



# The Polarization Ratio and PUNCH

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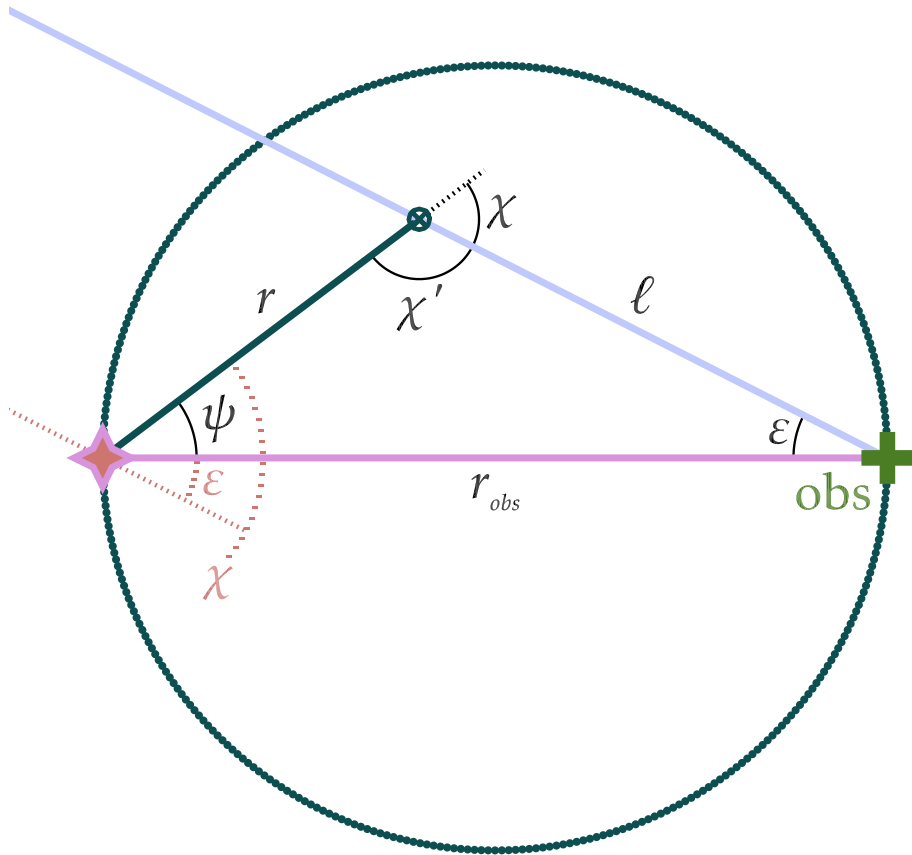
S. Gibson, C. DeForest, S. Cranmer,  
A. Malanushenko, D. Webb



# Polarization Ratio

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$$PR = \frac{B_R}{B_T} = \frac{tB - pB}{tB + pB} = \frac{1 - p}{1 + p}$$





## The P from PUNCH

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$$PR \approx \frac{\int_{\varepsilon}^{\pi} d\chi \cos^2 \chi n_e(\chi, \varepsilon)}{\int_{\varepsilon}^{\pi} d\chi n_e(\chi, \varepsilon)}$$



## Small-Sun Approximation

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$$r \gg r_{\odot}$$

If we want to introduce less than 1% error compared to exact calculation, this implies

$$r > 9r_{\odot} \text{ or } \varepsilon > 2.5^{\circ}.$$

Approximation valid in PUNCH/WFI field of view.



# Expanding Solar Wind

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$$n_e(\chi, \varepsilon; c) = \frac{n_{\odot}}{r_{obs}^c \sin^c \varepsilon} \sin^c \chi$$



# Expanding Solar Wind

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$$PR = \frac{1}{c+2} + \frac{\sin^{c+1} \chi \cos \chi \Big|_{\epsilon}^{\pi}}{(c+2) \int_{\epsilon}^{\pi} d\chi \sin^c \chi}$$



# Expanding Solar Wind

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$$PR = \frac{1}{c+2}$$



# Small Features

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$$n_e(\chi, \varepsilon; \Delta) = \tilde{n}_e(\chi, \varepsilon) \eta_{\Delta}(\chi - \chi_c)$$



# Small Features

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$$PR = \lim_{\Delta \rightarrow 0} \frac{\int_{\varepsilon}^{\pi} d\chi \cos^2 \chi \tilde{n}_e(\chi, \varepsilon) \eta_{\Delta}(\chi - \chi_c)}{\int_{\varepsilon}^{\pi} d\chi \tilde{n}_e(\chi, \varepsilon) \eta_{\Delta}(\chi - \chi_c)}$$



# Small Features

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$$PR = \frac{\cos^2 \chi_c \tilde{n}_e(\chi_c, \varepsilon)}{\tilde{n}_e(\chi_c, \varepsilon)} = \cos^2 \chi_c$$



## PR to Location

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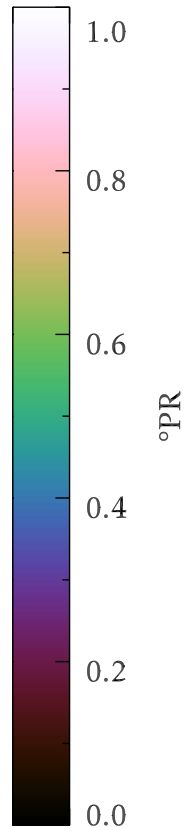
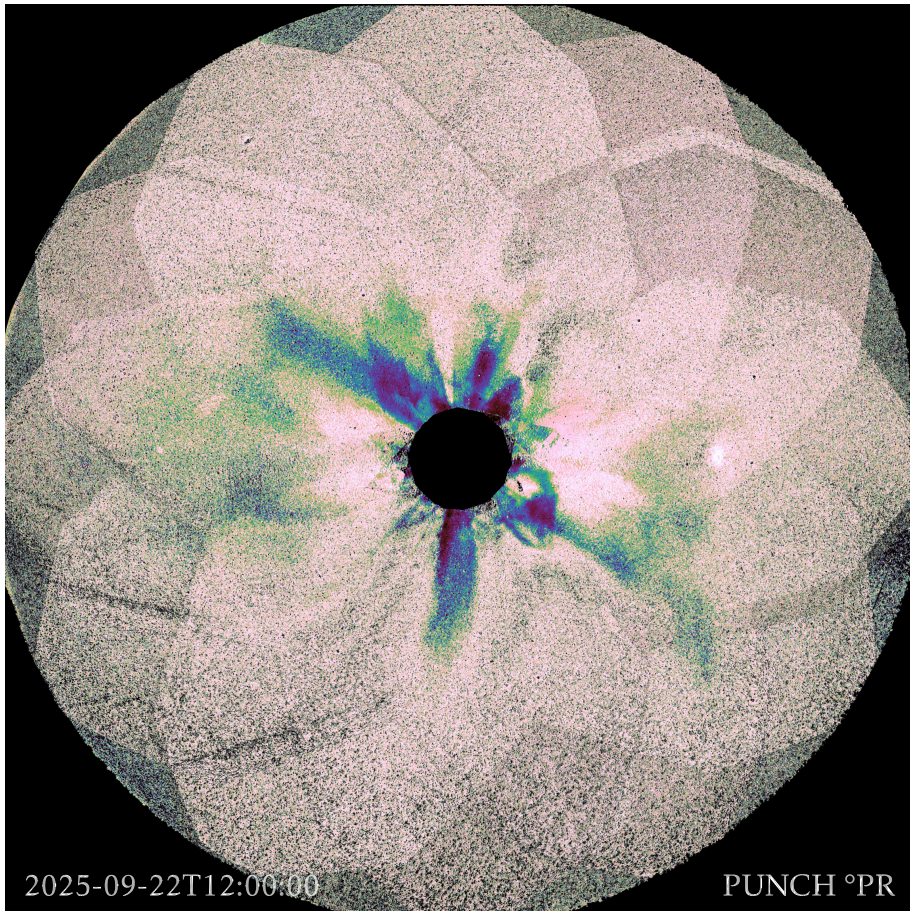
$$\chi_{in} = \cos^{-1} \left( +\sqrt{PR} \right)$$
$$\chi_{out} = \cos^{-1} \left( -\sqrt{PR} \right) = \pi - \chi_{in}$$

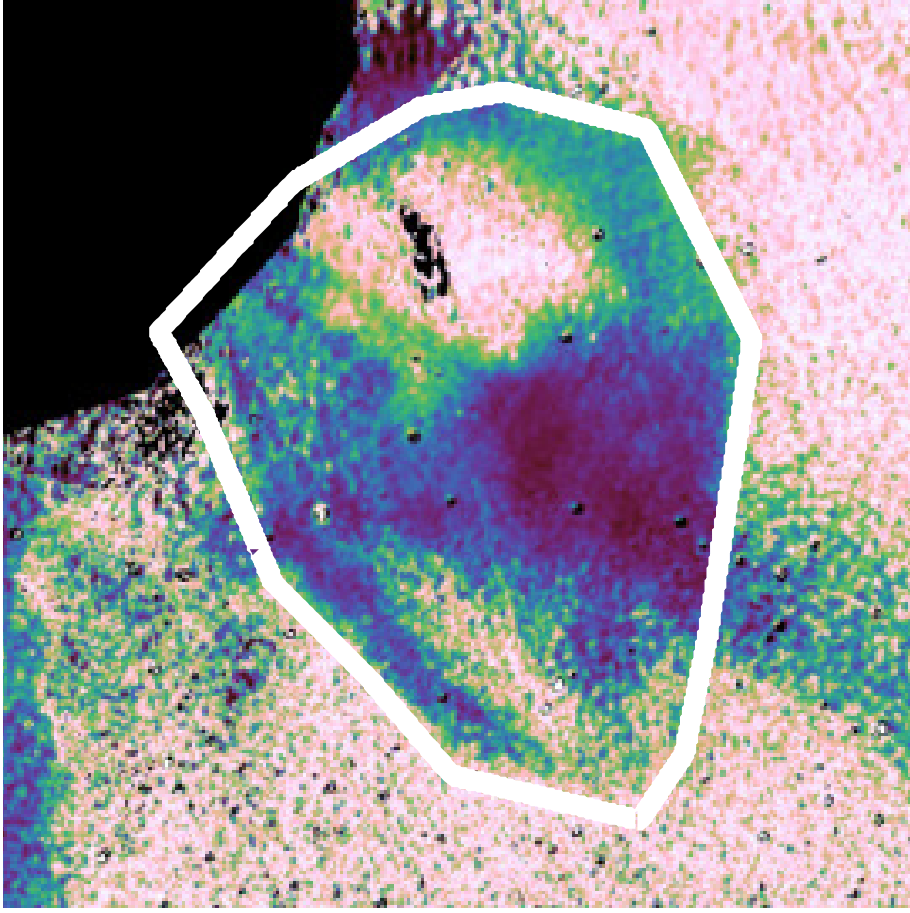


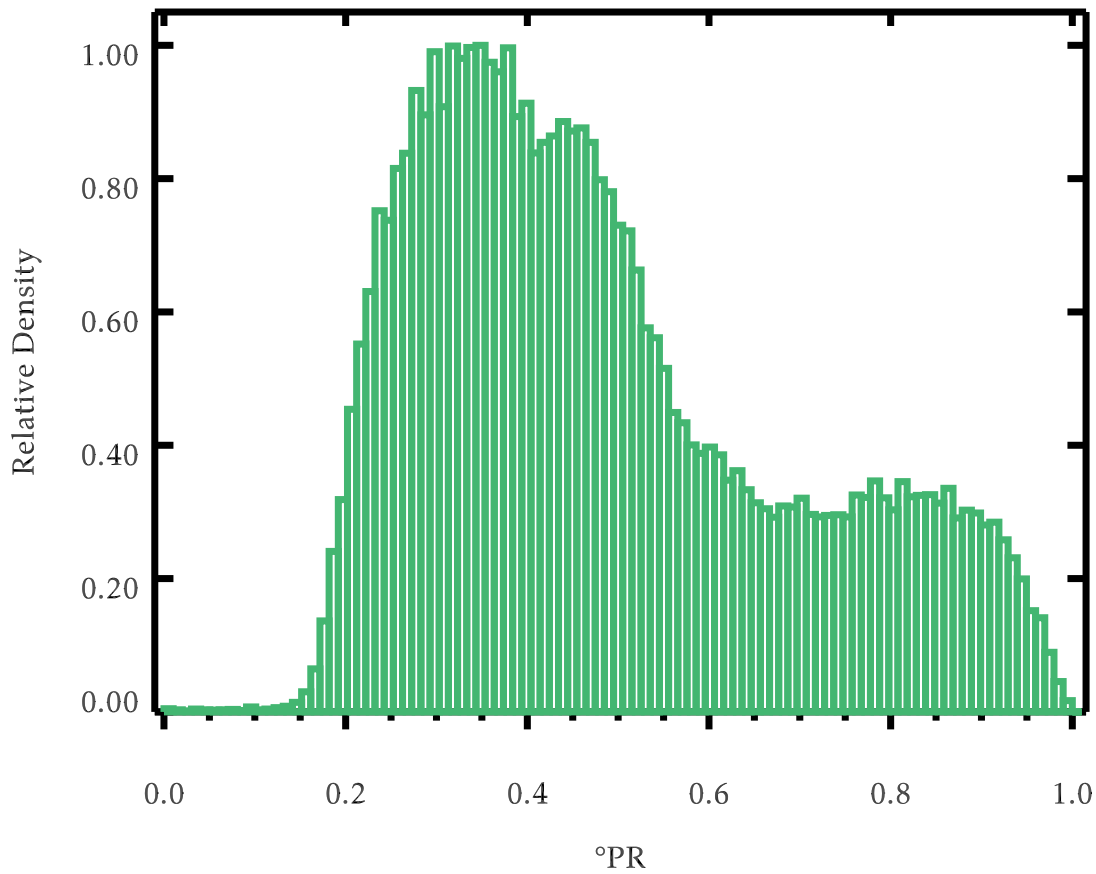
# PR to Location

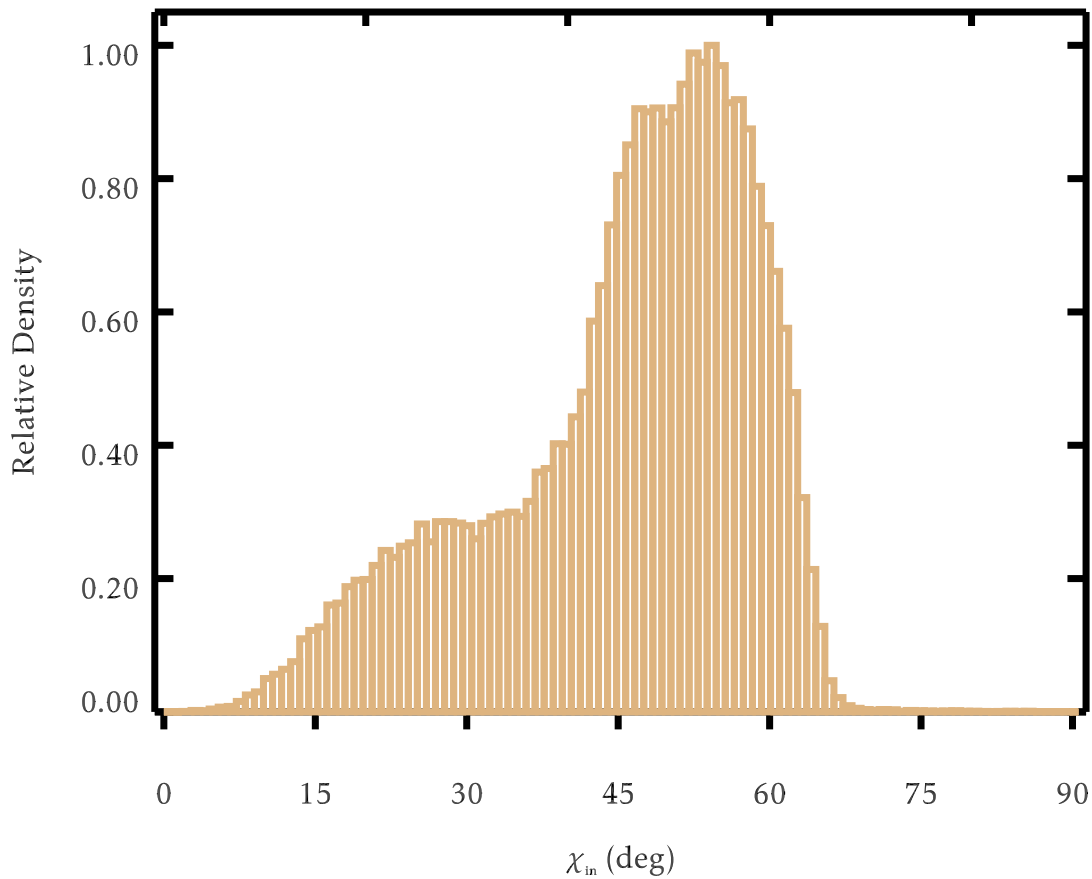
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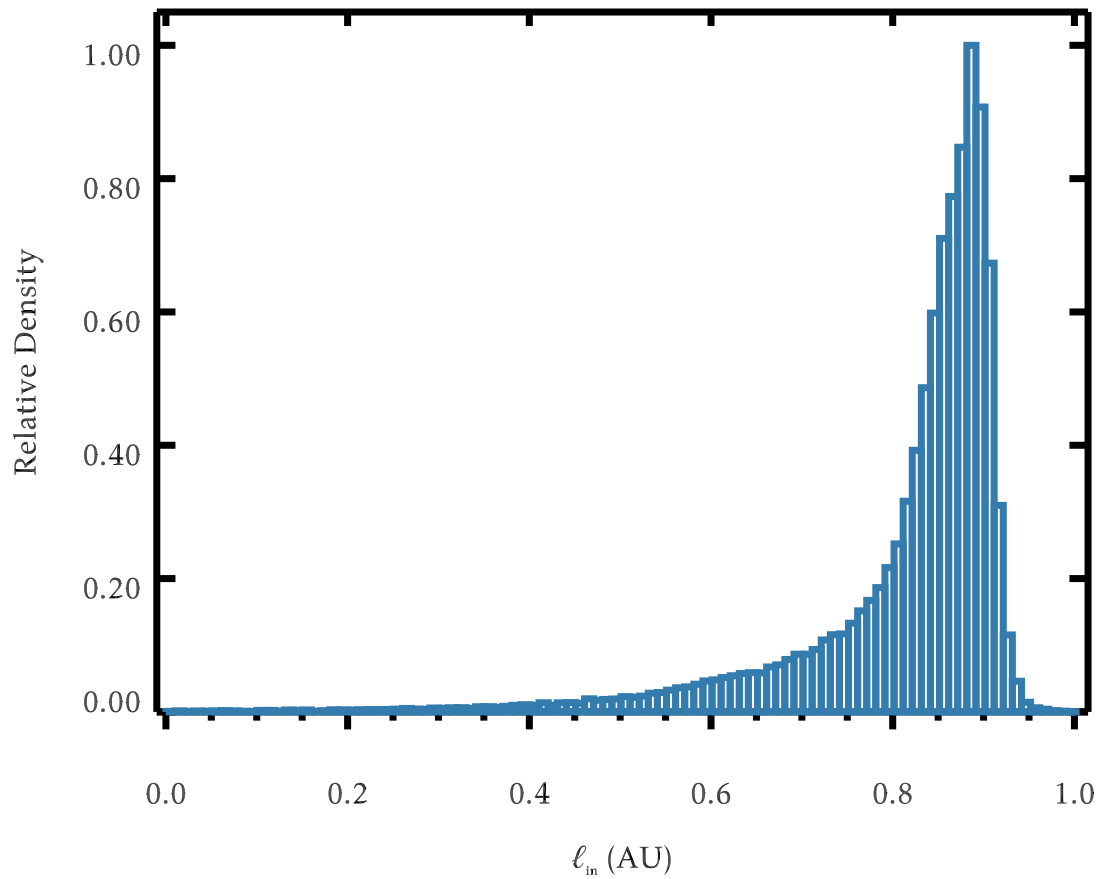
$$\frac{\ell}{r_{obs}} = \frac{\sin \psi}{\sin \chi'} = \frac{\sin(\chi - \varepsilon)}{\sin \chi}$$













# Small-Feature Limit: Clever or Absurd?

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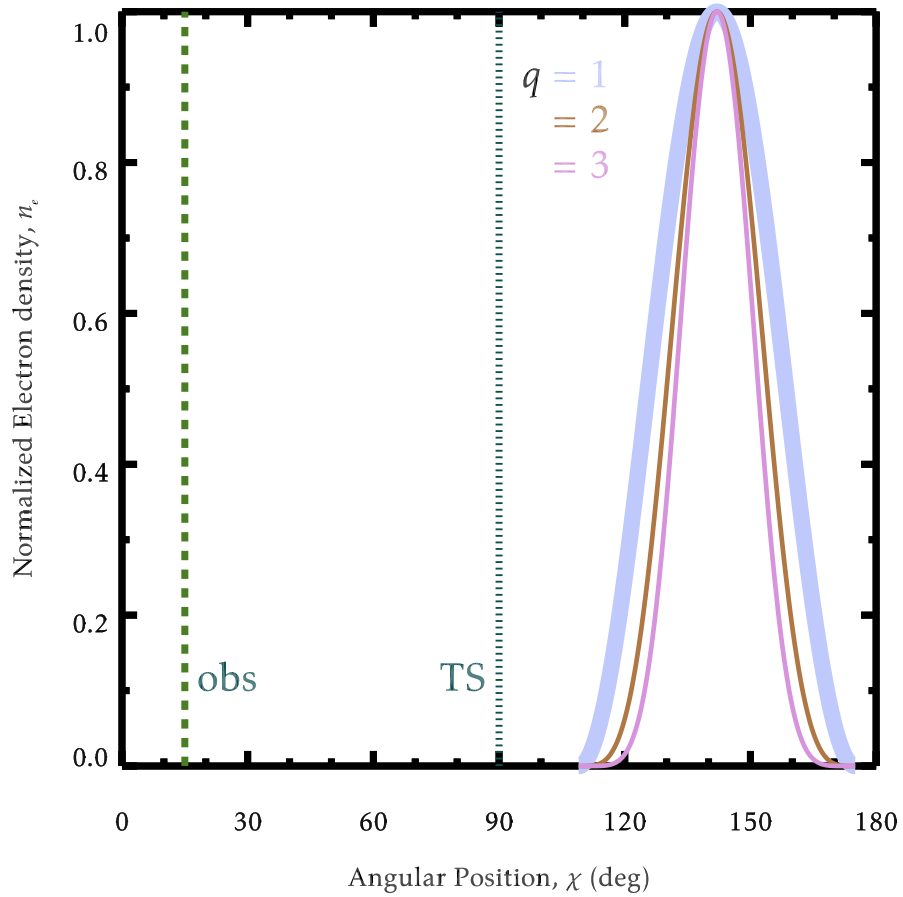
- Choose values for  $\chi_c$  and  $\Delta_\chi$
- Calculate  $PR$
- Estimate  $\chi_{sf} \approx \cos^{-1}(\pm\sqrt{PR})$
- Compare  $\chi_{sf}$  to ground-truth  $\chi_c$



# A Density Pulse

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$$n_e = n_0 \cos^{2q} \left[ \frac{\pi}{2\Delta_\chi} (\chi - \chi_c) \right] \Pi_{\chi_1, \chi_2}(\chi)$$

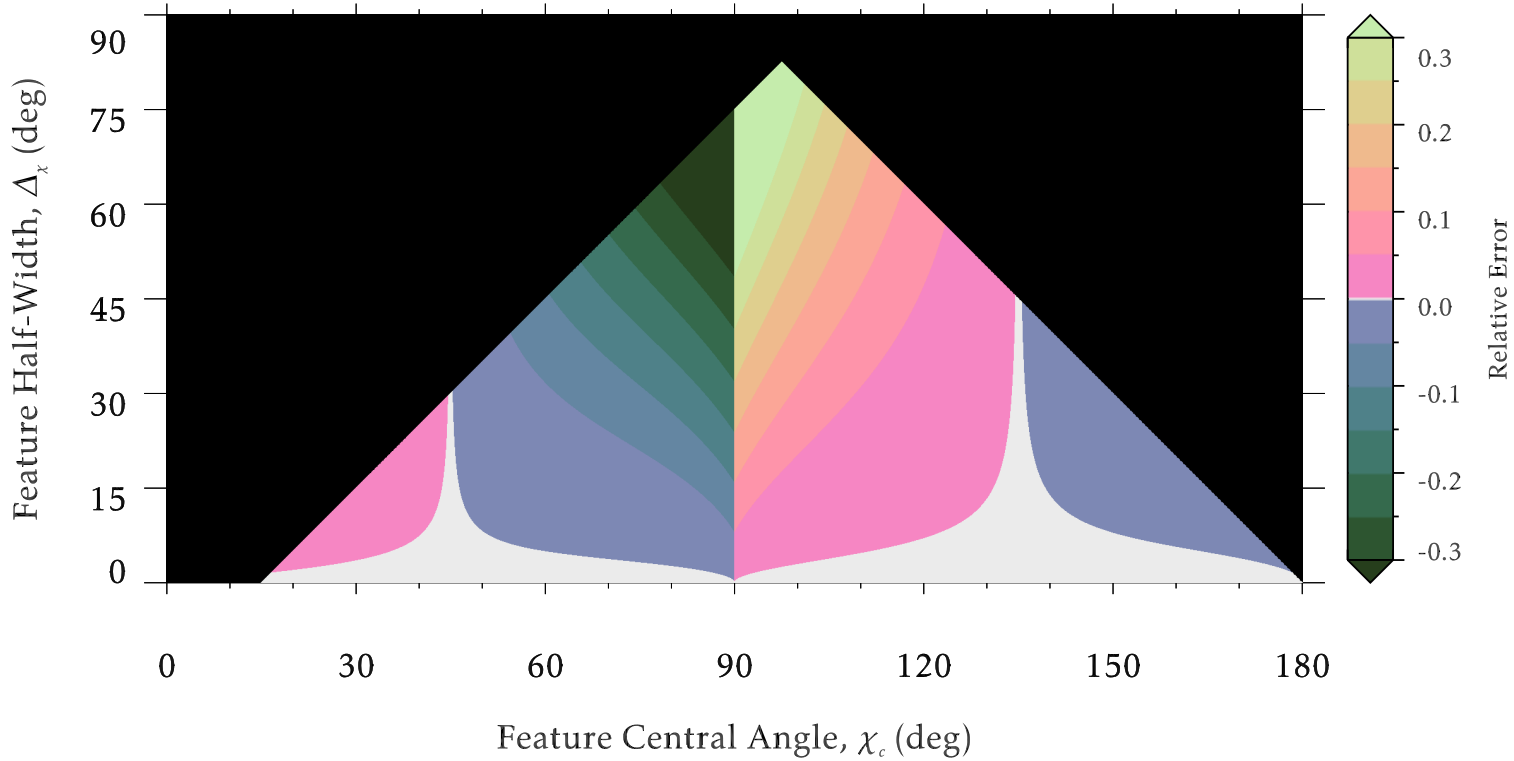




# A Density Pulse

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$$PR = \frac{1}{2} \left[ 1 + \frac{\pi^2}{(\pi + 2\Delta_\chi)(\pi - 2\Delta_\chi)} \cos 2\chi_c \operatorname{sinc} 2\Delta_\chi \right]$$





## Conclusion

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- $PR$  depends on  $\chi_c$  and  $\Delta_\chi$ .
- $\chi_c$  can be estimated from  $PR$  in the limit  $\Delta_\chi \rightarrow 0$ .
- Using the Small-Feature approximation to estimate location will introduce error.
- The error will be  $< 10\%$ , if
  - PUNCH is probing a single feature,
  - the half-width of the feature is  $< 20^\circ$ .



## Conclusion

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de Koning, C.A., Odstrcil, D., Gibson, S.E., DeForest, C.E., Pizzo, V.J., and Scott, C.J. 2026. For SIRs, CIRs and Beyond: Polarization Ratio to Feature Location. *Solar Physics*, Under Review.



## Conclusion

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Gibson, S.E., DeForest, C.E., de Koning, C.A., Cranmer, S.R., Fan, Y., Morgan, H., Provornikova, E., Malanushenko, A. and Webb, D. 2026. Polarization Diagnostics applied to Coronal Mass Ejections and the Background Solar Wind. *Solar Physics*, 301:33. doi:10.1007/s11207-026-02620-6.