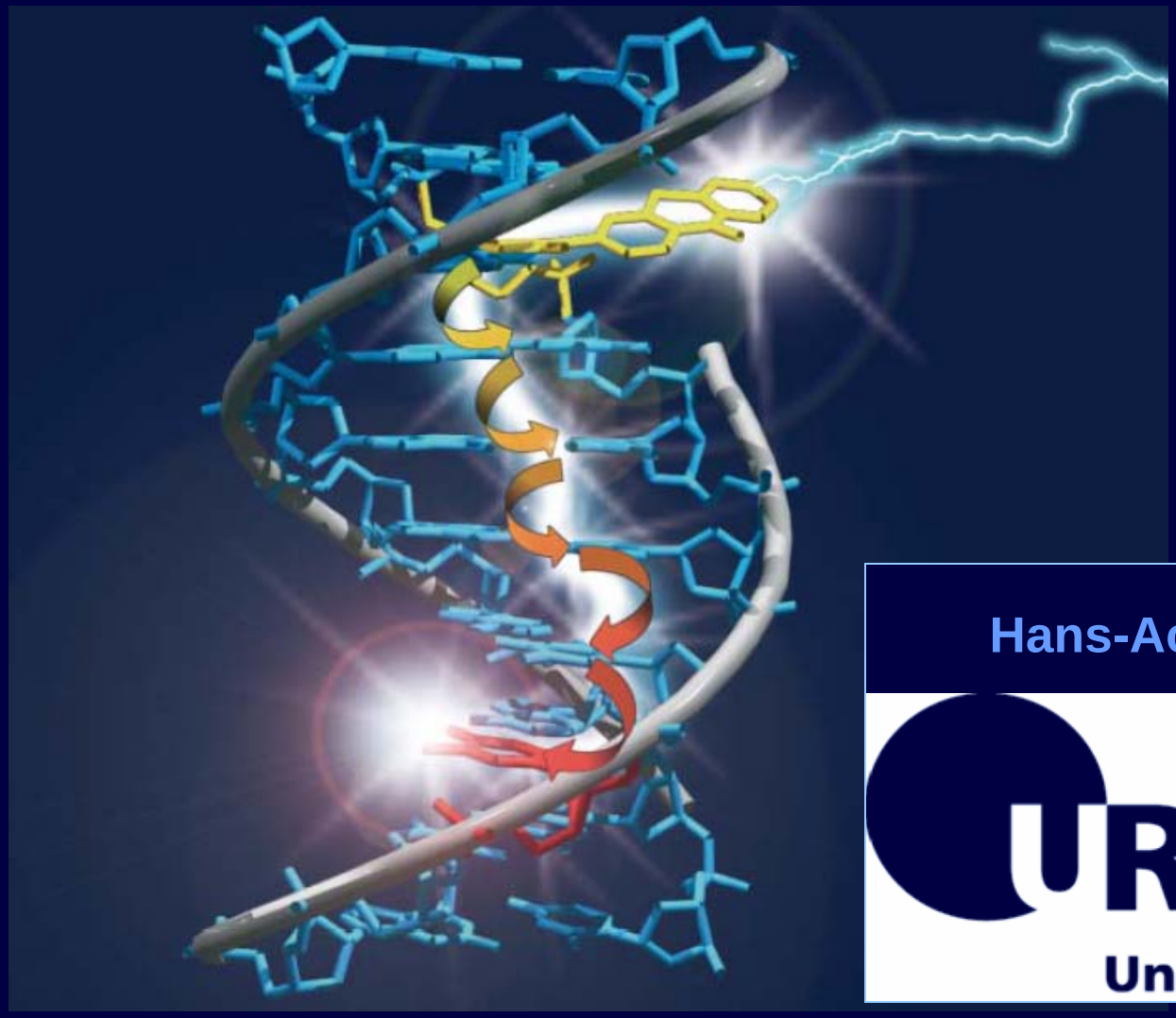
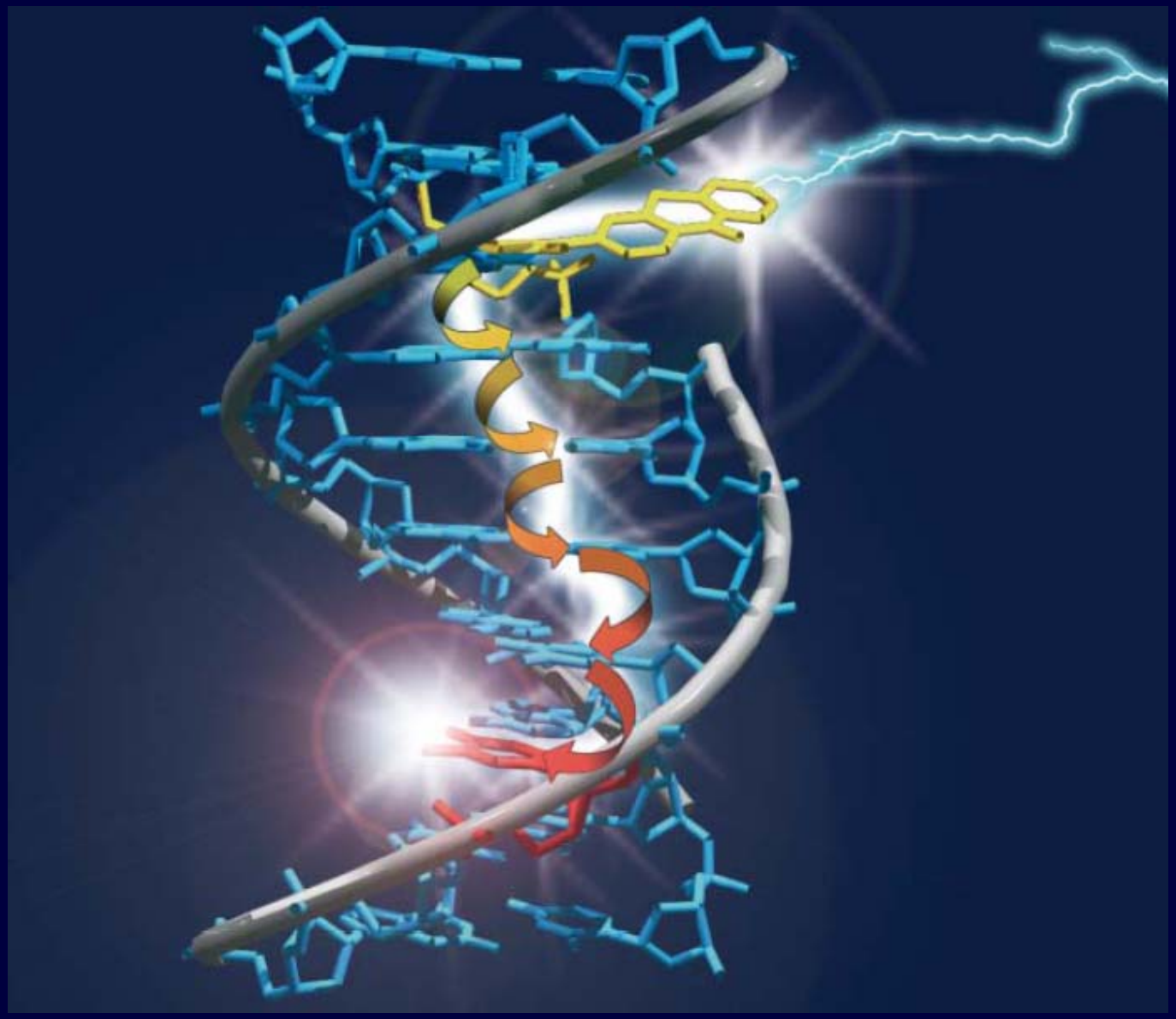
Functional DNA architectures: Photoinduced electron transfer and switchable optical properties



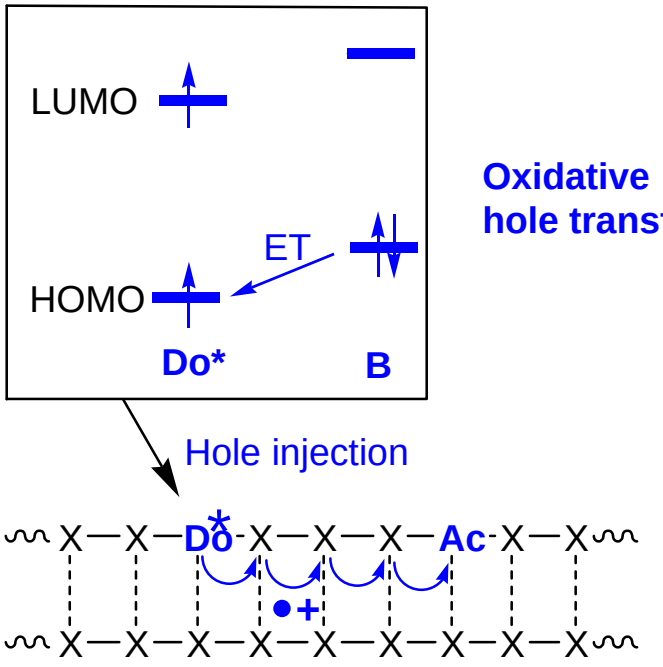
Hans-Achim Wagenknecht

Universität Regensburg

Part I+II: Photoinduced charge transfer in DNA

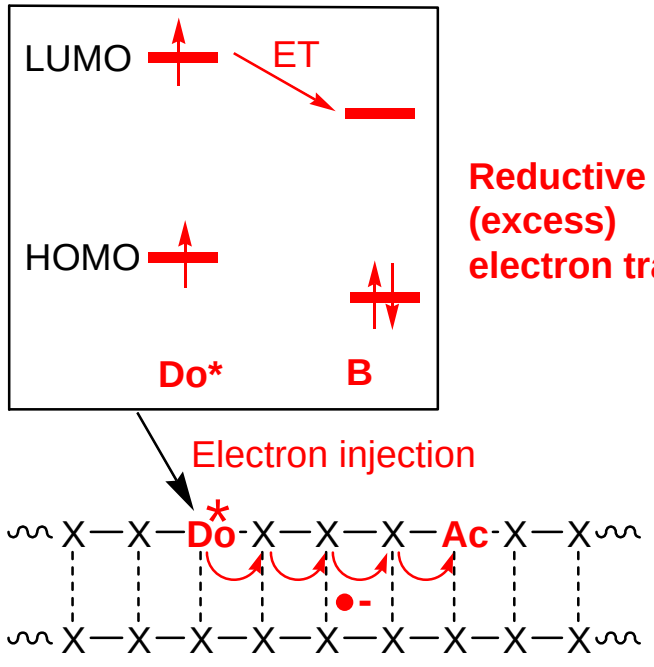


Hole transfer vs. electron transfer



Oxidative hole transfer

- **Superexchange**
- **Hopping**

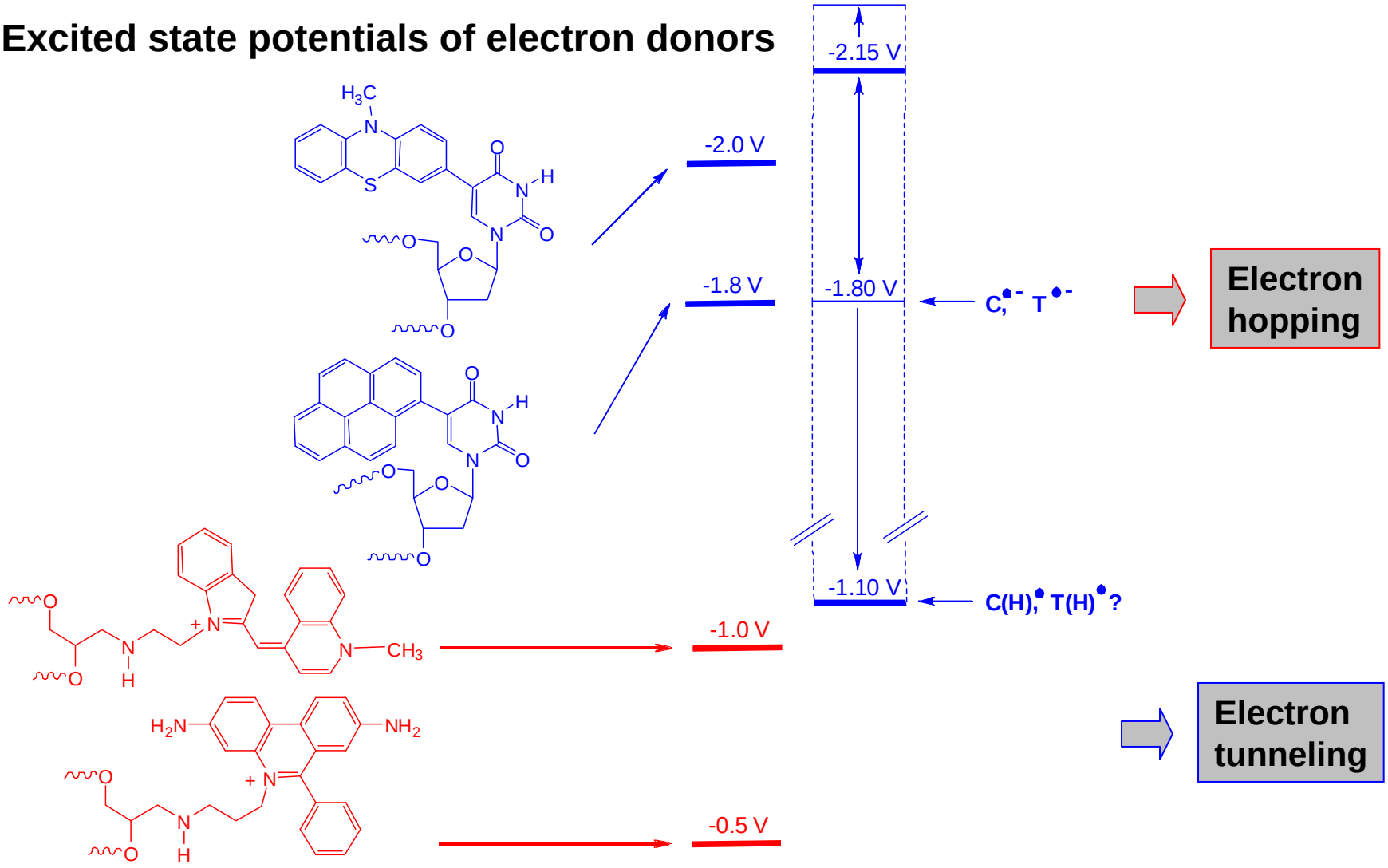


Reductive (excess) electron transfer

Proposed to be more suitable for nano/biotechnology:
- **faster**
- **more efficiently**
- **less (or no) damage**

H.-A. Wagenknecht (Ed.), *Charge Transfer in DNA*, Wiley-VCH, **2005**, 1.
Angew. Chem. Int. Ed. **2003**, *42*, 2454; *Curr. Org. Chem.* **2004**, *8*, 251; *Nat. Prod. Rep.* **2006**, *23*, 973.

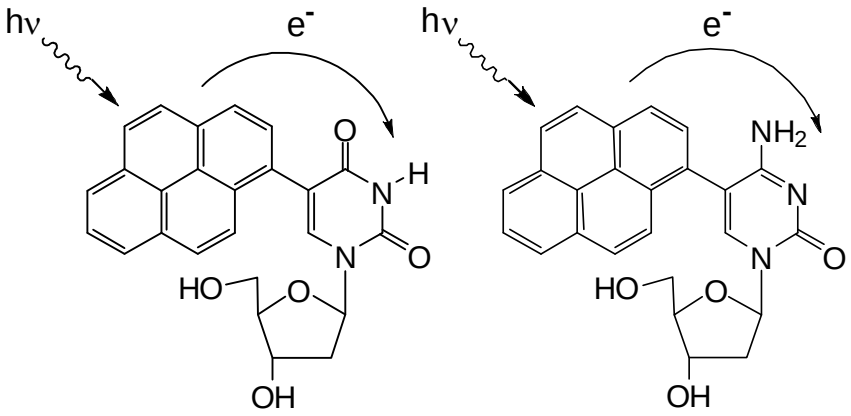
Excited state potentials of electron donors



H.-A. Wagenknecht (Ed.), *Charge Transfer in DNA*, Wiley-VCH, **2005**, 1.
Angew. Chem. Int. Ed. **2003**, *42*, 2454; *Curr. Org. Chem.* **2004**, *8*, 251; *Nat. Prod. Rep.* **2006**, *23*, 973.

Part I. Nucleoside models for electron transfer in DNA

Summary



Py-dU **Py-dC**

k_{ET}: 4.7 ps
pK_a = 5.5

k_{ET}: 40 ps
pK_a > 12

Redox potentials:

C and T as electron carriers in DNA

Nucleoside model studies:

- **T is reduced faster**
- **$dC^{\bullet -}$ exhibits strong basicity**

Implication for DNA:

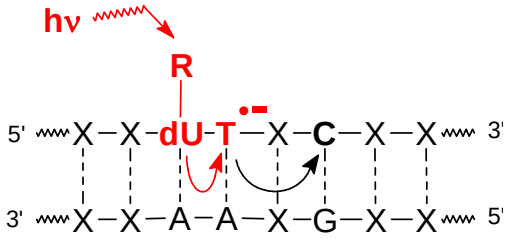
$dT^{\bullet -}$ is the major electron carrier

Synlett **2002**, 687.
Angew. Chem. Int. Ed. **2002**, *41*, 2978.
Chem. Commun. **2003**, 1878 .
Synthesis **2003**, 2335.
ChemPhysChem **2004**, *5*, 706
Chem. Phys. Lett. **2005**, *409*, 277.

Nicole Amann, Elke Mayer-Enthart
In collaboration with Torsten Fiebig, Boston

Part I. Reductive electron transfer in DNA

Electron injection studies



Chem. Eur. J. **2002**, *8, 4877-4883.*

Eur. J. Org. Chem. **2003**, *2498.*

Angew. Chem. Int. Ed. **2004**, *43, 1845.*

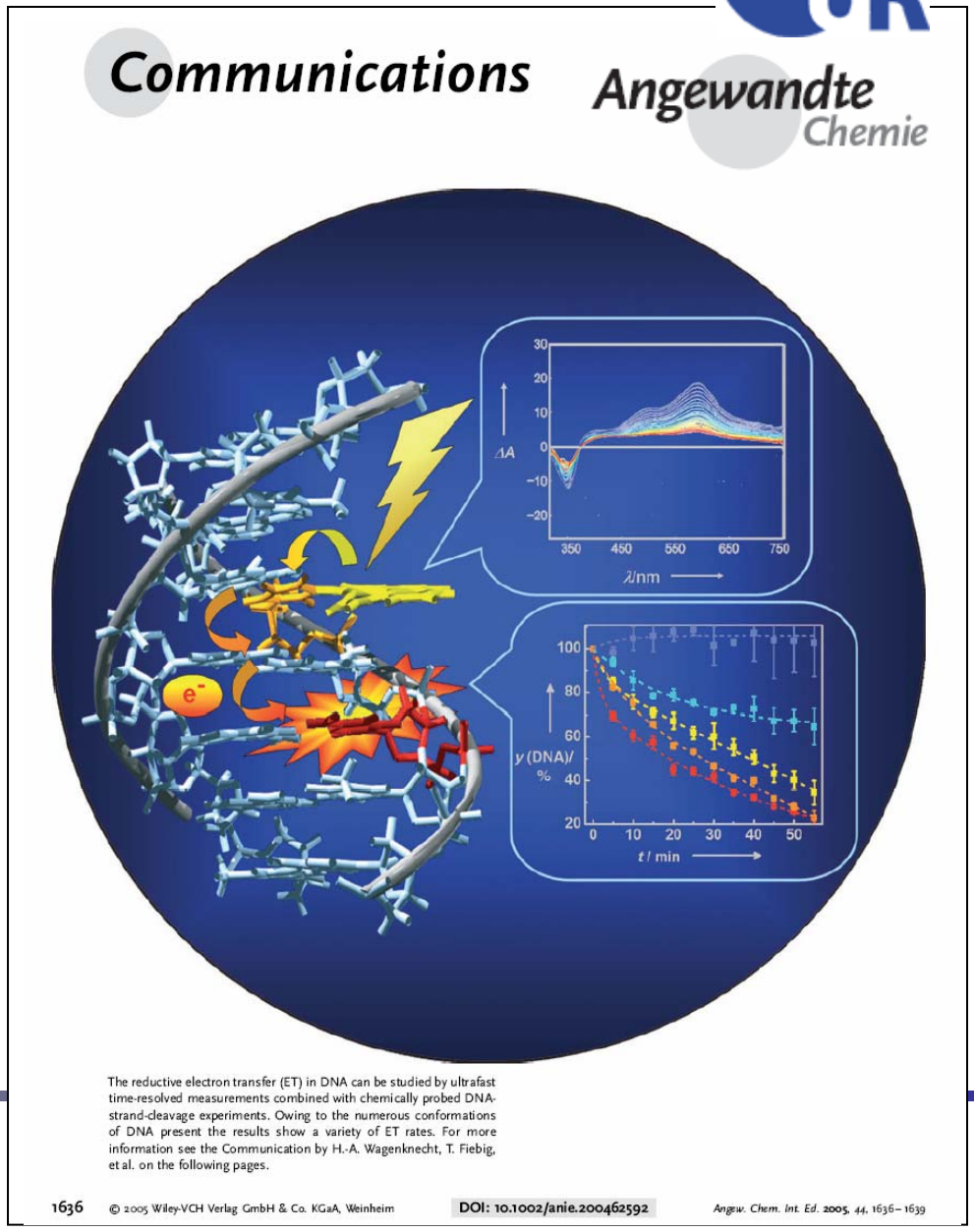
DNA studies

Angew. Chem. Int. Ed. **2003**, *42*, 2454.

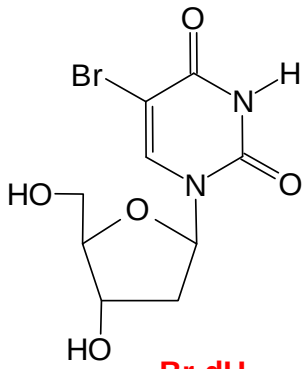
Chem. Eur. J. **2005**, *22*, 1871.

Angew. Chem. Int. Ed. **2005**, *44*, 1636.

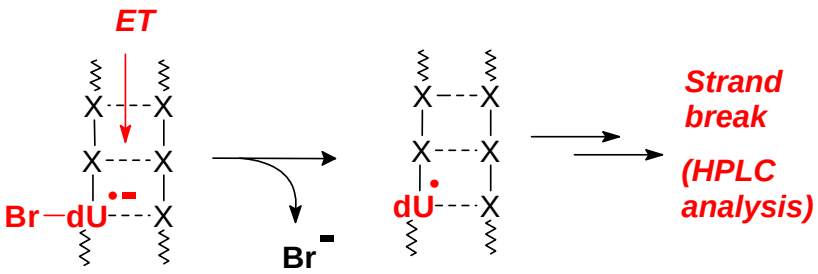
Proc. Natl. Acad. Sci. USA **2006**, *103*, 10192



Chemical electron acceptor



Br-dU



DNA studies

Angew. Chem. Int. Ed. **2003**, *42*, 2454.

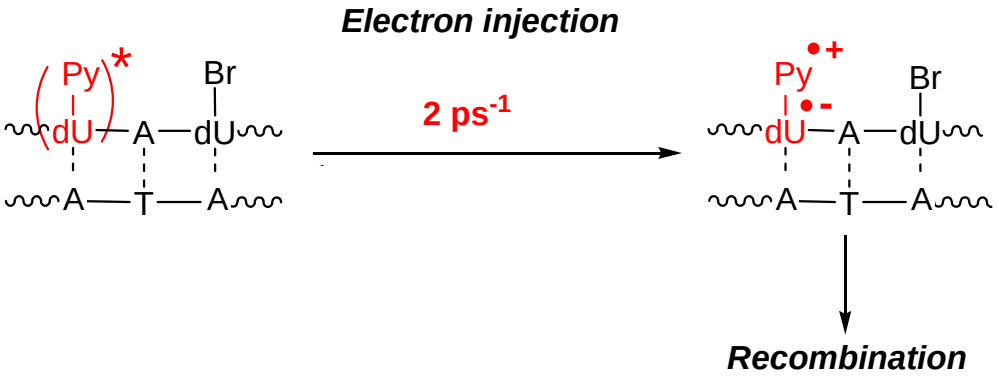
Chem. Eur. J. **2005**, *22*, 1871.

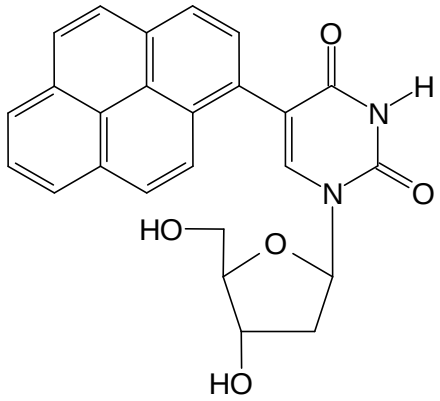
Angew. Chem. Int. Ed. **2005**, *44*, 1636.

Proc. Natl. Acad. Sci. USA **2006**, *103*, 10192

Part I. Reductive electron transfer in pyrene-modified DNA

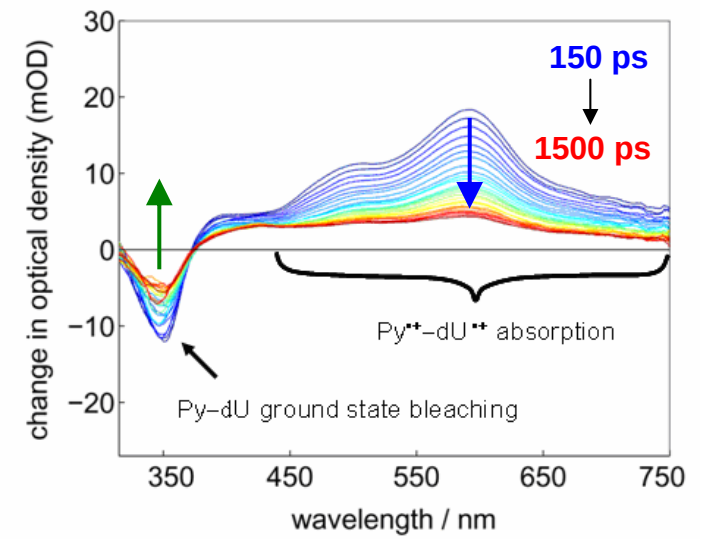
Time-resolved spectroscopy

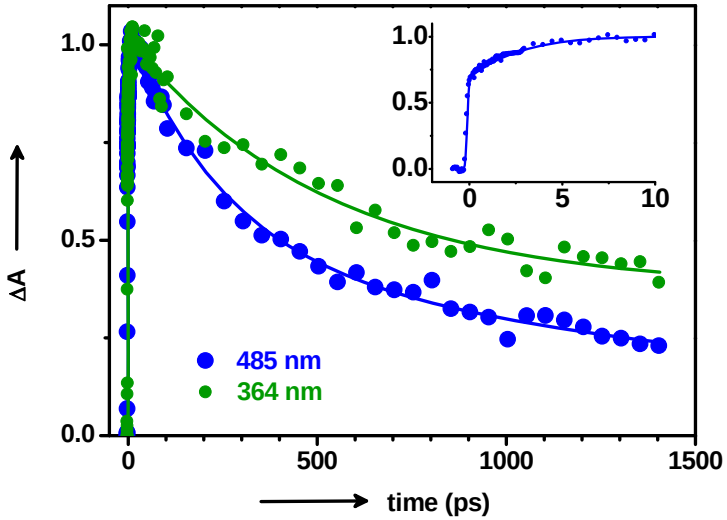




Py-dU

Time-resolved transient absorption spectra

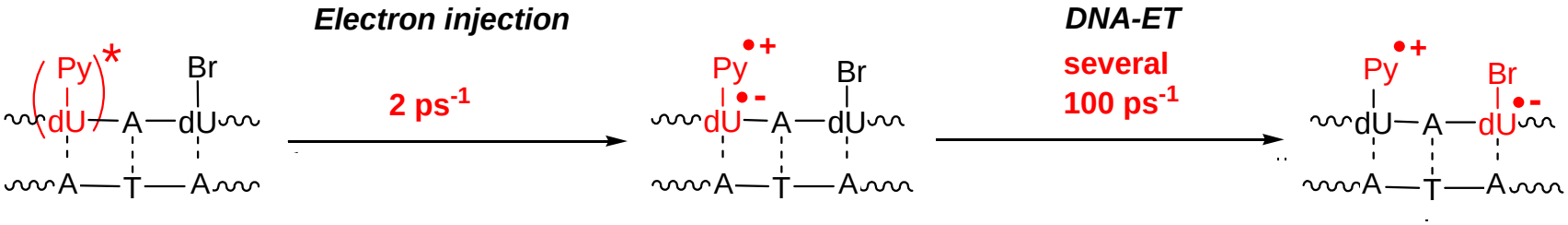


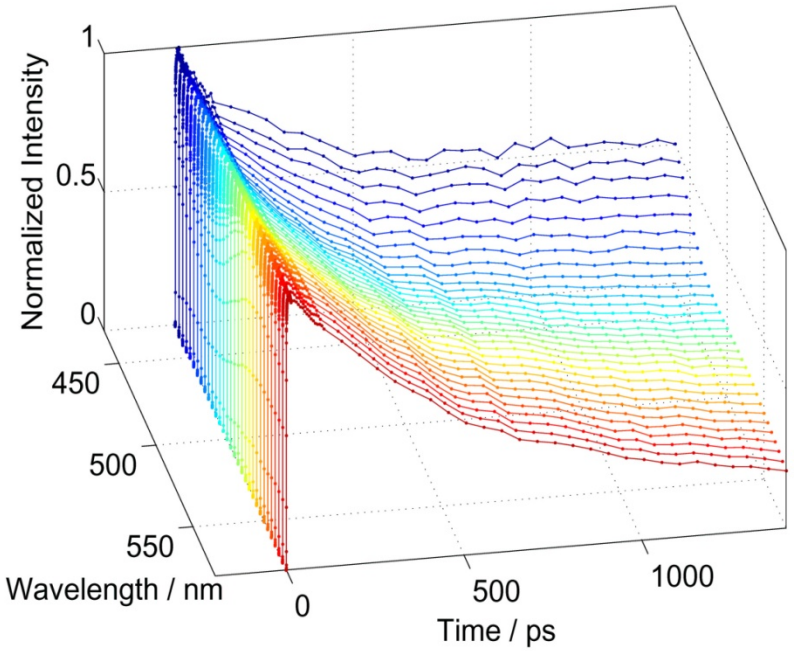


Chem. Eur. J. **2002**, *8*, 4877.
Angew. Chem. Int. Ed. **2005**, *44*, 1636.

Nicole Amann
Elke Mayer-Enthart, Peter Kaden

Influence of DNA dynamics





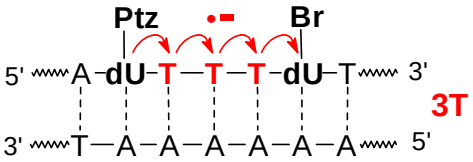
- **Electron injection is independent of conformational flexibility of DNA**
- **ET occurs on a manifold of time constants due to DNA base dynamics**

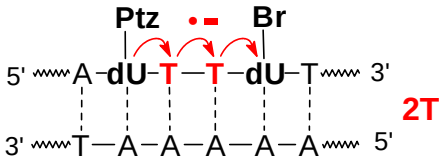
Conformational contribution of the DNA („Conformational gating“)

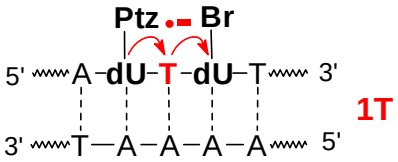
Chem. Eur. J. **2002**, *8*, 4877.
Angew. Chem. *Int. Ed.* **2005**, *44*, 1636.

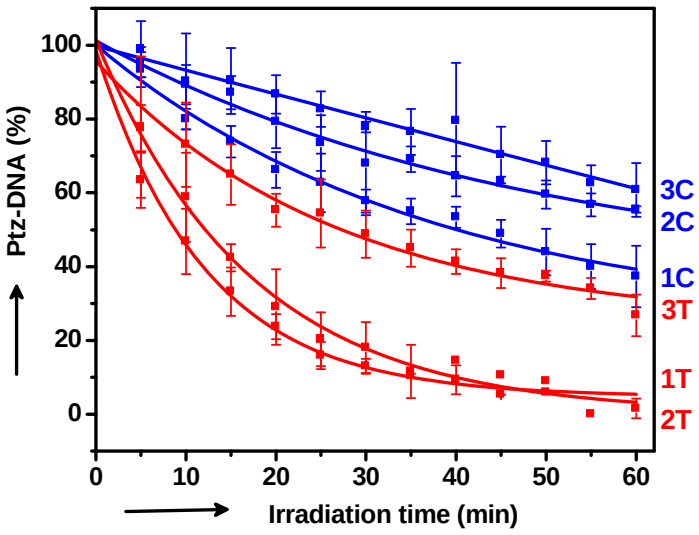
Nicole Amann
Elke Mayer-Enthart, Peter Kaden

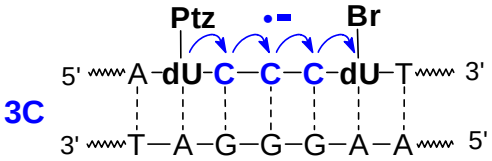
Chemical experiments

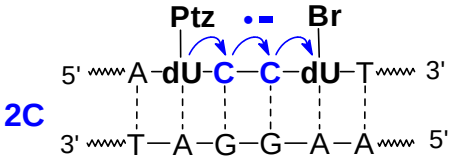


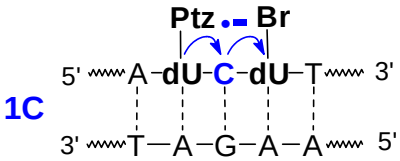






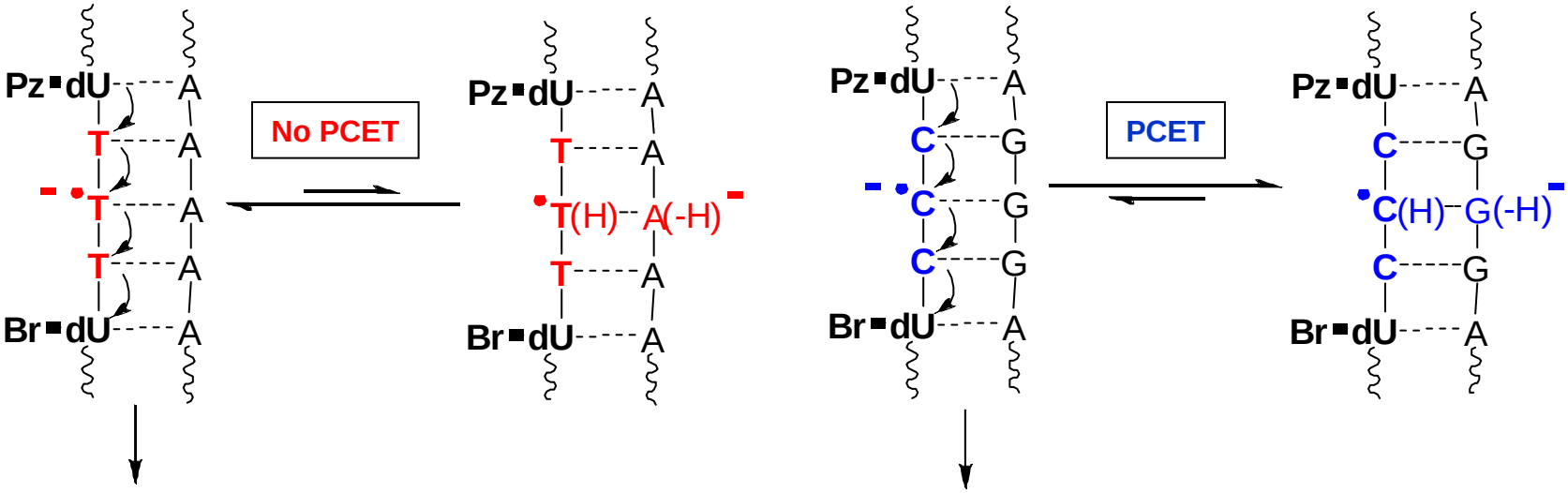






DNA base sequence and distance dependence

Mechanism of electron hopping

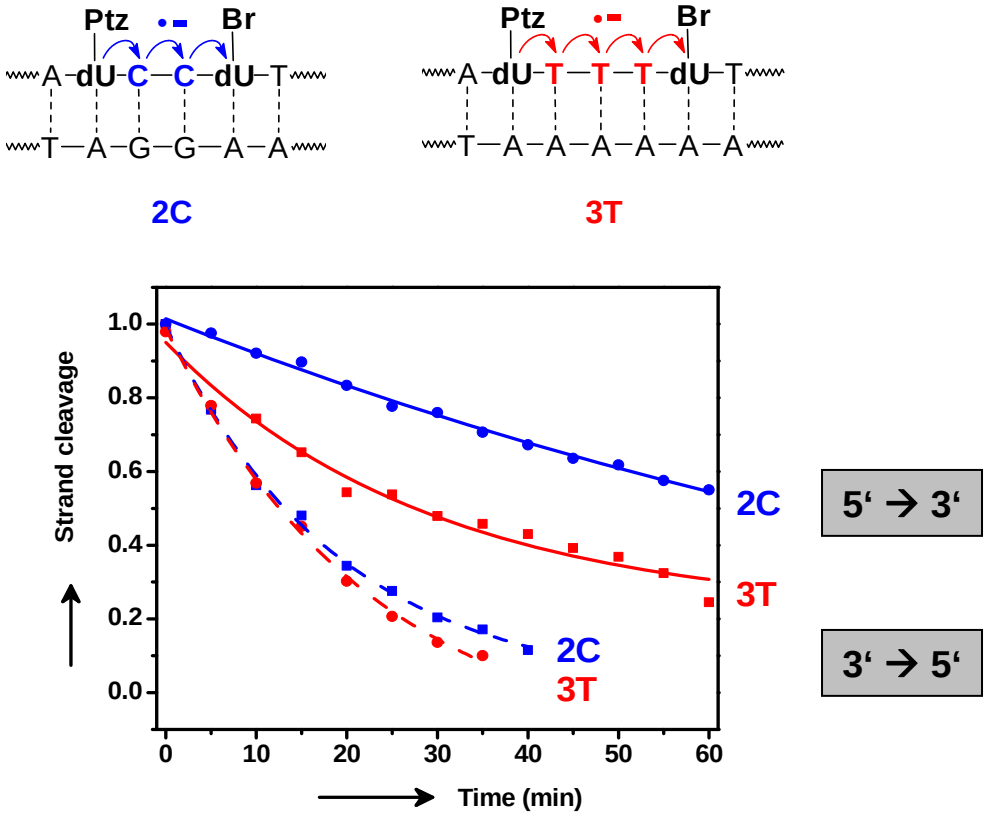


Efficient strand degradation

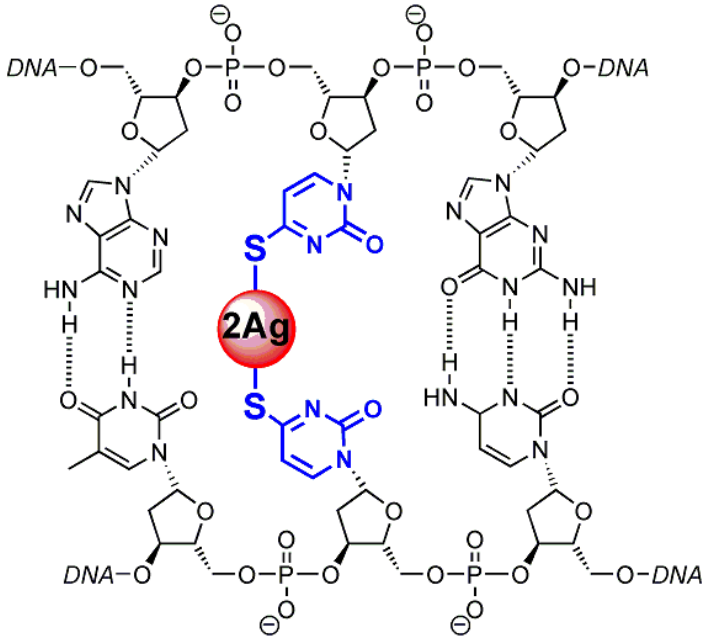
Less efficient strand degradation

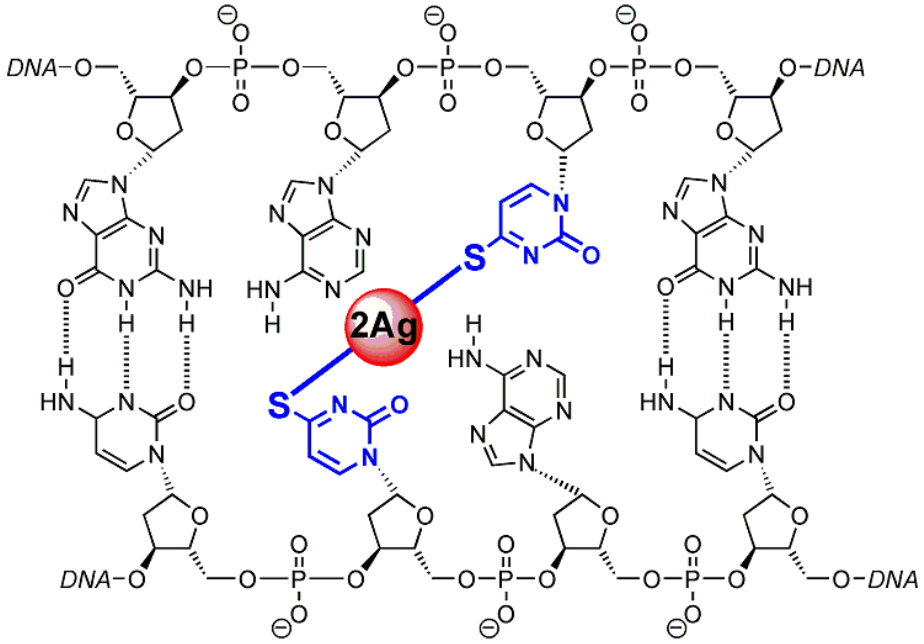
- **Each base pair can participate**
- **Question of long range ET in G-C rich DNA?**

Directionality



Thio-dU-Ag(I) base pairs

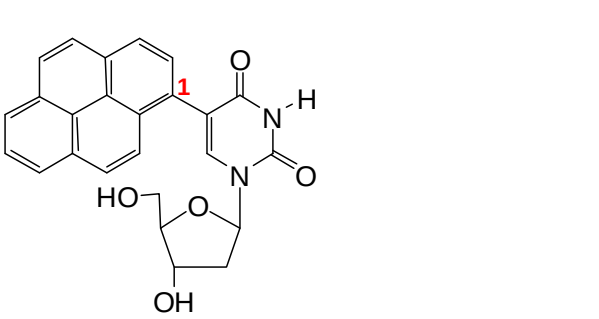


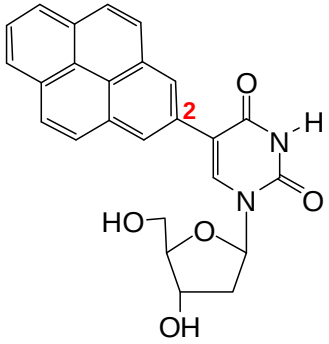


Janez Barbaric

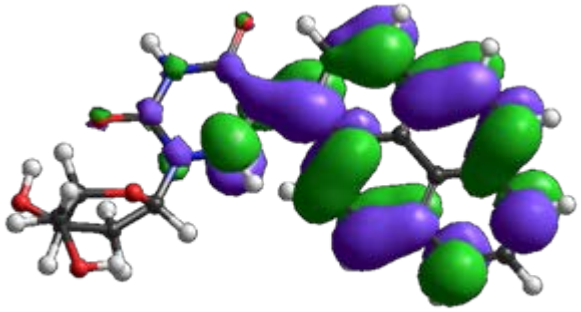
Based on metallated base pair by Simone Peters in the group of Elmar Weinhold, Aachen

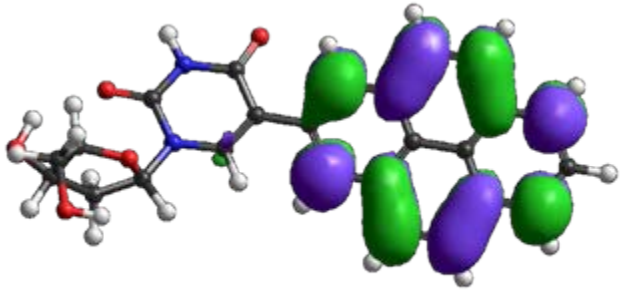
Photochemistry of pyrene-modified DNA bases





LUMO





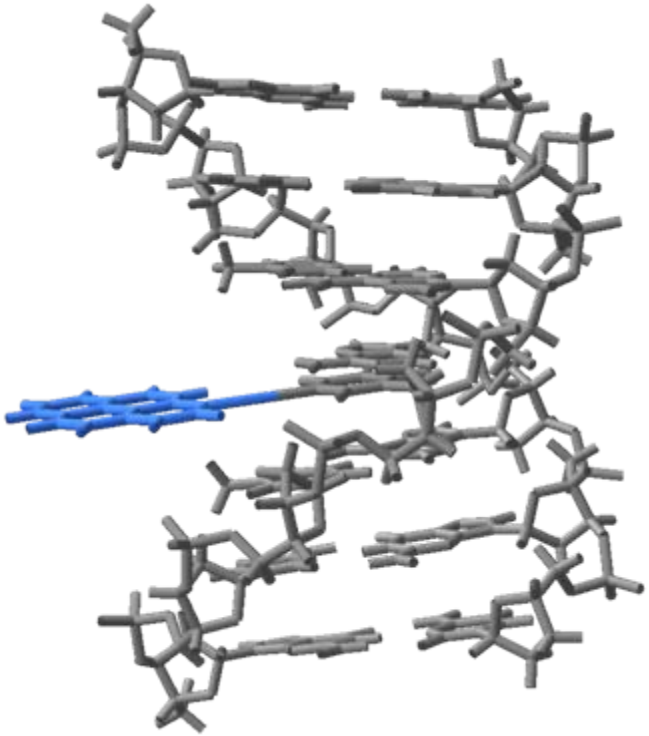
Exciplex

$(Py^{\bullet+}\ dU^{\bullet-})^{*}$

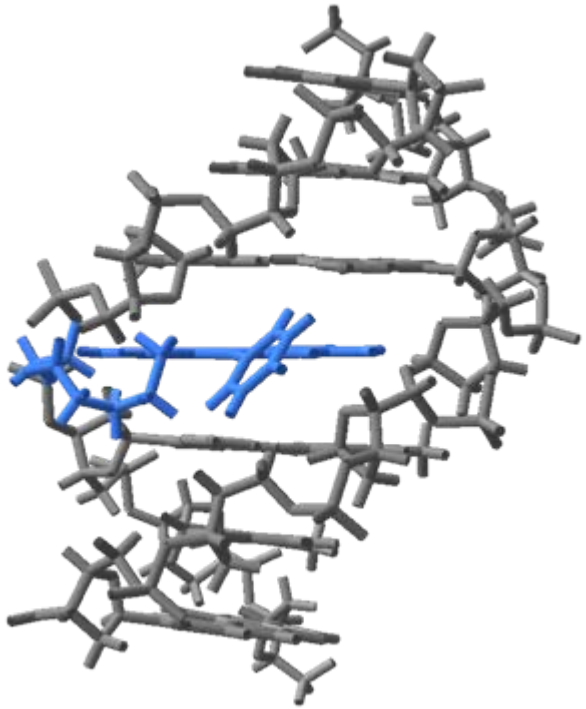
Locally Excited

Py^{*}-dU

Functionalization of DNA



DNA base modification

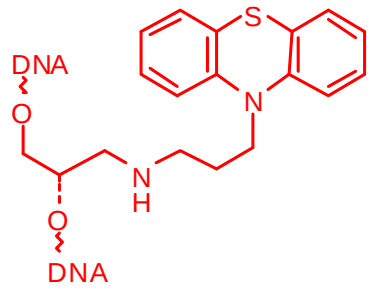


DNA base substitution

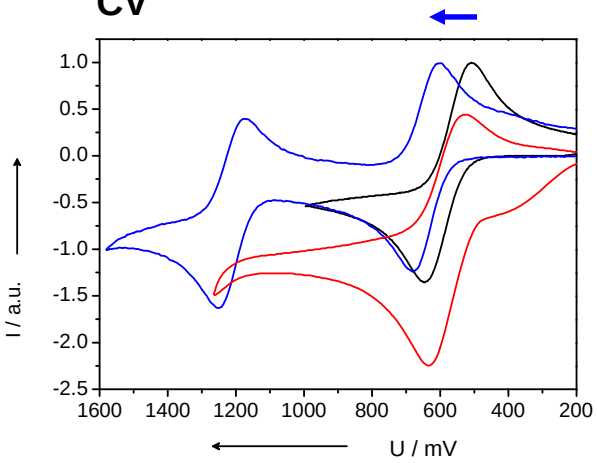
H.-A. Wagenknecht (Ed.), *Charge Transfer in DNA*, Wiley-VCH, **2005**, 1.
Angew. Chem. Int. Ed. **2003**, *42*, 2454; *Curr. Org. Chem.* **2004**, *8*, 251; *Nat. Prod. Rep.* **2006**, *23*, 973.

DNA Base substitution vs. base modification: Phenothiazine

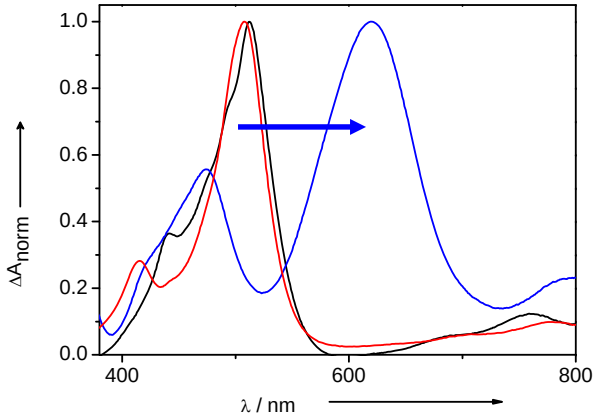
DNA base substitution



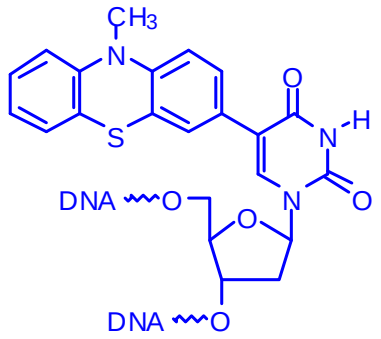
CV



Spectroelectrochemistry



DNA base modification



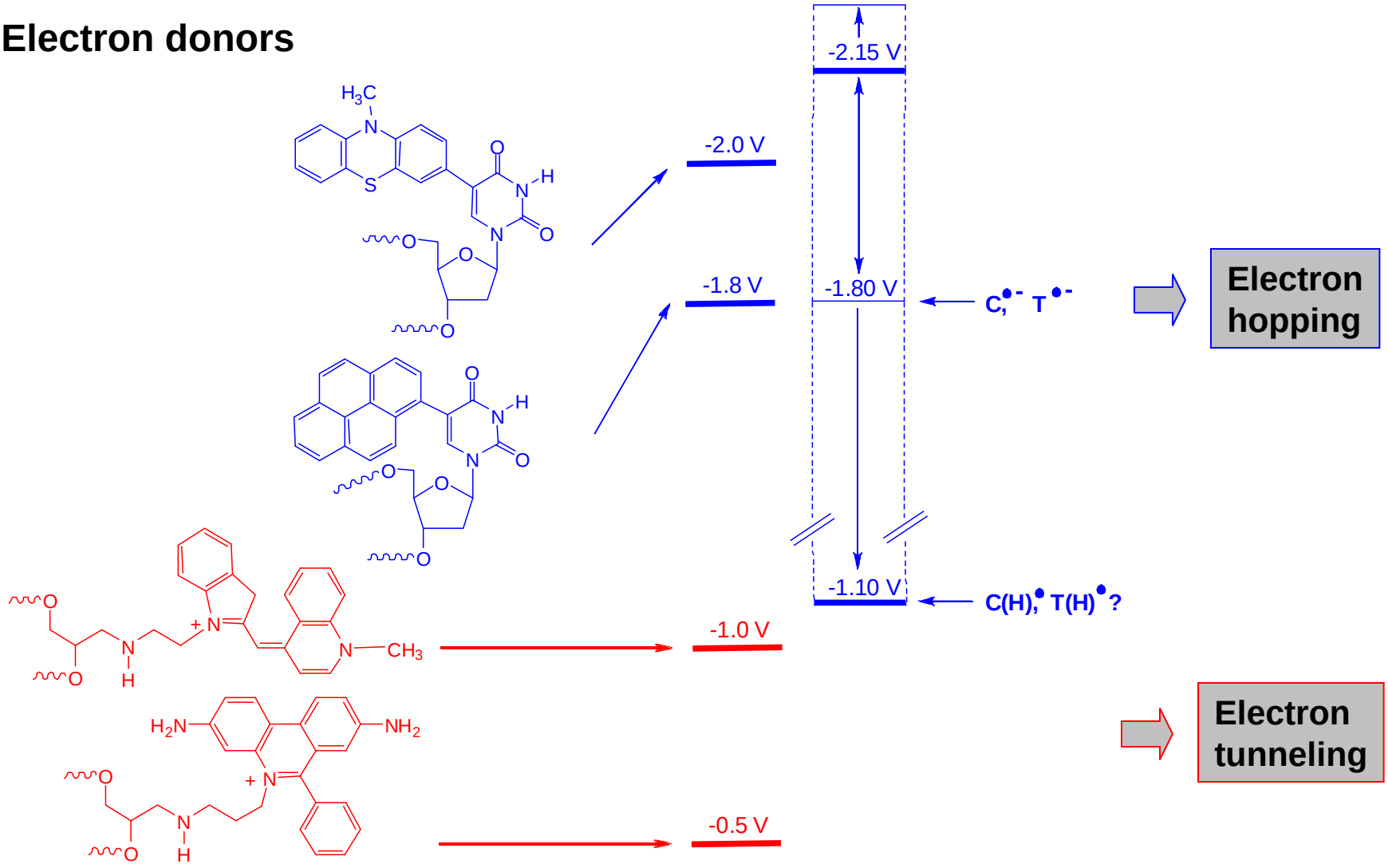
T_m values (17mer DNA)

Counterbase	
A	50 °C
C	50 °C
G	50 °C
T	49 °C

T_m values (17 mer DNA)

Counterbase	
A	**60 °C**
C	56 °C
G	55 °C
T	55 °C

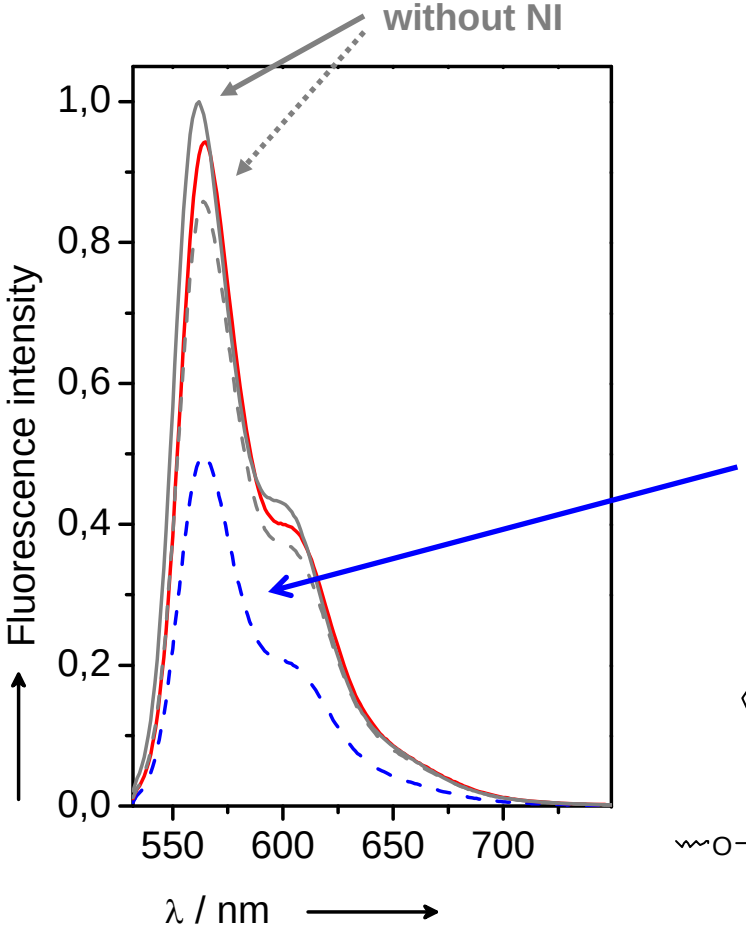
Electron donors

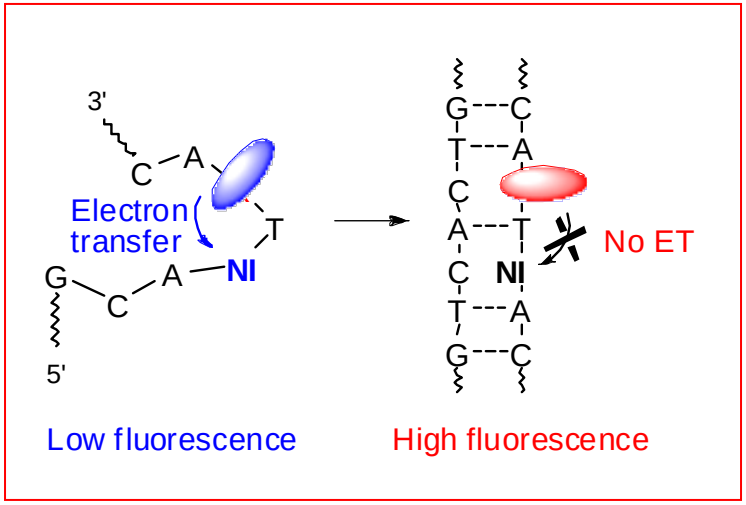


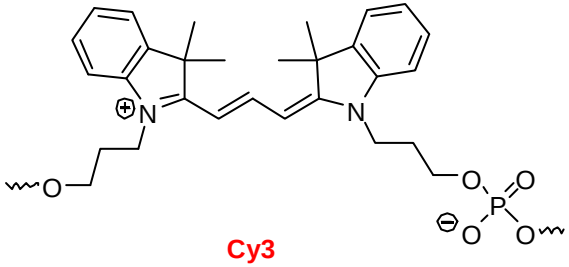
H.-A. Wagenknecht (Ed.), *Charge Transfer in DNA*, Wiley-VCH, **2005**, 1.
Angew. Chem. Int. Ed. **2003**, *42*, 2454; *Curr. Org. Chem.* **2004**, *8*, 251; *Nat. Prod. Rep.* **2006**, *23*, 973.

Part II: Charge transfer with cyanines

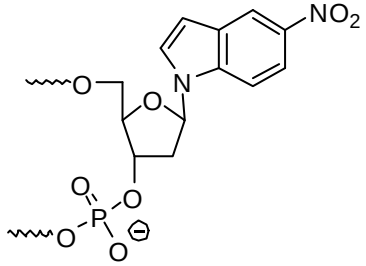
Non-intercalative mode: Cyanine dyes as the charge donor







Cy3



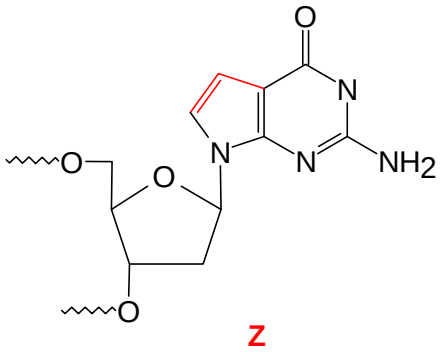
NI

J. Org. Chem. **2008**, *73*, 4263.

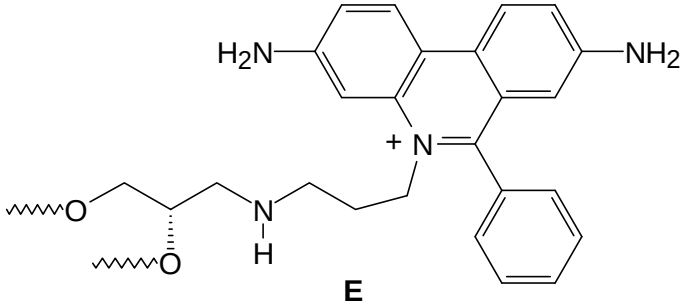
Florian Menacher
Moritz Rubner

Part II: Charge transfer in ethidium-modified DNA

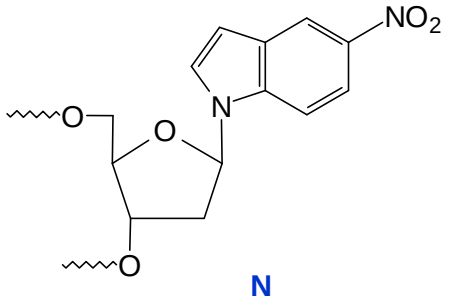
Hole vs. electron transfer with ethidium



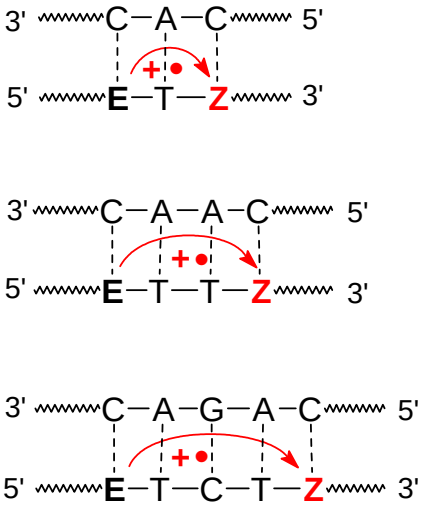
Z

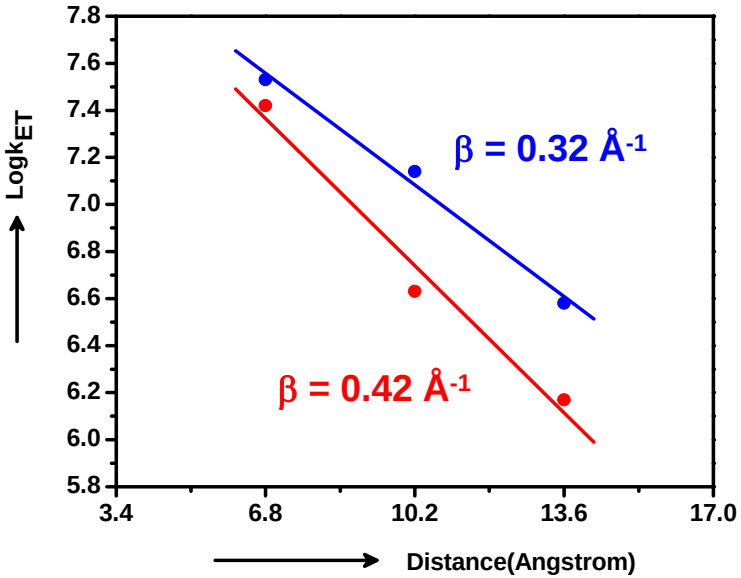


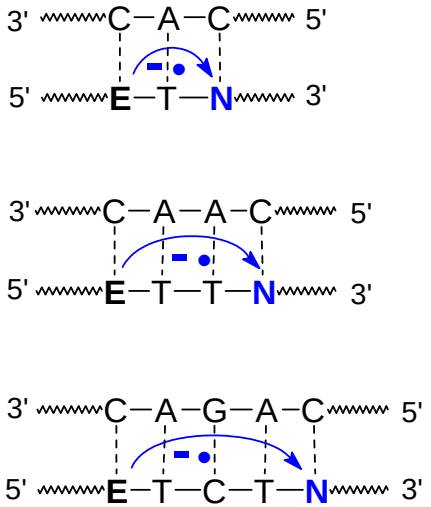
E



N





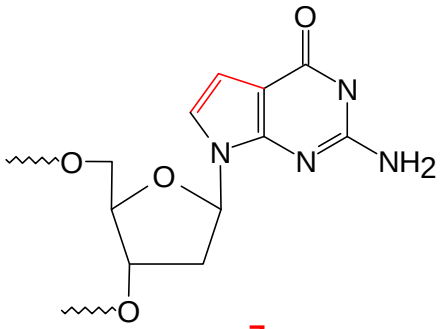


Proc. Natl. Acad. Sci. USA **2006**, *103*, 10192.

Nicole Amann, Robert Huber, Linda Valis
In collaboration with Torsten Fiebig, Boston

Part II: Charge transfer in ethidium-modified DNA

Intercalative mode: Ethidium as a charge donor



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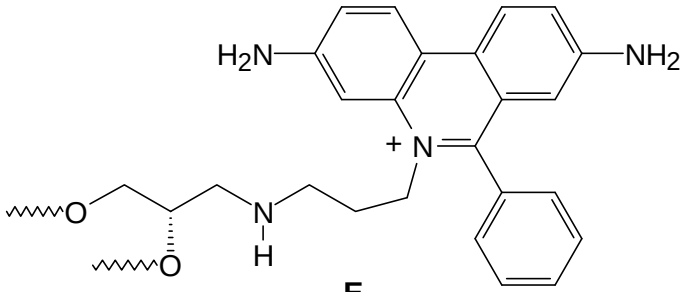
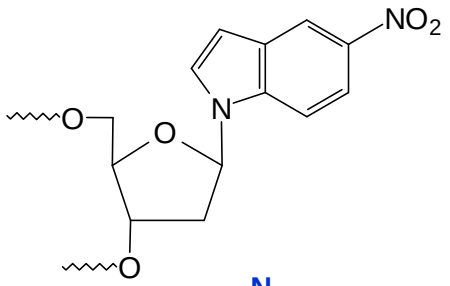


E



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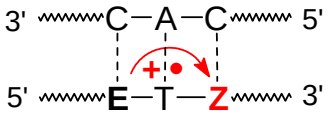
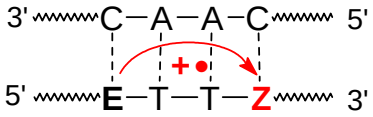
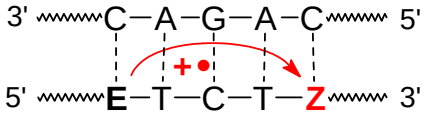
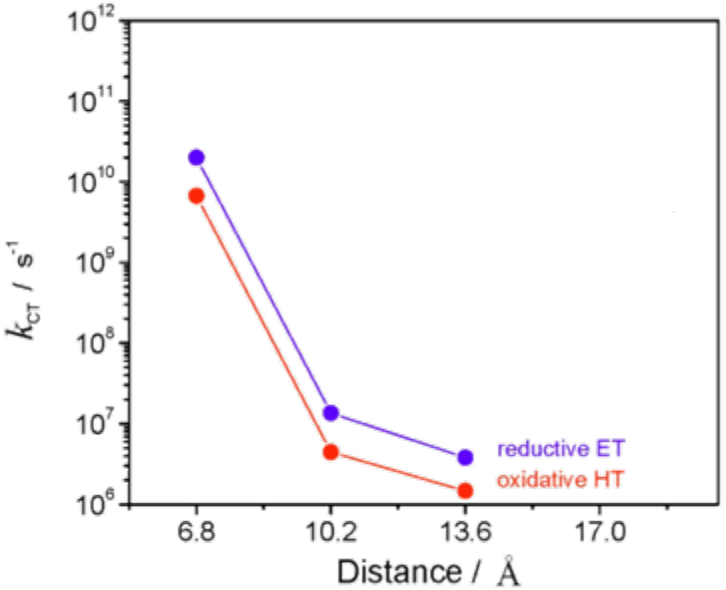
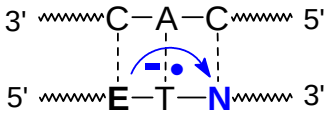
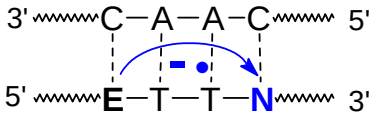


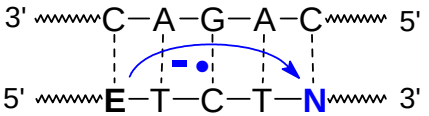










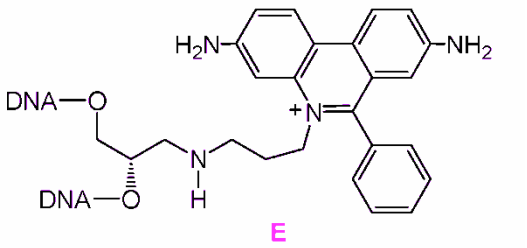


Proc. Natl. Acad. Sci. USA **2006**, *103*, 10192.

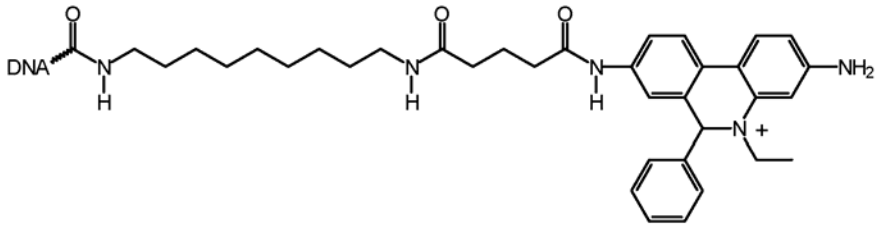
Nicole Amann, Robert Huber, Linda Valis
In collaboration with Torsten Fiebig, Boston

Part II: Charge transfer in ethidium-modified DNA

Conformational gating

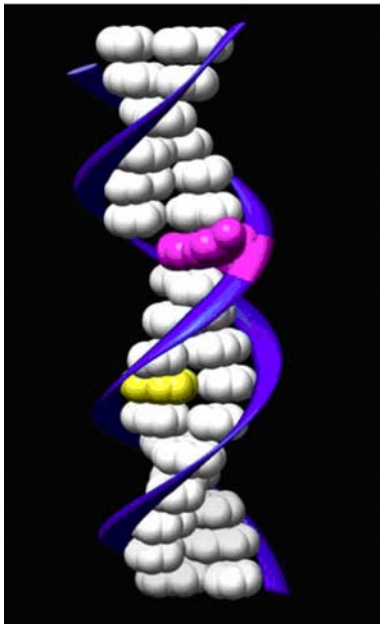


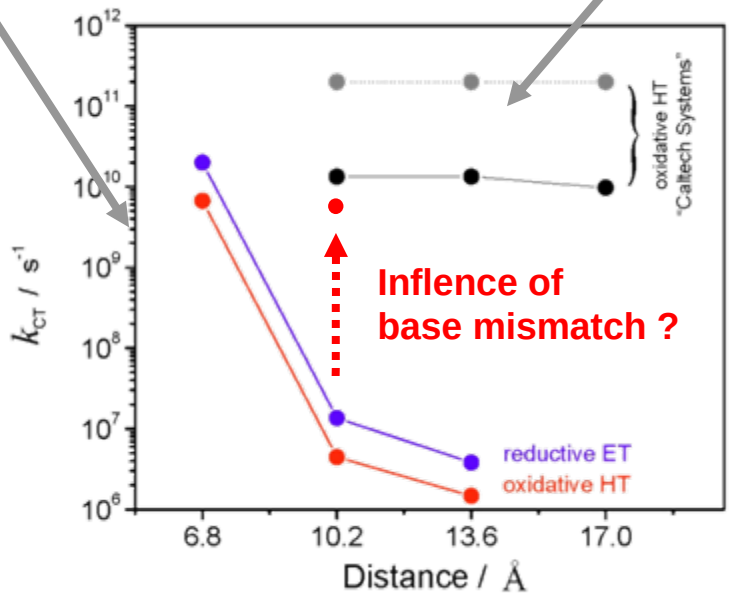
Ethidium base pair surrogate

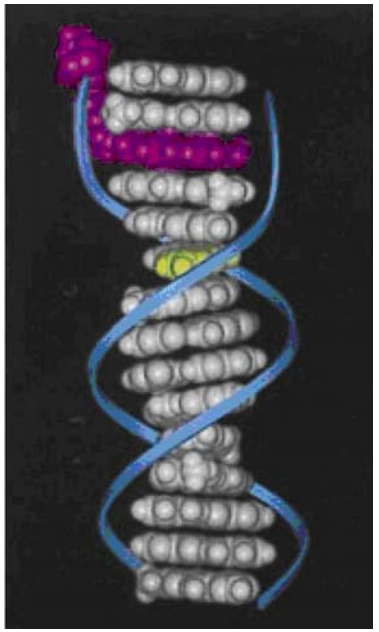


Ethidium linker in the "Caltech Systems"

rigid vs. flexible



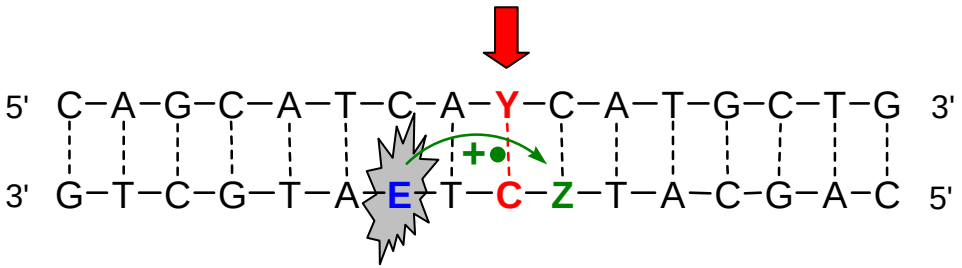




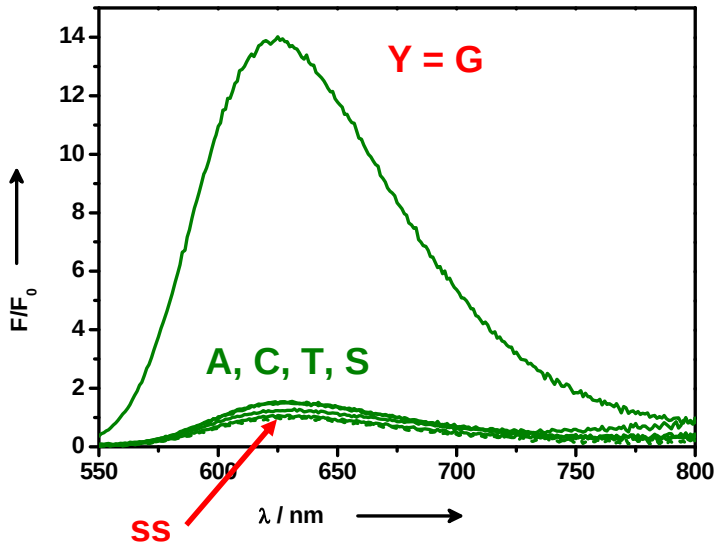
Proc. Natl. Acad. Sci. USA **2006**, *103*, 10192.

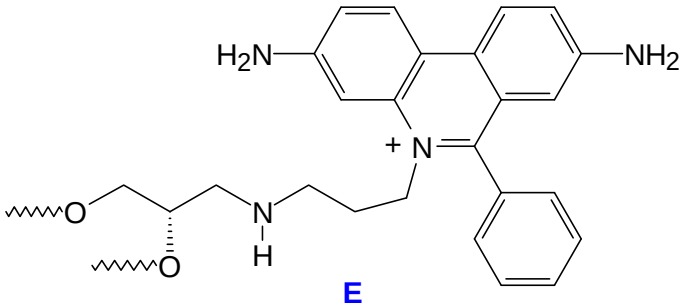
Nicole Amann, Robert Huber, Linda Valis
In collaboration with Torsten Fiebig, Boston

Single base mismatch detection



With charge transfer





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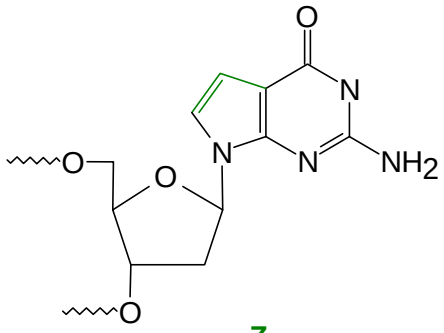


Z

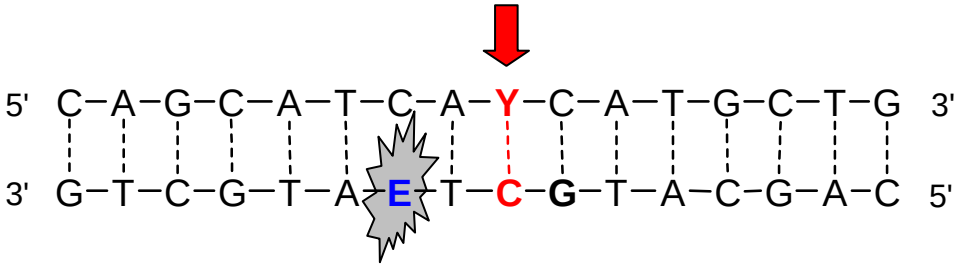
Strong match/mismatch discrimination

Org. Biomol. Chem. **2005**, *3*, 36.

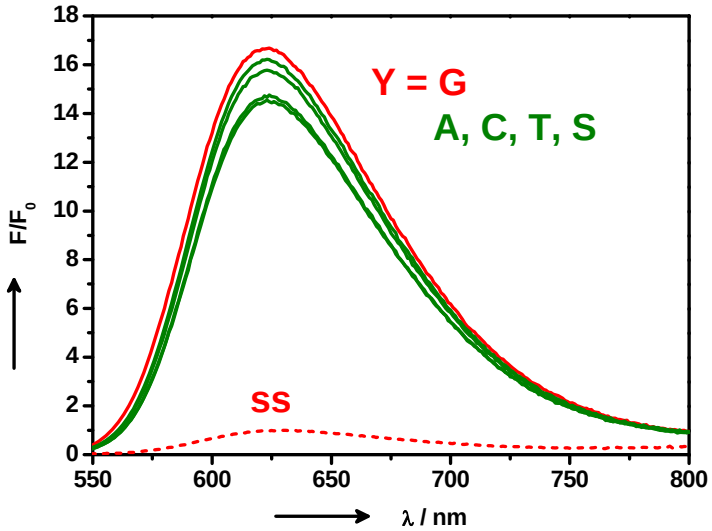
Nicole Amann
Linda Valis

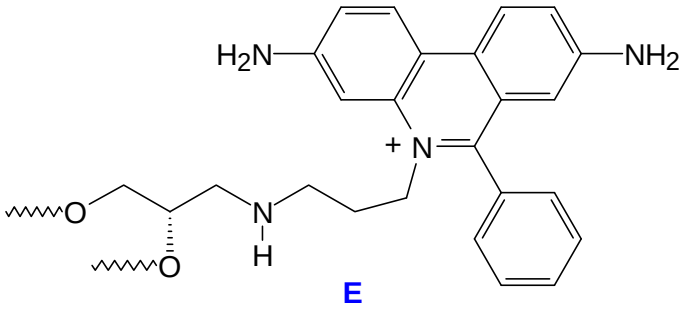
Part II. Charge transfer in ethidium-modified DNA

Single base mismatch detection



Control: without charge transfer





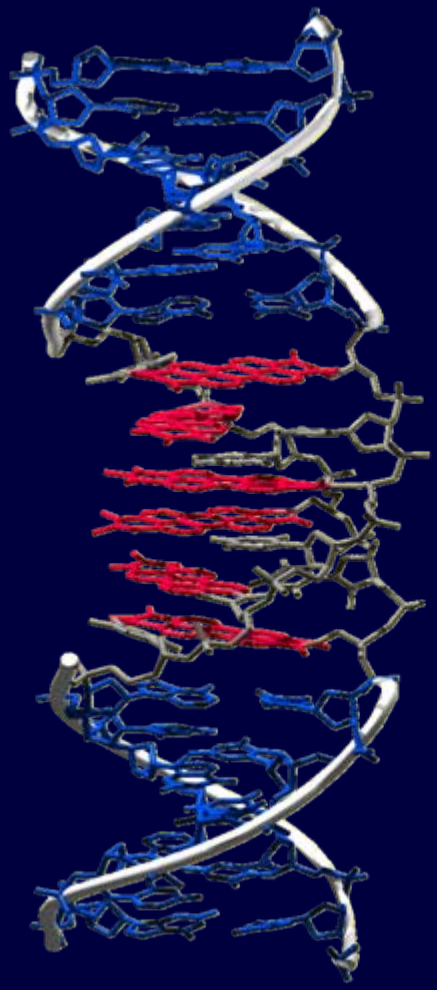
E

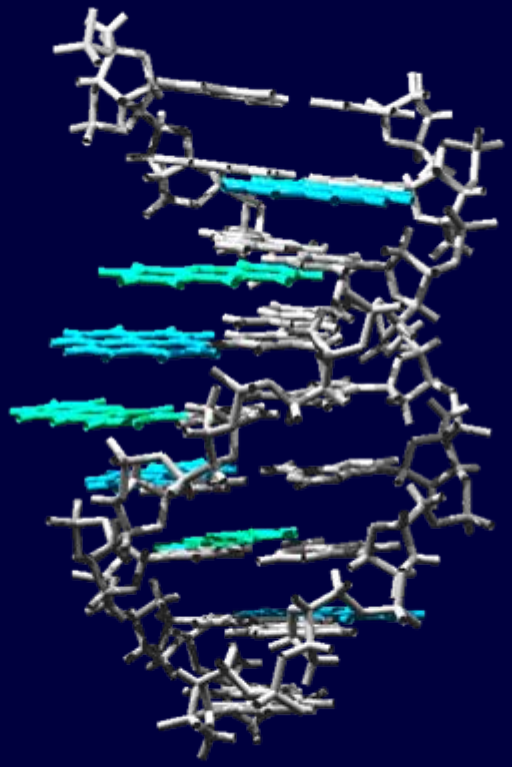
No significant match/mismatch discrimination

Org. Biomol. Chem. **2005**, *3*, 36.

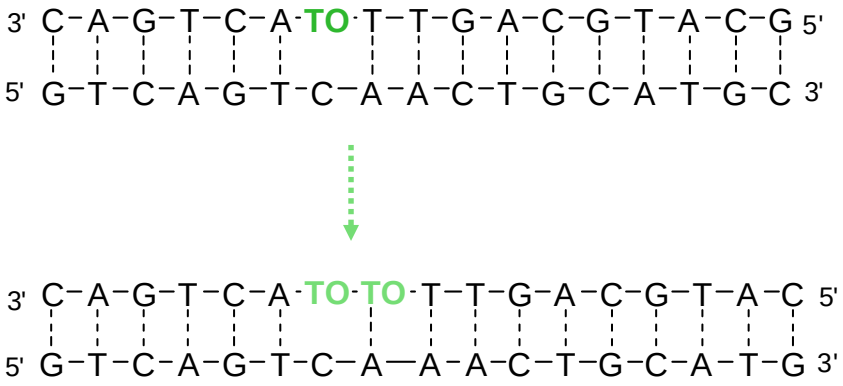
Nicole Amann
Linda Valis

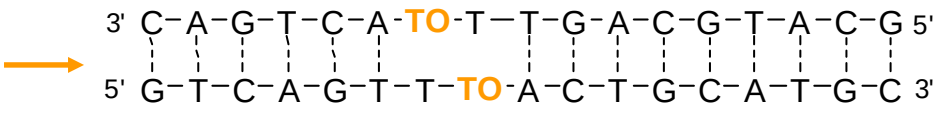
Part III: DNA architectures for switchable optical properties

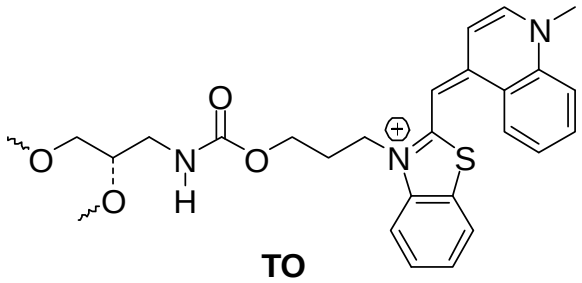




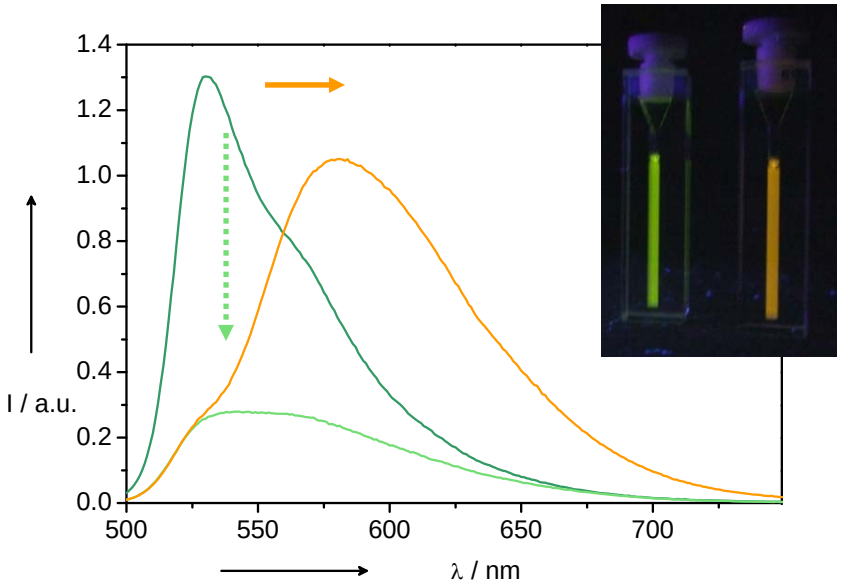
Interstrand thiazole orange dimers



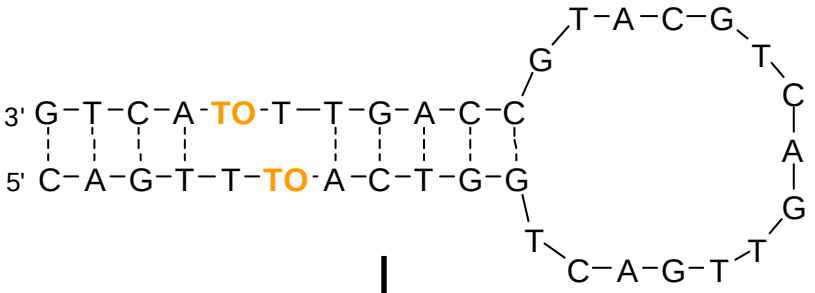


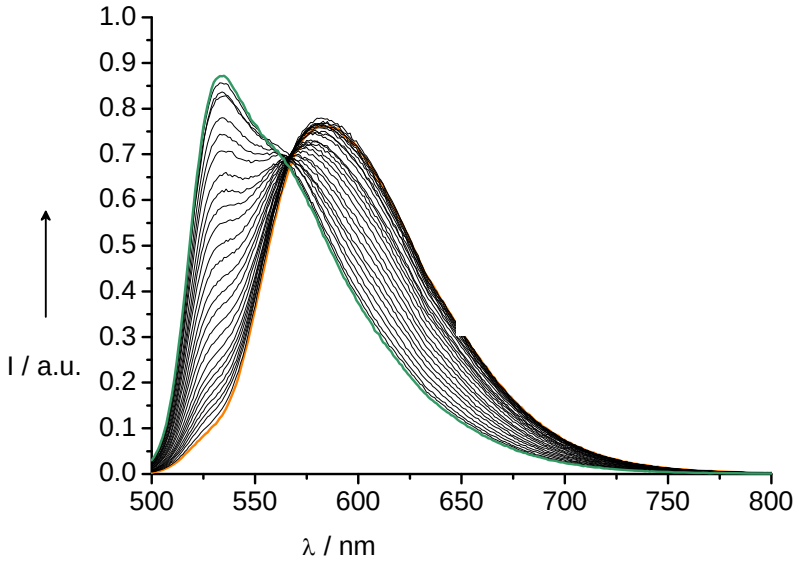


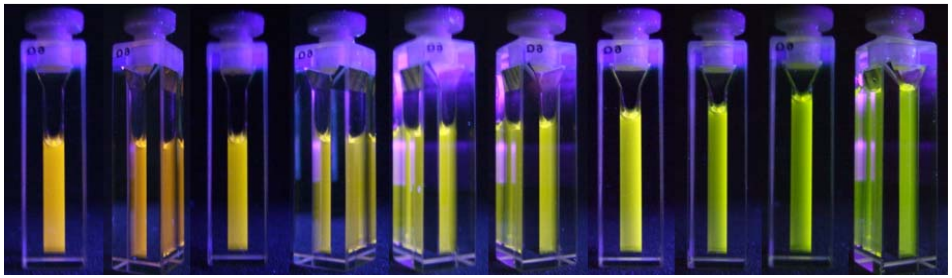
TO



Interstrand thiazole orange excimers



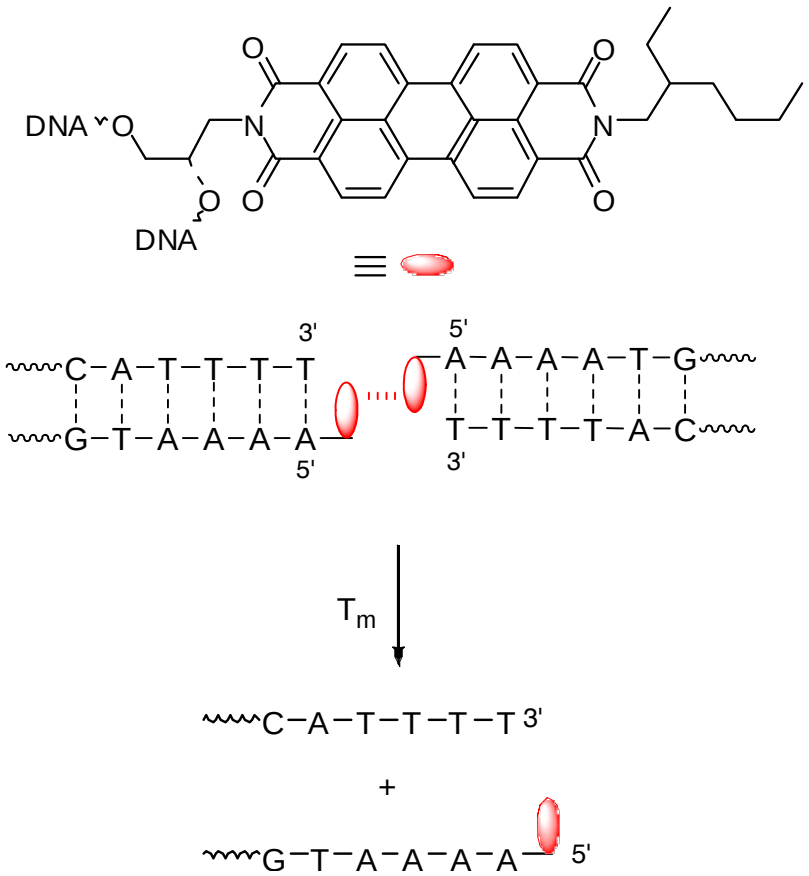


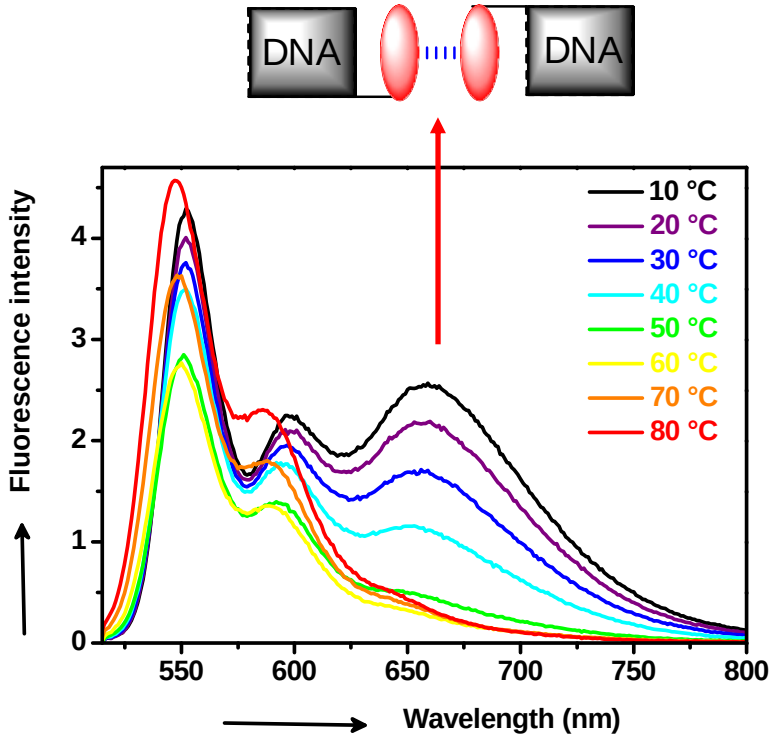


3' G-T-C-A-TO-T-T-G-A-C-C-G-T-A-C-G-T-C-A-G-T-T-G-A-C-T-G-G-T-C-A-TO-T-T-G-A-C 5'

5' A-A-C-T-G-G-C-A-T-G-C-A-G-T-C-A-A-C-T-G-A-C-C-A-G-T 3'

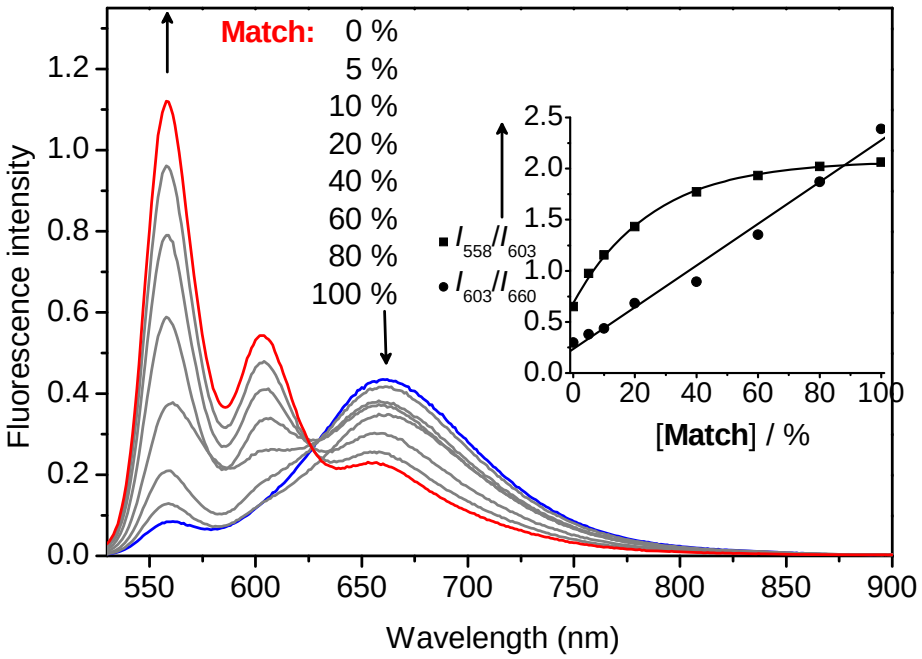
Aggregation of perylenebisimide-capped DNA

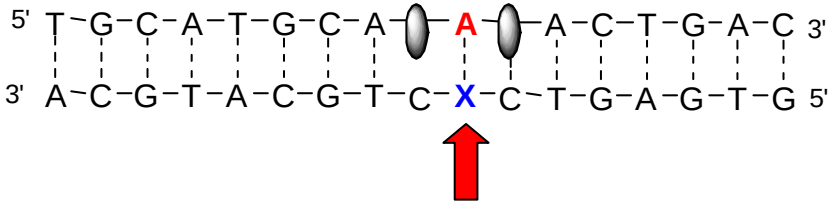




Org. Lett. **2006**, 8, 4191.

Interstrand perylenebisimide dimers

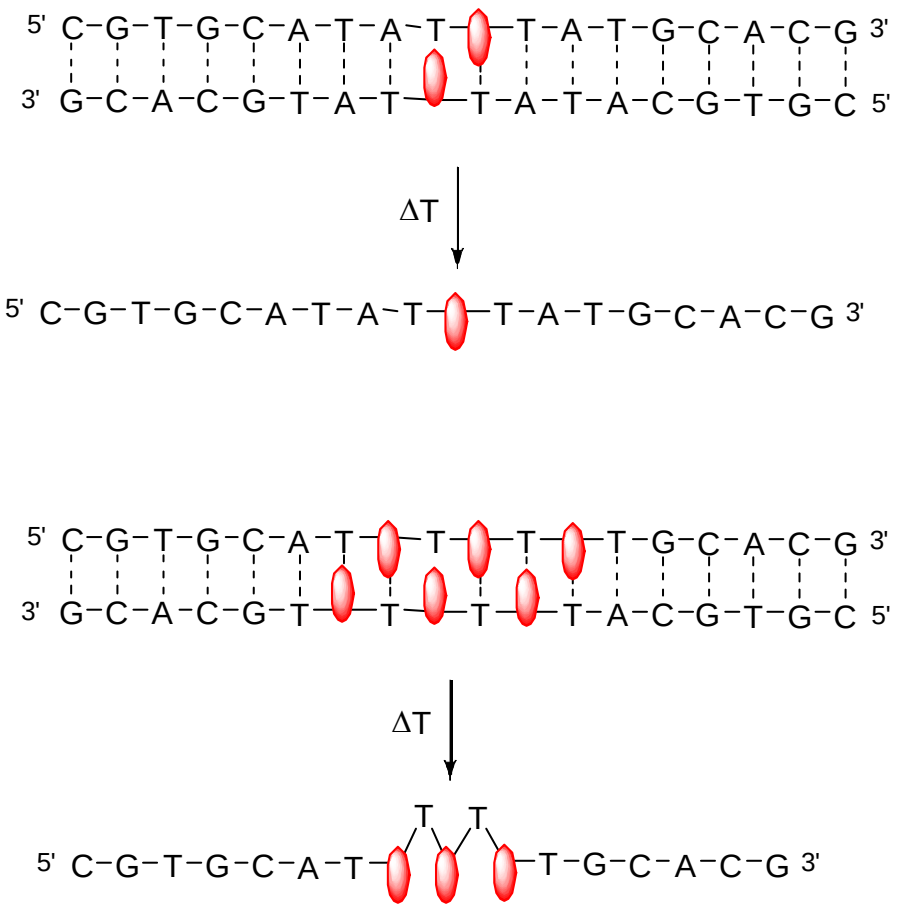


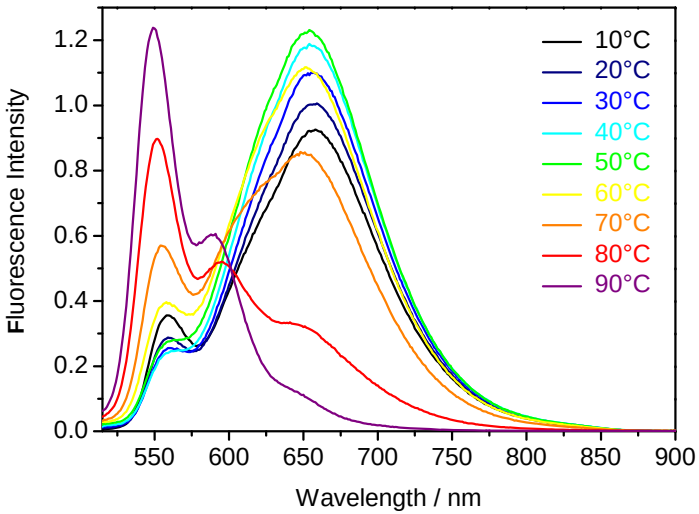


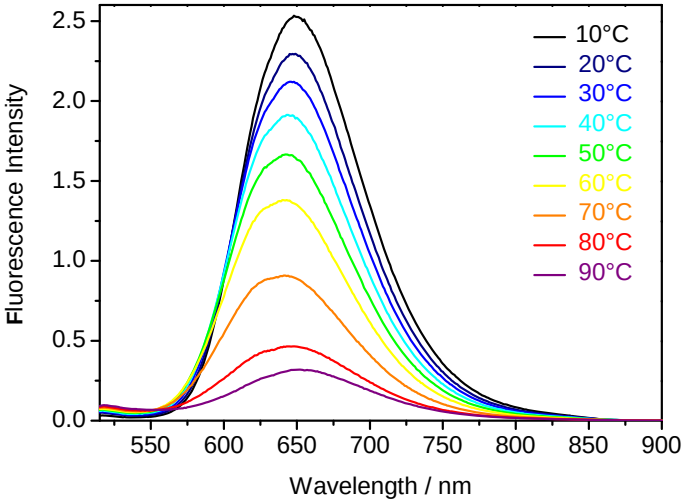
Match: X = T

Mismatches: X = C, A, G

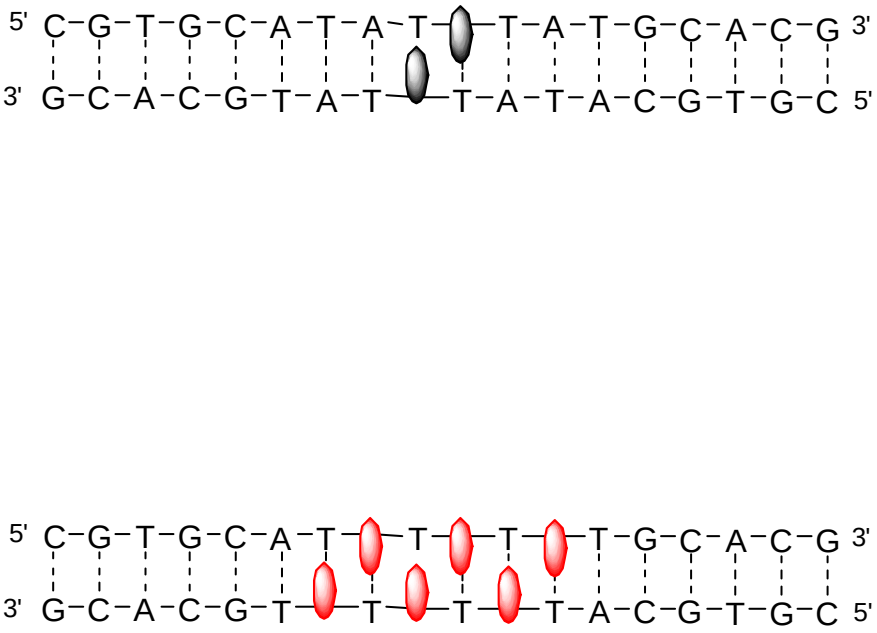
Interstrand perylenebisimide-zippers

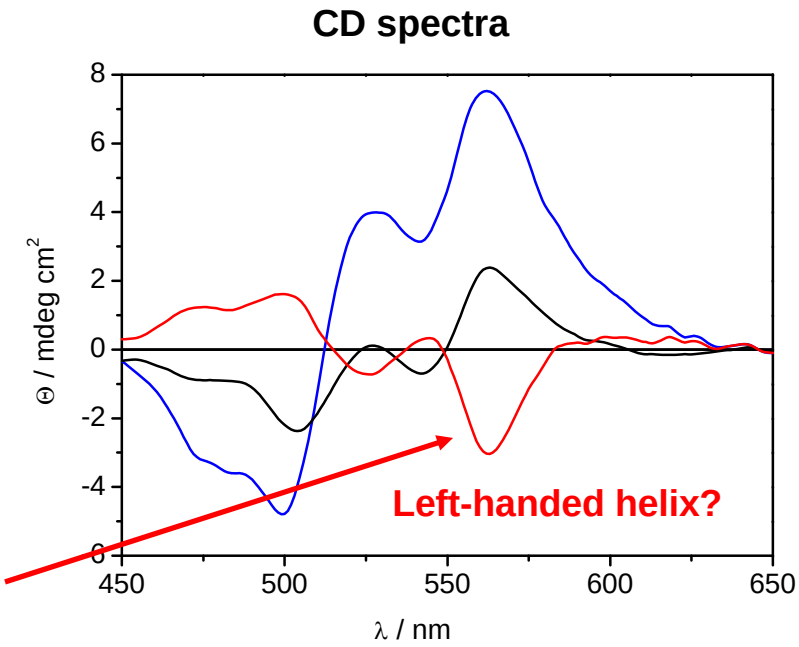


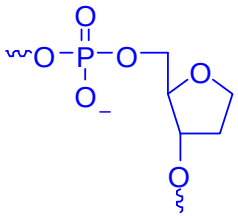




Interstrand perylenebisimide-zippers



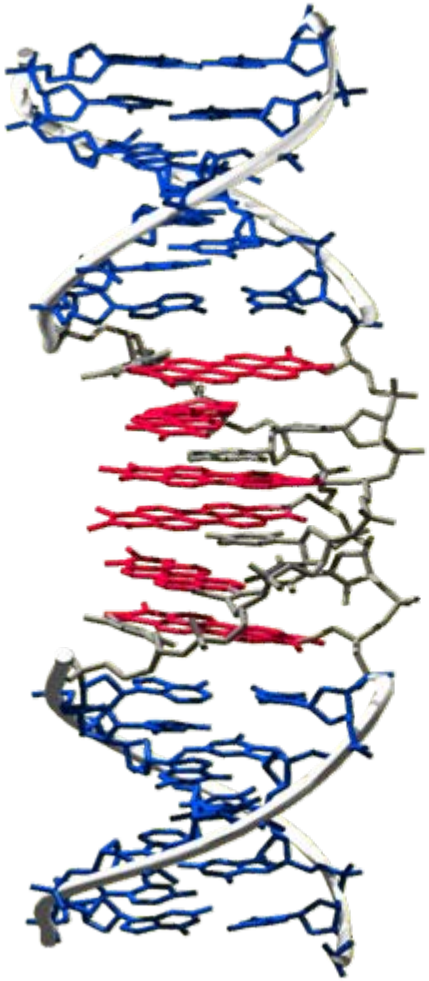


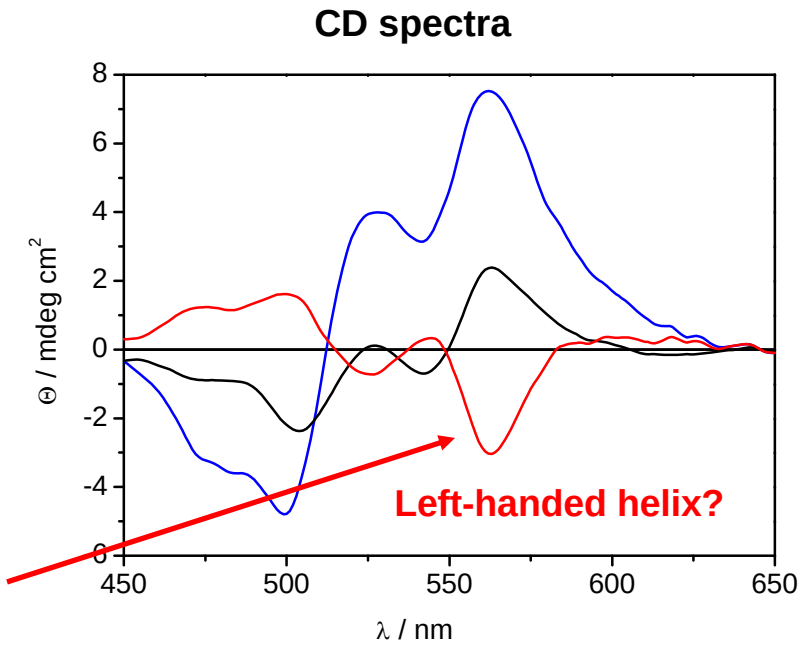


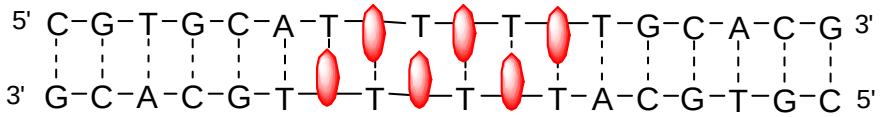
S

Interstrand perylenebisimide-zippers

35-45 ° left
85-95 °C right
35-45 ° left
85-95 °C right
35-45 ° left

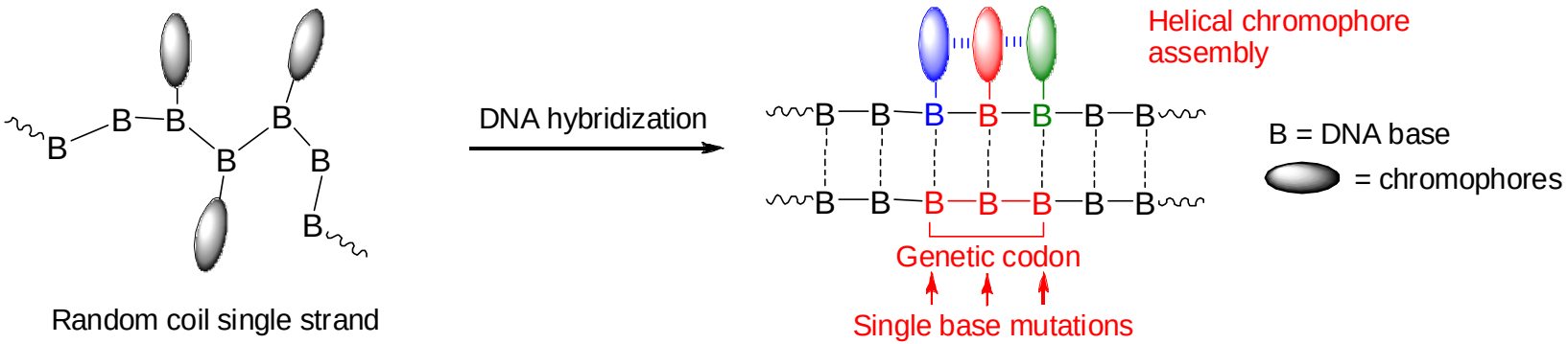






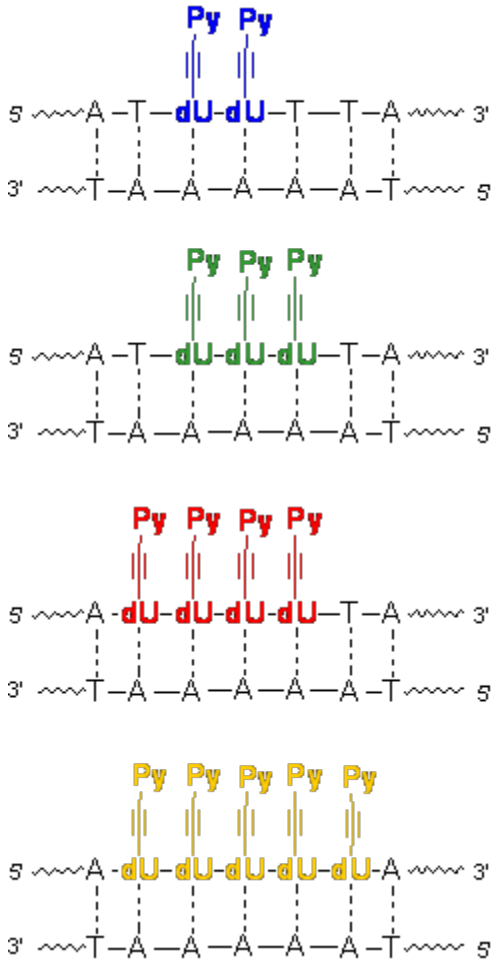
$\Delta\varepsilon = f(\sin(2\lambda))$

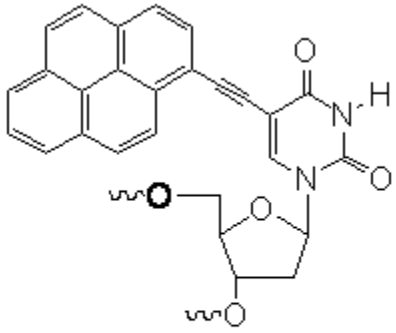
Multifluorophores based on DNA base modifications



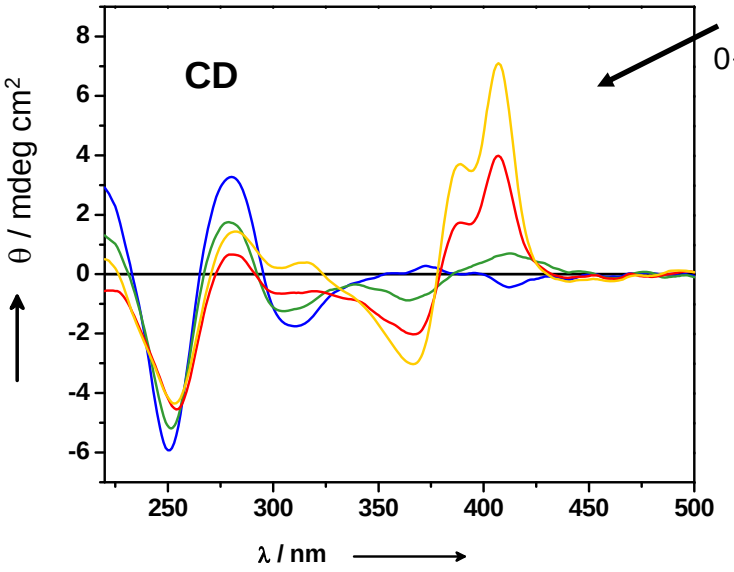
together with fs-resolved microarray readout

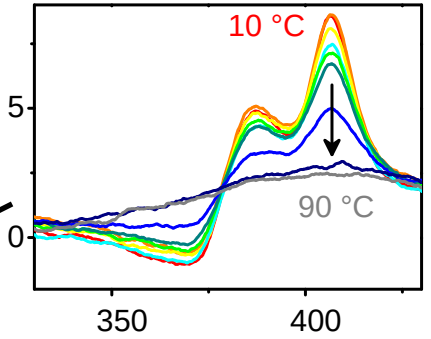
Multiple Py-≡-dU-labels





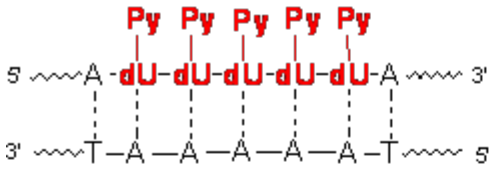
Py-in-dU

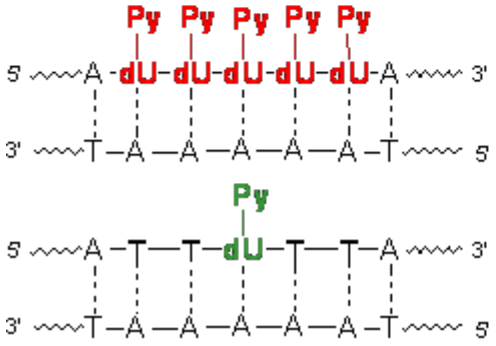


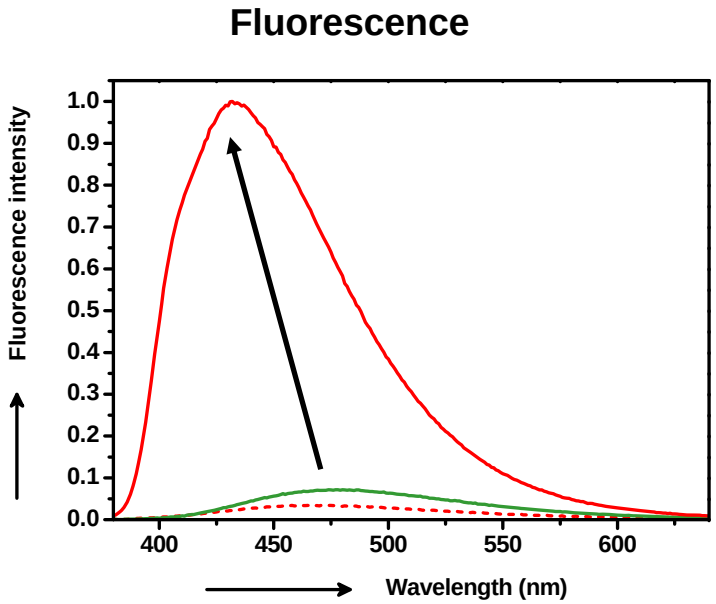


Org. Biomol. Chem. **2006**, *4*, 2088.

Multiple Py-dU-labels

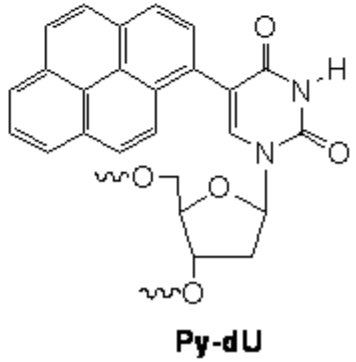






ds/ss = 22

$PydU_5$/$PydU_1$ = 11



Universität Regensburg

Vielberth-Symposium on Functional Nucleic Acids

(IV. Nucleinsäurechemie-Treffen)

10. – 11. September 2009

University of Regensburg (Germany)

REGENSBURGER UNIVERSITÄTS STIFTUNG HANS VIELBERTH

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ChemicalBiology
University of Konstanz

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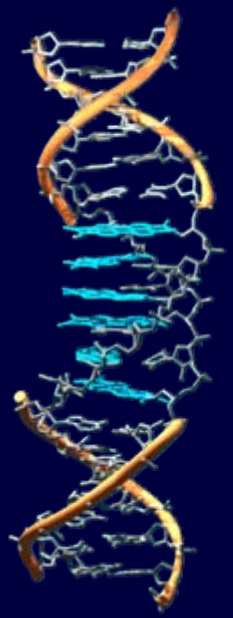


Lectures:

Hiroyuki Asanuma (Nagoya, JP)

Shankar Balasubramanian (Cambridge, UK)

Tom Brown (Southampton, UK)

Alexander Deiters (Raleigh, North Carolina, USA)

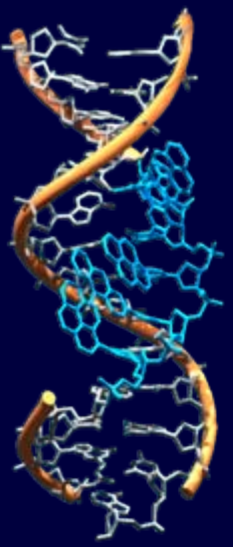
Alexander Heckel (Frankfurt, D)

Christian Leumann (Bern, CH)

Jens Müller (Münster, D)

Floyd Romesberg (Scripps La Jolla, USA)

Poster session including short poster talks



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VolkswagenStiftung

SEVENTH FRAMEWORK PROGRAMME

Alexander von Humboldt Stiftung/Foundation