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ECF22, Beograd, Serbia, Orationem Meam

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Stable and Unstable Growth of Crack Tip Precipitates

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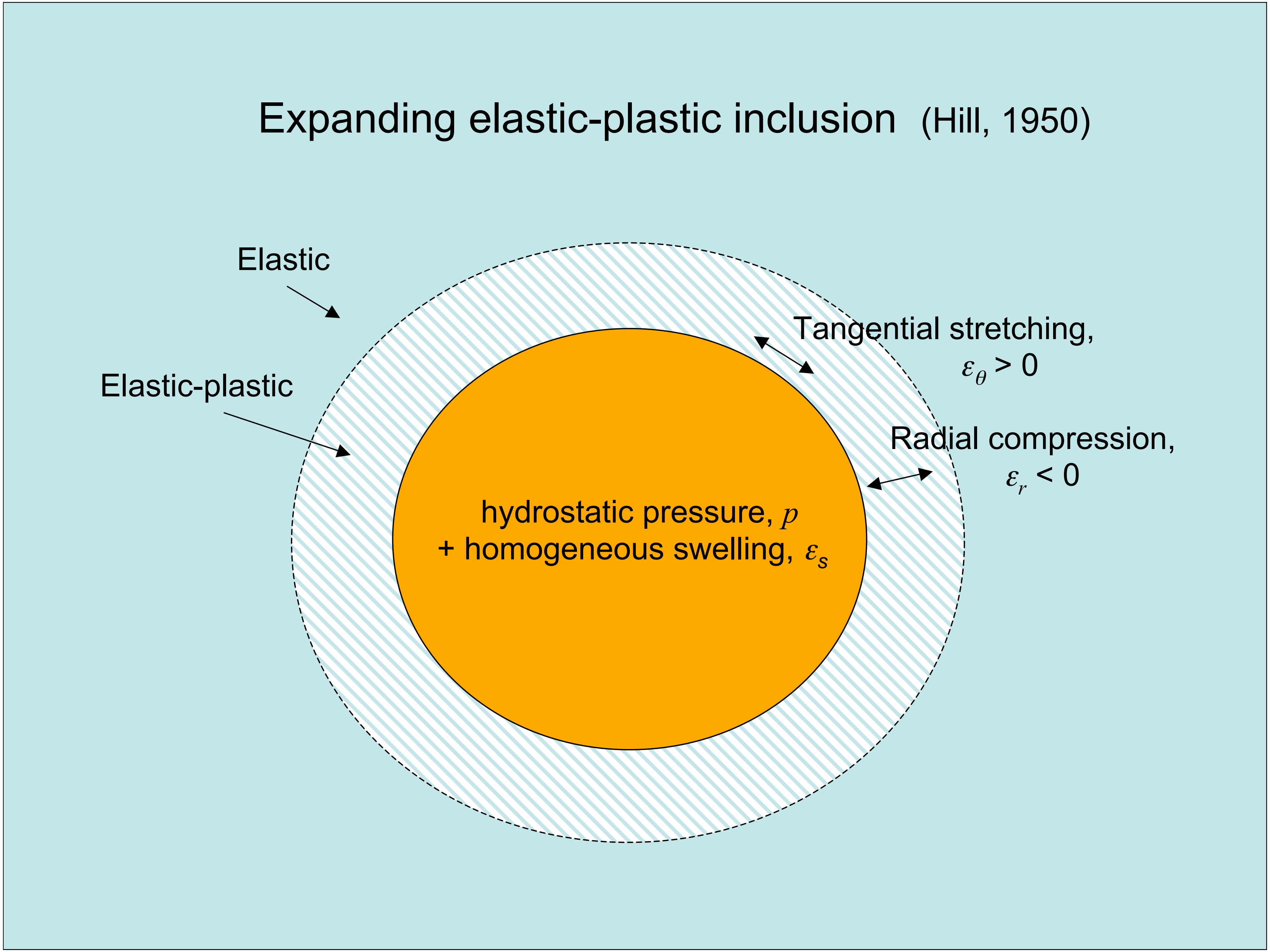
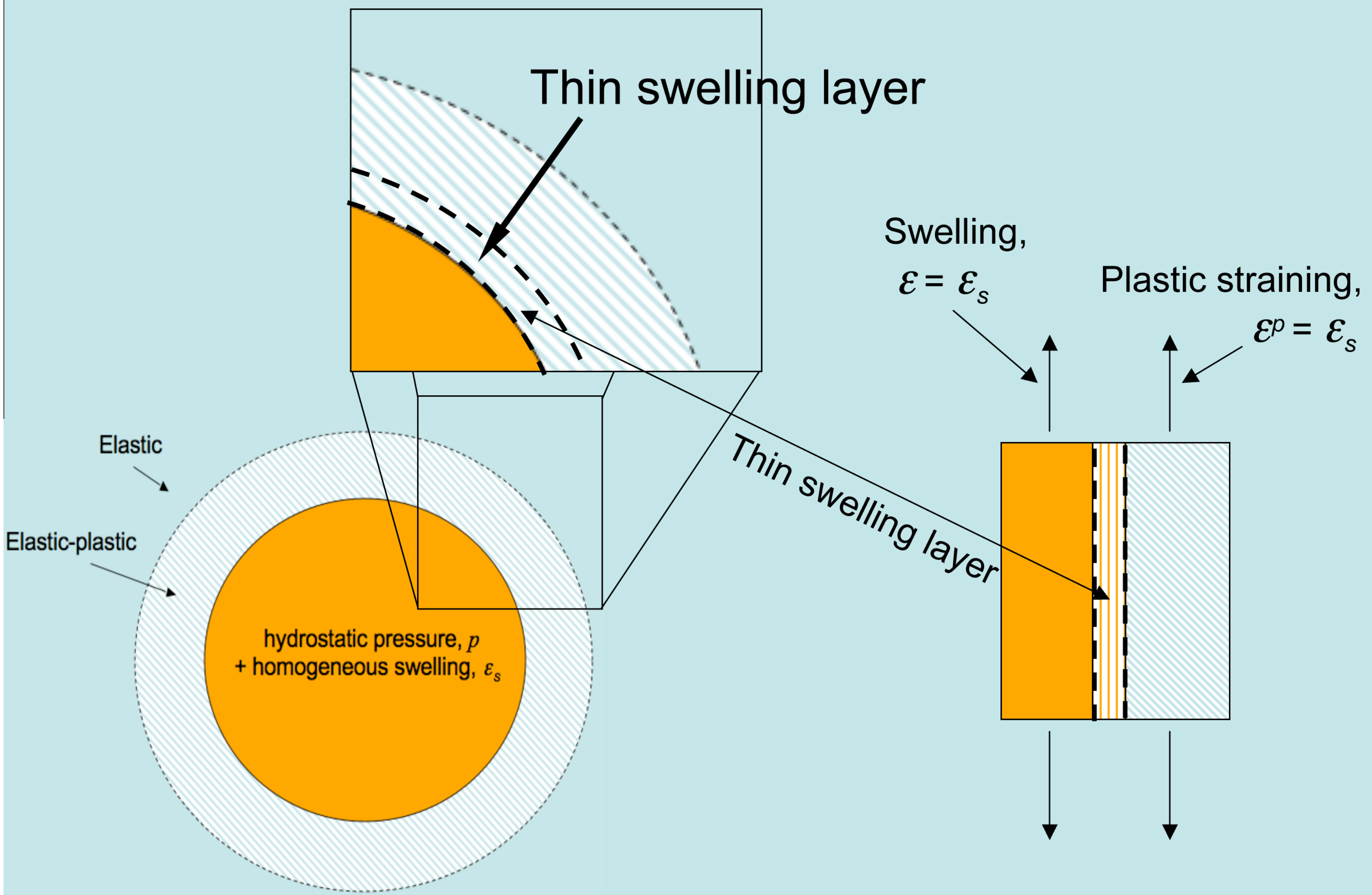
1. Tensile Stress in Expanding Precipitates

2. Expanding Crack Tip Precipitate


Expanding elastic-plastic inclusion (Hill, 1950)
Elastic
Elastic-plastic
Tangential stretching,
$\varepsilon_\theta > 0$
Radial compression,
$\varepsilon_r < 0$
hydrostatic pressure, p
+ homogeneous swelling, ε_s

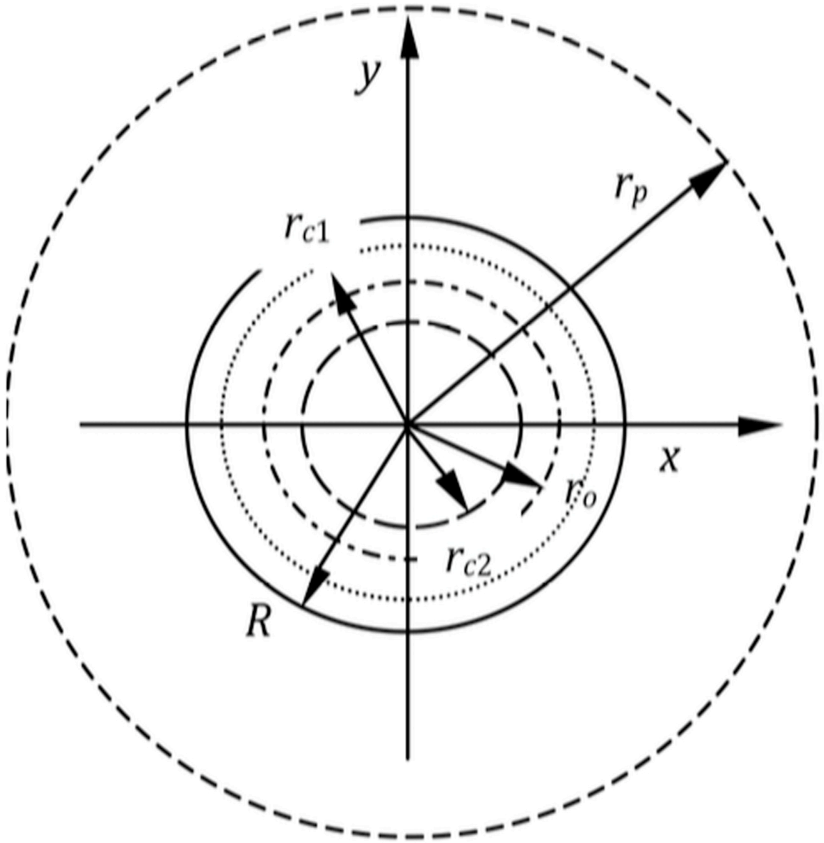
Thin layer increasing inclusion mass (and volume)



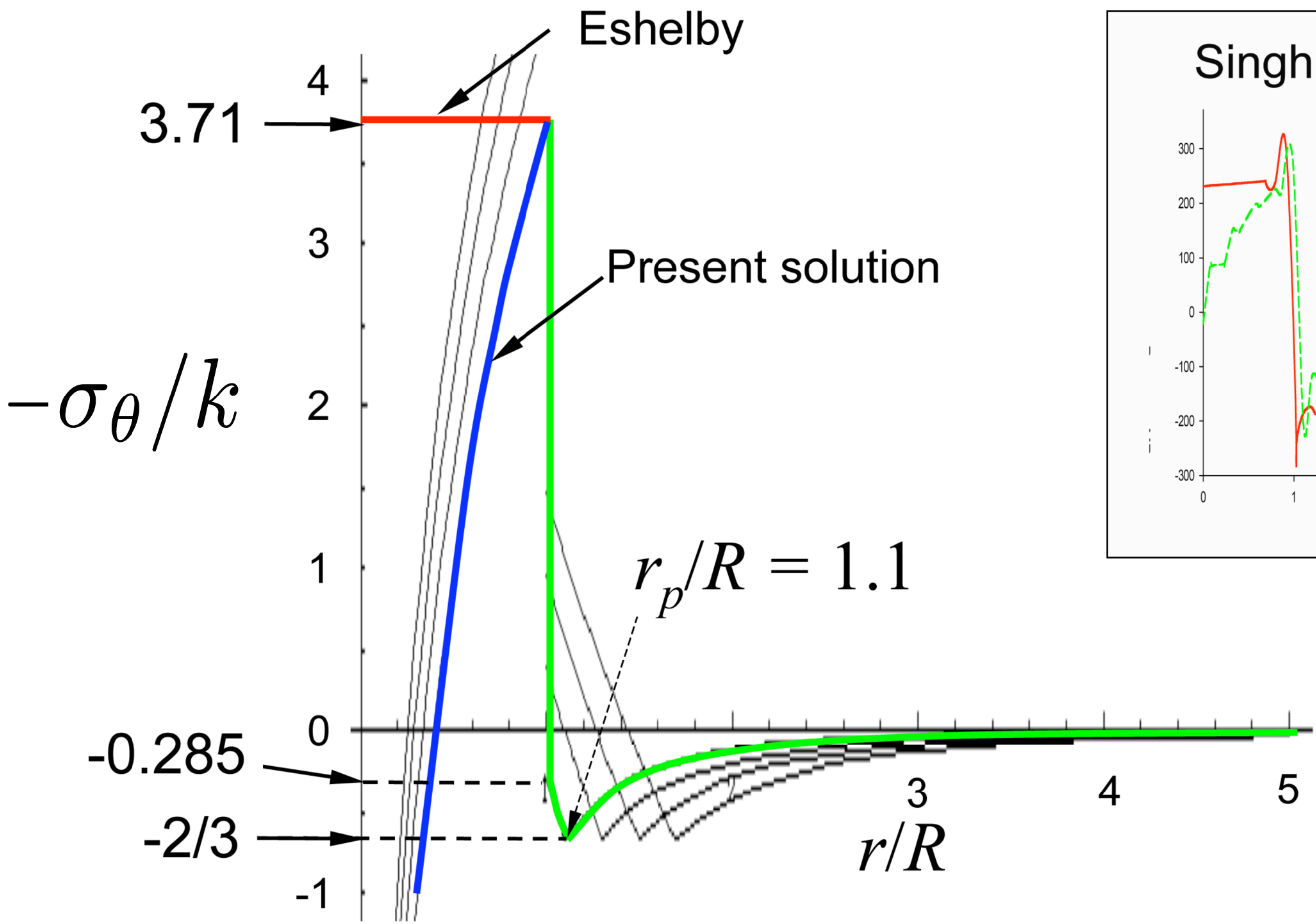
Characteristic regions in and around the precipitate

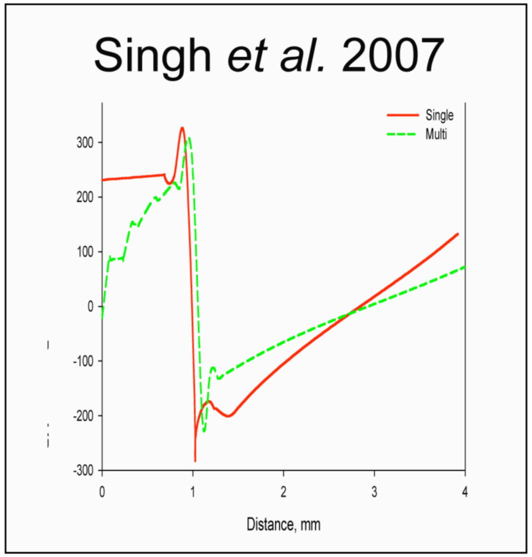
$$\sigma_r = 2k\left[2\ln\frac{r}{r_p} - \frac{2}{3}\right] \text{ and } \sigma_\theta = 2k\left[2\ln\frac{r}{r_p} + \frac{1}{3}\right] \text{ in } R < r \le r_p$$

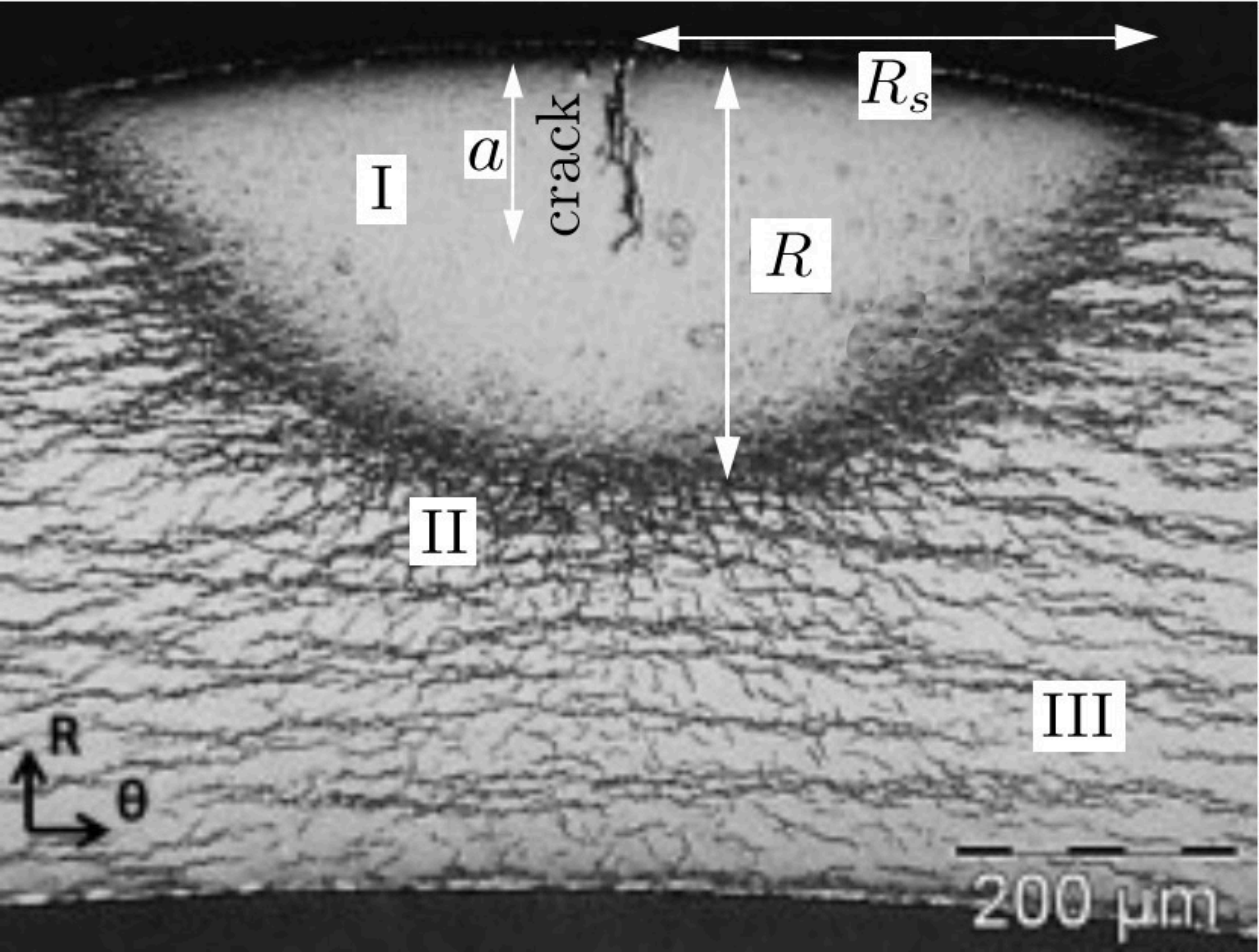
$$\sigma_r = 2k\left[2\ln\frac{R^2}{r\,r_p} - \frac{2}{3}\right] \text{ and } \sigma_\theta = 2k\left[2\ln\frac{R^2}{r\,r_p} - \frac{5}{3}\right] \text{ in } r \le R$$



Tangeltial stress, σ_θ/k vs. distance , r/R



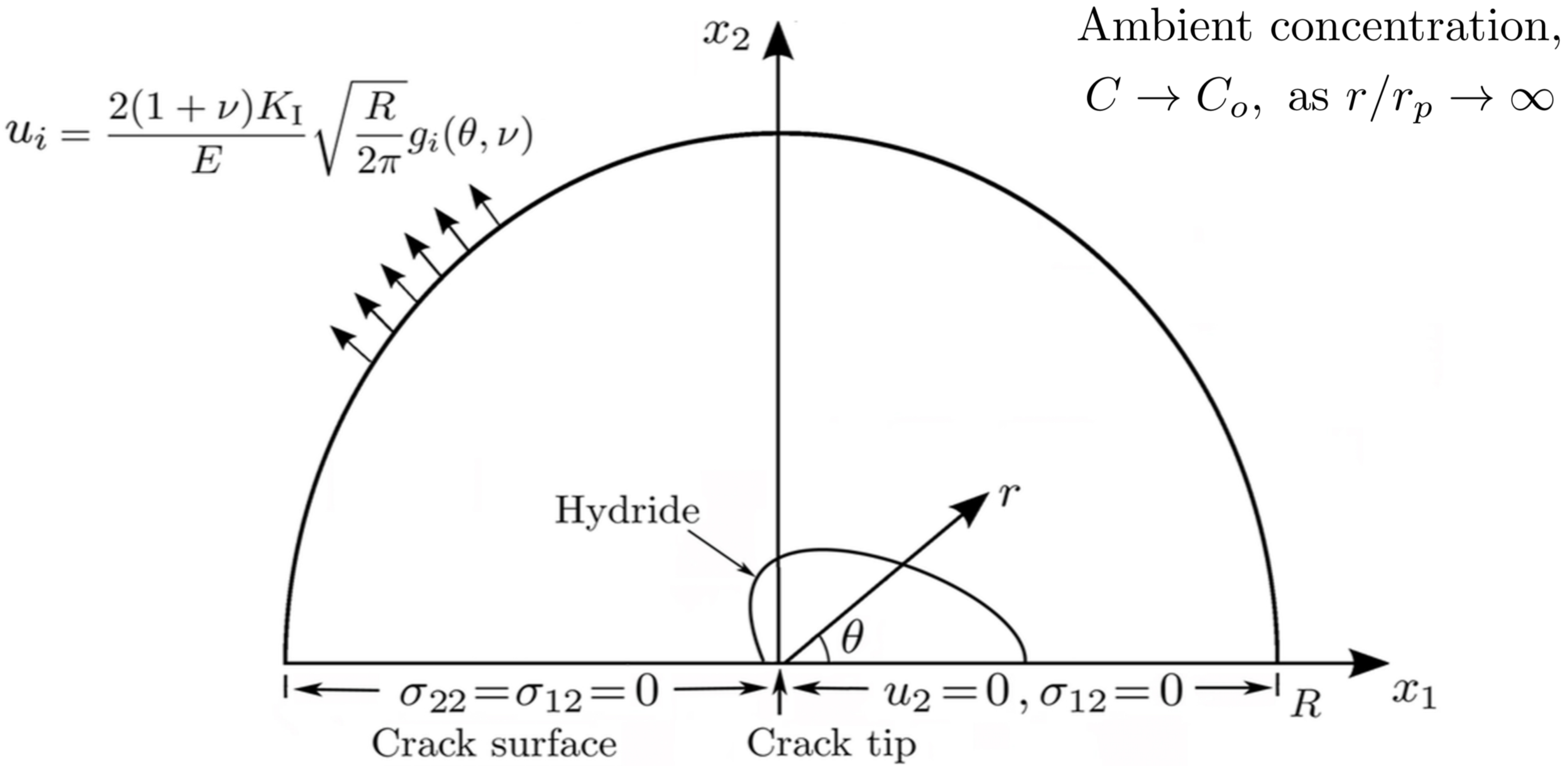




R_s
a
crack
I
R
II
III
R
θ
200 μm

2. Expanding Crack Tip Precipitate

Crack tip hydride



Einstein-Smoluchovski: $J = -D\nabla C + \frac{DCV}{kT}\nabla\sigma_h\,,$

$$J = 0 \Rightarrow\ -\ln C(x_i) + \frac{V}{kT}\sigma_h(x_i) = const.$$

B.C. $C \to C_a$ **and** $\sigma_h/\sigma_c \to 0$ **as** $r/r_h \to \infty$

$$\sigma_c = \frac{kT}{V}\ln\frac{C_c}{C_a}$$

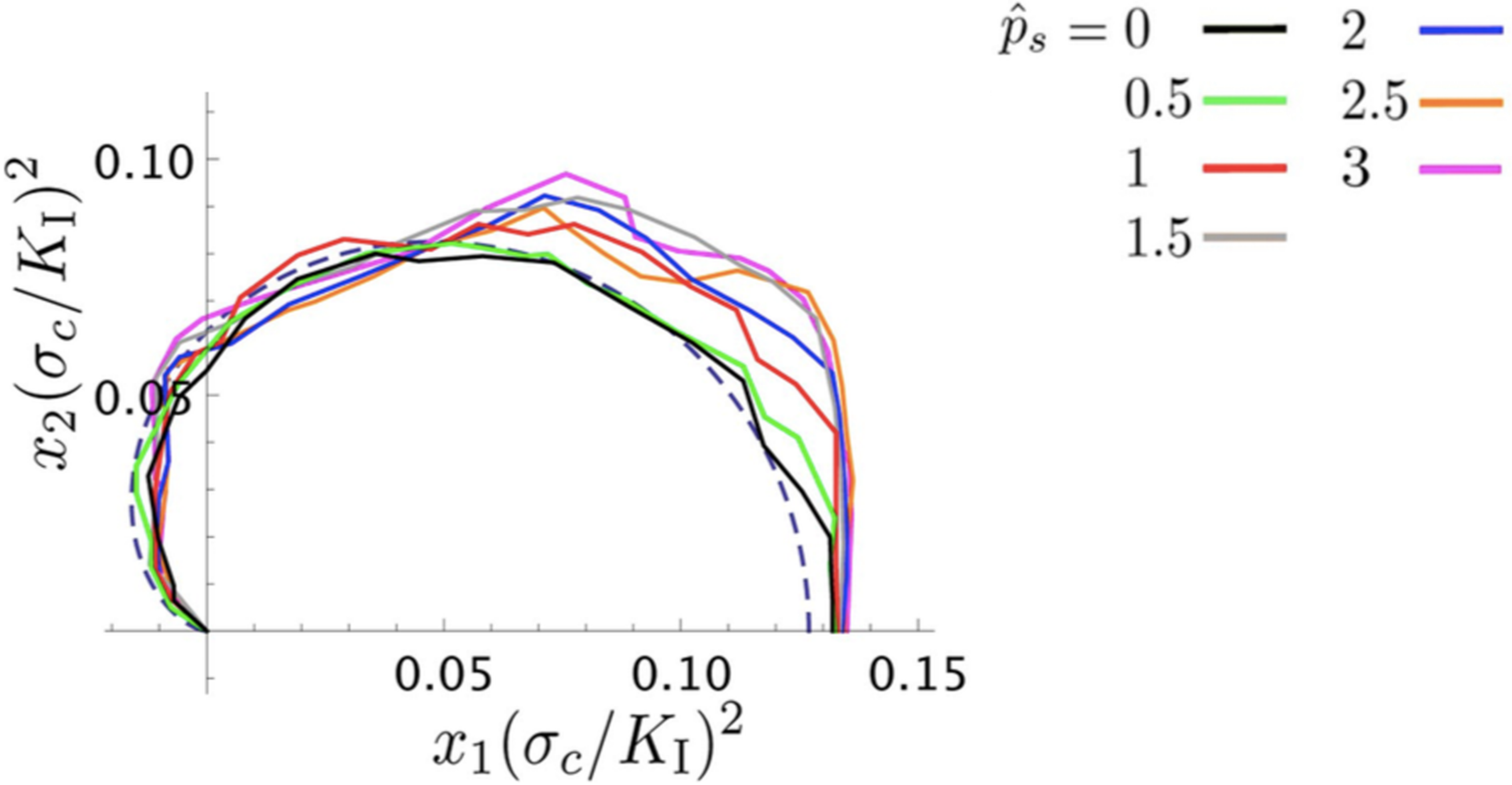
A single length scale and a parameter:

$$\left(\frac{K_{\mathrm{I}}}{\sigma_c}\right)^2 \quad \textbf{and} \quad \frac{p_s}{\sigma_c}$$

$$\sigma_c = \frac{K_{\mathrm{I}}}{\sqrt{2\pi r_h}} + \xi p_s \quad \Rightarrow \quad r_h = \frac{K_{\mathrm{I}}}{\sqrt{2\pi}(\sigma_c - \xi p_s)}$$

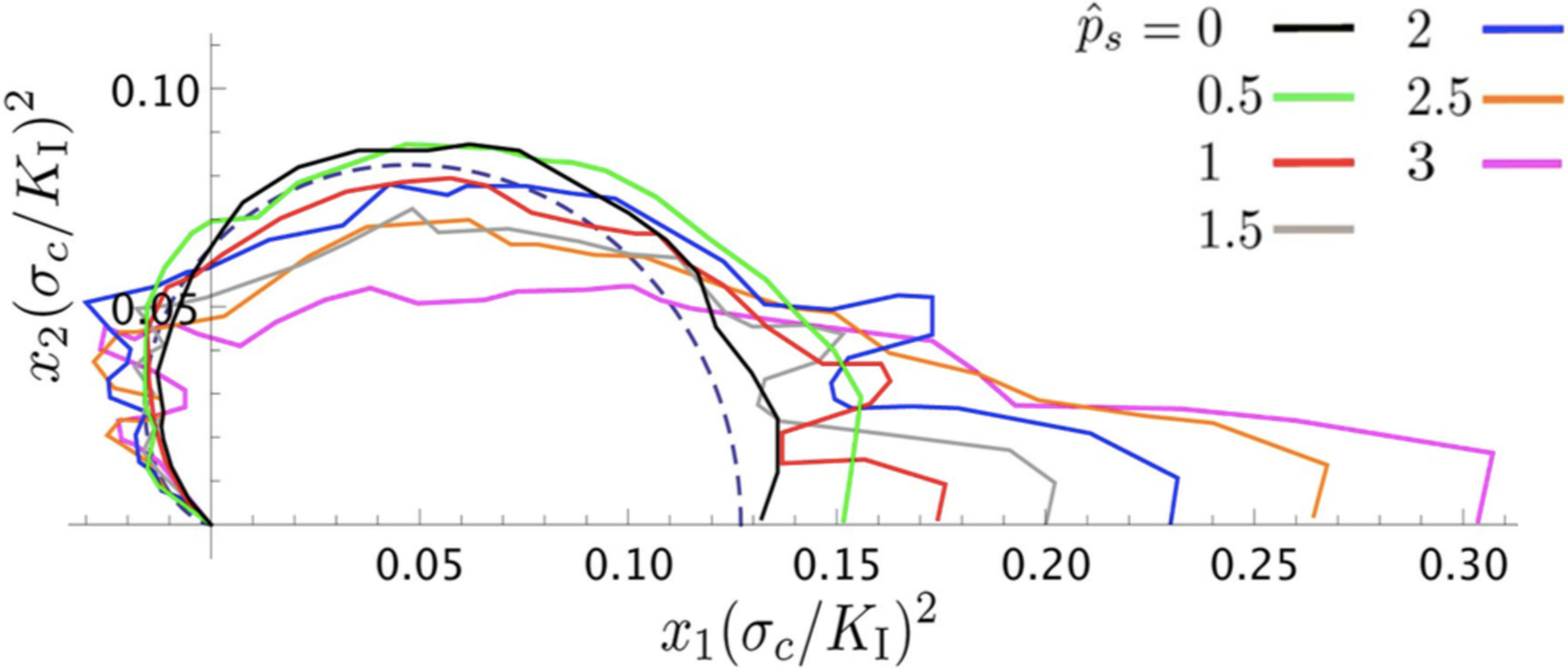
Hydride shape for isotropic cases

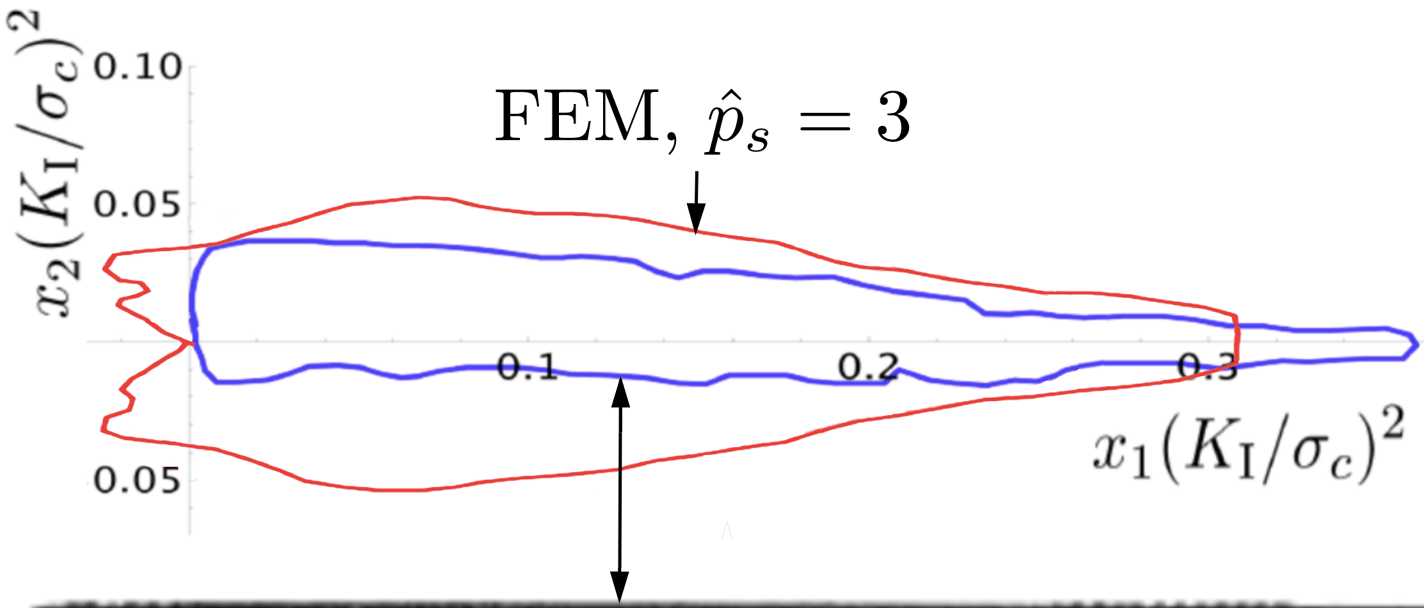
$$\epsilon_{11}^s = \epsilon_{22}^s = \epsilon_{33}^s = \epsilon^s$$



Hydride shape for anisotropic cases

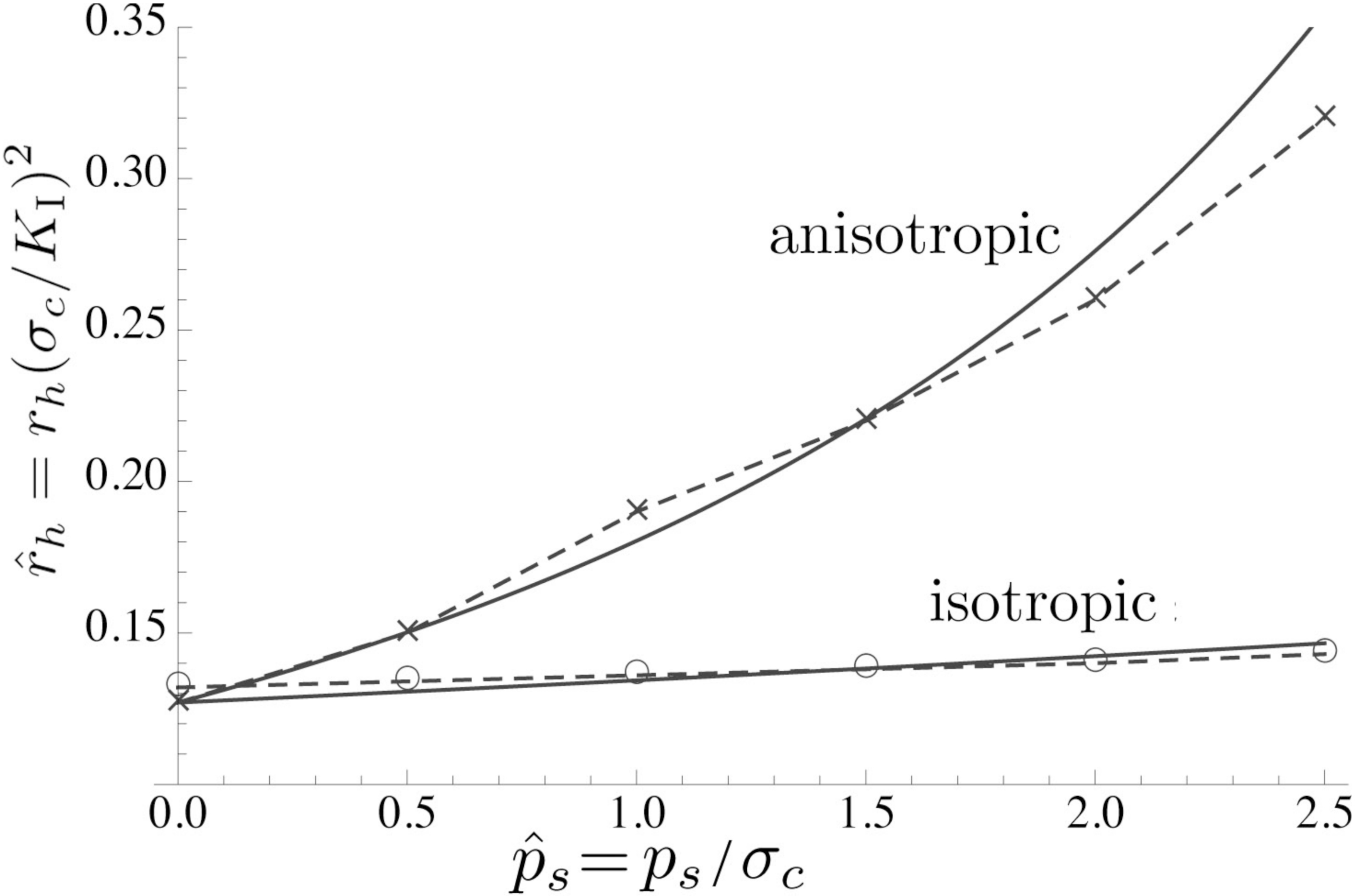
$$\epsilon_{22}^s = \epsilon^s,\ \epsilon_{11}^s = \epsilon_{33}^s = 0$$



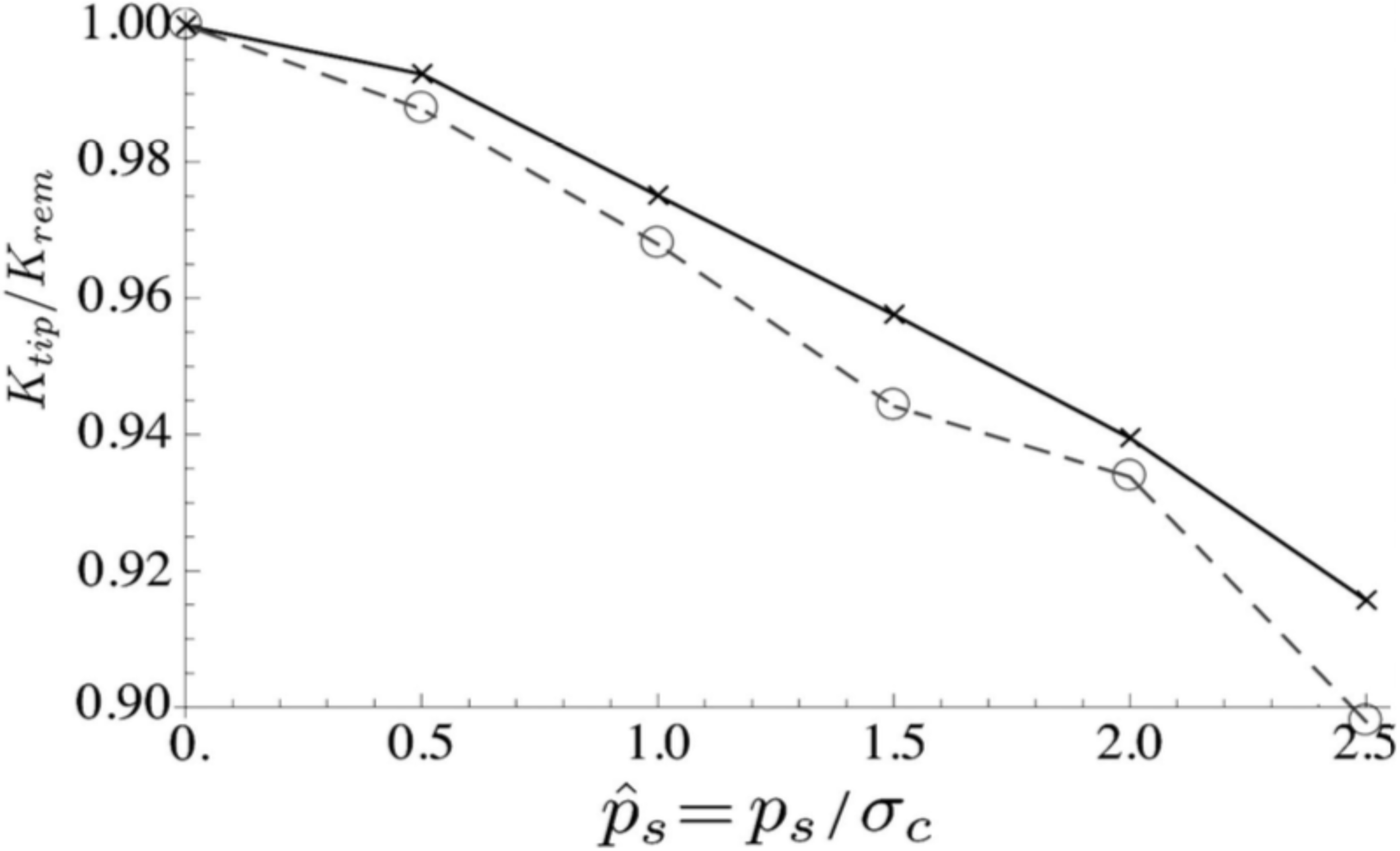


(c) observed crack tip hydride

(Metzger & Sauve, ASME 329, 1996, p.137)



0.35
0.30
0.25
0.20
0.15
$\hat{r}_h = r_h(\sigma_c/K_{\rm I})^2$
anisotropic
isotropic
0.0
0.5
1.0
1.5
2.0
2.5
$\hat{p}_s = p_s/\sigma_c$


1.00
0.98
0.96
0.94
0.92
0.90
K_{tip}/K_{rem}
0.
0.5
1.0
1.5
2.0
2.5
$\hat{p}_s = p_s/\sigma_c$

Conclusions

- Logarithmic Stress Singularity inside Expanding Precipitates
- Concentration and Stress Criteria are Equivalent
- Limited Growth for Low Expansion Strains
- Anisotropic Expansion gives a Strip Shaped Precipitate
- Crack Tip Shielding Increases with the Expansion Strain