Rotating HWP

pros and cons

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Measuring polarisation

- A single measurement with a polarimeter measures a mixture of intensity and polarisation

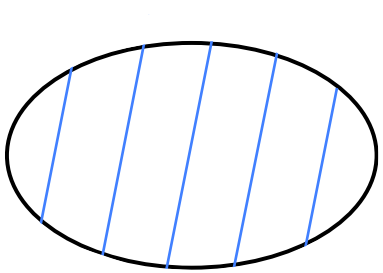
$$I + Q\cos 2\alpha + U\sin 2\alpha$$

- Obtaining polarisation requires differences between different such data samples
  - different detectors — Bandpass mismatch
  - same detector with ≠ orientation — Beam asymetry
  - (at ≠ times — low-frequency noise)

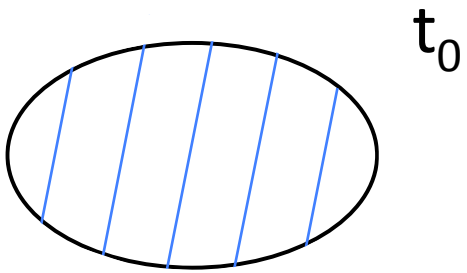
Motivations

- Modulation of polarisation
  - low-frequency noise
  - asymmetric beams

Without HWP



With HWP



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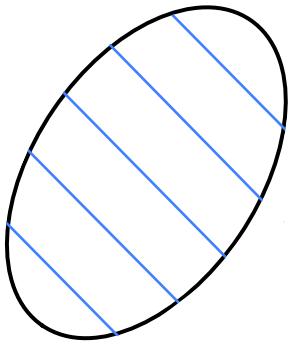
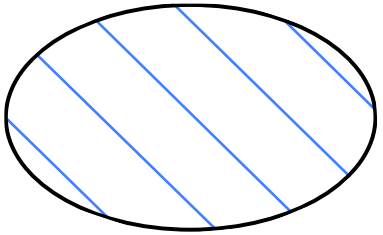


t_1

With HWP

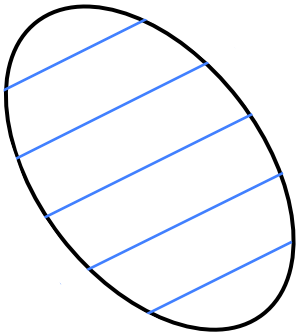


$t_0+\Delta t$

Motivations

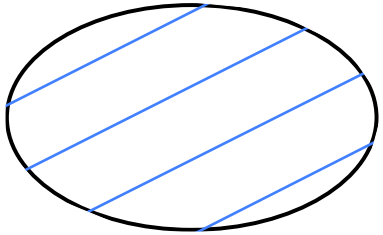
- Modulation of polarisation
  - low-frequency noise
  - asymmetric beams

Without HWP



t_2

With HWP



$t_0+\Delta t'$

The case for no HWP

- Not required
- Degrades the performance
- Source of complexity
- Technological challenge

Not required

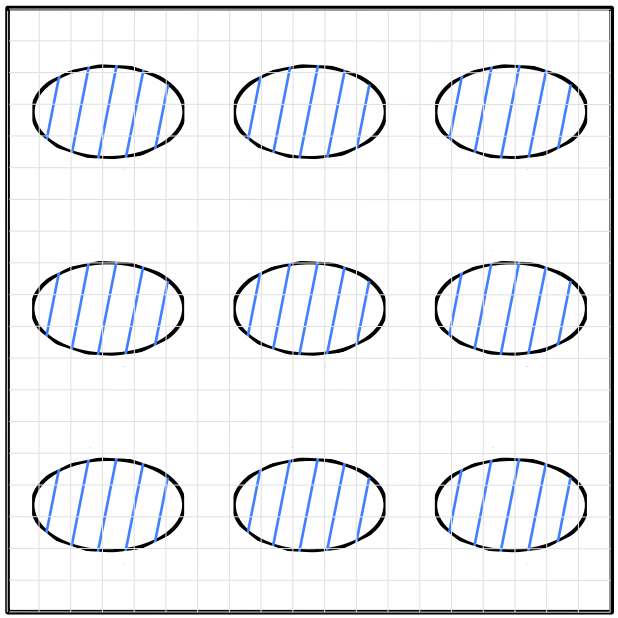
- Low-f noise removed by map-making
  - require redundancy and $f_{\rm spin} \geq f_{\rm knee}$
- Bandpass issues are solved by making single-detector maps (not possible with Planck)
- Beams: reconvolution possible

Not required

Map of

$$I + Q\cos 2\alpha + U\sin 2\alpha$$

convolved with an elliptical beam



Not required

Map of

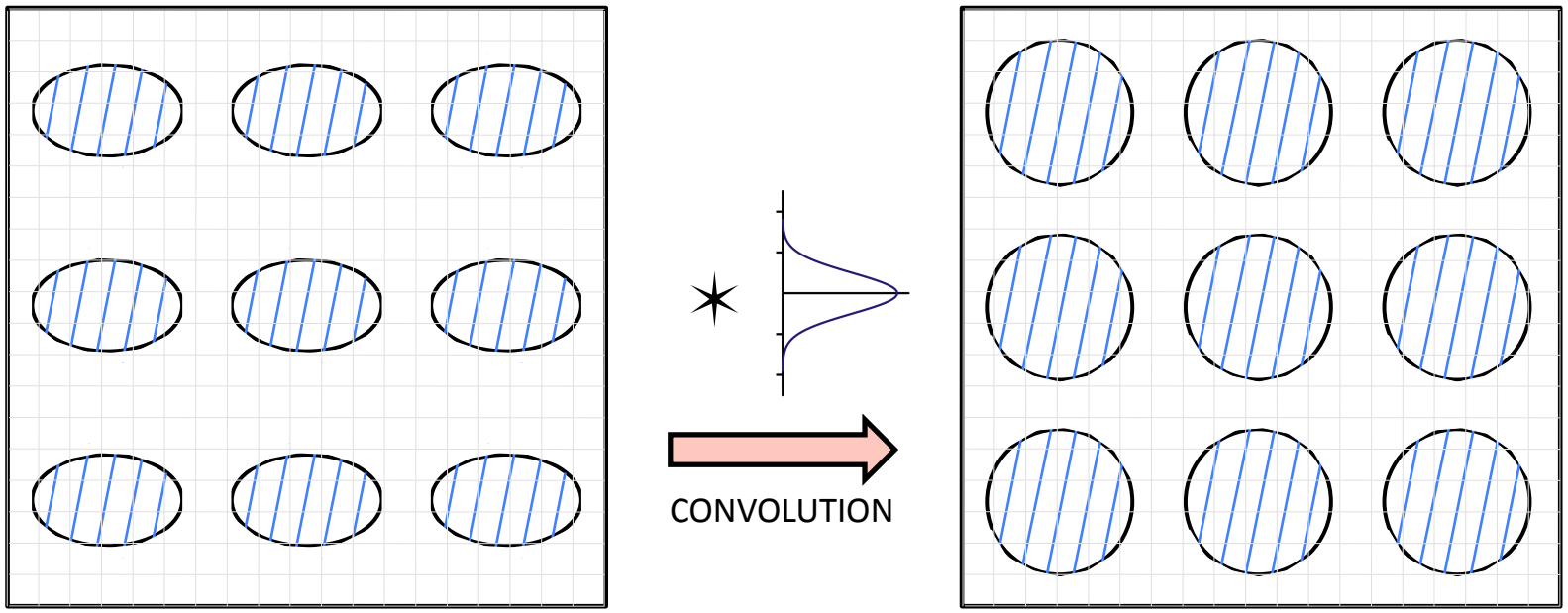
$$I + Q\cos 2\alpha + U\sin 2\alpha$$

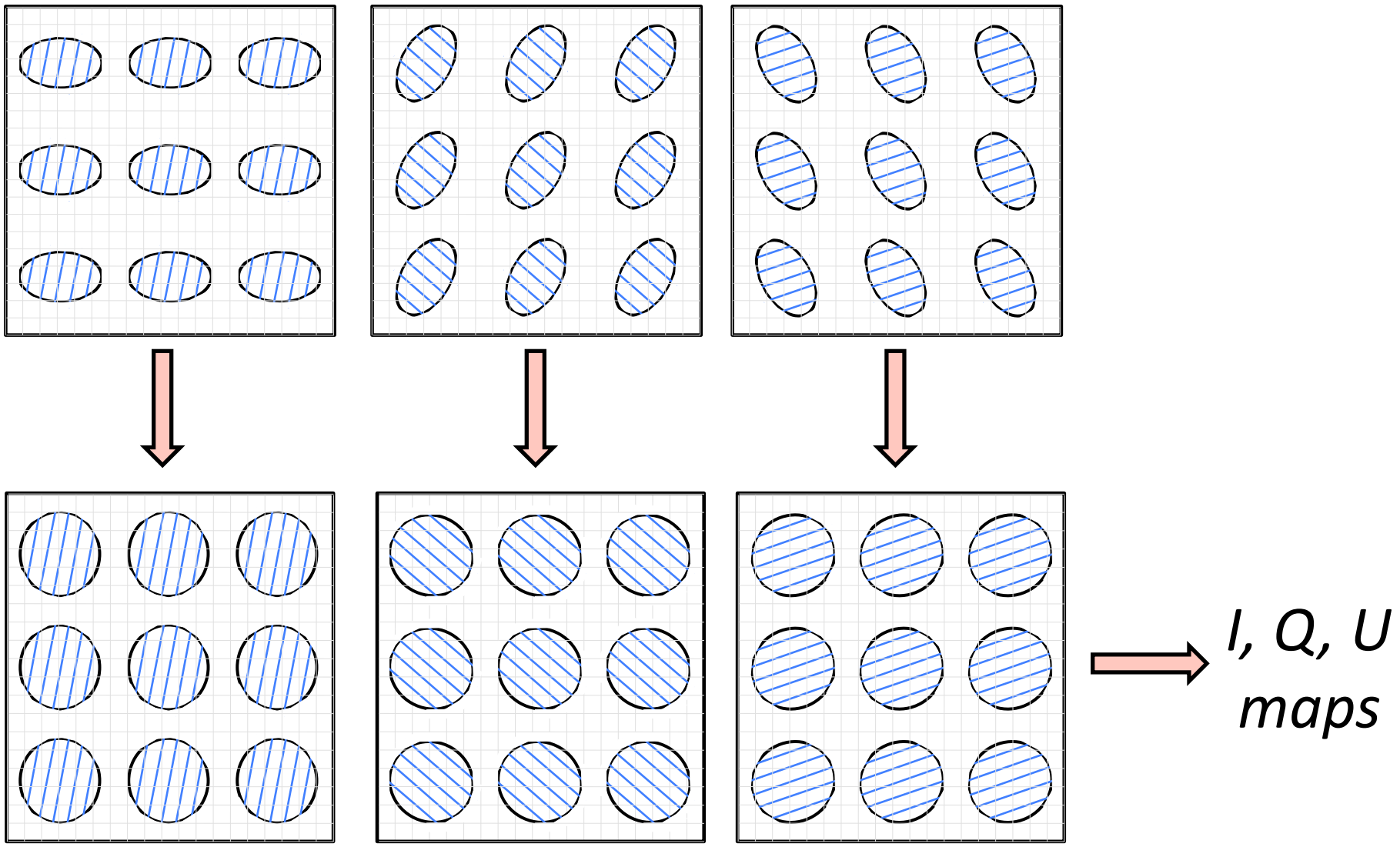
convolved with an elliptical beam

Map of

$$I + Q\cos 2\alpha + U\sin 2\alpha$$

convolved with a circular beam

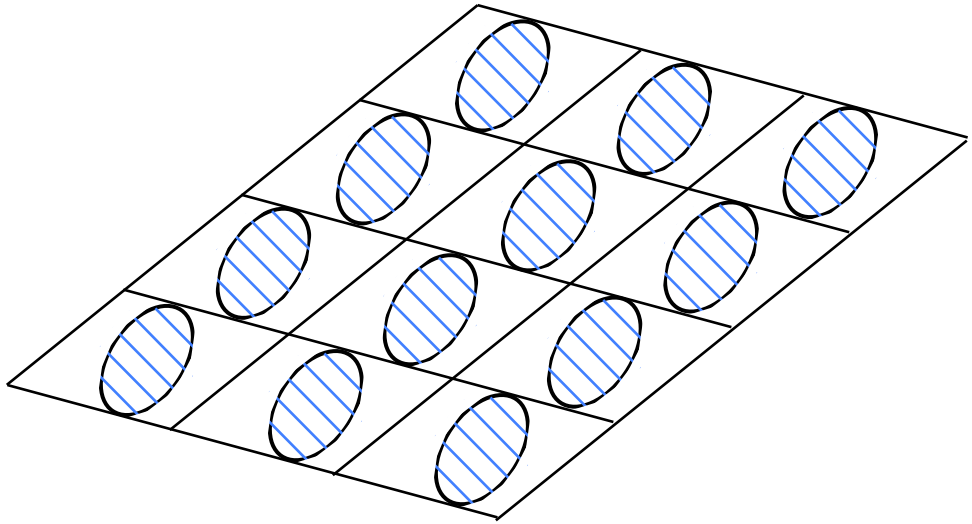



I, Q, U
maps

Not required

- Generalisable for real scanning
  - If every pixel is seen with all possible angles

One such set of observations for each angle



Not required

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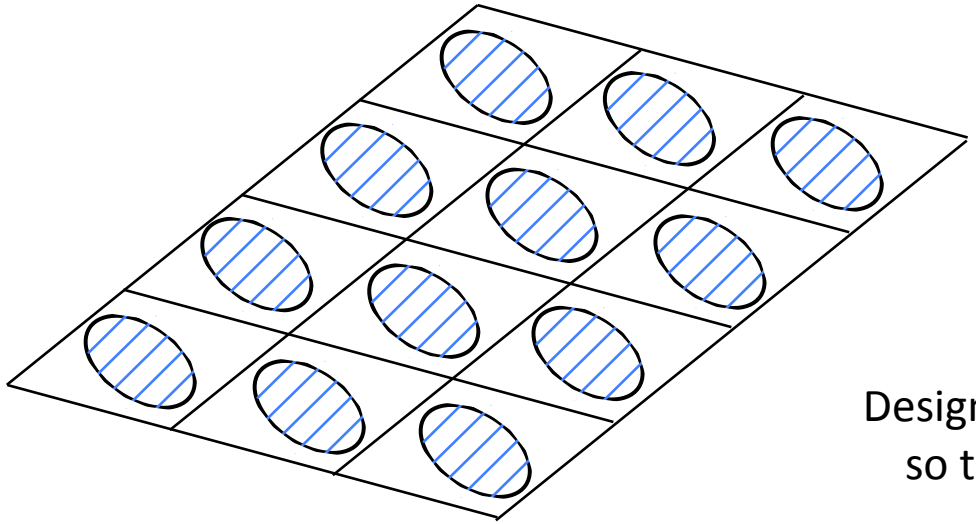
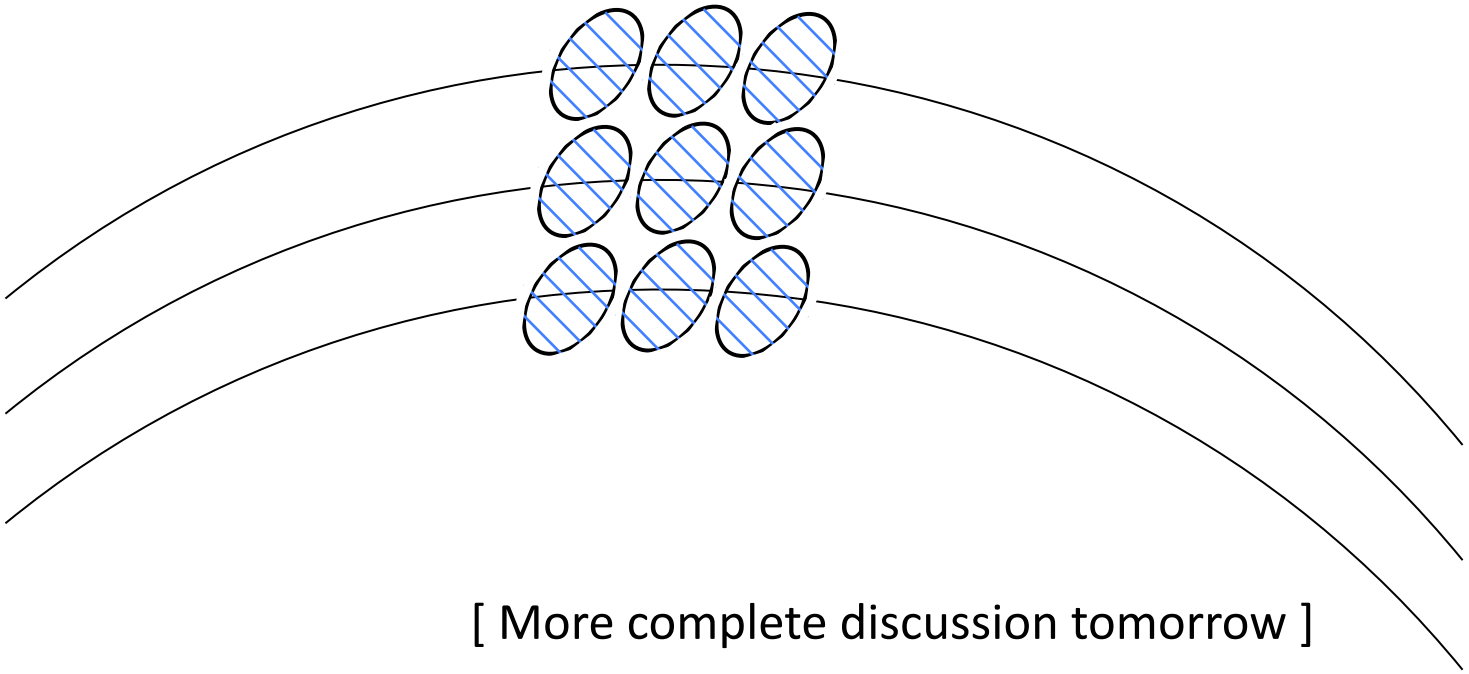


One such set of observations
for each angle

Design the scan strategy
so that it is the case

Not required

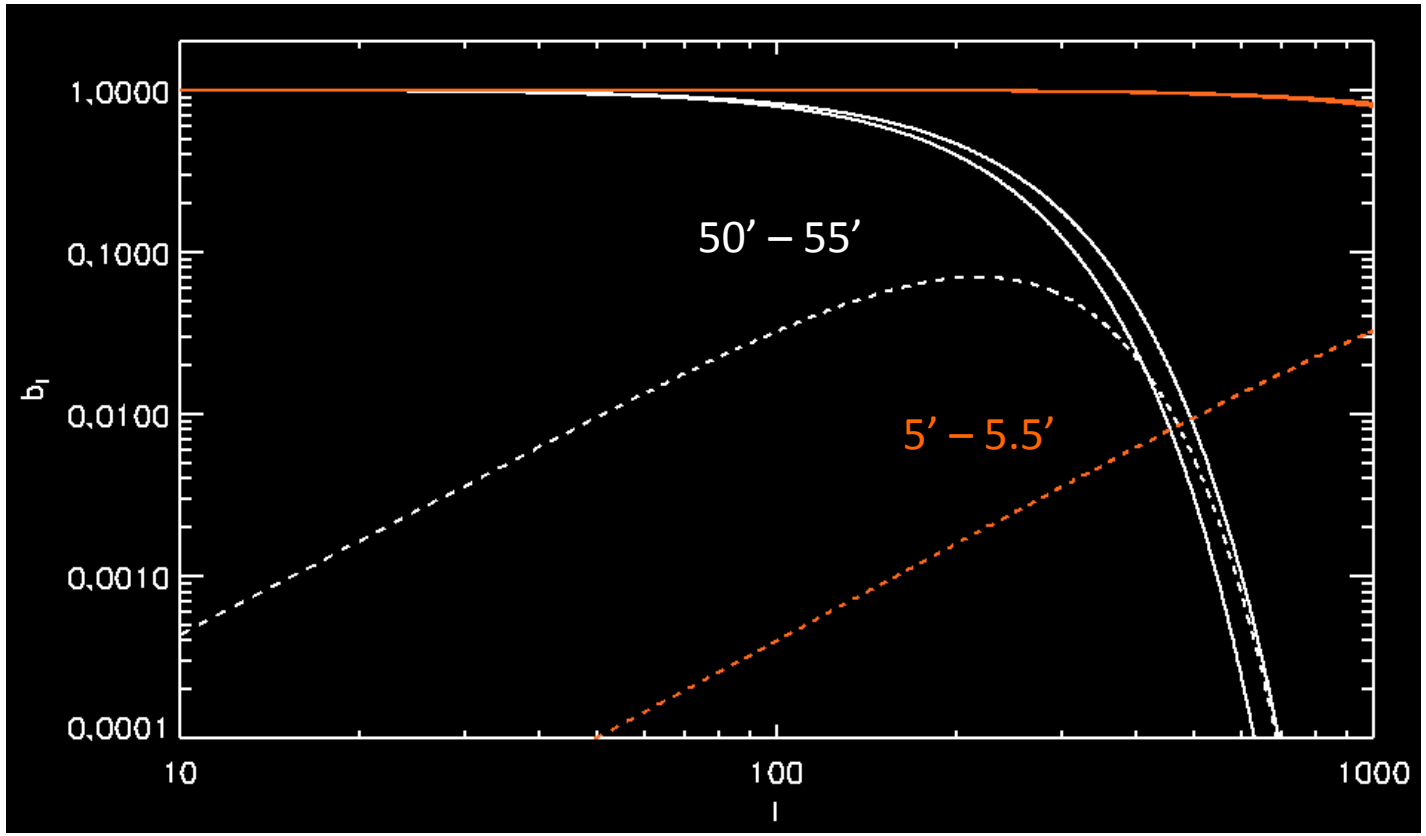
- Generalisable for real scanning
  - For any scan strategy with parallel scans



[More complete discussion tomorrow]

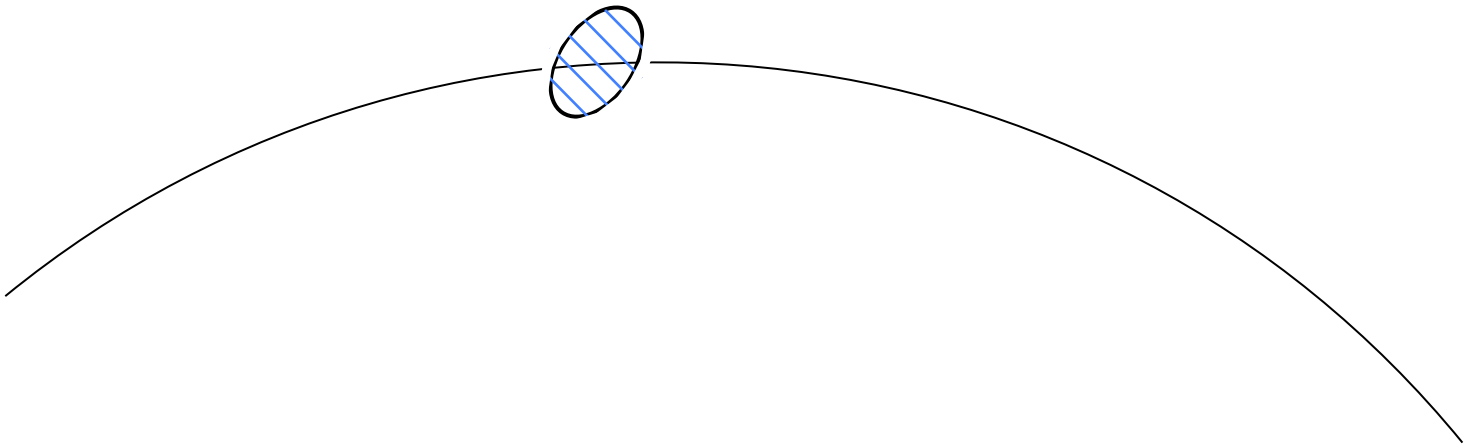
Not required

- Leakage of I into polarization maps $\propto a_{lm}\left(b_l^1 - b_l^2\right)$



Beam asymmetry does not matter much for small beams

Calibrate leakage



$$
\begin{aligned}
s(p) \;\simeq\;& I(p) + \eta\,(Q_{||}(p)\cos 2\psi + U_{||}(p)\sin 2\psi) \\
+\;& a_{||}\nabla^2_{||} I(p) + a_{\perp}\nabla^2_{\perp} I(p) + a_{\times}\nabla_{\perp}\nabla_{||} I(p) \\
+\;& b_{||}\nabla_{||}\left[I(p) + \eta\,(Q_{||}(p)\cos 2\psi + U_{||}(p)\sin 2\psi)\right] \\
+\;& b_{\perp}\nabla_{\perp}\left[I(p) + \eta\,(Q_{||}(p)\cos 2\psi + U_{||}(p)\sin 2\psi)\right] \\
+\;& 2\delta\,\eta\,[Q_{||}(p)\sin 2\psi + U_{||}(p)\cos 2\psi] \\
+\;& \epsilon I(p) + \xi\,[Q_{||}(p)\cos 2\psi + U_{||}(p)\sin 2\psi]\;.
\end{aligned}
$$

Beam ellipticity

Pointing

Pol. orientation

Calibration
+ polar. efficiency

The case for no HWP

- Not required
- Degrades performance
- Source of complexity
- Technological challenge

Degrades performance

- Frequency coverage
- Sensitivity
- Angular resolution

Frequency bands

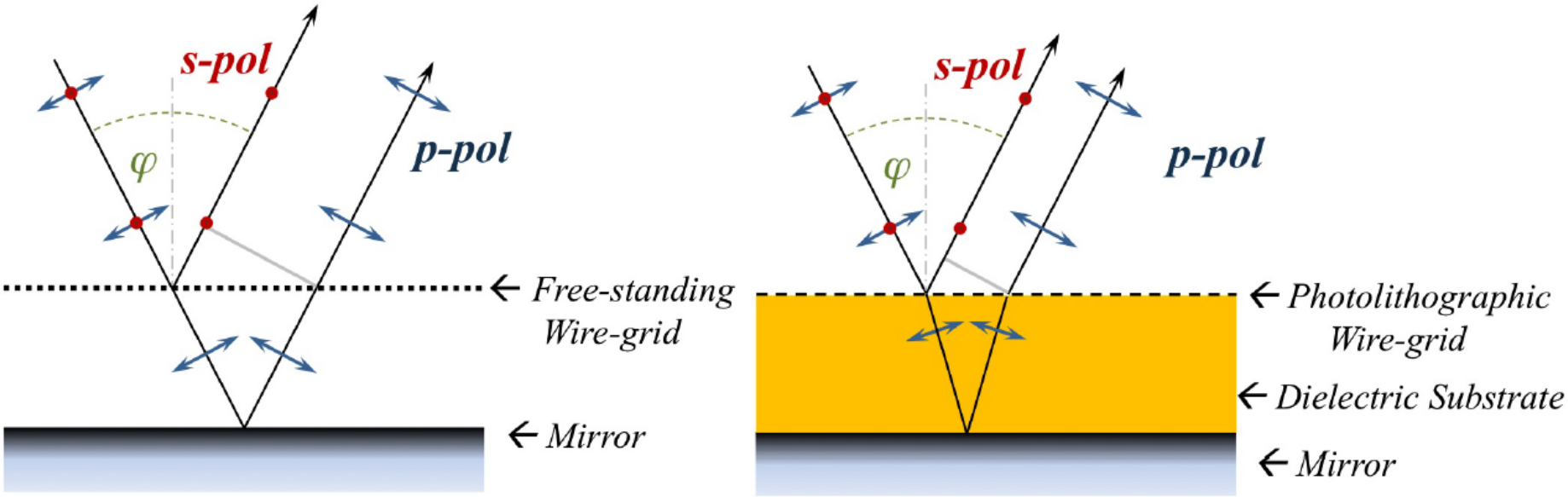
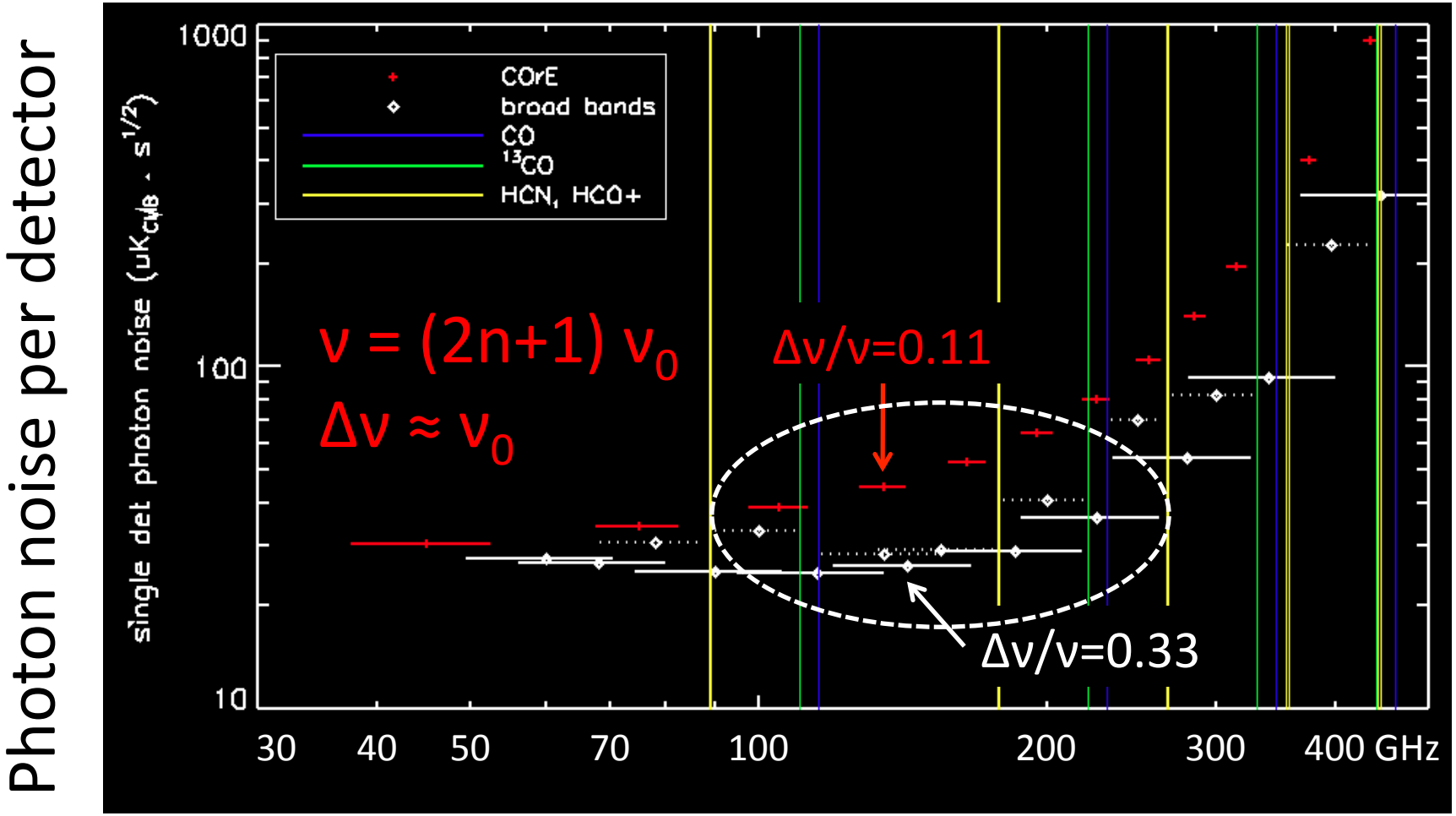


Figure 14: Left: Free-standing RHWP. Right: Dielectric substrate RHWP

Degrades performance



target CMB sensitivity: 2μK.arcmin

Minimal design with HWP (COrE)

ν (GHz)	$d\nu/\nu$	resol. arcmin.	N_{det}	ΔP_{map} (μK.arcmin)	comment
45	0.33	23.3'	6	35.1	synchrotron monitor
75	0.20	14.0'	86	10.6	synchrotron monitor
105	0.14	10.0'	744	4.0	boundary channel
135	0.11	7.8'	996	4.0	CMB channel
165	0.091	6.4'	1336	4.0	CMB channel
195	0.077	5.4'	1620	4.5	boundary channel
225	0.067	4.7'	1350	6.2	dust monitor
285	0.053	3.7'	750	14.5	dust monitor
375	0.040	2.8'	470	52.6	dust monitor

4000-5000 detectors for 2-2.4 μK.arcmin final CMB sensitivity

100 to 800 synchrotron detectors

2500 dust detectors (!)

≈ 7500 detectors

target CMB sensitivity: 2µK.arcmin

Minimal design without HWP

ν (GHz)	$d\nu/\nu$	resol. arcmin.	N_{det}	ΔP_{map} (μK.arcmin)	comment
60	0.35	8.4'	10	24.7	synchrotron monitor
68	0.35	7.4'	18	17.7	synchrotron monitor
90	0.35	5.6'	72	8.4	synchrotron monitor
115	0.35	4.4'	316	4.0	boundary channel
143	0.33	3.5'	336	4.0	CMB channel
185	0.35	2.7'	410	4.0	CMB channel
225	0.33	2.2'	660	4.0	boundary channel
280	0.33	1.8'	306	8.8	dust monitor
340	0.35	1.5'	160	20.7	dust monitor
445	0.35	1.1'	90	94.0	dust monitor

1700 detectors for 2 µK.arcmin final CMB sensitivity

100 synchrotron detectors

500 dust detectors (!)

≈ 2300 detectors

Degrades angular resolution

- 1.2m aperture: COrE
  - about 6’ for CMB
  - 6’ and 3’ for SZ
- 2.5m aperture (without HWP)
  - about 3’ for CMB,
  - 3’ and 1.5’ for SZ

The case for no HWP

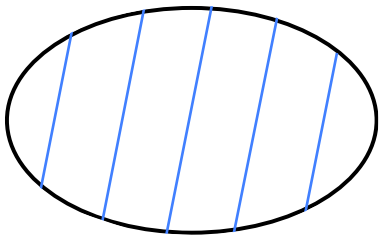
- Not required
- Degrades performance
- Source of complexity
- Technological challenge

Source of complexity

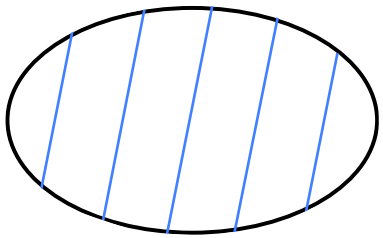
- The HWP will not only modulate polarisation
  - Pointing
  - Sidelobe pickup
  - All calibration parameters
  - …
- We will have to calibrate everything as a function of the HWP angle (!)

Example: pointing modulation

Without HWP



With HWP



Example: pointing modulation

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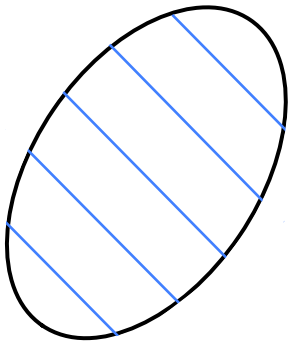

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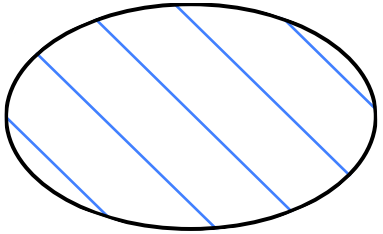

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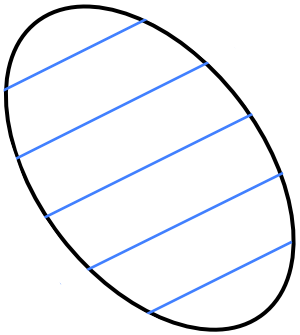

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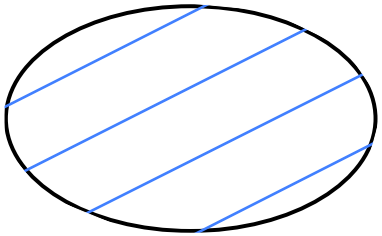

The case for no HWP

- Not required
- Degrades the performance
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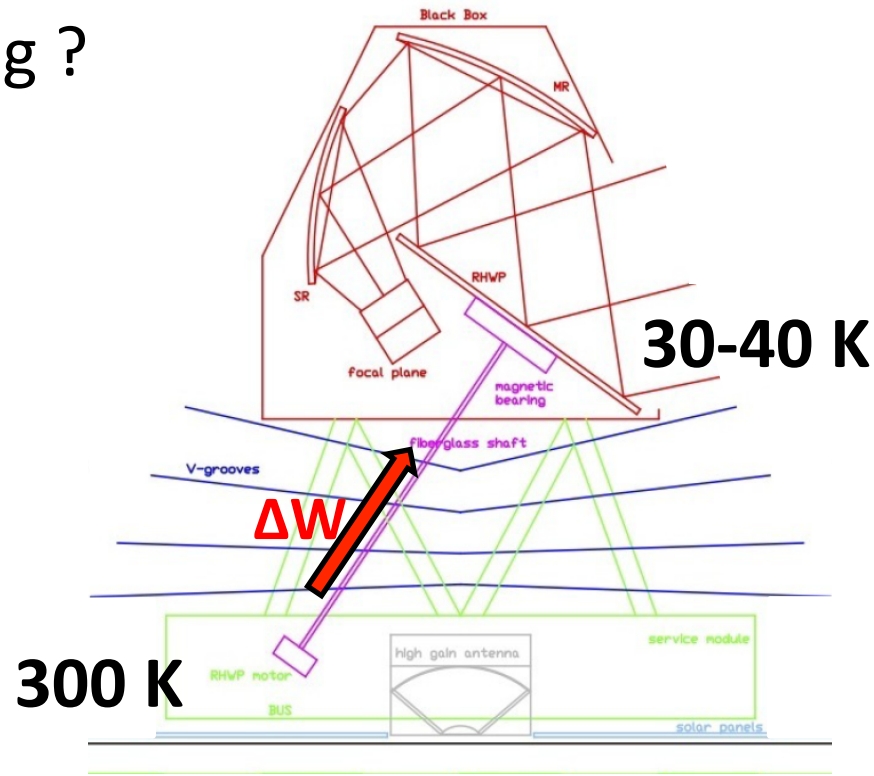
Technological challenge

- Can we make a large HWP (G. Pisano's talk)
- Can we rotate it at 30-40 K
- Impact on passive cooling ?



Conclusion

- Both options are possible — This critical question impacts all of the design and target science !
- Nice to have in theory but source of complexity
- My proposed baseline: no HWP
  - Explain why in the proposal, using theoretical arguments
  - Demonstrate it with simulations in the phase A study
- Keep it however as an option ?