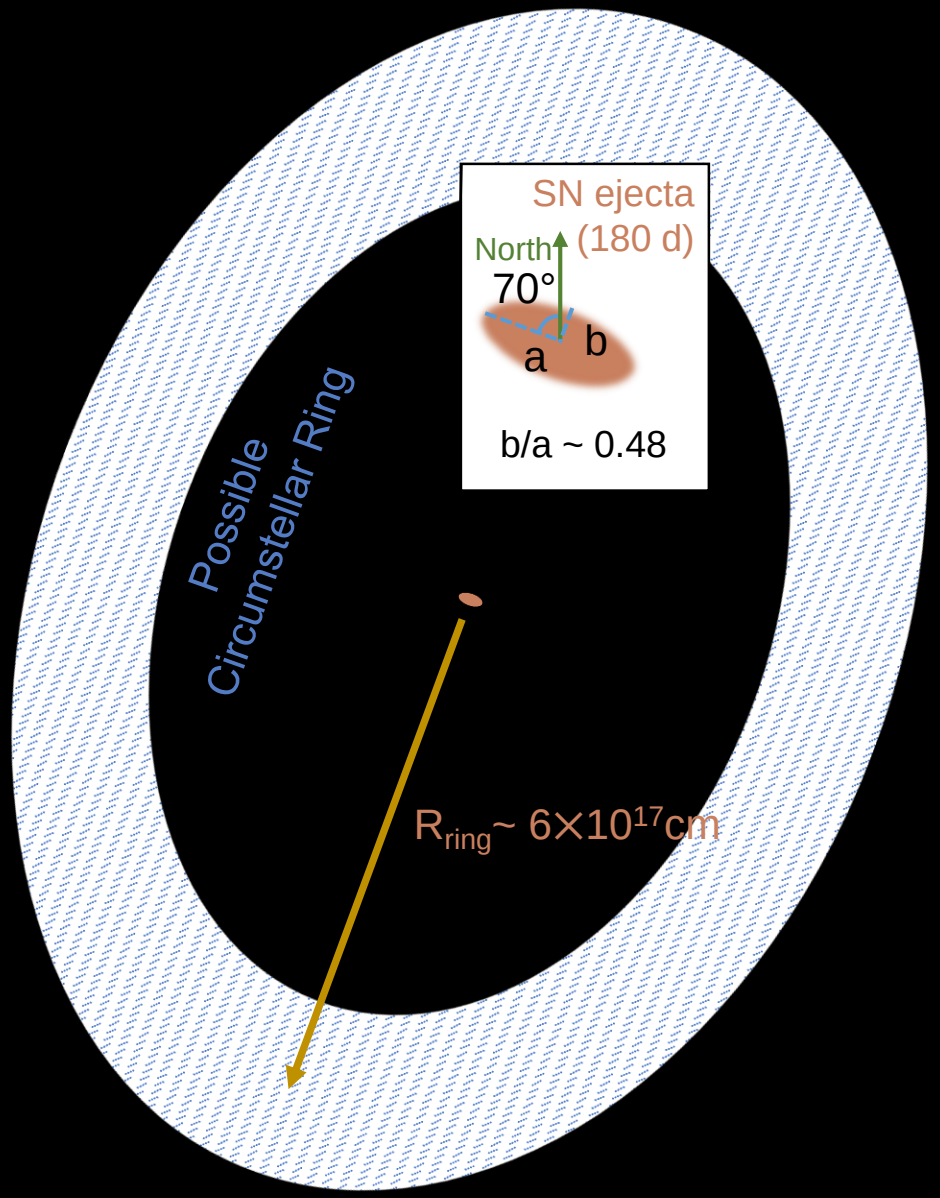
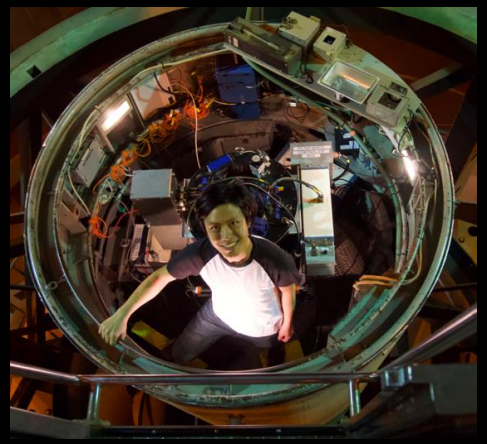
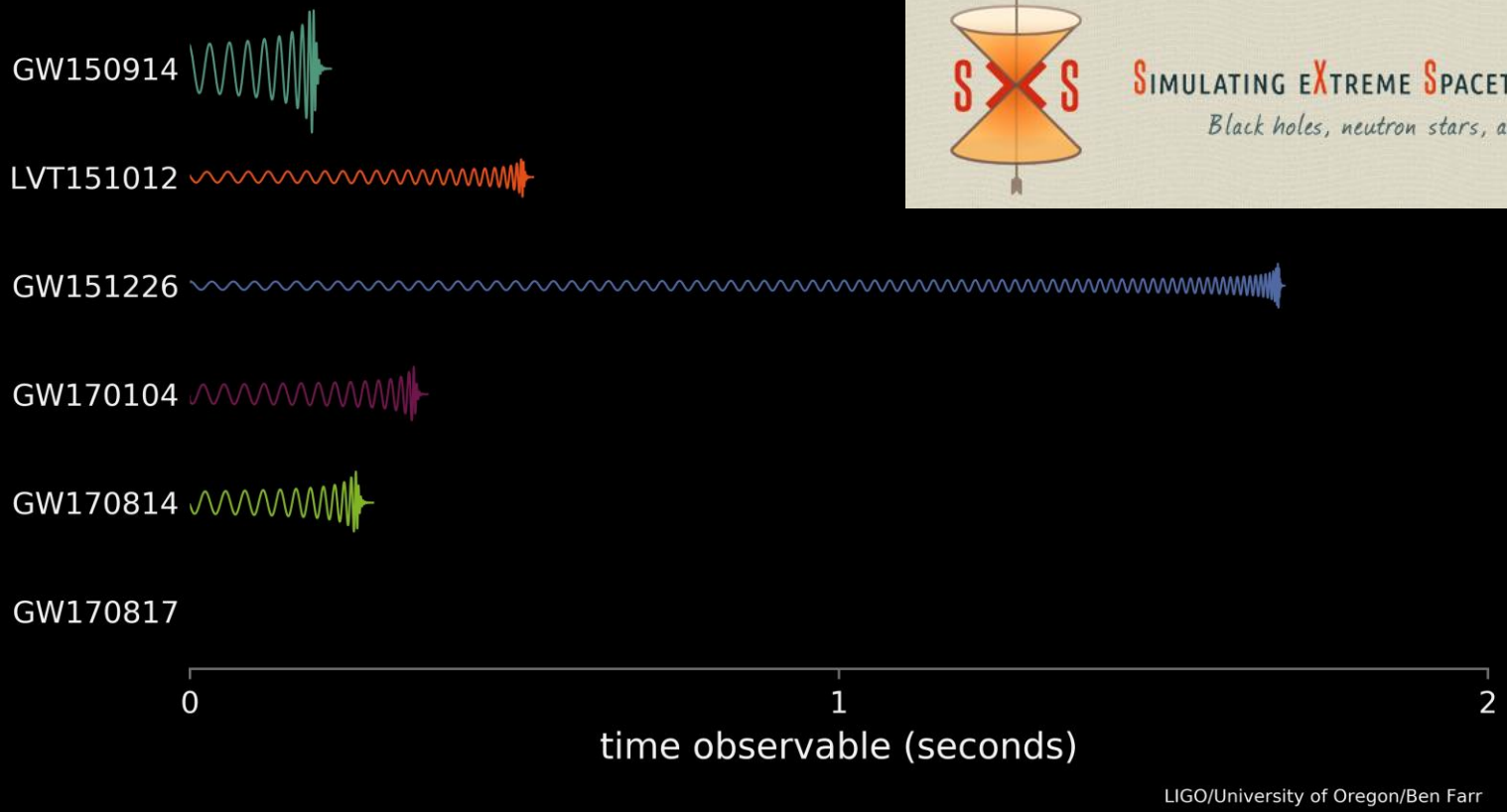
Namaskar



Tinyanont et al. 2021, Nature Astronomy



WIRC+Pol near-infrared spectropolarimeter at Palomar Observatory



The longest (~ 100 s), loudest (SNR ~ 32), closest (40 Mpc) signal we've ever observed!