Journal club

Genetic and neuronal modulation of *D. melanogaster* female receptivity

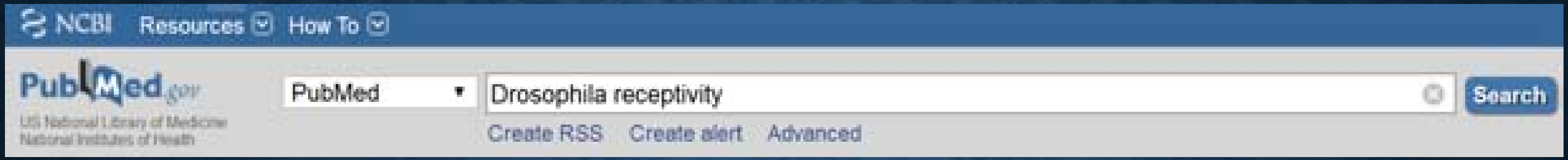
Organizer: Peng Qionglin

Invited members: Su Xiangbin, Pan Yufeng

2018-9-28

How do we specify the topic?

- 199 items were found when searching keywords, *Drosophila receptivity*, in NCBI.



- The full texts of 136 articles were downloaded by Su Xiangbin.
- General topics, such as post-mating behavior, were drafted out after quickly read through those articles by Peng Qionglin.
- Prof. Pan Yufeng joined in the group.

How do we cooperate in a group?

The first discussion:

determining an appropriate topic and divide it into three small specific topics

- Part I Overview, virgin female receptivity (Peng Qionglin)
- Part II Sex-peptide (SP) signaling in post-mating switch (Su Xiangbin)
- Part III Neuronal modulation of post-mating behaviors (Pan Yufeng)

The second discussion:

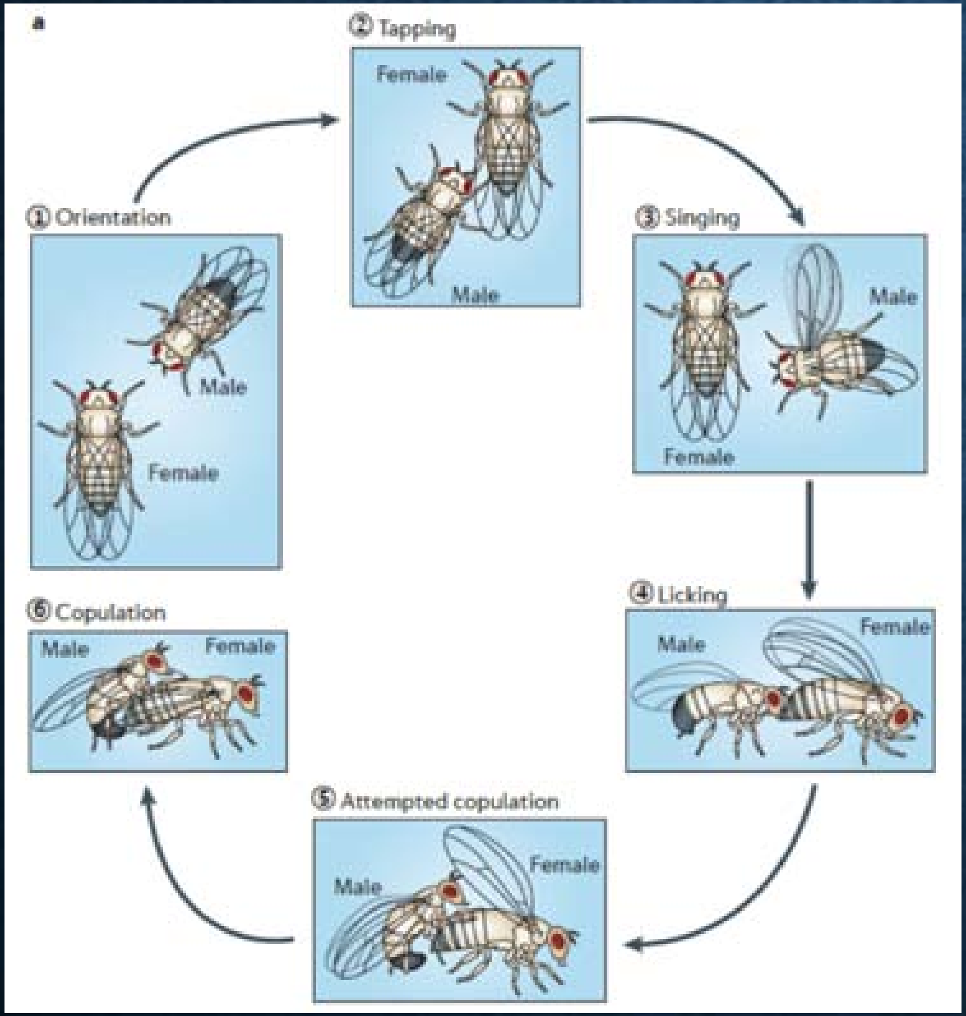
Combining three parts and rehearsing the journal report.

Genetic and neuronal modulation of *D. melanogaster* female receptivity

CONTENT

- Part I Overview, virgin female receptivity
- Part II Sex-peptide (SP) signaling in post-mating switch
- Part III Neuronal modulation of post-mating behaviors

Courtship in *Drosophila melanogaster*



Discrete steps of male mating behavior:

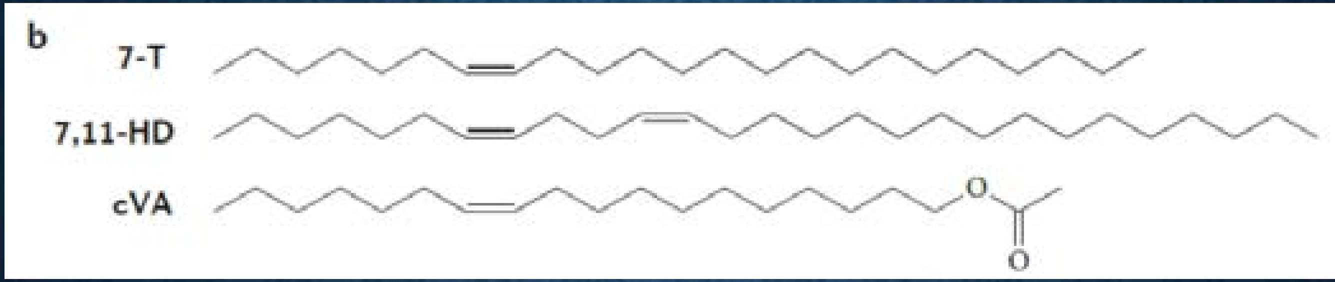
1. Orientation towards and following the female
2. Touching abdomen with the foreleg
3. Wing extension and vibration
4. Licking of the female's genitalia
5. Attempted copulation
6. copulation

Yamamoto, D. and M. Koganezawa (2013)

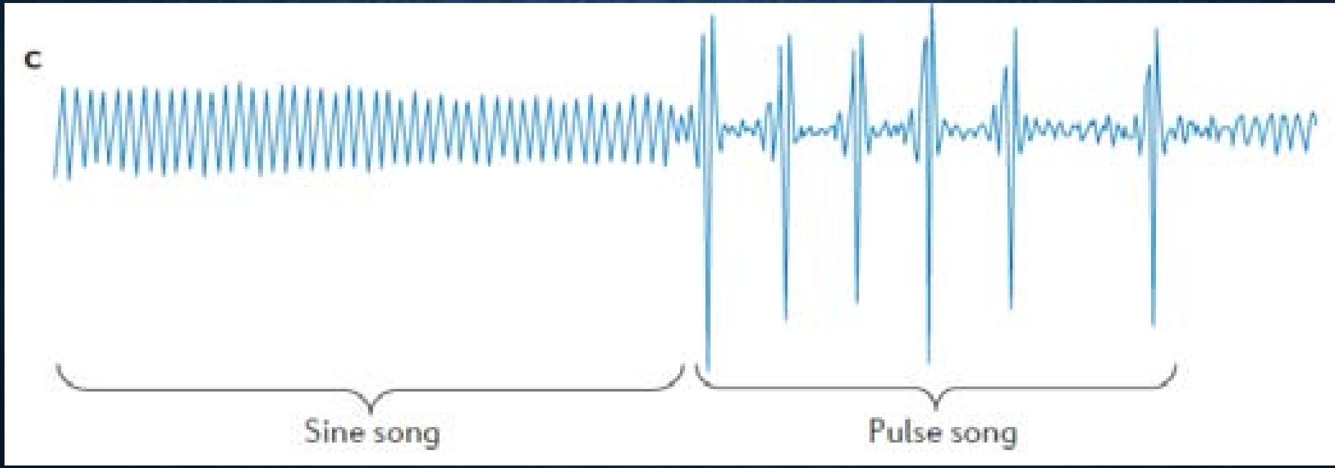
How does a female decide to copulate with a male?

-Two import male stimuli

Sex pheromones



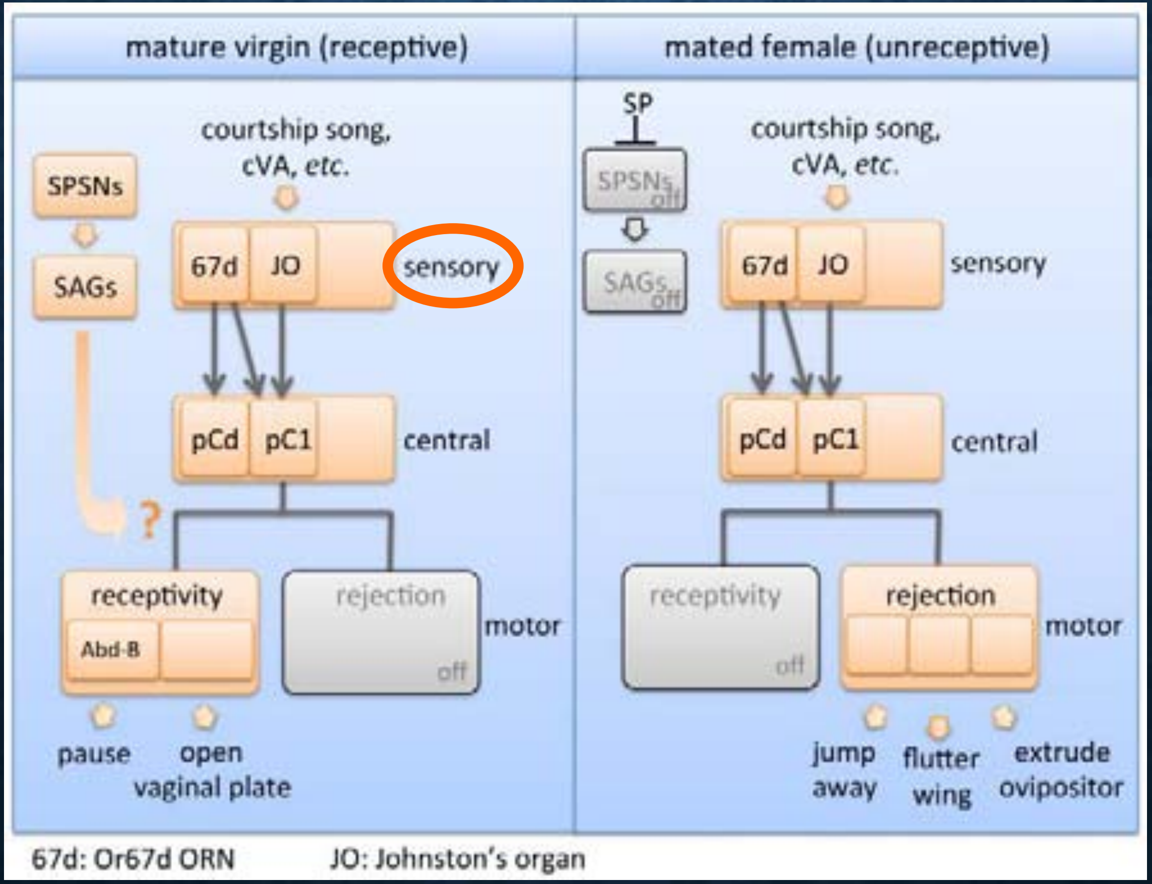
Courtship songs



Yamamoto, D. and M. Koganezawa (2013)

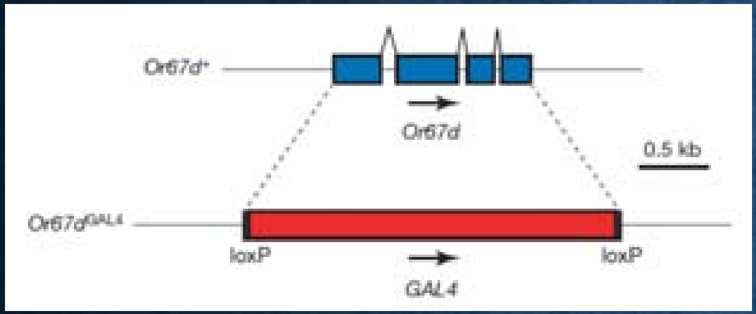
How does a female decide to copulate with a male?

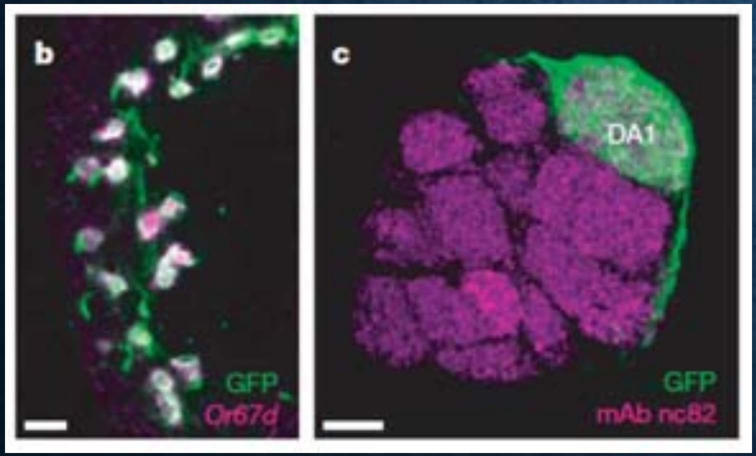
-Receptivity circuit inside female



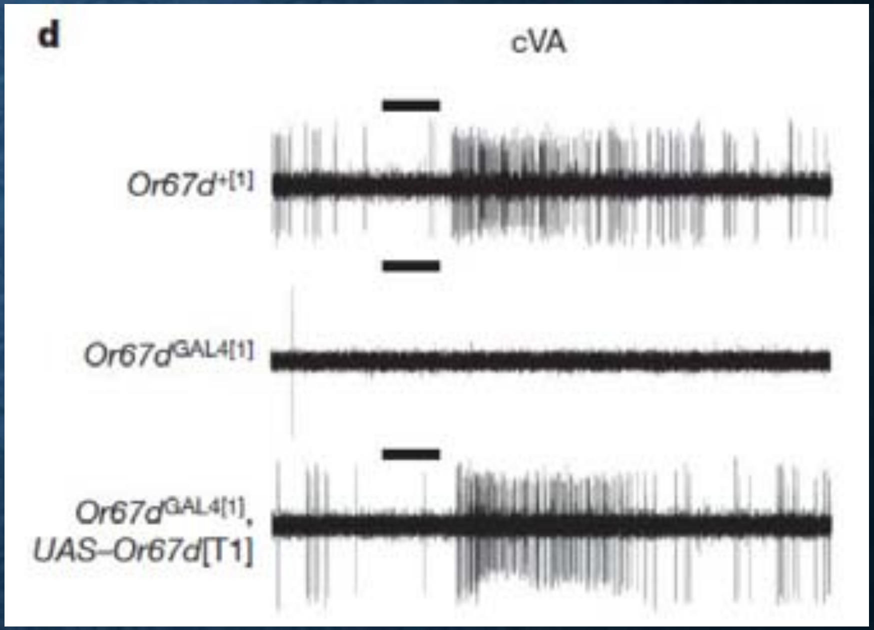
Liu, Y. and C. H. Yang (2014)

Or67d mediates physiological responses to cVA





Or67d^{Gal4}/UAS–mCD8–GFP



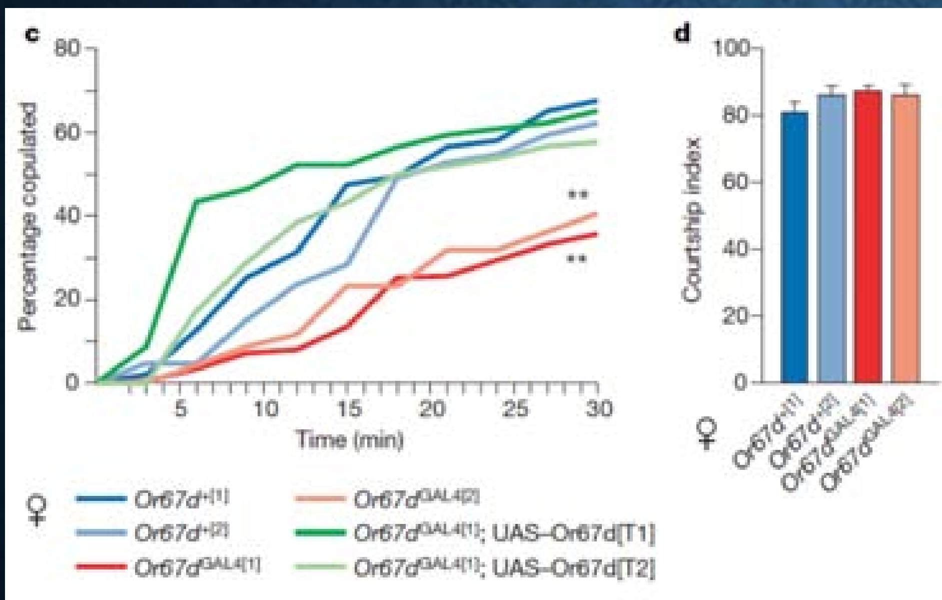
single-sensillum recording

The responses to cVA were quantitatively indistinguishable in males and females.

Kurtovic, A., et al. (2007)

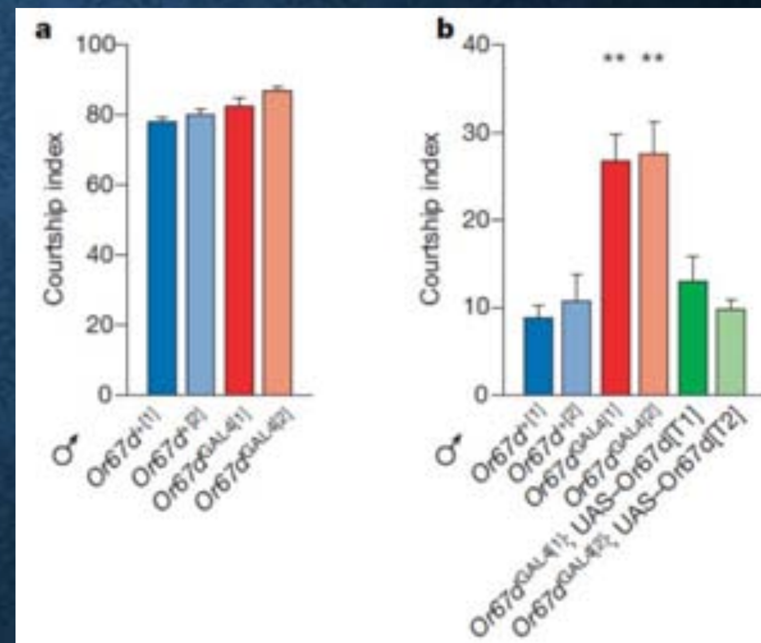
Or67d functions in male and female mating behaviors

Or67d^{Gal4} mutant females display reduced receptivity



female
WT male

Or67d^{Gal4} mutant males display male-male courtship



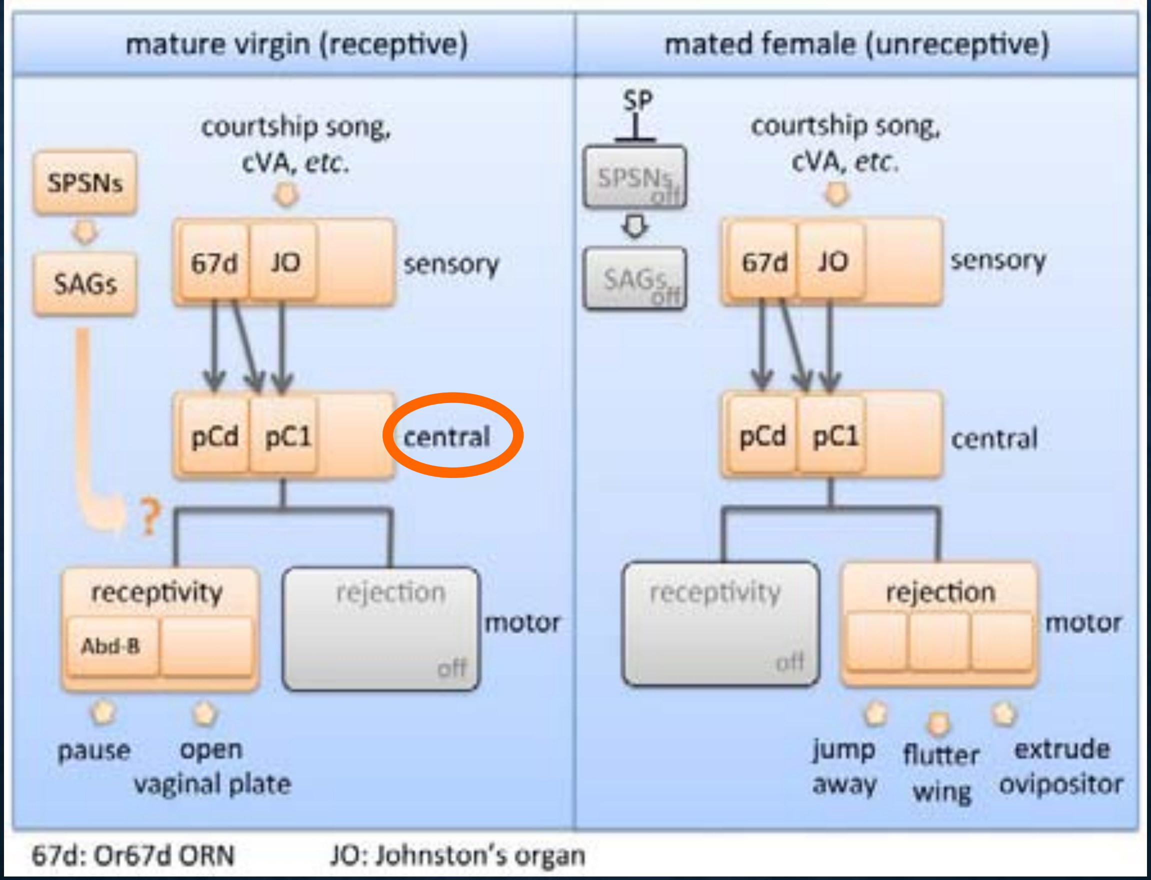
male
WT virgin female

male
WT male

Kurtovic, A., et al. (2007)

How does a female decide to copulate with a male?

-Receptivity circuit inside female



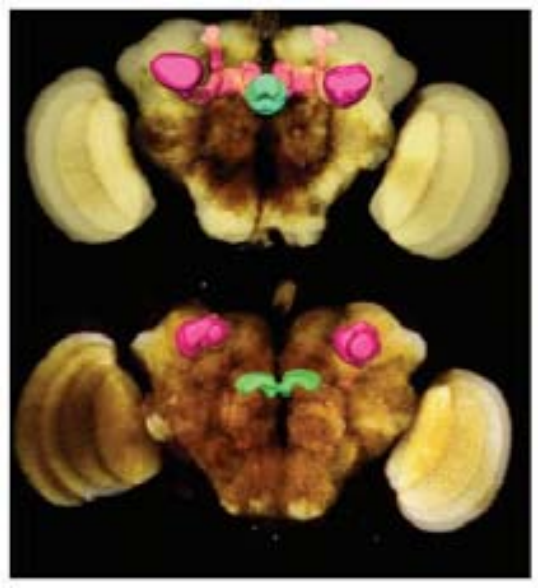
Liu, Y. and C. H. Yang (2014)

MB and EB maybe responsible for female receptivity

(a) Receptivity of female controls

Female	Mating/tested	Percent mating
Wild-type	225/231	97
icebox/wild-type	218/251	86
icebox/*icebox*	63/268	23

Female receptivity phenotype of ***icebox (ibx)*** mutants caused by a mutation in the L1-type cell adhesion molecule ***neuroglian (Nrg).***



CS

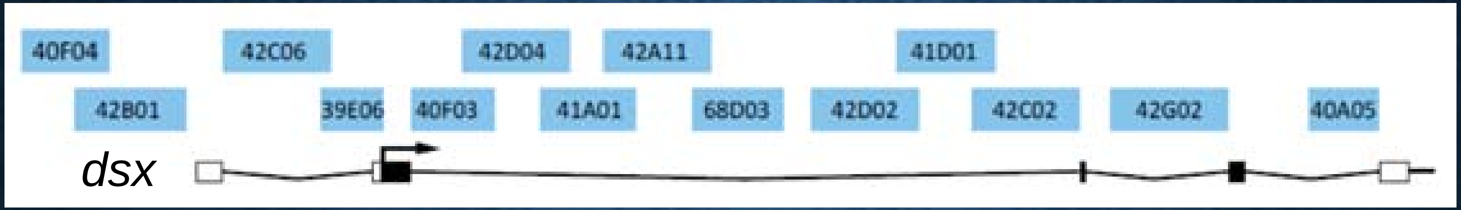
ibx mutant

MBs (magenta) and EBs (green)

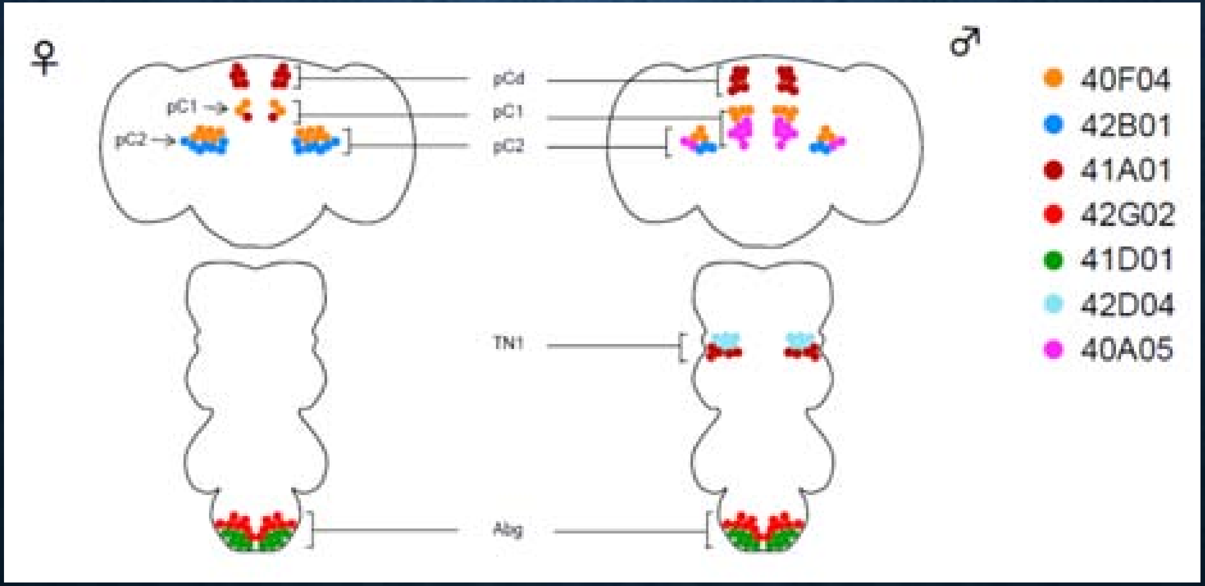
Carhan, A., et al. (2005)

Genetic subdivision of *dsx* neurons

Different *dsx* genomic fragments

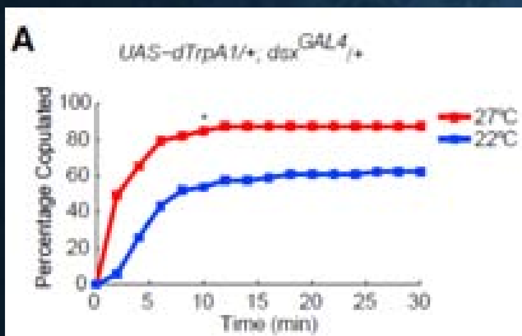


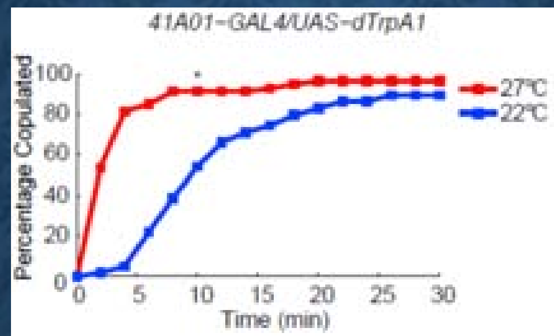
dsx fragment-GAL4 expression patterns

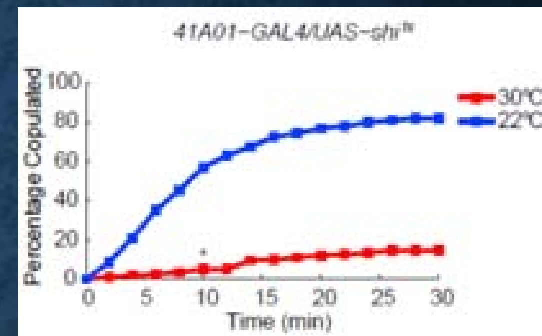


Zhou, C., et al. (2014)

dsx neurons and 41A01-GAL4 neurons are important for female receptivity

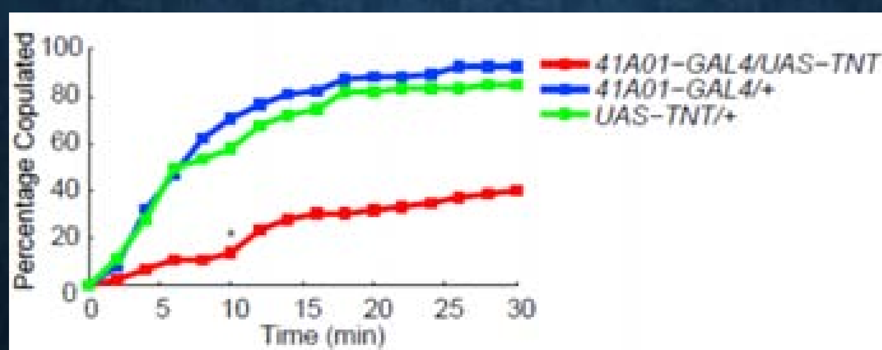






Activation-Enhances female receptivity

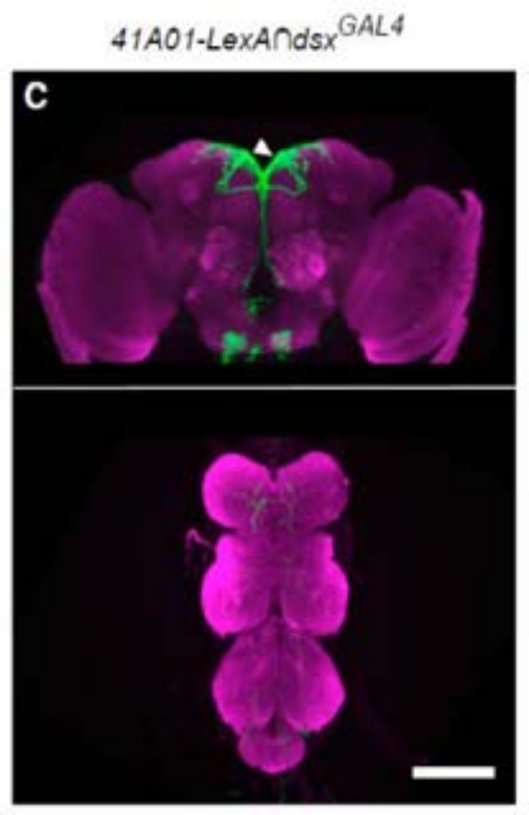
Silencing-Decreases female receptivity

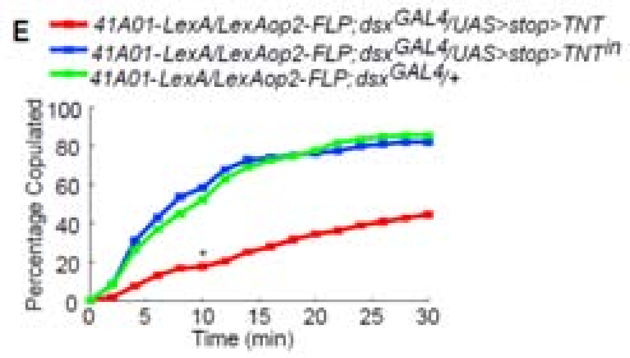


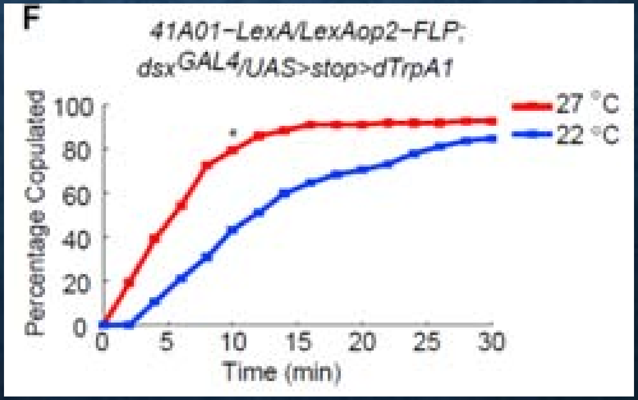
Silencing-Decreases female receptivity

Zhou, C., et al. (2014)

pCd neurons are important for female receptivity





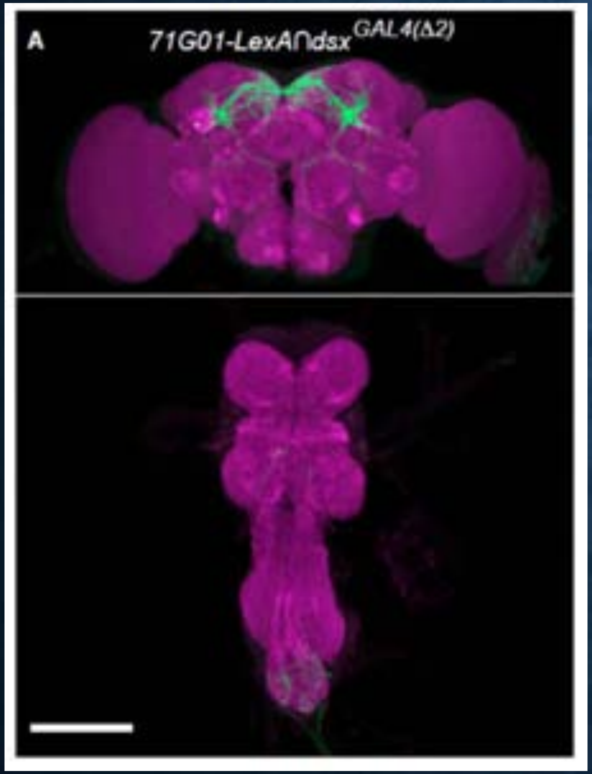


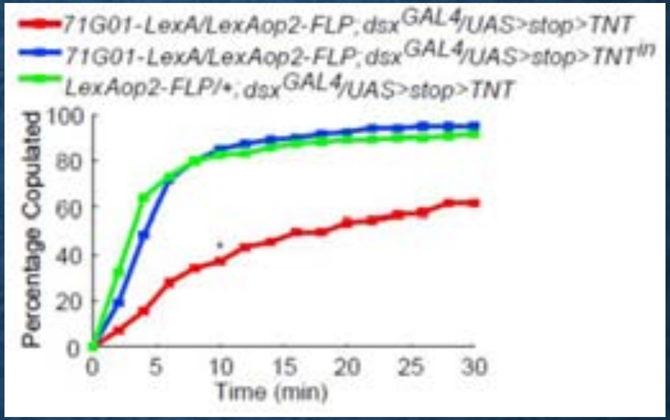
Silencing-Decreases female receptivity

Activation-Enhances female receptivity

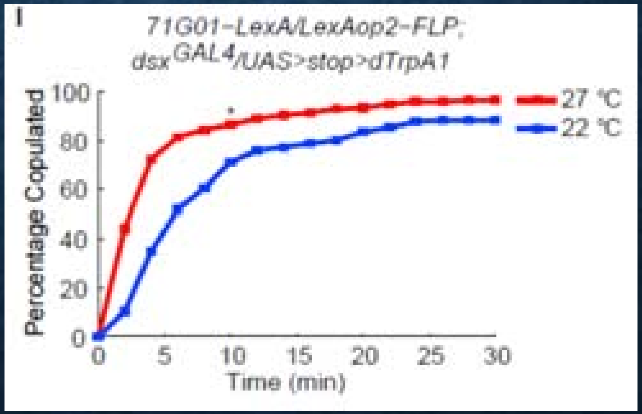
Zhou, C., et al. (2014)

pC1 neurons are important for female receptivity





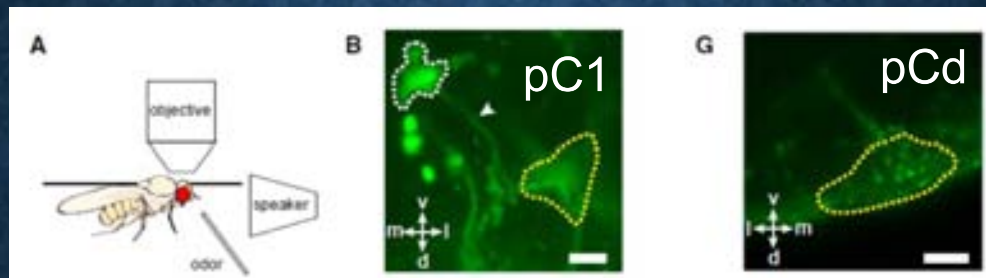
Silencing-Decreases female receptivity



Activation-Enhances female receptivity

Zhou, C., et al. (2014)

Calcium responses of female pC1 and pCd neurons to courtship song and cVA

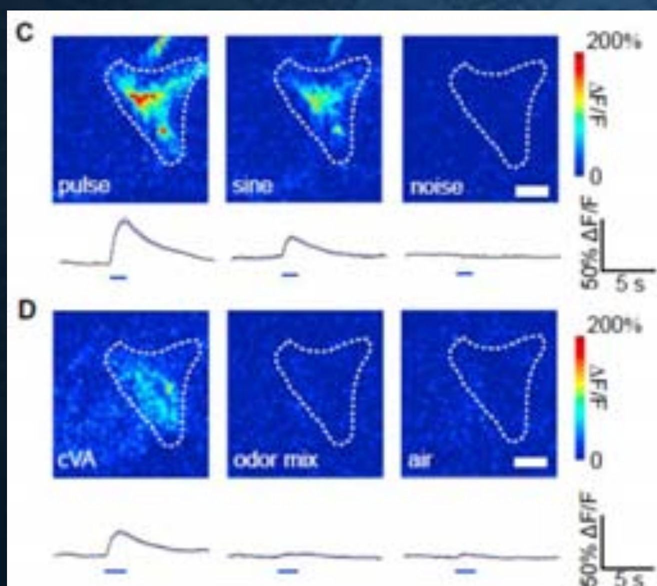


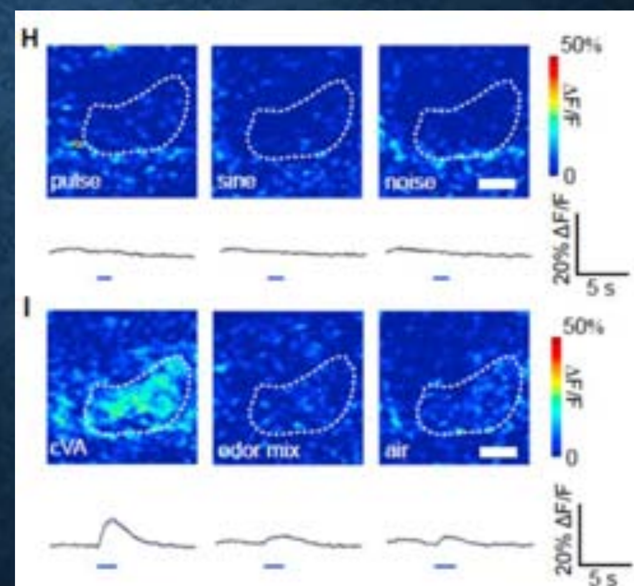
pC1 Neuron responses

pCd Neuron responses

courtship song

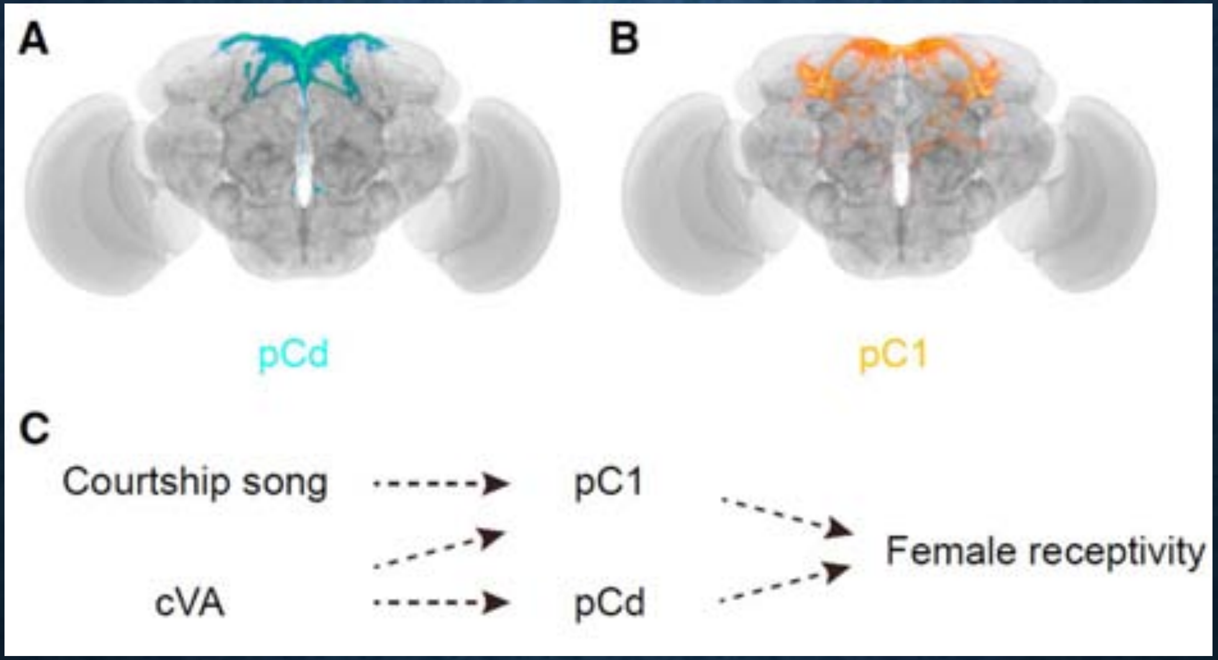
cVA





Zhou, C., et al. (2014)

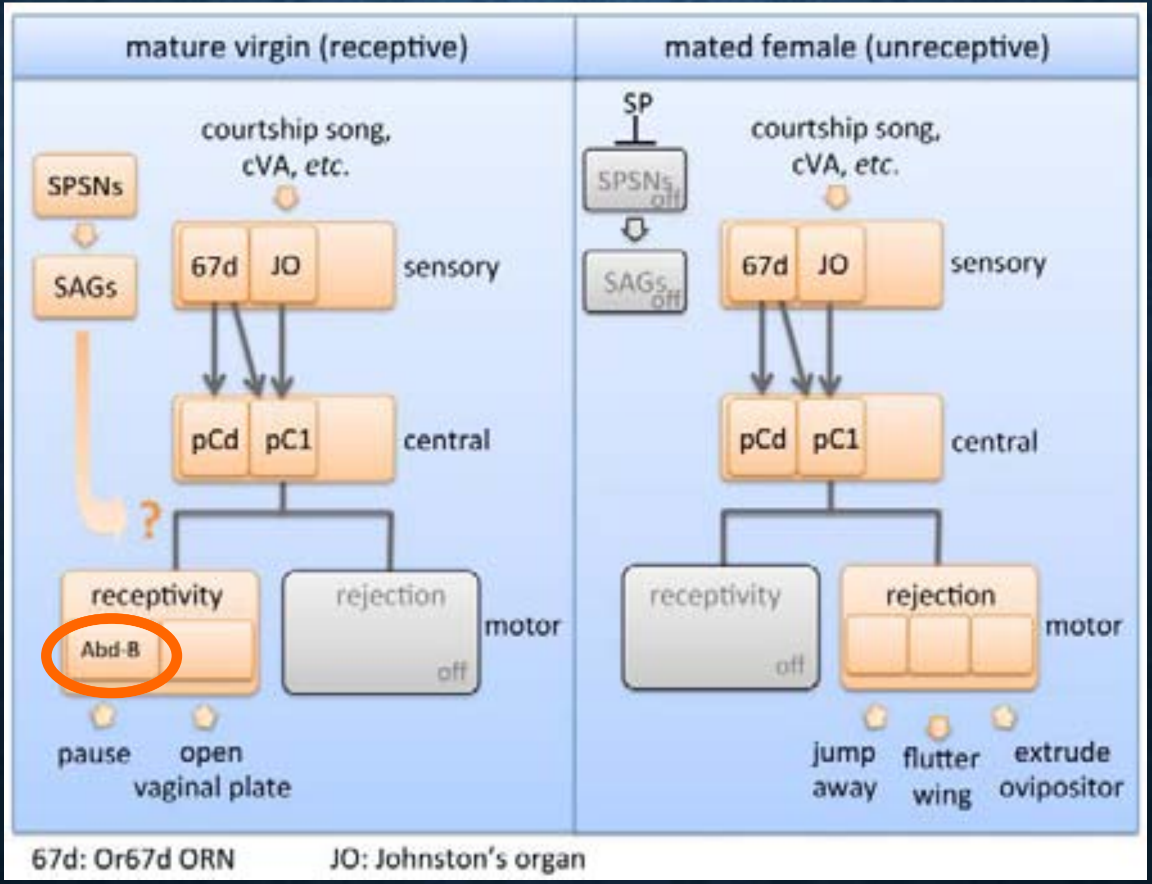
pCd and pC1 Neurons function in female receptivity



Zhou, C., et al. (2014)

How does a female decide to copulate with a male?

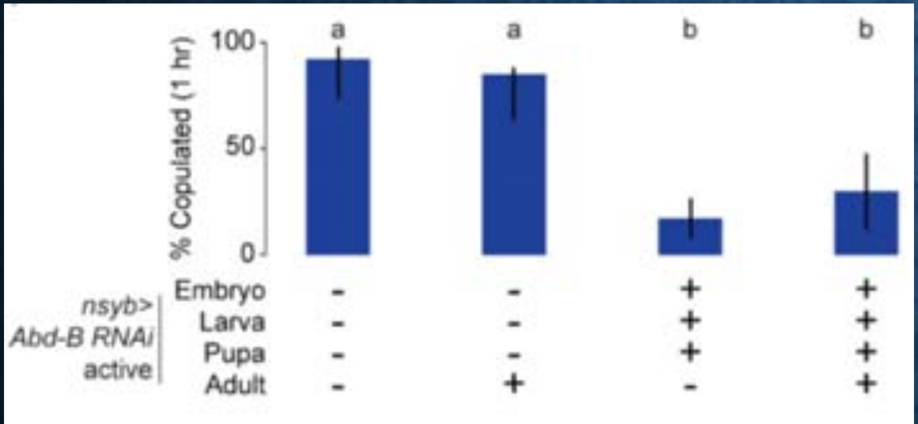
-Receptivity circuit inside female



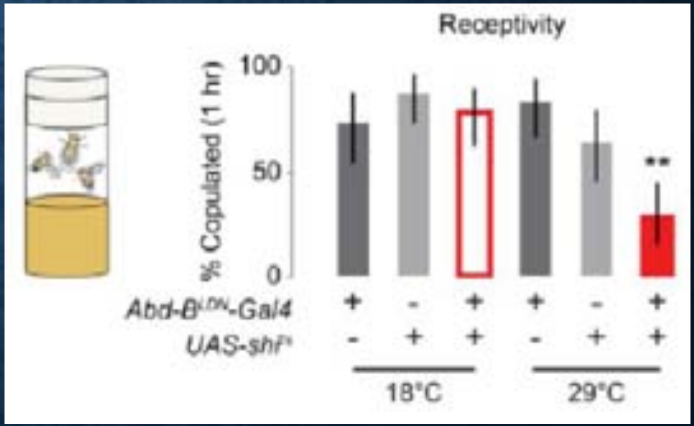
Liu, Y. and C. H. Yang (2014)

Abd-B are required for virgin female receptivity

***Abd-B* plays a developmental role in forming the female receptivity circuit**



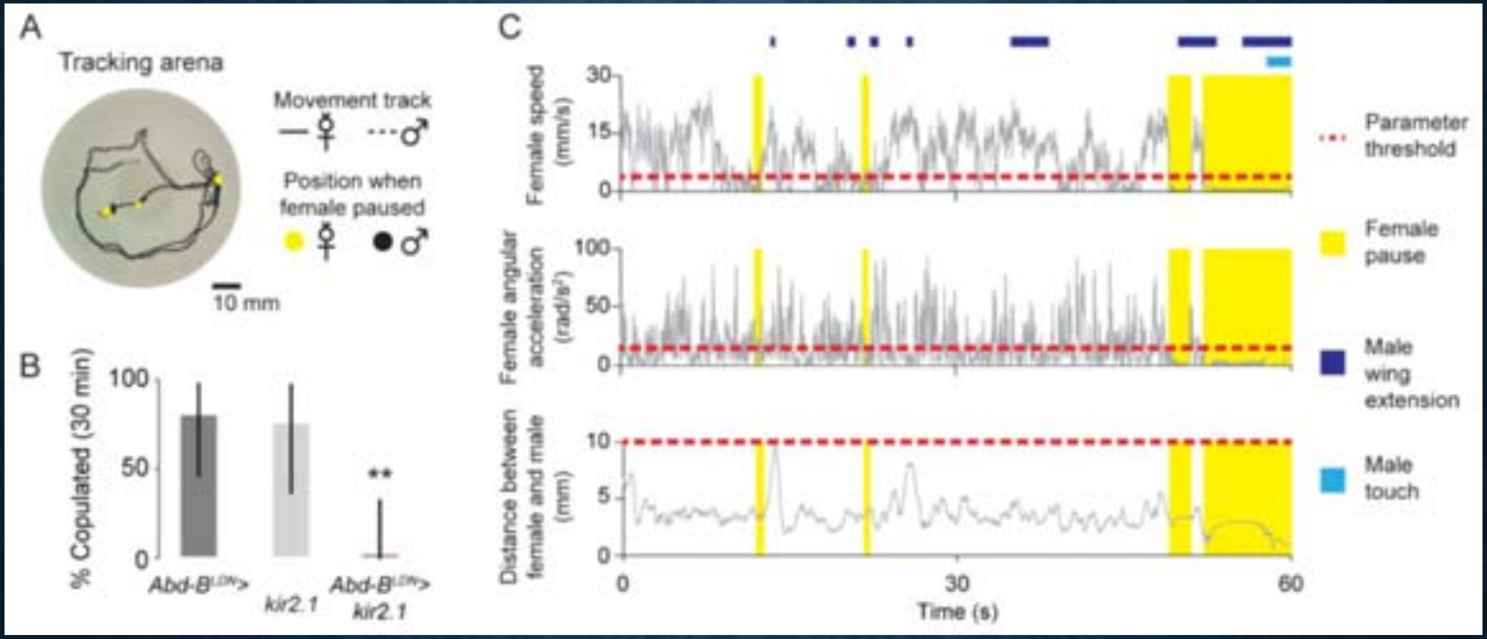
***Abd-B* neurons is functionally required for virgin female receptivity**

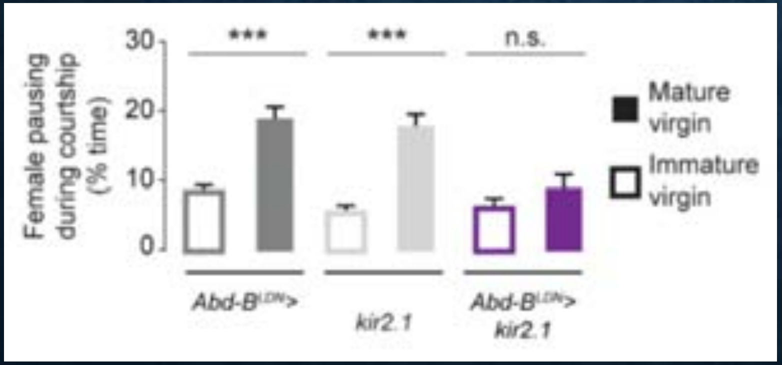


Abd-B， Abdominal-B
homeobox (Hox) transcription factor

Bussell, J. J., et al. (2014)

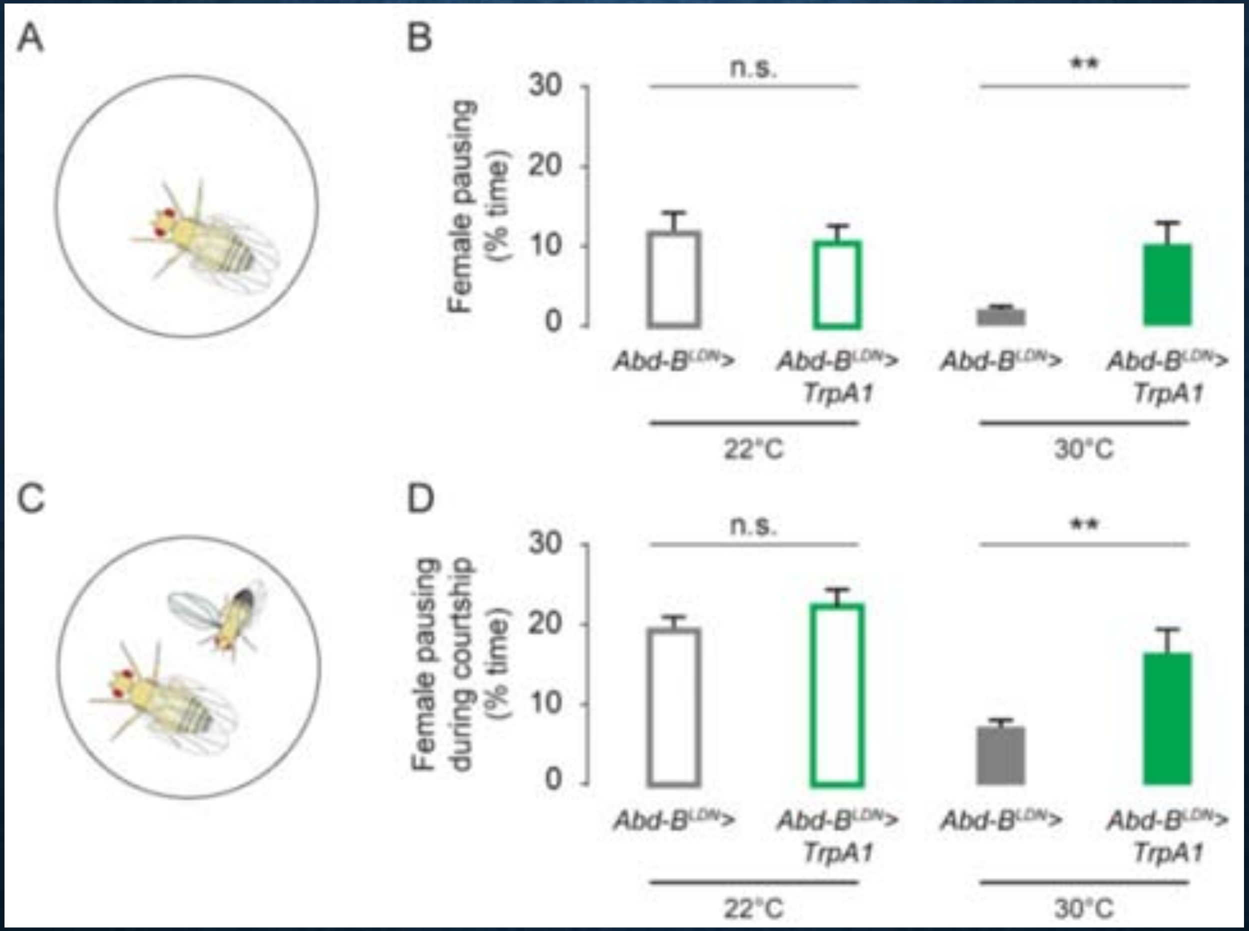
Silencing *Abd-B* neurons decreases pausing during courtship





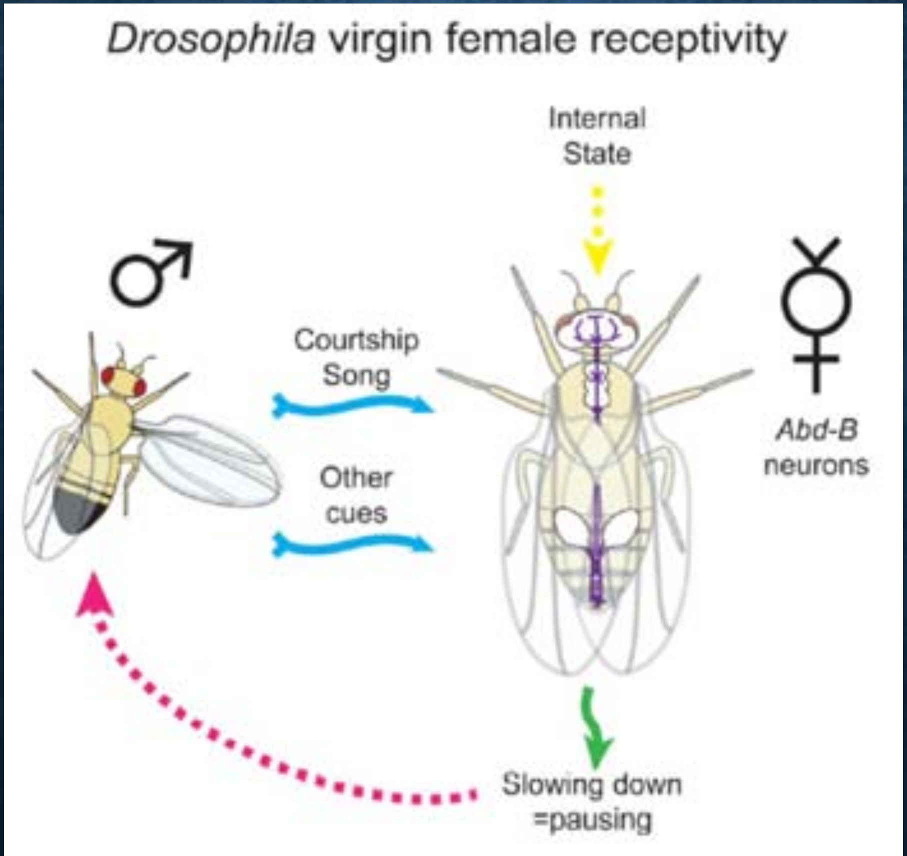
Bussell, J. J., et al. (2014)

Activating *Abd-B* neurons induces pausing



Bussell, J. J., et al. (2014)

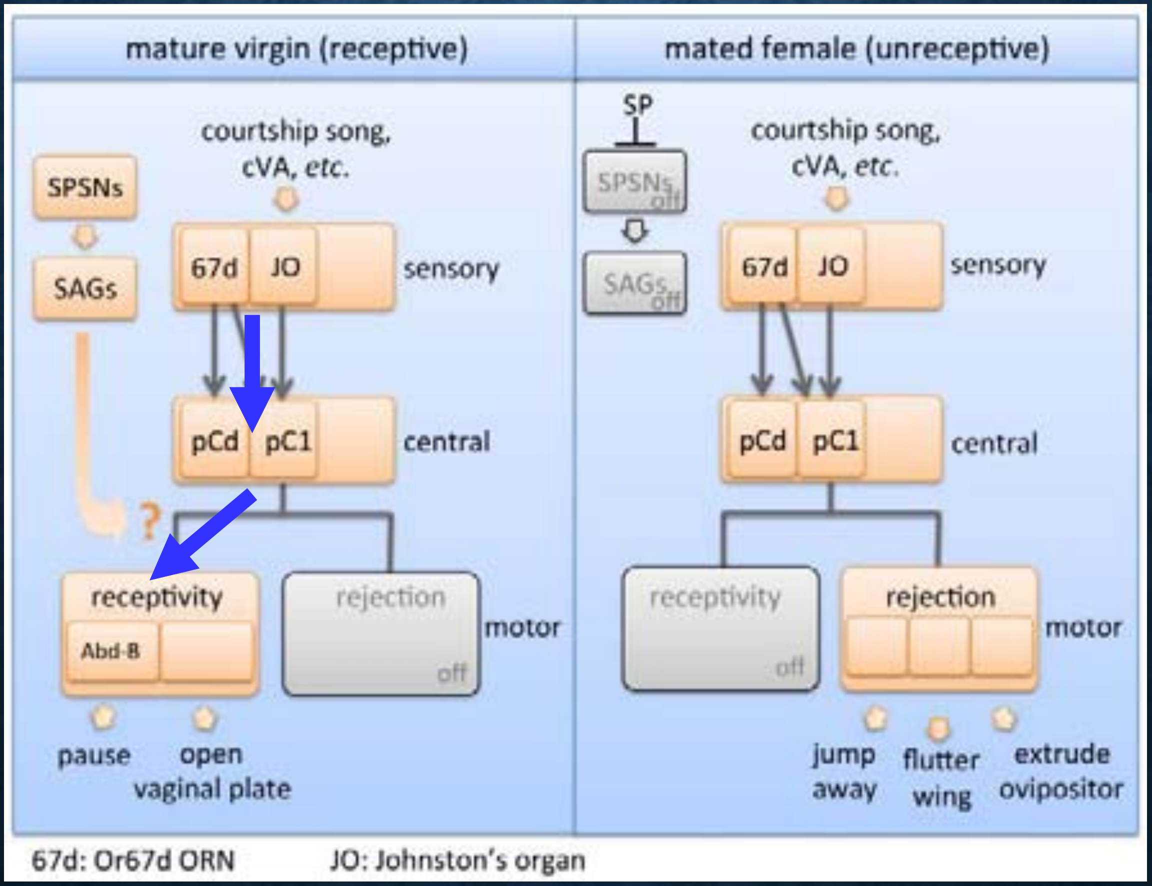
Abd-B neurons are required for virgin female receptivity



Bussell, J. J., et al. (2014)

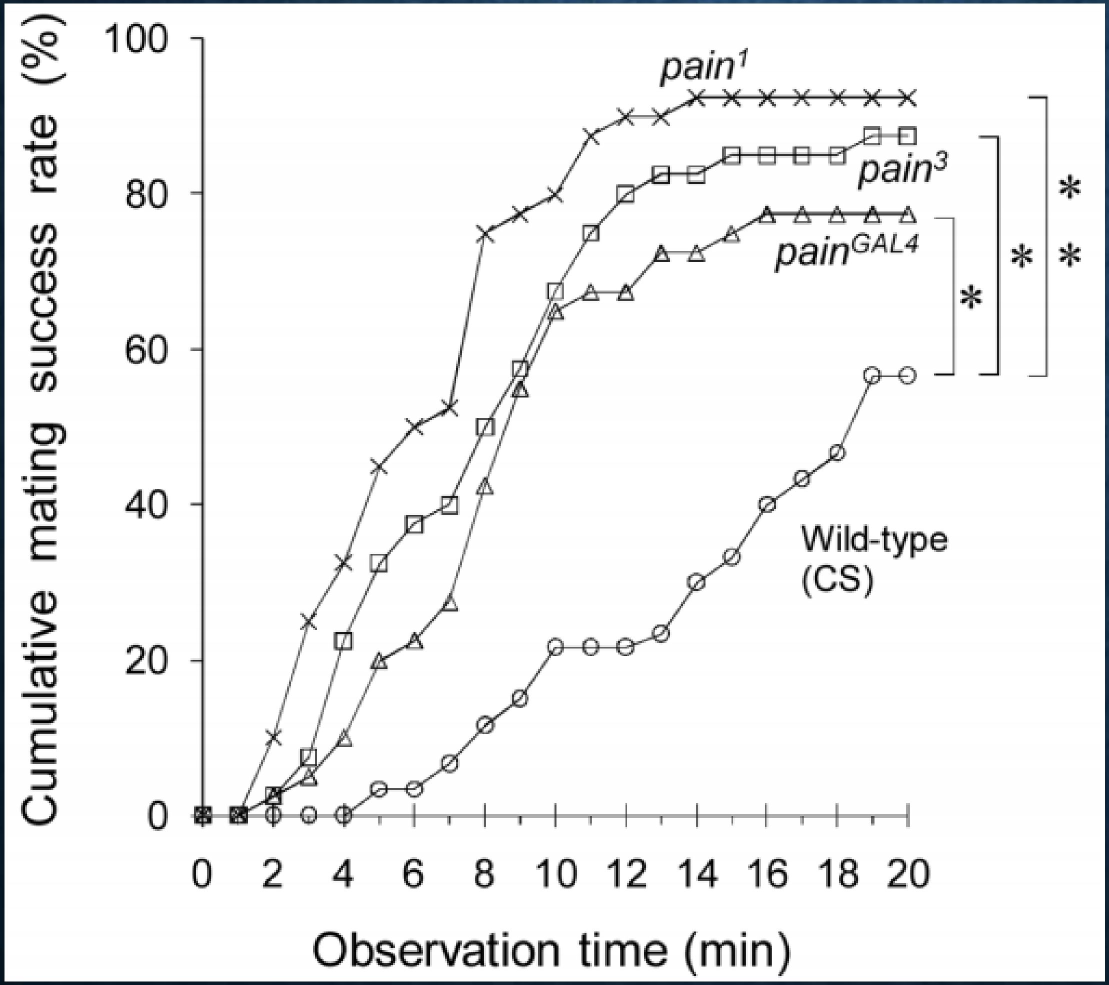
How does a female decide to copulate with a male?

-Receptivity circuit inside female



Liu, Y. and C. H. Yang (2014)

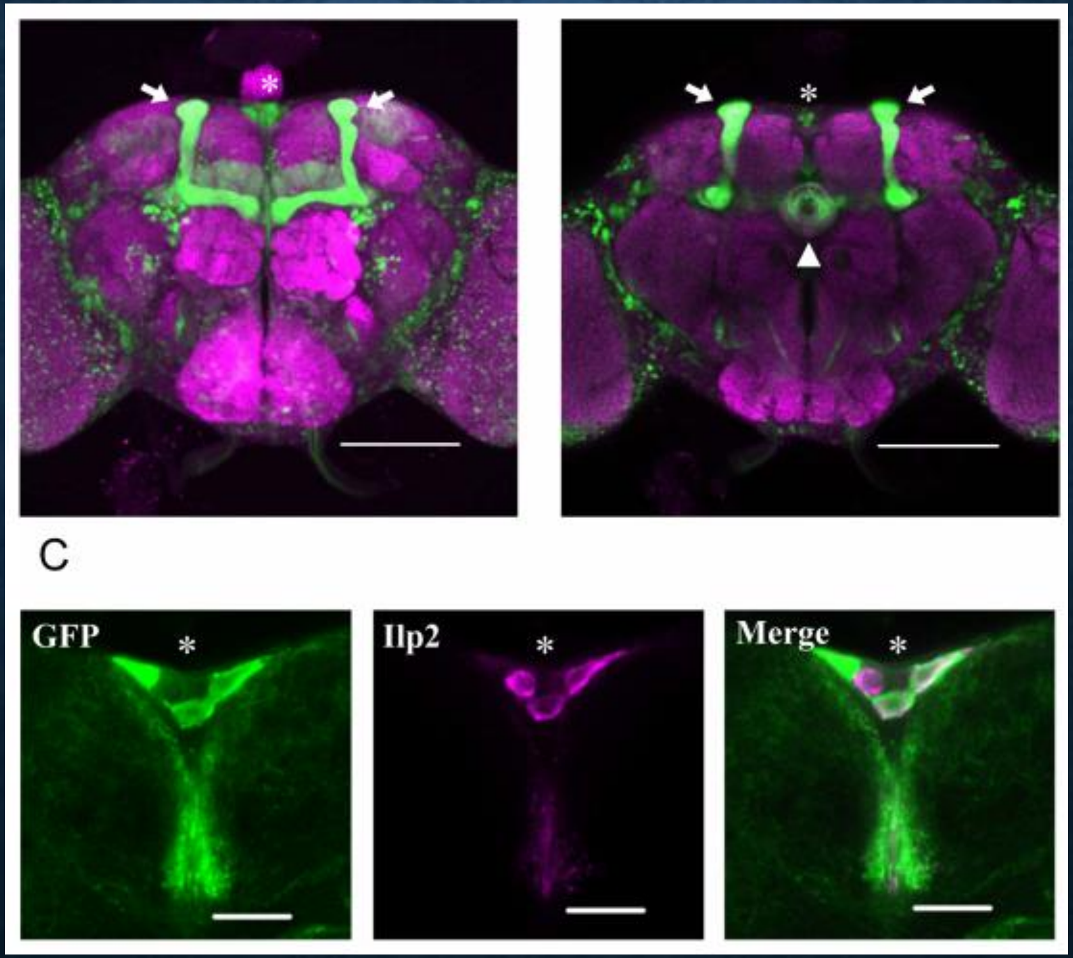
pain （*painless*） mutant females copulate earlier than wild-type females



pain:
a homolog of the mammalian *TRPA1/ANKTM1*

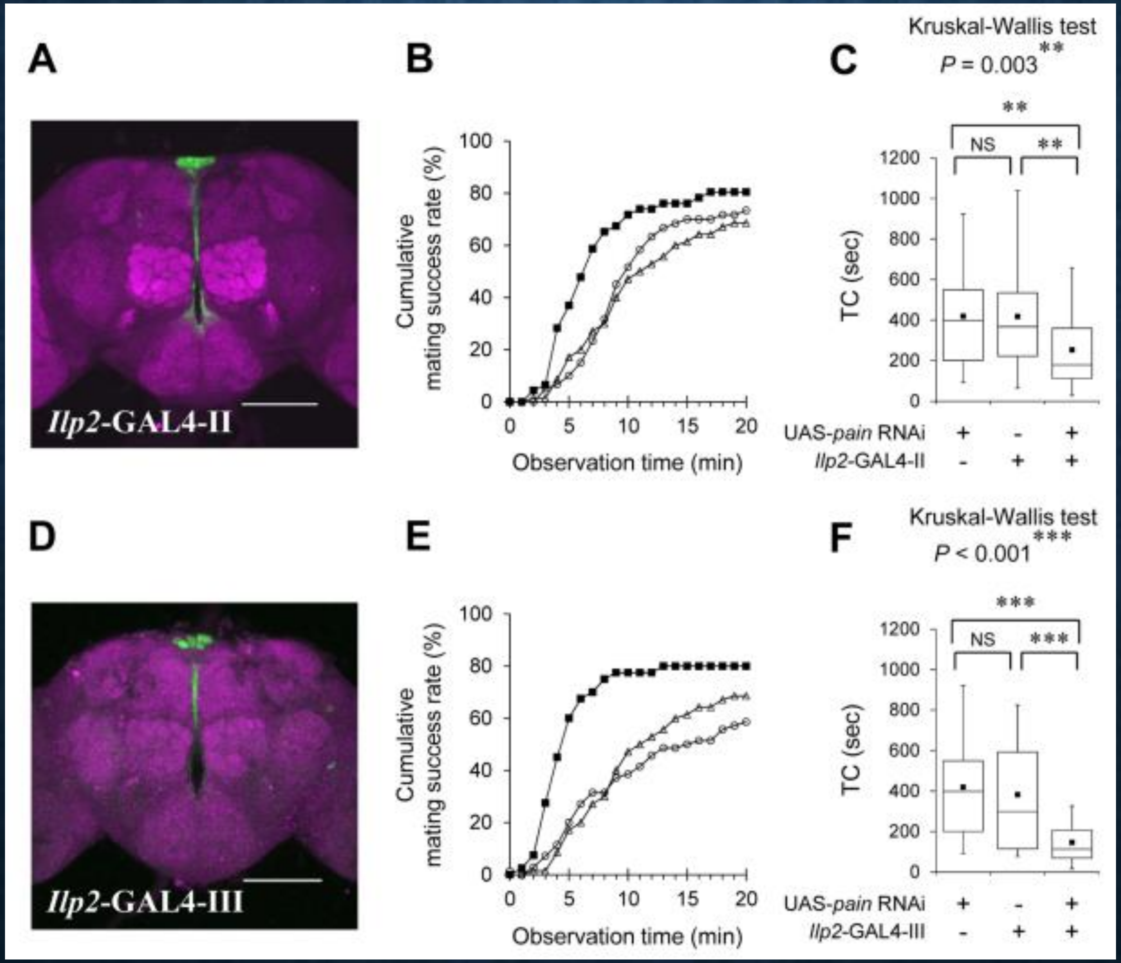
Sakai, T., et al. (2009)

pain-GAL4 drives GFP reporter expression in the female brain



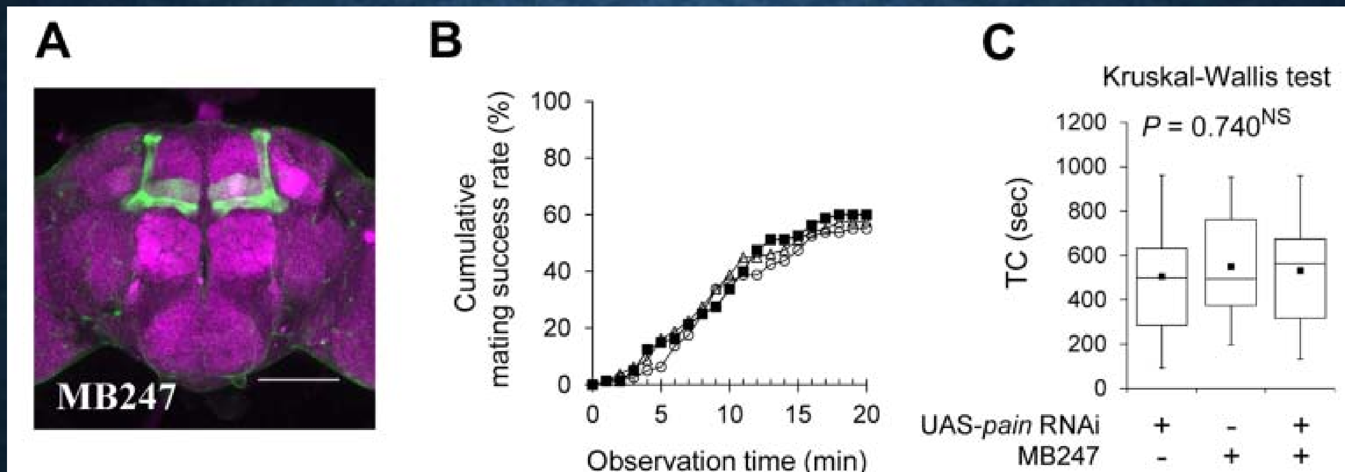
Sakai, T., et al. (2014)

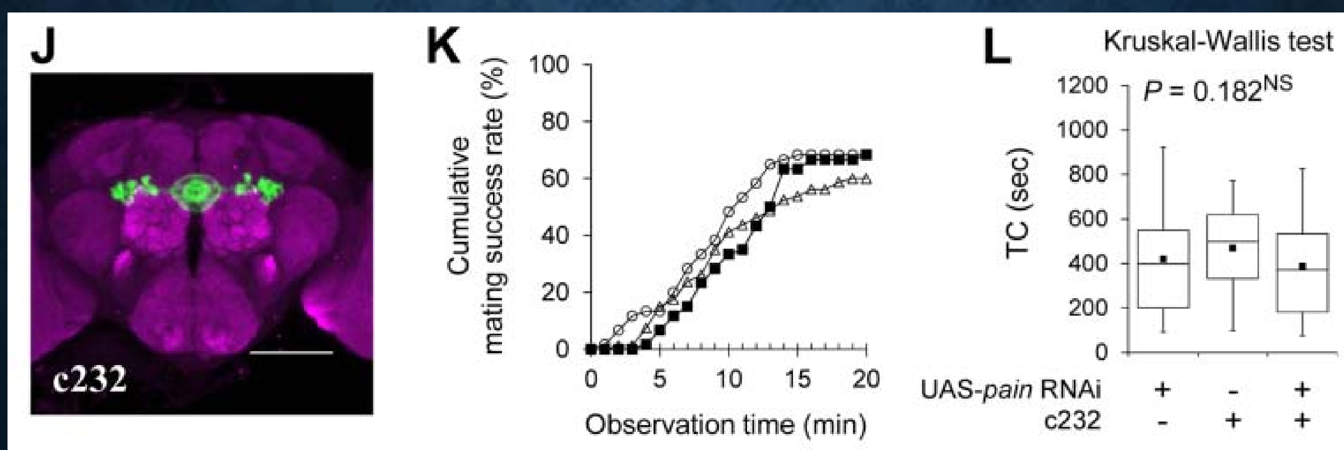
Knockdown of *pain* expression in IPCs enhances female sexual receptivity



Sakai, T., et al. (2014)

Knockdown of *pain* expression in the MBs or EB do not affect female sexual receptivity



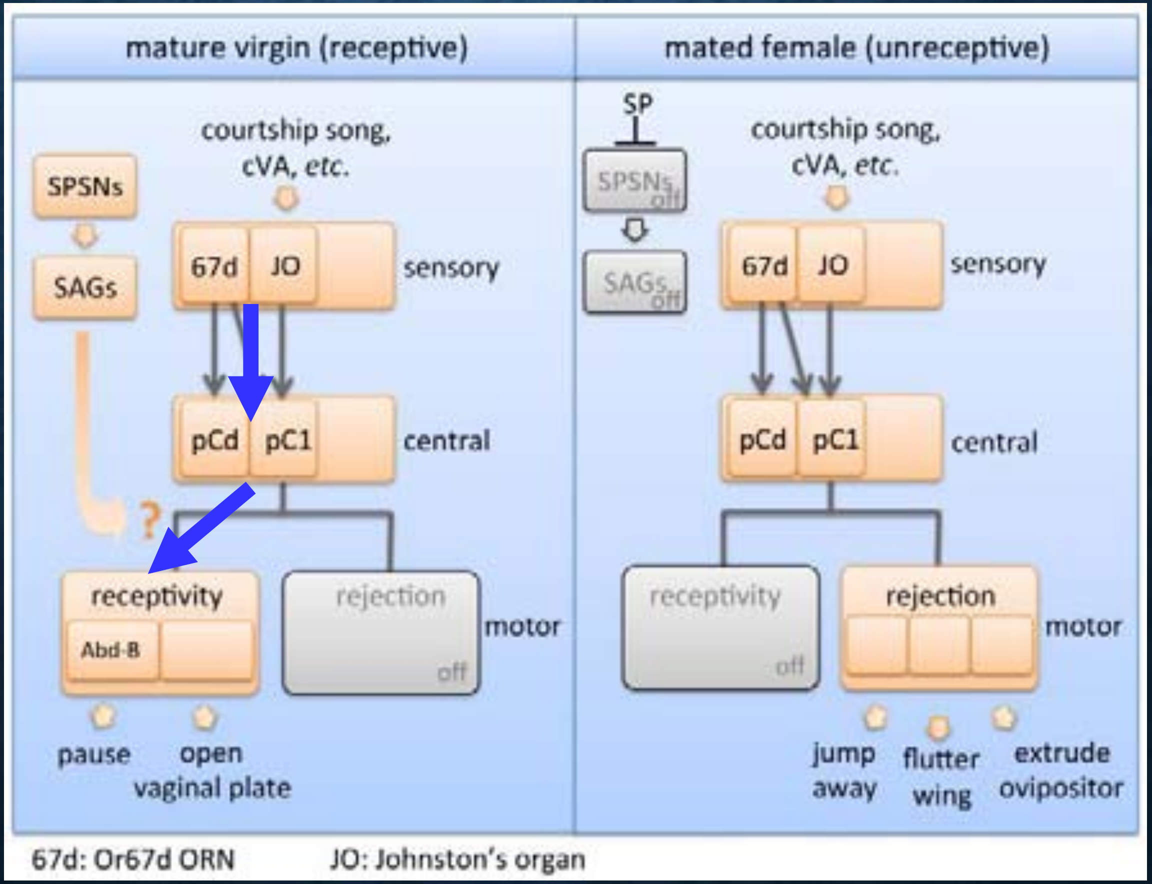


Sakai, T., et al. (2014)

How does a female decide to copulate with a male?

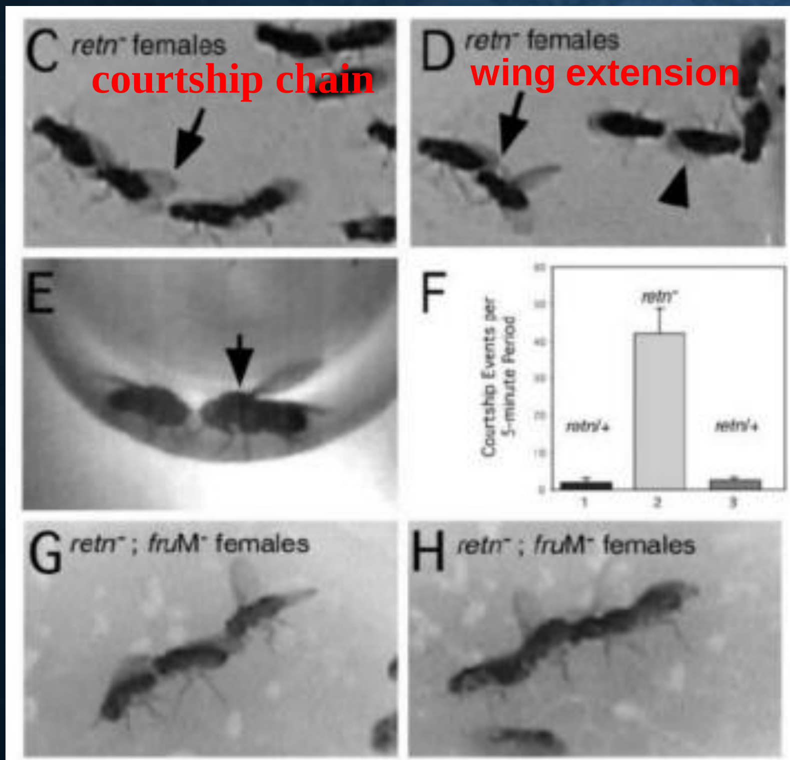
-Receptivity circuit inside female

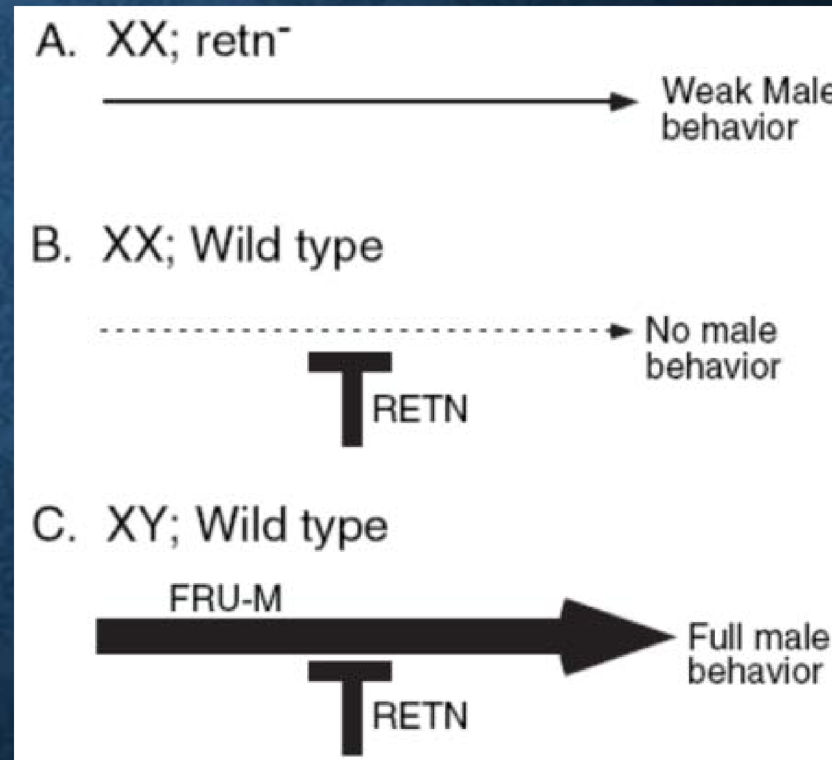
Other genes



Liu, Y. and C. H. Yang (2014)

retn （*retained/dead ringer*）female behavior



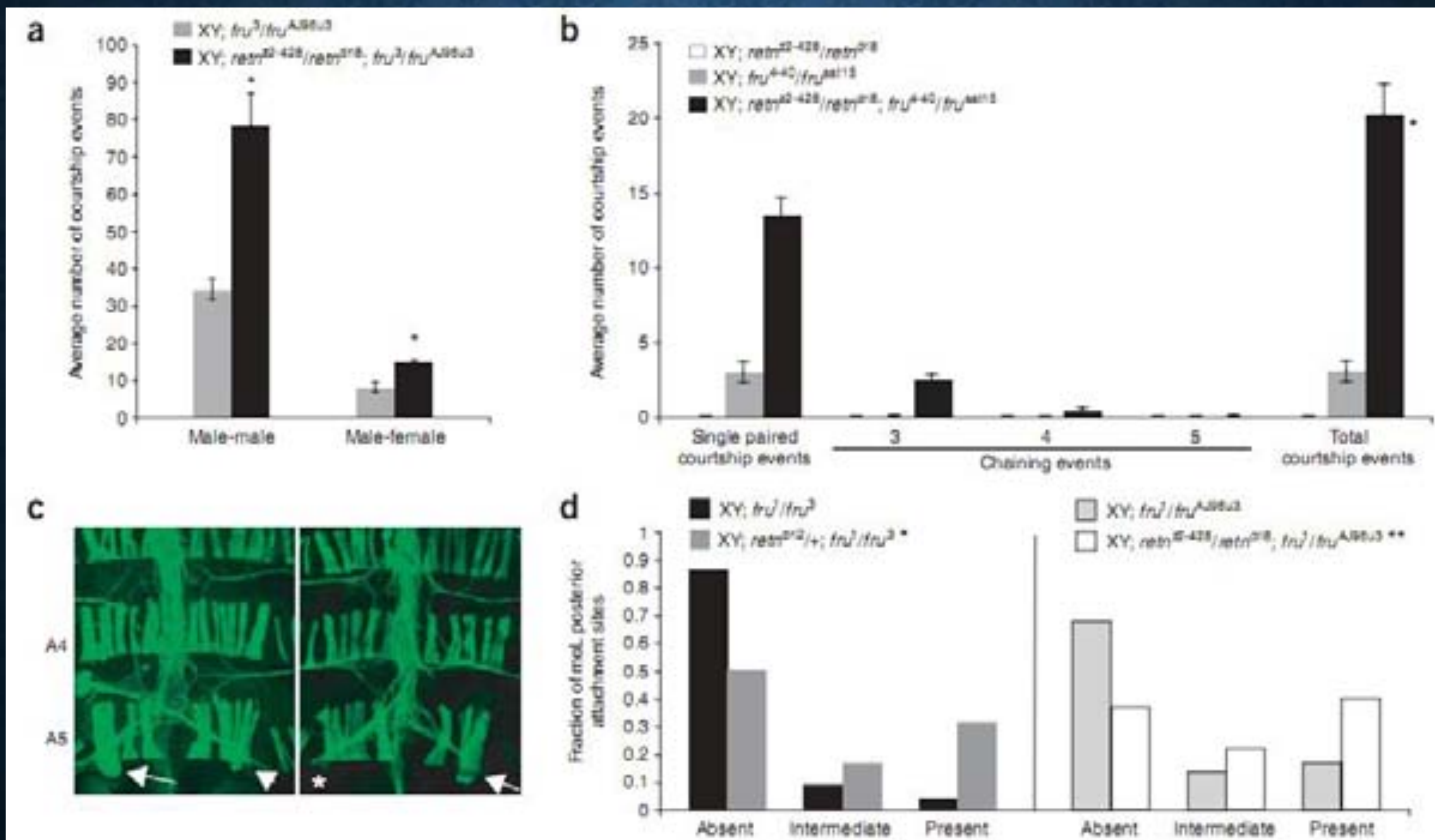


RETN: A-T Rich Interaction Domain (ARID) transcription factor

Ditch, L. M., et al. (2005)

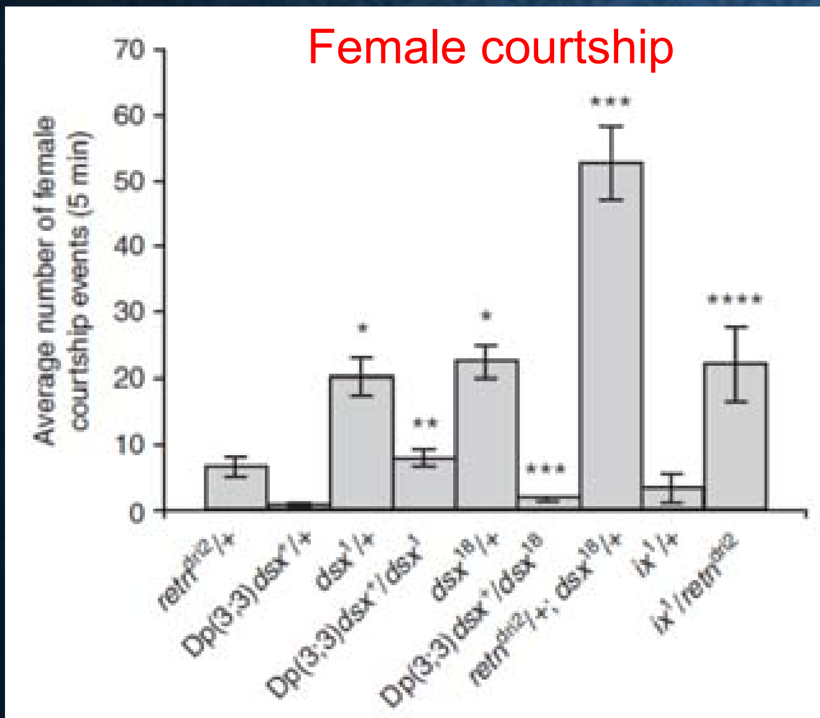
retn is antagonistic to *fru*^{M} in production of courtship and development of the moL

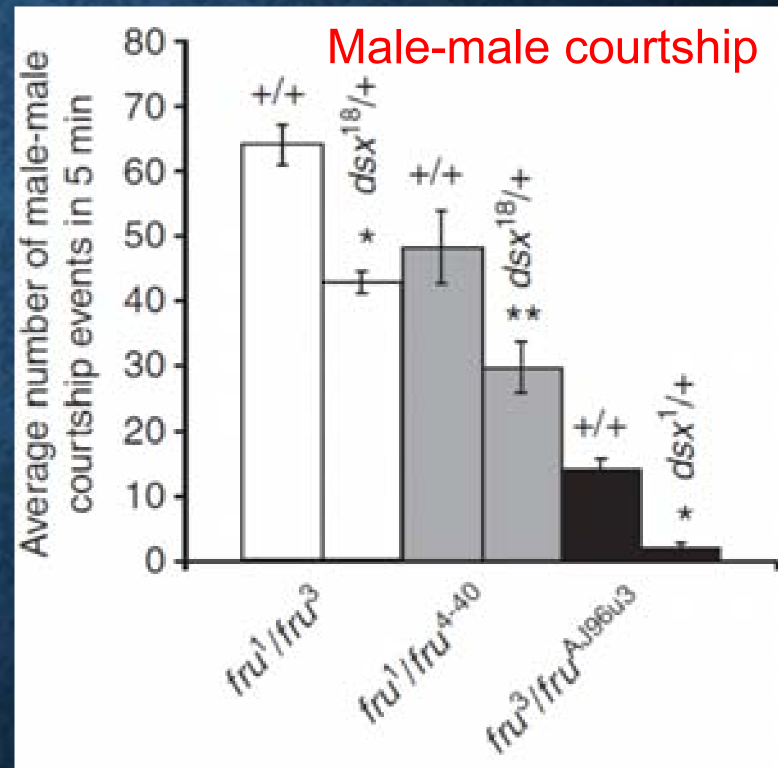
fru^{M}-males gain courtship activity with reduced *retn* function



Shirangi, T. R., et al. (2006)

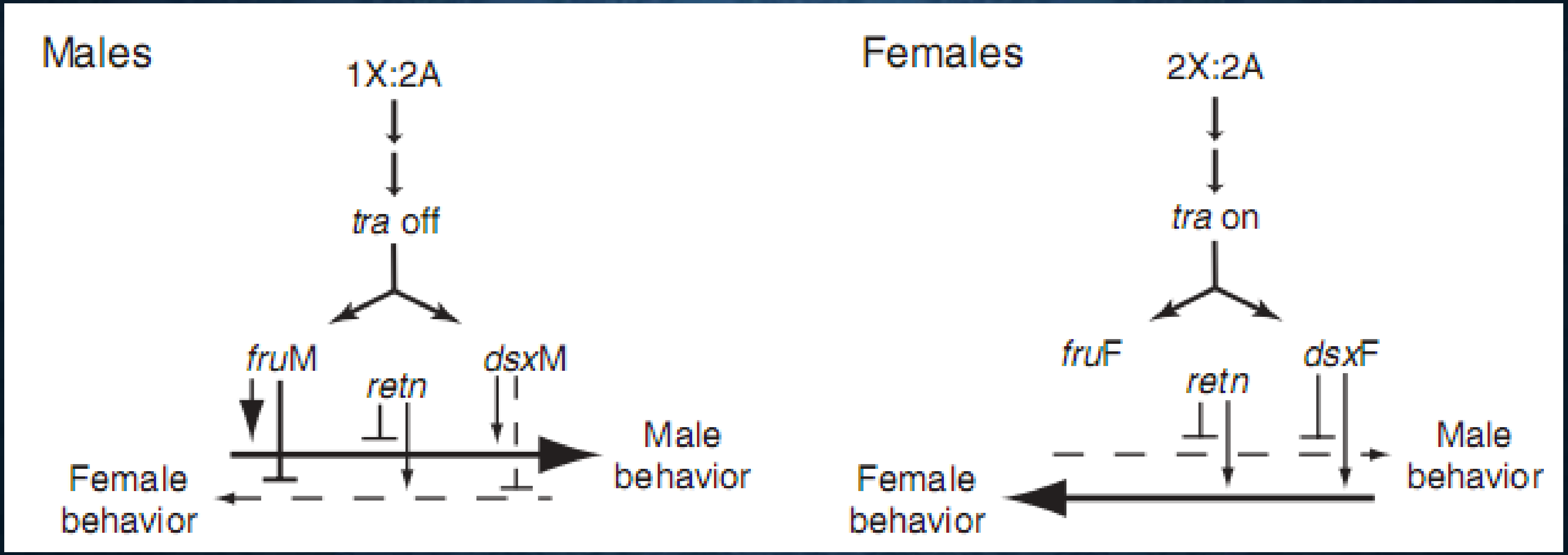
dsx controls sexual behavior





Shirangi, T. R., et al. (2006)

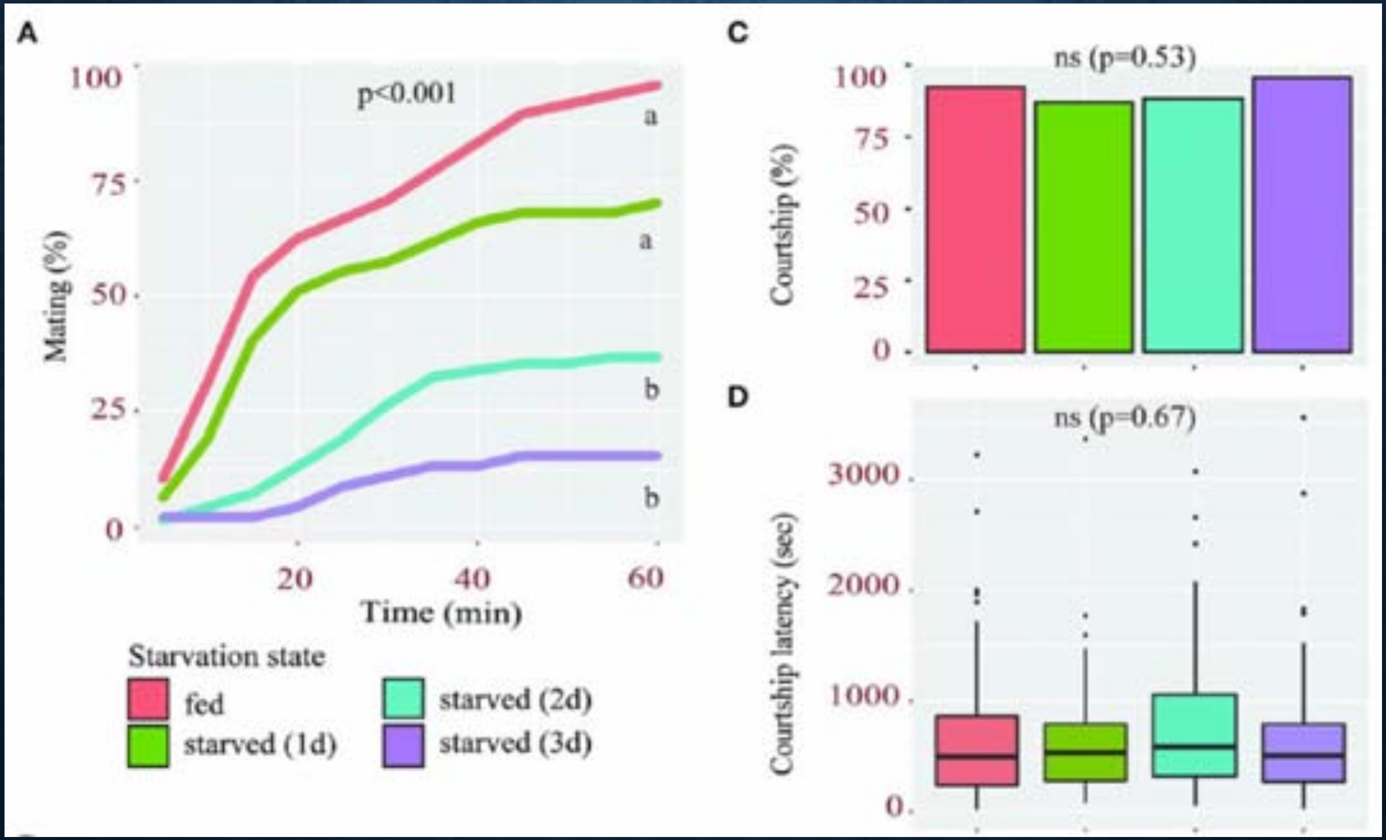
fru and *dsx* act as parts of a 'switch' system controlling sexual behavior



Shirangi, T. R., et al. (2006)

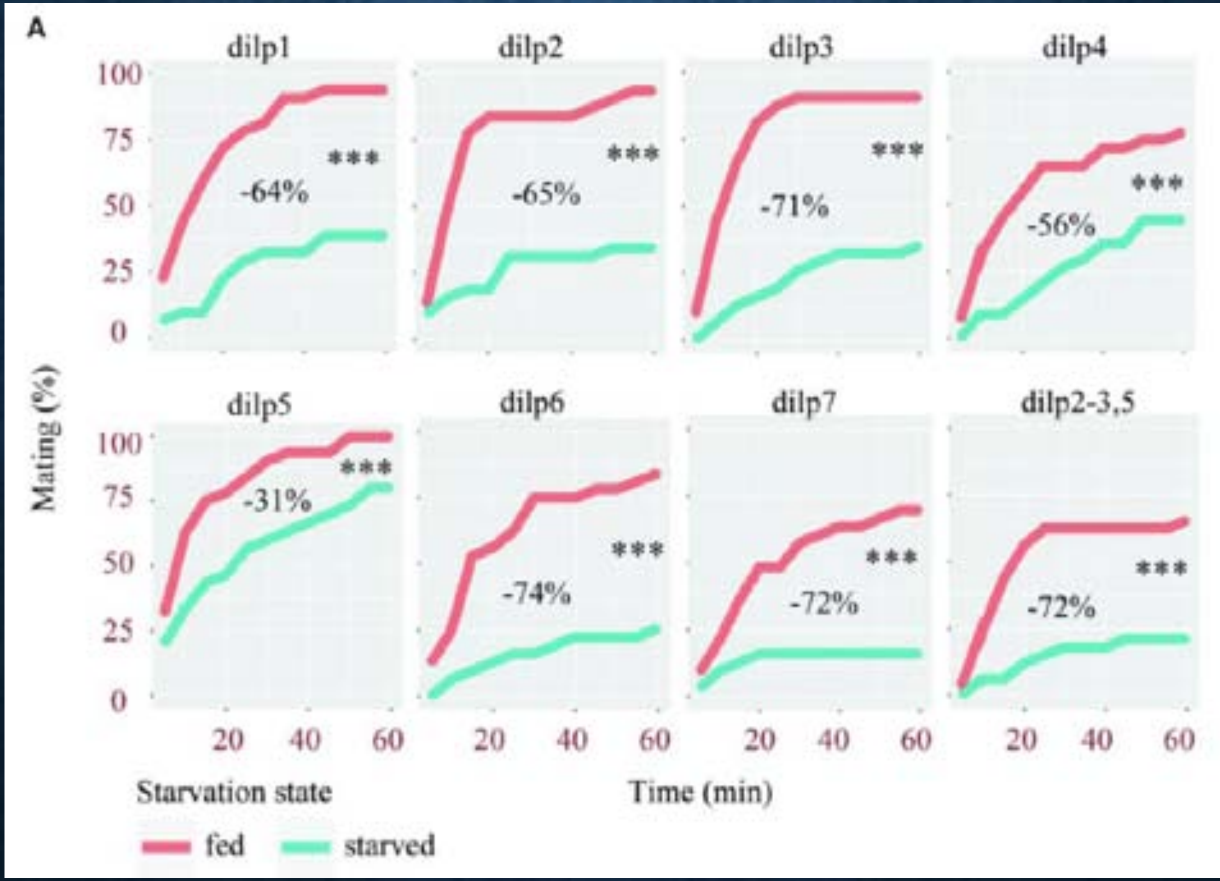
Insulin signaling regulates female sexual receptivity during starvation in *Drosophila*

Starvation regulates female sexual receptivity



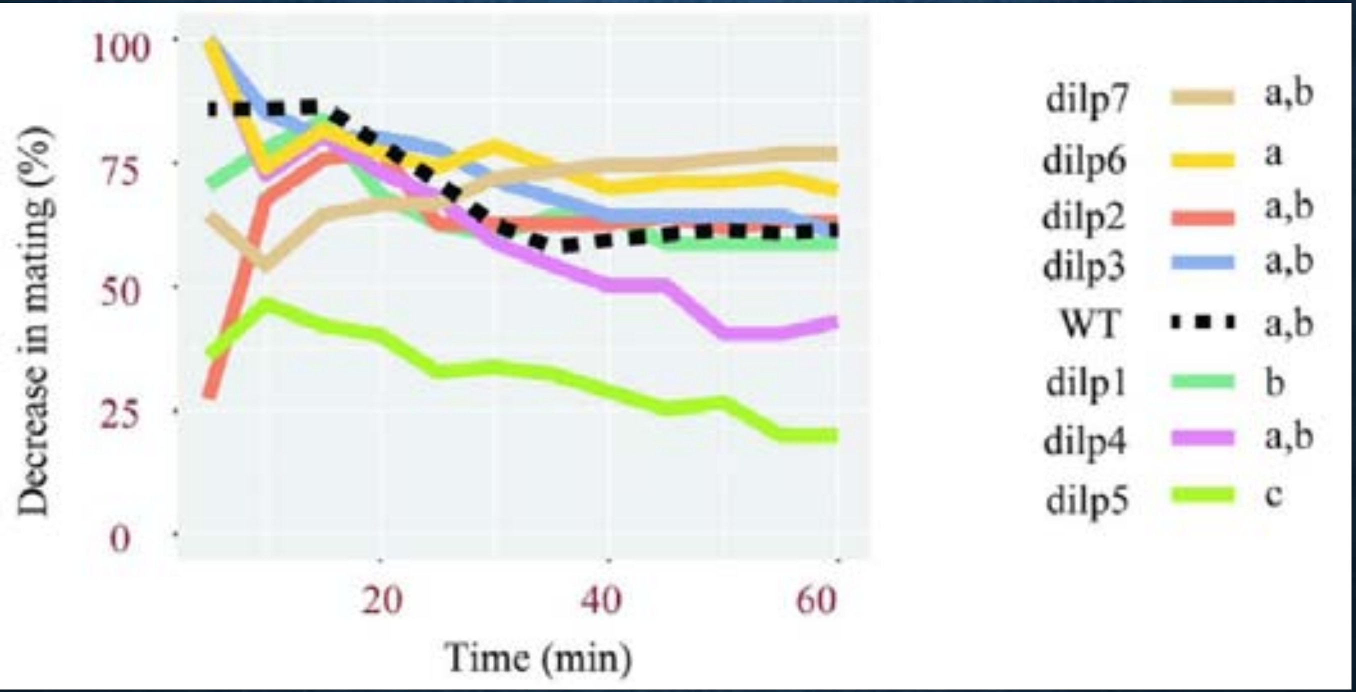
Lebreton, S., et al. (2017)

dilp genes showed significantly reduced sexual receptivity after starvation



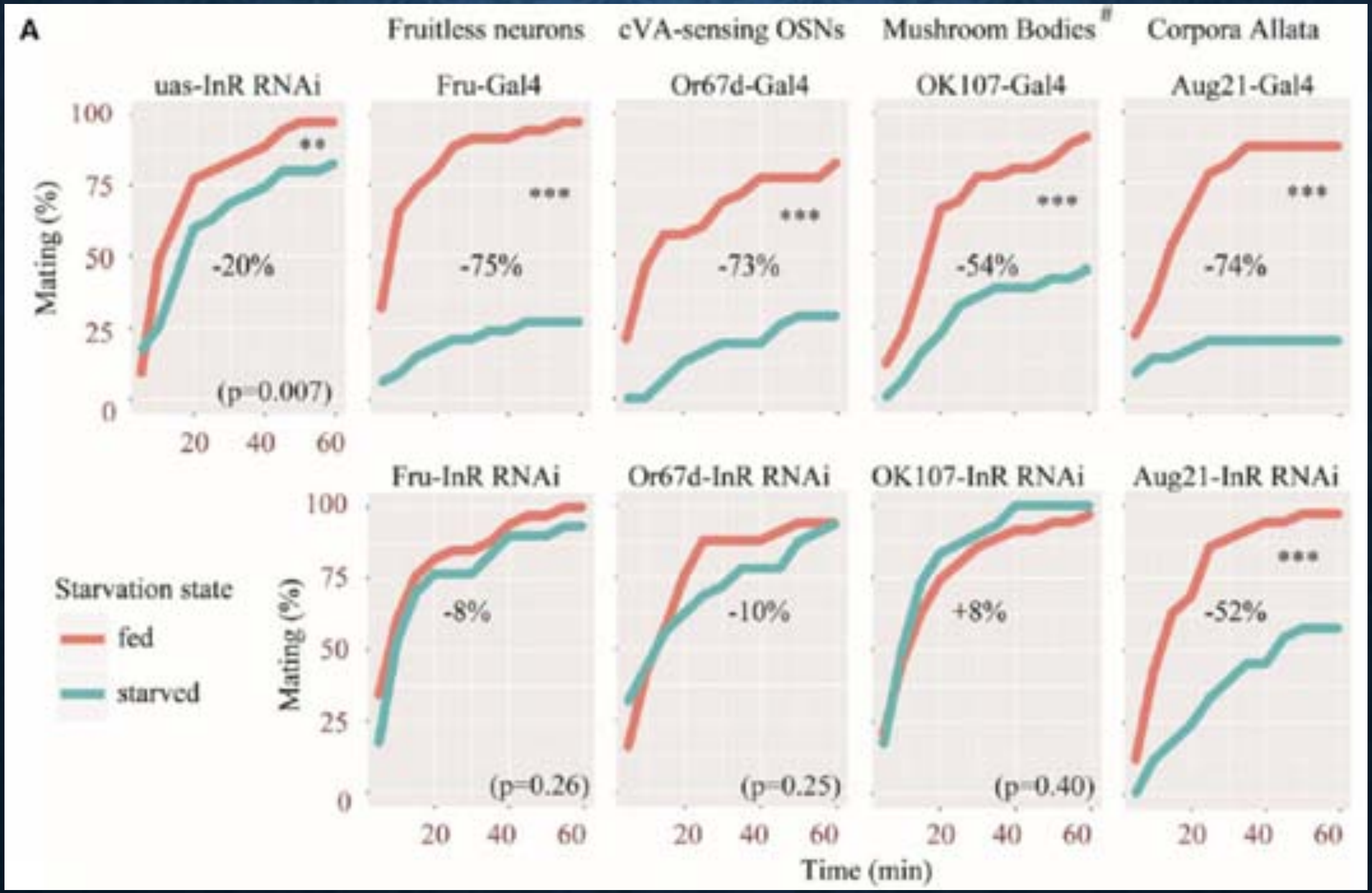
Lebreton, S., et al. (2017)

Mutations of single *dilp*s differentially affect female receptivity



Lebreton, S., et al. (2017)

Disrupting the insulin signaling in specific neuronal circuitries inhibits the effect of starvation on sexual receptivity



Lebreton, S., et al. (2017)

SUMMARY

- Whether virgin females accept males depends on multiple facts, courtship song, cVA, sensory neurons, CNS, transcription factors and so on.

- The mind of females would change after copulation, so called post-mating switch.

References

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- Bussell, J. J., et al. (2014). "Abdominal-B neurons control *Drosophila* virgin female receptivity." Curr Biol 24(14): 1584-1595.

References

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- Shirangi, T. R., et al. (2006). "A double-switch system regulates male courtship behavior in male and female *Drosophila* melanogaster." Nat Genet 38(12): 1435-1439.
- Lebreton, S., et al. (2017). "Insulin Signaling in the Peripheral and Central Nervous System Regulates Female Sexual Receptivity during Starvation in Drosophila." Front Physiol 8: 685.

CONTENT

- Part I Overview, virgin female receptivity
- Part II Sex-peptide (SP) signaling in post-mating switch
- Part III Neuronal modulation of post-mating behaviors

Overview：

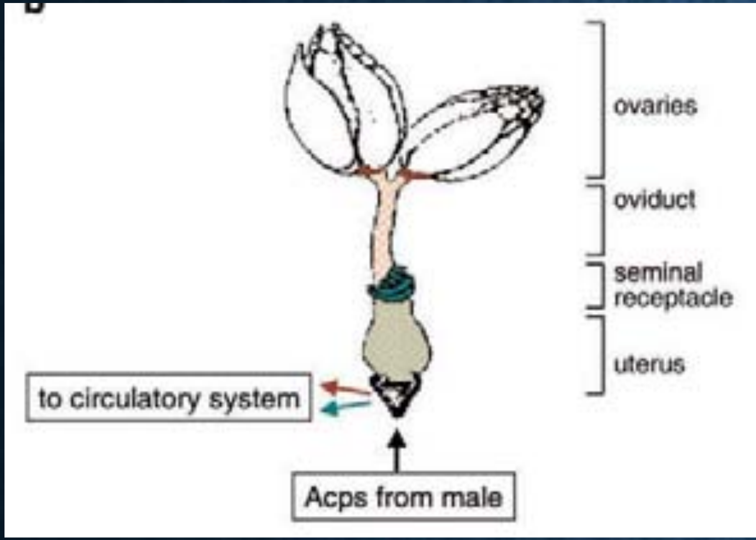


Fig. Female genital tract simplified map：

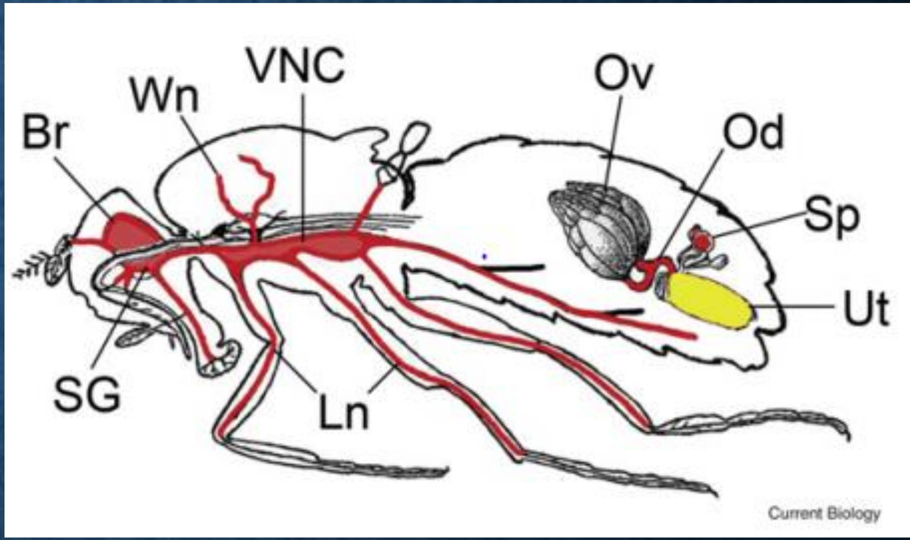
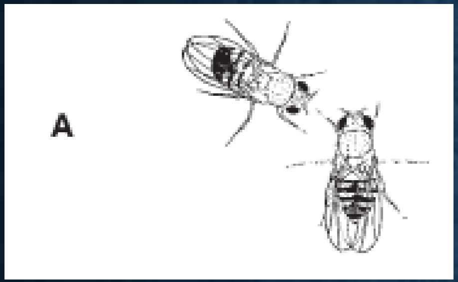


Fig. Distribution of sex Peptide Receptor and sp Binding Patterns in Adult Female Drosophila：

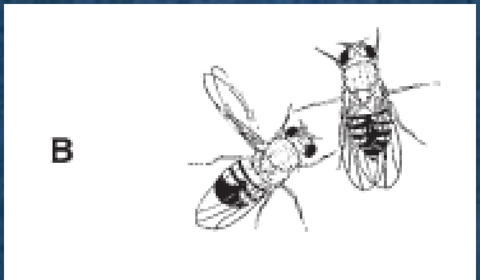
From:MF wolfneer. 2002. The gifts that keep on giving physiological functions and evolutionary dynamics of male seminal proteins in Drosophila.

From:E. Kubli. 2008. Sexual behaviour a receptor for sex control in Drosophila females.

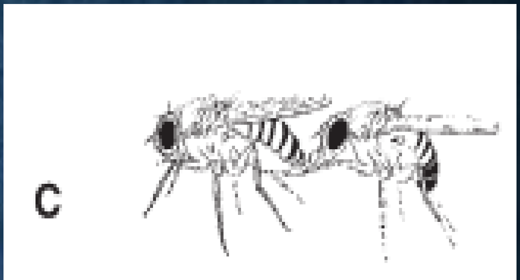
Mating behavior:



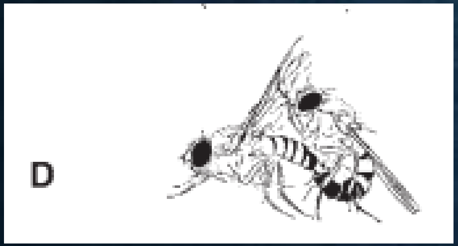
A. Orientation of the male towards the female.



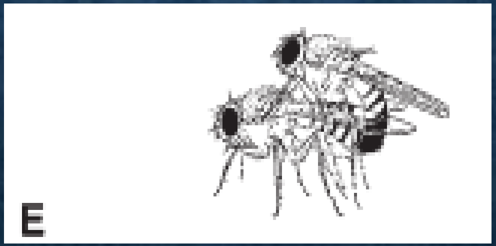
B. Love song of the male.



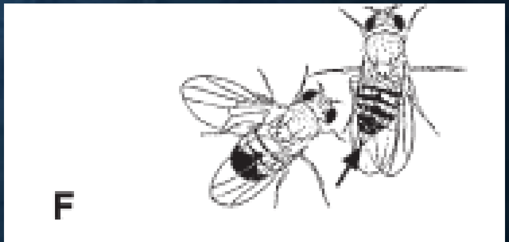
C. The male licks the genitalia of the female.



D. Attempted copulation.



E. Copulation.



F. A rejection response by the female.

From： E. Kubli. 2003. Sex peptides seminal peptides of the Drosophila male.

Female Post-mating behavior in *drosophila*：

1、Stimulate female egg production and ovulation.

2、Reduce their receptivity to mating.

3、Mediate sperm storage.

4、A mated female has a short lifespan.

seminal fluid

The function of sperm and seminal fluid proteins:

sperm	**Fertilization**
	Increase egg production rate
	Store sperm to maintain the state of intersection
	Sperm competition
seminal fluid proteins	**Increase egg production rate**
	Reduce female lifespan
	Reduce their receptivity to mating
	Mediate sperm storage

Accessory glands proteins：

Acps：accessory gland proteins

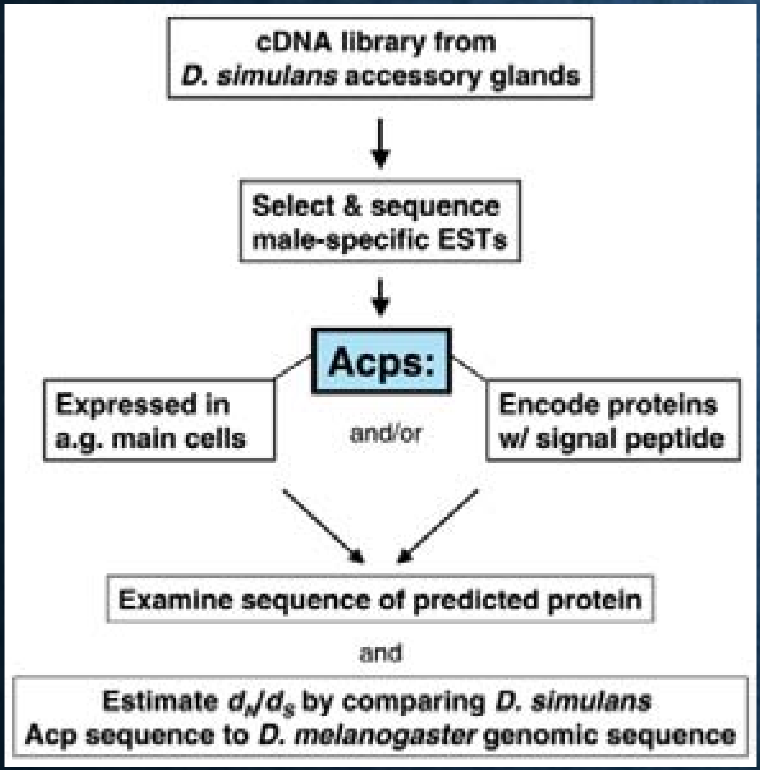


Fig. The “evolutionary EST screen” that identified Acp genes.

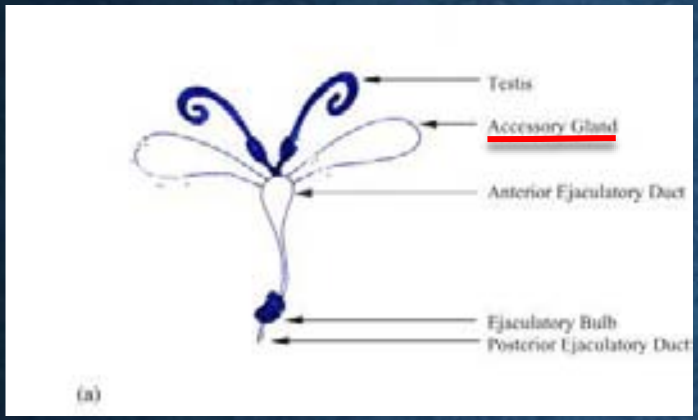
The 83 predicted Acps include:

- **Peptides (25) or prohormone precursors**
  - e.g. the ovulation hormone Acp26Aa (ovulin)
  - the ‘sex peptide” Acp70A
- **Glycoproteins**
  - e.g. the sperm storage protein Acp36DE
- **Modifying enzymes**
  - Proteases (9)
  - Protease inhibitors (8)
    - e.g. the trypsin inhibitor Acp62F
  - Lipases (6)
- **Many novel proteins**
- **~ 11% with signs of rapid evolution**

From:MF wolfneer. 2002. The gifts that keep on giving physiological functions and evolutionary dynamics of male seminal proteins in Drosophila.

Sites of synthesis of seminal fluid proteins:

Accessory glands proteins：



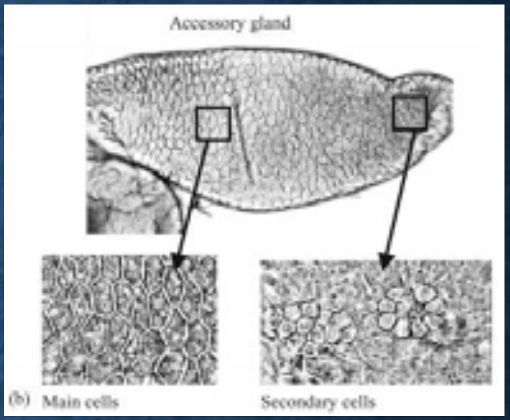


Table 1
Sites of synthesis of seminal fluid proteins

Site of synthesis	Nature of secreted substances	References
Accessory gland main cells	An estimated 83 accessory gland proteins, many with unknown functions. Acps include peptides, prohormones, glycoproteins, enzymes (putative proteases, protease inhibitors, lipases) and antibacterial peptides	[29,34,36,89,91,100,107,117]
Accessory gland secondary cells	Filaments of unknown constituents	[5,83]
Ejaculatory duct	Dup 99B (peptide)	[90]
	Esterase-6 (enzyme)	[44,71]
	Glucose dehydrogenase (enzyme)	[17,18]
	Andropin (peptide)	[66,89]
	Drosomycin (peptide)	[39]
Ejaculatory bulb	PEB-me (protein)	[63,67]
	cis-Vaccenyl acetate (lipid)	[14,16]
	Esterase-6 (enzyme)	[99,105]
	Drosomycin (peptide)	[39]

From: Tracey Chapman. 2004. Functions and analysis of the seminal fluid proteins of male Drosophila melanogaster fruit flies.

Table 2
Summary of known functions of seminal fluid peptides

Trait	Acp(s) responsible	References
Egg-laying	Acp70A	[21,29,62]
	Acp26Aa	[22,50–52]
	Dup99B[a]	[90]
Receptivity	Acp70A	[21,29,62]
	Dup99B[a]	[90]
Sperm storage	Main cell Acps	[56,112]
	Acp36DE	[12,78]
Sperm displacement	Main cell Acps	[49,86]
Sperm competition	Acp26Aa, Acp29AB, Acp36DE, Acp53Ea	[32]
	Acp36DE	[24]
Protection against bacterial infections	Andropin[b]	[89]
	Two unidentified Acps[b]	[66]
Protection against proteolysis	Acp62F[c]	[64]
	Acp76A[c]	[34,117]
Protection against fungal infections	Drosomycin[c]	[39]

[a] Phenotype is observed in response to ectopic injections, no effects of Dup99B are seen when females are mated to Dup99B-deficient males.
[b] In in vitro assays.
[c] Putative functions which need further confirmation, e.g. in assays with Acp-deficient males.

- Egg-laying: Acp70A（sex peptide）、Acp26Aa、Dup99B.
- Receptivity: Acp70A、Dup99B.
- Sperm storage: Acp36DE.

From: Tracey Chapman. 2004. Functions and analysis of the seminal fluid proteins of male Drosophila melanogaster fruit flies.

Summary：

1、Male *drosophila* provide information on post-mating behavior.

2、Multiple seminal fluid proteins work together on post-mating behavior.

3、Typical postmating behavior is mainly caused by sex peptide.

Sex-peptide controls female post-mating behavior in *Drosophila*.

Structure and function analysis in Sex peptide:

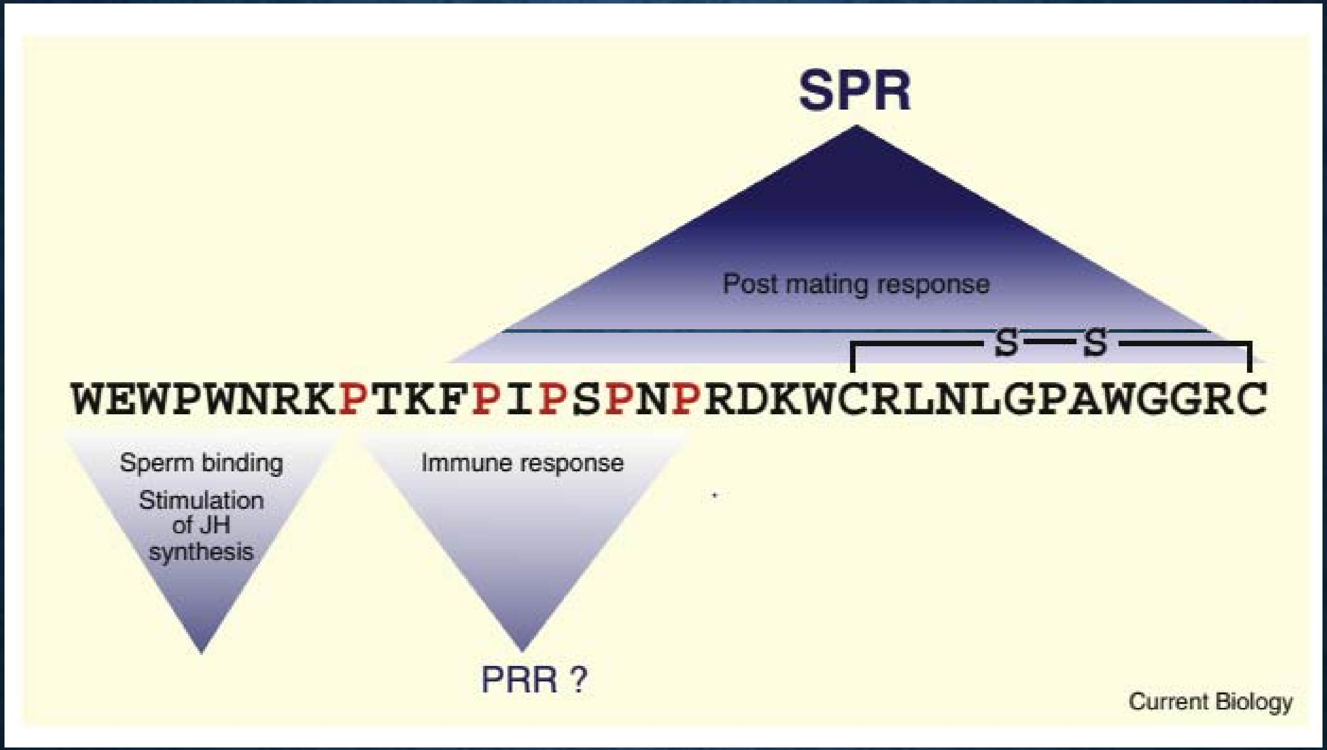


Fig. Structure–function relationship in Sex-peptide.
Several receptors may interact with SP. SP receptor very likely interacts with the carboxy-terminal part of SP known to be essential for eliciting the post-mating responses . The prolines indicated in red are hydroxylated and may interact with pattern recognition receptors (PRR) and thus induce antimicrobial peptide synthesis . The amino-terminal part of SP is essential for inducing the synthesis of juvenile hormone (JH) and for binding to sperm.

From:E. Kubli. 2008. Sexual behaviour a receptor for sex control in Drosophila females.

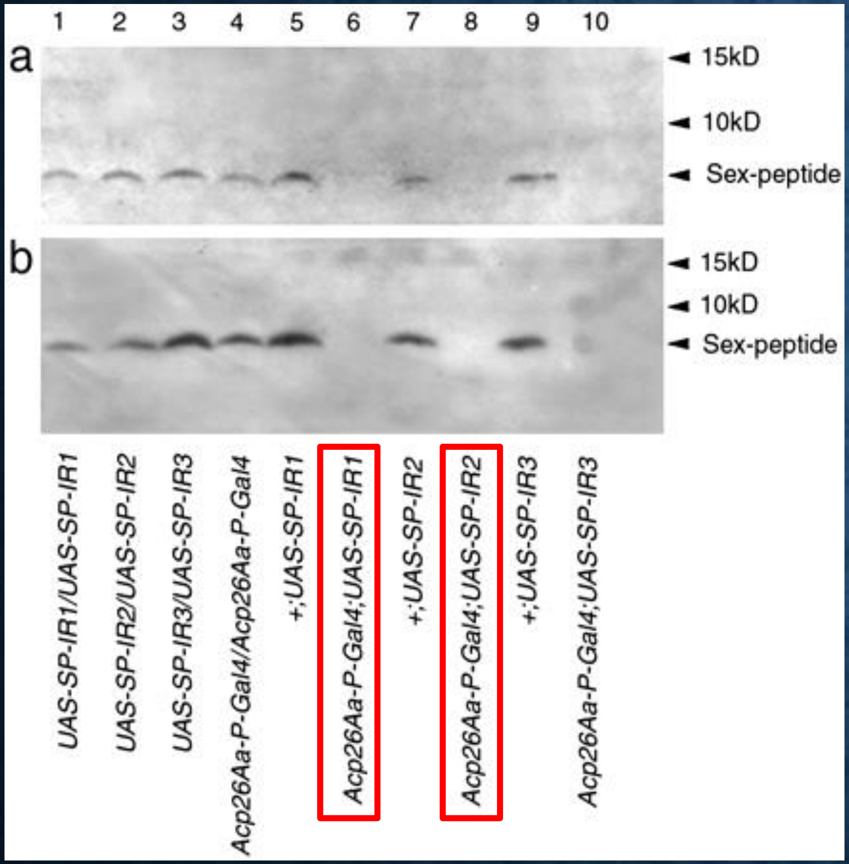


Fig. Female post-mating responses analyzed by using RNA interference:

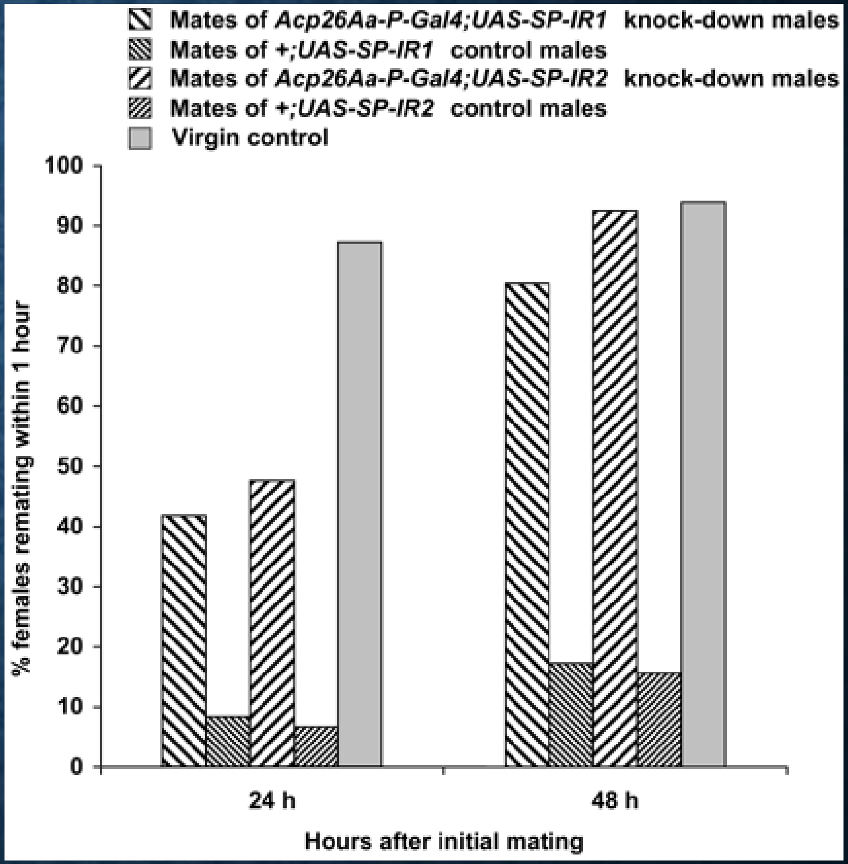


Fig. Effect of SP on female receptivity:

From: Tracey Chapman. 2003. The sex peptide of Drosophila melanogaster female post-mating responses analyzed by using RNA interference.

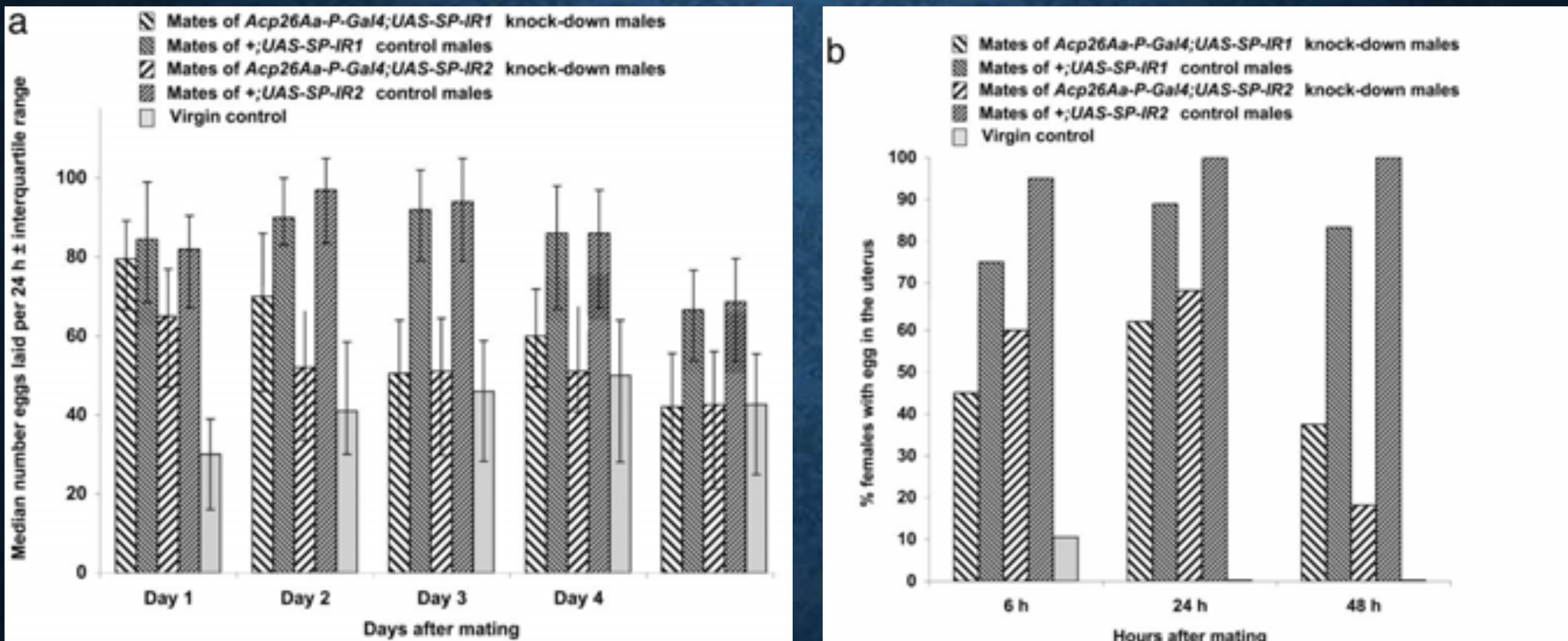


Fig a and b. Effect of SP on ovipostion and ovulation:

From: Tracey Chapman. 2003. The sex peptide of Drosophila melanogaster female post-mating responses analyzed by using RNA interference.

Molecular mechanisms of sex peptides and sex peptide receptors in post-mating response：

1、Gradual release of sperm bound sex-peptide controls female postmating behavior in Drosophila.

2、Sex peptide receptor mediates the post-mating switch in Drosophila reproductive behaviour.

3、SPR acts in neurvous system.

Sex peptide regulates the gradual release of sperm in female drosophila:

Ovulin →

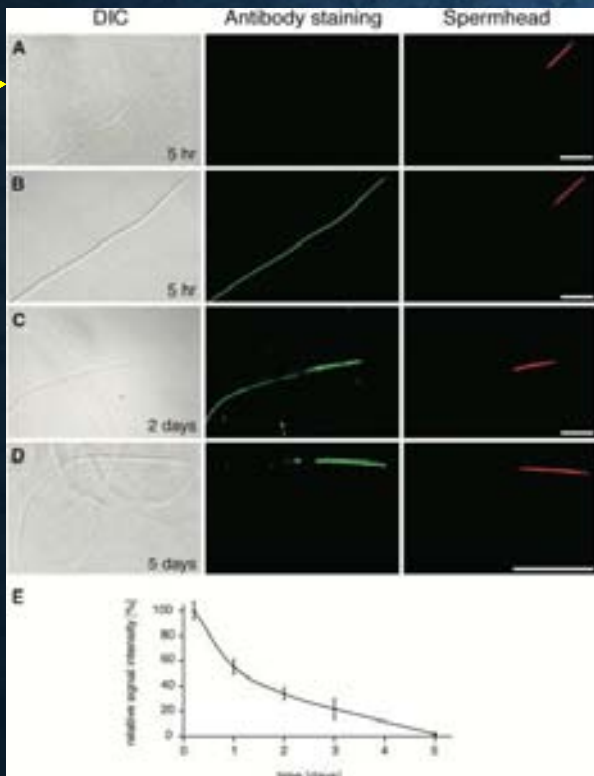


Fig. Sex-Peptide Binds to Sperm Stored in the Genital Tract of the Female.

SP_{1-36}:SP_{1-11}
AB:SP_{6-20} →

SP_{1-36}
AB:SP_{6-20} →

SP_{0}
AB:SP_{6-20} →

SP_{0} SP
AB:SP_{6-20} →

SP_{1-36}
AB:SP_{1-7} →

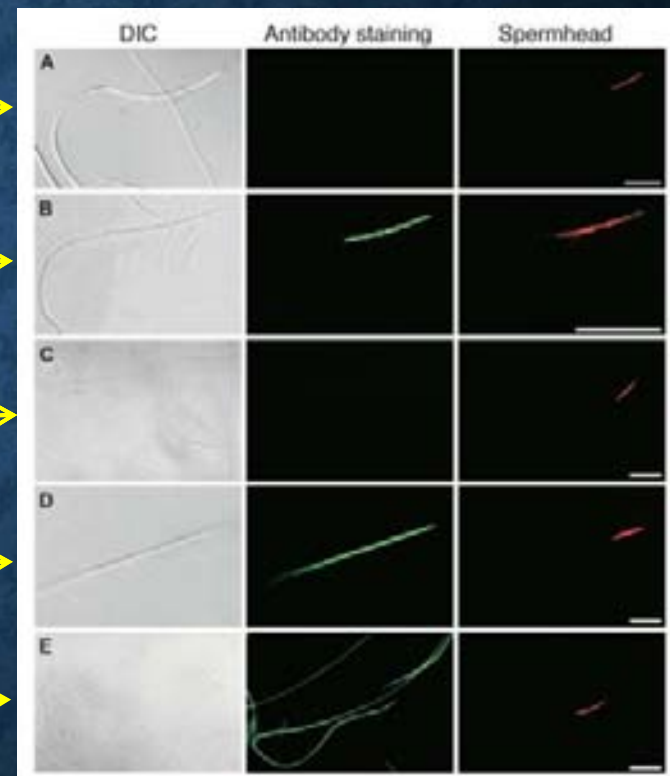


Fig. The C-Terminal Part of Sex-Peptide Is Gradually Cleaved off the Sperm Tail.

From: Jing Peng. 2005. Gradual release of sperm bound sex-peptide controls female postmating behavior in Drosophila.

Unmodifed SP →

SP lacking the N-terminal →

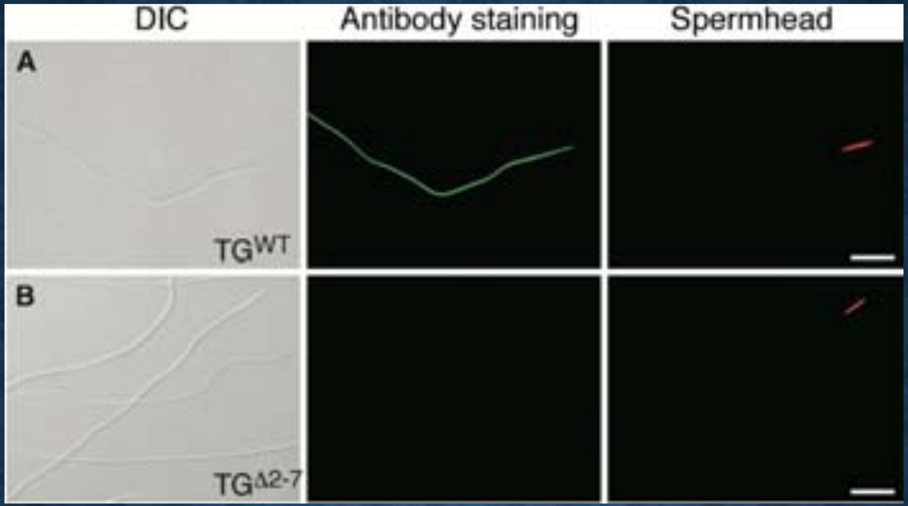


Fig. Sex-Peptide Lacking the N-Terminal End Cannot Bind to Sperm.

Unmodifed SP →

A modifed trypsin cleavage site. →

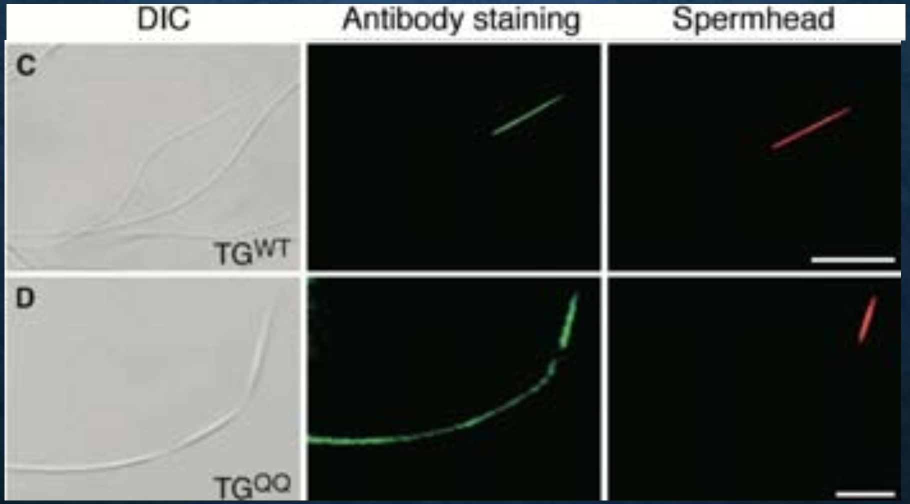


Fig. SP Containing a Modified Trypsin Cleavage Site Binds to Sperm Permanently and Cannot Be Cleaved.

From: Jing Peng. 2005. Gradual release of sperm bound sex-peptide controls female postmating behavior in Drosophila.

Conclusions:

In sum, the PMR of D. melanogaster females can be divided into two phases: the short-term PMR and the long-term PMR, respectively. The short-term PMR are induced immediately after mating mainly by free SP, the long-term PMR, lasting about one week, by the C-terminal SP fragment cleaved from SP bound to the sperm tail. Both responses likely elicit the PMR by binding of SP to specific sites in the central and peripheral nervous systems.

Molecular mechanisms of sex peptides in post-mating responses：

1、Gradual release of sperm bound sex-peptide controls female postmating behavior in Drosophila.

2、Sex peptide receptor mediates the post-mating switch in Drosophila reproductive behaviour.

3、SPR acts in neurvous system.

SPR is required for the post-mating switch induced by SP.

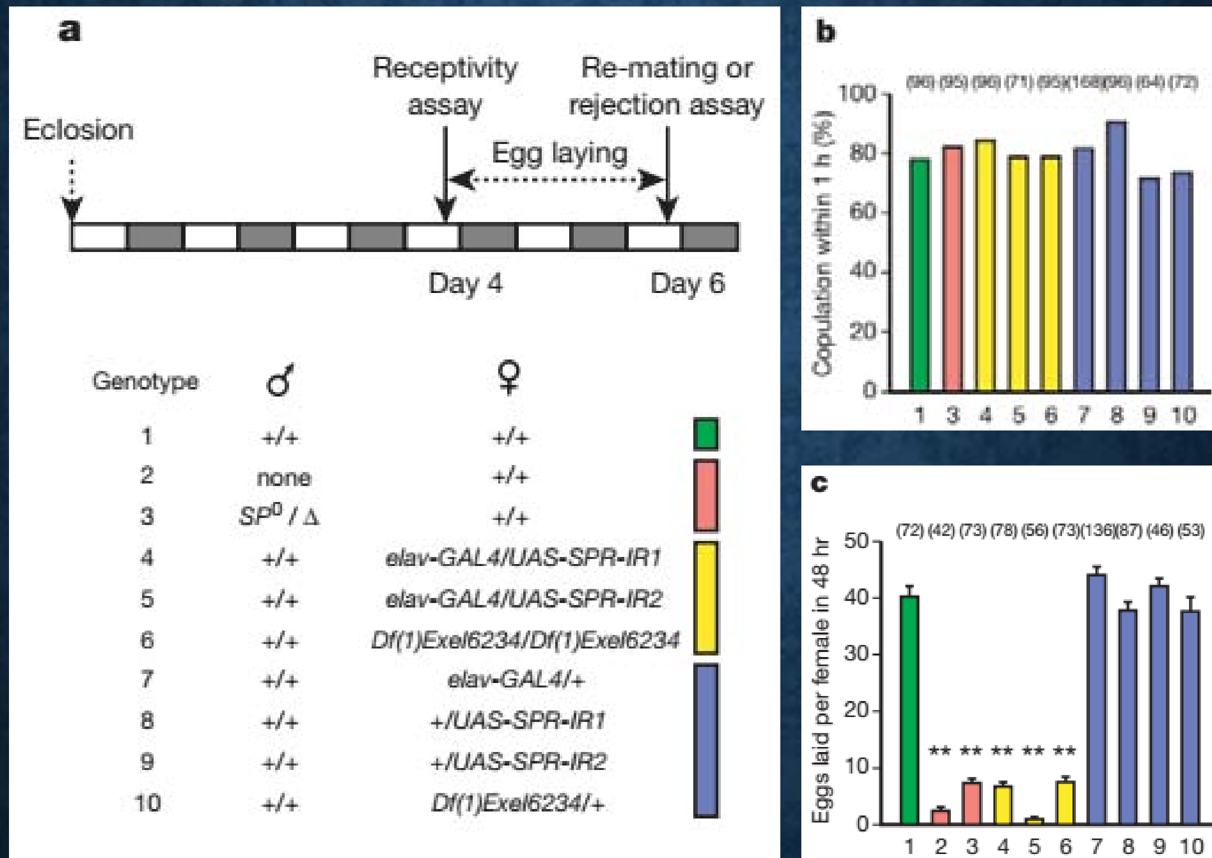


Fig a. Protocol for behavioural experiments in b–e. b, Receptivity of virgin females. c, Number of eggs laid per female

From: Nilay Yapici. 2008. A receptor that mediates the postmating switch in drosophila reproductive behavior.

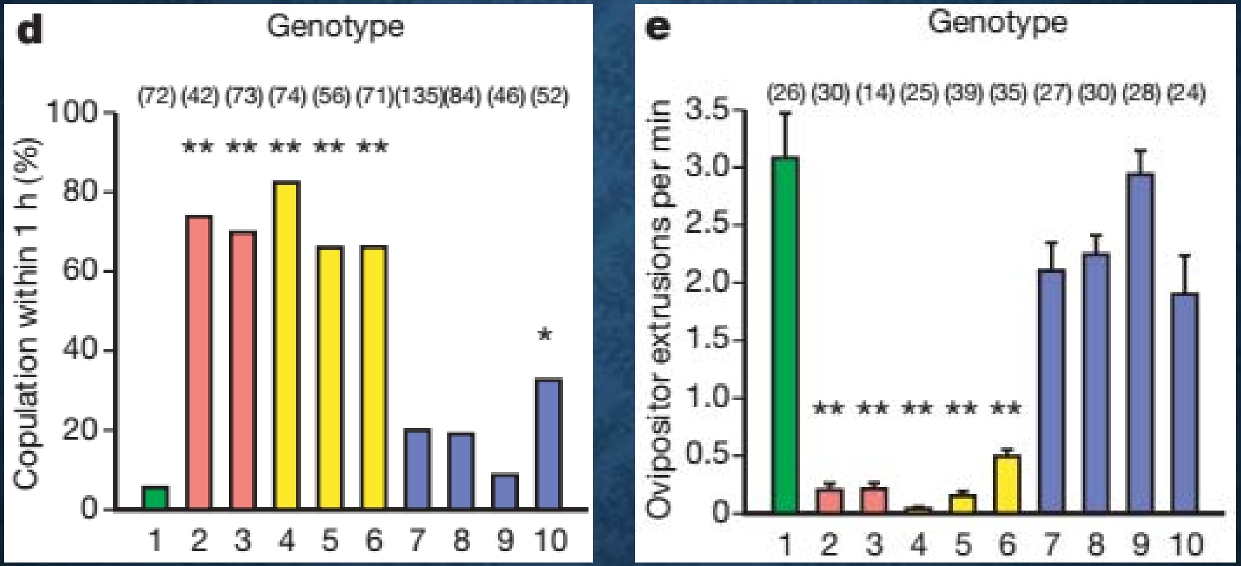


Fig d, Re-mating frequency. e, Ovipositor extrusions per minute during a ten-min courtship assay with a naive wild-type male.

From: Nilay Yapici. 2008. A receptor that mediates the postmating switch in drosophila reproductive behavior.

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J Insect Physiol. Author manuscript; available in PMC 2016 May 01.

Published in final edited form as:

J Insect Physiol. 2015 May ; 76: 1–6. doi:10.1016/j.jinsphys.2015.03.006.

Sex Peptide Receptor is required for the release of stored sperm by mated *Drosophila melanogaster* females

Frank W. Avila[*], **Alexandra L. Mattei**[*], and **Mariana F. Wolfner**

Department of Molecular Biology and Genetics, Cornell University, Ithaca, NY, USA

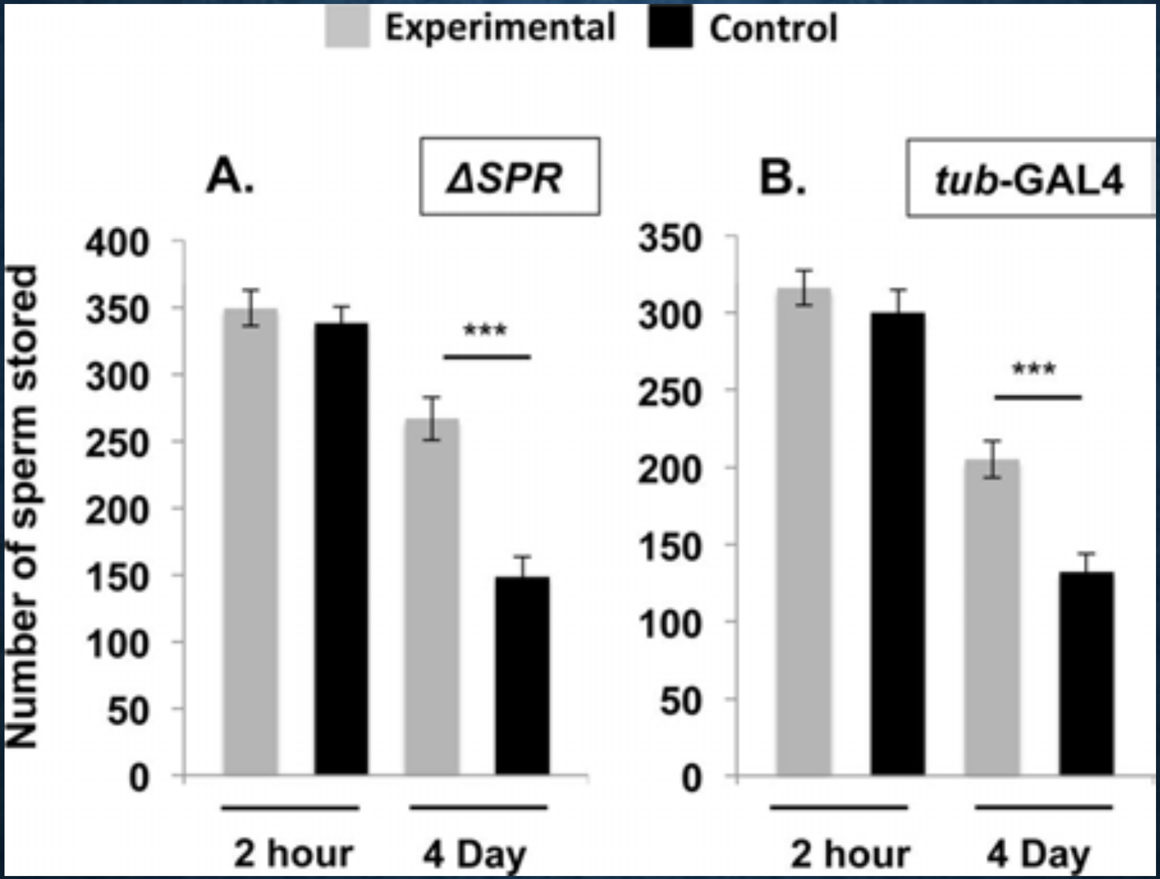


Fig. SPR is required to mediate SP’ s effect on sperm release from storage.

From: Nilay Yapici. 2008. A receptor that mediates the postmating switch in drosophila reproductive behavior.

Molecular mechanisms of sex peptides in post-mating responses

1、Gradual release of sperm bound sex-peptide controls female postmating behavior in Drosophila.

2、Sex peptide receptor mediates the post-mating switch in Drosophila reproductive behaviour.

3、SPR acts in neurvous system.

SPR is expressed in the female reproductive organs and nervous system.

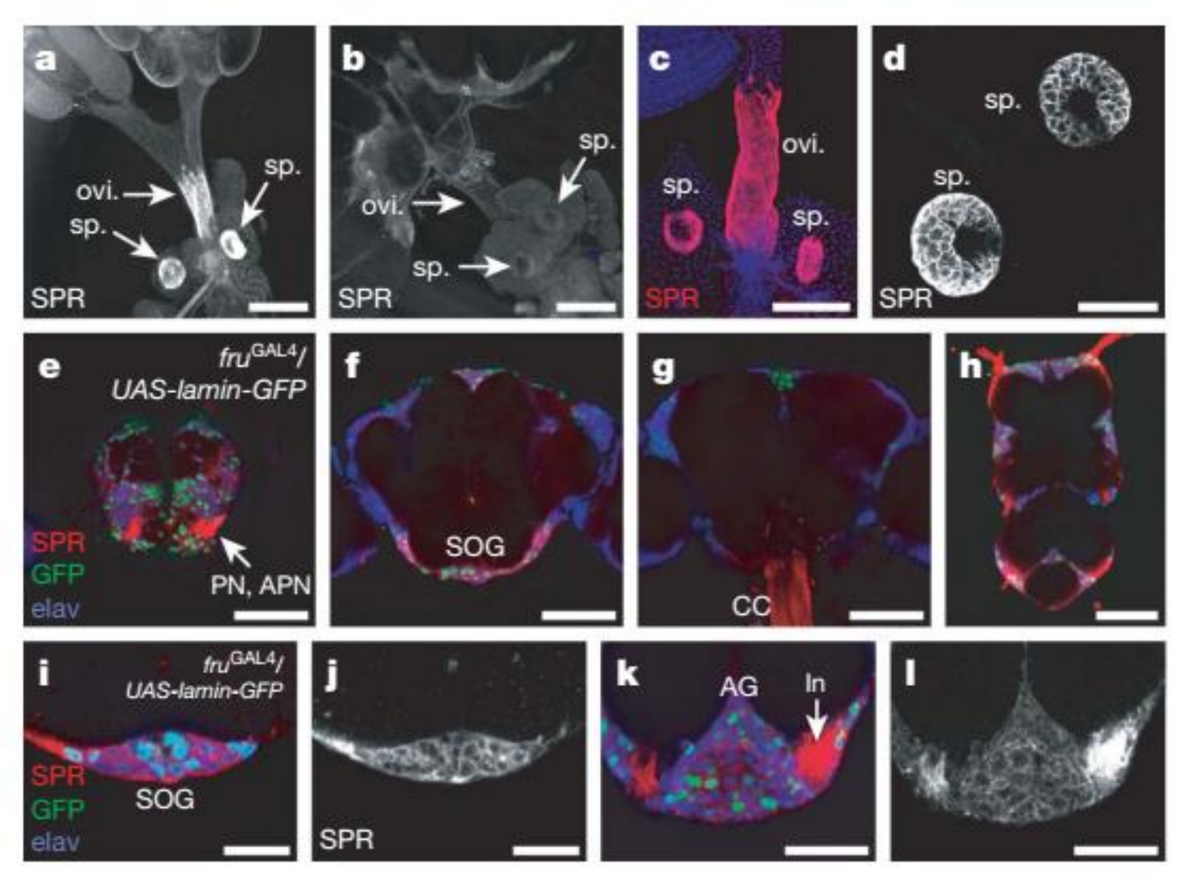


Fig. SPR is expressed in the female reproductive organs and nervous system.

From: Nilay Yapici. 2008. A receptor that mediates the postmating switch in drosophila reproductive behavior.

SPR acts in fru neurons.

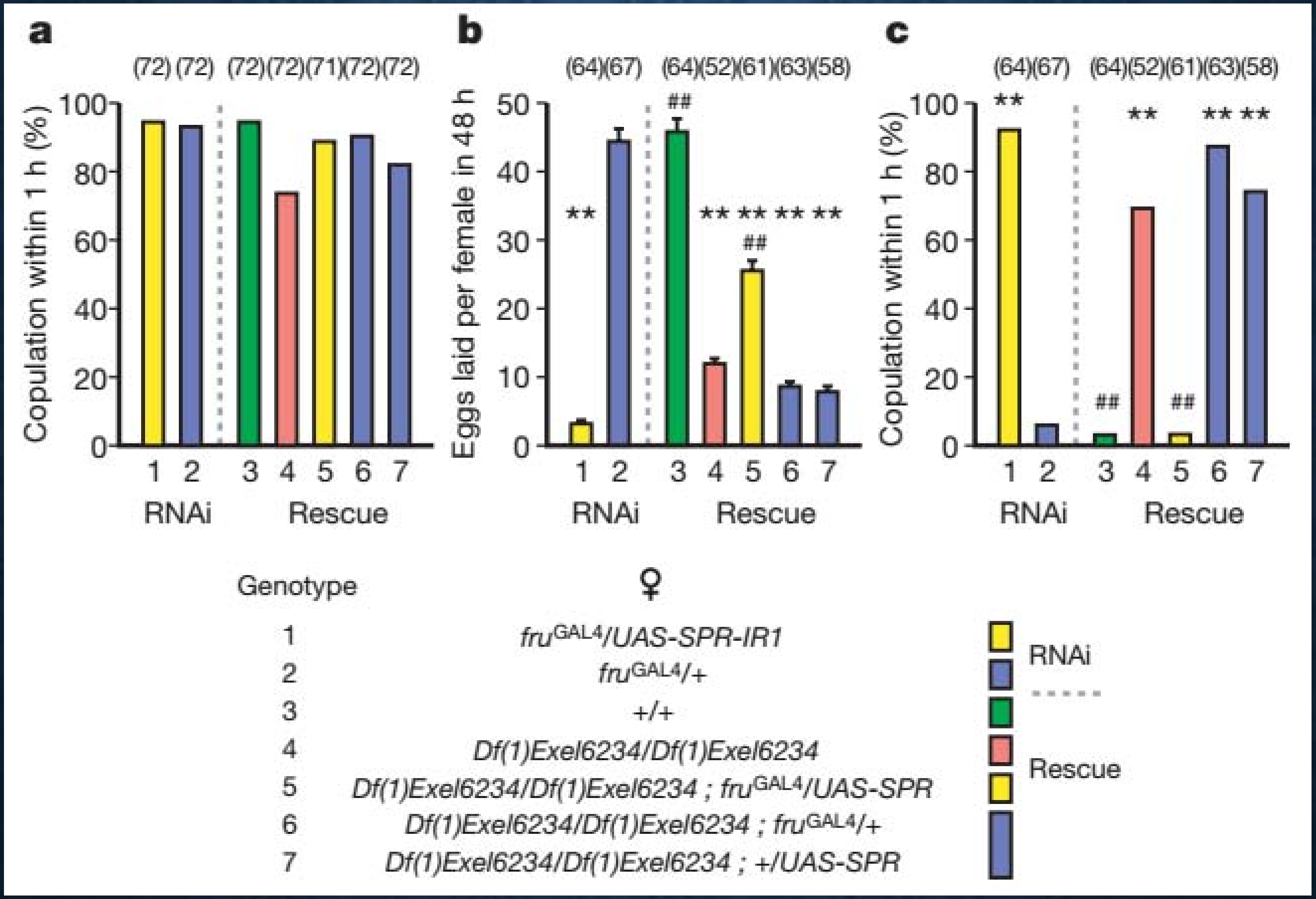
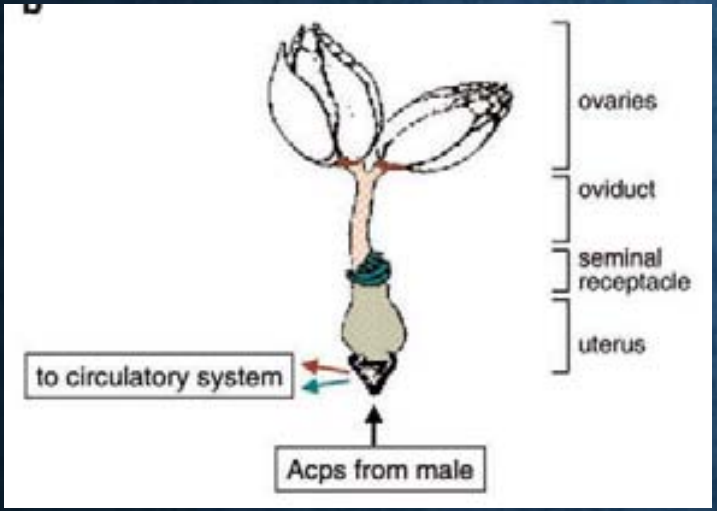
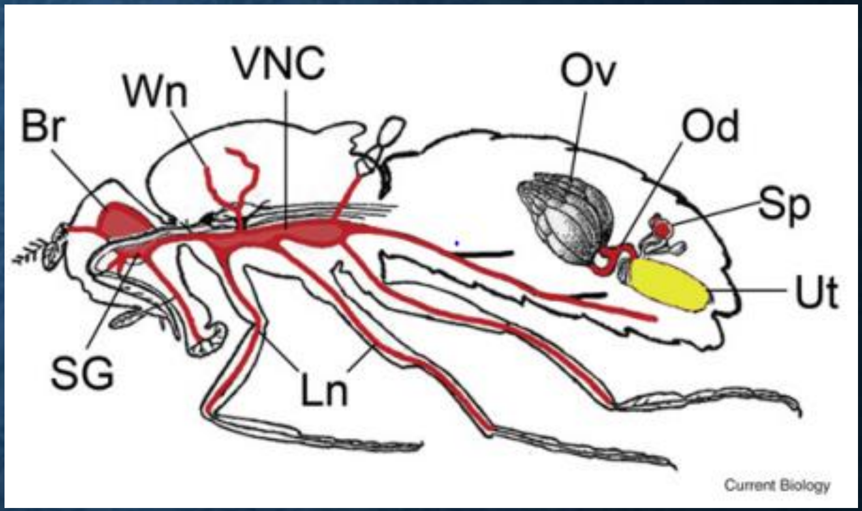


Fig: SPR acts in fru neurons. a, b, c, Receptivity (a), egg-laying (b) and re-mating (c) assays for females of the indicated genotype, mated with wild-type males

From: Nilay Yapici. 2008. A receptor that mediates the postmating switch in drosophila reproductive behavior.

Conclusions:





References:

MF wolfneer, et al. (2002). The gifts that keep on giving physiological functions and evolutionary dynamics of male seminal proteins in Drosophila. Heredity (Edinb); 88(2):85-93.

E. Kubli, et al. (2008). Sexual behaviour a receptor for sex control in Drosophila females.Curr Biol ;18(5):R210-2.

E. Kubli, et al. (2003). Sex peptides seminal peptides of the Drosophila male. Cell Mol Life Sci. 60(8):1689-704.

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Tracey Chapman, et al. (2004). Functions and analysis of the seminal fluid proteins of male Drosophila melanogaster fruit flies. Peptides; 25(9):1477-90.

References:

Nilay Yapici, et al. (2008). A receptor that mediates the postmating switch in drosophila reproductive behavior. Nature. ;451(7174):33-7.

Tracey Chapman, et al. (2003). The sex peptide of Drosophila melanogaster female post-mating responses analyzed by using RNA interference. Proc Natl Acad Sci U S A;100(17):9923-8.

Jing Peng,et al. (2005). Gradual release of sperm bound sex-peptide controls female postmating behavior in Drosophila. Curr Biol 8;15(3):207-13.

Nilay Yapici,et al. (2008). A receptor that mediates the postmating switch in drosophila reproductive behavior. Curr Biol. 10;22(13):1155-65. doi: 10.1016/j.cub.2012.04.062.

Peng J, et al. (2015). Sex peptide receptor is required for the release of stored sperm by mated Drosophila melanogaster females. Curr Biol. ;15(3):207-13.

CONTENT

- Part I Overview, virgin female receptivity
- Part II Sex-peptide (SP) signaling in post-mating switch
- Part III Neuronal modulation of post-mating behaviors

Journal club

Neuronal modulation of post-mating behaviors in *D. melanogaster* females

Pan Yufeng

2018-9-28

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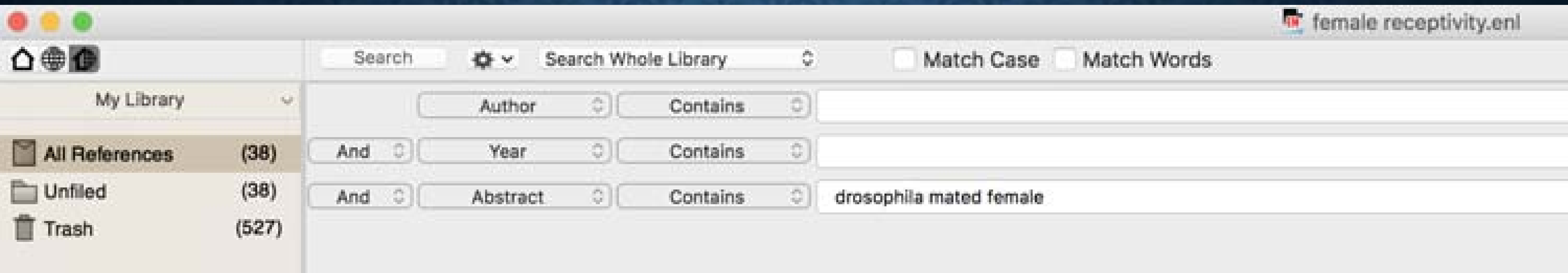


500+ papers: read titles and journal names;

38 papers : read abstract or more;

22 papers: this presentation.

What happens to female during mating?

- Transfer of sperm
- Transfer of seminal fluids including sex-peptide (SP)
- Transfer of male-specific pheromones (e.g. cVA)
- Physical contact/stimulation

What happens to female during mating?

- Transfer of sperm
- Transfer of seminal fluids including sex-peptide (SP)
- Transfer of male-specific pheromones (e.g. cVA)
- Physical contact/stimulation

→

- Fertilization
- SP-induced post-mating behaviors
- Reduce female attractiveness;
- Unknown

Question 1: how do mated females behave differently?

- Mated females consume more amino acids

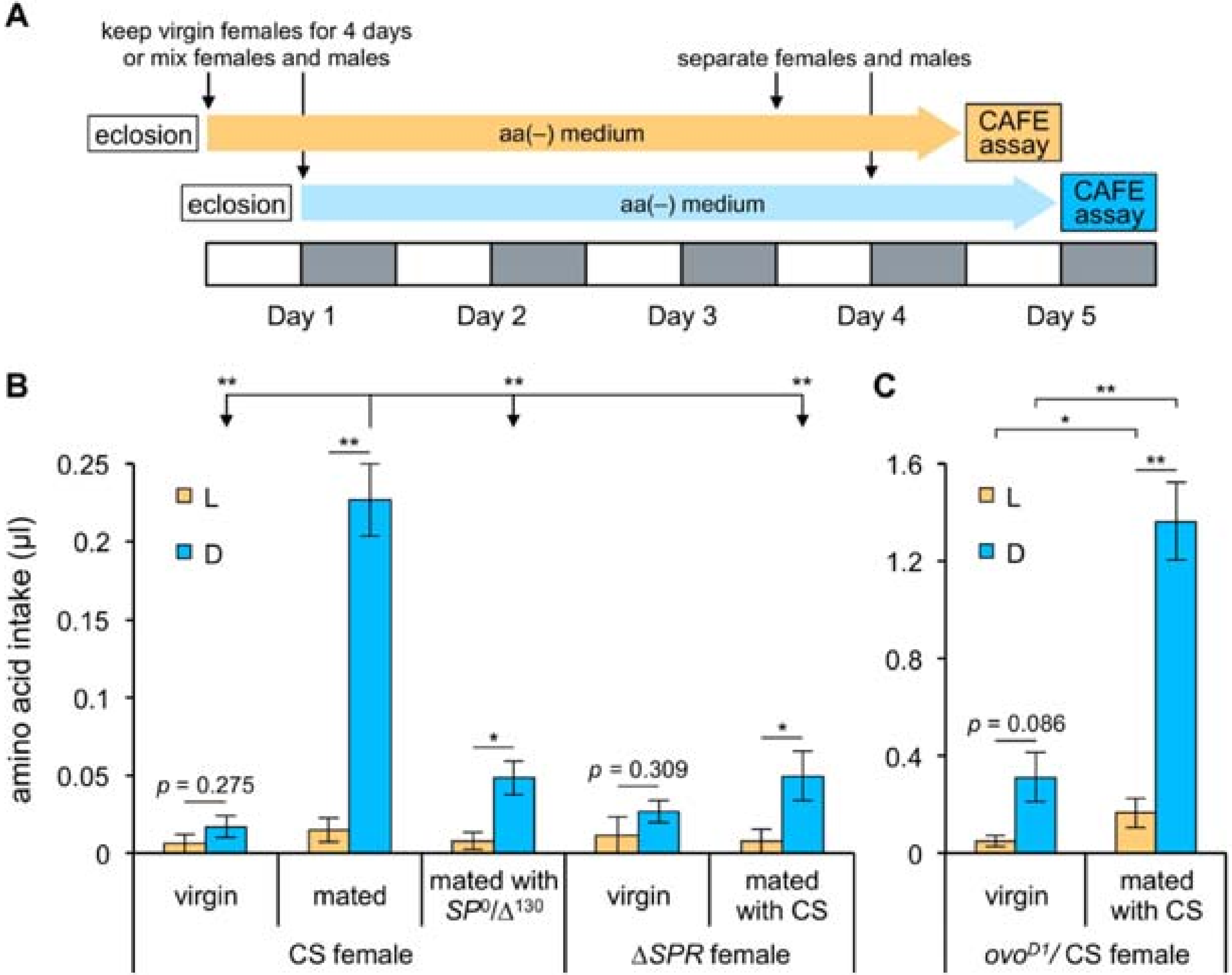


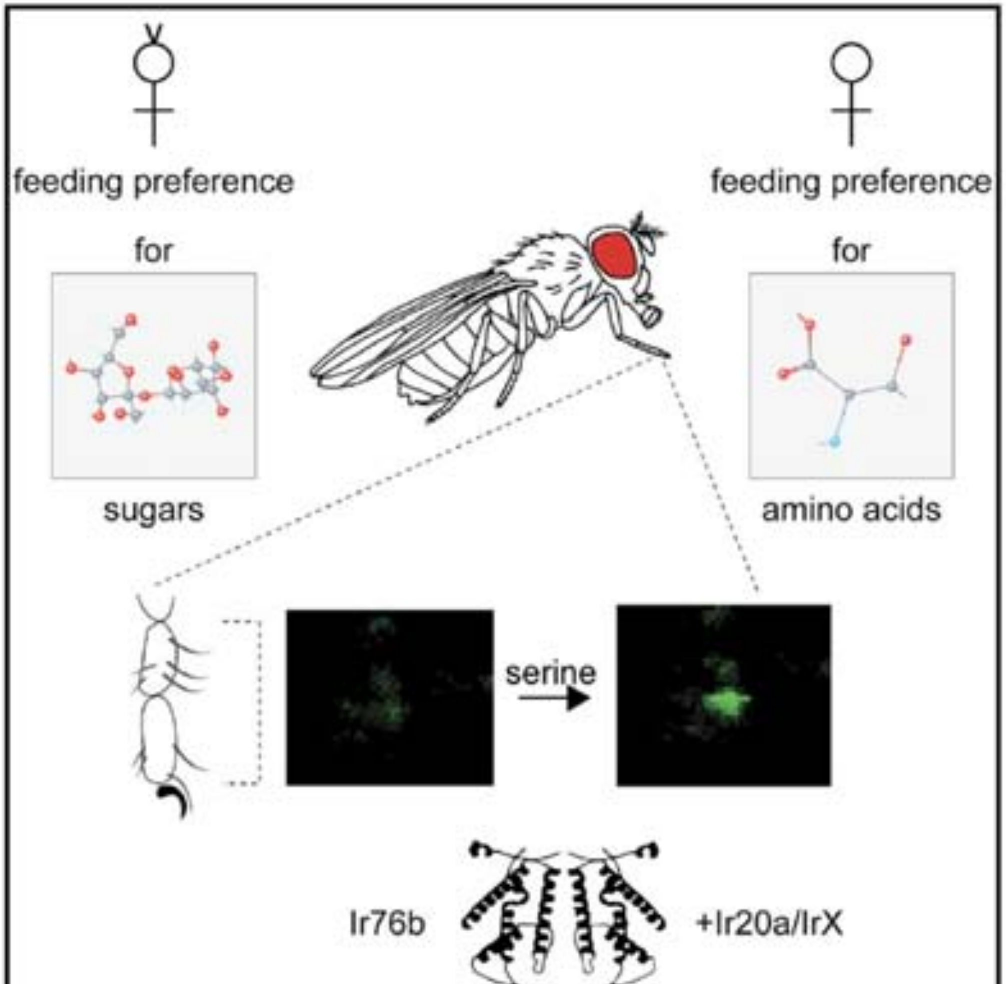
Fig 4. A post-mating signal elevates amino acid consumption during the dark phase. (A) The experimental scheme for the CAFE assays. Each L phase is shown by a white box and each D phase by a gray box. (B and C) Amino acid consumption during L (orange bars) and D (blue bars) phases was quantified using no-choice CAFE assays with the following strains: virgin CS females and CS females mated with CS or *SP*^{0}/Δ^{130} males (B;

Cell Reports

Article

A Molecular and Cellular Context-Dependent Role for Ir76b in Detection of Amino Acid Taste

Graphical Abstract



Authors

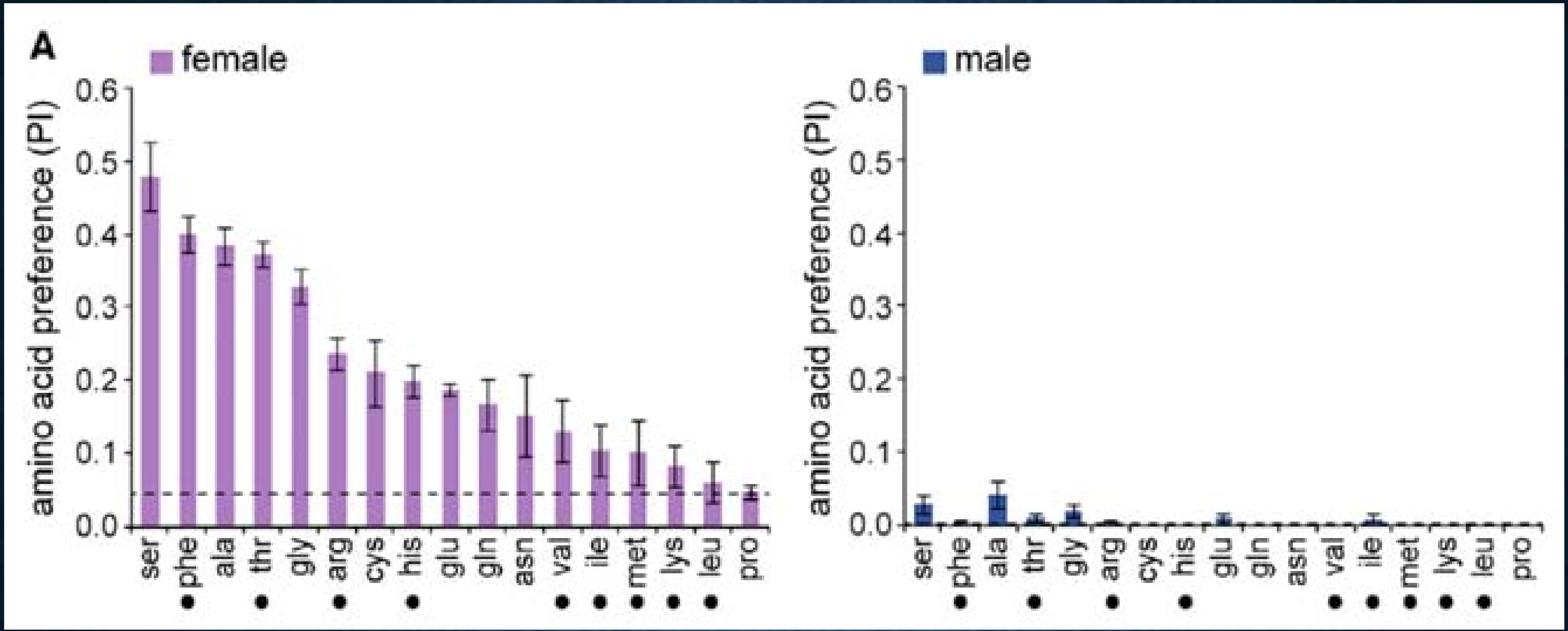
Anindya Ganguly, Lisa Pang, Vi-Khoi Duong, Angelina Lee, Hanni Schoniger, Erika Varady, Anupama Dahanukar

Correspondence

anupama.dahanukar@ucr.edu

In Brief

Ganguly et al. demonstrate that Ir76b mediates cellular and behavioral responses to amino acids that underlie post-mating yeast and amino acid feeding preferences of *Drosophila* females. Ir20a, possibly one among many factors, plays a role in changing Ir76b activity from an ungated salt receptor to an amino-acid-gated receptor.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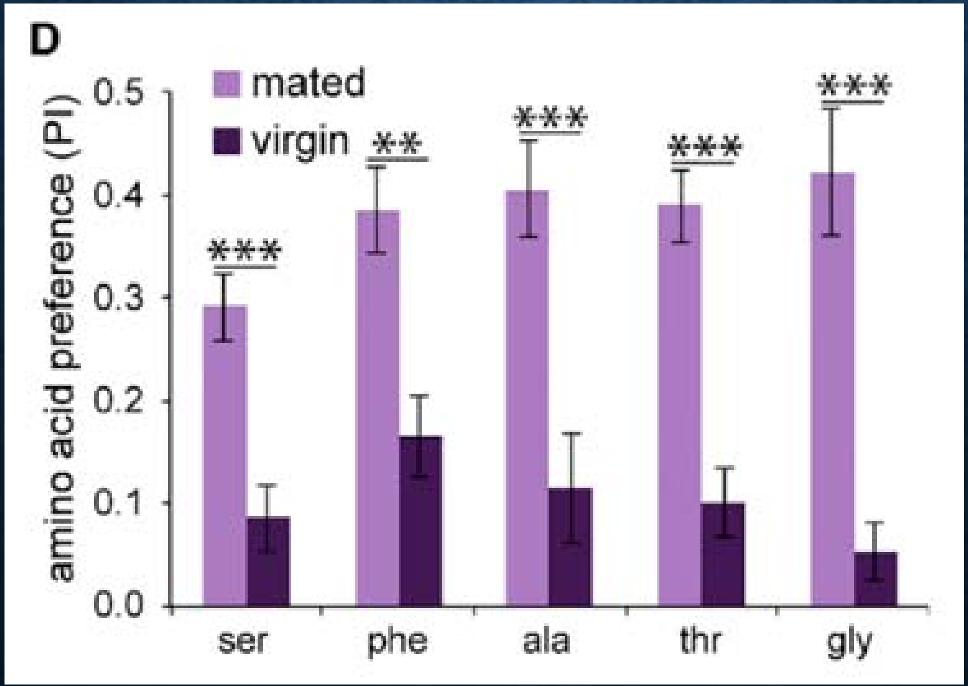
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Another study shows that mating has no influence on amino acids consumption

Cell Research

www.nature.com/cr
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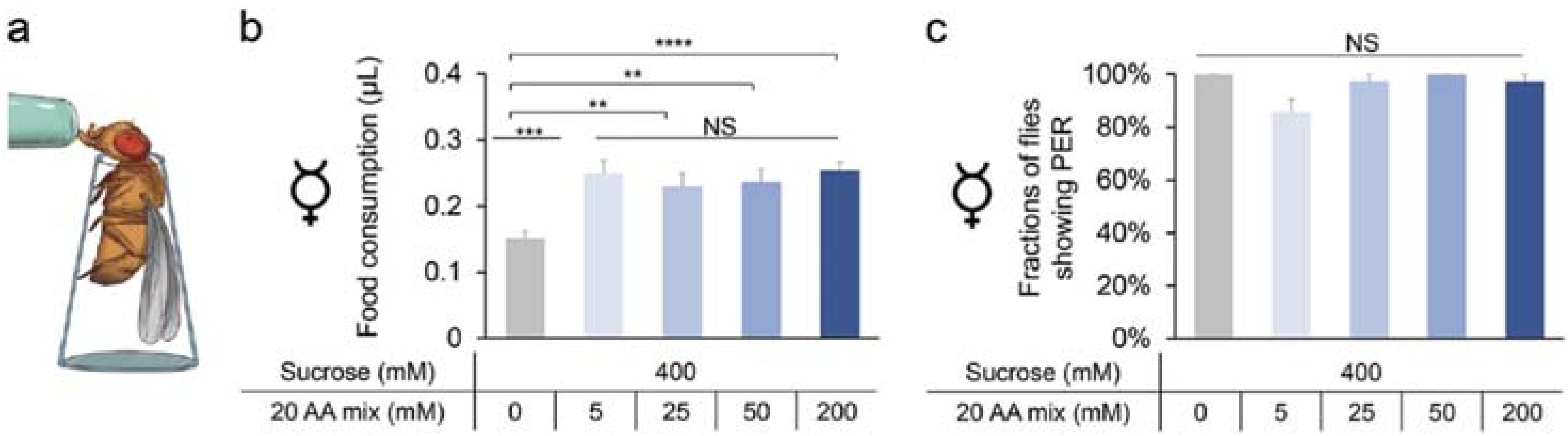
ARTICLE OPEN

A post-ingestive amino acid sensor promotes food consumption in *Drosophila*

Zhe Yang[1,2], Rui Huang[3,4], Xin Fu[5,6,7], Gaohang Wang[1,2], Wei Qi[1,2], Decai Mao[8], Zhaomei Shi[5], Wei L. Shen[5] and Liming Wang[1,2]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b
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NS
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0.4
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0.2
0.1
0
Food consumption (μL)
100%
80%
60%
40%
20%
0%
Fractions of flies showing PER
Sucrose (mM)
400
20 AA mix (mM)
0
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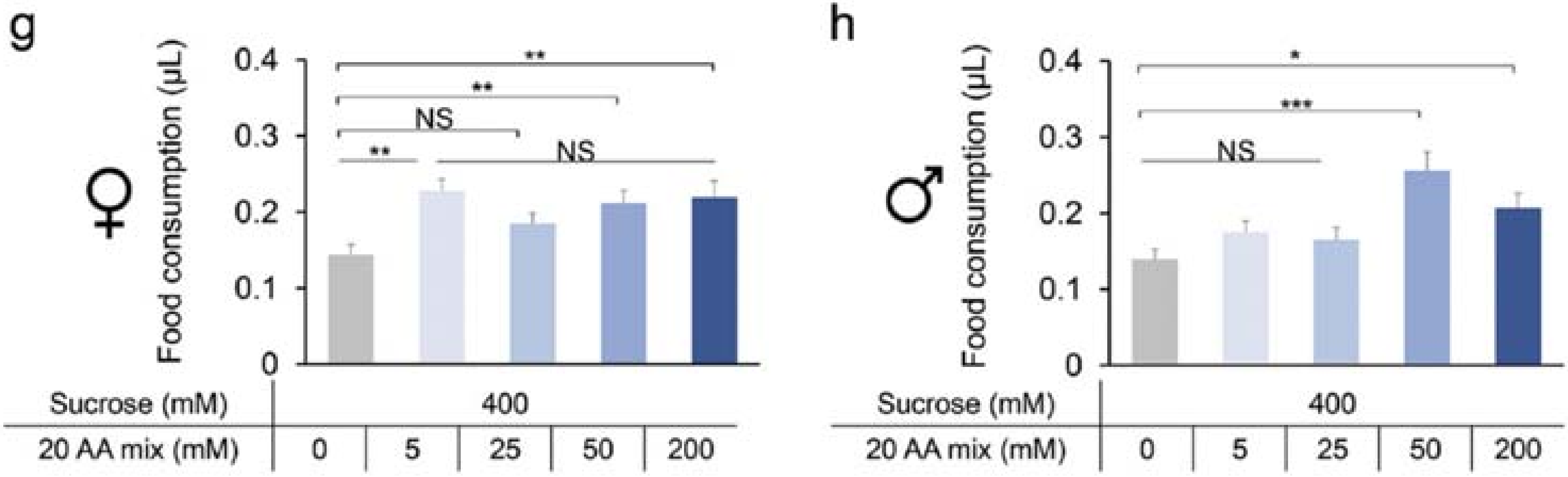
25
50
200
Sucrose (mM)
400
20 AA mix (mM)
0
5
25
50
200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Food consumption (μL)
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♂
Sucrose (mM)
400
20 AA mix (mM)
0
5
25
50
200
Sucrose (mM)
400
20 AA mix (mM)
0
5
25
50
200

Question 1: how do mated females behave differently?

- Mated females consume more amino acids
- Mated females are more aggressive

nature
ecology & evolution

Article | Published: 15 May 2017

Sperm and sex peptide stimulate aggression in female *Drosophila*

Eleanor Bath, Samuel Bowden, Carla Peters, Anjali Reddy, Joseph A. Tobias, Evan Easton-Calabria, Nathalie Seddon, Stephen F. Goodwin & Stuart Wigby

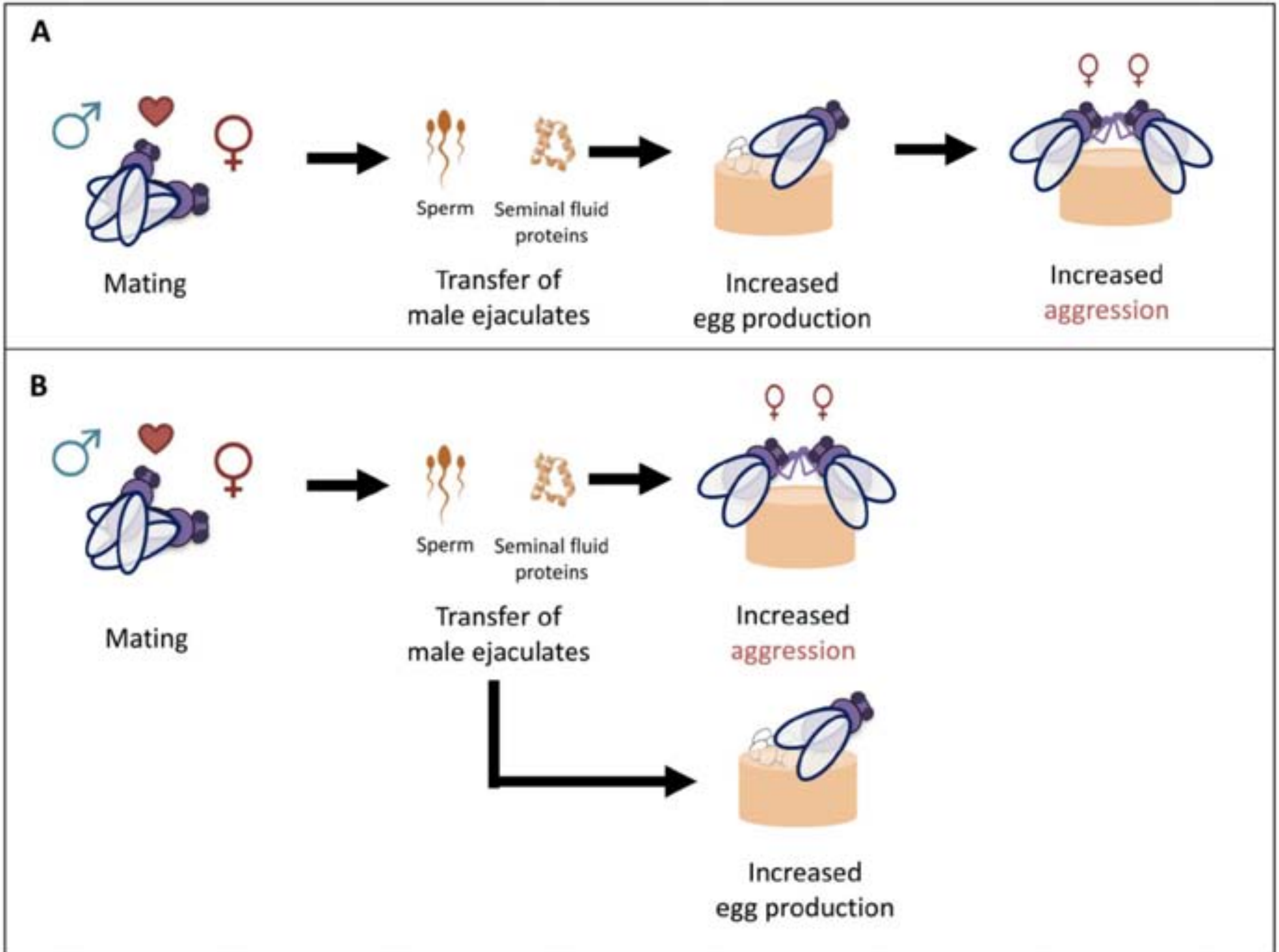


Figure 1. Two proposed pathways for mating-induced female aggression

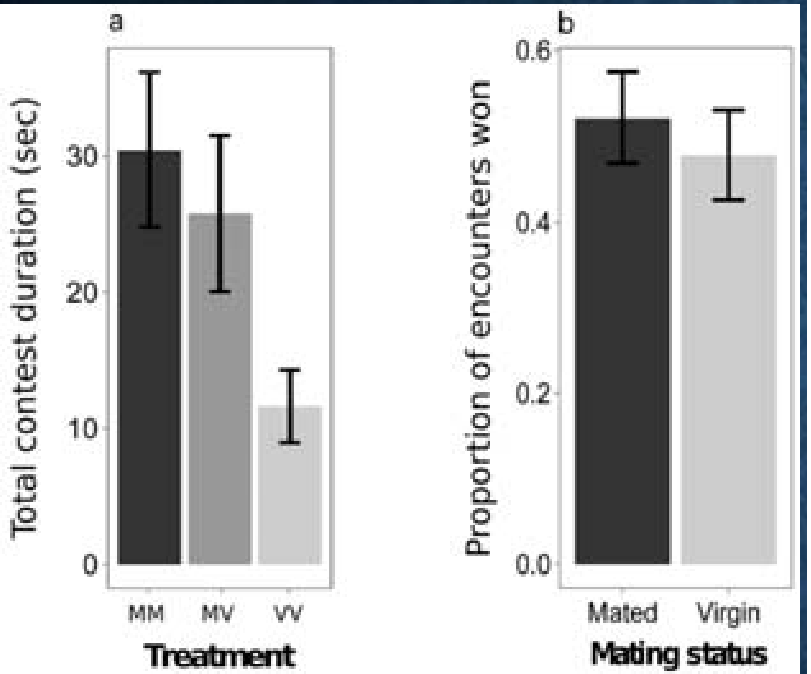


Figure 2. Mated females spend more time fighting than virgins but do not win more fights.

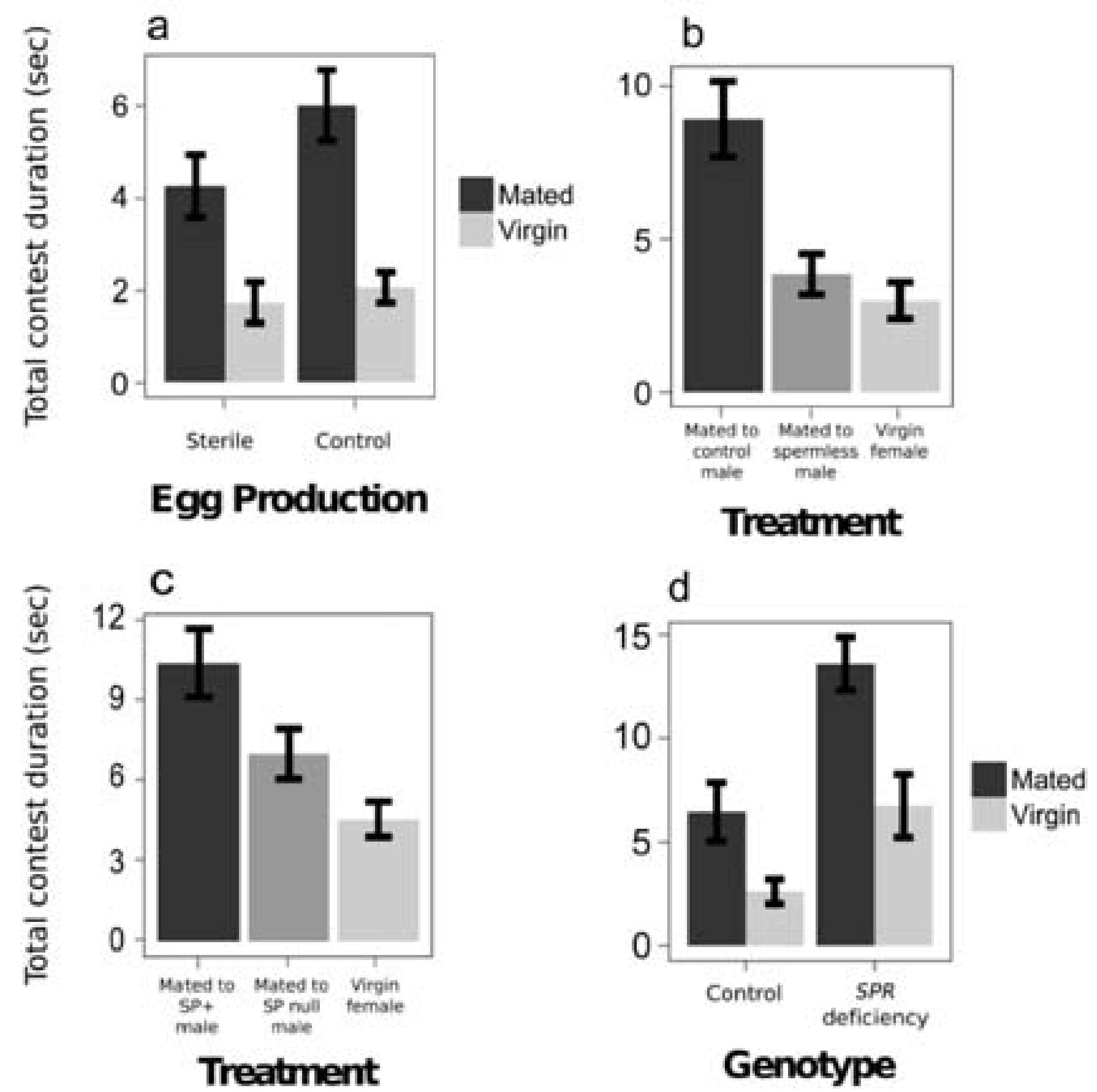


Figure 3. Effects of male ejaculate components, and female egg-production and sex peptide receptor on female total contest duration.

This is all the data this paper has.

Mentions in news, blogs & Google+

News articles (17) | Scientific blogs (4)

Butting heads: sex enrages female fruit flies
Breitbart News Network

Butting heads: sex enrages female fruit flies
Yahoo! News

Sex enrages female fruit flies – Reports
Uncova

Frisky Female Fruit Flies Become More Aggressive Towards Each Other After Sex
Science Newsline

Butting heads: sex enrages female fruit flies
Yahoo! News

Butting heads: sex enrages female fruit flies (AFP)
Yahoo! News

Make love, then war: Study shows sex enrages female fruit flies
The Malay Mail Online

Frisky female fruit flies become more aggressive towards each other after sex
Phys.org

Question 1: how do mated females behave differently?

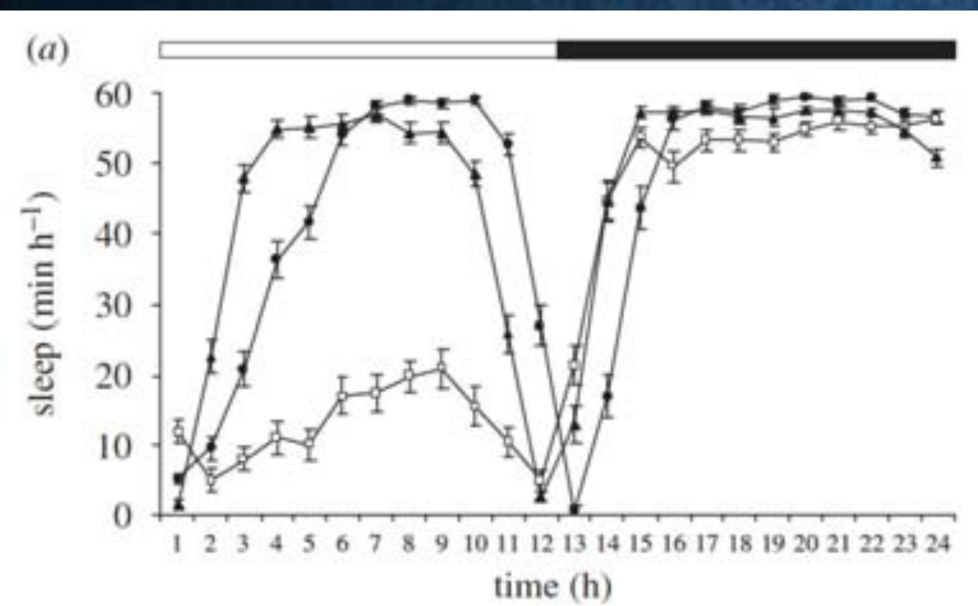
- Mated females consume more amino acids
- Mated females are more aggressive
- Mated females have increased locomotion activity

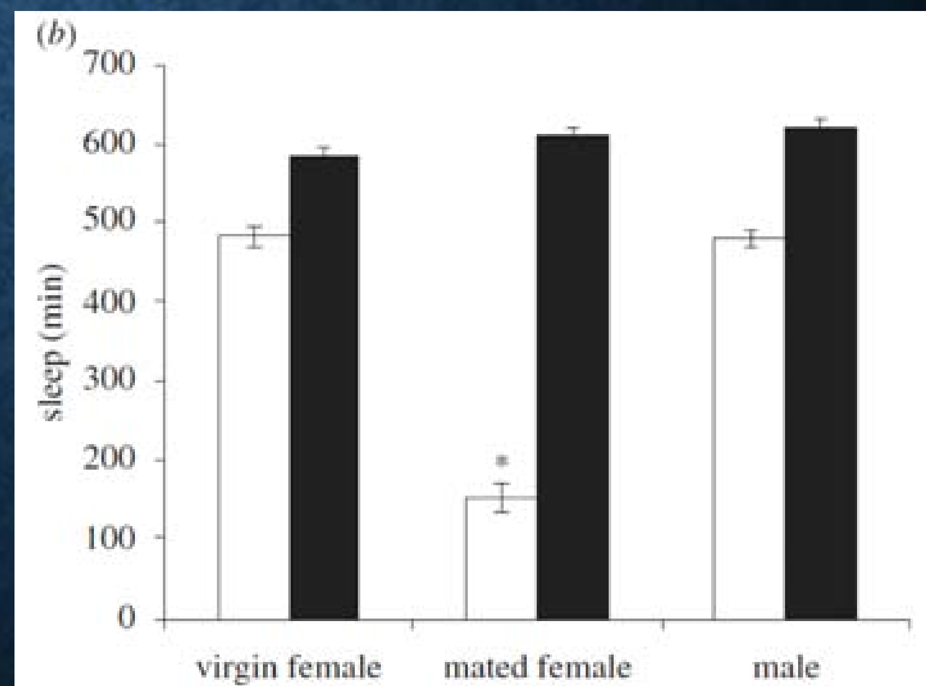
PROCEEDINGS OF THE ROYAL SOCIETY B

Proc. R. Soc. B (2010) **277**, 65–70
doi:10.1098/rspb.2009.1236
Published online 30 September 2009

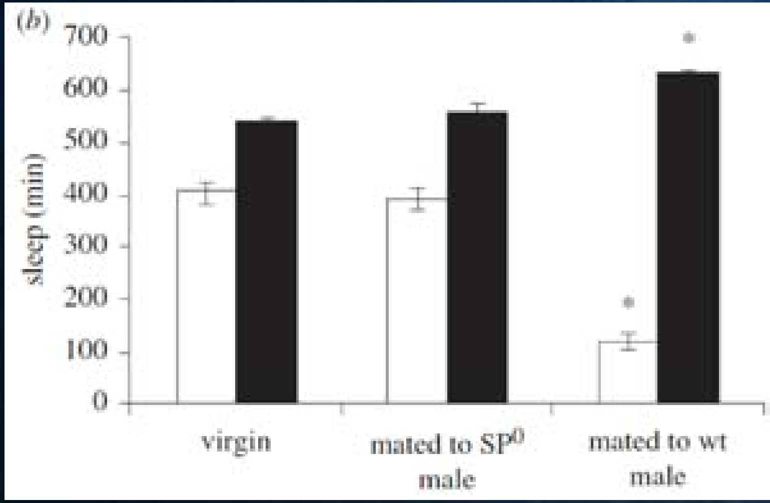
Drosophila male sex peptide inhibits siesta sleep and promotes locomotor activity in the post-mated female

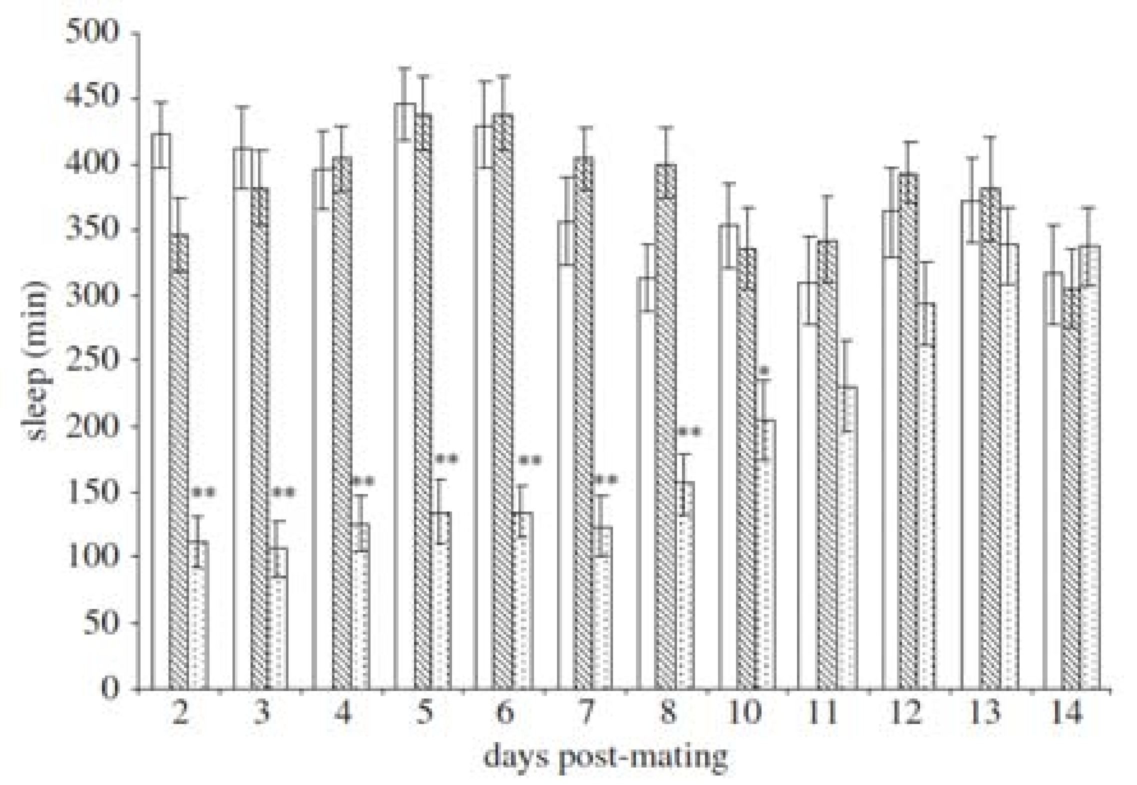
R. Elwyn Isaac[1,*], Chenxi Li[1], Amy E. Leedale[1] and Alan D. Shirras[2]





(filled circle, virgin female; open square, mated female; filled triangle, male)





open bar, virgin;
hatched bar, mated to SP0 male;
dotted bar, mated to wt male.

Question 1: how do mated females behave differently?

- Mated females consume more amino acids
- Mated females are more aggressive
- Mated females have increased locomotion activity
- Mated females have increased starvation resistance

Aging Cell (2007) **6**, pp723–726 Doi: 10.1111/j.1474-9726.2007.00322.x

SHORT TAKE

Mating increases starvation resistance and decreases oxidative stress resistance in *Drosophila melanogaster* females

Brandy Rush,[1] Sarah Sandver,[1] Jessica Bruer,[1] Robin Roche,[2] Michael Wells[2] and Jadwiga Giebultowicz[1]

2002; Kubli, 2003). Mated females show reduced sexual receptivity and a substantial increase in egg production. Mating also

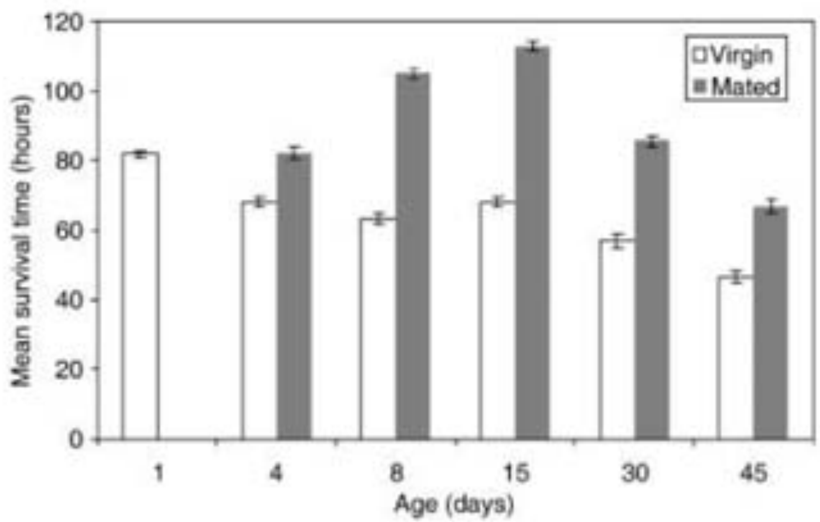
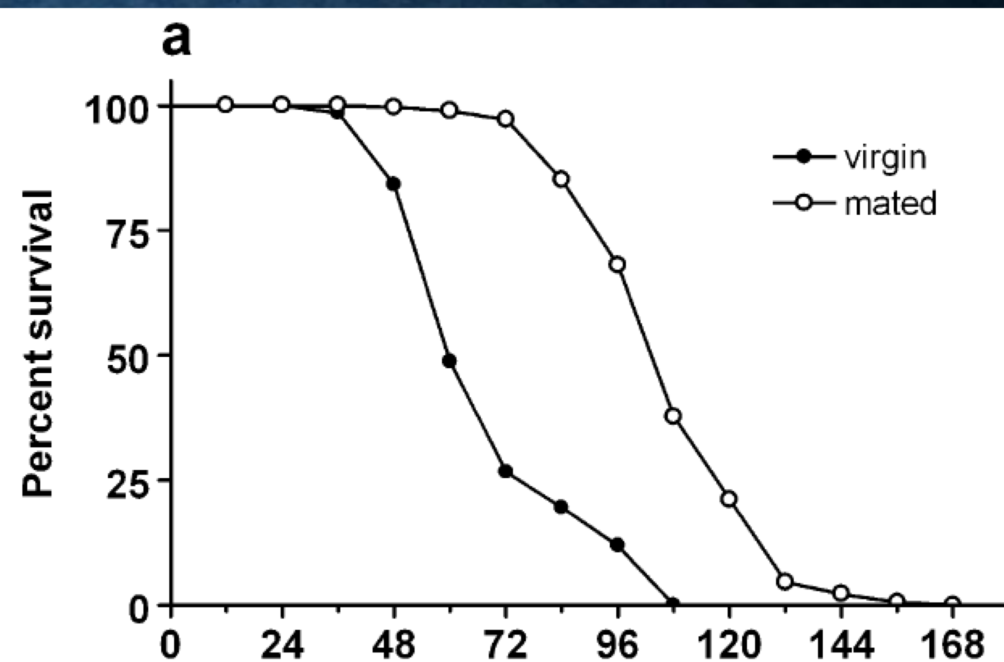


Fig. 1 Age-dependent profiles of starvation resistance in virgin and mated Canton-S females reared on molasses/cornmeal medium containing 7% yeast. Bars represent mean (± SEM) survival time, which was significantly longer for mated than for virgin females at every age tested (*t*-test: $P < 0.01$



Increased starvation resistance in mated females may depends on selective accumulation of lipids

Table 1 Fat, protein and glycogen content in mated and virgin females of *Drosophila melanogaster* subjected to starvation

	Before starvation		Starved 36 h		Starved 60 h	
Nutrient	Virgin	Mated	Virgin	Mated	Virgin	Mated
Triacylglycerols	55.2 ± 1	108.4 ± 10*	21.2 ± 0.7	69.8 ± 4.6*	11.1 ± 2	45.2 ± 6*
Proteins	199.0 ± 31	178.6 ± 34	202.9 ± 24	165.0 ± 30	223.4 ± 34	176.2 ± 39
Glycogen	18.2 ± 1	19.0 ± 2	2.1 ± 0.3	1.3 ± 0.6	0.6 ± 0.5	0.4 ± 0.2

All values are expressed in micrograms/fly; the data are means ± SEM values ($n = 5$, except $n = 3$ for virgins starved for 60 h).
The data are pooled from two experiments, in which either 15 or 20 flies were analyzed per sample.
Significant differences ($P < 0.01$) between the values for virgin and mated females obtained by unpaired *t*-test are indicated by *.

Ecology and Evolution
Open Access

"Cost" of virginity in wild *Drosophila melanogaster* females

Therese Ann Markow

Division of Biological Sciences, University of California, La Jolla, San Diego, California

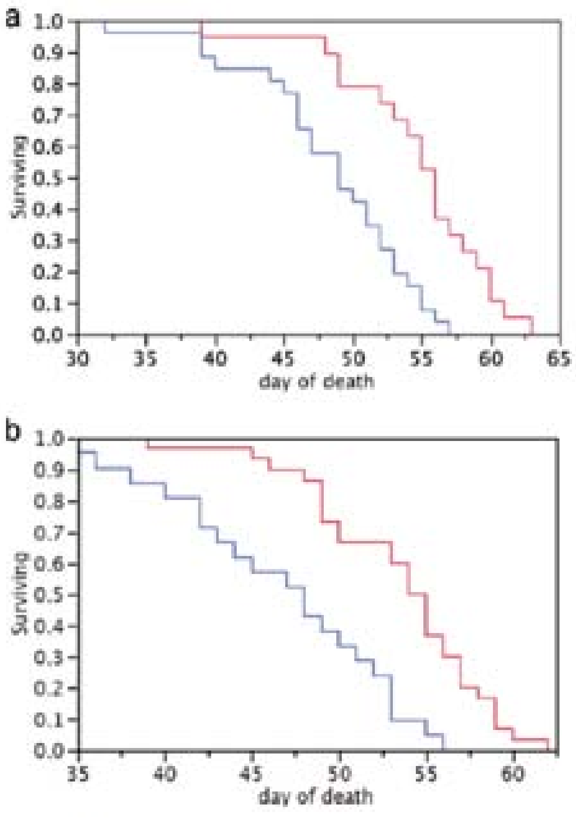


Figure 1. (A, B) Female survival after collection in the field for Replications 1 (top) and 2 (bottom). Virgin females are indicated by the blue line, randomly collected mated females are indicated by red. For Replication

In the first replication, there were 19 virgin and 26 mated females and the mated females lived an average of approximately 6 days longer

Rather than a "cost of mating," there appears to be a "cost of virginity" to female *D. melanogaster* in the wild.

Question 1: how do mated females behave differently?

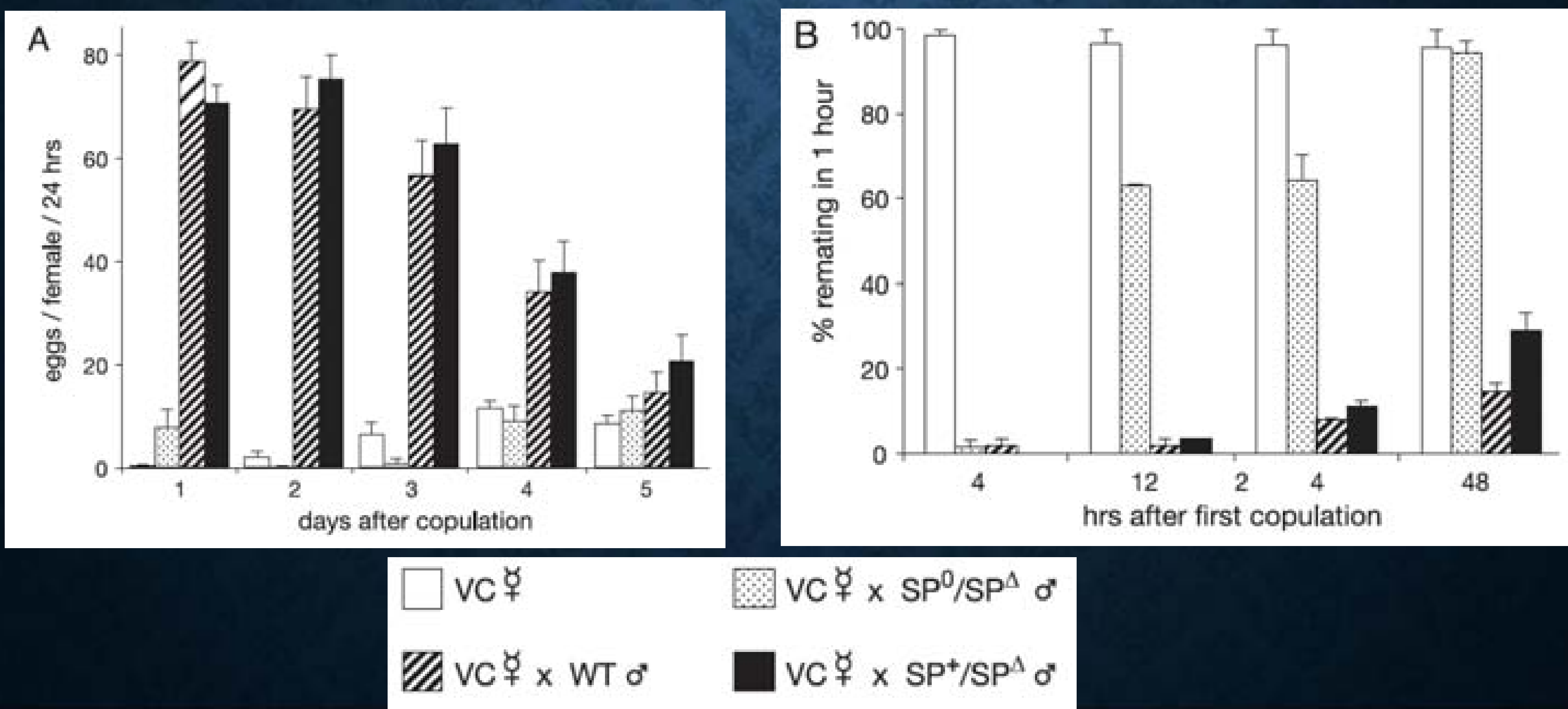
- Mated females consume more amino acids
- Mated females are more aggressive
- Mated females have increased locomotion activity
- Mated females have increased starvation resistance
- Mated females lay eggs and reject males

Sex-peptide is the molecular basis of the sperm effect in *Drosophila melanogaster*

Huanfa Liu and Eric Kubli*

Zoological Institute, University of Zurich-Irchel, Winterthurerstrasse 190, CH-8057 Zurich, Switzerland

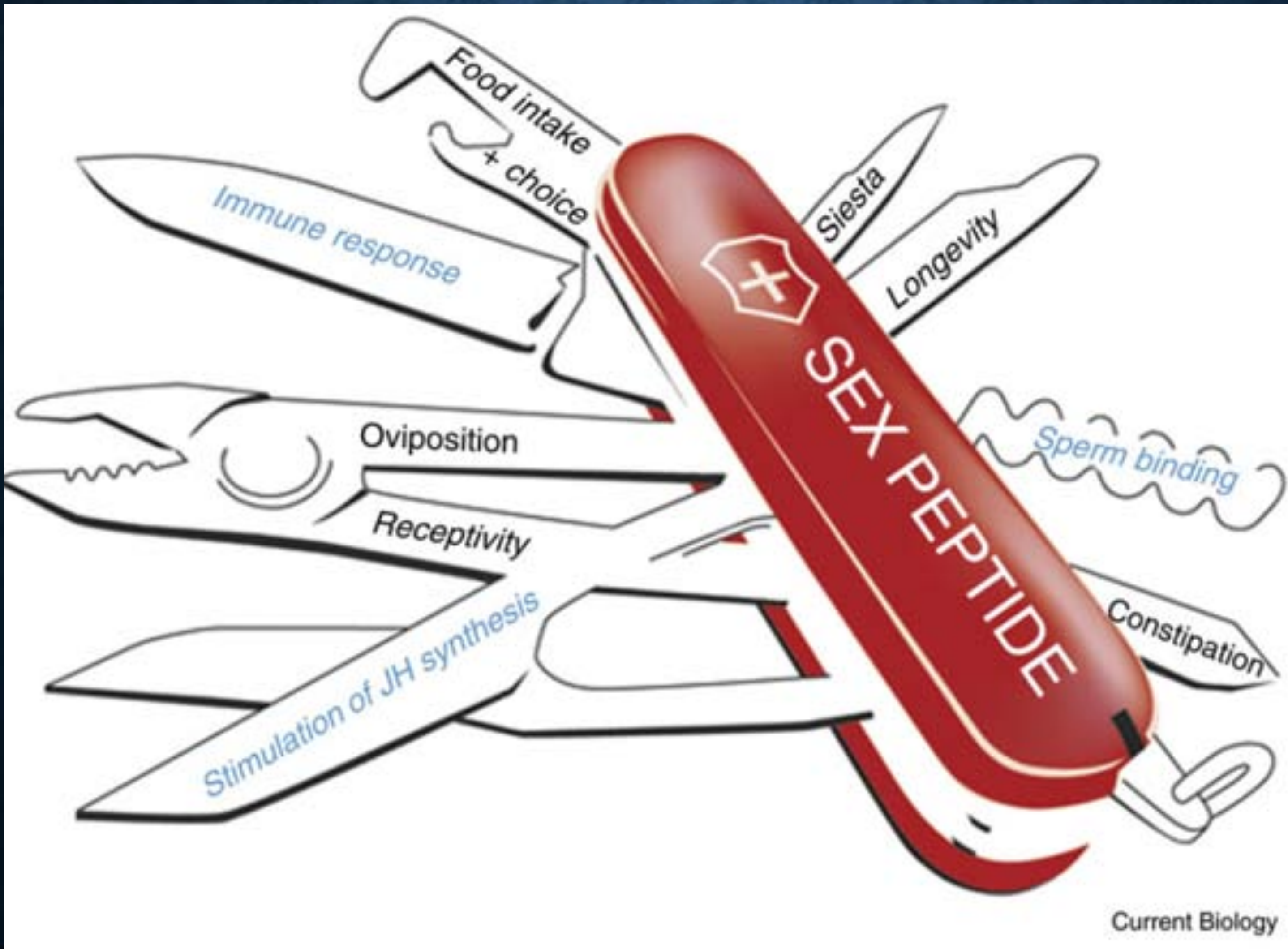
Edited by Wendell Roelofs, Cornell University, Geneva, NY, and approved May 21, 2003 (received for review March 25, 2003)



Current Biology Vol 22 No 13
R520

Dispatches

Sexual Behavior: How Sex Peptide Flips the Postmating Switch of Female Flies



Question 2: what's the neural basis for post-mating behaviors

- *fruGAL4* neurons are involved;

Correspondences

Shared neural circuitry for female and male sexual behaviours in *Drosophila*

This is all the data this paper has.

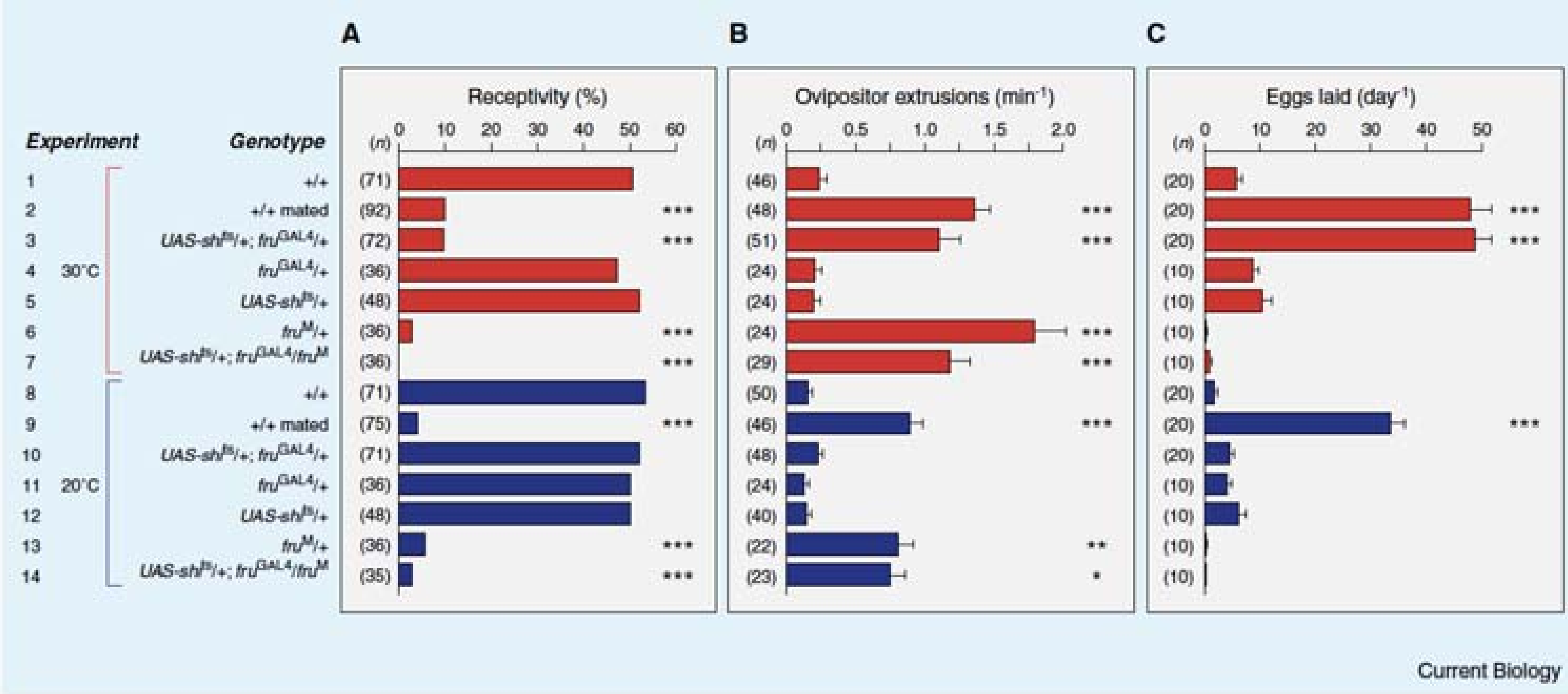


Figure 1. *fru*^{GAL4} neurons mediate female reproductive behaviours.

Vol 451 | 3 January 2008 | doi:10.1038/nature06483

nature

ARTICLES

A receptor that mediates the post-mating switch in *Drosophila* reproductive behaviour

Nilay Yapici[1]*, Young-Joon Kim[1]*, Carlos Ribeiro[1] & Barry J. Dickson[1]

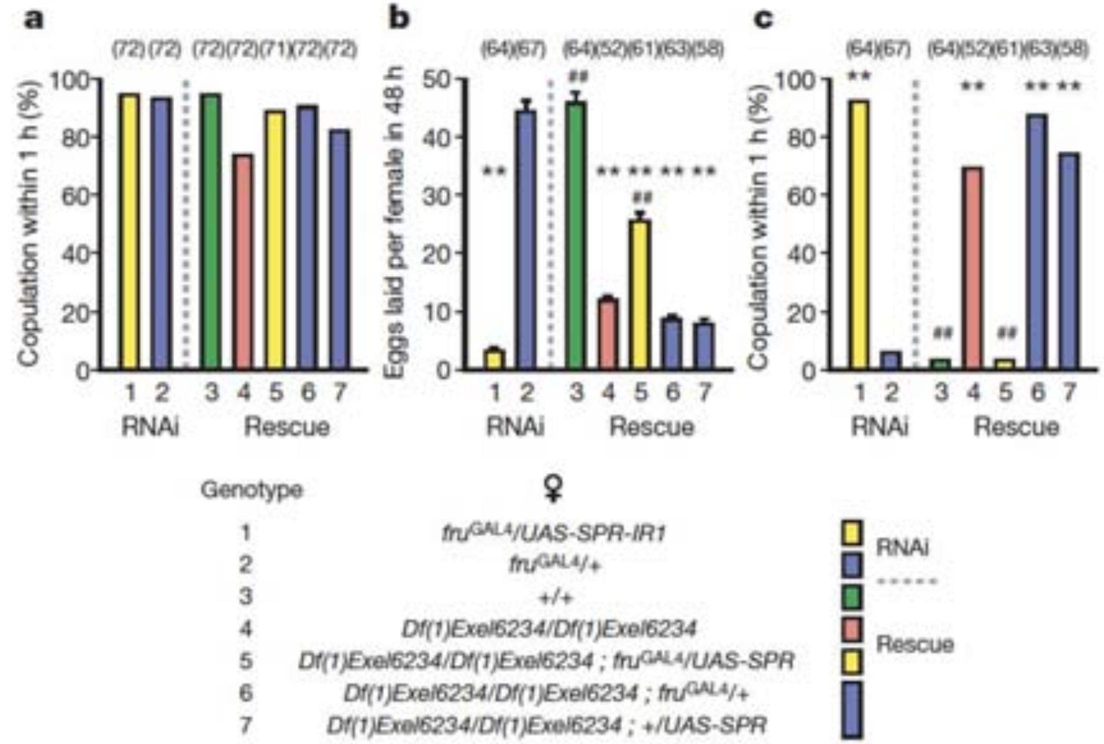


Figure 4 | SPR acts in *fru* neurons. a, b, c, Receptivity (**a**), egg-laying (**b**) and re-mating (**c**) assays for females of the indicated genotype, mated with wild-type males and assayed according to the protocol of Fig. 1a. For the RNAi

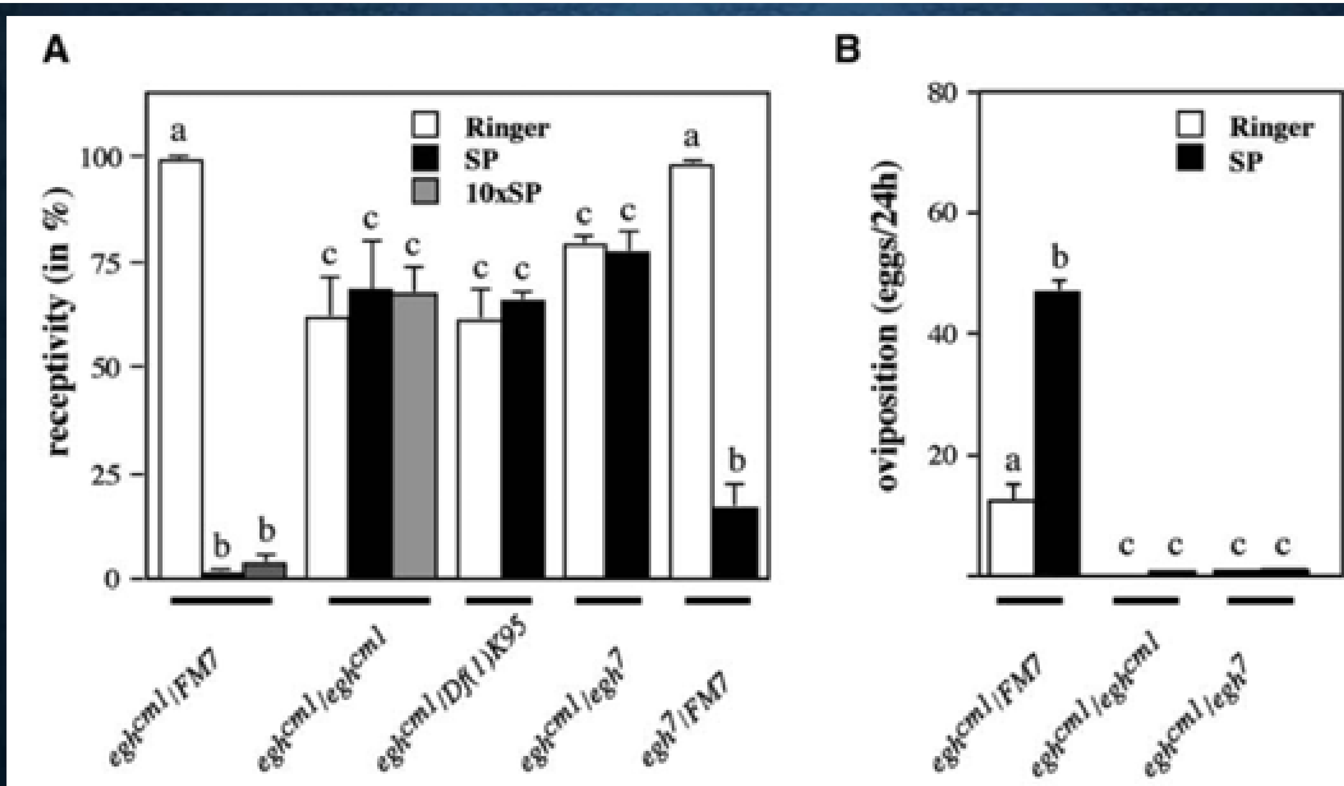
Question 2: what's the neural basis for post-mating behaviors

- *fruGAL4* neurons are involved;
- Subsets of ascending VNC neurons;

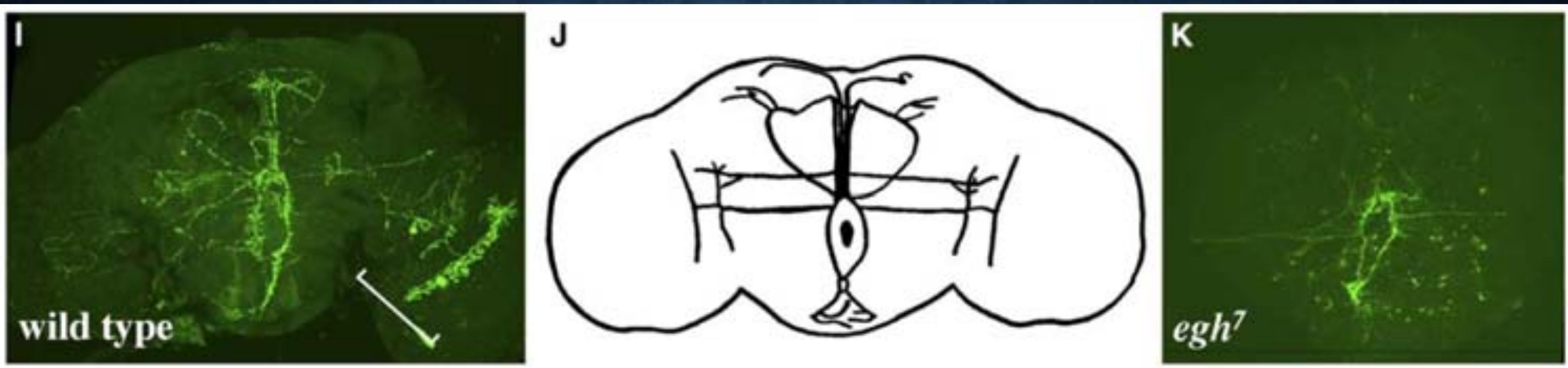
Current Biology 16, 1771–1782, September 19, 2006 ©2006 Elsevier Ltd All rights reserved DOI 10.1016/j.cub.2006.07.055

Article

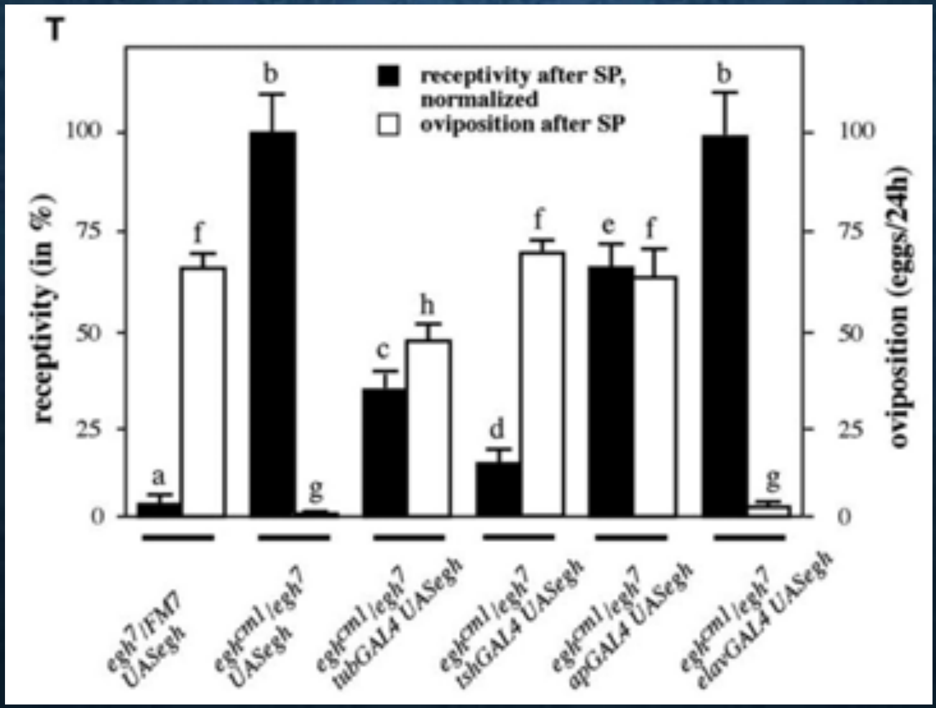
Sex-Peptide-Regulated Female Sexual Behavior Requires a Subset of Ascending Ventral Nerve Cord Neurons



The *egghead* gene involved in glycosphingolipid biosynthesis provides an essential component to the SP response.



Clonal analysis of VNC Ap neuronal projections to the central brain.



egh expression in VNC neurons (*tshGAL4*) rescues mutant phenotype.

Question 2: what's the neural basis for post-mating behaviors

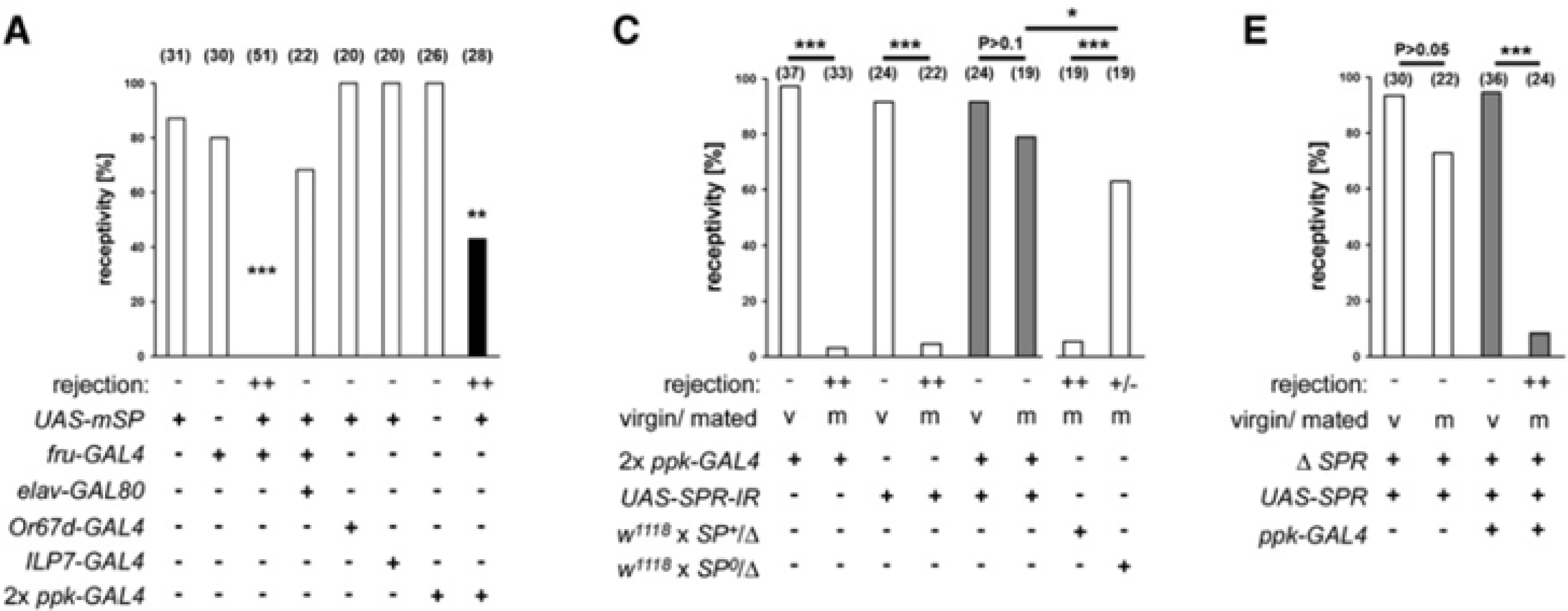
- *fruGAL4* neurons are involved;
- Subsets of ascending VNC neurons;
- *fru* and *ppk*-positive sensory neurons in the genital tract;

Neuron

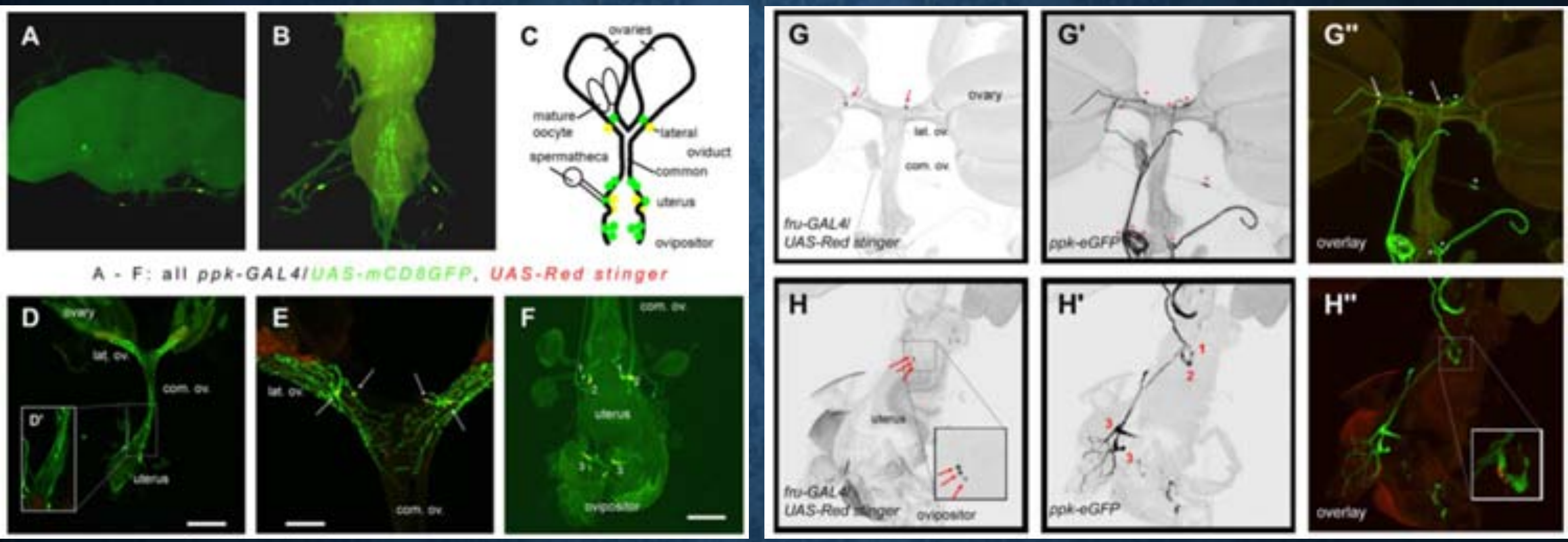
Report

Control of the Postmating Behavioral Switch in *Drosophila* Females by Internal Sensory Neurons

Chung-hui Yang,[1,3] Sebastian Rumpf,[1,3] Yang Xiang,[1] Michael D. Gordon,[2] Wei Song,[1] Lily Y. Jan,[1] and Yuh-Nung Jan[1,*]



ppk-GAL4 Labels SP-Responsive Neurons

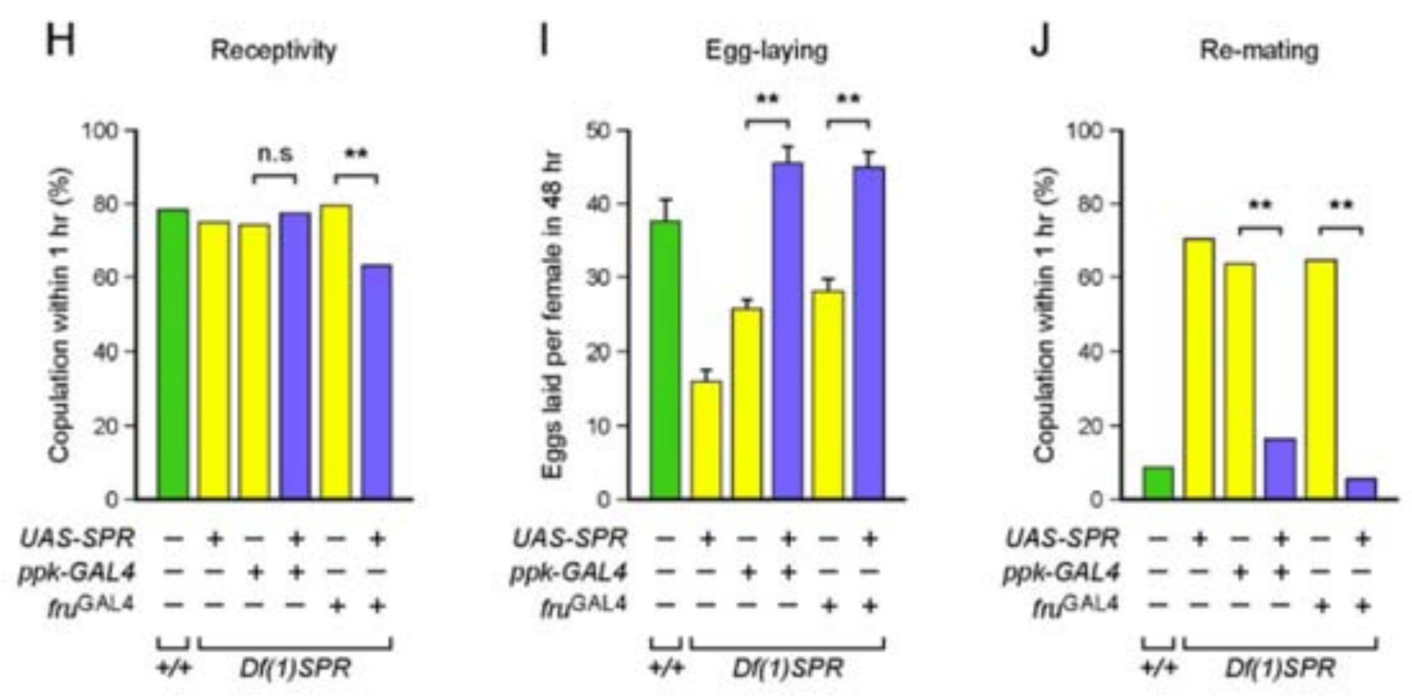


ppk-GAL4 and *fru-GAL4* Expression Overlap in Sensory Neurons on the Female Reproductive Tract

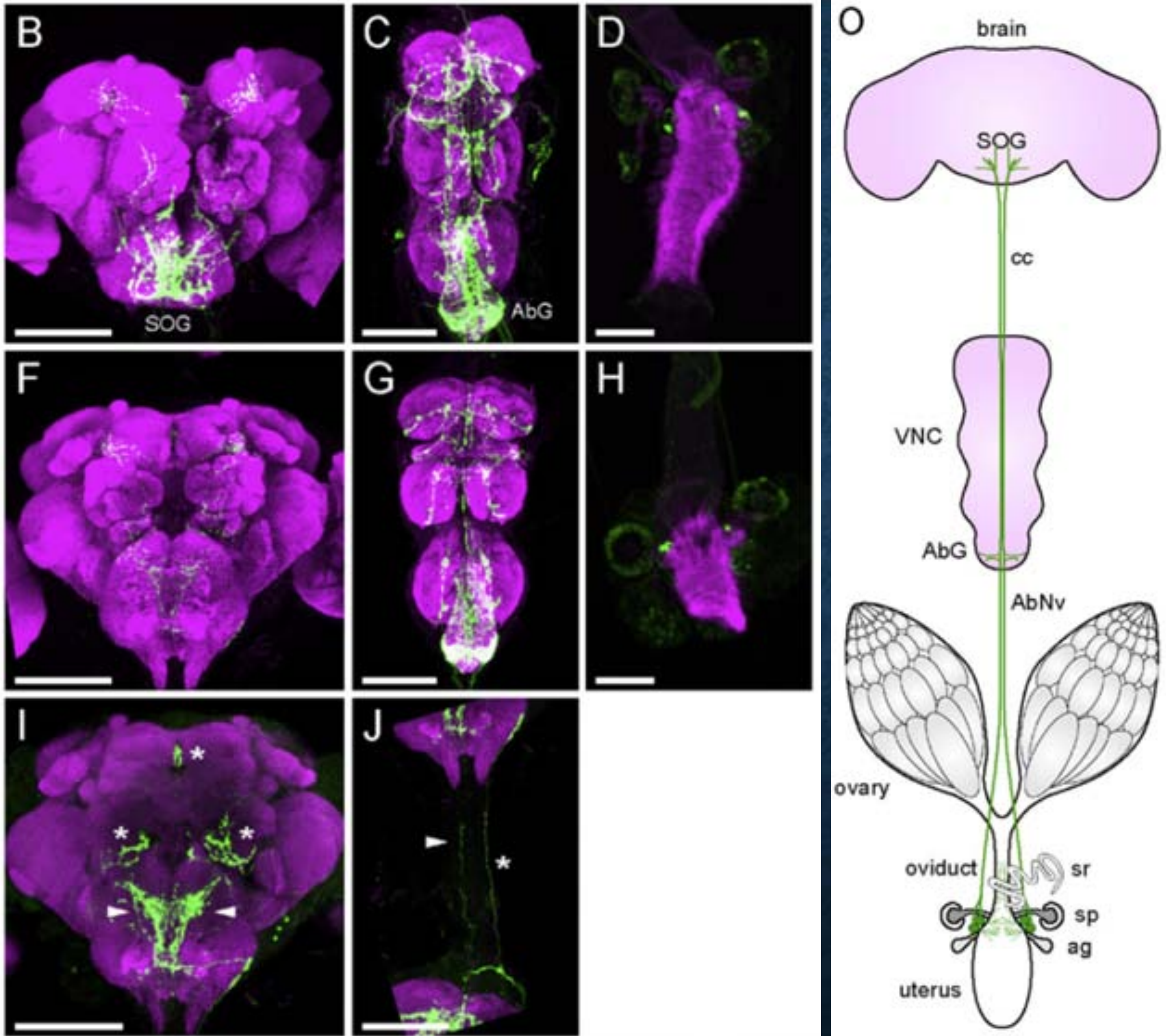
Neuron
Report

Sensory Neurons in the *Drosophila* Genital Tract Regulate Female Reproductive Behavior

Martin Häsemeyer,[1] Nilay Yapici,[1] Ulrike Heberlein,[2] and Barry J. Dickson[1,*]



SPR Acts in *ppk*+ *fru*+ Sensory Neurons


B
C
D
SOG
AbG
F
G
H
I
J
O
brain
SOG
cc
VNC
AbG
AbNv
ovary
oviduct
sr
sp
ag
uterus

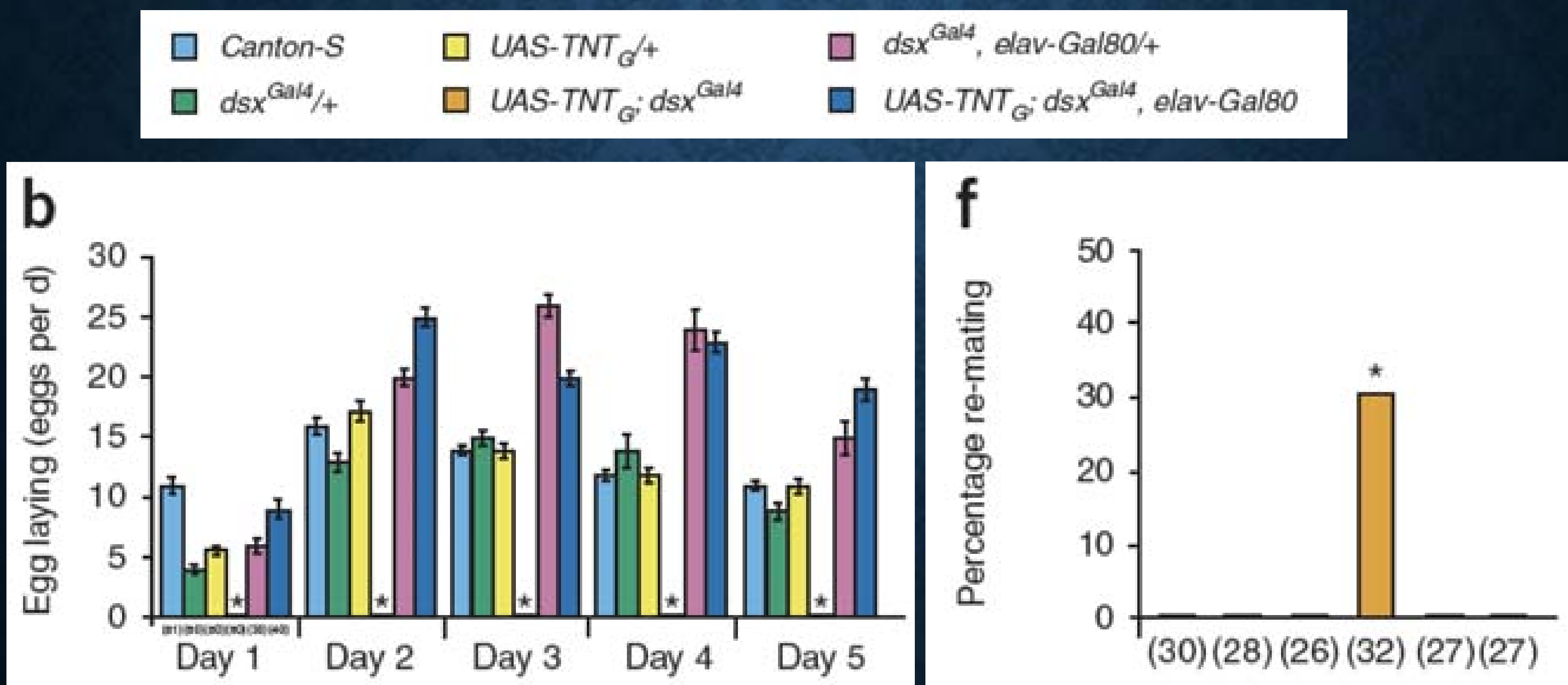
Question 2: what's the neural basis for post-mating behaviors

- *fruGAL4* neurons are involved;
- Subsets of ascending VNC neurons;
- *fru* and *ppk*-positive sensory neurons in the genital tract;
- *dsx* neurons are involved (several sub-types, **including *ppk*-positive sensory neurons, octopaminergic neurons, SAG neurons and Mip neurons**);

nature neuroscience

Control of sexual differentiation and behavior by the *doublesex* gene in *Drosophila melanogaster*

Elizabeth J Rideout[1,3,4], Anthony J Dornan[1,4], Megan C Neville[1,2,4], Suzanne Eadie[1] & Stephen F Goodwin[1,2]



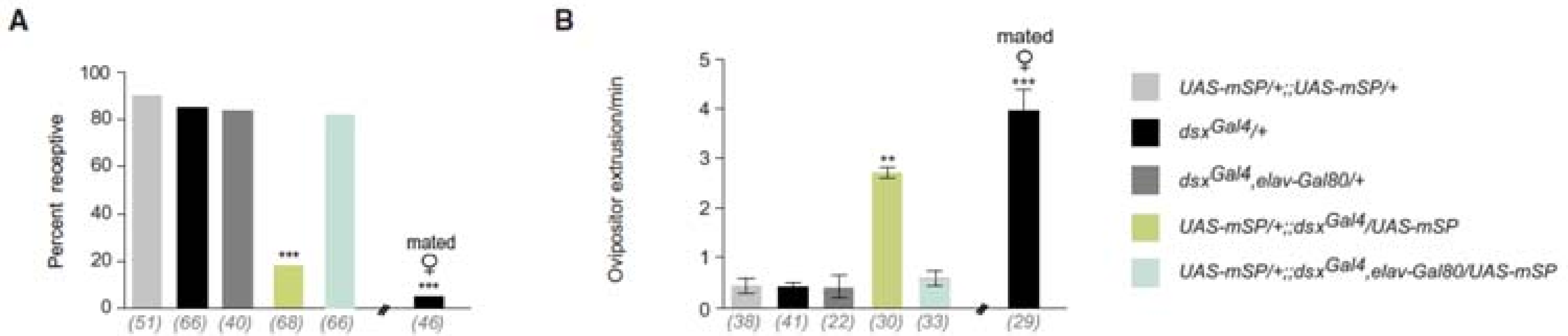
Current Biology 22, 1155–1165, July 10, 2012 ©2012 The Authors DOI 10.1016/j.cub.2012.04.062

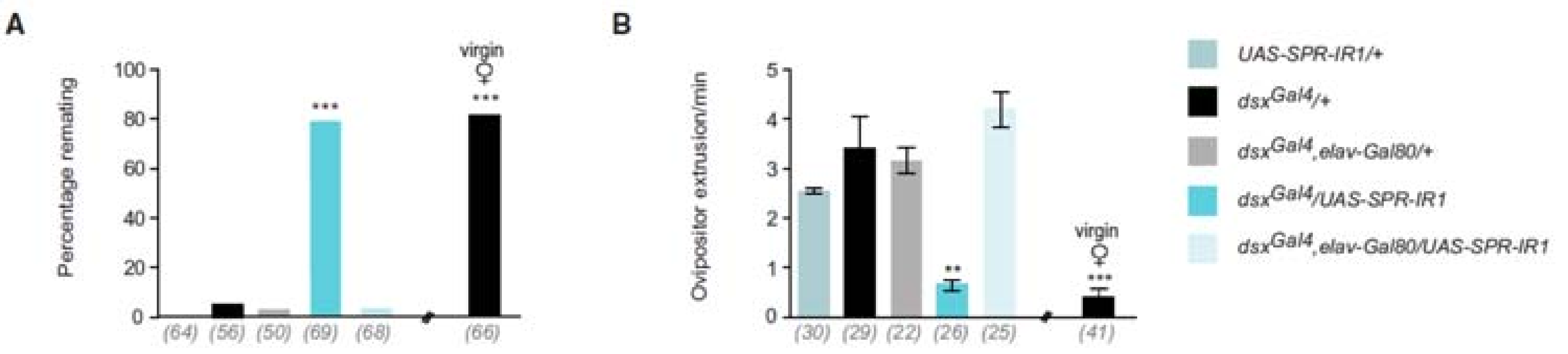
Article

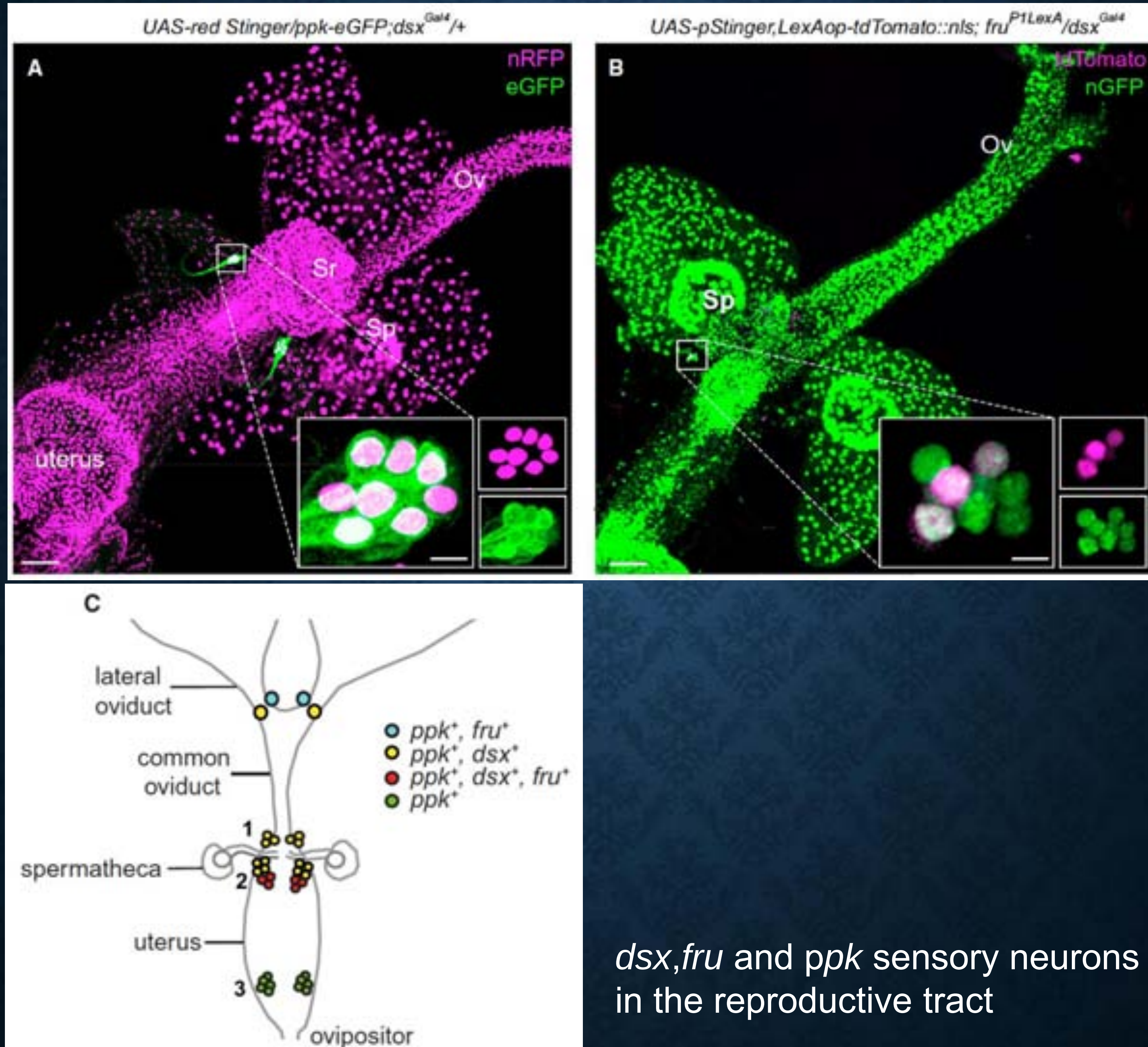
Neural Circuitry Underlying *Drosophila* Female Postmating Behavioral Responses

Carolina Rezával,[1] Hania J. Pavlou,[1] Anthony J. Dornan,[2] Yick-Bun Chan,[3] Edward A. Kravitz,[3] and Stephen F. Goodwin[1,*]

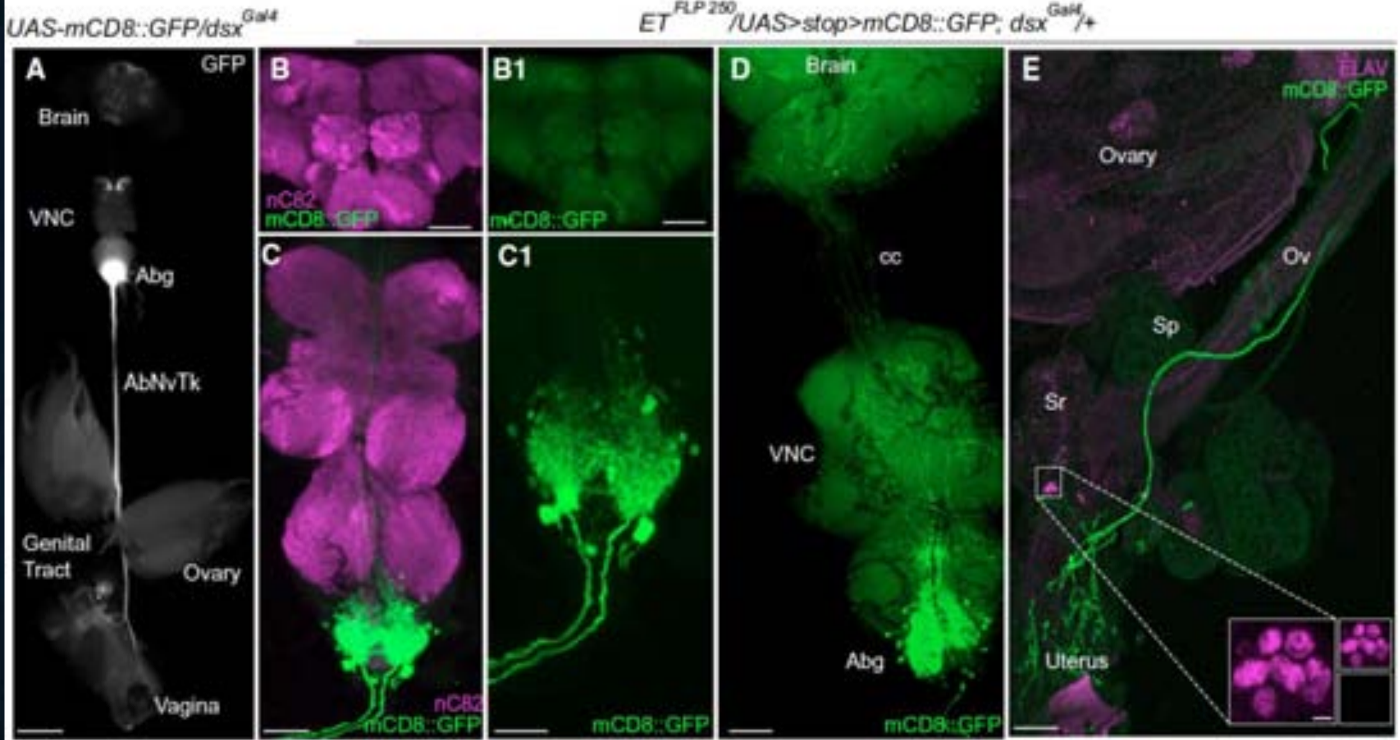
type and fitness before sanctioning mating [1]. An unreceptive female exhibits rejection behaviors such as kicking and ovipositor extrusion [1, 6–8]. A receptive female will facilitate copula-

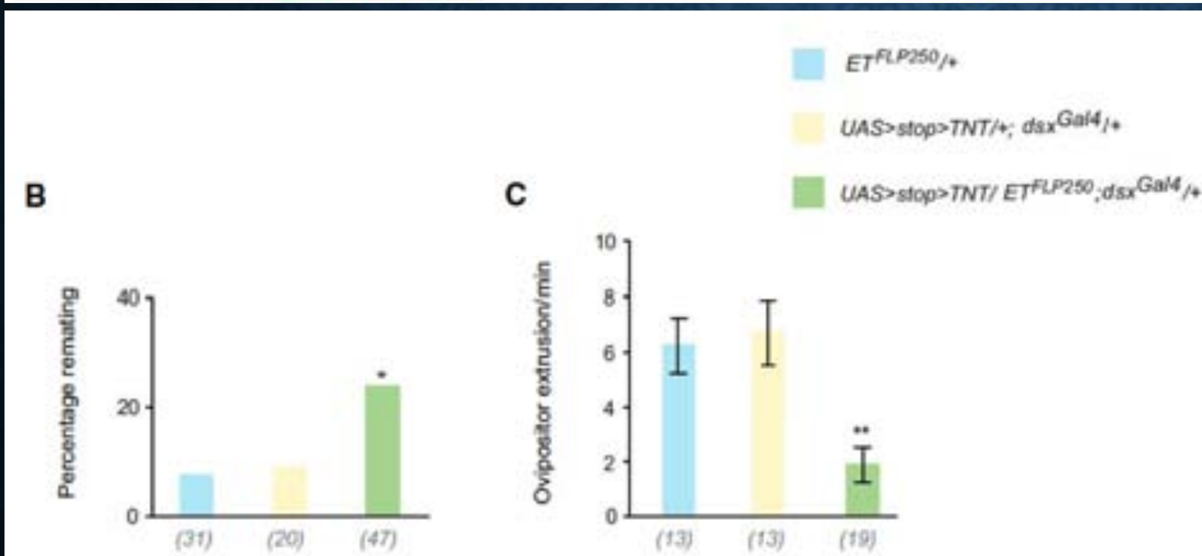


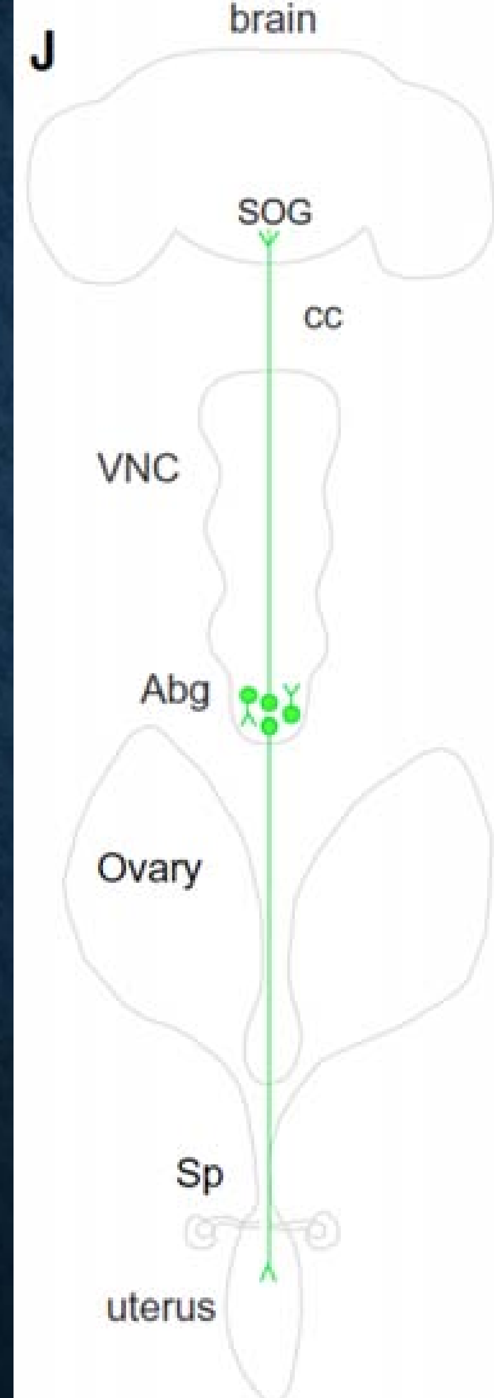




dsx,*fru* and p*pk* sensory neurons in the reproductive tract







dsx neurons in Abg involved in post-mating behaviors

Question 2: what's the neural basis for post-mating behaviors

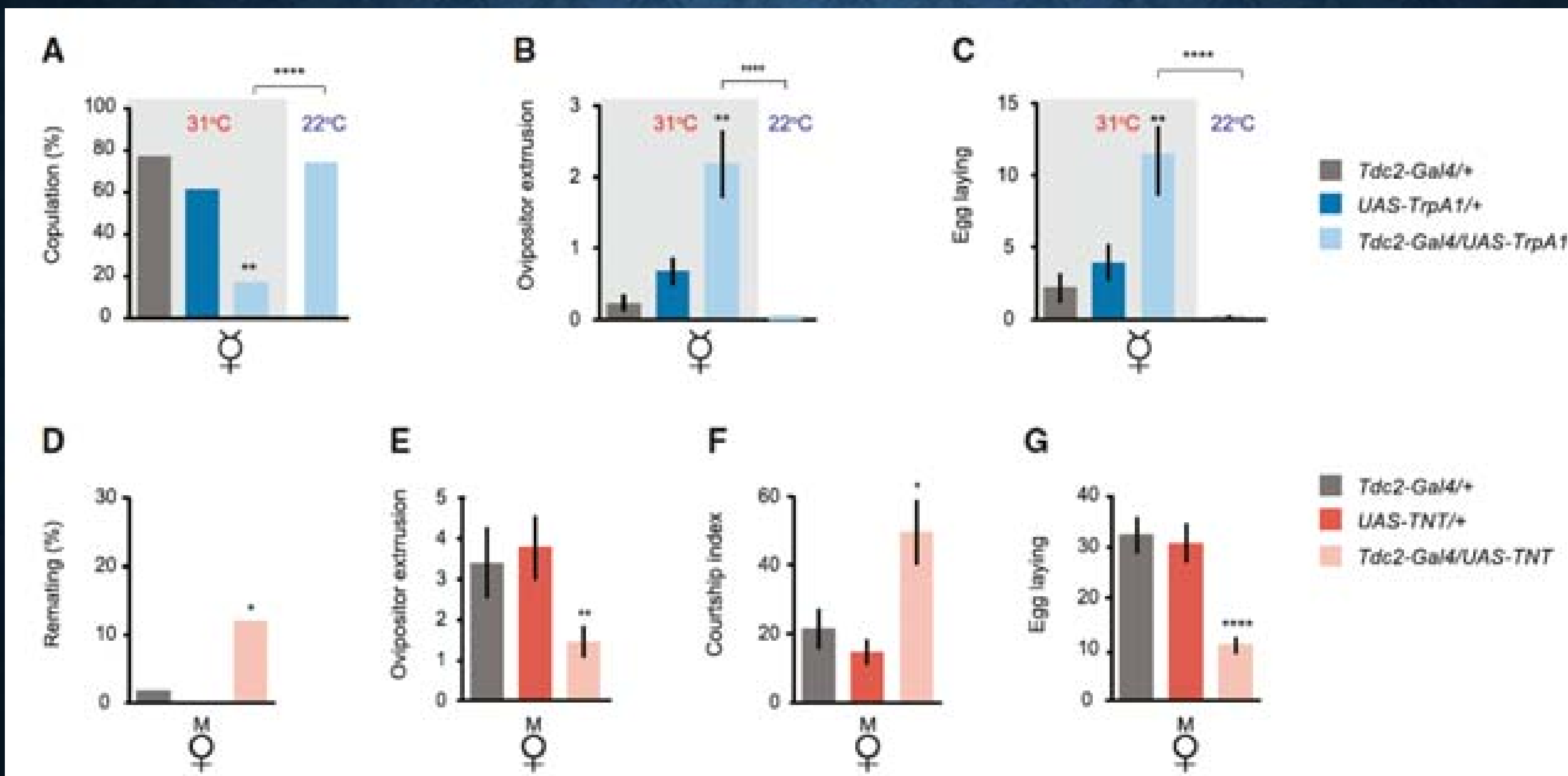
- *fruGAL4* neurons are involved;
- Subsets of ascending VNC neurons;
- *fru* and p*pk*-positive sensory neurons in the genital tract;
- *dsx* neurons are involved (several sub-types, including *ppk*-positive sensory neurons, octopaminergic neurons, SAG neurons and Mip neurons);

Report

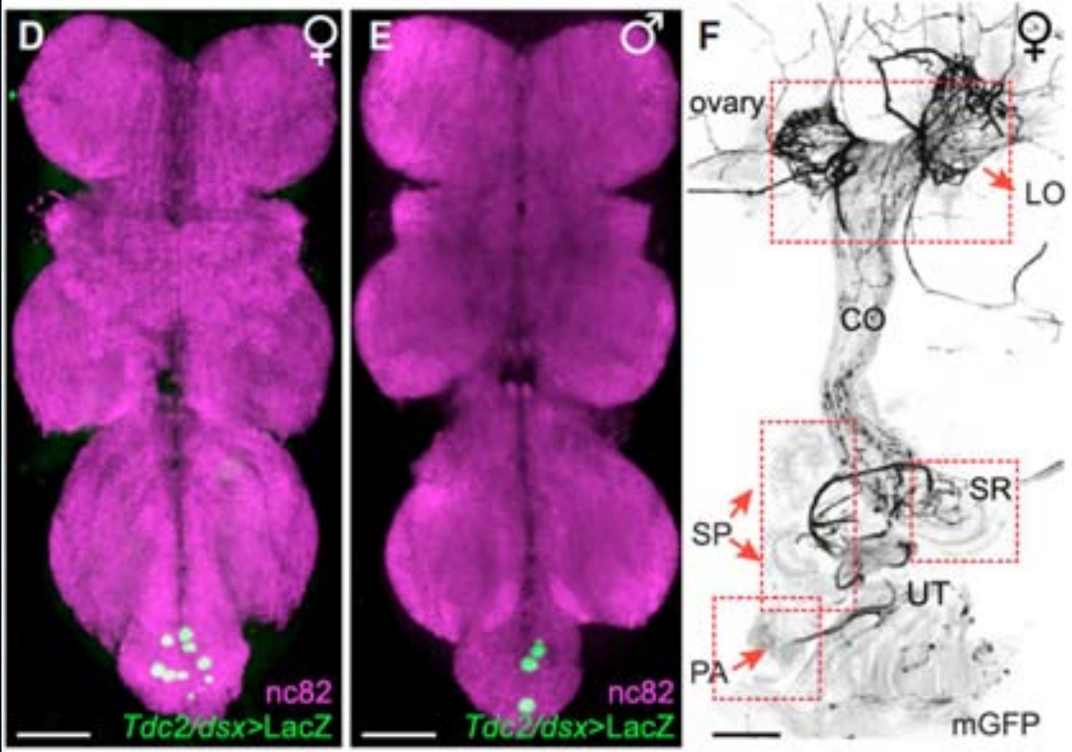
Sexually Dimorphic Octopaminergic Neurons Modulate Female Postmating Behaviors in *Drosophila*

Carolina Rezával,[1,*] Tetsuya Nojima,[1] Megan C. Neville,[1]
Andrew C. Lin,[2] and Stephen F. Goodwin[1,*]

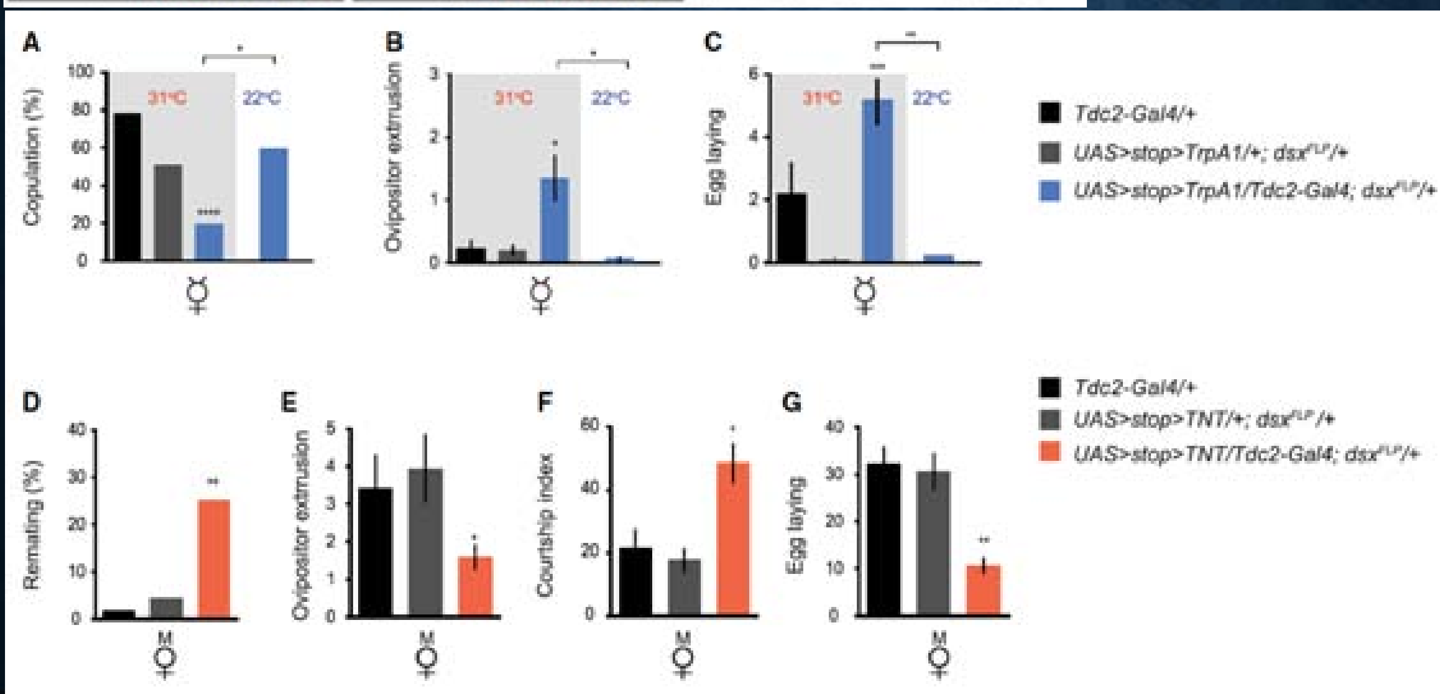
We first evaluated the effects of depleting OA on female behavior by testing a null mutation in the gene that encodes



Tdc2+ Neurons Are Involved in Post-mating Behaviors



Sexually Dimorphic *Tdc2/dsx*+ Abg neurons involved post-mating behaviors



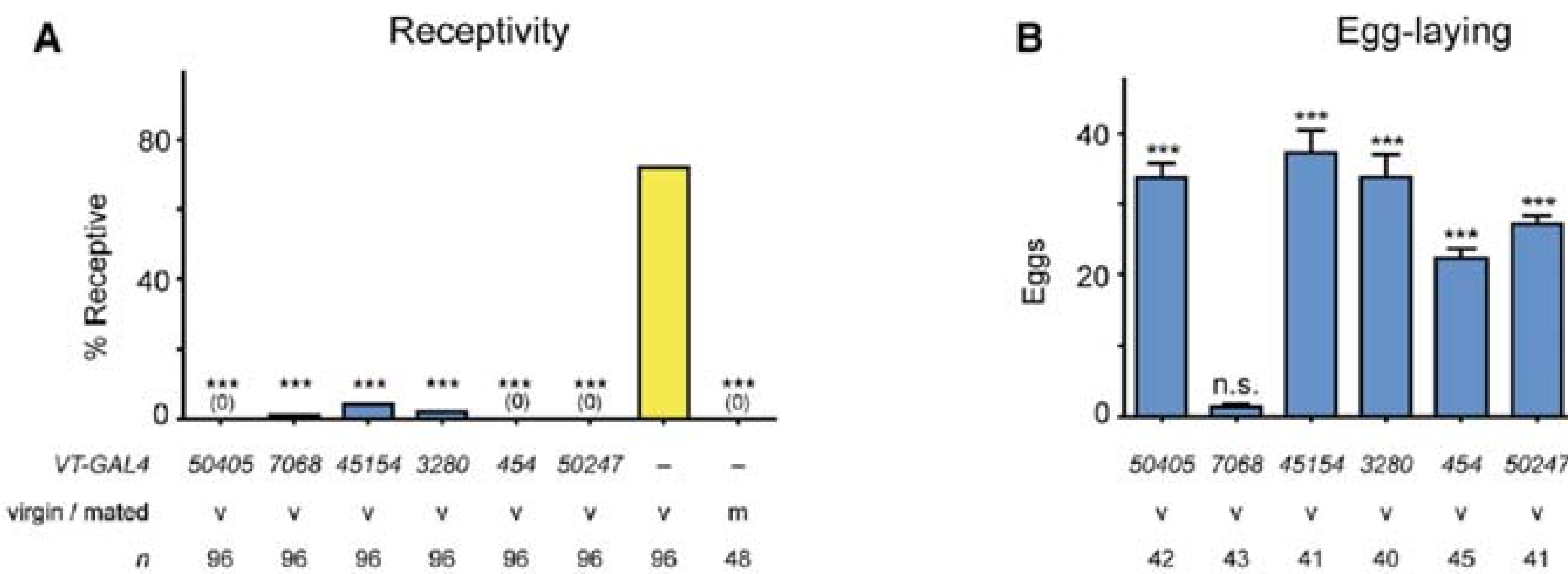
Question 2: what's the neural basis for post-mating behaviors

- *fruGAL4* neurons are involved;
- Subsets of ascending VNC neurons;
- *fru* and p*pk*-positive sensory neurons in the genital tract;
- *dsx* neurons are involved (several sub-types, including *ppk*-positive sensory neurons, octopaminergic neurons, SAG neurons and Mip neurons);

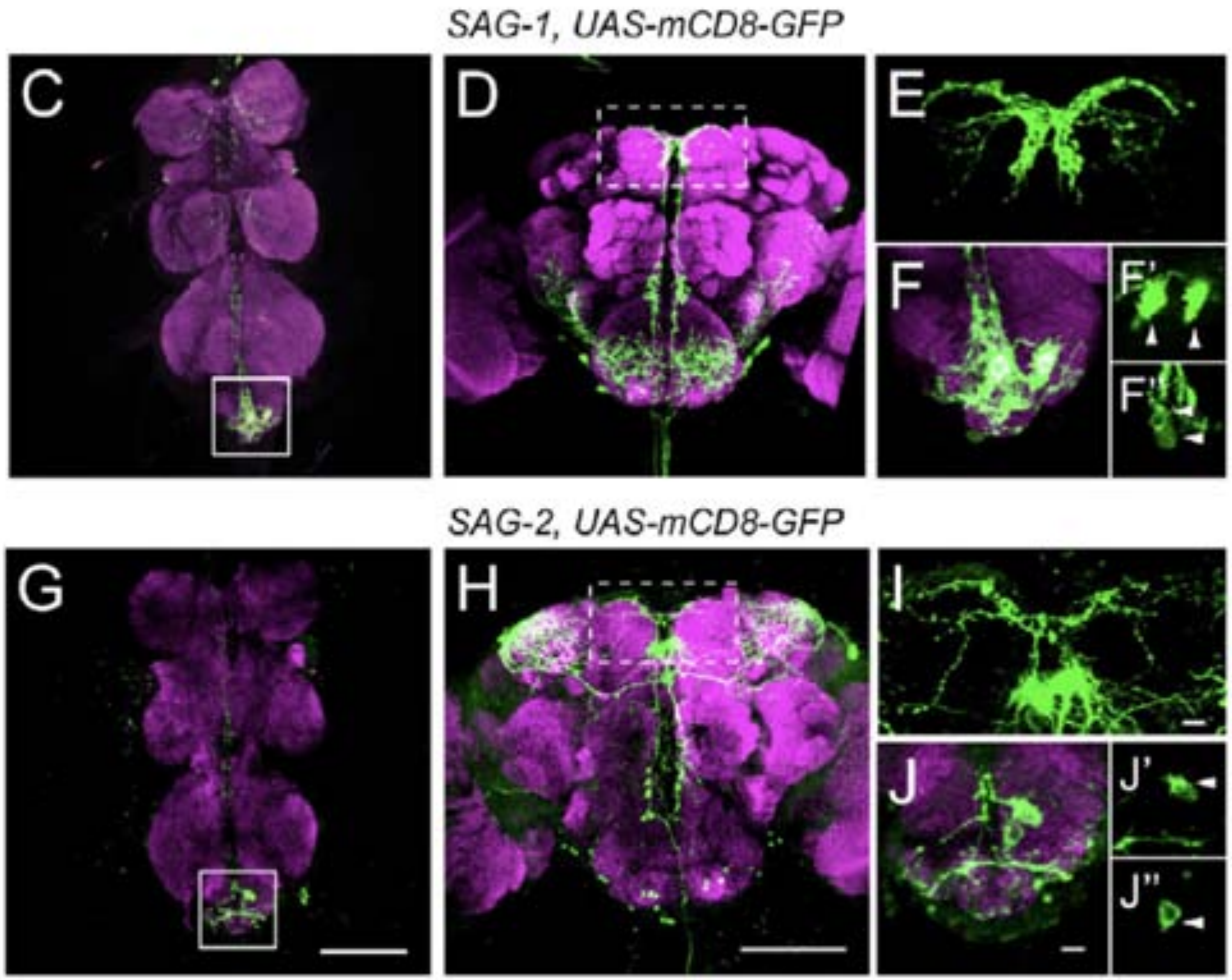
Neuron
Article

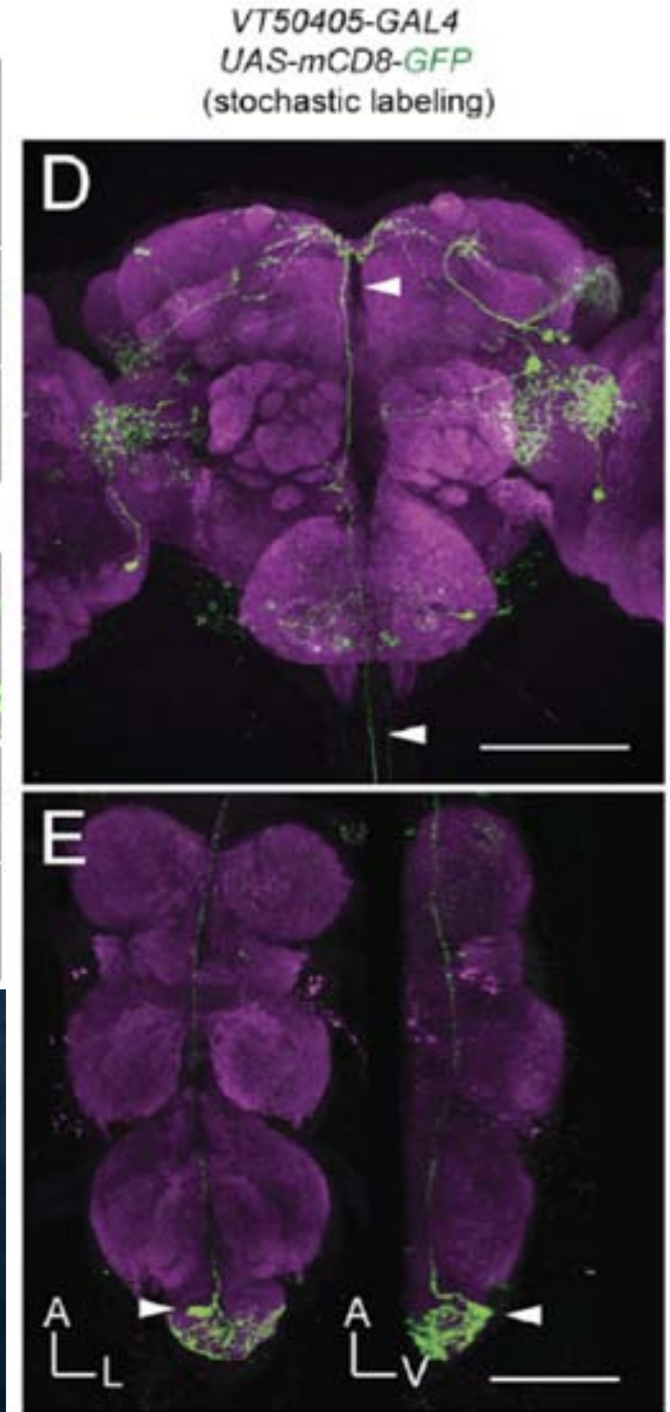
Ascending SAG Neurons Control Sexual Receptivity of *Drosophila* Females

Kai Feng,[1,2,5] Mark T. Palfreyman,[1,5,*] Martin Häsemeyer,[1,3] Aaron Talsma,[1] and Barry J. Dickson[1,4,*]

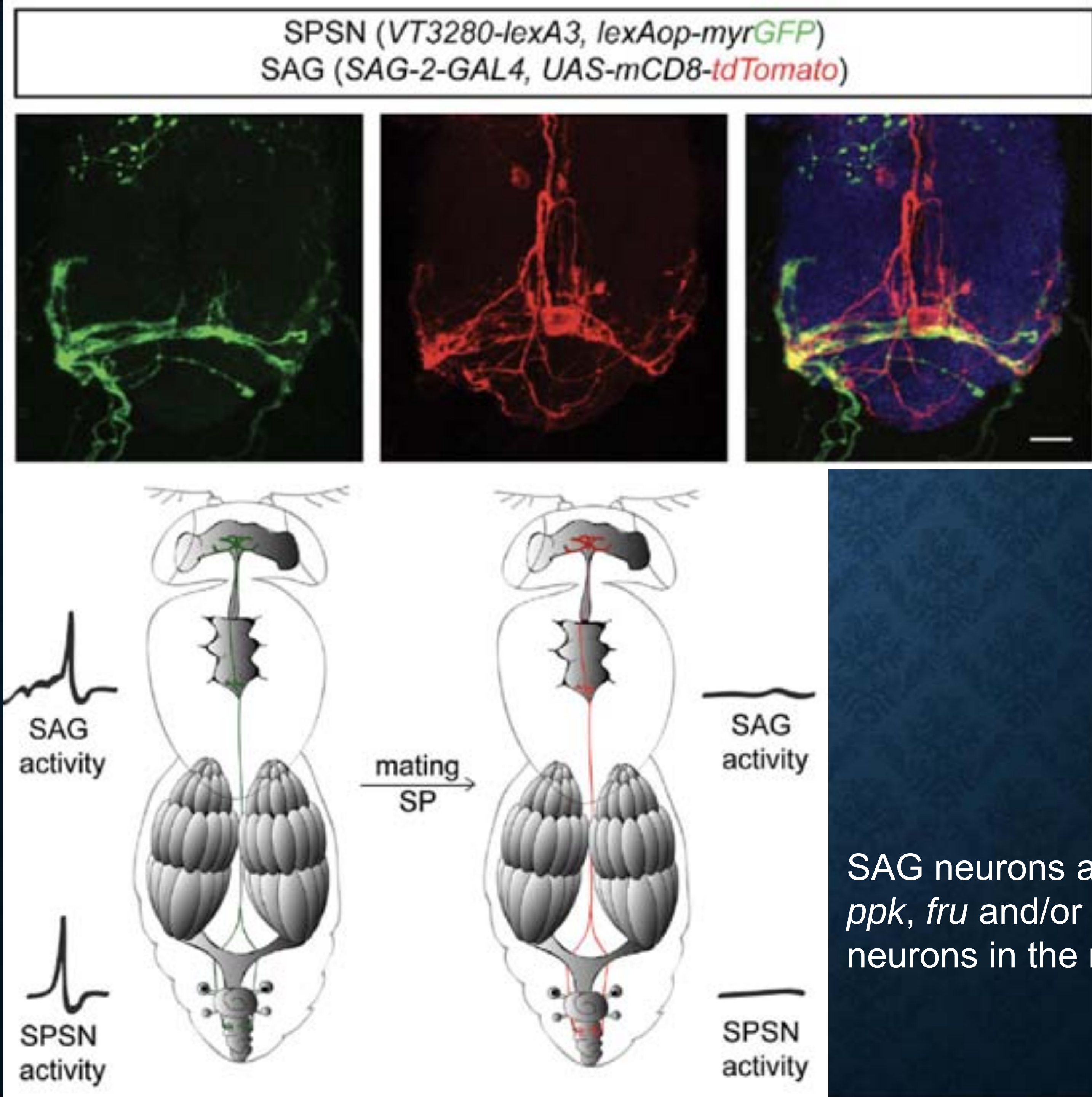


Identification of VT lines that induce post-mating behaviors when driving UAS-kir2.1

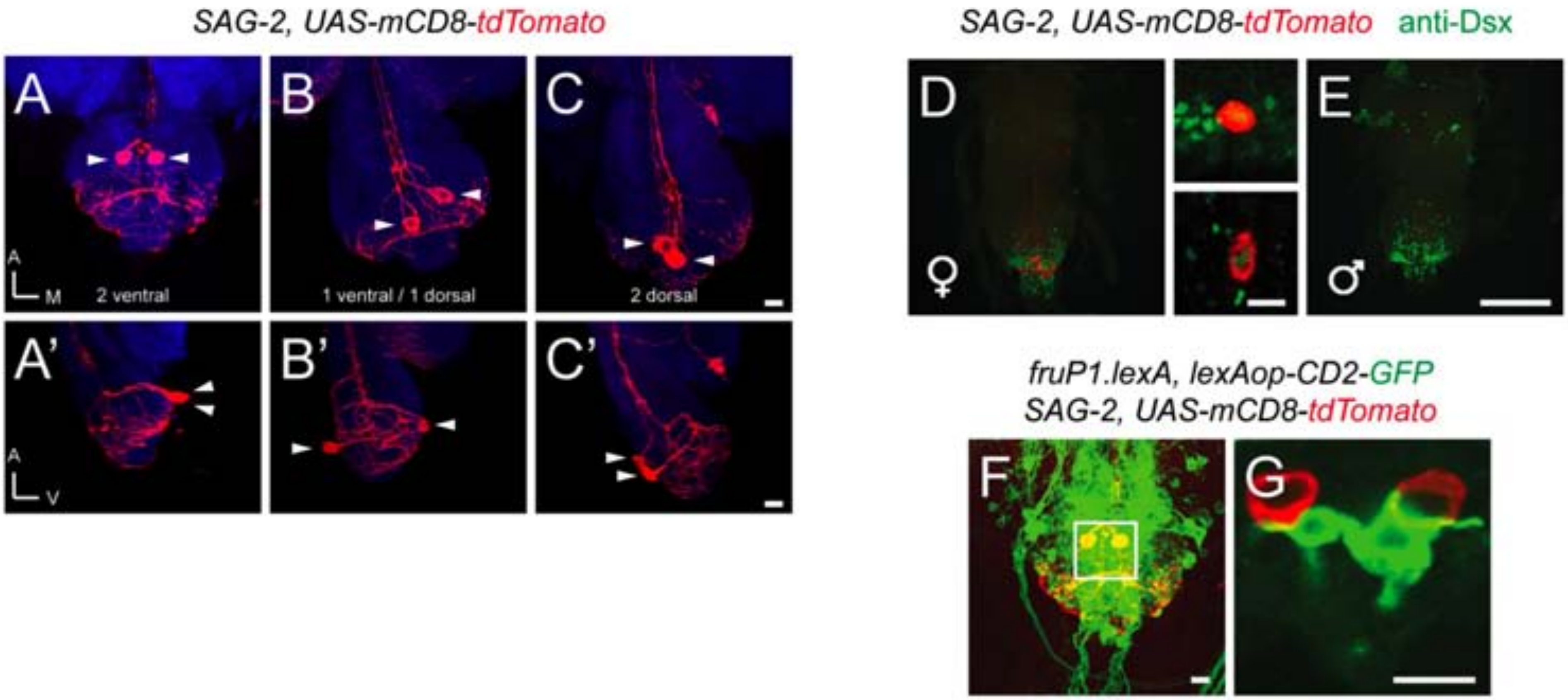

SAG-1, UAS-mCD8-GFP
C
D
E
F
F'
F''
SAG-2, UAS-mCD8-GFP
G
H
I
J
J'
J''


VT50405-GAL4
UAS-mCD8-GFP
(stochastic labeling)
D
E
A
L
A
V

SAG neurons



SAG neurons are downstream of *ppk*, *fru* and/or *dsx* sensory neurons in the reproductive tract.



SAG neurons are *dsx*-positive, but *fru*-negative

Question 2: what's the neural basis for post-mating behaviors

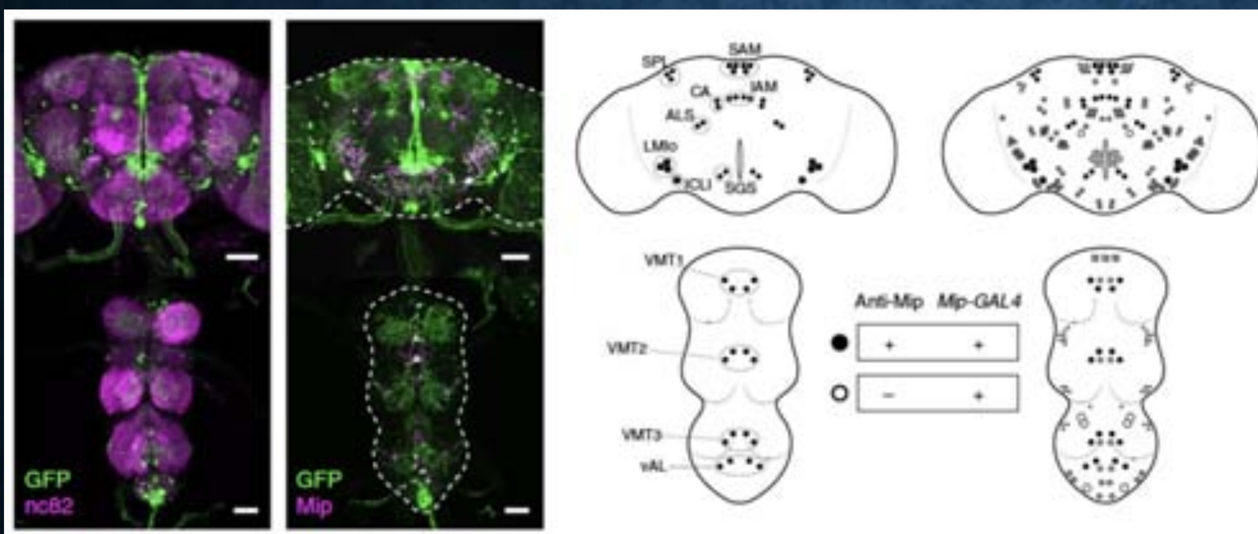
- *fruGAL4* neurons are involved;
- Subsets of ascending VNC neurons;
- *fru* and p*pk*-positive sensory neurons in the genital tract;
- *dsx* neurons are involved (several sub-types, including *ppk*-positive sensory neurons, octopaminergic neurons, SAG neurons and Mip neurons);

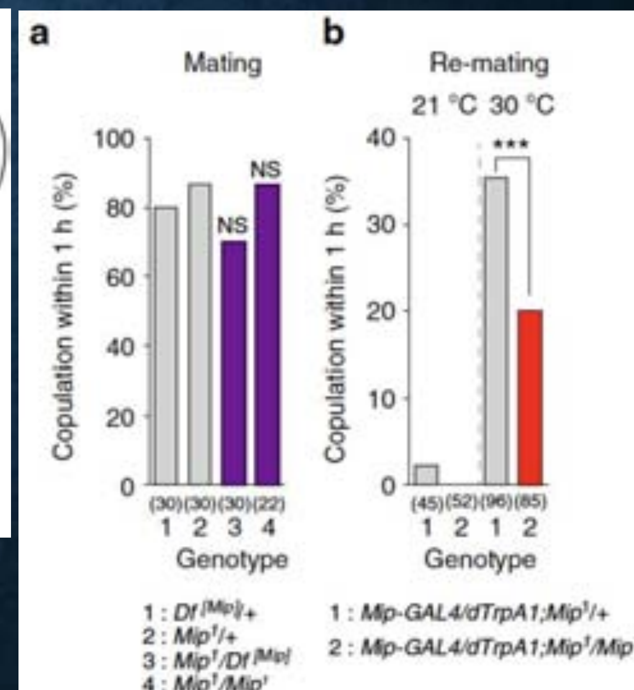
ARTICLE

DOI: 10.1038/s41467-017-01794-9 OPEN

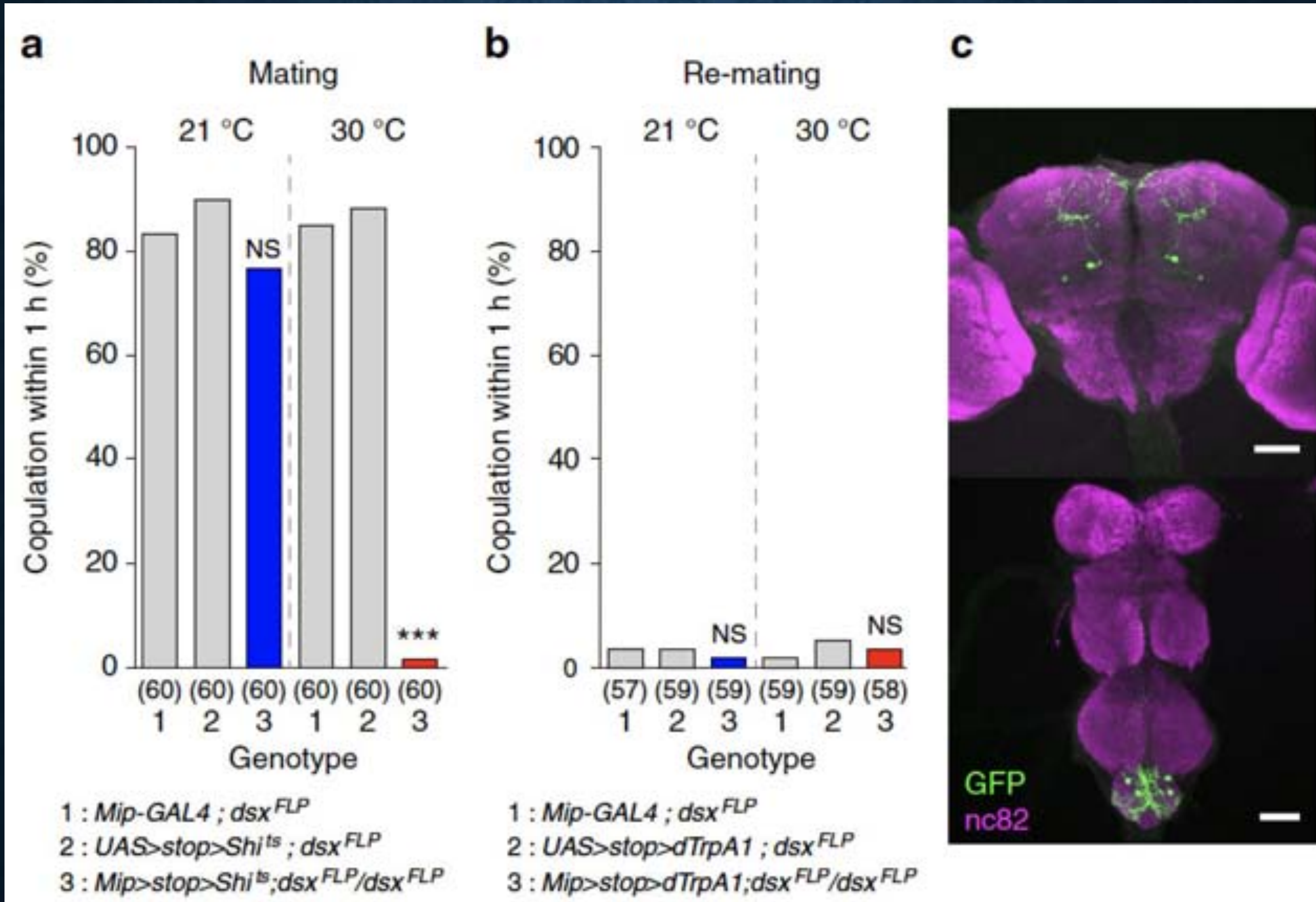
Female-specific myoinhibitory peptide neurons regulate mating receptivity in *Drosophila melanogaster*

Yong-Hoon Jang[1], Hyo-Seok Chae[1] & Young-Joon Kim[1]

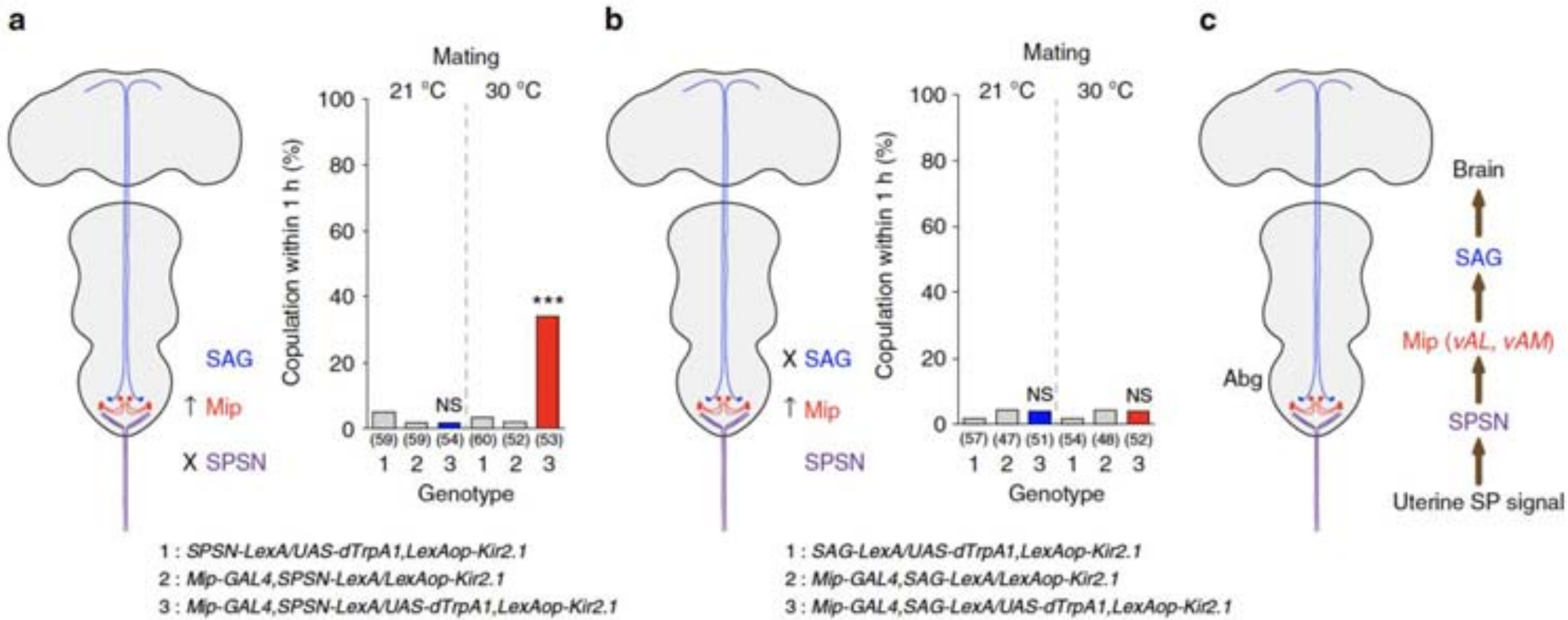




Mip-neurons are involved in post-mating behaviors



dsx-positive Mip neurons are involved in receptivity



Mip neurons may position within the SPSN and SAG signaling axis

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- 11 Kubli, E. & Bopp, D. Sexual behavior: how Sex Peptide flips the postmating switch of female flies. *Current biology : CB* **22**, R520-522, doi:10.1016/j.cub.2012.04.058 (2012).

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