CTA MWL / MULTI-MESSENGER LINKAGES IN AUSTRALIA

Ulisses Barres de Almeida,
for the CTA Consortium

Centro Brasileiro de Pesquisas Físicas

PURPOSE & OUTLINE OF THIS TALK

The purpose of this talk is to present the potential synergies between CTA science and data from other bands of the observational spectrum, in order to identify cooperation links between CTA and external facilities and research groups.

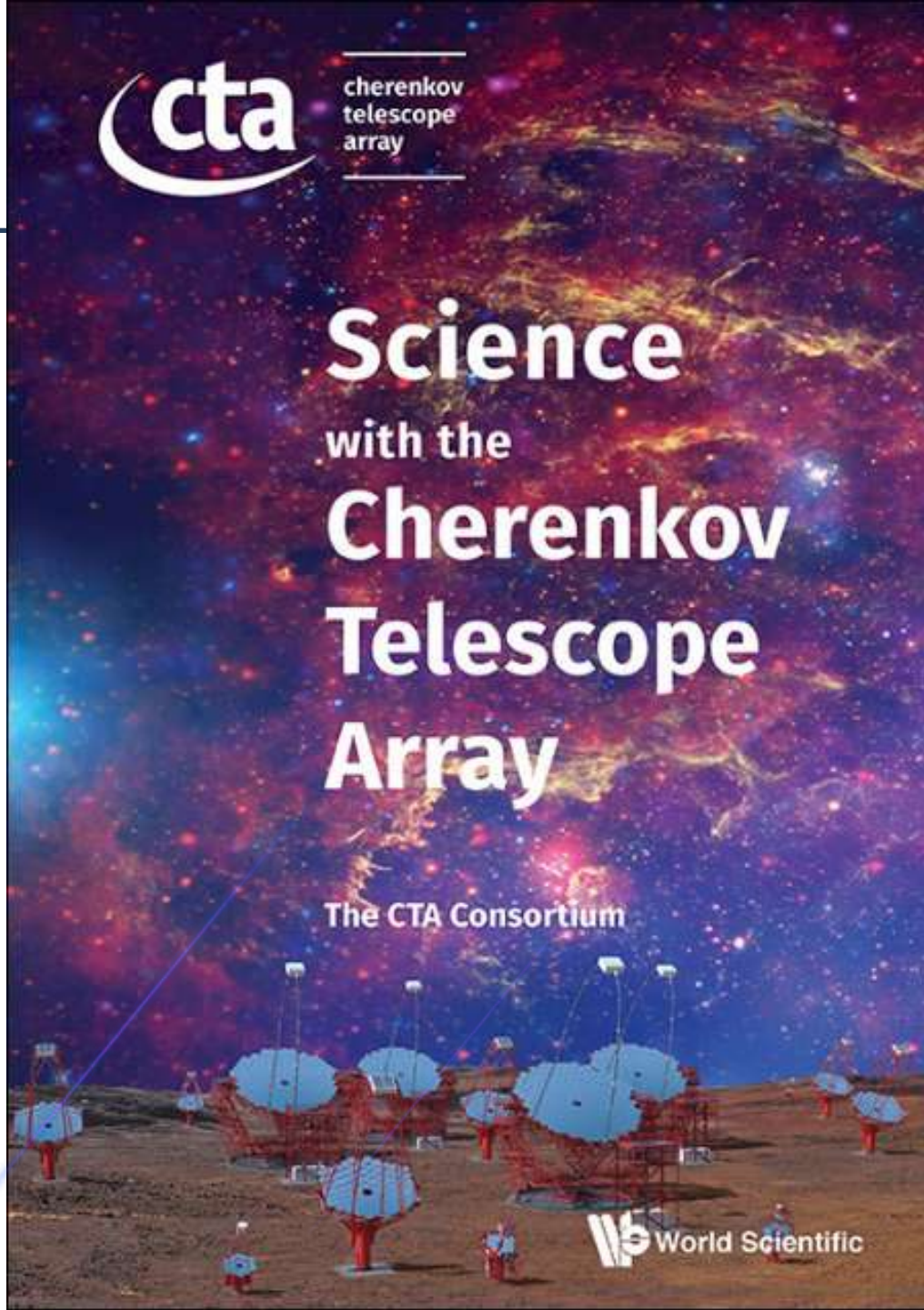
- Review of the internal survey for external data needs.
- A quick look into the different CTA science cases.
- Some comments on specific bands.
- Possible ways forward.

BASELINE DOCUMENT

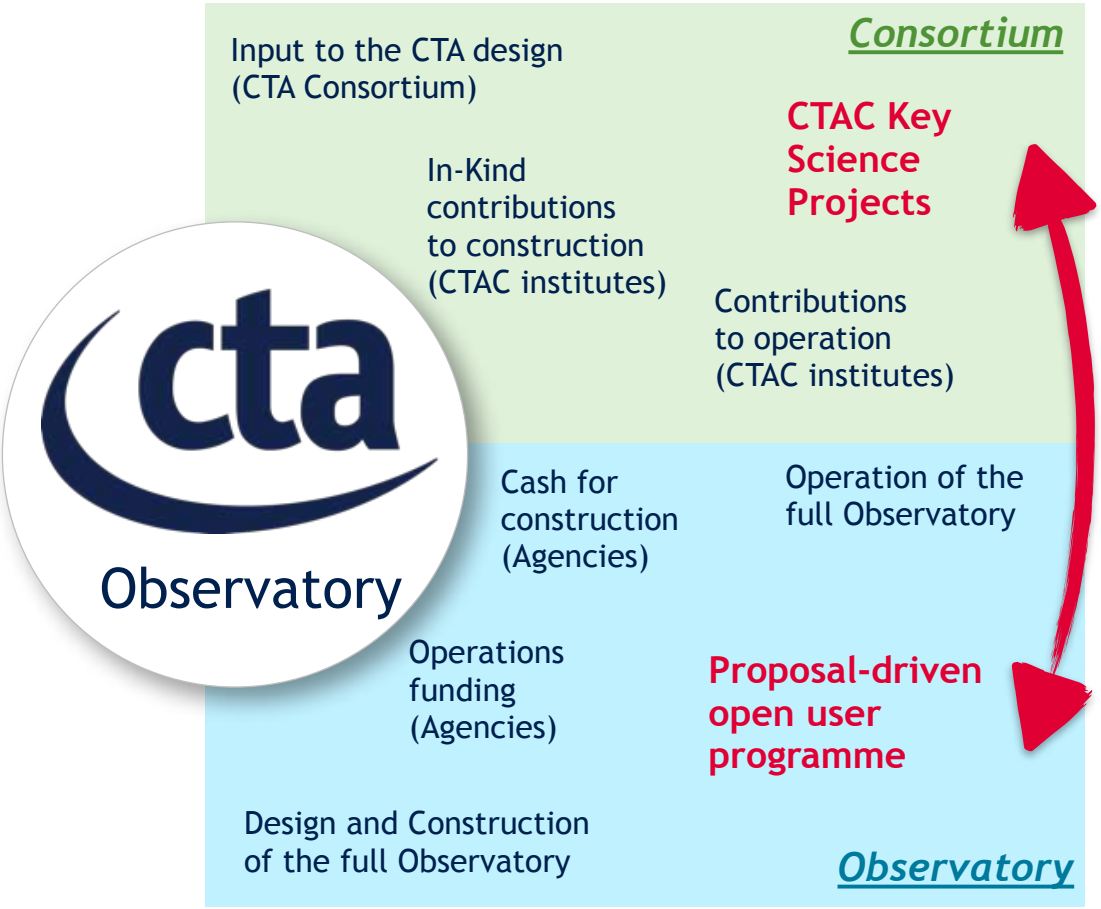
A complete outlook on the CTA science and potentials.

Now available as a book by World Scientific.

Open access in astro-ph:
arXiv:1709.07997

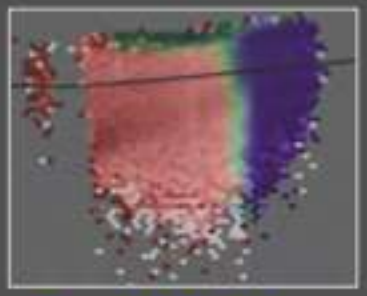


SCIENCE WITH THE CAT OBSERVATORY

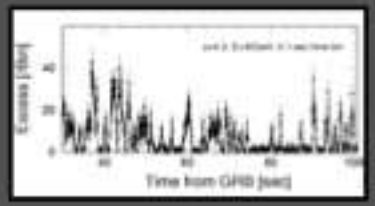


- Consortium Internal-time Key Science Projects
  - Providing the first fundamental observations, surveys and legacy data sets
    - Heavy time-demand projects
    - Reference for follow-up science
  - Open-up the discovery space for the next generation of VHE science
    - New sources and source classes
    - New phenomena and probing capabilities
  - Require MWL & MM linkages for reaching their goals
    - Associated data sets, catalogues, and follow-up, monitoring or ToO observational programmes

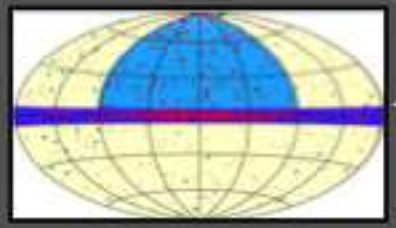
THE CTA KEY SCIENCE PROJECTS



Dark Matter Programme



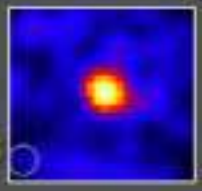
Transients



ExGal Survey

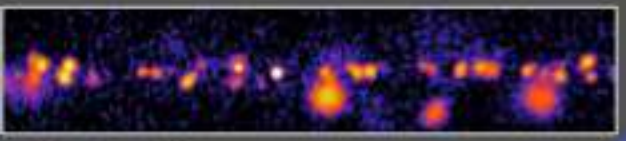
Extragalactic

Galaxy Clusters



Star Forming Systems

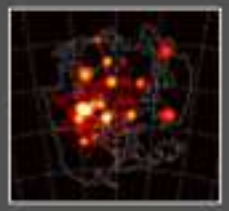
AGN



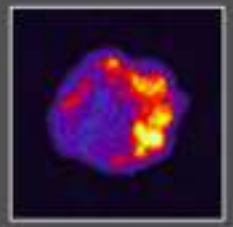
Galactic Plane Survey

Galactic

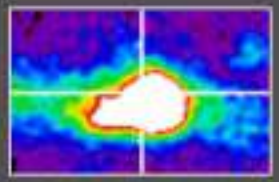
LMC Survey



PeVatrons

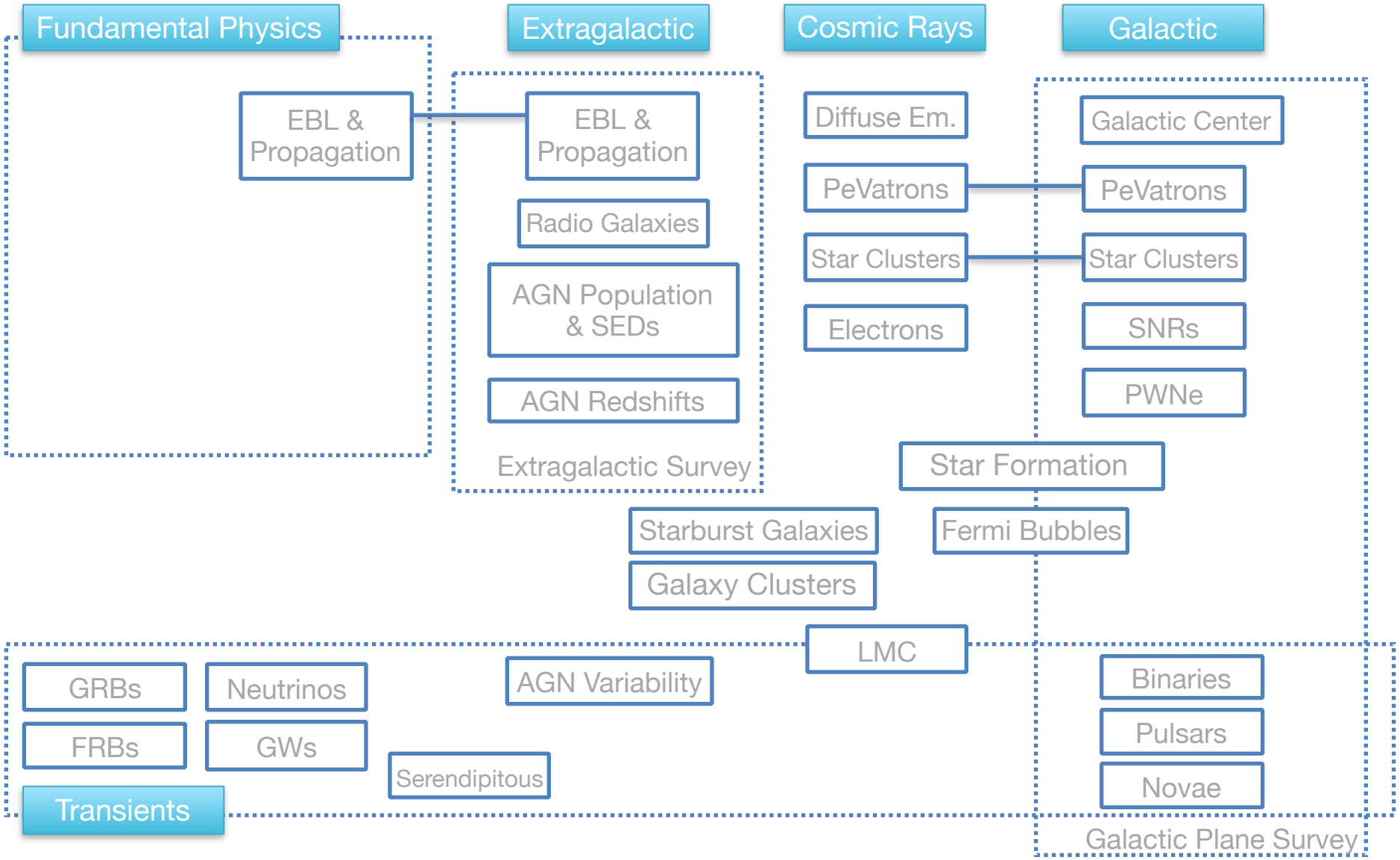


Galactic Centre Survey

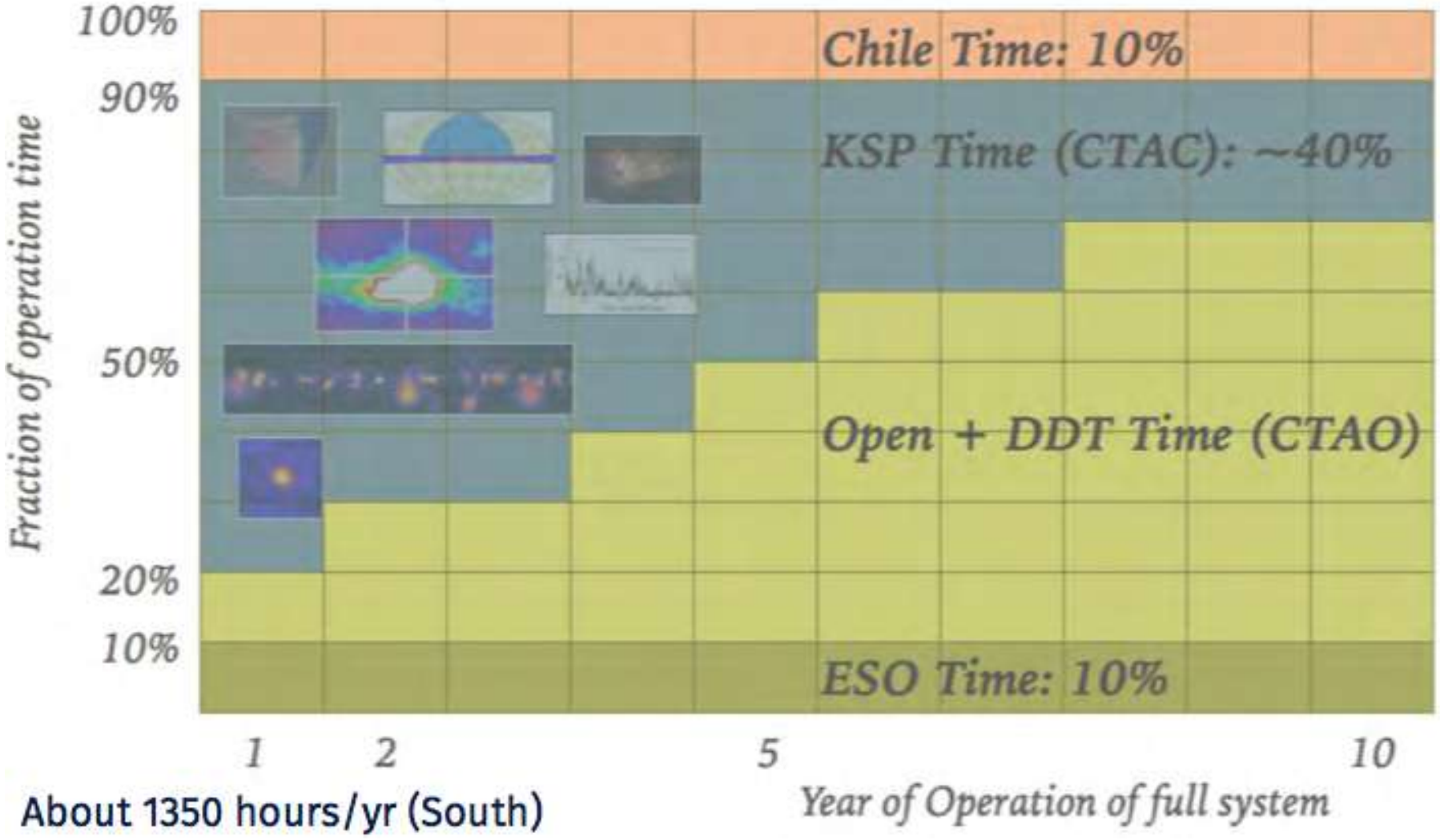


cta
cherenkov telescope array

SCIENCE CASES MAPPING



TIME BUDGET FOR CTA OBSERVATORY



EXTERNAL NEEDS MATRIX FROM ICRC 2019 PRESENTATION

Essential
Important
Useful

cta cherenkov telescope array

Band or Messenger	Astrophysical Probes	Galactic Plane Survey	LMC & SFRs	CRs & Diffuse Emission	Galactic Transients	Starburst & Galaxy Clusters	GRBs	AGNs	Radio Galaxies	Redshifts	GWs & Neutrinos
Radio	Particle and magnetic-field density probe. Transients. Pulsar timing.	●	●	●	●	●	●	●			●
(Sub)Millimetre	Interstellar gas mapping. Matter ionisation levels. High-res interferometry.	●	●		●	●	●	●	●		
IR/Optical	Thermal emission. Variable non-thermal emission. Polarisation.	●	●		●	●	●	●	●	●	●
Transient Factories	Wide-field monitoring & transients detection. Multi-messenger follow-ups.				●		●	●			●
X-rays	Accretion and outflows. Particle acceleration. Plasma properties.	●	●	●	●	●	●	●	●		●
MeV-GeV Gamma-rays	High-energy transients. Pion-decay signature. Inverse-Compton process	●	●		●	●	●	●	●		●
Other VHE	Particle detectors for 100% duty cycle monitoring of TeV sky.	●	●		●	●	●	●			●
Neutrinos	Probe of cosmic-ray acceleration sites. Probe of PeV energy processes.	●	●	●		●	●	●			●
Gravitational Waves	Mergers of compact objects (Neutron Stars). Gamma-ray Bursts.						●				●

SUMMARY OF EXTERNAL NEEDS I

Science Case	KSP Phase	VLBI	Radio cm	Radio mm	Optical OST	Optical (2+ m)	Optical Polar.	X-rays	Gamma
AGN Flares	Full KSP		52 h/y	1600h/y	640 h/y	280 h/y	1776h/y	500 h/y	surveys
AGN Monitor	Full KSP	288 h/y	13 h/y	390 h/y	148 h/y	64 h/y	1490h/y	288 h/y	surveys
AGN Pop.	Early-phase		3 h/y	13 h/y	5 h/y	113 h/y	10 h/y	42 h/y	surveys
AGN Spectra	Early-phase		8 h/y	210 h/y	210 h/y	110 h/y		210 h/y	surveys
AGN-z	Y1-3 full array				50 h/y	40 h/y			
Radio Galaxy	Y1-3 full array	12 h/y				24 h/y		18 h/y	surveys
Extr-Trans.	Early / Full		150 h/y	500 h/y		240 h/y	240 h/y	75 h/y	surveys
X-Gal Survey	pre-KSP		TBC	TBC				TBC	
Diffuse / CRs	pre-KSP								
GPS	pre-KSP		TBC					TBC	TBC
Gal. Trans	Early-Y3 / Full (?)	50 h/y	10 h/y	100 h/y		60 h/y	60 h/y	180 h/y	surveys
SFRs & LMC	pre-KSP							TBC	
Multi-Mess.	Early / Full		16 h/y	150 h/y		150 h/y	150 h/y	50 h/y	surveys
Serend.	Early / Full	TBC	25 h/y	250 h/y	200 h/y	100 h/y	100 h/y	50 h/y	TBC

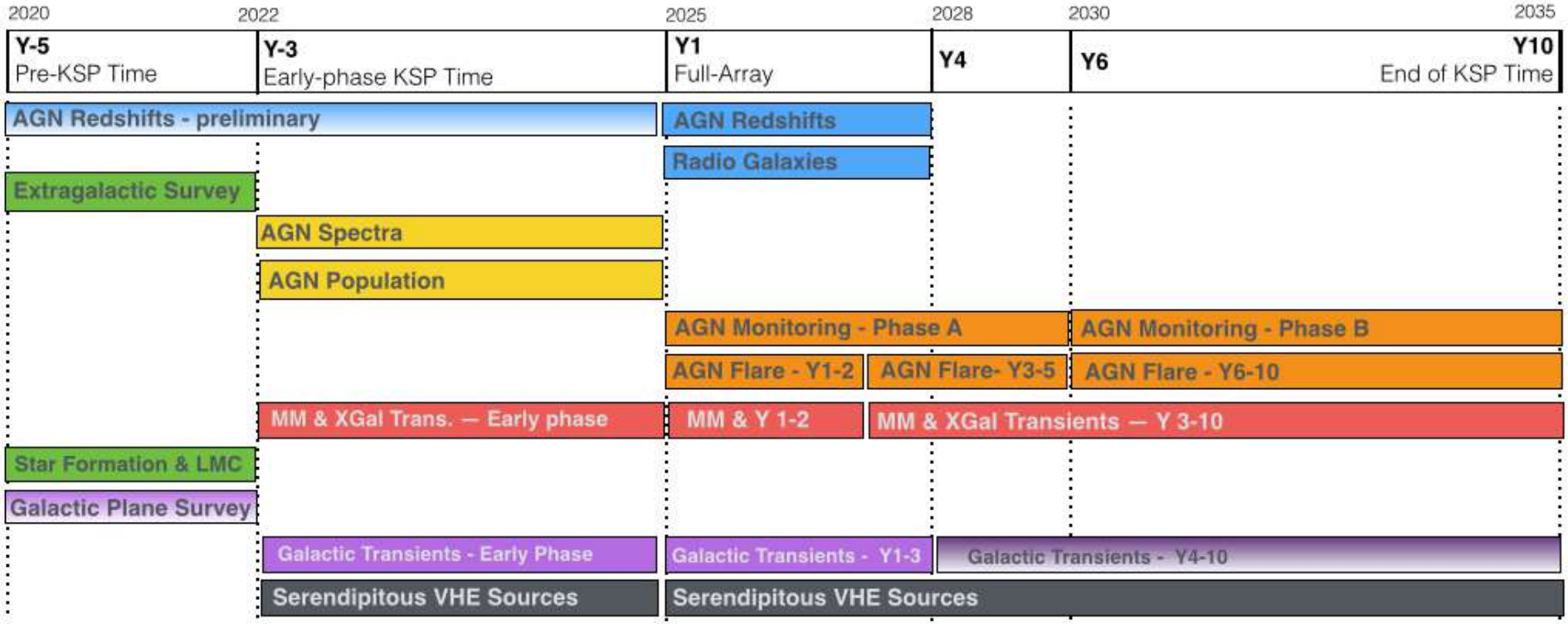
SUMMARY OF EXTERNAL NEEDS II

Science Case	KSP Phase	VLBI	Radio cm	Radio mm	Optical OST	Optical (2+ m)	Optical Polar.	X-rays	Gamma
Total North			140 h/y	1633h/y	795 h/y	582 h/y	2252h/y		
Total South			137 h/y	1580h/y	725 h/y	591 h/y	1594h/y		
Toral Time		350 h/y	277 h/y	3213h/y	1520h/y	1183 h/y	3826h/y	1415h/y	surveys

- Presented are the global needs (telescope time) from each band per science case
  - These are “general values”, not refined for:
    - Evolution of time demand over Key Science Project time
    - Estimates of what is already available “off the shelf” in terms of open data
  - Not all data demands have the same level of relevance, but here all demands are summed up
  - Overlap time demands from different science cases are considered in the total time budget.
- GeV gamma-ray data is considered for the current scenario with major survey instruments available, e.g. Fermi-LAT

TIMELINE OF EXTERNAL DATA NEEDS

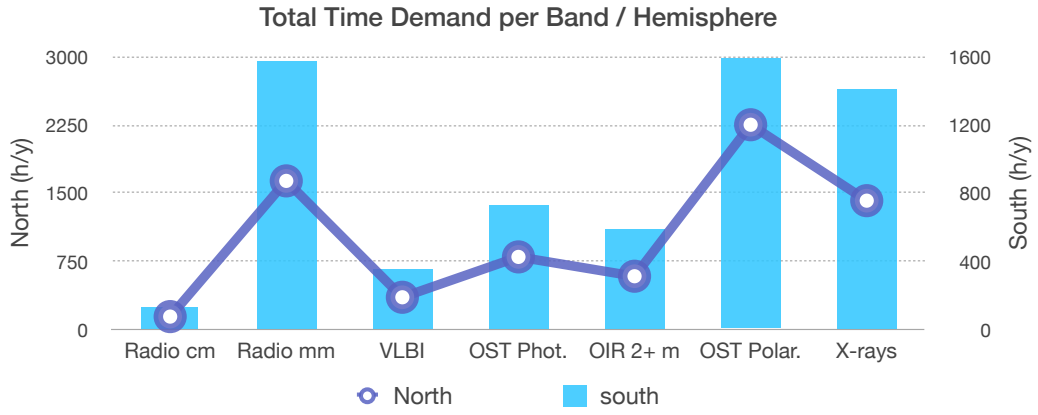
- The observational needs for CTA will vary over time for the first decade over which the KSPs will be carried out.
  - Below, a breakdown is presented of the different phases for the different KSPs and data access needs.



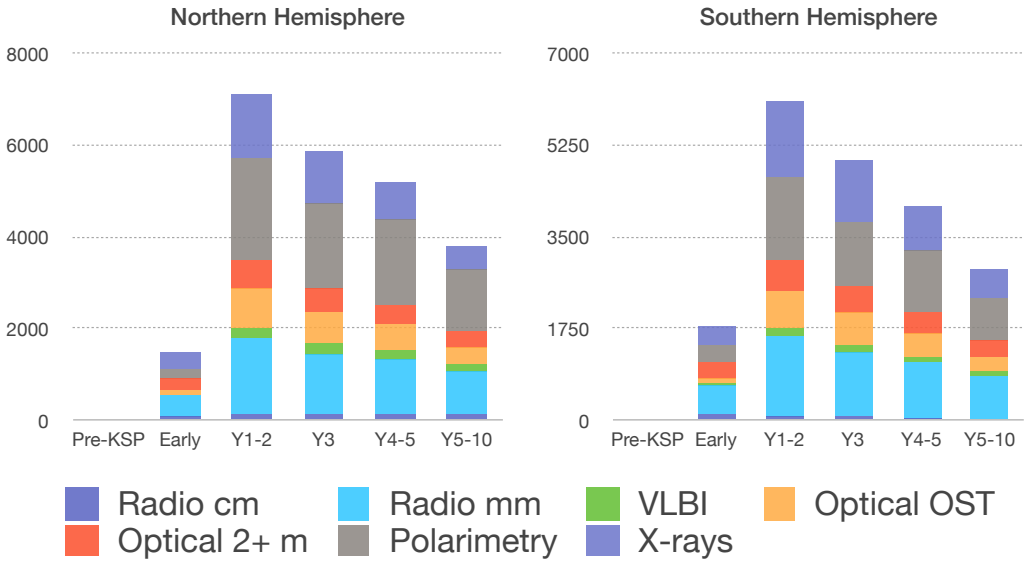
TEMPORAL BREAKDOWN OF NEEDS

		Pre-KSP Time	Early-phase	Full Array Y1-2	Full Array Y3	Full Array Y4-5	Full Array Y6-10
Radio cm-band	North		95 h/y	137 h/y	125 h/y	122 h/y	112 h/y
	South		105 h/y	70 h/y	58 h/y	50 h/y	40 h/y
Radio mm-band	North		450 h/y	1658 h/y	1320 h/y	1208 h/y	930 h/y
	South		550 h/y	1555 h/y	1222 h/y	1076 h/y	822 h/y
Radio VLBI	North			223 h/y	223 h/y	211 h/y	153 h/y
	South		50 h/y	127 h/y	127 h/y	97 h/y	49 h/y
Optical OST	North	25 h/y	100 h/y	850 h/y	671 h/y	531 h/y	374 h/y
	South	25 h/y	100 h/y	724 h/y	646 h/y	426 h/y	285 h/y
Optical (2+ m)	North	20 h/y	245 h/y	598 h/y	523 h/y	419 h/y	357 h/y
	South	20 h/y	305 h/y	578 h/y	504 h/y	404 h/y	340 h/y
Polarimetry OST	North		245 h/y	2232 h/y	1861 h/y	1861 h/y	1349 h/y
	South		305 h/y	1594 h/y	1225 h/y	1195 h/y	794 h/y
X-rays			355 h/y	1413 h/y	1166 h/y	848 h/y	530 h/y
GeV Gammas				—	—	—	—
VHE Gammas				—	—	—	—

SUMMARY STATISTICS



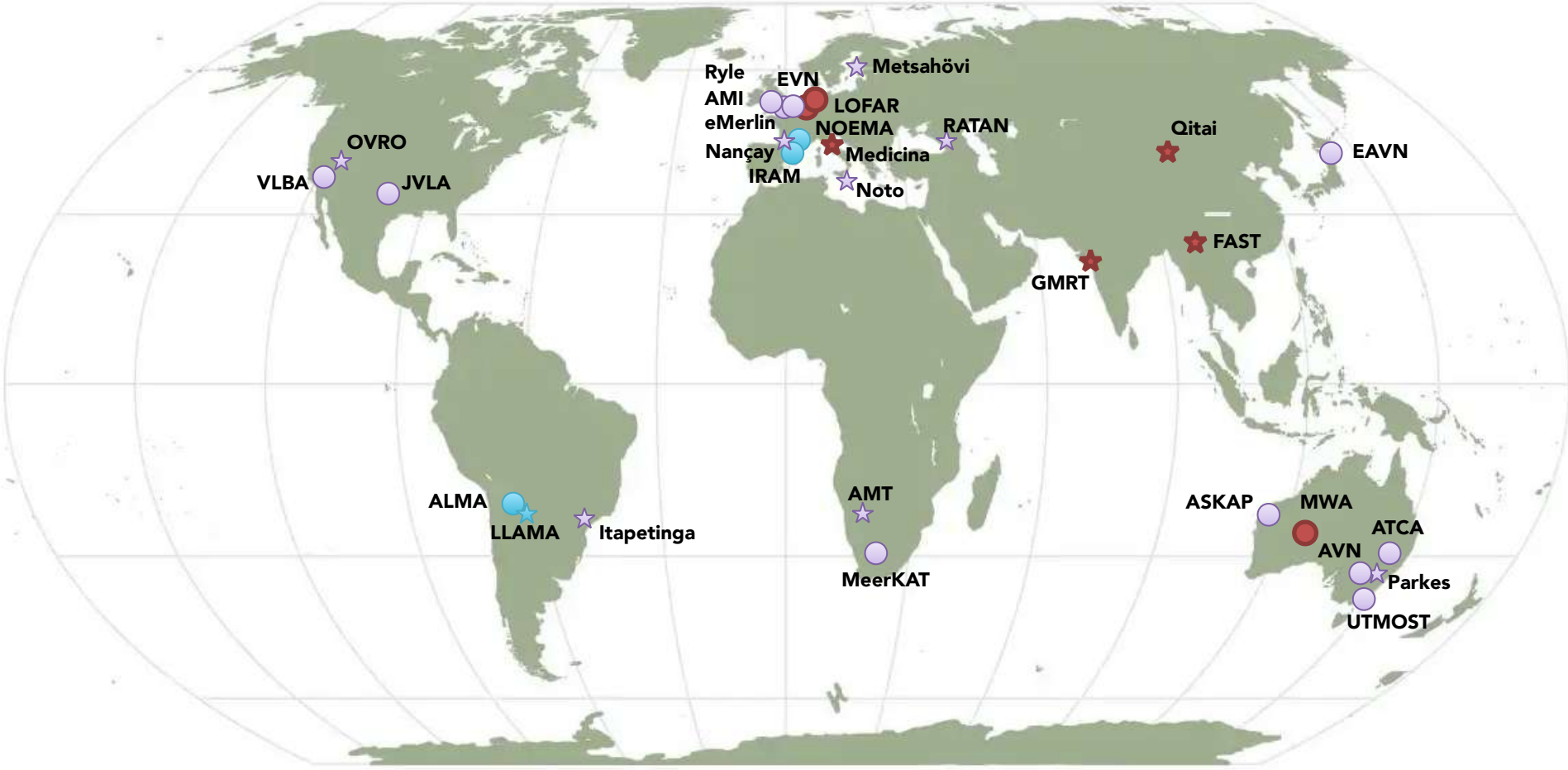
Time demand in each (frequency) band, for each hemisphere.



Temporal evolution of time demand for each phase of KSP.

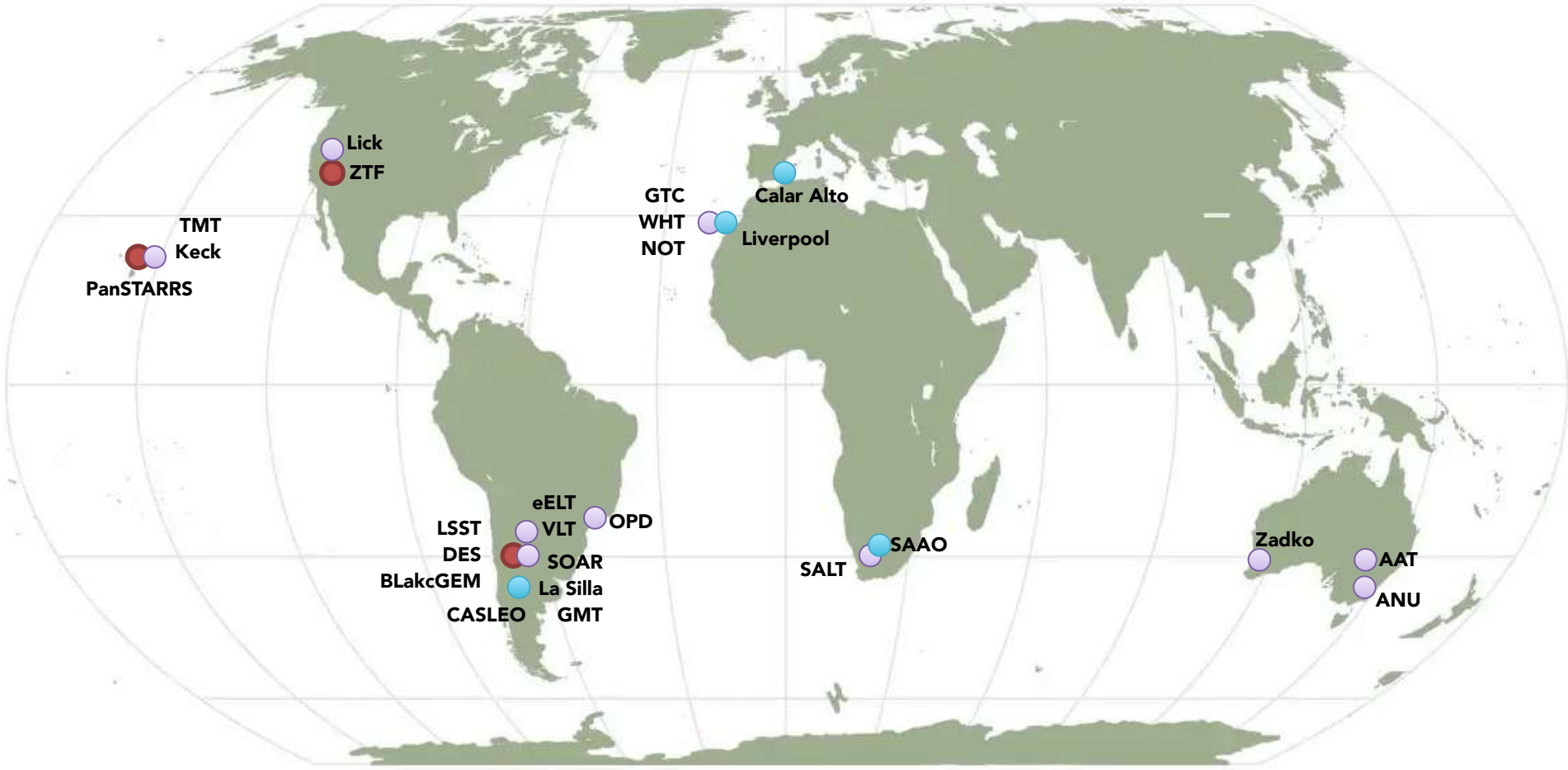
COMMENTS ON SPECIFIC BANDS

MAPPED RADIO FACILITIES



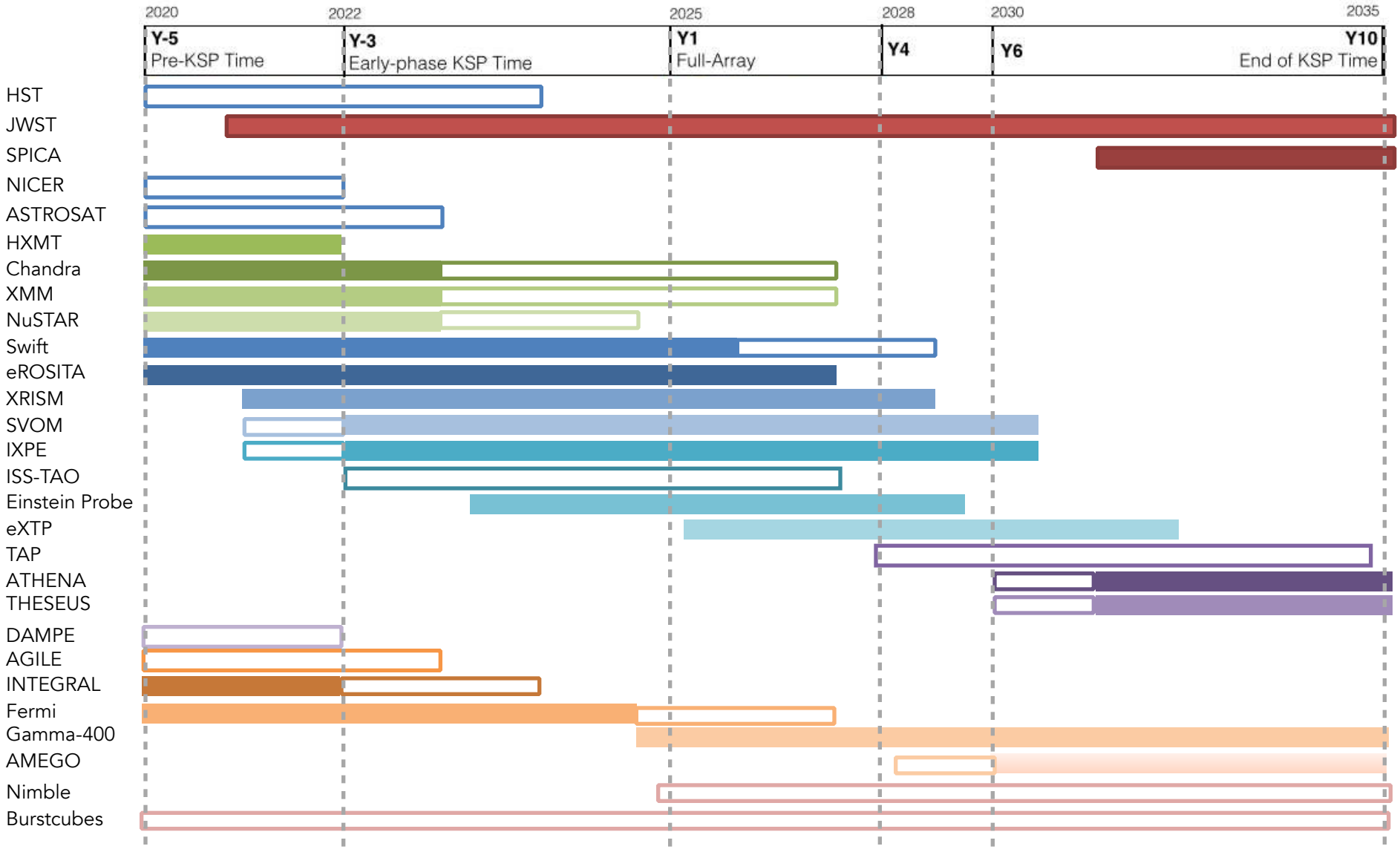
- Low Frequency Radio
- Mid-Hi Frequency Radio
- mm /sub-mm Radio
- monitoring / follow-up?

MAPPED OPTICAL FACILITIES



- Transient Factories
- Major OIR Facilities
- Polarimetric Capability

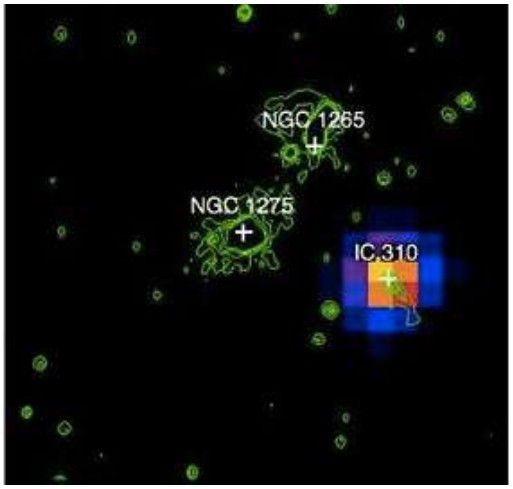
SATELLITE-BASED FACILITIES



DEMANDS ON RADIO SURVEYS

Radio survey data has been identified as an essential complement to several science cases of the CTA Key Science Programmes:

The study of galactic sources and diffuse emission, the LMC survey, as well as radio galaxies, galaxy clusters and starburst galaxies in the extragalactic realm.



Perseus Cluster seen in radio contours and Fermi-LAT.

Extragalactic:

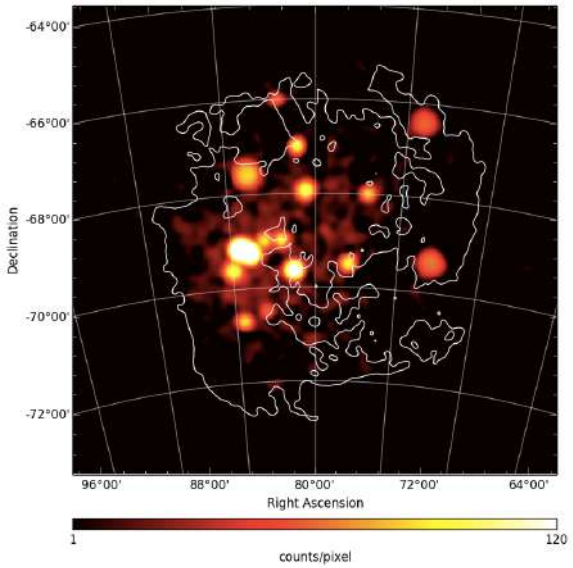
Minimum starburst targets for CTA KSP include M82, NGC 253, M31, Arp 220 — continuum, plus 21 cm and CO line data requested.

Potential Galaxy Cluster sources are Perseus (300 h CTA time), plus Ophiuchus, Coma, Norma, Centaurus and Virgo — MHz-GHz continuum data requested.

DEMANDS ON RADIO SURVEYS

Radio survey data has been identified as an essential complement to several science cases of the CTA Key Science Programmes:

The study of galactic sources and diffuse emission, the LMC survey, as well as radio galaxies, galaxy clusters and starburst galaxies in the extragalactic realm.



Simulated view of the LMC by CTA superposed to HI survey data.

SFR & LMC:

Low-Freq Radio Continuum survey — available sensitivity with MWA likely not sufficient for Wd1 region

Wd1 & Carina / Wd 2 regions — availability? request (e.g. SKA1-Low) if not available

Cygnus region — e.g. with LOFAR?

LMC survey data — include in GASKAP (HI / OH) plus NANTEN data (accessibility?)

OPTICAL MONITORING & FOLLOW-UP NEEDS

I - Optical data will be crucial in the monitoring and follow-up of VHE transients detected by CTA, especially those of extragalactic nature such as AGNs

Optical support telescope on site is likely to provide baseline coverage for flare follow-up and regular monitoring of circa 10 selected sources.

- Important to identify facilities which can complement this baseline coverage, with probable demand of several 10s h/year monitoring time in a 2-m class telescope + up to 100 h/year ToO time with response capability < day

II - Polarimetry is a particularly important complement to be (likely) provided by an OST on site, given high demands on monitoring time.

- Complementary longitude spread of the observational data is nevertheless important to complement e.g. AGN in flaring states.

III - Transient factories broker access / set-up essential to optimise CTA follow-up of transients.

RADIO MONITORING & FOLLOW-UP NEEDS

Radio follow-up and monitoring requirements from both Galactic Transients, and AGN sources.

- 10-year monitoring programme of 15 (11 N + 4 S) prominent sources
- plus ToO follow-up of active sources over extended (2-month period), with < week coverage: expected number of flares up to 100 per year.

Science Case	Preferred Facilities	Triggers by CTA	External Time	Triggers to CTA*	CTA Time	Follow-up
Binaries		< 10	< 80 h	2	20 h	few days / few weeks
Novae	SKA, AMI eMerlin,	< 10	< 80 h	2	20 h	few days / few weeks
uquasars	GMRT,ATCA JVLA, ALMA	< 2	< 80 h	2	20 h	few days / few weeks
magnetars, HMXBs +	MeerKAT, LOFAR	< 10	< 50 h	1	20 h	few days / few weeks
msec pulsars		< 10	< 50 h	1	20 h	few days / few weeks
		< 40	< 340 h	8	100 h	

Additional radio interferometry needs:

- VLBI monitoring of the Radio Galaxy M 87 is particularly important.
  - Monitoring programmes available: EAVN Hada et al.; EVN Giroletti et al.
- Plus joint monitoring of circa 15 pre-selected AGN sources to be followed by CTA for 10 years, with monthly cadence in VLBI.

WAYS FORWARD

CTA, for the first 10 years (2025-35) will have 40% of its time dedicated to internal consortium Key Science Projects

- The successful completion of these science cases will demand cooperation with external data at many fronts
  - surveys and catalogues
  - alerts and follow-ups
  - intense monitoring of transients
- Identification of facilitates that can provide such data (through MoUs, scientific cooperations on existing programmes, regular time demands) is a priority for CTA.

Particularly relevant for the near-term (as of now!) is to complement or identify missing survey data from radio, IR and X-rays that is crucial for some galactic and extragalactic science cases.

Let us establish the links to achieve some of these (mutual) goals through cooperation with Australian groups and facilities!

THANK YOU!

Thank you very much!

Contact me for MWL & Multi-messenger cooperation: ulisses@cbpf.br

EXAMPLE SCIENCE CASES

GALACTIC PLANE SURVEY

To be performed down to ~ 2 mCrab in the inner Galaxy -15° < l < 15° and Cygnus SF Region, and ~ 4 mCrab elsewhere in the GP

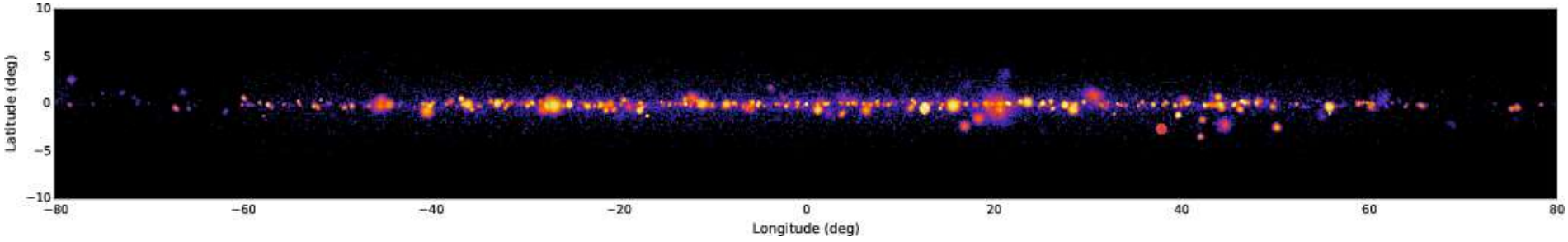
- Provide a complete census of Galactic VHE source populations
- Allow for a detailed study of the diffuse emission at the VHEs
- Production of multi-purpose catalogue and data sets

Multi-wavelength synergies:

Mostly archival data (catalogues and survey data) will be necessary to complement the VHE data;

It is expected that new discoveries may prompt additional observations from other bands, but this will be known only after the first results of the KSP, few years within CTA operation;

Specific science cases require specific data that if missing should be sought after as early as from next year, before the start of CTA operations



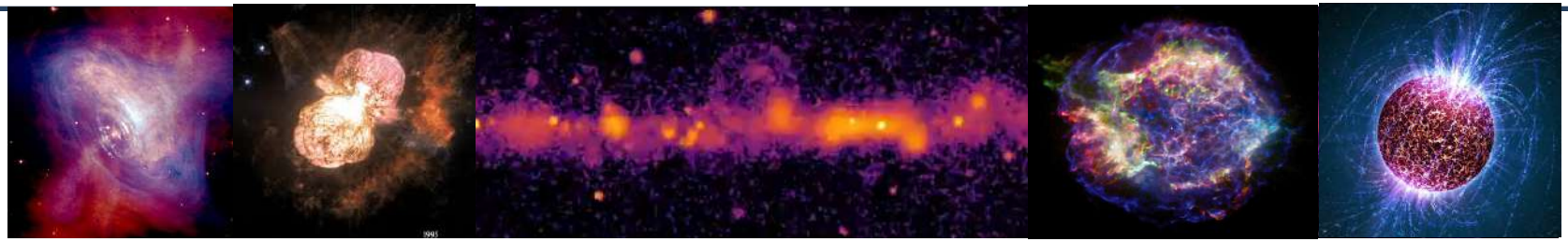
COSMIC-RAYS AND DIFFUSE EMISSION

Cosmic-ray physics is one of the principal science cases for CTA, and will be studied in multiple environments:

- Fermi bubbles;
- Diffuse gamma-ray emission;
- Search for PeVatron sources— e.g., RXJ1713-3946

- All supplementary data is expected to be obtainable from already-available catalogued or survey data, and include:
  - CO+CS molecular gas data from entire GP, to trace CR target matter;
    (e.g., CGPS, MOPRA, JCMT, Nobeyama, APEX, CfA)
  - OH, HI atomic gas data to trace cold gas tracing;
    (e.g., CGPS, GASKAP HI/OH, THOR HI/OH, HI4PI)
  - 500 MHz Radio recombination line data, for tracing ionised gas;
    (e.g., MWA, LOFAR, ATCA)
  - IR dust emission;

GALACTIC TRANSIENTS



	CTA Triggers	Follow-up strategy	CTA Time estimate
Binaries	< 10	2-3 day cadence, for few weeks	20 h
Novae	< 10	2-3 day cadence, for few weeks	20 h
uQuasars	< 5	2-3 day cadence, for few weeks	80 h
magnetar/ HMXBs	< 10	days to weeks	30 h
msec pulsars	< 10	weekly, for few months	20 h
PWNe Flares	?	daily, for few weeks	10 h

- External triggers as well as serendipitous detections by CTA during the GPS are to be followed-up by MWL facilities.
- Radio e.g., SKA*, ATCA, MeerKAT, AMI, eMerlin, GMRT, JVLA, ALMA, LOFAR.
- Optical e.g., Montsec, Calar Alto, GCT, ING, VLT, ESO, SALT, Keck.

GAMMA-RAY BURSTS. FRBs & MM TRIGGERS

The table below includes serendipitous detection estimates (not only from external triggers).

— MWL Follow-up only for CTA-detected sources.

— FRB and neutrinos estimate very uncertain.

Issues under discussion:

Relation to brokers and MWL alert networks;

Necessity of MoU for non-public alerts?

Access to data from transient factories.

Access to cosmic-ray and neutrino archival data?

Band	Science Case	CTA year triggers	Prompt CTA Observation	Est. CTA Detection	Detection Follow-up	Max. Time Exploration
CTA Follow-up of Primary Triggers	GWs	10+ (N+S)	2 h / trigger	2 per year	2h daily untill fade	Early: 20 h/site KSP: 5 h/site
	FRBs / others*	10+ (N+S)	2 h / trigger	O(1) year	?	Early: 50 h/site KSP: 10 h/site
	GRBs	24 (N+S)	2 h / trigger	4 per year	30h per trigger	Early: 50 h/site KSP: 50 h/site
	Neutrinos	10+ (N+S)	2 h / trigger	1-2 / year	?	Early: 20 h/site KSP: 5 h/site
CTA Follow-up of GeV Triggers	GWs	10+ (N+S)	2 h / trigger	2 per year	2h daily until fade	Early: 20 h/site KSP: 5 h/site
	FRBs / others*	—	—	O(1) year	—	—
	GRBs	24 (N+S)	2 h / trigger	4 per year	30h per trigger	Early: 50 h/site KSP: 50 h/site
	Neutrinos	—	—	1-2 / year	—	—
X-rays Follow-up	GWs	—	—	2 per year	25 hours	N.A.
	FRBs / others*	—	—	O(1) year	match CTA (c. 15 h/y)	N.A.
	GRBs	—	—	4 GRB/ year	15 h per GRB	30 h/year/site (total time)
	Neutrinos	—	—	1-2 / year	?	N.A.
Optical Follow-up	GWs	—	—	2 per year	25 hours +50h mon.	N.A.
	FRBs / others*	—	—	O(1) year	50 h/y/site; 10 h/y/site	N.A.
	GRBs	—	—	4 GRB / year	50 h per GRB	100 h/year/site (total time)
	Neutrinos	—	—	1-2 / year	?	N.A.
Radio Follow-up	GWs	—	—	2 per year	25 hours +50h mon.	N.A.
	FRBs / others*	—	—	O(1) year	100 h/y/site 20 h/y/site	N.A.
	GRBs	—	—	4 GRB/ year	100 h per GRB	200 h/year/site (total time)
	Neutrinos	—	—	1-2 / year	?	N.A.