Ultra-Long Duration Balloon (ULDB) Program Study

Interim Report

Prepared for:

The Space Sciences Directorate
April, 97

By:
The GSFC Study Team

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Purpose

The purpose of this interim report is to:

- document requirements information,
- identify technical challenges of the Ultra-Long Duration Balloon Program,
- provide input to the demonstration program at Wallops and
- provide information to non-balloon scientists and engineers regarding differences between balloon and space missions and potential opportunities for science.

Background, Goal and Organization

The ULDB Program study was initiated by NASA Headquarters in June 1996. There are three distinct but related projects currently underway. They are:

1. ULDB (≥100 day flight) Study: This is a science feasibility study to evaluate whether science goals can be met and to identify technical challenges to satisfy science needs.
2. The Demonstration Program: This is the initial ~100 day balloon flight demonstrating the capability of superpressure balloons and the type of science that can be accomplished. This will also show the technology available to successfully undertake such missions in the future.
3. Mission/Program: An Ultra-Long Duration Balloon Program will be the result of a successful demonstration program.

Goal

The goal of the ultra-long balloon program study is to create a ≥100 day balloon model which is technically feasible and within program cost constraints while maintaining existing balloon program. This program will identify commercial and existing spacecraft technologies and practices to improve performance and contain costs.

The ULDB program is significantly different from the current balloon program in that the expected science return is significantly greater than current balloon missions. In other words, it is more than simply extending current experiments over a longer time period. This program also expects to use technologies currently available in the spacecraft missions and commercial arenas to improve performance while containing costs.

Organization Of The Study Team

The study team includes personnel from NASA-GSFC, WFF and members from the science community. Figure 1 depicts the conceptual organization and information flow of the integrated study team. Each member of this study team brings specific areas of knowledge and experience. The roles of each member is broadly defined as follows:

GSFC Wallops Flight Facility Role

- Wallops will be the official residence of the balloon program.
- Strong experience base and expertise
- Organize the demonstration program based on GSFC findings
- Primarily responsible for Safety, Operations and Balloon

GSFC Greenbelt Role for demonstration for future program

- Science feasibility study
- Identify technologies and practices for transfer; operations and options
- Determine a model for 100 day balloon missions
- Expertise in long duration space missions and new satellite technologies

Organization Of The Study Team (Continued)

- Primary responsibility for recommending Communications Options, Power, Thermal, Pointing and Interface Standards

Science Community

- Provide requirements for strawman missions
- Provide feedback regarding technology options
- Direct and redirect study

NASA Headquarters

- Oversee and facilitate international aspects of the ULDB Program.
- Plan for and coordinate infrastructure supports, e.g., TDRSS.

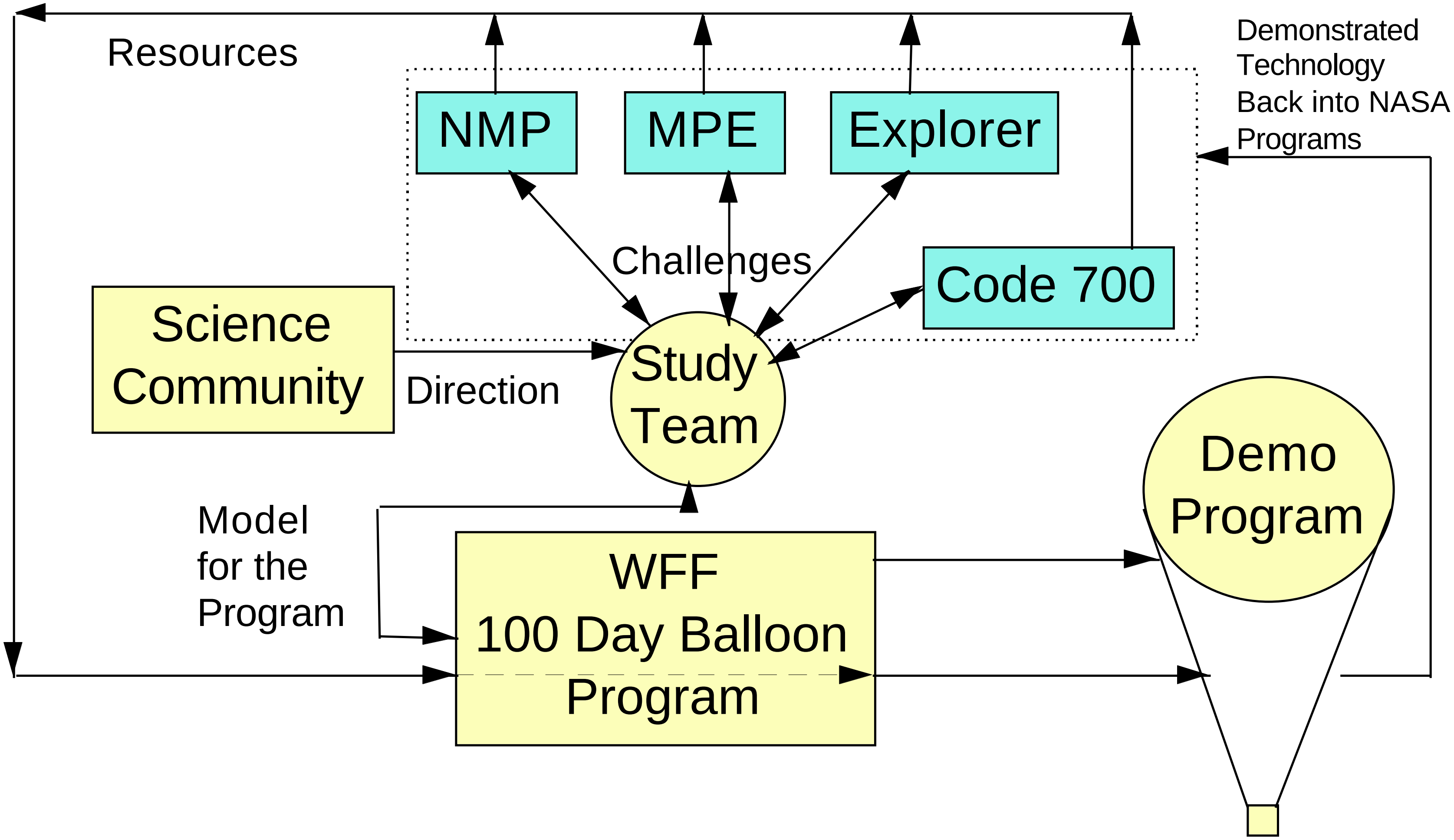

Figure 1 Conceptual Organization Of The Integrated Study Team

Schedule For The Study And The Demonstration Program

SUPERPRESSURE INITIATIVE MILESTONES

ULDB Program Schedule

4/15/97

June '96	Initial Planning Discussion
Oct. '96	GSFC Commitment
Nov. '96	Workshop Begins GSFC Study
Feb. '97	First Hangar Tests
4/11/97	Identify Demo. 2000 Science Candidates
4/15/97	Interim Req.s & Tech. (R&T) Rpt.
5/1/97	Establish Integrated Mgmt. Team (IMT)
6/24-25/97	Technology Workshop
9/1/97	Final R&T Report
10/15/97	Conceptual Design Review (CoDR)
11/17/97	Test Flight : Balloon Technology : 0.2 mcf (New Zealand)
2/2/98	Test Flight : Balloon Technology : 1-2 mcf (CONUS)
3/18/98	Preliminary Design Review
3/25/98	Select Demo. 2000 Science Instrument
9/15/98	Test Flight : Balloon Technology : Full Scale (CONUS)
10/14/98	Critical Design Review
11/16/98	Test Flight: Balloon-craft Systems (New Zealand)
3/12/99	Mission Readiness Review (MRR): Integrated Systems Flight
4/15/99	Test Flight: Integrated Systems (CONUS)
4/30/99	Select Mission 2001 Science Instrument
5/12/99	Mission Operations Review (MOR)
10/6/99	MRR: Demo. 2000 Flight
1/1/00	Demo. 2000 Flight (non-polar S.H.)
1/1/01	Mission 2001 Science Flight

The above is based upon the assumption that the IMT will be fully composed by May 1st.
The following discussion provides some details regarding the events that have occurred.

100 day balloon workshop Oct. 31, 1996-Nov. 1, 1996

- A workshop was organized to introduce the 100 day balloon program concept and study to the science community. Personnel from NASA HQ and GSFC (Greenbelt and WFF) participated in interactions with the science community to generate new concepts and requirements.

- The workshop was organized into “splinter groups” based on science discipline. Five splinter groups were formed: Atmospheric Science, Cosmic Ray, Gamma Ray, Infra Red and Solar Ray.

- The splinter groups were asked to develop ideas and specific requirements for strawman missions. These strawman missions had to define science that is not achievable under the current balloon program and identify enabling technologies important to other NASA missions such as the New Millennium, Mission to Planet Earth and the explorers and incorporate them into Long Duration Balloon missions to test them**.** The splinter groups were asked to provide the following information for each strawman mission.

    - Weight
    - Altitude Range
    - Power and power profile
    - Thermal requirements
    - Pointing knowledge and stability
    - Location of balloon, launch and desired drift
    - Data return requirements
    - Commanding requirements
    - PI operated or otherwise

Summary Of Results From The Workshop

A summary of expected performance requirements collected from workshop participants have been summarized in the following tables and charts.

Tables 1 and 2 are the collection of Strawman mission requirements from the science community.

Table 3 is a summary tabulation of the communications requirements.

Figure 2 displays the range of altitude requirements by science discipline and indicates the percentage of experiments that would be satisfied by certain altitudes.

Figure 3 displays the range of science instrument weight requirements by science discipline and indicates the percentage of experiments that would be satisfied by certain weight capabilities.

Figure 4 displays the range of science instrument power requirements by science discipline and indicates the percentage of experiments that would be satisfied by a certain power in Watts.

Figure 5 displays the range of science instrument pointing accuracy requirements by science discipline and indicates the percentage of experiments that would be satisfied by certain values in degrees, arcminutes, or arcseconds.

Figure 6 displays the range of science instrument data rate requirements by science discipline and indicates the percentage of experiments that would be satisfied by a various data rates.

SCIENCE DISCIPLINE	Discipline lead/PI	PROGRAM	AFFILIATION	LOCATION	ALTITUDE	POINTING ACCURACY	POINTING KNOWLEDGE	DATA RATE	DATA COLLECTION	COMMAND FREQUENCY	POWER REQUIREMENT	SCIENCE INST WEIGHT
Gamma Ray	Jack Tueller											
Consensus of Meeting splinter				40 N to 40 S latitude	115,000 min >130,000 des	arc min	NR	<10kbps min 100-300kbps	Low rate continuous	Continuous	100 - 500W	1500-3000 lb
High Resolution Imaging	Bill Craig		Columbia	Lower Latitudes	125,000 ft	Arc min, Sidereal	10 arc sec processing	400-600 kbd (300-	Continuous	Daily	200 - 300 W	2000 lb (1700 lb)
Compton Telescope	Elena Aprile		Columbia	S hemisphere	>125,000 ft	N/A	10 arc min	400-600 kbd	Continuous	Daily	300 W to 1 kW	2000 lb
Hard X- Ray Survey	Josh Grindlay	EXIST-LITE		40N to 40S lat.	125,000ft. (120kft. min.)	N/A	5 arcmin	100kbs continuous w/o compression	continuos, burst dumped ~4X/day	2-4X/day	300W	2000lb
Hard X- Ray Survey	Mike Pelling	HEXIS	UCSD	Mid latitudes	36 km min 40 km des	20 arc min	1 arc min	10kbs R/T tlm, 100 kbps	NR	Twice per day	150W	2200 lb
spectroscopy of diffuse lines	Juan Naya		GSFC	low latitudes	>110,000 ft	none	5 deg azimuth	4 Mbits/day	Continuous	twice daily	500 - 700 W	2000 lb
X-Ray/Gamma Ray Astronomy	Michael Cherry	MARGIE	LSU/Louisiana Tech/UNH	NR	NR	NR	NR	NR	NR	NR	NR	NR
High Resolution Imaging	Jack Tueller		GSFC	low latitudes	>125,000 ft	1 arc min	0.2 arc min	1 Kbps	Continuous	twice daily	300 W	2400 lb.
GRB Polarimetry	Scott Barthelmy		GSFC	low latitudes	>115,000 ft	N/A	1 deg	5 - 10 Kbps	Continuous	few per week	100 W	250 lb
Compton Telescope	Allen Zych	TIGRE		Low latitude southern	120,000 - 130,000 ft	NR	10 arc min	Sci 100 kbps TLM 5 kbps	Continuous	25 per day	500W	440-2200 lb
SOLAR	Brian Dennis											
X-ray spectroscopy	Bob Lin	HIREGS	UCB	Open	125,000 to 130,000ft	6 arc min	<1 arc sec	2 kbps hi pri Total10kbps	Daytime	Autonomous O.K. 100B/6hrs	400W 300W stby	1100lb
Gamma-ray spectroscopy	Edward Chupp		UNH/Columbia/GSFC	Hi latitude, max daylight	>/=115,000ft	10 arc min	0.5 arc min by inst	40 kbps 4kbps comp	Daytime	300 bps, 4/day	500W	3300lb
Hard X-ray, G-ray spectroscopy	Jim Ryan		UNH	Low latitudes	<5 g cm squ	3 deg	1 deg	1 GB/day	Daytime	Once per day after C/O	<200W	<500lb
Helioseismology Magnetic energy	David Rust	Flare Genesis	APL/JHU	Max daylight	>105,000ft	20 arc sec	20 arc sec	10 GB/day	Daytime	Medium autonomy	800W	<3300lb
Asterseismology	Derek I. Buzas	BLAST	Valdosta St. U	NR	>90,000ft	5 arc sec stab	39 arc sec	<10 MB/day	Night time	Minimal, safety	300W	2000 lb
	Ed Cheng			Tailor to Location	>100,000 ft	Few arc min	1 arc min	32-100 kbps	Continuous	Load or R/T <100/min	100 - 300 W	500-1000 lb
Solar G-mode, oblateness	Larry Twigg		GSFC	Polar trajectory	>115,000ft 125,000 des	1.5 arc min 7 arc sec stab	.1 arc sec autonomous	<10 MB/day flexible	Daytime	Near launch mainly auto	300W	800 lb
Solar	Bill Heaps	Solar disc sextant	GSFC	High latitude pref	115,000ft min 125,000 pref	Self pointing	NR	0.5 Mbps compressed	Day time	Early mission occasional	100W	800 lb
Cosmic Ray	Bob Streitmatter											
	Jim Adams		NRL	Polar, low cutoff	100,000 ft to 130,000 ft	NR	None	10 bps, burst rate 2kbps	Continuous	To dump data, minimal	≤500W continuos	500 lb
		TIGER	WU/GSFC/UM	>±50 deg.	115,000 ft >120,000 des	NR	NR	14 kbps	NR	Minimal	≤200W	1500 lb
		Si-Cal		Any	115,000 ft >120,000 des	NR	NR	200 kbps	NR	NR	250W	2200 lb
		JACEE+	LSU/UW/UAH/MSFC/Japan	Mid latitudes	100,000 ft >120,000 des	NR	NR	10 kbps	NR	NR	<150W	2000 lb
		SOFCAL		NR	100,000 ft >120,000 des	NR	NR	<200 kbps	NR	NR	200W	2000 lb
		BACH		>+/-50UH	100,000 ft 120,000 des	NR	NR	0.020 kbps	NR	NR	300W 50% Hi latitudes	750 lb
Cosmic Ray	E. G. Stassinopoulos	PHA Instrument	GSFC	> ±50°	100,000 ft 120,000 des	NR	NR	512 bytes per reading	Once per day	NR	+5V and -5V <2W	1 lb
Atmospheric	Bill Heaps											
			GSFC	Southern Alice Springs	>30km	Degrees	NR	20kbps	Continuous	NR	400W	440lb
Infrared	Ed Cheng											
Far IR		HFLOS		NR	98,5000 - 131,300ft	NR	NR	32kbps	NR	Daily	150W	330lb
	Gregory Tucker		SAO	High latitudes >70 degrees	>100,000 ft	20 arc sec	NR	1- 20 kbps	Continuous (dark)	Hourly	NR	<2000 lb
Cosmic anisotropy			Brown U	NR	NR	Spin scan	NR	200Bps	Night time	Daily	NR	1500 lb
Anisotropy package			GSFC	NR	NR	Spin scan	3', 1', 10" order of pref	200Bps	NR	NR	750W/600W	440-2200lb
CMB		HEMT		NR	NR	NR	NR	50kps, 5k compressed	NR	NR	150W operating	800lb
GEM/ICONS	M. Mahoney		JPL	NR	NR	NR	NR	10- 20 kbps (& raw video)	NR	1-100 min	200 W	440-660 lb
MISC												
Extra-Solar Planets	C. Ftaclas	Balloon Borne Detection of Extra-Solar Planets	MTU/JPL	High latitude, need 2 93+ day flts., one at each pole, night.	>30 km	<1 arcmin by balloon craft. <1 arcsec by instrument	NR	35 kbps	Need a dark sky	every 16 hours	NR	1000-3000 lb

NR = No Requirement
GB = Giga Byte
MB = Mega Byte
kbps = kilobits per second
R/T = Real-time

Table 1 Strawman Mission Requirements Summary

SCIENCE DISCIPLINE	Discipline lead/PI	PROGRAM	THERMAL REQUIREMENT	TIME PER OBSERVATION	RESPONSE TIME	SCIENCE DATA DELAY	DATA DURING COMMAND	EXPENDABLE REQUIREMENTS	PI OPERATION OR SUPPORT GRP	Recovery	Focal Length
Gamma Ray	Jack Tueller										
Consensus of Meeting splinter			Instrument cooling	Duty cycle min 50%, 100% des	R/T	Intermittent acceptable	Continuous	Cryogens	NR	NR	
High Resolution Imaging	Bill Craig		Normal Balloon	Hours	Some R/T	Daily	Desirable	None	PI	NR	
Compton Telescope	Elena Aprile		Normal Balloon	Hours	NR	Daily	Not required	Possibly Cryogens	PI	NR	
Hard X- Ray Survey	Josh Grindlay	EXIST-LITE	normal balloon; 0-20 deg C	continuous survey	R/T desired	real-time desired, 1 day minimum	not req.	None	PI	desired	
Hard X- Ray Survey	Mike Pelling	HEXIS	Inst 0-20 deg C elec 0-40 deg C	NR	NR	R/T to hours	Yes	NR	NR	NR	
spectroscopy of diffuse lines	Juan Naya		cryogenic	100 days	NR	weekly	not required	maybe cryogen	PI	NR	
X-Ray/Gamma Ray Astronomy	Michael Cherry	MARGIE	NR	NR	NR	NR	NR	NR	NR	NR	
High Resolution Imaging	Jack Tueller		normal	10 mins - 10 hours	NR	weekly some R/T	not required	none	PI	NR	8 meters
GRB Polarimetry	Scott Barthelmy		inst -10 to 44 deg C	continuous	need R/T for 500 bits	weekly some R/T	not required	none	PI	NR	
Compton Telescope	Allen Zych	TIGRE	0-30 deg C	NR	NR	5 kbps R/T S EOM	Cal prior to mode change	NR	PI	Recover data min	
SOLAR	Brian Dennis										
X-ray spectroscopy	Bob Lin	HIREGS	Det 0-20deg C Elec 0-40deg C	NR	NR	Recovery of data bank	NR	NR	PI pref	Highly Desirable	
Gamma-ray spectroscopy	Edward Chupp		NR	One flare above 20 MeV, min	NR	Recovery of data bank	NR	Liquid nitrogen	PI	Highly Desirable	
Hard X-ray, G-ray spectroscopy	Jim Ryan		0 to 20 deg C	One flare min	NR	NR	NR	NR	PI	Recovery of data	
Helioseismology Magnetic energy	David Rust	Flare Genesis	Balloon qualified	NR	NR	Recovery of data	NR	NR	PI pref	Critical	
Asterseismology	Derek l. Buzasi	BLAST	Stability of optical system	NR	NR	NR	NR	NR	NR	Recovery of data pref	
	Ed Cheng		Heater Control	Hours	Some R/T	Weekly, some R/T	Most Likely No	Cryogens	PI	NR	
Solar G-mode, oblateness	Larry Twigg		Good history	NR	NR	20 days	NR	NR	Pref strong PI	NR	
Solar	Bill Heaps	Solar disc sextant	Pref continuous sun viewing	Continuous in day light	NR	EOM	Cal prior to mode change	NR	PI	Recover data min	
Cosmic Ray	Bob Streitmatter										
	Jim Adams		-30° C to + 50 ° C	NR	NR	Any delay is okay	NR	NR	PI	to save replacement cost	
		TIGER	0≤T≤30° C	NR	NR	NR	NR	NR	NR	NR	
		Si-Cal	NR	NR	NR	NR	NR	NR	NR	NR	
		JACEE+	NR	NR	NR	NR	NR	NR	NR	Waterproof	
		SOFCAL	NR	NR	NR	NR	NR	NR	NR	NR	
		BACH	NR	NR	NR	NR	NR	NR	NR	NR	
Cosmic Ray	E. G. Stassinopoulos	PHA Instrument	NR	Continuous	NR	NR	NR	NR	NR	Desired, not required	
Atmospheric	Bill Heaps										
			NR	Continuous	NR	NR	NR	NR	NR	NR	
Infrared	Ed Cheng										
Far IR		HFLOS	NR	NR	NR	Daily	NR	NR	NR	NR	
	Gregory Tucker		Instrument cooling	20 minutes	R/T	R/T to 15 min delay	Required	Liquid helium	support group	NR	
Cosmic anisotropy			4 deg K cold plate	Night time	NR	Continuous	NR	Liquid Helium	NR	NR	
Anisotropy package			NR	NR	NR	Continuous	NR	NR	NR	Highly desired	
CMB		HEMT	NR	NR	NR	Continuous	NR	Liquid Helium	NR	NR	
GEM/ICONS	M. Mahoney		Instrument cooling	NR	R/T	R/T	Required	Cryogens	Open	NR	
MISC											
Extra-Solar Planets	C. Ftaclas	Balloon Borne Detection of Extra-Solar Planets	NR	30 min	R/T every 16 hours for acquisition of target (star)	Storage okay for later transmission	Required for acquisition, could compress for cellular.	Maybe, detector needs to be cooled.	PI	Desired, telescope expensive	6 m long telescope, off axis design. 1.5 m aperture.

Table 2 Strawman Mission Requirements Summary (continued)

100 Day Balloon Workshop - Envisioned Communication Requirements

Discipline	Proposal	PI	Program Acronym	Data Rate (kbits/sec)	Daily Data Volume (Mbits)	Mission Data Volume (Gbits)	Command Contacts per day
Gamma Ray	High Resolution Imaging	Bill Craig			0.60	0.06	1
Gamma Ray	Compton Telescope	Elena Aprile			0.60	0.06	1
Gamma Ray	Hard X-Ray Survey	Josh Grindlay	EXIST-LITE	100	8640.00	864.00	4
Gamma Ray	Hard X-Ray Survey	Mike Pelling	HEXIS	100	8640.00	864.00	1
Gamma Ray	Spectroscopy of Diffuse Lines	Juan Naya			4.00	0.40	2
Gamma Ray	High Resolution Imaging	Jack Tueller		1	86.40	8.64	2
Gamma Ray	GRB Polarimetry	Scott Barthelmy		10	864.00	86.40	1
Gamma Ray	Compton Telescope	Allen Zych	TIGRE	100	8640.00	864.00	25
Solar	X-Ray Spectroscopy	Bob Lin	HIREGS	10	864.00	86.40	0.1
Solar	Gamma-Ray Spectroscopy	Edward Chupp		40	3456.00	345.60	4
Solar	X/G-Ray Spectroscopy	Jim Ryan			8000.00	800.00	1
Solar	"Helioseismology, Mag. Energy"	David Rust			80000.00	8000.00	0.1
Solar	Asterseismology	Derek 1. Buzasi			80.00	8.00	0.1
Solar		Ed Cheng		100	8640.00	864.00	?
Solar	"Solar G-Mode, Oblateness"	Larry Twigg			80.00	8.00	0.1
Solar	Solar	Bill Heaps		500	43200.00	4320.00	0.1
Cosmic Ray		Jim Adams		2	172.80	17.28	0.1
Cosmic Ray			TIGER	14	1209.60	120.96	0.1
Cosmic Ray			Si-Cal	200	17280.00	1728.00	
Cosmic Ray			JACEE+	10	864.00	86.40	
Cosmic Ray			SOFCAL	200	17280.00	1728.00	
Cosmic Ray			BACH	0.02	1.73	0.17	
Atmospheric		Bill Heaps (?)		20	1728.00	172.80	
Infrared	Far IR		HFLOS	32	2764.80	276.48	1
Infrared		Gregory Tucker		20	1728.00	172.80	24
Infrared	Cosmic Anisotropy			0.2	17.28	1.73	1
Infrared	Anisotropy package			0.2	17.28	1.73	
Infrared	CMB		HEMT	50	4320.00	432.00	
Infrared	GEM/ICONS (raw video!)	M. Mahoney		20	1728.00	172.80	100
Extra-Solar Planets	Balloon Borne Detection of Extra-Solar Planets	C. Ftaclas		35	3024.00	302.40	1.5

Table 3 Communications Requirements Summary

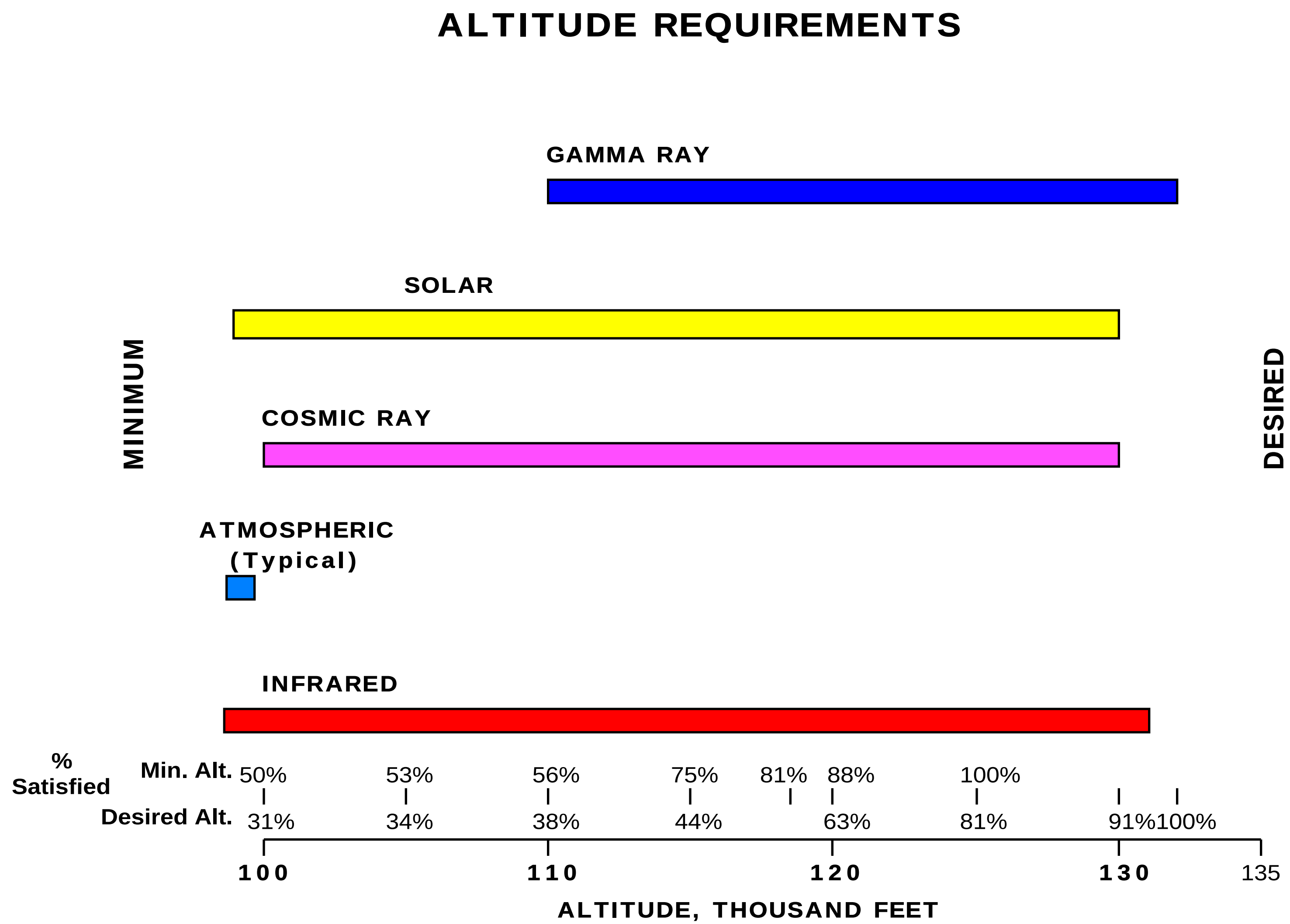

Figure 2 Altitude Requirements Summary

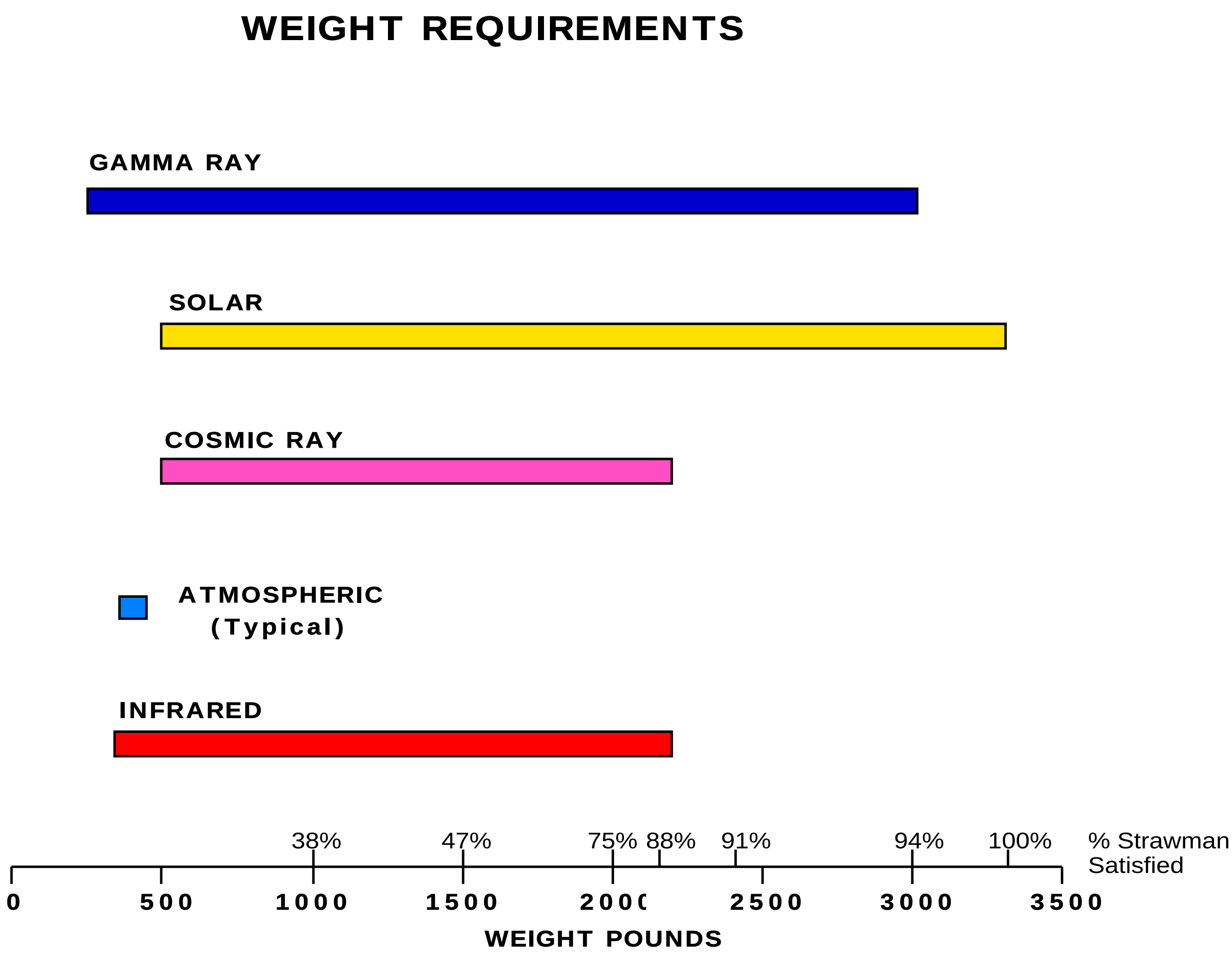

Figure 3 Weight Requirements Summary

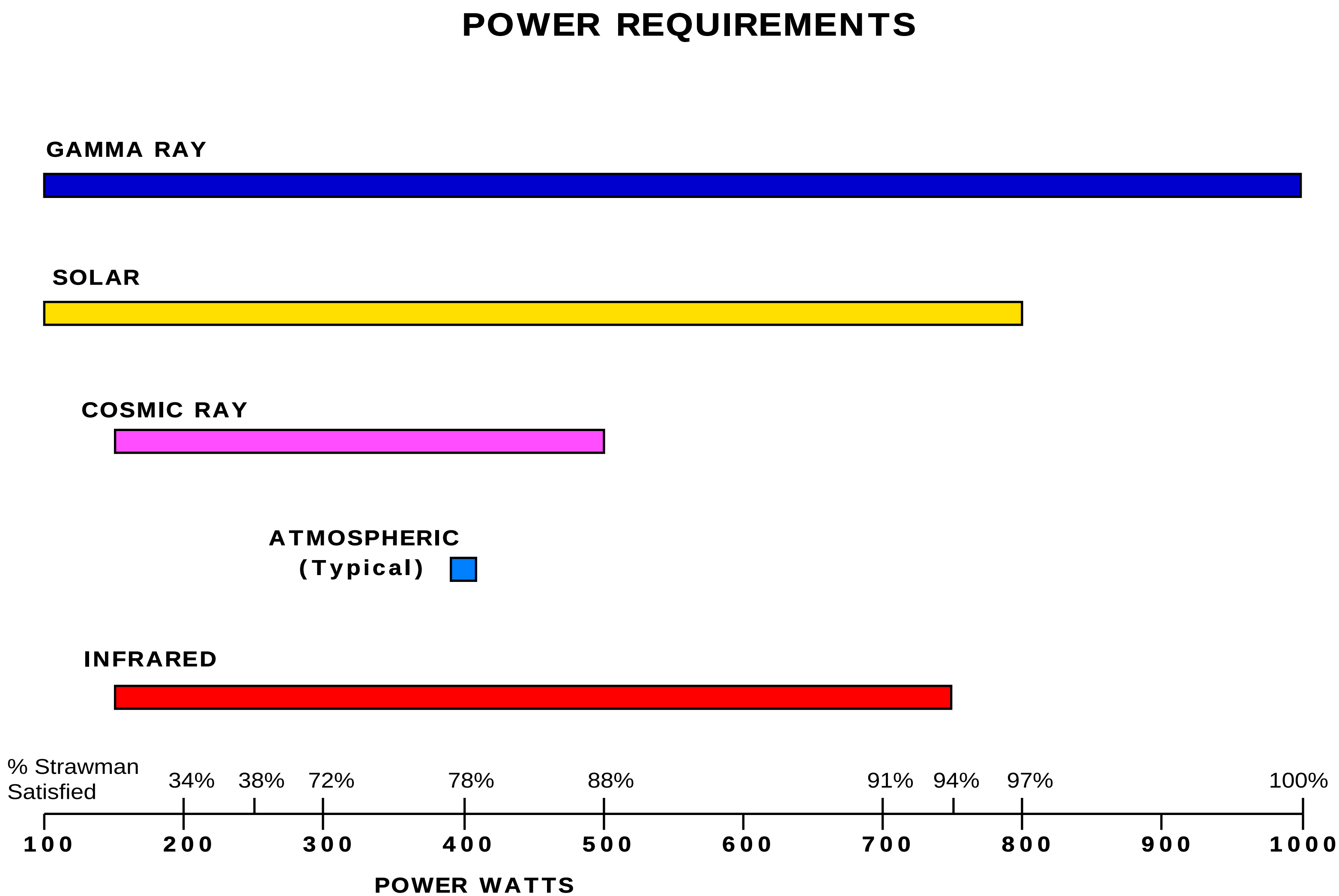

Figure 4 Power Requirements Summary

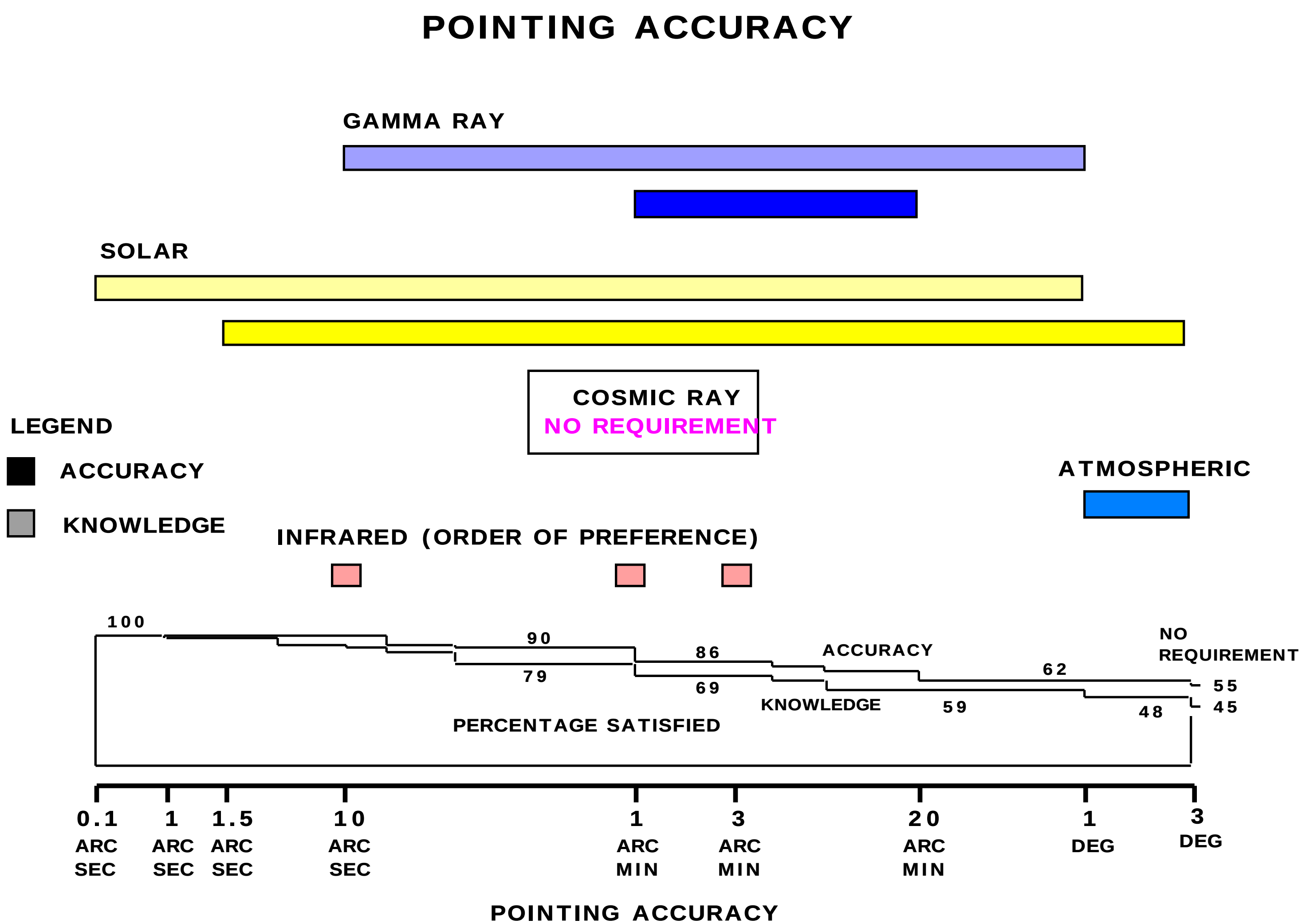

Figure 5 Pointing Requirements Summary

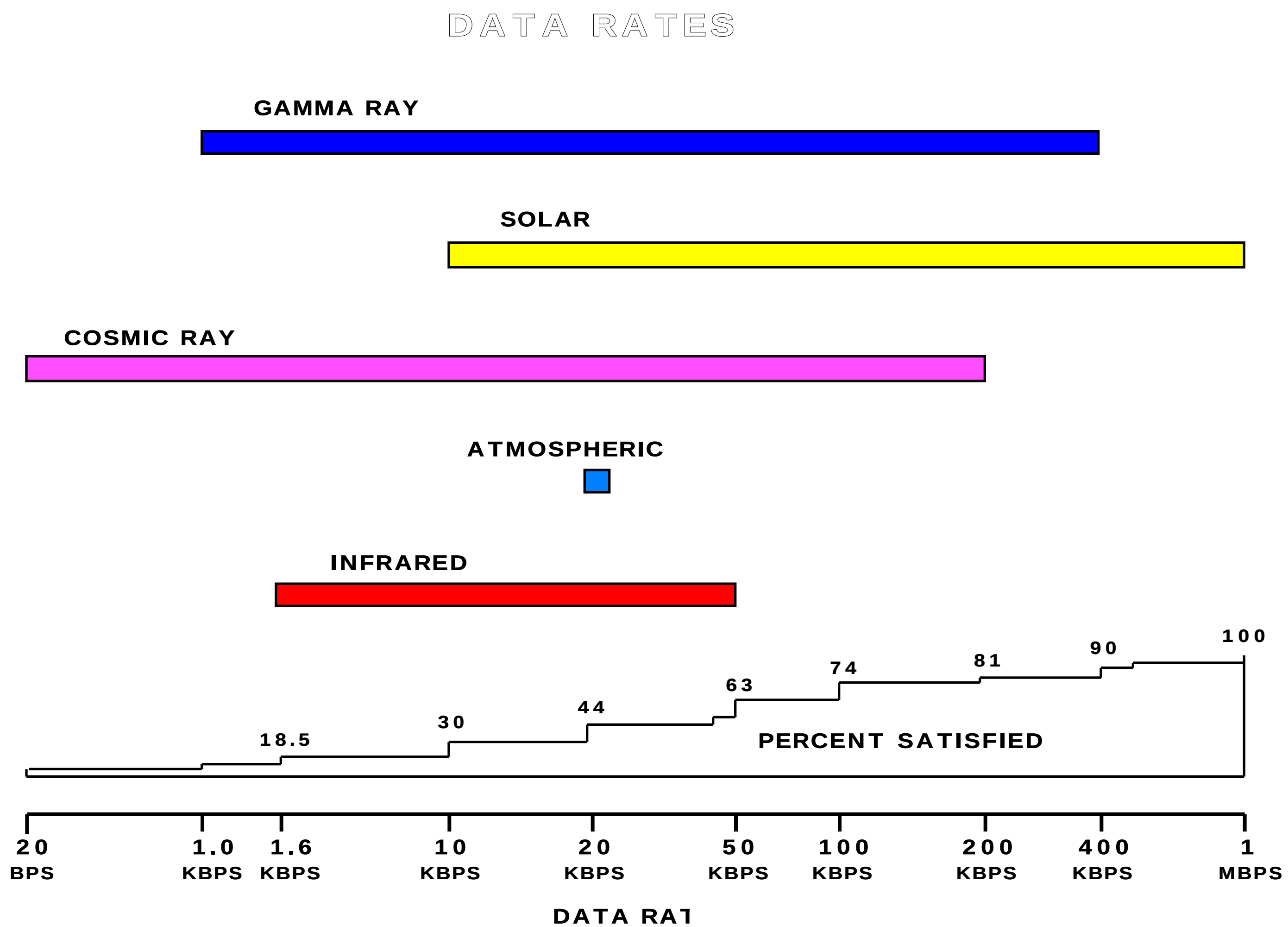

Figure 6 Data Rates Requirements Summary

Technical Challenges

Preliminary requirements based on 32 strawman experiments in the spreadsheet (the gamma-ray group consensus was not included in the statistics).

Minimum Science Requirements:

1. Need to achieve an altitude of >115 kft to satisfy 75 % of the strawman experiments.
2. Need to achieve an altitude of >125 kft to satisfy 100 % of the strawman experiments.
3. Need to achieve >400 Watts power to satisfy 78 % of the strawman experiments.
4. Need to float >2000 pounds science weight to satisfy 75 % of the strawman experiments.
5. Recovery is desired by most missions, but not required.
6. Latitudes higher than 70° are required by 7 experiments.
7. A thermal control system maintaining a temperature in the range from 0°C to 20°C appears to satisfy all the experiments.
8. Pointing accuracy/knowledge requirements range from none to spin scan, to a few degrees, down to sub-arcseconds. There are 3 to 4 distinct clusters to satisfy. Pointing under 1 arcminute will be a challenge.
9. Data collection occurs continuously for 11 experiments, daytime only for 6 experiments, night only for 4 experiments and 11 experiments provided no requirement.
10. 50 % of the experiment Principal Investigators wished to operate as a PI mission.
11. Per day data volumes up to 80 Gigabits.

Design Options Needed Based On Science Requirements

(Mission operations profiles or concepts based on the strawman science payload requirements from the October 96 workshop)

There are two concepts with different requirements based on latitude.

1. Inside The Arctic Or Antarctic Circles

- Night time operations require nonsolar power source
- Reliable communications for polar zones of exclusion
  - ♦ Geostationary communications satellites can not see poles
  - ♦ Many of the LEO, Little LEO & MEO communications ventures tend to have 60° inclined orbits, again excluding the poles
  - ♦ 🕮 Need to find those with coverage at the poles. There are at least 3 known candidates --
    IRIDIUM, low data rate
    GLOBALSTAR, 19 kbps
    ICONET, rates unknown
  - ♦ 🕮 Need to investigate Military Communication Satellites (U.S., Russian, etc.)
  - ♦ 🕮 Need to investigate amateur radio operators communication satellites.

🕮 Areas requiring further study. For details see section on list of identified technologies for further evaluation.

100 day missions will experience extreme day/night cycles

- ♦ need to design for 60 day long days and nights
  - 4 experiments want day time observations
    - this limits mission to ≤ 60 days
  - 2 experiments want continuous dark
    - this allows 100 day mission with substantial power needs
  - 1 experiment wants continuous observations
    - this allows 100 day mission (30 to 60 days sun then 40 to 70 days dark)
- ♦ this impacts the power design and
- ♦ the thermal design

- equipment needs to survive radiation at magnetic poles
- risk of cutbacks in NSF program (cost would become great)

2. **Low Latitude**

- 🕮 Need to investigate power systems sufficient for the science instrument and the support system
  - ♦ a sun tracking solar array or an omni directional array
  - ♦ battery or other storage for 12 hours
  - ♦ non-traditional power source, e.g., wind/electrical generator a few 1000 feet below balloon
- requires thermal control for 12 hour day/night cycle
- may require pointing control for communications antenna
- may require new international agreements
- inadvertent technology transfer considerations

🕮 Areas requiring further study. For details see section on list of identified technologies for further evaluation.

Design concepts common to both latitude options described above are as follows.

1. The payload will be "tracked" continuously from a central ground station.

2. Trajectory forecasts will be maintained and continuously updated.
   - forecasts will include wind predictions.

3. Real-time data and commanding will be available at the launch site, central ground station, and PI institution.
   - Need to design for a line of sight in flight checkout period after launch (~ 5-6 hours duration)
   - 50% of PIs want PI mode of operation.

4. Science data will be recovered at a frequency that insures mission success and no more than 25% of accumulated data is lost.

5. Science instrument pointing requirements show need for four different systems. Appropriate modular design and interface needed.
   - No pointing required
   - Spin scan system required
   - Pointing to one arcmin required
   - Pointing to arcsec and sub-arcsec required

Current Balloon Program Capabilities

- Power - The SIP provides 300 Watts, as an upper limit 600 Watts has been supported.

- Commanding & Data Return - Omni/TDRS supports 2 kbps, up to 6 kbps maximum supported.

- Thermal design - The thermal environment is much more severe than the typical spacecraft environment when looking at the cyclic thermal loads. The thermal analysis techniques and control methods employed for ballooning are fairly well established and have been proven on many flights. Most of the control methods are passive and do not require thermal blankets or complicated active systems. The tools currently used are TRASYS, SINDA, and TSS. Due to the long days and nights a totally passive system may not be possible. The required power allocation for thermal control may be higher than for a typical spacecraft which is around 5%.

- Automated operations - These include 1) an aneroid flight termination switch in the event a balloon descends below a minimum acceptable altitude for flight safety; 2) a burst detector which will terminate the flight in the event of a balloon structural failure; 3) an automated balloon differential pressure control/valve system for pressurized balloon systems; and 4) an automated ballast control system for the dropping of ballast for maintenance of altitude.

- Location of Balloon Craft - Balloon/ballooncraft position is determined on-board by redundant GPS receivers with the information transmitted to the ground station through the FM/PCM line of sight link, the INMARSAT Standard C over-the-horizon (OTH) link, the HF/ARGOS OTH link, or the TDRSS MA or SA link. In addition, position is also obtained vis ARGOS PTT's (Platform Transmitter Terminal) received at the Wallops Remote Operations Control Center or the Palestine Operations Control Center.

Areas Requiring Further Technical Definition

The information received from the science community has some requirements that appear technically challenging. This section attempts to describe some of the areas that require more technical definition.

Weight: Some of the strawman missions have requirements of up to 3300 lbs., many require 2000 lbs. For the demonstration mission only a 2000 lbs hang weight is advertised. This is a challenge for the ULDB program.

The system weight must be viewed from a system standpoint. There are many areas where the structural system can be "designed" instead of "built" for significant weight savings. This requires a weight analysis for each mission.

Power: Some of the strawman missions require over 800 Watts of power. The challenge is to meet higher power needs with manageable impact to weight and stability. An engineering trade study is needed to identify which power source might best meet the needs of the ULDB program. Some potential candidates for power sources are provided in the Summary List Of Technologies Under Consideration section beginning on page 40.

A combination of the different types of power systems may be the solution.

Location: Redundant GPS will provide location information. ARGOS is currently used as a backup position source.

Pointing Control: Several of the strawman missions require pointing control and knowledge. The challenge will be to achieve the desired accuracy in a craft acting like a pendulum with some elasticity in the load train. Also, for those missions requiring a lot of power the size of the solar arrays could introduce jitter into the system.

Candidate pointing systems for study are provided in the Summary List Of Technologies Under Consideration section beginning on page 40.

Terminate and Recovery Systems

Payload recovery is not a requirement.

- It is desired by the majority of PIs.
- High data rate line-of-sight telemetry and preemptive cut down plans for recovery and re-flight in case of payload failure may be feasible for some missions.

A study on feasibility and systems needed should be performed.

- An alternative concept could be developed for payloads that require recovery with defined tradeoffs.
- An aircraft could be made available at potential termination areas for cut down and recovery operations.
- Recovery systems (parachute) could be deployed on flights.
- Is a self-destruct system needed?
- Other terminate and recovery options for evaluation are:
  - ♦ steerable parachute systems to improve recovery operations,
  - ♦ ground transmitter to ease finding a lost payload,
    - look at animal collar systems,
    - emergency transmitter systems,
  - ♦ inflatable flotation devices,
  - ♦ "smart" auto cut down systems that use GPS + wind predictions, and
  - ♦ improved wind prediction.

Autonomous Operations: This is desired on many of the strawman missions and will likely be needed on most missions to handle functions like thermal stability, battery discharge and charge cycles, other day/night cycle activities, and to execute safety procedures under various scenarios such as failure of balloon location communications with the operations team. These systems need to be designed and tested to provide high probability of survival for 100 days at altitude.

Thermal: Thermal control needs to be maintained to within the required operations temperature range for both the science instrument and the support package. The tools currently use for thermal analysis are TRASYS, SINDA, and TSS. They are proven for the existing balloon programs; they have yet to be proven for the ULDB Program. The following tasks need to be undertaken to provide models to help evaluate different ideas for maintaining thermal control of the balloon craft packages.

1) Characterize the range of wind speeds likely to be encountered by a balloon payload at float. An initial estimate can be obtained from existing measurements of wind speed vs. altitude which NSBF takes with their routine soundings, by taking the derivative of this curve and multiplying by the length of the flight train.

2) Develop a model for wind cooling at float conditions. There is likely already such a model at least for pressure ~1 atm; if not it is fairly clear how to develop the framework, since the airflow is likely to be nearly laminar. If necessary, develop a plan to validate this model for float conditions.

3) Develop a model for convective cooling, or establish design rules under which convection can be safely ignored. These are only models to help determine thermal design. Since a consistent, half degree increase or decrease in the temperature could put the balloon craft into a non-operating state, a challenge will be to devise a test strategy that can ensure high probability of thermal survival of the balloon craft for ≥100 days. Additional systems for cooling or heating will be needed for some of the experiments. An area of concern is that these additional systems will impact power requirements for the balloon.

Communications: There appear to be low rate options that can accomodate both commanding and return of the balloon craft and science instrument engineering and housekeeping telemetry. Costs of various options needs to be studied. Options for the return of high rate science data are limited and need further study. Some of the strawman missions require real time response. Some of the experiments call for daily data return, daily commanding or even hourly commanding. This raises the question of what is an acceptable level of cost. TDRSS and Military satellites cannot be relied on to give balloons top priority, other options should be explored. Table 4 outlines initial information on some of the communications options that need further study. Figure 7 provides a high level concept for communications requirements and packaging schemes.

SATELLITE COMMUNICATIONS SERVICES

ROUGH COMPARISON TO PROVIDE PERSPECTIVE

Communications System	Voice BW Systems	Globalstar	TDRSS MA	TDRSS SSA and KSA	Commercial High Rate Systems
Data Rate	2.4 kbps Typical	19kbps	100kbps	1Mbps	1Mbps
Users Supported	20%	40%	75% All continuous users	100%	100%
Cost per Minute*	$1 to	$1	$9	$50	-
Cost per 100 Days, Continuous	$144k to $432k	$144k	$1.29M	Depends on DL data rate and contac	-
Data Volume per Day	26MB	205MB	1.08GB	10.8GB	10.8GI
Coverage	Depends on System	Global	ZOE at poles	ZOE at poles	-
New Balloon Technology	Commercial application	Commercial application	TDRSS antenna, Data storage for ZOE, 1GB	TDRSS antenna, Data storage for ZOE, 10GB	Need survey of systems and availability
Balloon Impact	Similar to existing system	Similar to existing system	Antenna and FOV	Antenna and FOV	-

* There may be additional costs to connect to satellite service

Table 4 Rough Comparison of Possible Satellite Communications Service Options

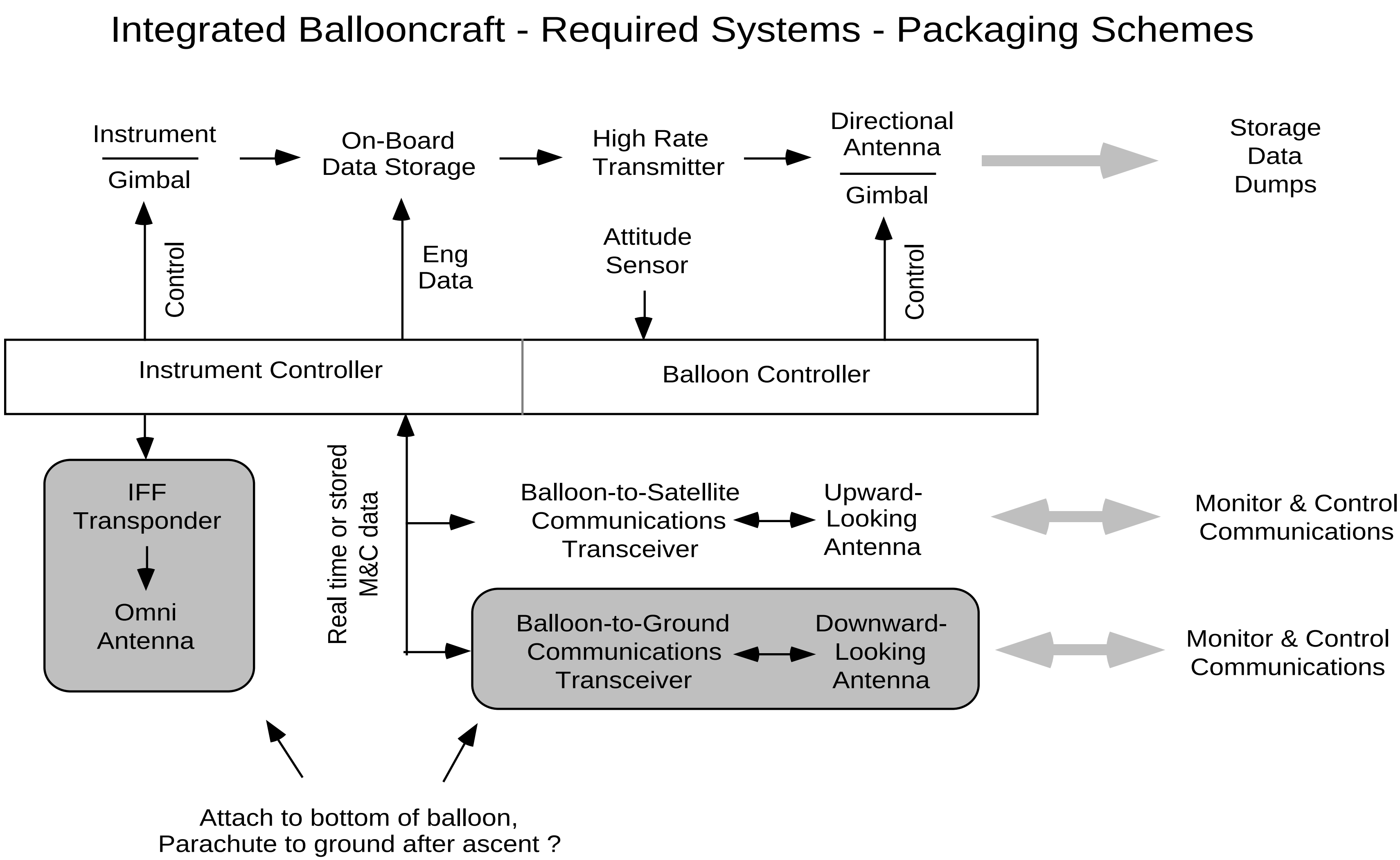

Figure 7 High Level Communications Concept

Continuous Coverage

Continuous coverage may not be possible, practically or due to cost. There are two ways to go: non-continuous communications, or meeting the PI's requirements. It is not clear if much thought has been given to continuous coverage issues such as personnel to monitor communications around the clock for 100 days or the cost to support such operations.

Zones of Exclusion

An initial calculation of the zones of exclusion is presented in Figure 8.   The ZOE is described for a 3 TDRSS system, expected in the future, not currently (2 TDRSS system). If the balloon drifts into these zones there needs to be an alternate way to contact the balloon for safety reasons. These issues are under study.

A hybrid solution of a 2 kbps communications connection for command and housekeeping and a higher rate line for data return may be appropriate and will be studied.

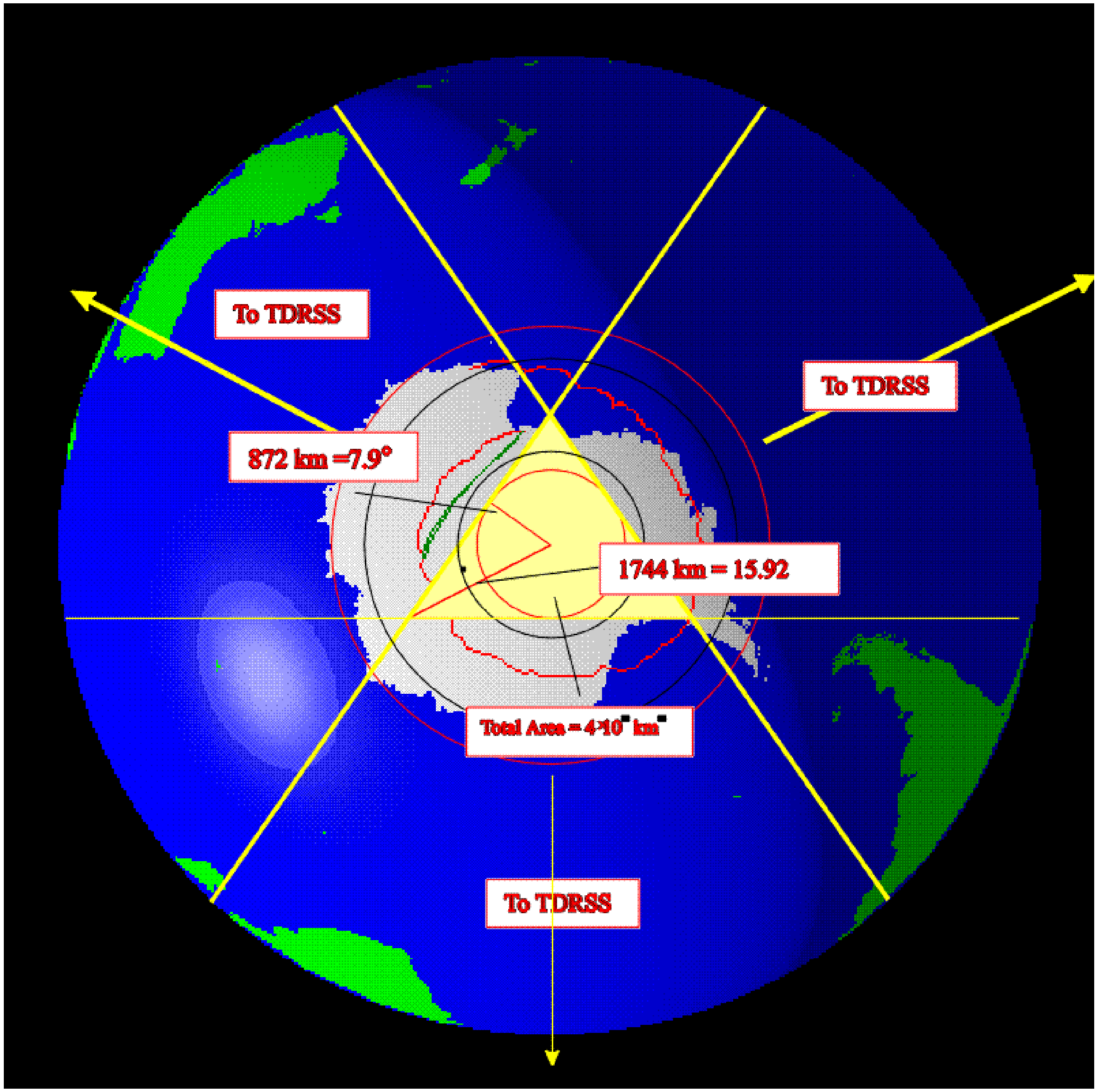

Figure 8 Plot of a Balloon Ground Trace and the ZOE at the Poles

System Engineering Information and Concerns

How might the physical environment affect the balloon craft? This relates to passage to altitude and in retrieval as well as operation at the limits of the atmosphere in the range of 100,000 ft to 130,000 ft. The balloons may fly mainly around the poles or in equatorial areas. Conditions that may affect the balloons performance and integrity are of concern. A summary of the known balloon environment follows.

Balloon Environment Summary

Balloon Behavior:

Balloon Ascent Rate : typical 800-1000 fpm. It takes around three hours to attain altitude.
Balloon Rotation Rates : typical < 60 deg/min at float
have seen during ascent/descent ~ 180 deg/min
Balloon Dynamics : (Vertical Oscillations & Frequency Forthcoming)

Loads:

Launch : typical < 1.5 g's
Ascent : typical < 1.1 g's due to wind shears, ballast drops, etc.
Terminate : typical < 10 g's
Impact Velocity : typical < 20 fps
Wind or wind shear effects TBD. This is particularly important for those experiments that require pointing accuracy and have large power demands.

Release acceleration - 10 g pulse when parasail opens.
The termination loading can be around 10 g's. We have typical curves for the acceleration and velocity at termination for balloon payloads. The implementation of a flight termination load reduction technique is now being explored using a rip stitch attenuator. This promises to reduce the 10 g loading by half or more. The technique used could also be tailored to the specific payload to reduce the shock loading even more. The method and procedure to do this has been determined and it is a matter of implementation and testing.

Landing acceleration (use airbags like the Mars lander)?
This is a known quantity, and much less severe than the release accelerations. Crush pads are not as elegant as an airbag system, but can be easily designed to do the job for minimal weight, minimal complexity and minimal cost.

A related issue to all of the accelerations that a payload may see concerns what constitutes a fully recovered payload. It is obviously not acceptable to have pieces fall off the payload at termination and then fall to the ground. Depending on the parts, it may be acceptable for them to become non-functional at termination or upon ground impact. This is an area for a trade study or cost benefit analysis. The core of the instrument which accounts for most of the cost of the payload may be able to handle the imposed acceleration loads. The associated costs and increased weight to ensure survivability of the other parts may not be worth it. Some items could be considered as "throw away" if the effort to ensure survivability costs more than replacement/refurbishment.

This should all be put in the context that the main acceleration event is after the operating portion of its life. This is exactly opposite of a launched spacecraft which sees its worst accelerations at launch before being put into operation. One could envision, for example, a detector system that is built to handle the launch acceleration, but not the termination event. To build the same detector that can survive the termination would be a significantly heavier and more expensive.

Atmospheric :

Tropics : -90C @ ~ 50-60 k-ft altitude
Polar : -45C @ ~ 30-35 k-ft altitude
mid-latitude : -55C @ ~45-60 k-ft --> -80C in summer
(seasonal & latitudinal fluctuations)
Temperature profile - Troposphere can reach -90°C and balloon can take 20 to 30 minutes to travel through the troposphere during launch. Launch temperature range can be from -10˚C to +40˚C

Chemical components and vapor levels TBD.

Radiation:

Solar Constant (seasonal) : 1358 W/m2 (nominal)
1312 W/m2 (minimum)
1404 W/m2 (maximum)

Albedo : 0.1 (minimum)
0.9 (maximum) polar

Earth Flux: 90.7 W/m2 (minimum, Tropospheric cloud top temperatures of -90°C)
594. W/m2 (maximum, Desert @ 320K planet temperature)

Electro-static gradients, Electro-magnetic fields TBD.

Lightning Strike:

A concern at high altitudes is lightning strikes at float altitude coming up from clouds below (which has happened catastrophically on one mission) when flying across severe storm boundaries and the type of payload. Special hardening of instrumentation or procedures may need to be developed.

Programmatic System Engineering Concerns

In studying the Balloon craft subsystems the Balloon Program needs to be tied into NASA objectives. We need to identify NASA needs that correspond to the Balloon Program needs. Examples are given below.

Data Collection - Which methods is more useful to future NASA missions? Satellite cellular command/TDRS telemetry link hybrid would be of interest to some small missions, what are other options?

Thermal - What new thermal control systems being designed for use in space might have application on balloons?

Power - Are there new solar cells, storage batteries, or fuel cells not yet tested that could be used on a balloon craft to provide test data useful for future space missions.

Pointing Control and Autonomous Operations - Can the balloon program perform pathfinder flights that test new technology that could be used on small satellites or proposed balloon exploration of other planets?

Risk Mitigation - Can any of the new technologies identified be flown on current LDB programs to reduce to the 100 day programs?

Differences between balloon and space mission or ground experiment

- Launch
  - Large static charges can be generated during balloon inflation
  - Minimal vibration
  - Three hours needed to attain altitude
  - Restrictions based on launch vehicle
- In Flight Check of Balloon craft
- Operation
  - Long day/night cycles
  - Long periods in the ZOE
- The Environment
  - Different radiation environment
  - Residual atmosphere

Other Issues Beyond The Scope Of This Study But Impacting The Program

- State Department Concerns on Technical Transfer.
- Risk Of Cutbacks In NSF Program (Cost Would Become Great).
- Adequacy of Launch support services.
  - Does the launch site need upgrading?
- General International Agreements.
- International involvement in development.

Summary List Of Technologies Under Consideration

(This is a partial list given that all study team members are not yet onboard.)
(This will be a summary list of items identified in the report, it is not yet complete.)

<u>Communications</u>

Use of various communications satellite options.

- TDRSS
- Commercial (Little LEO, LEO, MEO, Geosync.)
- Military (USA, Russian)
- Amateur Radio Operator Satellites

Use of new Antenna Technologies.

Also various options on storage media drops over recoverable site.

- Ruggedized Mass Data Storage Device

    We are seeking a very low cost, compact, rugged mass data storage system with >1 terabit capacity. We are seeking a reusable system in the <$100K range. Several of these systems will be used for on-board recording in the Advanced Long Duration Ballooning Program. Data will be recovered by parachuting to the ground (must withstand 10 g shocks). The drop package could be the whole system or just storage components. Multiple drops are required for reliable recovery of the data. The system needs to be able to operate at altitudes between 100000 and 130000 feet (pressures between 11 and 3 millibar). It needs to operate from a 28 V unregulated battery input. The operating temperature range without thermal control may be extreme so that extended operating temperature range is desirable.

Balloon Craft Location

- GPS
- Weather Based Predictions

Power Systems

Some potential candidates for power sources are:

- Solar Arrays
  - ♦ The system must be designed, weight and size, for the worst case operating conditions for each, the polar flights and the low latitude flights. The size of the system is not as much a concern as the size of the stowed system for launch. Deployable arrays, which can be either unrolled or inflated, may be a very desirable option. A sterling engine may also be an approach for using solar energy.
- New battery technology (rechargeable Lithium batteries?)
  - ♦ we want deep discharge but only 100 cycles + some TBD margin.
  - ♦ A fuel cell system can be attractive for high power "short" flights (1 kW, 20 days) or for moderate power for longer flights (200 W, 100 days). Fuel cells also offer the advantages of "waste heat" for thermal control, water drops for ballasting, and the possibility of using the waste water for thermal storage (solar heated during the day and acting as a supplemental heat at night).
- Flywheel energy storage systems
- Wind power generators suspended a few hundred or thousand feet below the balloon craft.

Thermal Systems

- Thermal Blankets that will work at balloon flight altitudes.
- High Efficiency Heat Pump System

  We are seeking a high efficiency active thermal control system for a long duration balloon experiment. Total thermal loads will be in the 300 to 1600 W range. Altitude of operation will be 100 to 130 kft (residual pressure between 11 and 3 millibars). The output thermal load must be radiated to the Earth or to space under all possible conditions (clouds, over water, over land, etc.) We require thermal control on the input side to +/- 10 degrees C with a goal of +/- 1 degree C. Thermal control must be maintained in daytime and nighttime conditions (12 hours daylight and 12 hours darkness at low latitudes). Expected mission lifetime is ~100 days and we require a mean time to failure >200 days.

Pointing and Control Systems

Candidates for study involving the pointing system are as follows:

- Improved sensors are the primary requirement for better pointing
  - ♦ Fiber optic gyros
  - ♦ Phase comparison GPS orientation measurement
  - ♦ Daytime star cameras (special cooling and baffles required)
- Drive mechanical systems
  - ♦ Improved decoupler - three axis floating ball suspension torque sensing decoupler.
  - ♦ Load train improvements
    - Better mechanical model
    - Increase stiffness
    - Non-magnetic and lighter using composites
  - ♦ Magnetic torque's or cold gas jets
  - ♦ Active damping for pendulum motion
  - ♦ Composite structure for less multipathing error in GPS and less magnetometer error
  - ♦ Active balancing systems

Superpressure Balloon Materials and Technology

Code 741 response

This represents sub-SMEX space mission technologies that are applicable to and interested in the ULDB.

Economical Approach

- A modular payload buss based on a commercial (industrial) PCA Pentium processor with a 1553 buss and R-442 I/O (Spartan type design).
- 1553 based GPS, sensor, and motor controls are available.

Power requirements especially with respect to the flight paths reveals a wide range of power options.

- At the low end a solar array rechargeable lead gel-cell will produce the power required at the lowest cost with a weight penalty.
- A more weight efficient and costlier approach would be a lithium primary system or a solar array silver-cell secondary system with individual cell charge control.

Next Steps

- Mission Operations Concept Document
- Identify Different Design And Technology Options
    - Communications Options
    - Power And Thermal Options
- Develop Cost Estimates For These Options