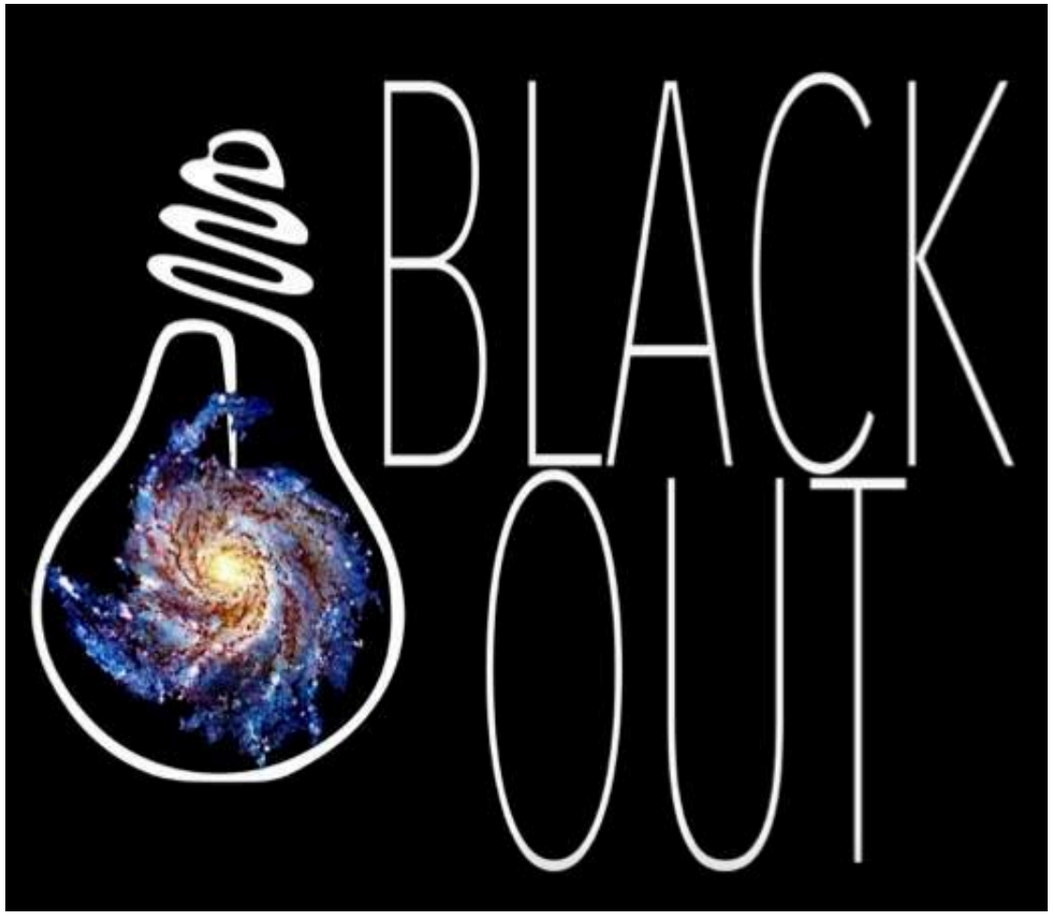
PRIN 2017

“Black hole winds and the baryon life cycle of galaxies:
the stone-guest at the galaxy evolution supper”

2017PH3WAT

03/11/2019 - ~~03/11/2022~~ 03/05/2023



PRIN 2017

“Black hole winds and the baryon life cycle of galaxies: the stone-guest at the galaxy evolution supper”

2017PH3WAT

03/11/2019 - ~~03/11/2022~~ 03/05/2023

PERSONALE DIFA + INAF-OAS

Marcella Brusa (DIFA)
Cristian Vignali (DIFA)
Giorgio Lanzuisi (OAS)
Massimo Cappi (OAS)
Mauro Dadina (OAS)
Angela Malizia (OAS)

Matilde Mingozzi (DIFA)
Ilaria Ruffa (DIFA)

THE PROJECT: OBJECTIVES AND WORK PACKAGES

1) Unbiased census of BH winds

2) Physics of multiphase gas

3) Local BH mass functions

4) BH wind models

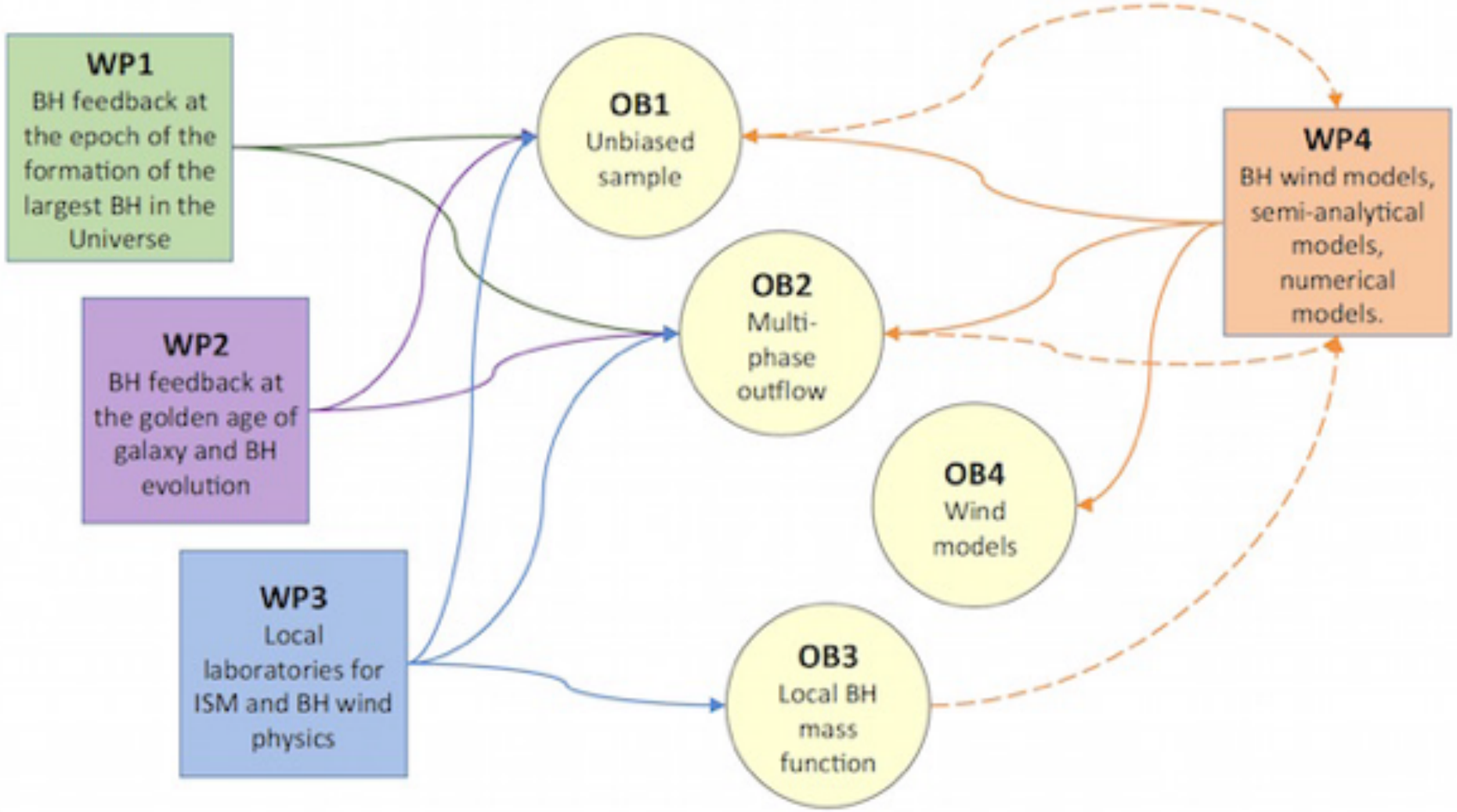
<u>in 4 WORK PACKAGES</u>

WP1: BH feedback at the epoch of the formation of the largest BH in the Universe

WP2: BH feedback at the golden age of galaxy and BH evolution

WP3: local laboratories for ISM and BH wind physics

WP4: BH wind models, emi-analytical models, numerical models



THE PROJECT: TEAM INVOLVEMENT OAS-UNIBO

	Staff involved
WP1	**Task 1.1 Leader: Piconcelli**, Participants: **RTD1 (analysis MUSE and ALMA data)**, Fiore, Grazian, Marconi, Venturi, Brusa, Vignali, La Franca,Duras
	Task 1.2 Leader: Fiore, Participants: **RTD1 (analysis ALMA data)**, **PostDoc2 (analysis ALMA data)**, Marconi, Piconcelli, Grazian, Gallerani
WP2	**Task 2.1 Leader: Marconi**, Participants: **PostDoc2 (analysis SINFONI data)**, Venturi, Fiore, Piconcelli, Mannucci, Cresci, Brusa, Vignali, Lanzuisi
	Task 2.2 Leader: Brusa, Participants: **RTD3 (analysis ALMA and mw data)**, Vignali, Mingozzi, Lanzuisi, Fiore, Piconcelli, Marconi, Cresci, Mannucci
WP3	**Task 3.1 Leader: Cresci**, Participants: **PostDoc1 (analysis ALMA and MUSE data)**, Marconi, Mannucci, Fiore, Piconcelli
	Task 3.2 Leader: Fiore, Participants: **RTD2 (analysis ALMA and MUSE data)**, Malizia, Piconcelli, Cresci, Marconi, Prandoni
	Task 3.3 Leader: Prandoni, Participants: Ruffa, Brusa, Lanzuisi, Fiore, Cresci, Marconi
	Task 3.4 Leader: La Franca, Participants: **RTD4 (BH mass functions)**, Marinucci, Bianchi, Matt, De Rosa, Cappi, Dadina, Malizia, Fiore, Brusa, Lanzuisi, Marconi, Zaino, Middei, Duras
WP4	**Task 4.1 Leader: Marinucci**, Participants: **RTD4 (BH nuclear wind models, development & comparison with observations)**, Bianchi, Matt, De Rosa, Cappi, Dadina, Zaino, Middei
	Task 4.2 Leader: Menci, Participants: Fiore, Piconcelli, Grazian, Gallerani, Marconi, Brusa, Marinucci.
	Task 4.3 Leader: Gallerani, Participants: **PostDoc3 (High-resolution, RT simulations with BH feedback)**, Orofino, Decataldo, Fiore, Marconi, Brusa, Allevato

BH feedback at the golden age

local laboratories for BH physics and winds

← Ionised gas, SINFONI/SUPER et al.

← molecular gas, ALMA/SUPER et al.

← MAGNUM

← IBISCO

← EIFFEL

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WP2	**Task 2.1 Leader: Marconi**, Participants: **PostDoc2 (analysis SINFONI data)**, Venturi, Fiore, Piconcelli, Mannucci, Cresci, Brusa, Vignali, Lanzuisi
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BH feedback at the golden age

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WP3:
NEW TASK Task 3.5
SUBWAYS

THE PROJECT: TEAM INVOLVEMENT OAS-UNIBO

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WP2	**Task 2.1 Leader: Marconi**, Participants: **PostDoc2 (analysis SINFONI data)**, Venturi, Fiore, Piconcelli, Mannucci, Cresci, Brusa, Vignali, Lanzuisi
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WP3:
NEW TASK Task 3.5
SUBWAYS

PostDoc	INAF	OARoma
PostDoc	INAF	OATs
PostDoc	UniBo	
PostDoc	RomaTRE	/ASI

PostDoc1: INAF OAA
PostDoc2: UniFI
PostDoc3: SNS

Post-doc@UNIBO / PRIN MIUR
Federica Ricci (1 Oct. 2020/1 Oct. 2022)

Post-doc@UNIBO / ASI+INAF
Gabriele Matzeu (1 Sept. 2020/1 Sept. 2022)

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WP3:
NEW TASK Task 3.5
SUBWAYS

PostDoc	INAF	OARoma
PostDoc	INAF	OATs
PostDoc	UniBo	
PostDoc	RomaTRE	/ASI

PostDoc1: INAF OAA
PostDoc2: UniFI
PostDoc3: SNS

Post-doc@UNIBO / PRIN MIUR
Federica Ricci (1 Oct. 2020/1 Oct. 2022)

Post-doc@UNIBO / ASI+INAF
Gabriele Matzeu (1 Sept. 2020/1 Sept. 2022)

+ PhD students involved: **Bertola, Costanzo, D'Amato, Pensabene**
+ staff INAF-OAS: **Comastri, Decarli, Gilli, Mignoli, Gaspari**

ARCETRI MEETING / first PART: OBJECTIVES

1) Unbiased census of BH winds

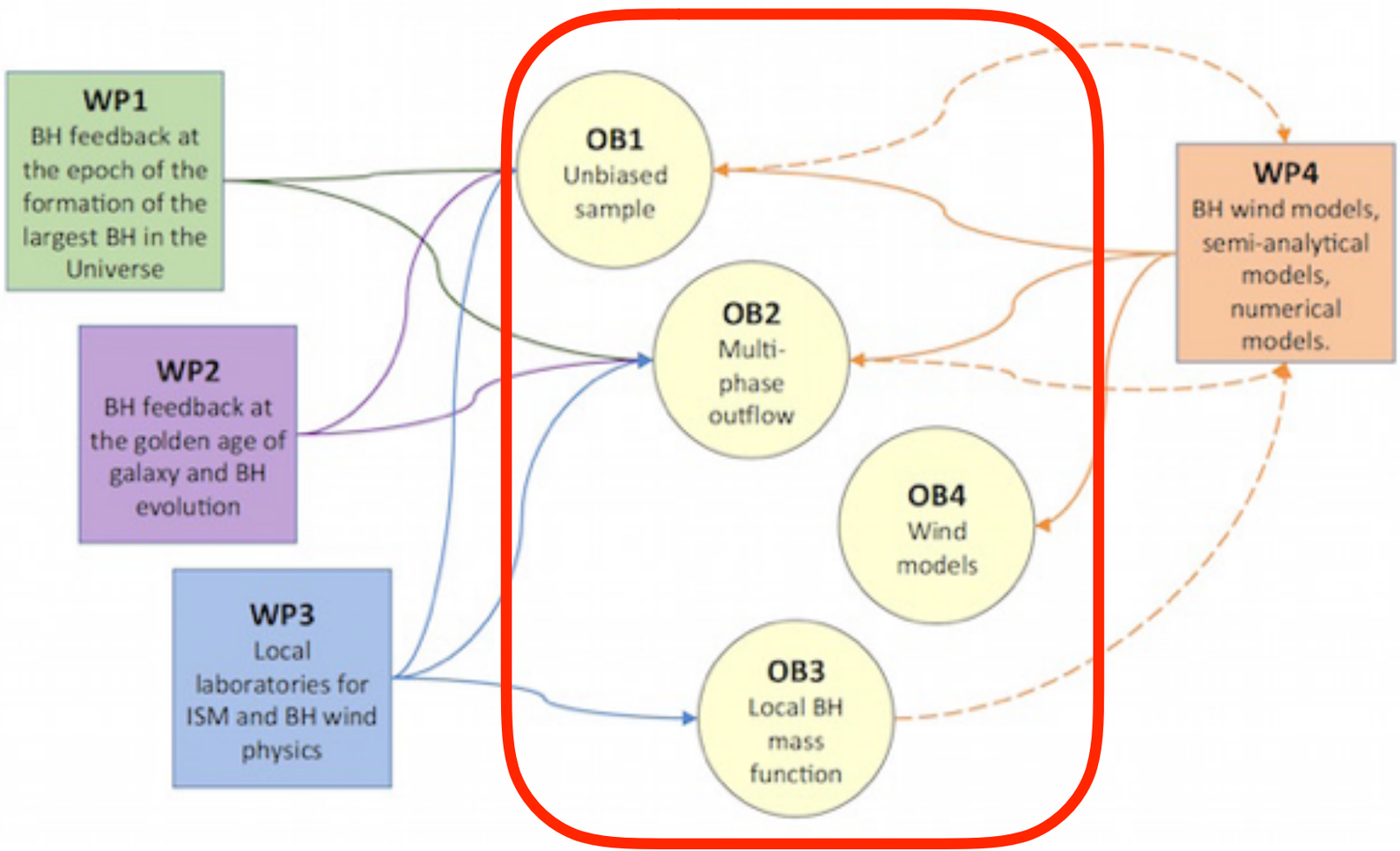
2) Physics of multiphase gas

3) Local BH mass functions

4) BH wind models

OBJECTIVES

Domanda 1:
Ci sono stati progressi in questi due anni?
qualcuno di questi obiettivi e' stato raggiunto,
o comunque c'e' stato lavoro per raggiungerlo?



ARCETRI MEETING / first PART: OBJECTIVES

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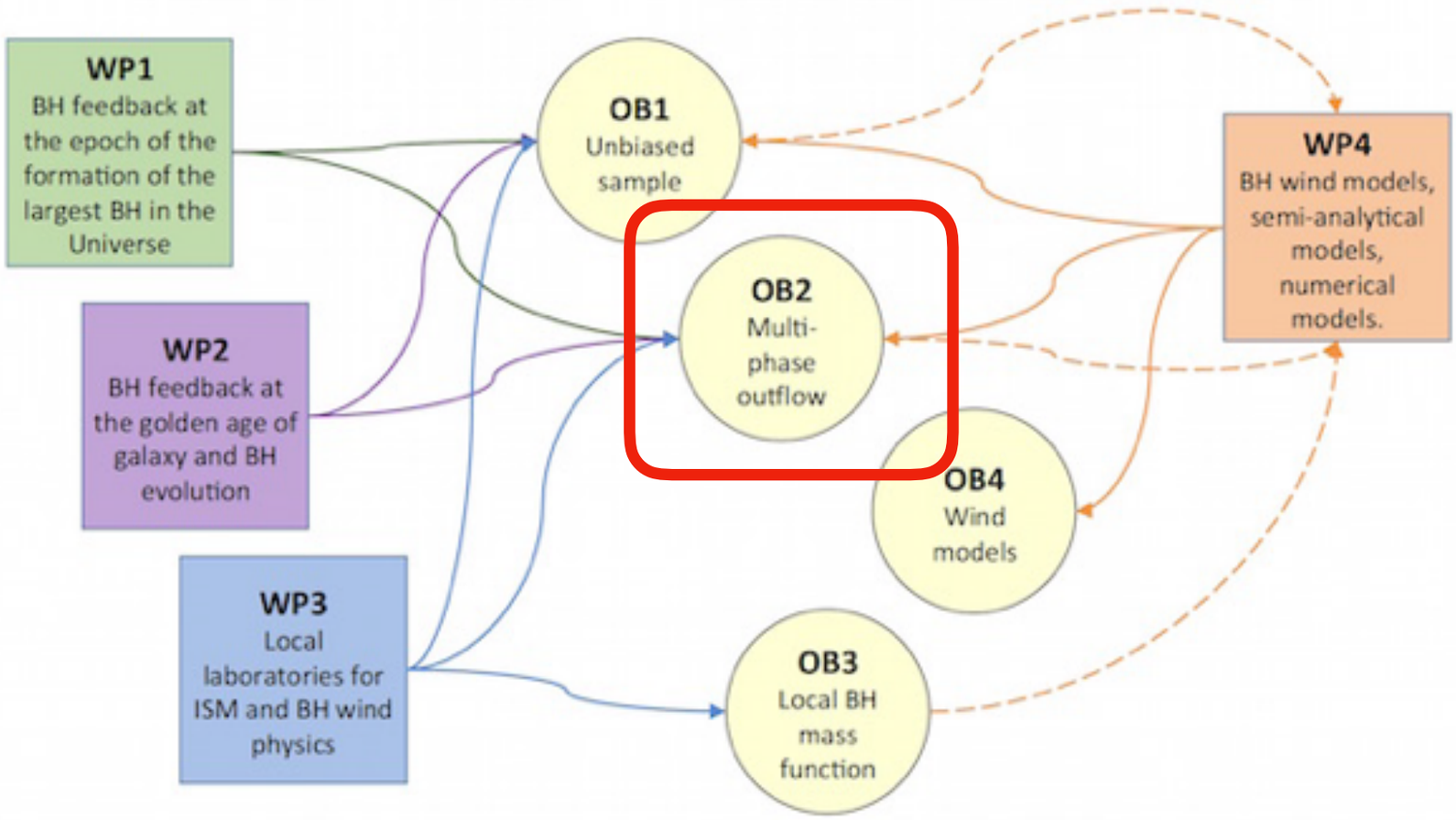
progresses (Bologna-led, incomplete list):

- investigation of multi-phase outflows in single sources:
  XID2028 (Brusa+2018, A&A)
  Mrk848 (Perna+2019, A&A)
  HS0810 (Chartas+2020, MNRAS)
  see also PDS456 (Bischetti+2019, A&A)

- investigation of multi-phase outflows in samples:
  SUBWAYS program (XMM and mw data coming;
  Brusa+, Bianchi +, Feruglio+,Panessa+, Kriss+)

- investigation of indirect evidence of AGN feedback/outflows:
  gas content of obscured AGN at z>1
  (Brusa+2018, Perna+2018, Circosta+2020, Bischetti+2020)
  positive feedback from a radio galaxy at z~1.7 (Gilli+2019)

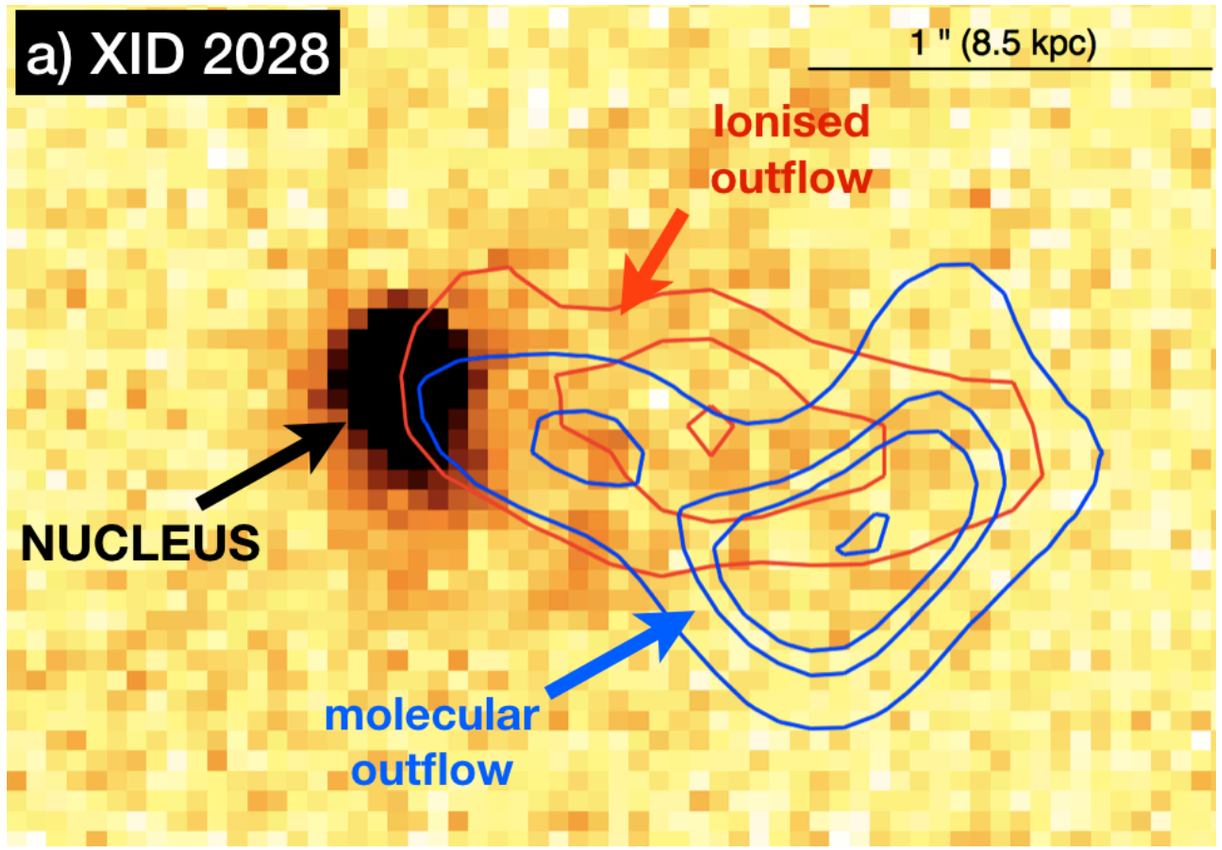


MULTIPHASE OUTFLOWS IN SINGLE SOURCES

XID2028 from XMM-COSMOS (*Brusa+2010, Brusa+2015)*

Brusa+2018

The molecular outflow is co-spatial with the ionized outflow



Total mass outflow rate: ~500-800 Msun/yr

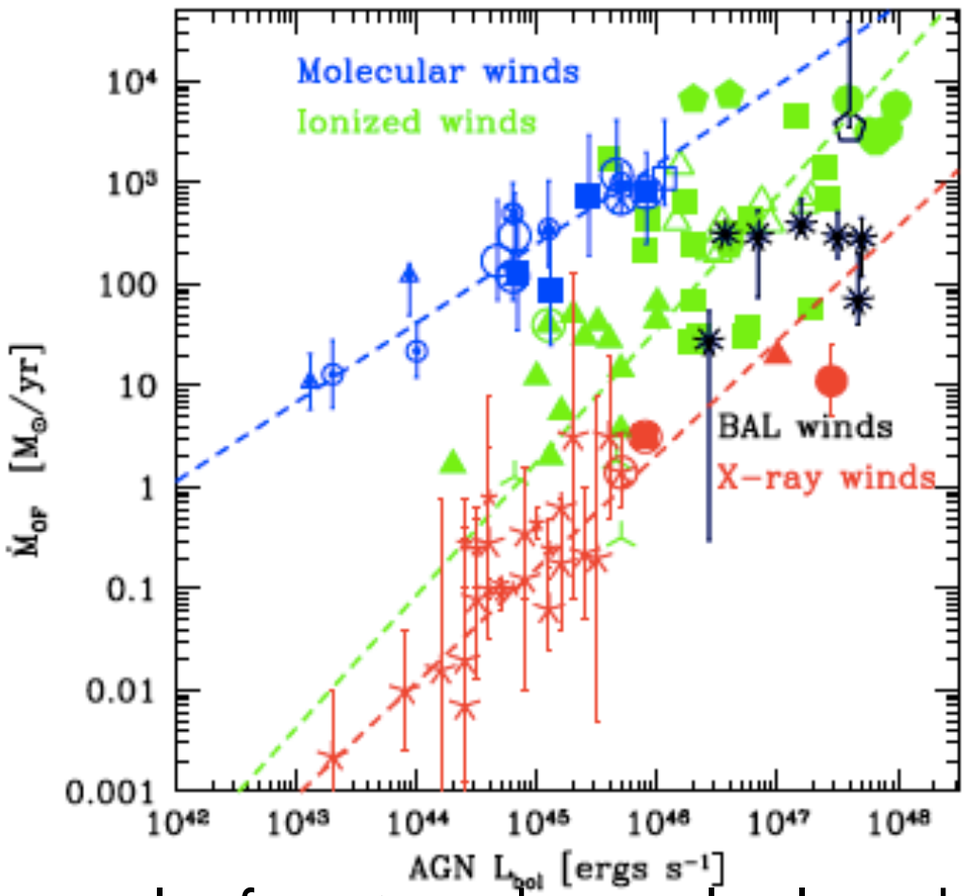
$\dot{M}_{ion}$ ~300 Msun/yr

$\dot{M}_{neu}$ ~80 Msun/yr

$\dot{M}_{mol}$ ~50-350 Msun/yr

(Largest uncertainty: α_{co} (0.13-0.8); see Richings&F-G18)

Fiore+2017



example of a system where molecular and ionised outflow components may be comparable

Is this the rule for all the luminous *obscured* systems?

ALMA Cycle 6 data of other 2 targets with powerful ionised outflows (XID5321, XID5395)

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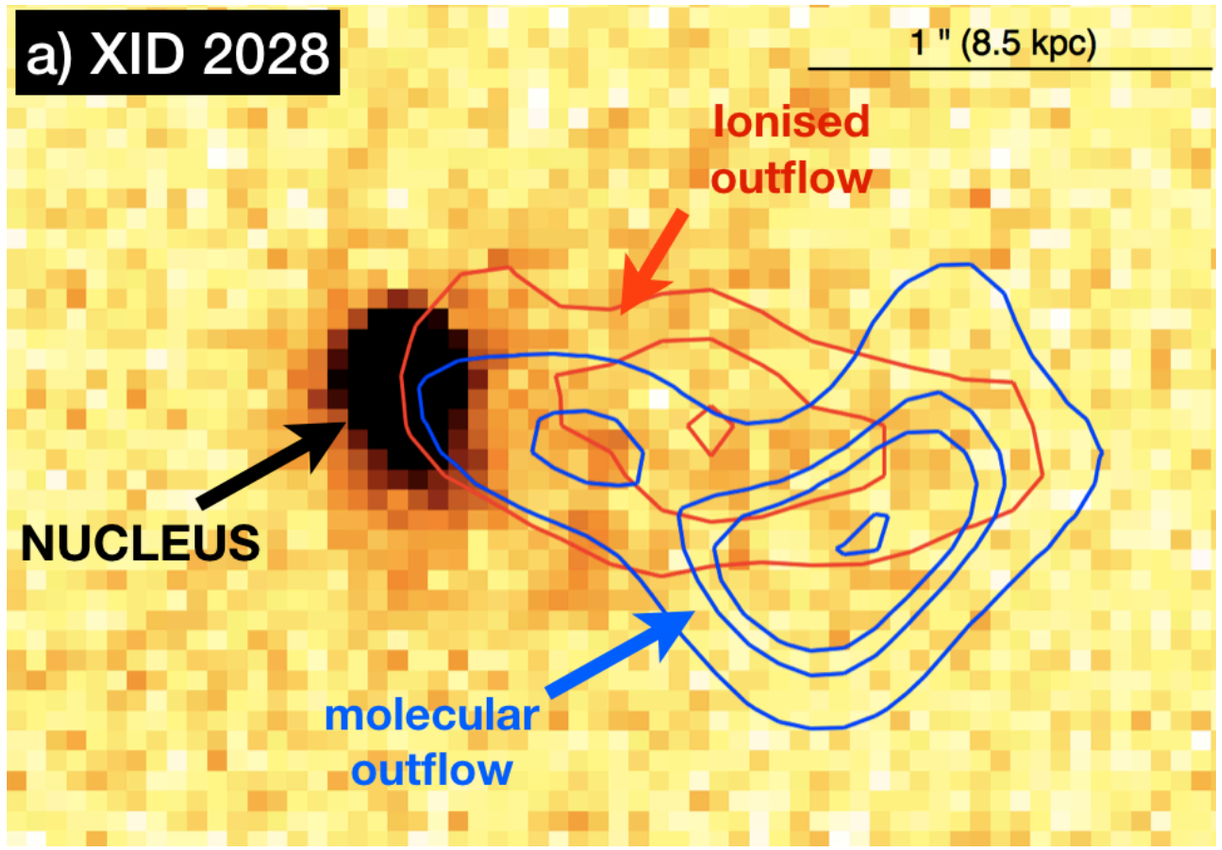

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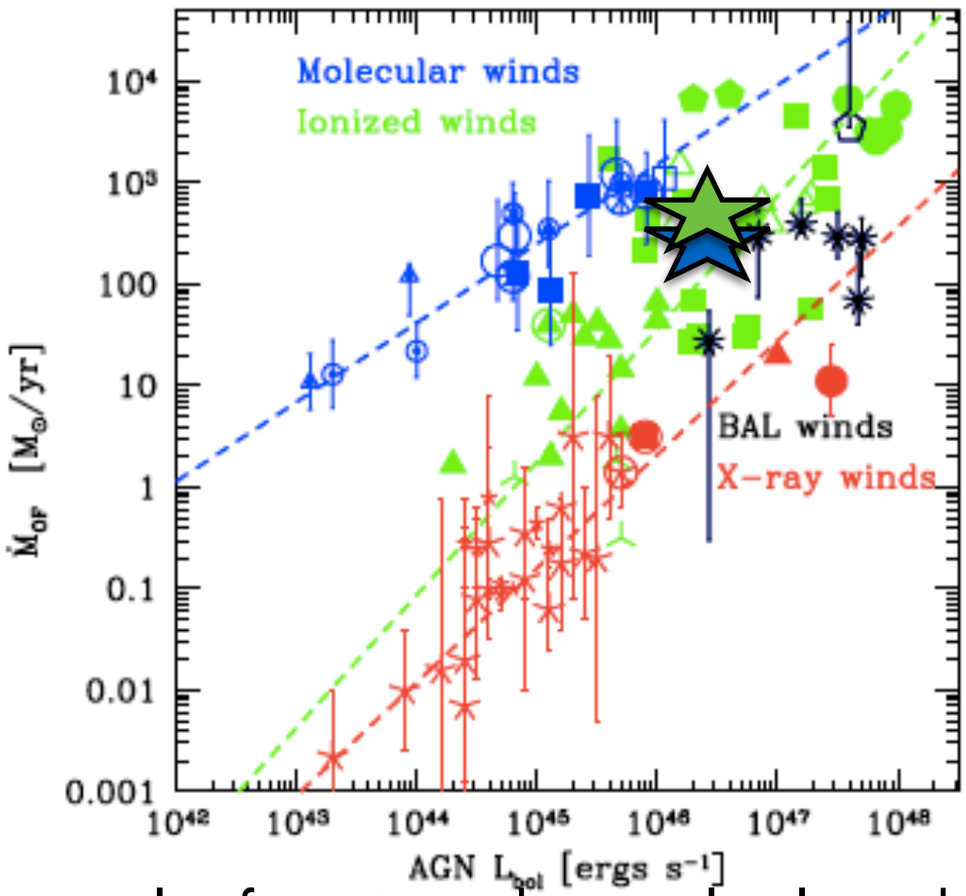

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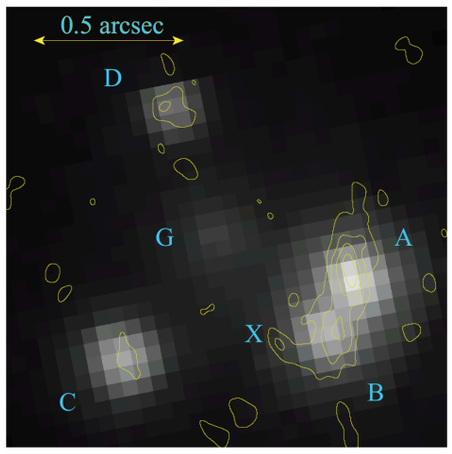
MULTIPHASE OUTFLOWS IN SINGLE SOURCES

Linking the small scale relativistic winds and the large scale molecular outflows in the $z = 1.51$ lensed quasar HS 0810+2554

G. Chartas,[1⋆] E. Davidson,[1] M. Brusa,[2,3] C. Vignali,[2,3] M. Cappi,[3] M. Dadina,[3]
G. Cresci,[4] R. Paladino,[5] G. Lanzuisi,[3] and A. Comastri[3]
[1] *Department of Physics and Astronomy, College of Charleston, Charleston, SC, 29424, USA*
[2] *Dipartimento di Fisica e Astronomia dell'Università degli Studi di Bologna, via P. Gobetti 93/2, 40129 Bologna, Italy*
[3] *INAF, Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, via P. Gobetti 93/3, 40129 Bologna, Italy*
[4] *INAF, Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, I-50125 Firenze, Italy*
[5] *INAF, Istituto di Radioastronomia, via Piero Gobetti 101, I-40129 Bologna, Italy*

2mm continuum, 0.1" vs. HST
4 images (A.B,C,D)



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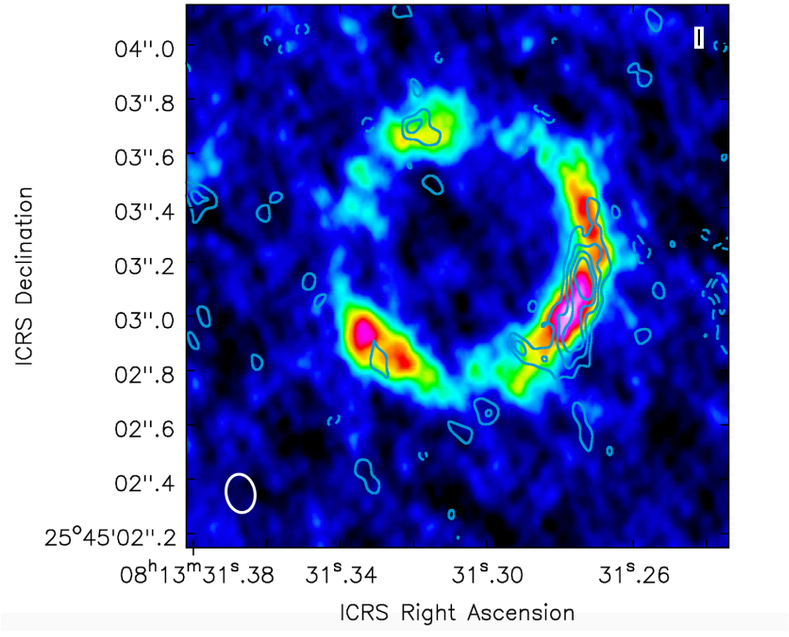
CO(3-2) + 2mm continuum, 0.1"
(also available CO(2-1))



Source plane reconstruction of flux and velocity maps
Compact. Rotating disk!

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CO(3-2) + 2mm continuum, 0.1"
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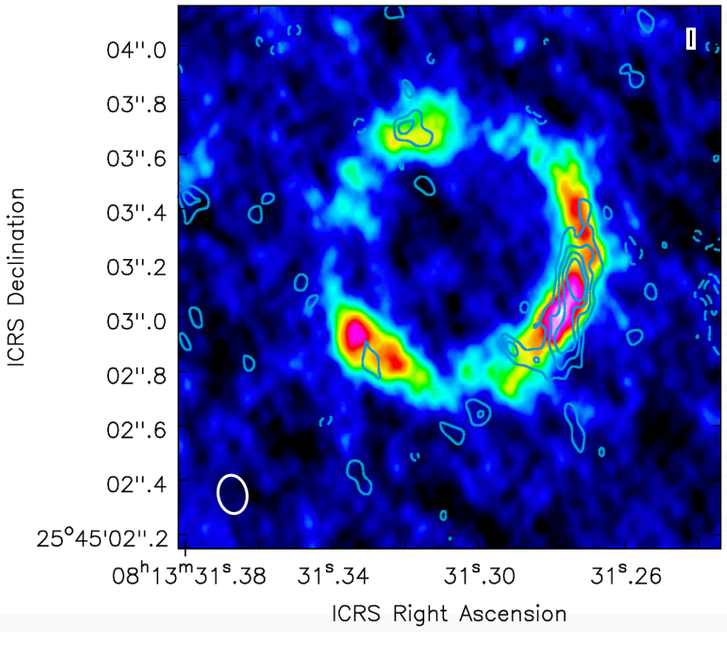

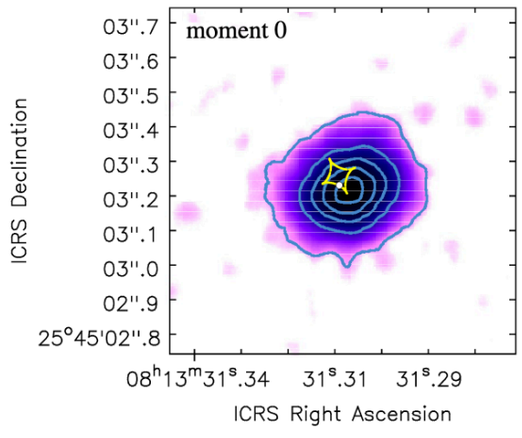

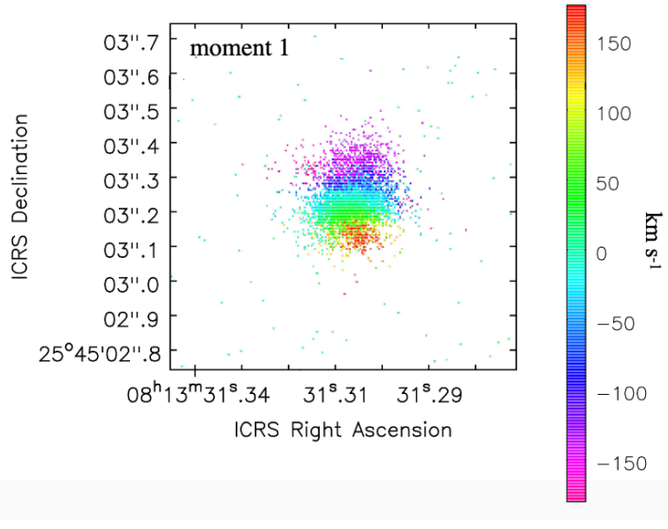

Source plane reconstruction of flux and velocity maps
Compact. Rotating disk!

MULTIPHASE OUTFLOWS IN SINGLE SOURCES

Linking the small scale relativistic winds and the large scale molecular outflows in the $z = 1.51$ lensed quasar HS 0810+2554

G. Chartas,[1⋆] E. Davidson,[1] M. Brusa,[2,3] C. Vignali,[2,3] M. Cappi,[3] M. Dadina,[3] G. Cresci,[4] R. Paladino,[5] G. Lanzuisi,[3] and A. Comastri[3]

[1] *Department of Physics and Astronomy, College of Charleston, Charleston, SC, 29424, USA*
[2] *Dipartimento di Fisica e Astronomia dell'Università degli Studi di Bologna, via P. Gobetti 93/2, 40129 Bologna, Italy*
[3] *INAF, Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, via P. Gobetti 93/3, 40129 Bologna, Italy*
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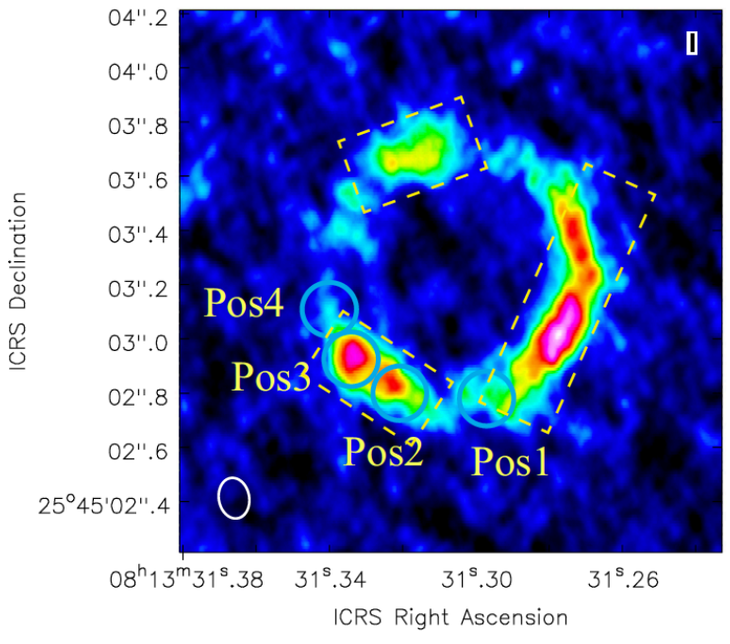
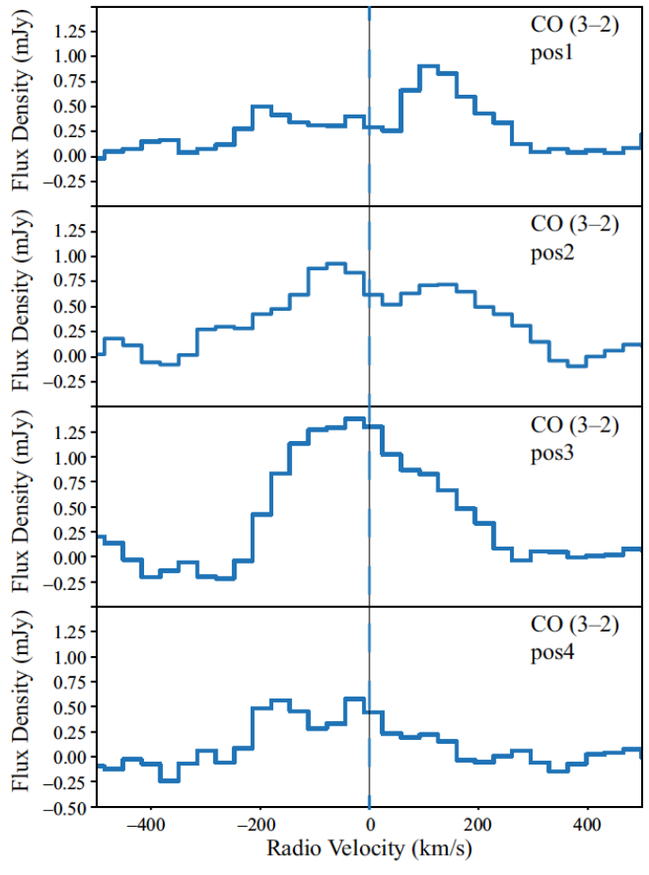
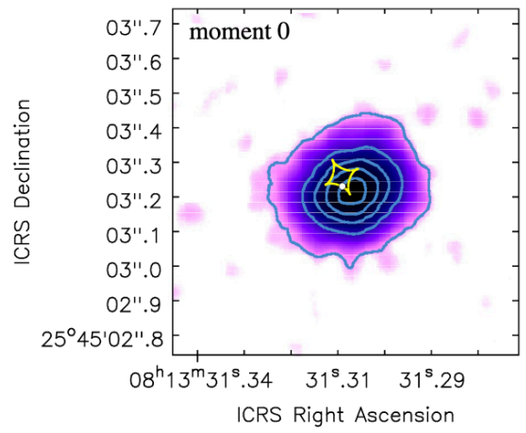
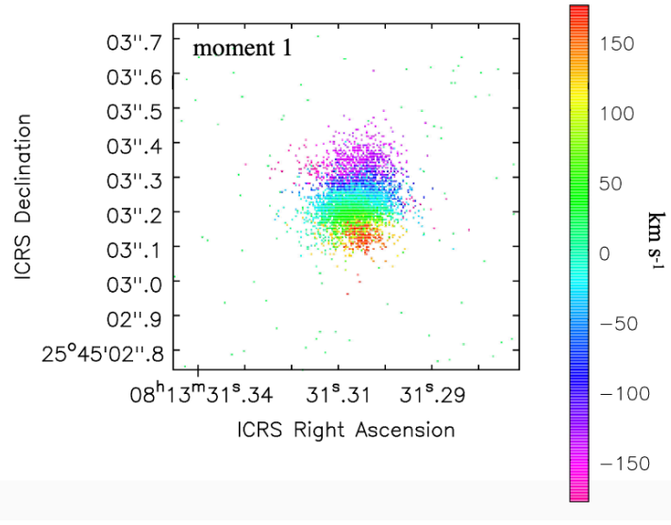




Spectra extracted from four different locations on the Einstein Ring **near image C.**
Doppler shift clearly visible





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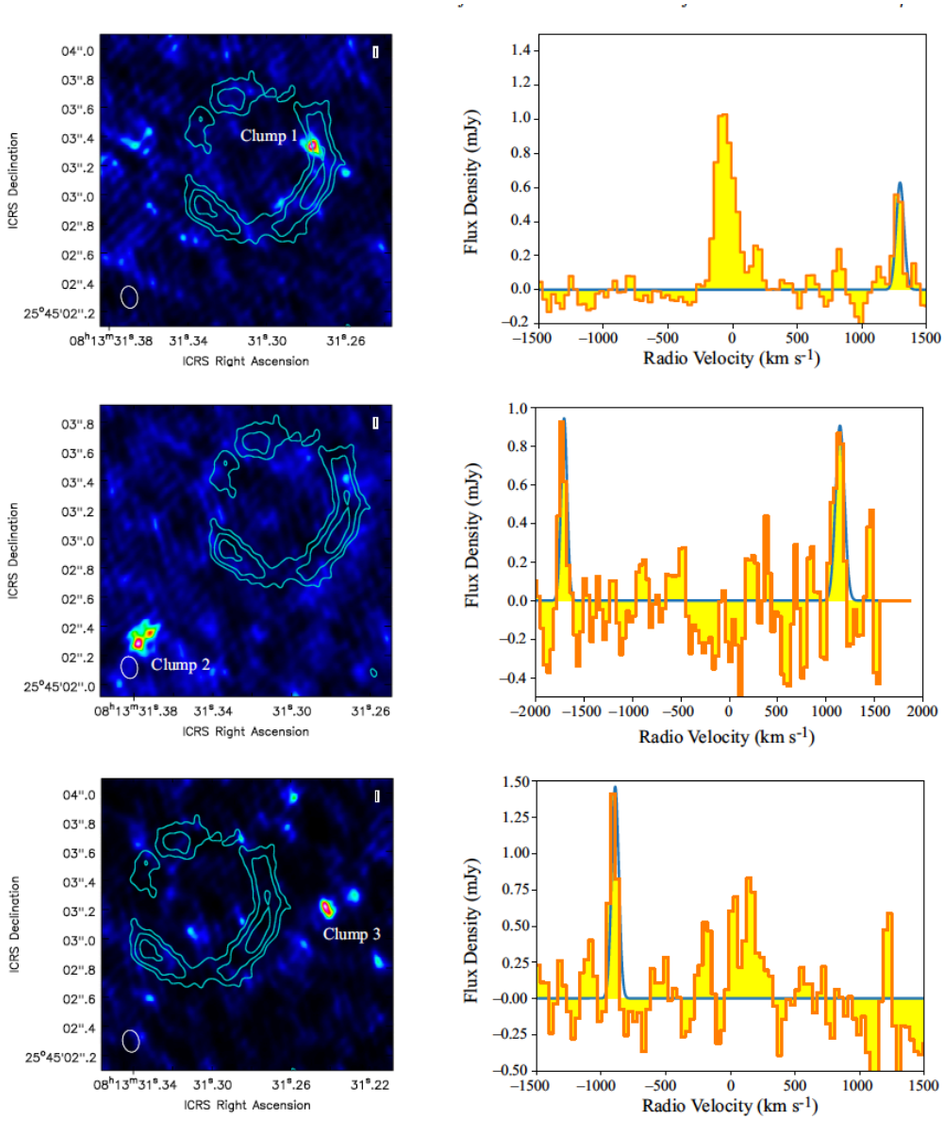
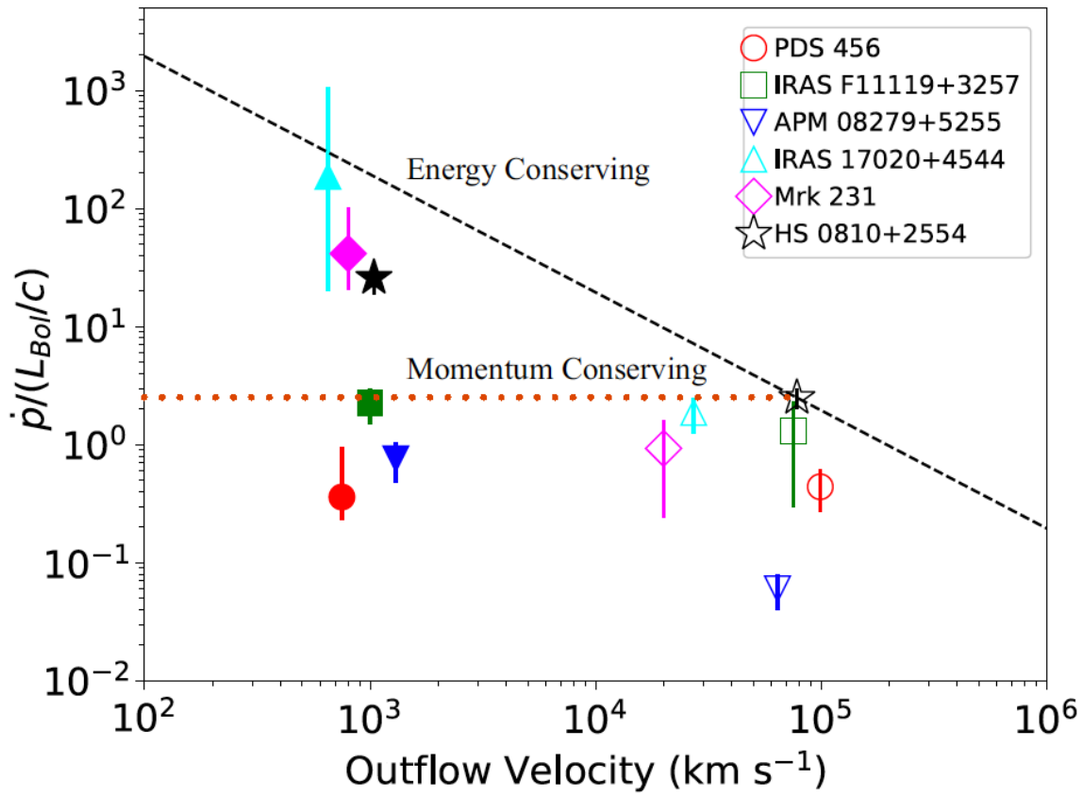


CO(3-2) redshifted/blueshifted clumps —> outflows

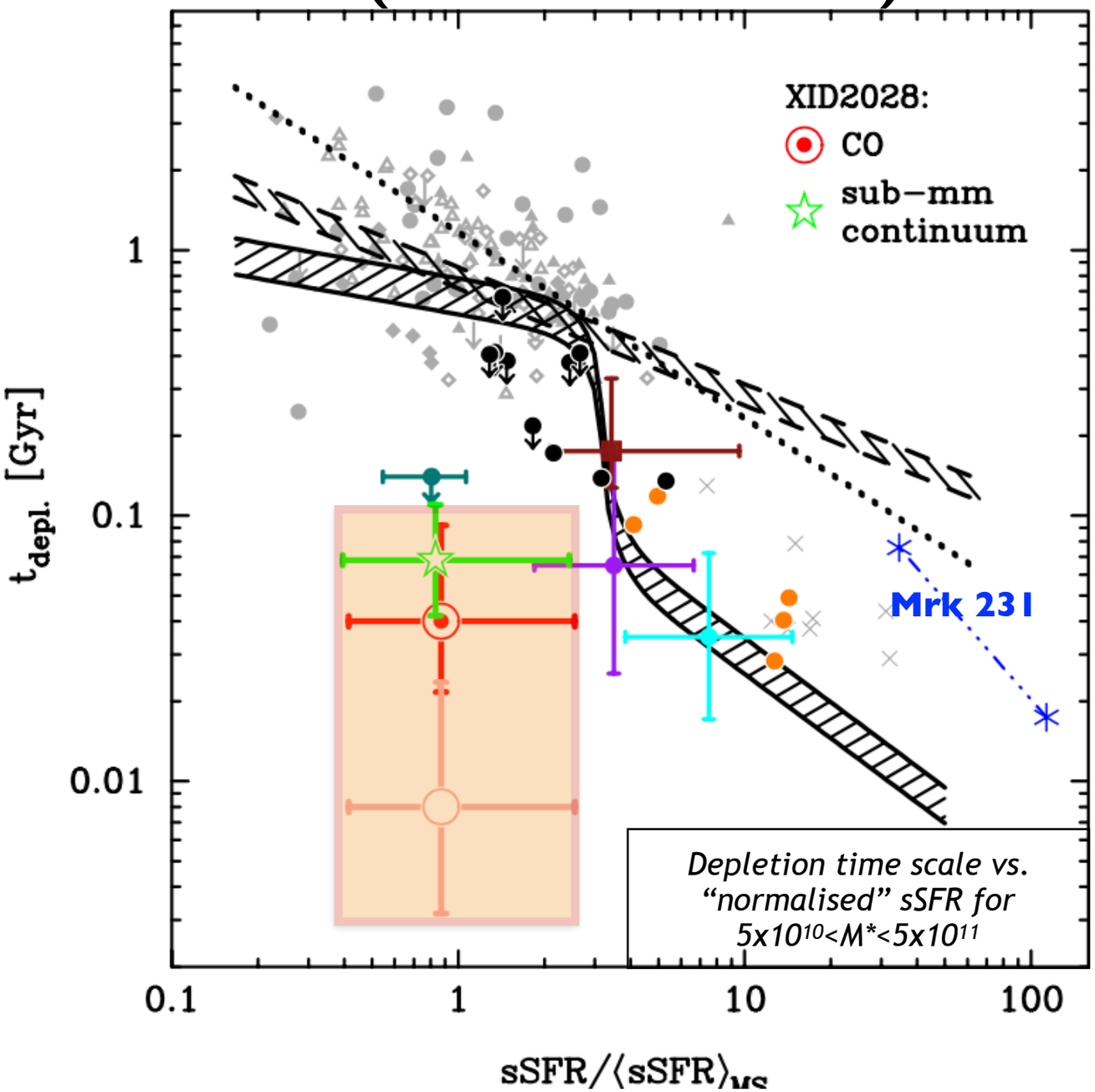


See Giulia Tozzi (Arcetri) work on ionised outflow

INDIRECT EVIDENCE OF AGN FEEDBACK/OUTFLOWS: GAS FRACTION

XID2028

Brusa et al. 2018 (see Brusa+2015 PdBI)



Depletion time scale 10x below that of inactive galaxies of similar SFR/M*

literature scaling relations
($z=1.6$ & $10.7<\log(M_*/M_\odot)<11.6$):

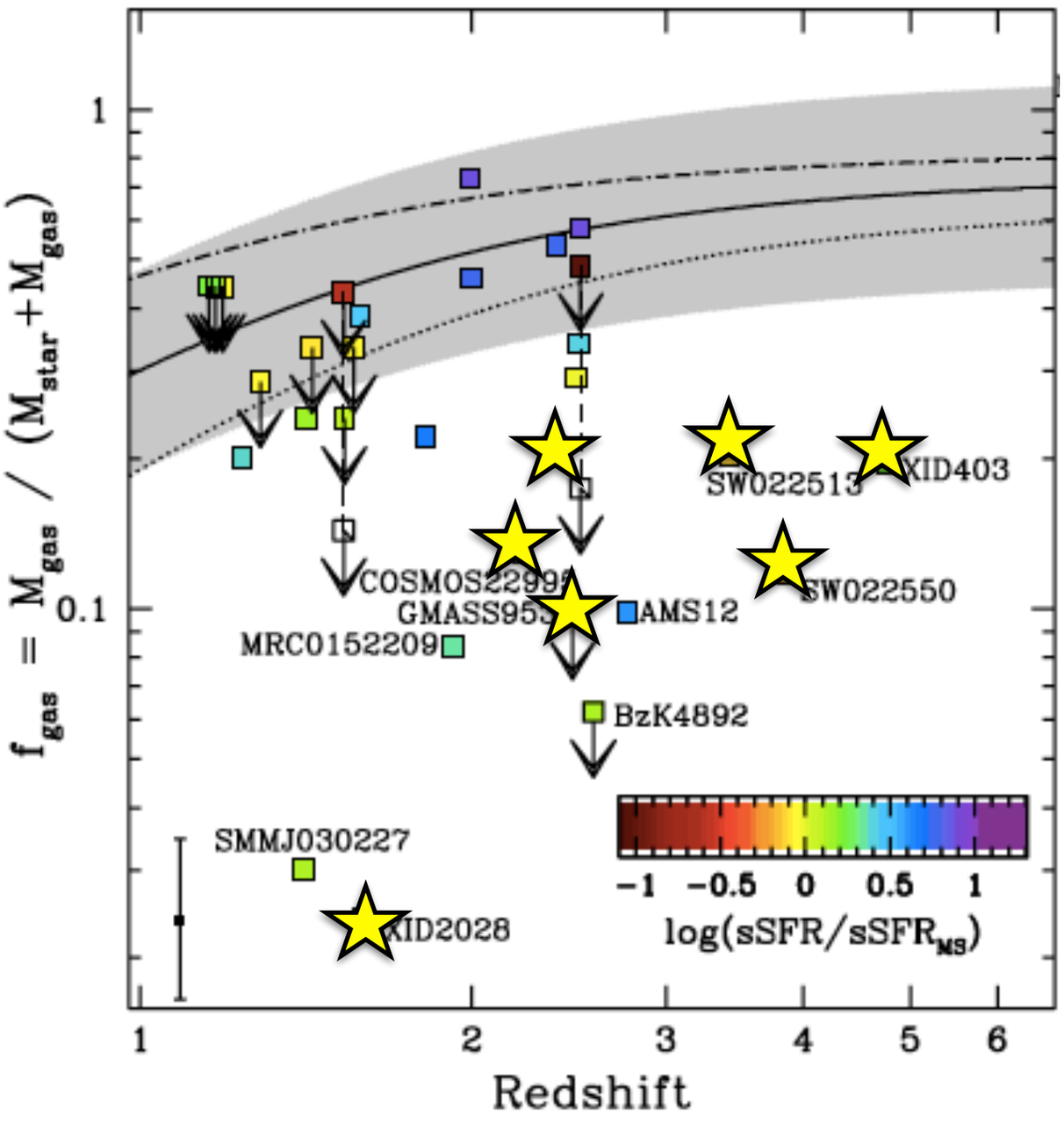
- Tacconi et al. (2017)
- Scoville et al. (2017)
- Sargent et al. (2014)

Evidence for higher SFE in converting into stars the residual gas ?

removal of molecular gas and/or change into ionised phase?

INDIRECT EVIDENCE OF AGN FEEDBACK/OUTFLOWS: GAS FRACTION

Perna+2018, A&A



Gas fractions for obscured quasars at z=1-6 *lower* than mass matched inactive samples

A factor 2-10 difference in gas fraction in AGN vs. non-AGN host

difference still present if α_{CO}=4

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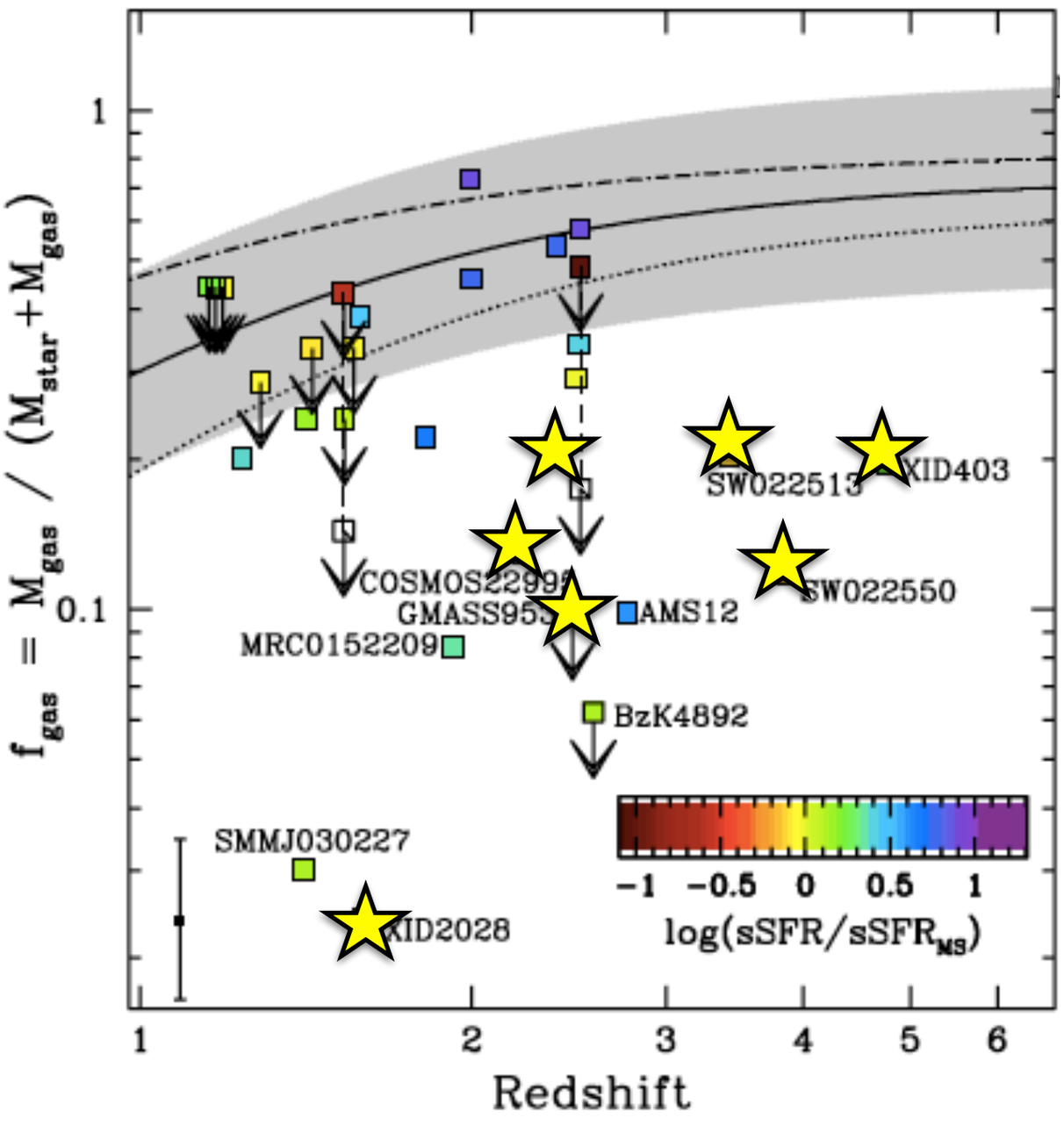

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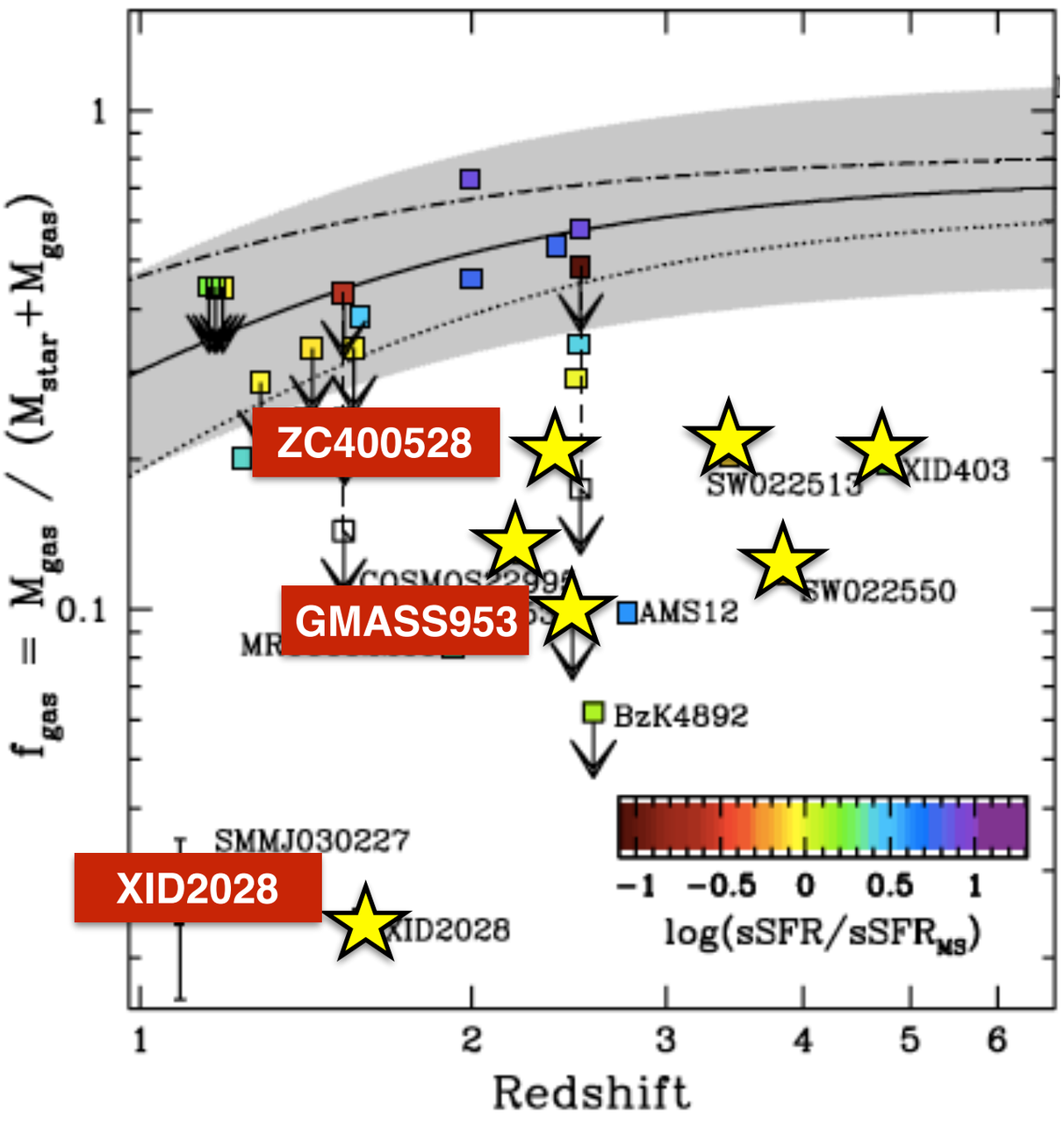

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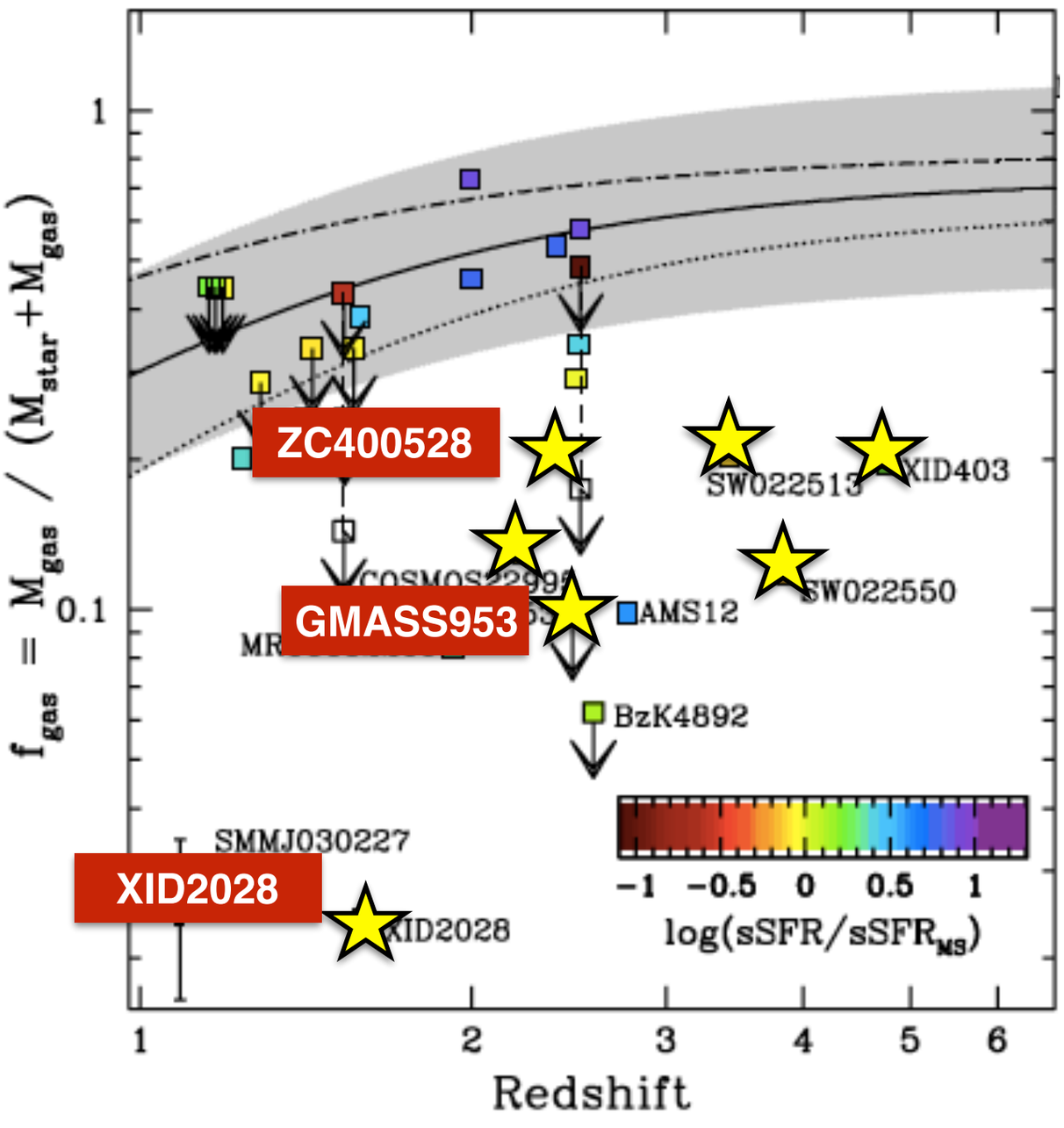

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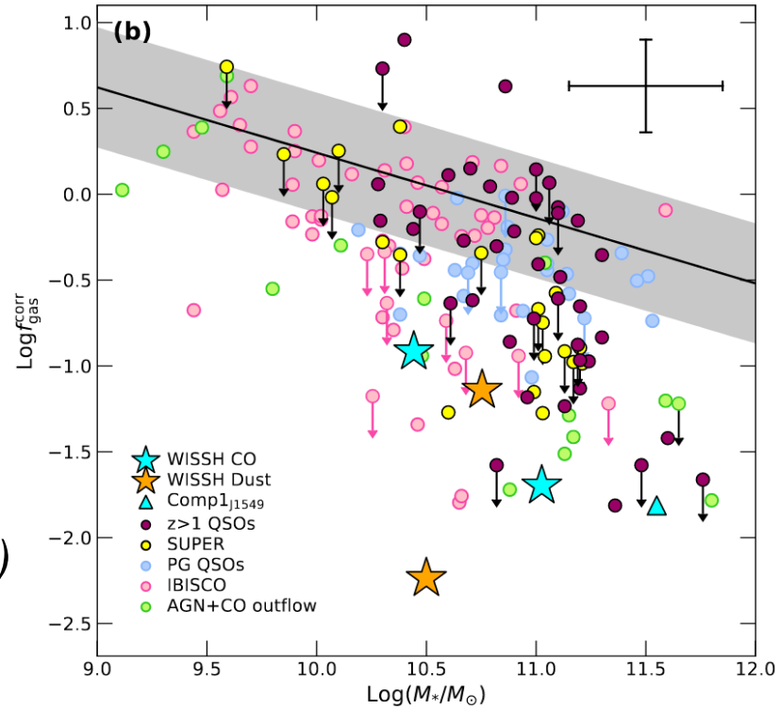
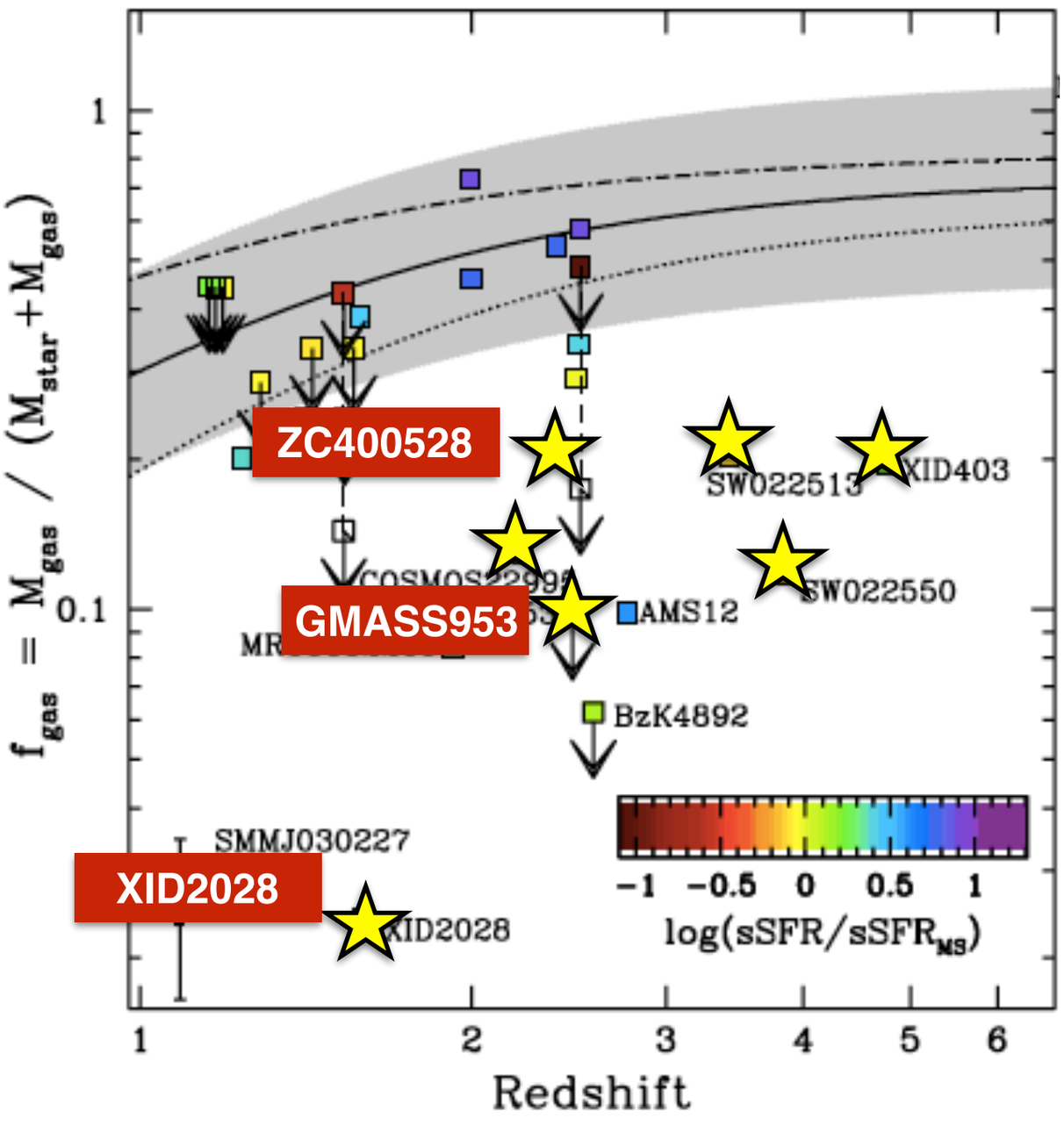
lower molecular gas fraction confirmed also in WISSH QSO (Bischetti+, submitted)



INDIRECT EVIDENCE OF AGN FEEDBACK/OUTFLOWS: GAS FRACTION

Perna+2018, A&A



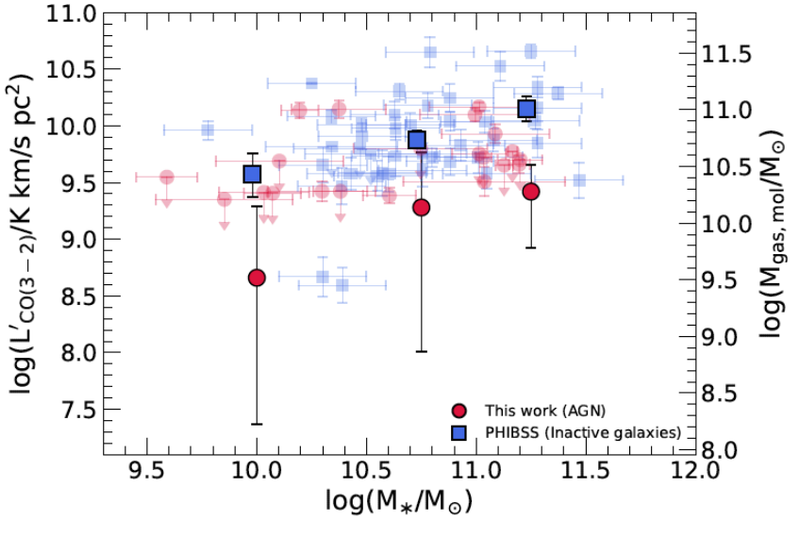
Gas fractions for obscured quasars at z=1-6 *lower* than mass matched inactive samples

A factor 2-10 difference in gas fraction in AGN vs. non-AGN host

difference still present if α_{CO}=4

AGN with outflows in at least one phase (large stars) displaying among the strongest deficits !

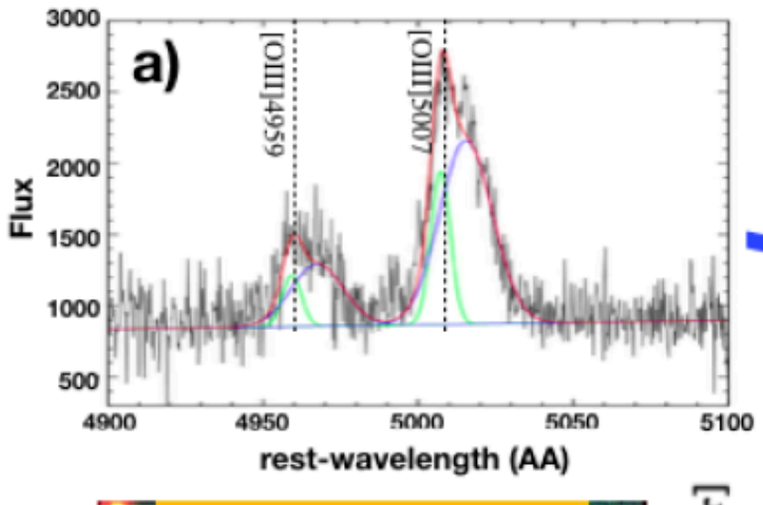
lower molecular gas fraction confirmed also in SUPER AGN (Circosta+, submitted)

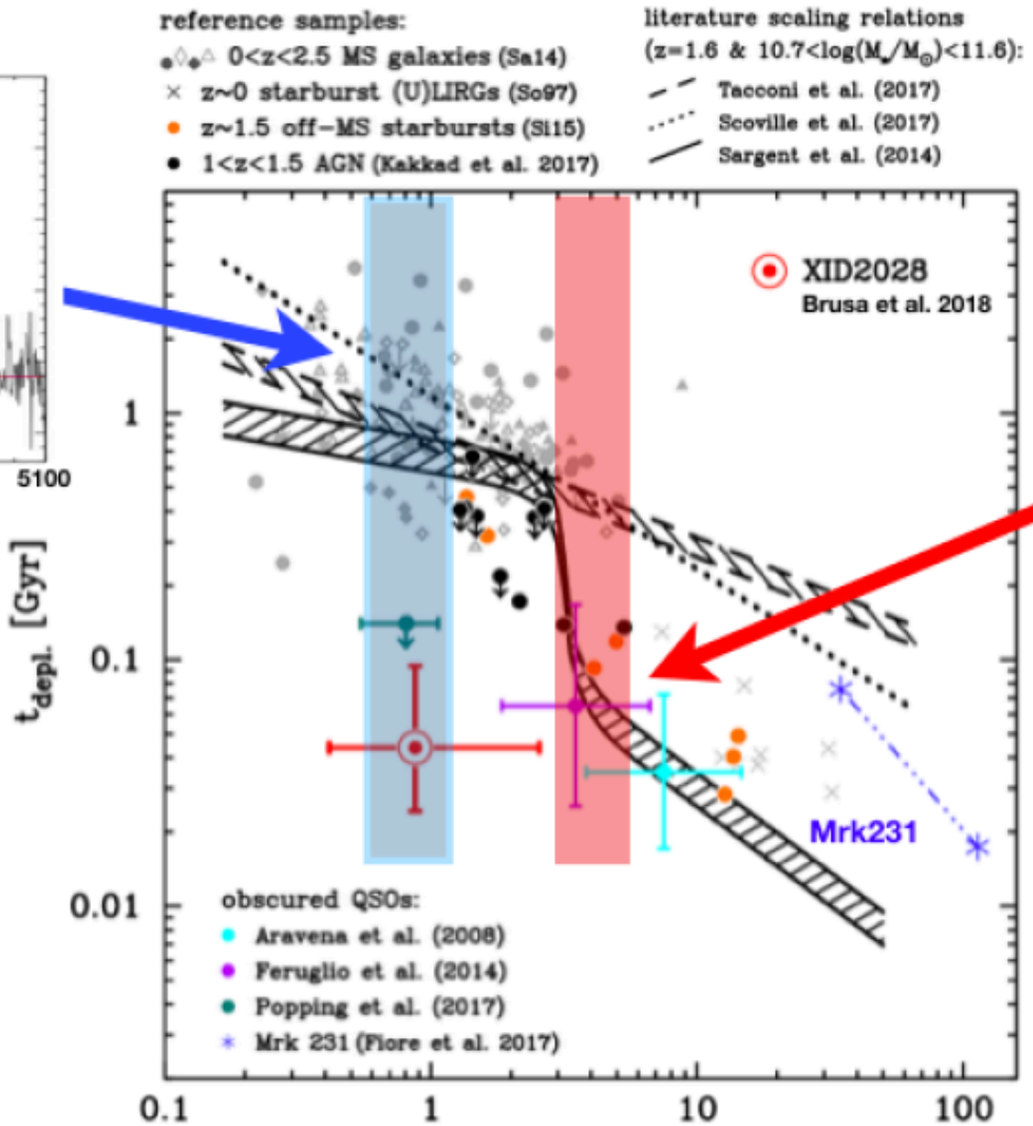


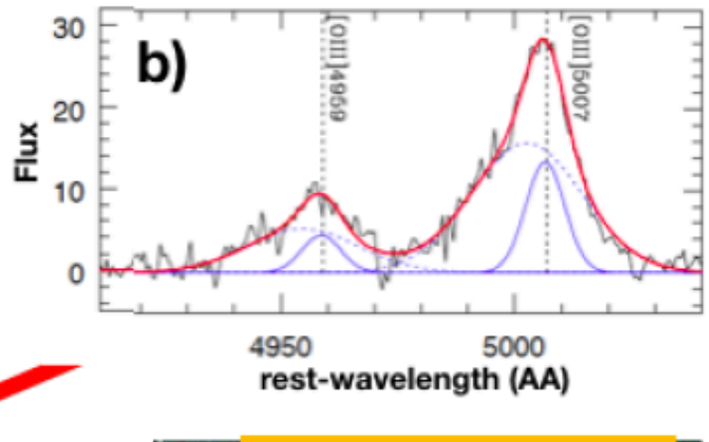
"tension" with local works (no difference): Rosario+2017, Husemann+2018, but see *IBISCO*

WORK IN PROGRESS: XID5321, XID5395

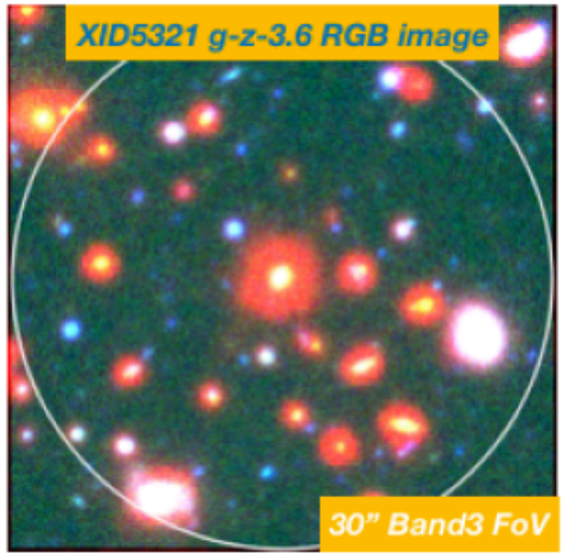
2 luminous obscured Quasars from XMM-COSMOS observed in CO(2-1) and CO(5-4) with ALMA at intermediate resolution (0.4”-1”)



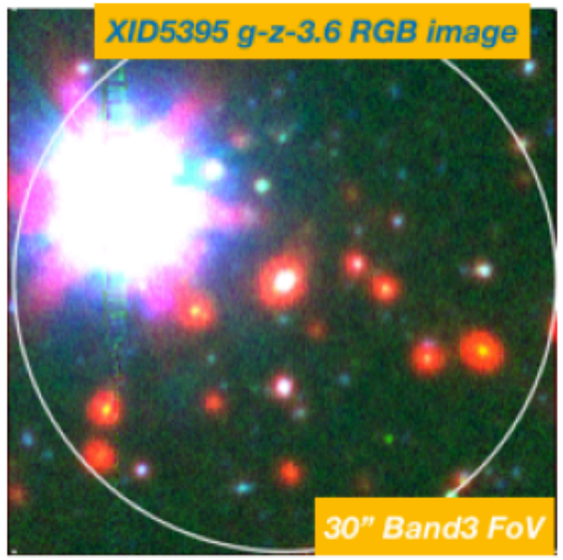




c)



d)



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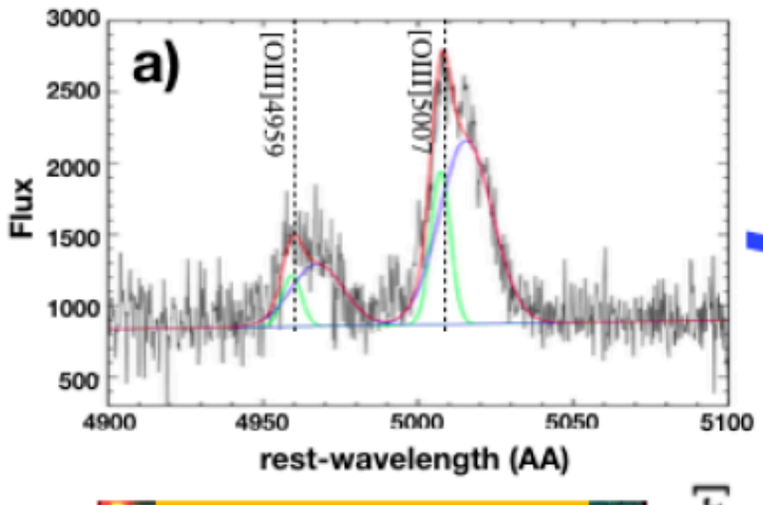
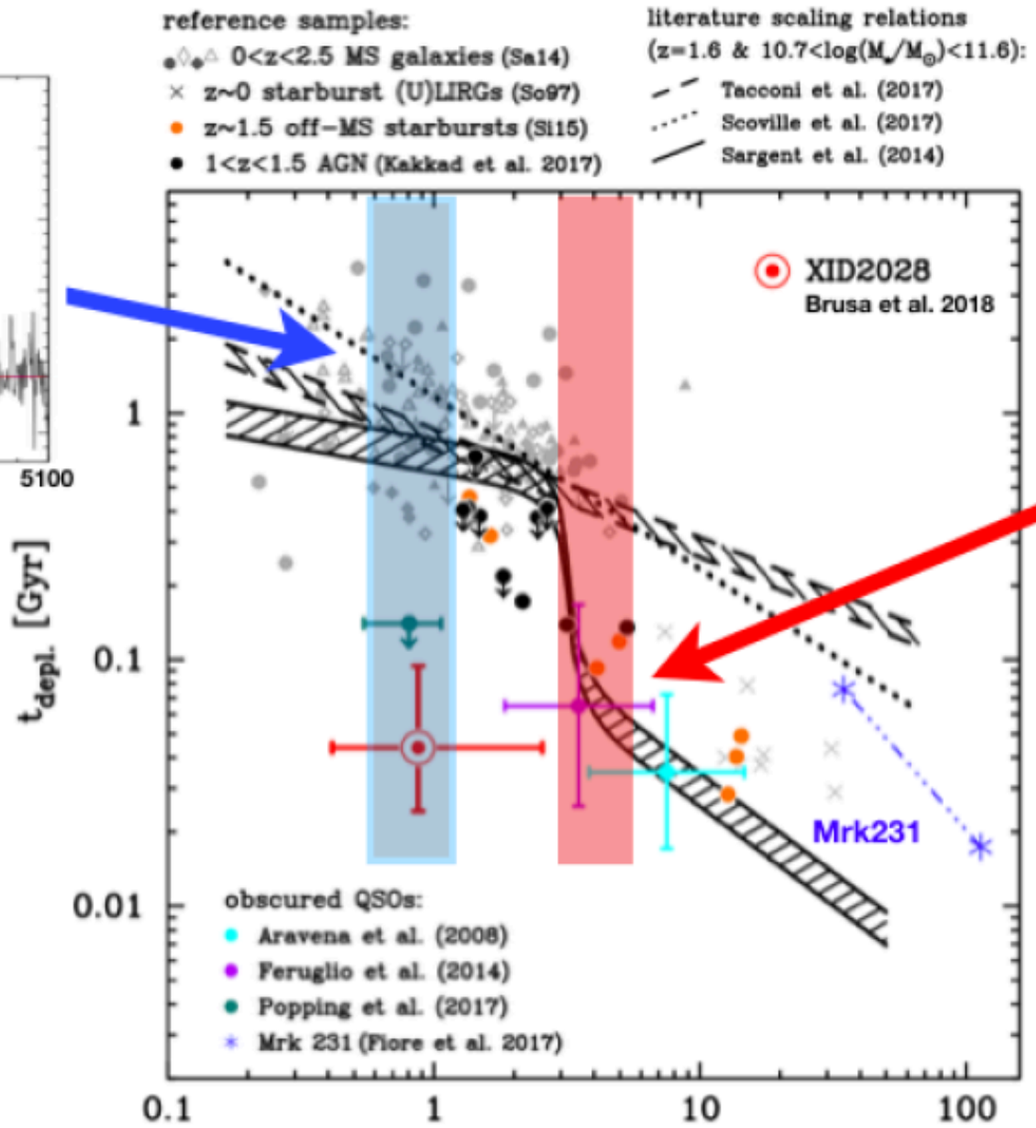
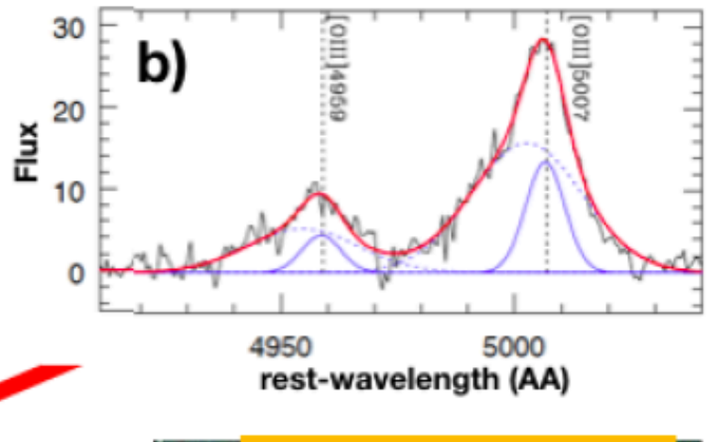
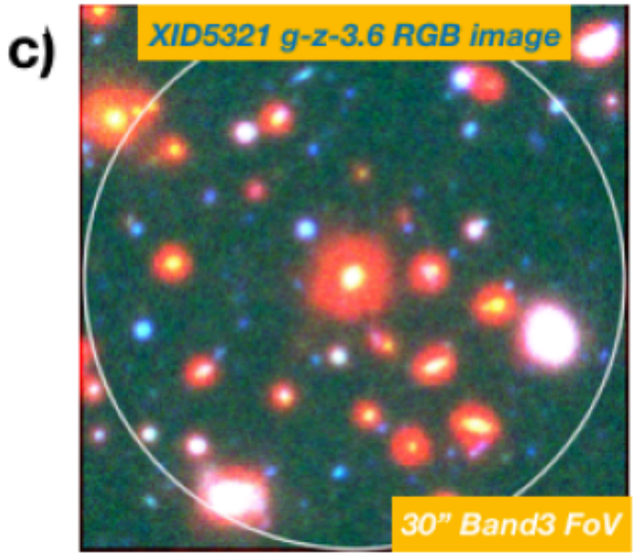
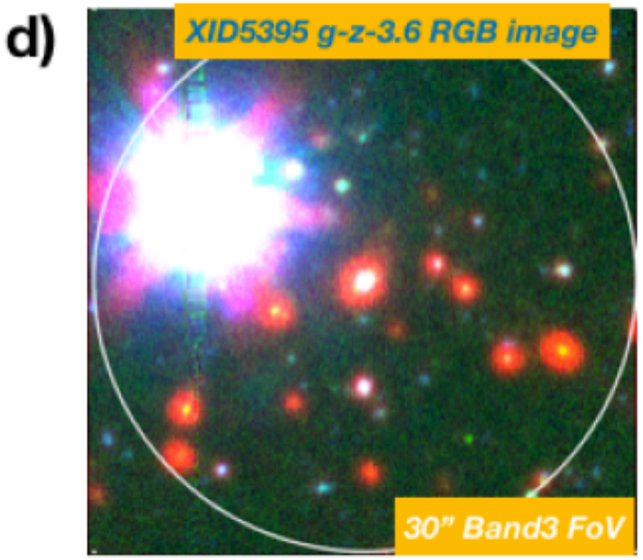










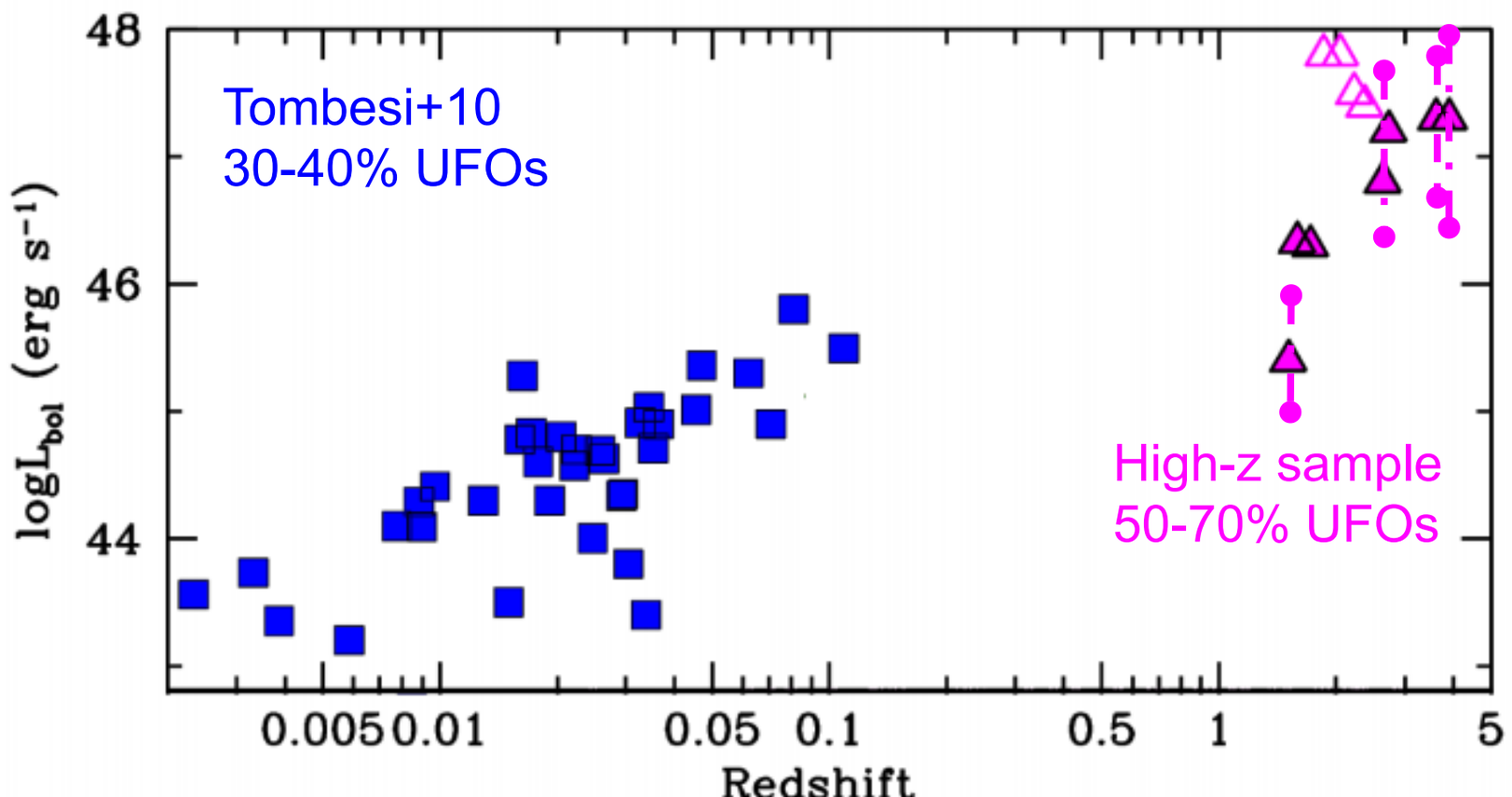
—> FEDERICA RICCI will take the lead of the project

SUBWAYS: SUPERMASSIVE BLACK HOLE WINDS IN X-RAYS

AGN disk wind studies limited to

1) $z < 0.1$ on a large sample (>50 objects) at Seyferts luminosities, $L_{bol}<10^{45}$ erg/s (Tombesi+10, Gofford+13)

2) $z > 1.5$ on small and sparse samples (<10 objects) at $L_{bol}>10^{46}$ erg/s (Chartas+09,16, Lanzuisi+12, Vignali+15, Dadina+18)



SUBWAYS:
SUPERMASSIVE BLACK HOLE WINDS IN X-RAYS

M. Brusa (PI), G. Lanzuisi (deputy),
X. Barcons, E. Behar, **S. Bianchi,** G. Bruni, **M. Cappi,** G. Chartas, **A. Comastri,** E. Costantini, **G. Cresci, M. Dadina,** B. De Marco, **A. De Rosa, C. Feruglio, F. Fiore, M. Gaspari, R. Gilli,** M. Giustini, P. Grandi, M. Guainazzi, J. Kaastra, A. King, S. Kraemer, G. Kriss, Y. Krongold, **F. La Franca**, A. L. Longinotti, **A. Luminari,** R. Maiolino, **A. Marconi,** S. Mathur, **G. Matt, G. Matzeu,** M. Mehdipour, A. Merloni, G. Miniutti, R. Morganti, E. Nardini, F. Panessa, M. Perna, P. O. Petrucci, **E. Piconcelli,** G. Ponti, D. Proga, F. Tombesi, E. Torresi, **C. Vignali, L. Zappacosta**

1.6Ms XMM-Newton LP accepted in AO18

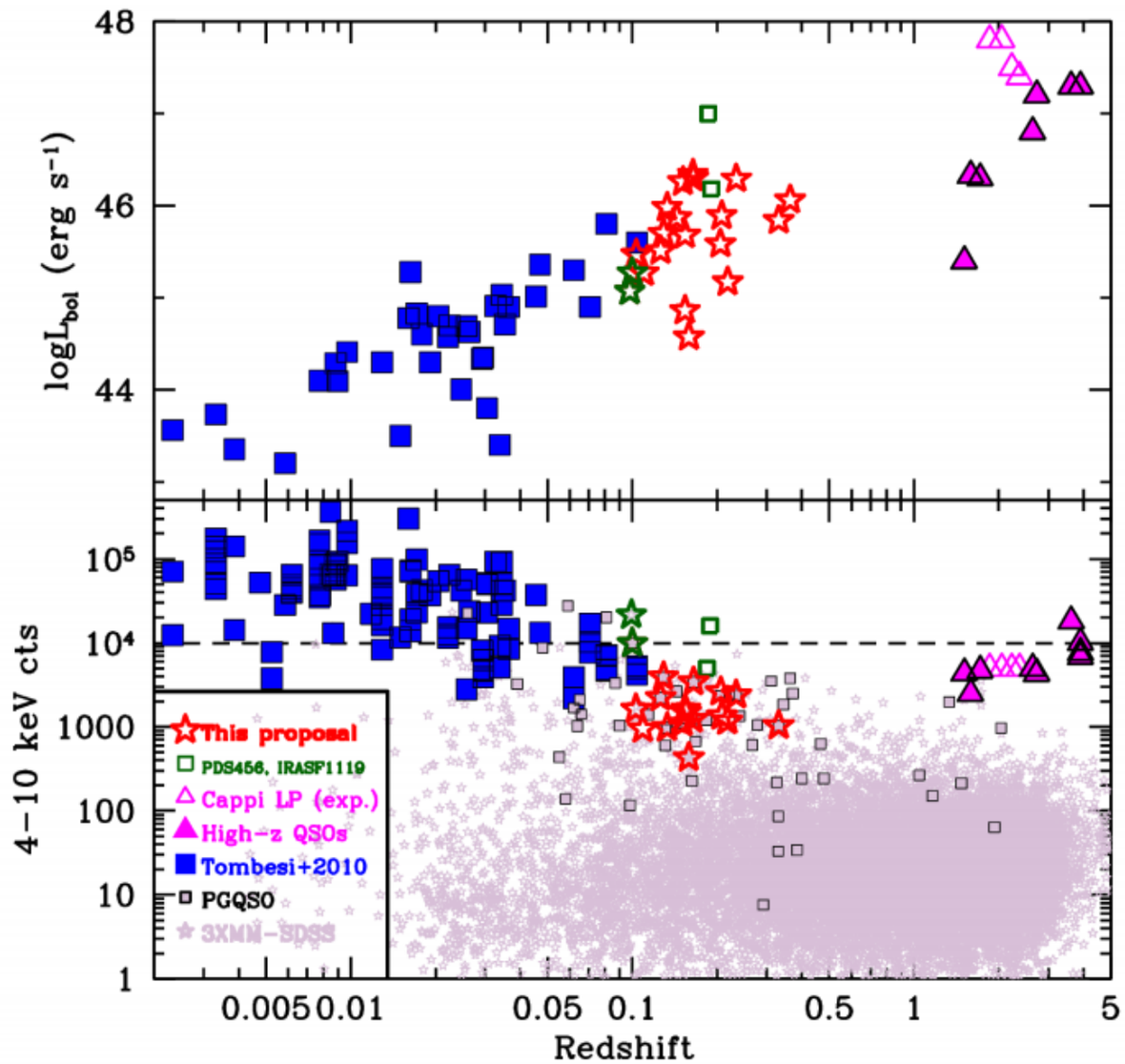
Selection criteria:

(1) presence in the 3XMM-DR7+SDSS-DR14 catalogs (or to the PG QSO catalog – crucial to tune the requested observing time

(2) redshift in the range z=0.1-0.5 (both WAs and UFOs can be studied)

(3) count rate larger than ~0.12 cts/s, to ensure ~10000 counts 4-10keV obtainable within a single XMM orbit

(4) BH Mass & Eddington ratio available



SUBWAYS:
SUPERMASSIVE BLACK HOLE WINDS IN X-RAYS

Goals:

(1) UFO detection fraction and duty cycle
expected 5-13 UFOs detections —> OBJ 1 (unbiased census of BH winds)

(2) UFO energetics
$\dot{M}_{out}$ and E_k derived assuming biconical wind geometry (plus new models, e.g. Luminari+18)

(3) Combined low and high-z/Lum sample
to study winds presence over 3-4 dex of L_{bol}, λ_{Edd}, M_{BH}

(4) Relation of UFO with large scale outflows
- 60% of the sample have indication of kpc-scale outflows in OIII (Perna+17)
- primary targets for MUSE, ALMA and NOEMA proposals

SUBWAYS:
ARCHIVAL SUBWAYS-LIKE TARGETS

Source	z	F2-10	Cnt 4-10	En.	Sig.	
PG0804+761	0.100	10e-12	9800(3000)	7.5	95.0	UFO?
PDS456	0.184	7.1e-12	>20000	9.0	99.99	UFO!
				9.6	99.99	
PG1416-129	0.128	3.2e-12	9700	8.6	99.0	WA, UFO?
PG1114+445	0.144	2.3e-12	>20000	7.9	99.9	UFO+WA!
				10.5	99.9	Not pub.
PG1402+261	0.164	1.8e-12	5000	-	-	WA
HB891257+286	0.091	1.4e-12	>20000	-	-	Coma Cluster...
2MASS0918+2117	0.149	1.2e-12	2000	7.7	99.9	UFO! Not pub.
				9.6	99.99	Not pub.

Nustar and Suzaku only:

IRASF11119+3257	0.189	1e-12				

UFO detection rate from this sample: >50%

SUBWAYS: SAMPLE

★19 allocated for XMM-Newton observations

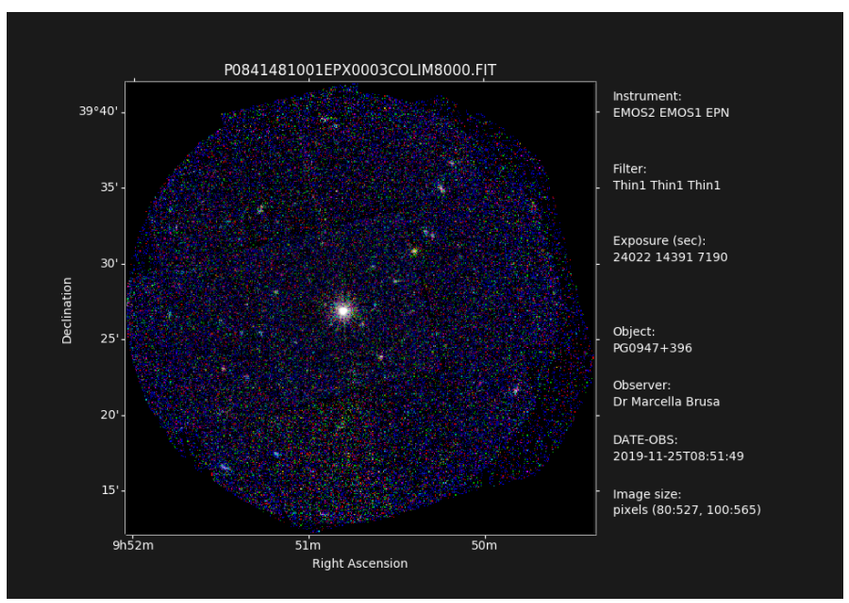
★17 observed by XMM-Newton
★ (2 scheduled in C not observed)

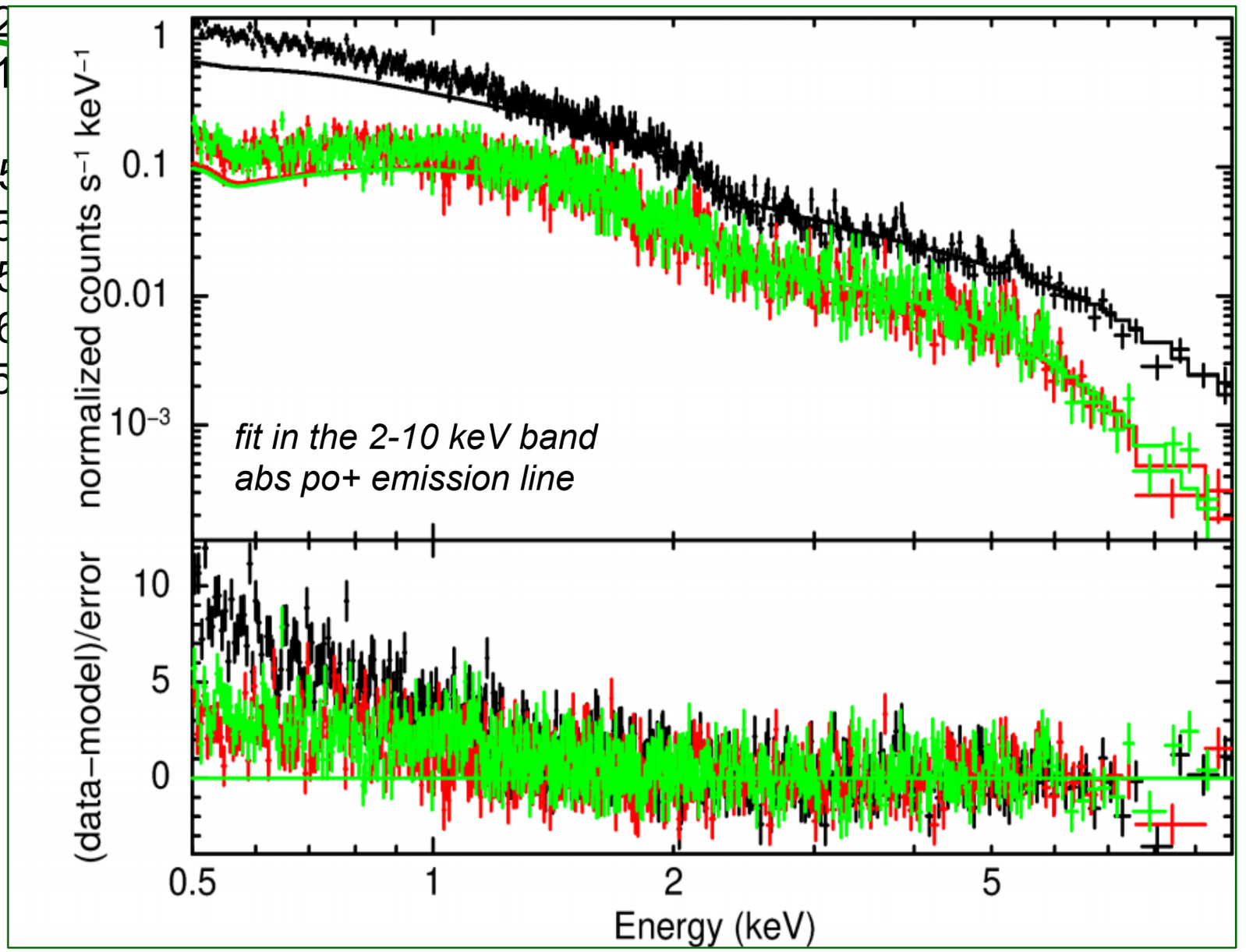
Name	Very QUICK analysis	Intrinsic HST abs from here:	NOEMA program	RA	DEC	z
PG0052+251	-	no	----	00 54 52.10	+25 25 37.99	0.154
PG0953+414	----------	maybe	cont detection	09 56 52.40	+41 15 22.00	0.234
PG1626+554	-	(pending obs)	cont detection	16 27 56.10	+55 22 32.02	0.133
PG1202+281	----------	no	(pending obs)	12 04 42.12	+27 54 12.11	0.164
PG1435-067	-	no	(pending obs)	14 38 16.10	-06 58 21.00	0.126
SDSSJ144414+0633	-	no	----	14 44 14.67	+06 33 6.77	0.207
2MASXJ165315+2349	**UFO?**	---	----	16 53 15.06	+23 49 42.96	0.103
PG1216+069	----------	no	(pending obs)	12 19 20.90	+06 38 39.01	0.331
PG0947+396	**UFO!**	(pending obs)	cont+CO detection	09 50 48.42	+39 26 50.64	0.205
WISEJ053756-0245	-	---	----	05 37 56.30	-02 45 13.27	0.11
HB89-1529+050	**UFO?**	yes	----	15 32 28.79	+04 53 58.46	0.218
PG1307+085	-	no	(pending obs)	13 09 47.00	+08 19 48.22	0.154
PG1425+267	-	yes	----	14 27 35.61	+26 32 14.63	0.364
PG1352+183	**UFO!**	no	(pending obs)	13 54 35.72	+18 05 18.05	0.151
2MASXJ105144+3539	----------	---		10 51 44.24	+35 39 30.76	0.159
2MASXJ0220-0728	-	no	----	02 20 14.58	-07 28 59.23	0.213
LBQS1338-0038	**UFO!**	yes	----	13 41 13.94	-00 53 14.97	0.237
2MASXJ140251+2631		yes	----	14 02 51.19	+26 31 17.63	0.188
PG1427+480		no	----	14 29 43.10	+47 47 26.02	0.221

Detected counts roughly within expectation
(~50% have >10.000 cts)

SUBWAYS: TARGETS WITH UFO

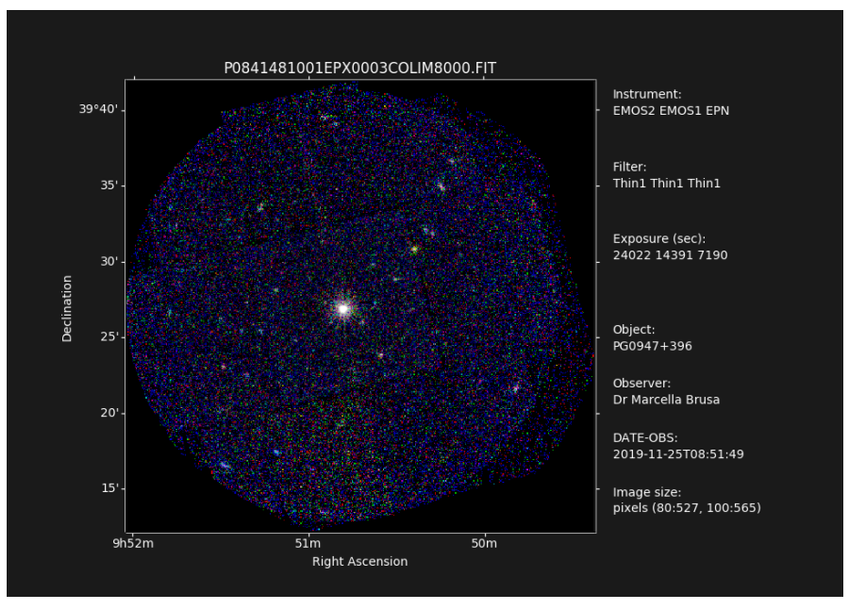
Source	z	F2-10	Cnt 4-10	En	Sign	
HB891529+050	0.218	1.20e-12	6500	8.4	95.0	UFO?
PG0052+251	0.154	6.55e-12	16862	-	-	
PG1435-067	0.126	1.20e-12	3917	-	-	
PG1626+554	0.133	3.00e-12	9646	-	-	
SDSSJ144414	0.207	2.51e-12	11132	-	-	
PG0947+396	0.205	1.44e-12	3174	9.6	99.9	UFO!
PG1307+085	0.154	3.52				
PG1352+183	0.151	1.31				
LBQS1338-0038	0.237	2.05				
PG1425+267	0.364	1.75				
2MASJ022014	0.213	1.25				
2MASJ165315	0.103	2.36				
WISE0537-0245	0.110	1.35				

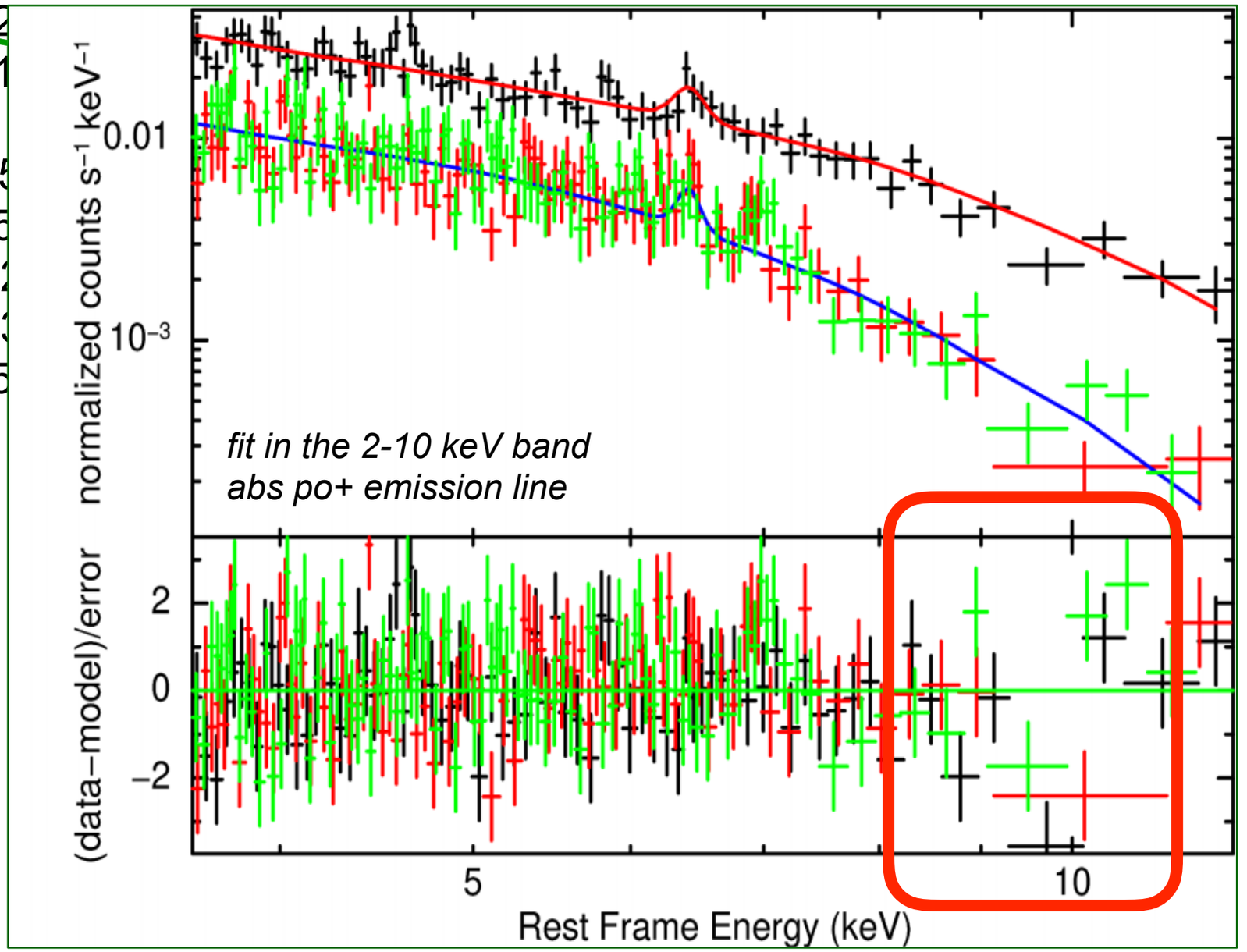




SUBWAYS: TARGETS WITH UFO

Source	z	F2-10	Cnt 4-10	En	Sign	
HB891529+050	0.218	1.20e-12	6500	8.4	95.0	UFO?
PG0052+251	0.154	6.55e-12	16862	-	-	
PG1435-067	0.126	1.20e-12	3917	-	-	
PG1626+554	0.133	3.00e-12	9646	-	-	
SDSSJ144414	0.207	2.51e-12	11132	-	-	
PG0947+396	0.205	1.44e-12	3174	9.6	99.9	UFO!
PG1307+085	0.154	3.52				
PG1352+183	0.151	1.31				
LBQS1338-0038	0.237	2.05				
PG1425+267	0.364	1.75				
2MASSJ022014	0.213	1.2				
2MASSJ165315	0.103	2.3				
WISE0537-0245	0.110	1.35				





SUBWAYS: TARGETS WITH UFO

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PG1626+554	0.133	3.00e-12	9646	-	-	
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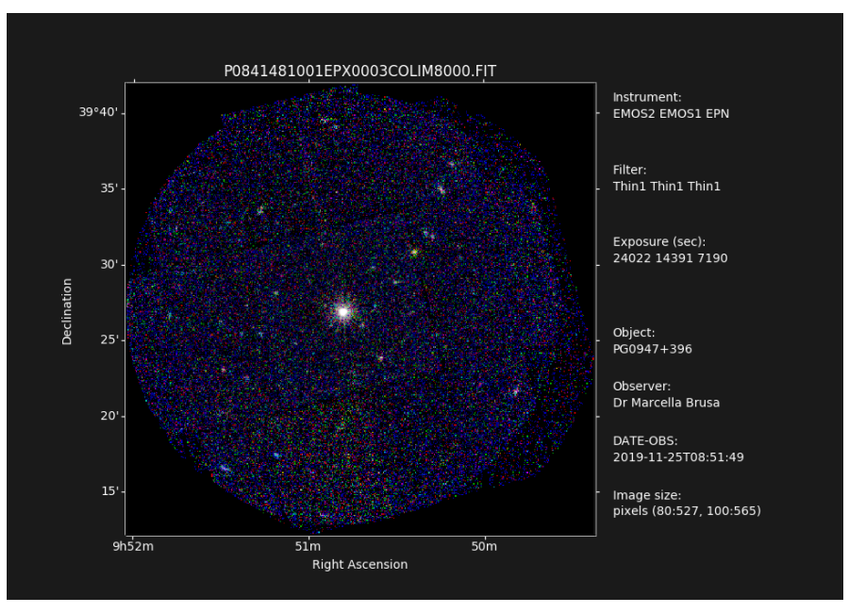

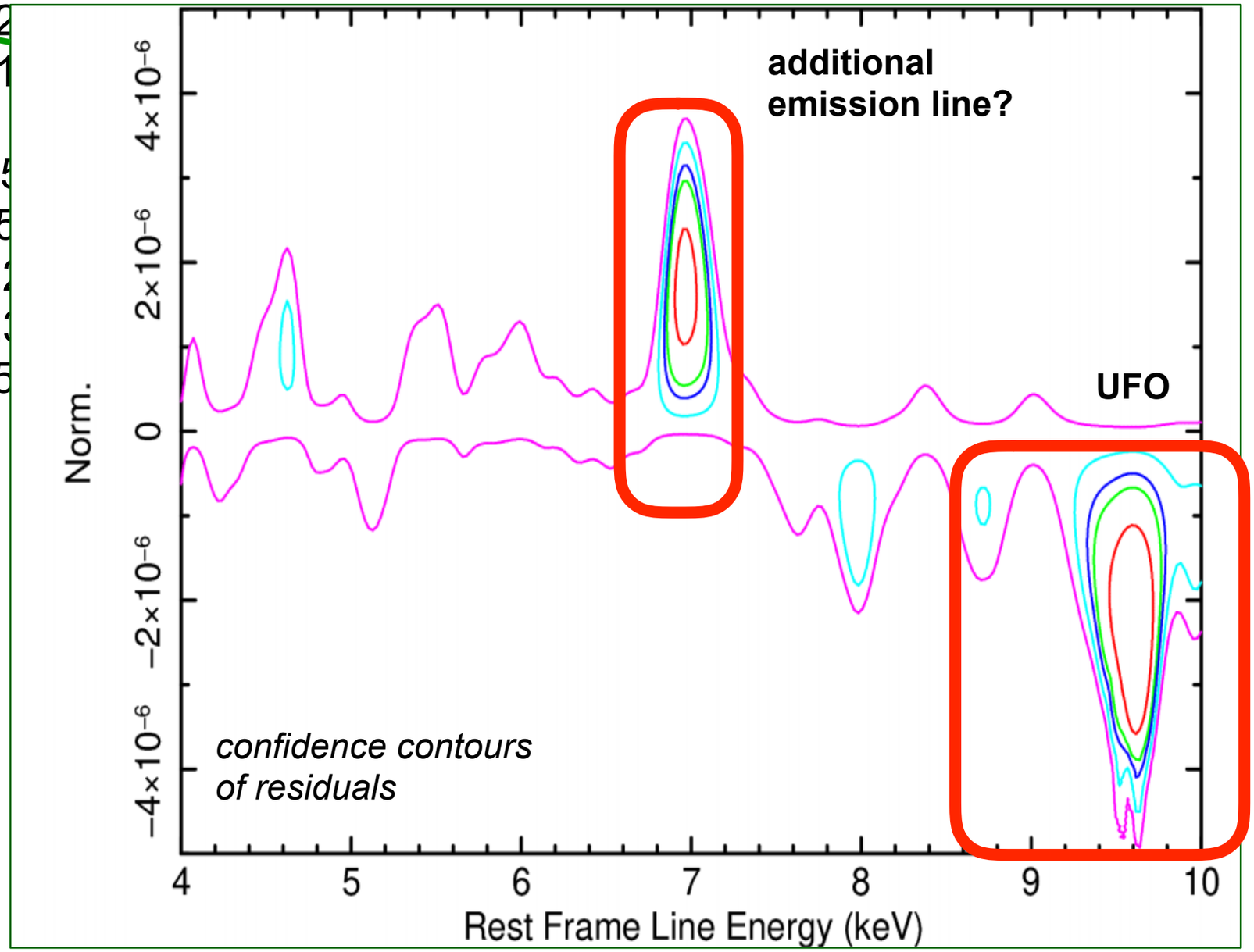

SUBWAYS: SAMPLE

★19 allocated for XMM-Newton observations

★17 observed by XMM-Newton
★ (2 scheduled in C not observed)

Name	Very QUICK analysis	Intrinsic HST abs from here:	NOEMA program	RA	DEC	z
PG0052+251	-	no	----	00 54 52.10	+25 25 37.99	0.154
PG0953+414	----------	maybe	cont detection	09 56 52.40	+41 15 22.00	0.234
PG1626+554	-	(pending obs)	cont detection	16 27 56.10	+55 22 32.02	0.133
PG1202+281	----------	no	(pending obs)	12 04 42.12	+27 54 12.11	0.164
PG1435-067	-	no	(pending obs)	14 38 16.10	-06 58 21.00	0.126
SDSSJ144414+0633	-	no	----	14 44 14.67	+06 33 6.77	0.207
2MASXJ165315+2349	**UFO?**	---	----	16 53 15.06	+23 49 42.96	0.103
PG1216+069	----------	no	(pending obs)	12 19 20.90	+06 38 39.01	0.331
PG0947+396	**UFO!**	(pending obs)	cont+CO detection	09 50 48.42	+39 26 50.64	0.205
WISEJ053756-0245	-	---	----	05 37 56.30	-02 45 13.27	0.11
HB89-1529+050	**UFO?**	yes	----	15 32 28.79	+04 53 58.46	0.218
PG1307+085	-	no	(pending obs)	13 09 47.00	+08 19 48.22	0.154
PG1425+267	-	yes	----	14 27 35.61	+26 32 14.63	0.364
PG1352+183	**UFO!**	no	(pending obs)	13 54 35.72	+18 05 18.05	0.151
2MASXJ105144+3539	----------	---		10 51 44.24	+35 39 30.76	0.159
2MASXJ0220-0728	-	no	----	02 20 14.58	-07 28 59.23	0.213
LBQS1338-0038	**UFO!**	yes	----	13 41 13.94	-00 53 14.97	0.237
2MASXJ140251+2631		yes	----	14 02 51.19	+26 31 17.63	0.188
PG1427+480		no	----	14 29 43.10	+47 47 26.02	0.221

UFO detection rate 23-30%?
(35-45% with archival sample…)
N.B: situation at ~May2020

Overall spectral complexity
(soft excess, WA, complex lines etc.)

SUBWAYS: FOLLOW-UP PROPOSALS

- HST COS (PI Kriss)
- FUV Spectroscopy of **16 QSOs** of the LP sample (no obscured sources). 27 Orbits requested, almost all data taken (2 missing).
- Will cover all important UV spectral features: OVI+Lyβ, Lyα, NV, SiIV, and CIV for ~simultaneous observatios

- NOEMA (PI Feruglio) CO lines, gas mass measurement
- **9 PG QSOs** at north, accepted in B category,
- some data already taken

- VLA (PI Panessa) 1.4,6GHz, radio core/continuum
- **almost full sample**, including some of the archival data, C priority

- NuSTAR (PI Bianchi) Continuum, Ecut, **full sample**
- MUSE (PI Cresci) [OIII] extend emission, **subsample visibile from ESO** – NOT accepted → to be resubmitted in P107 → suspended
- ALMA (PI Brusa): CO lines+continuum, gas mass+ outflow **subsample visibile from ALMA**, NOT accepted → to be resubmitted in Cycle 8 → moved to April 2021

- ***JWST?***

BLACKOUT KICK-OFF MEETING