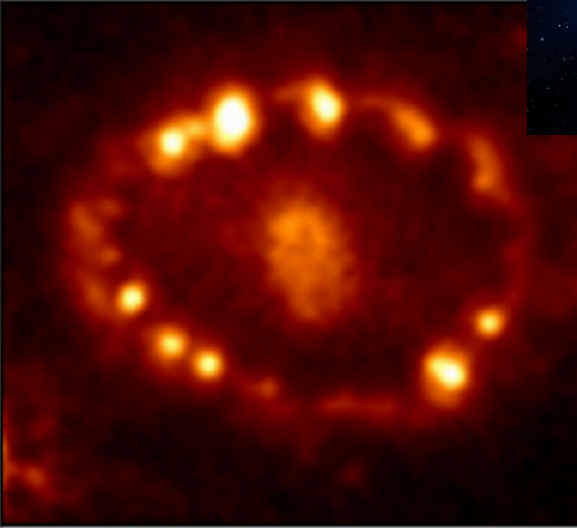
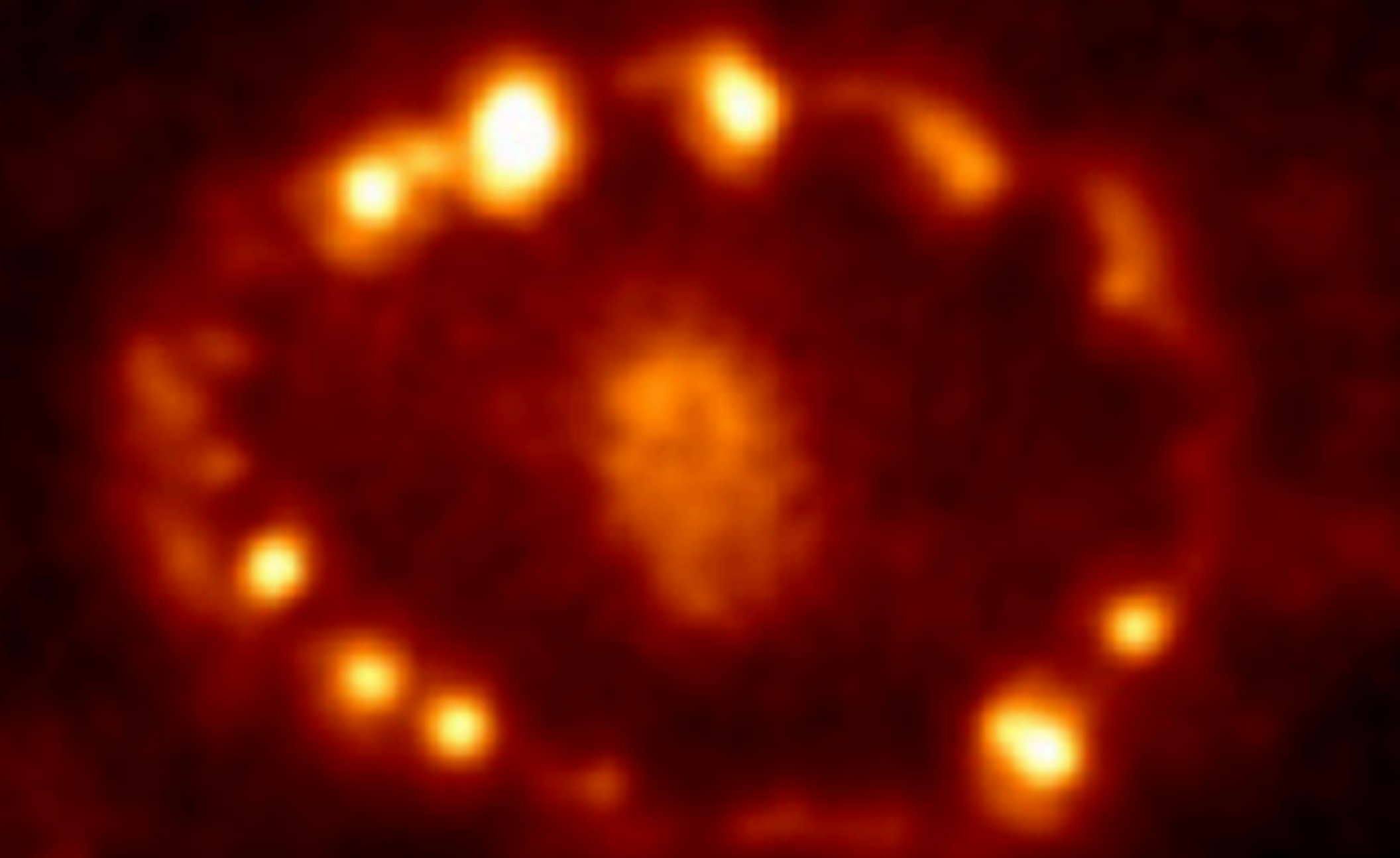


Time-domain data in Astronomy

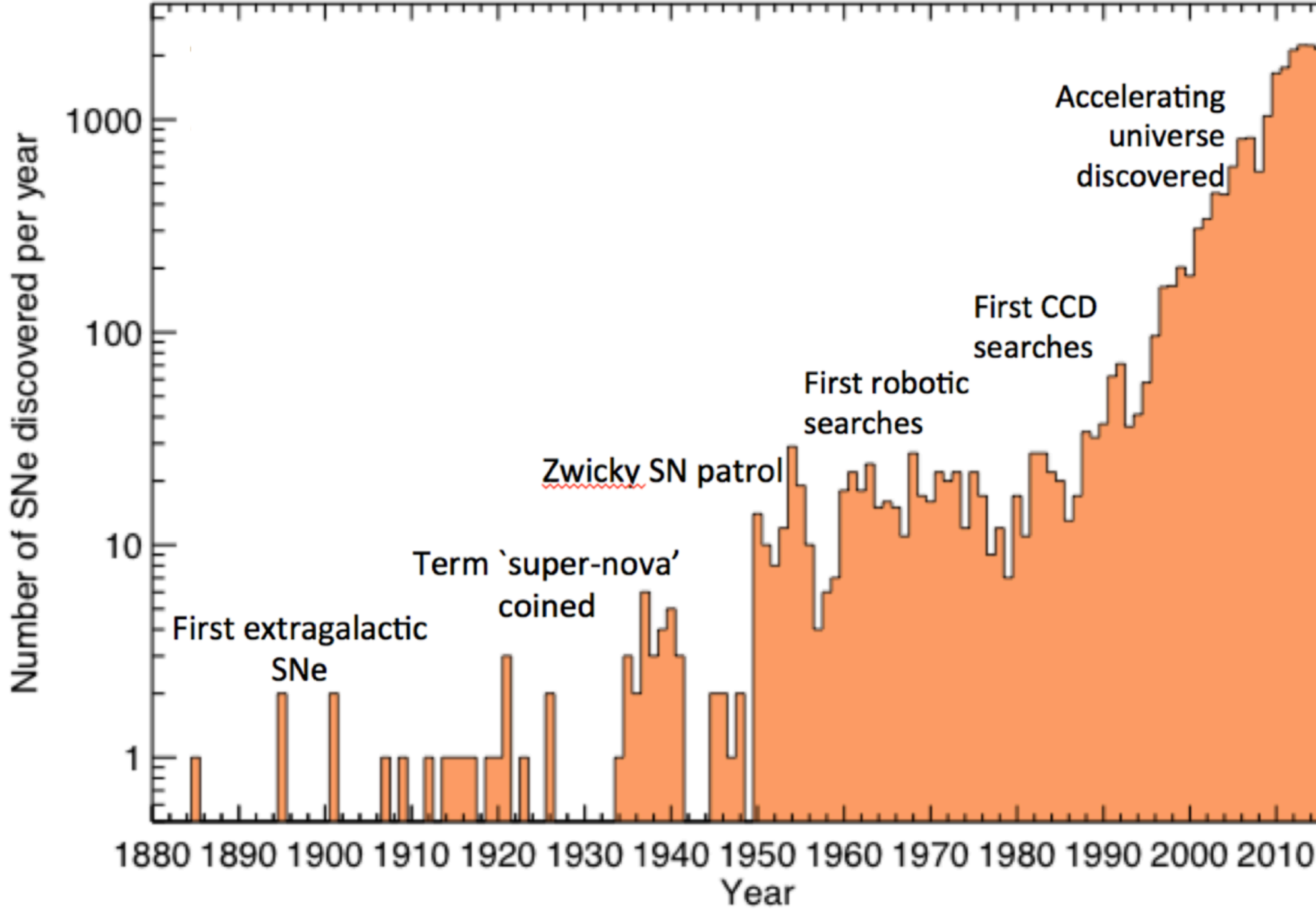
Seppo Mattila, *University of Turku*

<https://sites.utu.fi/sne/>

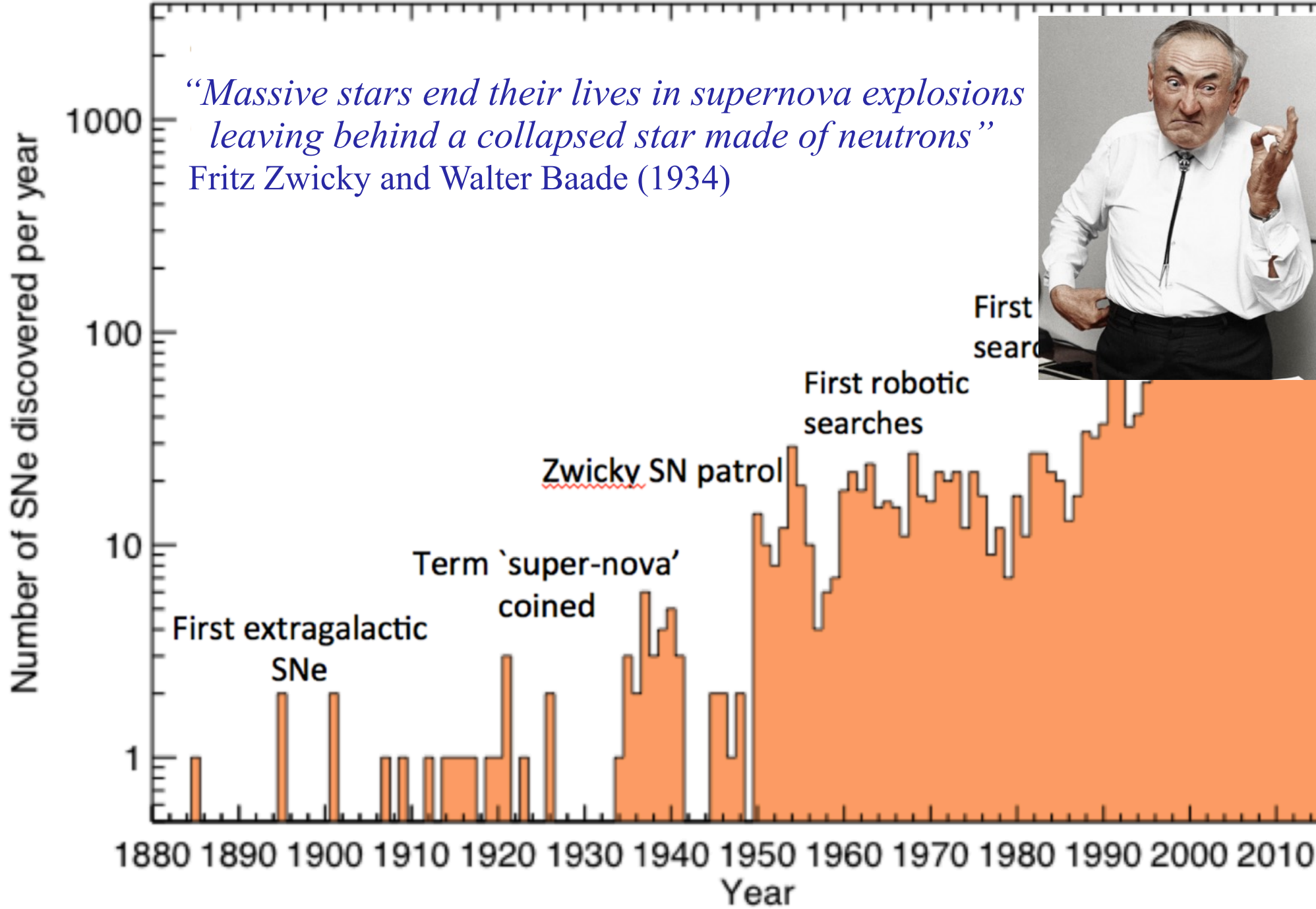


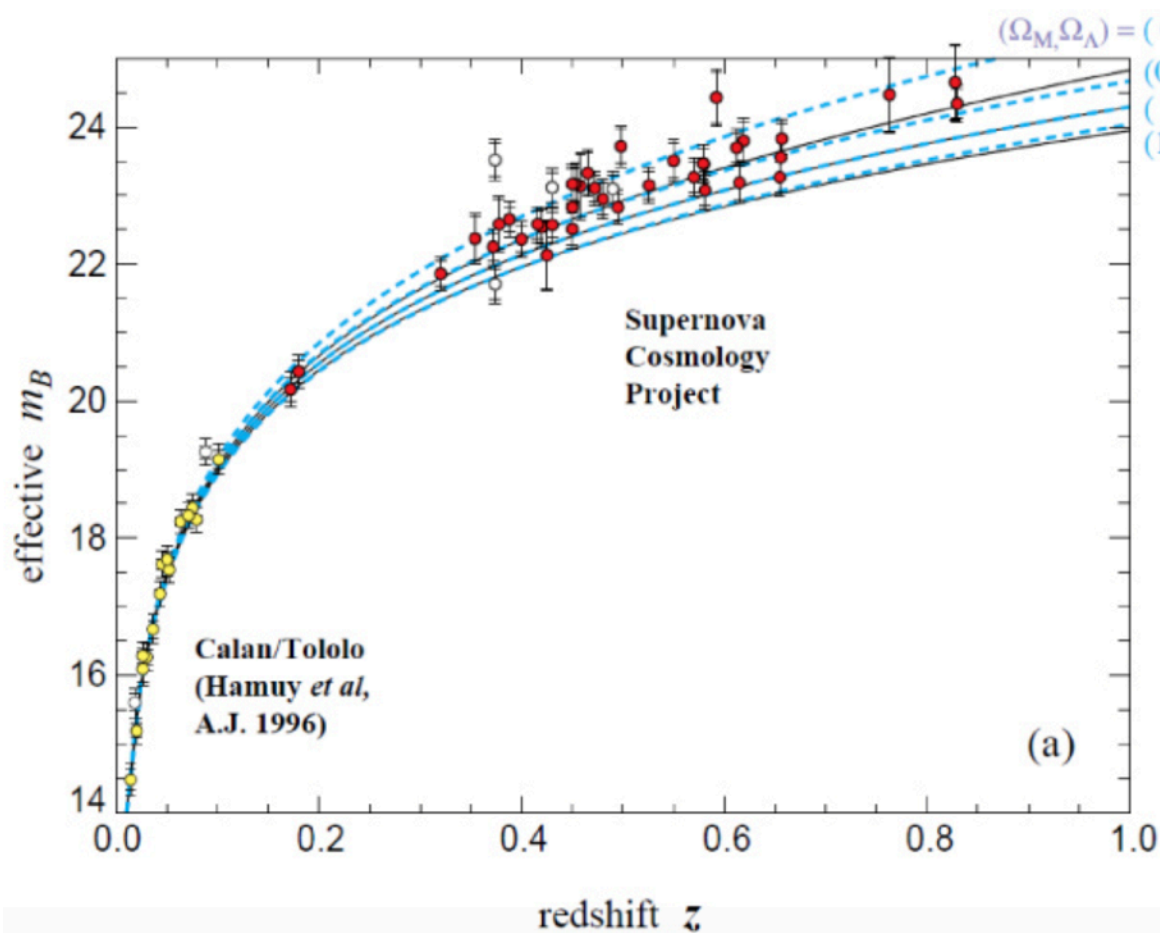


SN 1987A in the Large Magellanic Cloud at 50 kpc ($\sim 163\,000$ ly) distance

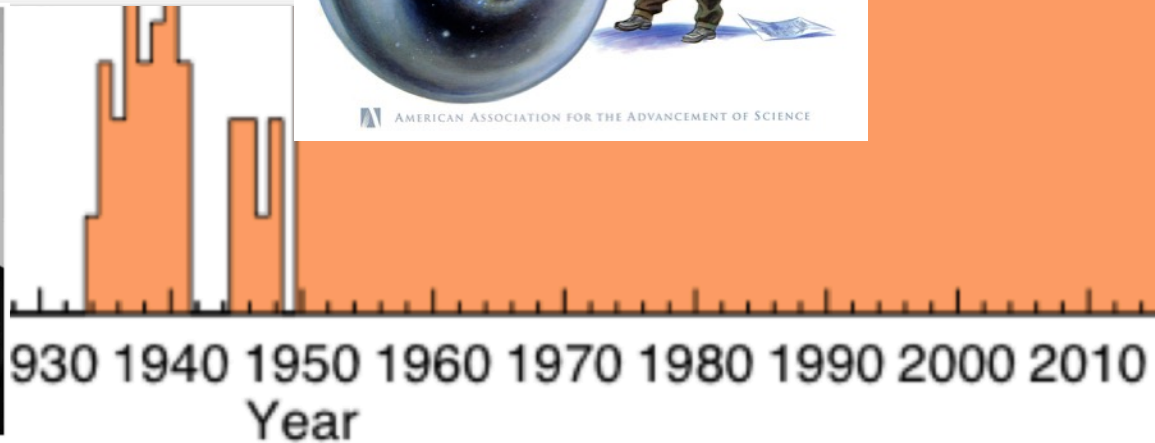
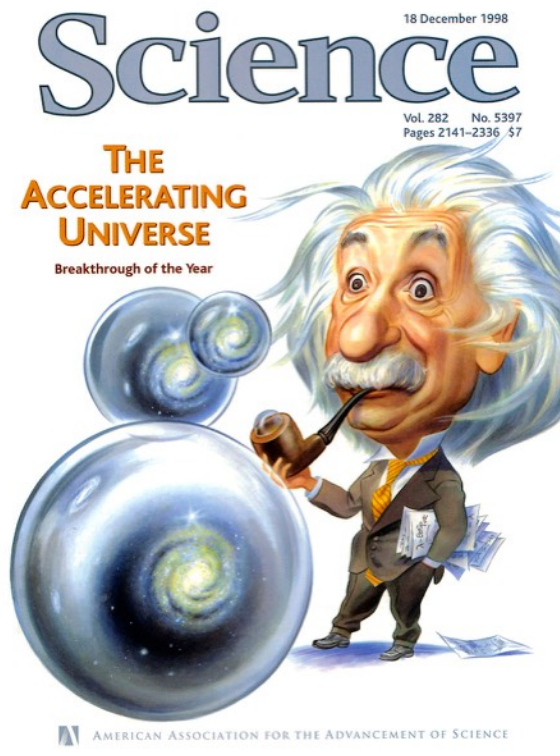


“Massive stars end their lives in supernova explosions leaving behind a collapsed star made of neutrons”
Fritz Zwicky and Walter Baade (1934)





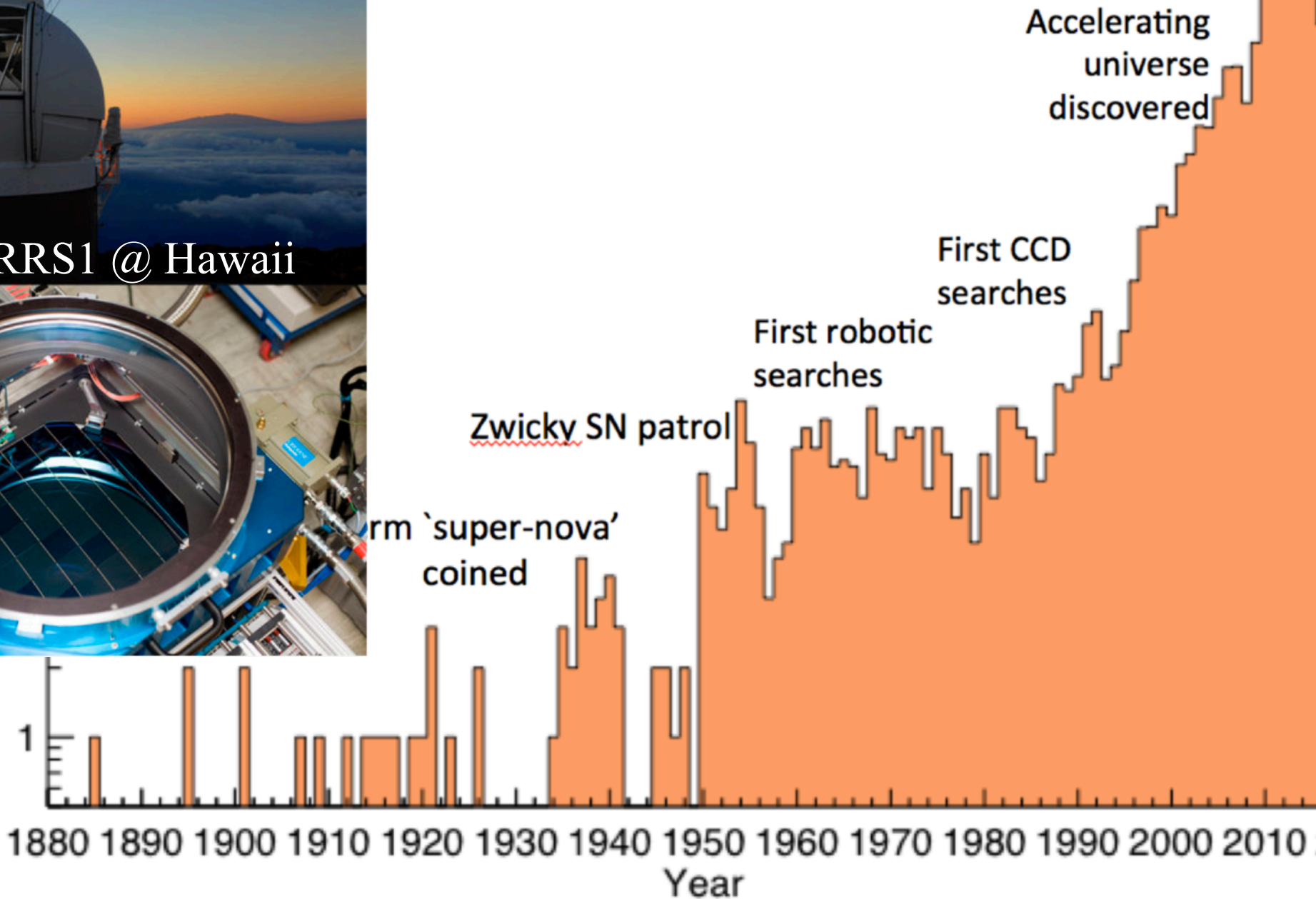
Accelerating universe discovered





Pan-STARRS1 @ Hawaii

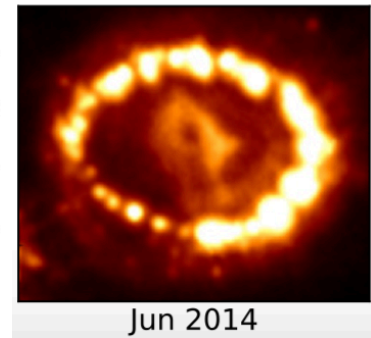
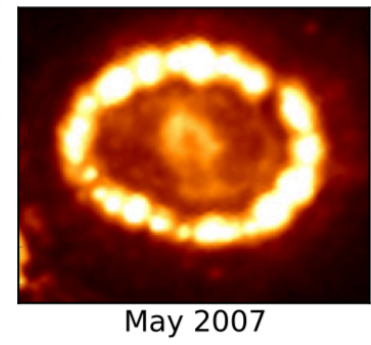
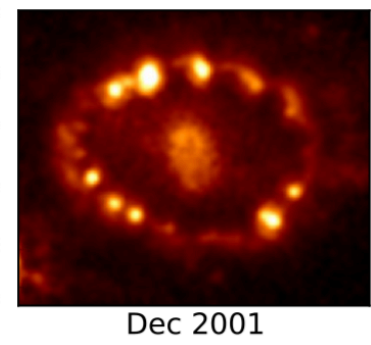
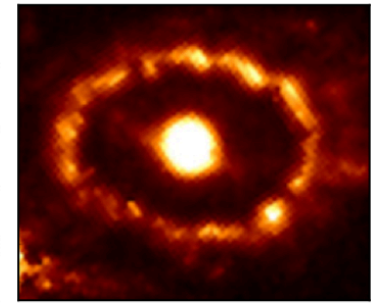
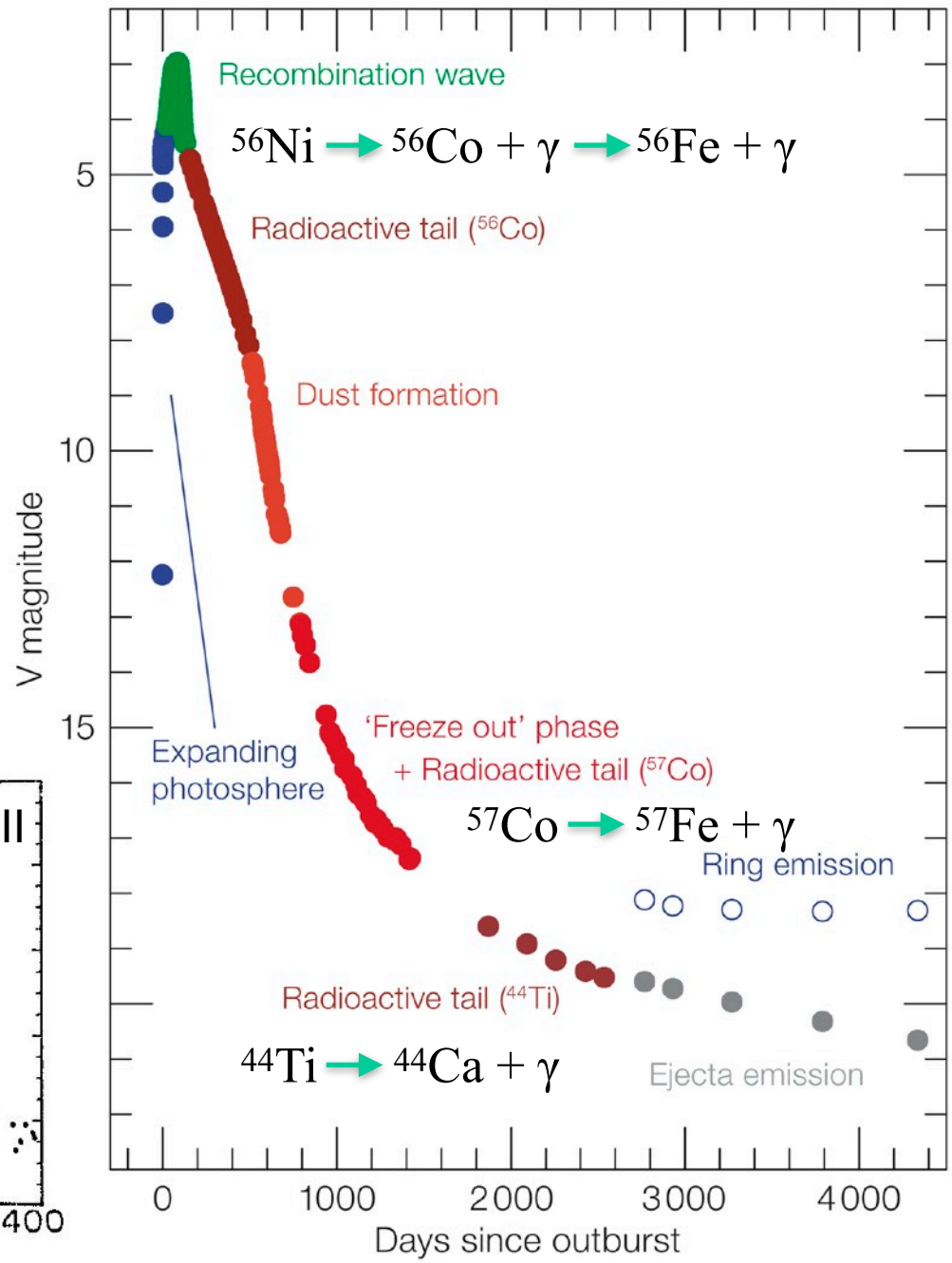
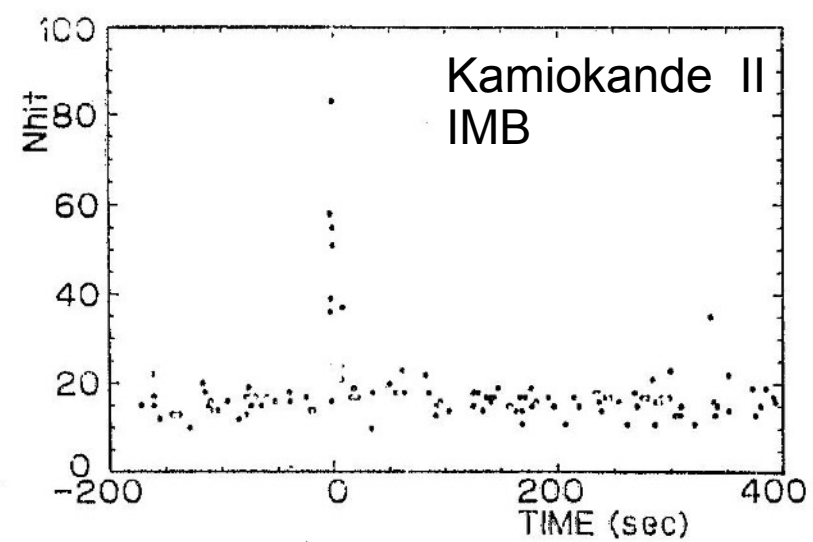
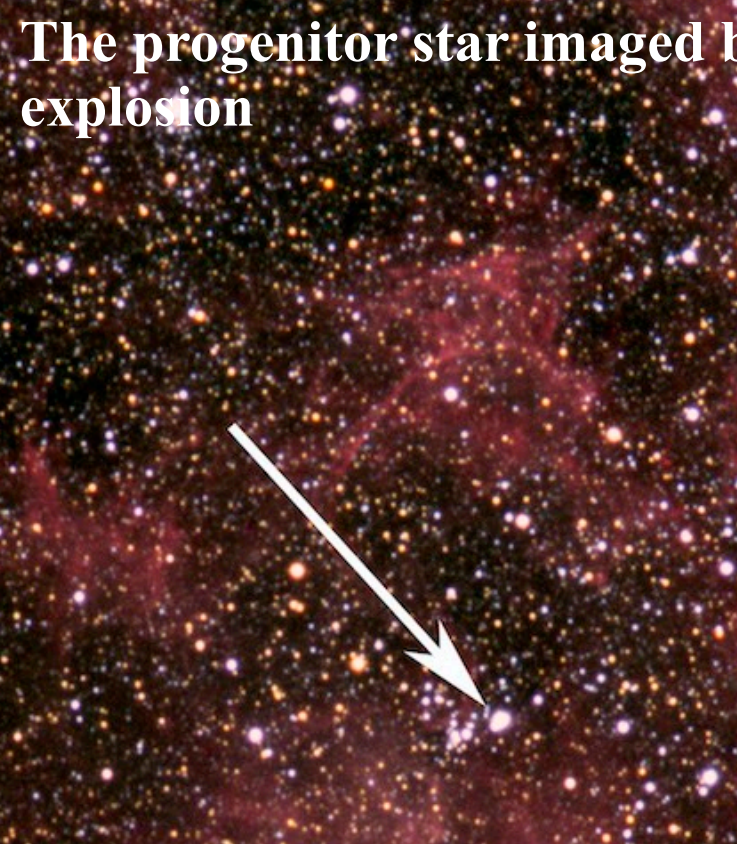
The era of very field field transient surveys

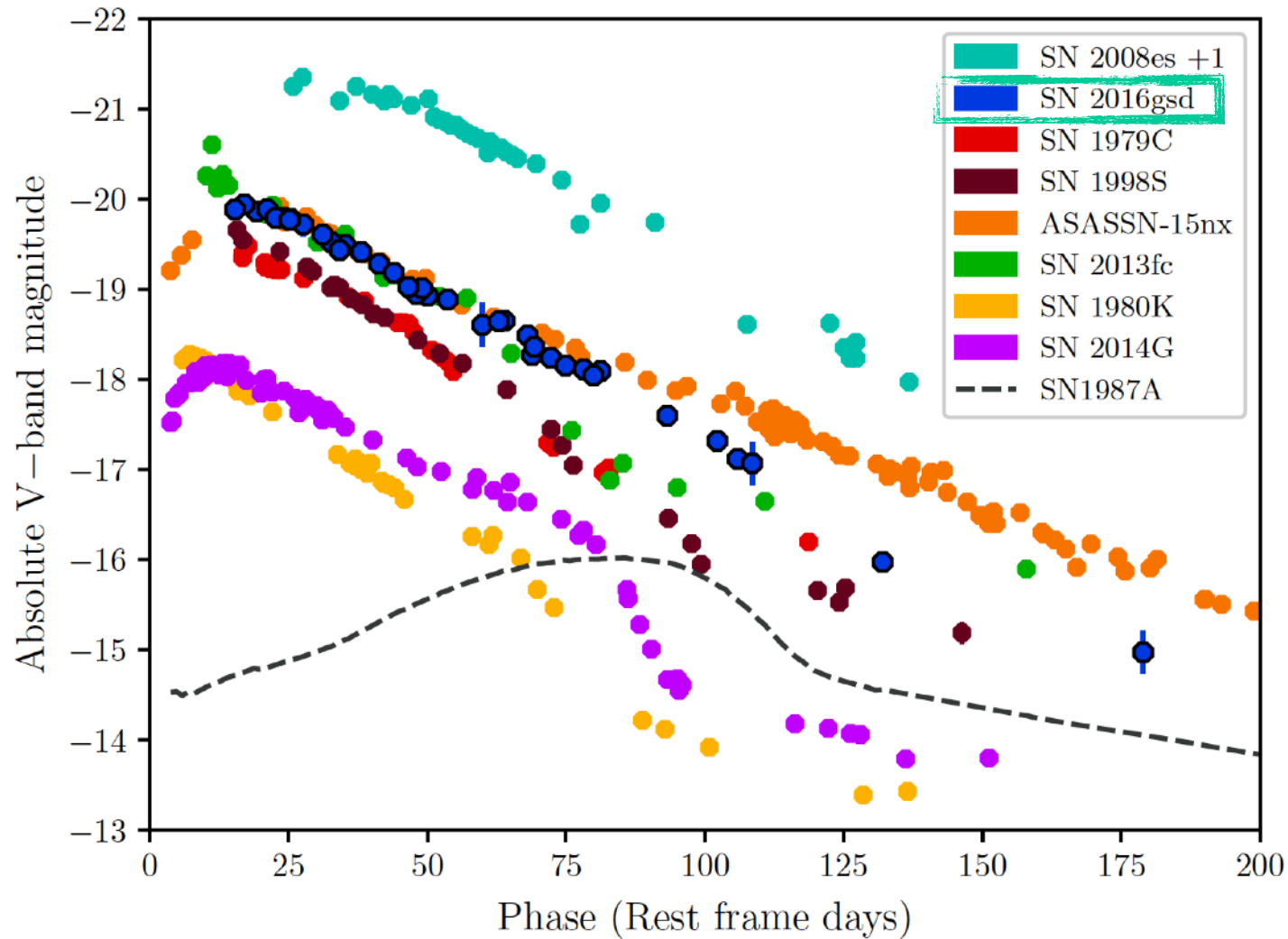


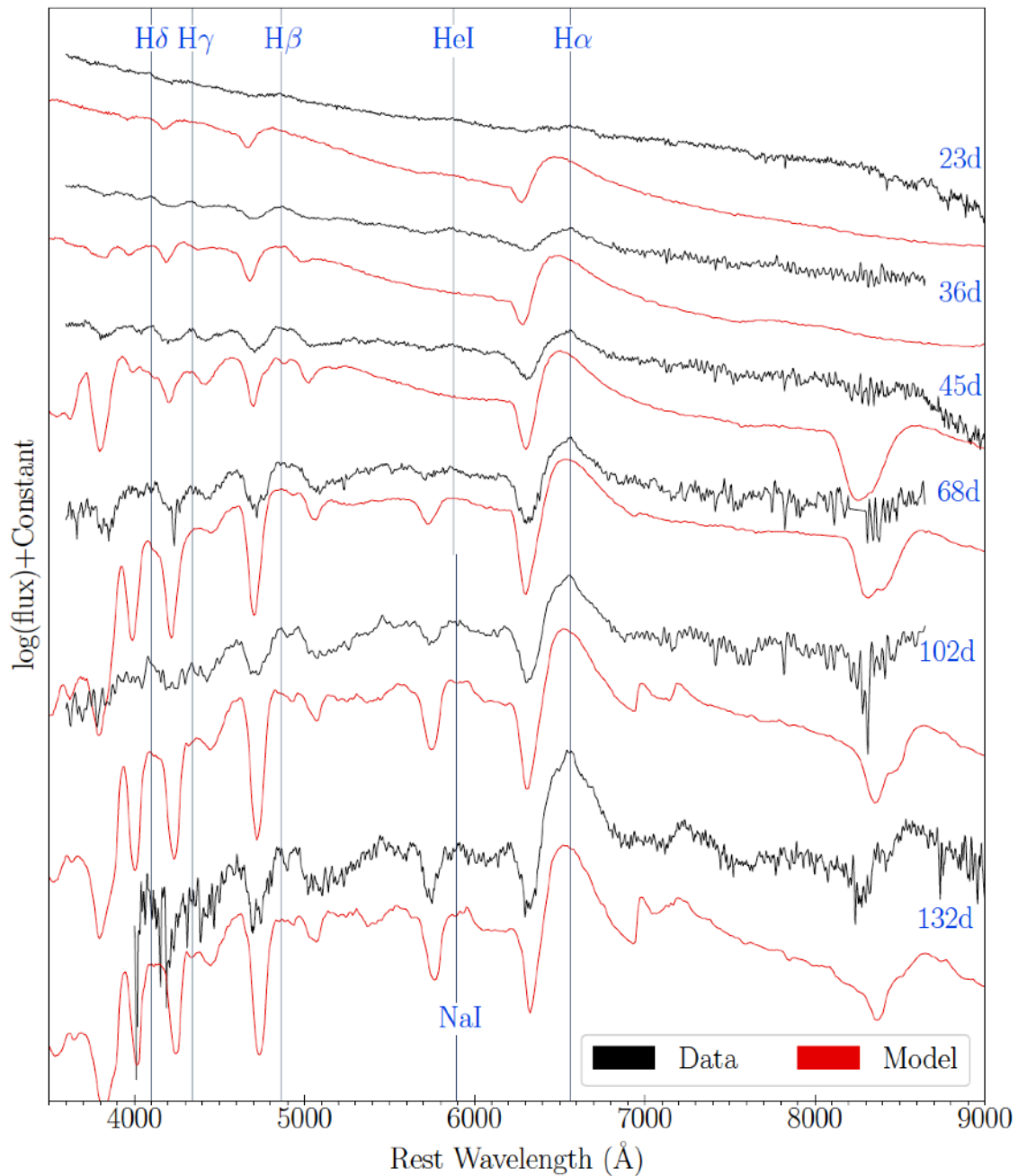
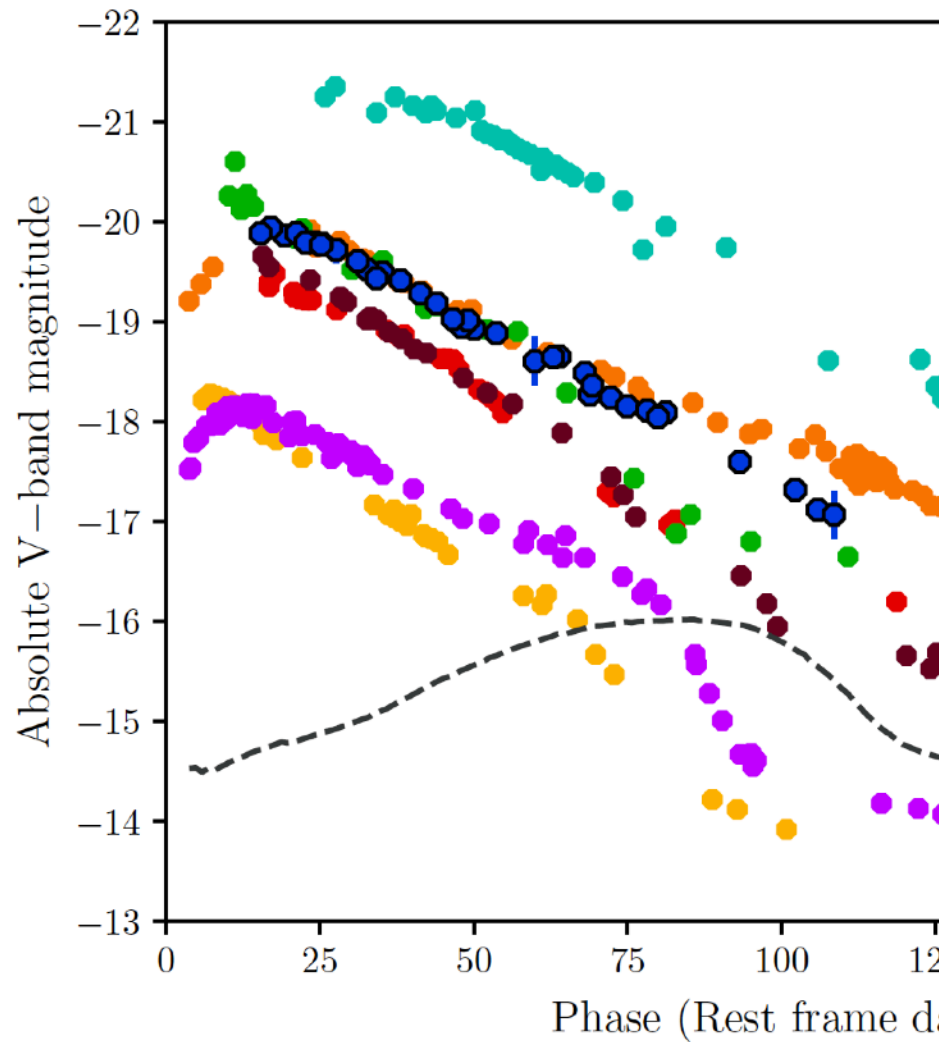


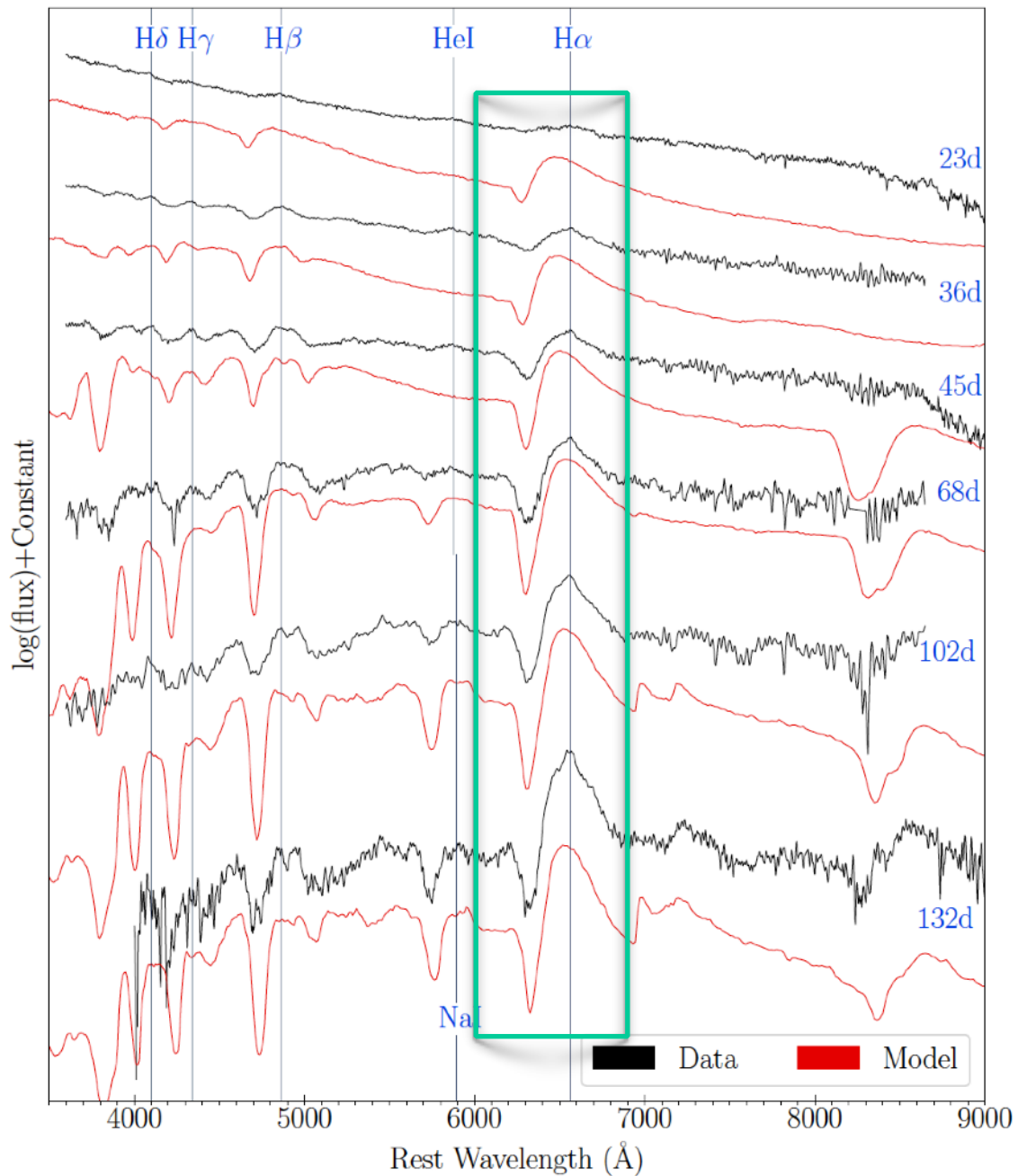
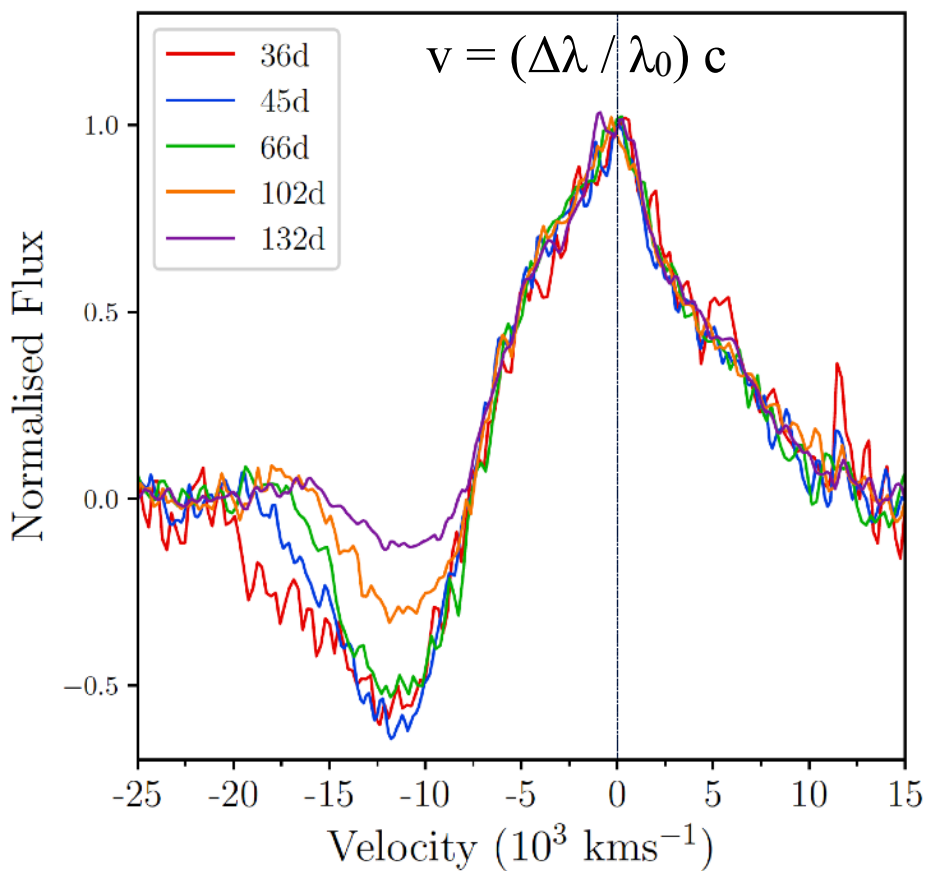
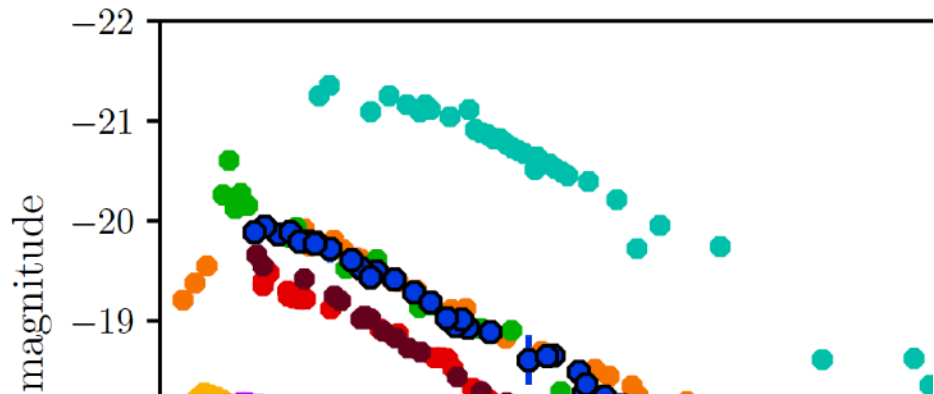


The progenitor star imaged before explosion

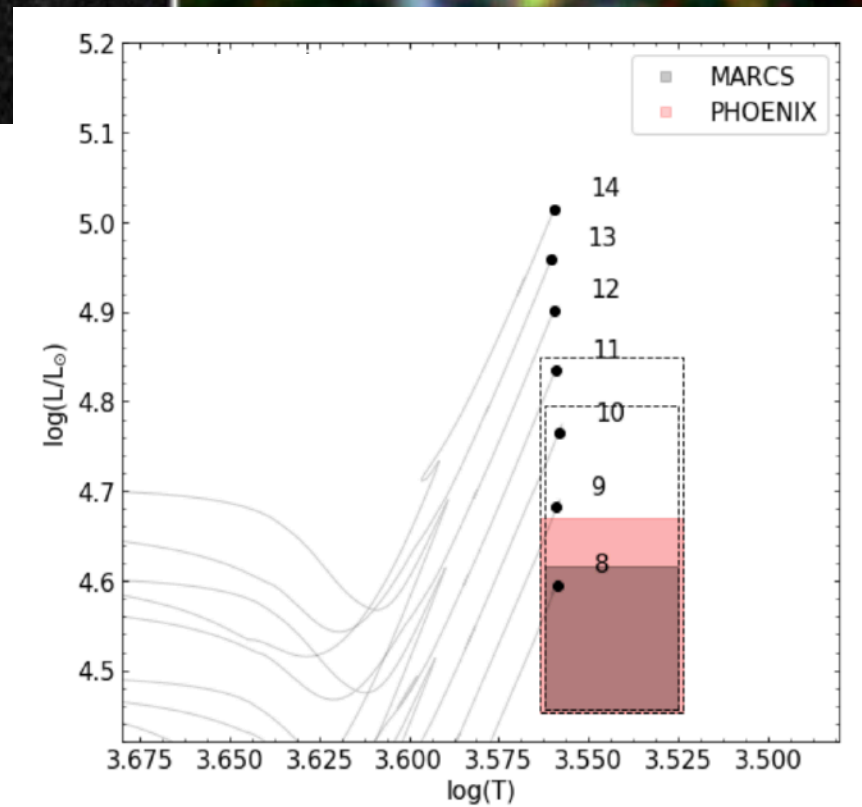
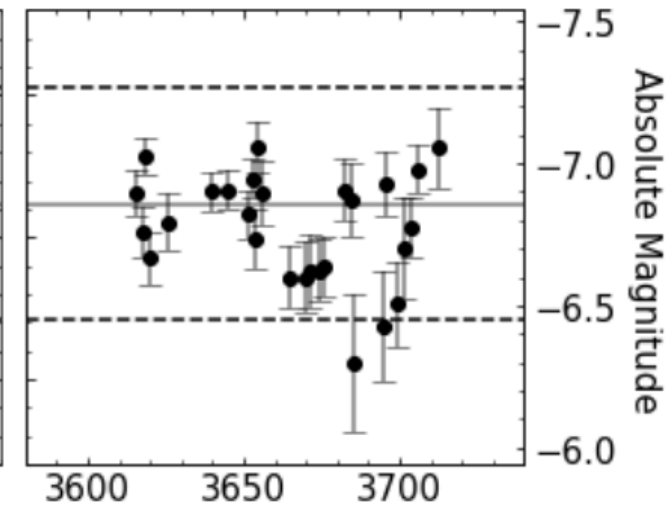
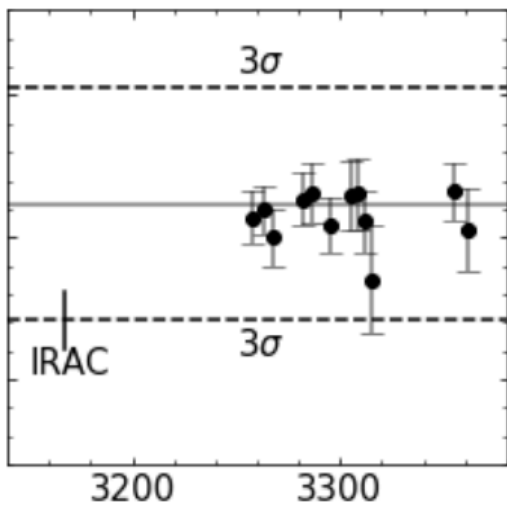
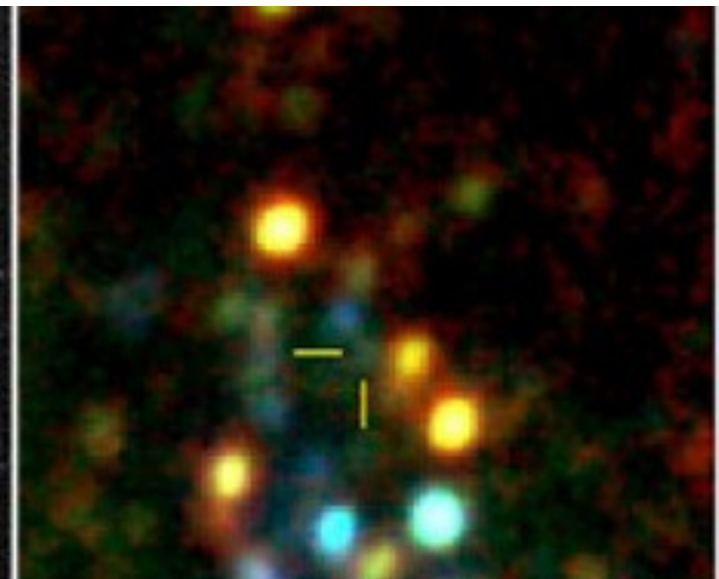
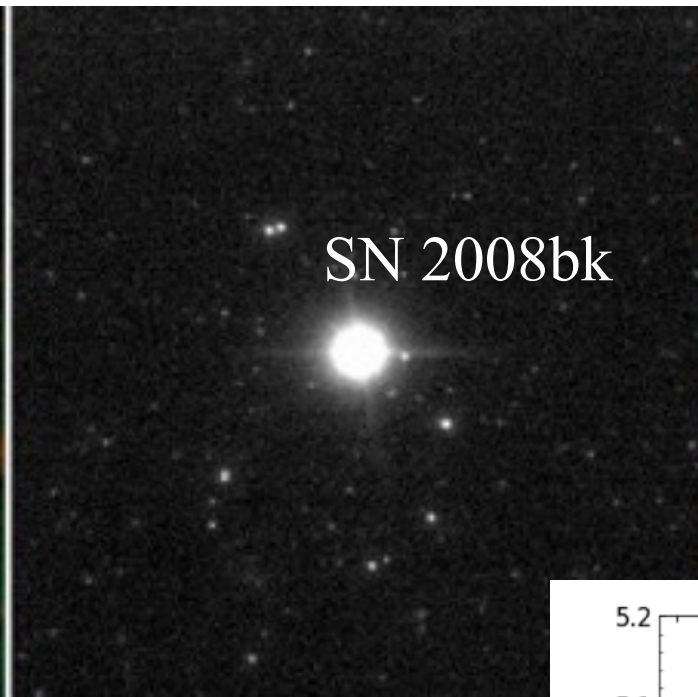
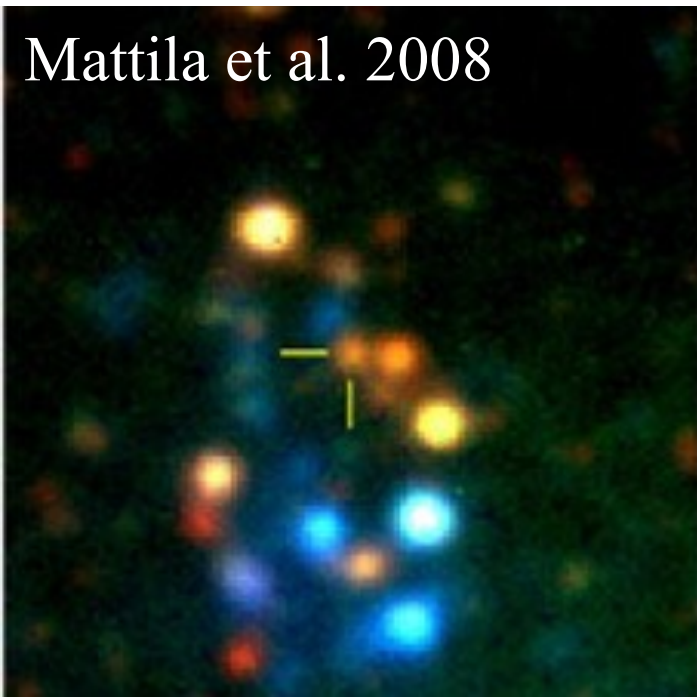








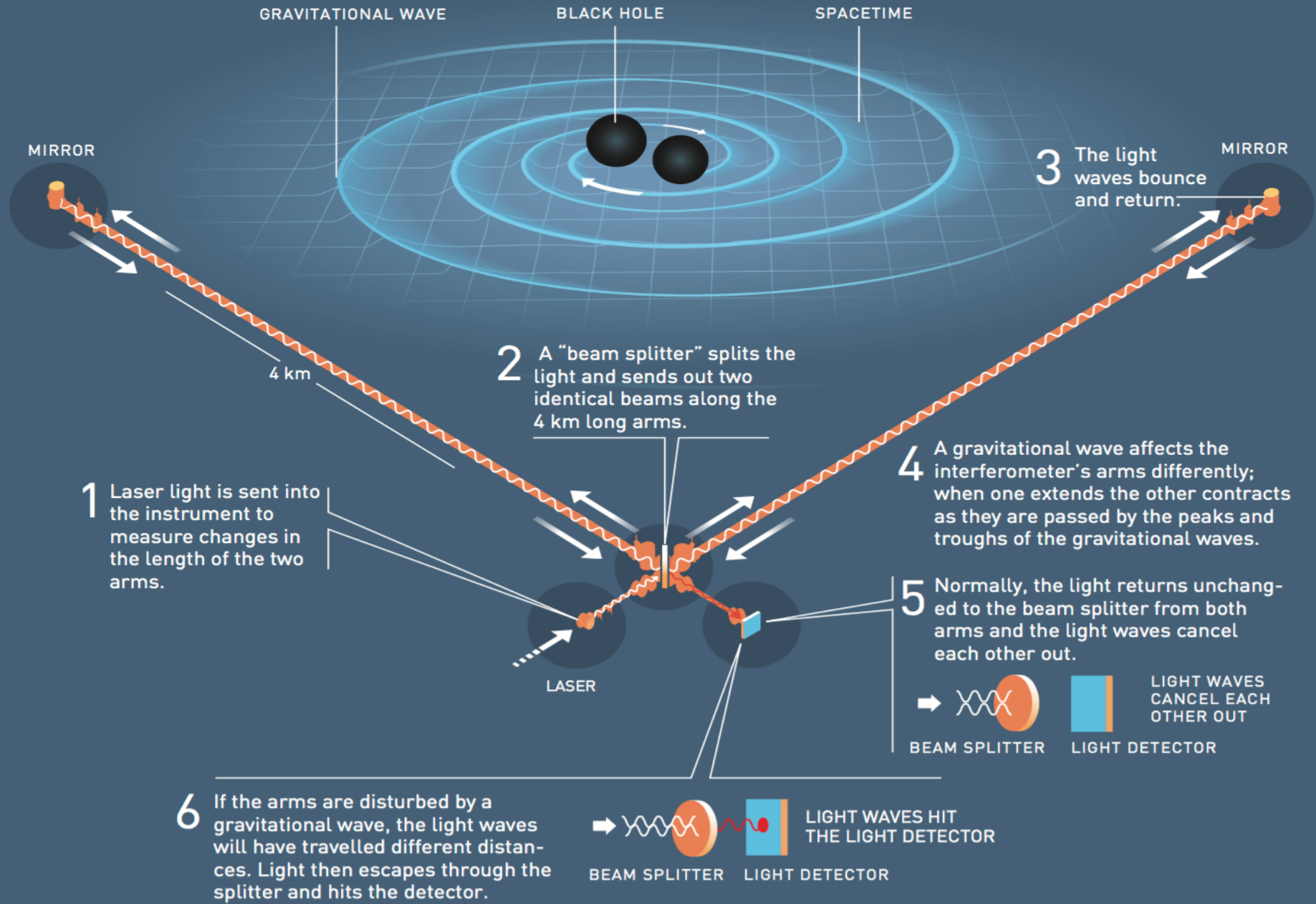
Mattila et al. 2008



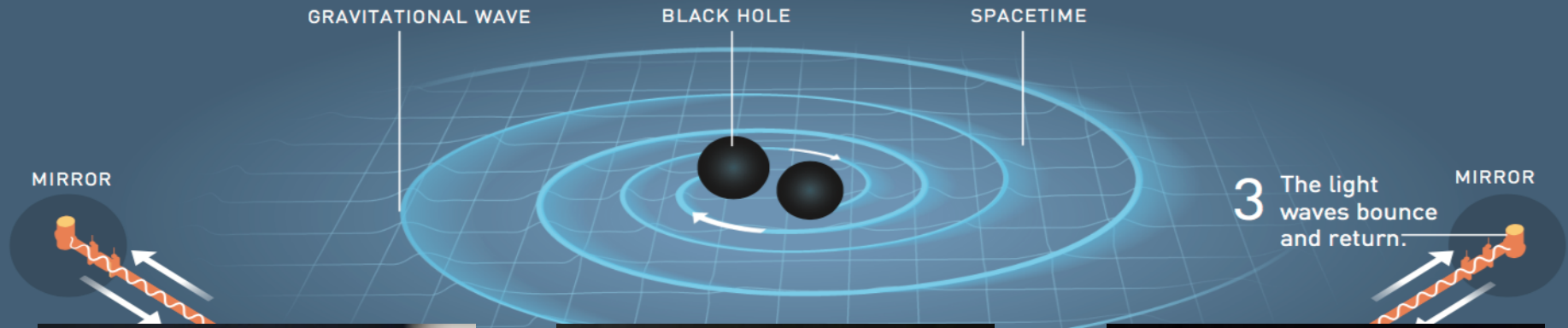
O'Neill et al. 2021



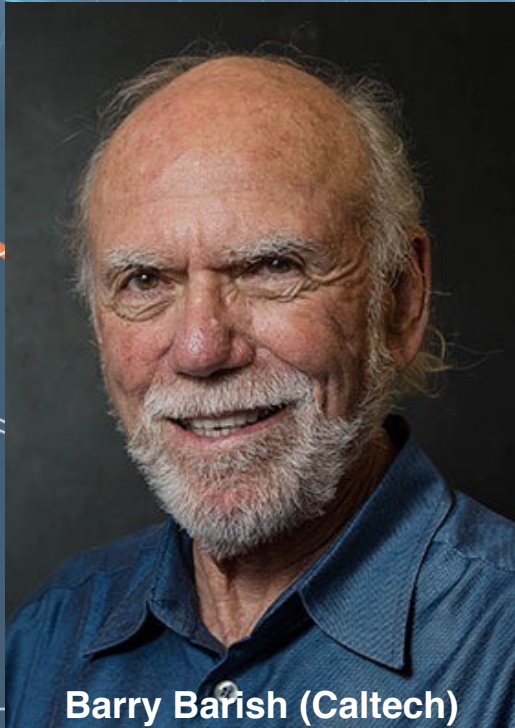
LIGO – A GIGANTIC INTERFEROMETER



LIGO – A GIGANTIC INTERFEROMETER



Rainer Weiss (MIT)



Barry Barish (Caltech)

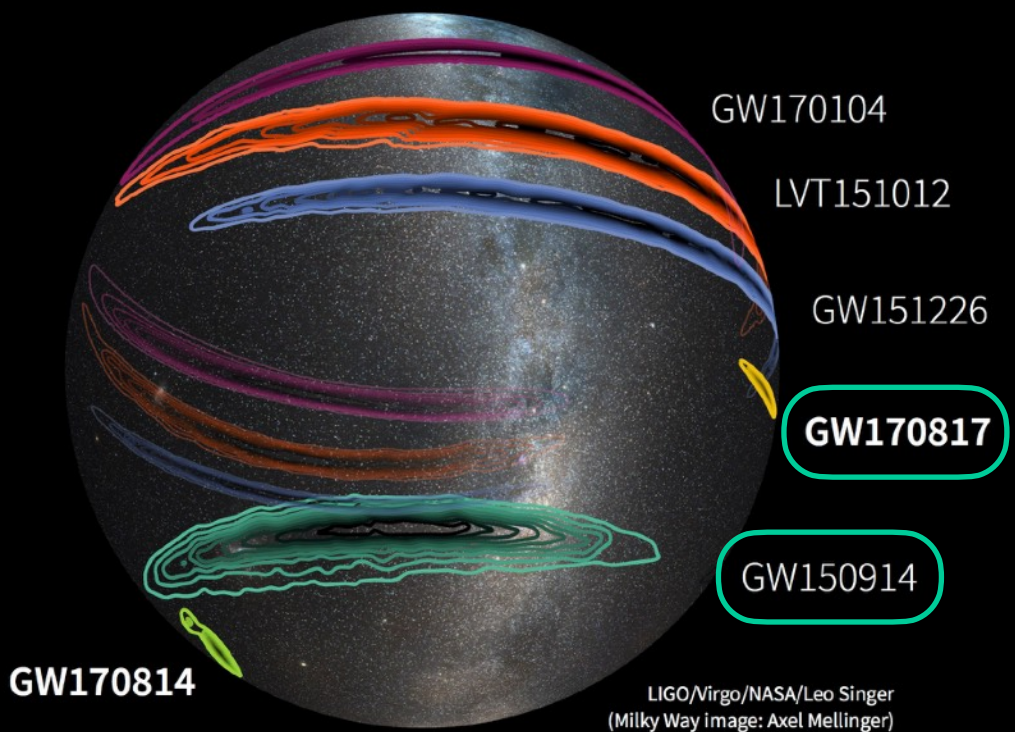
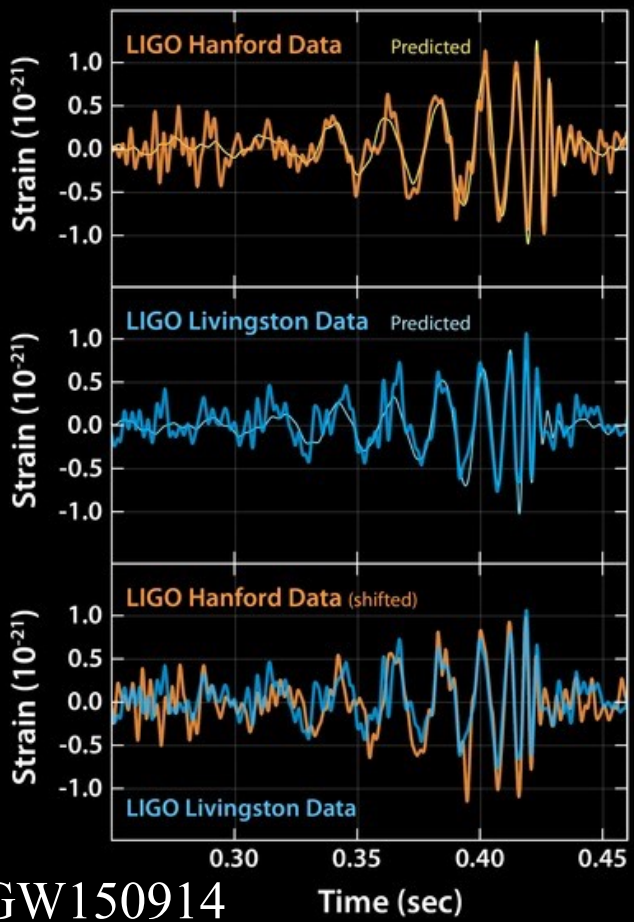
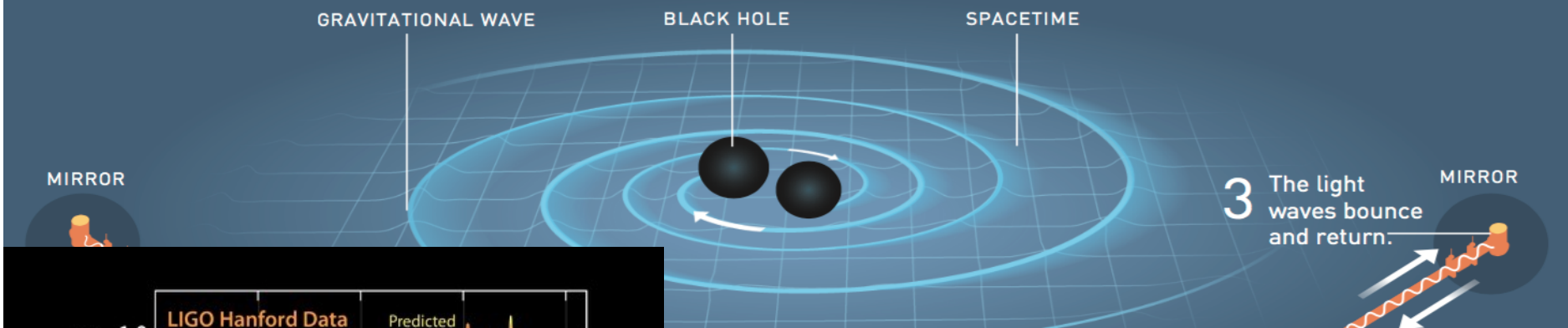


Kip Thorne (Caltech)

6 If the arms are disturbed by a gravitational wave, the light waves will have travelled different distances. Light then escapes through the splitter and hits the detector.

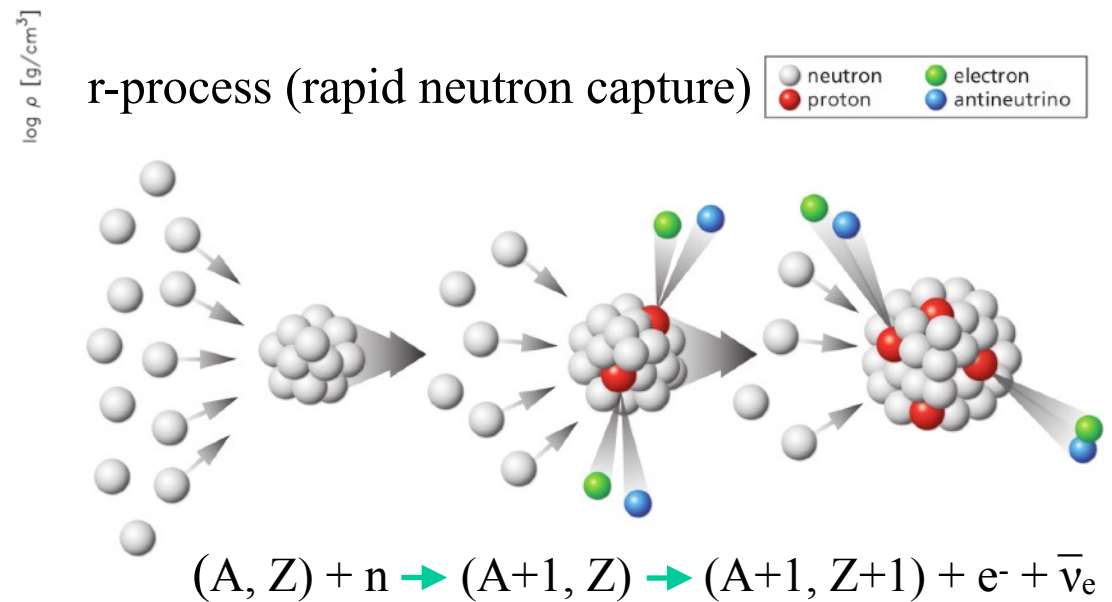
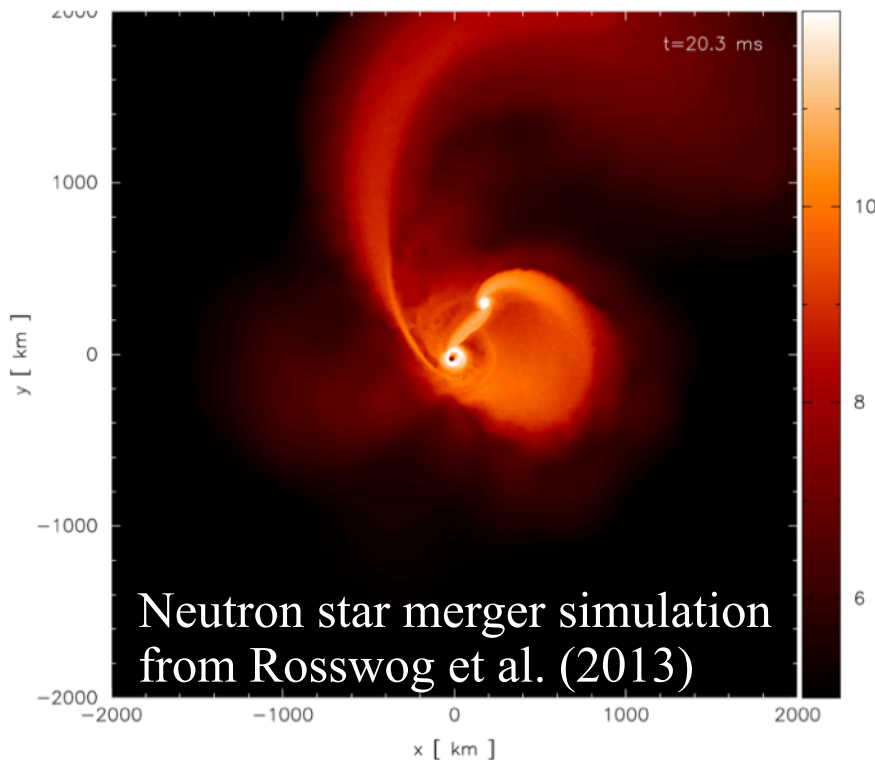


LIGO – A GIGANTIC INTERFEROMETER



Systematic search for electromagnetic counterparts

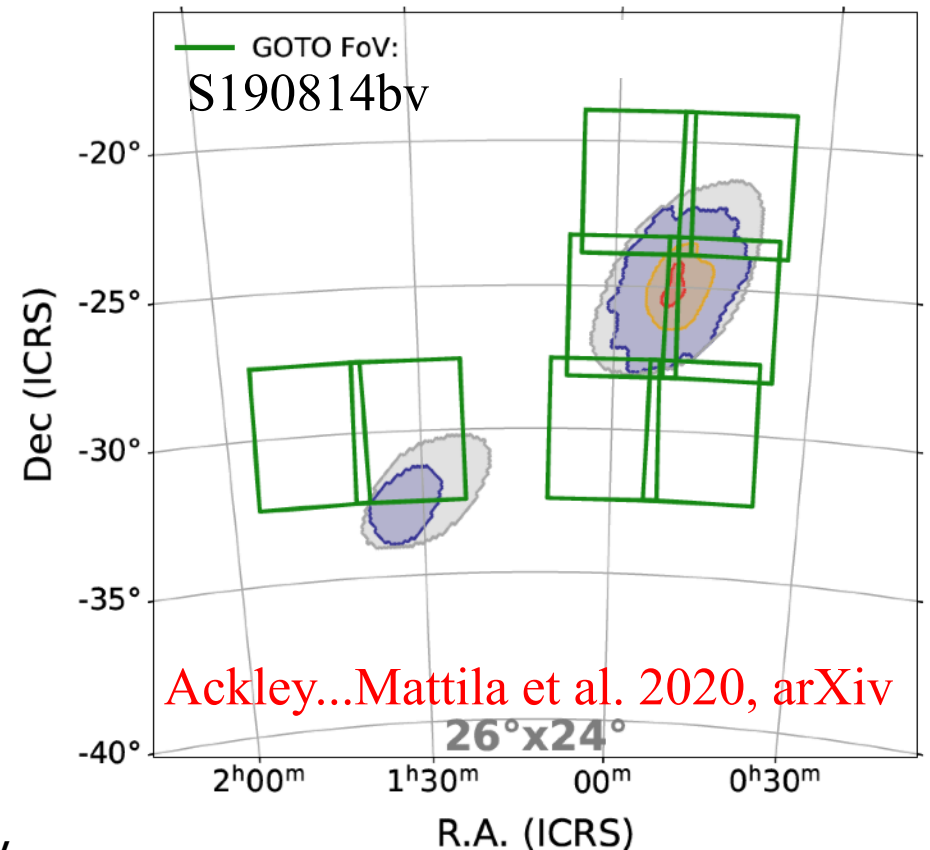
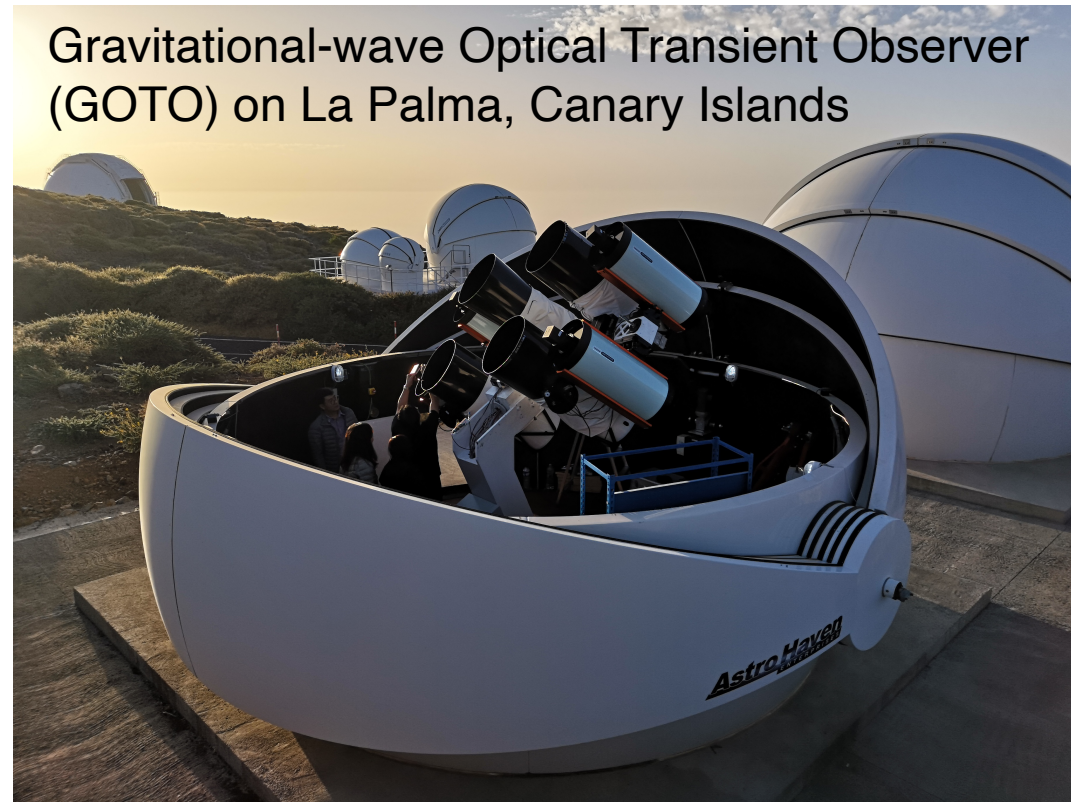
- Mergers of binary neutron star (NS) or black hole (BH) systems as angular momentum removed through gravitational waves (GW)
- NS² and NS+BH mergers expected to eject substantial amounts of extremely neutron-rich material, consistent with being a major source of r-process elements.
- Predicted to eject material with heavy radioactive isotopes that can power electromagnetic (EM) counterparts so called kilonovae



Systematic search for electromagnetic counterparts

- In the GW-EM follow-up large and complex error boxes need to be searched over quickly for rapidly evolving transients for rapid localization of viable candidates for spectroscopy

Gravitational-wave Optical Transient Observer (GOTO) on La Palma, Canary Islands

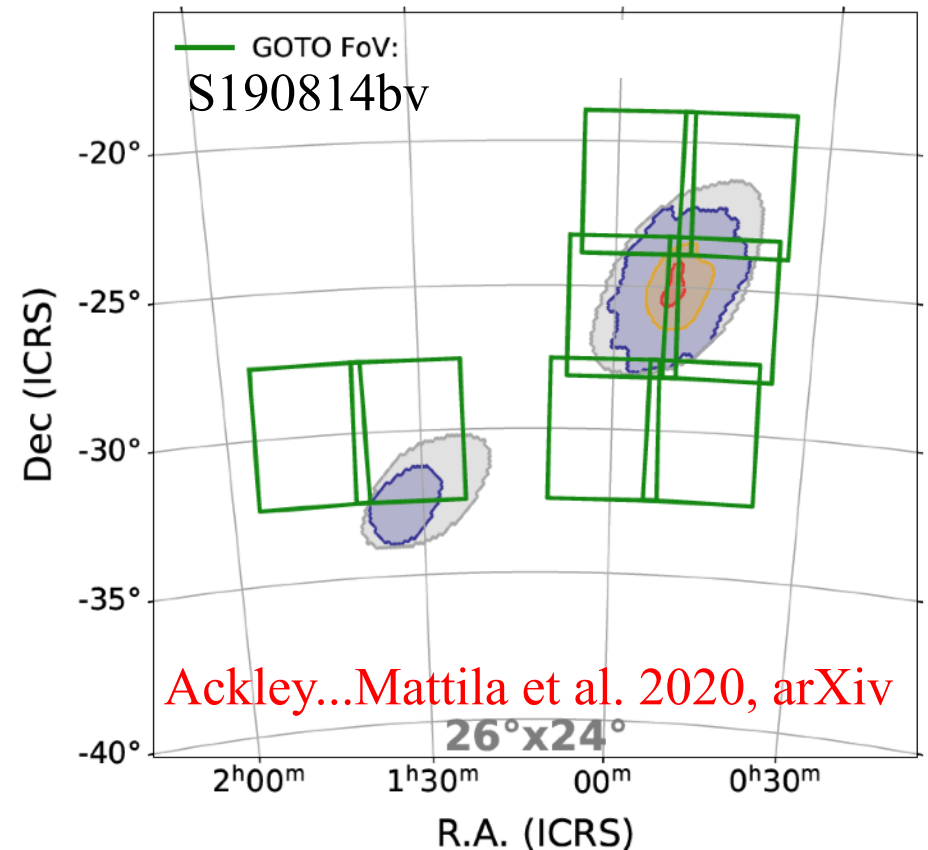


Led by University of Warwick and Monash University with Univ. of Turku a member of the consortium.

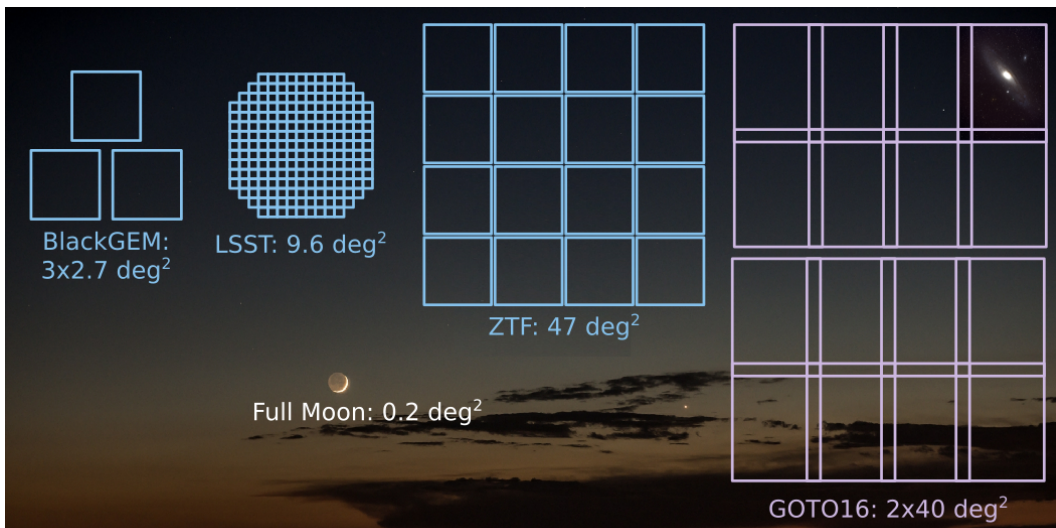
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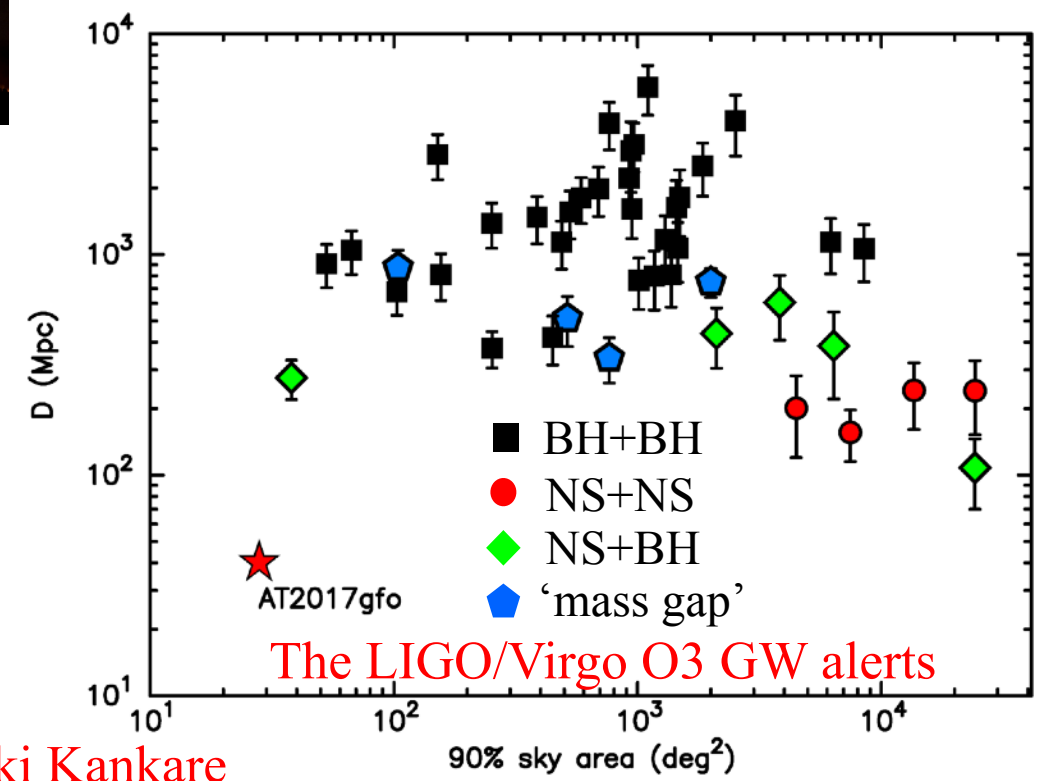
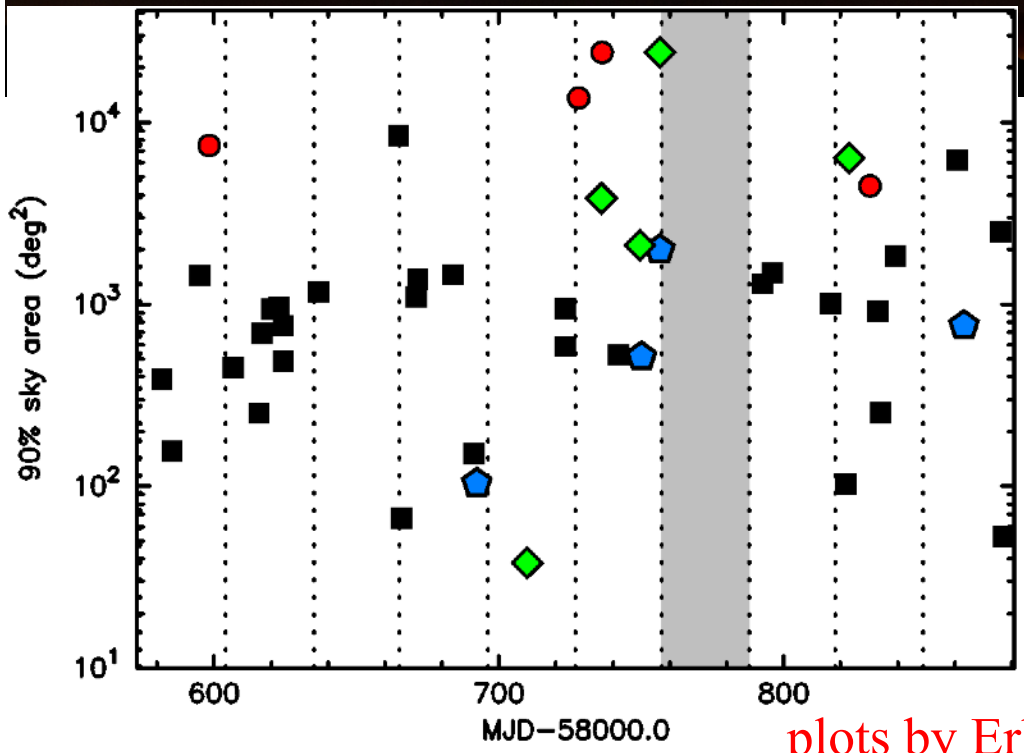
Nordic Optical Telescope (NOT) on La Palma, Canary Islands



Ackley...Mattila et al. 2020, arXiv



whole sky 41 253 deg^2



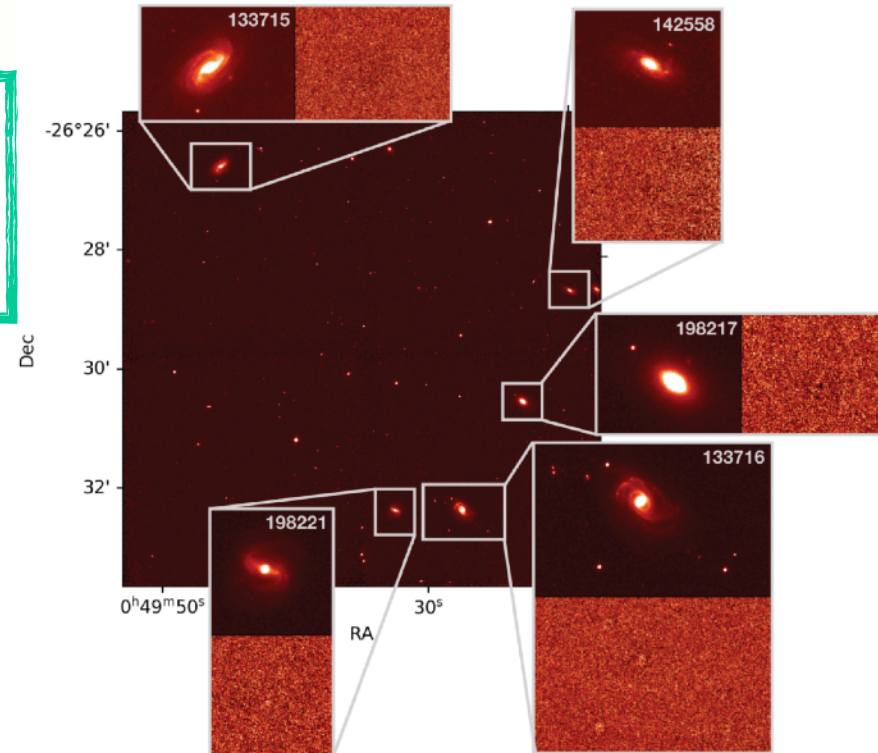
plots by Erkki Kankare

Ongrave

Over 250 astronomers (incl Univ. of Turku) from member states of ESO formed the “ElectromagNetic counterparts of GRAvitational wave sources at the VEry Large Telescope” consortium

Aiming at detailed spectroscopic and photometric follow-up of EM counterparts to GW sources

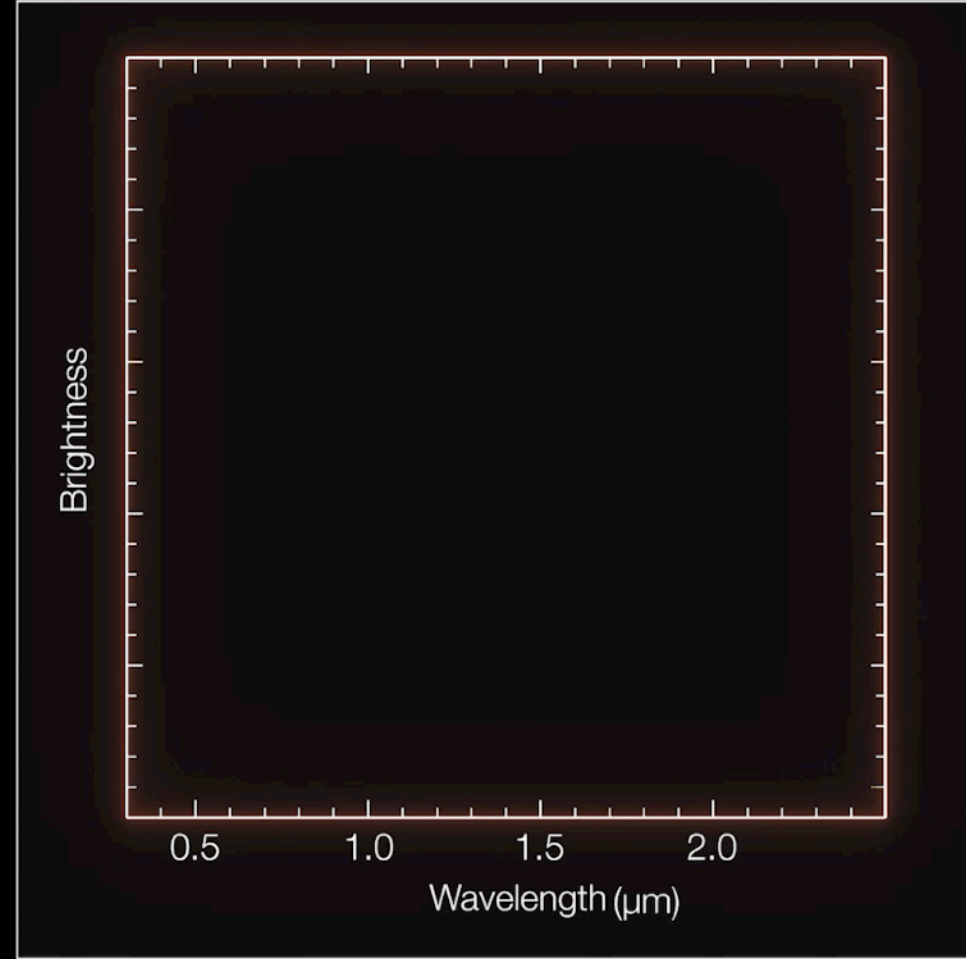
Photometric and spectroscopic search to identify the counterpart of the likely NS-BH merger S190814bv reported in Ackley...Mattila et al. 2020, arXiv



Photometric and spectroscopic follow-up of the kilonova counterpart of GW170814

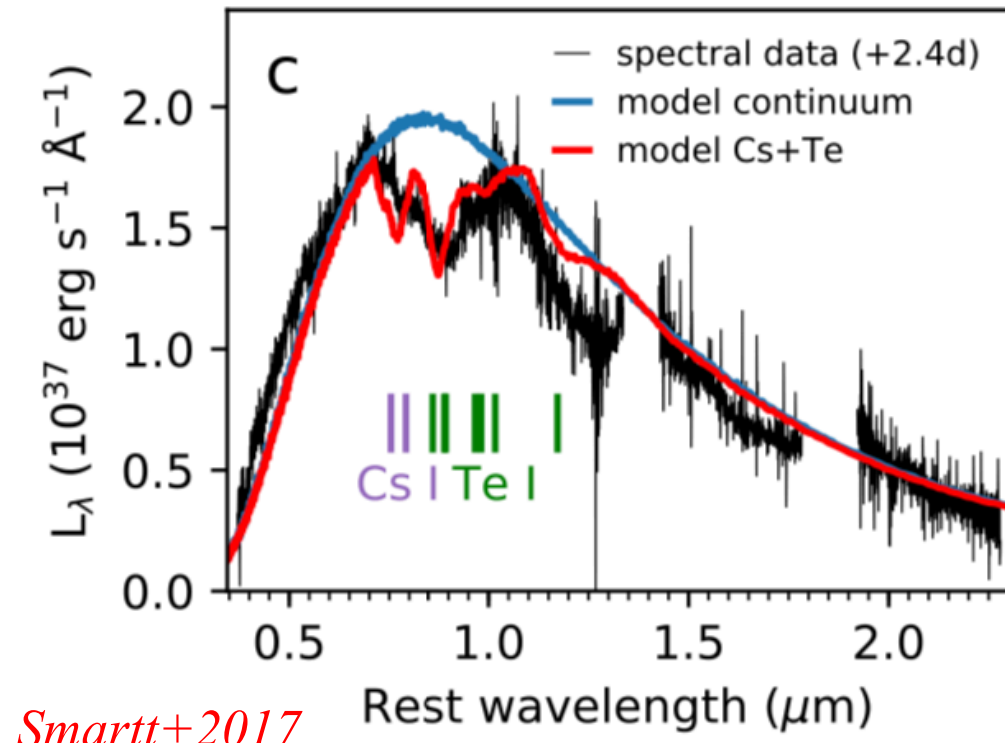
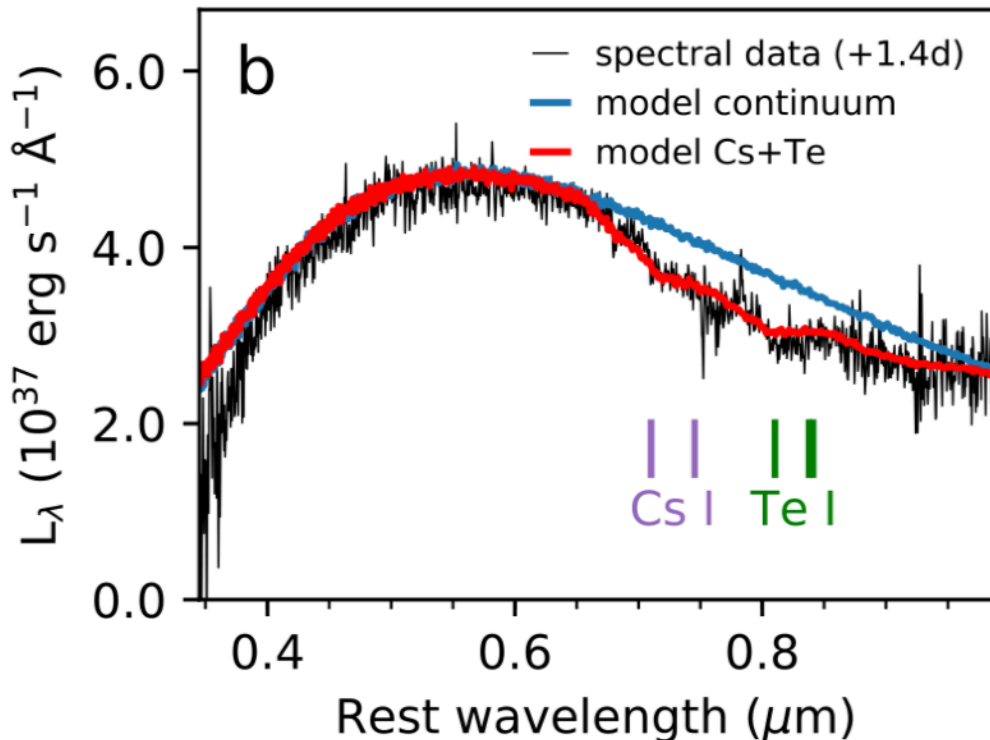


Time: -1225 days



GW170817: merger of two neutron stars

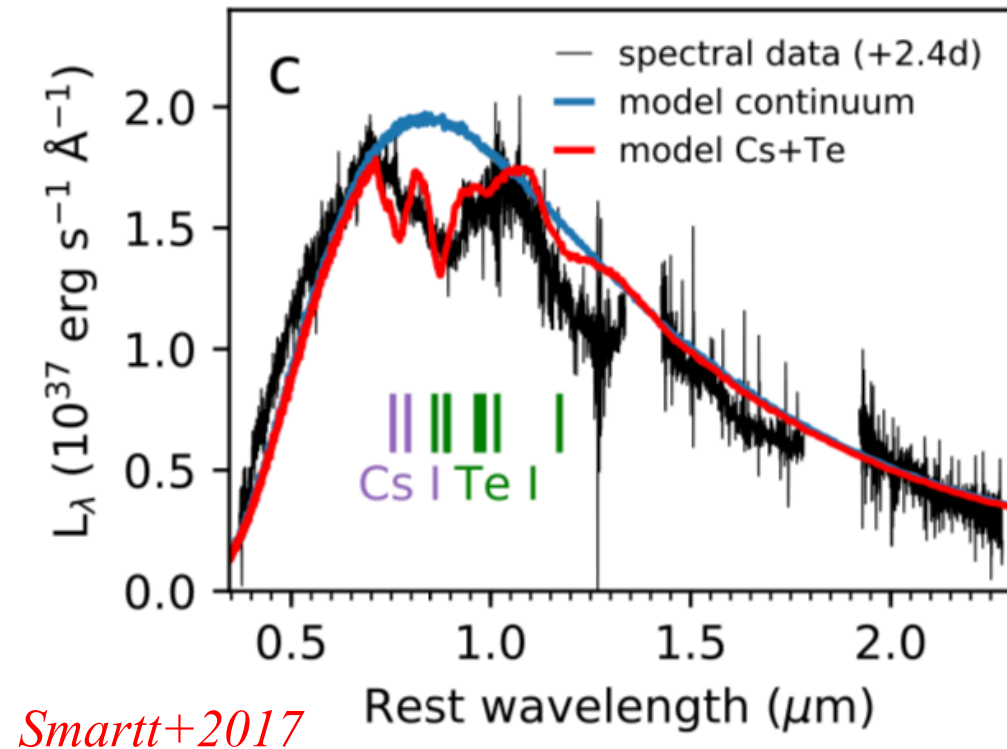
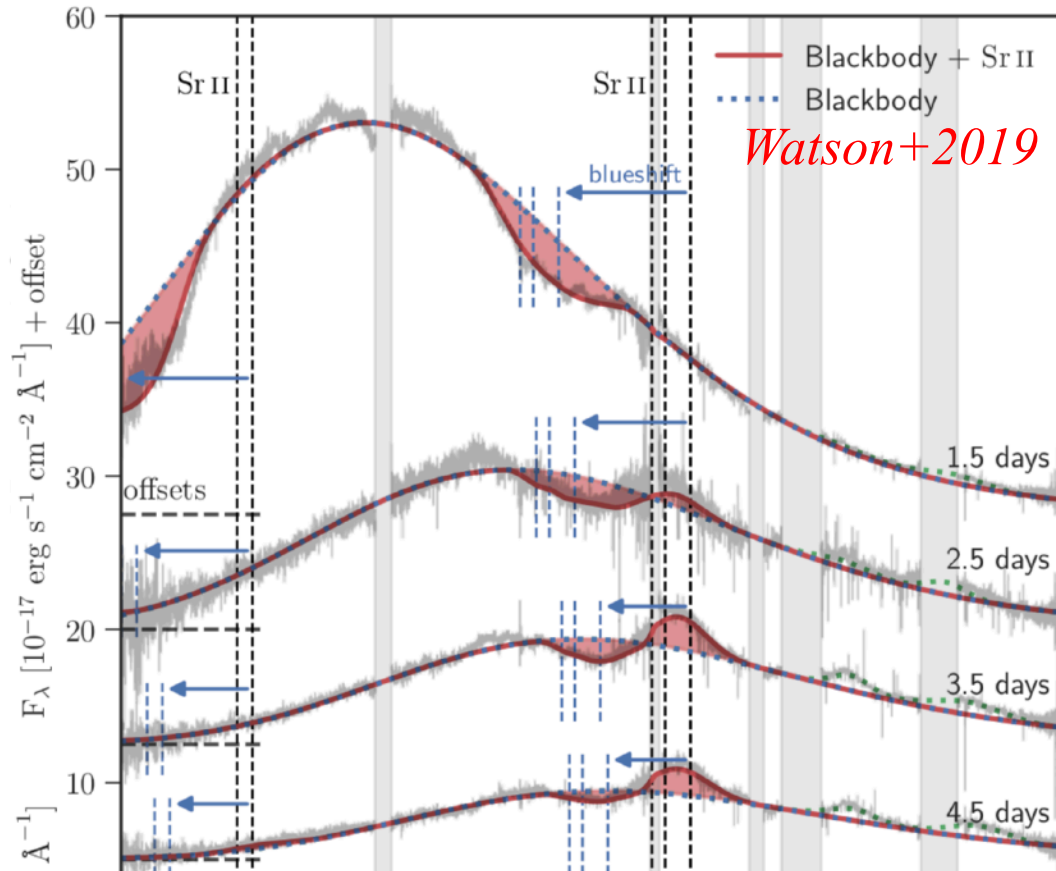
- NS² mergers predicted to eject material with heavy elements formed in the r-process
- Detailed spectroscopic observations of their EM counterparts can allow direct identification of the elements through their spectral signatures
- In the case of the kilonova counterpart of GW170817 the same absorption features identified to originate from different elements by different authors



Smartt+2017

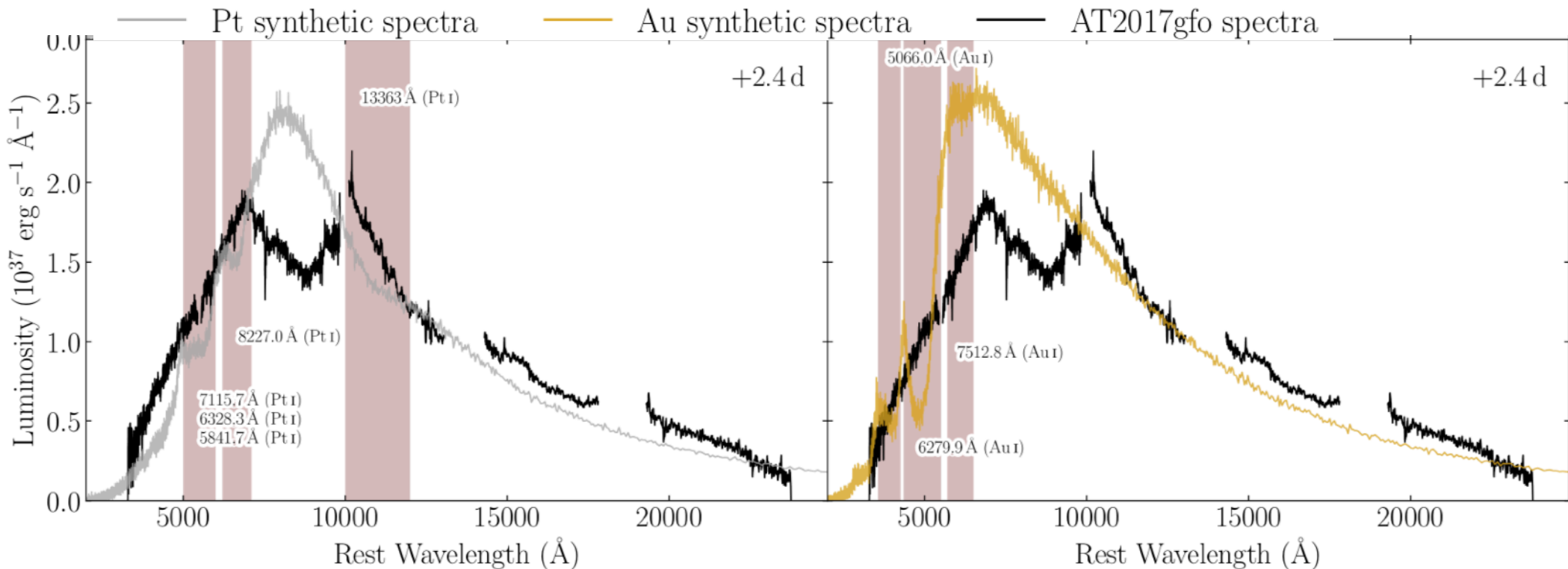
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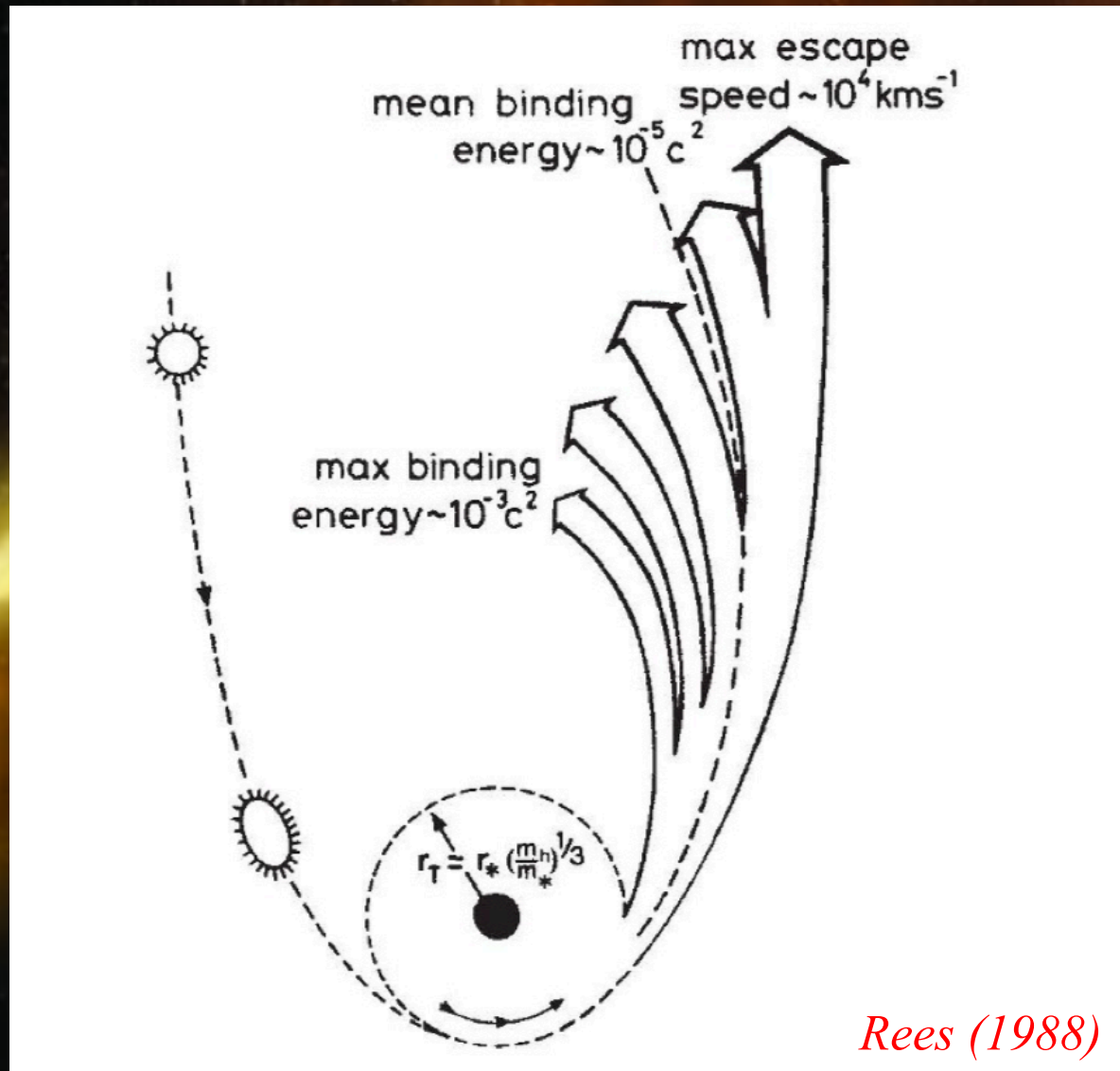
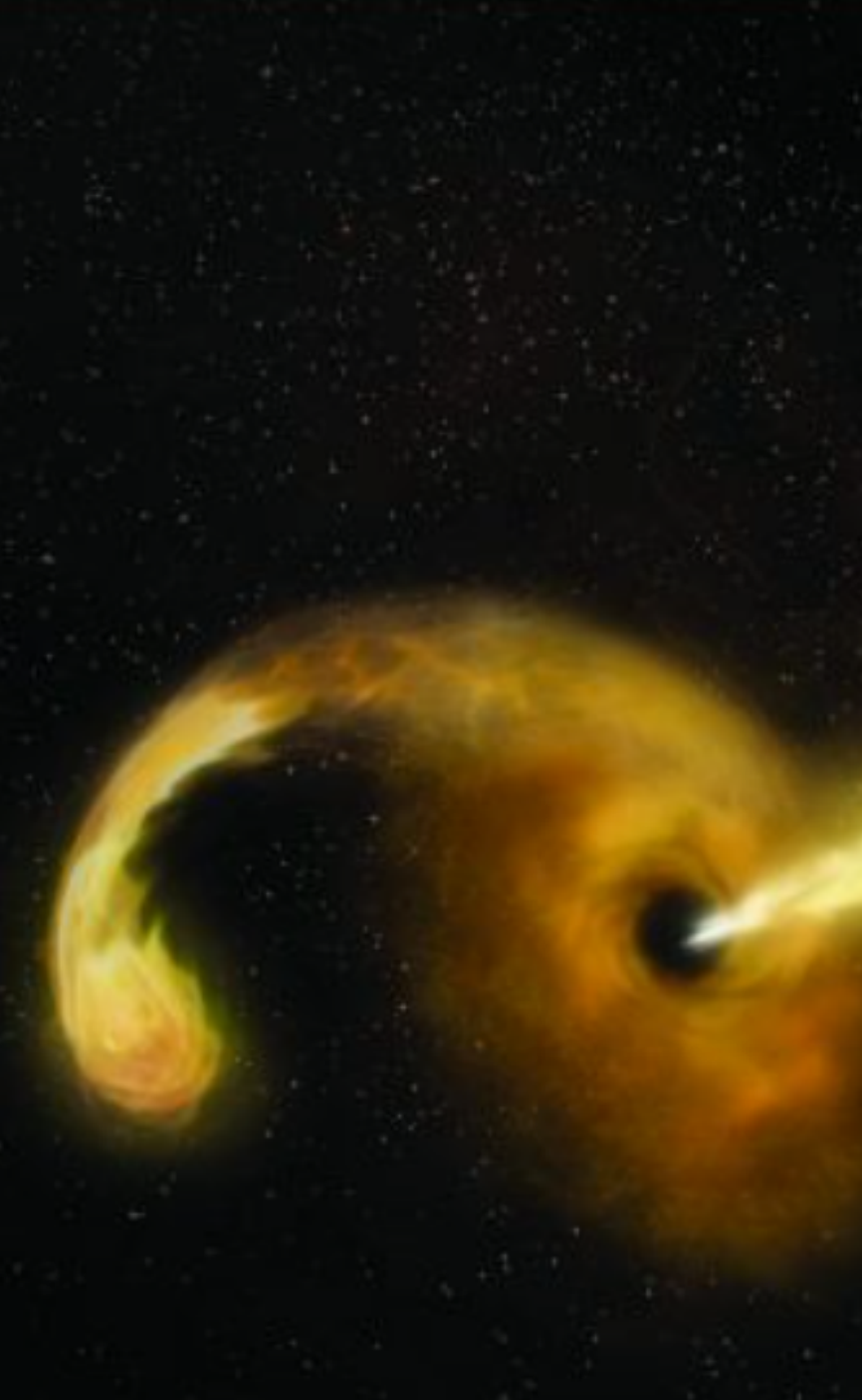


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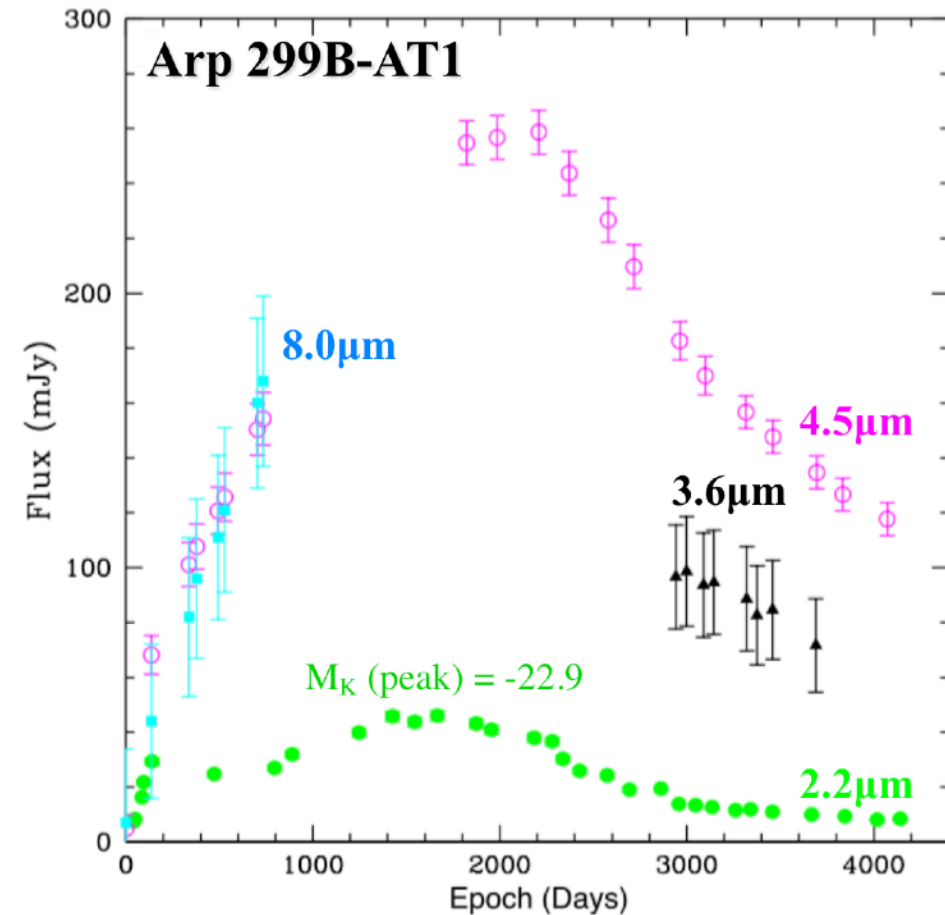
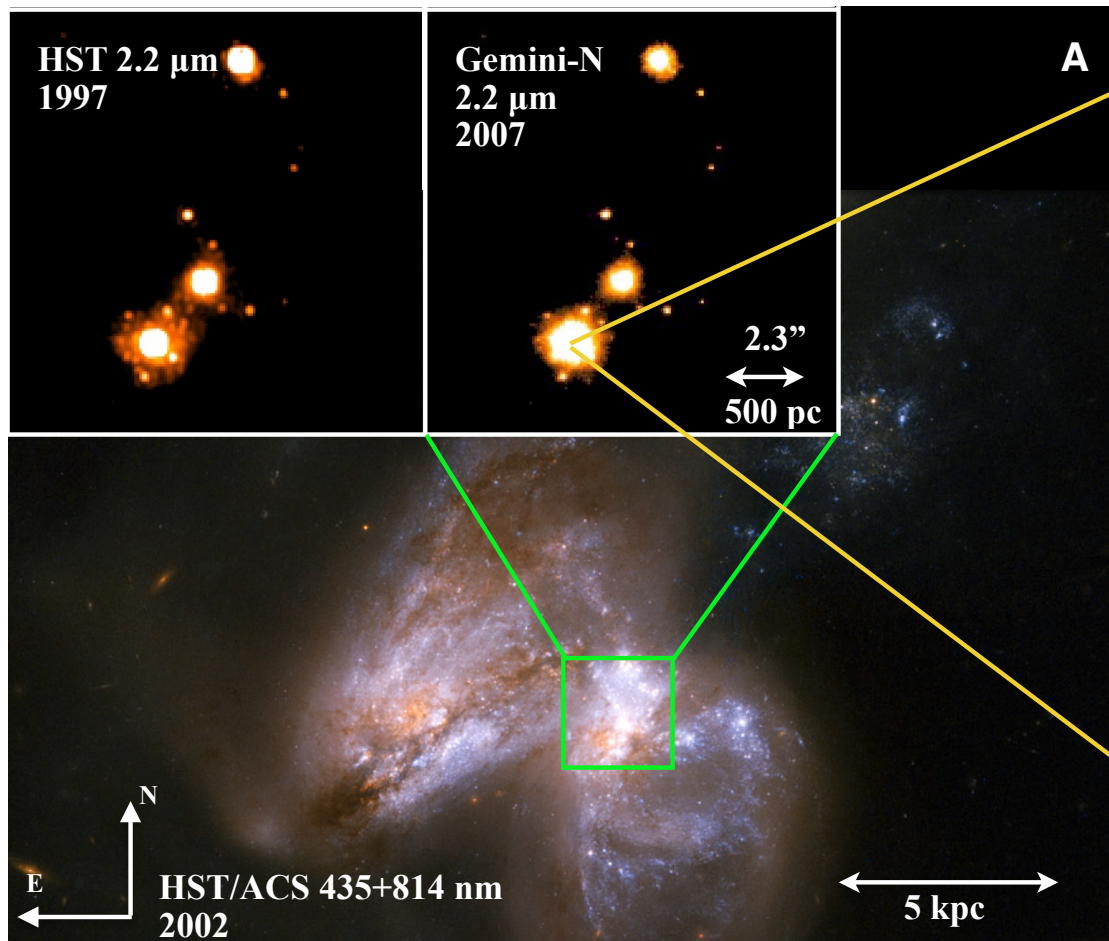






Extremely energetic tidal disruption event in a galaxy merger

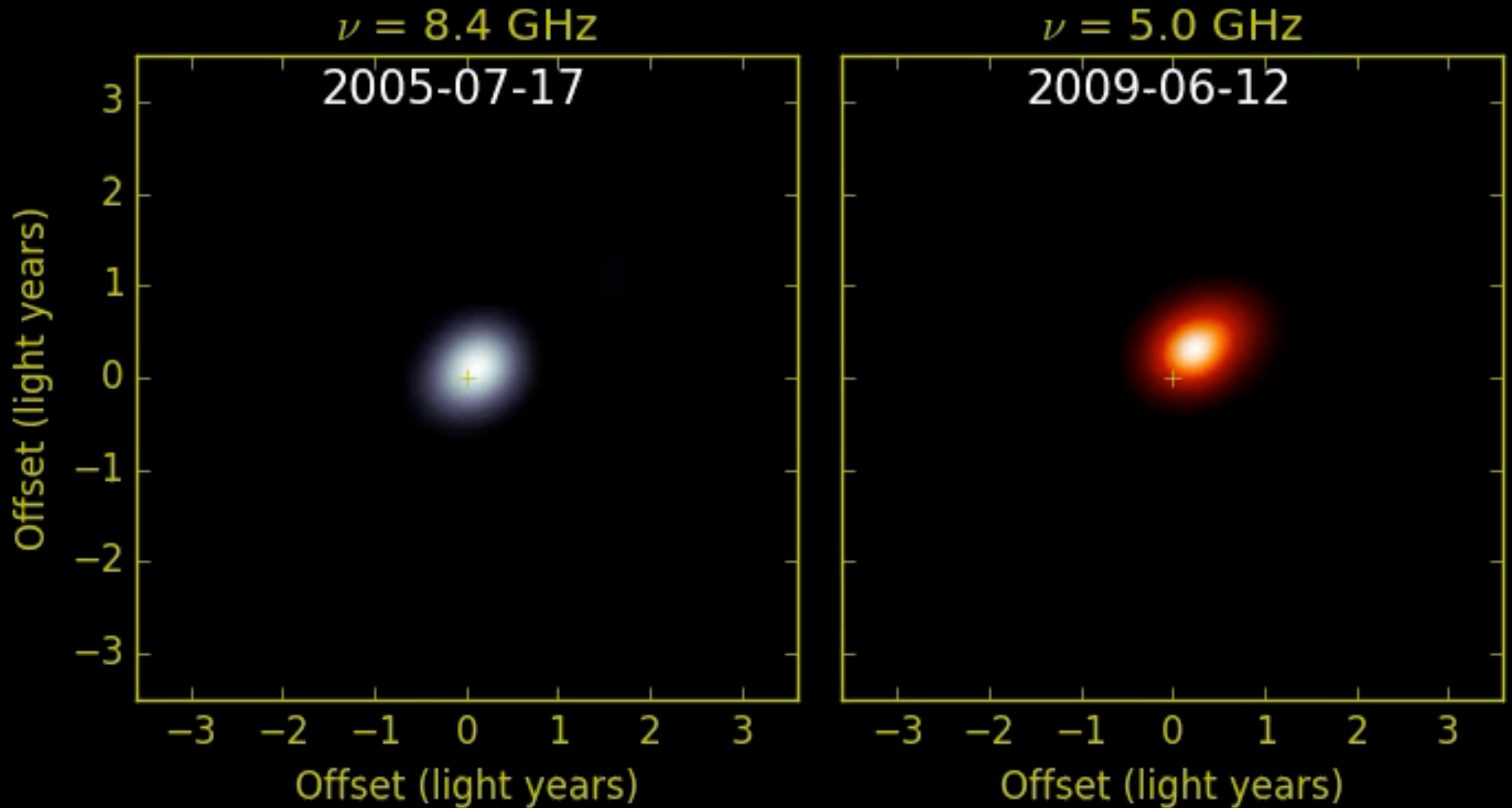
Near-IR 2.2 μm imaging revealed an extremely energetic and slowly evolving transient event that was coincident with a nucleus of a galaxy merger. The transients outshined the entire nucleus at IR and radio wavelengths but remained elusive in the optical.



The Global VLBI - Array



The Global VLBI – Array



Credit: Mattila, Perez-Torres et al. 2018 (Science)



Ft. Davis



St. Croix



V L A



Arecibo



Effelsberg



Yebes



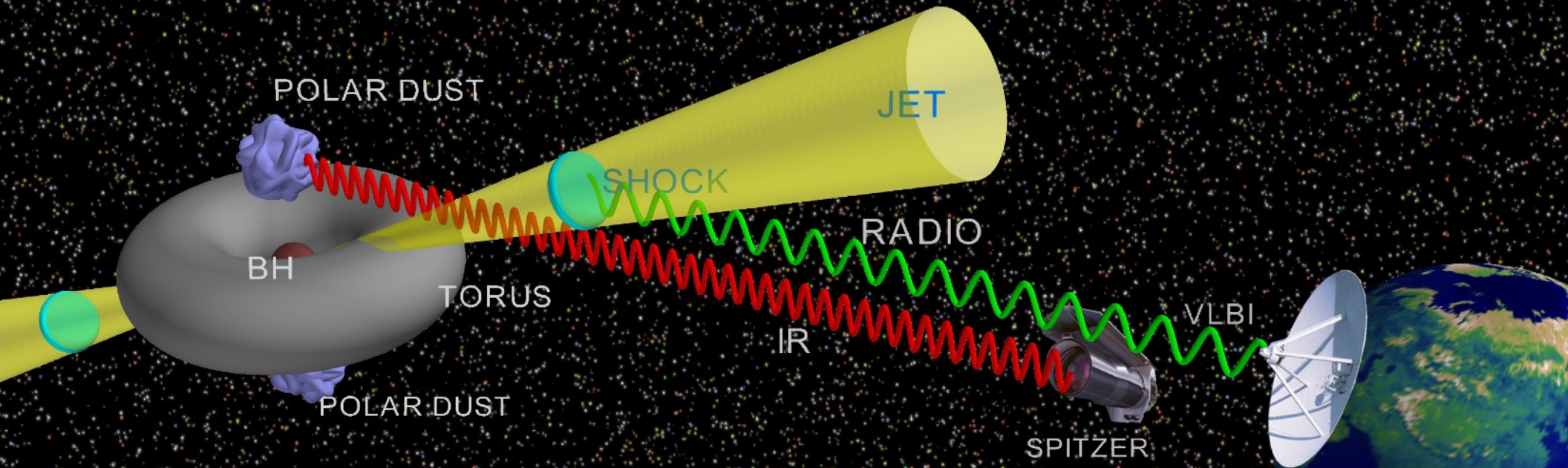
Wettzell



Torun



Hartebeesthoek



RESEARCH

BLACK HOLE PHYSICS

A dust-enshrouded tidal disruption event with a resolved radio jet in a galaxy merger

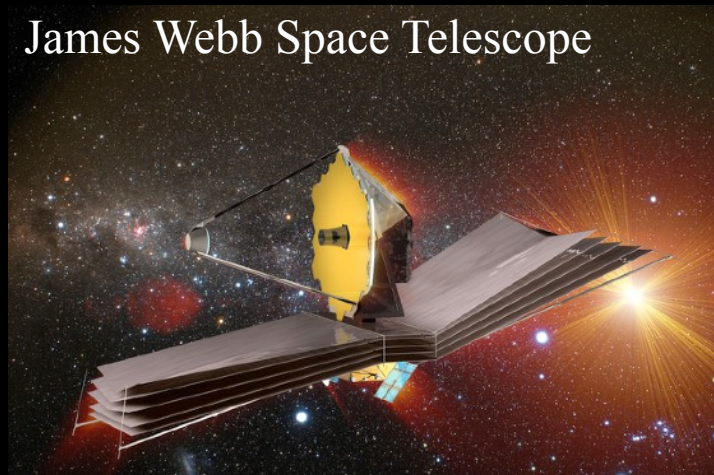
S. Mattila^{1,2*†}, M. Pérez-Torres^{3,4*†}, A. Efstathiou⁵, P. Mimica⁶, M. Fraser^{7,8}, E. Kankare⁹, A. Alberdi³, M. Á. Aloy⁶, T. Heikkilä¹, P. G. Jonker^{10,11}, P. Lundqvist¹², I. Martí-Vidal¹³, W. P. S. Meikle¹⁴, C. Romero-Cañizales^{15,16}, S. J. Smartt⁹, S. Tsygankov¹, E. Varenus^{13,17}, A. Alonso-Herrero¹⁸, M. Bondi¹⁹, C. Fransson¹², R. Herrero-Illana²⁰, T. Kangas^{1,21}, R. Kotak^{1,9}, N. Ramírez-Olivencia³, P. Väisänen^{22,23}, R. J. Beswick¹⁷, D. L. Clements¹⁴, R. Greimel²⁴, J. Harmanen¹, J. Kotilainen^{2,1}, K. Nandra²⁵, T. Reynolds¹, S. Ryder²⁶, N. A. Walton⁸, K. Wiik¹, G. Östlin¹²



Summary

- Over the past two decades research of astrophysical transients has gone through a rapid expansion from SN cosmology to TDEs and other rare stellar explosions
- Wide field telescopes now offer opportunities for the detection and study of the EM counterparts to GW sources, e.g., the discovery of the KN counterpart of GW170814
- Opportunities to learn about range of (astro)physics from detailed observations of transient events on time scales from hours to years
- Improved observational capabilities already offer completely new multi-wavelength and multi-messenger approaches in transient research with exciting future !

James Webb Space Telescope



39-m ELT built by the European Southern Observatory (ESO)

