Environmental Sensing

Functional elements of an environmental sensing / response network

Stimulus (an environmental signal)

Sensor (a receptor to detect the stimulus)

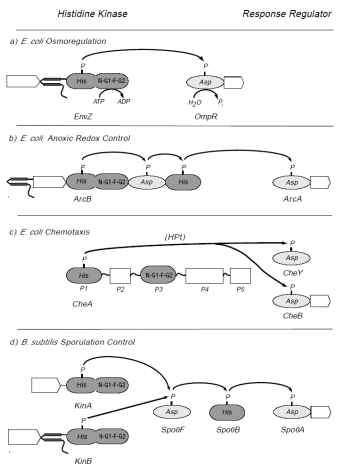
Transducer (converts the detected environmental stimulus into an internal signal)

Response regulator (responds to the internal signal by altering gene expression or cell function)

Feedback mechanism (shuts the system off as further events warrant)

Two-Component Regulatory Systems and Phosphorelay Systems

- many genes and operons are turned on or off in response to environmental conditions
  - the regulatory proteins involved are part of a two-component signal which links external events to regulation of gene expression



A system consists of two proteins:
A signal sensor and a response regulator

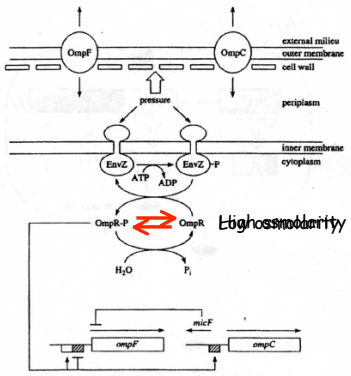
The sensor has an input domain and a transmitter domain

The regulator has an receiver domain and an output domain

The environmental signal is transduced by a phosphorelay

The sensor has a conserved histidine which can be phosphorylated and subsequently transferred to an aspartate residue on the response regulator.

The EnvZ/OmpR system:
A paradigm two component system



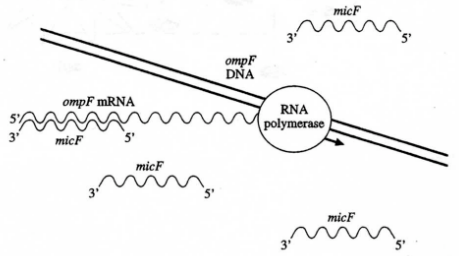
This two component system regulates the ratio of OmpC/OmpF in response to osmolarity

These proteins are Porins- OmpC is a narrow bore, OmpF is a large bore

EnvZ regulates OmpR-P levels with kinase/phosphatase activities

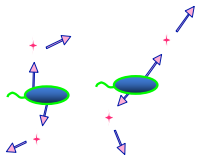
OmpR is a DNA binding protein that binds to high and low affinity sites at the *ompC* and *ompF* promoters

ompF expression is also controlled by antisense RNA

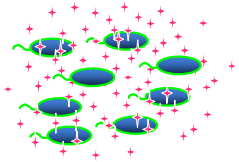


Quorum sensing: the basic idea

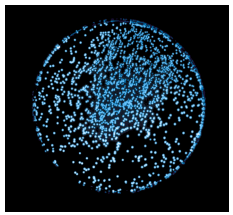
Low cell densities,
Low [QS signal],



High cell densities,
High [QS signal],

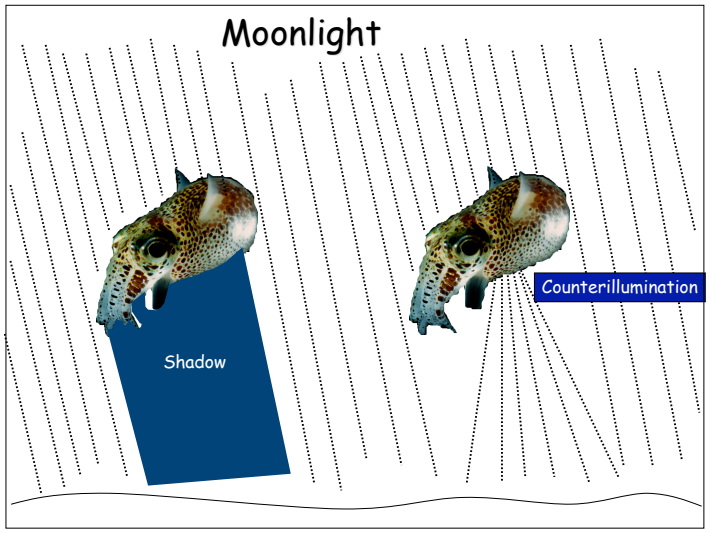


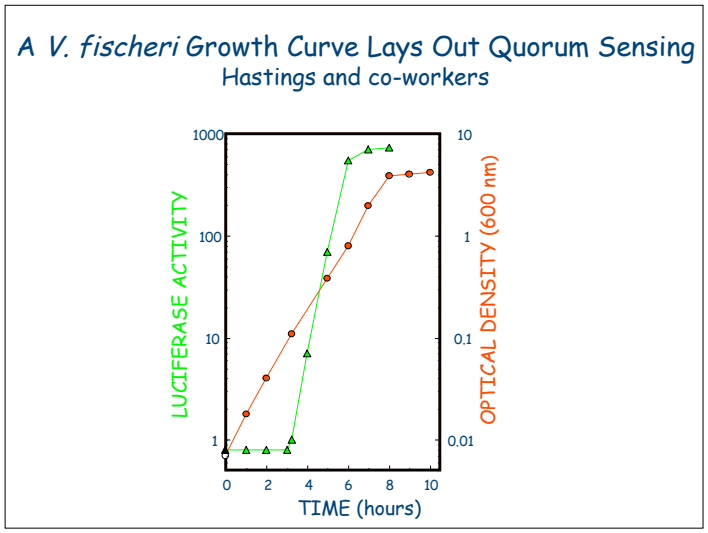
Scheme #1: Acyl-HSL Signaling
The *Vibrio fischeri* Paradigm

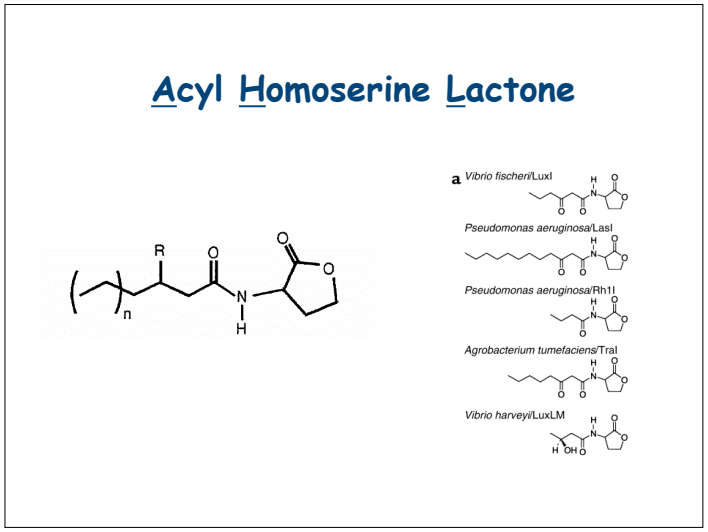


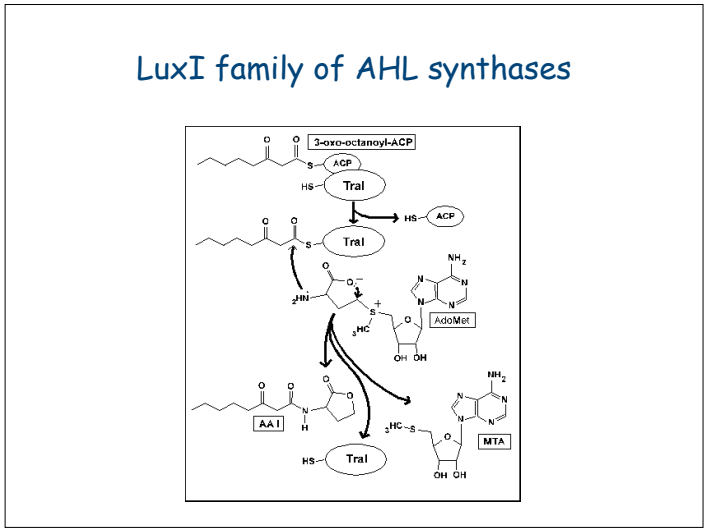
Vibrio fischeri

Euprymna scolopes

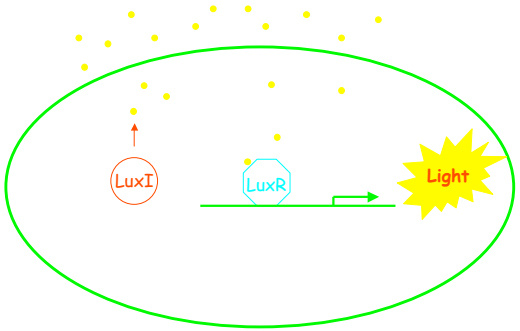

Moonlight
Shadow
Counterillumination


A V. fischeri Growth Curve Lays Out Quorum Sensing
Hastings and co-workers
LUCIFERASE ACTIVITY
OPTICAL DENSITY (600 nm)
TIME (hours)
1000
100
10
1
10
1
0.1
0.01
0
2
4
6
8
10


Acyl Homoserine Lactone
a
Vibrio fischeri/LuxI
Pseudomonas aeruginosa/LasI
Pseudomonas aeruginosa/Rh1I
Agrobacterium tumefaciens/TraI
Vibrio harveyi/LuxLM


LuxI family of AHL synthases
3-oxo-octanoyl-ACP
ACP
TraI
AdoMet
AA I
MTA

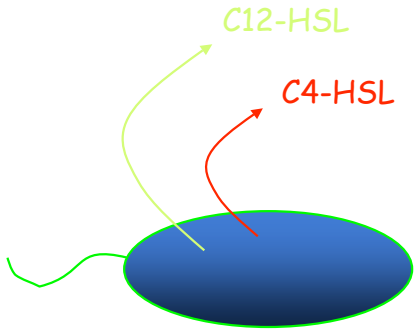
The basic components of the *V. fischeri* *lux* quorum sensing system



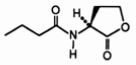
AHL signaling in different species

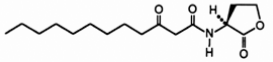
Species	QS-regulated function
Burkholderia cepacia	Secreted virulence factors
Yersinia enterocolitica	Cell aggregation
Agrobacterium tumefaciens	Conjugal plasmid transfer
Erwinia carotovora	Carbapenem antibiotics
Aeromonas hydrophila	Secreted virulence factors

P. aeruginosa Communicate via Two Quorum-Sensing Signals



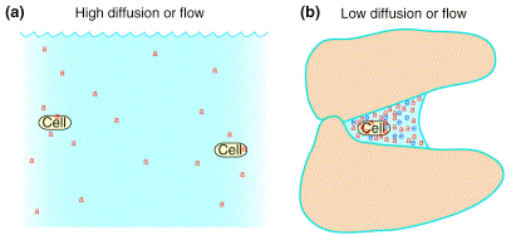
P. aeruginosa AHL systems

C4-HSL  RhlR-RhlI

C12-HSL  LasR-LasI

LasR-LasI regulates RhlR-RhlI.
LasR-I is atop the quorum sensing cascade.

Quorum Sensing or Diffusion Sensing?



Autoinducer is rapidly diluted when diffusion or flow are high, preventing wasteful secretion of degradative enzymes and other effectors.

Autoinducer accumulates when diffusion or flow are limited, inducing secretion of effectors only when they can be productive.

TRENDS in Microbiology

Scheme #2: AI-2 based signaling

Widely distributed

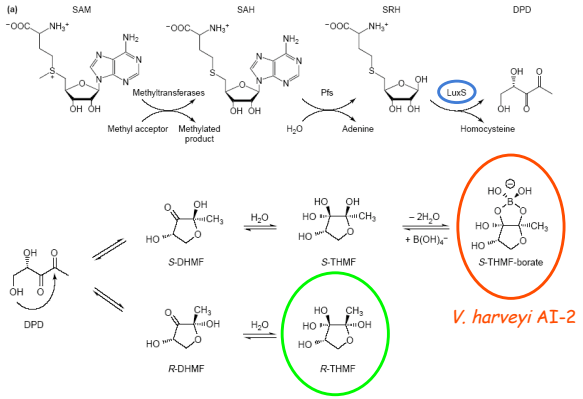
Characterized by *luxS* gene, which is involved in biosynthesis

AI-2 may be involved in inter-species quorum sensing.

Table 1
Bacteria that possess *luxS* genes

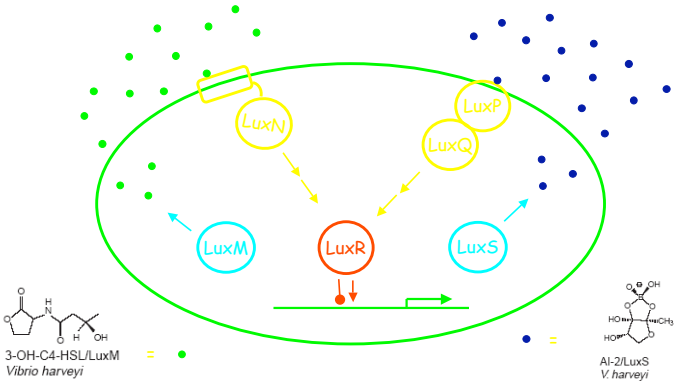
Actinobacillus pleuropneumoniae	*Helicobacter pylori*	*Salmonella paratyphi*
Bacillus anthracis	*Klebsiella pneumoniae*	*Salmonella typhi*
Bacillus cereus	*Lactobacillus gasseri*	*Salmonella typhimurium*
Bacillus halodurans	*Lactobacillus plantarum*	*Shigella flexneri*
Bacillus subtilis	*Lactococcus lactis*	*Sinorhizobium meliloti*
Bifidobacterium longum	*Leuconostoc mesenteroides*	*Staphylococcus aureus*
Borrelia burgdorferi	*Leuconostoc oenos*	*Staphylococcus epidermidis*
Campylobacter jejuni	*Listeria innocua*	*Streptococcus agalactiae*
Clostridium acetobolyticum	*Listeria monocytogenes*	*Streptococcus gordonii*
Clostridium difficile	*Neisseria gonorrhoeae*	*Streptococcus mutans*
Clostridium perfringens	*Neisseria meningitidis*	*Streptococcus pneumoniae*
Deinococcus radiodurans	*Oceanobacillus iheyensis*	*Streptococcus pyogenes*
Enterococcus faecalis	*Oenococcus oeni*	*Vibrio anguillarum*
Enterococcus faecium	*Pasteurella multocida*	*Vibrio cholerae*
Escherichia coli	*Pasteurella multocida*	*Vibrio harveyi*
Haemophilus ducreyi	*Porphyromonas gingivalis*	*Vibrio parahemolyticus*
Haemophilus influenzae	*Proteus mirabilis*	*Vibrio vulnificus*
Haemophilus somnus	*Salmonella enterica*	*Yersinia pestis*
Helicobacter hepaticus		

The biosynthesis and structure of AI-2

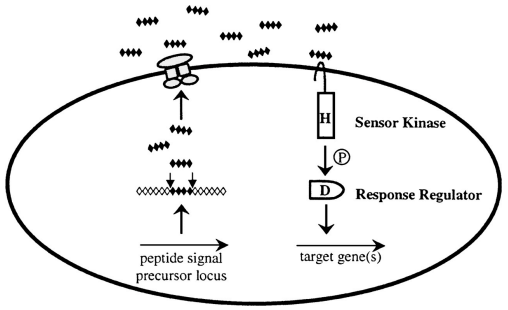


Henke, et al., 2004 Tr. Cell Biol. 14:648-656

The molecular scheme for AI-2 based signaling in *V. harveyi*

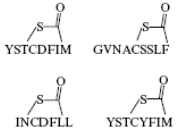
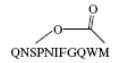


Scheme #3: Most Gram-positive quorum sensing involves peptide signal molecules

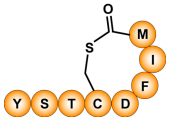


The "basic" scheme

TABLE 2. Specific structures of peptide signal molecules[a]

Organism	Name of signal	AA Sequence of mature molecule	Length of unprocessed precursor (AA)
Lactococcus lactis	Nisin A	ITSISLCTPGCKTGALMG CNMKTATCHCSIHVSK[b]	57
Lactobacillus plantarum	IF (PlnA)	KSSAYSLQMGATAI KQVKKLFKKWGW	48
Streptococcus pneumoniae	CSP (ComC)	EMRLSKFFRDFILQRKK	41
S. gordonii	CSP (ComC1)	DVRSNKIRLWWENIFFNKK	50
Bacillus subtilis	ComX pheromone	ADPITRQW[b]GDERGMT	55
	CSF (PhrC)		40
Staphylococcus aureus	AgrD		44
Enterococcus faecalis	cCF10	LVTLVFV	Not determined
	iCF10	AITLIFI	23
	cAD1	LFSLVLAG	Not determined
	iAD1	LFVVTLVG	23
	GBAP		242

A Case study of Gram-positive quorum sensing: *S. aureus agr* system



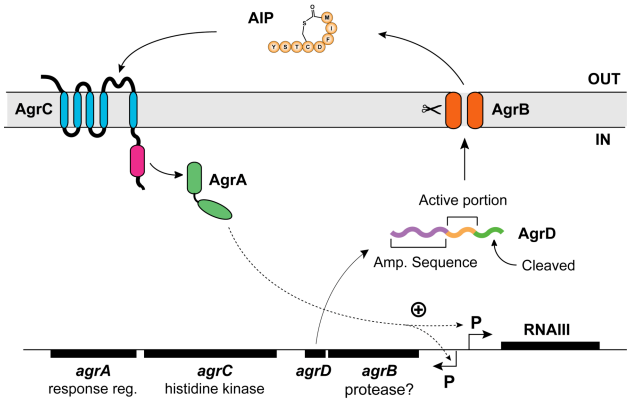
Autoinducing peptide "AIP"

When the cell-density increases, signal reaches a critical threshold and:

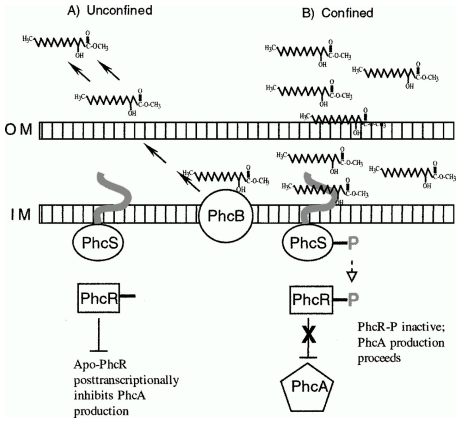
Up-regulates extracellular virulence factors

Down-regulates cell surface virulence factors

Molecular scheme for *S. aureus* quorum sensing



Scheme #4: *Ralstonia solanacearum* uses a volatile signaling molecule

3-OH palmitic acid methylester

Volatile signaling: The tip of the iceberg??