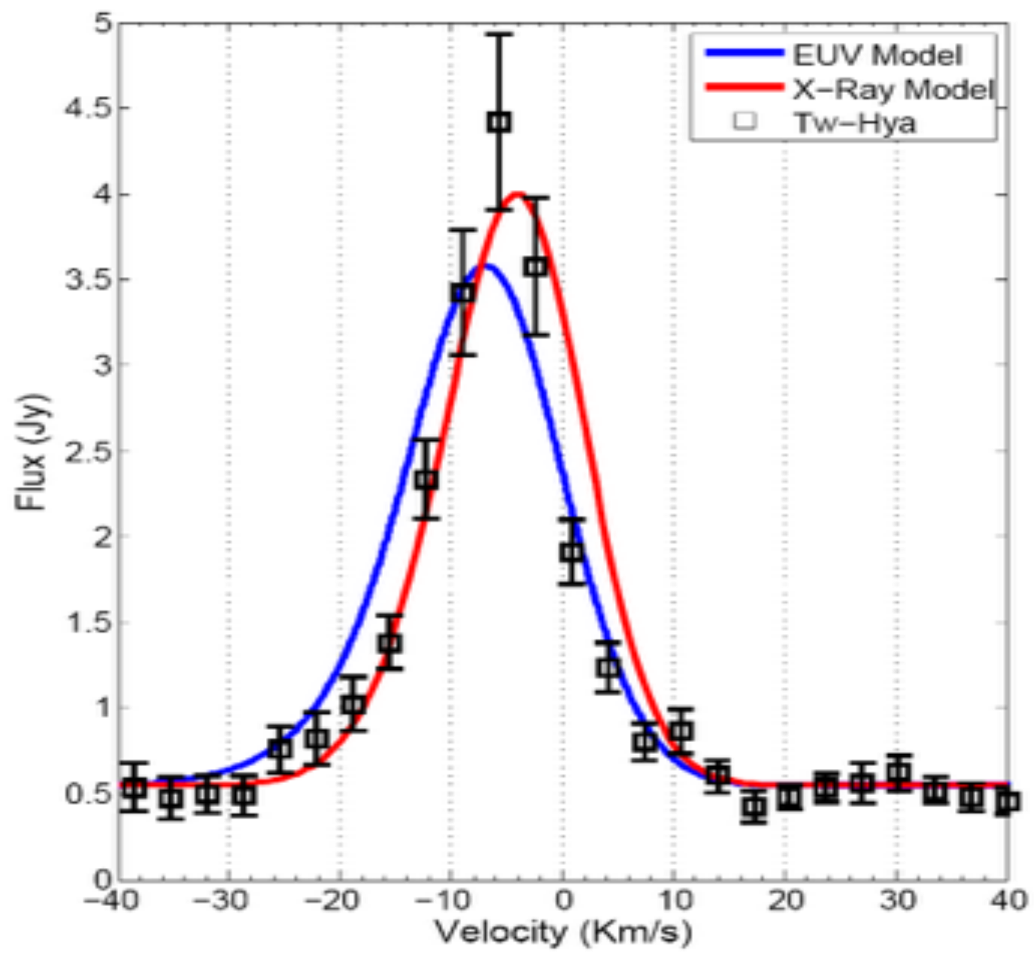
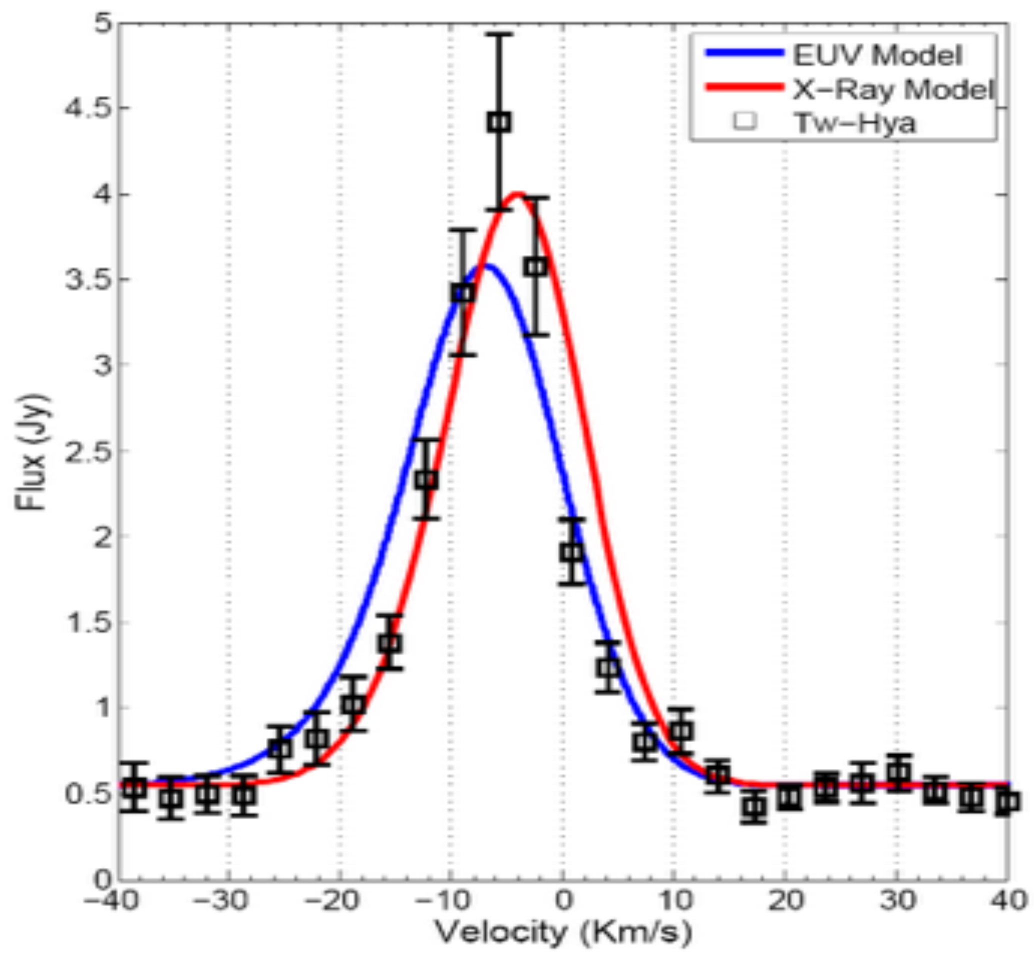
Blueshifted collisionally excited emission lines from YSOs: the smoking gun of a wind, but no useful tracers of the driving mechanism



Barbara Ercolano
University of Munich (LMU)

James Owen
Institute for Advanced Study (Princeton)

Blueshifted collisionally excited emission lines from YSOs: the smoking gun of a wind, but no useful tracers of the ~~driving mechanism~~ Mass Loss Rates



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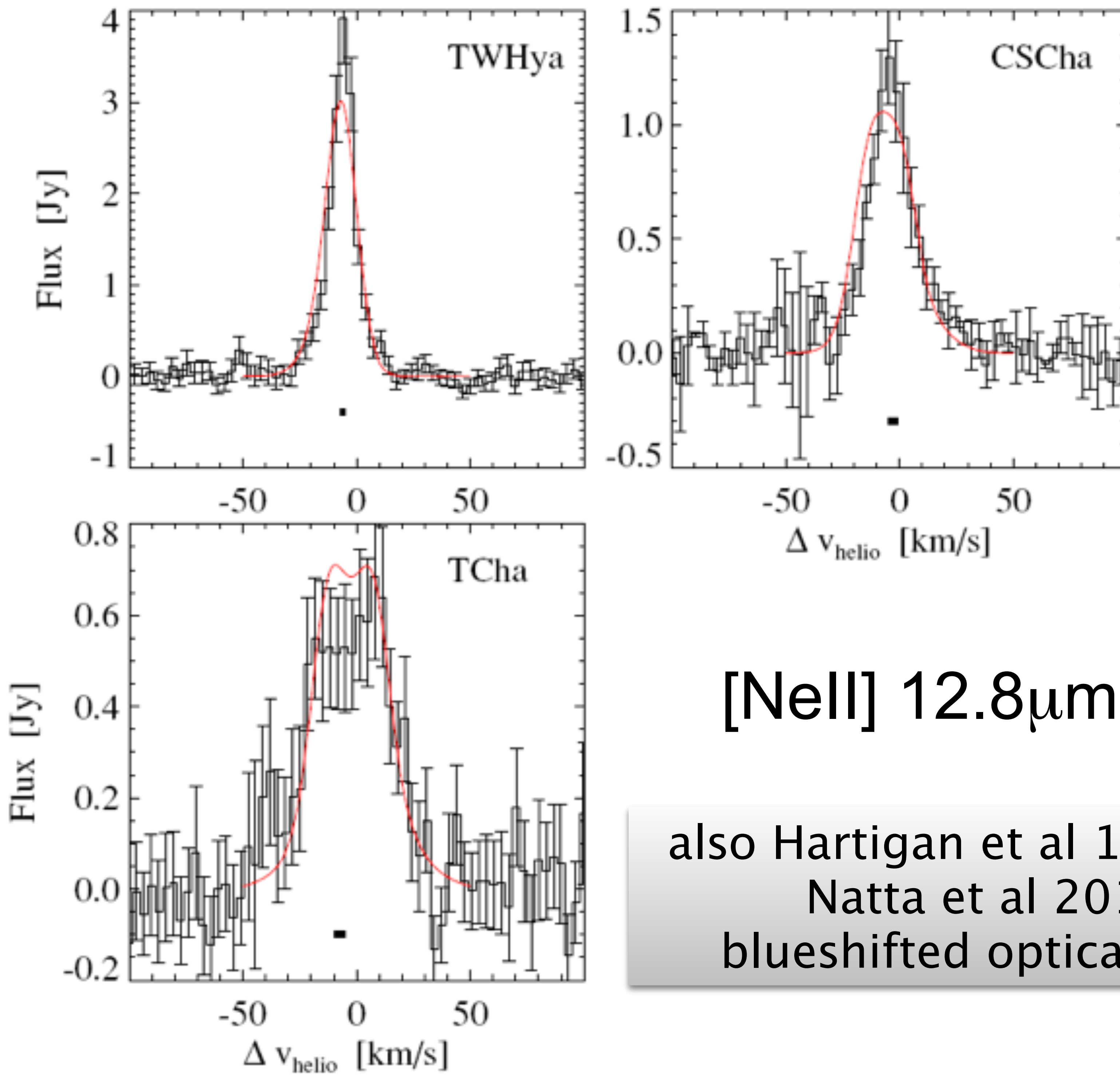
Can we 'see' the wind??

Pascucci & Sterzik, 2009

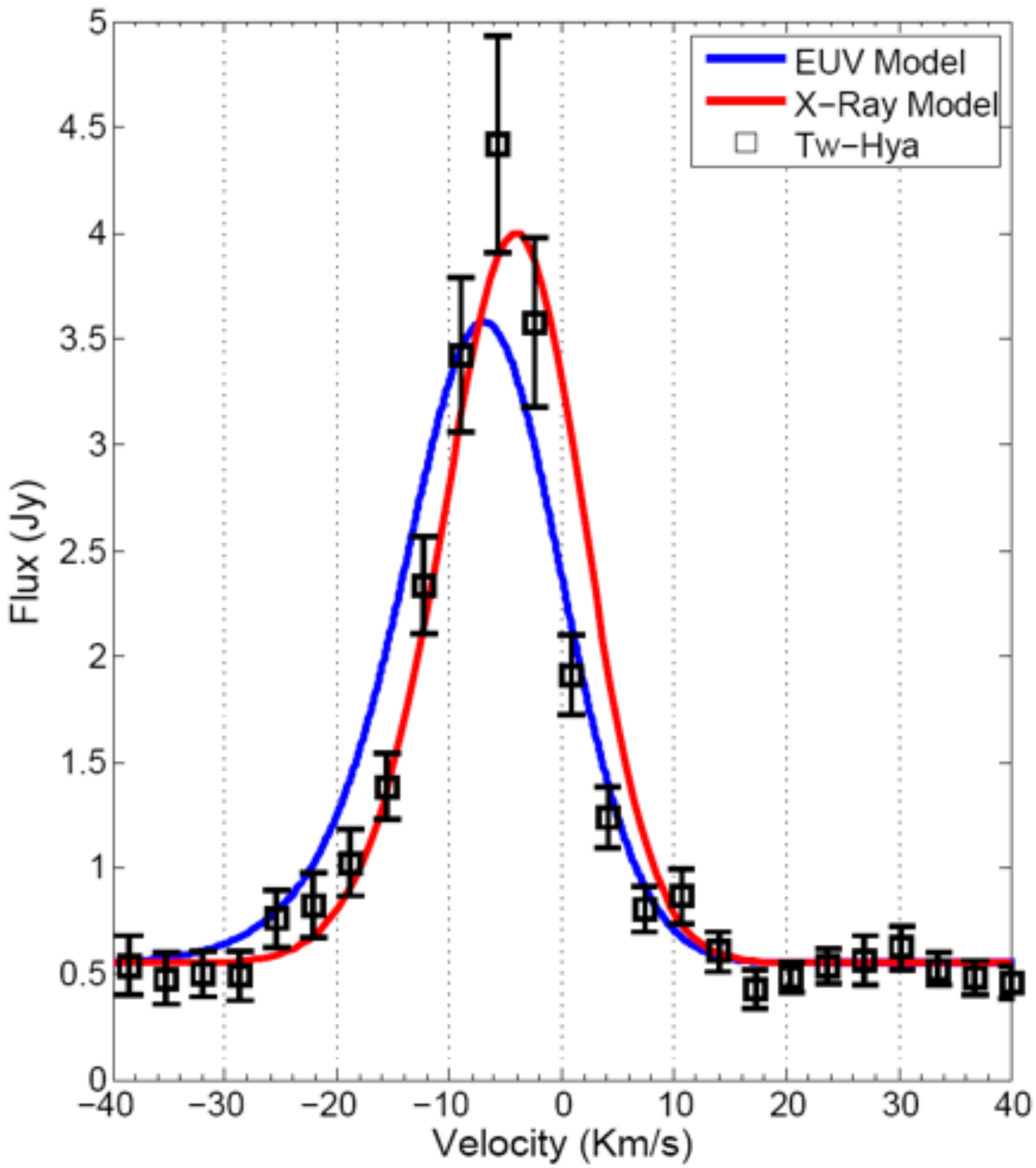


[NeII] 12.8μm

also Hartigan et al 1995 and
Natta et al 2014
blueshifted optical lines

Emission lines formed in the wind will appear blueshifted as the material moves radially towards the observer for specific lines of sight

[NeII] 12.8μm a wind diagnostic?



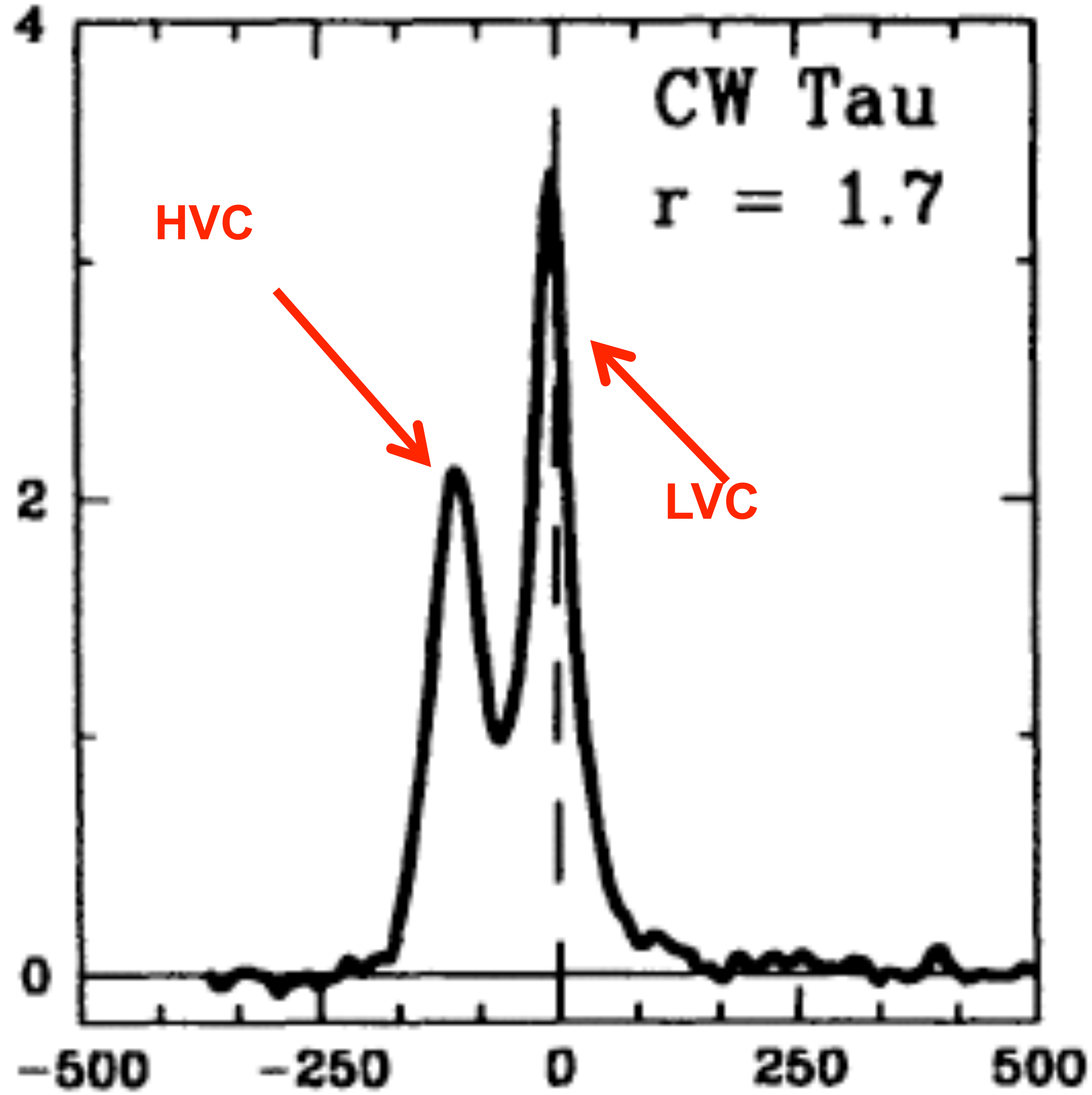
EUV wind - *fully ionised* - Ne^{+} and Ne^{++} formed via removal of valence electron from Ne^{0} and Ne^{+}

X-ray wind - *quasi-neutral* - Ne^{+} Ne^{++} formed via K-shell ionisation of Ne^{0} followed by multiple Auger ejections. Slow charge-exchange reaction between H^{0} and Ne^{+++} and negligible between H^{0} and Ne^{++}

Ercolano & Owen 2010 - X-ray – $\dot{M} \sim 10^{-8} M_{\odot}$ /yr

Alexander 2008 - EUV – $\dot{M} \sim 10^{-10} M_{\odot}$ /yr

[OI] 6300A a better wind diagnostic?



Hartigan et al 1995

But see also Gorti et al. OH dissociation?
see also Rigliaco et al (2013)

[OI] 6300A a better wind diagnostic?

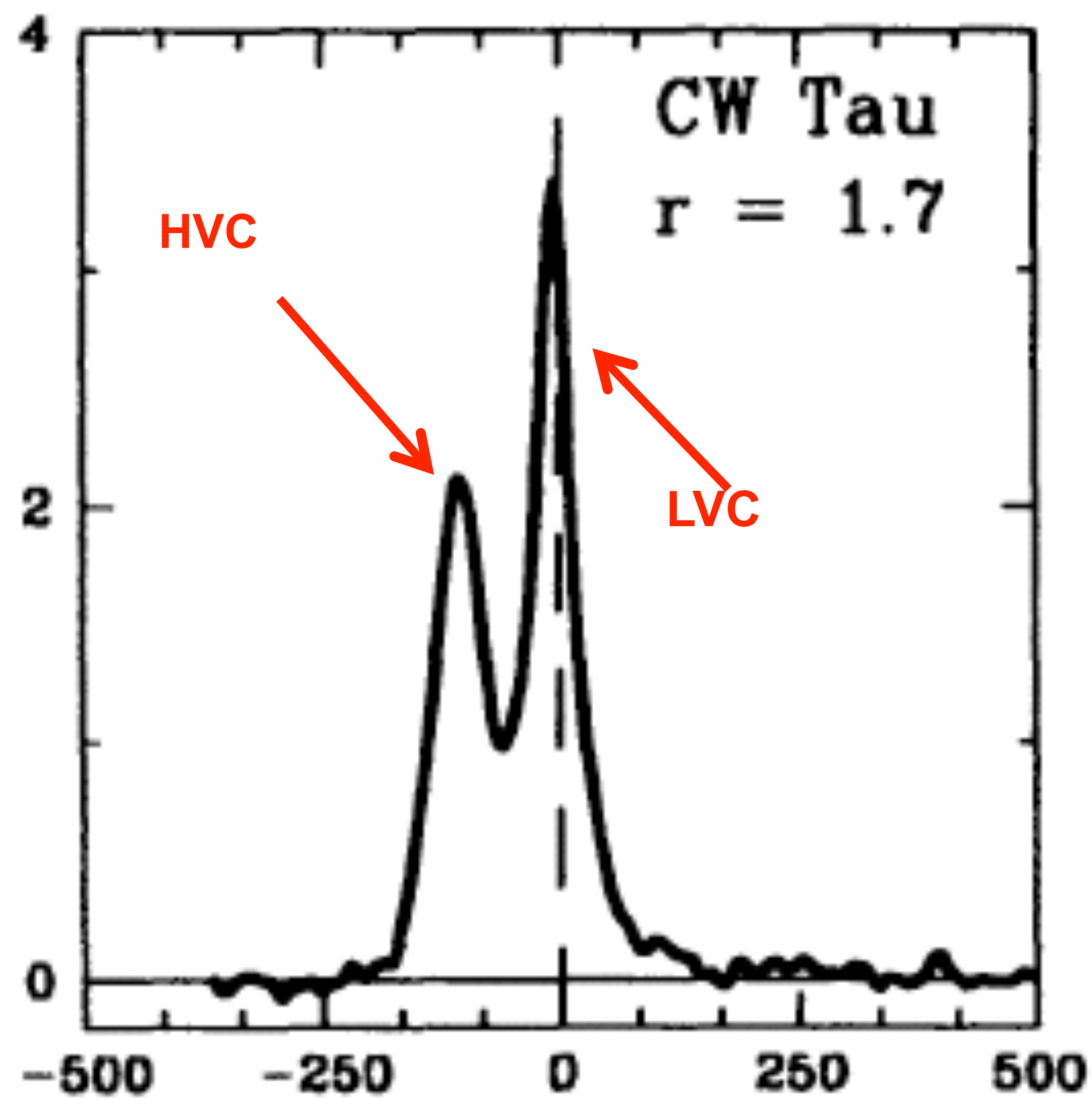
L(LVC) ~ 10

blueshifted by a few km/s

EUV wind is fully ionised
L([OI]) < 10
(Font et al 2004)

X-ray wind is quasi-neutral
L([OI]) > 10
(Ercolano & Owen 2010)

But see also Gorti et al. OH dissociation?
see also Rigliaco et al (2013)



Hartigan et al 1995

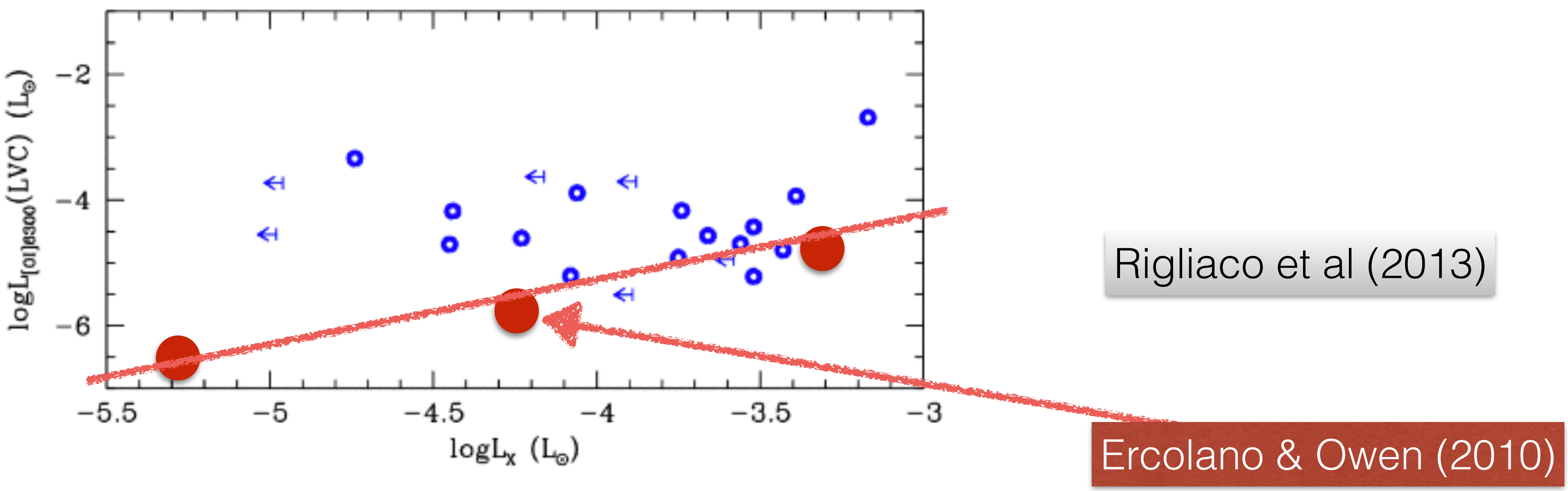
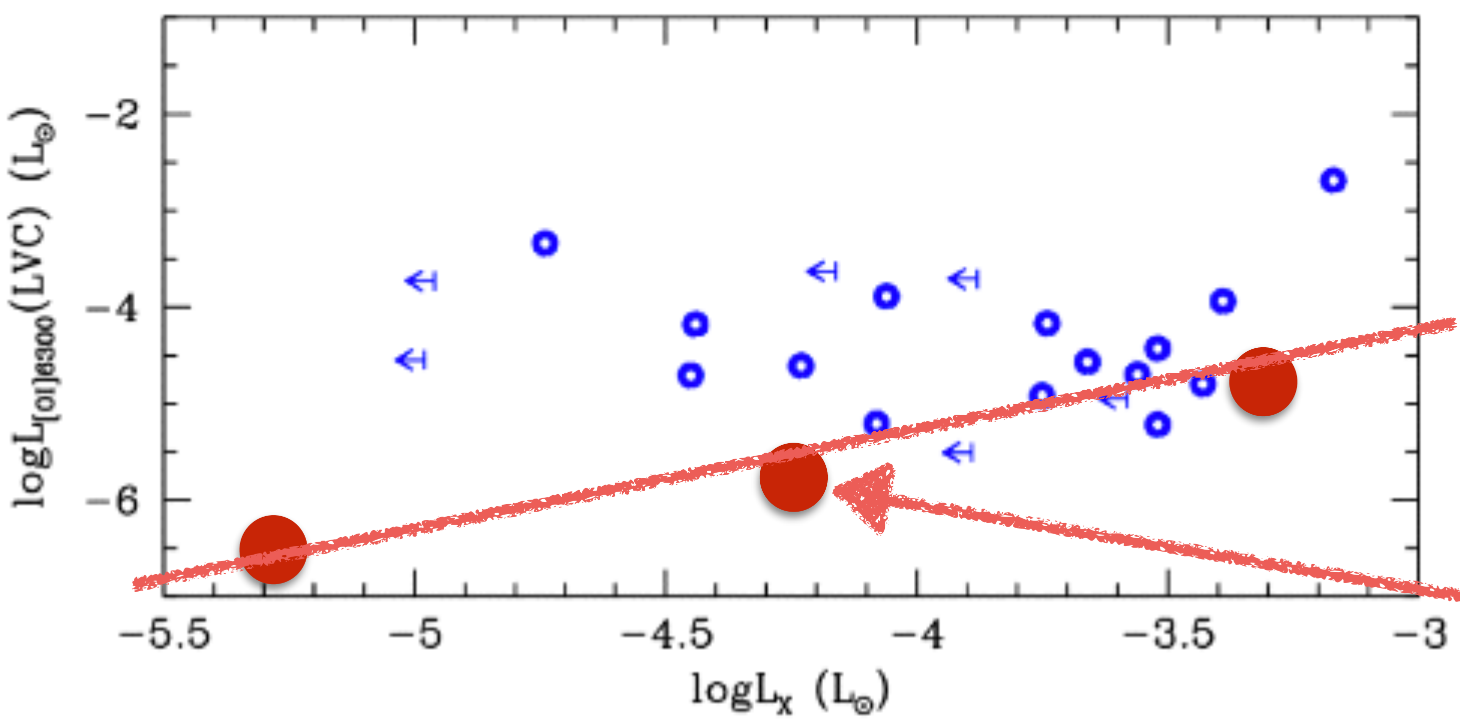


FIG. 5.— [O I] luminosity versus X-ray luminosity for the subsample of 21 Sample II objects with X-ray luminosities (L_X) found in the literature.



Rigliaco et al (2013)

Ercolano & Owen (2010)

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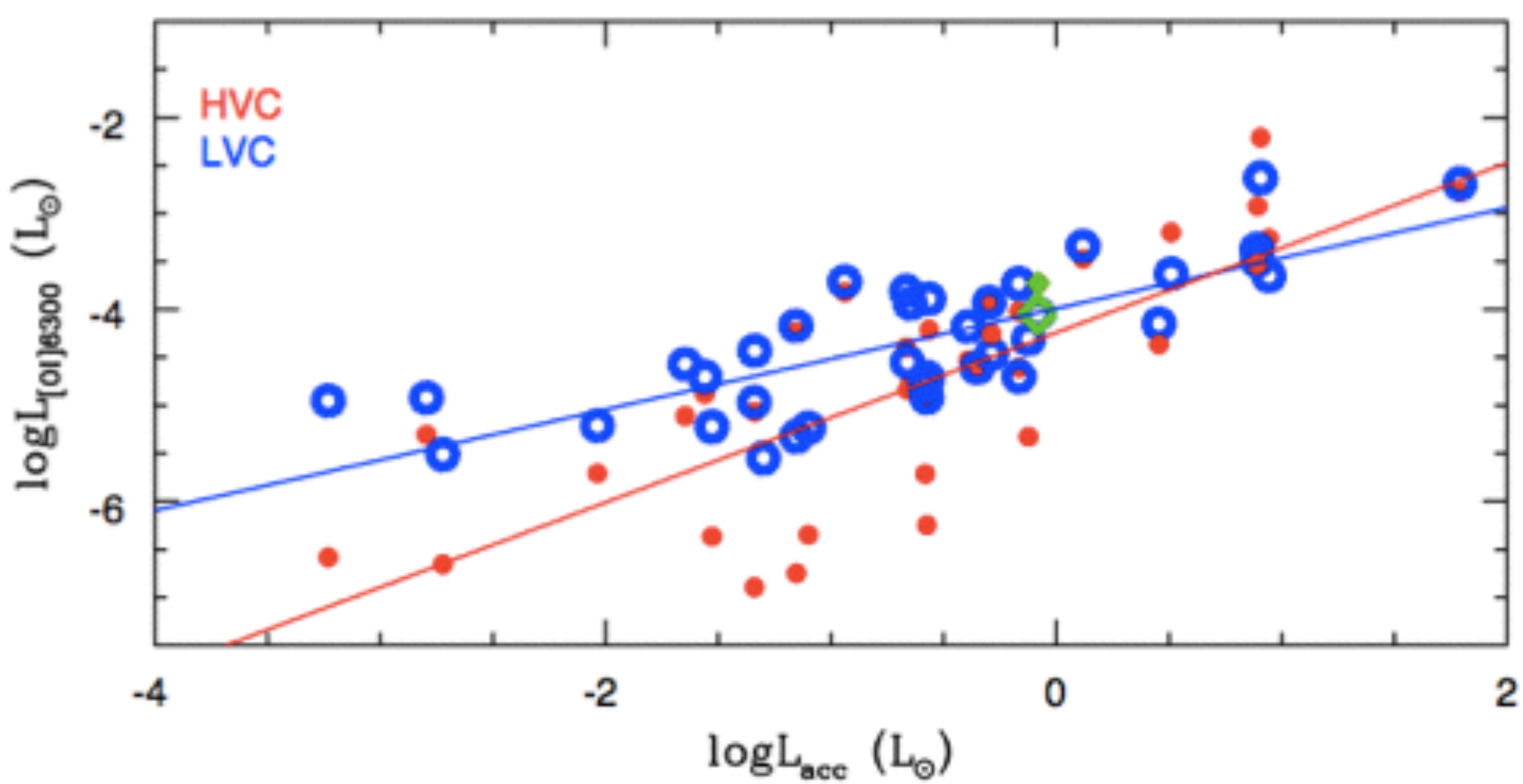

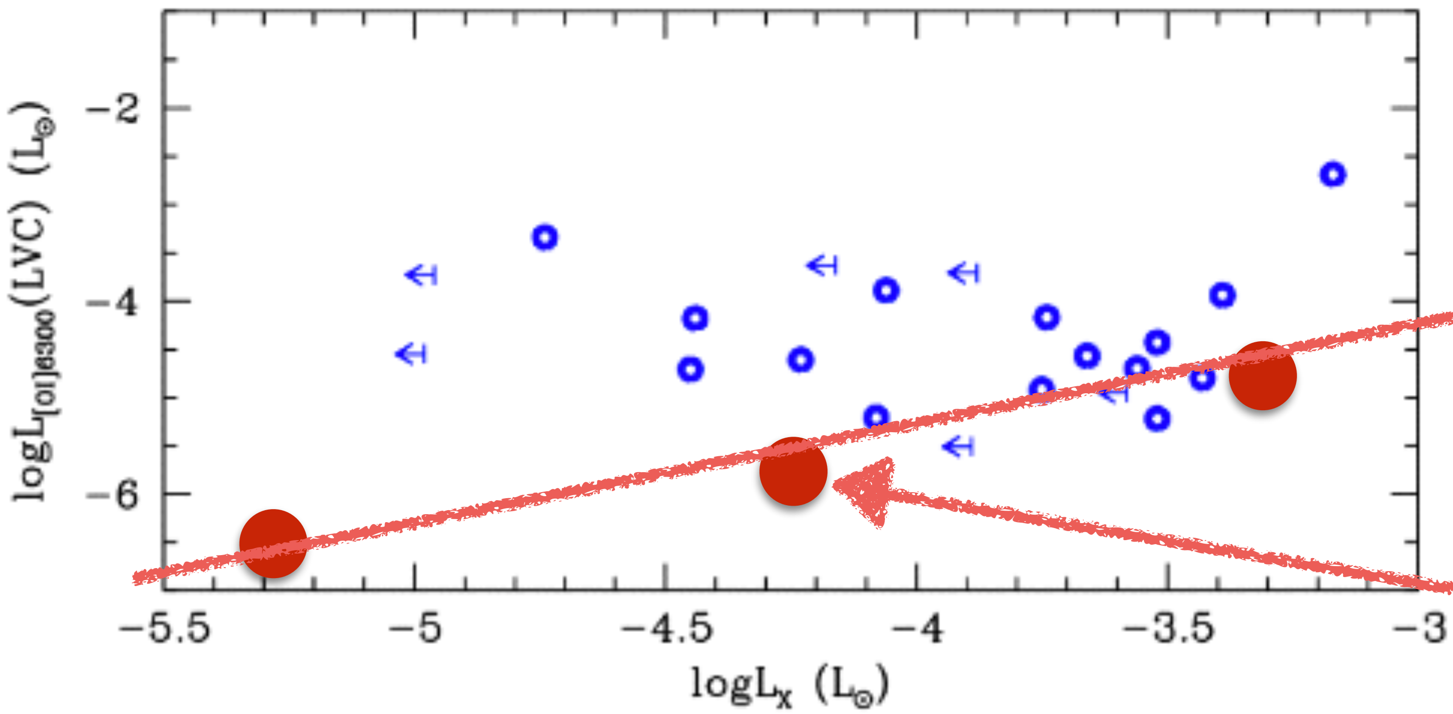

Rigliaco et al (2013)

Ercolano & Owen (2010)

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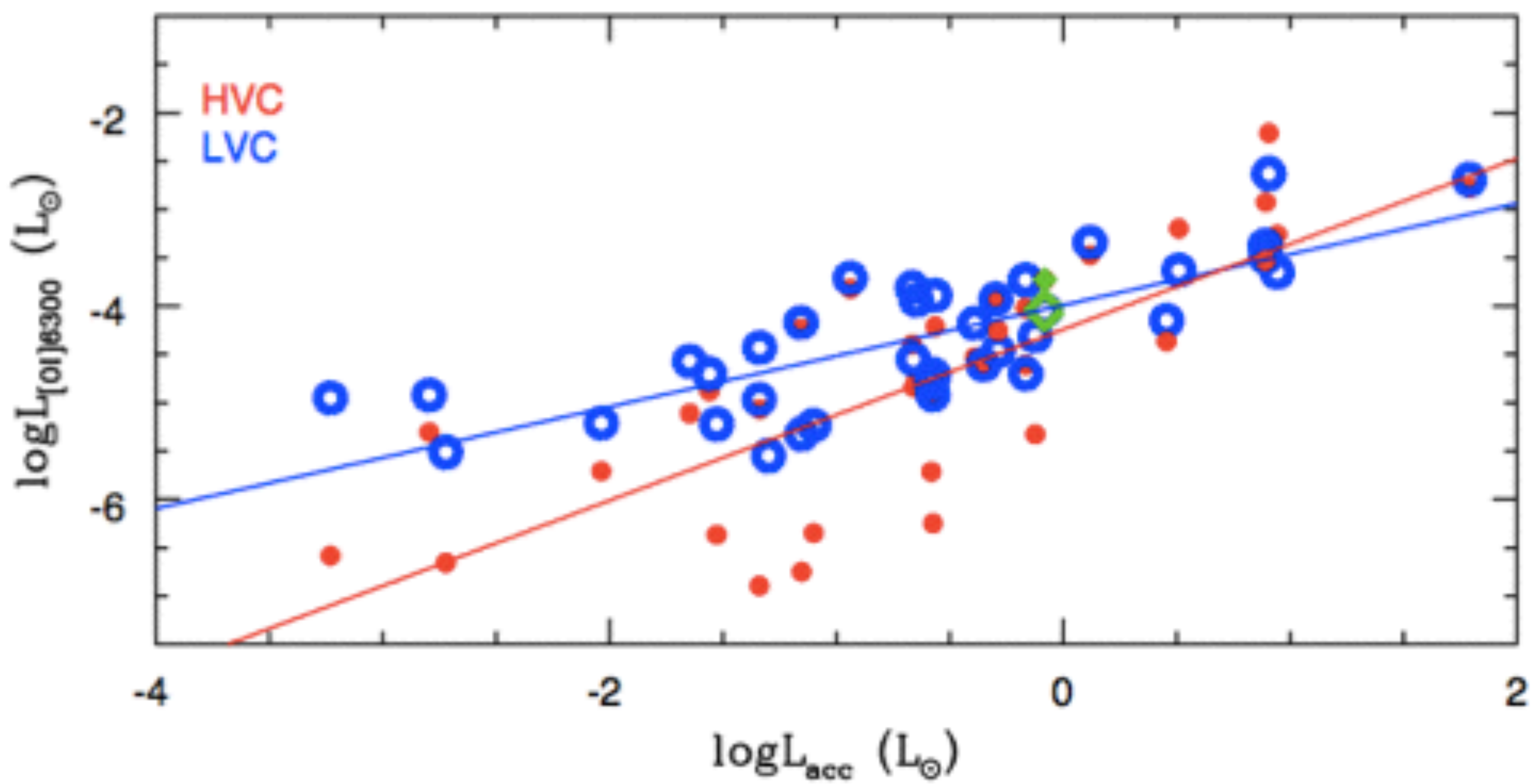


see also Natta et al. (2014) for a discussion of the [SII] 4069 line

2.4.1. *Collisionally Excited Lines*

See Various Textbooks e.g. Osterbrock
or here Hamann & Ferland 1999

Collisionally excited lines form by the internal excitation of an ion after electron impact.
equilibrium of the energy levels. For example, the equilibrium (detailed balance) equation fo

$$n_l n_e q_{lu} = n_u(\beta A_{ul} + n_e q_{ul}) \quad [cm^{-3}\ s^{-1}]$$

where n_e is the electron density, β is the probability for line photons escaping the local regi
lower states, and q_{lu} and q_{ul} are the upward and downward collisional-rate coefficients, res
most applications, the ions are mainly in their ground state and n_l is approximately the ionic

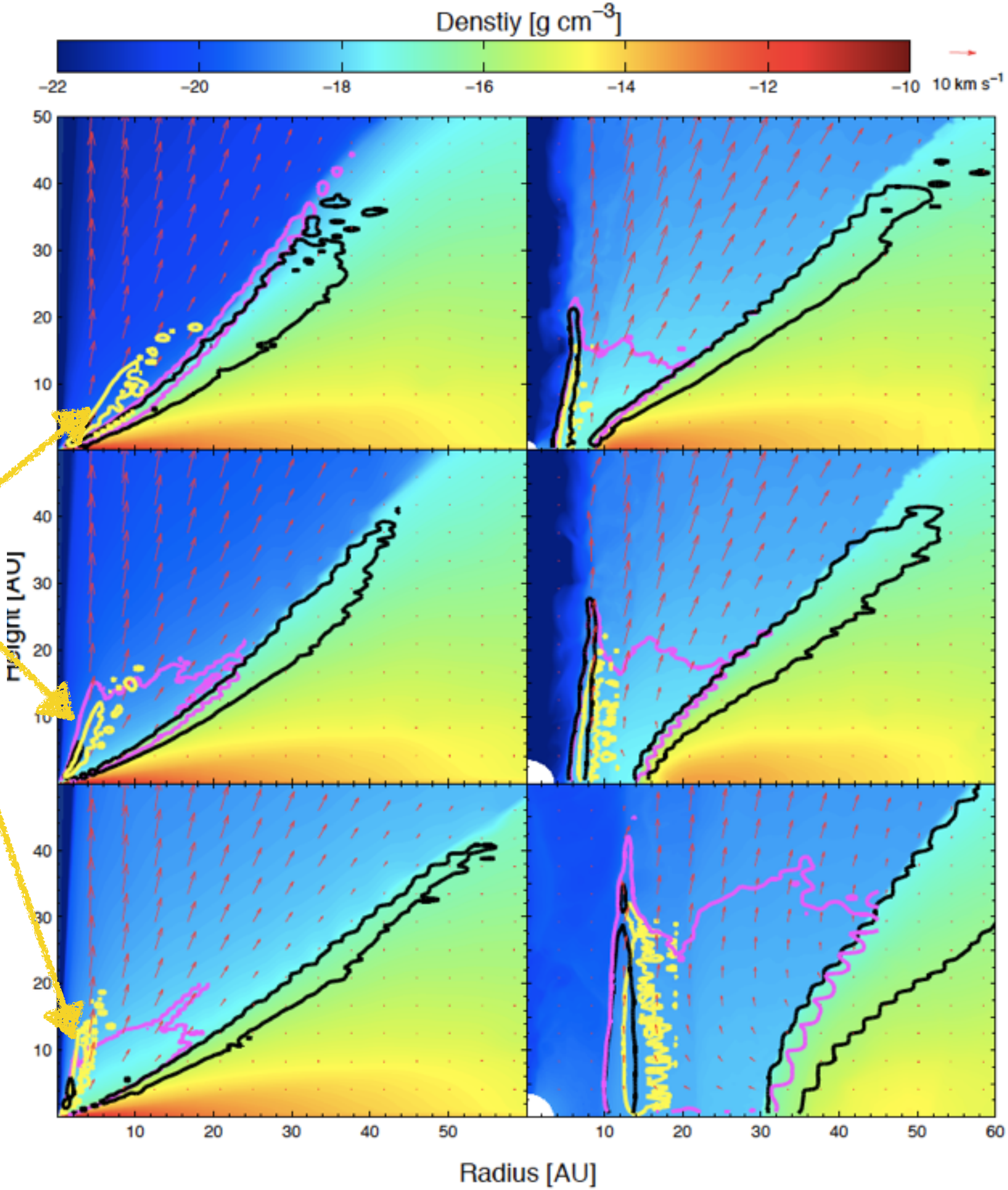
$$\epsilon_{coll} = n_u \beta A_{ul} h\nu_o = n_l \beta A_{ul} h\nu_o \left(\frac{n_e q_{lu}}{\beta A_{ul} + n_e q_{ul}}\right) \quad [ergs\ cm^{-3}\ s^{-1}]$$

where ν_o is the line frequency. This emissivity has a strong temperature dependence becaus
high-density limit we have,

$$\epsilon_{coll} = n_l \beta A_{ul} h\nu_o \frac{g_l}{g_u} \exp\left(-\frac{h\nu_o}{kT}\right)$$

and the levels are said to be thermalized. Line thermalization, where ϵ_{coll} no longer depe
oscillator strength, which therefore drops out of the factor $\beta A_{ul} \approx A_{ul}/\tau$ in Equation 3 if τ >>

OI 6300



from Ercolano & Owen (2010)

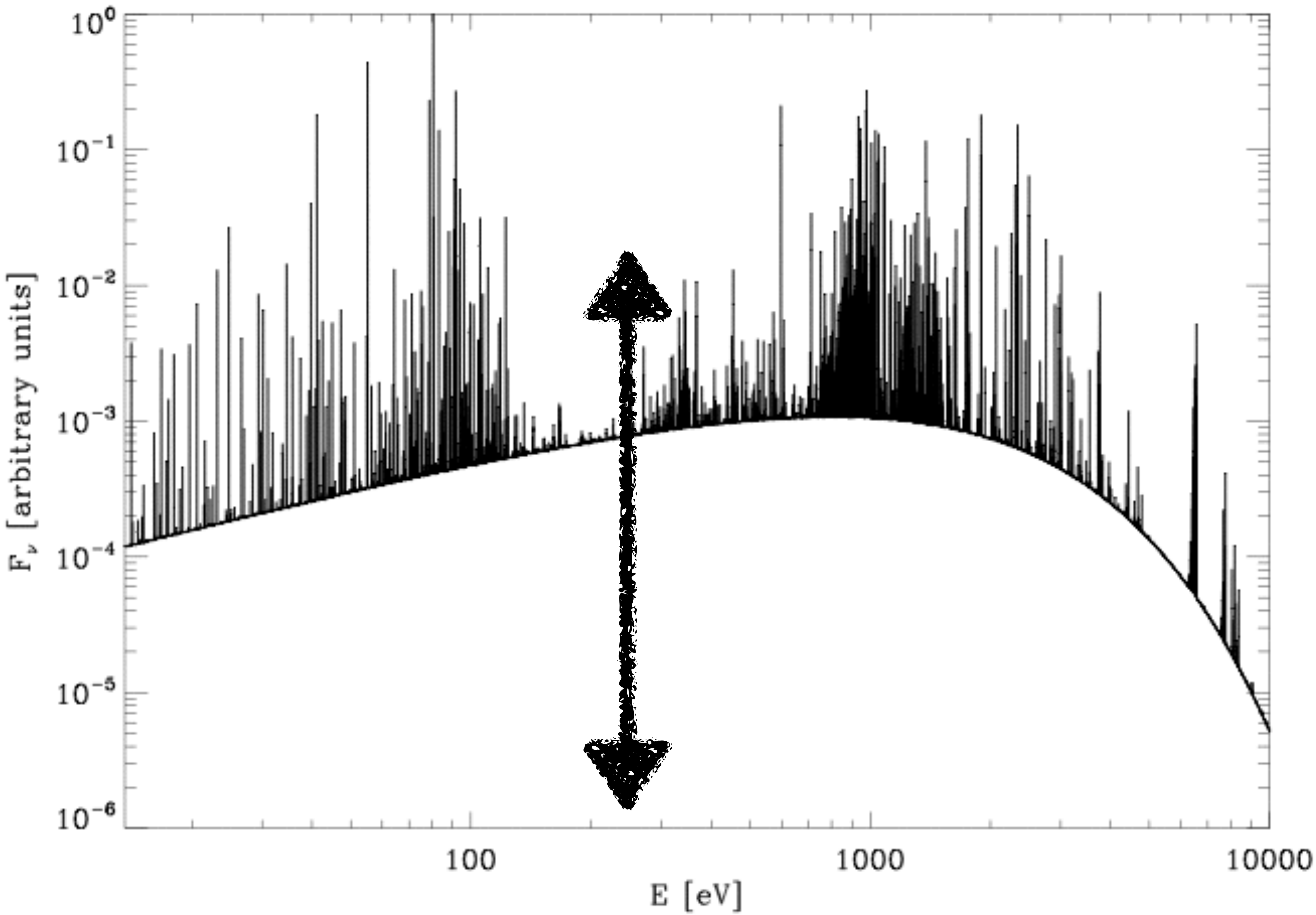
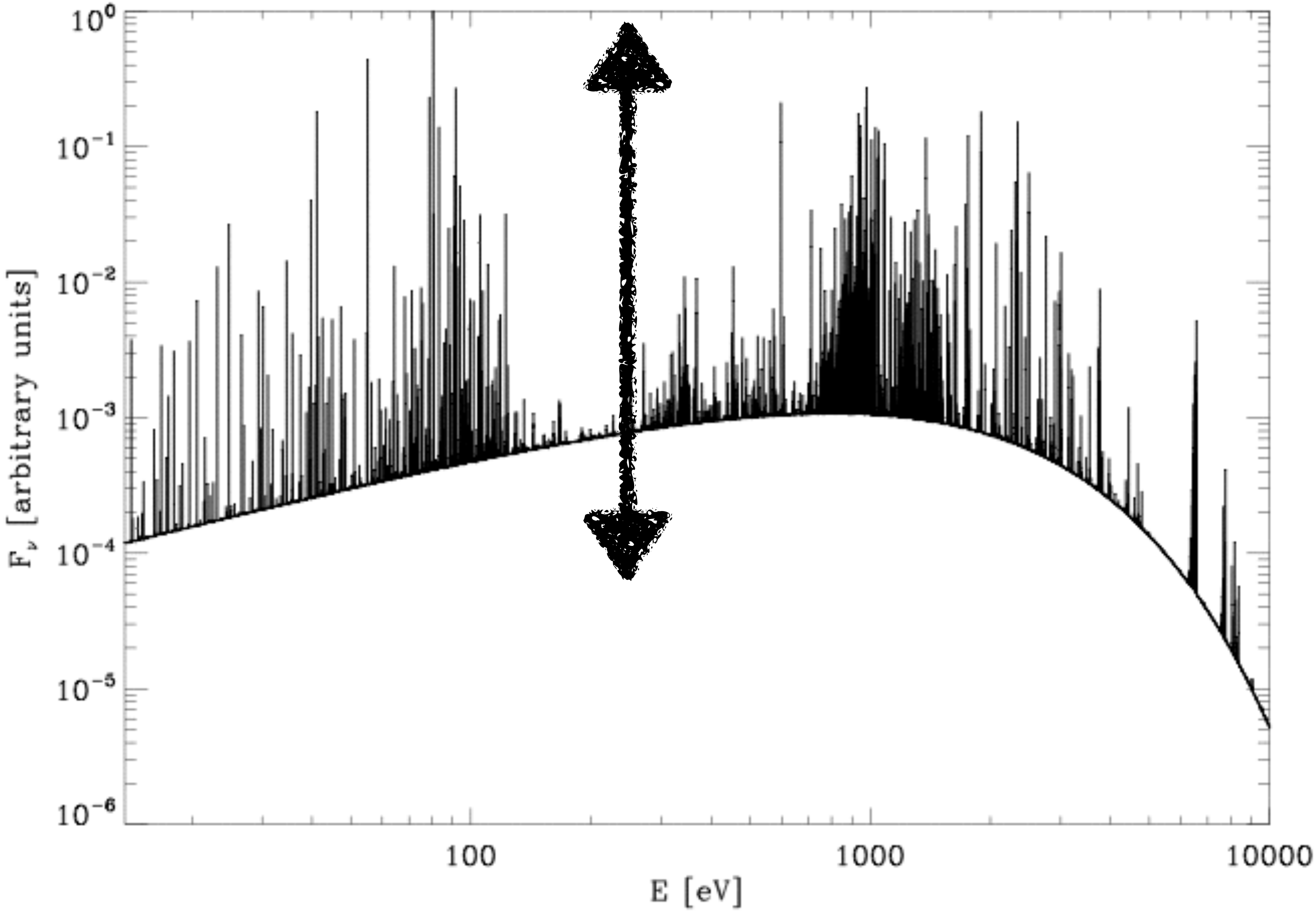


FIG. 1.— Isothermal model spectrum for $\mathrm{Log}(T_X) = 7.2$.



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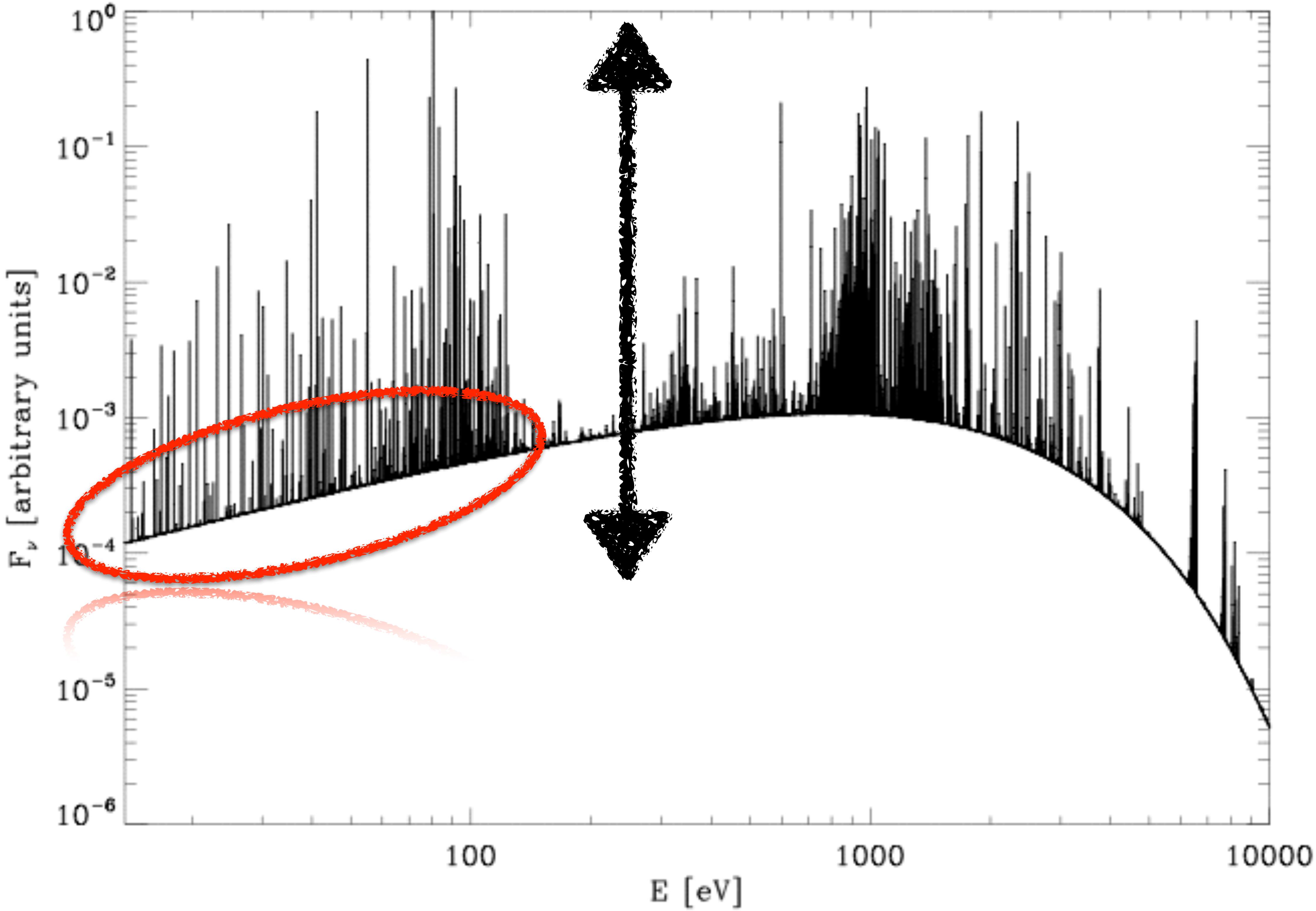

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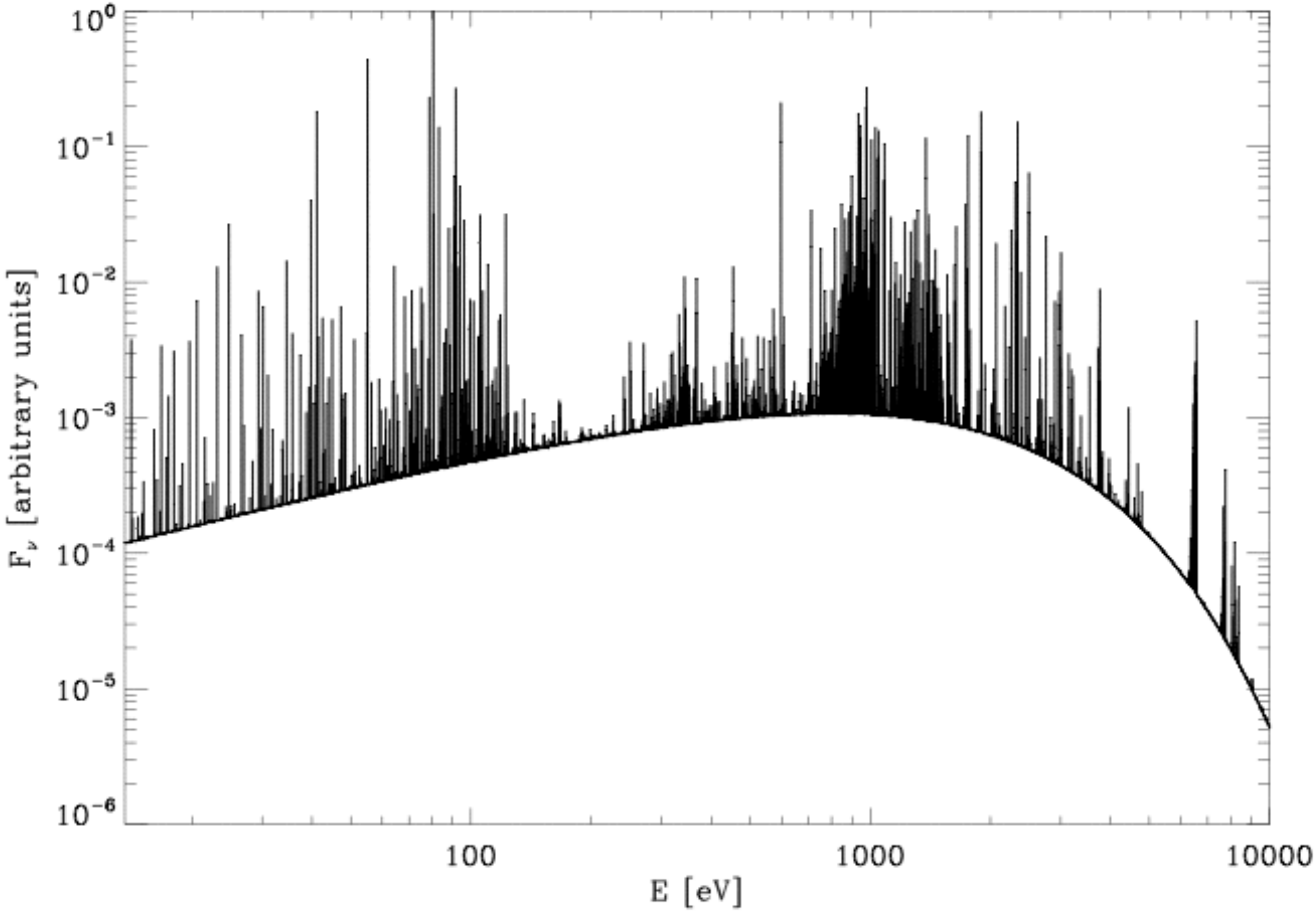

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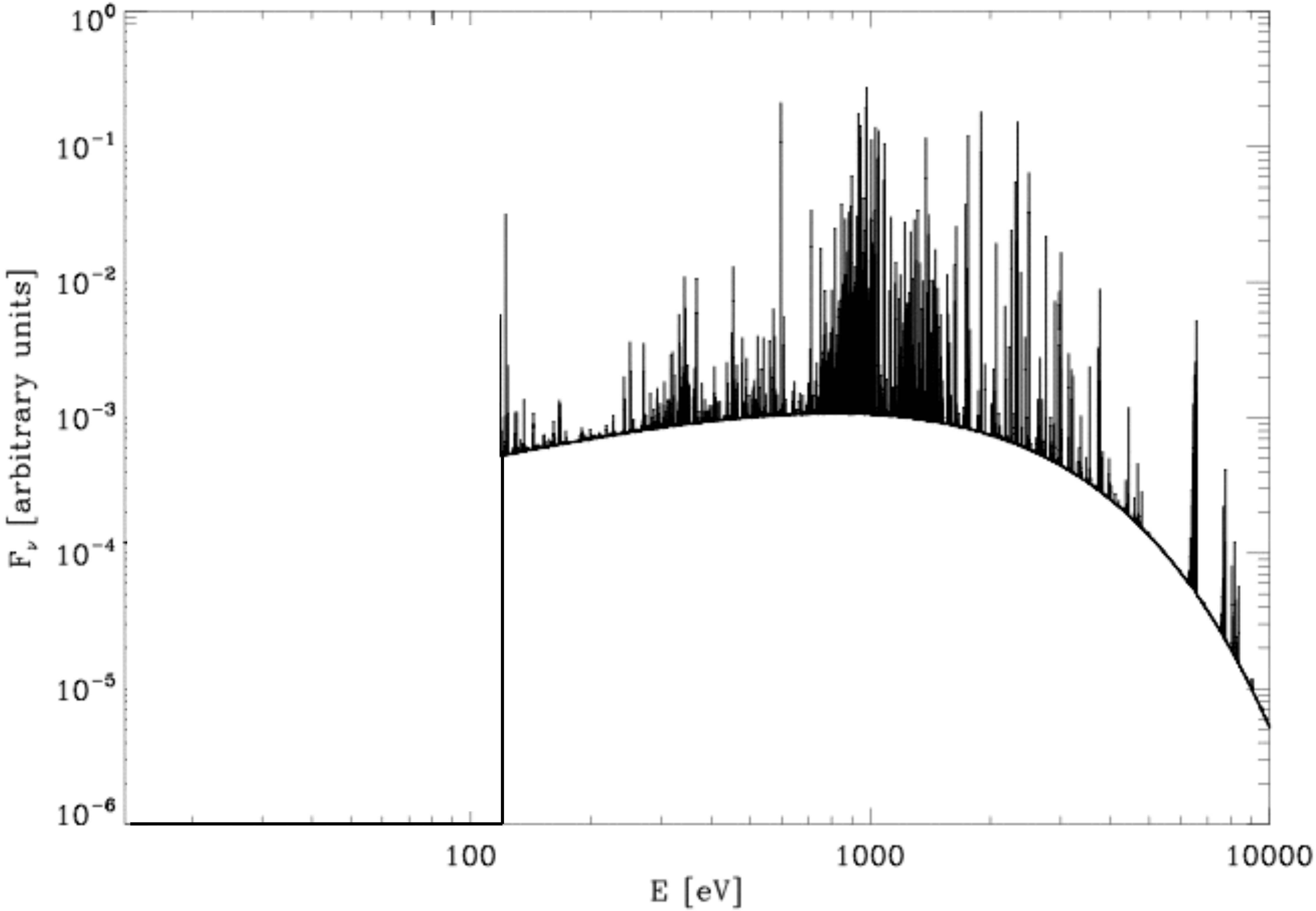

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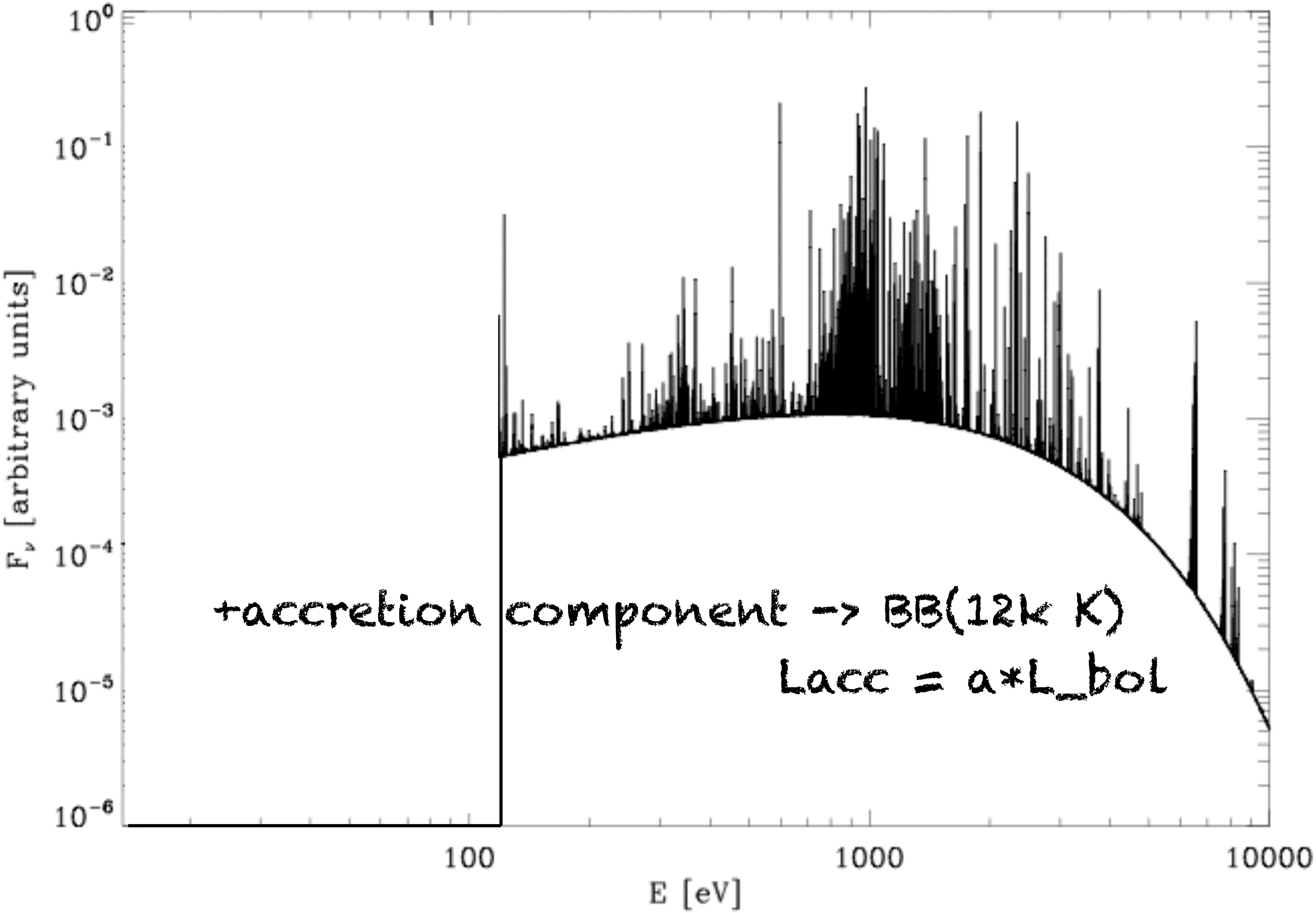

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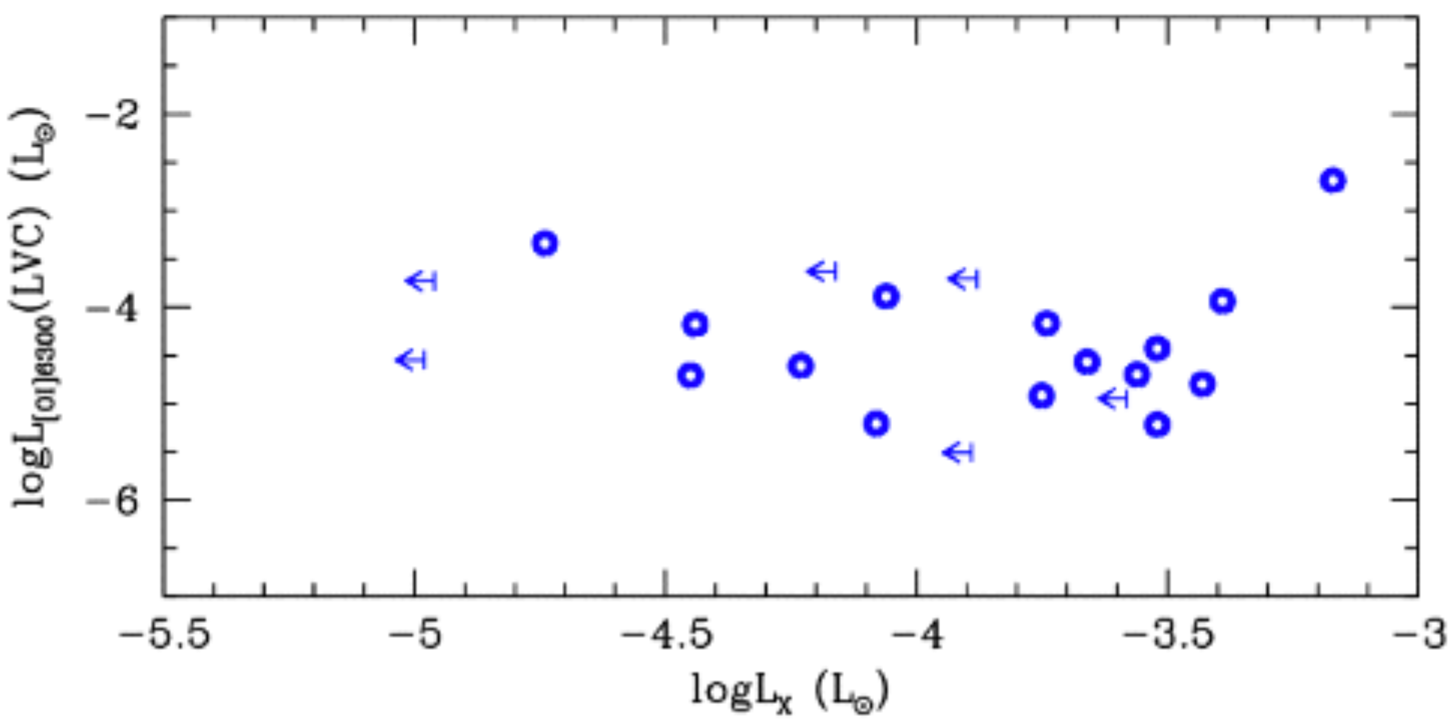
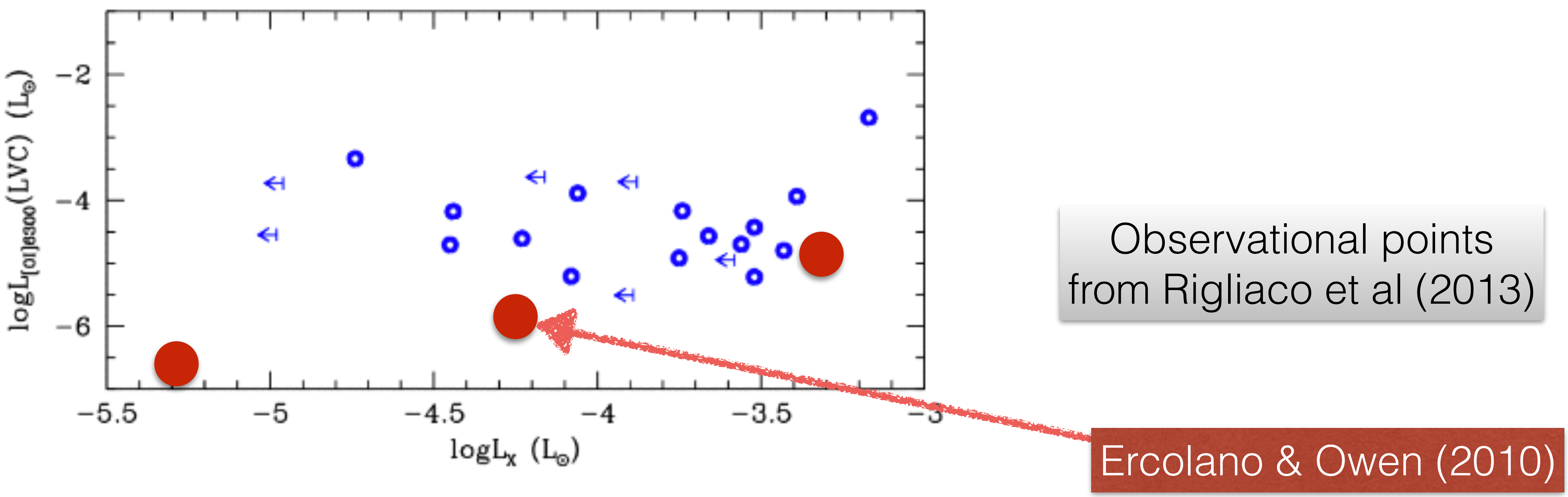


FIG. 5.— [O I] luminosity versus X-ray luminosity for the subsample of 21 Sample II objects with X-ray luminosities (L_X) found in the literature.

Observational points from Rigliaco et al (2013)



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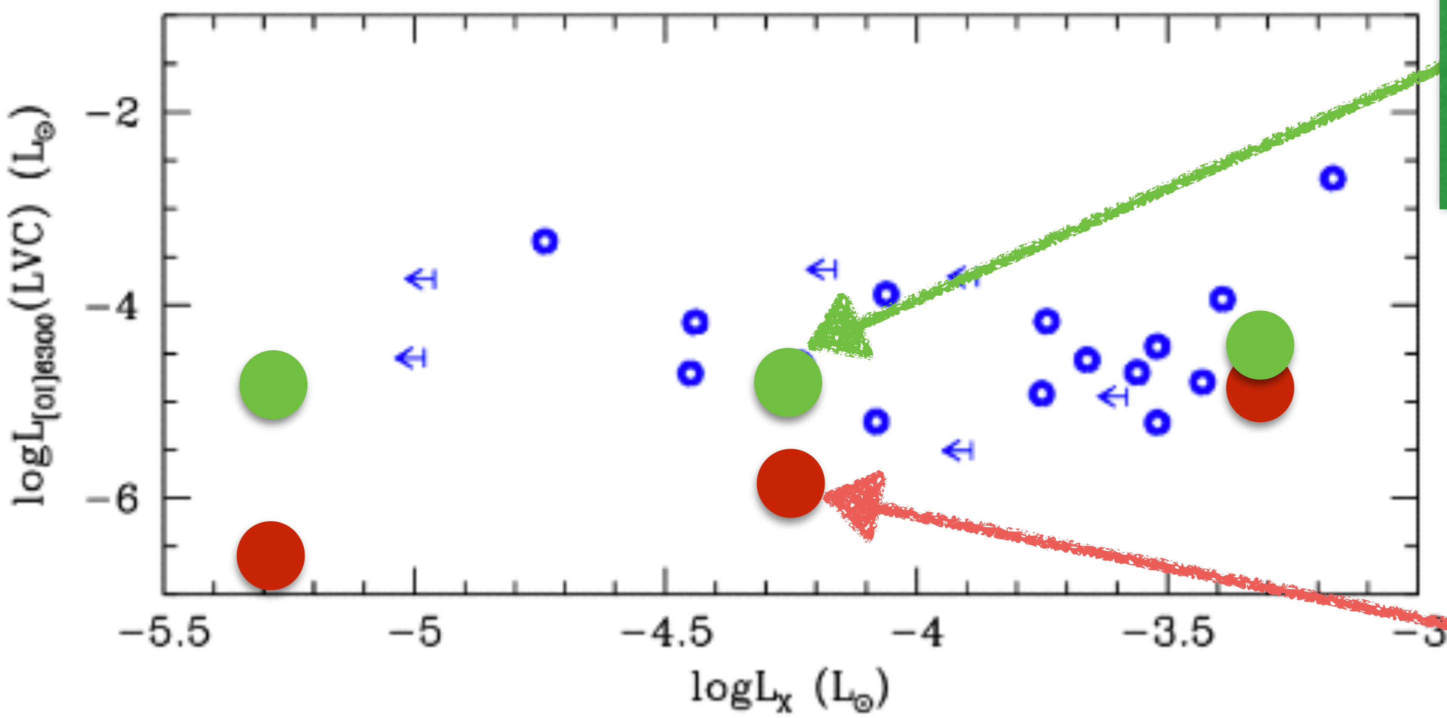

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Ercolano et al. (2016)
Lacc = Lbol; Chromospheric
UV (<100eV) suppressed

Observational points
from Rigliaco et al (2013)

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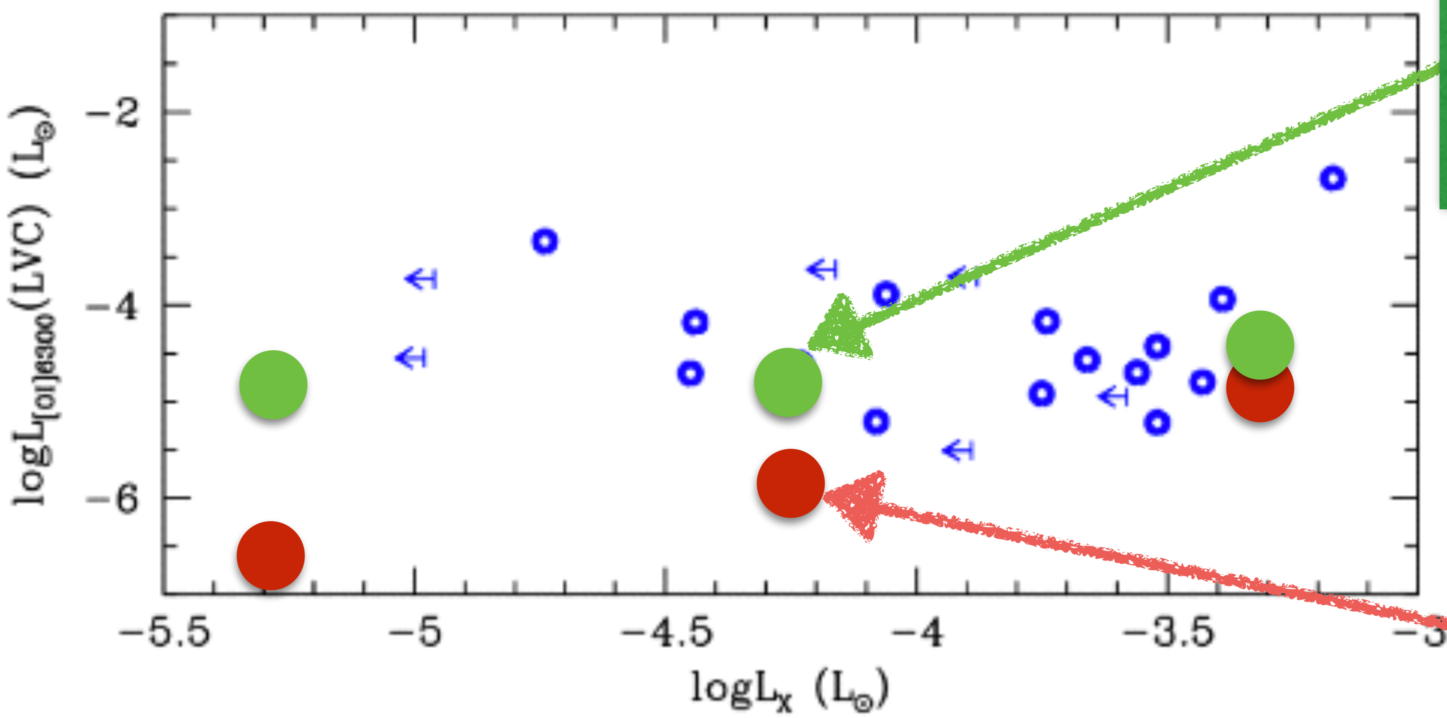

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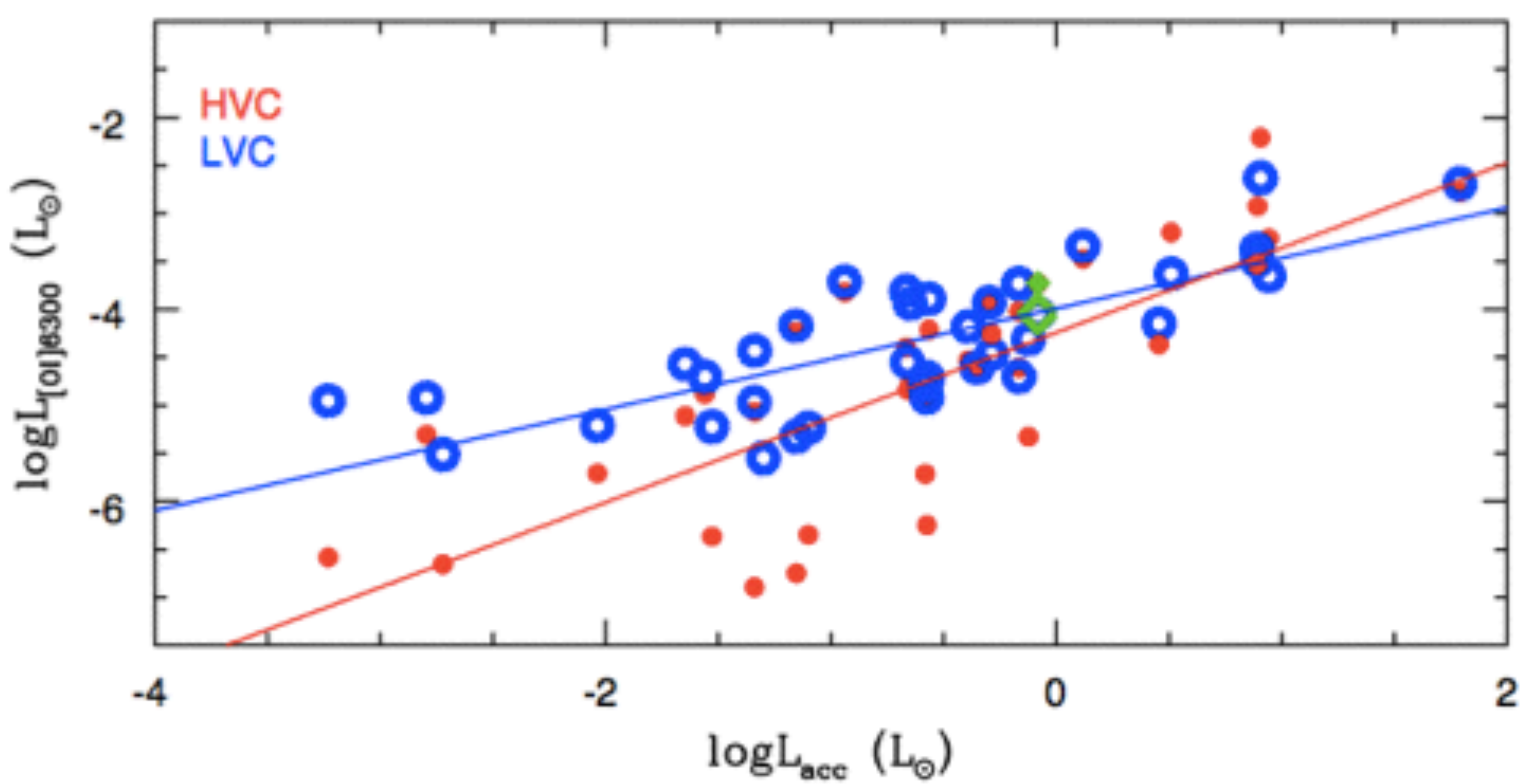

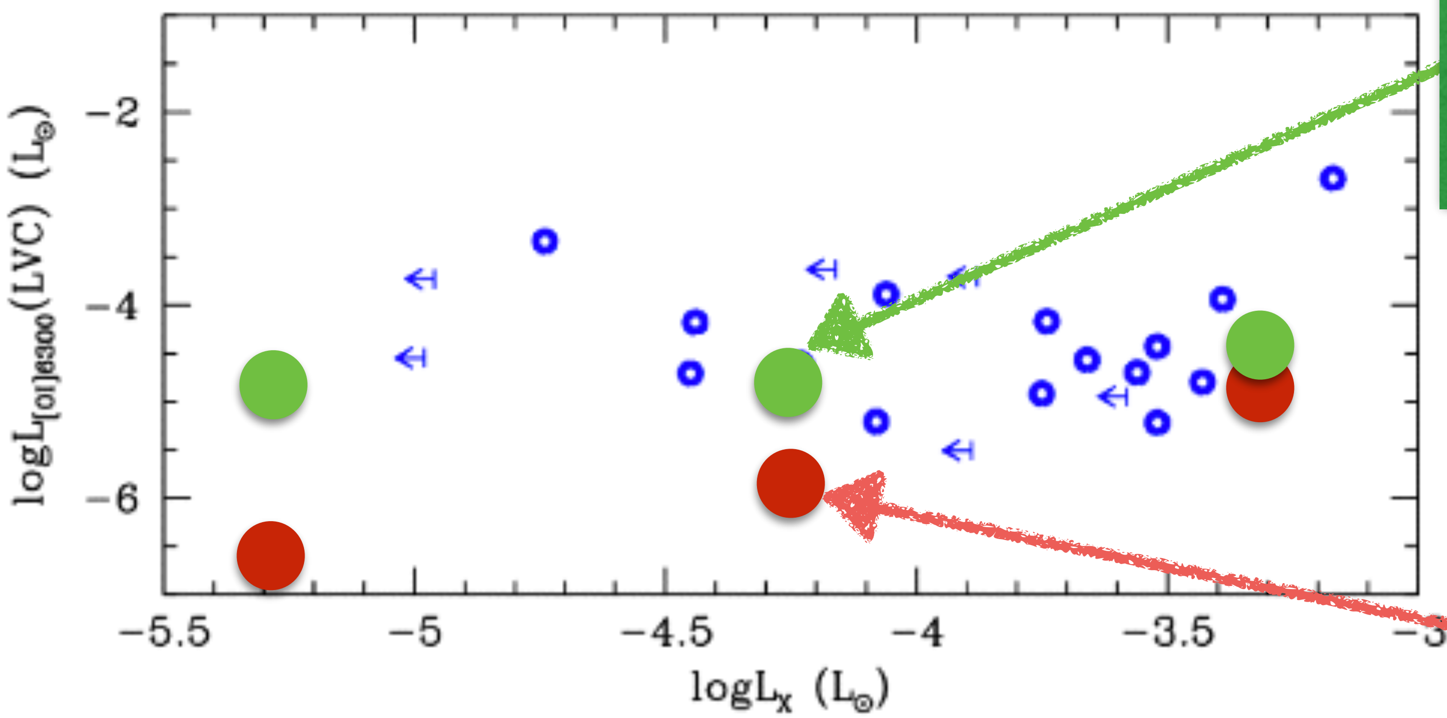

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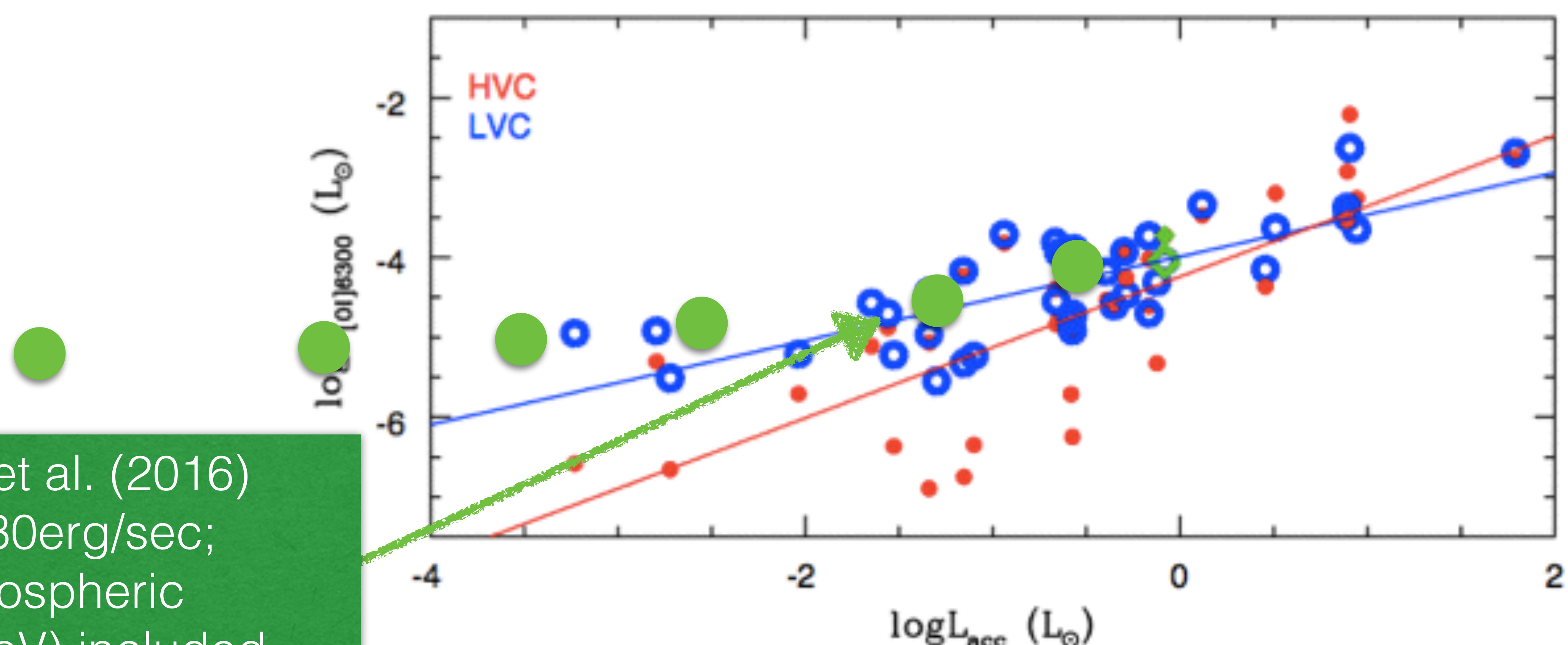
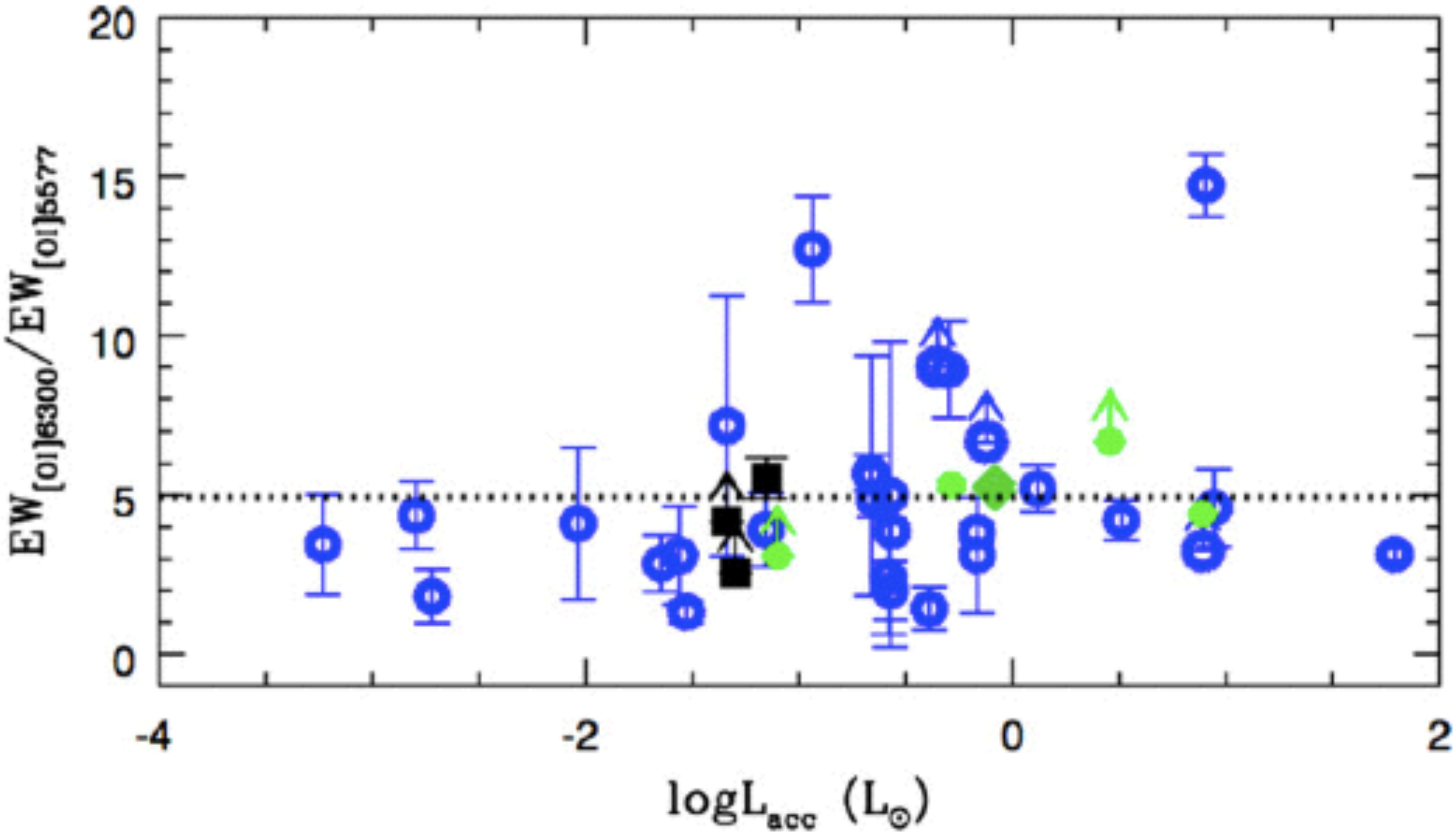
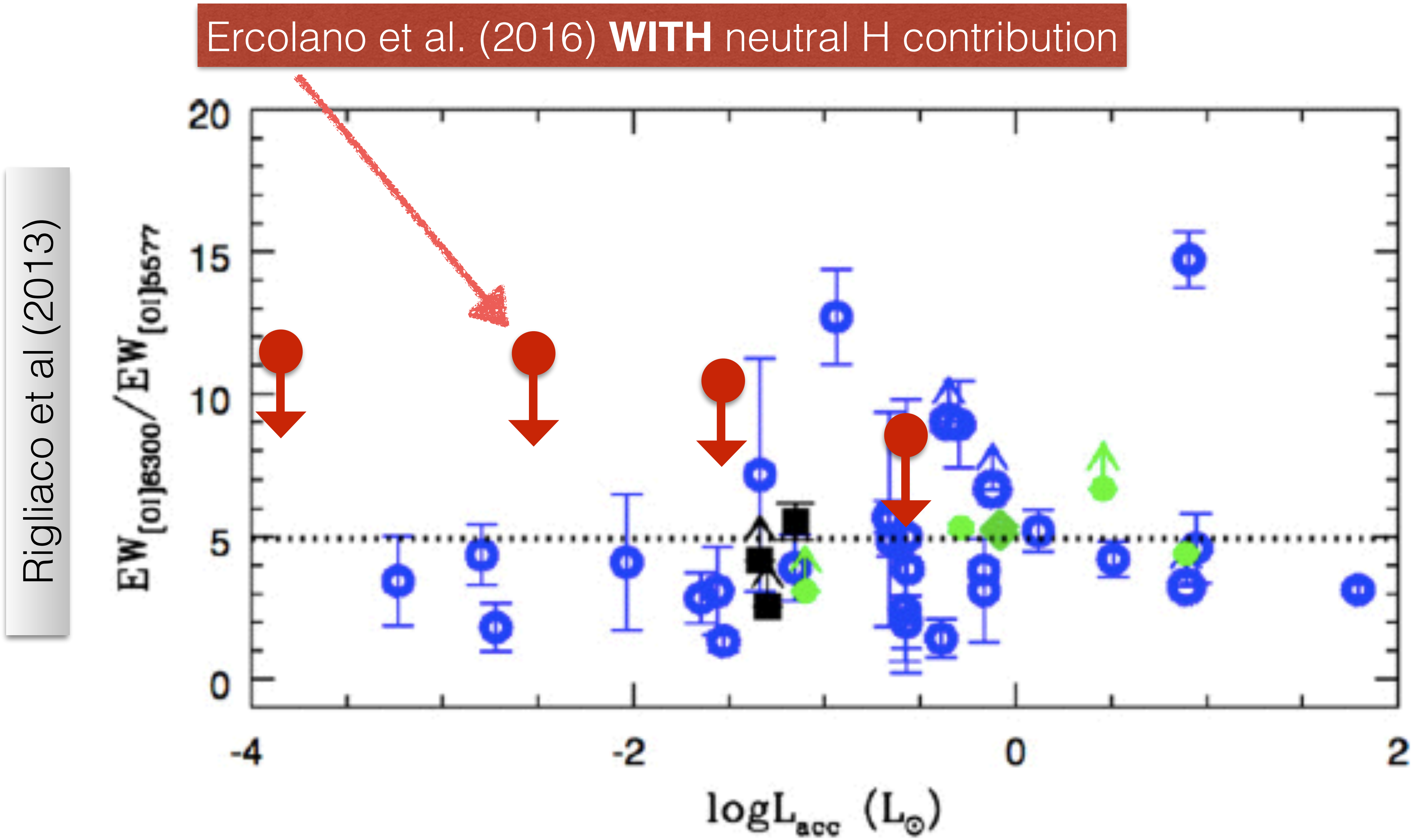
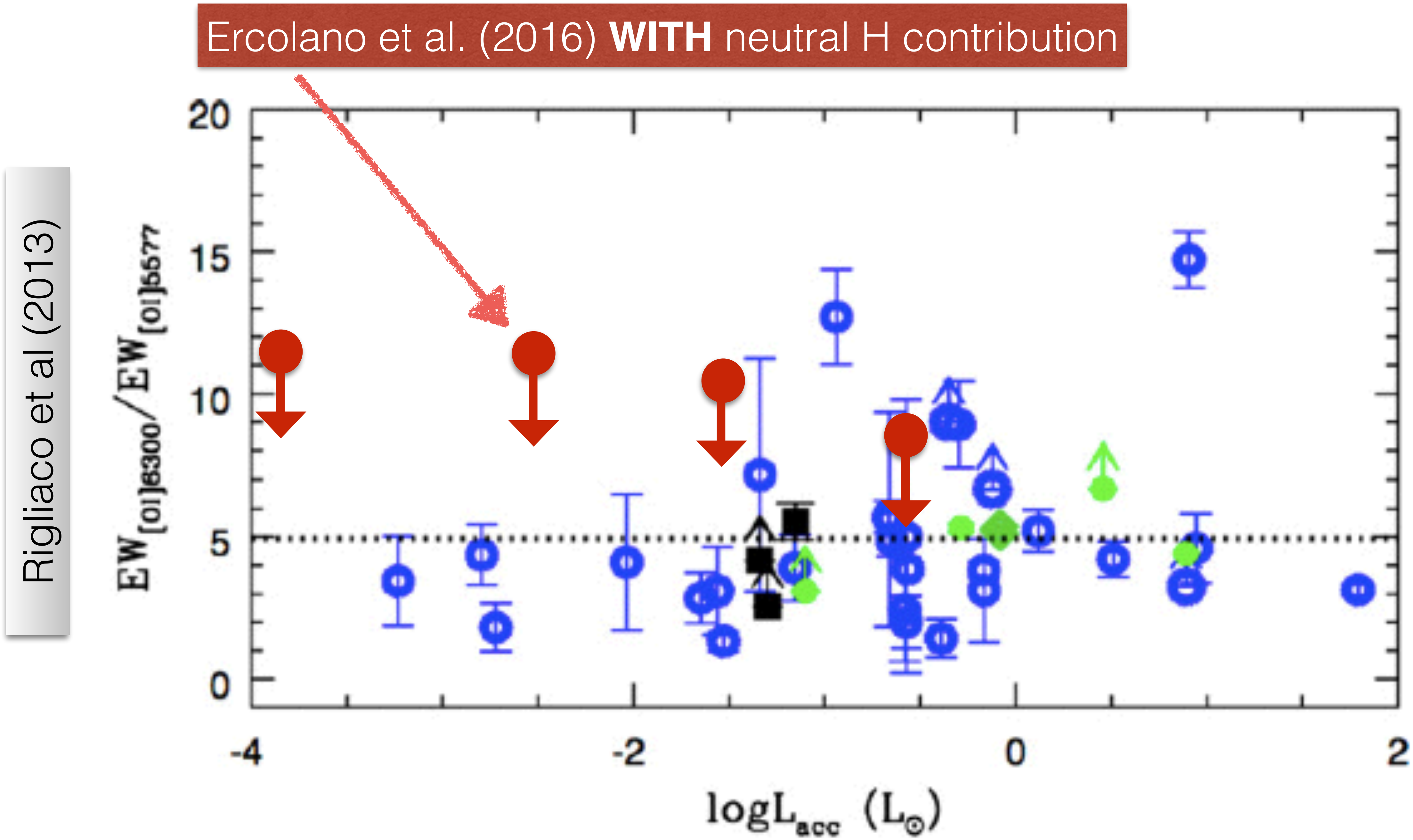


Rigliaco et al (2013)




Ercolano et al. (2016) WITH neutral H contribution
Rigliaco et al (2013)
20
15
10
5
0
-4
-2
0
2
$EW_{[OI]6300}/EW_{[OI]5577}$
$\log L_{acc}$ ($L_\odot$)

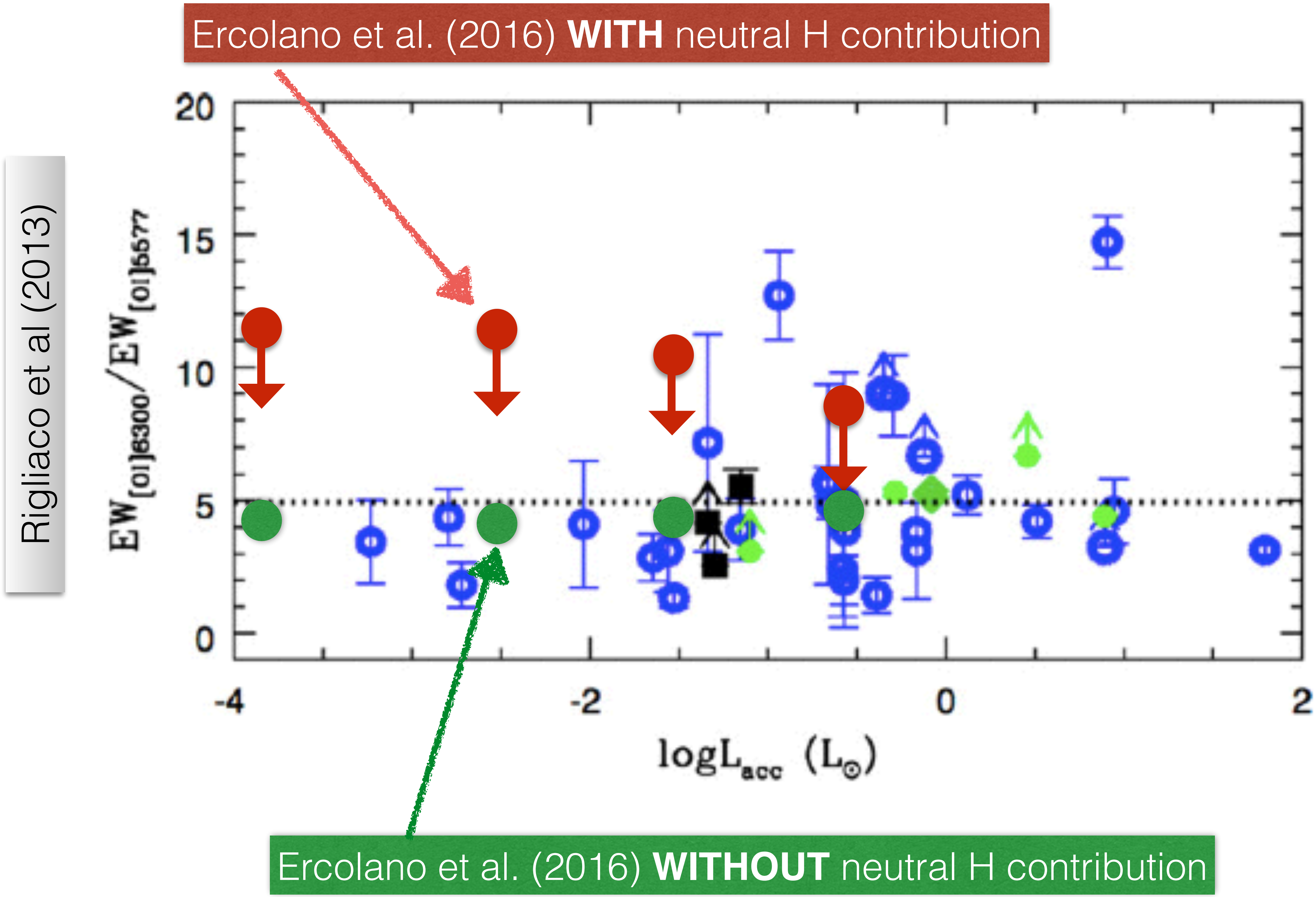


Problem:

Significant contribution from collisions with neutral H.

Atomic data exists only for the [OI] 6300 line but NOT for the [OI] 5577 line.

Hence only an upper limit to the [OI] 6300/[OI] 5577 ratio can be obtained.



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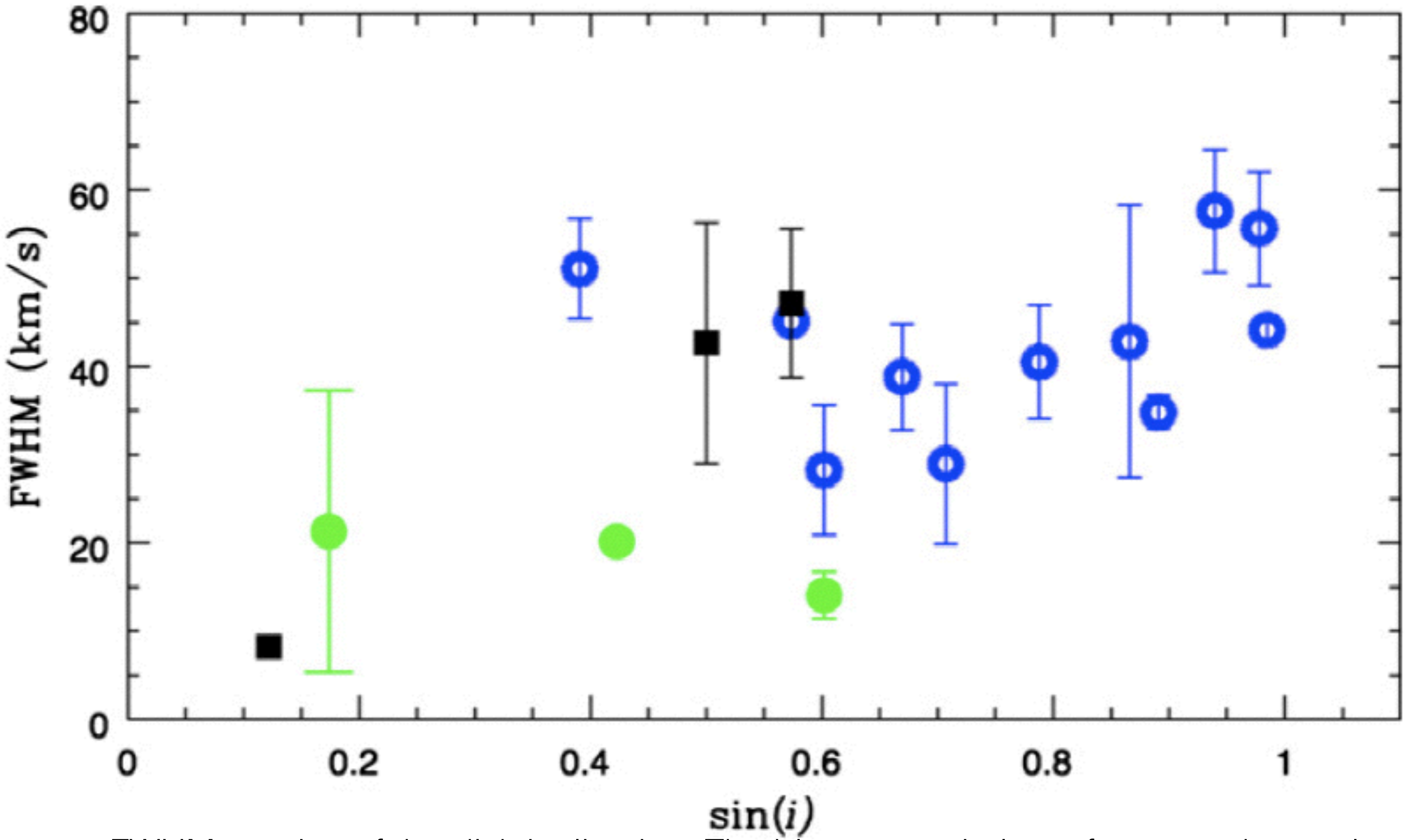
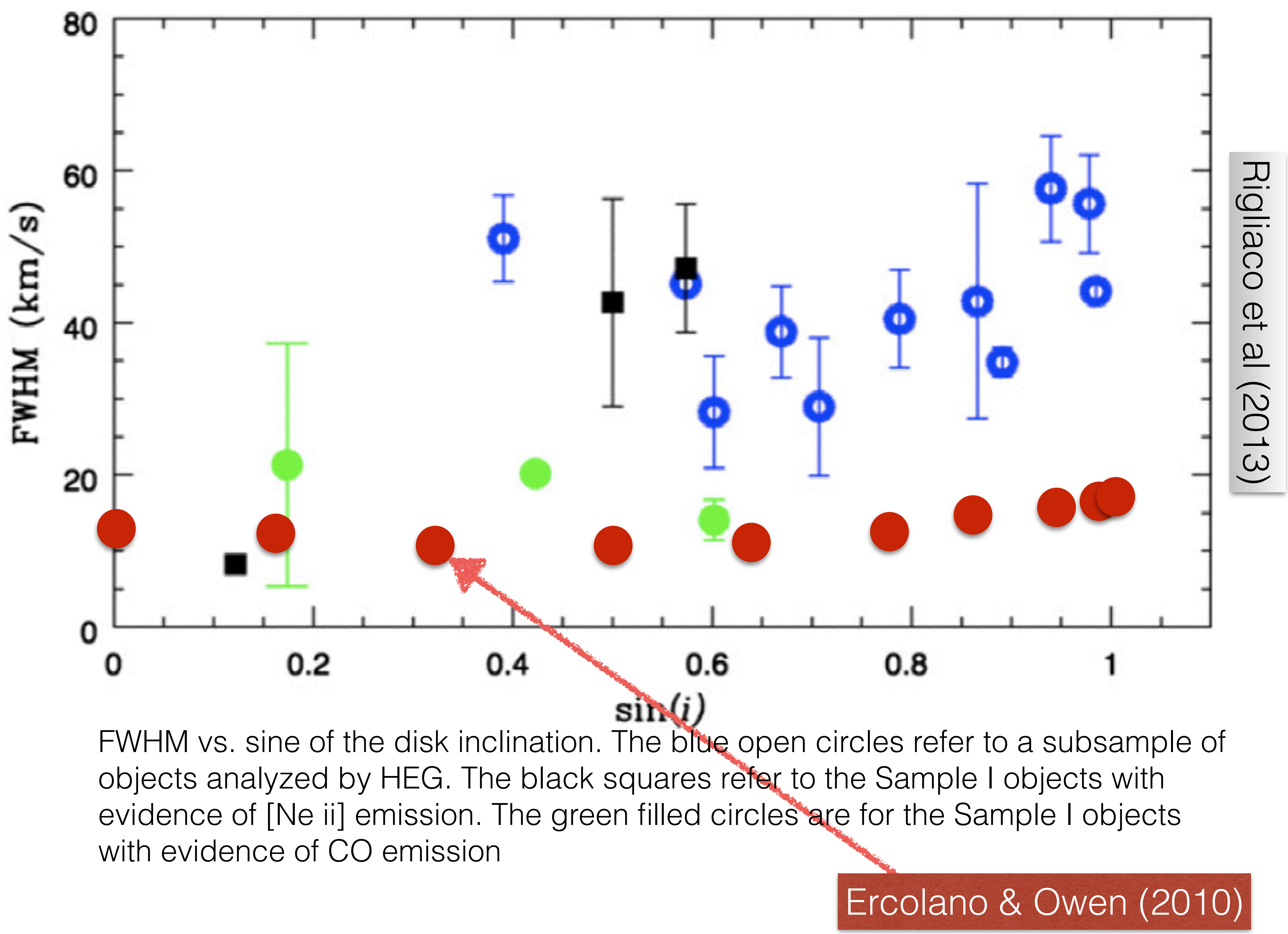


Rigliaco et al (2013)

FWHM vs. sine of the disk inclination. The blue open circles refer to a subsample of objects analyzed by HEG. The black squares refer to the Sample I objects with evidence of [Ne ii] emission. The green filled circles are for the Sample I objects with evidence of CO emission



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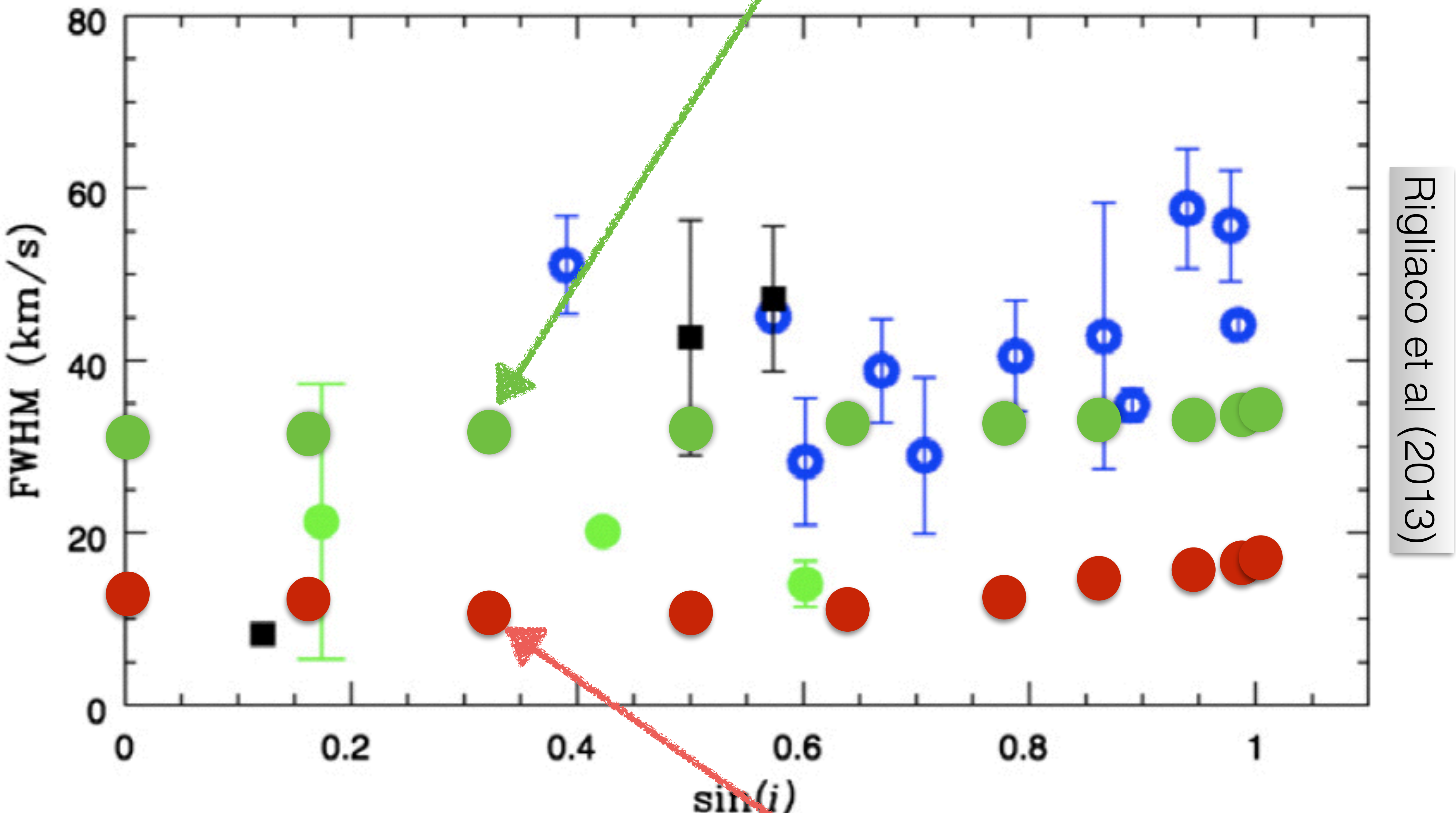
Ercolano et al. (2016)
Lacc = Lbol



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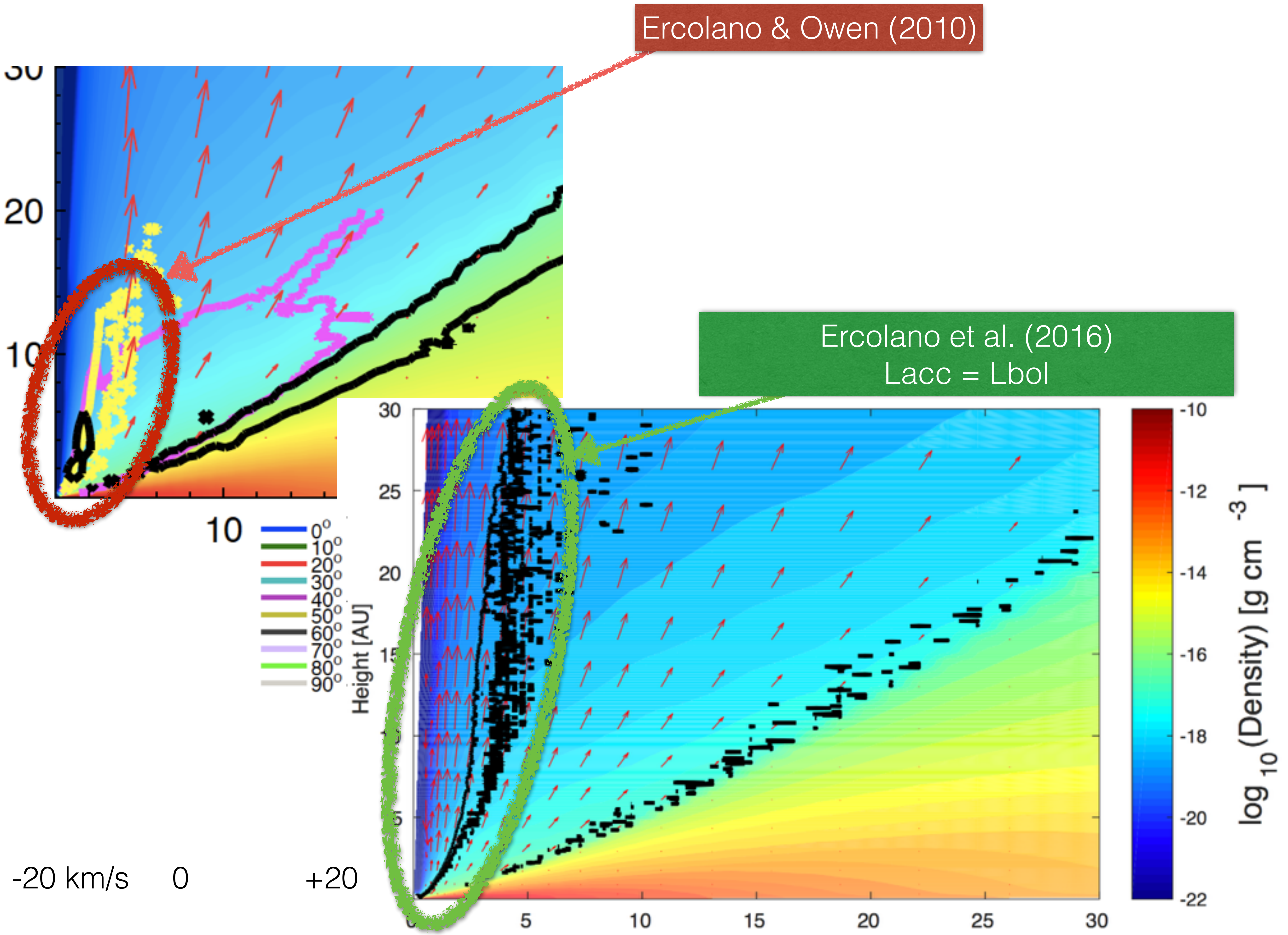
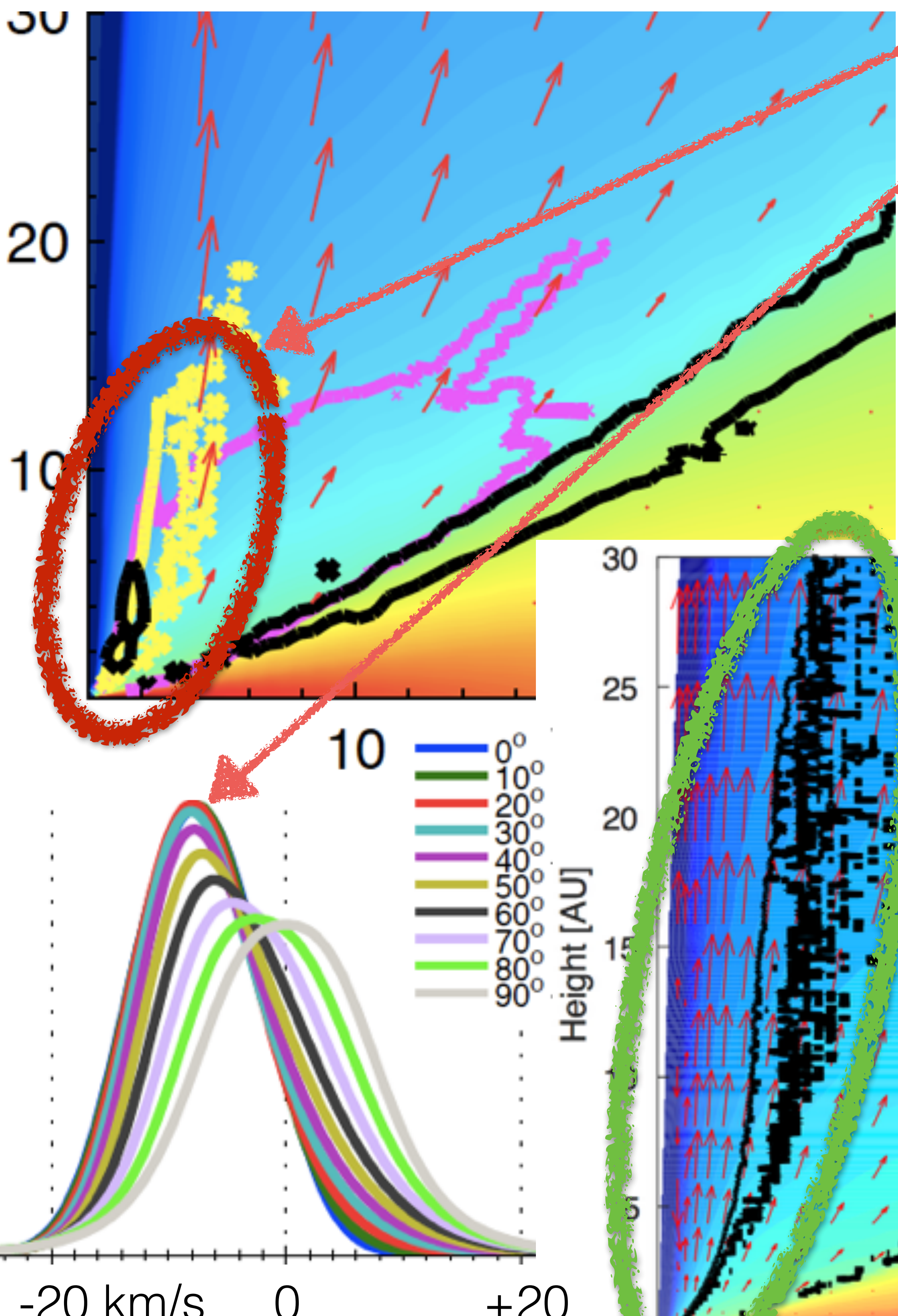
Ercolano & Owen (2010)

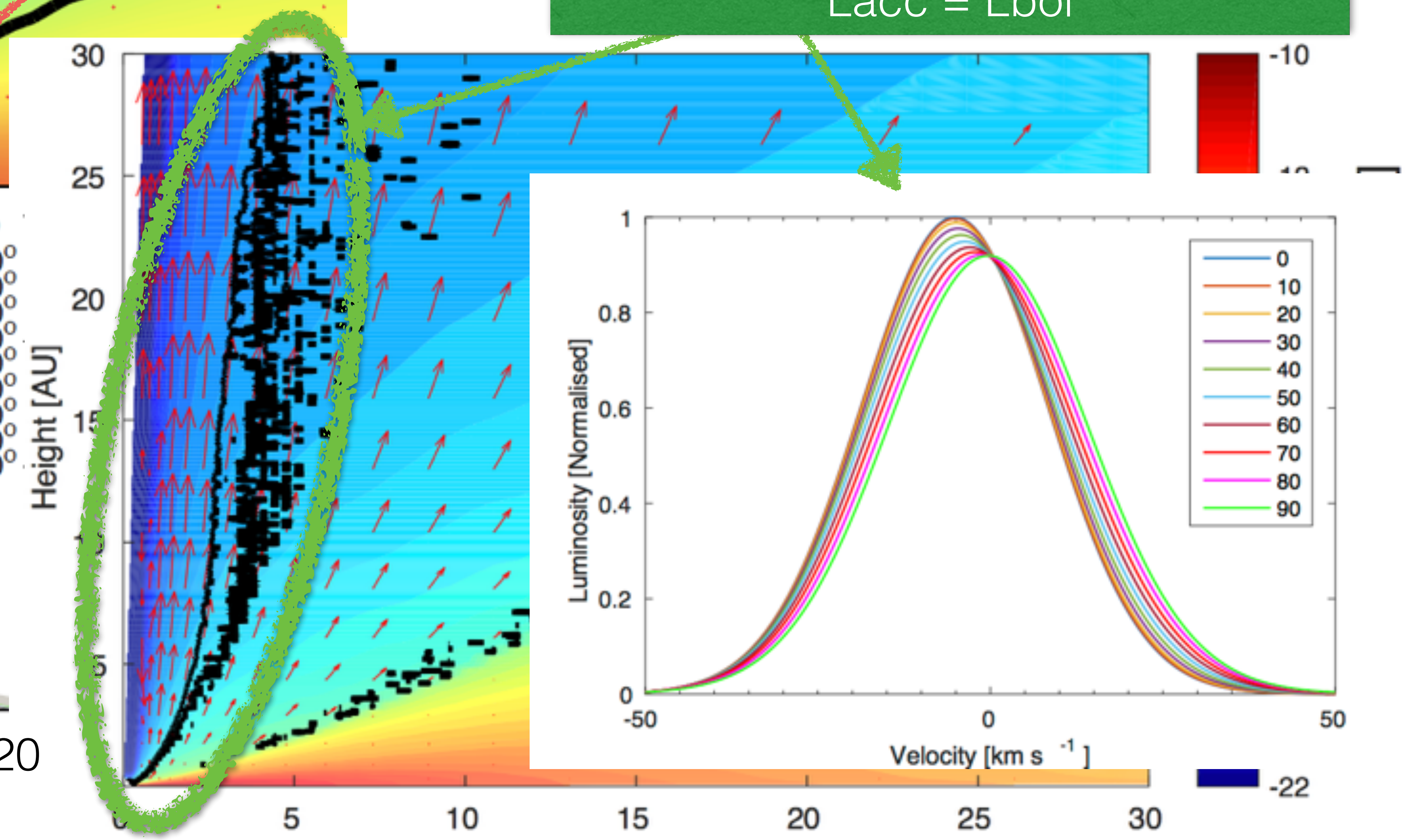

Ercolano & Owen (2010)
Ercolano et al. (2016)
Lacc = Lbol
20
10
10
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
-20 km/s
0
+20
Height [AU]
30
25
20
15
5
0
5
10
15
20
25
30
$\log_{10}$(Density) [g cm^{-3}]
-10
-12
-14
-16
-18
-20
-22

Ercolano & Owen (2010)

Accretion radiation is able to warm up the wind up to about 30AU above the disc mid plane (chromospheric EUV only up to ~14AU), hence sampling a larger range of wind velocities, which results in a larger FWHM for the forbidden lines.



Ercolano et al. (2016)
Lacc = Lbol



Conclusions

1. The observations are consistent with a thermal origin of the [OI] 6300 line (and other forbidden lines) in an X-ray driven photoevaporative wind

2. The emission region [OI] 6300 is mainly from the EUV warmed layer of the X-ray driven photoevaporative wind (hence the observed correlation with L_{acc})

3. The [OI] 6300/[OI] 5577 ratio agrees with observed values if the H^0 contributions to [OI]6300 are removed - A detailed study requires collision strengths for the [OI]5577 line

4. The FWHM from the models are in rough agreement with the observations

Conclusions

Blueshifted collisionally excited emission lines from YSOs: the smoking gun of a wind, but no useful tracers of Mass Loss Rates