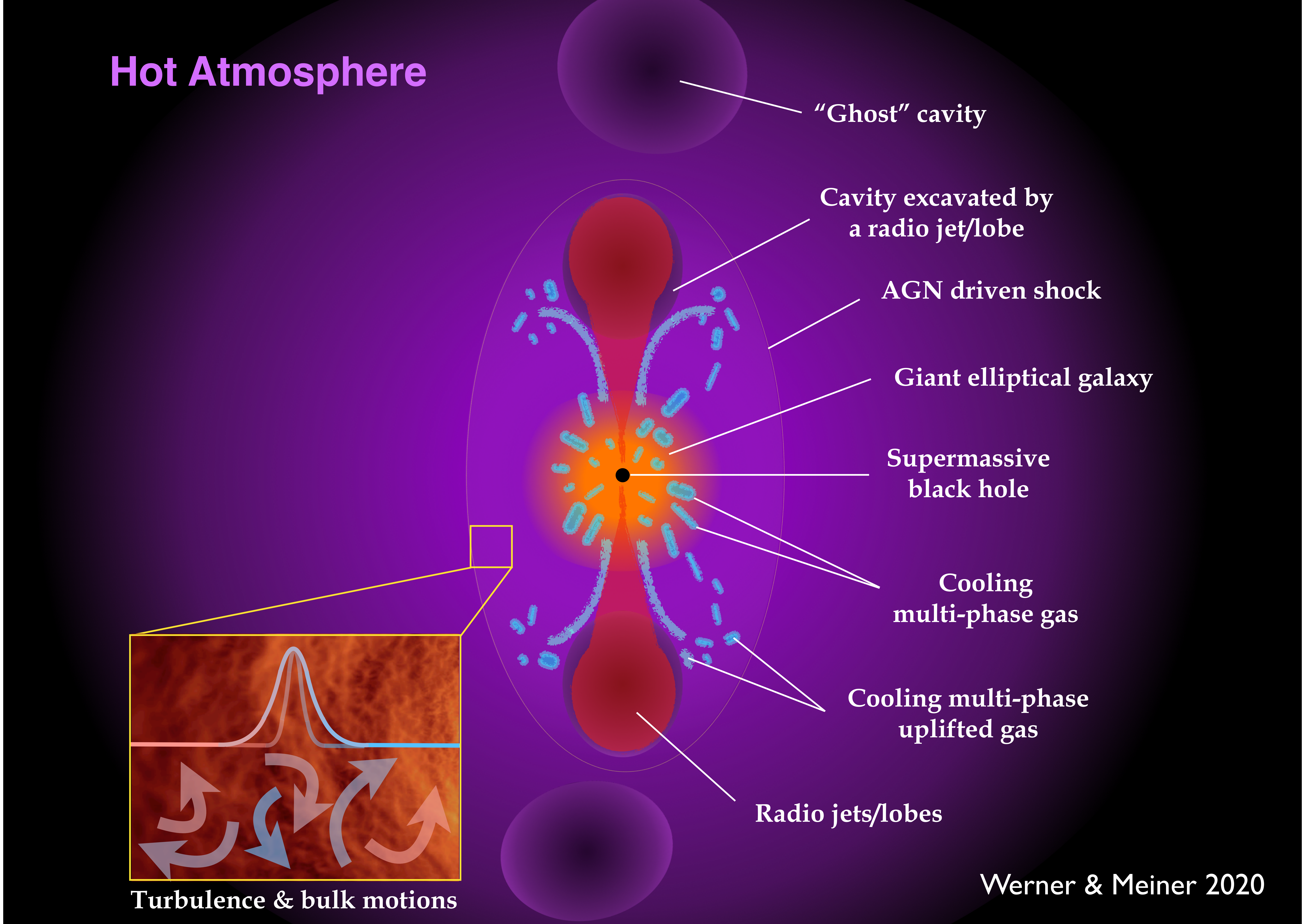
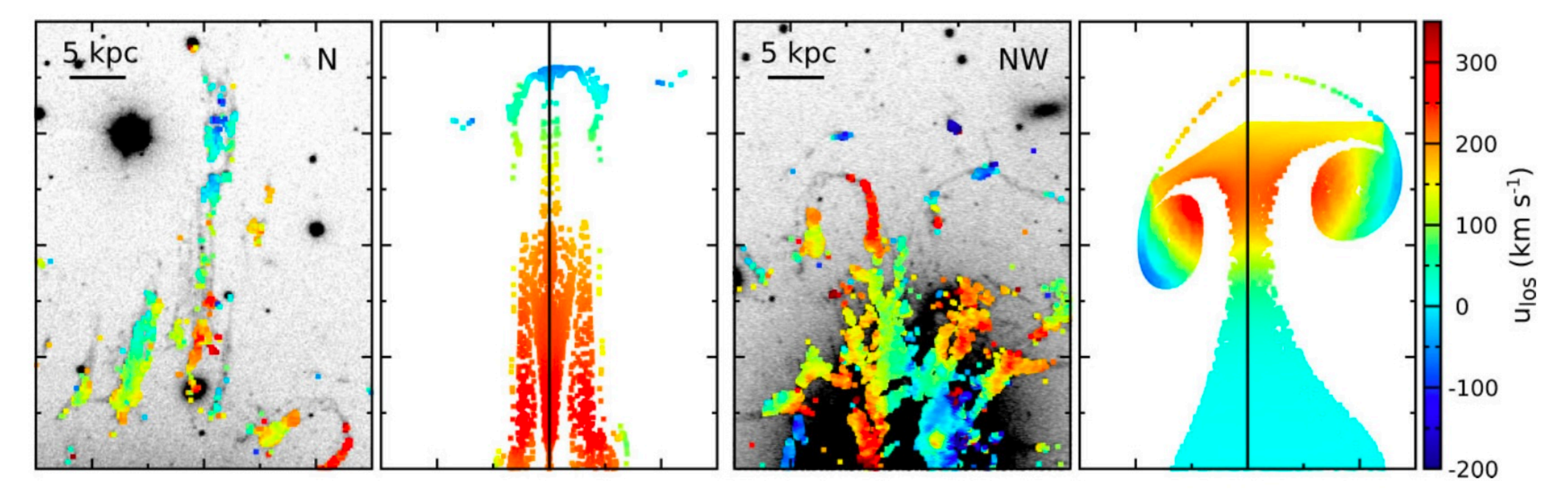
Observations of AGN induced dynamics of hot galactic and cluster atmospheres

Norbert Werner

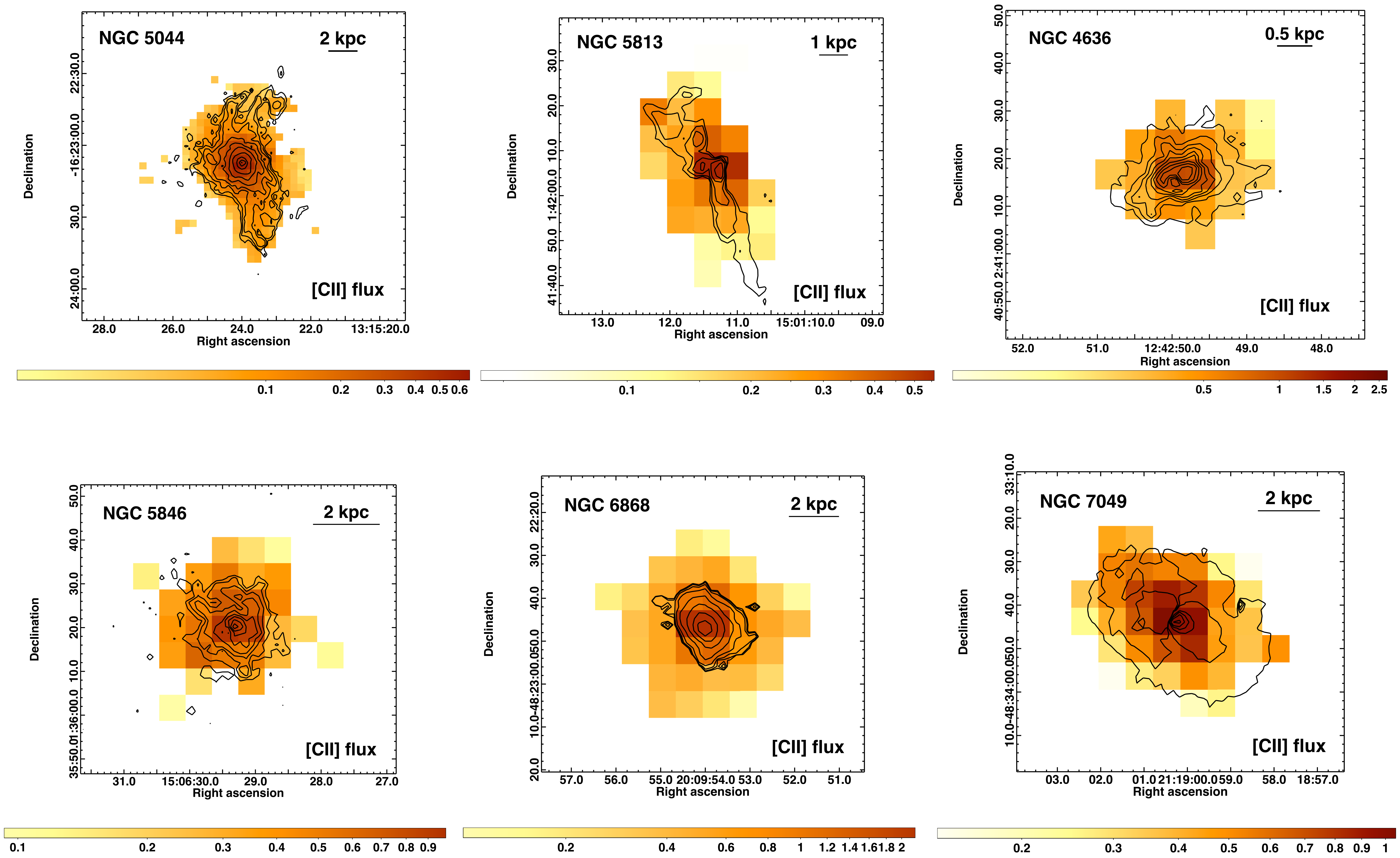

Hot Atmosphere
"Ghost" cavity
Cavity excavated by
a radio jet/lobe
AGN driven shock
Giant elliptical galaxy
Supermassive
black hole
Cooling
multi-phase gas
Cooling multi-phase
uplifted gas
Radio jets/lobes
Turbulence & bulk motions
Werner & Meiner 2020

Velocities behind rising bubbles



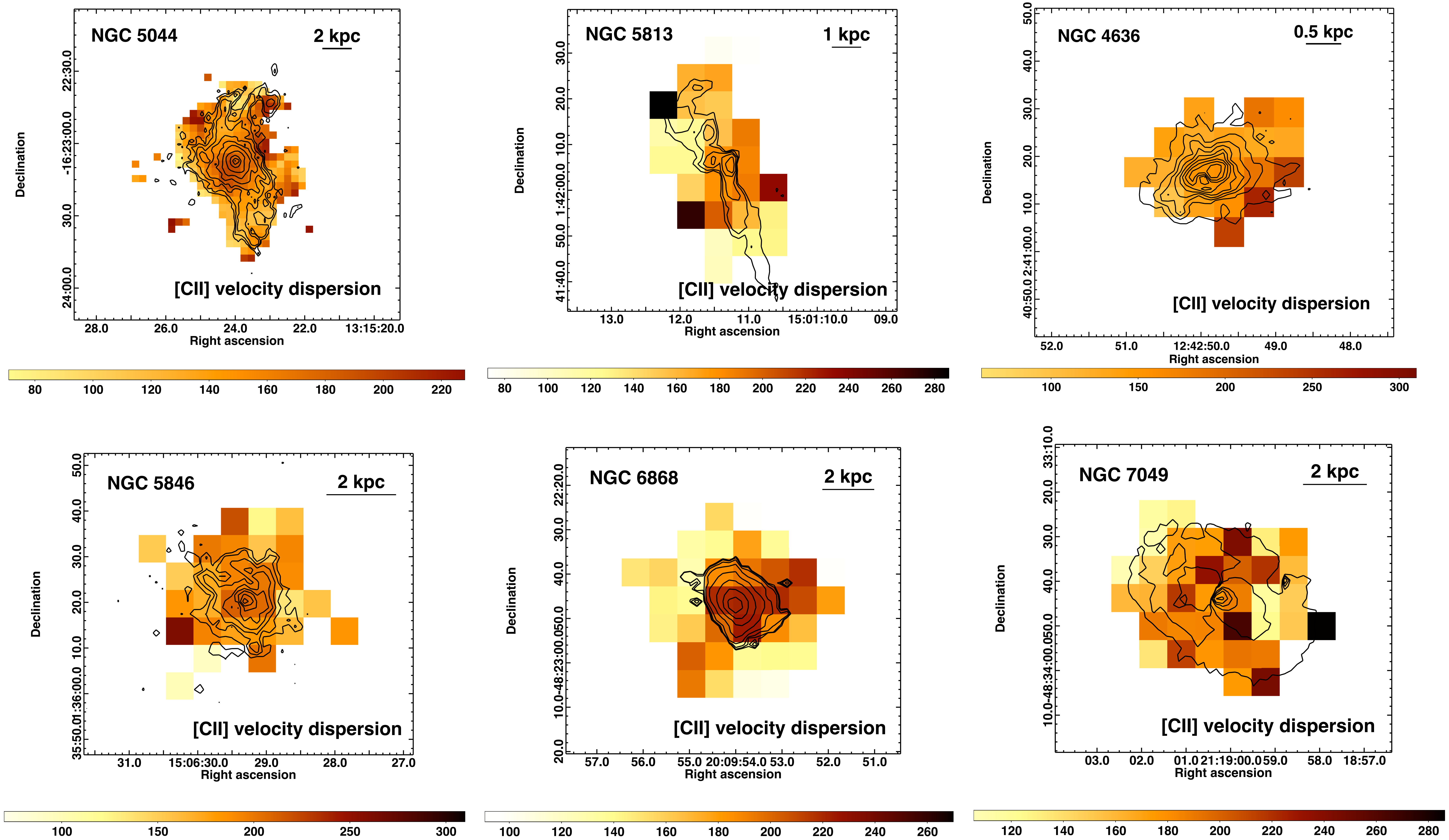
Congyao Zhang et al. 2022

[CII] EMISSION FOLLOWING Hα



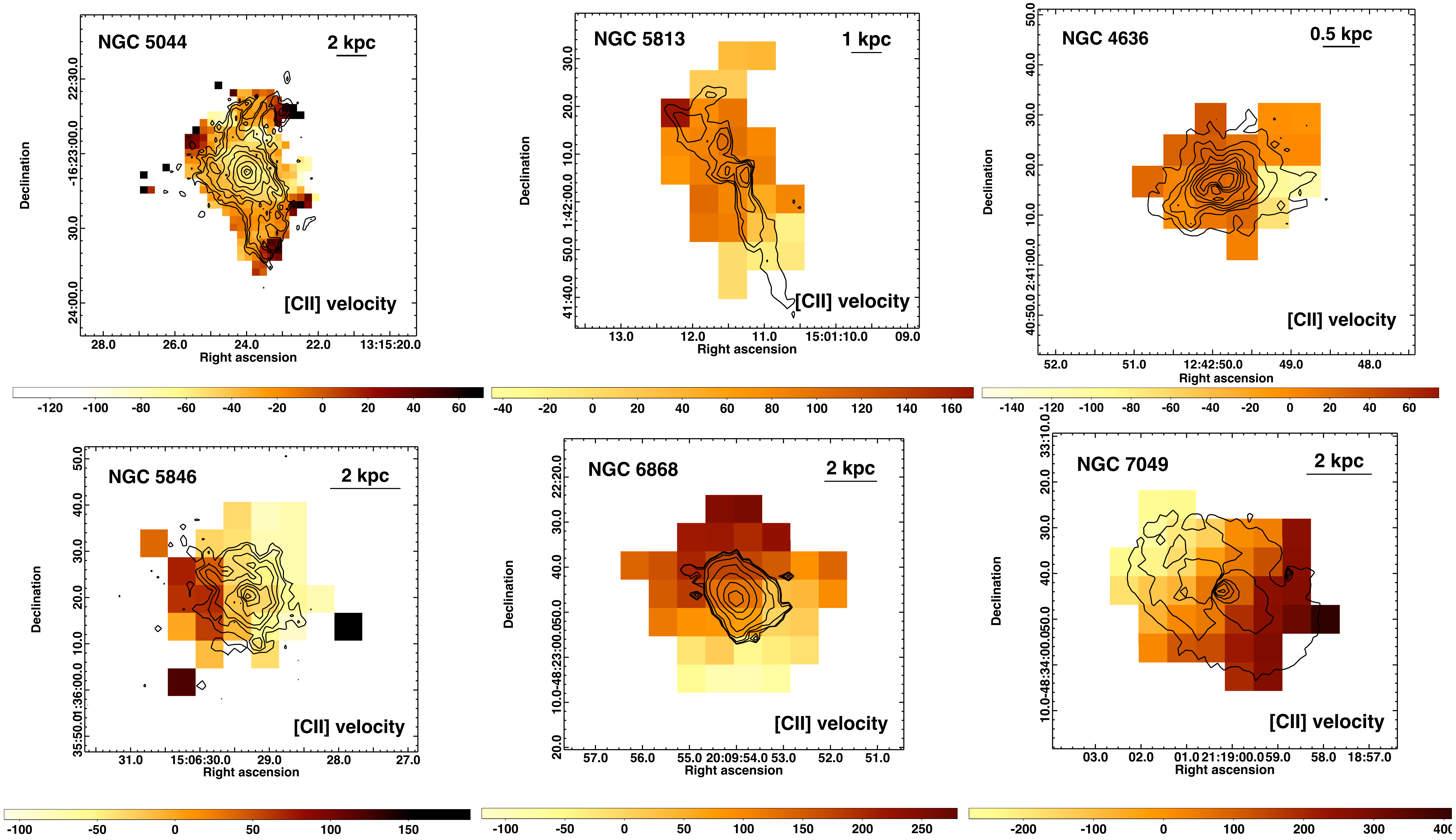
Werner et al. 2014

VELOCITY DISPERSIONS IN THE COLD ISM



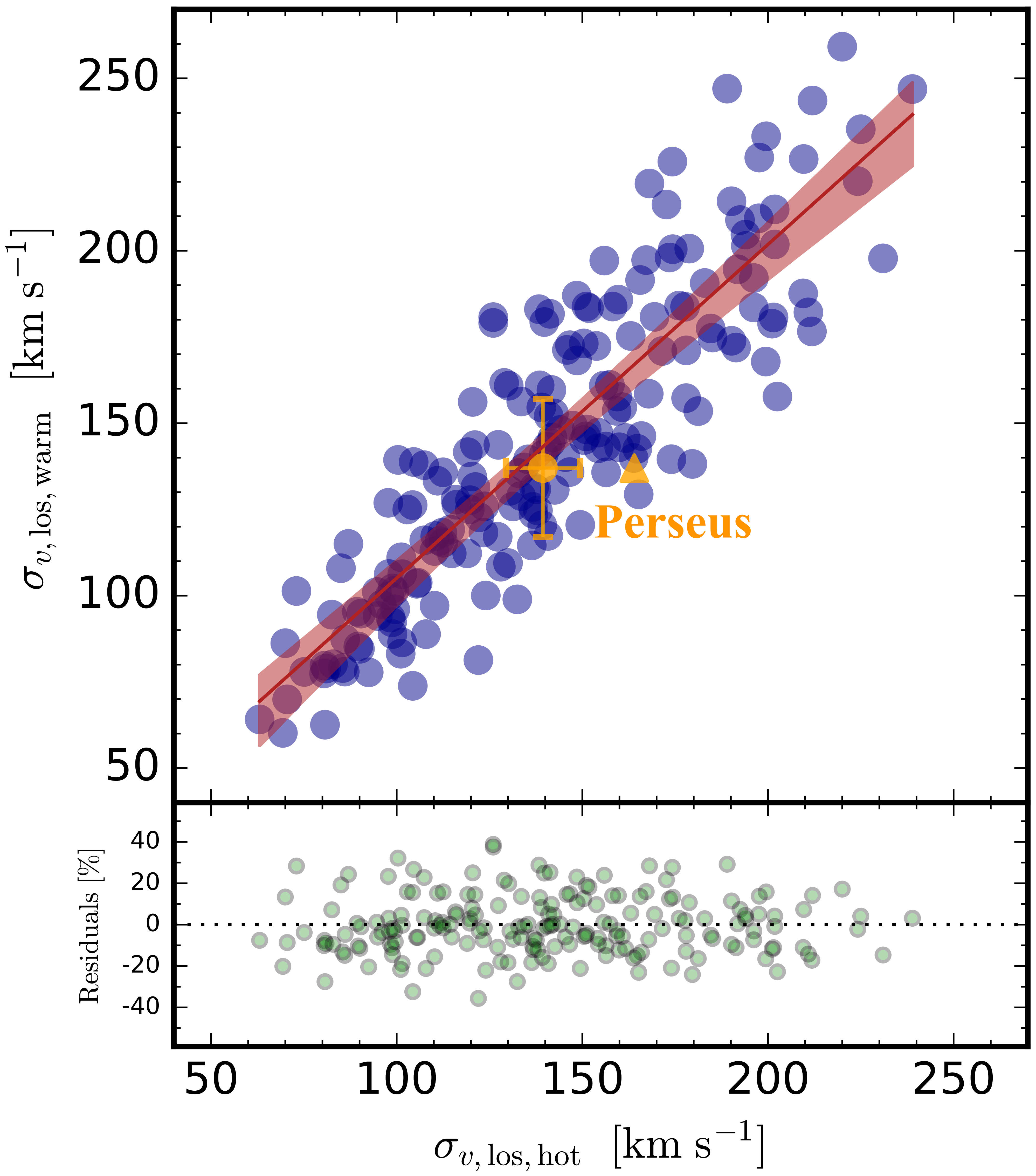
Werner et al. 2014

VELOCITIES OF THE COLD ISM



Werner et al. 2014

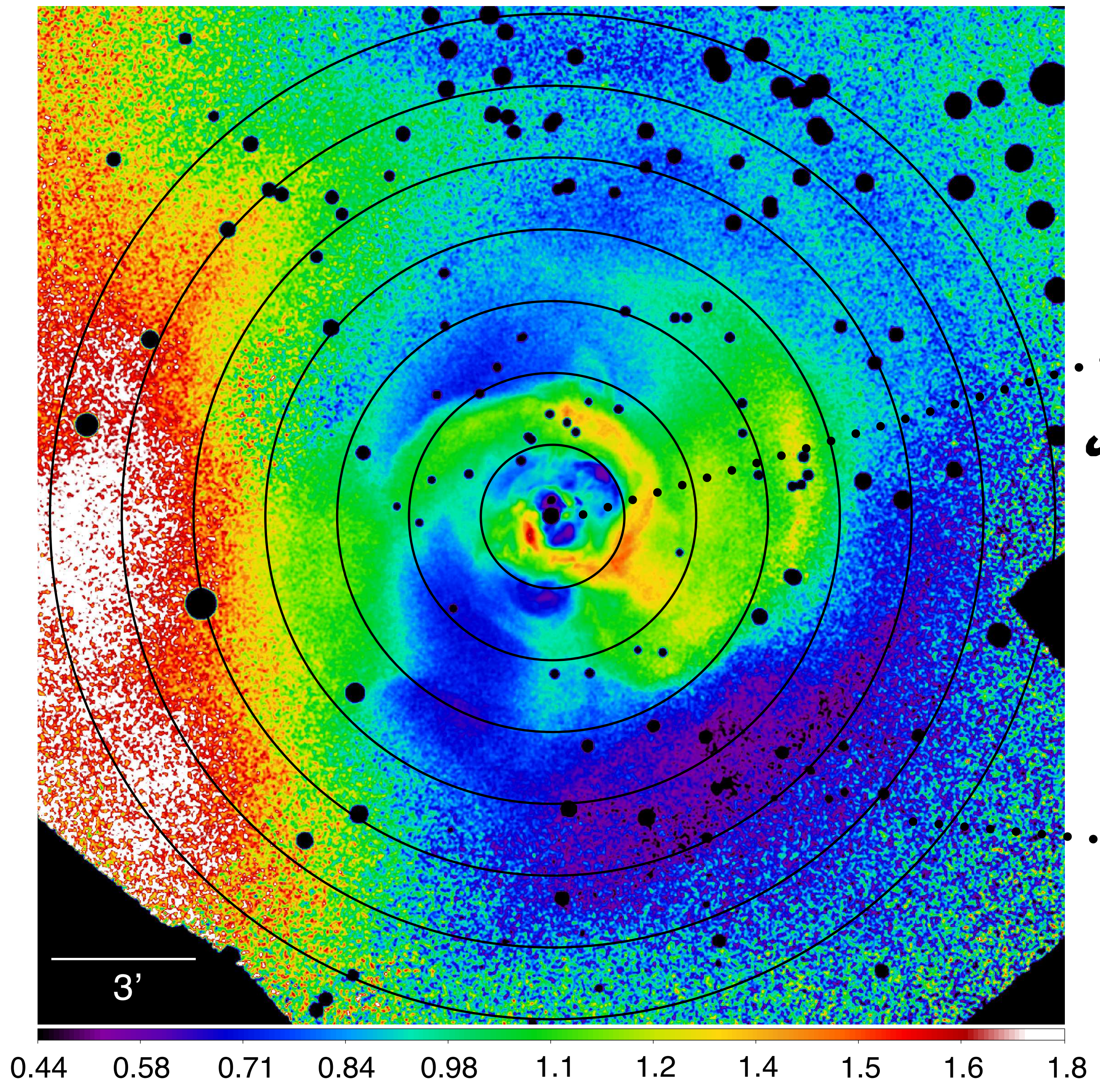
Cool gas tracing motions of the hot phase

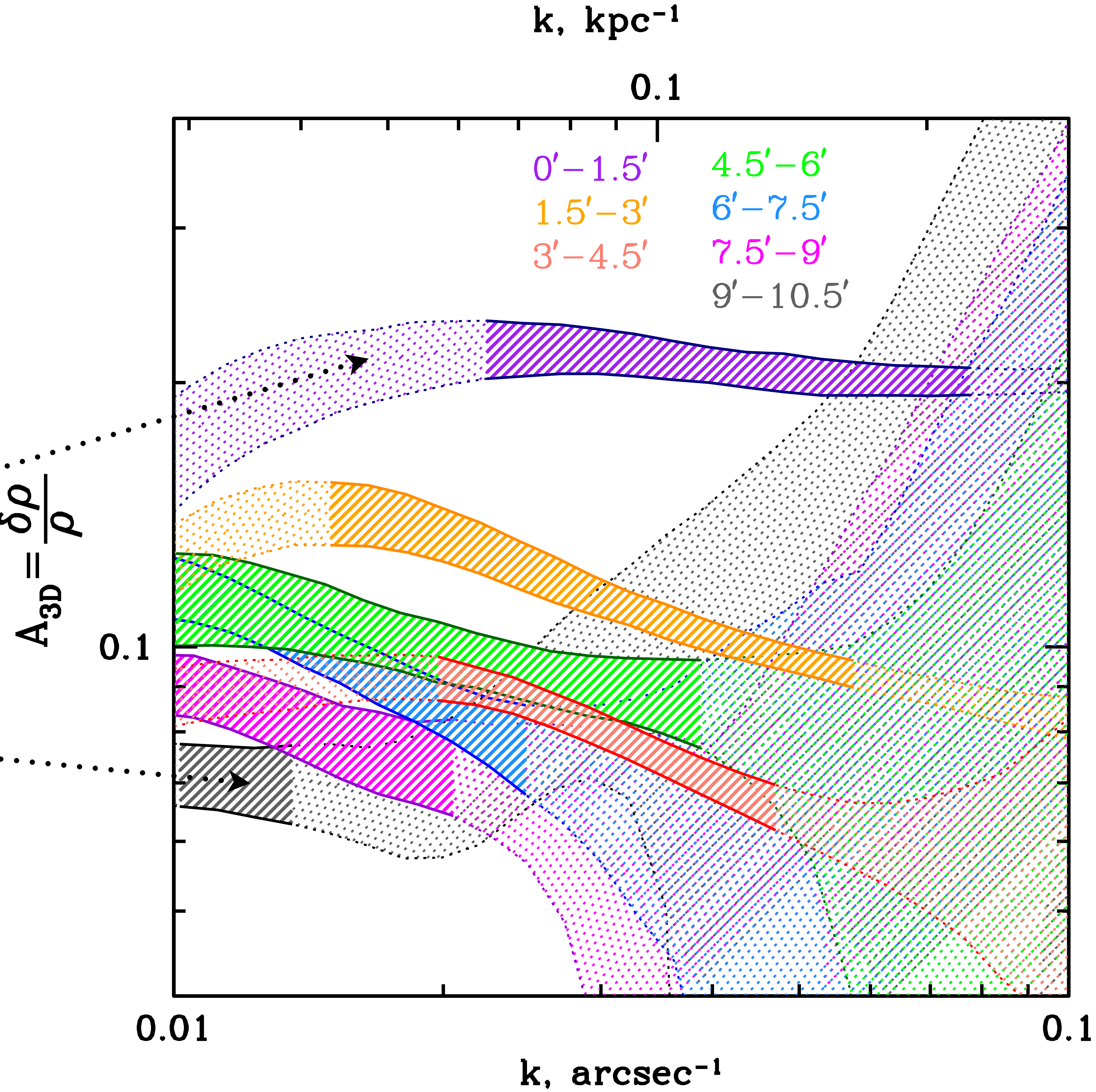


self-regulated
AGN jet feedback simulation run
by Gaspari et al. 2018

Amplitude of density fluctuations in Perseus

$$\frac{\delta\rho_k}{\rho} = \eta \frac{V_k}{c_s}$$



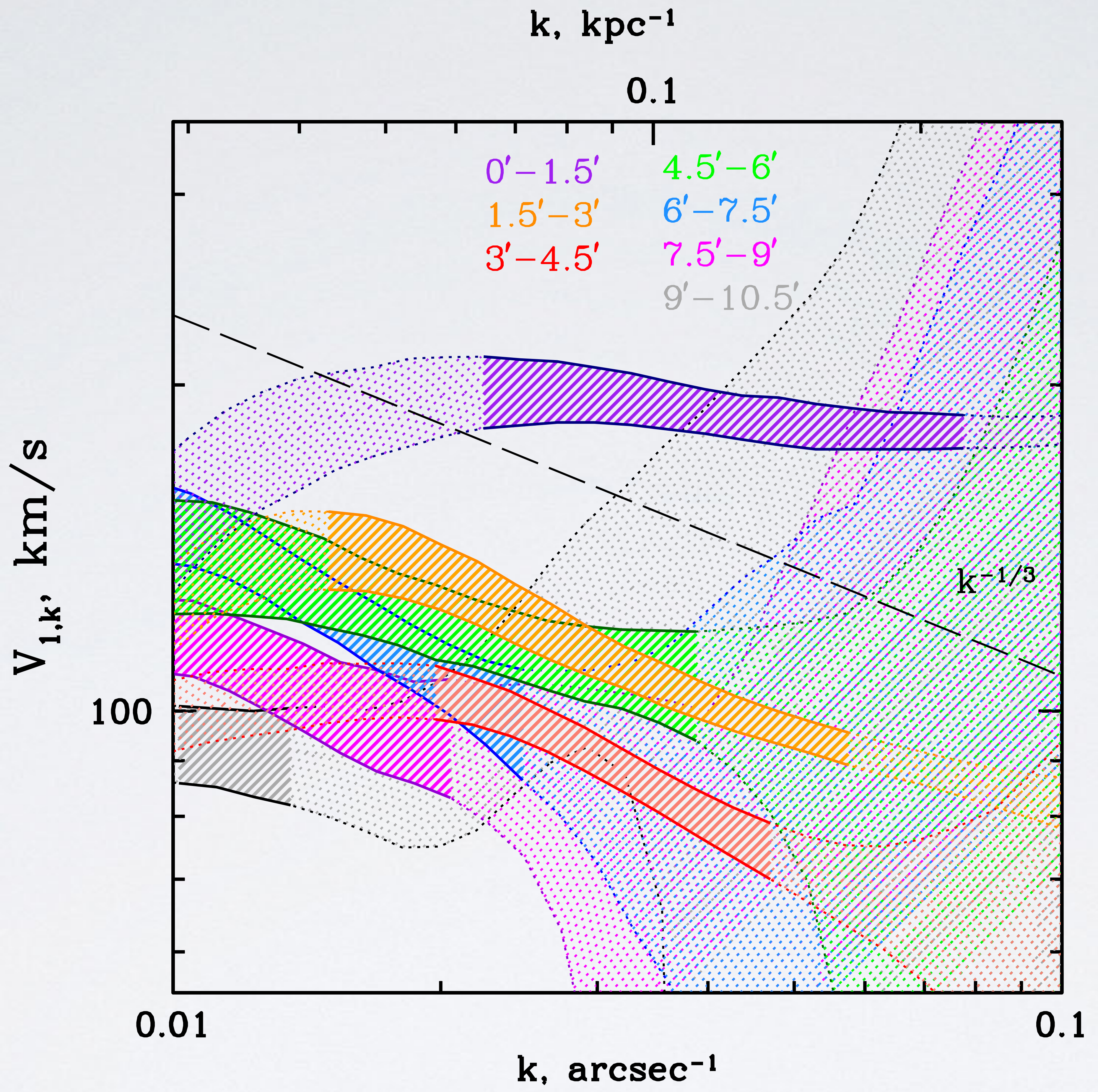


outside central 30 kpc:

$$\frac{\delta\rho_k}{\rho} \sim 7 - 15\%$$ on scales 6-30 kpc

Zhuravleva et al. 2014

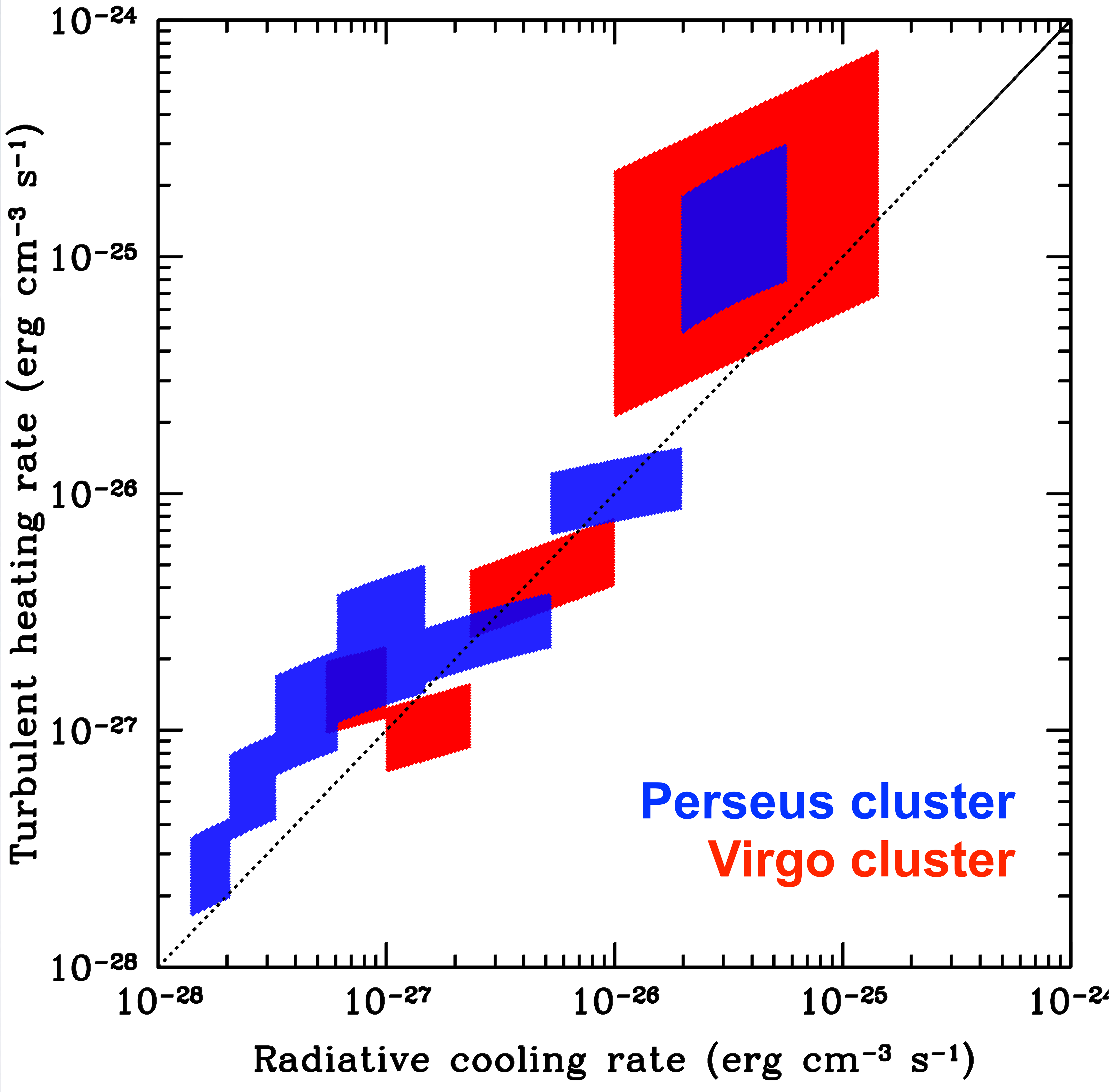
Velocity power spectrum in Perseus



- V higher towards the center —> power injection from the center
- larger V on smaller k —> consistent with cascade turbulence
- 70 km/s < $V_{1,k}$ < 200 km/s on scales 6-30 kpc (within central 200 kpc)

Zhuravleva et al., 2015

Turbulent dissipation in AGN feedback

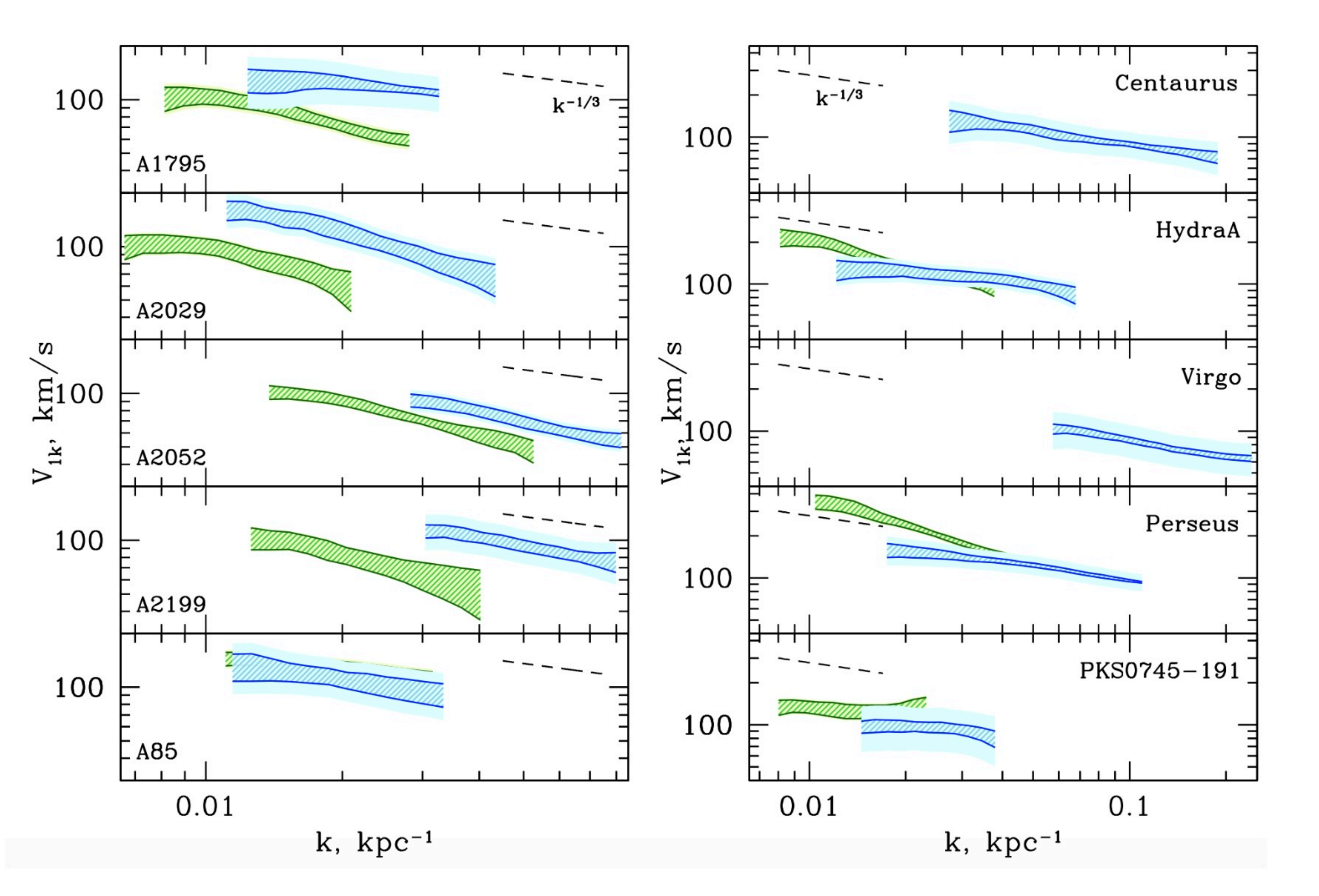


locally: cooling ~ heating

AGN —> Bubbles —> Turbulent dissipation —> Heat

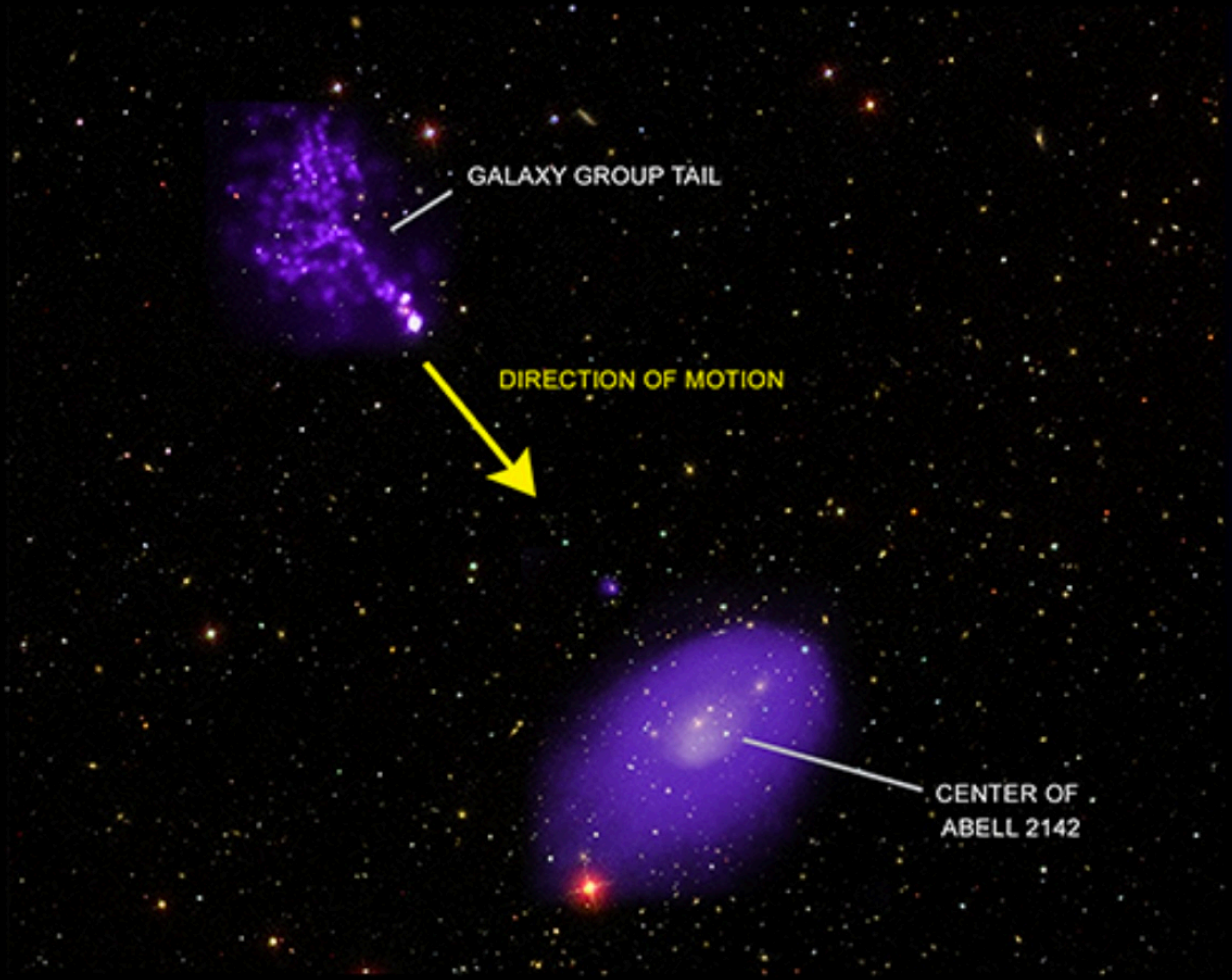
Zhuravleva et al. 2014b

Velocities in a cluster sample

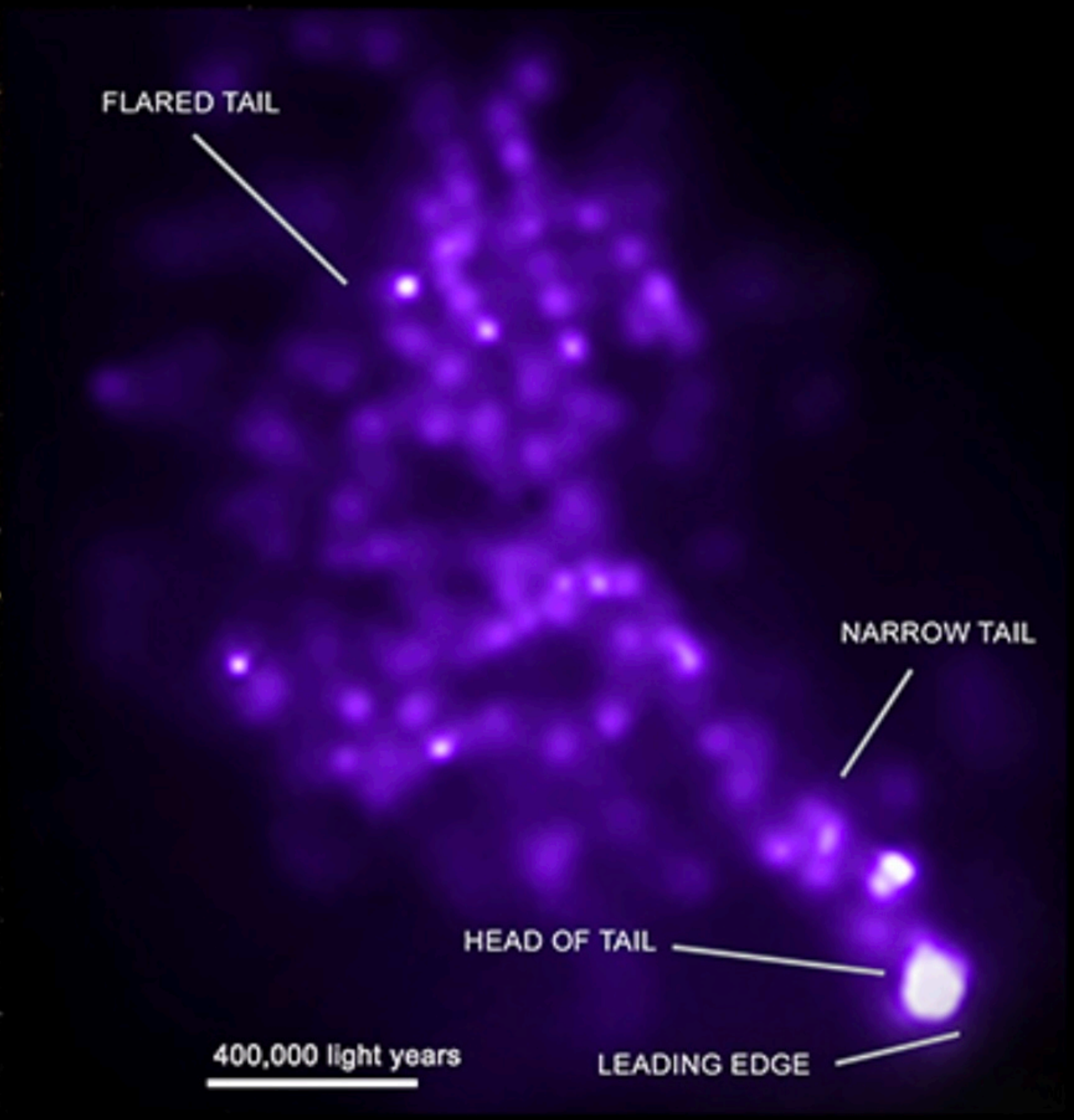


Zhuravleva et al. 2018

Velocities in a ram pressure stripped tail



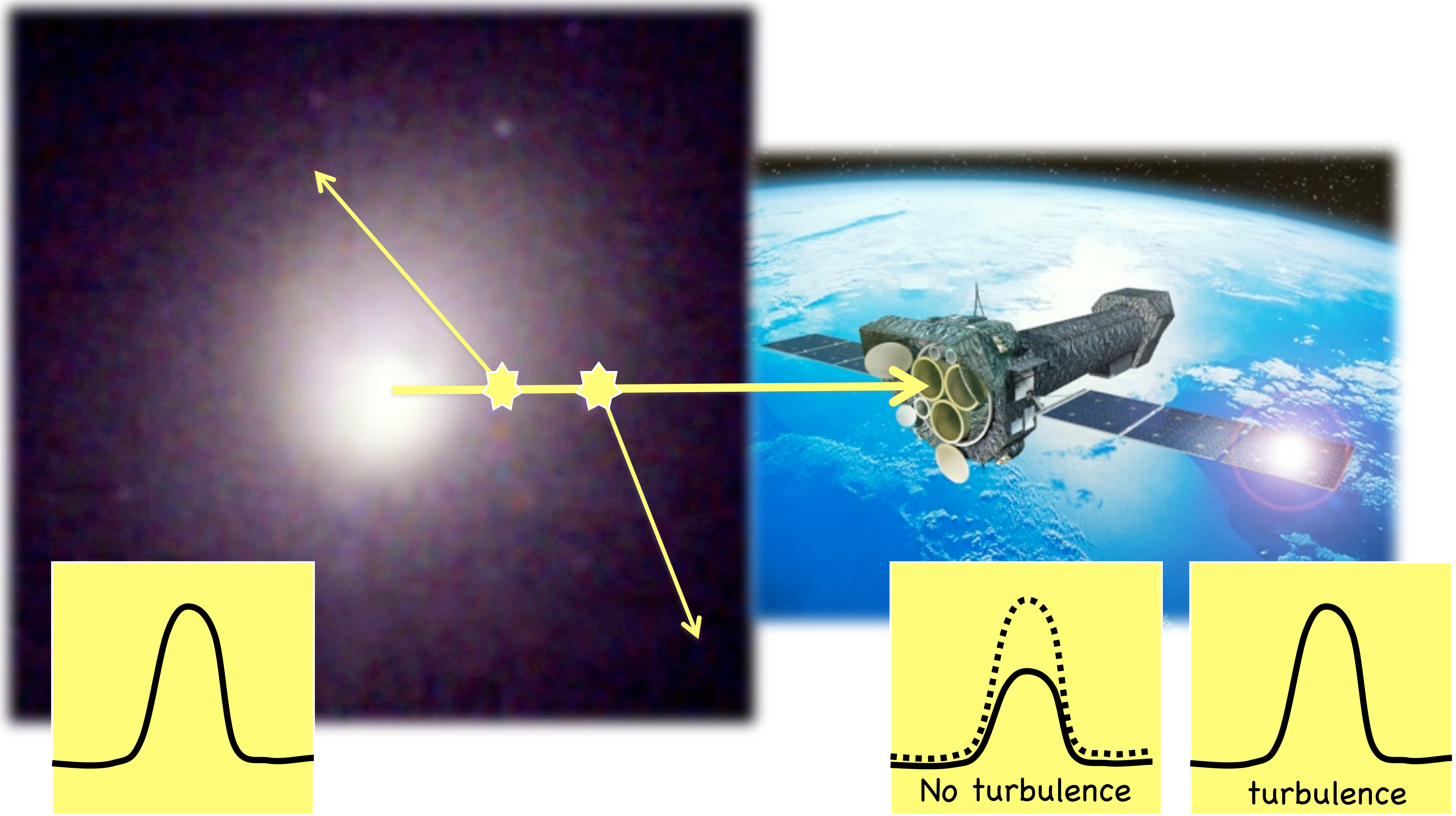
XRAY & OPTICAL



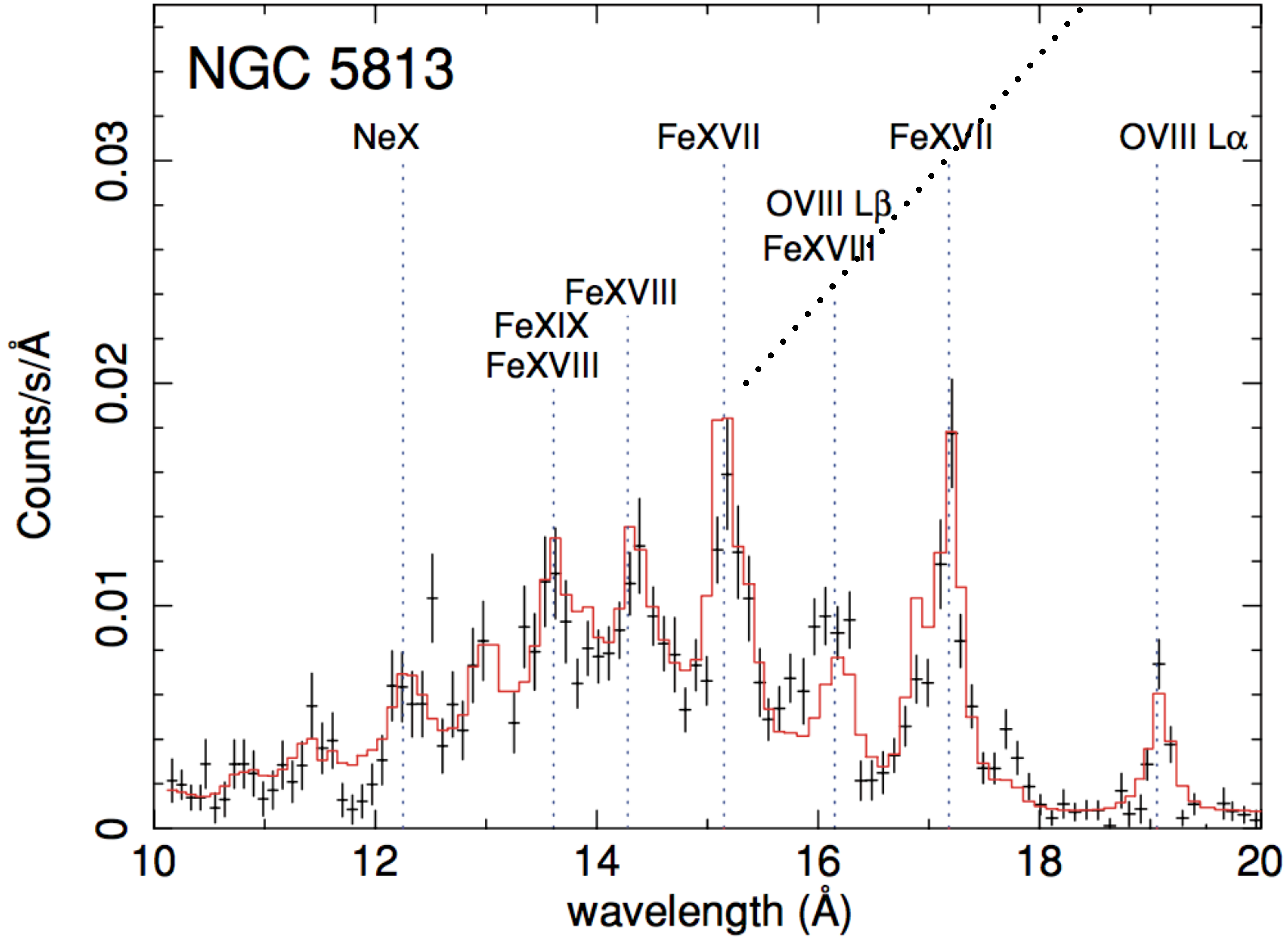
XRAY

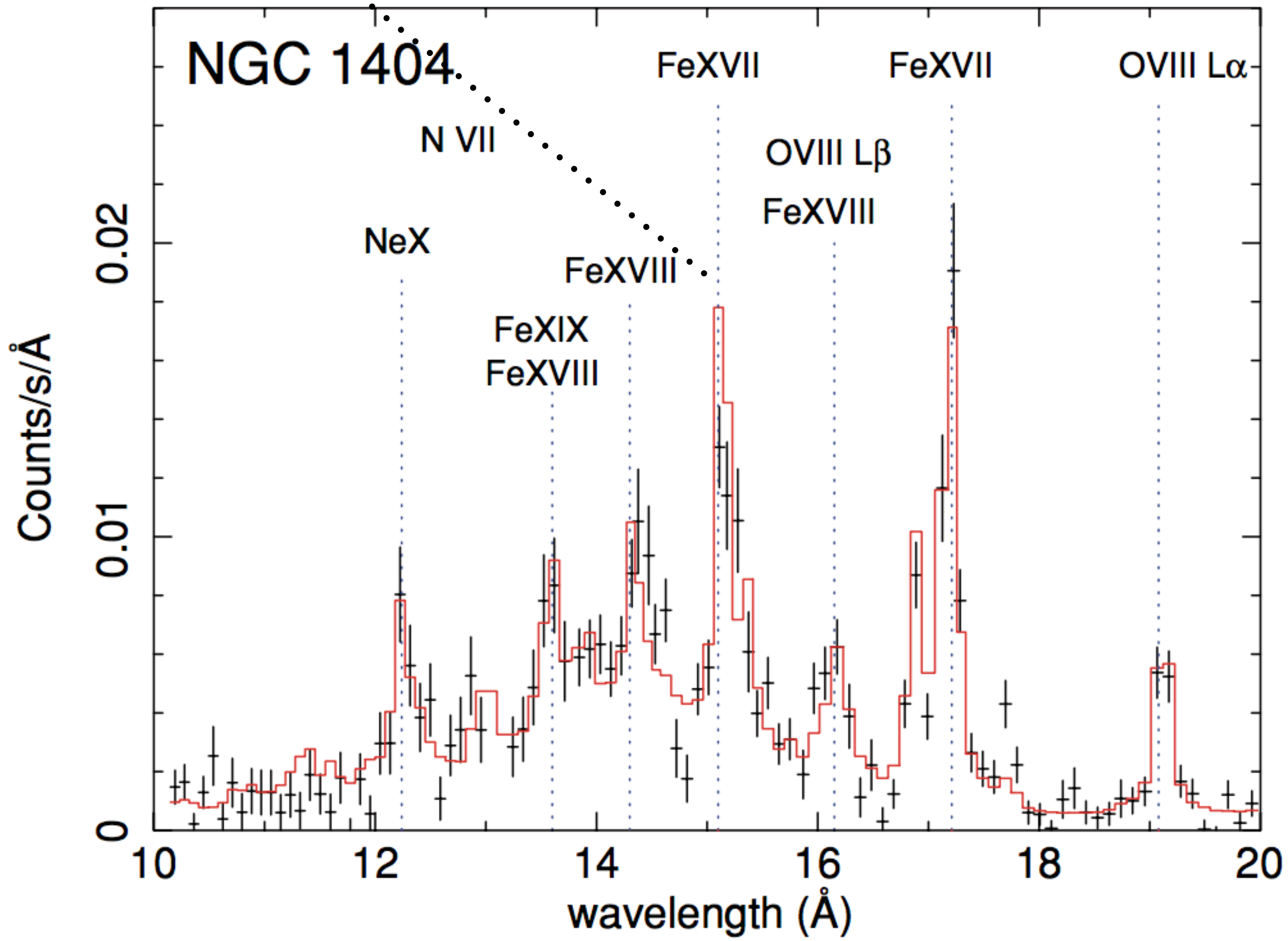
Credit:X-ray: NASA/CXC/Univ. of Geneva, D. Eckert. Optical: SDSS provided by CDS through Aladin

Resonance scattering in optically thick lines

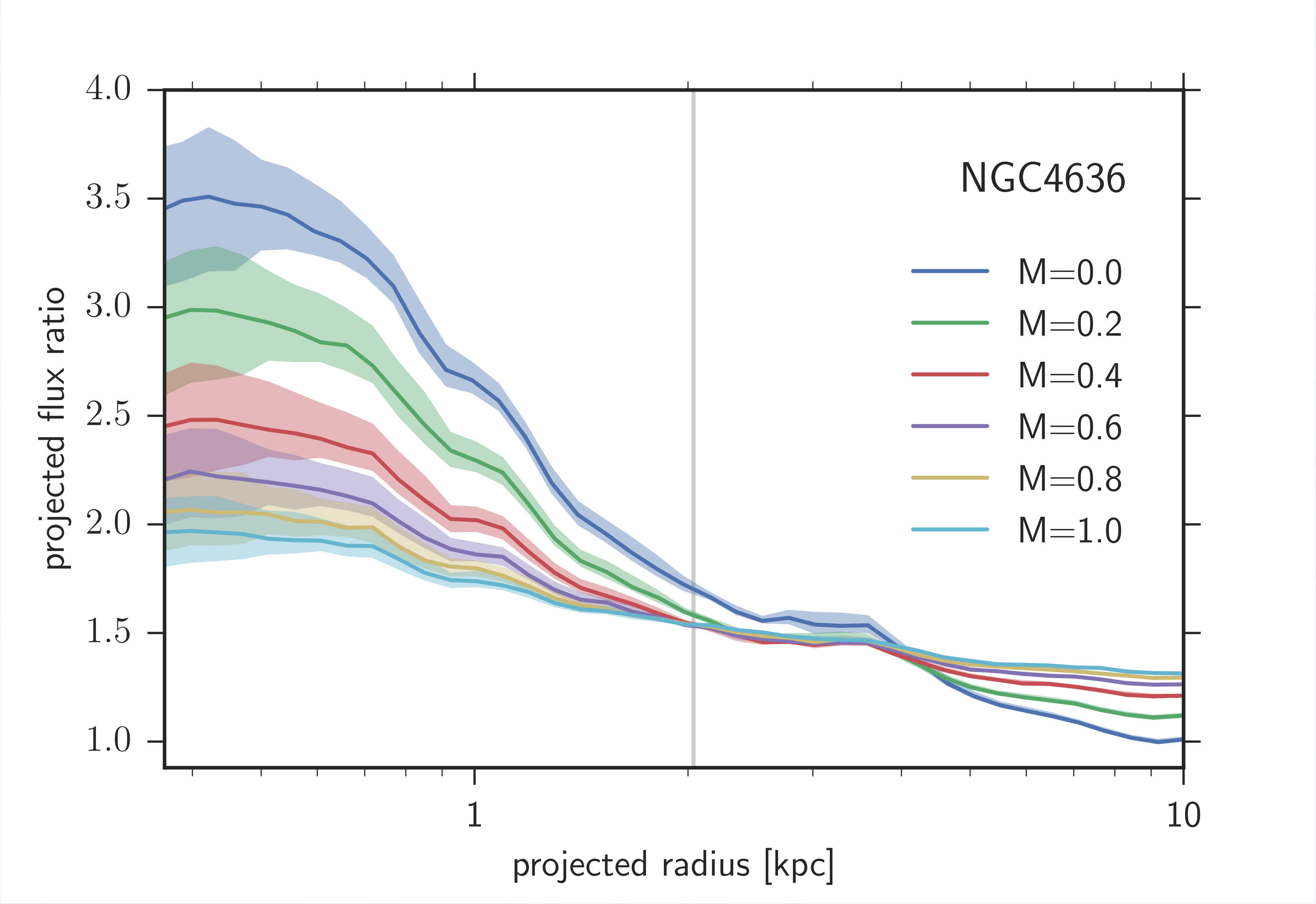


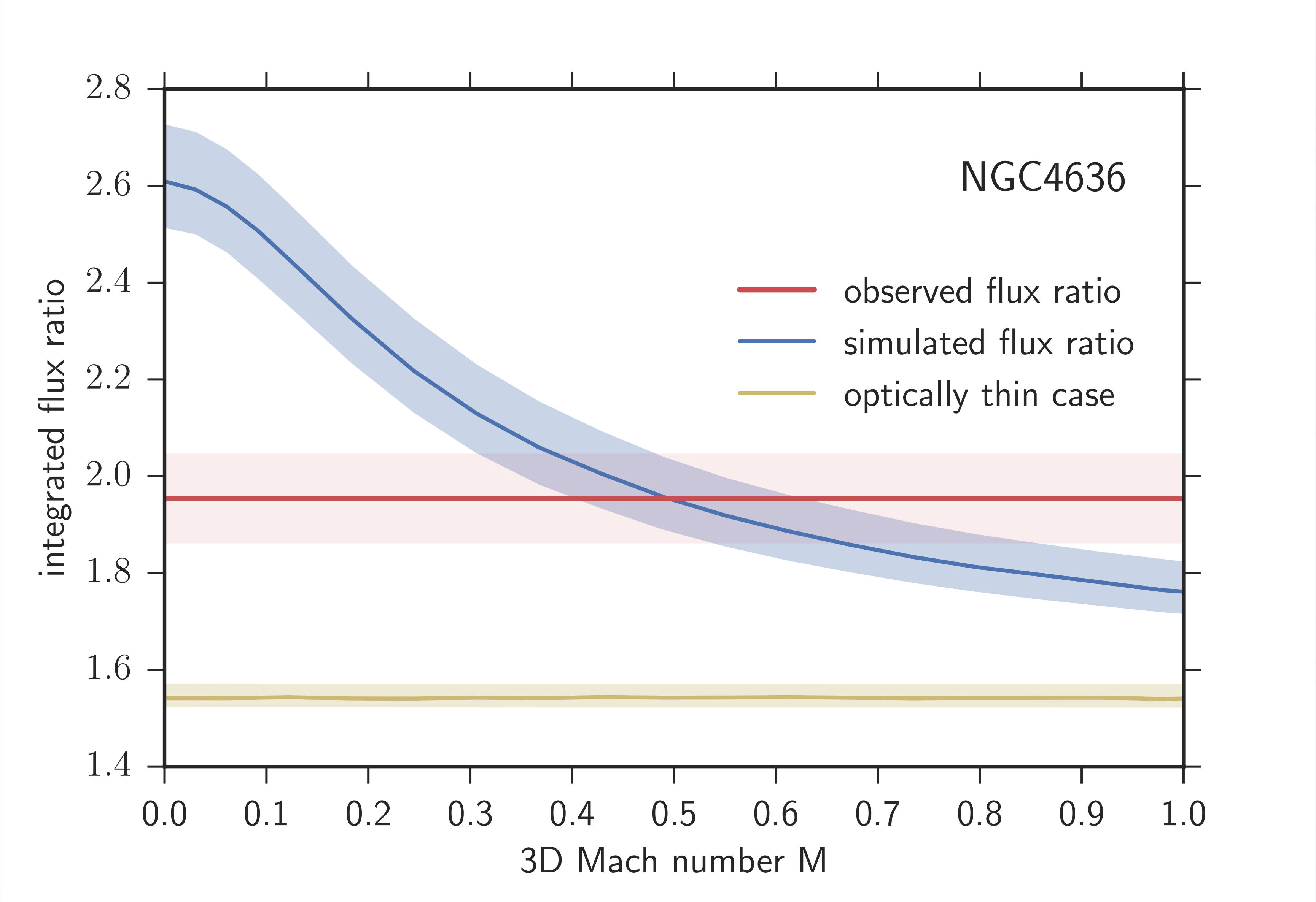
Line suppressed by resonance scattering

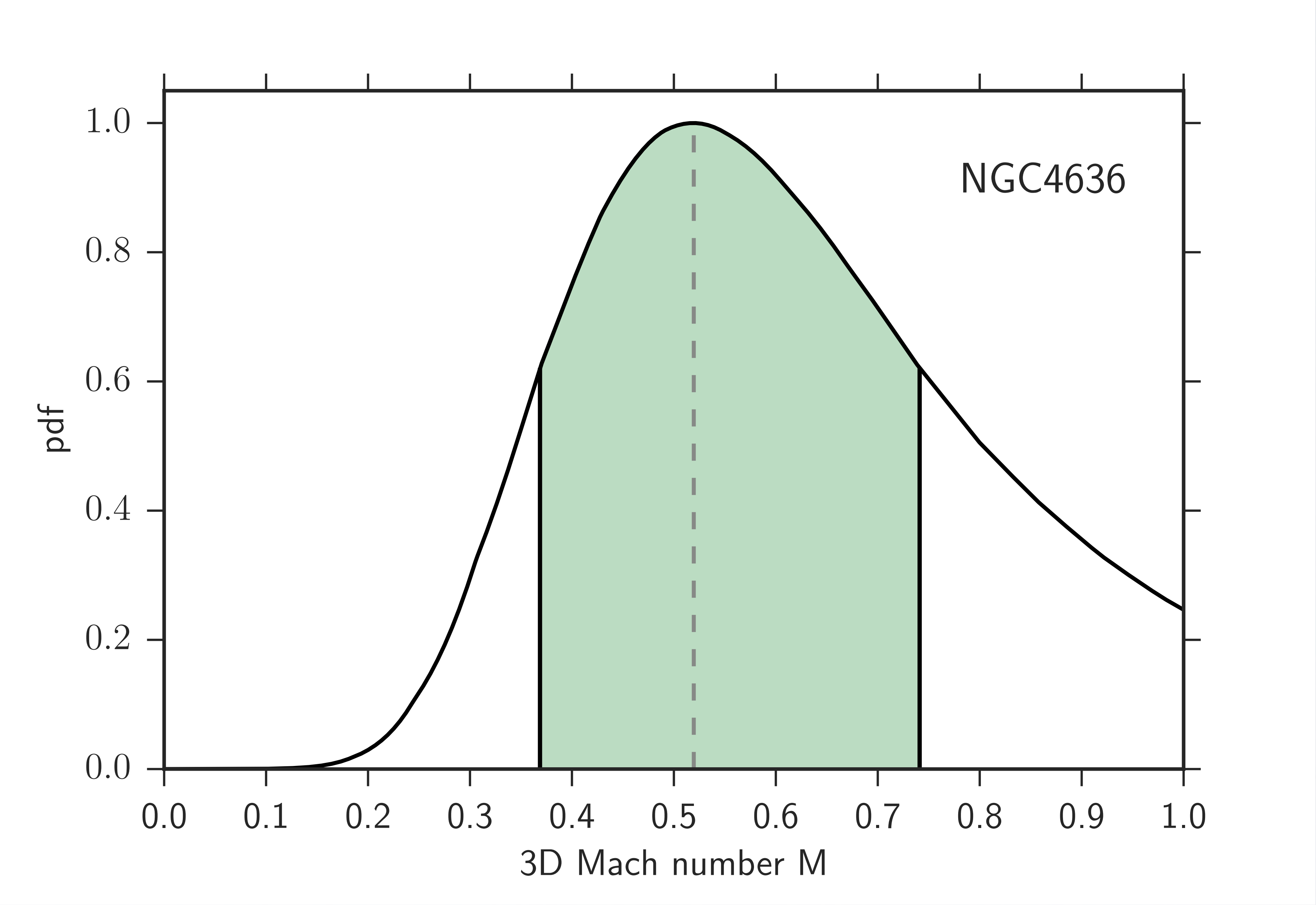




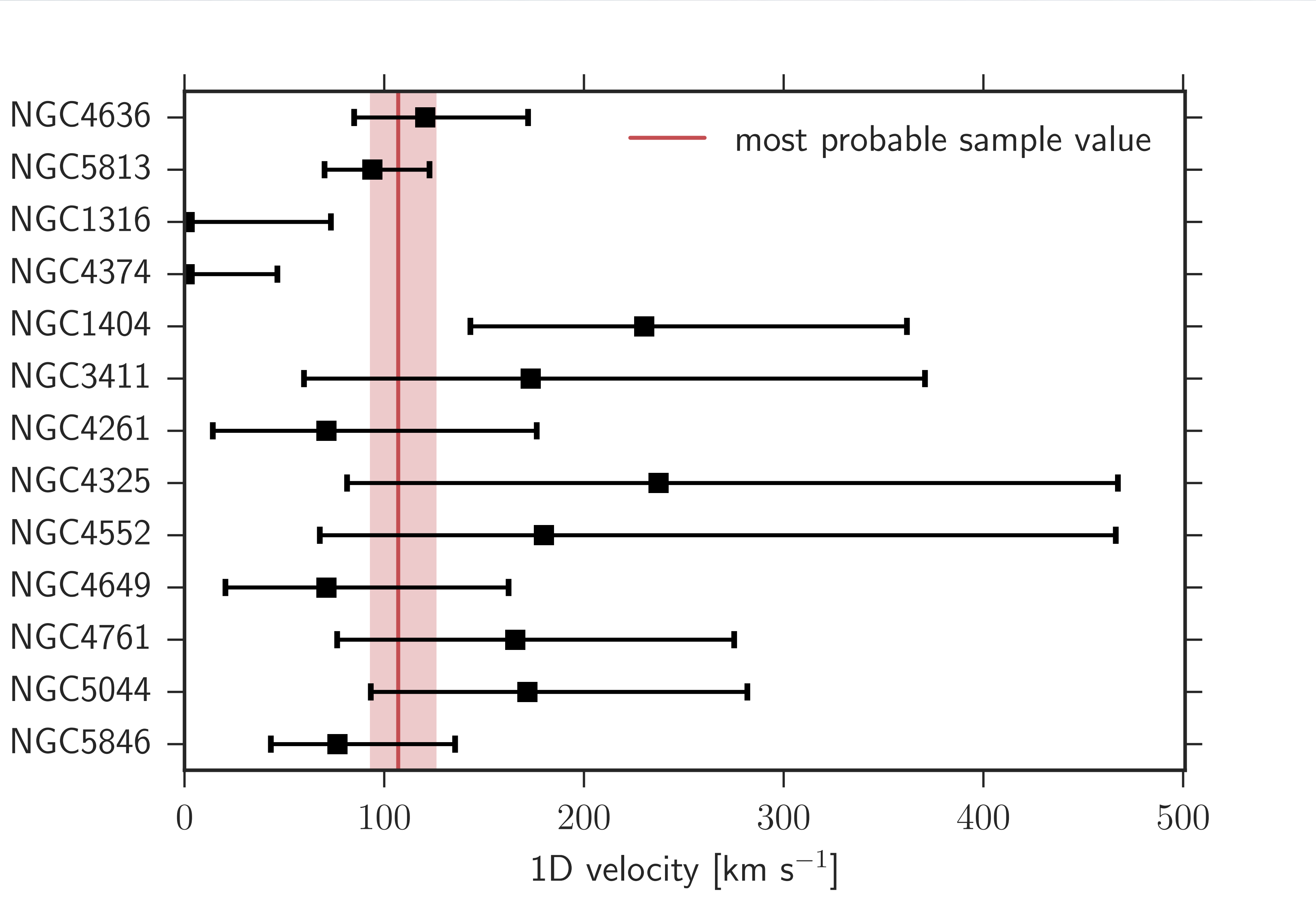
Werner et al. 2009

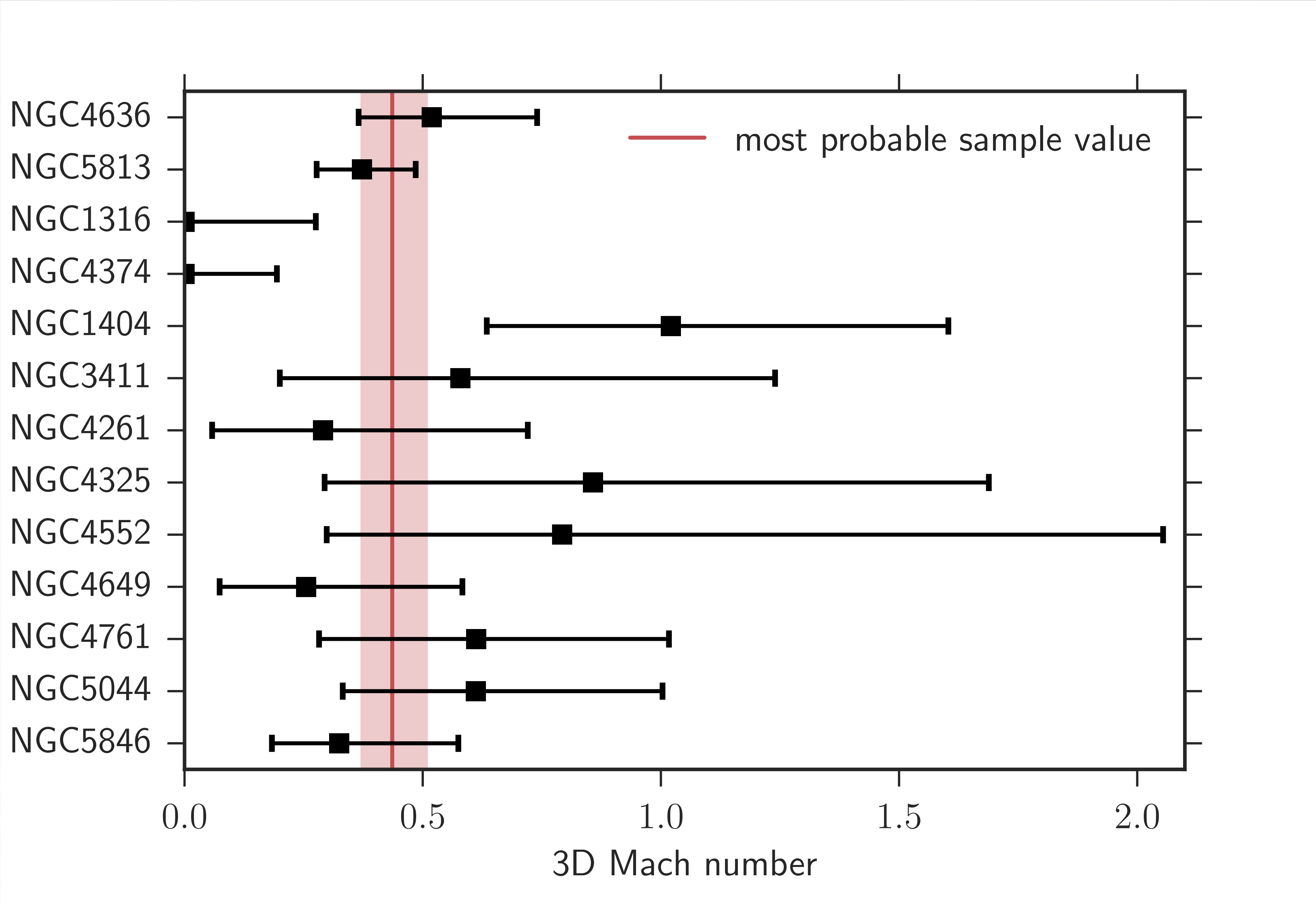


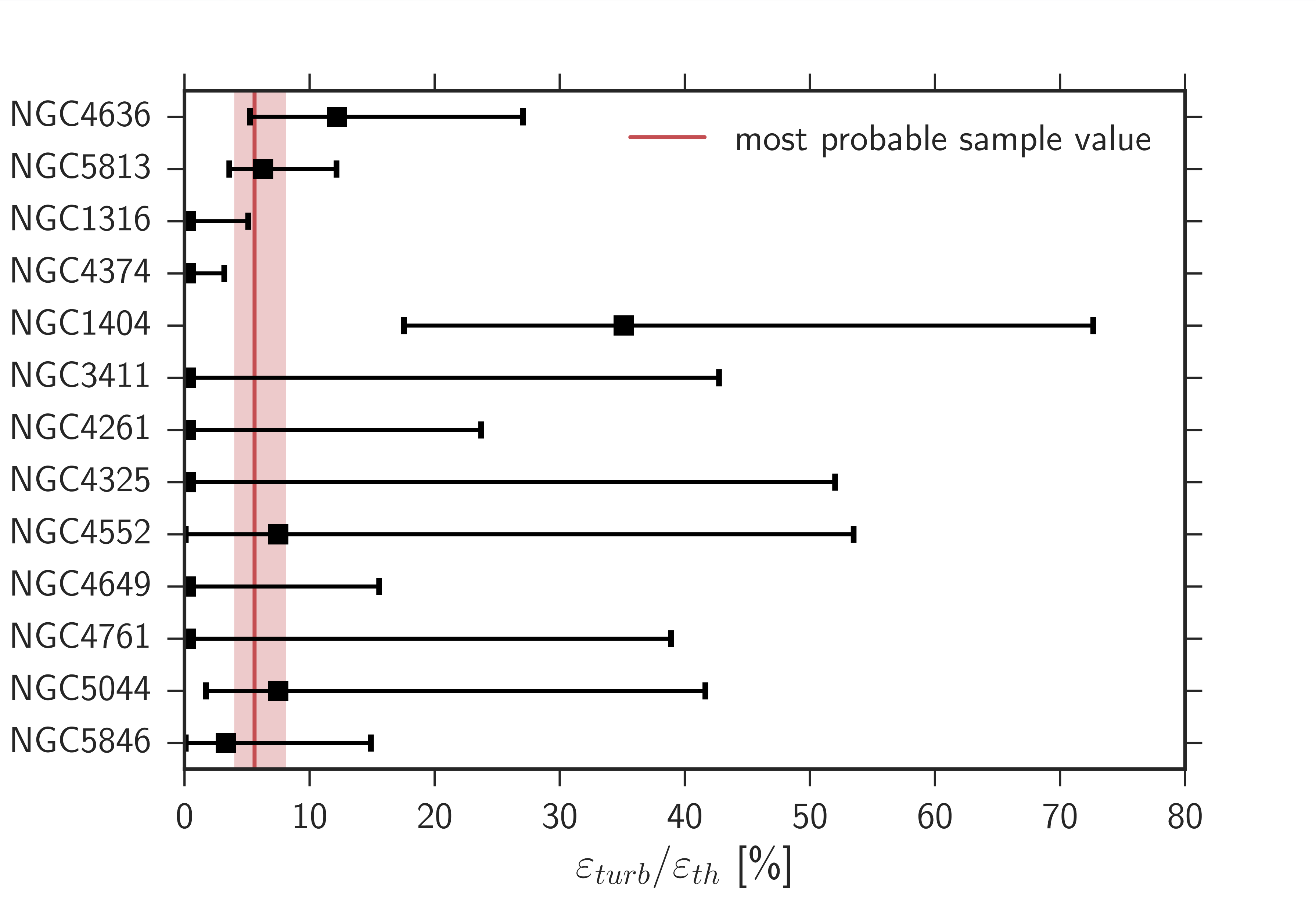




Ogorzalek et al. 2017



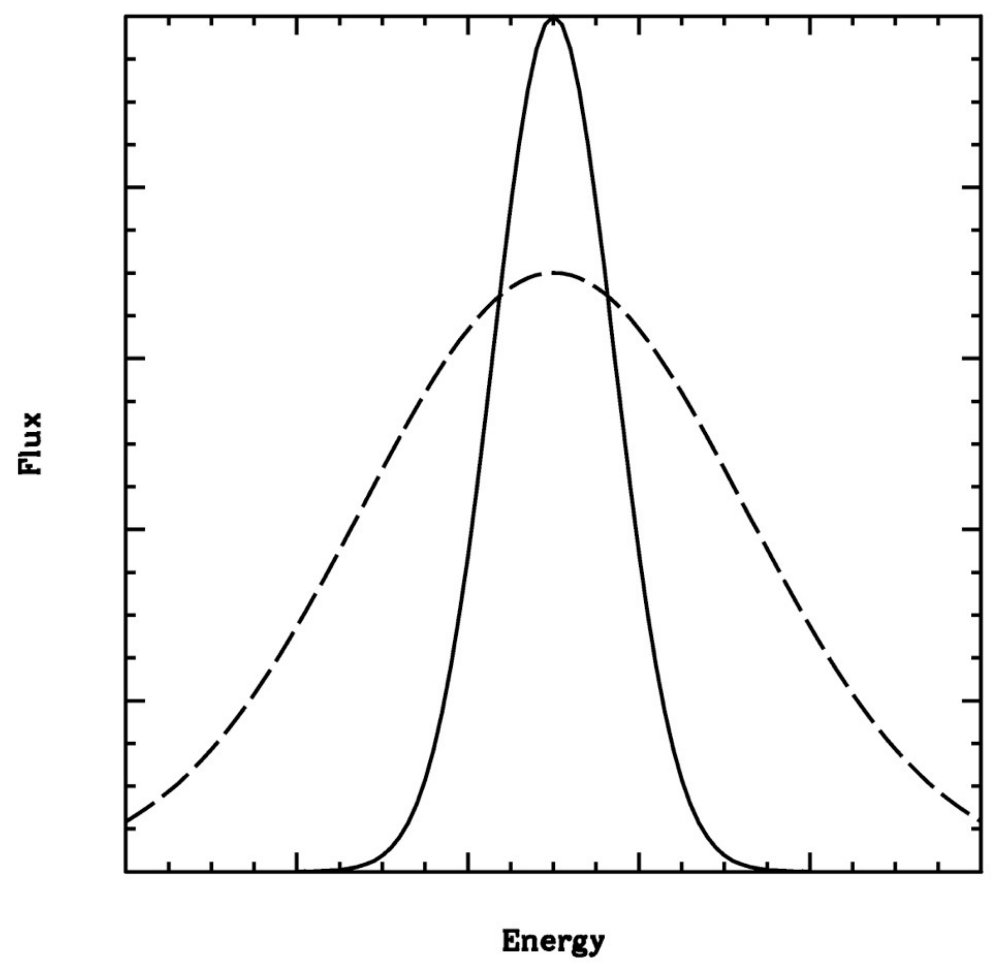




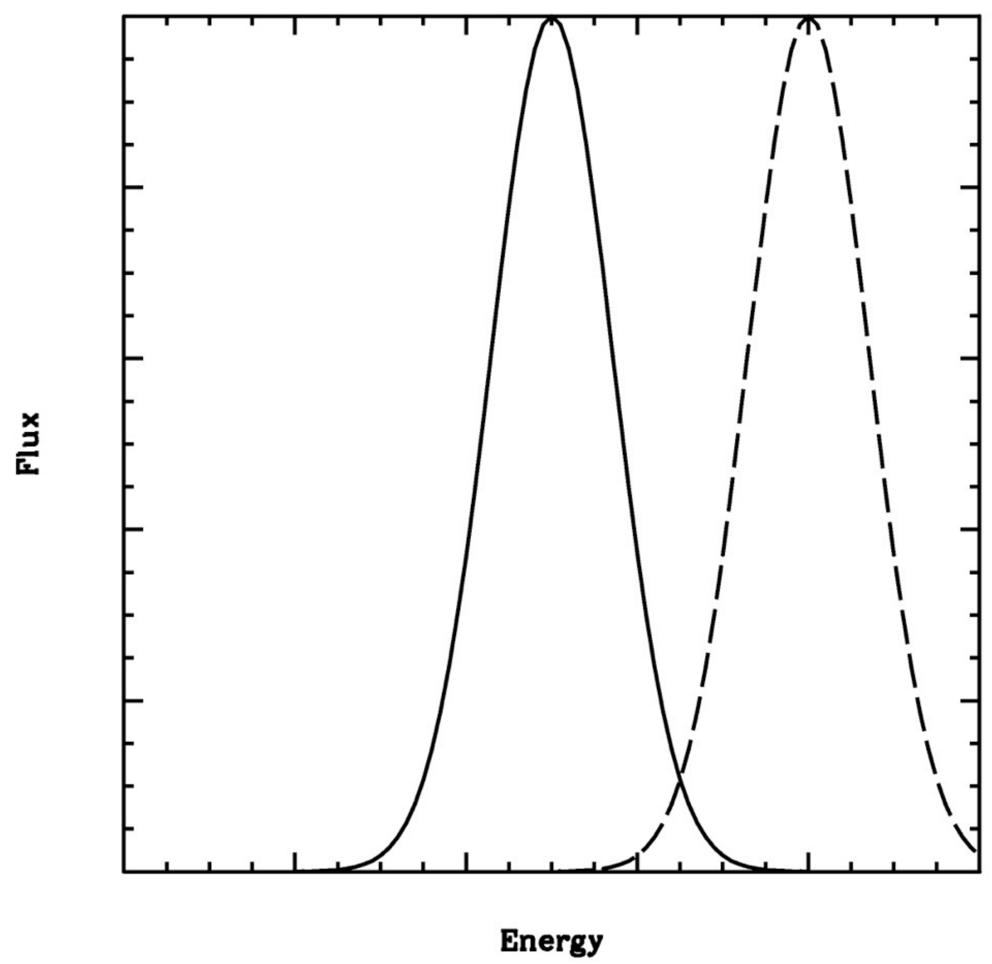
1D velocity 107 km/s
3D velocity of Mach 0.44
pressure support of 5.6 %

scatter consistent with zero
(but errors are large)

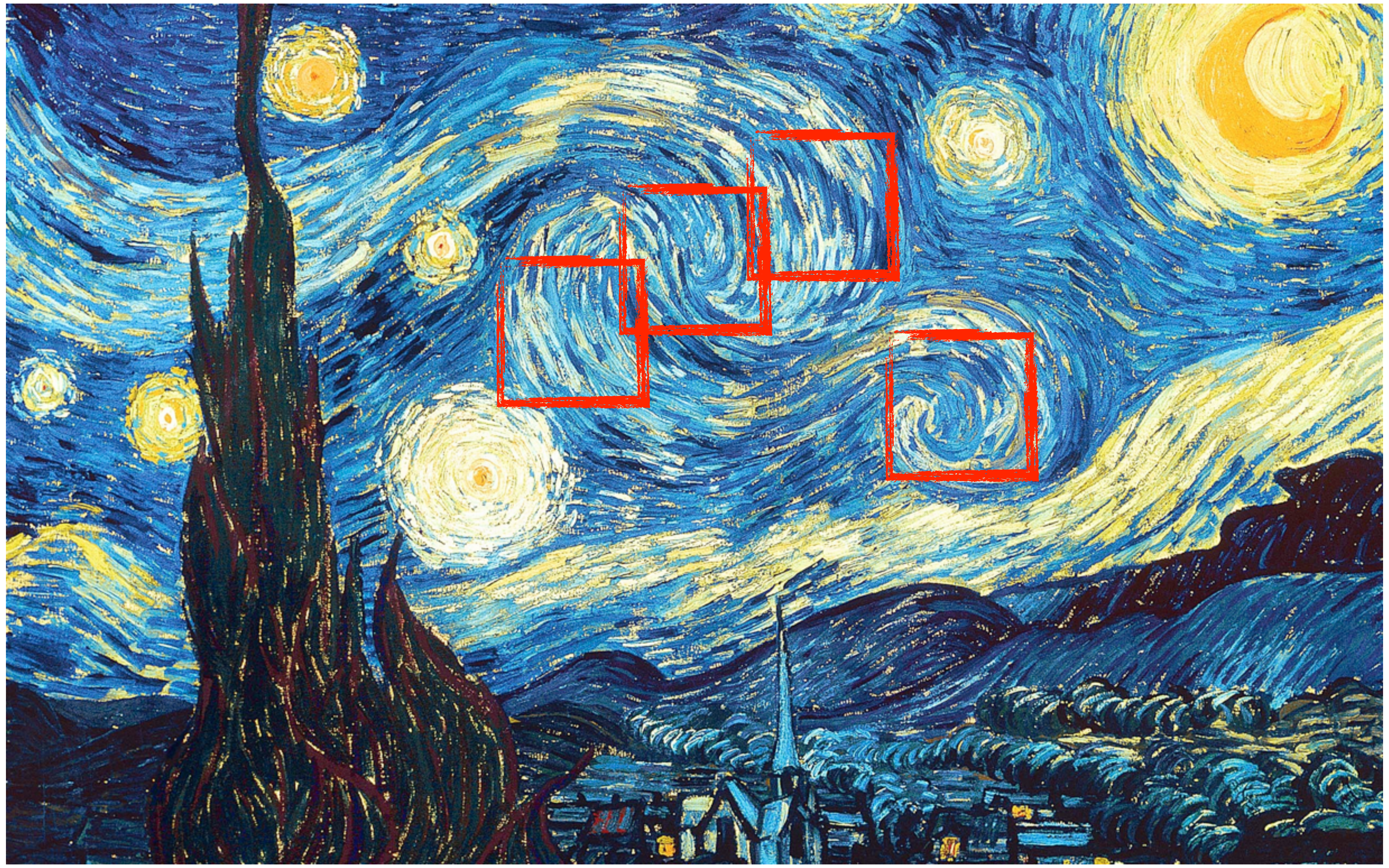
Turbulent and bulk motions



for gas motions on small spatial scales we expect significant line-of-sight velocity dispersion σ, resulting in line broadening, but no centroid shifts



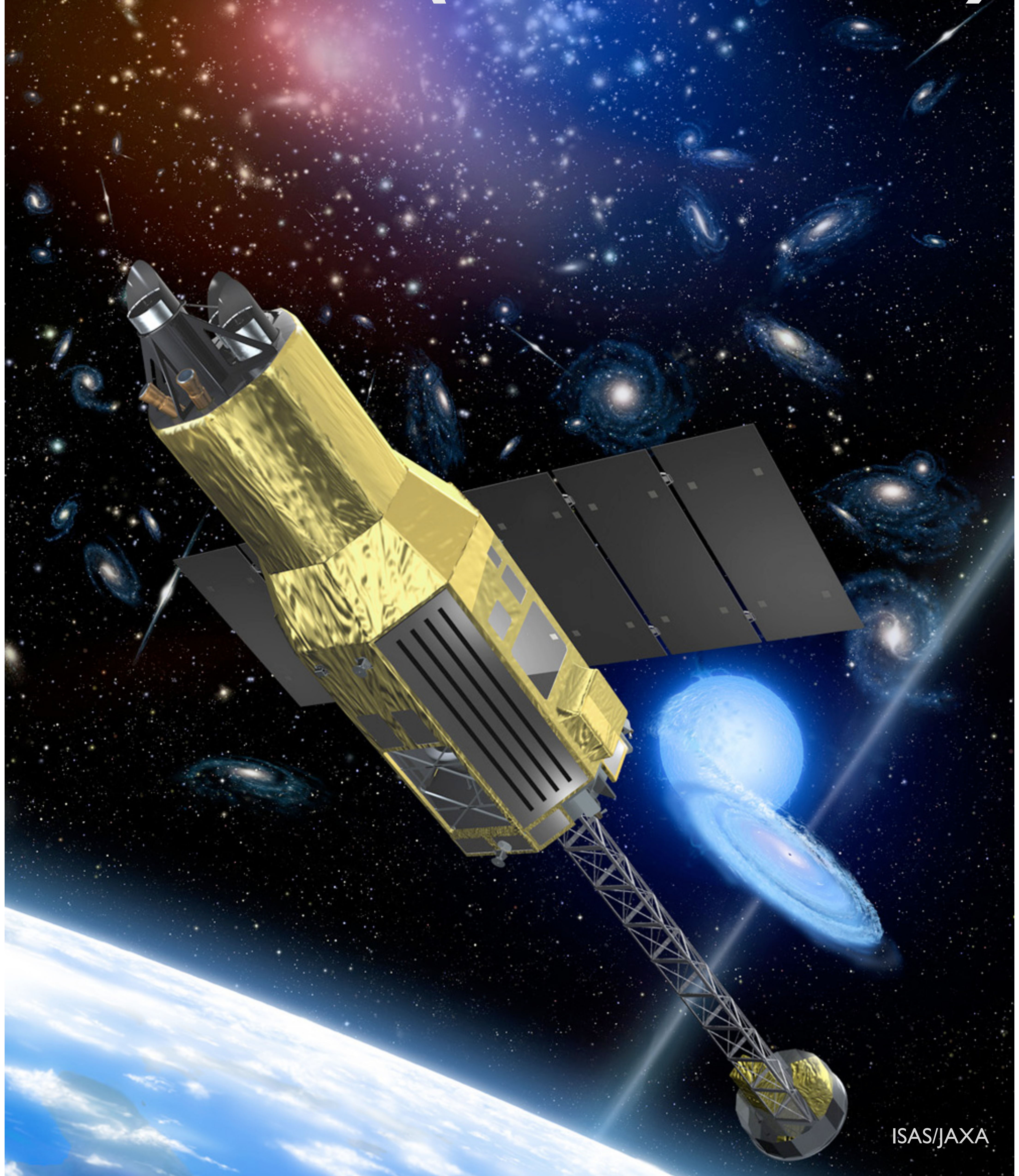
if the spatial scale of motions is large, then we expect significant centroid shifts



Hitomi (ASTRO-H)

JAXA
Japan Aerospace Exploration Agency

with a contribution of other Japanese universities and institutes



NASA

esa

SRON

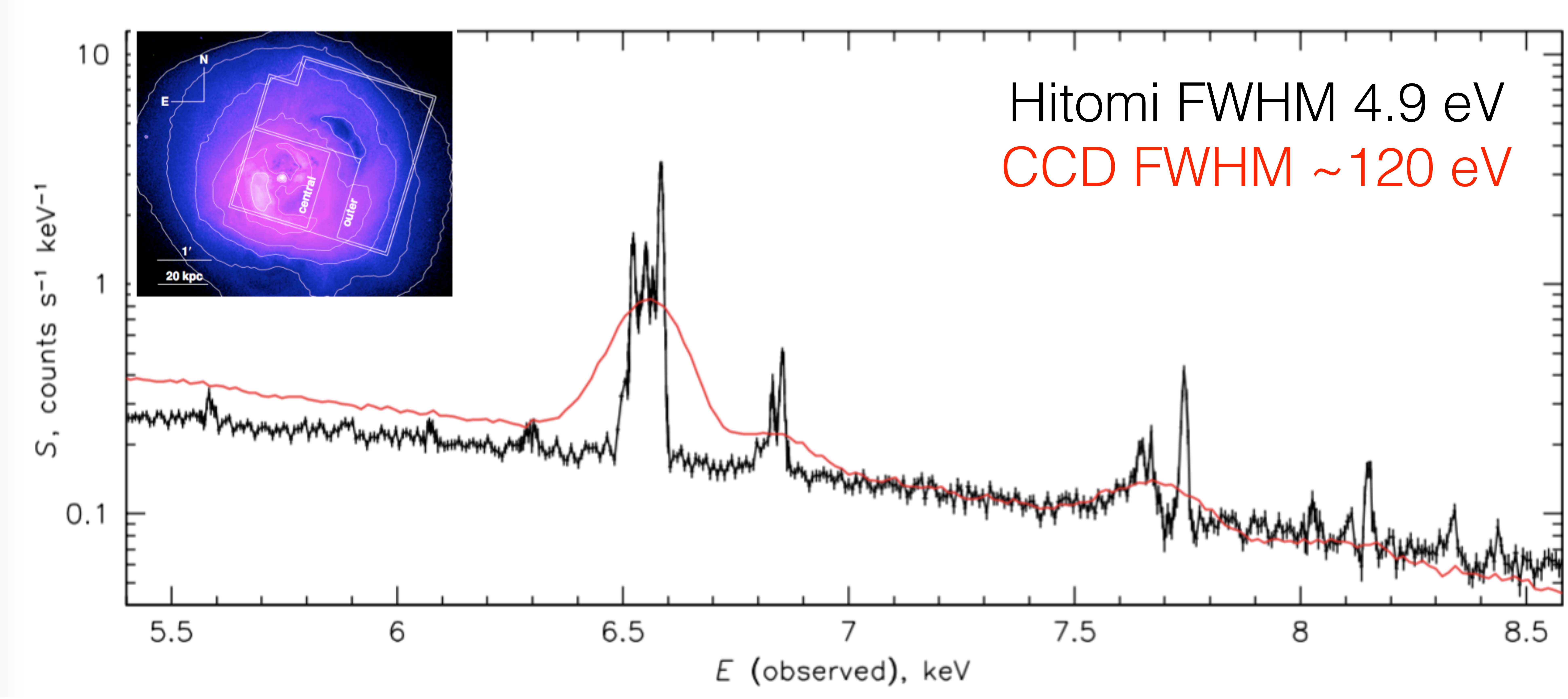
KIPAC

CSA ASC

with a contribution of other US/EU universities and institutes

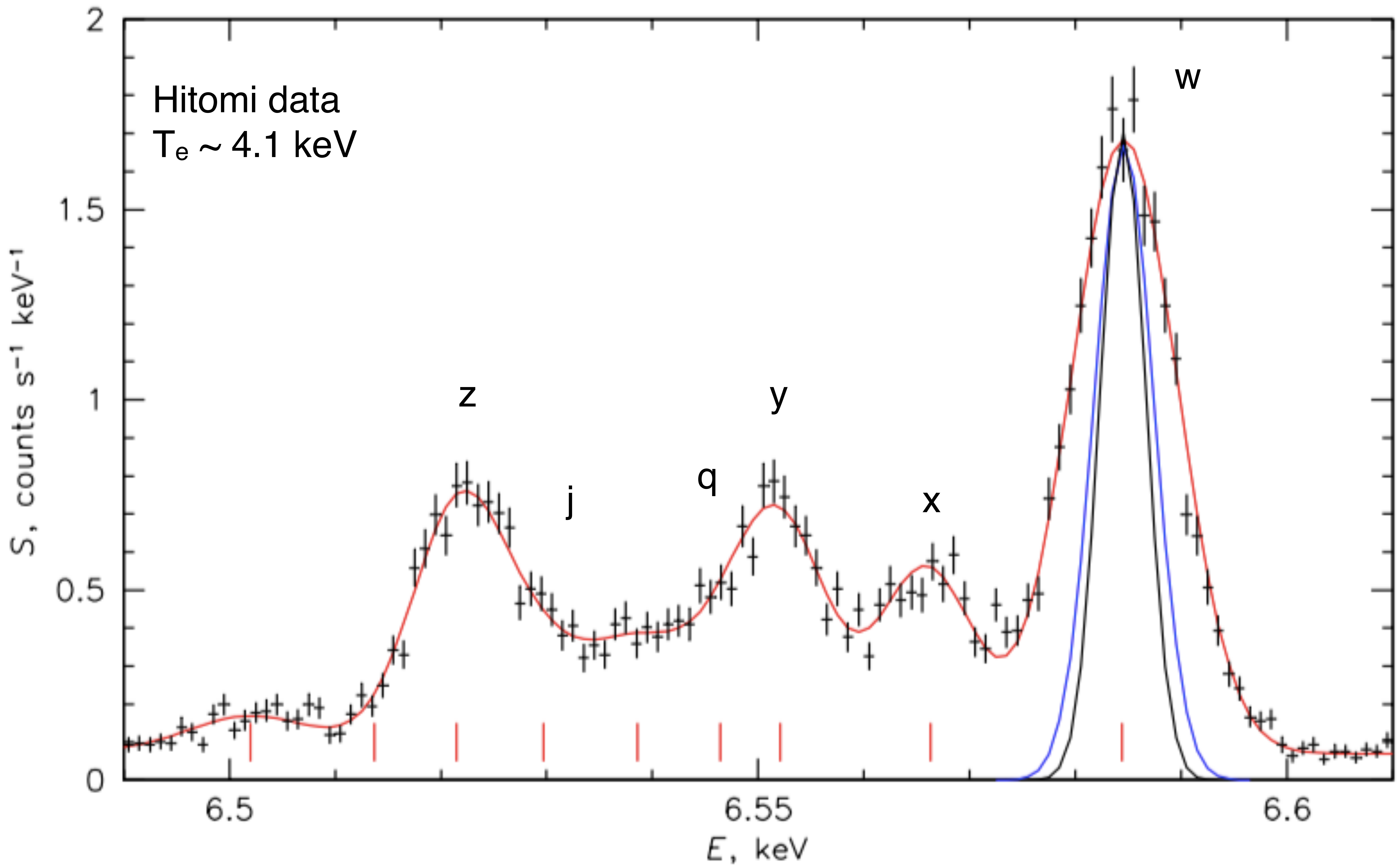
Hitomi (ASTRO-H) Observation

X-ray spectrum of the core of the Perseus cluster



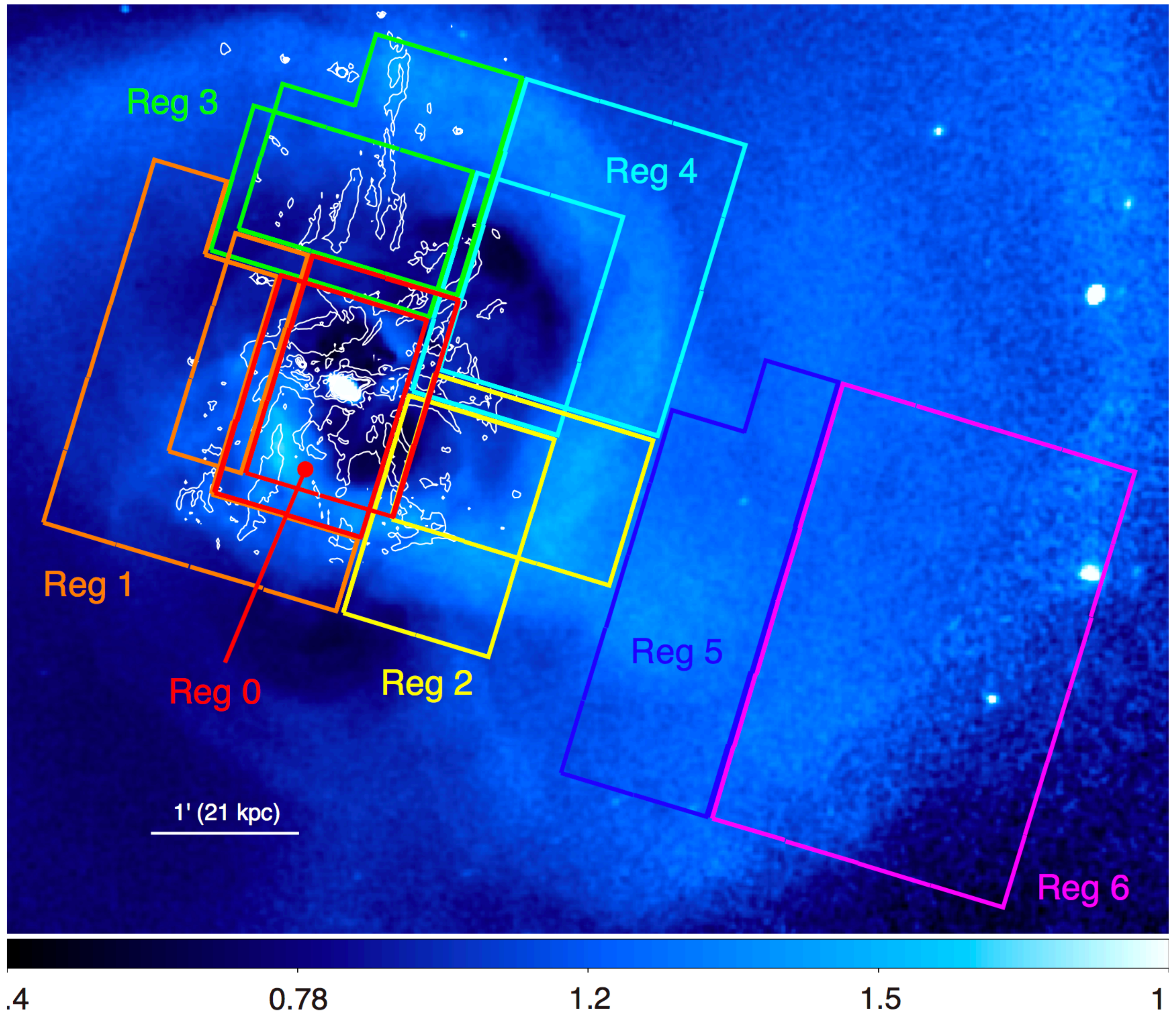
Hitomi collaboration, Nature, 2016

Fe XXV Heα

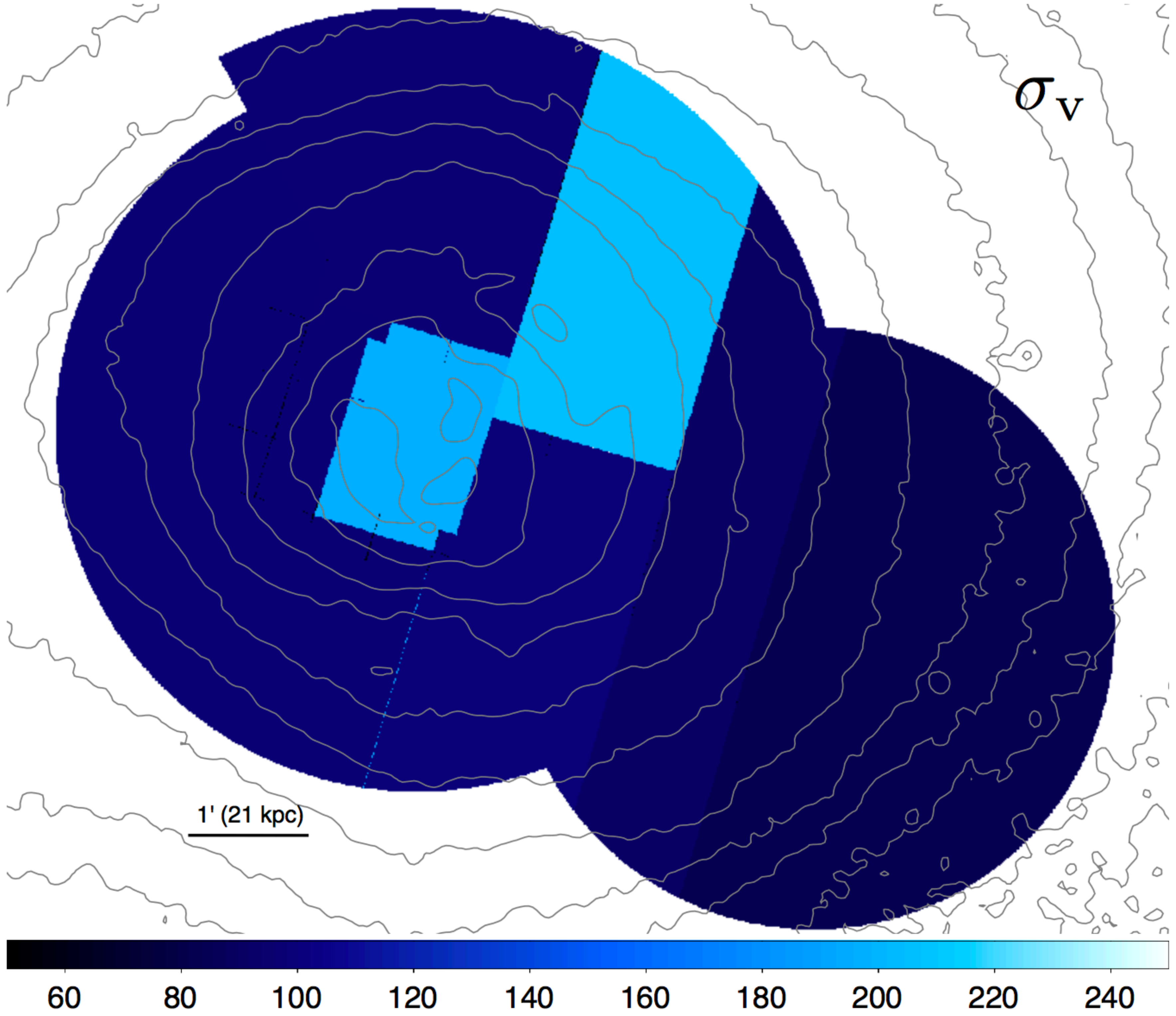


Hitomi collaboration, Nature, 2016

First Direct Velocity Measurements



line broadening

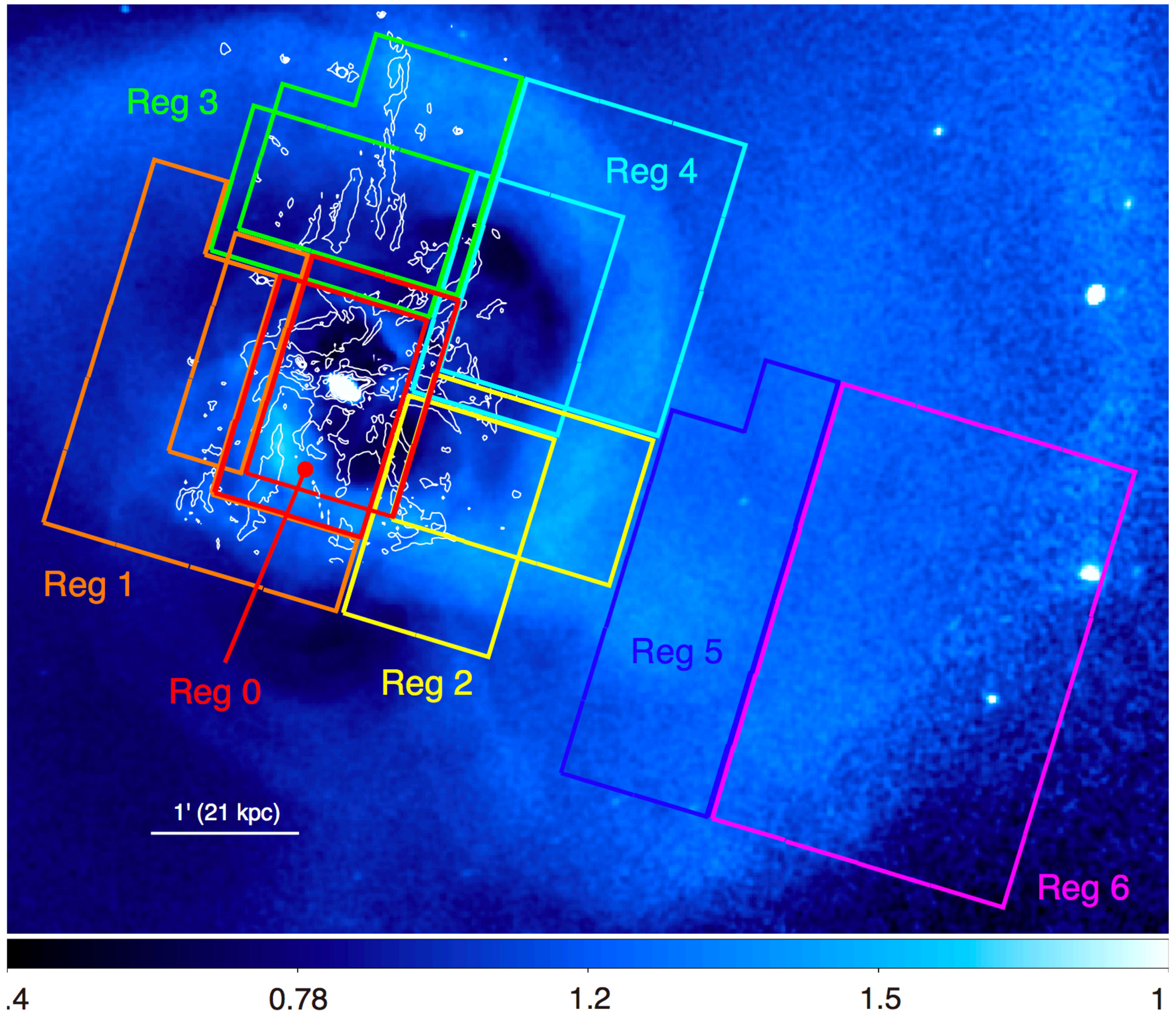


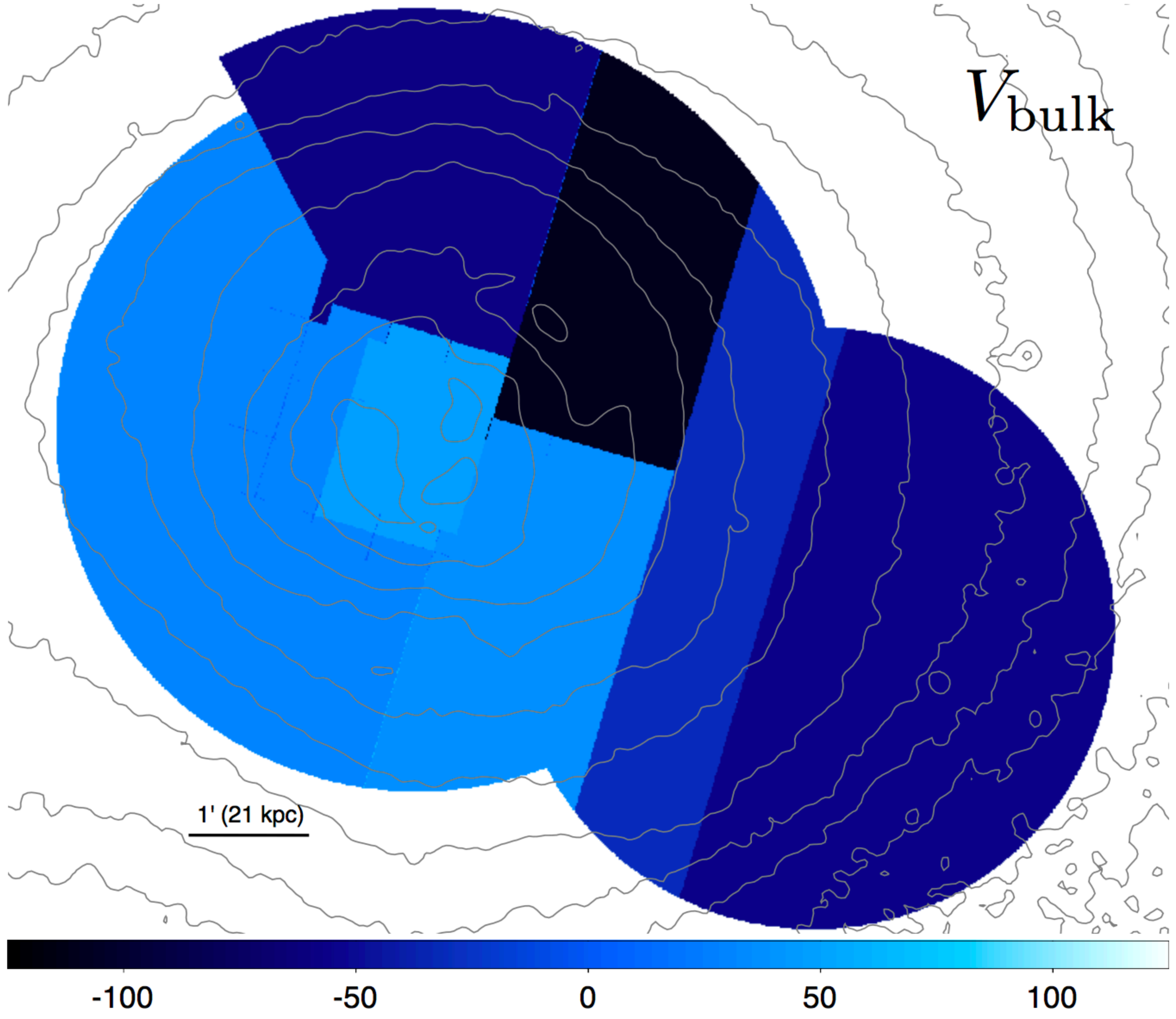
E_{turb}/E_{therm} ~ 2–6%

Hitomi collaboration, PASJ 2018

First Direct Velocity Measurements

line shifts

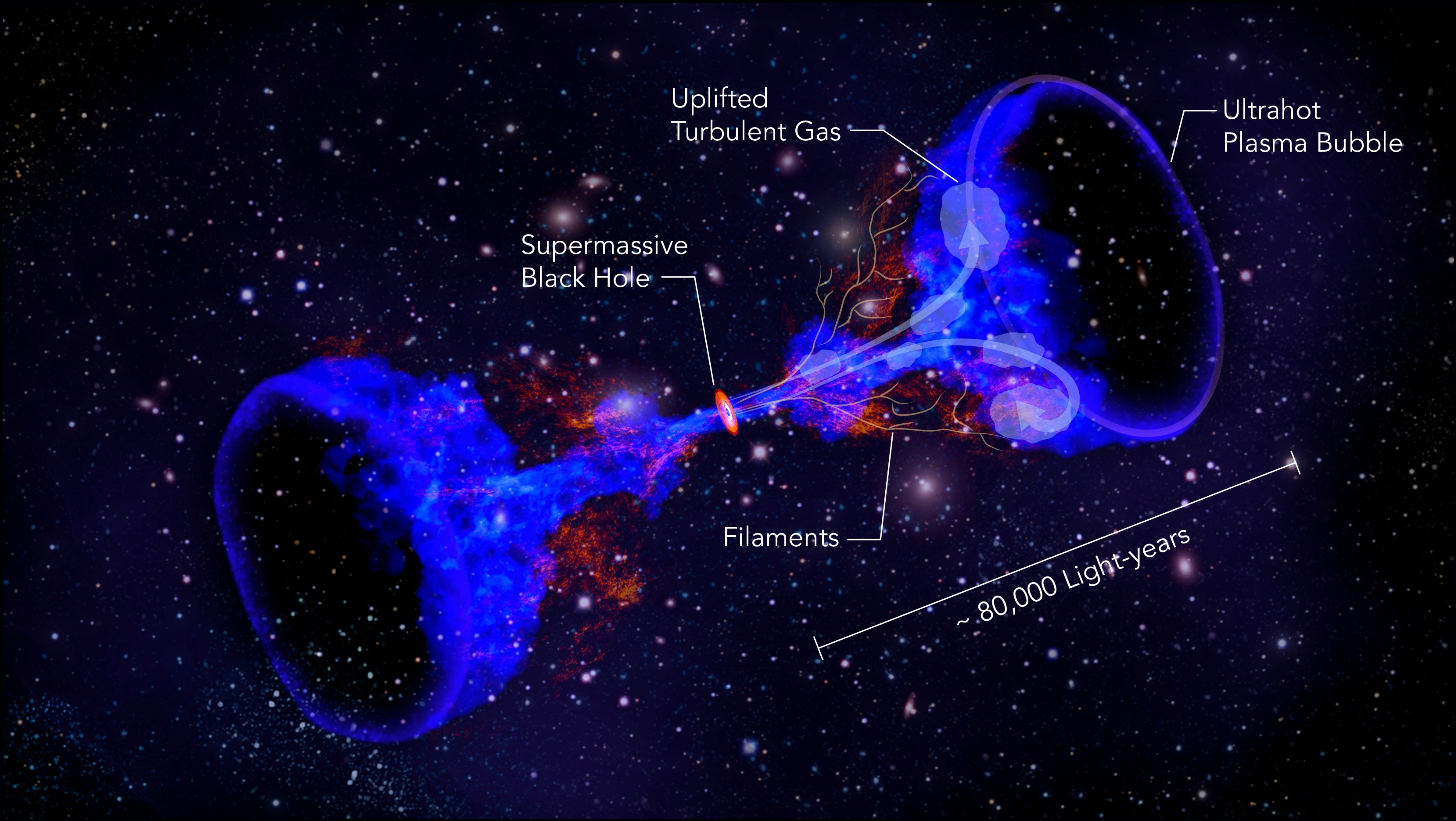


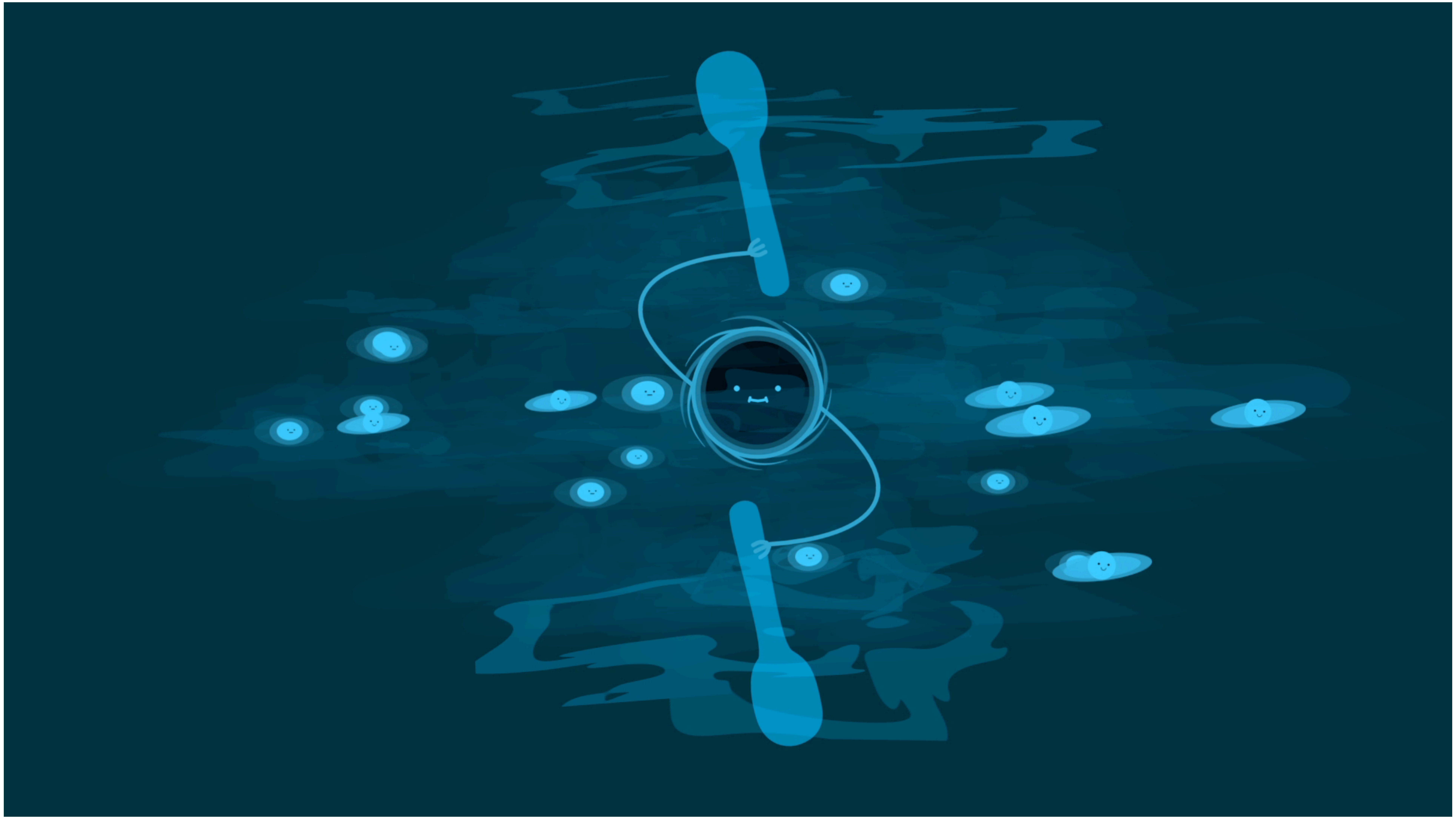


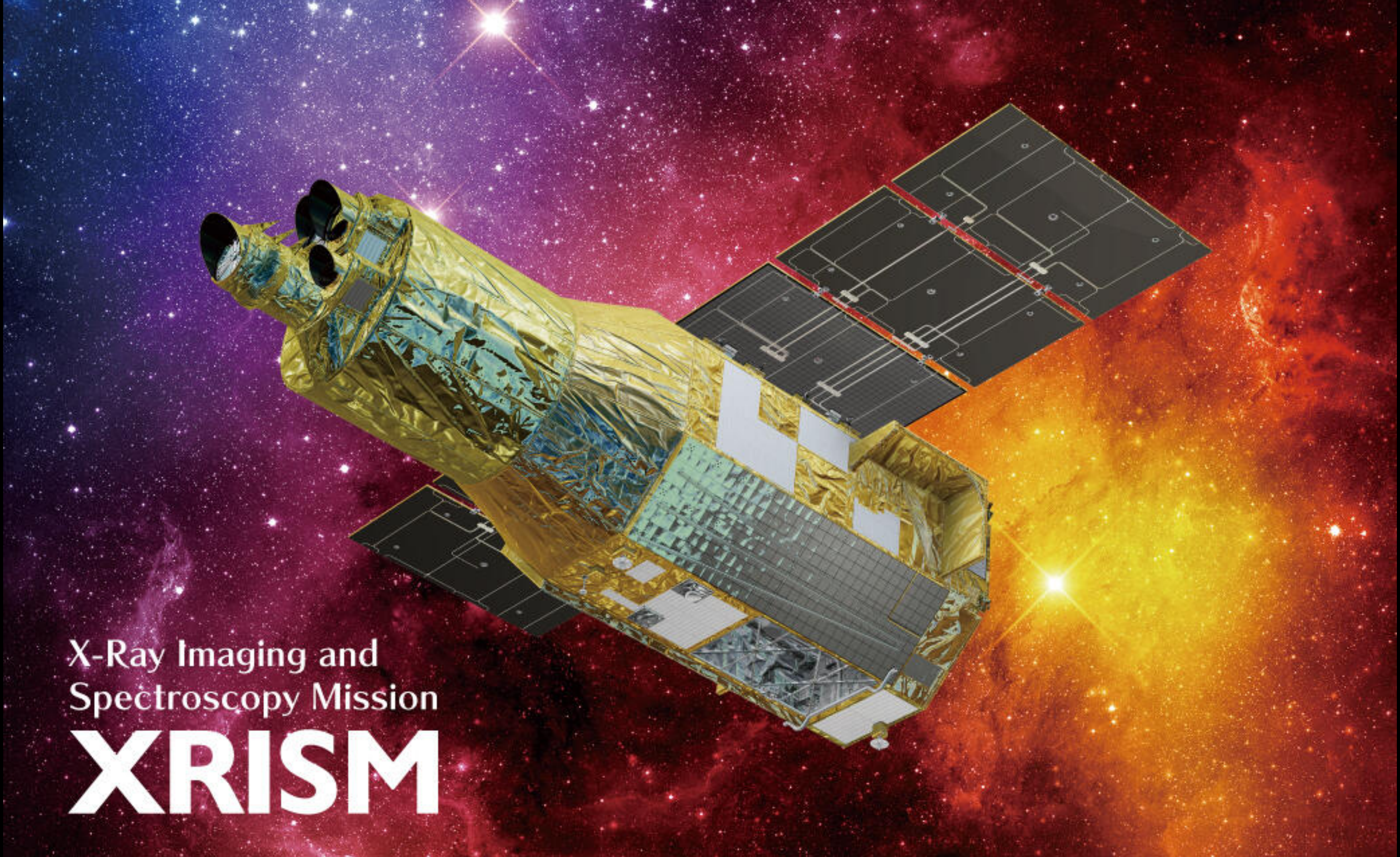
[km/s]

$$\frac{\epsilon_{\rm kin}}{\epsilon_{\rm therm}} = \frac{\mu m_{\rm p}(3\sigma_{\rm v}^2 + V_{\rm bulk}^2)}{3kT} \sim 0.02 - 0.07$$

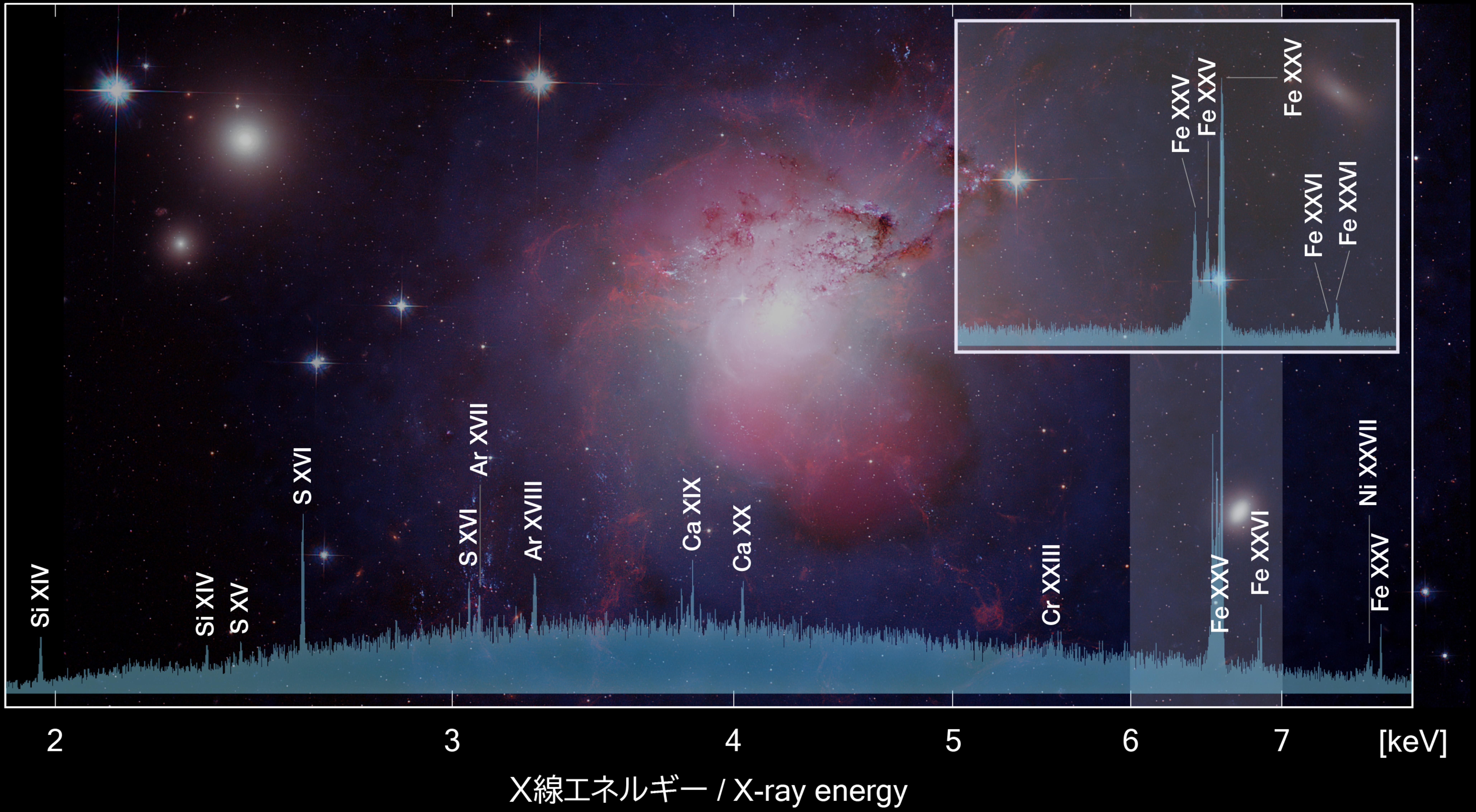
Hitomi collaboration, PASJ 2018

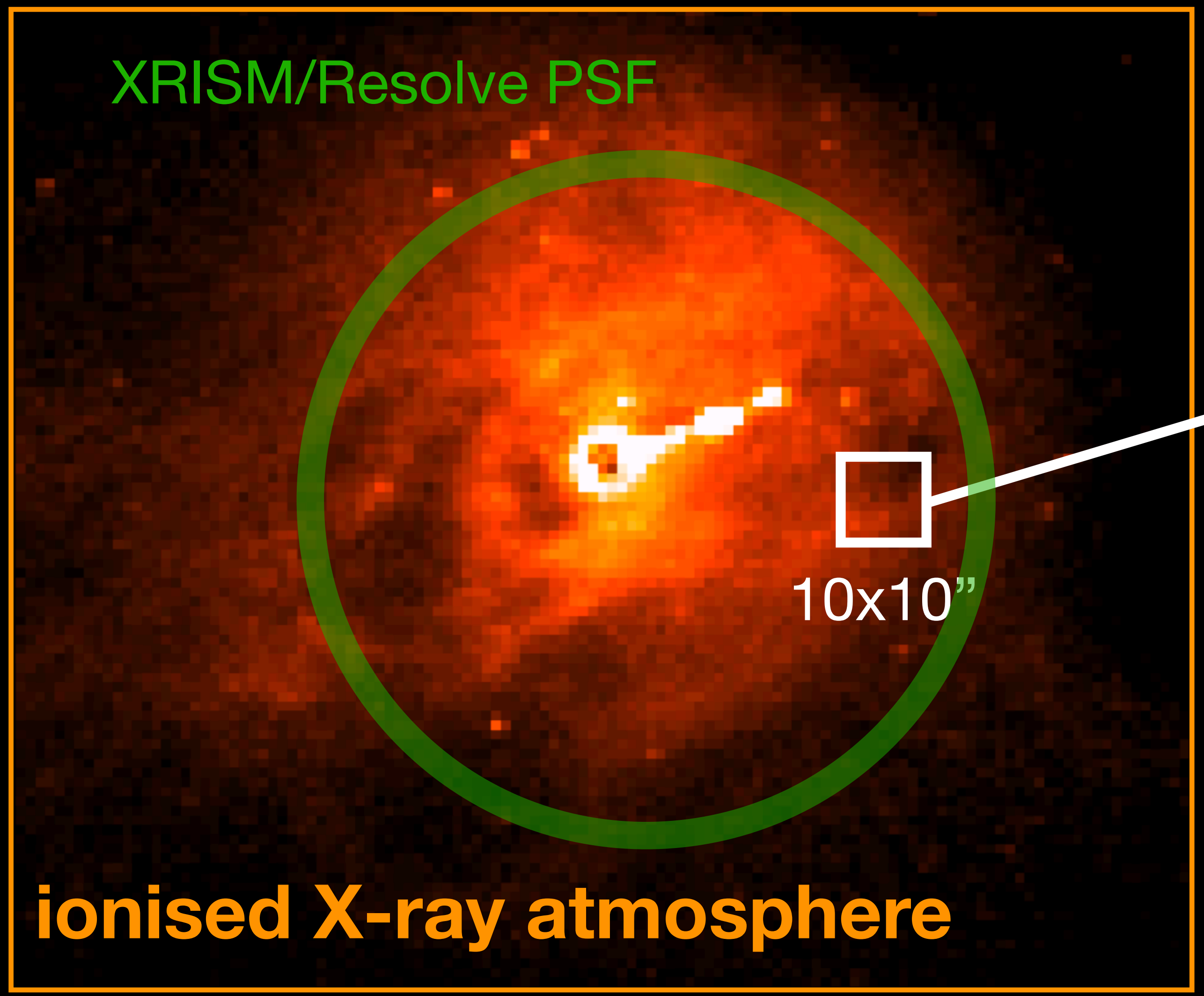

Uplifted
Turbulent Gas
Ultrahot
Plasma Bubble
Supermassive
Black Hole
Filaments
~ 80,000 Light-years

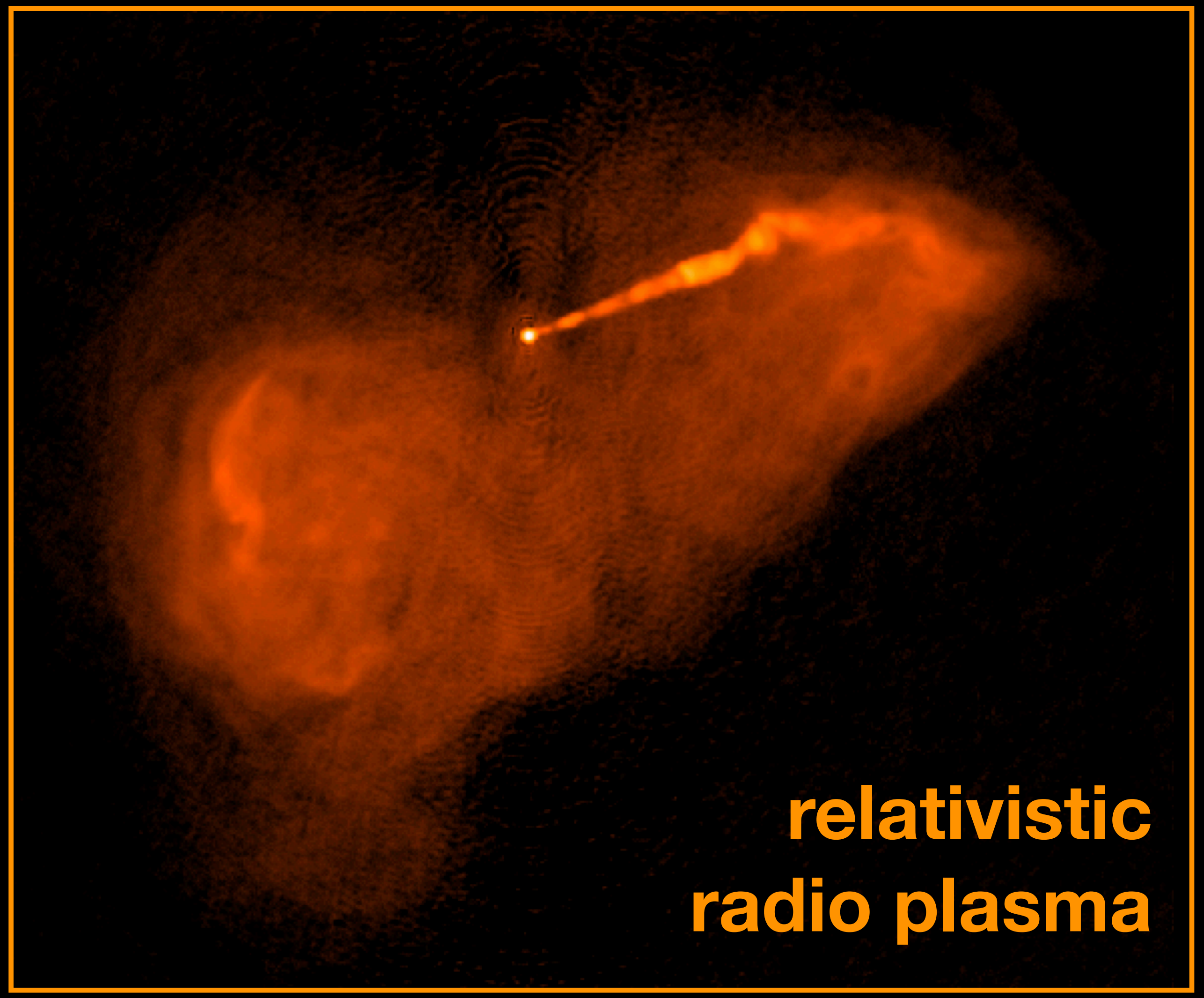


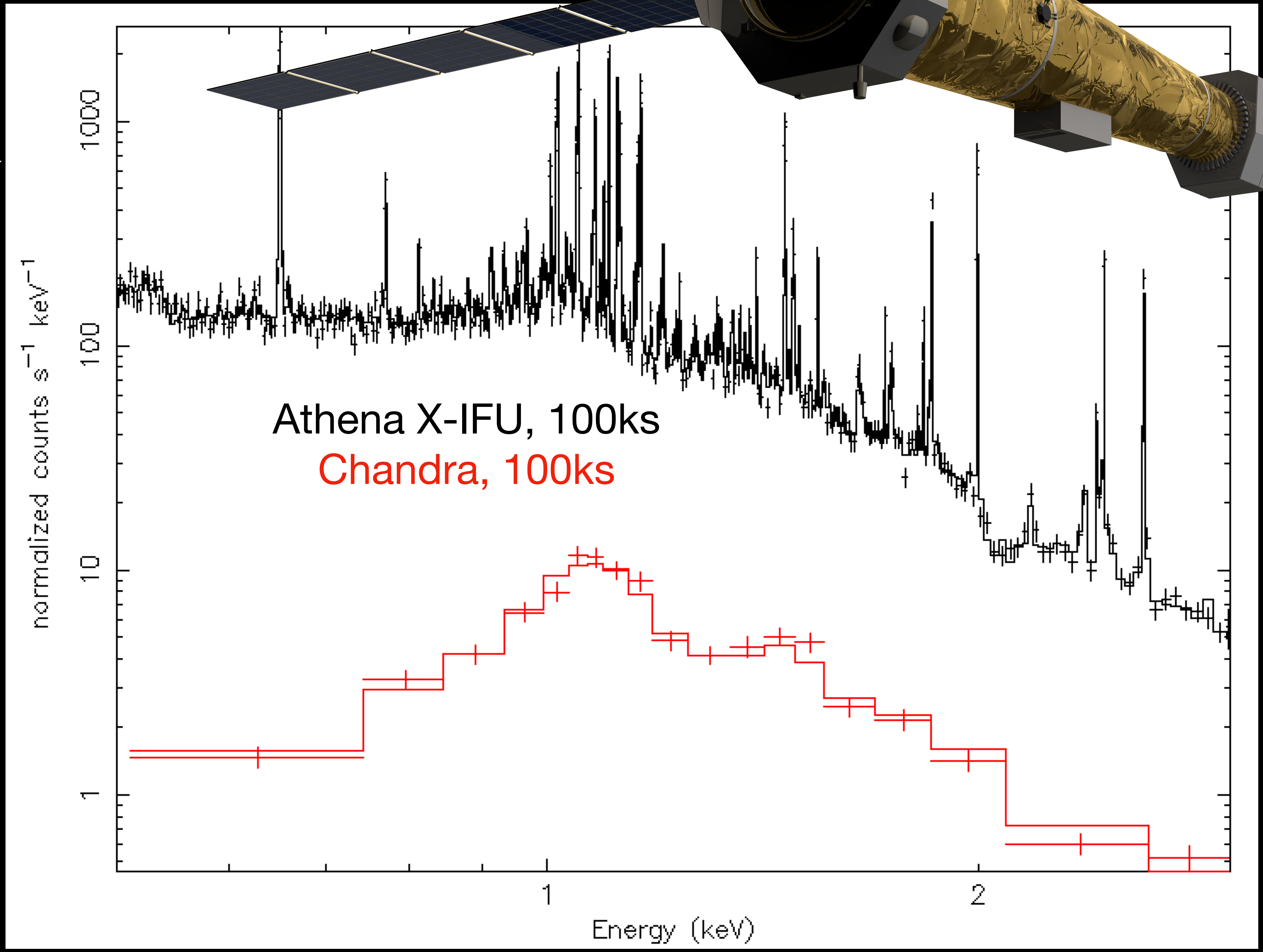

X-Ray Imaging and
Spectroscopy Mission
XRISM

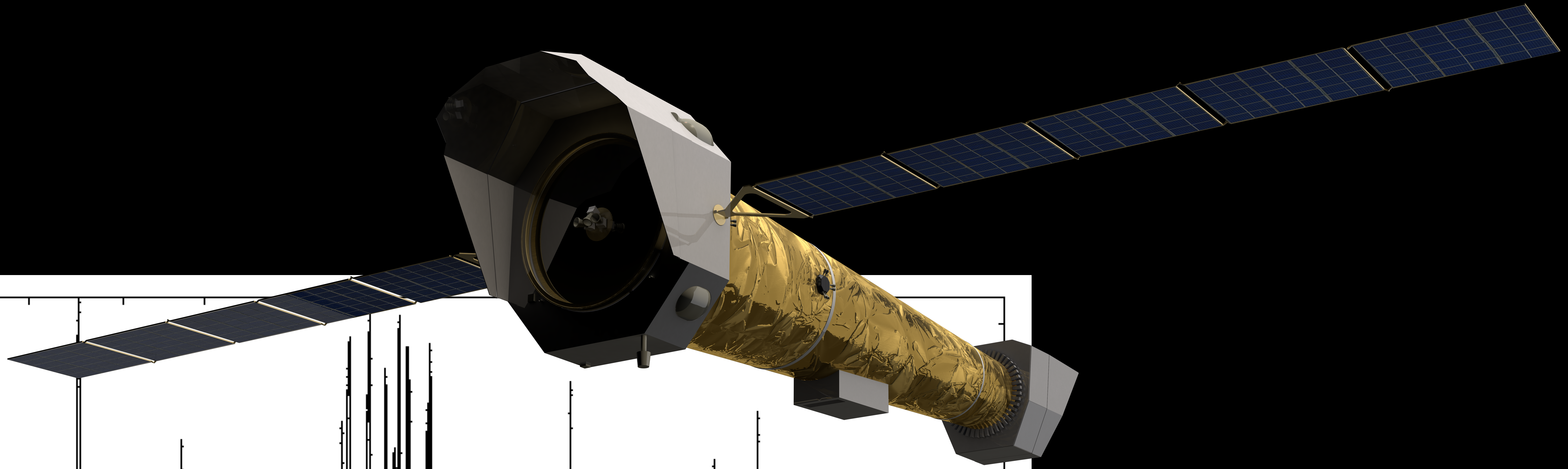
X-ray Spectrum of Perseus Galaxy Cluster Measured by XRISM Resolve





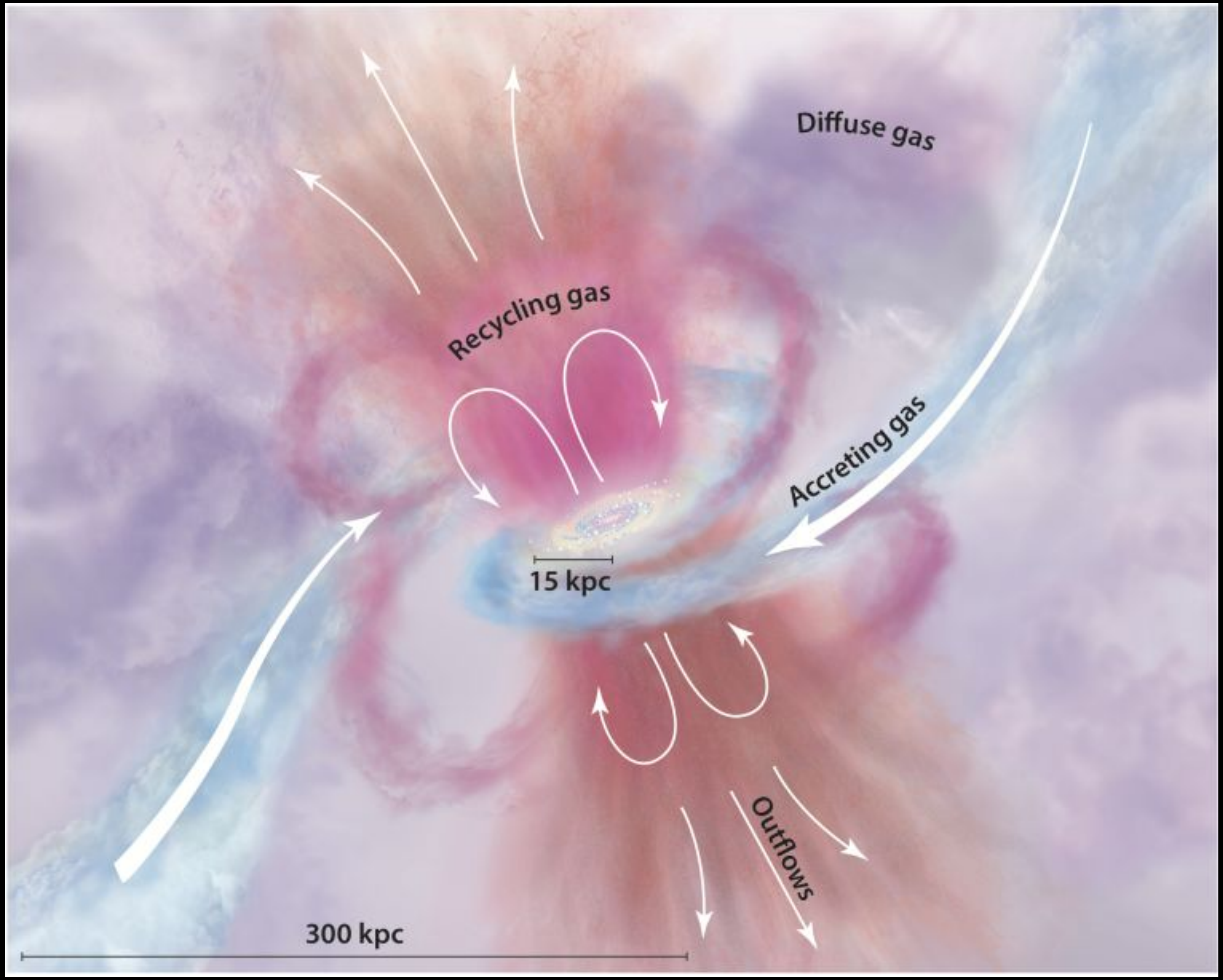






IFU
ATHENA
X-ray Integral Field Unit

The circumgalactic medium and baryon cycling

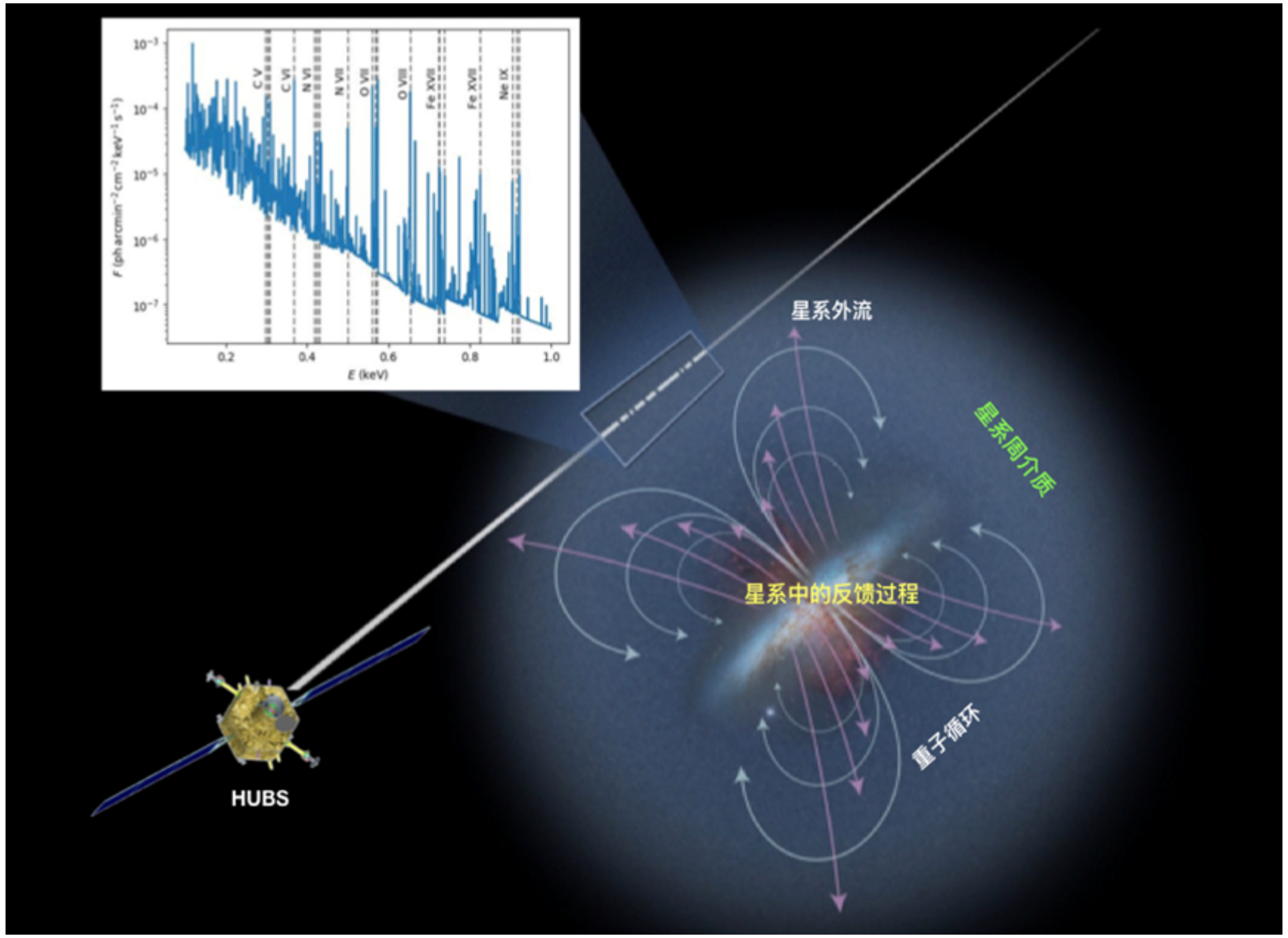


HUBS Mission Design

Slide from Sifan Wang,
see http://hubs.phys.tsinghua.edu.cn/

- High-resolution X-ray spectrometer
  - Energy range: 0.1-2 keV
  - Detector: TES microcalorimeter array
    - Main array: 60x60, energy resolution 2 eV @ 1 keV
    - Central array: 12x12 smaller pixels, energy resolution 0.6 eV @ 1 keV
- High-throughput X-ray telescope
  - Collecting area > 1000 cm^2
  - Field of view ~ 1 deg^2
  - Angular resolution < 1’

Hot Universe Baryon Surveyor



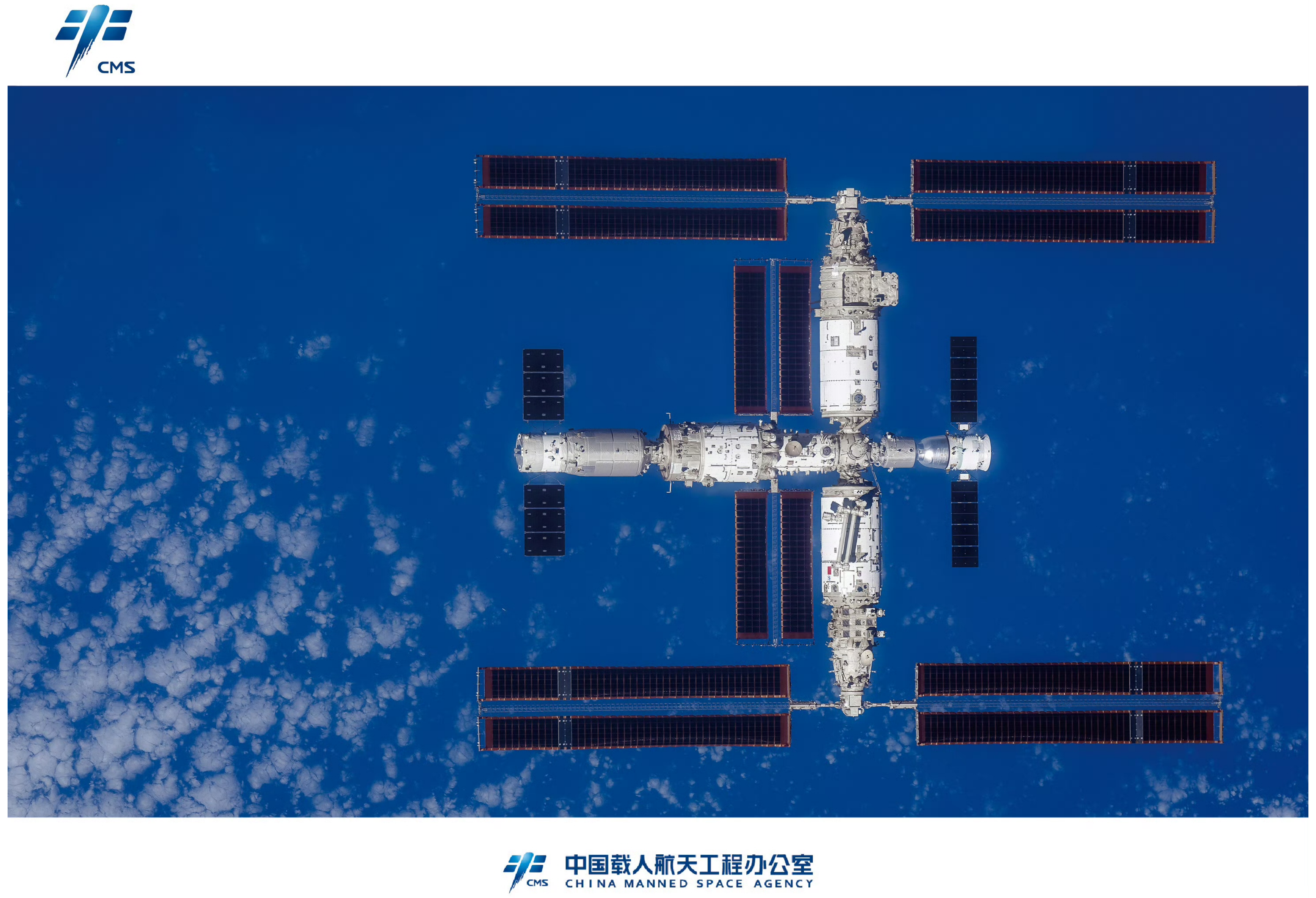
DIffuse X-ray Explorer (DIXE) HUBS Pathfinder

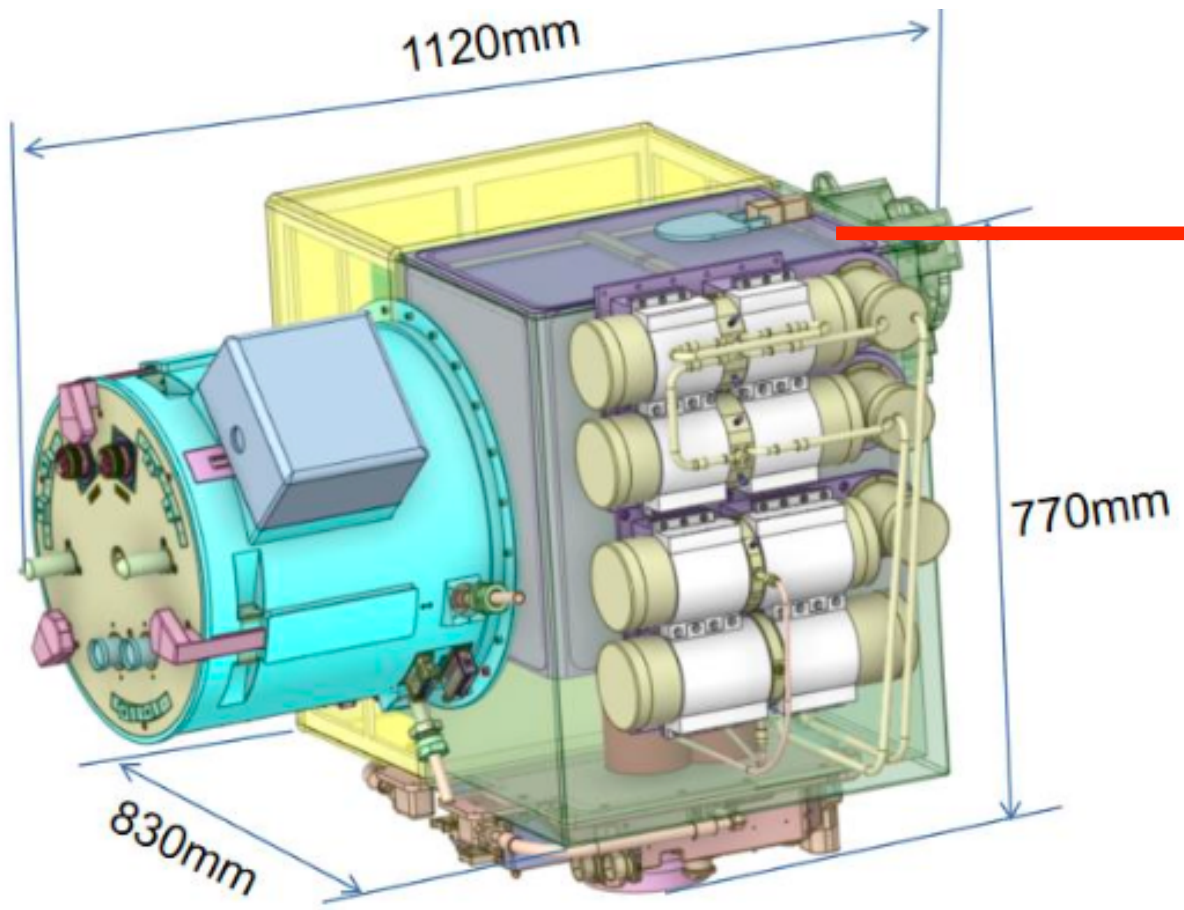
Slide from Sifan Wang,
see http://hubs.phys.tsinghua.edu.cn/

An experiment proposed for the China Space Station (CSS)

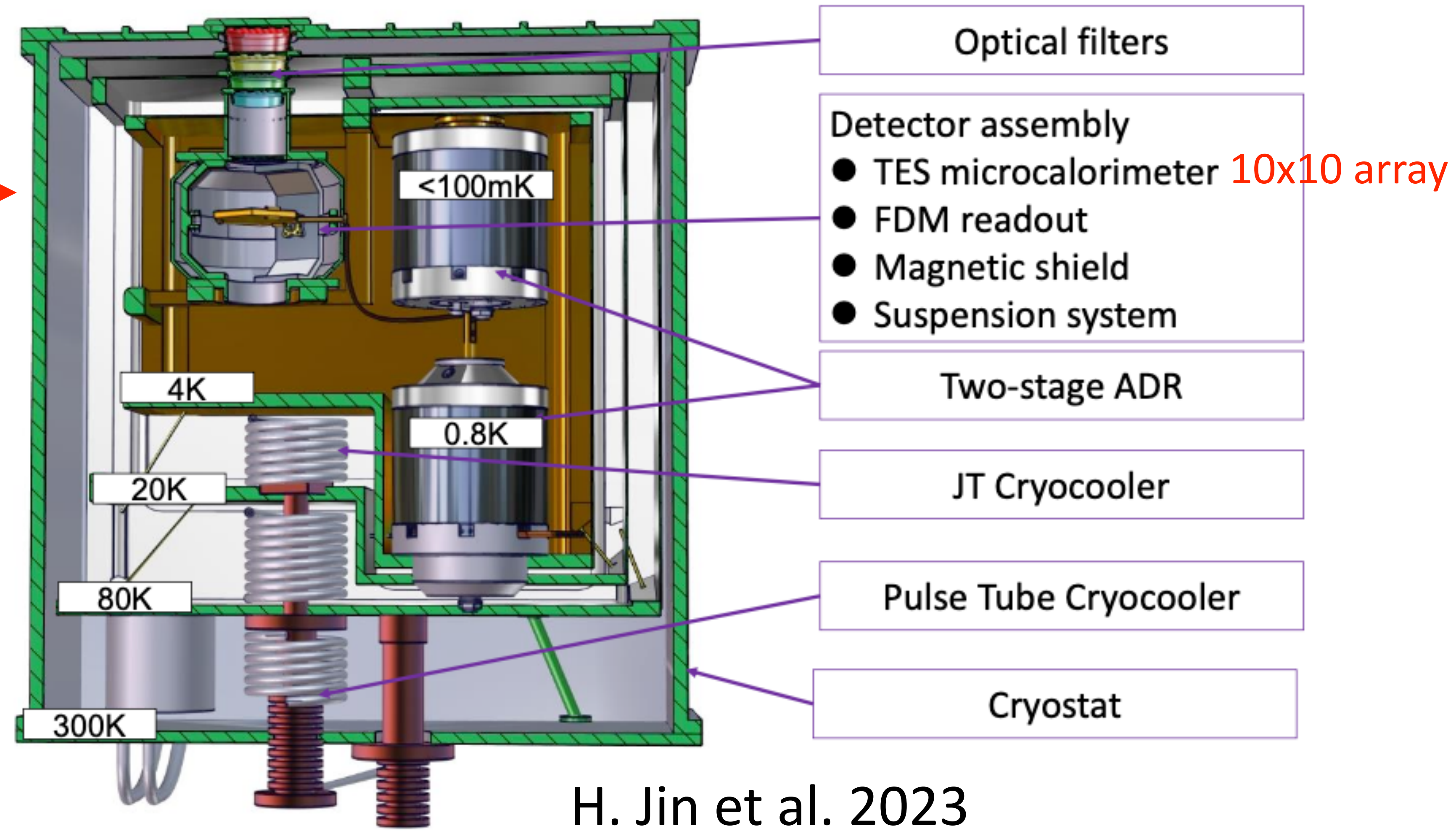
- Energy range: 0.1-10 keV
- Energy resolution: < 6 eV @ 0.6 keV
- Field of view: 10° (collimated)
- Effective area: 0.5 cm^2
- Grasp: 50 cm^2 deg^2
- Observing mode: scanning survey
- Period of operation: 2027-2029

Bring high-resolution X-ray spectroscopy to the whole sky!



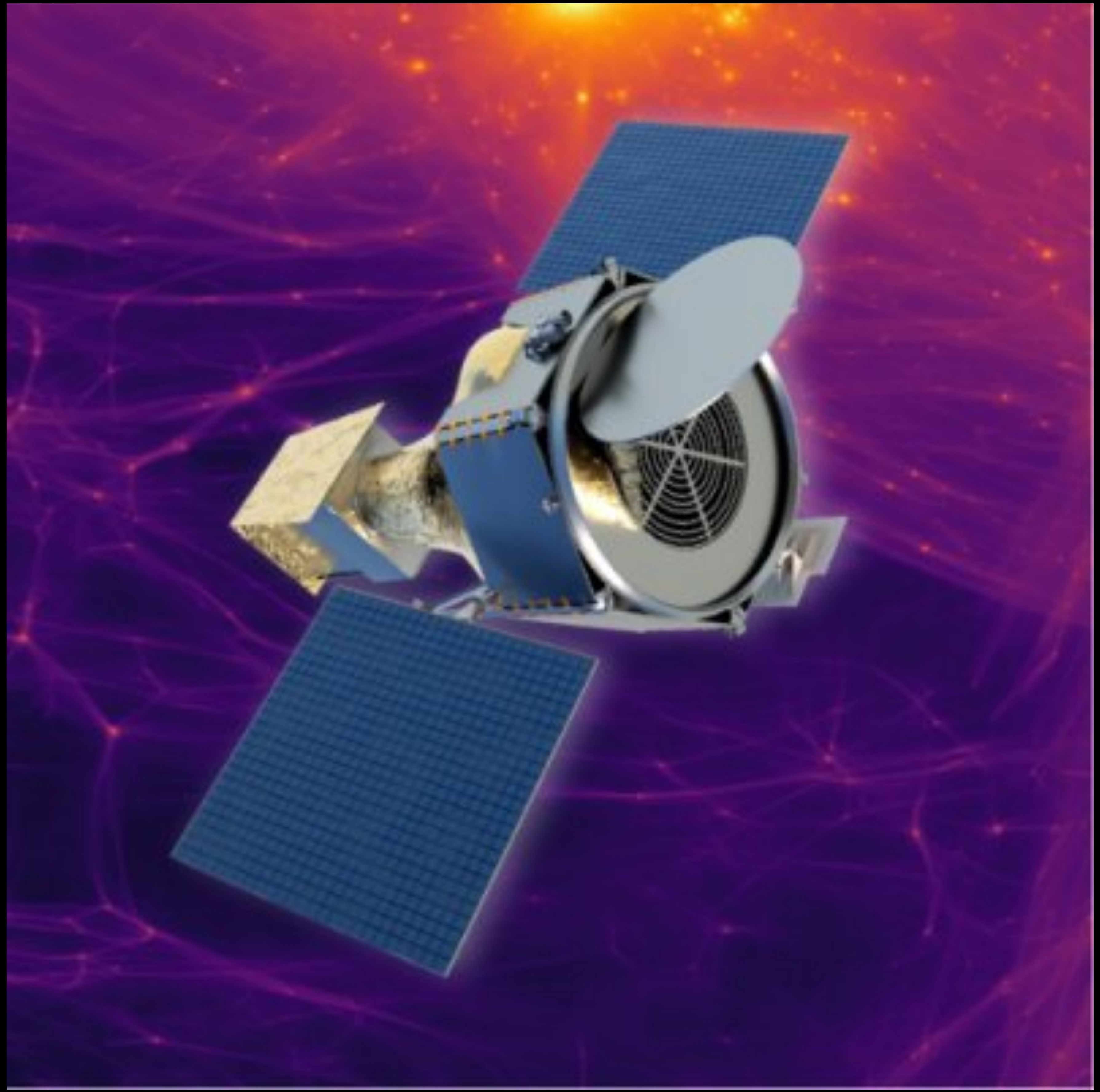


DIXE payload

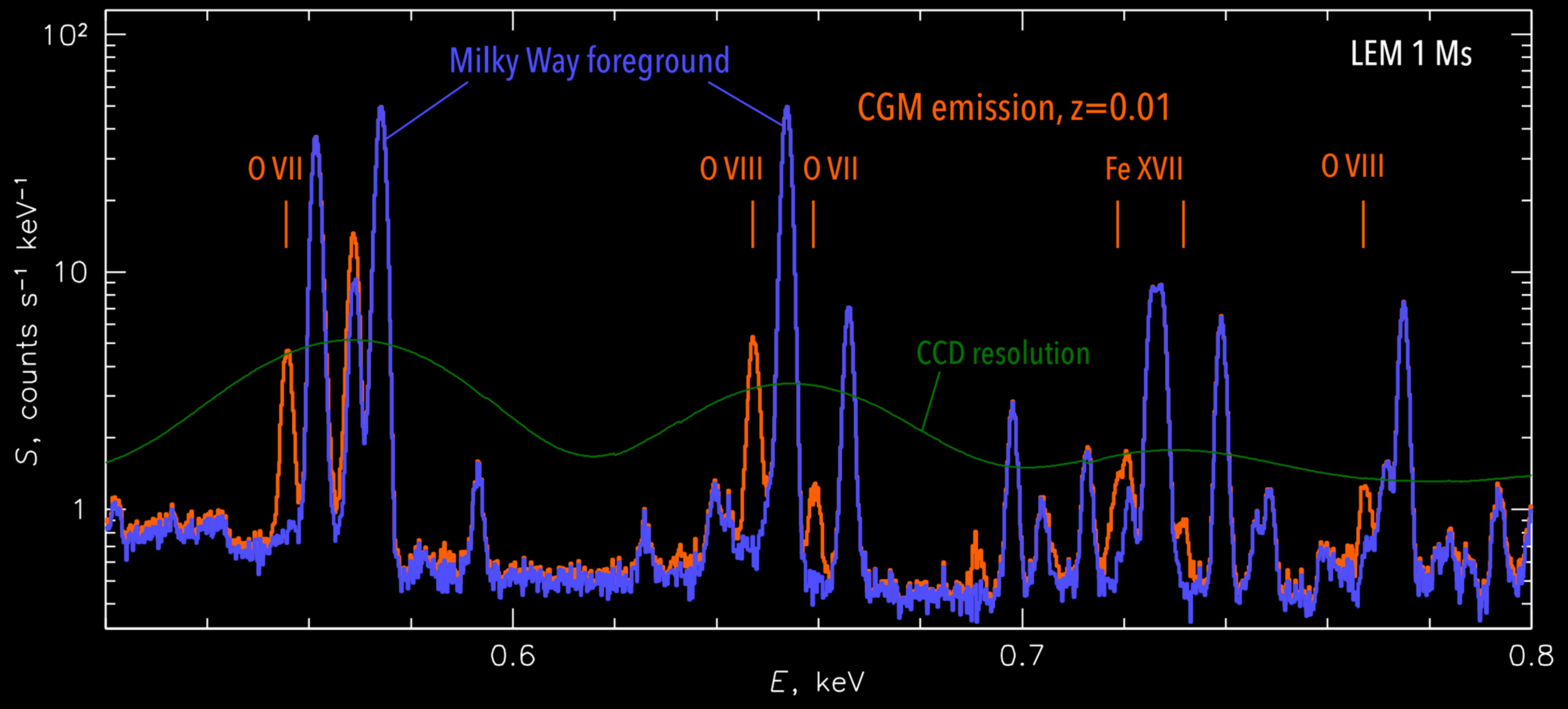


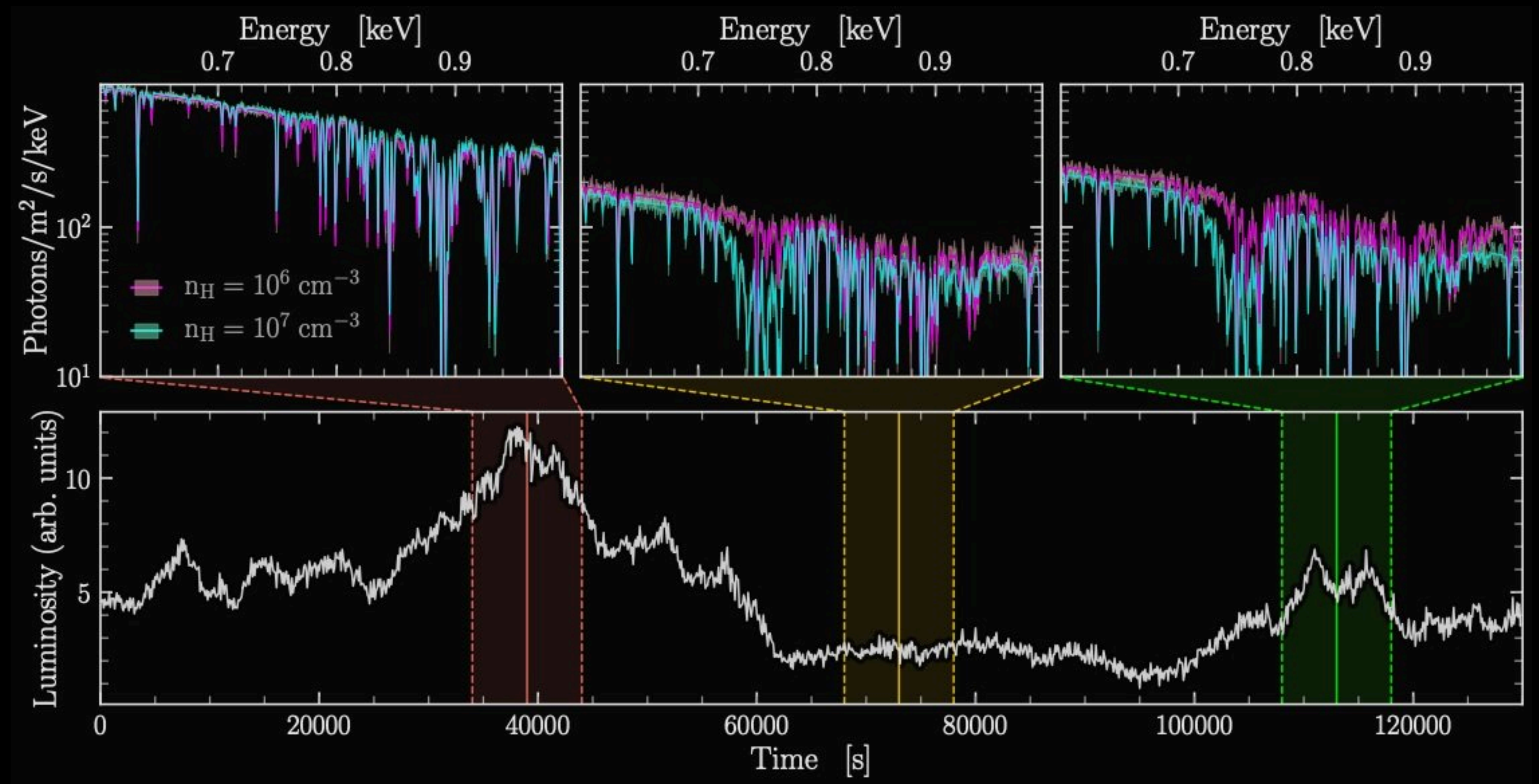
H. Jin et al. 2023

Line Emission Mapper - LEM



https://www.lem-observatory.org/





LEM vs. future spectroscopy missions

	LEM	XRISM	Athena	Lynx†	HUBS†
Energy band, keV	0.2–2	0.4–12	0.2–12	0.2–7	0.2–2
Effective area, cm^2					
0.5 keV	1500	50	6000	14000	500
6 keV	0	300	2000	...	0
Field of view	30'	3'	5'	5'	60'
Grasp* at 0.5 keV	1.3	<0.001	0.12	0.35	1.8
Angular resolution	15"	75"	5"	1"	60"
Spectral resolution	1 eV, 2 eV	7 eV	2.5 eV	3 eV	2 eV
Detector array, pix	118×118**	6×6	50×50**	300×300	60×60

* grasp = effective area × field of view, 10^6 cm^2 arcmin^2 ** equivalent square † future concepts