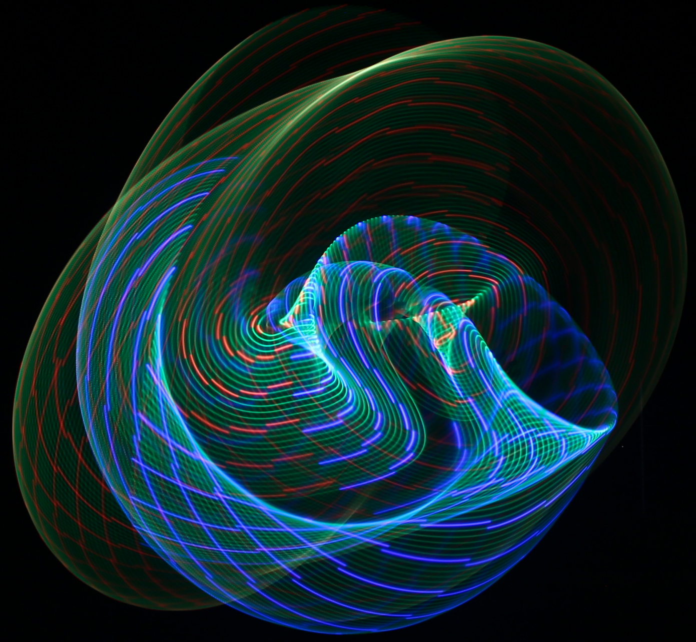
Quantifying the ”minimum” in adaptive minimum variance analysis of planetary plasma waves

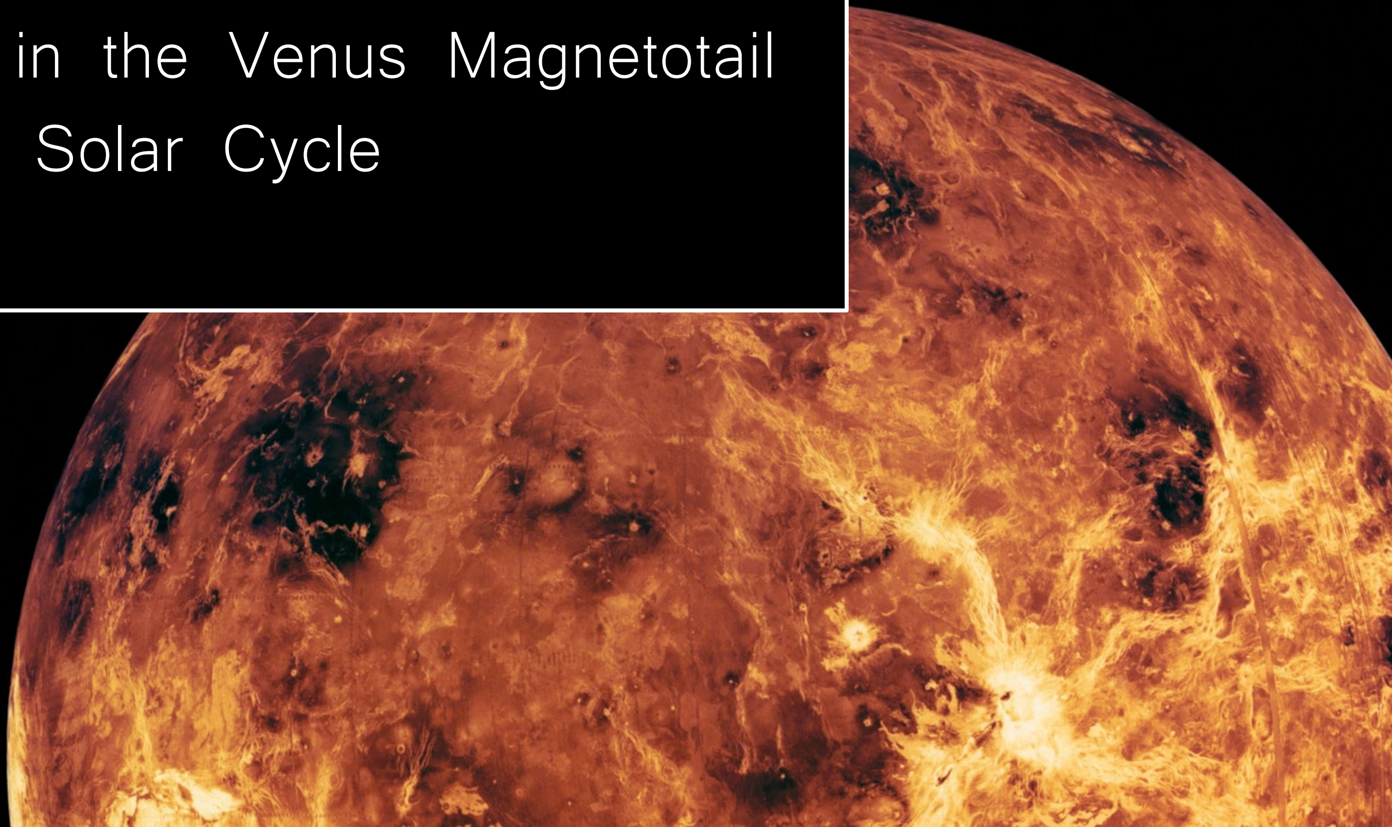
Alexandra Brosius
Lynn Wilson III



PPPL Graduate Summer School 2020

Planetary $\approx$ Venus
$\longmapsto$ *Upstream plasma environment*

1. Loss of water from Venus. I. Hydrodynamic escape of hydrogen (Kasting and Polllack 1983)
2. H+/O+ Escape Rate Ratio in the Venus Magnetotail and its Dependence on the Solar Cycle (Persson et al. 2018)



Planetary $\approx$ Venus

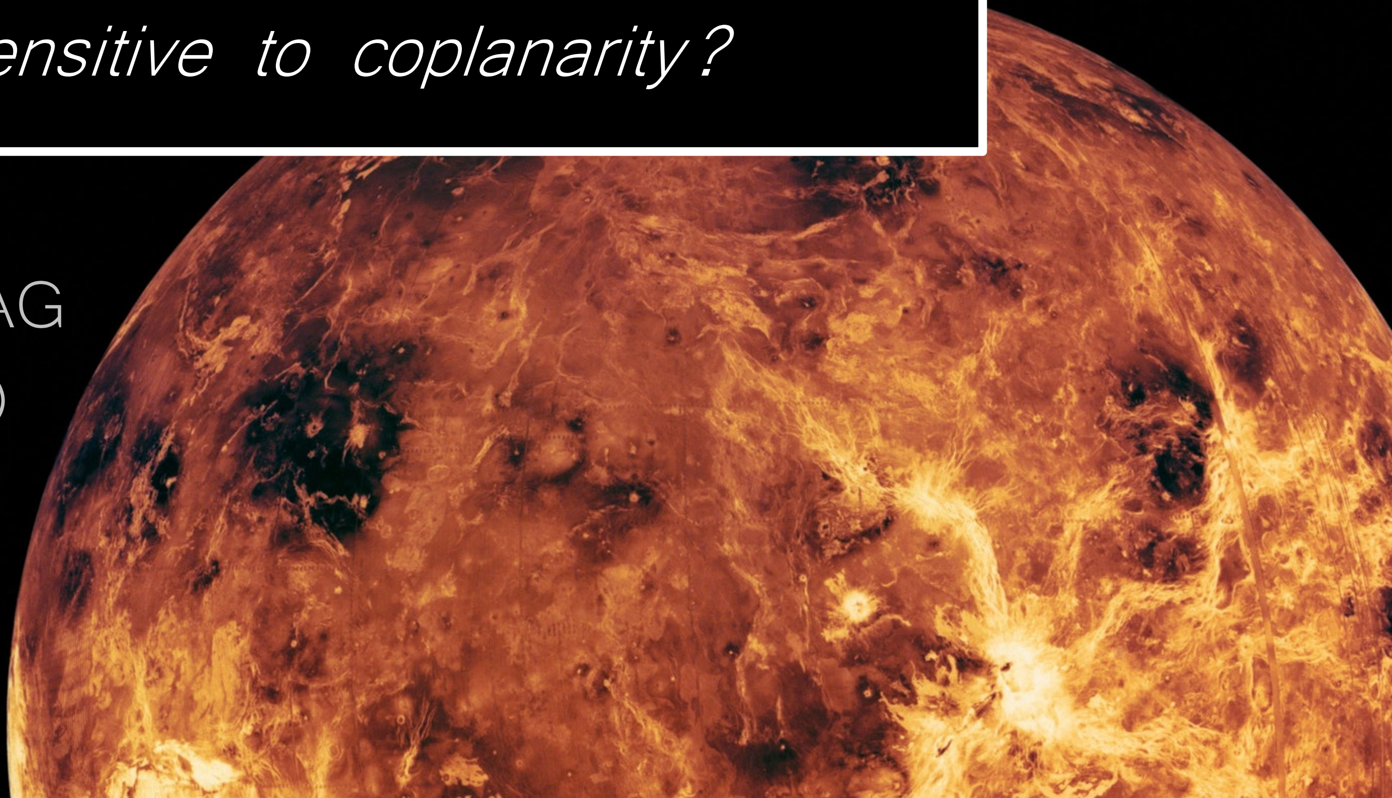
$\mapsto$ *Upstream plasma environment*

Motivation: characterize waves

Method: minimum variance analysis (MVA)

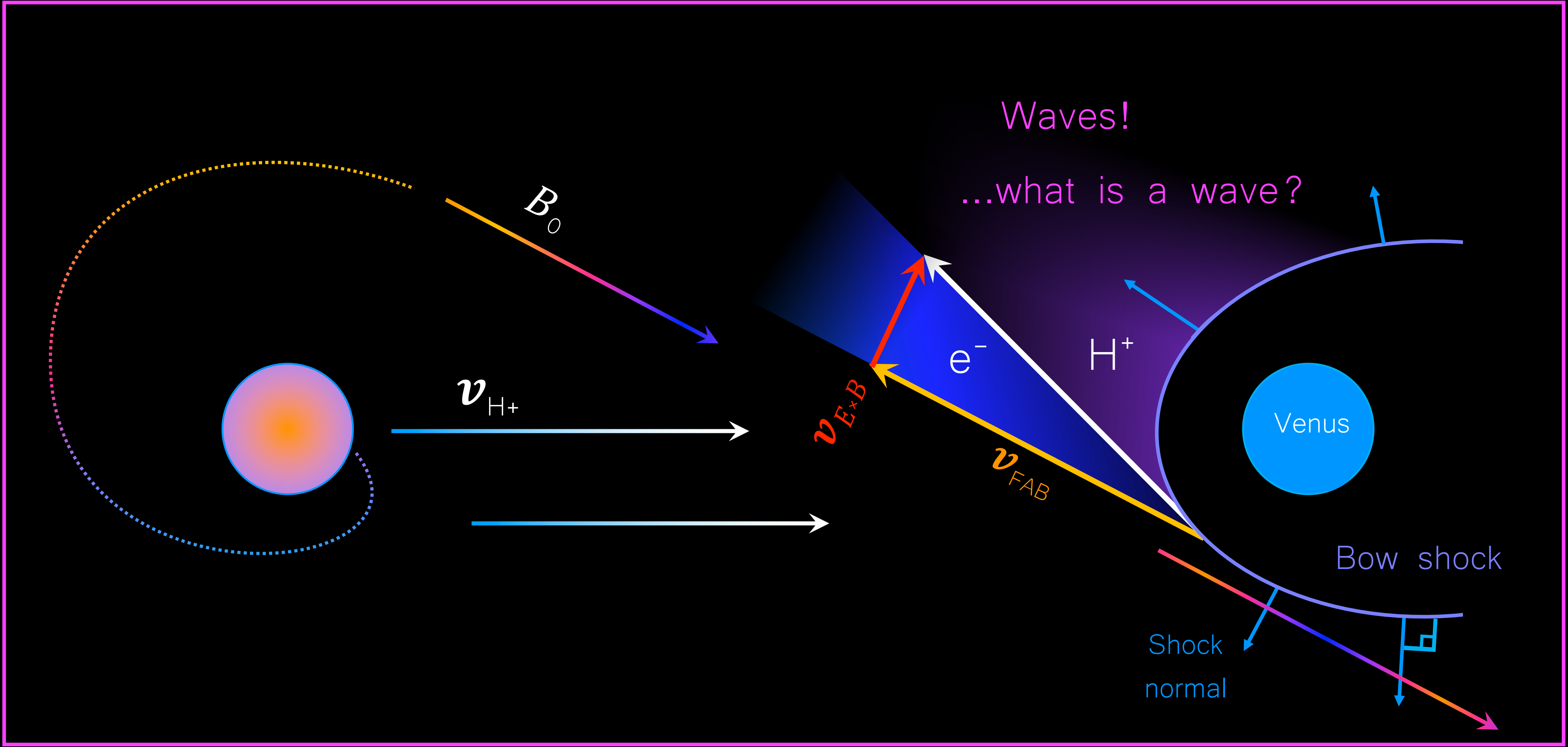
Question: *are wave angles sensitive to coplanarity?*

Venus Express 2006-2012 MAG instrument (Zhang et al. 2007)
32 samples/second; 42 orbits

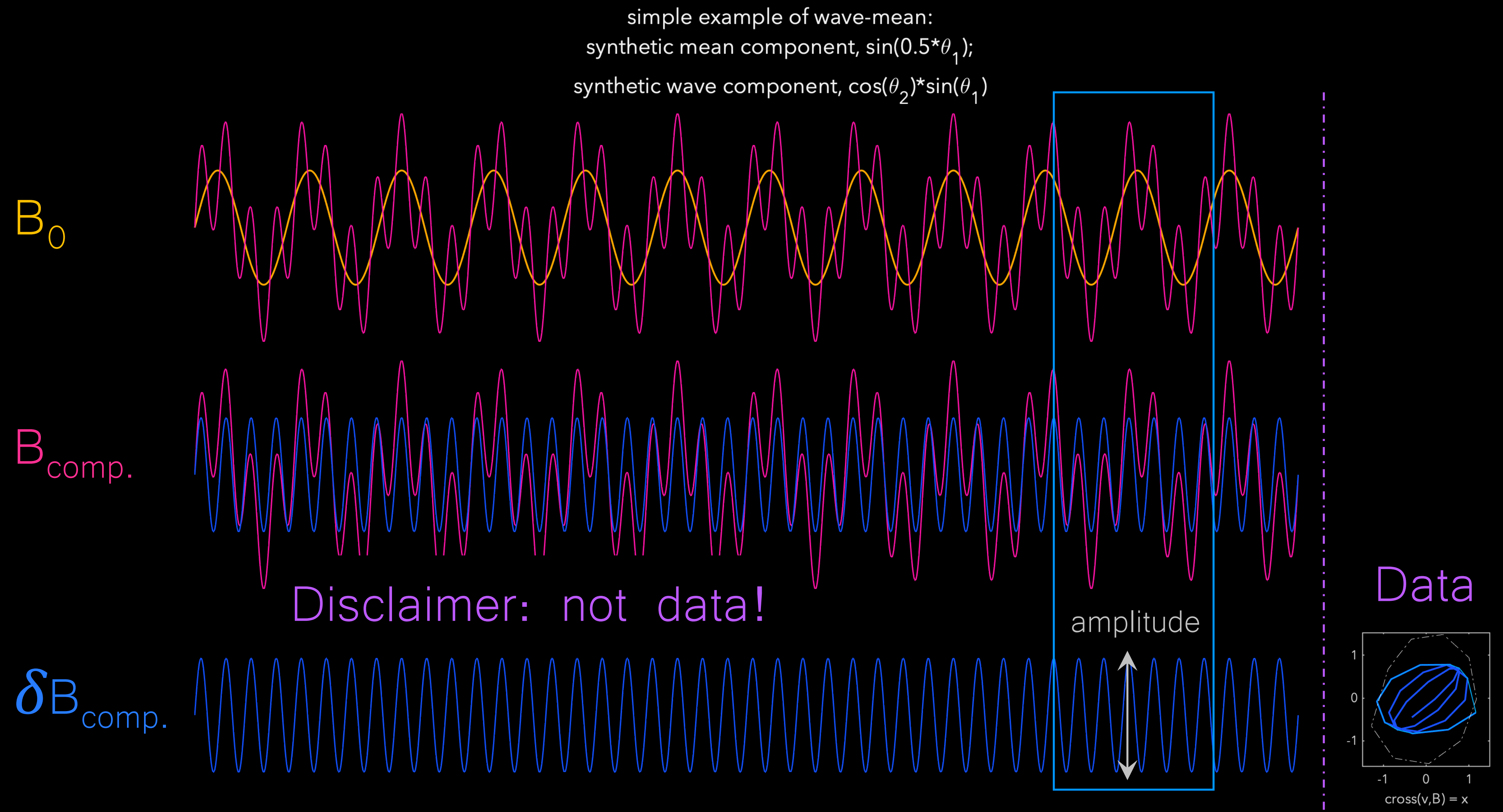


Ionization, charge separation & motion

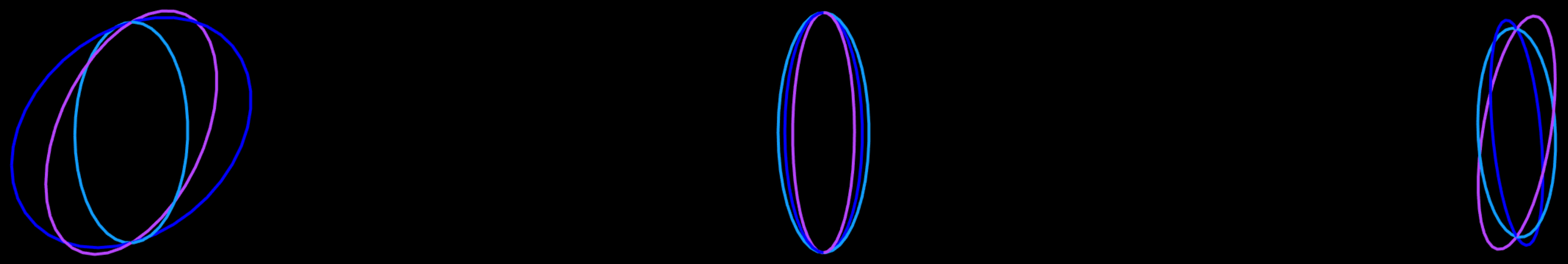
⟼ Ionosphere, magnetosphere, bow shock



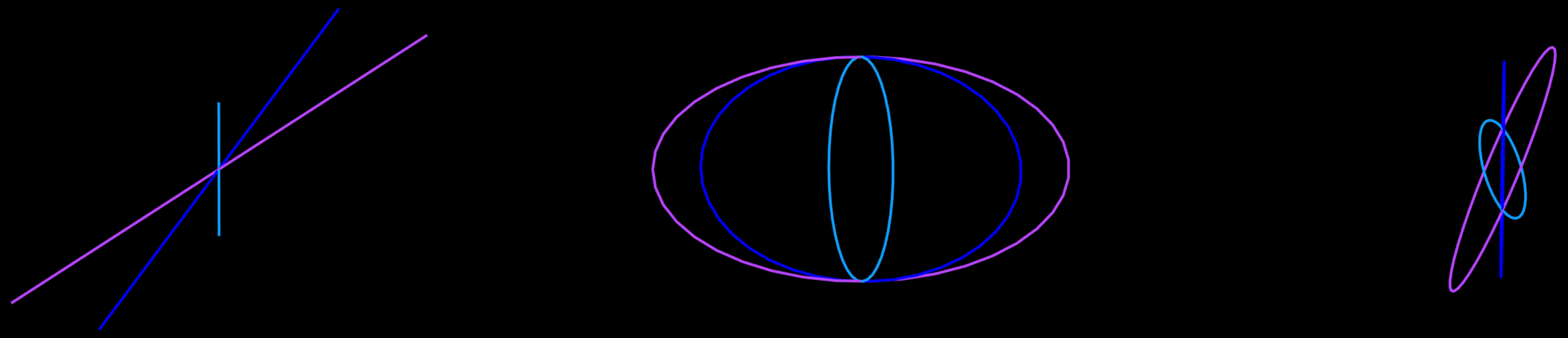
No changes in time series data
$\longmapsto$ *Any* wave interval length/position



How to choose int./min variance ratio...
⟼ What does "flat" mean?

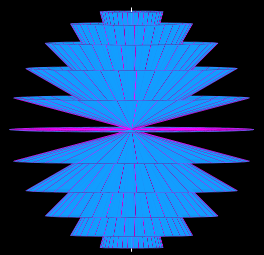


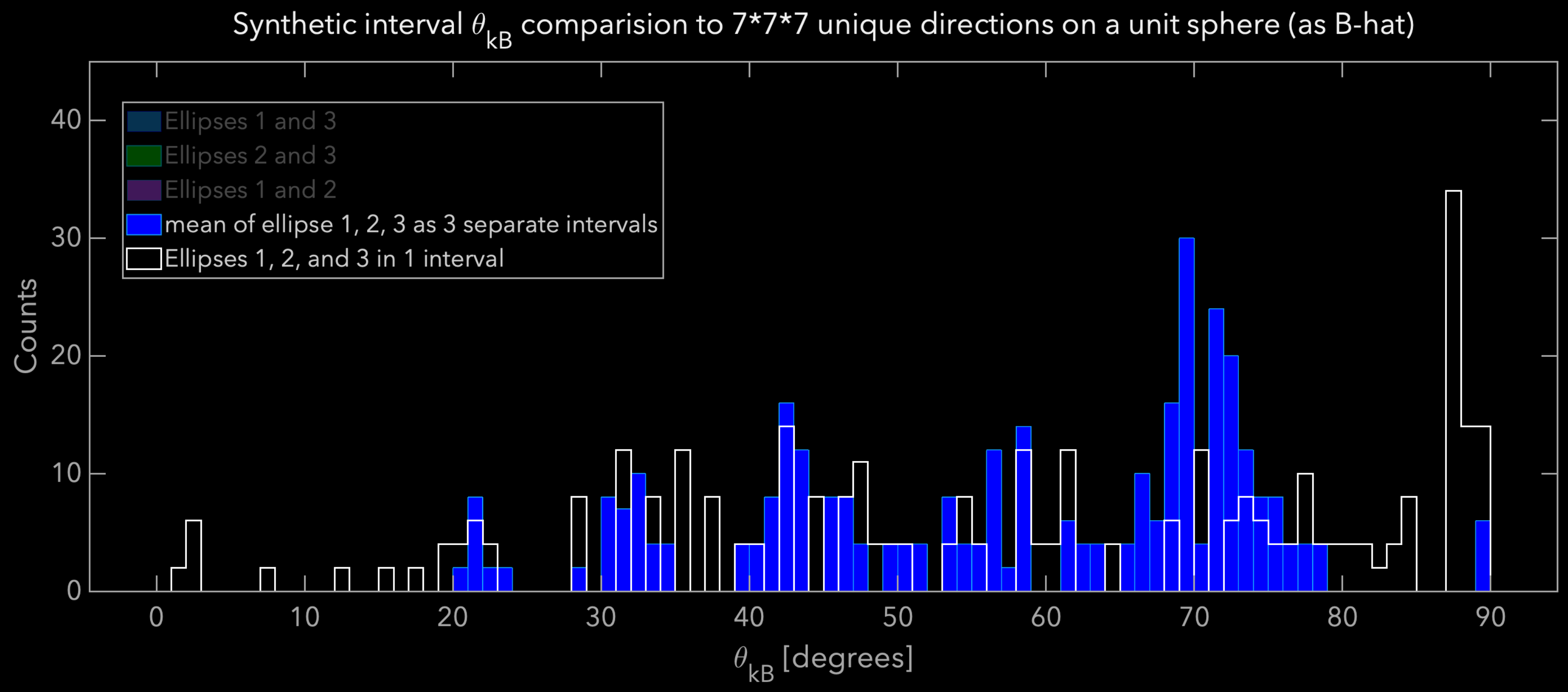
Disclaimer: not data!
(Just sine, cosine)



How to choose int./min variance ratio...

⟼ 347 B_0 directions (most are unique)





Disclaimer: not data! Ellipses from prev. slide

3 analysis cases: L10, L50, L100
⟼ Range of max/int. aspect ratios (1:4)

$$\frac{\lambda_{int}}{\lambda_{min}} \equiv \frac{\lambda_y}{\lambda_x} \geq 10$$

$$\frac{\lambda_y}{\lambda_x} \geq 50$$

$$\frac{\lambda_y}{\lambda_x} \geq 100$$

$$\frac{\lambda_{max}}{\lambda_{int}} \equiv \frac{\lambda_z}{\lambda_y} \leq 4$$

$$\frac{\lambda_z}{\lambda_y} \leq 4$$

$$\frac{\lambda_z}{\lambda_y} \leq 4$$

L10 (= λ10)

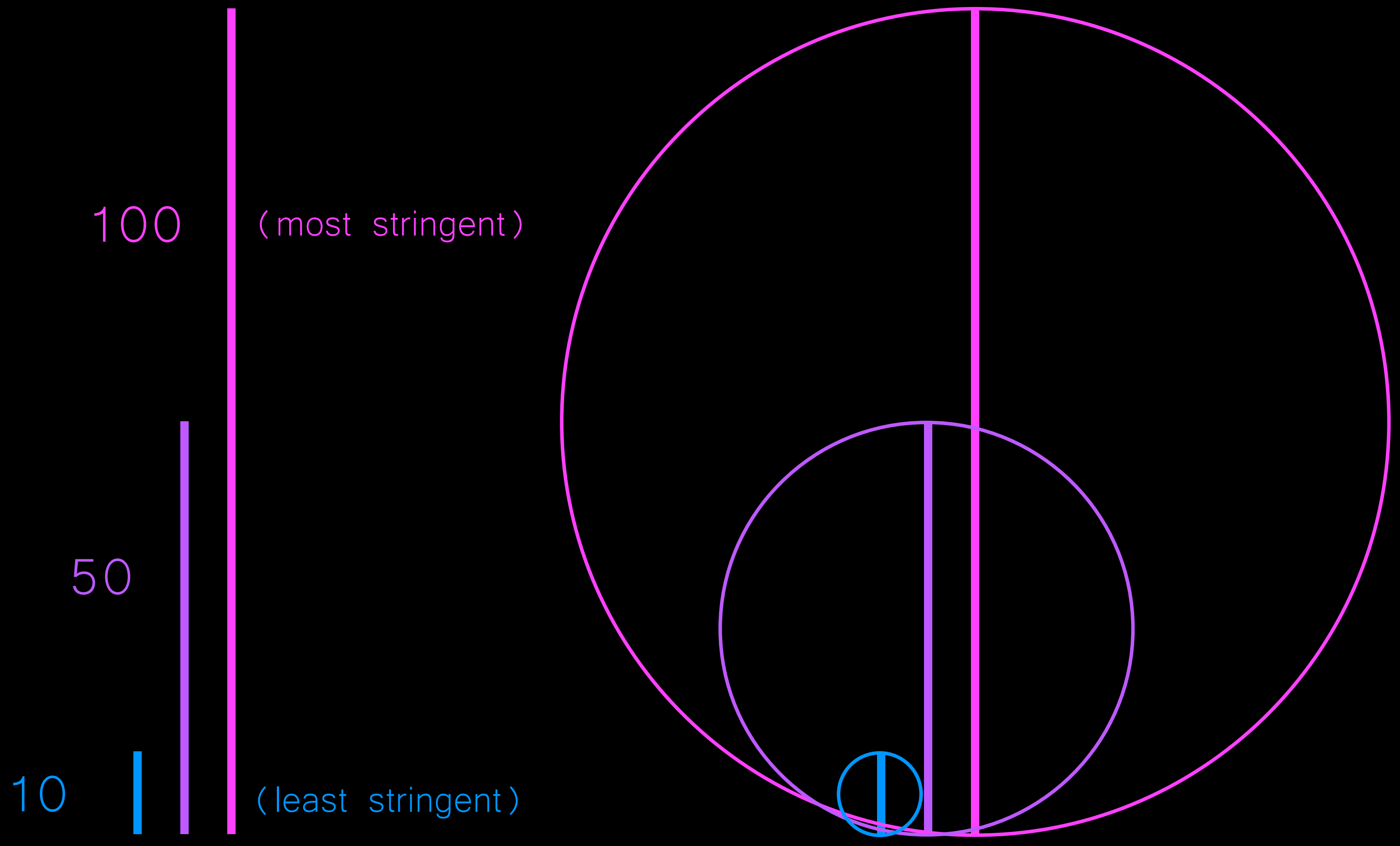
L50

L100

Sonnerup and Scheivle 1998, Giagkiozis wt al. 2018

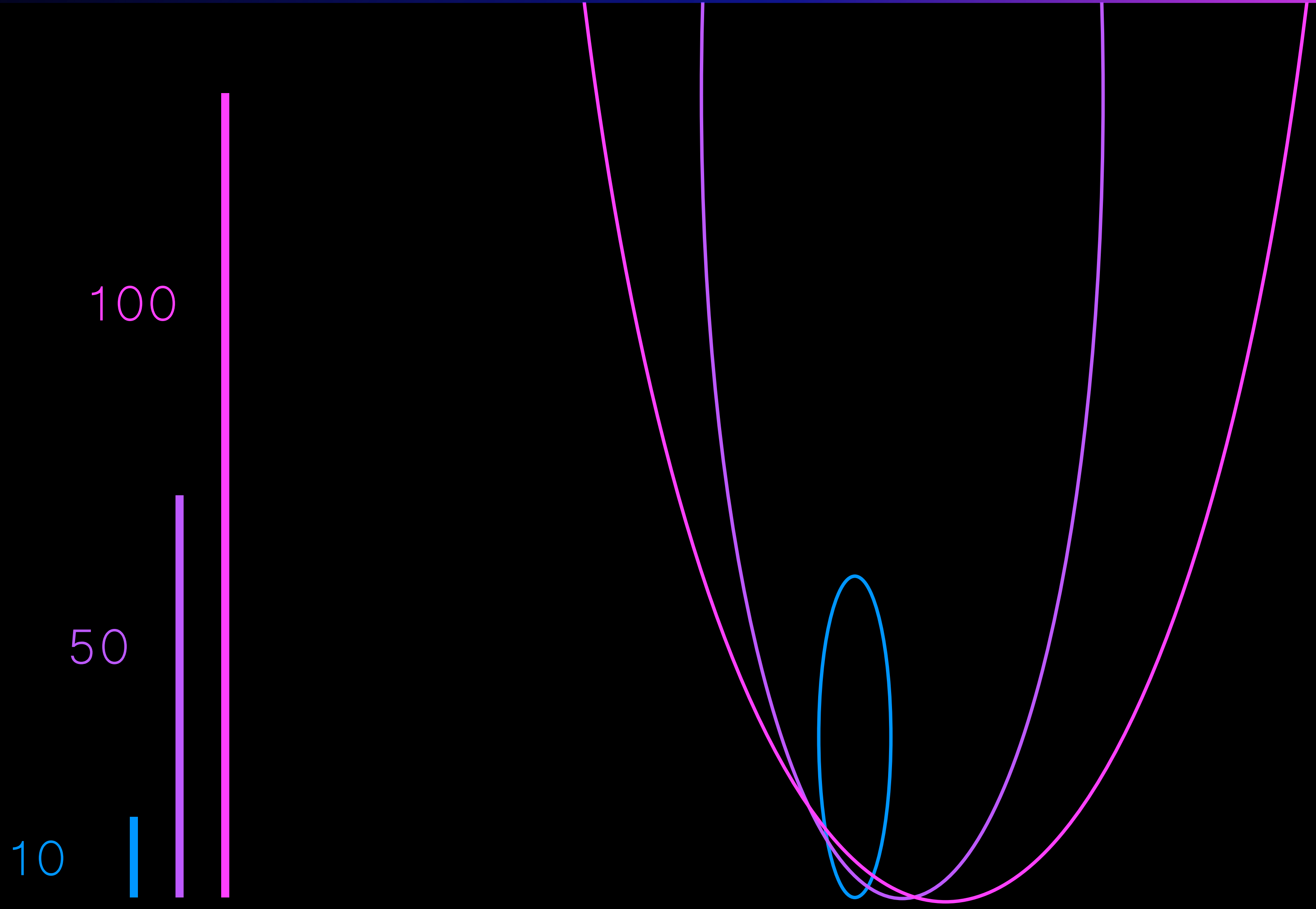
3 analysis cases: L10, L50, L100

⟼ Range of max/int. aspect ratios (1:4)



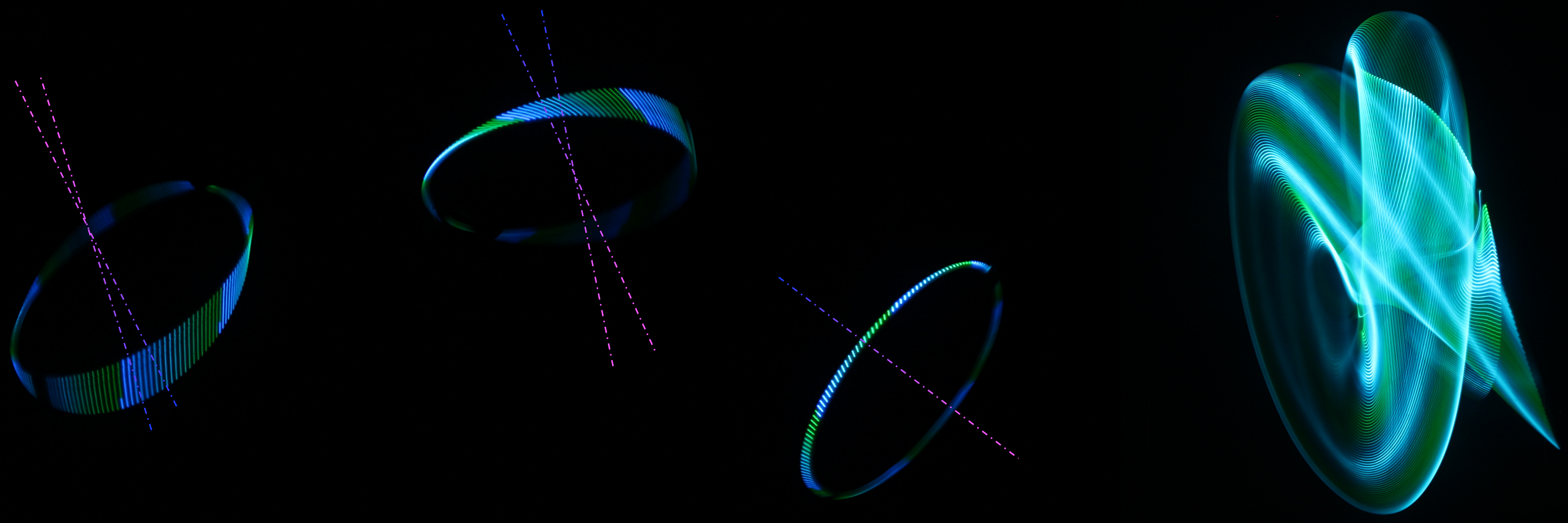
3 analysis cases: L10, L50, L100

⟼ Range of max/int. aspect ratios (1:4)

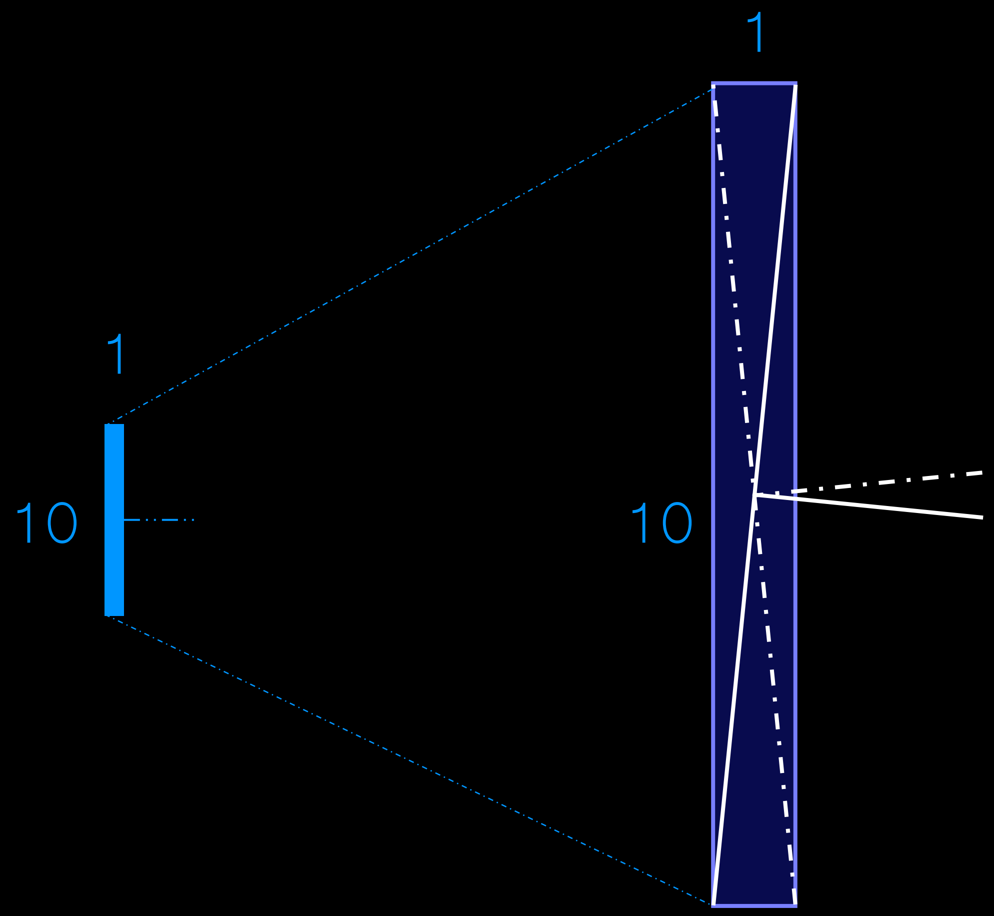


Why is L10 the least stringent?

⟼ Allowable normal vector planes



Why is L10 the least stringent?
$\longmapsto$ Allowable normal vector planes



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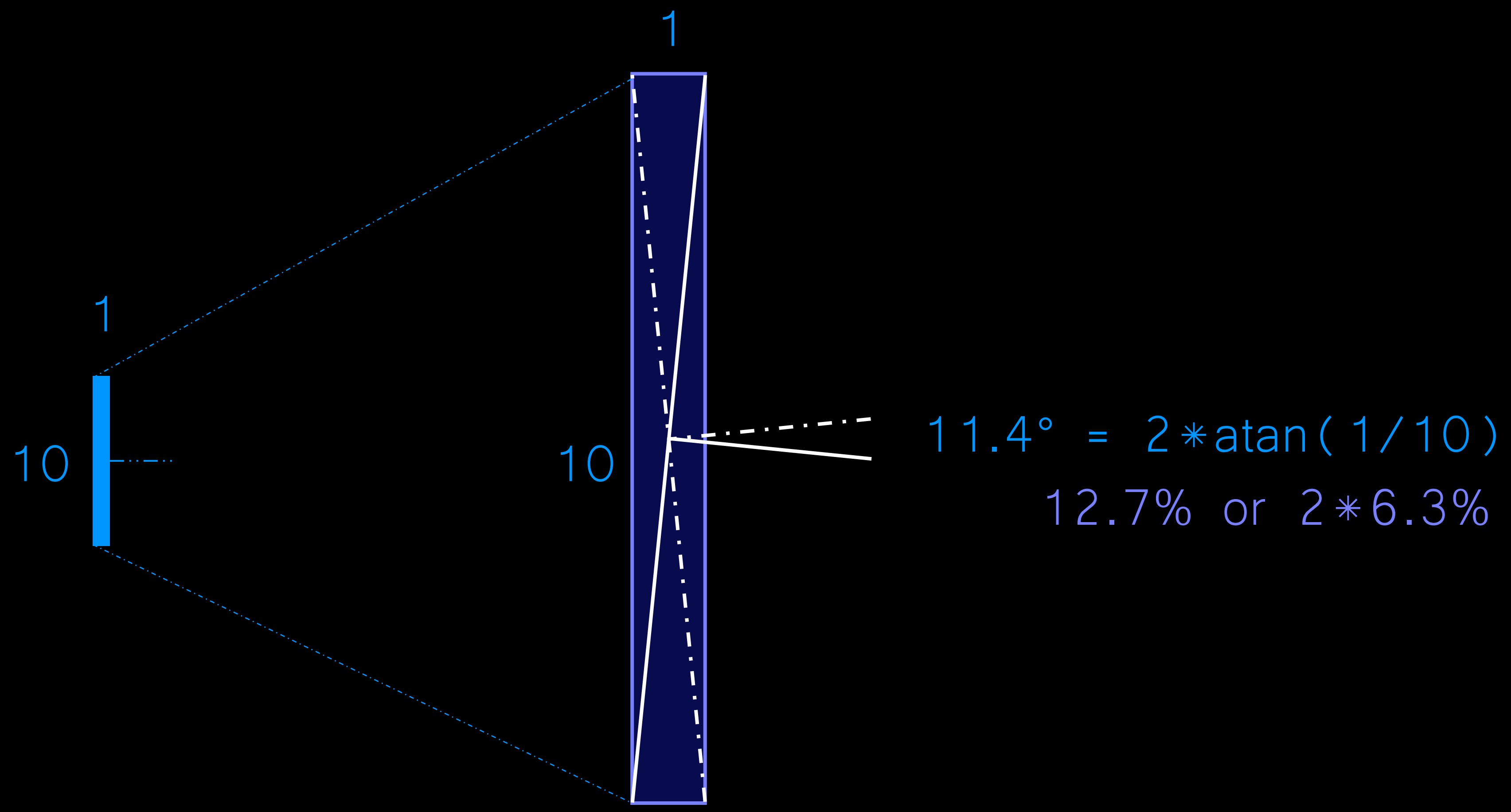
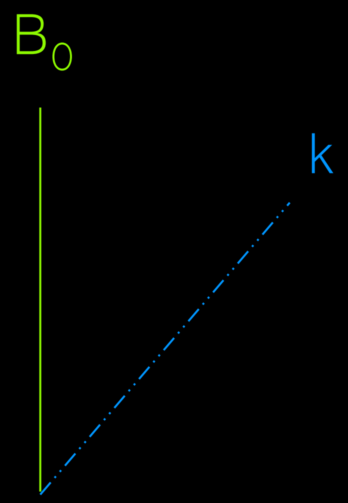
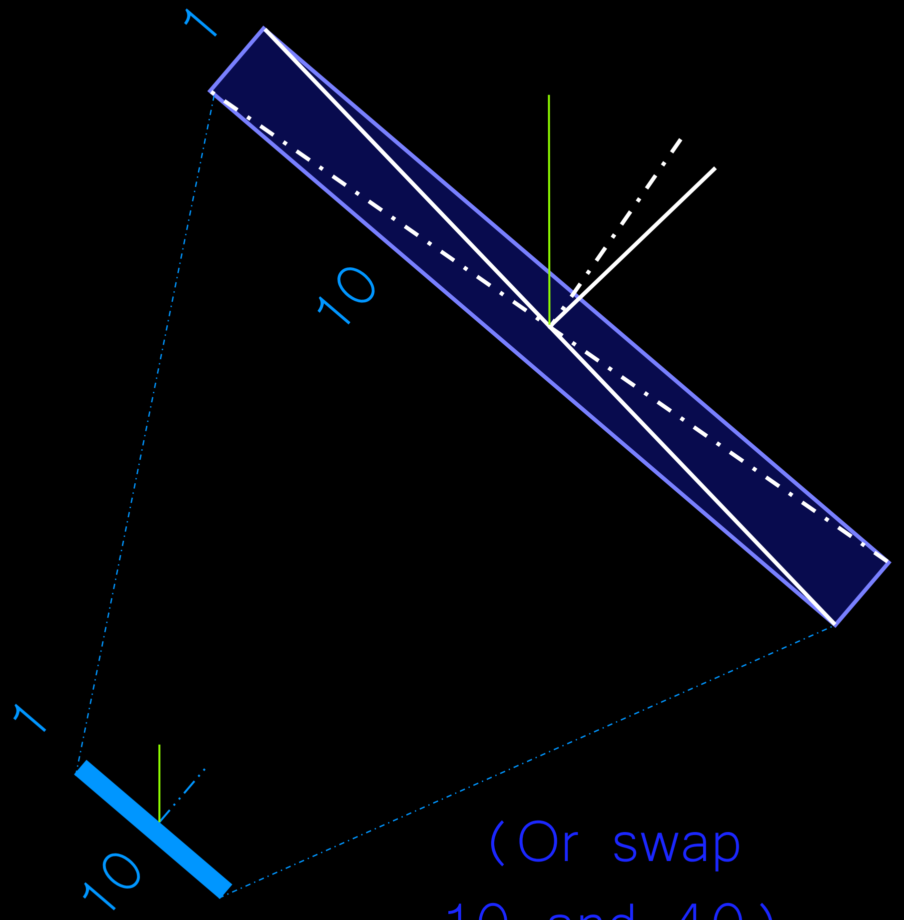


Why is L10 the least stringent?
⟼ Allowable normal vector planes

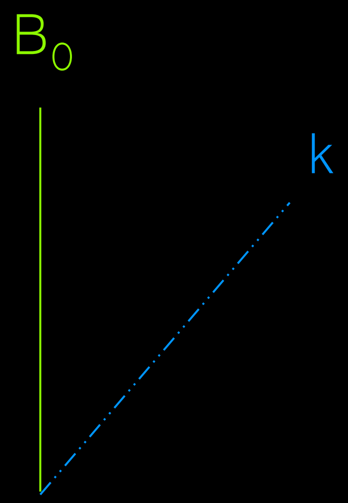


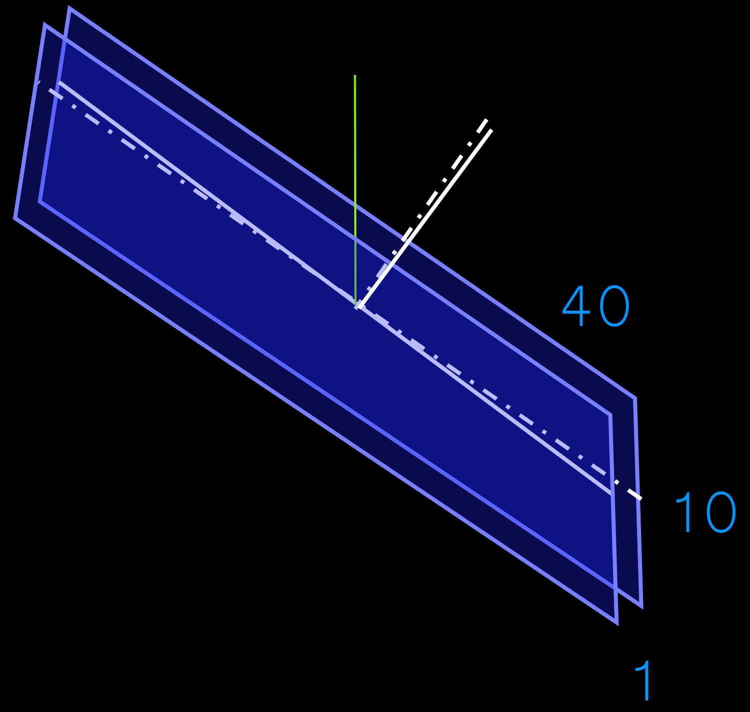


(Or swap 10 and 40)

Why is L10 the least stringent?

⟼ Allowable normal vector planes





(Or switch
10 and 40)

Method overview

⟼ Example time series & mean

1. Conditions, pre-processing

   L10,50,100;

   0.1 nT; 0.01 dB/B;

   0.5-4.4 Hz; Δf 0.1 Hz;

   n points: 1.5:3*cadence;

   *mean=3*n;*

2. Interval test loop

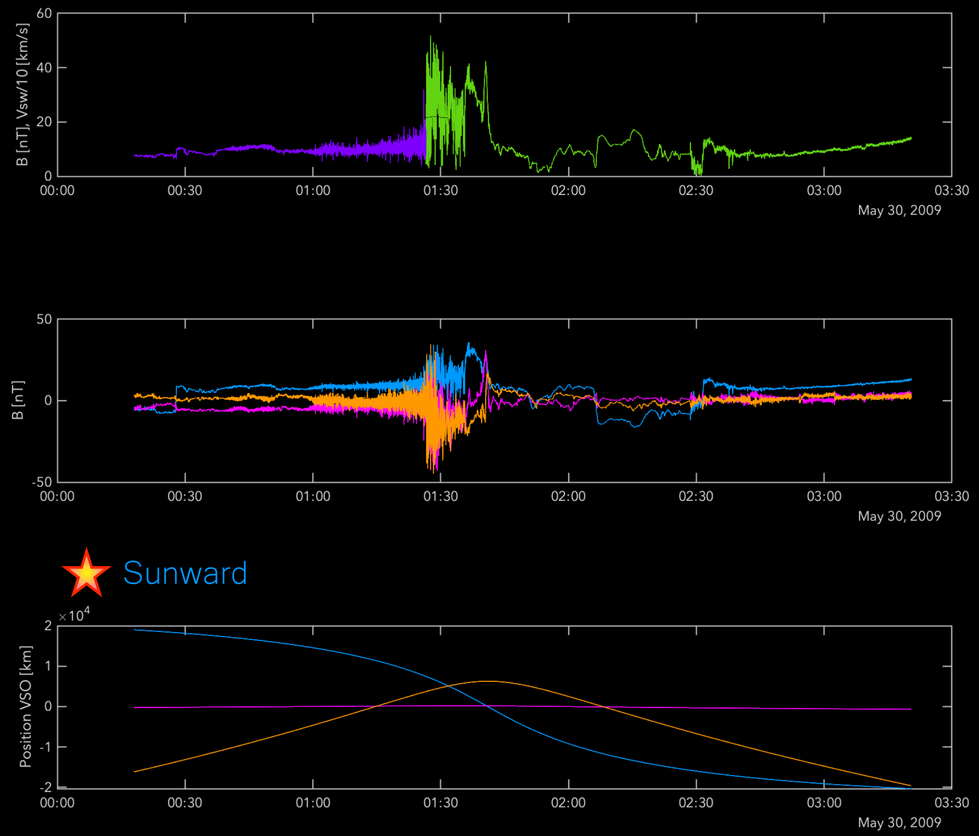
3. Interval calculations

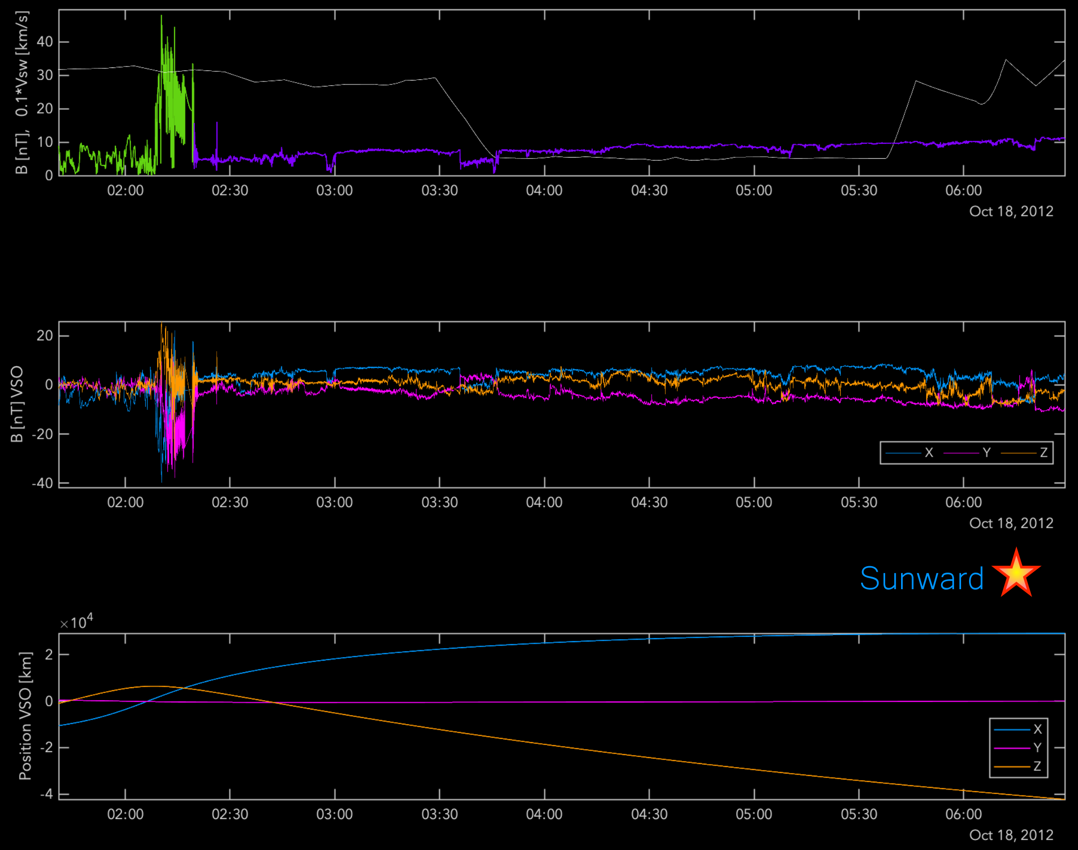
4. Post-processing

5. Results

Method overview
⟼ MAG example of 2/42 VEX orbits

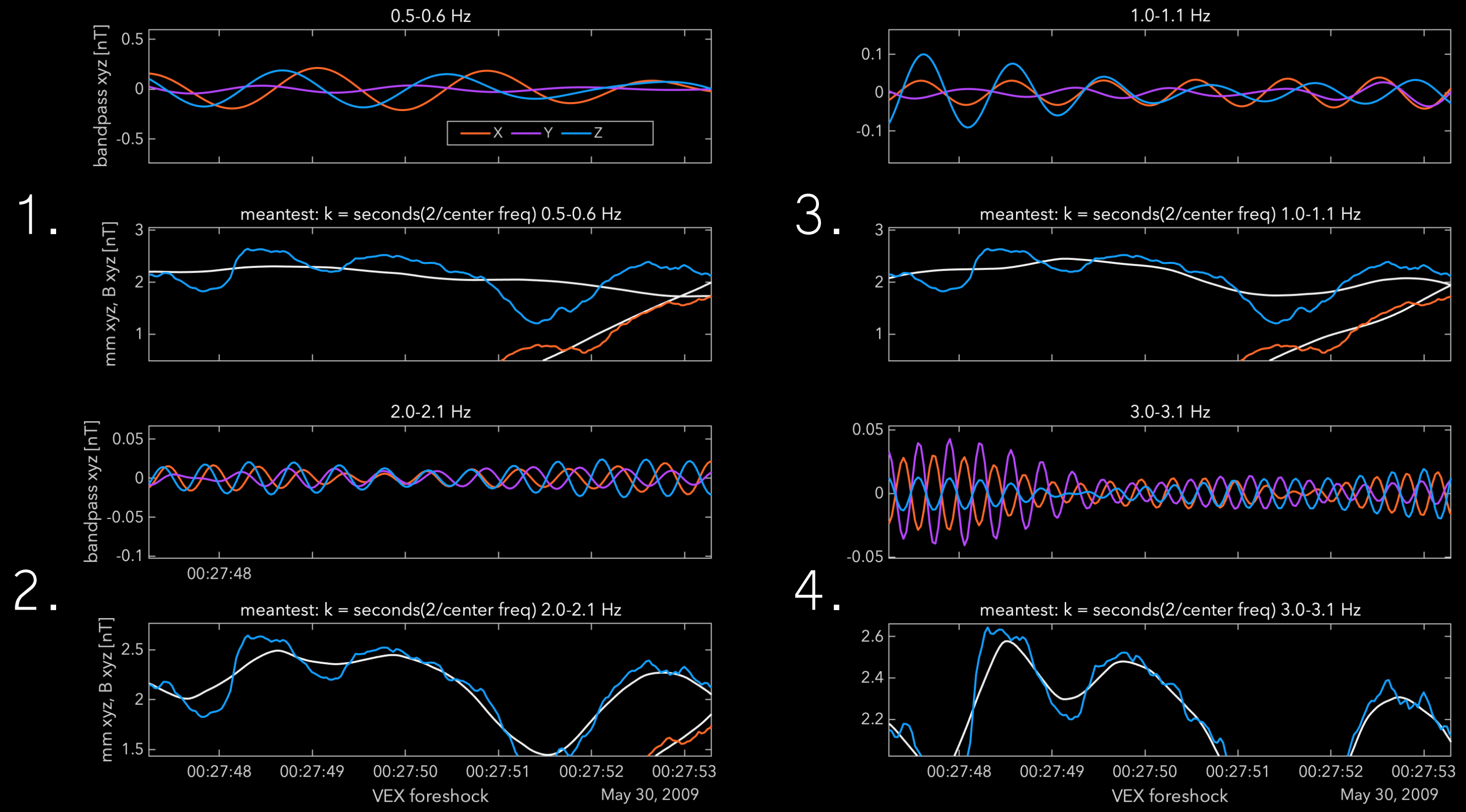
1. Conditions, pre-processing





Time series data
⟼ *Solar wind/foreshock*

1. Conditions, pre-processing
   *mean=3*n;*



Method overview

⟼ Test loop

1. Conditions, pre-processing

2. Interval test loop

   Shift by +0.5∗n & -0.5∗n;

   Subtract 0.5∗n from start & end;

   Sort by $\lambda_{int./min}$;

   Check for ΔP in B-normal plane;

3. Interval calculations

4. Post-processing

5. Results

Method overview

⟼ Analysis scheme, examples

1. Conditions, pre-processing

2. Interval test loop

3. Interval calculations

θ_{kB}, θ_{kS};

CH;

Examples;

4. Post-processing

5. Results

Method overview

⟼ Analysis scheme, examples

3. Interval calculations

Examples;

L10: $\lambda_{y/x}$ > 10, $\lambda_{z/y}$ <=4

- descending (worst) $\lambda_{y/x}$

0.45:0.55 | 0.50–0.60 | 0.55–0.65 | 0.60–0.70 | 0.65–0.75 | 0.70–0.80 | 0.75–0.85 | 0.80–0.90 | 0.85–0.95 | 0.90–1.00 | 0.95–1.05 | 1.00–1.10 | 1.05–1.15 | 1.10–1.20 | 1.15–1.25 | 1.20–1.30 | 1.25–1.35 | and so on | 4.30–4.40 | [Hz]

L100: $\lambda_{y/x}$ > 100, $\lambda_{z/y}$ <=4

- ascending (best) $\lambda_{y/x}$

0.45:0.55 | 0.50–0.60 | 0.55–0.65 | 0.60–0.70 | 0.65–0.75 | 0.70–0.80 | 0.75–0.85 | 0.80–0.90 | 0.85–0.95 | 0.90–1.00 | 0.95–1.05 | 1.00–1.10 | 1.05–1.15 | 1.10–1.20 | 1.15–1.25 | 1.20–1.30 | 1.25–1.35 | and so on | 4.30–4.40 | [Hz]

L50: $\lambda_{y/x}$ > 50, $\lambda_{z/y}$ <=4

- ascending (ok) $\lambda_{y/x}$

0.45:0.55 | 0.50–0.60 | 0.55–0.65 | 0.60–0.70 | 0.65–0.75 | 0.70–0.80 | 0.75–0.85 | 0.80–0.90 | 0.85–0.95 | 0.90–1.00 | 0.95–1.05 | 1.00–1.10 | 1.05–1.15 | 1.10–1.20 | 1.15–1.25 | 1.20–1.30 | 1.25–1.35 | and so on | 4.30–4.40 | [Hz]

all: frequency-dependent mean window, frequency-dependent max-min interval length

Method overview

⟼ Analysis scheme, examples

3. Interval calculations

Examples;

Example parameters								
BP [Hz]	Min actual	Min min	Max actual	Max max	Mean factor	N intervals	Case	Batch ID
4.3-4.4	15	12	24	24	0.4598	51	L10	456
4.1-4.2	15	12	24	24	0.4819	69	L100	456
3.95-4.05	15	12	24	24	0.5	83	L50	456
3.55-5.65	17	14	26	27	0.5556	39	L50	932
3.5-3.6	18	15	30	30	0.5634	63	L100	932
3.4-3.5	18	15	30	30	0.5797	51	L10	932
2.85-2.95	22	18	36	36	0.6897	78	L50	390
2.7-2.8	25	18	36	36	0.7273	69	L10	390
2.15-2.25	27	23	44	45	0.9091	26	L100	390
1.45-1.55	40	33	55	66	1.333	23	L100	440
1.4-1.5	42	35	68	69	1.3793	15	L50	440
0.55-0.65	98	81	162	162	3.333	12	L10	440

Method overview

⟼ Convex hull (CH) interval diagnostics

1. Conditions, pre-processing

2. Interval test loop

3. Interval calculations

4. Post-processing

ΔP FAC v×B & FAC ∇B×B;

CH ratio: sum, max, acos;

0.01 dB/B;

5. Results

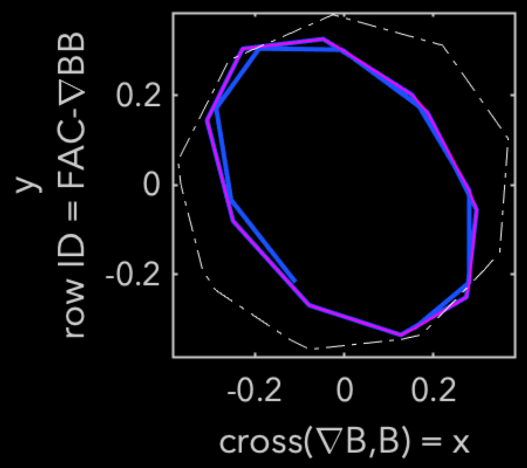
Method overview

⟼ Convex hull (CH) interval diagnostics

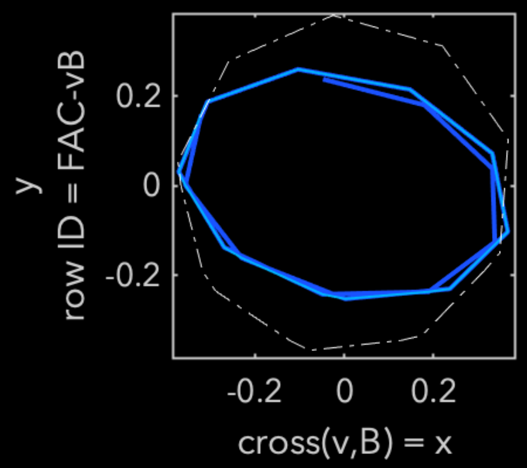
4. Post-processing

CH ratio;

$$\frac{CH(FAC_{xy})}{CH(MVA_{yz})} \equiv \frac{area\ FAC_{xy}}{area\ MVA_{yz}} \cong \cos(\theta_{kB})$$



1. FACxy/MVAyz (∇B cross B)

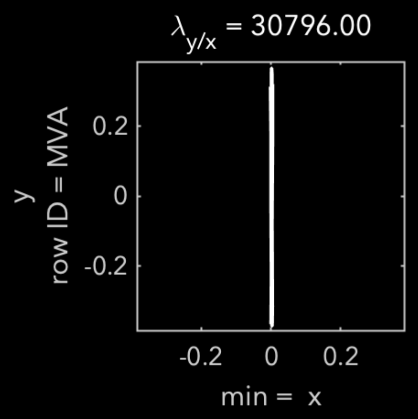


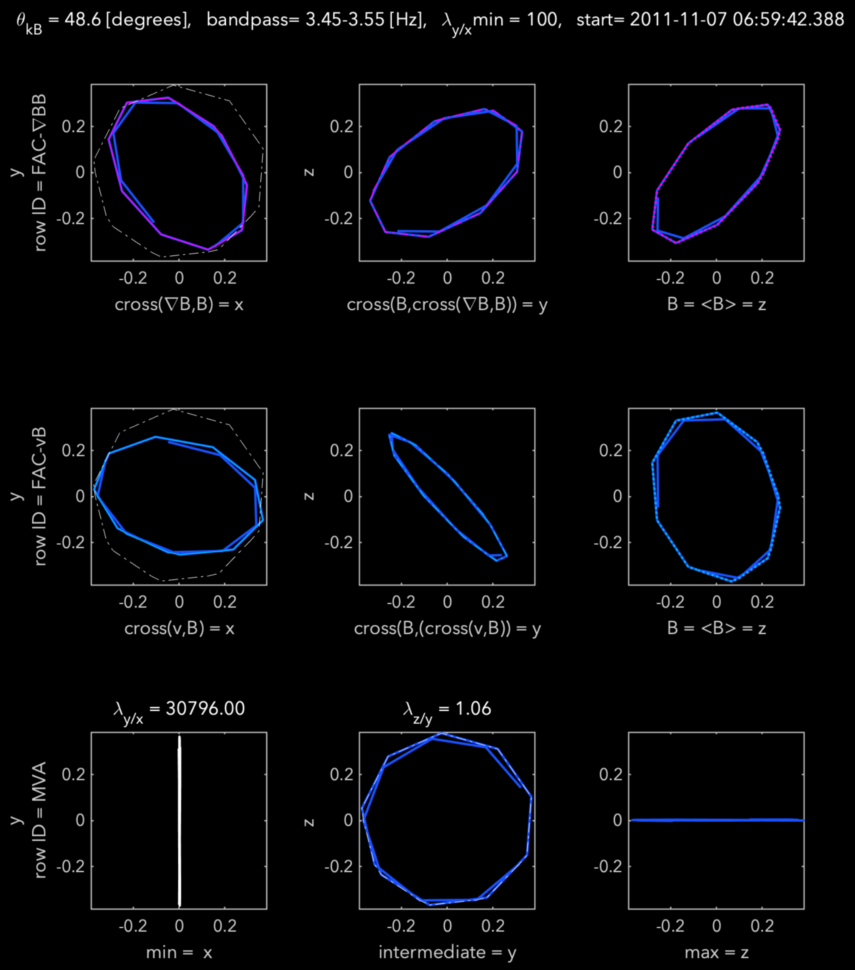
2. FACxy/MVAyz (v cross B)

all: [nT]

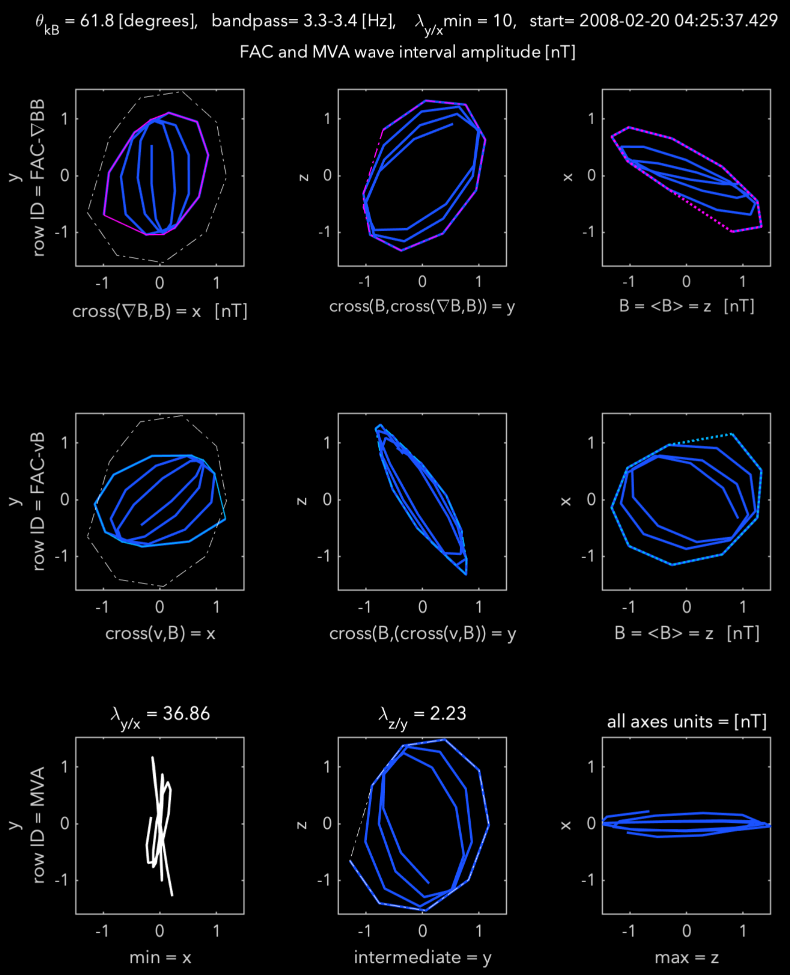
Method overview
⟼ Convex hull (CH) interval diagnostics

4. Post-processing
CH ratio;





all: [nT]



all: [nT]

Method overview
⟼ Quick look at shocks, histograms

1. Conditions, pre-processing

2. Interval test loop

3. Interval calculations

4. Post-processing

5. Results (L10,L100)

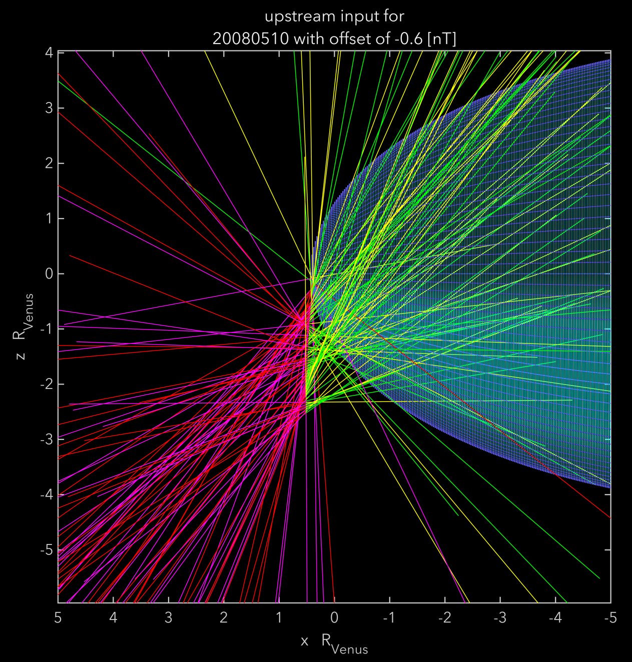
Per orbit;

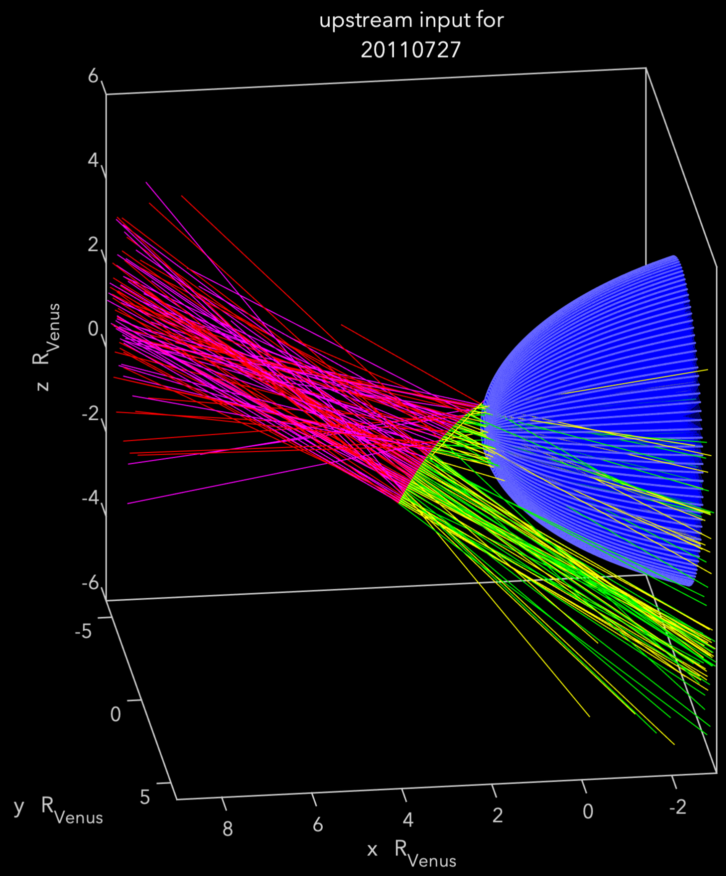
Per frequency;

Shock type;

Example orbits

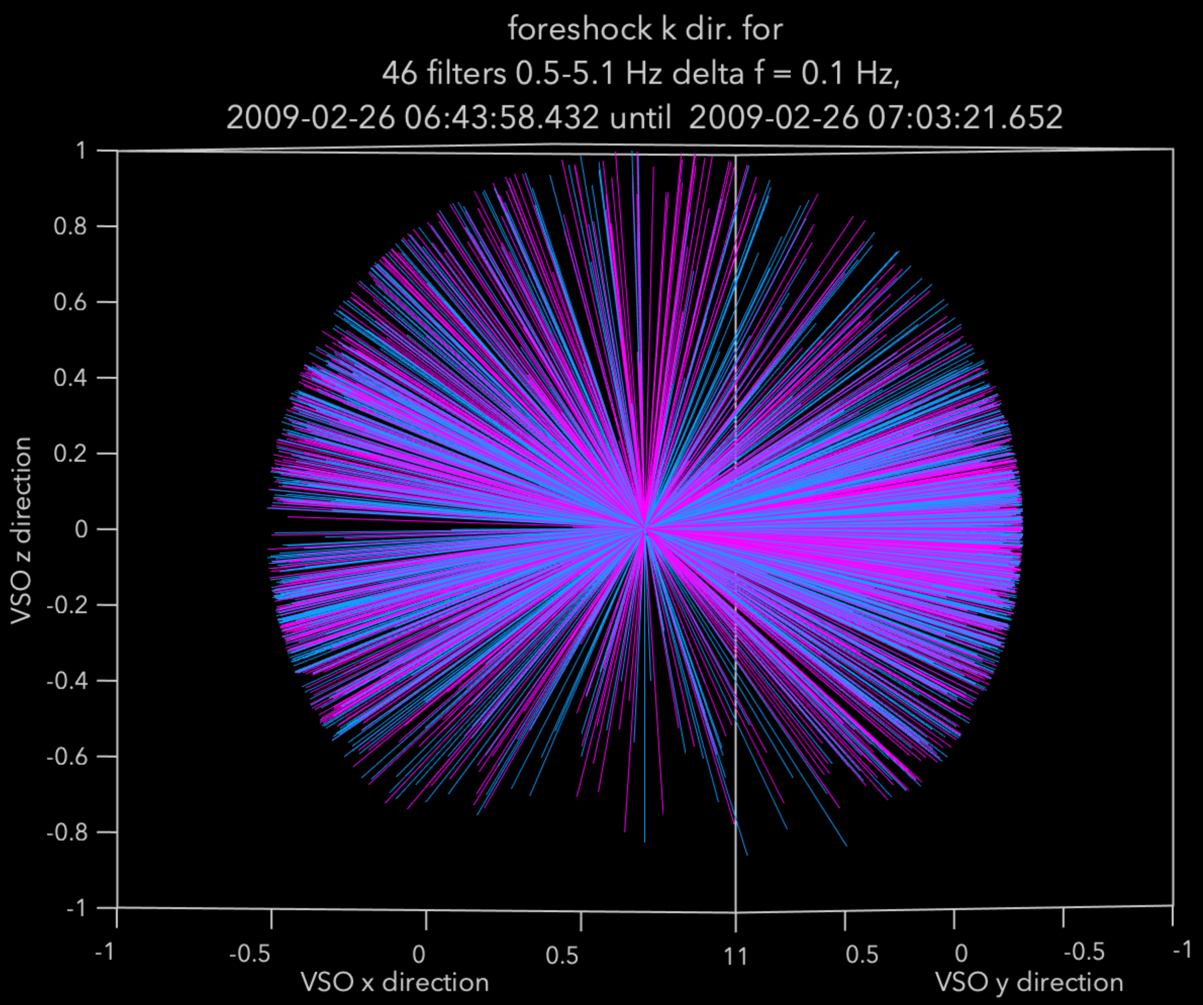
⟼ Magnetic field



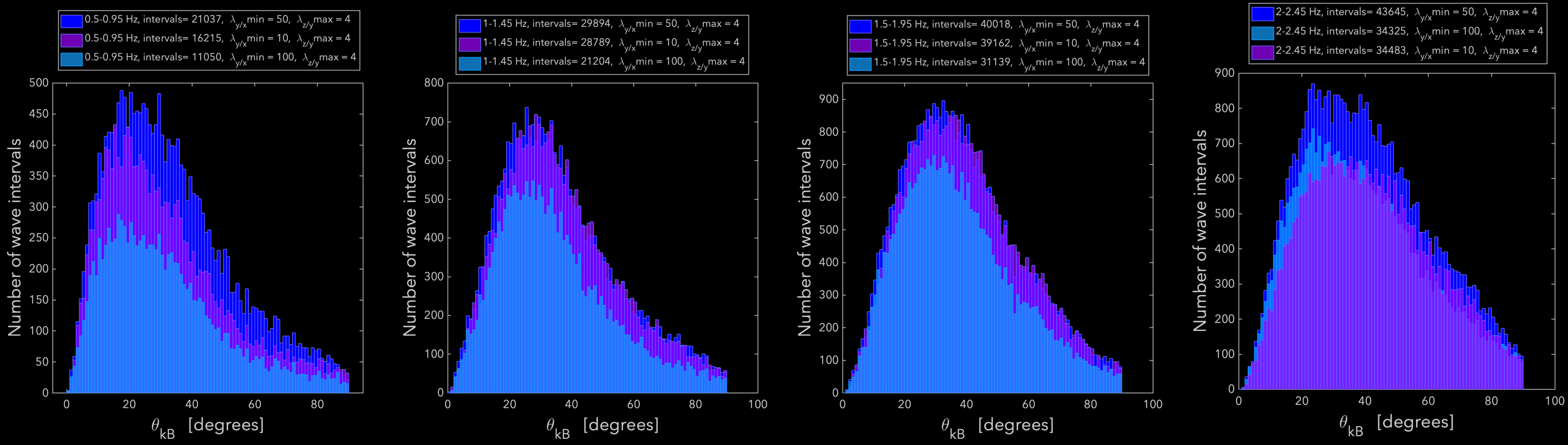


Example orbit

⟼ Wave vector directions

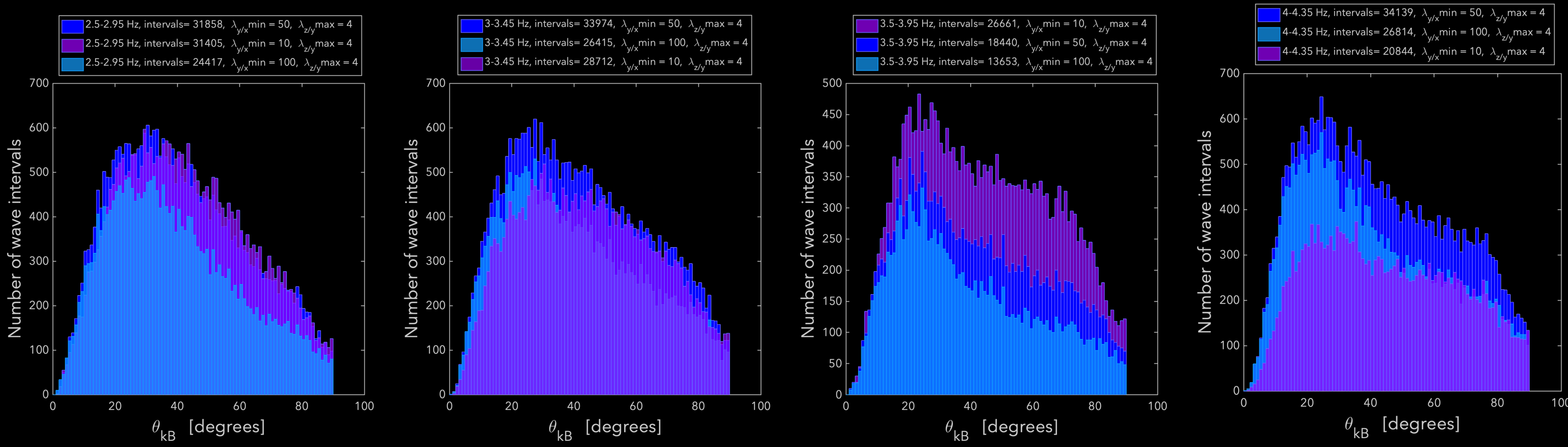


Frequency histograms 1st half
⟼ 0.5-1 Hz to 42-2.5 Hz



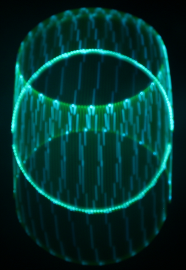
Frequency histograms 2nd half

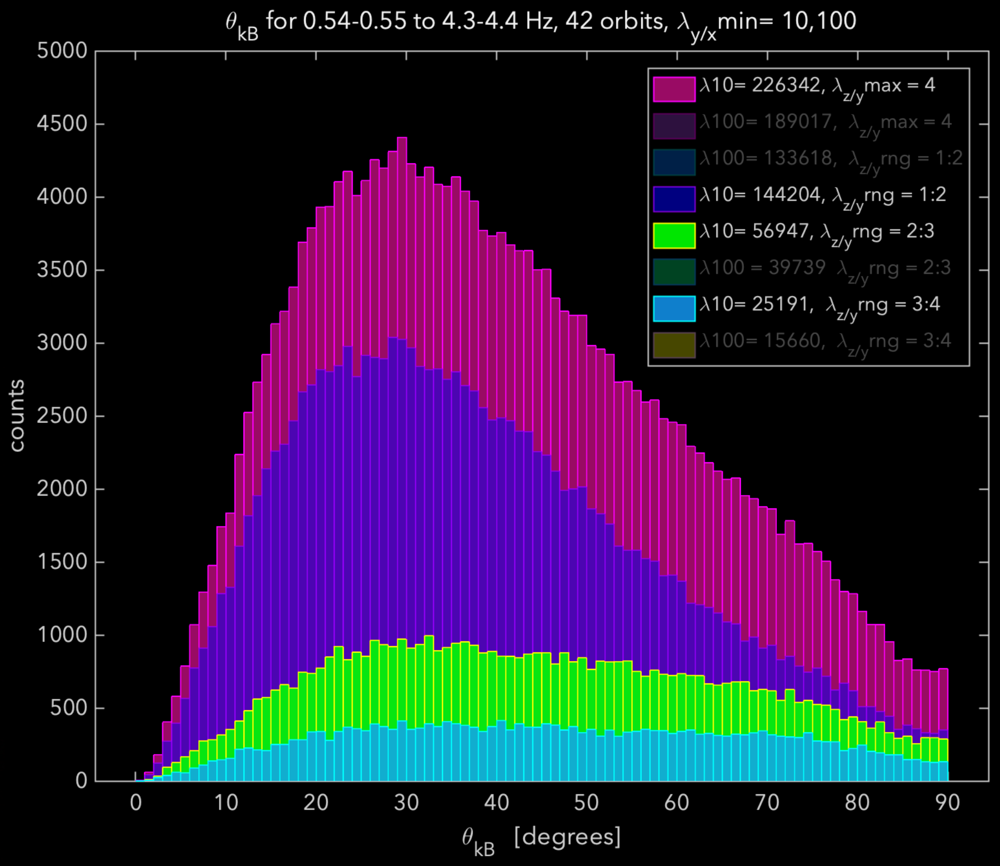
$\longmapsto$ 2.5-3 Hz to 4-4.4 Hz

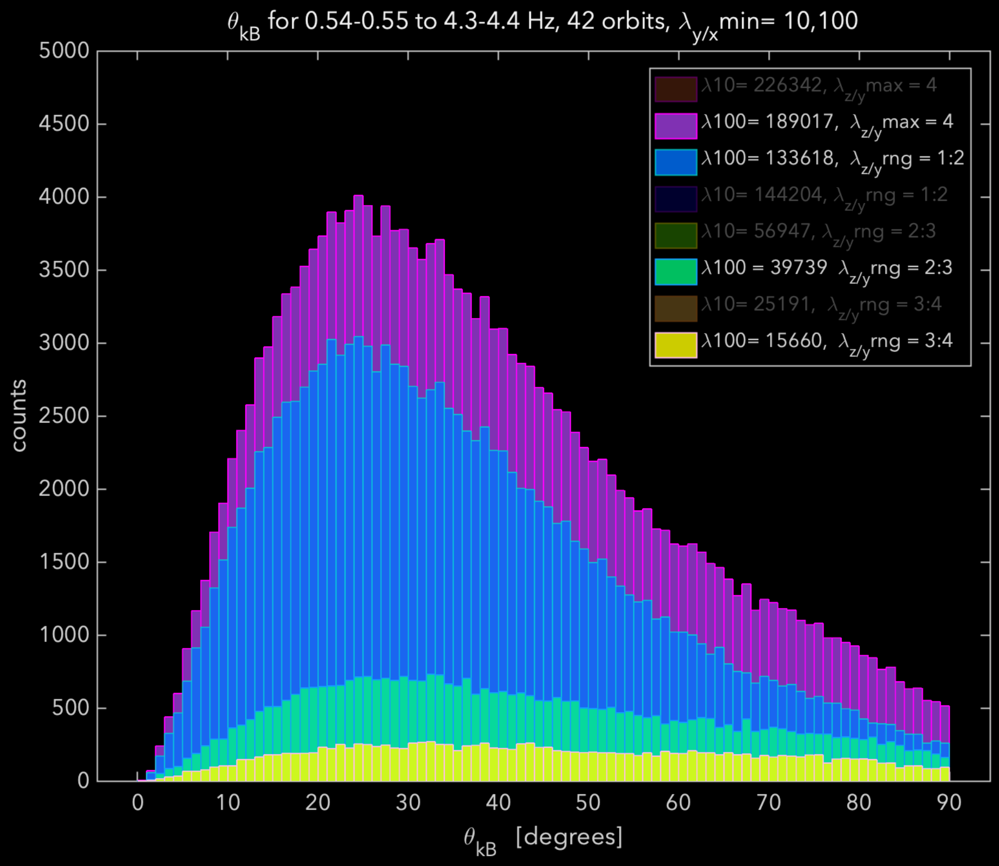


All frequencies: L10 θ_{kB} bias

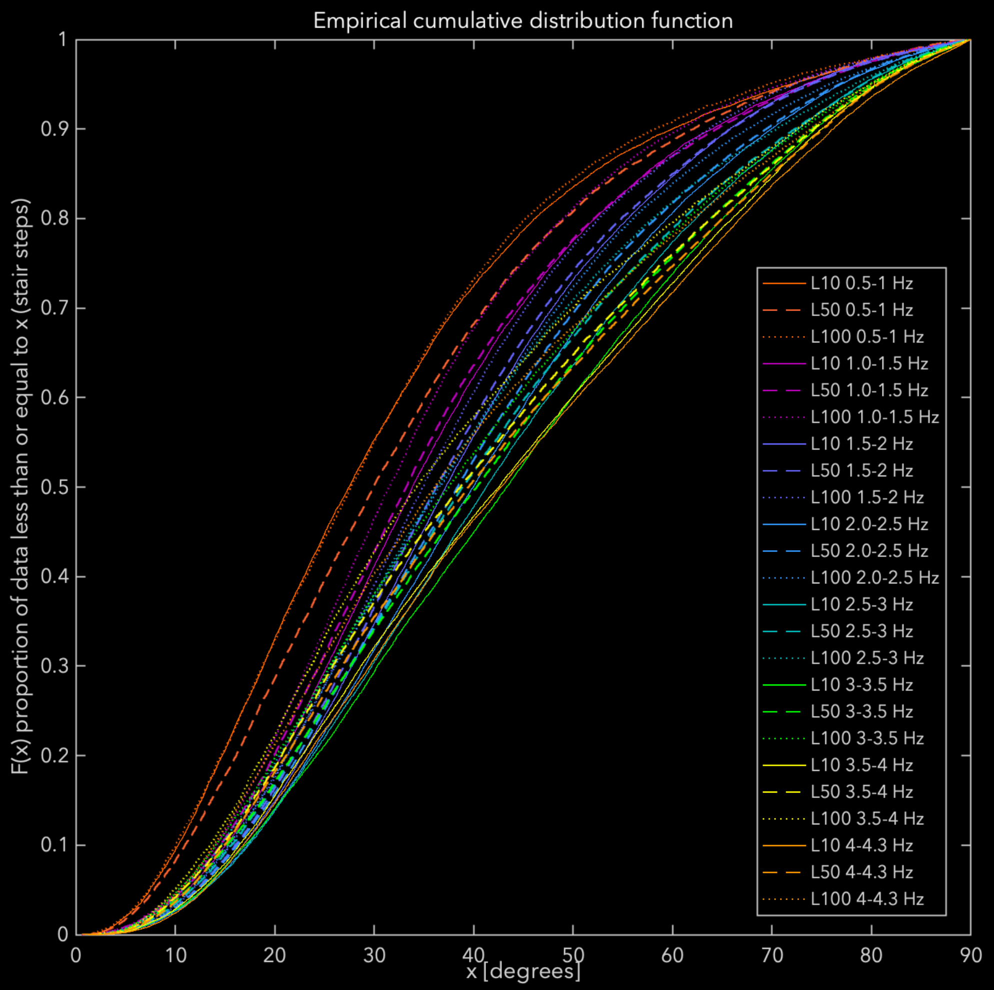
⟼ Why? Nonlinearity (geometry)







Empirical distribution function (stair steps) ⟼ Median and dist. comparisons

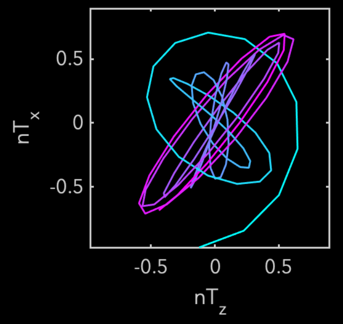


Statistics

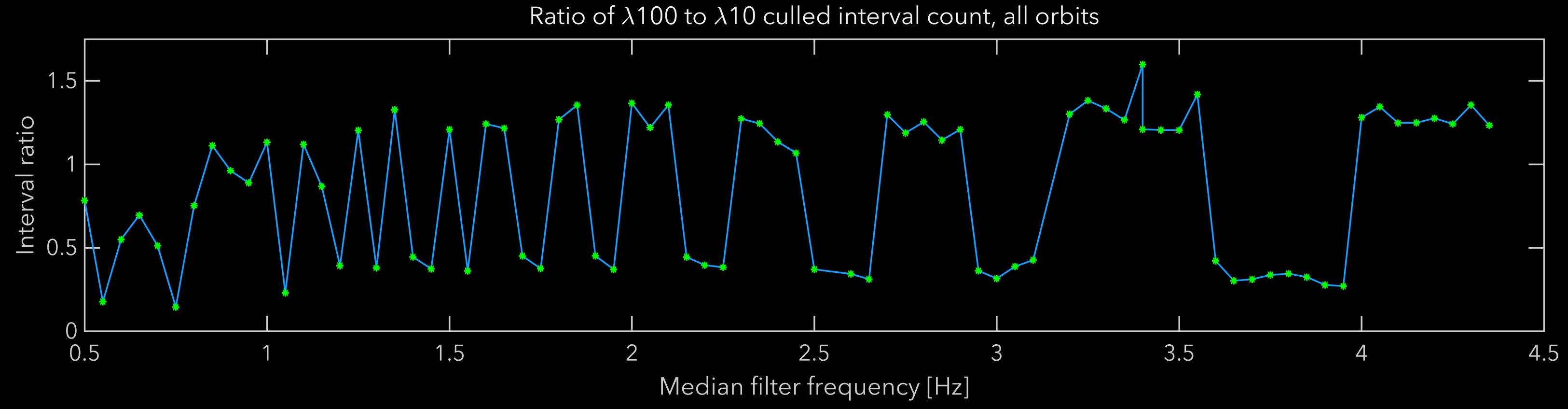
f mid [Hz]	z (median)	p (median)	p (distr.)	h (median)	h (distr.)	Case 1	Case 2	Batch ID
	12.61	e-36	e-30	1	1	10	50	
3.95-4.35	-13.72	e-43	e-36	1	1	100	50	456
	24.51	e-132	e-106	1	1	10	100	
	12.52	e-36	e-29	1	1	10	50	
3.4-3.9	-14.2	e-46	e-41	1	1	100	50	932
	26.08	e-150	e-131	1	1	10	100	
	17.33	e-67	e-61	1	1	10	50	
1.7-3.35	-19.28	e-83	e-60	1	1	100	50	390
	35.49	e-276	e-215	1	1	10	100	
	0.0253	0.9798	0.3999	0	0	10	50	
0.45-1.65	-12.42	e-35	e-29	1	1	100	50	440
	12.17	e-34	e-30	1	1	10	100	

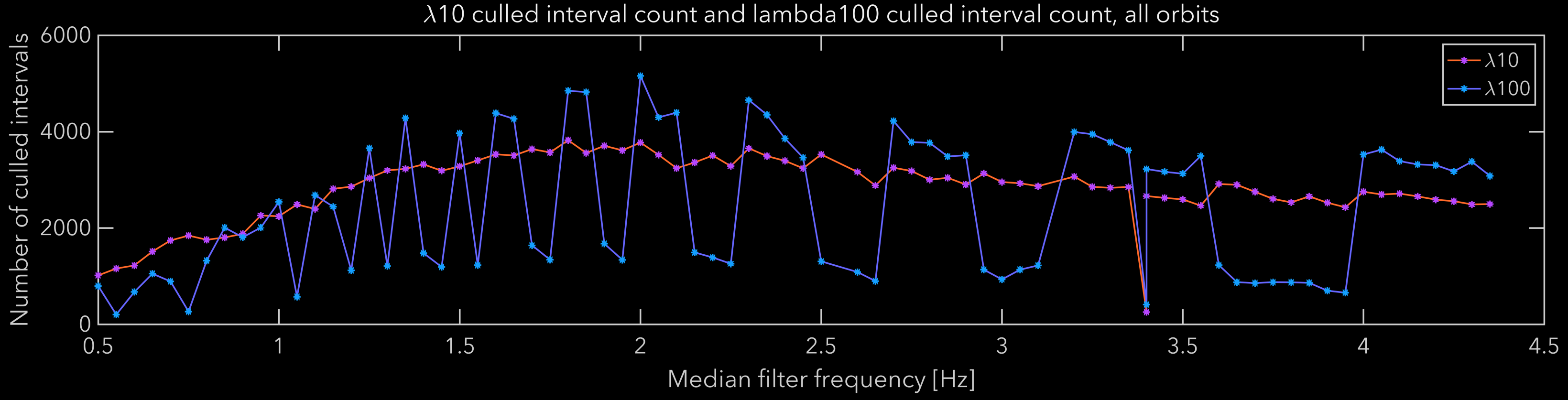
2 key distinctions

⟼ 1) non-criteria, 2) more than 1 wave



1. See above hodogram
2. Combine adjacent hodograms (examples!)



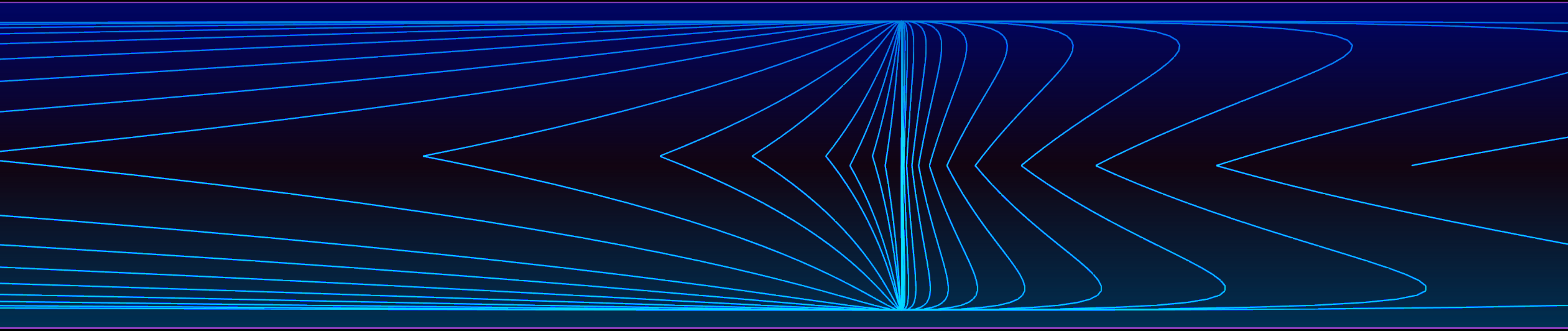


Thank you!

Key references:

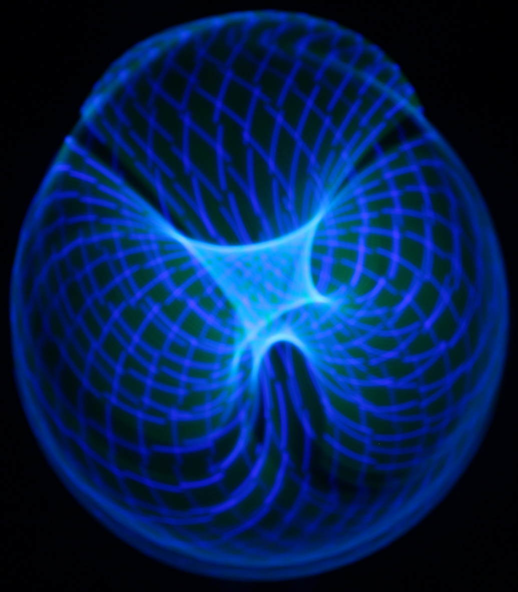
Zhang et al. 2007; Sonnerup and Scheivle 1998; Wilson III 2016 monograph; Giagkiozis et al. 2018; Sham et al. 2014; Collinson et al. 2016;

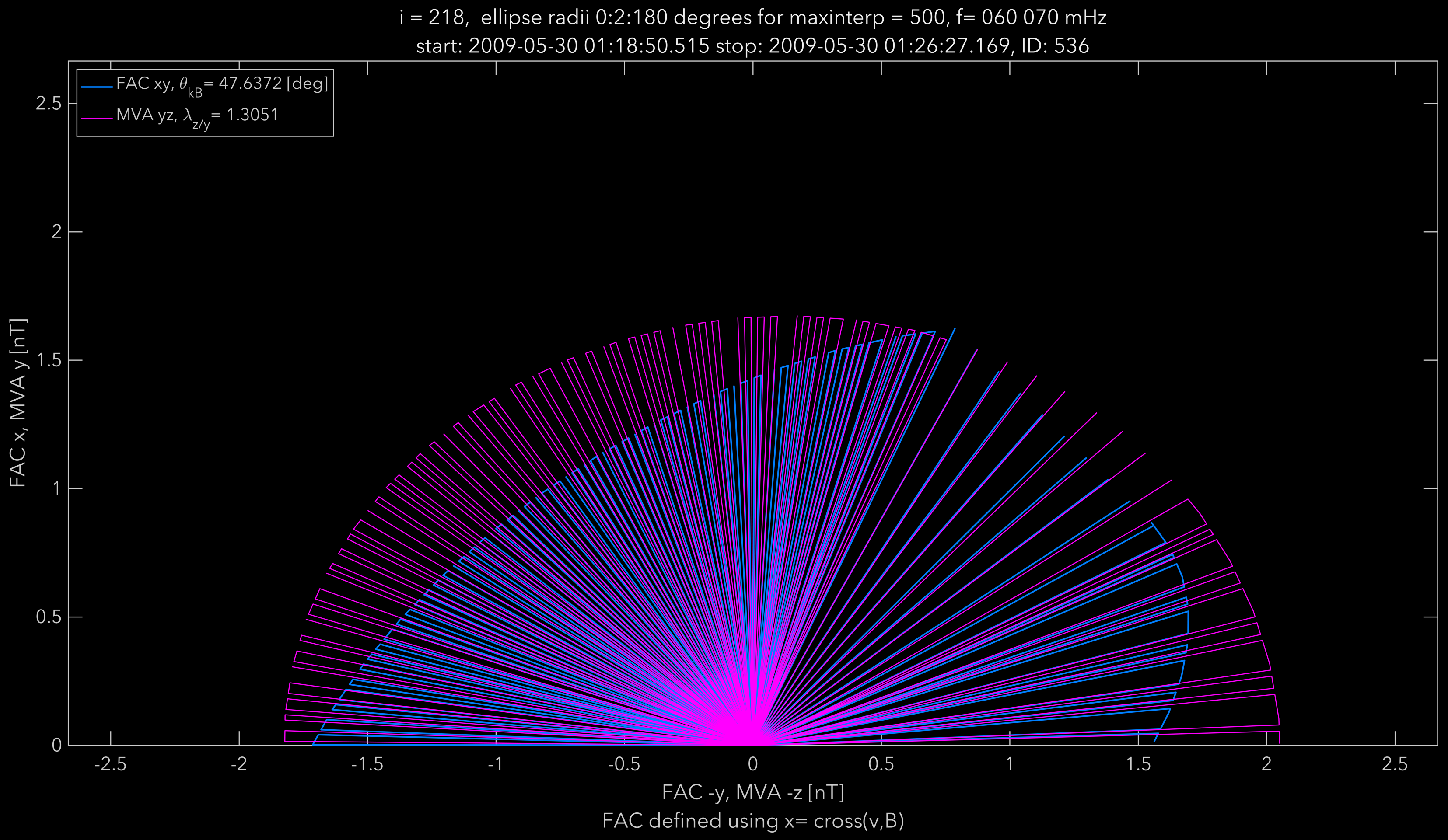
Acknowledgements: NASA, PPPL, snallygasters



Rotation in B_0–normal plane

$\longmapsto$ Look out for long exposure/smearing effect





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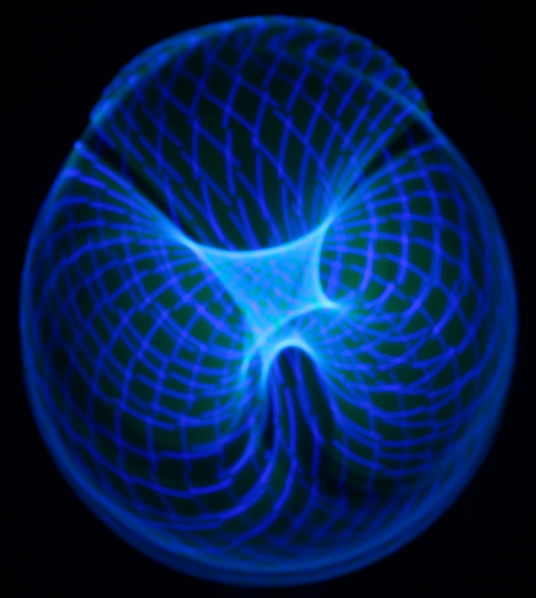
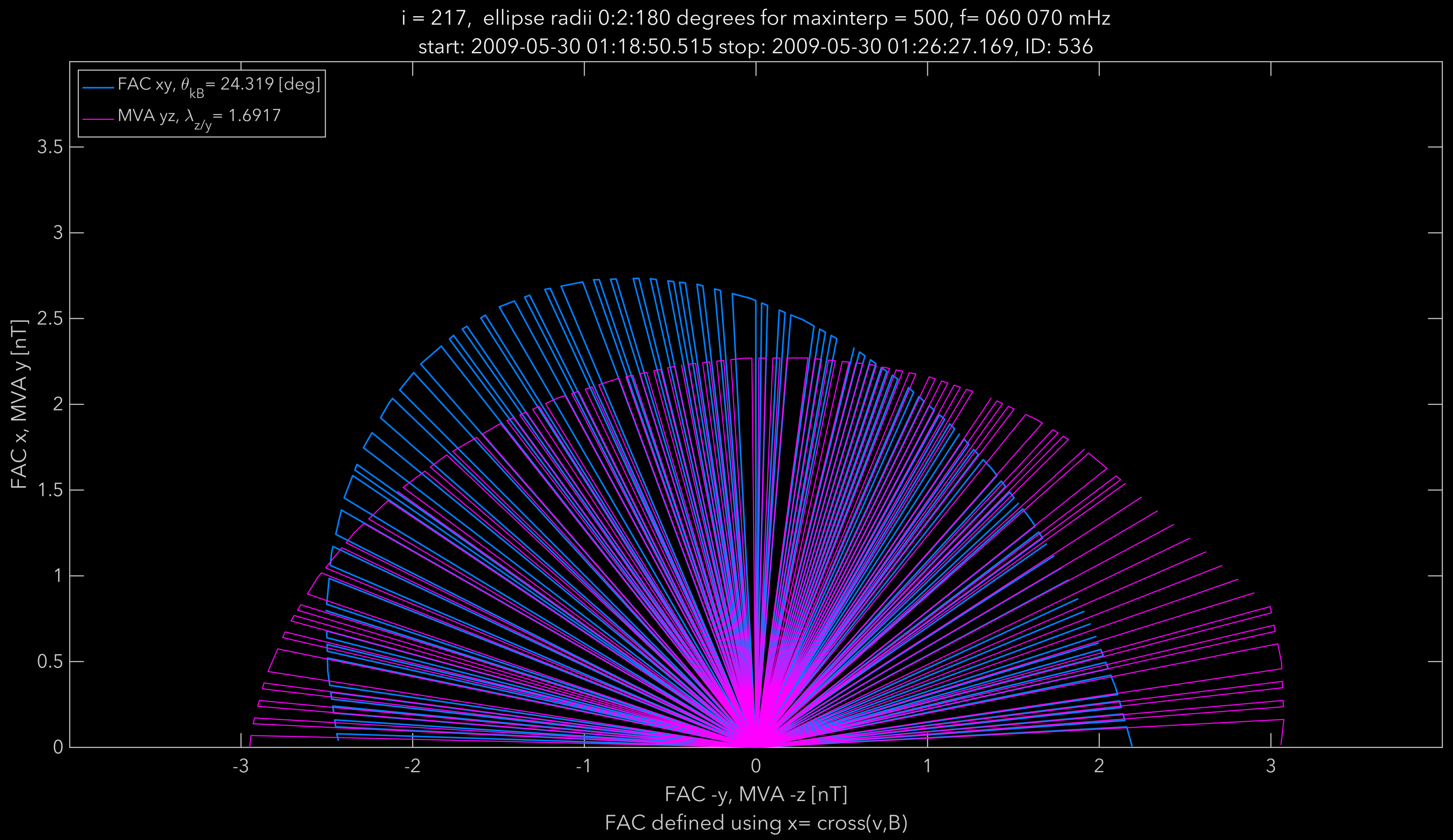
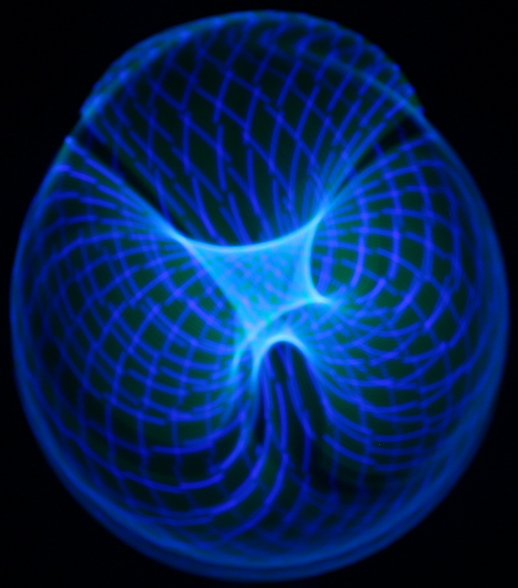
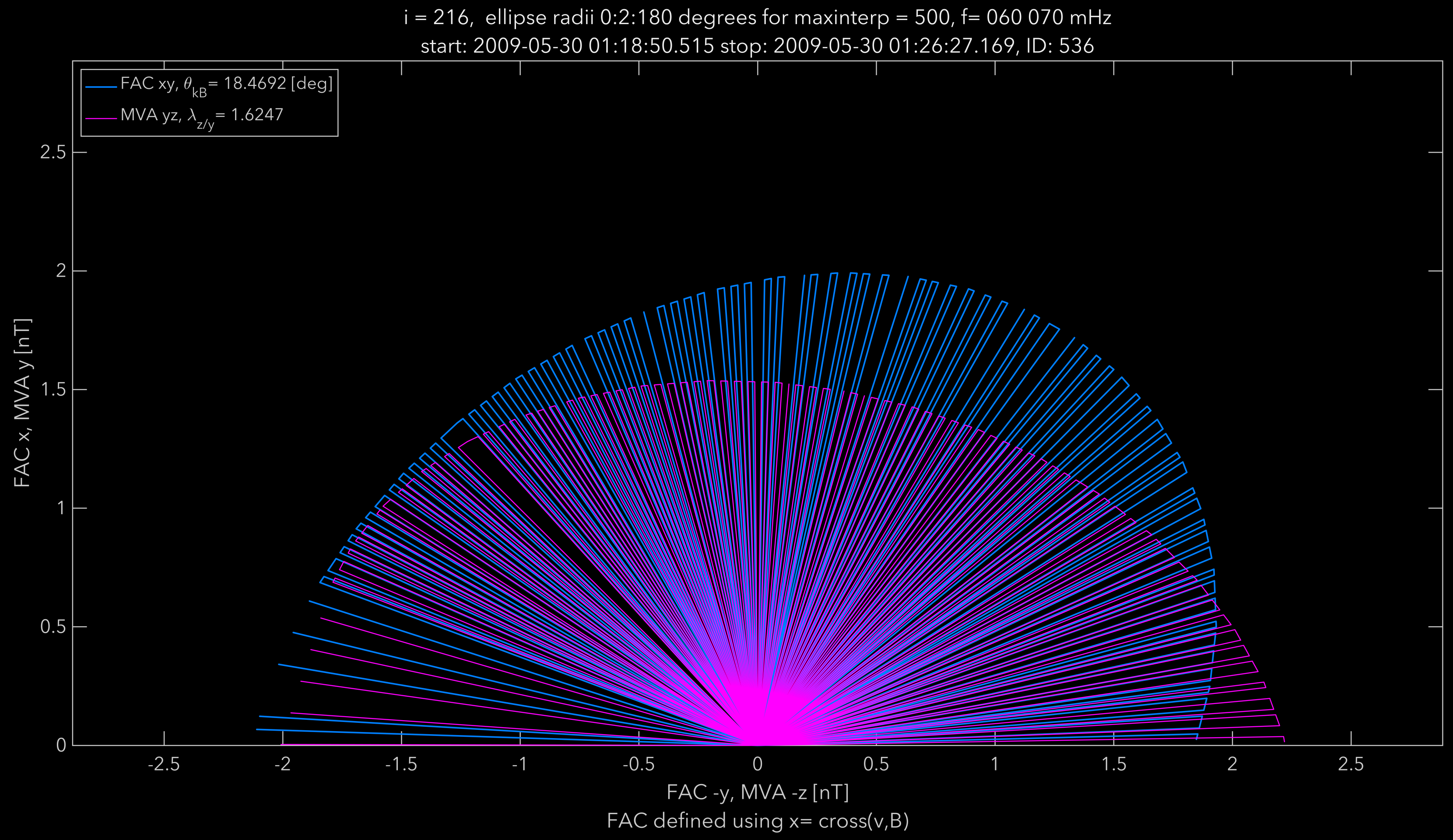




Rotation in B_0-normal plane

⟼ Look out for long exposure/smearing effect





Rotation in B_0-normal plane

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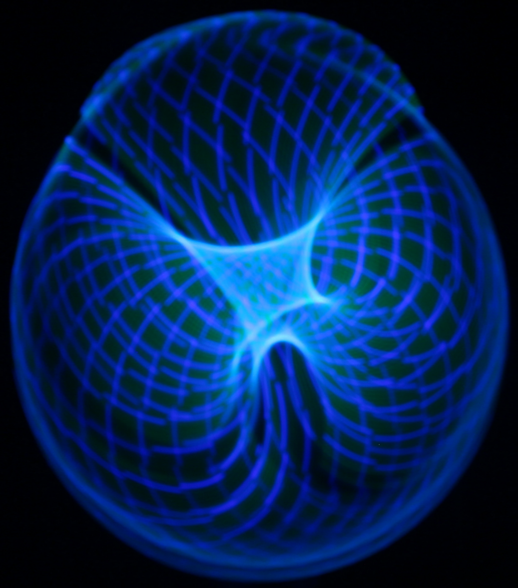
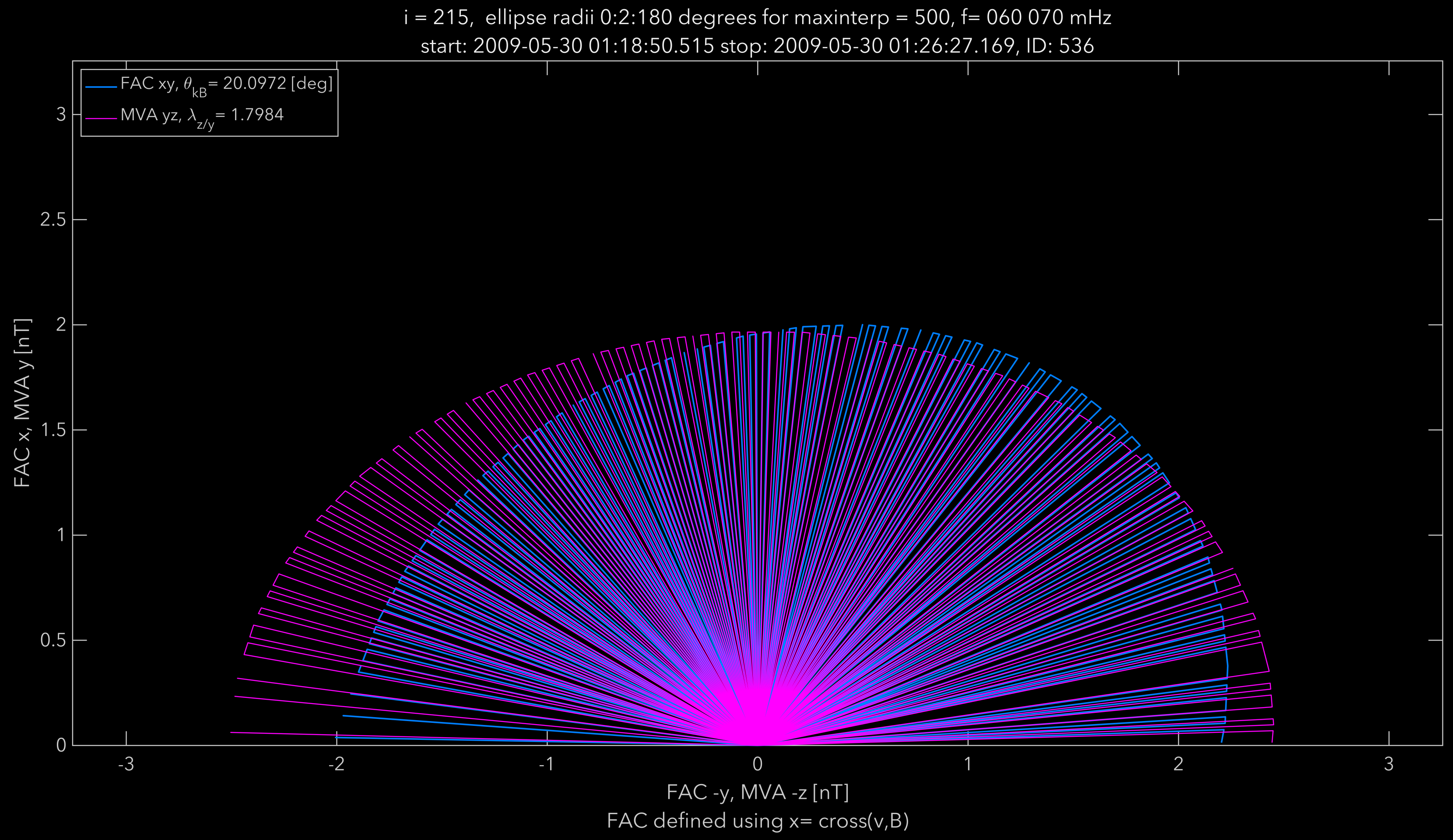
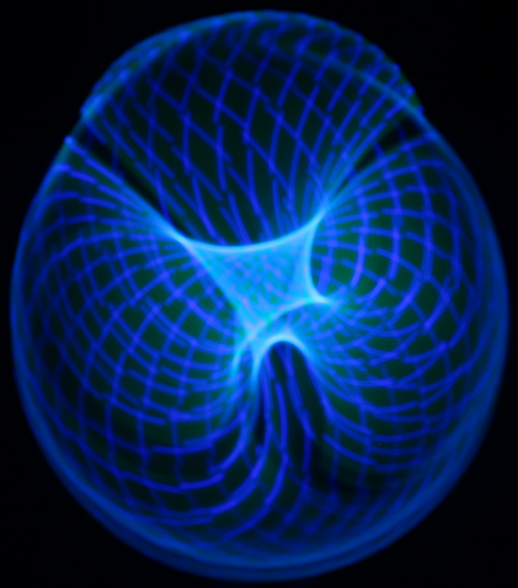
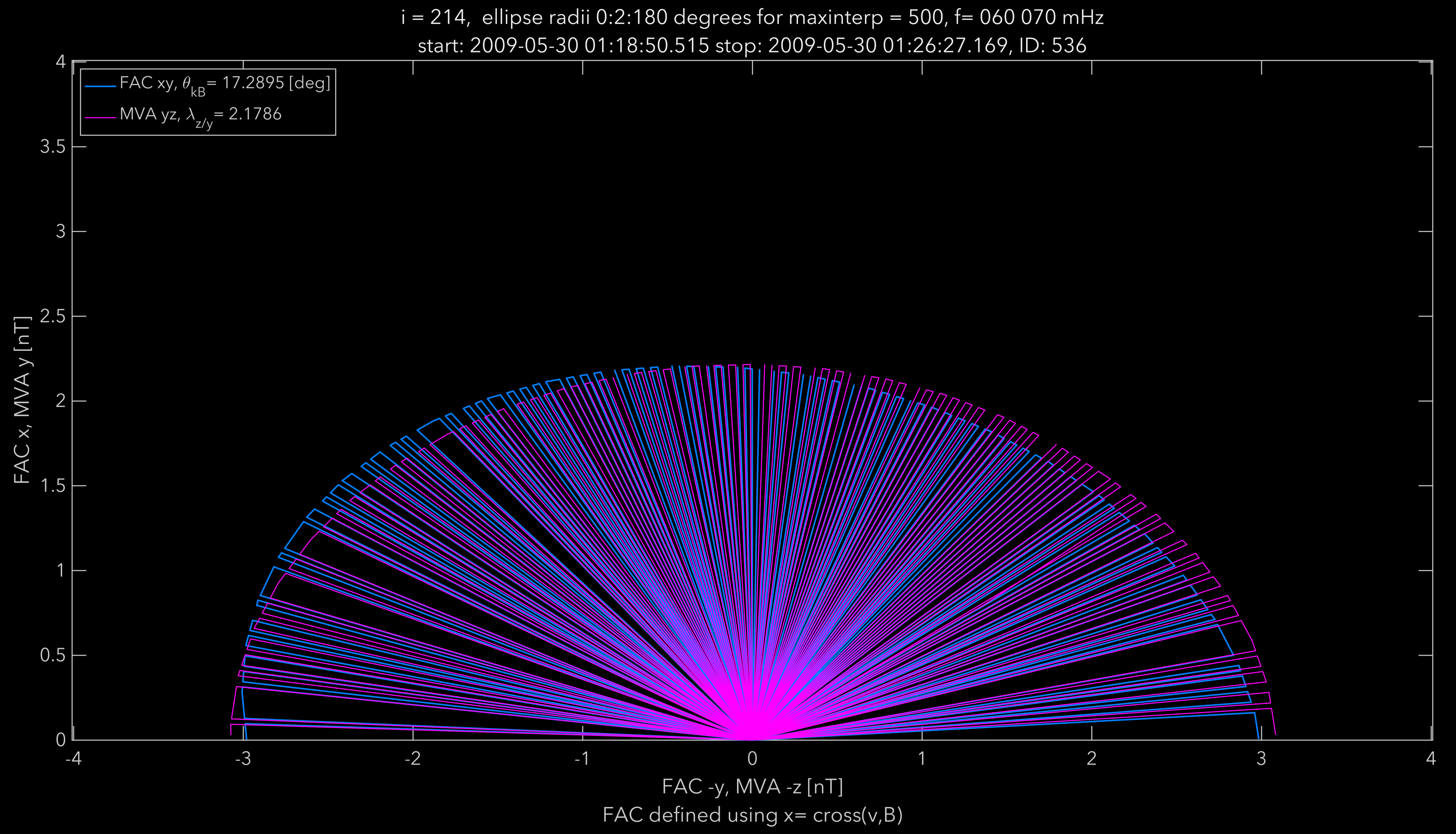




Rotation in B_0-normal plane

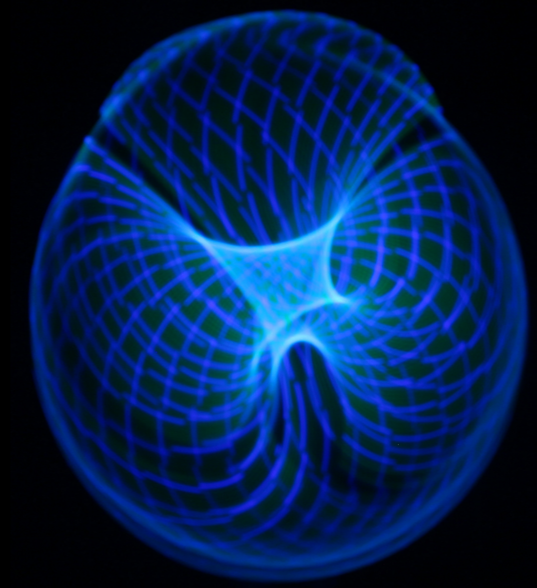
$\longmapsto$ Look out for long exposure/smearing effect

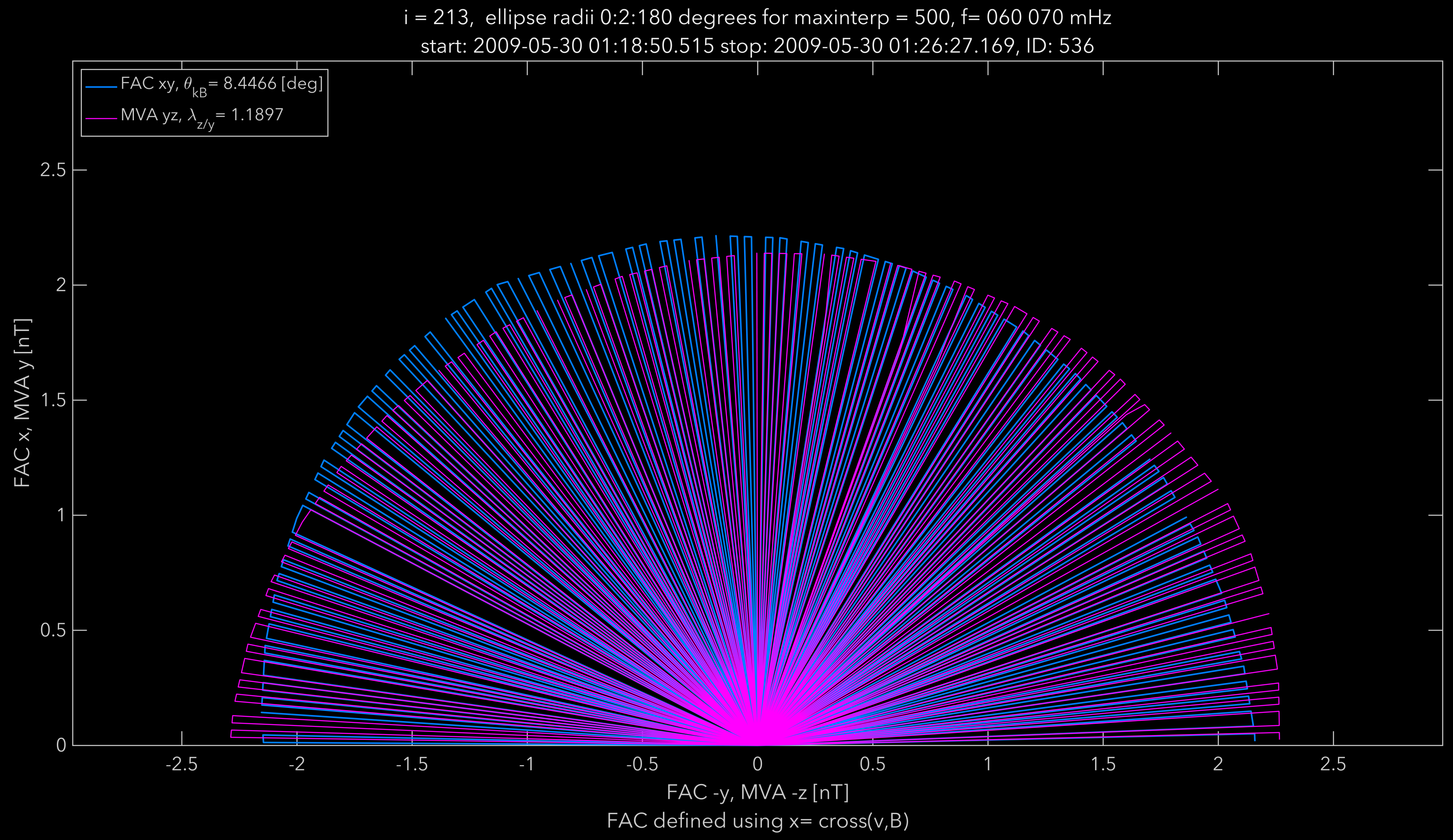




Rotation in B_0-normal plane

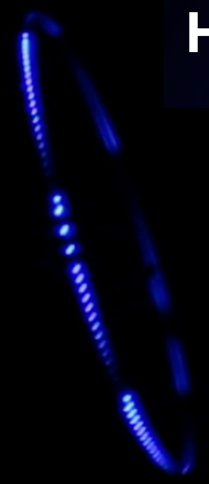
⟼ Look out for long exposure/smearing effect

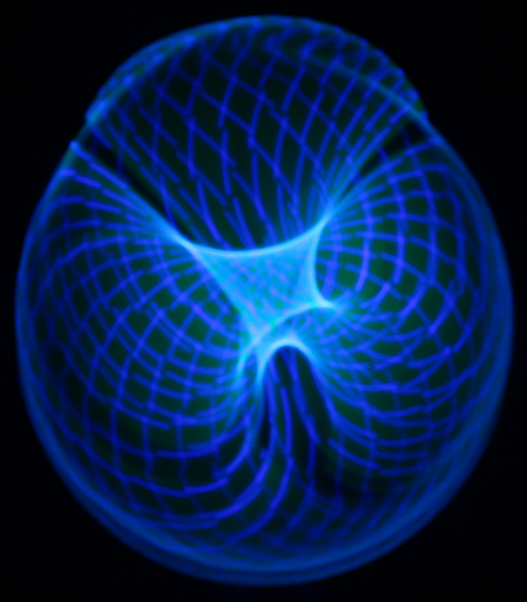


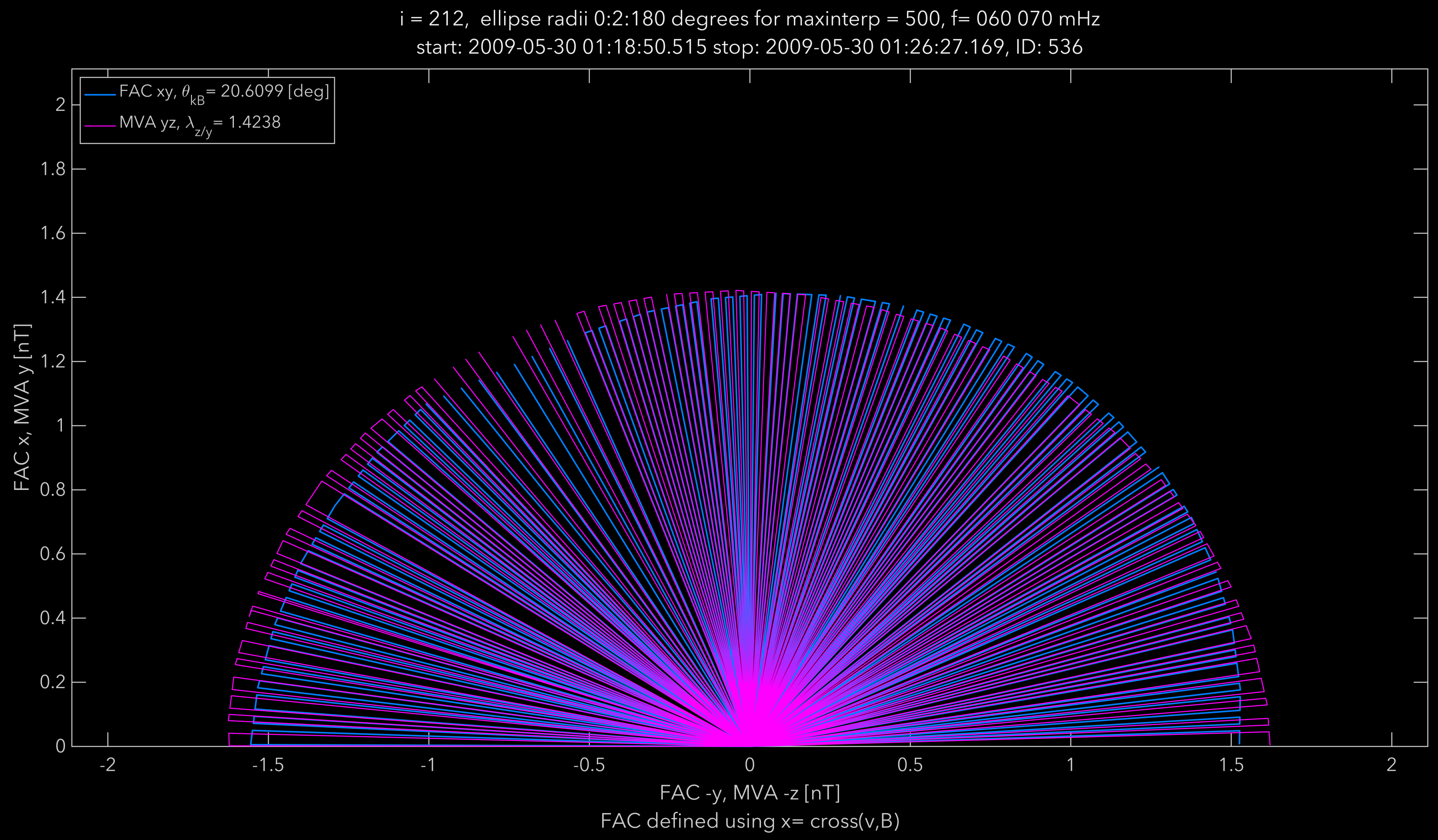


Rotation in B_0-normal plane

$\longmapsto$ Look out for long exposure/smearing effect

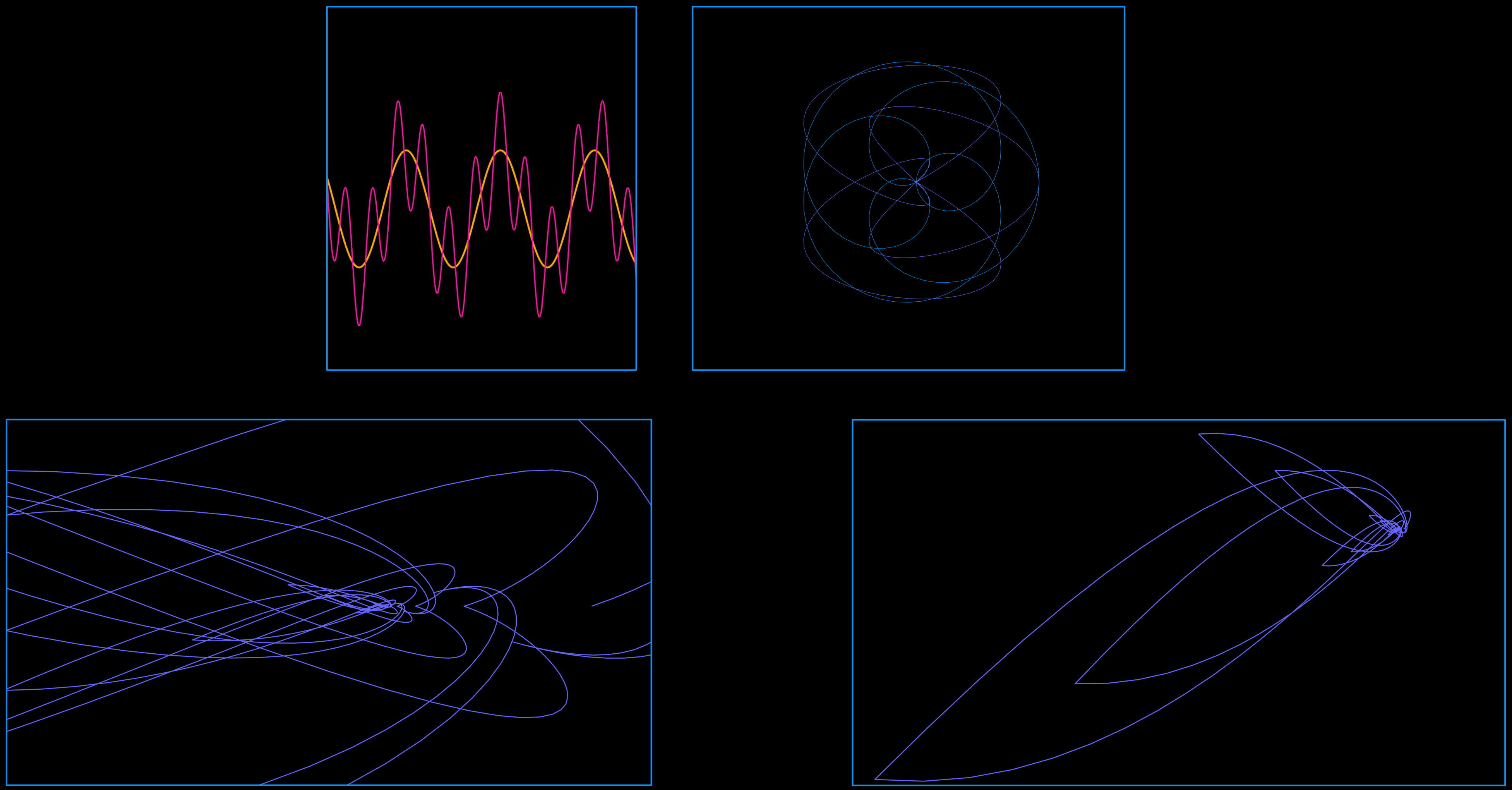






An aside regarding idealized “cat ear” waves

⟼ *Change envelope dependence...*



An aside regarding wave superposition ⟼ *Poi photography*