Thermonuclear eruptions and their astrophysical role in the SKA era

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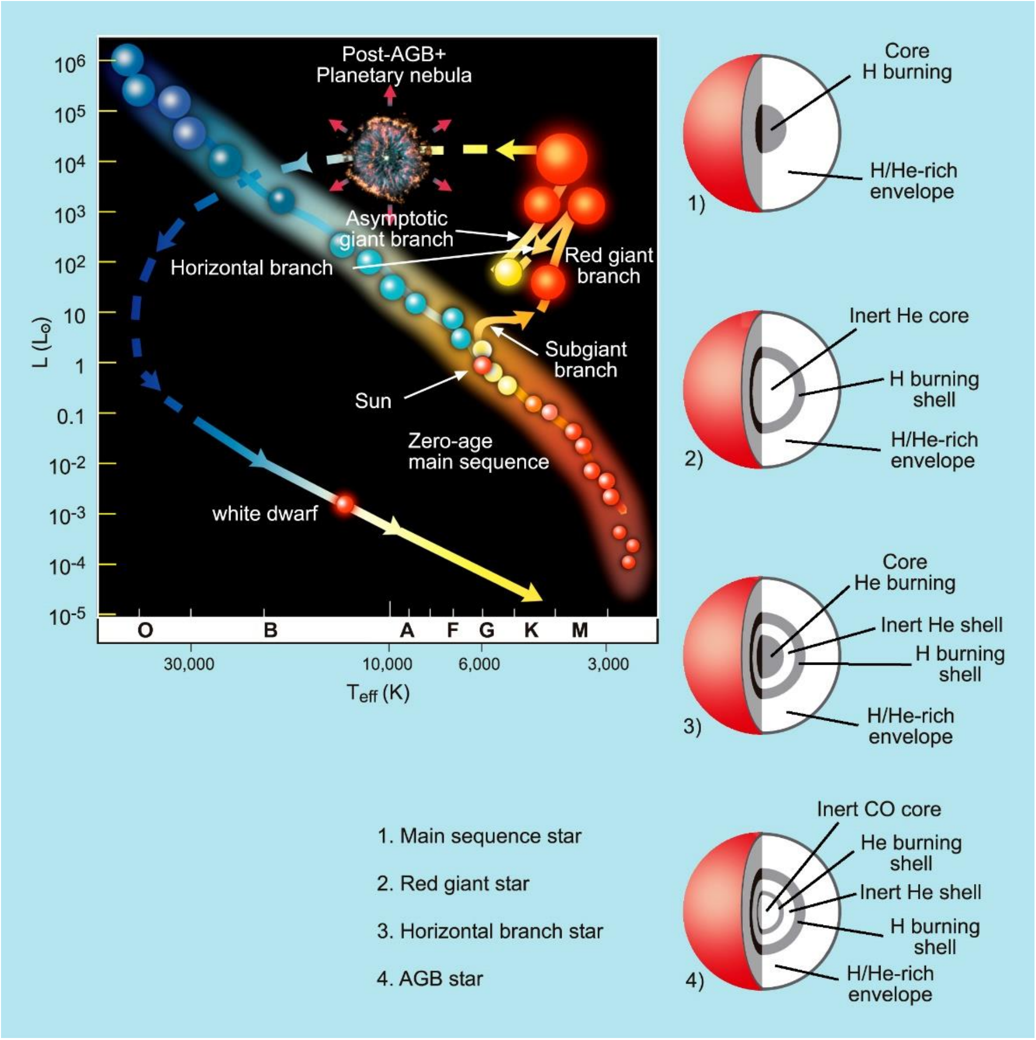
Thermonuclear reactions

Credit: SKA South Africa

- In stars, we can describe the random motions of particles due to kinetic energy
- At about 10^6 K short fusion episodes can start occurring during gravitational contraction (proton-capture reactions by light elements)
- At about 10^7 K we can actually start to fuse hydrogen in the central regions
- Once hydrogen is exhausted near the centre, the star departs from hydrostatic equilibrium. Core contracts and outer layers expand in size
- At about 10^8 K helium can fuse at the core, releasing energy that stabilises the star against further contraction



José 2015, Stellar Explosions: Hydrodynamics and Nucleosynthesis

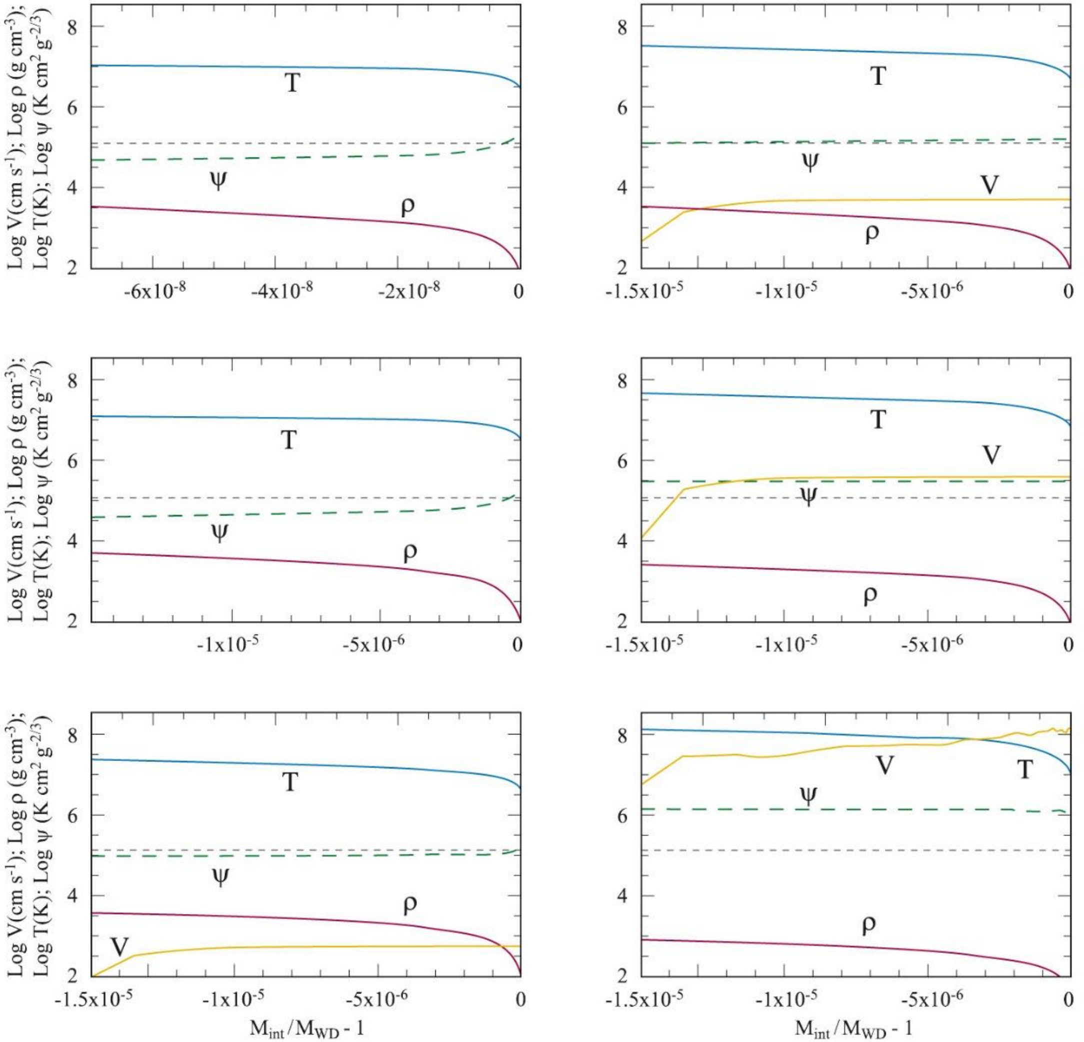
Thermonuclear reaction in a nova eruptions

Credit: SKA South Africa

- Conditions for degeneracy demand that thermal energy of the electrons is smaller than the Fermi energy

$$\frac{T}{\rho^{2/3}} < 1.3\text{x}10^5 \left(\frac{Z}{A}\right)^{2/3} \text{ K cm}^2\text{ g}^{-2/3}$$

- As matter piles up on the surface
  - The matter is compressed
  - Electrons at the bottom of envelope become degenerate
  - Initial burning (1.5x10^7 K) during accretion follows the pp-chain and must include the pep reaction
- Temperature at base of hydrogen rich envelope rises (energy rate production $\propto T^4$)
  - When $\sim$2x10^{7}K, hydrogen ignites in a thin shell by CNO reactions cycle
- As energy is released, temperature rises exponentially (T^{16})
  - Due to degeneracy pressure
  - However, limited to $\sim 10^8$K due to β^+ unstable nuclei – degeneracy is quenched
  - Now gas behaves as an ideal gas and a shell can expand



José 2015, Stellar Explosions: Hydrodynamics and Nucleosynthesis

Holistic view of novae

Credit: SKA South Africa

- Thermonuclear explosions on the surface of a white dwarf star

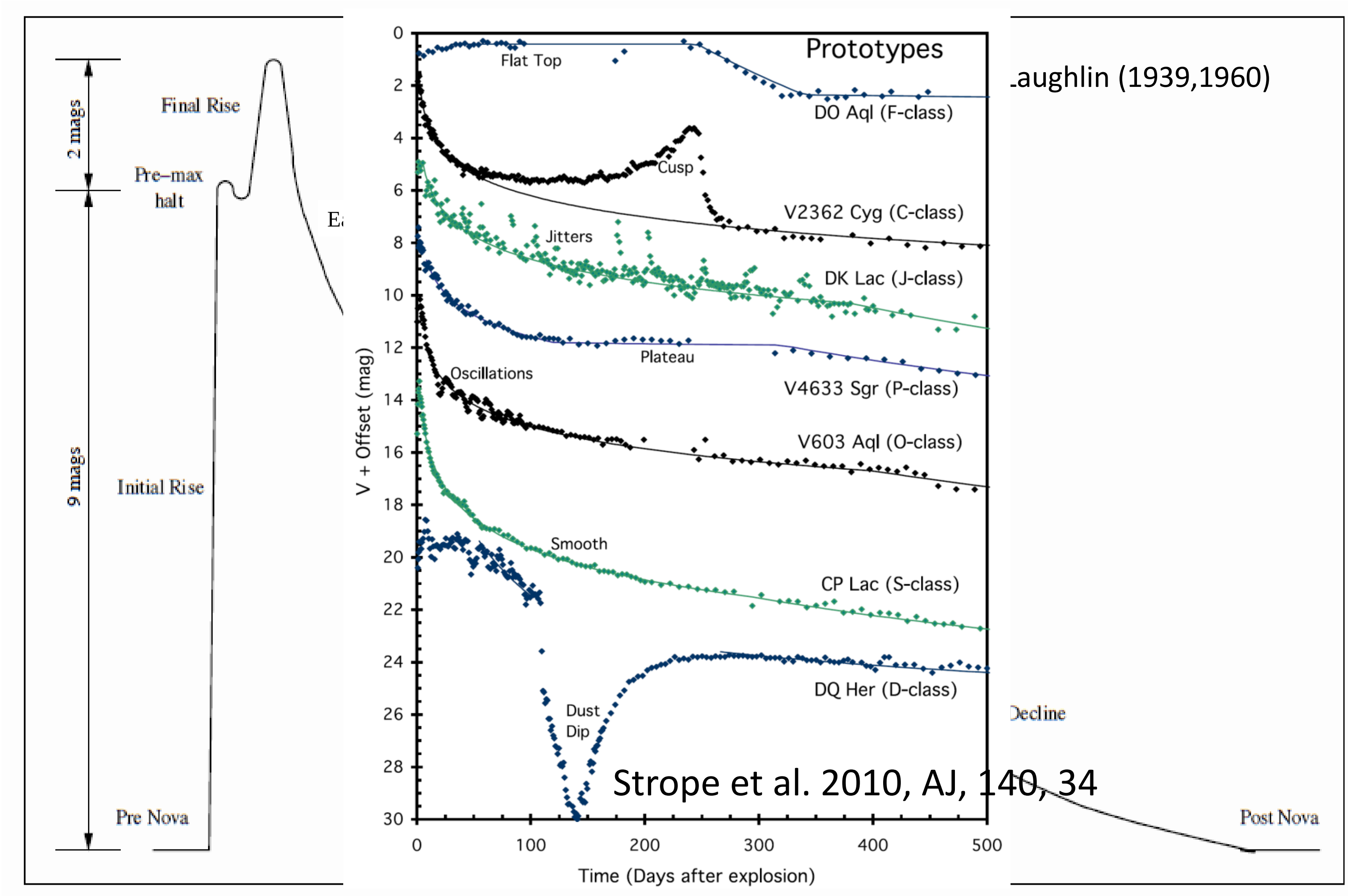
$$P_{\mathrm{crit}} = \frac{G M_{\mathrm{wd}}}{4\pi R_{\mathrm{wd}}^4} \Delta M_{\mathrm{env}}$$

- The most common stellar explosions in the local universe expelling heavy elements
- Galactic rate ~35/yr

Credit: NASA's Goddard Space Flight Centre

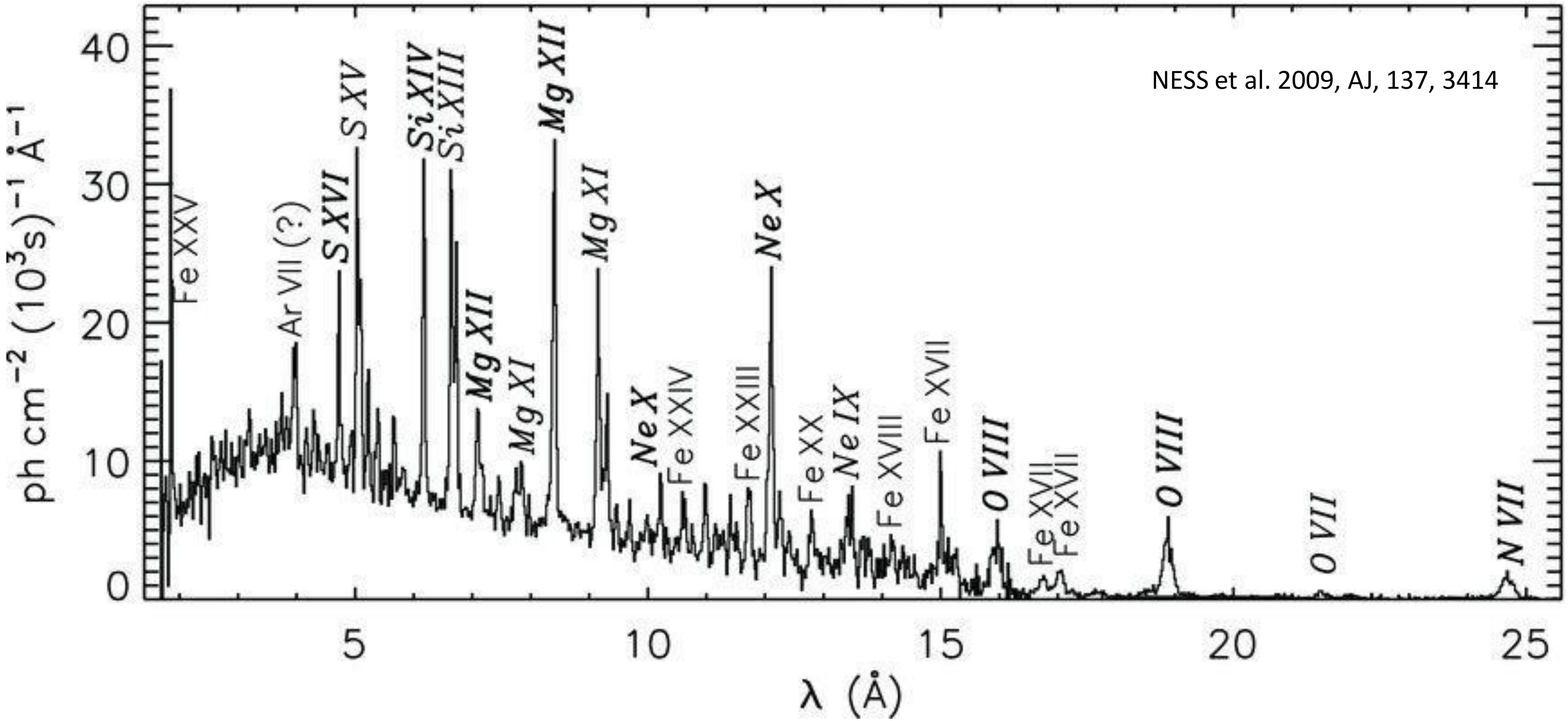
- Non-disruptive event, therefore can recur
- Laboratories for mixing mechanisms, nebular shaping, clumping mechanism, dust formation
- Understanding binary stellar evolution, progenitors of Type Ia supernovae…

Holistic view of novae



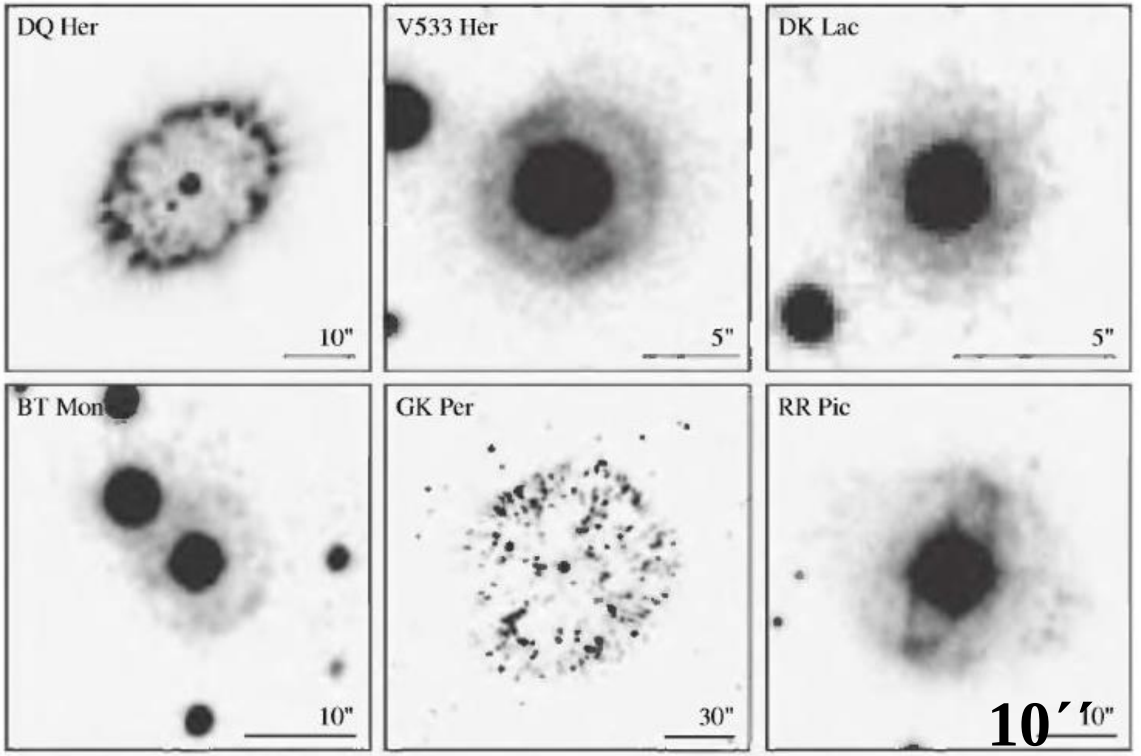
Strope et al. 2010, AJ, 140, 34

Holistic view of novae



Holistic view of novae

- Common-envelope phase (e.g. Livio et al. 1990, ApJ, 356, 250; Lloyd et al. 1997, MNRAS, 273, 137)
- The rotation of the WD (Kippenhahn & Thomas 1978, A&A, 63, 265)
- Localised termo. runaway (Shara 1982, ApJ, 261, 649)

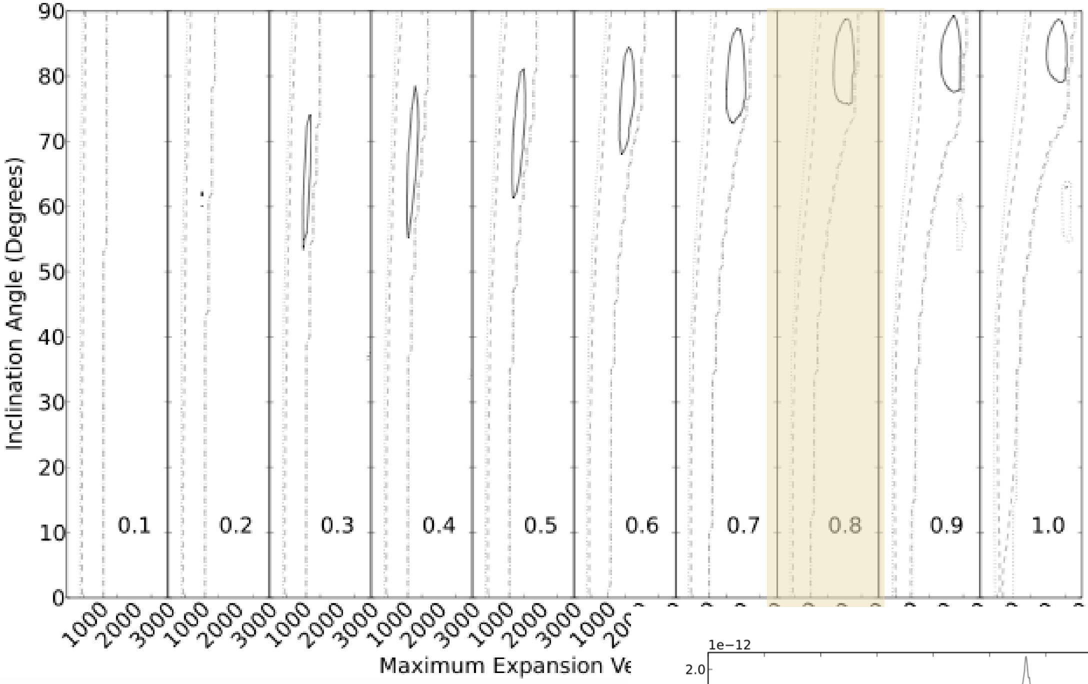


- When common-envelope and the WD rotation are combined the observed prolate remnants can be replicated (Porter et al. 1998, MNRAS, 296, 943)
- Multiple-episodes of ejection (Nelson et al. 2014, ApJ, 785, 78)?

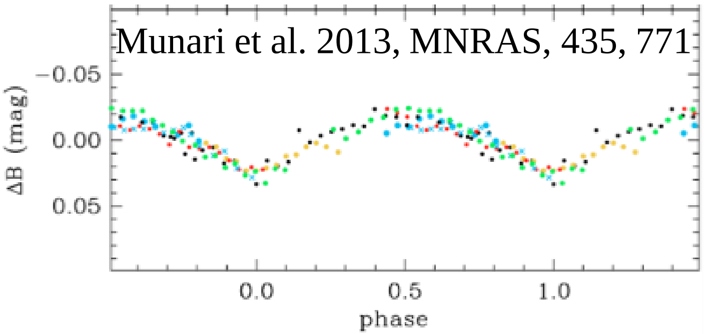
Nova V959 Mon (2012)

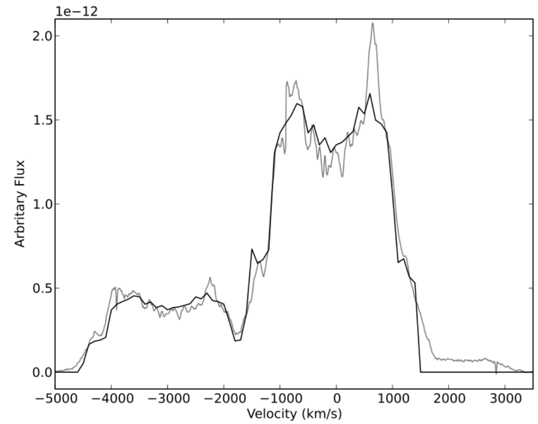
Credit: SKA South Africa

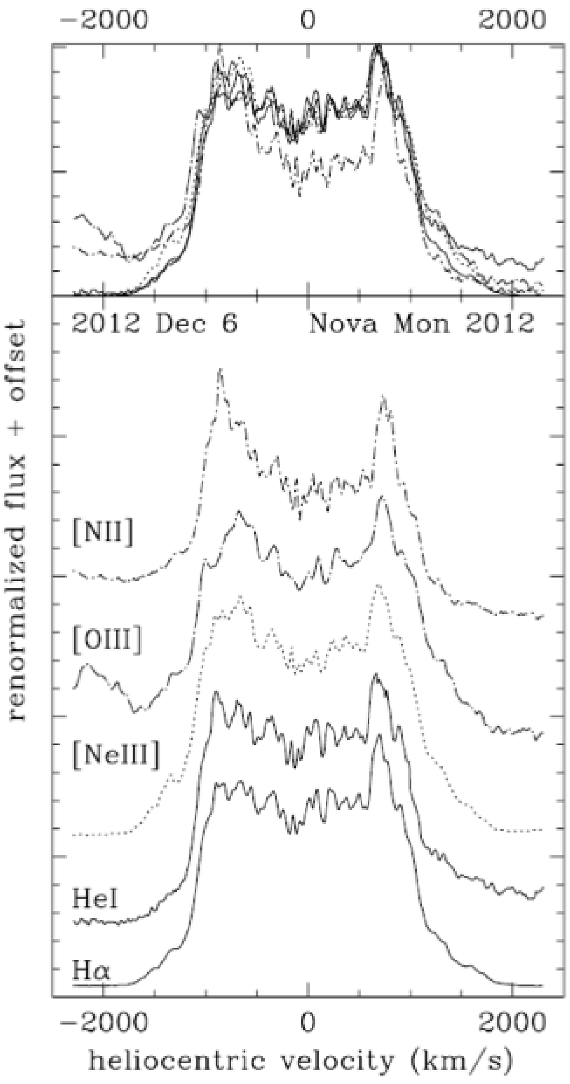
Ribeiro, Munari, & Valisa 2013, ApJ, 768, 1991



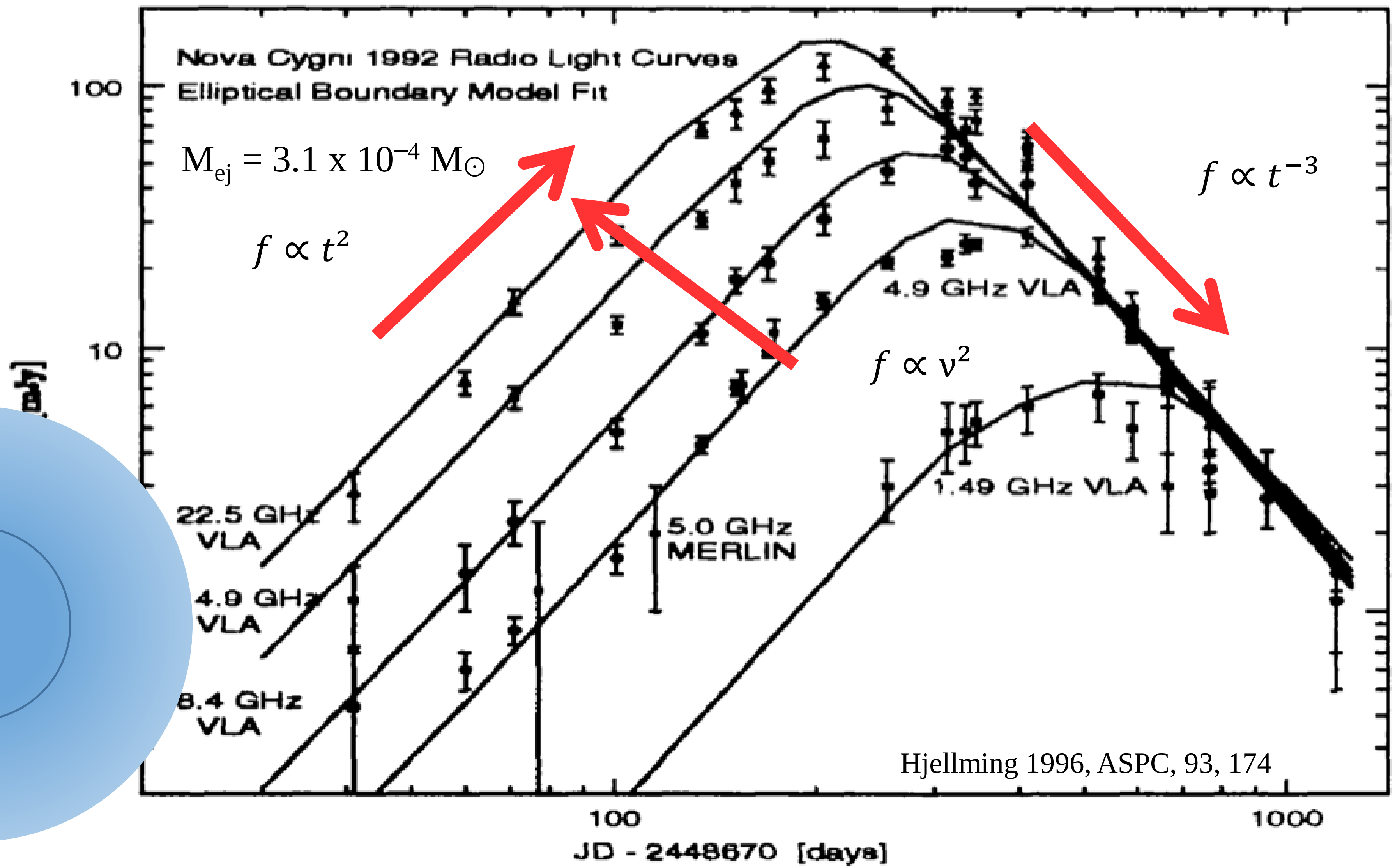
Munari et al. 2013, MNRAS, 435, 771

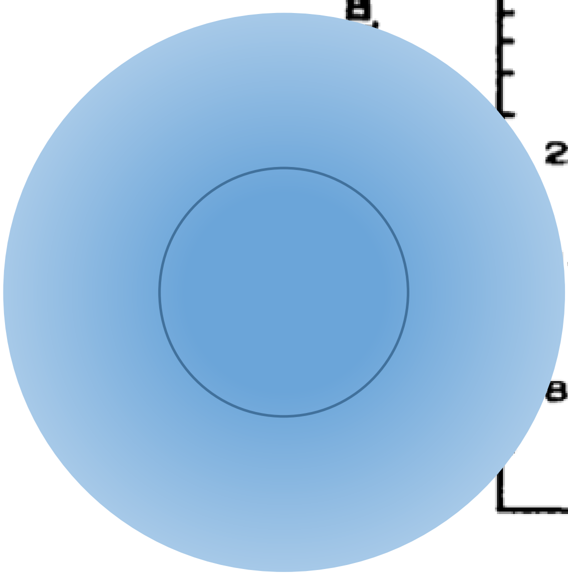






Radio observations of novae

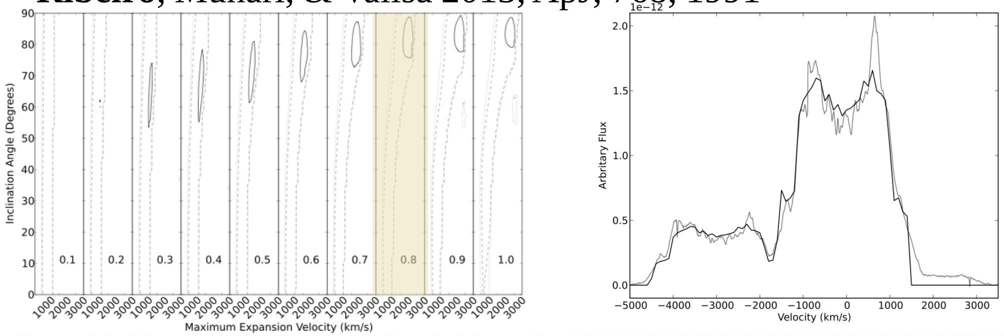


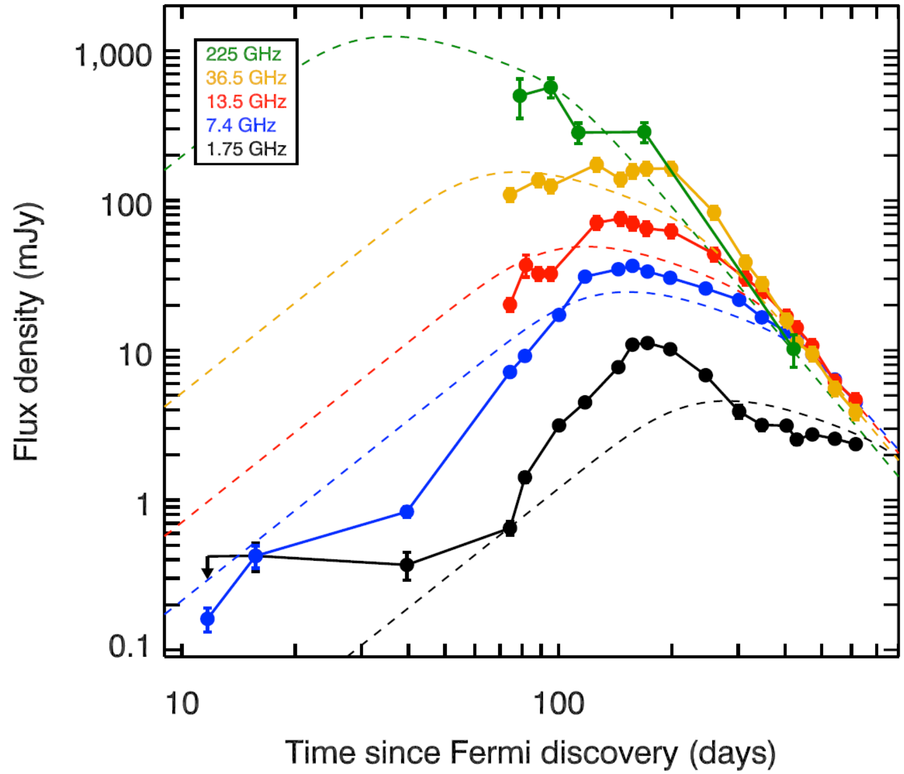


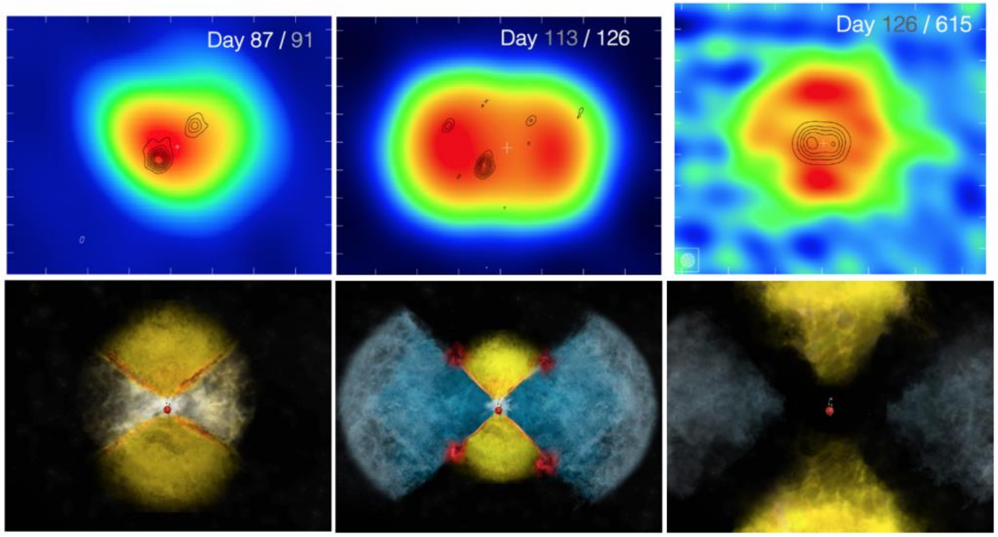
Nova V959 Mon (2012)

Credit: SKA South Africa

Ribeiro, Munari, & Valisa 2013, ApJ, 768, 1991



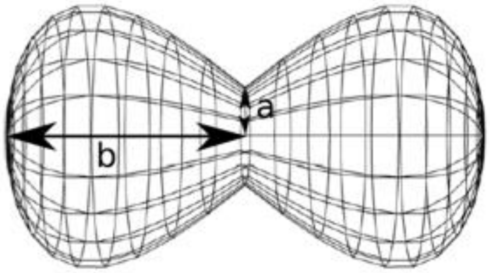




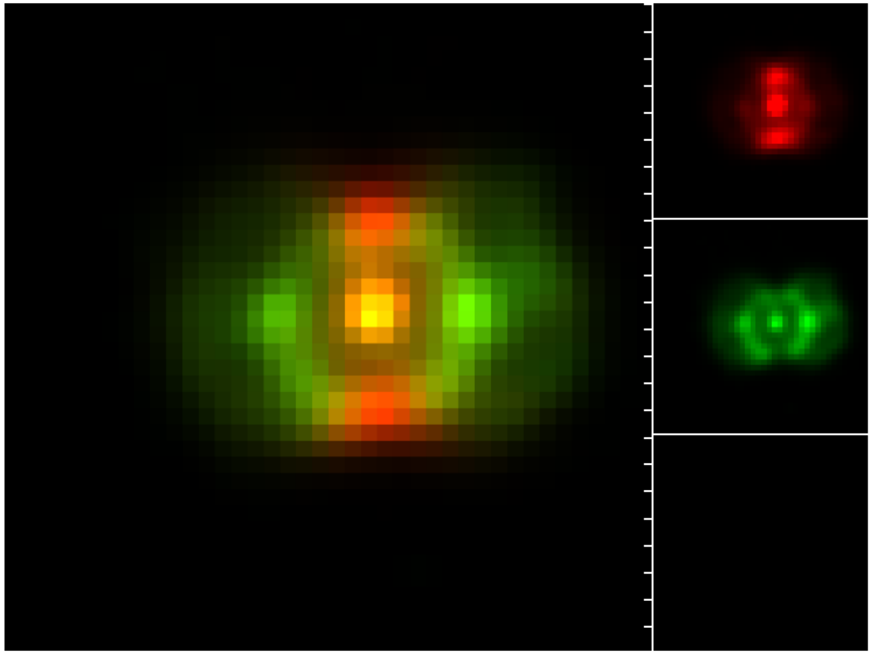
Chomiuk, …, **Ribeiro** et al. 2014, Nature, 514, 339
Credit: B. Saxton, NRAO/AUI/NSF

Nova V959 Mon (2012)

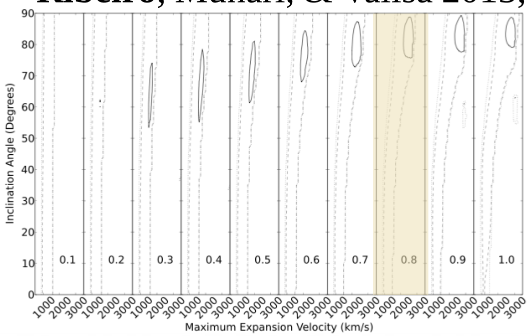
Credit: SKA South Africa

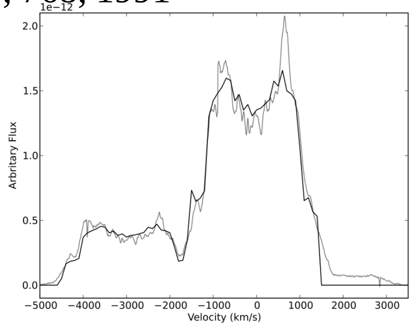


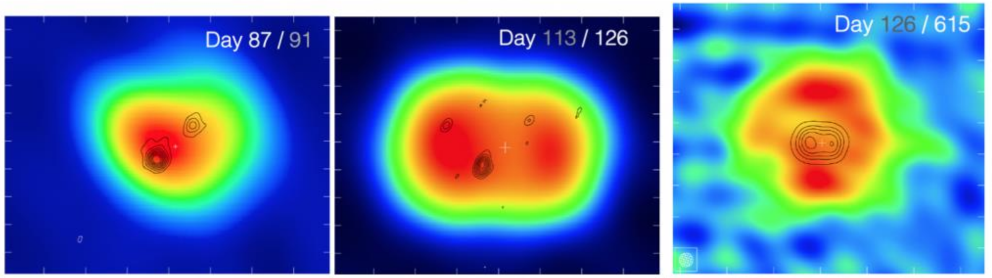
In preparation with Jeno Sokoloski at Columbia University

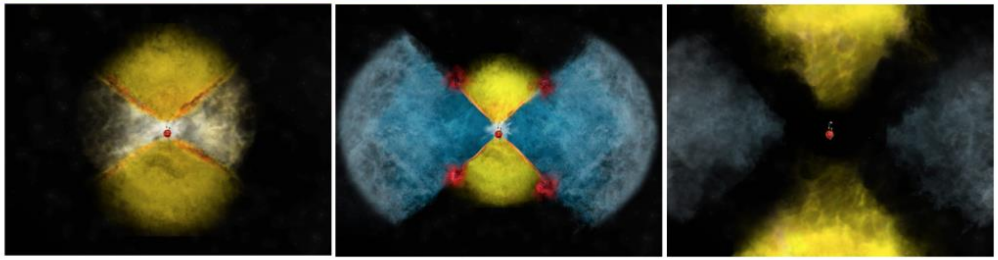


Ribeiro, Munari, & Valisa 2013, ApJ, 768, 1991









Chomiuk, …, **Ribeiro** et al. 2014, Nature, 514, 339
Credit: B. Saxton, NRAO/AUI/NSF

Non-thermal emission

Year	Object
2010 (7)	**V407 Cyg**

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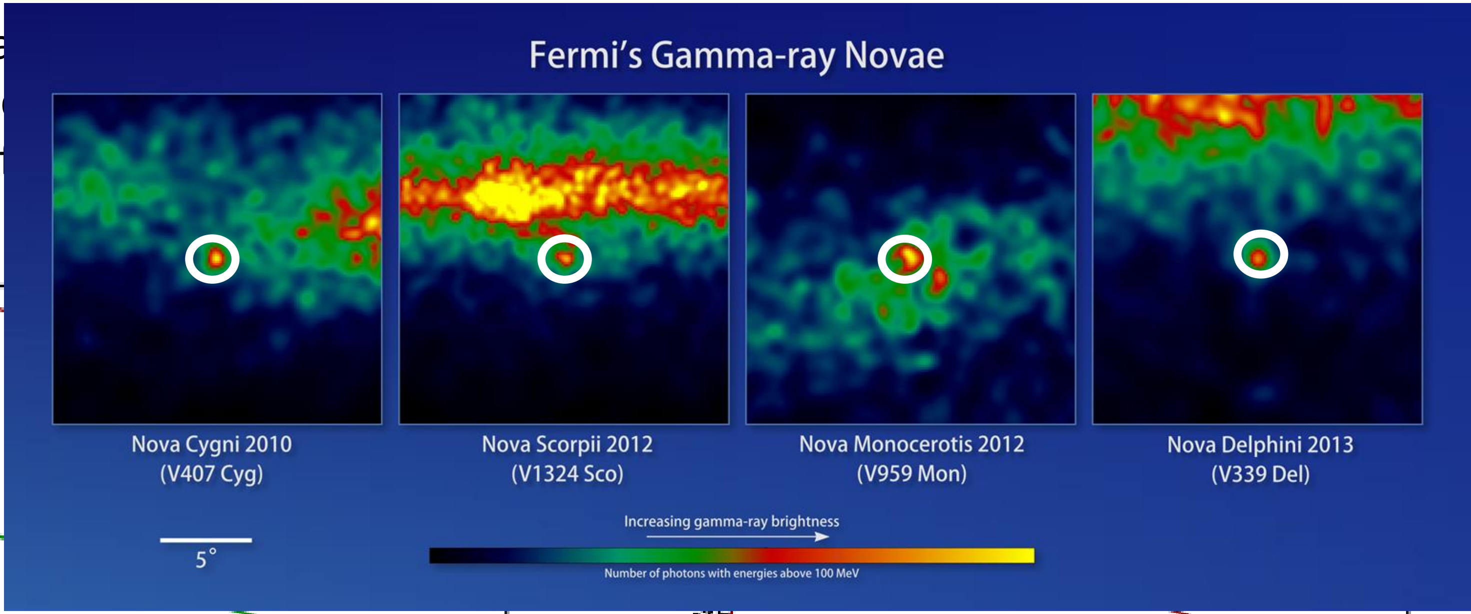
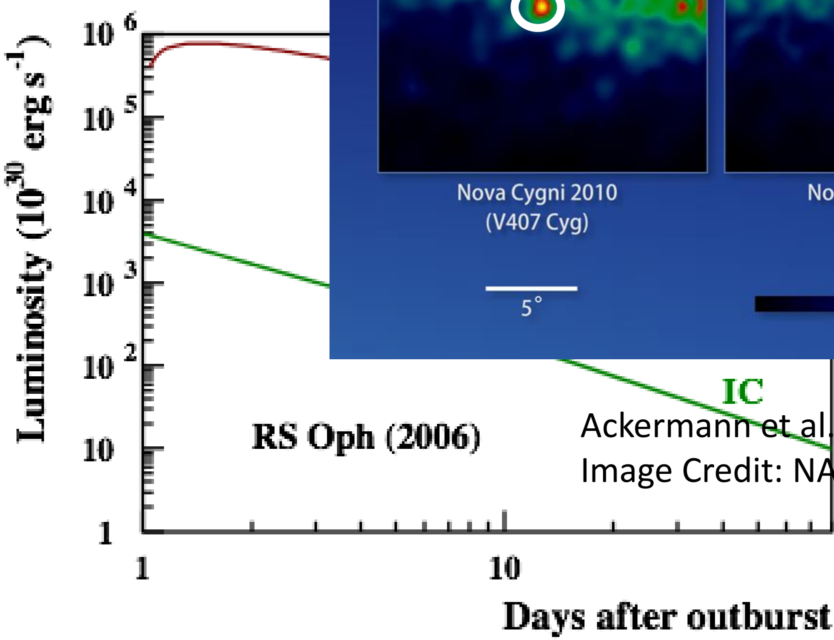
Tatische

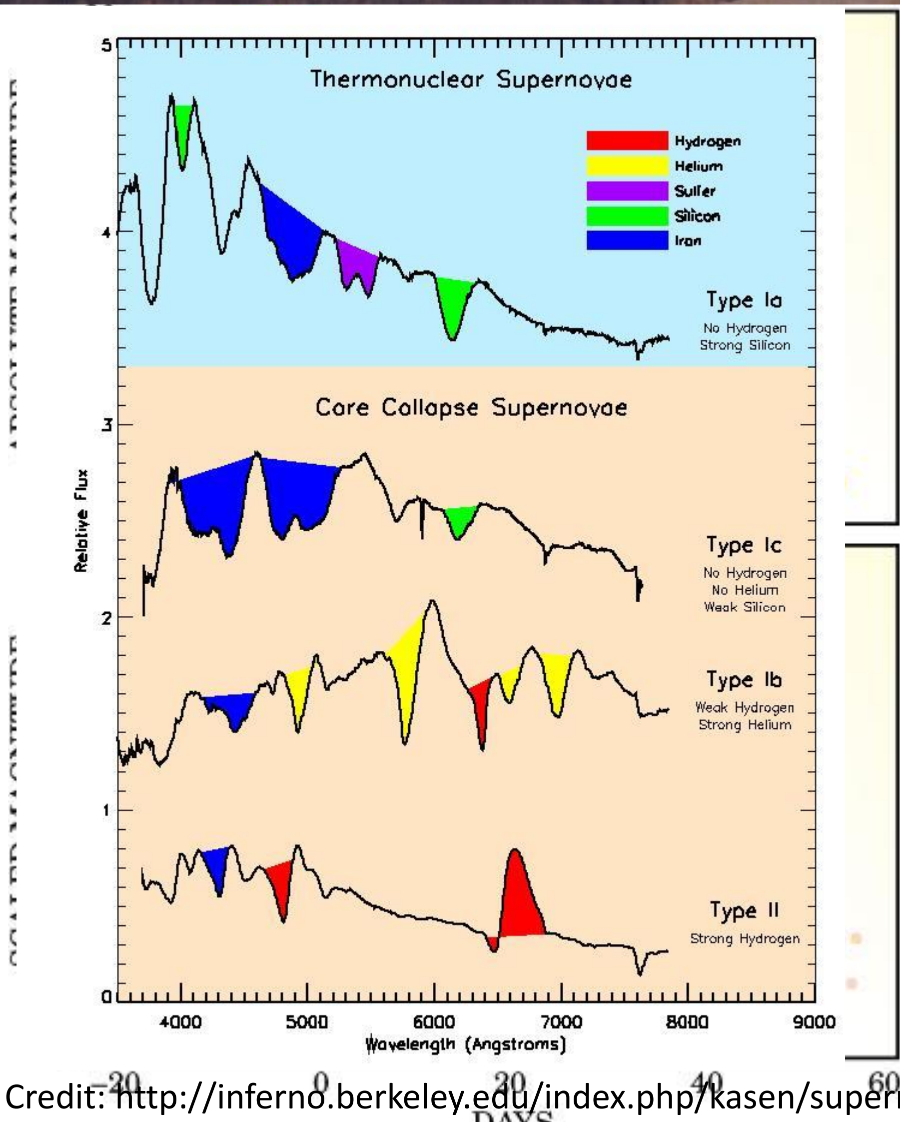




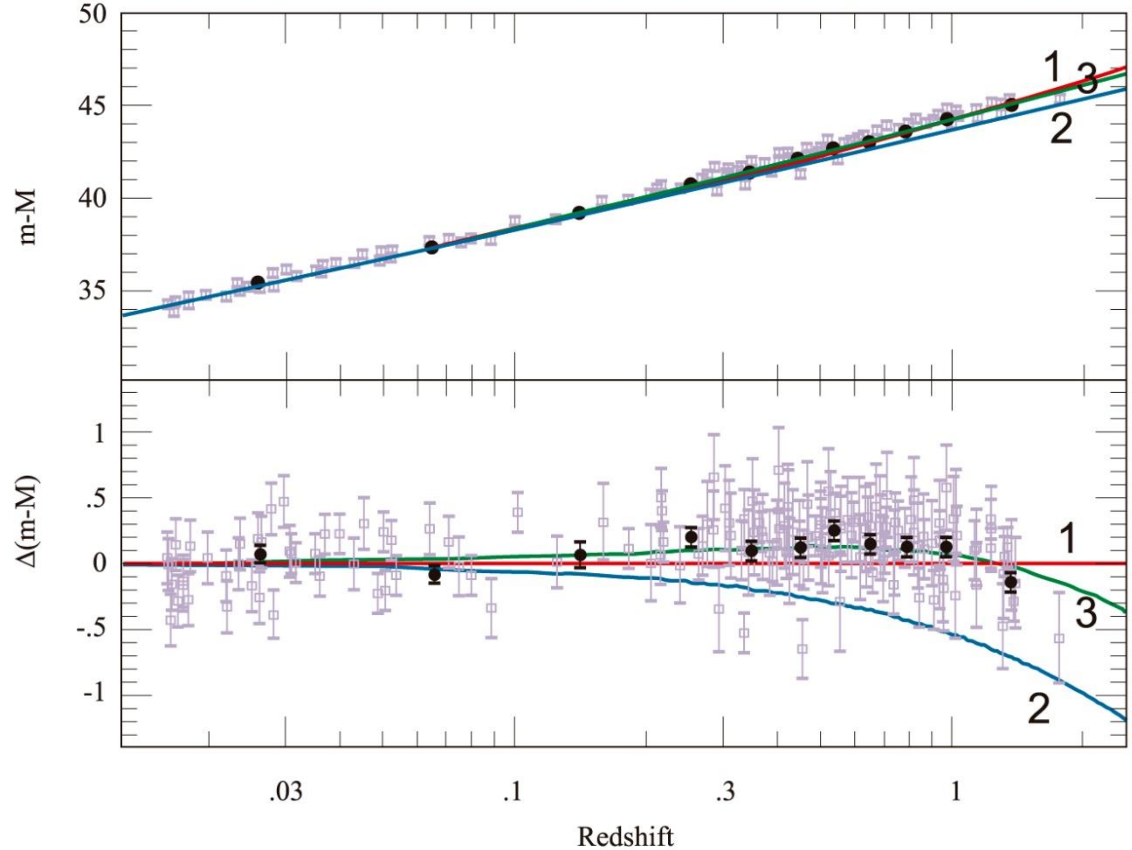
Ackermann et al. 2014, Science, 345, 6196
Image Credit: NASA/DOE/Fermi LAT Collaboration

Type Ia Supernovae

Credit: SKA South Africa



Credit: http://inferno.berkeley.edu/index.php/kasen/supernovae/

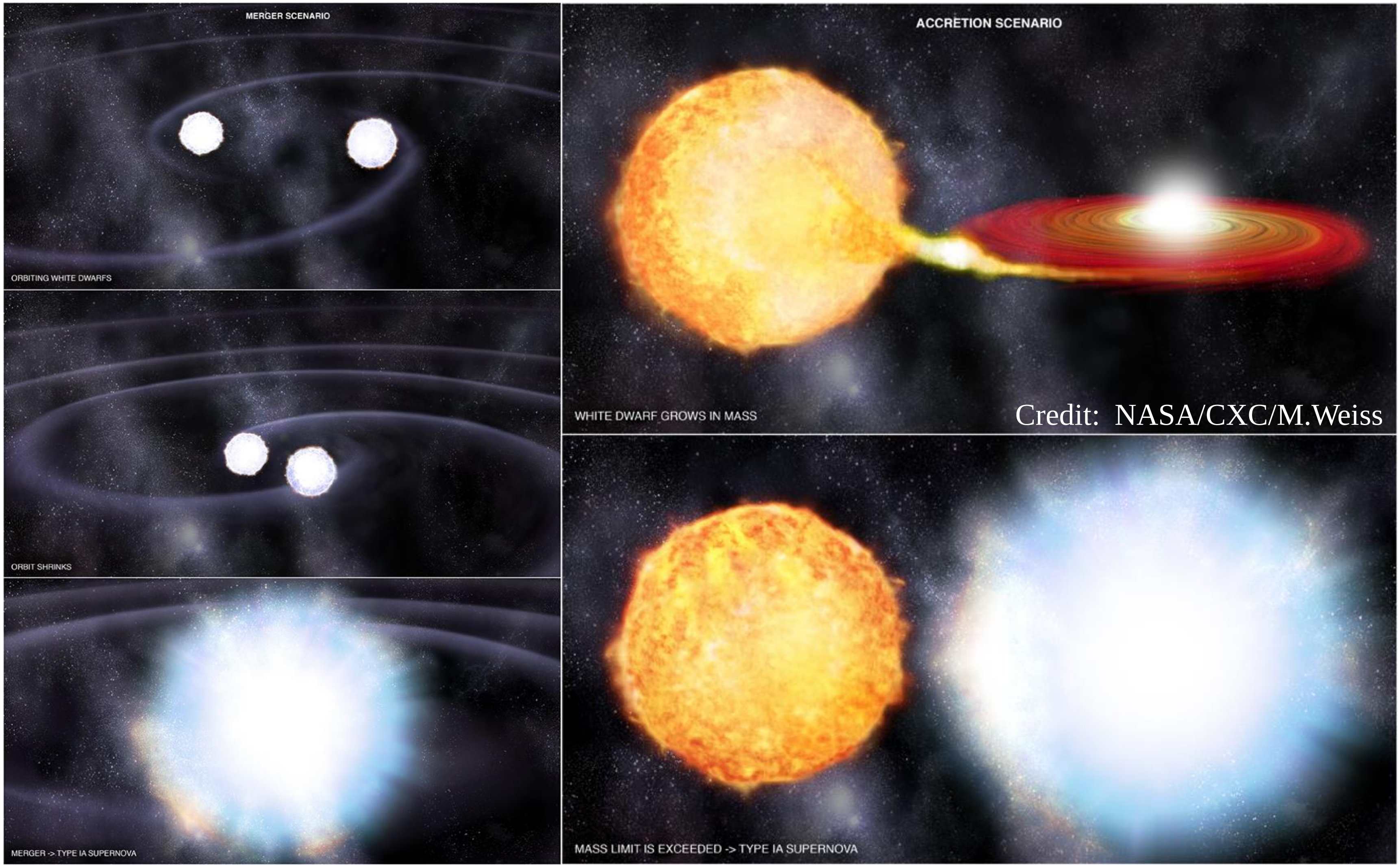


Davis et al. 2007, ApJ, 666, 716

José 2015, Stellar Explosions: Hydrodynamics and Nucleosynthesis

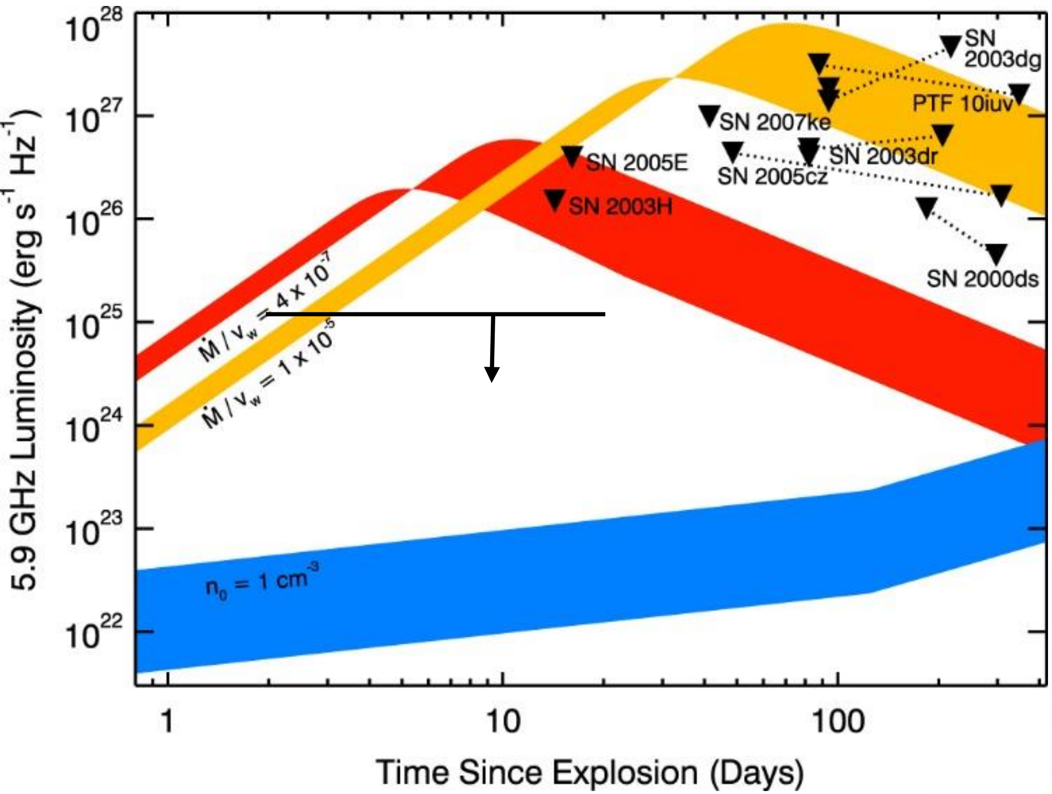
Type Ia Supernovae

Credit: SKA South Africa

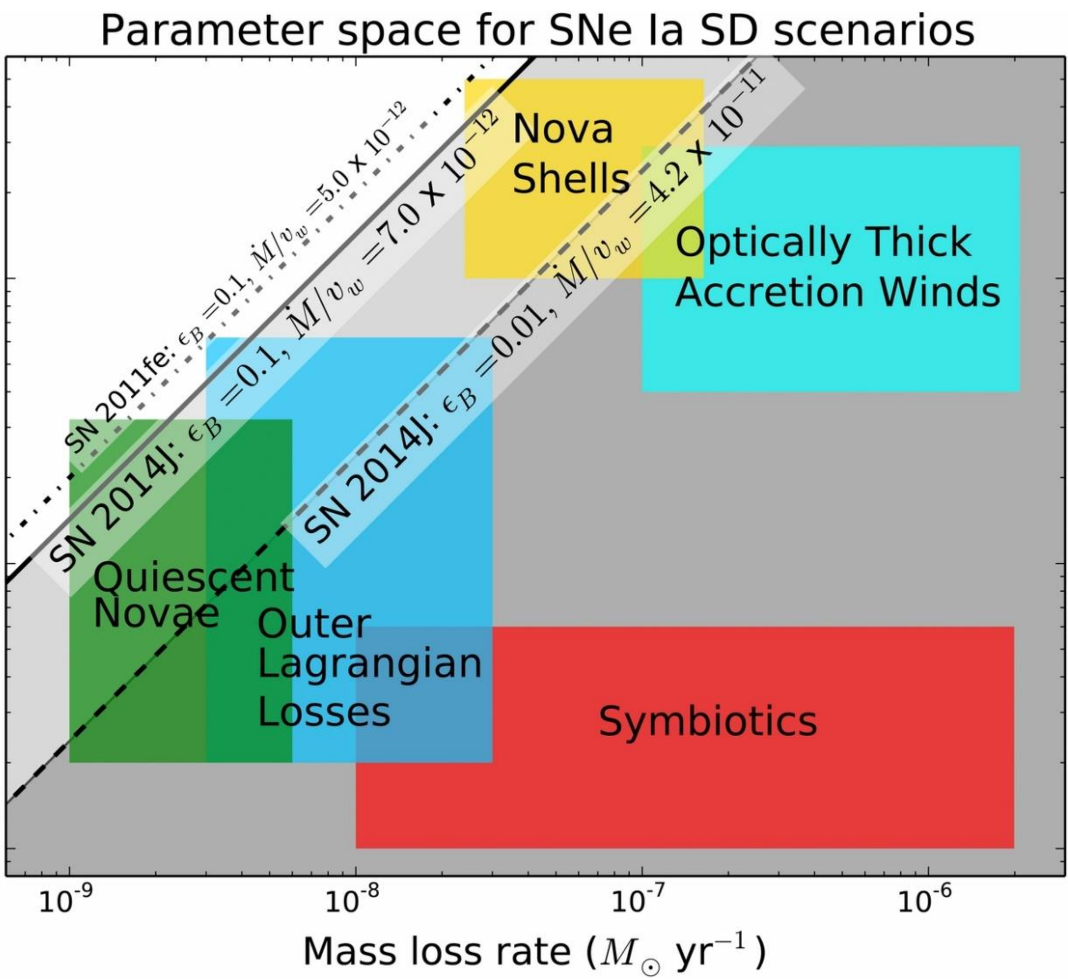


Credit: NASA/CXC/M.Weiss

Type Ia Supernovae



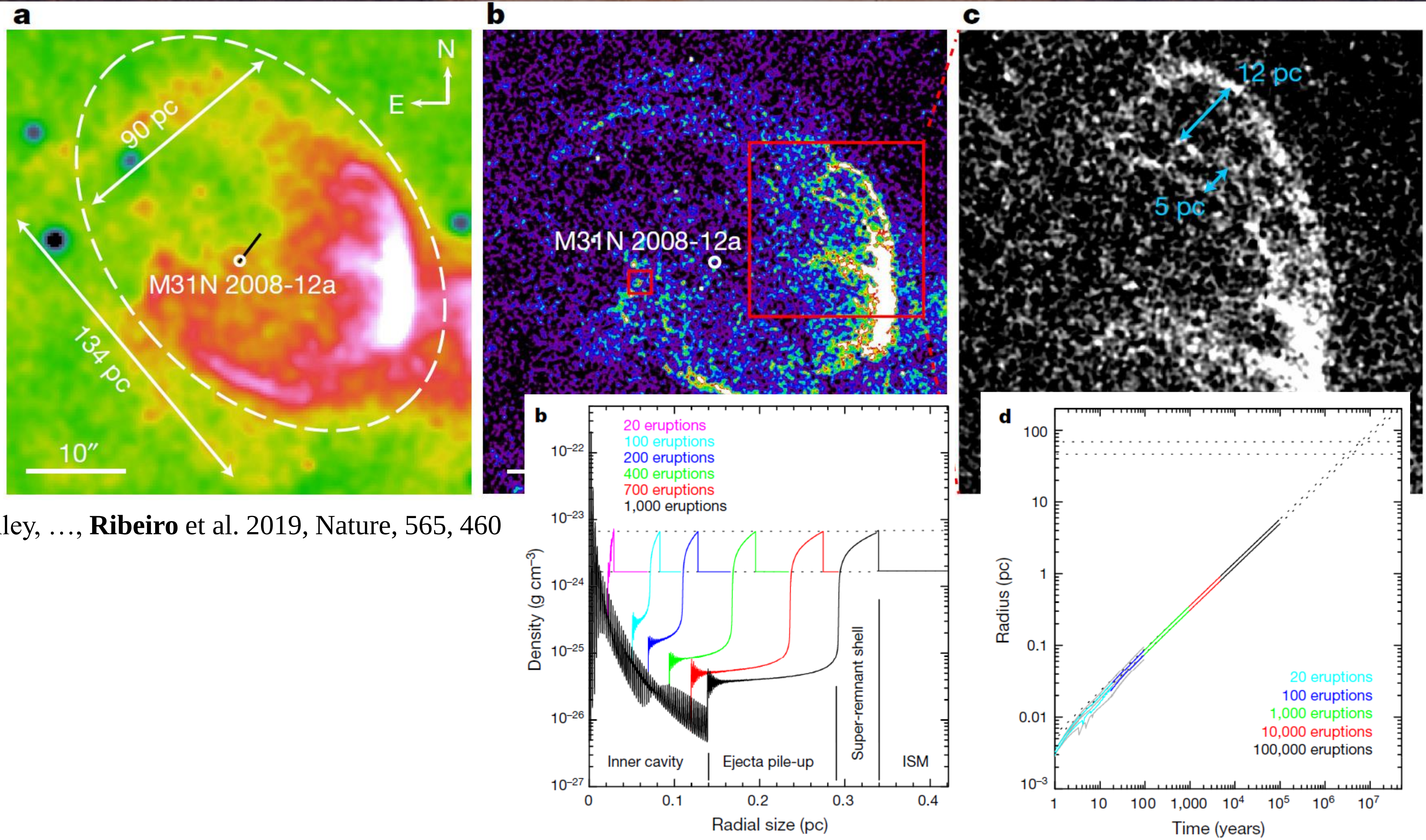
Chomiuk et al. 2016, ApJ, 821, 119
Chomiuk et al. 2012, ApJ, 750, 164



Pérez-Torres et al. 2014, ApJ, 792, 38
Chomiuk et al. 2012 ApJ, 750, 164

Locally relevant?

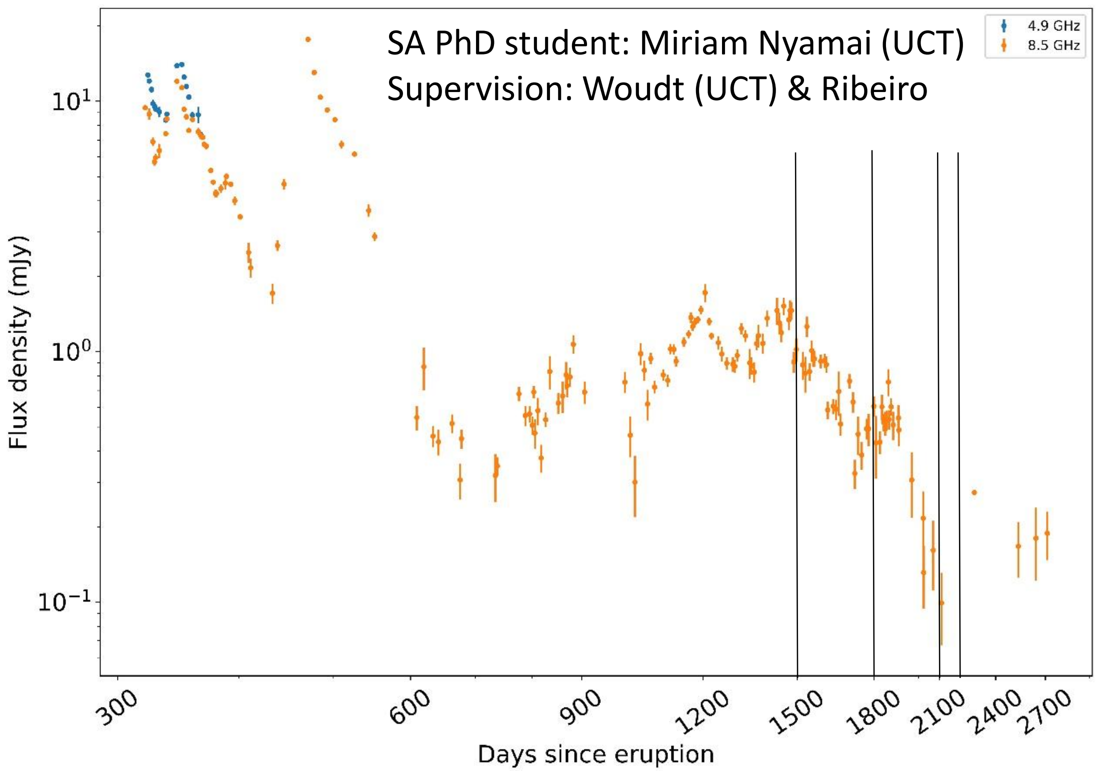
Credit: SKA South Africa

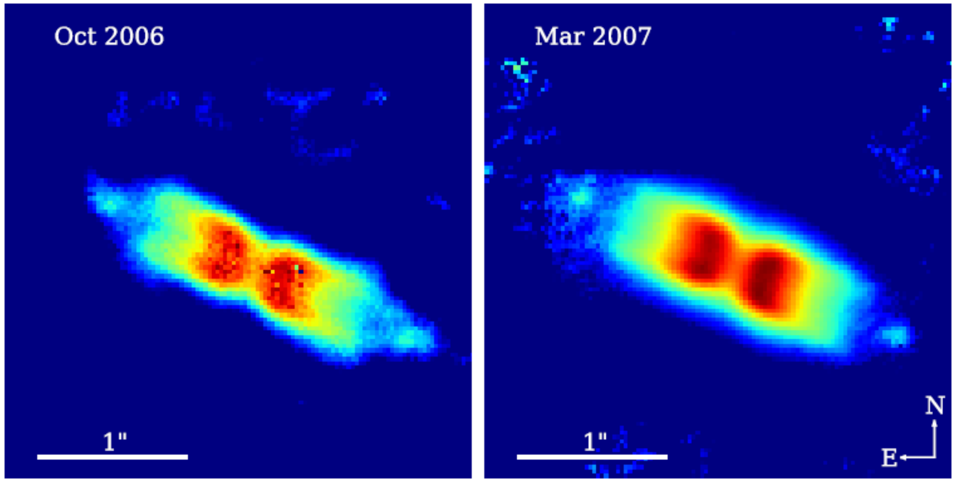


Darnley, …, **Ribeiro** et al. 2019, Nature, 565, 460

The tip of the iceberg

Credit: SKA South Africa



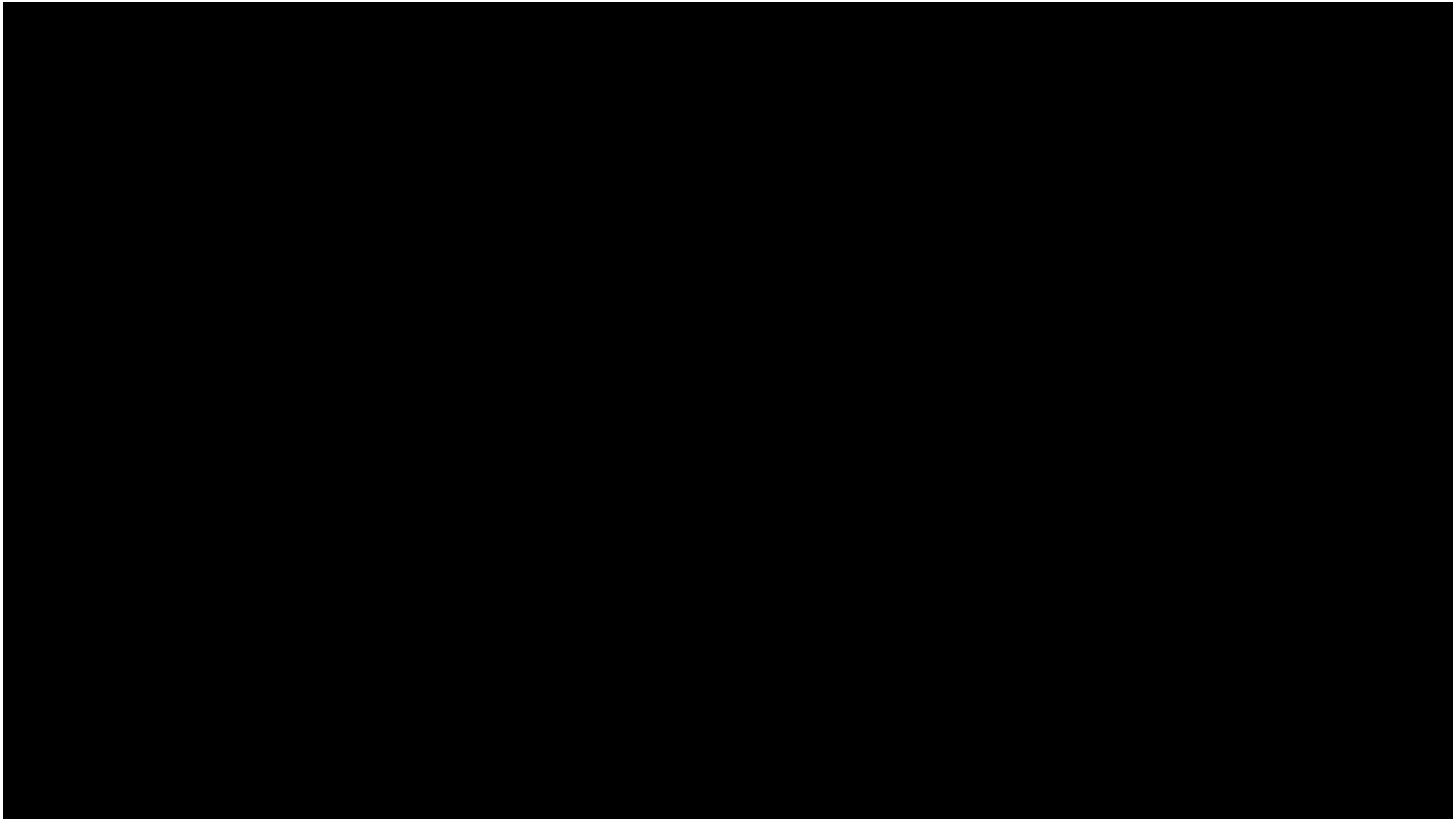


Woudt et al. 2009, Astrophysical Journal, 706, 738

- V455 Pup (30 December 2000)
- Carbon rich, Helium and no Hydrogen
- Near-infrared observations
- NAOS/CONICA – VLT
- Polar outflows at 6720 km/s
- Faster moving knots at 8450 km/s

The Square Kilometre Array (SKA)

Credit: SKA South Africa



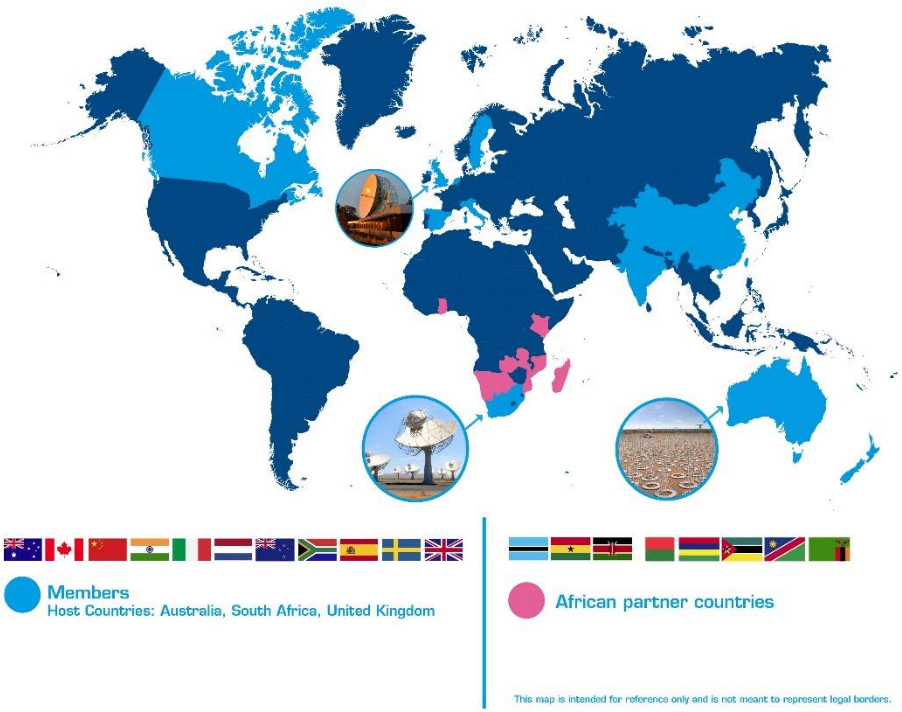
The SKA


Credit: SKA South Africa

- 3 sites; 2 telescopes + HQ, 1 Observatory
- 2 phases:
  - Phase 1 – Construction 2018-2024
  - Phase 2 – Construction 2024-2033

	SKA_LOW (Australia)	SKA_MID (South Africa)
Sensors	130k (500k) dipoles	197 (2000) dishes
Frequency range	50-350 MHz	0.45-15 GHz
Collecting area	0.4 km^2	0.3 km^2
Max baseline	65 (~5000) km	150 (~3000) km
Raw data output	157 Terabyte/sec 0.49 Zettabyte/yr	3.9 Terabyte/sec 122 Exabyte/yr
Science archive	0.4 Petabyte/day	3 Petabyte/day

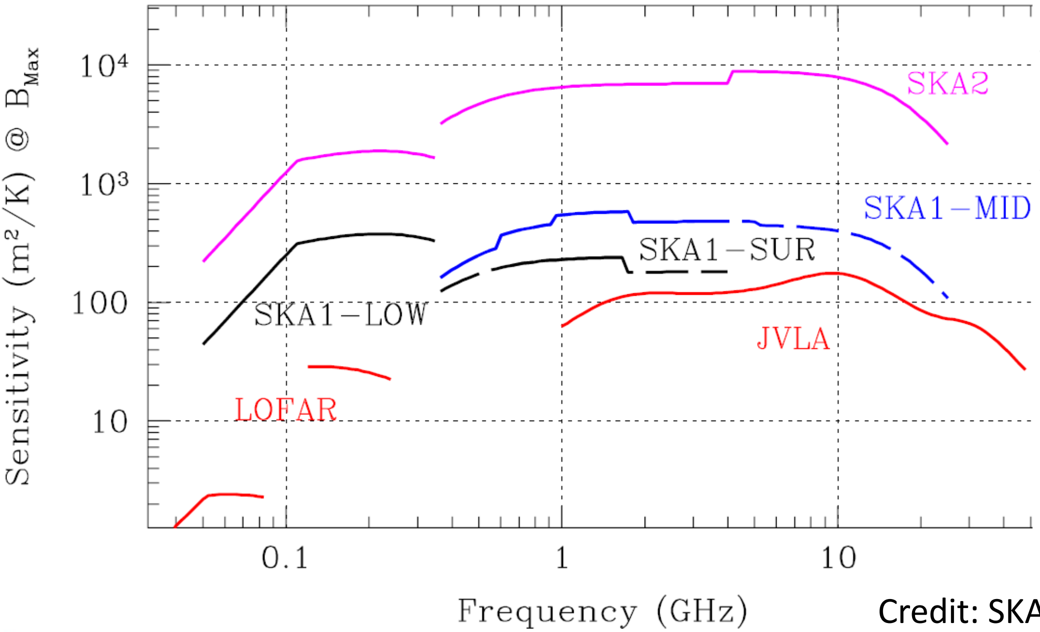
1 Zettabyte = 10^3 Exabyte = 10^6 Petabyte = 10^9 Terabyte = 10^{12} Gigabyte

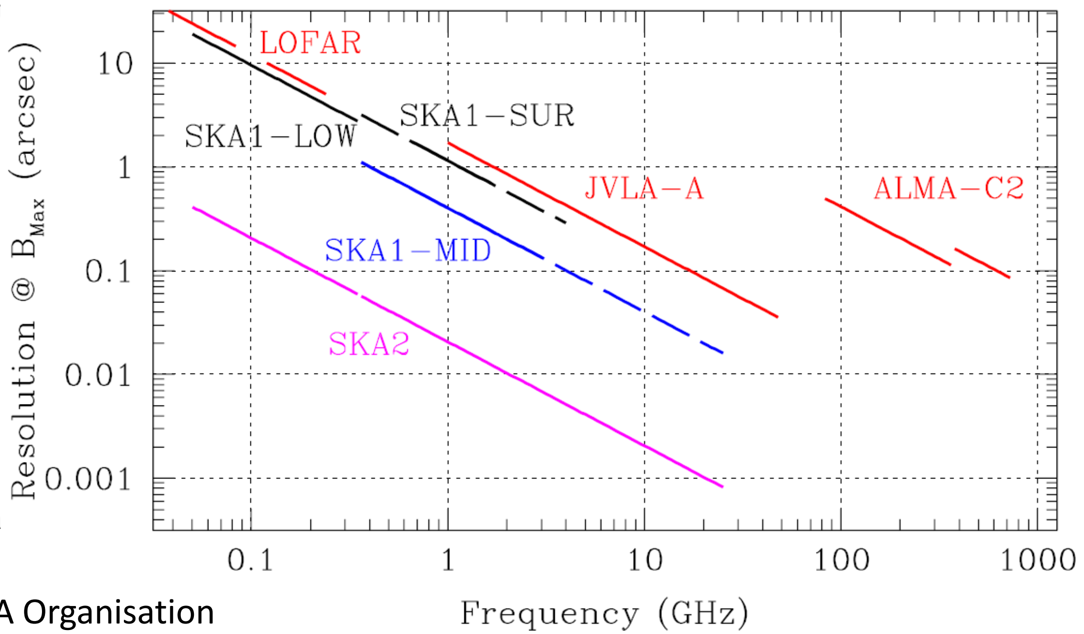


Credit: SKA Organisation

The SKA

Credit: SKA South Africa



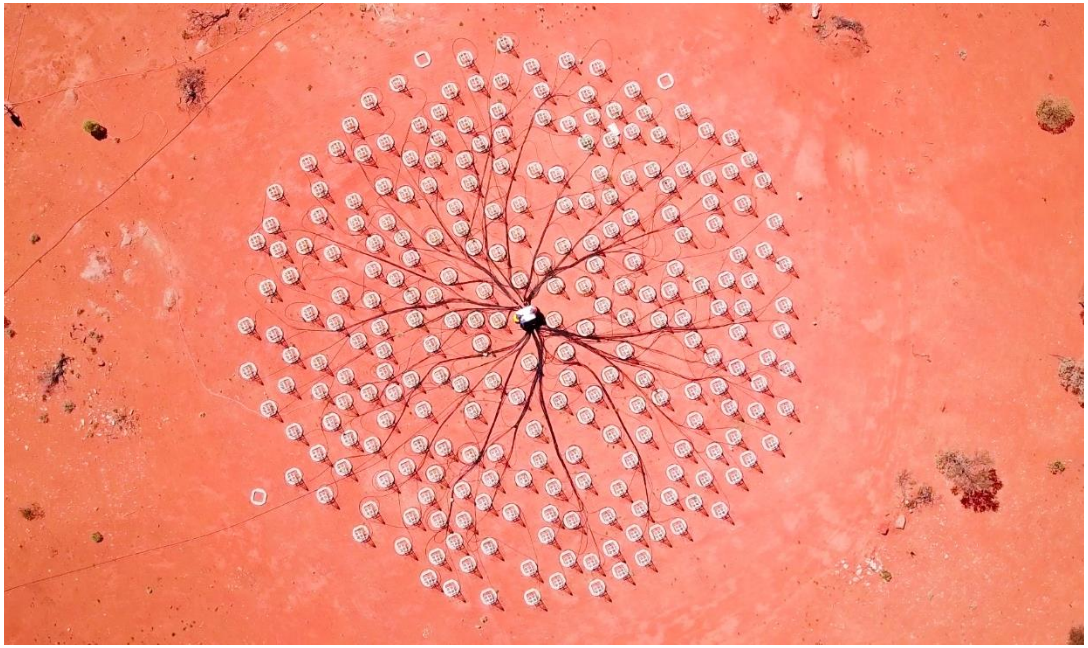


Credit: SKA Organisation

50 MHz **100 MHz** **1GHz** **10GHz**

The SKA

Credit: SKA South Africa

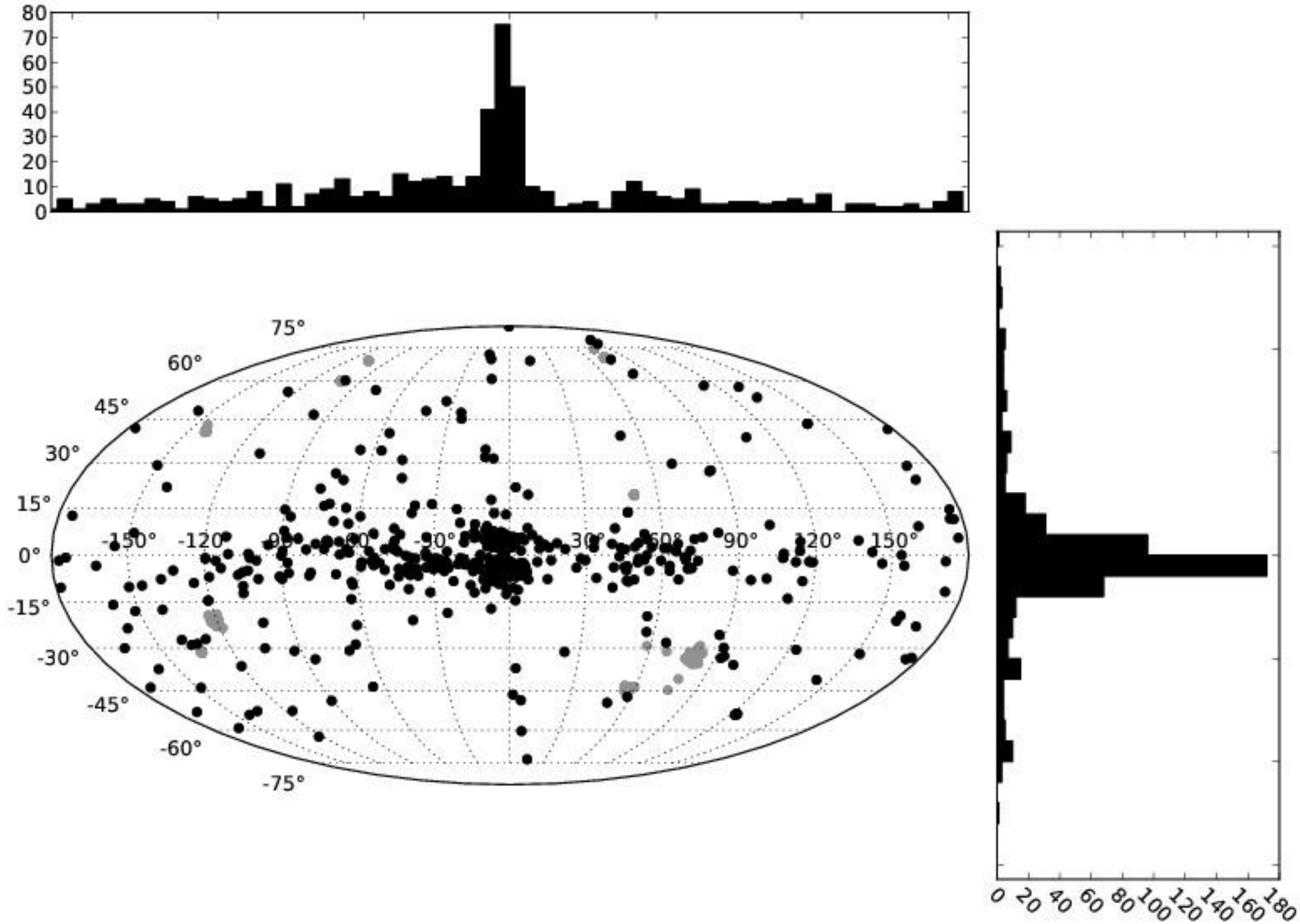


Credit: ICRAR/Curtin University

Credit: SKA Organisation

Novae in the SKA era

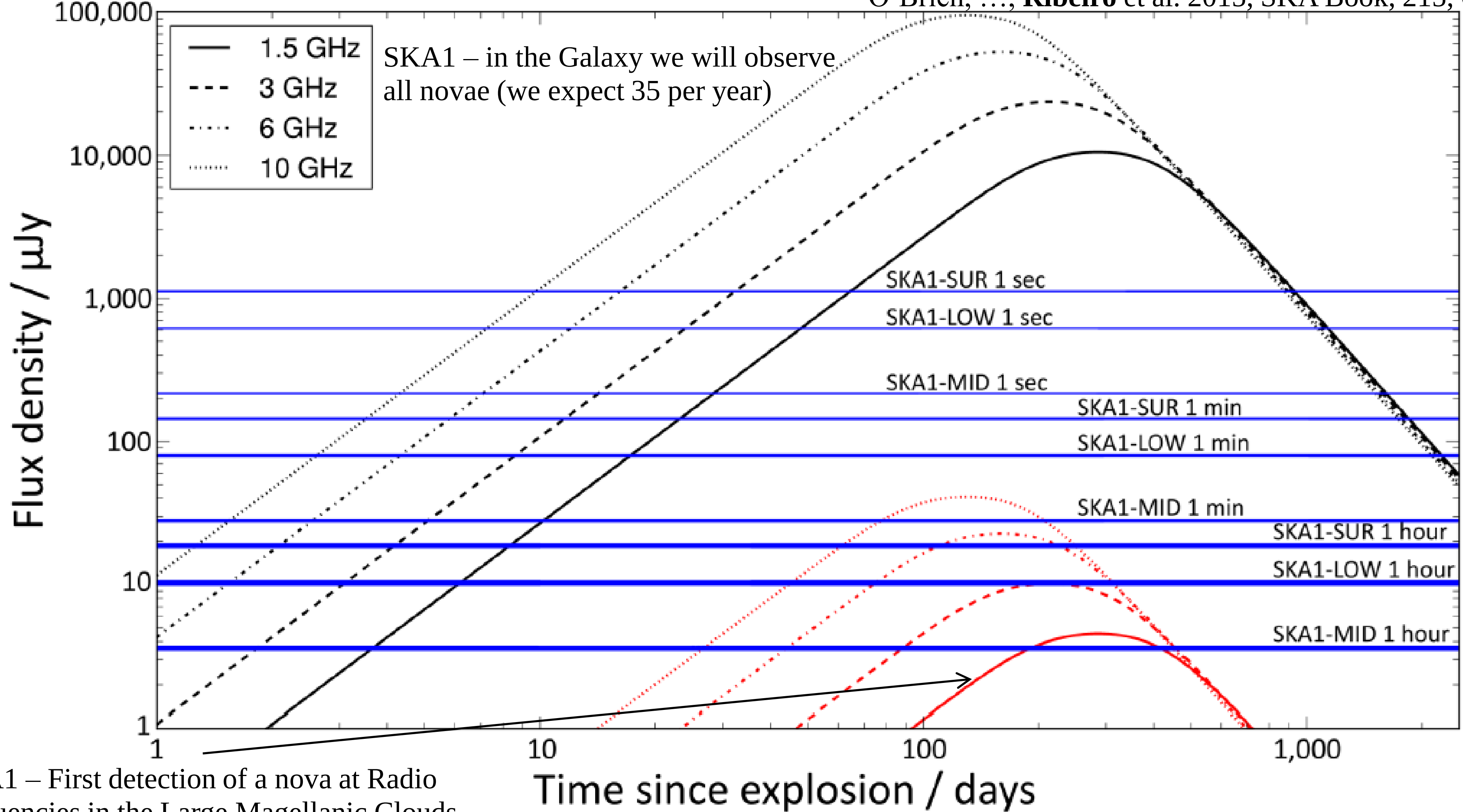
Credit: SKA South Africa



Novae in the SKA era

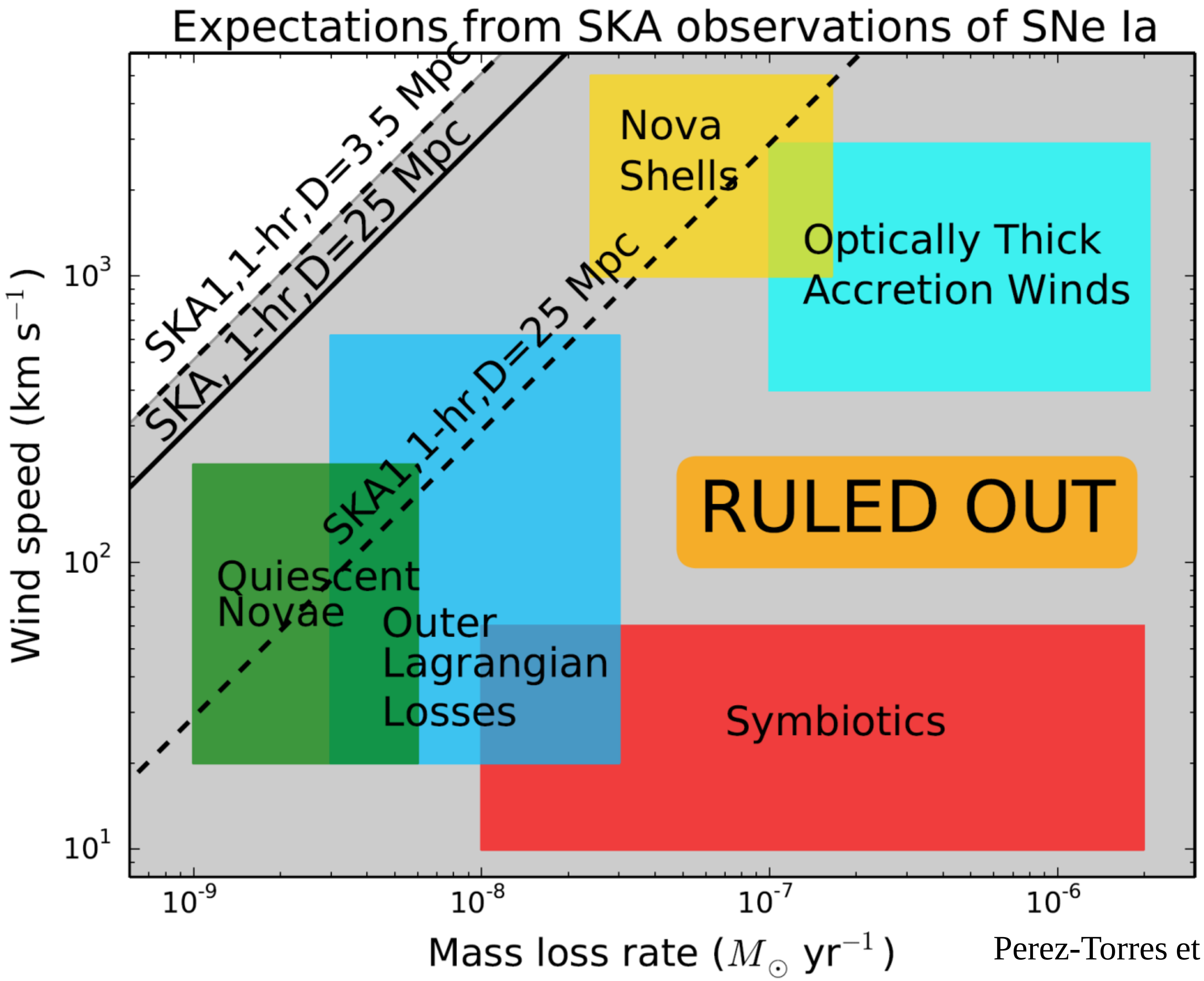
Credit: SKA South Africa

O’Brien, …, **Ribeiro** et al. 2015, SKA Book, 215, 62



SKA1 – First detection of a nova at Radio frequencies in the Large Magellanic Clouds

Type Ia supernova in the SKA era



Perez-Torres et al. 2014, AASKA, 060

MeerKAT – a SKA Precursor

Credit: SKA South Africa

- 64 dishes over an 8-km baseline
- 13.5-m offset Gregorian
- Compact core, extended baseline
- Most sensitive cm-wavelength instrument in the southern hemisphere
- First dish constructed in 2015, 64^{th} dish October 2017
- Full science second quarter 2018

Credit: SKA South Africa

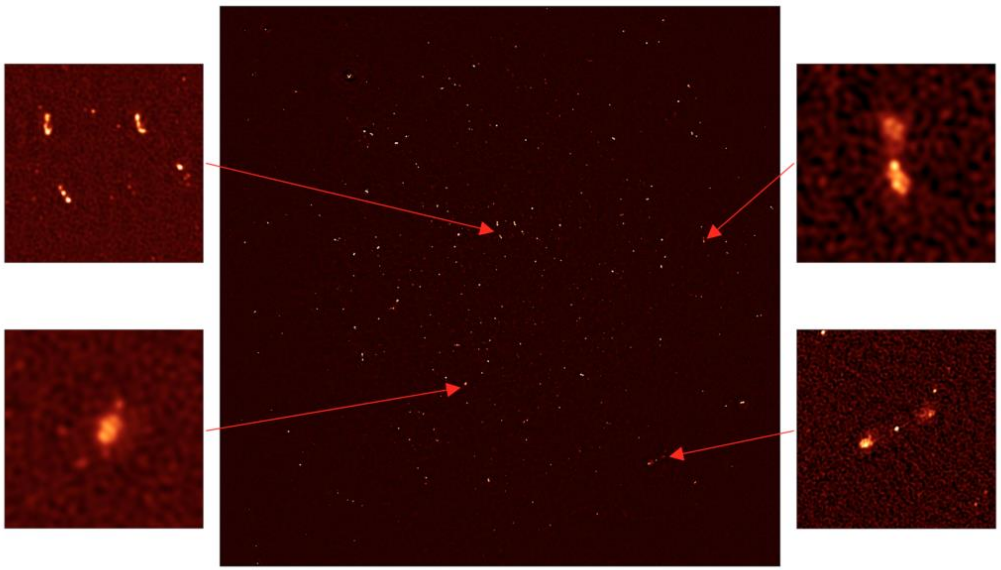
MeerKAT – a SKA Precursor

Credit: SKA South Africa

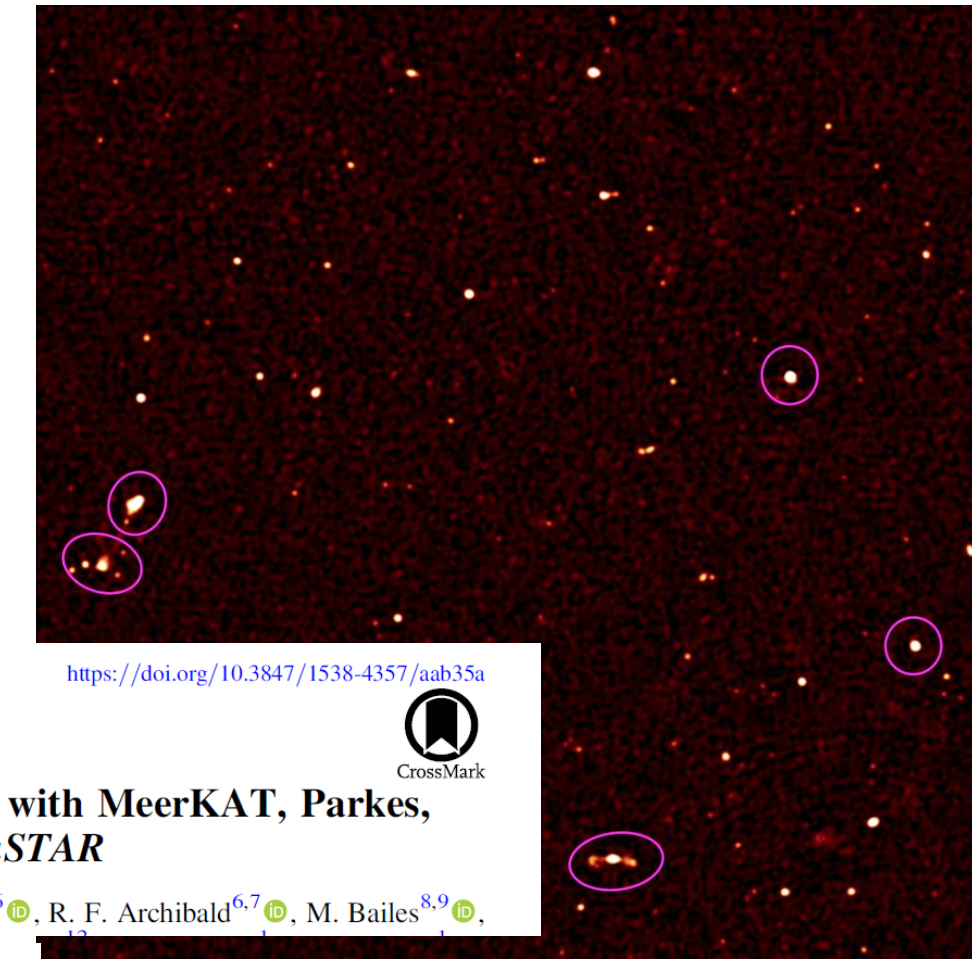
Credit: SKA South Africa

MeerKAT – a SKA Precursor

Credit: SKA South Africa



Credit: SKA South Africa



The Astrophysical Journal, 856:180 (11pp), 2018 April 1
https://doi.org/10.3847/1538-4357/aab35a

OPEN ACCESS

CrossMark

Revival of the Magnetar PSR J1622–4950: Observations with MeerKAT, Parkes, *XMM-Newton*, *Swift*, *Chandra*, and *NuSTAR*

F. Camilo[1], P. Scholz[2], M. Serylak[1,3,4], S. Buchner[1], M. Merryfield[2,5], V. M. Kaspi[6], R. F. Archibald[6,7], M. Bailes[8,9],

The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20
https://doi.org/10.3847/2041-8213/aa91c9

OPEN ACCESS

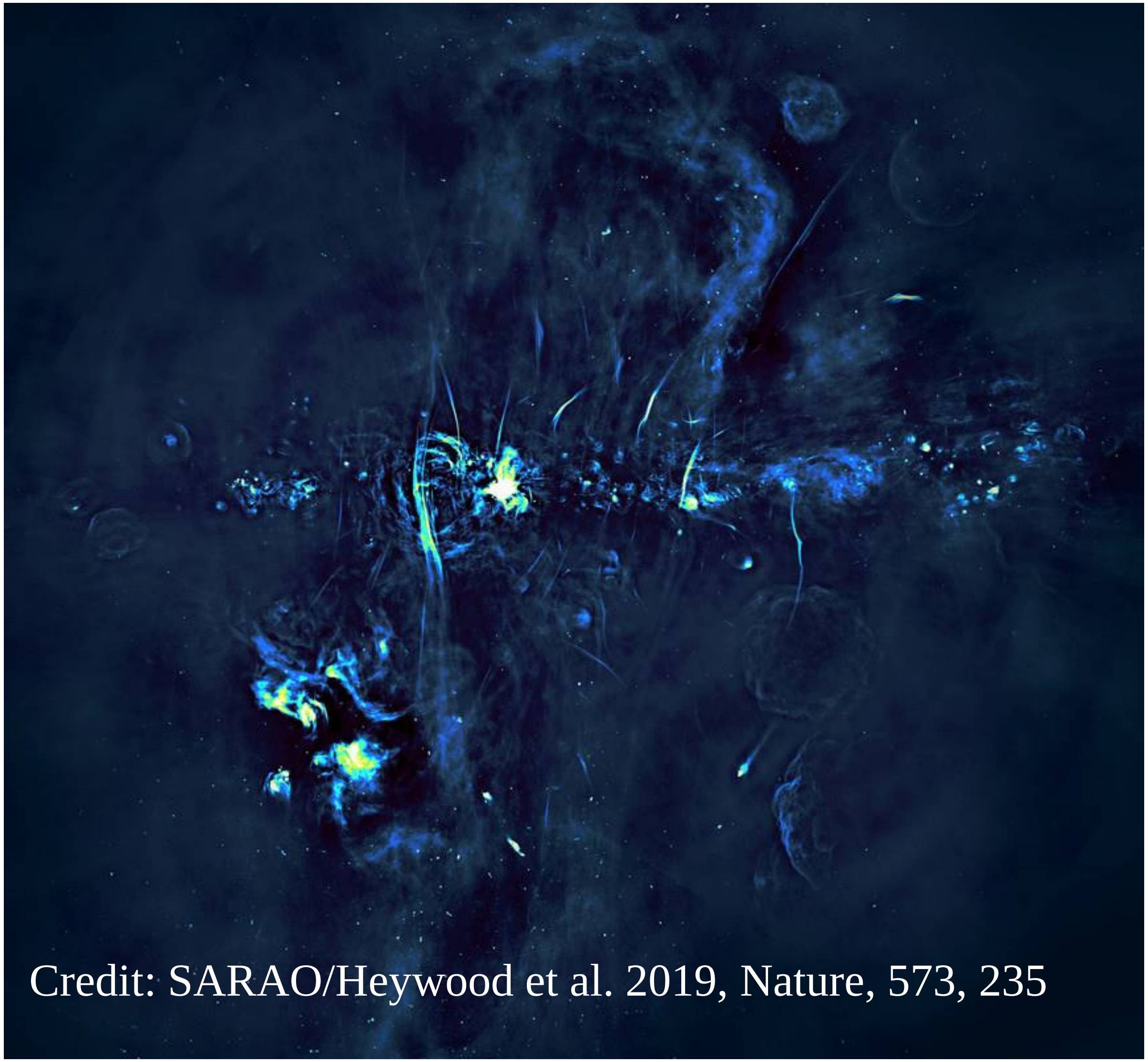
CrossMark

Multi-messenger Observations of a Binary Neutron Star Merger*

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc

MeerKAT – a SKA Precursor

Credit: SKA South Africa



Credit: SARAO/Heywood et al. 2019, Nature, 573, 235

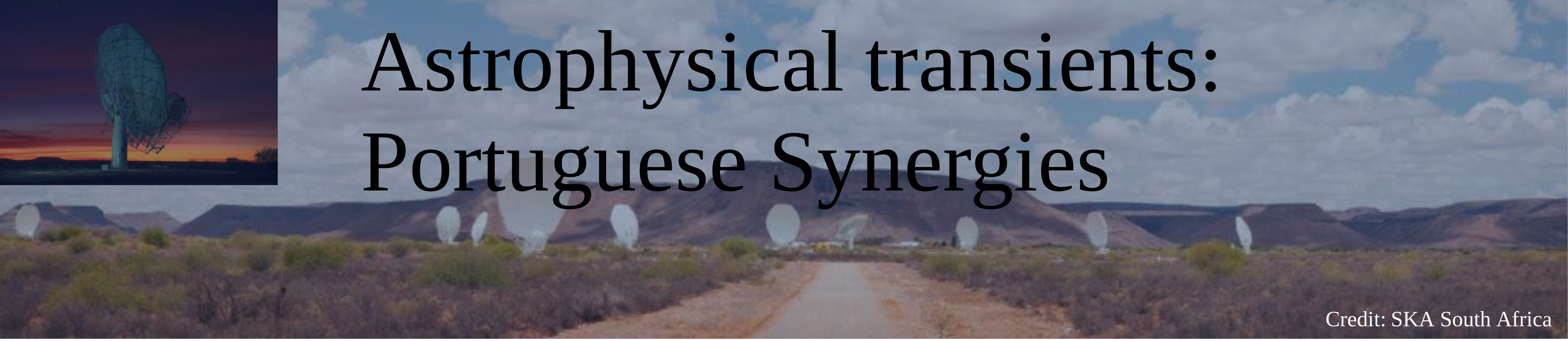
Final thoughts

Credit: SKA South Africa

- We need to understand the origin of gamma-ray emission in nova systems
- Much work is still required to determine accurately the ejecta mass history
- We need also to understand the accretion history of nova systems
- We need to detect more V445 Pup like objects
- Improved radio instruments have opened a new window for our understanding of the nova phenomenon
  - The SKA can discover all the novae in the Galaxy (in it’s observable sky)
  - The SKA will find the first extra-galactic nova
  - We will be able to do different population studies
- We are still on the hunt for what appears to be the elusive progenitor of Type Ia Supernovae
  - ThunderKAT@MeerKAT: systematic search of nearby (D < 20 Mpc) type Ia supernovae
  - Detection will validate the Single Degenerate model
  - Systematic non-detections will be constraining such that all Single Degenerate models are ruled out

Extra slides

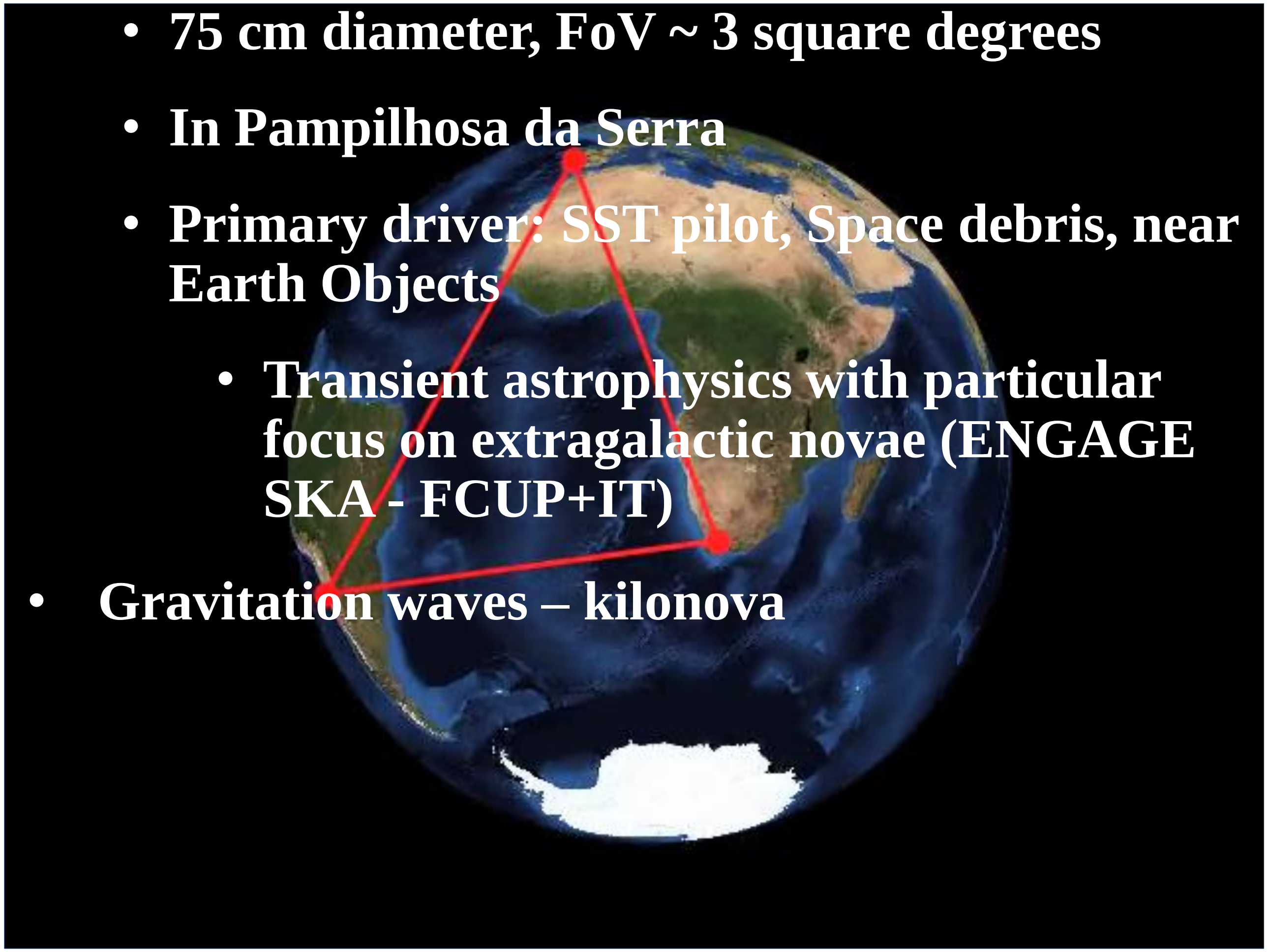
Credit: SKA South Africa



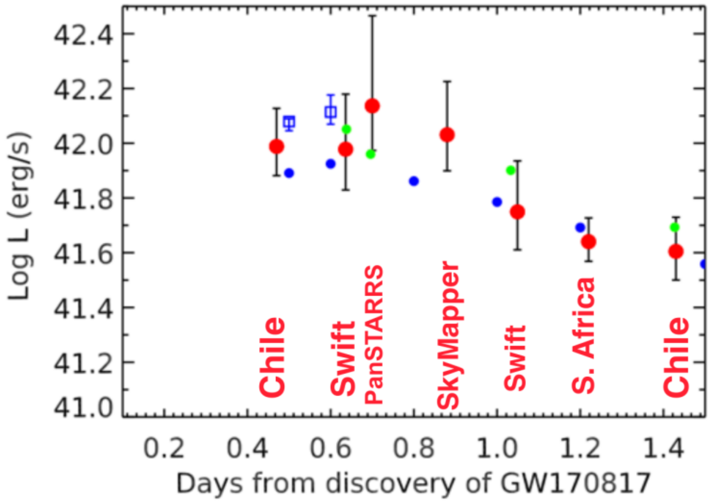
Astrophysical transients: Portuguese Synergies

Credit: SKA South Africa

- Grande Telescópio Óptico (FCUP/ENGAGE SKA)



  - **75 cm diameter, FoV ~ 3 square degrees**
  - **In Pampilhosa da Serra**
  - **Primary driver: SST pilot, Space debris, near Earth Objects**
    - **Transient astrophysics with particular focus on extragalactic novae (ENGAGE SKA - FCUP+IT)**
- **Gravitation waves – kilonova**



Stephen Smartt priv. communication

Astrophysical transients: the radio sample

Credit: SKA South Africa

Transient	Currently	SKA1	SKA2
Core-collapse Supernovae	~50 (over 30 yrs) Improved understanding of supernova proprieties	100s per yr Uncover larger supernova population	1000s per yr Star-formation rate of massive stars
Ia Supernovae	0 Only upper limits on the circumstellar gas	1 per 13 yrs??? Deeper radio limits to circumstellar gas	2 per yr??? Radio and X-ray can discriminate models
Novae	1-2 per yr Can determine individual fundamental quantities	~35 per yr This will unveil statistically complete populations	Similar studies will be possible to the Magellanic Clouds
Kilonovae	1 GW counterpart Start testing our theories	10s – 100s per yr??? Deeper searches and population studies	100s – 1000s per yr??? Completer population studies
…			