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ECF22 – Beograd, 2018

# Stable and Unstable Growth of Crack Tip Precipitates

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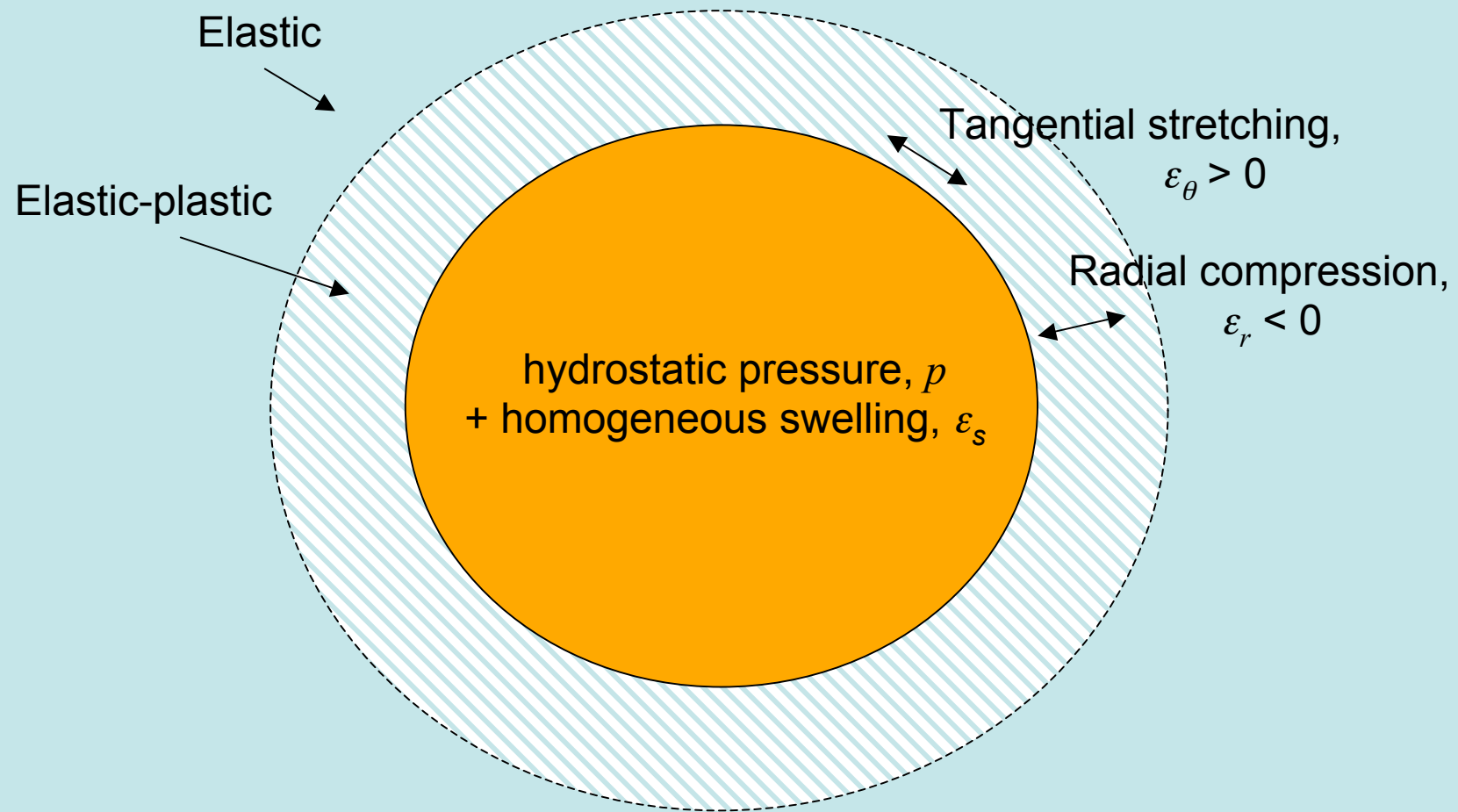


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1. Tensile Stress in Expanding Precipitates

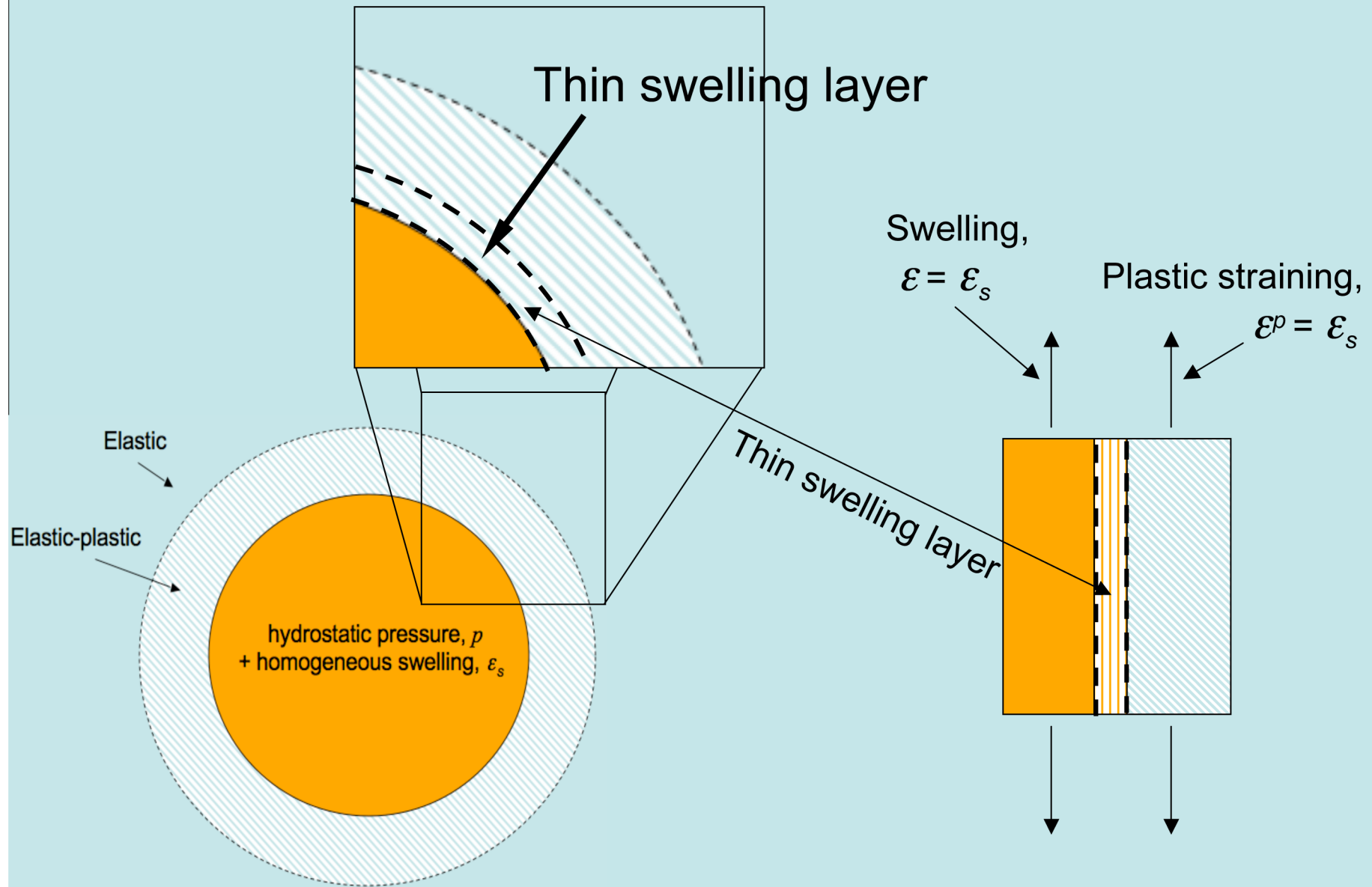
2. Expanding Crack Tip Precipitate

## Expanding elastic-plastic inclusion (Hill, 1950)





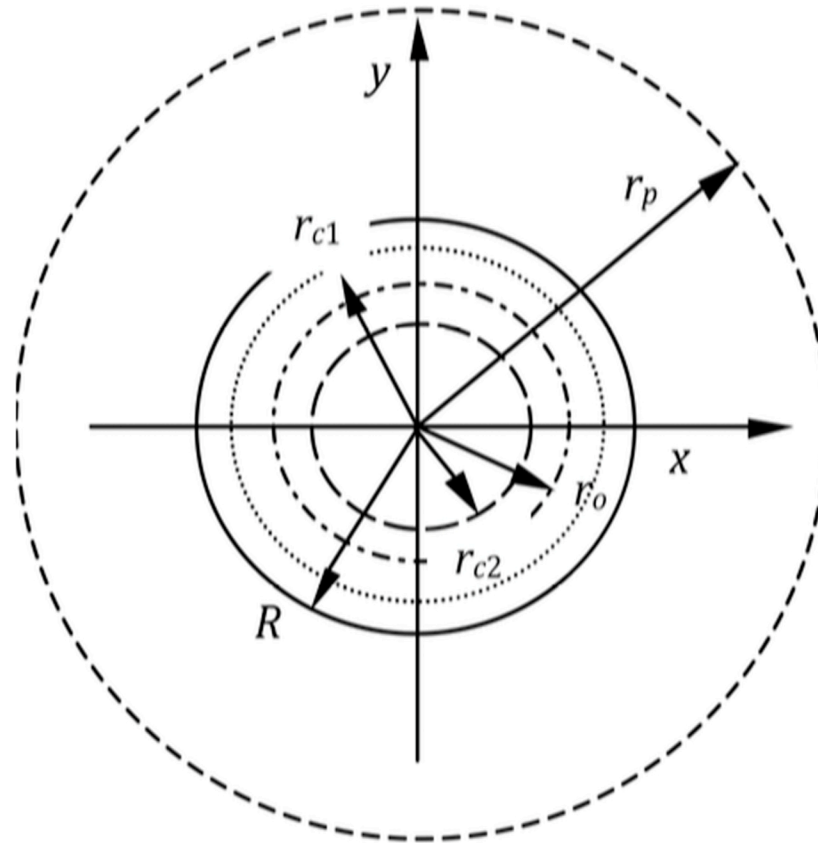
# Thin layer increasing inclusion mass (and volume)



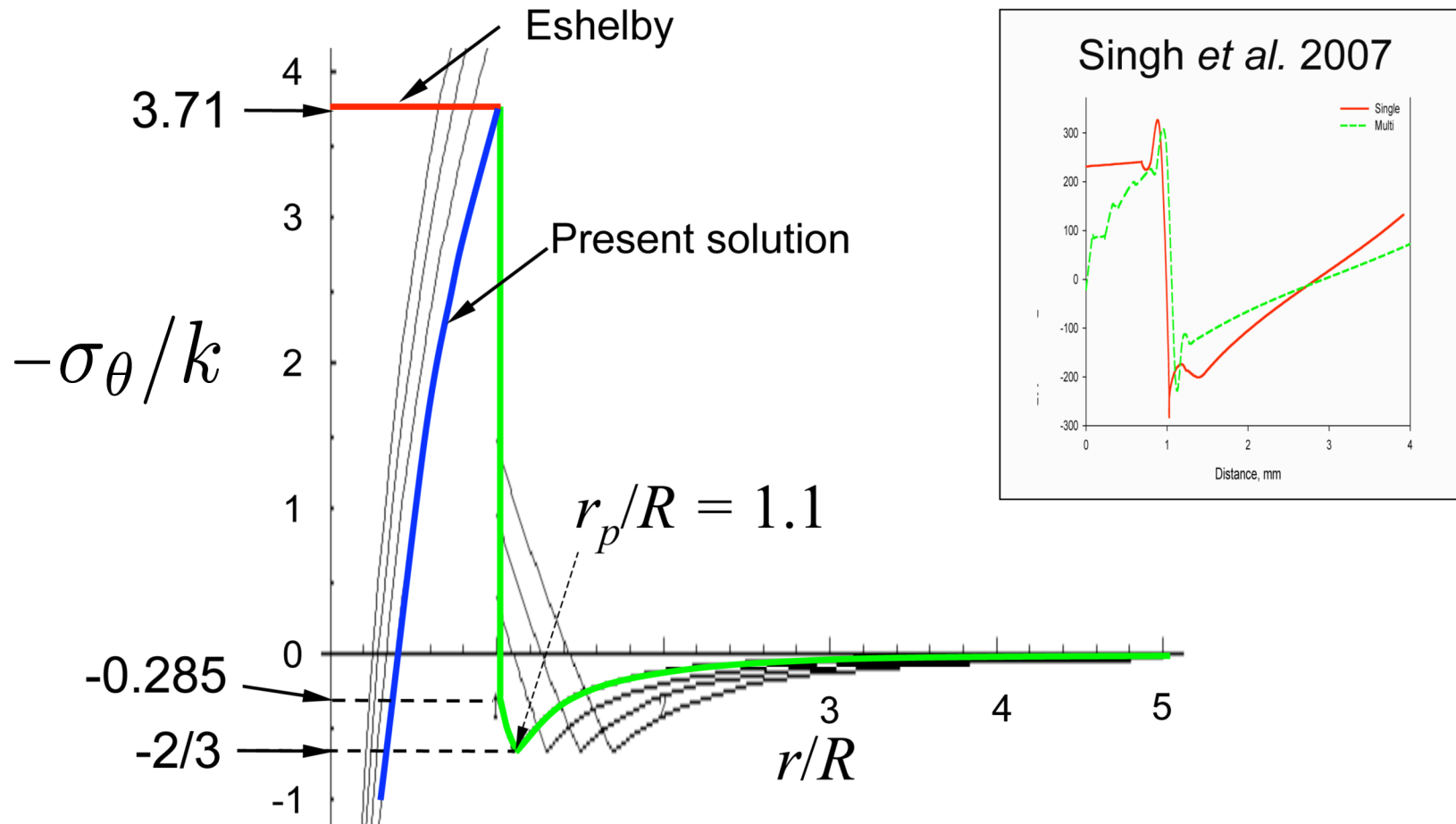
## Characteristic regions in and around the precipitate

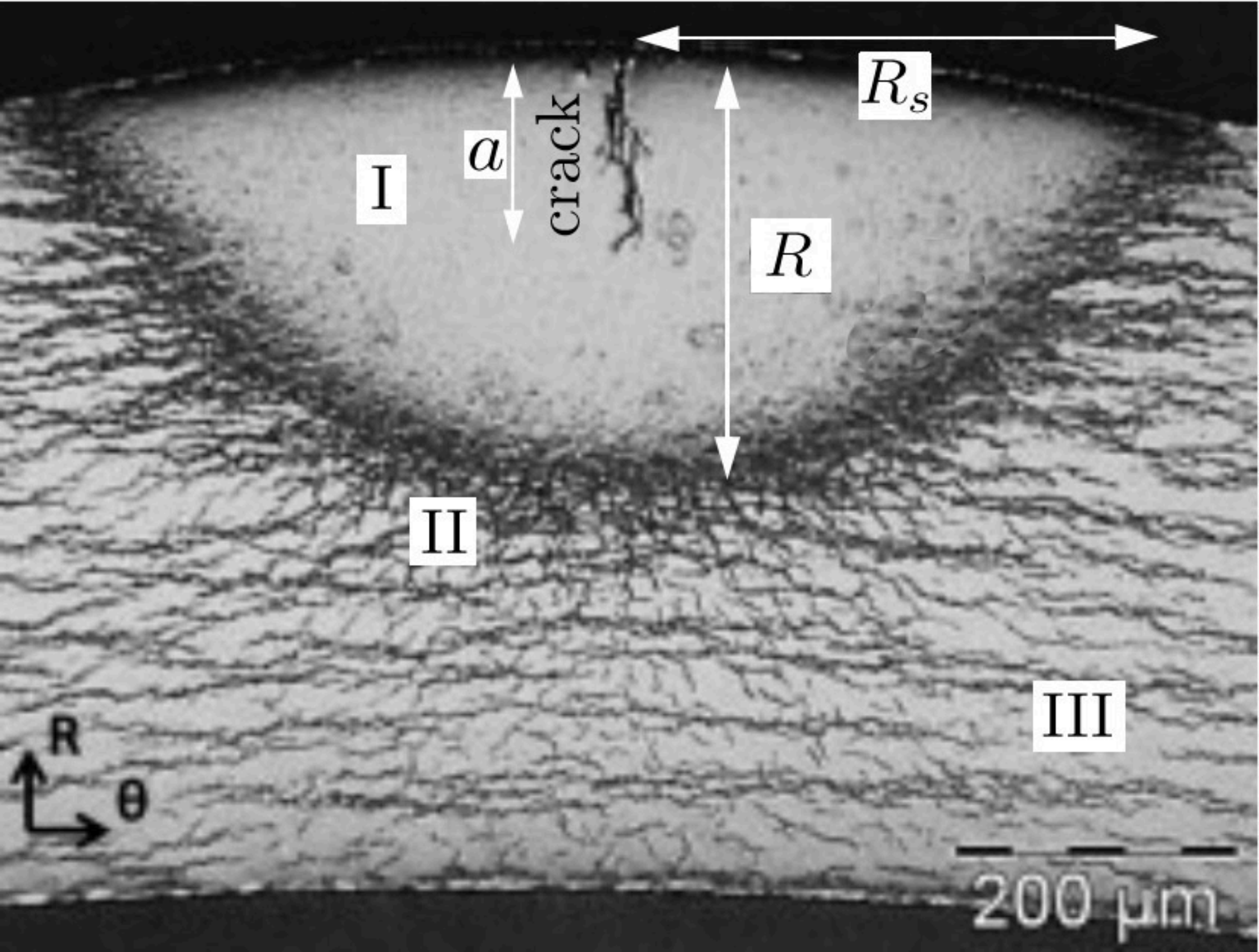
$$\sigma_r = 2k \left[ 2 \ln \frac{r}{r_p} - \frac{2}{3} \right] \quad \text{and} \quad \sigma_\theta = 2k \left[ 2 \ln \frac{r}{r_p} + \frac{1}{3} \right] \quad \text{in } R < r \leq r_p$$

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



# Tangential stress, $\sigma_\theta/k$ vs. distance, $r/R$



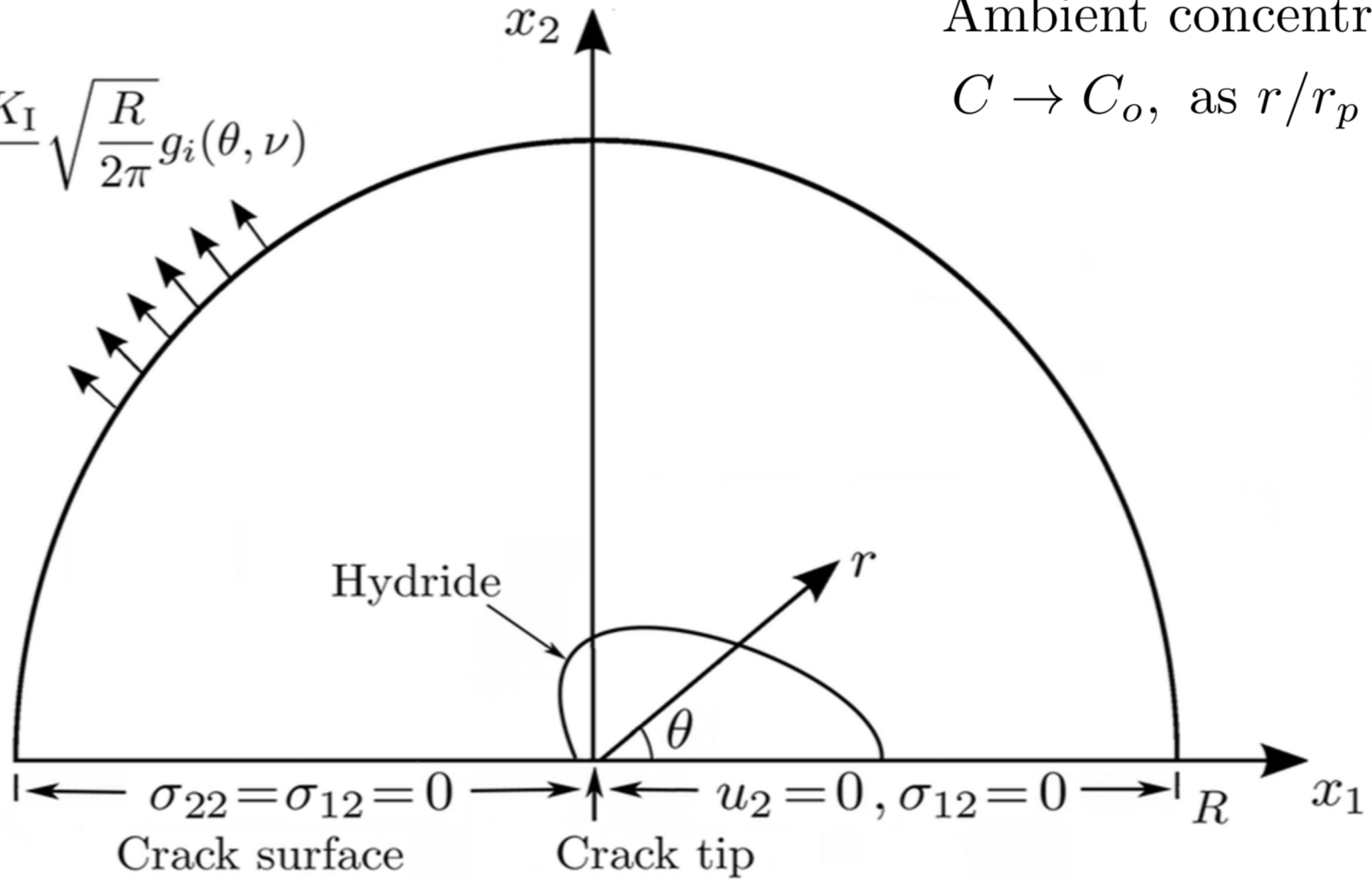


## 2. Expanding Crack Tip Precipitate

# Crack tip hydride

$$u_i = \frac{2(1 + \nu)K_I}{E} \sqrt{\frac{R}{2\pi}} g_i(\theta, \nu)$$

Ambient concentration,  
 $C \rightarrow C_o$ , as  $r/r_p \rightarrow \infty$



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

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

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

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

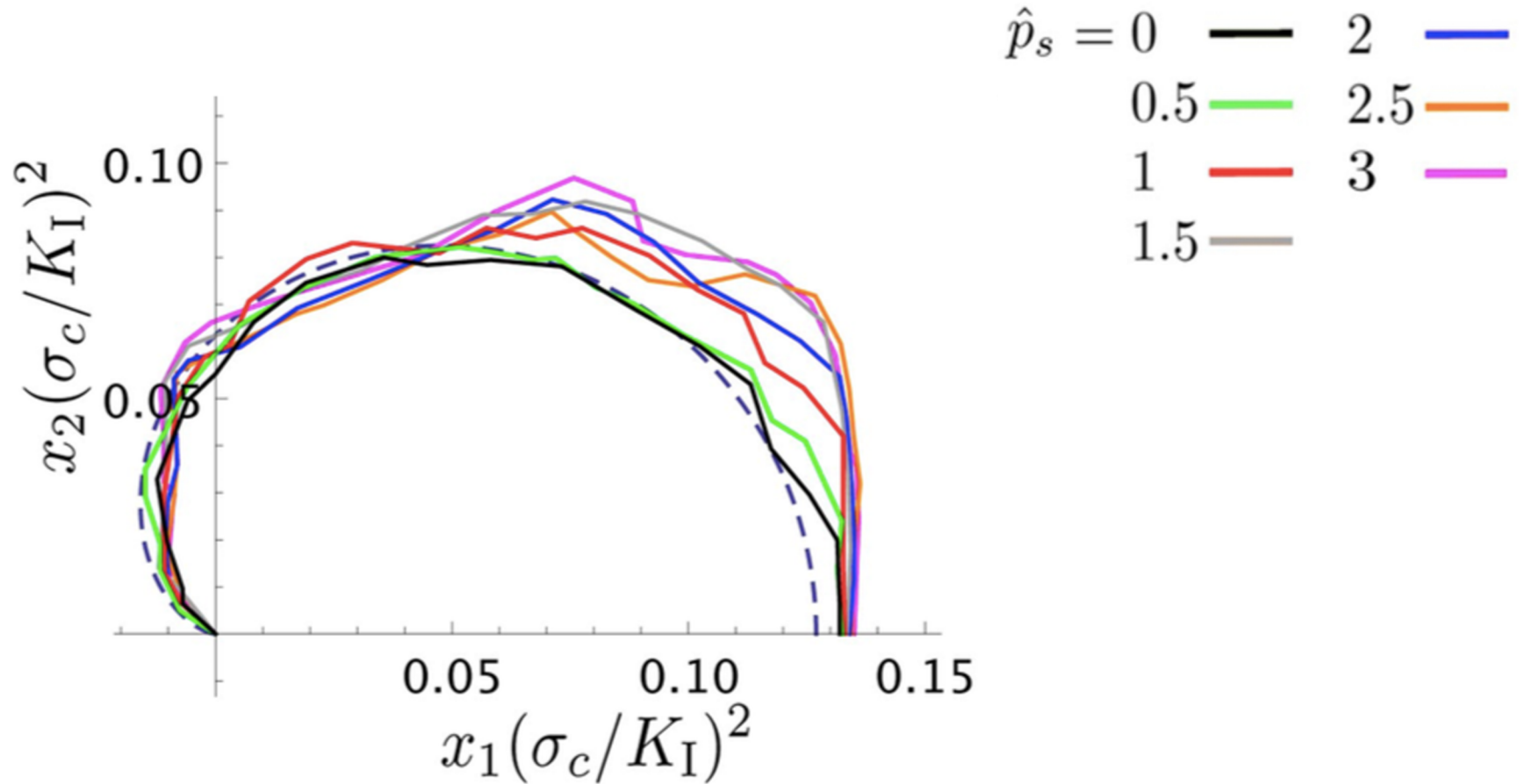
A single length scale and a parameter:

$$\left(\frac{K_I}{\sigma_c}\right)^2 \quad \text{and} \quad \frac{p_s}{\sigma_c}$$

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

# Hydride shape for isotropic cases

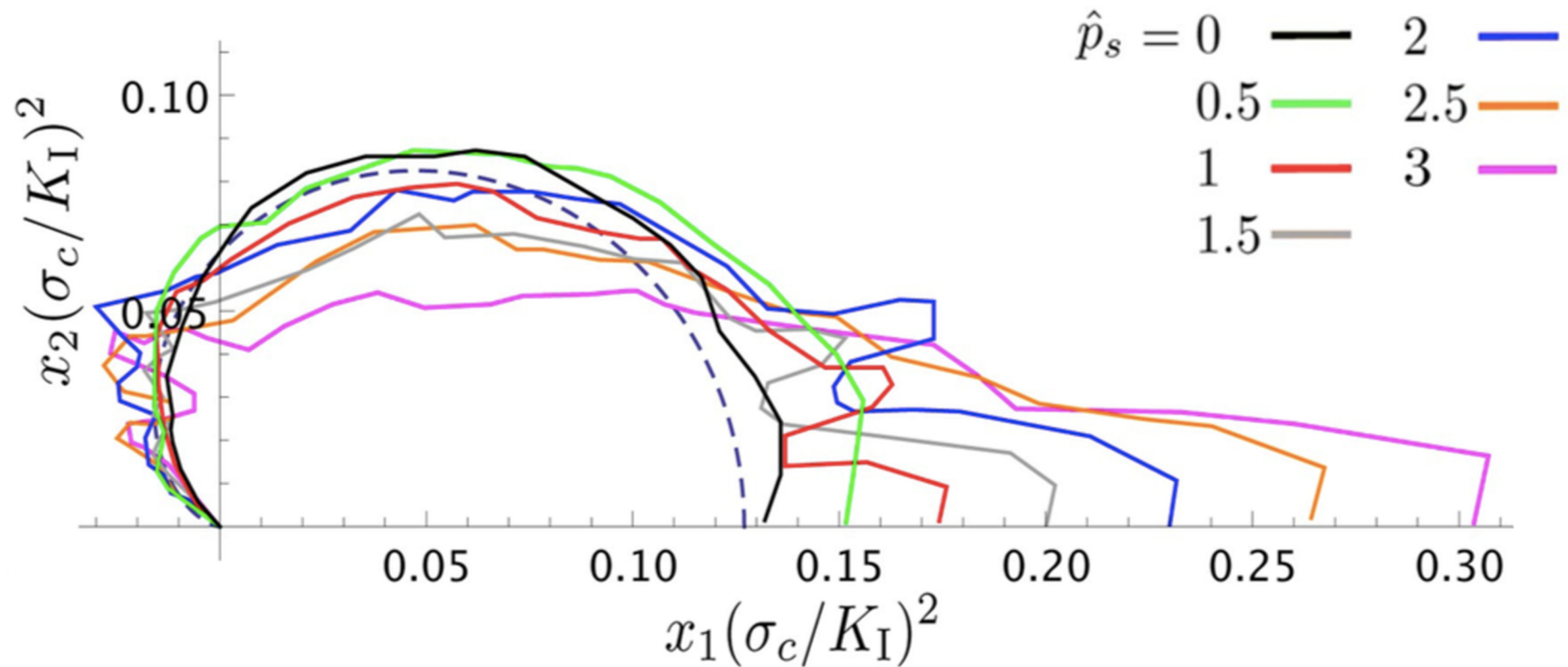
$$\epsilon_{11}^s = \epsilon_{22}^s = \epsilon_{33}^s = \epsilon^s$$

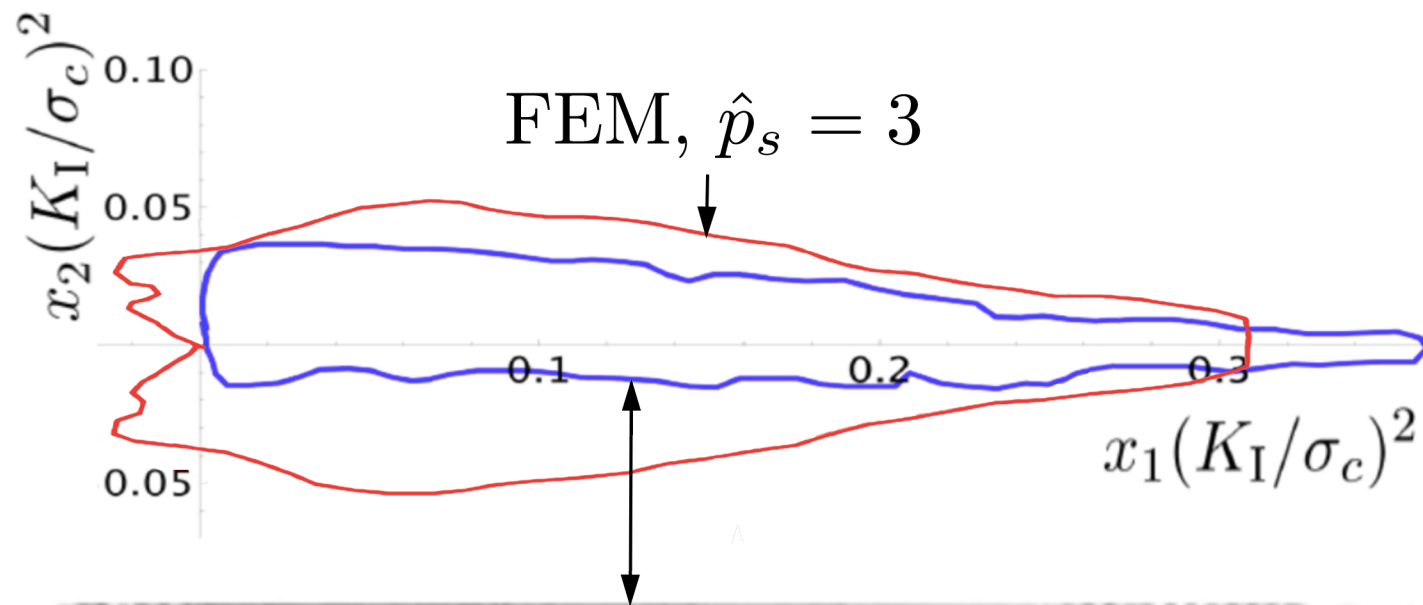




# Hydride shape for anisotropic cases

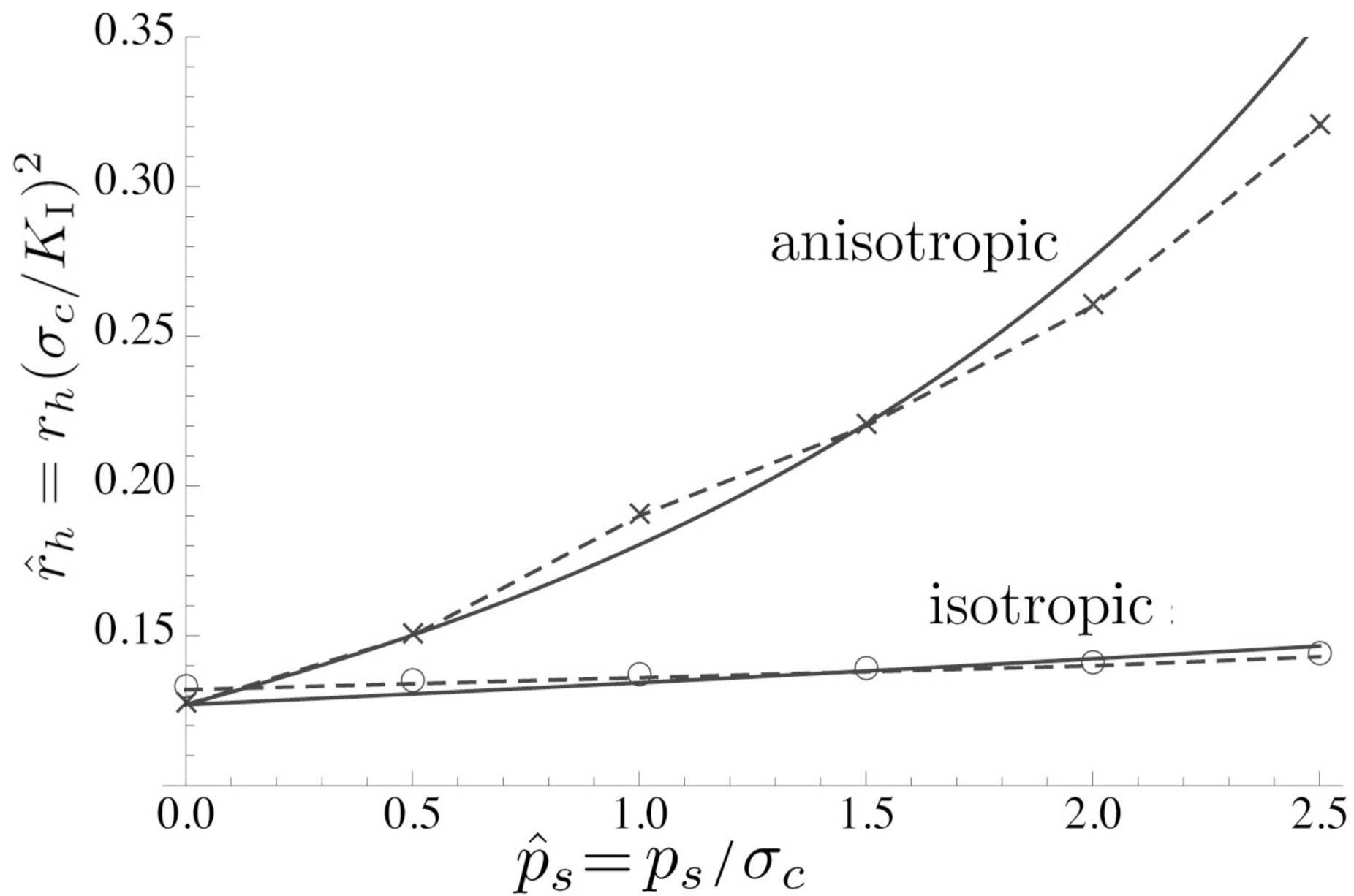
$$\epsilon_{22}^s = \epsilon^s, \quad \epsilon_{11}^s = \epsilon_{33}^s = 0$$

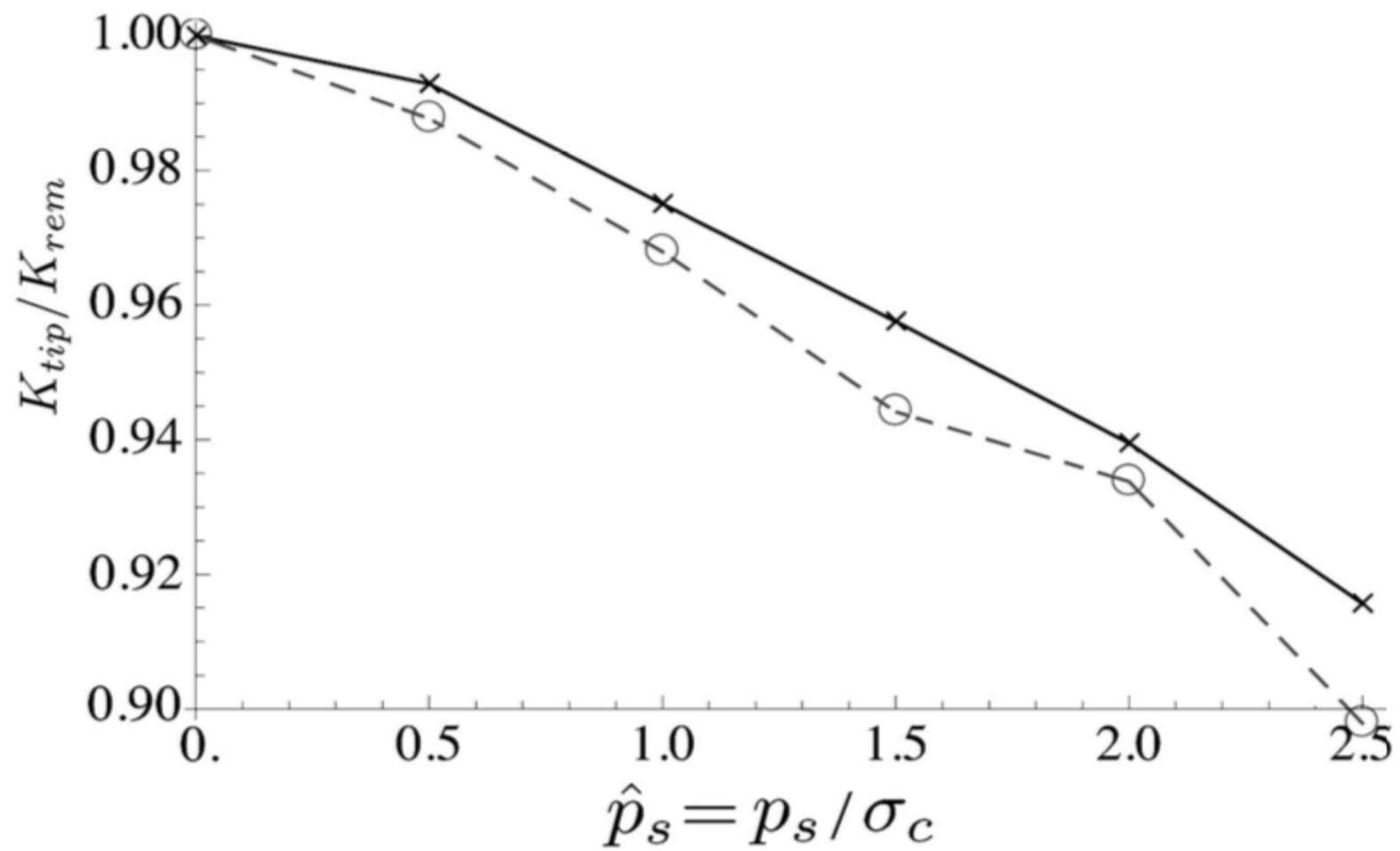




(c) observed crack tip hydride

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





# 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