



Imaging and imagining spatio-temporal variations of metabolism in a plant circadian rhythm

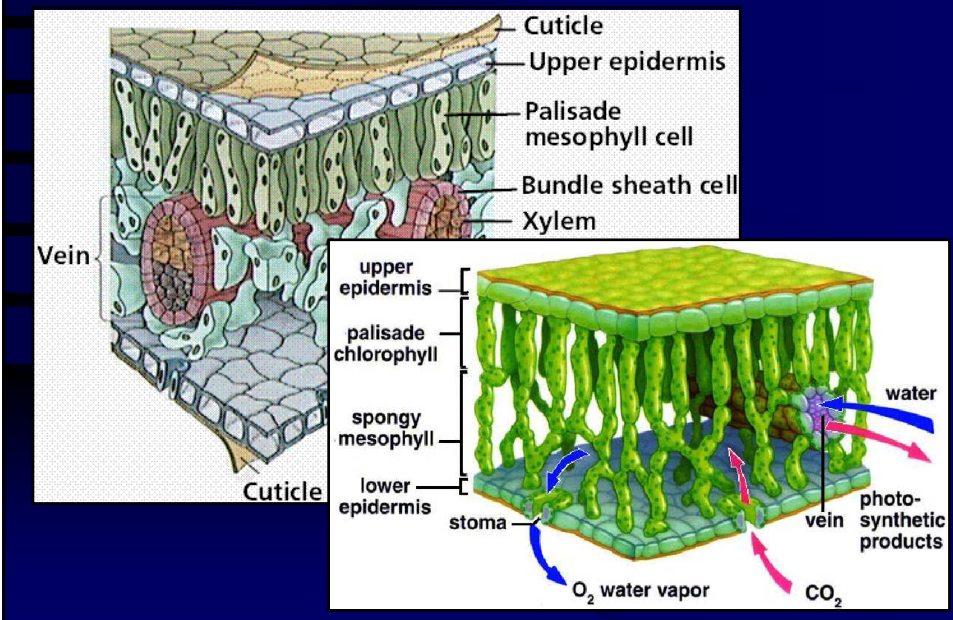
Uwe Rascher

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Leaves –oversimplified organs?

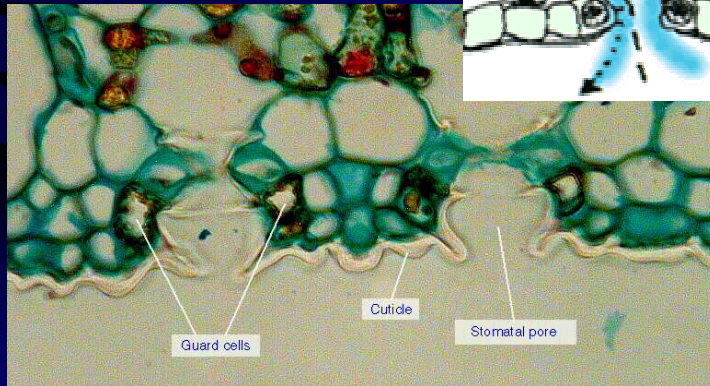
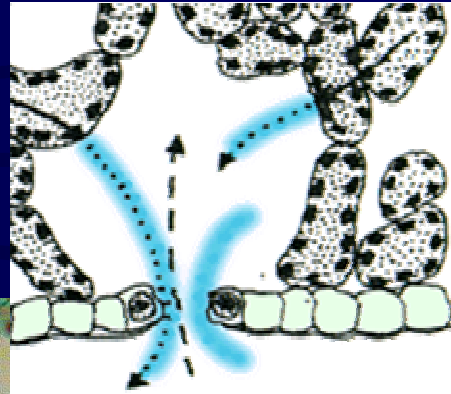


Vertical analysis of leaves

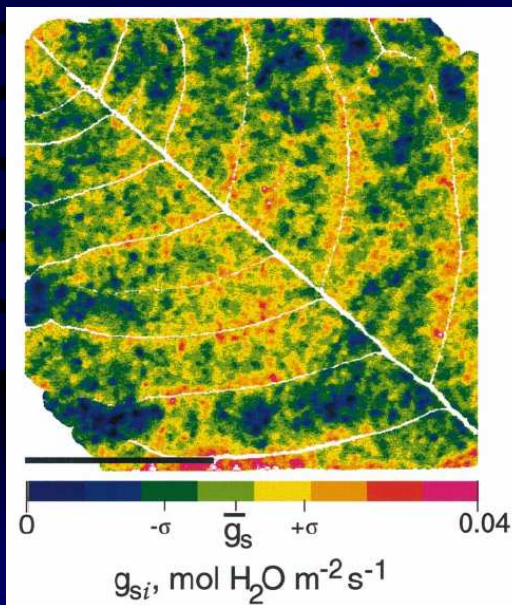


Stomata

control the gas-exchange between leaves and atmosphere and may show....

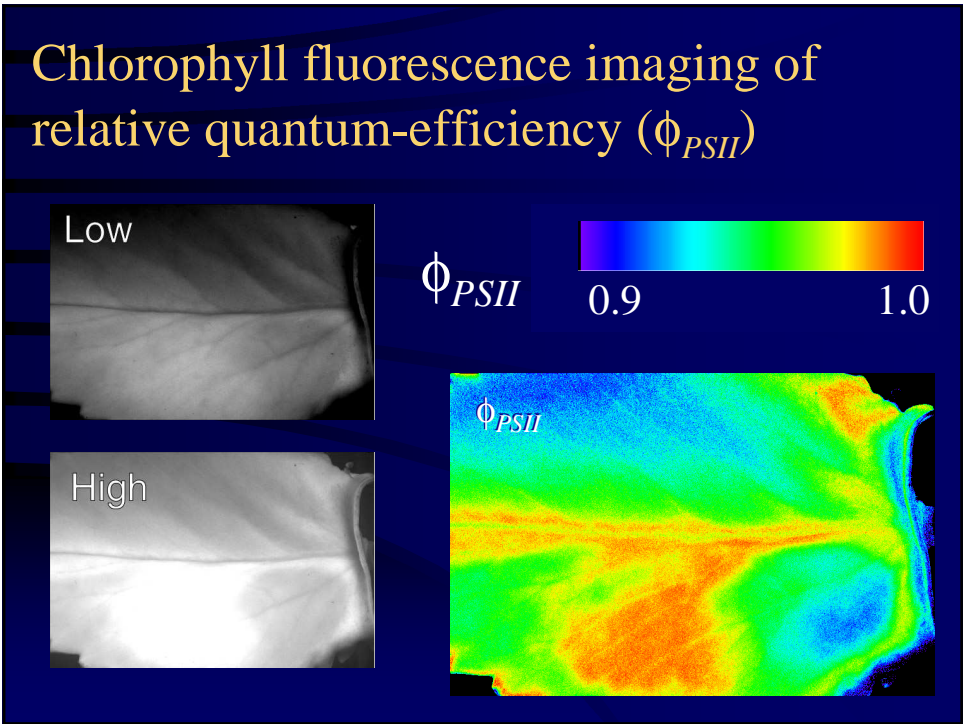
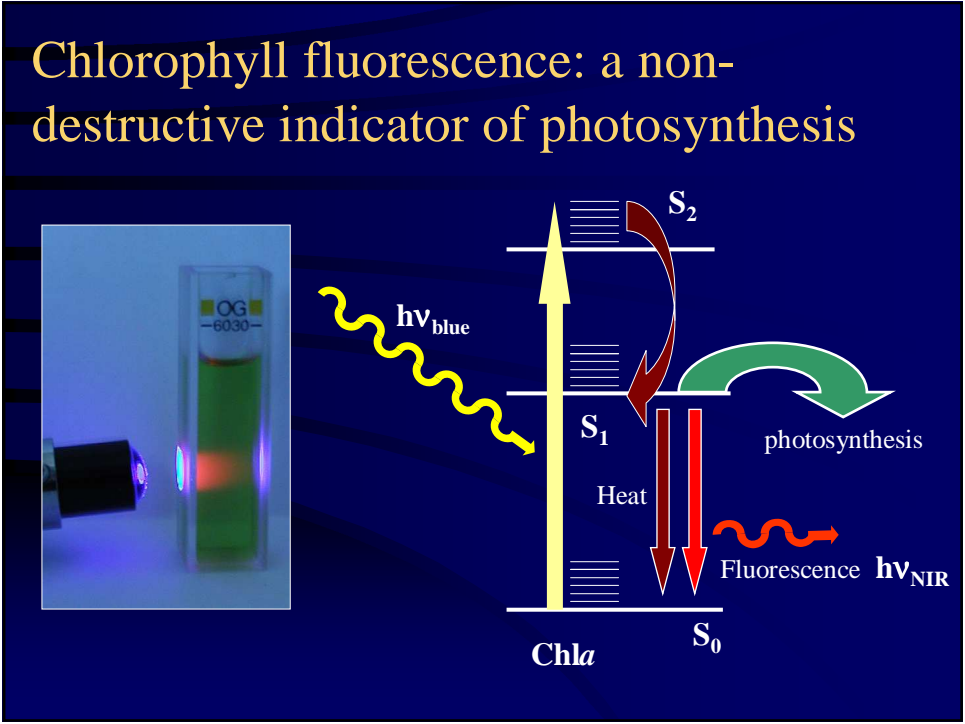


.... 'stomatal patchiness'

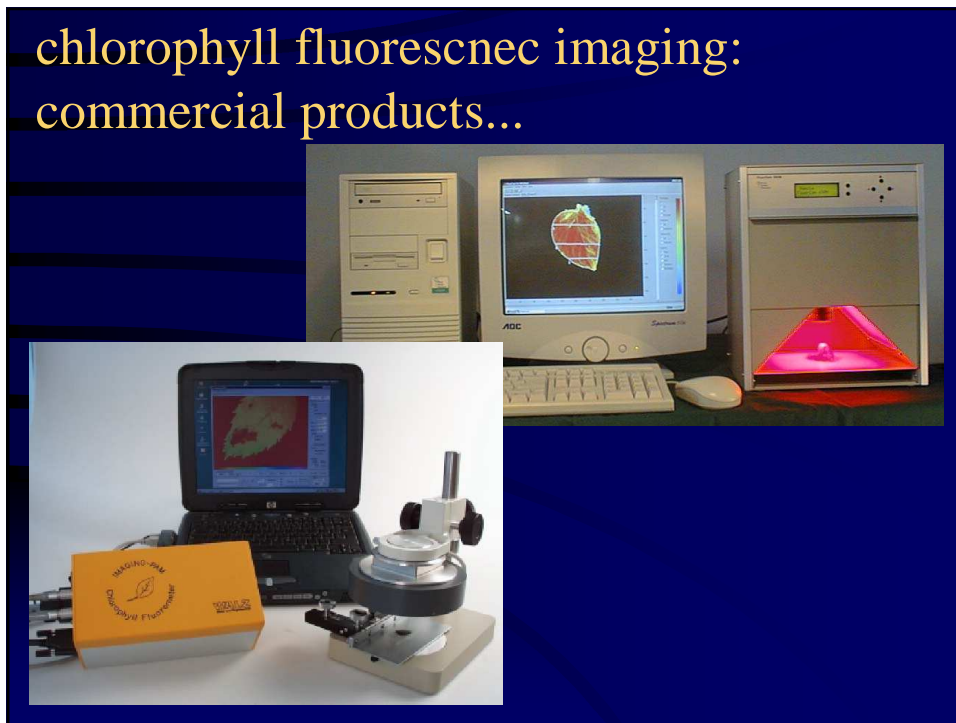


stomatal aperture may be heterogeneously distributed over leaves and, thus, photosynthesis of a single leaf can not be regarded to be homogeneous

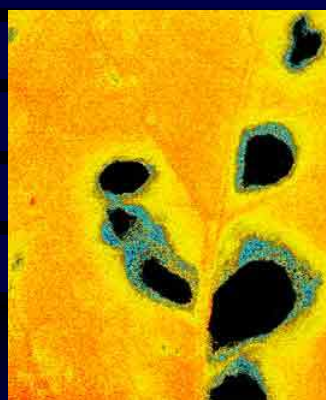
Meyer & Genty (1998)
Plant Physiol. 116, 947-957.



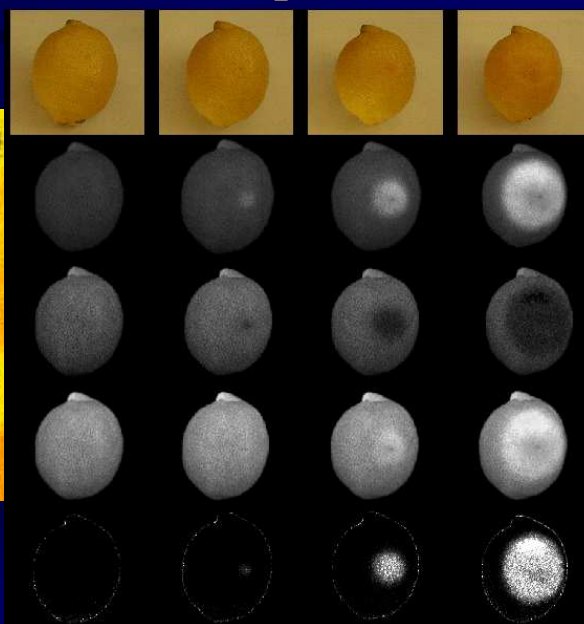
chlorophyll fluorescence imaging: commercial products...



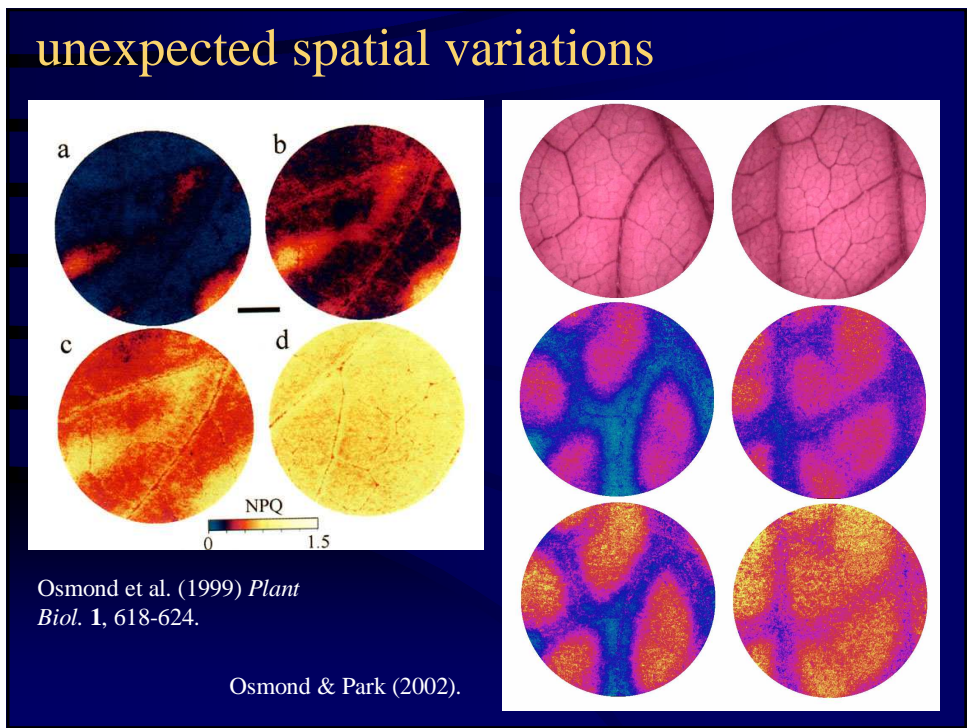
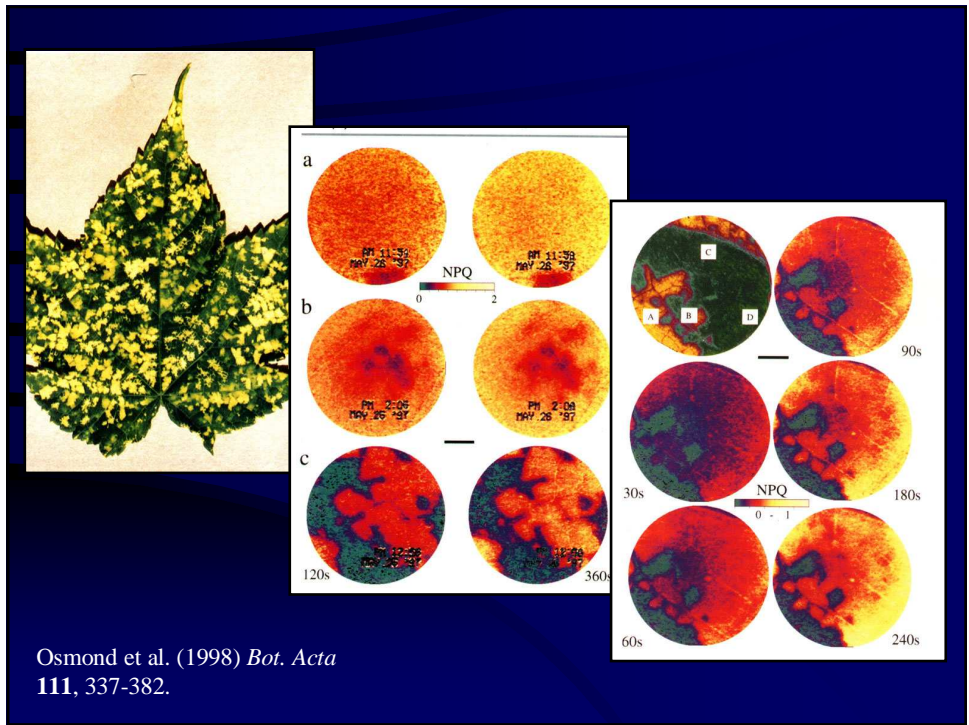
Chlorophyll fluorescence a powerful tool

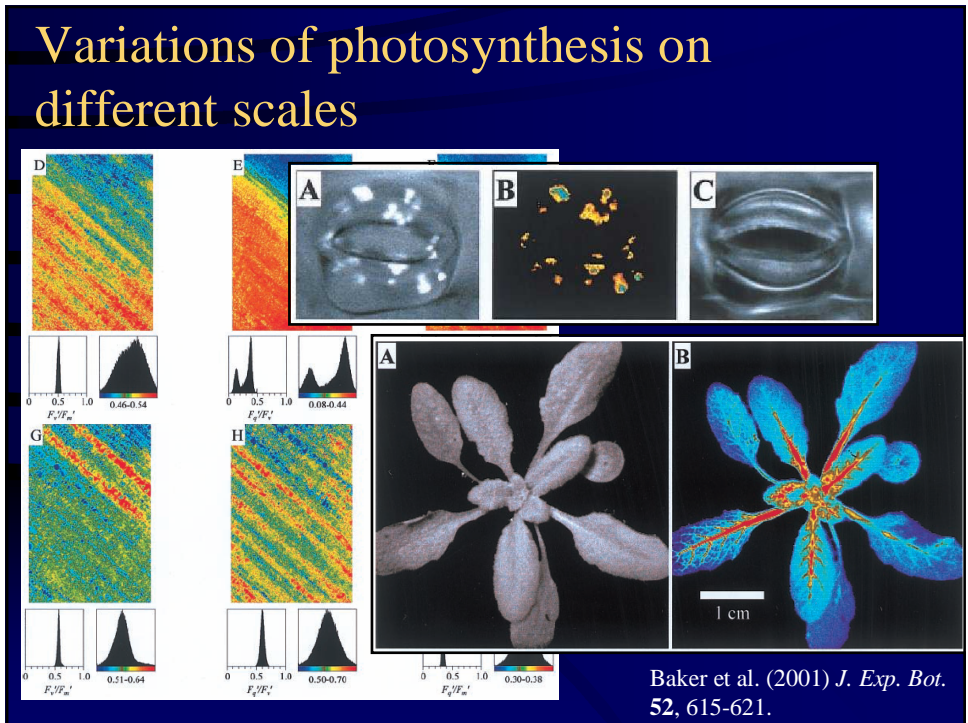


Nedbal L. (2001) unpublished data.



Imaging and Imagining Spatio-Temporal Variations of Metabolism in a Plant Circadian Rhythm

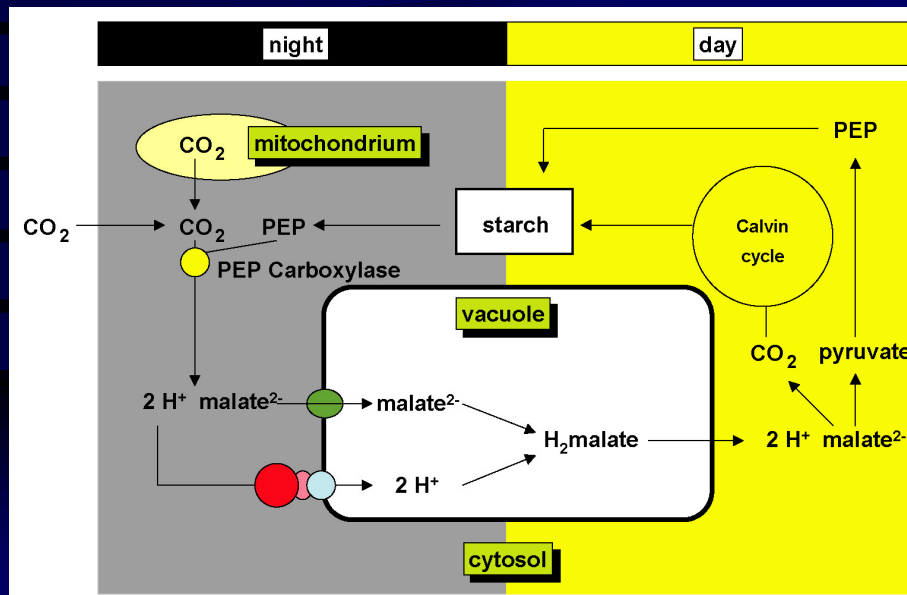




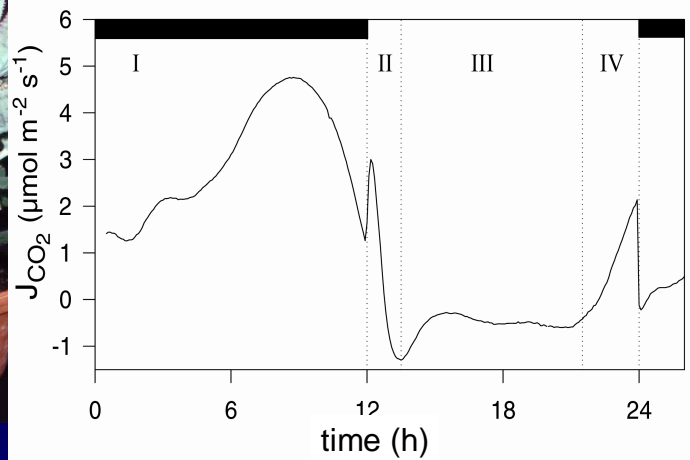
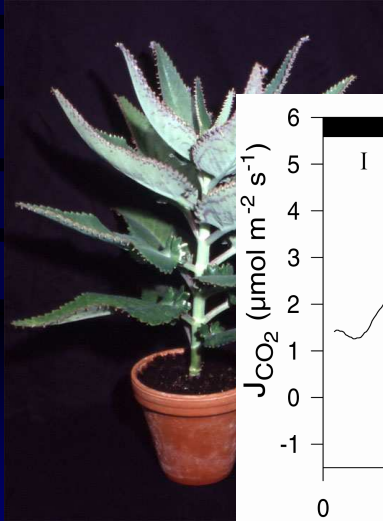
CAM – crassulacean acid metabolism



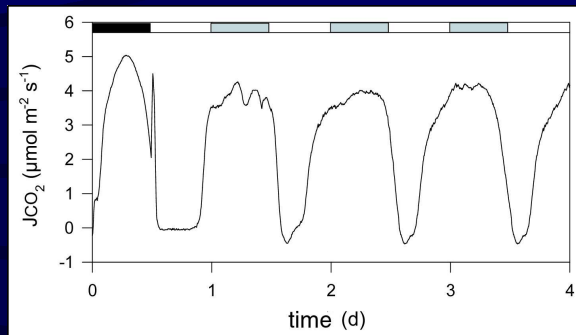
CAM – crassulacean acid metabolism



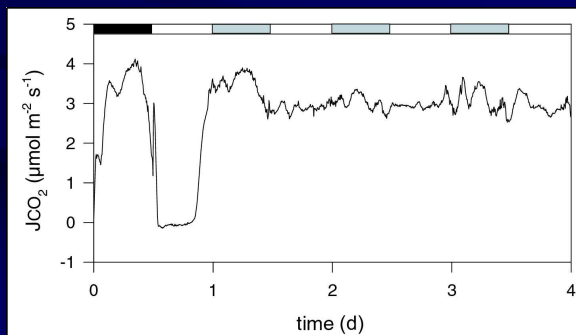
Kalanchoë daigremontiana -
an obligatory CAM-plant



21°C:
Endogenous
rhythm

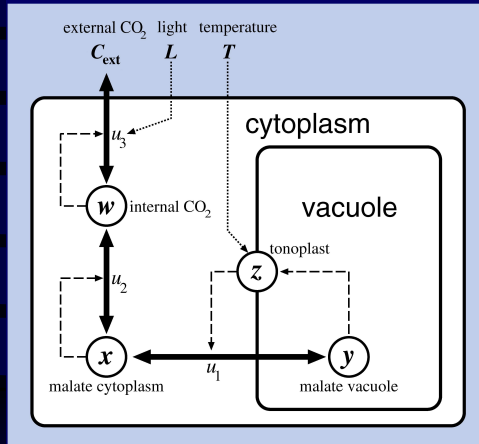


28°C:
Arrhythmic
behaviour



Lüttge & Beck (1992)
Planta 188, 28-38.

Skeleton model of CAM



$$\mathcal{E}\dot{w} = -u_2 + u_3$$

$$\mathcal{E}\dot{x} = -u_1 + u_2$$

$$\dot{y} = +u_1$$

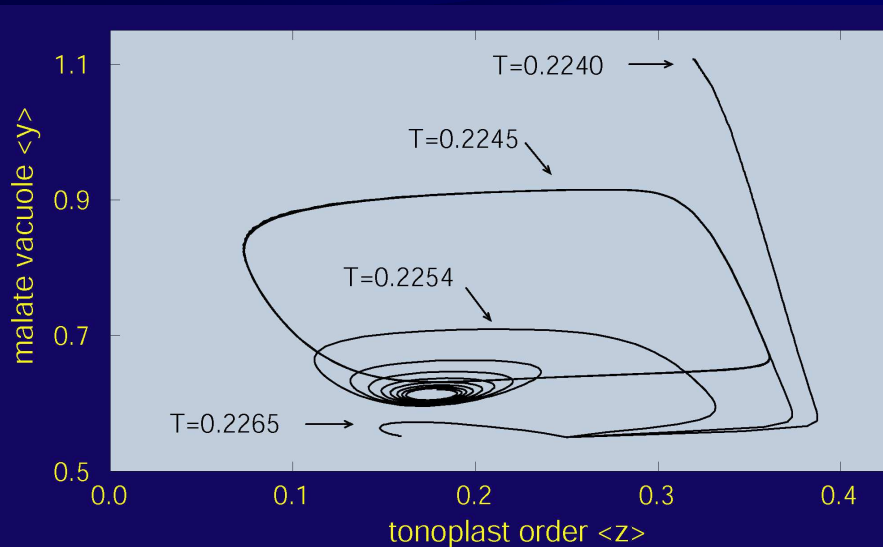
$$u_1 = c_1 x - c_2 P(z)y,$$

$$u_2 = c_3 w/x - c_4 x,$$

$$u_3 = c_5 \frac{(C_{ext}(t) - w)}{\exp(\alpha w)} - c_6 L(t) w + c_7 \left(\frac{L_K}{L(t) + L_K} \right) \left(\frac{w_T}{w + w_T} \right)$$

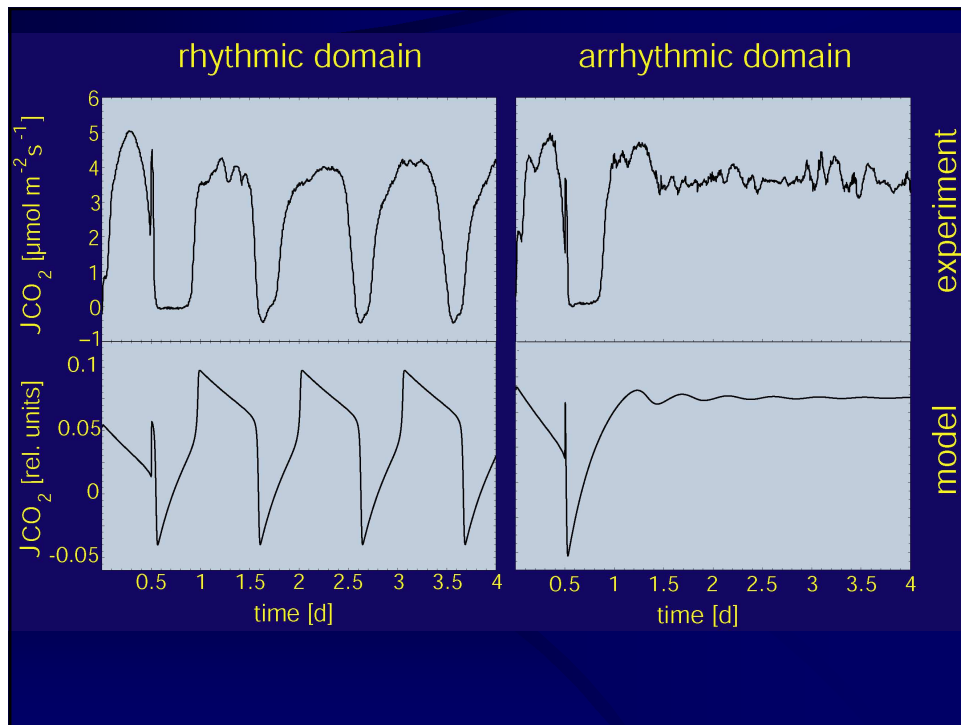
Blasius et al. (1997) *J. Theoretical Biol.* **184**, 345-351
 Blasius et al. (1998) *Plant Cell Environ.* **21**, 775-784
 Blasius et al. (1999) *Proc. R. Soc. Lond. B* **266**, 93-101

Limit cycle with two fix-points

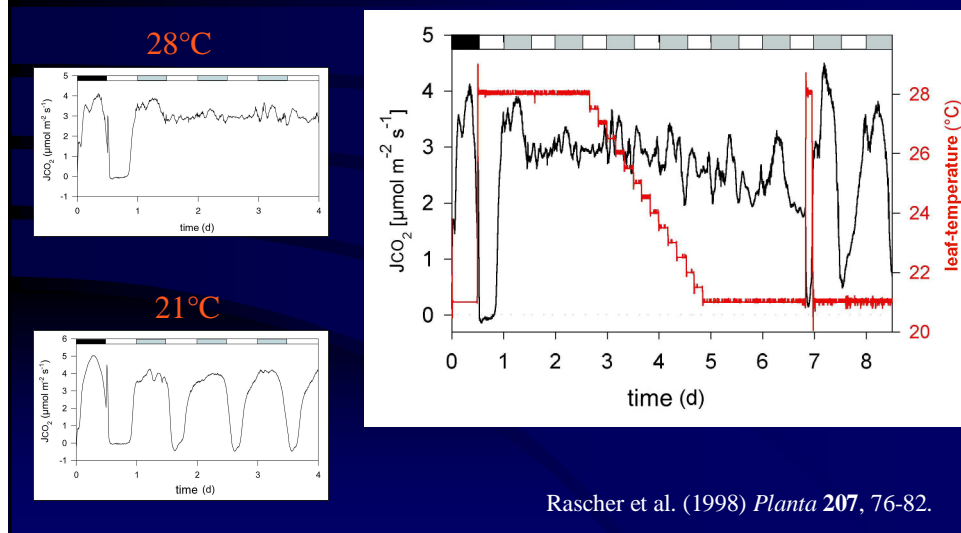


Blasius et al. (1999) *Proc. R. Soc. Lond. B* **266**, 93-101.

Imaging and Imagining Spatio-Temporal Variations of Metabolism in a Plant Circadian Rhythm

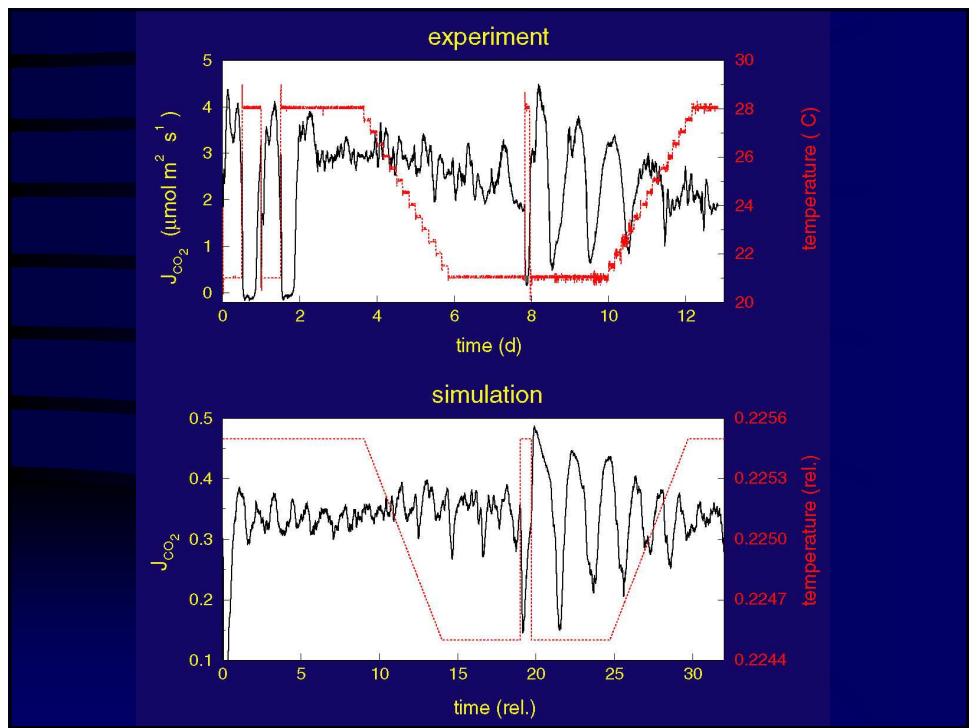
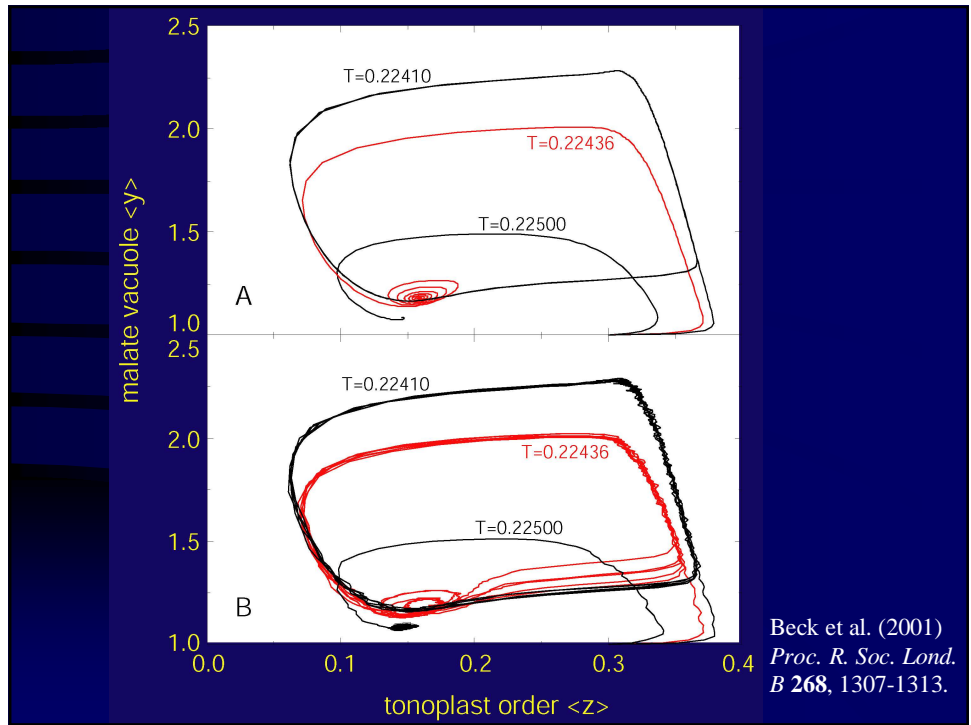


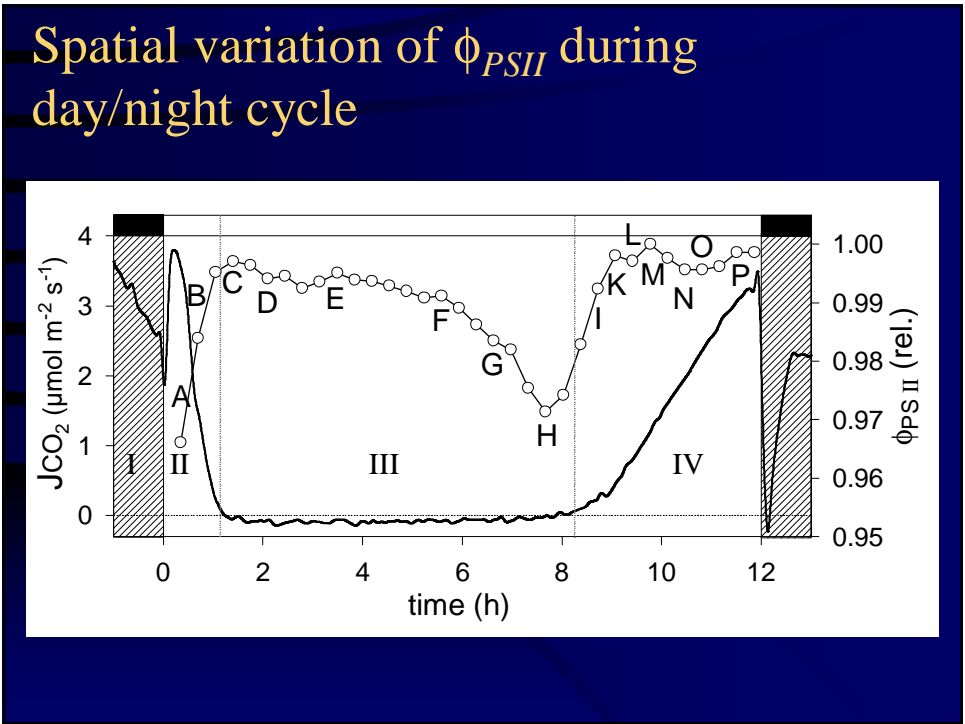
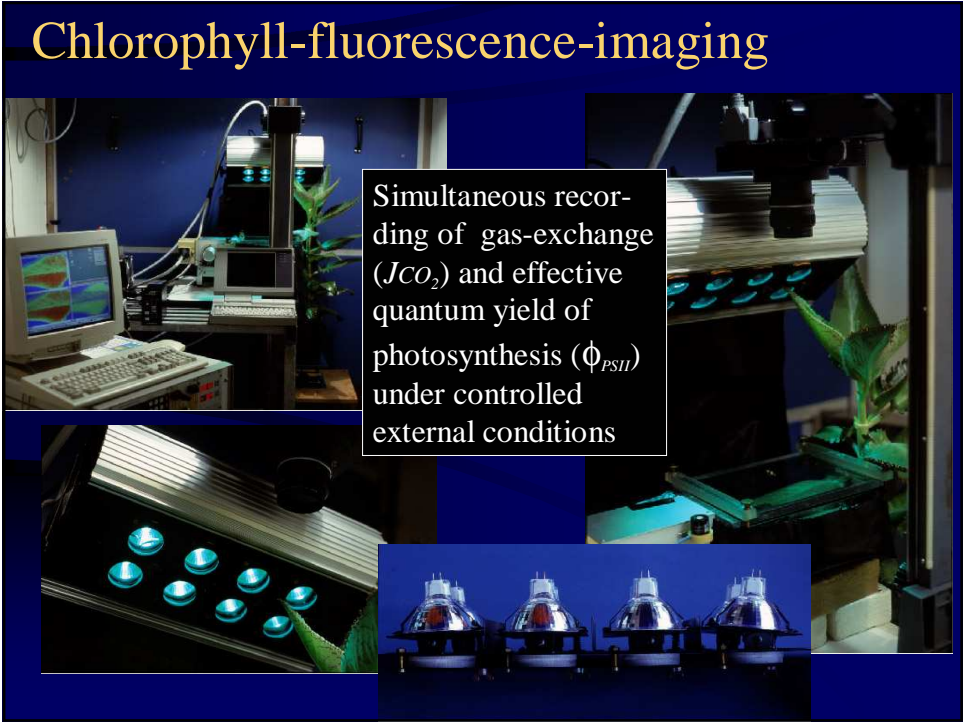
First experimental indication towards a decoupling of separated leaf-areas



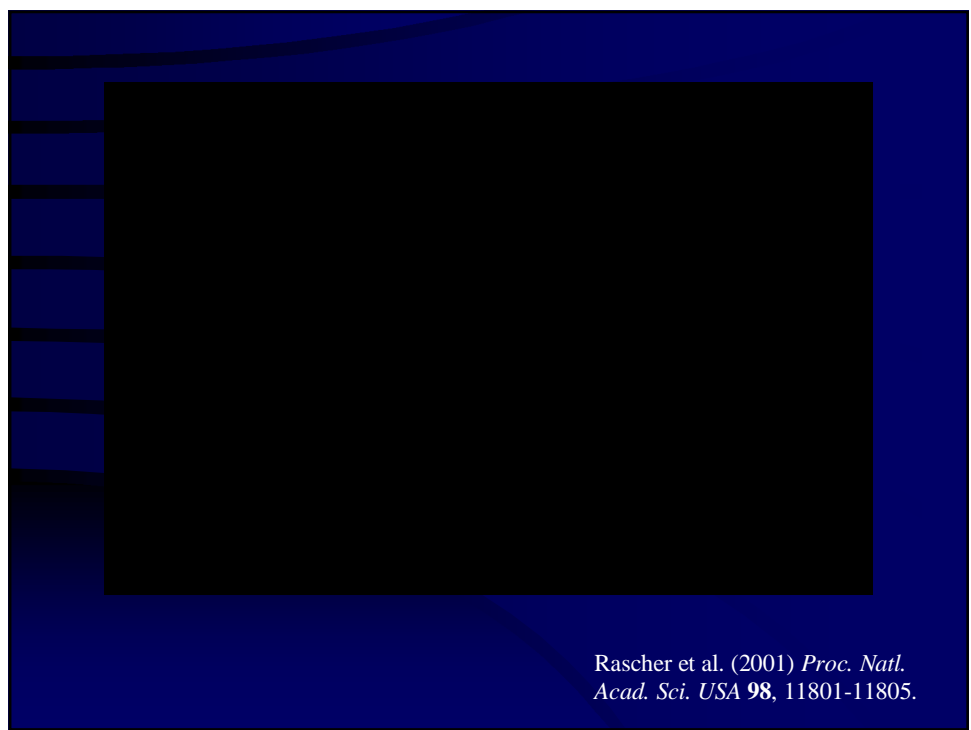
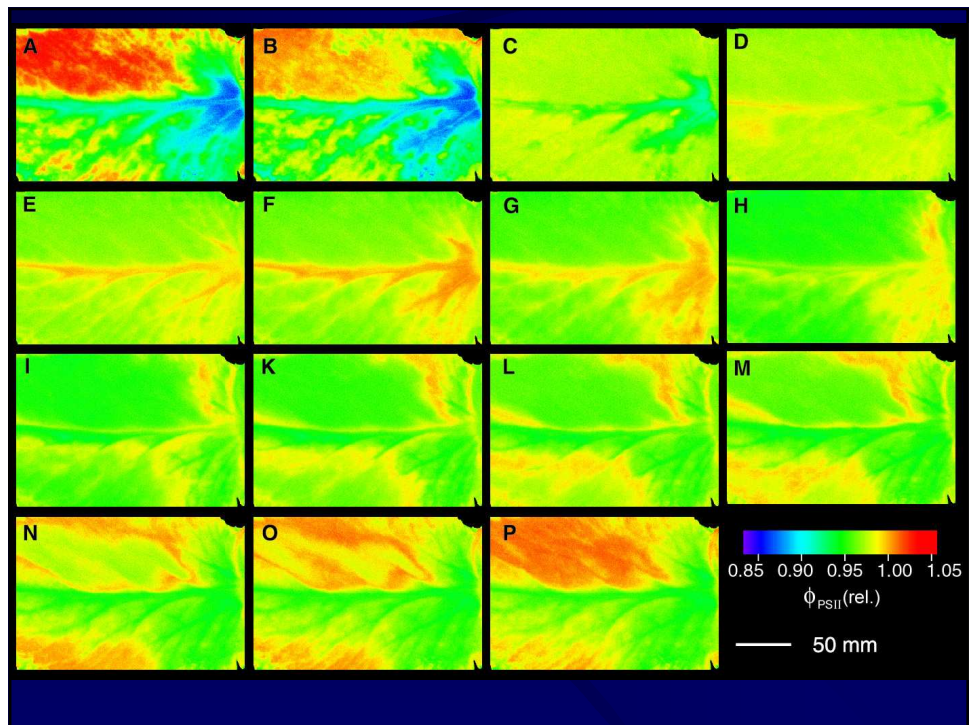
Rascher et al. (1998) *Planta* 207, 76-82.

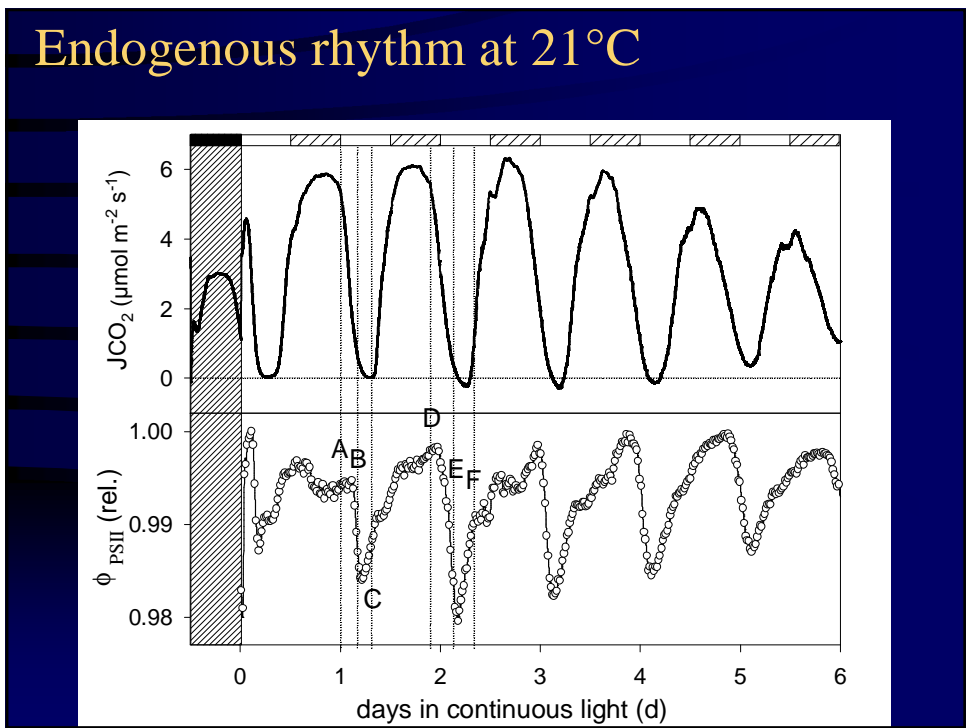
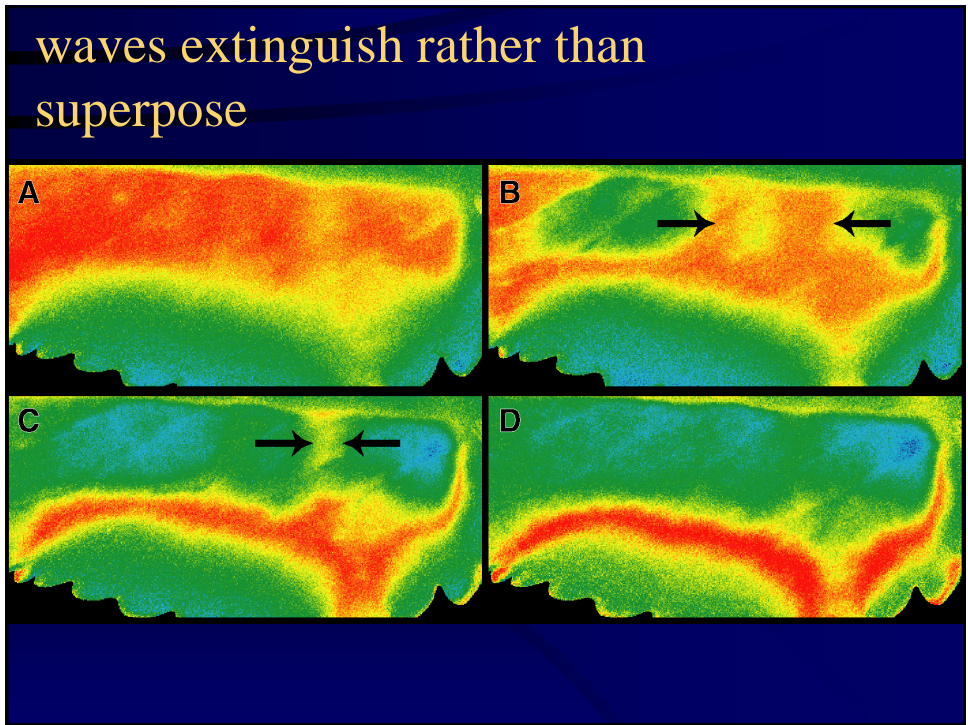
Imaging and Imagining Spatio-Temporal Variations of Metabolism in a Plant Circadian Rhythm

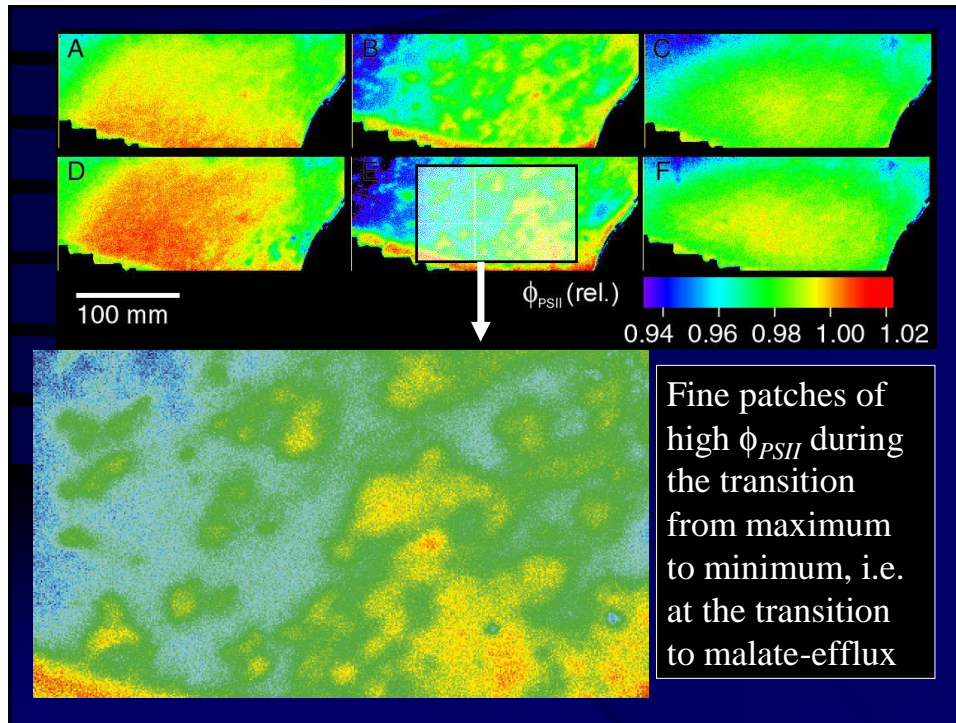




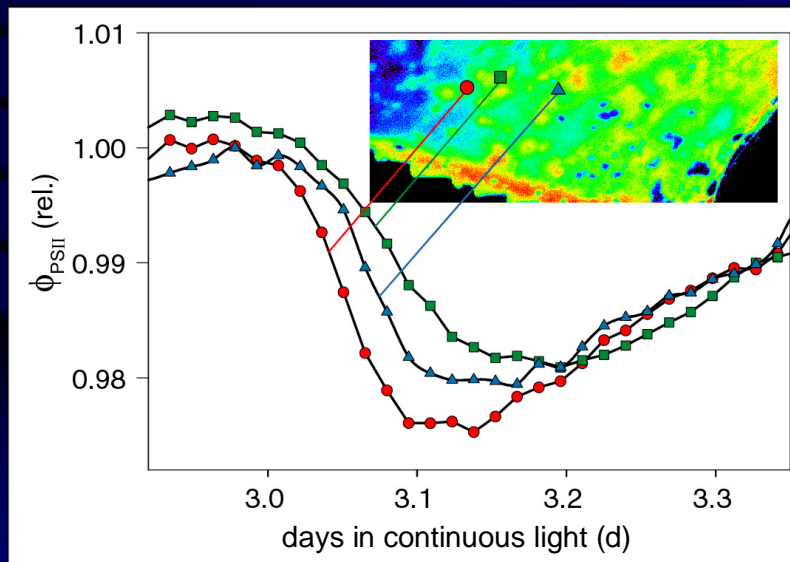
Imaging and Imagining Spatio-Temporal Variations of Metabolism in a Plant Circadian Rhythm



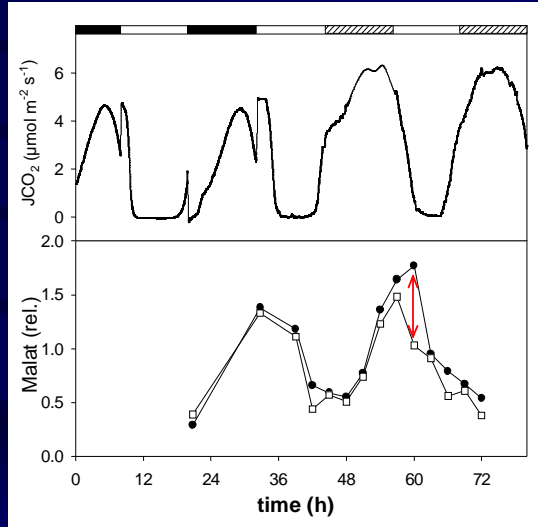
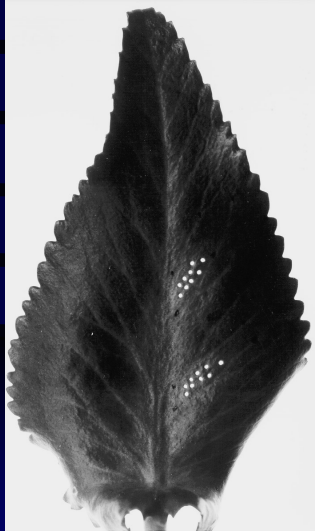




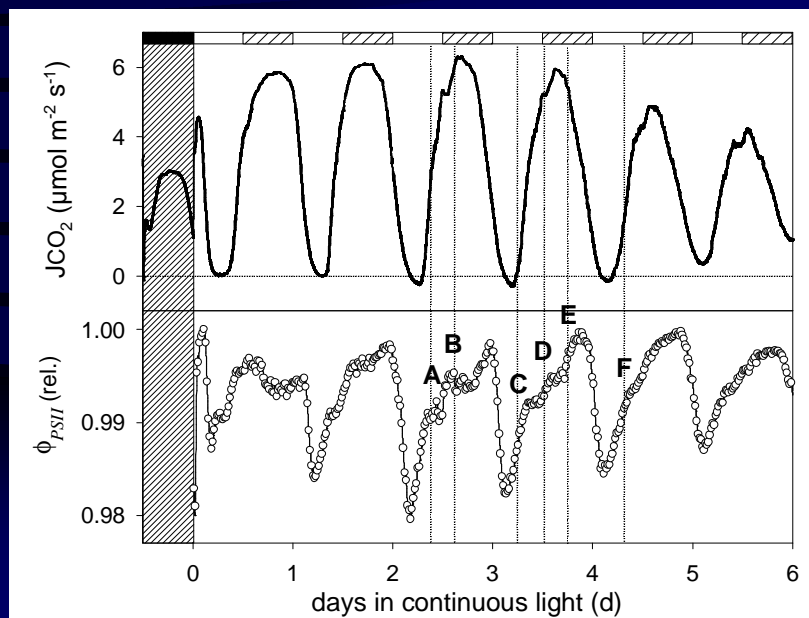
differences during the transition from maximum to minimum



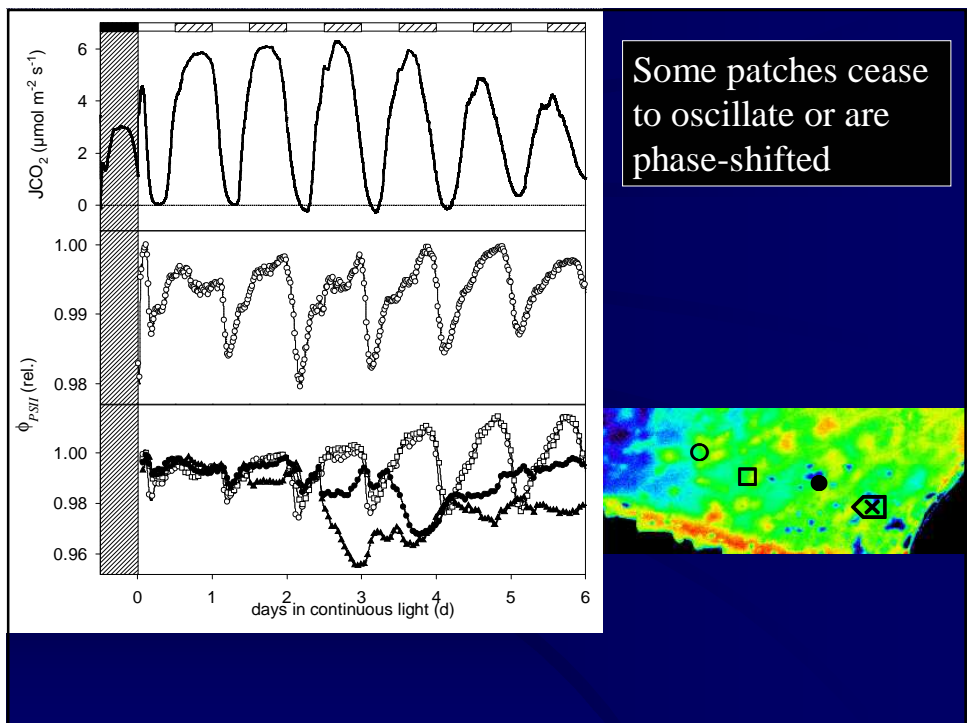
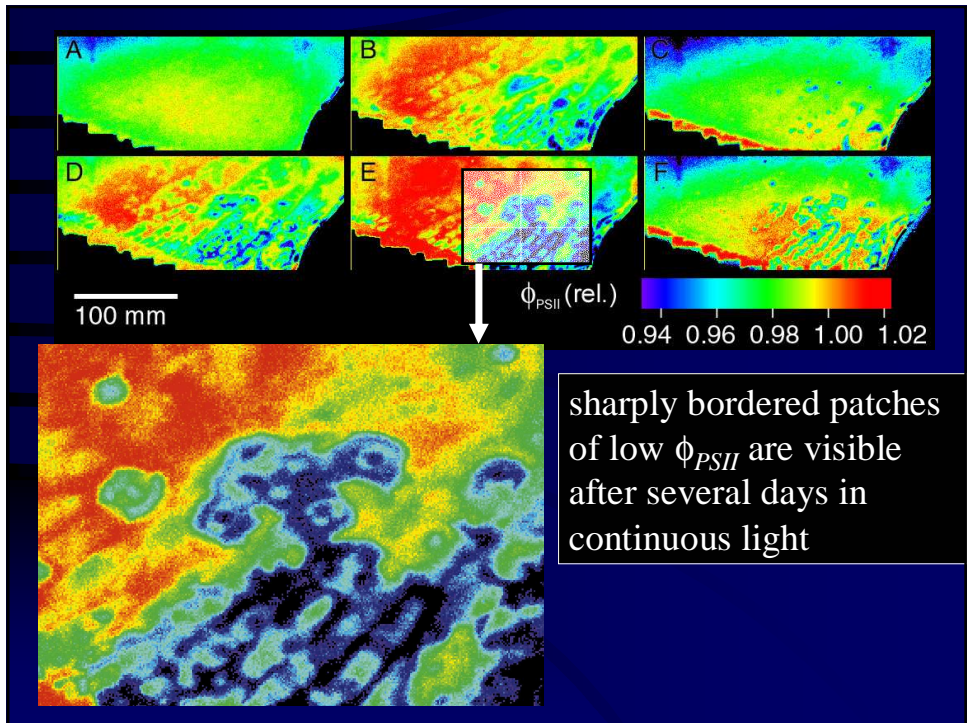
Micro-analysis of malate support this hypothesis



Endogenous rhythm at 21°C



Imaging and Imaging Spatio-Temporal Variations of Metabolism in a Plant Circadian Rhythm

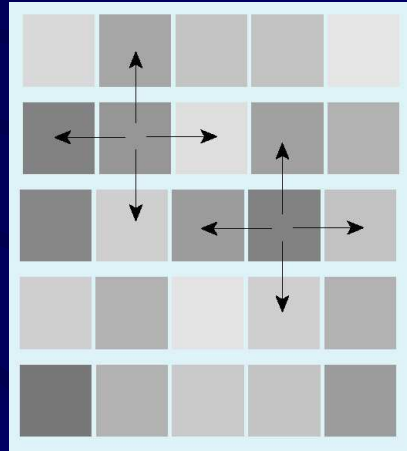


Quantification of heterogeneity - H(I)

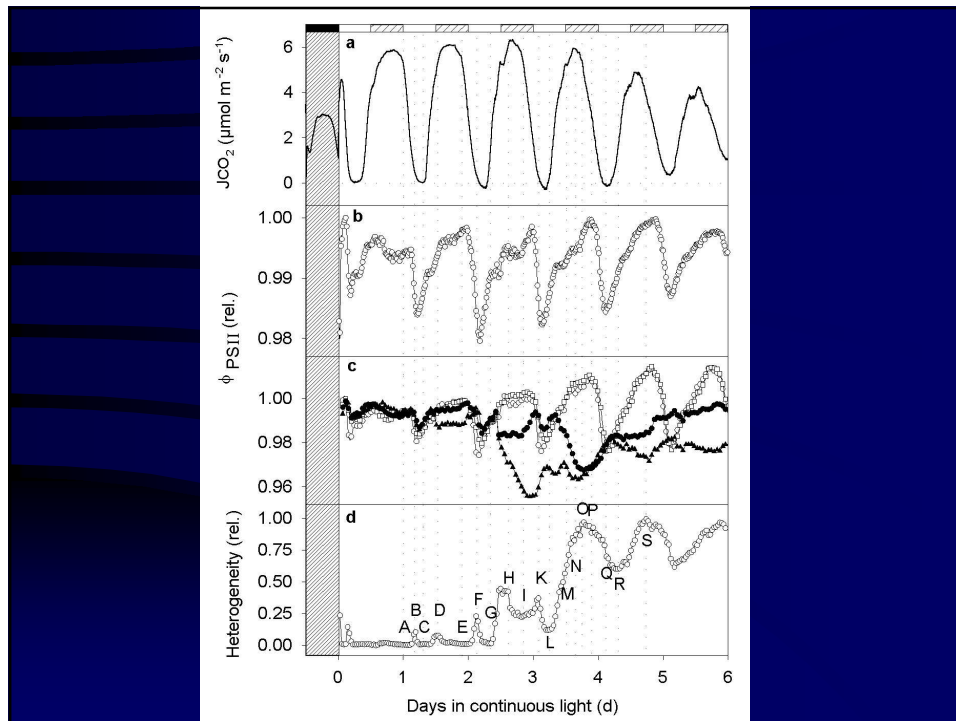
$$H[I] = \frac{1}{N^2} \sum_{ij} \frac{1}{|N_{ij}|} \sum_{b \in N_{ij}} \Theta(a_{ij}, b)$$

$$\Theta(a, b) = 1 - \left(\frac{|a - b|}{|\Sigma|} \right)$$

$H[I]$ quantifies the mean state distance between next neighbors of a matrix



Hütt & Neff (2001) *Physica A* 289, 498-516.

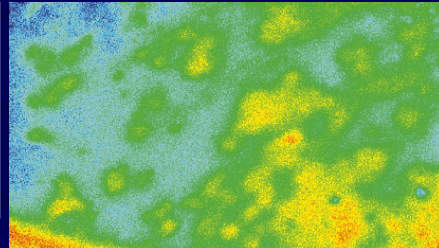


2 types of inhomogeneity during the endogenous CAM-rhythm

type 1:

patches of high ϕ_{PSII} during the transition from maximum to minimum

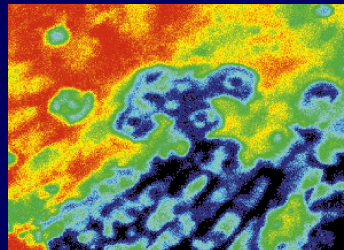
↳ dephased malate-efflux



type 2:

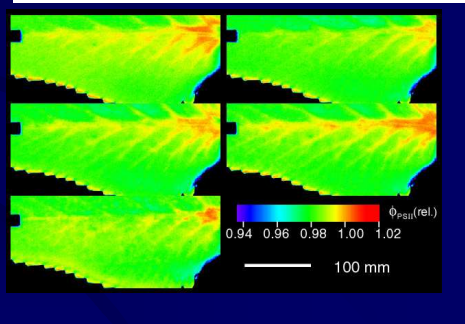
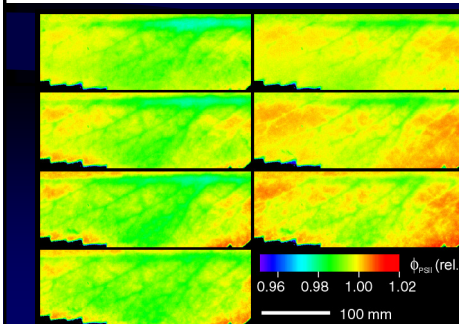
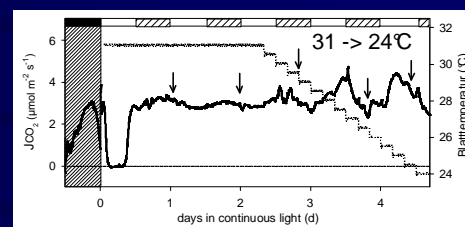
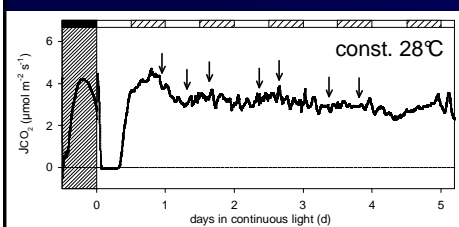
patches of low ϕ_{PSII} after some days in continuous light

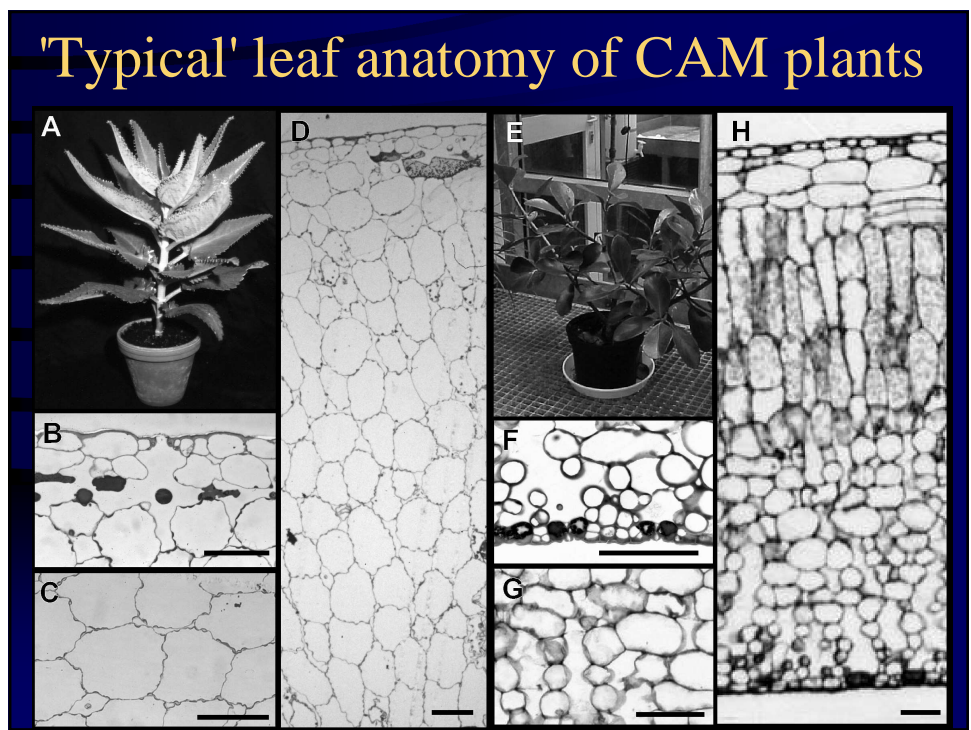
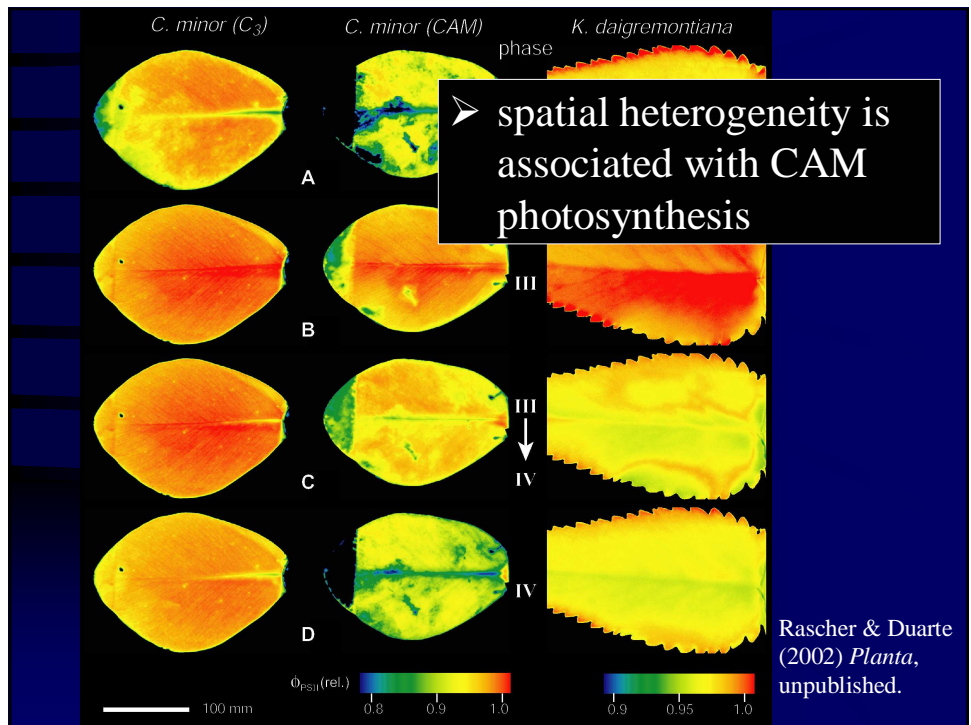
↳ some areas cease to oscillate



Rascher et al. (2001) *Proc. Natl. Acad. Sci. USA* **98**, 11801-11805.

Little inhomogeneity during the arrhythmic gas-exchange





more spatial phenomena on simple leaves

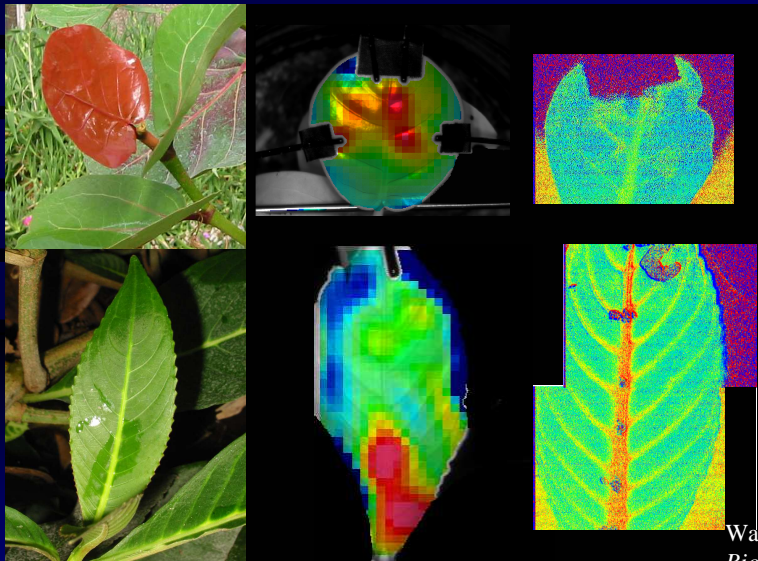


leaf growth shows complex temporal and spatial variations

(4.5 hours of time laps movie with max. growth rate of 4% per hour)

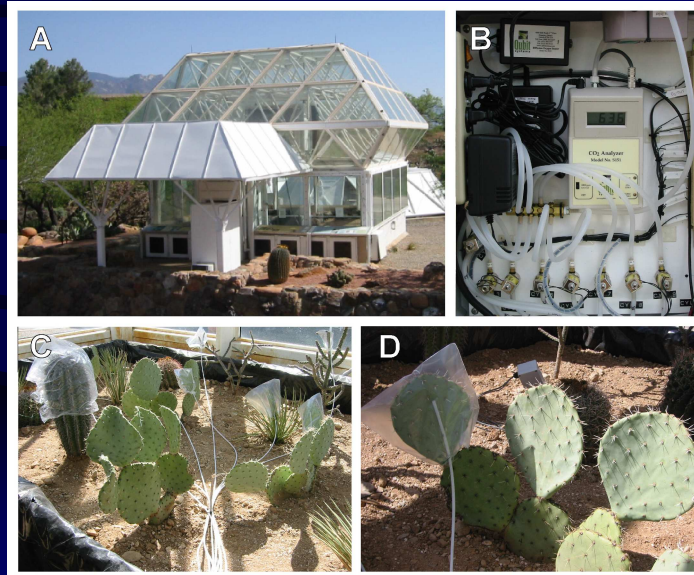
Walter et al. (2002) *Funct. Plant Biol.*, in press.

combined measurements of growth and photosynthesis

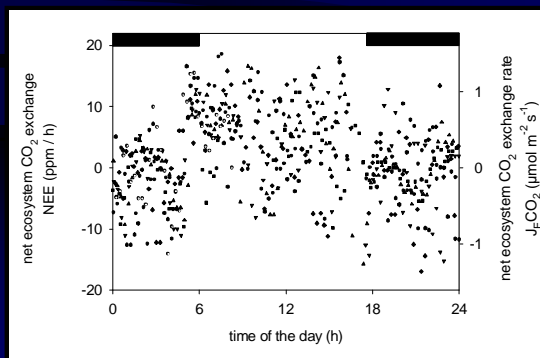
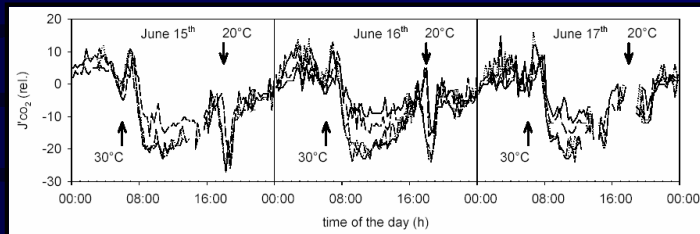


Walter et al. *Plant Biol.*, in press.

variations of photosynthesis on the larger scale



variations of photosynthesis on the larger scale



single pool
synchronization is
essential for
ecosystem behavior

Rascher et al. (2003) *Plant Ecology*, submitted.

Conclusion

- ◆ Leaves show pronounced spatial variations on different scales
- ◆ Chlorophyll fluorescence imaging is a powerful, nondestructive tool to investigate spatio-temporal heterogeneity of photosynthesis
- ◆ Crassulacean acid metabolism (CAM) serves as an interesting model system to evaluate dynamic spatio-temporal variations on really simple leaves
- ◆ *day/night cycle*: inhomogeneity in phase II, uniform ϕ_{PSII} during phase III and wave-fronts at the transition to phase IV.
- ◆ *endogenous rhythm*: two types of inhomogeneity of ϕ_{PSII}
- ◆ *arrhythm*: weak spatial inhomogeneity
- ◆ stochastic contributions to the observed patterns

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