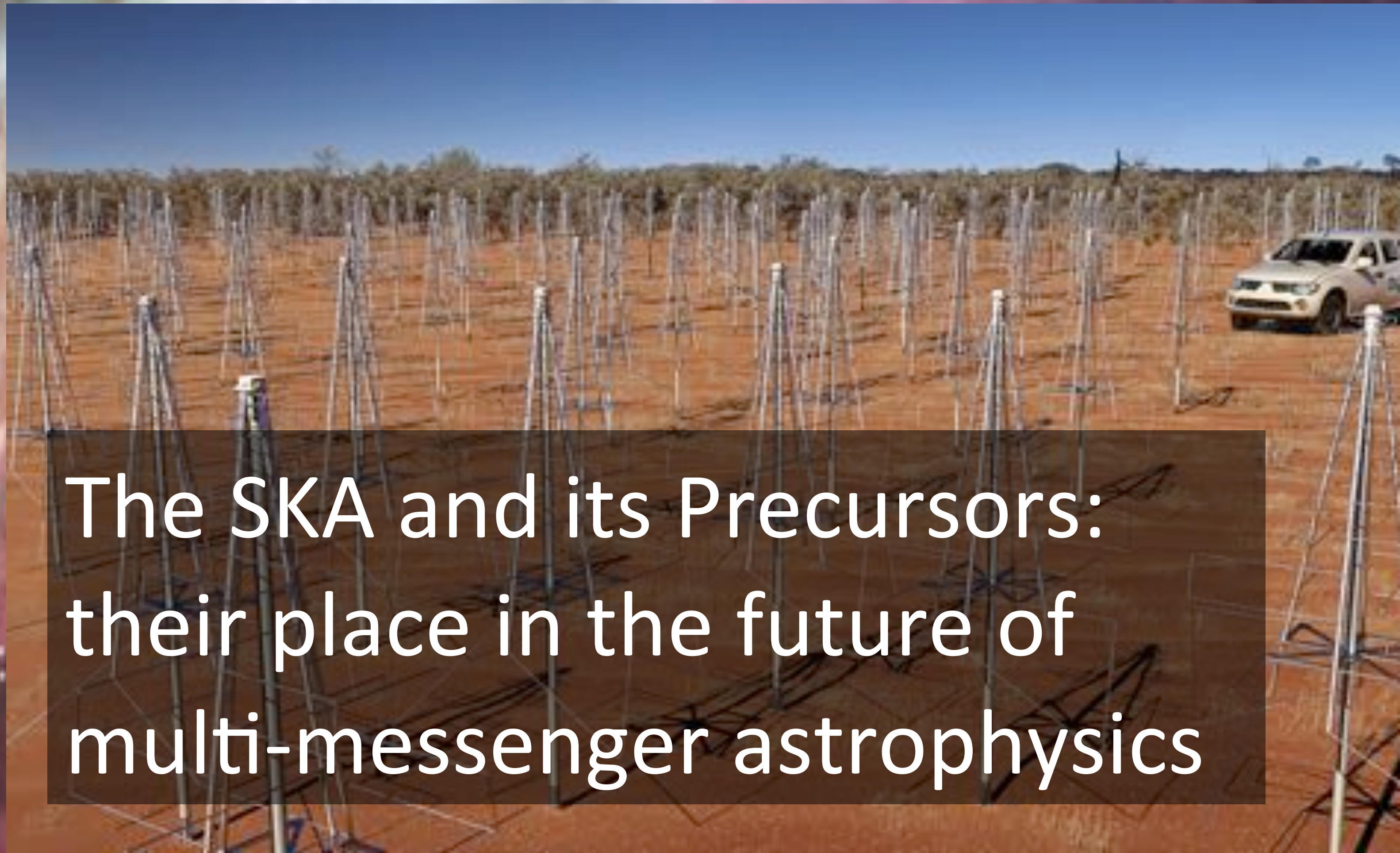
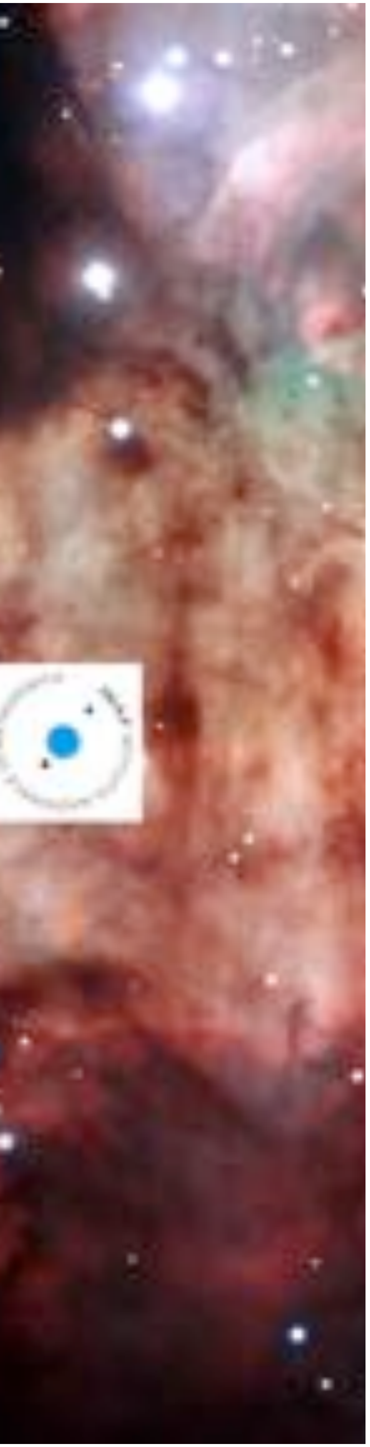
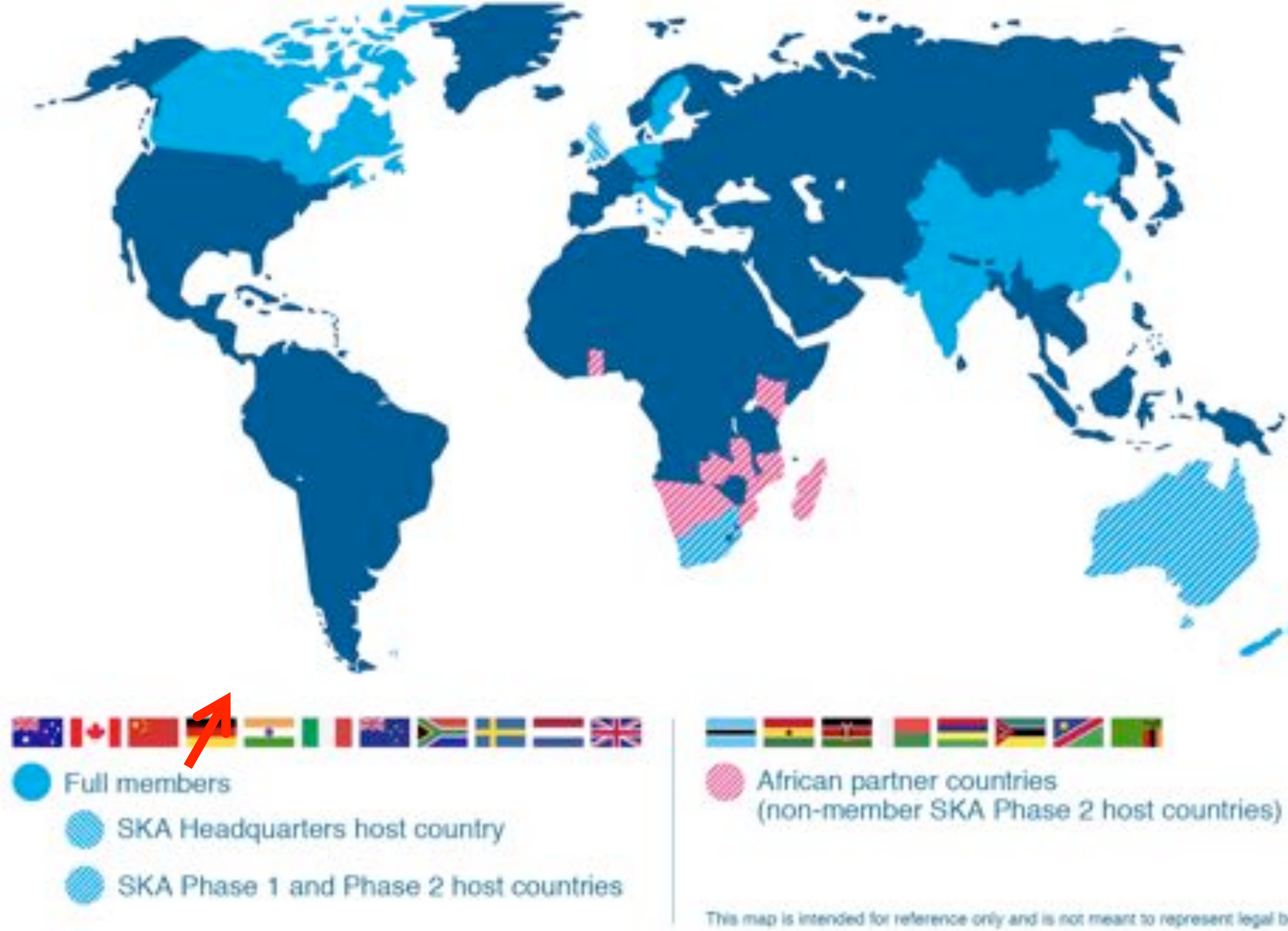


The SKA and its Precursors: their place in the future of multi-messenger astrophysics

STEVEN TINGAY
stingay@ira.inaf.it

Direttore, INAF-IRA
Head, Section II (Radio Astronomy) INAF Science Directorate





http://www.skatelescope.org

SKA Phase 1 implementation

Southern Africa

190 dishes including
MeerKAT 0.35 - 3 GHz

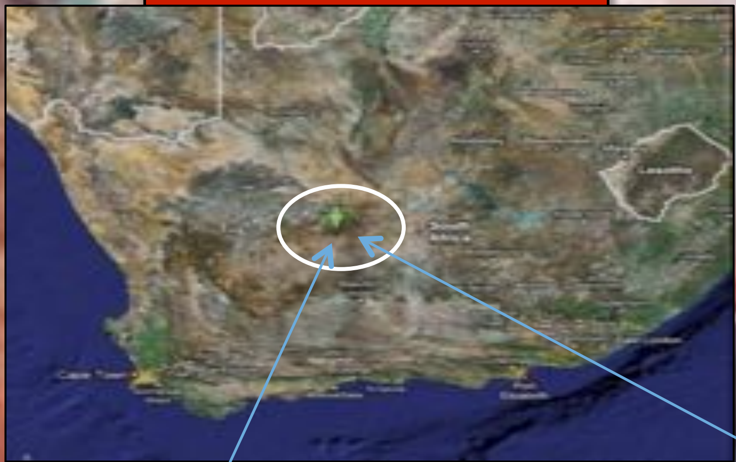
Australia

~130,000 SKA-low aperture array
stations
50 - 350 MHz

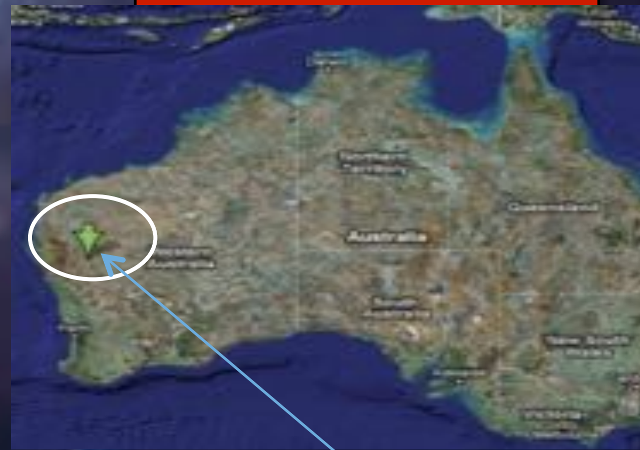
Adapted from Andy Faulkner (University of Cambridge)

SKA Phase 2 implementation

Southern Africa



Australia



~ 2700 dishes
0.35 – 10+ GHz

~ 250 dense aperture array stations
400 -1400 MHz

~2,000,000 SKA-low aperture ar
stations
50 - 350 MHz

Adapted from Andy Faulkner (University of Cambridge)

The Square Kilometre Array in Australia

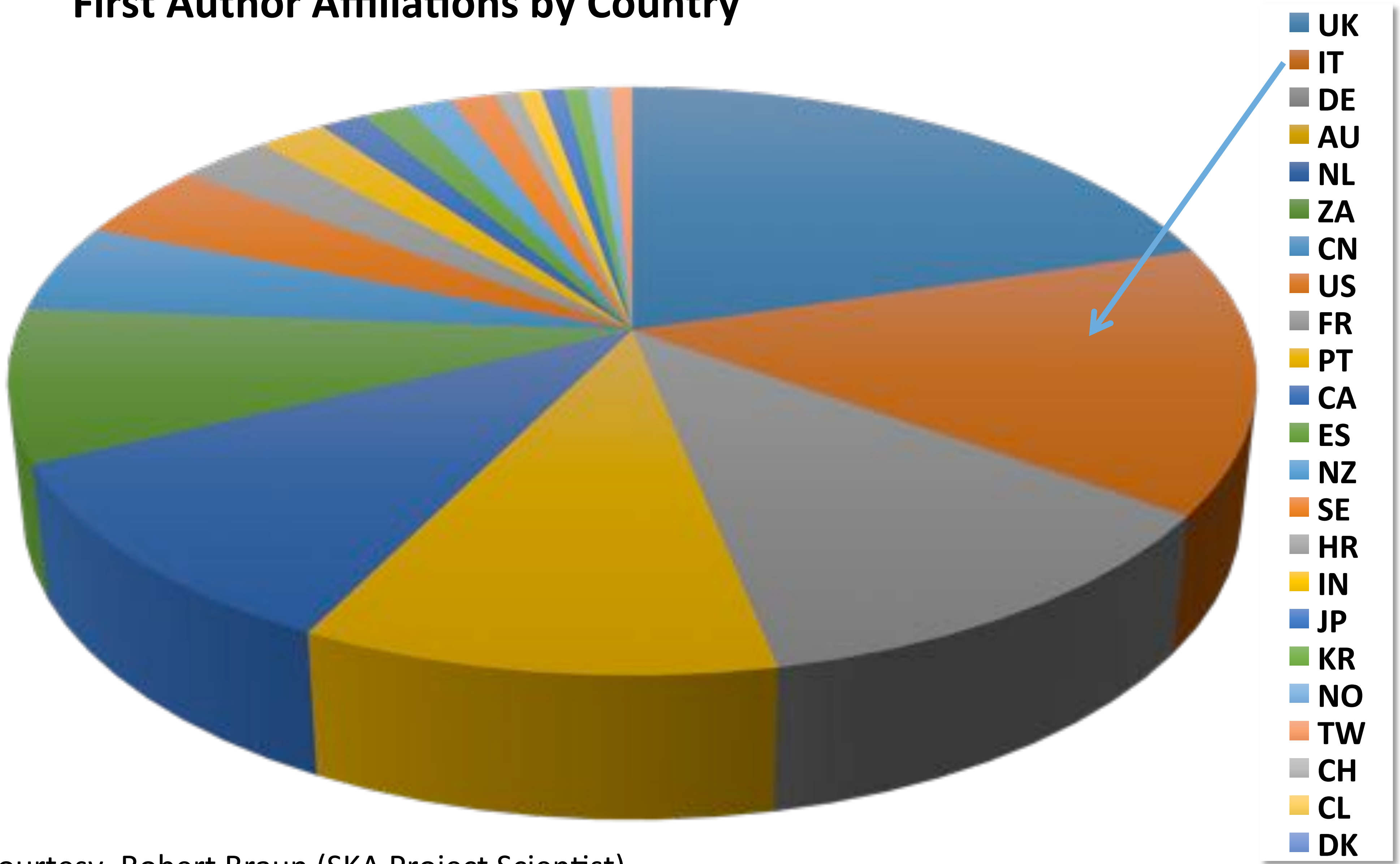
The Square Kilometre Array in South Africa

SKA science book 2015

(following meeting in Sicily in 2014)

- 135 chapters;
- 2000 pages;
- 1200 authors;
- 9 kg.

First Author Affiliations by Country



Courtesy, Robert Braun (SKA Project Scientist)

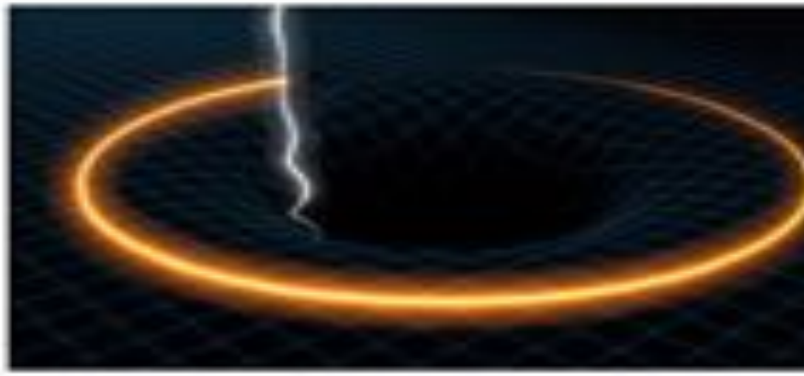
Galaxy evolution, cosmology and dark energy

Galaxy evolution, cosmology and dark energy

How do galaxies evolve? What is dark energy?
The acceleration in the expansion of the Universe has
attributed to a mysterious dark energy. The SKA will
investigate this expansion after the Big Bang by mapp
the cosmic distribution of hydrogen. more...

Strong-field tests of gravity using pulsars and black holes

Was Einstein right about gravity? The SKA will investigate the nature of gravity and challenge the theory of general relativity. more...



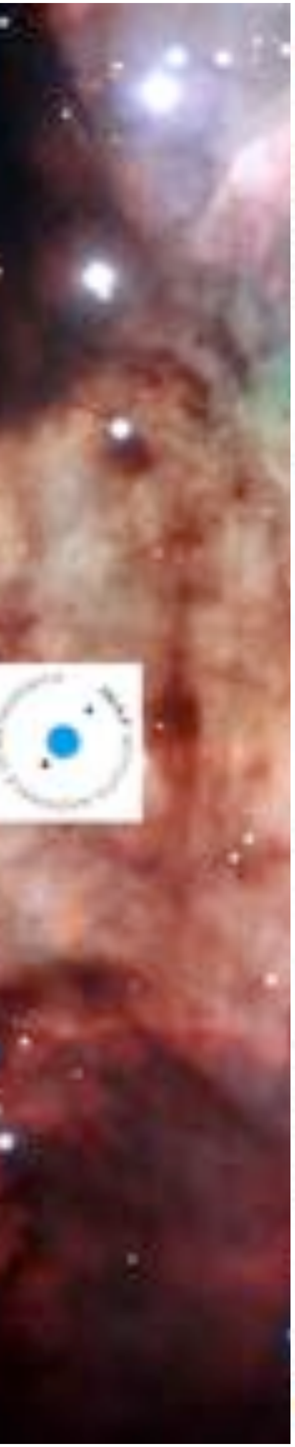
Strong-field tests of gravity using pulsars and blac holes

Investigating the origin and evolution of cosmic magnetism

The origin and evolution of cosmic magnetism

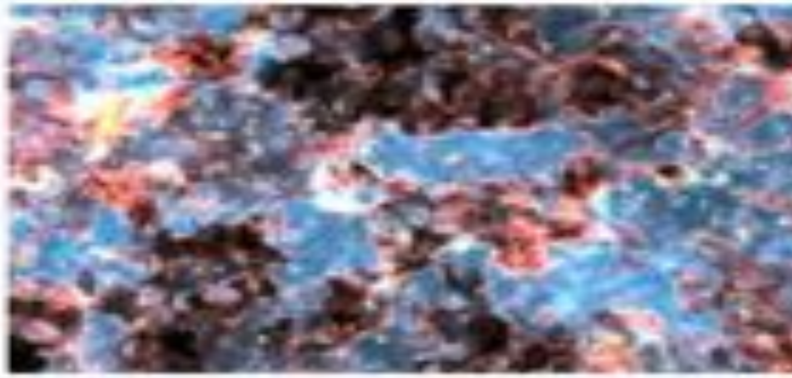
What generates giant magnetic fields in space?
The SKA will create three-dimensional maps of cosmi
magnets to understand how they stabilise galaxies, in
the formation of stars and planets, and regulate solar
stellar activity. more...

www.skatelescope.org



Probing the Cosmic Dawn

How were the first black holes and stars formed? The SKA will look back to the Dark Ages, a time before the Universe lit up, to discover how the earliest black holes and stars were formed. more...



Probing the dark ages – the first black holes and st

The cradle of life searching for life and planets

The cradle of life

Are we alone? The SKA will be able to detect very w extraterrestrial signals and will search for complex molecules, the building blocks of life, in space. more.

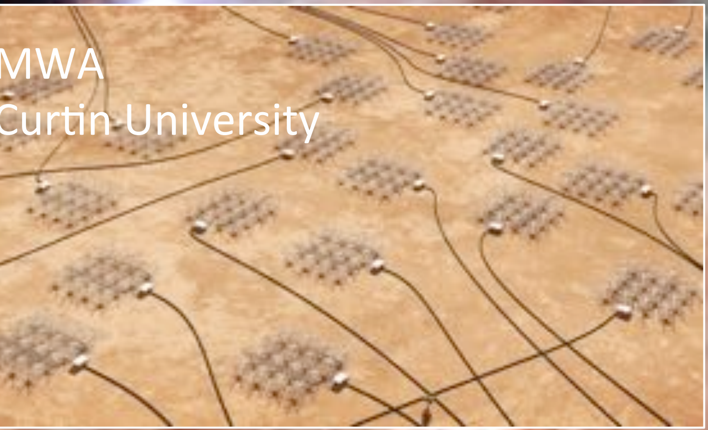
Flexible design to enable exploration of the unknown

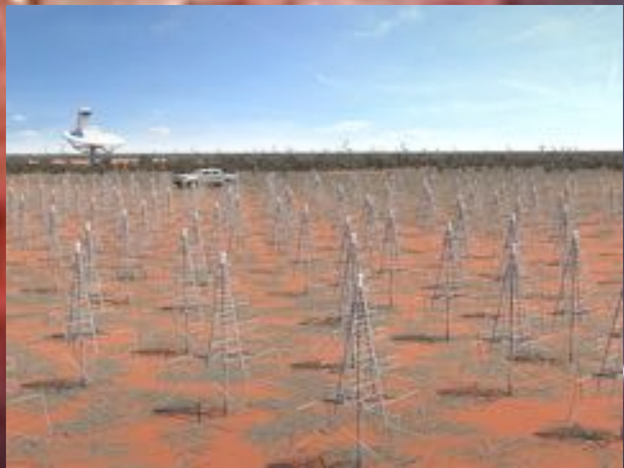
While this is truly exciting and transformational science, history has shown that many of the greatest discoveries have happened unexpectedly. The unique sensitivity and versatility of the SKA will make it a discovery machine.

We should be prepared for the possibilities.

For the full SKA science case in detail see the SKA Science book

Flexible design will enable exploration of th unknown

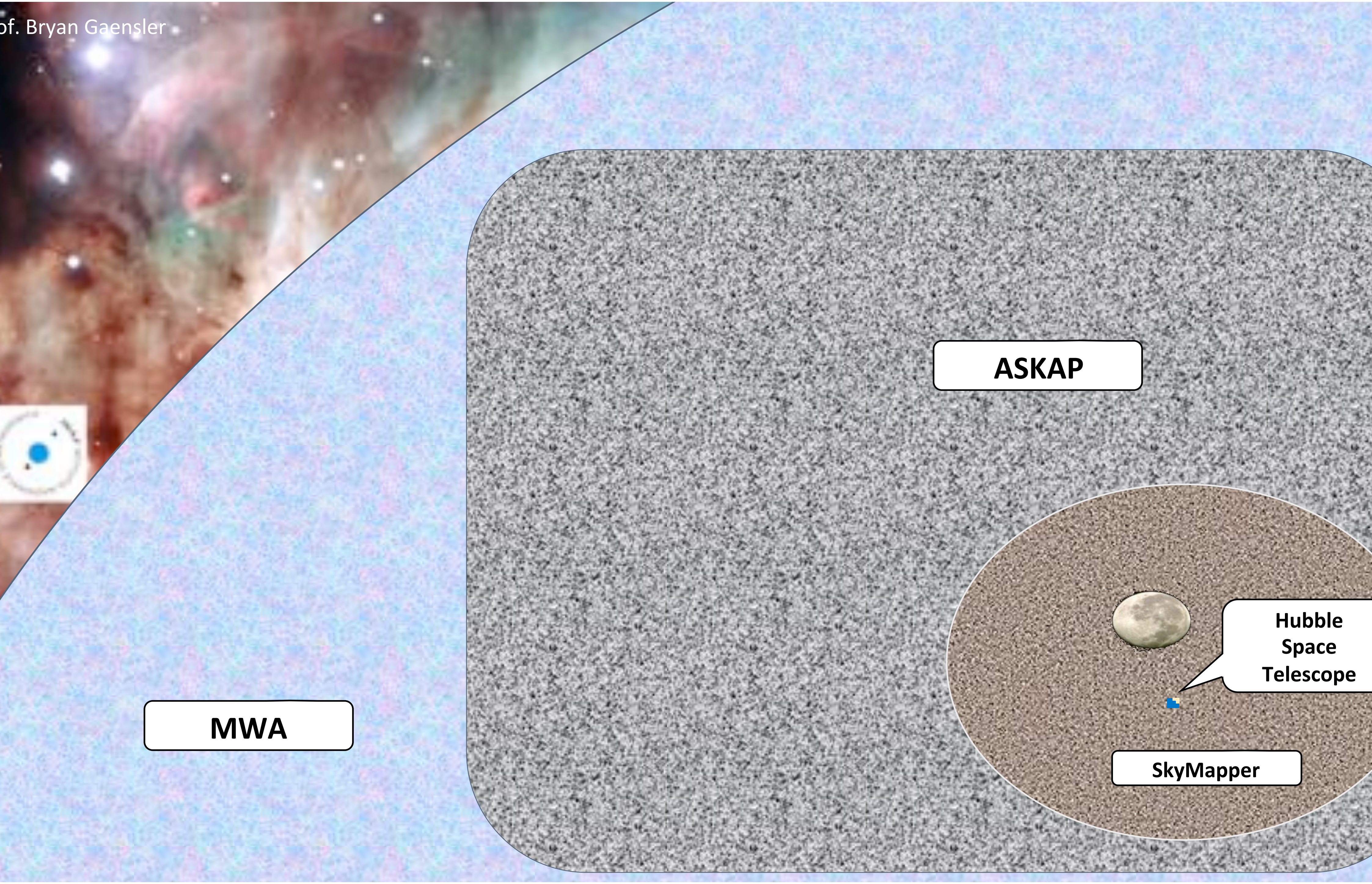




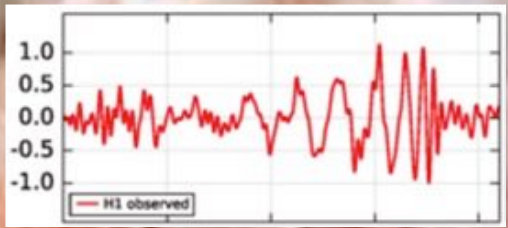
http://www.skatelescope.org

LOw Frequency Array (LOFAR)

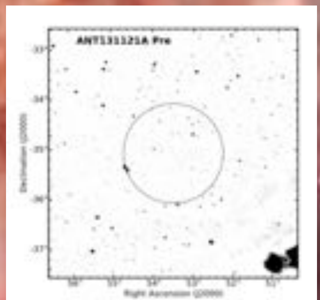
ASTRON


of. Bryan Gaensler
ASKAP
MWA
Hubble
Space
Telescope
SkyMapper

Radio astronomy in the multi-messenger era



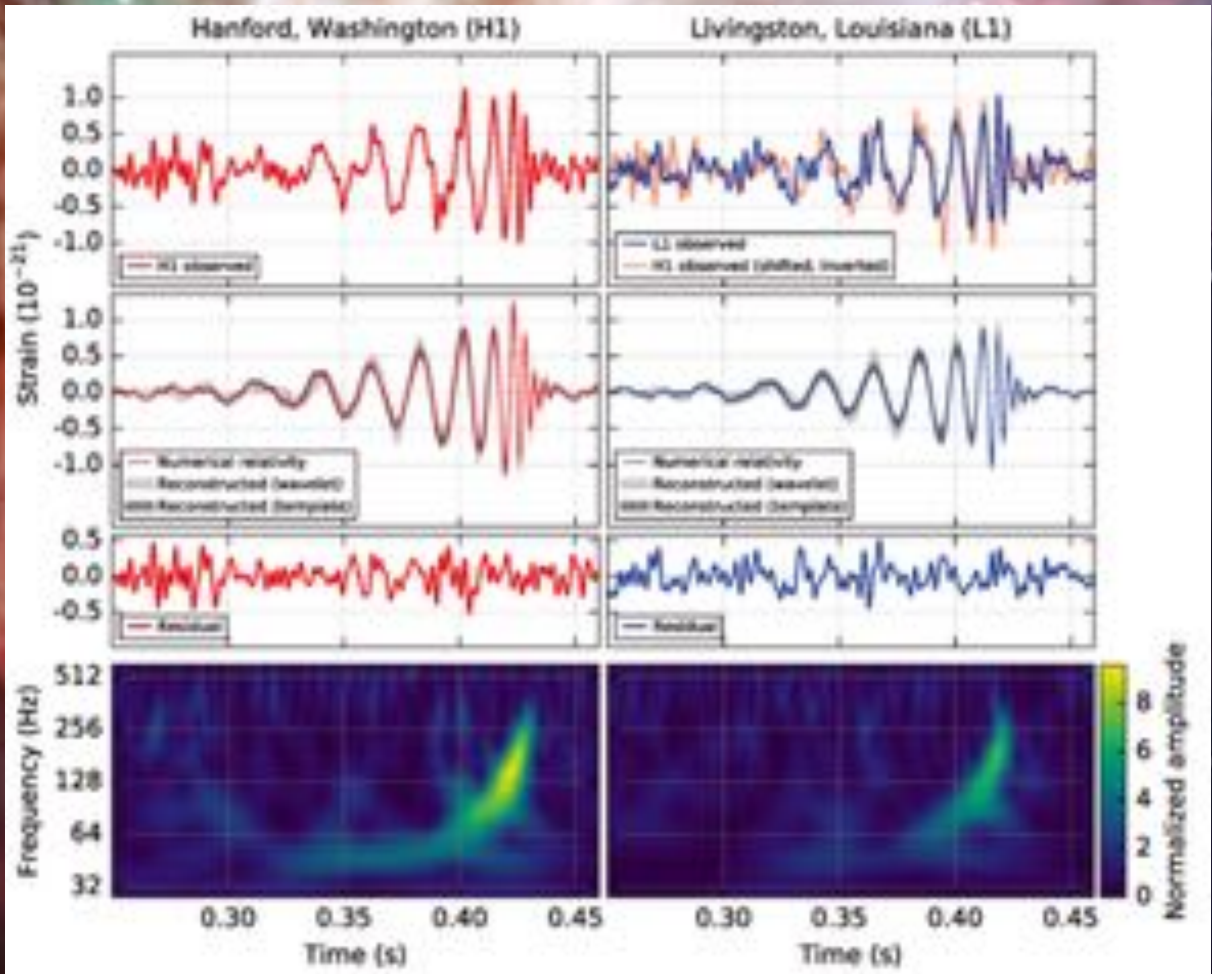
EM follow-up of gravitational wave events;



EM follow-up of neutrino detections;

Radio detections from cosmic rays/neutrinos.

Gravitational Waves

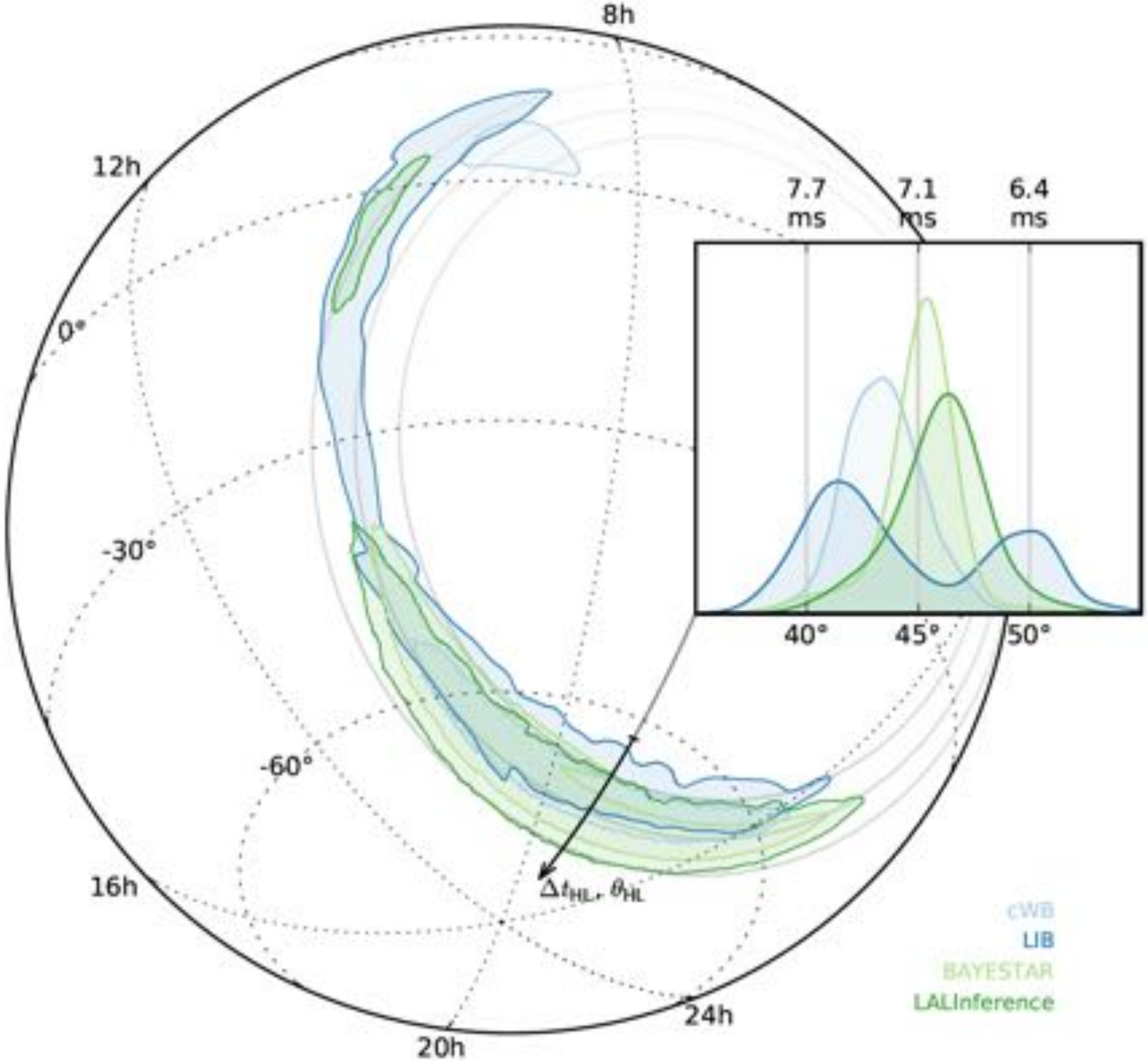


$36\ M_{solar} + 25\ M_{solar} \rightarrow 62\ M_{solar}$

Redshift ~ 0.1

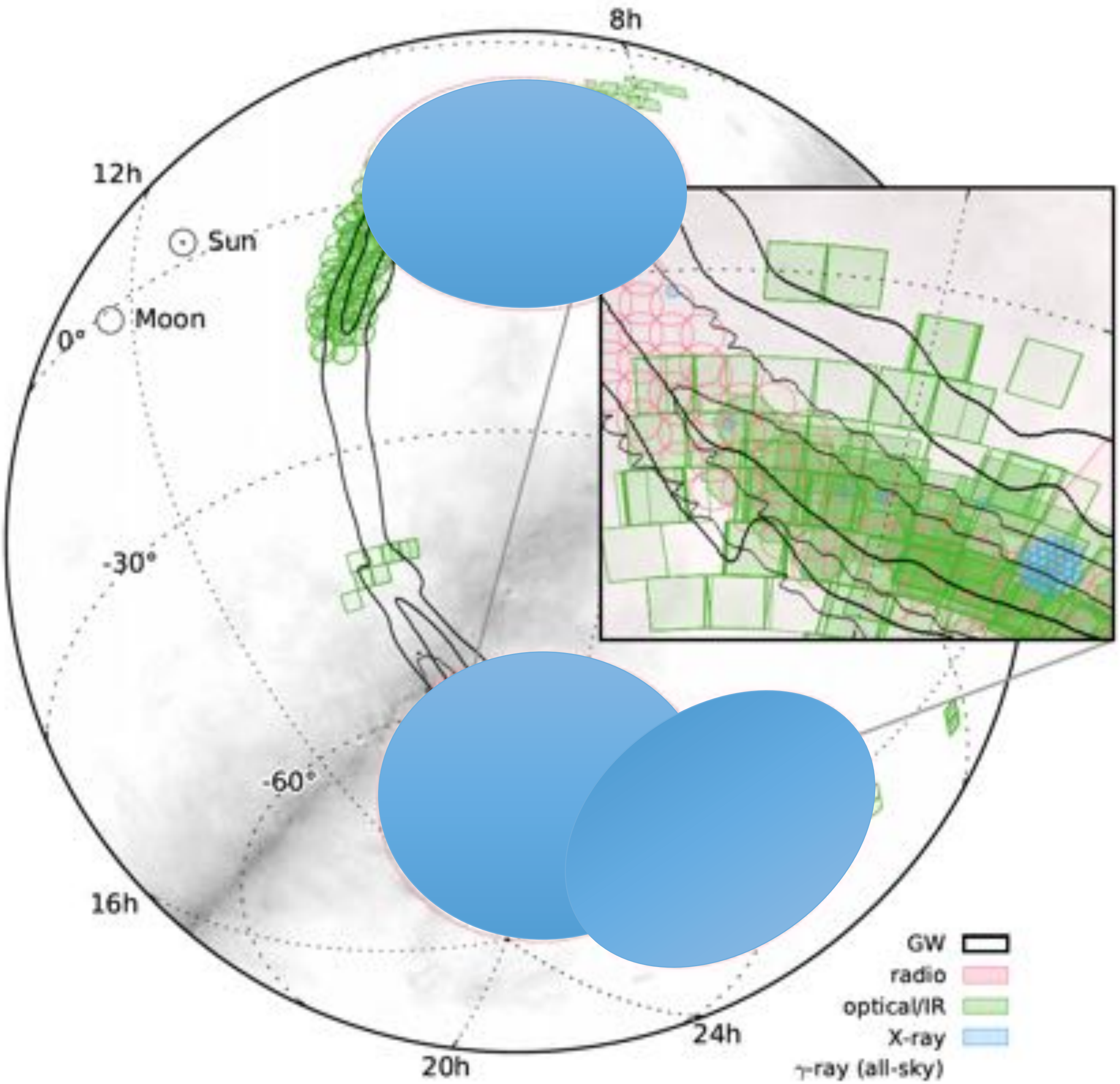
Localised to ~600 square deg. (~1% of sky

Abbott++2016



8h
12h
0°
-30°
-60°
16h
20h
24h
7.7 ms
7.1 ms
6.4 ms
40°
45°
50°
Δt_HL, θ_HL
cWB
LIB
BAYESTAR
LALInference

Abbott++2016



Abbott++2016

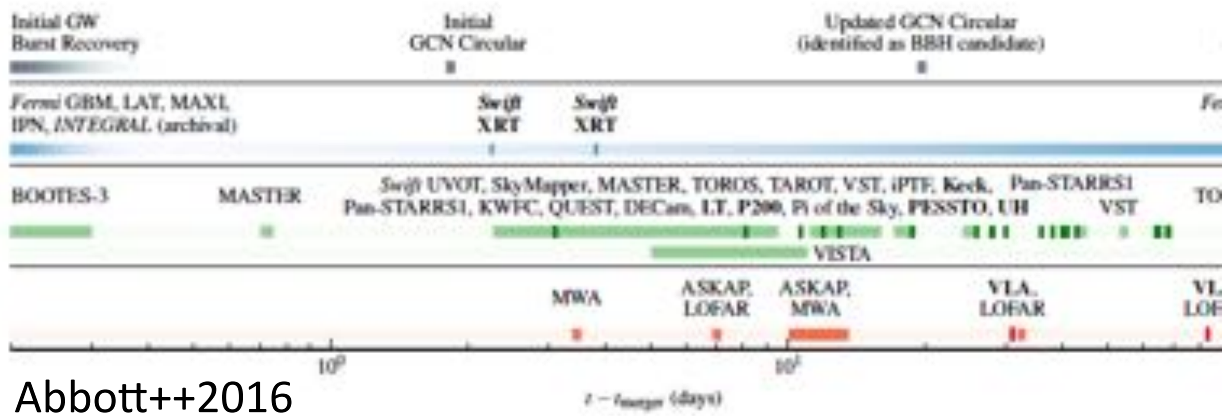
BH-BH -> r
EM signal
expected.

But, of cou
everyone
looked!

Practise fo
BH-NS......

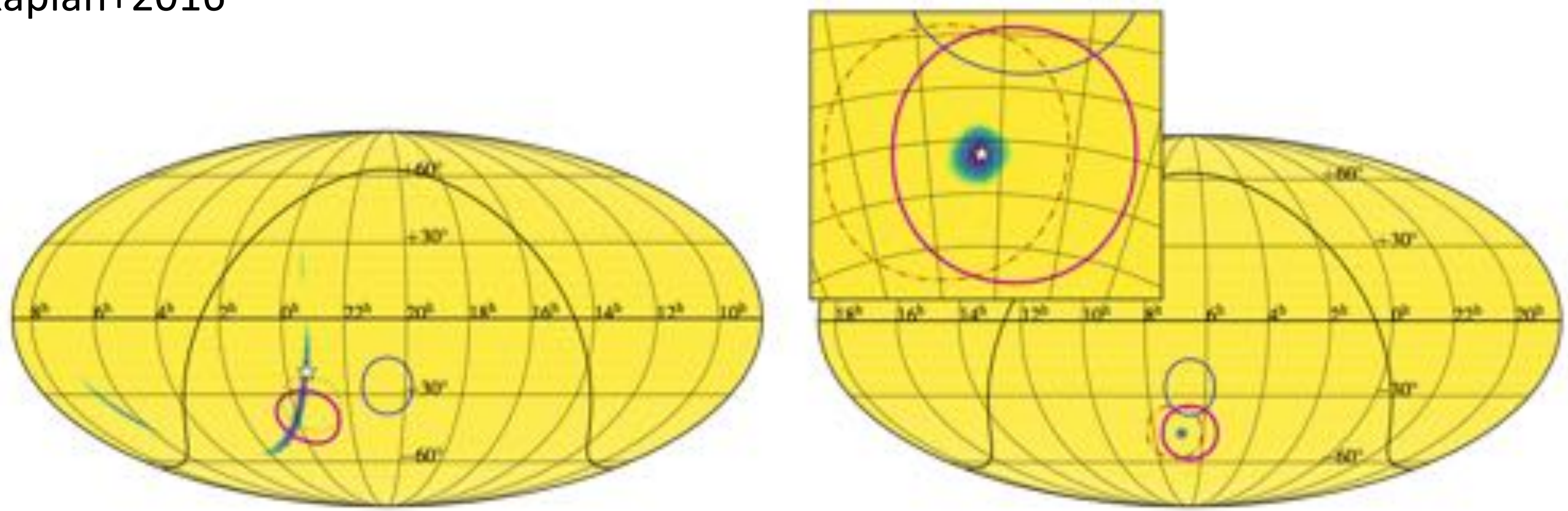
MWA FoV ~2800 sq. deg.

0 mJy RMS levels in ~3 min obs.



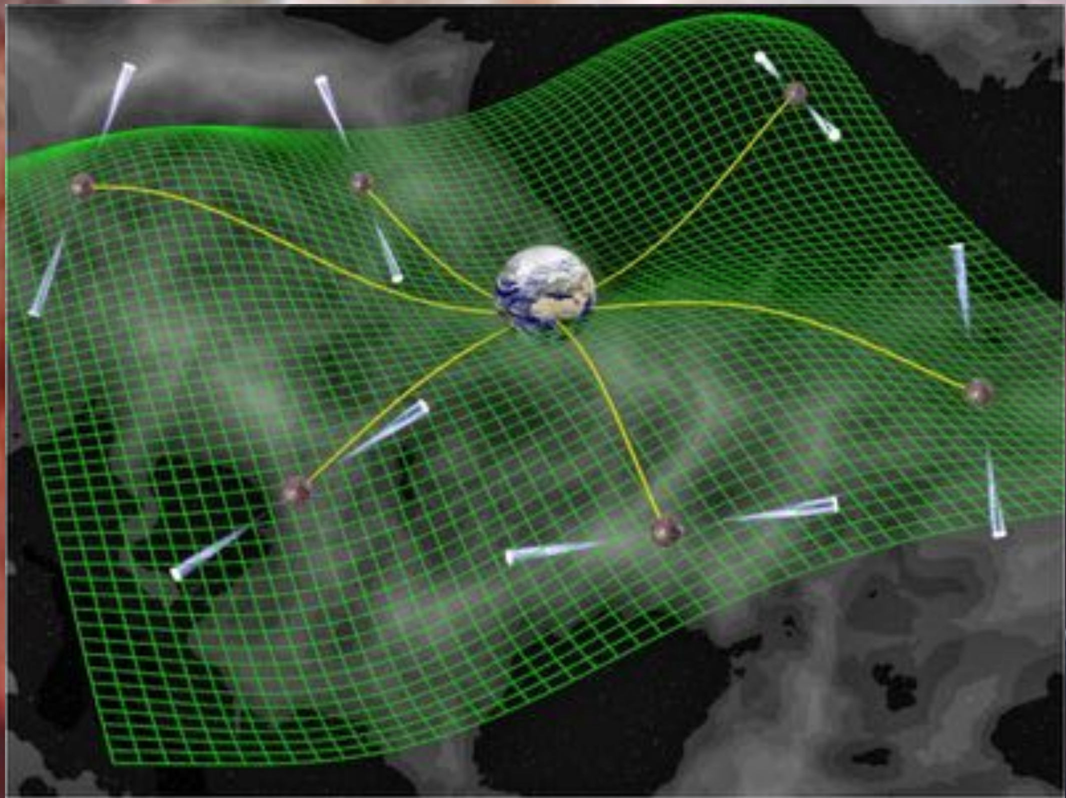
Abbott++2016

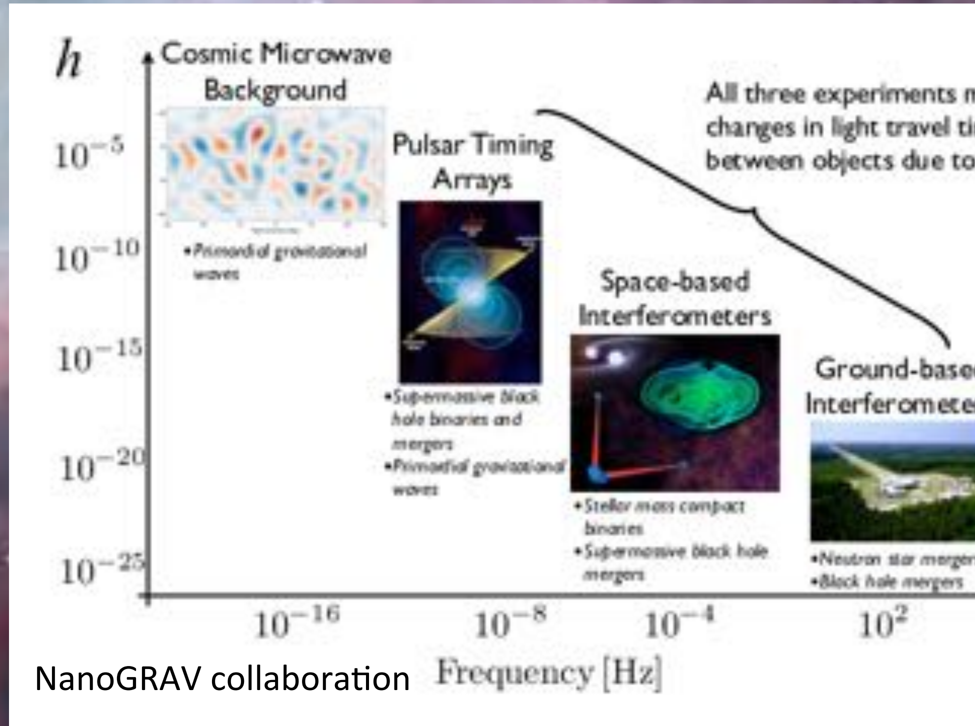
Kaplan+2016



Expectations for detection of promp radio emission fro GW events (<minu after merger of objects) with the MWA:

Detection of ~10 s transient at 0.1 – 1 ($\sim10^{38-39}$ erg/s for proposed models a expected distances





NanoGRAV collaboration

Direct GW detection with the SKA, using pulsars.

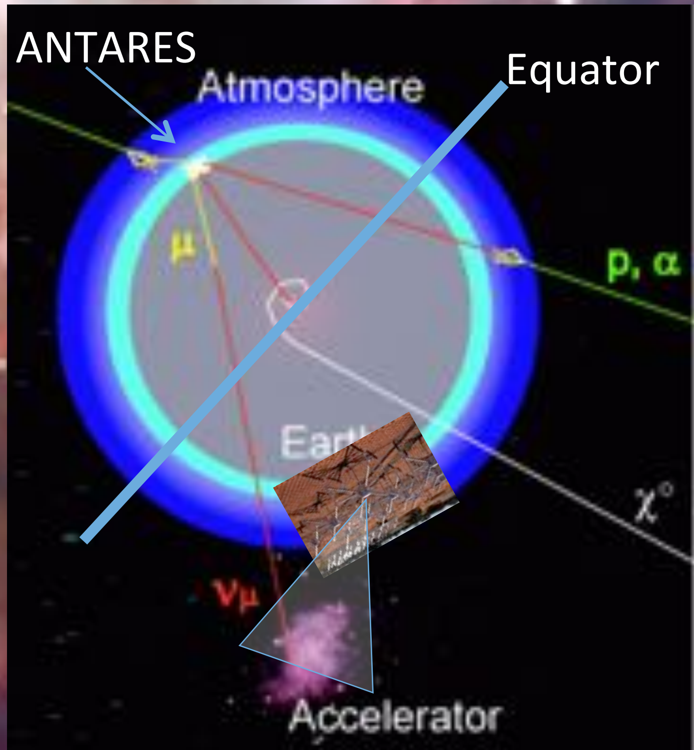
GWs cause changes in distance to pulsars, which changes the times of arrival of individual pulses.

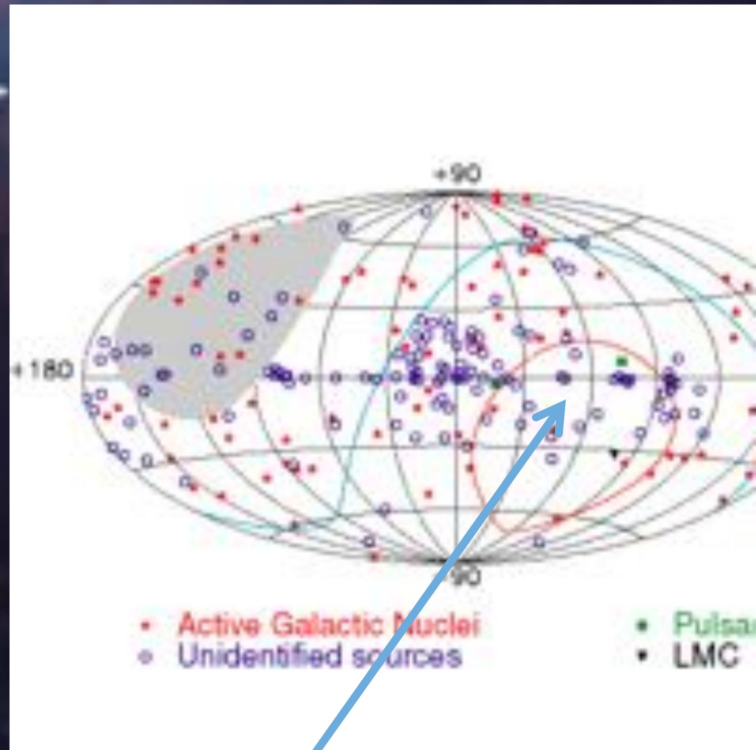
Sensitive radio telescopes (SKA) can monitor a la sample of pulsars to recover and localise the sou of GWs.

Neutrinos – EM counterparts

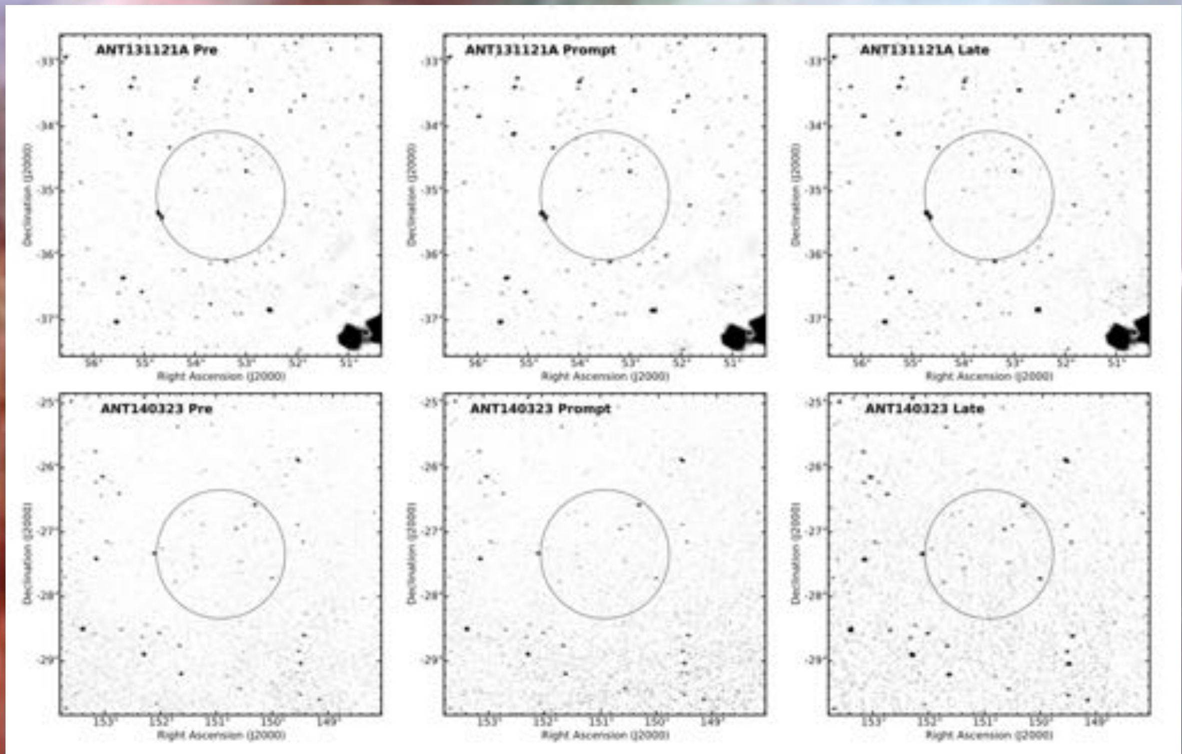
Neutrinos expected from:
- GRBs;
- Core collapse SNs;
- AGN/microquasers.

Only astrophysical neutrino signal to detected from SN1987A.





Sky ANTARES can see



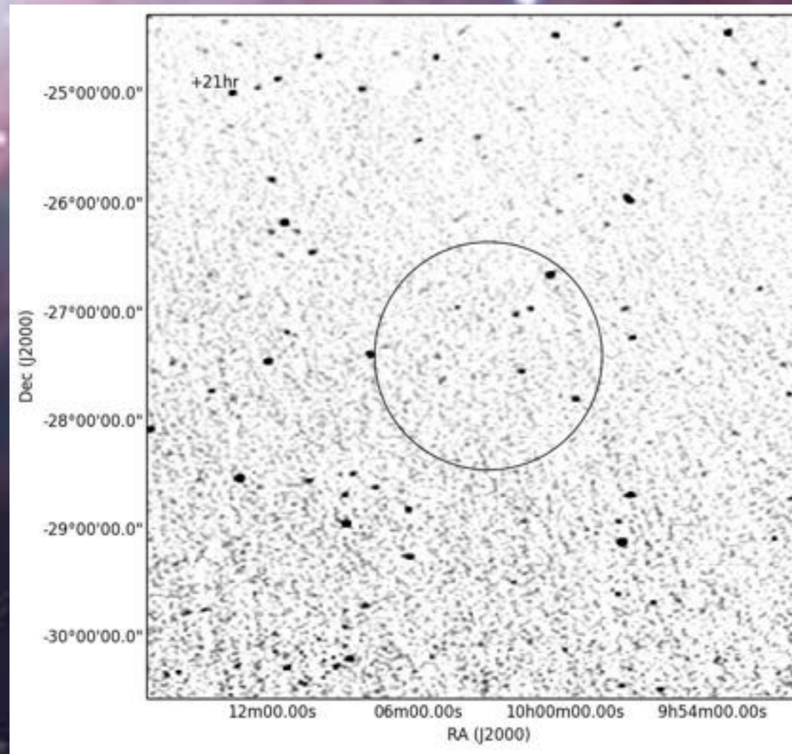


Table 1
Details of the two ANTARES events with simultaneous MWA observations

Trigger ID	UT date	UT time	RA (deg)	Dec (deg)	Energy (TeV)
ANT 131121A	2013 Nov 21	14:58:28	53.5	−35.1	∼ 1
ANT 140323A	2014 Mar 23	15:31:01	150.9	−27.4	∼ 4

1) Search list of ANTARES events that occur in FoV of MWA during observations;

2) Examine data pre-event, during event, and post-event to search EM signature.

Croft+2016

MURCHISON WIDEFIELD ARRAY LIMITS ON RADIO EMISSION FROM ANTARES NEUTRINO EVENTS

S. CROFT[1,2], D. L. KAPLAN[3], S. J. TINGAY[4,5], T. MURPHY[5,6], M. E. BELL[7], A. ROWLINSON[5,8,9], FOR THE MWA COLLABORATI

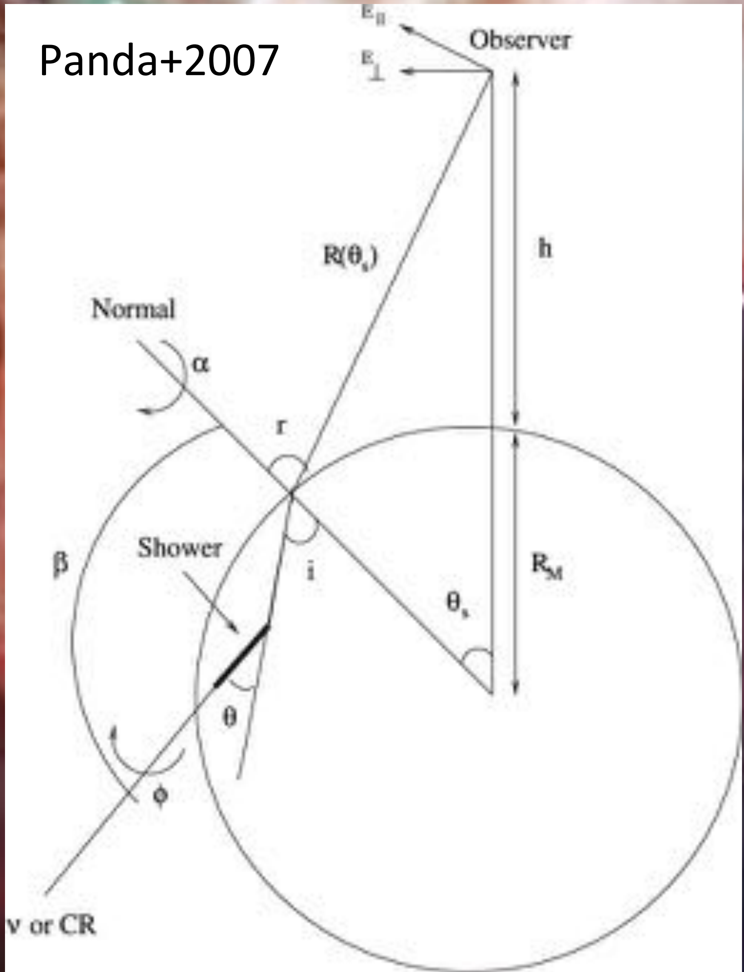
S. ADRIÁN-MARTÍNEZ[10], M. AGERON[11], A. ALBERT[12], M. ANDRÉ[13], G. ANTON[14], M. ARDID[10], J.-J. AUBERT[11], T. AVGITAS[1
B. BARET[15], J. BARRIOS-MARTÍ[16], S. BASA[17], V. BERTIN[11], S. BIAGI[18], R. BORMUTH[19,20], M. C. BOUWHUIS[19], R. BRUIJN[19,2
J. BRUNNER[11], J. BUSTO[11], A. CAPONE[22,23], L. CARAMETE[24], J. CARR[11], T. CHIARUSI[25], M. CIRCELLA[26], A. COLEIRO[15],
R. CONIGLIONE[18], H. COSTANTINI[11], P. COYLE[11], A. CREUSOT[15], I. DEKEYSER[27], A. DESCHAMPS[28], G. DE BONIS[22,23],
C. DISTEFANO[18], C. DONZAUD[15,29], D. DORNIC[11], D. DROUHIN[12], T. EBERL[14], I. EL BOJADDAINI[30], D. ELSÄSSER[31],
A. ENZENHÖFER[14], K. FEHN[14], I. FELIS[10], P. FERMANI[22,23], L. A. FUSCO[25,32], S. GALATÀ[15], P. GAY[15,33], S. GEISSELSÖDER[14
K. GEYER[14], V. GIORDANO[34], A. GLEIXNER[14], H. GLOTIN[35], R. GRACIA-RUIZ[15], K. GRAF[14], S. HALLMANN[14], H. VAN HAREN
A. J. HEIJBOER[19], Y. HELLO[28], J. J. HERNÁNDEZ-REY[16], J. HÖSSL[14], J. HOFESTÄDT[14], C. HUGON[37,38], C. W JAMES[14],
M. DE JONG[19,20], M. KADLER[31], O. KALEKIN[14], U. KATZ[14], D. KIESSLING[14], P. KOOIJMAN[19,39,21], A. KOUCHNER[15], M. KRETER
I. KREYKENBOHM[40], V. KULIKOVSKIY[18,41], C. LACHAUD[15], R. LAHMANN[14], D. LEFÈVRE[27], E. LEONORA[34,42], S. LOUCATOS[15,
M. MARCELIN[17], A. MARGIOTTA[25,32], A. MARINELLI[44,45], J. A. MARTÍNEZ-MORA[10], A. MATHIEU[11], T. MICHAEL[19], P. MIGLIOZ
A. MOUSSA[30], C. MUELLER[31], E. NEZRI[17], G. E. PĂVĂLAŞ[24], C. PELLEGRINO[25,32], C. PERRINA[22,23], P. PIATTELLI[18], V. POPA[2
T. PRADIER[47], C. RACCA[12], G. RICCOBENE[18], K. ROENSCH[14], M. SALDAÑA[10], D. F. E. SAMTLEBEN[19,20], A. SÁNCHEZ-LOSA[1
M. SANGUINETI[37,38], P. SAPIENZA[18], J. SCHMID[14], J. SCHNABEL[14], F. SCHÜSSLER[43], T. SEITZ[14], C. SIEGER[14], M. SPURIO[25,32
J. J. M. STEIJGER[19], T. STOLARCZYK[43], M. TAIUTI[37,38], C. TAMBURINI[27], A. TROVATO[18], M. TSELENGIDOU[14], D. TURPIN[11],
C. TÖNNIS[16], B. VALLAGE[15,43], C. VALLÉE[11], V. VAN ELEWYCK[15], E. VISSER[19], D. VIVOLO[46,48], S. WAGNER[14], J. WILMS[40],
J. D. ZORNOZA[16], J. ZÚÑIGA[16], FOR THE ANTARES COLLABORATION

A. KLOTZ[49,50], M. BOER[51], A. LE VAN SUU[52], FOR THE TAROT COLLABORATION

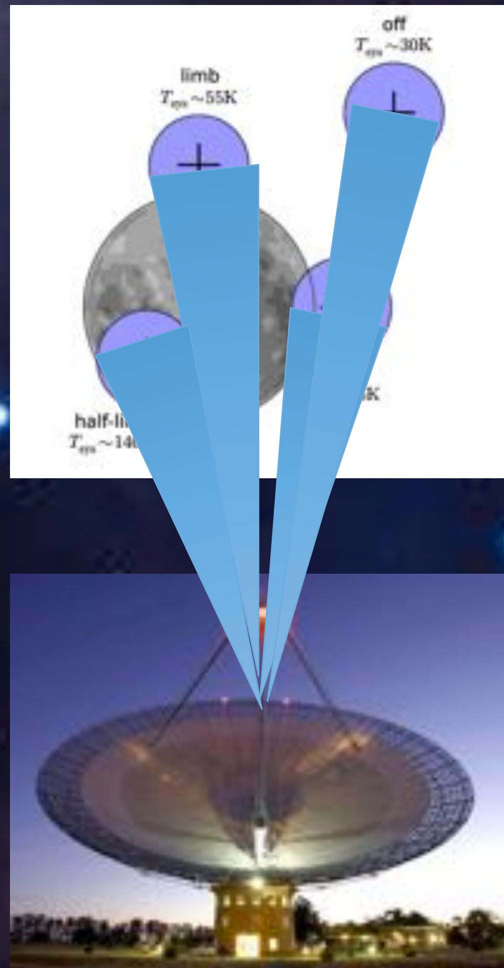
C. AKERLOF[53], W. ZHENG[1], FOR THE ROTSE COLLABORATION

Draft version March 9, 2016

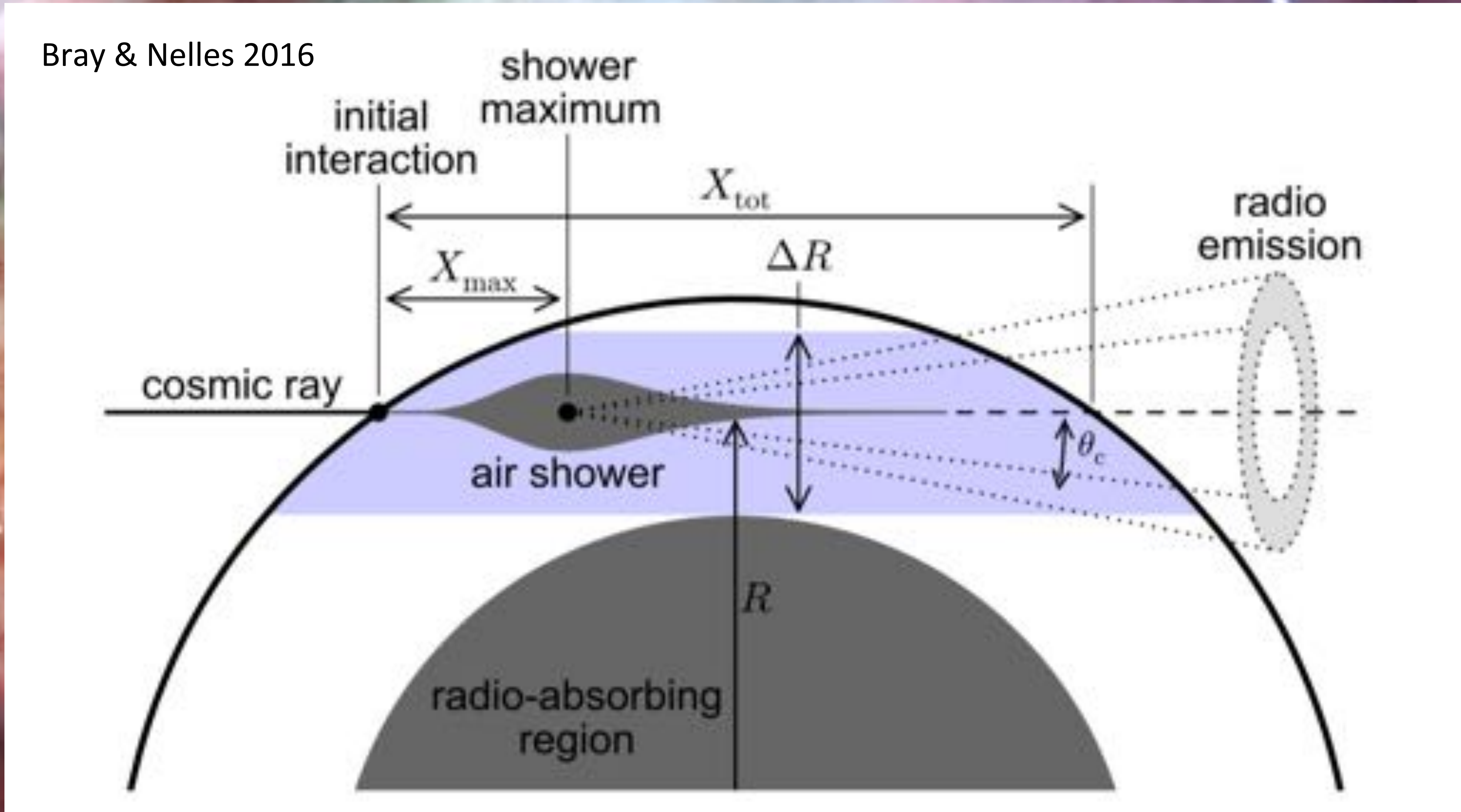
Radio Cherenkov emission from the Lunar Regolith



Panda+2007



Bray+2013



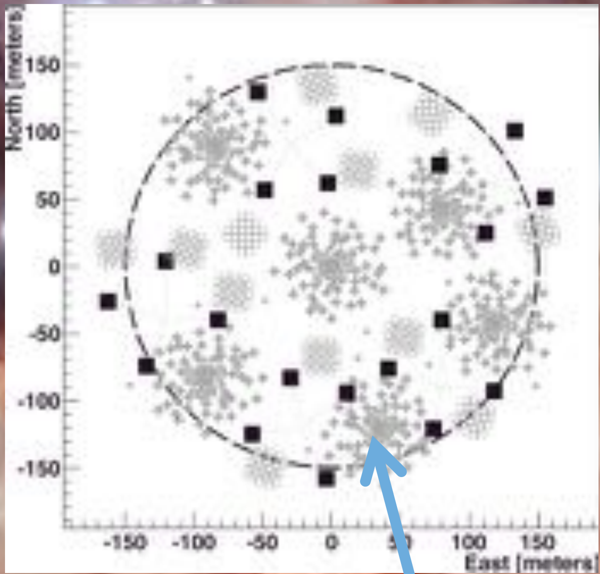
Using Jupiter atmosphere for particle detection: Not feasible – Moon is better

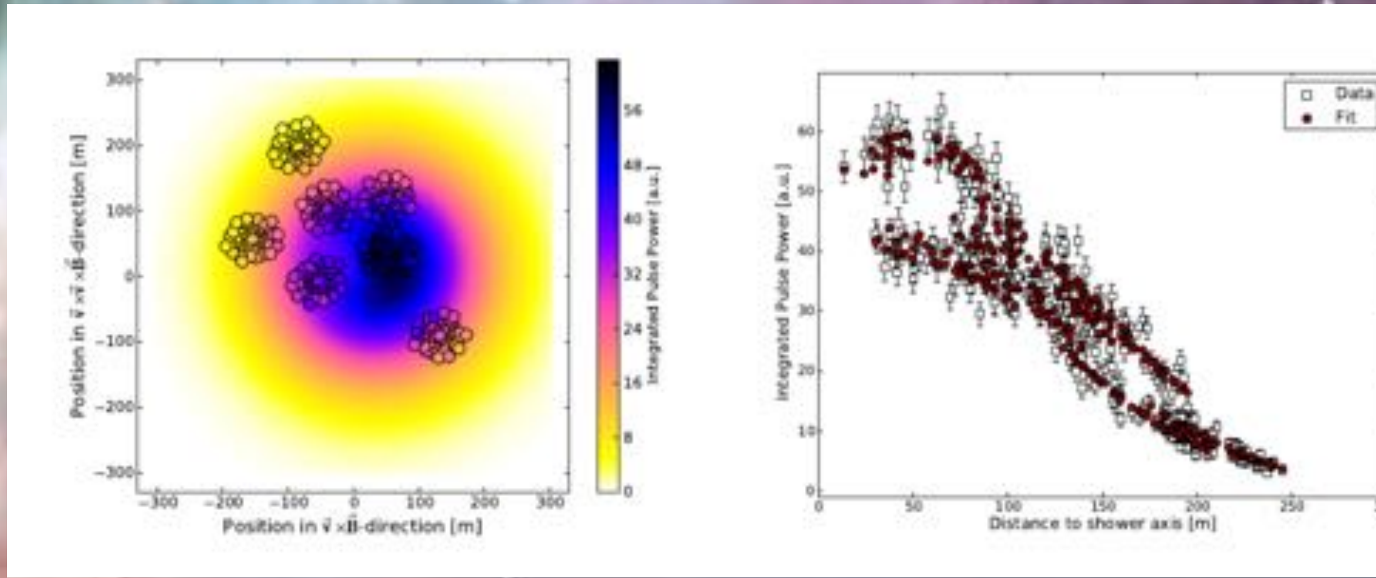
Radio emission from Cosmic Ray showers

LOw Frequency Array (LOFAR)

ASTRON

Radio emission from cosmic ray showers
by Jelley+1965, Nature, 205, 327



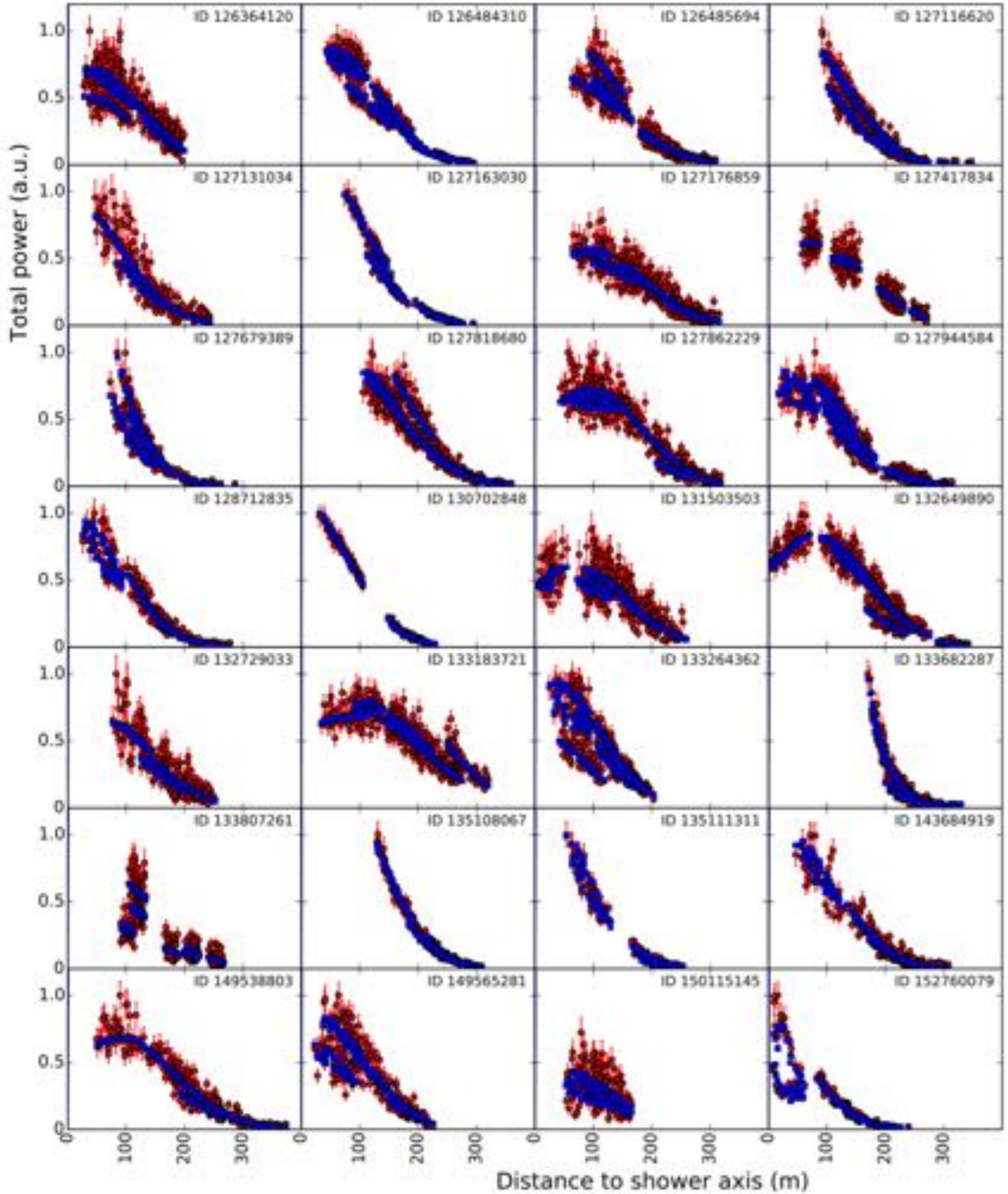


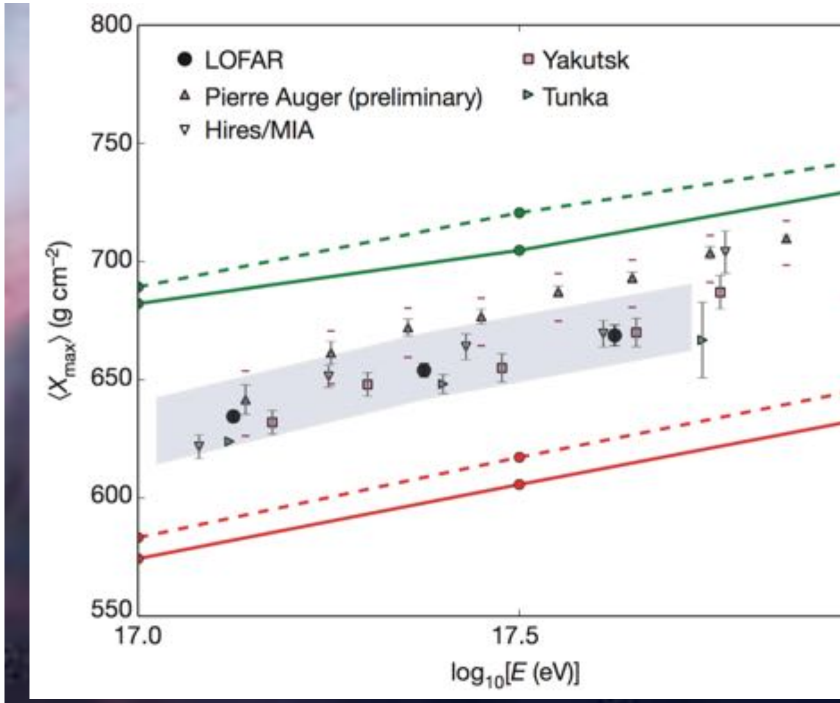
Much higher density of radio antennas than implemented at Auger (AERA).

- Arrival direction – from time of arrival of radio emission acro the geographical extent of the array. Directions to better tha deg;

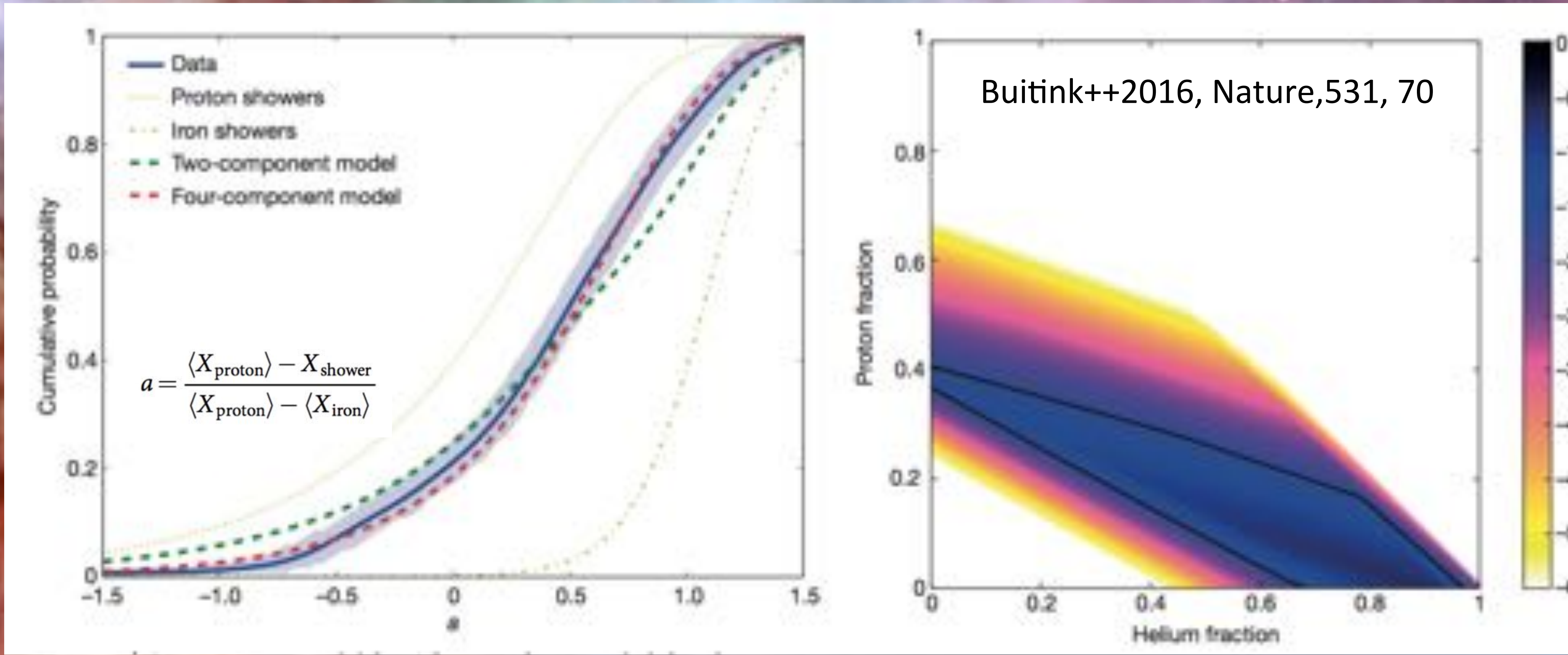
- Width of radio footprint is proportional to the height of show maximum, Xmax. Gives mass estimate of primary particle; (r footprint -> Xmax; particle detectors used for energy measurement).

- Monte Carlo simulation approach.





Buitink++2016, Nature,531, 70
(and Corrigendum)

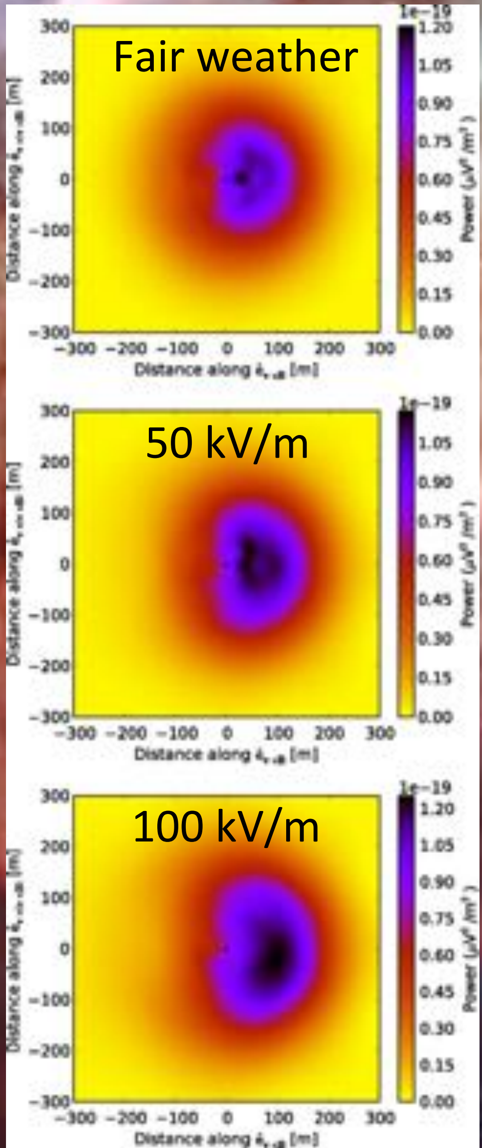


Best fit: (p, He, N, Fe) = (0%, 79%, 19%, 2%) – large (~80%) light element component at 10^{17-17}

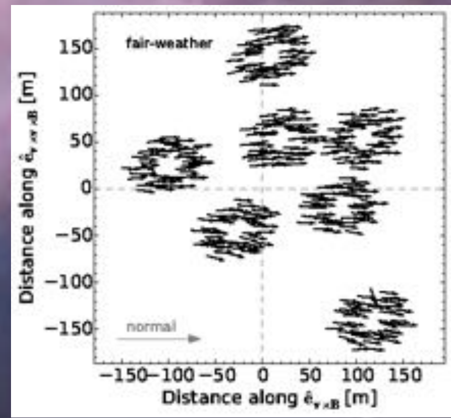
Constrain mixture of “heavy” and “light” elements, which is inconsistent with known galactic sources of cosmic rays and points to possible:

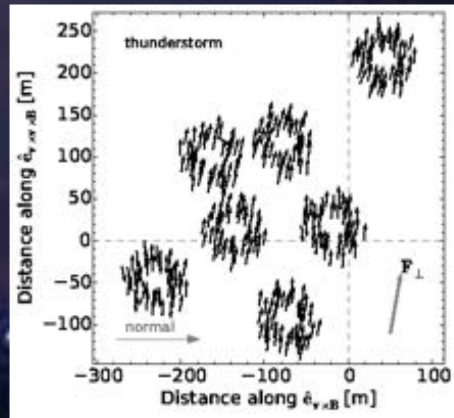
1. Extragalactic source (concluded to be unlikely);
2. New galactic source (e.g. explosions of Wolf Rayet stars into their stellar winds).

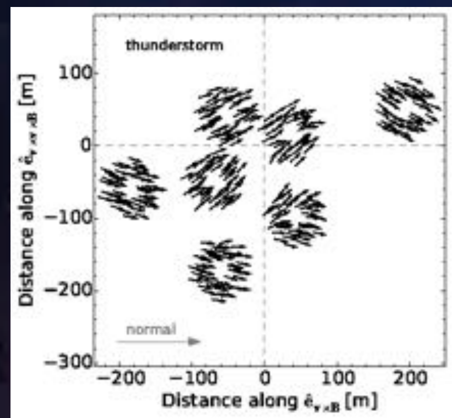
Simulations



astrophysics/particle physics/meteorology?







Trinh+2016

Schellart+2015

The future with the SKA

- More antennas: MWA /LOFAR -> ~1000; SKA -> ~100,000;
- Better geographical footprint (filled area of ~1 km diameter + high density < 5 km);
- Overall antenna distribution up to ~100 km extent;
- More bandwidth, more signal processing;
- Radio quiet location – important to discriminate between astrophysical and terrestrial signals;
- In the same epoch as LIGO/VIRGO, KM3NeT, Ice Cube, CTA etc etc.

Lunar detection of ultra-high-energy cosmic rays and neutrinos with the Square Kilometre Ar

J. D. Bray, J. Alvarez-Muñiz, S. Buitink, R. D. Dagkesamanskii, R. D. Ekers, H. Falcke, K. G. Gayley, T. Huege, C. W. James, M. Mevius, R. L. Mutel, R. J. Protheroe, O. Scholten, R. E. Spencer, S. ter Veen

https://arxiv.org/abs/1408.6069

Precision measurements of cosmic ray air showers with the SKA

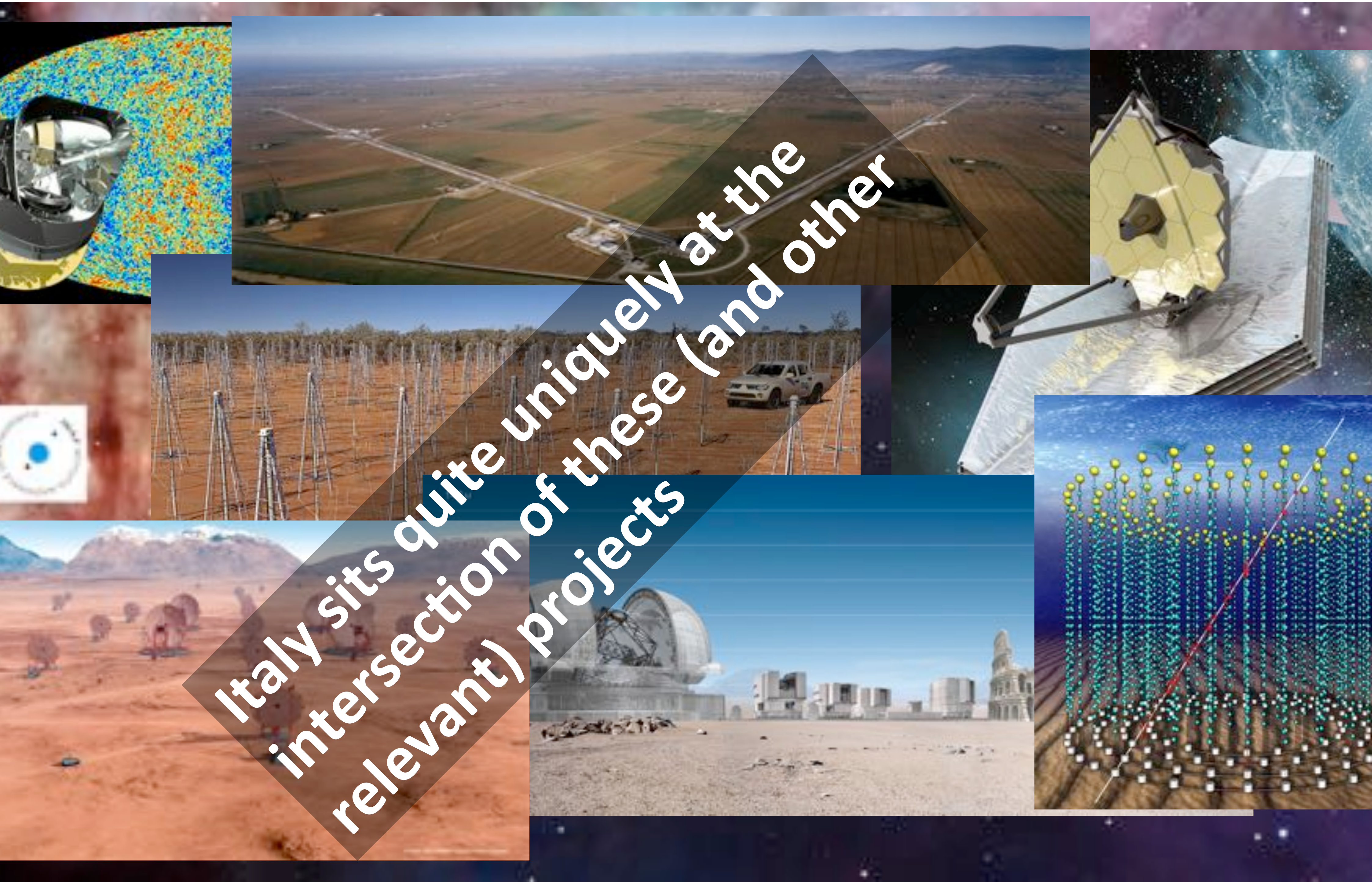
T. Huege, J.D. Bray, S. Buitink, R. Dallier, R.D. Ekers, H. Falcke, C.W. James, L. Martin, B. Revenu, O. Scholten, F.G. Schröder

https://arxiv.org/abs/1408.5288

NOTHING ON SKA AND GRAVITATIONAL WAVES (except with pulsars)!!!

Science case published in 2015 (pre-GW detection with LIGO).

But EM follow-up of GW and neutrinos basically covered by the capabilities of the “transient science” case for the SKA.


Italy sits quite uniquely at the intersection of these (and other relevant) projects

Summary

- The SKA will be the ultimate radio telescope at wavelengths longer than cm for the next 20+ years;
- The SKA will take its place among the future suite of grand-scale astrophysics infrastructure in a multi-wavelength, multi-messenger worl
- For astroparticle physics, the most relevant part of the SKA is the low frequency array (50 – 350 MHz), where Italian technology has a large footprint;
- The SKA precursor telescopes, in particular LOFAR and the MWA, are already taking part in a range of multi-messenger experiments:
  - First steps – big scope for a lot more future work.
- Italy is spectacularly well-placed to take advantage of this future:
  - We need people who understand the cultures of astronomy and particle physics t help “glue” everything/everyone together.