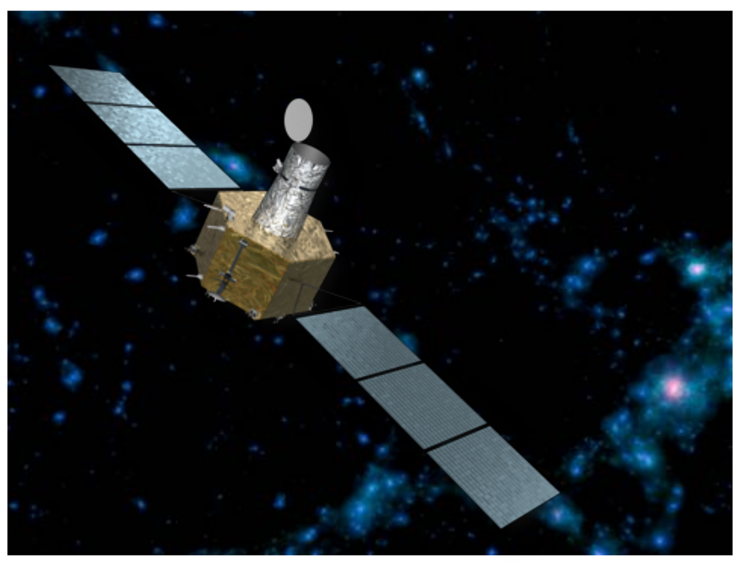

HUBS: Hot Universe Baryon Surveyor

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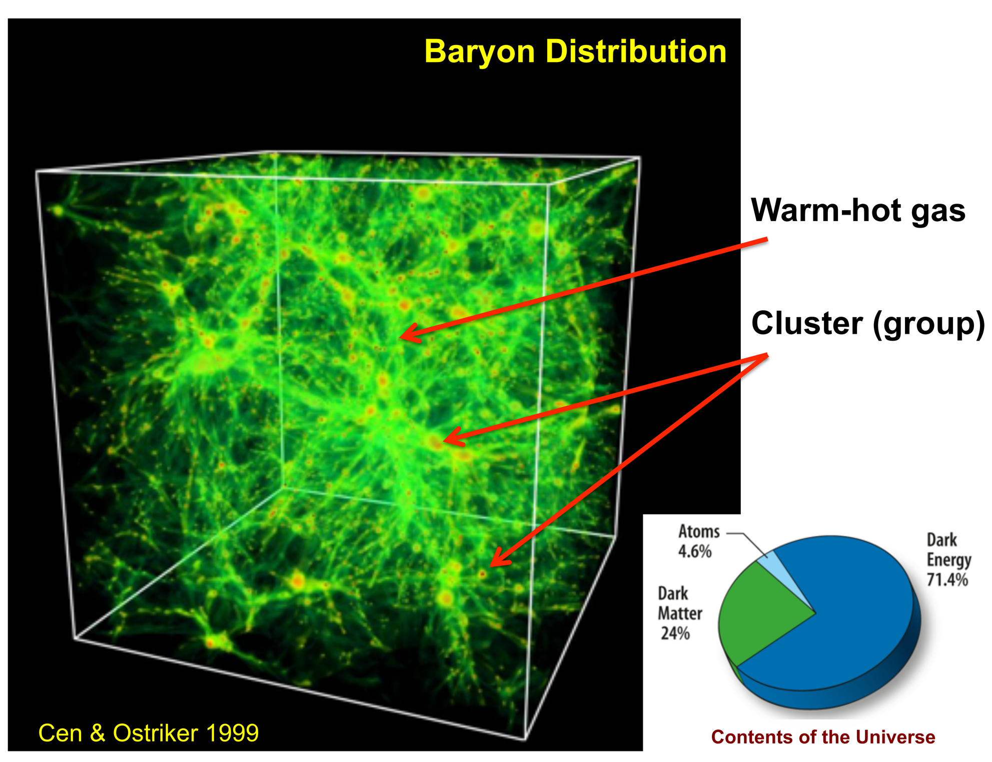
INTRODUCTION

Based on the measured abundances of primordial isotopes the theory of Big Bang Nucleosynthesis (BBN) tells us how many baryons were produced nearly at the birth of the universe. As the universe evolved, it cooled and, in a matter of minutes after the Big Bang, it could no longer sustain fusion, so the production of heavier isotopes ends. As it cooled further, neutral atoms began to form about 370,000 years after the Big Bang, locking up the electrons that had tied photons and matter together via scattering and allowing the photons to fill the entire universe, which produced what is now known as the cosmic microwave background (CMB). Precise measurements on the anisotropy of the CMB have allowed us to derive the values of key cosmological parameters, including the energy density of baryonic matter. The result implies that all of the BBN baryons were still there at the redshift of about 1100. Going down in redshifts, first stars and galaxies formed and evolved, when the baryons seem to go "missing" in optical surveys. In the present-day universe, only about half of the baryons are seen optically. This is the long-standing "missing baryon problem"



Theoretically, cosmological hydrodynamical simulations show a significant fraction of cosmic baryons were heated to temperatures of 10^{5-6} K by shocks that had been produced during the formation of large-scale structures. Radiation from such low-density, hot baryons lies mainly between far UV and soft X-ray wavelengths, making it difficult to detect observationally. Such a solution to the "missing baryon problem" has found significant support from indirect observations, through the absorption of radiation from distant quasars by the missing baryons or their distortion of the CMB spectrum.

The primary scientific objectives of HUBS include: (1) to directly detect X-ray emission from the hot baryons in the IGM or CGM, and characterize their physical and chemical properties; and (2) to study, based on the observations, the accretion and feedback processes that are thought to be highly relevant to the heating and chemical enrichment of the baryons in the CGM (and perhaps also IGM). The results are expected to help advance our understanding of galaxy formation and evolution significantly. Secondary objectives are many, including hot interstellar medium, diffuse X-ray background, supernova remnants, as well as charge exchange processes in the solar system.

PRELIMINARY DESIGN

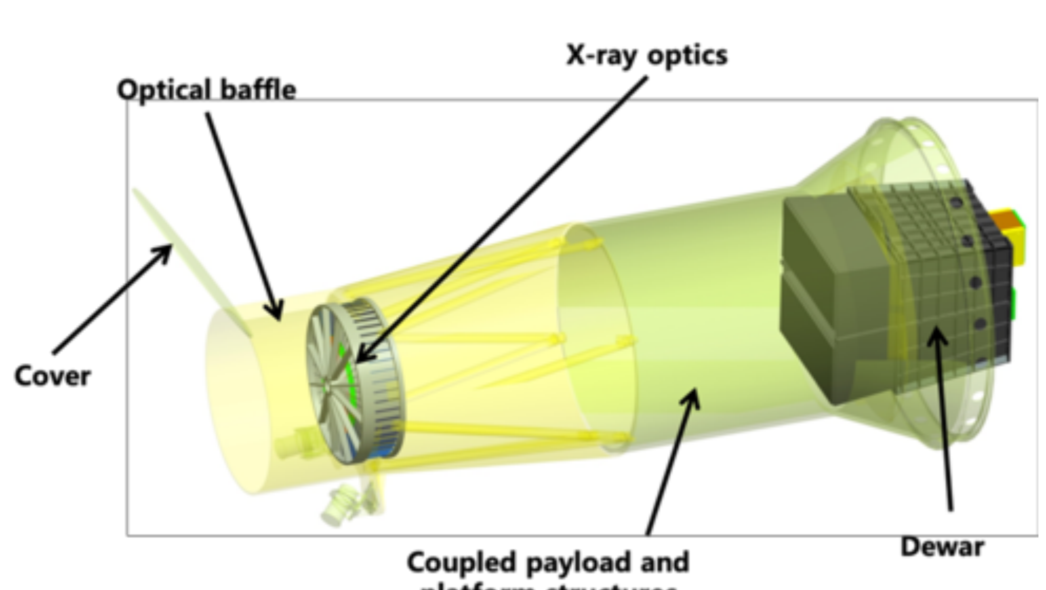
The most effective approach is to carry out high-throughput, high-resolution imaging spectroscopy in the soft X-ray band (< 2 keV), where the hot baryons are expected to manifest themselves in emission and absorption lines. The best spectral lines to focus on are associated with helium-like and hydrogen-like ions (especially oxygen lines at ~0.6 keV).

The HUBS imaging spectrometer will be based on the transition-edge sensor (TES) technology that is optimized for the softest X-ray band (0.1-2 keV) , where the oxygen lines are located. The design aims at maximizing the product of grasp ($A_{eff}\,\Omega$) and spectral resolution ($E/\Delta E$), for detecting extended X-ray emission,[2] and achieving moderate angular resolution at the same time:

- **Microcalorimeter Array**
  - **Regular array:** 60x60 TES plus large (500-1000 μm) X-ray absorbers, with 2 eV resolution
  - **Central subarray:** 3x3 regular pixels are replaced by an array of 12x12 smaller pixels, to realize sub-eV resolution, mainly for absorption line spectroscopy. The size of the subarray is chosen to adequately sample the point spread function of the telescope.
- **Cooling System**
  - **Ambient to 3 K:** 2-stage cryocoolers
  - **3 K to 50 mK:** 2-stage adiabatic demagnetization refrigerator (ADR)
- **X-ray Telescope**
  - **Field of view:** 1 deg^2
  - **Angular resolution:** 1' (HPD)
- **Bandpass and Thoughtput**
  - **Bandpass:** 0.1-2 keV
  - **Effective area:** 500 cm^2 (solid-angle-averaged), factored in filter transmission and detector efficiency
  - **Grasp:** 500 cm^2 deg^2

The grasp of HUBS is, therefore, over an order of magnitude larger than Athena X-IFU, and is, by design, complementary in primary scientific objectives.

HUBS adopts an integrated design of the scientific payload and the satellite platform.



ENABLING TECHNOLOGIES

The enabling technologies of HUBS include: TES array with large X-ray absorbers, SQUID-based multiplexing readout, cryocooler and ADR, and X–ray optics.

A 2-stage cryocooler design is baselined for providing a pre-cooled stage for the ADR. Two prototypes have been developed [3-5], with one referred to as Vuilleumier hybrid pulse tube cryocooler (VM-PTC), and the other High-frequency pulse tube cryocooler (HPTC). VM-PTC consists of a VM stage and a PT stage, and is able to reach 2.17 K, providing about 10 mW of cooling power. The HPTC consists of two PT stages, and is able to reach 3.5 K, providing about 6 mW of cooling power.

As for X-ray optics, the slumped glass technique is used to form light-weight, thin glass mirror shells, and the shells are then nested to to realize Wolter-I optics with a large effective area. A 21-shell prototype has been constructed and recently tested at the MPE PANTER facility. The measured angular resolution is 1.5' (HPD).

STATUS

HUBS has been proposed to China National Space Administration (CNSA) and is in CNSA's "Discovering the Extreme Universe" strategic plan. Approval is anticipated this year, for key technology development, which lasts for 5 years. A technical review will be conducted at the end of this period, to assess the TRLs of the key technologies. A positive outcome of the review would propel HUBS into the construction phase.

As proposed, HUBS is to be launched into a low-Earth orbit in 2030, with an expected operating lifetime > 5 years. The primary observing mode is deep pointing at selected galaxies, groups, and clusters, although the value of mini-surveys (of extended regions) or an all-sky survey is being discussed.

COLLABORATION

HUBS intends to sustain the scientific community's quest for a dedicated X-ray mission to detect the missing baryons over the past nearly two decades. At present, science definition and technology R&D are mainly being carried out by collaborating universities and research institutes in China, but international collaboration is strongly encouraged, by CNSA, at all levels, including observing strategies and target selection through the Science Working Groups, technology R&D, and auxiliary payloads (which enhance and/or broaden the scientific capabilities and objectives of HUBS).

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For more information, please visit the HUBS web site: *http://hubs.phys.tsinghua.edu.cn/en/*