**In Vivo Olefin Metathesis – challenges, approaches and applications – summaries**

Used in work

## Basic knowledge

* Nitro-Grela catalyst: NHC-based catalyst, very efficient for many reaction types:

A chemical structure with letters and numbers

Description automatically generated

* AquaMet – another good GHII, can be used in metathesis of water-insoluble substrates in ′′classical′′ organic solvents and in reactions in ionic liquids (sigma-aldrich):



* Grubbs-Hoveyda second generation – an NHC catalyst with benzylidene ligands that have a chelating ortho-isopropoxy group attached to the benzene rings and without any phosphines. For example:



* Click chemistry – field containing reactions with inert by-products, high yield and high selectivity.14
* Key characteristics of bioorthogonal reactions:14
  + Tolerance to water
  + High reaction rate
  + Reactions partners not commonly found in nature
  + Small reactants, in order to minimize perturbance to the biological system
* Bioorthogonal reactions:14
  + Native chemical ligation – between amino-terminal cysteine and a thioester, creates an amide bond.
  + Oxime/hydrazone ligation – creation of an imine-N or imine-O bond which is more resistant to hydrolysis than imine; relatively slow and reversible sometimes
  + Staudinger ligation – based on the Staudinger reaction that was discovered in 1919, an optimization based on a methyl ester enables efficient ligation between an azide and a triarylphophine. A model bioorthogonal reaction except its relative slowness.
    - Phosphines and phosphites are generally good bioorthogonal reactants.
  + Copper-catalyzed azide-alkyne cycloaddition (CuAAC) – since both alkynes and azides are small and biologically inert and the Cu(I) catalyst makes this reaction very fast, it's also a model student though limited by the harmful reactivity of Cu(I) which tends to oxidize and create superoxides.
  + Strain-promoted [3 + 2] reactions – rely on the high ring strain in cyclooctyne and cycloheptyne compound that enables high reaction rate in synthesis of heterocyclic compounds while avoiding Cu catalysts. Azides or other three-atom dipole species may be used.
  + Tetrazine ligation – two [4+2] cycloadditions between an electron-poor diene and an electron-rich dienophile; very fast without the need for catalysis and can be performed in vivo.
  + Photoinducible bioorthogonal chemistry – a set of reactions characterized by activation of a reactant through radiation, such as the reaction between tetrazoles and alkenes. Control of the light (e.g. with a laser) allows superb precision and selectivity, and the reaction is usually quite fast. Light can be used to generate reactants for other bioorthogonal reactions, like SPAAC.
  + Metal-catalyzed coupling reactions – Pd cross-coupling was problematic at first because of its non bio-compatible requirements but can be modified. One of the main problems is the inherent toxicity of some transition metals.

A deeper dive into GHII mechanism of reaction

## Catalysts (and specifically ligands)

* Catalysts can be small (one molecule/complex) or macro-molecular, like metalloenzymes or polymeric complexes.
* For a catalyst to reach its target inside the cell efficiently, and without being blocked by cellular barriers along the way, it often has a targeting functional group.
  + BODIPY (boron difluoride-dipyrromethene) motifs are lipophilic and fluorescent and allow internalization of the catalyst into microalgae lipid bodies1.
* The catalyst can be an artificial cofactor for an engineered holoenzyme.2
* 2 developed Streptavidin (SAV)-Ru-benzilydene:



* Modifying the enzyme's amino acids near the Ru allows optimization of the activity of the catalyst (how exactly does the amino acid change optimize the reaction?). For example, they can:2
  + Raise entropy
  + Reduce bulk and so minimize steric strain
  + Change hydrogen-bond interactions (and how does this help?)
* 3 developed HAS (human serum albumin)+Hoveyda-Grubbs metalloenzyme (Artificial Metalloenzyme – ArM), in which the negative charge of the protein prevents GSH (glutathione) interaction.
  + Next, they replaced the Cl on the Ru with I, and achieved better reactivity and great tolerance to blood components, probably because of the weaker hydrogen bonding (6). Similar results regarding iodide were reported in 6.
    - Bromide kind of sucks.6
  + The better reactivity is achieved due to the steric hindrance of the bulky iodide makes the intermediates more stable in comparison to the reactant.
  + AquaMet is okay in water but sucks in blood
* Ruthenium is the most stable metal for OM in air and water (requires more sources).4
* Phosphine ligands can catalyze in water but they kind of suck,4 and also suppress CM.9
* In GH (Grubbs-Hoveyda) protein-conjugated catalysts, one of the halide ligands is directed toward the protein and the other toward the surface. That's why ligand (e.g. halide with hydroxide) exchange is possible and can lead to catalyst degradation.6
* Ways the protein protects the catalyst:
  + Preventing some of the ligand exchange.6
  + Making dimerization of the catalyst less favorable sterically.6
* NO3-AquaMet catalyst, in which NO3 replaces either one or both of the chloride ligands, can be generated from AquaMet and nitrate-containing species – it decomposes quickly alone but gives a greater yield than AquaMet for RCM of N,N-diallyltosyl amine specifically (but not to other metatheses tested).7
* GHII is stable in air and moisture.8 (look in quoted articles as well)
* Beta-barrel structure is a good anchoring for metalloproteins because the compact sheets provide robustness against degrading agents.8
* Membrane-spanning beta-barrel proteins are usually larger than their hydrophilic counterparts and can accommodate large GHII catalysts.8
* Schrock carbenes suck as ligands (for our use-cases) because they're not stable in oxygen and moisture.9 (look in quotes)
* Isopropoxybenzylidene-based catalysts are less affected by water than phosphine-based catalysts (look at quoted).21
* Hydrophobic catalysts are better suited for aqueous conditions, because the catalyst and substrate molecules form an emulsion together.21
* One can use surfactants and beads to encapsulate the catalyst and enable recycling and more efficient catalysis.21
* NHC ligand donates elector and thus stabilizes the catalyst when catalyzing a reaction in proximity to S atoms, but phosphine ligands compete with the S atoms for coordination with the Ru.
* Schrock Mo catalysts can catalyze well CM of vinylglycine (press x for doubt), but its stability in air and moisture sucks.11
* For the catalyst to be soluble in water, it can contain a PEG or a charged group, like ammonium.11
* The ammonium also weakens the O–Ru coordination, resulting in fast initiation.11
* AquaMet (AM) sucks at catalyzing OM in DNA because of the attraction between its positive ammonium to the negative phosphate backbone of the DNA.12
* Cationic ligands can acidify the water around the catalyst, accelerating decomposition.12
* Ionic catalyst are more soluble than neutral ones.obviously?? but also 12
* CAACs improve resistance to degradation, also by water – they do undergo water-chloride exchange like NHCs, but the aqua species is relatively stable.12
* Anionic catalysts are very cool and soluble but the research was in 70 degrees so we can't trust them that much.12
* For most modern catalysts, temperature (and an organic solvent) has a stronger effect on rate and yield than the catalyst loading.16
* Alkylidenes are better than Hoveyda's isopropoxy catalysts in the formation of trisubstituted double bond in CM in relatively low temperatures.16
* For RCM in low temperatures – Grela's and Est catalysts are the best because of fast initiation and propagation.
* Phosphine catalysts are initiated by the dissociation of the phosphine group but in tethered catalysts like Hoveyda initiation requires breakage of the Ru-O bond.16–
* In cationic catalysts, the ammonium tag can be on the NHC, the benzylidene ring, the isopropoxy O or on a phosphine. They improve the solubility and can offer good yields in room temperature and aqueous conditions, some in as little as 2.5-3.5 hours.21 they're also easier to extract from the products.21
* EWGs on the catalyst greatly help as well (Grela and friends proved it).21
* In metalloenzymes, the length of the chain connecting the ruthenium complex to the enzyme is important – a longer chains can improve TONs, perhaps through enabling space for the reactant, but they shouldn't be too long (21, find more sources).
* HGII is highly toxic to cells(!!)22
* Surrounding the catalyst with a negative charge can prevent glutathione from interacting with it and deactivating it.22
* Internalization of an externally-applied metalloenzyme can be a challenge.
* PEG-based polymers are nice because they're biodegradable, and the intake through them decreases the toxicity of the ruthenium catalyst.22

Synthesis of catalysts

* For a metalloenzyme – the biotin-streptavidin technology2
  + The affinity between biotin and streptavidin is very high by nature, so when the metal catalyst is bonded to biotin it can be integrated to a streptavidin-derived protein.8 (look at quotes)
* Directed evolution through saturation mutagenesis on the amino acids close to the Ru can increase five-fold the cell-specific activity of the catalyst.2 This type of evolution can be perform substrate-specifically and thus we can develop the "ideal" enzyme for any type of reaction (personal observation, based on 2).
* Metalloprotein with a dative bond – the protein donates both electors in the covalent bond – offer easy dissociation of catalyst from the protein but are hard to design.8
* Covalent anchoring offers precise positioning.8
* Anchoring can be based on creating on enlarging a cavity – an artificial active site – inside the protein (through mutations), to which the catalyst will bind.8
* A relatively long spacer between the protein and the catalyst may be needed to accommodate the bulky carbene groups.8
* Partial denaturation and then renaturation of the protein can be utilized to unfold it for the conjugation of the catalyst to inner amino acid residues.8
* Dative anchoring of biotinylated HG-catalyst to human carbonic anhydrase II (hCAII) creates another metalloenzyme (21 quotes 23, should read 23 to confirm this).
* The peptide anchoring the HG catalyst to the protein may be attached to the NHC moiety and so covalently attached to the protein itself, like in chymotrypsin (21 quoting 24).
* Another metalloenzyme was synthesized from a genetically modified archean heat shock protein – again, the anchoring group was attached to the NHC ligand.

## Reactions

* Artificial RCM reaction in 1 and 2; useful for assessing activity and efficiency (though it sucks in water2):



* Another useful model RCM reaction:7



* "Natural" unsaturated fatty acids in microalgae are converted to olefin metathesis products with up to 79% conversion rate.
* The yield of most catalysts goes sharply down after incubation in blood because of deactivation (by GSH, for example); AlbRu-I achieves a good yield of 21% after incubation in blood for 24h.3
* AlbRu-I can be used to synthesize carboxylic acids.3
* One can split the available reactions into multiple groups:3
  + RCM
  + Sequential RCM/aromatization
  + Cross-metathesis:

Transferring an olefin to homoallylglycine didn't work but to Cys-like residues did work, probably because of the sulfur.9 (look in quoted article)

* + ROMP (ring-opening metathesis polymerization)
  + acyclic diene metathesis polymerization (ADMET)9
* Facilitate reaction:
  + Creation of 5/6 membered rings3
  + Protection of allylic hydroxyl group with pivalate group3
  + Sulfur-assisted metathesis mechanism ([??](https://pubmed.ncbi.nlm.nih.gov/21050005/)) – the helpful chalcogen group can also be installed to on protein "artificially".9
  + Lower pH – increases TON.6,21
  + MgCl2 – the magnesium ions disrupt chelate formation.9, 17 Also prevents binding of amino acid residues to the ruthenium and in the case of DNA modification, protects the DNA from decomposition by competing with Ru for attaching the phosphate backbone.21
  + NaCl, at least for some reactions and catalysts (find out why).12
  + Raising the temperature.16
  + tBuOH or DMSO as solvents (shame for in vivo, and be careful not to denature the protein).17
  + PEG-500 as a cosolvent.17
* Lower reaction yield:
  + Allylic hydroxyl group3
  + Water, of course (later on that)
  + GSH and histidine that coordinate to the metal center and can reduce the catalyst.7
  + Basic molecules – can deprotonate the metallocyclobutane and cause decomposition of the species – can be prevented by adding acids.7
  + Dimerization of the catalyst through the Ru.7
* The usage of pseudo-amino acids for metathesis allows the reaction to occur on the protein itself, but presents the additional challenge of conjugating the alkene to the protein
* Sac (s-allylcysteine) – a good residue for OM because the S coordinates with the Ru center and protects it from chelation while keeping it available for metallacyclobutane creation.10
  + The protein can be synthesized genetically or through direct allylation.10 Genetically, it's supplied externally and replaces a similar amino acid like methionine, or through amber stop codon reassignment.11
  + High yield substrates - allylic alcohols, ethers, and hexenyl glucoside, medium yield for allyl glycosides.10
  + Challenging substrates – bulky sugars with a short linking chain, alkenes with electron-withdrawing ammonium groups or acetamide.10
  + The metathesis partner needs to be slightly less reactive than the allyl sulfide.10
  + Linker-extended Sac is a bad bitch, both yield- and rate-wise,10 probably because the chain enables coordination with less steric strain than regular Sac.
  + Note – this is not a metalloprotein case – the ligand is a "regular" GHII and the **substrate** is a protein.
* Se-allylselecocysteine (Seac) is even better than Sac because selenium is softer than sulfur and thus more fitting for the ruthenium, AND it's faster as well – also enhanced with a longer linker chain and succeeds with difficult substrats.10
* The reaction must tolerate chelating or reactive residues of the protein.11
* The protein must be accessible for the metathesis, sterically and conformationally.11
* Cross-metathesis can be templated by hydrogen bonding.11 (look in quoted article)
* Free OH group in a sugar in CM can damage yield.11 (I think?)
* Forming tetrasubstituted double bonds is hard.16
* O-brotylserine is also a good UAA that can be modified by GHII in metathesis and genetically incorporated to a protein by an aminoactl-tRNA sythetase mutant in yeast.17

Why water sucks

* Even in "organic solvent settings" in industry, water is a frequent, often unavoidable contaminant – even 100ppm water can cause 60% drop in yield.5
* Water form hydrogen bonds with NH2, Cl and I and the most sensitive catalyst will be the one with the weakest bonds.
* Water does not affect E/Z selectivity, but increases isomerization in the location of the double bond.5
* Hydrogen bonding destabilizes the reaction-ready conformer of some RCM reactants (increases its energy).5
* The effect is double – both on the catalyst and the reactant.
* Fast-initiating catalysts are more vulnerable to decomposition by water because the active state is the one attacked by water.5
* Catalyst decomposition in water =(mostly) halide exchange leading to dihydroxy complexes and binuclear species (6 quoting others).6
* Water competes with the olefin to bind the catalyst.12

## Throughput, rate and byproducts (different types of selectivities)

* Both "free" and enzyme-bound Ru catalysts show Michaelis-Menten kinetics.2
* SAVmut outperforms both Hoveyda–Grubbs (HGII) and AquaMet (AQM) under some conditions.2
* AlbRu-I requires 1-5 mol% for efficient catalysis.3
* The decomposed Ru catalyst can trigger double bond migration and DNA degradation (look for the quoted articles in 5).5
* High concentration of the catalyst can lead to biomolecular coupling and thus to a lower TON for some catalysts.5
* Annoying side reactions like olefin isomerization after beta-hydride elimination did not occur in 6.
* 6 achieved maximum TONs of 50-70 for some RCM reactions with the Ru-I2protein conjugated catalyst.
* An improvement in yield can be kinetic – for example, NO3-AM produces a greater yield than AM in some cases, though they decompose in the same rate because it initiates faster and improves the catalytic activity of the active species.7
* E/Z selectivity can be influenced by the anchoring protein:8

A diagram of a chemical structure

Description automatically generated

* Note to self – should find articles regarding metalloproteins with multiple catalysts per protein and whether they improve yield.
* Although a large spacer helps conjugation, it harms catalytic activity because the catalyst is free to move around (and it's bad) and coordinates to unwanted residues.8
* Large proteins -> large cavities -> more potential interactions -> less activity (personal observation based on the article).8
* Side reactivity is observed when installing a chalcogen group on a protein using reagents like MSH.9
* Self-metathesis of the product can ruin stuff, especially if it doesn't re-enter the catalytic cycle and the desired product does.10
* The products of catalyst decomposition in water – ruthenium hydrides – can promote unwanted side reactions like double bond isomerization and migration.11
* Coordination of carbonyl to ruthenium can promote OM instead of oligomerization.11
* In aqueous conditions, a cationic CAAC catalyst showed improved TON (640 vs 420) and lowers double-bond isomerization in comparison to AquaMet.12
* Rate constants of reactions should be measured in aqueous condition, when possible, and include the catalyst concentration.14+common sense
* When reacting S- or Se- allyl- or allylhomo-cysteine in CM in aqueous conditions, good yields were achieved in 3-4 hours and little homodimerization was observed.17
* E/Z selectivity is questionable in conjugates though reactions typically proceed with E selectivity with GHII catalysts.17
* Metal complexes impurities may cause isomerization or decomposition of the product and may be toxic.21
* Metalloenzymes can achieve TONs of 20-80 for the model reaction, in body temperature.21

## Organisms and industry use-cases

* Microalgae offer high growth rate, minimal space and nutrient requirements and most importantly, are photoautotrophic and thus can produce by themselves reactants for olefin metathesis1.
* Unmodified carbene ligands can lower cell viability in microalgae1.
* E. coli periplasm (the space between the two plasma membranes of the bacteria) is beneficial for olefin metathesis because it contains mostly glutathione disulfide and not glutathione, which is a metathesis inhibitor.2
* Non natural metabolic pathways1,2 (???).
* In-vivo drug synthesis in disease site enables avoiding side-effects due to harm to healthy tissues.3
* Design of transition metal catalysts to catalyze prodrug uncaging reactions in living humans is challenging because many components in the blood can deactivate them.3
* The antitumor-drug creating reaction in 3:



* Combining prodrug and the appropriate catalyst can achieve better activity (e.g. tumor growth suppression) than administering the drug itself, because of the site-specific activity.3
* The rarity of alkenyl groups in aqueous solutions in organisms allows OM to be very specific.4
* OM enables creating cross-linked peptide-mimics that are more stable than the "natural" ones.4
* Uncaging following RCM in a molecule connected to the olefin ([here](https://pmc.ncbi.nlm.nih.gov/articles/PMC6823642/)).
* Catalytically labeling or deactivating target molecules.
* The carbon-carbon double bond created can create analogues to proteins with disulfide bonds.9
* Requirements for protein-modifying reactions:9
  + Low-r.t.
  + Aqueous media
  + Chemoselectivity
  + The protein must contain an alkene group
* CM was used to mimic a certain post-translational modification of histones.9
* Genetic editing can be used to synthesize proteins that contain alkene groups.9
* Glycosylation and acetylation are biologically relevant modifications that can modify protein reactivity, affinity and cell communication.10
* Another reason for protein OM is creating a secondary structure with higher stability or affinity towards ligands (or other targets).11 Examples (all in 11 unless specified otherwise):
  + Beta-turn analogues.
  + Alpha-helices cross-linking.11,21
  + "dicarba analogues" – mimicking disulfide bonds with the greater stability of the carbon-carbon bond – e.g. oxytocin.
  + Mimicking thioether bonds.
* PEGylation can increase the half-life of proteins.11
* Modifying DNA and nucleic acids in general can be very cool (find papers about it, 12 dimerized uridine).
* Usages of bioorthogonal chemistry:14
  + Tagging molecules – for example, metabolic engineering can include hijacking the cell's enzymes to incorporate bioorthogonal functional groups (e.g. azides and alkynes), which are recognized and bound by tags; care should be taken to achieve the desired specificity through complementary strategies, like uncaging.
  + Creating high-purity proteins via solid-phase protein synthesis (e.g. native chemical ligation)
  + Generating mimics of biological bonds with better characteristics, like stability. For example, substituted triazoles created in CuAAC are more stable than amides.
  + Modifying DNA
  + Genetic code expansion – creating a modified aminoacyl-tRNA-synthetase-tRNA pair that includes an unnatural amino acid (UAA) in place of the amber stop codon.
  + Cell imaging – a striking example of cell imaging in-vivo using bioorthogonal chemistry was achieved in 2008 – researchers labeled cell-surface glycans in a zebrafish cell line with an azide equivalent then reacted it with a fluorescent cyclooctyne variant (DIFO-488).15 The glycans were labeled distinctly through the zebrafish's development.
  + Drug development – discovering novel interactions, enabling target protein degradation and increasing the specificity in ADCs (antibody-drugs conjugates).
    - Radiotherapy candidates (?!?)
  + Uncaging of molecules (e.g. drugs) has been realized through many bioorthogonal reactions; the important part is the cleavage trigger.
    - Nanoparticles can be used for heterogenous catalysis.
  + Prodrugs – what are they good for?
    - Better absorbance, distribution and elimination
    - Better selectivity and circumventing side effects from affecting healthy tissue.
* Since bioorthogonal reactants are reactive, they can constitute a safety hazard, especially nitrogen compounds.14
* Energetic safety of the reactants can be estimated by calorimetry.14
* Most bioorthogonal reactions begin in-vitro and only after extensive reaction partners and/or catalyst optimization in aqueous media they are tested in vivo, if that's possible.14
* In-vivo reactions have strict requirements – low doses, high reaction rates, high yields.14
* Proteins are not everything!!
* Proteins in which Ahc was incorporated successfully (in E. coli; should compare with the beta barrel):17
  + Histone H3
  + Np276 – beta helix
  + SsbG glycosidase – TIM barrel
  + SarZ – DNA-binding protein
  + Qbeta – multimetric bacteriophage-coating protein
* Several Ru complexes cause genotoxic responses in vitro in Salmonella 2275 typhimurium strains TA98 and TA100 (Monti-Bragadin et al, 1975; Yasbin et 2276 al, 1980; Benkli et al, 2009). 2277 o Oral absorption of Ru is low (about 4%); the half-life of a parenteral dose is 2278 about 200 days. Ingested ruthenium compounds are retained in bones (Furchner 2279 et al, 1971) - Q3D(R2) ELEMENTAL IMPURITIES guidance for industry

## Papers and status

1. In Vivo Olefin Metathesis in Microalgae Upgrades Lipids to Building Blocks for Polymers and Chemicals – read and markered (not fully quoted)
2. Directed evolution of artificial metalloenzymes for in vivo metathesis – read, markered and quoted.
3. Catalytic olefin metathesis in blood – read, markered and quoted.
4. Olefin metathesis for chemical biology – read and markered (not fully quoted)
5. The Impact of Water on Ru-Catalyzed Olefin Metathesis: Potent Deactivating Effects Even at Low Water Concentrations – read, markered and quoted.
6. Grubbs-Hoveyda catalysts conjugated to a β-barrel protein: Effect of halide substitution on aqueous olefin metathesis activity – read, markered and quoted.
7. Kinetic Protection of a Water‐Soluble Olefin Metathesis Catalyst for Potential Use under Biological Conditions – read, quoted and markered.
8. Olefin metathesis catalysts embedded in β-barrel proteins: creating artificial metalloproteins for olefin metathesis – read, markered and quoted.

~~Progress towards bioorthogonal catalysis with organometallic compounds~~ – not OM :(

1. Modification of Proteins Using Olefin Metathesis - done, badly
2. Olefin cross-metathesis on proteins: investigation of allylic chalcogen effects and guiding principles in metathesis partner selection – read, markered and quoted.
3. Olefin Metathesis for Site-Selective Protein Modification
4. Anionic Olefin Metathesis Catalysts Enable Modification of Unprotected Biomolecules in Water – read, markered and quoted
5. Metathesis Reactions in Total Synthesis – read some (?)
6. Bioorthogonal chemistry – read, markered and quoted
7. In Vivo Imaging of Membrane-Associated Glycans in Developing Zebrafish – should not read, it's only an example.
8. In an Attempt to Provide a User's Guide to the Galaxy of Benzylidene, Alkoxybenzylidene, and Indenylidene Ruthenium Olefin Metathesis Catalysts – read, markered and quoted.
9. Genetic Incorporation of Olefin Cross-Metathesis Reaction Tags for Protein Modification.
10. Genetically Encoded Alkenes in Yeast – read, markered and quoted
11. Synthesis of Oxytocin Analogues with Replacement of Sulfur by Carbon Gives Potent Antagonists with Increased Stability – only to quote
12. Cell surface engineering by a modified Staudinger reaction – don't read, only quote
13. Aqueous olefin metathesis: recent developments and applications – read, markered and quoted
14. Biodegradable Grubbs-Loaded Artificial Organelles for Endosomal Ring-Closing Metathesis – read, markered and even used in paper
15. Carbonic anhydrase II as host protein for the creation of a biocompatible artificial metathesase – maybe just quote, another metalloenzyme
16. Creation of an artificial metalloprotein with a Hoveyda–Grubbs catalyst moiety through the intrinsic inhibition mechanism of α-chymotrypsin - maybe just quote, another metalloenzyme
17. A role for ring-closing metathesis in medicinal chemistry: mimicking secondary architectures in bioactive peptides

~~Olefin Metathesis-Based Fluorescent Probes for the Selective Detection of Ethylene in Live Cells~~ – not really about the OM reaction, but rather a side-usage. May be used for live-cells effects

1. Synthetic Multivalent Ligands as Probes of Signal Transduction/ Activating B Cell Signaling with Defined Multivalent Ligands
2. Allyl Sulfides Are Privileged Substrates in Aqueous Cross-Metathesis: Application to Site-Selective Protein Modification
3. Ruthenium Promoted On-DNA Ring-Closing Metathesis and Cross-Metathesis – should look for a newer one about DNA with catalytic and not stochiometric load.

* ~~Enabling olefin metathesis on proteins: chemical methods for installation of S-allyl cysteine (focus on the allyl-chalcogen effect)~~ not useful since 10 is better and was afterwards also:
  + Allyl sulphides in olefin metathesis: catalyst considerations and traceless promotion of ring-closing metathesis
* ~~Biocompatibility and therapeutic potential of glycosylated albumin artificial metalloenzymes~~ – article not available :(
* Selective activation of prodrugs in breast cancer using metabolic glycoengineering and the tetrazine ligation bioorthogonal reaction – shouldn't read it but it's a very cool example of prodrug activation, maybe it can be quoted
* Metathesis in Peptides and Peptidomimetics – pretty old, only if I have time

**General bioorthogonal stuff**

For reviews on metal-complex catalysis in biological systems, see a) L. Vigh, F. Jo\_ in Applied Homogeneous Catalysis with Organometallic Compounds, Vol. 3 (Eds.: B. Cornils, W. A. Herrmann),Wiley-VCH,Weinheim, 2002, pp. 1283 – 1289; b) \_.Csajb\_k, F. Jo\_ in Organometallic Chirality, Vol. 20 (Eds.: G. P\_lyi, C. Zucchi, L. Caglioti), Muchi Editore, Modena, 2008, pp. 69 – 86; c) P. Sasmal, C. Streu, E. Meggers, Chem. Commun. 2013, 49, 1581 – 1587. [3] For a review on palladium-mediated cross-coupling reactions in living systems, see J. Li, P. Chen, ChemBioChem 2012, 13, 1728 – 1731. [4] a) C. Streu, E. Meggers, Angew. Chem. 2006, 118, 5773 – 5776; Angew. Chem. Int. Ed. 2006, 45, 5645 – 5648; b) P. Sasmal, S. Carregal-Romero, A. Han, C. Streu, Z. Lin, K. Namikawa, S. Elliott, R. Klחster, W. Parak, E. Meggers, ChemBioChem 2012, 13, 1116 – 1120; c) P. Sasmal, S. Carregal-Romero, W. Parak, E. Meggers, Organometallics 2012, 31, 5968 – 5970. [5] a) R. Yusop, A. Unciti-Broceta, E. Johansson, R. S\_nchez-Mart\_n, M. Bradley, Nat. Chem. 2011, 3, 239 – 243; b) C. Spicer, T. Triemer, B. Davis, J. Am. Chem. Soc. 2012, 134, 800 – 803; c) N. Li, R. Lim, S. Edwardraja, Q. Lin, J. Am. Chem. Soc. 2011, 133, 15316 – 15319; d) J. Li, S. Lin, J.Wang, S. Jia, M. Yang, Z. Hoa, X. Zhang, P. Chen, J. Am. Chem. Soc. 2013, 135, 7330 – 7338; e) J. Weiss, J. Dawson, K. Macleod, W. Rybsko, C. Fraser, C. Torres- S\_nchez, E. Patton, M. Bradley, N. Carragher, A. Unciti- Broceta, Nat. Commun. 2014, 5, 3277; f) J. Li, J. Yu, J. Zhao, J. Wang, S. Zheng, S. Lin, L. Chen, M. Yang, S. Jia, X. Zhang, P. Chen, Nat. Chem. 2014, 6, 352 – 361; g) M. Yang, J. Li, P. Chen, Chem. Soc. Rev. 2014, DOI: 10.1039/c4cs00117f. [6] See also: a) K. Tishinov, K. Schmidt, D. H\_usinger, D. G. Gillingham, Angew. Chem. 2012, 124, 12166 – 12170; Angew. Chem. Int. Ed. 2012, 51, 12000 – 12004; b) Z. Chen, F. Vohidov, J. M. Coughlin, L. J. Stagg, S. T. Arold, J. E. Ladbury, Z. T. Ball, J. Am. Chem. Soc. 2012, 134, 10138 – 10145; c) K. K. Sadhu, T. Eierhoff,W. Rחmer, N.Winssinger, J. Am. Chem. Soc. 2012, 134, 20013 – 20016.

## Schedule

|  |  |  |
| --- | --- | --- |
| Task | Date | Status |
| 1. ~~In Vivo Olefin Metathesis…~~ 2. ~~Directed evolution of artificial metalloenzymes…~~ 3. ~~Catalytic olefin metathesis in blood~~ | 15.10.24 | Done |
| 1. ~~Olefin metathesis for chemical biology~~ 2. ~~The Impact of Water on Ru-Catalyzed Olefin Metathesis: Potent Deactivating Effects Even at Low Water Concentrations~~ 3. ~~Grubbs-Hoveyda catalysts conjugated to a β-barrel protein: Effect of halide substitution on aqueous olefin metathesis activity~~   ~~Answer Dr. Reem~~ | 19.10.24 | Only if subject is accepted!  Was accepted :)  Done |
| 1. ~~Kinetic Protection of a Water‐Soluble Olefin Metathesis Catalyst for Potential Use under Biological Conditions.~~ 2. ~~Olefin metathesis catalysts embedded in β-barrel proteins: creating artificial metalloproteins for olefin metathesis~~ | 23.10.24 | Done |
| 1. ~~Modification of Proteins Using Olefin Metathesis~~ | 25.10.24 | Done |
| ~~Reread the relevant info in course textbook~~   1. ~~Olefin cross-metathesis on proteins: investigation of allylic chalcogen effects and guiding principles in metathesis partner selection~~ 2. ~~Olefin metathesis for site-selective protein modification~~ 3. ~~Anionic Olefin Metathesis Catalysts Enable Modification of Unprotected Biomolecules in Water.~~ | 27,31.10.24 | Done |
| ~~Start sketching and writing the paper~~   1. Metathesis Reactions in Total Synthesis – don't read everything | 2.11.24 | Done (eh) |
| 1. ~~Bioorthogonal chemistry~~ 2. ~~Plan further~~ 3. ~~Bioorthogonal chemistry chapter – at least 2/3~~ | 9.11.24 | Done |
| 1. Not read it 2. ~~In an Attempt to Provide a User's Guide to the Galaxy of Benzylidene, Alkoxybenzylidene, and Indenylidene Ruthenium Olefin Metathesis Catalysts~~  * ~~start writing about in vivo OM applications~~ | 12.11.24 | Done |
| * finish most OM applications  1. ~~Genetic Incorporation of Olefin Cross-Metathesis Reaction Tags for Protein Modification.~~ | 15.11.24 | Kind of |
| 1. ~~Genetically Encoded Alkenes in Yeast~~ | 16.11.24 | Done |
| 21. ~~Aqueous olefin metathesis: recent developments and applications~~  22. ~~Biodegradable Grubbs-Loaded Artificial Organelles for Endosomal Ring-Closing Metathesis~~   * Write a bit about catalysts * Continue 2-3 use-cases * Plan some more | 20.11.24 |  |
| * Start general limitations (consult textbook papers * Continue general limitations |  |  |

Task pool

1. Create figure 1
2. Create figure 2
3. Google-translate Chauvin's article
4. Get OM chapter quotes