The Nature of X-rays from Young Stellar Objects in the Orion Nebula Cluster
-A Chandra HETG Legacy Project-

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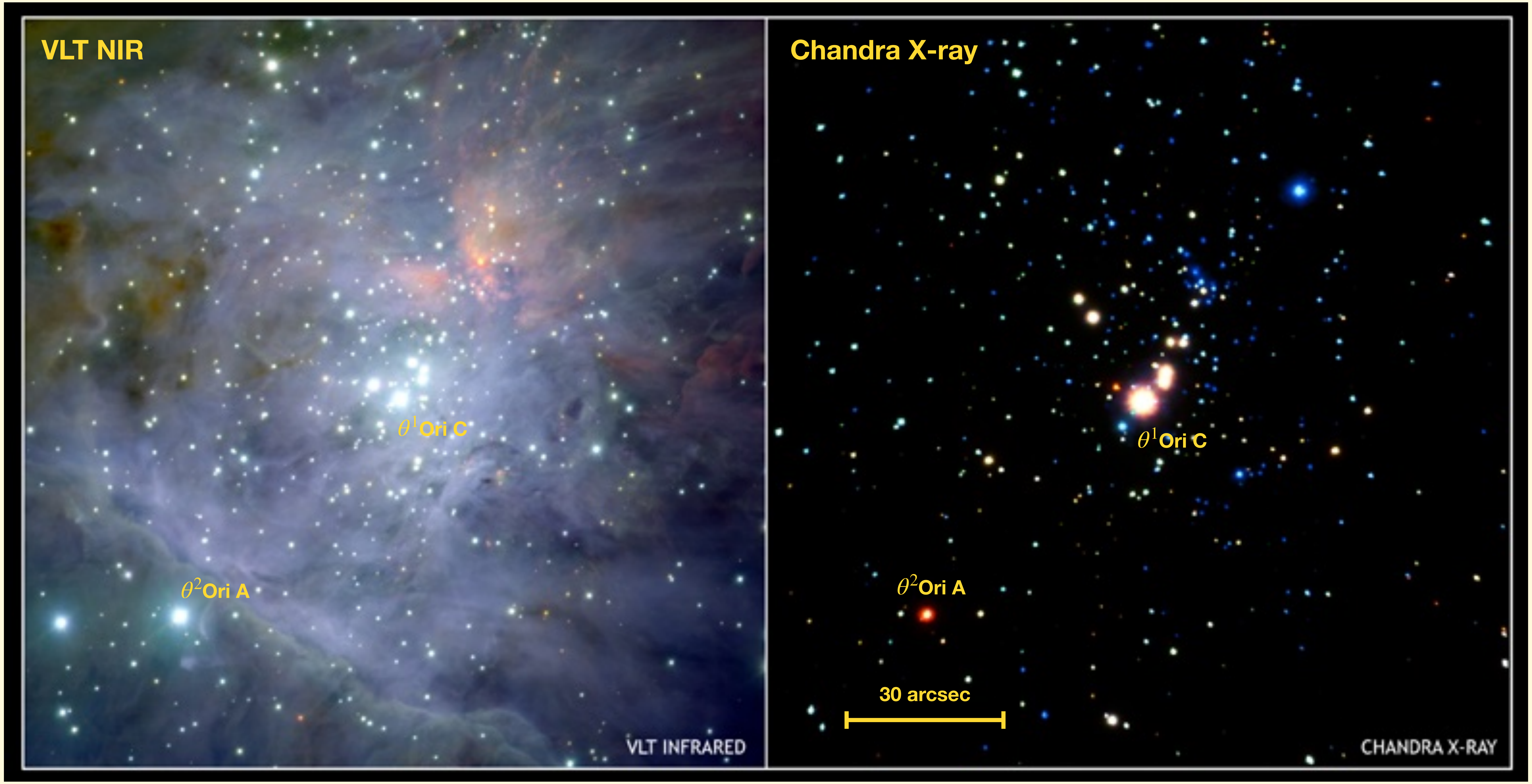
Image Credit: Rogelio Bernal Andreo

The Orion Nebula Cluster is the nearest site of massive star formation. It includes more than a thousand young (< 5 Myr), protoplanetary disk-hosting stars and a handful of massive early-type zero-age main sequence stars. An 840 ks ACIS-I imaging campaign (Getman et al. 2005) characterized X-ray emission from ~1600 young star systems (lower right image).



Credit: ESO/VLT/M.McCaughrean et al.

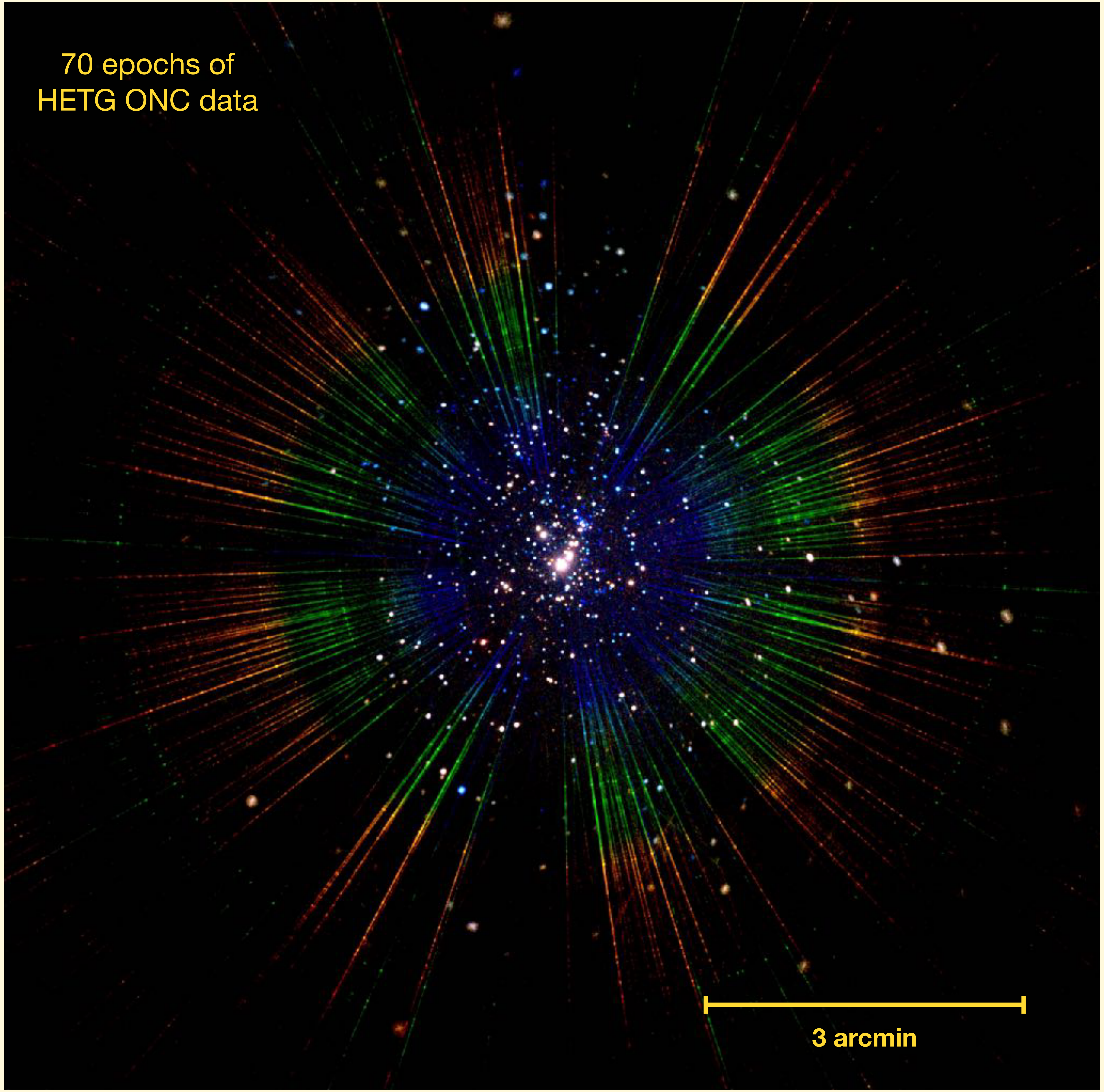
Credit:NASA/CXC/Penn State/E.Feigelson & K.Getman et al.

A Chandra HETG Legacy Project

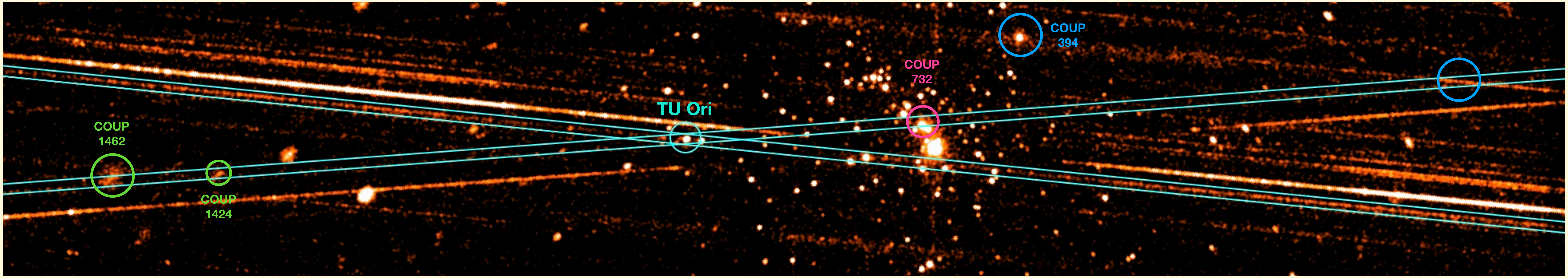
The ONC HETG project includes 70 observations taken over the lifetime of Chandra (1999-2020) spanning a total of ~2.1 megaseconds. The merged image of all 70 observations is shown (right).

The HETG instrument disperses light onto ACIS-S from every source in the field of view in a characteristic ‘X’ shape pattern. Since brighter sources disperse more events, the spectrum of the massive star θ^1 Ori C taken at multiple roll angles dominates this image. Colors represent X-ray energy from hard (blue) to soft (red).

At a distance of ~400 pc, the ONC represents the ideal crowded field target. It is close enough to provide enough counts for high resolution spectroscopy of stars and distant enough for many sources to fall near the telescope pointing where Chandra’s PSF is excellent.

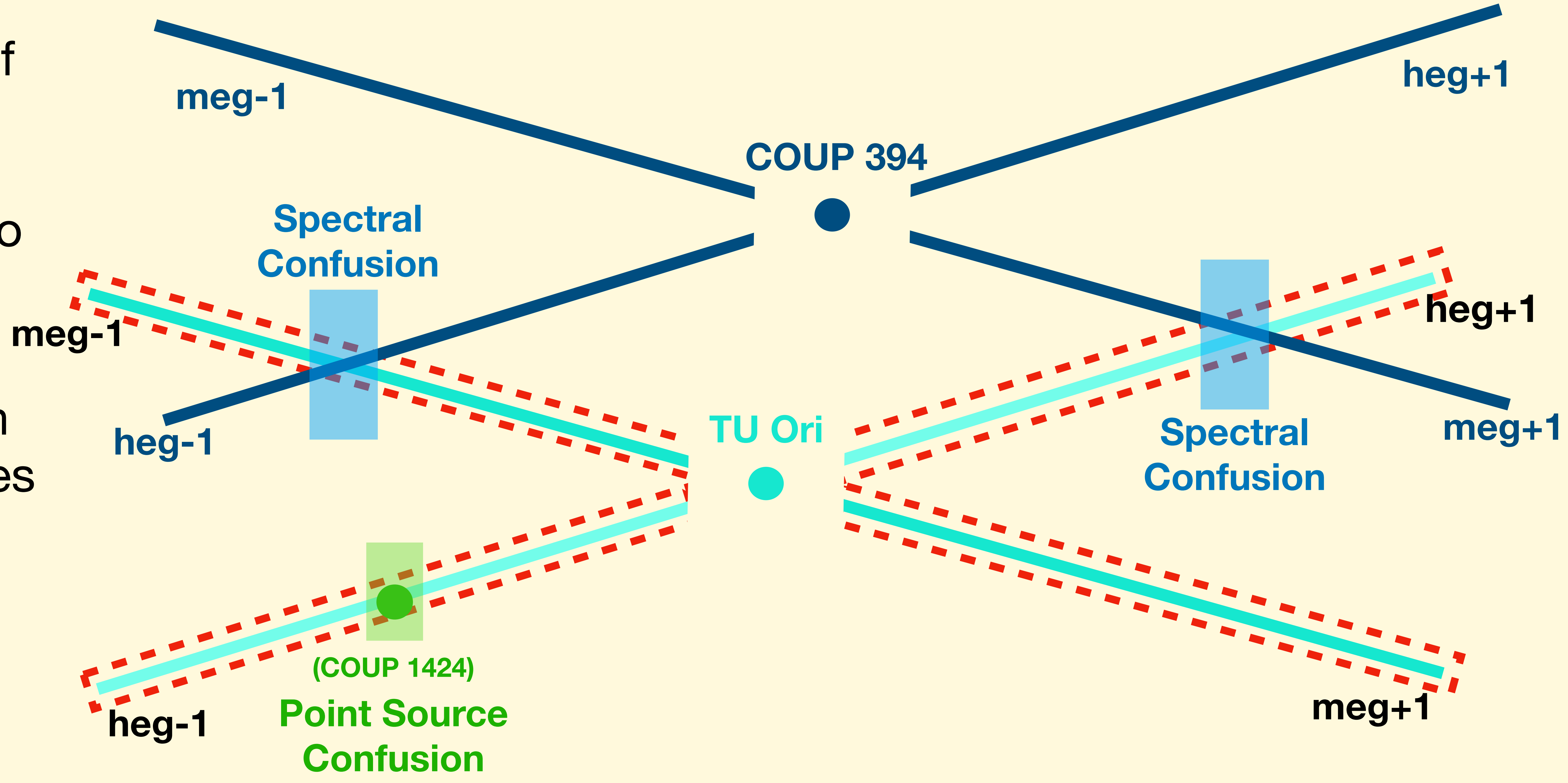


Accounting for Sources of Confusion in Each Extracted Spectrum



In a crowded field like the ONC, the dispersed spectra of and individual source overlaps (intersects) with other sources in the field of view. These sources of confusion must be accounted for in each epoch when attempting to jointly fit all 70 epochs.

A specialized python routine called CrissCross has been developed as part this project and accounts for all sources of potential confusion. For each extracted spectrum, CrissCross identifies the wavelength (energy) where confusion occurs so these can be accounted for in spectral fitting.



Characterizing the Spectra of Emission Line Dominated Stars

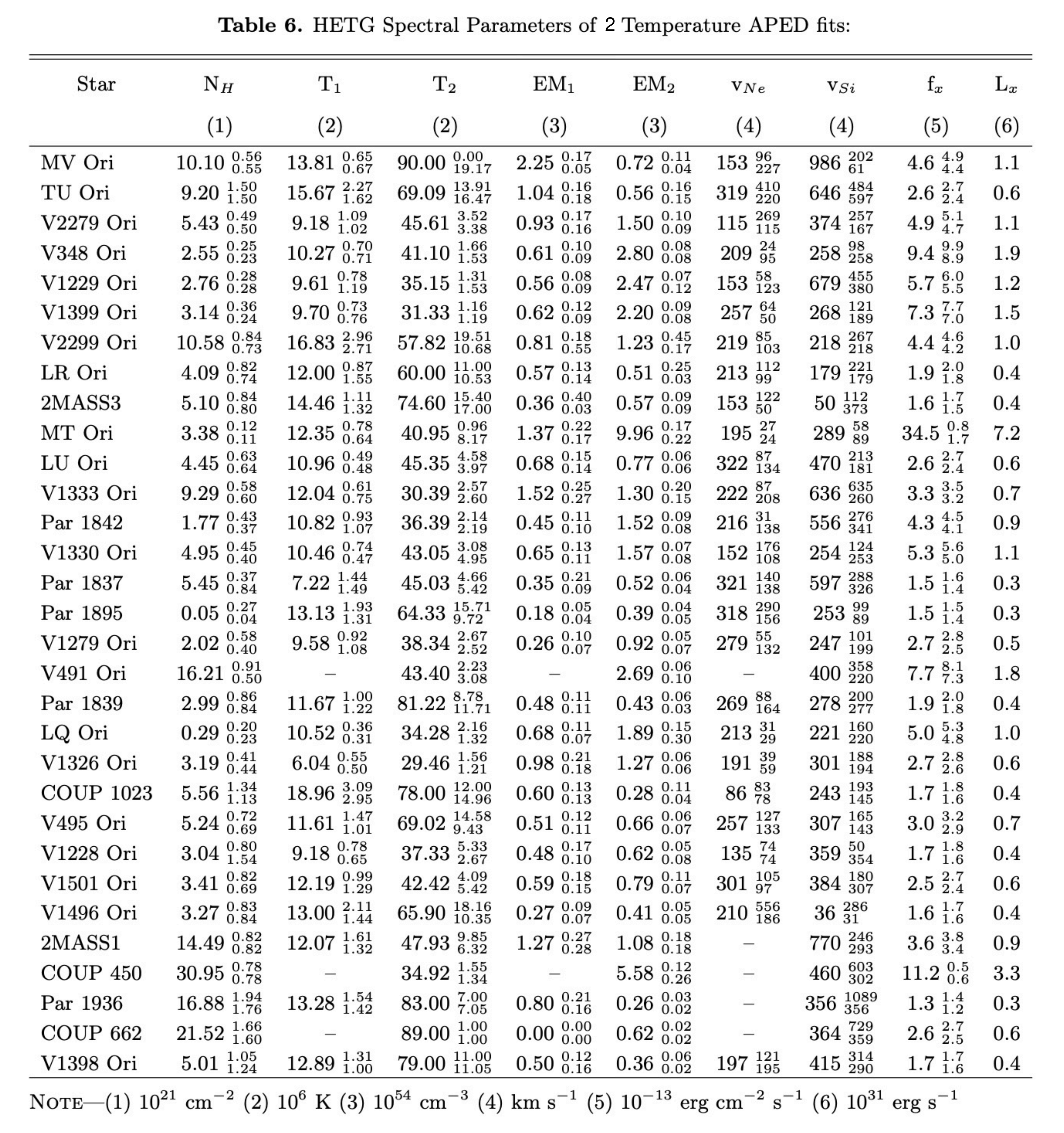
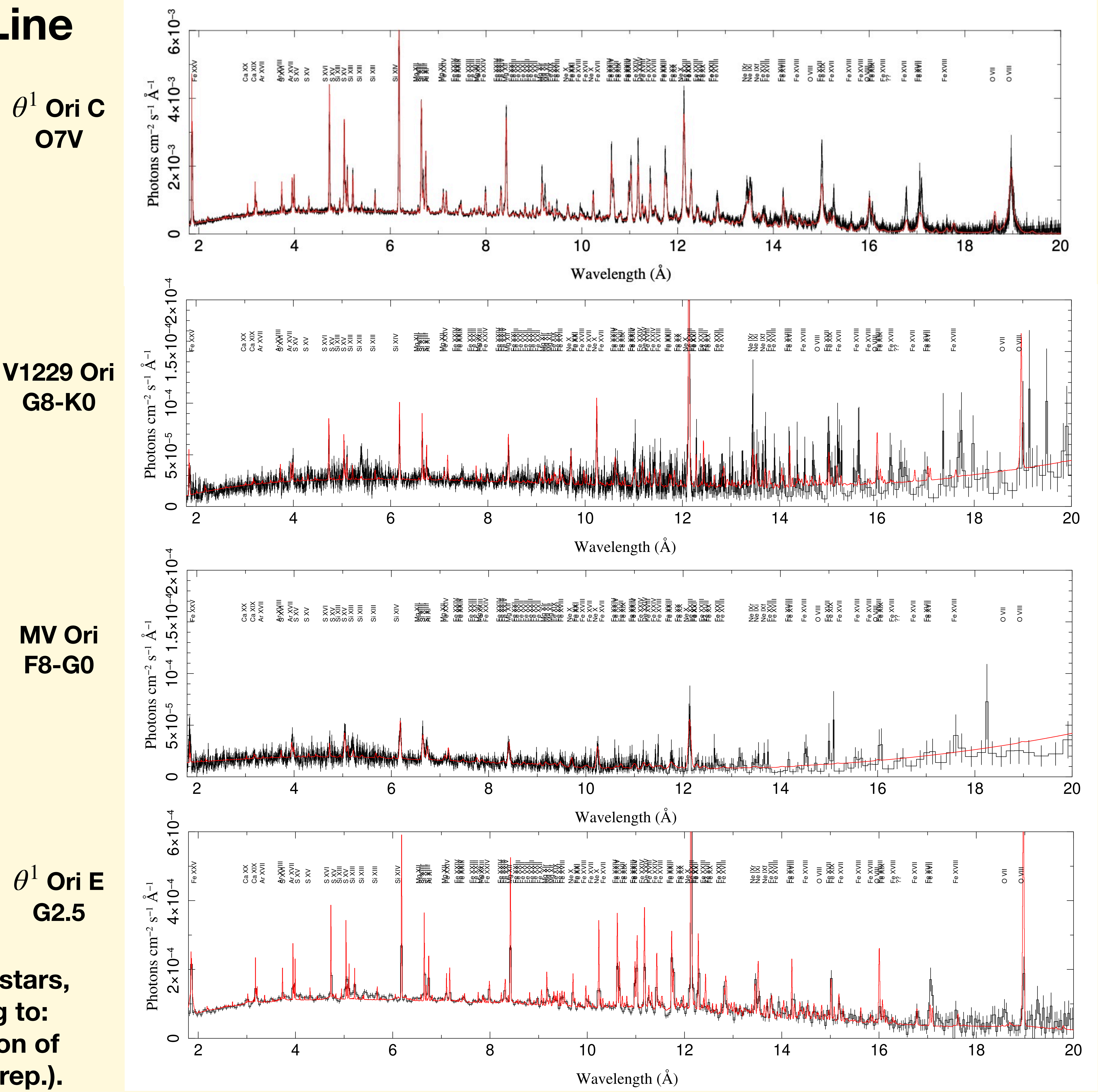


Table 6. HETG Spectral Parameters of 2 Temperature APED fits:

Star 	N_H (1)	T_1 (2)	T_2 (2)	EM_1 (3)	EM_2 (3)	v_{Ne} (4)	v_{Si} (4)	f_x (5)	L_x (6)
MV Ori	$10.10\,^{0.56}_{0.55}$	$13.81\,^{0.65}_{0.67}$	$90.00\,^{0.00}_{19.17}$	$2.25\,^{0.17}_{0.05}$	$0.72\,^{0.11}_{0.04}$	$153\,^{96}_{227}$	$986\,^{202}_{61}$	$4.6\,^{4.9}_{4.4}$	1.1
TU Ori	$9.20\,^{1.50}_{1.50}$	$15.67\,^{2.27}_{1.62}$	$69.09\,^{13.91}_{16.47}$	$1.04\,^{0.16}_{0.18}$	$0.56\,^{0.16}_{0.15}$	$319\,^{410}_{220}$	$646\,^{484}_{597}$	$2.6\,^{2.7}_{2.4}$	0.6
V2279 Ori	$5.43\,^{0.49}_{0.50}$	$9.18\,^{1.09}_{1.02}$	$45.61\,^{3.52}_{3.38}$	$0.93\,^{0.17}_{0.16}$	$1.50\,^{0.10}_{0.09}$	$115\,^{269}_{115}$	$374\,^{257}_{167}$	$4.9\,^{5.1}_{4.7}$	1.1
V348 Ori	$2.55\,^{0.25}_{0.23}$	$10.27\,^{0.70}_{0.71}$	$41.10\,^{1.66}_{1.53}$	$0.61\,^{0.10}_{0.09}$	$2.80\,^{0.08}_{0.08}$	$209\,^{24}_{95}$	$258\,^{98}_{258}$	$9.4\,^{9.9}_{8.9}$	1.9
V1229 Ori	$2.76\,^{0.28}_{0.28}$	$9.61\,^{0.78}_{1.19}$	$35.15\,^{1.31}_{1.53}$	$0.56\,^{0.08}_{0.09}$	$2.47\,^{0.07}_{0.12}$	$153\,^{58}_{123}$	$679\,^{455}_{380}$	$5.7\,^{6.0}_{5.5}$	1.2
V1399 Ori	$3.14\,^{0.36}_{0.24}$	$9.70\,^{0.73}_{0.76}$	$31.33\,^{1.16}_{1.19}$	$0.62\,^{0.12}_{0.09}$	$2.20\,^{0.09}_{0.08}$	$257\,^{64}_{50}$	$268\,^{121}_{189}$	$7.3\,^{7.7}_{7.0}$	1.5
V2299 Ori	$10.58\,^{0.84}_{0.73}$	$16.83\,^{2.96}_{2.71}$	$57.82\,^{19.51}_{10.68}$	$0.81\,^{0.18}_{0.55}$	$1.23\,^{0.45}_{0.17}$	$219\,^{85}_{103}$	$218\,^{267}_{218}$	$4.4\,^{4.6}_{4.2}$	1.0
LR Ori	$4.09\,^{0.82}_{0.74}$	$12.00\,^{0.87}_{1.55}$	$60.00\,^{11.00}_{10.53}$	$0.57\,^{0.13}_{0.14}$	$0.51\,^{0.25}_{0.03}$	$213\,^{112}_{99}$	$179\,^{221}_{179}$	$1.9\,^{2.0}_{1.8}$	0.4
2MASS3	$5.10\,^{0.84}_{0.80}$	$14.46\,^{1.11}_{1.32}$	$74.60\,^{15.40}_{17.00}$	$0.36\,^{0.40}_{0.03}$	$0.57\,^{0.09}_{0.09}$	$153\,^{122}_{50}$	$50\,^{112}_{373}$	$1.6\,^{1.7}_{1.5}$	0.4
MT Ori	$3.38\,^{0.12}_{0.11}$	$12.35\,^{0.78}_{0.64}$	$40.95\,^{0.96}_{8.17}$	$1.37\,^{0.22}_{0.17}$	$9.96\,^{0.17}_{0.22}$	$195\,^{27}_{24}$	$289\,^{58}_{89}$	$34.5\,^{0.8}_{1.7}$	7.2
LU Ori	$4.45\,^{0.63}_{0.64}$	$10.96\,^{0.49}_{0.48}$	$45.35\,^{4.58}_{3.97}$	$0.68\,^{0.15}_{0.14}$	$0.77\,^{0.06}_{0.06}$	$322\,^{87}_{134}$	$470\,^{213}_{181}$	$2.6\,^{2.7}_{2.4}$	0.6
V1333 Ori	$9.29\,^{0.58}_{0.60}$	$12.04\,^{0.61}_{0.75}$	$30.39\,^{2.57}_{2.60}$	$1.52\,^{0.25}_{0.27}$	$1.30\,^{0.20}_{0.15}$	$222\,^{87}_{208}$	$636\,^{635}_{260}$	$3.3\,^{3.5}_{3.2}$	0.7
Par 1842	$1.77\,^{0.43}_{0.37}$	$10.82\,^{0.93}_{1.07}$	$36.39\,^{2.14}_{2.19}$	$0.45\,^{0.11}_{0.10}$	$1.52\,^{0.09}_{0.08}$	$216\,^{31}_{138}$	$556\,^{276}_{341}$	$4.3\,^{4.5}_{4.1}$	0.9
V1330 Ori	$4.95\,^{0.45}_{0.40}$	$10.46\,^{0.74}_{0.47}$	$43.05\,^{3.08}_{4.95}$	$0.65\,^{0.13}_{0.11}$	$1.57\,^{0.07}_{0.08}$	$152\,^{176}_{108}$	$254\,^{124}_{253}$	$5.3\,^{5.6}_{5.0}$	1.1
Par 1837	$5.45\,^{0.37}_{0.84}$	$7.22\,^{1.44}_{1.49}$	$45.03\,^{4.66}_{5.42}$	$0.35\,^{0.21}_{0.09}$	$0.52\,^{0.06}_{0.04}$	$321\,^{140}_{138}$	$597\,^{288}_{326}$	$1.5\,^{1.6}_{1.4}$	0.3
Par 1895	$0.05\,^{0.27}_{0.04}$	$13.13\,^{1.93}_{1.31}$	$64.33\,^{15.71}_{9.72}$	$0.18\,^{0.05}_{0.04}$	$0.39\,^{0.04}_{0.05}$	$318\,^{290}_{156}$	$253\,^{99}_{89}$	$1.5\,^{1.5}_{1.4}$	0.3
V1279 Ori	$2.02\,^{0.58}_{0.40}$	$9.58\,^{0.92}_{1.08}$	$38.34\,^{2.67}_{2.52}$	$0.26\,^{0.10}_{0.07}$	$0.92\,^{0.05}_{0.07}$	$279\,^{55}_{132}$	$247\,^{101}_{199}$	$2.7\,^{2.8}_{2.5}$	0.5
V491 Ori	$16.21\,^{0.91}_{0.50}$	–	$43.40\,^{2.23}_{3.08}$	–	$2.69\,^{0.06}_{0.10}$	–	$400\,^{358}_{220}$	$7.7\,^{8.1}_{7.3}$	1.8
Par 1839	$2.99\,^{0.86}_{0.84}$	$11.67\,^{1.00}_{1.22}$	$81.22\,^{8.78}_{11.71}$	$0.48\,^{0.11}_{0.11}$	$0.43\,^{0.06}_{0.03}$	$269\,^{88}_{164}$	$278\,^{200}_{277}$	$1.9\,^{2.0}_{1.8}$	0.4
LQ Ori	$0.29\,^{0.20}_{0.23}$	$10.52\,^{0.36}_{0.31}$	$34.28\,^{2.16}_{1.32}$	$0.68\,^{0.11}_{0.07}$	$1.89\,^{0.15}_{0.30}$	$213\,^{31}_{29}$	$221\,^{160}_{220}$	$5.0\,^{5.3}_{4.8}$	1.0
V1326 Ori	$3.19\,^{0.41}_{0.44}$	$6.04\,^{0.55}_{0.50}$	$29.46\,^{1.56}_{1.21}$	$0.98\,^{0.21}_{0.18}$	$1.27\,^{0.06}_{0.06}$	$191\,^{39}_{59}$	$301\,^{188}_{194}$	$2.7\,^{2.8}_{2.6}$	0.6
COUP 1023	$5.56\,^{1.34}_{1.13}$	$18.96\,^{3.09}_{2.95}$	$78.00\,^{12.00}_{14.96}$	$0.60\,^{0.13}_{0.13}$	$0.28\,^{0.11}_{0.04}$	$86\,^{83}_{78}$	$243\,^{193}_{145}$	$1.7\,^{1.8}_{1.6}$	0.4
V495 Ori	$5.24\,^{0.72}_{0.69}$	$11.61\,^{1.47}_{1.01}$	$69.02\,^{14.58}_{9.43}$	$0.51\,^{0.12}_{0.11}$	$0.66\,^{0.06}_{0.07}$	$257\,^{127}_{133}$	$307\,^{165}_{143}$	$3.0\,^{3.2}_{2.9}$	0.7
V1228 Ori	$3.04\,^{0.80}_{1.54}$	$9.18\,^{0.78}_{0.65}$	$37.33\,^{5.33}_{2.67}$	$0.48\,^{0.17}_{0.10}$	$0.62\,^{0.05}_{0.08}$	$135\,^{74}_{74}$	$359\,^{50}_{354}$	$1.7\,^{1.8}_{1.6}$	0.4
V1501 Ori	$3.41\,^{0.82}_{0.69}$	$12.19\,^{0.99}_{1.29}$	$42.42\,^{4.09}_{5.42}$	$0.59\,^{0.18}_{0.15}$	$0.79\,^{0.11}_{0.07}$	$301\,^{105}_{97}$	$384\,^{180}_{307}$	$2.5\,^{2.7}_{2.4}$	0.6
V1496 Ori	$3.27\,^{0.83}_{0.84}$	$13.00\,^{2.11}_{1.44}$	$65.90\,^{18.16}_{10.35}$	$0.27\,^{0.09}_{0.07}$	$0.41\,^{0.05}_{0.05}$	$210\,^{556}_{186}$	$36\,^{286}_{31}$	$1.6\,^{1.7}_{1.6}$	0.4
2MASS1	$14.49\,^{0.82}_{0.82}$	$12.07\,^{1.61}_{1.32}$	$47.93\,^{9.85}_{6.32}$	$1.27\,^{0.27}_{0.28}$	$1.08\,^{0.18}_{0.18}$	–	$770\,^{246}_{293}$	$3.6\,^{3.8}_{3.4}$	0.9
COUP 450	$30.95\,^{0.78}_{0.78}$	–	$34.92\,^{1.55}_{1.34}$	–	$5.58\,^{0.12}_{0.26}$	–	$460\,^{603}_{302}$	$11.2\,^{0.5}_{0.6}$	3.3
Par 1936	$16.88\,^{1.94}_{1.76}$	$13.28\,^{1.54}_{1.42}$	$83.00\,^{7.00}_{7.05}$	$0.80\,^{0.21}_{0.16}$	$0.26\,^{0.03}_{0.02}$	–	$356\,^{1089}_{356}$	$1.3\,^{1.4}_{1.2}$	0.3
COUP 662	$21.52\,^{1.66}_{1.60}$	–	$89.00\,^{1.00}_{1.00}$	$0.00\,^{0.00}_{0.00}$	$0.62\,^{0.02}_{0.02}$	–	$364\,^{729}_{359}$	$2.6\,^{2.7}_{2.5}$	0.6
V1398 Ori	$5.01\,^{1.05}_{1.24}$	$12.89\,^{1.31}_{1.00}$	$79.00\,^{11.00}_{11.05}$	$0.50\,^{0.12}_{0.16}$	$0.36\,^{0.06}_{0.02}$	$197\,^{121}_{195}$	$415\,^{314}_{290}$	$1.7\,^{1.7}_{1.6}$	0.4

NOTE—(1) 10^{21} cm^{-2} (2) 10^6 K (3) 10^{54} cm^{-3} (4) km s^{-1} (5) 10^{-13} erg cm^{-2} s^{-1} (6) 10^{31} erg s^{-1}

With a set of ~40 high quality spectra covering a diverse population of stars, the HETG ONC legacy project will investigate plasma physics relating to: massive stellar winds, coronal abundances and flares, stellar irradiation of circumstellar disks, stellar accretion and more (Schulz et al. 2023, in prep.).



Data from Schulz et al. 2023 (in prep.)