FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Open Phenotyping and Analytics tools that Bridge the Gaps Between the Lab and the World

Towards knowledge-driven plant breeding of legumes for local and regional solutions

David M. Kramer
MSU-DOE Plant Research Lab
Michigan State University

Legume Innovation Lab

Feed the Future Innovation Lab for Collaborative Research on Grain Legumes

USAID FROM THE AMERICAN PEOPLE

MICHIGAN STATE UNIVERSITY

PRL

Take home messages From the Inaugural Keynote Presentations:

Dr. Paco Sereme: We need to double small holder productivity by 2030.

Dr. Robert Bertram:

- Investment in resilience to climate extremes saves money and lives. This involves understanding variations, not just baseline conditions. This involves myriad combinations in stresses and conditions.
- We need to:
  - Greatly accelerated improvements in management
  - Rapid acceleration of the breeding cycle
  - Integration of knowledge

Prof. Irv Widders:

- We need *diversity* as a strategy for resilience

All of these require advances in phenotyping, environment typing, data sharing and analytics that can guide modern crop management and breeding approaches.

Phenotyping for the 98%

ELSEVIER
www.elsevier.com/locate/worlddev

CrossMark

Development Vol. 87, pp. 16–29, 2016

http://dx.doi.org/10.1016/j.worlddev.2015.10.041

The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide[q]

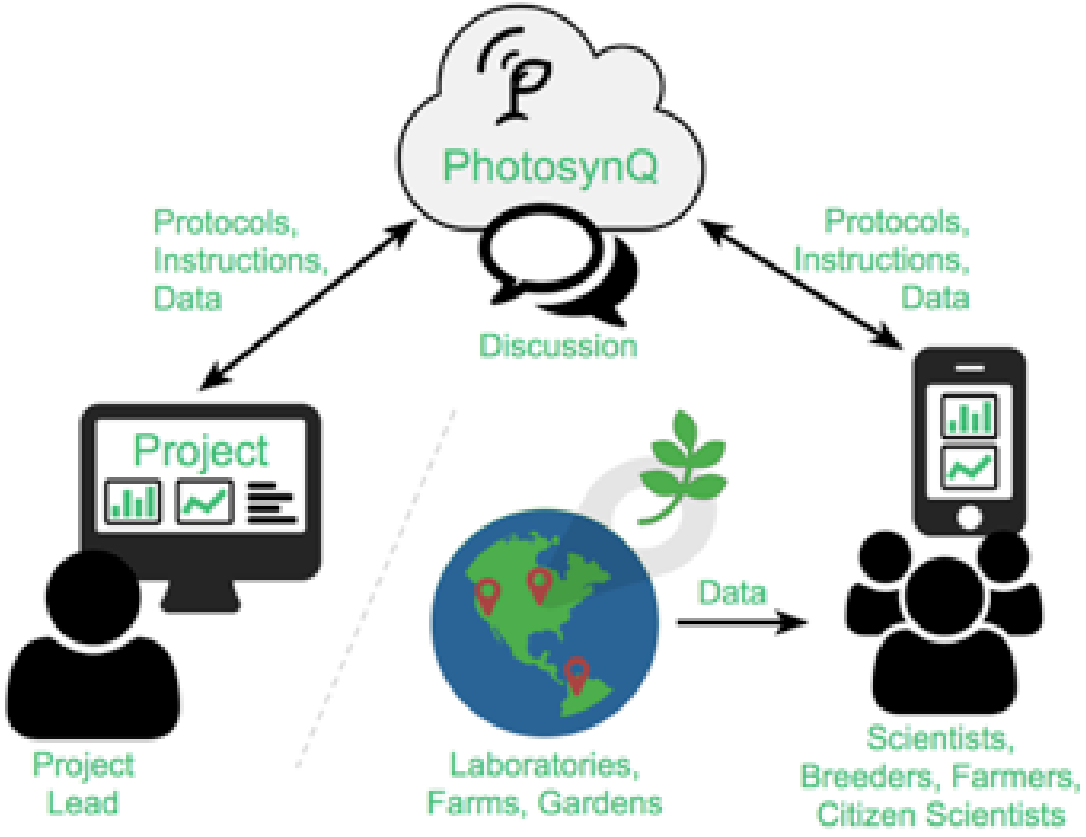
SARAH K. LOWDER, JAKOB SKOET and TERRI RANEY*
Food and Agriculture Organization of the United Nations, Rome, Italy

Summary. — Numerous sources provide evidence of trends and patterns in average farm size and farmland distribution worldwide, but they often lack documentation, are in some cases out of date, and do not provide comprehensive global and comparative regional estimates. This article uses agricultural census data (provided at the country level in Web Appendix) to show that there are more than 570 million farms worldwide, most of which are small and family-operated. It shows that small farms (less than 2 ha) operate about 12% and family farms about 75% of the world's agricultural land. It shows that average farm size decreased in most low- and lower-middle-income countries for which data are available from 1960 to 2000, whereas average farm sizes increased from 1960 to 2000 in some upper-middle-income countries and in nearly all high-income countries for which we have information.
Such estimates help inform agricultural development strategies, although the estimates are limited by the data available. Continued ef-

Problem 1: Most of the research and data tools for phenotyping are being targeted to large, "monocultural" farms. The costs of bringing the current systems to non-humongous farms is daunting, and it's not sure they will really work there.

We need new tools for small plots with high diversity of crops, environments and management approaches.

PHOTOSYNQ



The Big Ideas:

Bridge the gaps between:

Lab and world (environment)

Lab to world (people)

- Science is limited by access
  - instruments
  - expertise
  - data
  - Learn the important questions
- Data
  - Data scales
  - **No more orphan data!**
  - Science is knowledge limited!

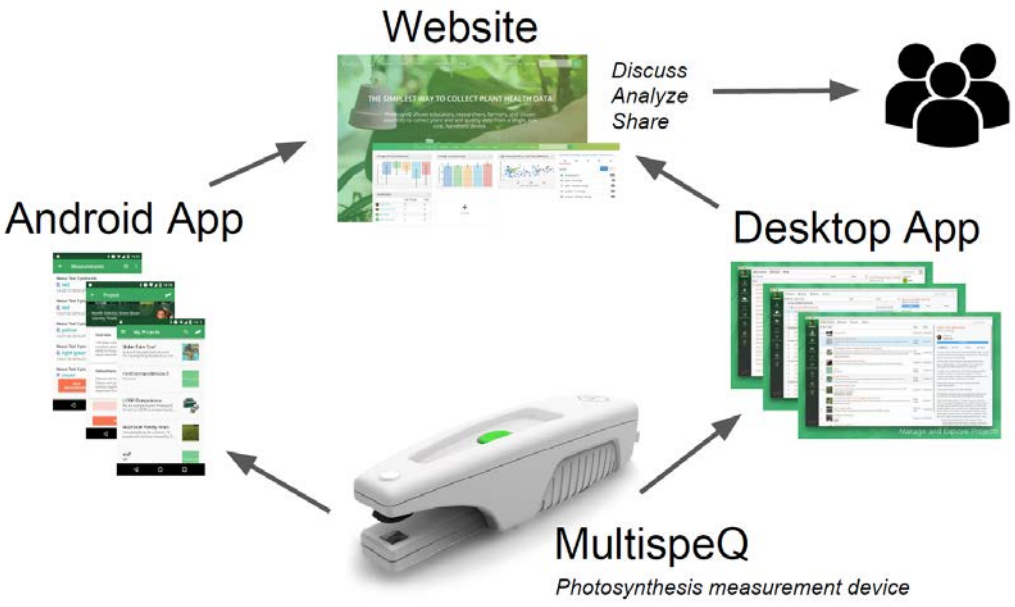
Basic and applied:

- actionable knowledge
- scientific knowledge

Kuhlgert et al (2016) Royal Soc. open Science 2016

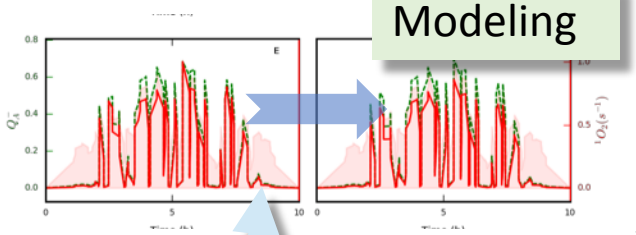
What is PhotosynQ?

PhotosynQ connects a sophisticated hand-held instrument (MultispeQ) to a web-based platform to store, visualize, map, and share plant health data



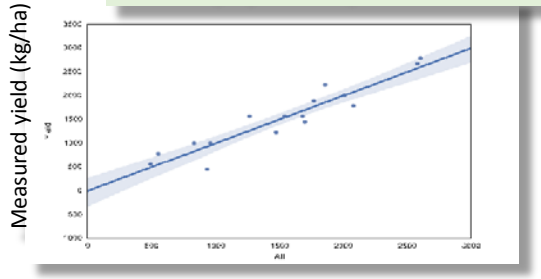
www.photosynq.org

Susan Chipandwe



Modeling

Early yield prediction



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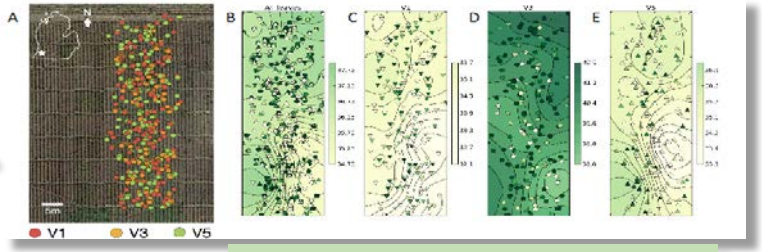
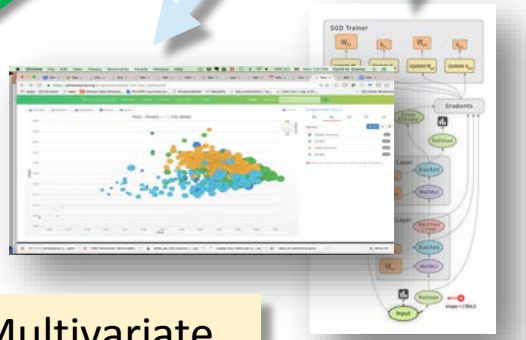
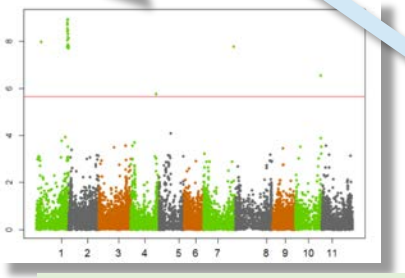


Early disease warning

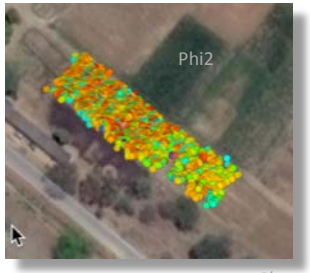


Multivariate analyses

Deep learning



QTL mapping



Geospatial dependences

python

How PhotosynQ.org is Bringing Cutting-Edge Plant Breeding to Improve Agriculture in Africa

1

Kelvin Kamfwa, plant breeder at U. Zambia. Goal: breed better beans for the specific conditions in Zambia.

2

Online and mobile phone apps create projects that guide users to make the right measurements.

MultispeQ

3

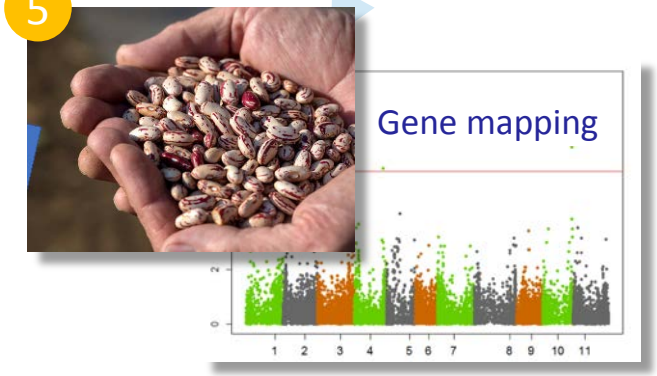
Sophisticated, **very low cost**, easy-to-use sensors send high quality data and metadata to PhotosynQ.

PHOTOSYNQ

6

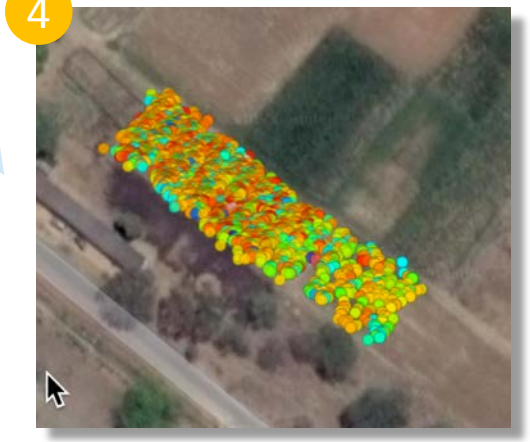
Meet local needs (like Kelvin's) and connect knowledge and expertise to solve problems worldwide through PhotosynQ community.

5



Identification of genes guides cutting edge plant breeding for hyper-local traits.

4



Free, open, on-line and community analytics and machine learning, reveal trends and make predictions.

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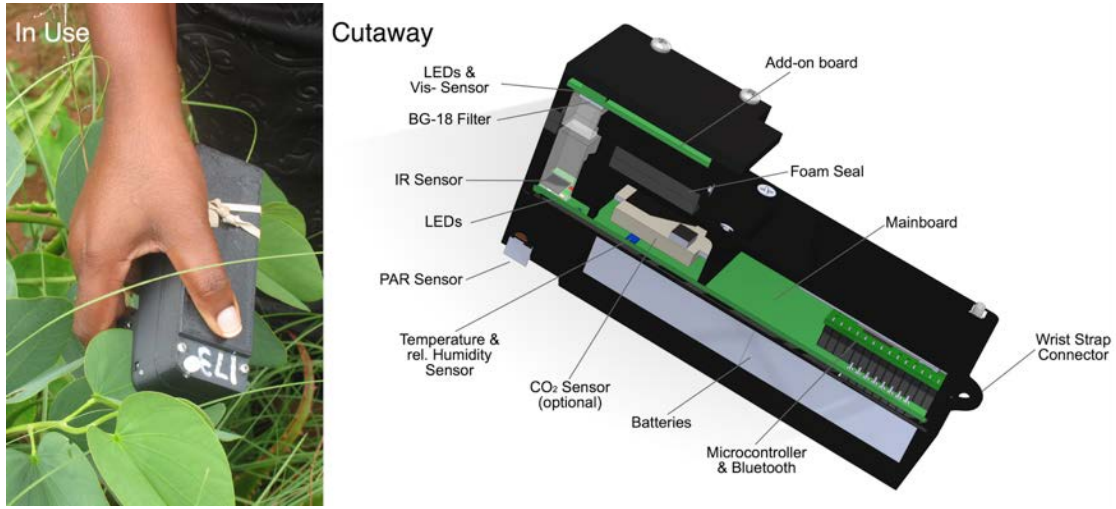
Legume Innovation Lab

MultispeQ



200 beta units

- Important/Interesting
- Interpretable
- High throughput <20 s
- Feasible
- Inexpensive

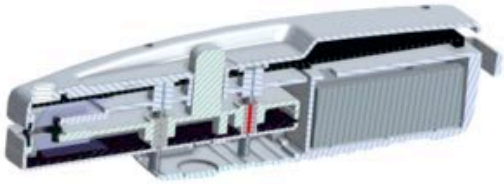
Open:

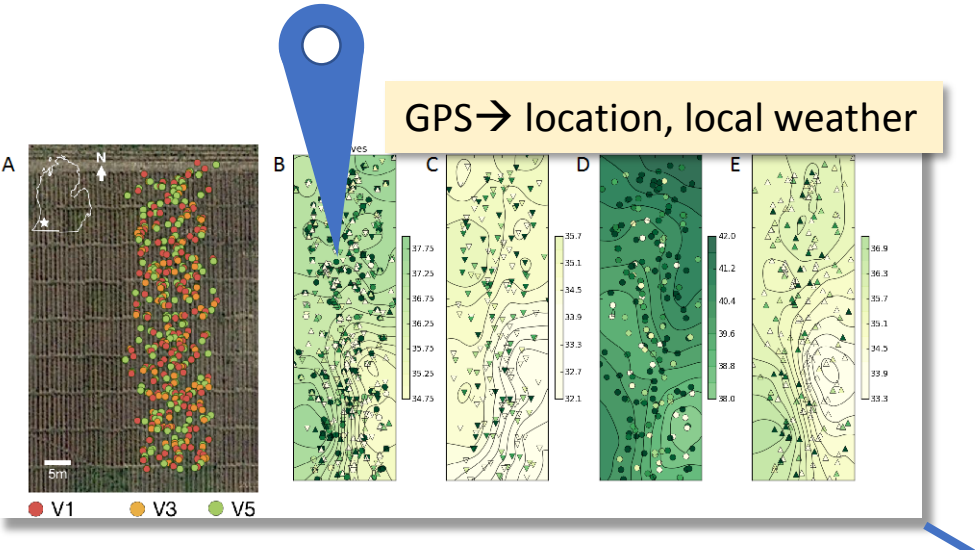
Expandable
Adaptable
Clone-able

>300-500 1.0 units

- $30-75K→ $600
- Collects multiple data and metadata
- Rapid, in situ measurements
- Guided (very easy to use!)
- Linked to PhotosynQ
  - communication
  - big data→global analyses
  - connection to expertise
  - Built in educational capacity

What can MultispeQ do?





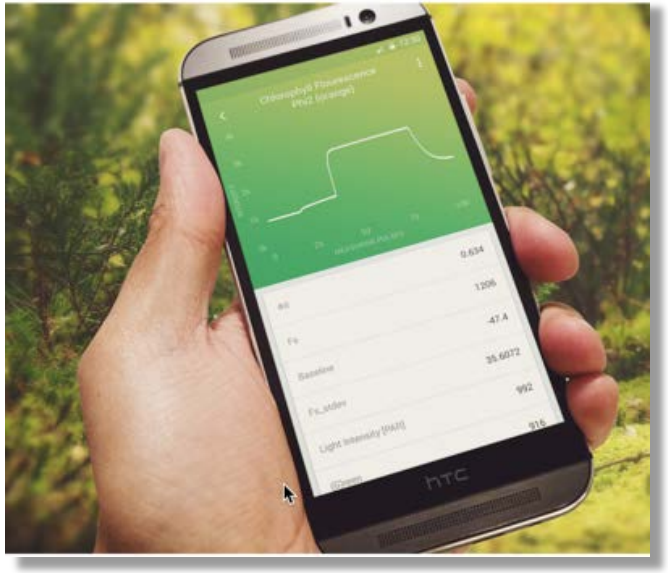
GPS→ location, local weather

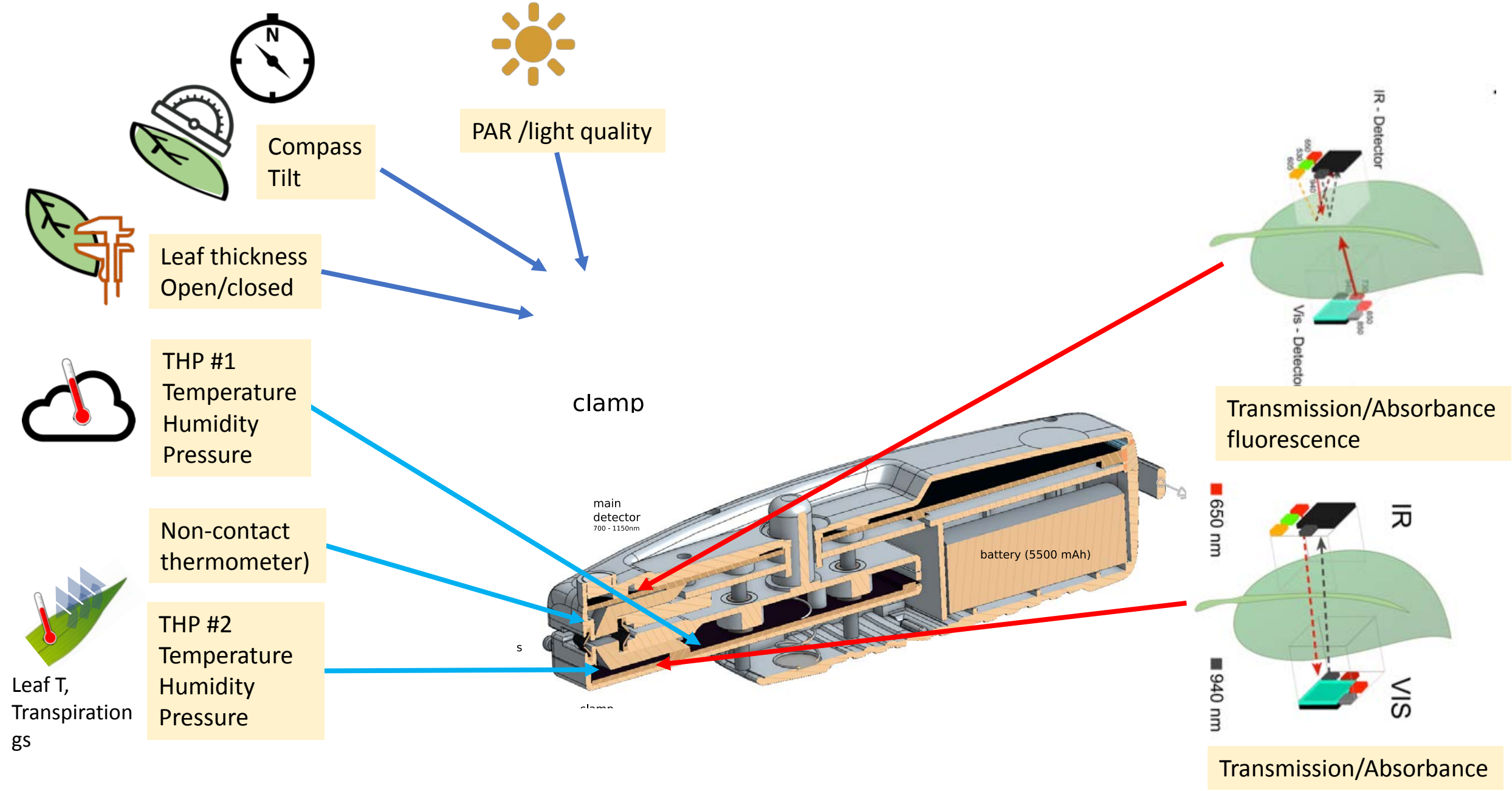
User input
Survey
Photos

User/ instrument information, protocols, macros, timing.

QR/bar codes

- Metadata: Species, genotype, experimental conditions, farmer, etc.



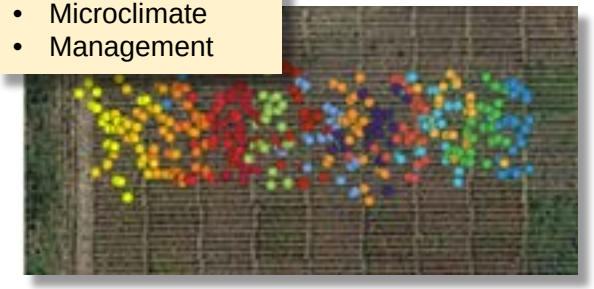


MultispeQ optical and environmental sensors

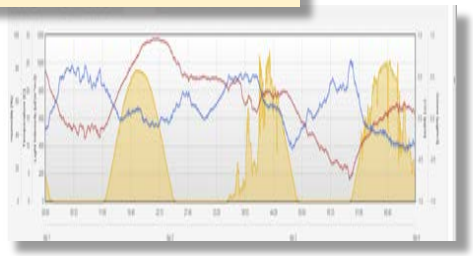
MultispeQ's multiple sensors give detailed information about a crop in a single 20-second assay.

QR/bar codes
- Metadata: Species, genotype, experimental conditions, farmer, etc.

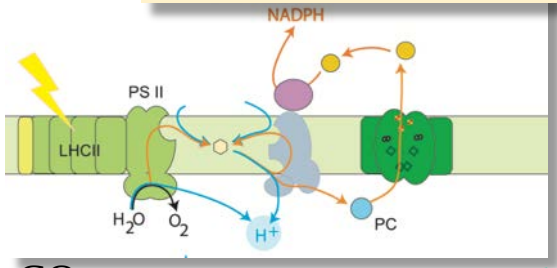
Geo-position
- Soil properties
- Microclimate
- Management

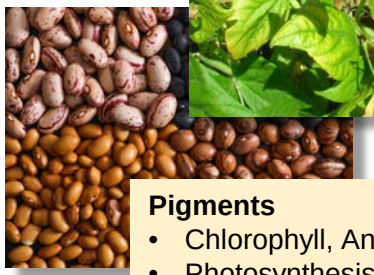


Microclimate/weather

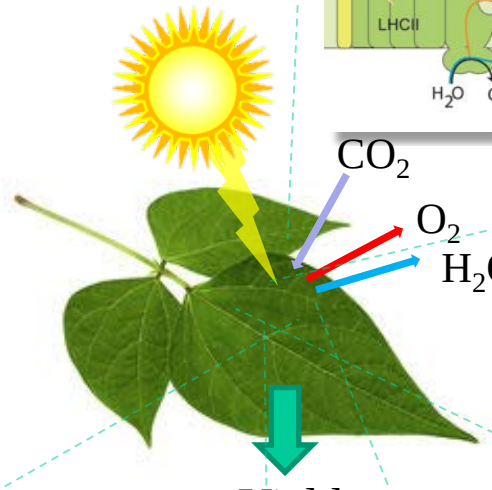


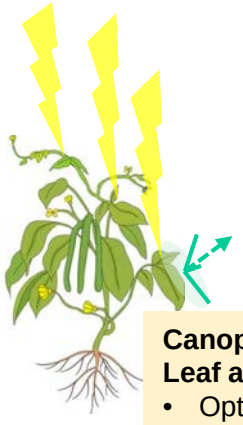
Photosynthetic control points
- Productivity/Efficiency
- Photodamage
- Photoprotection
- Assimilation/photorespiration
- Disease



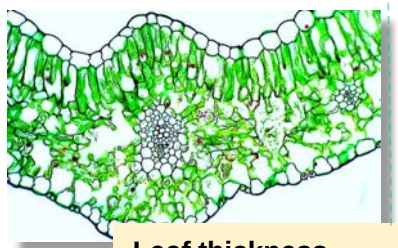


Pigments
- Chlorophyll, Anthocyanin, etc.
- Photosynthesis
- Disease, development
- Nitrogen status/N2 fixation
- Stress responses
- Fruit ripeness/quality

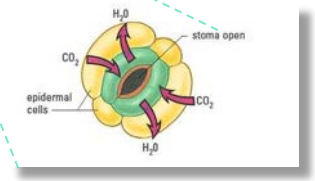




Canopy Light gradient
Leaf angle
- Optimal light use
- Crop spacing



Leaf thickness
- Insect resistance
- CO_2 fixation
- Photosynthetic efficiency



Stomatal conductance
- Water use efficiency
- Drought tolerance
- Assimilation

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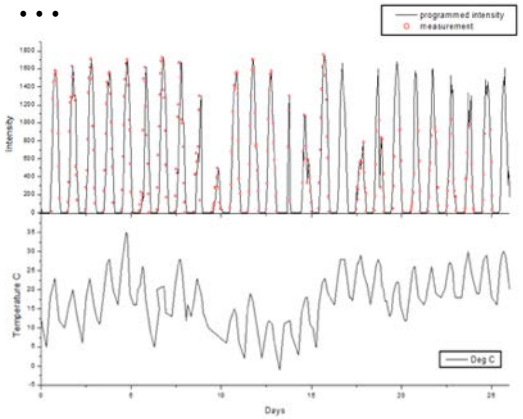
Designed as an “Information age” tool: RAPID collection of:

Data:
What was the plant doing?

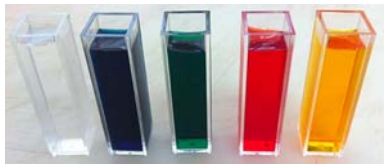
http://www.hort.cornell.edu/

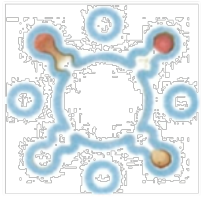
Metadata:
What were the conditions?
Where, when, who?
What was the genotype?
What was the climate?
…



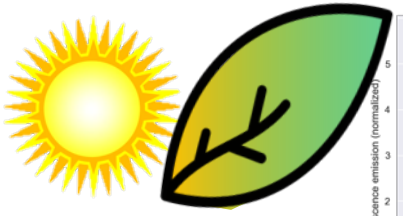
Output:
What was the outcome?
Yield
Disease
etc.

HyperspeQ

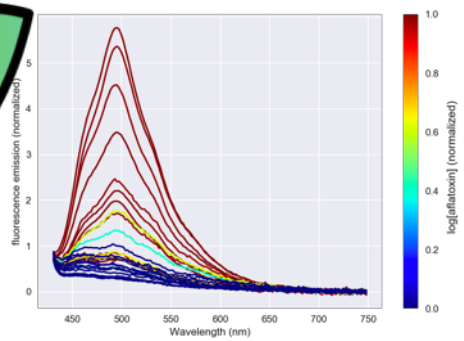




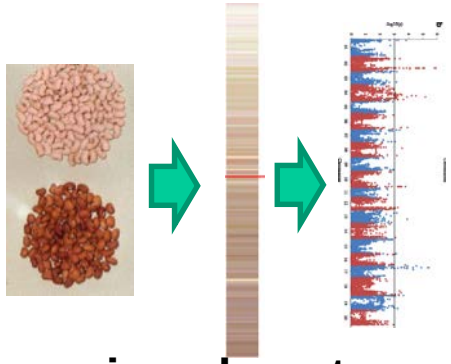
soil chemistry



radiometry, reflectance



aflatoxin



grain color, etc.

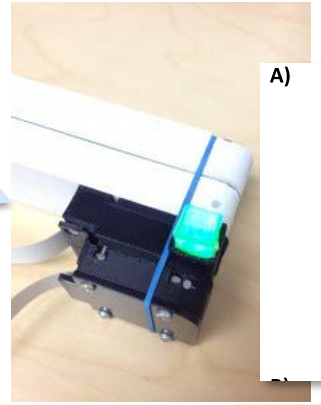
Poster: Atsuko Kanazawa

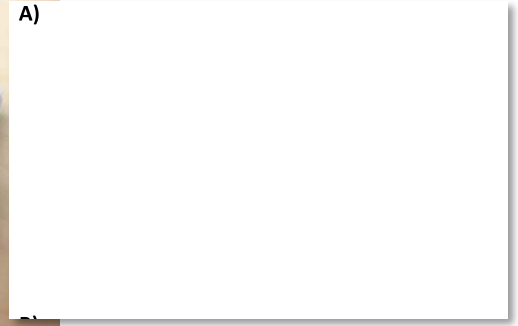
Leaf Thickness Gauge

PHOTOSYNQ

SoilspeQ Biological activity
See booth/Dan TerAvest

Soil probes

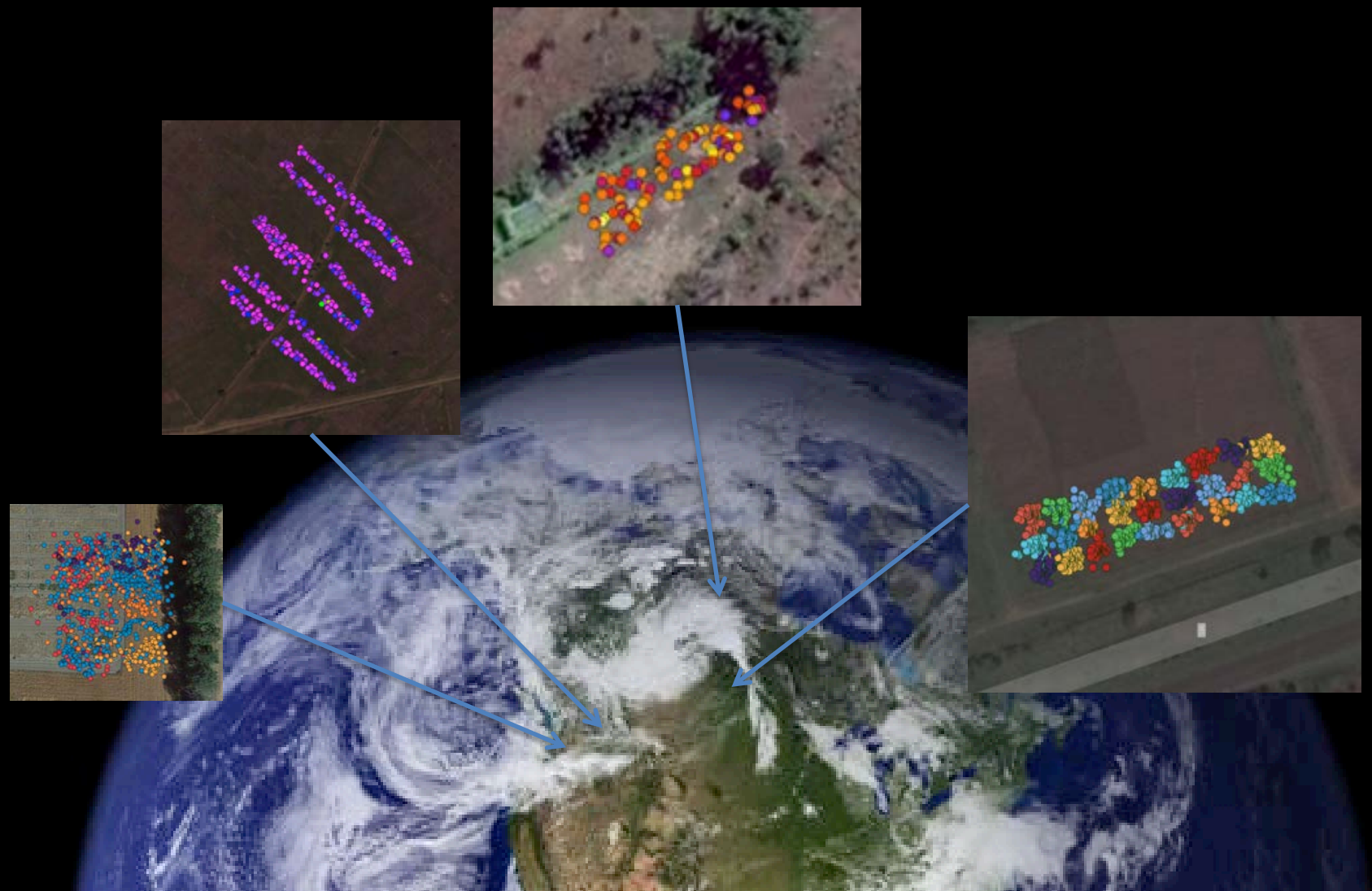




DNA-nanoprobes to detect:
- Viruses
- Bacteria
- Plant genotypes
- Contamination

Brad Day lab.

PhotosynQ.org connects data and metadata, from the farm to region to global scales. It aims to take a problem (high diversity) and turn it into an opportunity to understand crops at a deeper level, leading to new algorithms for management, crop improvement and decision making.

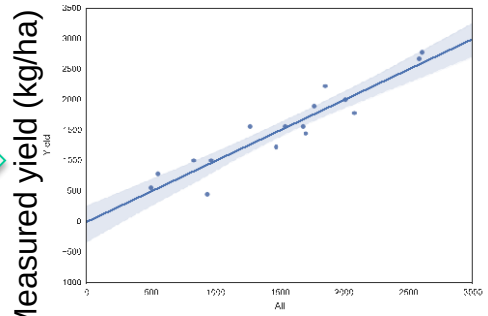



Join a Vibrant, Global Community
2230 Projects
2150 Users
591 K Contributions

2017 PhotosynQ Workshop

R1 plant stage

+

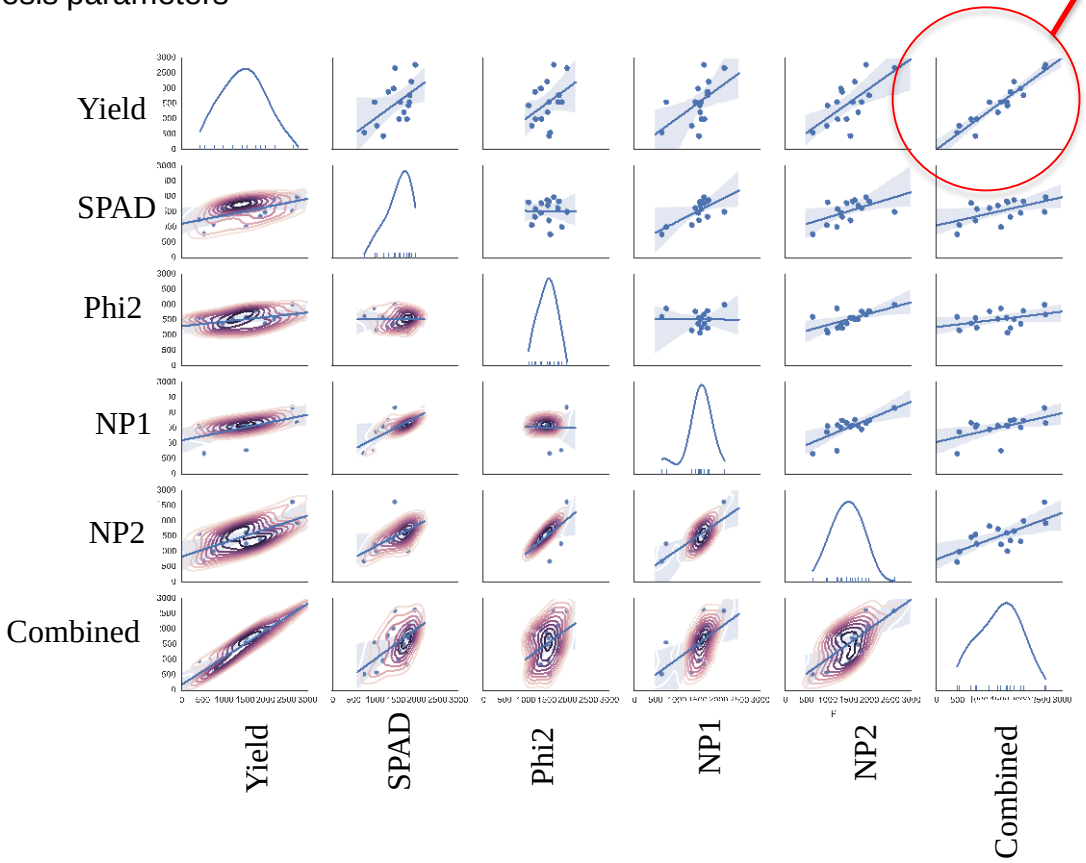


- Light, temperature, leaf position, time of day
- SPAD + five separate photosynthesis parameters
- Yield

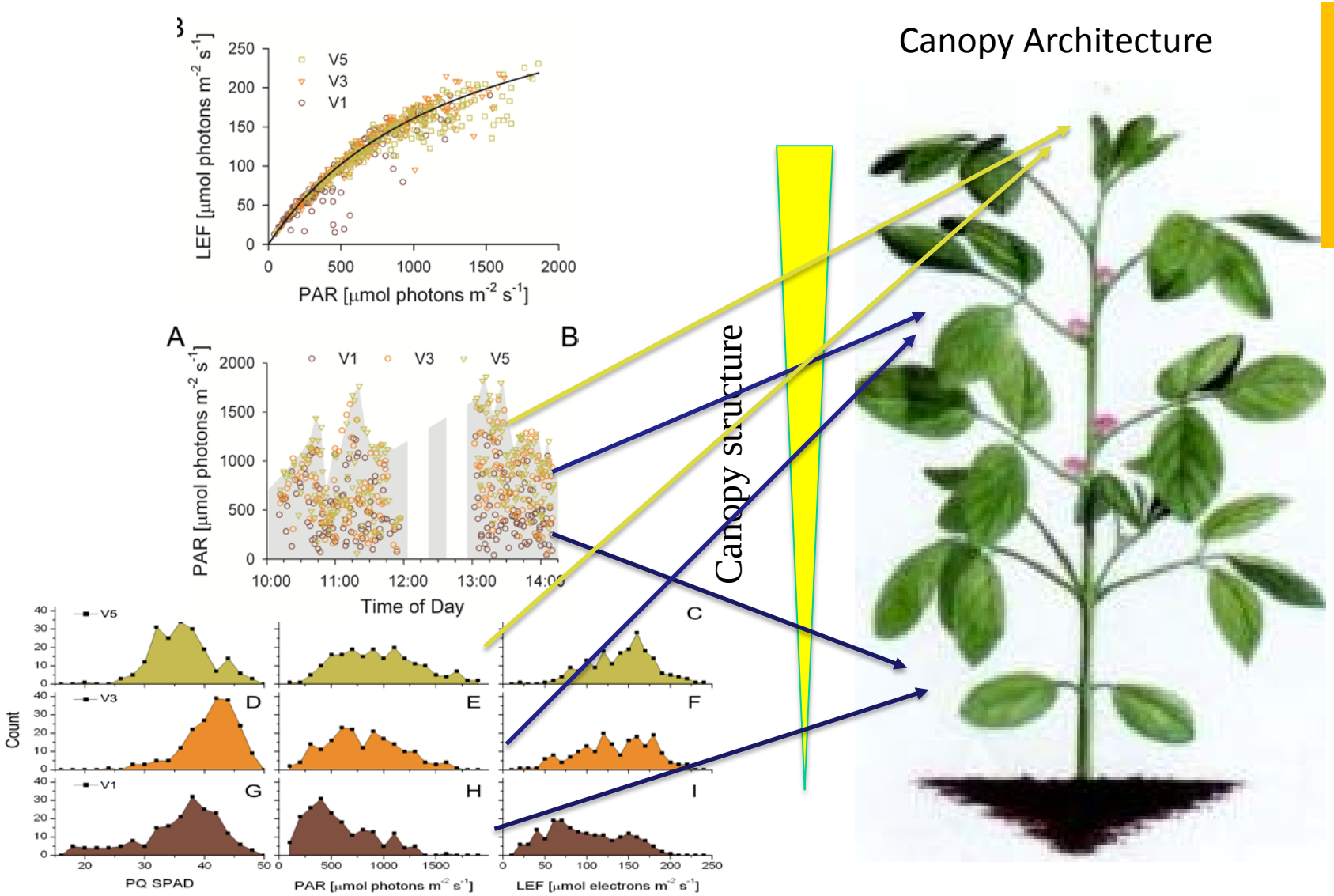
We can measure parameters that are related to yield.

BUT, high sensitivity requires multiple parameters.

High photosynthesis at any one time is not as important as good regulation!



Why so many sensors?

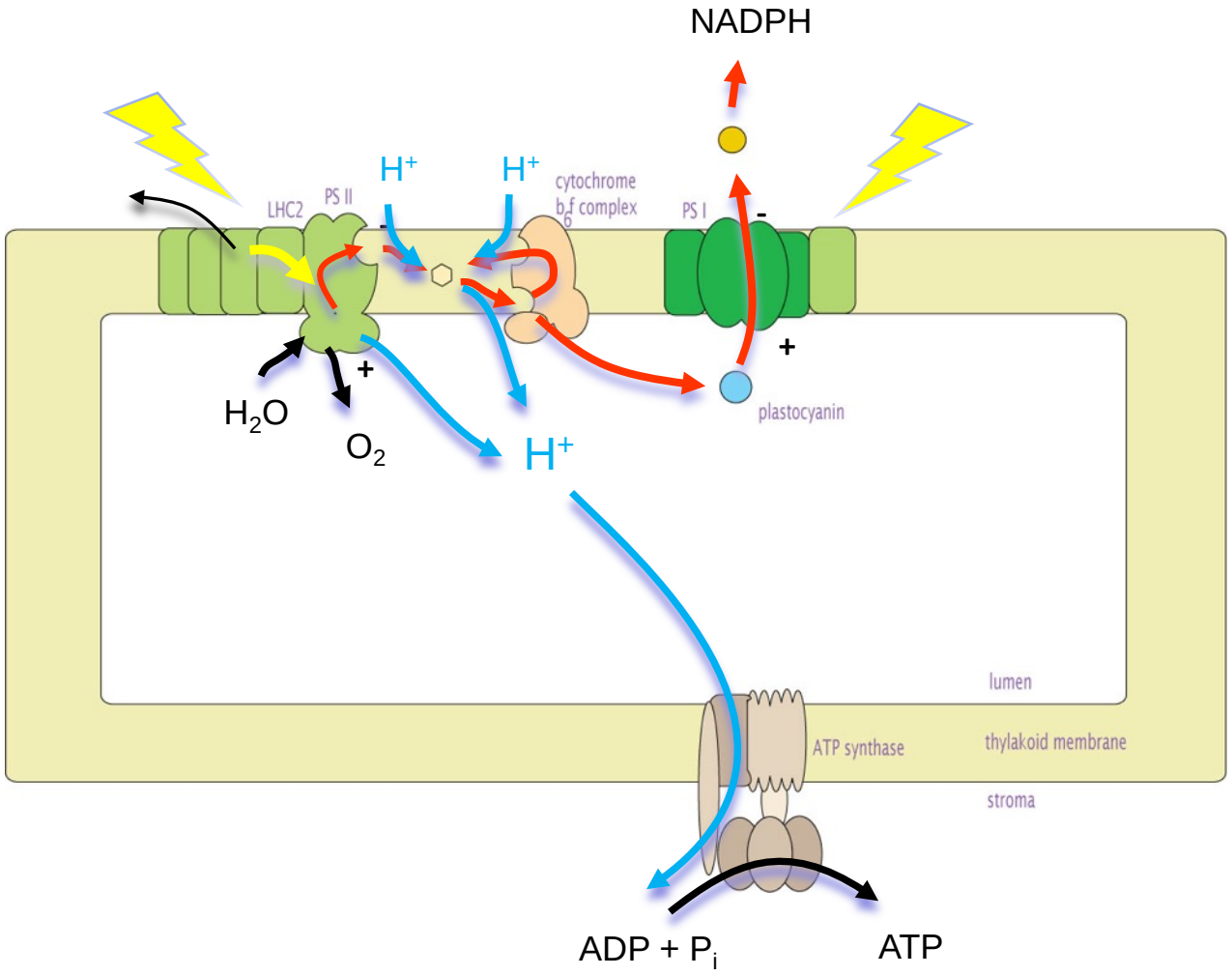


Environmental
Canopy structure
Developmental factors
Environmental factors
Genetic dependence

Kuhlgert et al (2016) Royal Soc. open Science 2016

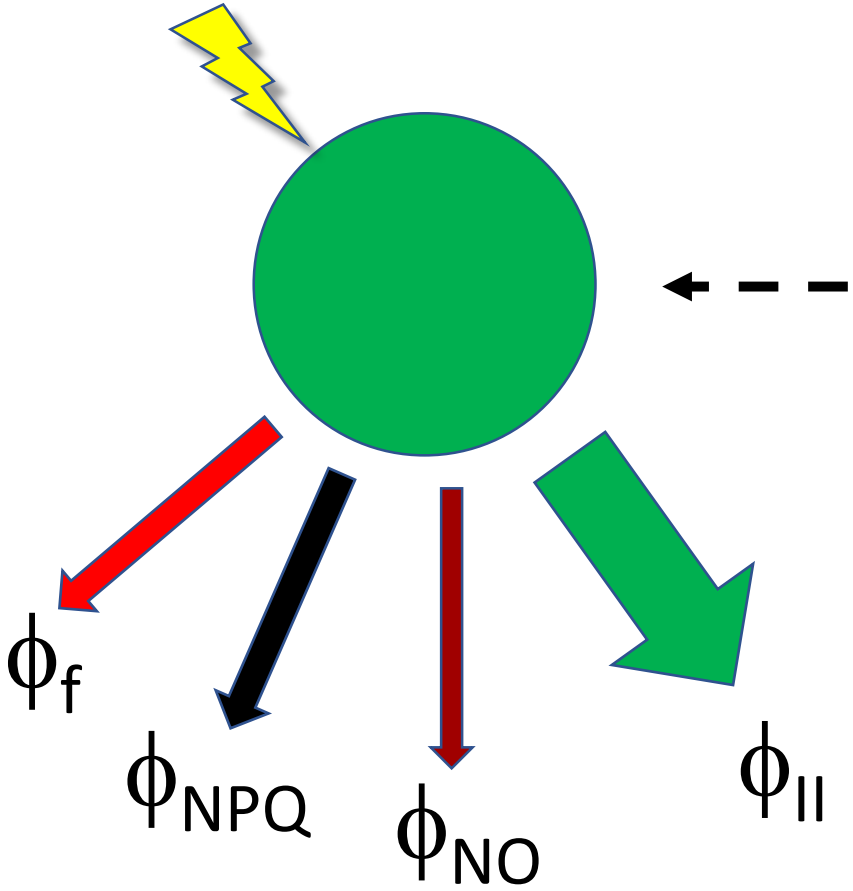
Contextualized data!

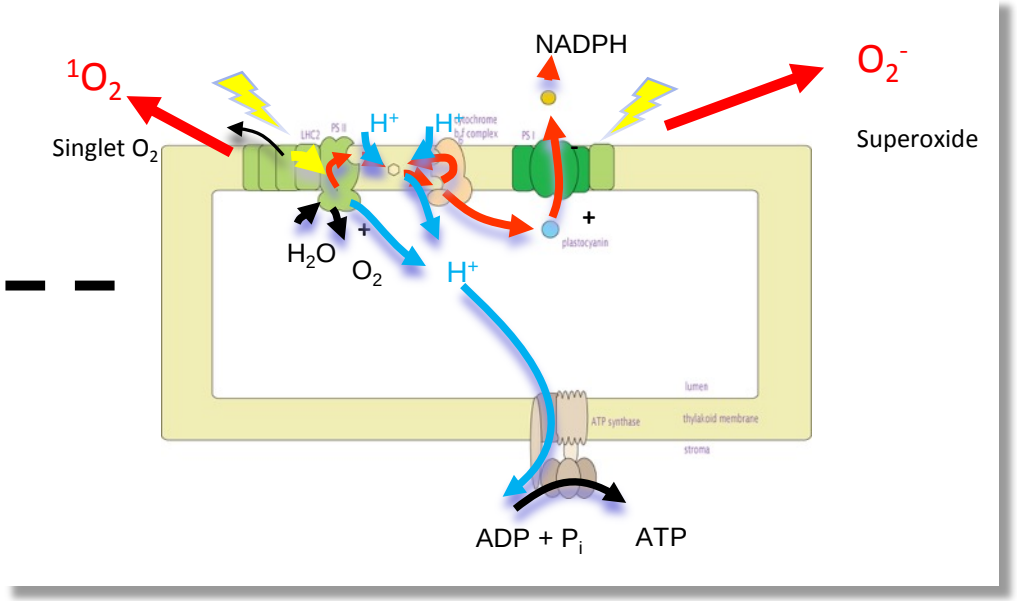
Why Photosynthesis?



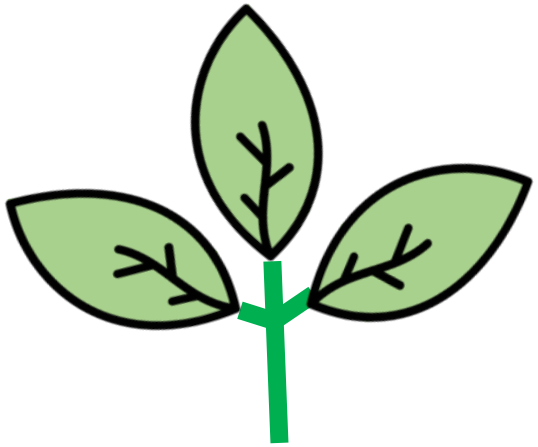
- Photosynthesis provides all the energy for crop productivity.
- We have many rapid, non-invasive, methods of measuring photosynthesis.

Very simple view of photosynthesis



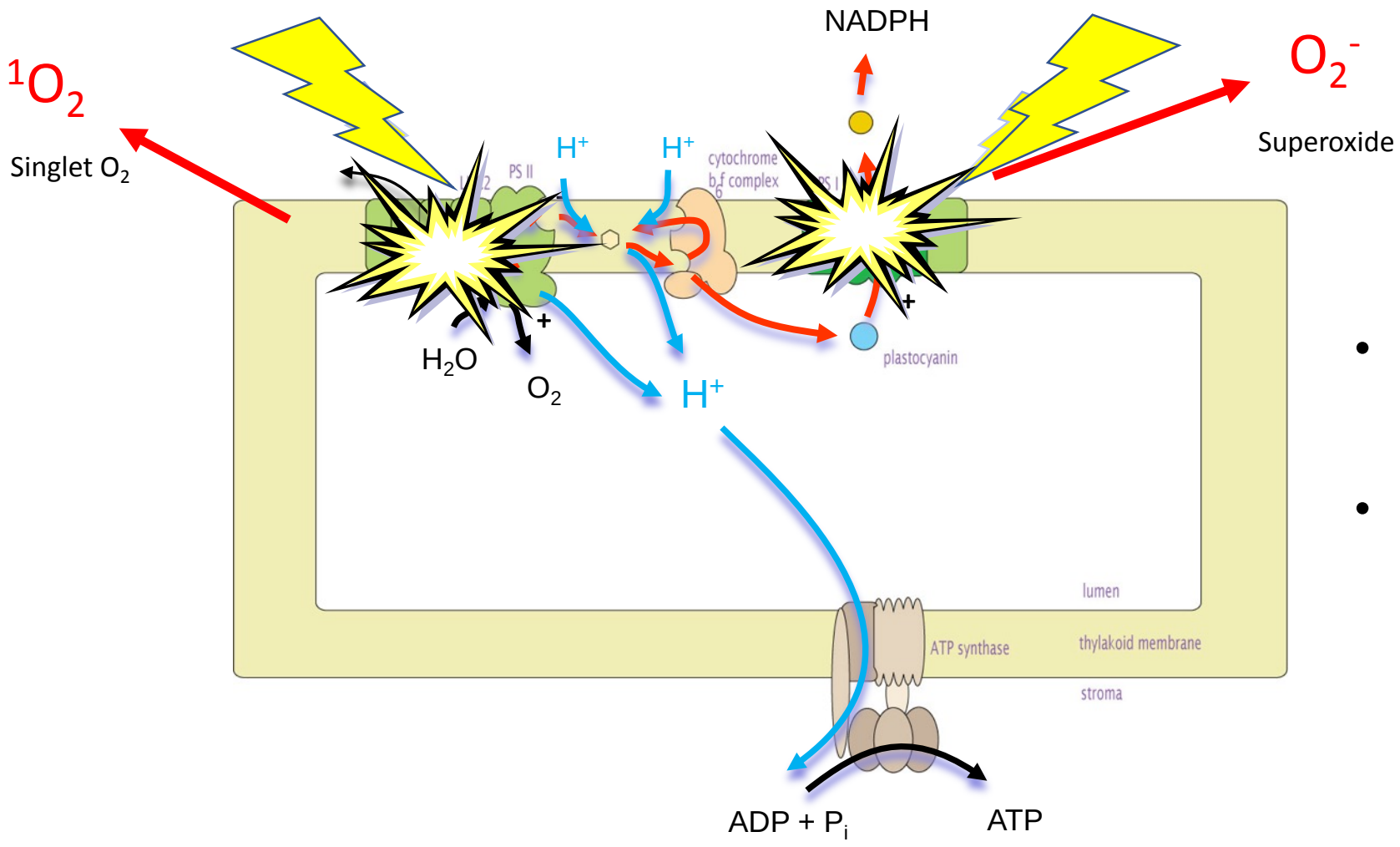


photosynthesis



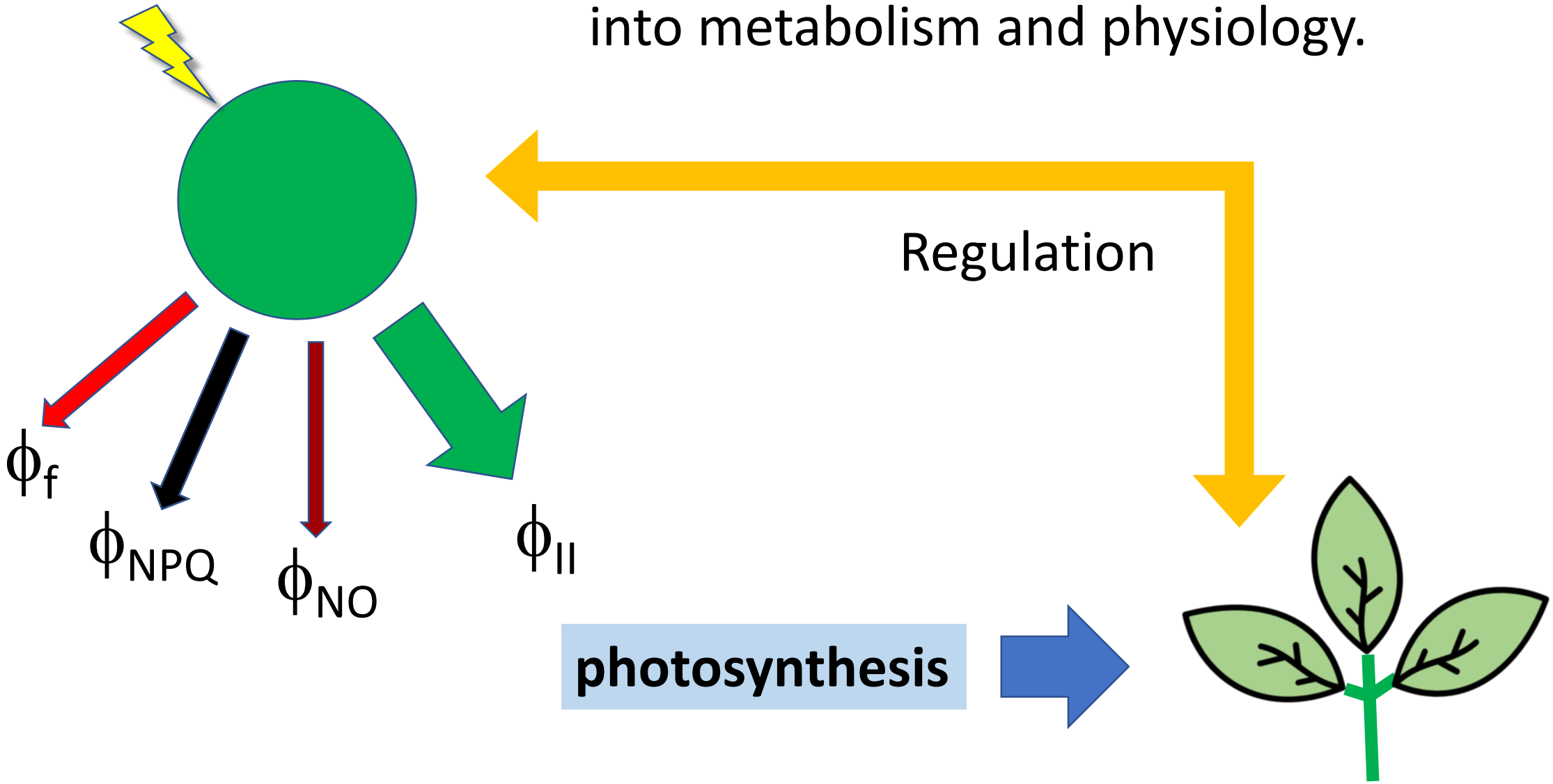
Energy for growth and productivity.

Photosynthesis is dangerous!

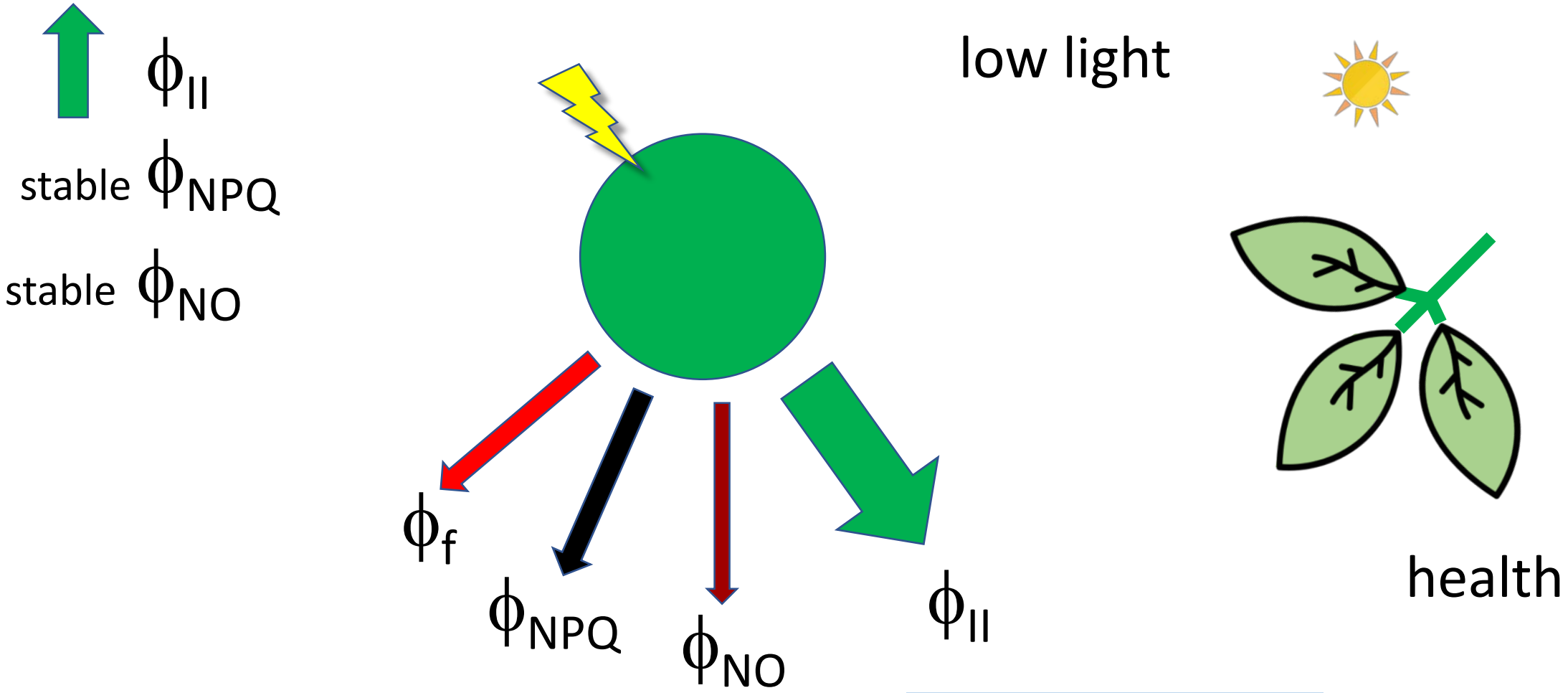


- Photosynthesis must be very well regulated!
- Must respond very rapidly to stresses.

Photosynthesis is tightly integrated into metabolism and physiology.



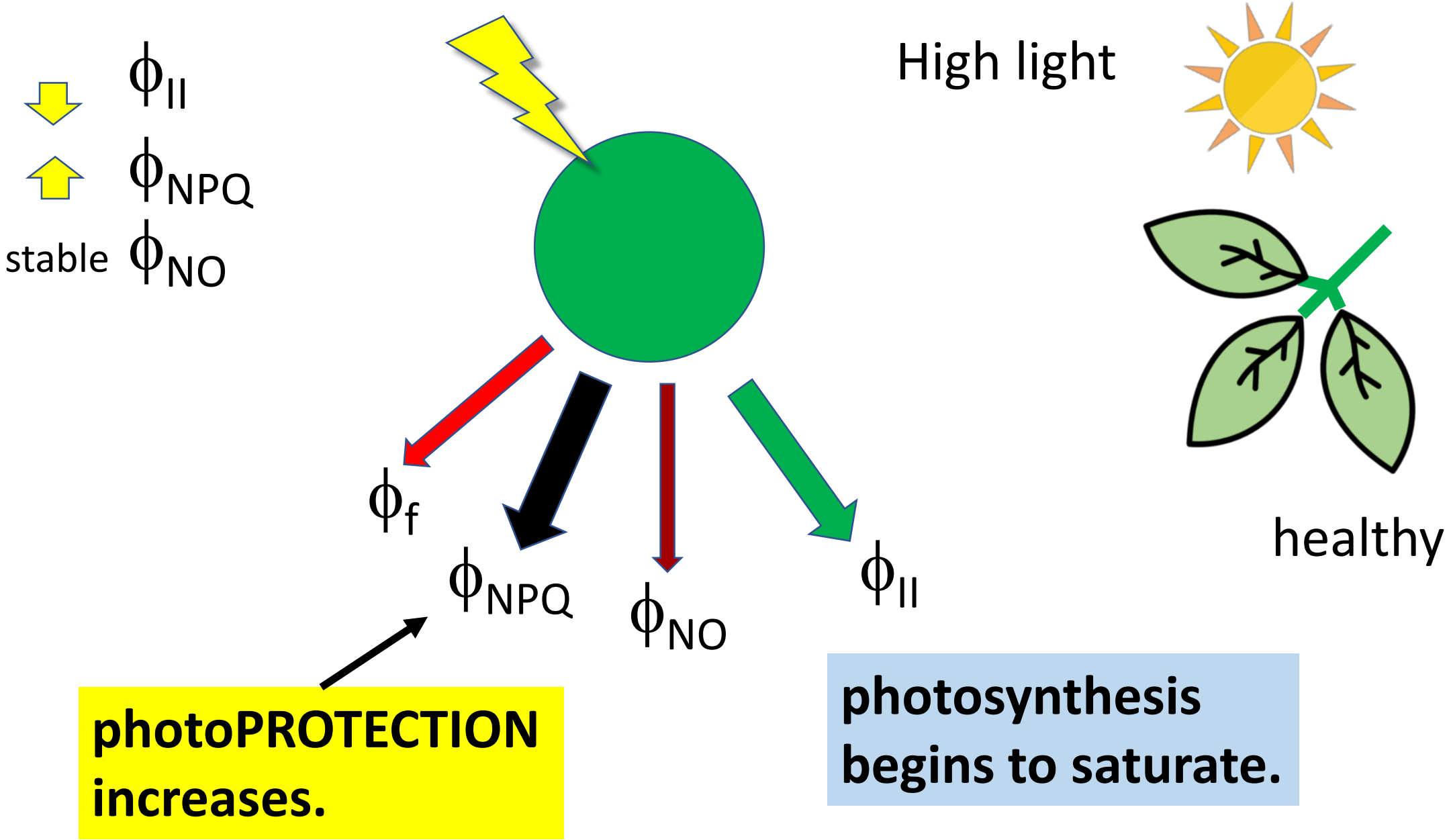
Photosynthesis can be an indirect monitor of many plant processes.



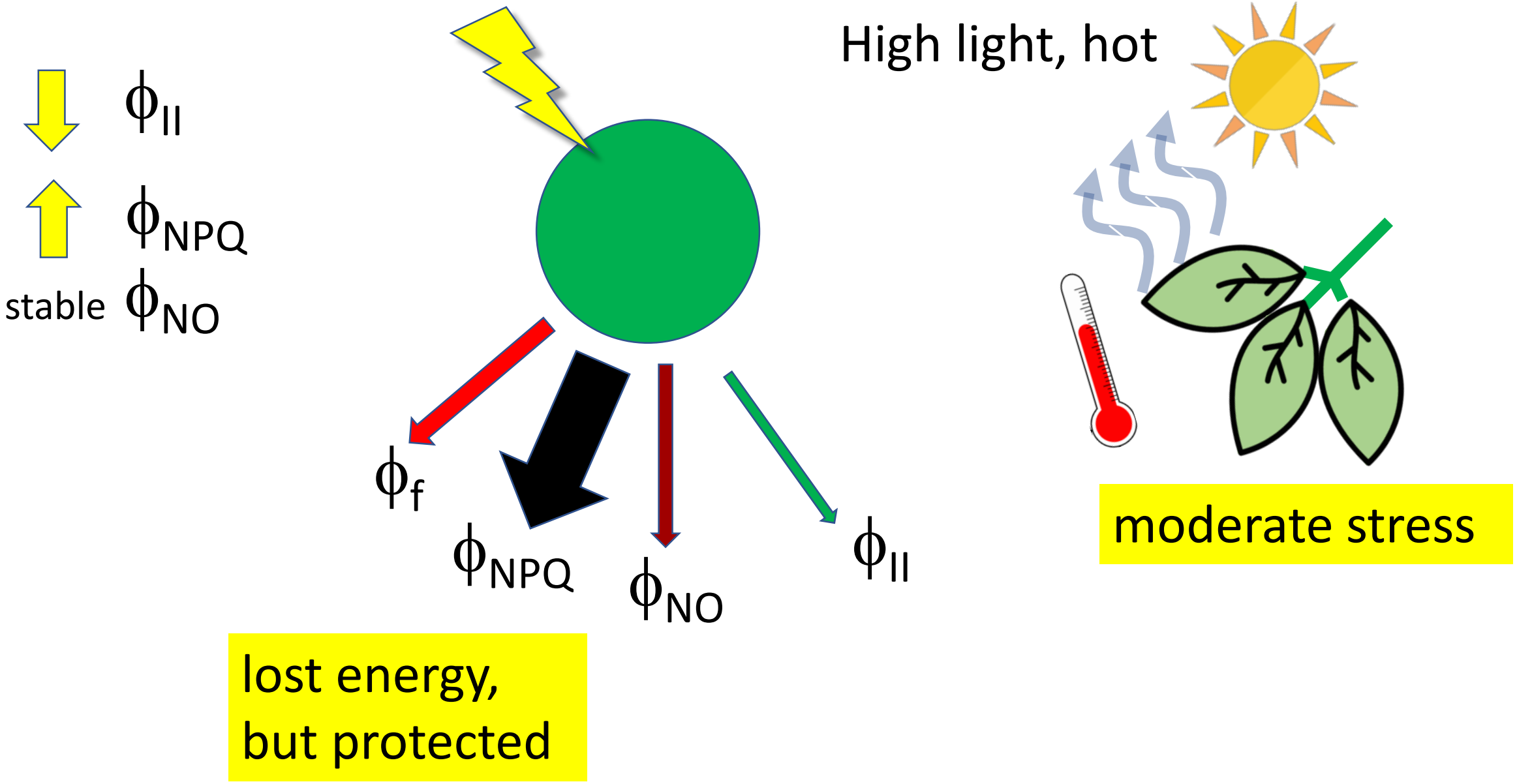
photosynthesis

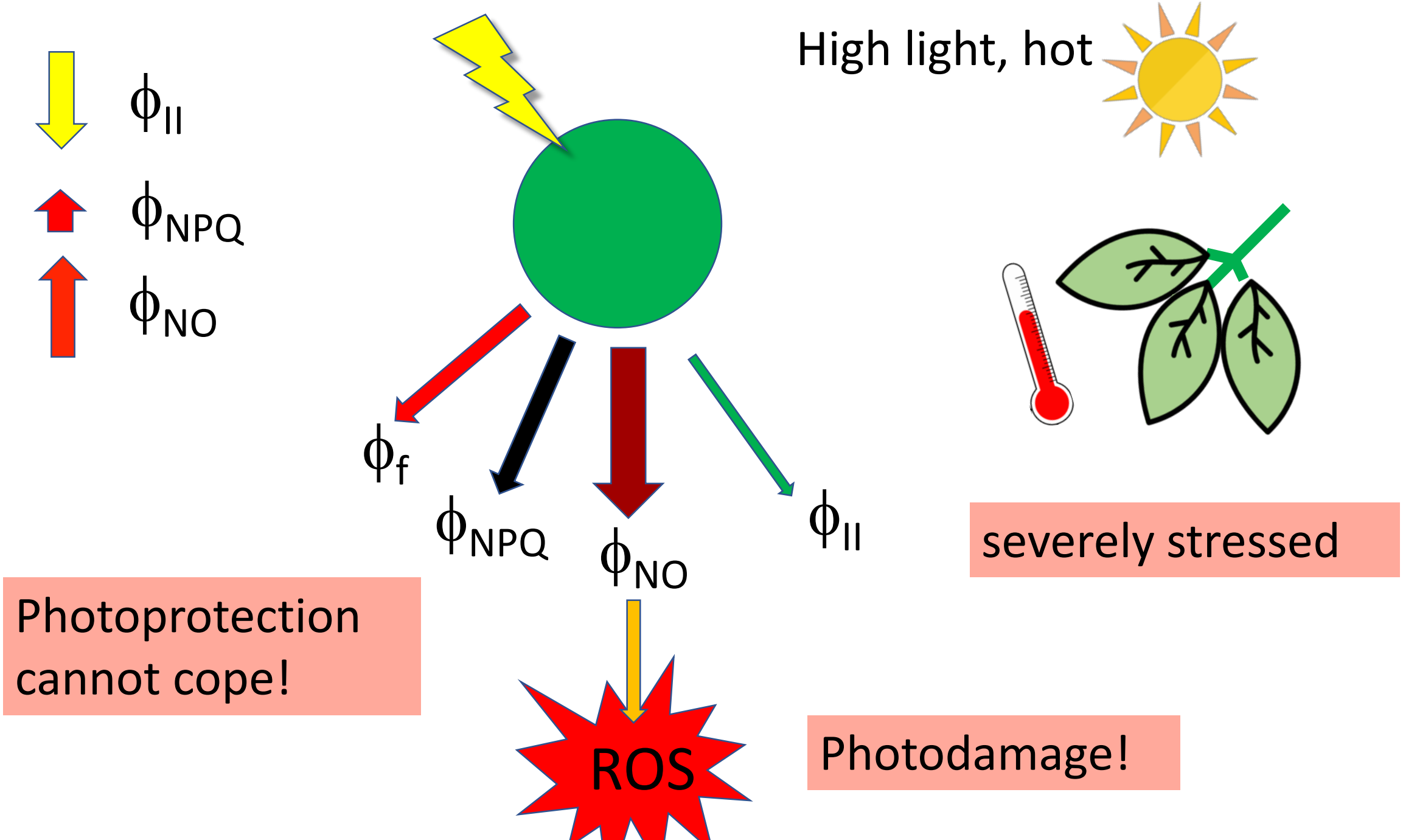
Energy for growth and productivity.

Tietz et al., (2017) Plant Cell & Environment

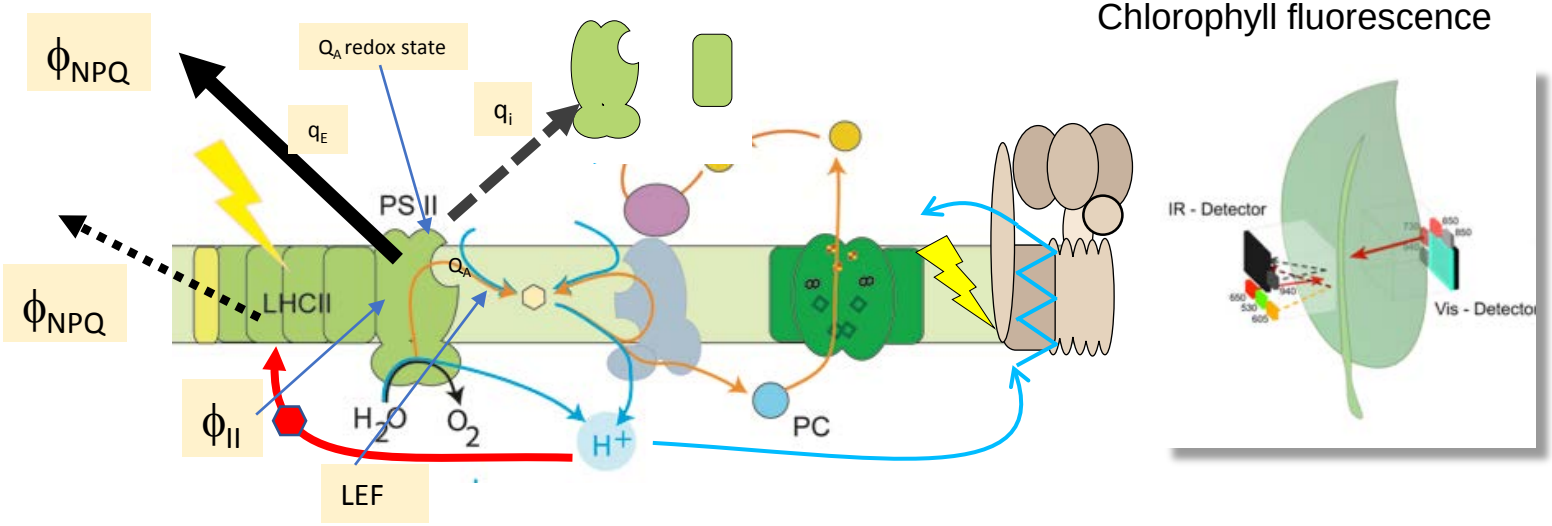


Wasteful, but protects against damage.

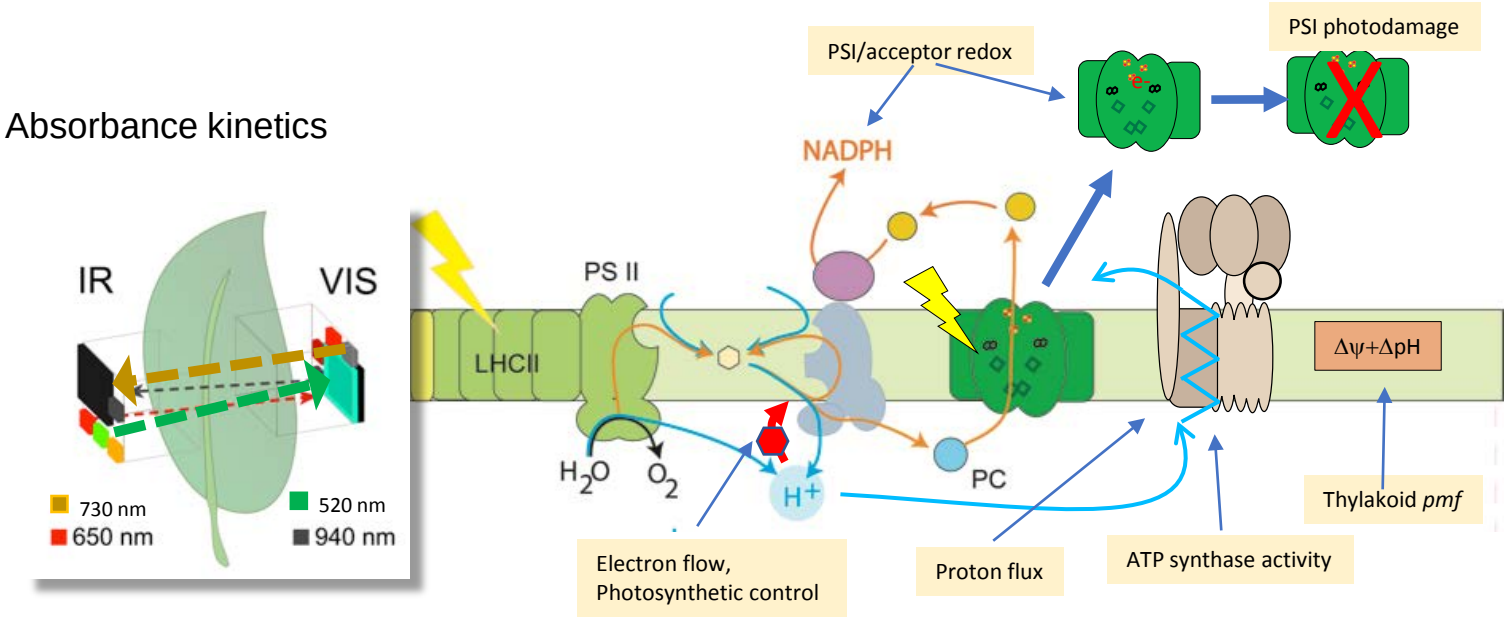

ϕ_{II}
ϕ_{NPQ}
stable ϕ_{NO}
High light, hot
ϕ_f
ϕ_{NPQ}
ϕ_{NO}
ϕ_{II}
moderate stress
lost energy,
but protected


ϕ_{II}
ϕ_{NPQ}
ϕ_{NO}
High light, hot
ϕ_f
ϕ_{NPQ}
ϕ_{NO}
ϕ_{II}
severely stressed
Photoprotection cannot cope!
ROS
Photodamage!

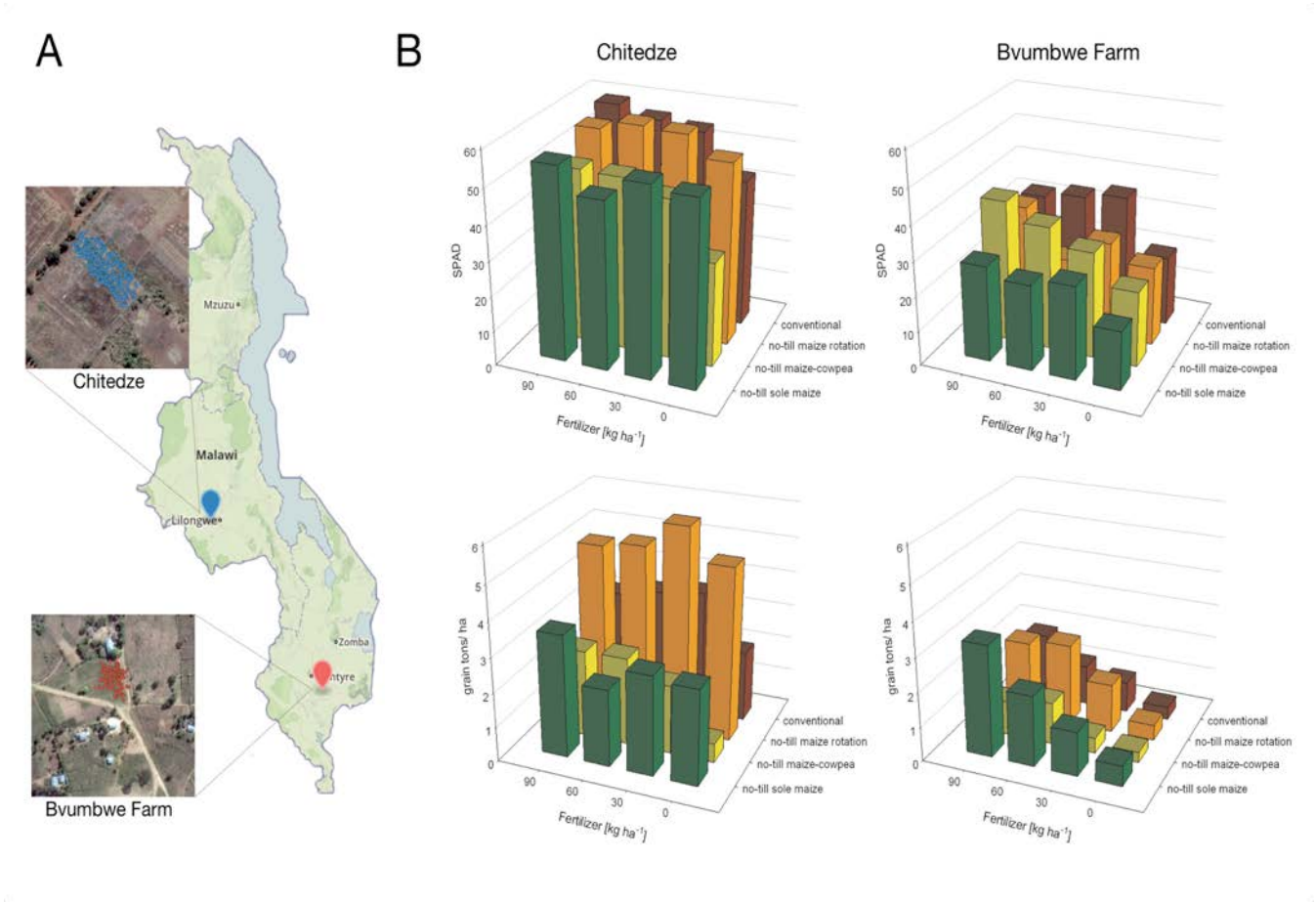
Chlorophyll fluorescence



Absorbance kinetics

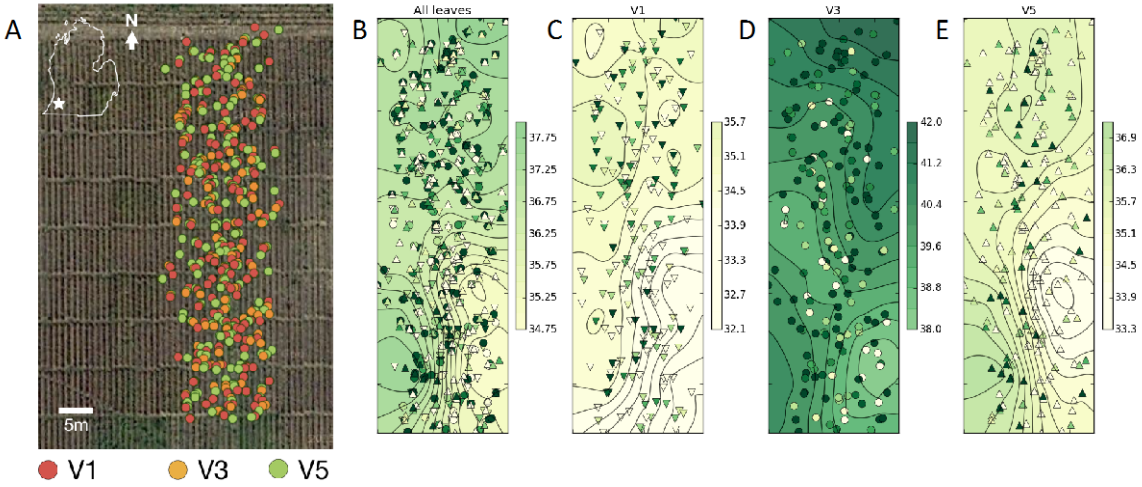


What did PhotosynQ learn?

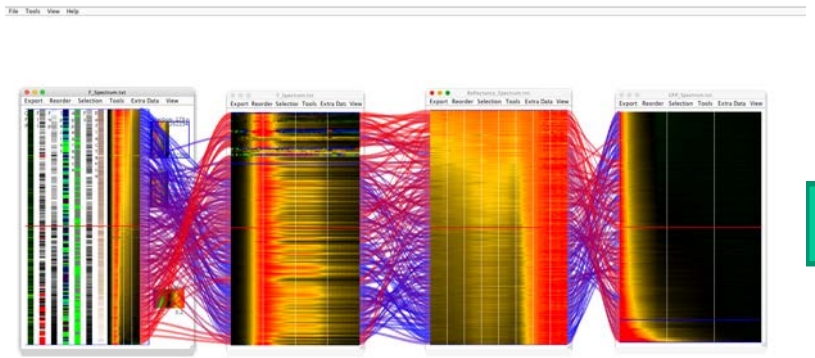


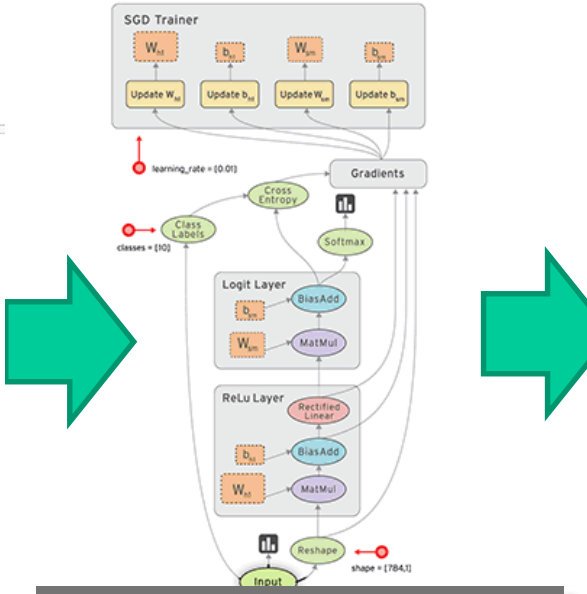
Conditions on research stations are very different than the farms; We need local assessments.

PhotosynQ as a plant disease “early warning system.”



Spatially resolved, time-resolved.





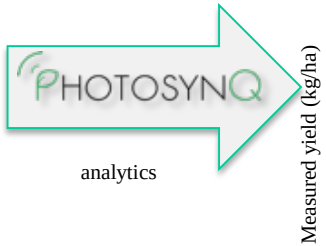
$R^2>0.7$

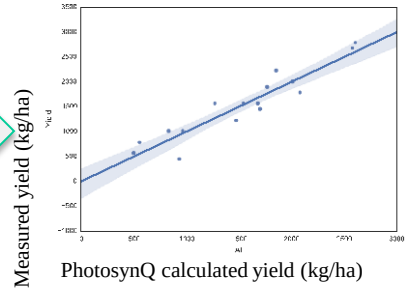
Kuhlgert et al (2016) Royal Soc. open Science

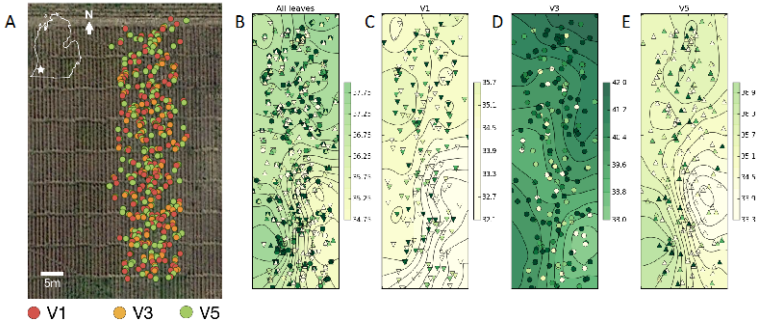
Deep learning algorithm.

R1 plant stage

+







Why are these important?

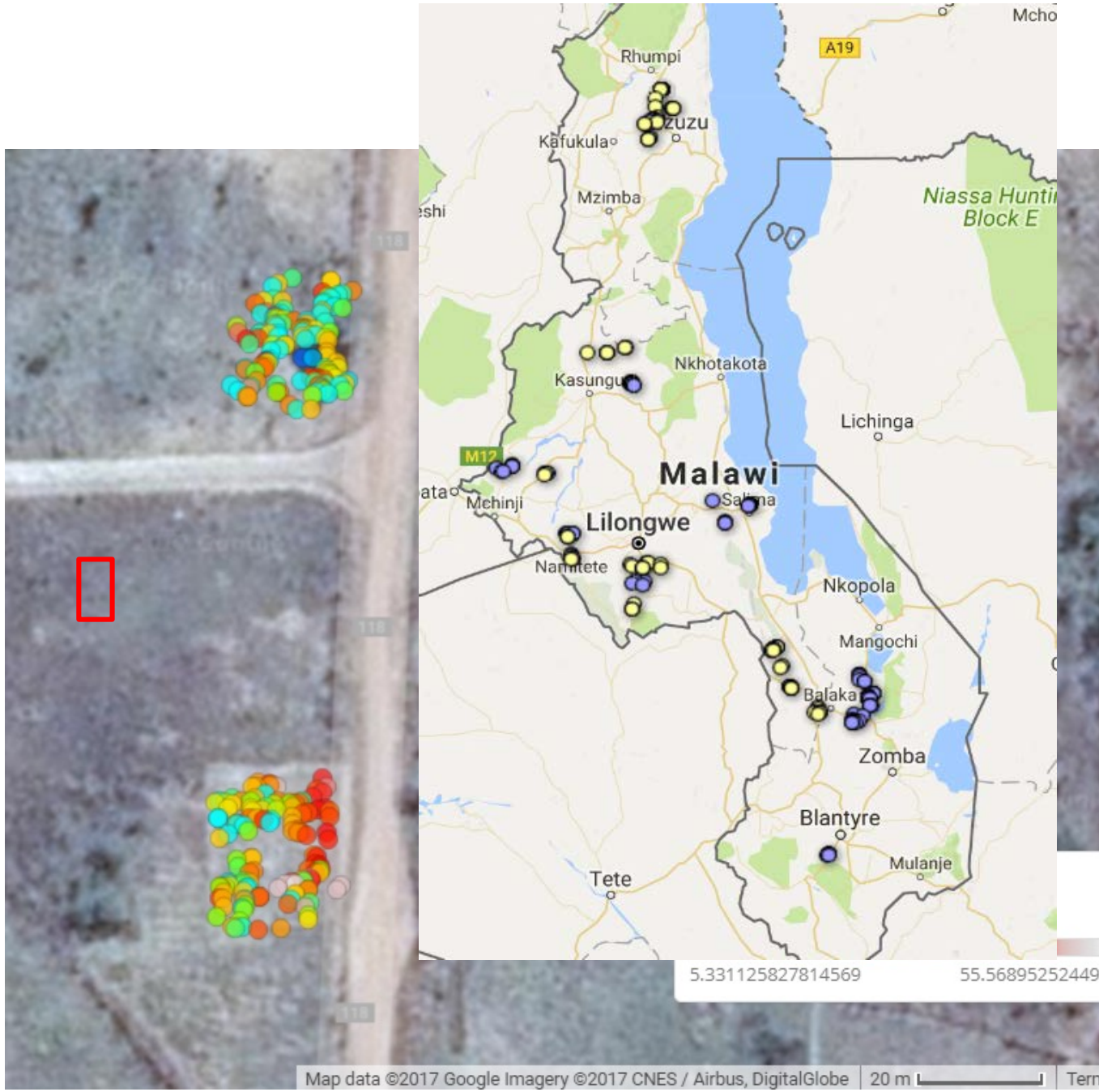
- Our community can make high quality measurements.
- The platform are measuring something important
- Clues to the underlying process: What does it mean that these photosynthesis parameters are so ‘predictive’ of yield?

- **Sets us up for possible direct practical applications for management and breeding.**

Dan TerAvest (Weds)

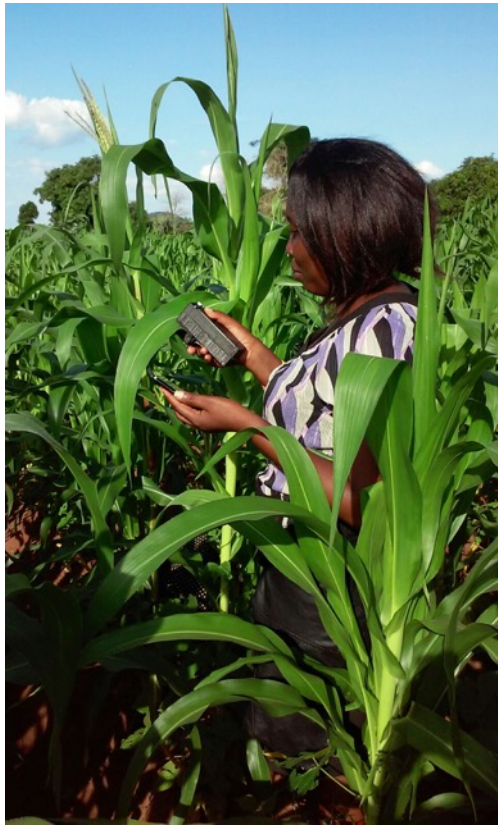
PhotosynQ as a management tool:

- Can PhotosynQ help visualize on-farm heterogeneity?
- Can PhotosynQ improve the recommendations made to farmers by allowing researchers, extension workers, etc. to conduct more appropriate on-farm trials?
- Can PhotosynQ be used to predict crop yields on smallholder farms? Either in real-time or in relation to a subset farms where yield data was collected?



Maize-legume cropping systems

- MultispeQ measurements were taken on 27 farms across three EPA's
- Determine the effect of legume-based crop rotations on smallholder farms
- Crops in rotation with maize included:
  - Groundnut
  - Groundnut + pigeonpea
  - Maize
  - Pigeonpea
  - Soybean
  - Soybean + pigeonpea



Why QTL mapping?

- “We need Rapid acceleration of the breeding cycle with modern approaches” Can we bring this technology to plant breeders in the world of small, highly diverse farms?

- QTL mapping is a challenging approach that requires all the principles of PhotosynQ to work together:
  - quality data collection
  - communications
  - data + meta date sharing/aggregation
  - analytics

- To make an “A management Device/App for Farmers,” we need high quality data. This approach will give us this type of data.

How PhotosynQ.org is Bringing Cutting-Edge Plant Breeding to Improve Agriculture in Africa

1

Kelvin Kamfwa, plant breeder at U. Zambia. Goal: breed better beans for the specific conditions in Zambia.

2

Online and mobile phone apps create projects that guide users to make the right measurements.

MultispeQ

3

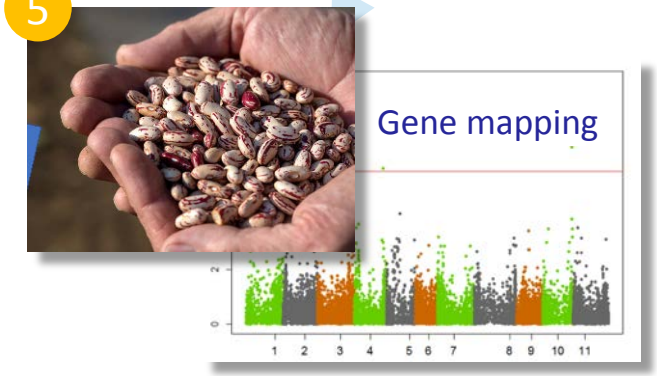
Sophisticated, **very low cost**, easy-to-use sensors send high quality data and metadata to PhotosynQ.

PHOTOSYNQ

6

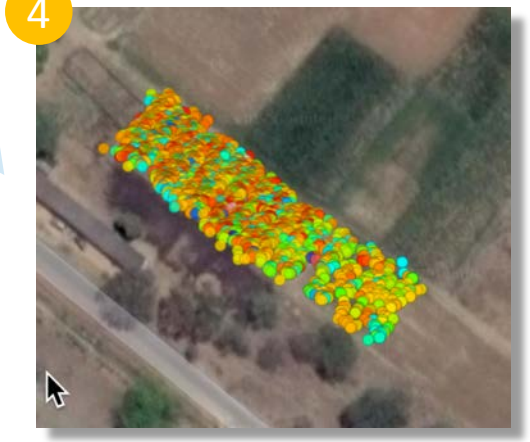
Meet local needs (like Kelvin's) and connect knowledge and expertise to solve problems worldwide through PhotosynQ community.

5



Identification of genes guides cutting edge plant breeding for hyper-local traits.

4



Free, open, on-line and community analytics and machine learning, reveal trends and make predictions.

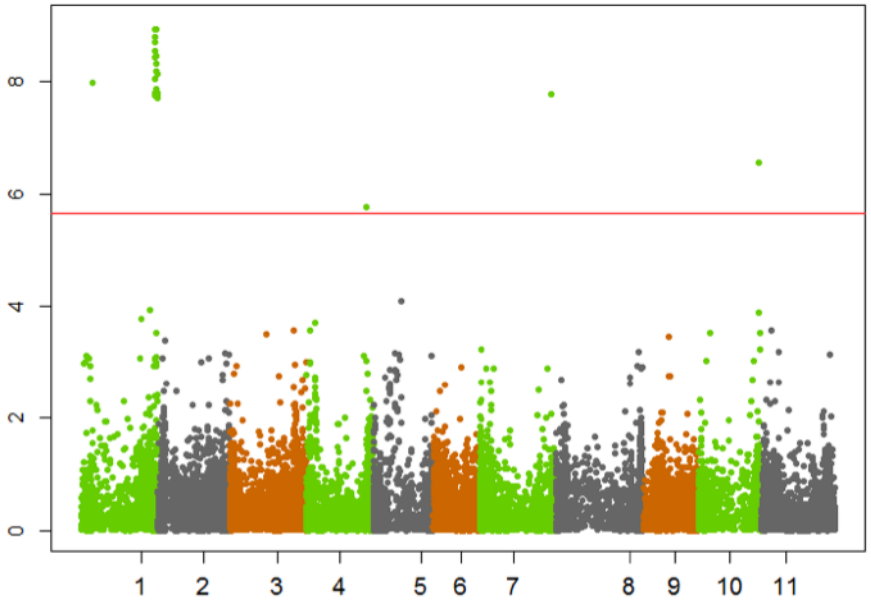
FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

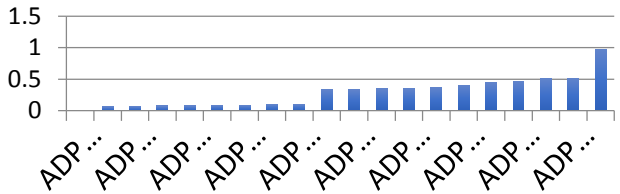
PARTNERING FOR INNOVATION

Legume Innovation Lab

GWAS for Photosynthetic Efficiency Trait

Realized steady-state efficiency Φ II





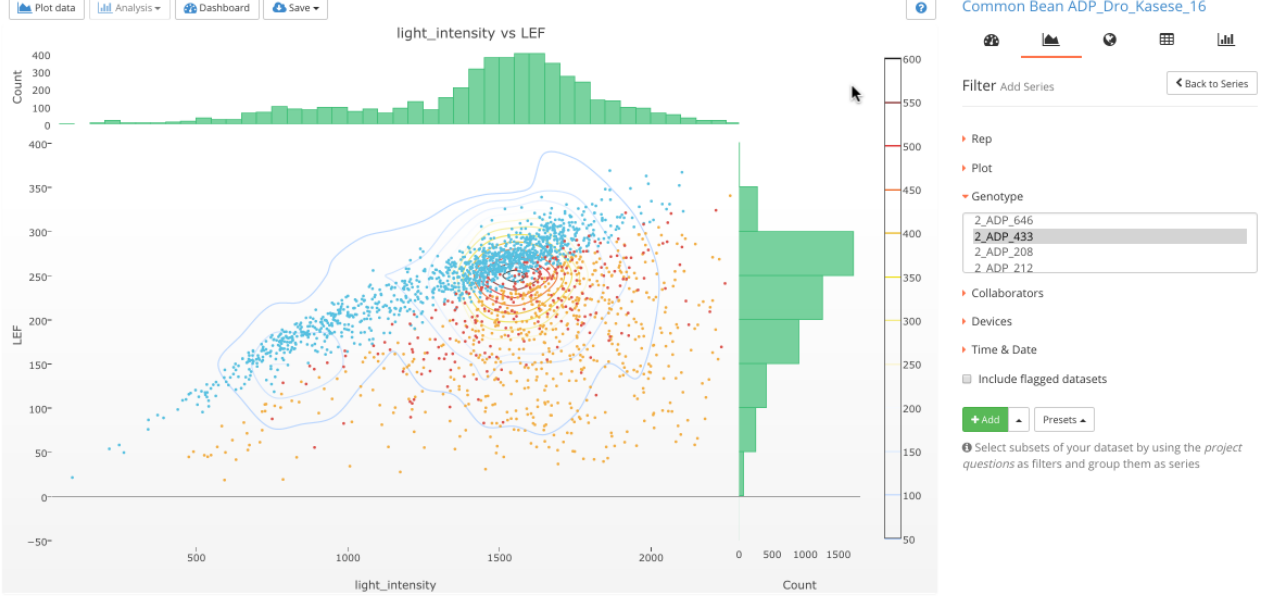
- ADP633=TARS-HT2 (Heat tolerant, ARS, PR)
- ADP006= W616465 (drought tolerant)
- ADP605=1132-V96 (heat tolerant)

Consistent with previous drought studies & pedigree info

Kamfwa et al., unpublished

Isaac Dramadri

Drought and heat stress in common beans using the ADP



Using PhotosynQ to screening for drought stress at Kasese drought nursery

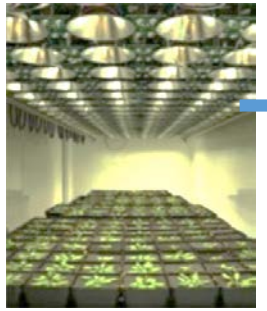
Dramadri Isaac O. (PhD Candidate, MSU)
Namusisi Margret (Intern)
Mugisha Paul (intern)
Adraca Kennedy (technician)
Keffa Sunday (technician)

Using PhotosynQ to screen ADP for drought stress at seedling stage at Namulonge

Dramadri Isaac O. (PhD Candidate, MSU)
Namusisi Margret (Intern)
Mugisha Paul (intern)

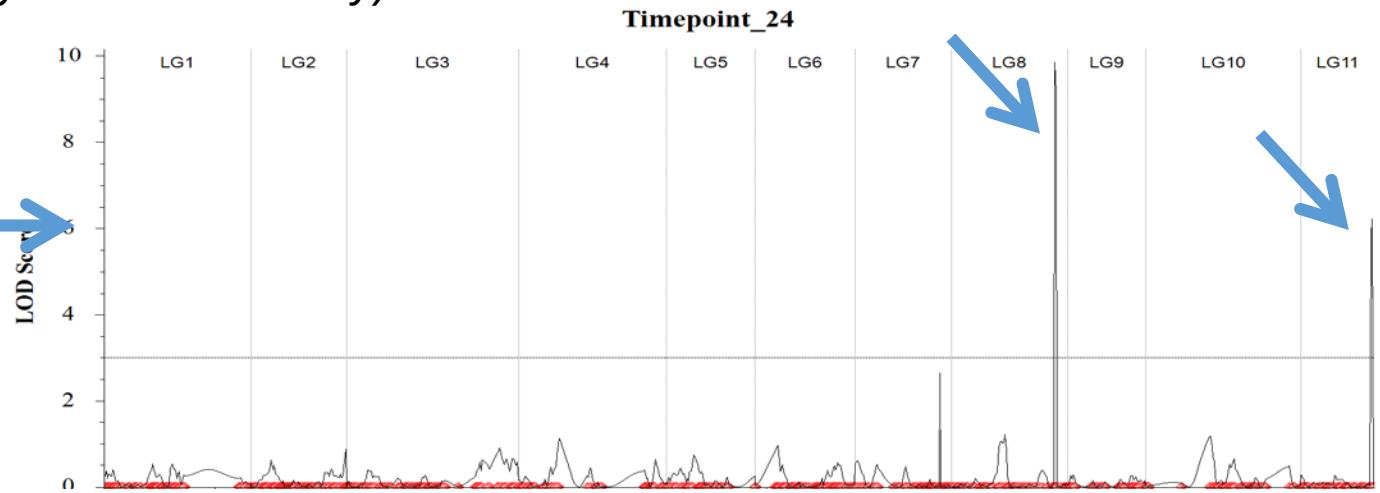
Donghee Hoh (MSU): QTLs in cowpea for cool night effects using PhotosynQ and DEPI

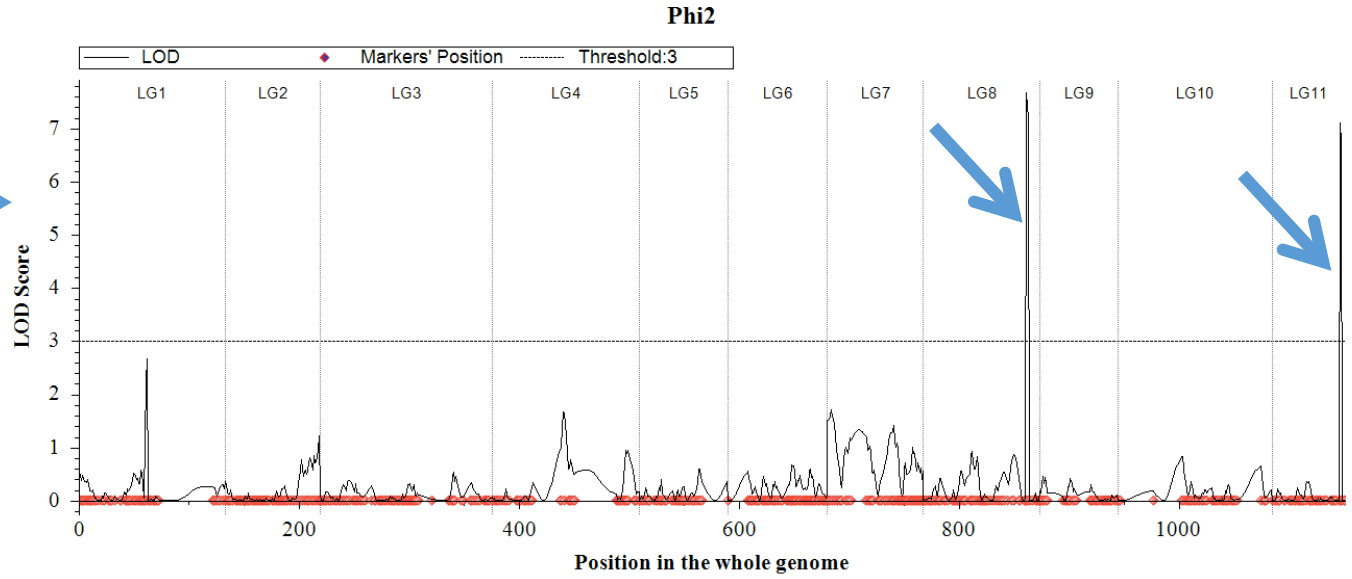
ΦII (photosynthetic efficiency)



DEPI

photosynQ

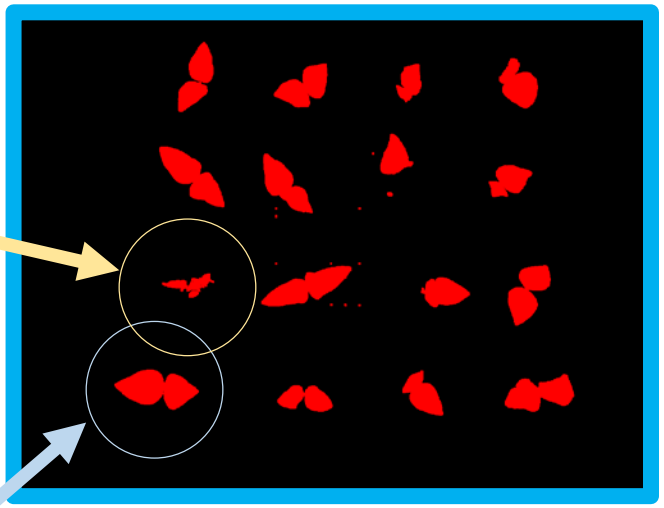




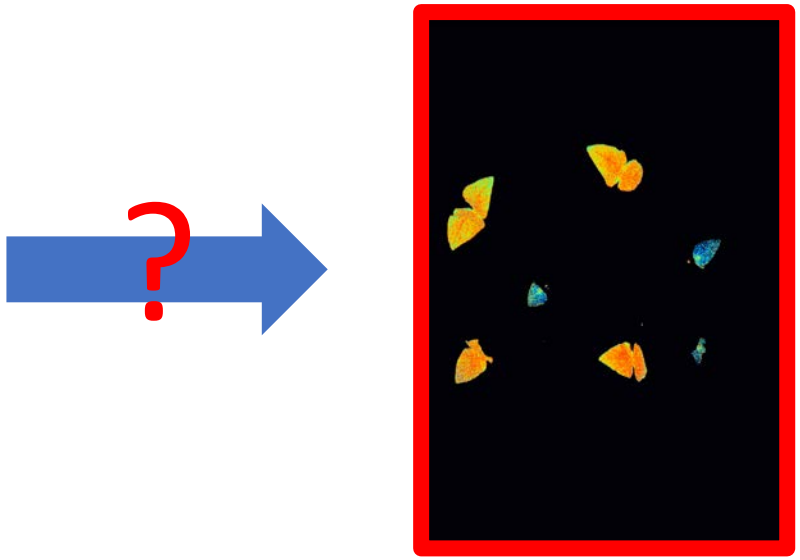
We are able to use multispeq for mapping QTLs in the field!
Also, we can map QTLs using DEPI simulated outdoor environment

1: Do leaf movement phenotypes protect against CNS damage?

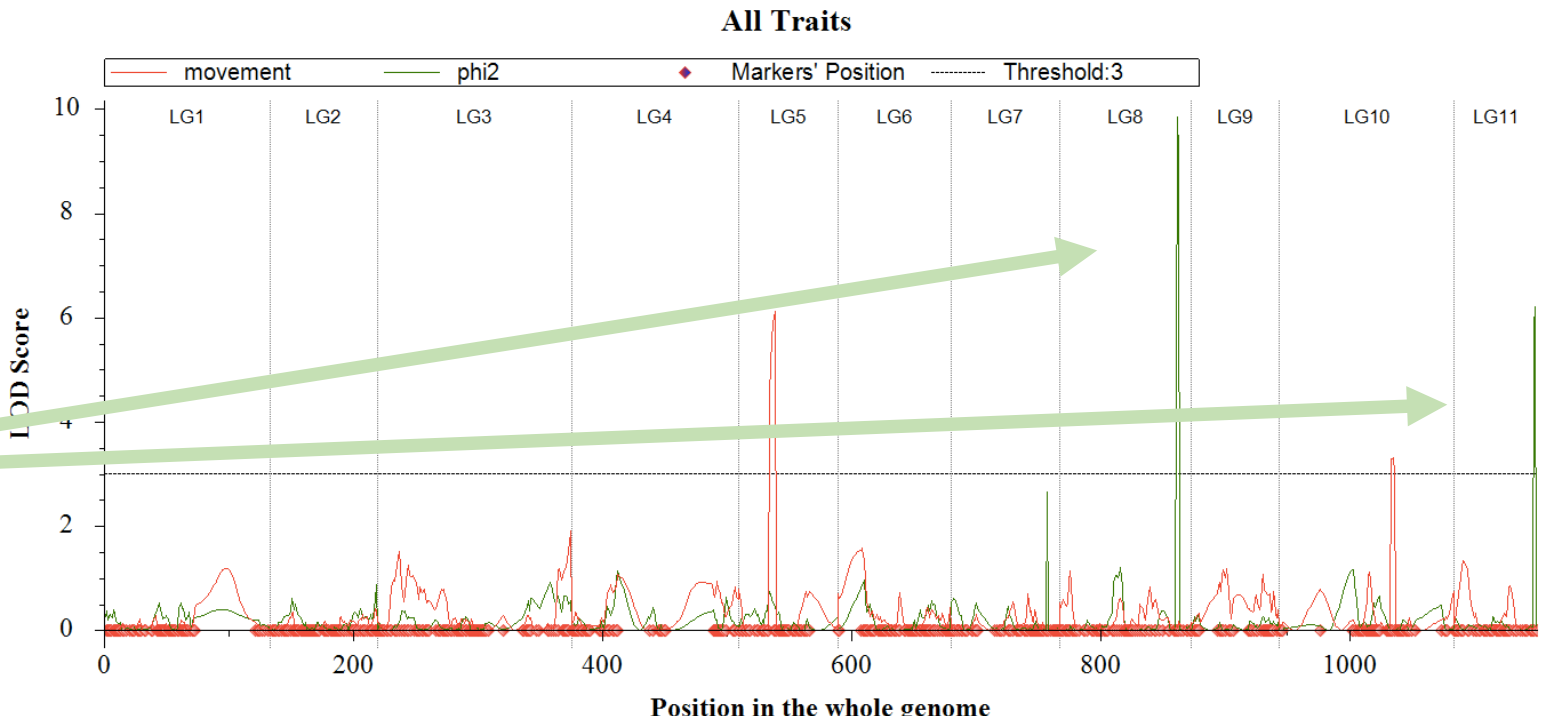
tolerant: large movements



Sensitive: small movements

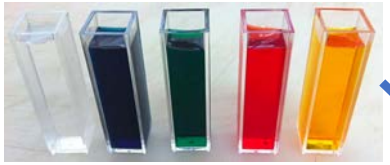


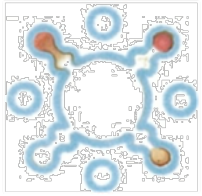
Enrichment of certain stress signaling genes

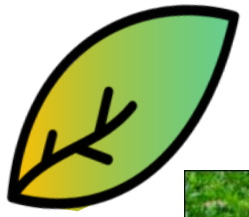


Isaac Osei-Bonsu (MSU’s Legume Scholar)

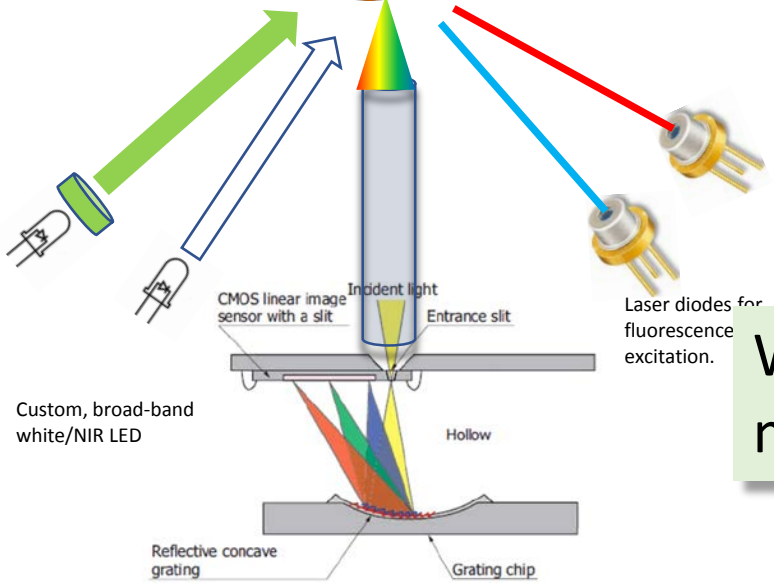
What’s next?







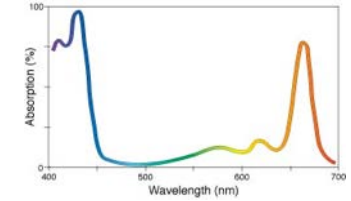
Custom, broad-band white, NIR or monochromatic LED



ıvelength-specific
) to measure
sorbance or
orescence changes

Custom, broad-band white/NIR LED

Laser diodes for fluorescence excitation.



What do you want to measure??

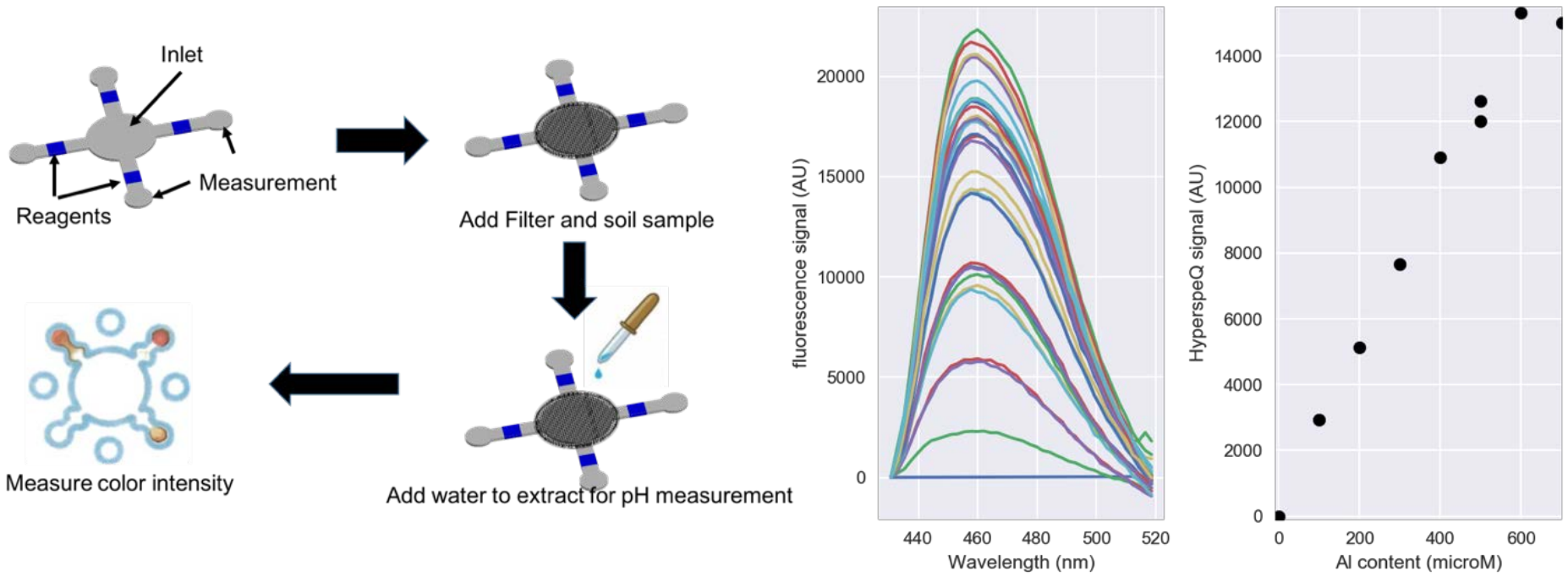
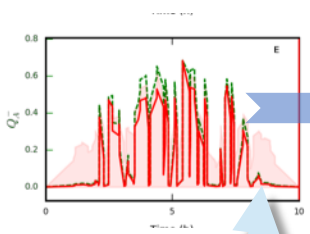


Figure 3. Detection of Al(III) in standard samples on mPADS using HyperspeQ prototype. The left panel shows the concept of the devices for measuring various soil parameters. The middle panel shows the spectral output of HyperspeQ from a series of samples of known concentration using the test version mPAD Al(III) assay. The right panel shows the dependence of signal size against the known concentration of Al(III).

Integrate modeling for climate resilience, yield potential.



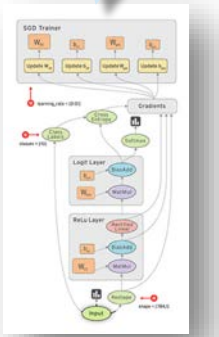
Modeling

Link to other open databases.

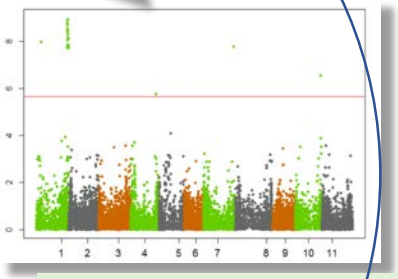
PHOTOSYNQ

Integrate QTL mapping software directly into the platform to greatly accelerate mapping trials.

What are the best parameters to measure, when and on what material?



Deep learning

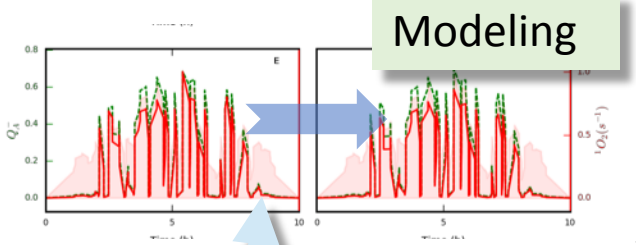


QTL mapping

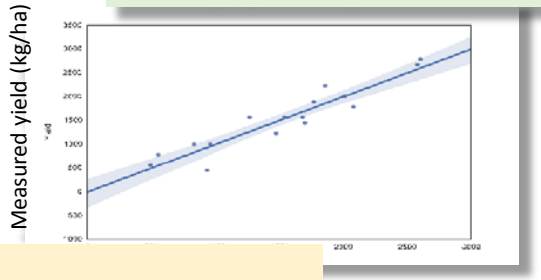
Can we test hypothetical mechanistic links between processes by comparing QTLs?

python

Susan Chipandwe

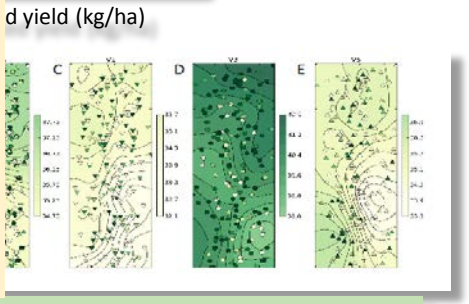


Modeling

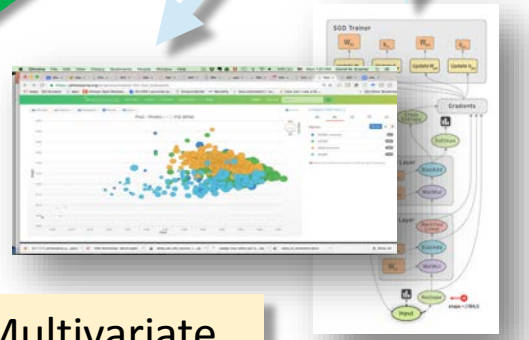


Early yield prediction

Can the platform empower woman researchers?

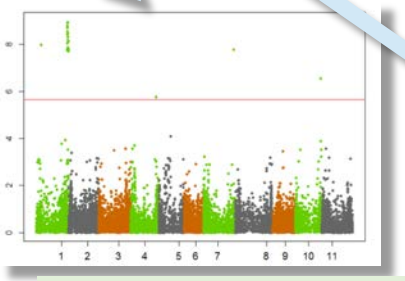


Early disease warning

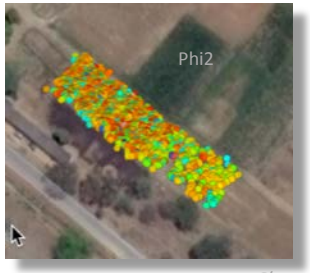


Multivariate analyses

Deep learning



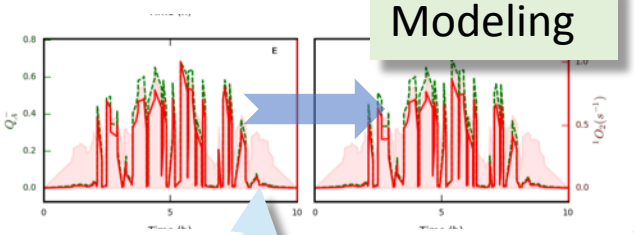
QTL mapping



Geospatial dependences

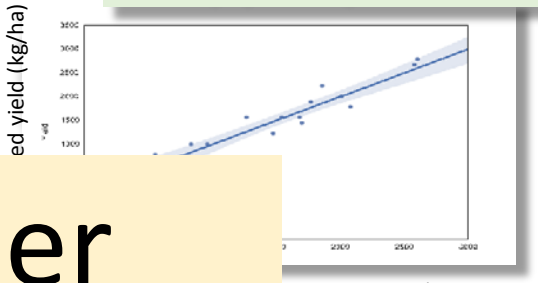
python

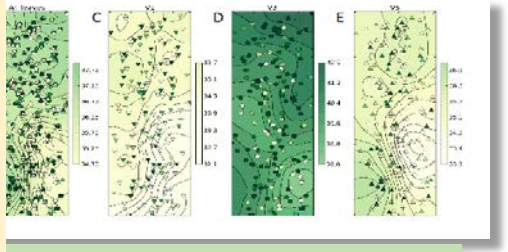
Susan Chipandwe



Modeling

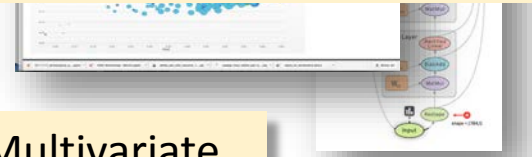
Early yield prediction





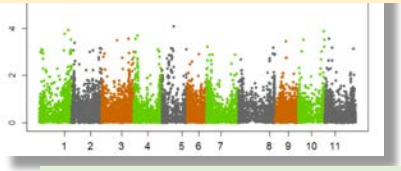
Early disease warning

What would a farmer do with knowledge gained from these measurements?

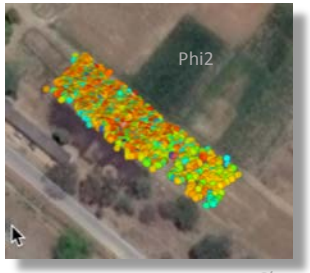


Multivariate analyses

Deep learning

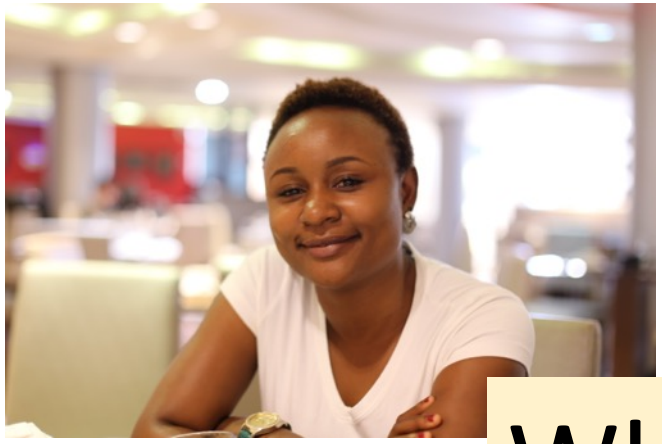


QTL mapping

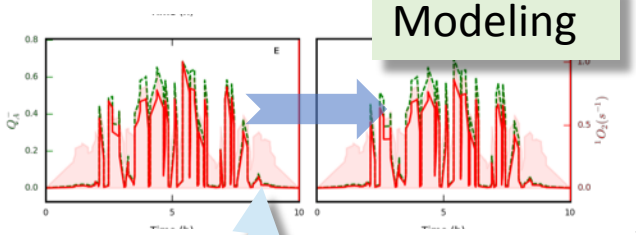


Geospatial dependences

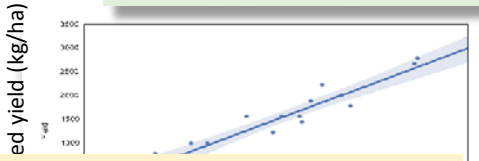
python



Susan Chipandwe

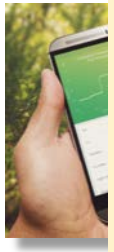


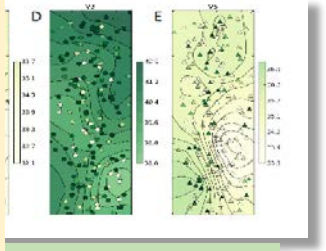
Modeling



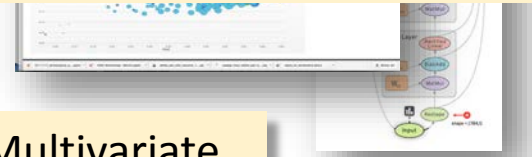
Early yield prediction

What do we need t do to use PhotosynQ daa to impact the breeding cycle for crop improvement?



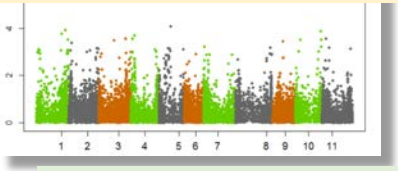


ase warning

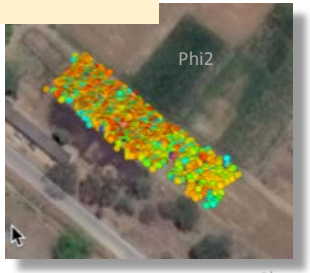


Multivariate analyses

Deep learning



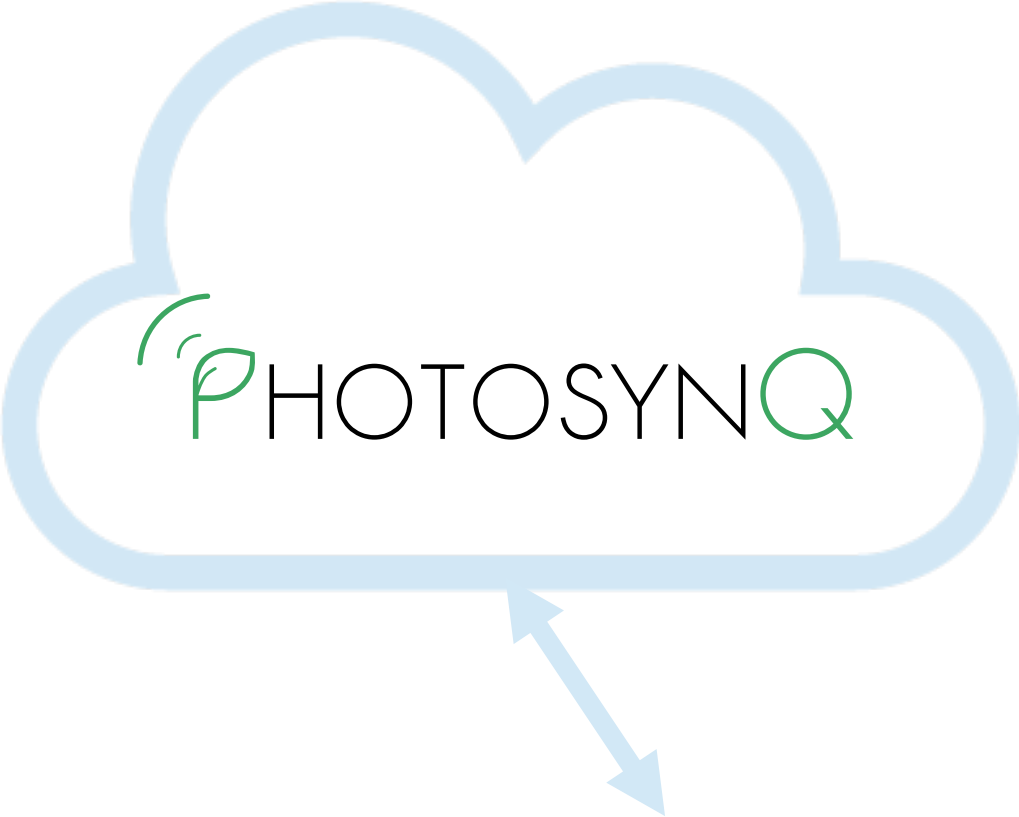
QTL mapping



Geospatial dependences

python

Use it, modify it, clone it.



What do you want to measure?

We need you to lead this!

We cannot do this all on our own…

Dr. Robert Bertram: *Innovation must be locally developed and led!*

Engineering, science, distribution, support networks, training…

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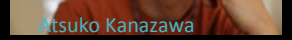
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