scintillation in admixtures based on noble gases (and why?)

D. Gonzalez-Diaz

(1st DISCO meeting)

‘Fast’ breakdown - experimental evidence in detectors

- Fast: opposed to ‘slow’ (driven by feedback at the cathode). The name tells NOTHING about the physical interpretation, except that it does not require of secondary processes at the cathode.
- Usually features a ‘precursor’ pulse.

[RAE64]

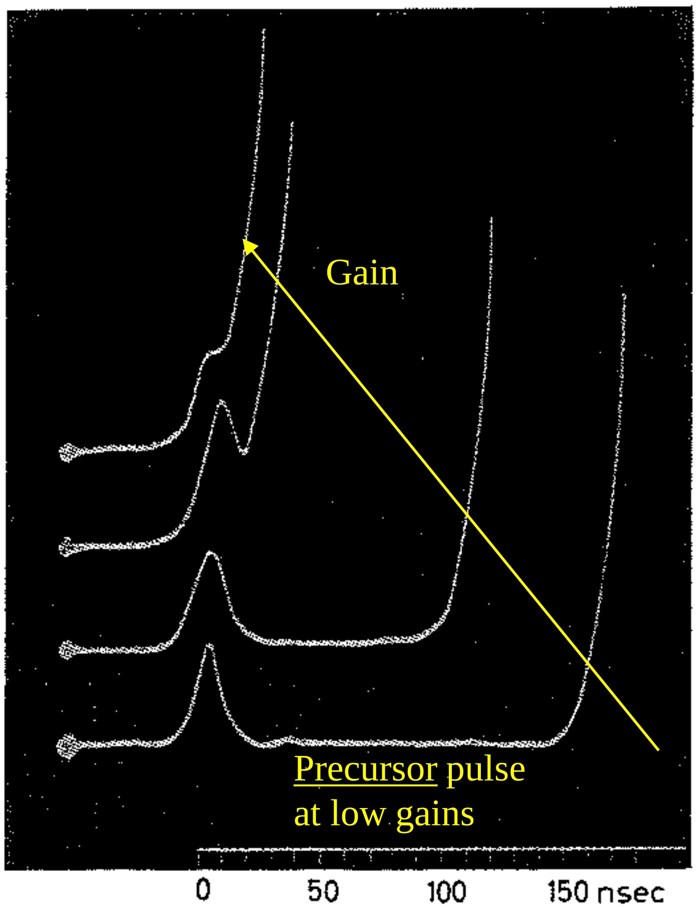
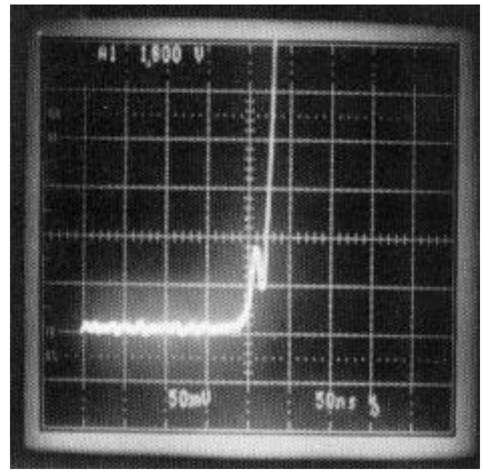


Figure 5.14. Current oscillograms of static breakdown in methylal. Optical method. $E/p = 64{\cdot}4$, $pd = 230$ ... $= 0{\cdot}8$ cm, $T_{-} = 90$ nsec $RC = 5$ nsec[36]

PPAC

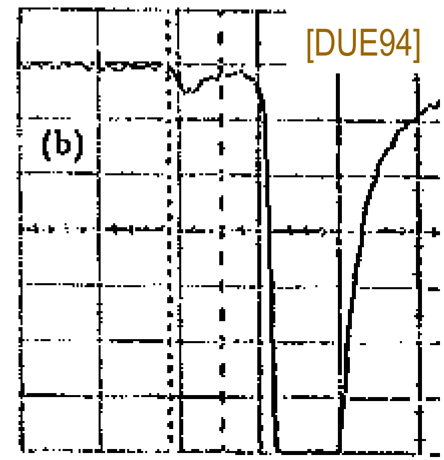
[FON91]



A signature of low-gain cathode streamer-only breakdown

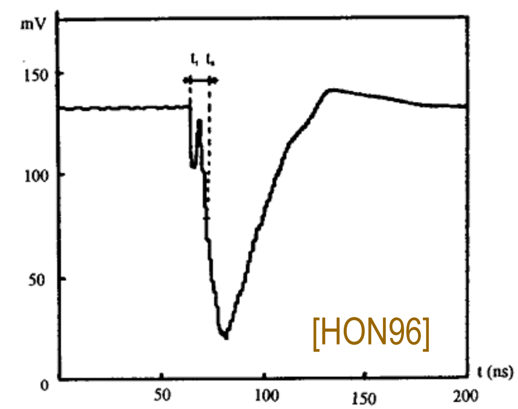
It certainly exists, but it may not be the only mechanism, or it may be the result of different physical processes.

RPC



[DUE94]

single-wire (SQS mode)



[HON96]

Fig. 1. The pulse shape of the SQS electrical signal $V = 2.45$ kV. Methylal/(Methylal + Ar) = 16.6%.

P. Fonte

‘Fast’ breakdown (‘photon-assisted/classical interpretation’)

$$\frac{\partial n_e(x,t)}{\partial t} + W_e\frac{\partial n_e}{\partial x} = S + \left(\alpha|W_e| - \frac{\partial W_e}{\partial x}\right)n_e; \qquad (1)$$

$$\frac{\partial n_i(x,t)}{\partial t} = S + \alpha|W_e|n_e; \qquad (2)$$

$$\frac{\partial n_{ph}(x,t)}{\partial t} = \delta|W_e|n_e; \qquad (3)$$

$$S(x,t) = \frac{Q}{2\lambda}\int_{-\infty}^{\infty}\frac{\partial n_{ph}(x',t)}{\partial t}\Omega(x-x') \cdot e^{-|x-x'|/\lambda}\,dx'; \qquad (4)$$

$$\Omega(x-x') = \frac{1}{2}\left(1 - \frac{(x-x')}{\sqrt{R_0^2+(x-x')^2}}\right)$$

photon-feedback term

1D hydro equations for electrons and ions with photon-feedback term

$$\frac{E(x)}{2\pi} = \int_{-x}^{0}\rho(x+x')(-1-g(x'))\,dx' + \int_{0}^{d-x}\rho(x+x')(1-g(x'))\,dx';$$

$$g(x') = \frac{x'}{(x'^2+R_0^2)^{1/2}}; \quad \rho(x) = e(n_i(x)-n_e(x))$$

$$\frac{E(x,t)}{2\pi} = -\int_{-(d+x)}^{-x}\rho(x+x')(-1-g(x')) \cdot dx' + \int_{-x}^{0}\rho(x+x')(-1-g(x'))\,dx' + \int_{0}^{d-x}\rho(x+x')(1-g(x'))\,dx' - \int_{d-x}^{2d-x}\rho(x+x')(1-g(x'))\,dx' \qquad (5)$$

Space-Charge cylinder

p	20 Torr
A, B, k	Corresponding to the mixture Ar + TEA
$W_{\max}$	5 cm/μs
E_v	300 V/cm
M	10^{-6}
λ	500 μm
N_{e0}	100 electrons
R_0	300 μm
σ_0	300 μm
X_0	-900 μm
G_0	4×10^6
d	4 mm.

?

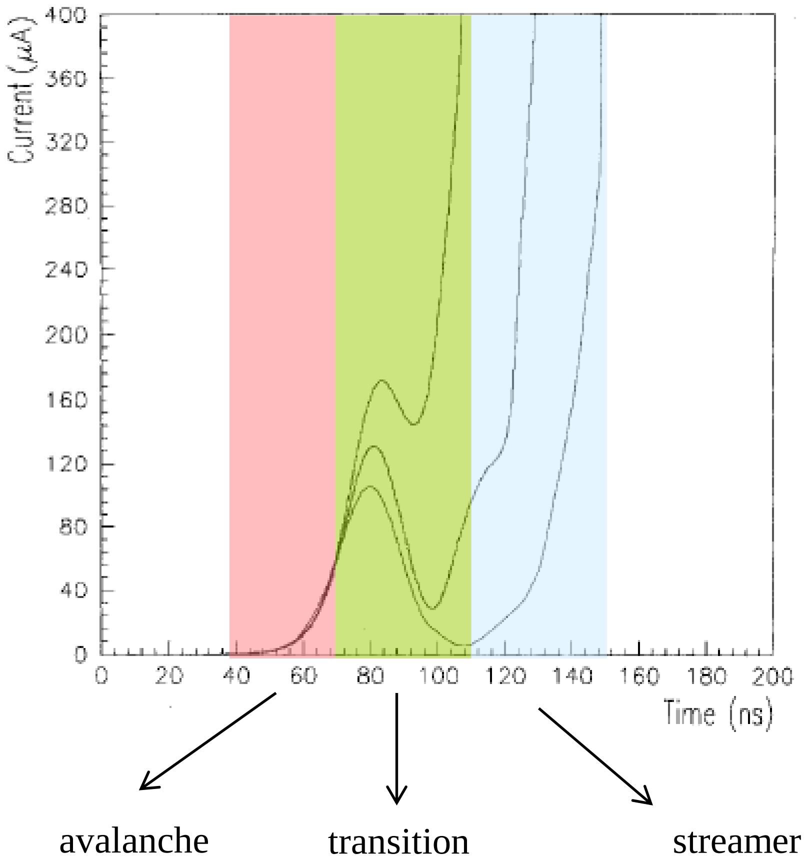
?

parameters

P. Fonte

‘Fast’ breakdown (‘photon-assisted/classical interpretation’)

simulation



Main (technical) objections:

- Many free parameters, some difficult to experimentally access (spectrum of emission, photo-ionization x-section)

->getting better these days.

- Hydro solutions neglect avalanche or ionization fluctuations, but those will likely trigger breakdown earlier than the average solution to the equations.
- Approximate: transverse dynamics becomes a parameter.

->Probably solvable with present computing power.

Other objections:

- No quantitative comparison with data.
- Does not seem to reconcile well with the fact that improvements on maximum gain with quencher concentrations above some ~1% are very modest.
- Contrary to common wisdom, it does not need of Space-Charge to progress, except if invoking enhanced charge-recombination at low fields, making the process even more difficult to describe.
- It does not seem to be general enough to explain most known systematics on MPGD detectors.

P. Fonte

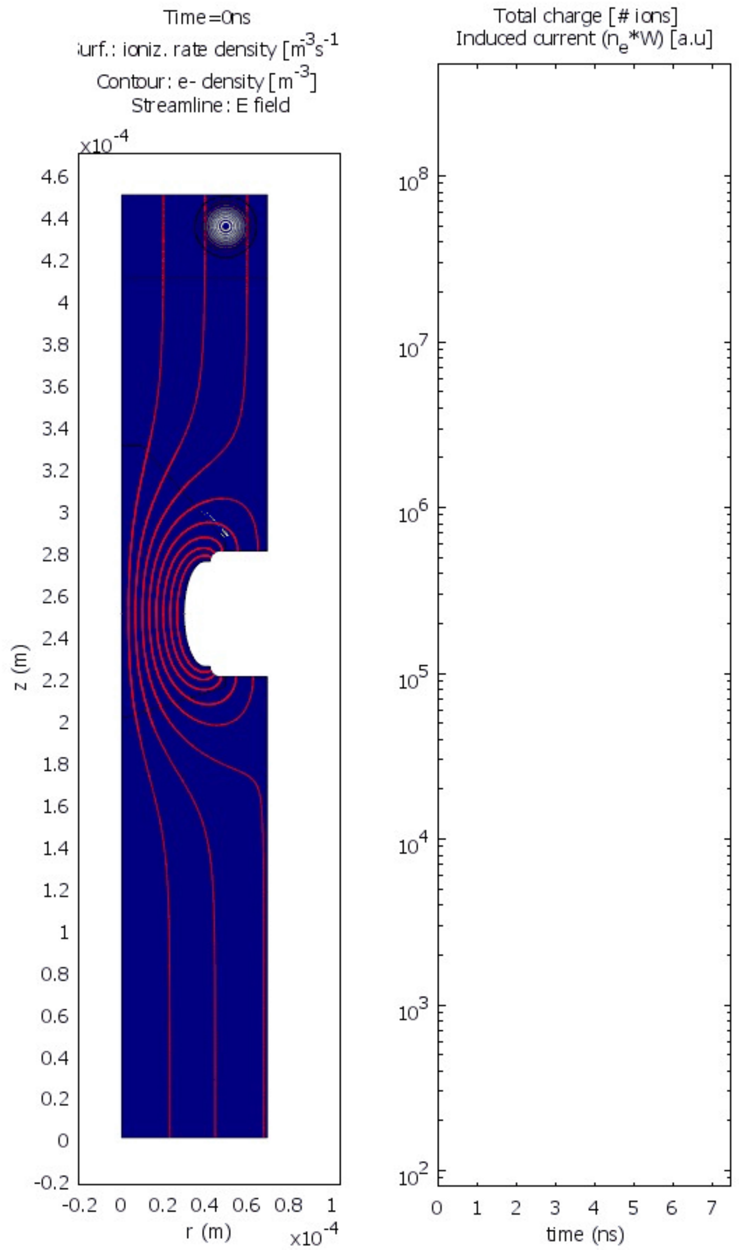
‘Fast’ breakdown (‘diffusion-assisted/modern interpretation’)

GEM

hole: 60 µm
gap: 100 µm
N_0=100 e^-
V=1250V

precursor is present as well:

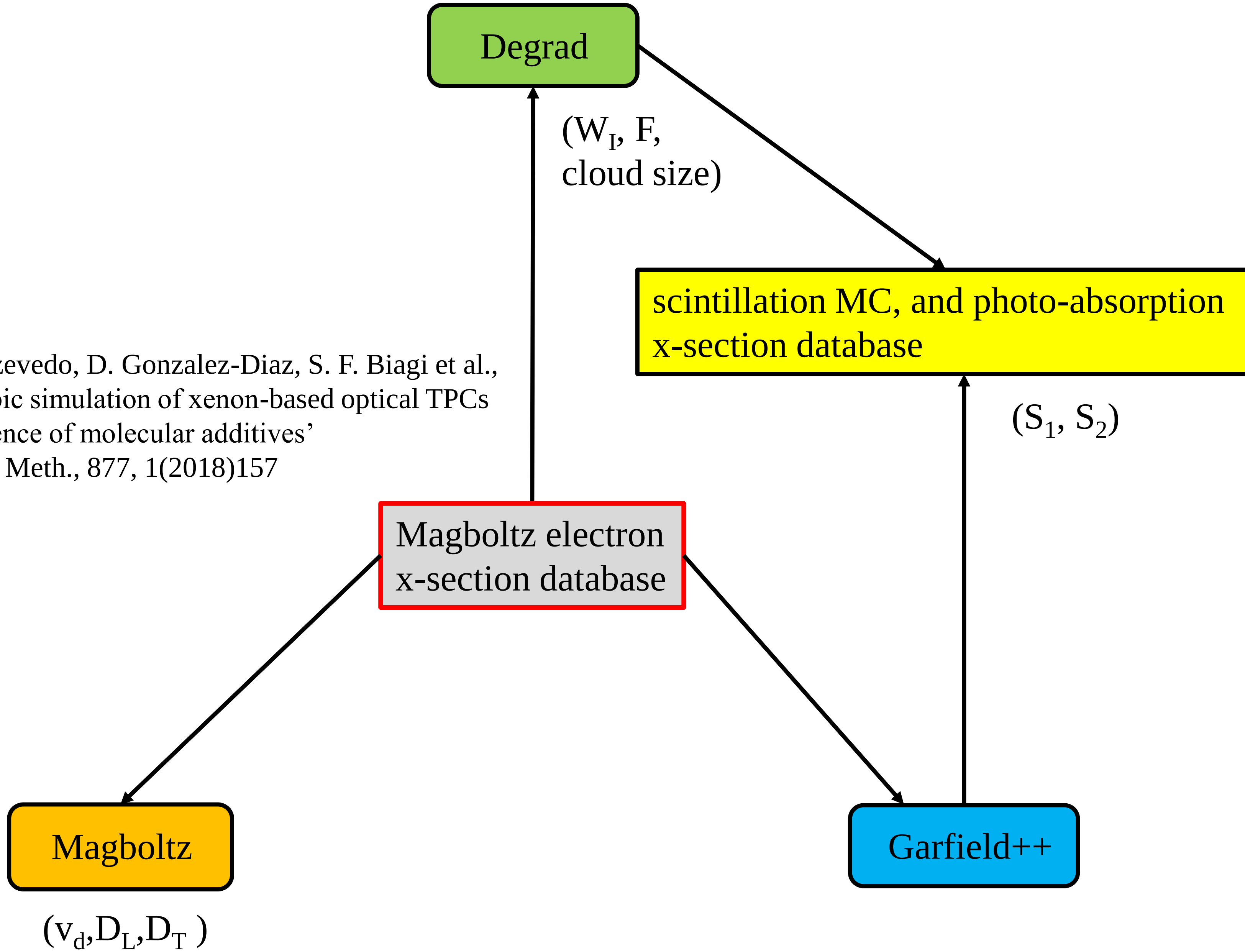
Can we learn something from its shape, relative probability, delay with respect to the streamer signal… that will help at pinning down the underlying mechanisms?



P. Fonte

let us proudly introduce…

a microscopic software for electron and photon transport in gas



C. D. R. Azevedo, D. Gonzalez-Diaz, S. F. Biagi et al.,
'Microscopic simulation of xenon-based optical TPCs
in the presence of molecular additives'
Nucl. Instr. Meth., 877, 1(2018)157

supported by '*new scintillating gases and structures for next-generation scintillation-based gaseous detectors*'
(RD51 common project)

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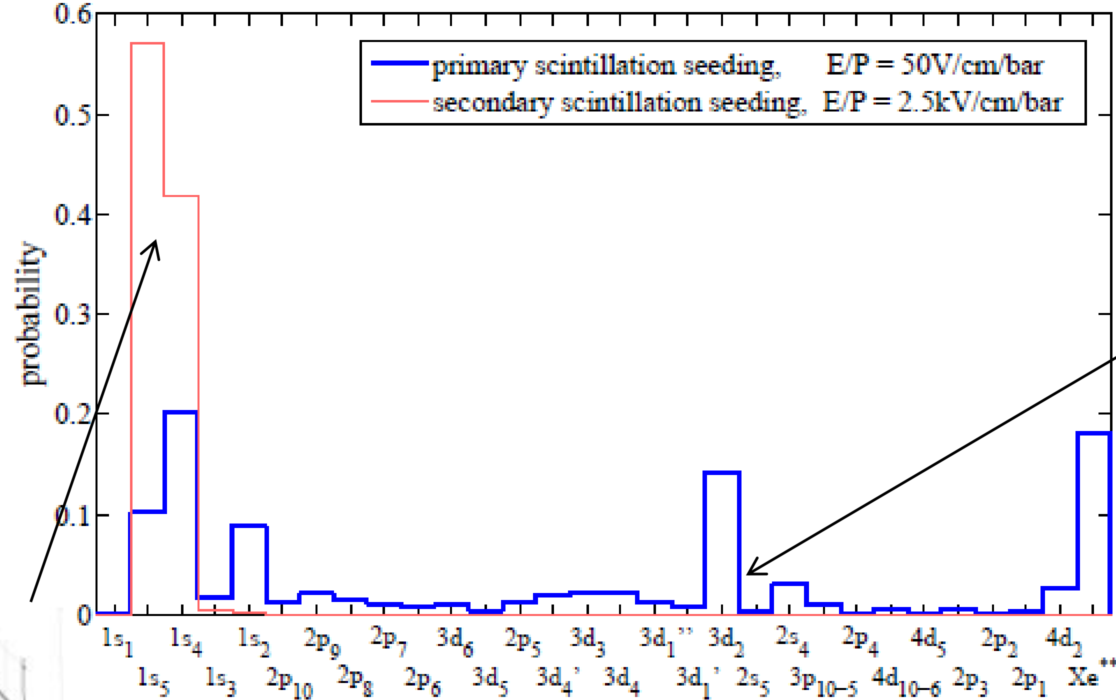
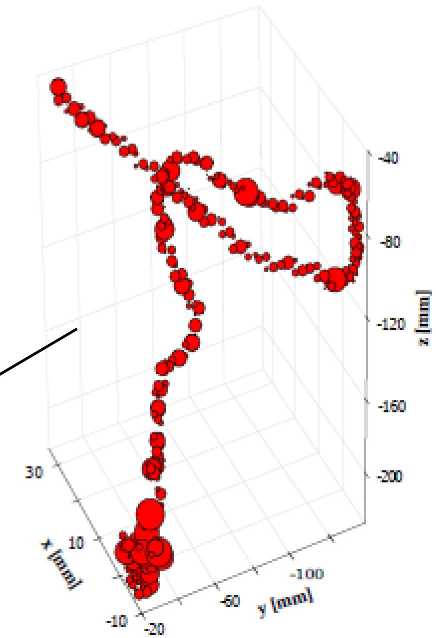
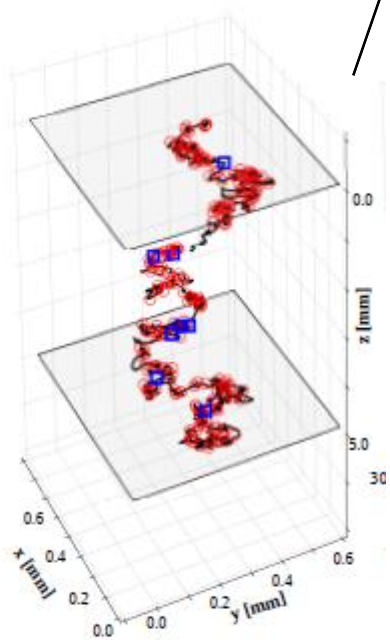
computation of probability distribution of excited states

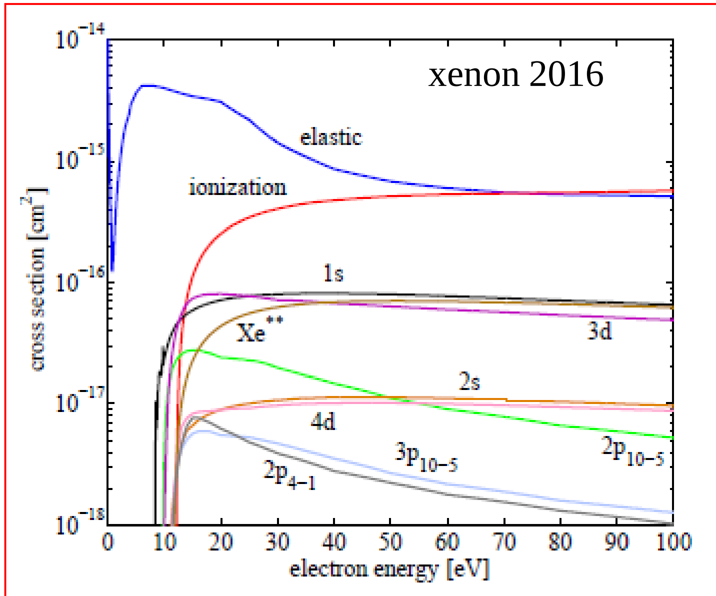




Degrad

Garfield++





computation of atomic cascade

decay constant

2-body collision rates

3-body collision rates

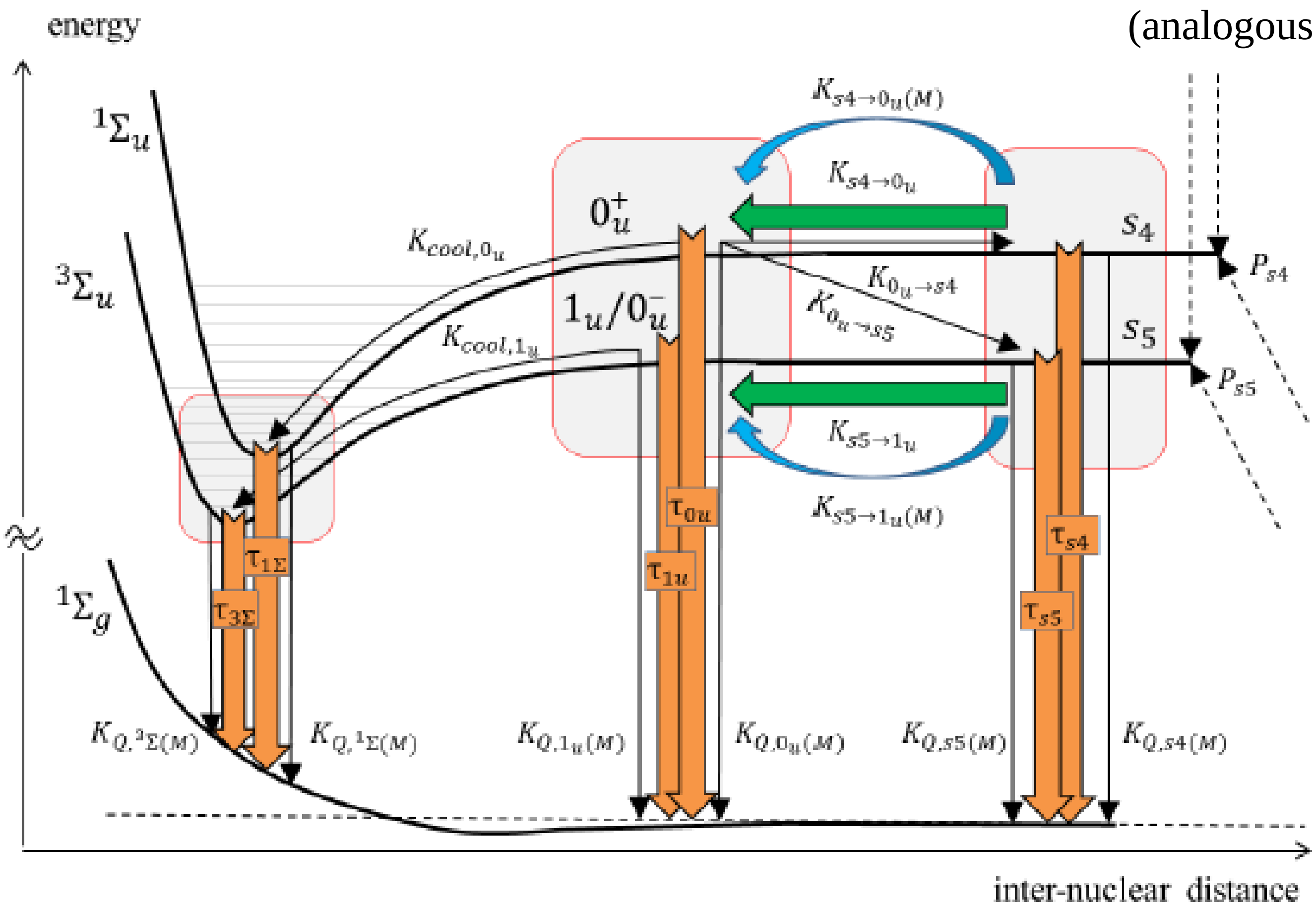
state (Paschen)	state (Racah)	energy [eV]	$\sum_j A_{ij}$ [ns^{-1}]	K_2@1bar [ns^{-1}]	K_3@1bar [ns^{-1}]
$1s_1$	-	0.000	-	-	-
$1s_5$	$6s[3/2]_2$	8.315	2.33×10^{-11}	4.94×10^{-5}	0.1465
$1s_4$	$6s[3/2]_1$	8.437	$0.281/n_H$	-	0.0855
$1s_3$	$6s'[1/2]_0$	9.447	1.28×10^{-8}	0.2224	-
$1s_2$	$6s'[1/2]_1$	9.570	$0.246/n_H$	2.4954	-
$2p_{10}$	$6p[1/2]_1$	9.580	0.026	3.7802	-
$2p_9$	$6p[5/2]_2$	9.686	0.027	2.7425	-
$2p_8$	$6p[5/2]_3$	9.721	0.031	1.8036	-
$2p_7$	$6p[3/2]_1$	9.789	0.028	4.3979	-
$2p_6$	$6p[3/2]_2$	9.821	0.036	2.0062	-
$3d_6$	$5d[1/2]_0$	9.890	4.36×10^{-3}	9.7649	-
$3d_5$	$5d[1/2]_1$	9.917	$0.015/n_H$	4.8328	-
$2p_5$	$6p[1/2]_0$	9.933	0.031	0.1599	0.4273
$3d'_4$	$5d[7/2]_4$	9.943	4.34×10^{-3}	4.8676	-
$3d_3$	$5d[3/2]_2$	9.959	8.16×10^{-3}	4.8664	
$3d_4$	$5d[7/2]_3$	10.039	7.34×10^{-3}	4.8510	
$3d''_1$	$5d[5/2]_2$	10.157	1.21×10^{-3}	4.8649	
$3d'_1$	$5d[5/2]_3$	10.220	1.39×10^{-3}	4.8639	
$3d_2$	$5d[3/2]_1$	10.401	$3.04\times10^{-3}/n_H$	1.3637	
$2s_5$	$7s[3/2]_2$	10.562	0.018	4.9415	
$2s_4$	$7s[3/2]_1$	10.593	$0.178/n_H$	4.9415	
$3p^*_{10-5}$	-	10.902	0.010	12.6008	
$2p_4$	$6p[3/2]_1$	10.958	0.024	10.3277	
$4d^*_{10-6,4,3}$	-	10.971	0.014	5.9298	-
$4d_5$	$6d[1/2]_1$	10.979	0.018	4.8426	-
$2p_3$	$6p[3/2]_2$	11.055	0.036	11.6125	-
$2p_2$	$6p[1/2]_1$	11.069	0.033	10.3277	-
$2p_1$	$6p[1/2]_0$	11.141	0.027	10.4018	-
$4d_2$	$6d[3/2]_1$	11.163	$0.716/n_H$	4.8674	-
Xe^{**}	-	11.7	-	12.35	-

each value represents a vector!

-	$1s_1$	$1s_5$	$1s_4$	$1s_3$	$1s_2$	$2p_{10}$	$2p_9$	$2p_8$	$2p_7$	$2p_6$
$1s_1$	-	0	0	0	0	0	0	0	0	0
$1s_5$	$1^{(1)}$	-	0	0	0	0	0	0	0	0
$1s_4$	0	0	-	0	0	0	0	0	0	0
$1s_3$	0	$0.11^{(2,3)}$	$0.89^{(2,3)}$	-	0	0	0	0	0	0
$1s_2$	0	$0.010^{(2,3)}$	$0.079^{(2,3)}$	$0.247^{(3)}$	-	$0.663^{(4)}$	0	0	0	0
$2p_{10}$	0	$0.014^{(3)}$	$0.116^{(3)}$	$0.216^{(4)}$	$0.654^{(4)}$	-	0	0	0	0
$2p_9$	0	0	0	$0.3604^{(4)}$	$0.1351^{(3)}$	$0.405^{(4)}$	-	$0.099^{(4)}$	0	0
$2p_8$	0	0	0	$0.178^{(3)}$	$0.110^{(3)}$	$0.245^{(3)}$	$0.466^{(3)}$	-	0	0
$2p_7$	0	0	0	$0.348^{(3)}$	$0^{(2)}$	$0.011^{(2)}$	$0.067^{(2)}$	$0.539^{(2)}$	-	$0.034^{(3)}$
$2p_6$	0	0	0	$0.234^{(3)}$	$0.001^{(2)}$	$0.001^{(2)}$	$0.345^{(3)}$	$0.259^{(3)}$	$0.161^{(3)}$	-

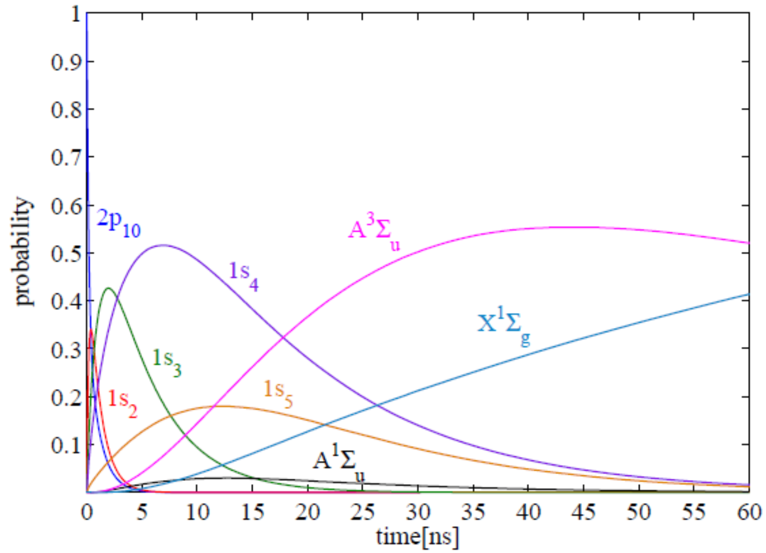
computation of excimer pathways

(analogous for $2p_5$ and Xe**)

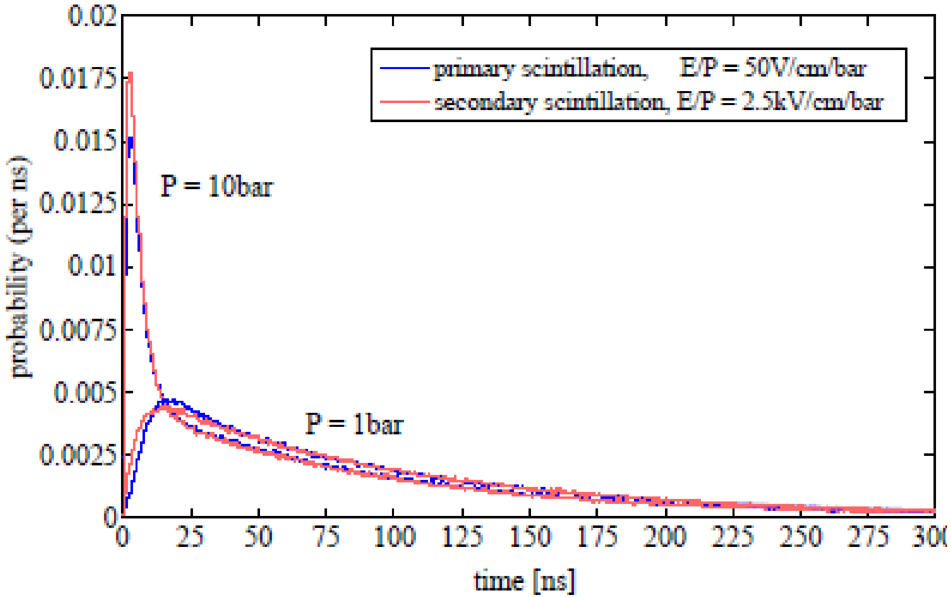


$\tau_{^3\Sigma}$	100 ns[(1)]	$K_{Q,^3\Sigma(M)}$	11.12 ns^{-1}	$K_{s_5\to 1_u}$	0.1465 ns^{-1}[(1)]	$K_{s_5\to 1_u(M)}$	116 ns^{-1}
$\tau_{^1\Sigma}$	4.55 ns[(1)]	$K_{Q,^1\Sigma(M)}$	12.85 ns^{-1}	$K_{s_4\to 0_u}$	0.0855 ns^{-1}[(1)]	$K_{s_4\to 0_u(M)}$	116 ns^{-1}[(6)]
τ_{1_u}	40 ns[(1)]	$K_{Q,1_u(M)}$	11.12 ns^{-1}	$K_{0_u\to s_4}$	1.43 ns^{-1}[(1)]		
τ_{0_u}	5 ns[(1)]	$K_{Q,0_u(M)}$	12.85 ns^{-1}	$K_{0_u\to s_5}$	6.42 ns^{-1}[(1)]		
τ_{s_5}	42 s[(2)]	$K_{Q,s_5(M)}$	11.12 ns^{-1}[(4)]	$K_{cool,0_u}$	1.72 ns^{-1}[(1)]		
τ_{s_4}	$3.56 \times n_H$ ns[(3)]	$K_{Q,s_4(M)}$	12.85 ns^{-1}[(5)]	$K_{cool,1_u}$	1.72 ns^{-1}[(1)]		

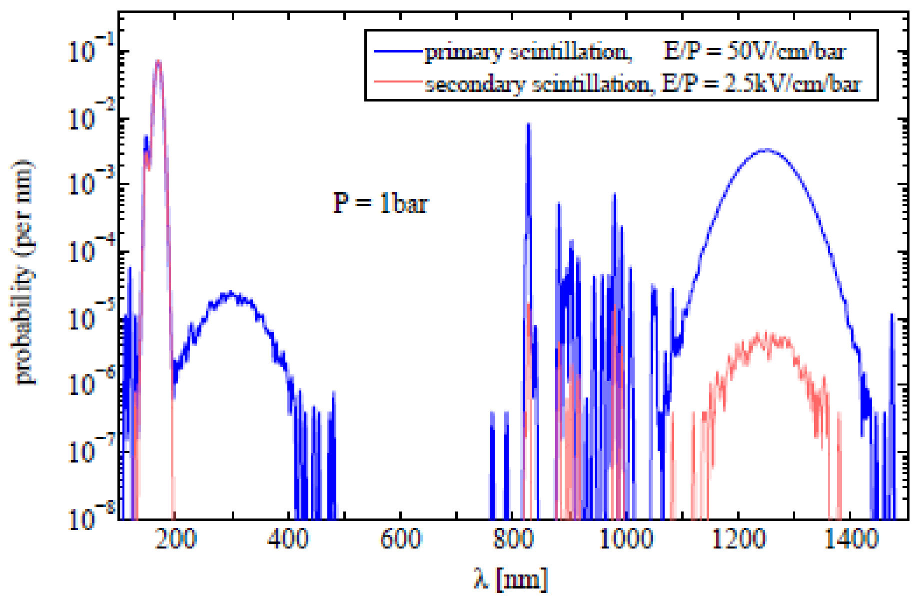
example of electron transport + light production code



time distribution



energy spectra



light transparency

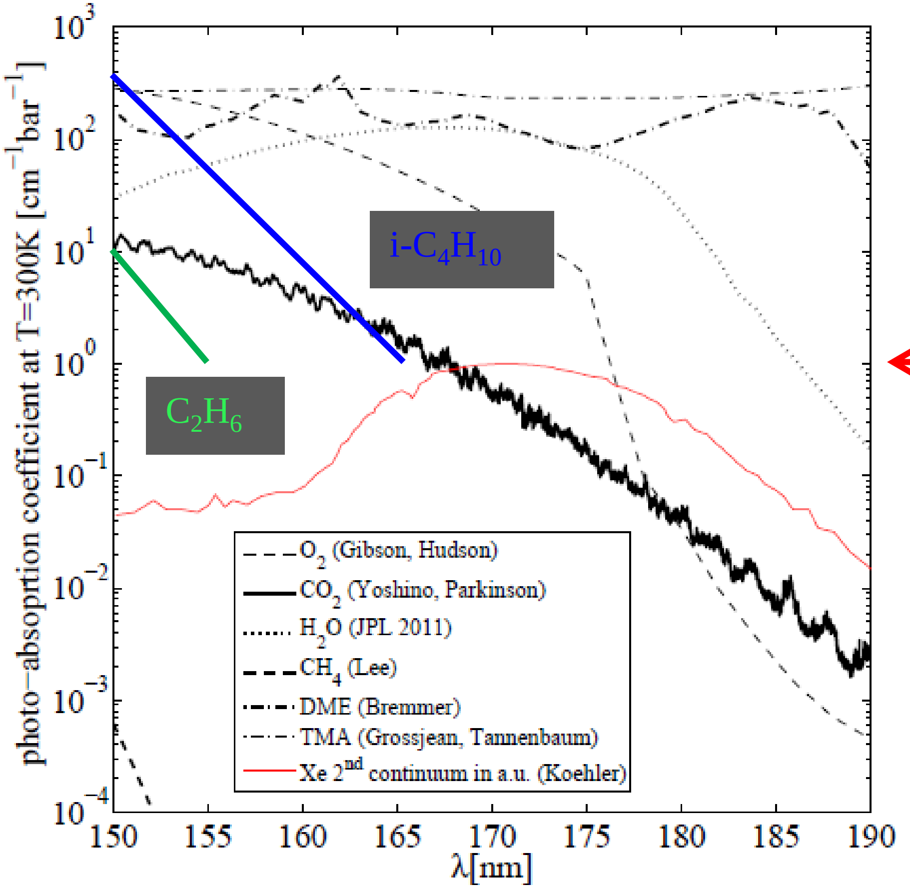


Fig. 1. Compilation of photo-absorption coefficients of some relevant TPC admixtures at around $T = 300$K in the region corresponding to the Xenon 2nd continuum, [9–18]. The reference spectrum from Koehler has been overlaid as a thin continuous line [2]. For H_2, N_2 and CF_4 there is no data in the region shown, and their cross-sections are plausibly orders of magnitude below that of CH_4.

$$\Pi = \frac{1}{P_o} N_o \sigma_a(\lambda)$$

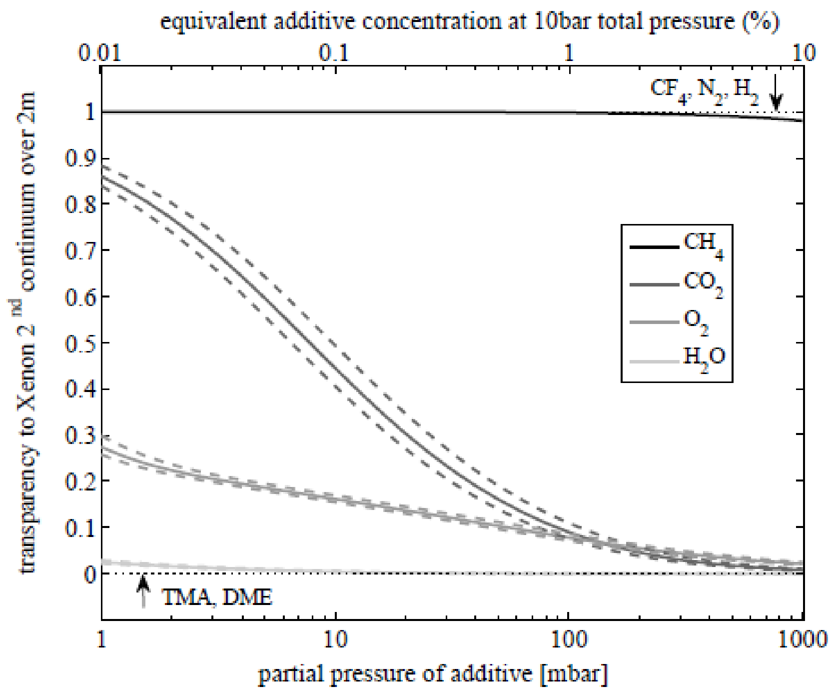
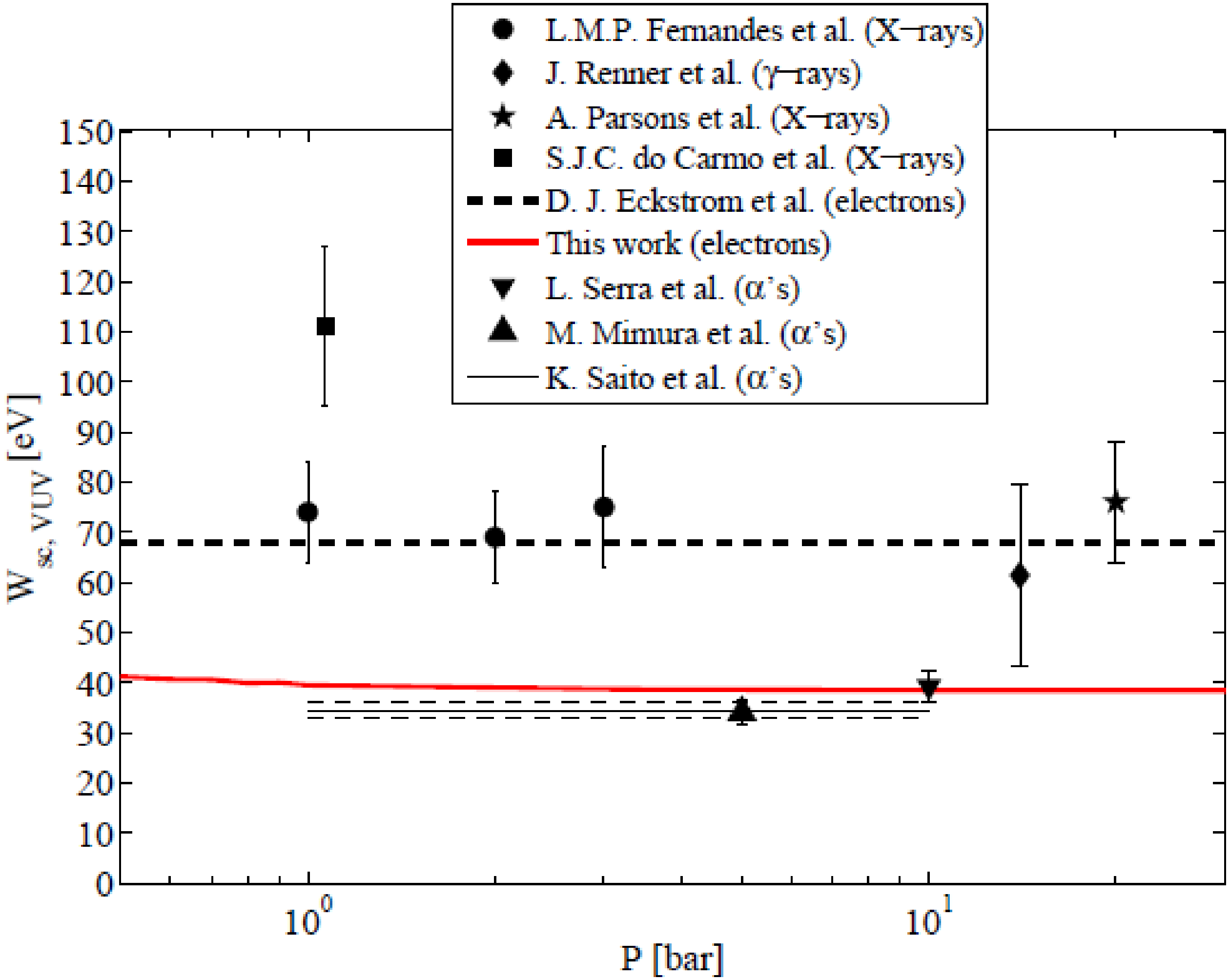


Fig. 2. Estimated transparency to scintillation from Xenon 2nd continuum as a function of partial pressure of the additive, over a 2 meter-long TPC. Dashed lines are obtained assuming 20% errors in the cross-sections.

$$\mathcal{T} \equiv \frac{\int_o^\infty \frac{dN}{d\lambda}\Big|_{2^{nd}} e^{-N\sigma_a(\lambda)L} \, d\lambda}{\int_o^\infty \frac{dN}{d\lambda}\Big|_{2^{nd}} \, d\lambda}$$

comparison with data: primary scintillation yields

VUV region



IR region

simulated

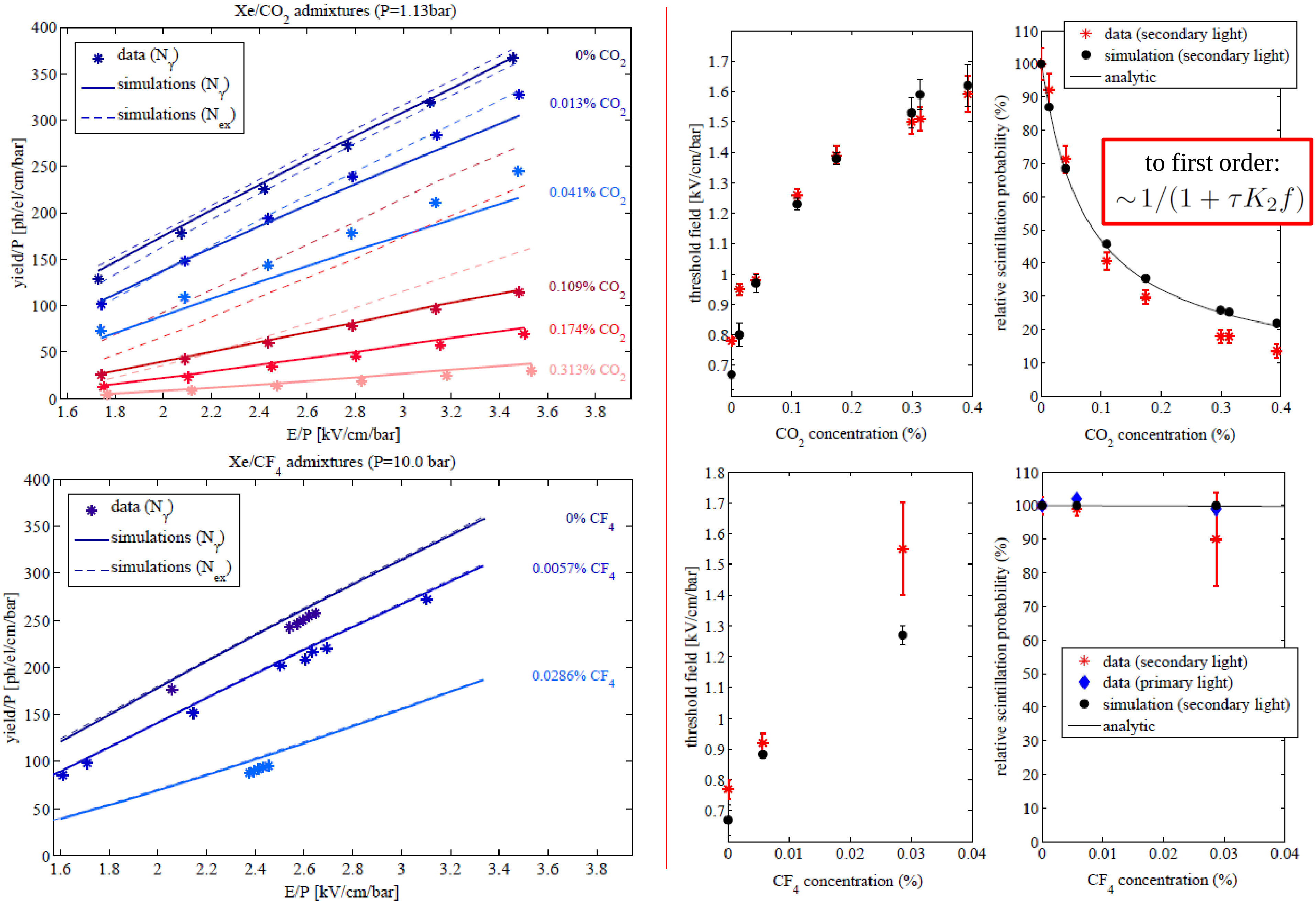
$$W_{sc,IR} = 86\text{eV at } 2.5\text{bar}$$

measured (α's)

$$W_{sc,IR} < 48 \pm 7 \text{ eV}$$

comparison with data: secondary scintillation (EL) yields

$$\mathcal{P}_{scin} = 1 - \mathcal{P}_Q = \frac{N_\gamma}{N_{ex}}$$



to first order:
$\sim 1/(1 + \tau K_2 f)$

comparison with data: feedback parameter β (related to maximum gain; arguably, to streamer formation too)

Secondary avalanches in gas mixtures

Özkan Şahin [a,*], İlhan Tapan [a], Rob Veenhof [b]

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$\boxed{\sim 1/(1+\tau K_2 f)}$ **!**

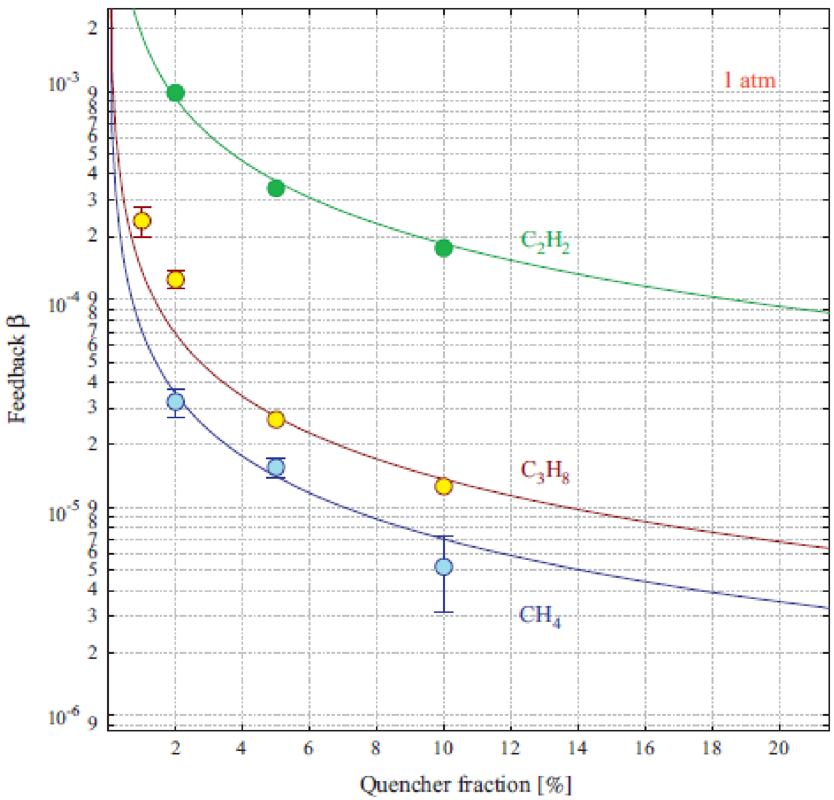

Fig. 2. Photon feedback β versus quencher fraction. The circles are fits using Eq. (1) and the solid lines are proportional to $\boxed{1/f_q}$

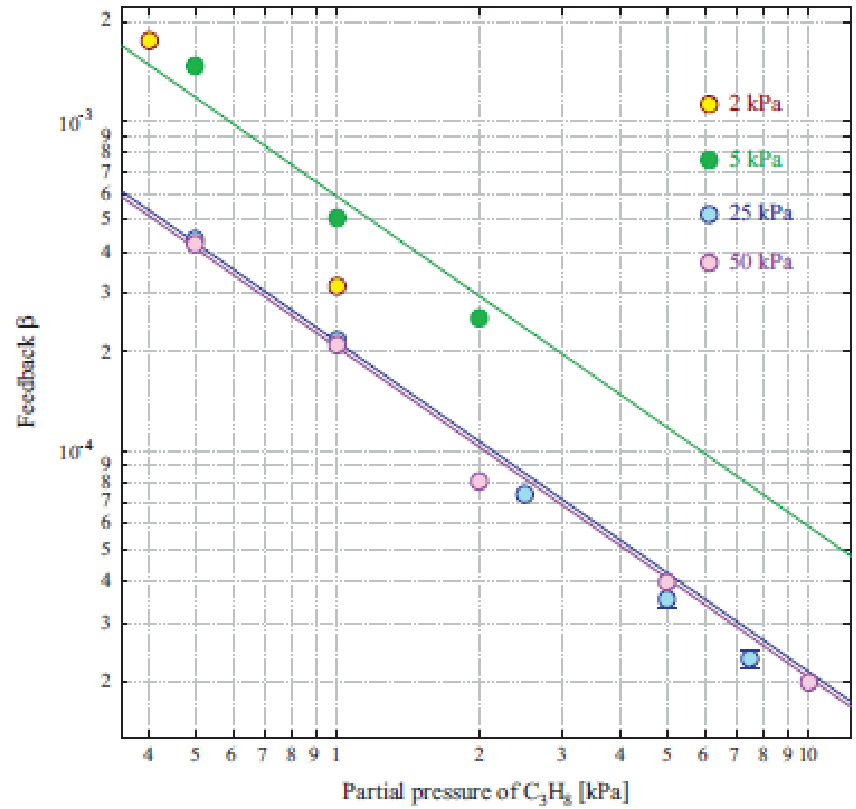

Fig. 3. Photon feedback β versus partial pressure of C_3H_8. The circles are fitted feedback parameters and the solid lines are the fits with $\boxed{1/(f_q p_{gas})}$.

current and future activities

- The lab is focused on the study of scintillating mixtures and structures for next generation neutrino, dark matter and nuclear physics experiments.
- There are 3 UHVacuum-grade systems, pressure-compatible (up to 10bar), with recirculation, purification and gas monitoring.
- Scintillation studies are focused on the xenon-band (170nm) but we would like to extend these studies to visible (CMOS camera already purchased) and harder VUV (down to Ar-band, at least).

funding situation

- The procured lab's equipment for this project is worth 150kE, and additional resources are available for the next 3years (60kE, at least).
- No major concerns with hardware stability/availability.
- Main problem is the availability of manpower. Students in Santiago are good, but the present funding scheme does not allow hiring. The situation will likely improve next year, but it is unlikely that manpower can be allocated to this project (but hardware can).