Departamento de Imagen y Diseño, INAOE/A. Gómez-Ruiz/SDSS/Longinotti et al. 2018

Dissecting AGN feedback: the extraordinary multi-phase outflow in the NLSy1 IRAS17020+4544

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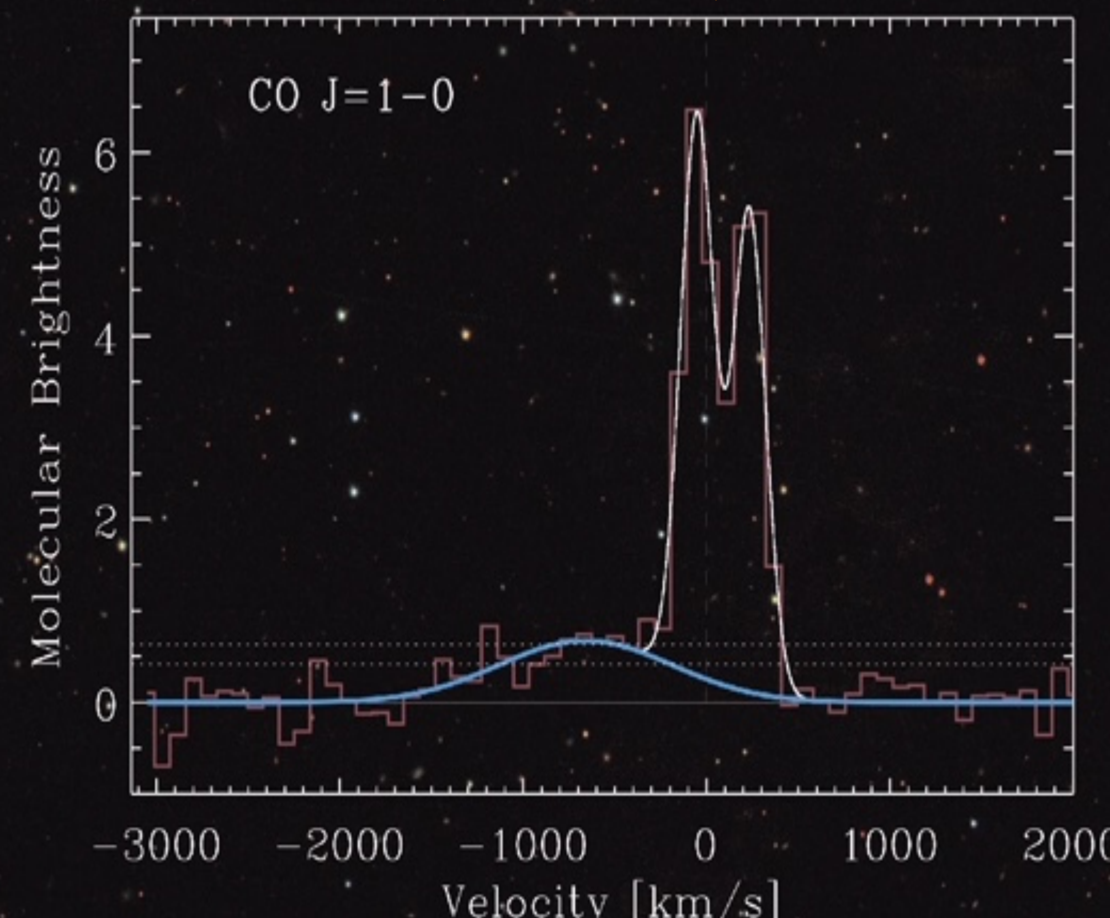
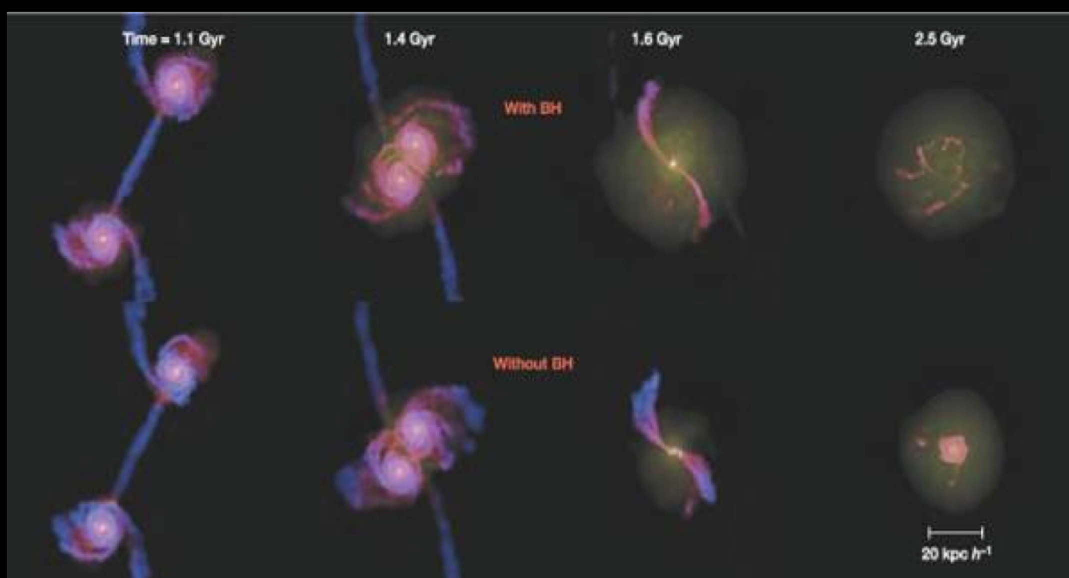


Debopam Som *(Ohio State US)*

AGN feedback via AGN winds?

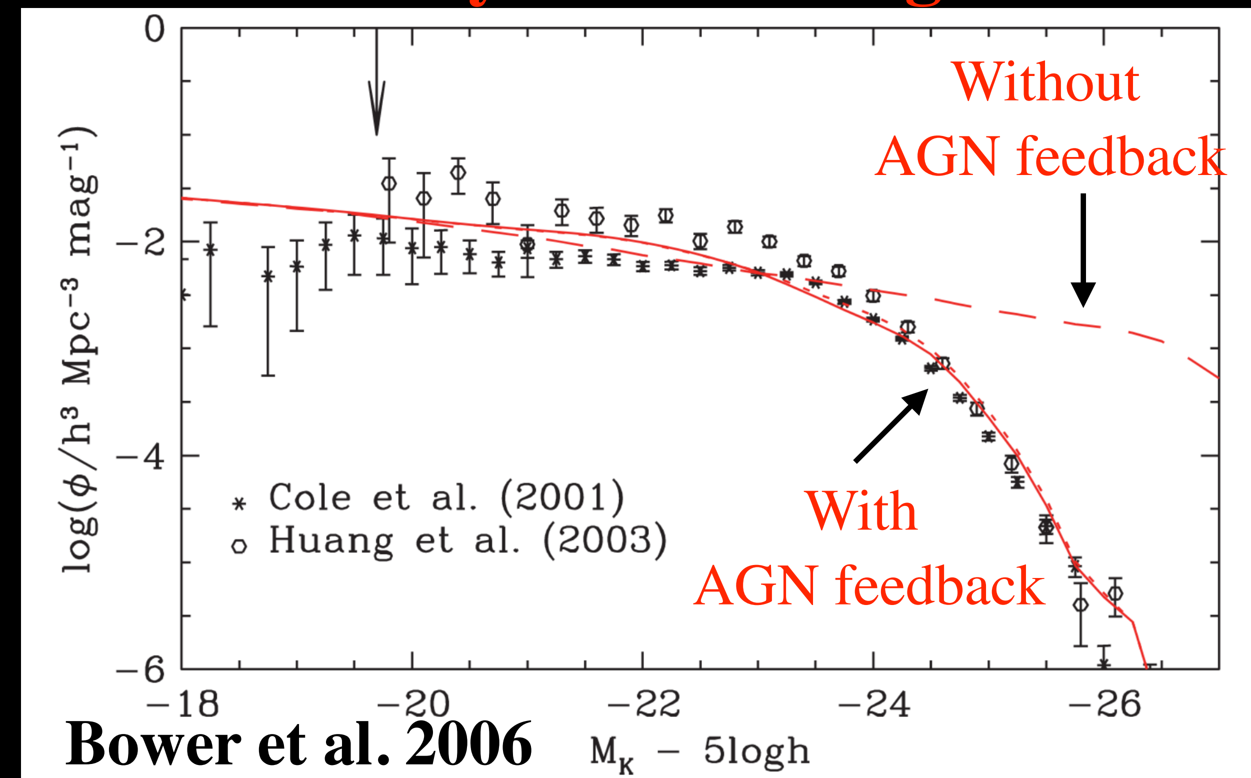
Outflows may provide the connection between BH and host galaxies required to reconcile theory & observations

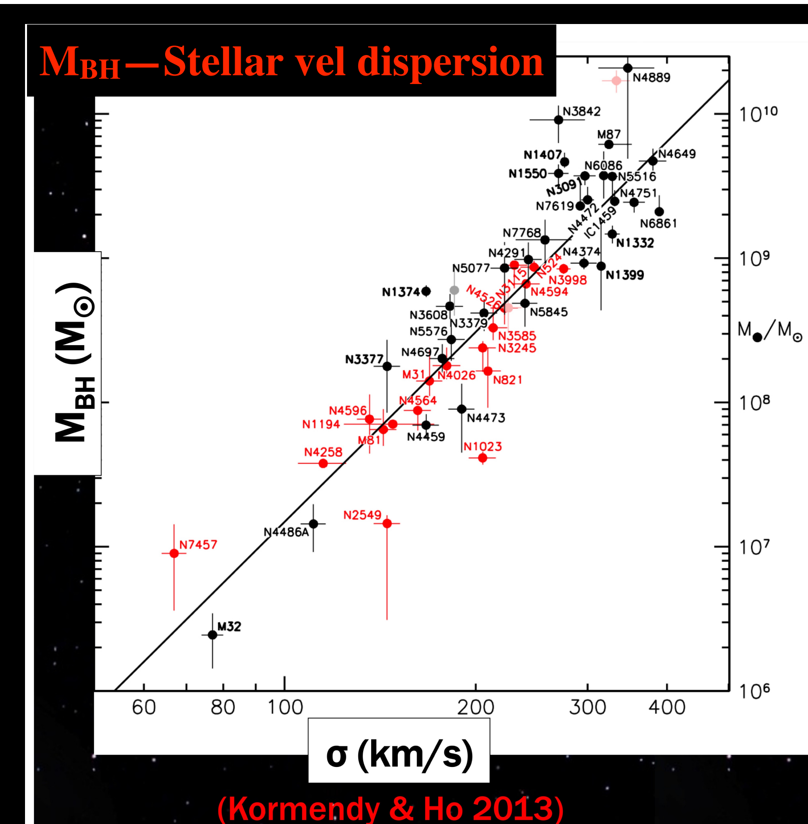


Hydrodynamical simulations of galaxy mergers require SF to be regulated by BH feedback ***Di Matteo et al. 2005***

If the power of AGN feedback is equivalent to a tiny fraction of the AGN luminosity (0.5–5%), this process can regulate the growth of the galaxy by altering its star formation
Hopkins & Elvis 2010

Luminosity function of galaxies





Wind Output Rate: Ultra Fast Outflows (UFO) vs Warm Absorbers

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

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

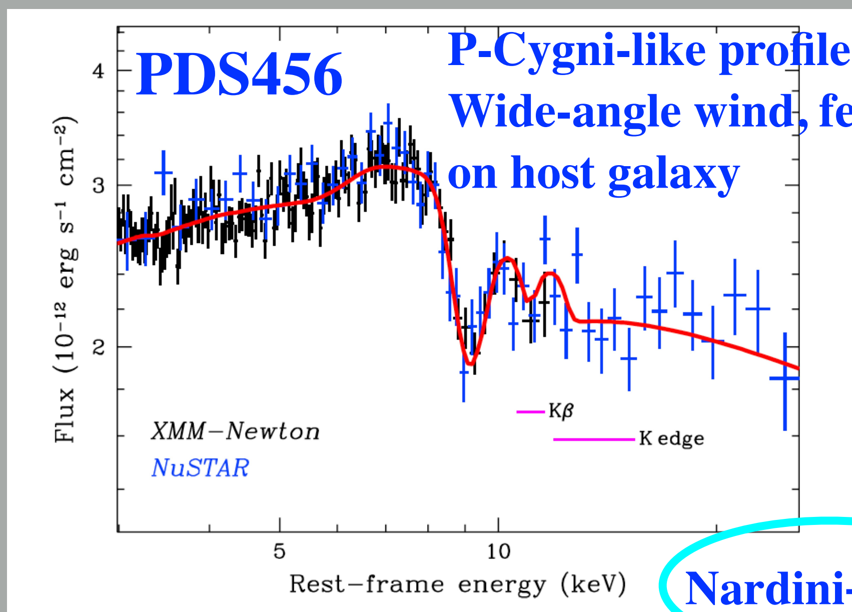
Mass outflow rate — Solid angle — Column density — Outflow v — Launching radius

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

Mechanical power of the wind depends strongly on wind velocity:
if this kinetic energy rate amounts to 0.5-5% of the AGN radiative luminosity, the outflow is able to blow out the galaxy gas at large scale and quench its star formation

2015: Golden year for AGN fast winds

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



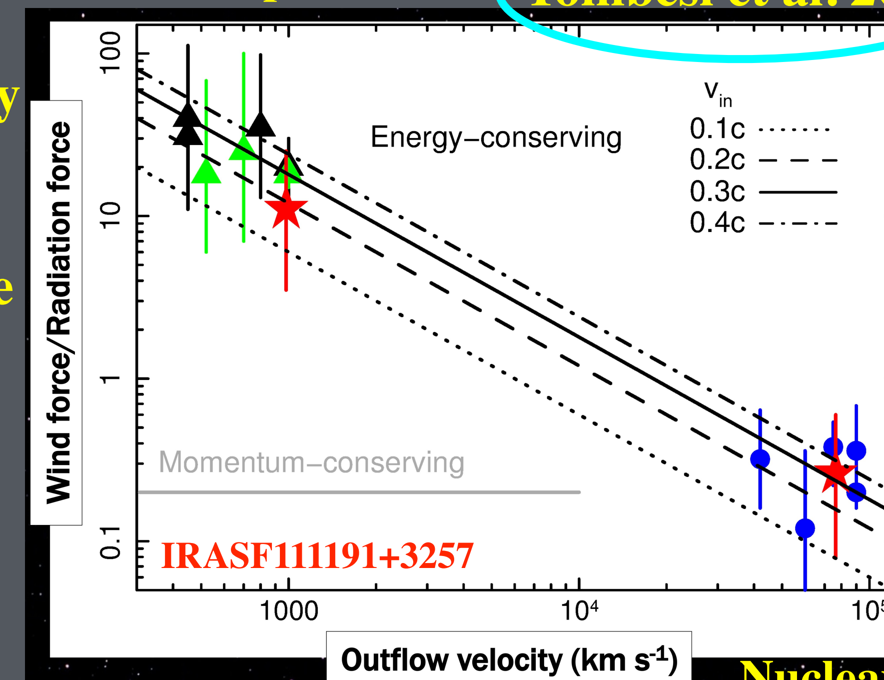
P-Cygni-like profile
Wide-angle wind, feedback on host galaxy

Nardini+2015

Molecular winds at Kpc-scale

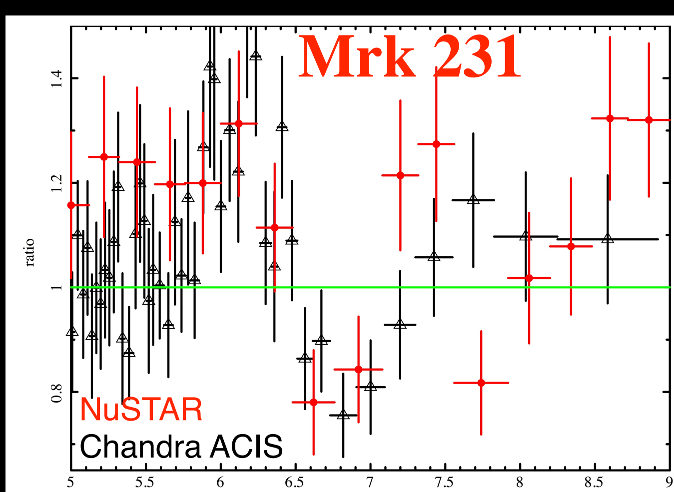
Tombesi et al. 2015

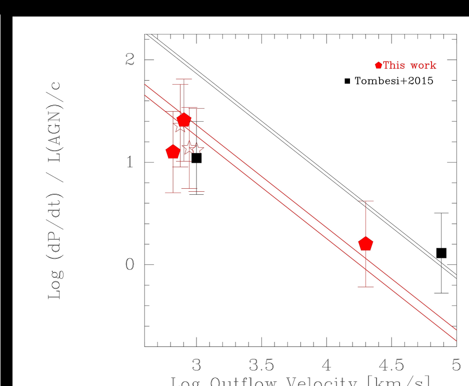
Connection of X-ray fast wind and massive molecular outflows follows the prescription of an energy driven outflows (momentum not constant)



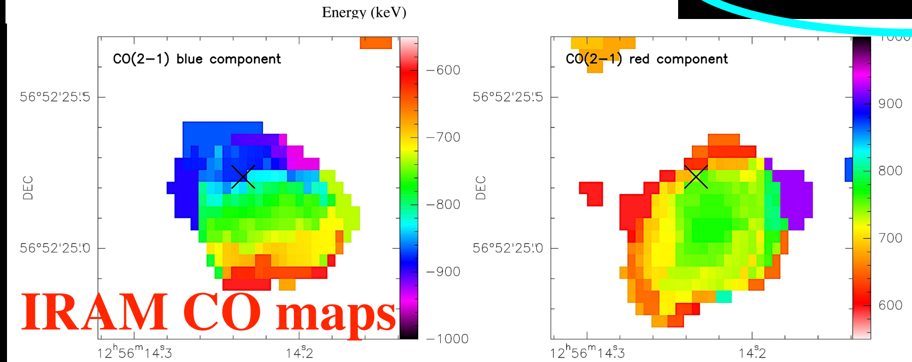
see also Cicone et al. 2014

Nuclear Disk Winds





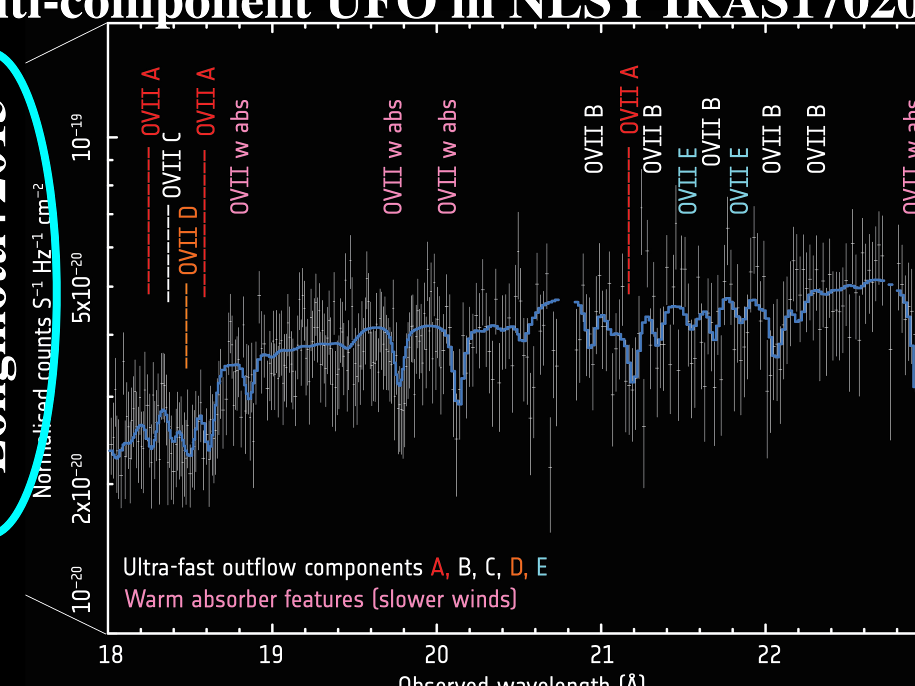
Feruglio et al. 2015



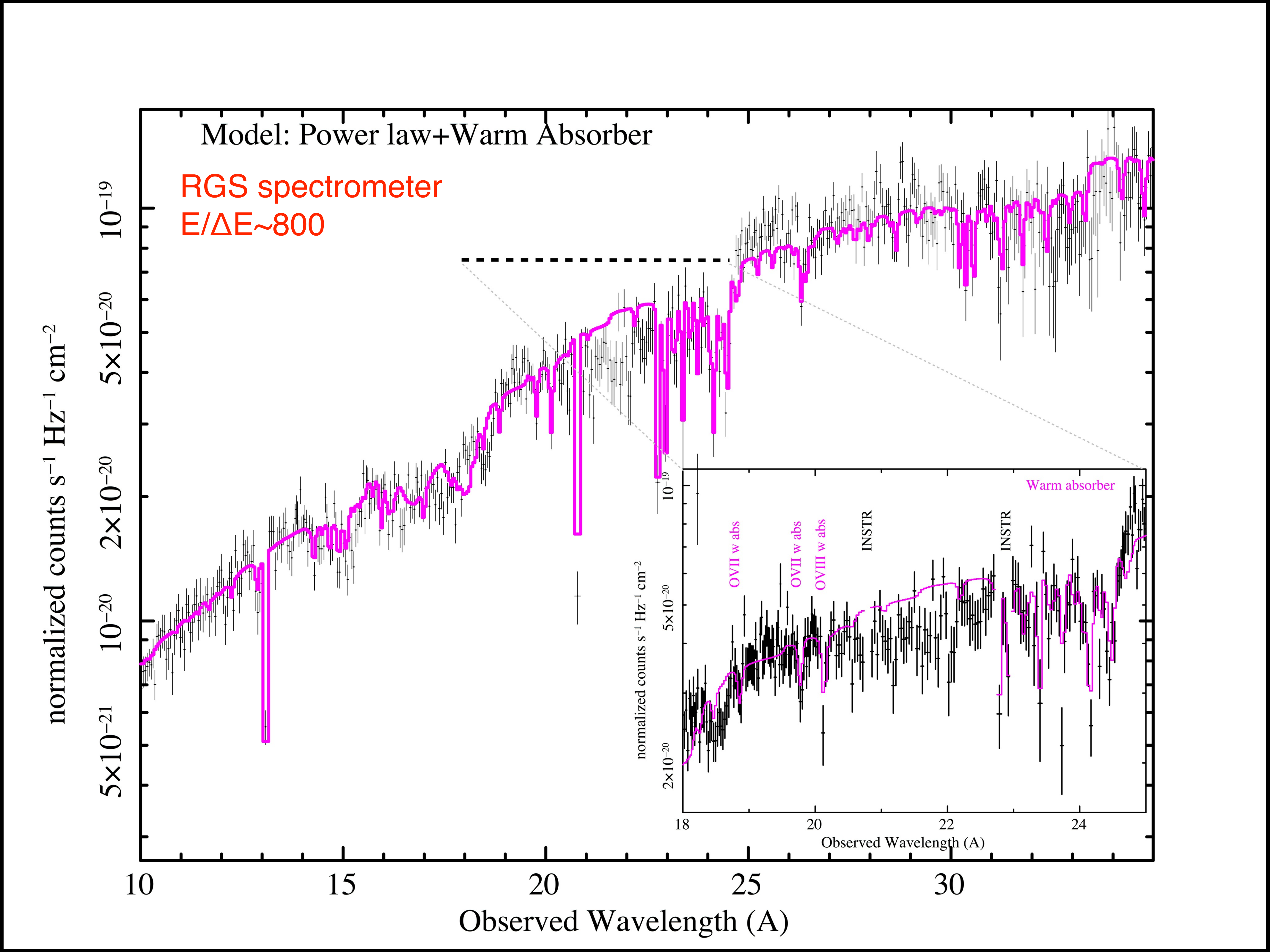
The relation of the momentum flux for the two wind phases suggests that the nuclear wind is driving the giant molecular outflow

Multi-component UFO in NLSY IRAS17020

Longinotti+2015



First view of an UFO at X-ray high-resolution reveals a stratified, multi-component wind

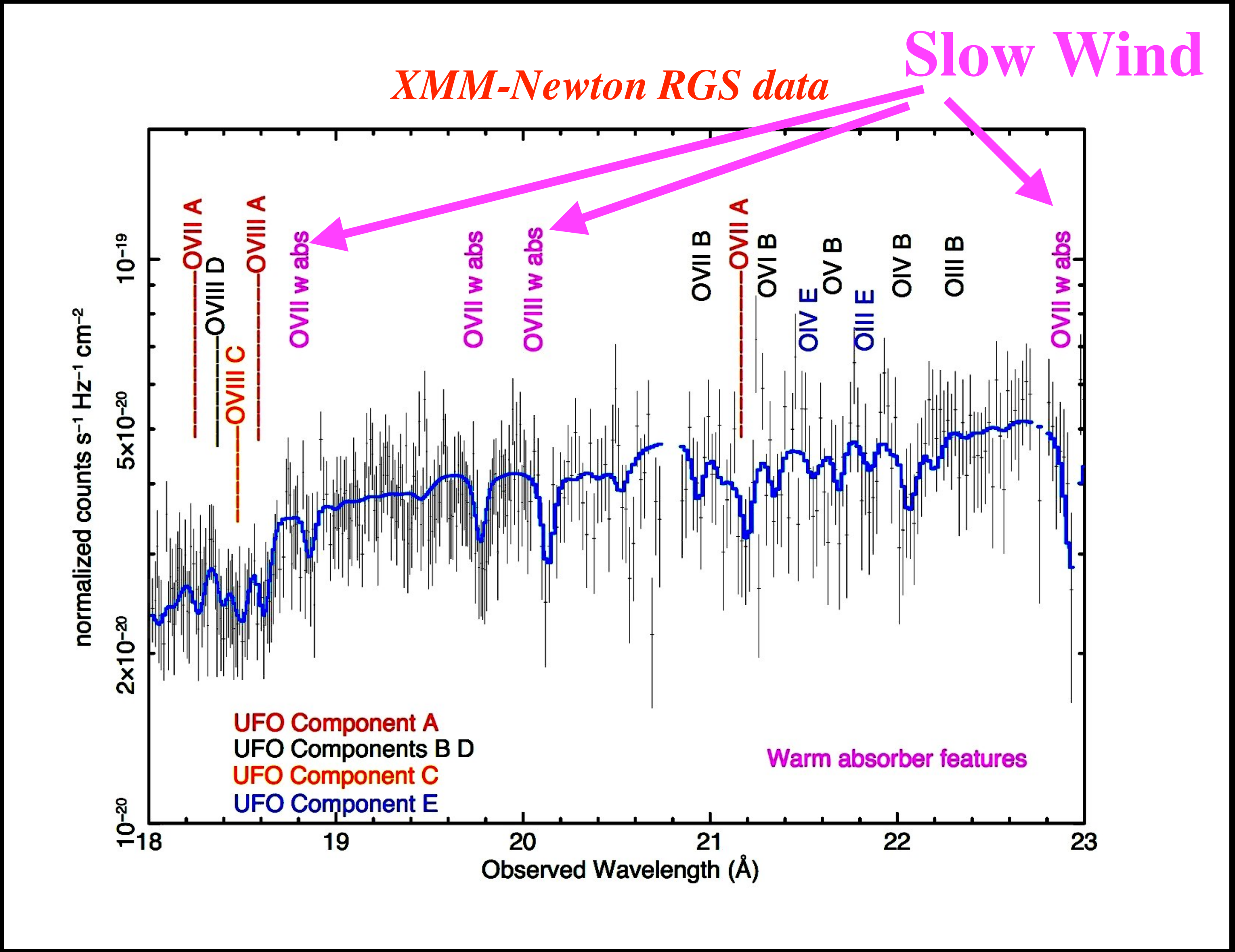


Fast + Slow winds with complex velocity pattern in IRAS17

5 UFO distinct components wide range of ionization and N_H outflowing at same velocity ~30,000 km/s (*Longinotti et al. 2015*)

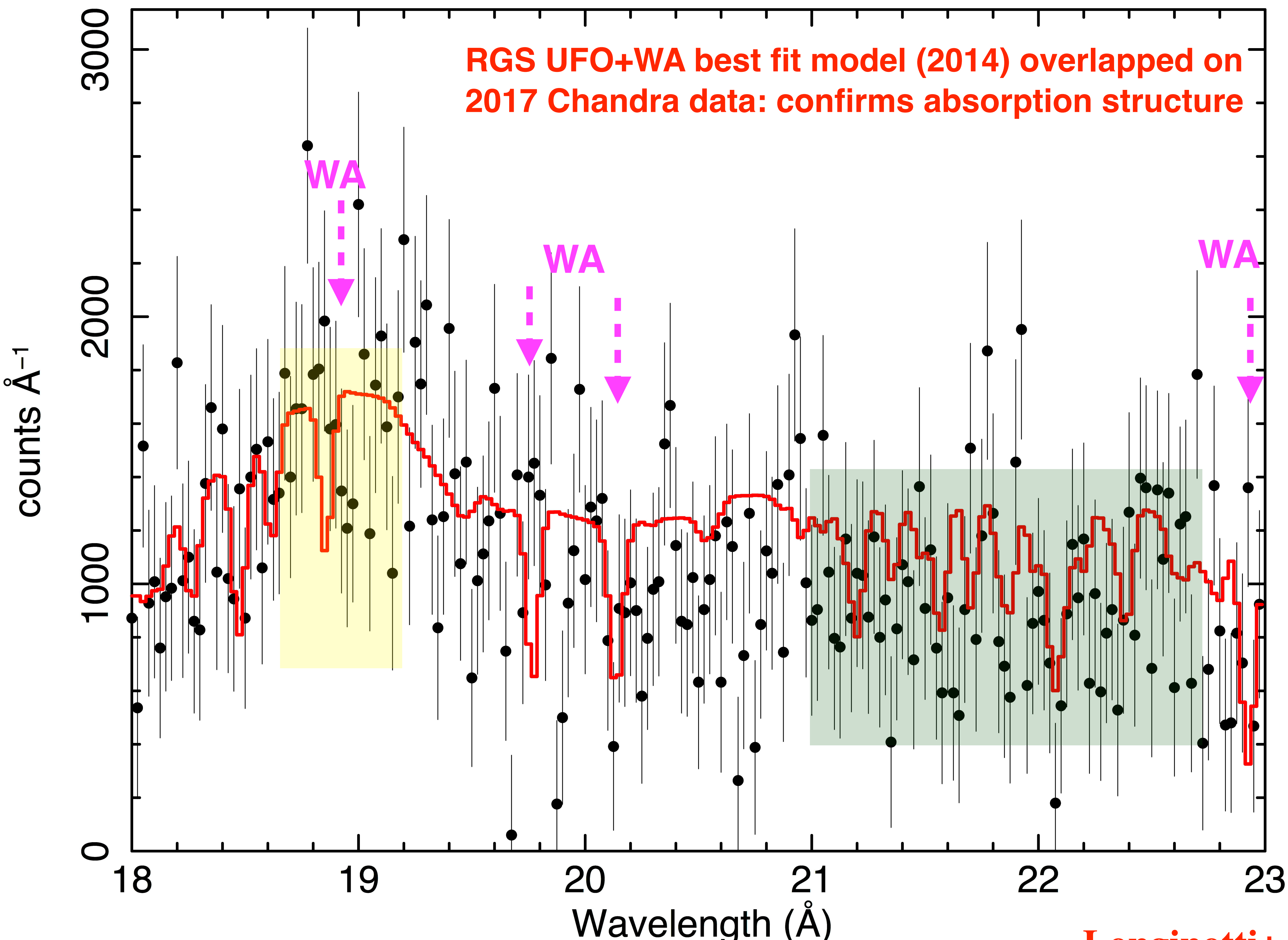
4 components of warm absorber with "standard"velocities 10^2-10^3 km/s variable inflow/outflow between XMM 2004-2014 (*Sanfrutos et al. 2018*)

Unusual feedback properties in the X-ray multi-component fast wind later observed in other NLSy1:
IRAS13224-3809 Parker et al 2017
PG1211+143 Reeves et al 2018
Mrk 1044 Krongold et al submitted



- **IRAS17020+4544 host galaxy is a barred Spiral**
- **L_{bol} ~ 5×10^{44} erg s^{-1} (not as QSO, ULIRG)**
- **No evidence of merger/disturbed morphology/ dust obscuration**
- **Small black hole ~ 6 $\times10^6$ $M_\odot$ and High $\dot{M}$**

Chandra LETG look at IRAS17020+4544 (250 ks)



Longinotti+ in prep.

Evolution of the slow wind in IRAS17020+4544

-Slow Wind components 3 and 4 decreased their velocity
-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?

XMM 2014 | **XMM 2004**

	2014			Outflow v		2004			Outflow v	
Component	$\log U$	$\log N_{\mathrm{H}}$[a]	v_{turb}[b]	v[c]	ΔC	$\log U$	$\log N_{\mathrm{H}}$[a]	v_{turb}[b]	v[c]	ΔC
WA 1 (rest)	$-1.88^{+0.03}_{-0.02}$	$21.09^{+0.01}_{-0.01}$	160 ± 30	-320 ± 70	530	$-2.10^{+0.07}_{-0.06}$	$21.01^{+0.03}_{-0.11}$	170 ± 60	-380 ± 160	100
WA 2 (rest)	$-0.57^{+0.05}_{-0.04}$	$21.12^{+0.03}_{-0.04}$	<40	-430 ± 90	120	$-0.57^{+0.08}_{-0.11}$	$21.25^{+0.11}_{-0.20}$	<50	-490 ± 110	61
WA 3 (outflow)	-2.47 ± 0.02	20.93 ± 0.01	<40	2300 ± 200	90	$-2.81^{+0.07}_{-0.19}$	$20.88^{+0.03}_{-0.03}$	<60	4000 ± 200	34
WA 4 (inflow)	$0.35^{+0.11}_{-0.16}$	$20.84^{+0.16}_{-0.14}$	100 ± 60	-1750 ± 250	24	$-1.3^{+0.3}_{-0.4}$	$20.6^{+0.2}_{-0.4}$	110 ± 70	-2900 ± 200	14
UFO 1	$-2.47^{+0.15}_{-0.19}$	$20.10^{+0.06}_{-0.09}$	50[f.]	26900 ± 200	27	$-2.2^{+0.3}_{-0.2}$	20.4 ± 0.2	50[f.]	28500 ± 1000	9
UFO 2	$2.63^{+0.04}_{-0.13}$	23.70 ± 0.15	50[f.]	”	7	…	…	…	…	…
UFO 3	$-0.35^{+0.12}_{-0.19}$	$20.4^{+0.2}_{-0.4}$	50[f.]	24100 ± 100	5	$-0.30^{+0.05}_{-0.07}$	$21.27^{+0.15}_{-0.19}$	50[f.]	23900 ± 100	36
UFO 4	$-1.22^{+0.10}_{-0.05}$	$20.85^{+0.03}_{-0.06}$	50[f.]	”	4	…	…	…	…	…

M. Sanfrutos et al. 2018 ApJ

Can shocked outflow model explain IRAS17?

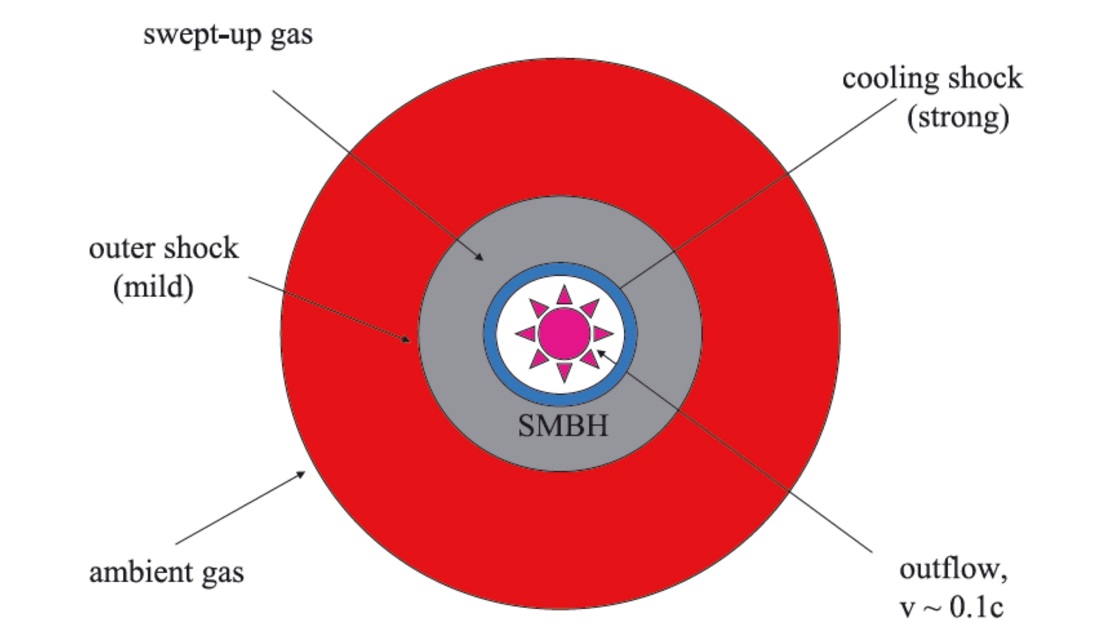
Fast outflow radiatively launched at accretion disk scale at v_out ≥ 10^4 km/s

The wind shocks with the ambient medium producing two shock fronts separated by a contact discontinuity

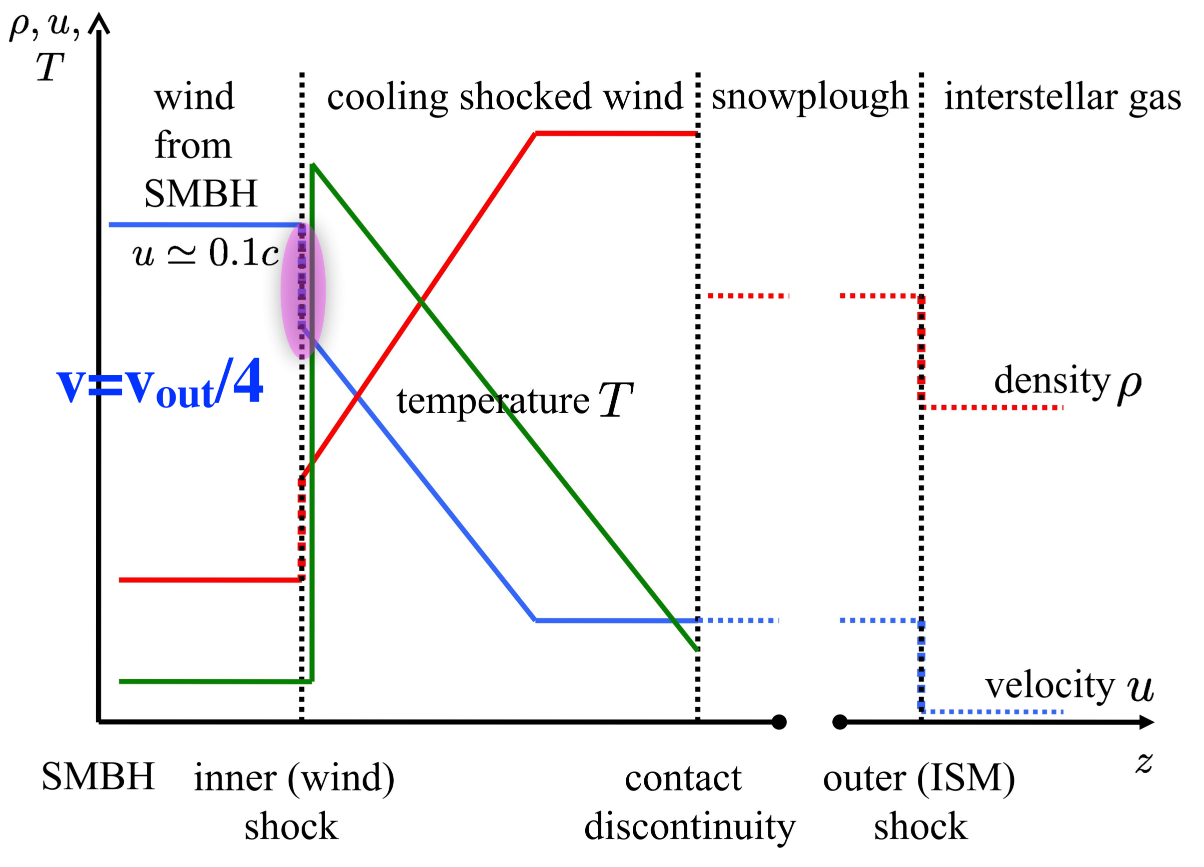
The shocked ambient gas could decelerate to velocity of the order of 100 km/s, the wind shock (reverse) maintains its high velocity while entraining the ambient gas and pushing it further out

The density of the impacting wind and of the impacted medium are different

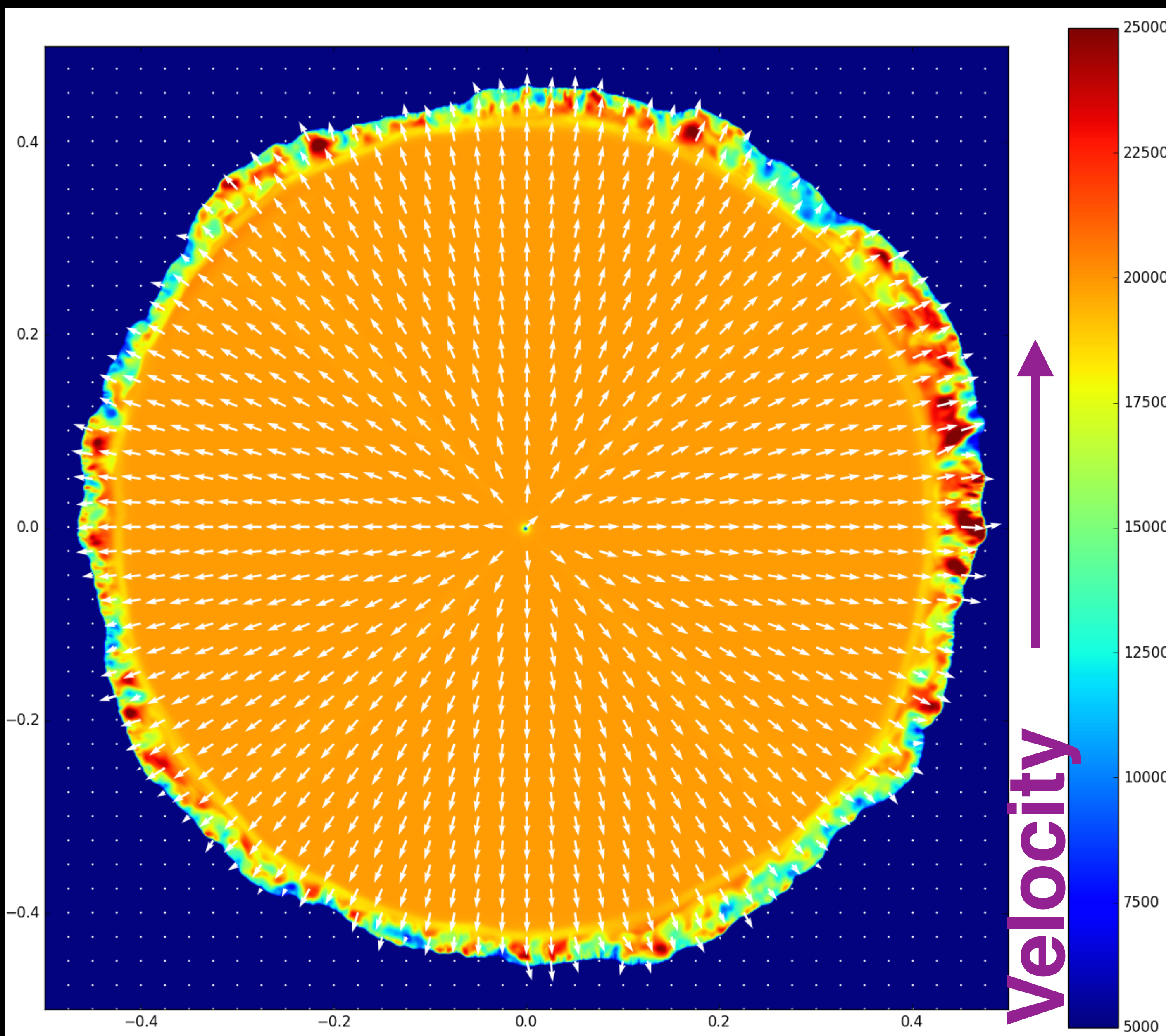
King 2010
Faucher-Giguere & Quataert 2012
Zubovas & King 2012
King & Pounds 2015



(A. King 2010)



Simulated shocked outflow with instabilities



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

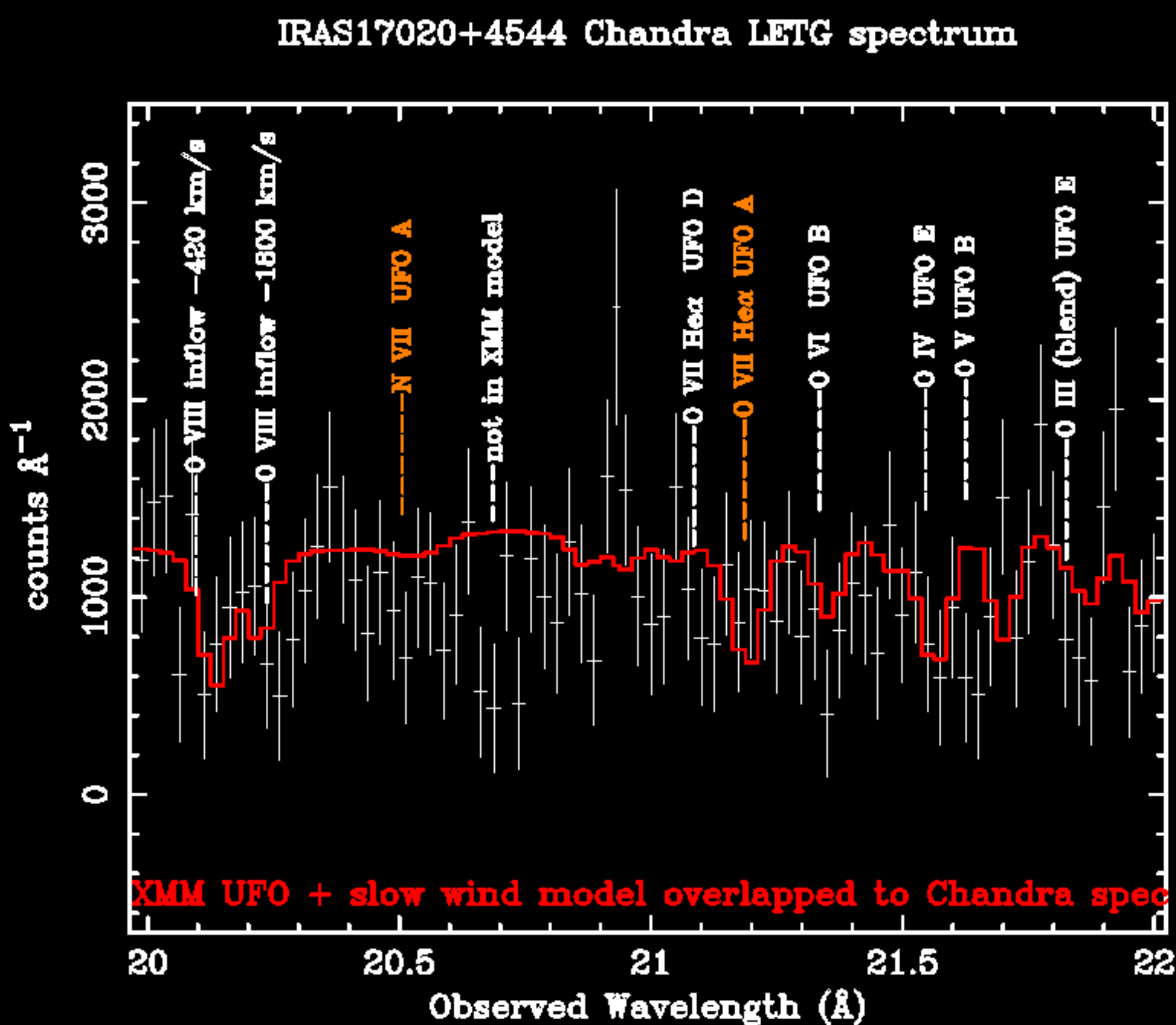
Expansion time: 20 yr

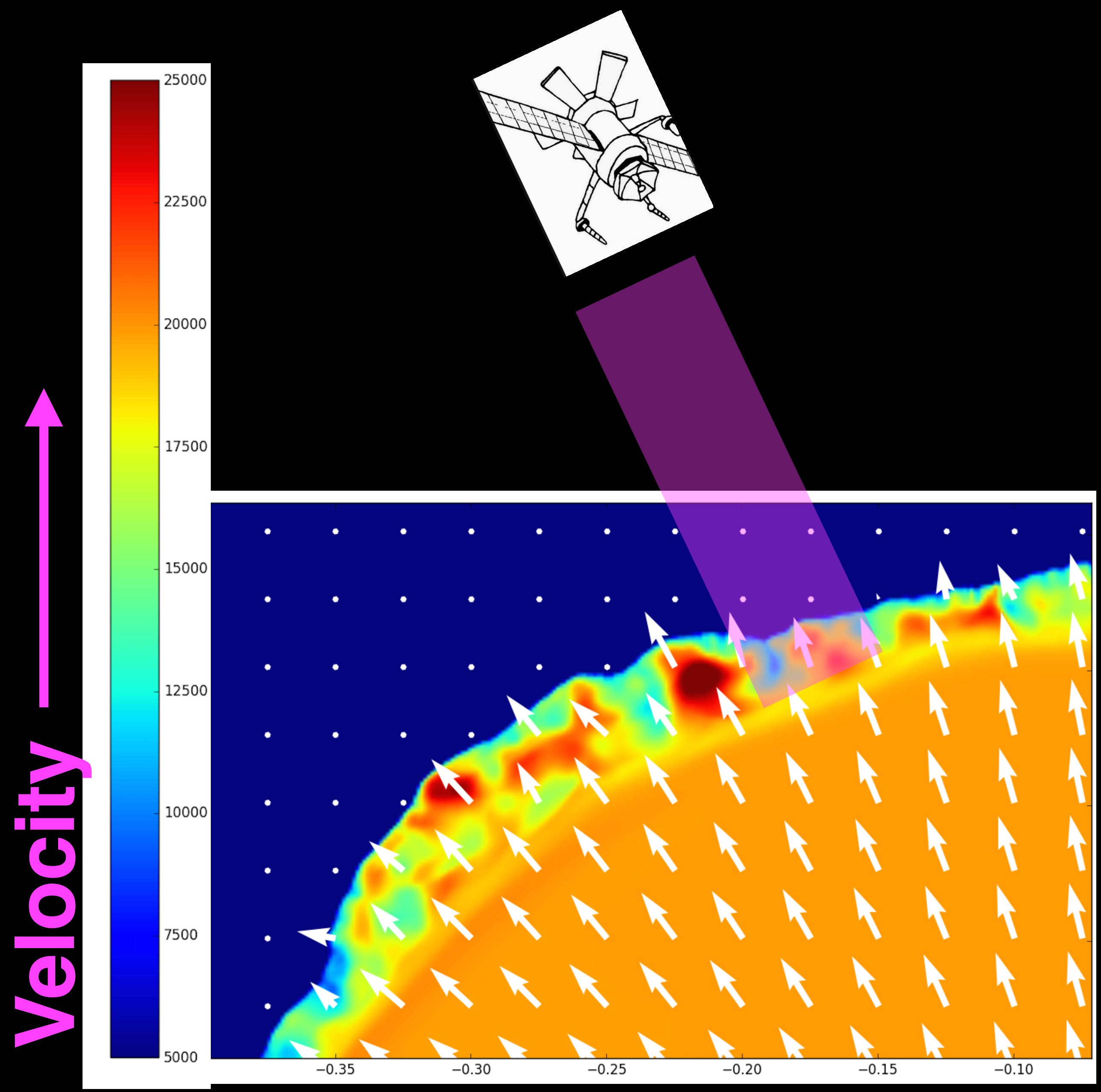
Sim by P. Velazquez, based on GUACHO code
Esquivel & Raga 2013 ApJ
(Instituto de Ciencias Nucleares, UNAM)

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



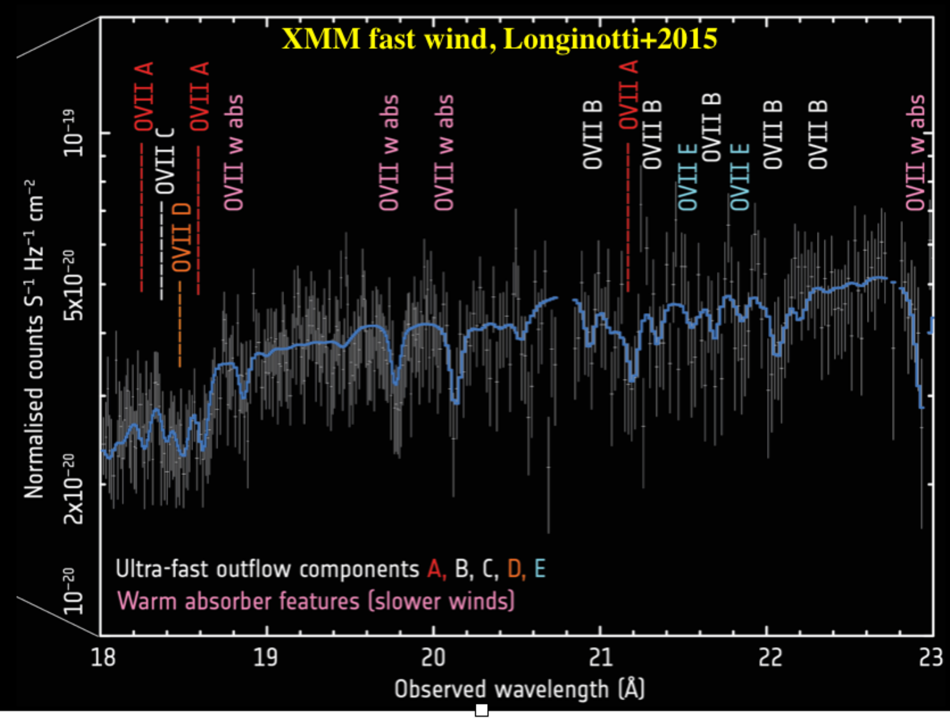


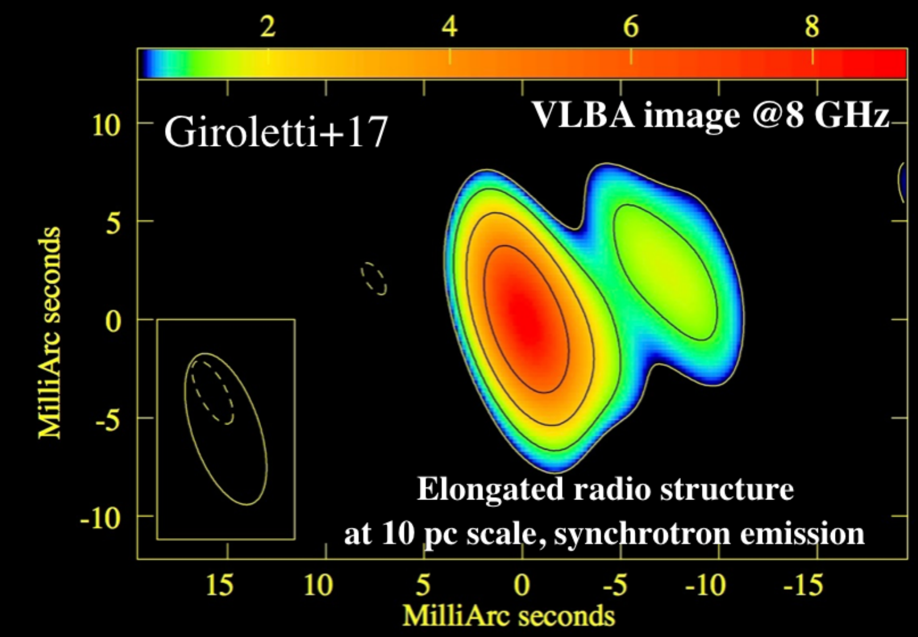
Longinotti 2018 1808.01043

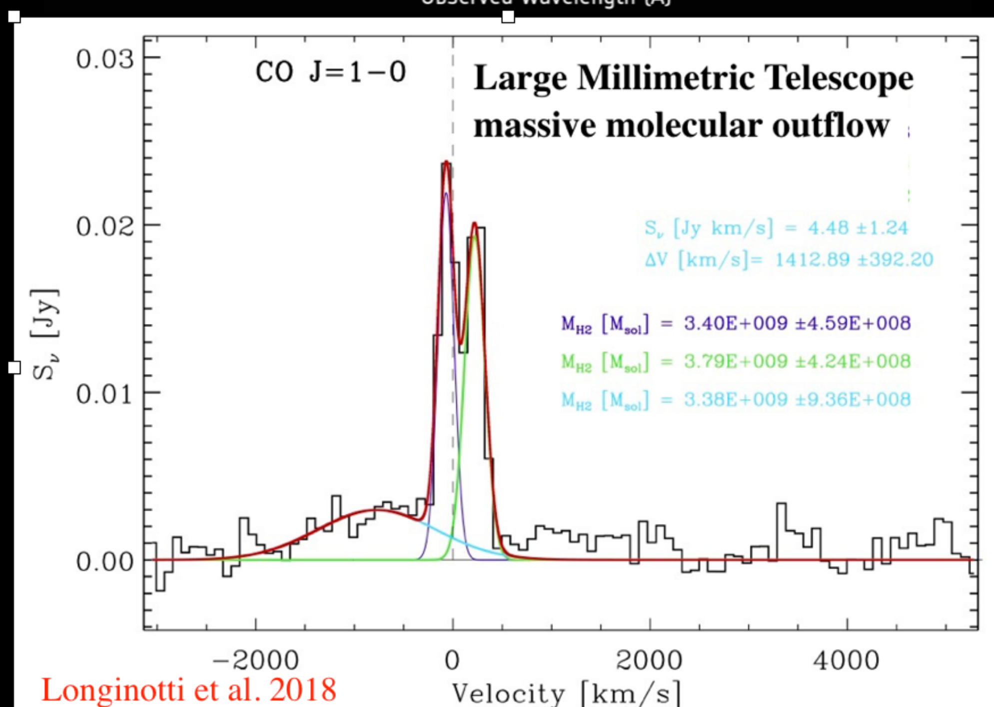
Let’s leave the nuclear region and see what’s happening in the host galaxy…

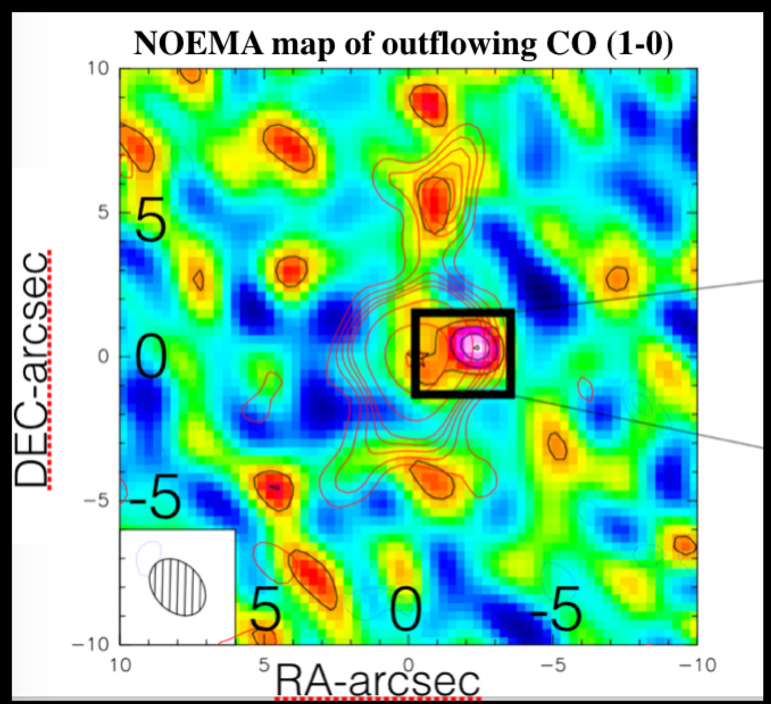
multi-phase winds!

suggesting that an AGN-driven wind may be affecting the galaxy at large scales

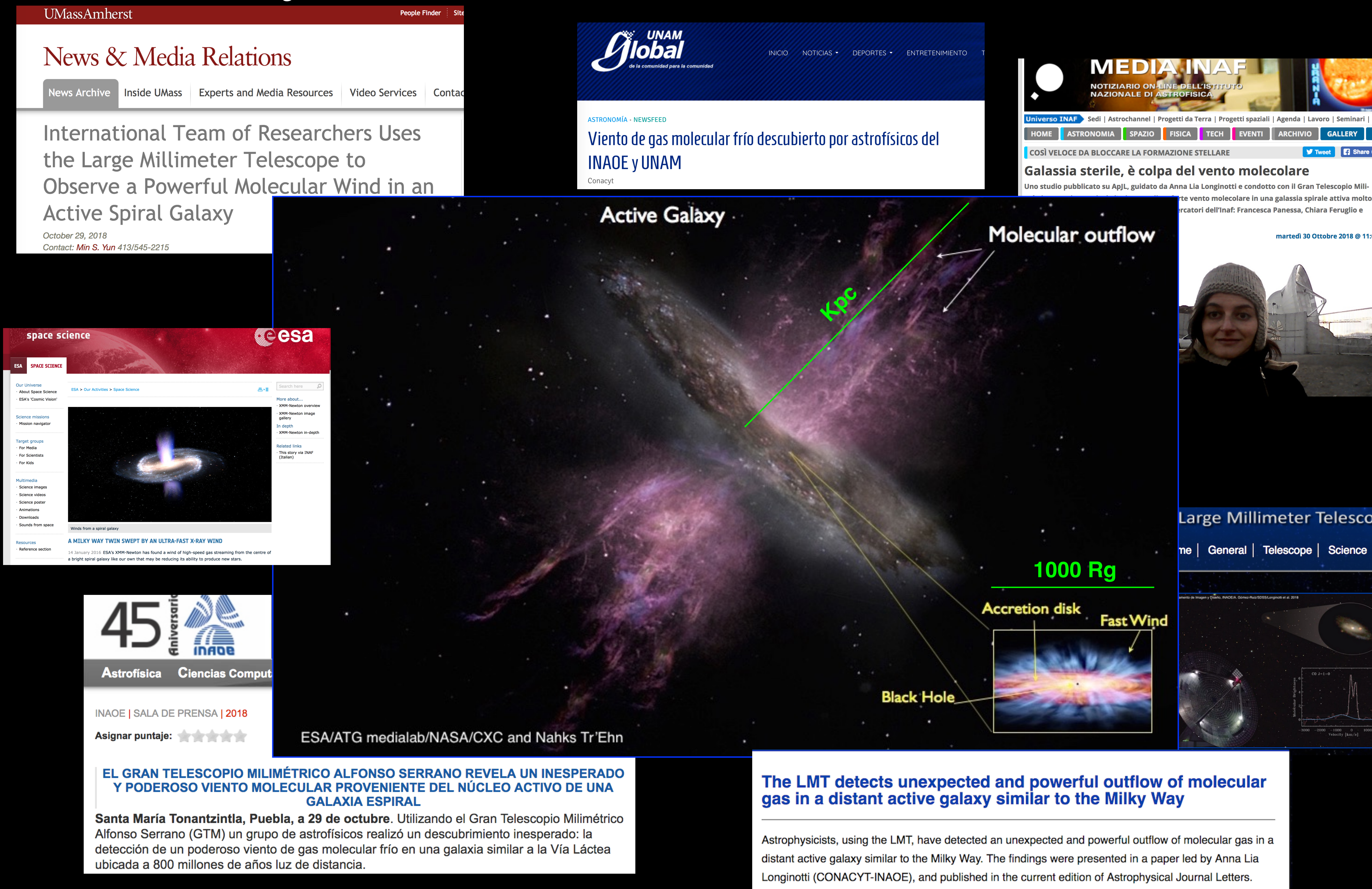








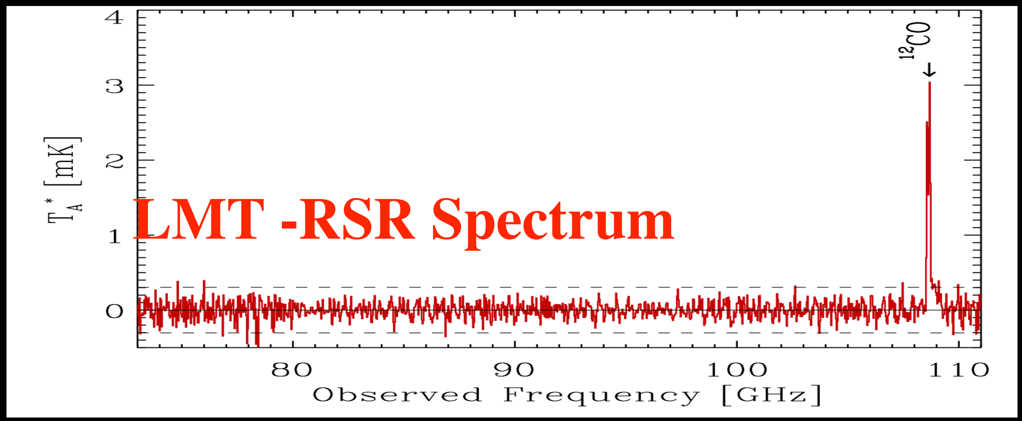
Connection
X-ray disk wind with Molecular Outflow



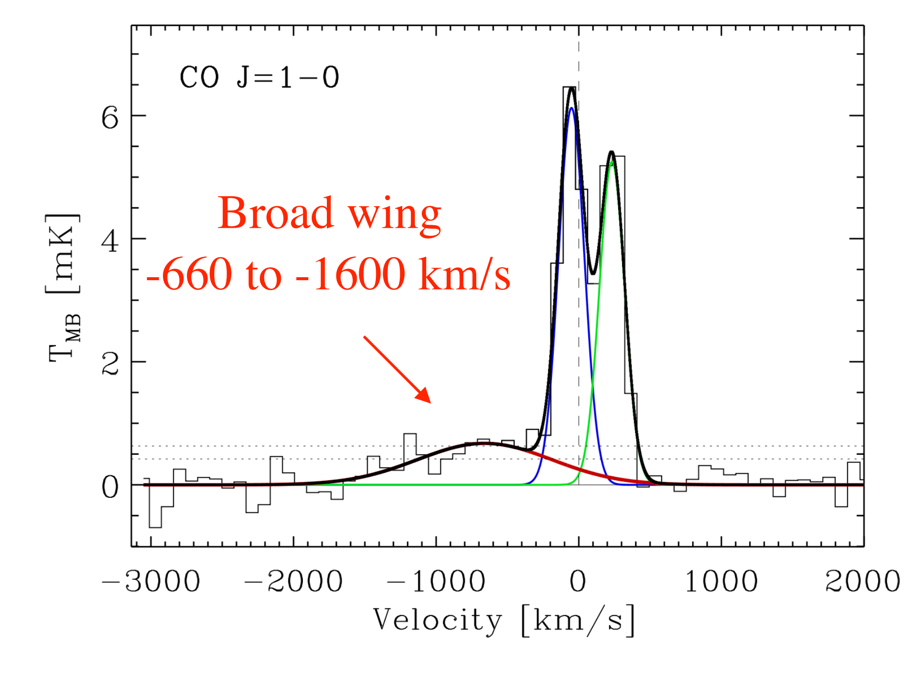
Connection X-ray-Molecular Outflows in IRAS17

Longinotti et al. 2018 ApJL

Component	FWHM	Centroid	Integrated Intensity	L_{CO} ($\times 10^8$)	M_{CO}	α (CO-to-H2)
	[km s^{-1}]	[km s^{-1}]	[mK km s^{-1}]	[K km/s pc^2]	[10^8 $M_\odot$]	[M$\odot$ (K km s^{-1} pc^2)$^{-1}$]
Broad wing	1112	-660	798±252	3.08± 0.97	1.54± 0.49	0.5
Line A	213	-51	1390±114	5.37± 0.44	4.62± 0.38	0.86
Line B	210	233	1171±110	4.53± 0.42	3.89± 0.36	0.86



Rotational transition of the carbon monoxide molecule (CO J = 1-0) ~108GhZ

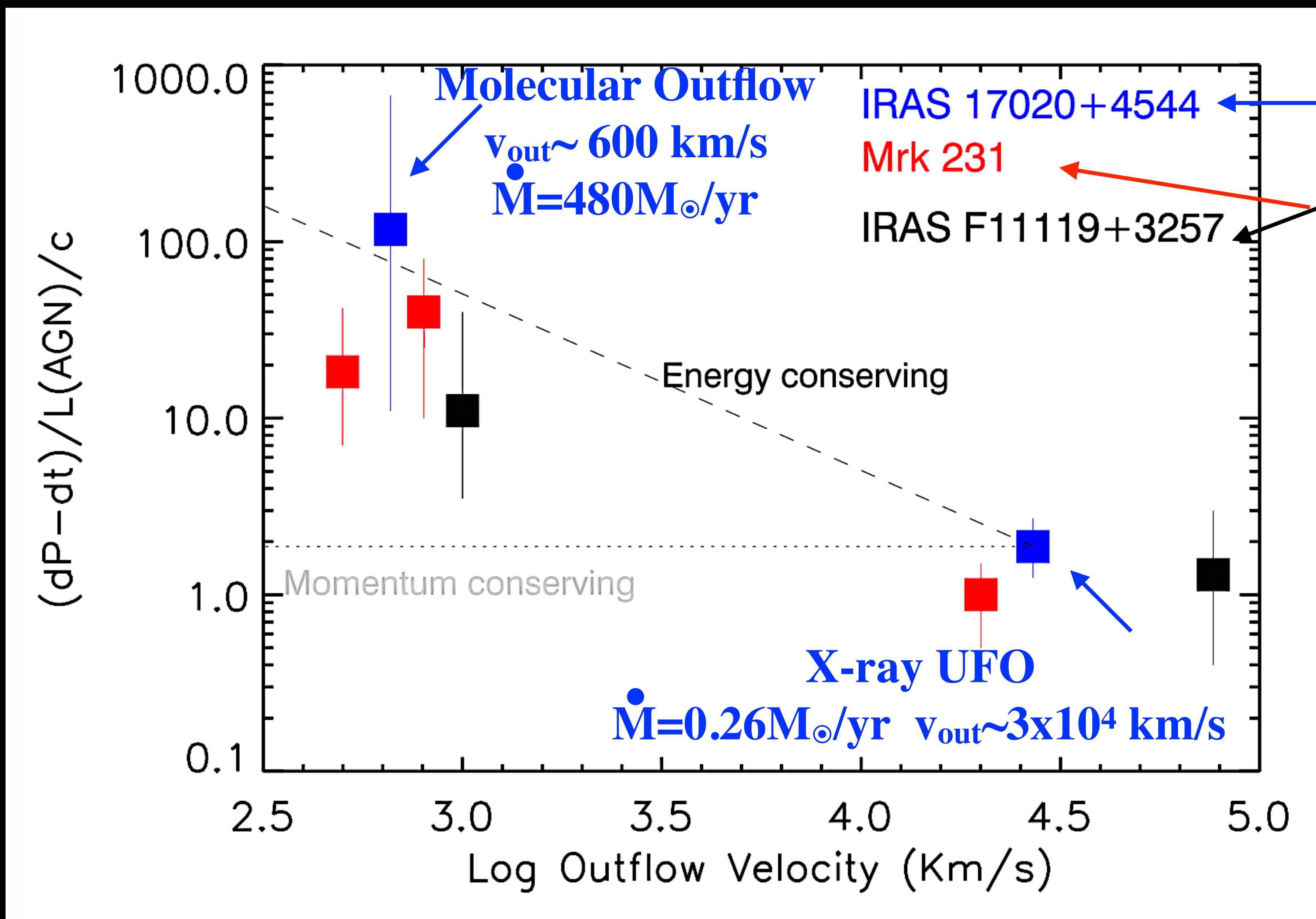


Connection X-ray-Molecular Outflows in IRAS17

$$\dot{M}_{\rm of} = 3 \times \frac{v_{\rm max,of} \times M({\rm H_2})_{\rm of}}{R_{\rm of}}$$

$$\dot{P}_{out} = \dot{M}_{out} \times v_{out}$$

Wind force/radiation force



NL Seyfert 1 Galaxy

QSO-ULIRG

The momentum flux of the wind is related to the velocity with which the gas is pushed outward.

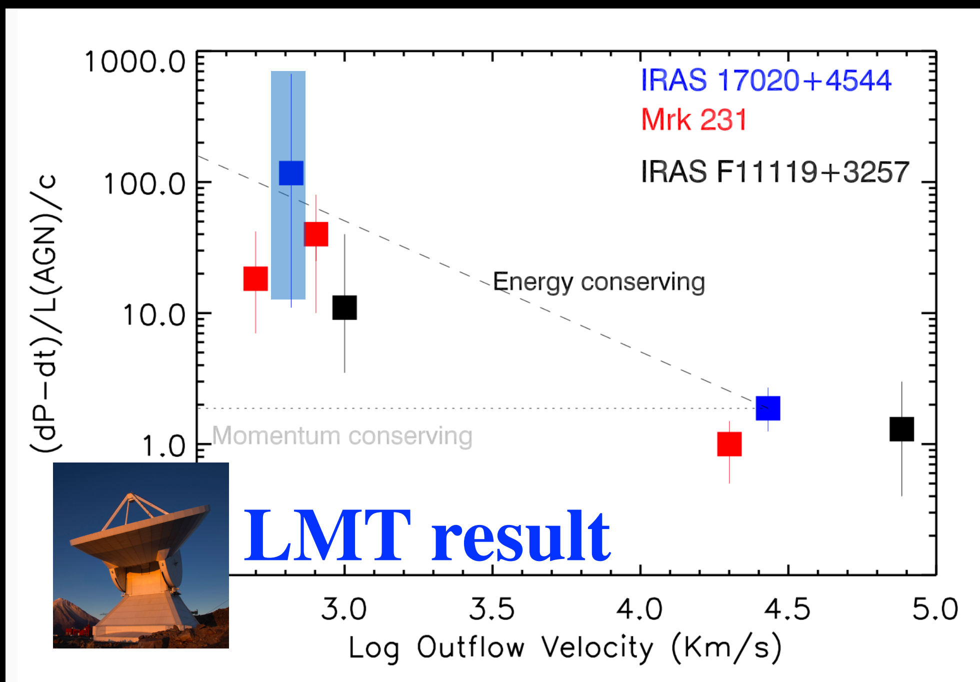
The relative proportion of the wind momentum and of the radiation force at nuclear scale (X-ray) and at galaxy scale (CO gas) determines if the wind is momentum-conserving or energy-conserving

Energy-conservation from nuclear wind to galaxy scale

$$\dot{P}_{[CO]} / \dot{P}_{[X]} = v_{\rm out\_X} / v_{\rm out\_CO}$$

NOEMA confirms Energy Driven outflow in IRAS17

Longinotti+ 2018 ApJ Letters

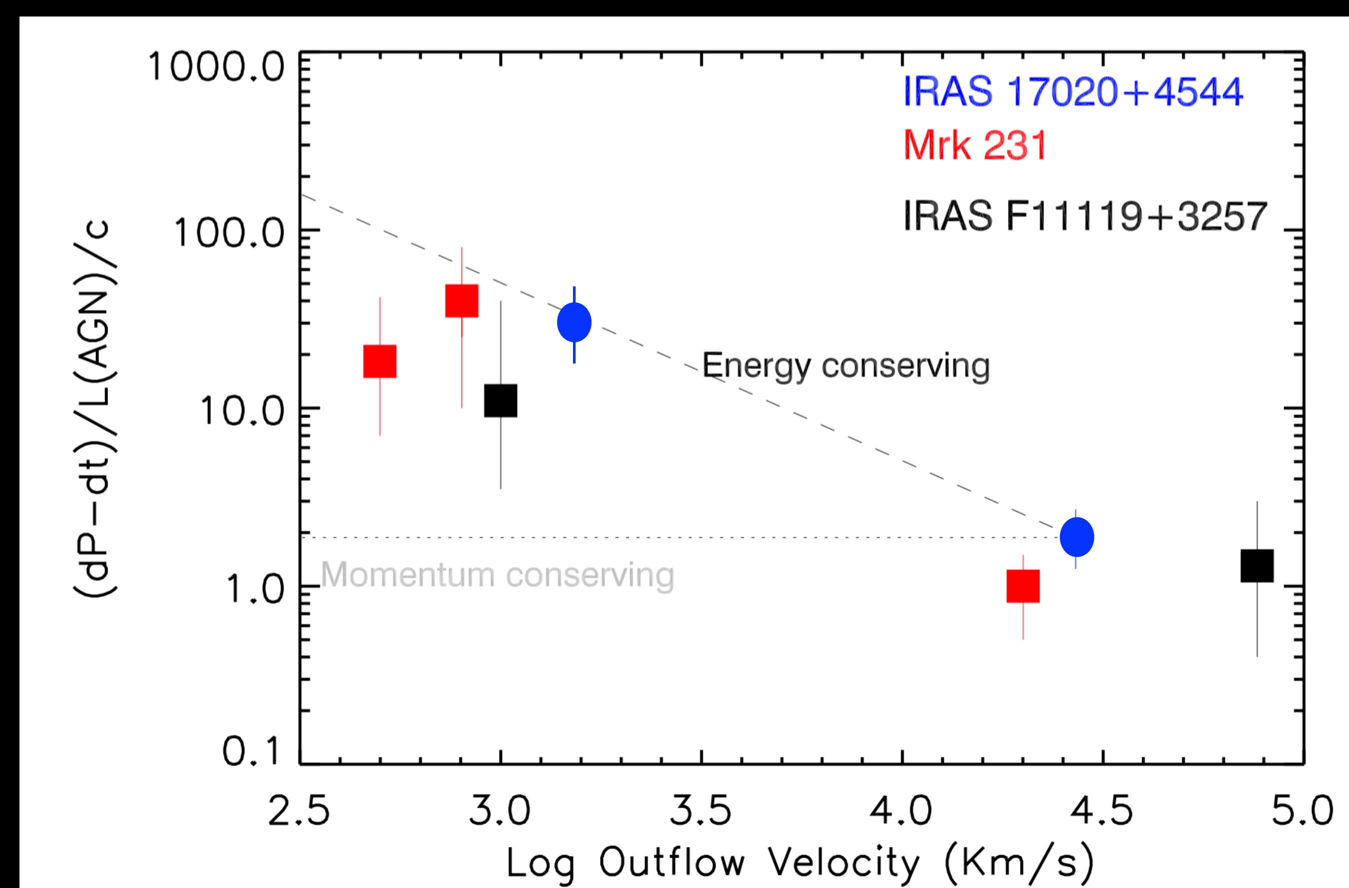


How many source of uncertainties ? **Many!**

- **Mass outflow rates (outflow velocity, M[CO], CO-to-H2 conversion factor)**
- **Wind spatial extent and geometry**
- **Bolometric luminosity**

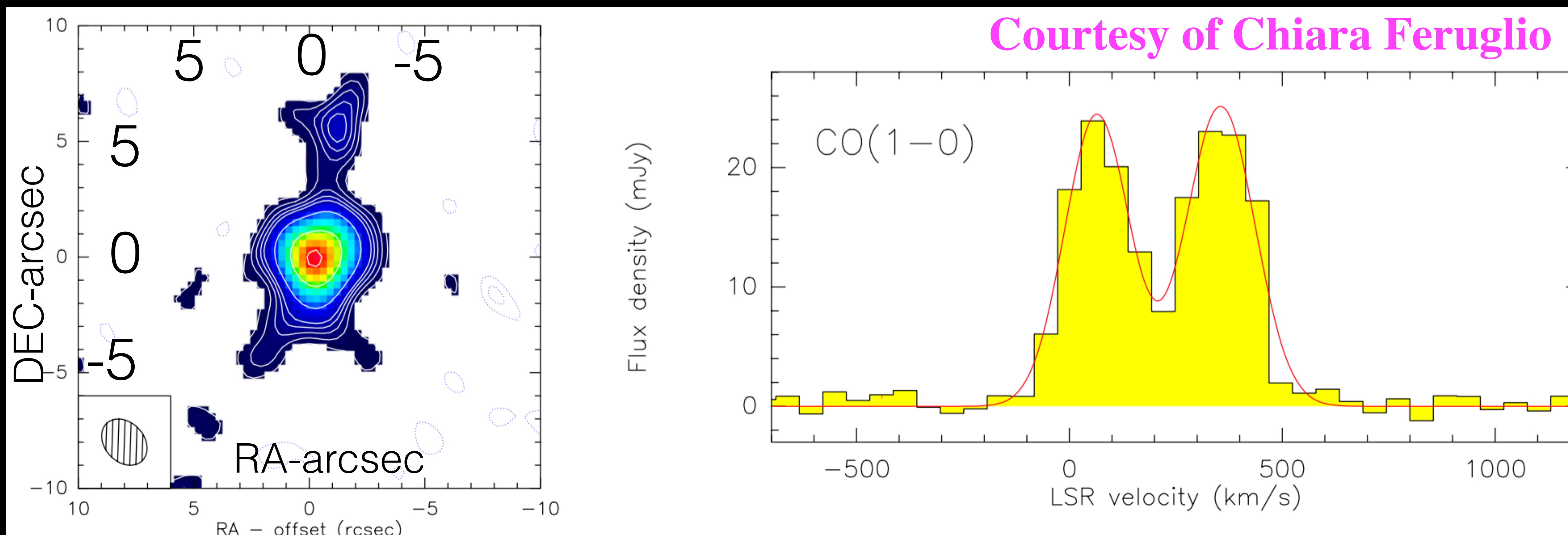
….mitigated in our new interferometry data

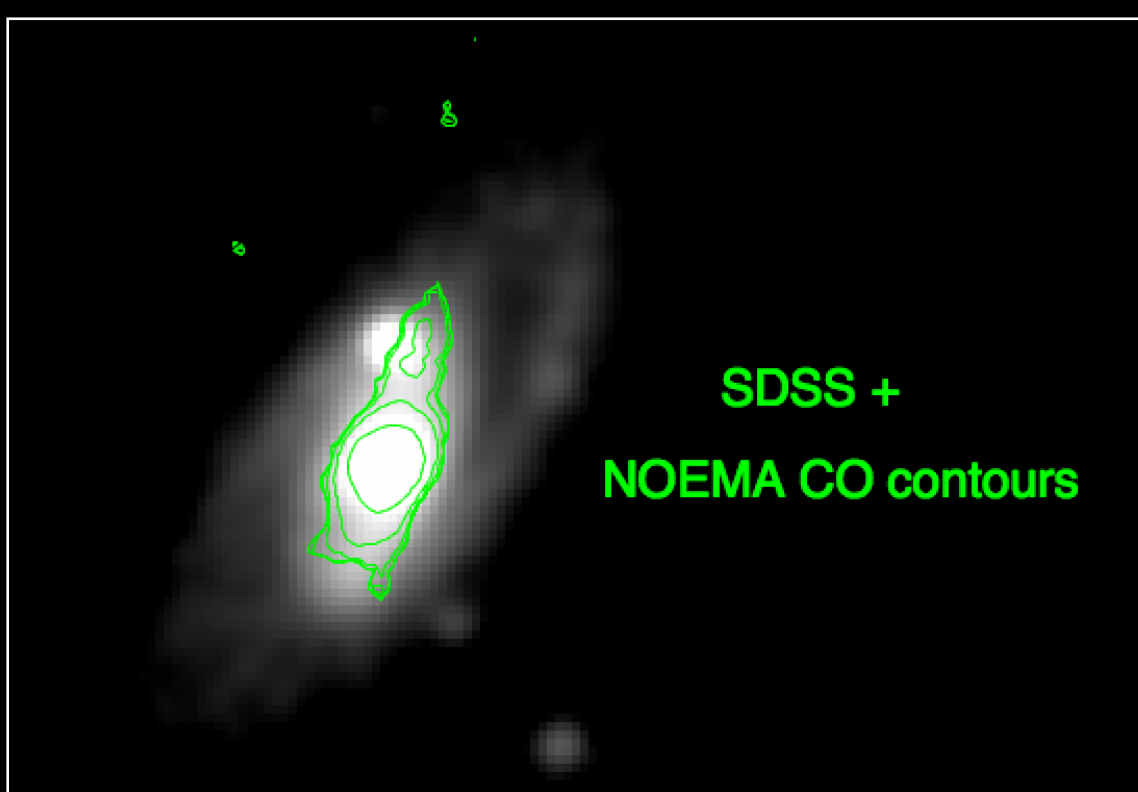
NOEMA PdB Interferometer



Preliminary

IRAS17: NOEMA interferometry view of molecular gas from the galaxy



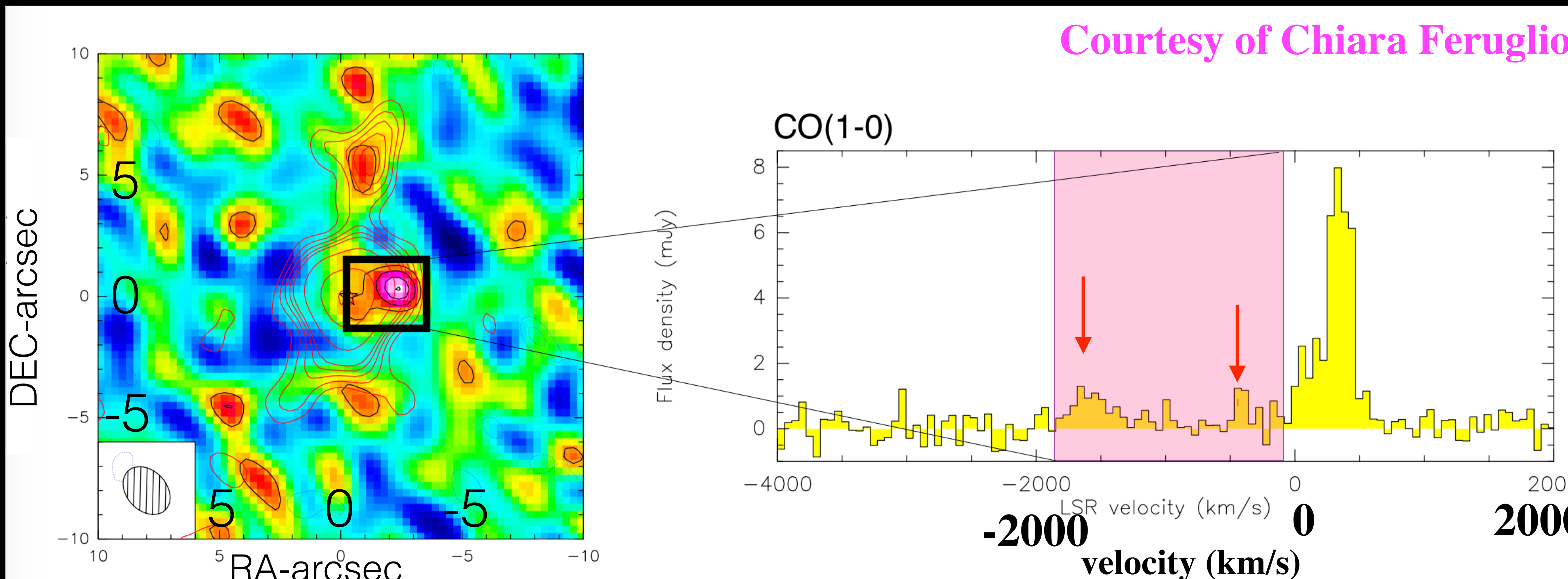


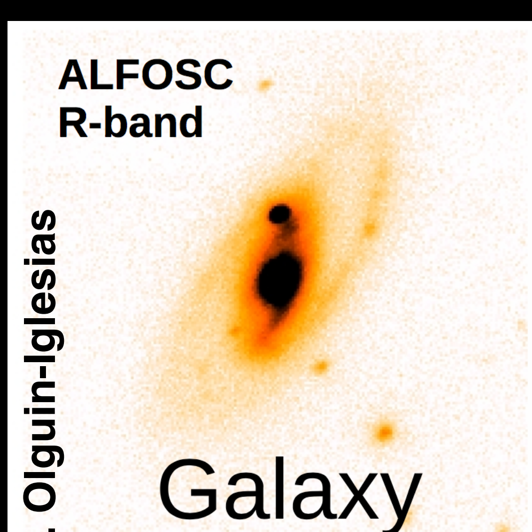
- **Velocity integrated CO 1-0 emission map**
- **Line integrated on vel range of 760 km/s (no outflow, CO distribution consistent with rotation in the galaxy)**
- **Spectrum extracted from the region with signal above 2σ**

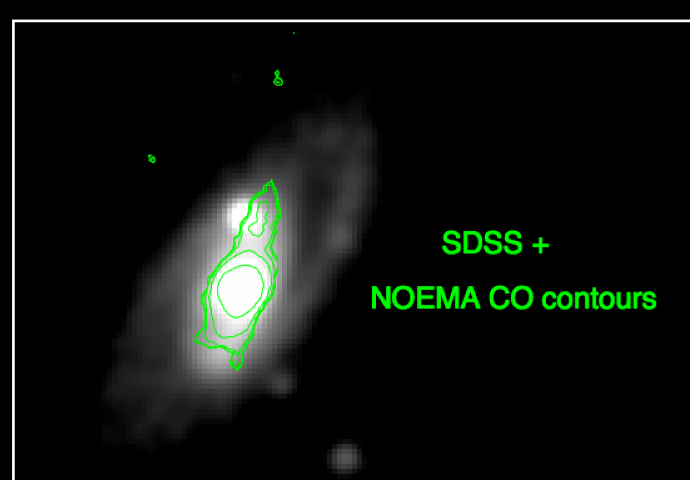
Q. Salomé in prep.

Preliminary

IRAS17: NOEMA interferometry view of the molecular outflow







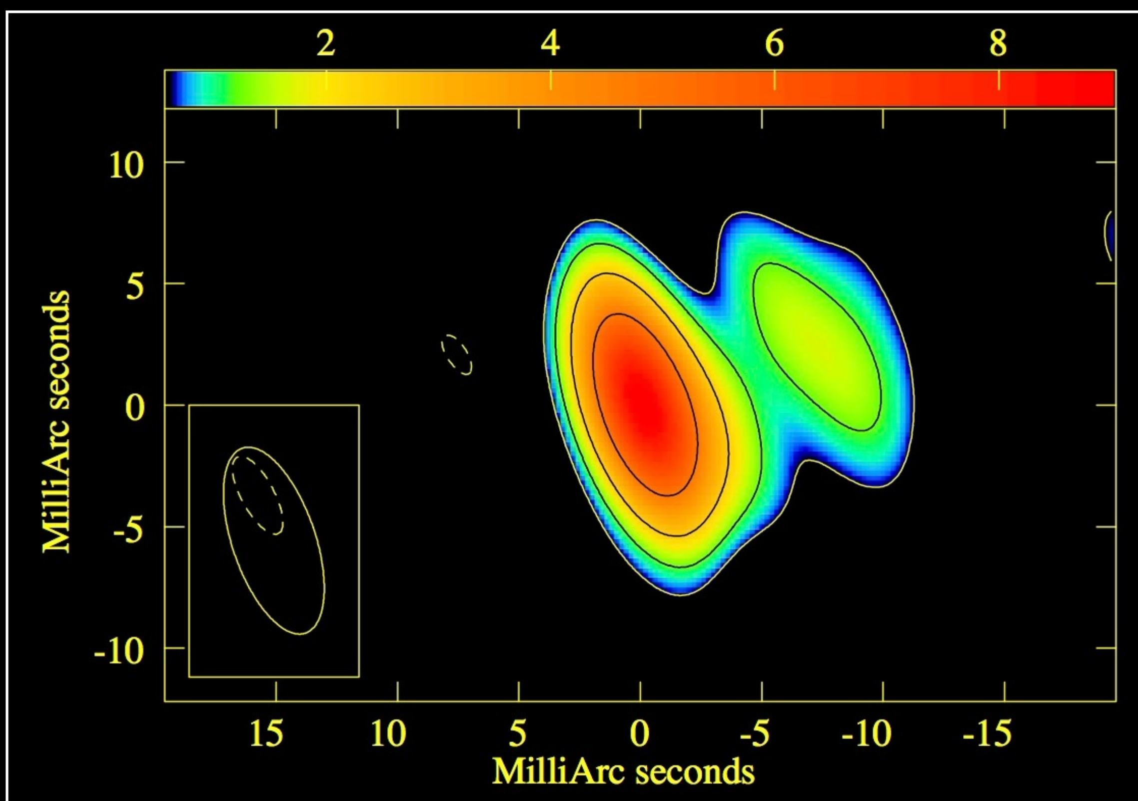
- Line integrated on a velocity range of ~1600 km/s
- Outflow in the velocity integrated CO map detected at 6.5σ, spatial scale ~3kpc
- Possibly two velocity components

Longinotti+ in prep.

Radio Properties of IRAS17: consistent with shocks?

Giroletti et. al 2017 A&A

VLBA image @8 GHz



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

VLBA Observations in 2000 and 2014

Compact bright core, secondary fainter component

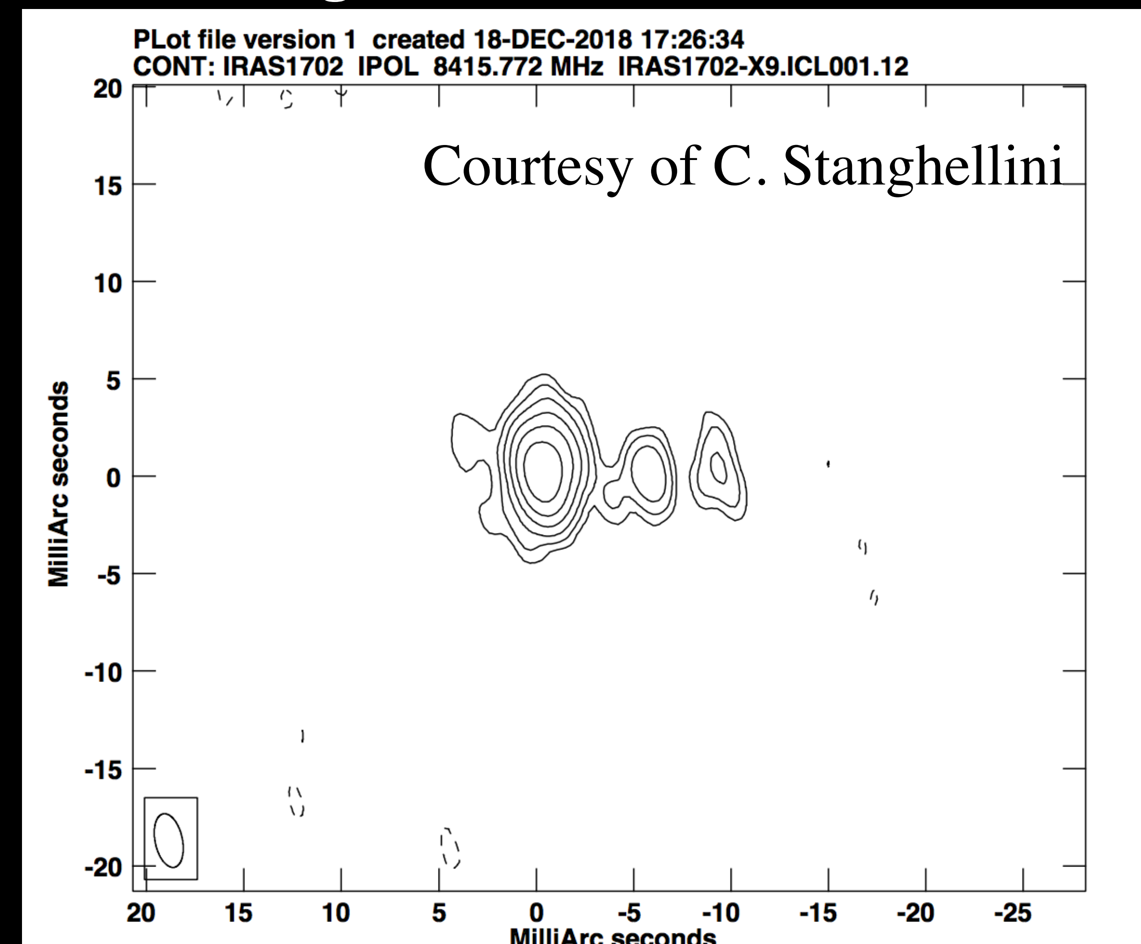
Steep spectral index possibly synchrotron (shocks?)

Elongated jetted structure /outflow at ~10 pc scale

Possible connection with X-ray outflow?

Ongoing work…

VLBA image @8.4 GHz



VLBA Observations in 2017

Source resolved in 3 components

No clear core detected

No expansion detected

Radio source on RQ—RL threshold

Origin of radio emission still unclear

Preliminary

HST/COS view of IRAS17: any UFO?

November 2018, 9 orbits

Ongoing work by Debopam Som and Yair Krongold

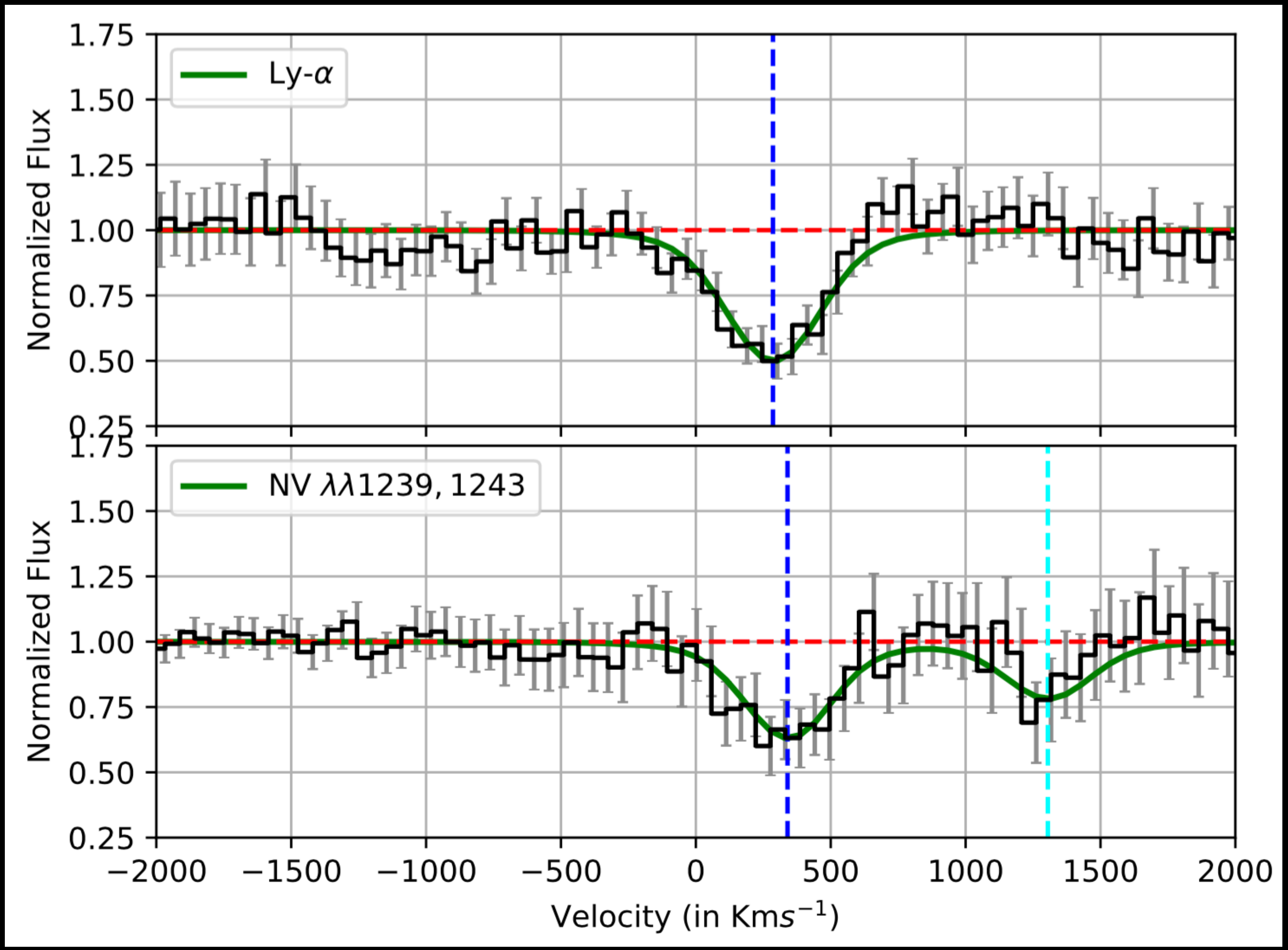
Voigt profile fits (1σ error bars)

Absorption near the inflow velocity of ~300 km s^{-1} was detected clearly in the Lyα and NV transitions. Agreement with X-ray slow winds in shocked outflow?

Other weaker lines are possibly present at -1000 and 1700 km/s

No detection of UFO UV counterpart: possibly too shallow (low ionization X-ray winds have low NH), or non-simultaneity

(XMM 2014, Chandra 2016-2017, COS 2018)



Systematic search in UV spectra of X-ray UFO sources: negative result

Kriss+2018

Conclusions and outlook

The Narrow Line Seyfert Galaxy IRAS17020+4544 has proved so far to be an excellent laboratory to dissect, track and possibly understand the effect of a powerful nuclear X-ray wind during its encounter and journey through the interstellar medium

This extensive multi-wavelength campaign was addressed to follow the evolution of the shocked outflow initiated by this wind in its propagation at larger scale

We will seek other observations to corroborate the outflow properties (IFU for the ionized gas, additional radio and X-rays data, and future X-rays High-res instruments)

…but other sources? → **"SUBWAYS" Poster #405 by Marcella Brusa**

Thanks for your attention!