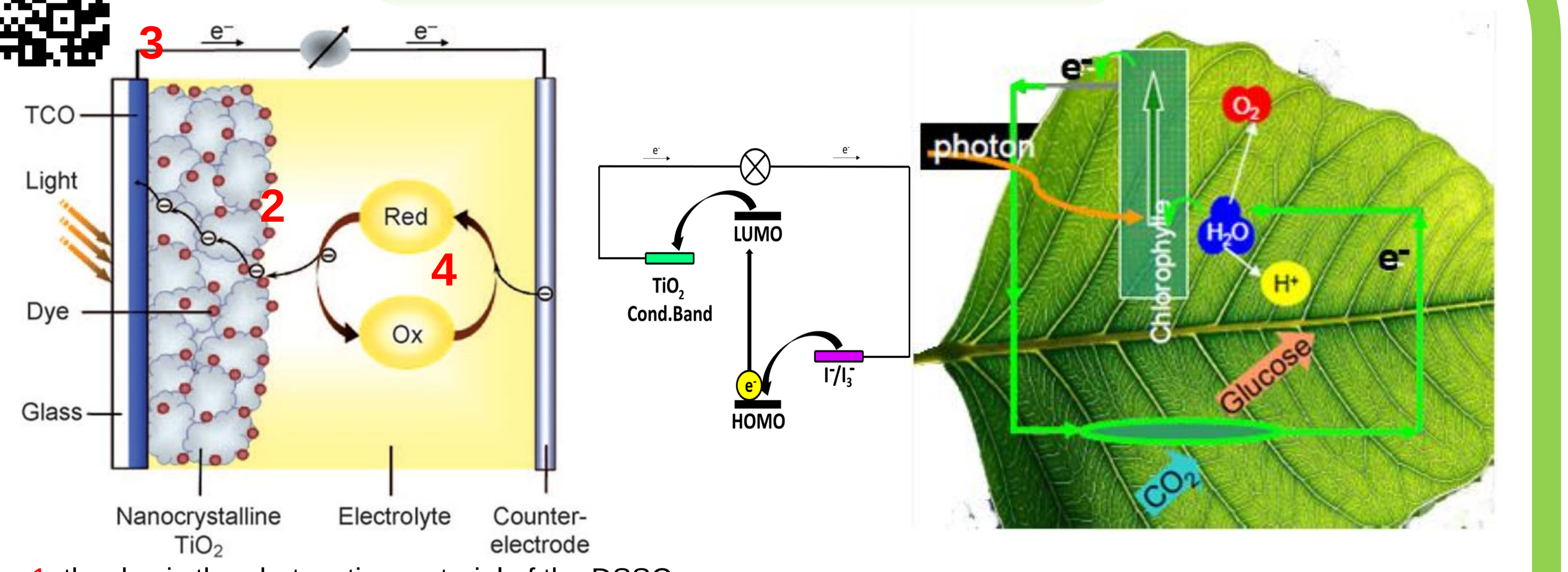
Charging a cell phone with a glass of fruit juice?

Thalia Wildhorn, Loughlin Dudley, Giacomo Alliata, Klara Bonneau, Mathis Dubrul, Fanny Guedj, Daniel Lefebvre, Eric Martinet and Cyril Aumaitre

Cité Scolaire Internationale & nano@school, Grenoble, FRANCE

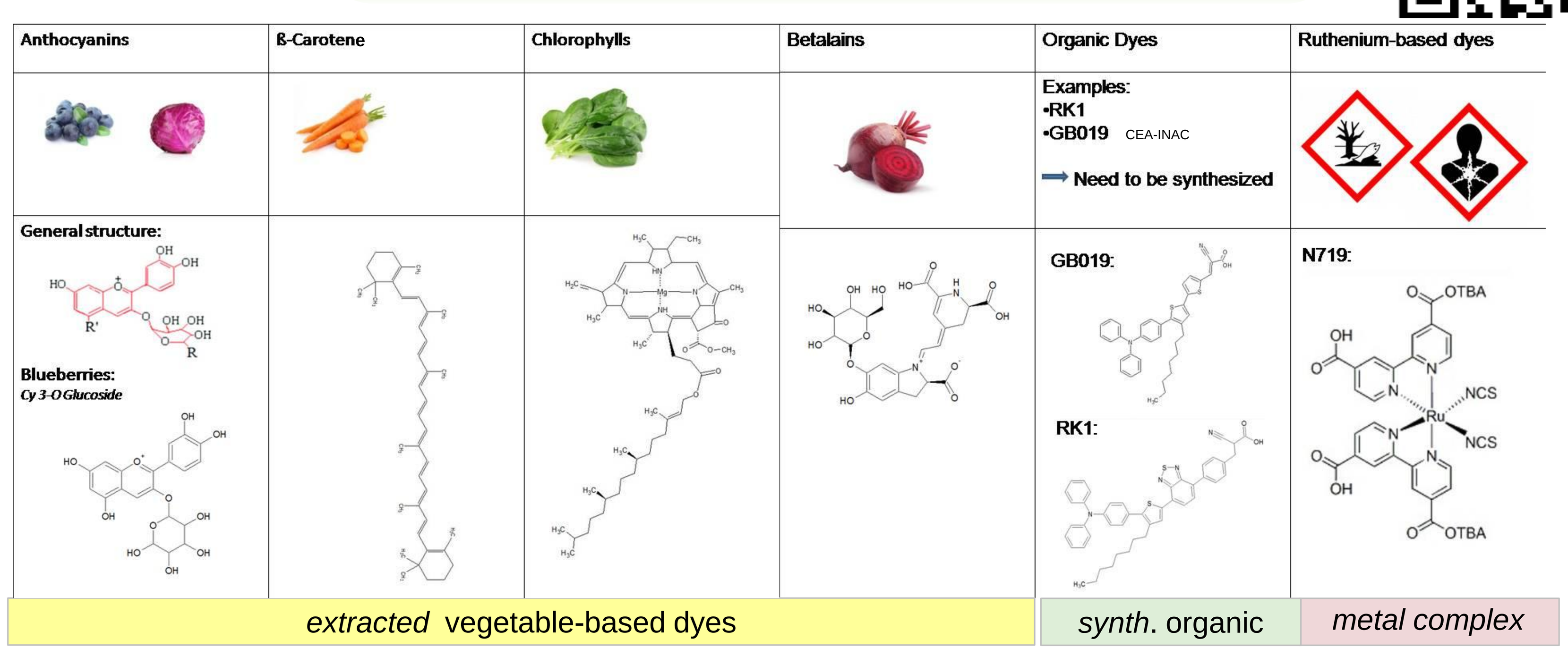
BACKGROUND: Dye-sensitized solar cells (DSSCs) were invented in 1991 by M. Grätzel. They are inspired by photosynthesis. Compared to silicon-based solar photovoltaic cells, their main advantages are low-cost production, performance in diffuse light and multicolor options. DSSCs are becoming more and more interesting with a large variety of dyes, including vegetable dyes extracted from fruits, algae, flowers and leaves, which are used as light harvesting elements.

How DSSCs work



1. the dye is the photoactive material of the DSSC
2. the dye absorbs photons from light and uses their energy to promote an electron from the HOMO state to the LUMO state
3. excited electrons are injected into the TiO_2 semiconductor which conducts them into the circuit
4. the electrolyte regenerates the dye

Characterization of dye families



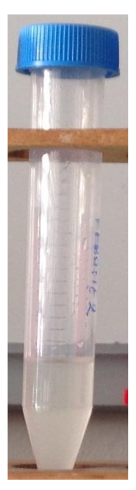
Conjugated-bonds and chromophores induce batho- and hyper-chromic shifts. Electrons' delocalization from S(HOMO) to S*(LUMO) state is necessary for injection into TiO_2

MOTIVATION: Light-weight portable power packs for mobile applications are emerging as one of many industrial applications of DSSCs, with cells made from synthetic dyes and showing over 11% power conversion efficiency in laboratory (1.5% in commercial Gcell module).

We investigated the possibility of using a DSSC incorporating natural pigments extracted from vegetables for charging a cell-phone battery. In order to understand the limitations of such vegetable-based DSSCs, we carried out a series of experiments, including dye extraction and stability measurements, absorption spectroscopy, photovoltaic performance measurements and the charging of a battery. We also used simple models to identify the limitations of our device.

Choice of vegetable dye

Extraction in ethanol



β-carotene from **carrots** has no hydroxyl groups, which limits its bonding with ethanol.

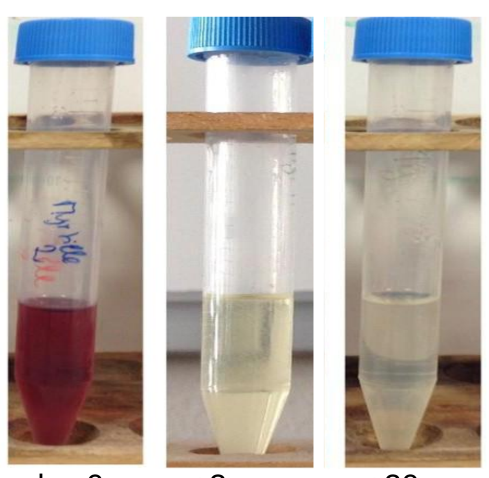
Anthocyanin from **blueberries** on the other hand has many such groups.

Anthocyanins show:

- + efficient extraction in ethanol
- + harvesting of solar spectrum
- + adsorption to TiO_2 compared to chlorophylls
- +/- dye stability: UV-degradation & precipitation

Stability of the dye

Even successfully extracted dyes show degradation over time due to **heat** and **UV-bleaching**.



day 0 +3 +20

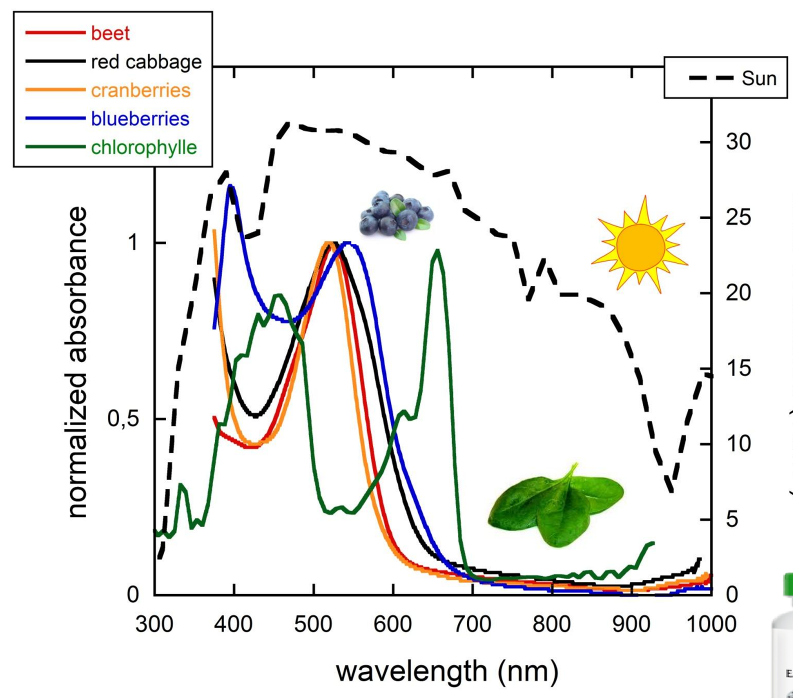
40 °C + UV-light

Kept in the fridge, the dye does not age as quickly.

+2 months

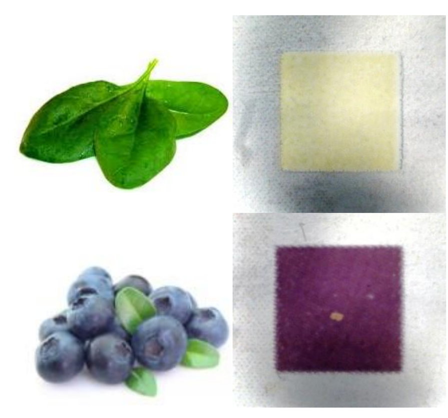
4 °C + dark

Harvesting sunlight spectrum (AM1.5)



Dye adsorption on TiO_2 electrode

Spinach on TiO_2



Berries on TiO_2

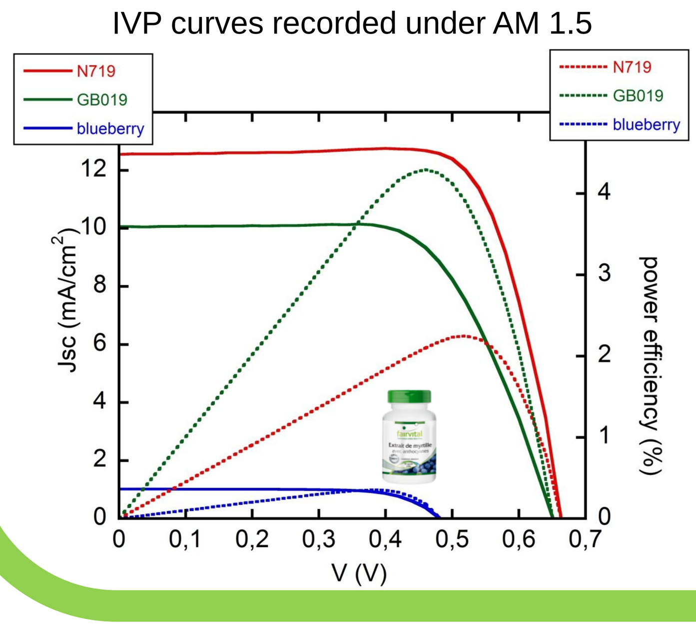
Use of blueberry powder allows experiment repetition

Device performance

DSSC characteristics

Blueberry DSSC

IVP curves recorded under AM 1.5



Figures of merit

Photovoltaic parameters of the best performing device for each dye obtained under simulated AM 1.5 illumination.

Dye	J_{sc} /mA.cm^{-2}	V_{oc} /mV	FF /%	**Yield/ %**	Ref
N719	12.6	663	75	**6.2**	This study
N719	17.8	846	75	**11.2**	(I)
GB019	10.1	655	66	**4.3**	This study
(blueberry)	1.02	481	72	**0.35**	This study
	3.14	520	/	**0.64**	(I)

Yield η : power efficiency

$$\eta_{max} = P_{elec} / P_{sun} = J_{sc} \cdot V_{oc} \cdot FF / \phi_{sun}$$

Solar irradiance ϕ_{sun} = 100 mW/cm², AM1.5

What is limiting the yield? (*kinetics & nanoeffects*)

Yield results from IPCE, the Internal Photon to Collected Electron efficiency

$$IPCE(\lambda) = \eta_{abs}(\lambda) \times \eta_{inj} \times \eta_{coll}$$

rate equations

η_{inj} injection efficiency into TiO_2 ≅ 100% *limited by* (6)

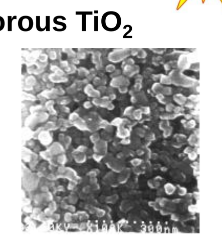
η_{coll} collection efficiency into anode *limited by* (4)

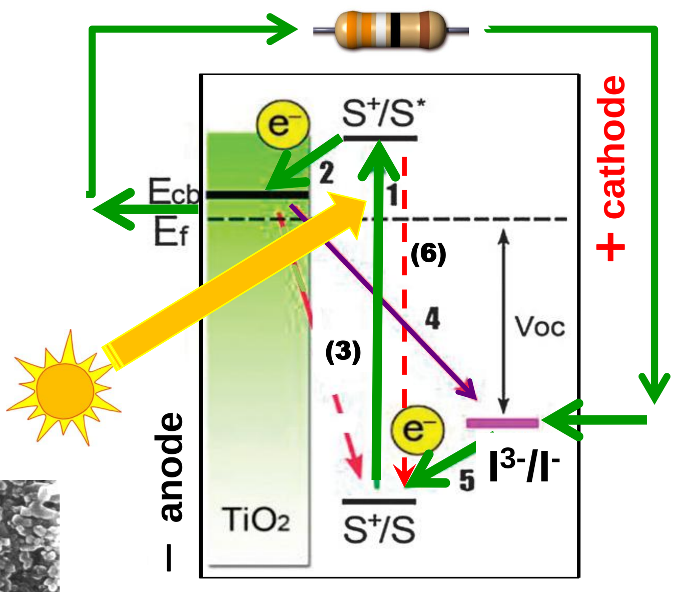
fractal nature of nanoporous TiO_2

80 m²/g TiO_2, **roughness x 2300**

closed pack spheres 20nm ∅

$\eta_{abs}(\lambda)$ absorption efficiency : *from 1% to 99%*

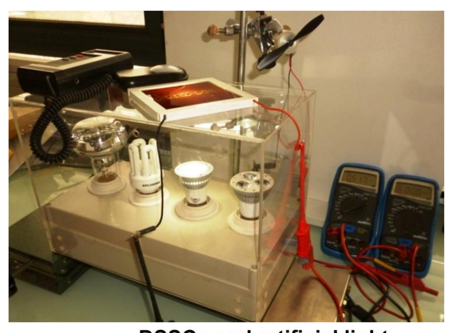




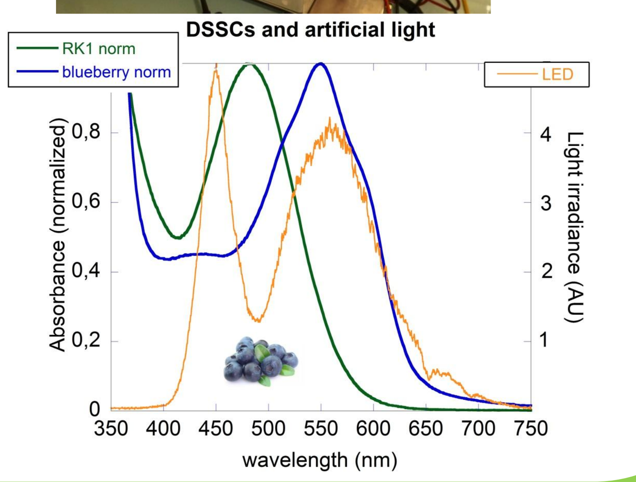
V_{oc} # $n(TiO_2)$, *rate-limiting step* = (4)

J_{sc} # $n(TiO_2)/\tau_{eff,1\text{-}2\text{-}ext\text{-}5}$, *rate-limiting step* = (5)

Performances under diffuse and artificial lights



***mW* range** coupling with 81 cm² demo. cell



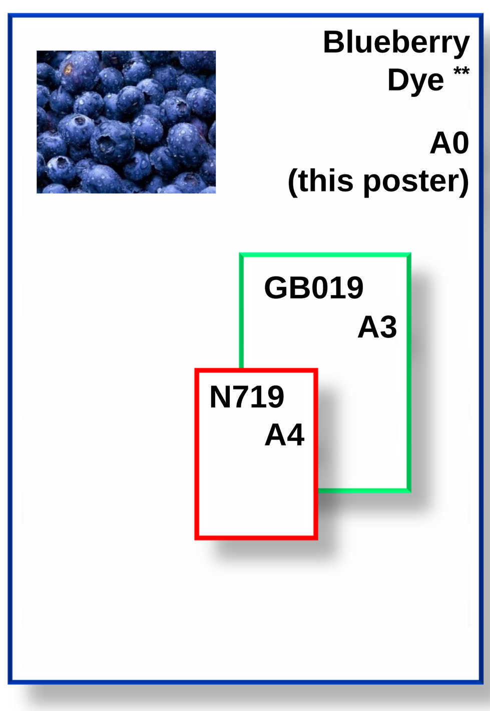
Charging a cell phone battery

Gcell®

Charging a 2900 mA.h Li-ion (3.7 V) cell phone battery (Iphone6s) in 2 hours under AM 1.5 (100 mW/cm²) in Grenoble (48° latitude):

- Modules = series association of 5 to 10 cells
- $A(m^2) = \dfrac{3{,}7}{\eta\,(\%)}\ \dfrac{Q(mAh)}{\Delta t\,(h)}$

Dye	*A* (cm²)	V_{oc} (mV)	N_{serie} cell/module	Yield η (%)	*P* (mW)	origin	Ref.
N719 (Ru)	0.36	663	1(6)	6.2	2.3	Solaronix®	this study
GCell300 (Ru)	300 (11x27)	723	11		461	G24 Power®	
Arcane (m-free)	81 (1x81)	609	1	**0.34**	28	Solaronix®	
GB019 (m-free)	0.36	655	1(6)	4.3	1.6	CEA-LEMOH	this study
Blueberries* (vegetable)	0.36	481	1(8)	0.35	0.13	Capsules myrtillus, Fairval®	this study
Blueberries** (vegetable)		520	1(8)	0.64		/	(I)



Conclusions

Our study: *vegetable*-based DSSCs for light-energy conversion and storage

- **Extrapolation to ≅ 1 m² for 5.4 W module necessary for "fast" 2-hour charging of a cell phone: scaling-up issues need to be considered**
- 100 µW demonstrated with a 0.36 cm² *blueberry cell* at AM 1.5 (1000 W/m²) standard SUN irradiance
- A potential for indoor energy harvesting for applications in the mW regime
- Photosynthesis also inspires other "artficial leaves' devices"

this project was endorsed by UNESCO– International Year of Light 2015

Bibliography : I. G. Calogero *et al*, *Vegetable-based dye sensitized solar cells,* ***Chem. Soc. Rev.***, 2015, **44**, 3244-3294, **II**. D. Joly *et al.*, ***Energy Environ. Sci.***, 2015, **8**, 2010-2018, **III**. *Dye Sensitized Solar Cells*, ed. K. Kalyanasundaram, EPFL press, Lausanne, Switzerland, **2010**, ISBN 9781439808665, **IV**. http://gcell.com/, last consulted 2015/01/11.

With the support of: Nanoatschool program, CIME-Nanotech, Institut Français de Singapour, ISYF 2016.

Special thanks for their help & encouragement: Th. GRIFFO (CSI) *un grand merci de toute l'équipe*, T. David, R. Demadrille, C. Gateau (ARCANE), *CEA*, G. Blaire, A. Bsiesy, A. Kaminski, D. Riassetto, C. Verrier, *PHELMA/CIME*, CSI board, H. Stanley and colleagues, high-school students & parents.