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THERMODYNAMIC INSIGHTS INTO MICRO(PLASTIC) POLLUTION IN THE ENVIRONMENT: INTERFACIAL PROCESSES, CHEMICAL SYNERGISM AND ECOLOGICAL IMPLICATIONS

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INTRODUCTION

Microplastics have become ubiquitous contaminants in aquatic and terrestrial environments. Beyond their physical presence, they act as heterogeneous interfaces capable of modifying adsorption equilibria, chemical speciation and contaminant transport.

Interactions among microplastic surfaces, dissolved ligands and metal ions generate cooperative effects that cannot be explained by classical additive models.

OBJECTIVE

To develop a thermodynamic interpretation of (micro)plastic pollution by investigating:

- Interfacial adsorption processes;
- Surface complexation mechanism;
- Heterogeneous chemical synergism;
- Non-additive contaminant behavior;
- Ecological implications of altered speciation.

THERMODYNAMIC INTERPRETATION

Surface-mediated processes include:

- ✓ Adsorption equilibria;
- ✓ Surface complexation
- ✓ Competitive binding
- ✓ Ternary complex Formation.

Possible interfacial species:

- ✓ Metal – Surface (≡S - M)
- ✓ Metal – Ligand (ML)
- ✓ Metal – Ligand-surface (≡S - ML)

These interactions modify equilibrium boundaries and influence contaminant mobility, bioavailability and toxicity.

HETEROGENEOUS CHEMICAL SYNERGISM

Classical Additive Prediction:

Effect (MP + Ligand) = Effect (MP) + Effect (Ligand)

Observed Environmental Response:

Effect (MP + Ligand) = Effect (MP) + Effect (Ligand) + S

where:

S > 0 → Synergism
S = 0 → Additivity
S < 0 → Antagonism

THERMODYNAMIC CRITERION FOR NON-ADDITIVITY

$$S = E_{(observed)} - \sum E_i$$

S – synergistic contribution
$E_{(observed)}$ – experimentally observed effect
$\sum E_i$ – sum of individual contributions

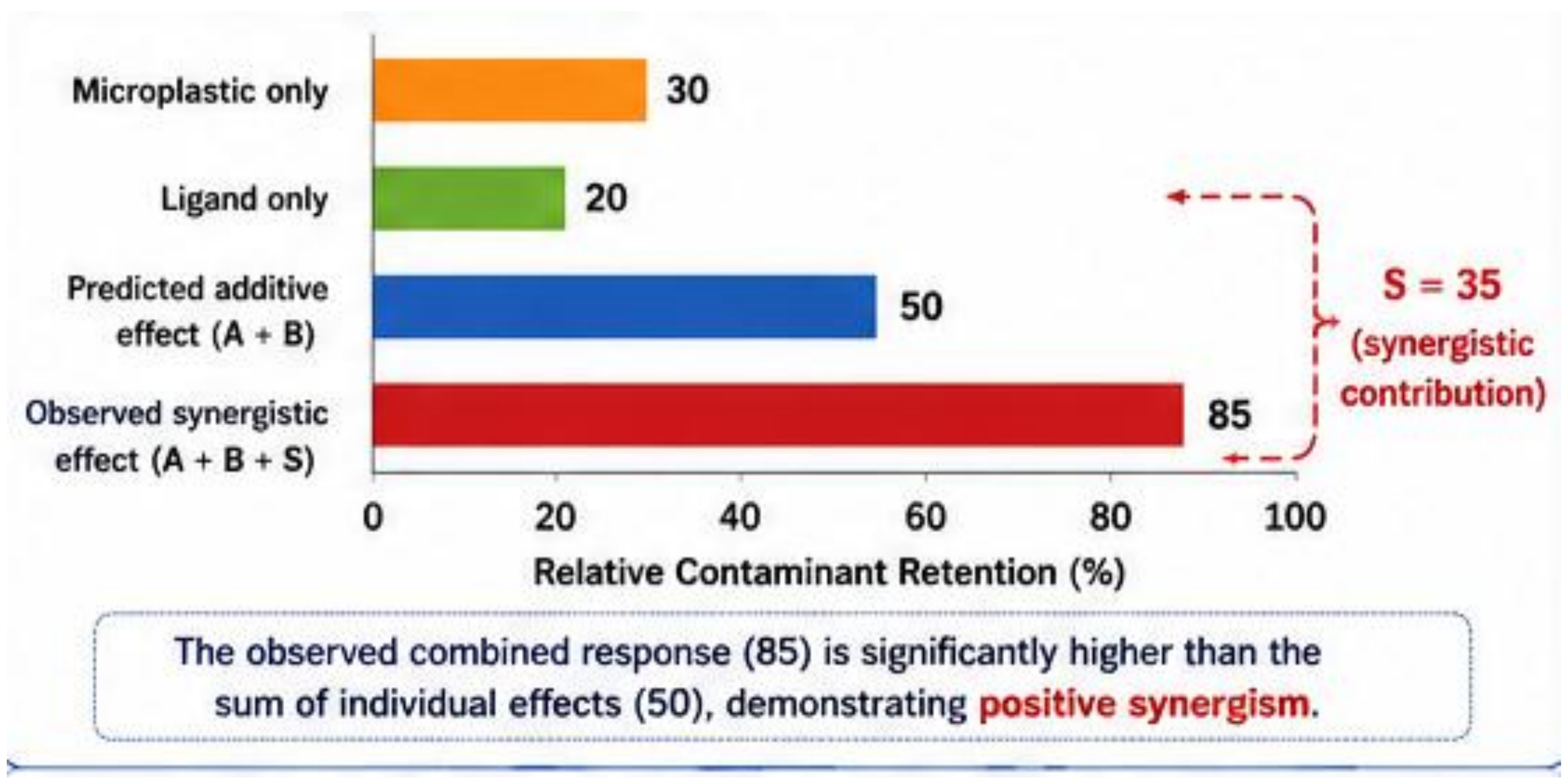

Fig. 1. Additive prediction vs. observed synergism

RESULTS & DISCUSSION

Microplastics are not passive contaminant carriers. They are active thermodynamic interfaces capable of generating heterogeneous chemical synergism, modifying pollutant speciation and producing non-additive environmental effects.

MAIN FINDINGS:

- ❖ Microplastics actively participate in environmental equilibria.
- ❖ Surface-mediated interactions alter chemical speciation and pollutant distribution.
- ❖ Cooperative (synergistic) interactions enhance contaminant retention.
- ❖ Multi-component complexes lead to non-additive behavior.
- ❖ Environmental conditions strongly control heterogeneous synergism.
- ❖ Pollutant persistence and ecological risk may increase significantly.

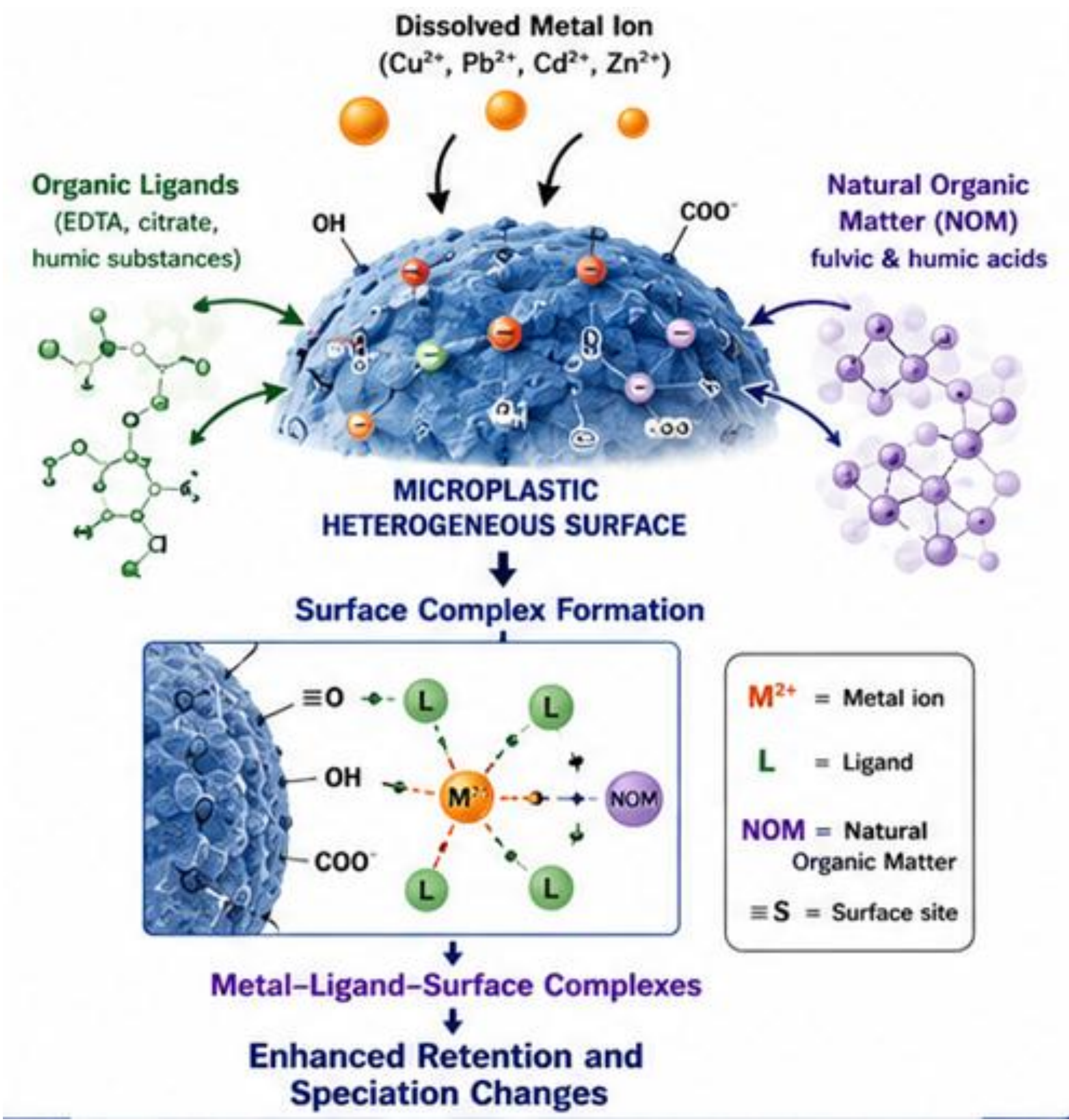

Fig. 2. Microplastic - Metal – Ligand interaction network

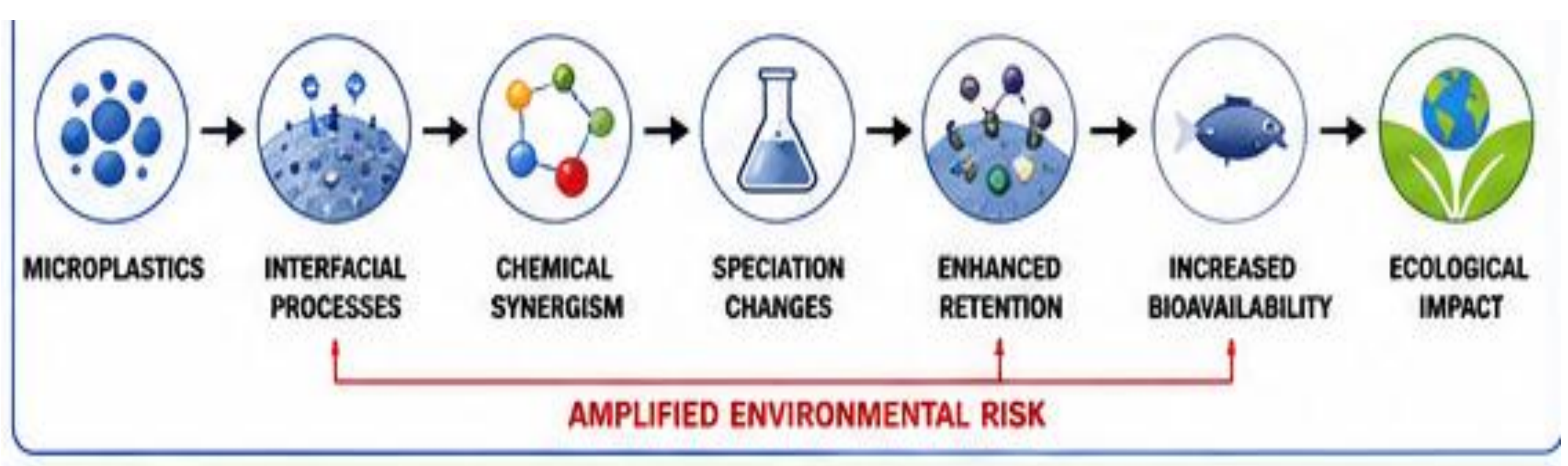

Fig. 3. Environmental impact pathway

CONCLUSION

- Microplastics should be considered active thermodynamic components rather than passive carries.
- Heterogeneous chemical synergism provides a mechanistic explanation for non-additive pollutant behavior.
- Thermodynamic modeling offers a powerful tool to predict contaminant fate, transport and ecological impact.
- Future environmental risk assessments should explicitly incorporate synergistic interfacial interactions involving microplastics, ligands and metal ions.

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