# Competition vs. cooperation in the anterior cingulate cortex

Jason Sherfey
Cognitive Rhythms Collaborative
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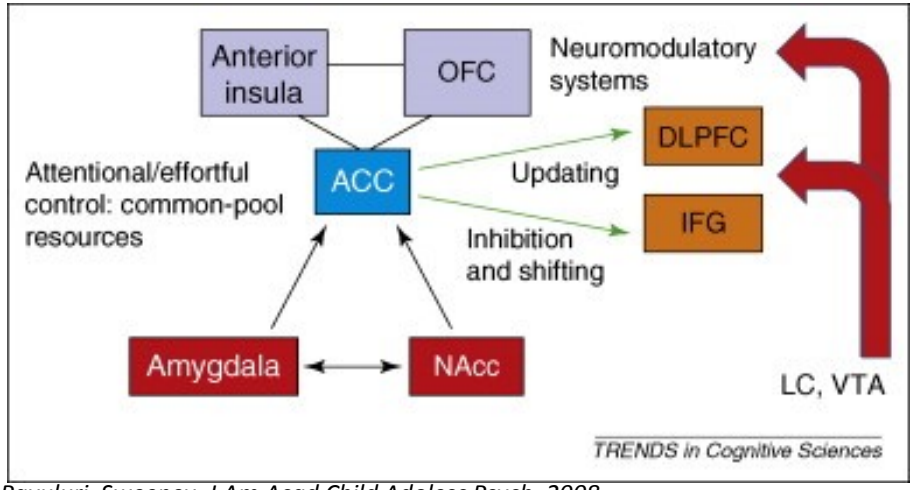
# ACC is a hub receiving diverse inputs

From multiple systems:

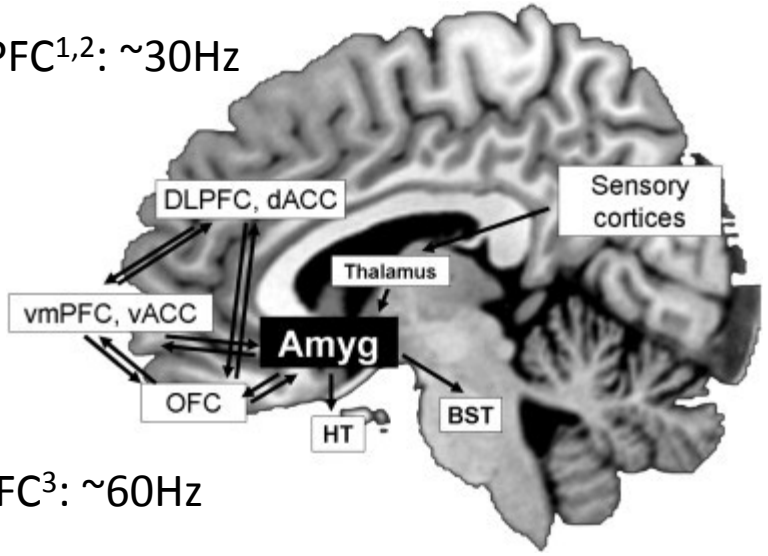
Affective Cognitive




*Pavuluri, Sweeney, J Am Acad Child Adolesc Psych. 2008*

At different frequencies:

LPFC[1,2]: ~30Hz




OFC[3]: ~60Hz

BLA: 35-45Hz A2: 30-50Hz

Question: How does ACC respond to combinations of inputs at different frequencies: **competition** versus **cooperation**.

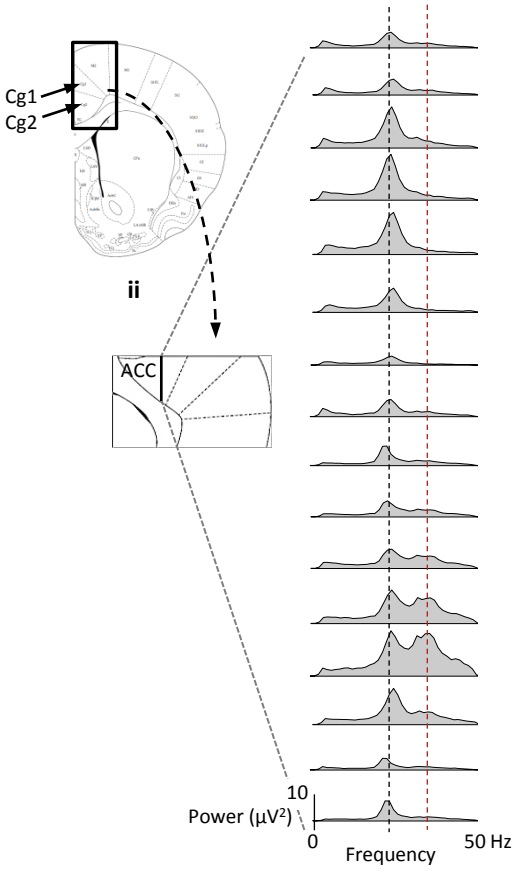
Approach:

1. Develop experimentally-constrained models of layer-specific cell types and networks in ACC.
2. Study response of competing assemblies to multiple inputs with different frequencies.

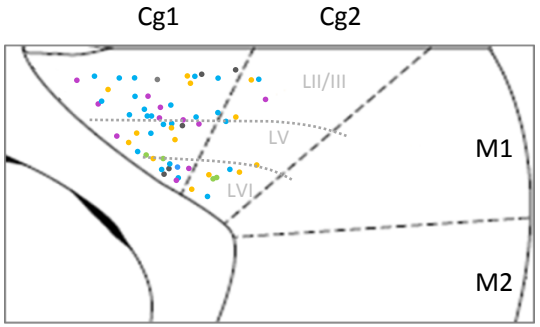
*[1] Siegel, Warden, Miller. PNAS 2008. [2] Buschman, Denovellis, Diogo, Bullock, Miller. Neuron 2012. [3]* Pennartz, van Wingerden, Vinck. *Annals of NY Acad of Sciences* 2011.

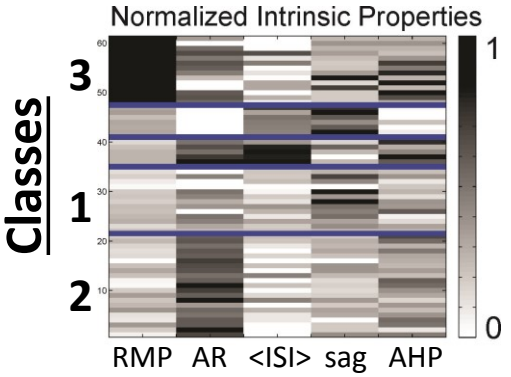
# ACC cells and networks exhibit diverse properties

## Network rhythms

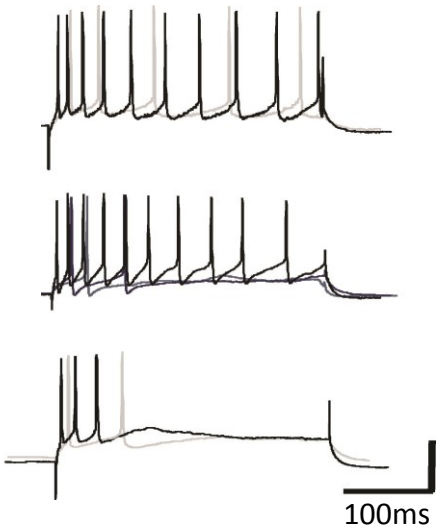



## Cell types identified by classifying intrinsic properties

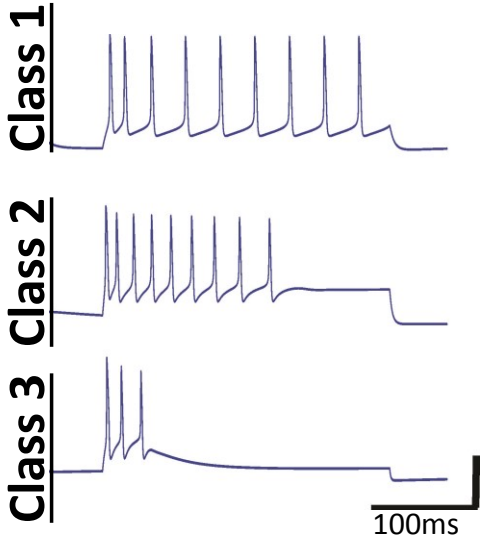


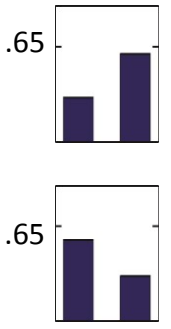

## Recorded cell



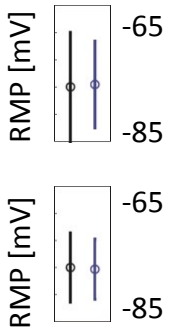

## Model cell




## Layers



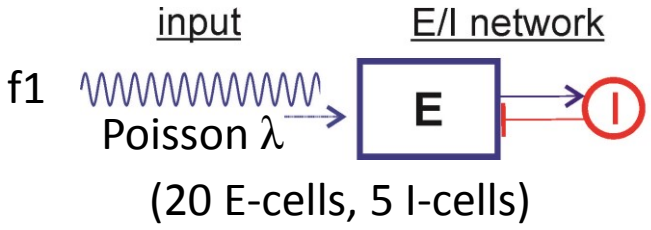

## Diversity



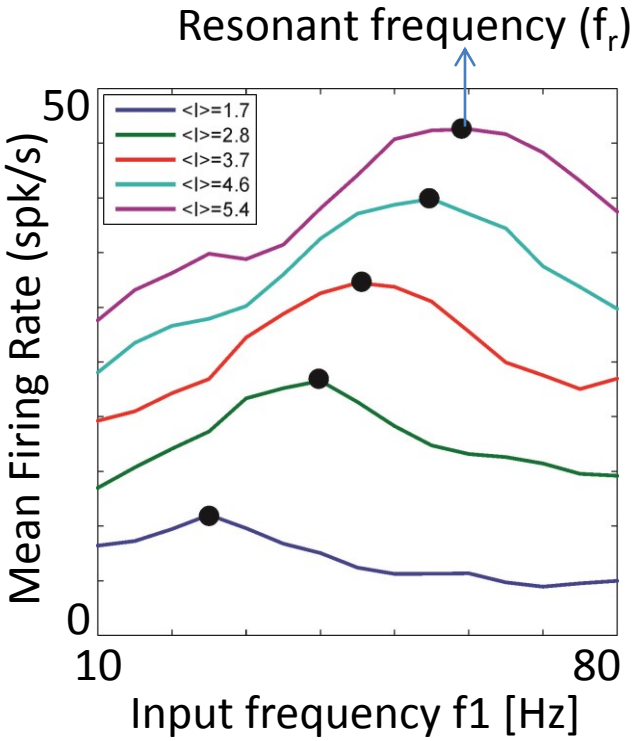

## Heterogeneous populations

*All data provided by the LeBeau lab.*

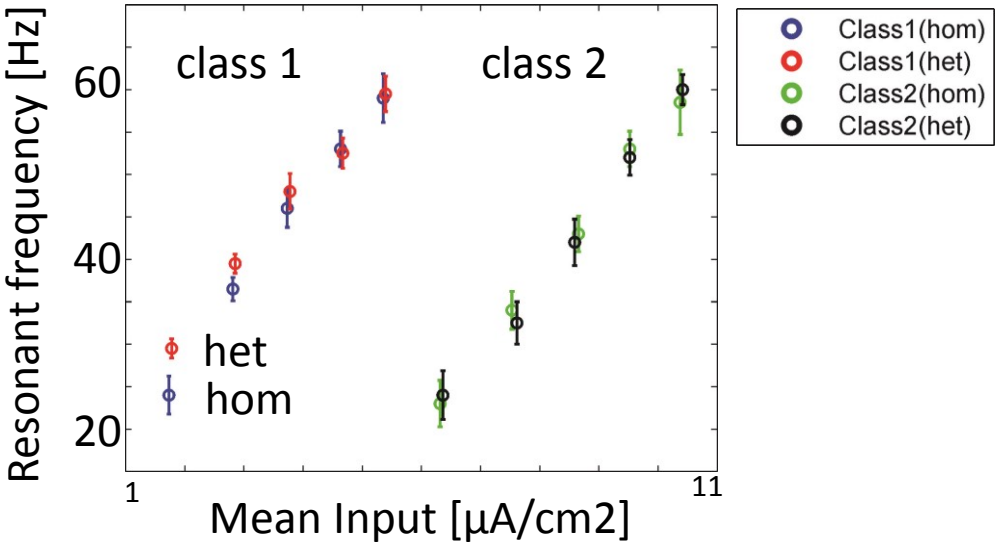
# Network resonance depends on cell class




Network tuning profile (class 1)



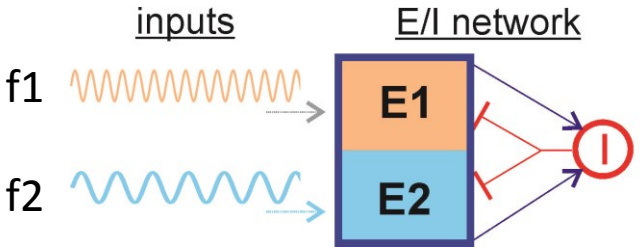

Resonant frequency vs drive

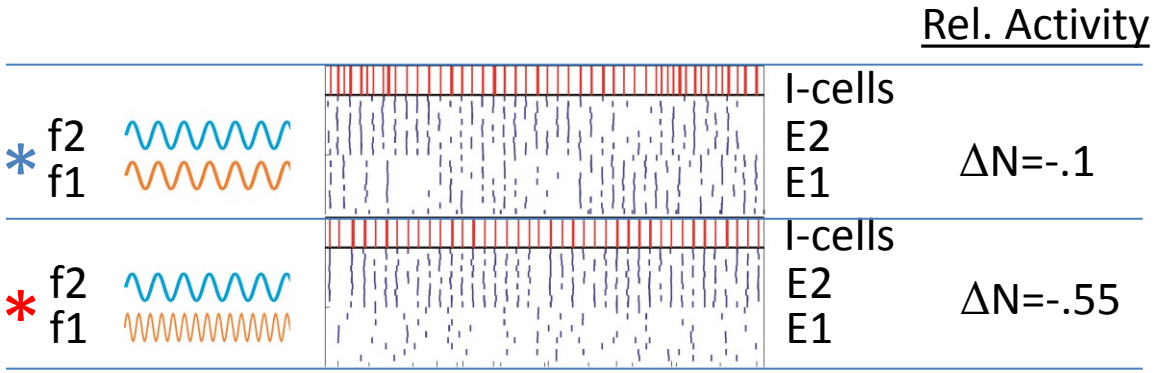



- Resonant frequency $f_r$ increases with mean drive (e.g., increasing synaptic weight or input spike rate)
- RMP heterogeneity increased resonant frequency at low drives in deep layer cells (class 1)

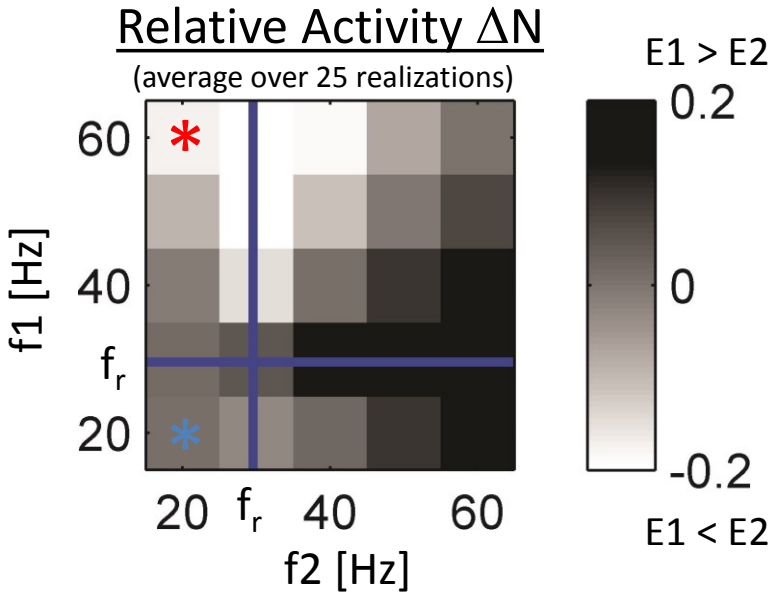
# Network resonance biases assembly competition

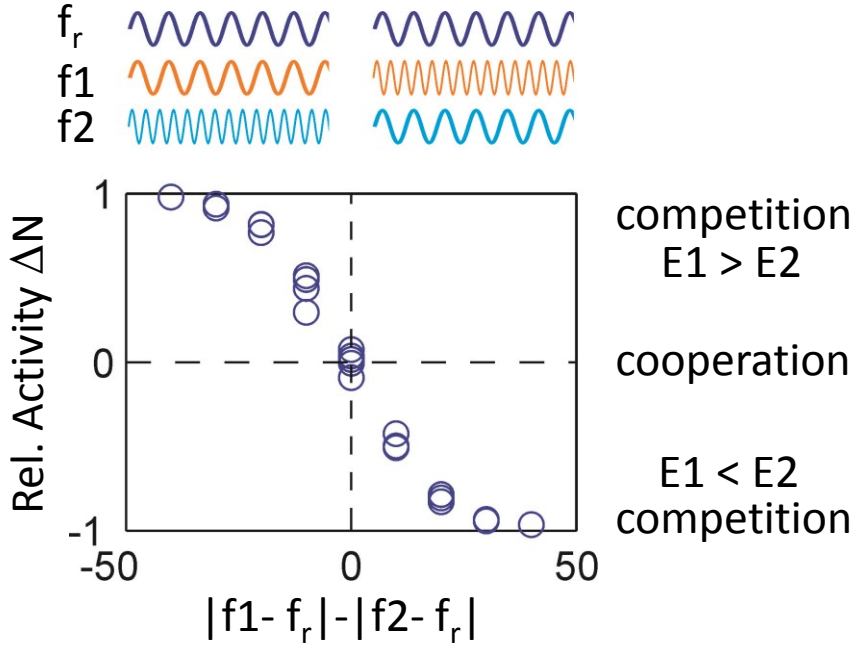
Network with two assemblies



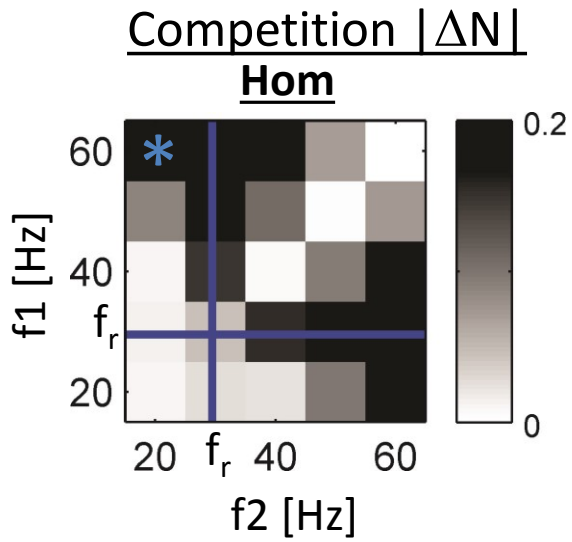

Mean inputs to E1 and E2 are equal, only the spectral content of the inputs differs.

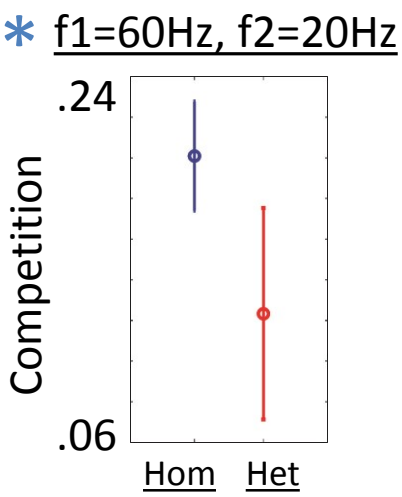


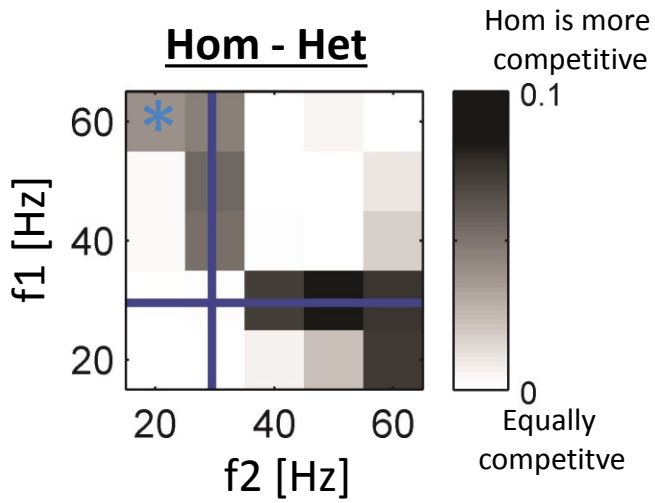



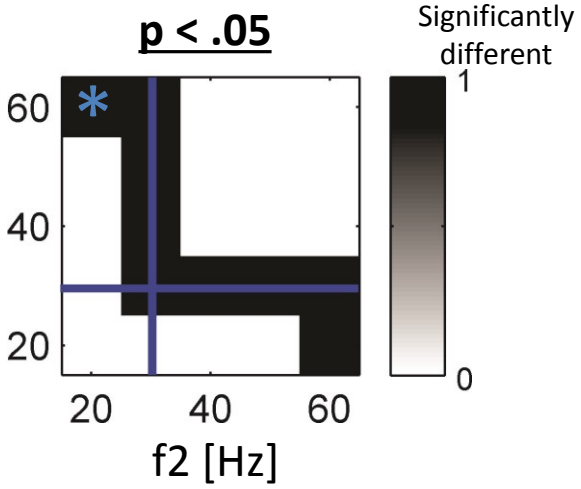

**Relative proximity of inputs to resonance determines whether assemblies compete or cooperate. Greater proximity to resonance induces competitive advantage.**

# Heterogeneity can decrease competition in beta-resonant deep layer cells (class 1)



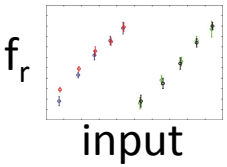



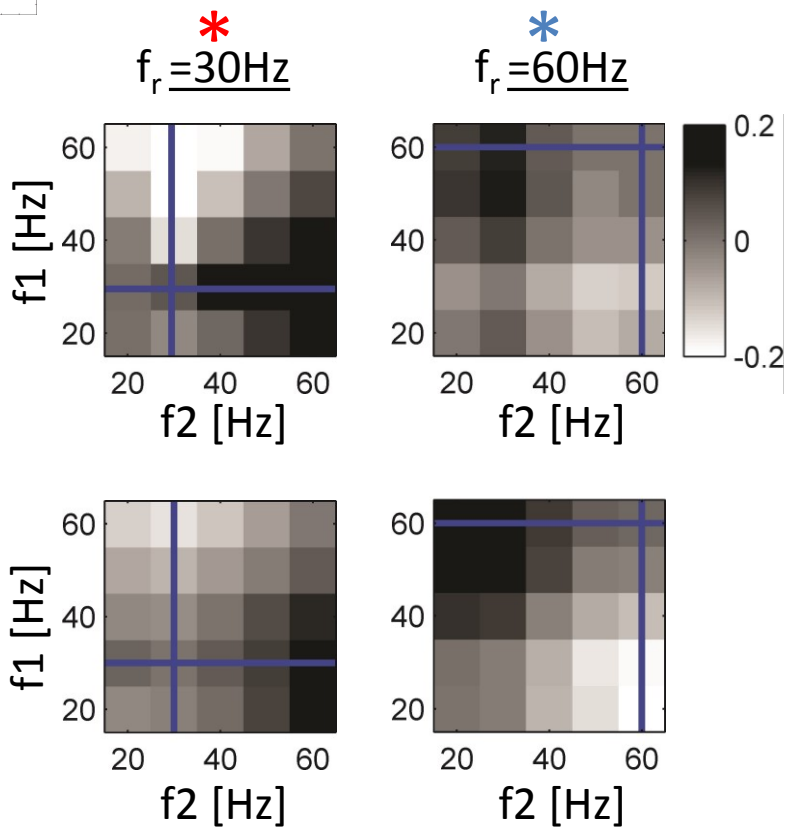



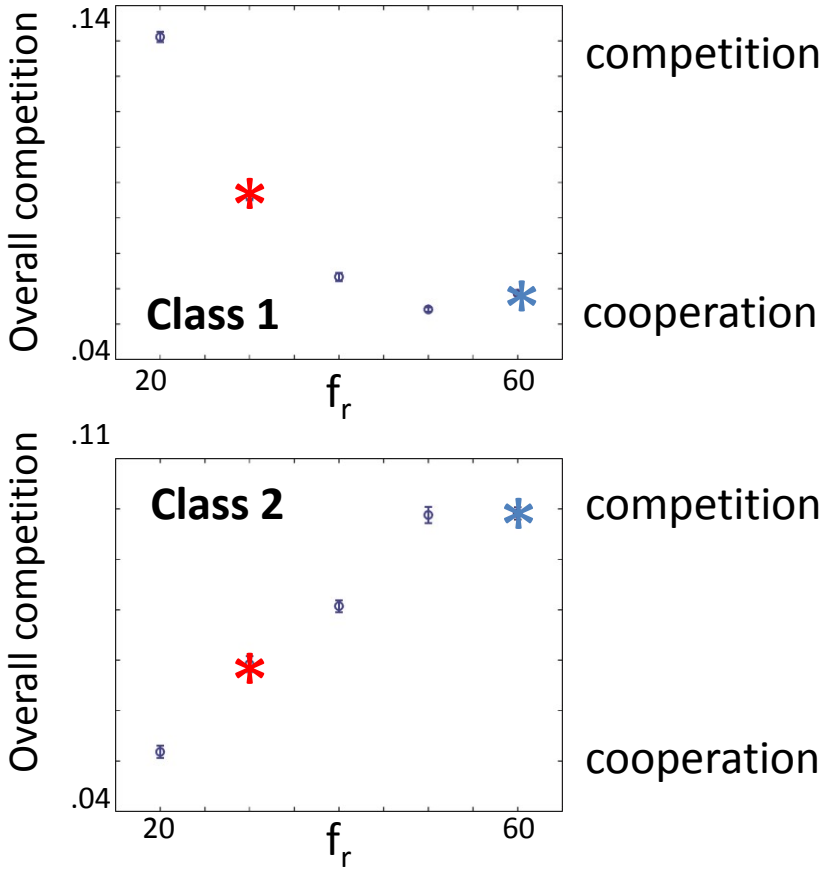

**Heterogeneity facilitates cooperativity in the beta-resonant regime.**

# Resonance-mediated bias depends on cell class



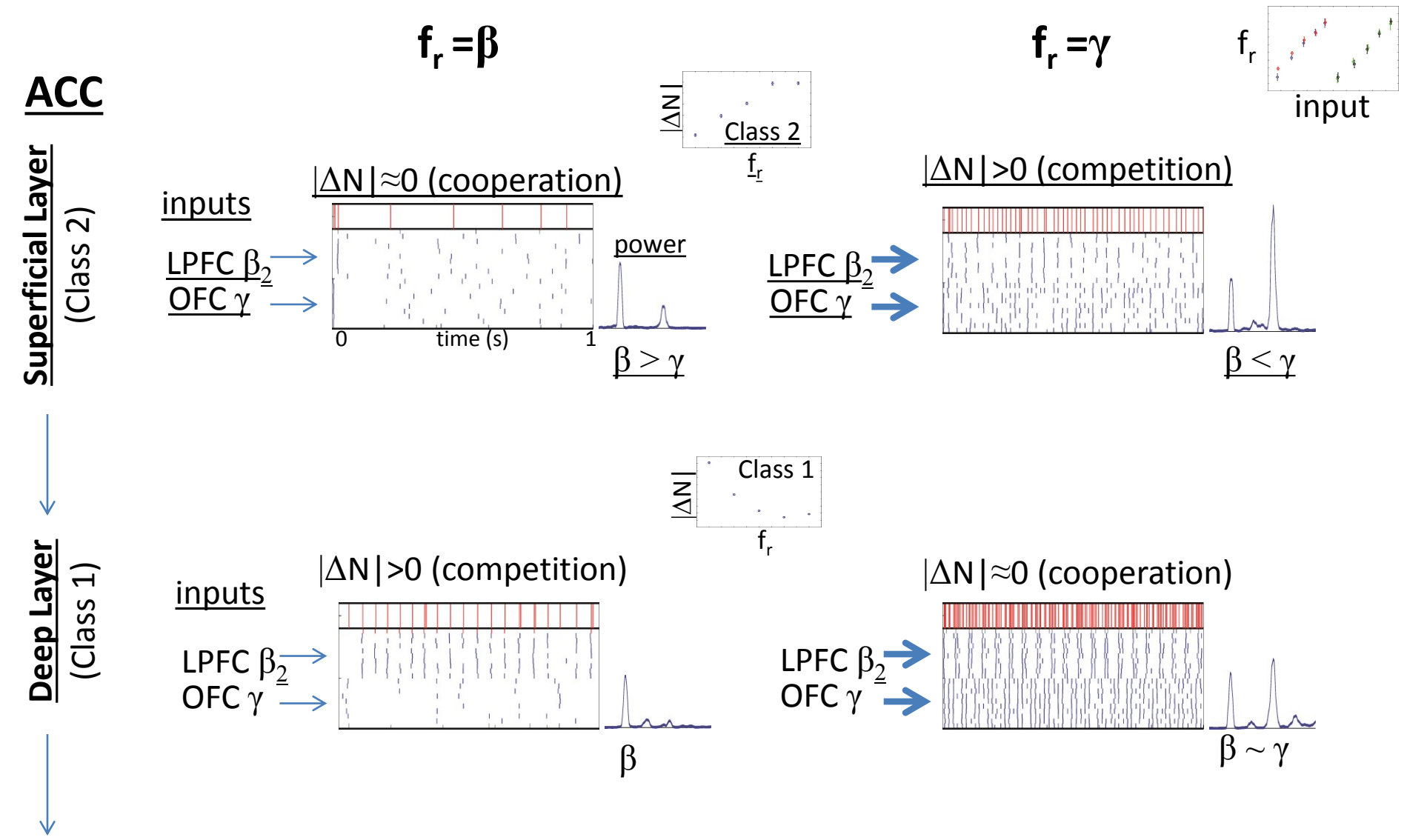

Relative Activity




Class 1 (mostly-deep layer) cells are most competitive for beta-resonant regimes. Class 2 (mostly-superficial layer) cells are most competitive in gamma-resonant regimes.

# Implications for laminar processing



# Implications for laminar processing
# Affective control: OFC → ACC

**ACC**

**Deep Layer** (Class 1)

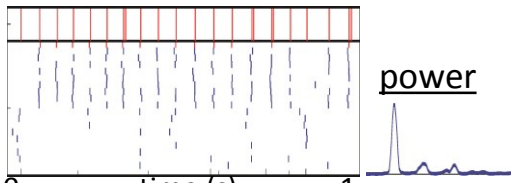
$f_r = \beta$

$|\Delta N| > 0$ (competition)

inputs

LPFC $\beta_2$

**OFC** $\gamma$

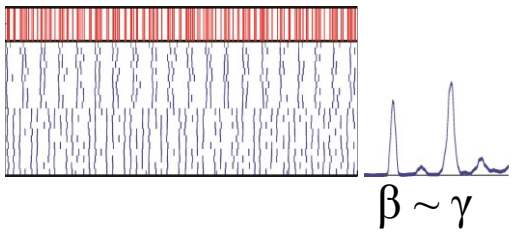



$f_r = \gamma$

$|\Delta N| \approx 0$ (cooperation)

LPFC $\beta_2$

**OFC** $\gamma$




OFC gamma ("evidence") builds up over time

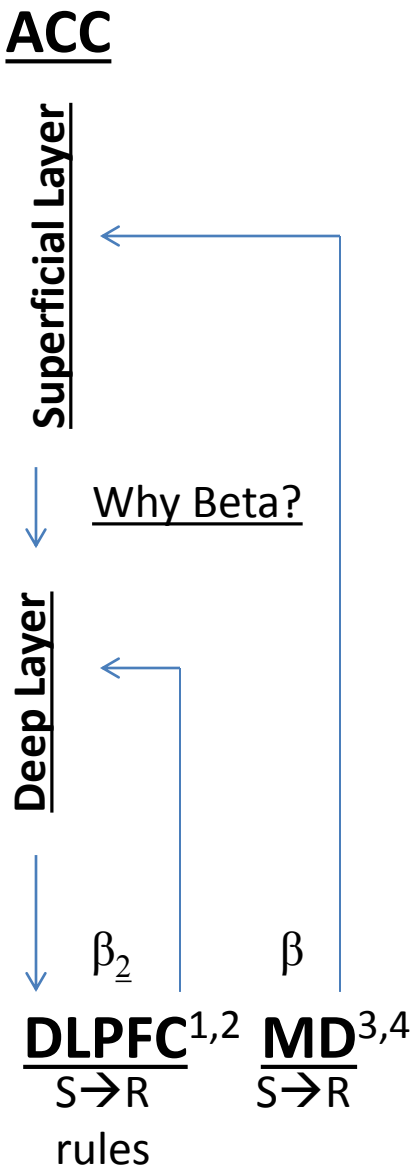
OFC gamma ~ inhibition
Initially, OFC gamma is weak
ACC is in beta-resonant regime
ACC not involved in inhibition

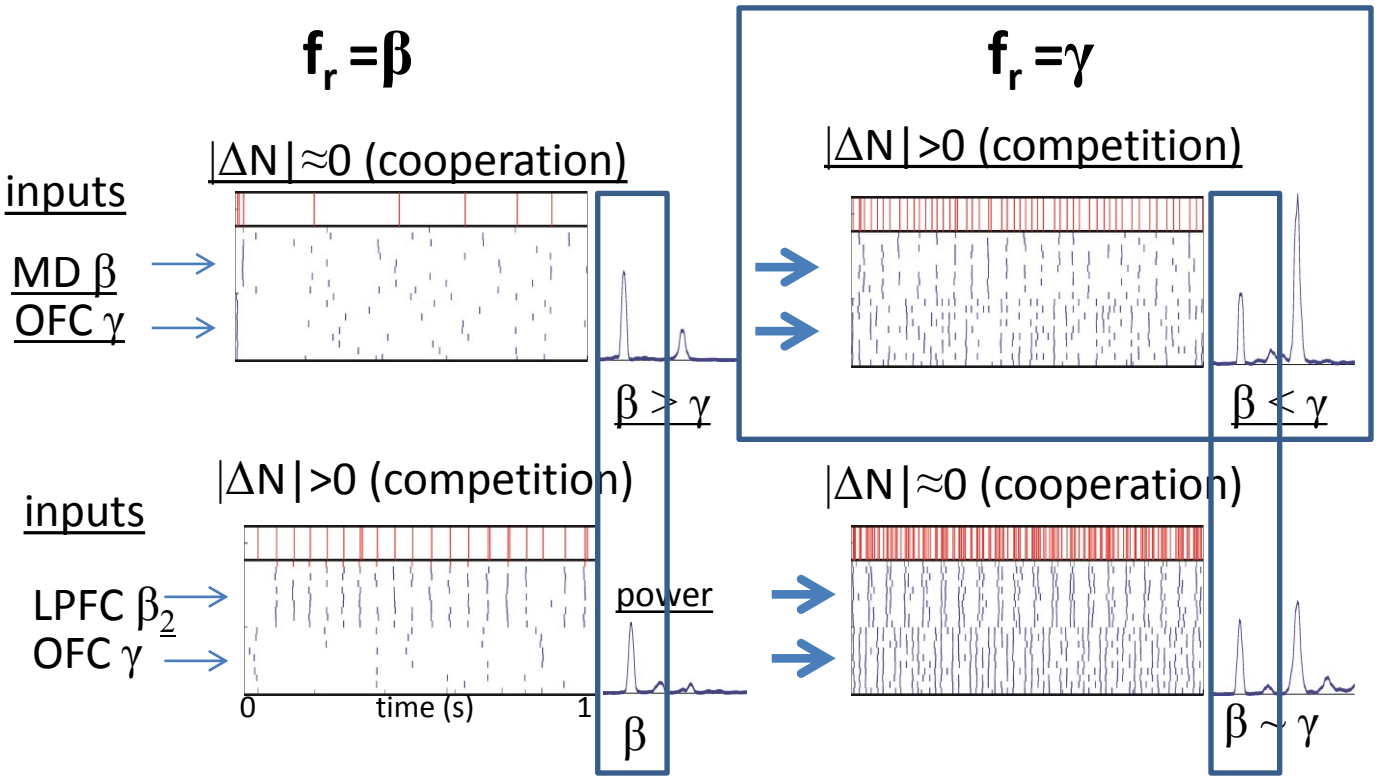
ACC enters gamma-resonant regime
ACC recruited for behavioral inhibition

Outputs to subcortical structures
(e.g., BG indirect pathway)

Pennartz, van Wingerden, Vinck. *Annals of NY Acad of Sciences* 2011.

# Implications for laminar processing
# Cognitive control: ACC ←→ DLPFC, MD




- Beta-rhythmic inputs are reflected in both beta-resonant and gamma-resonant regimes
- Whether spike rates are low or high, ACC may support:
  - ACC/DLPFC beta synchrony for rule selection
  - ACC/MD beta synchrony correlated with performance

*[1] Siegel, Warden, Miller. PNAS 2008. [2] Buschman, Denovellis, Diogo, Bullock, Miller. Neuron 2012. [3] Parnaudeau 2013. [4] Funahashi 2013.*

# Conclusions

1. Proximity to resonance determines whether two assemblies compete or cooperate.
2. Deep layer cells are most competitive for weak (e.g., low firing rate) and beta-rhythmic inputs.
3. Superficial layer cells are most competitive for strong (e.g., high firing rate) and gamma-rhythmic inputs.
4. Heterogeneity can decrease competition in weakly driven deep layer cells, possibly supporting the maintenance of multiple assemblies.
5. There are systems level implications for the coordination of cognitive and affective systems.

# Acknowledgements


- Nancy Kopell

- Fiona LeBeau
- Natalie Adams

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- Michelle Mccarthy