Memo 2: LFT3 Science Operations — Initial Design Framework

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1 Introduction

This memo outlines the science operations of the L FT3 mission and lays out observation strategies to achieve the proposed science goals. These strategies take into account several mission constraints, including power availability, data transfer limits, and a mission life of 20 weeks (although this may be extendable with additional funding). An overview is given in the LFT3 white paper (Memo 1). Due to its location on the farside of the Moon, data transfer from LFT3 must occur via piggybacking off a lunar orbiting satellite, which limits total data transfer to 100 GB per month. Over the 20-week mission, this restricts the total transferable science data to be within 500 GB. There is also a stark contrast in power available to the payload during lunar day (100 W) and lunar night (30 W). This limits most of the power-consuming science operations to the lunar day (i.e., 1680 hours), with only minimal observing modes during the lunar night. Further details are outlined in the document below.

This memo is organized as follows. We first describe the types of observation strategies used by LFT3 in Section 1.1 and the corresponding science data products produced in Section 1.2. The science operations of LFT3 during lunar day and lunar night are described in Sections 1.3 and 1.4, respectively. The allocation of resources (such as time and data volume) among the different science targets is discussed in Section 1.5. A brief summary of the document is provided in Section 1.6.

1.1 Types of science observations

The science objectives of LFT3 can be addressed through two observational approaches: `real-time observations` and `targeted observations`. `Real-time observations` are designed to capture sporadic transient signals, such as those expected from FRBs and potential technosignatures. In this mode, every field observed by LFT3 is continuously processed by an onboard real-time pipeline that searches for candidate events. When a candidate is identified, the pipeline can trigger a dump of raw voltage data (stored temporarily in a ring buffer) or higher cadence dynamic spectra for detailed post-analysis. In contrast, `targeted observations` are used for known sources of interest. These are analyzed by `high-resolution dynamic spectrum` (explained further in the next Section), and the settings for such observations (such as time resolution, frequency resolution, number of stokes parameters to record, and the choice of beam) are driven by the requirements of the primary target. Importantly, since LFT3's beam can encompass multiple types of sources simultaneously, a single `targeted observation` may yield data relevant to secondary science objectives as well. This multi-purpose data usage strategy is discussed in more detail in Section 1.5.

1.2 Science data products

Before going into the details of the observation strategy, we first describe four different formats of science data products generated by the payload, namely, `baseband data`, `sky-complete spectra`, `high-resolution dynamic spectra`, and the onboard `event catalog`. As the raw `baseband` data volume is extremely large (2 GB per second of observing[1]), only small segments of `baseband` data corresponding to transient and technosignature events of high

[1]10 beams sampling complex voltages [4 bit real and 4 bit imag components] at 2 polarisations.

significance are downlinked back to Earth. The `sky-complete spectra` captures the beam-averaged spectra of the sky with a coarse frequency resolution (1 MHz) and long-time integrations (5 minutes). These coarse spectra are collected simultaneously for all science fields observed by the payload, as this helps map out the background sky as seen from the Lunar farside (with no RFI or ionosphere). As a compromise between the large data volume of `baseband` recordings and the `sky-complete spectra`- which offer very coarse resolution but occupy minimal data storage (0.0002 MB per second of observing)- LFT3 can also generate `high-resolution dynamic spectra` that strike a balance between scientific detail and data volume. The frequency and time resolution of the `high-resolution dynamic spectra` is determined by the primary science target being studied.

All `targeted observations` performed by LFT3 produce `high-resolution dynamic spectra`, and the corresponding resolutions and data rates are tabulated in Table 1. Lastly, the payload also maintains an onboard `event catalog` that stores pulse properties (such as pulse arrival time, pulse width, polarisation fraction, etc) for pulses seen by the payload. A very small SNR threshold of 5σ is set for a pulse to be cataloged, as we can very easily catalog a large number of low-SNR pulses (including false positives) in a non-data-intensive manner using the `event catalog`. Event catalog "deltas" are transmitted back to Earth on a regular cadence during the lunar day. Towards the end of the payload life, statistics from this `event catalog` can be used for population studies (by comparing the number of pulses in the catalog with expected number of false positives from triggers on noise events), and is discussed in APPENDIX C.

Targeted Observation	**Science**	**Time res**	**Freq res**	**No. channels**	**Polarisation**	**data rate (MB/s)**
	Technosignatures	0.2	10 Hz	5×10^6	I	50
	Pulsars	1 ms	0.5 MHz	100	I	0.2
	FRB analogs	1 ms	0.5 MHz	100	I	0.2
	Flare stars	1 s	0.5 MHz	100	I, V	0.0004
	Solar system	0.1 s	1 MHz	50	I, V	0.002
	Exoplanets	1 ms	0.5 MHz	100	I, V	0.4
	Studies of Sun	1 ms	0.5 MHz	100	I, V	0.4
	H I studies	5 s	1 kHz	5×10^4	I	0.02
	RRL	5 s	0.5 kHz	1×10^5	I	0.04

	Science	**data type**	**Data rate**
Real-time	Technosignatures	`baseband data` (for SNR > 15)	2 GB/s
	Transients	`baseband data` (for SNR > 15) `dynamic spectrum` (10 $<$SNR$<$ 15) `event catalog` (SNR$>$ 5)	2 GB/s 0.2 MB/s few bytes/s
	Sky-averaged spectra (for cosmology and lunar RF monitoring)	`sky complete spectra` (generated for all observing fields)	0.0002 MB/s

Table 1: Data volume produced by the `real-time observations` and `targeted observations` for different science cases. We note that `targeted observations` only produce `high-resolution dynamic spectra`, while the `real-time system` produces different science data products for different science cases. We compute the data rate assuming the `high resolution dynamic spectrum` to hold values as a `float16` datatype. Note that the `high-resolution dynamic spectrum` is abbreviated to just `dynamic spectrum` in the above table due to space limitations.

1.3 Science operations (Lunar Day)

The schematic diagram of the overall payload science operations during the lunar day is shown in Figure 1. Based on the science object being observed as a `targeted observation`, the payload outputs `high resolution dynamic spectra` that is saved for transmission back to Earth. Alongside the targeted observing system, the raw voltages are also run through a `real-time observing` pipeline, which makes `sky-averaged spectra` for all observed fields, whilst also searching for technosignature and transient candidates. The `real-time observing` block and the `targeted observation` processing block of LFT3 are shown in Figure 1 and further discussed below.

1.3.1 Real-time processing

Science blocks (A), (B), and (C) (shown in Figure 1) operate real-time onboard the payload, thus requiring substantial CPU and GPU processing capabilities to support the technosignature and transient search pipeline. Block (A) continuously analyzes each observed field for Doppler shifting narrow band signals, as expected from extraterrestrial technosignature targets. In the event of the detection of a high SNR candidate, `baseband` data of 1s duration

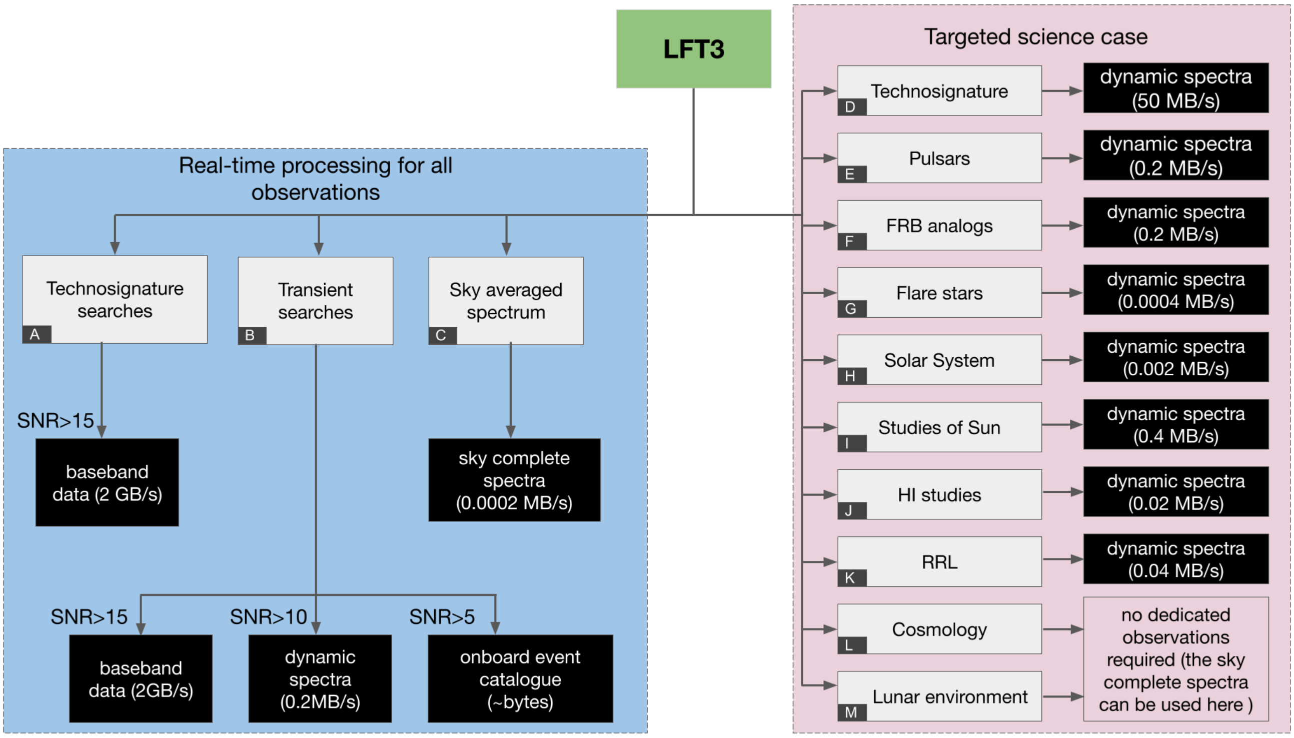

Figure 1: A block diagram showing the science operations of the LFT3 payload during lunar day. In gray blocks we show the different science observations performed and the corresponding science data products in black blocks. Science blocks labeled (a)-(m) are described further in the text. We note that the `high resolution dynamic spectrum` is just abbreviated to `dynamic spectrum` in the above flow chart in the best interest of space.

(uncompressed size of 2 GB) is saved for transmission back to Earth for further analysis. Block (B), the real-time transient search module, generates three types of data products based on the SNR of detected events. For SNR > 15, 1s of `baseband` data is sent back to Earth. For events with SNR between 10 and 15, a `high resolution dynamic spectra` is transmitted. For events with SNR between 5 and 10, the pulse properties are archived by the onboard `event catalog`. Block (C) continuously generates `sky-complete spectra` of 5 minutes integration and 1 MHz frequency resolution for each observed field. These sky-complete spectra contributes to both the cosmology and lunar radio-frequency environment studies, thus ruling out the need to perform `targeted observations` for these two science cases. In order to ensure that all the measured `sky-complete spectra` have the same integration depth of 5 minutes, we constrain the LFT3 hardware to change beam pointing of the frequencies being observed only in intervals of 5 minutes. Due to the sky rotation of the apparent sky from the farside of the Moon, no sky averaging effects are expected to affect our measurements (the apparent sky on the moon rotates by about $0.5°$ every hour).

1.3.2 Targeted observations

Science blocks (D)-(K) of Figure 1 show the `targeted observations` performed by the telescope. At any given time of observing, the science target being studied sets the frequency, time resolution and beams of the `high resolution dynamic spectra` being produced. Note that, as already described in the previous section, no `targeted observations` have to be performed for Cosmology (L) and lunar RF environment studies (M), as the `sky complete spectrum` obtained from the real-time block (C) can be used for these (unless otherwise required). Unlike the real-time search for technosignatures performed by science block (A), targeted technosignature observations can also be performed and are shown as science block (D) in Figure 1. This could be scans of known exoplanets, and the non-detection of a technosignature can be used to place EIRP limits on these systems (discussed further in APPENDIX A). Likewise, targeted observations of known FRB repeaters can also be performed, science block (F), alongside the real-time transient search system. The capacity of LFT3 to observe transients such as pulsars and FRB-like signals is discussed in APPENDIX A. The science data volumes produced by these `targeted observations` are listed in Table 1. Also, as previously mentioned, in order to ensure that the `sky-complete spectra` generated by the real-time system has the same integration time over all fields observed by LFT3, beam pointing and frequencies observed by `targeted observations` can only be changed in 5-minute intervals, except for a potential small set of specific fast-sweep modes.

1.4 Science operations (Lunar Night)

Because the payload power is limited to just 30W of power during lunar nights (that lasts 14 Earth days as well as dusk/dawn periods), it is infeasible to perform observations at full capacity during this time or to downlink observations during this period. As a result, only `real-time` observing at reduced capacity (at HF and VHF-Lo frequencies, as they are dominated by the Sun during lunar day), and `sky-complete` observing are carried out at night to minimize power usage. The science data from the `real-time` system would be saved on the onboard 20TB storage, and will only be downlinked to Earth in the subsequent lunar day. Additionally, the heat generated by onboard processing keeps the payload warm during the cold lunar nights for survival.

1.5 Resource allocation for different sciences

Targeted science	**Data rate** (kB/s)	**Science priority** (1-5)	**Data utility**
Technosignatures	50000	5	2
Pulsars	200	4	50
FRB analogs	200	5	500
Flare stars	0.4	4	25000
Solar system	2	3	500
Studies of Sun	400	2	0.25
HI studies	20	2	5
RRL	40	2	2.5

Table 2: Science data product parameters for various observational targets. We compute the data rate assuming the dynamic spectrum holds measurements as a *float16* datatype. Note that only the `targeted observations` are considered here.

In this Section, we outline how the observing time can be optimally divided across the different science targets for best scientific utility. As a first step, this requires ranking the different science targets based on their priority for the LFT3 mission. We define scientific priority on a log-scale from 1-5, with 5 being the highest priority. Note that this initial ranking serves as a preliminary baseline.

As technosignature candidate and FRB-like transient discovery are the primary goals of the mission, we rank them as priority 5. Although pulsars and flare stars are also transient classes that fall within the primary goal of LFT3, due to their persistent presence in the sky (unlike sporadic FRBs) we have assigned them a slightly lower priority of 4. As mentioned in the white paper, the low-frequency radio emission from the outer planets in our Solar System have not yet been validated since their original discovery by the Voyager space mission, thus ranking them next on the LFT3's scientific priority as 3. All other science goals are ranked 2 as they are either always persistent in the sky (mitigating the urgent need for them to be observed), or less impactfully augment Earth-based observing facilities. Using the defined priorities (which scale logarithmically), the scientific utility of the data can be calculated as

$$\text{data utility} = \frac{10^{\text{priority}}}{\text{data rate (kB/s)}}. \tag{1}$$

The data utility along with the priorities are tabulated in Table 2. Due to the large FOV observed by the payload, targets from various science goals can reside together within the beam, thus observations can be simultaneously re-purposed for different science goals. The primary science goal of an observation only sets the frequency and time resolution (and number of Stokes parameters recorded) of the science data being transmitted back to Earth, and can be used for secondary science goals. This cross-utility of data is mapped out in Table 3, and the last row sums up this cross-utility of data to determine the total utility of observing a particular source as the primary science target. From Table 3 we note observing the Sun as the primary science target has the most cross-utility as the data can be simultaneously be used for 4 other high priority science goals.

We use ratios of this total utility factor to divide the total available observing time (10 Sun lit weeks, i.e., 1680 hours) between the different science goals. Using the mentioned division of observation time between the different science goals, we list the total number of hours available to each science goal as a primary or secondary target in Table 4. From Table 4, we note that 17.5 hours of LFT3's observing time is used in studying Pulsars as the primary science, however, 848.4 hours of more data (used to observe the Sun and FRBs as the primary target) is suitable for studying pulsars within the FOV, rendering 51.5% of LFT3's targeted observations usable for Pulsar science.

From the proposed breakdown of observations, the `targeted observations` produce a total of 1278 GB of uncompressed science data from 10 weeks of constant observing. This can be further compressed using lossless compression algorithms to save on the total data transmitted back to Earth. Alongside all the `targeted observations` during the lunar day and standby mode observations during lunar night, science block (C) is constantly producing `sky-complete spectra`, which over the entire 20 weeks life of LFT3 produces 2.4 GB of uncompressed data.

	Technosignatures	Pulsars	FRB	Flare stars	Solar System	Sun	HI	RRL
Technosignatures	2							
Pulsars		50	50			50		
FRB		500	500			500		
Flare stars				25000		25000		
Solar system					500	500		
Sun						0.250		
HI	5						5	5
RRL	2.5							2.5
Total utility	9.5	550	550	25000	500	26050.25	5	7.5

Table 3: Matrix showing the cross-utility of `targeted observations` performed of various science goals. As columns, we show the primary science goal, and as rows we show the different secondary science goals that the same data can be used for. In the last row, we mention the total science utility of performing `targeted observation` of a particular science goal.

	Science	**Observing time**		**Total**	**Percentage of**
		as primary target	**as secondary target**		**total time/data**
Targeted Observations	Technosignatures	0.3 hrs 54.5 GB	0 hrs 0 GB	0.3 hrs 54.5 GB	< 0.1% 4.3 %
	Pulsar	17.5 hrs 12.6 GB	848.4 hrs 1209.1 GB	866 GB 1221.7 GB	51.5% 95.6%
	FRB analogs	17.5 hrs 12.6 GB	848.4 hrs 1209.1 GB	866 GB 1221.7 GB	51.5% 95.6%
	Flare stars	787.4 hrs 1.1 GB	830.9 hrs 1196.5 GB	1628.3 GB 1221.7 GB	96.9% 93.7%
	Solar system	15.9 hrs 0.1 GB	830.9 hrs 1196.5 GB	846.8 GB 1197.6 GB	50.4% 93.7%
	Studies of Sun	830.9 hrs 1196.5 GB	0 hrs 0 GB	830.9 GB 1196.5 GB	49.5% 93.7%
	H1 studies	0.2 hrs < 0.1 GB	0.5 hrs 54.6 GB	0.7 GB 54.6 GB	< 0.1% 4.3%
	RRL	0.2 hrs < 0.1 GB	0.3 hrs 54.6 GB	0.5 GB 54.6 GB	< 0.1% 4.3%

	Science	**Observing time**	**Data generated**
Real-time	Technosignatures	3360 hrs (100% of mission life)	2 GB/s
	Transients	3360 hrs (100% of mission life)	2 GB/s (SNR> 15) 0.2 MB/s (10 <SNR< 15) few bytes/s (5 <SNR< 10)
	Sky-averaged spectra (for cosmology and lunar RF monitoring)	3360 hrs (100% of mission life)	2.4 GB (total)

Table 4: Observing duration and data output for each science target. The top block shows data for **targeted observations** as both primary and secondary targets. The bottom block lists the contributions from **real-time observations**.

1.6 Summary

This memo presents the initial design framework for LFT3 science operations, outlining observation strategies and data products based on current payload assumptions. The details are provisional and will be refined in a future memo following the final definition of the spectrometer and other subsystems.

In conclusion,

1. LFT3 performs two types of observations, namely, `real-time observations` and `targeted observations`;
2. LFT3 produces 4 different types of science products, i.e, `baseband` data, `sky-complete spectra`, `high-resolution dynamic spectra`, and `event catalog`;
3. `sky-complete spectra` produces 1MHz resolution spectra with 5 minute integrations during the entire life of the mission. This is estimated to produce 2.4 GB of un-compressed data. This also limits the beam pointing and frequencies observed to be changed only in intervals of 5 minutes, except for some potential fast-sweep modes;
4. `targeted observations` are only performed during the lunar day, while the `real-time observing` is performed during lunar day and lunar night.

Appendices

A Detectability of techno signatures and fast transients by LFT3

In this Section, we provide a brief overview of the payload's sensitivity towards it primary science goals, namely, transients and technosignatures. In order to demonstrate LFT3's capacity to detect single pulse events such as FRBs, we show LFT3's capability to detect significant fraction of the CHIME[2] FRBs, thus justifying its use as a FRB search machine. The radiometer equation for single pulse events is given by,

$$SNR = \frac{S \times \sqrt{n_{pol} \times \Delta b}}{SEFD(\nu)} \times \sqrt{\frac{\Delta W}{\Delta T}}, \tag{2}$$

where S is the peak flux density of the FRB in Jys, n_{pol} is the number of polarisations, Δb is the bandwith in Hz, SEFD(ν) is the system equivalent flux density at a frequency ν, ΔW is the pulse width in seconds, and ΔT is the instrument's sampling time. Using the above radiometer equation, in Figure 2 we show the number of CHIME FRBs detectable at $> 5\sigma$ significance, for various sampling rates. With LFT3's 100 MS/s sampling, we expect several hundreds of CHIME FRBs detectable by LFT3, even in regions of increased sky noise such as towards the Galactic plane.

We extend this analysis to evaluate the detectability of known pulsars listed in the ATNF catalog[3]. For a pulsar with period P and pulse width W, radiometer equation is,

$$SNR = s_\nu \times \frac{\sqrt{n_{pol} \times t \times \Delta b}}{SEFD(\nu)} \times \sqrt{\frac{P - W}{W}}. \tag{3}$$

Using the average SEFD at 400 MHz and Eq 3, we find that LFT3 should detect over 200 known pulsars with just 10 seconds of observing per target.The sky distribution of these detectable pulsars is shown in Figure 3. Given that 50% of the LFT3 observations are usable for pulsar science (see Table 4), we should be able to study over hundreds of pulsars using LFT3 over 100s of periods.

We also plan to conduct targeted observations of known exoplanetary systems in the search for technosignatures. In the absence of a detection, we can place upper limits on the Effective Isotropic Radiated Power (EIRP) of these systems using the relation (obtained from (1)),

$$EIRP(W) < 1.12 \times 10^{12} \times \sigma \times R^2 \tag{4}$$

where R is the distance to the star system in pc, and σ is the noise calculated as $\sigma = SEFD(\nu)/\sqrt{n_{pol} \times \Delta\nu \times t}$. With our proposed system, the EIRP limits that can be achived for 10 minute integration is shown in Figure 4 (assuming that the bandwidth of the transmitter is 10kHz).

[2] `https://www.chime-frb.ca/catalog`
[3] `https://www.atnf.csiro.au/research/pulsar/psrcat/download.html`

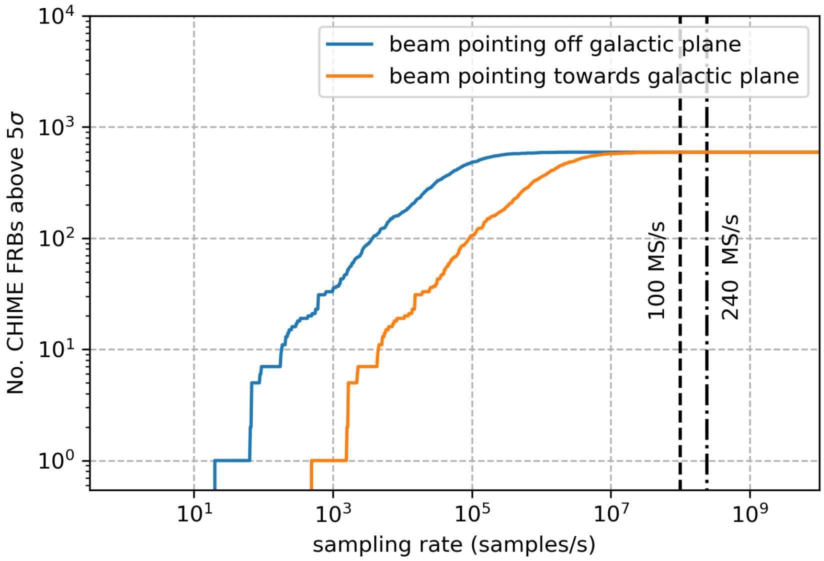

Figure 2: Simulated no. of detections of Chime FRBs at 400 MHz as observed by LFT3 for different sampling rates. In blue we show the no-of FRB like signals for off galactic plane pointints with reduced sky noise, and in orange we show the corresponding detection rate but for beam pointings towards the galactic plane. In the figure we also show a vertical lines the two different sampling rates (i.e, 100 MS/s and 240 MS/s) considered for LFT3.

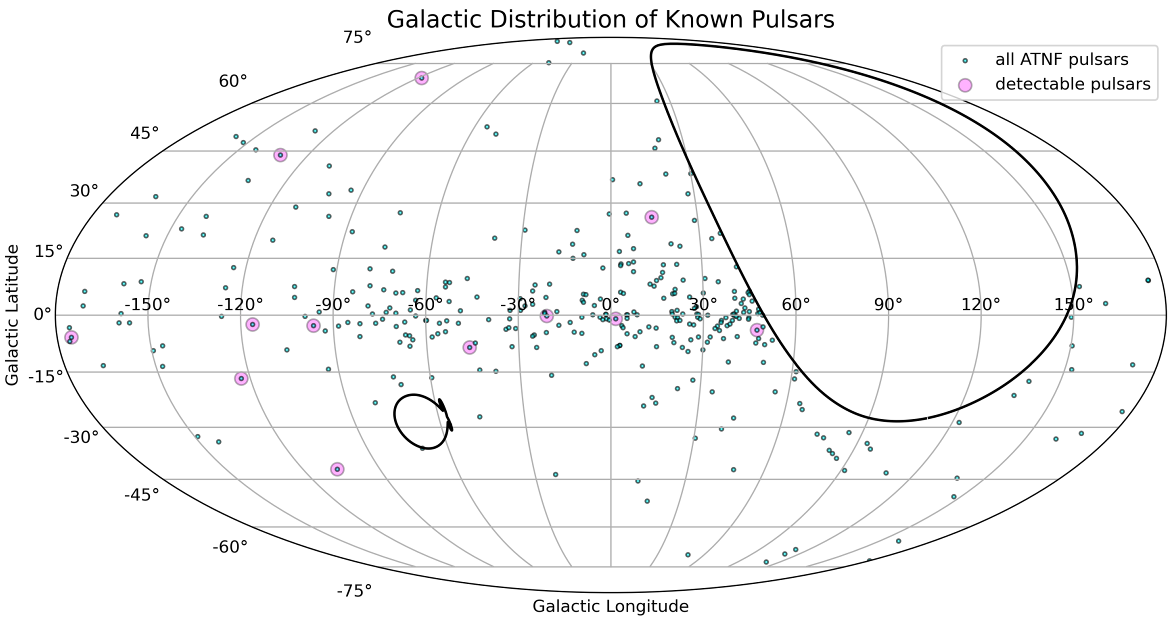

Figure 3: Distrubution of Pulsars detectable by LFT3 in 10 hours of observation at 400 MHz.

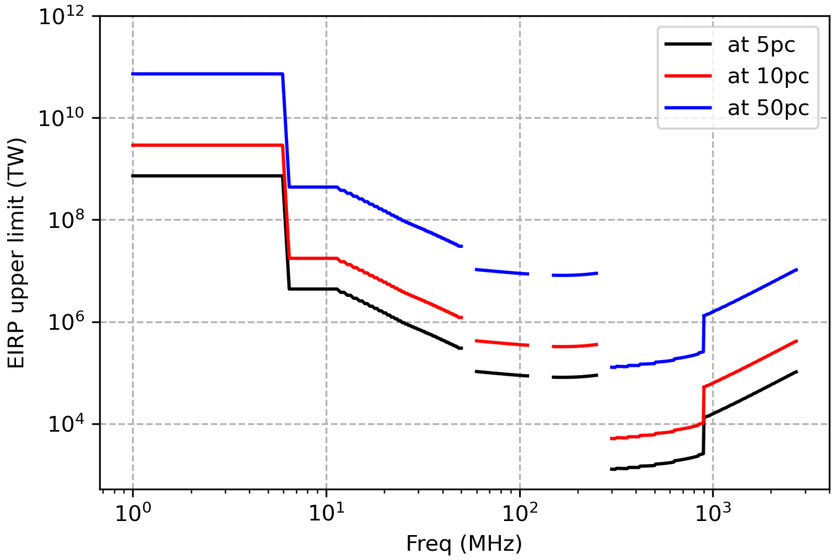

Figure 4: The EIRP limits achievable by 10 minutes of observation by LFT3 at different frequencies (for 10kHz bandwidth). Using lines of different colors we also show how the EIRP limit scales with distance.

B List of Science targets LFT3

In this section, we compile together a list of targets that will be observable as targeted science observations by LFT3. Below is a summary of the targets

1. Technosignatures: the RECONS[4] star catalog and Mars,
2. Pulsars: a subset of ATNF catalog, that are detectable with few seconds of observing,
3. FRB: CHIME repeaters,
4. Flare stars: The Sydney Radio Star Catalog[5],
5. Solar system: Jupiter, Neptune, and Uranus,
6. Sun studies: Sun
7. H1 studies: galactic and extra galactic sources,
8. RRL studies: galactic and extra galactic sources.

A compiled list of all science target objects that are of interest to LFT3 can be found in `https://github.com/ScienceMoonshot/catalogs`

C Noise statistics: False positives

In this Section, we estimate the expected number of false positives in the `event catalog`. For a baseband sampling rate of 100 MS/s, continuous observing for the entire 20 weeks life of the mission would expect to produce approx. 7×10^9 false positives (per beam and per polarisation) for a 5σ threshold (assuming Gaussian statistics). We estimate these false positives to create < 3GB of data in the `event catalog`. Any significant excess than the expected number of false positives in the `event catalog` would inform us of a low brightness transient population detected by LFT3. The distribution of this excess on the sky, can be used to determine if they are of galactic or extragalactic in origin.

[4] `http://www.recons.org/`
[5] `https://radiostars.org/data/`

D Alternative hardware designs

In this section, we explore how the science operations would change in light of few alternative hardware designs for the LFT3 payload.

D.1 Higher sampling rate

All science operations in this document are based on a 100 MS/s sampling rate, corresponding to a 50 MHz instantaneousness bandwidth. A higher sampling rate of the 240 MS/s (120 MHz bandwidth) is currently being considered for the LFT3 hardware. This upgrade in bandwidth, combined with the instrument's large field of view, would significantly enhance its survey capabilities and increase the likelihood of serendipitous detections of transients and techno signature candidates.

In terms of science operations, this higher sampling rate primarily affects the `baseband data` to be down-linked for high-SNR transient events and technosignature candidates. To accommodate this bandwidth upgrade without significant impact on aspects of the mission, the system would operate with only four beams (as opposed to 11 beams considered previously) at any given time. Under this configuration, `baseband data` from four dual-polarisation beams sampled at 240 MS/s would yield a data rate of 1.92 GB/s—lower than the 2 GB/s rate considered in the baseline design.

However, data rates for `targeted observations` (see Table 1) would increase by a factor of $\times 2.4$ to cover the expanded bandwidth. This however can be mitigated by selecting a 50 MHz sub-band for `targeted observations`, preserving the current data rate assumptions.

E LFT3 Science goals

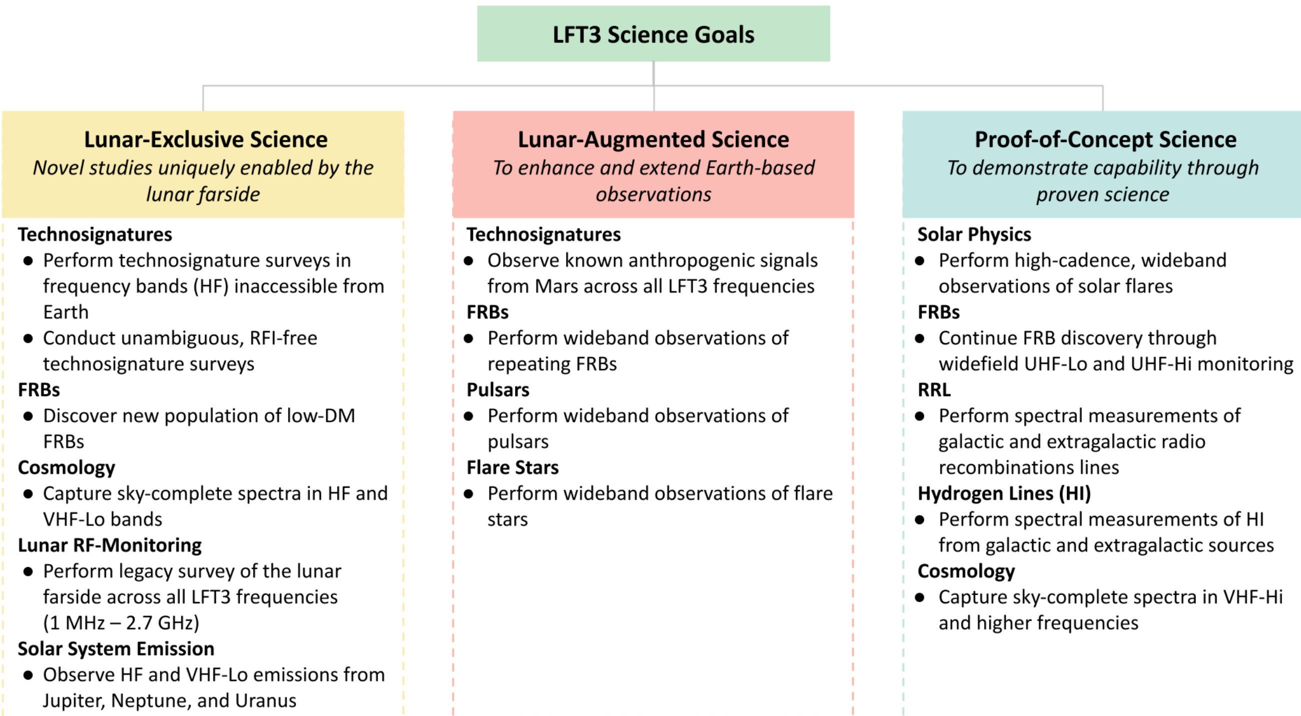

Figure 5: A block diagram illustrating the science goals of LFT3. The goals are organized into three categories: Lunar-Exclusive, Lunar-Augmented, and Proof-of-Concept, reflecting the nature of the science compared to Earth-based observations.

In this section, we outline the scientific goals of the LFT3 mission. The proposed sciences are organised into three categories and depicted in Figure 5:

1. Lunar-Exclusive Science: Observations that can only be conducted from the radio-quiet environment of the lunar farside. These studies represent entirely new avenues of discovery, science that can not be repeated from anywhere on Earth due to its ionospheric and RFI limitations.
2. Lunar-Augmented Science: Observations that complement and extend Earth-based science by leveraging the unique properties of the lunar farside to achieve broader frequency coverage, longer dwell times, or avail of the pristine, RFI-free environment. These studies push the boundaries of what is possible from Earth alone.
3. Proof-of-Concept Science: Well-established scientific investigations, previously conducted on Earth, now repeated from the lunar farside to validate system capabilities, ensure operational reliability, and continue important studies of known phenomena.

E.1 Lunar-Exclusive Science

E.1.1 Technosignatures

The lunar farside offers a uniquely quiet environment for technosignature searches, free from the persistent RFI that affects all Earth-based observations. This includes access to the HF band (1 - 50 MHz), which is entirely blocked by Earth's ionosphere and has never before been searched. Potential signals are expected to be narrowband and closely resemble terrestrial interference, so they are likely to be masked in ground-based surveys, regardless of the sophistication of current RFI mitigation techniques. Observing from the farside would enable the first truly unambiguous, RFI-free search for technosignatures, in bands that have thus far been inaccessible from Earth.

E.1.2 Fast Radio Bursts

Understanding the low-frequency emission properties of Fast Radio Bursts (FRBs) is critical for uncovering their origins and source populations. LFT3 would allow us to observe these as-of-yet unexplained phenomena in the HF and FM bands without RFI. These observations could reveal entirely new populations of low-dispersion FRBs, and hold great potential for unlocking a deeper understanding of their nature and origins.

E.1.3 Cosmology

LFT3 would enable the first RFI-free spectra of the faint 21 cm signal from neutral hydrogen during the Cosmic Dark Ages in the HF and VHF-Lo bands. These sky-complete spectra could reveal how the first structures formed in the early Universe. The radio-quiet conditions of the lunar farside offers an extreme sensitivity that is essential for detecting this faint signal, which is otherwise buried beneath strong galactic foregrounds.

E.1.4 Lunar RF-Monitoring

Despite the expectation that the lunar farside be a pristine RF environment, there are many potentials for RFI from unexpected sources such as lunar communication orbiters or further spacecraft. The dynamic spectra taken of the lunar farside by LFT3 during its operational period will provide an important record of the baseline and evolution of its RF environment, something no other mission currently proposed will do before it is changed by future space missions.

E.1.5 Solar System Emission

LFT3 is uniquely suited to probe low-frequency emission generated by the gas giants of our solar system. It offers a rare opportunity to confirm emissions from planets such as Neptune and Uranus, emissions that were first and last detected by the Voyager missions and cannot be verified from Earth due to ionospheric interference. Validating and studying these emissions with long-term observations from the lunar farside would carry significant implications for understanding their planetary atmospheres and magnetospheres.

E.2 Lunar-Augmented Science

E.2.1 Technosignatures

Using advanced, real-time processing similar to Earth-based systems, LFT3 would be able to autonomously identify anthropogenic signals across its entire frequency range. This would allow us to validate technosignature detection by observing known narrowband communication signals from Mars, giving us a benchmark for testing detection methods.

E.2.2 FRBs

Complimenting ground-based telescopes, LFT3's unique vantage point would enable clearer insights into repeating FRBs by performing wideband, high-time-resolution observations of these FRBs at low frequencies. Coordinated observations could achieve unprecedented localisation precision, something that would be of significant value to this field.

E.2.3 Pulsars

LFT3 would enable the wideband, low-frequency observation of pulsars without ionospheric distortion and RFI. This would allow for detailed studies of pulsar emission physics, pulse structures, and surrounding media at frequencies inaccessible from the ground. Continuous monitoring would also improve detection of subtle pulsar behaviour that is harder to detect from Earth.

E.2.4 Flare Stars

Wideband, low-frequency observations of radio flare stars using LFT3 would provide unique insights into stellar magnetic activity, star-exoplanet interactions, and the plasma environments of these young, active stars, advancing our understanding of planetary and stellar evolution.

E.3 Proof-of-Concept Science

E.3.1 Solar Physics

LFT3 would be able to perform high-cadence, wideband low-frequency observations of solar flares and coronal mass ejections, as well as interplanetary scintillation measurements to track solar wind structures and CME-driven shocks with greater precision than Earth-based instruments.

E.3.2 FRBs

LFT3 will continue advancing FRB discovery by conducting widefield monitoring across the UHF-Lo and UHF-Hi bands.

E.3.3 Radio Recombination Lines

Without ionospheric distortion or interference, LFT3 would be able to perform clean spectral measurements of galactic and extragalactic RRLs, allowing us to probe the physical conditions of the cold ionised interstellar medium for insights not as easily accessible from Earth-based telescopes.

E.3.4 Hydrogen Lines (HI)

LFT3 would offer a clear, interference-free platform for spectral observations of the 21 cm neutral hydrogen (HI) line from galactic and extragalactic sources. This will complement ground-based HI surveys and improve our understanding of galaxy formation and the large-scale structure of the cosmos.

E.3.5 Cosmology

LFT3 would be able to perform all-sky spectral surveys at VHF-Hi and higher frequencies, enabling comprehensive cosmological studies and helping to further probe cosmic evolution and signals from the early Universe with minimal interference.

References

[1] C. D. Tremblay and S. J. Tingay, "A SETI survey of the Vela region using the Murchison Widefield Array: Orders of magnitude expansion in search space," *Publications of the Astronomical Society of Australia*, vol. 37, p. e035, Sep. 2020. doi: 10.1017/pasa.2020.27. [Online]. Available: https://ui.adsabs.harvard.edu/abs/2020PASA...37...35T