Magnetic View of AGN Disk-Winds

<u>Keigo Fukumura</u> (James Madison University, USA) fukumukx@jmu.edu

Demos Kazanas (NASA/GSFC) Chris Shrader (NASA/GSFC) Francesco Tombesi (NASA/UMD) Ehud Behar (Technion, Israel) Ioannis Contopoulos (Academy of Athens, Greece)













1) X-Ray Absorbers ~ AGN Disk-Winds

2) Generic Features of MHD-driven Outflows

3) Observables4) Summary



Credit: The European Space Agency (ESA)

AGN Disk-Winds (WAs + UFOs)

Ubiquitous across diverse Seyferts/QSOs populations

→ Can learn

 [1] column: N_H
 [2] ionization: ξ = L_{ion}/(nr²)
 [3] LoS velocity: v_{LoS}
 [4] geometry, global property, disk physics, AGN feedback...

- WAs -V_{out} ~100 - 1,000 km/s log ξ ~ -1 to 4 N_H ~ 10²⁰⁻²² cm⁻²

~ UFOs (soft + Fe K) □ v_{out}/c ~ 0.1 – 0.7 □ log ξ ~ 3-6 □ N_H ~ 10²³⁻²⁴ cm⁻²



General Review: e.g.

Blustin+05, Reynolds+97, Laor&Brandt02, Crenshaw+03, Crenshaw&Kraemer12, Tombesi+13, Laha+(14,16)...etc.

Classical MHD Models: e.g. Blandford+Payne82 (BP82), Contopoulos+Lovelace94 (CL94), Konigl+Kartje94 (KK94)...etc.



Outstanding Questions

Flow Geometry?
 Continuous or patchy?
 Defining quantities?
 How are they launched?

Some "good" indicators for MHD-driven winds...

High ξ, v, N_H (UFOs) w/ gratings
 Flat (or slightly varying) <u>AMD</u>
 Insufficient force multiplier
 Process of elimination by "R" and "ξ"...



Absorption Measure Distribution (AMD)



What does AMD tell us?

$$n \propto r^{-p}, \qquad \xi \equiv \frac{L}{nr^2} \propto r^{p-2} \Rightarrow r \propto \xi^{\frac{1}{p-2}} \qquad \therefore \Delta N_H = n \cdot \Delta r \propto \xi^{-\frac{2p-3}{p-2}} \Delta \xi$$
$$AMD \equiv \frac{\Delta N_H}{\Delta(\log \xi)} = \xi \frac{\Delta N_H}{\Delta \xi} \propto \xi^{-\frac{p-1}{p-2}} \qquad v_{out} \propto \xi^{\frac{1}{2(2-p)}} \qquad \text{Behar09}_{\text{Kazanas+12}}$$

Hence, p~1 wind AMD ~ const \rightarrow n ~ r⁻¹ Favored by minimization argument of B-energy (B₀~ r⁻¹) in the disk. e.g. CL94, KK94

$$N_{H} = \int_{in}^{out} n(r) dr \propto \ln(r_{out}/r_{in})$$

Toroidal rotation efficiently converted into poloidal motion, □ Plasma accelerated along a field line while $V_{base} \sim V_{esc} \sim r^{-1/2}$ □ $N_{H} \sim const$ per decade in radius □ $v_{out} \sim \xi^{1/2}$

Kazanas+12

$$\dot{M} \approx nr^2 v \approx r^{-1} r^2 r^{-1/2} \approx r^{1/2}$$

$$\dot{E}_k = \dot{M} v^2 \propto r^{-1/2}, \dot{P} = \dot{M} v = const.$$

outflow rate 🗲 <u>exterior</u> kinetic power 🗲 <u>interior</u>

What does AMD tell us?

$$n \propto r^{-p}, \qquad \xi = \frac{L}{nr^2} \propto r^{p-2} \Rightarrow r \propto \xi^{\frac{1}{p-2}} \qquad \therefore \Delta N_H = n \cdot \Delta r \propto \xi^{-\frac{2p-3}{p-2}} \Delta \xi$$
$$AMD = \frac{\Delta N_H}{\Delta(\log \xi)} = \xi \frac{\Delta N_H}{\Delta \xi} \propto \xi^{-\frac{p-1}{p-2}} \qquad \qquad \text{Behar09}_{\text{Kazanas+12}}$$

What about other slope?

 p=3/2 for <u>BP82 MHD winds</u>
 → AMD~ξ, ξ~r^{-1/2}, v_{out} ~ ξ, N_H ~ r^{-1/2} (slowly dropping)
 p=2 for <u>spherical winds</u> & <u>asymptotically coasting radiative winds</u> As soon as wind reaches v~v_{coast}, ionization freezes at ξ ~ ξ_o
 → singular blueshift, monochromatic ξ
 → N_H ~ r⁻¹ (rapidly dropping)
 → AMD not a function of ξ (i.e. very narrow)

Are we seeing MHD-driven winds???

<u>Multi-λ campaign of Mrk 509</u>



Indicating magnetic-origin?

WAs in NGC 4151



Magnetized Disk-Wind Models

(e.g. Fukumura+10a,b,14,15)

Steady-state, axisymmetric ideal MHD eqns. (P_{rad}=0)



Toroidal (Keplerian) to poloidal motion transition.

Magnetic Disk-Wind Models

(e.g. Fukumura+10a,b,14,15)

Steady-state, axisymmetric ideal MHD eqns. (P_{rad}=0)

Disk treated	$ abla \cdot (ho \mathbf{v}) = 0$	$({\rm mass\ conservation})$,	$n(r, \theta) \equiv rac{ ho(r, heta)}{r} = n_o x^{2q-3} \mathcal{N}(heta)$
as BC	$ abla imes {f B} = {{4\pi}\over{c}}{f J}$	(Ampere's law) ,	μm_p
	$\mathbf{E} + \frac{\mathbf{v}}{\mathbf{c}} \times \mathbf{B} = 0$	(ideal MHD) ,	$N_{H}(\Delta r, heta) ~\equiv~ \int_{\Delta r} n(r, heta) dr$
	$\widetilde{ abla} imes \mathbf{E}=0$	(Faraday's law) ,	$\Psi(r,\theta) = (r/r_{\theta})^{q} \psi(\theta) \Psi_{\theta} ,$
$ ho(\mathbf{v}\cdot abla)\mathbf{v}=- abla\mathbf{p}- ho$	$\nabla \Phi_{\mathbf{g}} + rac{1}{c} (\mathbf{J} imes \mathbf{B})$	(momentum conservation),

Generic MHD-Wind Properties

Mass-invariant (across XRBs and AGNs)
 Inner part of the wind is inherently near-relativistic
 Accommodate both UFOs (inner) and WAs (outer)
 SED (e.g. Γ and α_{OX}) "breaks" mass-invariant!
 allows for diverse ionization structure!

WAs in XRB GRO J1655-40



density slope: n ~ r $^{-1.2}$ \rightarrow control global feature



Fukumura+17, Miller+(06,08), Kallman+09

Magnetic WAs in XRB GRO J1655-40

 $\mathbf{O}_{\text{obs}} = 80^{\circ}$

♦ n_o = 9.3e17 cm⁻³

MHD-driven XRB winds

accretion disk

X-ray winds

density slope: n ~ r $^{-1.2}$ \rightarrow control global feature

We calculate progressive spectra along LoS



Fukumura+17, Nature Astronomy, 230th AAS Press Release (Texas)

Fe K UFO in PG 1211+143



 $\begin{array}{ll} \underline{\text{Best-fit MHD wind model with } r^{-1}:} & \alpha_{\text{OX}} = -1.5 \text{ assumed} \\ \theta_{\text{obs}} = 49^{\circ} \\ N_{\text{H}}(\text{FeXXV}) = 1.2 \times 10^{23} \text{ cm}^{-2}, \log \xi_{\text{c}} = 5.3, \text{ v/c} = 0.115 \\ R(\text{FeXXV}) = 235 \text{ R}_{\text{S}}, \text{ R}_{\text{trunc}} = 29.3 \text{ R}_{\text{S}} \\ M_{\text{out}}(\text{FeXXV}) = 2.56 \text{Msun/yr}, \quad \chi^2/\text{dof} = 198.54/128 \\ \end{array}$

Faster layer of MHD-winds (at smaller radii) is inherently present regardless of $L/L_{edd} \rightarrow Outflow$ velocity Func(F_v and θ)

QSO: Velocity vs. Ionizing SED



Faster layer of MHD-winds (at smaller radii) can be "visible" → Outflow velocity depends on SED hardness

<u>Magnetic WAs in NGC 3783</u>

900 ks (stacked) Chandra/HETG/METG spectrum

Kaspi+02



n~ r^{-1.15} to r^{-1.29} derived from AMD Behar+09

Kaspi+01

SED (PL: $\Gamma_{\rm X} \sim 1.8$)

 $L_{ion} = 1.5e43 \text{ erg/s}$

WAs in NGC 3783

(MHD-wind solutions) + (AMD) + (xstar) \rightarrow spectra

1 co271ya1 17.812 17.855 4.8677 3.8287 4.86513 6.17466 6.0899 6.9999 6.09913 6.06913469 1.4602.10 ¹⁰ 6.52574 3.4287 6.12393 6.09913469 1.6503.10 ¹⁰ 6.52574 3.42475 16.617 1 17.174 17.652 16.8133 4.57776 3.90439 5.08634 6.22371 6.13939 0.099134679 1.5513.412 6.0324 4.22 1.644.91 5 f2640y1 17.812 17.0313 4.35776 3.72214 4.79976 6.12399 6.04136 0.422322 1.50617 1.54158.40 ² 6.04324 4.22 1.644.91 6 f264111 15.532 1.2158 5.57776 3.92994 3.67655 6.22867 0.40913464 7.2087.814 ² 3.16175 232.54 1 m7251yb1 17.929 17.2691 5.8776 3.6764 6.42374 6.22467 0.40913469 1.3872.16 ²⁷ 5.8324 4.0775 1483.31 1 m7251yb1 17.982 <th></th> <th>Ion</th> <th>$log(r_p)$</th> <th>$log(r_{1/2})$</th> <th>log(r/rs)_p</th> <th>$log(\xi_{min})$</th> <th>$\log(\xi_{max})$</th> <th>log(T_{min})</th> <th>$log(T_{max})$</th> <th>τ_p</th> <th>NHtot</th> <th>$log(n_p)$</th> <th>$log(\xi_p)$</th> <th>$v_{out,p}[km/s]$</th>		Ion	$log(r_p)$	$log(r_{1/2})$	log(r/rs) _p	$log(\xi_{min})$	$\log(\xi_{max})$	log(T _{min})	$log(T_{max})$	τ _p	NHtot	$log(n_p)$	$log(\xi_p)$	$v_{out,p}[km/s]$
2 cocluya 18.262 17.8333 5.30776 3.66974 4.20235 6.0989 0.00043544 7.27787.10 ²¹ 5.5218 4.5775 6.21216 1 11274ea1 18.172 17.6922 5.21776 3.59499 4.08776 6.1637 4.09233.10 ³ 1.74423.10 ²⁷ 5.62394 4.222 1644.498 6 6.613 6.0221632 1.74423.10 ³ 5.60674.40 ² 5.60274 6.04334 4.22 1644.498 7 6.75140,11 18.532 18.248 5.37776 3.75214 4.67966 6.23246 6.30642 0.11074 2.21694.4.10 ¹⁸ 5.42242 3.16175 2823.75 7 6.75140 18.532 18.2163 5.37776 3.93692 3.6763 6.23246 6.30644 0.110744 2.21694.4.10 ¹⁹ 5.13173 3.6823 1.337714 4.0765 5.03776 3.6763 6.22246 6.30644 0.0116143 1.337714 4.07675 4.07075 4.0717 4.0833 4.07775 4.0213.376 18.6421 <th>1</th> <th>co27Lya1</th> <th>17.812</th> <th>17.0555</th> <th>4.85776</th> <th>3.82857</th> <th>4.86513</th> <th>6.17846</th> <th>6.60909</th> <th>0.000124049</th> <th>1.46002×10^{22}</th> <th>6.04324</th> <th>4.22</th> <th>1813.44</th>	1	co27Lya1	17.812	17.0555	4.85776	3.82857	4.86513	6.17846	6.60909	0.000124049	1.46002×10^{22}	6.04324	4.22	1813.44
3 n121ypa1 17.652 10.813 4.7776 3.9943 5.06654 6.22471 6.6339 0.000710879 1.5516.10 ²⁷ 6.52284 4.3725 2021.16 5 fr26Lypa1 17.812 17.0833 4.8776 3.75294 4.8796 6.12939 6.6138 0.022562 1.56458.10 ²⁷ 6.6334 4.22 1044.67 6 fr26Lypa1 17.812 17.0833 4.8776 3.75274 4.7996 6.12989 0.018074 7.5222.10 ²⁴ 5.64324 4.22 1044.67 7 fr22Lya1 18.352 18.2164 5.97776 3.99299 3.7663 6.22641 0.18074 7.2227.40 ²⁴ 5.21554 3.10175 2027.54 10 fr24Lia2 18.532 18.2164 5.97776 3.02929 3.67649 6.22674 0.011161 3.3377.41 ³⁵ 5.81324 4.0775 448.18 11 m25Lyba1 17.092 17.2661 5.93776 3.0417 4.62246 6.29776 0.011161 3.347775 4.82124	2	co26Lya	18.262	17.8333	5.30776	3.68974	4.20235	6.0989	6.39989	0.00045354	7.27978×10^{21}	5.52574	3.84075	1768.72
4 n1274ea1 18.172 17.6892 5.1776 3.52944 4.38374 6.61276 6.6233 1.02833.10 ⁻² 1.50867.1423.10 ²¹ 6.6294 4.22 1644.69 5 fc2clypl 17.6121 17.6385 4.85776 3.7221 4.67997 6.1296 6.61296 0.0046066 1.51459.16 ²² 6.6424 4.22 1644.67 7 fc2clypl 13.252 13.2164 5.97776 3.2994 3.67655 6.2986 0.0016074 2.20873.16 ²¹ 5.11674 3.61875 2021.79 7 fc2clypl 17.6920 13.7164 5.97776 3.2994 3.67655 6.2383 6.00174 6.00174.06 ²¹ 5.21624 3.61875 2021.79 10 fc2clypl 17.2992 17.2092 13.7167 3.6763 6.2734 6.9017 6.90174 1.3776.19 ¹² 5.30274 3.61874 4.9918 11 mr2dlypl 17.2092 13.7277 3.6174 4.9593 6.4226 6.53276 0.900134255 1.377991 5.31874 4.6927 5.3774 3.99 352.63 11 m	3	ni28Lya1	17.632	16.8183	4.67776	3.90439	5.06634	6.22471	6.6393	0.000718679	1.56316×10^{22}	6.25024	4.3725	2021.18
5 fc2clyal 17.812 17.812 17.833 4.85776 3.75291 4.87977 6.12939 6.6139 0.08046085 1.5687.16 ²¹ 6.64324 4.22 1644.67 7 fc2clya 18.352 17.6444 5.35776 3.47369 4.12396 6.6139 0.08046085 1.51459 1.62243 6.12674 4.222 3.761 1.332.27 9 fc2clya 18.322 18.2164 5.57776 3.29299 3.87649 6.22346 0.0807146 2.2167.142 5.12174 3.61875 2922.4 10 fc2clyal 17.7291 5.63776 3.6782 4.68396 6.29376 0.40973469 3.1372.122 5.83724 4.67075 1499.38 11 mc2lyal 18.492 18.4067 5.46376 3.47649 6.23274 6.4091346 0.4012745 5.83724 4.67075 1499.38 11 mc2lyal 18.492 18.4071 18.4993 5.4776 6.49132 6.5976 6.4447102 5.93726 6.4447102 <	4	ni27Hea1	18.172	17.6692	5.21776	3.52954	4.33874	6.01276	6.46257	4.89233×10^{-9}	1.74423×10^{17}	5.62924	3.9125	1216.11
6 f=221,ya 16.322 17.842 17.0335 4.85776 3.47266 6.1239 6.64228 0.04046565 1.54159×10 ⁻²¹ 6.42244 4.22 1.54116 7 f=221,ya 16.352 18.2163 5.57776 3.47663 6.22341 6.26646 0.0106764 2.2087×10 ²¹ 5.2124 3.61075 2032.79 9 f=241+i3 16.532 18.2165 5.57776 3.29298 3.87655 6.22341 6.20676 0.0097164 2.2087×10 ²¹ 5.2124 3.61075 2032.43 11m mm251,yal 17.992 17.2692 5.03776 3.6721 4.65266 6.09133 6.50976 0.0000536980 1.33672×10 ²⁷ 5.33624 4.07075 1489.18 11m m251,ybl 16.082 17.376 5.12776 3.64124 4.98936 6.04228 6.54361 0.0001772 1.7484.11 ²⁹ 5.7374 3.99 1352.46 11f c.2201,yal 18.522 17.7093 5.39776 3.64224 4.30329 5.89576 6.44611 0.0001772 1.7484.11 ²¹ 5.7374 3.99 1352.46	5	fe26Lya1	17.812	17.0383	4.85776	3.75291	4.87977	6.12403	6.613	0.0252632	1.50687×10^{22}	6.04324	4.22	1644.98
$ \begin{array}{c} 7 \\ 7 \\ 7 \\ 7 \\ 7 \\ 7 \\ 7 \\ 7 \\ 7 \\ 8 \\ 7 \\ 8 \\ 7 \\ 8 \\ 7 \\ 8 \\ 7 \\ 8 \\ 7 \\ 8 \\ 7 \\ 8 \\ 7 \\ 8 \\ 7 \\ 8 \\ 7 \\ 7$	6	fe26Lyb1	17.812	17.0385	4.85776	3.75274	4.87968	6.12399	6.61298	0.00406868	1.54159×10^{22}	6.04324	4.22	1644.67
8 fe24(is1 15.522 18.2163 5.97776 3.93902 3.87663 6.22341 6.20664 0.9106764 2.21034 0.52154 3.61075 2922.75 10 fe24(is2 18.532 18.2164 5.57776 3.92989 3.87649 6.22341 6.20676 0.09071464 2.20778.10 ²¹ 5.21524 3.61075 2922.4 11 mn25Lyb1 17.992 17.2692 5.03776 3.6761 4.68296 6.09133 6.56976 0.090534930 1.33672.10 ²² 5.83624 4.0775 1499.18 13 mn24 18.442 16.0907 3.61134 4.59903 6.04286 6.54366 0.000167621 1.27999.10 ²² 5.73274 3.99 3352.63 14 cr24Lyb1 18.082 17.7083 5.9776 3.21899 4.30323 5.98766 6.0427407 1.14461.10 ²² 5.73274 3.99 3352.46 17 cr20Lyb1 18.352 17.7093 5.9776 3.28894 4.30323 5.98756 6.44510 0.6047	7	fe25Lya	18.352	17.8444	5.39776	3.47369	4.19296	5.98782	6.39428	0.111074	7.52022×10^{21}	5.42224	3.76	1130.27
9 fe24(in2 18.522 18.2164 5.87776 3.92994 3.87655 6.22336 6.20675 0.80871464 2.20873.16 ²¹ 5.21524 3.61075 2022.58 11 mm251ya1 17.992 17.2691 5.03776 3.6722 4.68206 6.0913 6.5698 6.09033458 1.33778.16 ²¹ 5.83624 4.0775 1493.38 11 mm24 18.442 18.0807 5.48776 3.6714 4.68206 6.09127 6.5676 6.090053608 1.33778.16 ²¹ 5.31874 3.6625 2979.98 13.52.44 11 cr241yp1 18.082 17.3761 5.12776 3.61125 4.58993 6.04255 6.54361 0.00017022 1.2794.18 ²² 5.73274 3.99 1352.46 11 cc201yp1 18.352 17.7093 5.39776 3.28969 4.30338 5.8976 6.44515 0.00074207 1.14461.10 ²² 5.42224 3.76 88.1.143 11 cc201yb1 18.352 17.7995 3.28969 4.1327 5	8	fe24Lia1	18.532	18.2163	5.57776	3.93002	3.87663	6.22346	6.20684	0.0106764	2.21034×10^{21}	5.21524	3.61075	2032.79
	9	fe24Lia2	18.532	18.2164	5.57776	3.92994	3.87655	6.22341	6.20679	0.00791046	2.20873×10^{21}	5.21524	3.61075	2032.58
11 mm25(ya1 17.992 17.2691 5.03776 3.6782 4.68296 6.69127 6.56976 0.000334953 1.33778.10 ²² 5.83624 4.47075 1489.38 13 mm24 18.442 18.0087 5.40776 3.07871 4.66206 6.09127 6.56976 0.00033493 1.33778.10 ²¹ 5.33672 4.47075 1493.18 14 cr24Lya1 18.082 17.3761 5.12776 3.61125 4.58993 6.04225 6.54366 0.0001702 1.2794.16 ²² 5.7274 3.99 1352.46 15 cr23Lya1 18.352 17.7093 5.30776 3.28969 4.9338 5.93766 6.44515 0.0007207 1.18461.16 ²² 5.4224 3.76 880.979 113 callya1 18.322 18.493 5.93776 3.28969 4.1023 5.7779 6.11057 0.00423161 0.00423421 6.02948.16 ²¹ 4.80124 3.3 627.952 12 callya1 18.622 17.393 5.60776 3.0256 3.1117 5.77895 6.1057 0.00423421 0.02948.16 ²¹ 4.80124 3.3 <th>10</th> <th>fe24Lia3</th> <th>18.532</th> <th>18.2165</th> <th>5.57776</th> <th>3.92989</th> <th>3.87649</th> <th>6.22336</th> <th>6.20676</th> <th>0.00111161</th> <th>2.2677×10^{21}</th> <th>5.21524</th> <th>3.61075</th> <th>2032.4</th>	10	fe24Lia3	18.532	18.2165	5.57776	3.92989	3.87649	6.22336	6.20676	0.00111161	2.2677×10^{21}	5.21524	3.61075	2032.4
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	11	mn25Lya1	17.992	17.2691	5.03776	3.6782	4.68206	6.09133	6.5698	0.000334358	1.33778×10^{22}	5.83624	4.07075	1489.38
mr.14 mr.24 ls.42 ls.42 ls.48776 s.18776 s.1134 4.59993 6.64288 6.64288 6.64361 0.00017672 1.2799×112 ²¹ 5.73274 3.99 ls352.46 16 cr.231yal ls.852 17.7093 5.39776 3.28969 4.30338 S.99776 6.44515 0.00017672 1.18461.16 ¹²² 5.42224 3.76 881.143 17 c.201yla ls.852 17.7094 5.93776 3.0216 3.71473 5.73951 6.11657 0.00421906 6.02496.10 ²¹⁴ 4.80124 3.3 677.352 20 calslya ls.622 ls.631 3.0956 4.11226 5.73696 6.34584 0.01930335 1.0736×.10 ²² 5.11174 3.53 684.064 22 ar181yal ls.622 17.9393 5.66776 3.0958 4.11226 5.73697 6.34584 0.0193035 1.0736×.10 ²² 5.11174 3.53 683	***12	mn25Lyb1	17.992	17.2692	5.03776	3.6781	4.68196	6.09127	6.56976	0.0000536903	1.33672×10^{22}	5.83624	4.07075	1489.18
14 $(r^241ya1$ 18.082 17.376 5.12776 3.61134 4.59093 6.04295 6.54366 0.0001702 1.2799×10 ²² 5.73274 3.99 1352.63 15 $(r^241yb1$ 18.082 17.761 5.1125 4.59093 6.04295 6.54366 0.0001702 1.2799×10 ²² 5.73274 3.99 1352.63 17 $(ra21ya1$ 18.522 17.7093 5.37776 3.28094 4.30329 5.89566 6.44511 0.00012017 1.1846*.10 ²² 5.42224 3.76 881.979 20 $(ra191ya)$ 18.852 17.7093 5.93776 3.02266 3.71421 5.73579 6.11057 0.60423107 1.1846*.10 ²² 5.42224 3.76 880.979 21 $(ra191ya)$ 18.682 18.483 5.93776 3.02266 3.71421 5.73579 6.110857 0.60423107 1.1846*.10 ²² 5.11174 3.53 684.064 22 $ar181ya1$ 18.622 17.73992 5.66776 3.09569 4.11226 5.7376 6.34584 0.00671 0.0831345 5.5144*.10 ²¹ 4.51638 3.08825 <th>***13</th> <th>mn24</th> <th>18.442</th> <th>18.0087</th> <th>5.48776</th> <th>3.94677</th> <th>4.05624</th> <th>6.25274</th> <th>6.32476</th> <th>0.00125745</th> <th>6.84×10^{21}</th> <th>5.31874</th> <th>3.6825</th> <th>2079.98</th>	***13	mn24	18.442	18.0087	5.48776	3.94677	4.05624	6.25274	6.32476	0.00125745	6.84×10^{21}	5.31874	3.6825	2079.98
15 cr24Lybl 18.082 17.3761 5.12776 3.61125 4.5093 6.04288 6.54361 0.000176702 1.279 $\times 10^{22}$ 5.73274 3.99 1352.46 .16 cr21Lyal 18.532 18.099 5.57776 3.2462 5.97455 5.9268 6.2777 0.00042181 6.6477.10 ²¹ 5.21524 3.61075 94.147 17 c202Lyal 18.532 17.7094 5.39776 3.22899 4.3033 5.80576 6.44515 0.000923117 1.18461 $\times 10^{22}$ 5.42224 3.76 881.143 c302Lybl 18.522 17.7094 5.39776 3.02206 3.71473 5.73551 6.11057 0.0049246 6.02948 10^{21} 4.80124 3.3 677.352 20 c319Lyb 18.592 18.403 5.93776 3.02133 3.71421 5.73979 6.11035 0.00421422 6.02395 10^{21} 4.80124 3.3 677.093 21 ar18Lyal 18.622 17.9392 5.66776 3.0958 4.11226 5.76697 6.3458 0.01388 1.07437 $\times 10^{22}$ 5.11174 3.53 684.064 .***22 ar18Lyal 18.622 17.9333 5.66776 3.09589 4.11226 5.78979 6.63458 0.013831 5.107395 10^{21} 5.11174 3.53 684.064 .***24 ar18Lyal 18.622 17.9333 5.66776 3.09589 4.11227 5.78979 6.64561 0.083335 5.1447 $\times 10^{32}$ 5.11174 3.53 683.943 24 al6(yal 18.6988 18.1832 5.94451 2.89993 3.9034 5.66653 6.22398 0.016298 9.363854 5.5144 $\times 10^{31}$ 4.79348 3.29475 532.28 21 ar18Lybl 18.6988 18.1834 5.94451 2.89993 3.90303 5.66652 6.2239 0.016593499 9.35845 $\times 10^{21}$ 4.79348 3.29475 532.28 21 al6(yg 18.8988 18.1834 5.94451 2.89993 3.90303 5.66652 6.2239 0.00593499 9.35845 $\times 10^{21}$ 4.79348 3.29475 532.28 21 al14Lyal 19.1618 18.4741 6.20757 2.68552 3.65547 5.37626 6.67844 0.020140 8.24274 $\times 10^{21}$ 4.49906 3.06631 405.93 21 al14Lyal 19.1618 18.4743 6.20757 2.68552 3.65547 5.37626 6.67844 0.020140 8.24274 $\times 10^{21}$ 4.49906 3.06631 405.83 31 al14Lyd 19.1618 18.4743 6.20757 2.68552 3.65547 5.37626 6.67844 0.020140 8.24274 $\times 10^{21}$ 4.49906 3.06631 405.83 33 fc23 18.7188 19.0037 5.76451 3.7024 3.20980 6.20356 6.2036 6.07844 0.020140 8.24274 $\times 10^{21}$ 4.49906 3.06631 405.83 34 fc22 18.802 19.1607 5.64776 3.12114 3.06533 5.80151 5.77724 0.076628 10.13871 $\times 10^{21}$ 4.49947 3.3725 710.512 35 fc225253527 18.802 19.1607 5.74751 3.72424 5.9269 6.30547 5.73726 6.67844 0.020140 8.22474 $\times 10^{21}$ 4.49947 3.3725 710.512 36	14	cr24Lya1	18.082	17.376	5.12776	3.61134	4.59003	6.04295	6.54366	0.00110235	1.27999×10^{22}	5.73274	3.99	1352.63
16 $cr231ya1$ 18.53218.6995.577763.341623.074555.92268 6.27776 0.06423181 6.4647×10^{-1} 5.15124 3.16075 948.147 17 $ca201yb1$ 18.35217.70945.39776 3.28994 4.30338 5.89576 6.44515 0.06923117 1.18461×10^{-2} 5.42224 3.76 880.147 19 $ca101ya$ 18.89218.403 5.93776 3.02266 3.71473 5.73561 6.11057 0.62948×10^{-21} 4.80124 3.3 677.352 20 $ca101yb$ 18.62217.9392 5.66776 3.0958 4.11226 5.73597 6.1035 0.0608335 1.07396×10^{-22} 5.11174 3.53 664.664 22 $ar181yb1$ 18.62217.9393 5.66776 3.0958 4.11227 5.78597 6.3458 0.0638325 1.67396×10^{-22} 5.11174 3.53 664.664 22 $ar17$ 19.1378 18.64 6.10351 3.60896 3.51467 6.0929 6.06671 0.0831345 5.5144×10^{-21} 4.5163 3.08825 1276.68 224 $ar161$ 18.988 18.1834 5.94451 2.89993 3.90335 5.6652 6.2239 0.0633499 3.5388×10^{-21} 4.79348 3.29475 532.282 225 $s161y11$ 18.9888 18.1834 5.94451 2.89923 3.90335 5.66526 6.2239 0.6053149 3.5388×10^{-21} 4.79348 3.29475	***15	cr24Lyb1	18.082	17.3761	5.12776	3.61125	4.58993	6.04288	6.54361	0.000176702	1.2794×10^{22}	5.73274	3.99	1352.46
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	***16	cr23Lya1	18.532	18.099	5.57776	3.34162	3.97455	5.92268	6.27776	0.00423181	6.6487×10^{21}	5.21524	3.61075	948.147
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	17	ca20Lya1	18.352	17.7093	5.39776	3.28909	4.30338	5.89576	6.44515	0.00574207	1.18461×10^{22}	5.42224	3.76	881.143
	^^^18	ca20Lyb1	18.352	17.7094	5.39776	3.28894	4.30329	5.89568	6.44511	0.000923117	1.18406×10^{22}	5.42224	3.76	880.979
$ \begin{array}{c} 2.0 \\ c_{1}91yb \\ 18, 892 \\ 18, 4936 \\ 18, 622 \\ 17, 9393 \\ 5, 66776 \\ 3, 09569 \\ 4, 11227 \\ 5, 78597 \\ 6, 30958 \\ 4, 11227 \\ 5, 78597 \\ 6, 3458 \\ 0, 00308335 \\ 1, 07396 \times 10^{22} \\ 5, 11174 \\ 3, 53 \\ 684, 664 \\ 4, 11217 \\ 5, 78597 \\ 6, 3458 \\ 0, 00308335 \\ 1, 07396 \times 10^{22} \\ 5, 11174 \\ 3, 53 \\ 684, 964 \\ 4, 79348 \\ 3, 29475 \\ 532, 342 \\ 4, 79348 \\ 3, 29475 \\ 532, 342 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 79348 \\ 3, 29475 \\ 532, 283 \\ 14, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 996 \\ 3, 06631 \\ 405, 883 \\ 140, 966 \\ 3, 06831 \\ 405, 883 \\ 140, 986 \\ 3, 06831 \\ 405, 883 \\ 140, 986 \\ 3, 06831 \\ 405, 883 \\ 140, 986 \\ 3, 06831 \\ 405, 883 \\ 140, 986 \\ 3, 06831 \\ 405, 883 \\ 140, 947 \\ 3, 3725 \\ 7, 10, 516 \\ 140, 996 \\ 3, 06831 \\ 405, 883 \\ 140, 947 \\ 3, 3725 \\ 7, 10, 516 \\ 140, 996 \\ 3, 06831 \\ 405, 883 \\ 140, 947 \\ 3, 3725 \\ 7, 10, 516 \\ 140, 996 \\ 3, 06831 \\ 405, 883 \\ 140, 947 \\ 3, 3725 \\ 7, 10, 516 \\ 140, 947 \\ 3, 3725 \\ 7, 10, 516 \\ 140, 947 \\ 3, 3725 \\ 7, 10, 516 \\ 140, 947 \\ 3, 3725 \\ 7, 10, 516 \\ 140, 947 \\ 3, 37$	***19	ca19Lya	18.892	18.403	5.93776	3.02206	3.71473	5.73051	6.11057	0.024996	6.02948×10^{21}	4.80124	3.3	627.352
21ar18ar18l8c22l793925.667763.09584.112265.786066.345840.0191888 1.07437×10^{22} 5.111743.53684.06424s16118.62217.93925.667763.095694.112175.785976.345840.00308355 1.07396×10^{21} 5.111743.53684.94324s16118.898818.18325.944512.889983.903145.606636.223980.1062989.36385 \times 10^{21}4.793443.29475532.28325s161yg18.898818.18345.944512.889923.993035.606526.22390.0177319.3519 \times 10^{21}4.793483.29475532.28327s1519.337118.89366.382823.395123.994055.904050.4294214.67279 \times 10^{21}4.499963.06631405.93***29si141ya119.161818.47436.207572.665523.655475.376266.078440.06981918.24274 \times 10^{21}4.499963.06631405.883***30si141yd19.161818.47436.207572.665523.655465.376266.078440.009926738.2317 \times 10^{21}4.499963.06831405.883***32fe24Li4p118.53218.21655.77763.929893.676496.207670.0215671.89788 \times 10^{21}4.499963.06831405.883***32fe2318.718819.00772.685523.655465.376266.078440.09	*** 20	ca19Lyb	18.892	18.4036	5.93776	3.02133	3.71421	5.72979	6.11035	0.00421422	6.02396×10^{21}	4.80124	3.3	627.003
 ar181yb1 18.622 17.9393 5.66776 3.09569 4.11217 5.78597 6.3458 0.00308335 1.07396×10²² 5.1114* 3.53 683.943 ar17 19.1378 18.64 6.1832 5.94451 2.88998 3.90314 5.60652 6.2239 0.0106298 9.36385×10²¹ 4.79348 3.29475 532.242 51514 18.8988 18.1834 5.94451 2.88993 3.90303 5.60652 6.2239 0.010731 9.35918×10²¹ 4.79348 3.29475 532.283 27 515 19.3371 18.8936 6.38282 3.99512 3.29801 5.90405 5.90405 0.429421 4.67279×10²¹ 4.28942 2.90083 952.737 2.68552 3.65547 5.3764 6.07844 0.0211402 8.24274×10²¹ 4.49096 3.06831 405.885 3.141yb1 19.1618 18.4743 6.20757 2.68552 3.65547 5.37626 6.07844 0.0211402 8.2423×10²¹ 4.49096 3.06831 405.885 3141yb1 19.1618 18.4743 6.20757 2.68552 3.65546 5.37626 6.07844 0.0211402 8.2423×10²¹ 4.49096 3.06831 405.883 3141yb1 19.1618 18.4743 6.20757 2.68552 3.65546 5	21	ar18Lya1	18.622	17.9392	5.66776	3.0958	4.11226	5.78606	6.34584	0.0191888	1.07437×10^{22}	5.11174	3.53	684.064
	***22	ar18Lyb1	18.622	17.9393	5.66776	3.09569	4.11217	5.78597	6.3458	0.00308335	1.07396×10^{22}	5.11174	3.53	683.943
24 sl6Lyal 18.8988 18.1832 5.94451 2.88998 3.99314 5.606652 6.2239 0.1070731 9.3591×10 ²⁴ 4.79348 3.29475 532.342 ***25 sl6Lypl 18.8988 18.1834 5.94451 2.88992 3.99303 5.60652 6.2239 0.0107311 9.3591×10 ²⁴ 4.79348 3.29475 532.283 27 sl5 19.3371 18.8936 6.38222 3.39512 3.29801 5.90405 5.90405 0.429421 4.67279×10 ²¹ 4.28942 2.90083 952.737 ***28 si14Lyb1 19.1618 18.4743 6.20757 2.68552 3.65547 5.37626 6.07844 0.0608191 8.24293×10 ²¹ 4.49996 3.06631 405.885 ***30 si14Lyg 19.1618 18.4743 6.20757 2.68552 3.65546 5.37626 6.07844 0.0092673 8.23917×10 ²¹ 4.49996 3.06631 405.883 ***31 si14Lyd 19.1618 18.4743 6.20757 2.68552 3.65546 5.37626 6.07844 0.0092673 8.23917×10 ²¹ 4.49096 3.066	***23	ar17	19.1378	18.64	6.18351	3.60896	3.51487	6.00929	6.00671	0.0831345	5.51414×10^{21}	4.51863	3.08825	1276.08
 ***25 sl6Lyb1 18.8988 18.1834 5.94451 2.88992 3.90303 5.60652 6.2239 0.0170731 9.35919×10²¹ 4.79348 3.29475 532.283 27 sl5 19.3371 18.8936 6.3282 3.39512 2.29801 5.90405 5.90405 6.429421 4.67279×10²¹ 4.28942 2.90083 5.2737 ***29 si14Lyp1 19.1618 18.4743 6.20757 2.68552 3.65547 5.37626 6.07844 0.0068191 8.24274×10²¹ 4.49096 3.06831 405.885 ***33 si14Lyd 19.1618 18.4743 6.20757 2.68552 3.65546 5.37626 6.07844 0.0092673 8.23917×10²¹ 4.49096 3.06831 405.883 ***32 fe23 18.7188 19.0037 5.74776 3.12114 3.06533 5.80151 5.79724 0.0502461 1.69708×10²¹ 4.90474 3.3725 710.516 fe22s2s2p3p45 18.802 19.1607 5.44776 3.12114 3.06533 5.80151 5.79724 0.0762249 1.88938×10²¹ 4.90474 3.3725 710.516 fe22s2s2p3p45 18.802 19.1607 5.44776 3.12114 3.06533 5.80151 5.79724 0.0762249 1.88938×10²¹ 4.90474 3.3725	24	s16Lya1	18.8988	18.1832	5.94451	2.88998	3.90314	5.60663	6.22398	0.106298	9.36385×10^{21}	4.79348	3.29475	532.342
***26 $s16Lyg$ 18.8988 18.1834 5.94451 2.8892 3.9933 5.60652 6.2239 0.00593499 9.35888 $t10^{-1}$ 4.79348 3.29475 532.28 ***27 $s15$ 19.3371 18.8936 6.38282 3.39512 3.29801 5.99405 5.99405 0.429421 4.67279 $t10^{21}$ 4.28942 2.99083 952.737 ***28 $s114Lya1$ 19.1618 18.4743 6.20757 2.68558 3.65557 5.3764 6.07852 0.378807 8.24878 $t10^{21}$ 4.49996 3.06831 405.883 ***29 $s114Lya1$ 19.1618 18.4743 6.20757 2.68552 3.65547 5.3762 6.07844 0.0608191 8.24274 $t10^{21}$ 4.49996 3.06831 405.883 ***29 $s114Lya1$ 19.1618 18.4743 6.20757 2.68552 3.65546 5.37626 6.07844 0.06992673 8.2391 $t0^{21}$ 4.49996 3.06831 405.883 ***31 $s114Lya1$ 19.1618 18.4743 6.20757 2.68552 3.65546 5.37626 6.07844 0.00992673 8.2391 $t0^{21}$ 4.49996 3.06831 405.883 ***33 $fe24$ 18.7188 19.0037 5.76451 3.74024 3.2098 6.10703 5.86297 0.0592461 1.69708 $t10^{21}$ 5.21524 3.61075 2032.4 ***33 $fe22$ 18.802 19.1607 5.84776 3.12114 3.06533 5.80151 5.79724 0.07186249 1.89838 $t10^{21}$ 4.90474 3.3725 710.512 ***5 $fe222s2p3p2P$ 18.802 19.1607 5.84776 3.12114 3.06533 5.80151 5.79724 0.0768249 1.89838 $t10^{21}$ 4.90474 3.3725 710.512 ***35 $fe222s2p3p45$ 18.802 19.1607 5.84776 3.12114 3.06533 5.80151 5.79724 0.0768249 1.89838 $t10^{21}$ 4.90474 3.3725 710.512 ***35 $fe222s2p3p45$ 18.802 19.1607 5.84776 3.12114 3.06533 5.80151 5.79724 0.0768249 1.89838 $t10^{21}$ 4.90474 3.3725 710.518 ***39 $fe221$ 19.4327 18.8408 6.47841 2.44488 3.33861 5.18377 5.92919 0.109004 8.25415 $t10^{21}$ 5.42224 3.76 1129.69 38 mg12Lyb1 19.4327 18.841 6.47841 2.44468 3.33861 5.18347 5.92919 0.100403 7.09089 $t10^{21}$ 4.17949 2.82546 290.689 40 mg12Lyg 19.4327 18.841 6.47841 2.44468 3.3386 5.18347 5.92918 0.0348968 7.09114 $t1.7949$ 2.82546 290.689 40 mg12Lyg1 19.4327 18.841 6.47841 2.44468 3.3386 5.18346 5.92918 0.0348968 7.09114 $t1.7949$ 2.82546 290.686 41 ne10Lya1 19.7942 19.3142 6.83999 2.11062 2.91897 4.9622 5.66957 0.0161404 6.33448 $t10^{21}$ 3.76368 2.59913 187.52 42 ne10Lyb1 19.7942 19.3143 6.83999 2.11076 2.91897 4.9622 5.66987 0.161404 6.33448 $t10^{2$	^^^25	s16Lyb1	18.8988	18.1834	5.94451	2.88993	3.90303	5.60652	6.2239	0.0170731	9.35919×10^{21}	4.79348	3.29475	532.283
27 s15 19.3371 18.8936 6.38282 3.39512 3.29801 5.90405 5.90405 0.429421 4.67279×10 ⁴¹ 4.28942 2.90083 952.737 ***28 si14Lyal 19.1618 18.4741 6.20757 2.68558 3.65557 5.3764 6.07852 0.378807 8.24878×10 ²¹ 4.49096 3.06831 405.885 ***29 si14Lyg 19.1618 18.4743 6.20757 2.68552 3.65547 5.37626 6.07844 0.00992673 8.23917×10 ²¹ 4.49096 3.06831 405.883 ***32 fe24Li4p1 18.532 18.2165 5.57776 3.92989 3.87649 6.22336 6.20676 0.0191163 2.21431×10 ²¹ 5.40048 3.4465 1581.32 9 ***32 fe23 18.7188 19.0037 5.76451 3.74024 3.20988 5.8015 5.79724 0.0502461 1.69708×10 ²¹ 5.90474 3.3725 710.512 *** 34 fe22 18.802 19.1607 5.84776 3.12114 3.06533 5.80151 5.79724 0.0768249 1.89838×10 ²¹ <td< th=""><th>***26</th><th>s16Lyg</th><th>18.8988</th><th>18.1834</th><th>5.94451</th><th>2.88992</th><th>3.90303</th><th>5.60652</th><th>6.2239</th><th>0.00593499</th><th>9.35888×10^{21}</th><th>4.79348</th><th>3.29475</th><th>532.28</th></td<>	***26	s16Lyg	18.8988	18.1834	5.94451	2.88992	3.90303	5.60652	6.2239	0.00593499	9.35888×10^{21}	4.79348	3.29475	532.28
28 s114Lya1 19.1618 18.4741 6.20757 2.68558 3.65557 5.3764 6.07852 0.378807 8.24878×10 ²¹ 4.49996 3.06831 405.93 ***29 si14Lyb1 19.1618 18.4743 6.20757 2.68552 3.65547 5.37626 6.07844 0.0608191 8.24274×10 ²¹ 4.49996 3.06831 405.885 ***30 si14Lyg 19.1618 18.4743 6.20757 2.68552 3.65546 5.37626 6.07844 0.00992673 8.24293×10 ²¹ 4.49096 3.06831 405.883 ***32 fe21Lipd1 18.532 18.2165 5.57776 3.92989 3.87649 6.22336 6.20676 0.0191163 2.21431×10 ²¹ 5.0048 3.66531 405.883 ***33 fe22 18.802 19.1607 5.84776 3.12114 3.06533 5.8015 5.79724 0.0211567 1.88938×10 ²¹ 4.90474 3.3725 710.512 ***35 fe22sp3p2P 18.802 19.1607 5.84776 3.12114 3.06533 5.80151 5.79724 0.0211567 1.88983×10 ²¹ 4.90474 <td< th=""><th>27</th><th>s15</th><th>19.3371</th><th>18.8936</th><th>6.38282</th><th>3.39512</th><th>3.29801</th><th>5.90405</th><th>5.90405</th><th>0.429421</th><th>4.67279×10^{21}</th><th>4.28942</th><th>2.90083</th><th>952.737</th></td<>	27	s15	19.3371	18.8936	6.38282	3.39512	3.29801	5.90405	5.90405	0.429421	4.67279×10^{21}	4.28942	2.90083	952.737
 sil4Lybi 19.1618 18.4743 6.20757 2.68552 3.65547 5.37626 6.07844 0.0608191 8.24274×10²¹ 4.49996 3.06831 405.883 sil4Lyd 19.1618 18.4743 6.20757 2.68552 3.65546 5.37626 6.07844 0.0211402 8.24274×10²¹ 4.49996 3.06831 405.883 405.883 445.883 45.83 45.2414 18.532 18.2165 5.57776 3.92989 3.87649 6.22336 6.20676 0.0191163 2.21431×10²¹ 5.21524 3.61075 2.032.4 4.90474 3.3725 710.512 4.90474 3.3725 710.512 4.90474 3.3725 710.512 4.90474 3.3725 4.90474 4.90474 3.3725 4.90474 4.90474 4.3725 4.9249 5.98759 6.39399 0.0109004 8.25415×10²¹ 4.90474 3.3725 4.102.4448 3.3861 5.18347 5.92914 0.0215671 4.19949 4.8247 4.9249 4.90474 3.3725 4.1129.69 4.129.69 4.129.69 4.129.69 4.129.69 4.129.69 4.129.69 4.129.61<	28	sil4Lyal	19.1618	18.4741	6.20757	2.68558	3.65557	5.3764	6.07852	0.378807	8.24878×10 ²¹	4.49096	3.06831	405.93
$ \frac{19}{31} = 10 + 10 + 10 + 10 + 10 + 10 + 10 + 10$	***29	sil4Lybl	19.1618	18.4743	6.20757	2.68552	3.65547	5.37626	6.07844	0.0608191	8.24274×10^{21}	4.49096	3.06831	405.885
31 $S1141y0$ 19.161818.47436.207572.685523.655465.376266.078440.009926738.23917×10 ⁻²² 4.499963.06831405.883***32fe24Li4p118.53218.21655.577763.929893.876496.223366.206760.01911632.21431×10 ²¹ 5.215243.610752032.4***32fe2318.718819.00375.764513.740243.209866.107035.862970.05024611.69708×10 ²¹ 5.000483.44651581.32y34fe2218.80219.16075.847763.121143.065335.801515.797240.02115671.88938×10 ²¹ 4.904743.3725710.512*** 35fe222s2p3p4518.80219.16075.847763.121143.065335.801515.797240.01154371.89858×10 ²¹ 4.904743.3725710.51636fe22s1p1erComb18.35217.8455.397763.473274.192495.987596.393990.01090048.25415×10 ²¹ 4.904743.3725710.51637mg12Lyb119.432718.84086.478412.44483.338725.183575.929240.6255597.09622×10 ²¹ 4.179492.82546290.68940mg12Lyg19.432718.8416.478412.444683.338615.183465.929180.03489687.09115×10 ²¹ 4.179492.82546290.68641ne10Lya119.794219.31426.839992.110762.918974.962	*** 30	sil4Lyg	19.1618	18.4743	6.20757	2.68552	3.65546	5.37626	6.07844	0.0211402	8.24293×10^{21}	4.49096	3.06831	405.883
****32Te24114p118.53218.21655.577763.929893.876496.223366.206760.01911632.21431×10 ⁻¹ 5.215243.610752032.4****33fe2318.718819.00375.764513.740243.200986.107035.862970.05024611.69708×10 ²¹ 5.000483.44651581.329****33fe2218.80219.16075.847763.121143.065335.80155.797240.02115671.88938×10 ²¹ 4.904743.3725710.512***<35fe22s2p3p2P18.80219.16075.847763.121143.065335.801515.797240.01563291.89838×10 ²¹ 4.904743.3725710.51636fe22s2p3p4S18.80219.16075.847763.121143.065335.801515.797240.1154371.89855×10 ²¹ 4.904743.3725710.51637fe25InterComb18.35217.8455.397763.473274.192495.987596.393990.01090048.25415×10 ²¹ 5.422243.761129.6938mg12Lya119.432718.8416.478412.444683.338615.183475.929190.1004037.09089×10 ²¹ 4.179492.82546290.68940mg12Lyg19.432718.8416.478412.444683.33865.183465.929180.03489687.09115×10 ²¹ 4.179492.82546290.68641ne10Lya119.794219.31436.839992.110762.918974.9623 </th <th>31</th> <th>S114Lyd</th> <th>19.1618</th> <th>18.4743</th> <th>6.20757</th> <th>2.68552</th> <th>3.65546</th> <th>5.37626</th> <th>6.07844</th> <th>0.00992673</th> <th>8.23917×10²¹</th> <th>4.49096</th> <th>3.06831</th> <th>405.883</th>	31	S114Lyd	19.1618	18.4743	6.20757	2.68552	3.65546	5.37626	6.07844	0.00992673	8.23917×10 ²¹	4.49096	3.06831	405.883
****33Te2318.718819.00375.764513.740243.200986.107035.86297 0.0502461 1.69708×10 ⁻¹² 5.000483.74651581.32934fe2218.80219.16075.847763.121143.065335.80155.79724 0.0211567 1.88938×10 ²¹ 4.904743.3725710.512***35fe222s2p3p4S18.80219.16075.847763.121143.065335.801515.79724 0.0768249 1.89838×10 ²¹ 4.904743.3725710.51636fe222s2p3p4S18.80219.16075.847763.121143.065335.801515.79724 0.0768249 1.89855×10 ²¹ 4.904743.3725710.51637fe25InterComb18.35217.8455.397763.473274.192495.987596.39399 0.0109004 8.25415×10 ²¹ 5.422243.761129.6938mg12Lya119.432718.84086.478412.44483.338725.183575.92914 0.625559 7.09622×10^{21} 4.179492.82546290.68940mg12Lyg19.432718.8416.478412.444683.33865.183465.92918 0.0348968 7.09115×10^{21} 4.179492.82546290.68641ne10Lya119.794219.31426.839992.110822.919054.96235.669951.00596.3314×10 ²¹ 3.763682.50913187.5242ne10Lyb119.794219.31436.839992.110762.91897 <t< th=""><th>~~ 32</th><th>Te24L14p1</th><th>18.532</th><th>18.2165</th><th>5.5///6</th><th>3.92989</th><th>3.87649</th><th>6.22336</th><th>6.20676</th><th>0.0191163</th><th>2.21431×10²¹</th><th>5.21524</th><th>3.61075</th><th>2032.4</th></t<>	~~ 32	Te24L14p1	18.532	18.2165	5.5///6	3.92989	3.87649	6.22336	6.20676	0.0191163	2.21431×10 ²¹	5.21524	3.61075	2032.4
34Te2218.80219.16075.847763.121143.065335.80155.79724 0.0211567 1.88938×10 ⁻²¹ 4.904743.3725710.51236fe222s2p3p2F18.80219.16075.847763.121143.065335.801515.79724 0.0768249 1.89838×10 ²¹ 4.904743.3725710.51836fe22s2p3p4S18.80219.16075.847763.121143.065335.801515.79724 0.0768249 1.89838×10 ²¹ 4.904743.3725710.51836fe22s1nterComb18.35217.8455.397763.473274.192495.987596.33399 0.0109004 8.25415×10 ²¹ 4.904743.3725710.51838mg12Lya119.432718.84086.478412.44483.338725.183575.92924 0.625559 7.09622×10 ²¹ 4.179492.82546290.68940mg12Lyg19.432718.8416.478412.444683.338615.183475.92919 0.100403 7.09089×10 ²¹ 4.179492.82546290.68641ne10Lya119.794219.31426.839992.110822.919054.96225.669951.00596.3314×112 ²¹ 3.763682.50913187.5242ne10Lyb119.794219.31436.839992.110762.918974.96225.66987 0.161404 6.33448×10 ²¹ 3.763682.50913187.5243al13Lya119.40718.7756.452762.559413.395815.25095.9	*** 33	Te23	18./188	19.0037	5.76451	3.74024	3.20098	6.10703	5.86297	0.0502461	1.69708×10^{21}	5.00048	3.4465	1581.32 ₉₇₁₅
35 $1622252p3p2P$ 18.802 19.1607 5.84776 3.12114 3.06533 5.80151 5.79724 0.0788249 1.89838×10^{-1} 4.90474 3.3725 710.516 36 $fe222s2p3p48$ 18.802 19.1607 5.84776 3.12114 3.06533 5.80151 5.79724 0.115437 1.89838×10^{-1} 4.90474 3.3725 710.516 37 $fe25InterComb$ 18.352 17.845 5.39776 3.47327 4.19249 5.98759 6.39399 0.0109004 8.25415×10^{21} 5.42224 3.76 1129.69 38mg12Lya1 19.4327 18.8408 6.47841 2.4448 3.33872 5.18357 5.92924 0.625559 7.09622×10^{21} 4.17949 2.82546 290.741 39mg12Lyg1 19.4327 18.841 6.47841 2.44468 3.33861 5.18347 5.92919 0.100403 7.09089×10^{21} 4.17949 2.82546 290.689 40mg12Lyg 19.4327 18.841 6.47841 2.44468 3.3386 5.18346 5.92918 0.0348968 7.09115×10^{21} 4.17949 2.82546 290.689 41ne10Lya1 19.7942 19.3142 6.83999 2.11082 2.91905 4.9623 5.66995 1.0059 6.33914×10^{21} 3.76368 2.50913 187.488 43al13Lya1 19.407 18.775 6.45276 2.55941 3.39581 5.2509 5.95254 0.161404 6.334	34 ***25	Tezz follolananan	18.802	19.1607	5.84776	3.12114	3.06533	5.8015	5.79724	0.0211567	1.88938×10 ²¹	4.90474	3.3725	710.512
36 162252525343 18.802 19.1007 5.84776 5.12114 5.06353 5.80151 5.79724 0.113437 1.83635×10 4.90474 5.3725 710.516 37 fe25InterComb 18.352 17.845 5.39776 3.47327 4.19249 5.98759 6.39399 0.0109004 8.25415×10 ²¹ 5.42224 3.76 1129.69 38 mg12Lya1 19.4327 18.8408 6.47841 2.4448 3.33872 5.18357 5.92924 0.625559 7.09622×10 ²¹ 4.17949 2.82546 290.741 39 mg12Lyg1 19.4327 18.841 6.47841 2.44468 3.33861 5.18347 5.92919 0.100403 7.09089×10 ²¹ 4.17949 2.82546 290.689 40 mg12Lyg 19.4327 18.841 6.47841 2.44468 3.3386 5.18347 5.92918 0.0348968 7.09115×10 ²¹ 4.17949 2.82546 290.689 41 ne10Lya1 19.7942 19.3142 6.83999 2.11082 2.91905 4.9623 5.66995 1.0059 6.33914×10 ²¹ 3.76368 2.50913	35	fe222s2p3p2P	18.802	19.1607	5.84776	3.12114	3.00533	5.80151	5.79724	0.0768249	1.89838×10	4.90474	3.3725	710.518
37Tegenricer comb18.33217.843 5.39716 3.47327 4.19249 5.98739 6.39399 0.0109064 8.22413×16^{-10} 5.42224 5.76^{-11} 1129.69^{-11} 38mg12Lya119.432718.8408 6.47841 2.4448 3.33872 5.18357 5.92924 0.625559 7.09622×10^{21} 4.17949 2.82546 290.741 39mg12Lyg19.432718.841 6.47841 2.44468 3.33861 5.18347 5.92919 0.100403 7.09089×10^{21} 4.17949 2.82546 290.689 40mg12Lyg19.432718.841 6.47841 2.44468 3.33861 5.18347 5.92918 0.0348968 7.09115×10^{21} 4.17949 2.82546 290.689 41ne10Lya119.794219.3142 6.83999 2.11082 2.91905 4.9623 5.66995 1.0059 6.33914×10^{21} 3.76368 2.50913 187.428 42ne10Lyb119.794219.3143 6.83999 2.11076 2.91897 4.9622 5.66987 0.161404 6.33448×10^{21} 3.76368 2.50913 187.428 43al13Lya119.40718.775 6.45276 2.55941 3.39581 5.2509 5.92524 0.0179118 6.67579×10^{21} 4.20899 2.8492 37.51 44si132p19.598119.2444 6.64382 2.45725 2.98389 5.18941 5.70669 1.58642 4.38881×10^{21} 3.98927 2.67615	27	fe2ZZSZPSP4S	10.002	17 945	5.84776	3.12114	4 10240	5.80151	5.79724	0.115457	1.89855×10 9.26416 $\times 10^{21}$	4.90474 5.42224	3.3725	1120 60
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	20	mg12Lyc1	10.332	10 0400	6 47941	2 4/32/	4.19249	5.90739	6.39399 E 02024	0.0109004	7.00622×10^{21}	4 17040	2 92546	200 741
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	30	mg12Lyd1	19.4327	18 841	6 47841	2.4440	3 33961	5 19347	5 92919	0.02000	7.03022×10^{-7}	4.17949	2.82546	290.741
41mg12/yg19.432718.431 0.44463 2.44463 3.5360 5.16340 5.2518 0.043636 1.05113×10^{-1} 4.17349 2.12340 23080 41ne10Lya119.794219.3142 6.83999 2.11082 2.91905 4.9623 5.66995 1.0059 6.33914×10^{21} 3.76368 2.50913 187.52 42ne10Lyb119.794219.3143 6.83999 2.11076 2.91897 4.9622 5.66987 0.161404 6.33448×10^{21} 3.76368 2.50913 187.52 43al13Lya119.40718.775 6.45276 2.55941 3.39581 5.2509 5.95254 0.0179118 6.67579×10^{21} 4.20899 2.8492 337.51 44si132p19.598119.2444 6.64382 2.45725 2.98389 5.18941 5.70669 1.58642 4.3881×10^{21} 3.98927 2.67615 292.565	40	mg12Lyg	19 /327	10.041	6 47841	2.44468	3 3386	5 19346	5 92919	0.100405	7.09005×10^{-7}	4.17949	2,02546	290.686
42 nel0Lyb1 19.7942 19.3142 6.83999 2.11052 2.91807 4.9622 5.66987 0.161404 6.33448×10^{21} 3.76368 2.50913 187.488 43 al13Lya1 19.407 18.775 6.45276 2.55941 3.39581 5.2509 5.95254 0.0179118 6.67579×10^{21} 4.20899 2.8492 337.51 44 si132p 19.5981 19.2444 6.64382 2.45725 2.98389 5.18941 5.70669 1.58642 4.3881×10 ²¹ 3.98927 2.67615 292.565	40	mg±∠∟yg ng10lya1	19 7942	19 3142	6 83999	2.11082	2 91905	4 9623	5 66995	1 0059	6.33914×10^{21}	3 76369	2.02040	187 52
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	42	ne10Lydi	19 7942	19 3143	6 83000	2.11076	2.91903	4 9677	5 66987	0 161404	6 33448 v 10 ²¹	3 76368	2.50913	187 488
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	43	al 131 va1	19 407	18 775	6 45276	2 55941	3 39581	5 2509	5 95254	0 0170110	6.67579×10^{21}	4 20200	2.30313	337 51
	43	sil32n	19 5981	19 2444	6 64382	2.33341	2 98389	5 18941	5 70669	1 58642	4 38881 $\times 10^{21}$	3 98927	2.0492	292 565
45 si133p 19.5981 19.2451 6.64382 2.45747 2.98295 5.19211 5.70562 0.274165 4.37928 \times 10 ²¹ 3.98977 2.67615 292.442	45	si133n	19,5981	19.2451	6.64382	2.45747	2.98295	5.19211	5.70562	0.274165	4.37928×10^{21}	3.98927	2.67615	292.442
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	46	si134n	19.5981	19.2451	6.64382	2.45747	2.9829	5.19222	5.70557	0.0973068	4.37776×10^{21}	3.98927	2.67615	292.436

<u>WAs in NGC 3783</u>

Kaspi+01 SED $n \sim r^{-1.15}$ wind

wind density at base: 1.7e11 – 1.1e13 [cm⁻³] Inclination: 30° – 50°

Fukumura, in prep.

preliminary





More about NGC 3783





Out[1949



Why magnetic-origin?

♦ Generic ability to launch ionized winds
 - UFOs @ smaller radii (~ hundreds of R_S)
 - WAs @ larger radii (~ sub pc to pc scale)

♦ Can describe global outflow conditions
 - Radial (LoS) density distribution → AMD
 - Helical motion → Transverse motion

Can explain observable (non-)correlations
 - AMD, V_{out}(ξ), N_H(ξ), spectral shape
 - V_{out}(UFO) vs. L/L_E , SED dependence...etc.

