Hot Universe Baryon Surveyor

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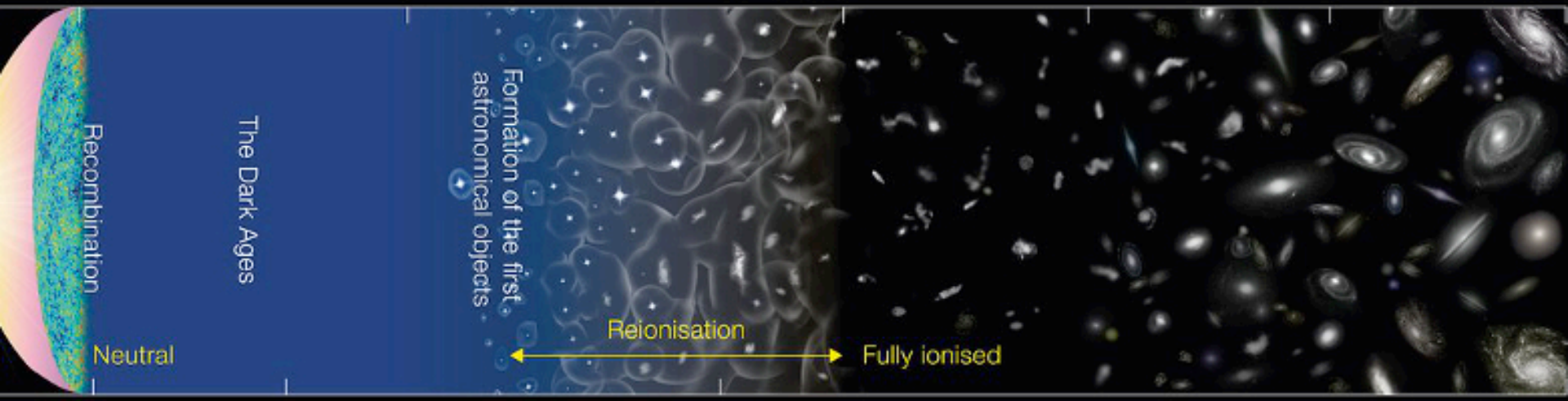
Galaxy formation and “missing baryons”

Years since Big Bang

~400,000 | 0.1 billion | 1 billion | 4 billion | 8 billion



CMB
BBN

Dark ages

Pop III stars

Reionization

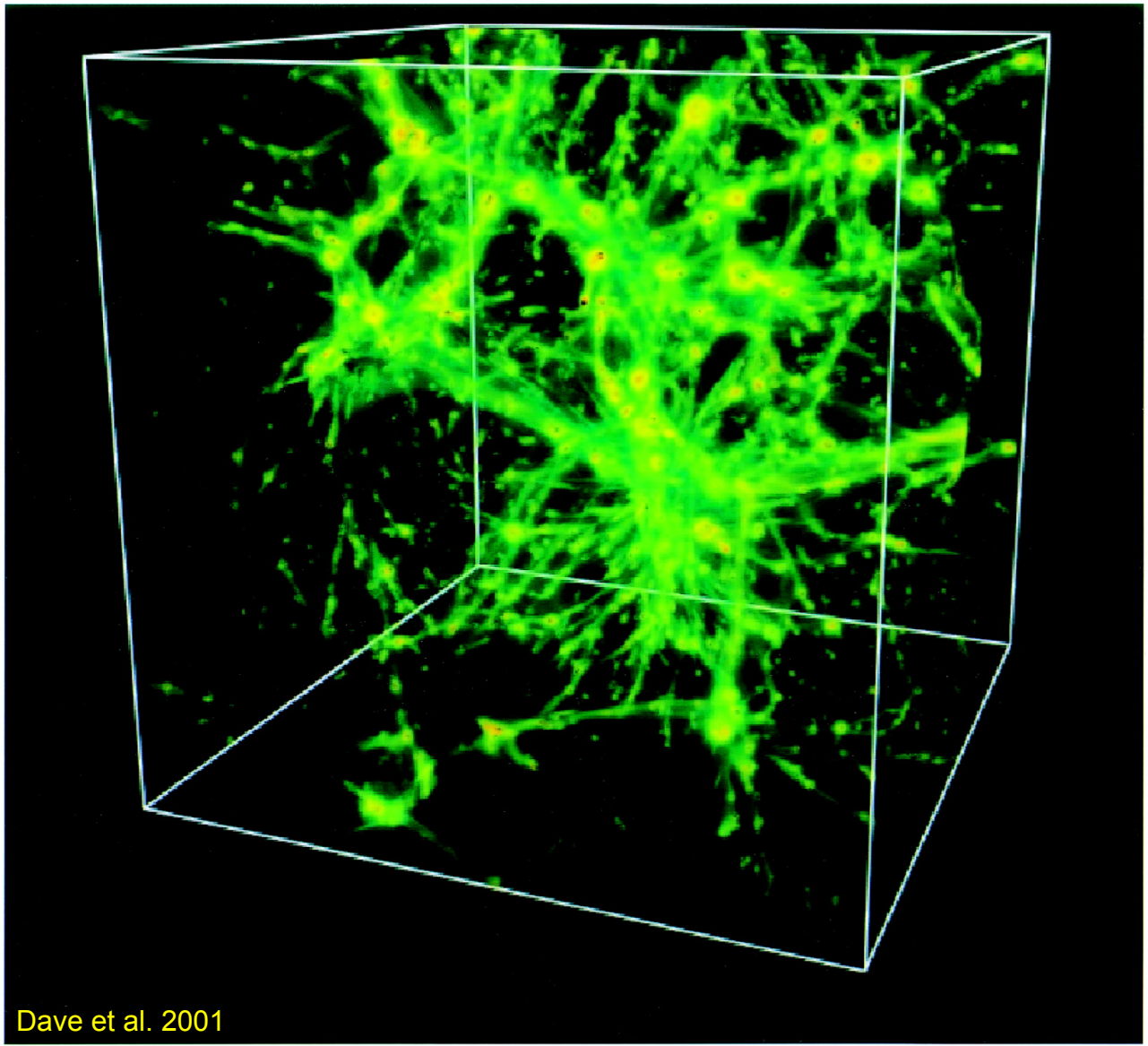
Galaxy form

As galaxies evolve,

baryons go “missing”

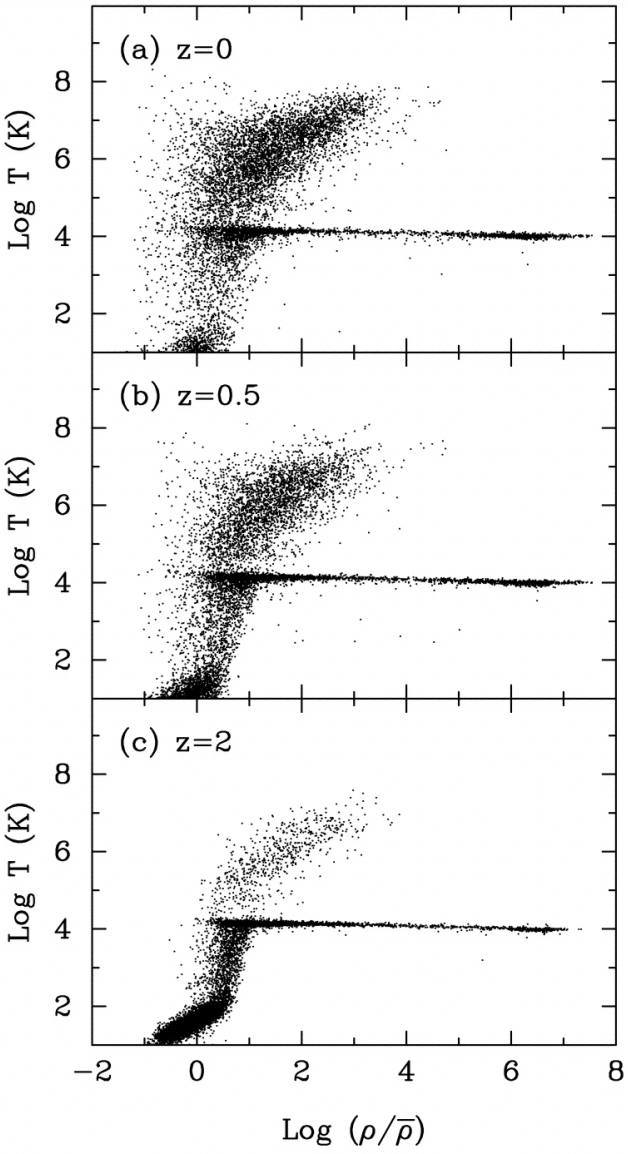
Local universe

Where?



Dave et al. 2001

Croft et al. 2001



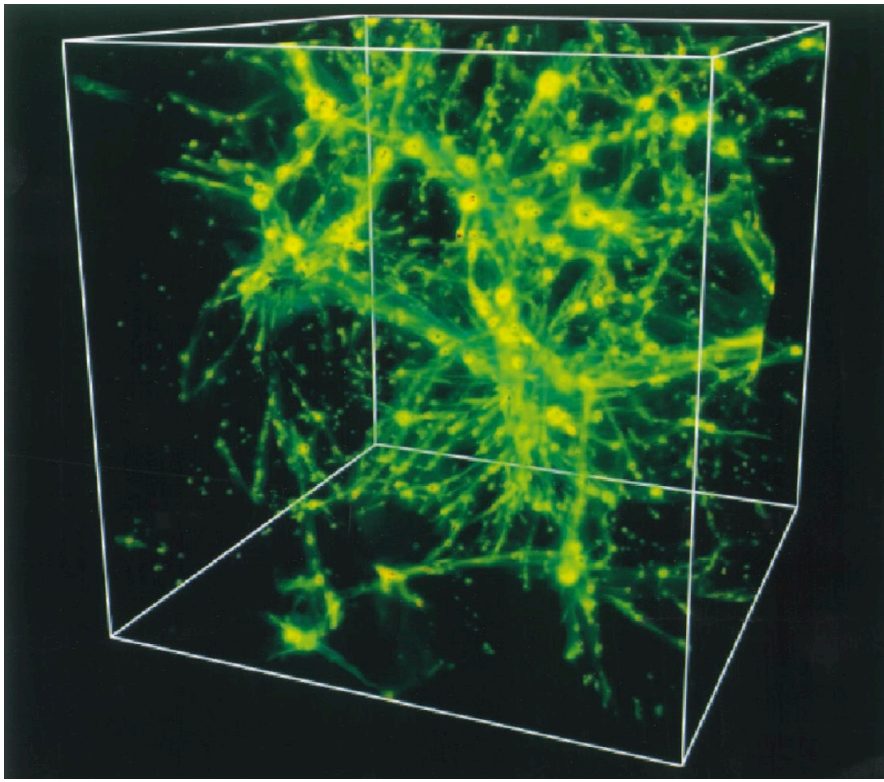
Problems to address

- 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?

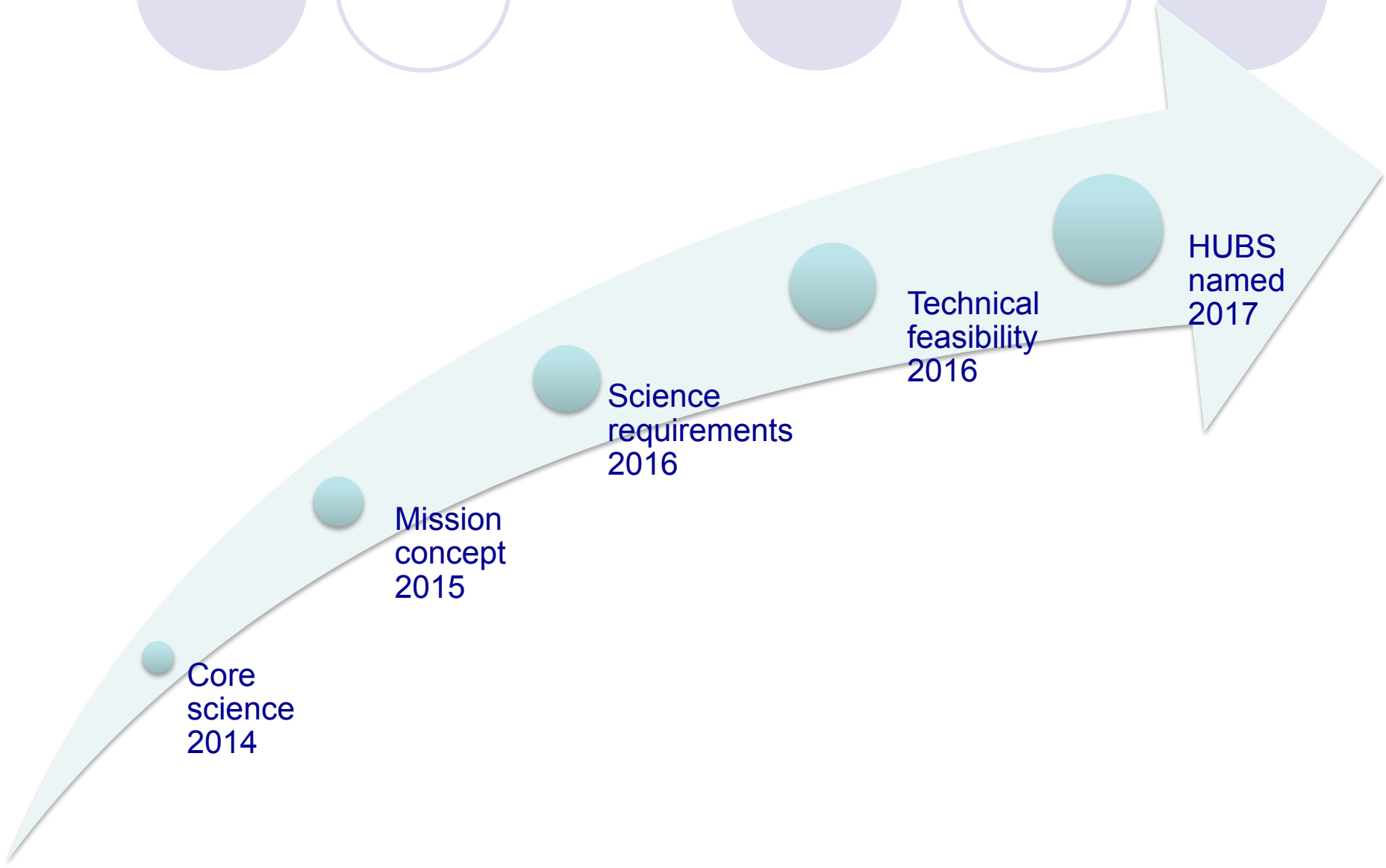
High-resolution X-ray spectroscopy!

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


物理

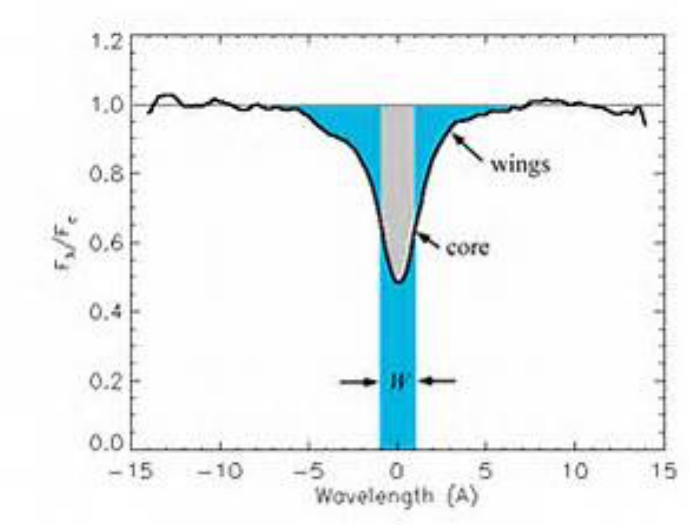
Mission concept

- 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: $A_{eff} > 1000\ cm^2$
  - FoV: $\Omega_{FoV} \sim 1\ deg^2$
  - Moderate spatial resolution: *~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:

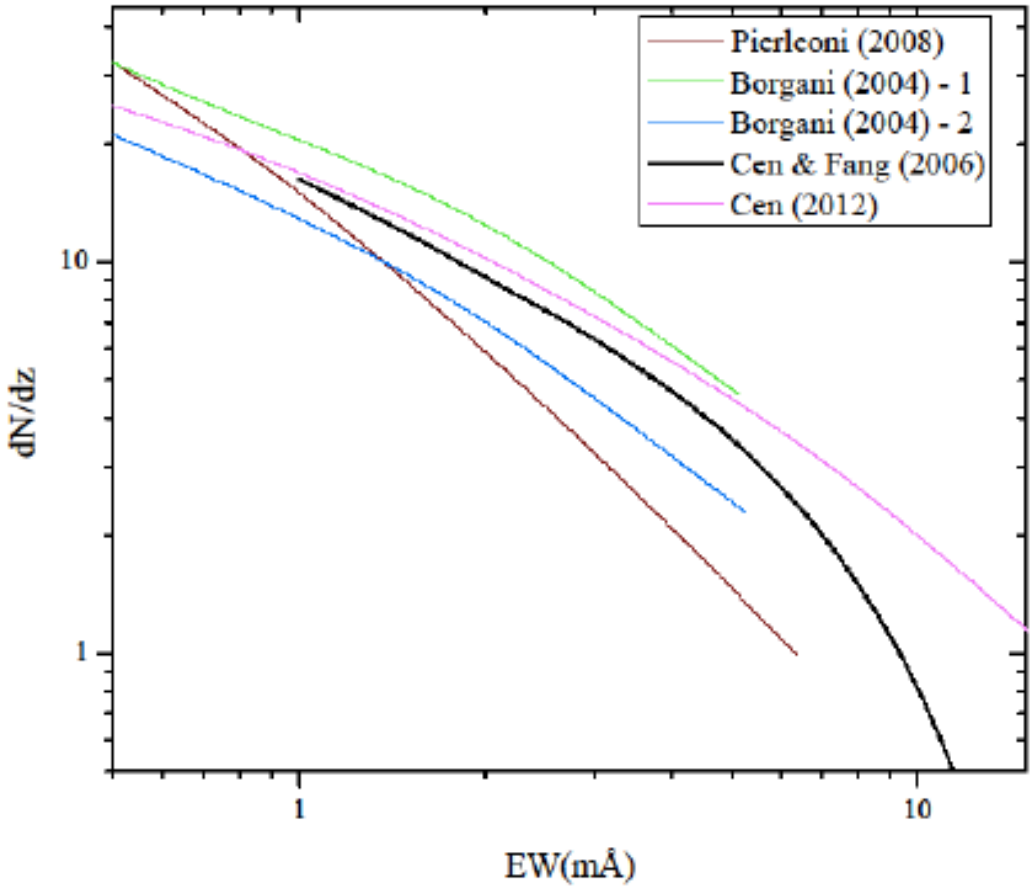
- Effective area
- resolving power

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

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 mA*

Figure of Merit: emission lines

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

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

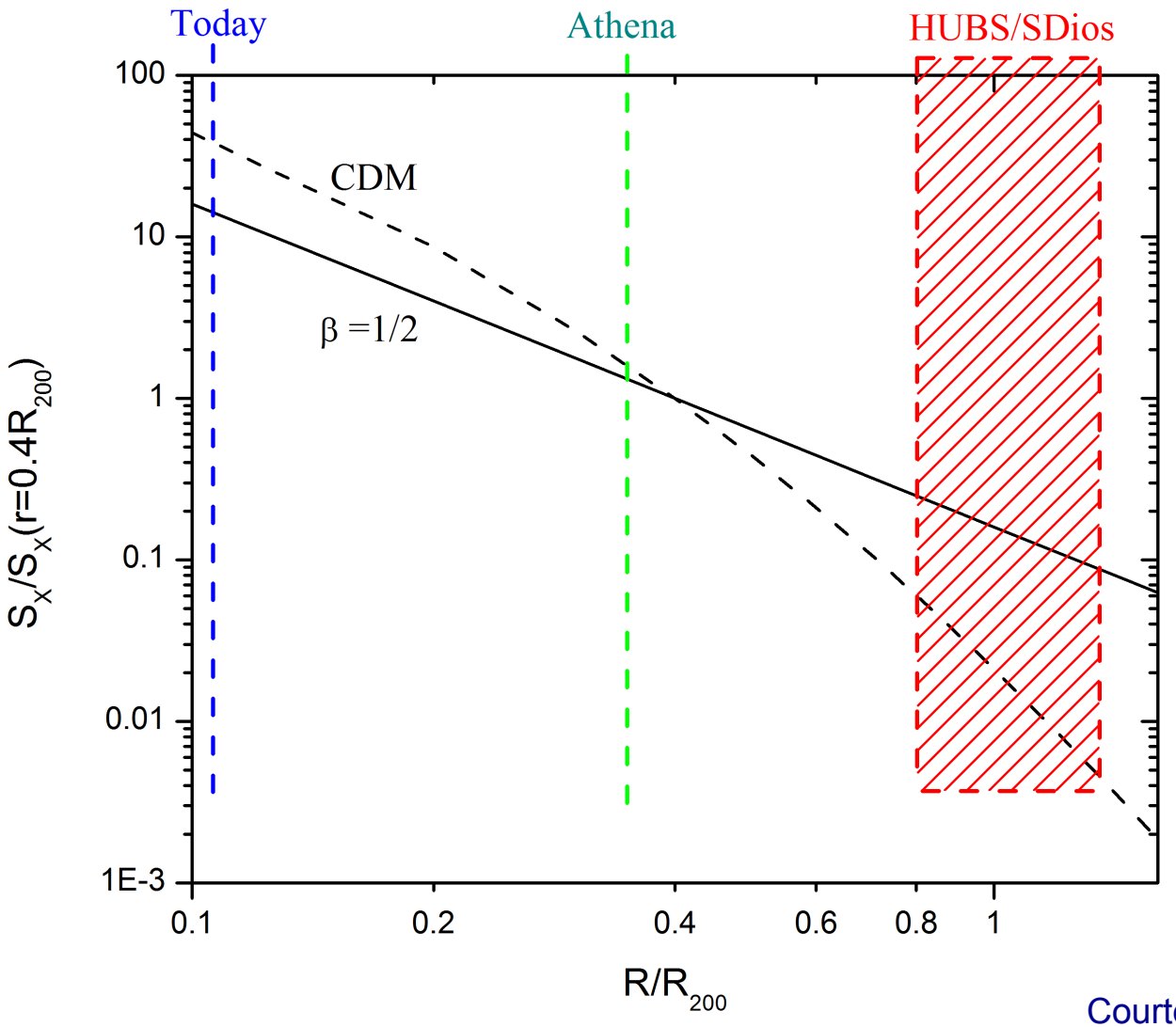
The instrumental figure-of-merit is

$$FoM = \sqrt{R A_{eff} \Omega_{FOV}}$$

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

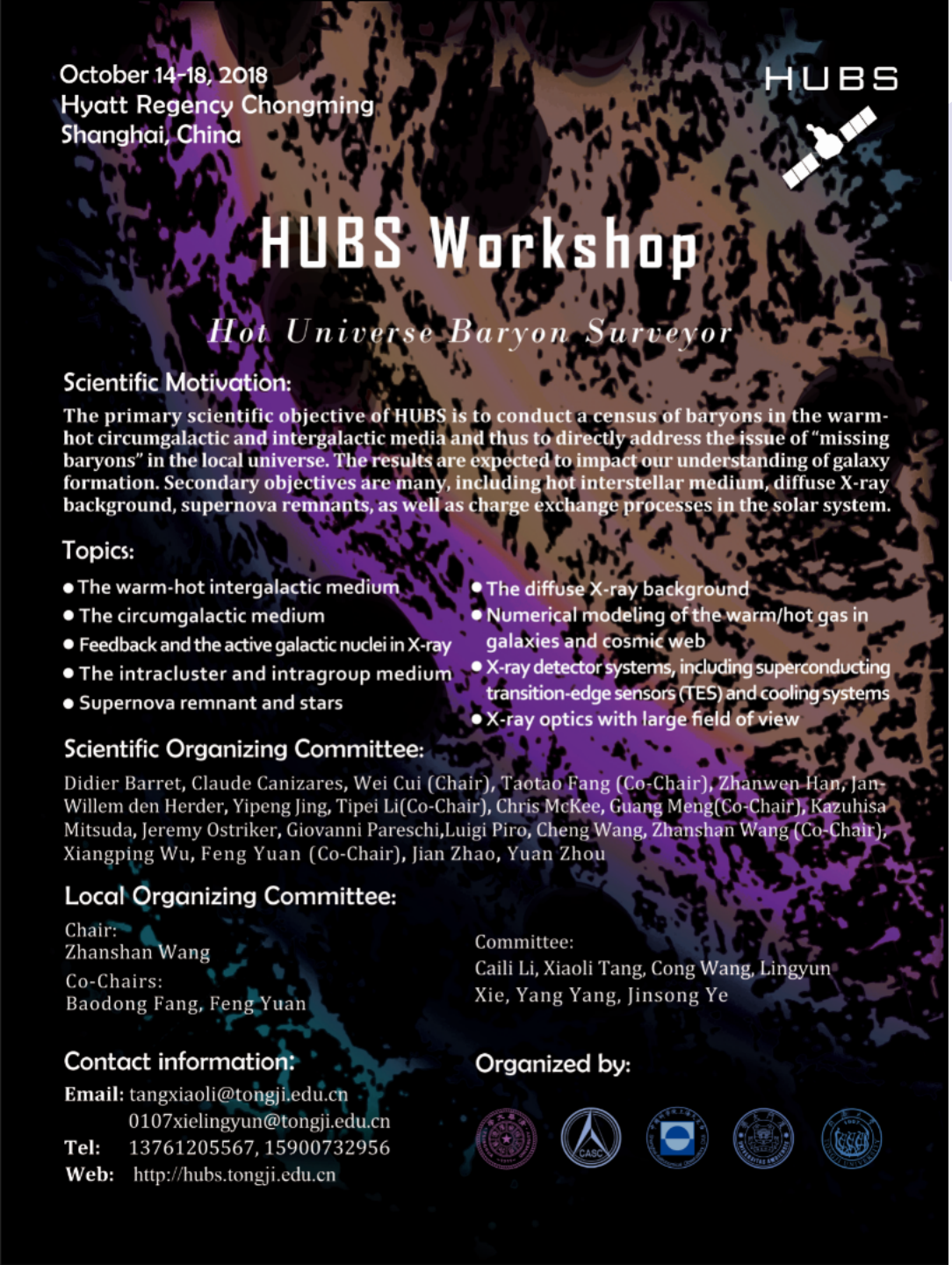
- All-sky survey

HUBS R&D

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



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/