For CIRs and Beyond: Polarization Ratio to Feature Location

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CIR Science: The P from PUNCH

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

CIR Science: The P from PUNCH

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

CIR Science: Background

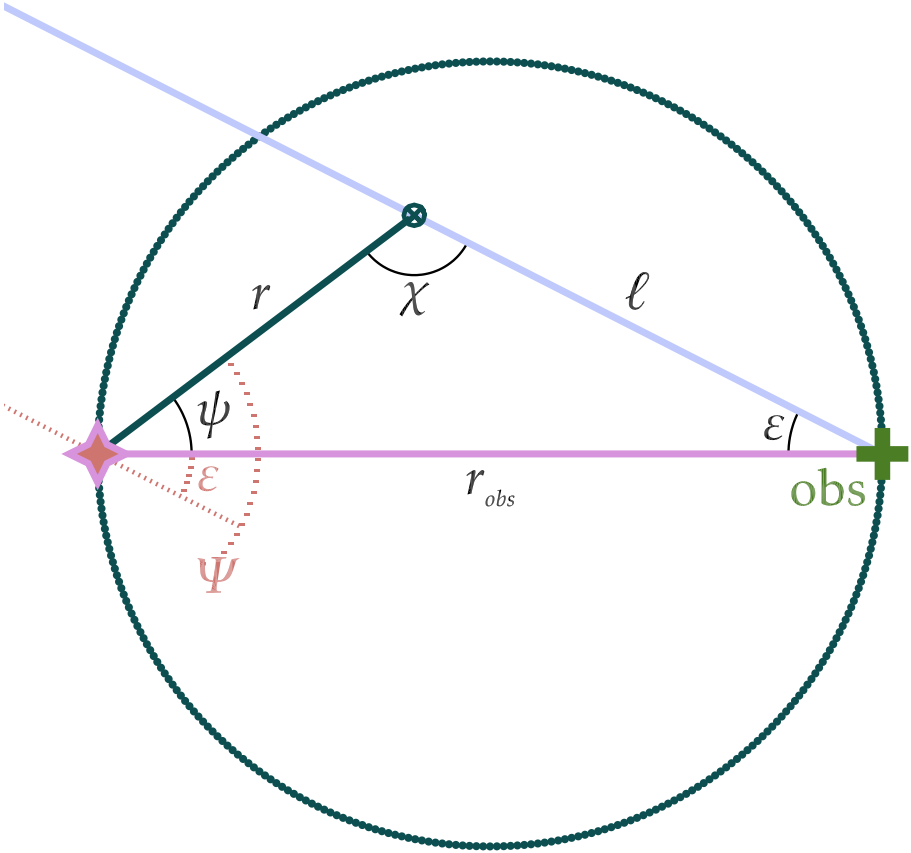
- Billings, 1966
- Howard & Tappin, 2009
- Inhester, 2016
- de Koning et al., 2025

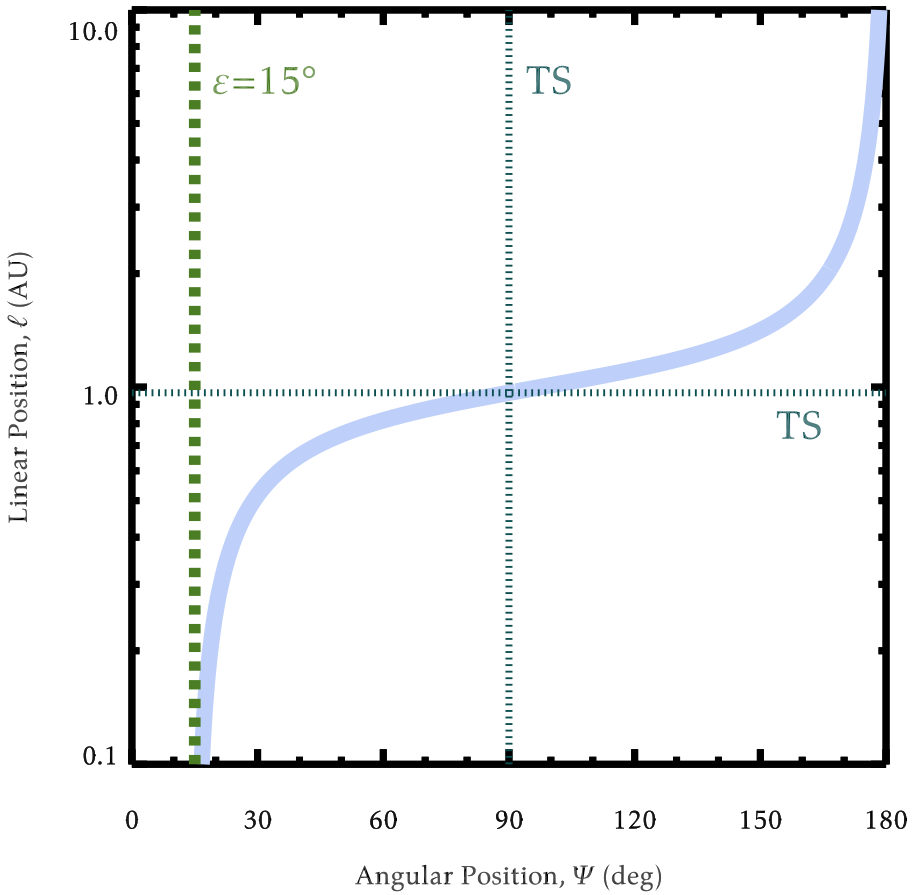
CIR Science: Small-Sun Approximation

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

Practically – approximation introduces less than 1% error compared to exact calculation – this implies $r > 9r_{\odot}$ or $\varepsilon > 2.5°$.

Approximation valid in WFI field of view.

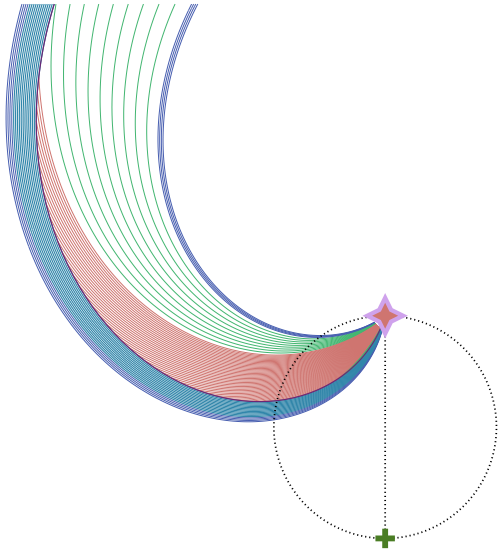

r
χ
ℓ
ψ
ε
Ψ
r obs
ε
obs

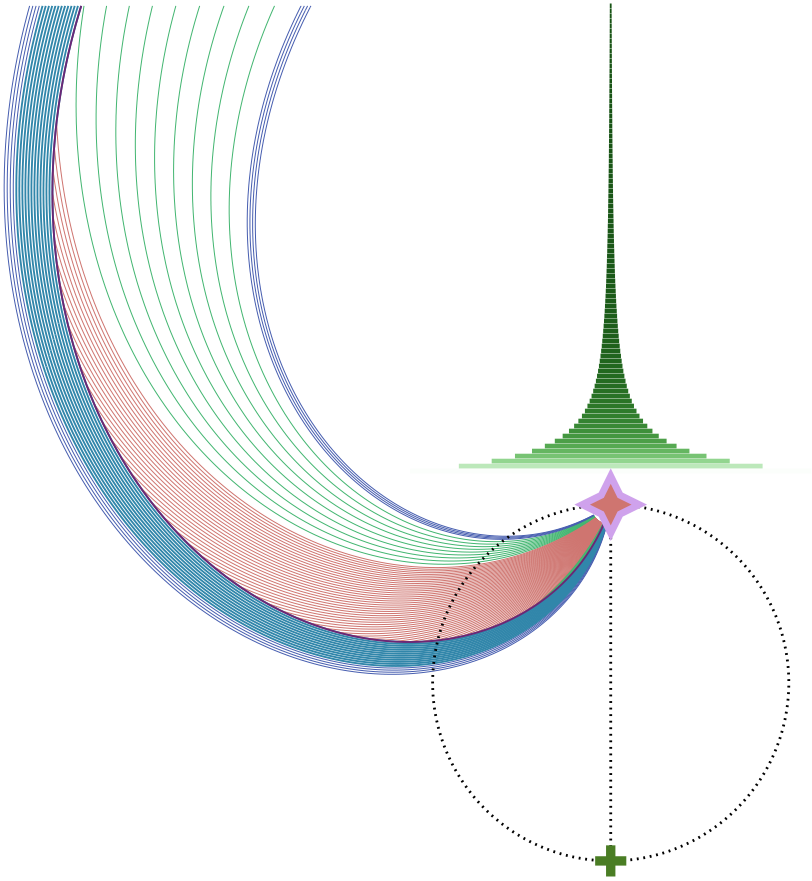

10.0
1.0
0.1
ε=15°
TS
TS
Linear Position, ℓ (AU)
0
30
60
90
120
150
180
Angular Position, Ψ (deg)

CIR Science: The P from PUNCH

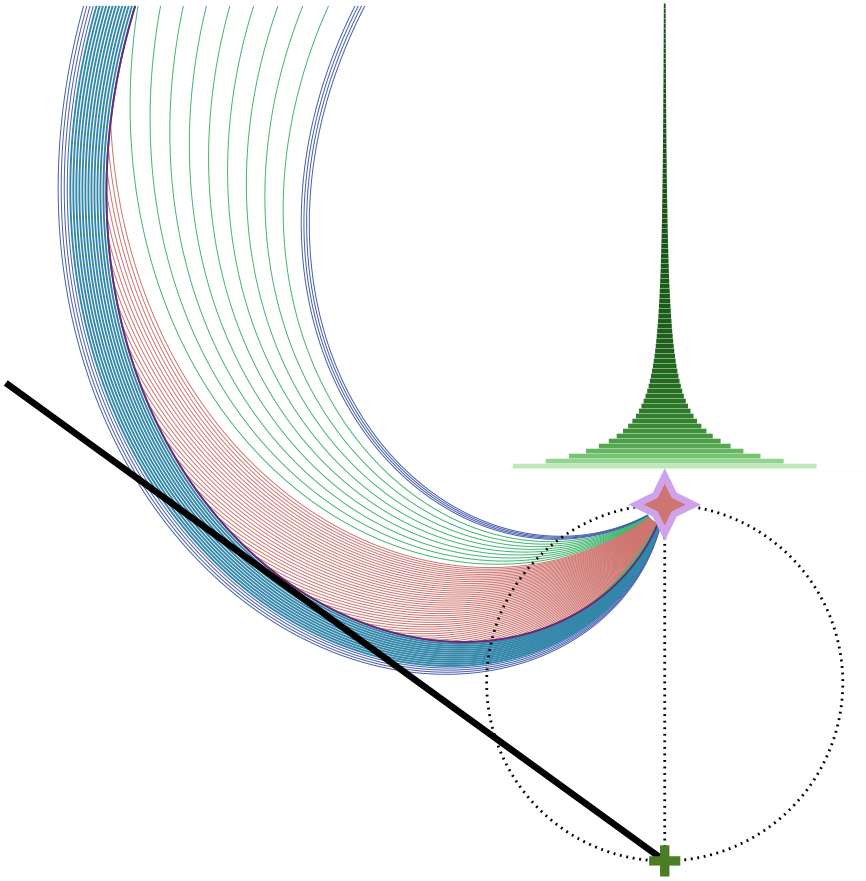
$$PR \approx \frac{\int_{\varepsilon}^{\pi} \mathrm{d}\Psi \cos^2\Psi \, n_e(\Psi,\varepsilon)}{\int_{\varepsilon}^{\pi} \mathrm{d}\Psi \, n_e(\Psi,\varepsilon)}$$

CIR Electron Density

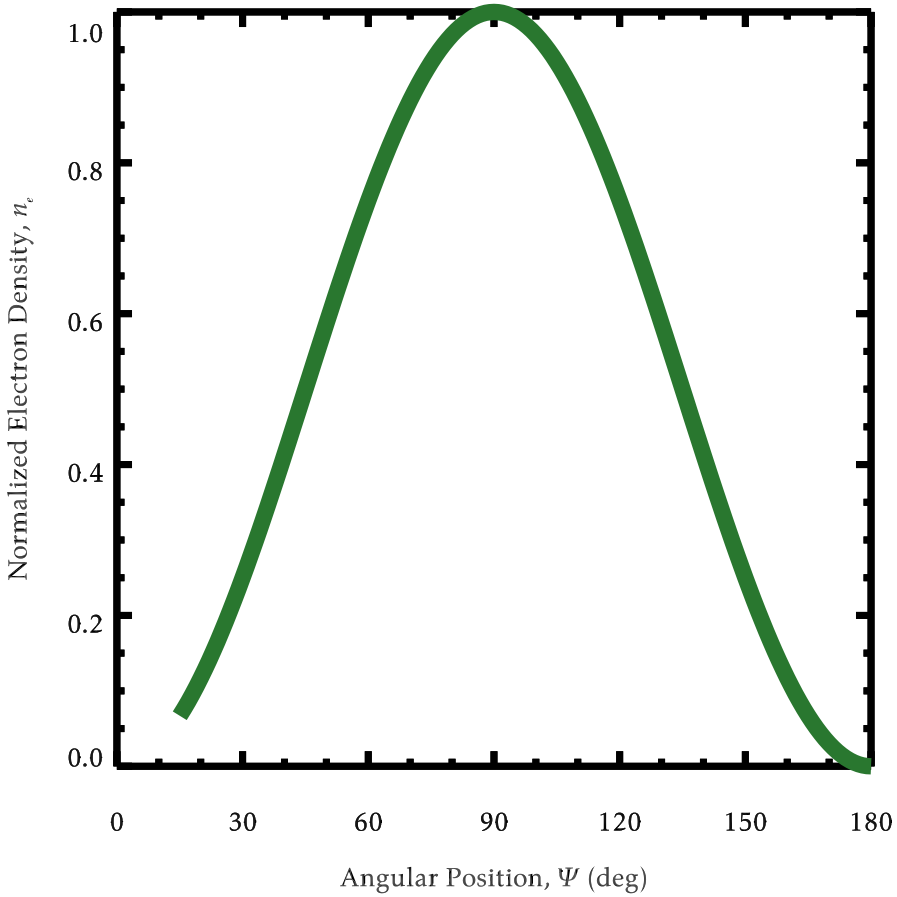




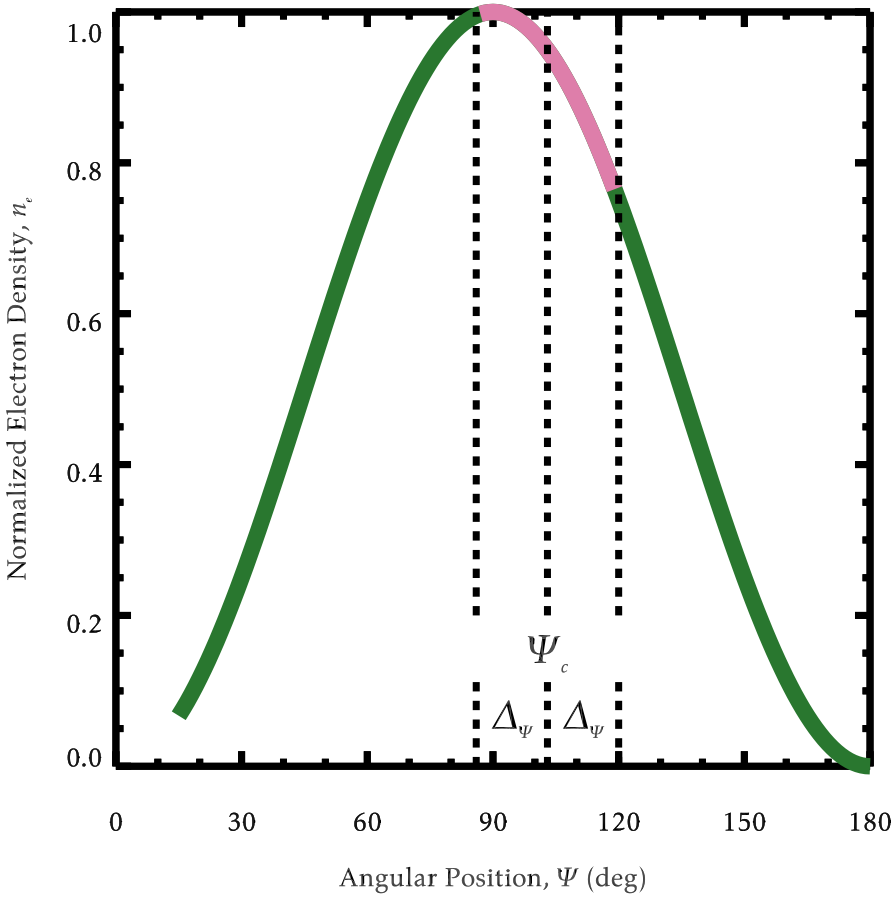
$$n_{sw} \propto r^{-2}$$



$$n_{sw} \propto r^{-2}$$



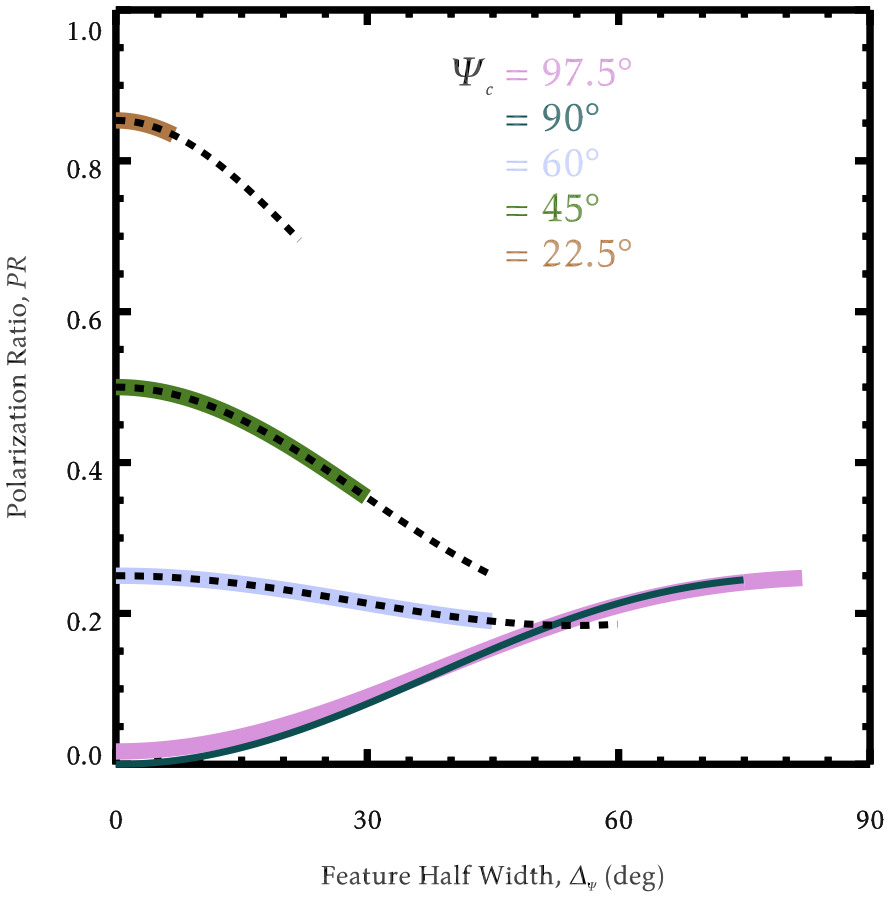
$$n_e \propto \frac{\sin^2 \Psi}{\sin^2 \varepsilon}$$

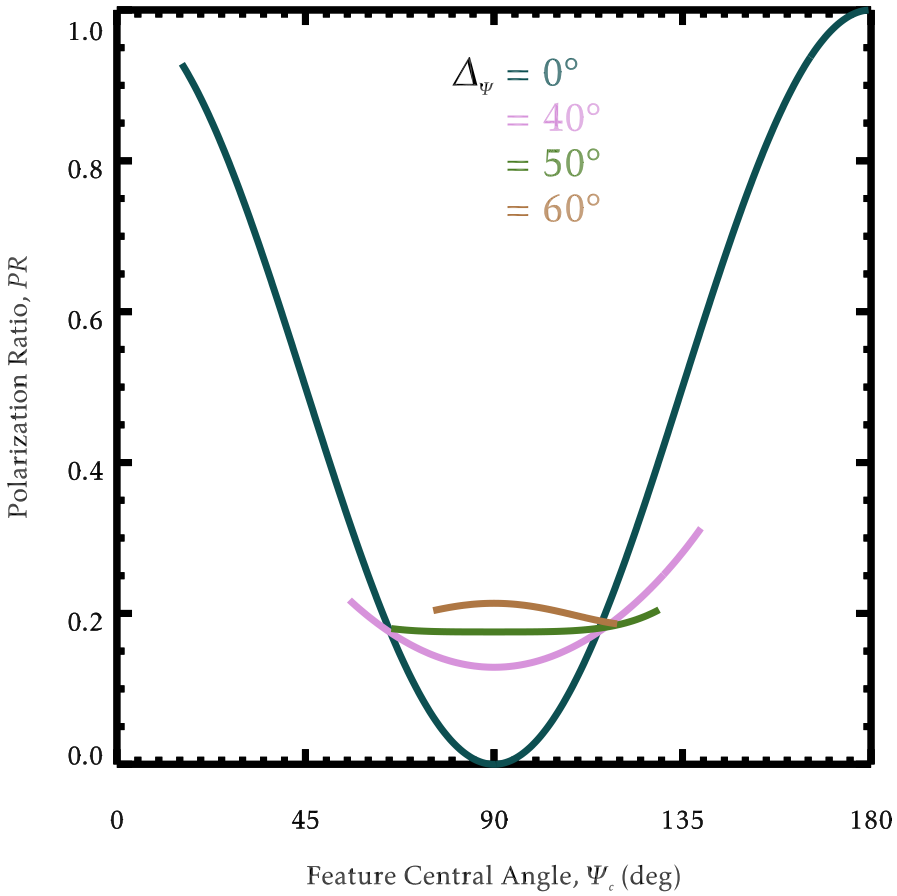


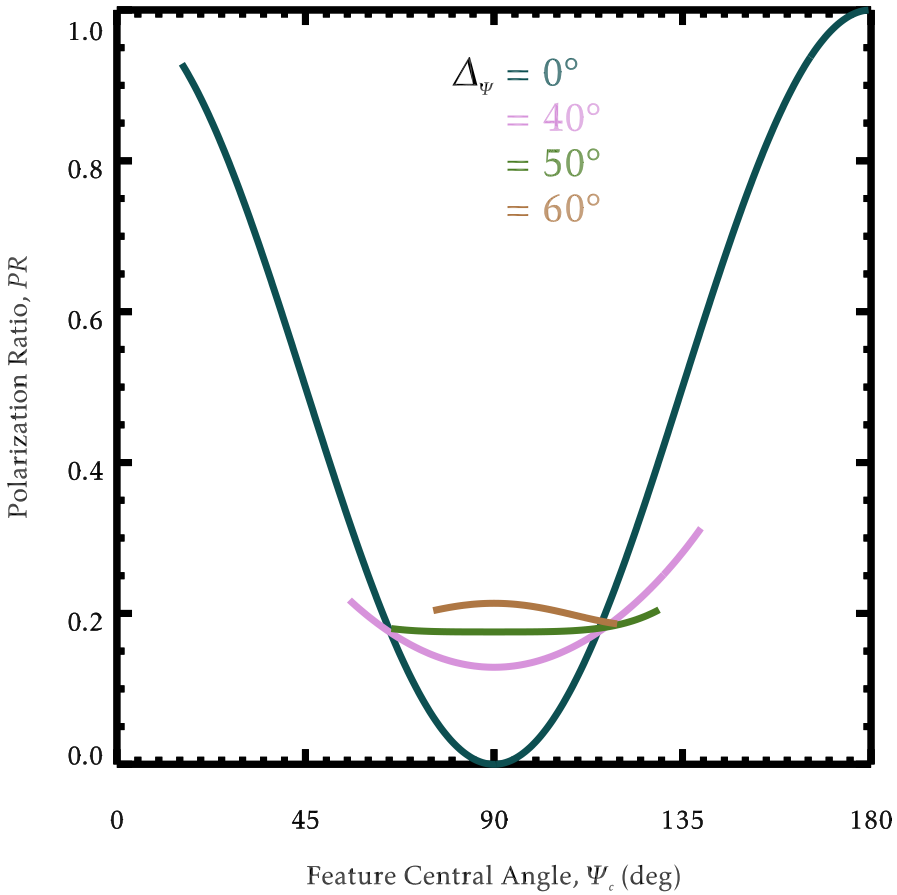
$$n_e \propto \frac{\sin^2 \Psi}{\sin^2 \varepsilon} \times \Pi_{\Psi_1,\Psi_2}(\Psi)$$

CIR Science: The P from PUNCH

$$PR \approx \frac{1}{4}\left(\frac{1-\cos 4\Psi_c \operatorname{sinc} 4\Delta\psi}{1-\cos 2\Psi_c \operatorname{sinc} 2\Delta\psi}\right)$$


Ψ_c = 97.5°
= 90°
= 60°
= 45°
= 22.5°
1.0
0.8
0.6
0.4
0.2
0.0
Polarization Ratio, PR
0
30
60
90
Feature Half Width, Δ_ψ (deg)


1.0
0.8
0.6
0.4
0.2
0.0
Polarization Ratio, PR
Δ_Ψ = 0°
= 40°
= 50°
= 60°
0
45
90
135
180
Feature Central Angle, Ψ_c (deg)

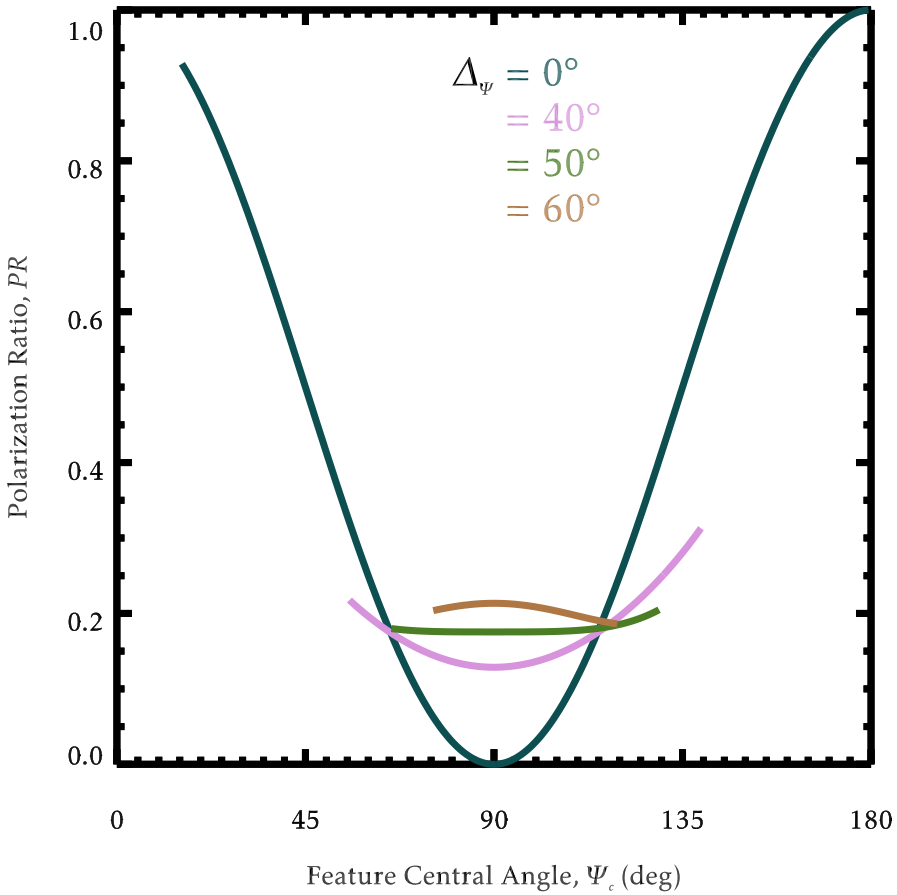


Dark Blue Curve:

Small Feature Limit

$$\Delta\Psi \rightarrow 0$$

$$PR \rightarrow \cos^2 \Psi_c$$



Dark Blue Curve:

Small Feature Limit

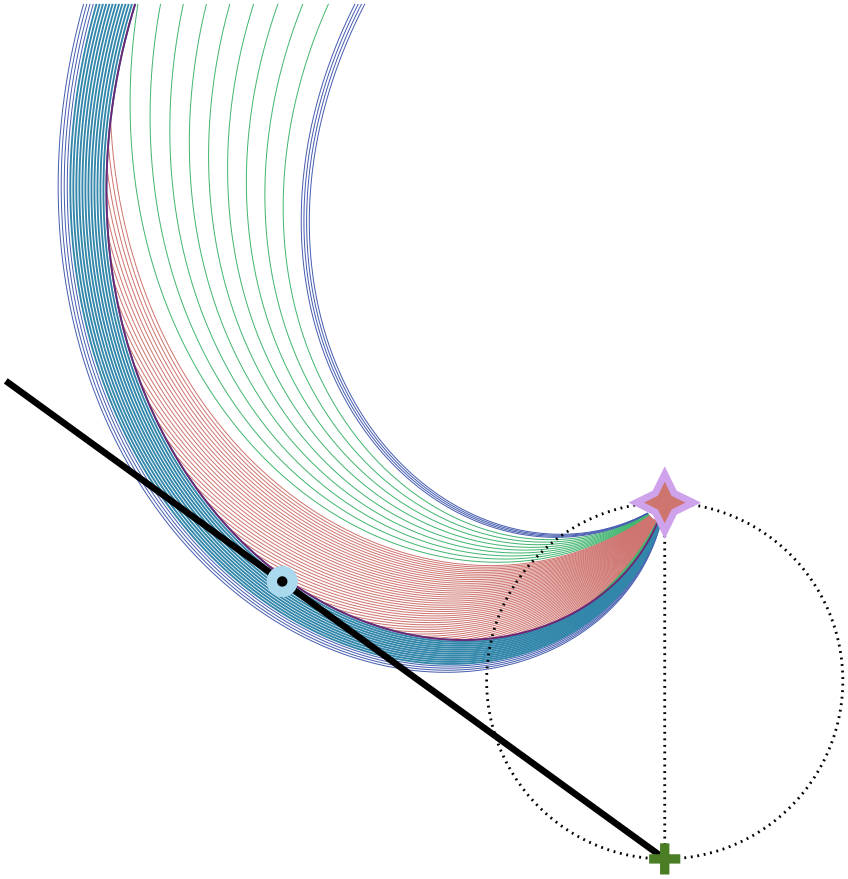
$$\Delta\Psi \rightarrow 0$$

$$PR \rightarrow \cos^2 \Psi_c$$

Super

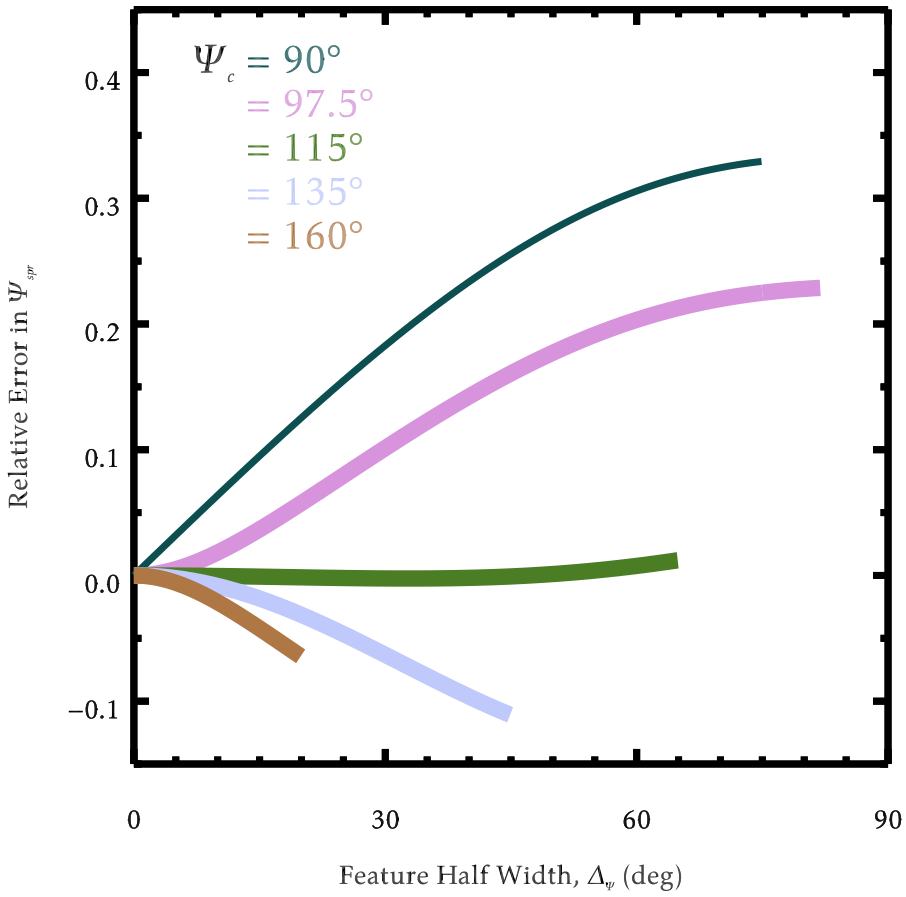
Particle

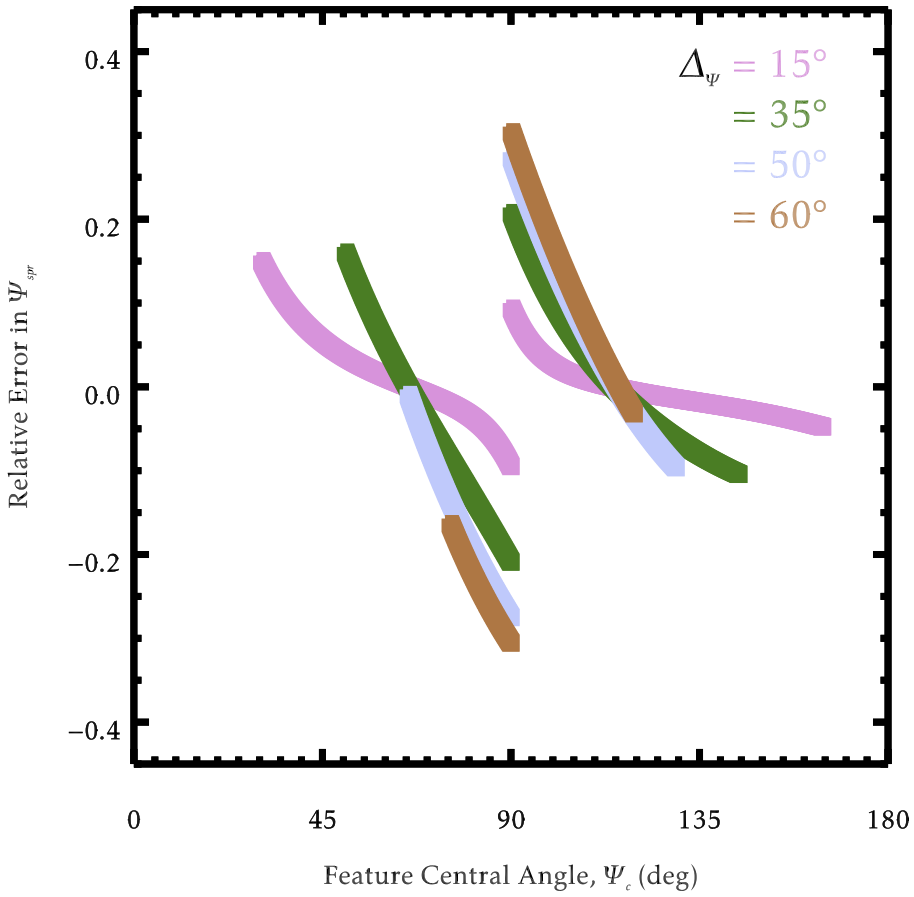
Construction



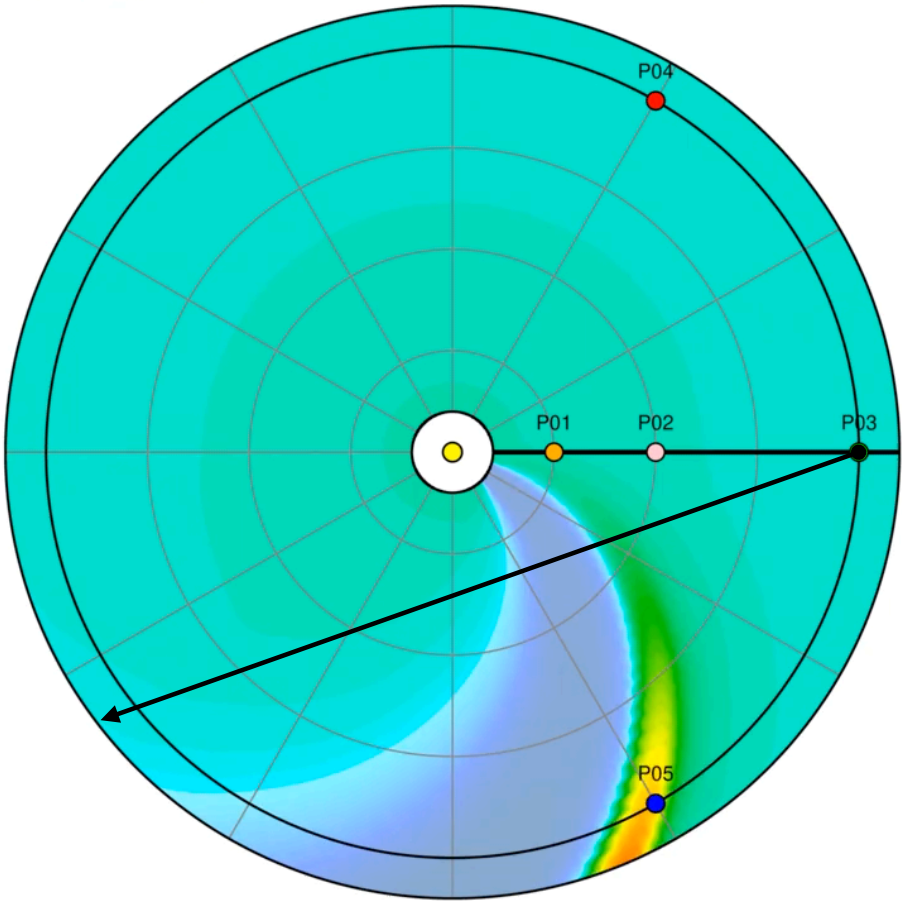
SPC: Clever or Absurd?

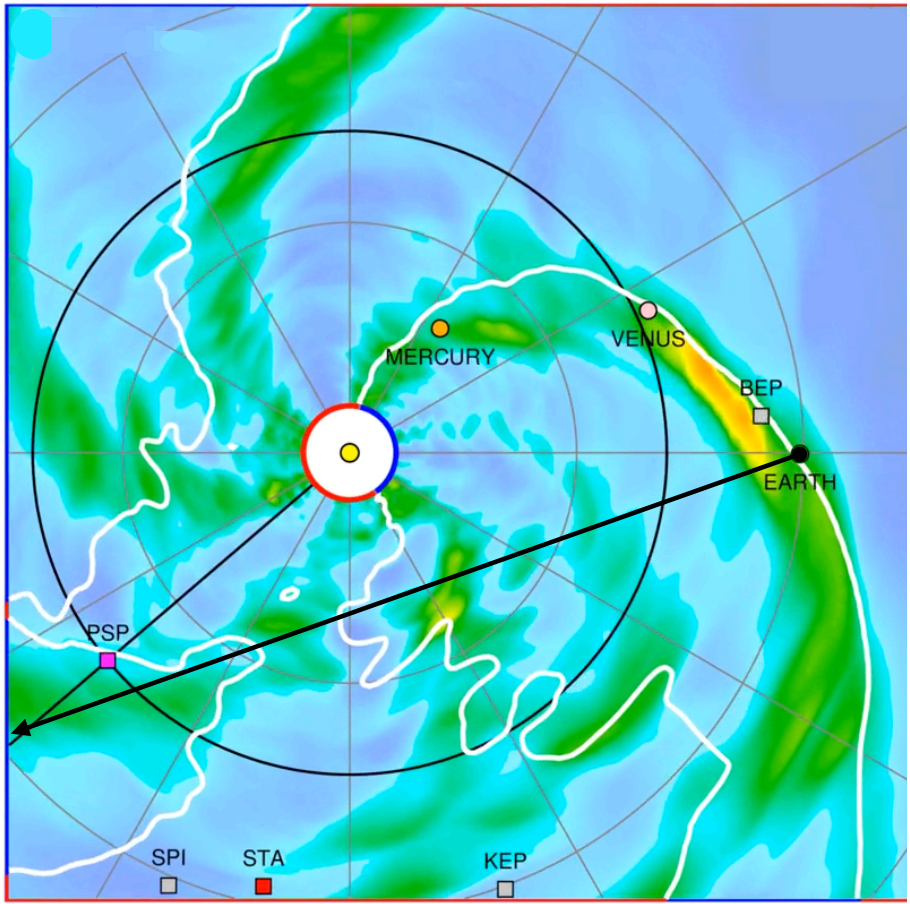
- Choose values for Ψ_c and $\Delta\Psi$
- Calculate PR
- Estimate $\Psi_{spc} \approx \cos^{-1}\left(\pm\sqrt{PR}\right)$
- Compare Ψ_{spc} to ground-truth Ψ_c


Ψ_c = 90°
= 97.5°
= 115°
= 135°
= 160°
0.4
0.3
0.2
0.1
0.0
−0.1
Relative Error in Ψ_{syn}
0
30
60
90
Feature Half Width, Δ_ψ (deg)


Δ_ψ = 15°
= 35°
= 50°
= 60°
0.4
0.2
0.0
−0.2
−0.4
Relative Error in Ψ_{sym}
0
45
90
135
180
Feature Central Angle, Ψ_c (deg)

BUT!


P04
P01
P02
P03
P05


MERCURY
VENUS
BEP
EARTH
PSP
SPI
STA
KEP