

Towards a more comprehensive classification of satellite viruses

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Our recent Comment on the nature and place of the so-called virophages in the viral world (Virophages or satellite viruses? *Nature Rev. Microbiol.* **9**, 762–763 (2011))¹ has caught the attention of researchers favouring the virophage concept and initiated a debate on this matter. We welcome the Correspondence article from Desnues and Raoult (Virophages question the existence of satellite viruses. *Nature Rev. Microbiol.* 16 Feb 2012 (doi:10.1038/nrmicro2676-c3)² — which follows a similar Correspondence article from Matthias Fischer³, to which we have responded previously⁴ — and take this occasion to reiterate our conclusion that the general biological properties and behaviour of Sputnik and Mavirus are not at all novel in the virosphere and have been previously described for satellite viruses^{1,4}.

In their Correspondence article, Desnues and Raoult again point out the allegedly unique features of Sputnik and Mavirus: complexity of virion and genome organizations, lack of sequence similarity to other currently isolated viruses, structural relationship to viruses with double- β -barrel capsid proteins^{5,6}, effect on helper virus production and host cell survival, intracellular localization and specific genome expression signals². All these arguments we have addressed and refuted in our two previous communications^{1,4}.

Desnues and Raoult also argue that the parallels we have drawn between the infection characteristics of the Sputnik–mammavirus and satellite tobacco necrosis virus (STNV)–TNV systems^{1,4} are inappropriate — in their words, “equivalent to comparing cows and apples” — because unlike for Sputnik–mammavirus, “the replication cycle of the STNV–TNV couple does not have a transcription stage” (REF. 2). However, contrary to this belief, replication and transcription in many positive-sense RNA viruses are discernible processes and, in fact, can be uncoupled experimentally in members of the family *Tombusviridae*⁷, the viral family to which TNV belongs. It is also not true that “RNA-dependent RNA polymerase (RdRp) ... is a typical viral enzyme that is not found in eukaryotic, bacterial or archaeal genomes”, as functional RdRps, albeit non-homologous to the viral enzymes, are encoded in fungal, nematode and plant genomes⁸. More generally, the reluctance of the authors to consider the parallels between (satellite) viruses with RNA and DNA genomes is surprising, if not alarming. It is also not clear how “Virophages question the existence of satellites” (the title of their Correspondence article); the existence of satellite viruses is an unquestionable fact.

Furthermore, although classical satellite viruses, both those with single-stranded

RNA genomes (STNV) and single-stranded DNA genomes (adeno-associated virus), typically decrease the production of their helper viruses to non-detectable amounts (see the section entitled ‘Effect of the satellite virus on the helper virus’ in our Comment)¹, Desnues and Raoult point out that in the case of STNV–TNV the production of the helper virus is sometimes increased during a co-infection⁹. However, this is not a typical situation. It has been suggested that under certain circumstances STNV alters host cell physiology, rendering the cell susceptible to TNV infection (that is, increasing the number of TNV-susceptible cells)⁹. The effect on helper virus production at the infected-cell level would nevertheless be negative. More generally, the extent of the effect a satellite virus has on its helper virus largely depends on the ratio of the two viruses (satellite particles per helper particle) during a co-infection. For Mavirus–*Cafeteria roenbergensis* virus and Sputnik–mammavirus, this ratio has not been estimated (at least, such estimates have not been reported)^{10,11}, precluding meaningful comparisons with other, more comprehensively studied satellite virus–helper virus systems.

In our Comment we pointed out the shortcomings associated with the current classification scheme of satellite viruses — or, more accurately, the lack of one¹. (Notably, in the ninth report of the International Committee on Taxonomy of Viruses (ICTV), Sputnik is classified together with other satellite viruses¹²). In their Correspondence article, Desnues and Raoult also criticize the ICTV classification of satellite viruses and attempt “to go beyond semantics” by suggesting the introduction of “a new group called ‘viruses

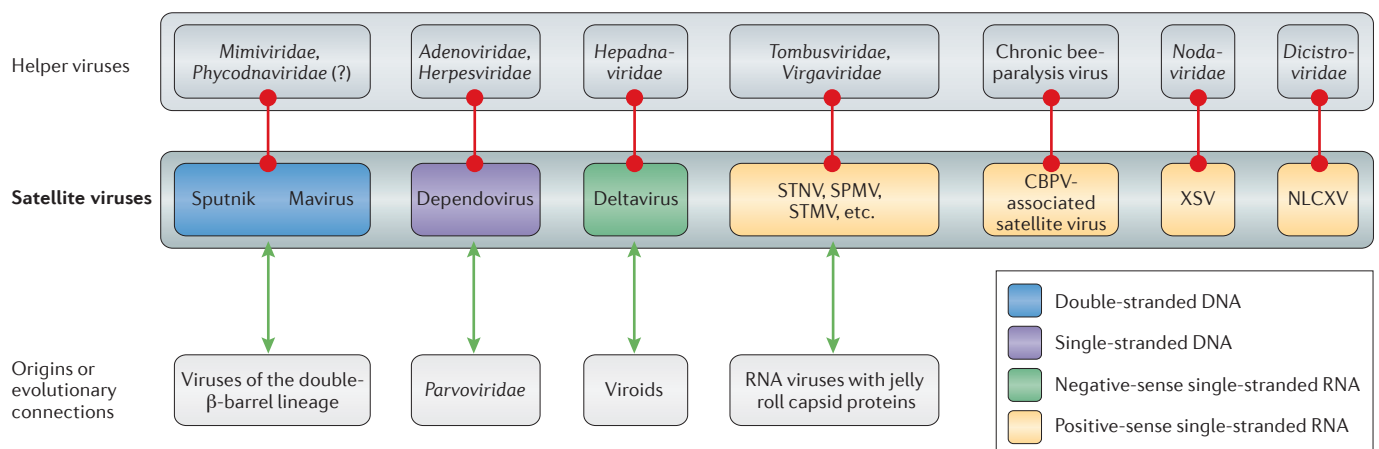


Figure 1 | Satellite viruses and their classification. The currently known satellite viruses are grouped into family-level taxa (boxes) on the basis of available sequence and structural information. Satellite virus groups are coloured according to their genome types. Associated helper viruses are indicated above each group of satellite viruses. In addition, possible

evolutionary relationships to other viruses or viroids are shown in the lower row. SPMV, satellite panicum mosaic virus; STMV, satellite tobacco mosaic virus; XSV, extra small virus; NLCXV, *Nilaparvata lugens* commensal X virus; CBPV, chronic bee-paralysis virus.

of Viruses', encompassing virophages and traditional satellite RNA viruses"; in other words, they propose to rename the currently existing class 'satellite viruses' as 'viruses of Viruses'. Instead, we propose to adopt, in our opinion a more meaningful scheme for classification of satellite viruses into family-level (and perhaps higher-level) taxa (FIG. 1). This approach is compatible with the current ICTV classification scheme for 'autonomous' viruses and would be a firm step towards bringing conceptual order to the classification of satellite viruses and the virosphere in general¹³.

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Competing interests statement

The authors declare no competing financial interests.