Photochemical Activation of Cycloenones and Consecutive Trapping of Reactive Intermediates - An *ab initio* Study

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Abstract

Upon irradiation with light in the UV spectral range, α,β-enones are capable of undergoing various isomerizations and rearrangements towards reactive species. These photoproducts are of great synthetic utility as they are available for interception with trapping agents to form complex adducts. In order to rationalize the preference of certain reactions by molecules with a specific substitution pattern, mechanistic insights become necessary. In this work, the excited state-to-ground state relaxation pathways in two cyclic enones were deduced from experimental data and static calculations at a very high level of theory (XMS-CASPT2, CCSD(T), DFT).

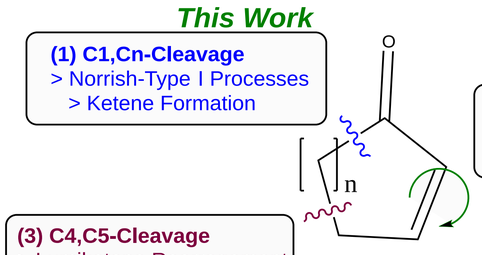
This Work

(1) C1,Cn-Cleavage
> Norrish-Type I Processes
> Ketene Formation

This Work

(2) One Bond Flip (OBF)
> E/Z-Isomerization
> Photochemical Michael-Additions

(3) C4,C5-Cleavage
> Lumiketone Rearragement
> Type B Rearrangement



Lowest lying excited state-to-ground state crosssings in cycloenones

Workflow

Ground State (DFT (wB97X-D) & DLPNO-CCSD(T))
- **Conformers**: Boltzmann Weights
- **Transition States**: Reaction Rates
- **Vibrational Frequencies**: Sampling from Quantum Wigner Distribution

Excited States (XMS-CASPT2)
- **Critical Points** on and Crossings between PES
- **Transition Probabilities**

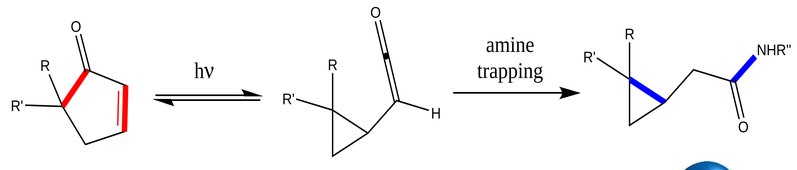
UV-vis Absorption Spectra (XMS-CASPT2)
- **Initial Conditions**
- **Intersection with Experiment**

Non-adiabatic Dynamics (XMS-CASPT2)
- **Trajectory surface hopping:** Relaxation Rates, Branching Ratios/Photoproducts, PES Model Refinement

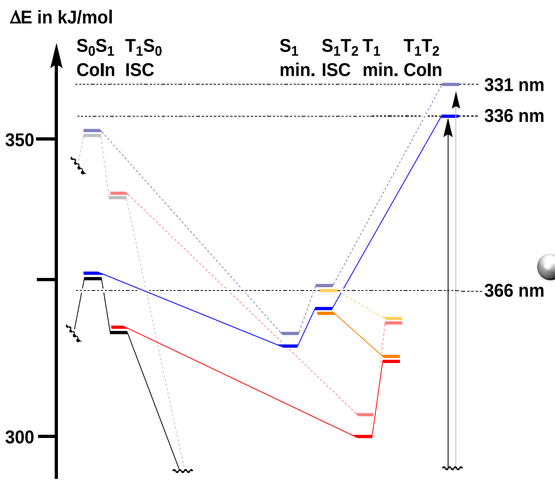
Kinetik Model

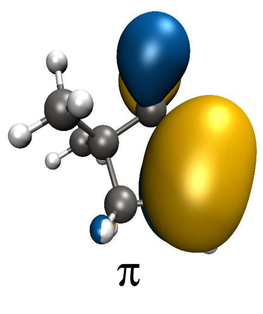
***in silico*-guided organic synthesis**

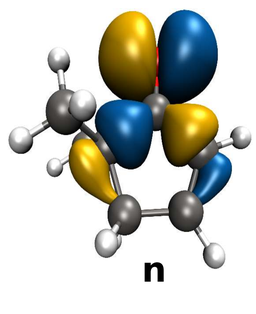
Cyclopentenone - α-Cleavage and Amine Trapping [1]

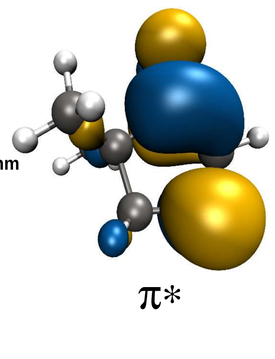


▶ Stabilization of α-cleavage ES/GS crossings below the Franck-Condon niveau enables rearrangement in both singlet and triplet manifolds





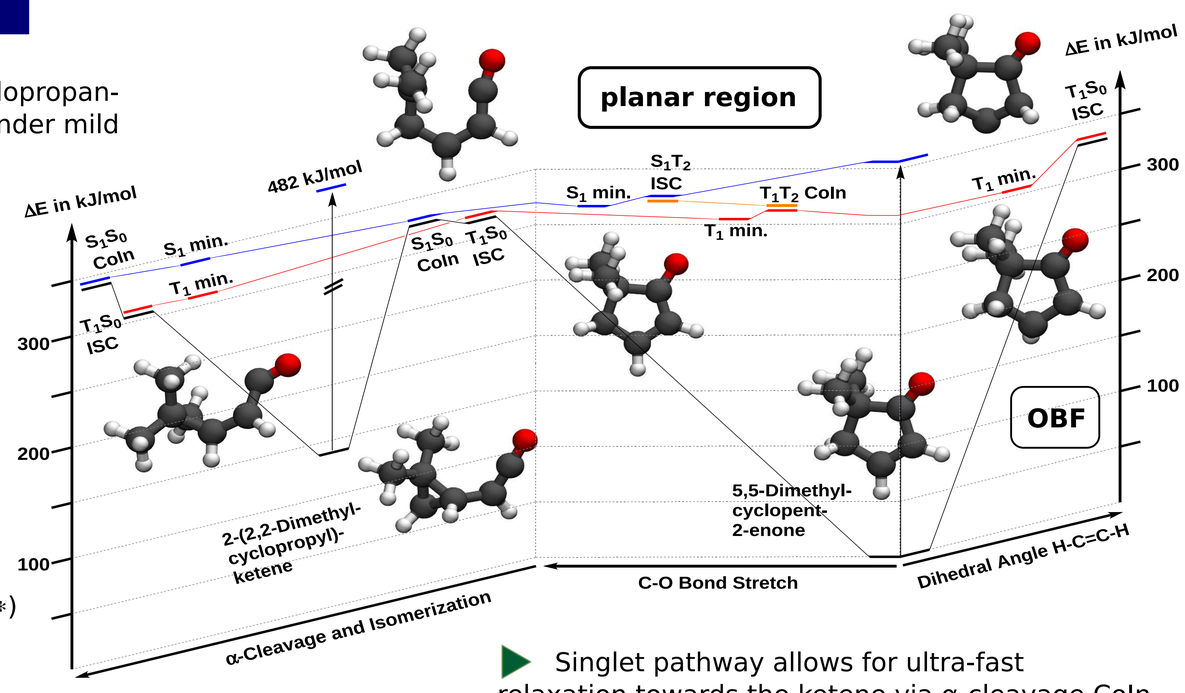




▶ 2,2-Disubstituted cyclopropan-acetic amides accesible under mild reaction conditions

▶ Orbitals of the (8/7) active space contributing significantly to the $S_0 \rightarrow S_1$ ($n\pi^*$) and $S_0 \rightarrow S_2$ ($\pi\pi^*$) excitations

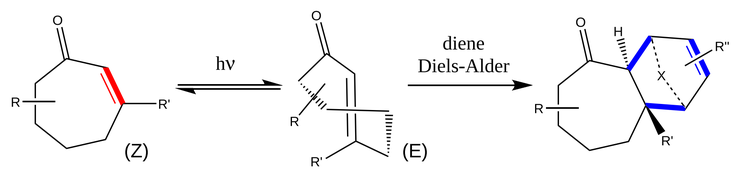
High quantum yield expected for the rearrangement in both manifolds



▶ Singlet pathway allows for ultra-fast relaxation towards the ketene via α-cleavage CoIn

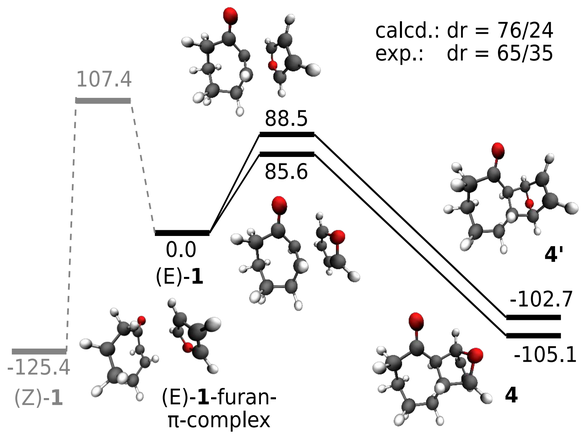
▶ Rapid ISC into planar triplet state allows for relaxation towards both the ketene and return to the Franck-Condon region - Spin-orbit coupling strength at α-cleavage ISC exceed the OBF-crossing by an order of magnitude

Cycloheptenone - E/Z-Isomerization and Diels-Alder Coupling [2]

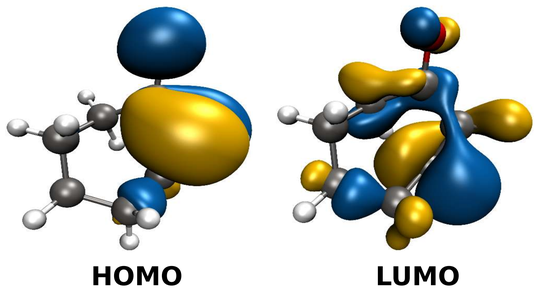


▶ Diels-Alder reactions from E-isomer out-compete isomerization towards Z-isomer in vibrationally relaxed ground state

▶ Unusual preference for the exo-product explicable within D/I-AS model [3]



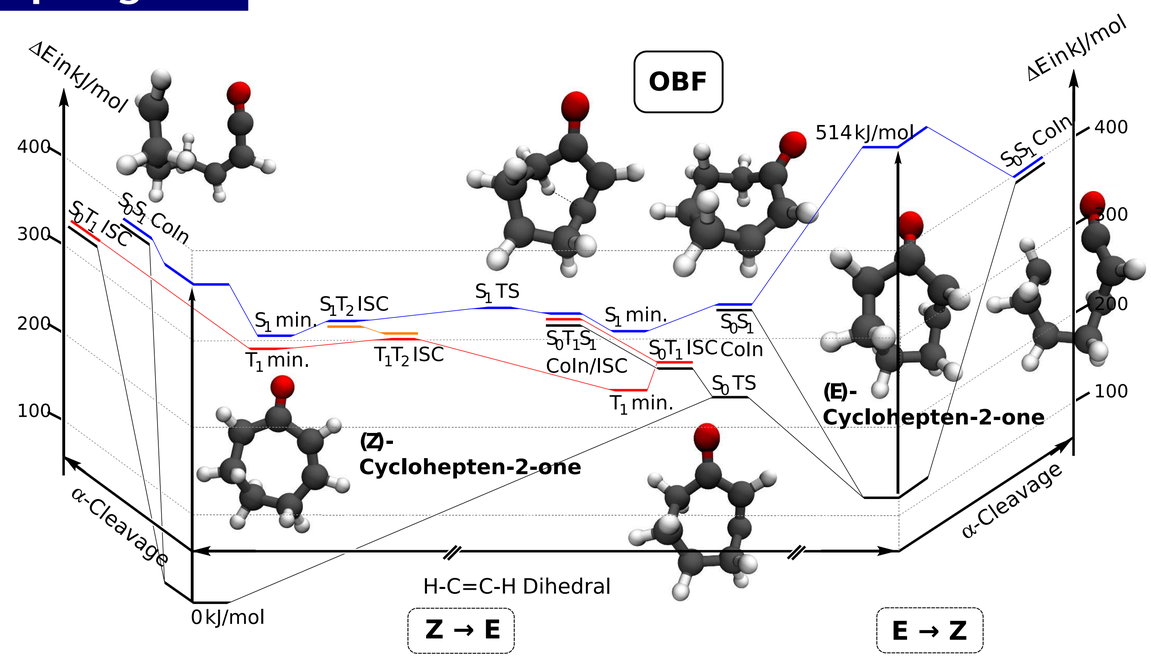
▶ Polycyclic, trans-configured ketones accesible in good dia-stereoselectivity under mild reaction conditions



▶ Frontier Orbitals of the lowest OBF-CoIn displaying transannular orbital interactions

Steady state equilibrium and side reactions likely depend on lifetime of vibrationally excited E-Isomer

Efficient isomerization due to ring strain relief and transannular interactions explicable from extended two electron two orbital theory [4]



Z → E

▶ Only pathways through OBF crossings accesible, triplet path thought to be dominating

▶ Spin-orbit coupling small - slow process with molecules 'trapped' in OBF-triplet minimum

E → Z

▶ Ultra-fast relaxation with singlet pathways dominating

▶ Outcome is either retention of configuration (OBF) or photo-destruction (H-transfer or ketene-formation)

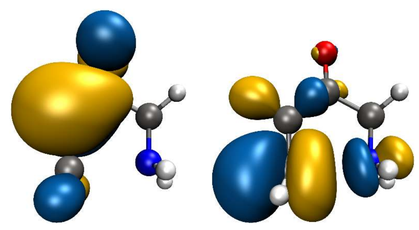
Outlook

Non-adiabatic dynamics simulation of photorelaxation processes

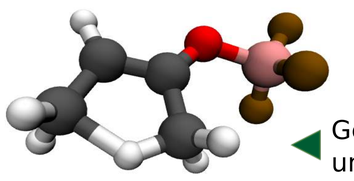
Substituent effects: Rationalization and Quantification

Novel and mild synthetic protocols

Frontier orbitals with amino substituent on side chain ▶



◀ Geometry distortion of S_0S_1 CoIn under Lewis acid coordination



References

[1] N. Jeremias, M. T. Peschel, C. Jaschke, R. de Vivie-Riedle, T. Bach, J. Org. Chem. **2022**, XX, X, XXXX.

[2] D. P. Schwinger, M. T. Peschel, C. Jaschke, C. Jandl, R. de Vivie-Riedle, T. Bach, J. Org. Chem. **2022**, 87, 7, 4838.

[3] F. M. Bickelhaupt, K. N. Houk, Angew. Chem. Int. Ed. **2017**, 56, 10070.

[4] A. Nenov, R. de Vivie-Riedle, J. Chem. Phys. **2012**, 137, 7, 074101.

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