

Thermoresponsive Phage-Based System for Rare Earth Element Separation

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May 04, 2026

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Importance



- Rare earth elements (REEs) are essential for modern technologies
- Used in renewable energy, electronics, and advanced materials

Challenge



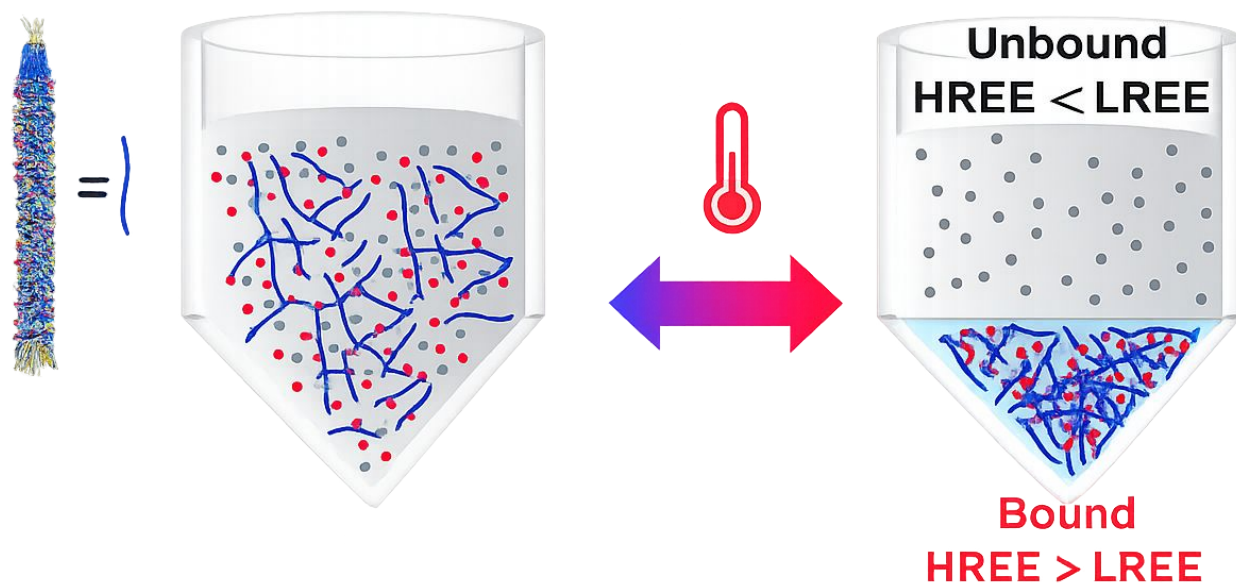
- REEs have very similar chemical properties
- This makes selective separation extremely difficult

limitation



- Current methods rely on harsh chemicals
- Require complex and multi-step processes
- Often inefficient and environmentally unfriendly

A more selective and sustainable separation method is needed



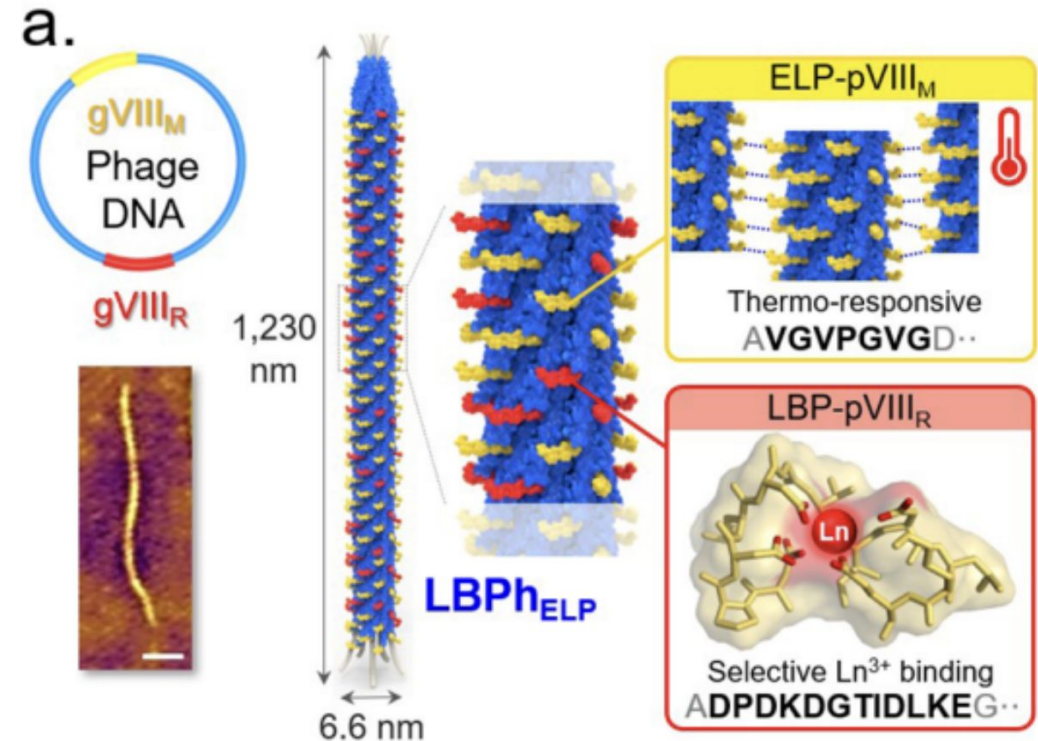
- LBP enables selective binding to rare earth elements
- ELP triggers temperature-responsive aggregation upon heating
- This allows separation of bound REEs from solution
- Integrates binding and separation into one system

LBP

- LBP (Lanthanide-Binding Peptide)
- Specifically binds to rare earth elements (Ln^{3+} ions)
- Provides selectivity in the separation process

ELP

- ELP (Elastin-Like Peptide)
- Undergoes aggregation at elevated temperature
- Enables phase separation of bound complexes



Separation Mechanism

Binding

LBP selectively binds to rare earth ions (Ln^{3+}) in solution

Heating

Increasing temperature triggers ELP phase transition

Aggregation

ELP induces aggregation of phage-REE complexes

Separation

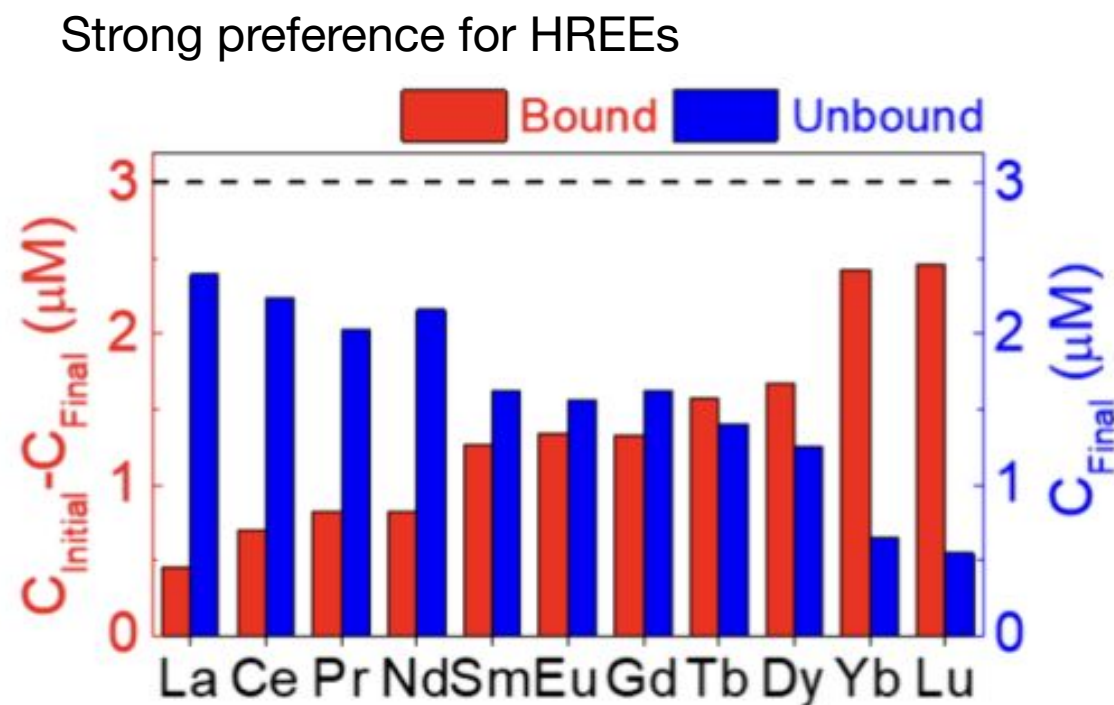
Aggregated complexes separate from the solution

Release

Lowering pH releases the bound REEs for recovery

Take away: Separation is controlled by temperature and pH

- **Temperature-dependent aggregation**
→ Triggered by ELP phase transition
- **Reversible system**
→ Aggregation and redispersion
- **Selective REEs bonding**
→ Minimal binding to other metal ions
- **Preference for heavy REEs (HREEs)**
→ Stronger binding toward heavier lanthanides



Significance of the System



- Enables selective separation of rare earth elements (REEs)
→ Addresses challenges of similar chemical properties



- Reduces reliance on harsh chemicals
→ More environmentally friendly approach



- Simplifies separation process
→ Integrates binding and separation into one system



- Potential for scalable and tunable design
→ Applicable to other metal ion separations

A simple, selective, and sustainable platform for REE separation

Research Objective

Goal: Apply virus-based REE separation system in practice

Construct



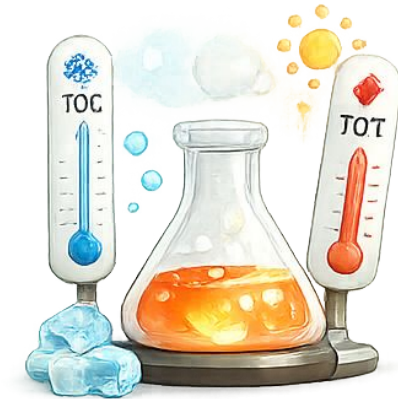
- Construct engineered bacteriophage (LBP + ELP)
→ Combine binding and thermo-responsive elements

Validate



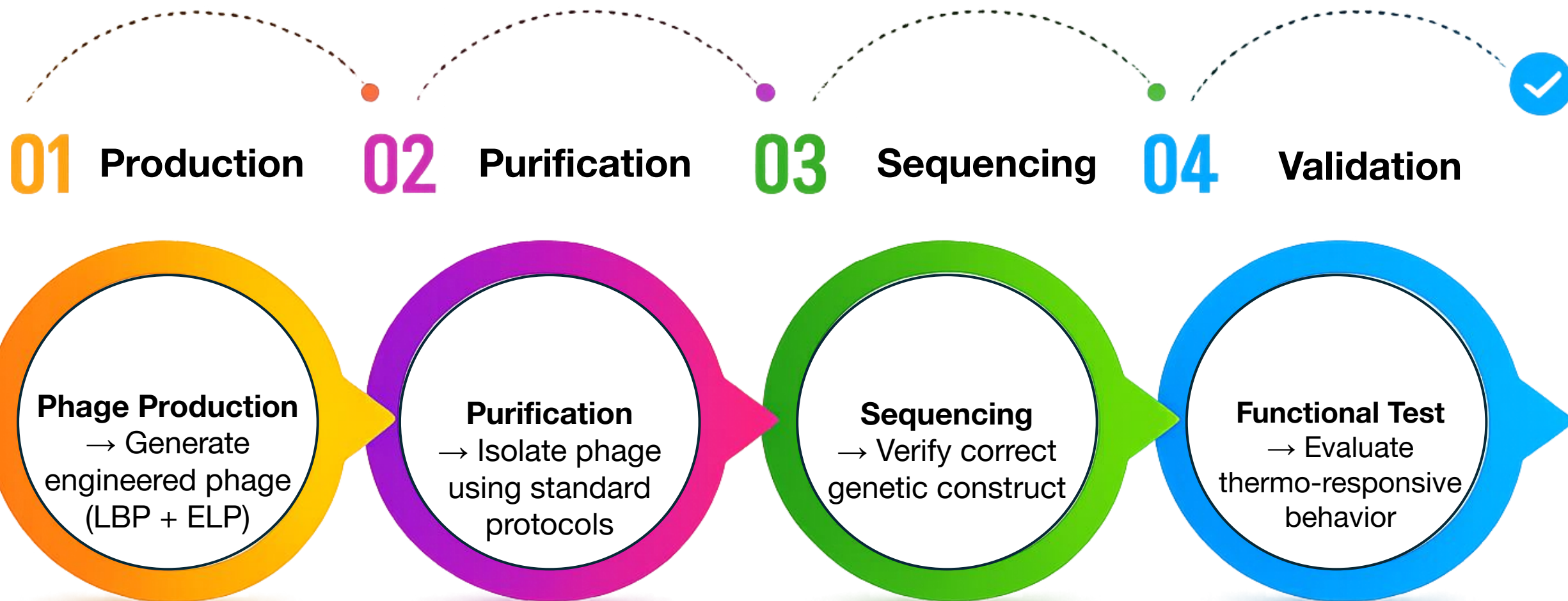
- Validate successful phage design
→ Confirm expression and functionality

Test



- Evaluate thermo-responsive aggregation behavior
→ Test separation performance under temperature change

Experimental Approach



Produced phage and performed purification

RESULT:

- Wild-type phage dominated the population
- Engineered phage was not sufficiently enriched

ISSUE:

- Mixed phage population made it difficult to isolate engineered phage

INTERPRETATION:

- Wild-type phage likely has a faster replication rate
- Insufficient selection pressure during amplification

Performed Sanger sequencing
Attempted Nanopore sequencing

RESULT:

- Sequencing did not show expected engineered construct

ISSUE:

- Unable to detect ELP insert (VPGVG motif)

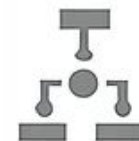
INTERPRETATION:

- Sample likely dominated by wild-type phage
- Engineered phage was not sufficiently enriched
- Mixed population interfered with sequencing signal



Problem

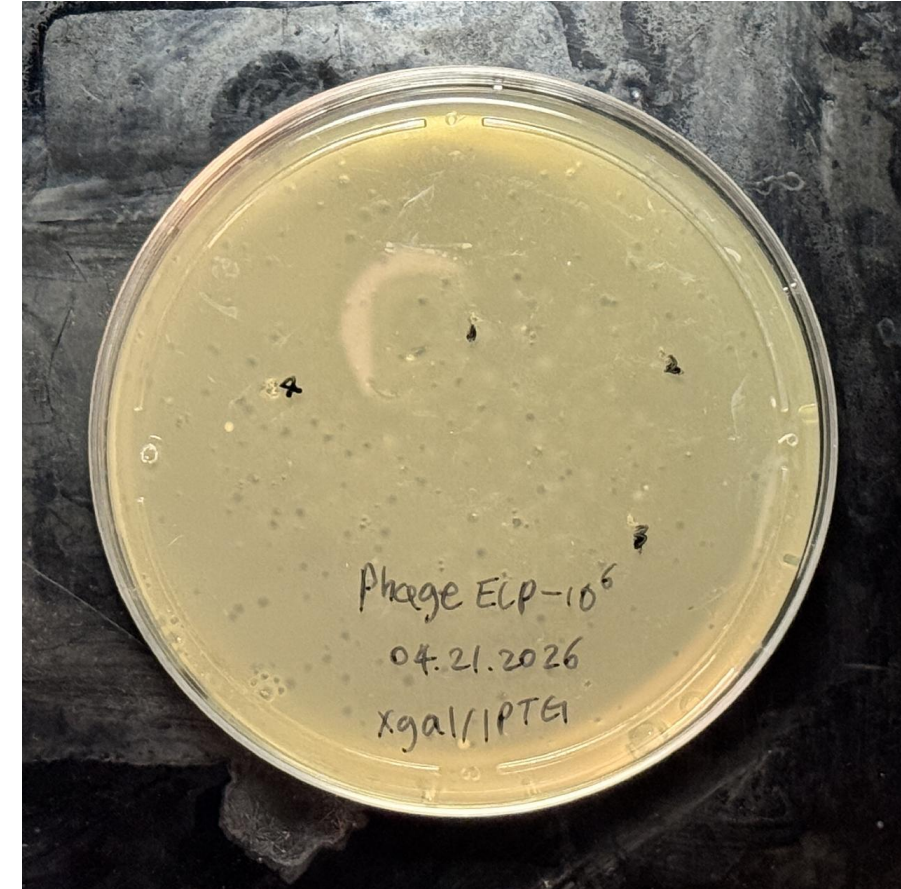
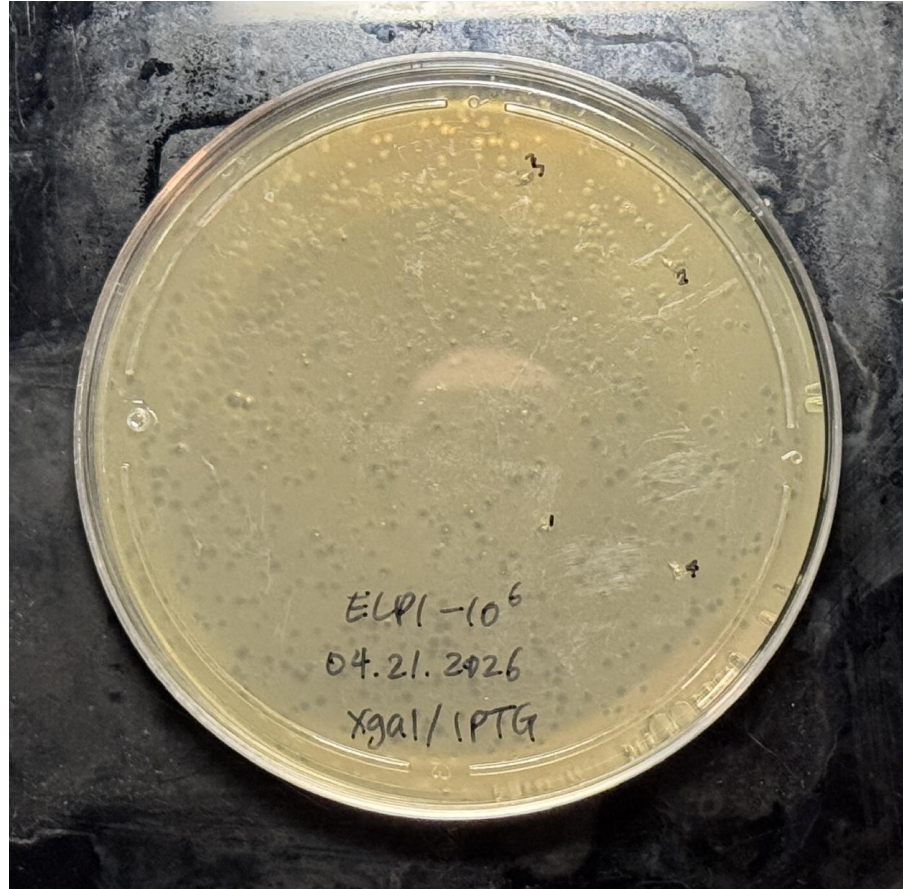
- Mixed phage population dominated by wild-type
- Failed sequencing due to lack of enrichment



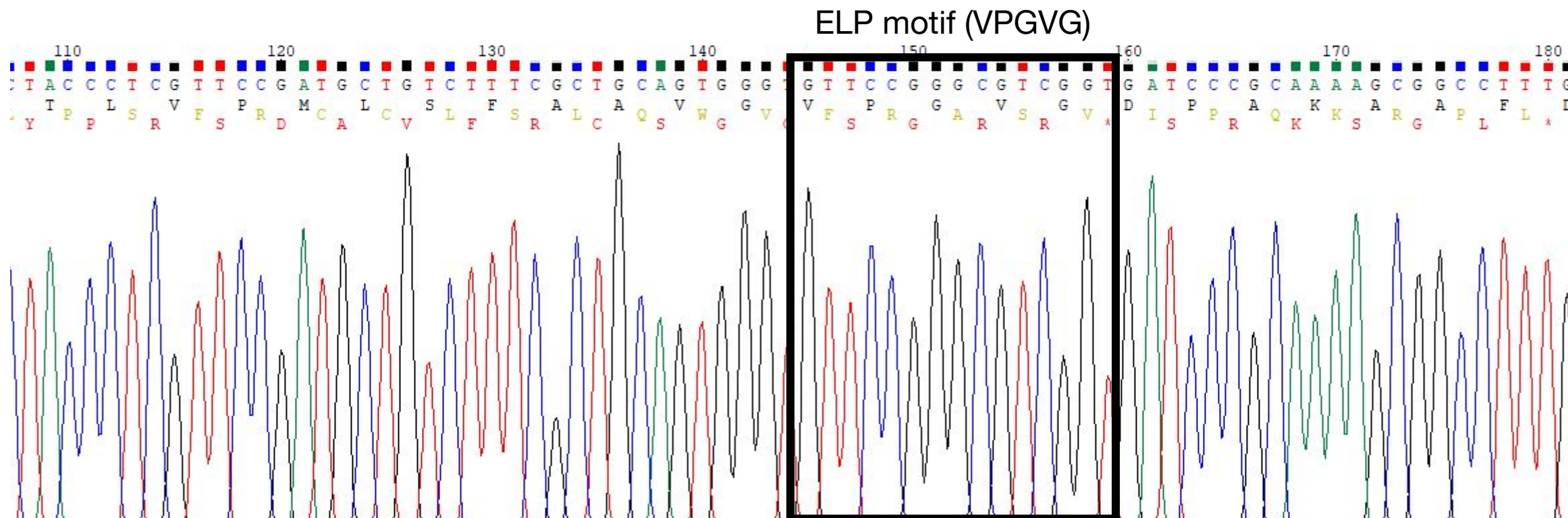
Solution

- Switched to plaque assay
 - Isolated single plaques (clonal enrichment)
 - Reduced wild-type interference
- Successfully recovered ELP sequence

Plaque Assay for Clonal Isolation

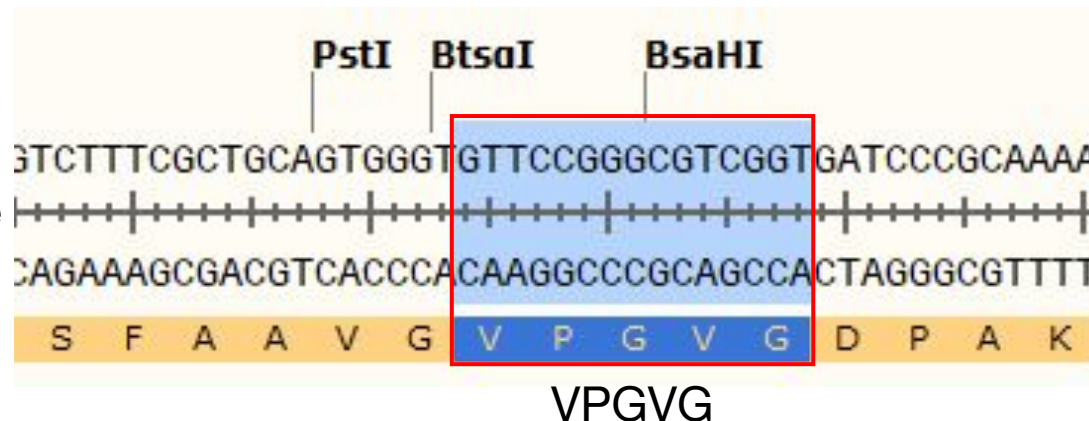


- Performed plaque assay on phage stock
- Observed discrete plaques indicating single phage clones
- Selected plaques for downstream sequencing

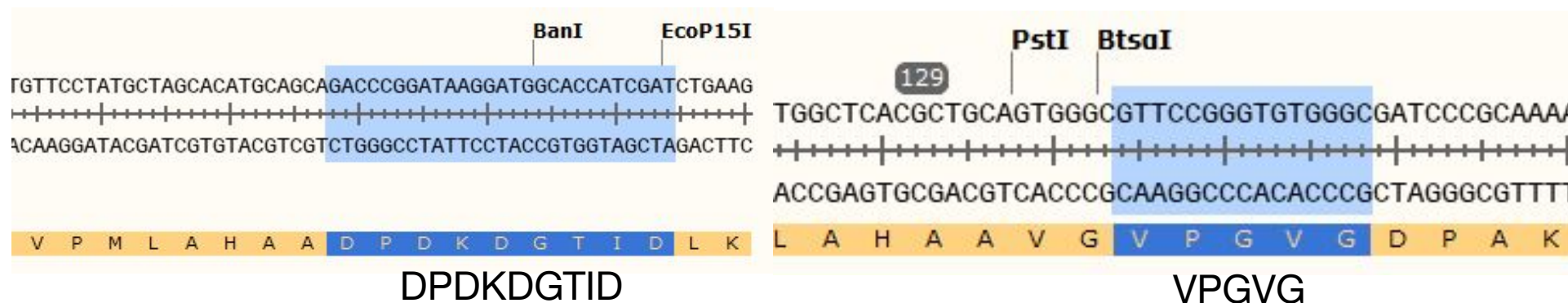


- Clear VPGVG motif detected → confirms ELP insert
 - Derived from isolated plaques (clonal population)
- Plaque assay enabled successful enrichment and sequencing

Successful confirmation of
ELP-expressing phage sequence



Successful confirmation
of LBPh-ELP-expressing
phage sequence



- VPGVG motif confirmed at expected insertion site
 - Consistent detection across constructs
- Confirms successful enrichment of engineered phage

ELP Functional Validation



Before heating (soluble) □ After heating (aggregation)

- ELP-expressing phage shows temperature-dependent aggregation
- Solution becomes turbid after heating due to ELP phase transition
 - Confirms functional expression of ELP insert

RESULT:

- Wild-type phage outcompeted engineered phage during initial amplification
- Plaque assay enabled the isolation of clonal phage populations
- Sequencing confirmed successful insertion of ELP sequence (VPGVG motif)

IMPACT:

- Functional validation demonstrated temperature-dependent aggregation
- Confirms successful expression and functionality of engineered ELP phage

- Improve selection pressure during amplification
- Optimize phage yield and enrichment efficiency
- Quantitatively characterize ELP phase behavior
- Explore applications of ELP-displaying phage

