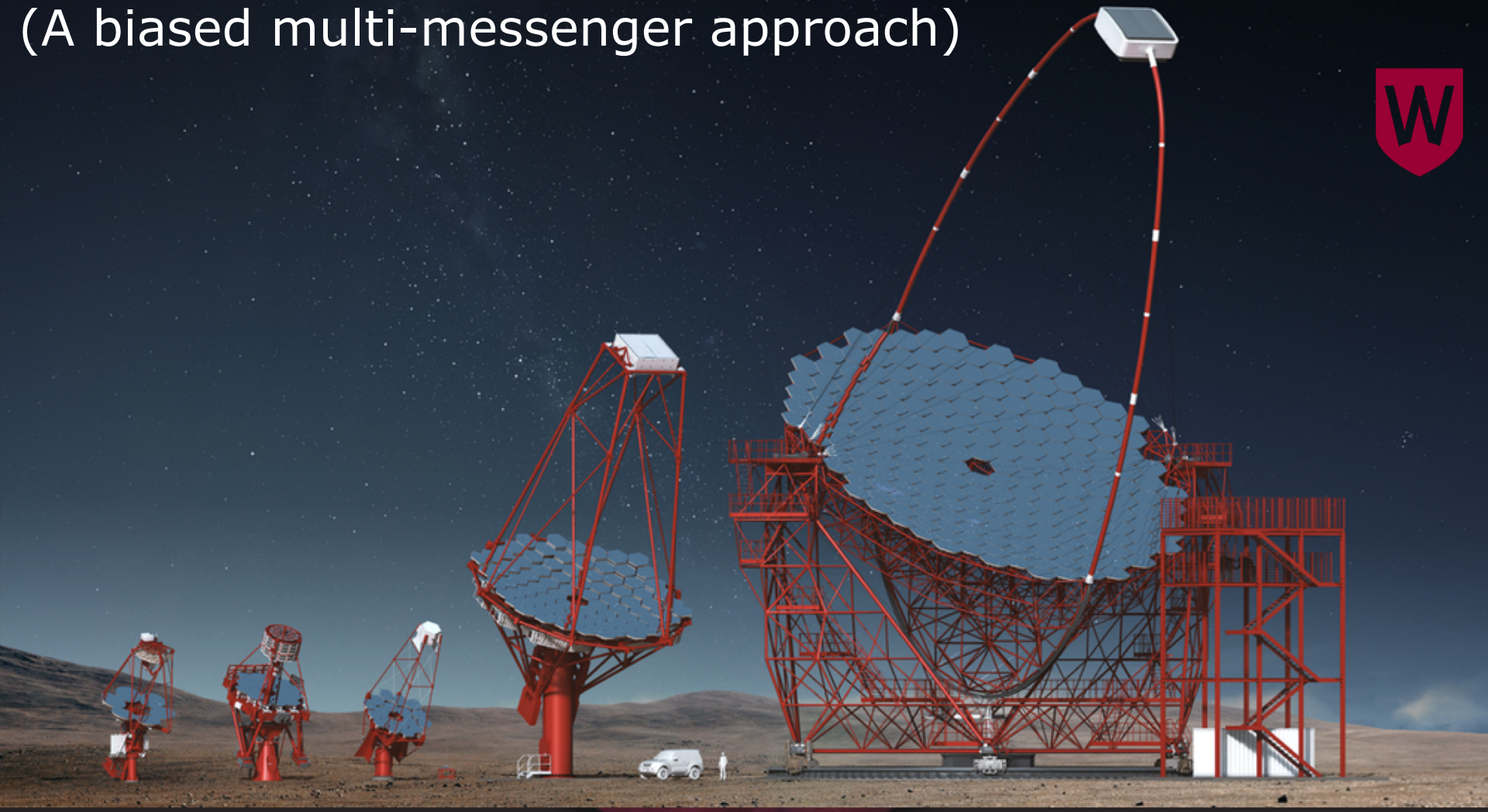
Future Telescopes

(A biased multi-messenger approach)



Miroslav Filipovic *Western Sydney University (for OzCTA)*

PENRITH OBSERVATORY

westernsydney.edu.au/observatory

Bamberg, *March 2018*

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DISCLAIMER

•I AM NOT RESPONSIBLE FOR BUILDING ANY NEW TELESCOPE PRESENTED HERE IN THIS TALK OR THAT ANY ASSOCIATED ORGANISATION(S) PAYED ME FOR PROMOTING THEIR PROJECT. ACTUALLY, I AM VERY SKEPTICAL THAT ANY OF THESE PROJECTS WILL HAPPEN ON TIME OR WITHIN THE PRESENT PROJECTED BUDGET. I STRONGLY DENY ANY RESPONSIBILITY FOR THEIR DELAY OR (MIS)BUDGET. FOR MORE INFORMATION'S -- ASK YOUR GOVERNMENT AGENCY. IT IS MOST LIKELY THAT I MISSED YOUR FAVORITE TELESCOPE AND I APOLOGIES FOR THAT. IF YOUR FAVORITE TELESCOPE IS NOT MENTION AT ALL AND YOU ARE WORKING IN A FIELD OF EXTRASOLAR PLANETS, GRAVITATIONAL ASTRONOMY THEN ASK MANAMI FOR REFUND – YOU ARE ATTENDING WRONG CONFERENCE.

Obligatory ASKAP-EMU photo

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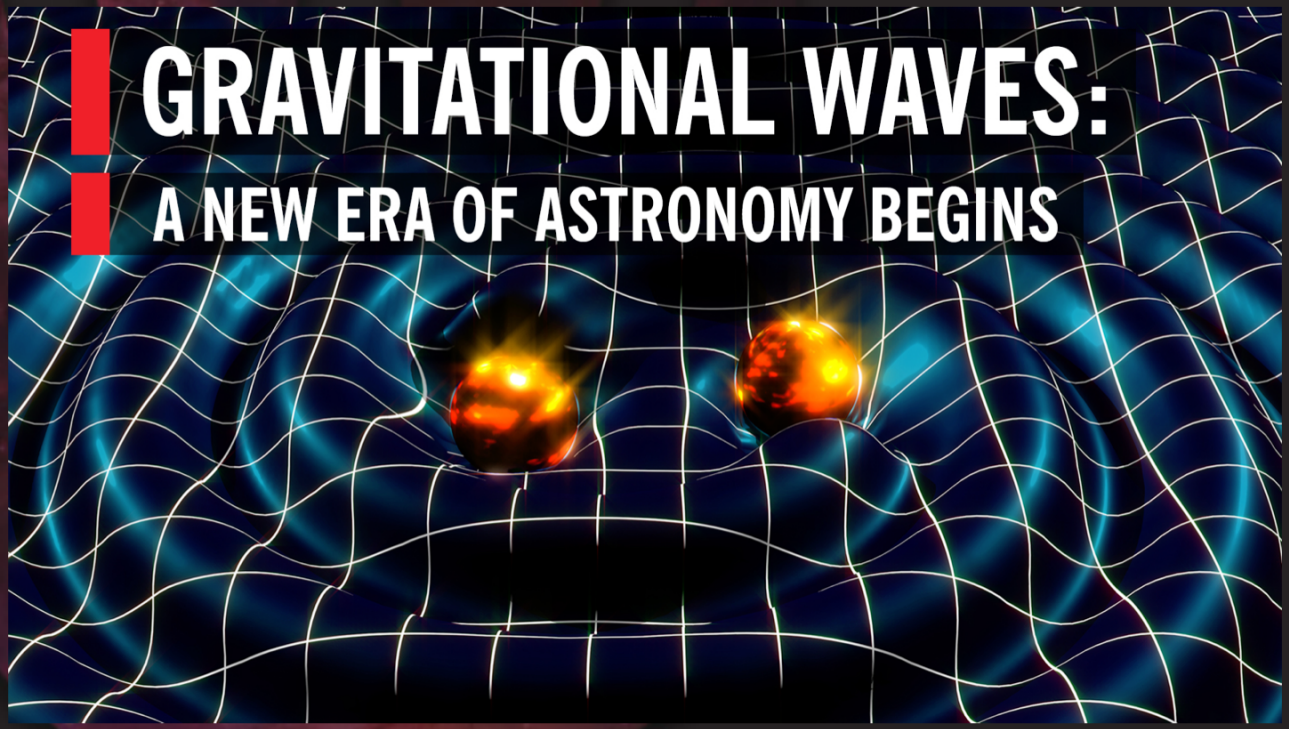
ERA OF:

- Big(er) Telescopes?
- Big(er) ideas & questions?
- Big(er) money!
- Big disappointments?
- Machine Learning

- SURVEYS!!!!!!!!!!



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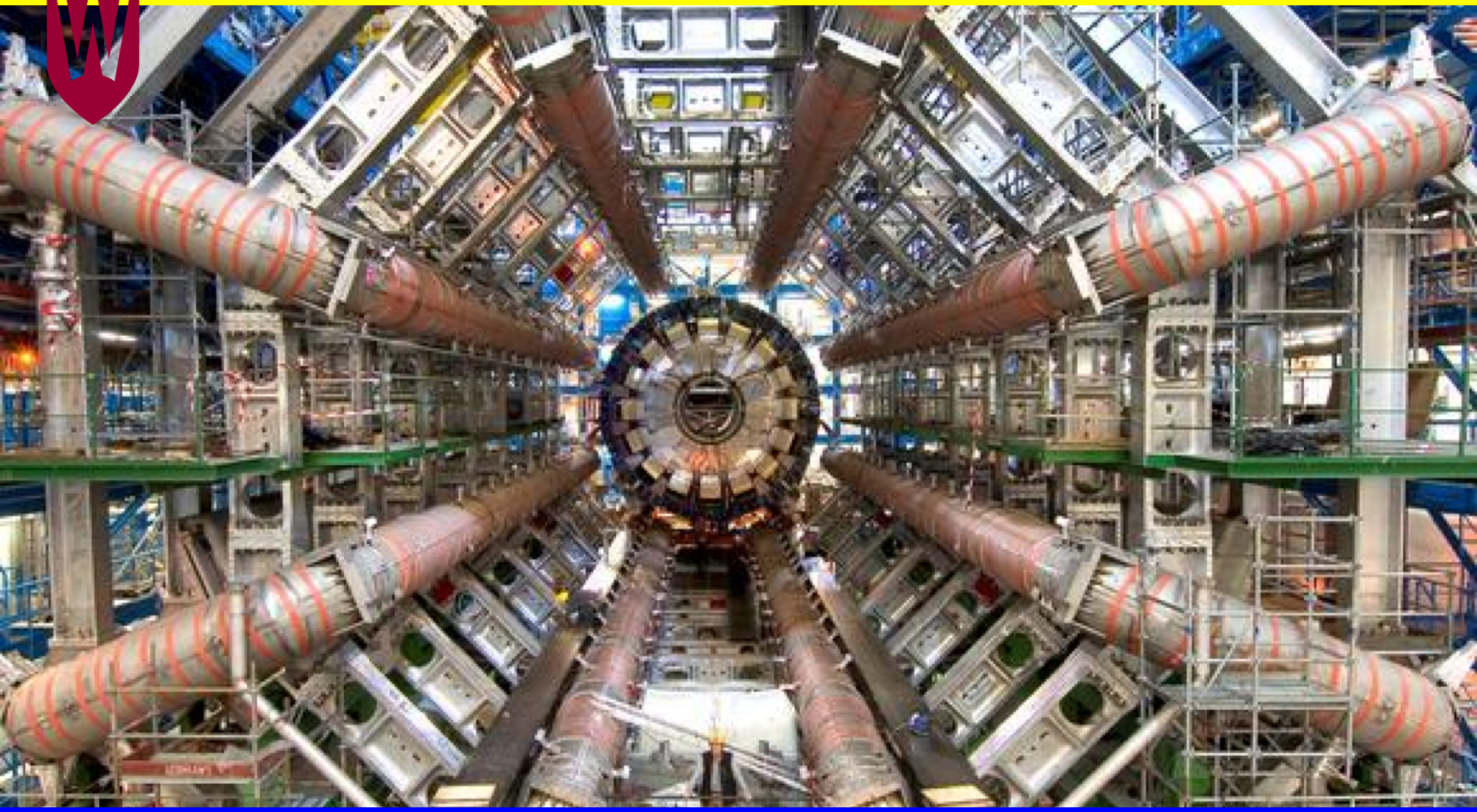
Discovering the unknown-unknowns in big data

Courtesy of Ray Norris

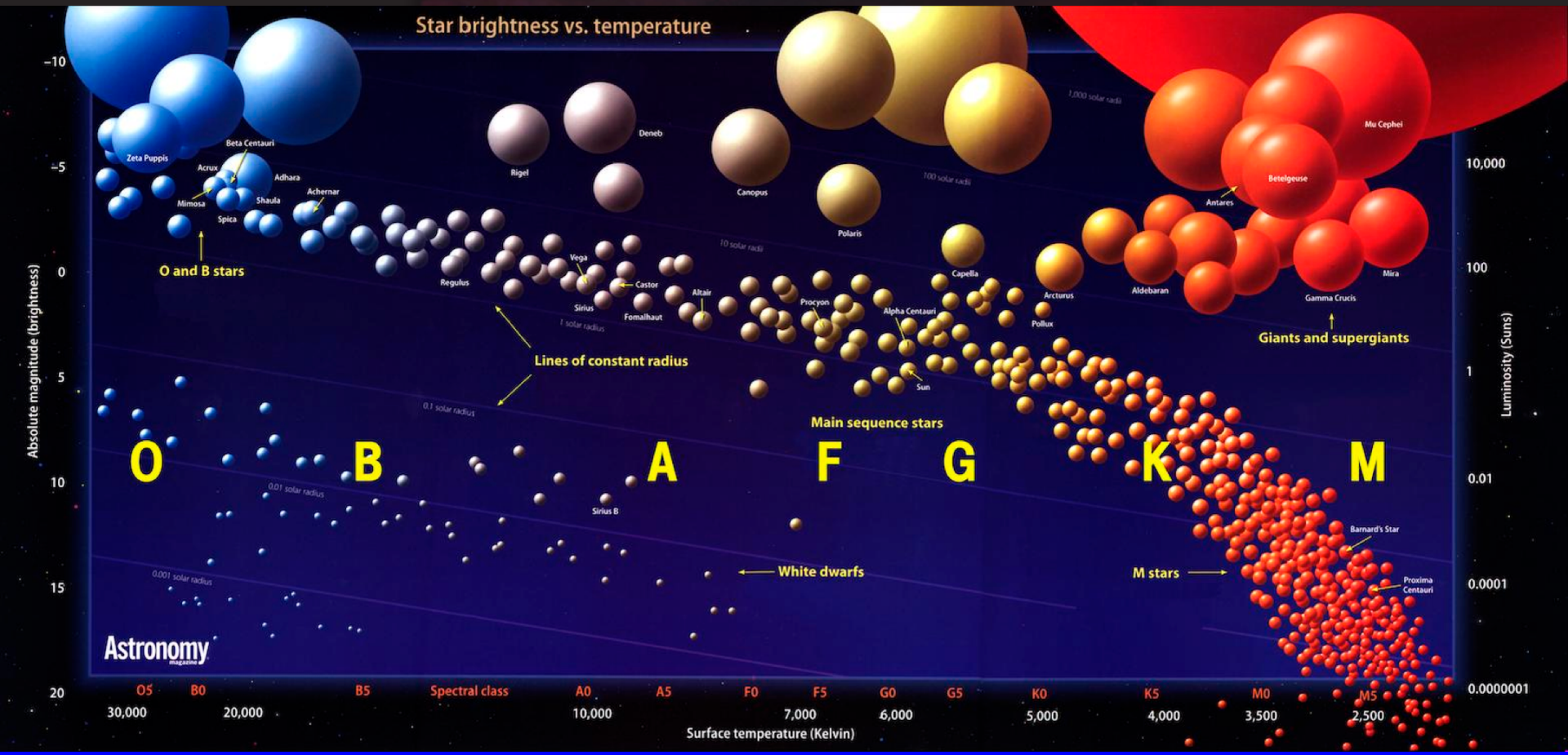
HOW DOES SCIENCE WORK?



- Karl Popper: experiments test theory!
  - e.g. High energy physics, LHC, Higgs Boson
  - Falsifiable predictions remain the "gold standard" of good science

Courtesy of Ray Norris

Kuhn et al. showed Popperian science is not the only mode (e.g. exploration, understanding, insight)



ASTRONOMY USUALLY WORKS MORE IN AN "EXPLORER" MODE

Courtesy of Ray Norris

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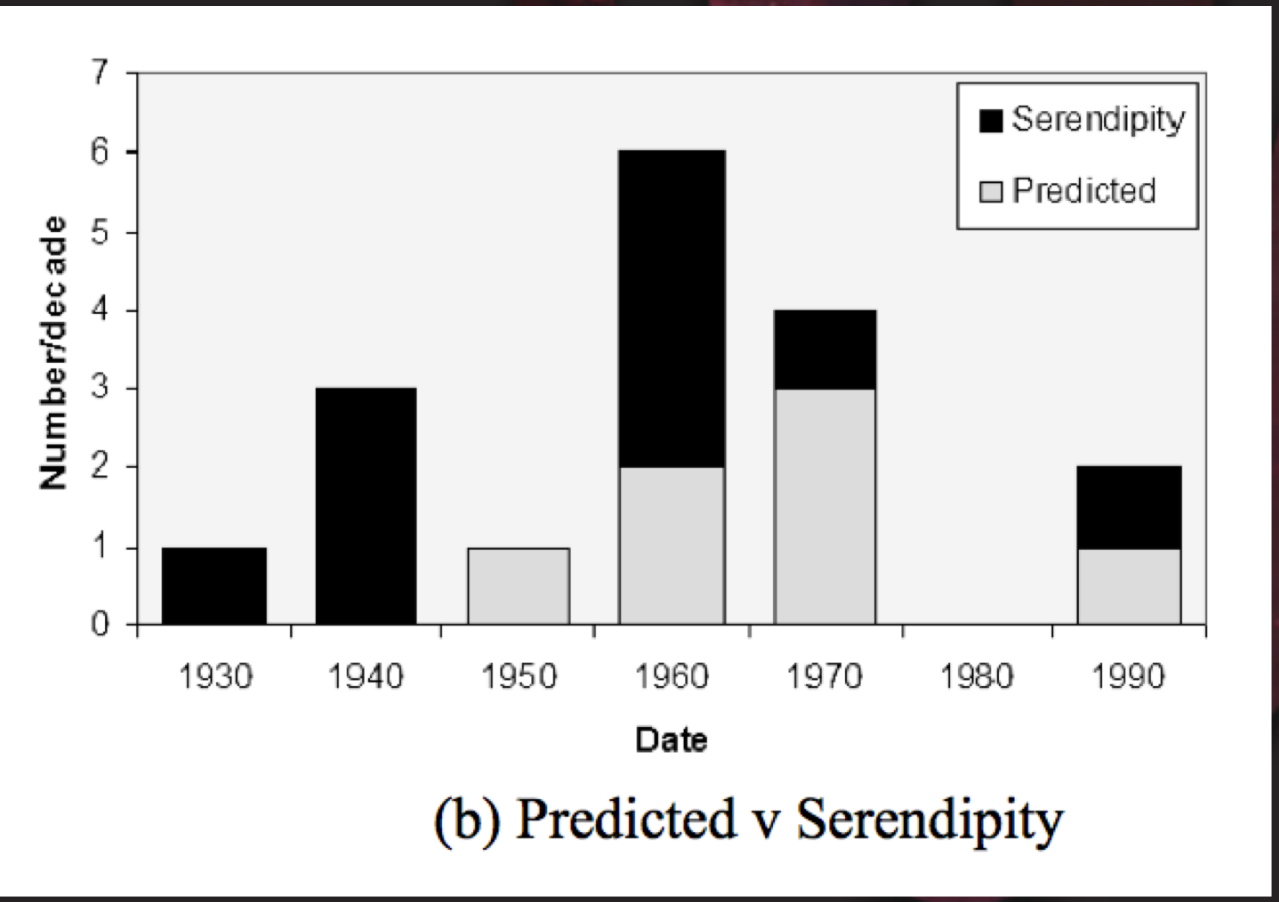
WHAT FRACTION OF DISCOVERIES IN ASTRONOMY WERE "POPPERIAN"?



+1 for dark energy (2012)

Serendipity:11
Predicted: 7

From Ekers (2009) PoS(sps5)007

DISCOVERIES WITH HST
(SEE E.G. LALLO: *ARXIV:1203.0002)*

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Project	Key project	Planned ?	Nat. Geo. top ten?	Highly cited?	Nobel prize?
Use Cepheids to improve value of H0	✔	✔	✔	✔	
study intergalactic medium with uv spectroscopy	✔	✔			
Medium-deep survey	✔	✔			
Image quasar host galaxies		✔	✔		
Measure SMBH masses		✔	✔		
Exoplanet atmospheres		✔	✔		
Planetary Nebulae		✔	✔		
Discover Dark Energy			✔	✔	✔
Comet Shoemaker-Levy			✔		
Deep fields (HDF, HDFS, UDF, FF, etc)			✔	✔	
Proplyds in Orion			✔		
GRB Hosts			✔		

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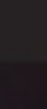

Summary:

Of the "top ten" HST discoveries:

- **1 was a key project**
- **4 were planned by astronomers but were not key projects**
- **5 were totally unexpected (e.g. dark energy)**

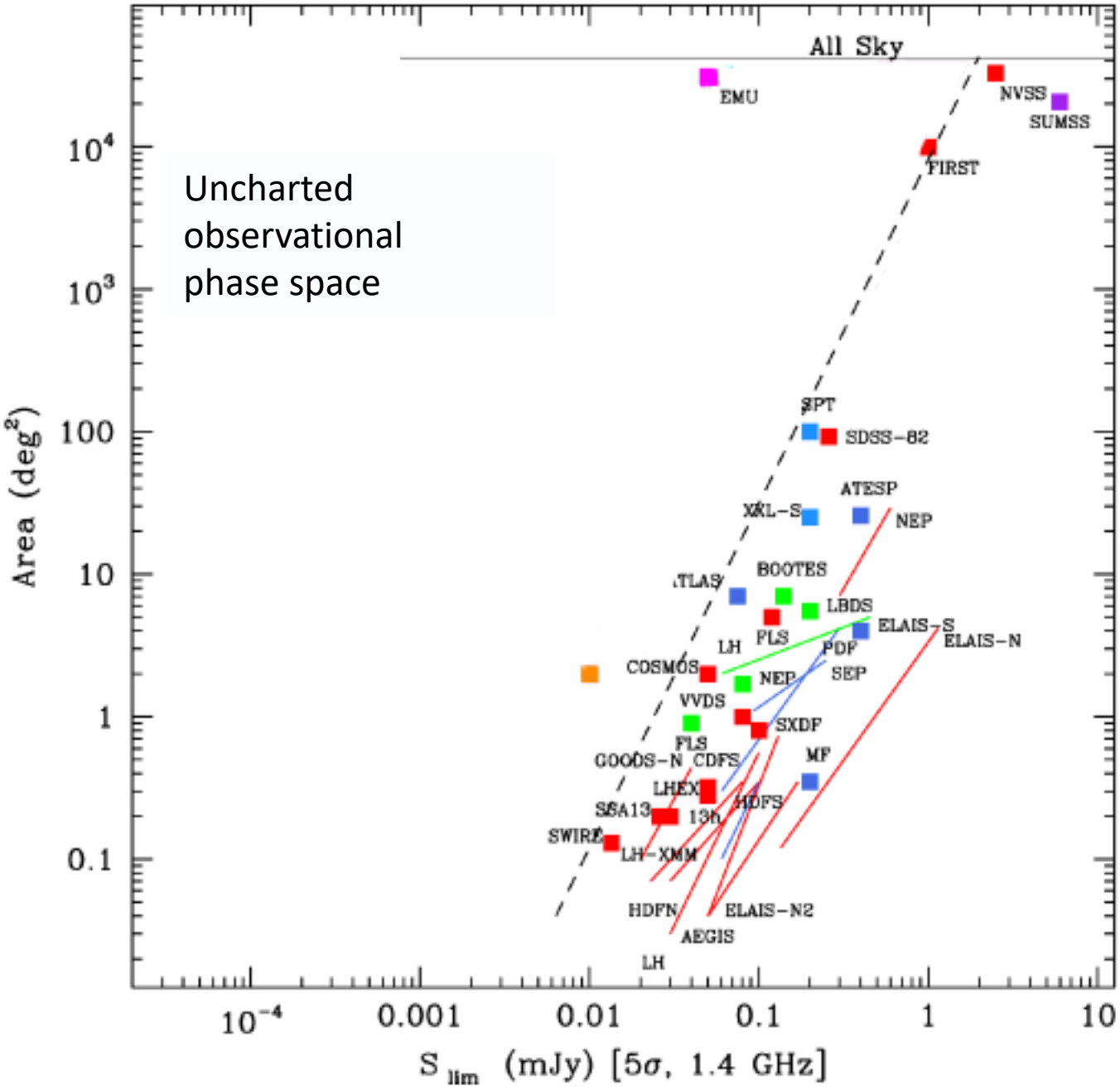

Diagram courtesy of Isabella Prandoni

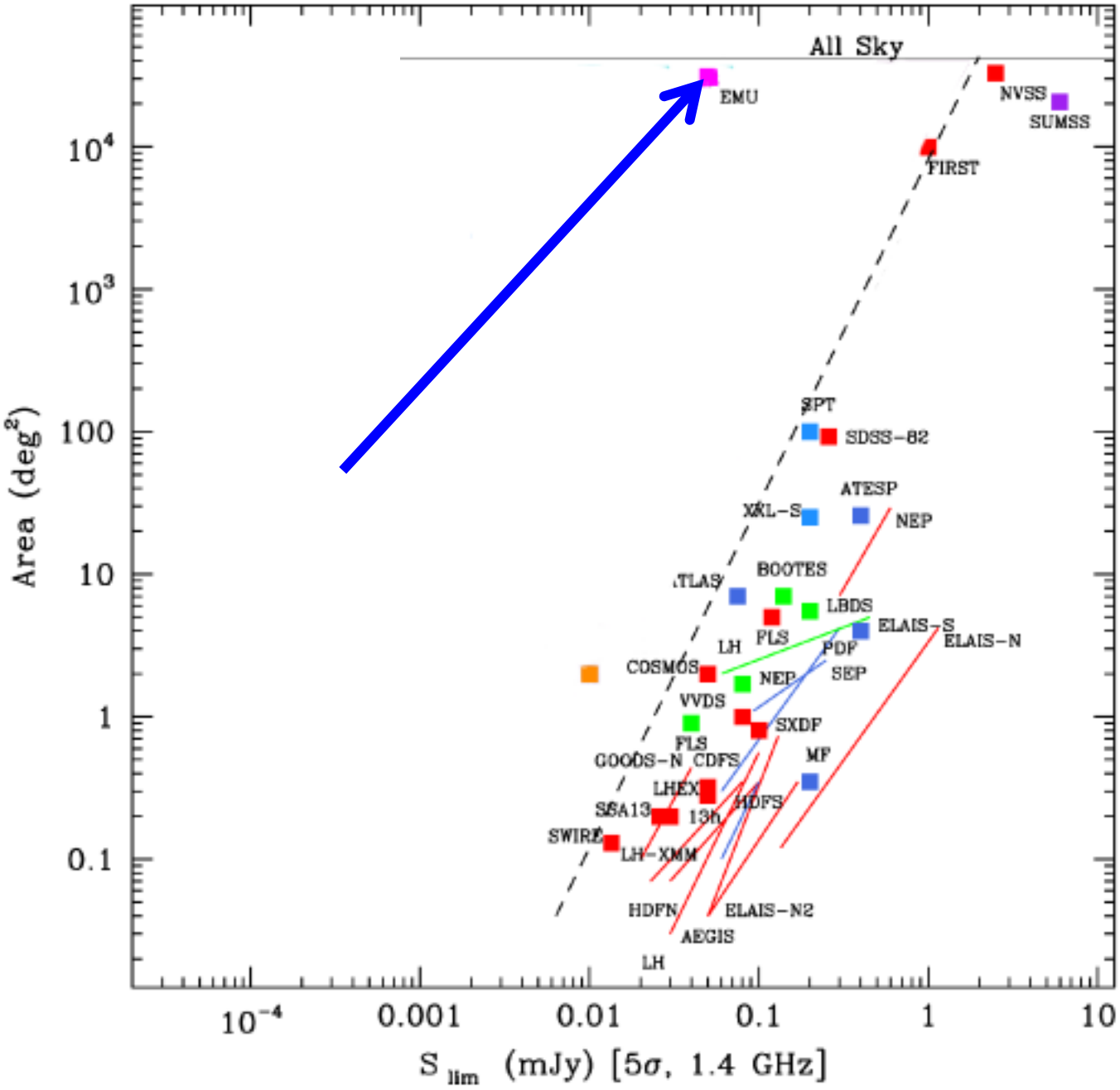

Diagram courtesy of Isabella Prandoni

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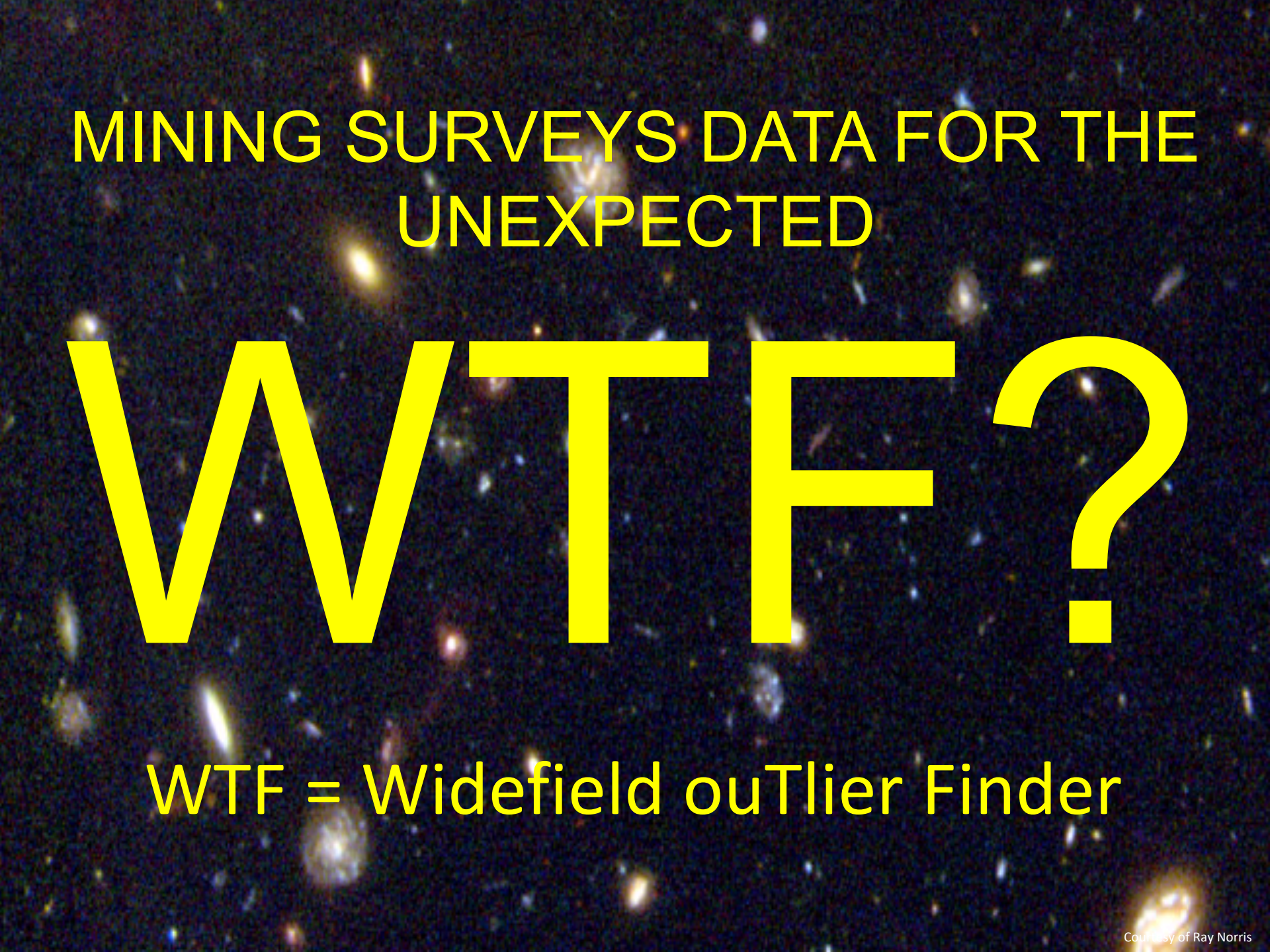
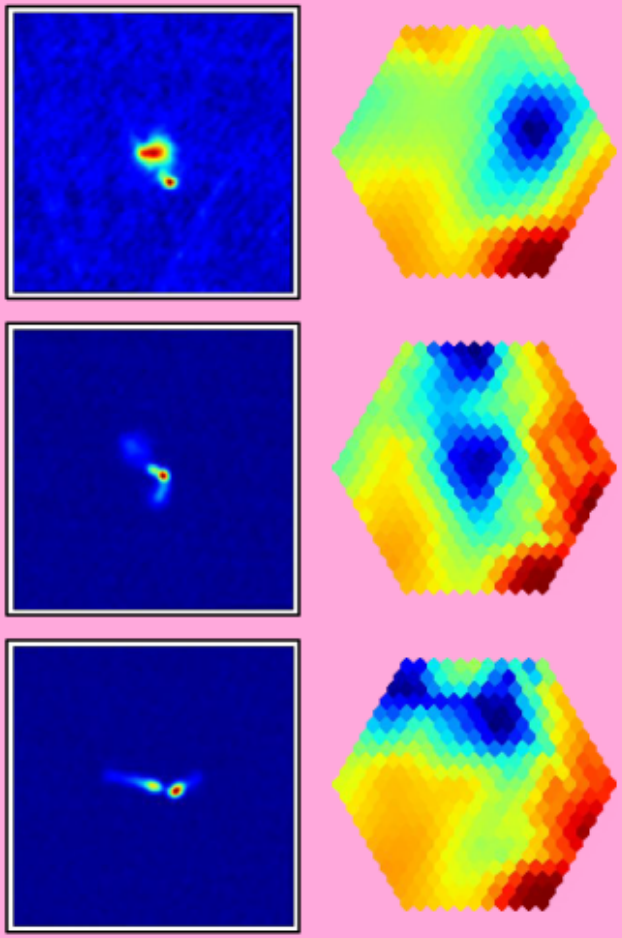
WHAT DOES NEW TELESCOPES NEED TO DO TO DISCOVER THE UNEXPECTED?

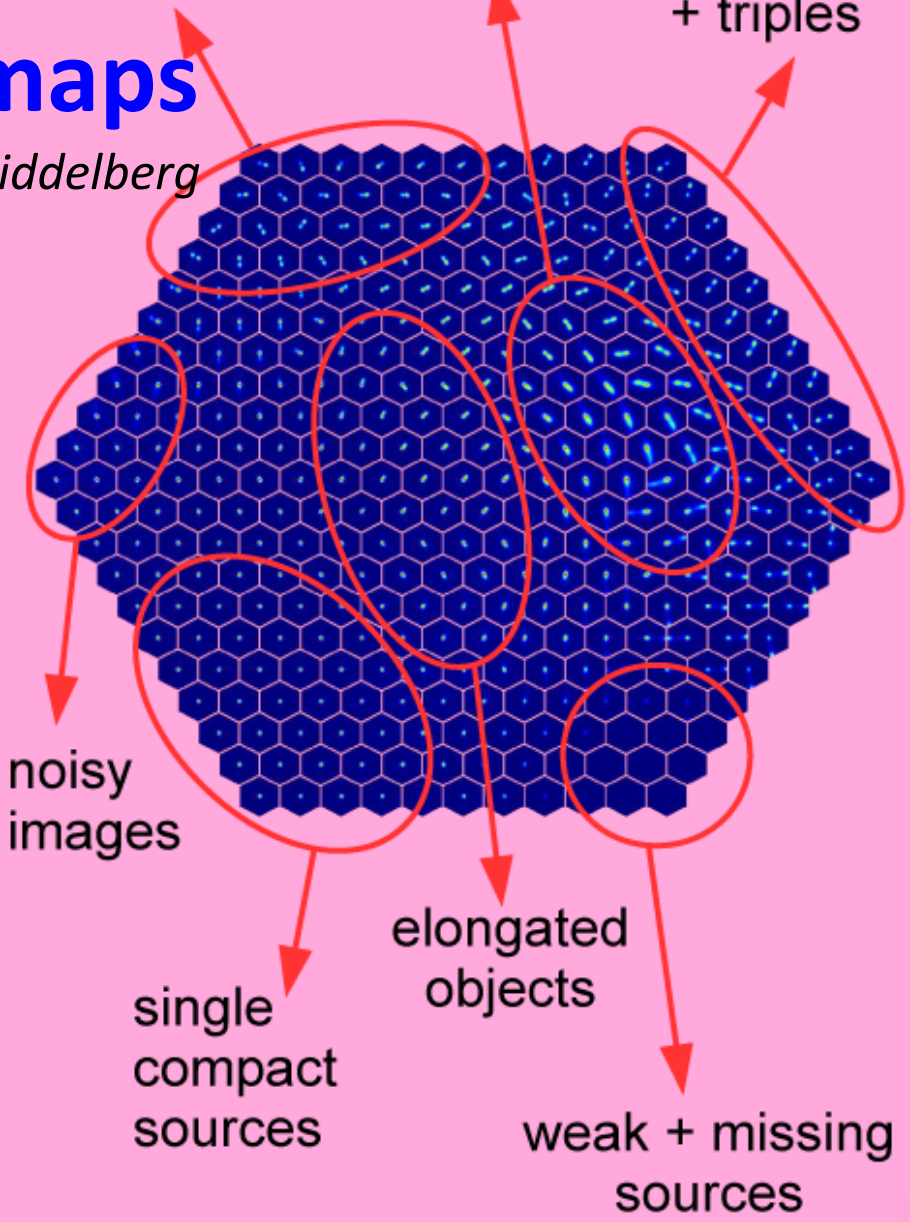
- **Maximise the volume of new phase space**
  - A good surrogate is to use # of known objects
  - Maximised by an all-sky survey
- **Retain flexibility**
  - don't optimise the telescope ONLY for your science goals
- **Develop data mining software to search for the unexpected**
  - This will be an important part of data-intensive research


MINING SURVEYS DATA FOR THE UNEXPECTED
WTF?
WTF = Widefield ouTlier Finder
Courtesy of Ray Norris

Self-organised maps

courtesy Kai Polsterer & Enno Middelberg



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gamma ray
X-ray
ultraviolet
visible
infrared
microwave
radio

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ISM-Bamberg 2018

SNRs.XrayBinaries.PWN.QSO.MolecularClouds.Galaxies.BlackHoles.AGNs.Pulsars.Stars.clusters.HIIRegions.PNe.CR.MagFields….
OriginOfLife?
Instruments.DATASCIENCE.
eROSITA.CTA.MOPRA.MWA.LOFAR.CHANDRA.XMM-NEWTON.HST…

PRESENT

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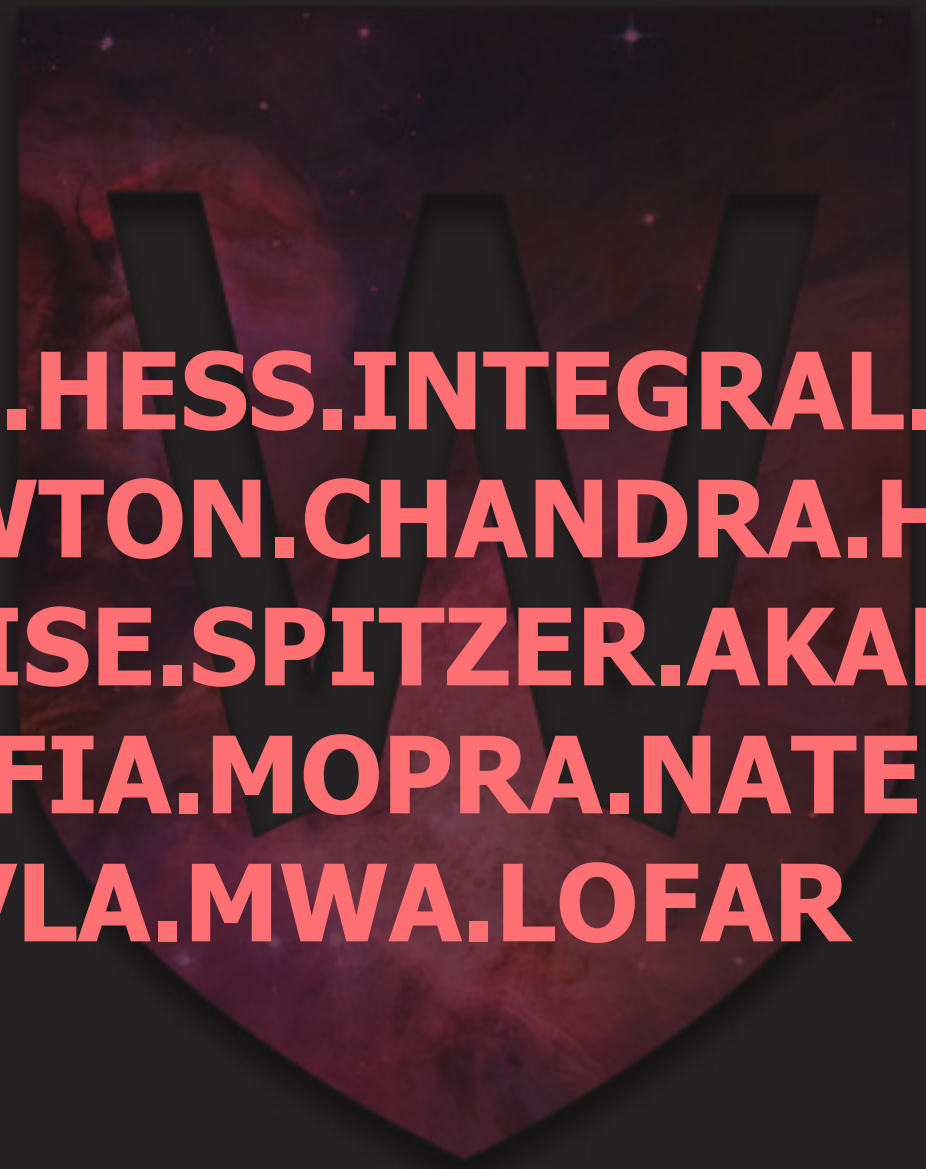

ICECUBE.HESS.INTEGRAL.FERMI.XMM_NEWTON.CHANDRA.HST.KECK.VLT.WISE.SPITZER.AKARI.HERSCHEL.SOFIA.MOPRA.NATEN2.ALMA.ATCA.VLA.MWA.LOFAR

...

FUTURE

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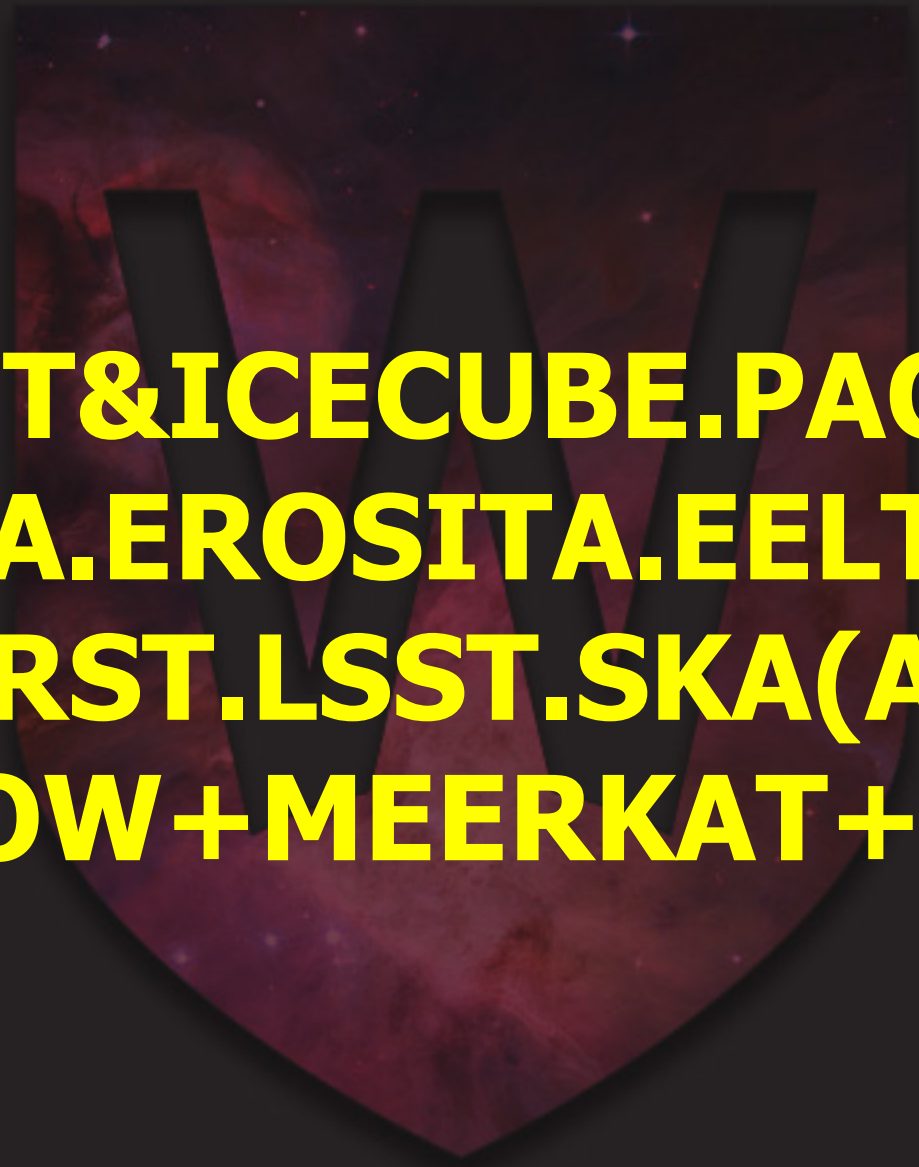


KM3NET&ICECUBE.PAO.CTA.
ATHENA.EROSITA.EELT.GMT.J
W.WFIRST.LSST.SKA(ASKAP+
MWALOW+MEERKAT+FAST)

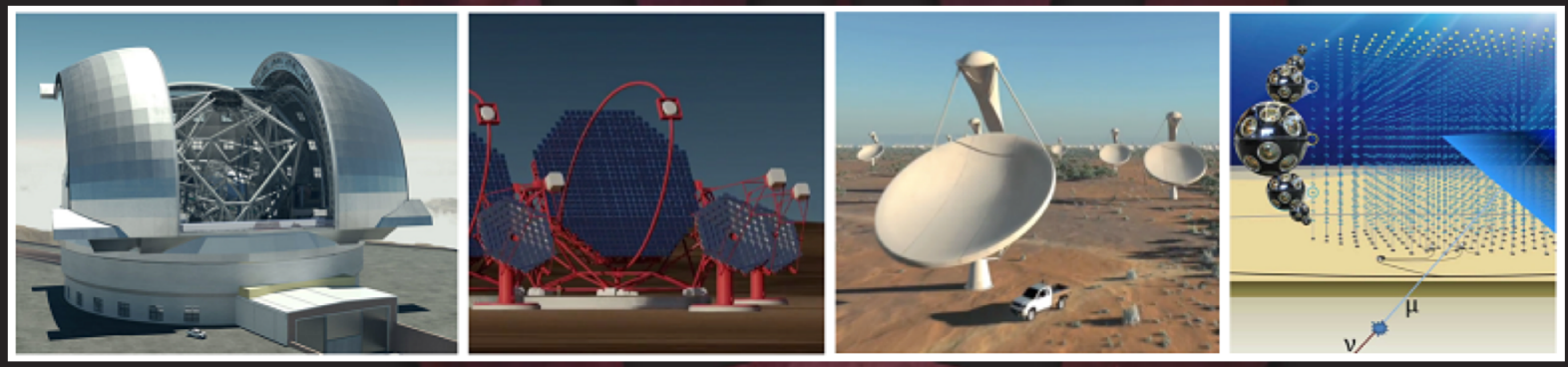
...

Asterics

Astronomy ESFRI & Research Infrastructure Cluster

Horizon 2020
European Union funding
for Research & Innovation

The Astronomy ESFRI and Research Infrastructure Cluster



15MEuro programme to tap synergies between:
E-ELT, CTA, SKA, KM3NeT

https://www.asterics2020.eu

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NEUTRINO ASTRONOMY

KM3NeT & IceCube

NEUTRINO ASTRONOMY: QUESTIONS TO ANSWER

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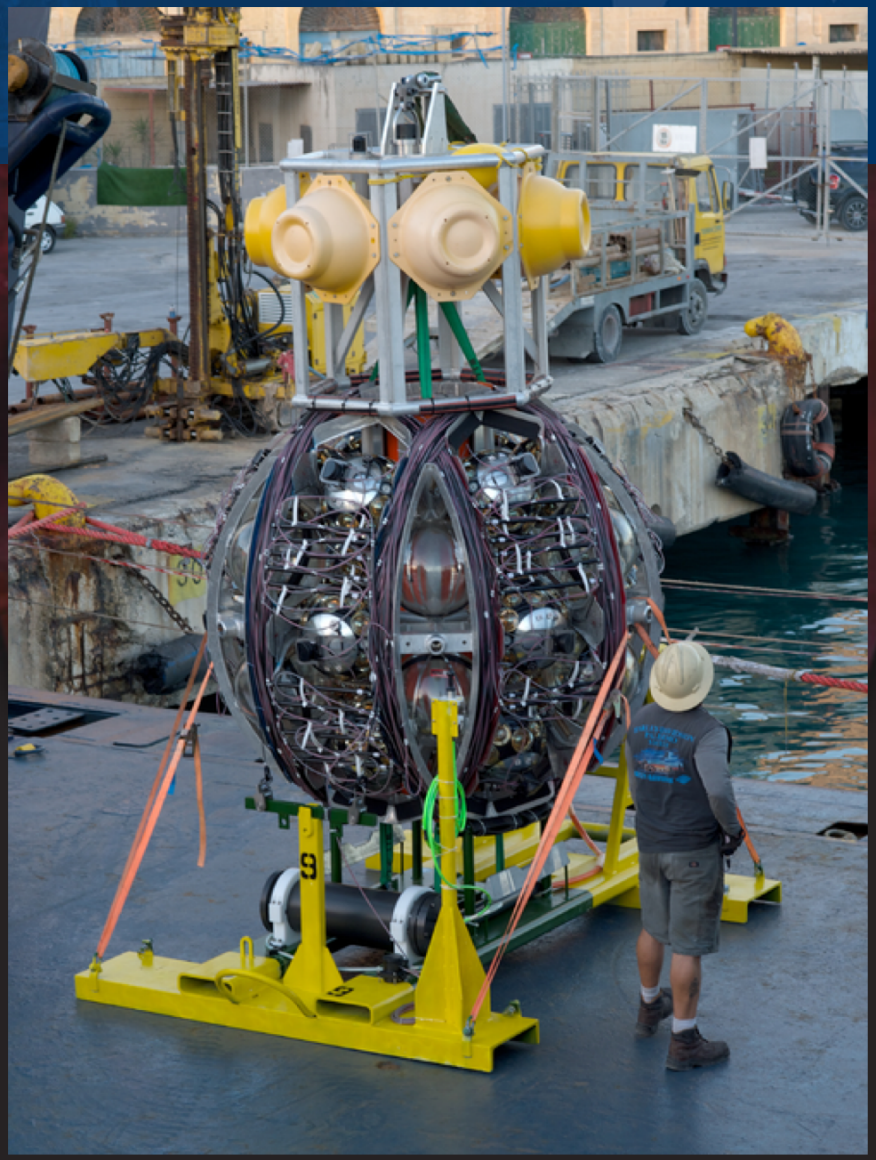
- What are the sources of the cosmic neutrinos, i.e. where do they come from?
- Can we correlate neutrinos with other cosmic messengers (electromagnetic radiation, gravitational waves)?
  → Multi-messenger astronomy
- What do they tell us about astrophysics?
- What do they tell us about neutrino physics?
- What do they tell us about Dark Matter?

We need more and full-sky data of best possible quality !

THANKS to: U. Katz

The future:
KM3NeT, GVD, IceCube(-Gen2)



WHAT ARE THE PLANS?

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- Future projects: KM3NeT and IceCube-Gen2

- KM3NeT-ORCA:
  Dense array, ν physics
  Construction 2018-2021
- KM3NeT-ARCA:
  High-energy ν telescope
  Construction 2018-2021

- IceCube-Upgrade proposal:
  Dense array with 7 strings,
  R&D and ν/DM physics
  Construction 2021-22
- Gen2:
  High-energy ν telescope
  Surface array
  Radio array ?
  Densely instrumented array?
  Construction 2023-2030 ?

- And also: GVD in Lake Baikal

THE KM3NET CONCEPT

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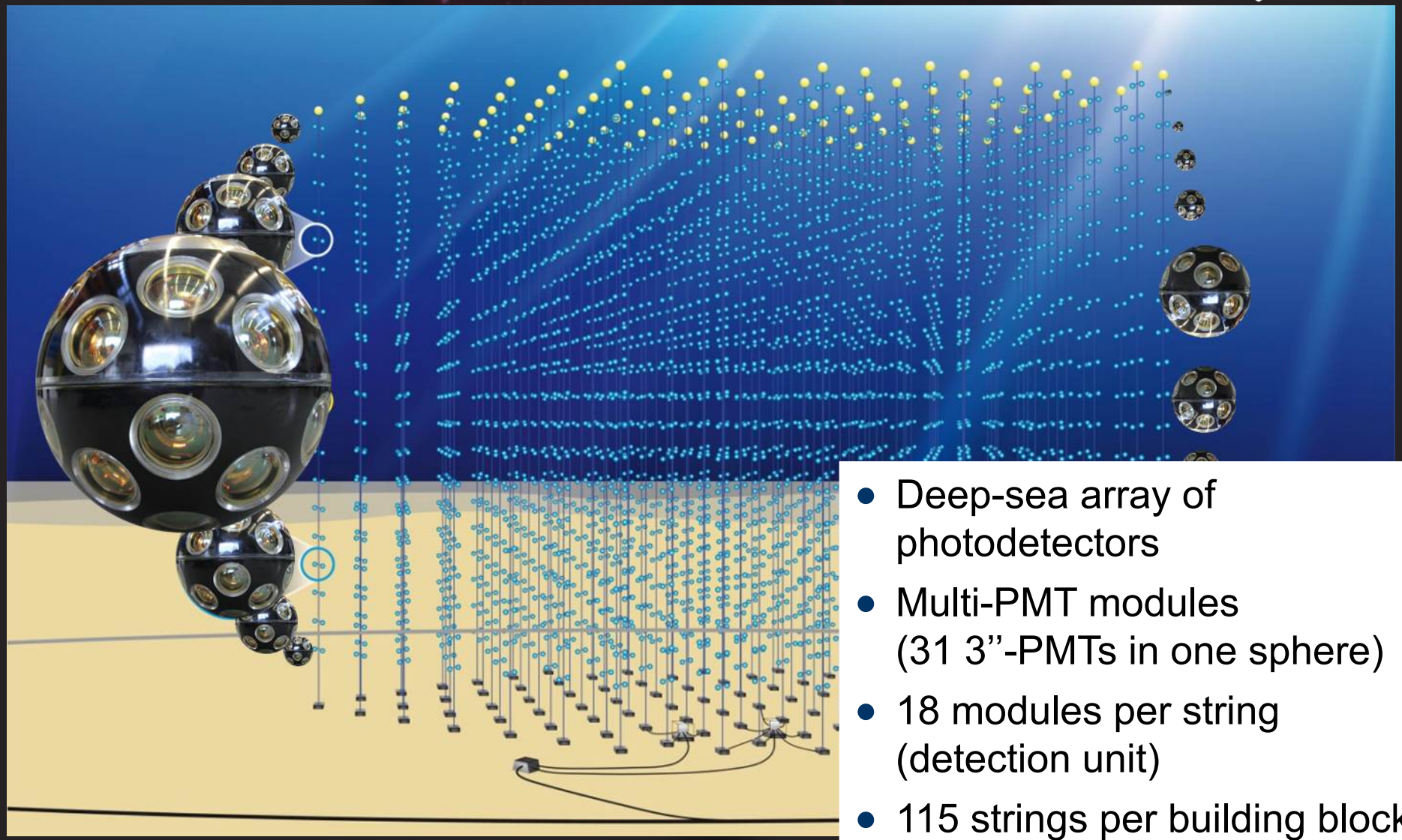

- Deep-sea array of photodetectors
- Multi-PMT modules (31 3’’-PMTs in one sphere)
- 18 modules per string (detection unit)
- 115 strings per building block
- All data to shore

KM3NeT development

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Phase	Blocks/ strings	Primary deliverables / site(s)	Funding Construction
1	0.2/31	Proof of feasibility and first science results; KM3NeT-Fr + KM3NeT-It sites	Fully funded; 2015-2019
2.0	2/230	Measurement of neutrino signal reported by IceCube; All-flavor neutrino astronomy; KM3NeT-It site	Partly funded, further applications pending; 2018-2021
	1/115	Neutrino mass hierarchy; KM3NeT-Fr site	
3	6/690 + 1/115	Neutrino astronomy including Galactic sources; Multiple sites	t.b.d. ?

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Gamma-Ray ASTRONOMY

Cherenkov Telescope Array

The Cherenkov Telescope Array

- Next generation gamma-ray observatory
- Huge improvement in all aspects of performance

x10 better sensitivity, better FoV + angular resolution, wider energy coverage, collection area >few km, wider survey capabilities

- User facility / proposal-driven observatory

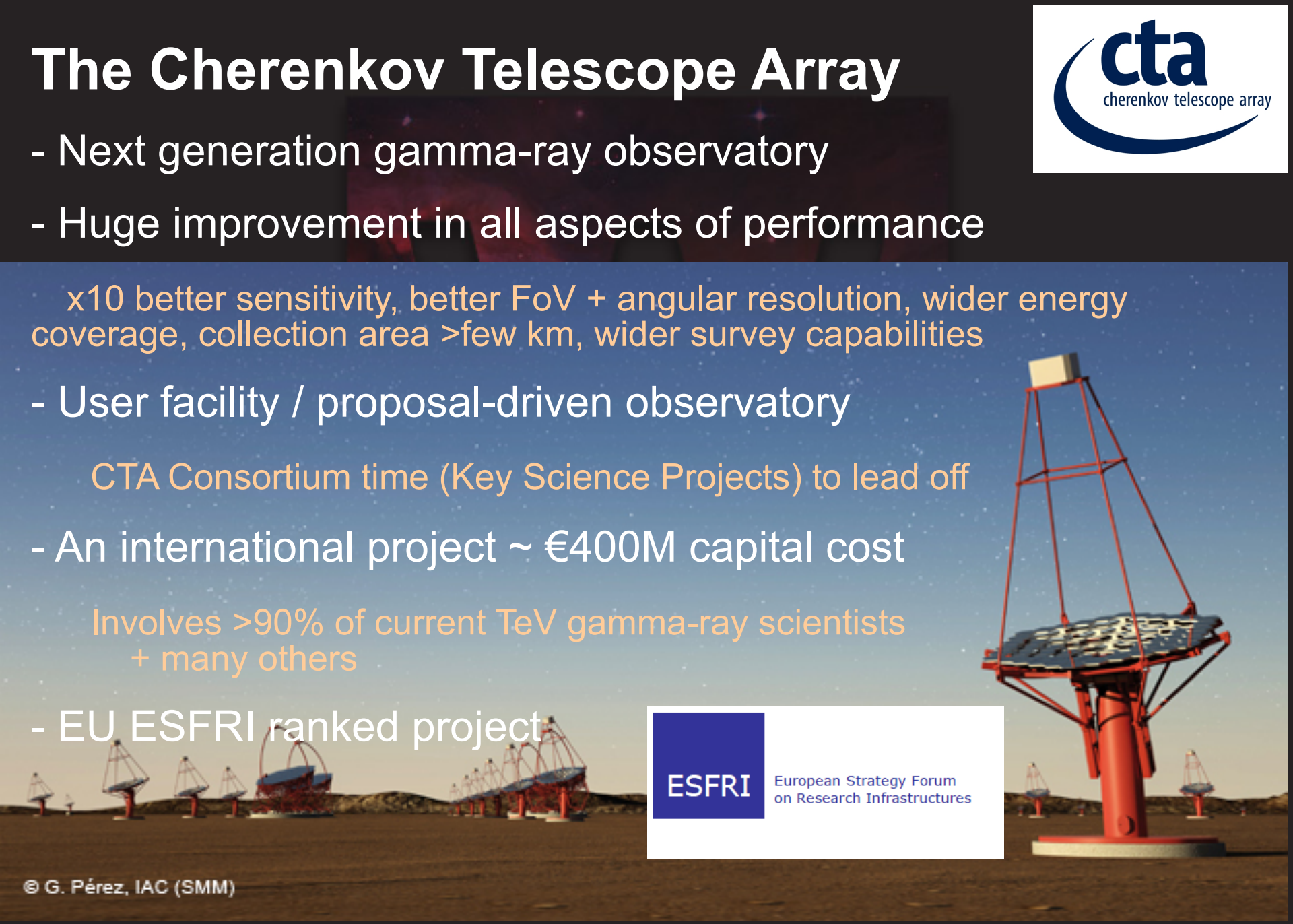
CTA Consortium time (Key Science Projects) to lead off

- An international project ~ €400M capital cost

Involves >90% of current TeV gamma-ray scientists + many others

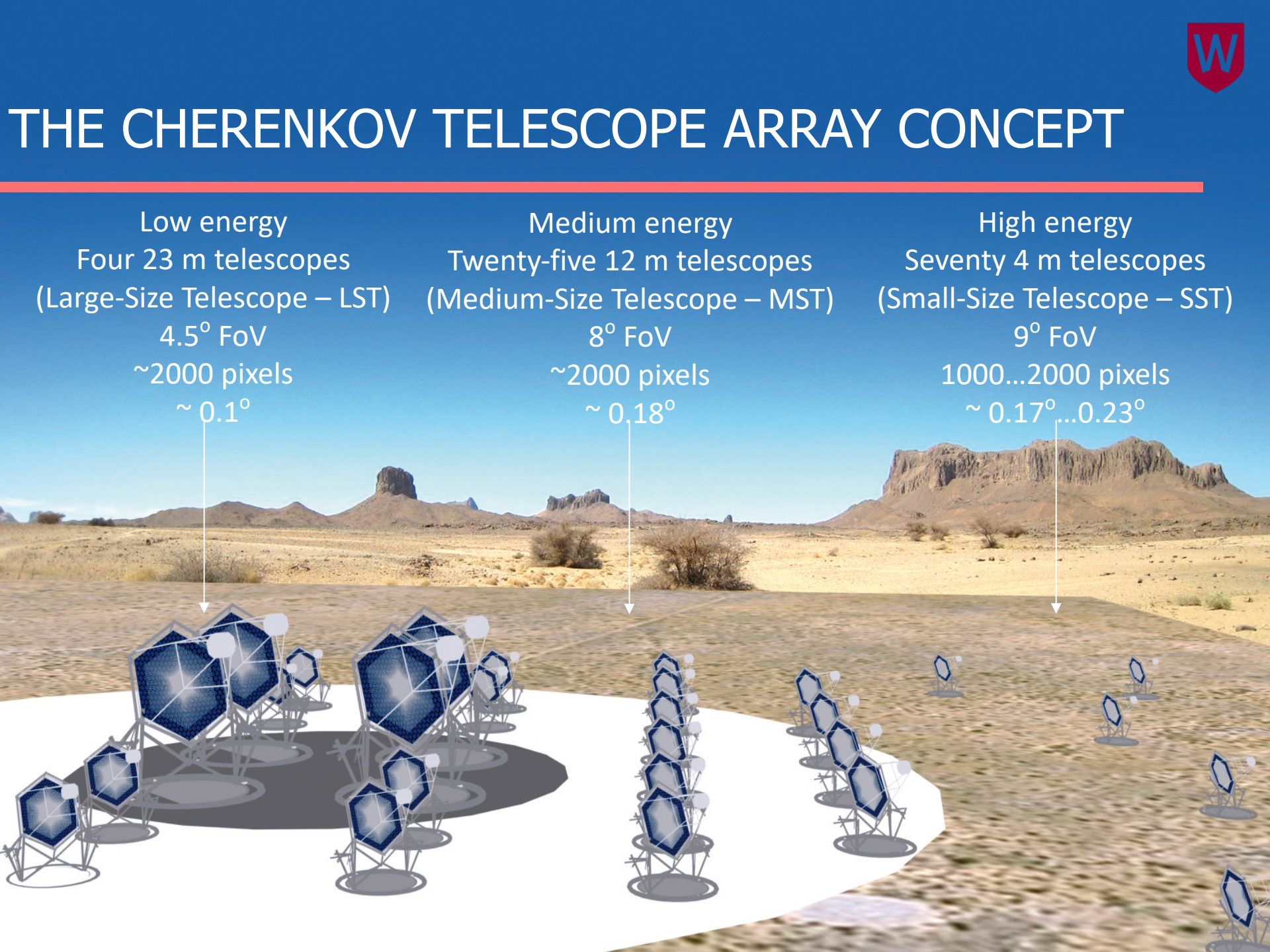
- EU ESFRI ranked project

ESFRI European Strategy Forum on Research Infrastructures



© G. Pérez, IAC (SMM)

THE CHERENKOV TELESCOPE ARRAY CONCEPT



CTA Consortium (CTAC)

December 2017

32 Countries
over 200 Institutes
over 1300 Members

CTA sites selected 16 July 2015

Ground breaking Oct. 9, 2015

13 June 2016 - CTA HQ (Bologna)
- CTA Data Management Centre (DESY Berlin)

CTA South : Paranal, Chile

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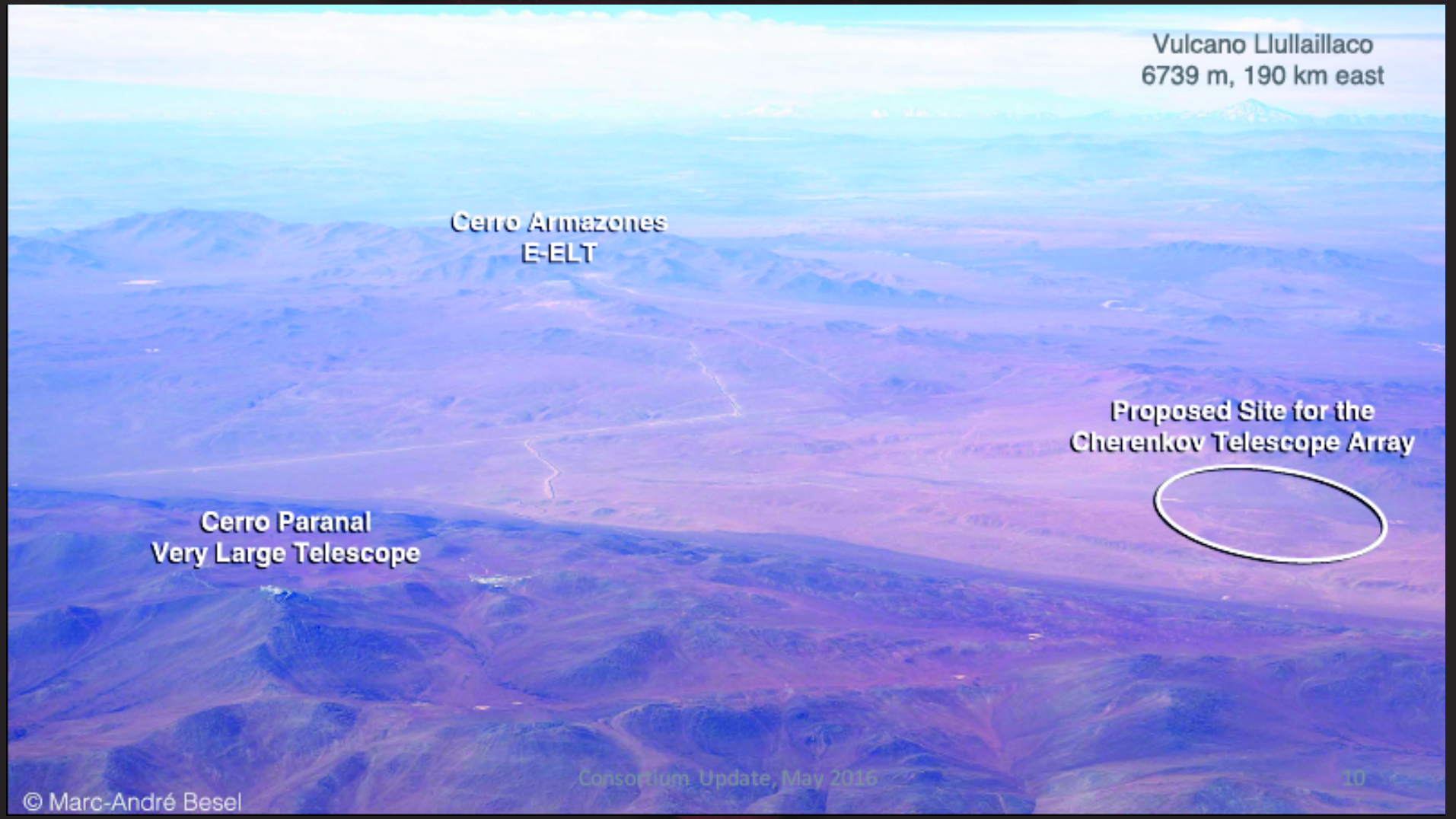

Site negotiations with ESO have been concluded;
The site agreement between ESO and CTA has been signed,
There are still negotiations with the Chilean government now.

CTA Timeline and MWL Synergies

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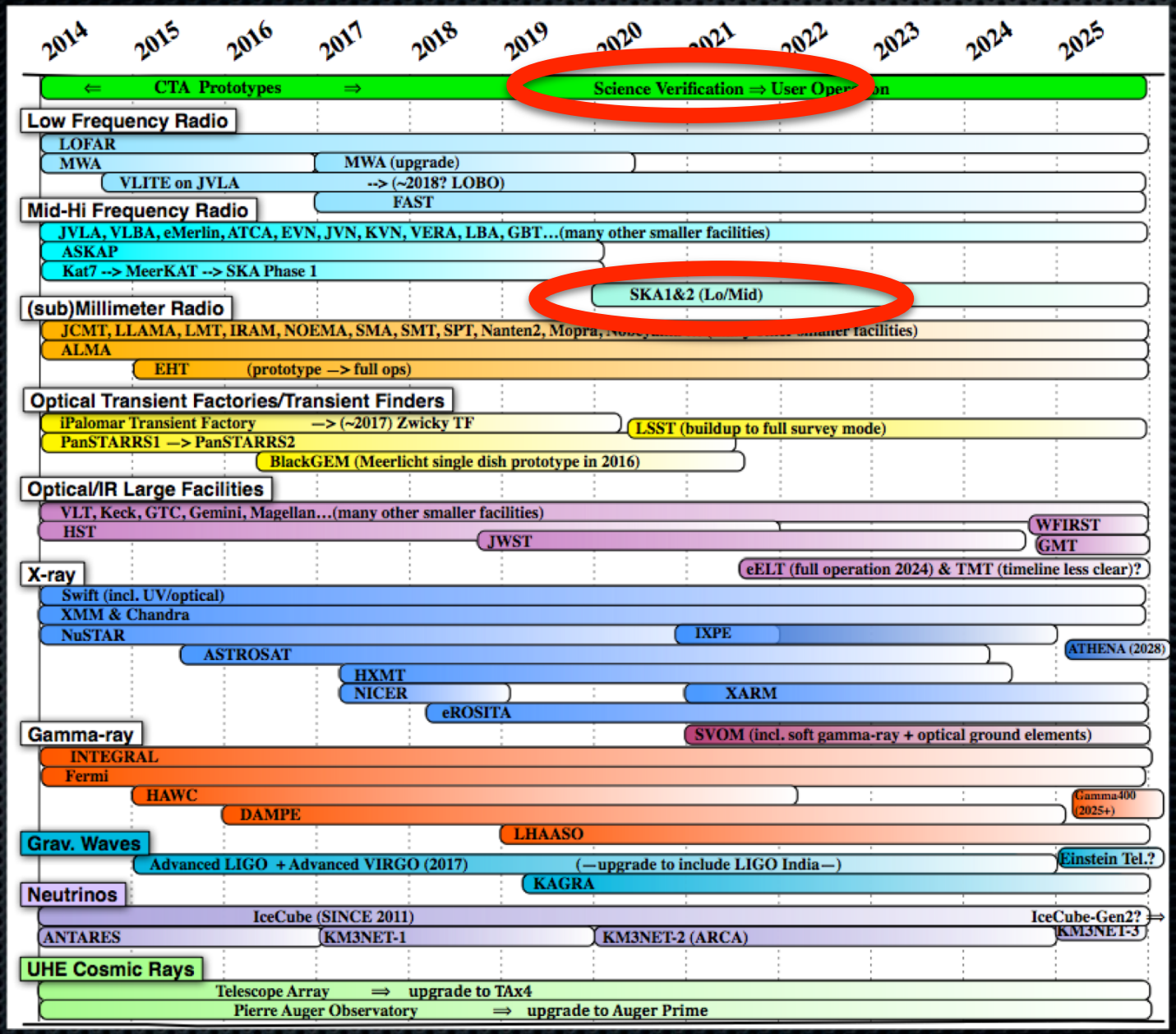
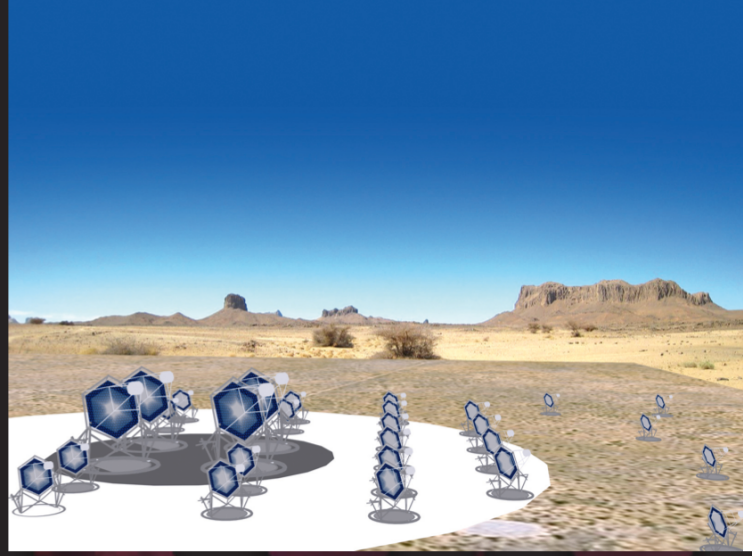
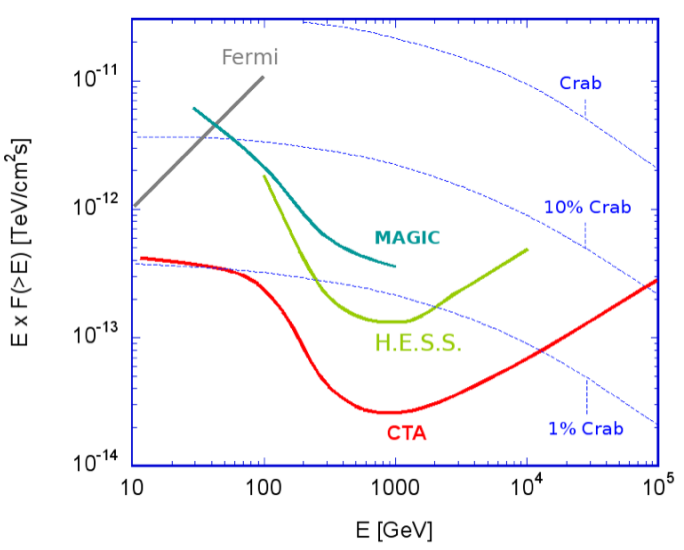


CTA





1. The core energy range from about 100 GeV to about 10 TeV
2. Significant improvements in angular resolution -- **arcmin**

To achieve these goals, a typical CTA layout will implement three types of telescopes:

- a core array of a few large diameter (23 m) telescopes for the detection of the lowest energy showers,
- a mid-sized array of 12 m telescopes optimizing the sensitivity around 1 TeV, and
- a sparse array of small-sized (4 m) telescopes over a wide surface for the observations of the highest energies.

A. The main array located in the Southern hemisphere (Chile) will be mainly devoted to the study of Galactic sources, due to the density of sources in the central regions of our Galaxy and the richness of their morphology.
B. A complementary array, located in the Northern hemisphere (Canary Islands) and optimized for the low energies (10 GeV-1 TeV) will be focused on the study of AGN.

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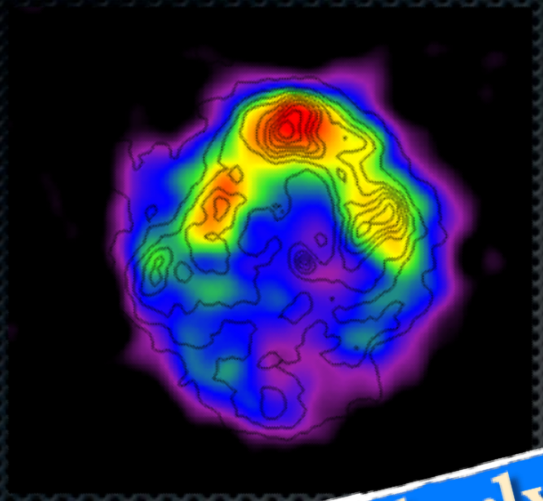
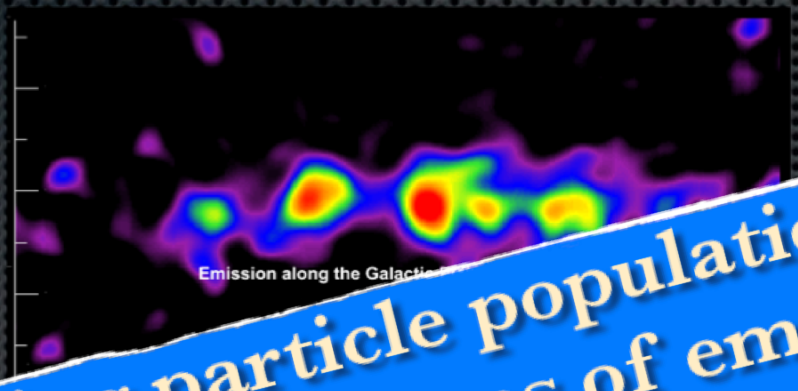
Many types of sources shine in both radio and γ-rays

Supernova remnants/PWN

CR interactions in diffuse gas/Galactic Center

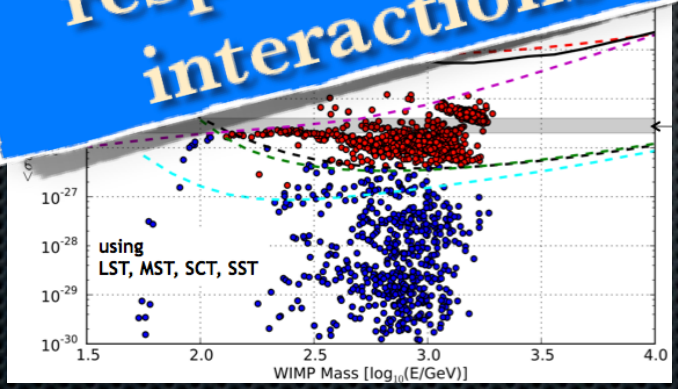
GRBs/Transients

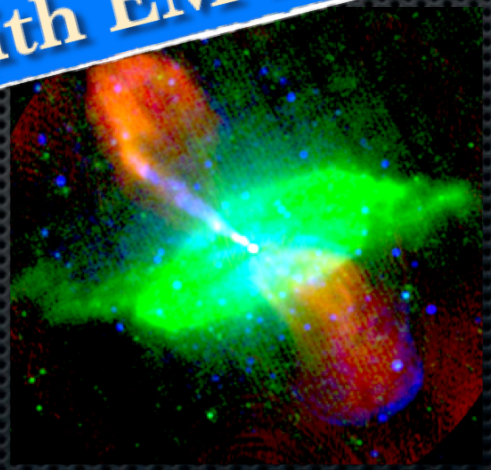


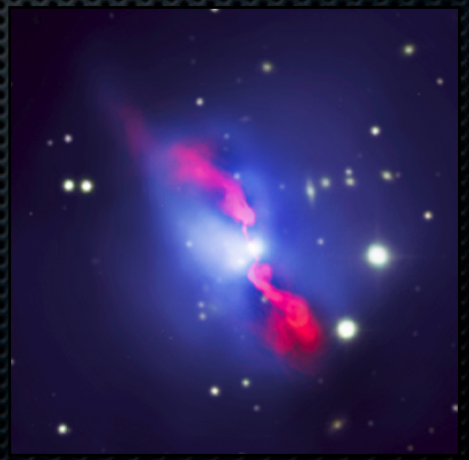


Same underlying particle population/process responsible for both types of emission via interactions with EM fields and matter

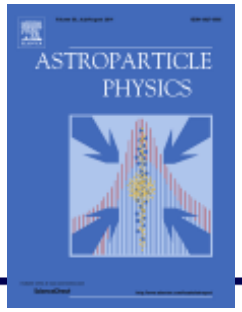
Clusters of Galaxies







CTA Science Case - on arXiv soon



Special Issue Vol 43, Pg 1-356 (Mar 2013)

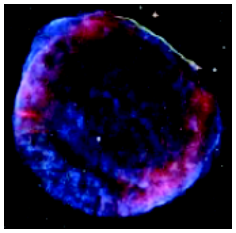
KEY SCIENCE PROJECTS

- Galactic Plane Survey
- Galactic Centre Survey
- Large Magellanic Cloud Survey
- Extragalactic Survey
- Transients
- Cosmic-Ray PeVatrons
- Star-Forming Systems
- Active Galactic Nuclei
- Clusters of Galaxies
- Dark Matter
- Non-Gamma-Ray Science

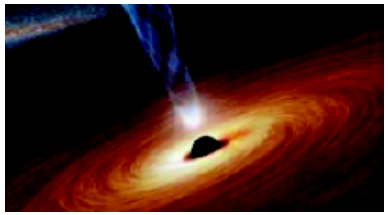
  intensity interferometry
  fast optical transients – milli-magnitude
  occultations (Kuiper belt population..)

Three Themes

1. Cosmic Particle Acceleration



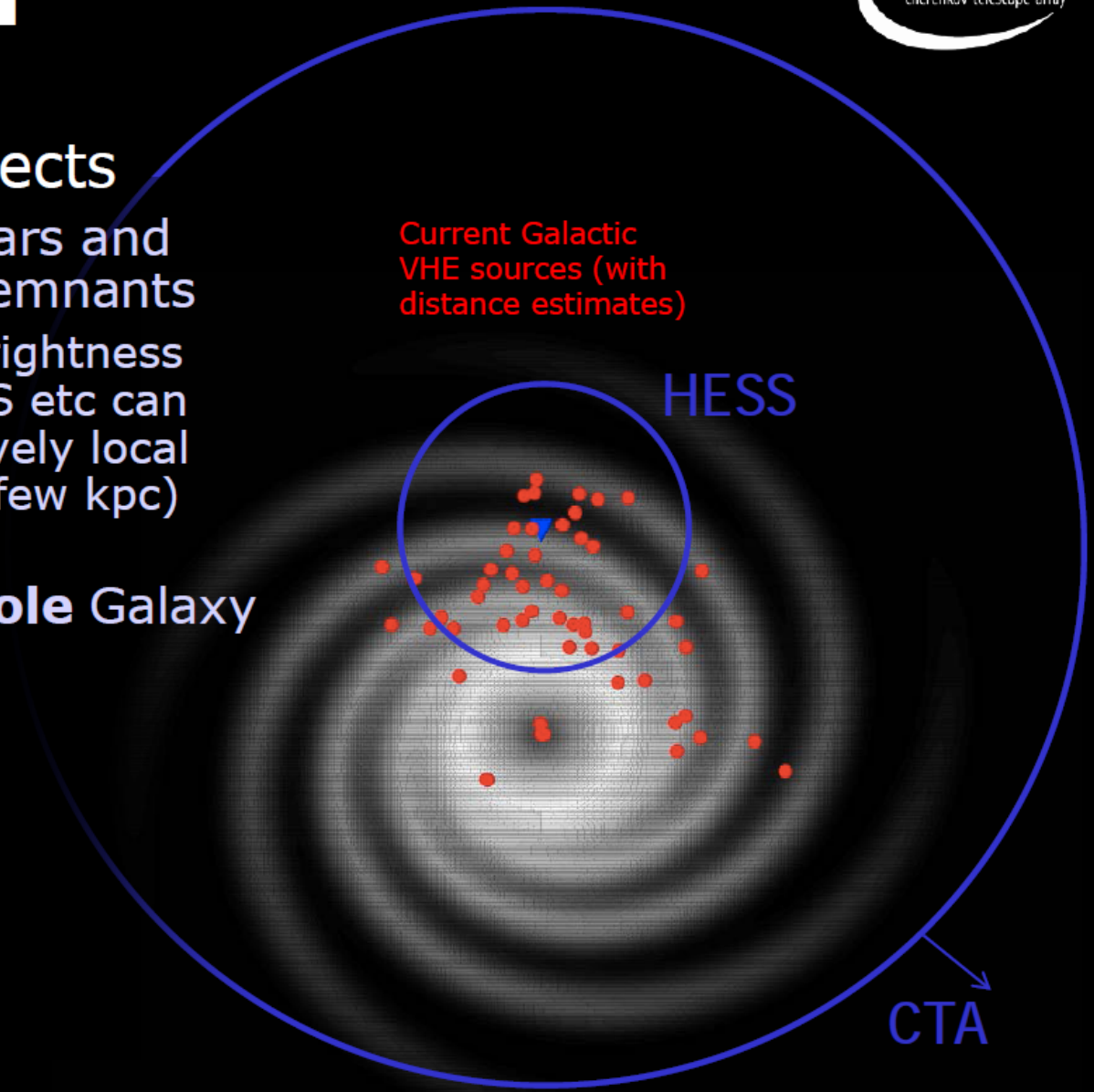
2. Probing Extreme Environments



3. Physics Frontiers: Beyond Standard Model

CTA Reach

- e.g. Galactic objects
  - Newly born pulsars and the supernova remnants
    - have typical brightness such that HESS etc can see only relatively local (typically at a few kpc) objects
  - CTA will see **whole** Galaxy
- Survey speed ~300×HESS



CTA Galactic Science

HESS Galactic Plane Survey (HGPS) – Skymaps

→ 77 sources (13 new sources) Deil et al 2015

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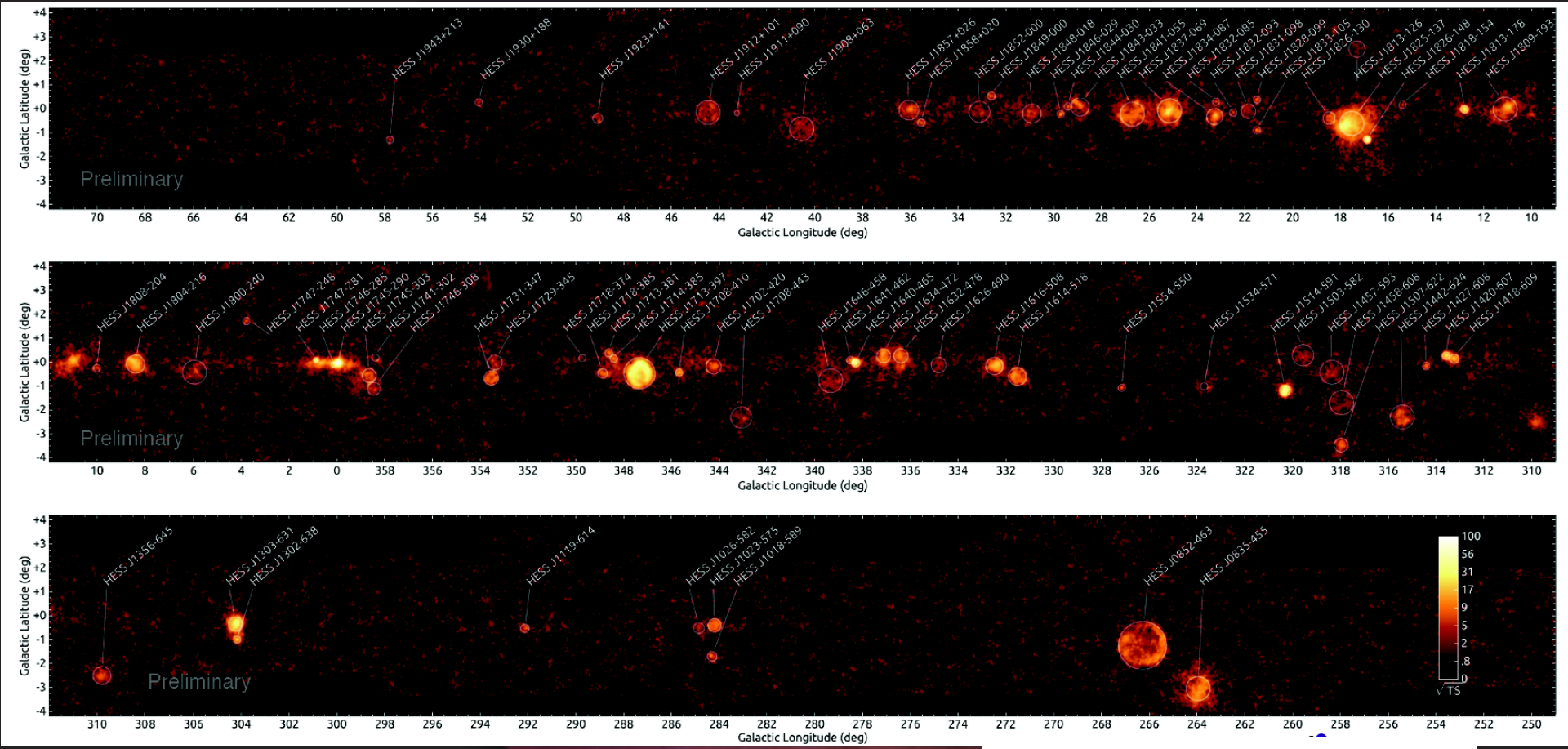
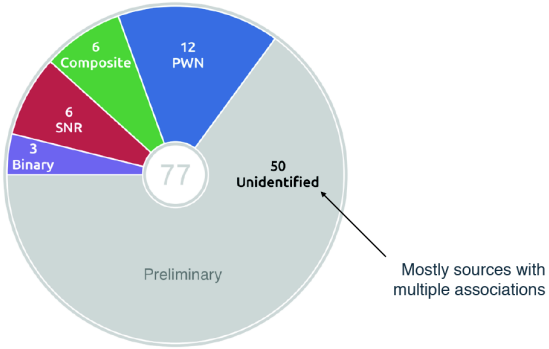
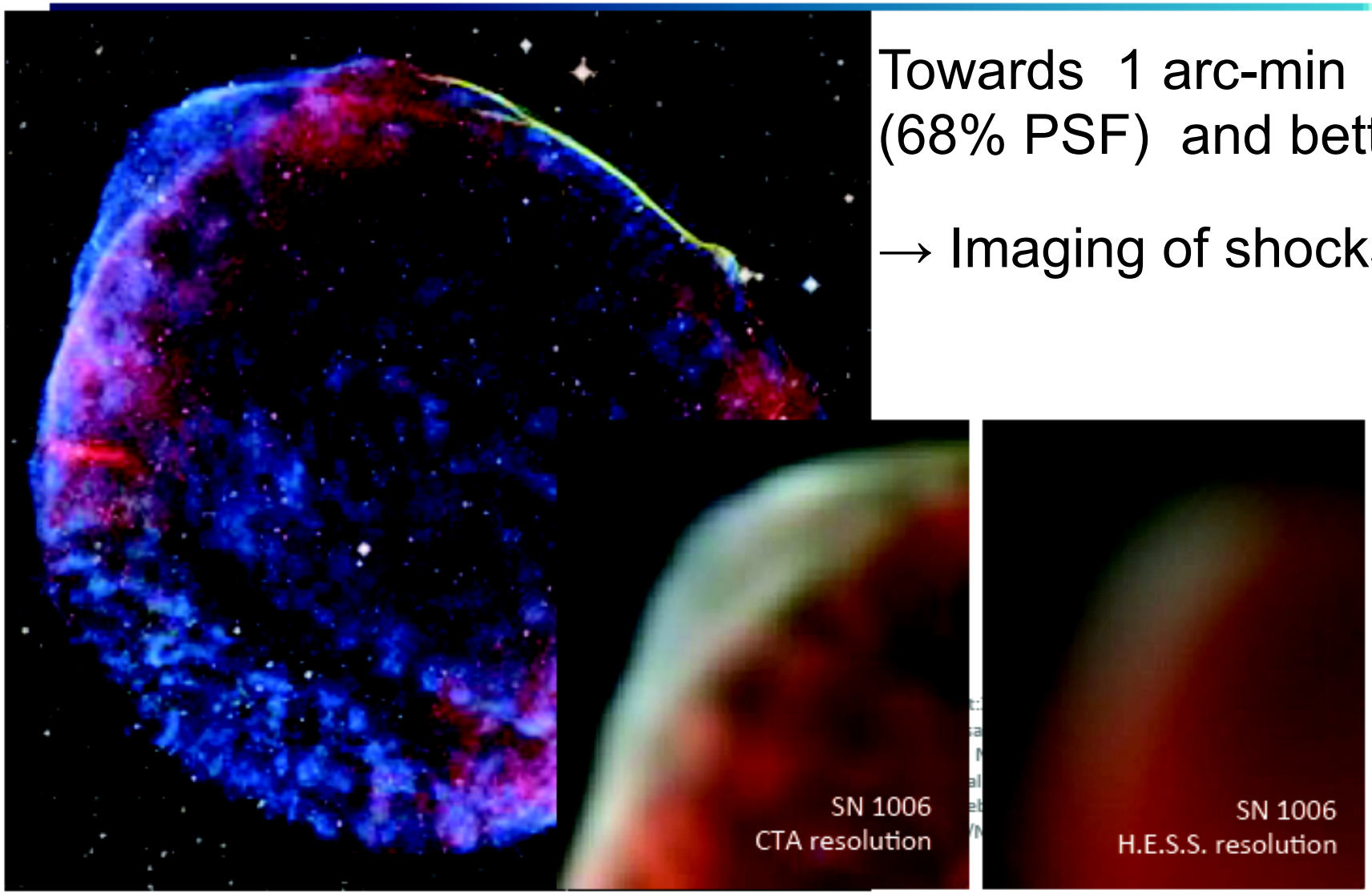


12 – pulsar wind nebulae
6 – SNRs
6 – composite SNRs
3 – binary (NS/BH + star)
50 – unidentified (confused associations)
Several potential PeVatrons (hard spectra >10 TeV)



Angular resolution



Towards 1 arc-min (68% PSF) and better

→ Imaging of shocks!

CTA LMC SN 1987A

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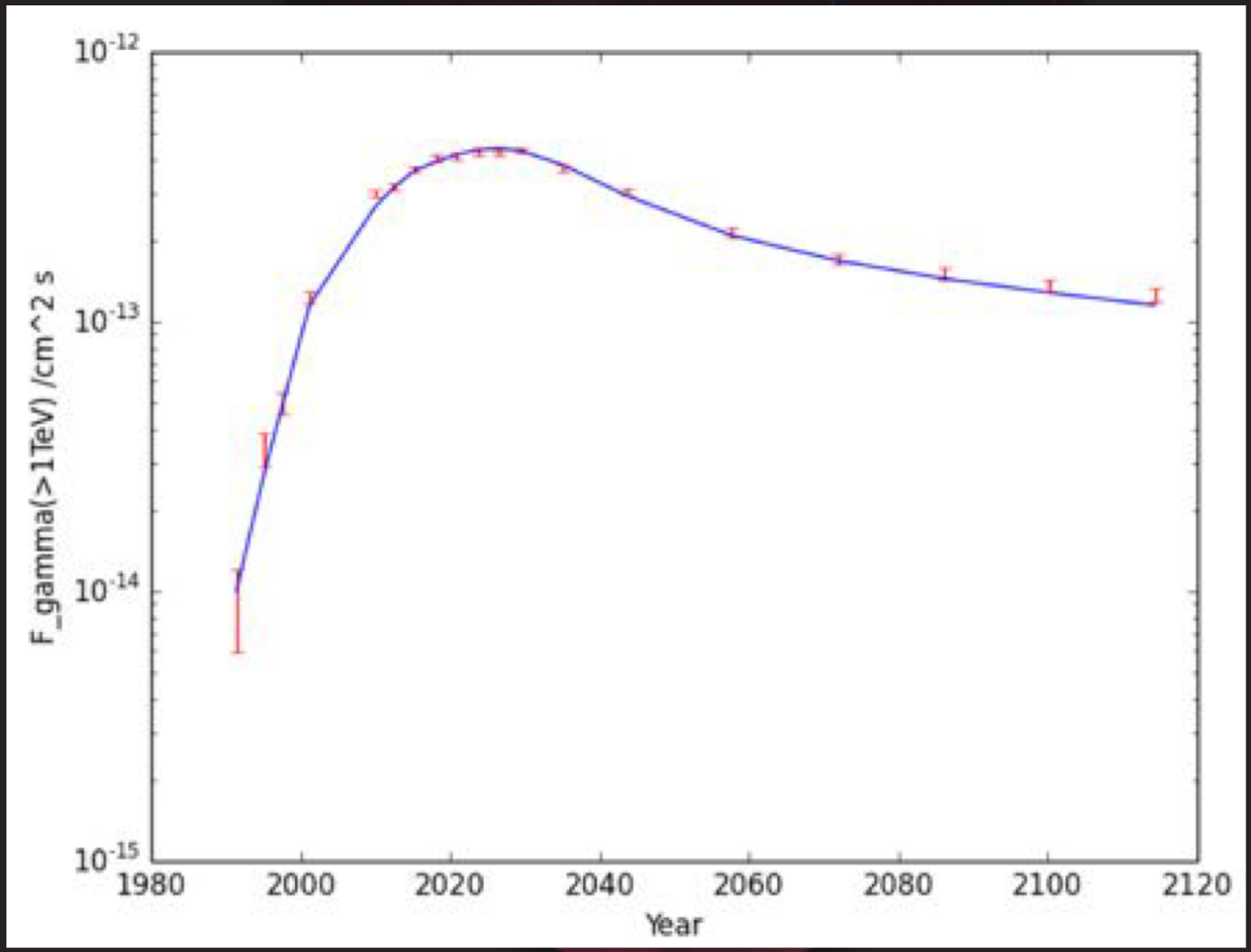

Predicted gamma-ray light curve for SN1987A (blue, from E.G. Berezhko, priv. com.) and anticipated detections with CTA for several 50h observations distributed over decades (red point

Gamma Rays & ISM

- ISM gas is an essential ingredient in understanding gamma-ray sources

→ What accelerates the particles?
→ What types of particles are accelerated?

- Critical requirements of ISM surveys
→ (sub)arcmin CO surveys (Mopra, Nobeyama..)
→ wide CO coverage (Nanten2)
→ dense gas (Mopra, ATCA, ASKAP)
→ atomic gas (ASKAP)
→ dark gas (ASKAP, HEAT, DATE5....)

→ angular resolution perfectly matched with CTA (& hi-res deep HESS obs)
→ CTA needs these new ISM surveys..

(c) F. Acero & H. Gast

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X-ray ASTRONOMY

eROSITA & ATHENA

eROSITA
(The German Quest to X-ray Sky)

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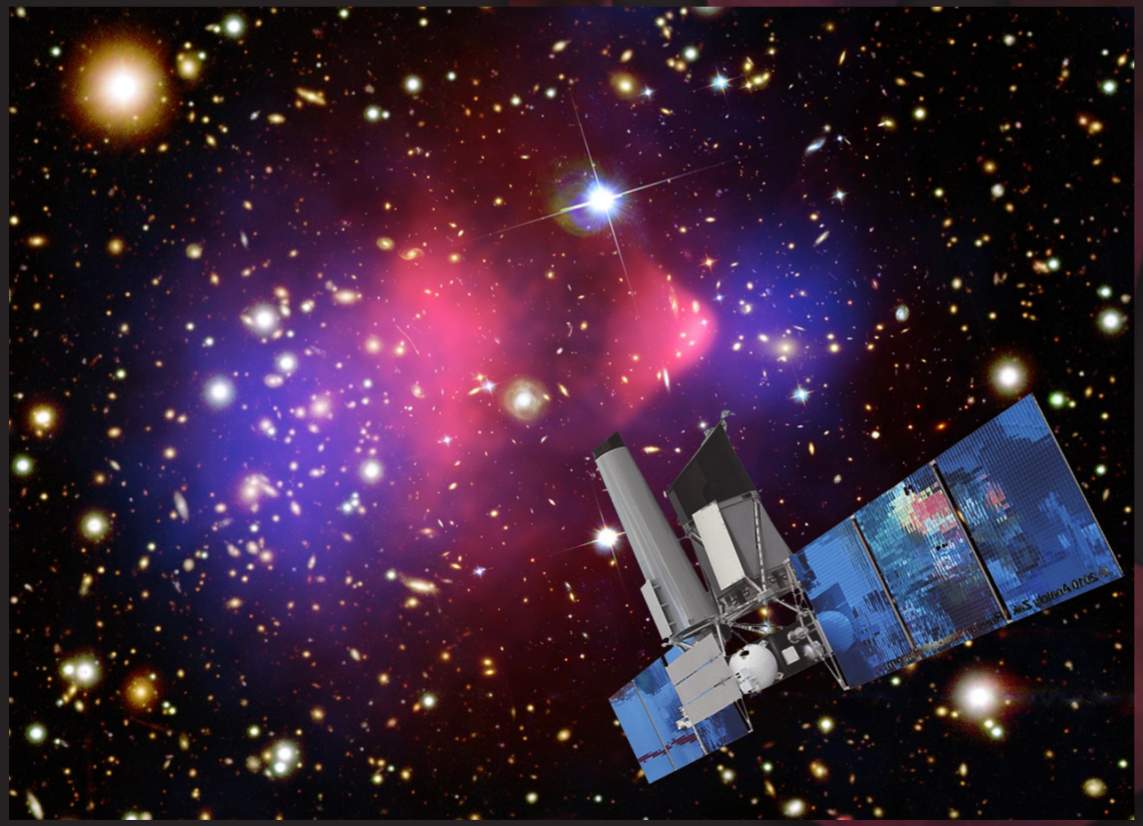


extended ROentgen Survey with an Imaging Telescope Array

EY

Detection of 100.000 Galaxy Clusters test cosmological models!

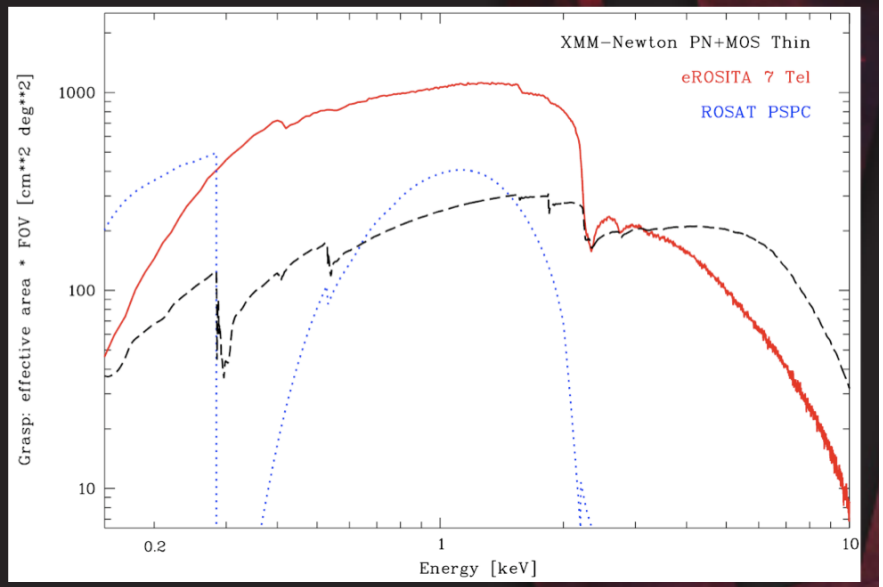
How?

- All-Sky Survey (4 yr)
- Deep Survey (the whole sky, ½ yr)
- additional Pointings

eROSITA

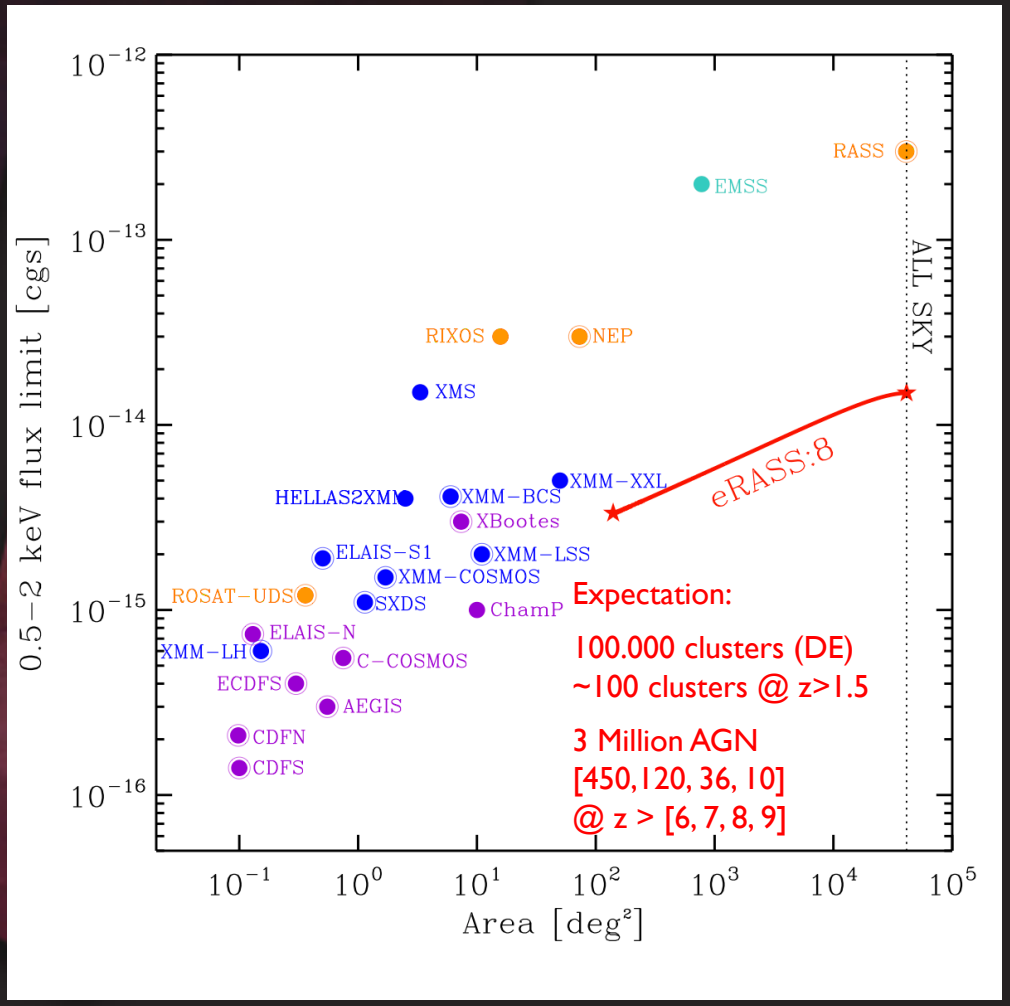
- Large effective area:
  many mirror shells x several modules
- Large Field of View:
  Ø = 1 degree, CCD: 2.88×2.88cm^2
- Good spatial resolution:
  15 arcsec on-axis

Sensitivity



~ 30 × ROSAT

~ 2 × XMM-Newton (MOS+PN)



➡ deep survey of the whole Sky!

SOURCES

- 1970s: 4th Uhuru catalogue: 339 sources
- 1978-1981: Einstein: 835 sources
- 1990-1999: ROSAT: 125000 bright sources
- 1999ff: Chandra: 94767 (CSC)
- 1999ff: XMM-Newton: 191870 sources (2XMM)
- 201Xff: XMM-Newton: 0.5M sources (3XMM)

- 201Xff: eROSITA: 3 000 000 sources

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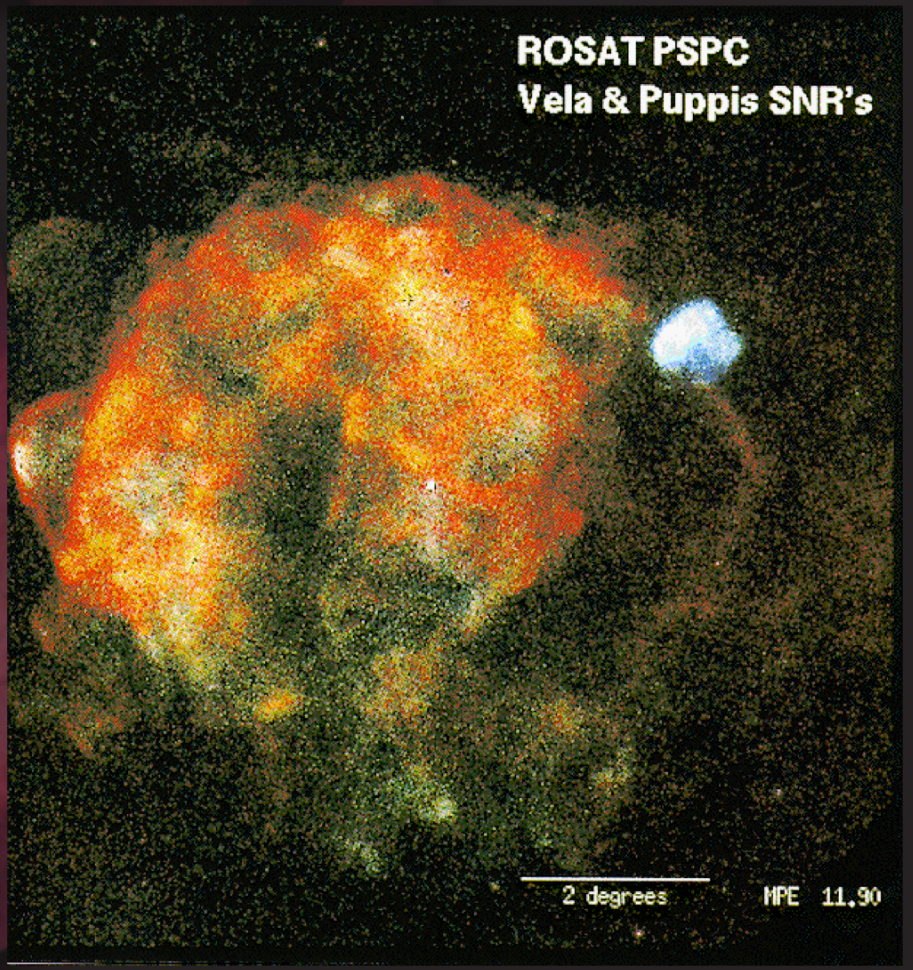
LOTS OF SCIENCE

- AGN evolution
- Time resolved accretion physics
  (variabilities hours - years)
- Stellar variability on different time scales
- Interstellar Medium *(spectroscopy, dust scattering etc.)*
- GRB afterglows (~50)
- CVs, XBs, Isolated Neutron Stars, SNRs etc.



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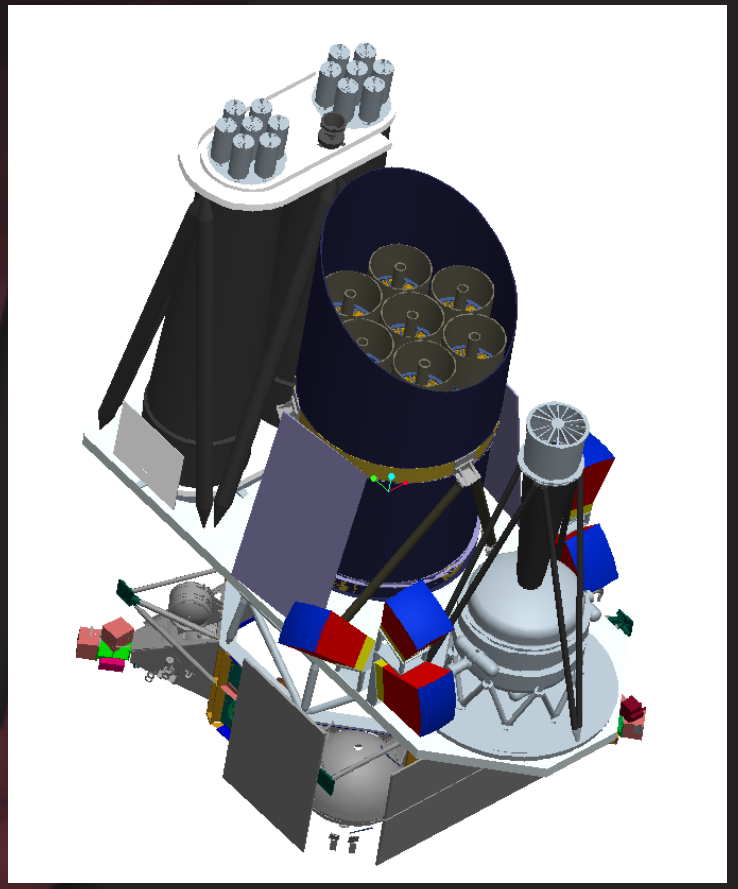
SRG-MISSION

- Спектр рентген-гамма (SRG)

- Launch: 2019? from Baikonur
- Launcher: PROTON
- Platform: ????????
- Orbit: Langrange Point L2

- Payload: ART-XC (IKI)
  eROSITA (MPE+…)



- Mission: 4 yrs scanning survey + 3.5 yrs pointing + …

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IT IS ALL ABOUT DARK ENERGY (OR FORCE?)

ATHENA - THE *HOT AND ENERGETIC UNIVERSE*

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Athena will be a large X-ray observatory offering spatially-resolved X-ray spectroscopy and deep wide-field X-ray spectral imaging with performance greatly exceeding that offered by current X-ray observatories like *XMM-Newton* and *Chandra*, or by missions like *Hitomi* and *SRG/eROSITA*.

A single X-ray telescope with a fixed 12 m focal length and mirror with effective area at 1 keV of 1.4 m^2

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Optical ASTRONOMY

JW, GMT, E-ELT, LSST, WFIRST

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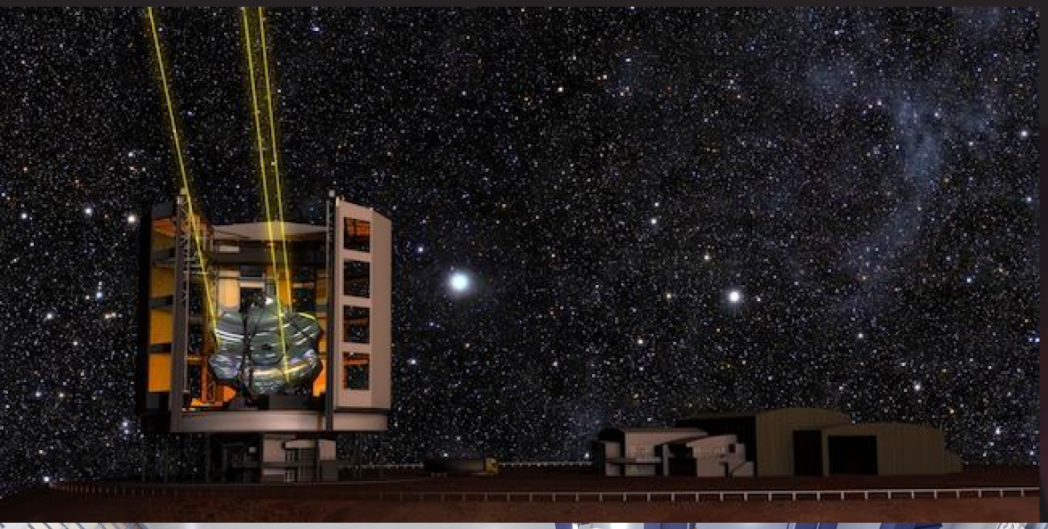
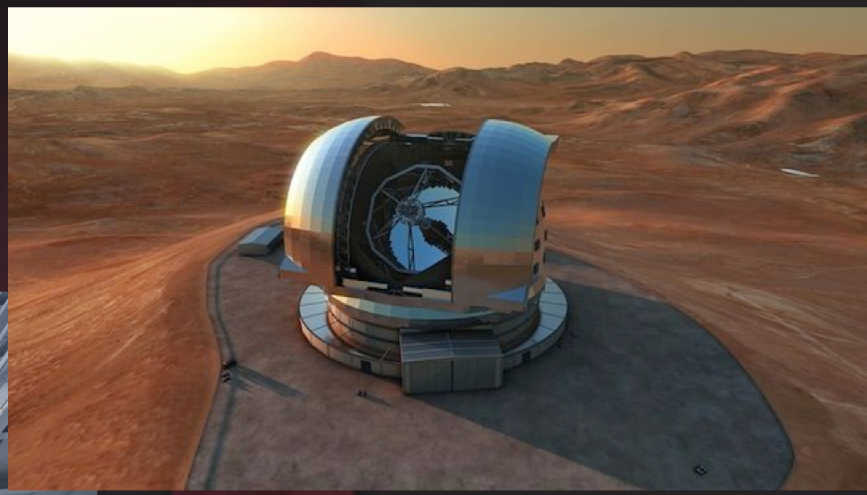
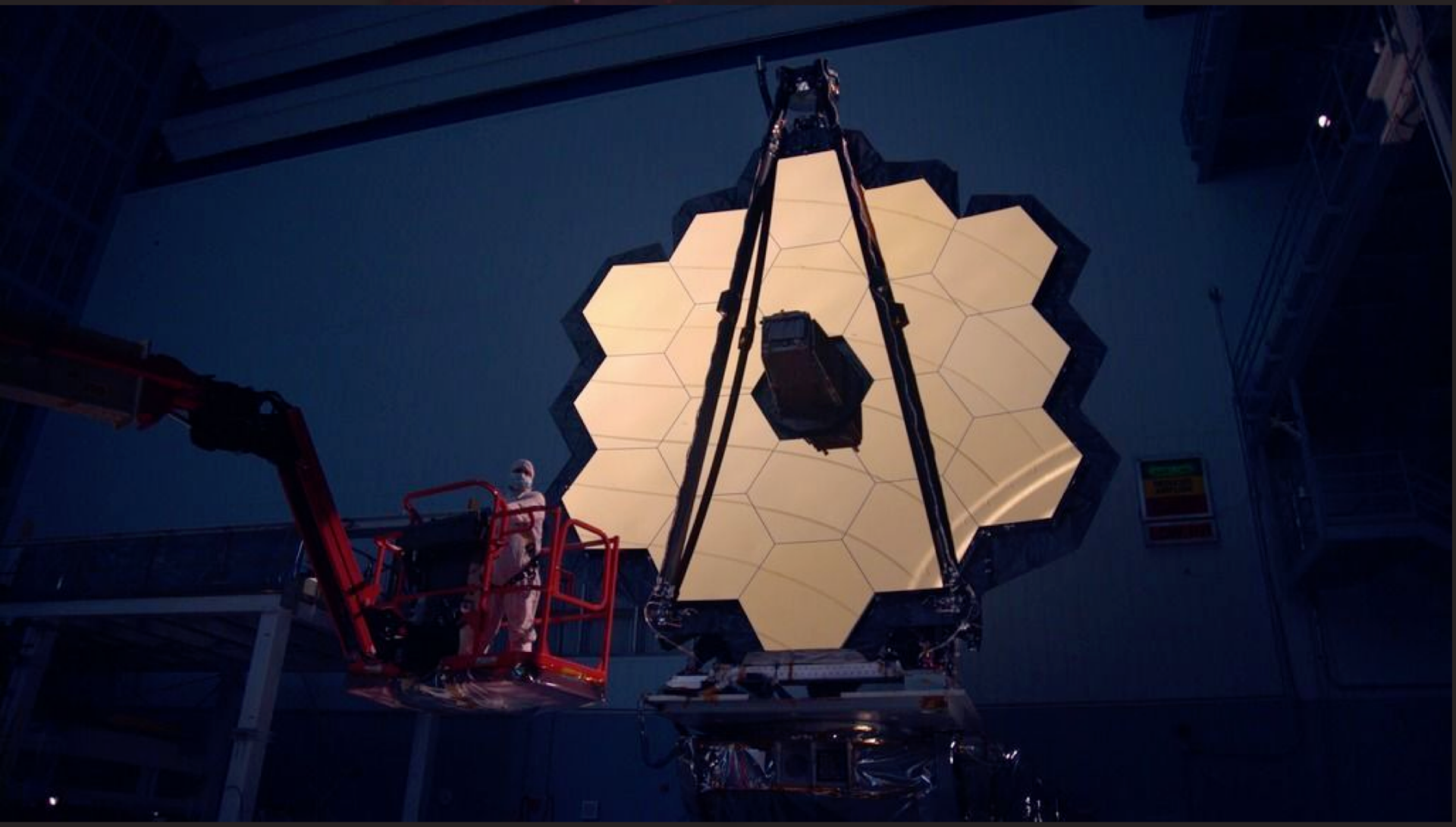




James Webb Space Telescope



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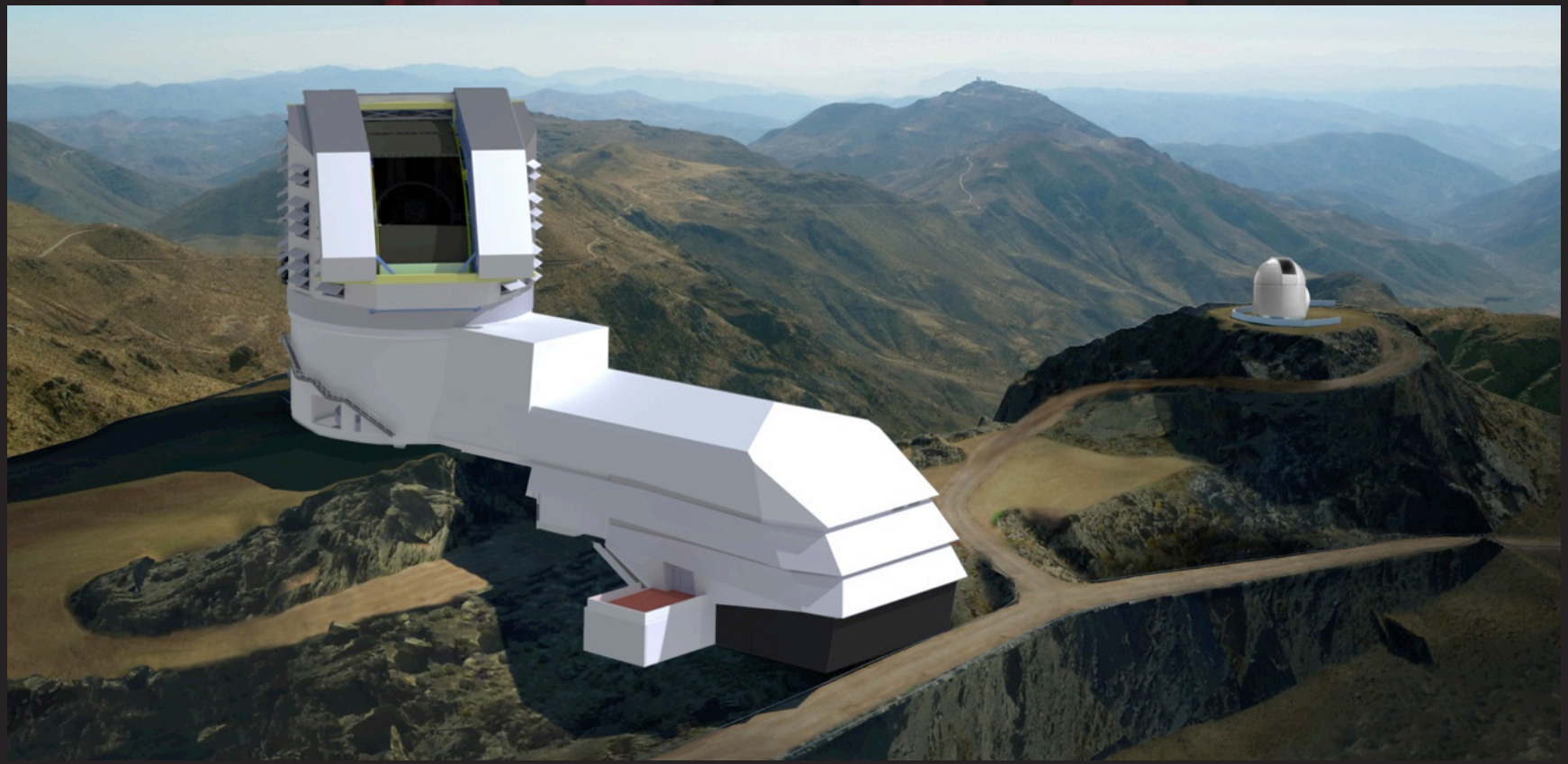
Large Synoptic Survey Telescope



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WHAT IS LSST?

- 8.4-m optical telescope, under construction at Cerro Pachon, Chile
- 3.2 gigapixel camera, each image 3.5 deg
- 6 ~optical bands*: ugrizy*
- 10 year survey of the Southern sky – 18,000 deg^2
- 825 visits per pointing
- 15 Tb per night
- First science light in 2021

Table 1: Wide-field Imaging Survey Depths. These are all 5σ point source detection limits, with the exception of SDSS which is the 95 percent detection repeatability limit.

Bands	u	v	g	r	i	z	y
SDSS (DR7)	22.0	-	22.2	22.2	21.3	20.5	-
SkyMapper	21.5	21.5	2[illegible] 26.3	[illegible]0	21.0	20.2	-
DES (Final Pass)	-	-	26.[illegible]	26.0	25.3	24.7	23.0
PanStarrs1 (3 Year)	-	-	23.9	23.8	23.7	23.0	NA
LSST (First Pass)	23.9	-	25.0	24.7	24.0	23.3	22.1
LSST (Final)	26.1	-	27.4	27.5	26.8	26.1	24.9

- Expected LSST PSF ~0.7'' full-width at half maximum

WHAT SCIENCE WILL LSST DO?

- What is the mysterious **dark energy** that is driving the acceleration of the cosmic expansion?
- What is **dark matter**, how is it distributed, and how do its properties affect the formation of stars, galaxies, and larger structures?
- How did the **Milky Way** form, and how has its present configuration been modified by mergers with smaller bodies over cosmic time?
- What is the nature of the outer regions of **the solar system**?
- Is it possible to make a complete inventory of smaller bodies in the solar system, especially the potentially hazardous **asteroids** that could someday impact the Earth?
- Are there **new exotic and explosive phenomena** in the Universe that have not yet been discovered?

RADIO ASTRONOMY

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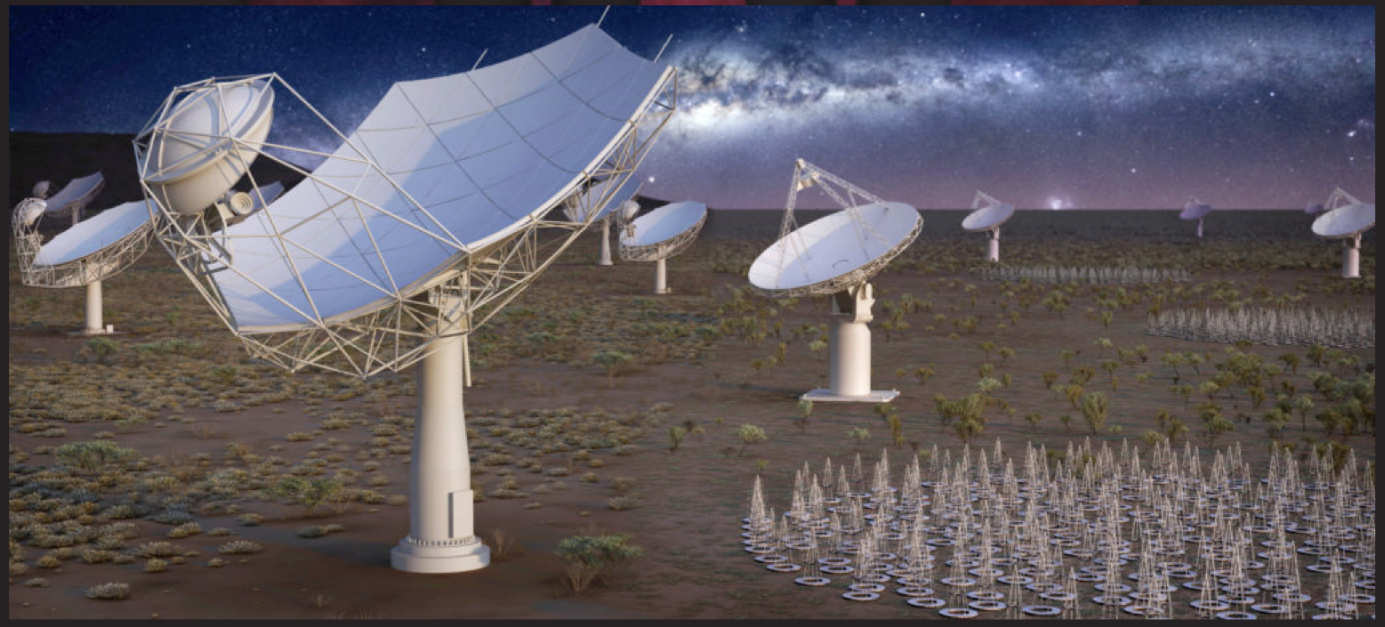
SKA: ASKAP, MWA, MeerKAT, FAST



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Five Hundred Meter Aperture Spherical Radio Telescope

Radio… (HI, Continuum…)

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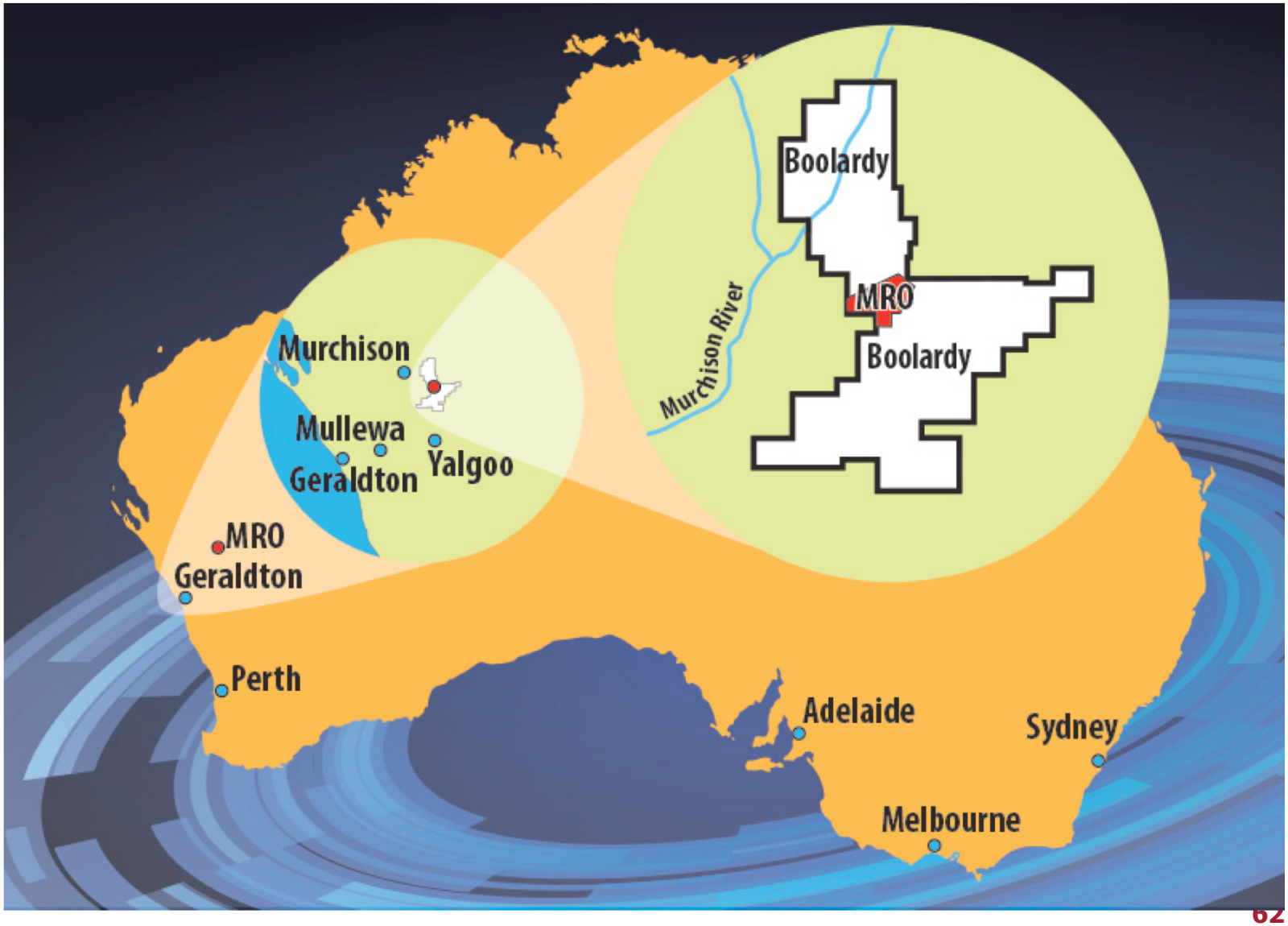
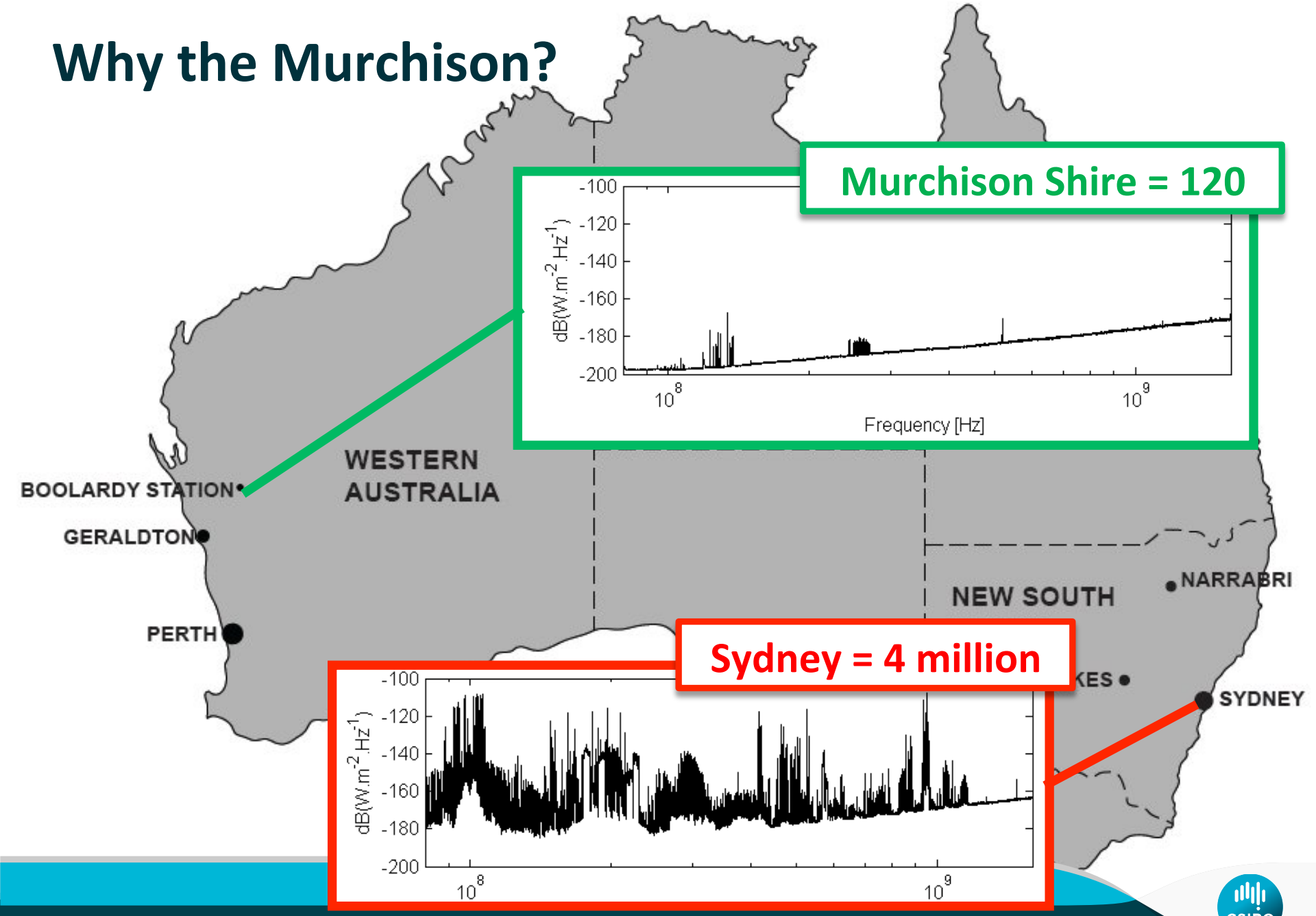
Mopra.ATCA.MWA.ASKAP.Parkes.MOST.VLBI.Tid?


Boolardy
MRO
Boolardy
Murchison River
Murchison
Mullewa
Geraldton
Yalgoo
MRO
Geraldton
Perth
Adelaide
Sydney
Melbourne

Why the Murchison?

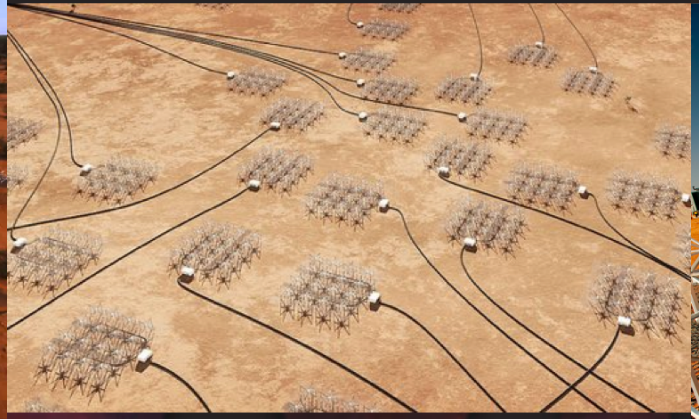


Slide courtesy of Antony Schinkel

MRO power station

- Provide 850 kW (peak 1.1 MW)
- 4 diesel generators
- 5280 solar panels, 1.6 MW capacity
- 2.5 MWHr Lithium ion battery (largest in Australia

Slide courtesy of Antony Schinkel


Murchison Widefield Array

- Low Freq. RT (80-300 MHz)
- MK-I and soon MK-II
- Resolution >90”
- Polarisation – Mag Field
- New Legacy Surveys
- SNR-PWN-AGN-SFS

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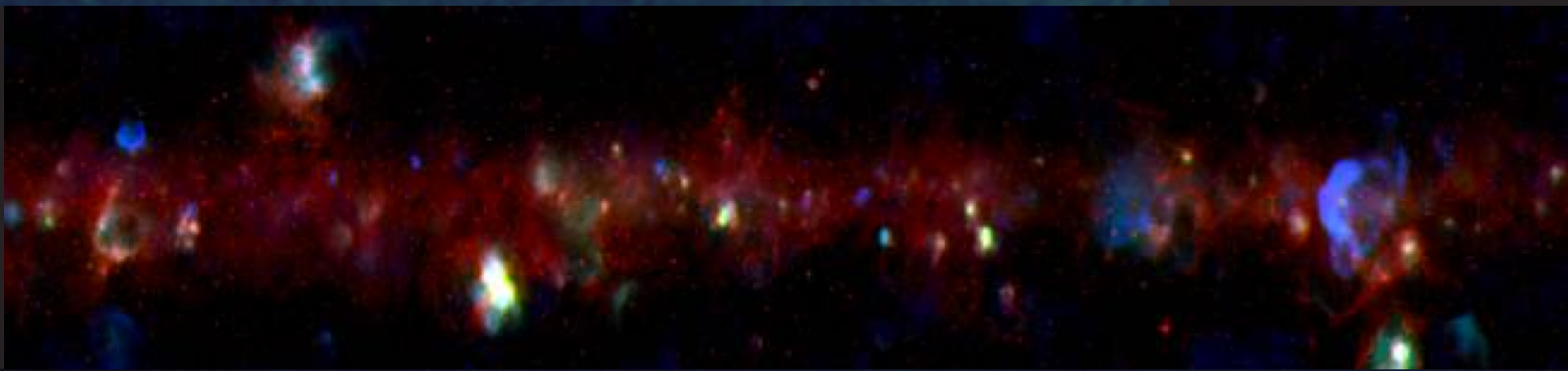
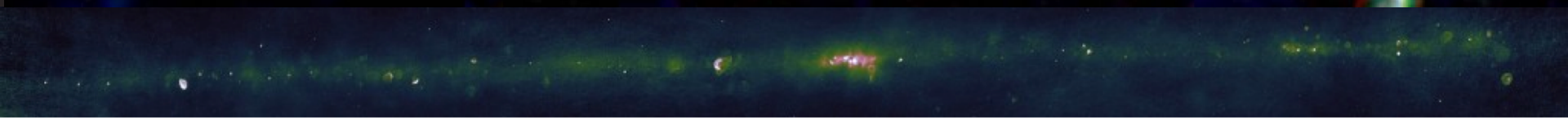
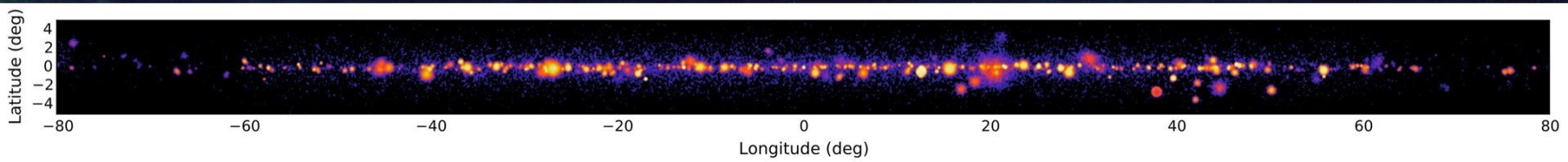
MWA & HESS







ASKAP =
Australian Square Kilometre Array pathfinder

A revolutionary new $185m radio telescope in WA

ASKAP

ASKAP

- The best RT in South-H
- RC & HI 30sqdeg
- 700-1800MHz with ~10”
- 36 Telescopes – PAF’s
- Polarisation – Mag Field
- SURVEYS:
  - CONTINUUM: EMU (70M objects),
  - HI: Wallaby, GASKAP
  - Polarisation: POSSUM
- AGN-SNR-PWN-CGs

PAFs -> Big Data

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Data Rate to correlator = 100 Tbit/s

= 3000 Blu-ray disks/second

= 62km tall stack of disks per day

= world internet bandwidth in June 2012

Processed data volume = 70 PB/year

What is EMU?

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What is EMU?

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- EMU is a deep (10μJy rms) radio sky survey project which will use the new ASKAP
- It will have about 40 times the sensitivity,
- six times the resolution and will detect 70 million galaxies.

As a result, it will be able to probe star forming galaxies up to distances of z=1, AGNs to the edge of the Universe, and will undoubtedly uncover new classes of object.

PARKES

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- Wider frequency range
- Short-spacing's
- Fast Radio Bursts
- Pulsar Timing

- AGN-SNR-PWN-CGs

..AND… MEERKAT + JVLA, ALMA, MERLIN,…

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What I didn't talk about: ANTARTIC ASTRONOMY, GW ASTRONOMY Extrasolar Planets ASTRONOMY SORRY!

CONCLUSSIONS

CHALENGES:

MONEY

TIME

TECHNOLOGY?

We acknowledge the Wajarri Yamaji people as the traditional owners of the ASKAP site