Feedback in a Seyfert Galaxy produced by a multi-component X-ray ultra-fast wind: the case of IRAS17020+4544

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A Milky Way twin swept by an ultra-fast X-ray wind

January 2016

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Il 'venticello' che spegne le stelle

Un team di astronomi a cui hanno partecipato due ricercatori INAF ha individuato per la prima volta un vento ad alta velocità che fuoriesce dal buco nero ospitato nella regione centrale di una galassia a spirale, molto simile per conformazione alla nostra. Questo vento può interagire con l'ambiente galattico e riuscire a spazzare via il gas in essa presente, andando così a ostacolare il processo di formazione di nuove stelle

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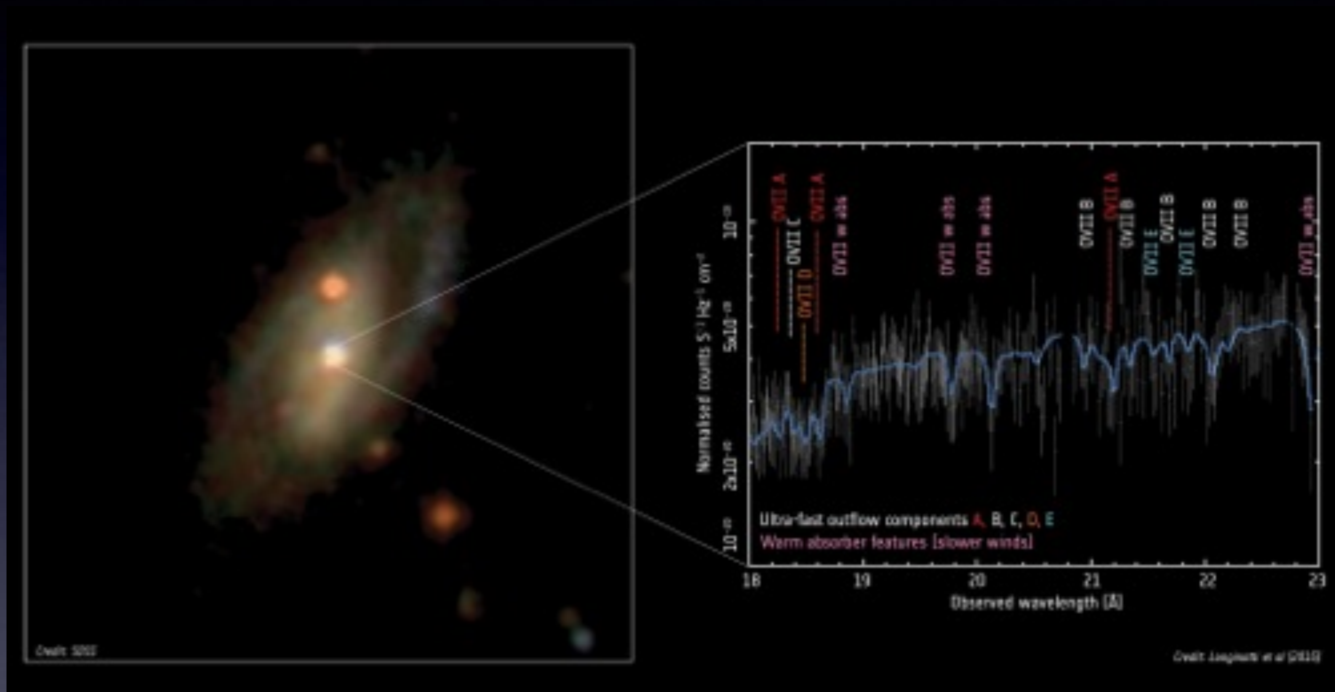
Vientos vertiginosos en una galaxia "gemela" de la Vía Láctea

Resources
- Reference section

A MILKY WAY TWIN SWEPT BY AN ULTRA-FAST X-RAY WIND

14 January 2016 ESA's XMM-Newton has found a wind of high-speed gas streaming from the centre of a bright spiral galaxy like our own that may be reducing its ability to produce new stars.

A Milky Way twin swept by an ultra-fast X-ray wind



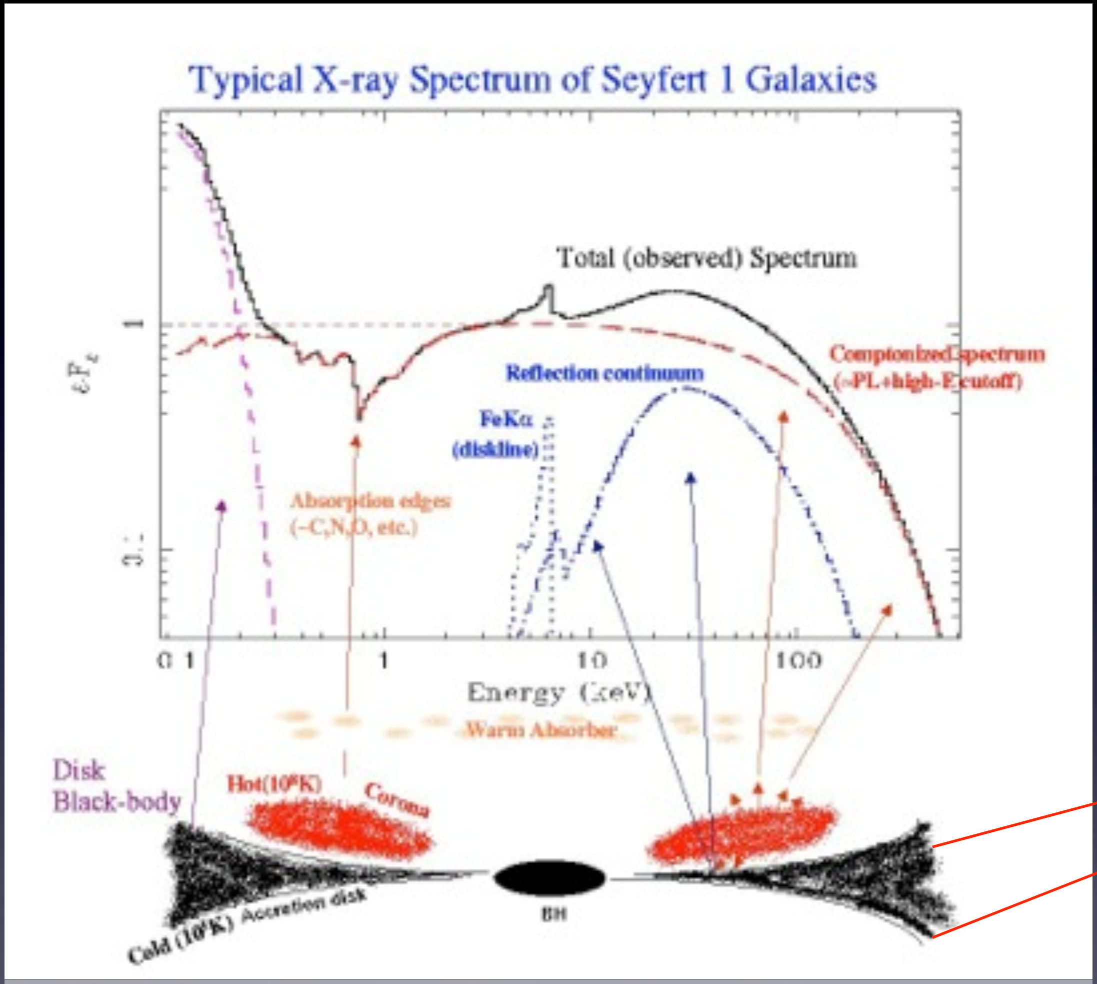
X-ray winds at high velocity
"Milky Way twin"
"swept by a wind"

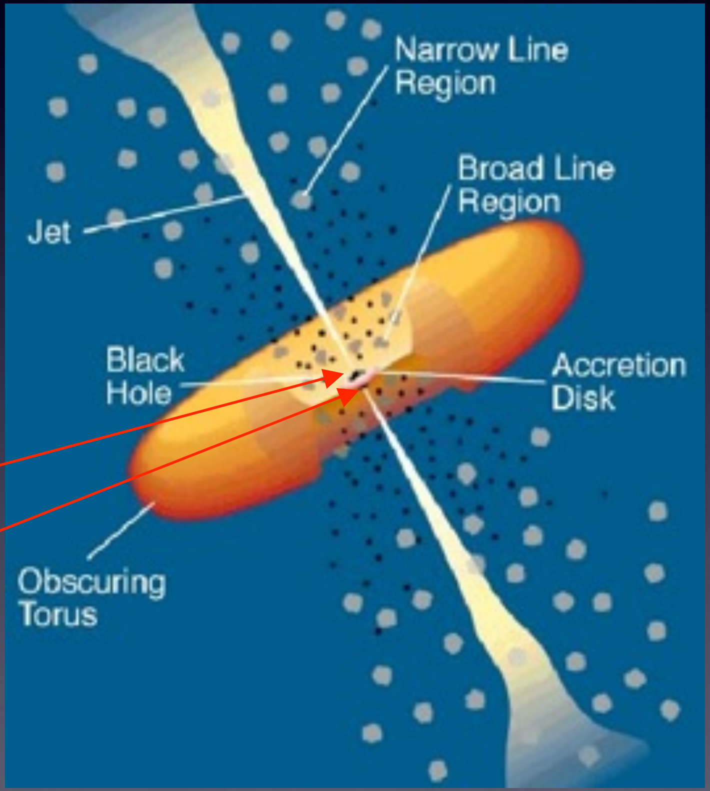
Ultra Fast Outflows (UFO)
Spiral Galaxy IRAS17020+4544
AGN Feedback

Outline

- Brief introduction on X-ray winds in Active Galactic Nuclei and their relevance to AGN feedback
- Results from X-ray spectroscopy of Ultra Fast Outflows
- Discovery of a sub-relativistic accretion disc wind and its feedback properties in the Narrow Line Seyfert 1 IRAS17020+4544 (*Longinotti et al. 2015- ApJL)*

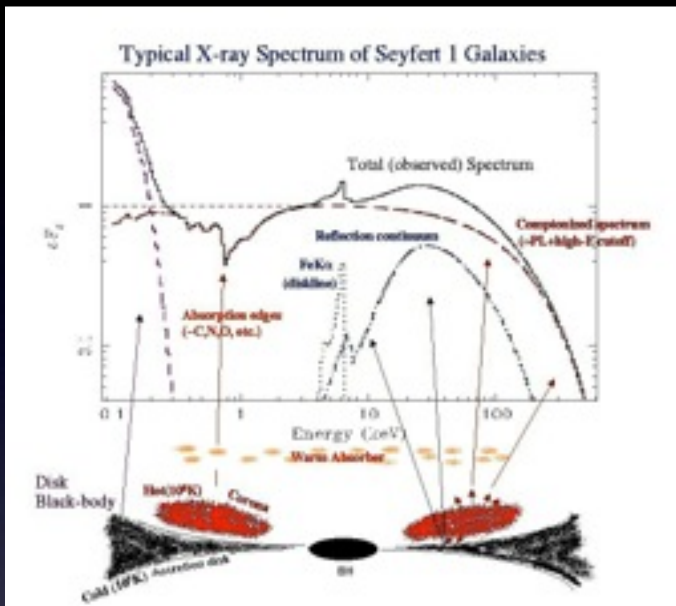
AGN: X-raying the central region

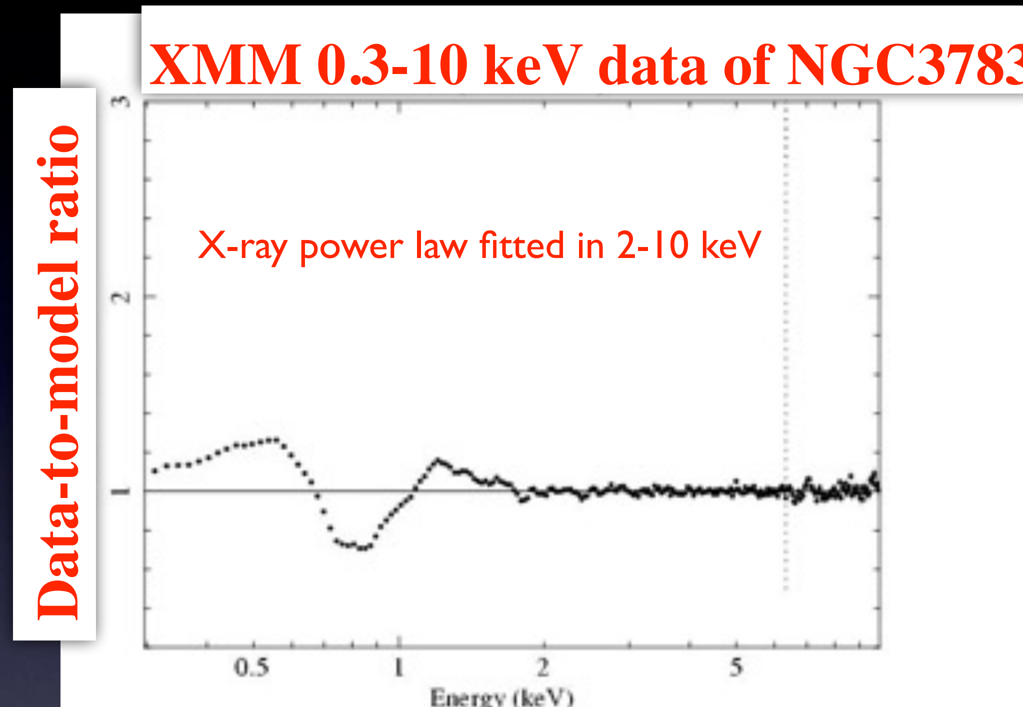




From Urry & Padovani

Absorption in Type 1 AGN: ionized gas

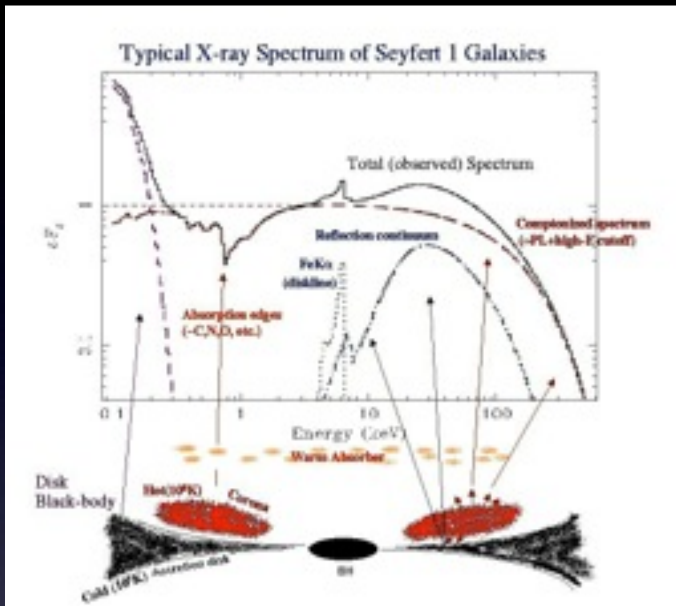




-50% of Seyfert 1
-Outflows velocity 10^{2-3} km/s
-Wide range of Ionization states
-Column density 10^{20-22} cm^{-2}
-Associated to UV outflow
-Location: disk, torus or NLR?

Warm Absorber seen in CCD spectrum

Absorption in Type 1 AGN: ionized gas



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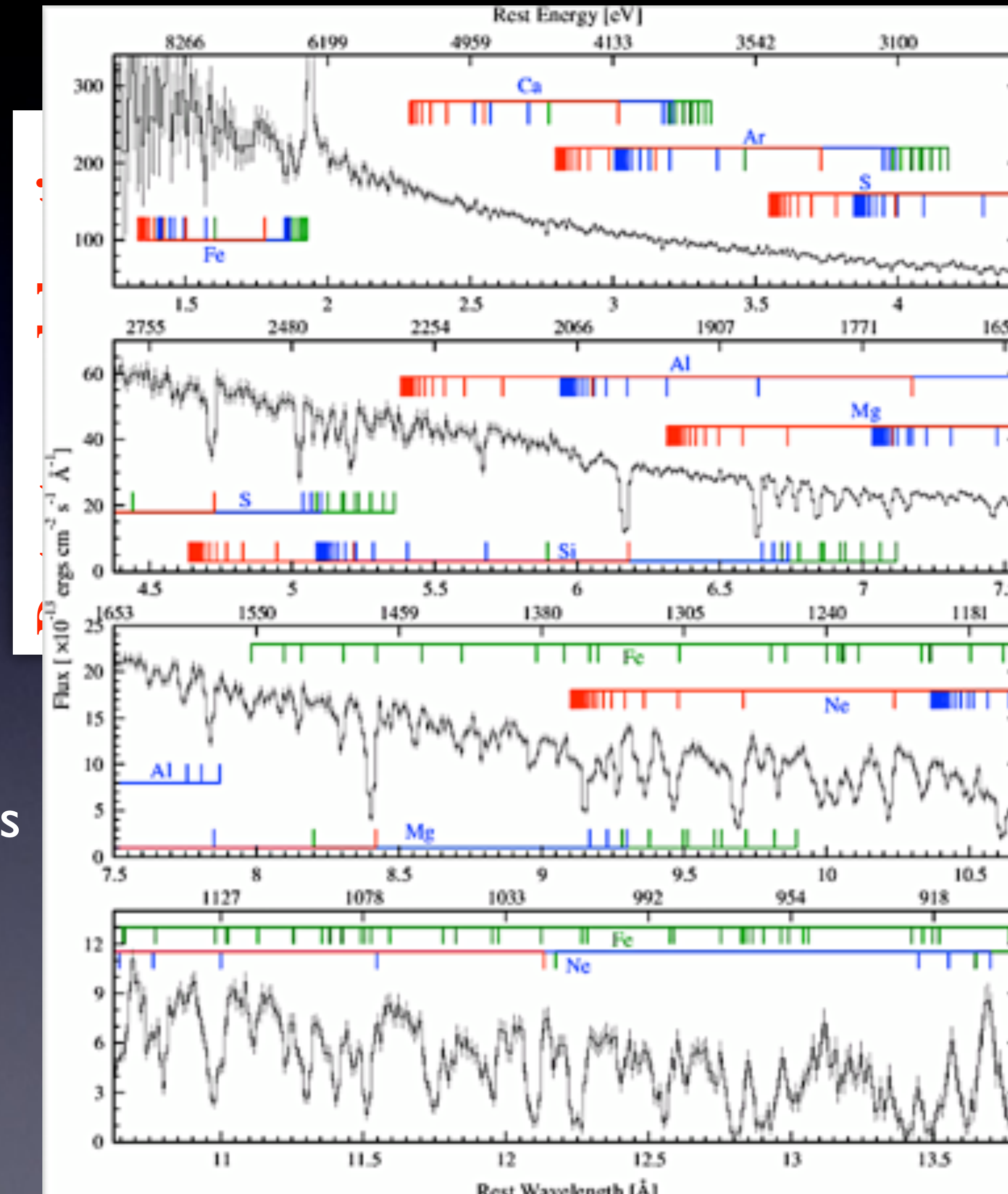
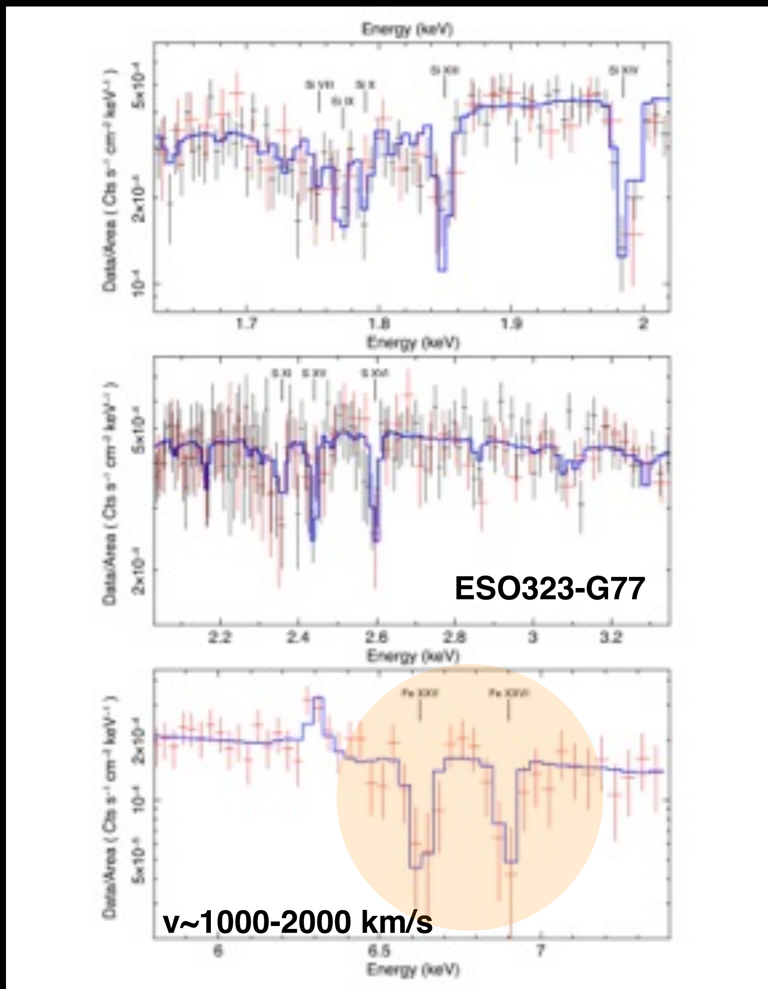
NGC 3783 Chandra HETG 900 ks
Kaspi et al. 2002, Krongold+03

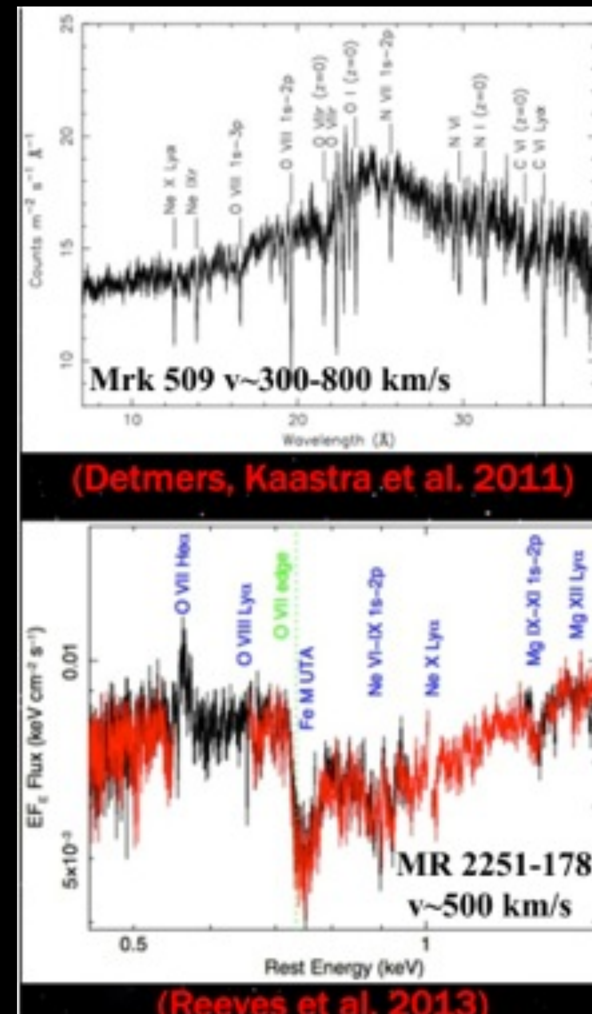


Observations of X-ray slow winds



Sanfrutos et al. 2016

Chandra HEG spectrum



XMM-Newton RGS spectra

Relevance of X-ray winds

The observed velocity shift (almost always to the blue) provides evidence that material is traveling outward from the central region of AGN.

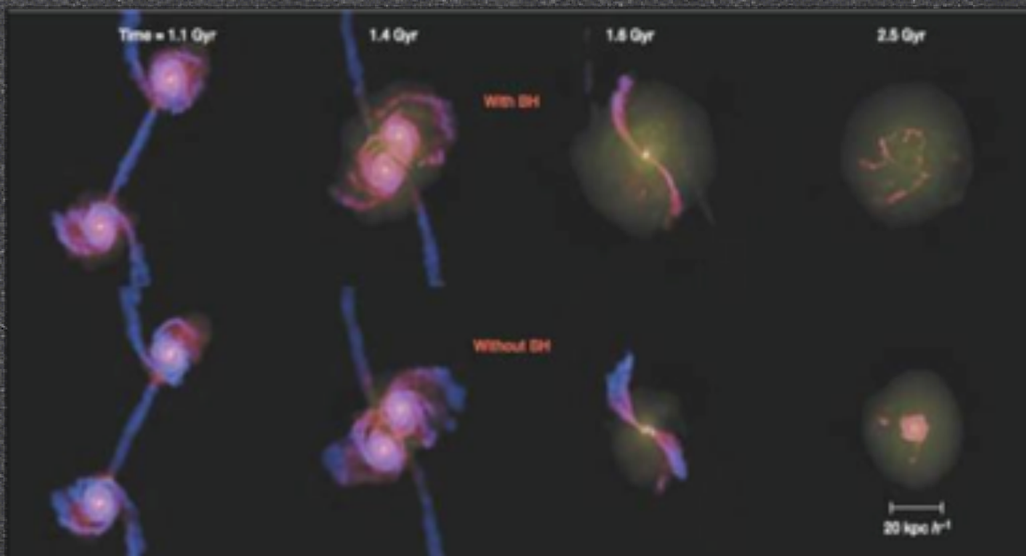
If this material eventually leaves the AGN, then outflows might carry significant mass out of the AGN and, as a consequence, give a substantial contribution to the chemical enrichment of the intergalactic medium (IGM)

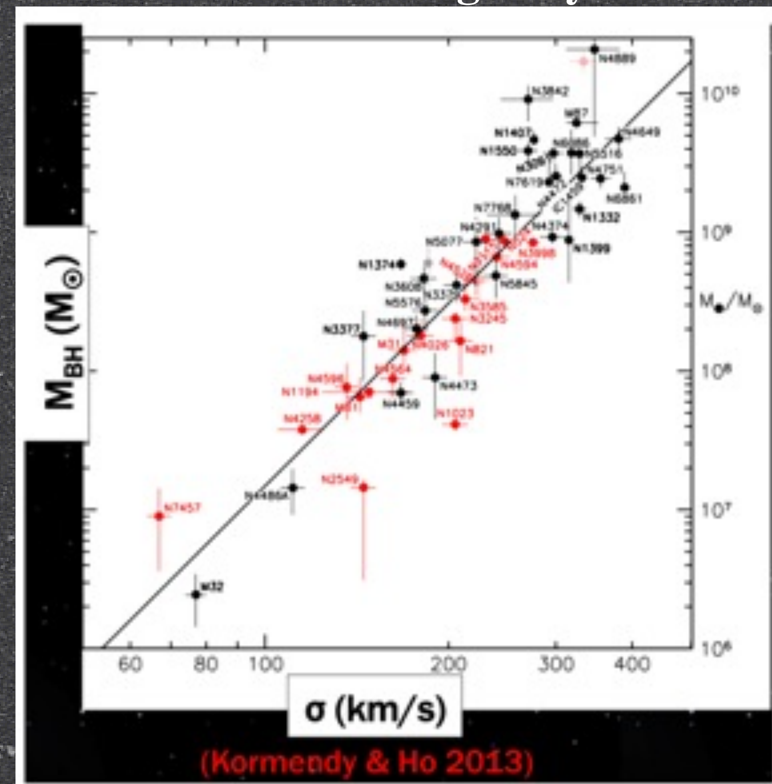
Credit: ESA/ATG Medialab, The Why Files

AGN Feedback

SMBH and host galaxy relation

Di Matteo et al. 2005





The outflow can also impact the development of the host galaxy itself.
If it is as strong as 0.5–5% of the AGN luminosity, then AGN feedback can regulate the growth of the galaxy and the growth of the central black hole as well
Di Matteo et al. 2005; Hopkins et al. 2010

Can winds produce feedback?

$$\dot{M}_{\rm out} \sim \Omega\, N_{\rm H}\, m_{\rm p}\, v_{\rm out}\, R_{\rm in}$$

★ Solid angle: frequency of BH wind signatures among local AGN

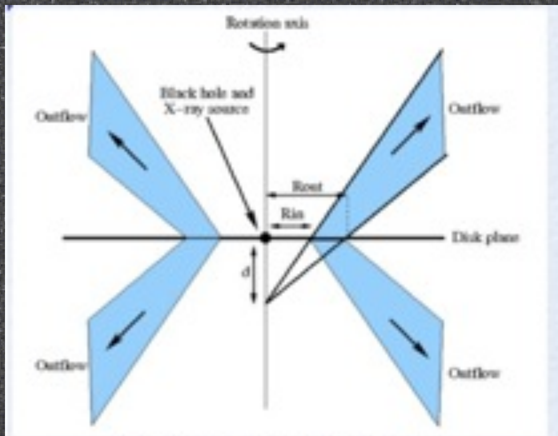
★ Column density: modelling of absorption by photo-ionised gas

★ Outflow velocity: line's energy shift following identification

★ Launch radius: ionisation state of the gas and escape velocity

It is still unclear whether disk winds have sufficient mechanical energy to power feedback on galactic scales

Models of accretion disk winds

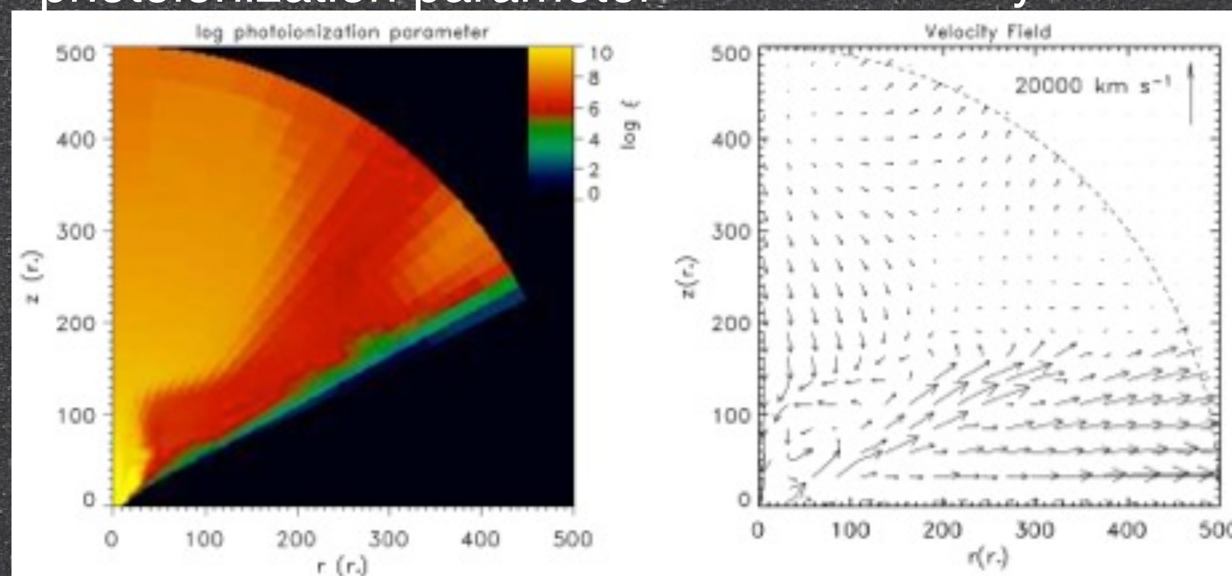


Sim et al. (2008, 2010 a,b)

Disk winds simulations of radiatively driven disk winds produce blue-shifted Fe K absorption (Proga & Kallman 2004)

Color map of photoionization parameter

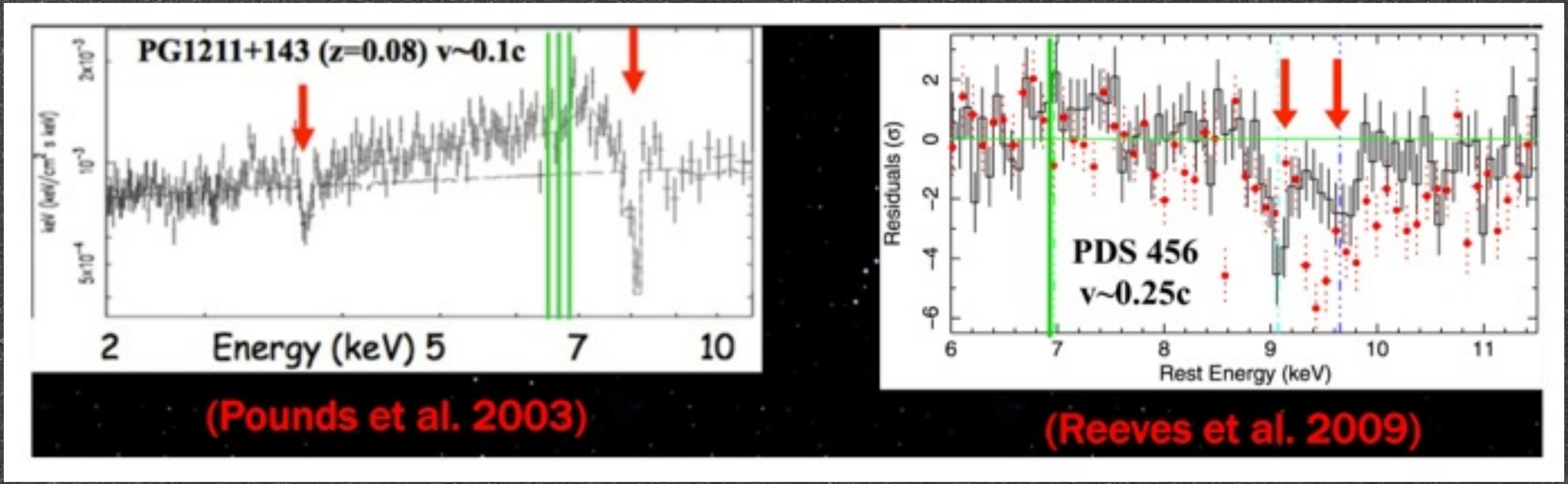
Velocity Field



Disk Rotation Axis

Disk midplane

Ultra Fast Outflows (UFOs): what are they?



Properties from systematic studies (Tombesi et al. 2010, 11,13; Gofford et al. 2013)

-Present in 30-40% of X-ray samples
-Outflow velocity ~ 0.1-0.3c
-Mass outflow rate ~0.01-1 $M_{\odot}$ yr^{-1}

- Observed in the Fe K band as blue shifted absorption lines by highly ionized Iron
- Debate on their reality in the X-ray community

Debate on the existence of X-ray Ultra Fast Outflows (UFOs)

- The absorption signature of Fe XXV and Fe XXVI is blue-shifted to a spectral region where the effective area of ALL current X-ray satellites decreases fast

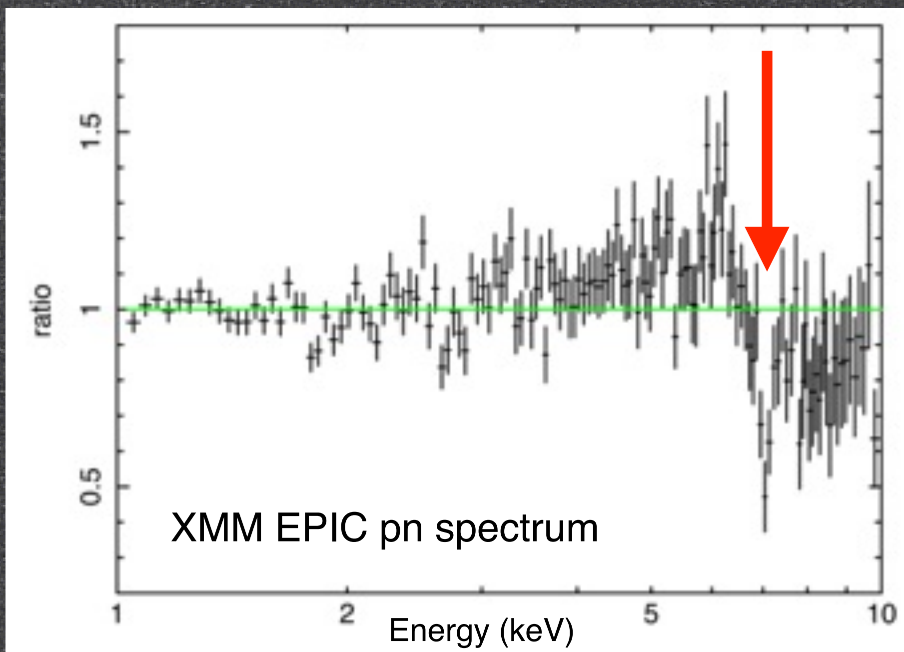
- The instrumental background starts rising up above 7-8 keV

- Calibration uncertainties and limited bandpass play their part (both XMM and Suzaku reach 10 keV)

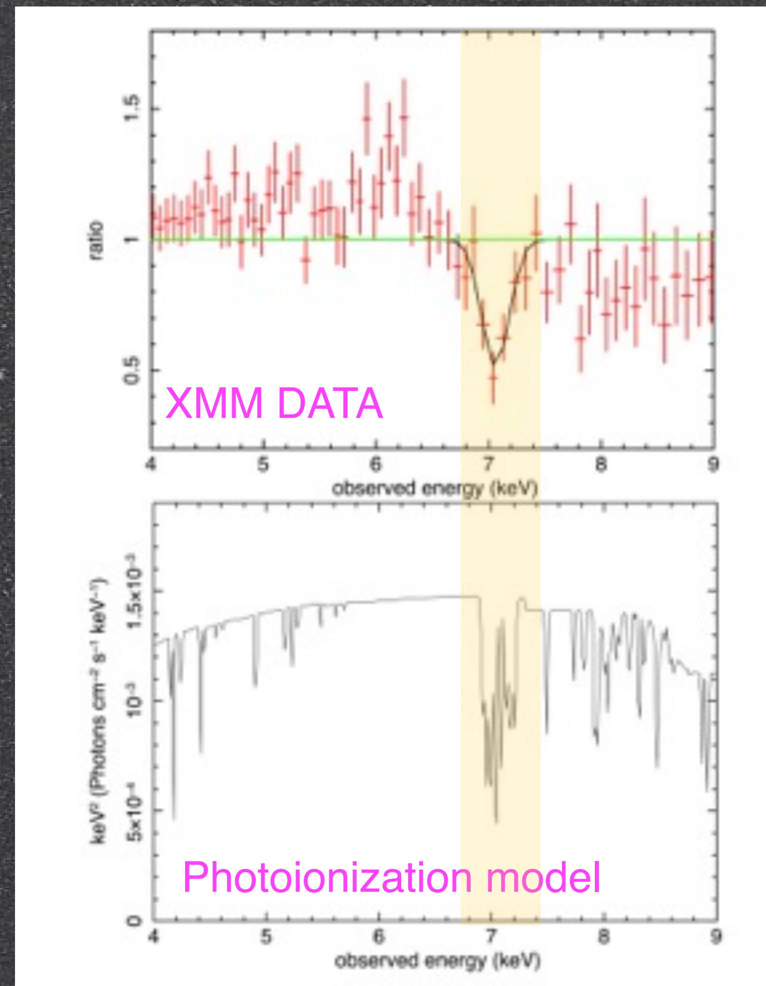
- No possibility to resolve the absorption features at CCD resolution since Chandra High Energy Grating spectrometer not sensitive enough

Spectral Signatures of UFOs

PG1211+143, first UFO detected in 2003
Fe XXV-XXVI absorption blue-shifted
to v_{out}~0.1 c

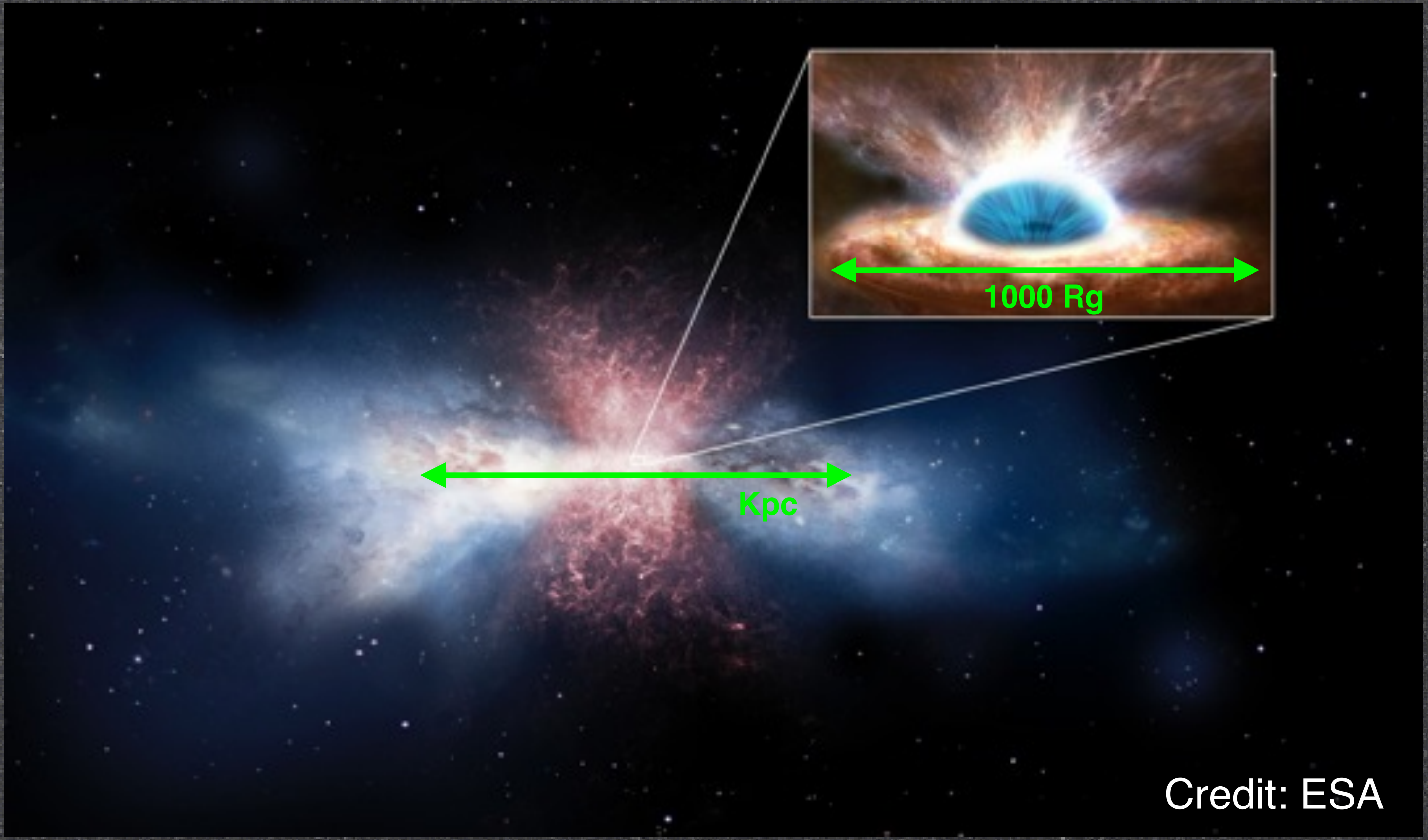


Several doubts on the reality of these features as a well established phenomenon still persist



King & Pounds 2015 ARA&A..53..115K

Can BH activity affect galaxies at such large scale?

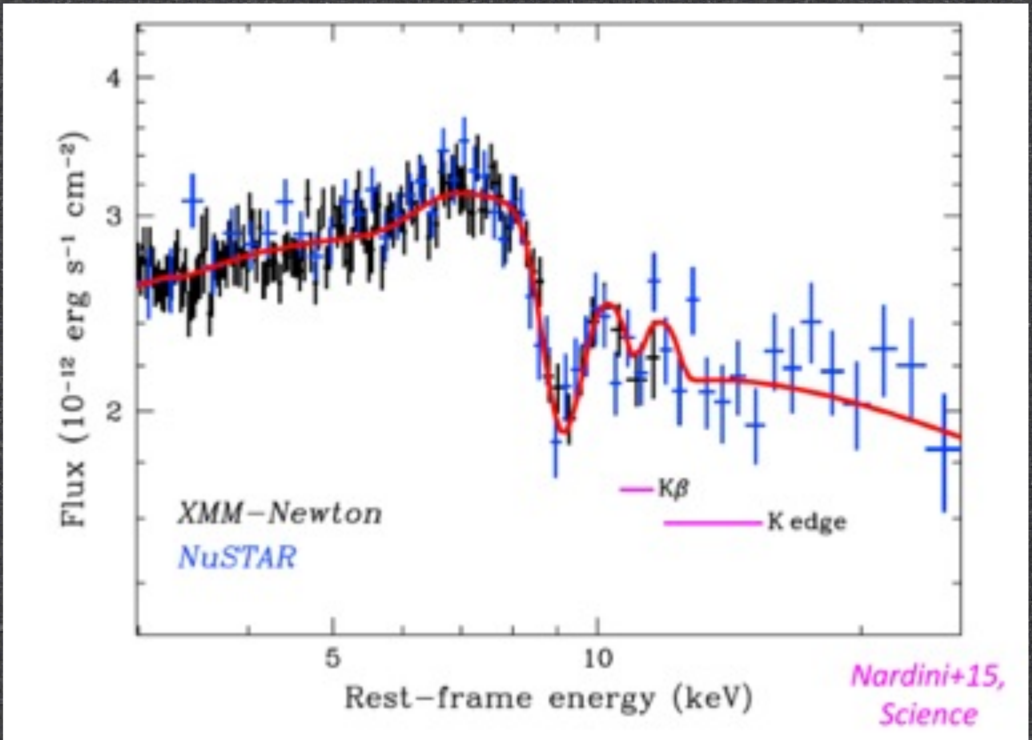


Disk winds as feedback triggers

Prototype of fast wind at Fe K: QSO PDS 456

Systematic detection of broad absorption trough above 7 keV, ionized disk wind with velocity ~0.3c (Reeves et al.)

$L_{Bol} \sim 10^{47}$ erg s^{-1} $M_{BH} \sim 10^9 M_\odot$



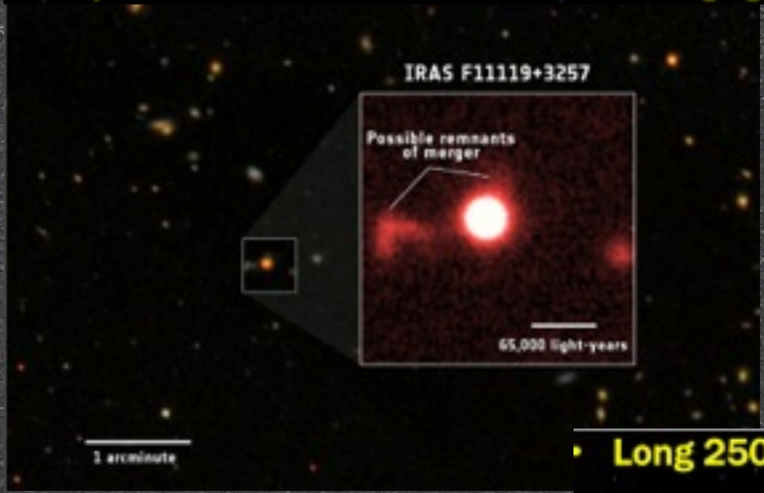
5 XMM/NuSTAR Obs:
P-Cygni-like profile
Wide-angle wind
$M_{out} \sim 0.2\ L_{Bol}$

Enough energy deposition to produce feedback on the host galaxy (Hopkins & Elvis 2010)

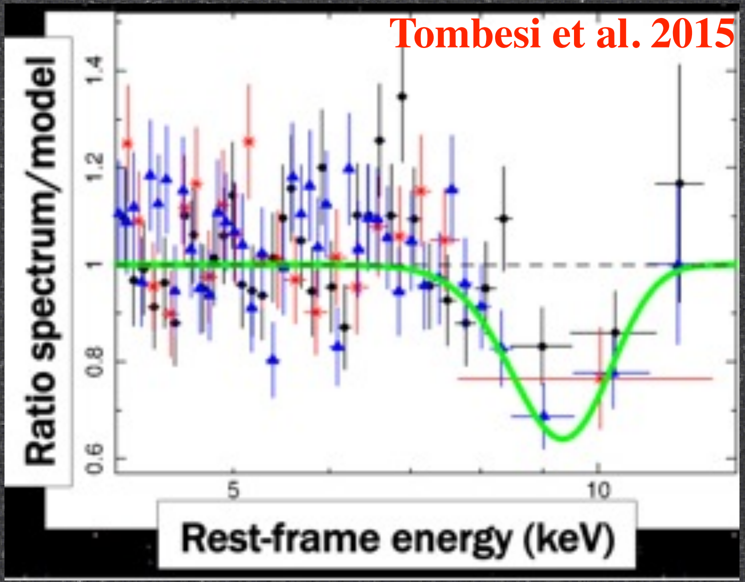
Connection of X-ray winds to molecular outflows (I)

Tombesi et al. 2015

- IRAS F11119+3257, ULIRG z=.189, QSO luminosity 10^{46}erg/s
- Herschel spectrum of the OH 119μm P-Cygni line profile
- Molecular outflow 1000 km/s, 800 $M_\odot$ yr^{-1} at >300 pc
- Depletion of the reservoir of "star-making" gas



Credit: NASA's Goddard Space Flight Center/SDSS/ S. Veilleux

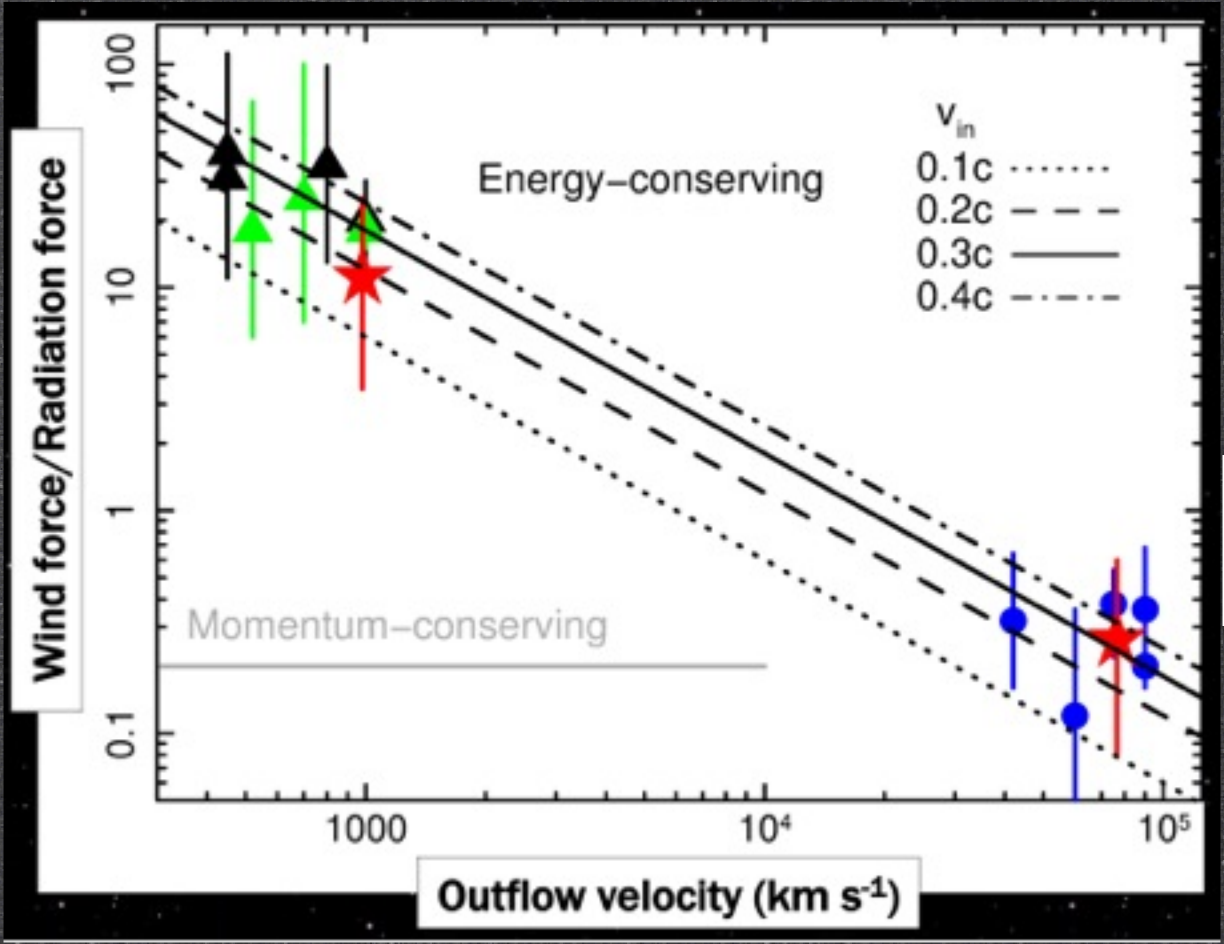


- Long 250ks Suzaku observation in May 2013
- Detection (6.5sigma) broad absorption line at rest-frame E=9.82keV
- Excluded slower absorber (edge) and disk reflection (variability, luminosity)
- XSTAR fit: v=0.255c, logxi=4.11, Nh=6×10^{24}, covering fraction >0.85

Connection of X-ray winds to molecular outflows (II)

OH outflows
CO outflows

$\frac{(dP/dt)}{L_{AGN}/c}$



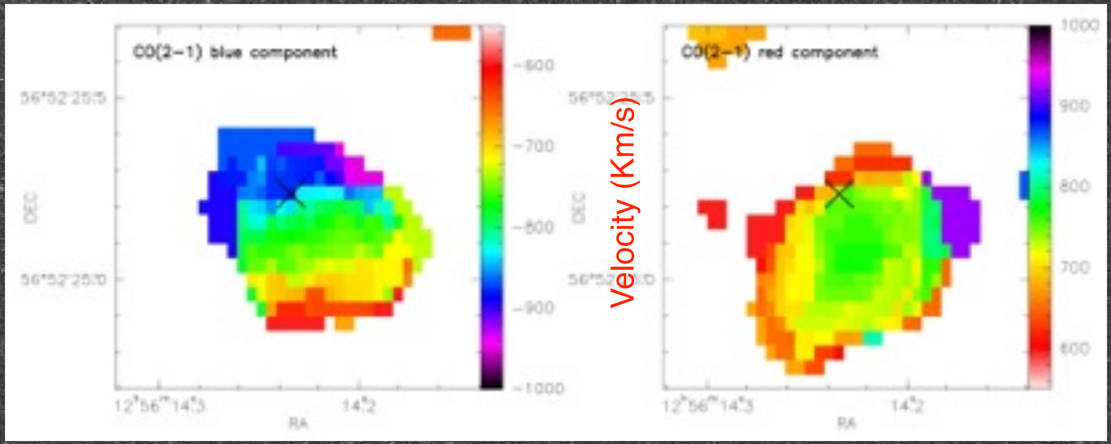
X-ray UFOs

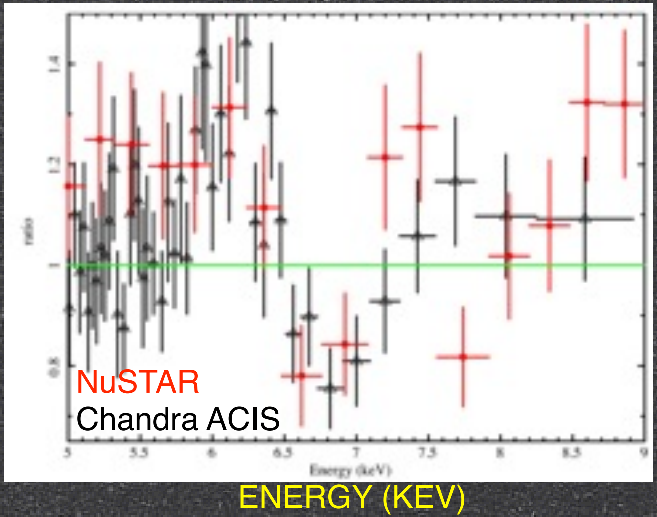
IRASF111191+3257

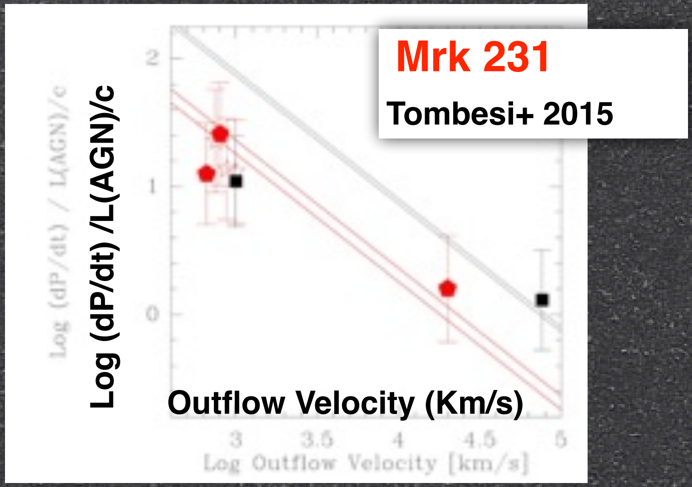
Tombesi et al. 2015

Multi-phase winds in Mrk 231

Similar result found in another ULIRG Mrk 231 by Feruglio et. al 2015
CO outflow (IRAM) + Fe K UFO (Chandra)







$L_{Bol} \sim 5 \times 10^{45}$ erg/s

Molecular Outflow extended on ~1 kpc scale

$\dot{M}_{out} \sim$ 500-1000 M yr^{-1}

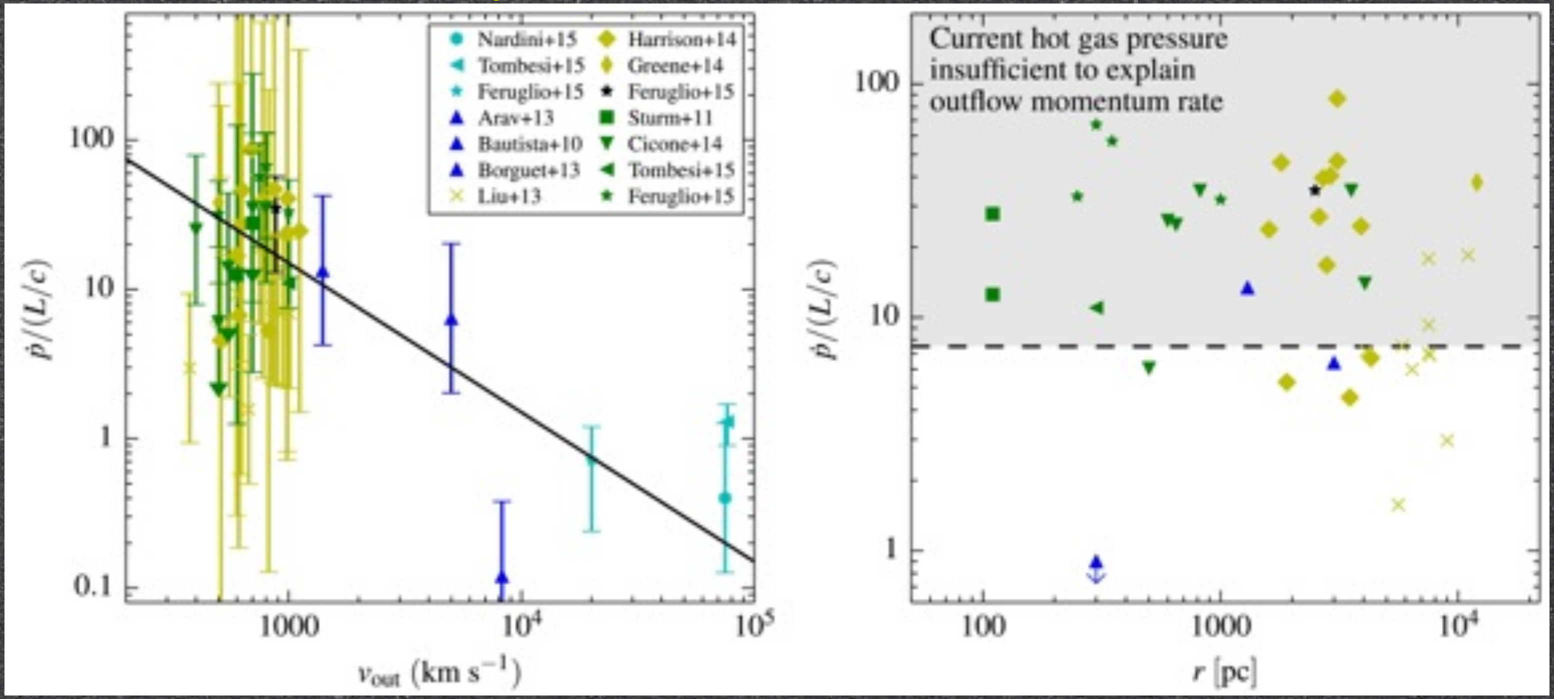
$\dot{M}_{UFO} = [0.3 - 2.1]\ M_{\odot} yr^{-1}$

V_{out} ~20000 km/s

Compilation of galaxy-scale outflows in QSOs with L=10^{45} - 10^{47} ergs/s

Outflows momentum vs outflow velocity

Momentum vs distance of the outflow from the QSO



Stern et al. 2016

Molecular gas
Ionized UV gas
Highly ionized X-ray gas
Ionized gas in optical emission lines

Need for an “early boost” of momentum in QSOs outflows

“Most of the observed momentum fluxes are within the gray region, indicating that the current hot gas pressure is insufficient to explain the large (albeit uncertain) momentum fluxes inferred of present galaxy-scale outflows.

This suggests that the observed galaxy-scale outflows and/or the quasar luminosity evolved systematically since the outflows were launched from the nucleus, as would be the case if the outflows obtained their large momentum fluxes in an earlier phase in which the quasars were buried and obscured in the optical”

Stern et al. 2016

X-RAY HIGH-RESOLUTION SPECTROSCOPY REVEALS FEEDBACK IN A SEYFERT GALAXY FROM AN ULTRA-FAST WIND WITH COMPLEX IONIZATION AND VELOCITY STRUCTURE

A. L. Longinotti[1,2,3], Y. Krongold[2], M. Guainazzi[3,4], M. Giroletti[5], F. Panessa[6], E. Costantini[7], M. Santos-Lleo[3], and P. Rodriguez-Pascual[3]

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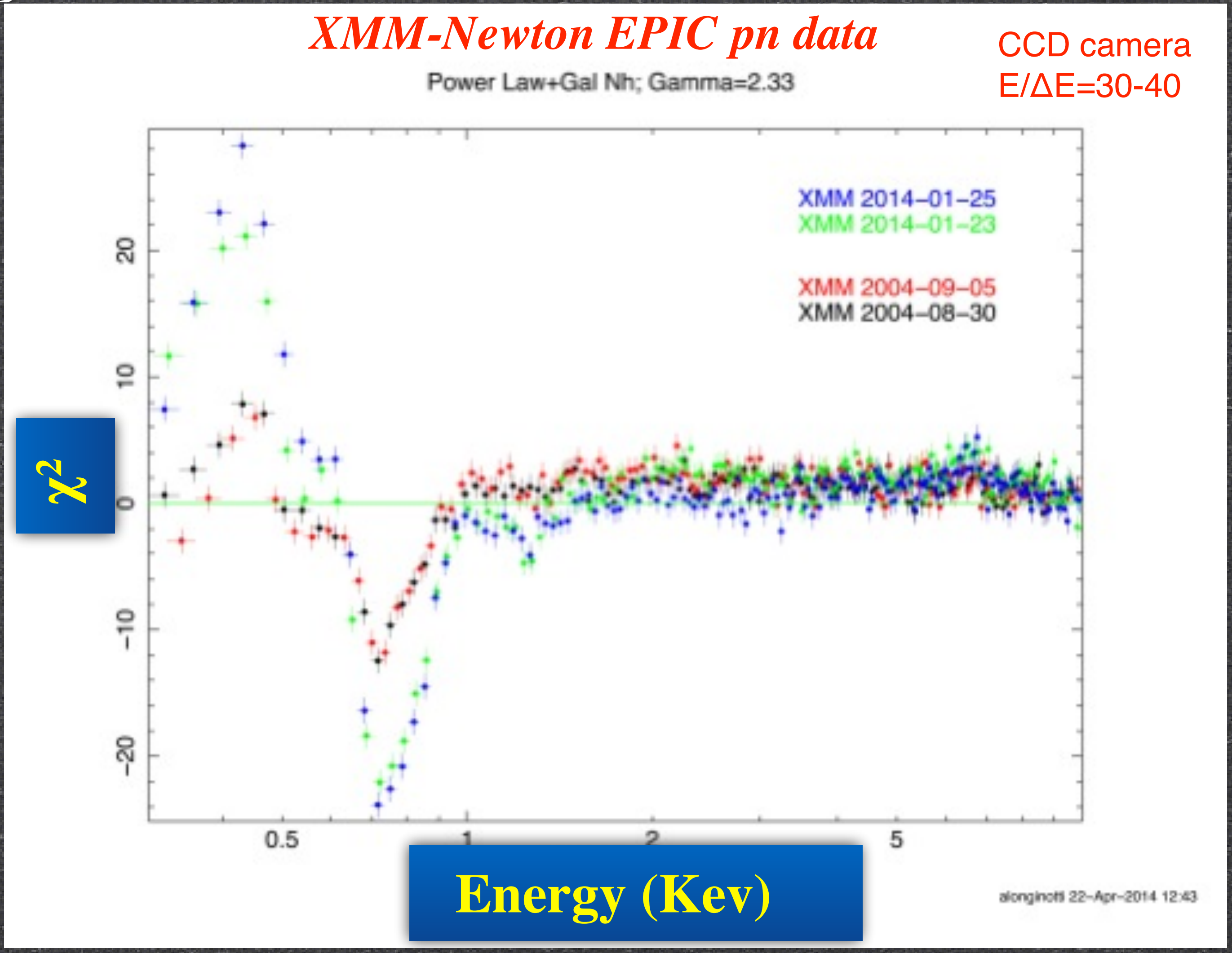
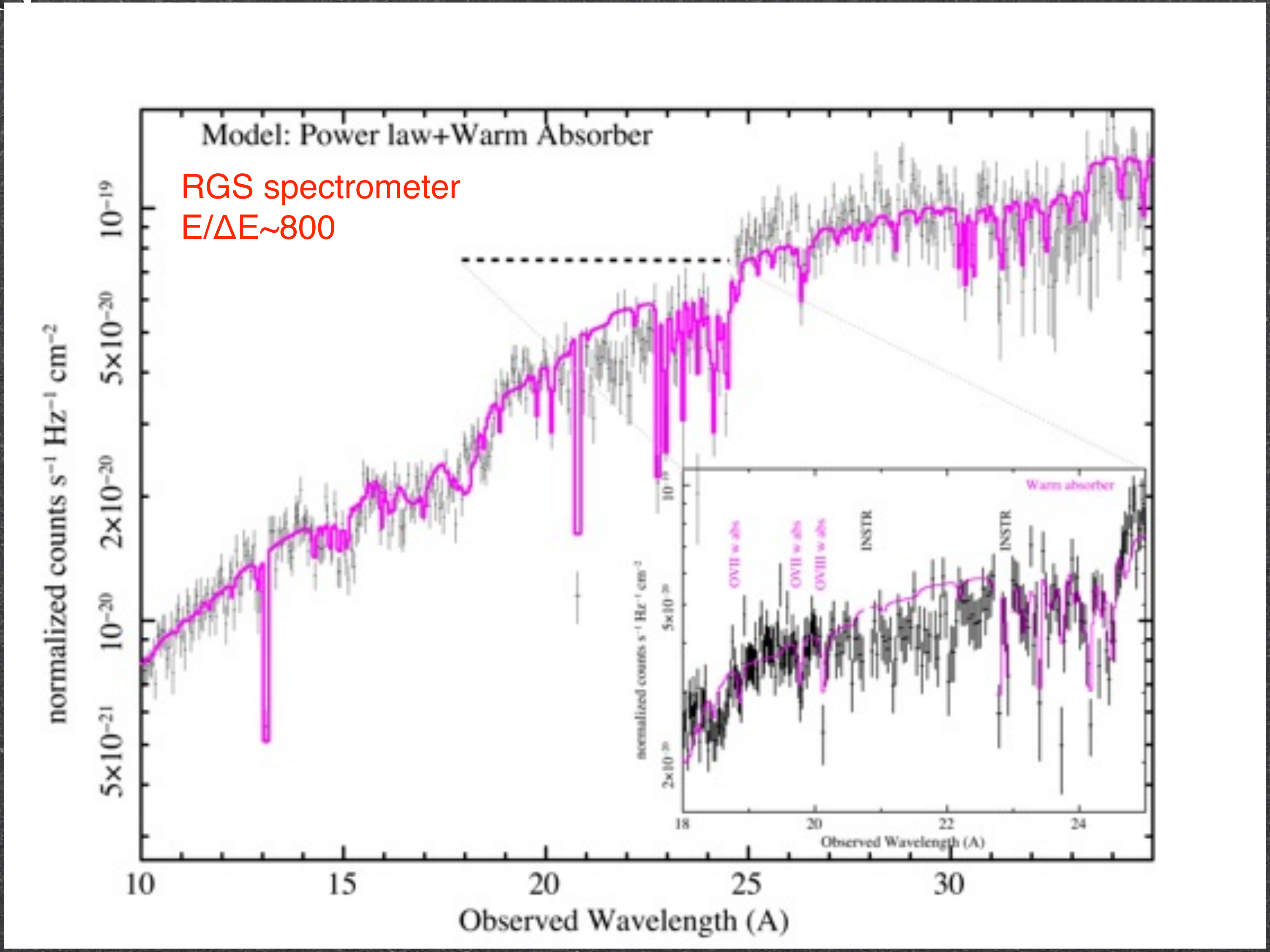
ApJ Letters 813 L39

First view of an UFO at X-ray high-resolution: IRAS17020+4544



First view of an UFO at X-ray high-resolution: IRAS17020+4544



The multi-component ultra fast outflow

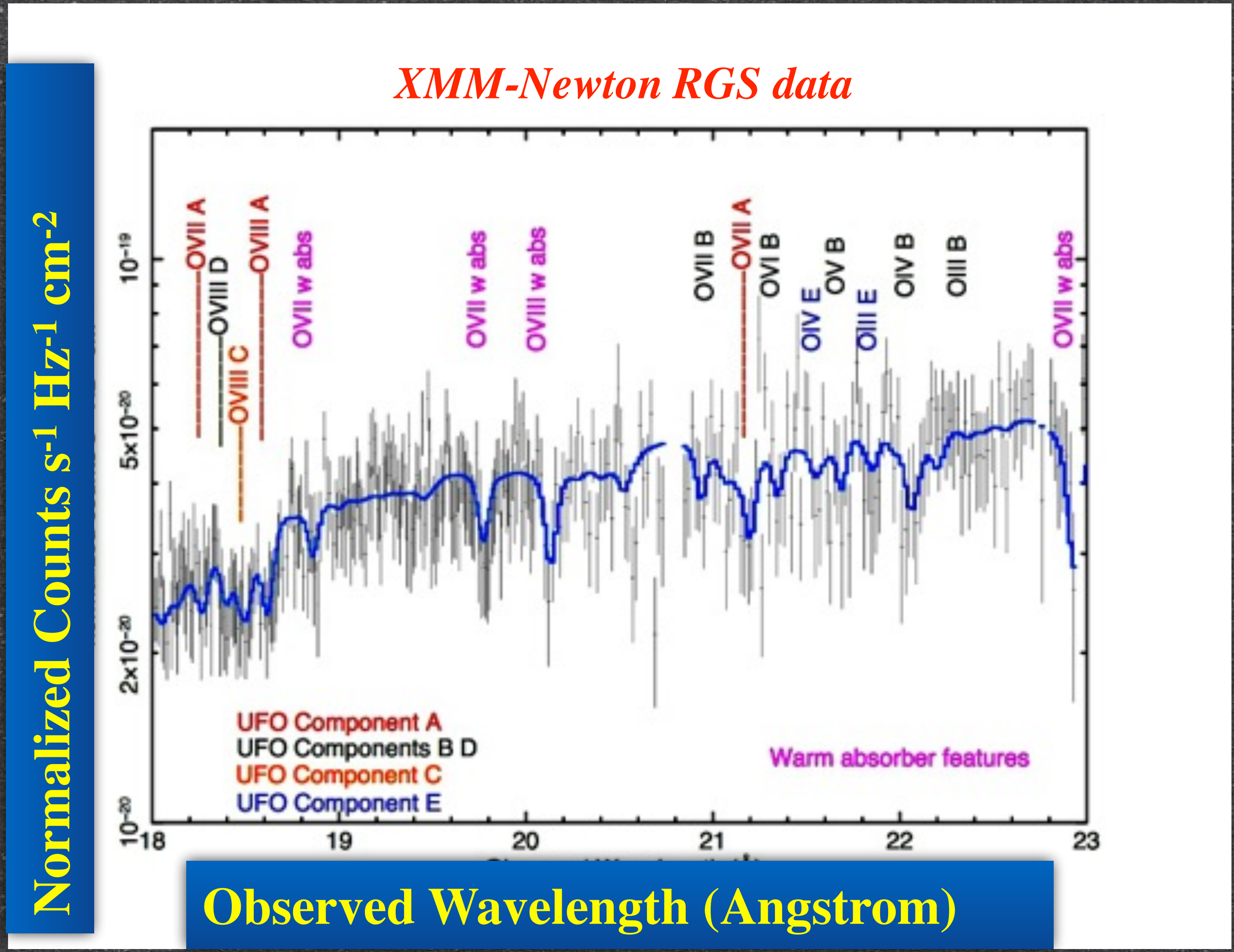


Table 1
List of Absorption Lines Individually Detected above a 2σ Threshold

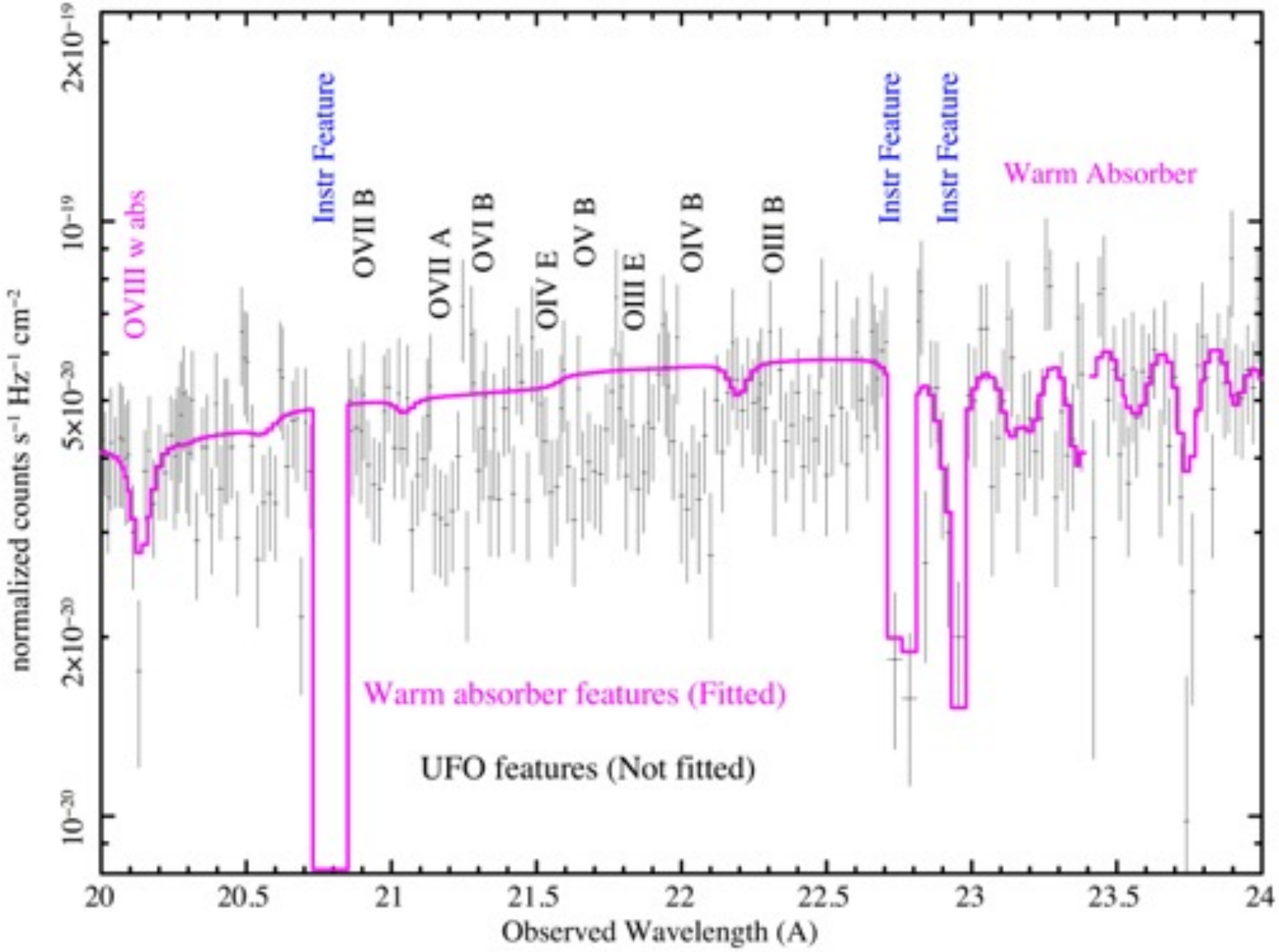
Obs λ (Å)	Intensity (10^{-5} ph cm^{-2} s^{-1})	ΔCstat	Sign. σ	Line ID
$21.18^{+0.02}_{-0.02}$	$-2.7^{+0.60}_{-0.60}$	34	4.5	O VII
$22.03^{+0.04}_{-0.02}$	$-3.01^{+0.89}_{-0.73}$	32	3.4	O IV
$18.60^{+0.03}_{-0.03}$	$-1.54^{+0.55}_{-0.55}$	19	2.8	O VIII
$21.67^{+0.03}_{-0.03}$	$-2.17^{+0.80}_{-0.80}$	21	2.7	O V
$21.83^{+0.03}_{-0.01}$	$-2.28^{+0.92}_{-0.92}$	18	2.5	O III
$21.55^{+0.03}_{-0.02}$	$-1.76^{+0.85}_{-0.91}$	8	2.0	O IV
$20.93^{+0.02}_{-0.03}$	$-1.61^{+0.83}_{-0.82}$	10	2.0	O VI

Individual Gaussian absorption lines

PHASE absorption lines (self-consistent model)

Table T4: List of absorption lines from the ultra fast outflow

Ion -	Rest λ Angstrom	Obs λ Angstrom	Predicted EW Angstrom	UFO comp -
OVII	21.601	21.203	40.46	A
OVII	18.627	18.284	13.71	A
OVIII	18.969	18.619	41.83	A
OIII	23.090	22.388	1.60	B
OIII	23.070	22.368	1.34	B
OIV	22.770	22.077	14.63	B
OIV	22.740	22.048	16.36	B
OIV	22.660	21.971	7.74	B
OV	22.374	21.693	22.20	B
OVI	22.019	21.349	21.10	B
OVI	21.800	21.137	8.43	B
OVII	21.601	20.944	18.73	B
OVII	18.627	18.060	7.66	B
OVIII	18.969	18.397	22.38	C
OVII	21.601	21.080	9.96	D
OVII	18.627	18.178	2.49	D
OVIII	18.969	18.512	23.02	D
OII	23.345	22.113	6.58	E
OII	23.292	22.063	5.71	E
OIII	23.090	21.871	8.06	E
OIII	23.070	21.852	6.83	E
OIII	23.030	21.814	4.95	E
OIII	23.000	21.786	1.09	E
OIV	22.770	21.568	7.38	E
OIV	22.740	21.540	8.06	E
OIV	22.660	21.464	2.37	E
OV	22.374	21.193	3.80	E



OVIII w abs
Instr Feature
OVII B
OVII A
OVI B
OIV E
OV B
OIII E
OIV B
OIII B
Instr Feature
Instr Feature
Warm Absorber
Warm absorber features (Fitted)
UFO features (Not fitted)
normalized counts s⁻¹ Hz⁻¹ cm⁻²
Observed Wavelength (A)

Multi-component ultra fast disk wind in IRAS17020+4544

Properties from the X-ray spectrum

Table 2
Parameters of the Five UFO Components Detected in the RGS Spectrum

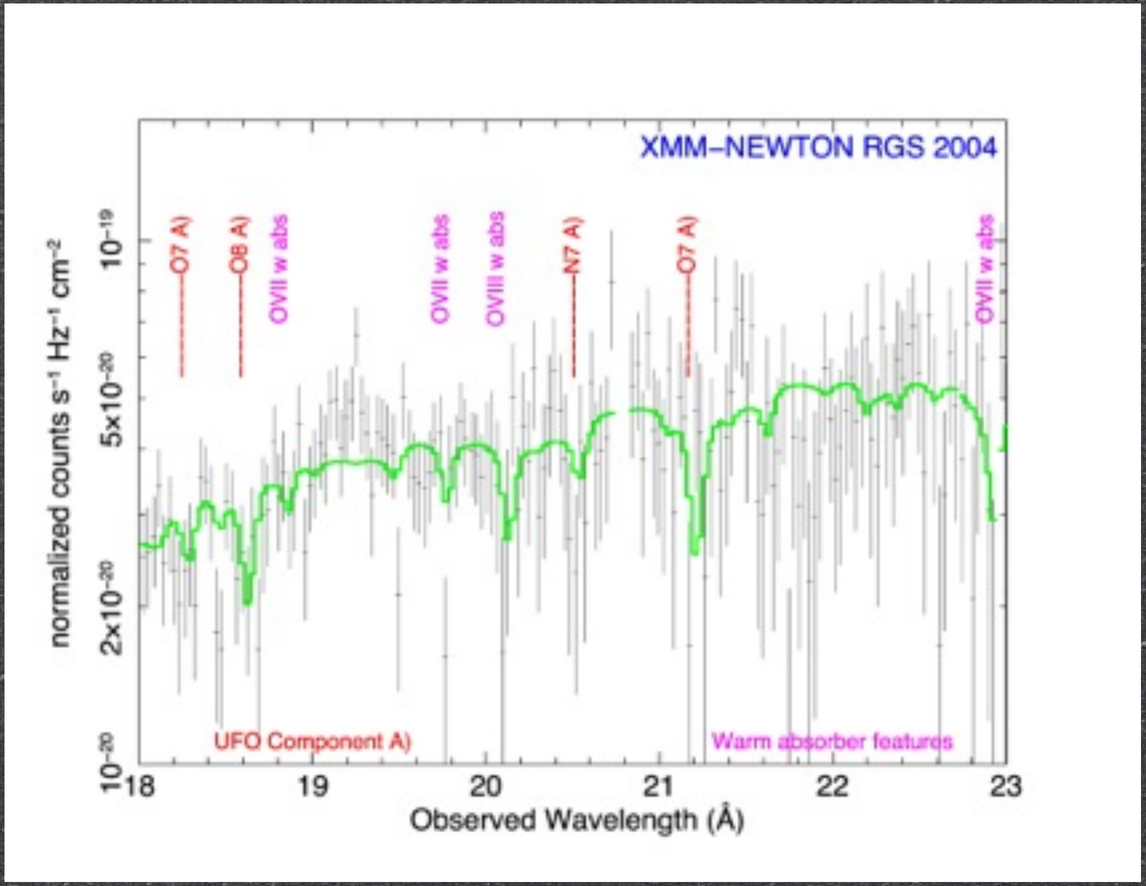
UFO Component Index	log U (erg cm s^{-1})	Log N_H (cm^{-2})	v_{out} (km s^{-1})	Statistics ΔC_{stat}	Significance
Comp (A)	$-0.39^{+0.30}_{-0.15}$	$21.47^{+0.18}_{-0.21}$	23640^{+150}_{-60}	45	9.0σ
Comp (B)	$-1.99^{+0.33}_{-0.26}$	$20.42^{+0.21}_{-0.58}$	27200^{+240}_{-240}	26	5.3σ
Comp (C)	$2.58^{+0.17}_{-0.85}$	$23.99^{+0}_{-1.86}$	27200^{+300}_{-270}	10	3.6σ
Comp (D)	$0.33^{+1.79}_{-0.40}$	$21.42^{+0.84}_{-1.28}$	25300^{+210}_{-180}	12	2.6σ
Comp (E)	$-2.92^{+0.51}_{-0.14}$	$19.67^{+0.34}_{-0.36}$	33900^{+360}_{-270}	10	2.0σ

Note. The statistical improvement (fifth column) refers to the addition of each PHASE component to the model comprising the continuum, the warm absorbers, and the previous UFO components. The significance is estimated through Monte Carlo methods.

Five distinct outflow Components with a wide range of ionization levels and column density, yet outflowing approximately at the same speed:

never observed before!

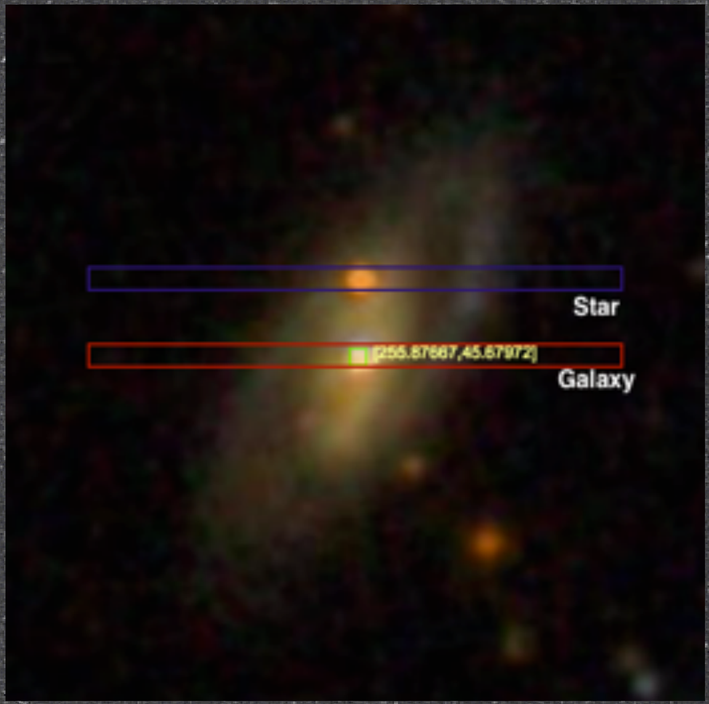
What about variability of the ultra fast outflow?

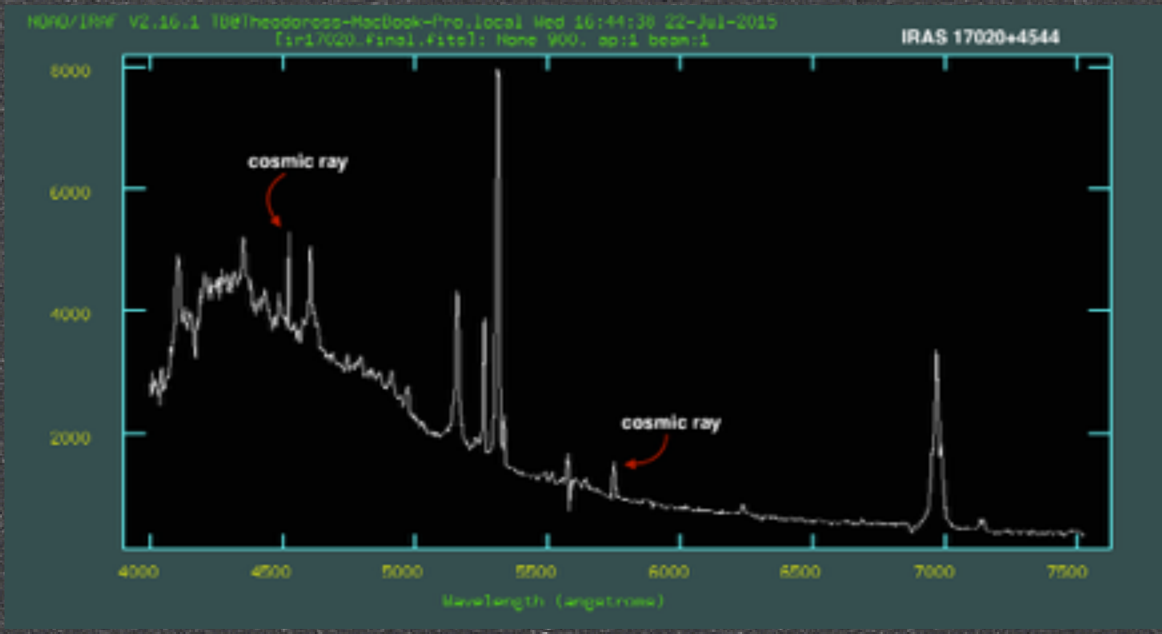


RGS spectrum
10 years earlier
~40 ks

UFO Component A
still detected

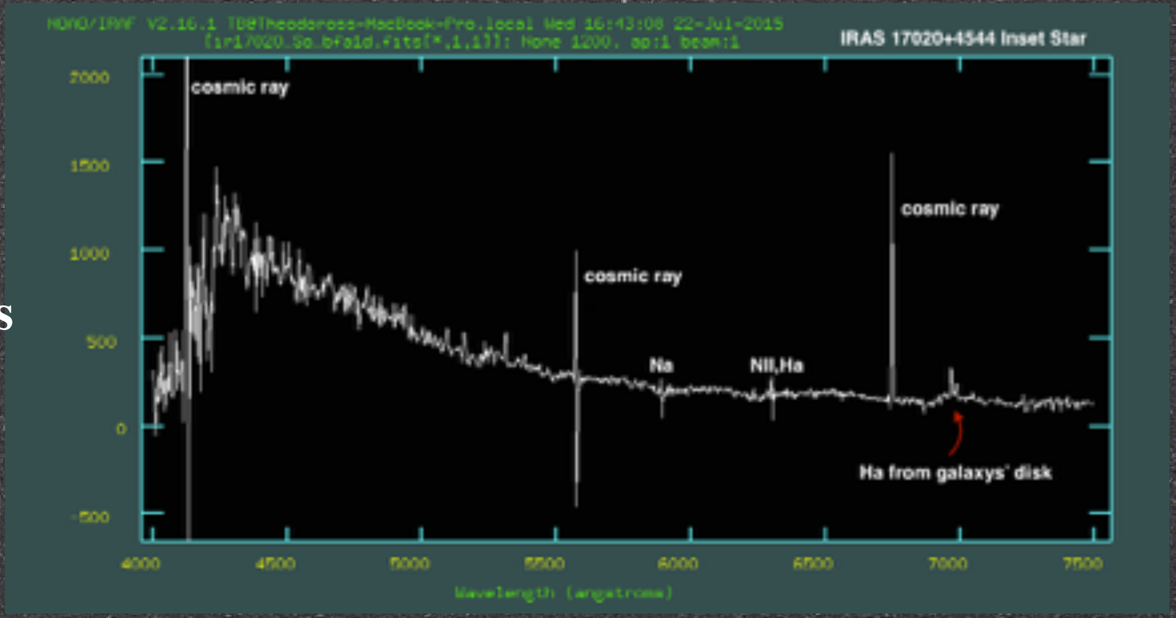
Wind seems stable
on a 10 yr time scale,
while UFOs were
thought to be transient

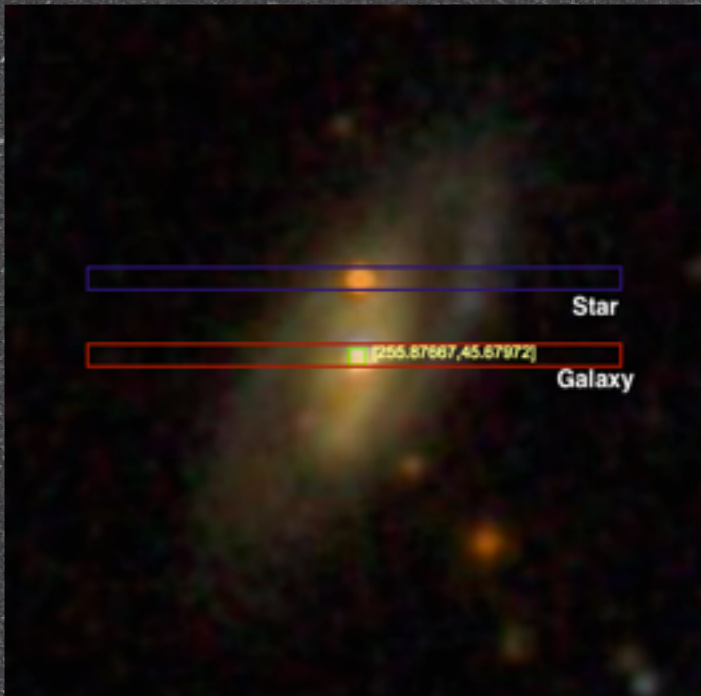


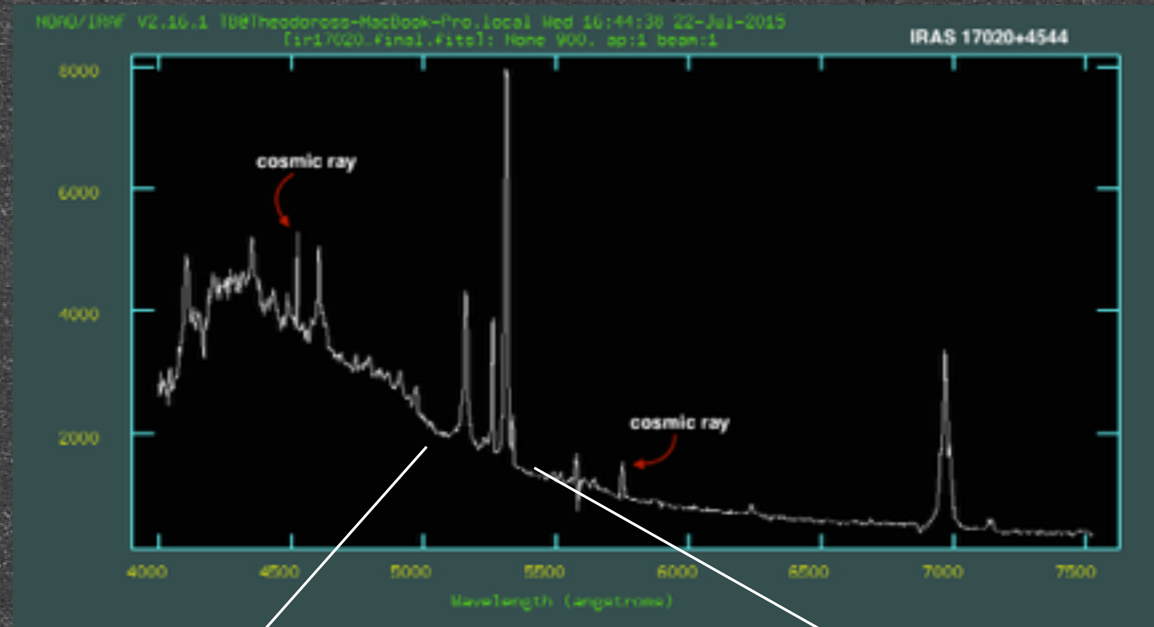


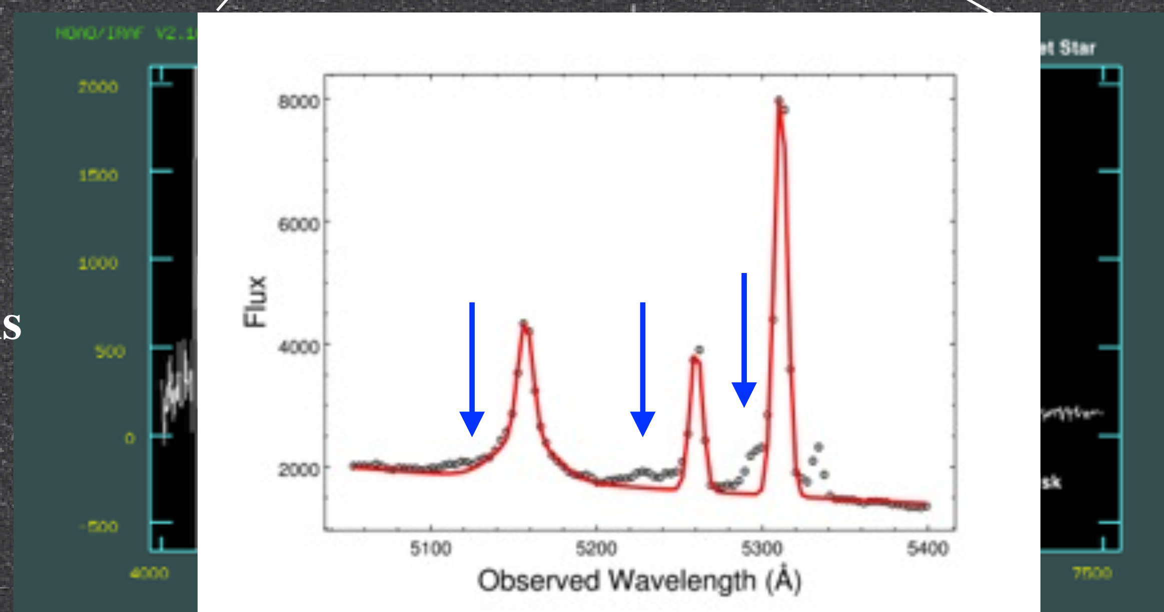
San Pedro Martir Observatory, courtesy of T. Bitsakis:

Spectrum confirms z=0.0604
Hβ FWHM~2500 km/s, confirms Narrow Line Seyfert 1







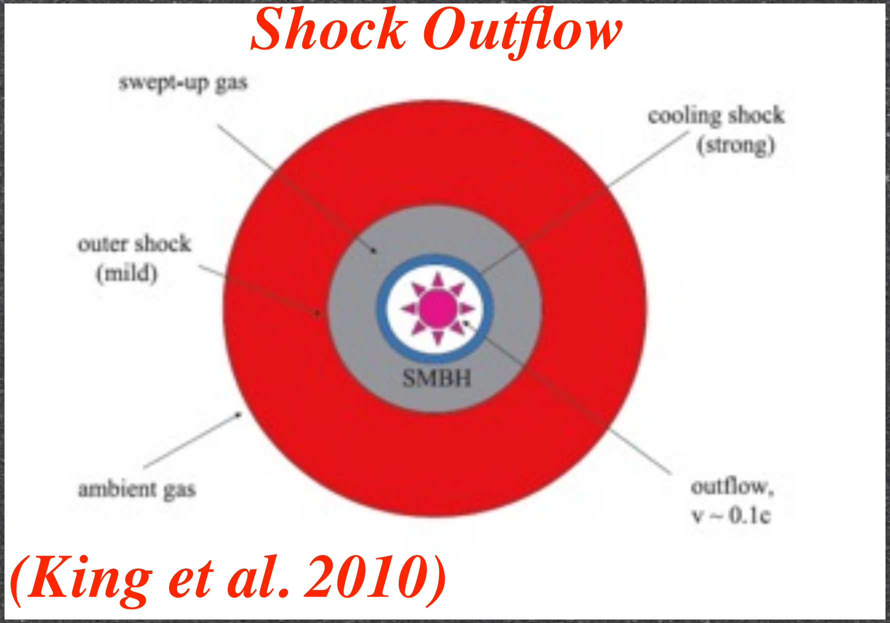


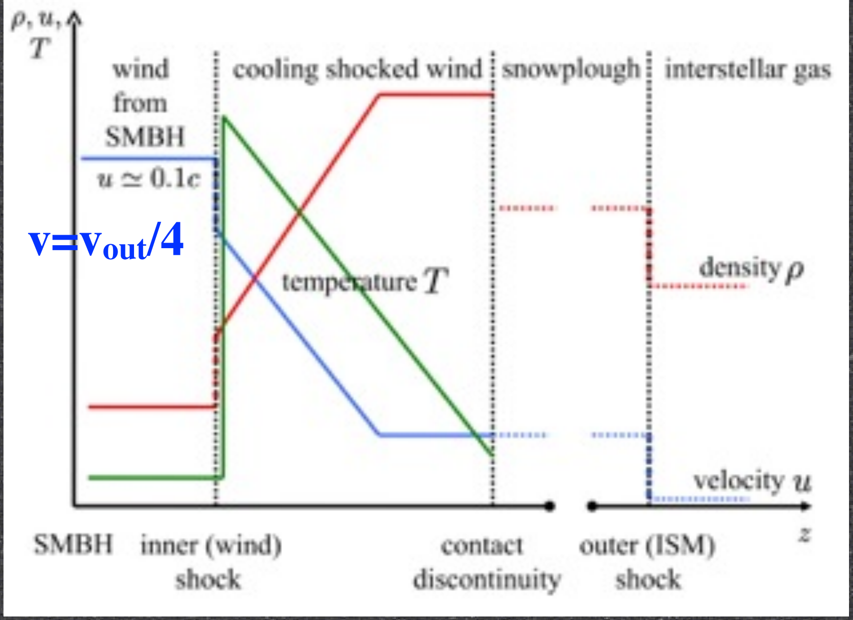
San Pedro Martir Observatory, courtesy of T. Bitsakis:

Spectrum confirms z=0.0604
Hβ FWHM~2500 km/s, confirms Narrow Line Seyfert 1

Evidence for blue wings very suggestive of an outflow with v~1000 km/s

Accretion disc winds models



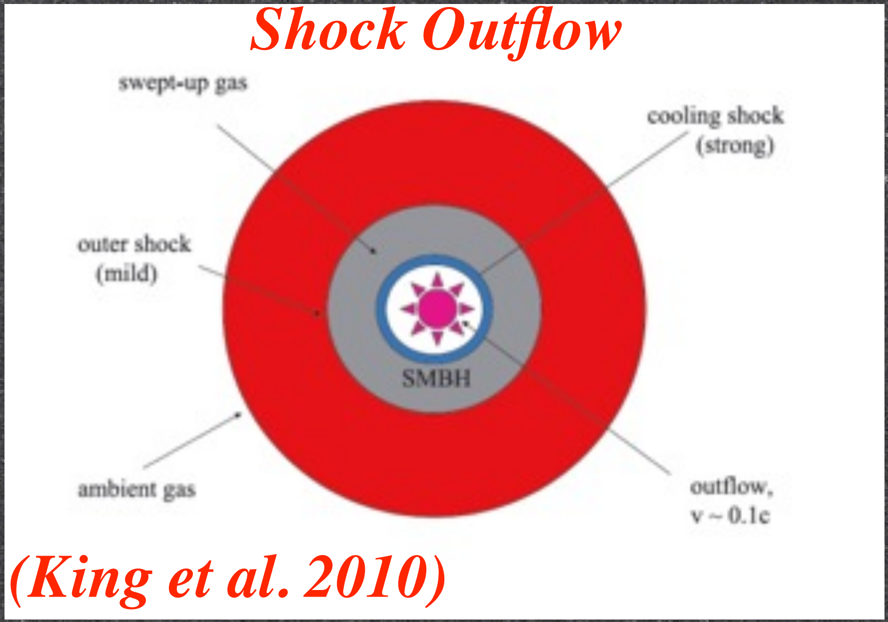


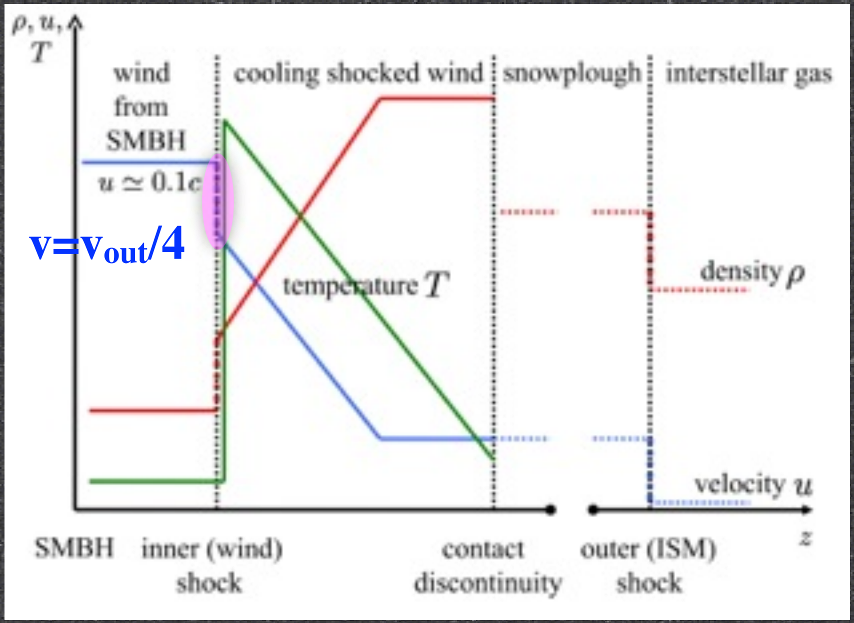
Models of disk winds predict only highly ionized features (FeXXV, XXVI > 7 keV)

Our XMM CCD data show marginal evidence for two absorption lines consistent with ionized Fe K blue-shifted at v_{out}~0.34c

v(UFO RGS)~24,000-33,000 km s^{-1} v(UFO CCD)~102,000 km s^{-1}

Accretion disc winds models





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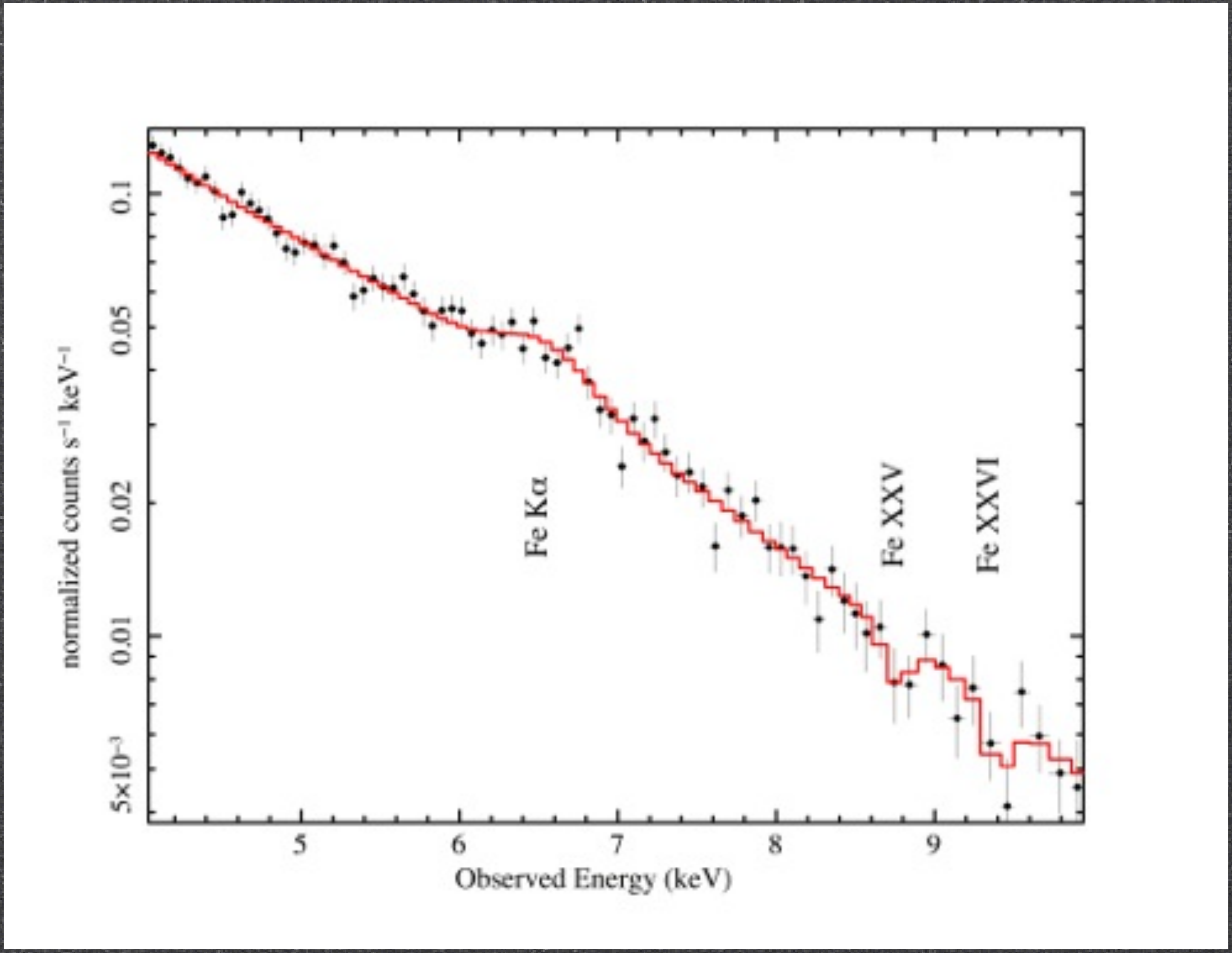
A fast outflow in the Fe K band too?



Fe XXV

E=8.75± 0.13 keV

EW=49±43 eV

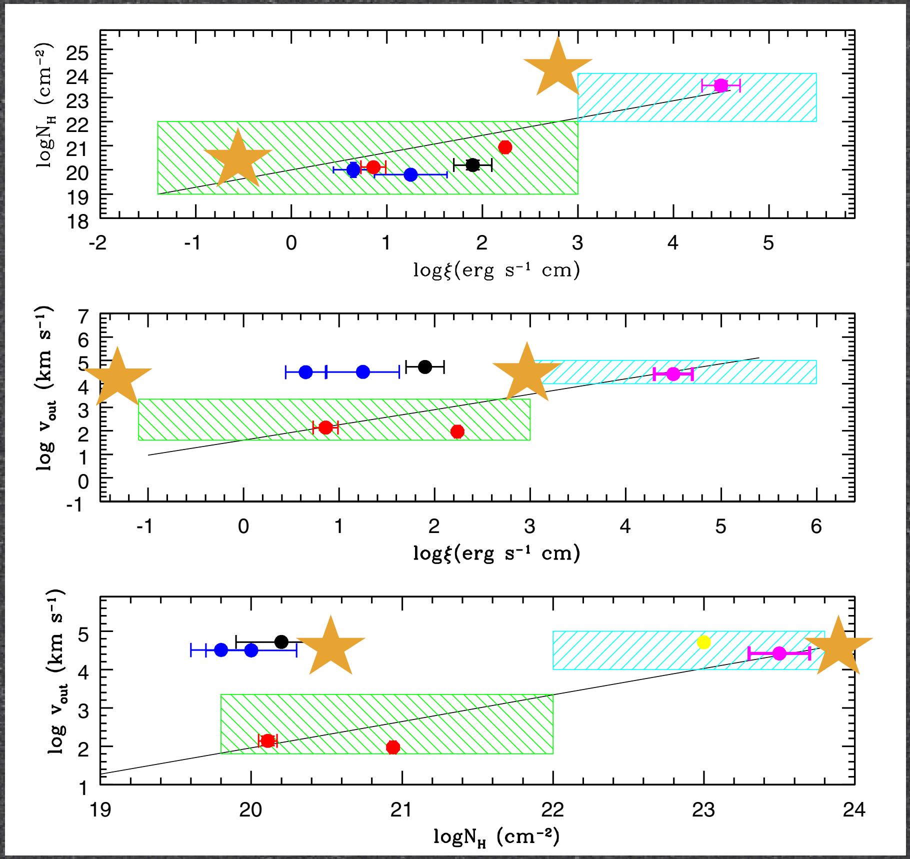
Fe XXVI

E=9.39± 0.10 keV

EW= 64±50 eV

v_{out}~ 0.34c

What about the Warm absorbers-Ultra Fast Outflow unification postulated by Tombesi et al. 2013 ?

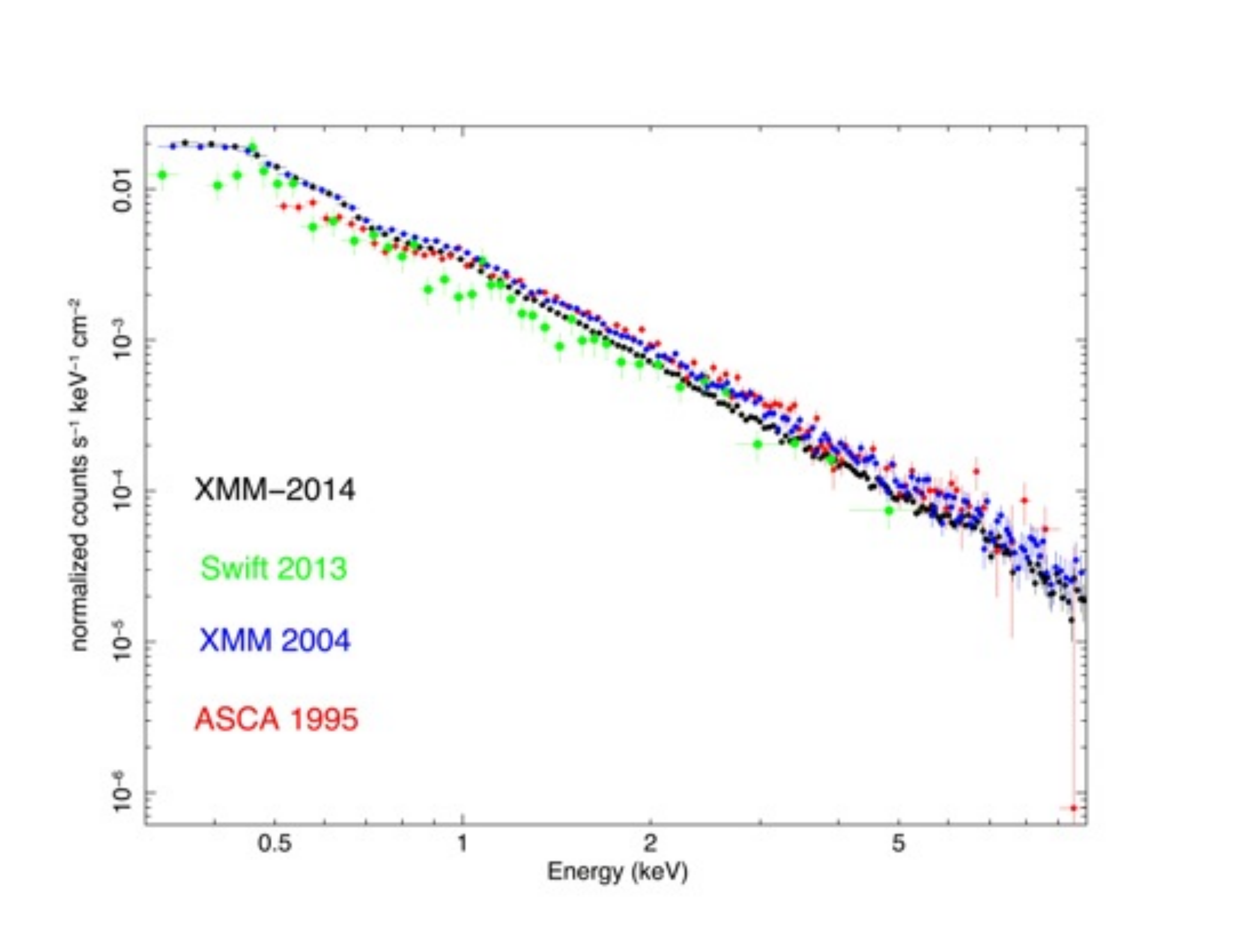


Gupta et al. 2015

★ IRAS17020+4544
UFO Component A and C

Presence of multiple wind components clearly highlights other parameters space in the relation

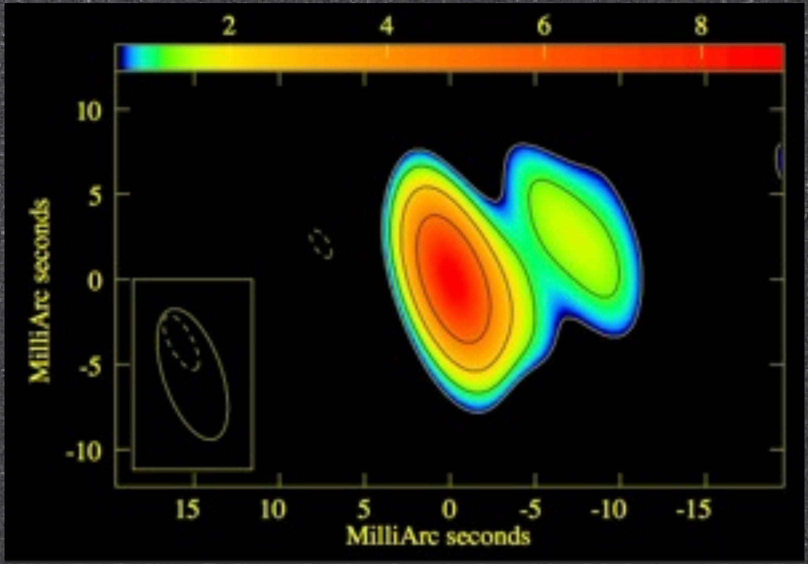
IRAS17020+4544: a non-variable Narrow Line Seyfert 1



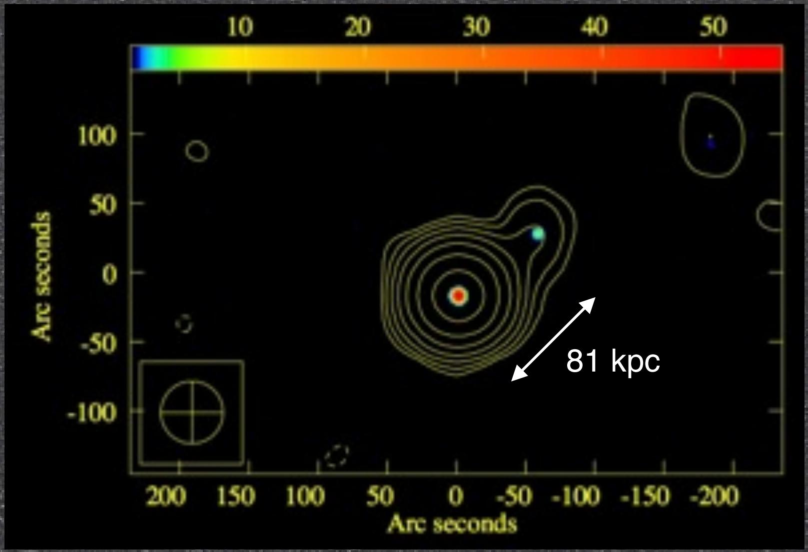
Radio Properties of IRAS17020+4544

Courtesy of M. Giroletti

VLBA image @8 GHz



Large scale image @1.4 GHz:
FIRST (colours) and NVSS (contours)



$P_{1.4\ GHz}=10^{24}$ W Hz^{-1} $T_b=10^8$ K

VLBA Observations in 2000 and 2014

Compact bright core plus a secondary fainter component at 1.2'

Steep spectral index indicates synchrotron spectrum (magnetic fields)

Elongated jetted structure /outflow at ~10 pc scale moving at v~ 0.1*c*

Possible connection with X-ray outflow?

Feedback in IRAS17020+4544

Mass and Energy outflow rates can be determined from the observable quantities in the data and assuming the outflow velocity of the wind is equal to the escape velocity:

$$r = \frac{2GM_B H}{v_{out}^2}$$

$$\dot{M}_{out} = 4\pi \mu r N_H v_{out} m_p C_f$$

$$\dot{E} = \frac{1}{2} \dot{M}_{out} v_{out}^2$$

UFO component C

$N_H \sim 10^{24}$ cm^{-2}

$v_{out} \sim 27{,}000$ km s^{-1}

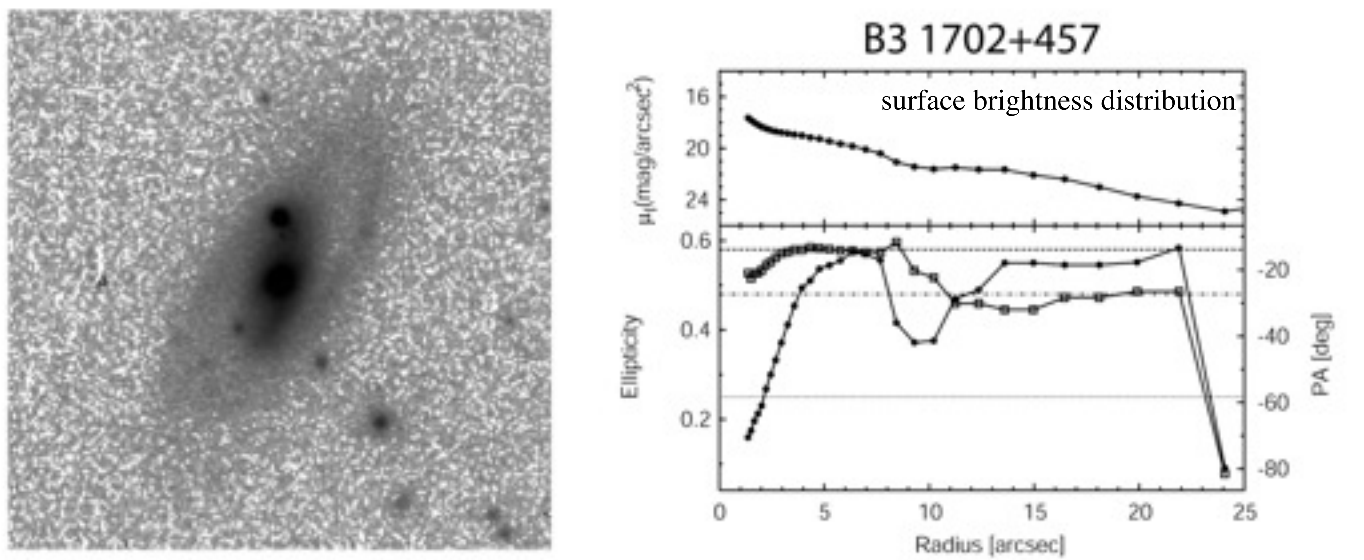
$\dot{M}_{out}(C) \sim 0.26$ Cf $M_\odot$ yr^{-1}

$\dot{E}(C) \sim 6 \times 10^{43}$ Cf erg s^{-1}

$$\frac{\dot{E}(C)}{L_{bol}} = 11\%\ \mathrm{Cf}$$

Energy rate sufficient to power feedback (Hopkins & Elvis 2010)

Implications for galaxy evolution



Ohta et al. 2007

- IRAS17020+4544 host galaxy is a barred Spiral
- $L_{bol} \sim 5 \times 10^{44}$ erg s^{-1}, significantly lower than other cases of feedback from X-ray winds (QSO, ULIRG)
- No evidence of merger/disturbed morphology/dust obscuration
- Small black hole $\sim 6 \times 10^6$ $M_\odot$
- High Accretion Rate

A Milky Way twin?

Faucher-Giguère & Quataert 2012

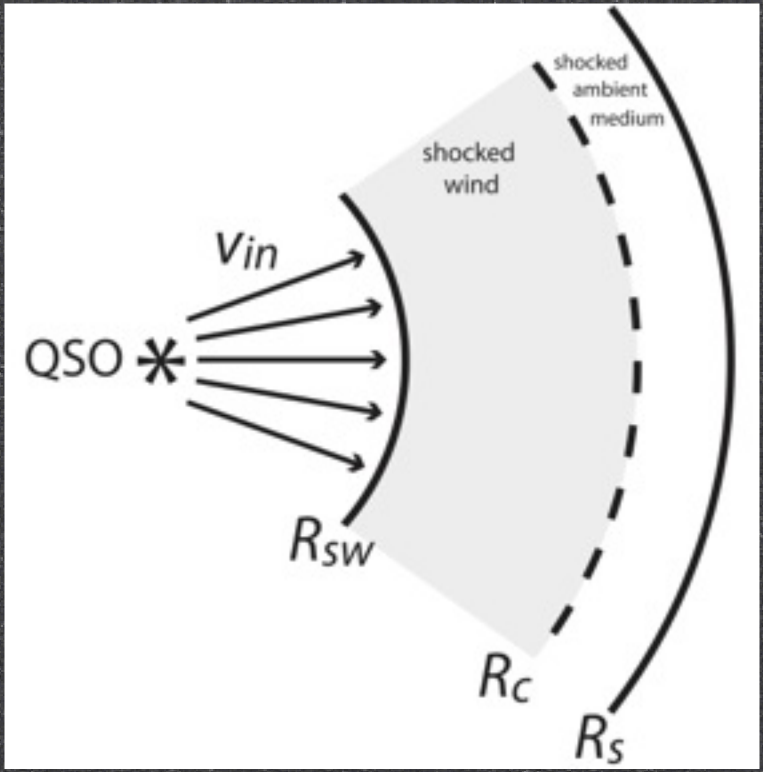
“Energy-conserving outflows predict the existence of shocked wind bubbles. We argue here that such bubbles are consistent with current observations”

[…]

“Shocked wind bubbles expanding normal to galactic discs may also explain the large-scale bipolar structures observed in some systems, including around the Galactic Centre, and can produce significant radio, X-ray and γ -ray emission.”

[…]

“Thus, the *Fermi* bubbles may be the relics of an energy-conserving AGN outflow.”

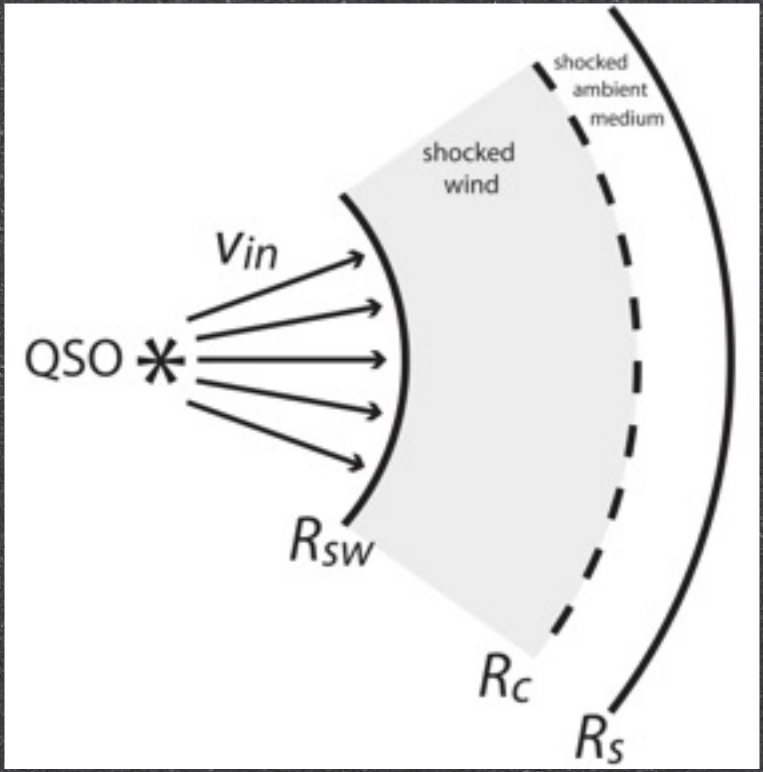


A Milky Way twin?

The X-ray wind in the "Milky Way twin" IRAS17020+4544

the very first detected in a spiral galaxy at moderate luminosity

may well be revealing the existence of the shocked wind mechanism that in our Galaxy was capable to inflate the Fermi Bubbles $6x10^6$ years ago

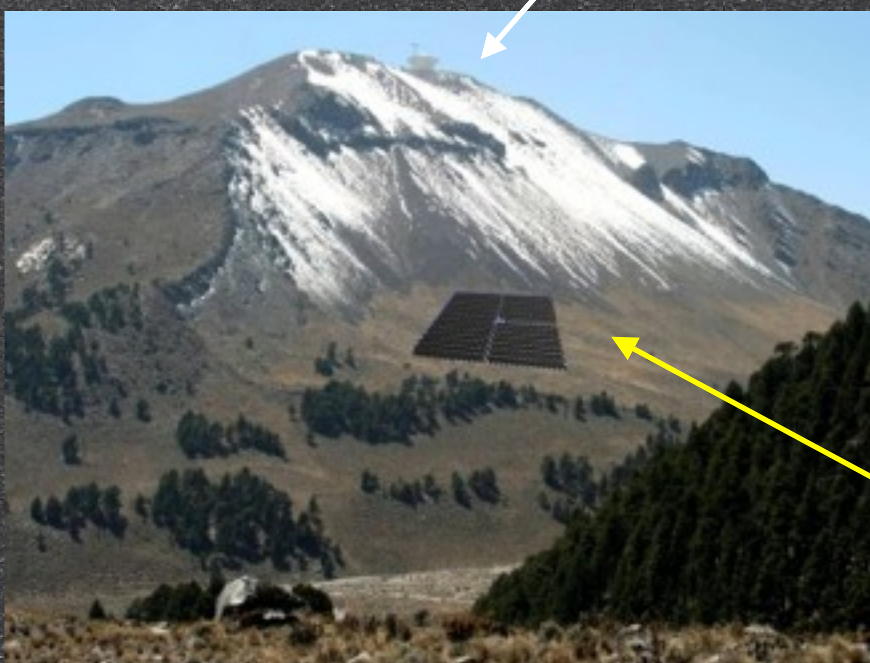


Take away messages

- Discovery of a fast outflowing wind with a very rich ionization structure (O_{III} to O_{VIII}), multiple velocity components and lack of variability
- Possible higher velocity/ionization counterpart would confirm the shock outflow model
- Feedback in an undisturbed Seyfert Galaxy with moderate luminosity seems to defy current galaxies evolution models
- XMM-Newton still provides new discoveries after 15 years !

Future Winds in IRAS17020+4544

- Chandra time granted for deep (250 ks) high-res spectroscopy of the low ionization UFO (LETG down to ~ 40 Angstrom)
- Additional Radio VLBI observations to investigate the extended structure (granted)
- Applied for HST/COS for first time UV spectroscopy of absorption troughs associated to X-ray ultra fast outflow
- Existing observations with Large Millimeter Telescope (LMT) reveal strong evidence for molecular outflows in IRAS17



GTM: Gran Telescopio Milimetrico

RSR Spectrograph 73-111 GHz

AzTEC Continuum Camera 273 GHz

HAWC: High Altitude Water Cherenkov Observatory, 4100 m

Thank you!