It is claimed:

1. An immunogen, comprising:

a recombinant Mumps virus (MuV) F ectodomain trimer stabilized in a prefusion conformation by one or more amino acid substitutions in protomers of the trimer, the amino acid substitutions comprising cysteine substitutions that form a non-natural disulfide bond to stabilize the MuV F ectodomain trimer in the prefusion conformation.

2. The immunogen of claim 1, wherein the cysteine substitutions are located at one or more of MuV F positions 86 and 215, positions 155 and 161, positions 165 and 231, positions 206 and 223, positions 209 and 214, and positions 221 and 255.

3. The immunogen of claim 1 or claim 2, wherein the recombinant MuV F ectodomain trimer is stabilized in the prefusion conformation by a non-natural disulfide bond between the cysteine substitutions in protomers of the trimer at MuV F positions 206 and 223.

4. The immunogen of any one of the prior claims, wherein the cysteine substitutions at:

MuV F positions 86 and 215 are N86C and A215C substitutions;

MuV F positions 155 and 161 are K155C and L161C substitutions;

MuV F positions 165 and 231 are V165C and M231C substitutions;

MuV F positions 206 and 223 are V206C and A223C substitutions;

MuV F positions 209 and 214 are P209C and P214C substitutions; and

MuV F positions 221 and 255 are I221C and M255C substitutions.

5. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer comprise a F_2 protein comprising or consisting of MuV F positions 20-100 and a F_1 ectodomain comprising or consisting of MuV F positions 104-469, 104-476, or 104-483.

6. The immunogen of any one of the prior claims, wherein the protomers of the trimer further comprise a mutation to remove a F1/F2 furin cleavage site of the MuV F ectodomain and optionally a first residue of a fusion peptide of a F1 ectodomain.

7. The immunogen of claim 6, wherein the mutation to remove the F1/F2 furin cleavage site and the first residue of the fusion peptide comprise a deletion of MuV F positions 101-103 with positions 100 and 104 fused by a peptide linker.

8. The immunogen of claim 7, wherein the peptide linker is a Gly-Gly-Gly linker.

9. The immunogen of any one of the prior claims, wherein the positioning of the amino acid substitutions is according to a reference MuV F proteins sequence set forth as SEQ ID NO: 1.

10. The immunogen of any one of the prior claims, wherein the protomers of the MuV F ectodomain trimer comprise an amino acid sequence at least 90% identical to

residues 20-483 of any one of SEQ ID NOs: 3-8,

residues 20-476 of any one of SEQ ID NOs: 11-16, 26, or 51, or

residues 20-469 of any one of SEQ ID NOs: 19-24; and

wherein the protomers comprise the one or more amino acid substitutions that stabilize the MuV F ectodomain trimer in the prefusion conformation.

11. The immunogen of claim 10, wherein the protomers of the MuV F ectodomain trimer comprise or consist of the amino acid sequence set forth as

residues 20-483 of any one of SEQ ID NOs: 3-8,

residues 20-476 of any one of SEQ ID NOs: 11-16, 26, or 51, or

residues 20-469 of any one of SEQ ID NOs: 19-24.

12. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer are fused C-terminally to a trimerization domain.

13. The immunogen of claim 12, wherein the trimerization domain comprises a GCN4 trimerization domain, a T4 fibritin trimerization domain, or both.

14. The immunogen of claim 13, wherein

the GCN4 trimerization domain comprises an amino acid sequence set forth as IEDKIEEILSKIYHIENEIARIKKLIGEAP (SEQ ID NO: 33);

the T4 fibritin trimerization domain comprises an amino acid sequence set forth as GYIPEAPRDGQAYVRKDGEWVLLSTFL (SEQ ID NO: 34); and/or

the trimerization domain comprising both the GCN4 and T4 fibritin trimerization domains comprises an amino acid sequence set forth as IEDKIEEILSKIYHIENEIARIKKLIGEAPGSGYIPEAPRDGQAYVRKDGEWVLLSTFL (SEQ ID NO: 35).

15. The immunogen of any one of claims 12-14, wherein the protomers of the MuV F ectodomain trimer fused to the trimerization domain comprise an amino acid sequence at least 90% identical to

residues 20-513 of any one of SEQ ID NOs: 3-8,

residues 20-506 of any one of SEQ ID NOs: 11-16, 26, or 51, or

residues 20-499 of any one of SEQ ID NOs: 19-24; and

wherein the protomers comprise the one or more amino acid substitutions that stabilize the MuV F ectodomain trimer in the prefusion conformation.

16. The immunogen of claim 15, wherein the protomers of the MuV F ectodomain trimer fused to the trimerization domain comprise or consist of the amino acid sequence set forth as

residues 20-513 of any one of SEQ ID NOs: 3-8,

residues 20-506 of any one of SEQ ID NOs: 11-16, 26, or 51, or

residues 20-499 of any one of SEQ ID NOs: 19-24.

17. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer are linked to a heterologous protein.

18. The immunogen of claim 17, wherein the heterologous protein is an ectodomain head or ectodomain stalk and head of a MeV H protein or a MuV HN protein.

19. The immunogen of claim 18, wherein the ectodomain head or ectodomain stalk and head of the MeV H protein or the MuV HN protein is fused C-terminally to a trimerization domain that is fused C-terminally to the protomer of the recombinant MuV F ectodomain trimer.

20. The immunogen of claim 19, wherein the protomers of the MuV F ectodomain trimer linked to the trimerization domain and the ectodomain of the MeV H protein or the ectodomain of a MuV HN protein comprise an amino acid sequence set forth as residues 20-966 of SEQ ID NO: 27, residues 21-981 of SEQ ID NO: 28, or residues 20-1006 of SEQ ID NO: 29.

21. An immunogen, comprising:

a recombinant Measles virus (MeV) F ectodomain trimer stabilized in a prefusion conformation by one or more amino acid substitutions in protomers of the trimer, the amino acid substitutions comprising one or more of the following:

cysteine substitutions at one or more of MeV F positions 48 and 284, positions 90 and 225, positions 141 and 270, positions 165 and 171, positions 173 and 245, positions 175 and 241, positions 212 and 236, positions 216 and 233, positions 219 and 224, positions 99 and 117, positions 100 and 117, positions 101 and 117, positions 102 and 117, and positions 103 and 117 that form a non-natural disulfide bond;

a phenylalanine substitution at MeV F position 175; and

a proline substitution at MeV F position 194.

22. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer further comprise one or more additional amino acid substitutions.

23. An isolated immunogen, comprising:

a trimer of fusion proteins, each fusion protein comprising or consisting of, in an N- to C-terminal direction, a trimerization domain, an optional peptide linker, and one or more copies of a MuV HN ectodomain head or a MeV H ectodomain head; or

a trimer of fusion proteins, each fusion protein comprising or consisting of, in an N- to C-terminal direction, one or more copies of a MuV HN ectodomain head or a MeV H ectodomain head, an optional peptide linker, a trimerization domain, an optional peptide linker, and one or more copies of a MuV HN ectodomain head or a MeV H ectodomain head; or

a trimer of fusion proteins, each fusion protein comprising or consisting of, in an N- to C-terminal direction, one or more copies of a MuV HN ectodomain head or stalk and head or a MeV H ectodomain head or stalk and head, an optional peptide linker, a trimerization

domain, an optional peptide linker, and one or more copies of a MuV HN ectodomain head or stalk and head or a MeV H ectodomain head or stalk and head.

24. An isolated immunogen, comprising:
a dimer of a MeV H ectodomain head;
a dimer of a MeV H ectodomain stalk and head;.
a dimer of a MuV HN ectodomain head; or
a dimer of a MuV HN ectodomain stalk and head.

25. The immunogen of any one of the prior claims, conjugated to a heterologous carrier.

26. The immunogen of any one of the prior claims, wherein the immunogen is soluble.

27. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer are fused to a transmembrane domain by a peptide linker, or directly fused to the transmembrane domain.

28. The immunogen of claim 27, wherein the protomers of the recombinant MuV F ectodomain trimer comprise a full-length F_1 protein.

29. A virus-like particle comprising the immunogen of any one of the prior claims.

30. A self-assembling protein nanoparticle comprising the immunogen of any one of the prior claims.

31. A nucleic acid molecule encoding the immunogen of any one of the prior claims.

32. The nucleic acid molecule of claim 31, operably linked to a promoter.

33. A vector comprising the nucleic acid molecule of claim 32.

34. The vector of claim 33, wherein the vector is an RNA vector.

35. A method of producing an immunogen, comprising:
expressing the nucleic acid molecule of any one of claims 33-34 in a host cell; and
purifying the immunogen.

36. The immunogen produced by the method of claim 35.

37. An immunogenic composition, comprising the immunogen, the nucleic acid molecule, the vector, or the virus like particle, of any of one of claims 1-34 and 36, and a pharmaceutically acceptable carrier.

38. Use of the immunogenic composition of claim 37 in the manufacture of a medicament for eliciting an immune response to MuV F in a subject, wherein an effective amount of the immunogenic composition is to be administered to the subject to elicit the immune response.

39. The use of claim 38, wherein the immune response inhibits MuV infection in the subject.

40. The use of claim 38 or 39, wherein the subject is an adult who was previously immunized with a live attenuated vaccine to MuV and the administration boosts the immune response to the MuV.