Space and rate codes in tectum-pretectum control calibrated hunting manoeuvres

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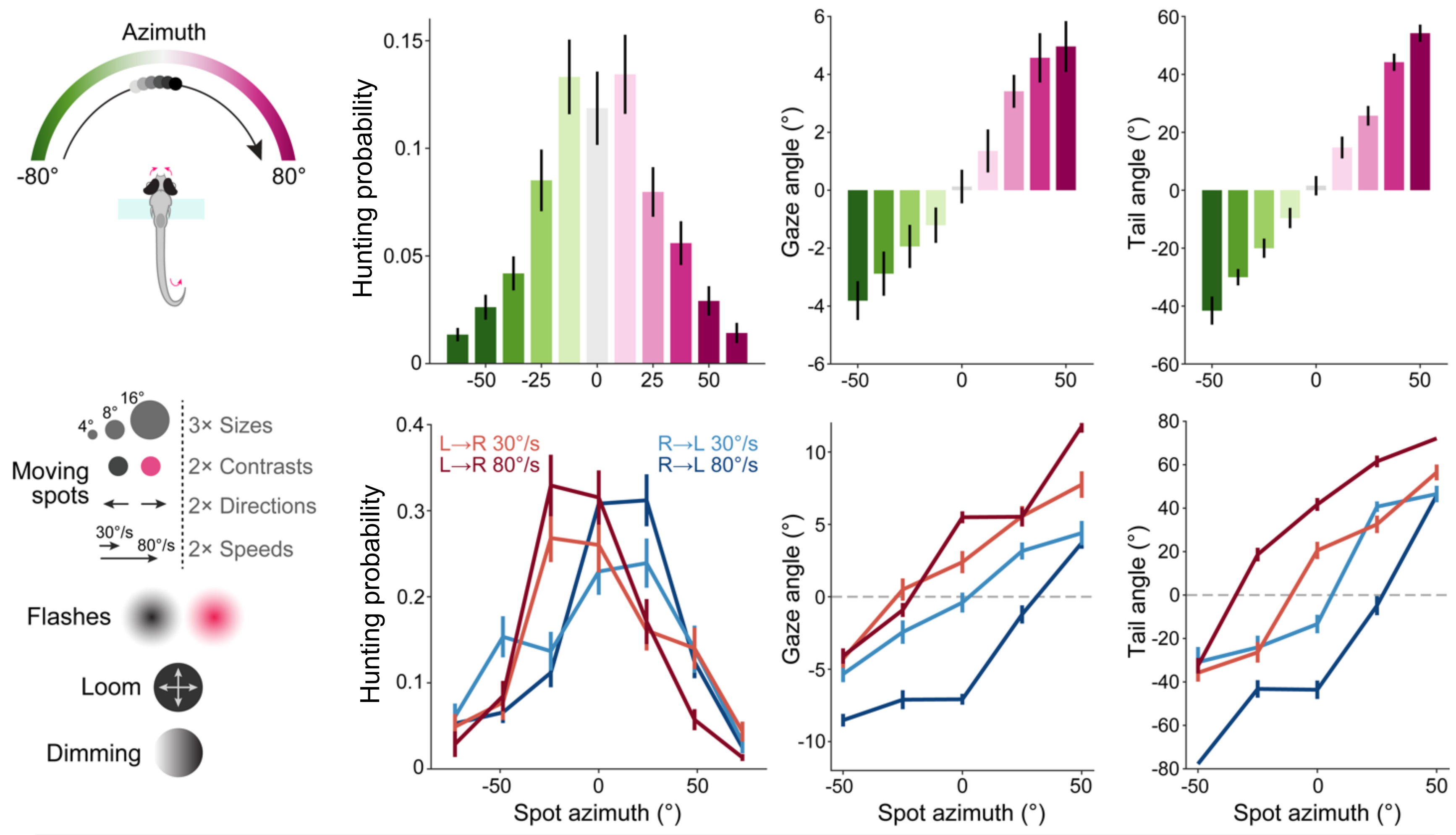
Summary

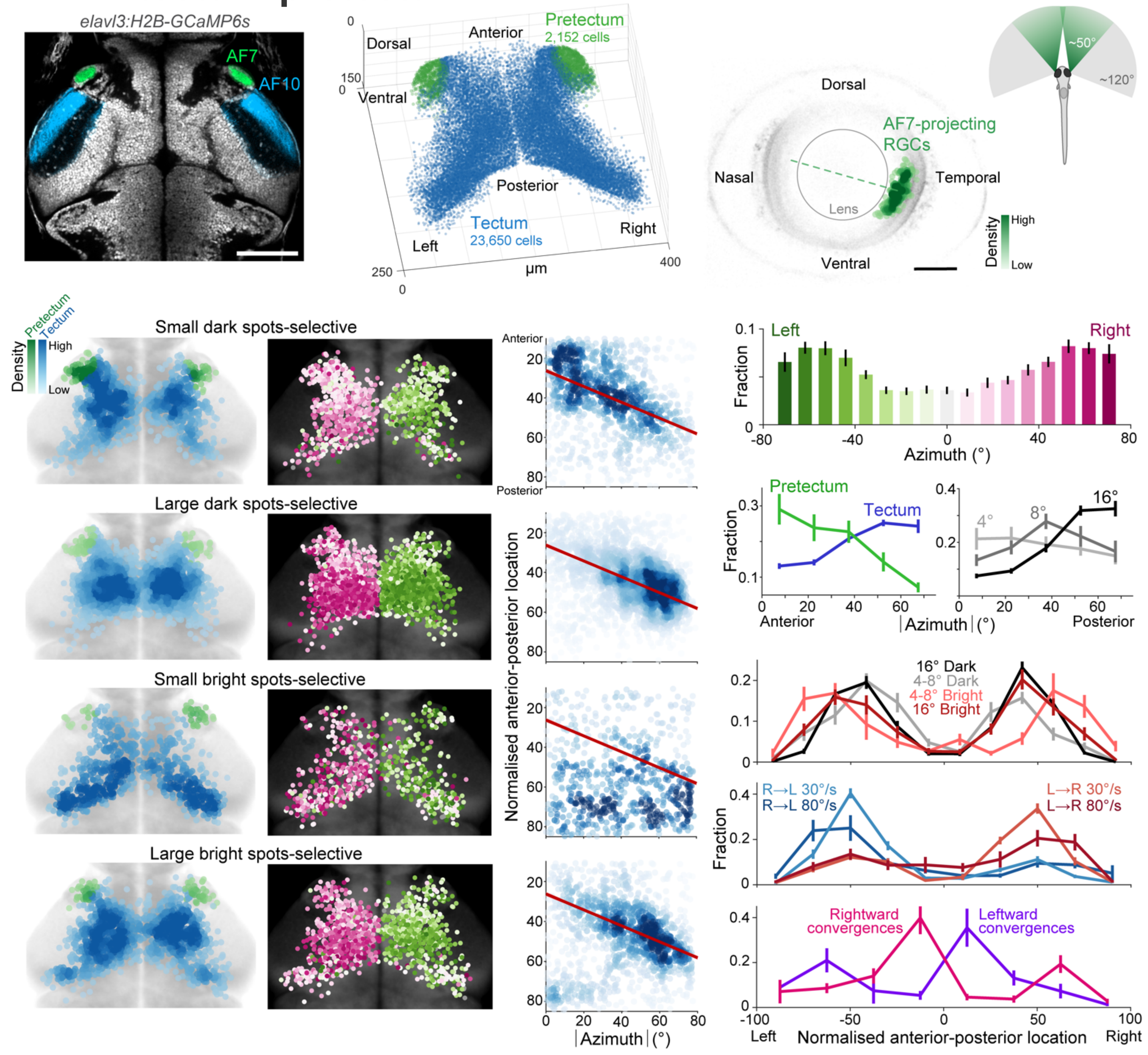
We found that larval zebrafish finely calibrate hunting manoeuvres according to prey location, direction and speed and that these visual properties show biased topographic representations in tectum-pretectum, with pretectum mostly representing anterior visual space. Our functional calcium imaging and optogenetic stimulation data indicate that a pretectal rate code in combination with a tectal space code accurately steer hunting manoeuvres to efficiently track moving targets. Analyses of projection patterns suggest that differential activation of ipsi/contra-lateral tectobulbar pathways underlie the recruitment of distinct downstream motor programmes.

1 Hunting manoeuvres are calibrated according to stimulus location, direction and speed



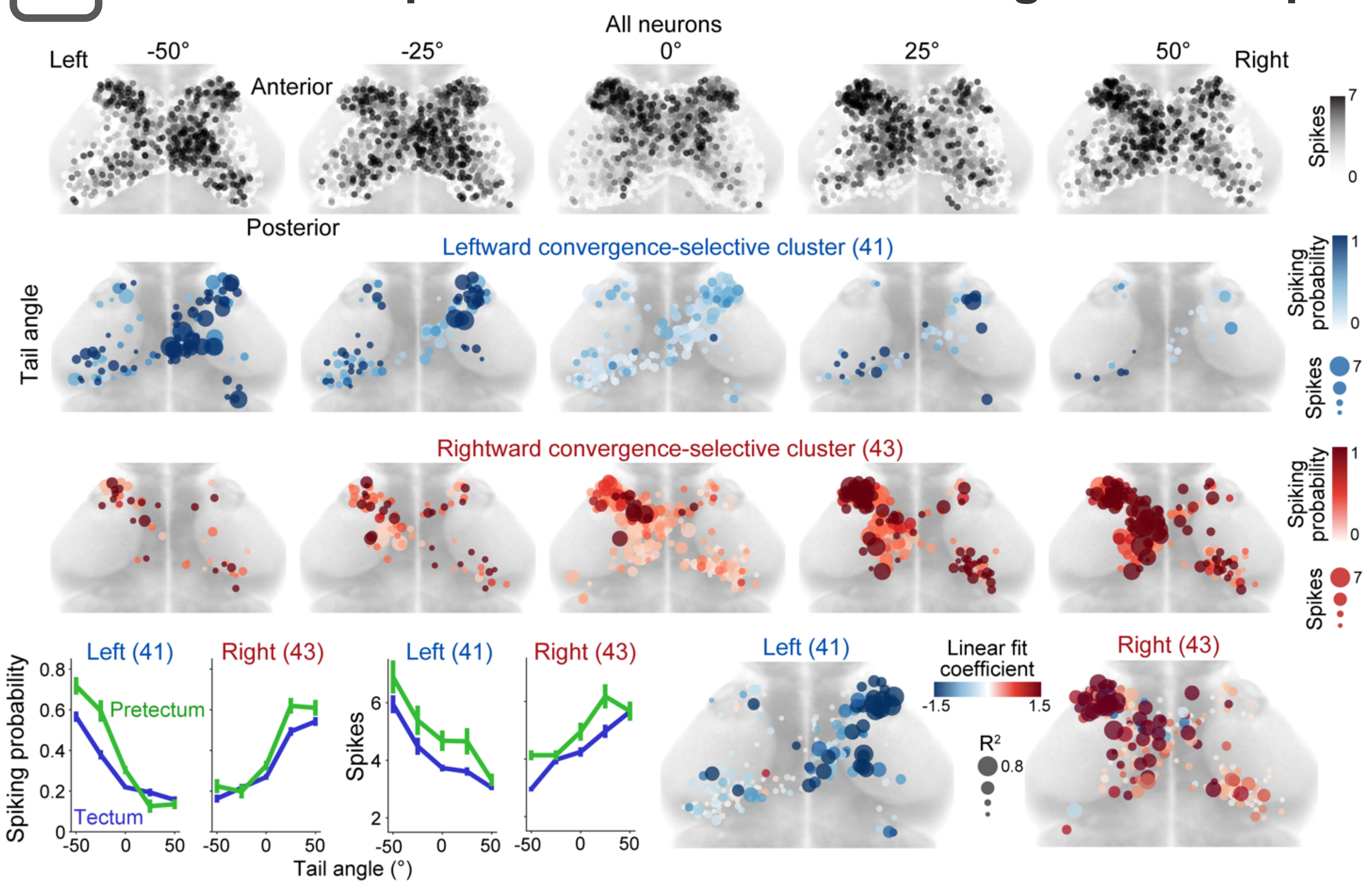
- We provided a range of visual stimuli to tethered larval zebrafish and monitored their eye and tail movements. Stimuli included spots moving across ~160° of frontal visual space and dark looming disks.
- Hunting was preferentially initiated when prey-like visual stimuli were in frontal locations of visual space.
- Larvae could finely calibrate gaze and tail amplitude of hunting manoeuvres according to stimulus azimuth.
- The steering of hunting movements was shifted either ipsi- or contra-laterally to stimulus location depending on stimulus direction and speed.

2 Biased topographic representations of prey-like stimuli in tectum-pretectum



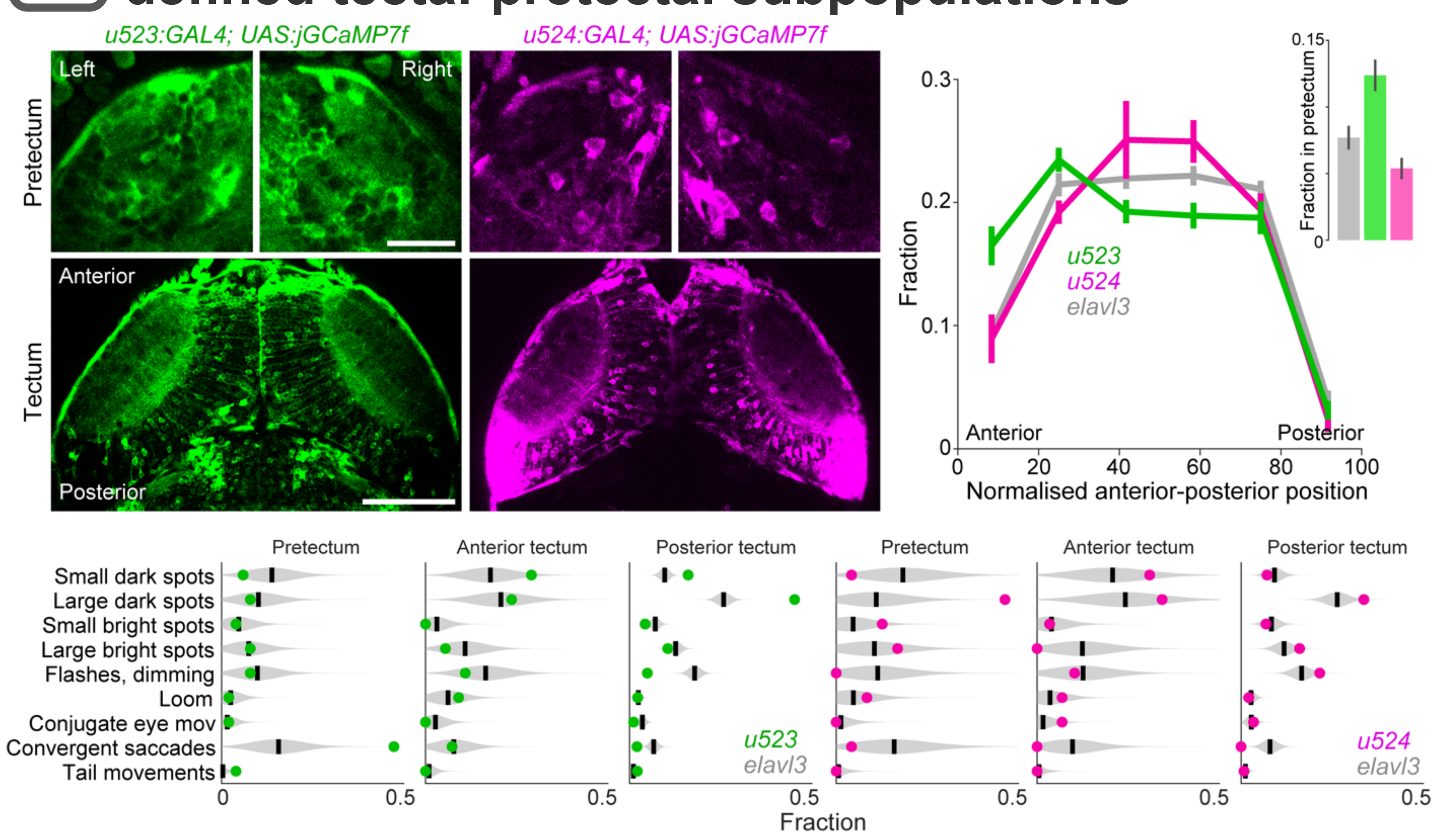
- Estimation of visual receptive fields revealed that most spot-tuned neurons conform to a retinotopic map where azimuth is mapped along the anterior-posterior axis of the tectum. However, neurons with different feature tuning show distinct, heterogeneous distributions, with dark small spot-selective neurons mostly representing anterior visual space while dark large spot-selective representing posterior.
- Both functional and anatomical data showed a bias for anterior visual space in pretectum.
- Representations of motion direction and speed were also biased along anterior-posterior axis and between left-right hemispheres. Temporal-to-nasal movement was over-represented in each hemisphere with slow motion-selective neurons biased to anterior locations and fast motion-selective neurons biased to posterior locations.

3 Combined space-rate codes in hunting motor maps



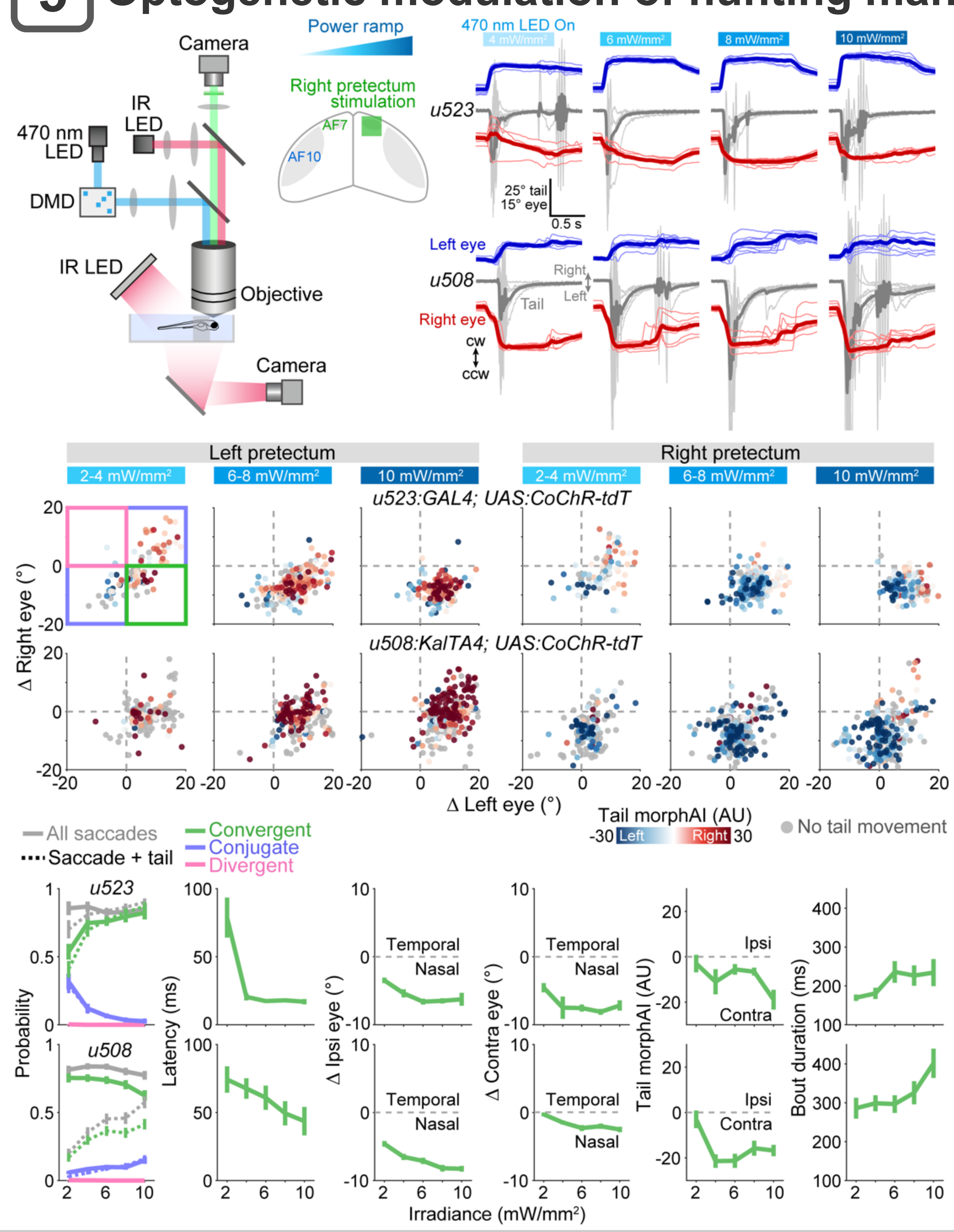
- Maps of hunting-triggered activity showed symmetric activation of anterior regions during non-lateralised hunting manoeuvres, while lateralised manoeuvres were associated with increased activity in regions contralateral to movement direction.
- We found a gradient of activity recruitment across pretectum → anterior tectum → posterior tectum as amplitude of lateralised tail movements increased, consistent with a space code. A substantial fraction of neurons was also located in the posterior tectum ipsilateral to tail movement direction.
- Spiking probability and number of spikes fired by individual tectal-pretectal neurons were modulated by laterality and amplitude of tail movements, indicative of a population rate code.

4 Genetic access to functionally and anatomically defined tectal-pretectal subpopulations



- Cells labelled by the *u523:GAL4* line tend to be located in anterior tectal regions while the *u524:GAL4* line labels cells in posterior tectum. In *u523:GAL4*, a higher fraction of cells is labelled in pretectum vs. tectum than in the pan-neuronal line *elavl3:H2B-GCaMP6s*, while in *u524:GAL4* the pretectal cell fraction is lower.
- The *u523:GAL4* line tends to label hunting-selective neurons in pretectum and anterior tectum. This functional enrichment is particularly high in pretectum. The *u524:GAL4* line labels few if any neurons belonging to this functional group.

5 Optogenetic modulation of hunting manoeuvre steering



- Patterned illumination was used to focally activate pretectum with increasing irradiance in tethered *u523:GAL4* or *u508:KalTA4; UAS:CoChR-tdTomato* transgenic larvae.
- In both transgenic lines, pretectal stimulations induced hunting initiation (i.e. eye convergences) associated with tail movements directed contralaterally to the stimulated hemisphere.
- Increasing stimulation power induced gradually larger nasal shifts in eye position and more lateralised tail movements of longer duration, consistent with a rate code of hunting manoeuvre steering in pretectum.
- Tectal activations supported a space code such that stimulating increasingly posterior regions gradually shifted hunting movements ipsilaterally.

6 Tectal-pretectal projection patterns

Tectum and pretectum have biased projection patterns, with tectum preferentially innervating ipsilateral hindbrain targets via uncrossed axonal pathways, while pretectum-anterior tectum showing prominent crossed projections to contralateral midbrain-hindbrain targets.