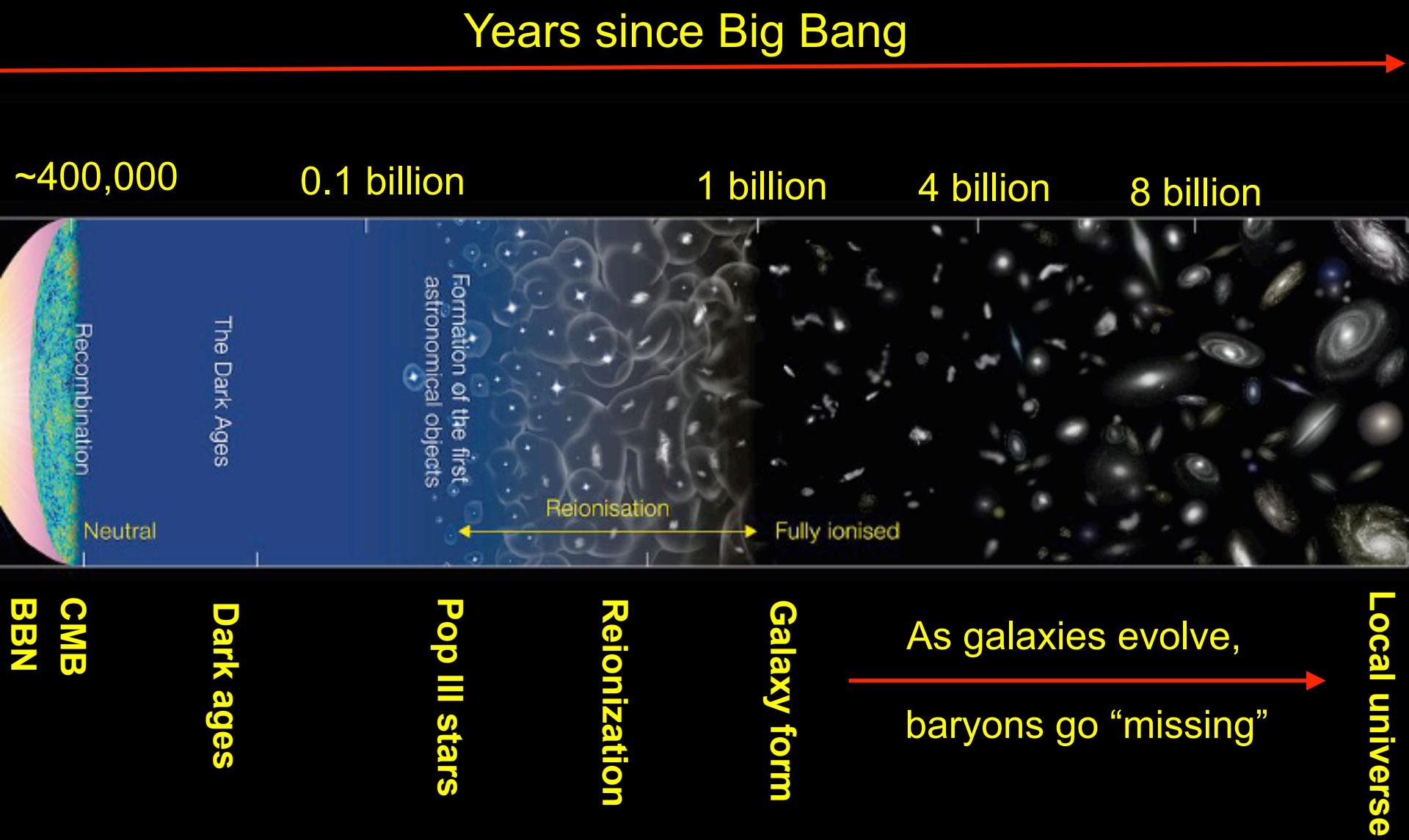


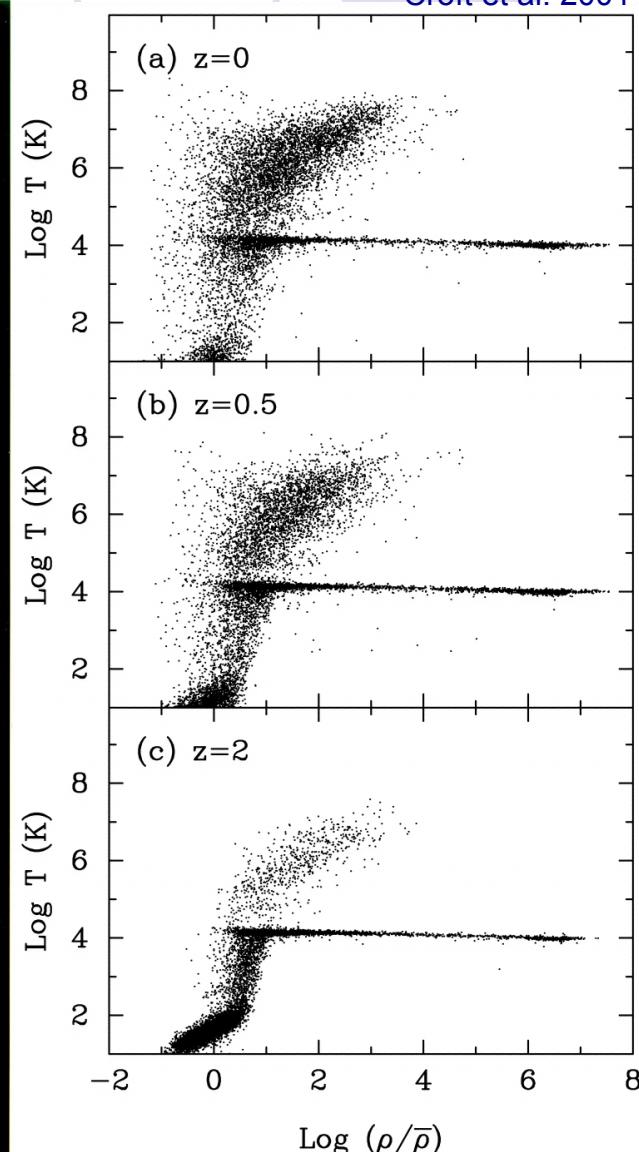
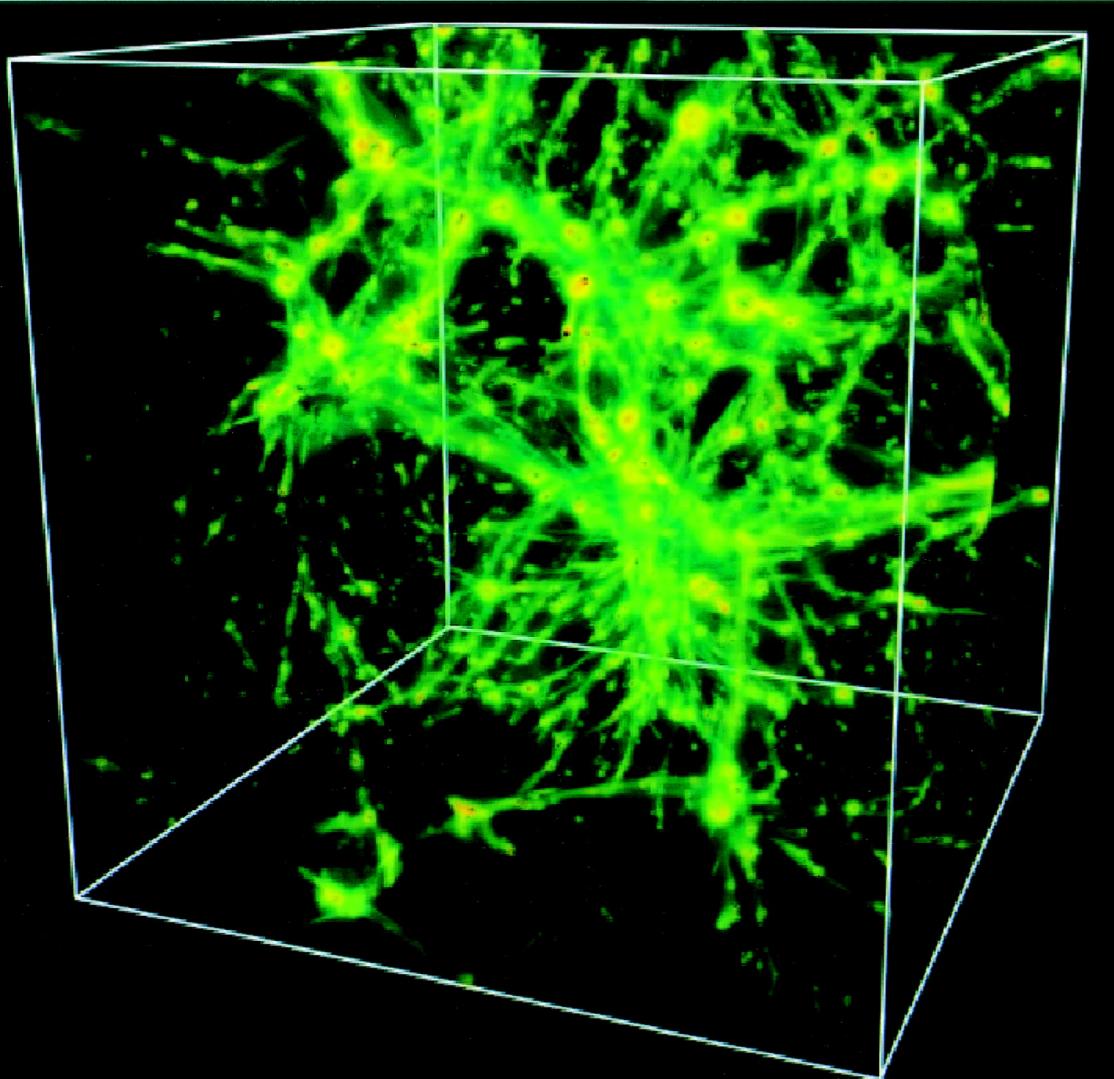
Hot Universe Baryon Surveyor

Wei Cui
Tsinghua University

Galaxy formation and “missing baryons”



Where?



Problems to address

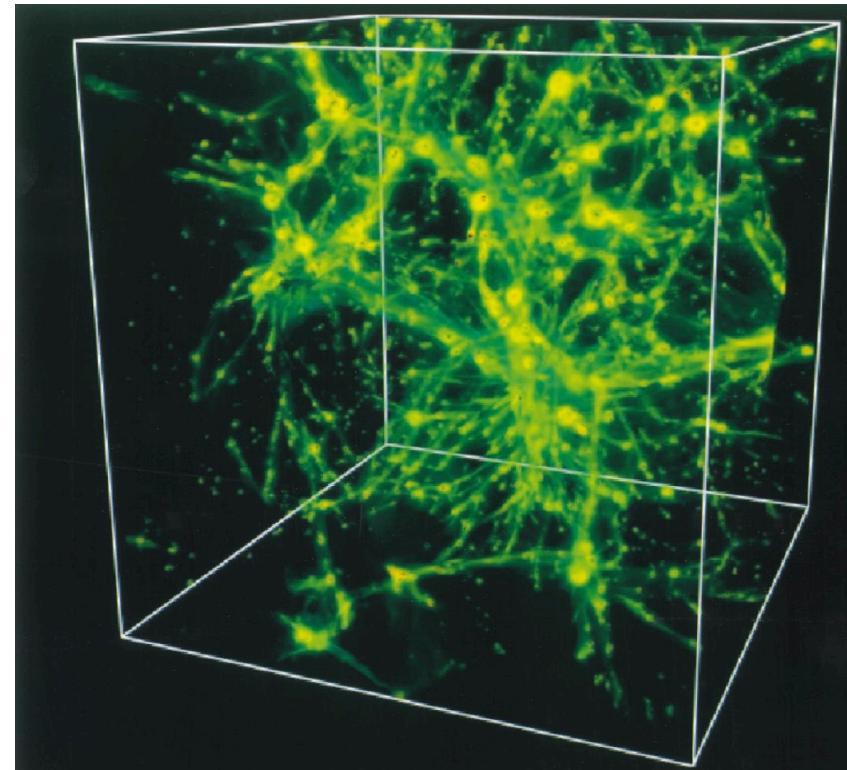
- Is significant amount of hot gas present in the cosmic filamentary structures?
 - Account for cosmic missing baryons
- Are the hot halos of galaxies more extended than previously detected?
 - Account for missing baryons in galaxies
- Is the hot gas sufficiently enriched to account for the cosmic metallicity?
 - Account for missing metals

How to detect hot baryons?

High-resolution X-ray spectroscopy!

At the virial temperature of gas in galaxies, groups, and the cosmic web ($10^{5.5}$ - $10^{6.8}$ K), nearly all dominant ion transitions occur in the X-rays.

Best tracers: O VII and O VIII lines



Hot Universe Baryon Surveyor (HUBS)

Core
science
2014

Mission
concept
2015

Science
requirements
2016

Technical
feasibility
2016

HUBS
named
2017

The First HUBS Collaboration Meeting

Tsinghua University, Beijing, China
June 28, 2017

Participating institutions:

China Academy of Space Technology

Institute of High Energy Physics

Technical Institute of Physics and Chemistry

Purple Mountain Observatory

Qian Xueshen Laboratory of Space Technology

Shanghai Astronomical Observatory

Shanghai Institute of Microsystems and IT

Shanghai Engineering Center for Microsats

SRON-Netherlands Institute for Space Research

Xian Institute of Optics and Precision Mechanics

Peking University

Shanghai Jiaotong University

Shanghai University

Tianjin Normal University

Tokyo University of Science

Tongji University

Tsinghua University

University of Sci and Tech of China

University of Wisconsin-Madison

Xiamen University



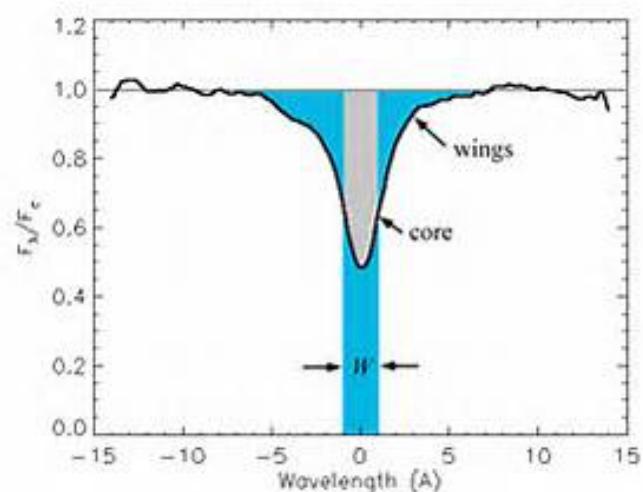
Mission concept

- A hybrid TES array optimized for soft X-rays
 - Energy range: 0.1-2 keV
 - 60×60 pixel array, with 2 eV energy resolution
 - 12×12 central sub-array with smaller pixels, optimized for absorption line spectroscopy with sub-eV resolution below 1 keV
- High throughput X-ray optics with large FoV
 - Effective area: $A_{\text{eff}} > 1000 \text{ cm}^2$
 - FoV: $\Omega_{\text{FoV}} \sim 1 \text{ deg}^2$
 - Moderate spatial resolution: $\sim 1'$
- Low-inclination near-Earth orbit
 - For low particle background
- Launch: ~ 2030
 - > 5 years life

Figure of Merit: absorption lines

In term of equivalent width,

$$EW = \int_{E-\Delta E/2}^{E+\Delta E/2} \left(\frac{I}{I_c} - 1 \right) dE$$



The detectability of weakest *absorption lines* is proportional to the square root of the product:

- Effective area
- resolving power

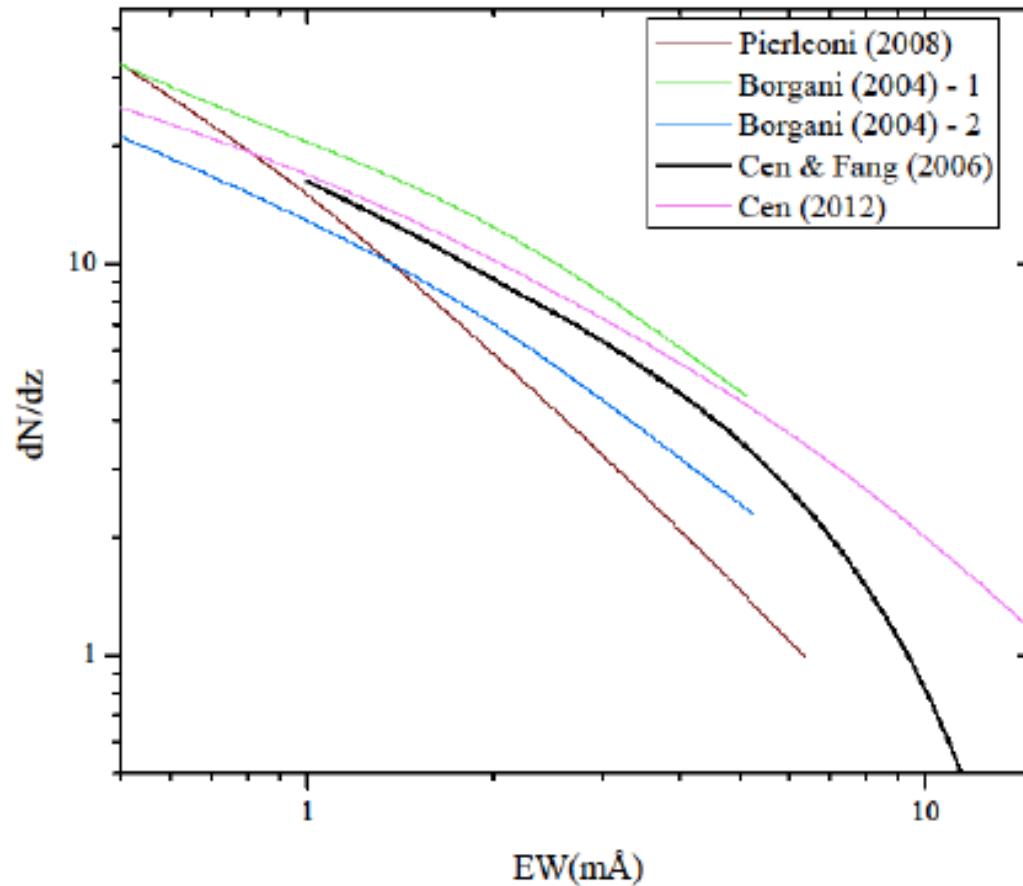
$$FoM = \sqrt{RA_{\text{eff}}}$$

Comparison: absorption lines



| Mission | Instrument | Technology | R@0.6 keV | A _{eff} @0.6 keV (cm ²) | FoM | EW limit (mA) |
|----------------|-----------------|-------------|-----------|--|-------|---------------|
| Chandra | LETG/ ACIS-S | Grating | 600 | 10 | 77 | 48 |
| XARM | XRISM | Calorimeter | 100 | 70 | 84 | 44 |
| XMM- Newton | RGS | Grating | 500 | 45 | 150 | 25 |
| HUBS | XQSC | Calorimeter | 600 | 1000 | 775 | 4.8 |
| Athena | X-IFU | Calorimeter | 240 | 5000 | 1095 | 3.4 |
| Arcus | | Grating | 2500 | 900 | 1500 | 2.5 |
| Lynx | | Grating | >5000 | >4000 | >4475 | <0.8 |

O VII absorption lines



Design requirement: $EW < 10 \text{ mA}$

Figure of Merit: emission lines

For a given confidence level, the minimum detectable EW of an emission line is

$$EW \geq \left(\frac{S}{N} \right) \left(\frac{E}{I_c TRA_{\text{eff}} \Omega_{\text{FOV}}} \right)^{1/2}$$

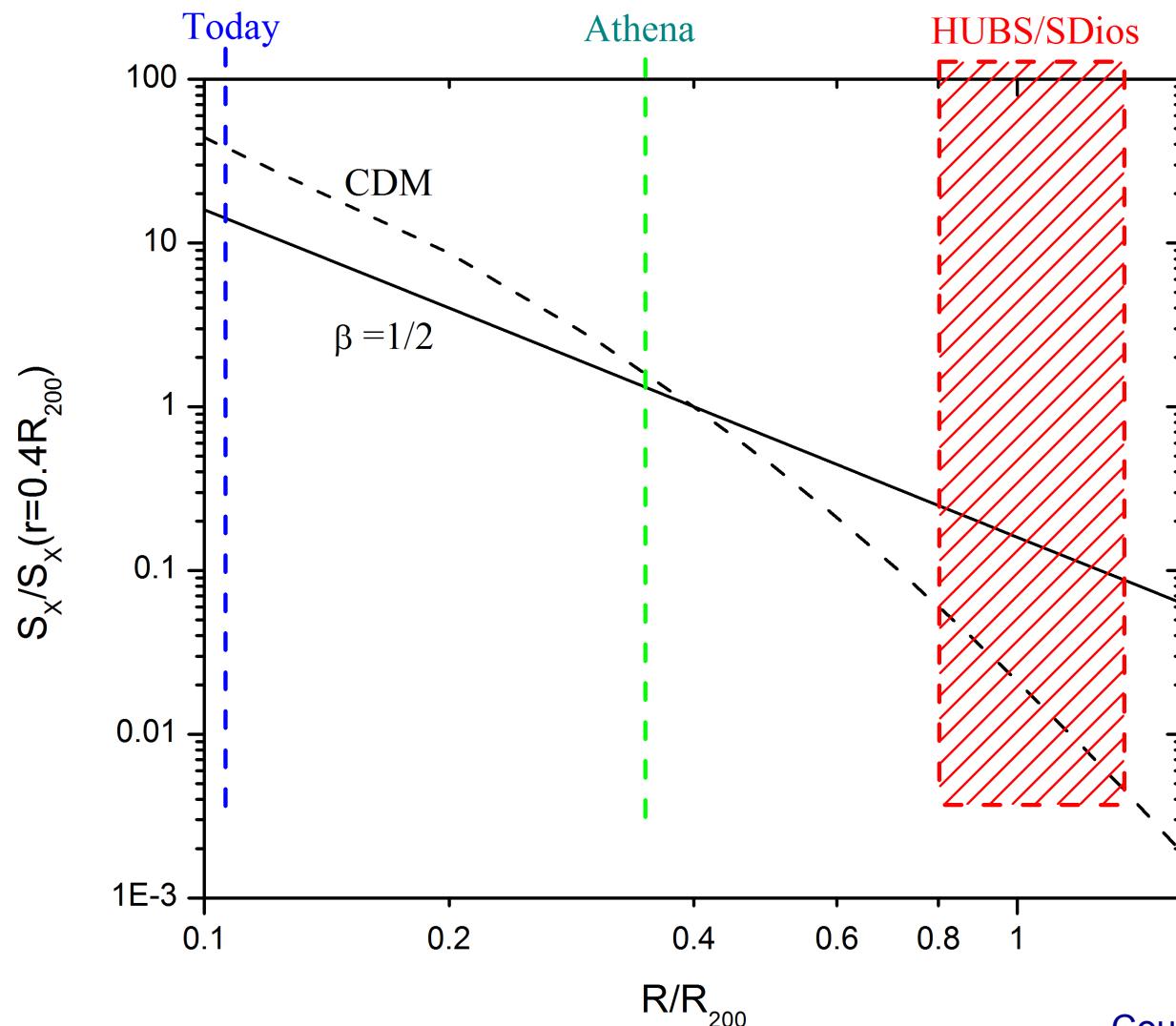
The instrumental figure-of-merit is

$$FoM = \sqrt{RA_{\text{eff}} \Omega_{\text{FOV}}}$$

Comparison: emission lines

| Mission | Instrument | Technology | R@0.6 keV | A _{eff} @0.6 keV (cm ²) | Ω_{FOV} (deg ²) | FoM |
|---------|------------|-------------|-----------|--|------------------------------------|-----|
| XARM | XRISM | Calorimeter | 100 | 70 | 0.0023 | 4 |
| Athena | X-IFU | Calorimeter | 240 | 5000 | 0.0069 | 91 |
| Lynx | | Calorimeter | 200 | 10000 | 0.0069 | 117 |
| HUBS | XQSC | Calorimeter | 300 | 1000 | 1 | 548 |

Probing the outskirts of galaxies



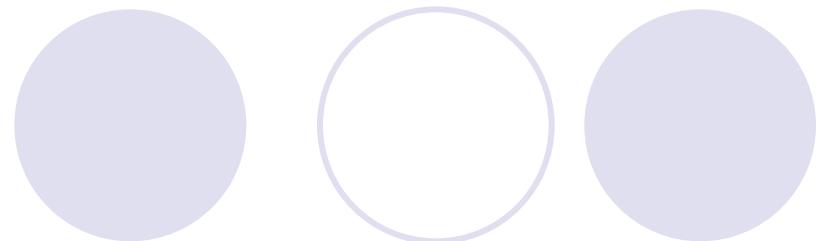
Courtesy J. Bregman

HUBS science and observing strategies

- Key science drivers
 - Galaxies, groups, clusters
 - AGN and stellar feedback
 - WHIM
- Observatory science
 - Diffuse X-ray background
 - Hot interstellar medium
 - Charge exchange
 - Supernova remnants
 - Hot stars and stellar coronae
 -
- Deep pointings
- Small-area surveys
- All-sky survey

HUBS R&D

- TES array
 - Optimized for 0.1-2 keV
 - Mo/Cu, Ti/Au, Mo/Au
- TES array readout
 - TDM vs FDM (and CDM)
- Magnetic shielding
 - Lessons from Micro-X
- Cryogen-free cooling system
 - Cryocoolers
 - ADR
- Wide FoV optics



Tsinghua, PMO

UW-Madison, SRON

SIMIT, SRON

Tsinghua, UW-Madison

IPC

Tsinghua, UW-Madison

Tongji Univ.

Path forward

- The CAS National Space Science Center (NSSC) approved the project for conceptual study at the beginning of 2018
 - Advancing key technologies to TRL>3 by 2020
- Chinese National Space Agency (CNSA) is formally the governmental agency that is responsible for civil space programs in China, similar to NASA or JAXA
 - Will propose HUBS for Phase A study, advancing TRL to 5-6, by 2024
- Having HUBS approved in ~2025
 - Launch in ~2030

October 14-18, 2018
Hyatt Regency Chongming
Shanghai, China

HUBS Workshop

Hot Universe Baryon Surveyor

Scientific Motivation:

The primary scientific objective of HUBS is to conduct a census of baryons in the warm-hot circumgalactic and intergalactic media and thus to directly address the issue of “missing baryons” in the local universe. The results are expected to impact our understanding of galaxy formation. Secondary objectives are many, including hot interstellar medium, diffuse X-ray background, supernova remnants, as well as charge exchange processes in the solar system.

Topics:

- The warm-hot intergalactic medium
- The circumgalactic medium
- Feedback and the active galactic nuclei in X-ray
- The intracluster and intragroup medium
- Supernova remnant and stars
- The diffuse X-ray background
- Numerical modeling of the warm/hot gas in galaxies and cosmic web
- X-ray detector systems, including superconducting transition-edge sensors (TES) and cooling systems
- X-ray optics with large field of view

Scientific Organizing Committee:

Didier Barret, Claude Canizares, Wei Cui (Chair), Taotao Fang (Co-Chair), Zhanwen Han, Jan-Willem den Herder, Yipeng Jing, Tipei Li(Co-Chair), Chris McKee, Guang Meng(Co-Chair), Kazuhisa Mitsuda, Jeremy Ostriker, Giovanni Pareschi,Luigi Piro, Cheng Wang, Zhanshan Wang (Co-Chair), Xiangping Wu, Feng Yuan (Co-Chair), Jian Zhao, Yuan Zhou

Local Organizing Committee:

Chair:
Zhanshan Wang

Co-Chairs:
Baodong Fang, Feng Yuan

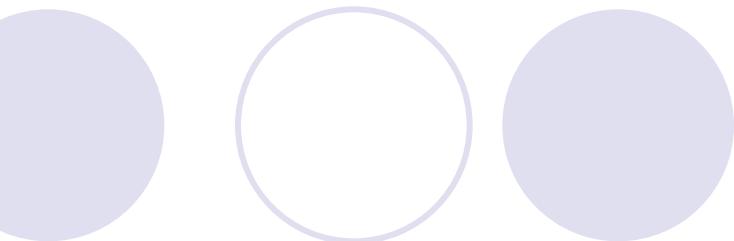
Committee:
Caili Li, Xiaoli Tang, Cong Wang, Lingyun Xie, Yang Yang, Jinsong Ye

Organized by:



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NCSA strongly encourages international collaboration on science missions!

HUBS web page:

<http://heat.tsinghua.edu.cn/~hubs/>

for now, but will be moved to:

<http://hubs.tsinghua.edu.cn/>