Using X-ray velocity measurements as a new probe of AGN feedback in massive galaxies

Anna Ogorzalek

KIPAC, Stanford

with Irina Zhuravleva, Steve Allen, Ciro Pinto, Norbert Werner, Adam Mantz, Becky Canning, Andrew Fabian, Jelle Kaastra, and Jelle de Plaa

X-ray Universe, Rome, June 9 2017

Feedback in massive galaxies:

Feedback in massive galaxies:
What is providing the energy?
How is the energy dissipated?

Feedback in massive galaxies:
What is providing the energy?
How is the energy dissipated?

AGN feedback

e.g. Fabian+2012

weak shocks & sound waves

e.g. Fabian+2003, Forman+2007

turbulent dissipation

e.g. Zhuravleva+2014

and many more

e.g. cosmic ray heating, bubble mixing, radiative heating, turbulent mixing ...

Feedback in massive galaxies: What is providing the energy? **How** is the energy dissipated?

AGN feedback

e.g. Fabian+2012

weak shocks & sound waves

e.g. Fabian+2003, Forman+2007

turbulent dissipation

e.g. Zhuravleva+2014

and many more

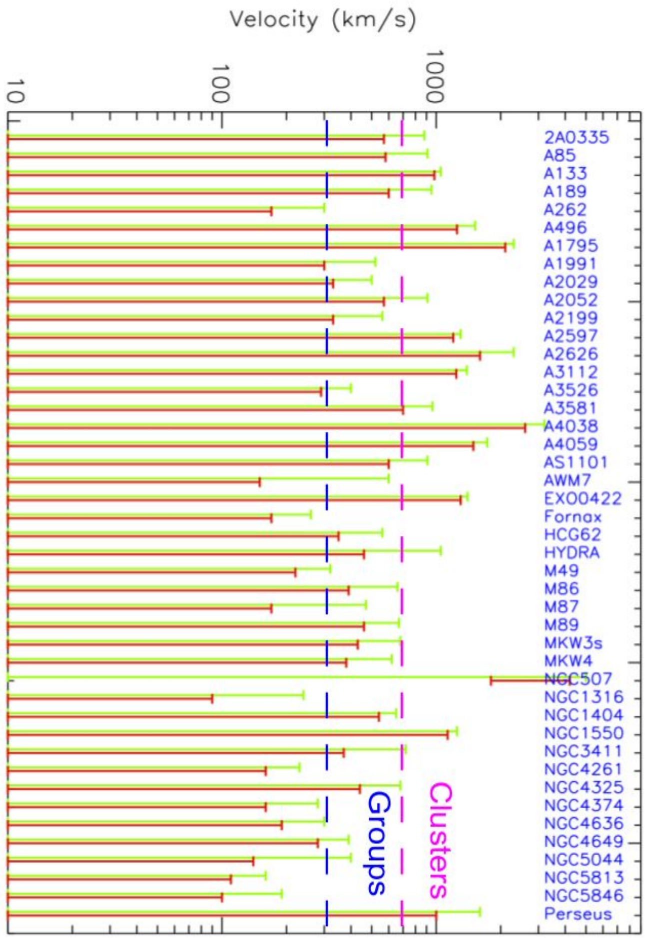
e.g. cosmic ray heating, bubble mixing, radiative heating, turbulent mixing ...

What is the role of turbulence in AGN feedback in giant galaxies?

Werner+2009

Measuring turbulent velocities in massive galaxies

Measuring turbulent velocities in massive galaxies

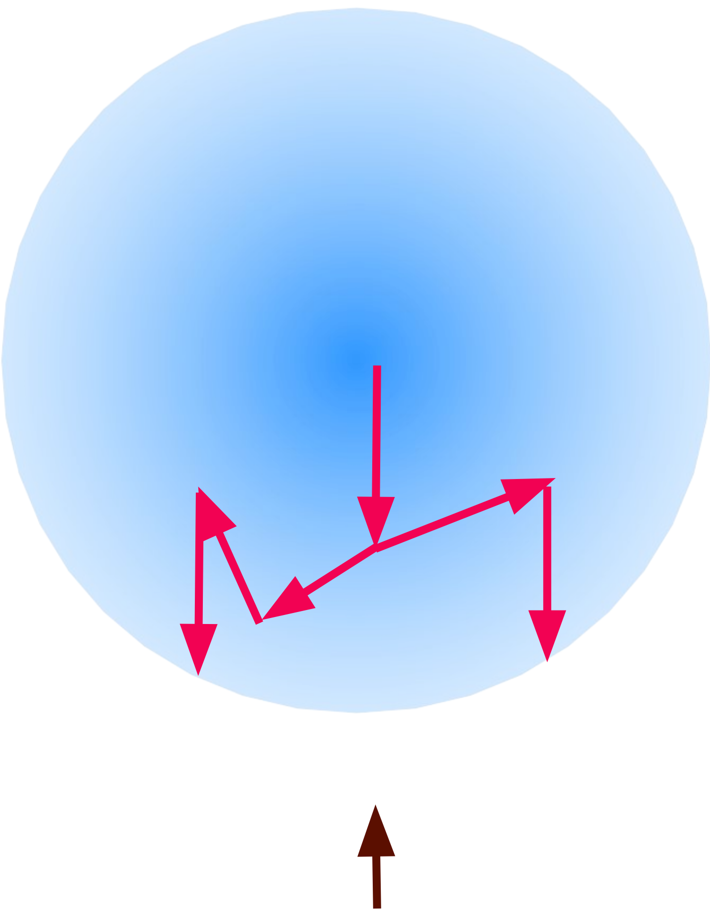


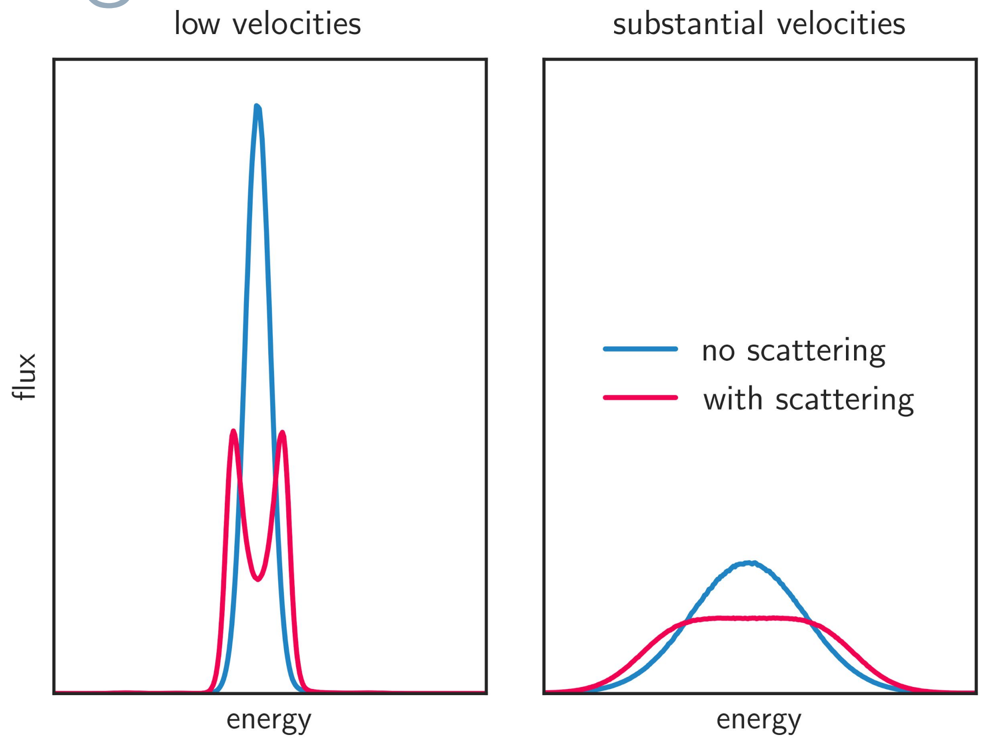
Pinto+2015

- Directly:
  spectral line broadening
  (e.g. Sanders+2013, Pinto+2015)

- Indirectly:
  resonant scattering
  (e.g. Xu+2002, Churazov+2004, Werner+2009, de Plaa+2012)

Resonant scattering



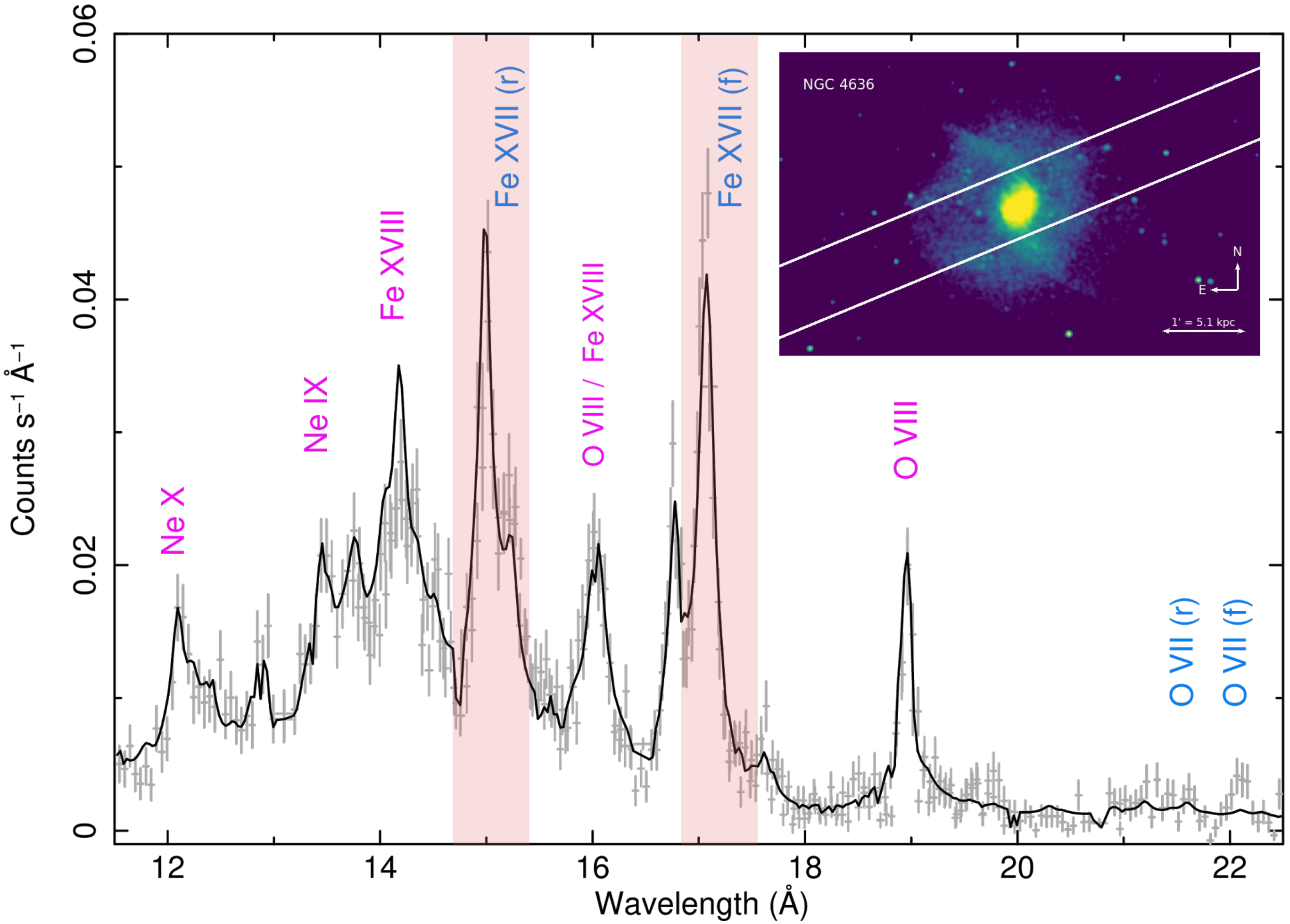


$$RS \sim \tau \sim \frac{1}{\Delta E_{Dopp}} \sim \frac{1}{v_{turb}}$$

See also Kosuke Sato-san's talk

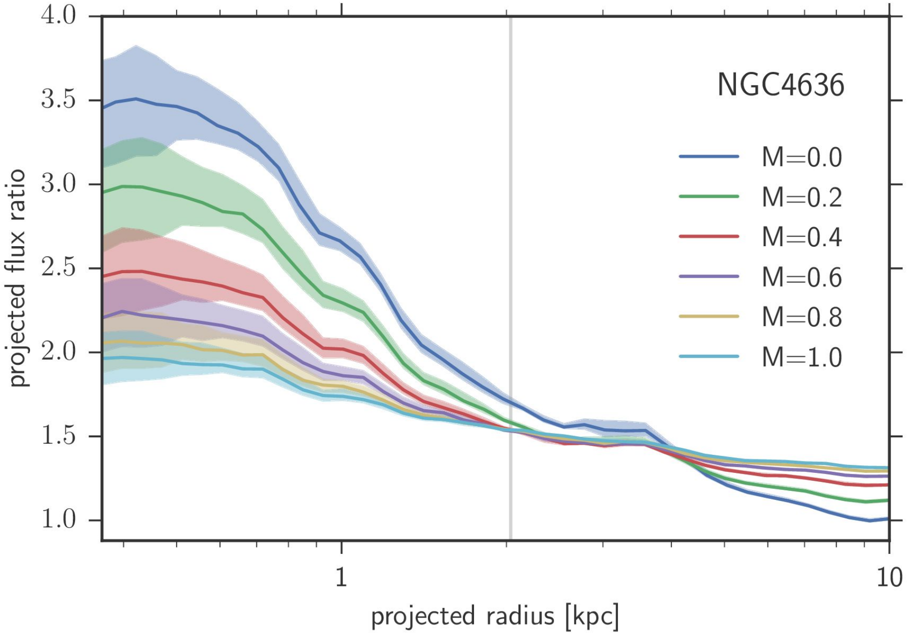
Gilfanov+1987, Shigeyama+1998,
Sazonov+2002, Churazov+2010

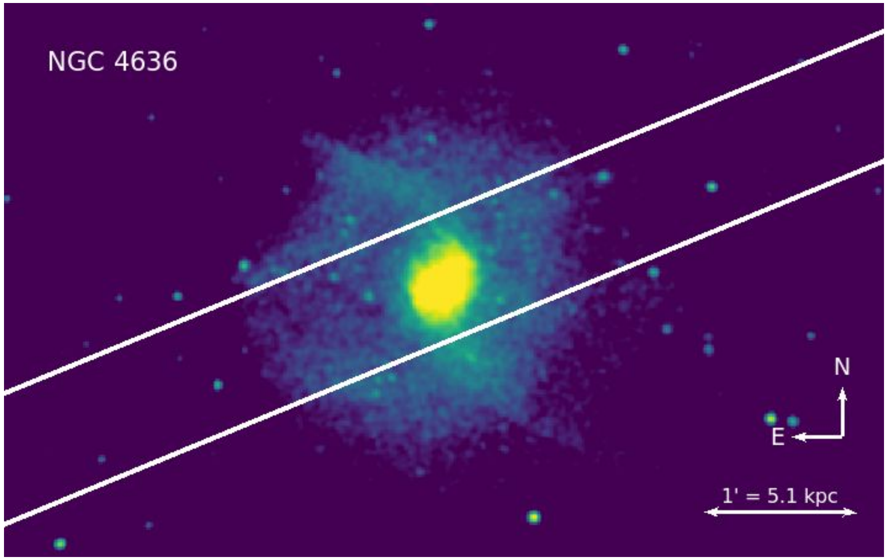
Resonant scattering modelling



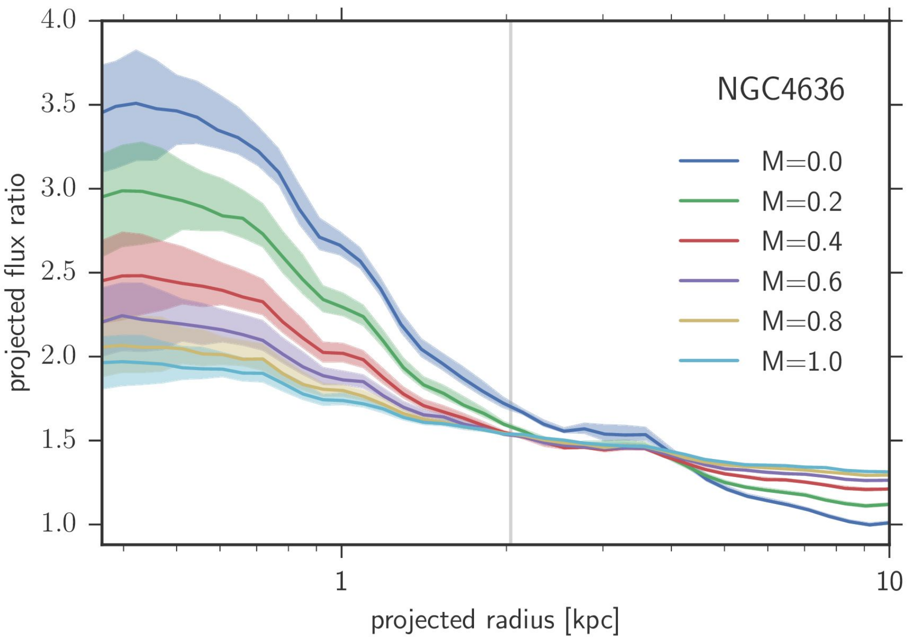
Werner+2009, Pinto+2015, Ahoranta+2016, Ogorzalek+2017

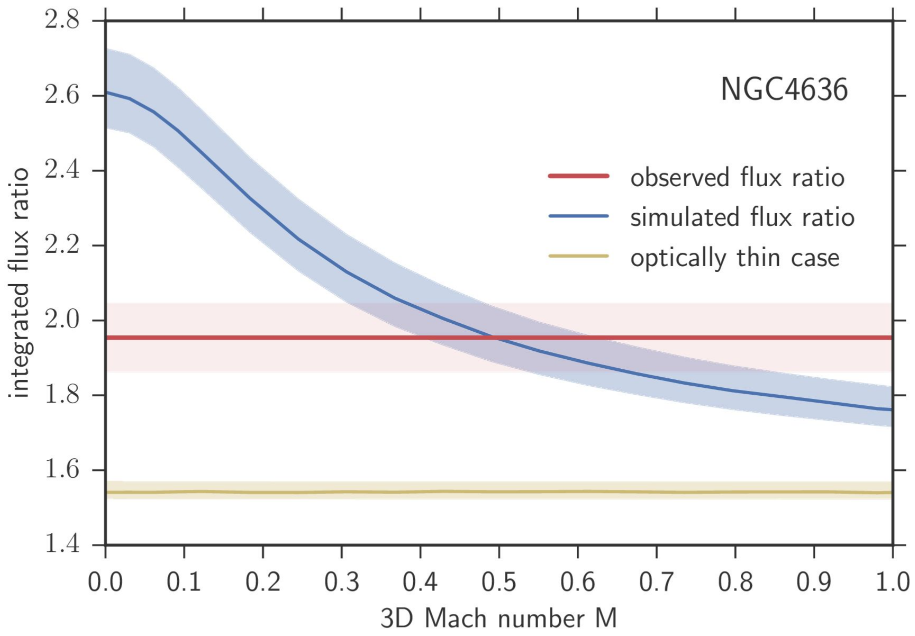
Resonant scattering modelling



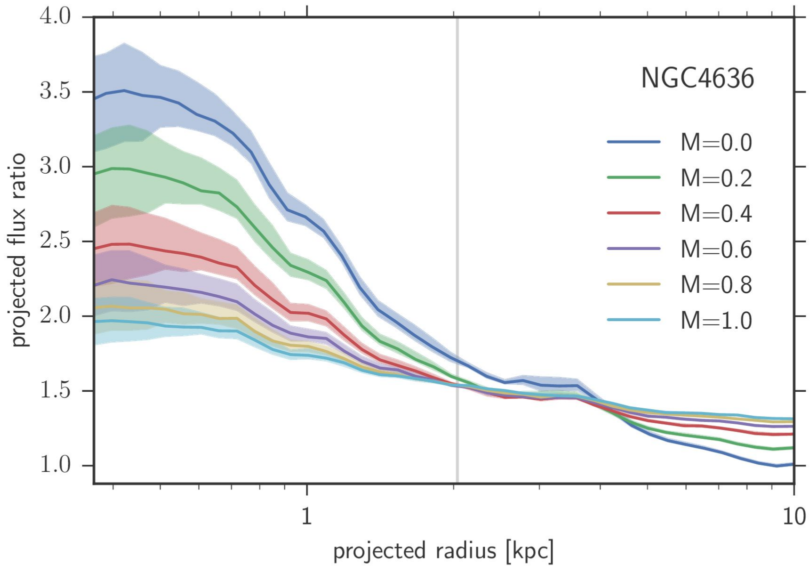


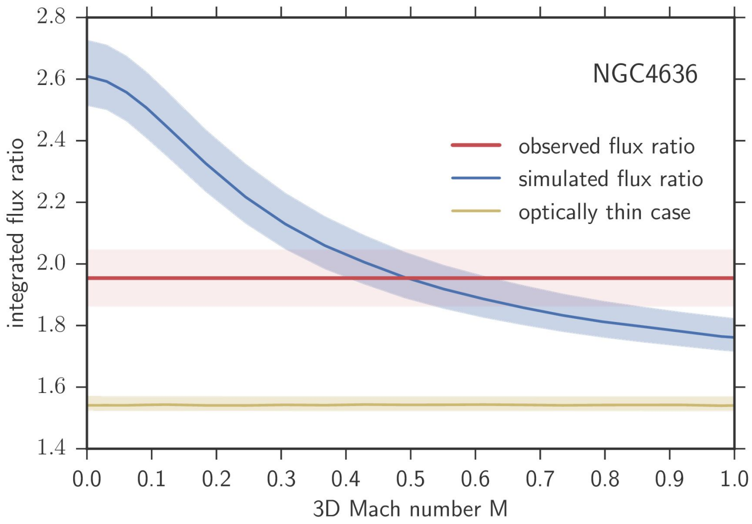
Resonant scattering modelling

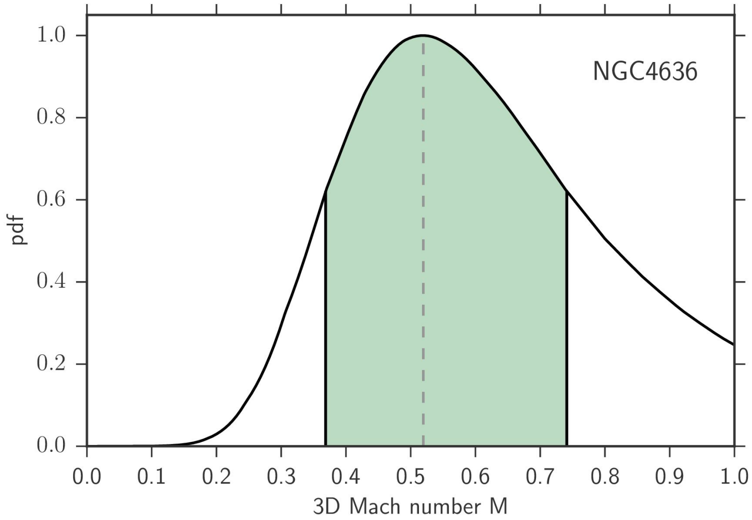




Resonant scattering modelling



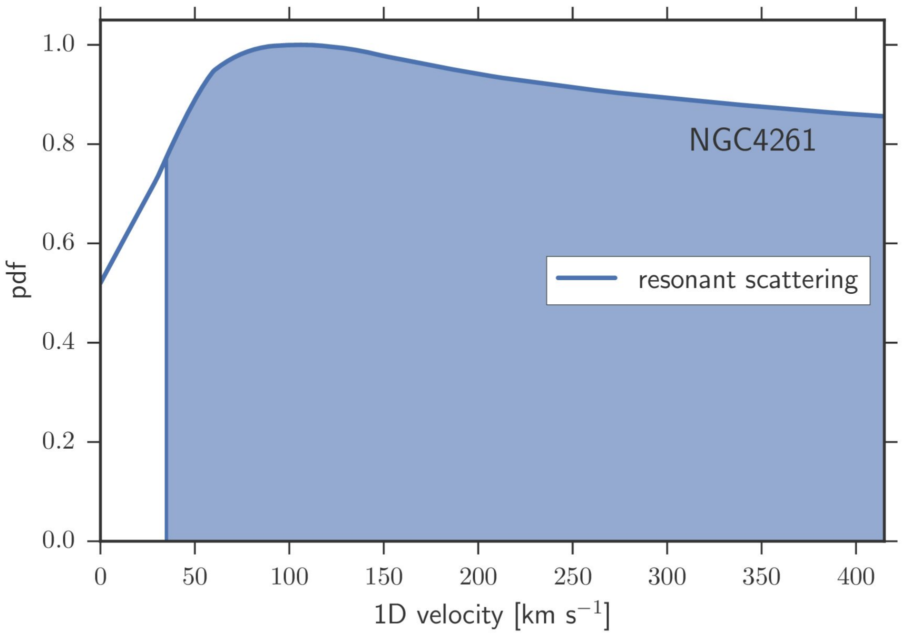


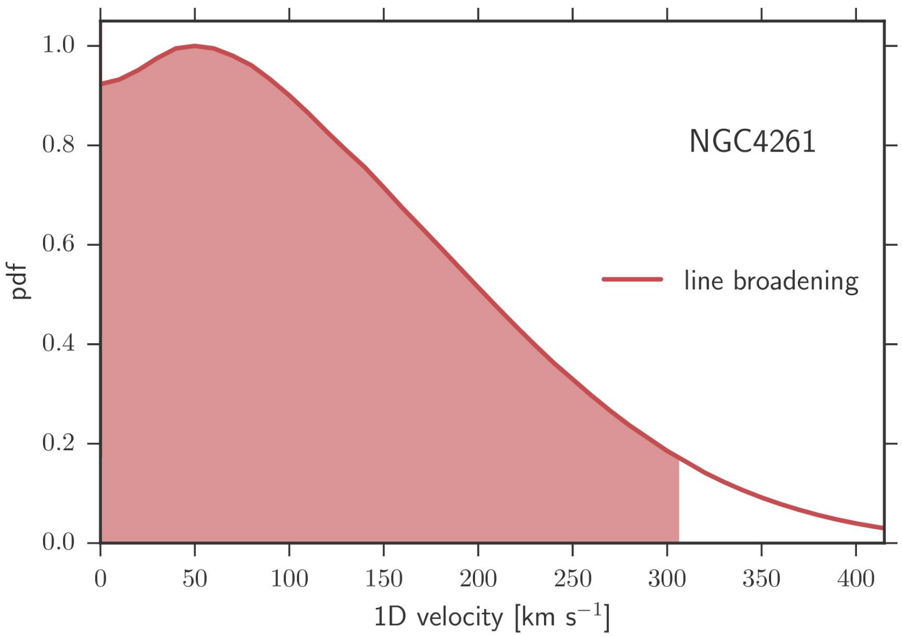


V1D ~ 120 km/s
M3D ~ 0.52

Resonant scattering vs line broadening

Resonant scattering vs line broadening



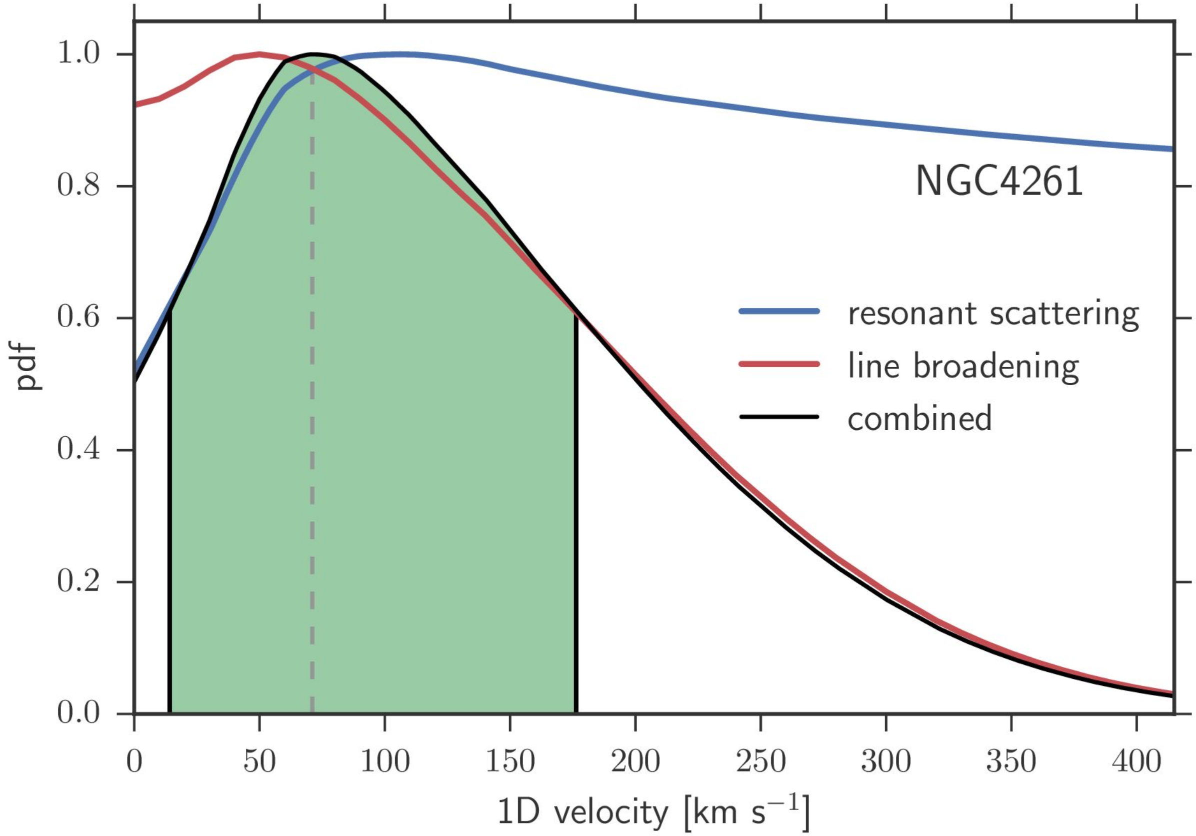


V1D > 35 km/s

V1D < 305 km/s

Resonant scattering AND line broadening

Resonant scattering AND line broadening

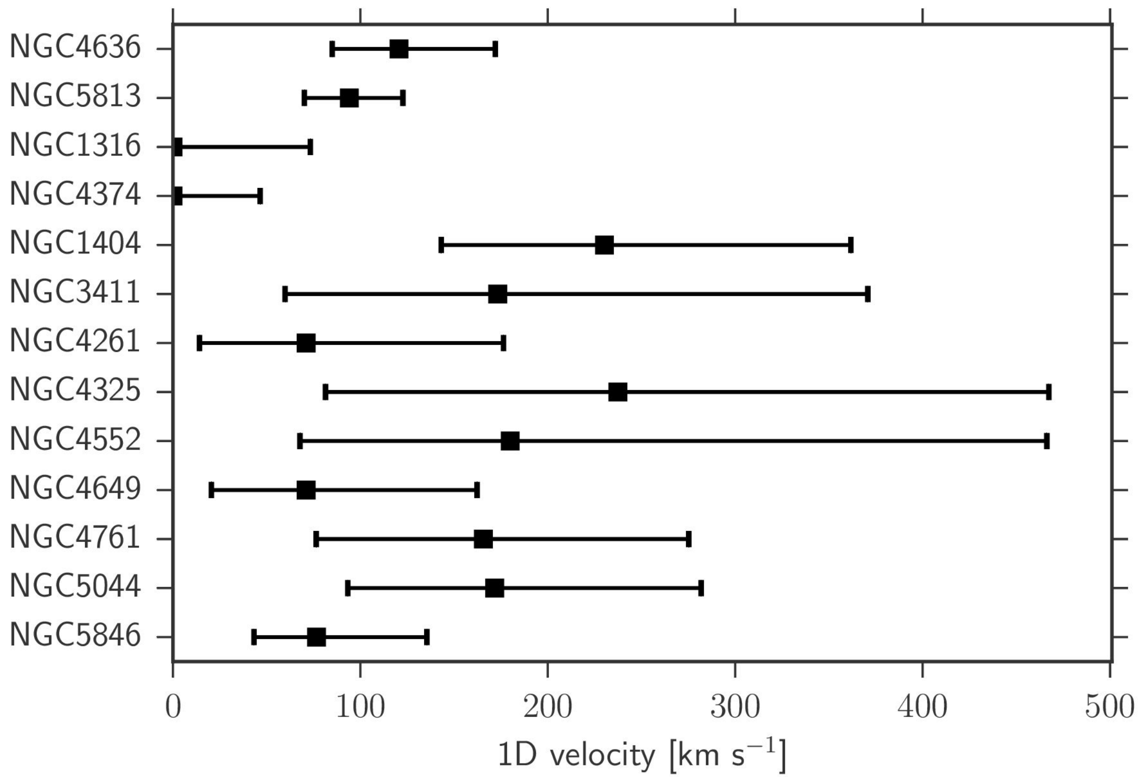


V1D = 71 km/s

68% limits: 14-176 km/s

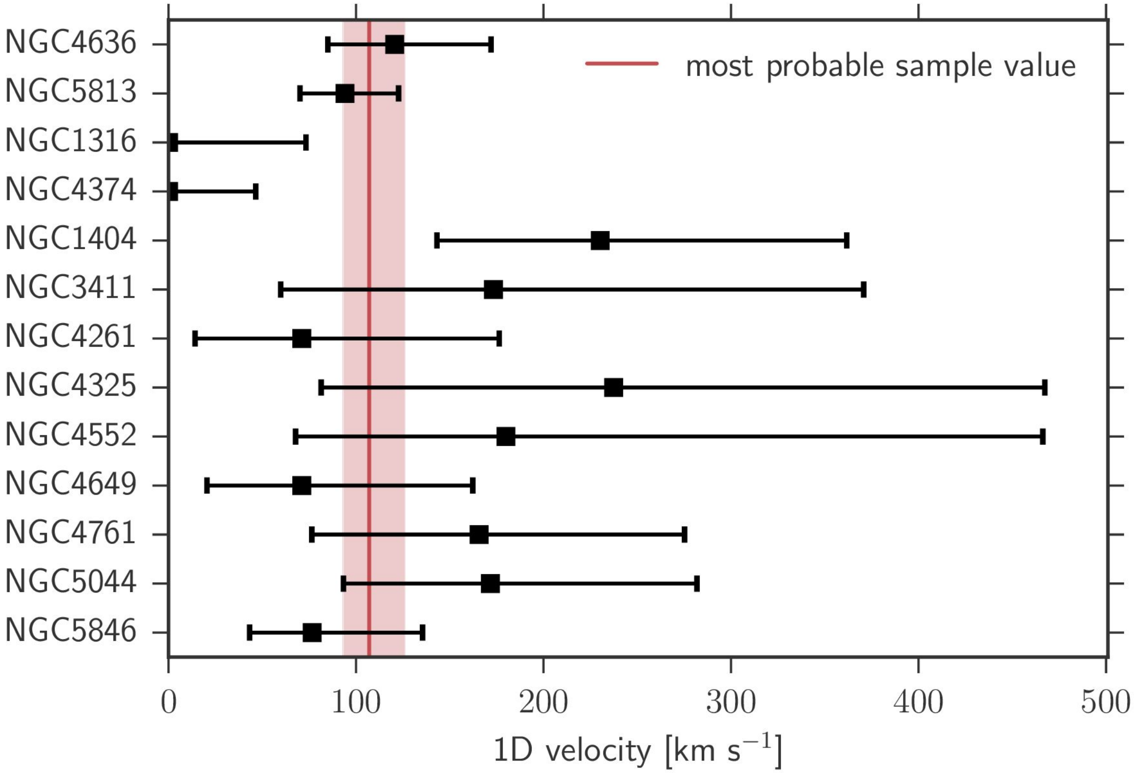
Turbulent velocity measurements in a sample of galaxies

Turbulent velocity measurements in a sample of galaxies



Ogorzalek+2017

Turbulent velocity measurements in a sample of galaxies

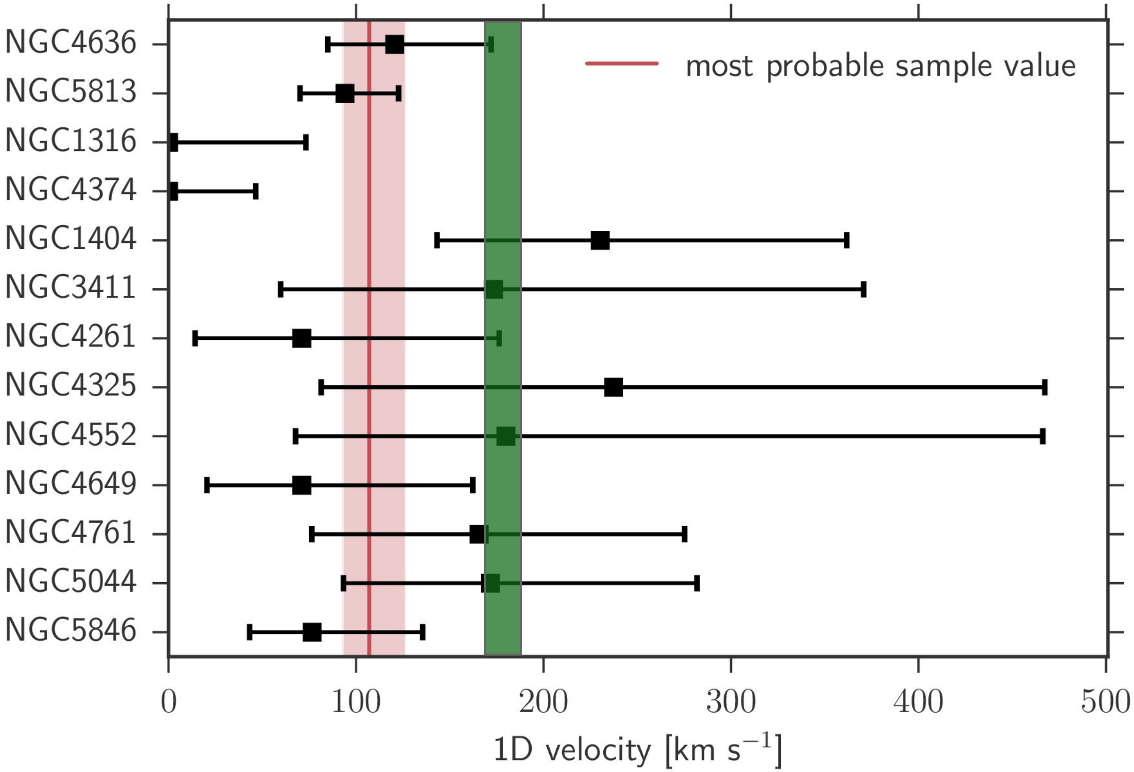


v ~ 110 km/s (1D)
M ~ 0.45 (3D)

within < 10 kpc
(typically ~ 3-5 kpc)

Ogorzalek+2017

Turbulent velocity measurements in a sample of galaxies



v ~ 110 km/s (1D)

M ~ 0.45 (3D)

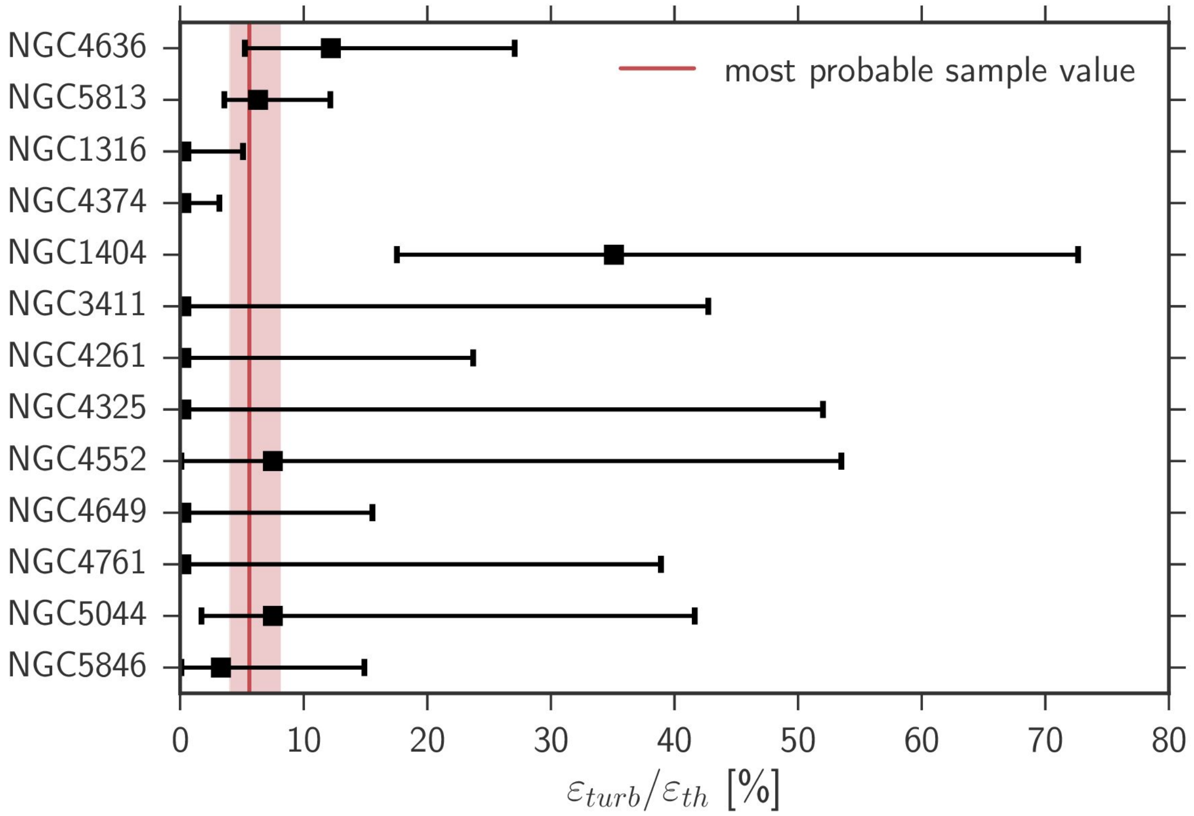
within < 10 kpc

(typically ~ 3-5 kpc)

Hitomi Collab. 2016,

Hitomi Perseus: v ~190 km/s, inner ~30 kpc

Non-thermal pressure support

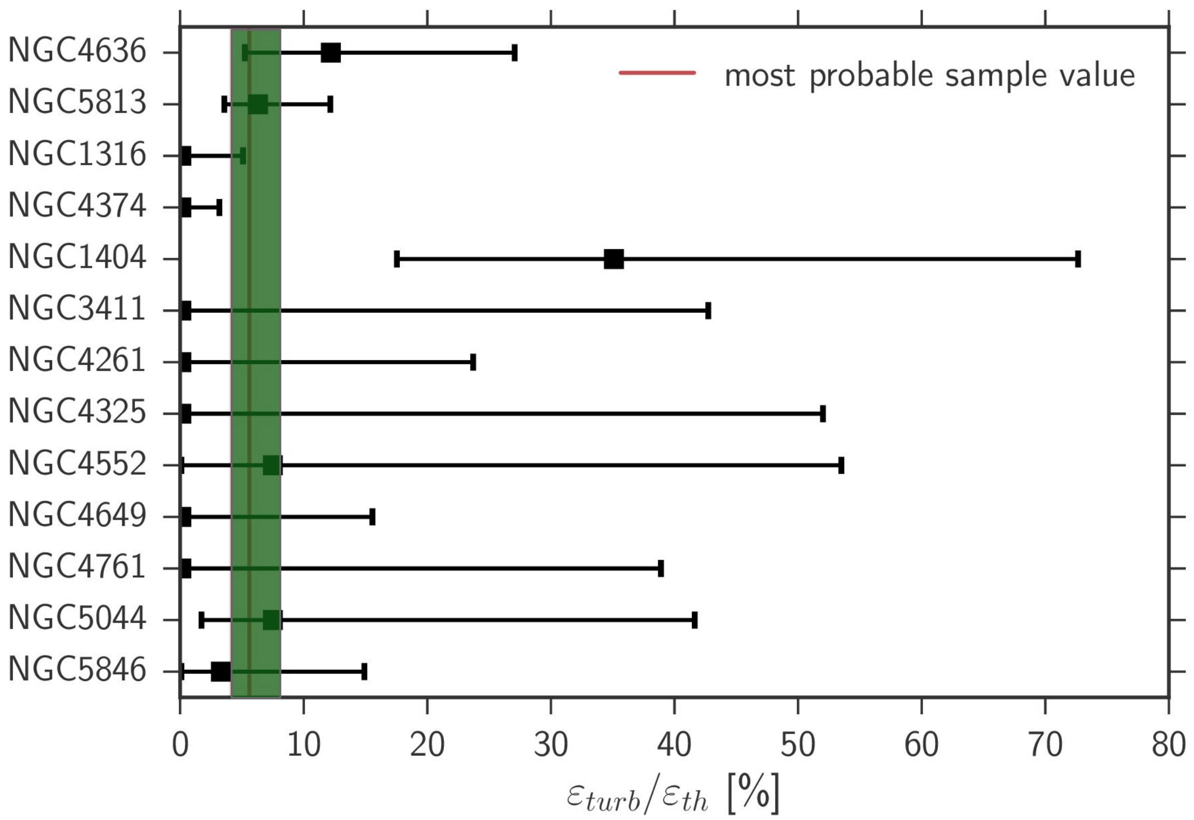


$\varepsilon_{turb}/\varepsilon_{thermal}$ ~ 6%

within < 10 kpc
(typically ~ 3-5 kpc)

Ogorzalek+2017

Non-thermal pressure support



$\varepsilon_{turb}/\varepsilon_{thermal}$ ~ 6%

within < 10 kpc
(typically ~ 3-5 kpc)

Hitomi Perseus: $\varepsilon_{turb}/\varepsilon_{thermal}$ ~ 4-8%, inner ~30 kpc Hitomi Collab. 2016

Can turbulence heat galaxy cores?

Can turbulence heat galaxy cores?

- Is $Q_{turb} = Q_{cool}$? $Q_{turb} \sim v_{1,k}^3 k$
- What are the spatial scales of motions? (Effective length? RGS aperture width?)

Can turbulence heat galaxy cores?

- Is $Q_{turb} = Q_{cool}$? $Q_{turb} \sim v_{1,k}^3 k$
- What are the spatial scales of motions? (Effective length? RGS aperture width?)

- Typically in our sample turbulent heating is sufficient to offset the radiative cooling

V~ 110 km/s, L ~ 5 kpc ⇒ M_{bal} ~0.42

M_{obs}~0.44

Main uncertainties and assumptions

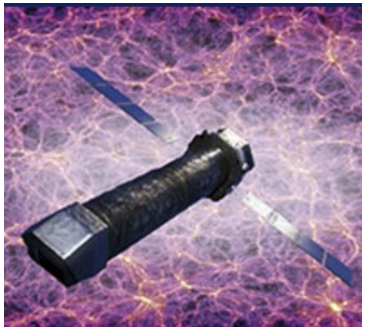
- Atomic data / plasma codes
- PSF of RGS and source spatial extent

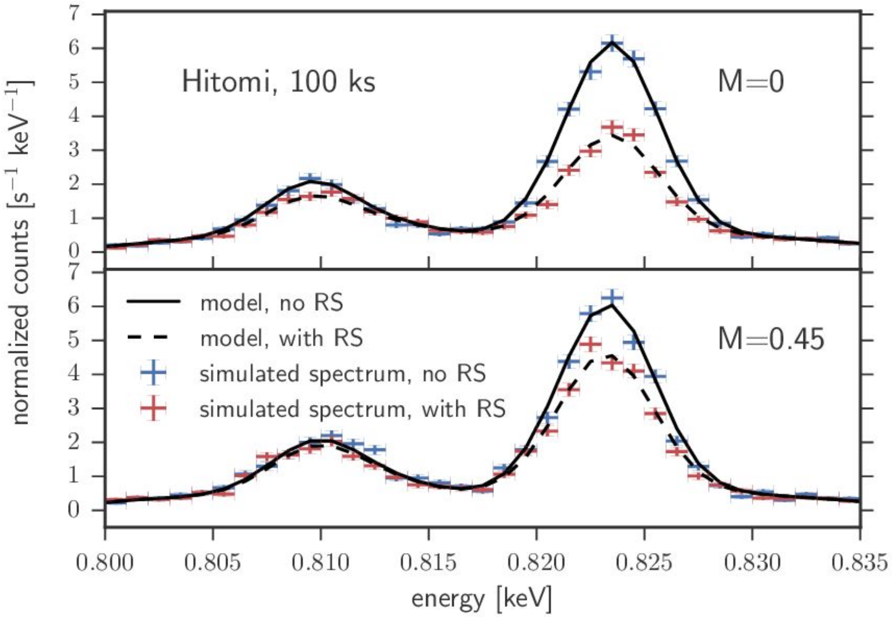
- Abundance profiles
- Isotropy of motions
- Spherical symmetry of galaxies
- Kolomogorov spectrum of turbulence

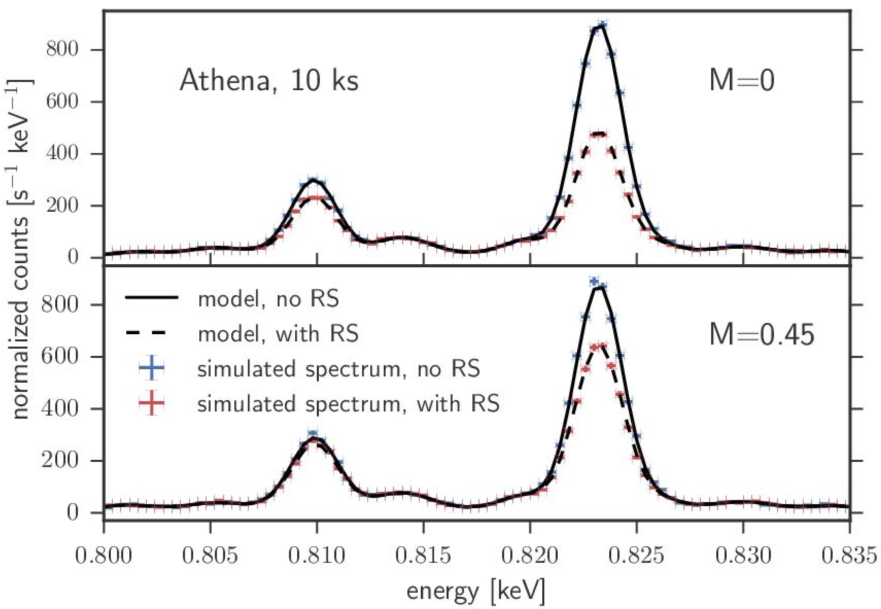
Future: possibilities with RGS

- Unique science achievable only with RGS
- More RGS observations will allow to:
  - Measure velocities close to the black hole
  - Understand spatial scales of turbulence
  - Constrain presence of any velocity trends in the sample

Future: new X-ray missions







Ogorzalek+2017

Typical velocity broadening in galaxies:
~0.3 eV
Athena's resolution: ~2 eV

anna.ogorzalek@stanford.edu

Conclusions

- Our measurements of turbulence in 13 massive galaxies show a common velocity of ~110 km/s
- Turbulence is typically sufficient to offset radiative cooling in galactic cores
- To study heating and AGN feedback in detail we need more RGS observations, better understanding of spatial scales of motions, and more precise atomic data
- Resonant scattering serves as an important velocity probe, especially in galaxies, and is crucial for correct interpretation of future high resolution X-ray spectra

Thanks!