"99 Luftballons"

Tim Eifler (JPL/CalTech) email: tim.eifler@jpl.nasa.gov

Discover how the universe works, explore how it began and evolved is one of NASA's major mission objectives (NASA Strategic Plan 2014). The nature of cosmic acceleration, the mass of neutrinos, testing the laws of gravity on very large scales, constraining inflationary scenarios, and understanding the formation and evolution of galaxies and cosmic structures are at the core of several NASA missions. The James Webb Space Telescope (JWST), Euclid, and the Wide-Field Infrared Survey Telescope (WFIRST), but also DOE's ground-based Large Synoptic Survey Telescope (LSST) focus on these areas of astrophysical research.

These missions are highly synergistic: LSST will cover 18,000 deg^2 in 6 optical bands to ~27th i-band magnitude depth; it's image quality however is limited by Earth's atmosphere. Euclid will cover 15,000 deg^2 with exquisite image quality but it is 2.5 magnitudes shallower, it only uses one broad optical band, and it only overlaps with LSST for ~6,000 deg^2. WFIRST will be as deep as LSST but will only cover 2,100 deg^2. When combined and carefully coordinated these missions are superior to the sum of their parts, however they fall short of the "99 Luftballon" mission concept.

This concept is based on NASA's recently developed Ultra-Long Duration Balloon (ULDB) capability, which enables a combination of diffraction limited angular resolution, extreme stability, space-like backgrounds, and long mission duration (~100 days). The combination of lightweight mirrors and advanced detector technology enables the design of large ULDB missions (2+m mirror with Gpix camera) that have significant advantages in wavelength coverage and image quality compared to the ground and significant cost advantages compared to space missions.

It is only logical to consider the science potential of multiple large ULDB missions that follow a similar design; we envision a wide-field camera similar to Euclid VIS instrument, which observes in 1 broad optical band (550-900nm) to maximize photon throughput. Table 1 shows our assumed mission parameters for a single Small (1.2m mirror diameter), Medium (1.8m), Large (2.4m) ULDB flight. We note that in addition to the mirror size (Table 1 actually specifies the mirror area), we increase the camera Field-of-View (FoV) when going from Small to Large, which implies a significant increase of number of pixels of the detector. The last row in Table 1 shows the covered area of the ULDB mission compared to the 6-year Euclid mission.

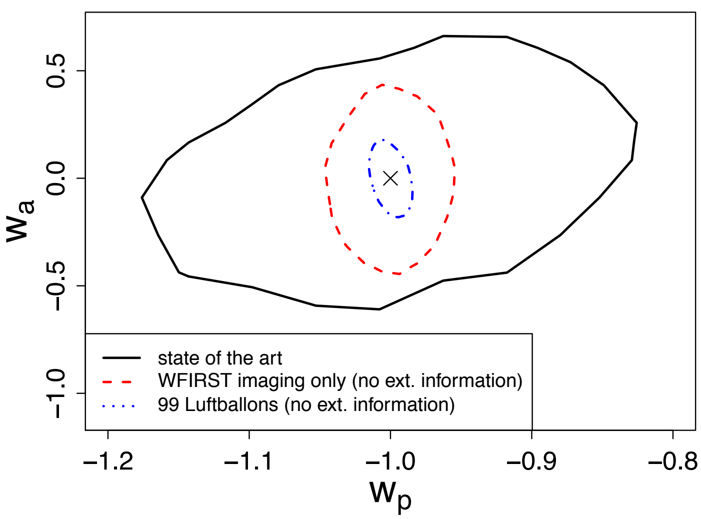
Table 1. Assumed mission parameters for a Small, Medium, Large ULDB. The last row contains the computed survey area at Euclid depth.

	Euclid	Small	Medium	Large
Dark time per day (h)	24	12	12	12
Mission duration (d)	2195	100	100	100
Camera FoV (deg^2)	0.57	1	1.5	2
Primary Mirror (m^2)	1.13	1.13	2.55	4.52
Survey Strategy	0.6	1	1	1
$A_{\rm survey}$ (deg^2, Euclid depth)	15,000	1,000	3,382	7,993

Following Table 1 we find that 2 Large ULDB missions can cover as much as 16,000 deg^2 at Euclid depth and imaging quality. An increase of the survey depth from 24.5 to 27 (aka LSST or WFIRST depth) increases the required survey time by a factor of ~10 (flux scales as $2.5^{(27-24.5)}$), which translates to approximately 20 Large ULDB missions for the 16,000 deg^2.

An improved version of this mission concept would replace the broad 550-900nm optical band with narrower multi-band photometry. This allows for obtaining redshift information of the observed galaxies and it enables more precise modeling of the (wavelength dependent) PSF. A first order calculation (assuming that signal-to-noise scales with the width of the filter) shows that 99 ULDBs can cover the 16,000 deg^2 at LSST/WFIRST depth in 4 (partly overlapping) bands, each of width ~280 nm, covering 270-1000nm wavelength. This exceeds LSST's wavelength coverage and it indicates the superior imaging speed and wavelength coverage in the Blue-UV from a sub-orbital platform compared to ground-based observations. The exact parameters of the 99 Luftballons probe mission (depth, area, number of photometric bands) should be subject to further study; minor reductions in survey depth can be used to increase the number of photometric bands. **In combination these 99 ULDB missions approach the science return of an LSST telescope in space, hence they reach a completely new level of discovery potential compared to currently planned post-2020 astrophysics missions.**

As an example, we forecast the constraining power of the 99 Luftballons mission on the cosmic acceleration parameters w_p-w_a (see Fig. 1). We emphasize however that myriad science areas beyond cosmic acceleration (galaxy formation, transients, nearby galaxies, exoplanets, Milky Way studies, etc.) will benefit from this type of imaging survey.



Cosmic Acceleration Forecasts of the WFIRST imaging survey and the 99 Luftballons mission that include several cosmological probes: Cosmic Shear, Galaxy Galaxy Lensing, and Galaxy Clustering. The state of the art constraints combine information from Planck, BOSS (Baryon Oscillation Spectroscopic Survey), and JLA (Joint Lightcurve Analysis) supernova. Forecasts are based on the CosmoLike forecasting software (Krause&Eifler 2016).

The implementation of the 99 Luftballons concept is challenging, e.g. the infrastructure to launch this many ULDBs over only a couple of years does not yet exist. In addition, we note that flying such a wide-field detector array and large telescope mirror on a balloon has not happened to date (the BLAST mission has already flown a 2m primary mirror though).

On the other hand the modularity of this concept has enormous advantages:

- Updated instrumentation is easy to implement
- Improvements to the mission strategy are easy to implement
- Risk minimization: a single mission failure is of hardly any consequence to the probe
- Cost savings through mass production of the ULDBs and instruments
- Probability to recover and reuse the instrument is larger than 0%.
- Enormous synergistic potential with space-based IR missions (JWST, WFIRST)

The idea to design a probe mission as a multitude of ULDBs (at ~10M USD per ULDB) is certainly unorthodox, however the science return on astrophysics rivals that of a 6m class telescope in space. In combination with IR information from space missions **one can think of the 99 Luftballon mission as NASA's HST COSMOS survey, but covering 16,000 deg^2 instead of 1.6 deg^2.**

References: Krause, E., Eifler,T., CosmoLike - Cosmological Likelihood Analyses for Photometric Galaxy Surveys, *eprint arXiv:1601.05779* (2016)