

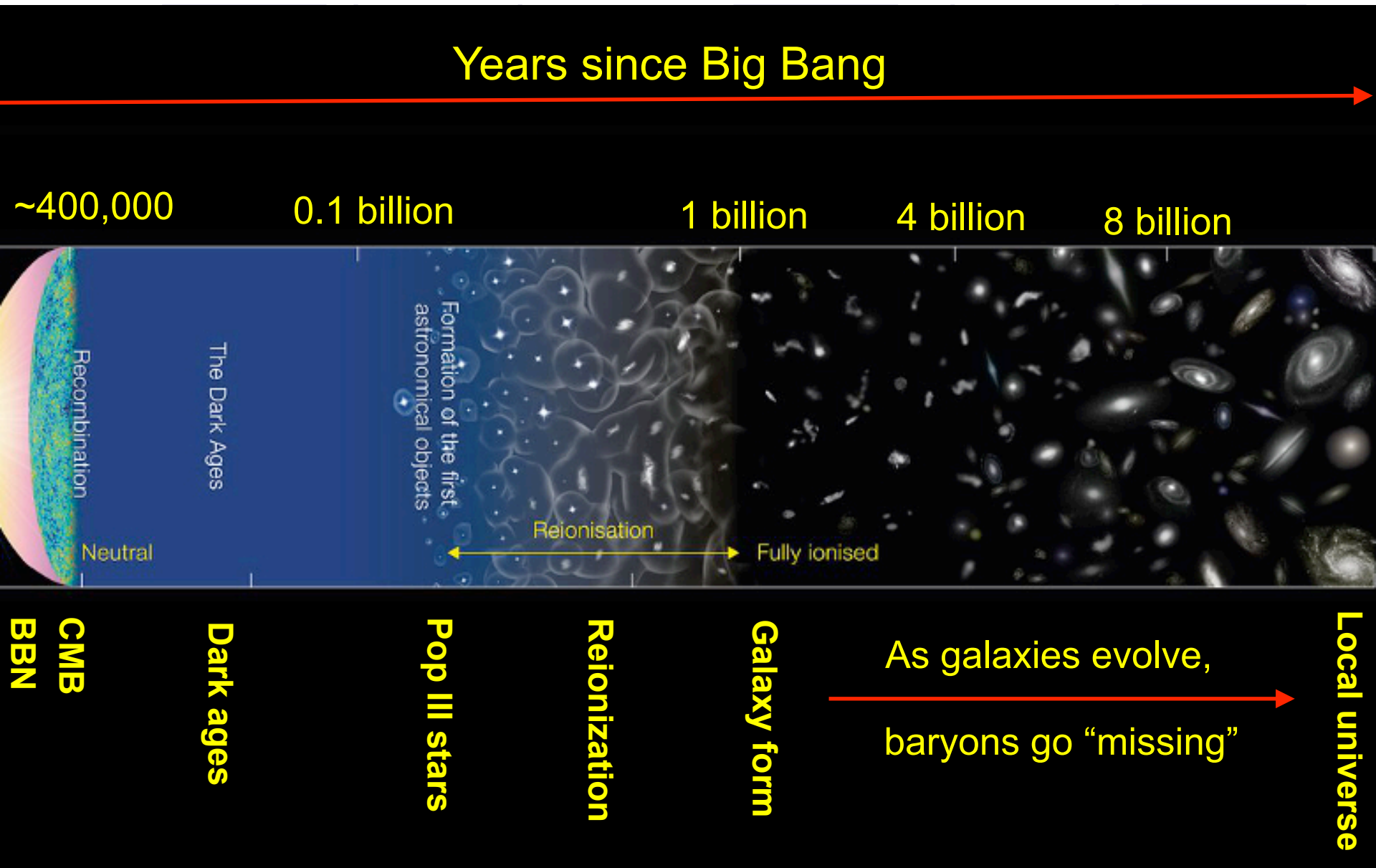


# Hot Universe Baryon Surveyor

Wei Cui

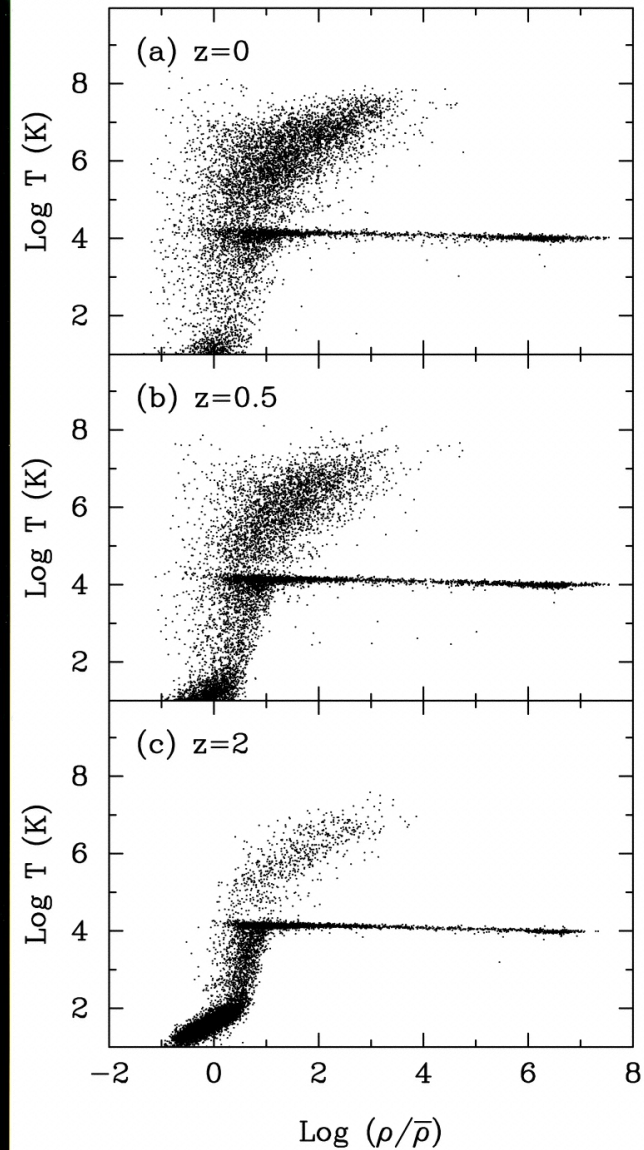
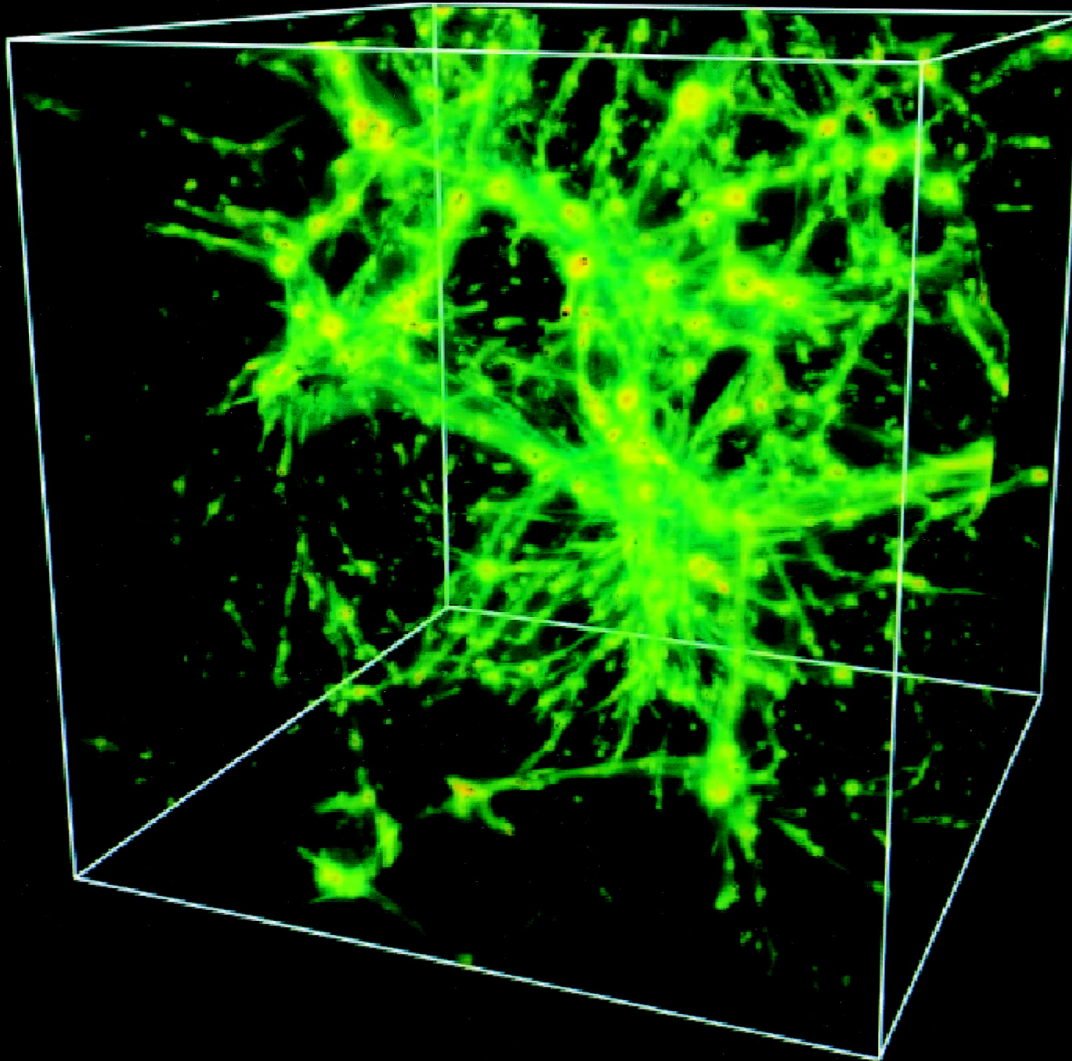
Tsinghua University

# Galaxy formation and “missing baryons”



# Where?

Croft et al. 2001



Dave et al. 2001

# 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

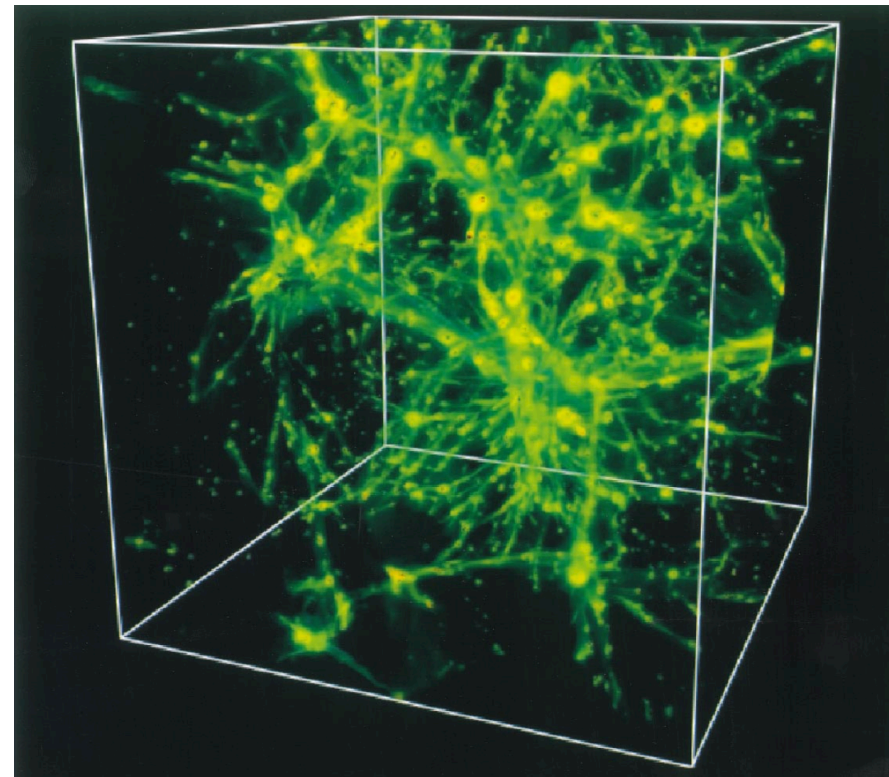


# How to detector hot baryons?

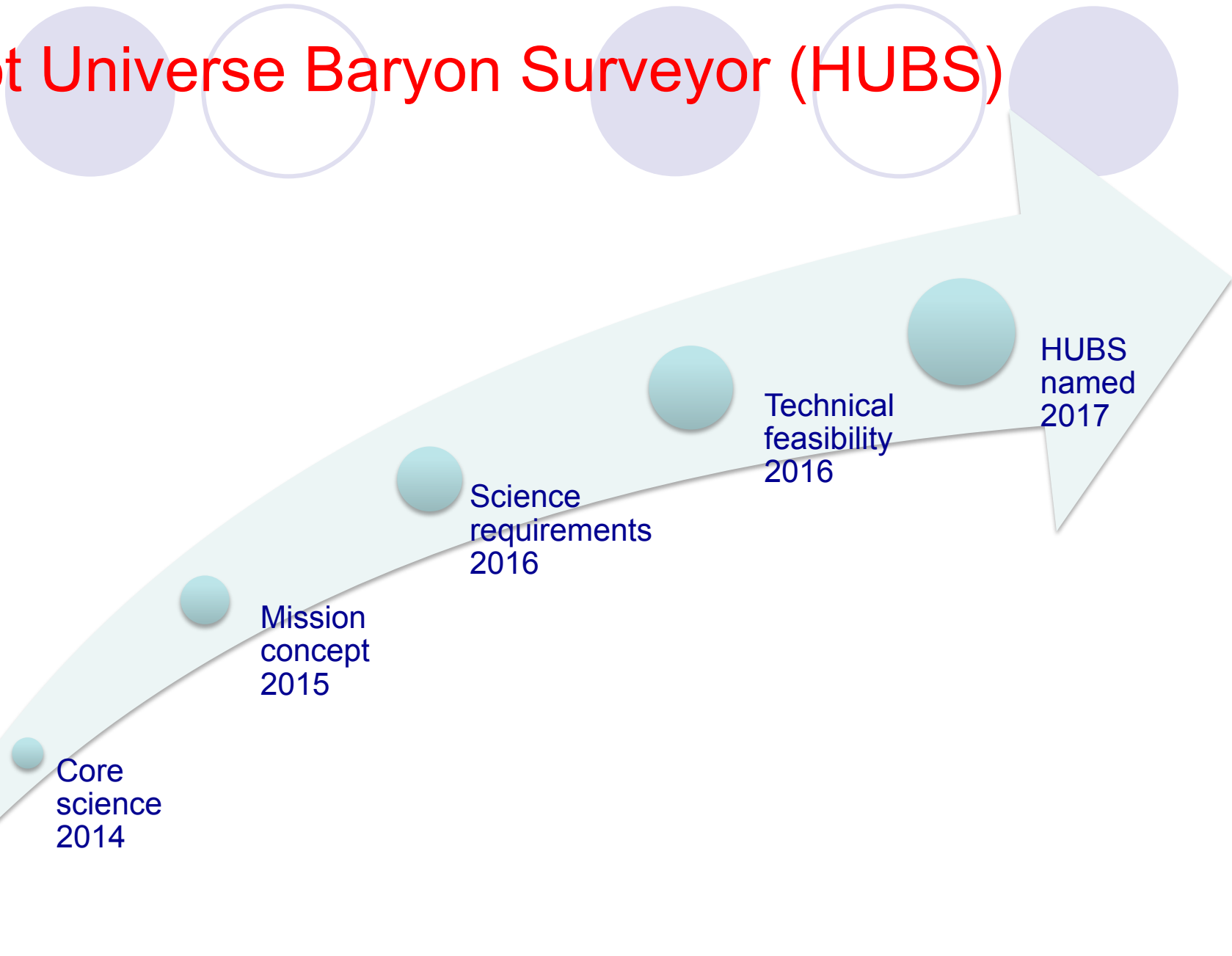
High-resolution X-ray spectroscopy!

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)



# The First HUBS Collaboration Meeting

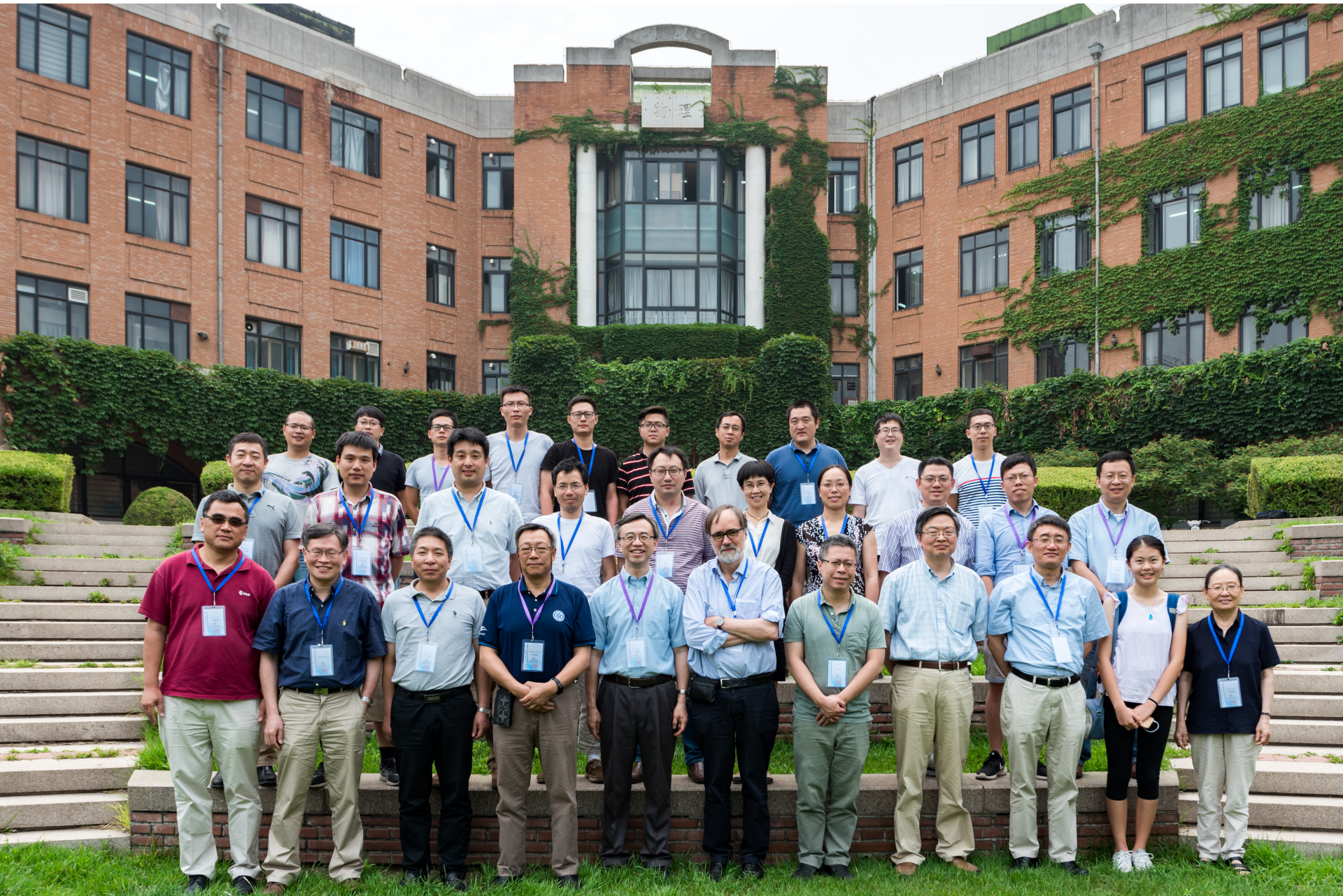
Tsinghua University, Beijing, China  
June 28, 2017

## 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

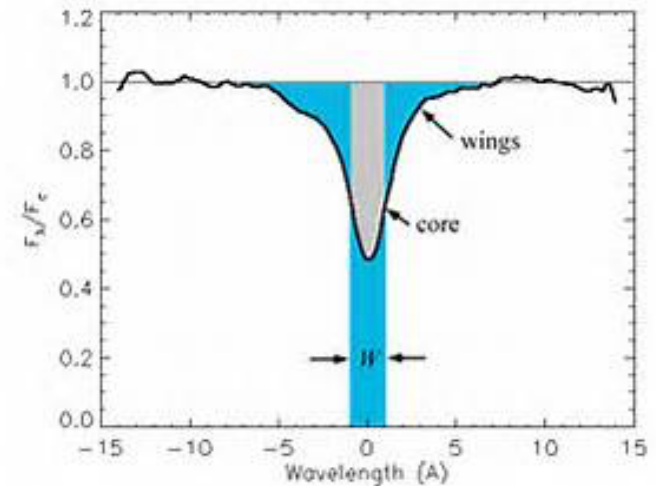
- A hybrid TES array optimized for soft X-rays
  - Energy range: 0.1-2 keV
  - 60x60 pixel array, with 2 eV energy resolution
  - 12x12 central sub-array with smaller pixels, optimized for absorption line spectroscopy with sub-eV resolution below 1 keV
- High throughput X-ray optics with large FoV
  - 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:  $\sim 2030$ 
  - $> 5$  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

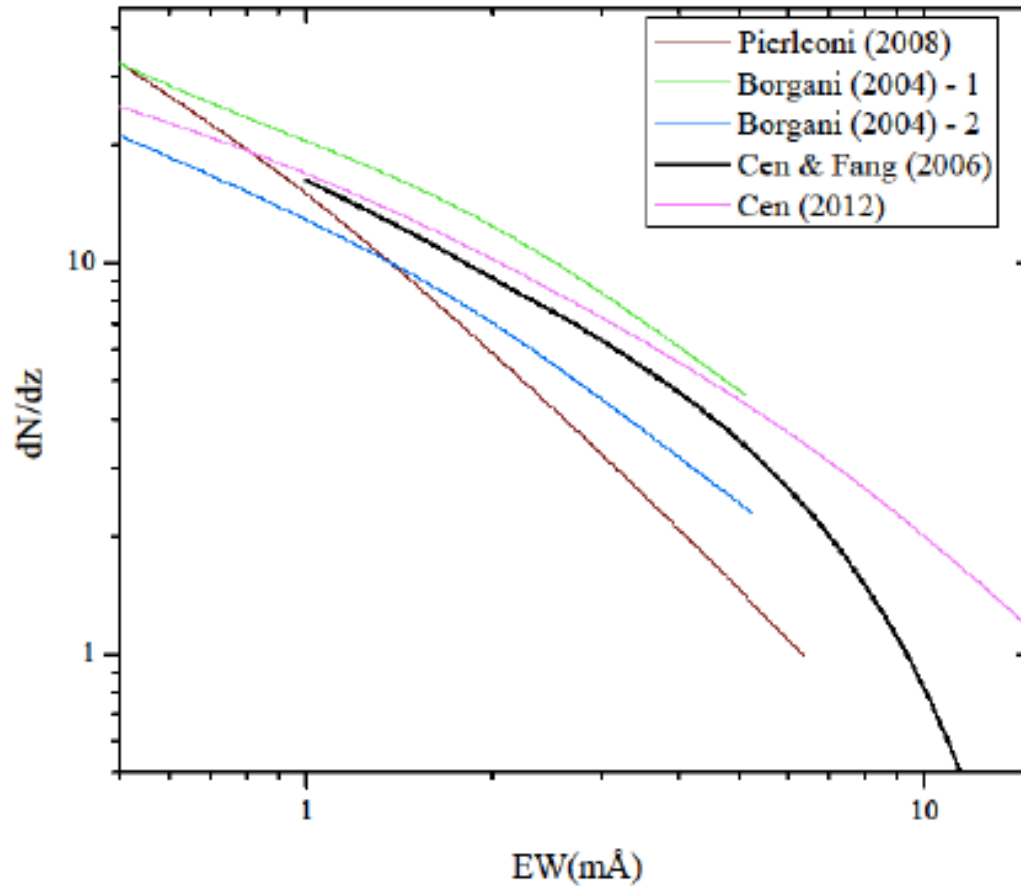
$$FoM = \sqrt{RA_{eff}}$$

# Comparison: absorption lines



Mission	Instrument	Technology	R@0.6 keV	A <sub>eff</sub> @0.6 keV (cm <sup>2</sup> )	FoM	EW limit (mÅ)
Chandra	LETG/ACIS-S	Grating	600	10	77	48
XARM	XRISM	Calorimeter	100	70	84	44
XMM-Newton	RGS	Grating	500	45	150	25
<b>HUBS</b>	<b>XQSC</b>	<b>Calorimeter</b>	<b>600</b>	<b>1000</b>	<b>775</b>	<b>4.8</b>
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:  $EW < 10 m\text{\AA}$

# Figure of Merit: emission lines

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

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

The instrumental figure-of-merit is

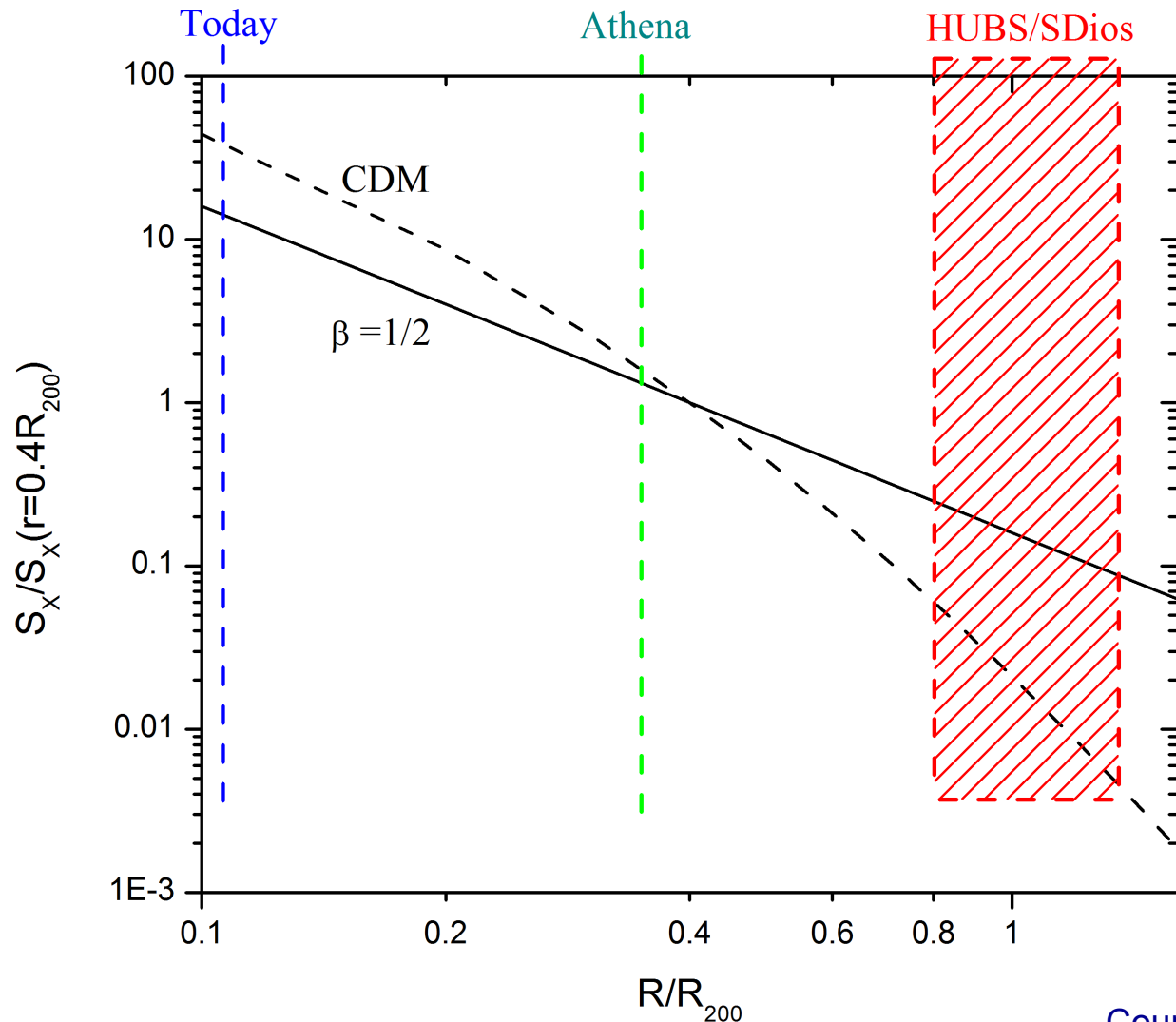
$$FoM = \sqrt{RA_{eff} \Omega_{FOV}}$$

# Comparison: emission lines

Mission	Instrument	Technology	$R@0.6$ keV	$A_{\text{eff}}@0.6$ keV (cm <sup>2</sup> )	$\Omega_{\text{FOV}}$ (deg <sup>2</sup> )	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

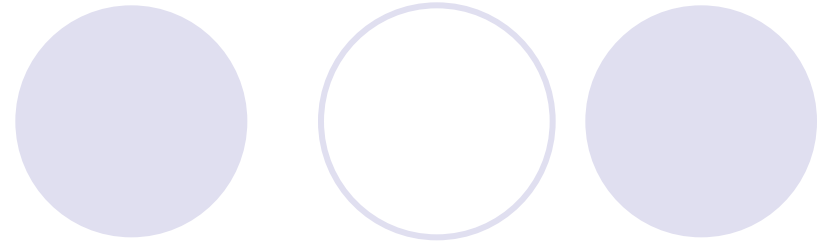
## ■ Observatory science

- 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



# 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

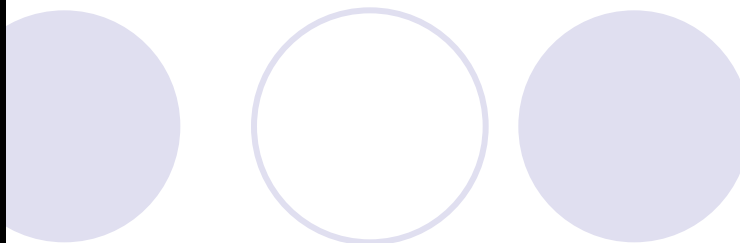
## Contact information:

Email: tangxiaoli@tongji.edu.cn  
0107xielingyun@tongji.edu.cn  
Tel: 13761205567, 15900732956  
Web: <http://hubs.tongji.edu.cn>

## Organized by:



Vienna, Austria, Aug. 31, 2018



**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/>