

VIRUSES RULE THE SEA

CMORE SUMMER COURSE

2012

GRIEG STEWARD

CENTER FOR MICROBIAL OCEANOGRAPHY: RESEARCH AND EDUCATION

DEPARTMENT OF OCEANOGRAPHY

UNIVERSITY OF HAWAII AT MANOA

OUTLINE OF THE TALK

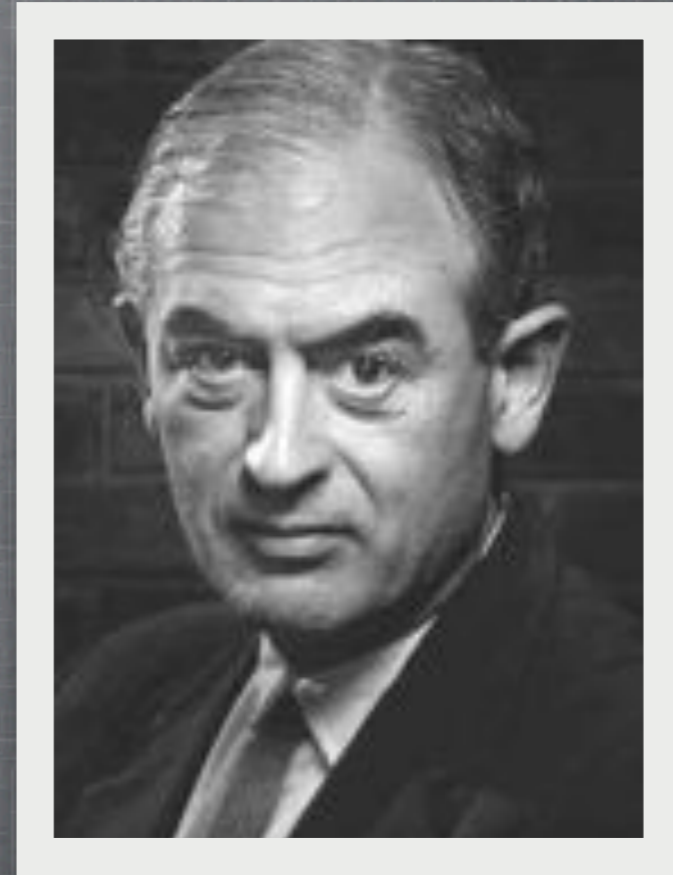
- Introduction to viruses
- Why viruses rule the sea
- Why viral diversity matters
- Vignettes of some of our work:
 1. RNA viruses
 2. Isolation of new virus-host systems
 3. Fractionation of cells and Viruses

WHAT ARE VIRUSES?

Let's ask some experts



André Lwoff (1902-1994)
Nobel Prize 1965



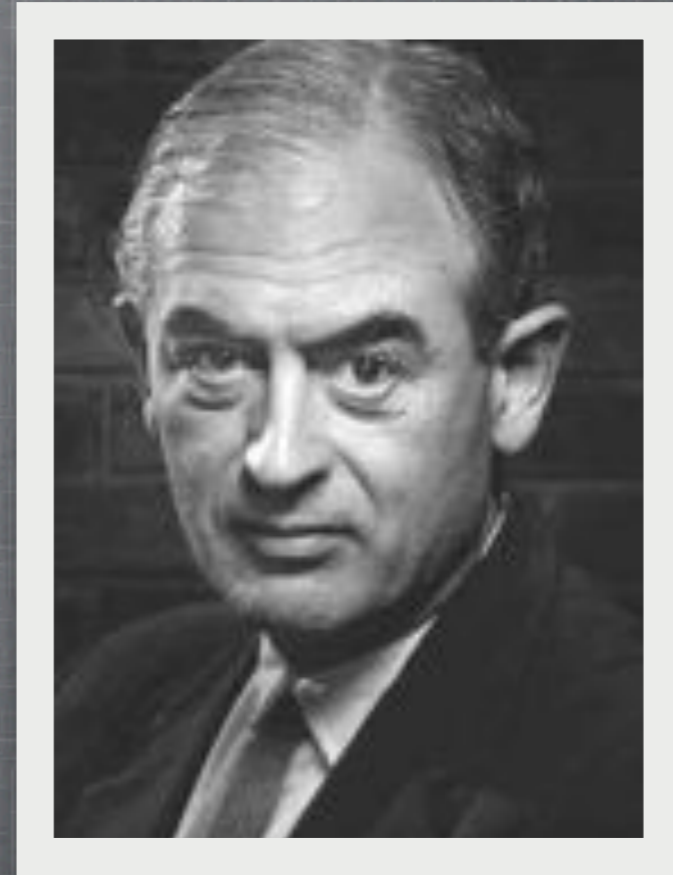
Sir Peter Medawar (1915-1987)
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A VIRUS IS A VIRUS!

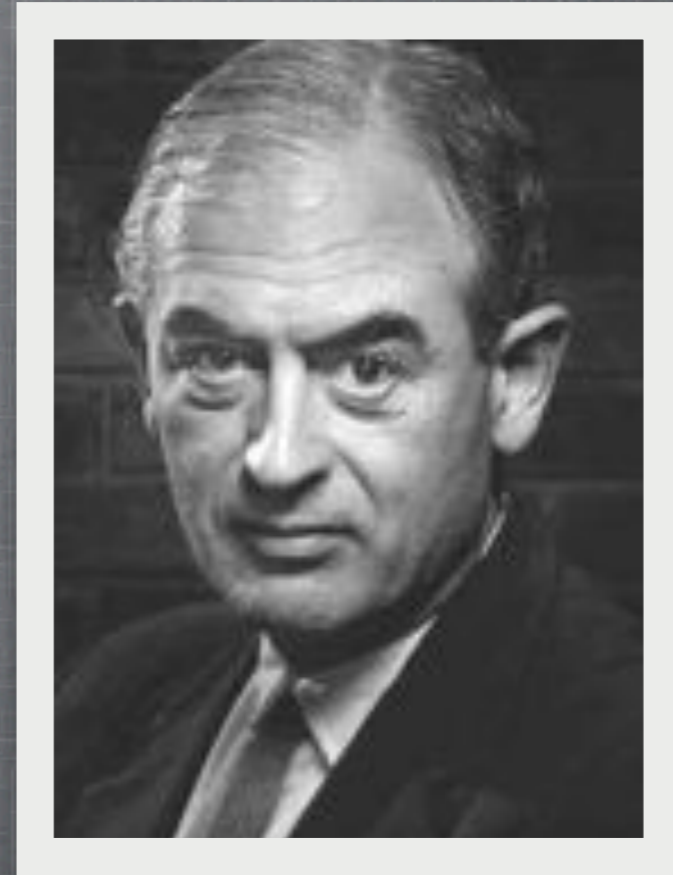
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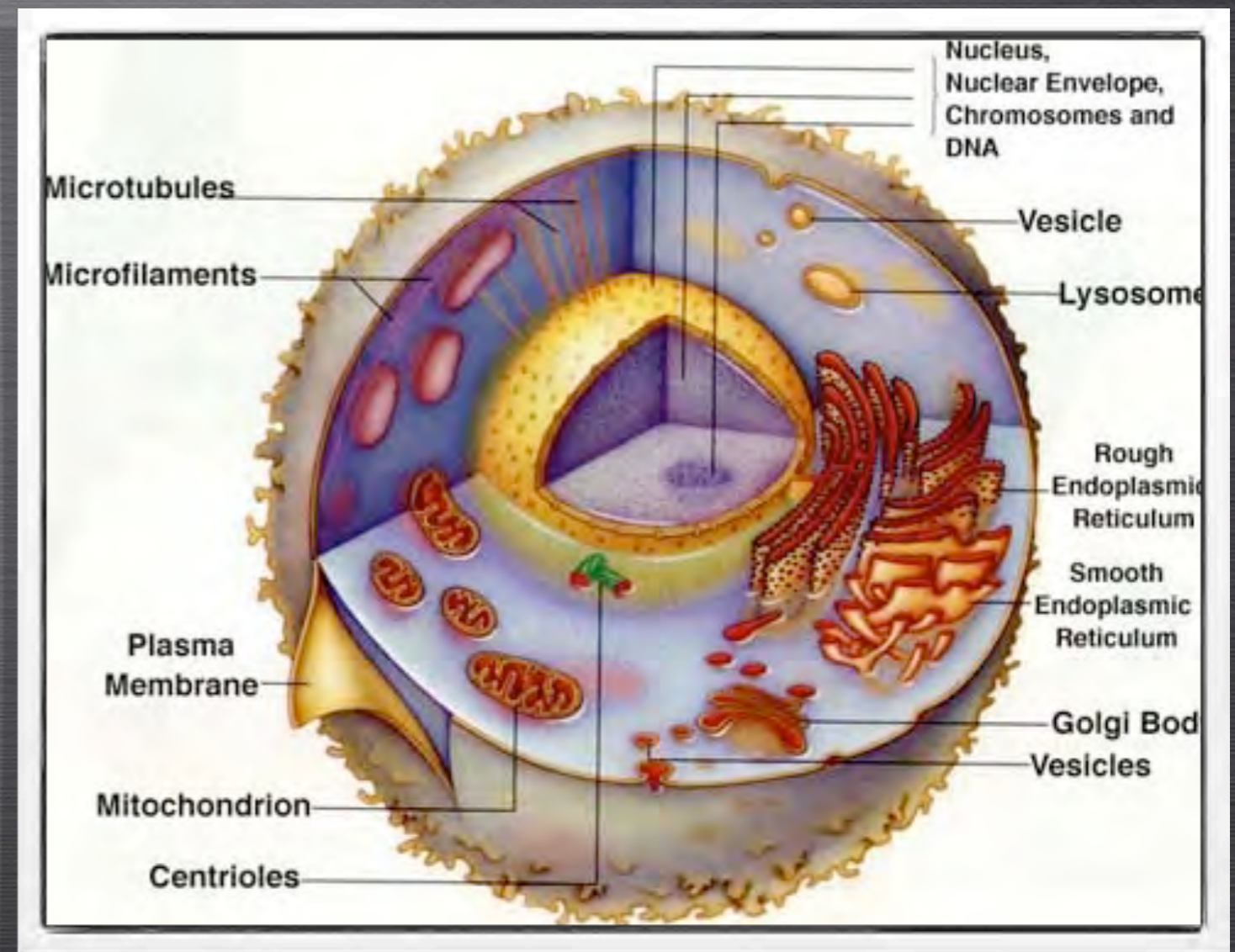
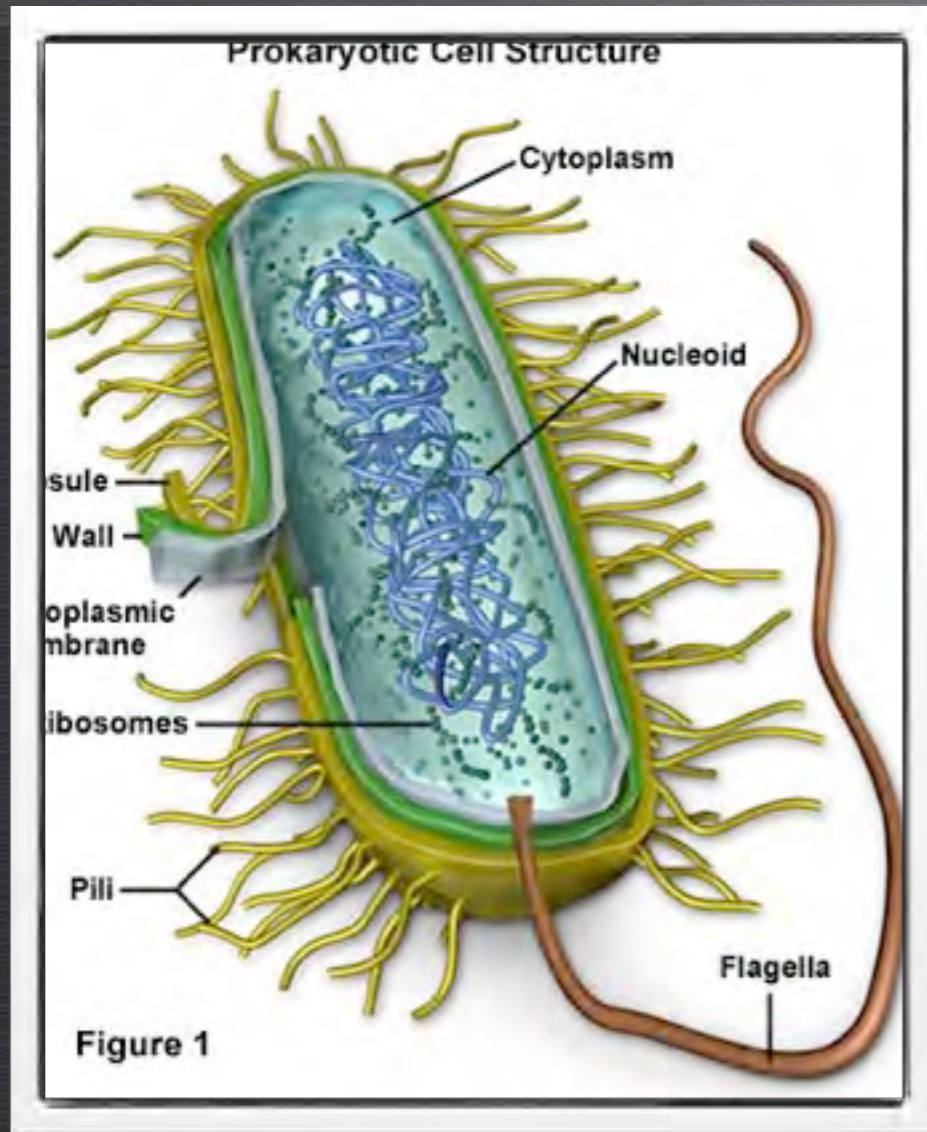


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**A VIRUS IS A PIECE OF
BAD NEWS WRAPPED
IN PROTEIN**

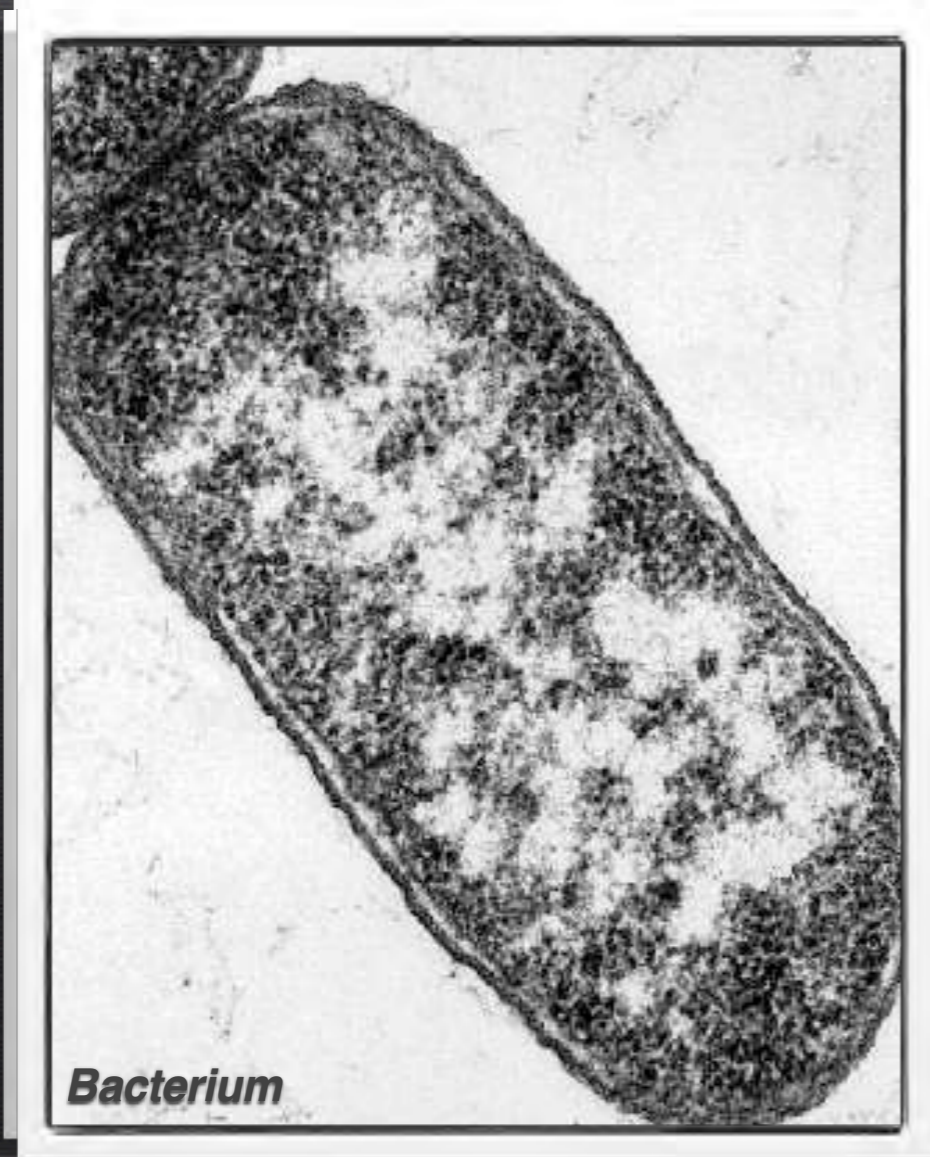
PROKARYOTE

EUKARYOTE

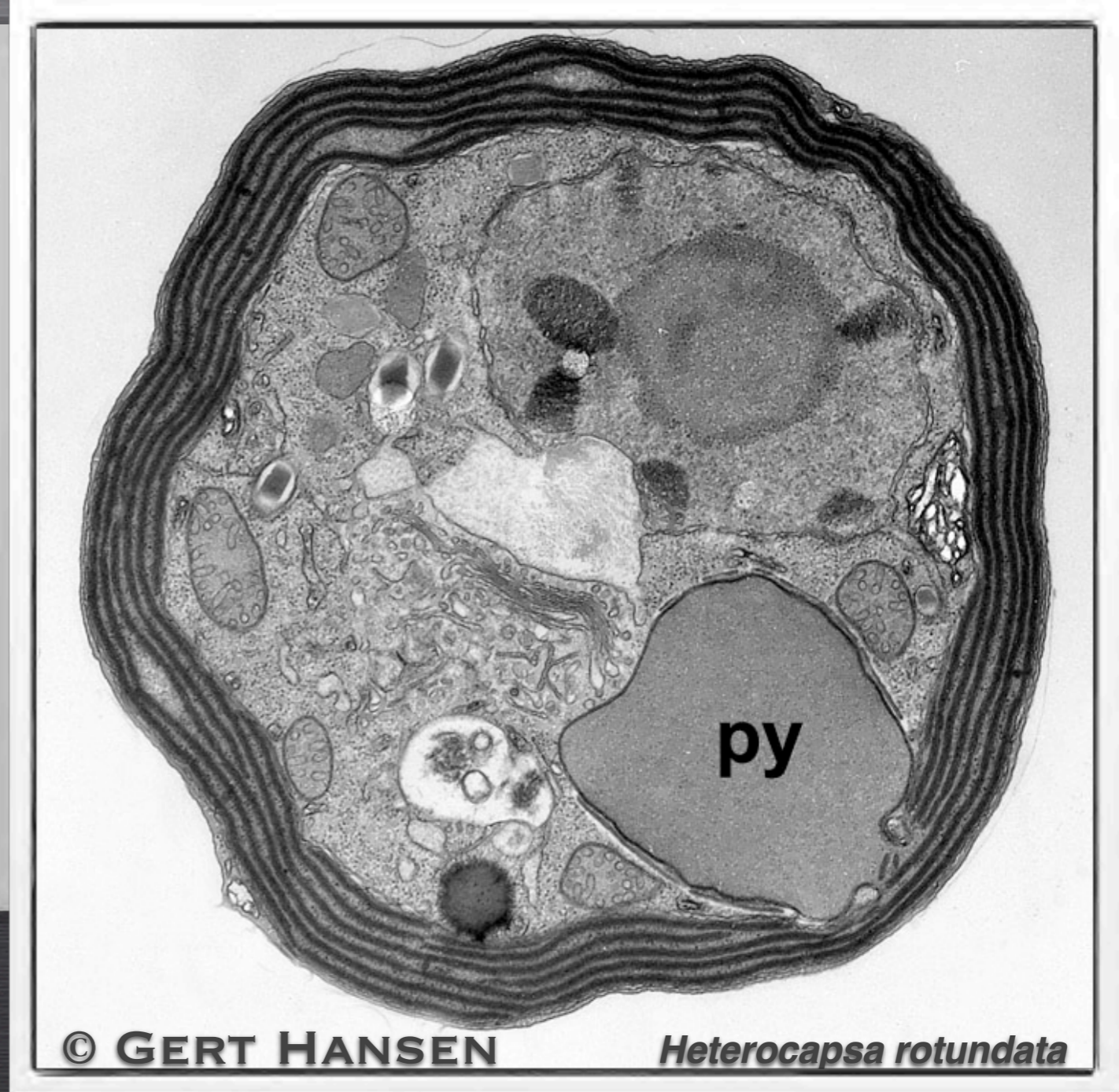


CELLULAR LIFE

PROKARYOTE



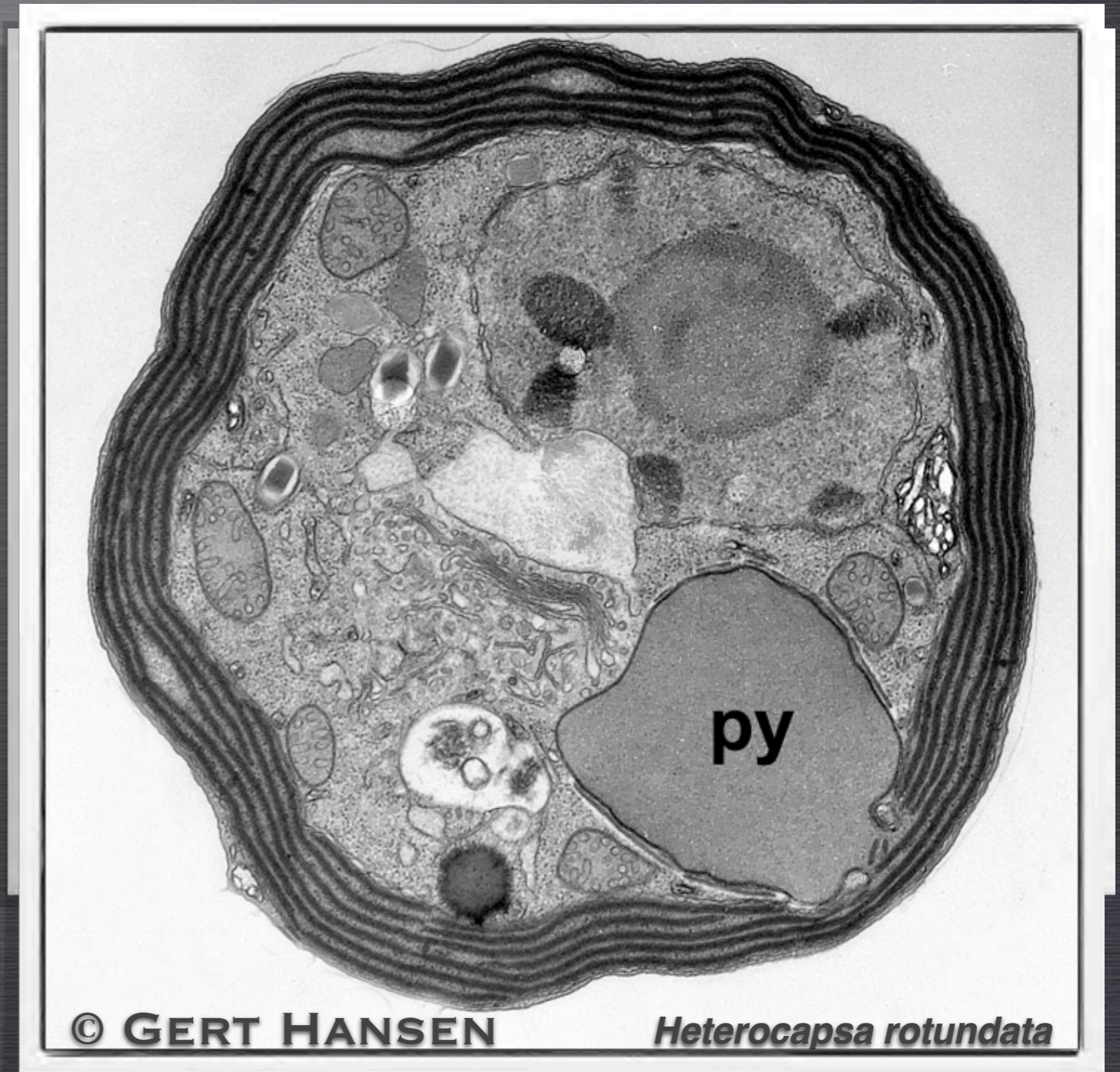
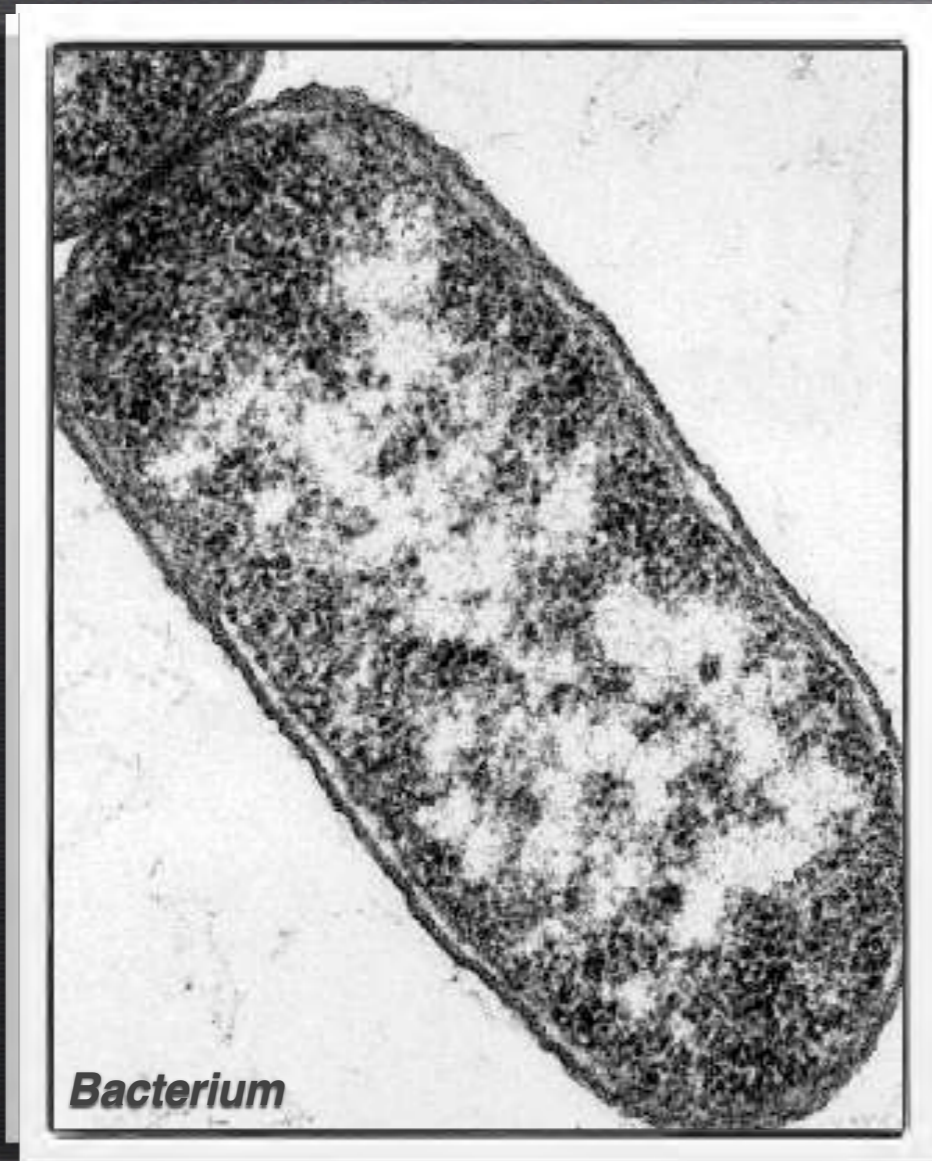
EUKARYOTE



CELLULAR LIFE

PROKARYOTE

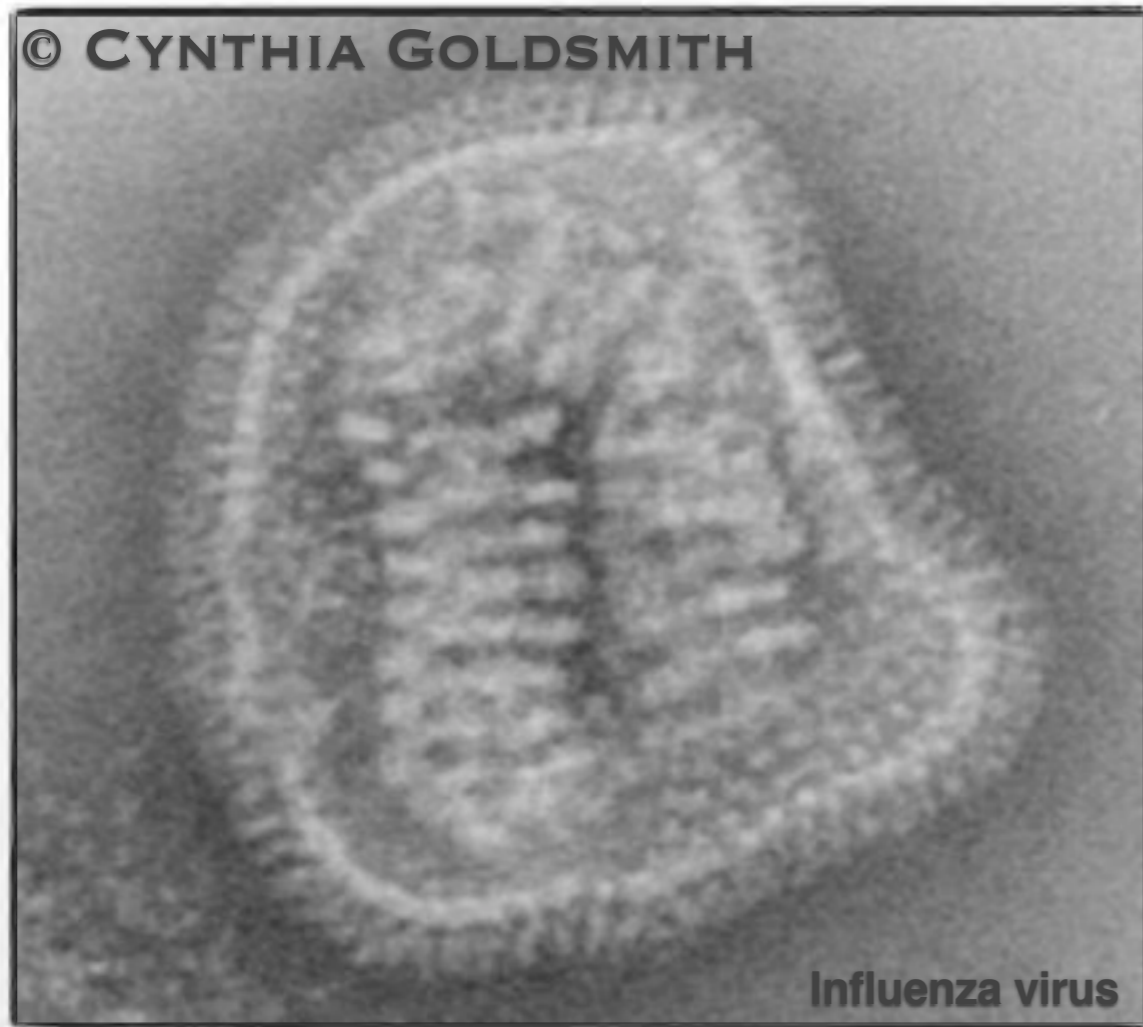
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CELLULAR LIFE

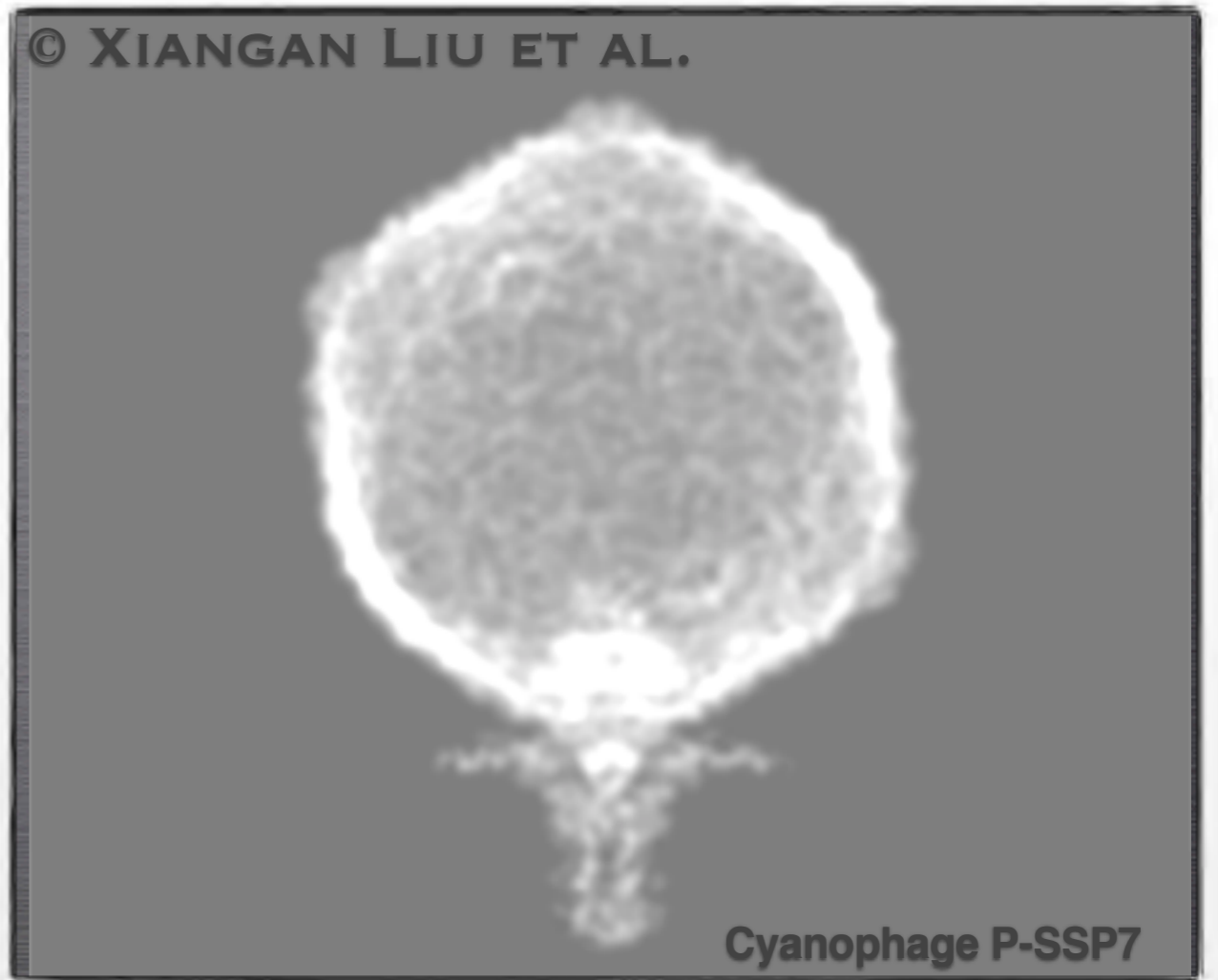
CAN WE CALL VIRUSES “ACELLULAR”?

© CYNTHIA GOLDSMITH



Influenza virus

© XIANGAN LIU ET AL.



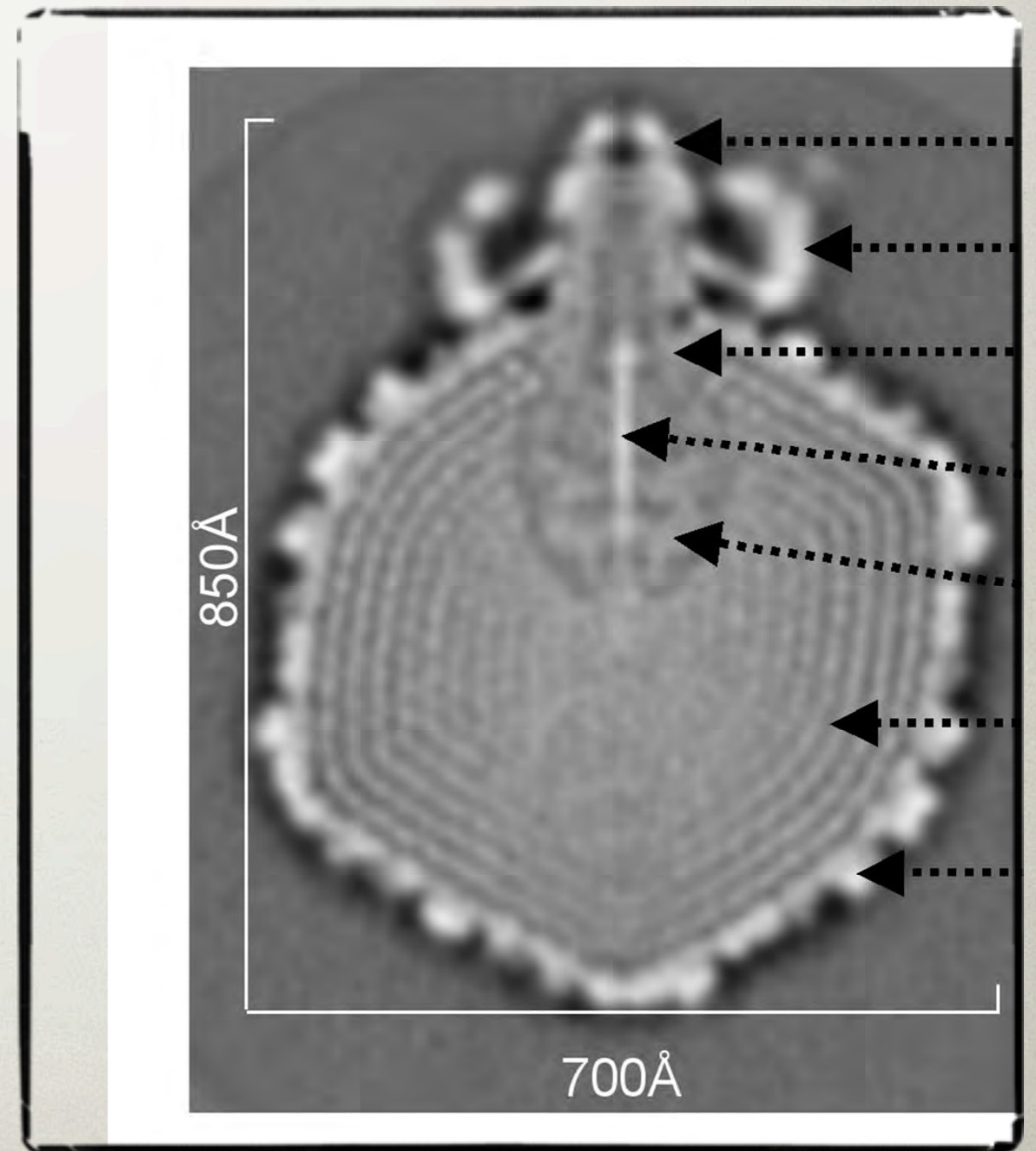
Cyanophage P-SSP7

VIRUSES ARE ALSO “CELLULAR”

BUT THESE “CELLS” HAVE NO METABOLISM

WHAT ARE VIRUSES?

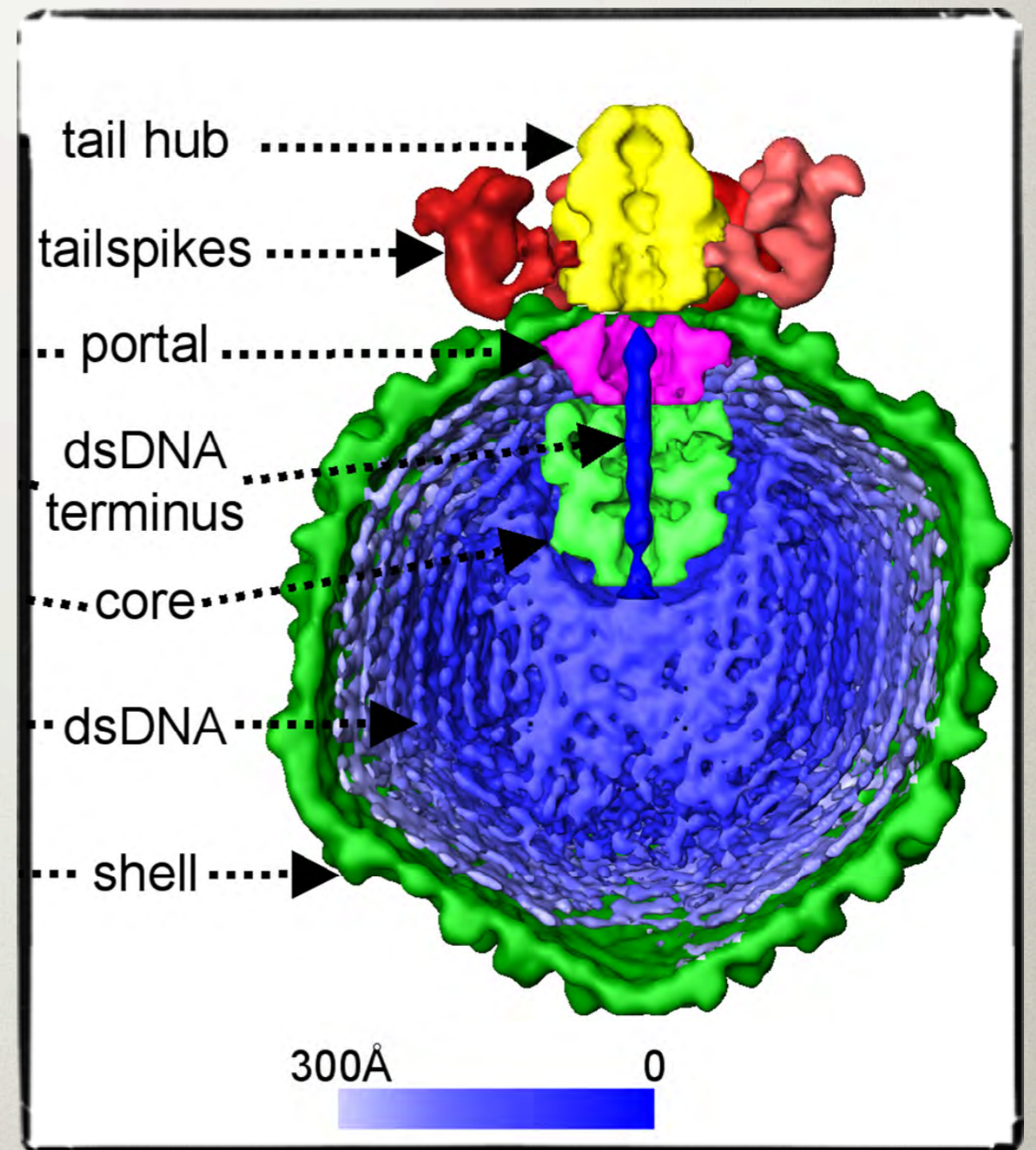
- Infectious agents that can replicate only inside a host cell
- Relatively simple:
 - A set of instructions (**DNA or RNA**)
 - A protective coat
 - No motility
 - No metabolism



Bacteriophage Epsilon 15

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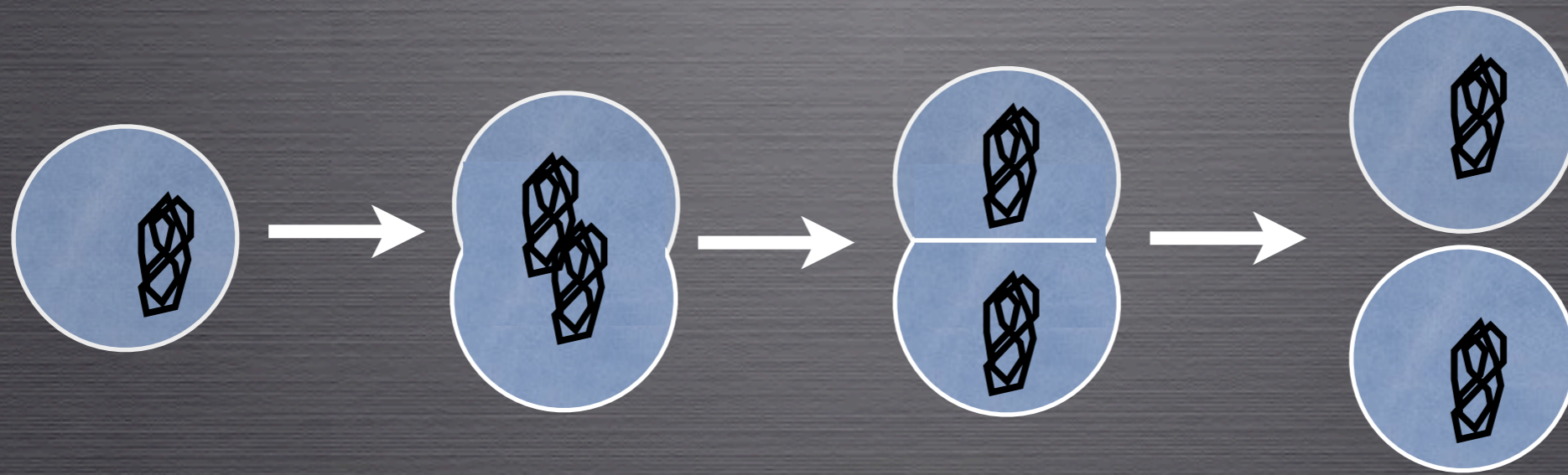
Bacteriophage Epsilon 15

A FUNDAMENTALLY DIFFERENT LIFESTYLE

PROKARYOTES AND EUKARYOTES: REPLICATION BY FISSION

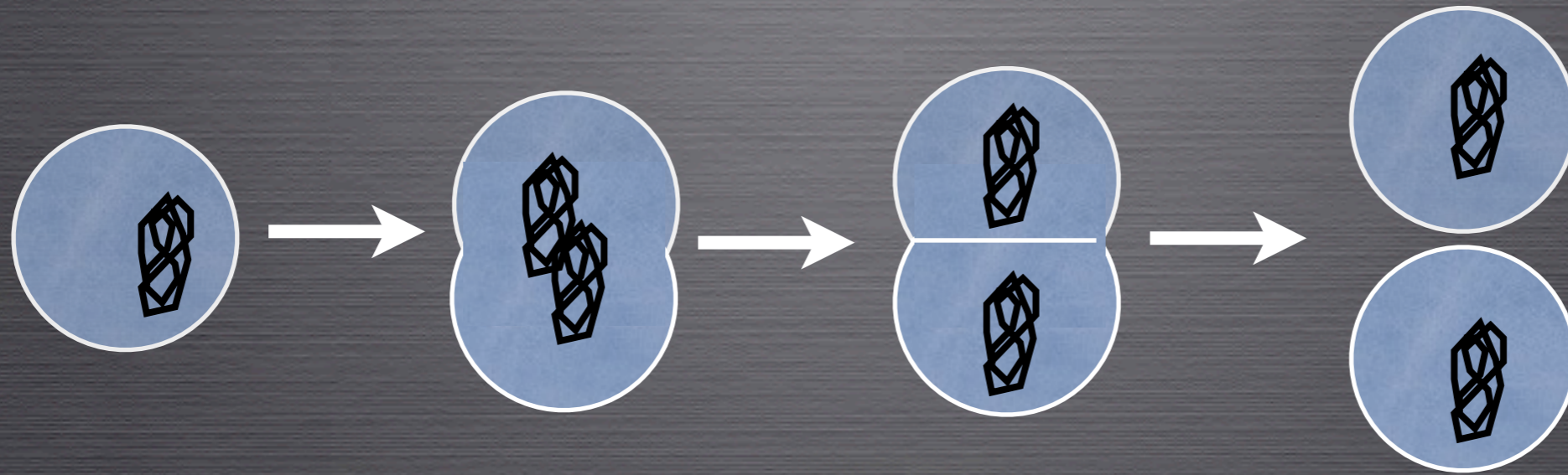
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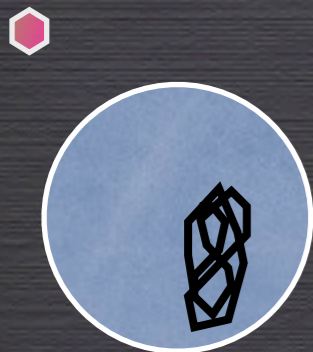


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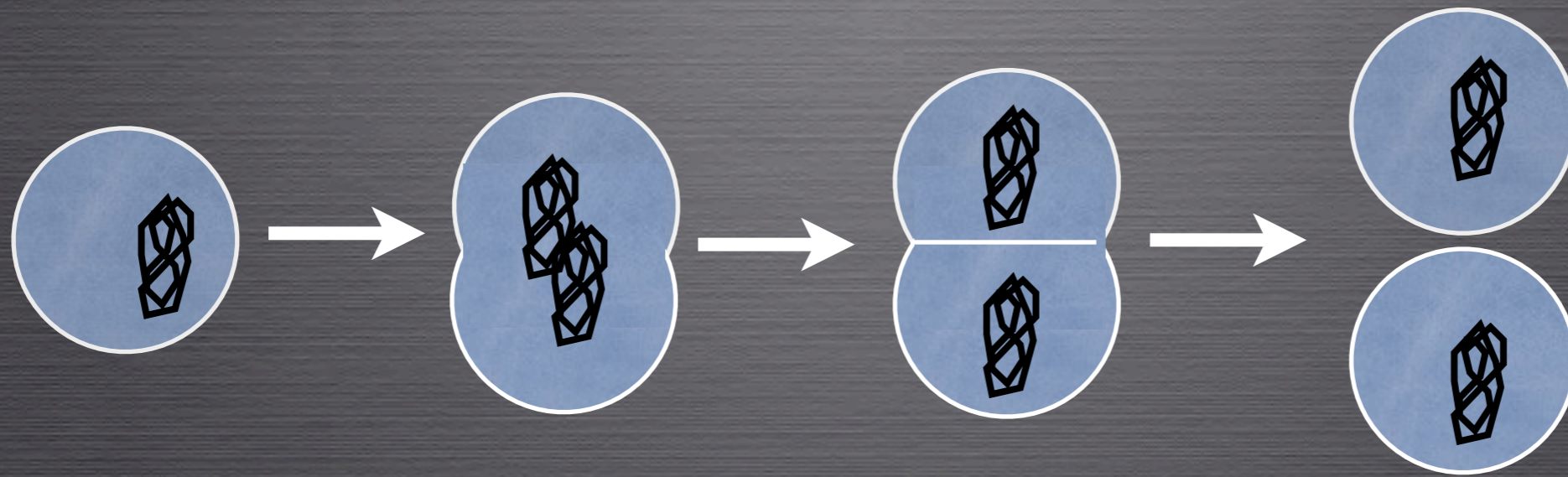


VIRUSES: REPLICATION WITHIN CELLS BY ASSEMBLY

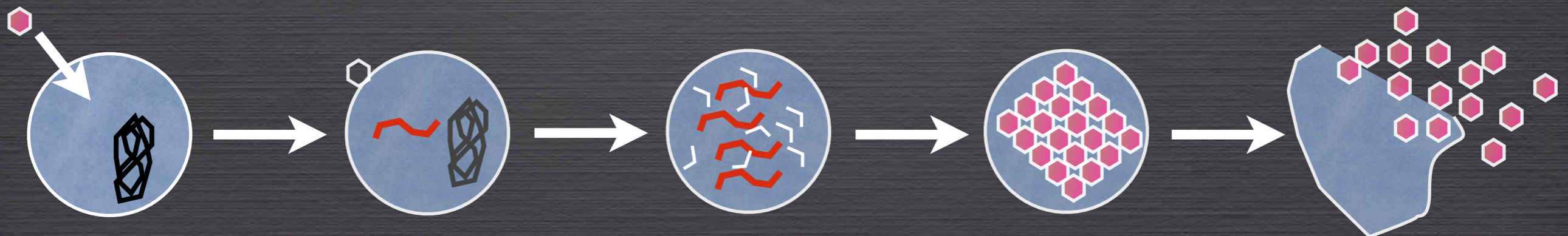


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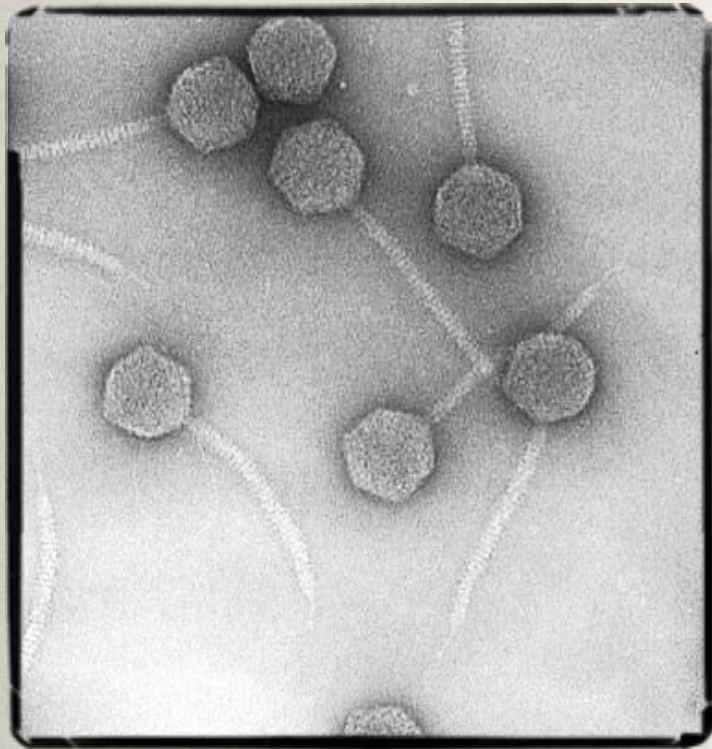
PROKARYOTES AND EUKARYOTES: REPLICATION BY FISSION



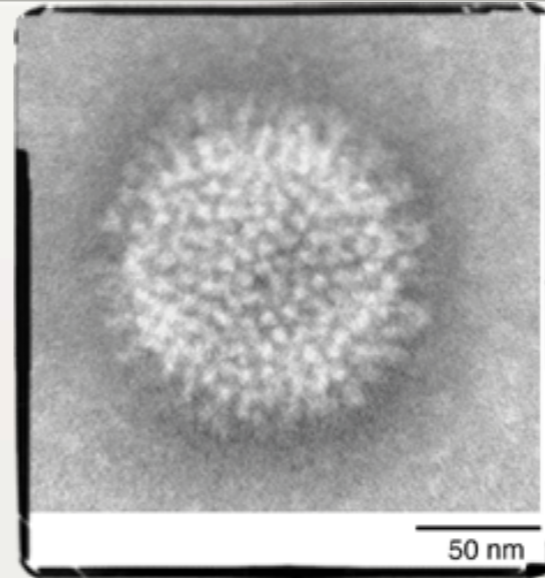
VIRUSES: REPLICATION WITHIN CELLS BY ASSEMBLY



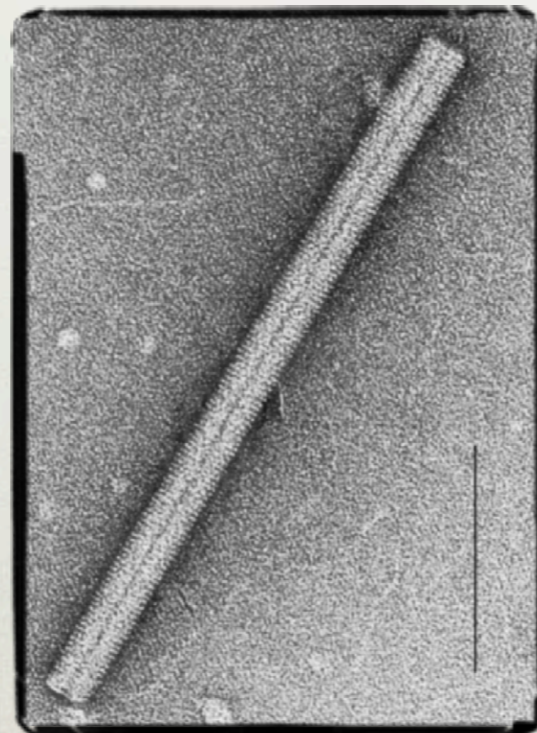
MANY SHAPES AND SIZES



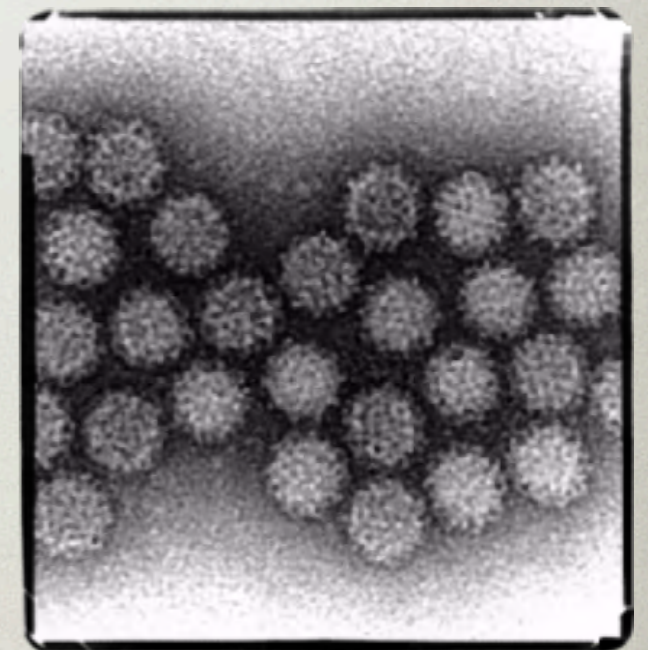
Siphovirus
(bacteria)



Influenza
(Humans, birds,
pig, seals)



Tobamovirus
(Tobacco plant)



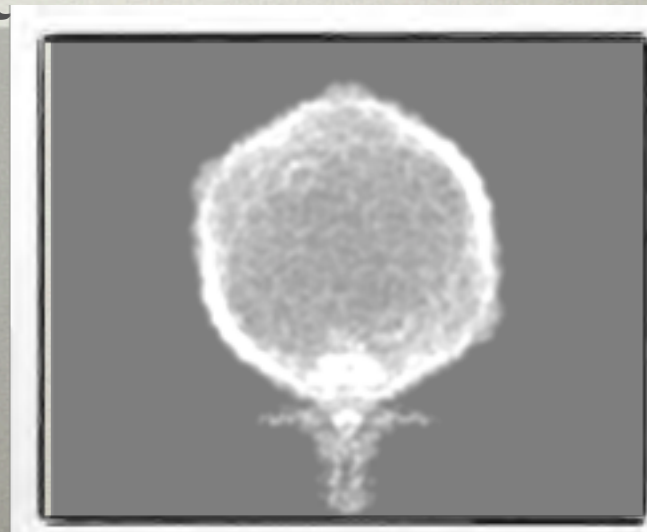
Calicivirus
(vertebrates)

THE CONTINUUM OF EXTRACHROMOSOMAL GENETIC REBELS

- **Transposons and Inteins** - no direct mechanism of cell entry or exit (must hitch a ride)
- **Plasmids** - direct transfer between hosts, no explicit extracellular stage
- **Viruses** - cell entry and exit mechanisms with **extracellular stage** and distinct **phenotypes**

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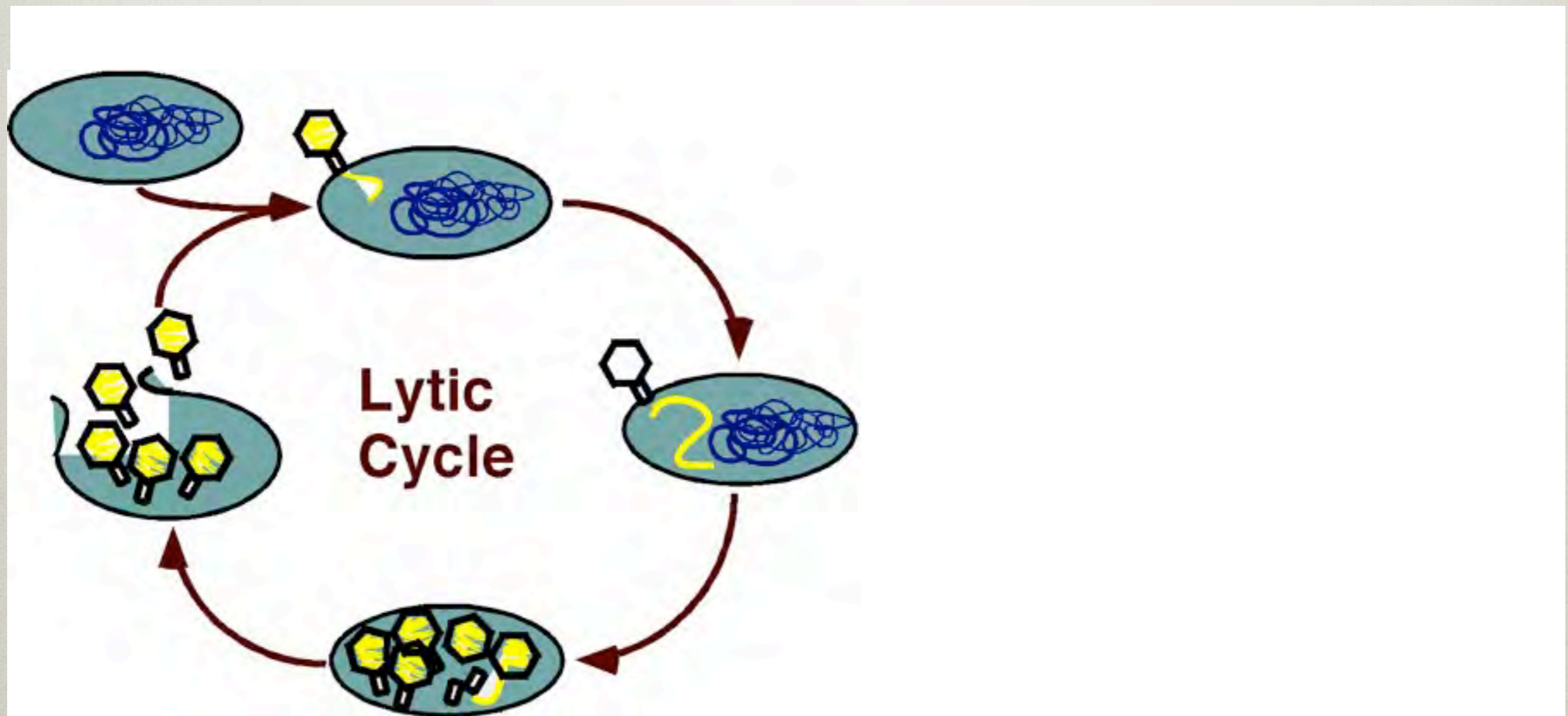
SO, ECOLOGICALLY, WHAT ARE VIRUSES?

- Predators?
- Pathogens?
- Symbionts?

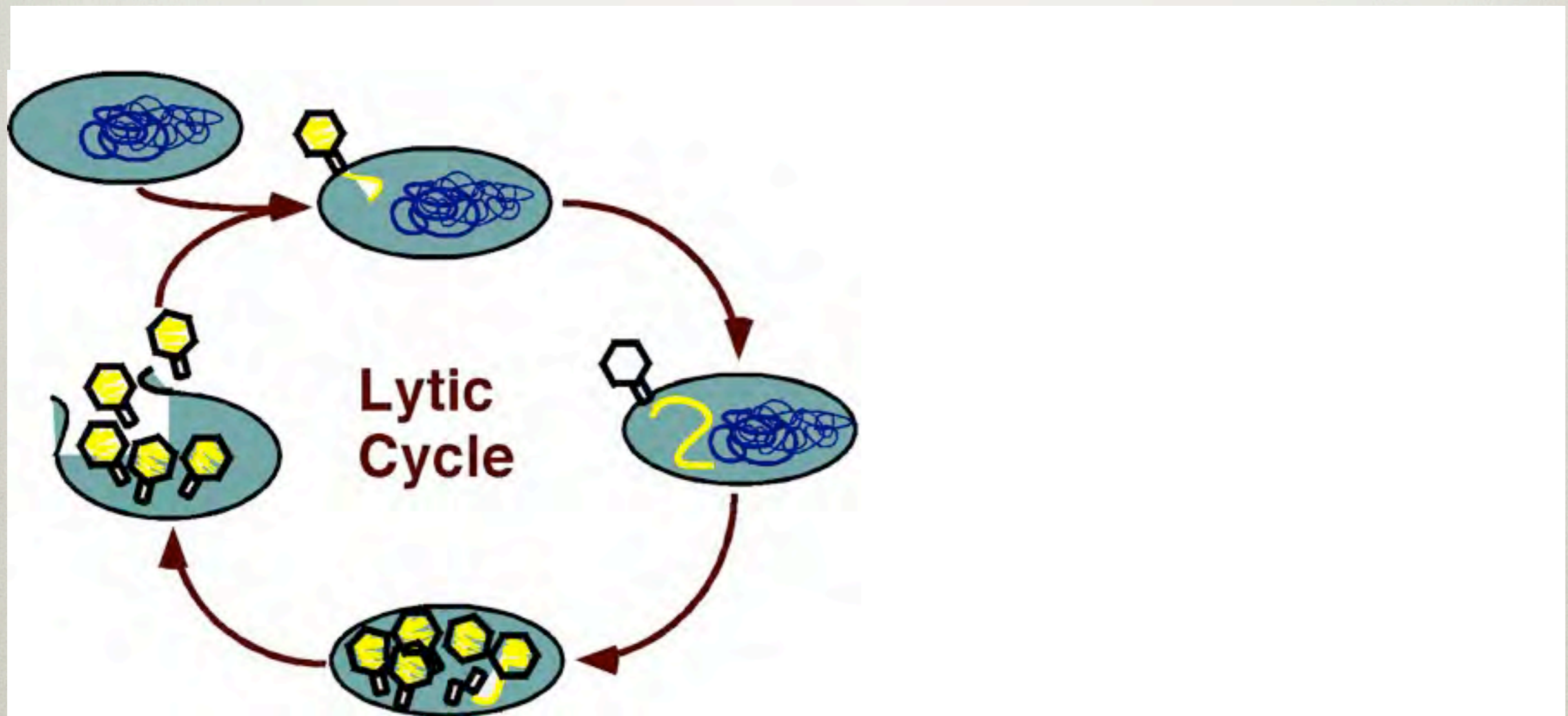
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MODES AND CONSEQUENCES OF INFECTION



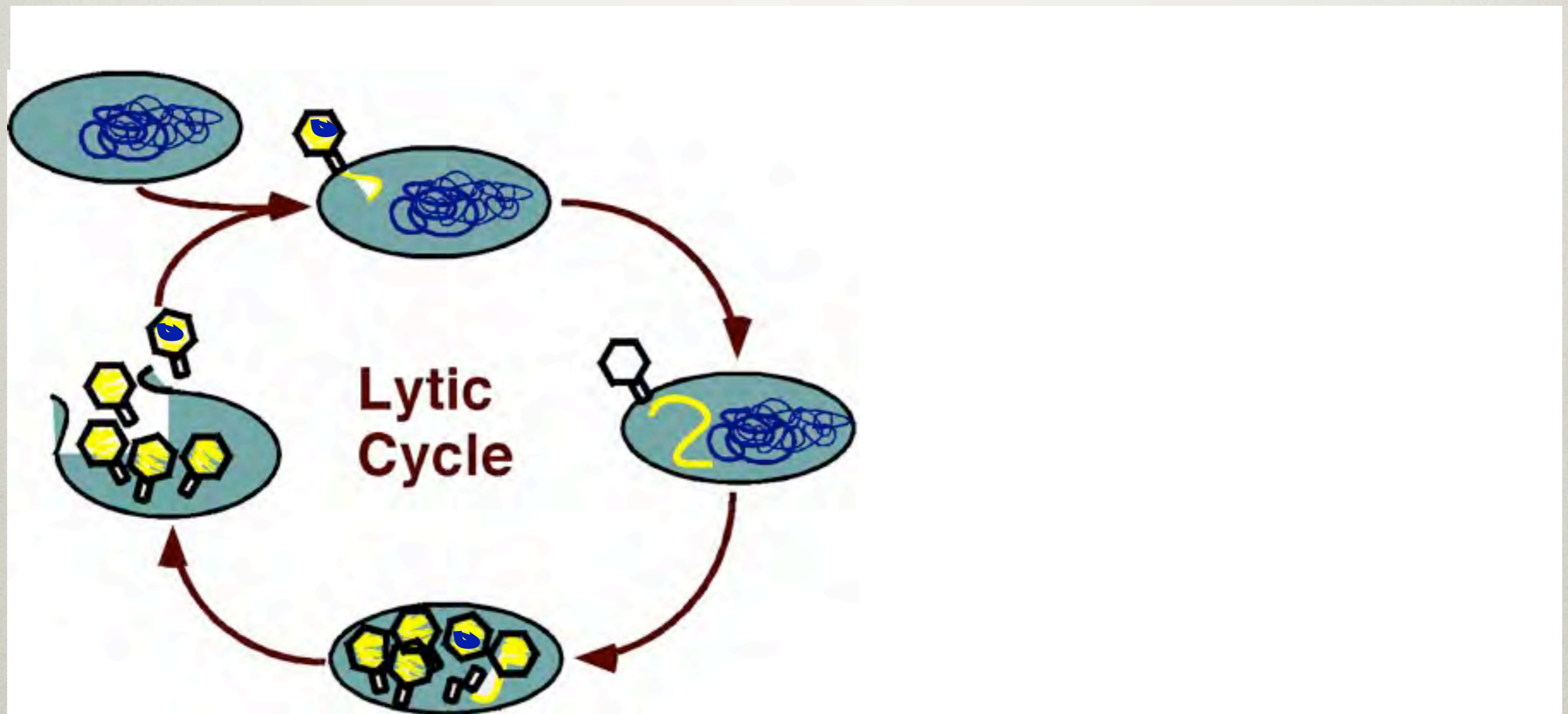
MODES AND CONSEQUENCES OF INFECTION



Parasitoid

MODES AND CONSEQUENCES OF INFECTION

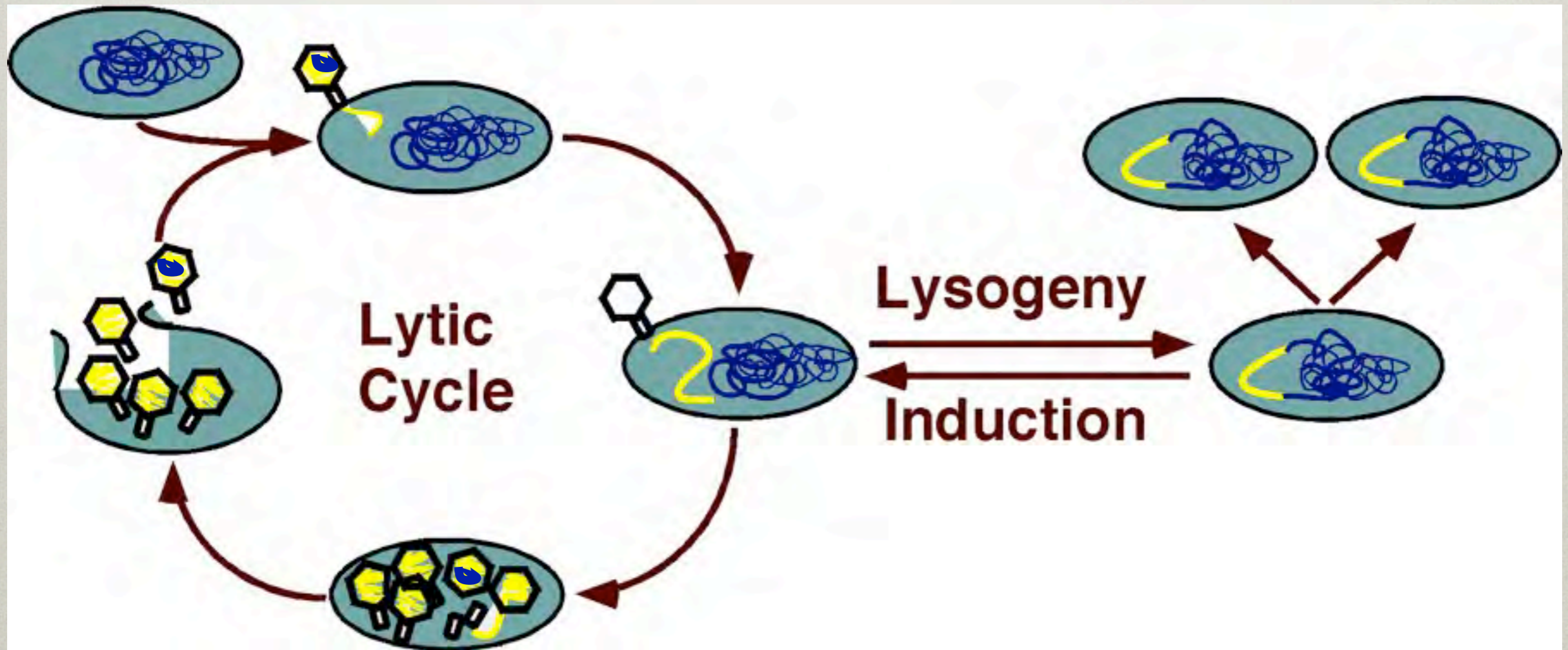
Transduction



Parasitoid

MODES AND CONSEQUENCES OF INFECTION

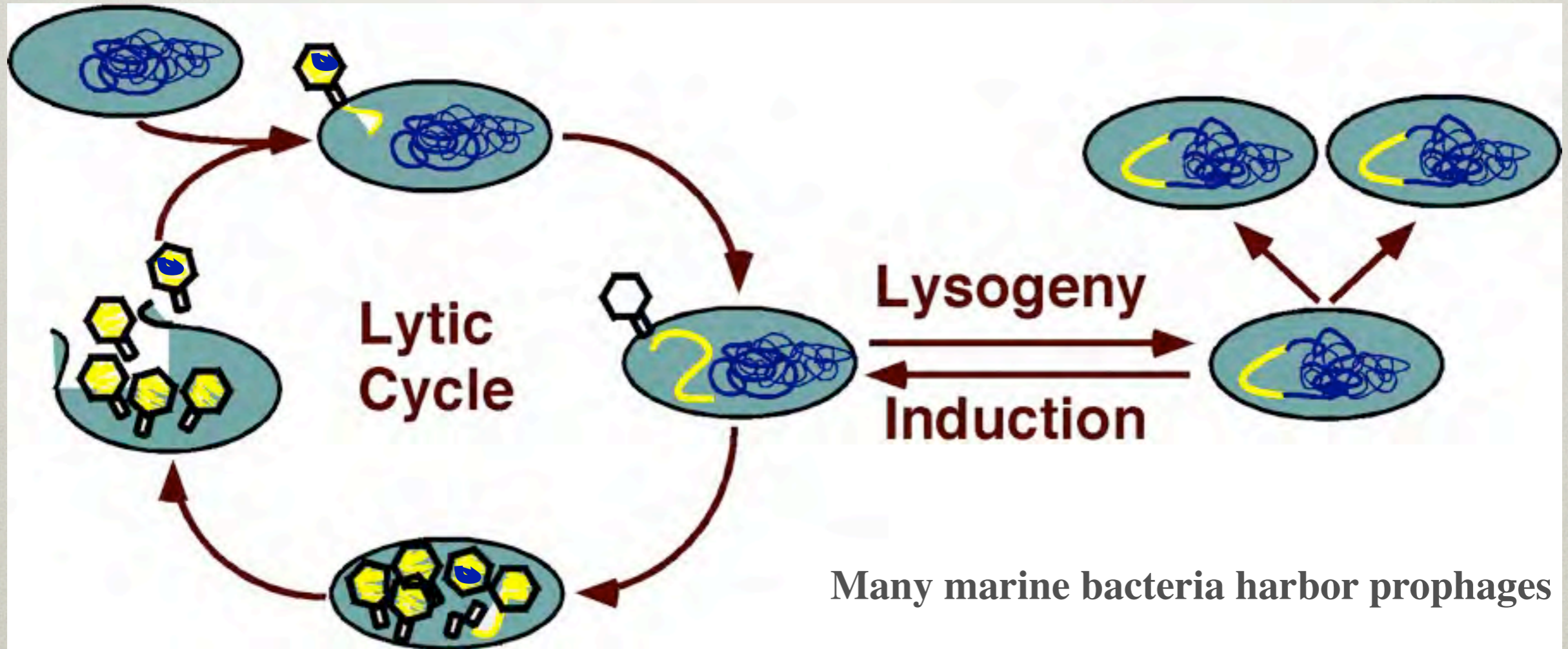
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MODES AND CONSEQUENCES OF INFECTION

Transduction



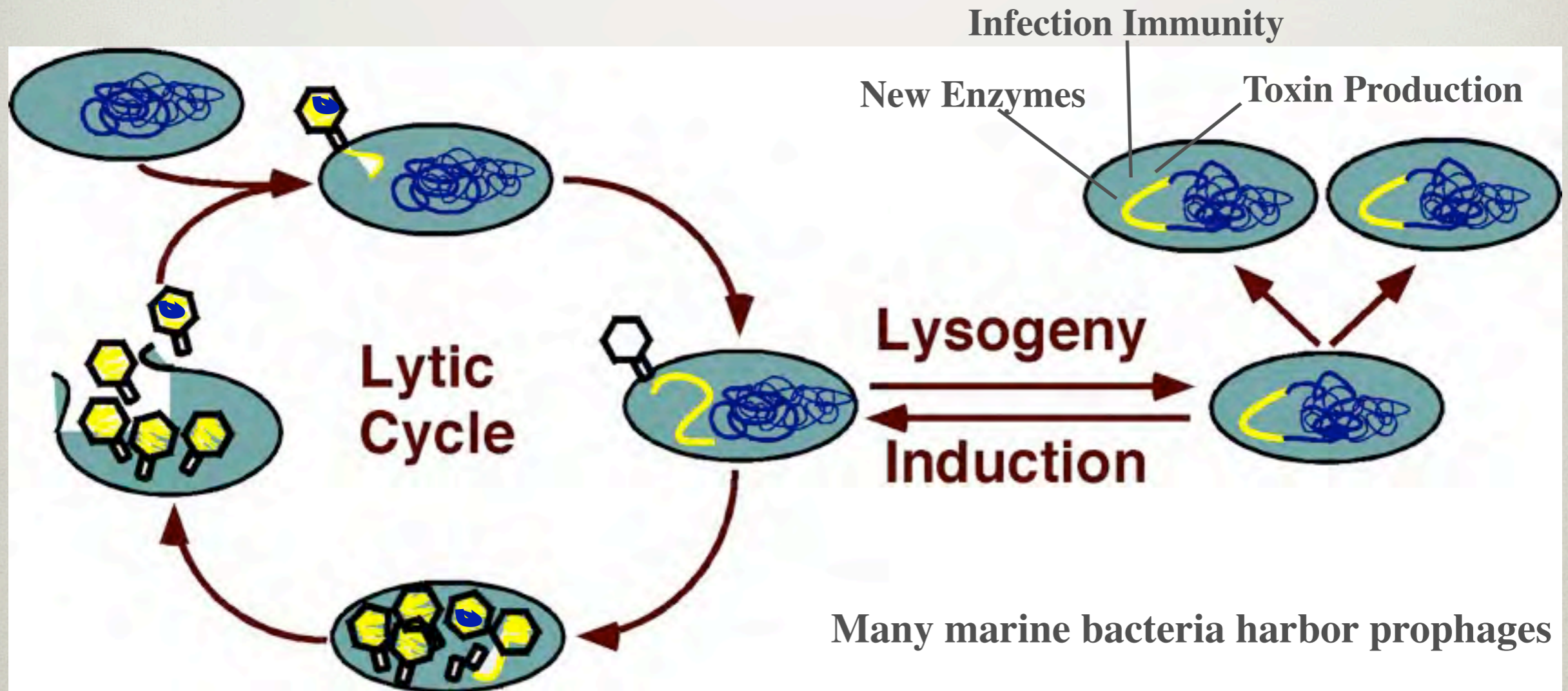
Many marine bacteria harbor prophages

Parasitoid

MODES AND CONSEQUENCES OF INFECTION

Transduction

Lysogenic Conversion

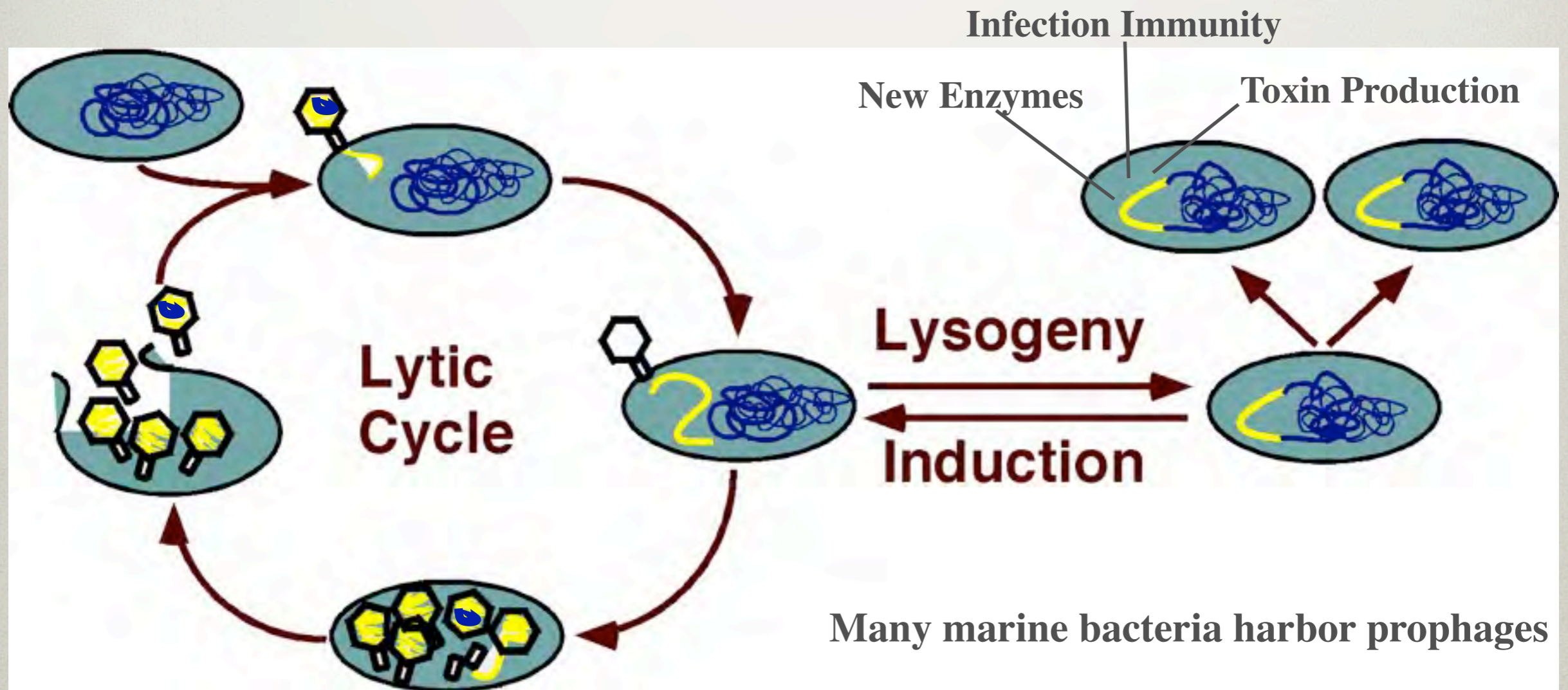


Parasitoid

MODES AND CONSEQUENCES OF INFECTION

Transduction

Lysogenic Conversion



Parasitoid

Mutualism

INFECTION
CAN BE
LETHAL
AND UGLY



Turtle Herpesvirus

INFECTION CAN BE BEAUTIFUL



Vase of Flowers (detail) -Jan van Huysum 1722

CAN VIRUSES MAKE US HUMAN?

Apparently, YES!



Image by Jane Ades, NHGRI

CAN VIRUSES MAKE US HUMAN?

essay by L.P. Villareal (2004)
Proc. Am. Phil. Soc.

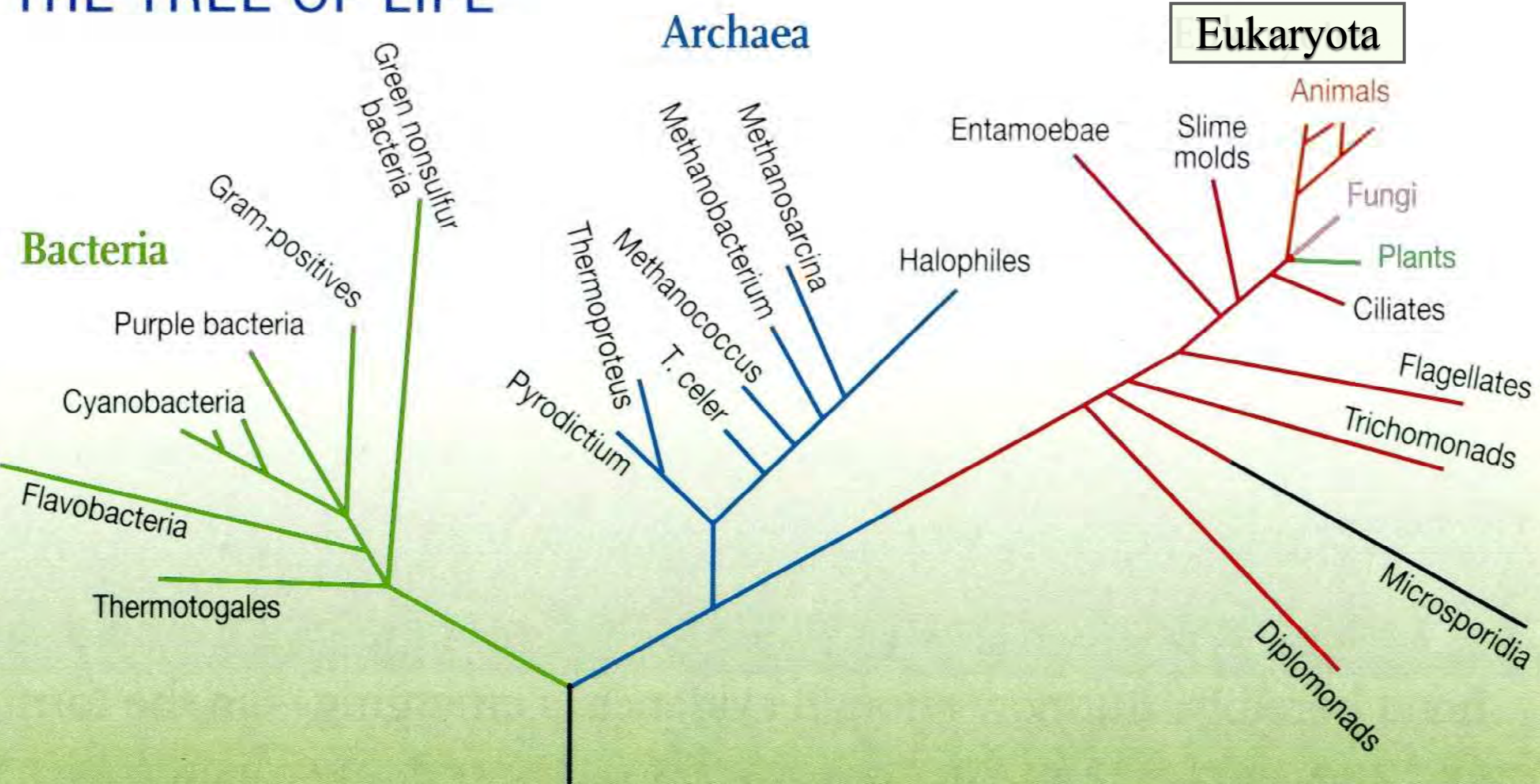
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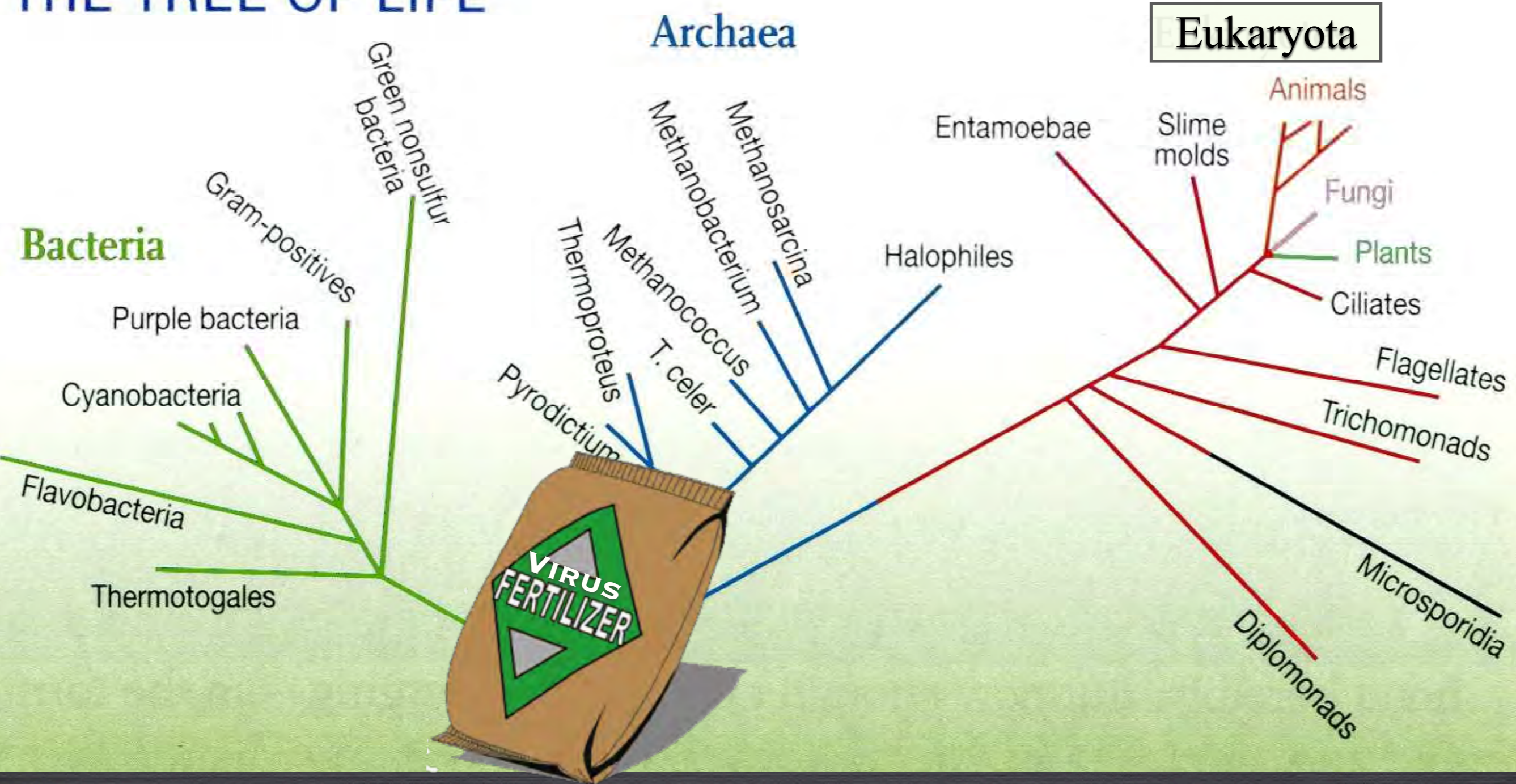
WHERE ARE THE VIRUSES?

THE TREE OF LIFE



WHERE ARE THE VIRUSES?

THE TREE OF LIFE

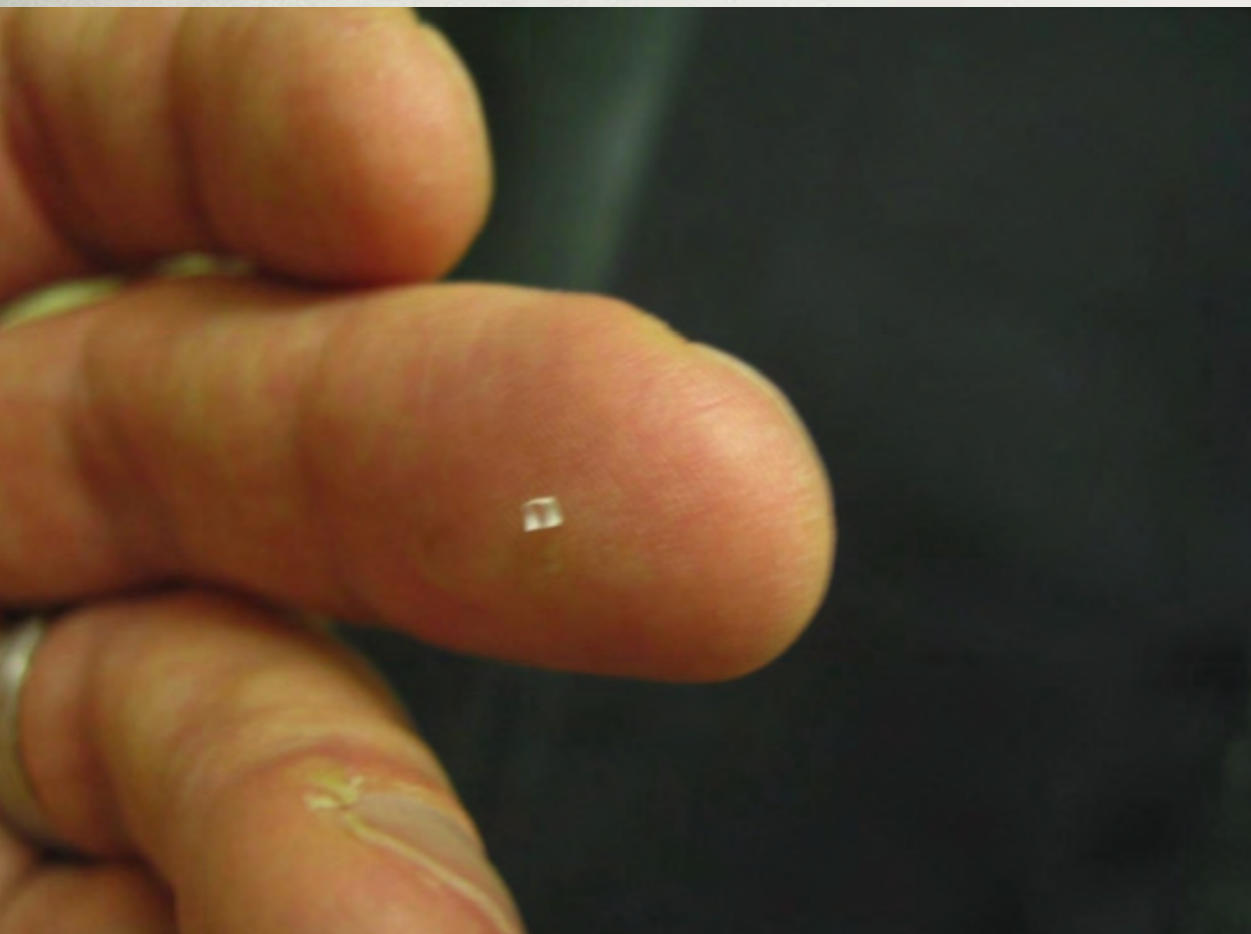


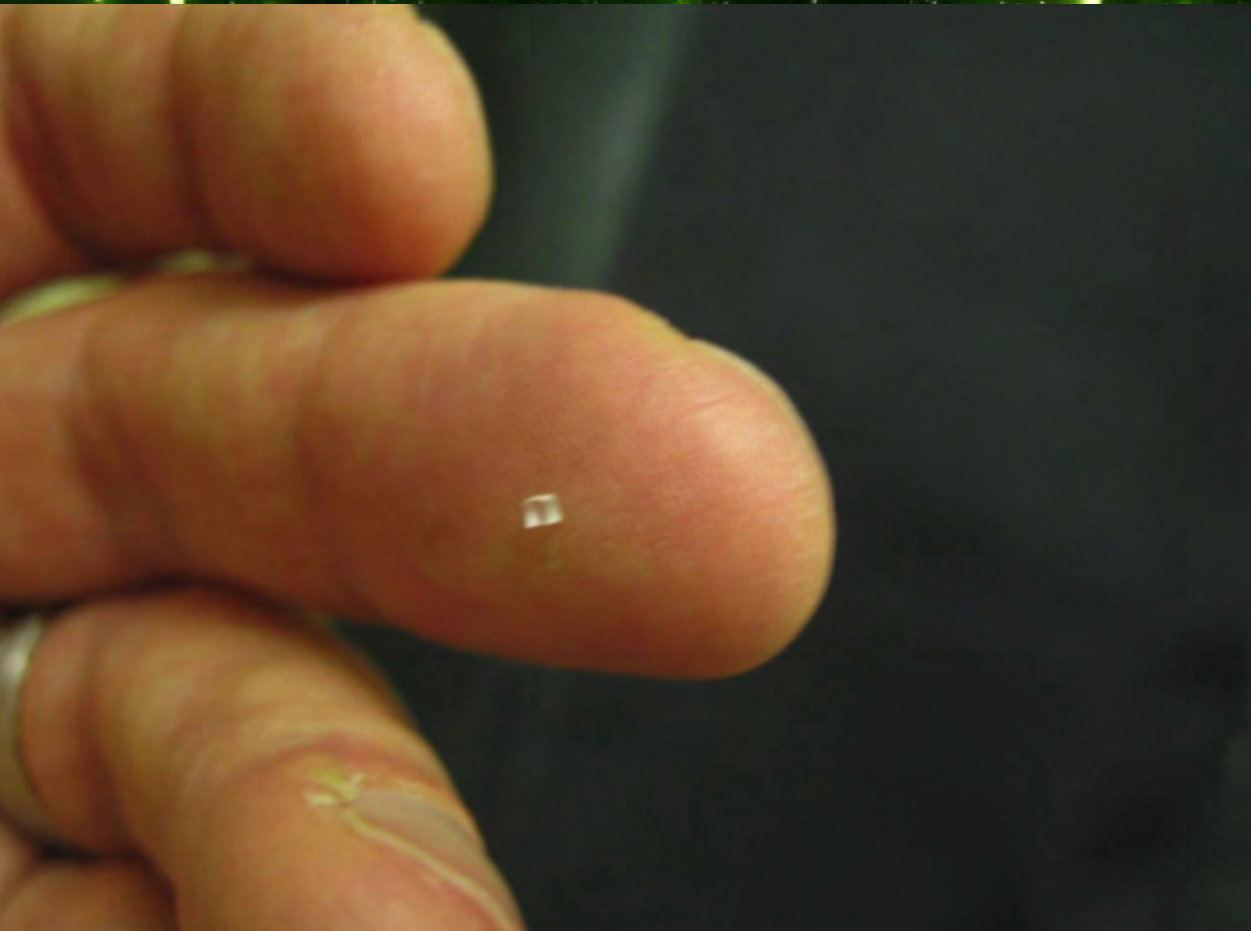
VIRUSES RULE THE SEA!!

- They are abundant
- Every living thing is subject to viral infections (from bacteria to whales)
- They affect biogeochemical cycles
- They drive evolution

VIRUSES DOMINATE THE PLANKTON

VIRUSES DOMINATE THE PLANKTON





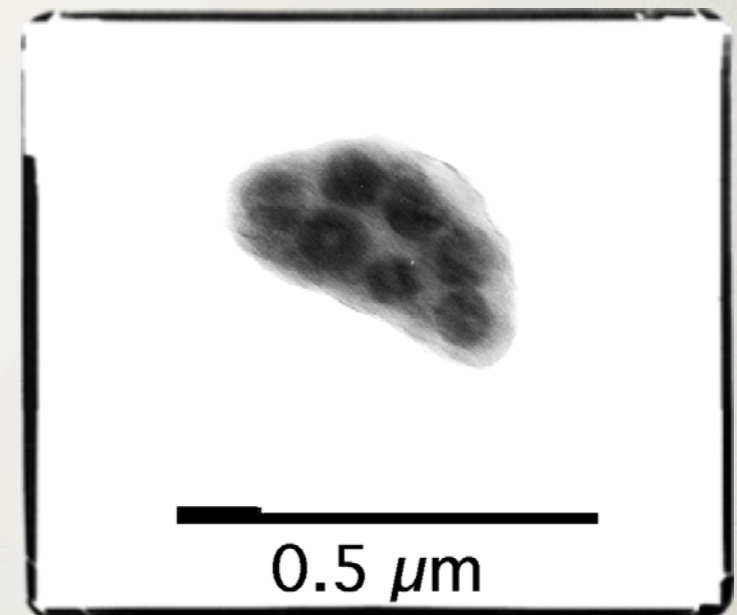
Studying Viral Diversity in the Sea

THE MOTIVATION

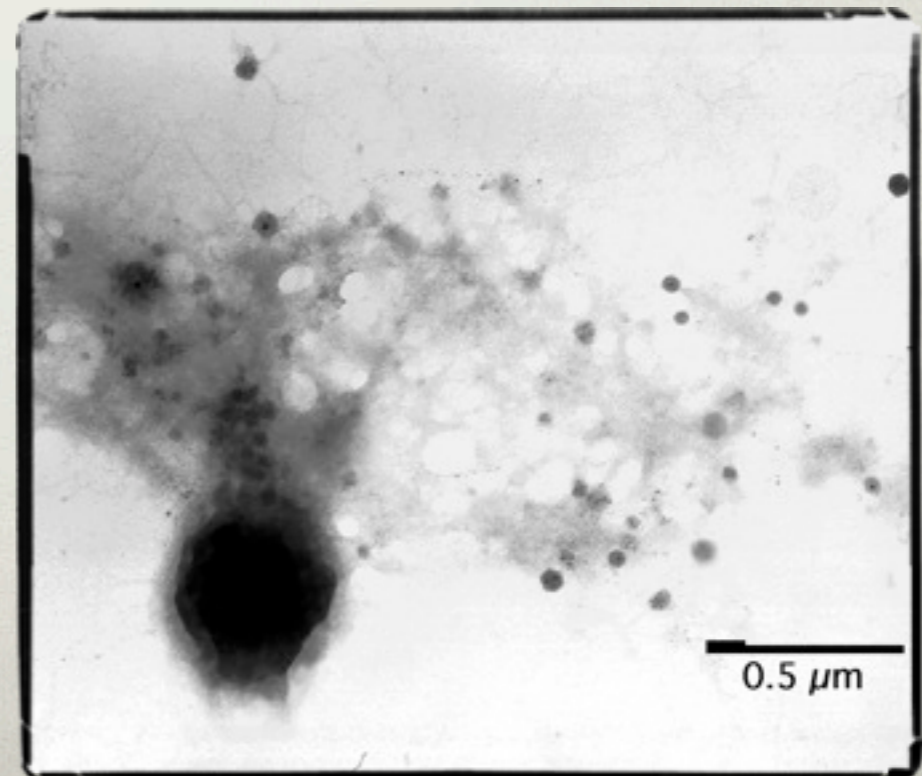
Viruses are relatively host specific

- Many viruses infect only one species or even only one strain within a species
- Some viruses have broad host range
- Occasionally, viruses can mutate and “jump” hosts

VIRUSES KILL PLANKTON

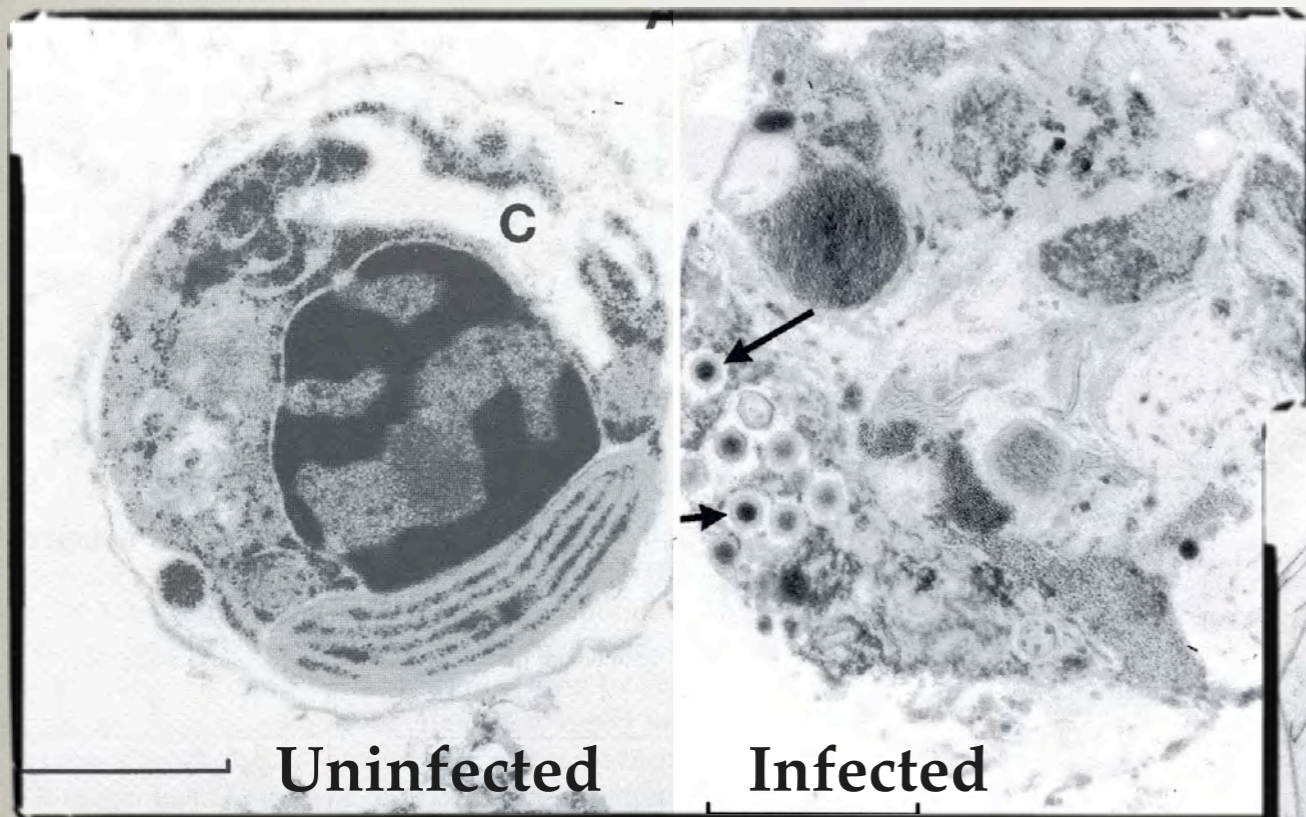


Infections of Bacteria

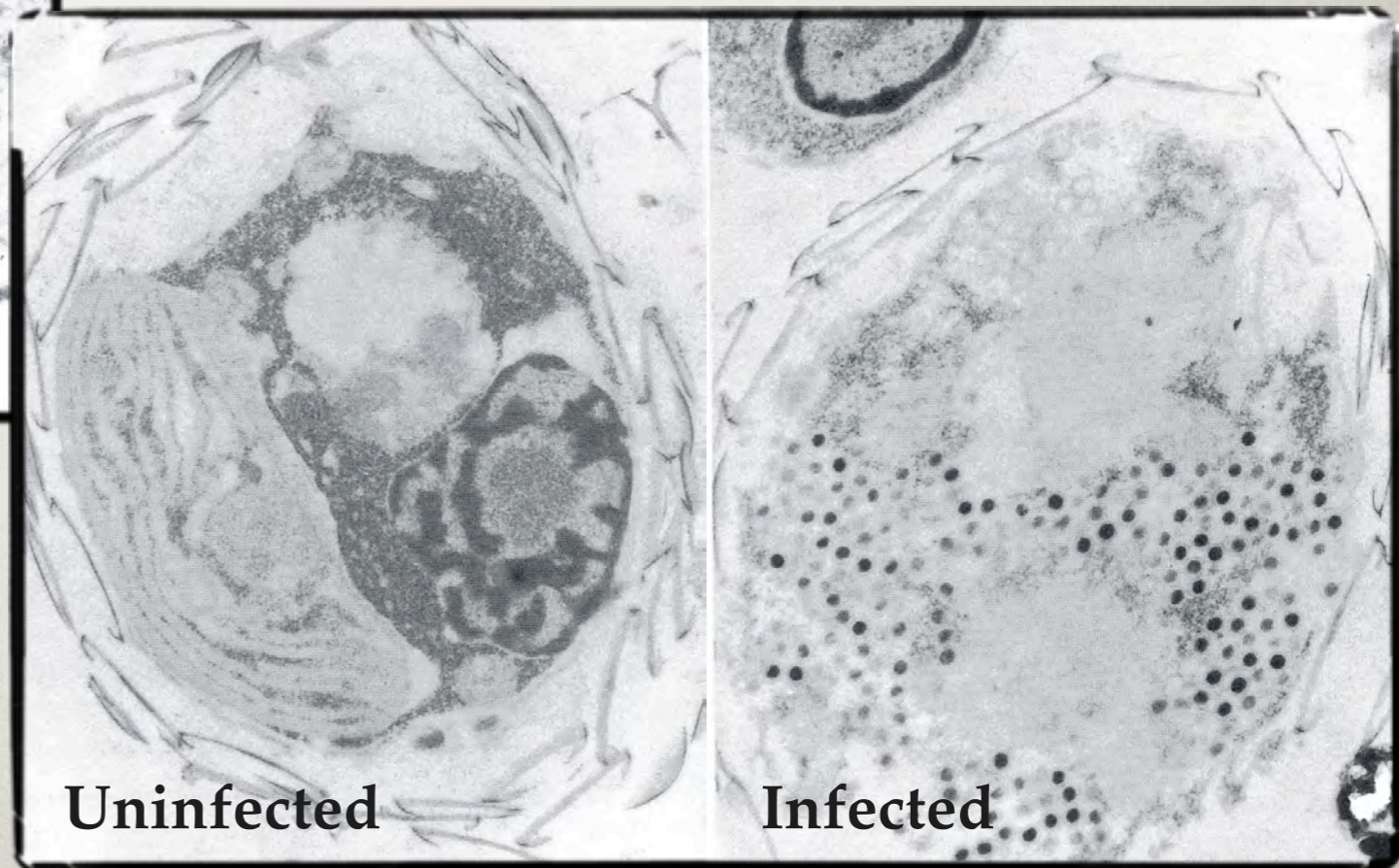


VIRUSES KILL PLANKTON

Infections of Protists



E. huxleyi



Chrysochromulina spp.

Studying Viral Diversity in the Sea

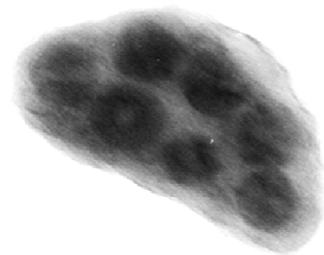
THE MOTIVATION

- Viruses make things HAPPEN!:
 - Mortality
 - Horizontal Gene Transfer
 - Lysogenic Conversion

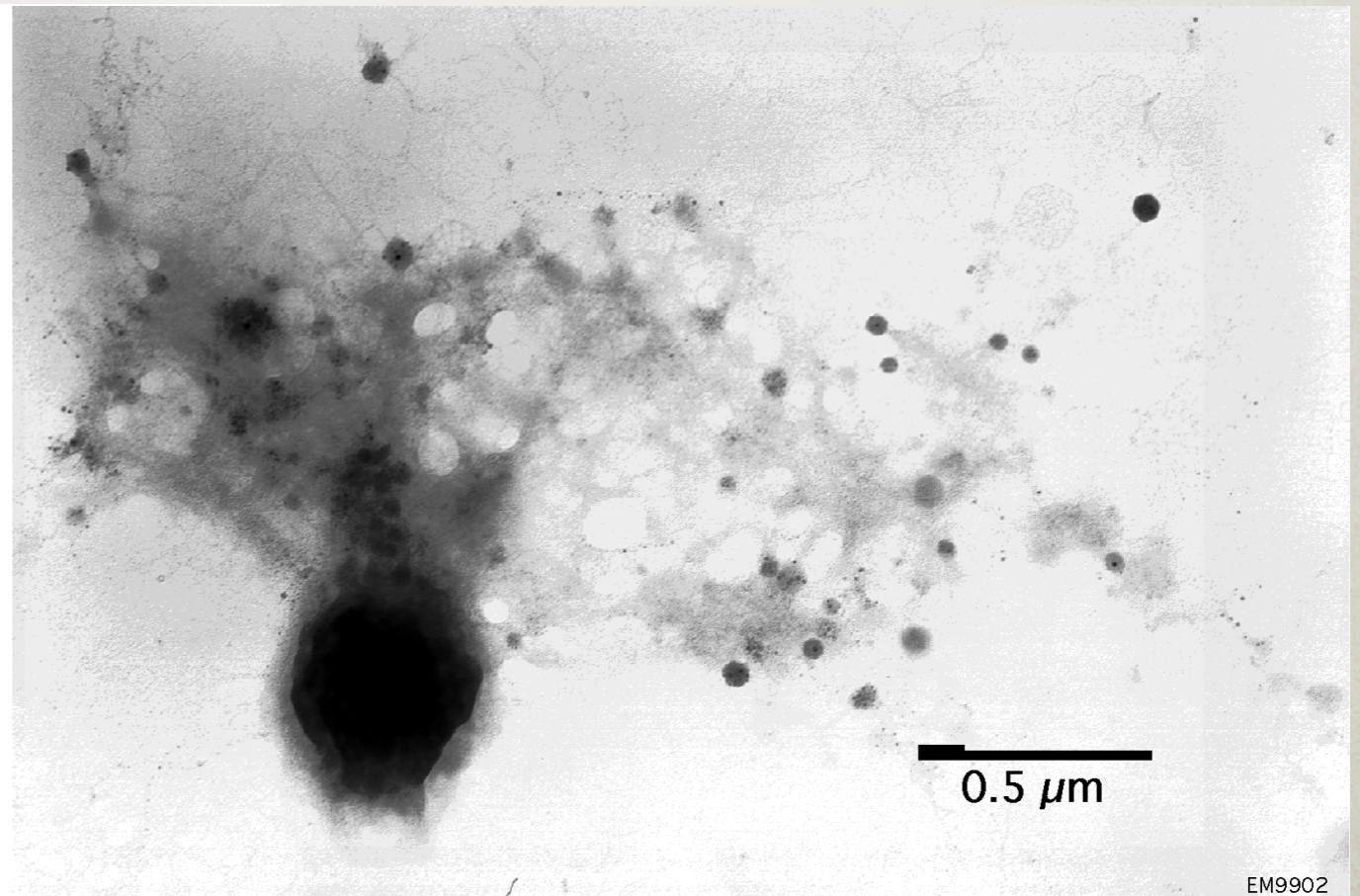
Studying Viral Diversity in the Sea

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0.5 μm



0.5 μm

EM9902

Studying Viral Diversity in the Sea

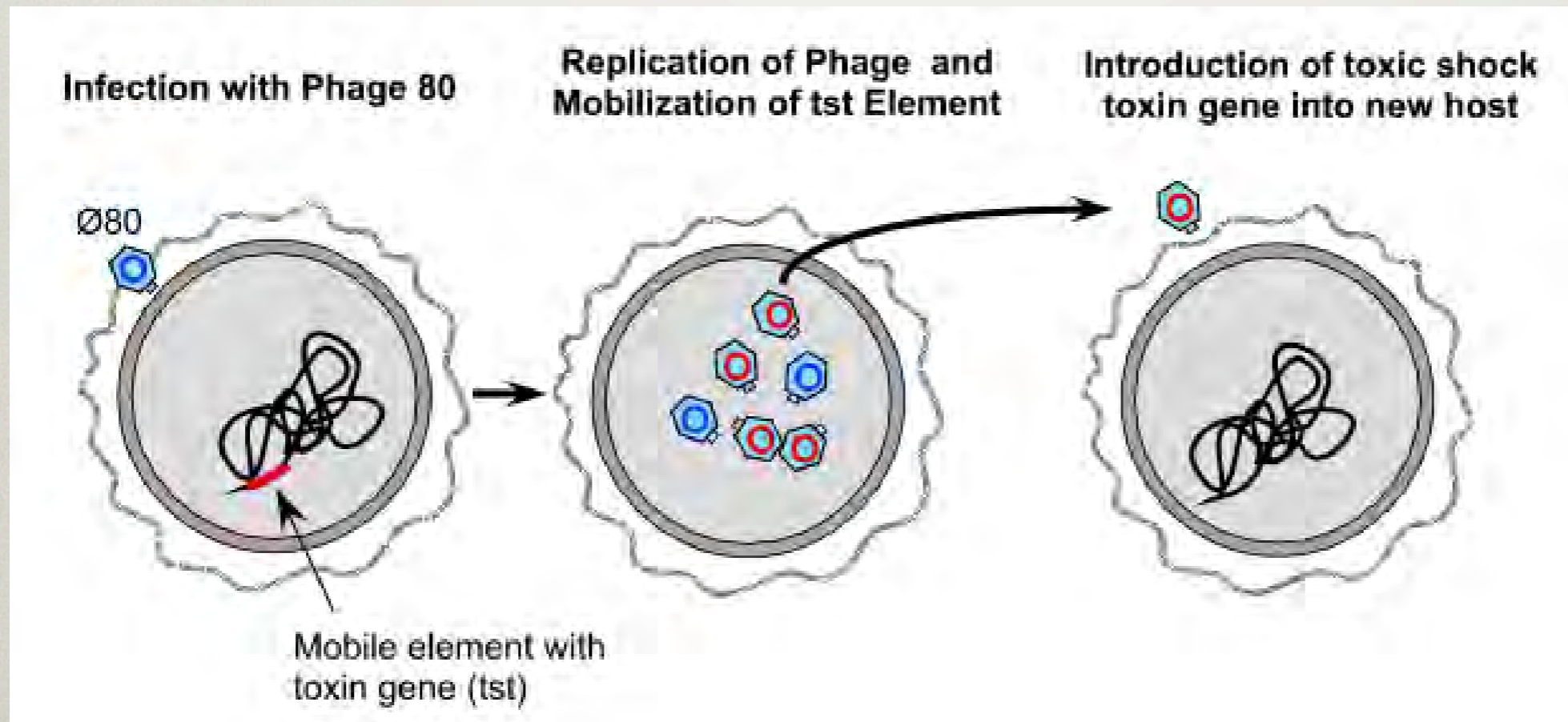
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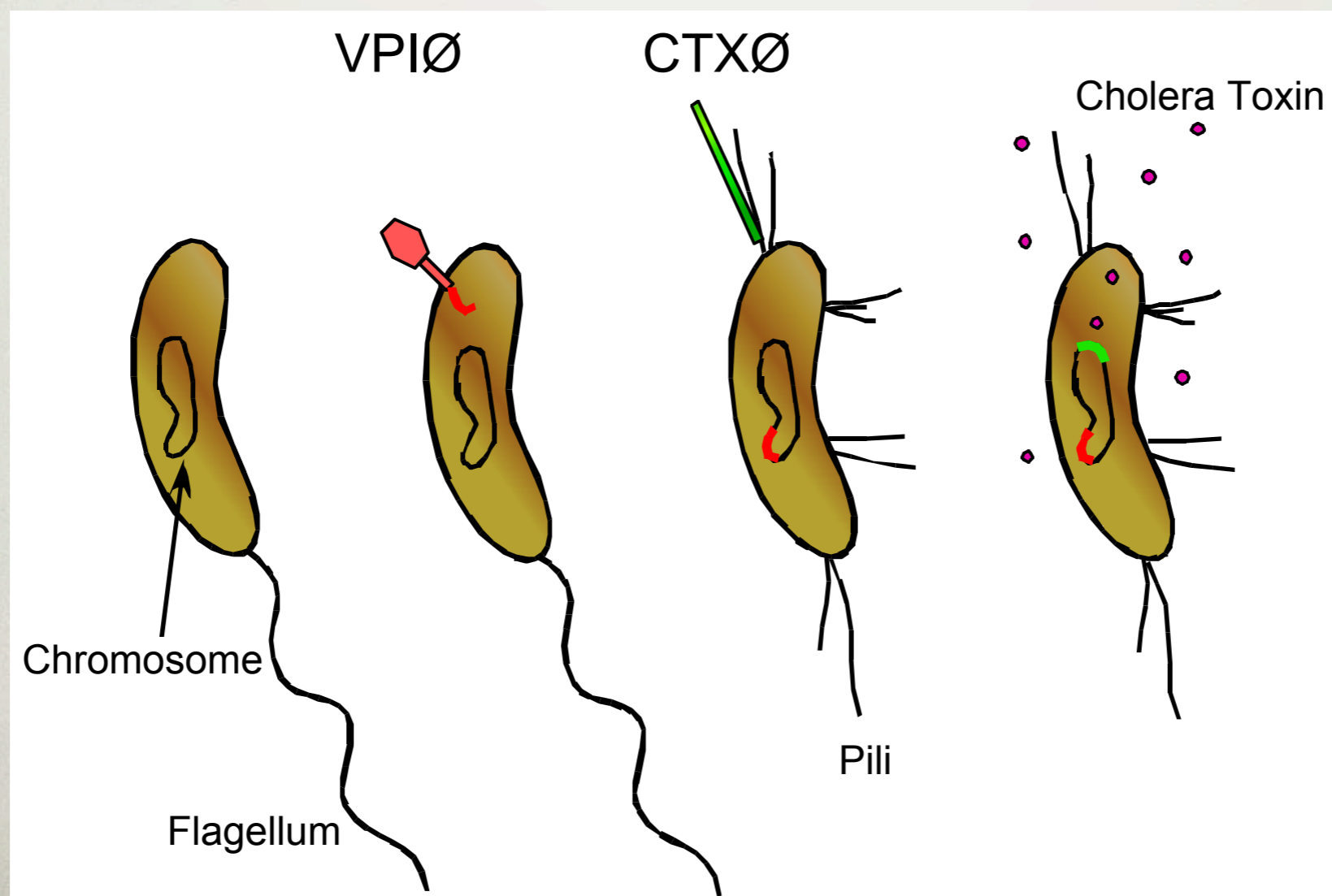
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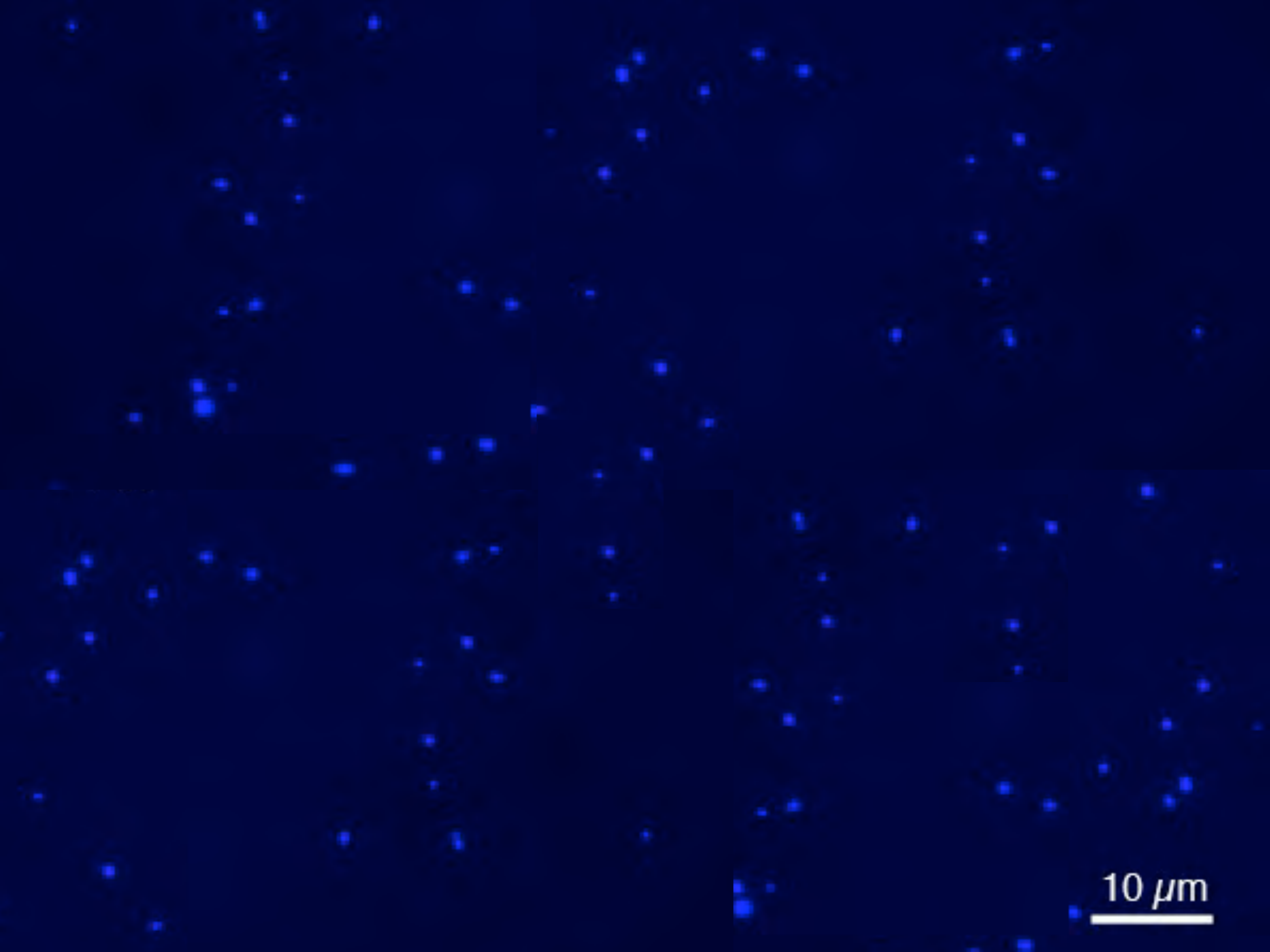
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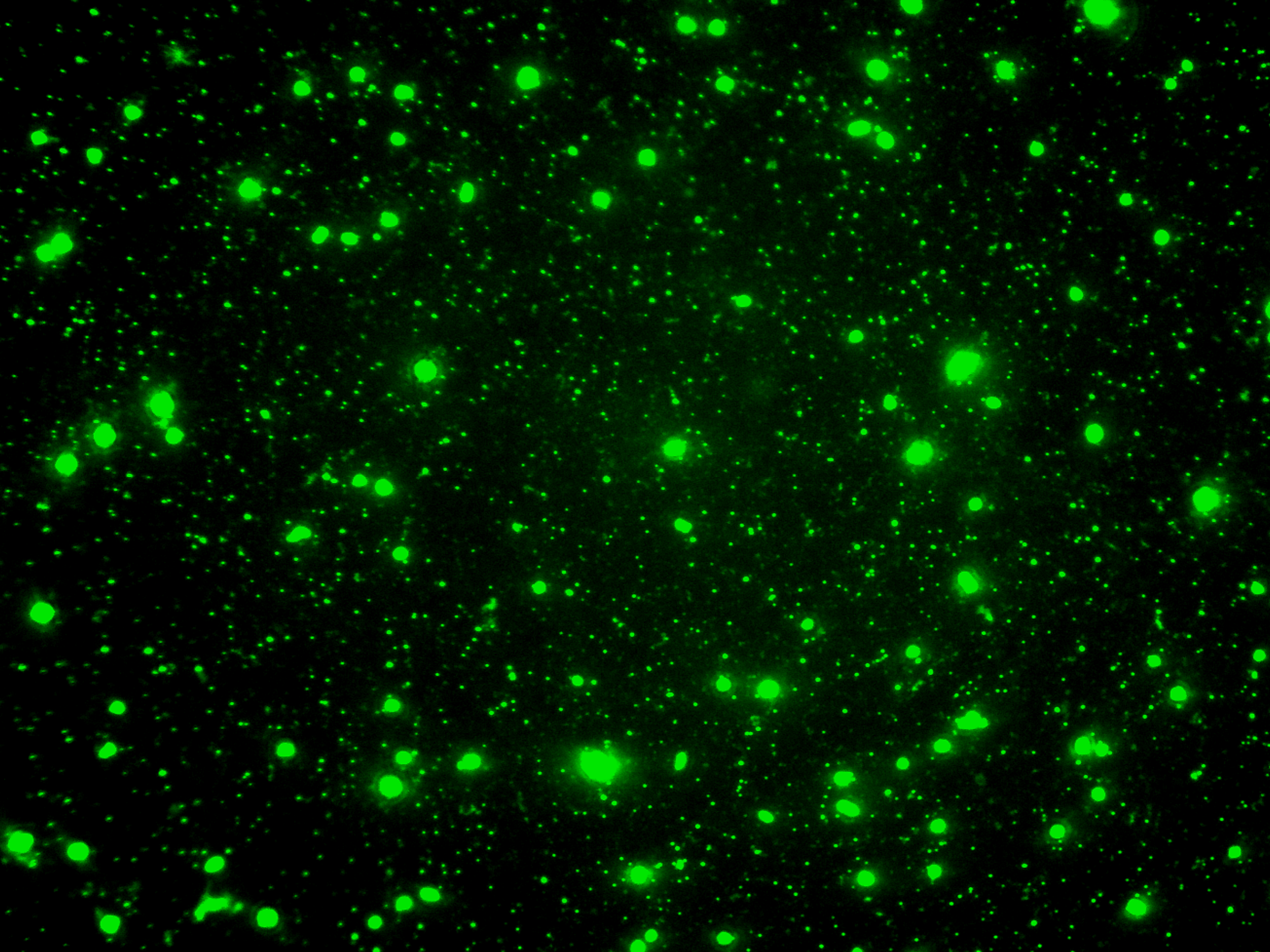
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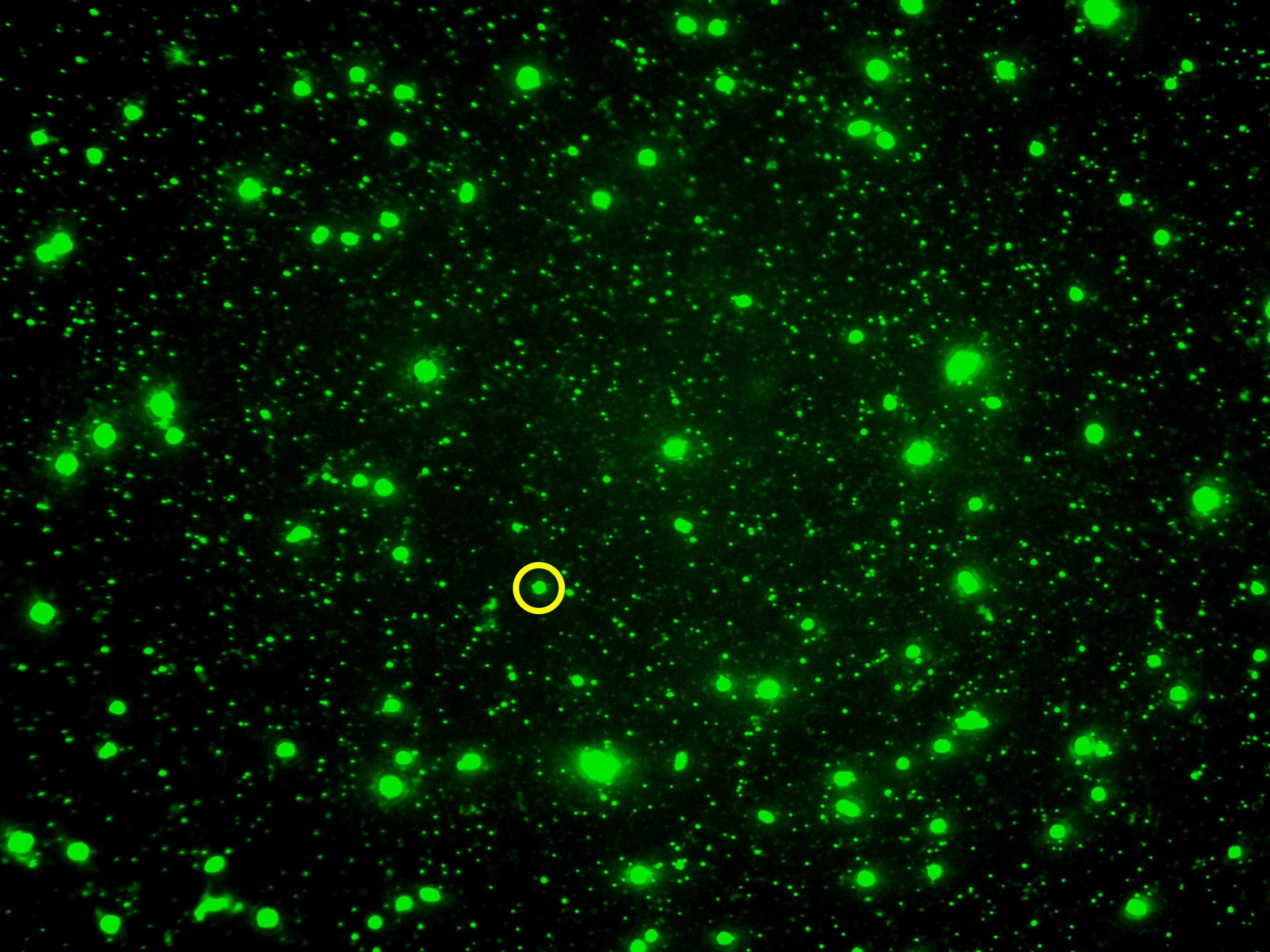
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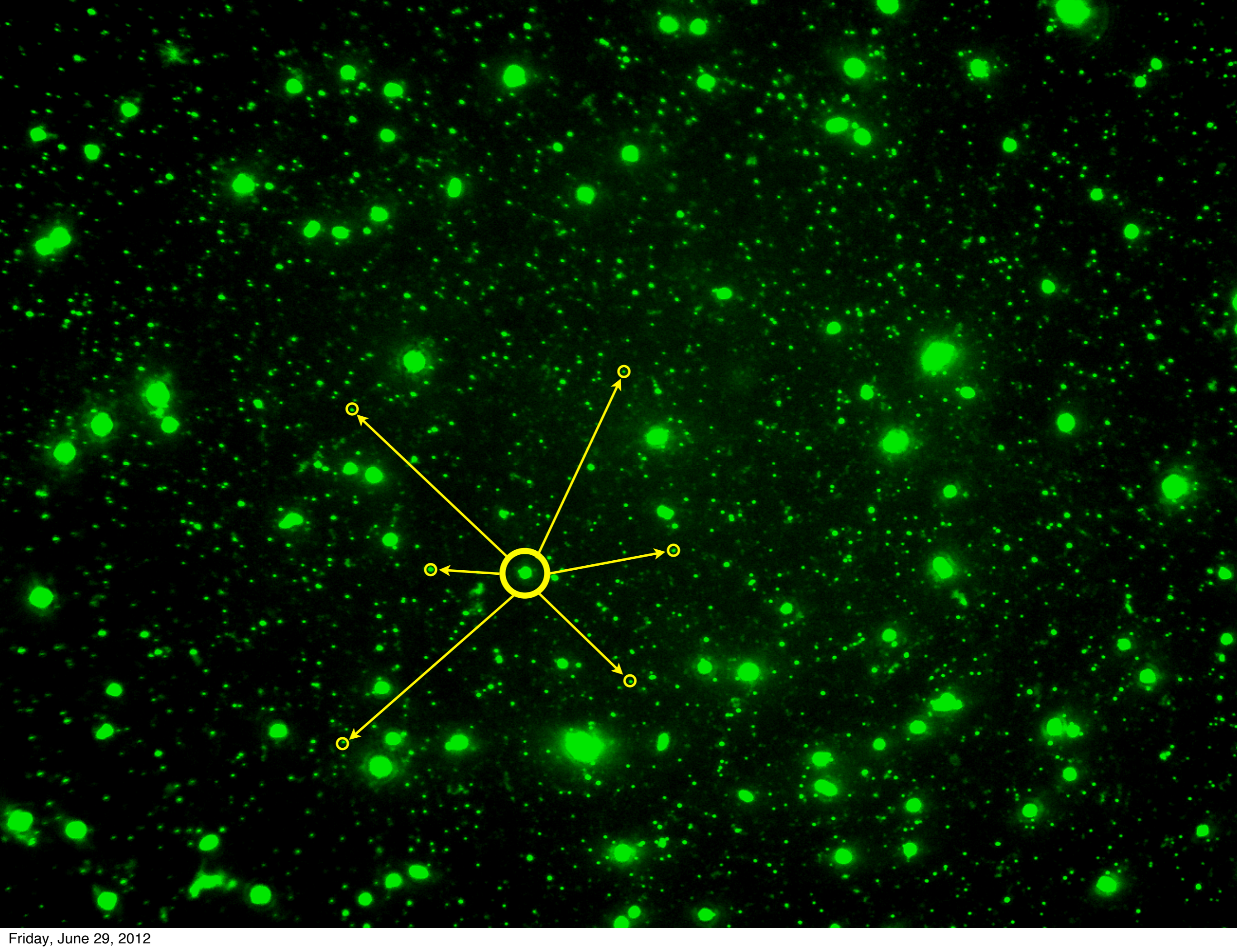


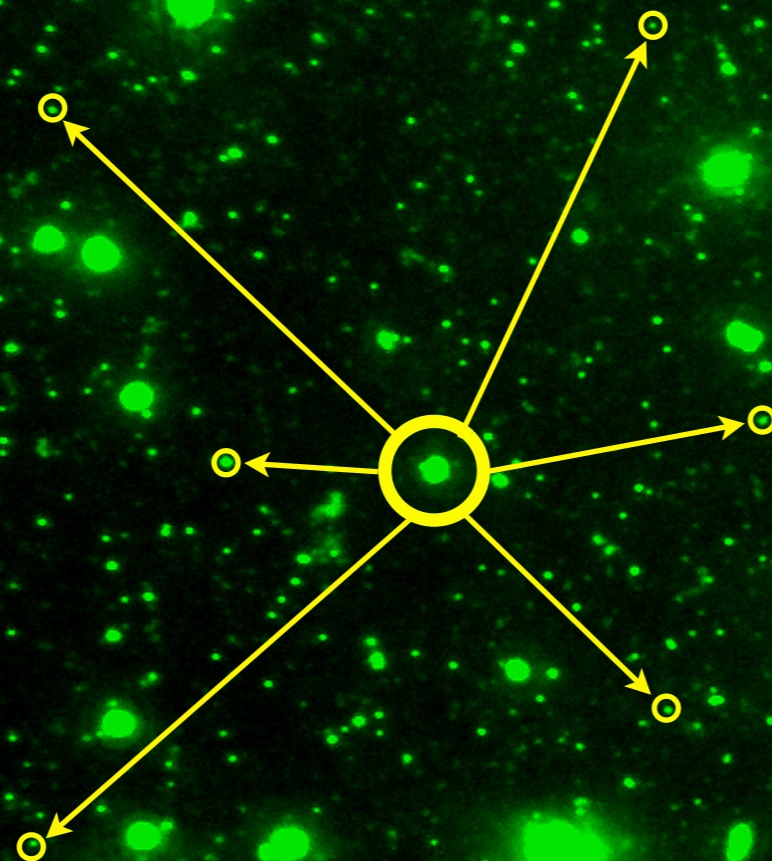


10 μm



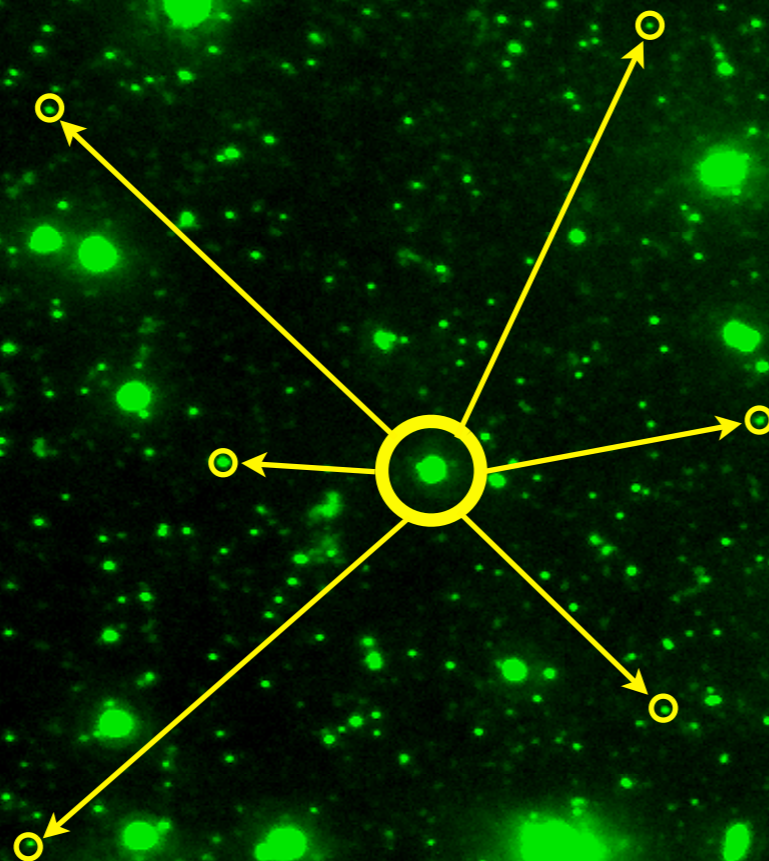






**> 1 BILLION INFECTIONS PER DAY
IN EACH CUBIC METER**

TO UNDERSTAND THE
ECOLOGY OF THE
PLANKTON
NEED TO KNOW THE
“EXTENDED GENOTYPE”



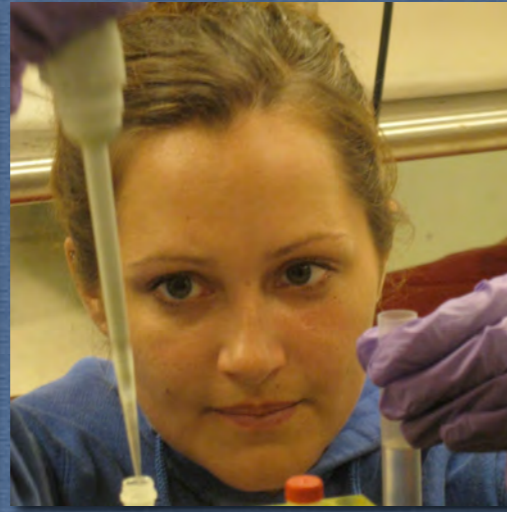
> 1 BILLION INFECTIONS PER DAY
IN EACH CUBIC METER

MARINE VIRAL ECOLOGY LAB (MARVEL)

Marine Virus Team



Alex Culley



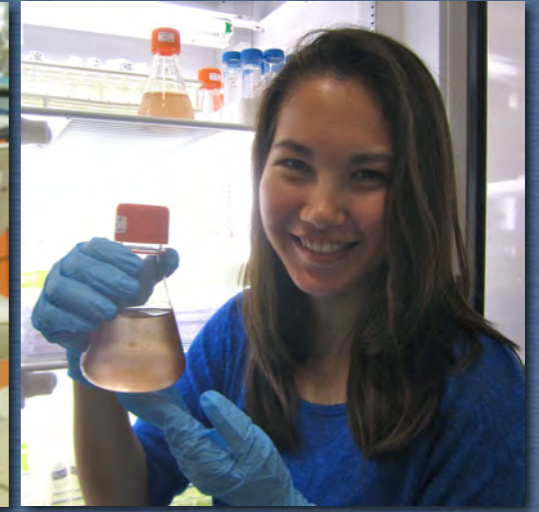
Jackie Mueller



Chris Schvarcz



Gordon Walker



Teresa Porter

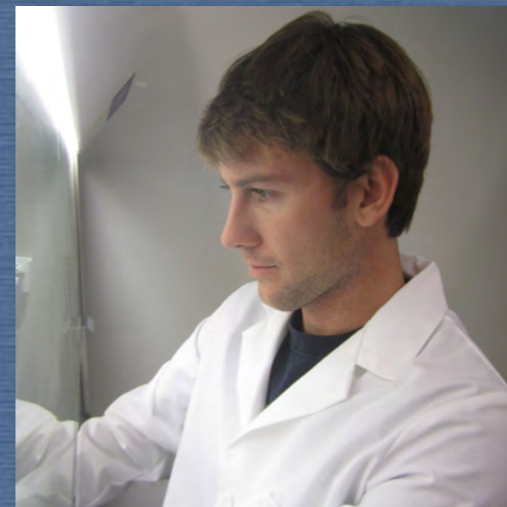
Vibrio Ecology Team



Olivia Nigro



La'Toya James



Shaun Giancaterino

MARVEL PROJECTS

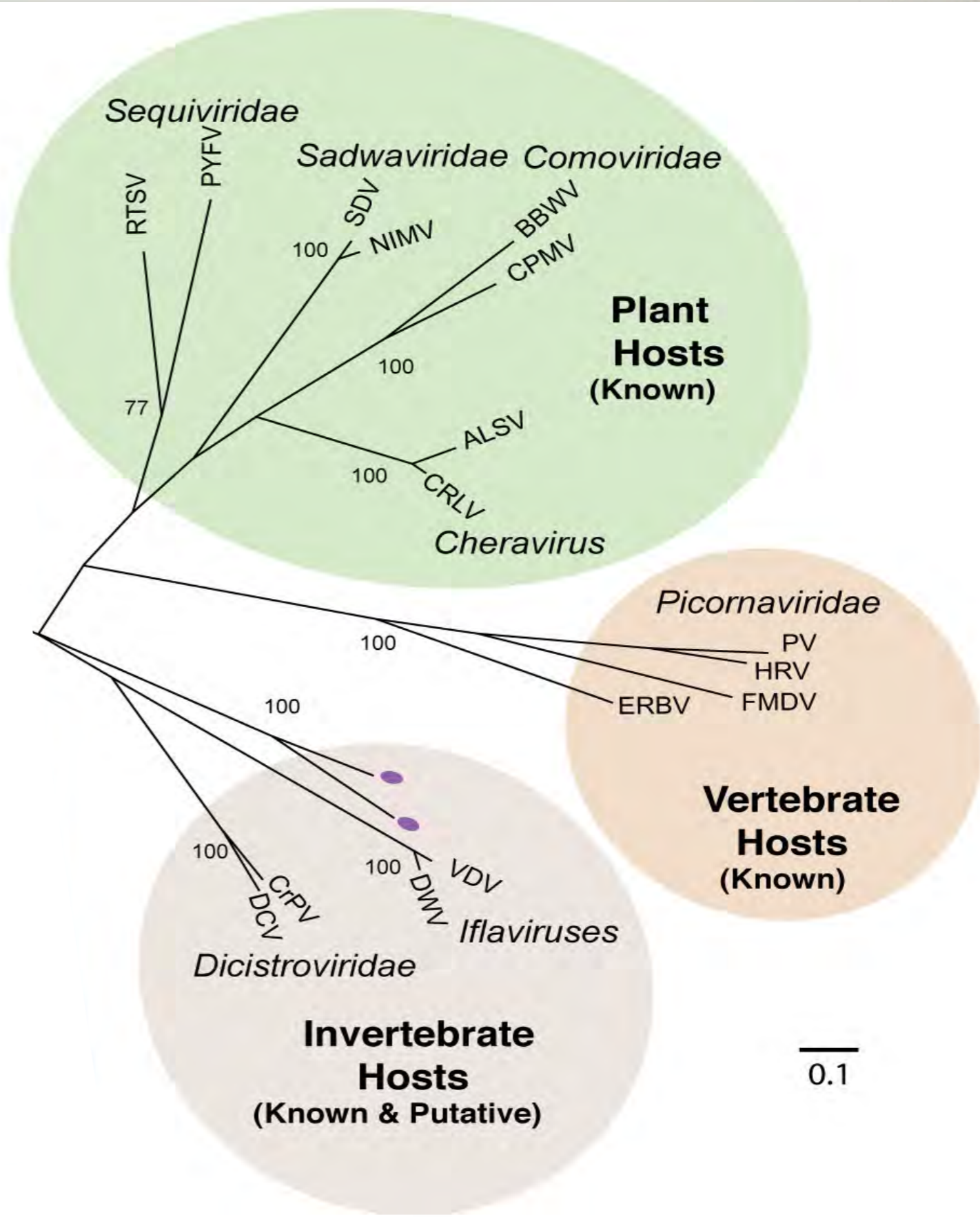
(selected)

- RNA viruses - rising stars
- New host-virus systems - a growing appreciation
- Physical Fractionation - a new dimension

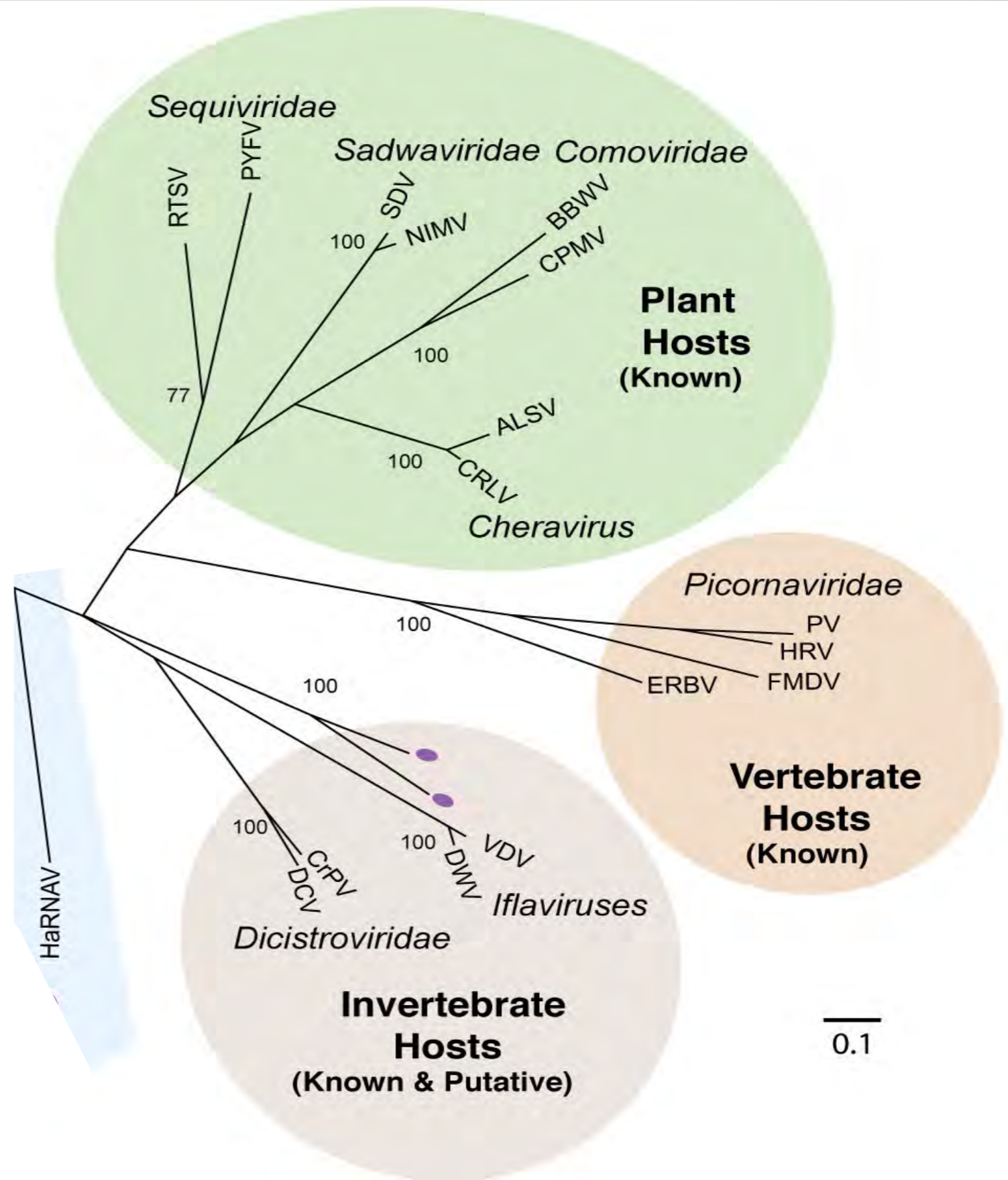
WHAT ABOUT RNA VIRUSES?

MOST WORK HAS BEEN DONE ON DNA-CONTAINING VIRUSES

- DNA easier to work with
- RNA viruses were assumed to be rare
 - assume most are bacteriophages
 - most phages contain DNA
- Metagenomic surveys seem to confirm this (95% of recognizable sequences are phage-like)



Tree of the known Picornavirales based on RdRP



Tree of the known Picornavirales based on RdRP

FIND CONSERVED REGIONS TO DESIGN PRIMERS

PCV-1	ERHLAAVLNYSMPNVPASQLSQSLYRQAE SAKNGFIISLPRVKAFDVLTEMDOVHF KSSS	62
PPV	ERHMEAL LNYGTRNIPVDNVDYNLYQG CIDTVKNGLRSLPRVKAFDVLTELNLVSYKSSIT	128
BCV-3	EGHMQA I LAY AQP DTPRETFDQ TIWDQAYTAVQNELRSLPKARAFDVNTELDKVPYEQSS	128
FCCV	QAHIDSIMQYDRPKLPQP - - TNAAWNTTQHVRTQFARMKQVQ T LSYL - QLDOVKWVRSS	118
RSCV	DCHVDAILAYRRQKLPEP - - TD D VWNQTKQHTLQLFRRFPKITPI SYK - SFDEVKWISSS	118
	: * : : : * : : : : : : : : : : : : : : : : * : *	

II

PCV-1	SAGYNYTGRKGLIGDENHSRAISIAKAVLWSAIKDDGEGIEHVIRTSVPDVGYTRTQLTD	122
PPV	AAGYNYMGA KGPFDGYNHKQAIRRARATVGDVSDNGIEGLRRAITTA VPDVGYTRTQLTD	188
BCV-3	SAGYGYRSHKGPFGGETHMRAISRVPKPTLMTAIRPDEEGPEYTI LESVPDI GYTRTQLAD	188
FCCV	AAGYGYVGRKS --DNDNYFRAR - KTAFTIAEKLNHDRDYGPLALEDSTPDI AFTRTQLCQ	175
RSCV	SAGYGYVGHKG --DGDNYLKAR - RTAVTIAEKLDHDRNYAPEA INQSTPDVAFTRTQLSQ	175
	: *** * : * : : : * : : : : : : : : : : * : : * : * : * : *	

PCV-1	LLEKTKVRQVWGRAFHYYLLEGLVA YPFIQTVM SHKTFI HAGQDPLISVPRLLSDVALN -	181
PPV	LTEKTKIRNVWGRAFHYYLIEGT SADPLIRMF SKTKSFYHIGRDPDLSVPDVLSETAGK -	247
BCV-3	LREKTKVRGVWGRAFHYYLIEGTAARPLLENFM LGTIFMHIGSDPQLSVPRILHQMREG	248
FCCV	IKVVKRIRNVWGEAFHYV LLEGLFADPIIQHFIRNKSFYF IGEDPLLAVPRIVEKILSE -	234
RSCV	VKVKTKVRNVWGEAFHYV LLEGLFADPLINFFSNEESFYFIGNPLLSVPTLIEEIFKS -	234
	: * * : * * * * * : * : * : * : * : * : * : * : * : * : *	

III

IV

PCV-1	CKWIYSLDWSQF DATVSRFEIHA AFDI IKS YVD FPNYETEQAF EITRQLFIHKKVAAPDG	241
PPV	ARWLYAIDWKQF DATVSRFEINA AFDIIMDLIE FPNYPTYVAFELSRQLFIHKKIAAPDG	307
BCV-3	SKWLYALDWS SFDSSVTRFEINCAFNLLKERIE FPNTEELAFELSRILFHKKLAAPDG	308
FCCV	QDYVYMF DWSGF DASVQEWEIFAFS LLESILIFPS SVESYIWHFIE LFIYRKIAAPNG	294
RSCV	KDYVYAF DWSGF DASVQEWEIFAQ CLES QLI FPSNVEAQIWRFI VE LFIYRKIAAPNG	294
	: : * : * * : * : * : * : * : * : * : * : * : * : * : * : * : *	

V

PCV-1	YIYESHKGIPSGSYTSLVGSII NYLRINYLWRLITGHPPQQCHTLGDDSLVG	294
PPV	YIYWSHKGIPSGSYFTSII GSIINRLRIEYLWRKITGHGPLACYTQGGDDSLSC	360
BCV-3	NIYMIHKGIPSGSYTSLVGSVVNR LRIEYIWRVIFSRSPHRCYTQGGDDSLIG	361
FCCV	KVYLKTLGIPSGSCFTNII GSI VNYVRIQYLF FRLTNN - FVTVFTHGDDSLVG	346
RSCV	TLFLKTLGIPSGSCFTNMI GSVVNYVRIQYMFKKLTD D - FVEAYTHGDDSLAA	346

FIND CONSERVED REGIONS TO DESIGN PRIMERS

PCV-1	ERHLAAVLNYSMPNVPASQLSQSLYRQAE SAKNGFIISLPRVKAFDVLTEMDOVHF KSSS	62
PPV	ERHMEAL LNYGTRNIPVDNVDYNLYQG CIDT VKINGLRSLPRVKAFDVLTELNLVSYKSSIT	128
BCV-3	EGHMQA I L A Y A Q P D T P R E T F D Q T I W D Q A Y T A V Q N E L R S L P K A R A F D V N T E L D K V P Y E Q S S	128
FCCV	QAHIDSIMQYDRPKLPQP--TNAAWNTTQHVRTQFARMKQVQTL SYL-QLDOVKWVRSS	118
RSCV	DCHVDAI L A Y R R Q K L P E P -- T D D V W N Q T K Q H T L Q L F R R F P K I T P I S Y K - S F D E V K W I S S S	118
	: * : : : * : : : : : : : : : : : : : : : : : : * : * :	

II

PCV-1	SAGYNYTGRKGLIGDENHSRAISIAKAVLWSAIKDDGEGIEHVIRTSVPDVG IRTQLID	122
PPV	AAGYNYMGA K G P F D G Y N H K Q A I R R A R A T V G D V S D N G I E G L R R A I T T A V P D V G T R T Q L I D	188
BCV-3	SAGYGYRSHKGPFGGETHMRAISRVPKPLMTAIRPDEEGPEYTI LESVPDI G IRTQLID	188
FCCV	AAGYGYVGRKS--DNDNYFRAR-KTAF T I A E K L N H D R D Y G P L A L E D S T P D I A T R T Q L C Q	175
RSCV	SAGYGYVGHKG--DGDNYLKAR-RTAVT I A E K L D H D R N Y A P E A I N Q S T P D V A T R T Q L S Q	175
	: * * * : * : : : : : : : : : : : : : : : : * * : :	

PCV-1	LLEKTKVRQVWGRAFYI LLEGLVA Y P F I Q T V M S H K T F I H A G Q D P L I S V P R L L S D V A L N -	181
PPV	LTEKTKI RNVWGRAFYI LIEGT SADPLIRMF SKT K S F Y H I G R D P L D S V P D V L S E T A G K -	247
BCV-3	LREKTKVRGVWGRAFYI LIEGTAARPLLENFMLGTIFMHIGSDPQLSVPRILHQM K R E G	248
FCCV	IKVKRKI RNVWGEAFHYV LLEGLFADP I I Q H F I R N K S F Y F I G E D P L L A V P R L V E K I L S E -	234
RSCV	VKVKTKVRNVWGEAFHYV LLEGLFADP L I N F F S N E E S F Y F I G R N P L L S V P T L I E E I F K S -	234
	: * * * : * * * : * * * : * * * : * * * : * * * : * * * : * * * : * * * : * * * : * * * :	

III

IV

PCV-1	CKWIYSLDWSQF DATVSRFEIHA AFDI I K S Y V D F P N Y E T E Q A F E I T R Q L F I H K K V A A P D G	241
PPV	ARWLYAIDWKQF DATVSRFEINA AFDI I M D L I E F P N Y P T Y V A F E L S R Q L F I H K K I A A P D G	307
BCV-3	SKWLYALDWS S F D S S V T R F E I N C A F N L L K E R I E F P N E E T E L A F E L S R I L F I H K K L A A P D G	308
FCCV	QDYVYMF D W S G F D A S V Q E W E I R F A F S L L E S I L I F P S S V E S Y I W H F I I E L F I Y R K I A A P N G	294
RSCV	KDYVYAF D W S G F D A S V Q E W E I R F A F Q C L E S Q L I F P S N V E A Q I W R F I V E L F I Y R K I A A P N G	294
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V

PCV-1	YIYESHKGIPSGSYYSIIVGSIINYLRINYLWRLITGHPPQQCHTLGDDSLVG	294
PPV	YIYWSHKGIPSGSYFTSIIIGSIINRLRIEYLWRKITGHGPLACYTQGGDSLSC	360
BCV-3	NIYMIHKGIPSGSYYSIIVGSIIVNRLRIEYIWRVIFSRSPHRCYTQGGDSLIG	361
FCCV	KVYLKTLGIPSGSCFTNIIGSIIVNYVRIQYLF FRLTNN-FVTVFTHGDDSLVG	346
RSCV	TLFLKTLGIPSGSCFTNMIIGSIIVNYVRIQYMFKKLTD D-FVEAYTHGDDSLAA	346

FIND CONSERVED REGIONS TO DESIGN PRIMERS

PCV-1	ERHLAAV ¹ LNYSMPNVPASQLSQSLYRQAE ² SAKNGFIISLPRVKA ³ FDVLT ⁴ EMDQV ⁵ PFKSS ⁶ S	62
PPV	ERHMEAL ¹ LN ² YGT ³ RNIPVDNVDYNLY ⁴ QGCID ⁵ TVKNG ⁶ LRSLPRVKA ⁷ FDVLT ⁸ ELNLVSYKSS ⁹ T	128
BCV-3	EGHMQA ¹ ILAY ² AQ ³ PDTPRET ⁴ FDQ ⁵ TIWDC ⁶ AYTAVQNELRSLPKARAFDVN ⁷ TEL ⁸ DKVPYE ⁹ QSS	128
FCCV	QAHID ¹ SIMQY ² DRPKLP ³ QP--TNAAWNTT ⁴ QHV ⁵ RTQ ⁶ FARM ⁷ DKV ⁸ QTL ⁹ SYL-QLDOVK ¹⁰ WVRSS	118
RSCV	DCHVD ¹ AILAY ² RRQ ³ KLPEP--TD ⁴ DVWN ⁵ QTKQHTL ⁶ QL ⁷ FRR ⁸ FPKIT ⁹ PI ¹⁰ SYK-SFDEVK ¹¹ WISS ¹² S	118
	: * : : : * : : : : : : : : : : : : : : : * : *	

II

PCV-1	SAGYNYTGRKGLIGDENHSRAISIAKAVLWSAIKDDGEGIEHVIRTSVPDVGTRTQLAD	122
PPV	AAGYNYMGA ¹ KGPF ² DGYNHKQAIRRARATVGDVSDNGIEGLRRAITTA ³ VPDVGTRTQLAD	188
BCV-3	SAGYGYRSHKGP ¹ GGETHMRAISR ² VKPTLMTAIRPDEEGPEY ³ TILESVPDI ⁴ GTRTQLAD	188
FCCV	AAGYGYVGRKS--DNDNYFRAR-KTAF ¹ TIAEKL ² NHDRDYGP ³ LALED ⁴ STPDI ⁵ ATR ⁶ TQLCQ	175
RSCV	SAGYGYVGHKG--DGDNYLKAR-RTAV ¹ TIAEKL ² DHDR ³ NYAP ⁴ EAIN ⁵ QS ⁶ TPDVA ⁷ TRTQLSQ	175
	: *** : * : * : : : : : * : : : : : : : : : * : : *	

PCV-1	LLEKTKV ¹ RQVWGRA ² FHYILL ³ LEGLVA ⁴ Y ⁵ PF ⁶ IQT ⁷ VM ⁸ SHK ⁹ TFI ¹⁰ HAG ¹¹ QDPL ¹² ISV ¹³ PR ¹⁴ LLSD ¹⁵ VALN-	181
PPV	LIEKTKIRNVWGRA ¹ FHYILL ² IEG ³ T ⁴ SAD ⁵ PLIRMF ⁶ SK ⁷ TS ⁸ FY ⁹ HIG ¹⁰ RD ¹¹ PLDS ¹² VPD ¹³ VLS ¹⁴ ETAGK-	247
BCV-3	LREKTKV ¹ RGVWGRA ² FHYILL ³ IEG ⁴ TA ⁵ AR ⁶ PLLEN ⁷ FML ⁸ GT ⁹ IF ¹⁰ MHIG ¹¹ SD ¹² PQ ¹³ LSV ¹⁴ PR ¹⁵ ILH ¹⁶ QMK ¹⁷ REG	248
FCCV	IKV ¹ KRKIRNVWGE ² AFHYVLL ³ LEGLF ⁴ AD ⁵ P ⁶ II ⁷ QH ⁸ FI ⁹ RN ¹⁰ K ¹¹ S ¹² F ¹³ Y ¹⁴ FI ¹⁵ GED ¹⁶ PL ¹⁷ LAV ¹⁸ PR ¹⁹ LVE ²⁰ KILSE-	234
RSCV	VK ¹ V ² KTKV ³ RNVWGE ⁴ AFHYVLL ⁵ LEGLF ⁶ AD ⁷ PL ⁸ IN ⁹ FFS ¹⁰ NEE ¹¹ S ¹² F ¹³ Y ¹⁴ FI ¹⁵ GR ¹⁶ N ¹⁷ PL ¹⁸ LSV ¹⁹ PT ²⁰ LIEE ²¹ IF ²² KS-	234
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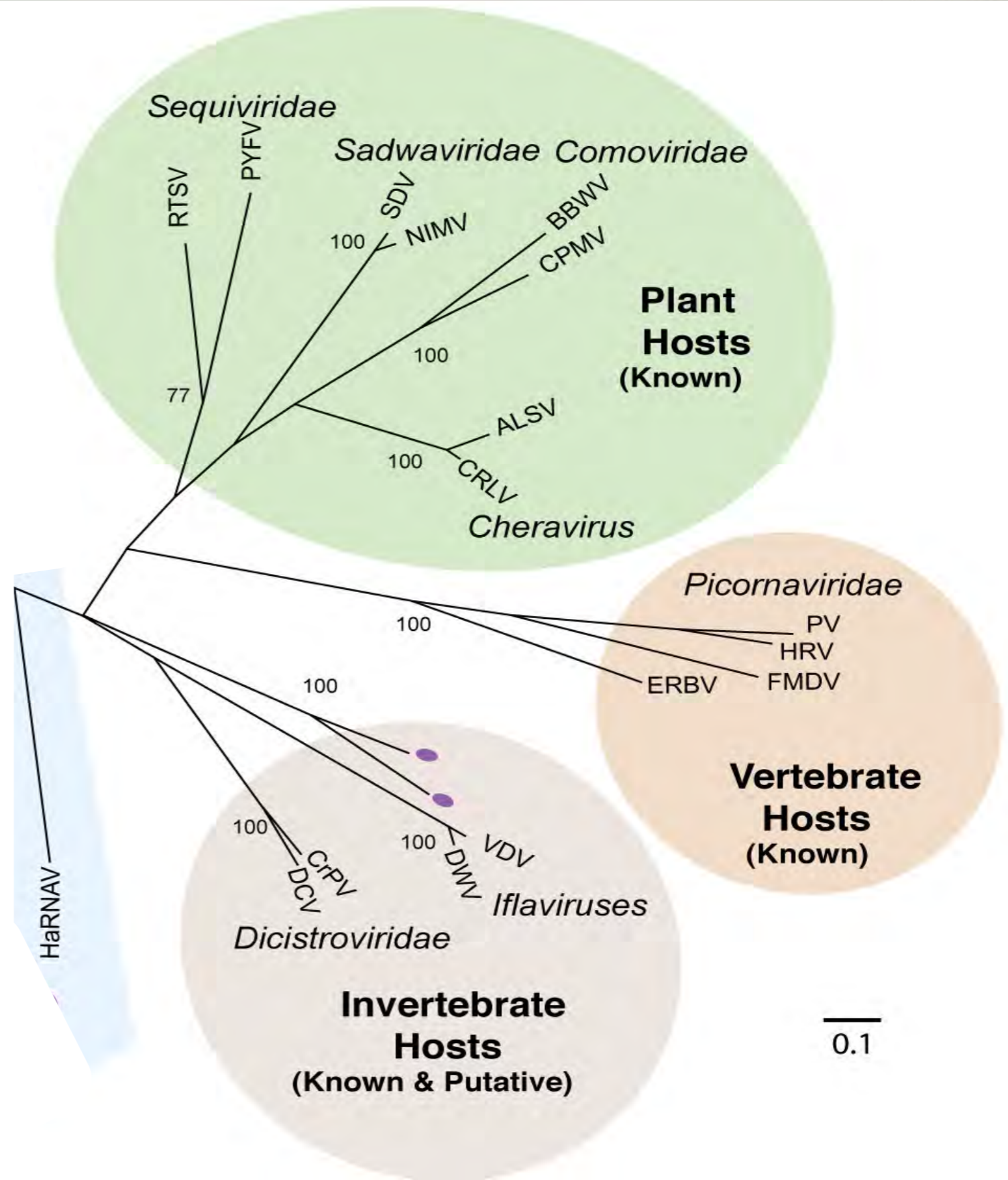
III

IV

PCV-1	CKWIYSLDWSQF ¹ DATVSRFEI ² HAAFD ³ IIKS ⁴ YVD ⁵ FPNYETE ⁶ QAFE ⁷ ITRQ ⁸ LFIHK ⁹ KVA ¹⁰ APD ¹¹ GG	241
PPV	ARWLYAIDWKQF ¹ DATVSRFEI ² NAAFD ³ IIMDLIE ⁴ FPNYPTY ⁵ VAFEL ⁶ SRQ ⁷ LFIHK ⁸ KIA ⁹ APD ¹⁰ GG	307
BCV-3	SKWLYALDWS ¹ SFDSSVTRFEINCAF ² NLL ³ KERIE ⁴ FPNEETE ⁵ LAFEL ⁶ SRIL ⁷ FIHK ⁸ KLA ⁹ APD ¹⁰ GG	308
FCCV	QDYVYMF ¹ DWSGF ² DASVQE ³ WEIR ⁴ FAFS ⁵ LES ⁶ ILIF ⁷ PS ⁸ SVESY ⁹ IWH ¹⁰ FIIE ¹¹ LFIY ¹² RKIA ¹³ APNG	294
RSCV	KDYVYAF ¹ DWSGF ² DASVQE ³ WEIR ⁴ FAFQCLES ⁵ QLIF ⁶ PS ⁷ NVEA ⁸ QI ⁹ WR ¹⁰ FI ¹¹ VEL ¹² FIY ¹³ RKIA ¹⁴ APNG	294
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V

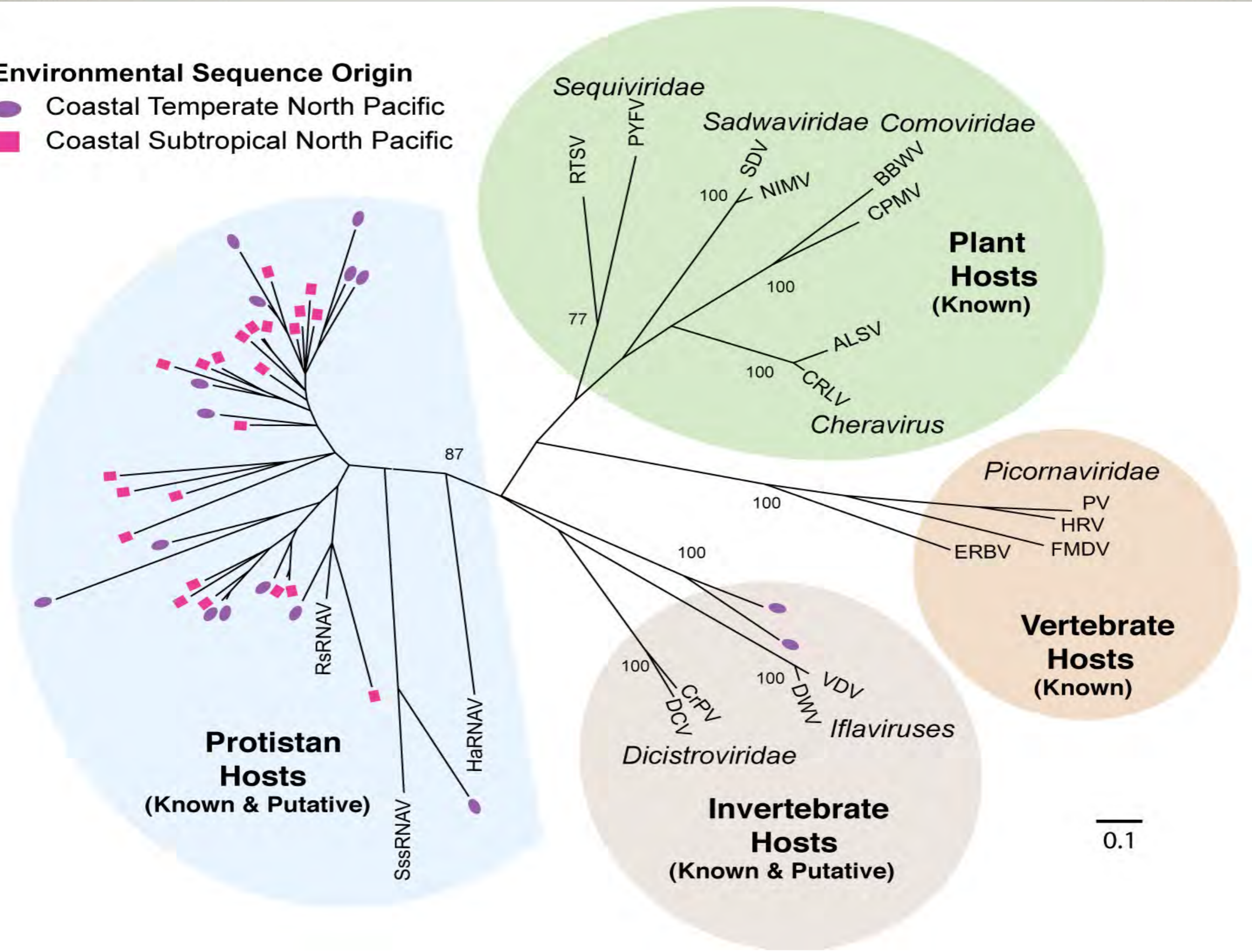
PCV-1	YIYESHK ¹ GIPSGSY ² YTS ³ LVGSI ⁴ INYL ⁵ LRINYL ⁶ WRL ⁷ ITGH ⁸ PPQ ⁹ QCH ¹⁰ TDG ¹¹ DDSI ¹² VG	294
PPV	YIYWSHK ¹ GIPSGSY ² FTS ³ IIGSI ⁴ INRL ⁵ RIEYL ⁶ WRK ⁷ ITGH ⁸ GPL ⁹ ACY ¹⁰ TDG ¹¹ DDSI ¹² SC	360
BCV-3	NIYMIHK ¹ GIPSGSY ² YTS ³ IVGSI ⁴ VNRL ⁵ RIEYI ⁶ WRV ⁷ IF ⁸ SRSPH ⁹ RCY ¹⁰ TDG ¹¹ DDSI ¹² LG	361
FCCV	KVY ¹ LKTL ² GIPSGSC ³ FTNI ⁴ IIGSI ⁵ VNY ⁶ VRI ⁷ QY ⁸ LF ⁹ FRL ¹⁰ TNN-F ¹¹ VT ¹² VFT ¹³ TDG ¹⁴ DDSI ¹⁵ VG	346
RSCV	TLF ¹ LKTL ² GIPSGSC ³ FTNMI ⁴ GS ⁵ VN ⁶ YVRI ⁷ QY ⁸ M ⁹ FK ¹⁰ KL ¹¹ TDD-F ¹² VEAY ¹³ TDG ¹⁴ DDSI ¹⁵ AA	346



Tree of the known Picornavirales based on RdRP

Environmental Sequence Origin

- Coastal Temperate North Pacific
- Coastal Subtropical North Pacific



Tree of the known Picornavirales based on RdRP

DO RNA VIRUSES MATTER?

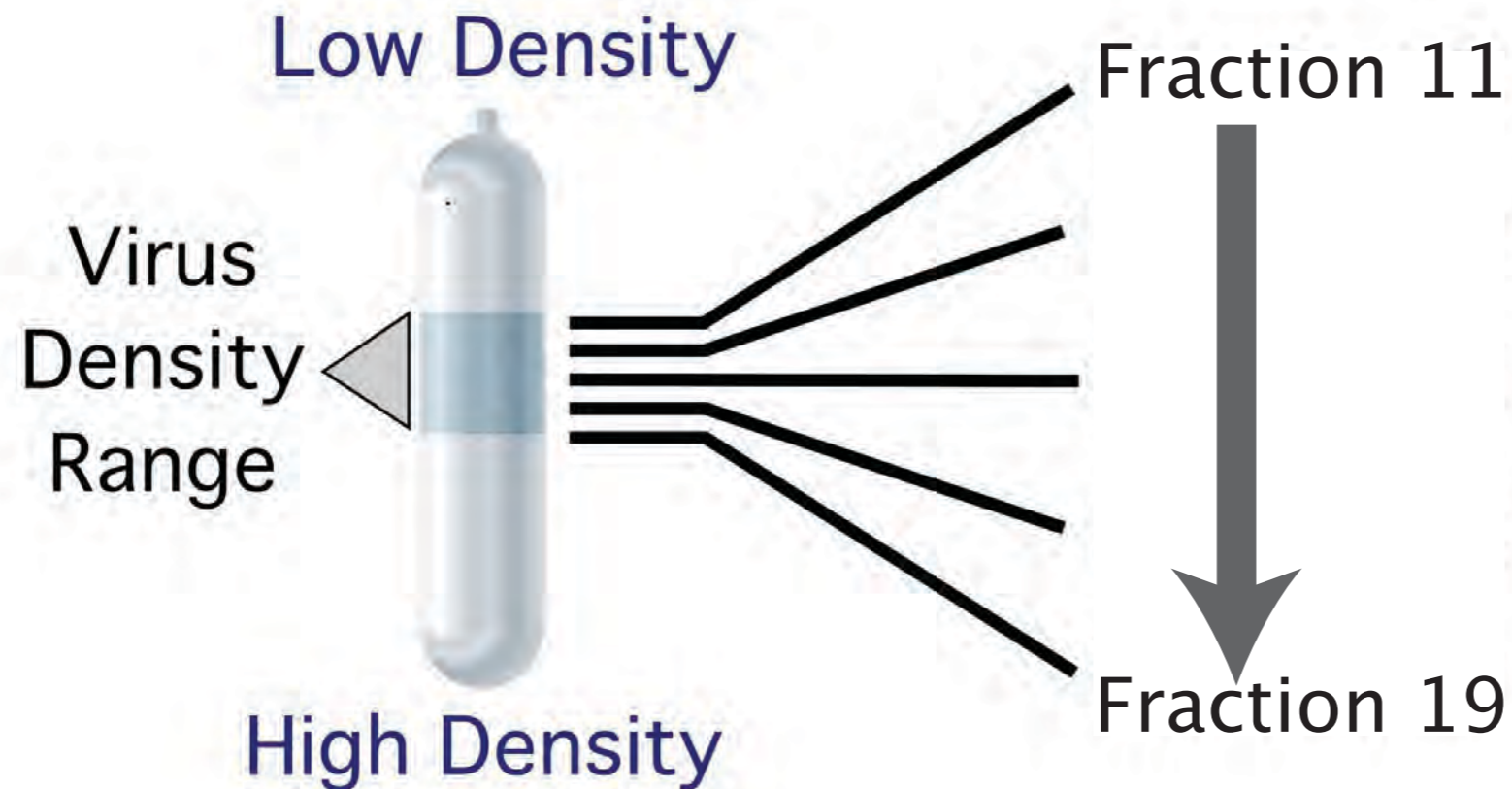
- Picorna-like viruses very common
- RNA viral metagenomes dominated by picornavirads and other eukaryote-infecting types
- No RNA-containing phages!

**Are RNA viruses bit players or major stars
in the pageant of the sea?**

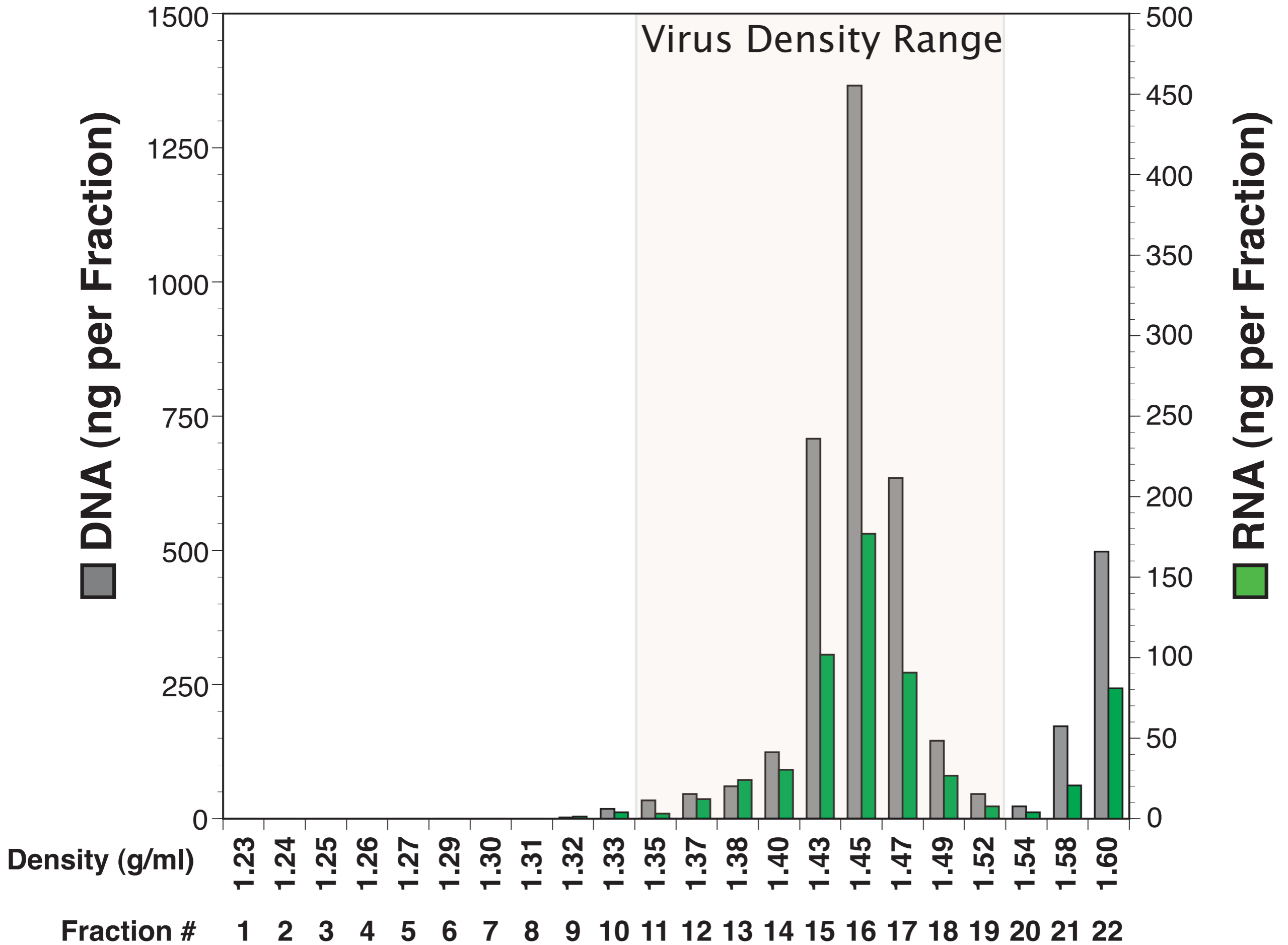
DO RNA VIRUSES MATTER?

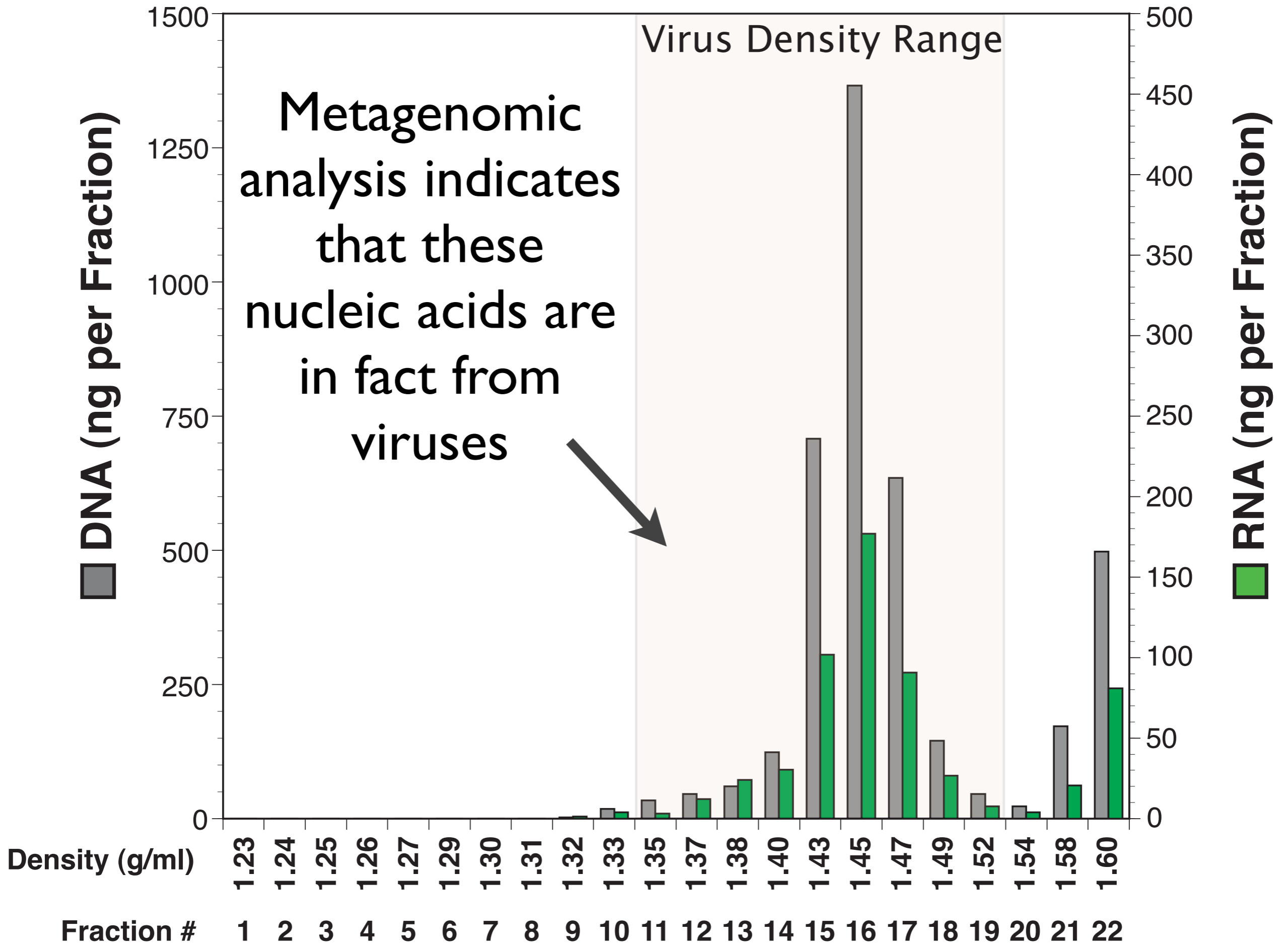
- Picorna-like viruses very common
- RNA viral metagenomes dominated by picornavirads and other eukaryote-infecting types
- No RNA-containing phages!

FRACTIONATION OF VIRUSES IN CsCl GRADIENT



Extract and Quantify
DNA and RNA from
each fraction





FROM NUCLEIC ACID MASS TO VIRAL ABUNDANCE

Assume:

RNA viruses are single-stranded and average 8 kb

DNA viruses are double-stranded and average 50 kb

FROM NUCLEIC ACID MASS TO VIRAL ABUNDANCE

Assume:

RNA viruses are single-stranded and average 8 kb

DNA viruses are double-stranded and average 50 kb

Genome Copies (billions per liter)

<i>Date</i>	01 Aug 2009	07 July 2010	08 July 2010	
<i>RNA Virus</i>	2.98	0.33	0.28	
<i>DNA Virus</i>	1.62	0.62	0.30	Average
% RNA Viruses	65%	35%	48%	49%

FROM NUCLEIC ACID MASS TO VIRAL ABUNDANCE

Assume:

RNA viruses are single-stranded and average 8 kb

DNA viruses are double-stranded and average 50 kb

Genome Copies (billions per liter)

Date 01 Aug 2009 07 July 2010 08 July 2010

RNA Virus 2.98 0.33 0.28

DNA Virus 1.62 0.62 0.30 **Average**

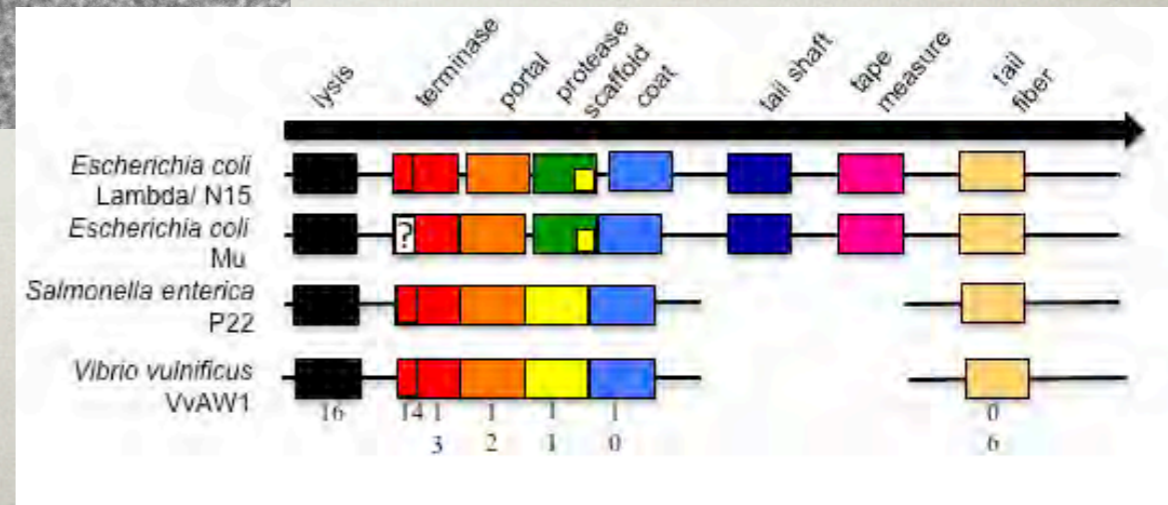
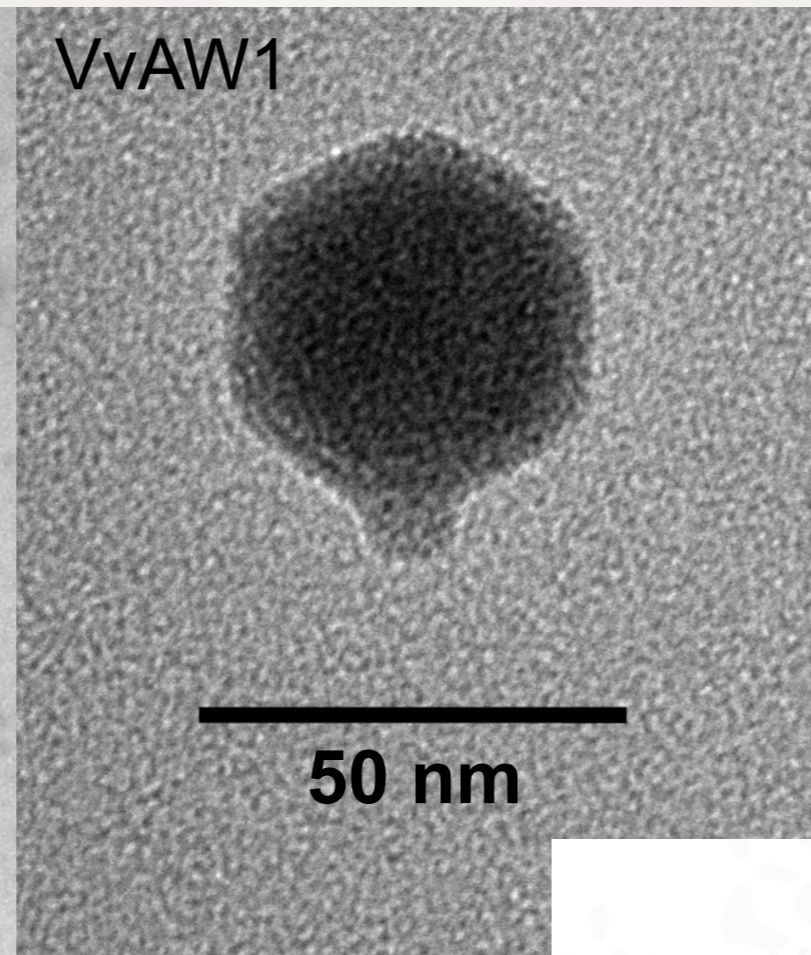
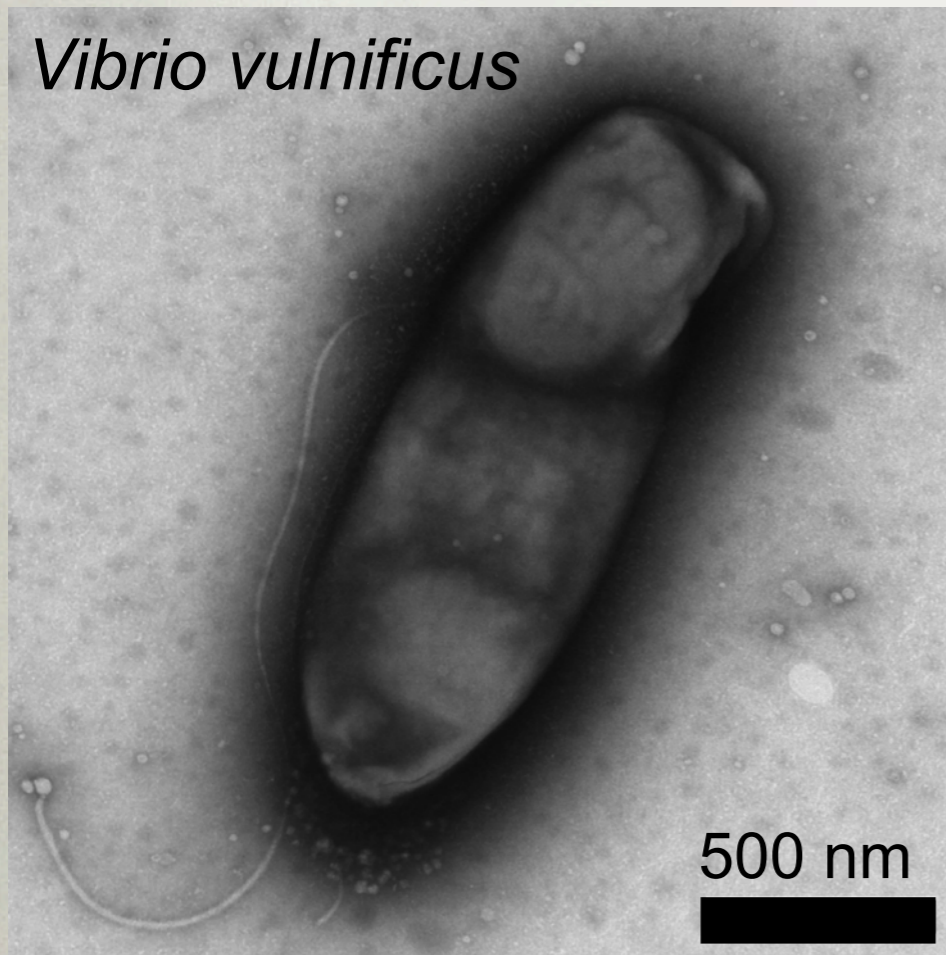
% RNA Viruses 65% 35% 48% 49%

We have been missing HALF of the viruses in the sea

CULTIVATION OF VIRUS-HOST SYSTEMS

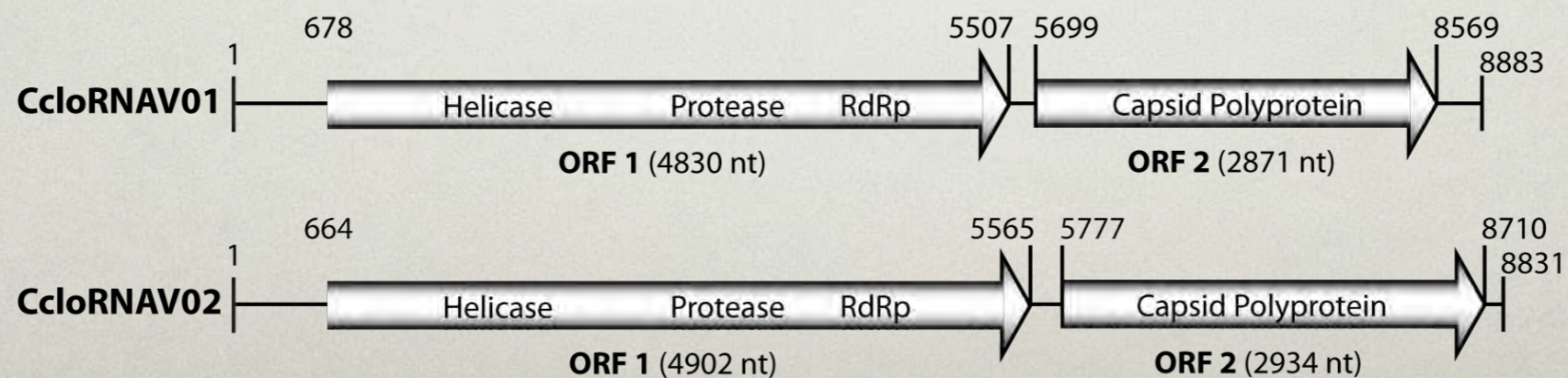
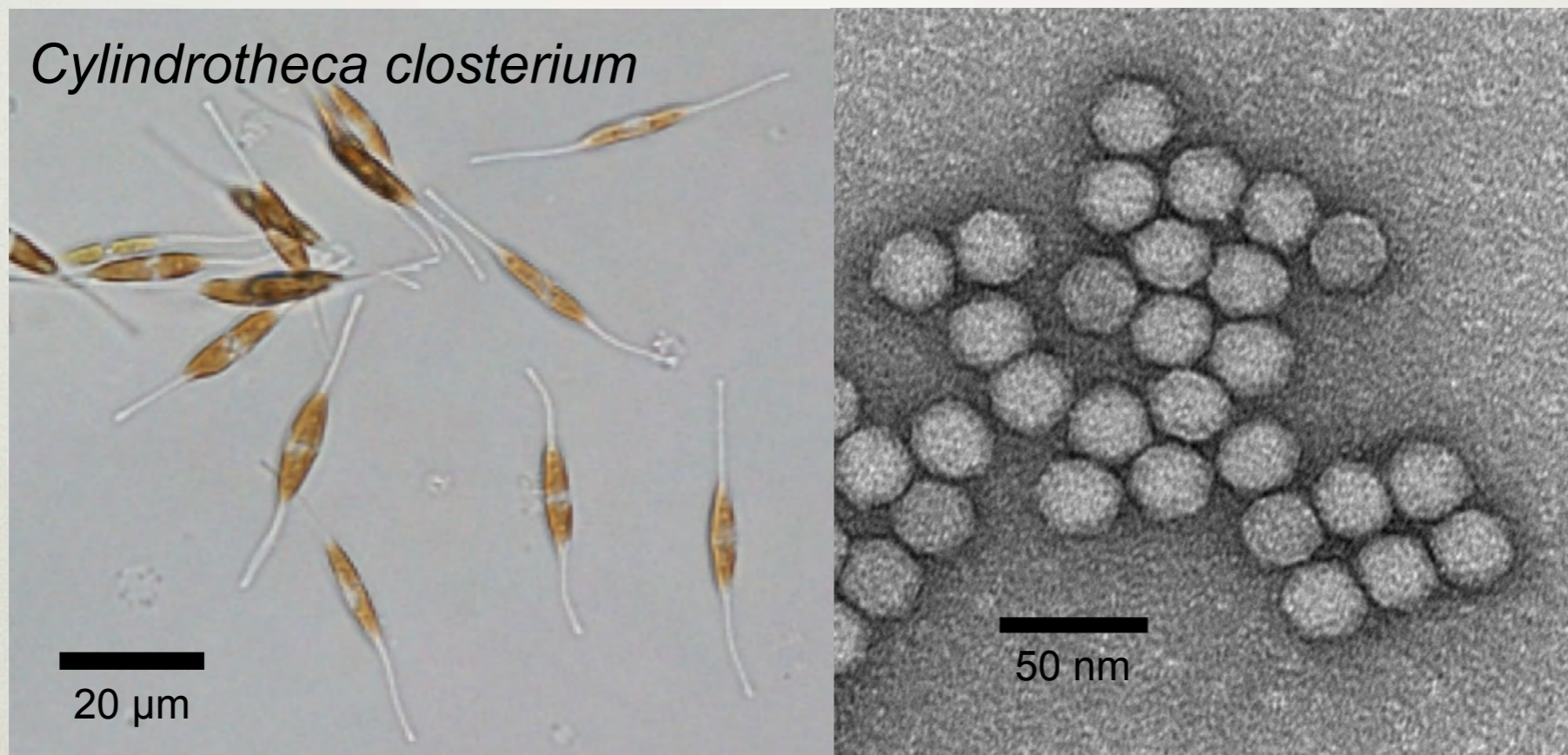
CULTIVATION HIGHLIGHTS

First genome of a pathogenic *Vibrio vulnificus*



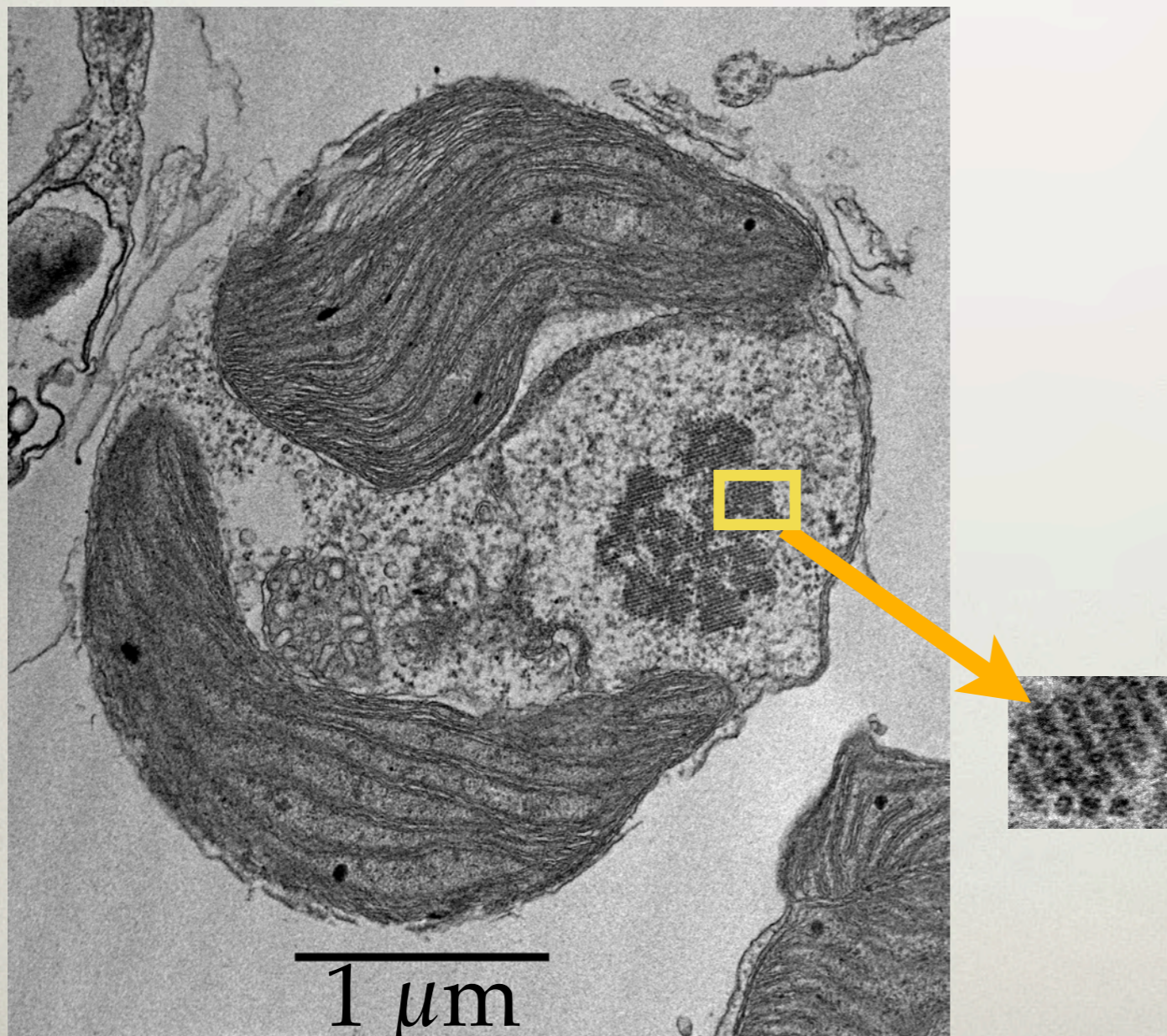
CULTIVATION HIGHLIGHTS

First genomes of viruses infecting pennate diatoms



CULTIVATION HIGHLIGHTS

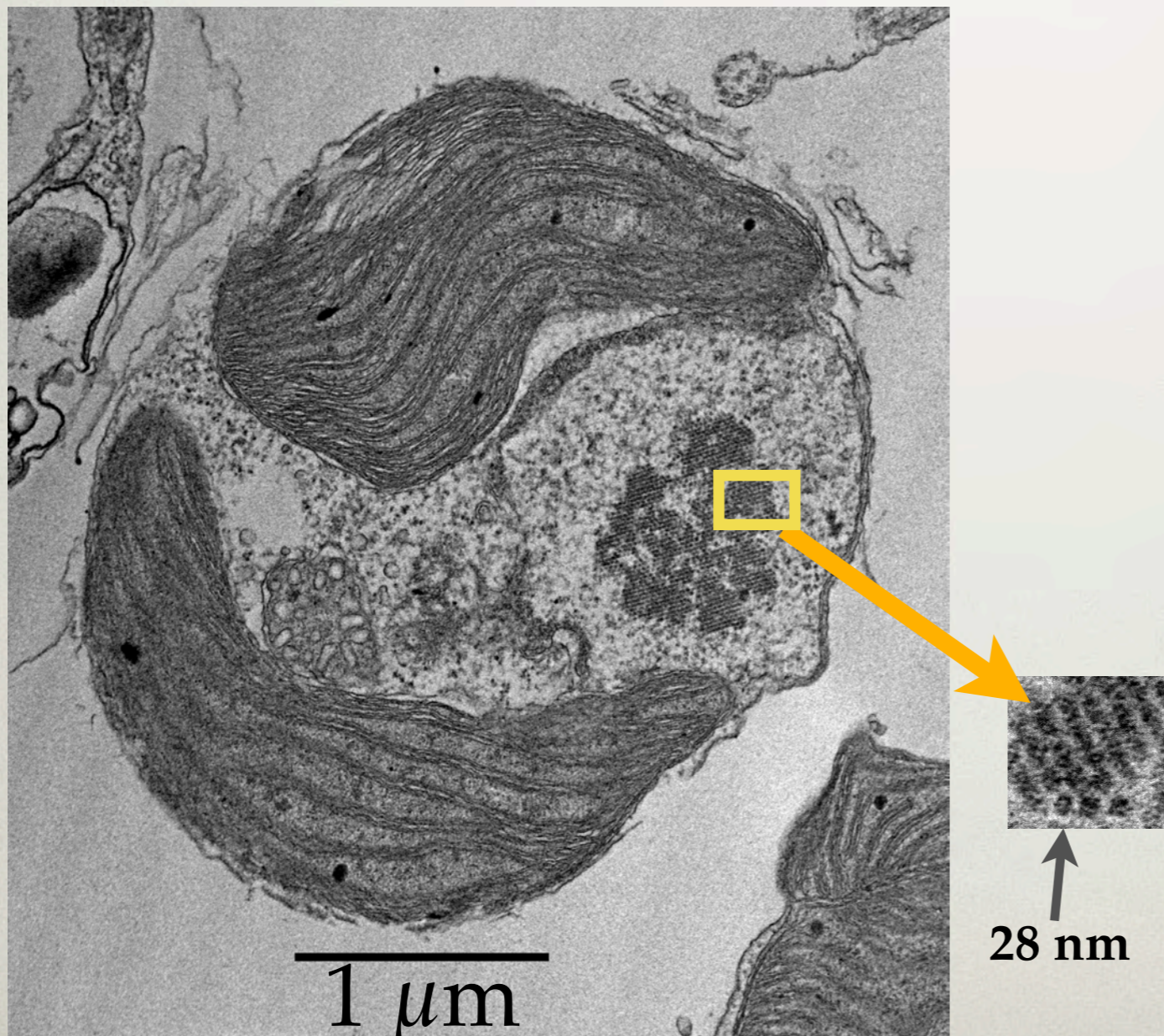
Smallest and largest viruses yet reported for marine phytoplankton



Raphidophyte

CULTIVATION HIGHLIGHTS

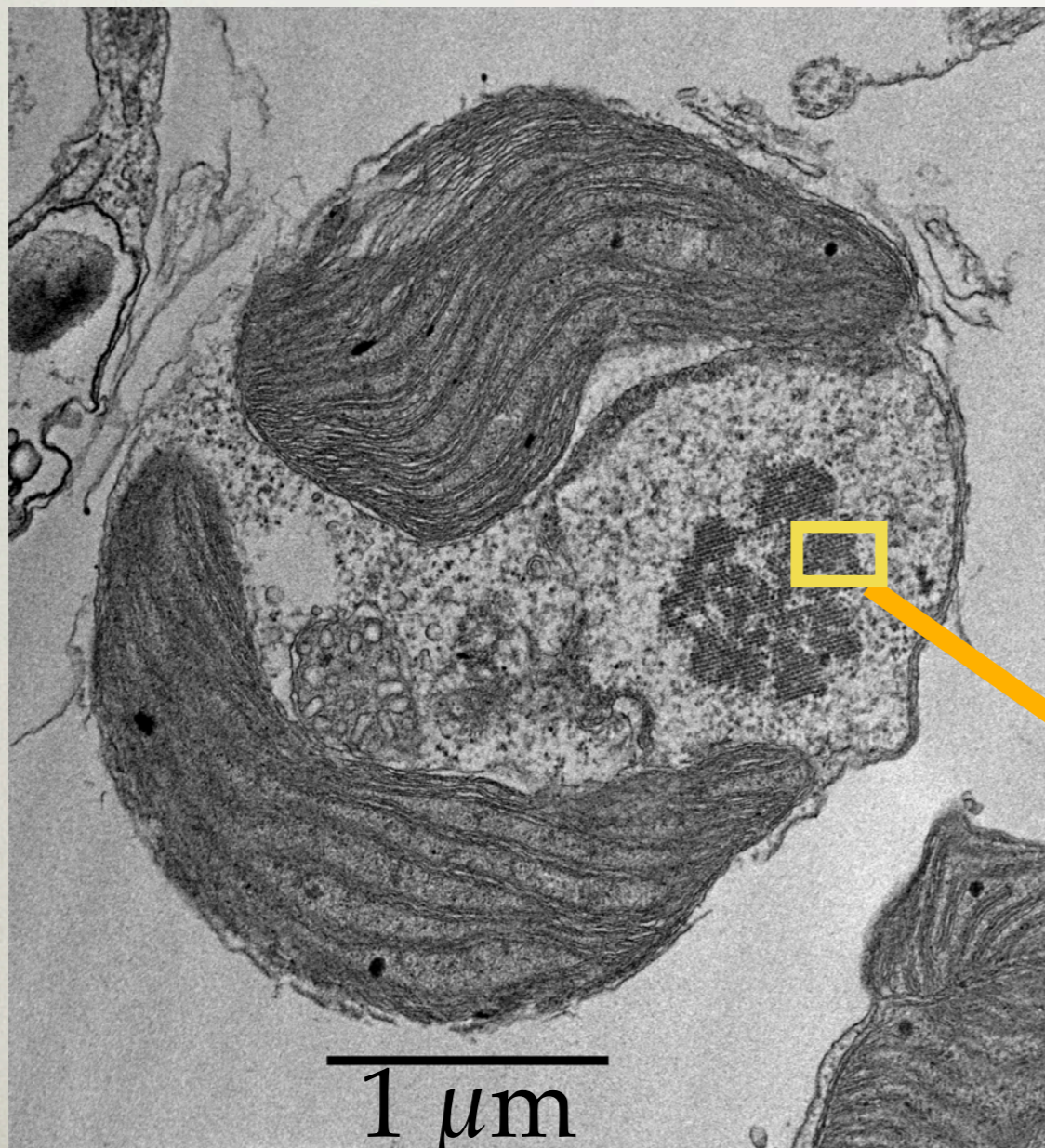
Smallest and largest viruses yet reported for marine phytoplankton



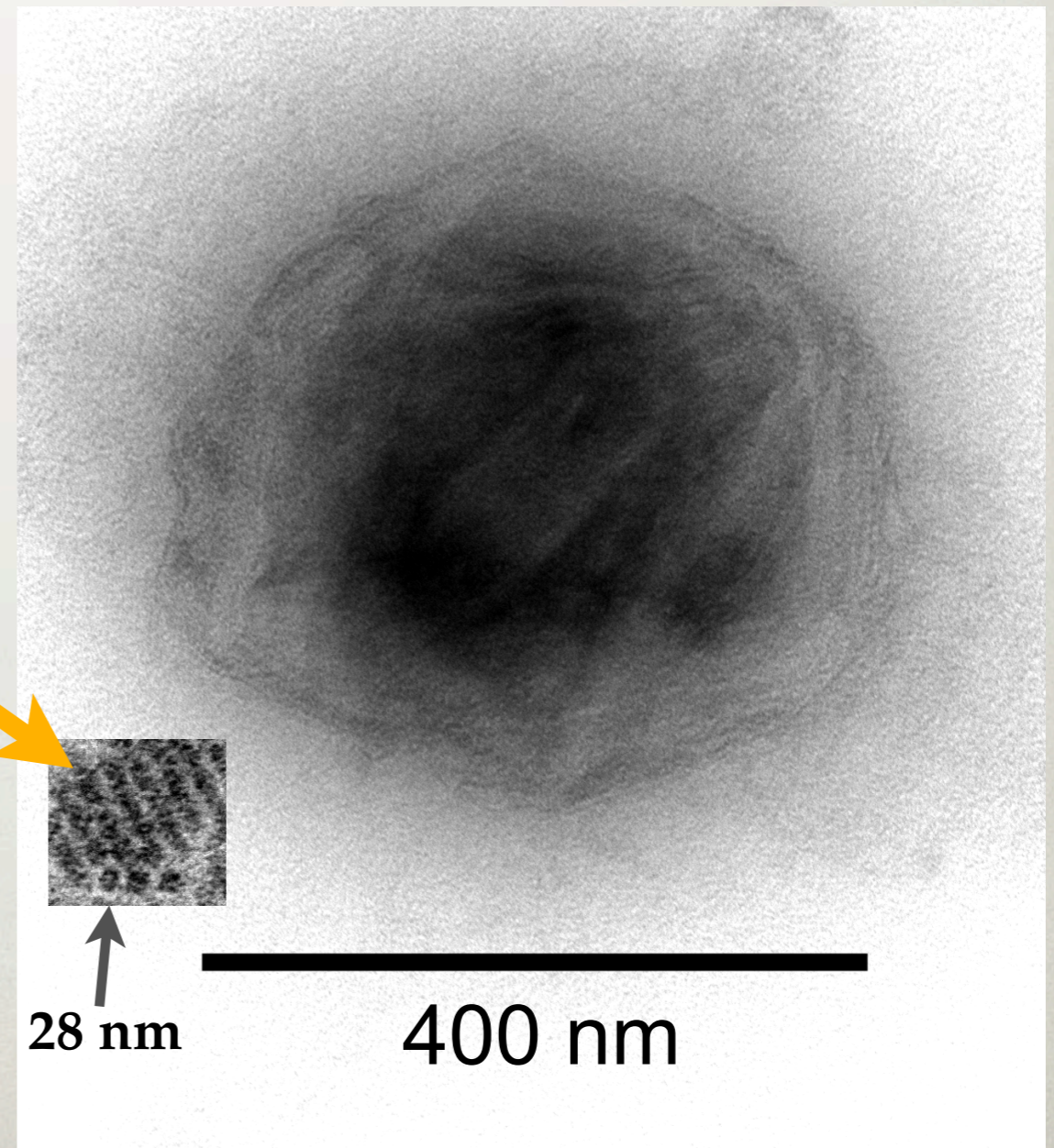
Raphidophyte

CULTIVATION HIGHLIGHTS

Smallest and largest viruses yet reported for marine phytoplankton



Raphidophyte



Florenciella spp.

ACKNOWLEDGMENTS

- CMORE
- National Science Foundation
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- The MarVEL Personnel

