Ultra Fast Outflows and their connection to accretion and ejection processes in AGN

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Talk Outline

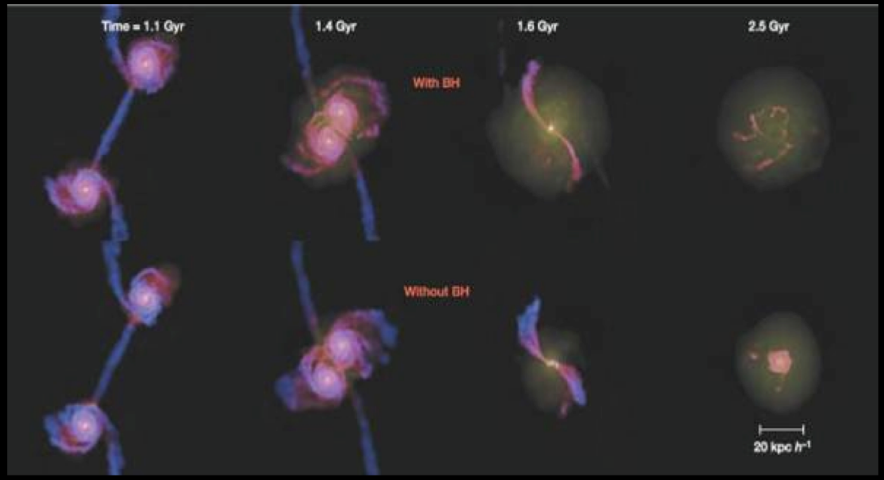
- Brief overview of Ultra Fast Outflows
- Connection of UFO with winds in other bands and with slower X-ray outflows (Warm Absorbers)
- UFO and AGN feedback
- Future perspectives

AGN winds: why they are relevant? (I)

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

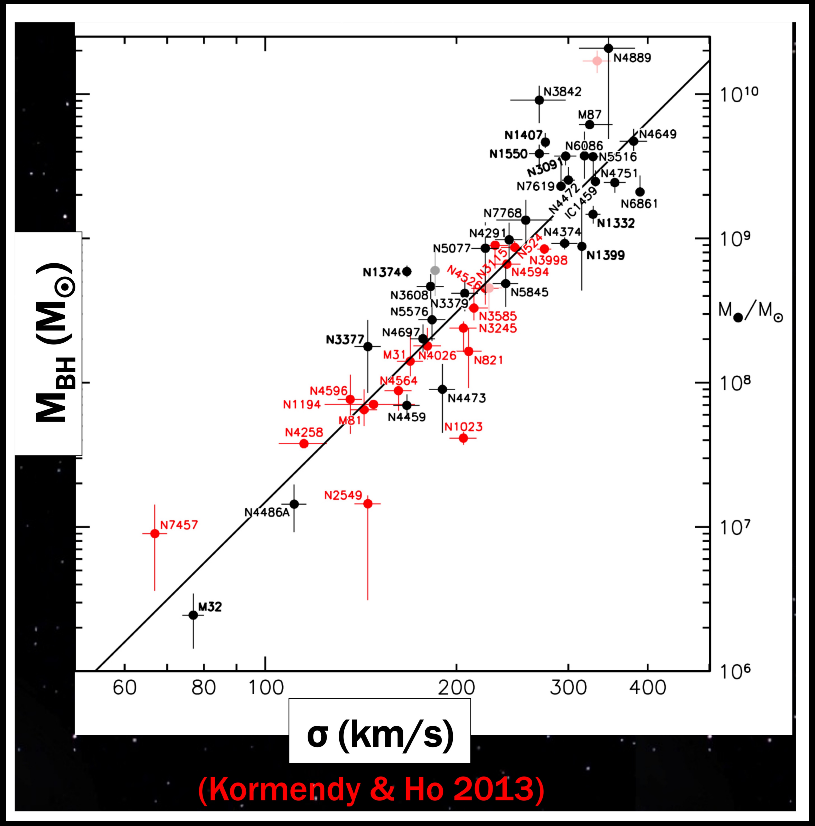


Di Matteo et al. 2005

Outflows may provide the connection between BH and host galaxies

If AGN feedback is 0.5–5% of the AGN luminosity it can regulate the growth of the galaxy and of the central black hole

Hopkins et al. 2010



(Kormendy & Ho 2013)

Wind Output Rate: UFO vs Warm Absorbers

Outflow velocity makes the difference (not only in the name!):

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

Mass outflow rate | Solid angle | Column density | Outflow v | Launching radius

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

The mechanical power of the wind depends strongly on velocity

Properties of AGN Winds in X-rays spectra (in a nutshell)

Gratings spectra offer higher detail diagnostics (historically on warm absorbers):

-Outflow velocity (generally 10^{2-3} km/s but see UFO)
-Wide range of Ionization states in the outflowing gas
-Column density 10^{20-22} cm^{-2}
-Associated to UV outflow (kinematics)
-Location mostly probed by variability studies (torus, accretion disk, NLR)
-Covering factors of ionized gas

CCD spectra offer photons and (often) larger samples in the archives:

-50% of Seyfert 1
-Column density 10^{20-23} cm^{-2}
-Ionized gas in high z sources (higher Luminosity range) often not accesible by grating spec
-Path for variability studies (more photons, repeated observations, multiple exposures in archives)

X-ray AGN winds: where we stand now ?

Courtesy of M. Guainazzi

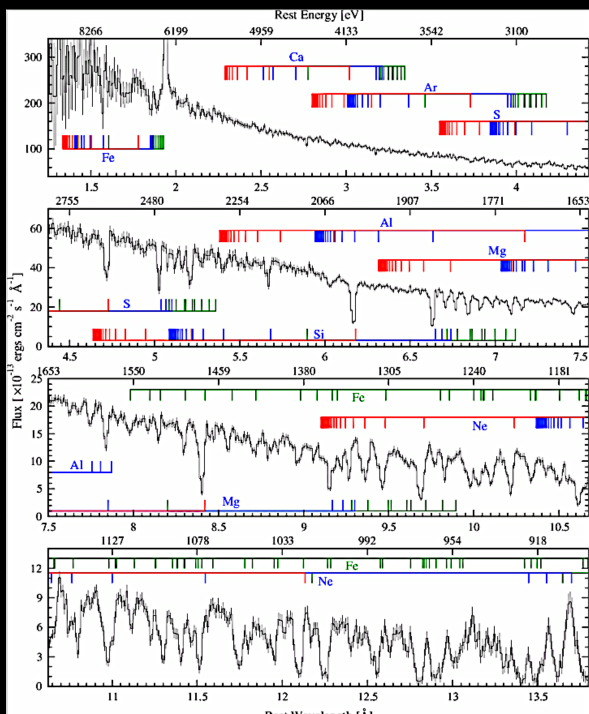
Paper	Instrument	N	Mimimum incidence
McKernan+07	HETG	15 Type I AGN	WA: ~67%
Tombesi+10	EPIC-pn	42 RQ-AGN	WA: ~60% UFOs: ~34%
Gofford+13	XIS	51 Type 1-1.9 AGN	UFO: ~40%
Laha+14 (WAX)	EPIC-pn+RGS	26 Seyferts 1-1.5 + 1 LINER	WA: $77\pm9^{+3}_{-14}$%
Tombesi+14	EPIC-pn/XIS	26 RL-AGN	UFO: 50±20%

"RQ"=Radio-Quiet; "RL"=Radio-Loud

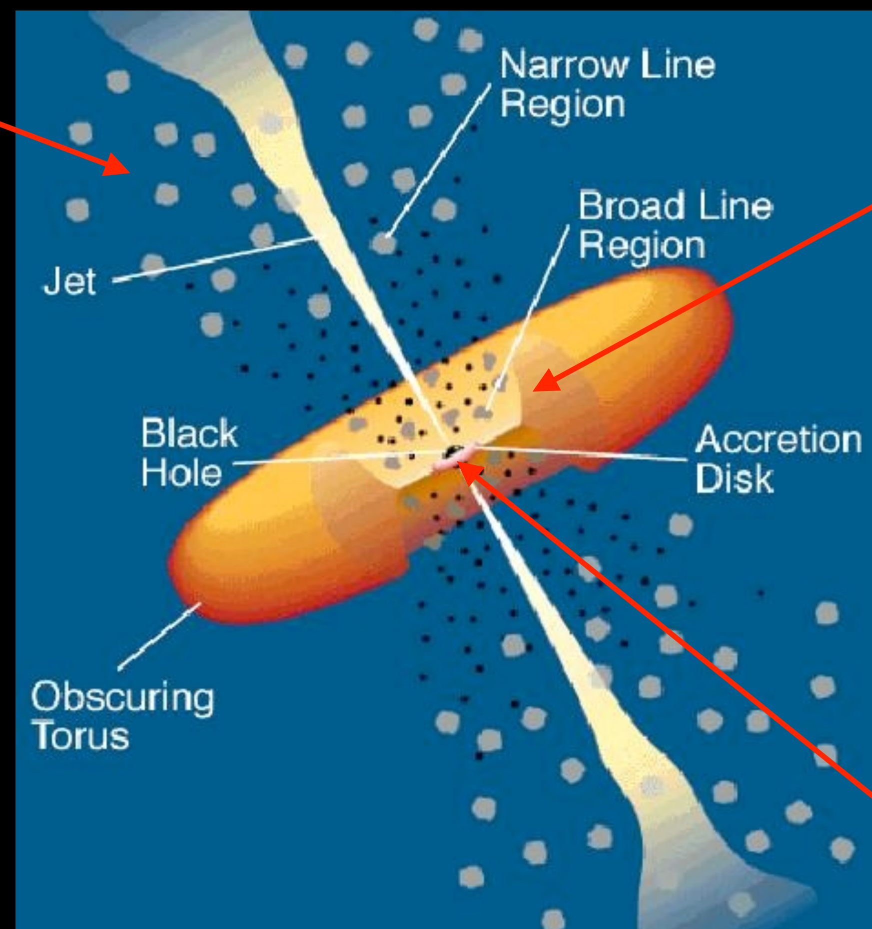
AGN winds: why they are relevant? (II)

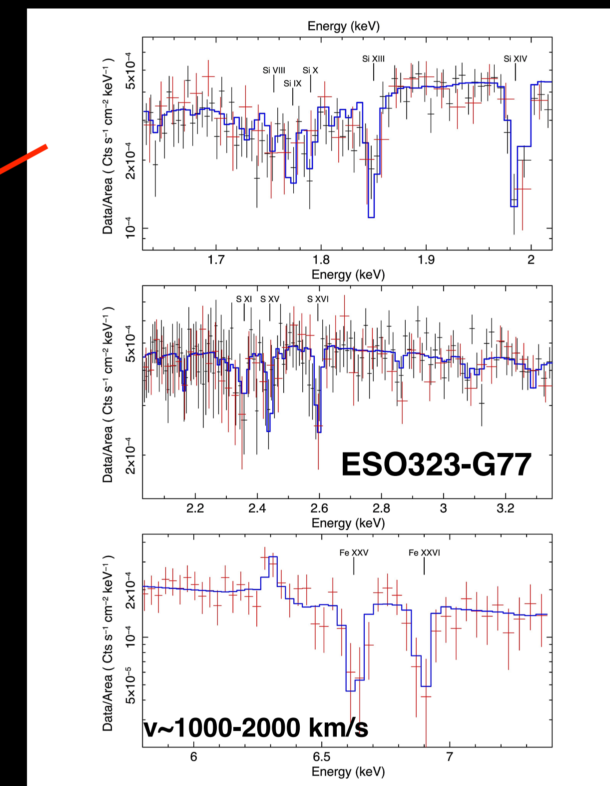
The ionized gas revealed in the spectra does not have a definitive collocation in the classical Unification model

Sanfrutos et al. 2016



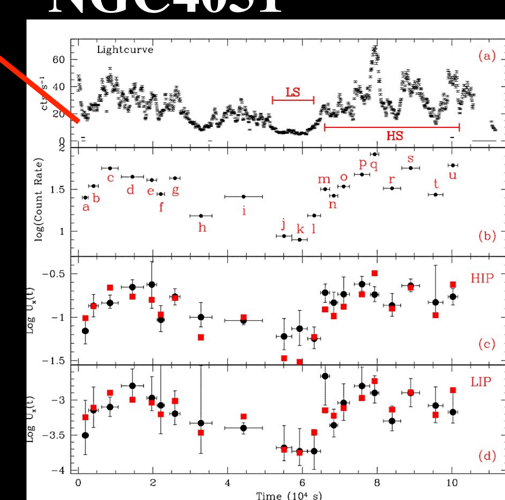
NGC 3783 Chandra HETG 900 ks
Kaspi et al. 2002, Krongold+03





Chandra HEG spectrum

NGC4051



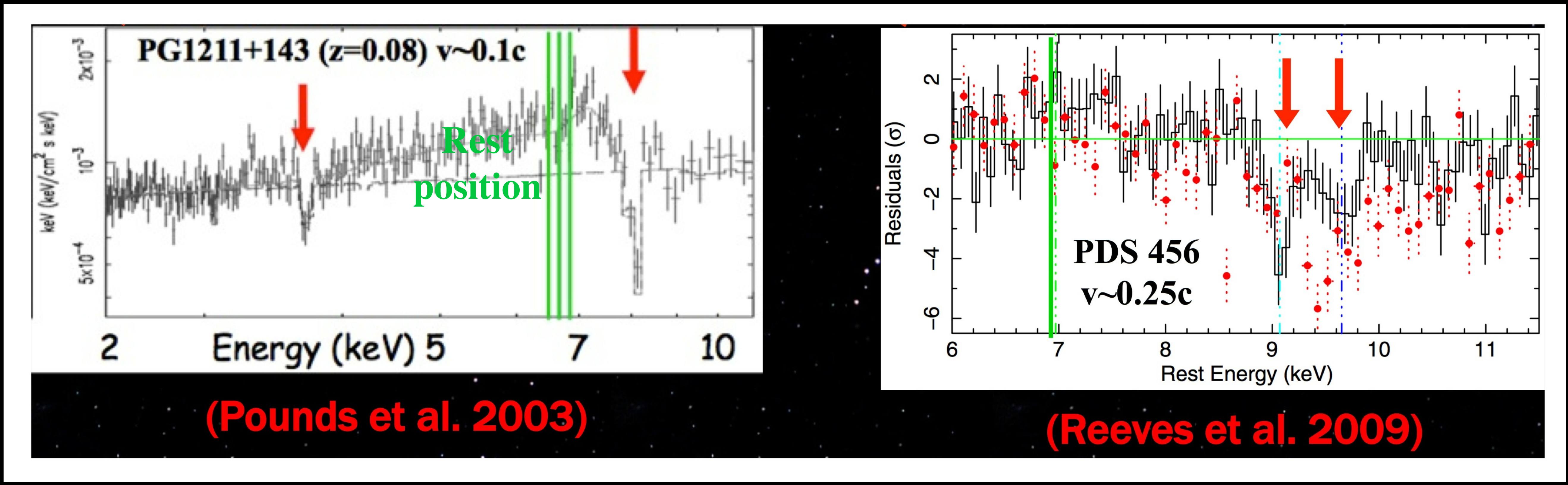
Krongold et al. 2007

Wind location (and launching radius) is key to understand how they form

Theoretical models & Simulations

Ultra Fast Outflows (UFOs): what are they?

Observed in the Fe K band as blue shifted absorption lines by highly ionized Fe



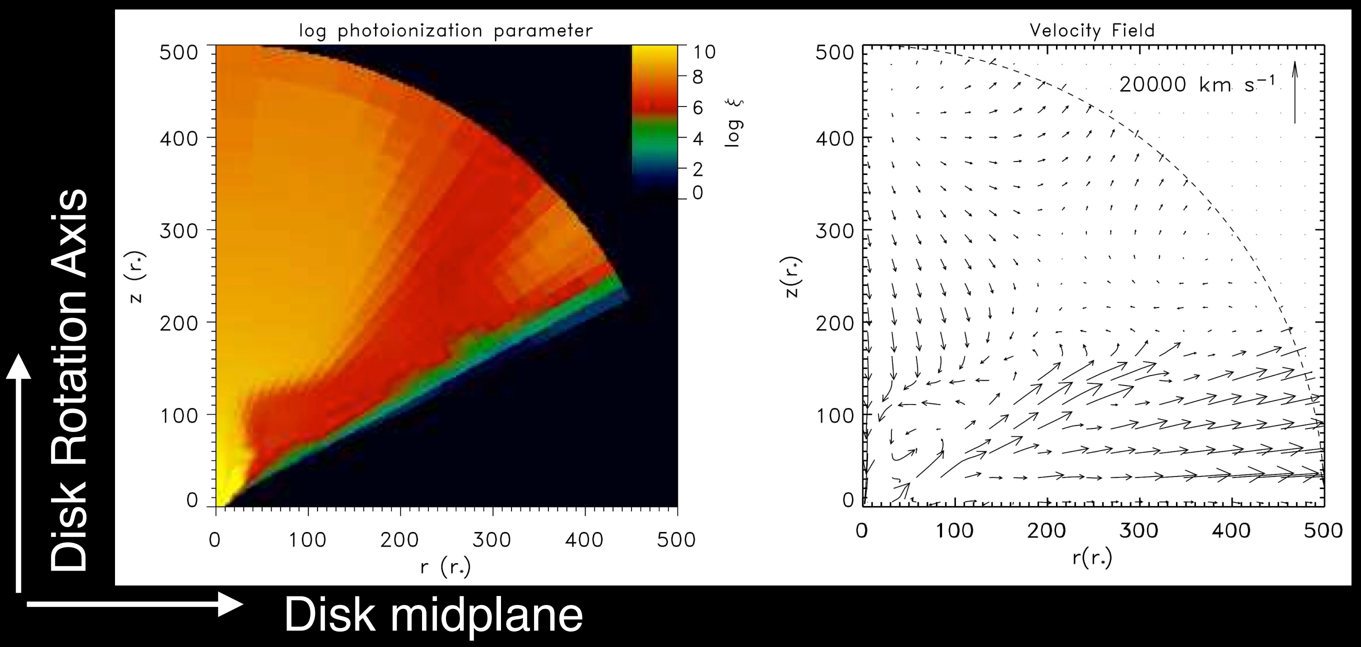
Properties from systematic studies at CCD resolution (XMM-EPIC, Suzaku) (Tombesi et al. 2010, 11,13; Gofford et al. 2013,2015)

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

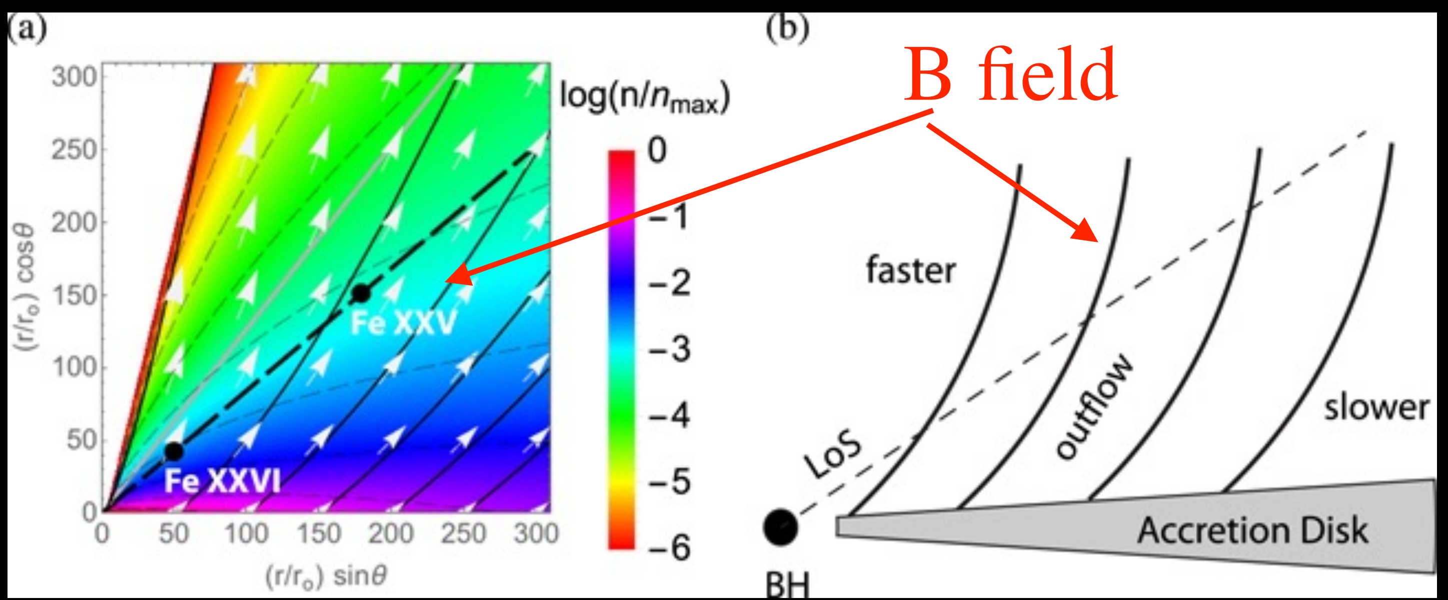
~~-Long and animated debate on their reality in the X-ray community~~

Launching mechanism: disk winds

Color map of ionization parameter **Velocity Field**



Simulations of radiatively driven disk winds produce blue-shifted highly ionized Fe absorption
Proga & Kallman 2004
Sim et al. 2008, 2010

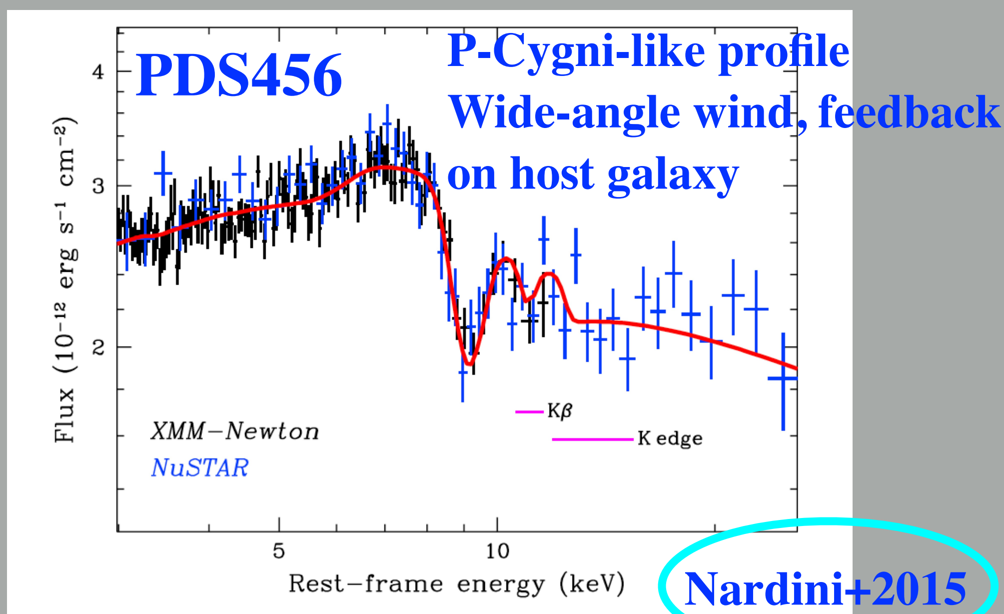


Magnetically driven outflows reproduce observed properties of highly ionized ultra fast outflows
Fukumura et al. 2015

UFO observed in RL sources
Tombesi et al. 2013

2015: Golden year for AGN fast winds

Several new discoveries, most of all supported by evidence for multi-phase AGN outflows

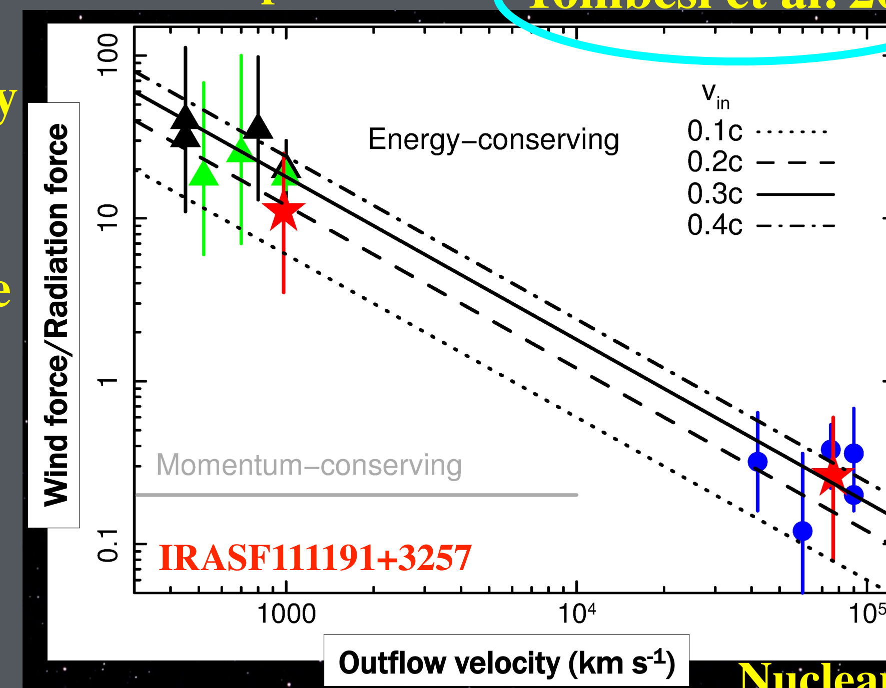


Nardini+2015

Molecular winds at Kpc-scale

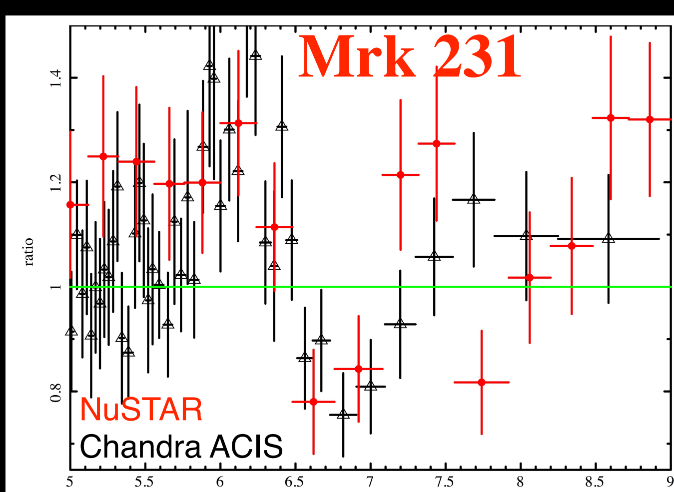
Tombesi et al. 2015

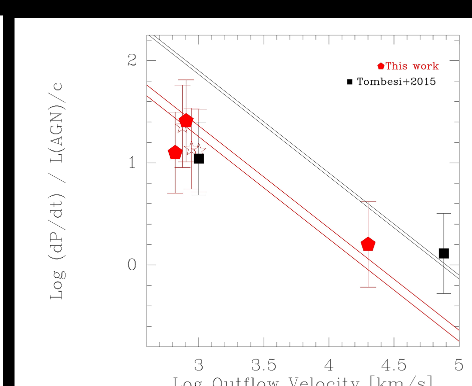
Connection of X-ray fast wind and massive molecular outflows follows the prescription of an energy driven outflows (momentum not constant)



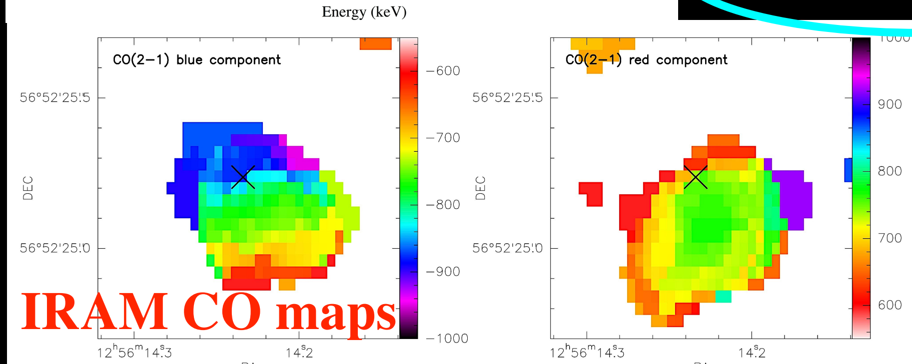
see also Cicone et al. 2014

Nuclear Disk Winds



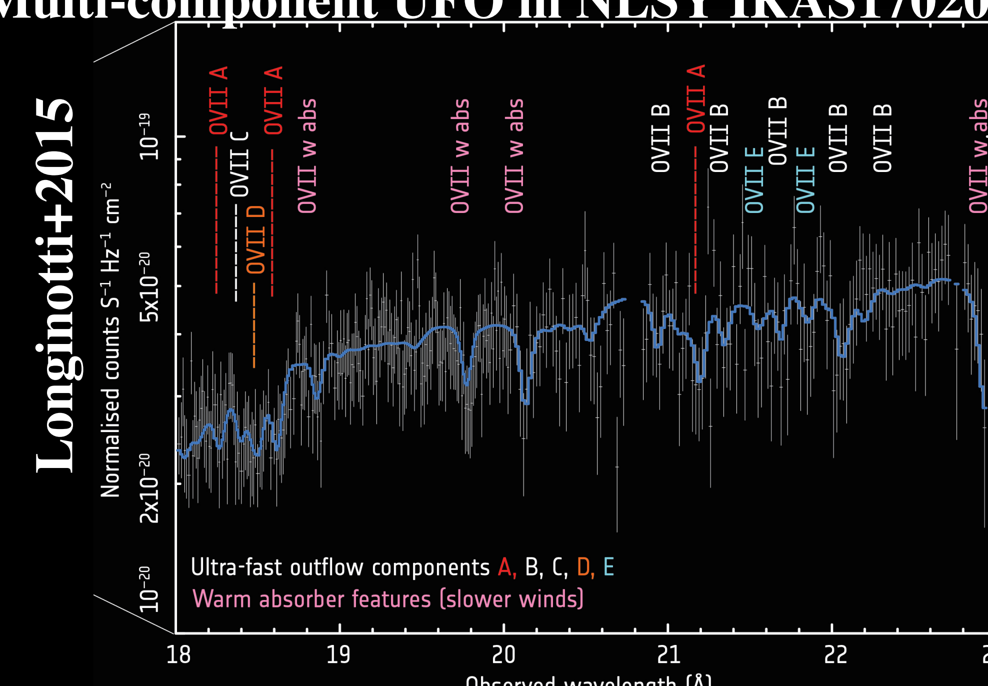


Feruglio et al. 2015



The relation of the momentum flux for the two wind phases suggests that the nuclear wind is driving the giant molecular outflow

Multi-component UFO in NLSY IRAS17020



Recent chronology of multiple components of soft X-ray UFO in grating spectra

- **Tentative evidence for soft X-ray fast winds at V≤0.1c reported in Chandra gratings of NLSy1 Akn 564 and Mrk 590** *Gupta et al. 2013, 2015 ApJ*

- **XMM gratings revealed outflowing highly ionized Ne and L-shell Fe in PDS456 at 0.1-0.2c probably associated to the massive FeK wind** *Reeves et al. 2016 ApJ*

- **Outflow at v=0.23c responding to flux variation in NLSy1 IRAS13224-3809, soft and FeK UFO stronger at low flux** *Parker et al. 2017, Nature*

- **Two ionization components (H and He-like N, O, Ne and Fe L) of wind at v ~ 0.06c found in PG1211+143** *Reeves et al. 2018 ApJ*

- **Multi-components fast and slow outflows in NLSy1 IRAS17020+4544** *Longinotti et al. 2015 ApJL, Sanfrutos et al. submitted, Longinotti et al. in prep.*

- **Four wind components outflowing at v=0.08-0.16c in the NLSy1 Mrk 1044** *Krongold et al. in prep.*

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Let’s move beyond Fe K

More Ions other than Iron!

Multi-components UFO in Mrk 1044

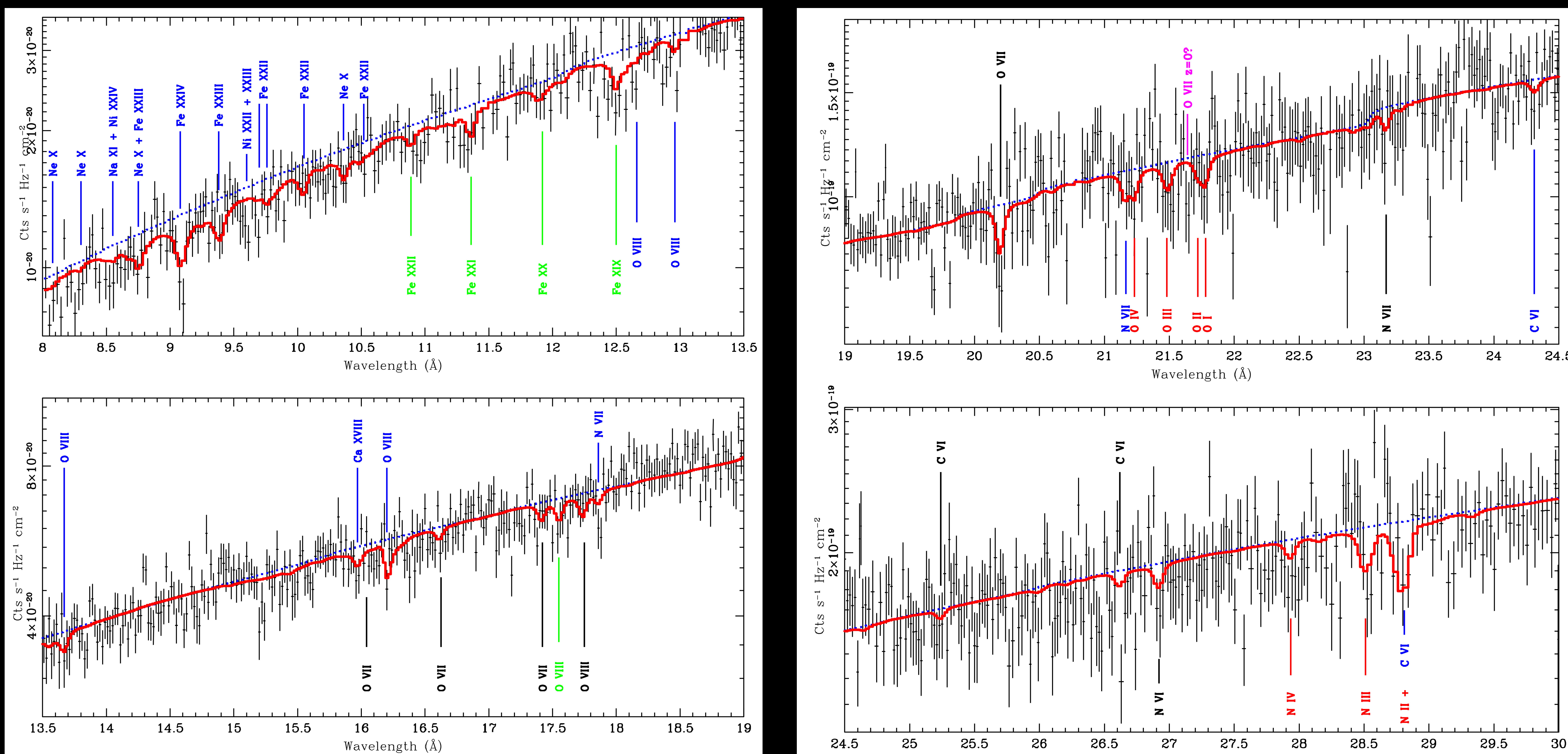
MRK 1044 NLSy1 L_{bol}=5x10^{44}erg/s M_{BH} ~1.4x10^{6} $M_{\odot}$

4 components of fast wind in RGS spectra, the strongest detected at 9σ

LogU = 2.12 LogNH= 23.32 v_outflow~ 48000 km/s

Other three outflowing at ~ 25000 km/s

Krongold et al. in prep.



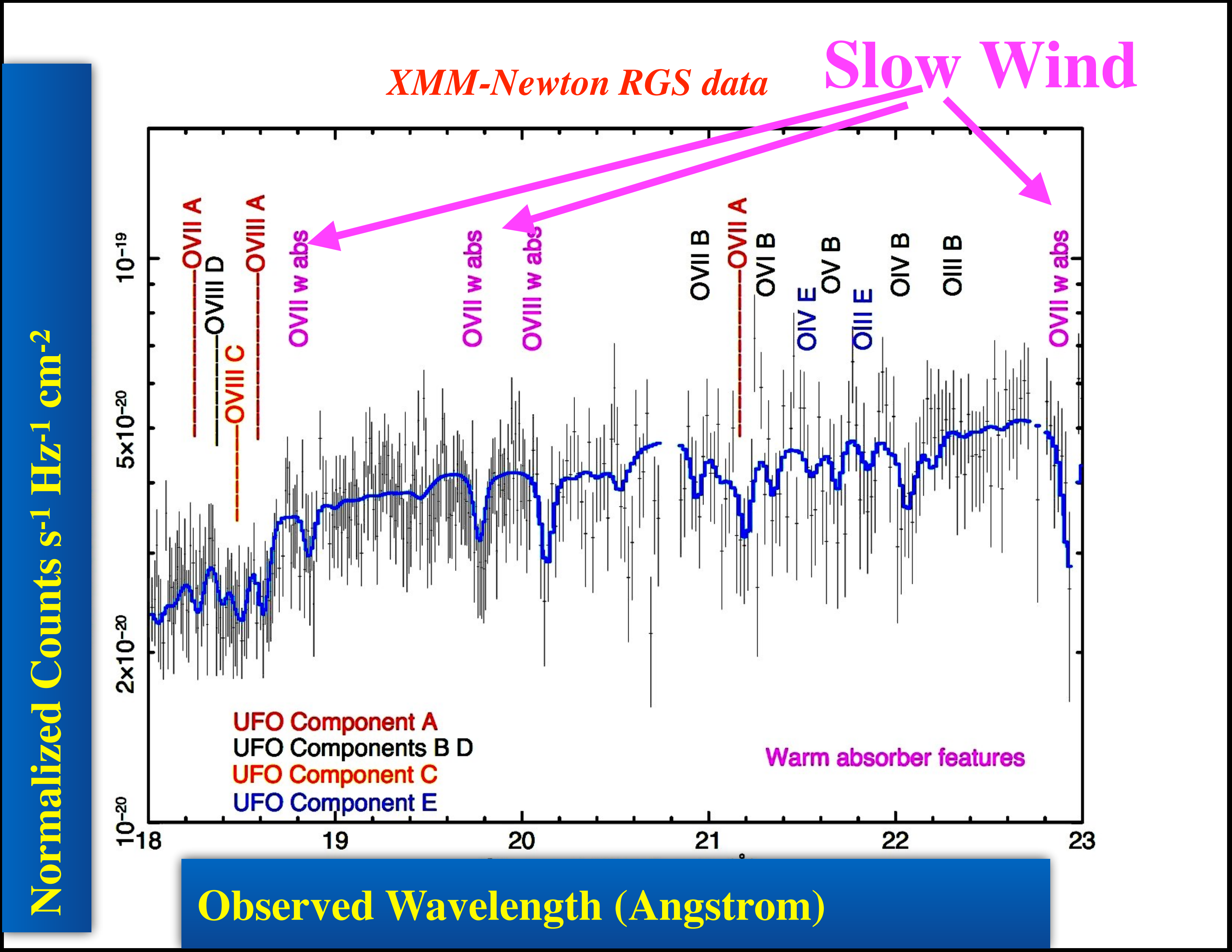
Fast and slow winds in NLSy1 IRAS 17020+4544

Photoionized gas modeled by PHASE code
Krongold et al. 2003

4 components of warm absorber with "standard" velocities 10^2-10^3 km/s

WA inflowing ~2000 km/s (*Sanfrutos+ submitted.*)

WA not overlapping UFO



Chandra LETG spectroscopy 250 ks confirms UFO presence, detailed modeling is ongoing

Multi-component ultra fast outflow in IRAS17020+4544

Longinotti et al. 2015 ApJ Letters

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.

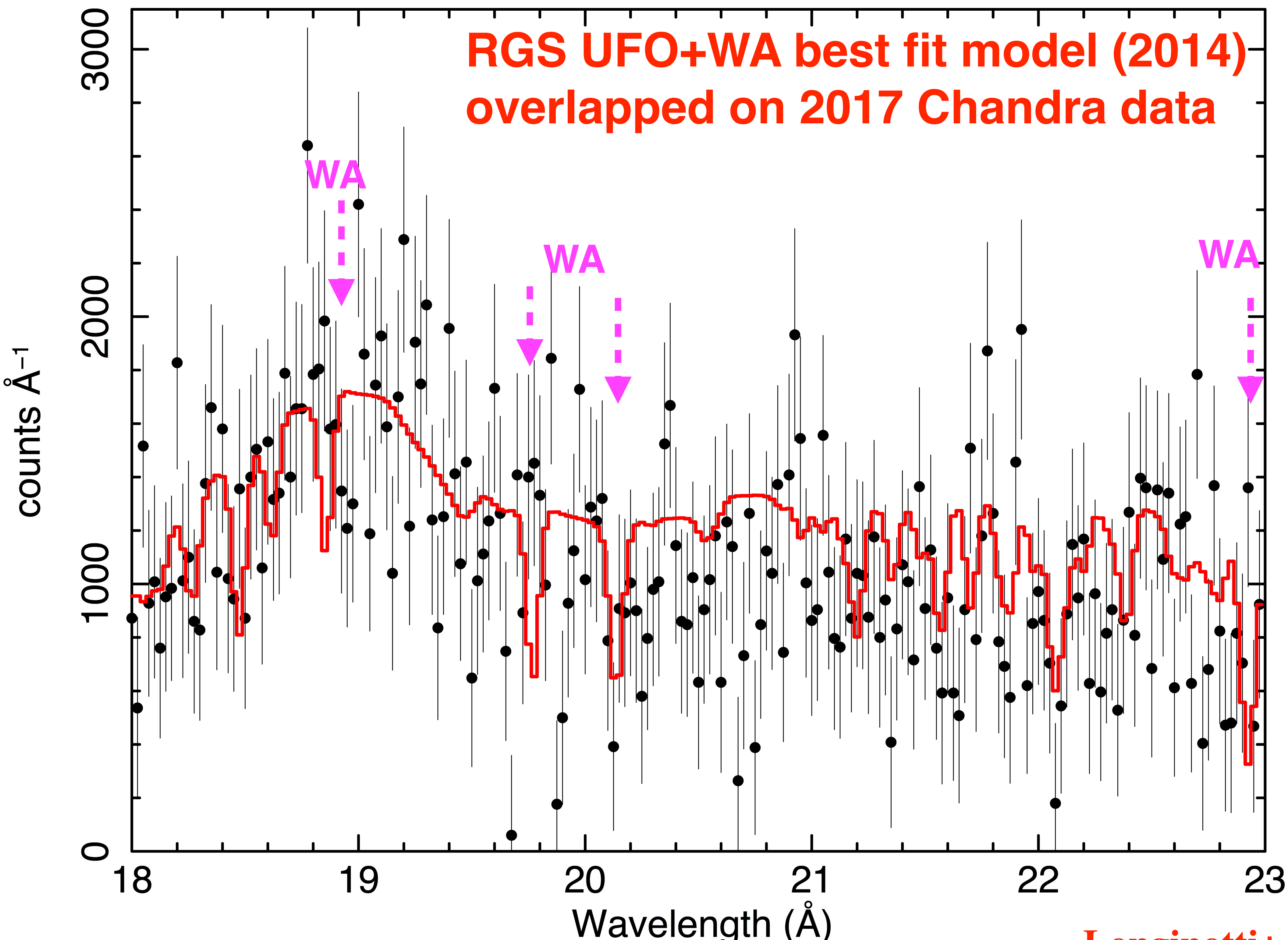
Detailed UFO properties seen for the first time in an X-ray spectrum

Five distinct components with wide range of ionization and N_H outflowing at same velocity

Lack of variation in RGS spec of 2004 implies outflow is stable on ~10 yr time scale

Disk ultra fast wind does not have to produce only Fe K absorption

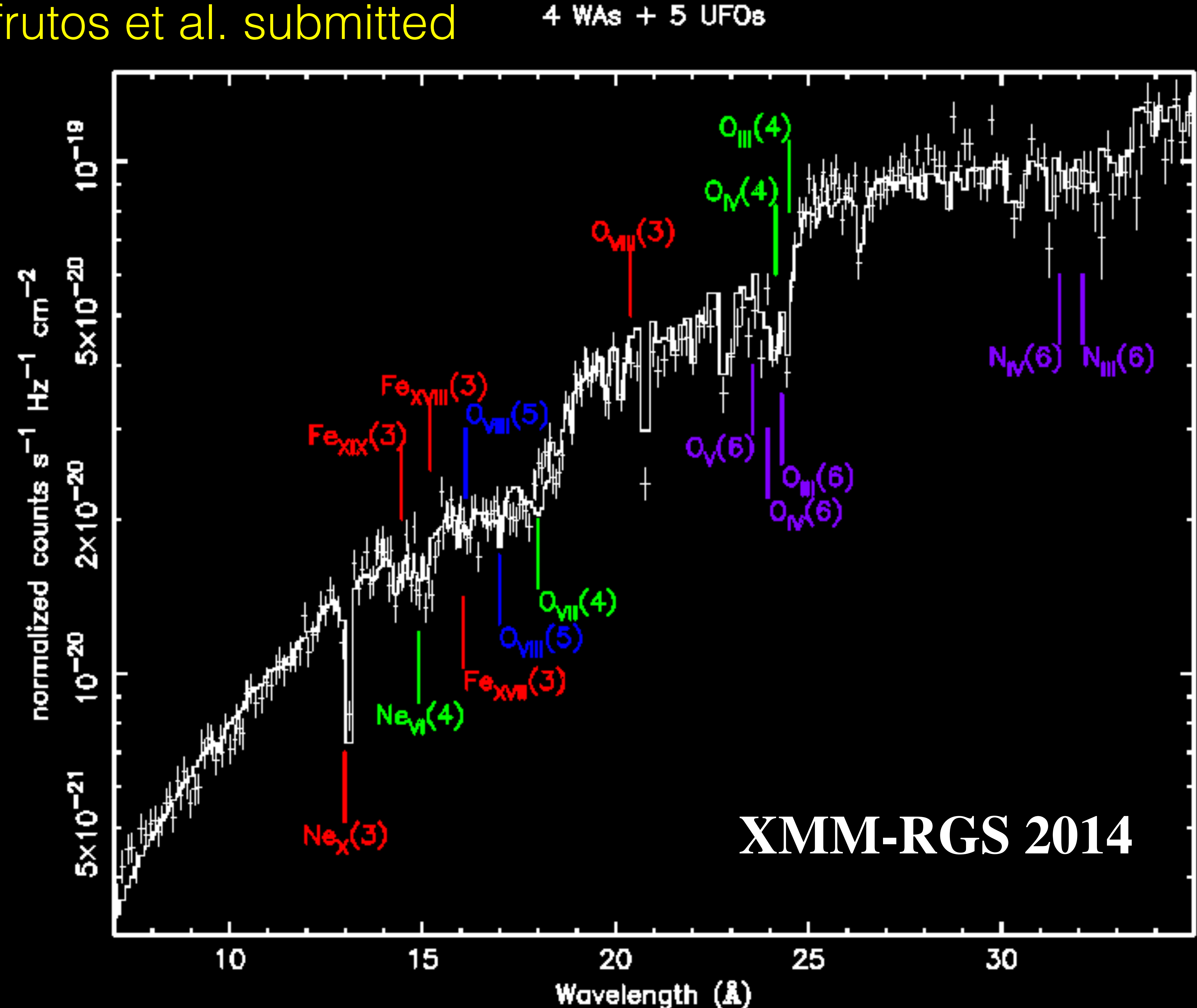
Chandra LETG look at IRAS17020+4544 (250 ks)



Longinotti+ in prep.

The slow wind in IRAS17020+4544

M. Sanfrutos et al. submitted



M. Sanfrutos et al. submitted

Slow wind in IRAS17020+4544

Both XMM-grating data of 2014 and 2004 show warm absorber in outflow and inflow

Wa in 2014 | Wa in 2004

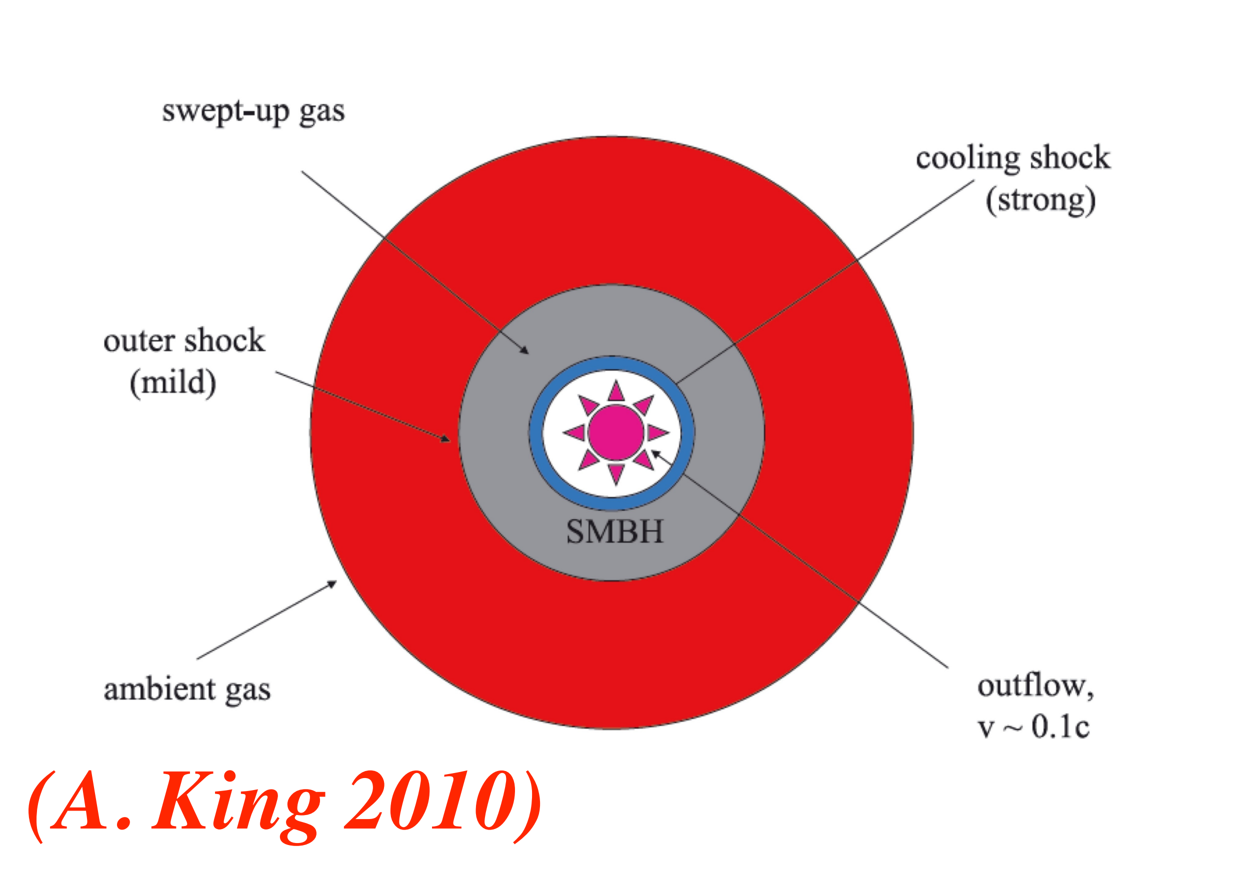
	$\log U$	$\log N_{\rm H}$ [a]	v [b]	ΔC		$\log U$	$\log N_{\rm H}$ [a]	v [b]	ΔC
1	$-1.897^{+0.022}_{-0.005}$	$21.22^{+0.03}_{-0.04}$	-260^{+50}_{-70}	207	1	$-1.88^{+0.11}_{-0.19}$	$21.06^{+0.12}_{-0.19}$	-210^{+150}_{-130}	54
2	-2.58 ± 0.04	$20.34^{+0.17}_{-0.10}$	2200^{+150}_{-130}	81	2	-2.9 ± 0.2	20.8 ± 0.2	3800^{+700}_{-300}	44
3	$-0.37^{+0.04}_{-0.10}$	$21.18^{+0.06}_{-0.11}$	-420^{+150}_{-50}	26	3	-0.02 ± 0.24	21.3 ± 0.2	1400^{+200}_{-300}	22
4	$0.40^{+0.14}_{-0.19}$	$20.8^{+0.3}_{-0.2}$	-1800 ± 200	25	4	$-0.50^{+0.10}_{-0.18}$	$21.27^{+0.15}_{-0.27}$	-2800^{+500}_{-300}	22

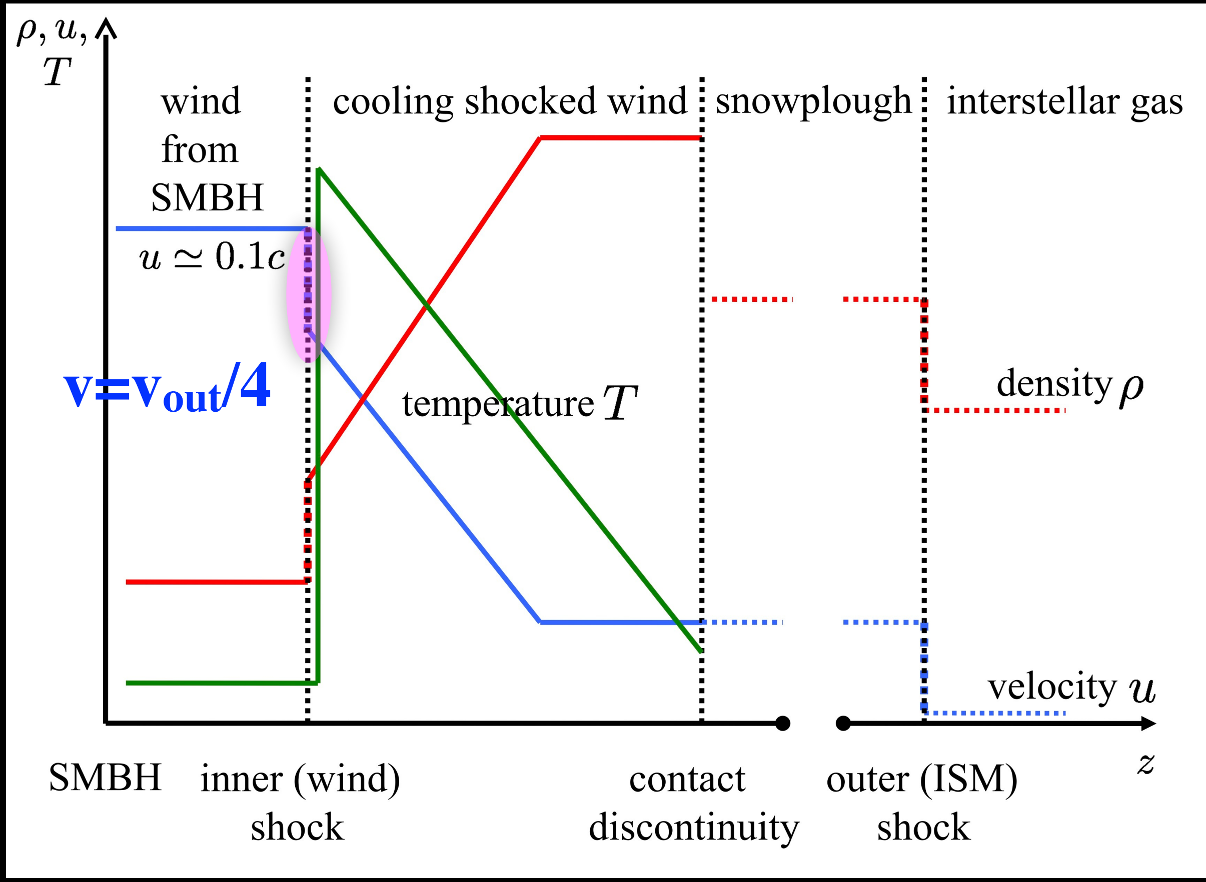
Slow Wind components 2 and 4 are faster than 10 years later
Fast wind seems persistent (confirmed by Chandra's look in 2017)
Source luminosity stays constant

How can we explain co-existence of a stable UFO with a variable warm absorber without continuum flux variations?

Shocked outflow model and IRAS17

In this model the accretion disc wind launched with velocity v_out suffers an isothermal shock with the circumnuclear gas that produces the effect of slowing the wind to a velocity v ~v_out/4.





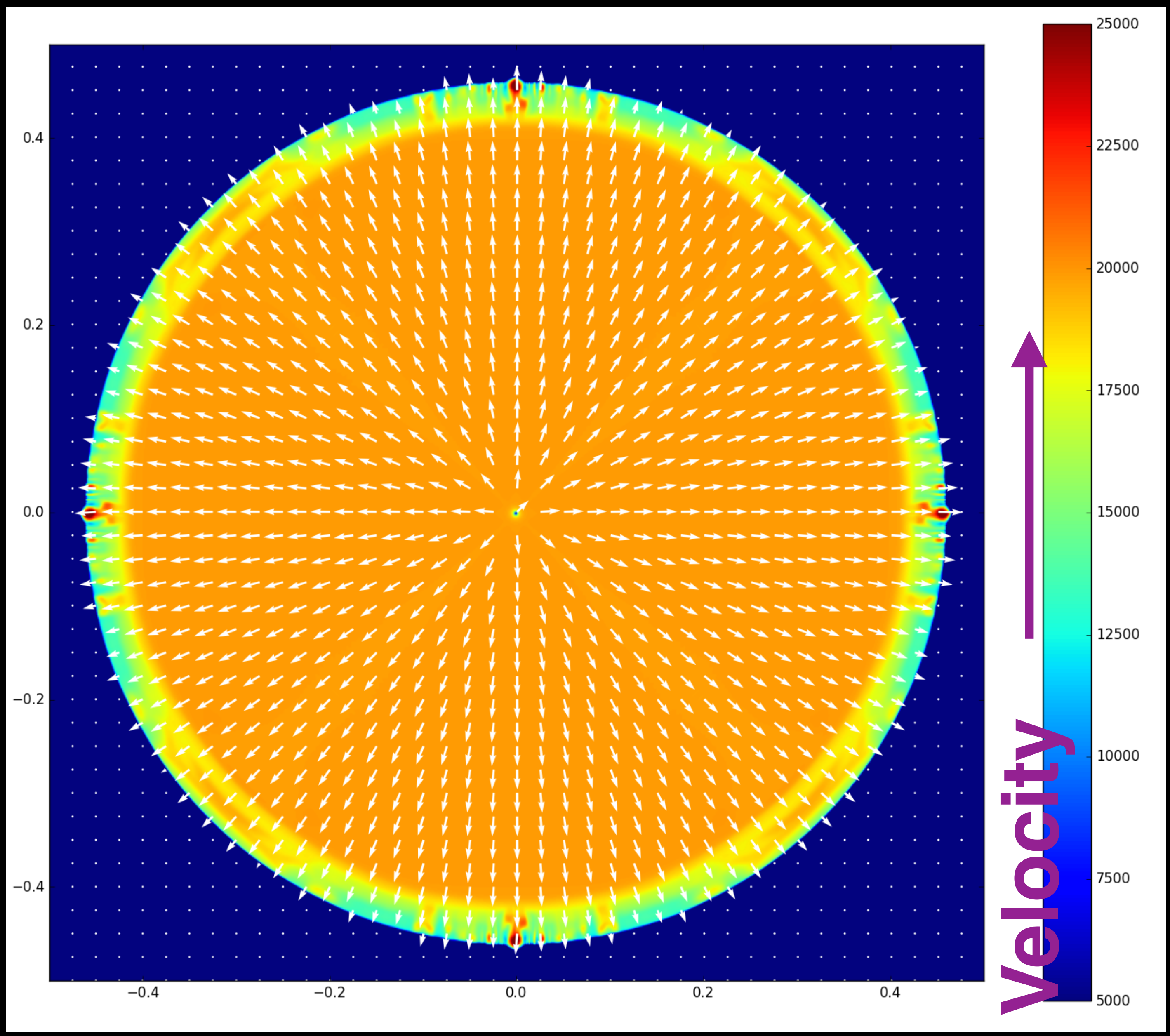
Models of disk winds predict only highly ionized features (FeXXV, XXVI > 7 keV)

XMM CCD data show marginal evidence for 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}

Shocked outflow predicts also that gas can fall back and be seen as an inflow

Simulated shocked outflow



3-D numerical hydrodynamical simulation

Mean density of outer medium: 1/cm^3

BH mass: $10^6 M_\odot$ (IRAS17 M_{BH})

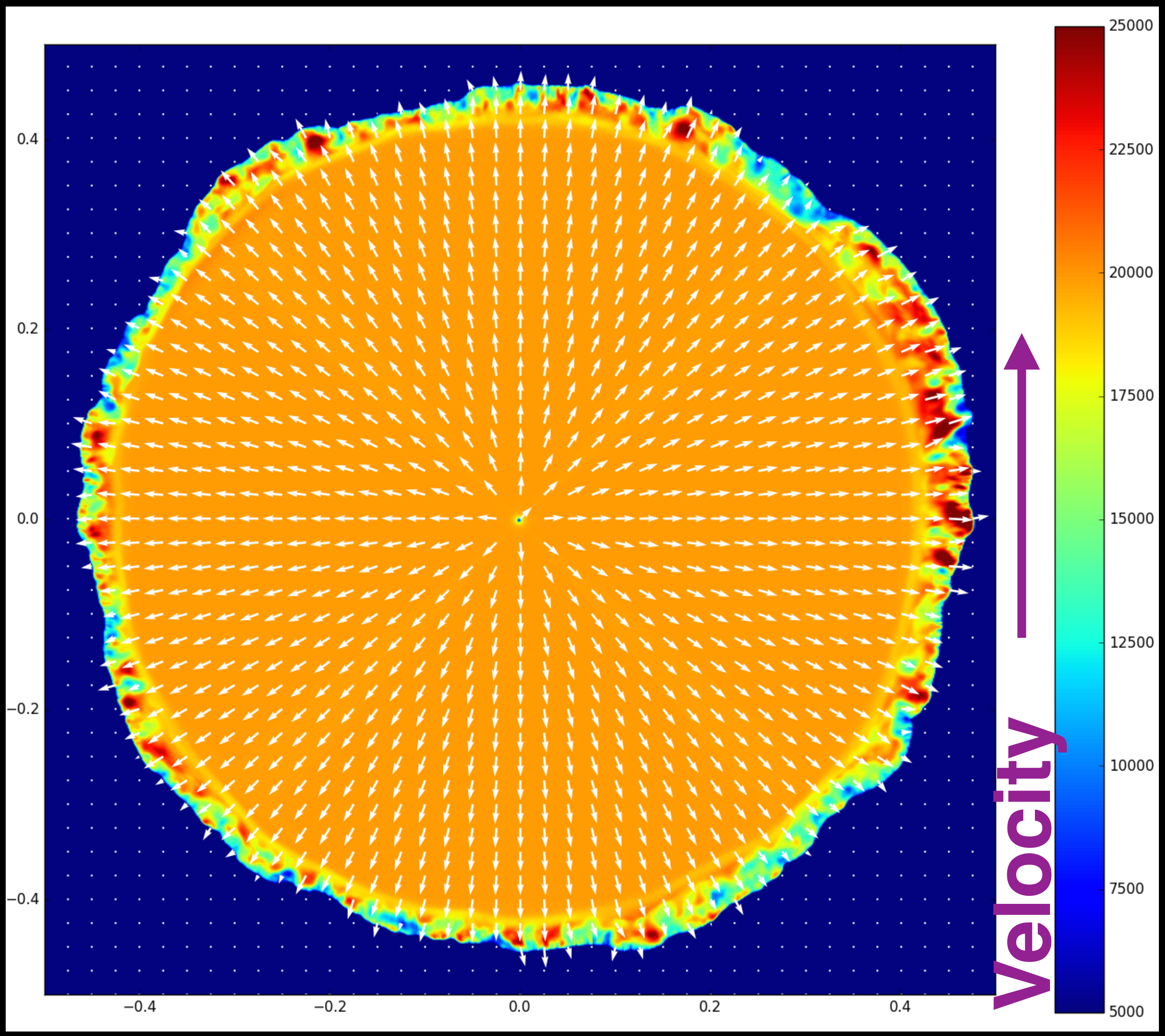
Density gradient (in and out of the shock) induce Rayleigh-Taylor instability that keeps slowing down shocked gas (similar to SN remnants)

Expanding shock pushed within a turbulent medium by an inner wind with V_{out}=20,000 km/s

Expansion time: 20 yr

Sim by P. Velazquez, based on GUACHO code
Esquivel & Raga 2013 ApJ
(Instituto de Ciencias Nucleares, UNAM)

Simulated shocked outflow with instabilities



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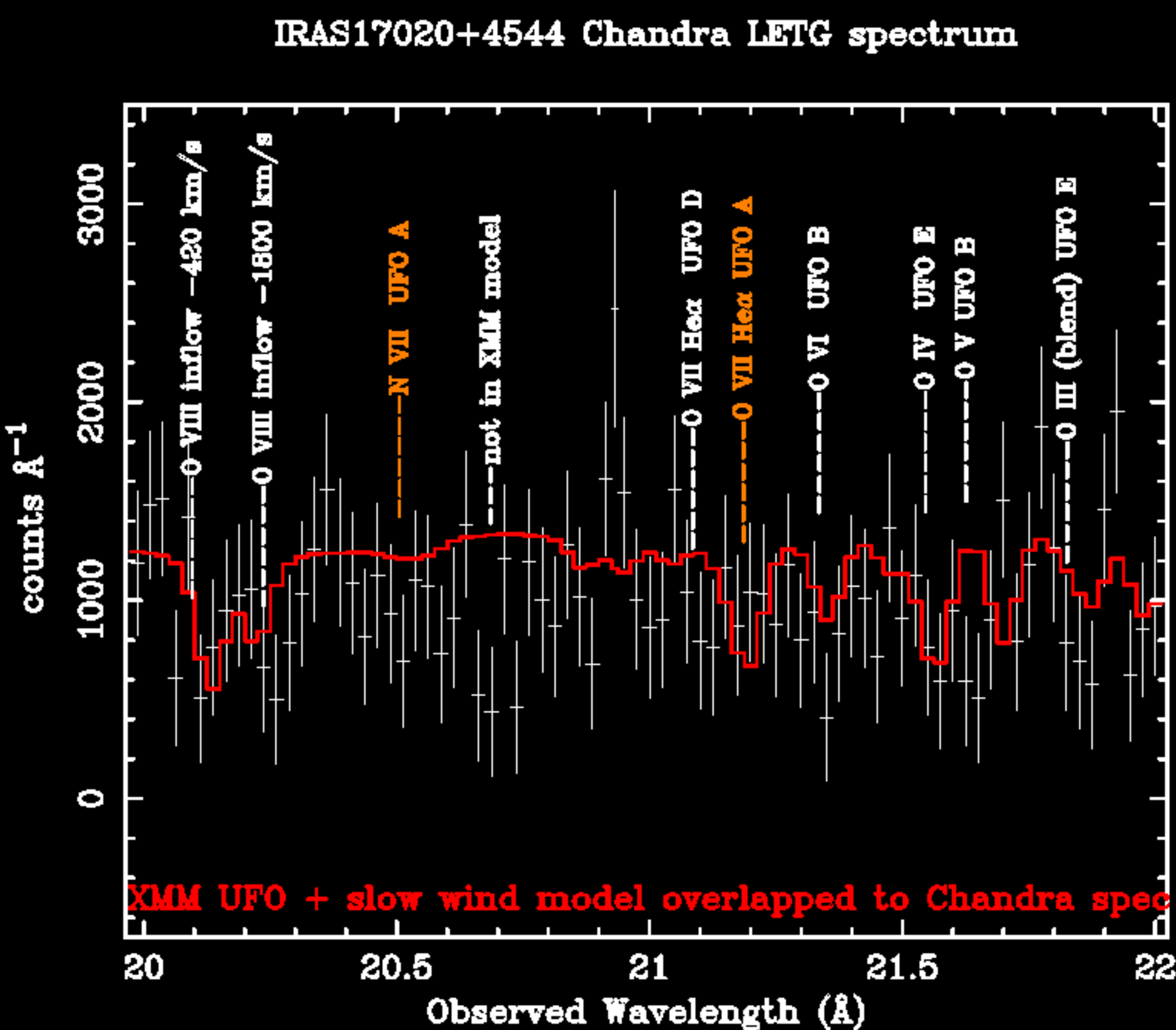
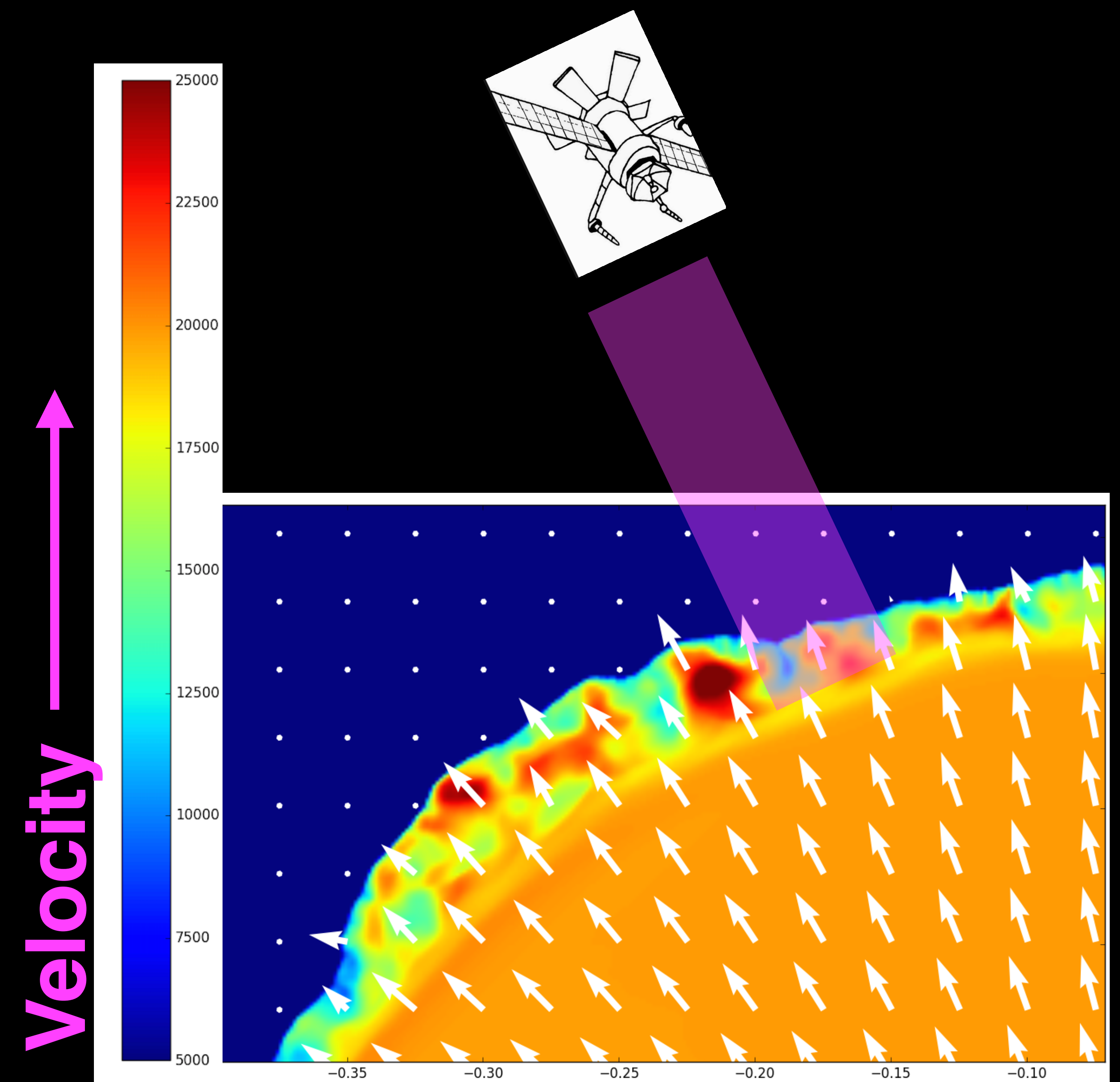
Shocked outflow with instabilities may explain multi-velocity wind components

Our line-of sight crosses several “fingers” of gas with different V_{out}

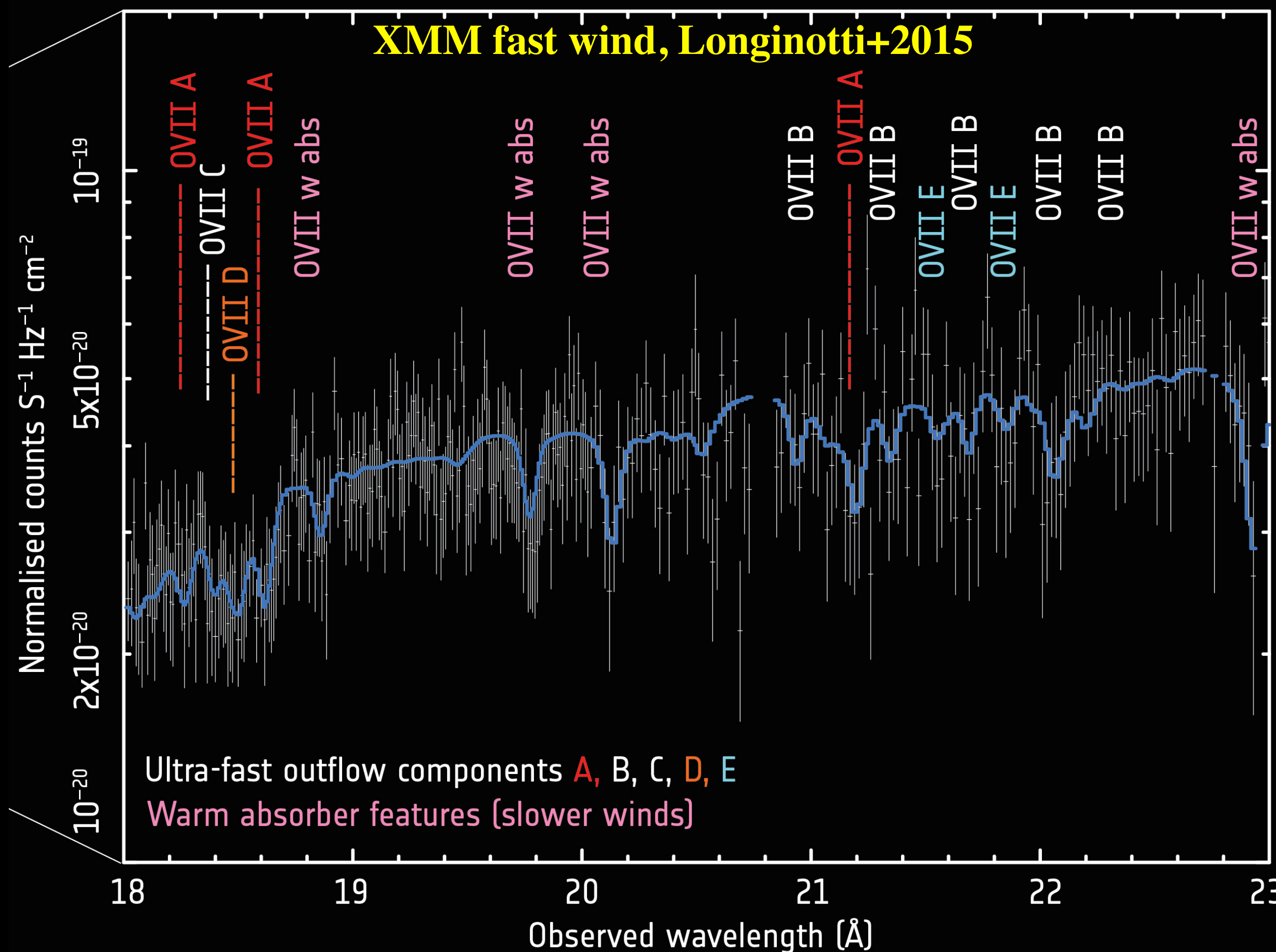
Work in progress on column density and temperature (ionization) distribution

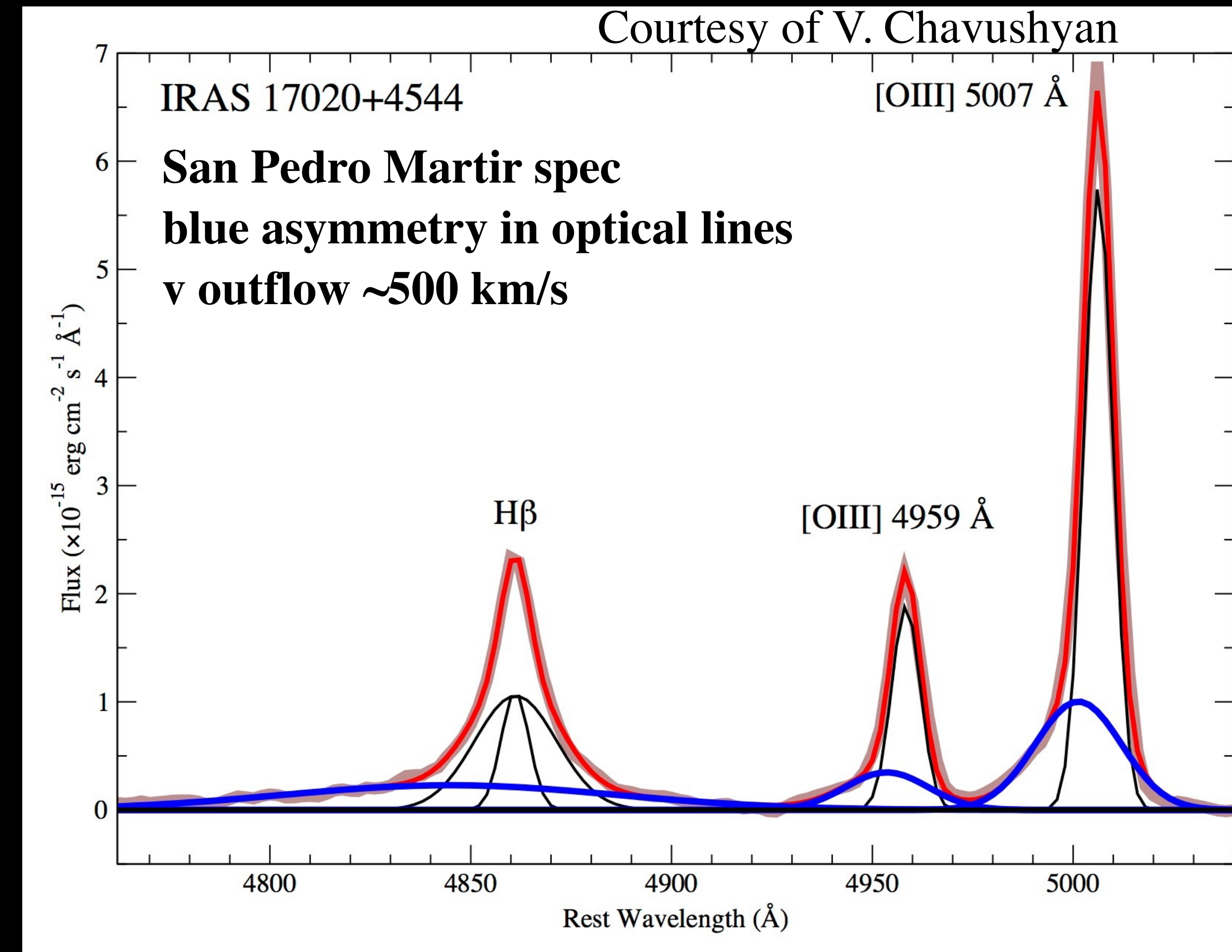


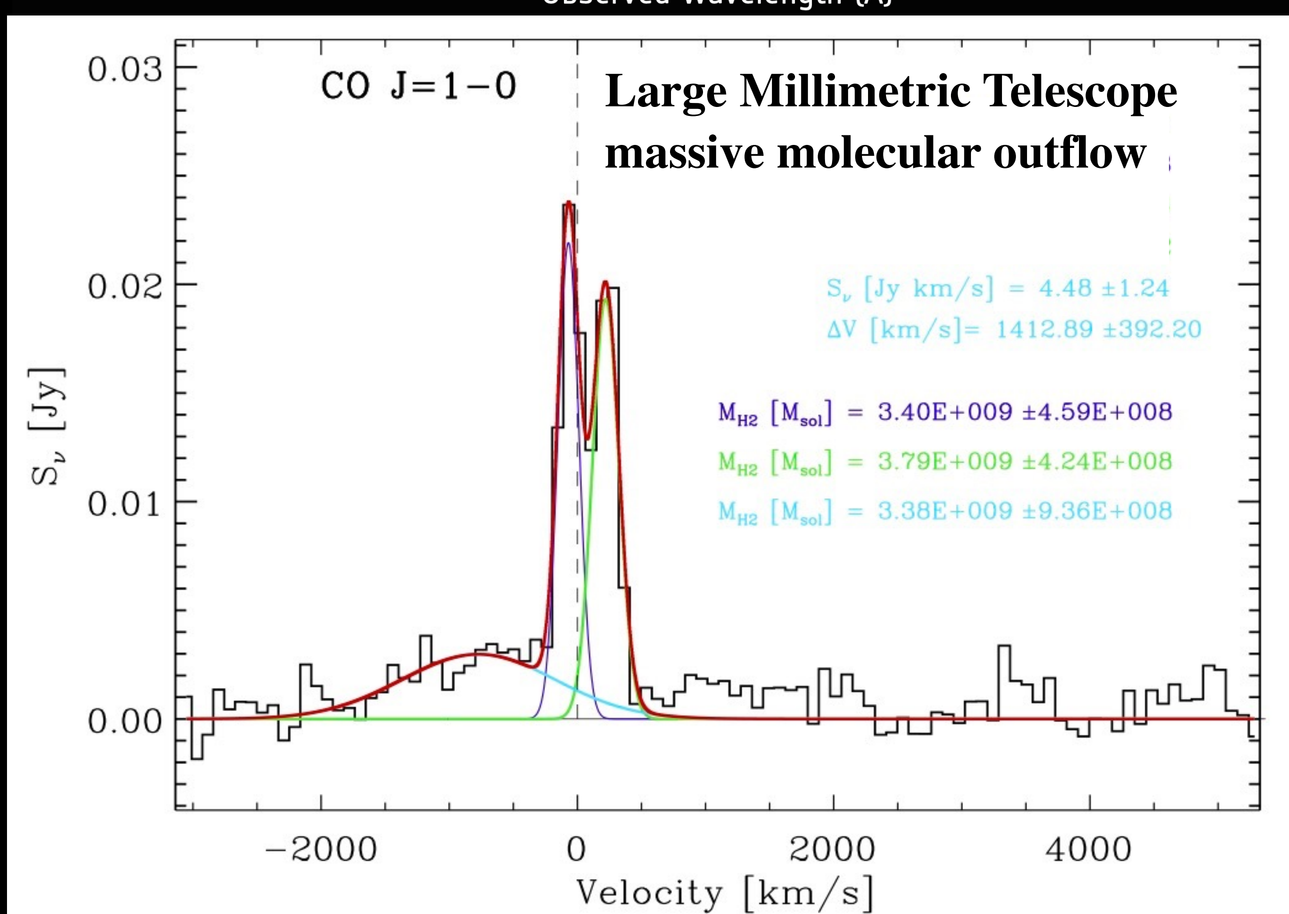


Other hints of a shocked outflow in IRAS17020+4544 beside X-rays:

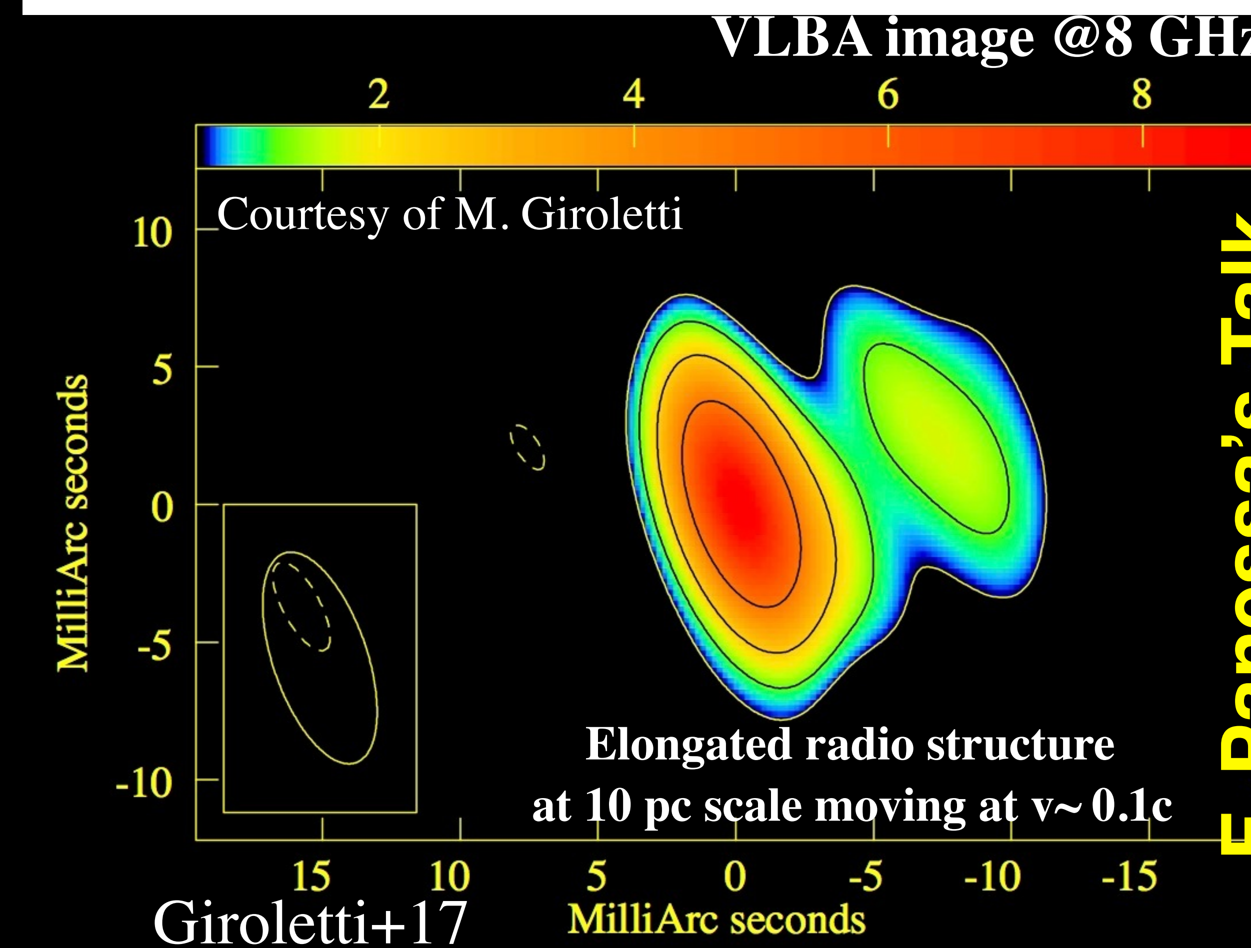
we have evidence for multi-phase winds suggesting that an AGN-driven wind may be affecting the galaxy at large scales



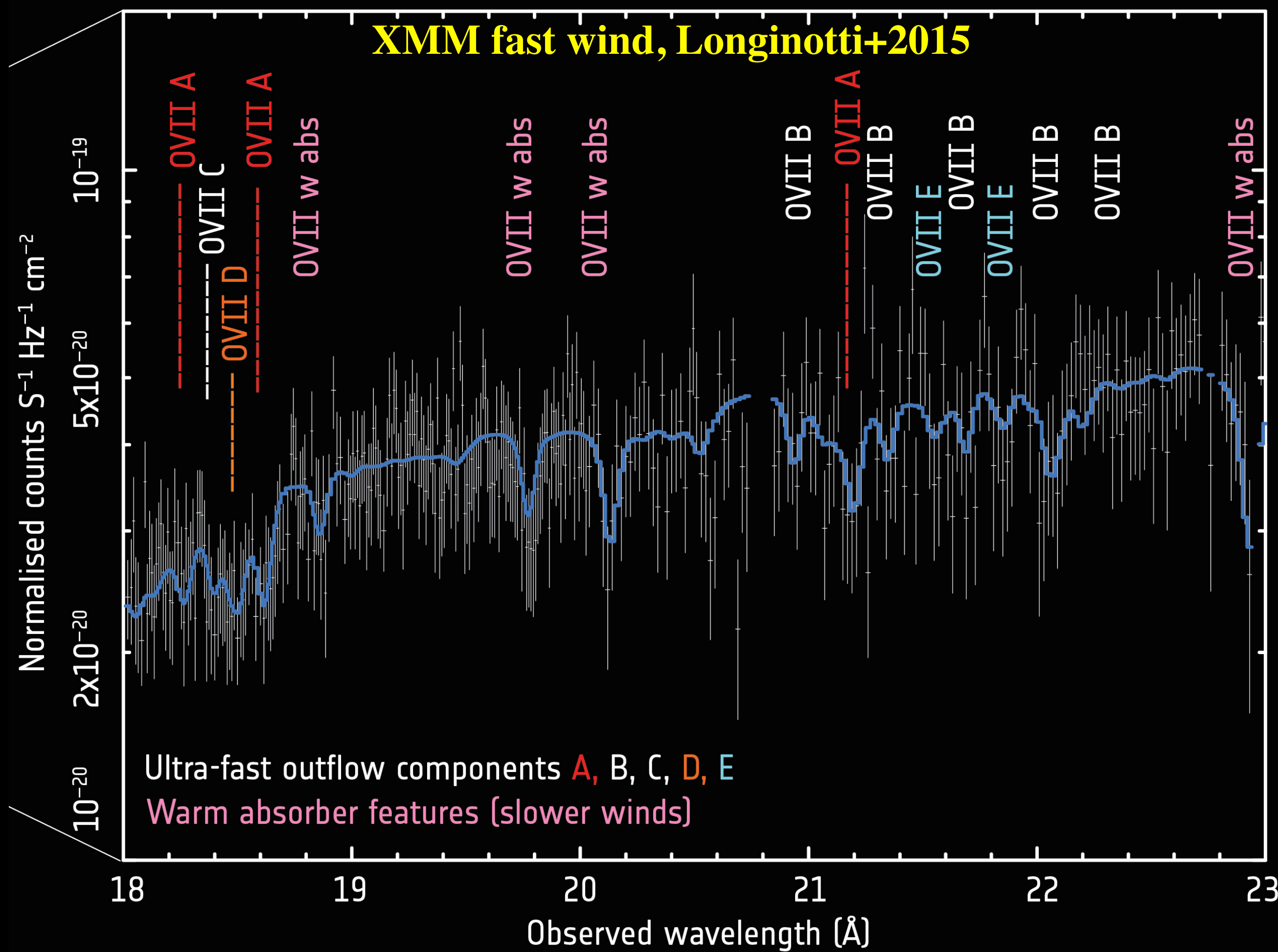




Courtesy of O. Vega Casanova

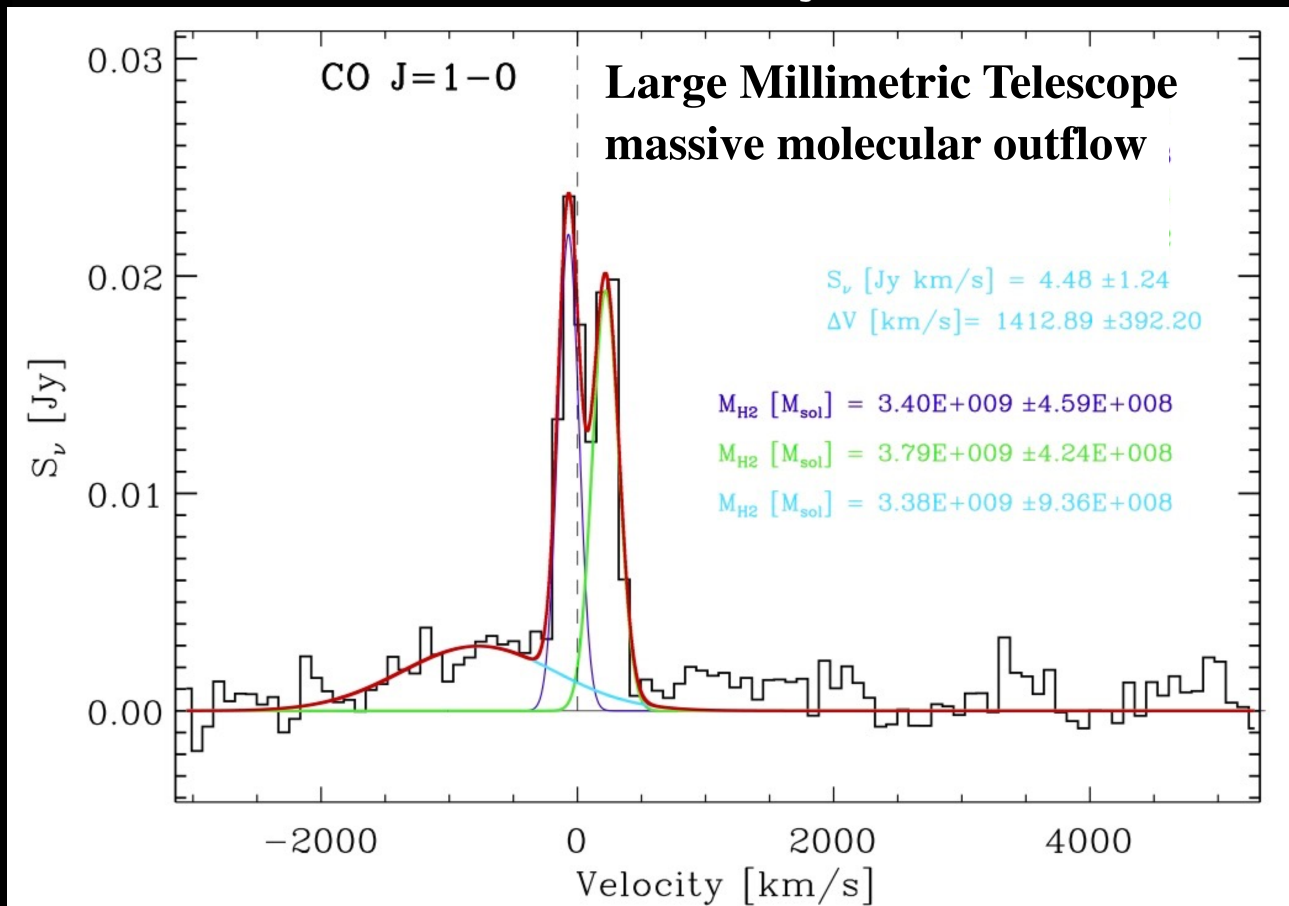


F. Panessa's Talk



AWAITING NEW DATA:

NOEMA (map molecular gas)
HST COS (UV counterpart of UFO)



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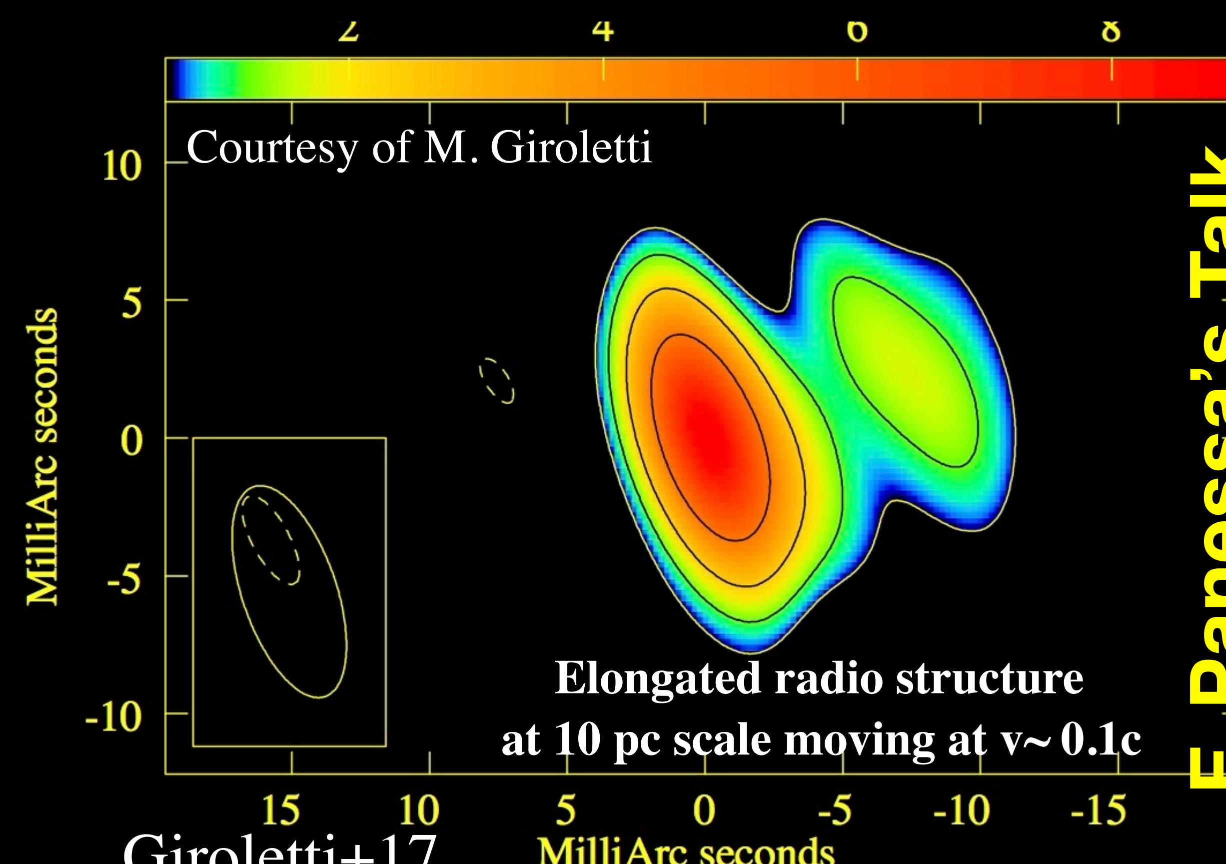


Giroletti+17

F. Panessa's Talk

Feedback in IRAS17

Assuming the outflow velocity of the wind equal to the escape velocity, the energy output rate is sufficient to power feedback to the host galaxy (Hopkins & Elvis 2010)

UFO component C

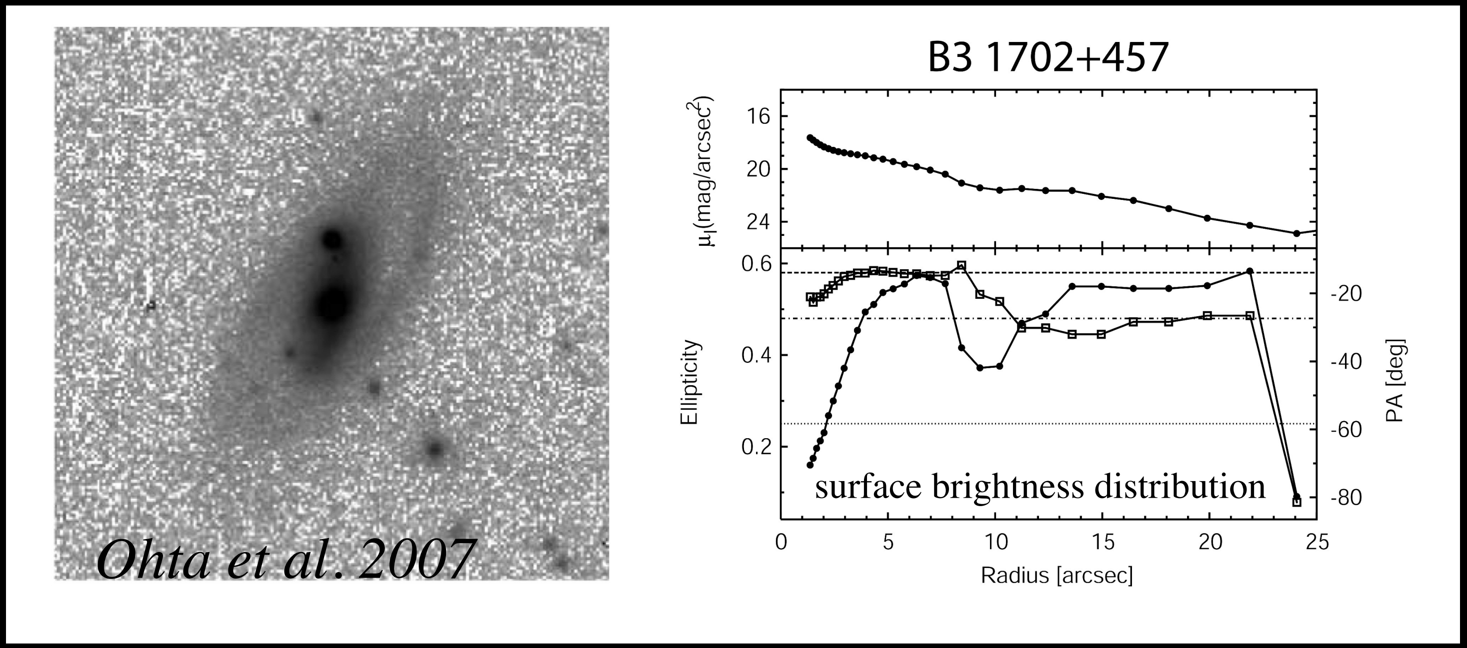
$N_H \sim 10^{24}$ cm^{-2}

$v_{out} \sim 27{,}000$ 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}

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



- **IRAS17020+4544 host galaxy is a barred Spiral**
- **$L_{bol} \sim 5 \times 10^{44}$ erg s^{-1} much 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**

To Feed or not to Feed?

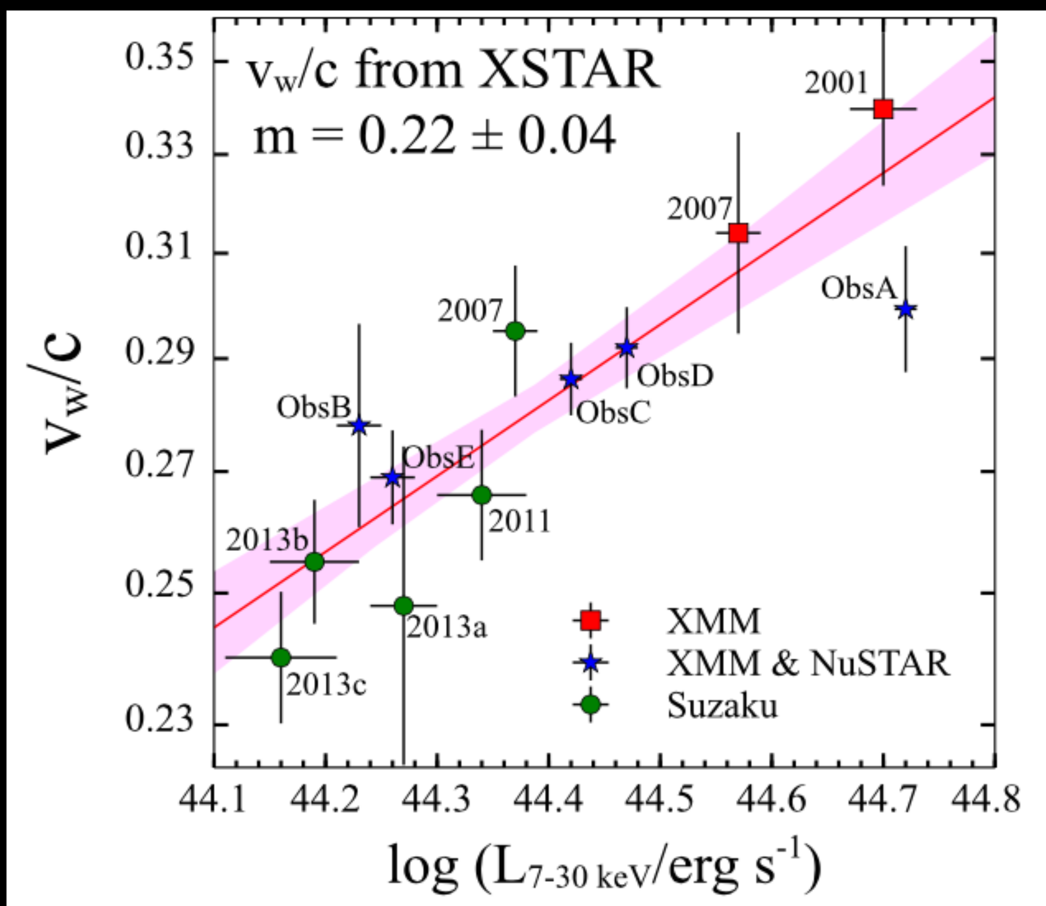
Large injection of energy into the ISM of the AGN host galaxy requires high outflow velocity and column density.
Sources that feedback above the "magical" threshold of 0.5–5% of the AGN luminosity

QSO/ULIRGS	PDS456	$L_{bol} \sim 10^{47}$ erg/s	$M_{BH} = 10^{9}\ M_\odot$
	Mrk 231	$L_{bol} \sim 5 \times 10^{45}$ erg/s	$M_{BH} = 8.7\times10^{7}\ M_\odot$
	IRASF111191+3257	$L_{bol} \sim 10^{46}$ erg/s	$M_{BH} = 1.6\times10^{7}\ M_\odot$
NLSy1	IRAS 17020+4544	$L_{bol} \sim 5\times10^{44}$ erg s^{-1}	$M_{BH} = 6\times10^{6}\ M_\odot$
	Mrk 1044	$L_{bol} \sim 5\times10^{44}$ erg s^{-1}	$M_{BH} = 1.4\times10^{6}\ M_\odot$
	IRAS13224-3809	$\langle L_{bol} \rangle \sim 5\times10^{44}$ erg s^{-1}	$M_{BH} = 6\times10^{6}\ M_\odot$

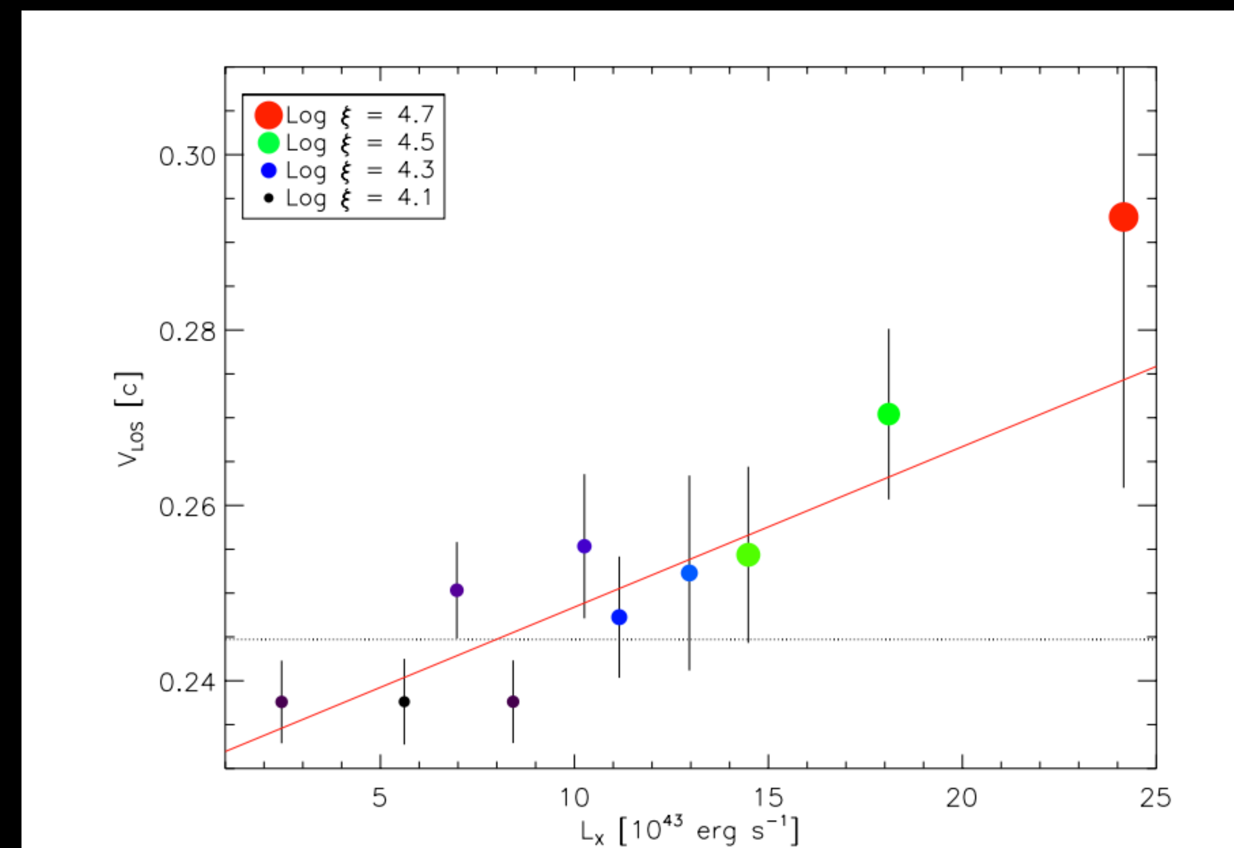
PG1211+143 (Chandra/HST UFO 2018): 0.02%

Luminosity dependence of UFO

QSO PDS 456
Matzeu et al. 2017



NLSy1 IRAS13224-3809
Pinto et al. 2018

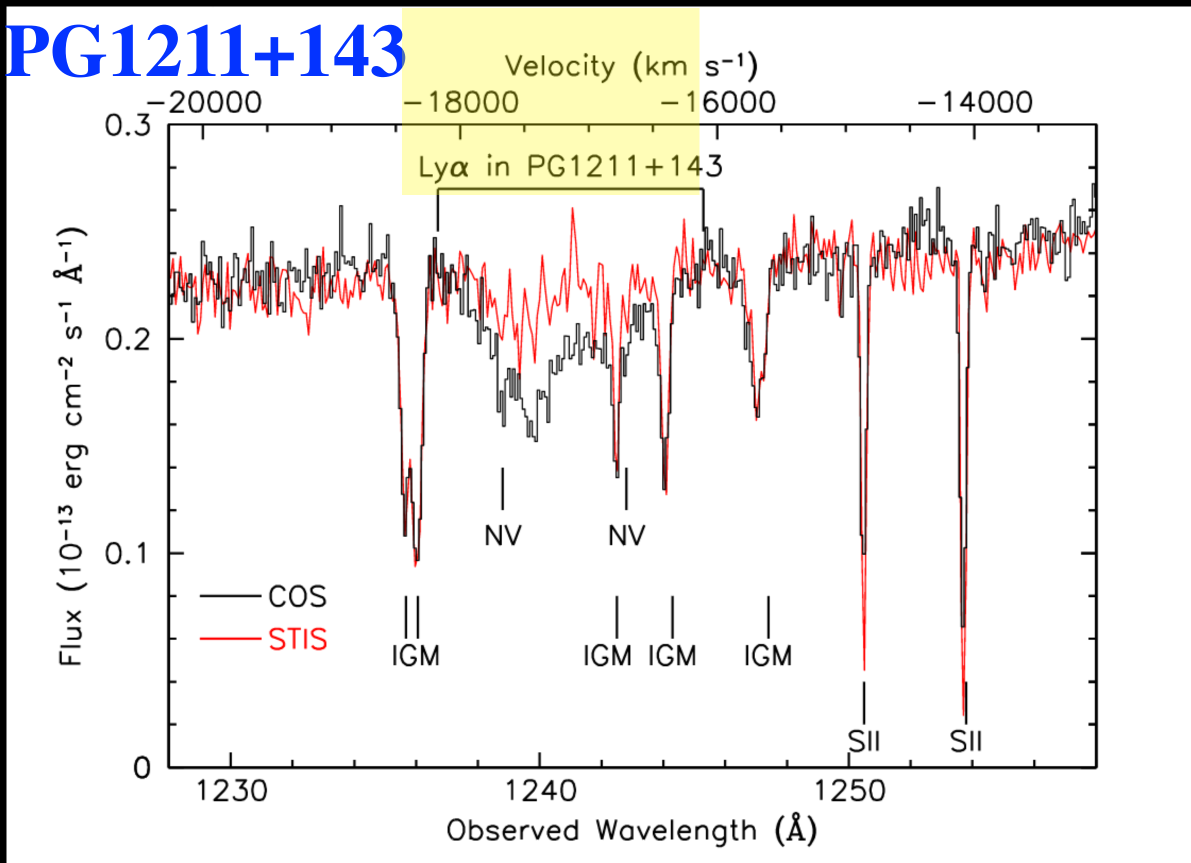


Correlations between the outflow velocity and the X-ray continuum luminosity seem to imply that

the disk wind is faster at higher luminosity

UFO in HST/COS spectra: clumpy winds

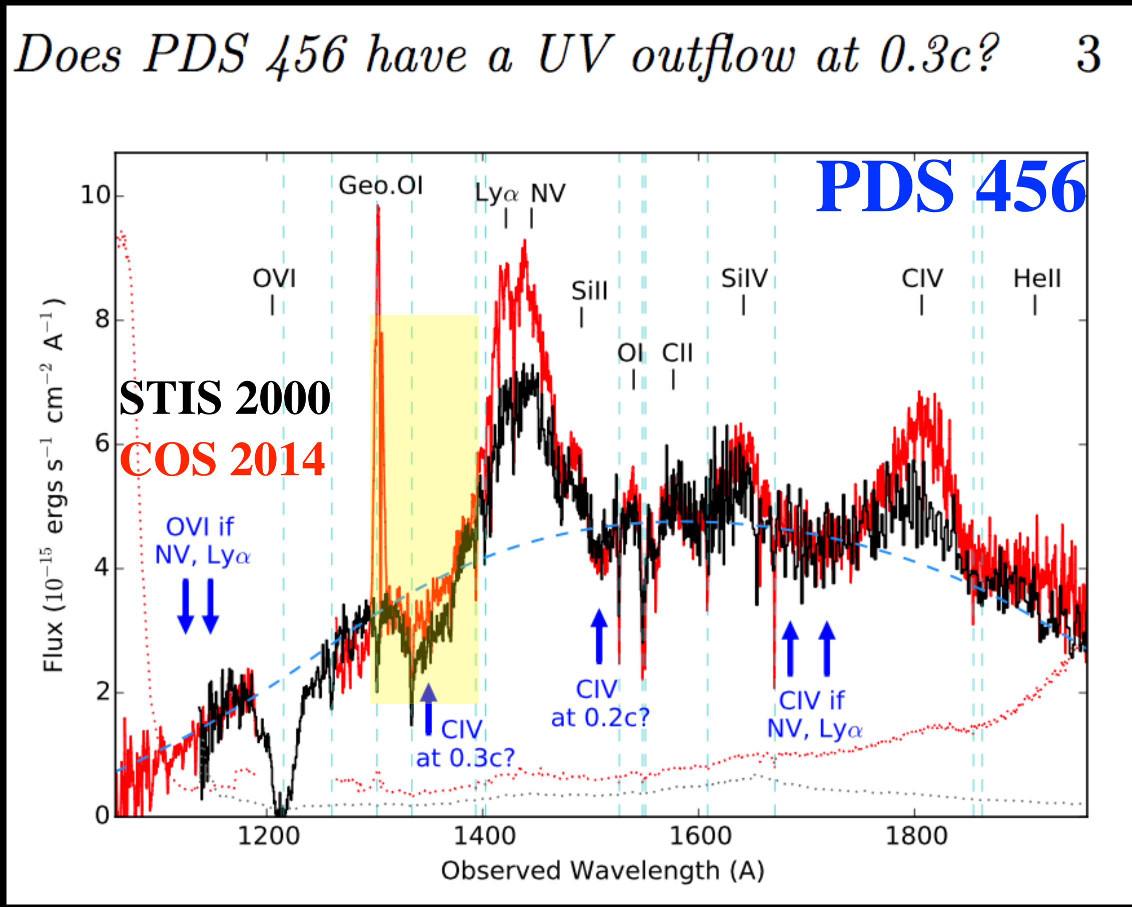
UFO QSO PG1211 *Kriss et al. 2018*



Broad HI Lyα outflowing at -17,000 km/s

Simultaneous detection of X-ray UFO (H-He-like Ne, Mg, Si) outflowing at -17,300km/s in Chandra HETG (*Danehkar+ 2018*)

UFO QSO *Hamann et al. 2018*



CIV BAL outflowing at ~0.3c would be the fastest UV wind ever detected

Velocity matches well the X-ray UFO, although data are not simultaneous…

Systematic search in UV spectra of X-ray UFO sources: negative result *Kriss+2018*

Conclusions and outlook

- **NLSy1 sources seem preferred to host multi-components UFO (but mind the "archival bias"). Analogy with high L QSO and role of high accretion rate to be investigated**

- **Feedback in "normal" Seyfert Galaxies (smaller BH) to be considered**

- **Even if no feedback, understanding accretion disc winds in local sources, how they are produced and how they interact with the host galaxy material is very important for gaining insights on high-Z sources where X-ray winds are difficult to observe by current facilities!**

- **Connect X-ray winds with outflows in other bands to effectively test energy-driven outflows: mapping/observing radio and molecular outflow in sources with X-ray UFO is fundamental**

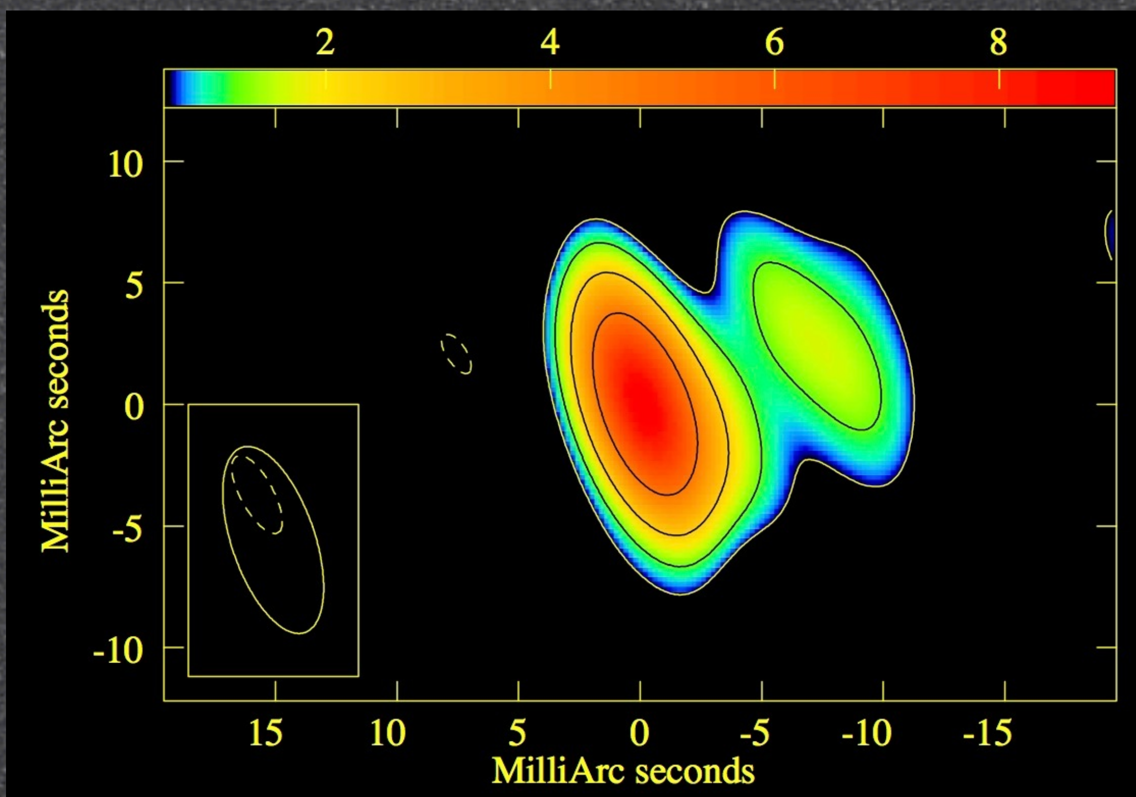
Thanks for your attention!

Additional material

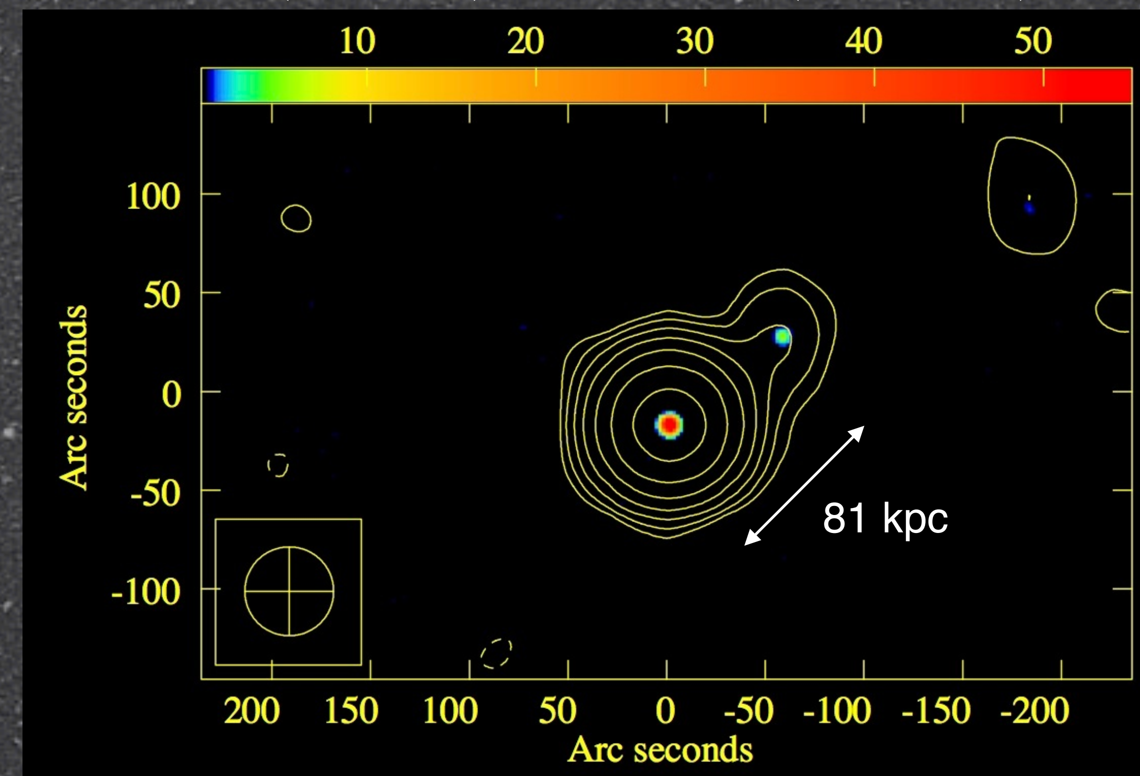
Radio Properties of IRAS17020+4544

Giroletti et. al 2017 A&A

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?