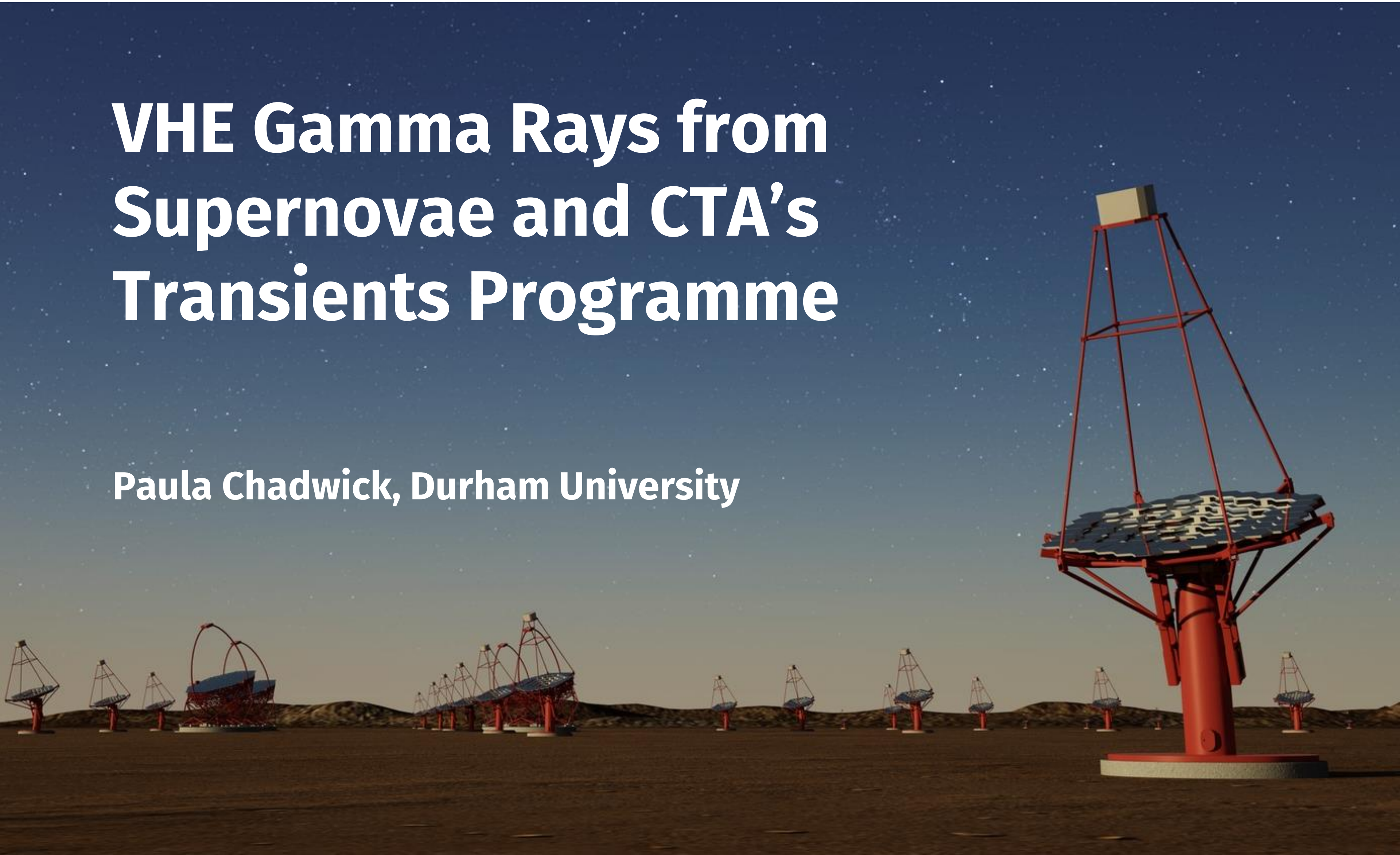
VHE Gamma Rays from Supernovae and CTA's Transients Programme

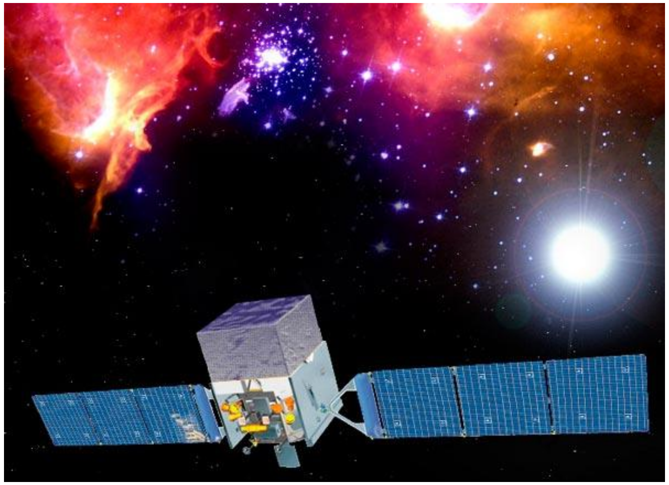
Paula Chadwick, Durham University



Outline

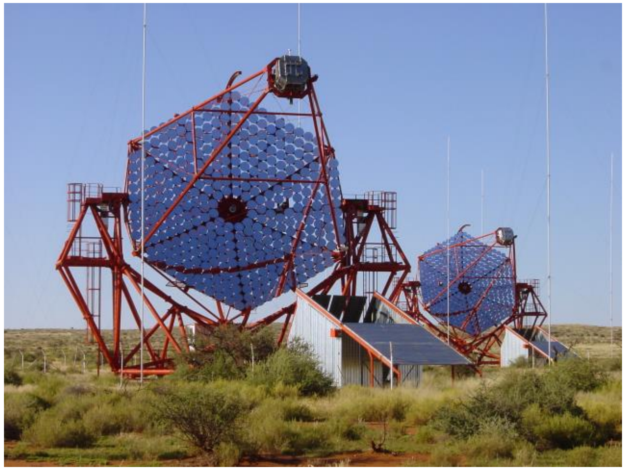
- Detecting VHE gamma rays
- The cosmic ray-supernova connection
- VHE gamma rays and prompt emission from SNe
- The Cherenkov Telescope Array and its transient programme

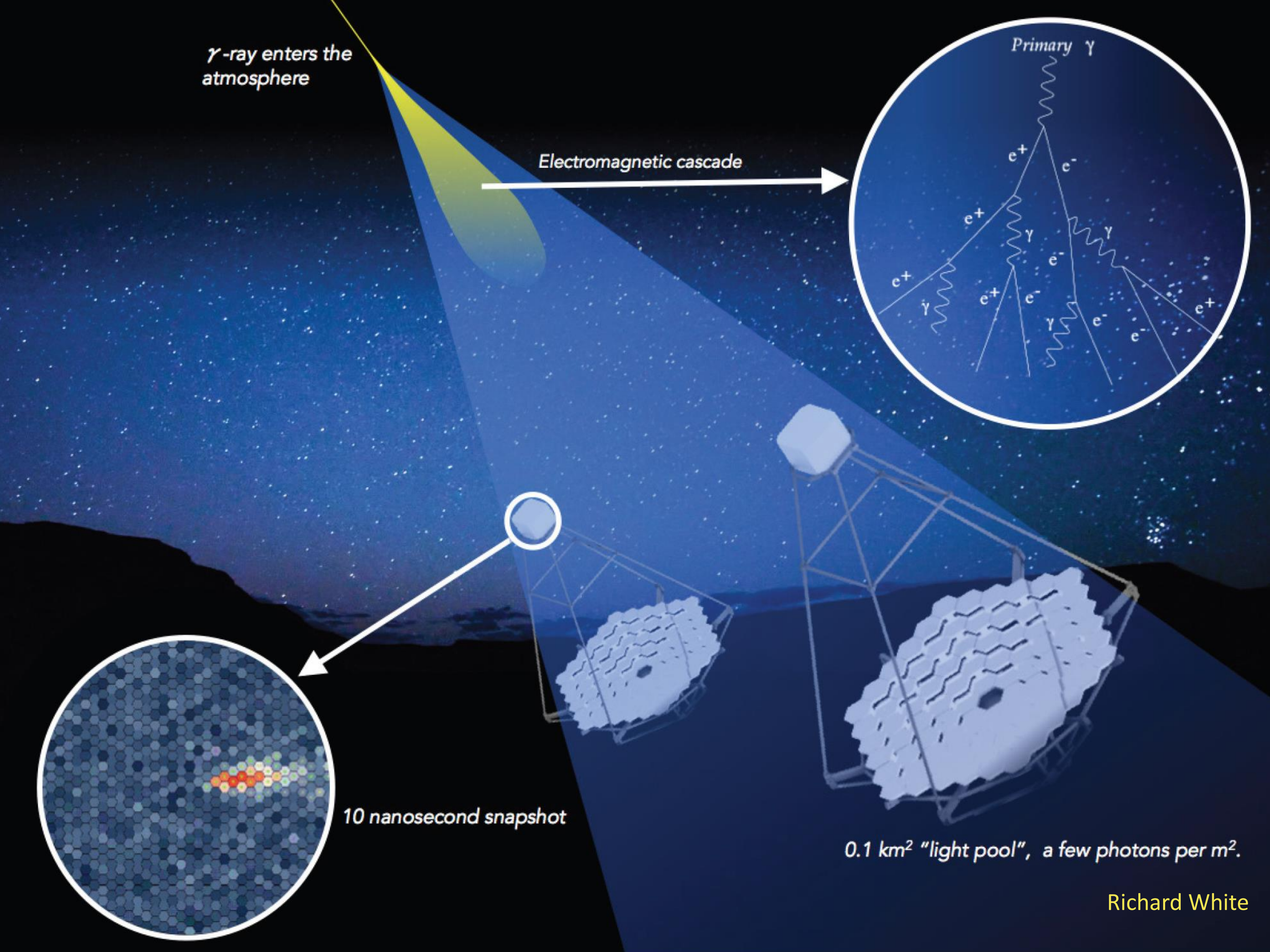
Space vs. Ground



Space
Few MeV to ~100 GeV (Fermi: ~100 MeV to ~100 GeV)
Collection area ~ m^2 -> low instantaneous sensitivity, drop off at high energies
Poor angular resolution ~ 1 deg.
BUT large field-of-view, all-sky capability

Ground
Few 10s of GeV to few 100 TeV
Collection area ~ 10^4 m^2 -> excellent instantaneous sensitivity
Better angular resolution ~0.1 deg.
BUT smaller field-of-view, low duty cycle





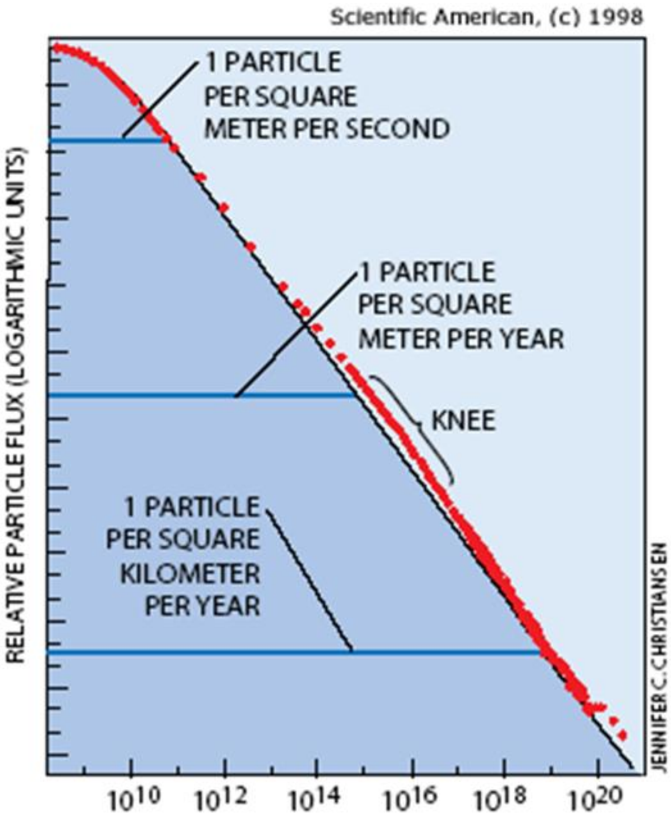
Richard White

Present Imaging Atmospheric Cherenkov Telescopes

The use of multi-pixel cameras allows for very effective background suppression.

SNe and Cosmic Rays

- Most CRs – at least up to ~ 3 x 10^{15} eV – are Galactic
- One supernova produces around 10^{46} J
- Assume one SN every 100 years
- Provides a total power of ~ 3 x 10^{36} W
- Each SN needs to put around 10% of its energy into high energy particles to maintain CR flux
- Shock acceleration can naturally explain the power law spectrum
- Heavy elements are also produced naturally
- Several shell SNRs are detected in VHE gamma rays – typically a few 100 to a few 1000 y.o.



But is it that simple?

- Are we sure the emission is produced by hadrons rather than electrons?
  - Yes for some older remnants interacting with gas ('pion bump' is seen at GeV energies)
  - Neutrino measurements important!
- But no evidence SNRs contain CRs with E ~ 10^{15} eV
  - e.g. Cas A (Ahnen et al., A&A, 602, A98 (2017))
- Suggestion that max CR energy is reached days to months after the SN event
  - e.g. Voelk & Biermann (1988), Bell et al. (2013) Cardillo et al. (2015), Marcowith et al. (2018)....
- This requires a high enough circumstellar density
  - Also depends on shock radius & velocity, B-field & turbulence

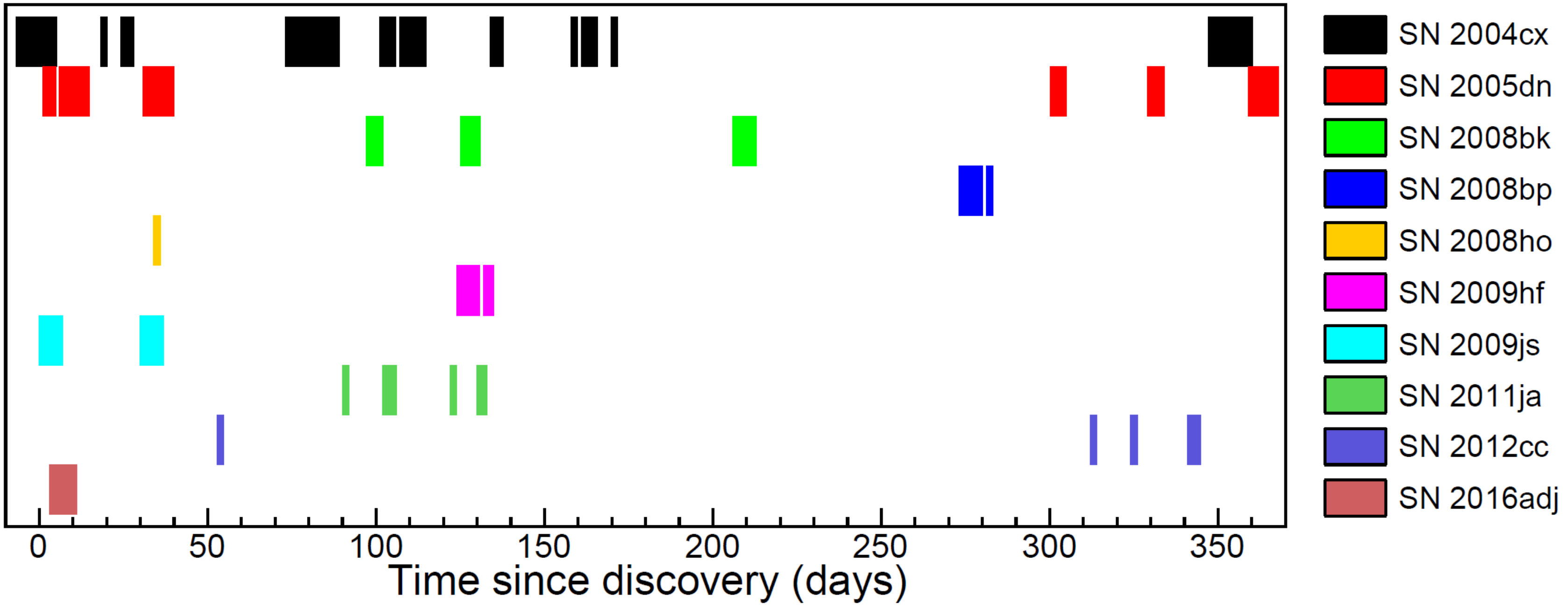
H.E.S.S. Observations of SNe - 1

- Observations of 10 core-collapse SNe between Dec 2003 and Dec 2014
- Most observations serendipitous, ToO observations of SN216adj
- All extragalactic

SN Name	Host galaxy	RA [J2000]	DEC [J2000]	Dist. [Mpc]	Type	Disc. date
SN 2004cx	NGC 7755	23h47m52.86s	−30°31′32.6″	26 ± 5	II	2004-06-26
SN 2005dn	NGC 6861	20h11m11.73s	−48°16′35.5″	38.4 ± 2.7	II	2005-08-27
SN 2008bk	NGC 7793	23h57m50.42s	−32°33′21.5″	4.0 ± 0.4	IIP	2008-03-25
SN 2008bp	NGC 3095	10h00m01.57s	−31°33′21.8″	29 ± 6	IIP	2008-04-02
SN 2008ho	NGC 922	02h25m04.00s	−24°48′02.4″	41.5 ± 2.9	IIP	2008-11-26
SN 2009hf	NGC 175	00h37m21.79s	−19°56′42.2″	53.9 ± 3.8	IIP	2009-07-09
SN 2009js	NGC 918	02h25m48.28s	+18°29′25.8 ″	16 ± 3	IIP	2009-10-11
SN 2011ja	NGC 4945	13h05m11.12s	−49°31′27.0″	5.28 ± 0.38	IIP	2011-12-18
SN 2012cc	NGC 4419	12h26m56.81s	+15°02′45.5″	16.5 ± 1.1	II	2012-04-29
SN 2016adj	NGC 5128	13h25m24.11s	−43°00′57.5″	3.8 ± 0.1	IIb	2016-02-08

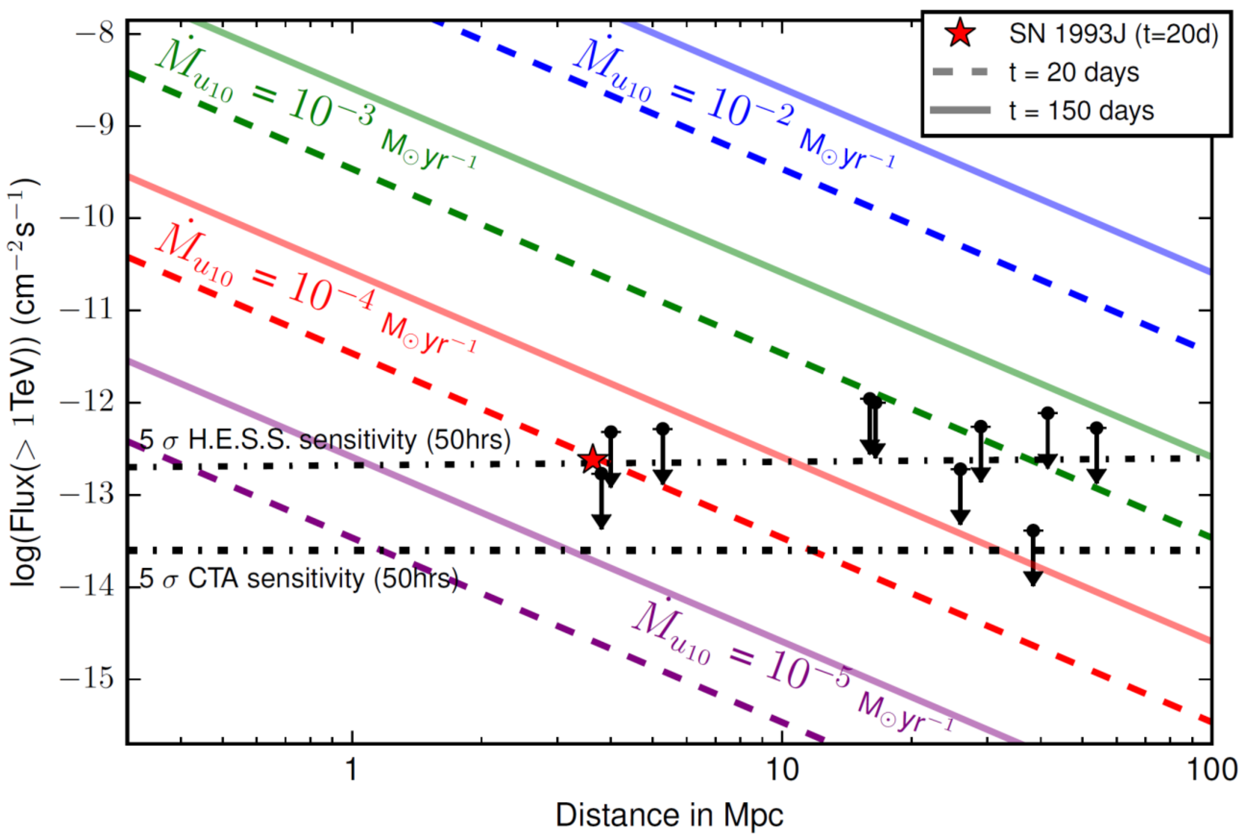
H.E.S.S. Collaboration, Astronomy & Astrophysics, Volume 626, id.A57 (2019)

H.E.S.S. Observations of SNe - 2



- None detected
- Why not?
  - Low mass loss rate/wind velocity of progenitor: environment not dense enough for significant particle acceleration
  - Photon-photon absorption – expected to be significant up to ~20 days after SN

The important plot...



$$F_\gamma \propto \left[\frac{\dot{M}}{u_W}\right]^2 \left(\frac{1}{d^2}\right)\left(\frac{1}{t}\right)$$

u_W = progenitor wind velocity, $\dot{M}$ = progenitor mass loss rate, t = time since SN explosion, d = distance

Dwarkadas, MNRAS, 343, 3368 (2013)

10 GeV	100 GeV	1 TeV	10 TeV	100 TeV

1000 γ / h km²

10 γ / h km²

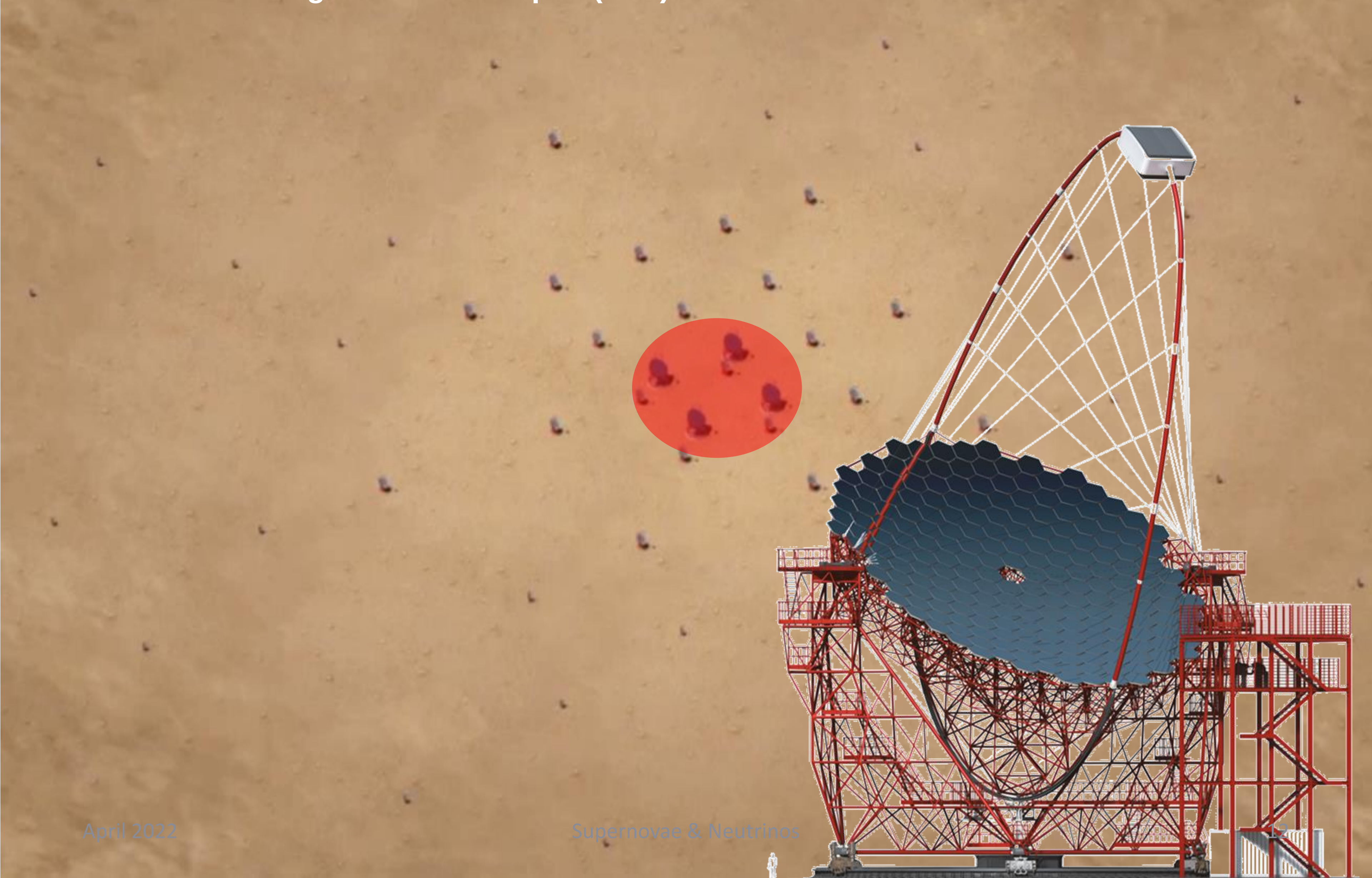
0.1 γ / h km²

Southern array
of Cherenkov telescopes
- about 3 km across

Stolen from Werner Hofmann!

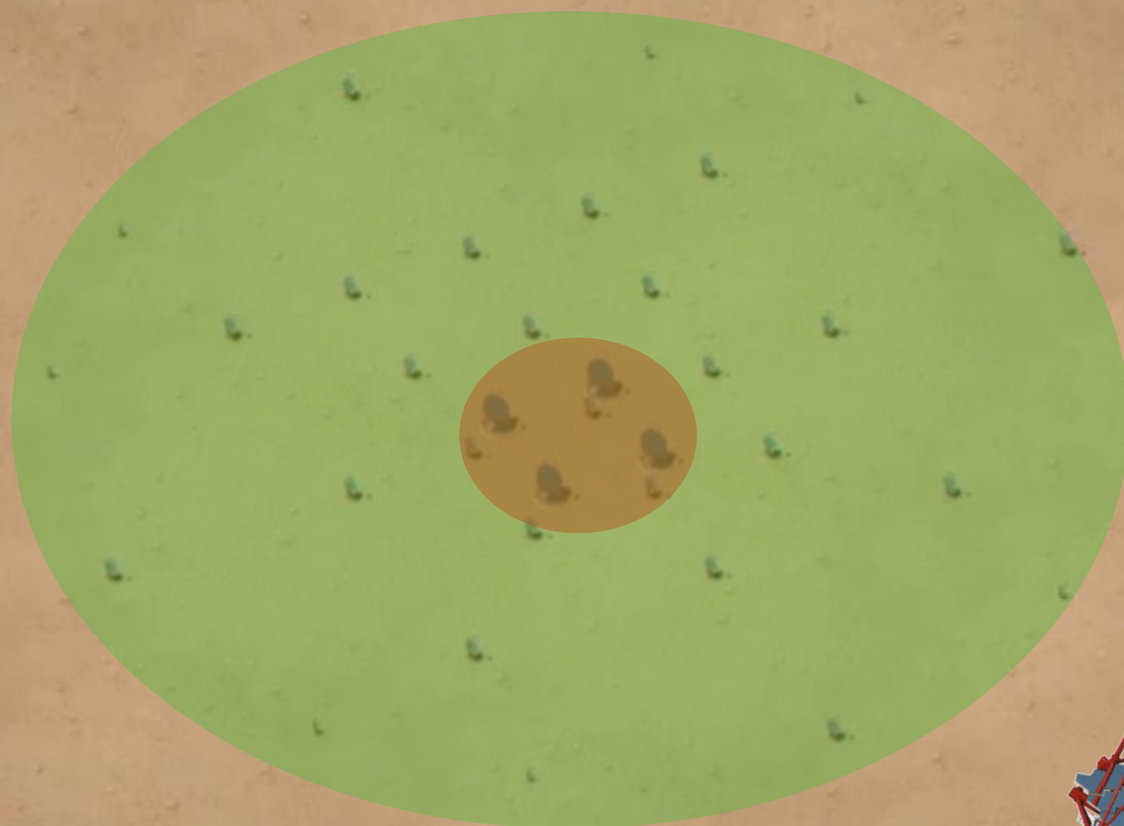
10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV

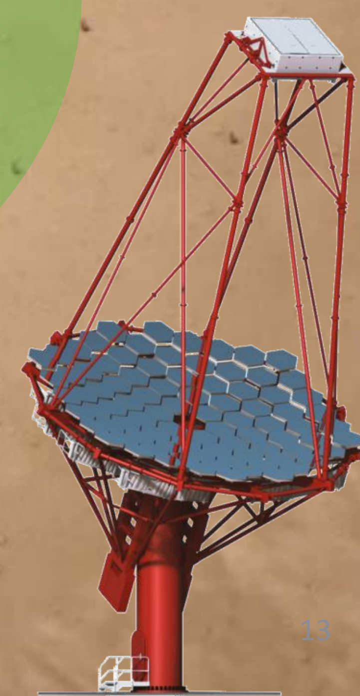
4 x 23 m Ø Large Size Telescopes (LST)



10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV

25 x 12 m ∅ Medium Size Telescopes (MST) (North: 15)

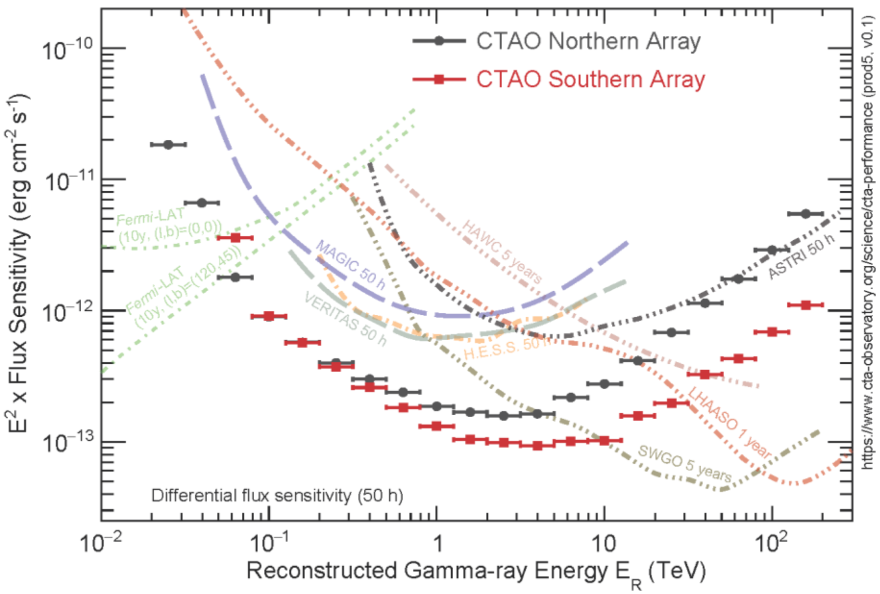


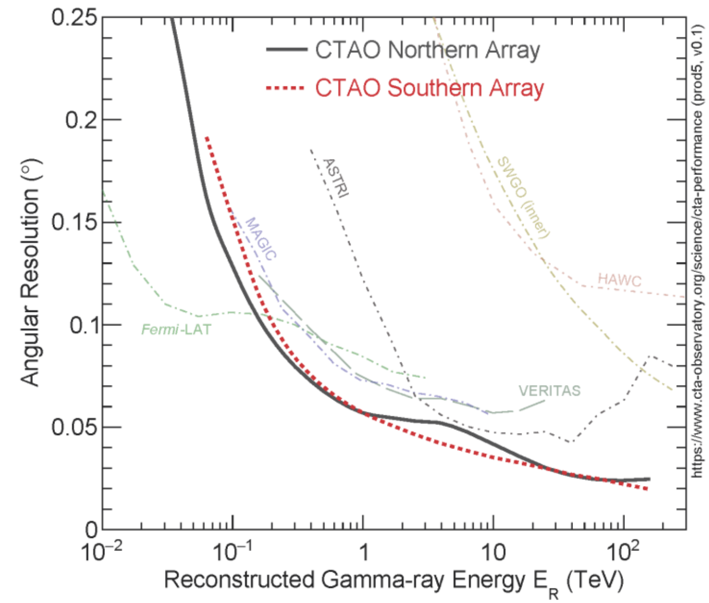


10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV

70 x 4 m ø Small Size Telescopes (SST) (South)

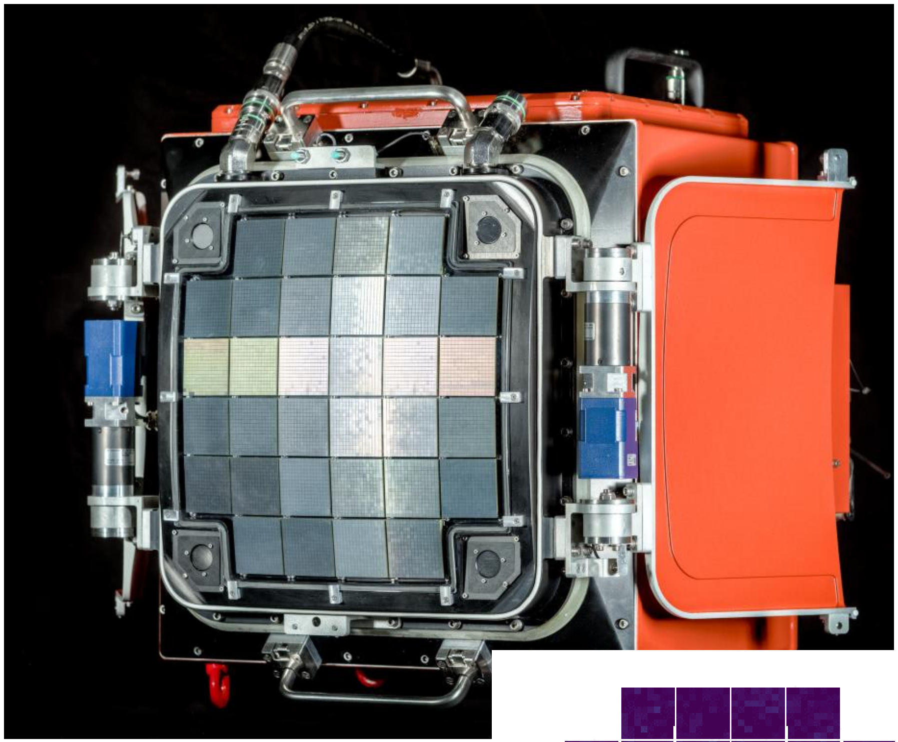
CTA Performance – Alpha Configuration

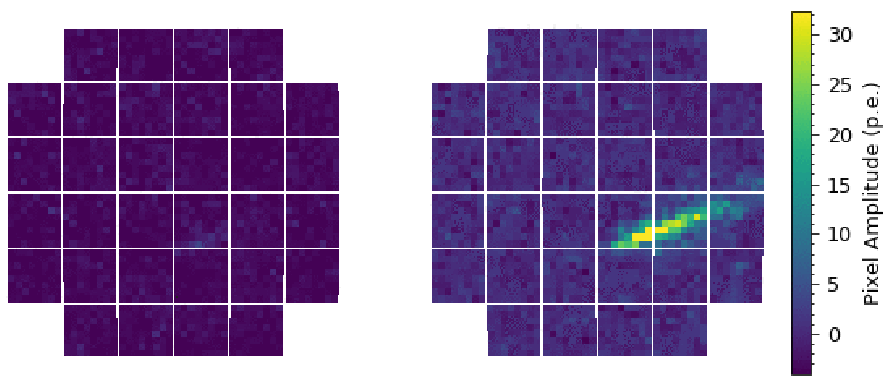




Initial – Alpha – Configuration consists of an array configuration of 4 LSTs and 9 MSTs in the northern site (CTAO-North), and 14 MSTs and 37 SSTs in the southern site (CTAO-South).

UK Contribution – SST Cameras



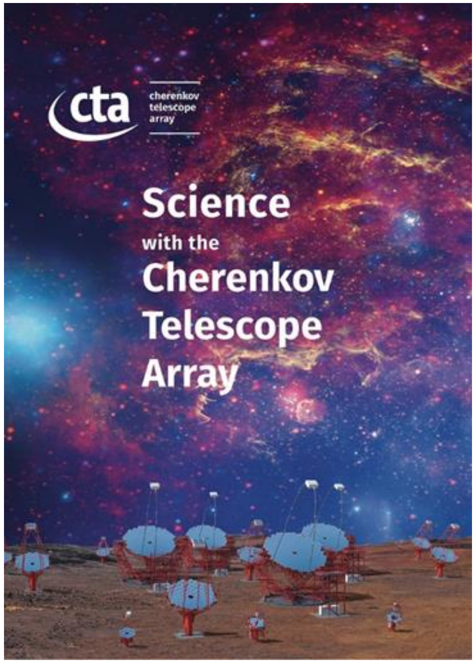


Collaboration: Australia, Germany, Japan, Netherlands & UK

UK experimental groups: Armagh, Durham, Leicester, Liverpool, Oxford

CTA Science

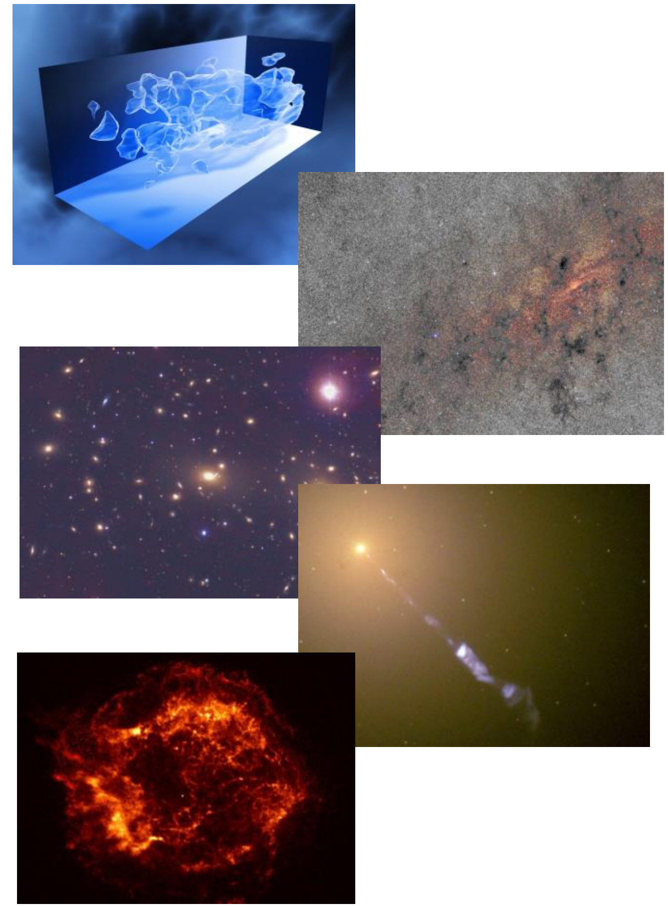
- **Theme 1: Cosmic Particle Acceleration**
  - **How and where are particles accelerated?**
  - **How do they propagate?**
  - **What is their impact on the environment?**
- Theme 2: Probing Extreme Environments
  - Processes close to neutron stars and black holes?
  - **Processes in relativistic jets, winds and explosions?**
  - Exploring cosmic voids
- Theme 3: Physics Frontiers – beyond the SM
  - What is the nature of dark matter? How is it distributed?
  - Is the speed of light constant for high energy photons?
  - Do axion-like particles exist?



ArXiv: 1709.07997

Key Science Projects (KSPs)

1. Dark Matter Programme
2. Galactic Centre
3. **Galactic Plane Survey**
4. Large Magellanic Cloud Survey
5. Extragalactic Survey
6. **Transients**
7. Cosmic-ray PeVatrons
8. Star-forming Systems
9. Active Galactic Nuclei
10. Clusters of Galaxies
11. Beyond Gamma Rays

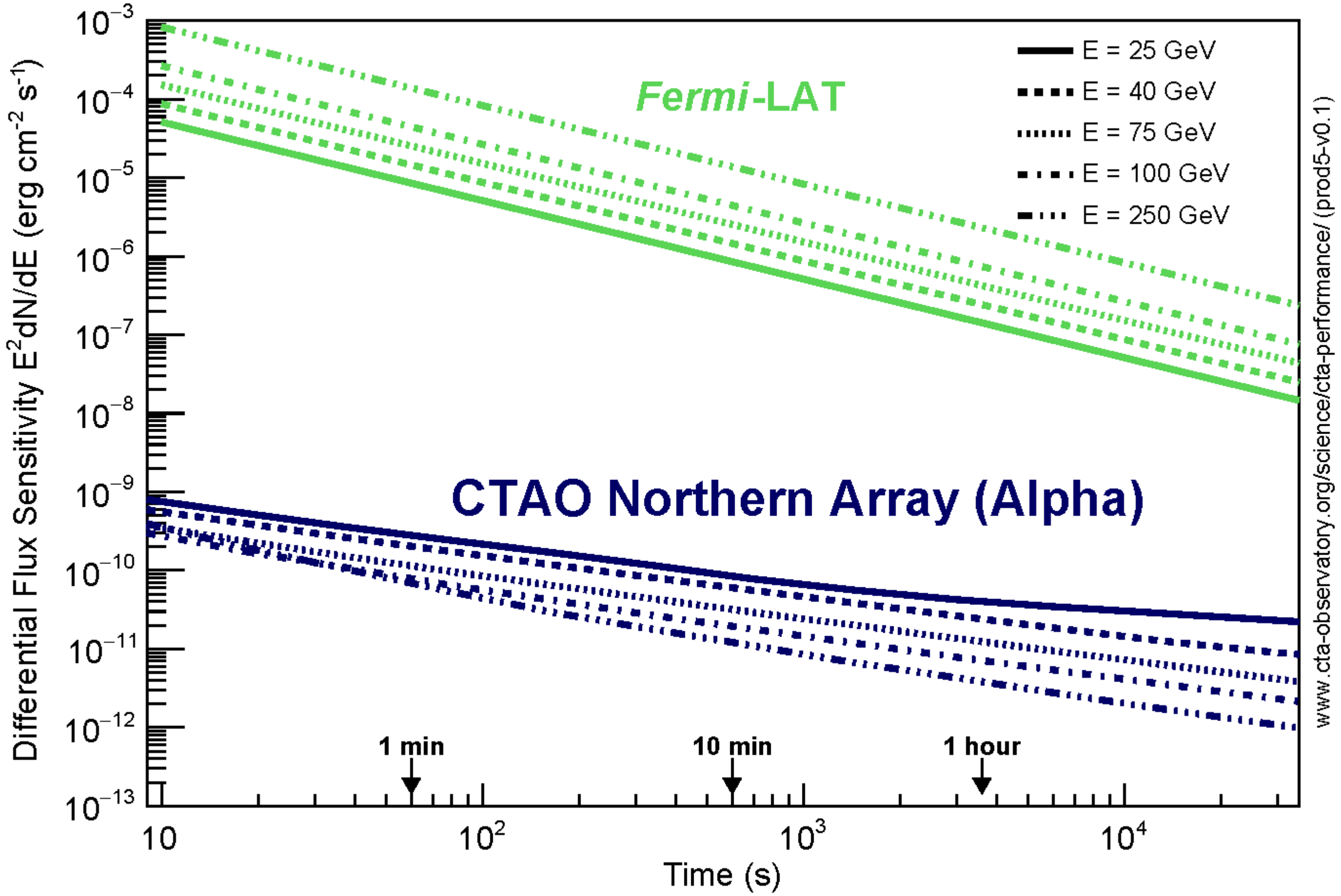


Transients

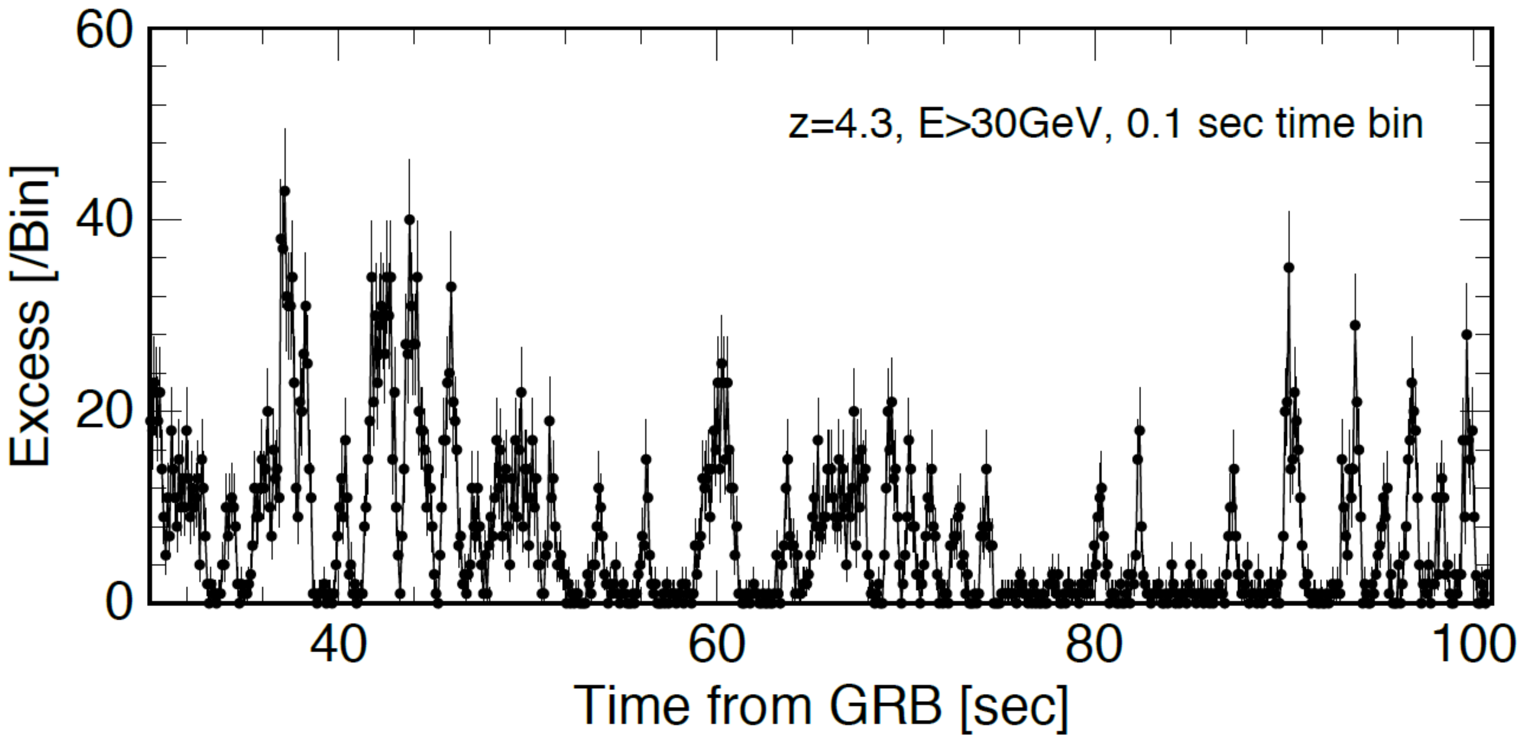
- Follow-up observations of:
  - Gamma-ray bursts
  - Galactic transients
  - X-ray, optical & radio transients
  - High-energy neutrino transients
  - Gravitational wave events
  - Serendipitious VHE transients (identified with CTA)
- VHE transient survey
  - Using divergent pointing to cover a large FoV

Image: Superbossa.com, C. Righi

Instantaneous Sensitivity



Simulated GRB Light Curve



Simulated CTA light curve of GRB 080916C at z = 4.3 at E > 30 GeV with 0.1s time binning plotted from 30 s after burst offset.

Stay tuned: https://www.cta-observatory.org

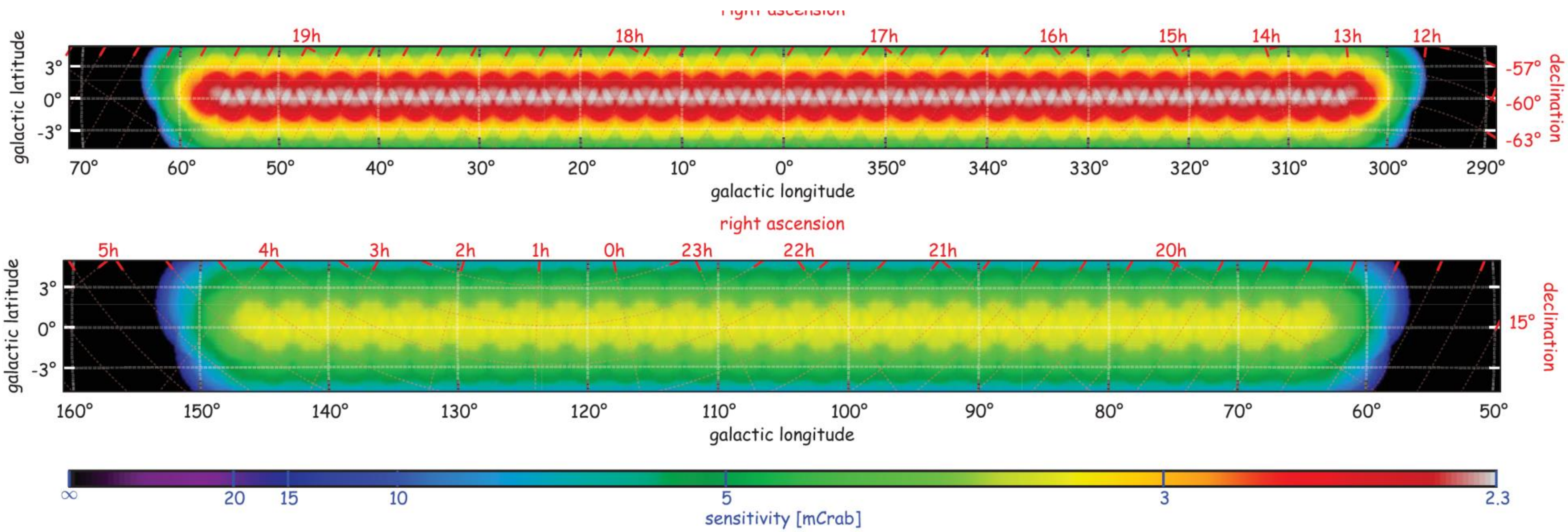
With thanks to all my colleagues in CTA from whom I stole slides, graphs etc.

Backup Slides

Milestones

- ERIC signed 2022
- Five years of construction thereafter
- Early science 2024/5?
- Dependent on status as we come out of the pandemic

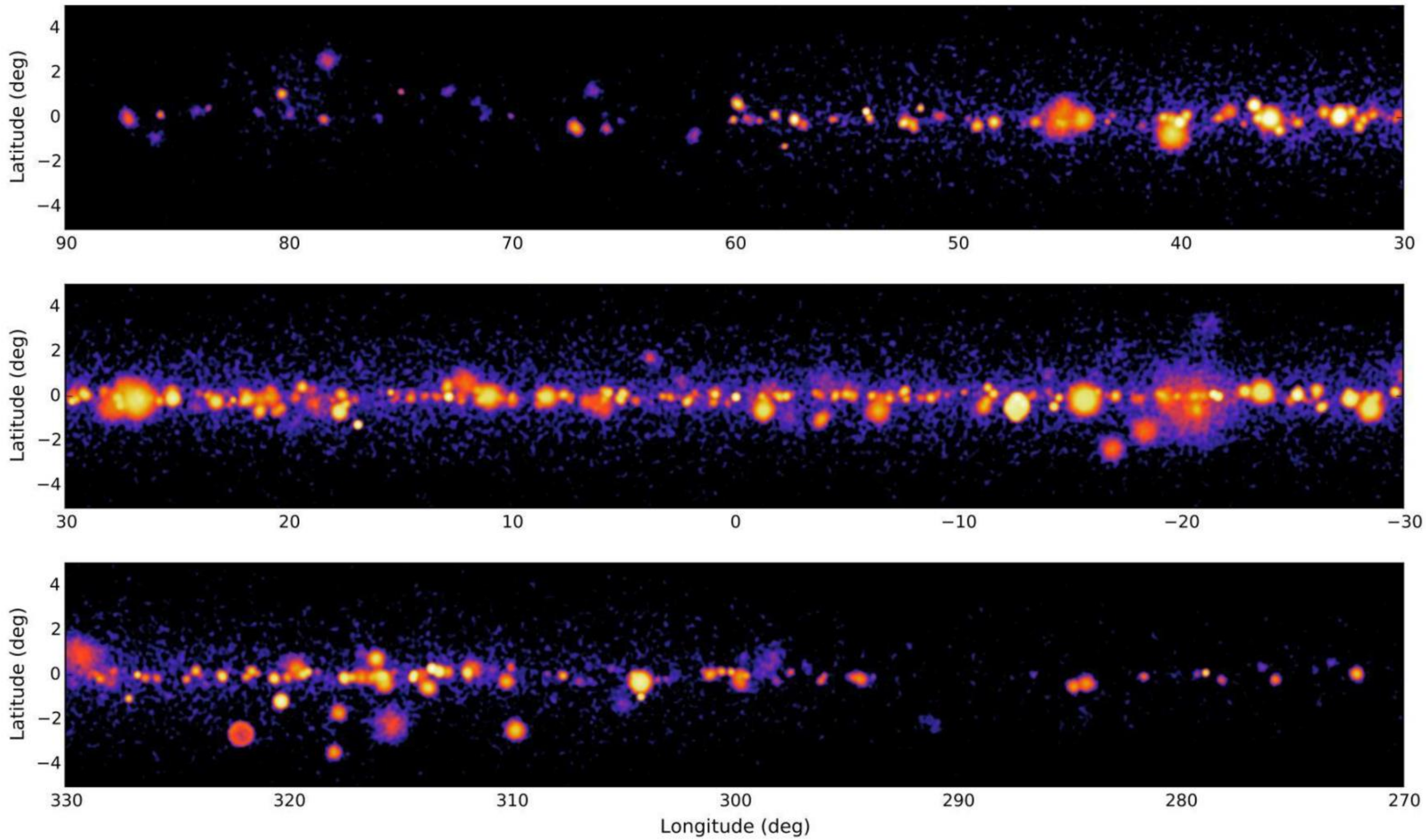
Survey Coverage



	STP (Years 1 – 2)		Total (Years 1 – 10)	
Galactic Longitude	**Sensitivity**	**Eq. Exposure**	**Sensitivity**	**Eq. Exposure**
SOUTH				
300° – 60° , Inner region	**2.7 mCrab**	**11.0 h**	**1.8 mCrab**	**28.6 h**
240° – 300° , Vela, Carina			**2.6 mCrab**	**13.2 h**
210° – 240°			**3.2 mCrab**	**8.8 h**
NORTH				
60° – 150° , Cygnus, Perseus	**4.2 mCrab**	**6.3 h**	**2.7 mCrab**	**15.8 h**
150° – 210° , anti-Centre, etc.			**3.8 mCrab**	**7.9 h**

Image shows coverage after the first 2 years of full operation.

Potential for Source Confusion



Simulation of CTA GPS based on source populations – MWL observations will be a must.