CASP16
RNA-Puzzles Assessments

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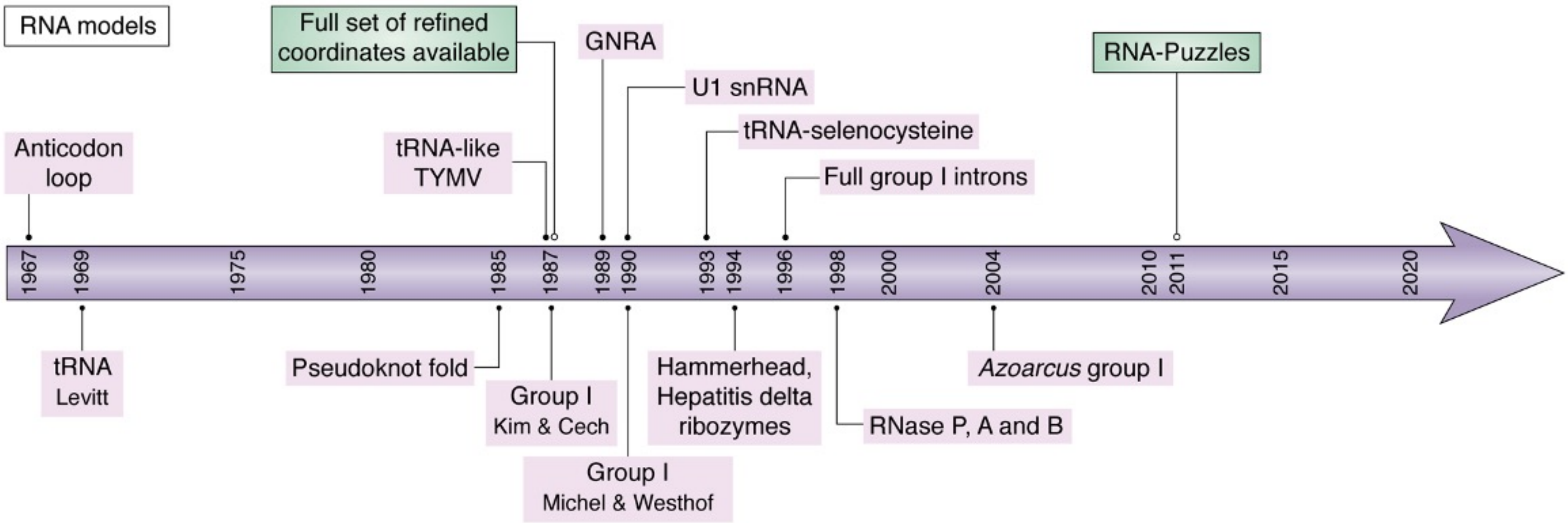
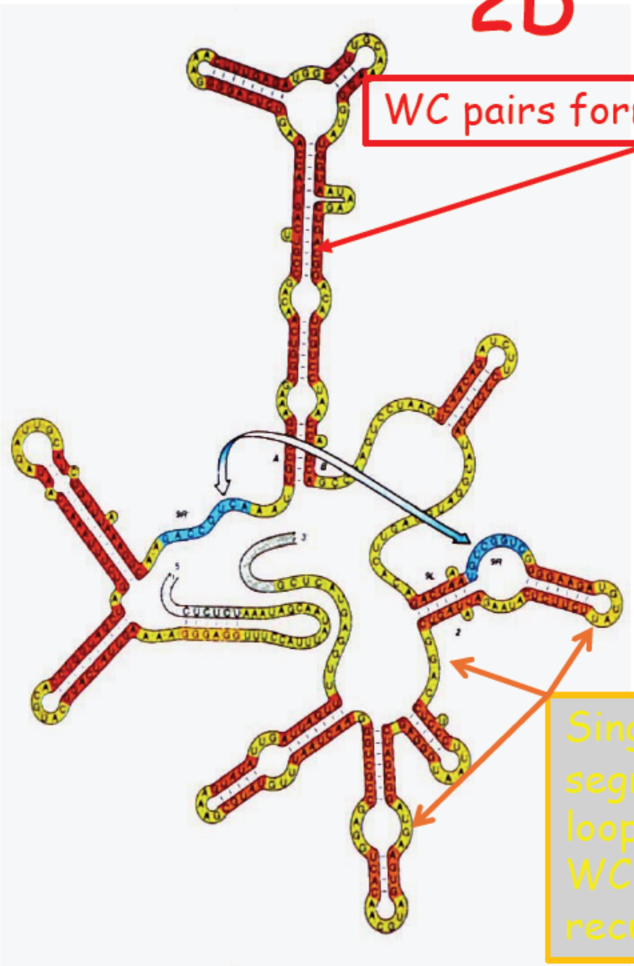
http://www.rnapuzzles.org/

Quick timeline on RNA Modelling

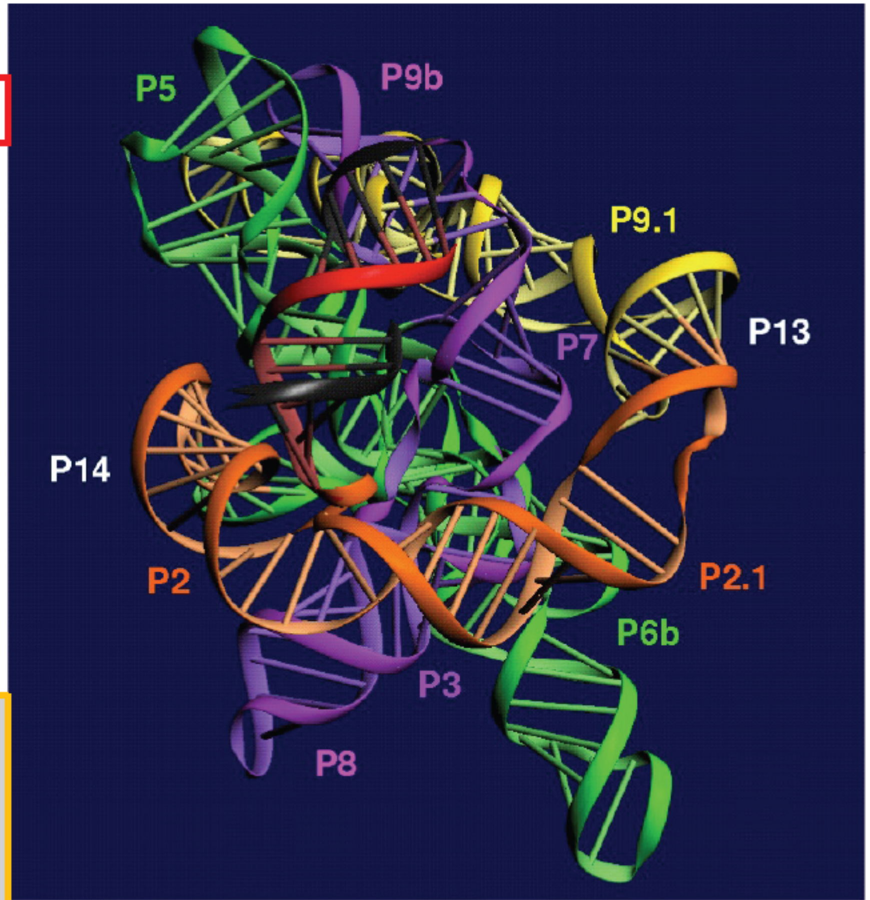


An RNA-centric historical narrative around the Protein Data Bank,
E. Westhof, N.B. Leontis, J. Biol. Chem. (2021) 296,100555

2D



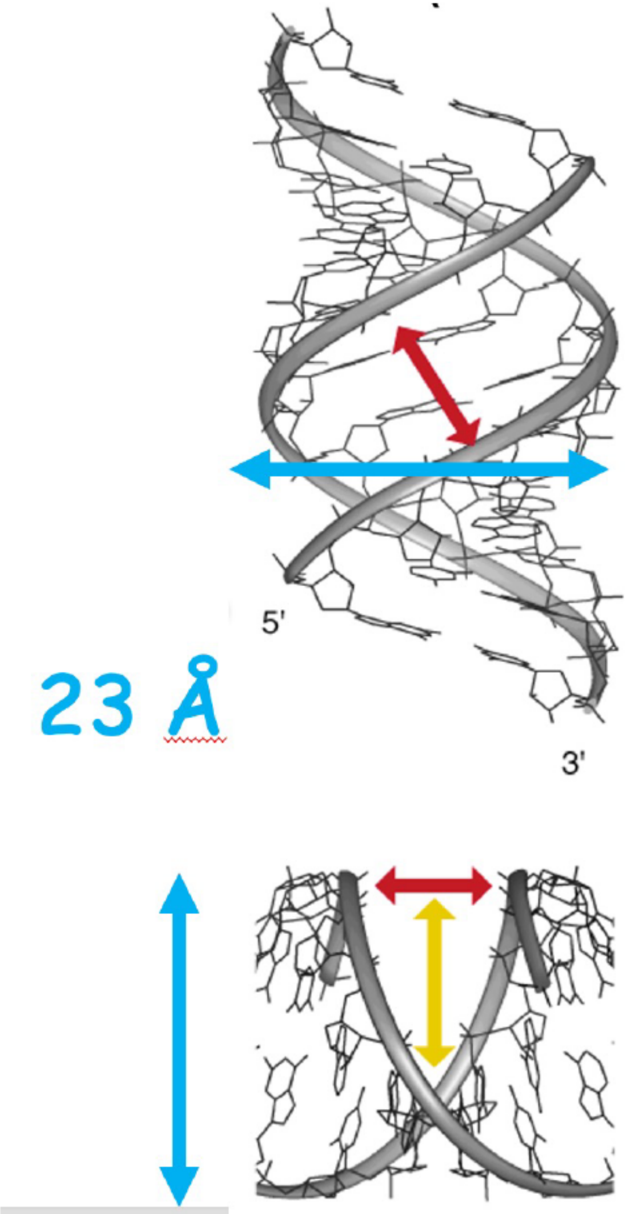
3D

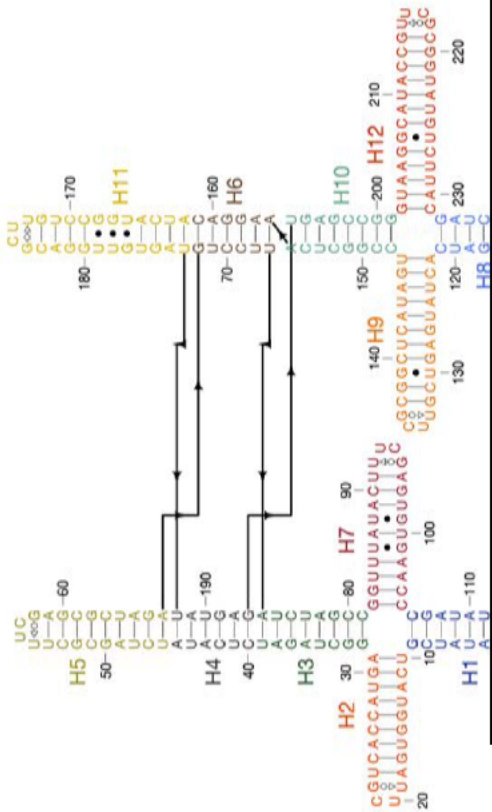


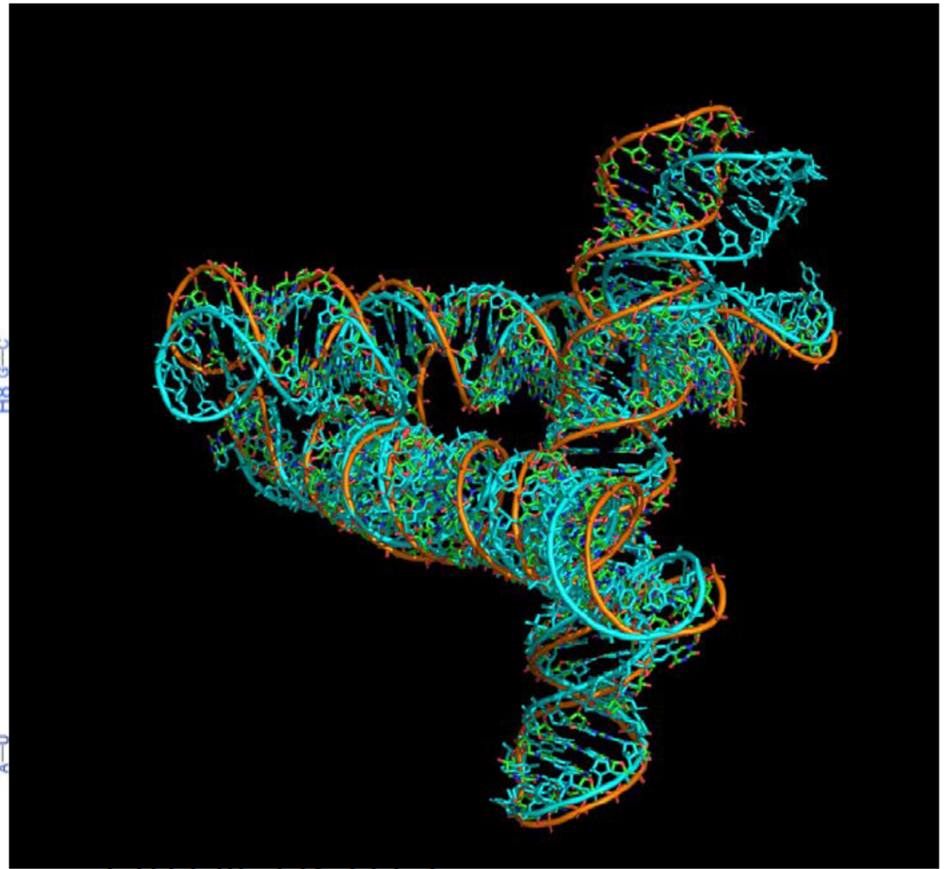
F. Michel et al., Biochimie 1982
T. Cech, Sci. Am. 1986

F. Michel & E. Westhof, J Mol Biol 1990
V. Lehnert et al. Chemistry & Biology 1996

RNA helices are bulky with weak bendability;
The 5' and 3' ends junctions must link (their lengths are critical).

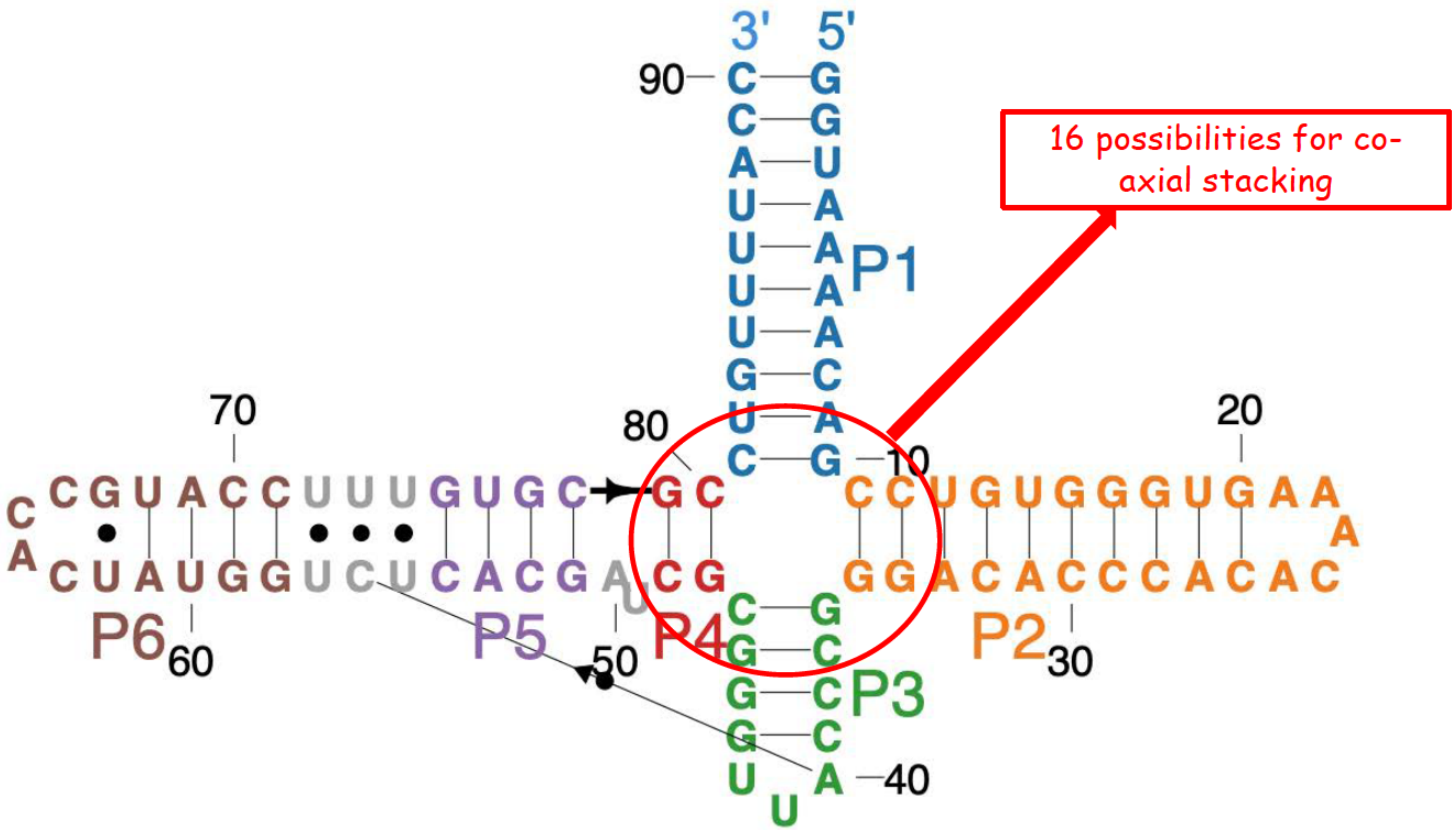




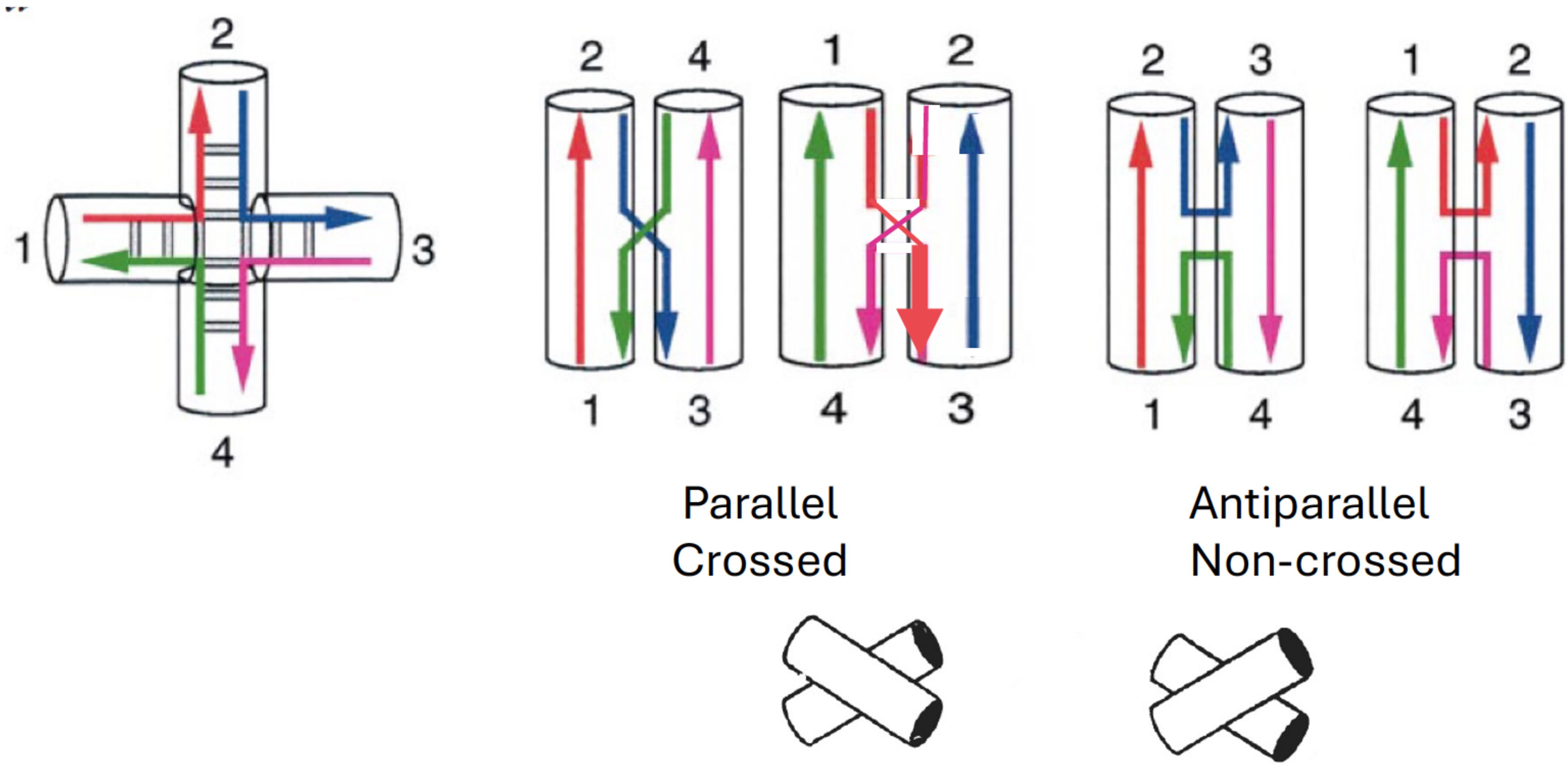


CRT128 / TS232_1
RMSD 4.3 Å
DI 4.9

A four-way Junction without unpaired nts at the junction

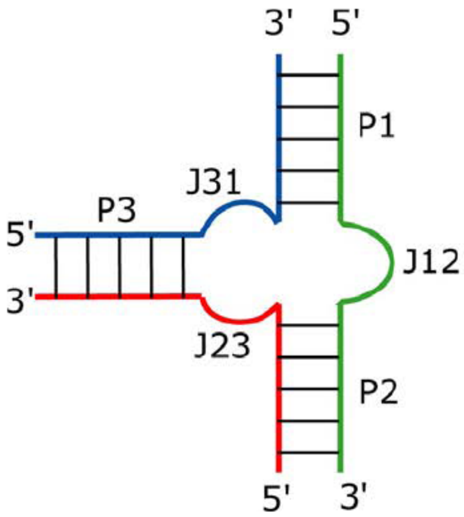


A four-way Junction without unpaired nts at the junction

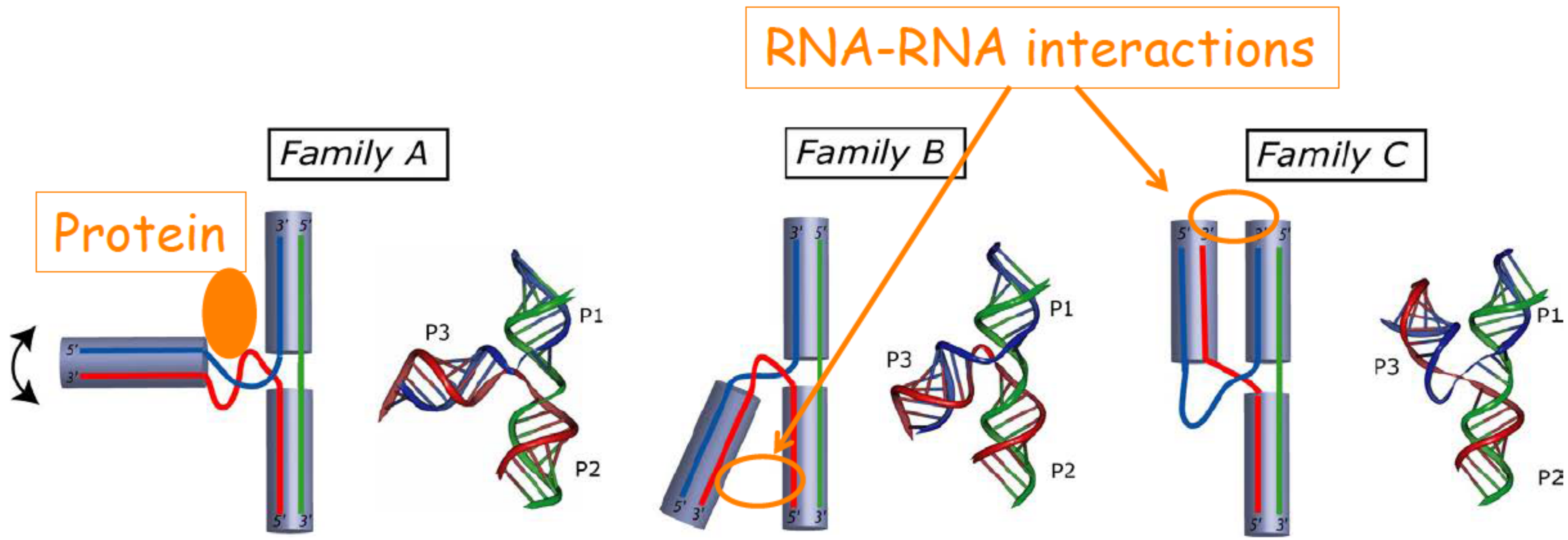


Plus chirality of the co-axial helices !

Nature Struct Biol 6, 897 (1999)

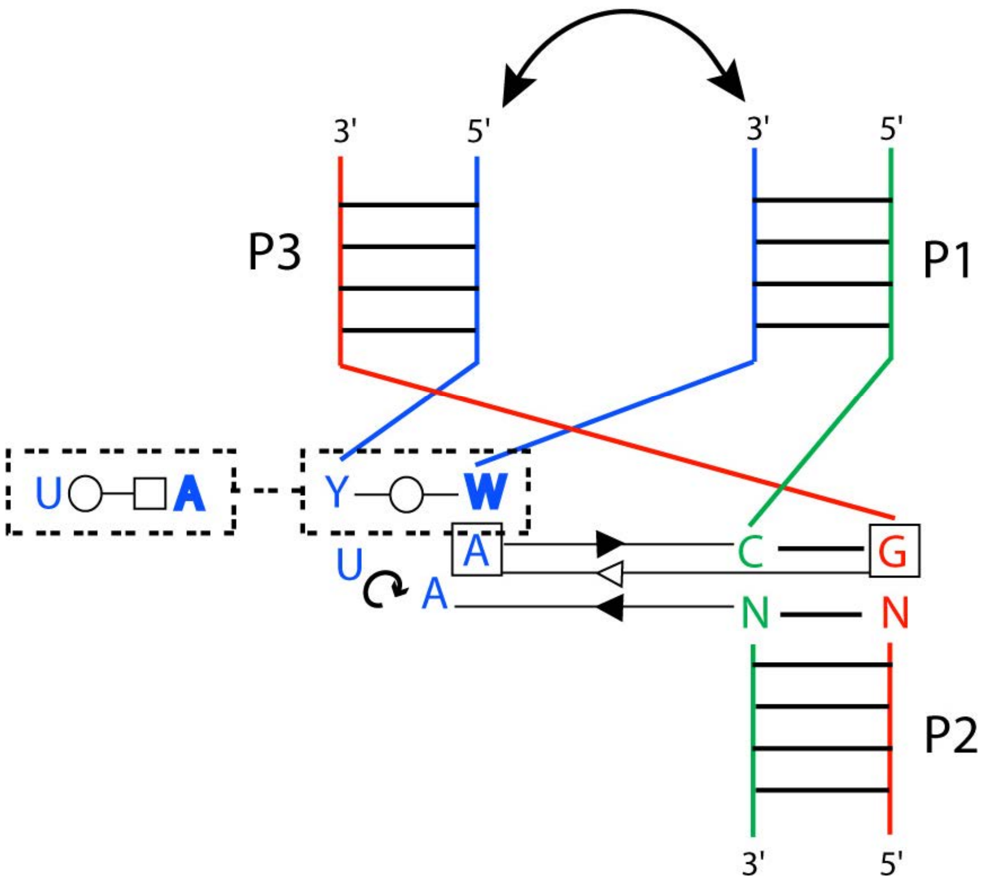


	J31	J23	J12
A Cases:10	2±1 <	6±3	2±2
B Cases:6	4±2 ~	4±2	4±2
C Cases:17	6±3 >	3±2	2±3

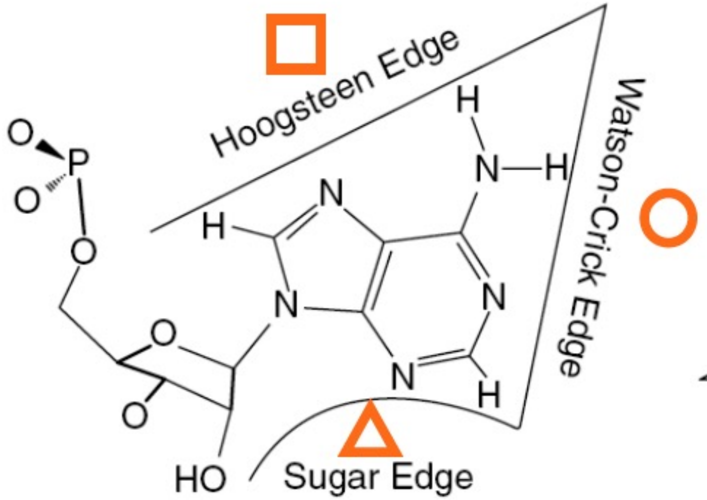


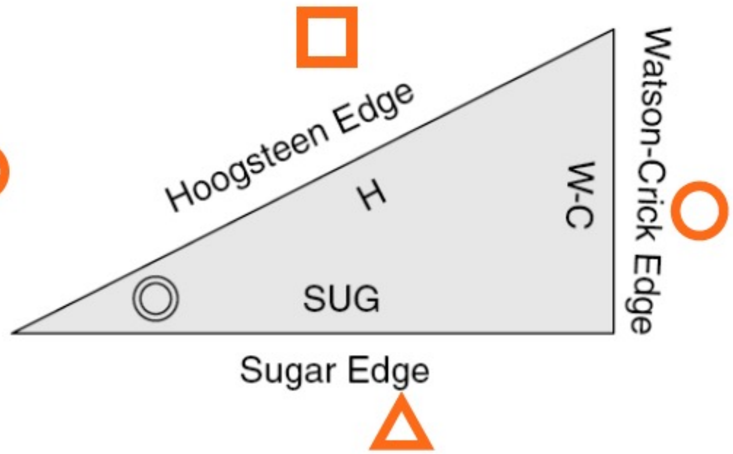
RNA 12, 83 (2006).

Family C



Each base has three edges available for H-bonding





The 2D structure is defined by the interactions between the side-chains, the bases, not the sugar-phosphate backbone.

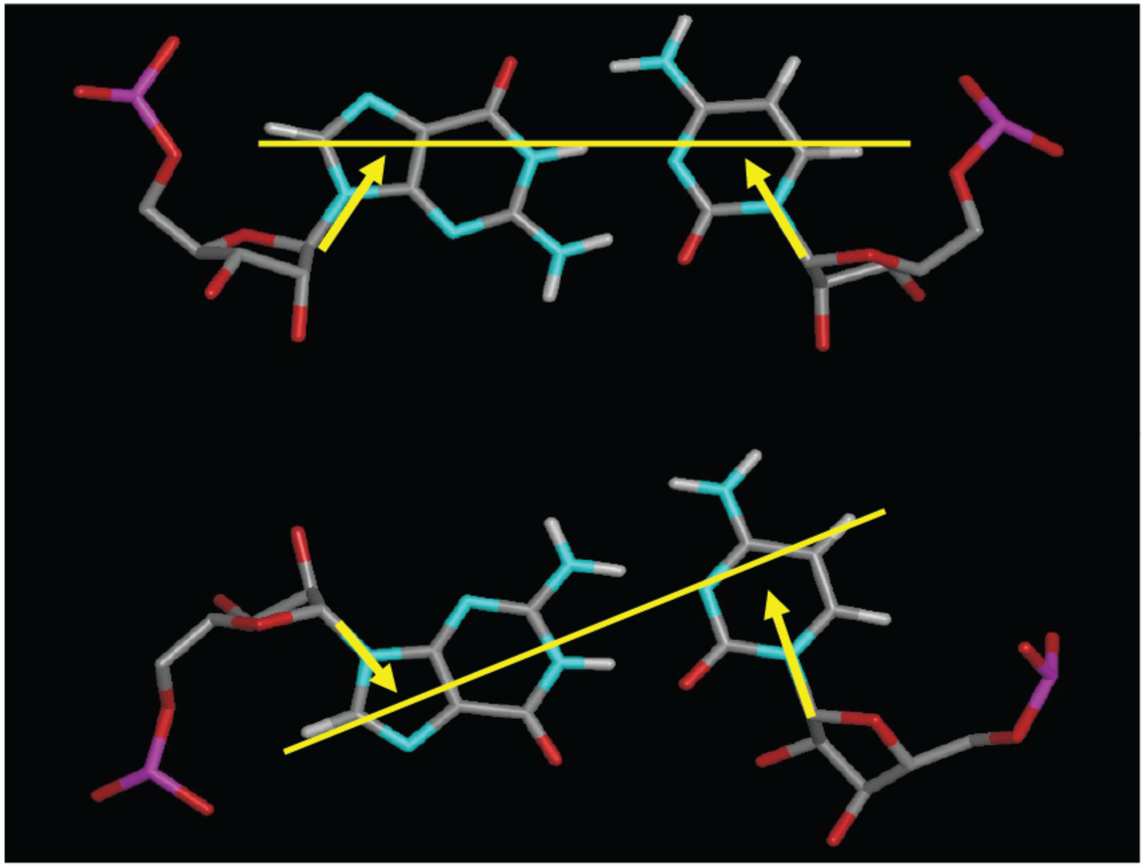
Two orientations of approach for the two bases

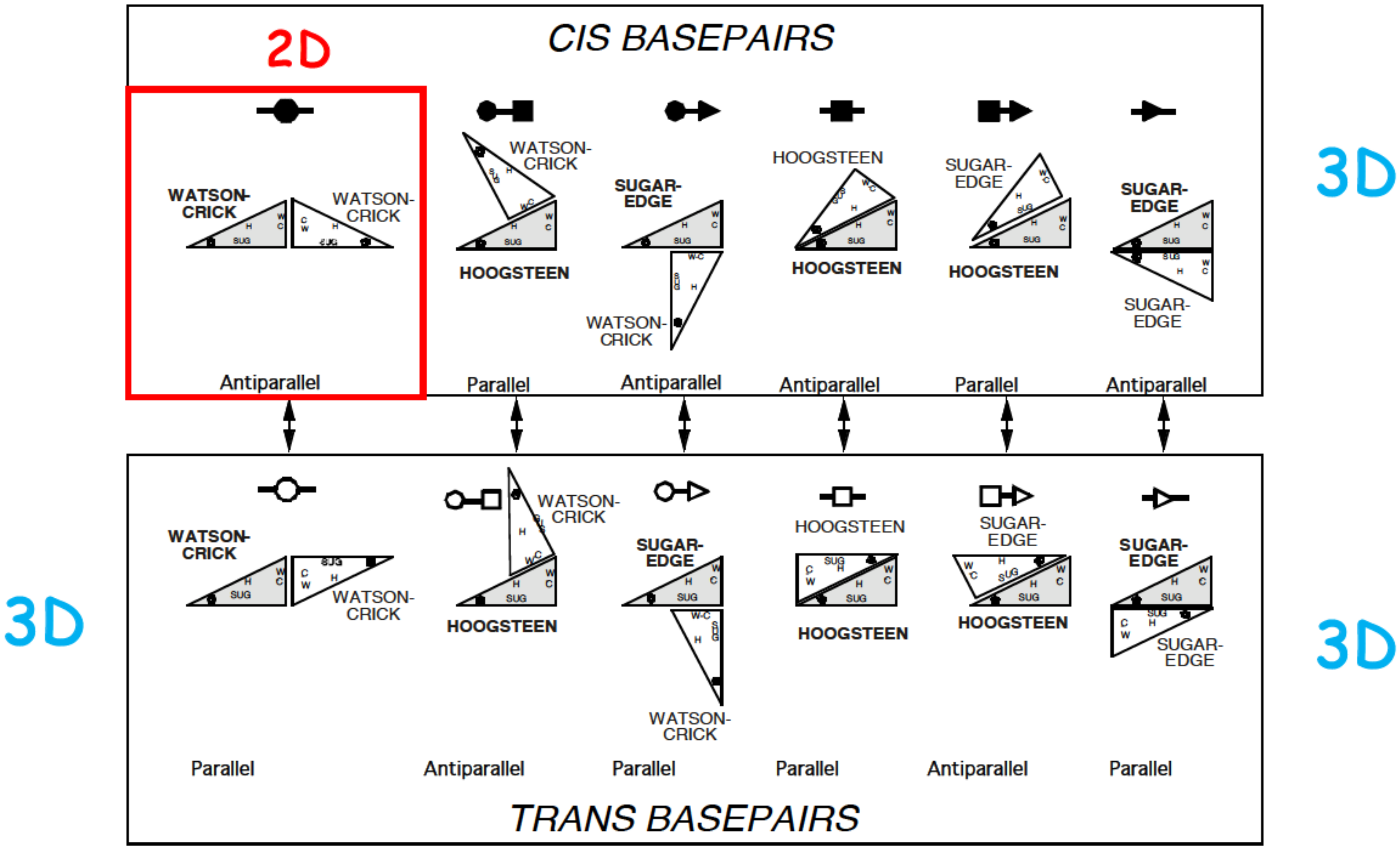
- *Cis* (*default*)

● ■ ▲

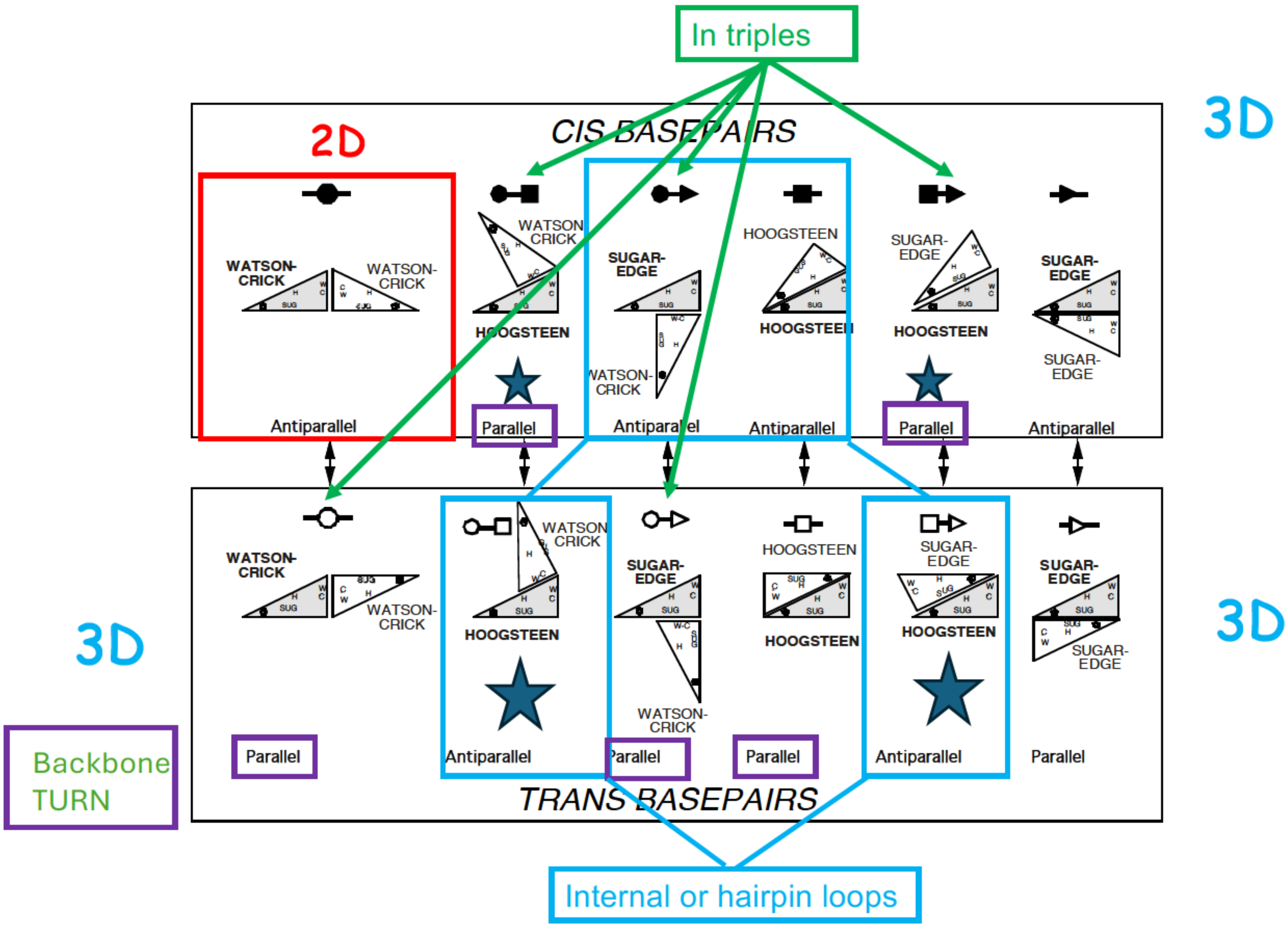
- *Trans*

○ □ △



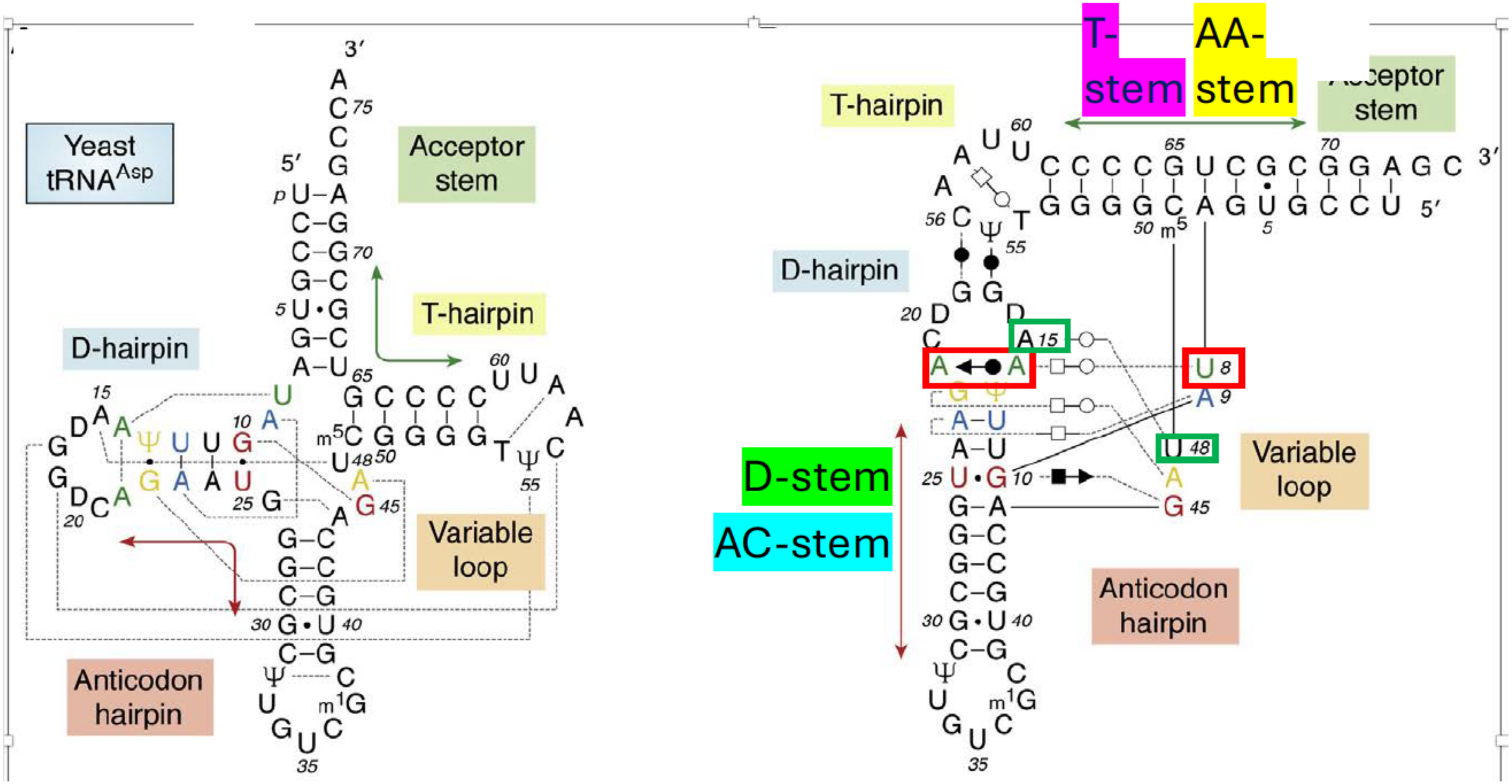


NATURE (1992) 358: 459-460 DOI: 10.1038/358459b0

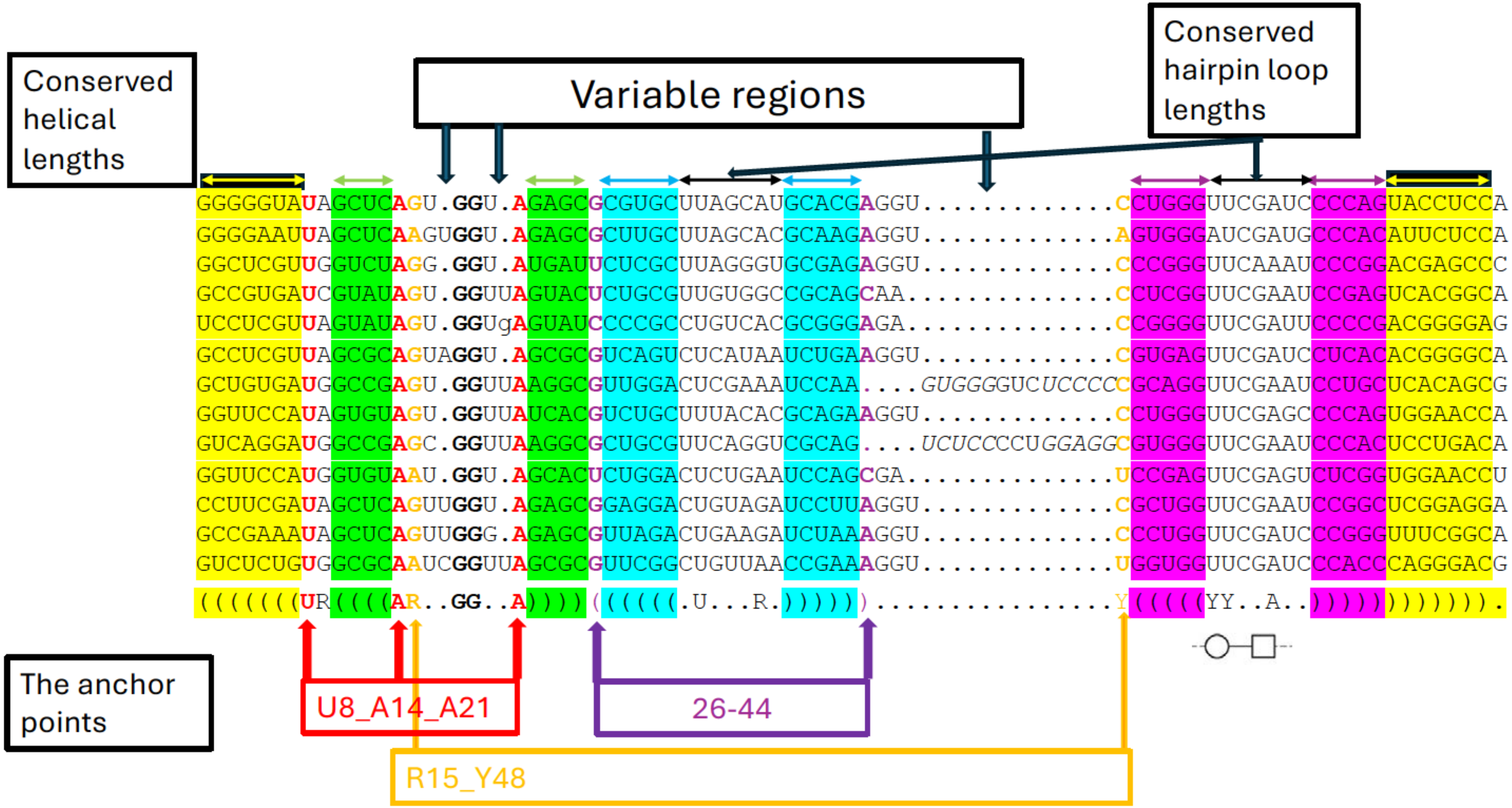


In triples
3D
CIS BASEPAIRS
2D
WATSON-CRICK
WATSON-CRICK
Antiparallel
WATSON CRICK
HOOGSTEEN
Parallel
SUGAR-EDGE
WATSON-CRICK
Antiparallel
HOOGSTEEN
HOOGSTEEN
Antiparallel
SUGAR-EDGE
HOOGSTEEN
Parallel
SUGAR-EDGE
SUGAR-EDGE
Antiparallel
WATSON-CRICK
WATSON-CRICK
Parallel
WATSON CRICK
HOOGSTEEN
Antiparallel
SUGAR-EDGE
WATSON-CRICK
Parallel
HOOGSTEEN
HOOGSTEEN
Parallel
SUGAR-EDGE
HOOGSTEEN
Antiparallel
SUGAR-EDGE
SUGAR-EDGE
Parallel
3D
3D
Backbone TURN
TRANS BASEPAIRS
Internal or hairpin loops

An RNA Architecture results from the integration of several interaction networks: Watson-Crick base pairs (2D), and non-Watson-Crick base pairs, stacking bases,...

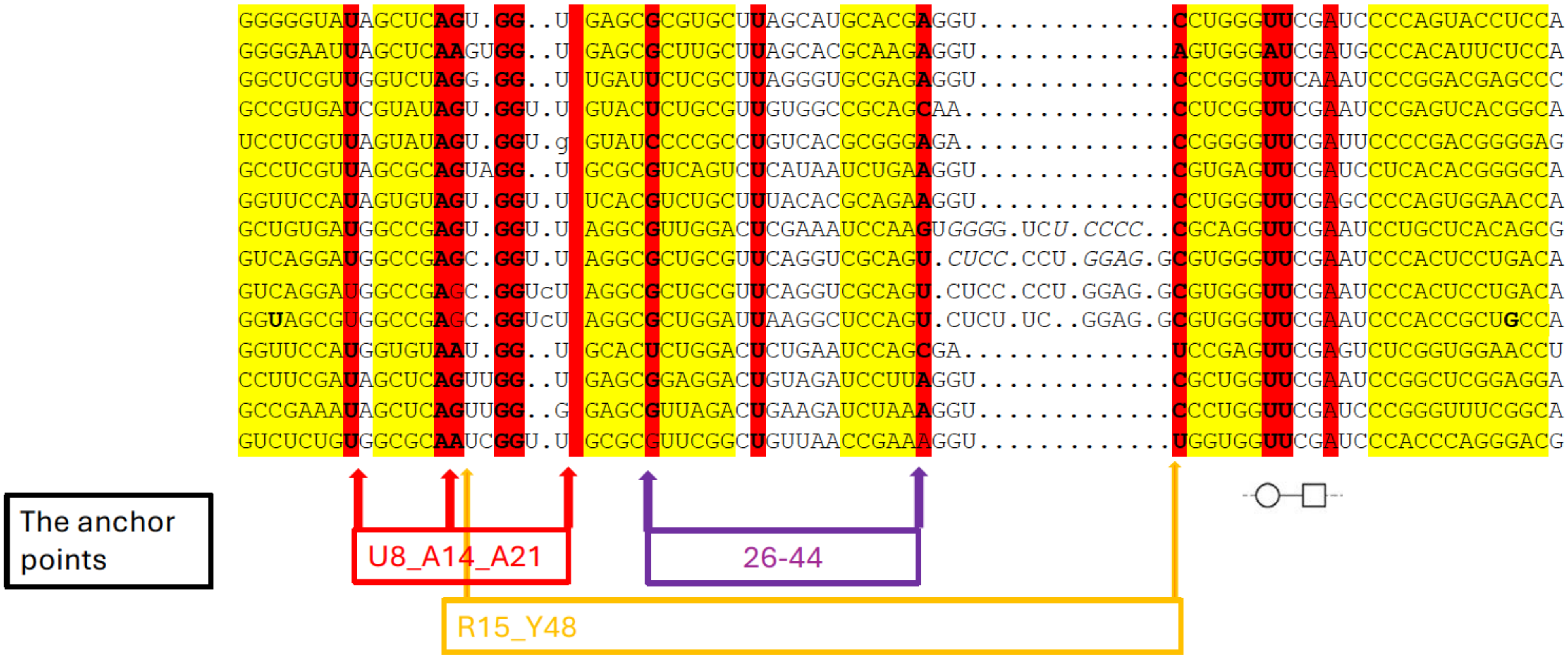


Like a native experimental structure, an accurate model should explain the conservation, semi-conservation, absence of gaps,…of structural alignments



Example on some human cytoplasmic tRNAs

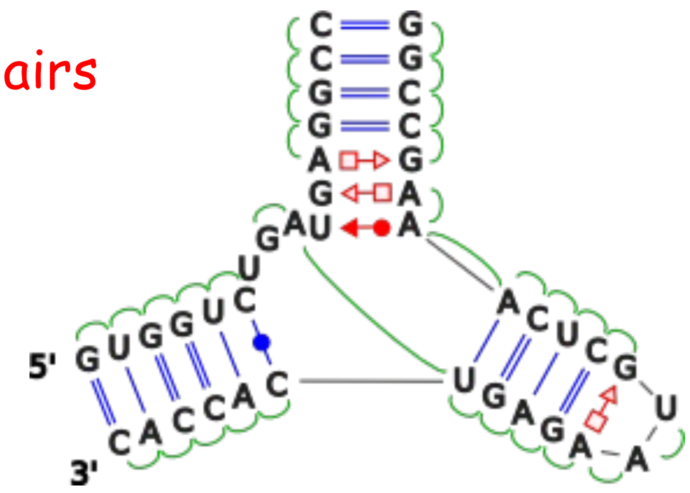
In yellow, helices of 2D structures, in red tertiary pairs of 3D structure, in white loop regions



Metrics for comparisons based on Interaction Networks

Set of base-base interactions constitute the elementary structural building units of RNA molecules

- Watson-Crick base pairs
- Non Watson-Crick base pairs
- Base stacking



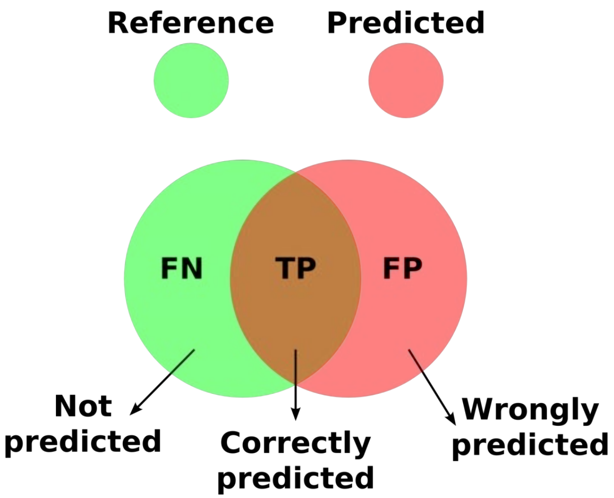
Good Structure Prediction
|| ^
v ||
Correct Interaction Network

Parisien et al. RNA (2009), 15:1875–1885.

INF - Interaction Network Fidelity

INF: How well the predicted model (**P**) fits the interaction network of the reference model (**R**)?

$$INF = MCC(P,R) = \sqrt{\frac{|TP|}{|TP|+|FP|} \times \frac{|TP|}{|TP|+|FN|}} \in [0,1]$$



For
- Watson-Crick base pairs: INFwc
- Non Watson-Crick base pairs: INFnwc
- Base stacking: INFstack

Deformation Index

$$\mathrm{DI(A,B) = RMSD(A,B)/INF(A,B).}$$

Meaningful RMSD as INF approaches 1 (i.e., the majority of the interactions in A are reproduced in B).

Parisien et al. RNA (2009), 15:1875-1885.

RNA Puzzles

- *RNA-Puzzles* is a collective blind experiment for the evaluation of automatic RNA three-dimensional structure prediction.

- It relies on voluntary RNA structuralists.

- And voluntary teams of RNA modelers and contributors.

Started 12 years ago with José Cruz (now in Lisbon)

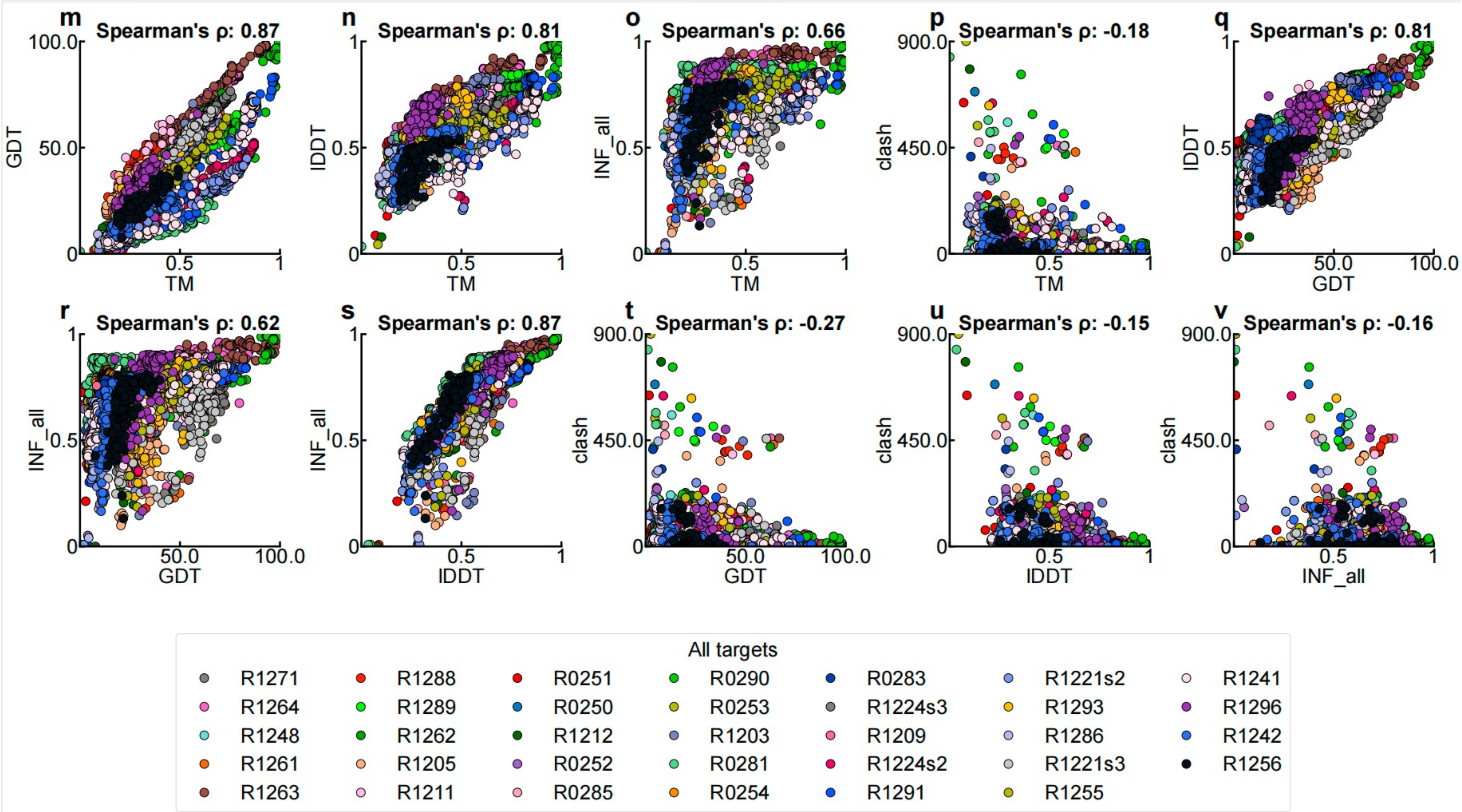
Continued since with Zhichao Miao (now in Guangzhou)

RNA Puzzles differences with CASP

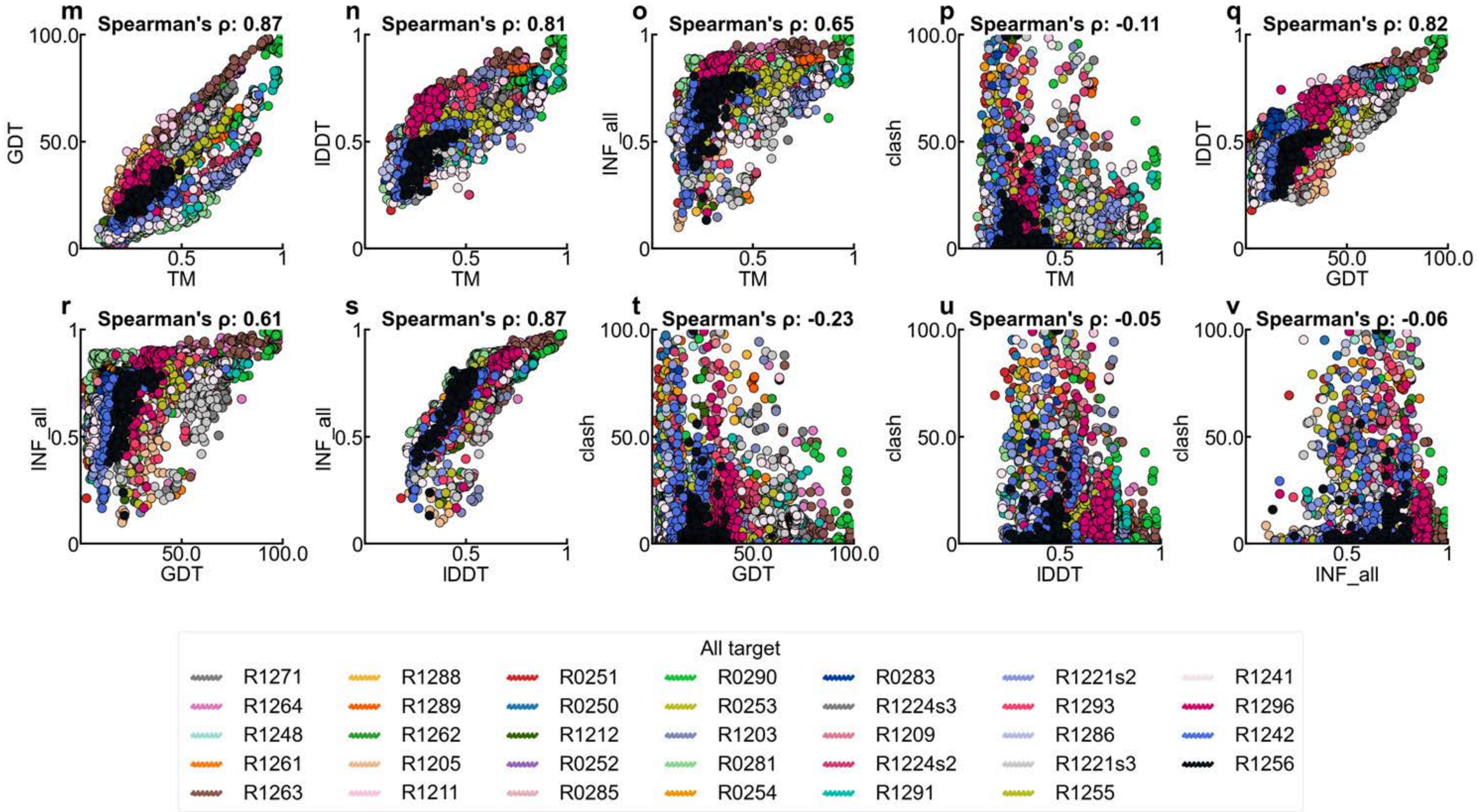
- *New Puzzles are accepted continuously on a rolling basis*

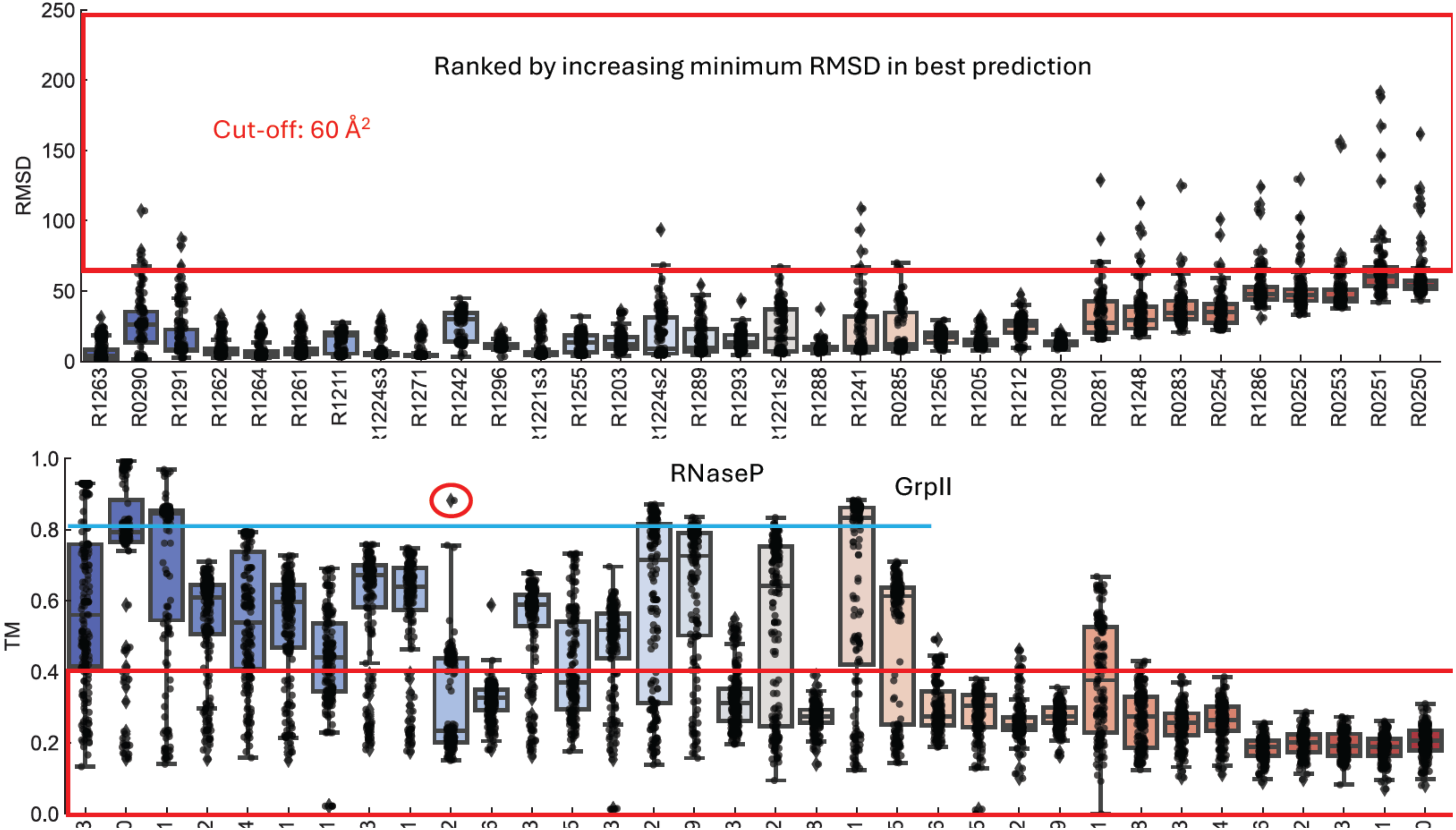
- We have an agreement with CASP about the absence of Puzzles during the CASP contest period (May-August every two years).

Correlations between different metrics

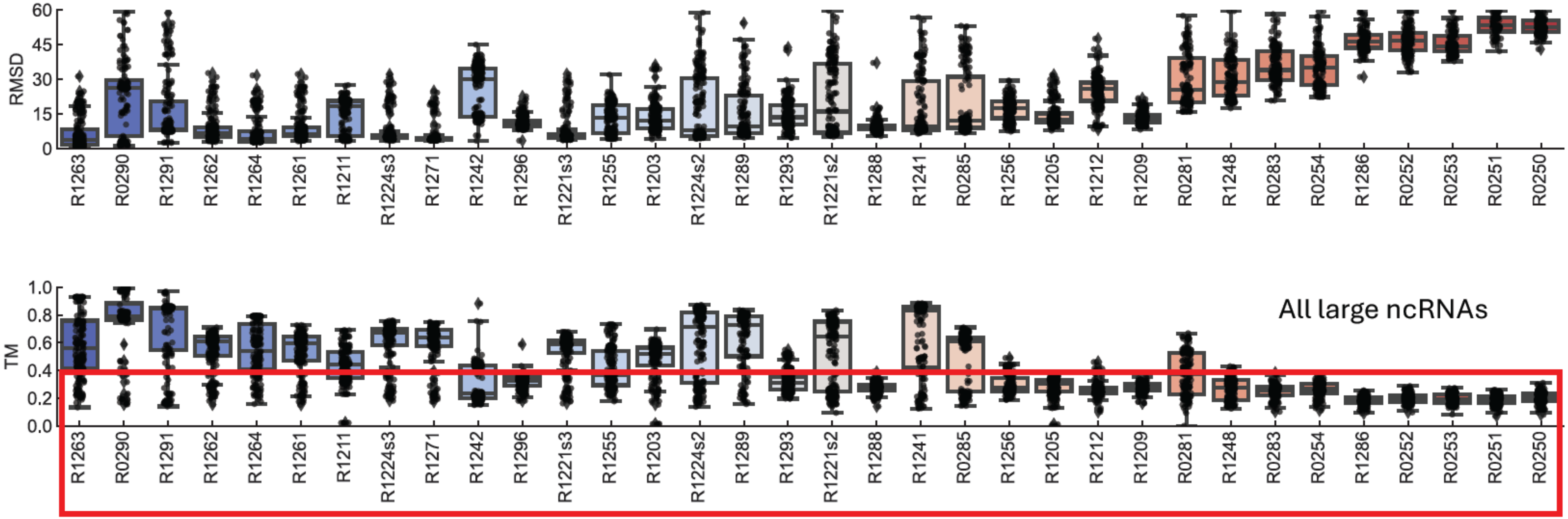


Correlation between different metrics(clashscore < 100)



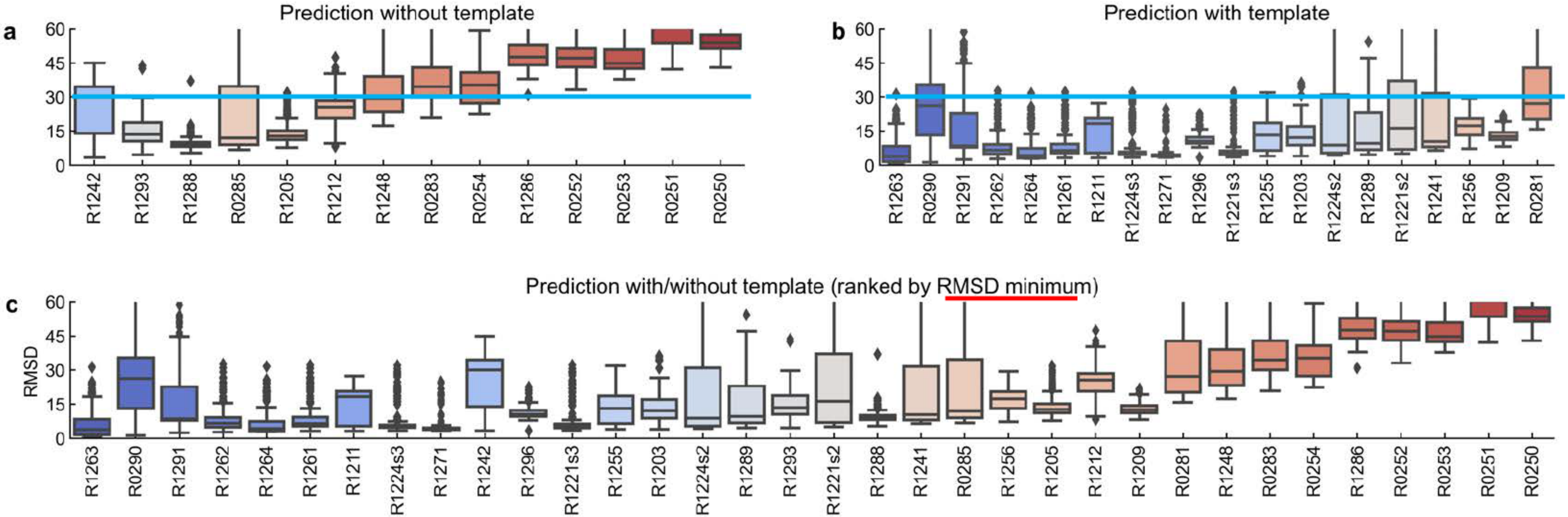


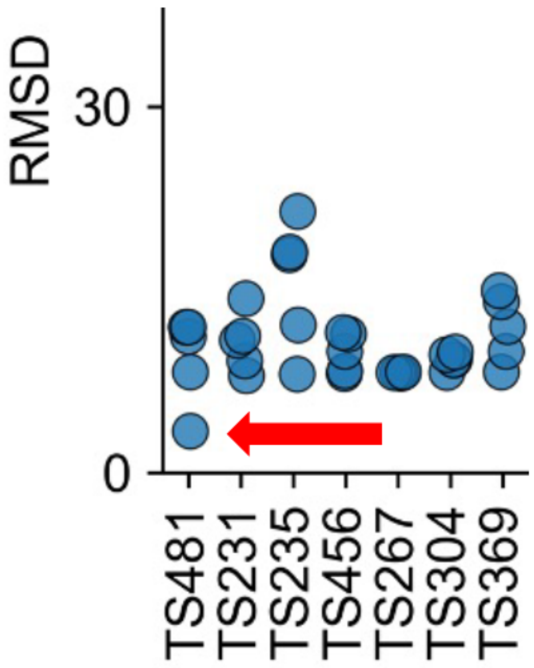
Ranked by increasing minimum RMSD in best prediction
Cut-off: 60 Å2
RMSD
TM
RNaseP
GrpII
R1263
R0290
R1291
R1262
R1264
R1261
R1211
R1224s3
R1271
R1242
R1296
R1221s3
R1255
R1203
R1224s2
R1289
R1293
R1221s2
R1288
R1241
R0285
R1256
R1205
R1212
R1209
R0281
R1248
R0283
R0254
R1286
R0252
R0253
R0251
R0250

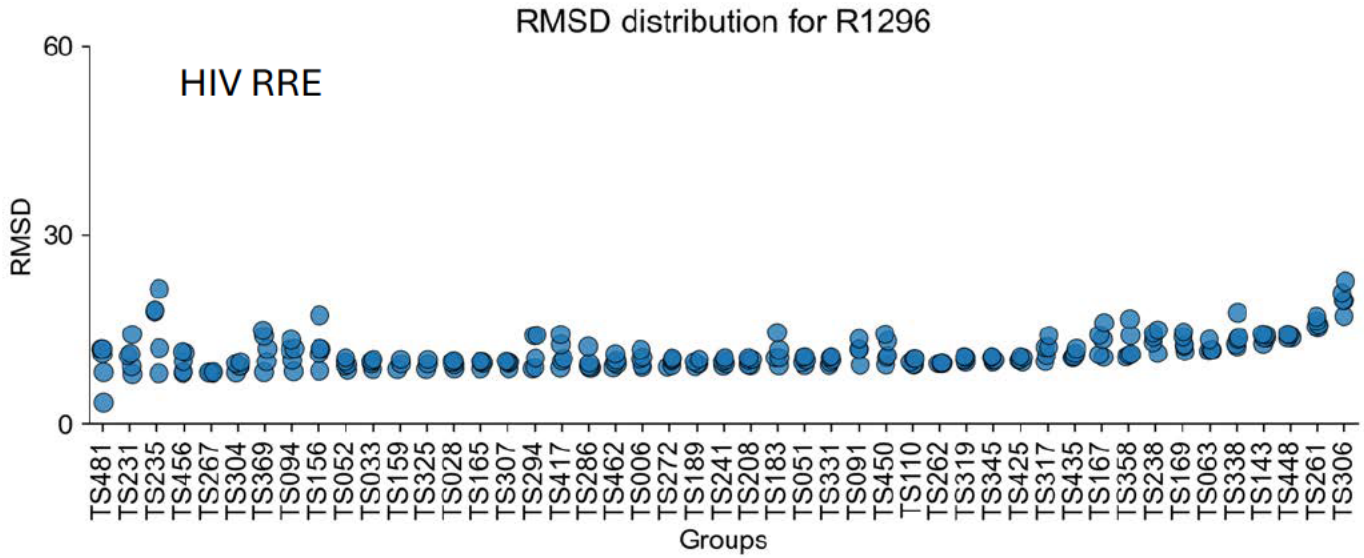


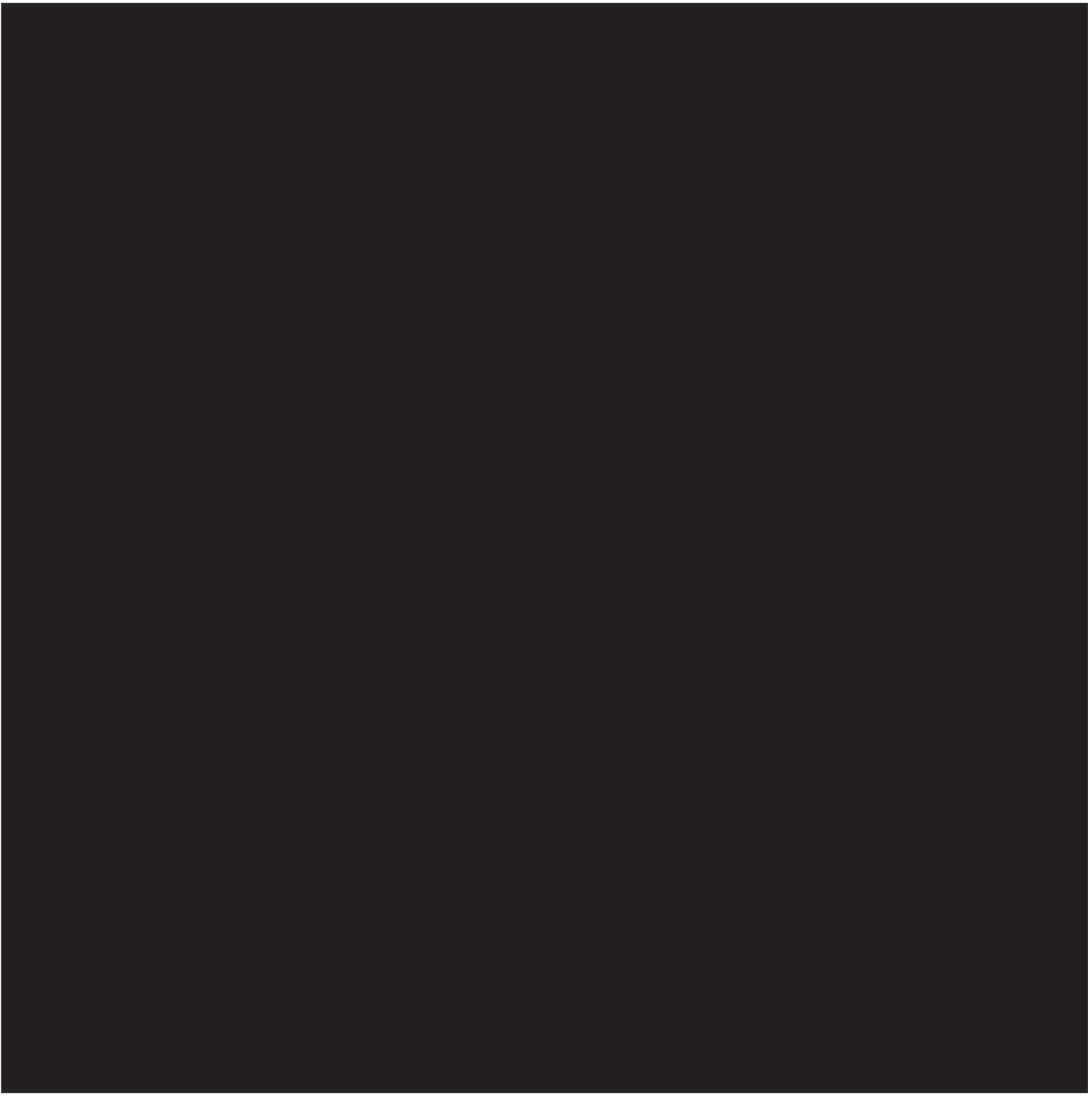
With a cutoff below 0.4, too many targets would be eliminated

All large ncRNAs
GOLLD, ROOL, OLE

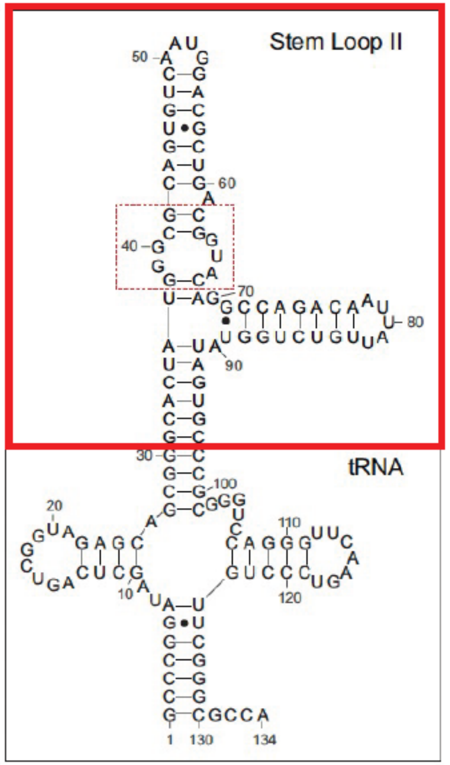



RMSD
30
0
TS481
TS231
TS235
TS456
TS267
TS304
TS369

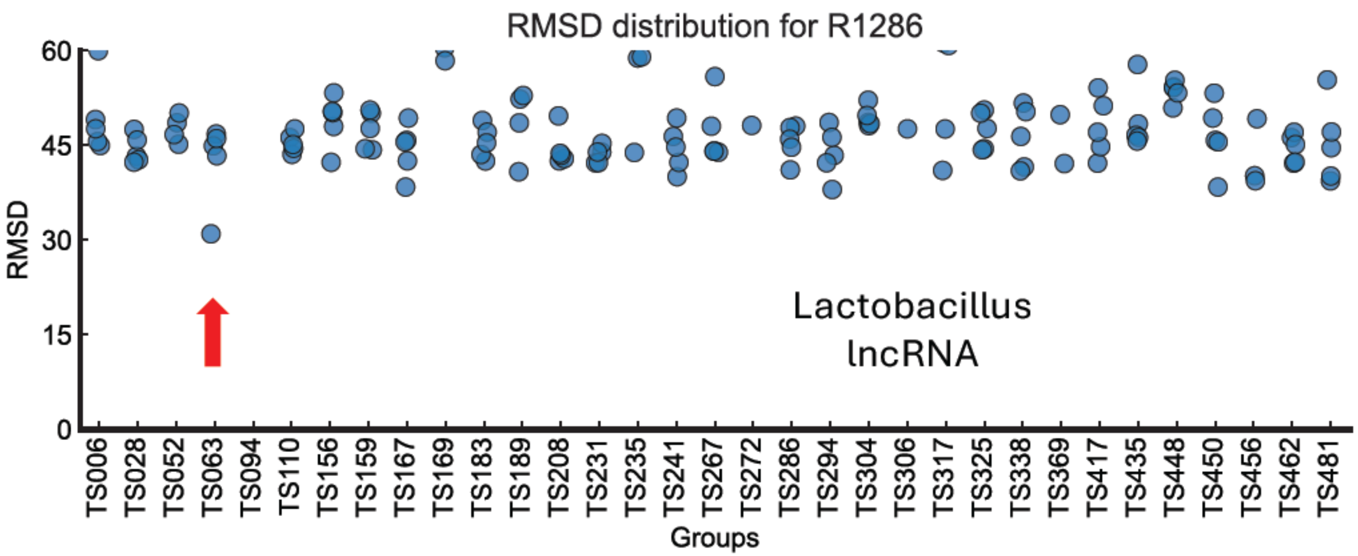

RMSD distribution for R1296
HIV RRE
RMSD
60
30
0
TS481
TS231
TS235
TS456
TS267
TS304
TS369
TS094
TS156
TS052
TS033
TS159
TS325
TS028
TS165
TS307
TS294
TS417
TS286
TS462
TS006
TS272
TS189
TS241
TS208
TS183
TS051
TS331
TS091
TS450
TS110
TS262
TS319
TS345
TS425
TS317
TS435
TS167
TS358
TS238
TS169
TS063
TS338
TS143
TS448
TS261
TS306
Groups



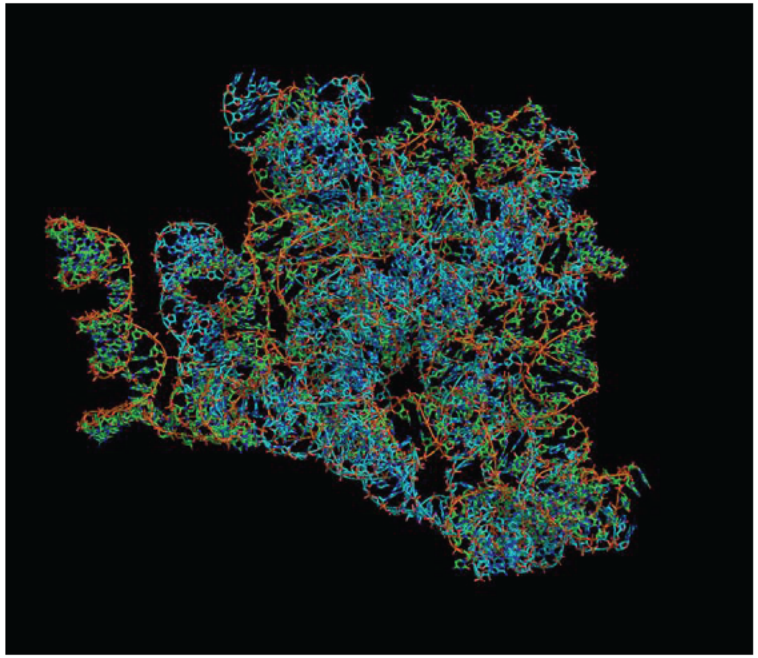
R1209 (R1296) shortened version of the 3w jct of R1203 (published)

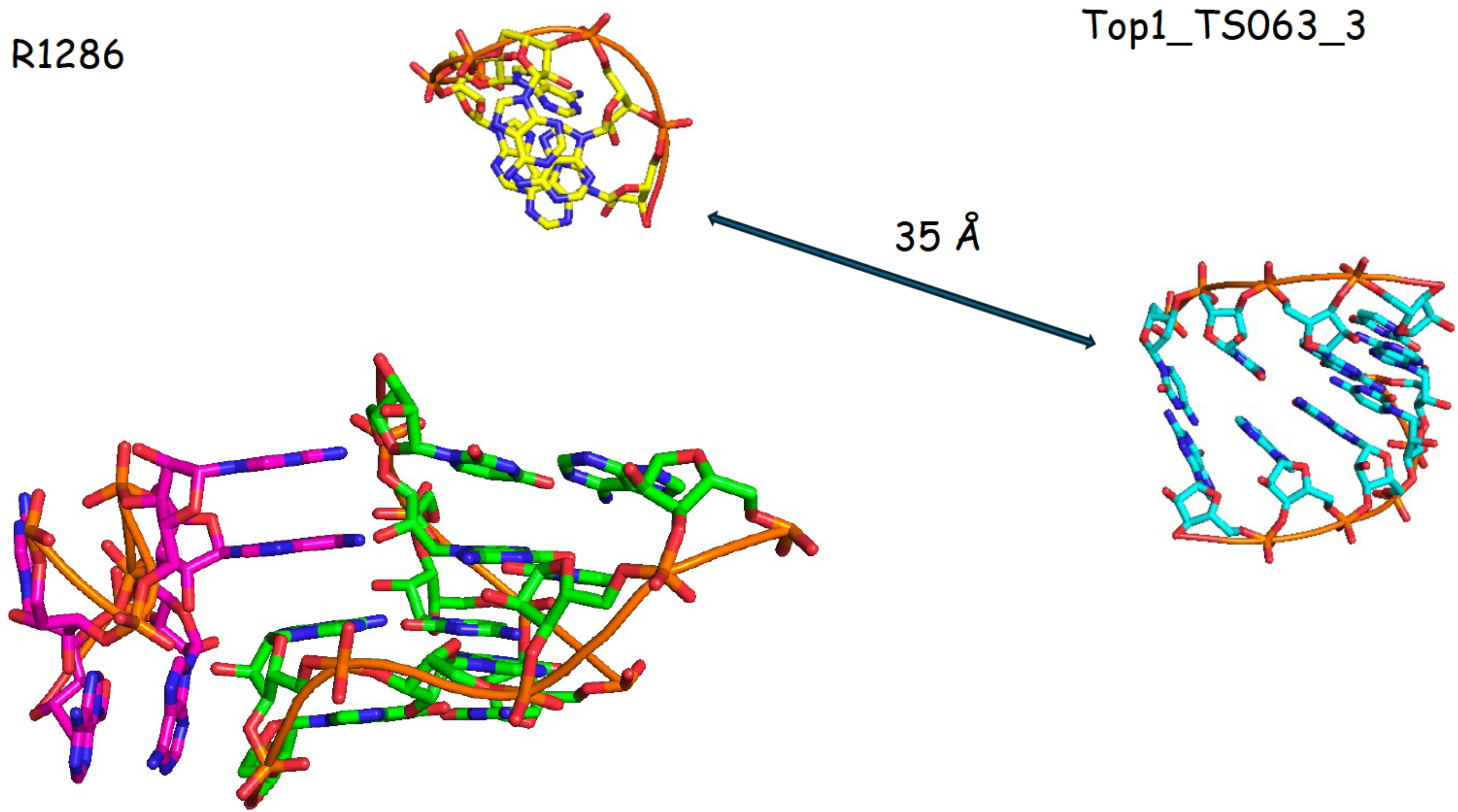


Nature Comm 15, 4198 (2024) 8UO6



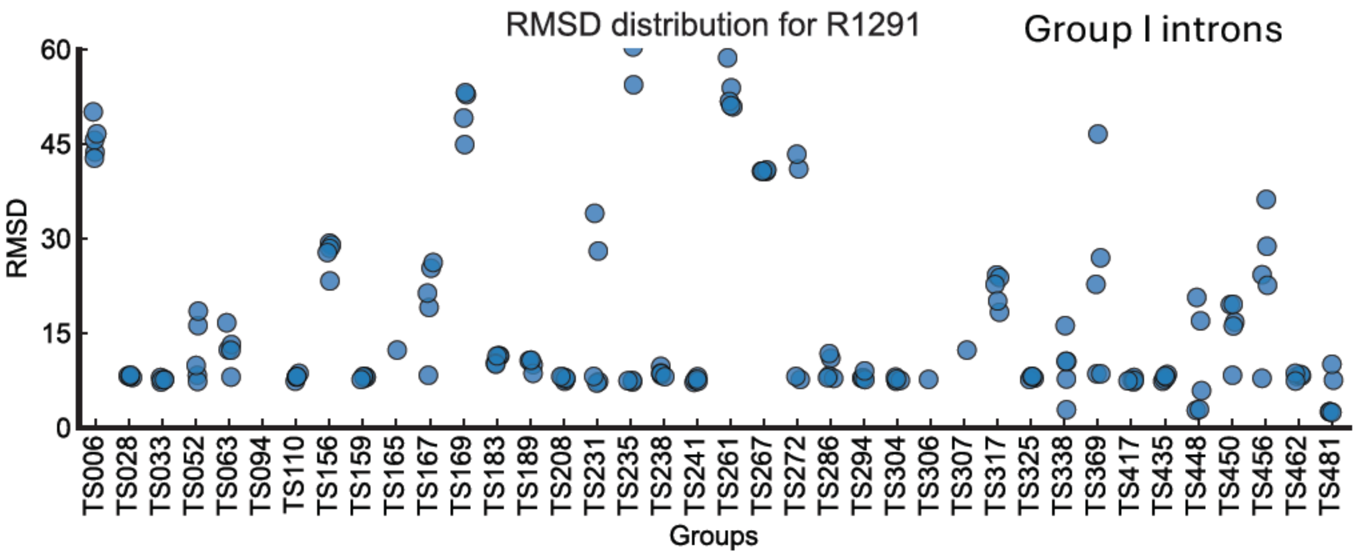
R1286
TS063_3
31.0 Å

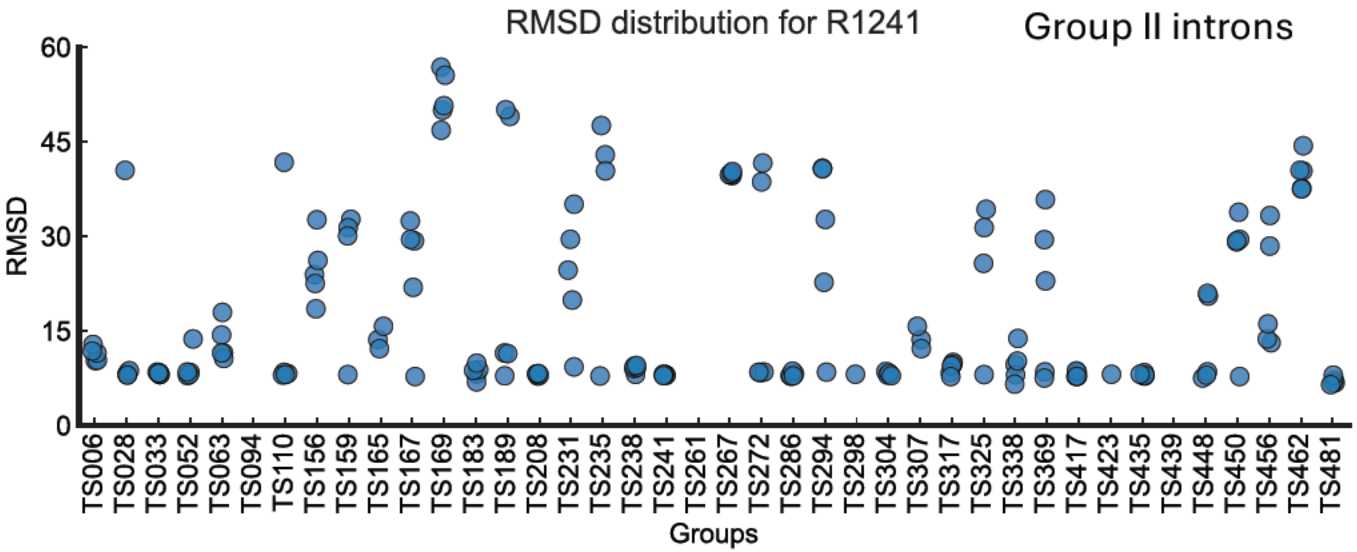



R1286
Top1_TS063_3
35 Å

Global fold is not sufficient (and sometimes deceptive)
to capture the key 3D features

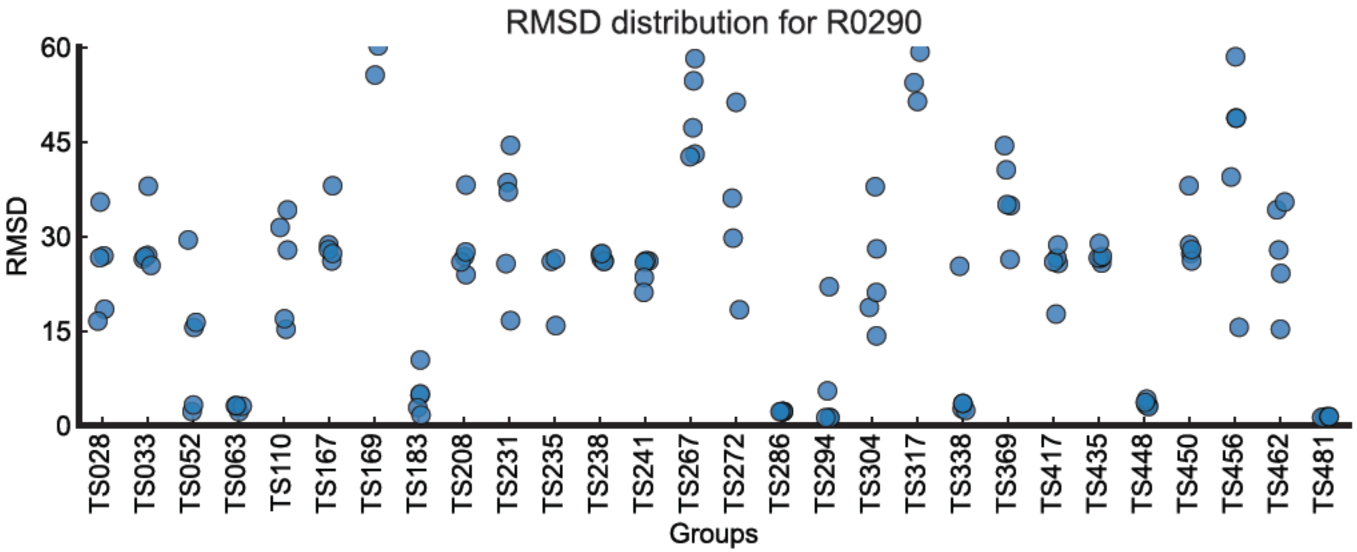
that maintain the architecture
and
explain the biological function





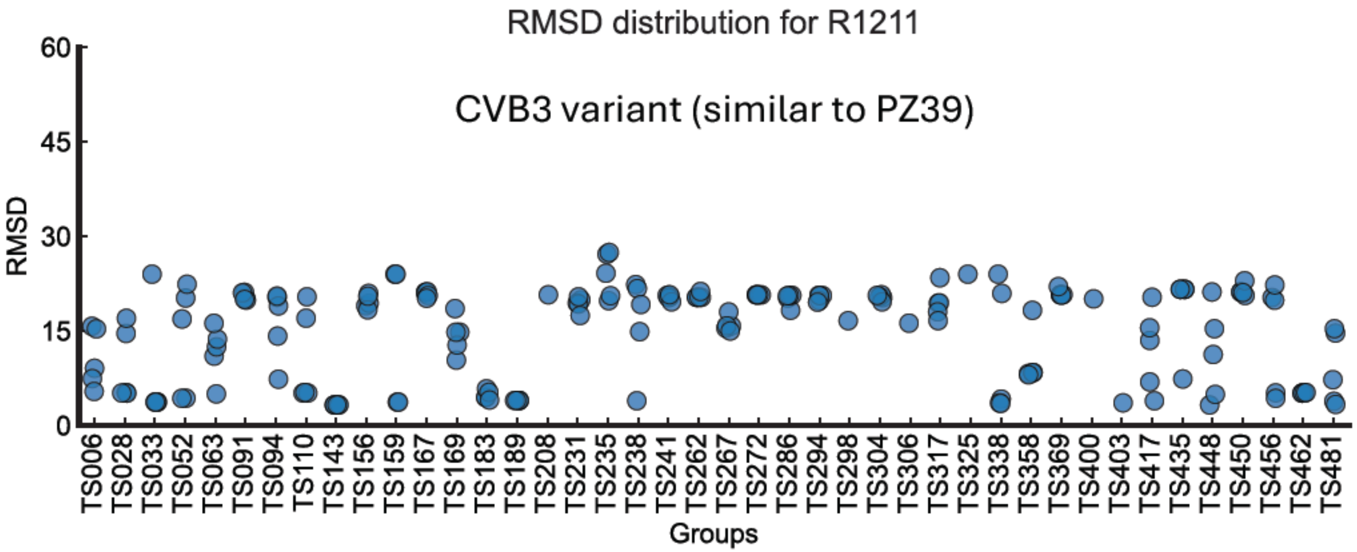
Large ribozymes (> 400 nts) well-known, many structures and alignments.

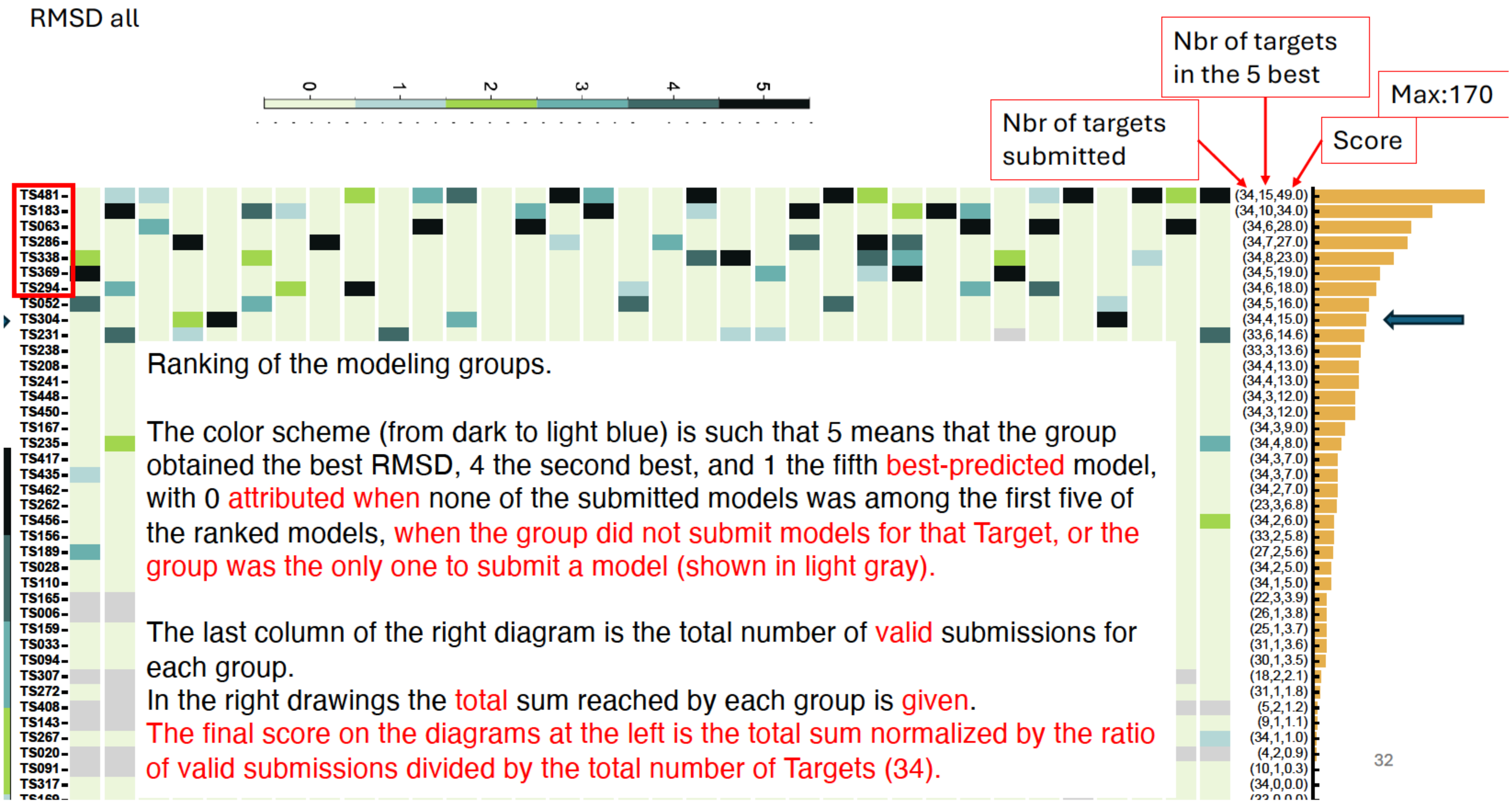
Many groups did a decent job; but very large distribution.



HYER
Group I intron like

As for Group I and II, many groups cannot homology-model or use properly available templates





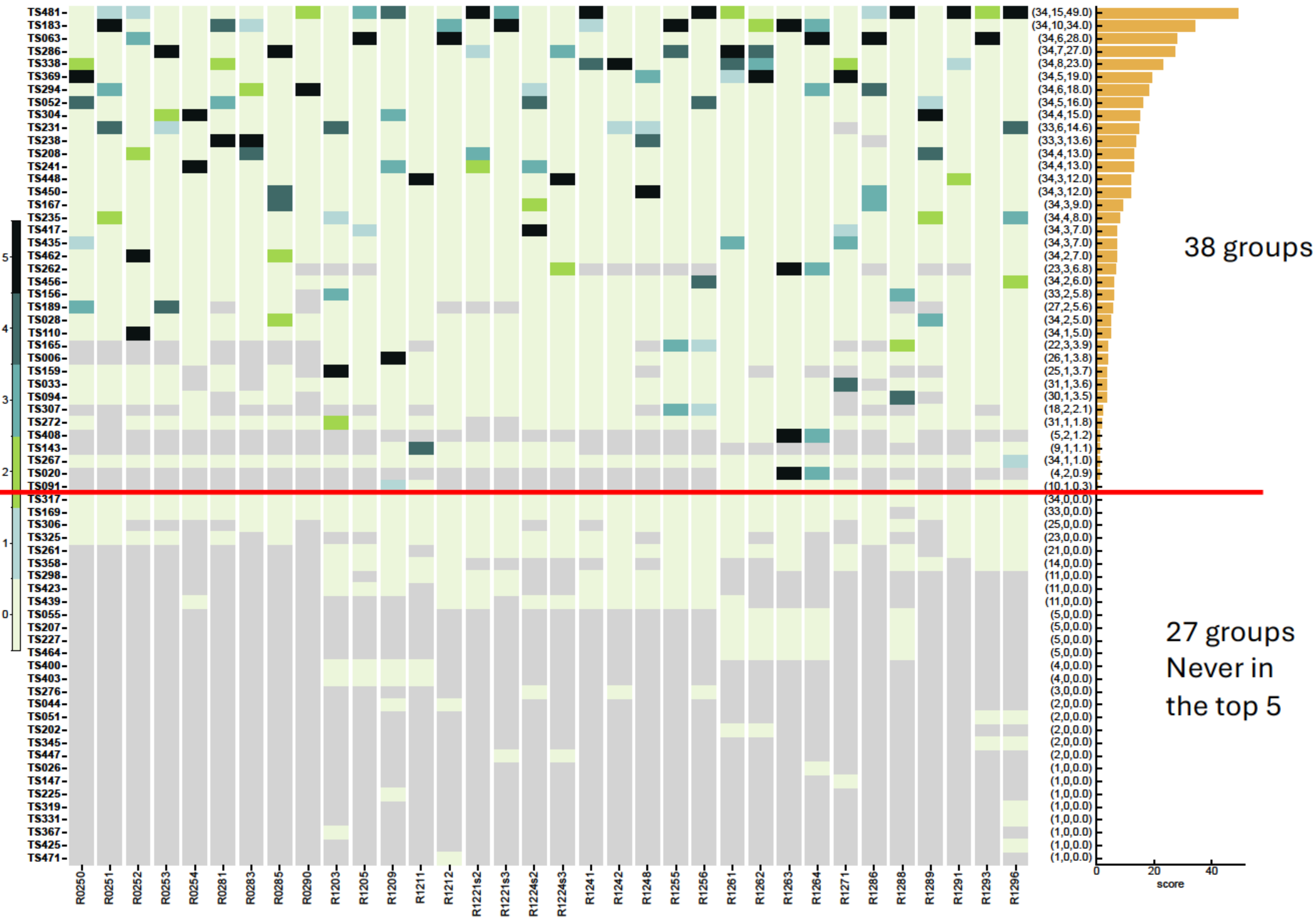
Ranking of the modeling groups.

The color scheme (from dark to light blue) is such that 5 means that the group obtained the best RMSD, 4 the second best, and 1 the fifth best-predicted model, with 0 attributed when none of the submitted models was among the first five of the ranked models, when the group did not submit models for that Target, or the group was the only one to submit a model (shown in light gray).

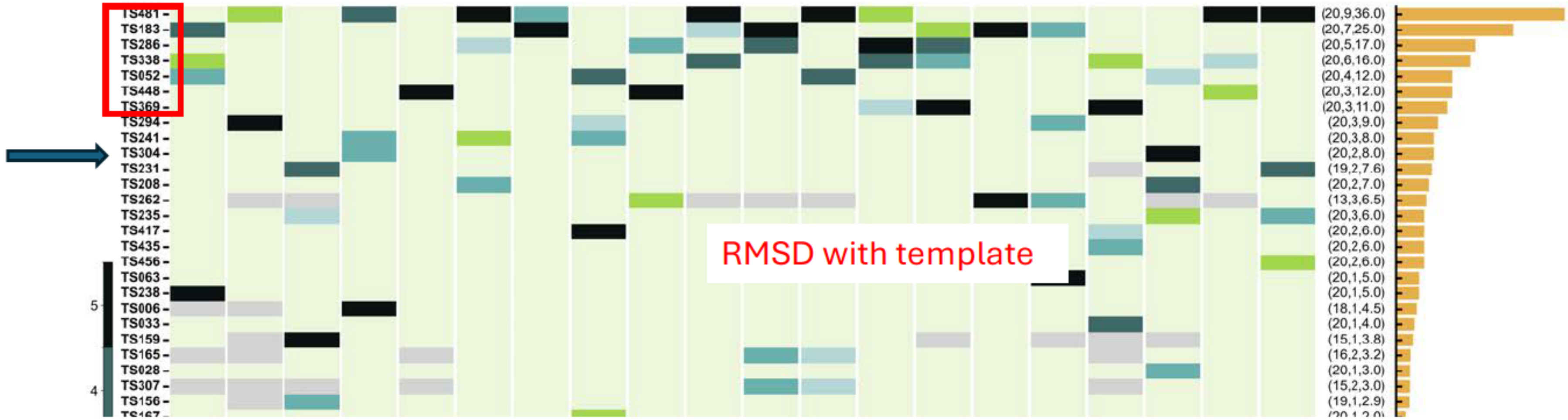
The last column of the right diagram is the total number of valid submissions for each group.

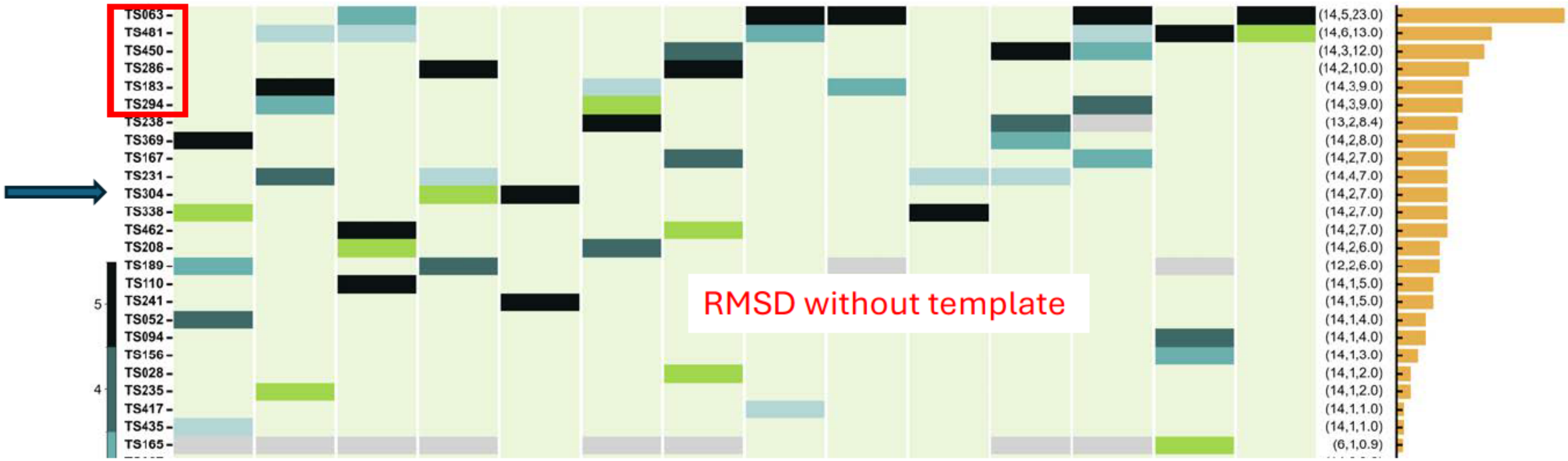
In the right drawings the total sum reached by each group is given.

The final score on the diagrams at the left is the total sum normalized by the ratio of valid submissions divided by the total number of Targets (34).

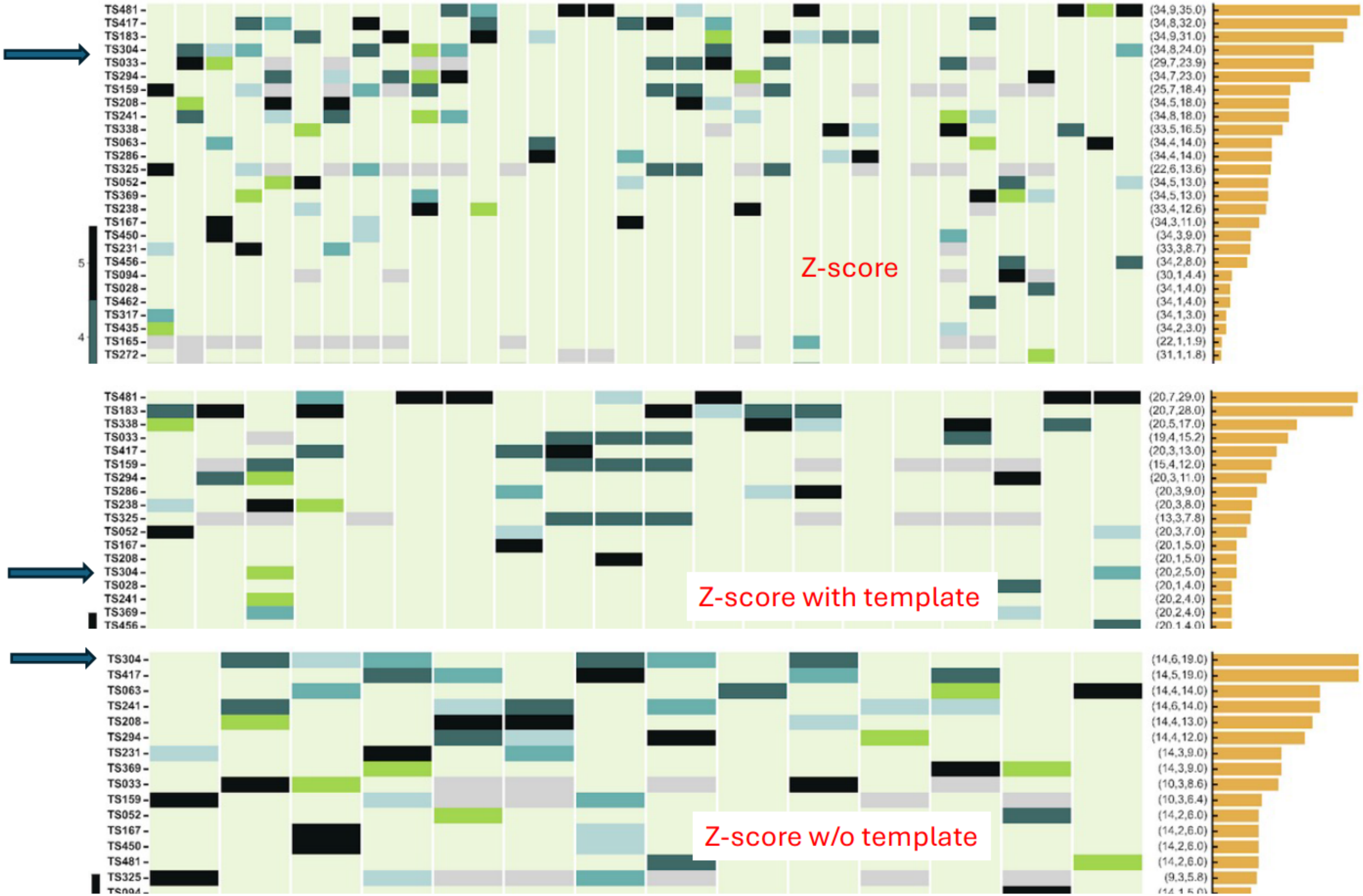


RMSD all


TS481
TS183
TS286
TS338
TS052
TS448
TS369
TS294
TS241
TS304
TS231
TS208
TS262
TS235
TS417
TS435
TS456
TS063
TS238
TS006
TS033
TS159
TS165
TS028
TS307
TS156
5
4
RMSD with template
(20,9,36.0)
(20,7,25.0)
(20,5,17.0)
(20,6,16.0)
(20,4,12.0)
(20,3,12.0)
(20,3,11.0)
(20,3,9.0)
(20,3,8.0)
(20,2,8.0)
(19,2,7.6)
(20,2,7.0)
(13,3,6.5)
(20,3,6.0)
(20,2,6.0)
(20,2,6.0)
(20,2,6.0)
(20,1,5.0)
(20,1,5.0)
(18,1,4.5)
(20,1,4.0)
(15,1,3.8)
(16,2,3.2)
(20,1,3.0)
(15,2,3.0)
(19,1,2.9)


TS063
TS481
TS450
TS286
TS183
TS294
TS238
TS369
TS167
TS231
TS304
TS338
TS462
TS208
TS189
TS110
TS241
TS052
TS094
TS156
TS028
TS235
TS417
TS435
TS165
5
4
RMSD without template
(14,5,23.0)
(14,6,13.0)
(14,3,12.0)
(14,2,10.0)
(14,3,9.0)
(14,3,9.0)
(13,2,8.4)
(14,2,8.0)
(14,2,7.0)
(14,4,7.0)
(14,2,7.0)
(14,2,7.0)
(14,2,7.0)
(14,2,6.0)
(12,2,6.0)
(14,1,5.0)
(14,1,5.0)
(14,1,4.0)
(14,1,4.0)
(14,1,3.0)
(14,1,2.0)
(14,1,2.0)
(14,1,1.0)
(14,1,1.0)
(6,1,0.9)

$$Z_{RNA} = \frac{1}{3}\left[Z_{TM} + Z_{GDT\_TS}\right] + \frac{1}{8}\left[Z_{INF} + Z_{lDDT}\right] + \frac{1}{12} Z_{clash}$$


TS481 (34,9,35.0)
TS417 (34,8,32.0)
TS183 (34,9,31.0)
TS304 (34,8,24.0)
TS033 (29,7,23.9)
TS294 (34,7,23.0)
TS159 (25,7,18.4)
TS208 (34,5,18.0)
TS241 (34,8,18.0)
TS338 (33,5,16.5)
TS063 (34,4,14.0)
TS286 (34,4,14.0)
TS325 (22,6,13.6)
TS052 (34,5,13.0)
TS369 (34,5,13.0)
TS238 (33,4,12.6)
TS167 (34,3,11.0)
TS450 (34,3,9.0)
TS231 (33,3,8.7)
TS456 (34,2,8.0)
TS094 (30,1,4.4)
TS028 (34,1,4.0)
TS462 (34,1,4.0)
TS317 (34,1,3.0)
TS435 (34,2,3.0)
TS165 (22,1,1.9)
TS272 (31,1,1.8)
5
4
Z-score
TS481 (20,7,29.0)
TS183 (20,7,28.0)
TS338 (20,5,17.0)
TS033 (19,4,15.2)
TS417 (20,3,13.0)
TS159 (15,4,12.0)
TS294 (20,3,11.0)
TS286 (20,3,9.0)
TS238 (20,3,8.0)
TS325 (13,3,7.8)
TS052 (20,3,7.0)
TS167 (20,1,5.0)
TS208 (20,1,5.0)
TS304 (20,2,5.0)
TS028 (20,1,4.0)
TS241 (20,2,4.0)
TS369 (20,2,4.0)
TS456 (20,1,4.0)
Z-score with template
TS304 (14,6,19.0)
TS417 (14,5,19.0)
TS063 (14,4,14.0)
TS241 (14,6,14.0)
TS208 (14,4,13.0)
TS294 (14,4,12.0)
TS231 (14,3,9.0)
TS369 (14,3,9.0)
TS033 (10,3,8.6)
TS159 (10,3,6.4)
TS052 (14,2,6.0)
TS167 (14,2,6.0)
TS450 (14,2,6.0)
TS481 (14,2,6.0)
TS325 (9,3,5.8)
Z-score w/o template

RMSD all	RMSD w Template	RMSD w/o Template	TM all	TM w Template	TM w/o Template	Z-score all	Z-score w Template	Z-score w/o Template
481	481	63	481	481	63	481	481 Ex-ae	304 Ex-ae
183	183	481	183	183	208	417	183	417

With the five best in each of the 9 plots and counting the number of times each group appears:
6 groups occupy the 1st or the 2nd positions: 481, 417, 304, 208, 183, 063.

TS481 : 7, 6 times 1st & 1 times 2nd

TS183 : 5, 5 times 2nd

TS063: 2, 2 times 1st

TS304: 1, 1 time 1st (AF3-server)

TS417: 2, 2 times 2nd

TS208: 1, 1 time 2nd

Final ranking: TS481 > TS183

(TS063, TS208, TS304, TS417)

RNA-Puzzles

Some general remarks

- There is no single comprehensive SCORING function for assessing accuracy.

Some scores are local or more global; most are based on atomic coordinates without consideration of inter-residue contacts. INF is the only one where base pairing is assessed.

- No single prediction method stands out yet.

The successful ones are knowledge-based and use various specific force fields and statistical models. They encode certain RNA structure folding rules and allow for the intervention of human experts. Success still depends on the type of puzzle and on the human expertise.

- The future?

A combination of current methods with the powerful AI generalizing folding rules extracted from large datasets.The systematic use of multiple sequence alignments would lead to a more evolution-based modeling.

Some general remarks

- Global fold is not sufficient (and deceptive) to capture the key 3D features maintaining the architecture and explaining the biological function:

  Non-Watson-Crick pairs and RNA modules, key molecular recognition patterns

- What are the problematic structural features?

  Non-Watson-Crick pairs. Crowded interfaces and ligand binding. Handling ions. Clash scores !

- Impact of experimental uncertainty?

  With « low-quality » or poorly-resolved cryo-EM, only the enveloppes (global folds) can be compared; atomic-based tools are less appropriate (fitting difficulties/errors during model building).

Issues and questions

- A clear separation between best methods for fitting with accuracy into cryo-EM maps and best methods for producing models without experimental data （besides sequences).
- Many RNAs with homologous structures (group I introns, group II introns, RNaseP,...). Being able to fit a new sequence on well-established templates is useful and important, but it does not contribute to prediction of UNKNOWN RNAs.

What are the results, especially in terms of accuracy achieved by the participants?

- With template, the accuracy is allright although there is still a surprising large spread in the results.
- Without template, the outcome is poor and irregular. But the targets were very ambitious!
- The distinction Template vs. Non-Template is central to the prediction methodology and to the final assessments.
- This distinction is not easy, especially with AI methods, and may need some clarifications

http://www.rnapuzzles.org/

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