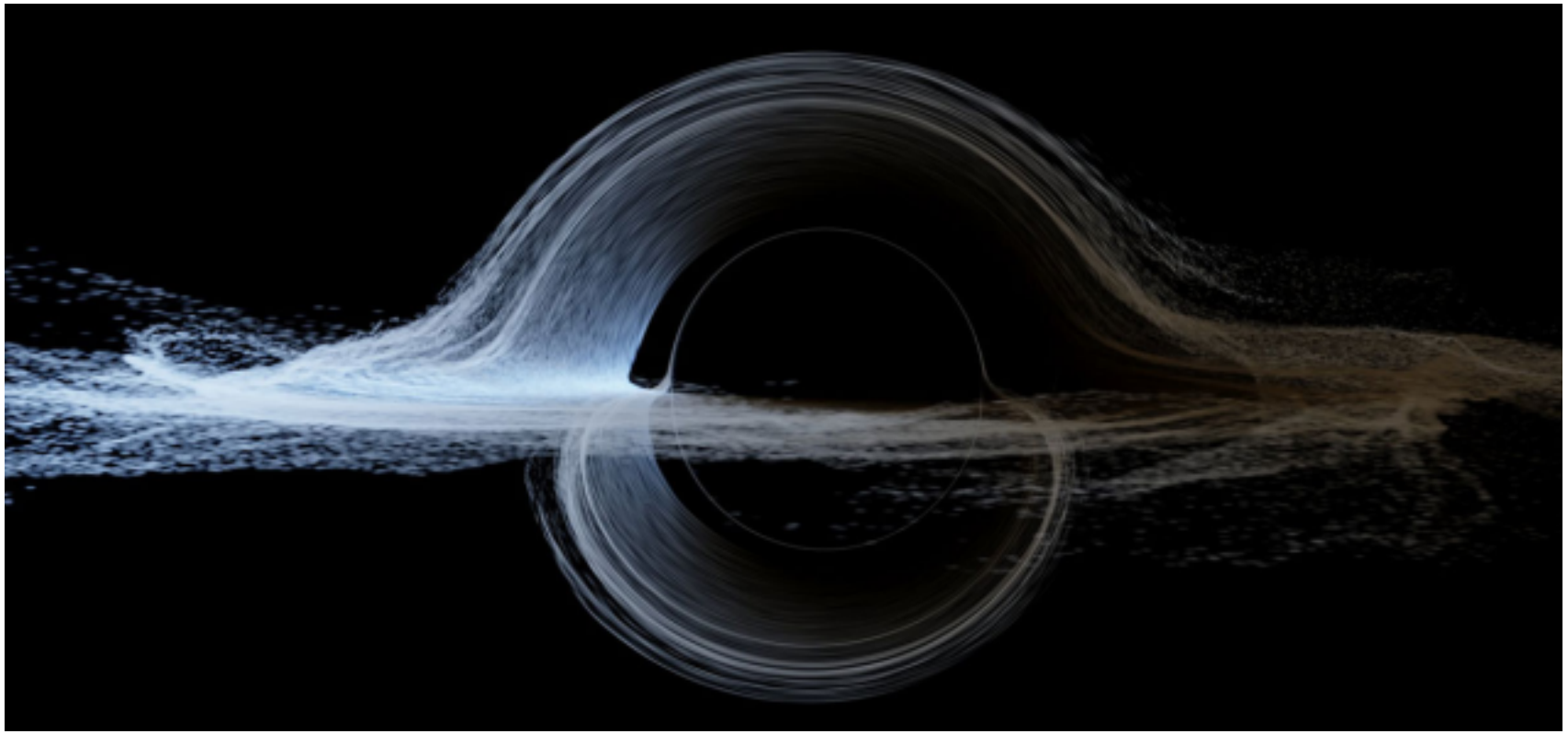
Magnified Views of Relativistic Outflows in Gravitationally Lensed Quasars



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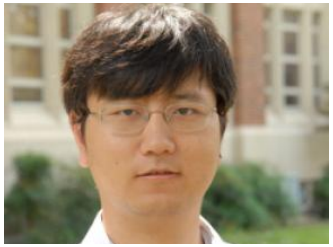
Carter Rhea (CofC)



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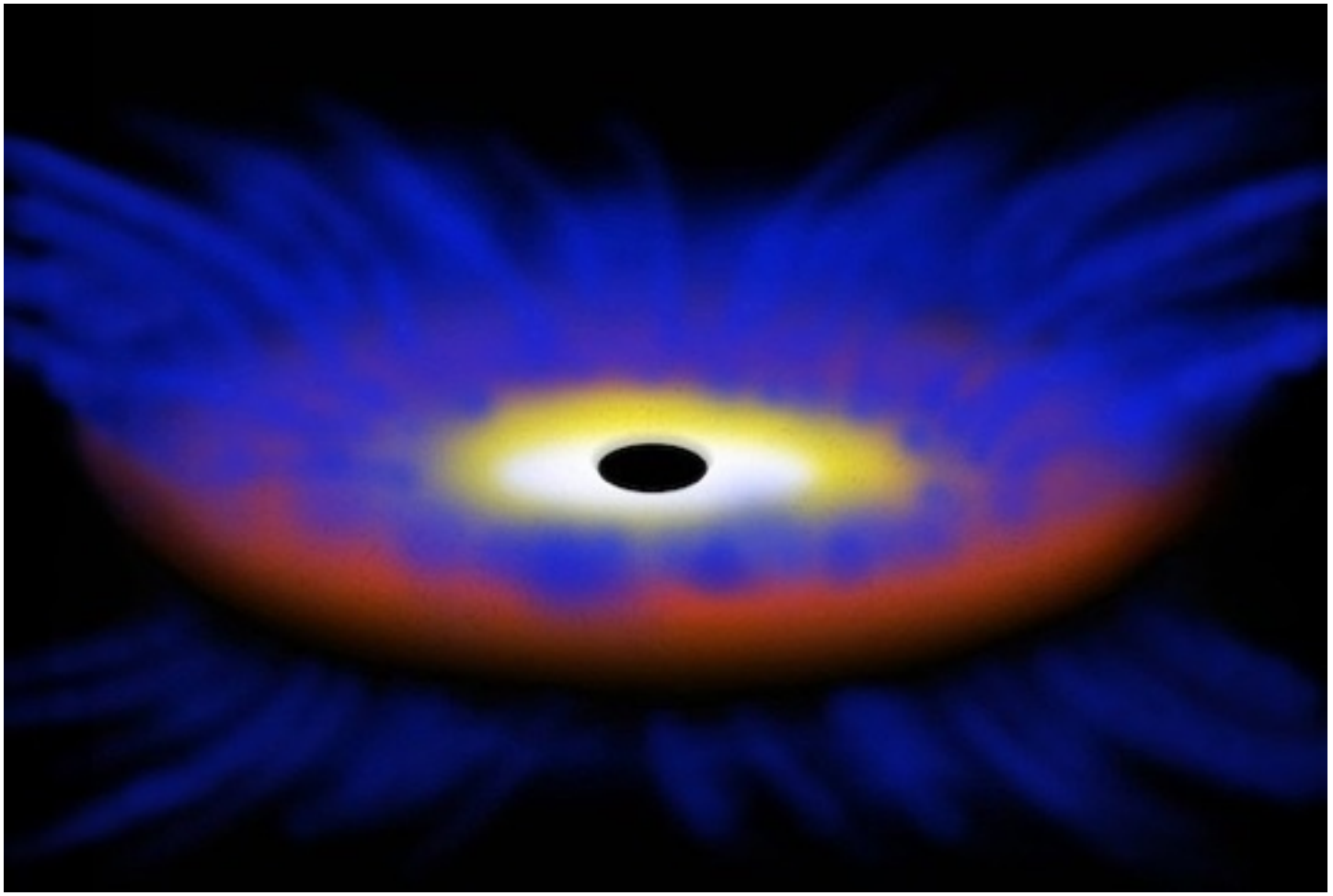
Quasar Winds



AGN Winds

z > 1 AGN with reported relativistic winds over small scales (10-100rg):

Object	Type	z	v/c	Reference
APM 08279+5255	BALQSO	3.91	0.2-0.75	(Chartas et al. 2002, ApJ, 579, 169)
HS1700+6416	NALQSO	2.735	0.12-0.59	(Lanzuisi et al. 2012, A&A, 544, A2)
H 1413+117	BALQSO	2.56	0.23 and 0.67	(Chartas et al. 2007, ApJ, 661, 678)
PG 1115+080	miniBALQSO	1.72	0.1 and 0.4	(Chartas et al. 2003, ApJ, 595, 85)
SDSS J1353+1138	miniBALQSO	1.63	0.43	(Chartas et al. 2016 in prep)
PID352	FRII	1.6	0.05	(Vignali et al. 2015, A&A, 583, A141)
HS0810+2554	NALQSO	1.51	0.1 and 0.4	(Chartas et al. 2016, ApJ, in press)

Observations of ultraluminous infrared galaxies have revealed large-scale molecular outflows traced in OH and CO extending over kpc scales with velocities exceeding ~ 1000 km s^{-1} and with massive outflow rates (up to ~1200 $M_{\odot}$ yr^{-1}) AGN with reported massive outflows over large scales (~kpc) :

Object	Type	z	v	Reference
SDSS J1148+5251	QSO	6.4189	1400 km/s	(Maiolino et al. 2012, Cicone et al. 2014)
XID5395	QSO	1.5	1300km/s	(Brusa et al. 2016)
SDSS J1356+1026	QSO	0.123	500km/s	(Sun et al. 2014)

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Several Properties of the z >1 Quasars with Relativistic Winds

Object	z	$\log(M_{\rm BH})$ $(M_\odot)$	$L_{\rm Bol}/L_{\rm Edd}$	v_{out}/c	$\dot{\rm M}$ $\rm M_\odot\ yr^{-1}$	$\dot{\rm E}_{\rm K}/L_{\rm bol}$	$\dot{\rm p}/(L_{bol}/c)$
APM08279	3.91	10.	3.6	0.2–0.75	220^{+145}_{-150}	$0.4^{+0.3}_{-0.3}$	1.5
HS1700	2.735	10.4	0.63	0.12–0.59	4–6	0.01–0.18	0.1
H1413	2.55	9.39	0.10	0.23–0.67	—	—	—
PG1115	1.72	8.96	0.12	0.1–0.4	15^{+13}_{-10}	$5.3^{+2.5}_{-3.5}$	26
SDSS1353	1.63	9.13	0.40	0.43	60^{+50}_{-40}	5^{+4}_{-3}	22
PID352	1.6	8.7	0.16	0.14	$1.7^{+5.1}_{-1.4}$	$0.1^{+0.1}_{-0.07}$	1.3
HS0810	1.51	8.6	0.04	0.1–0.4	$3.4^{+2.7}_{-2.1}$	9^{+8}_{-6}	45

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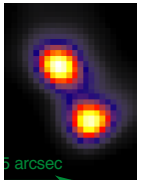
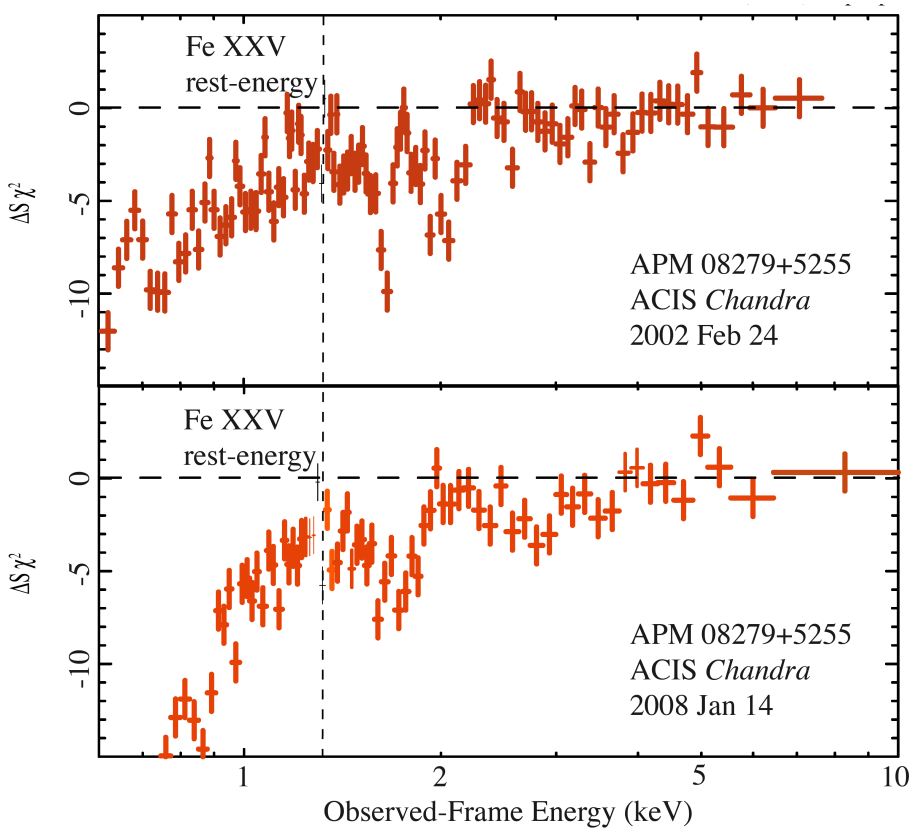
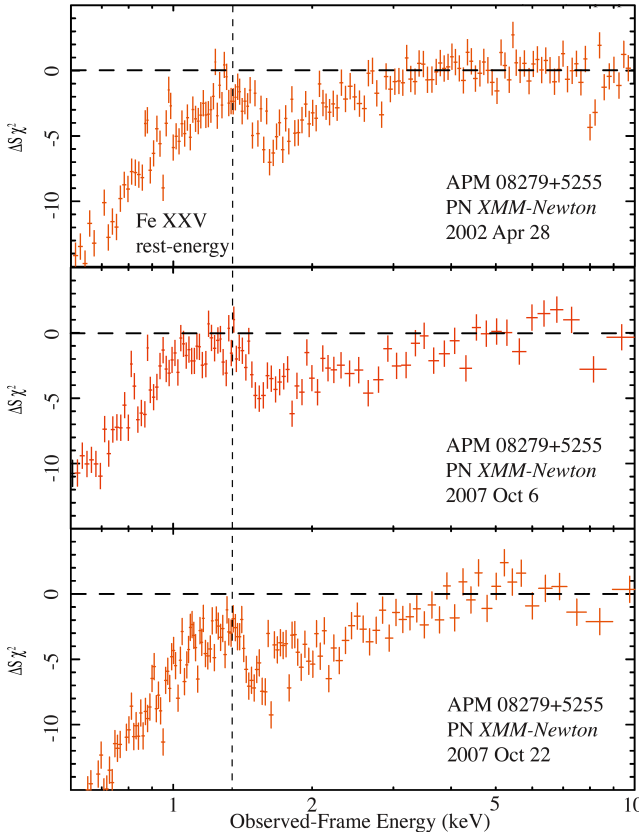
Quasar Outflows Observed in a BAL Quasar



z = 3.91 APM 08279+5255





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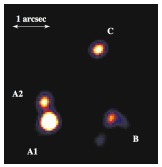
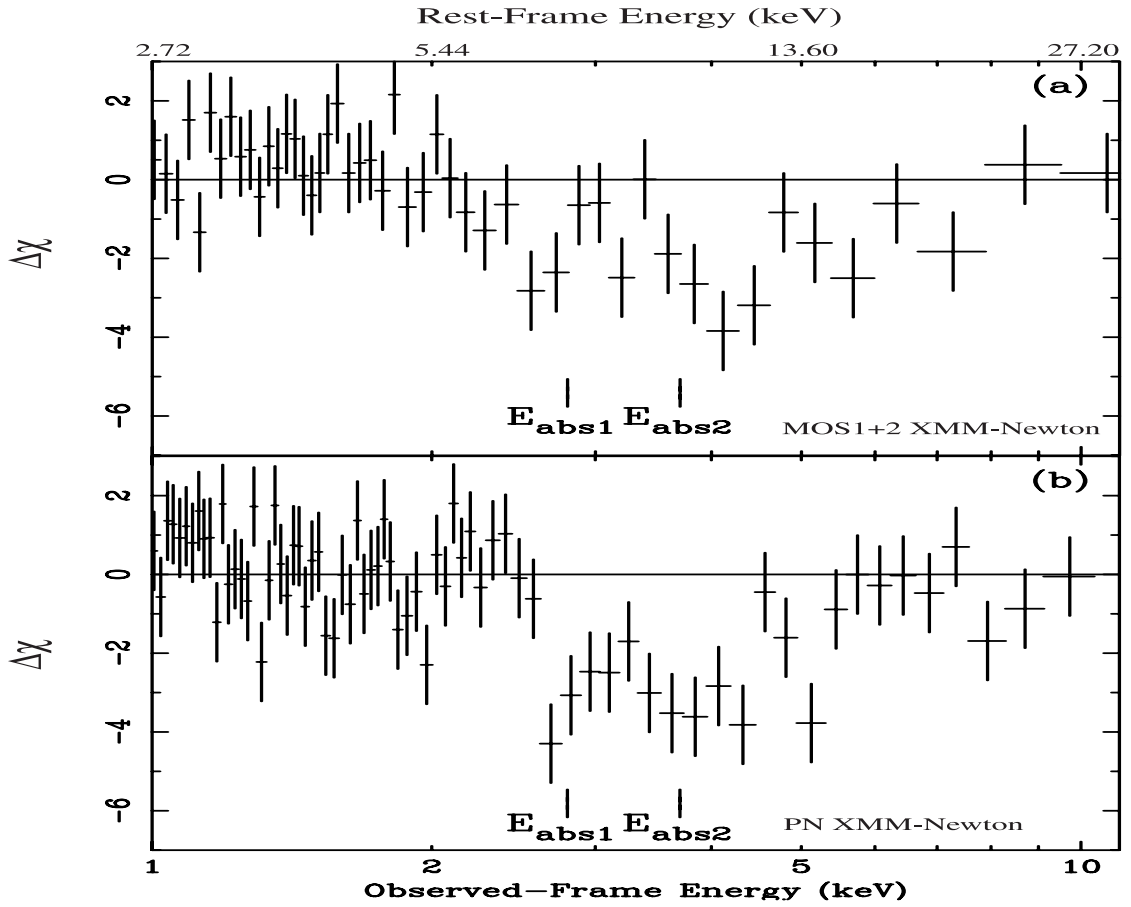
Quasar Outflows Observed in a mini-BAL Quasar



z = 1.72 PG 1115+080



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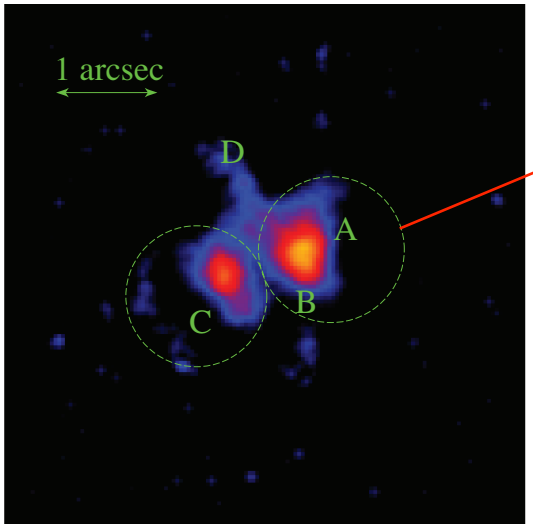
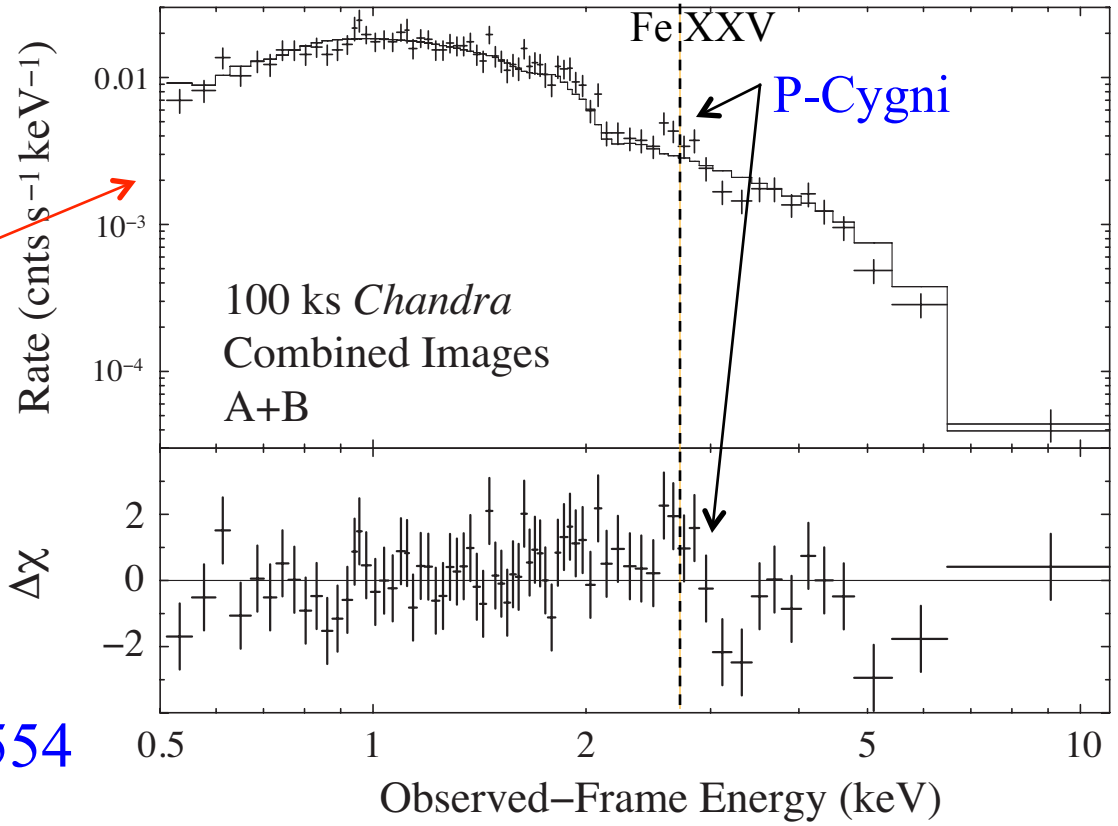
Quasar Outflows Observed in a NAL Quasar





NAL quasar HS 0810+2554

$z = 1.51$

$M_{BH} \sim 4 \times 10^8\ M_\odot$

$v_{\_X\text{-ray}} = 0.1c$

$v_{\_UV} = 0.06c$

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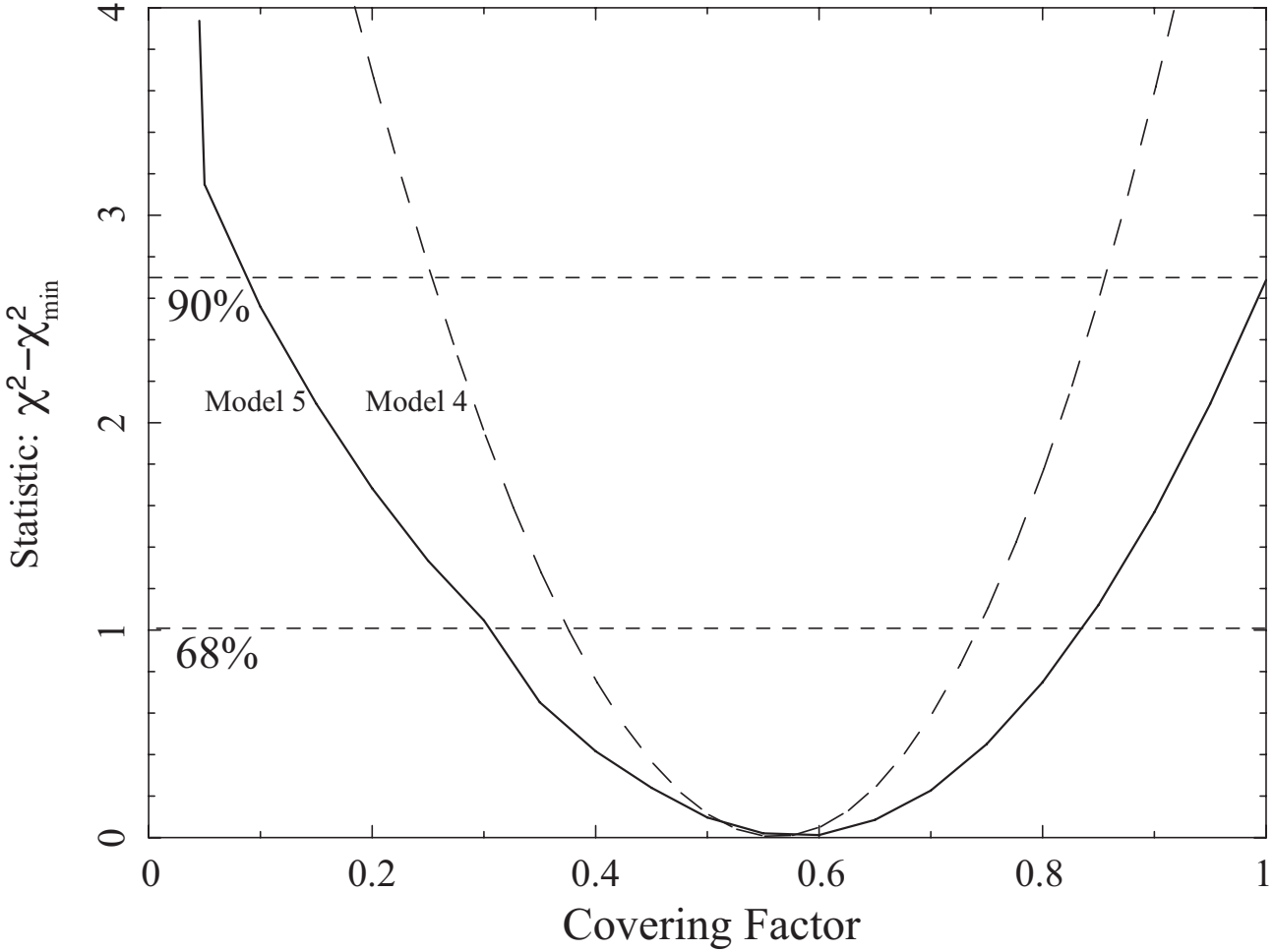
Wide-Angle Outflow of HS 0810



χ^2 confidence contour of the covering factor of the wind. The best-fit value of the covering factor is f_C = 0.6(-0.2,+0.3) (68%)

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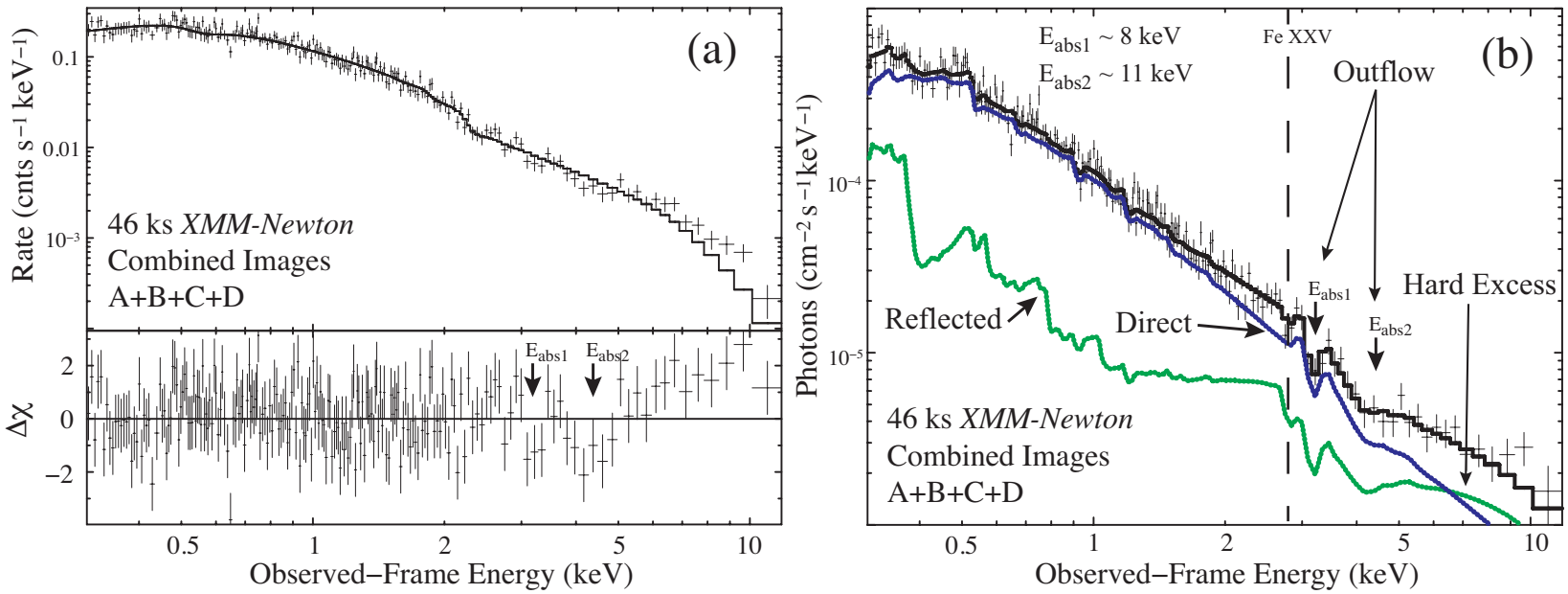
Relativistic Outflows in NAL Quasar HS 0810



(a) 46 ks XMM-Newton spectrum of all images of HS 0810+2554.

(b) shows the data shown in panel (a) overplotted with the unfolded best-fit model comprised of a photoionizaton (XSTAR) and reflection model (PEXMON).

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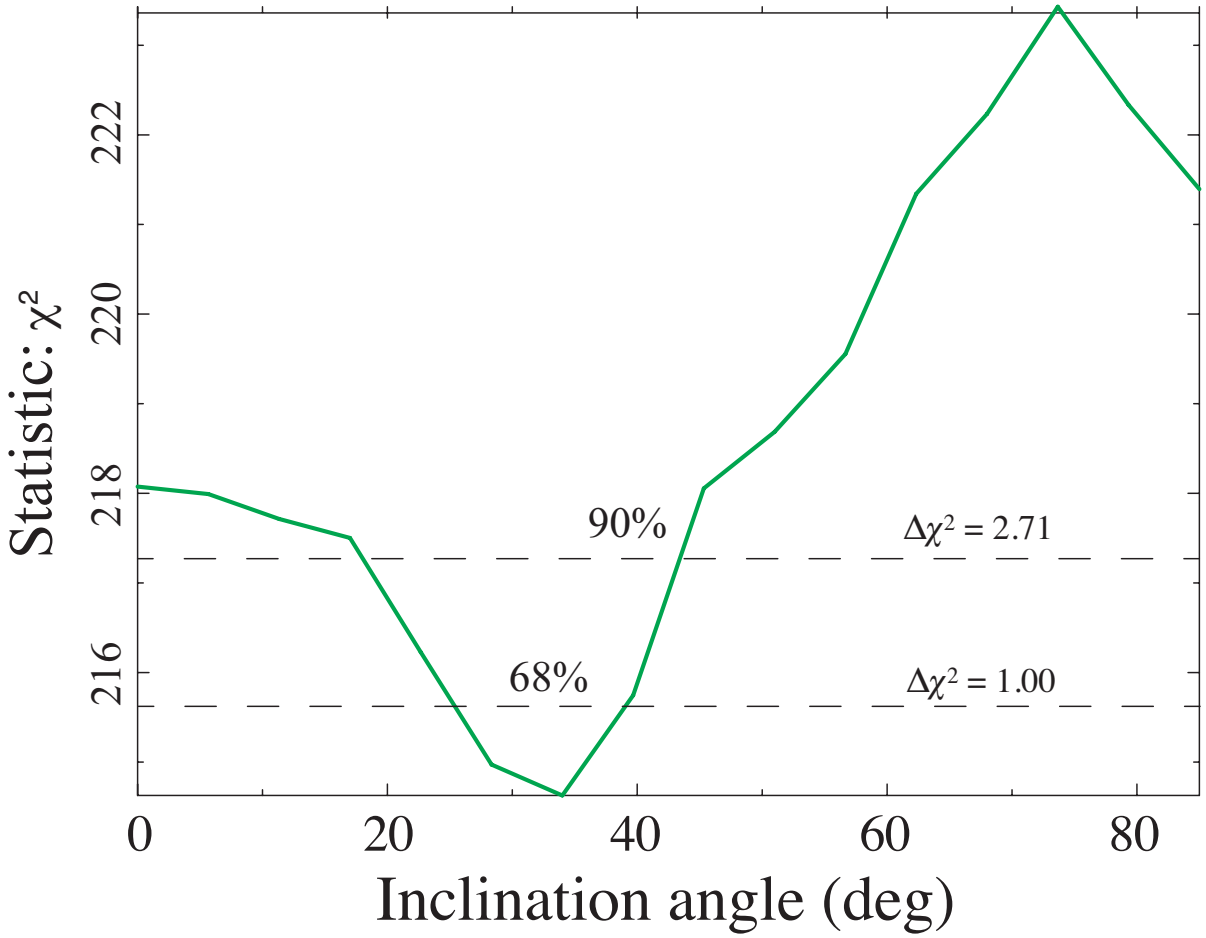
Relativistic Outflows in NAL Quasar HS 0810



Fits to the XMM-Newton spectrum of HS 0810 constrain the inclination angle of the accretion disk. The best-fit value of about ~ 30° is consistent with models that posit NALQSOs as objects observed at relative low inclination angles.

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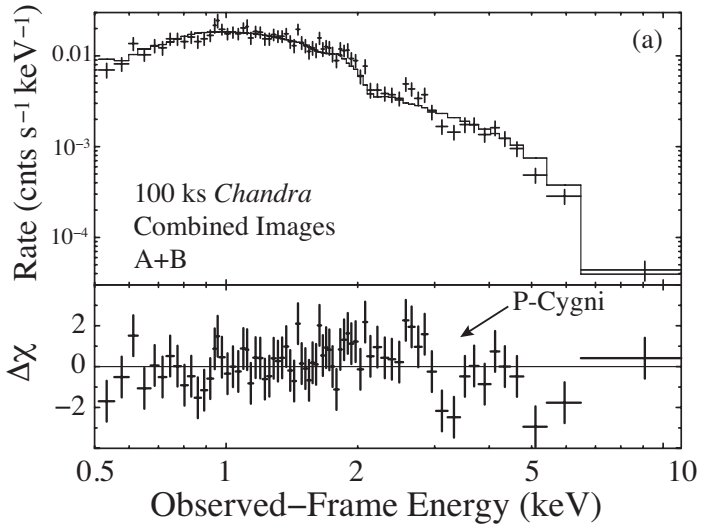
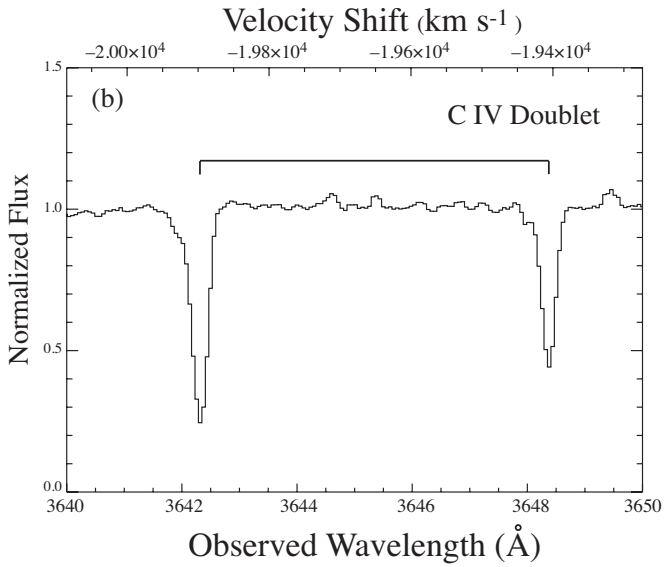
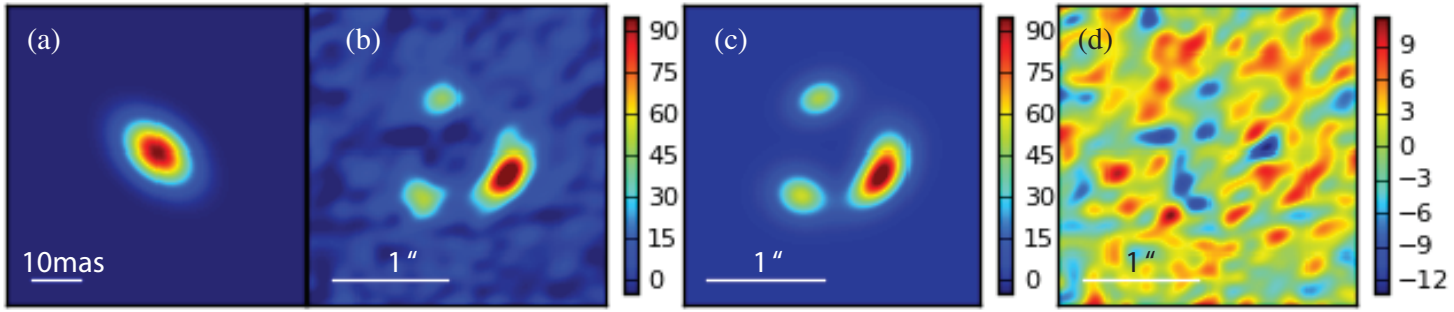
Small scale outflow in HS0810 may be driving a larger scale outflow



Chandra



VLT/UVES



8.4GHz VLA (Jackson et al. 2015)

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Winds in Lensed mini-BAL Quasars

We have recently initiated a mini X-ray survey of gravitationally lensed $z = 1.63 - 3.6$ SDSS mini-BAL quasars with *XMM-Newton*. The main goals are:

(a) Investigate whether relativistic outflows of X-ray absorbing material are a common property of mini-BAL quasars.

(b) Infer the range of outflow properties in a sample of mini-BAL quasars.

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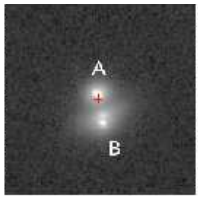
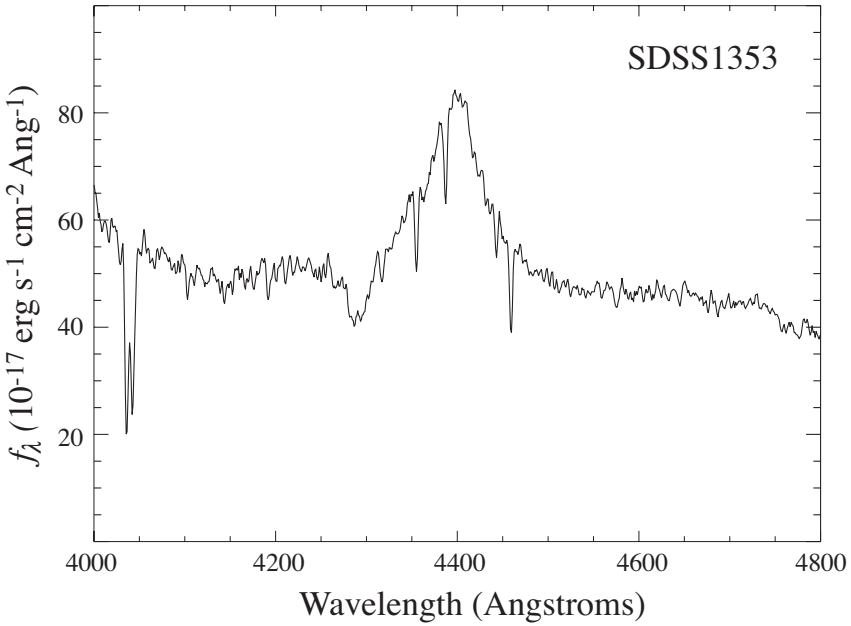
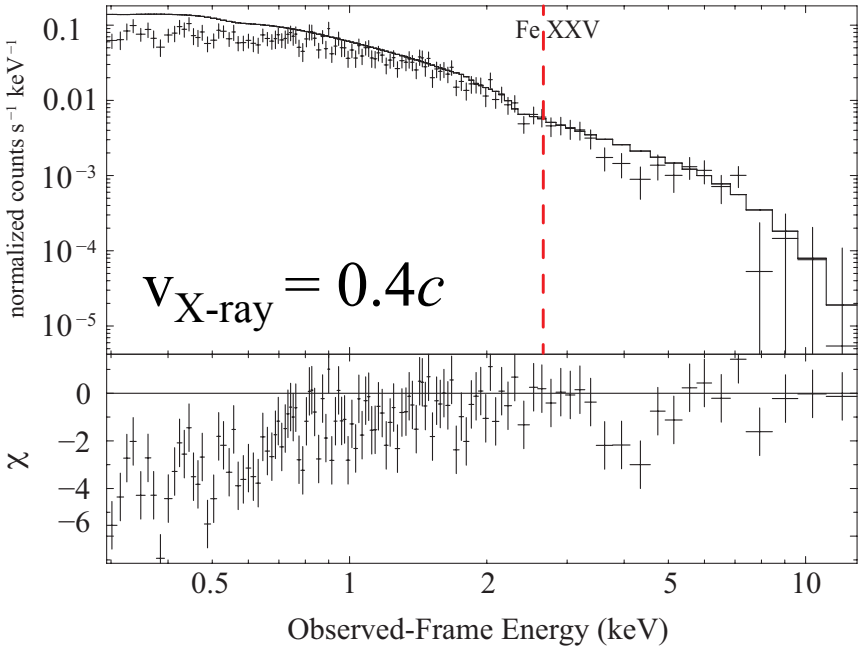
Winds in Lensed mini-BAL Quasar SDSS J1353



z = 1.63 SDSS J1353





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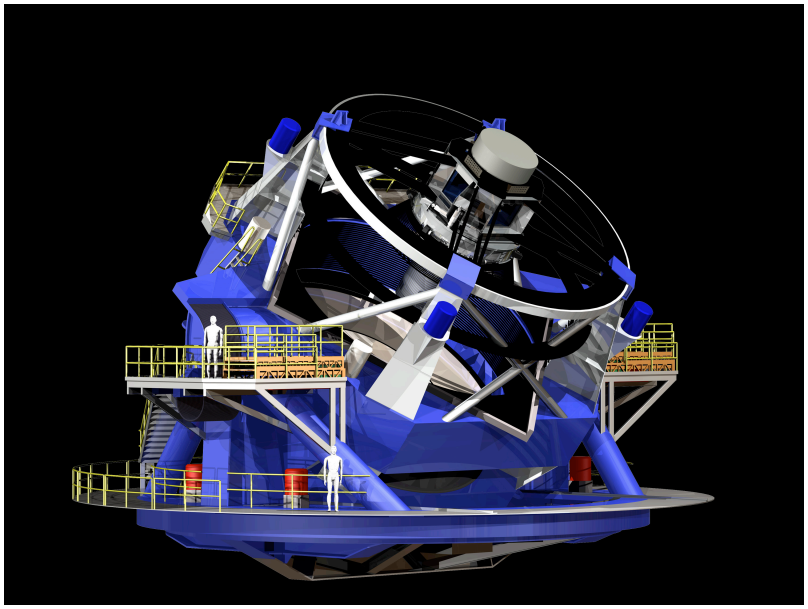
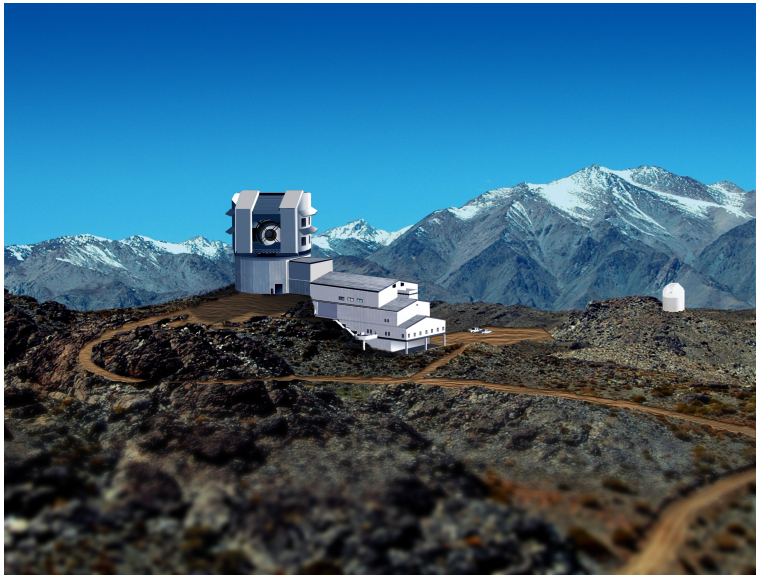
Looking Ahead





The Large Synoptic Survey Telescope(LSST) will discover ~ 4000 gravitationally lensed quasars that will allow:

- Statistical studies of black hole accretion disk sizes as a function of black hole mass
- Studies of the evolution of black hole disk sizes with redshift
- Studies of the evolution of the dark matter fraction of the lens galaxies with redshift
- Studies of the mean stellar mass in cosmologically distant galaxies.

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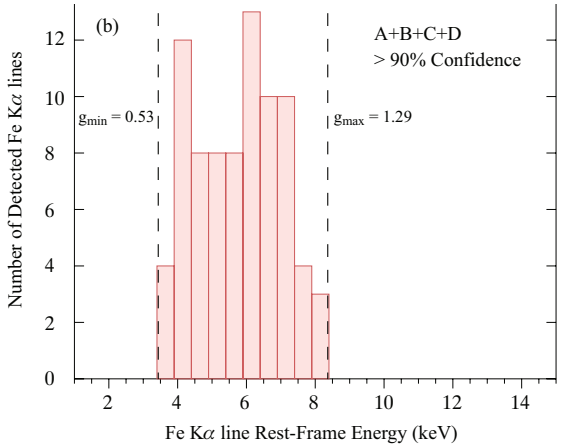
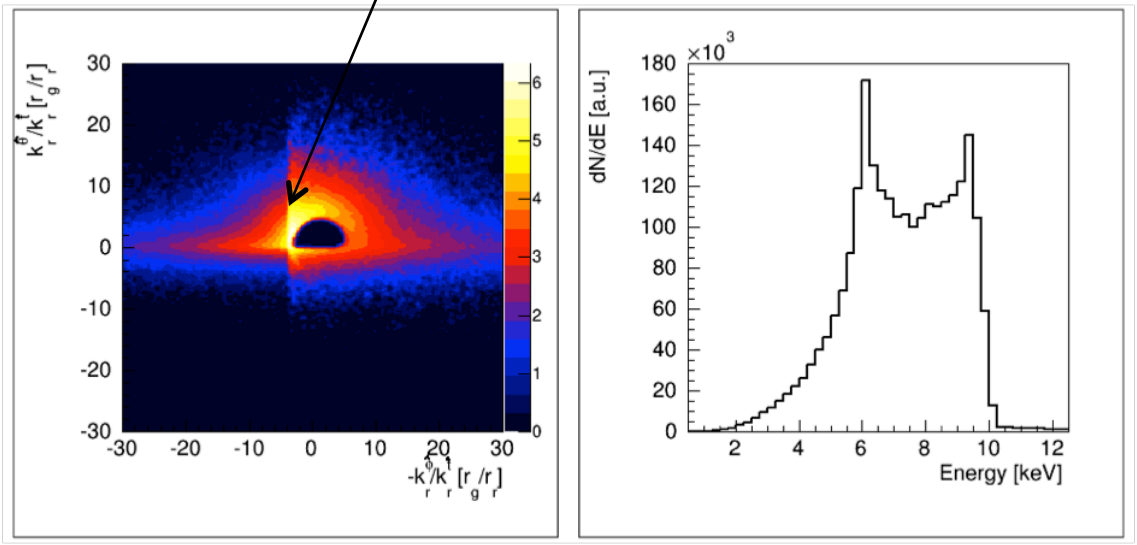
g-distribution method (see poster F13 by Lukas Zalesky)

The g-distribution method provides a new and independent technique of constraining the ISCO, black hole spin, and inclination angle in high redshift quasars by **measuring energy shifted iron lines**.



Fold Caustic



Krawczynski et al. 2016, in prep

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Looking Ahead

- **Increase the sample size of z > 1 quasars** with high S/N spectra to infer the frequency of winds in quasars near the peak of AGN activity.
- **Observe more z >1 lensed quasars** as they become available (ie LSST)
- Linking the energetics of **small scale** relativistic outflows to those of **larger scale molecular outflows**.
- Search for **correlations of outflow properties of z >1 quasars** with L_{Bol}/L_{Edd}, M_{BH}, SED
- Compare simulations and observations to better **understand the driving mechanism** of relativistic winds.
- Obtain **high-spectral resolution P-Cygni profiles** detected in quasar winds to infer their geometry.

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