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Innovative hyperspectral remote sensing methods for pre-visual stress detection in the context of biosecurity

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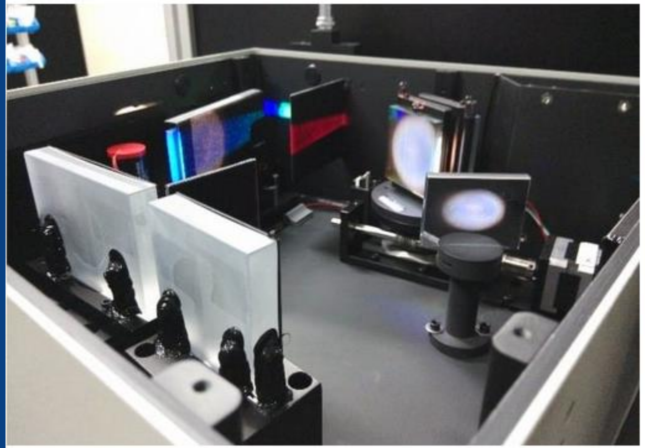

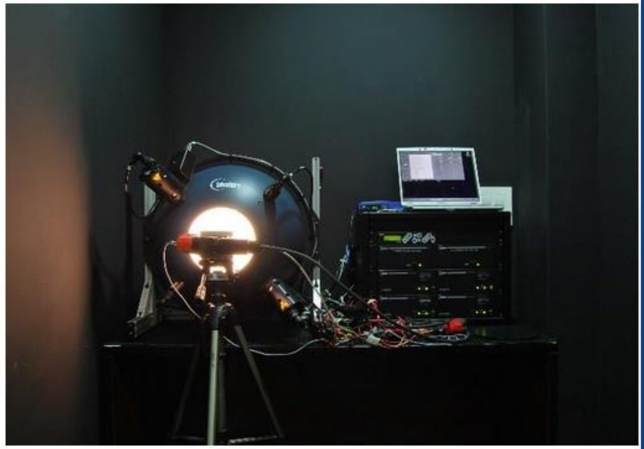

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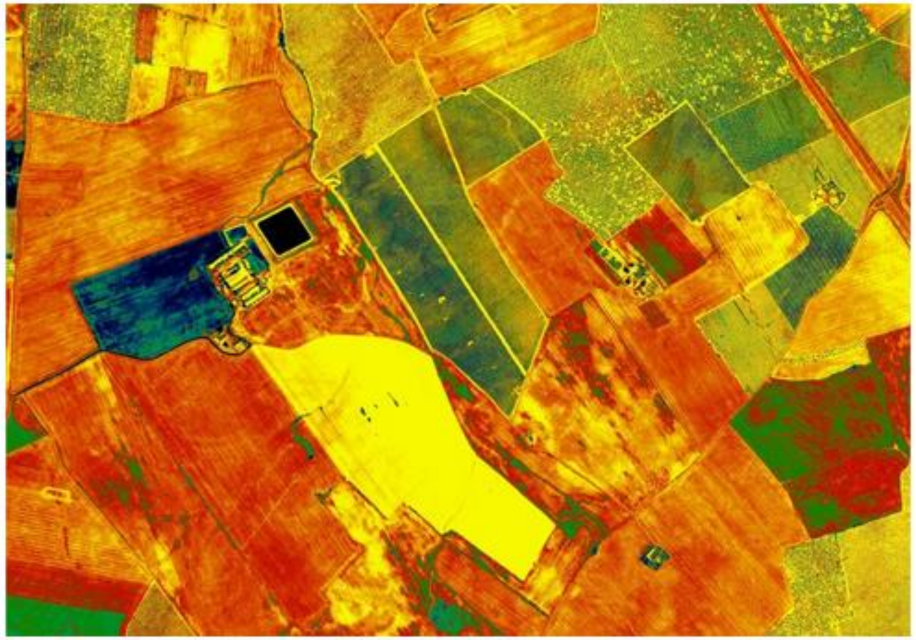

The University of Melbourne airborne imaging spectroscopy facility

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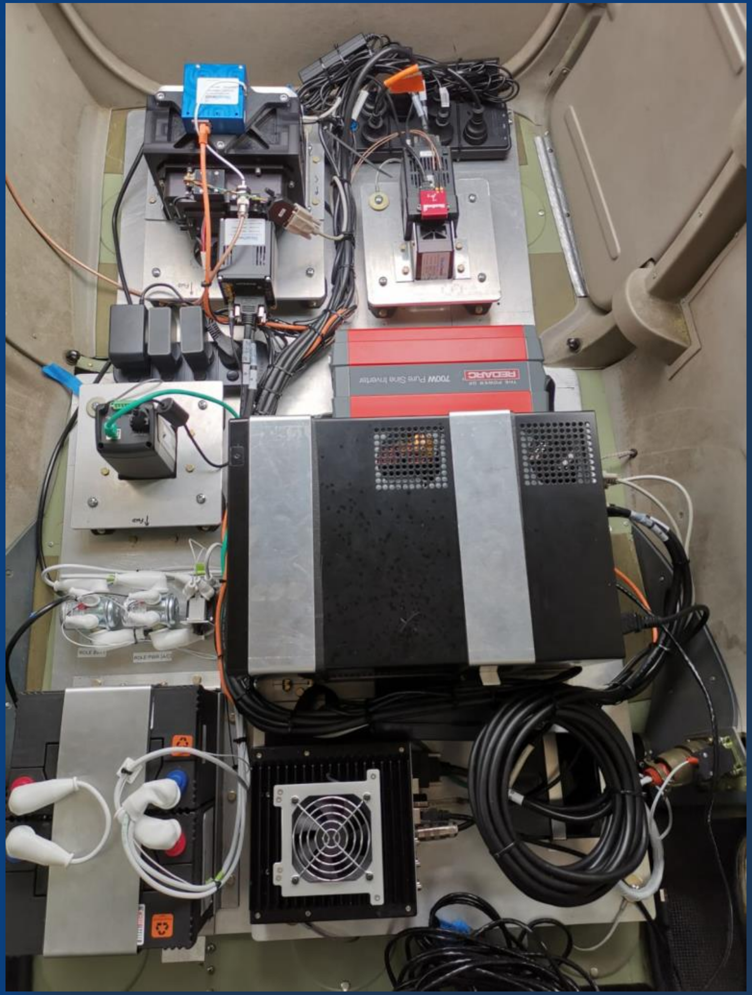

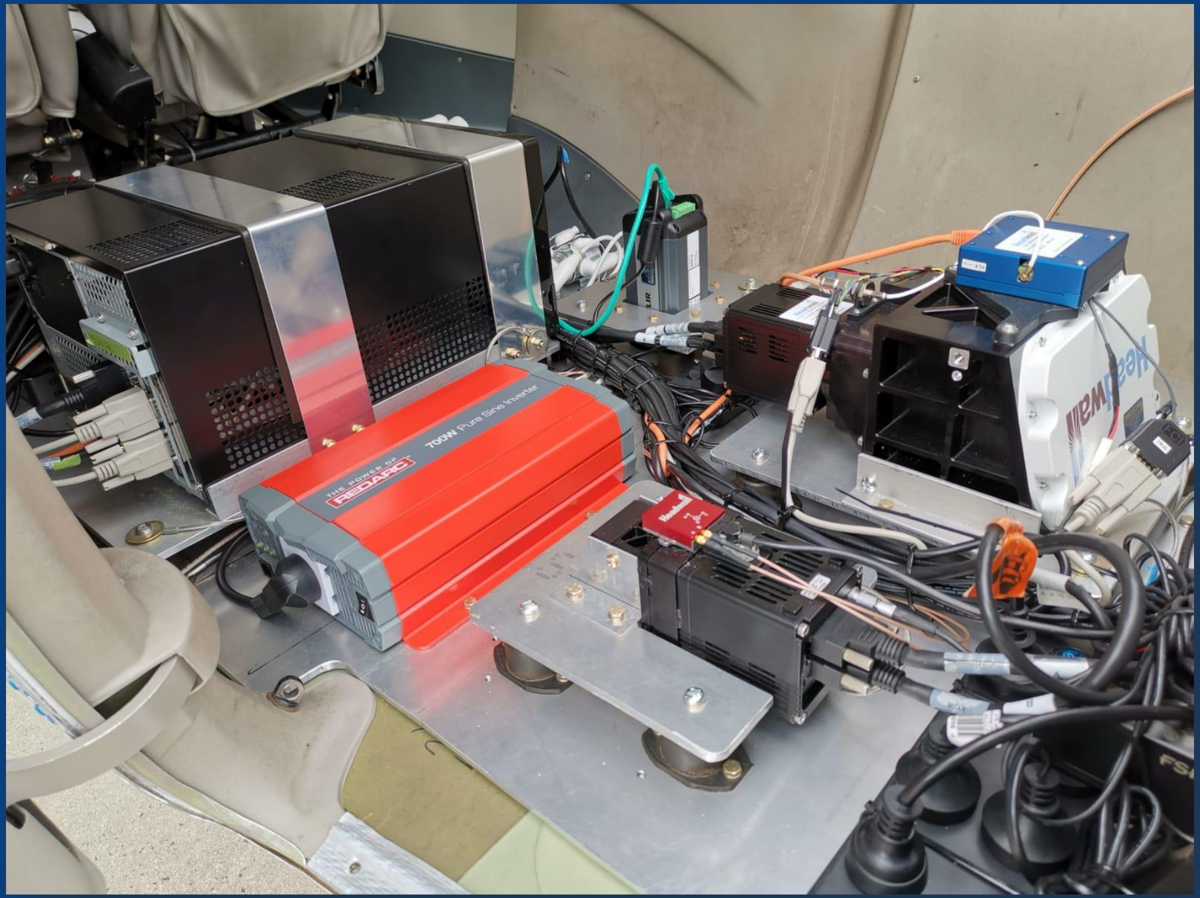

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JRCs
Italy
Germany
Belgium
Holland
Luxembourg
Spain

Agencies
Each MS

European Commission – Joint Research Centre (JRC)

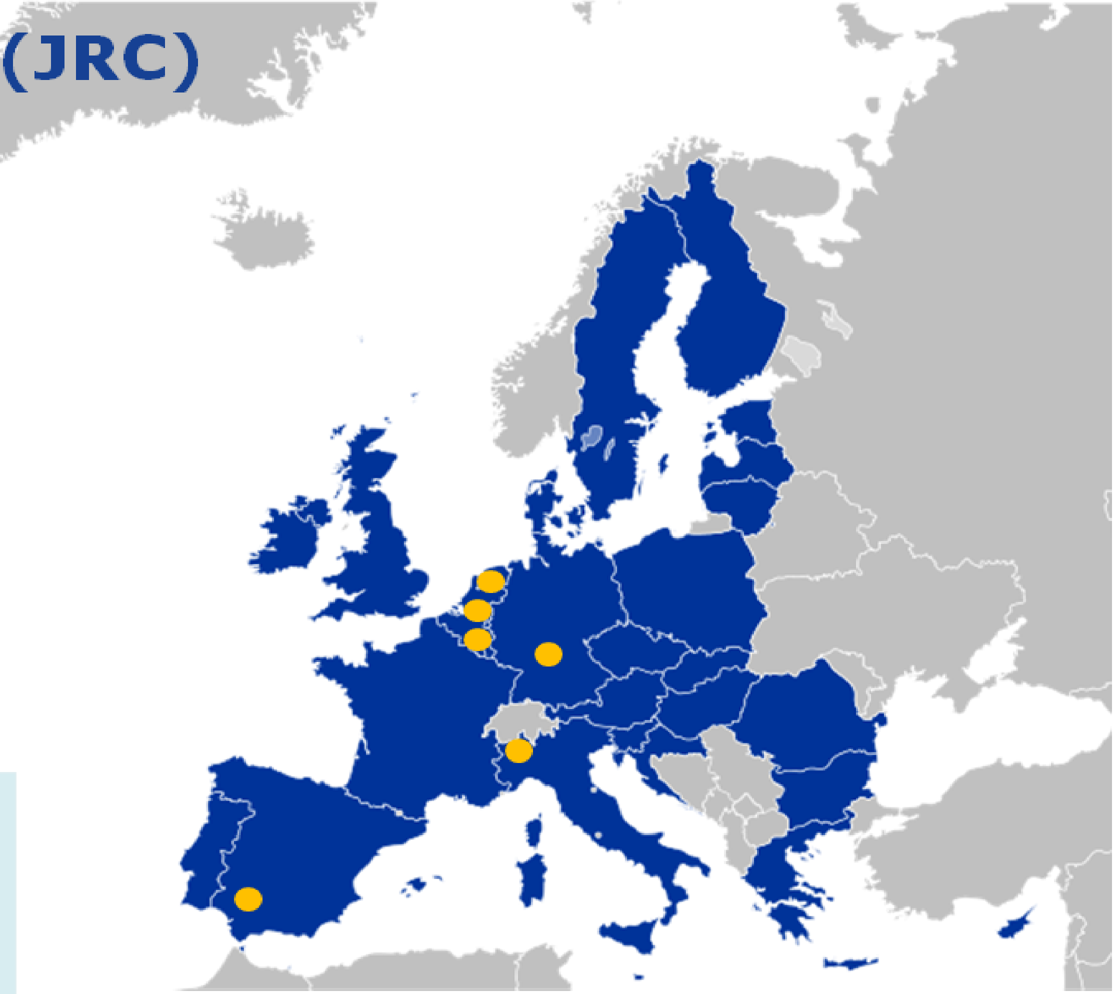
European Commission

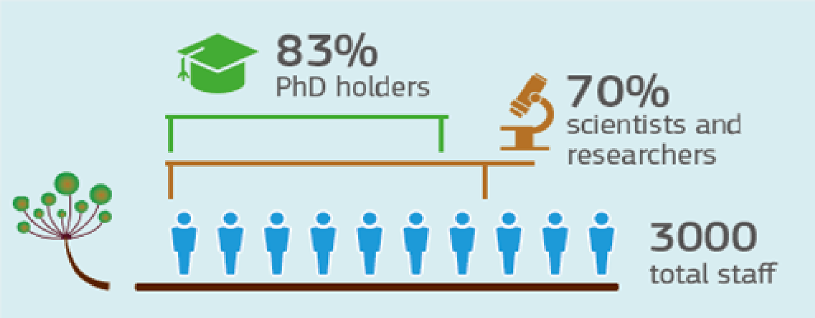
The in-house scientific service of the European Commission.

Six operational research directorates in 5 sites

Focus on the policy priorities of the EC; partner with policy DGs

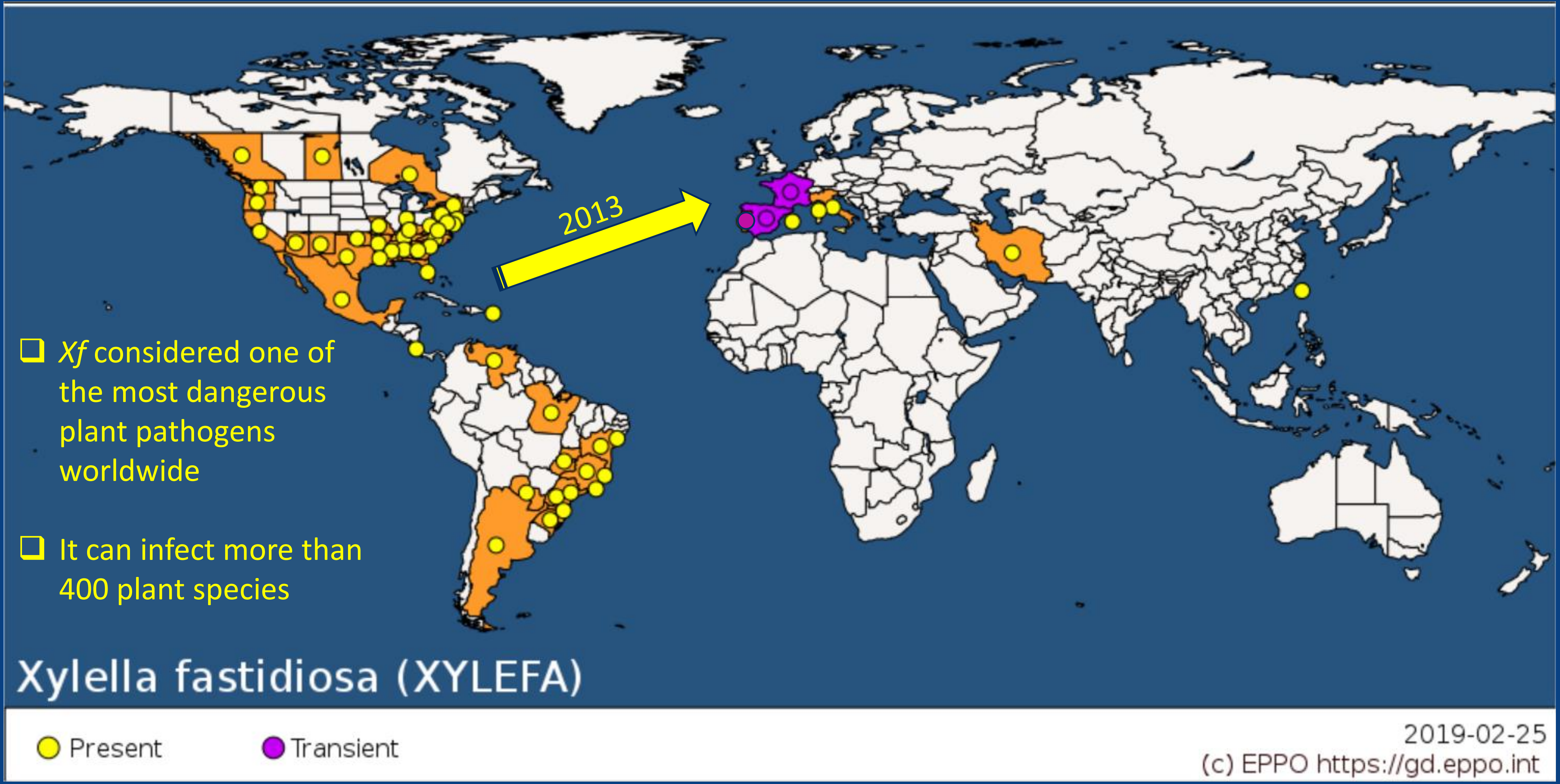
Independent of private, commercial or national interests





Joint Research Centre

Xylella fastidiosa



- *Xf* considered one of the most dangerous plant pathogens worldwide
- It can infect more than 400 plant species

Gallipoli, Ottobre 2013

Gallipoli, 9 Luglio 2015

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Can Apulia’s olive trees be saved?

Science | Jul. 21, 2016

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XF ACTORS

→ 29 partners from 14 countries, including 4 non-EU (USA, Brazil, Costa Rica and Taiwan)

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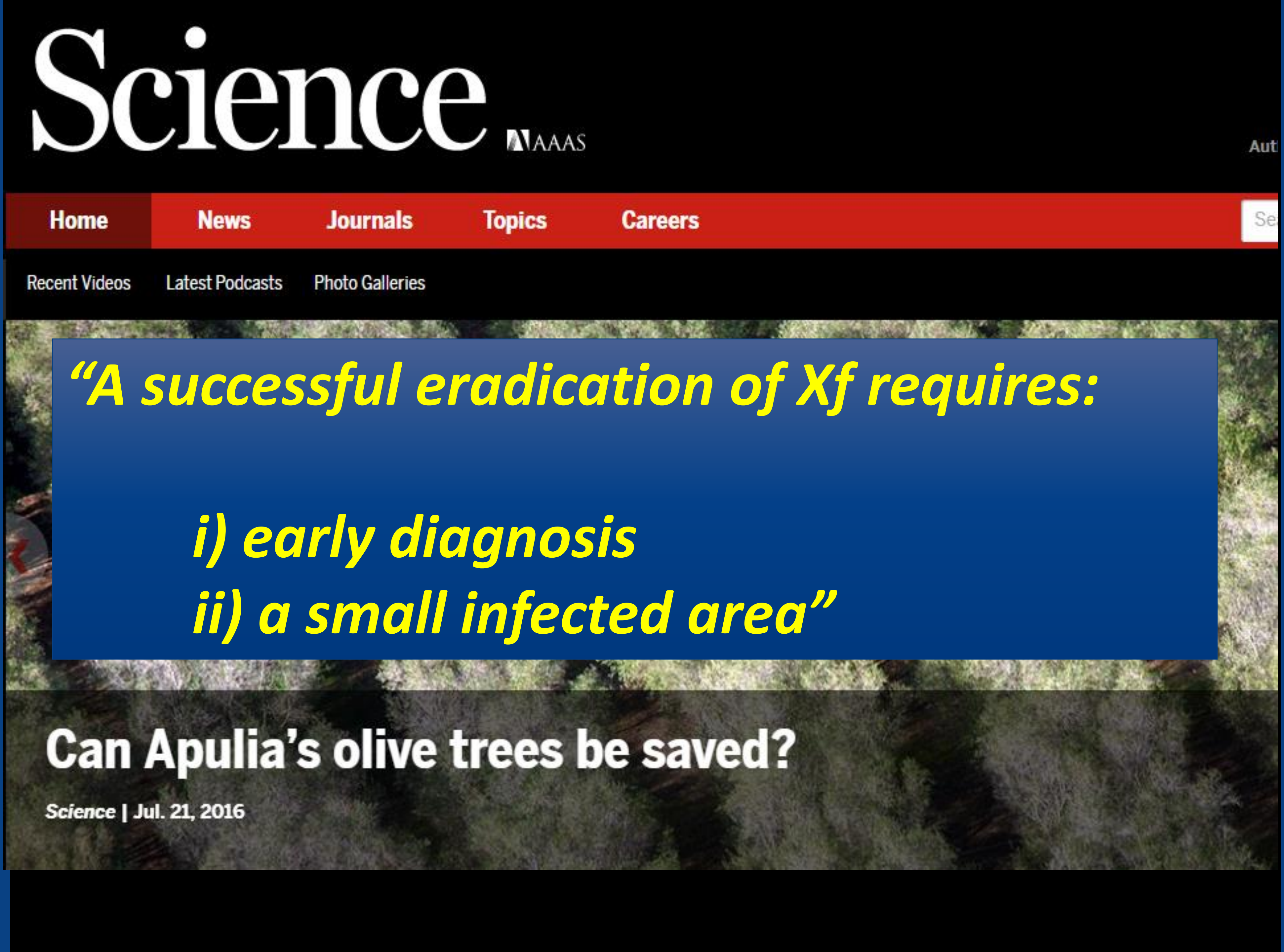

"A successful eradication of Xf requires:

i) early diagnosis
ii) a small infected area"

"The development of fast methods for early detection of the disease across large areas is critical"

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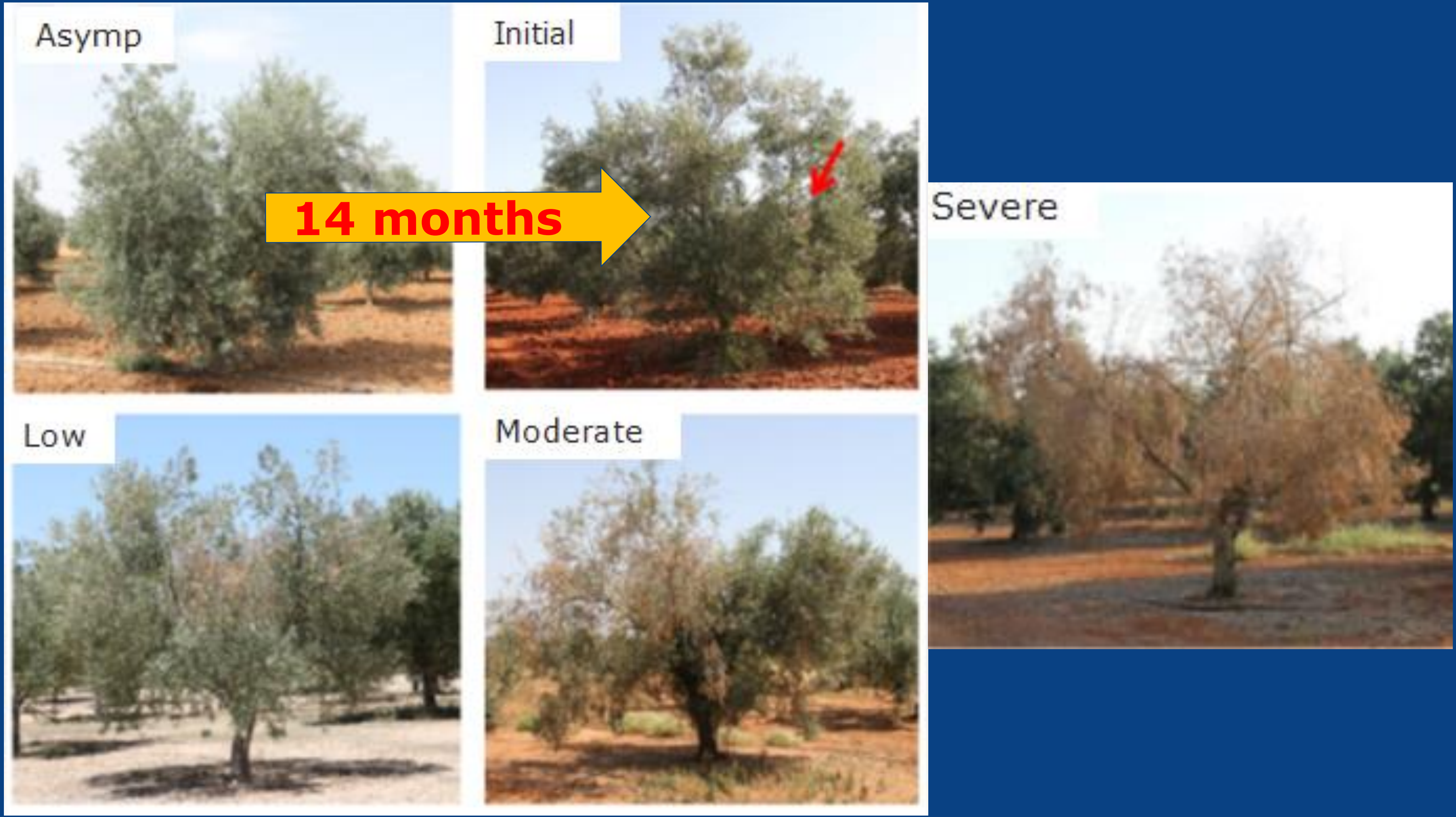
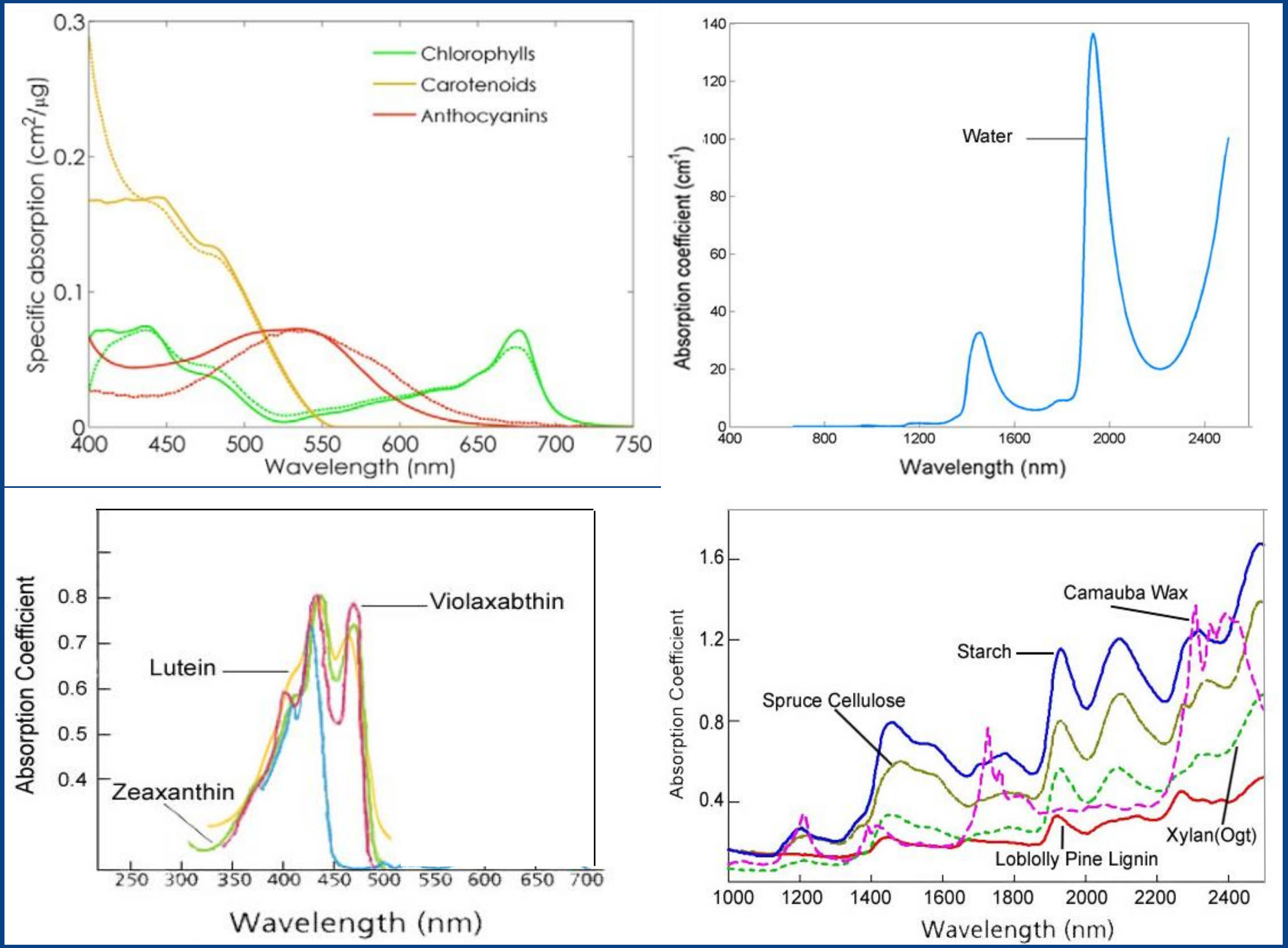
Visual and *pre-visual* symptoms detection



Biochemistry quantification from hyperspectral



PROSPECT
(Jacquemoud & Baret, 1990)

Separation of total chlorophylls from total carotenoids

PROSPECT-5
(Feret *et al.*, 2008)

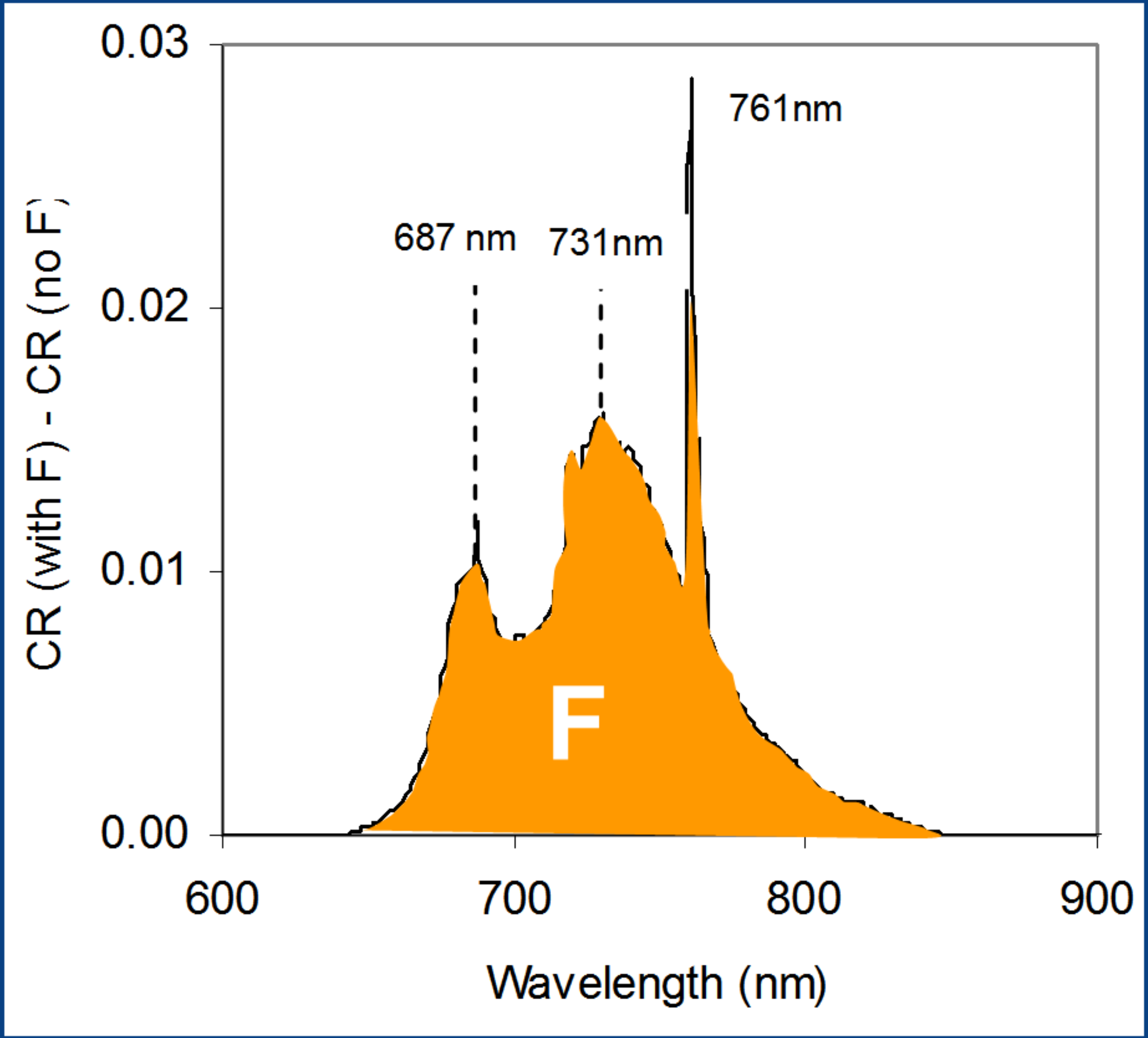
Anthocyanins, chlorophylls and carotenoids

PROSPECT-D
(Feret *et al.*, 2017)

Xanthophyll dynamics Fluspect-CX
(Vilfan *et al.*, 2018)

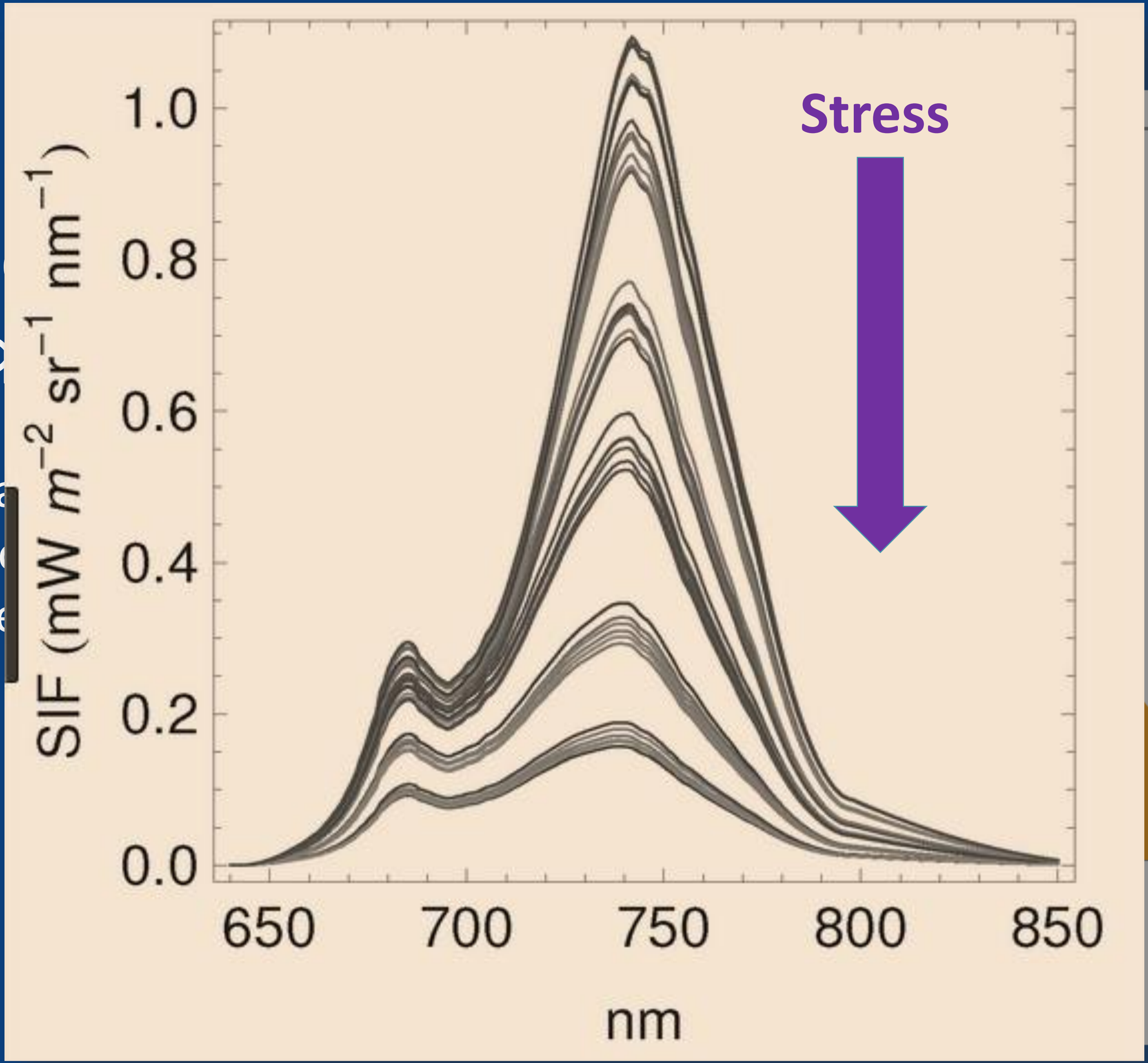
Solar-induced Chlorophyll Fluorescence quantification

→ ~2% of the total incoming radiation
→ Linked to photosynthesis
→ High spectral resolution required
→ Early indicator of stress

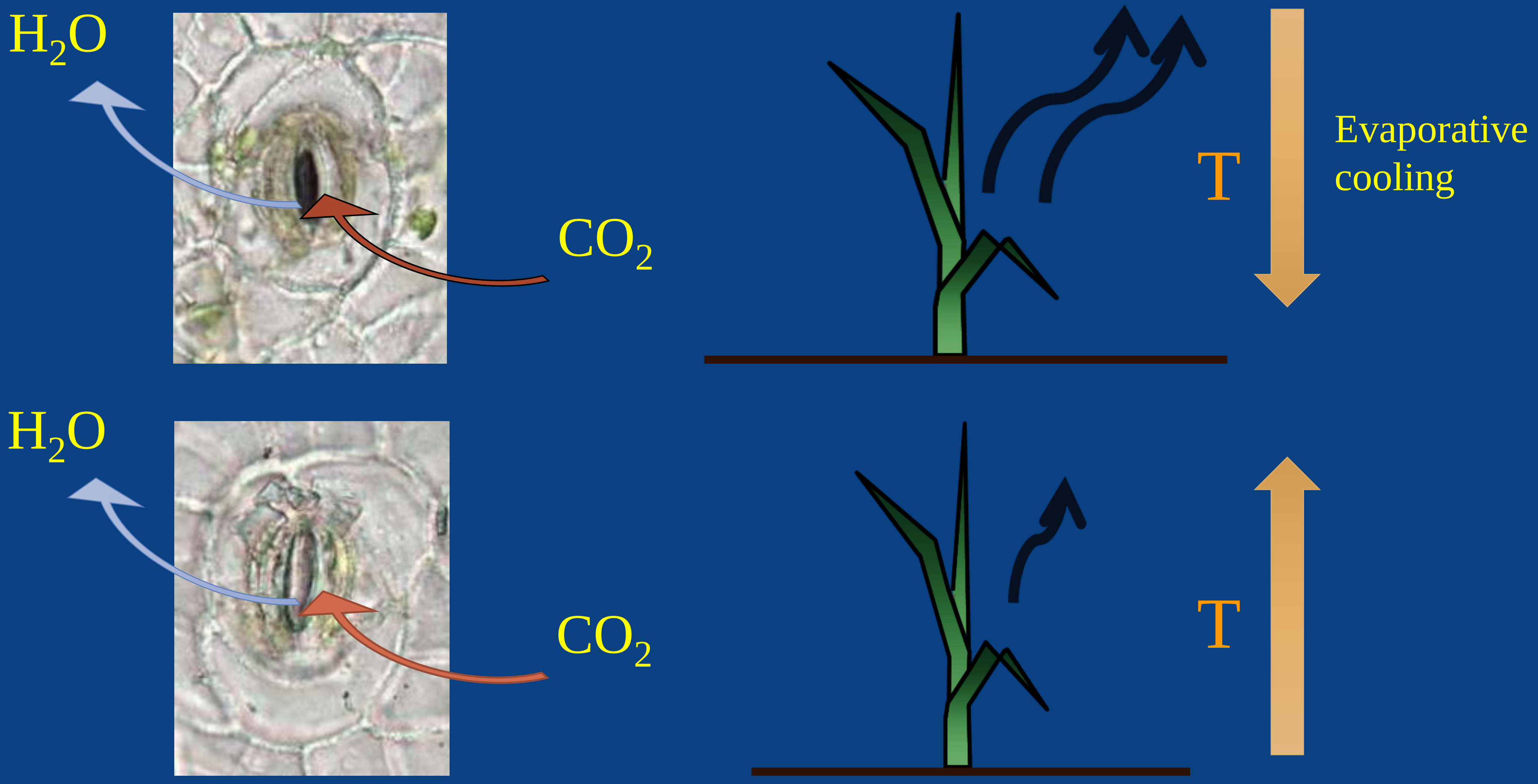


Solar-induced
Fluorescence o

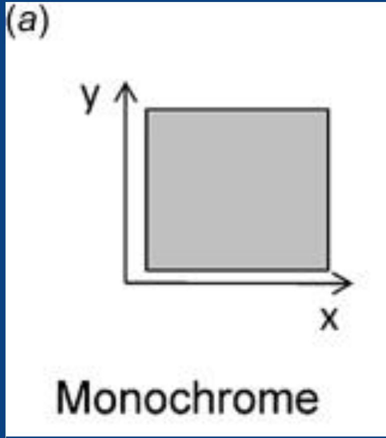
- → ~2% of the tota
- → Linked to phot
- → High spectral re
- → Early indicator



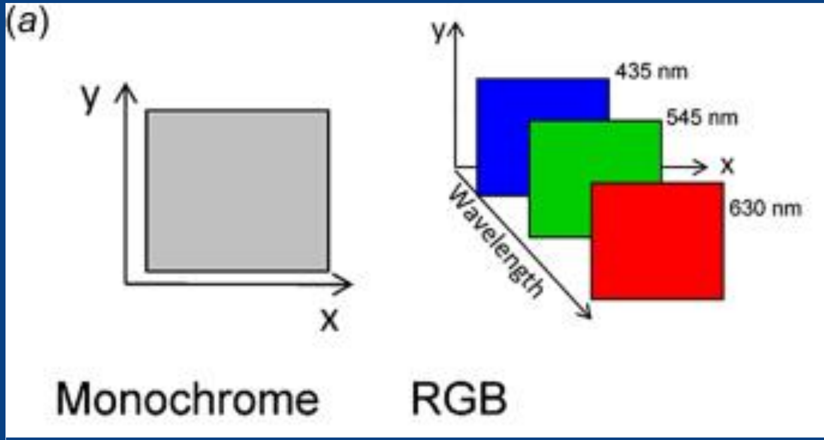
Stomata closure - Temperature



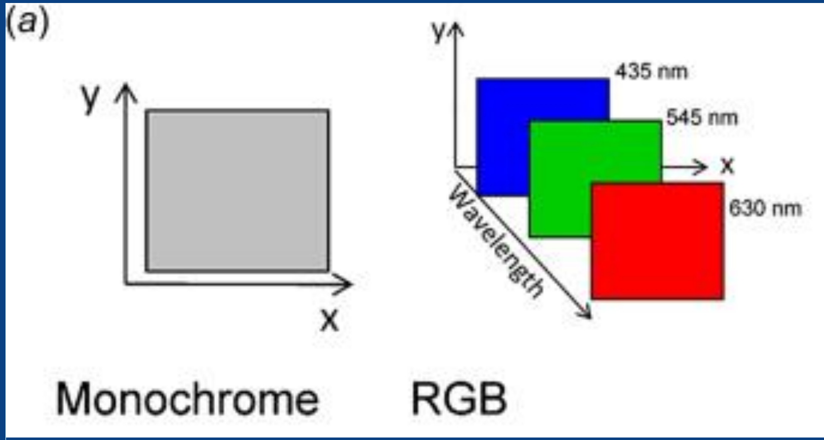
Imaging Spectroscopy

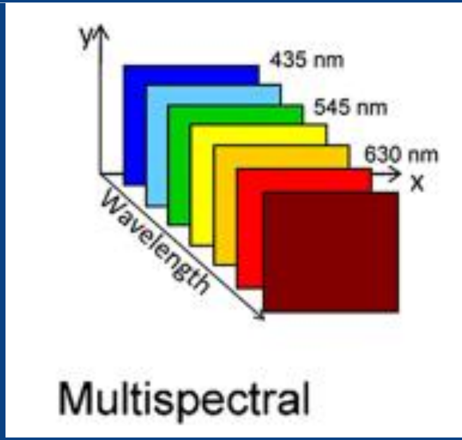


Imaging Spectroscopy

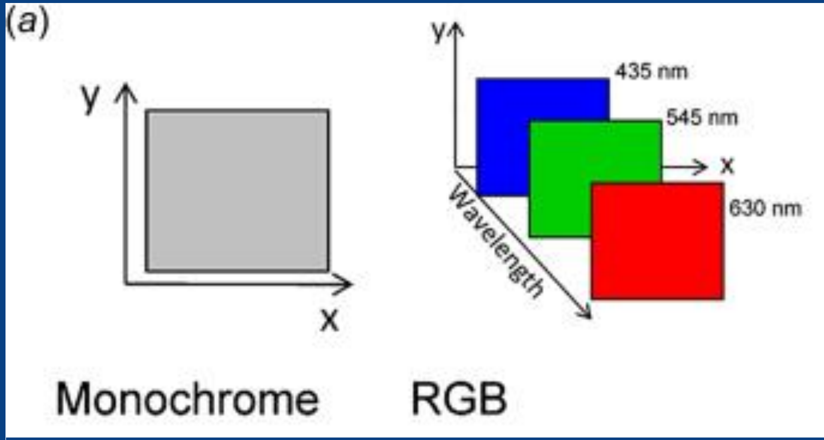


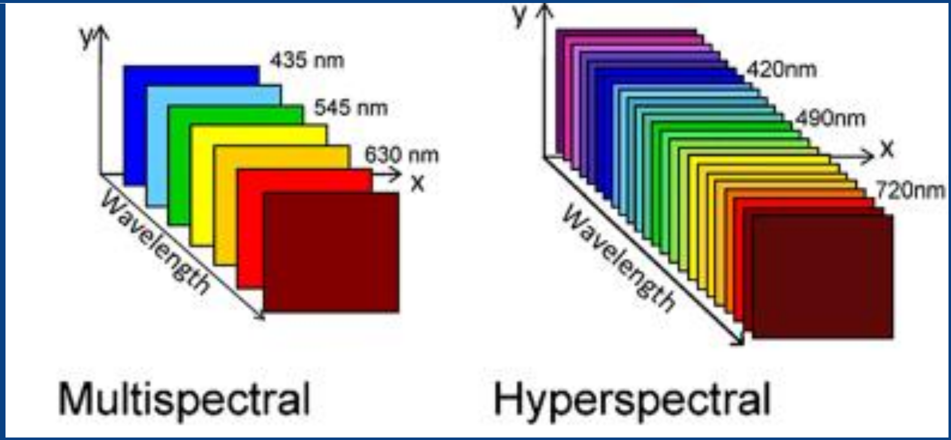
Imaging Spectroscopy





Imaging Spectroscopy





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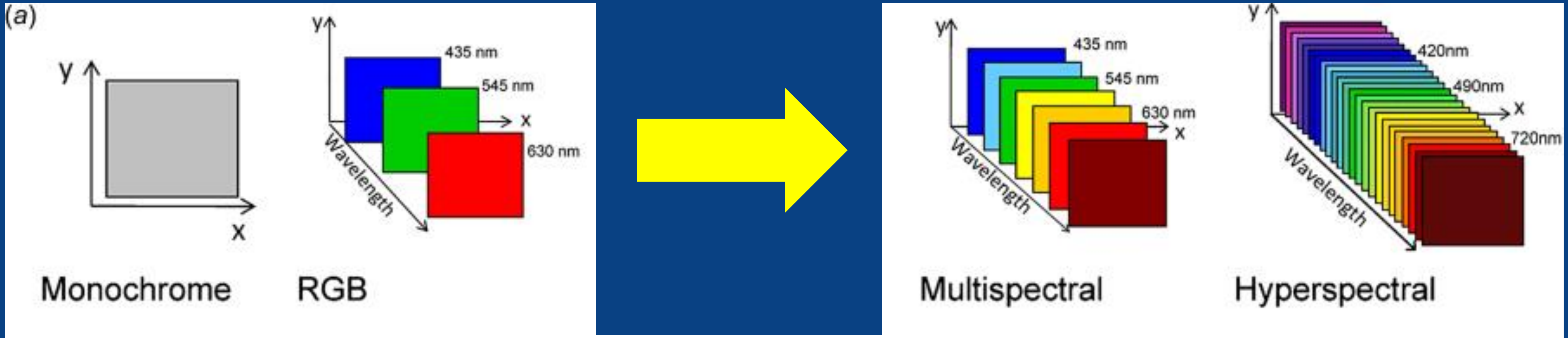
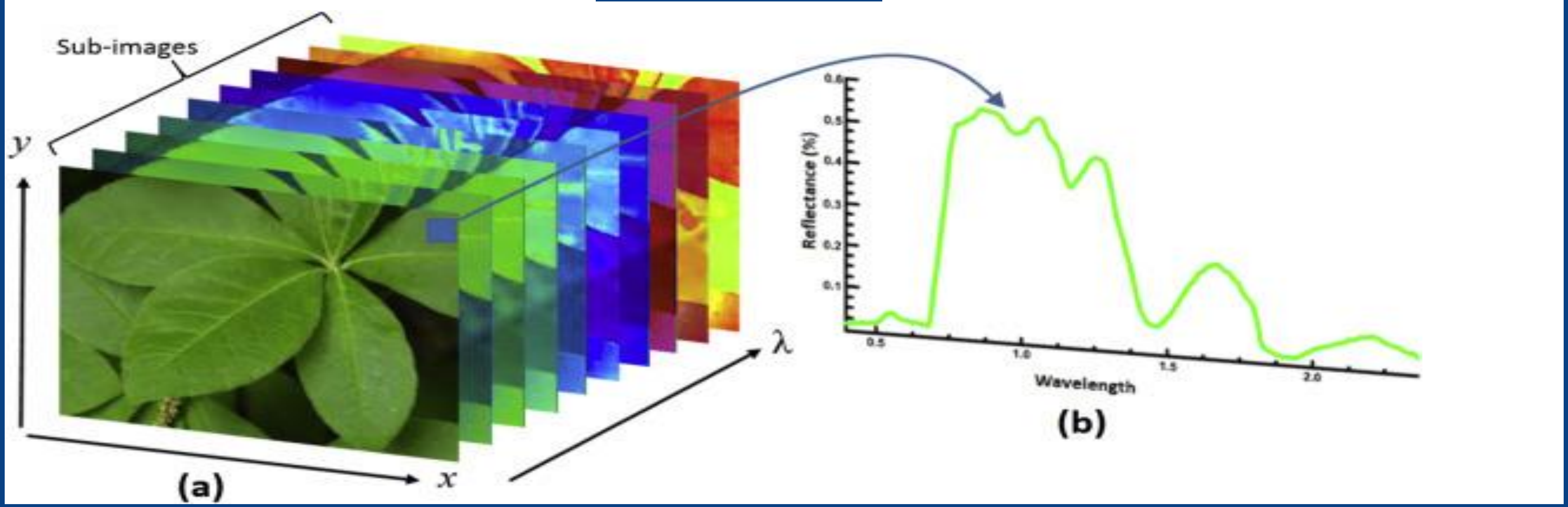
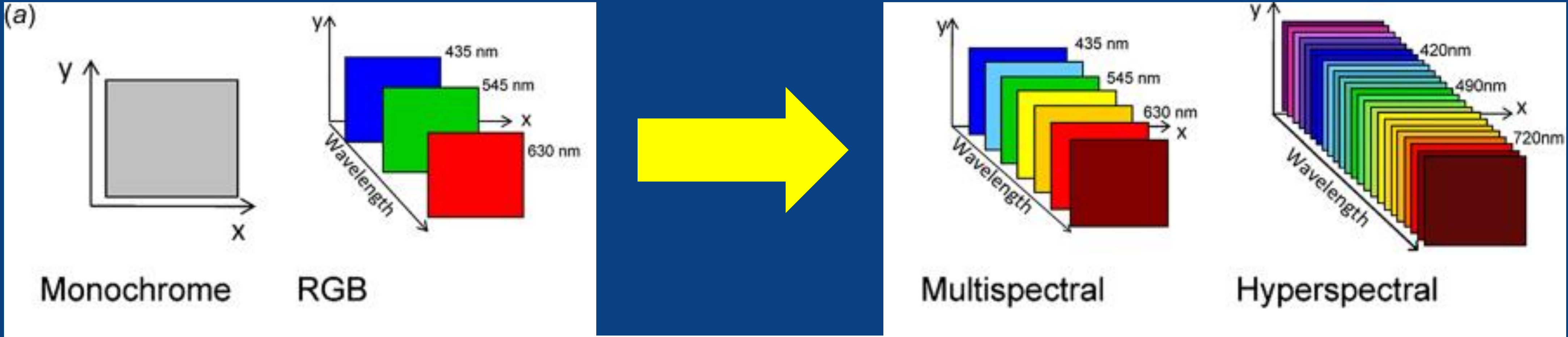
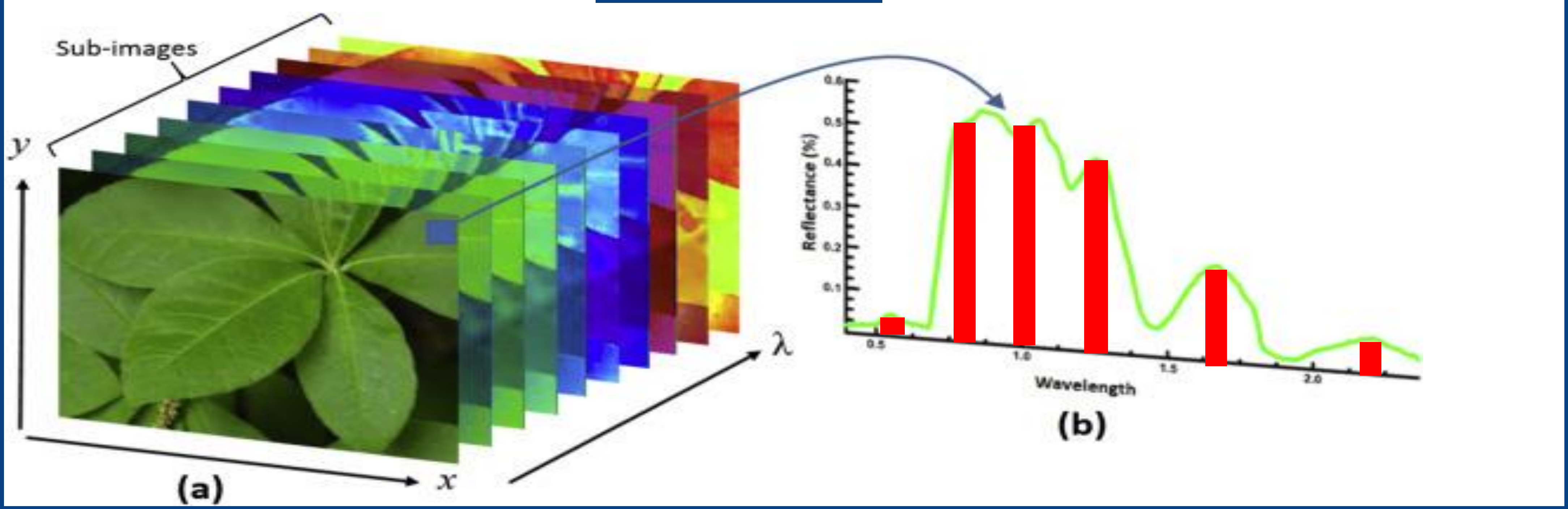




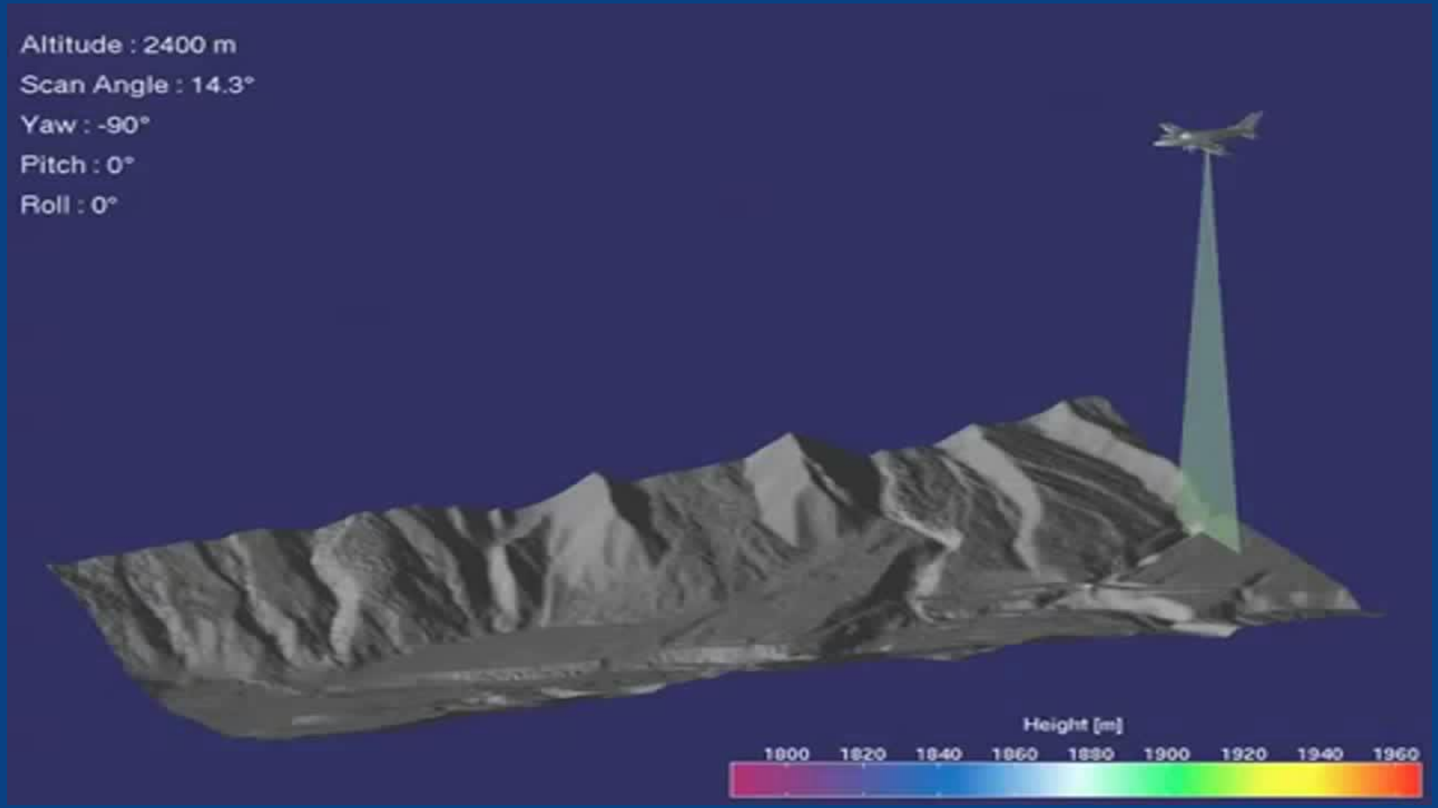
Imaging Spectroscopy



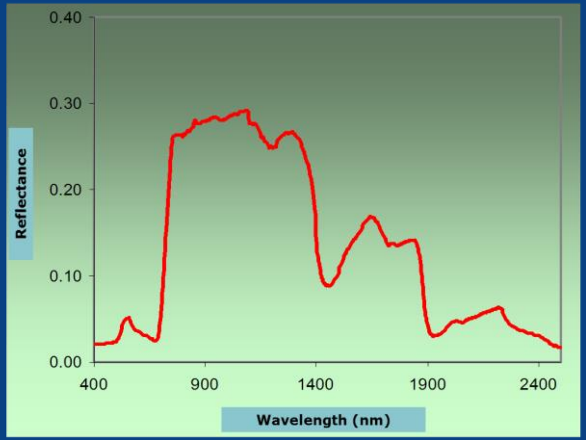


Imaging spectroscopy

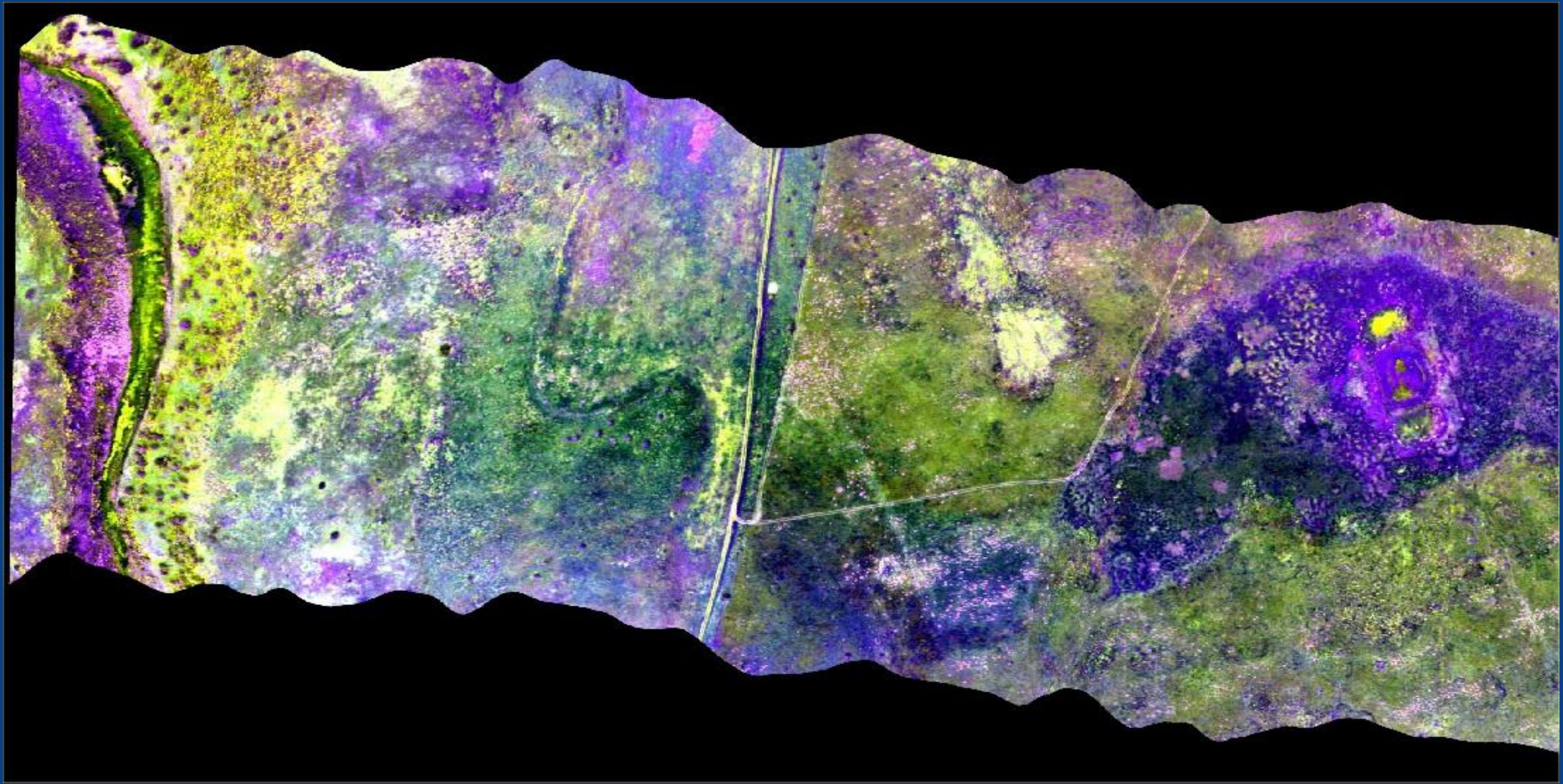
→ hyperspectral remote sensing
→ scanning the surface with a linear sensor
→ images with 150-300 spectral bands



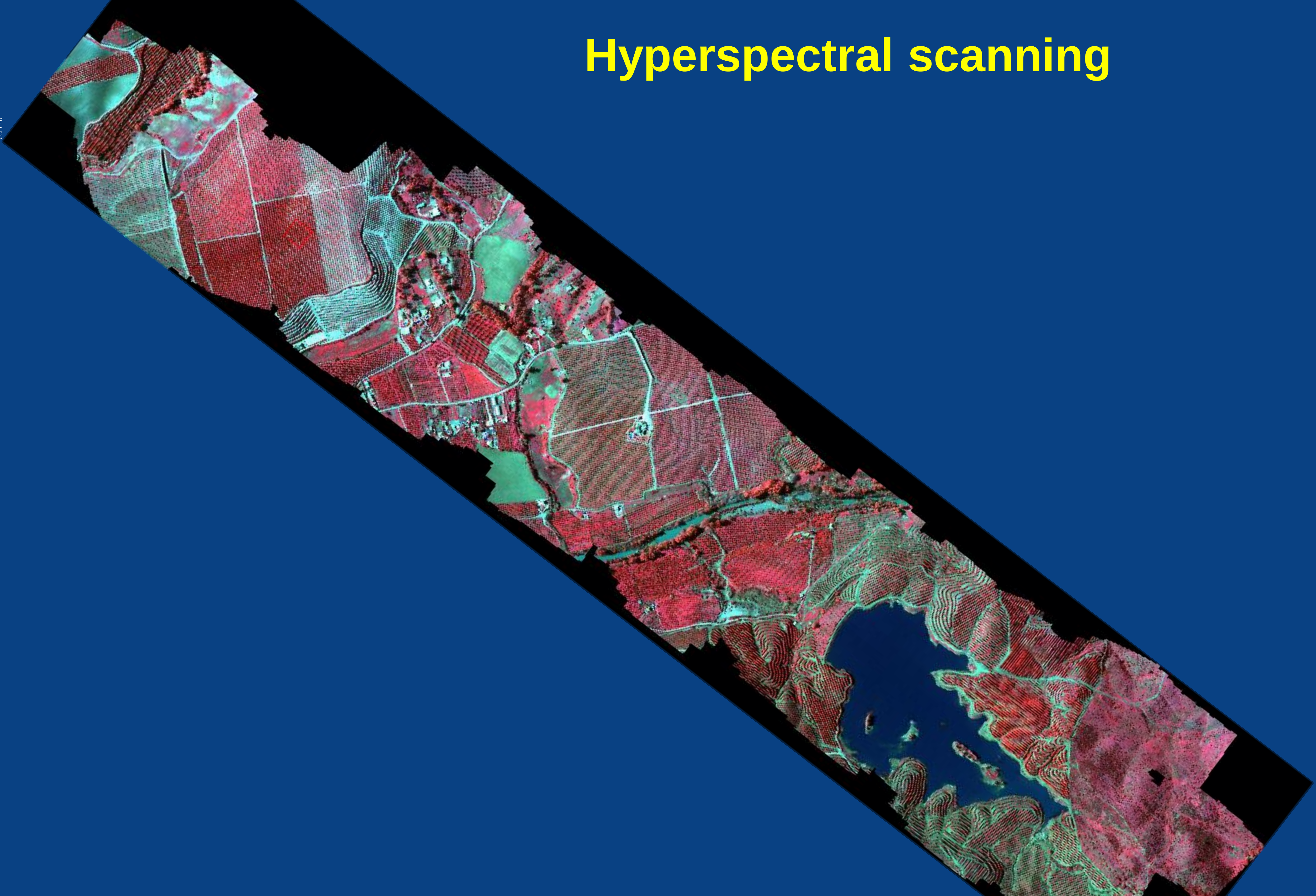
Contiguous spectral information



Hyperspectral scanning



Hyperspectral scanning



Hyperspectral scanning

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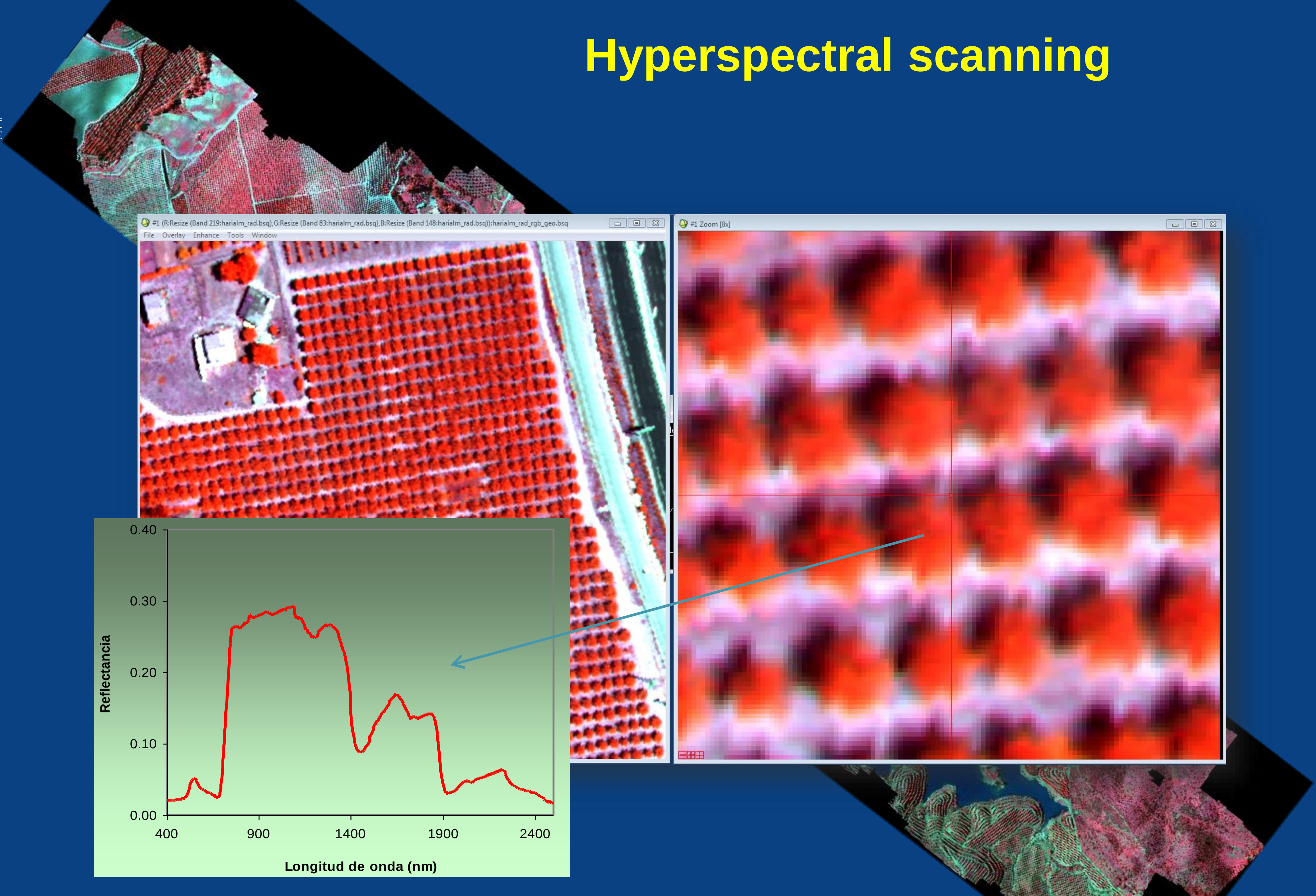

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Year 2000

CASI Hyperspectral Imager

Computer for imagery acquisition

Storage device

Inertial navigation system

Hyperspectral imager

Year 2011

Year 2015

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Year 2018

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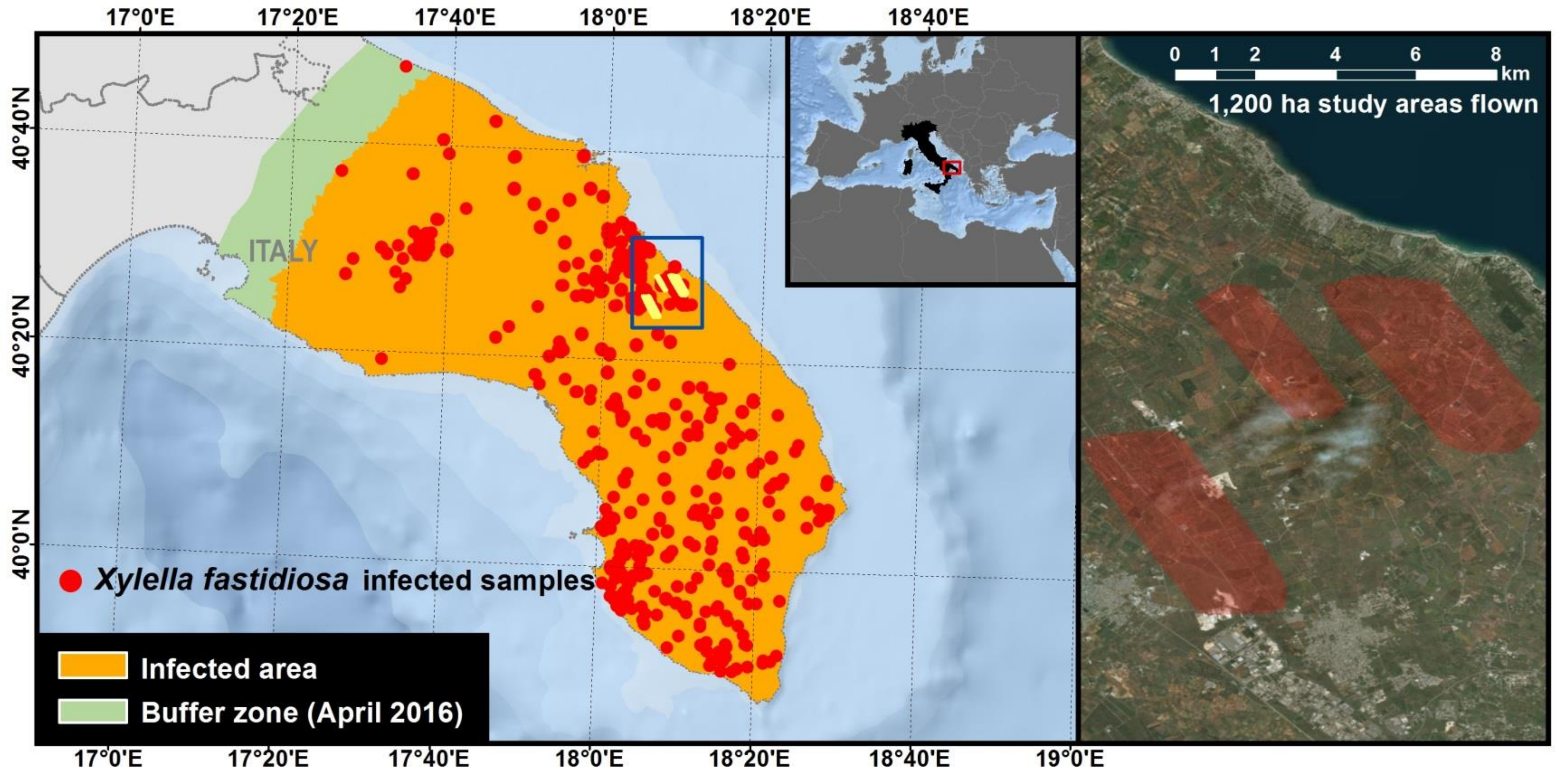
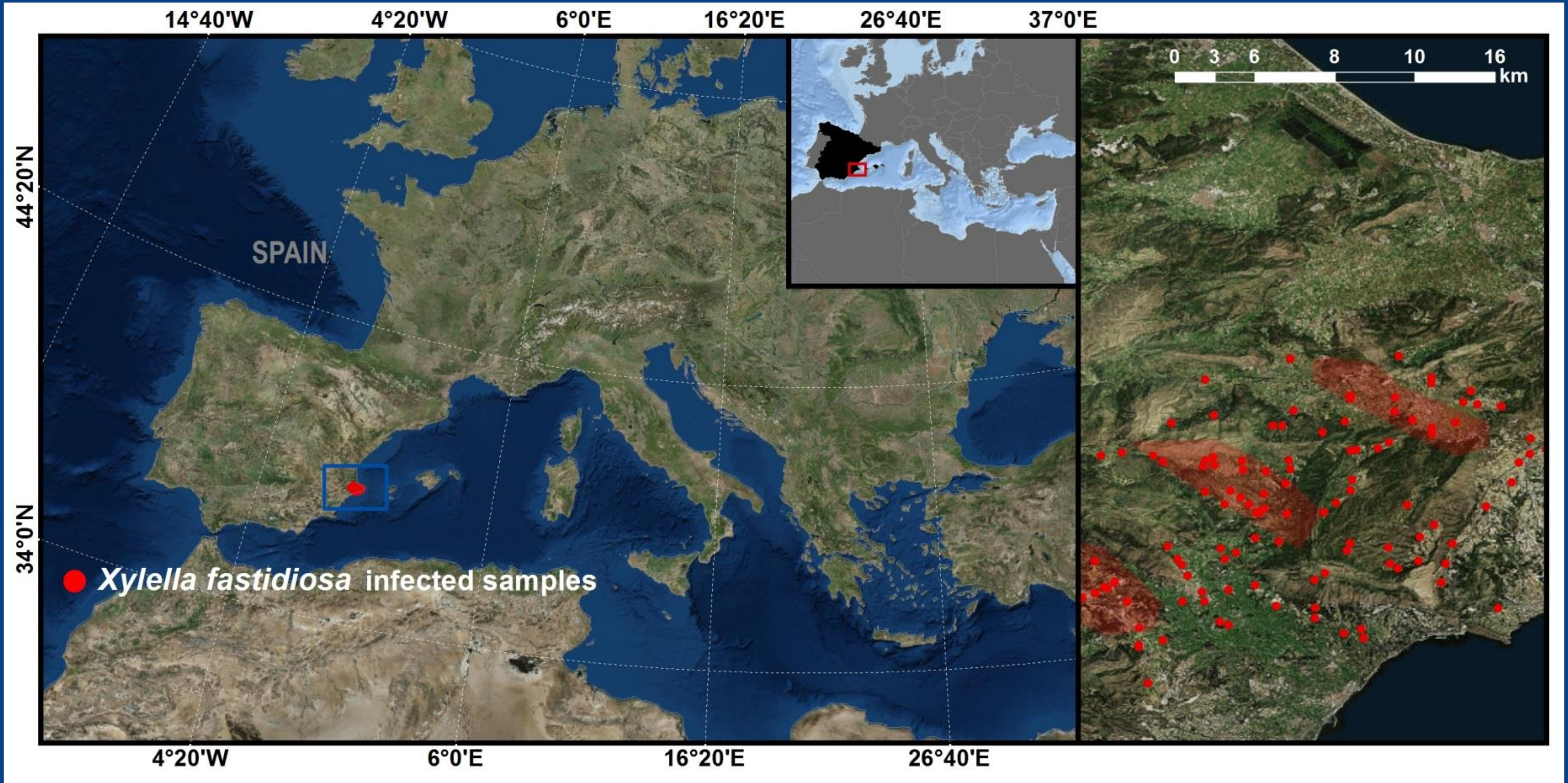
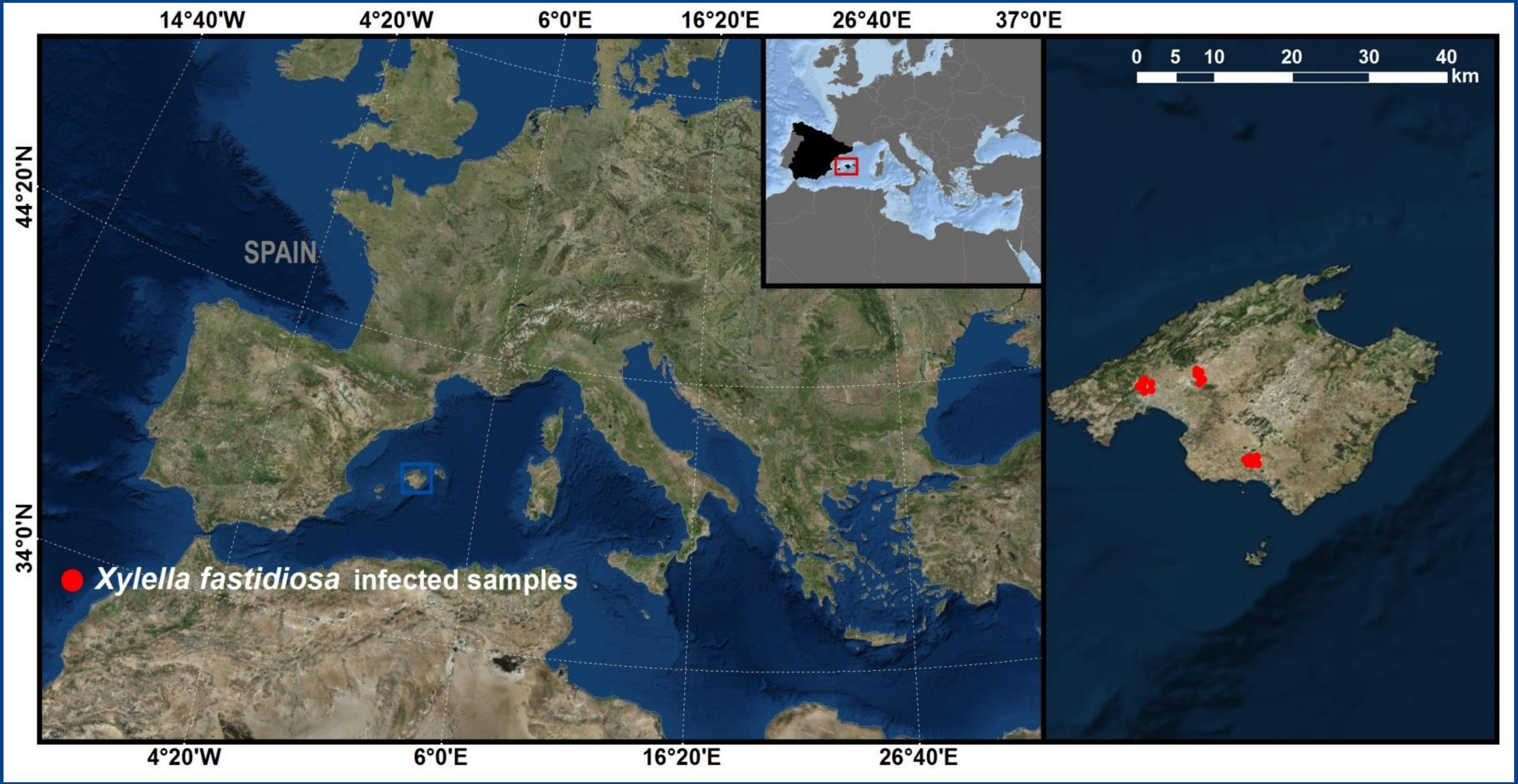
Airborne campaign in the Puglia region



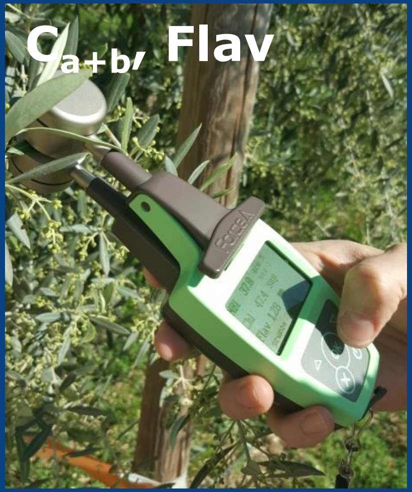
Airborne campaign in Alicante region



Airborne campaigns in the Balearic Islands



Leaf physiological measurements



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Airborne campaigns from Brindisi airport (Puglia)

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Airborne campaigns from Brindisi airport (Puglia)

Camera setup

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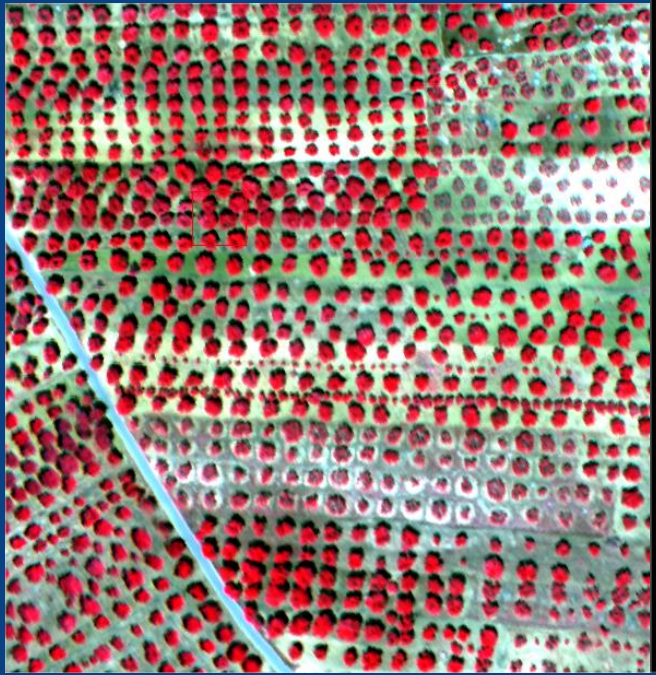
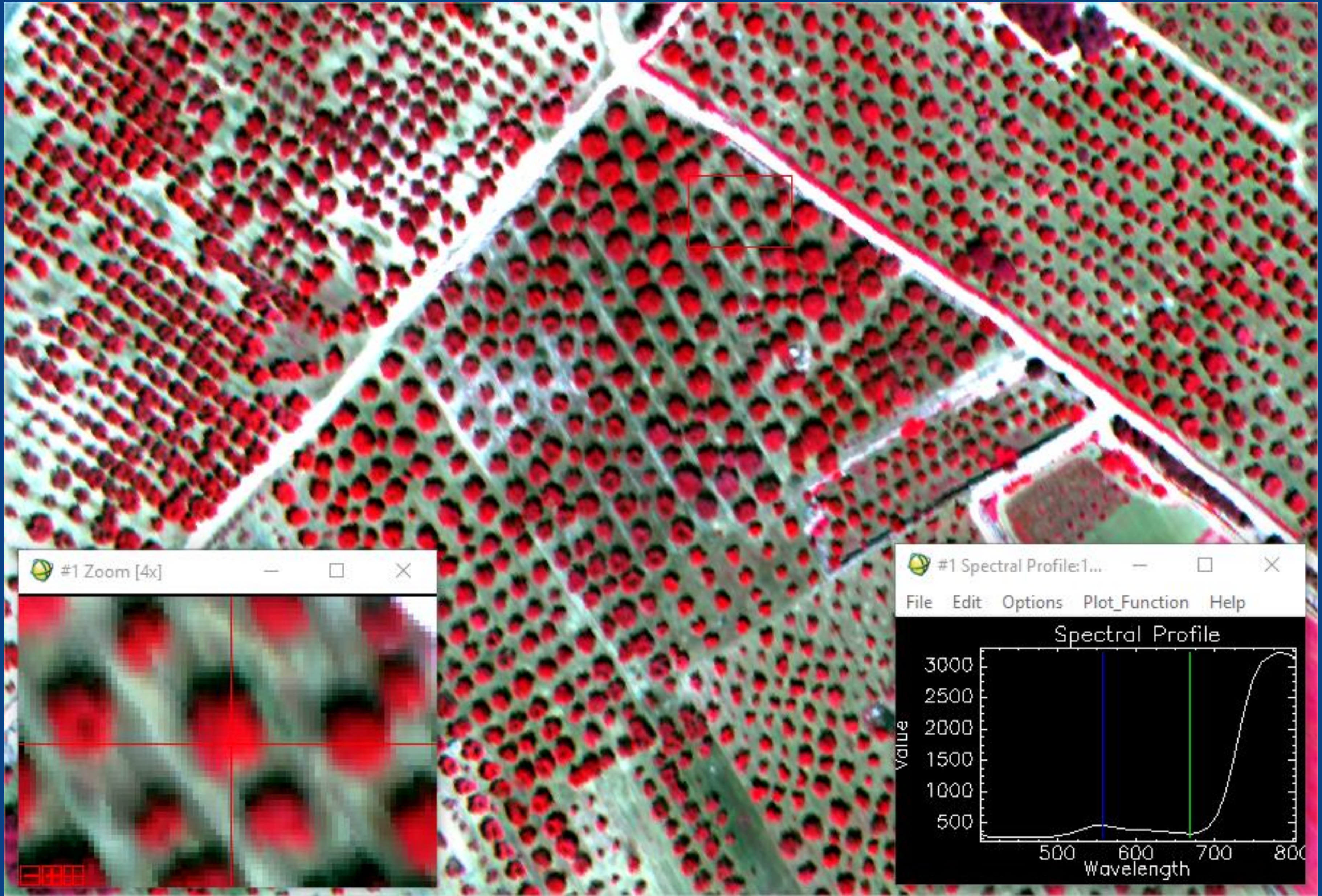
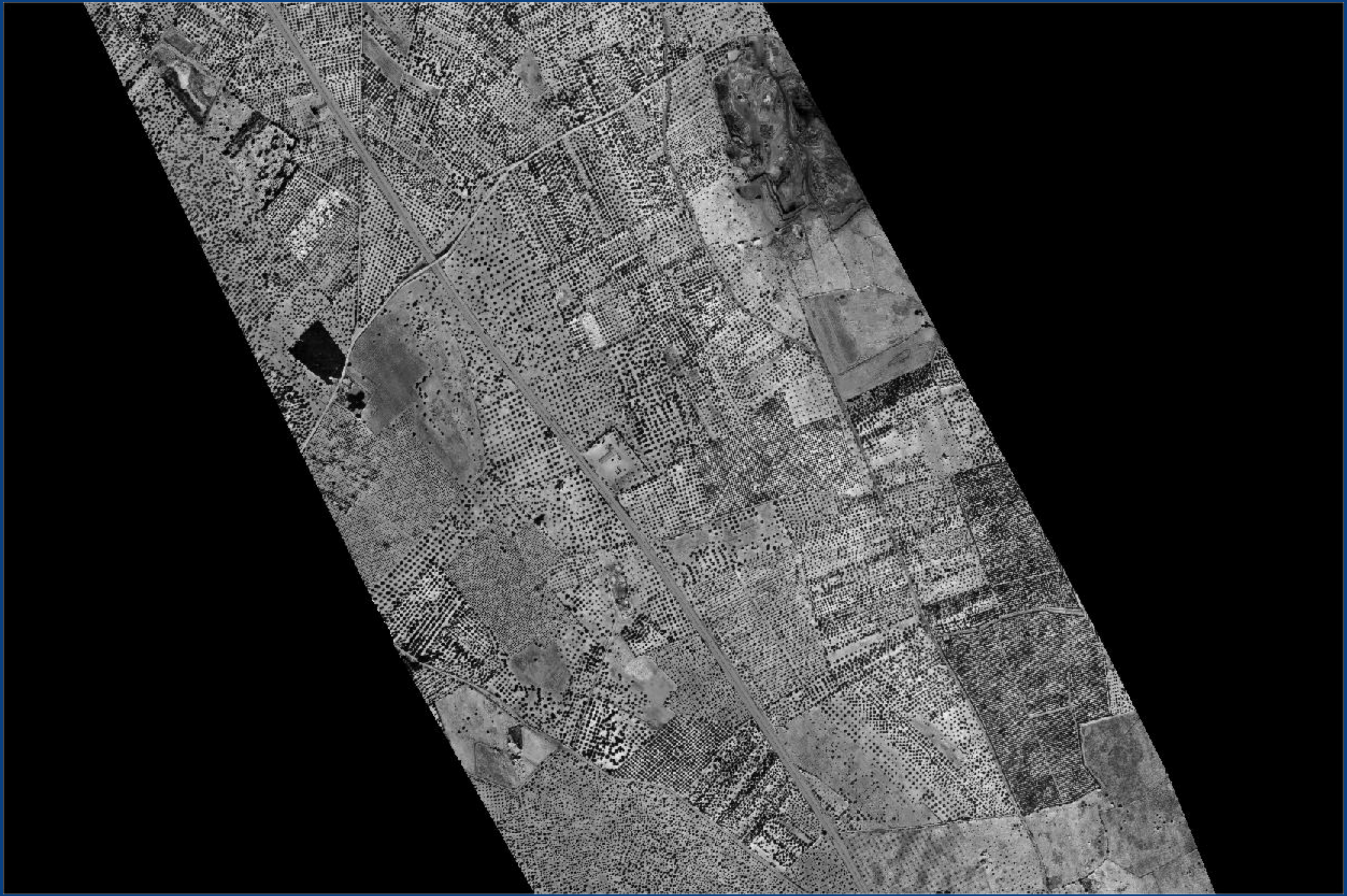
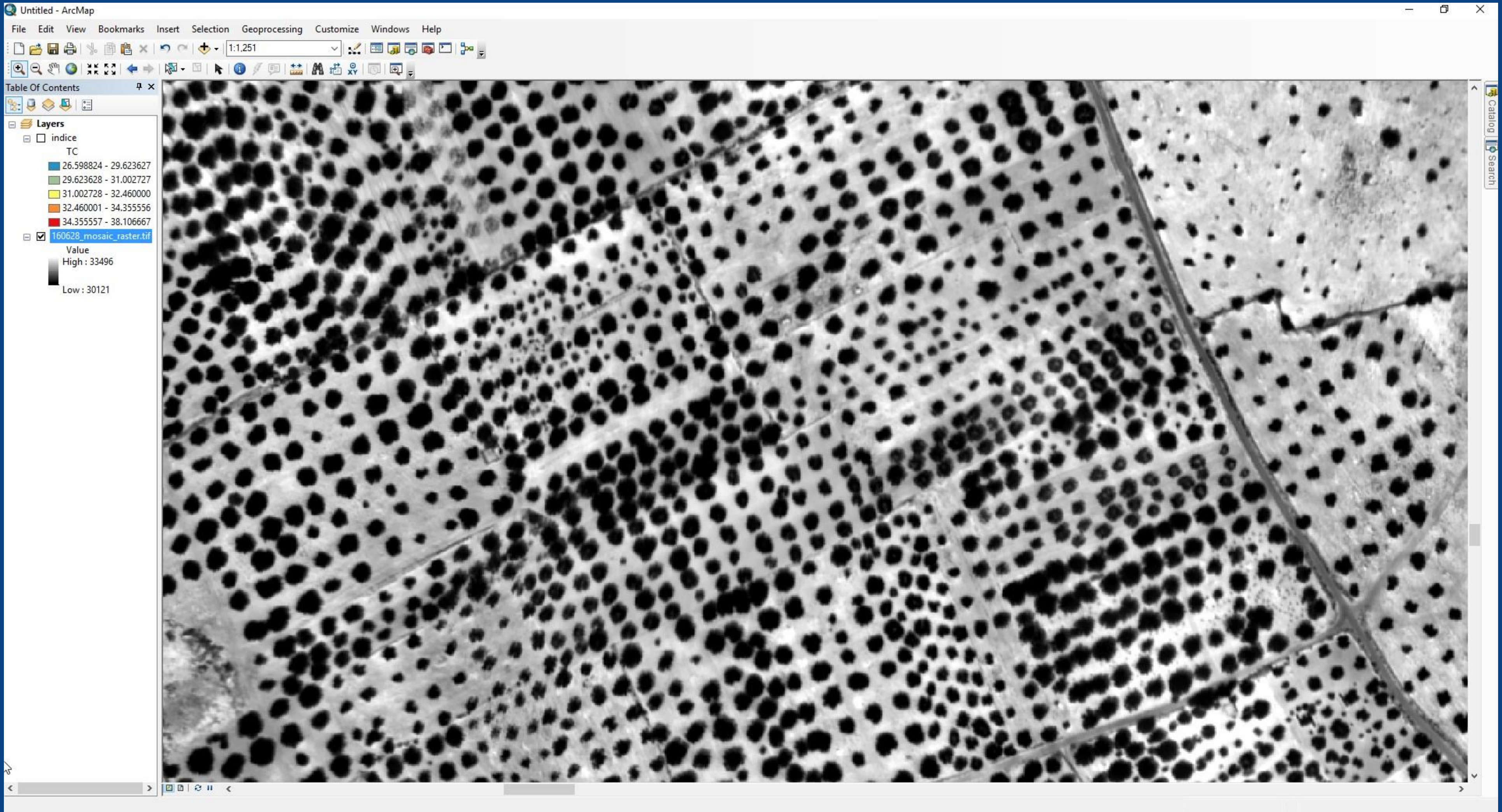
Hyperspectral 45 cm



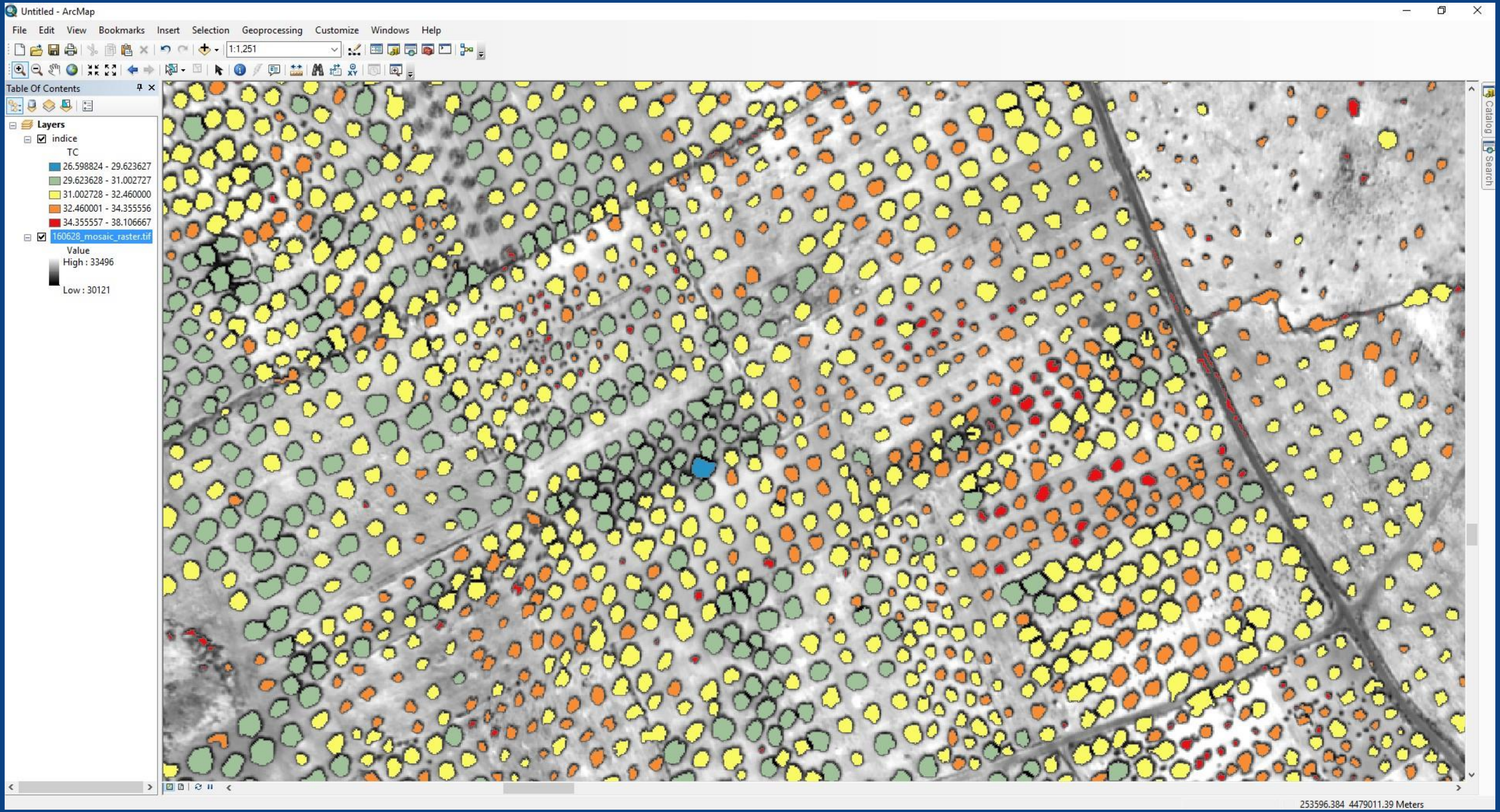
Hyperspectral 45 cm







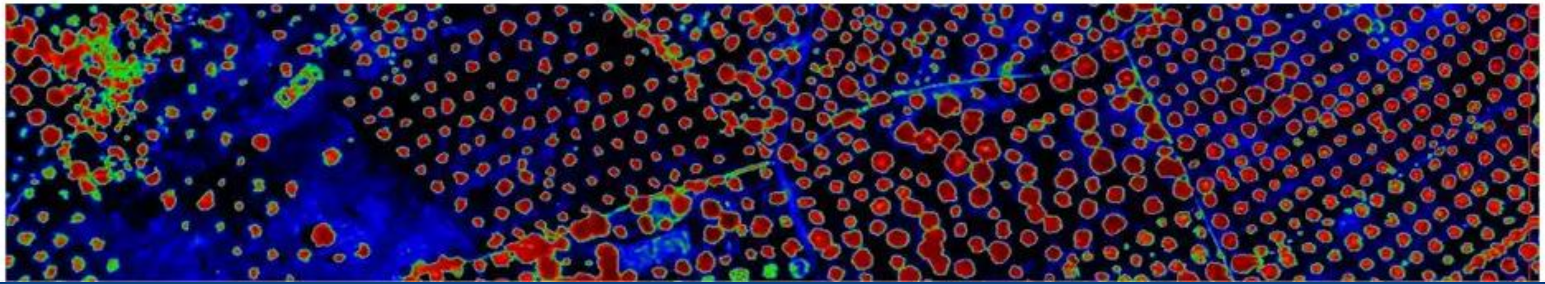
Thermal 60 cm



Thermal 60 cm

Flying cameras can spot lethal disease sweeping through world's olive groves

Fast-spreading *Xylella fastidiosa* is devastating species from citrus to oak trees, but can now be detected from the air



nature plants

https:/

Previsual symptoms of *Xylella fastidio* revealed in spectral plant-trait alterat

P. J. Zarco-Tejada[1*], C. Camino[2], P. S. A. Beck[1], R. Calderon[2], A. Hornero[2,3]
R. Hernández-Clemente[3], T. Kattenborn[4], M. Montes-Borrego[2], L. Susca[5], M.
V. Gonzalez-Dugo[2], P. R. J. North[3], B. B. Landa[2], D. Boscia[6], M. Saponari[6] an

Plant pathogens cause significant losses to agricultural yields and increasingly threaten food security[1], ecosystem integrity and societies in general[2–5]. *Xylella fastidiosa* is one of the most dangerous plant bacteria worldwide, causing several diseases with profound impacts on agriculture and the environment[6]. Primarily occurring in the Americas, its recent discovery in Asia and Europe demonstrates that *X. fastidiosa*'s geographic range has broadened considerably, positioning it as a reemerging global threat that has caused socioeconomic and cultural damage[7,8]. *X. fastidiosa* can infect more than 350 plant species worldwide[9], and early detection is critical for its eradication[8]. In this article, we show that changes in plant functional traits retrieved from airborne imaging spectroscopy and thermography can reveal *X. fastidiosa* infection in olive trees before symptoms are visible. We obtained accuracies of disease detection, confirmed by quantitative polymerase chain reaction, exceeding 80% when high-resolution fluorescence quantified by three-dimensional simulations and thermal stress indicators were coupled with photosynthetic traits sensitive to rapid pigment dynamics and degradation. Moreover, we found that the visually asymptomatic trees originally scored as affected by spectral plant-trait alterations, developed *X. fastidiosa* symptoms at almost double the rate of the asymptomatic trees classified as not affected by remote sensing. We demonstrate that spectral plant-trait alterations caused by *X. fastidiosa* infection are detectable previsually at the landscape scale, a critical requirement to help eradicate some of the most devastating plant diseases worldwide.

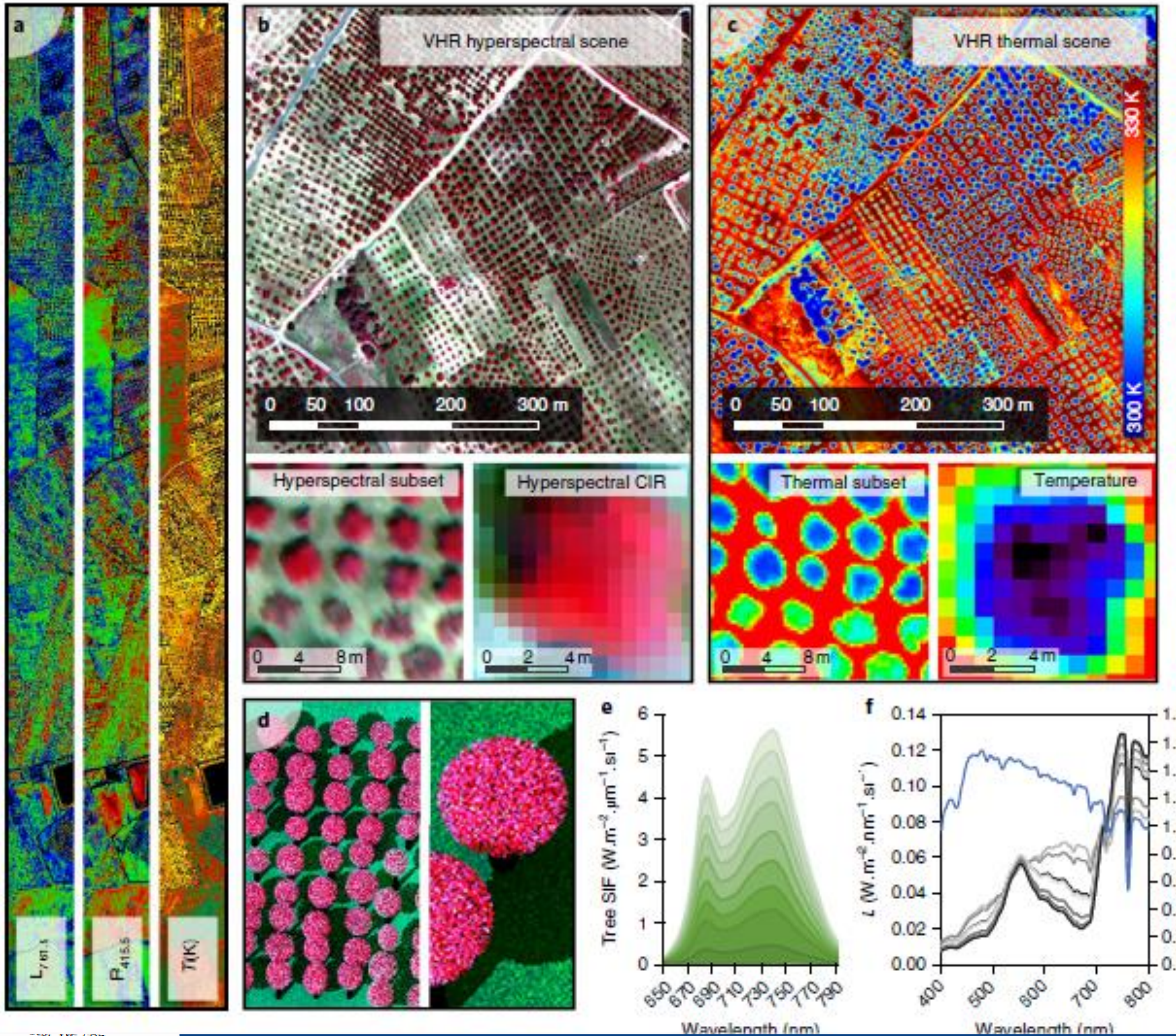
Xylella fastidiosa is considered one of the most dangerous plant pathogens worldwide[6]. It can infect more than 350 plant species[9], causing diseases in several crops and large economic losses[8]. In the United States and Brazil, this xylem-limited plant pathogenic bacterium is associated with detrimental diseases in high-value crops, such as Pierce's disease in grapevines and variegated chlorosis in citrus, respectively[10]. Its spread has recently gained a global dimension[11]: already widely distributed in the Americas and detected in Iran and Taiwan, *X. fastidiosa* has been known to be present in Europe since 2013 after its official identification in Italy[12], causing economic and societal damage[8].

The spread of *X. fastidiosa* within Europe has thus far not been contained[7]. Outbreaks detected in Franc… have raised co…

the Mediterranean agriculture[8]. Th… subspecies of *X. fastidiosa* (that is, … in Europe broadens the threat to sev… almond, citrus and grapevine, but a… as elms, oaks and sycamores. A majo… tainment arises from its very wide h… do not cause symptoms in some hos… the infected hosts continuing to ac… threat is further exacerbated because … xylem-sap-sucking insects without an… and because of increased global trade.

Alarms have been raised by both … community[8] and the media[7], pointi… *X. fastidiosa* will require robust monit… plants that show little to no signs of … infection. A major limitation of standar… ods based on red and near-infrared (NI… ized difference vegetation index (NDVI… obtained from broadband satellite sens… only for detecting the advanced stages … when canopy defoliation, leaf wilting an… In addition, current hyperspectral satel… tial resolution to distinguish individual … *X. fastidiosa* eradication efforts involving i… tate high spatial resolution (that is, submet… and thermal data to assess subtle changes … traits, a technology that can be potentially … with airborne platforms[14].

We carried out intensive multiyear in… than 7,000 trees and airborne imaging da… finding that physiological alterations cause… tion at the previsual stage were detectable i… assessed remotely by hyperspectral and the… firmed the presence of *X. fastidiosa* infection in all selected orchards by testing at least two symptomatic trees per plot by quantitative polymerase chain reaction[15] (qPCR) assay. In addition, we sampled one of the olive fields more extensively for an orchard-level validation of the remote sensing model testing, by qPCR … of the 157 trees spanned the f…



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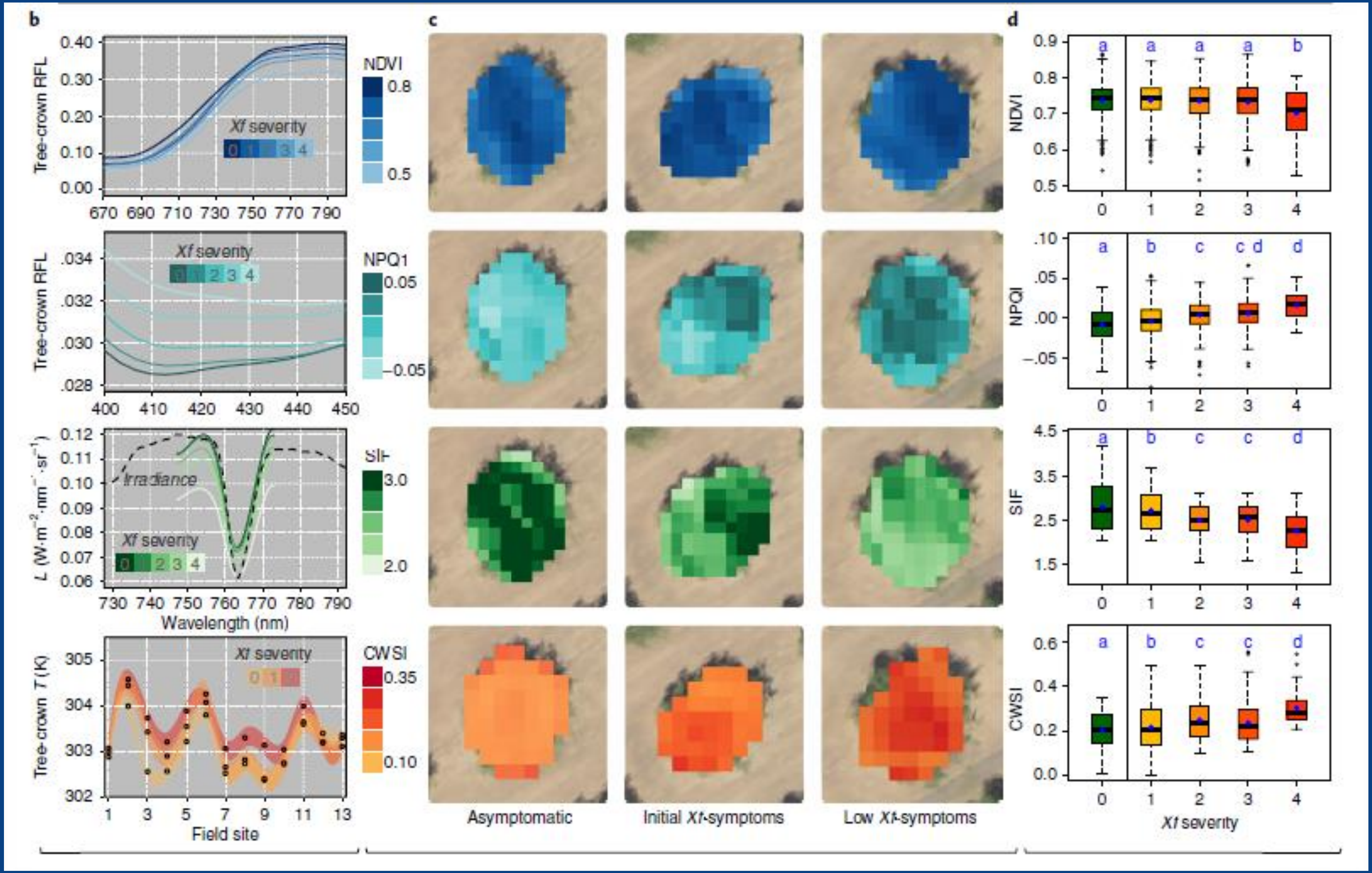
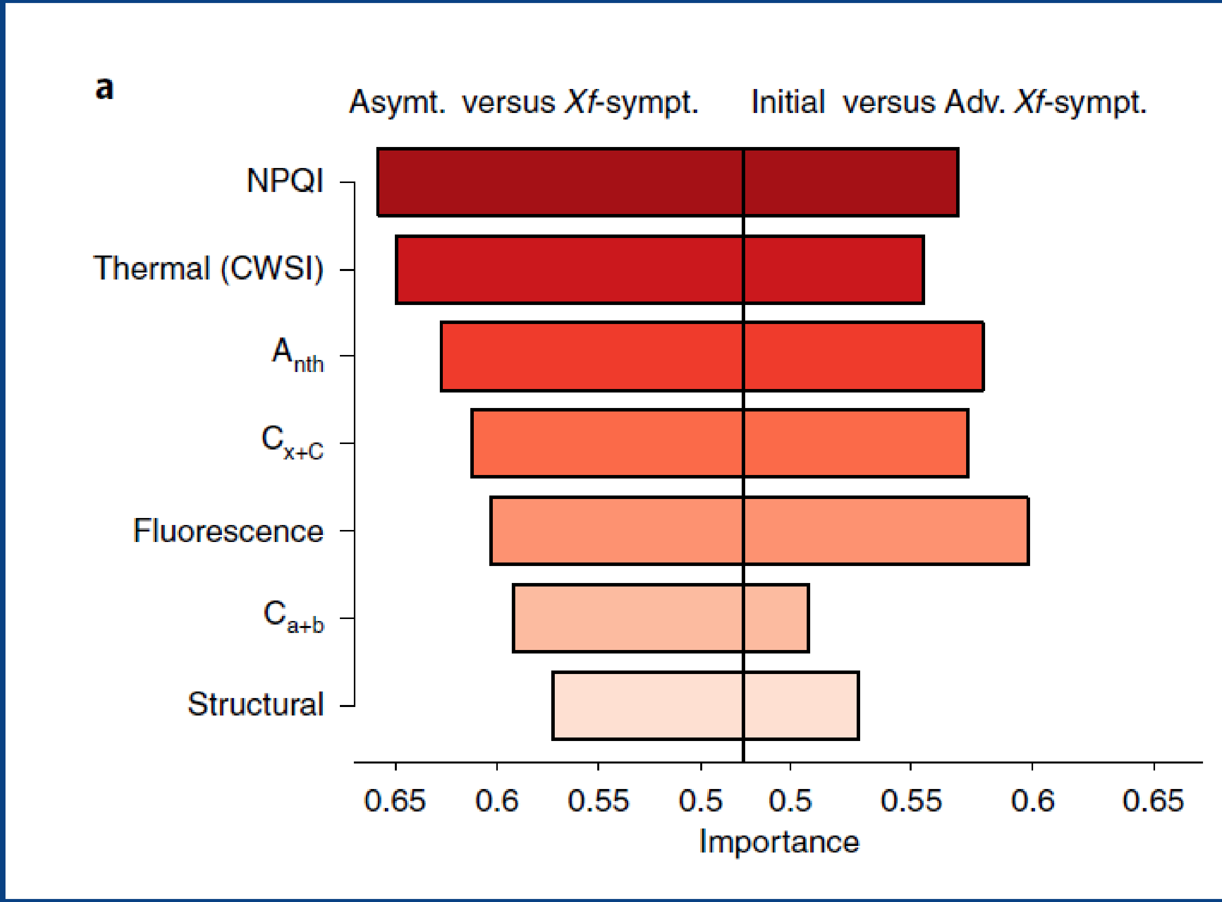
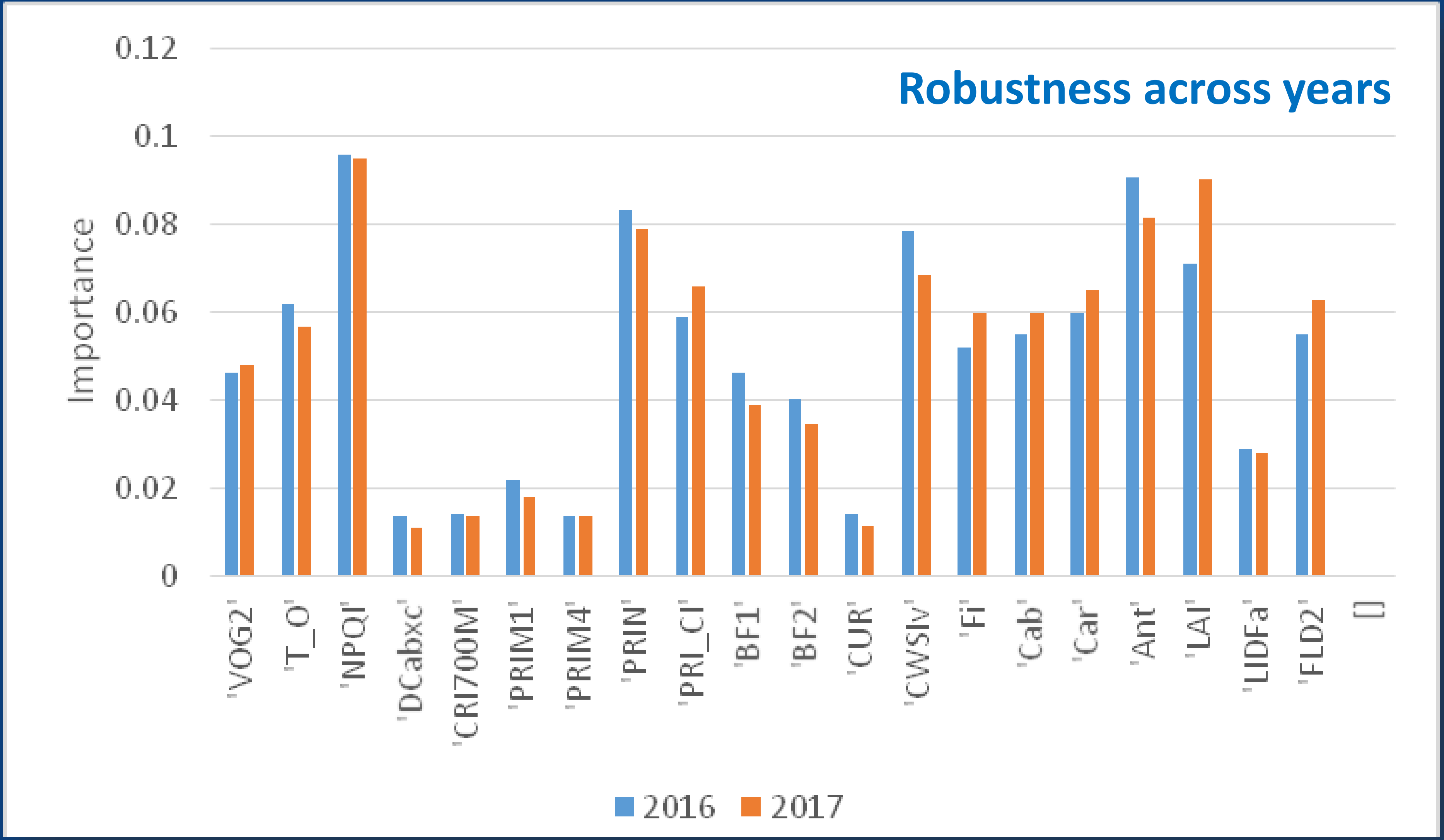


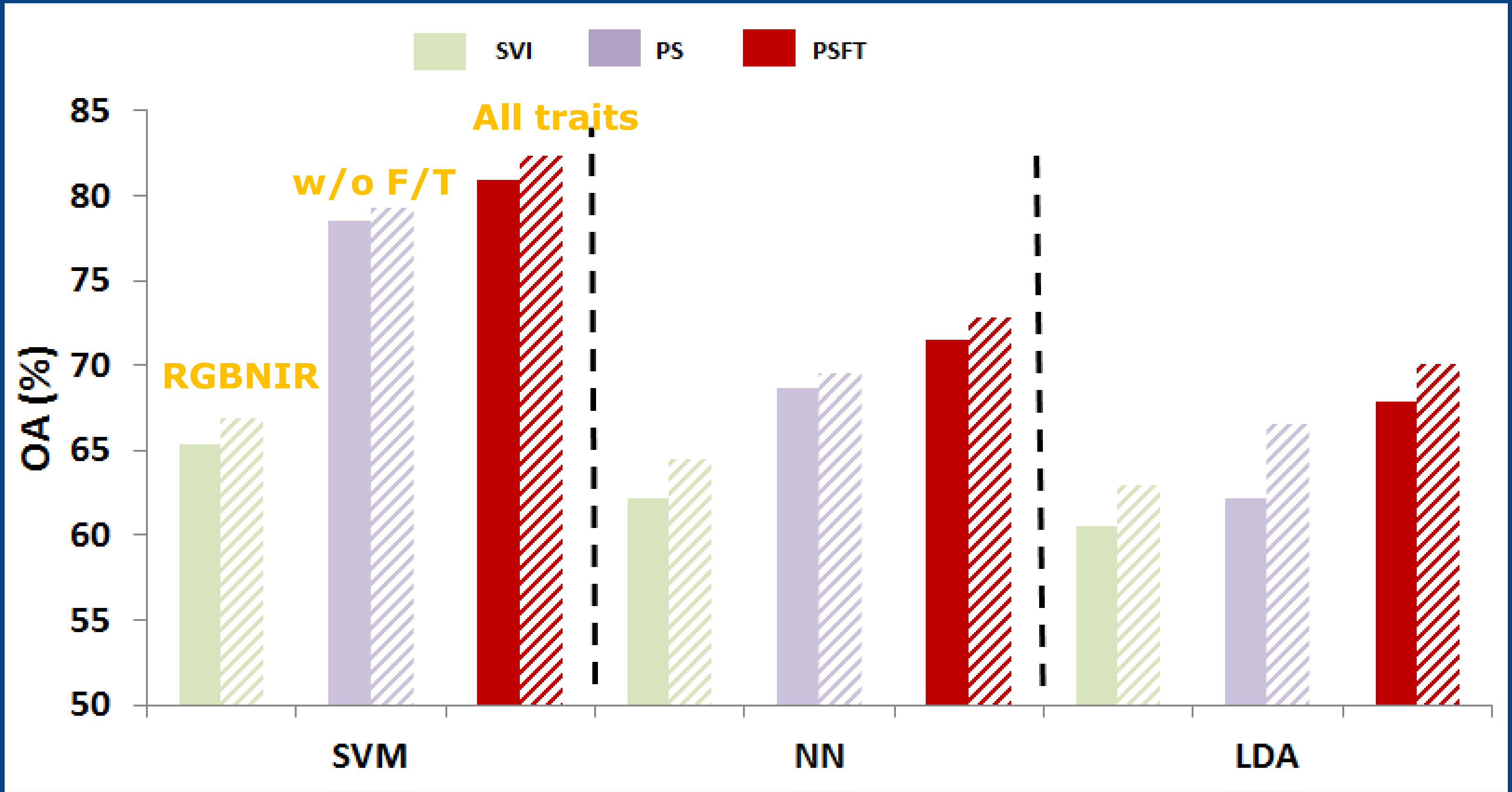
Sensitivity of Plant Traits to *Xf* symptoms



Sensitivity of Plant Traits to *Xf* symptoms

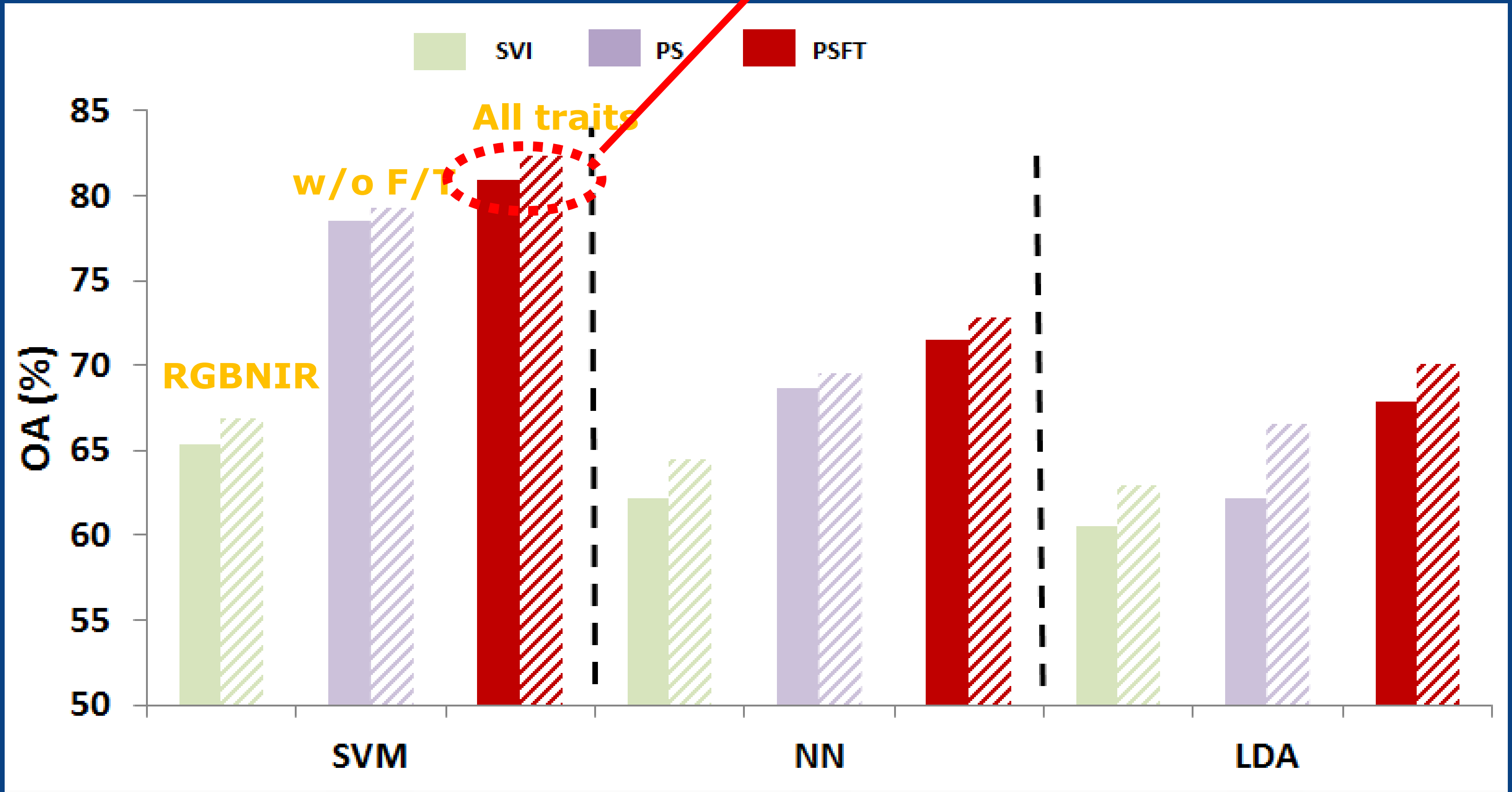


Overall accuracy – 2 year dataset



Overall accuracy – 2 year dataset

False Positives ?



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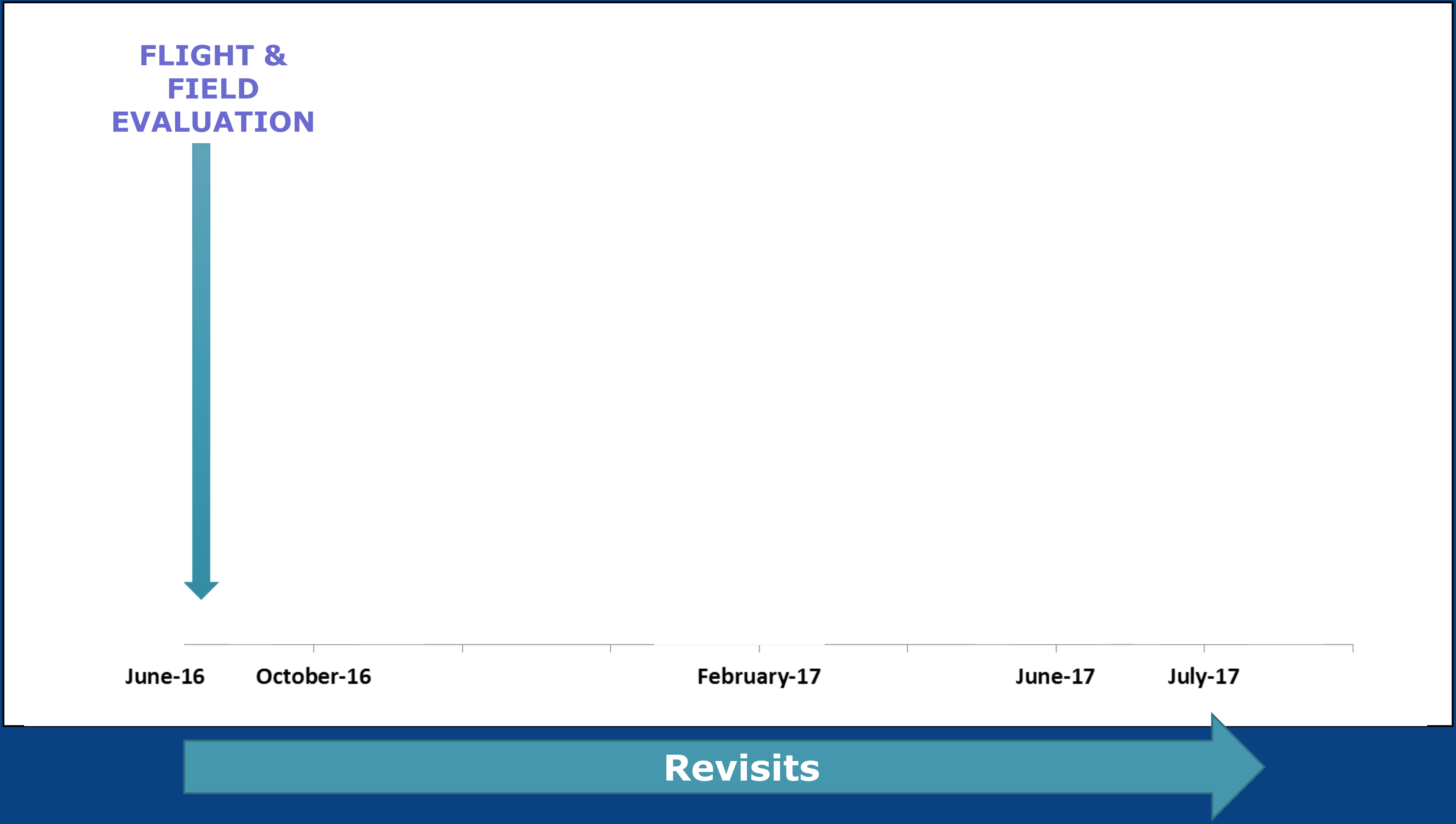
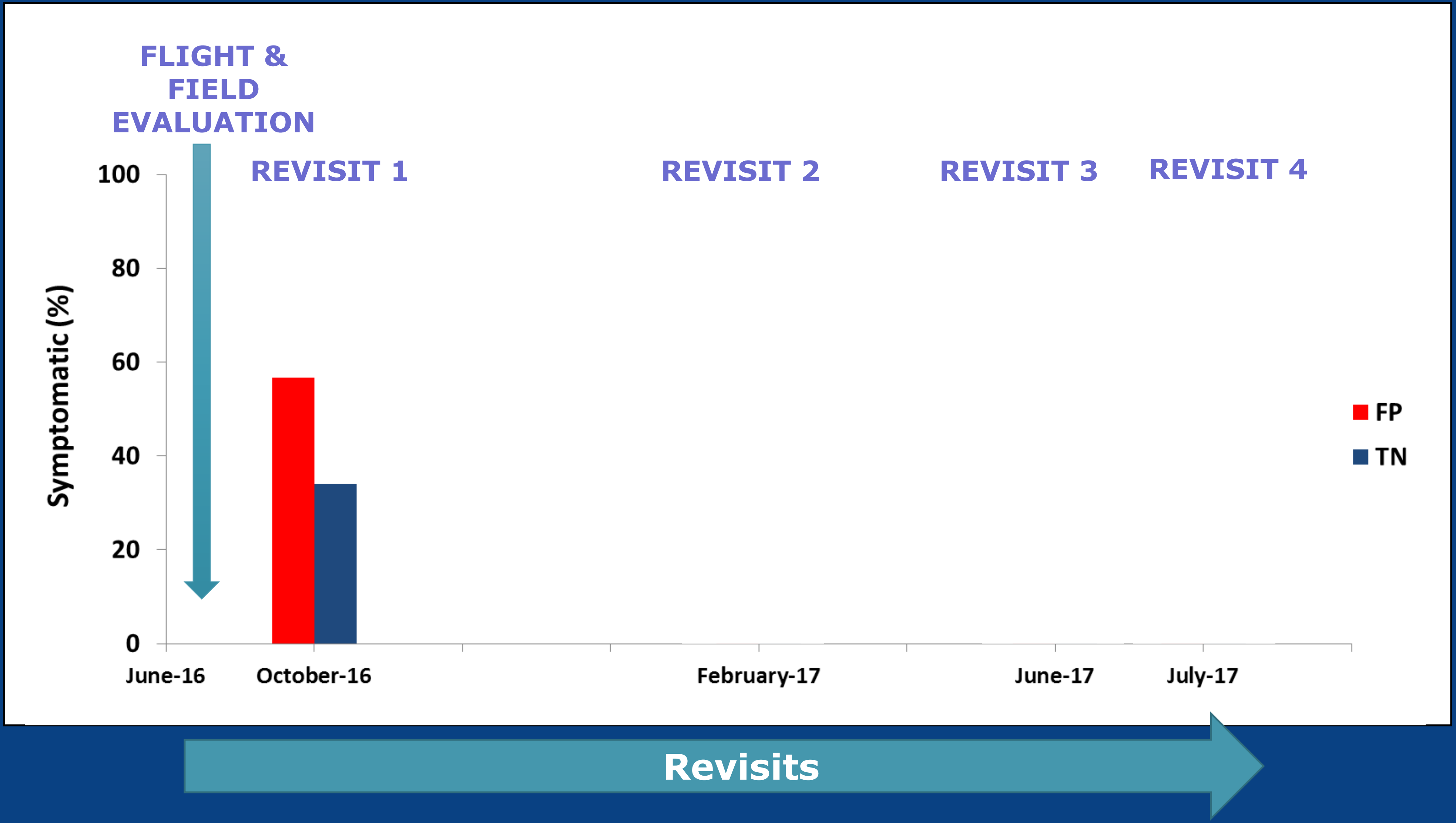
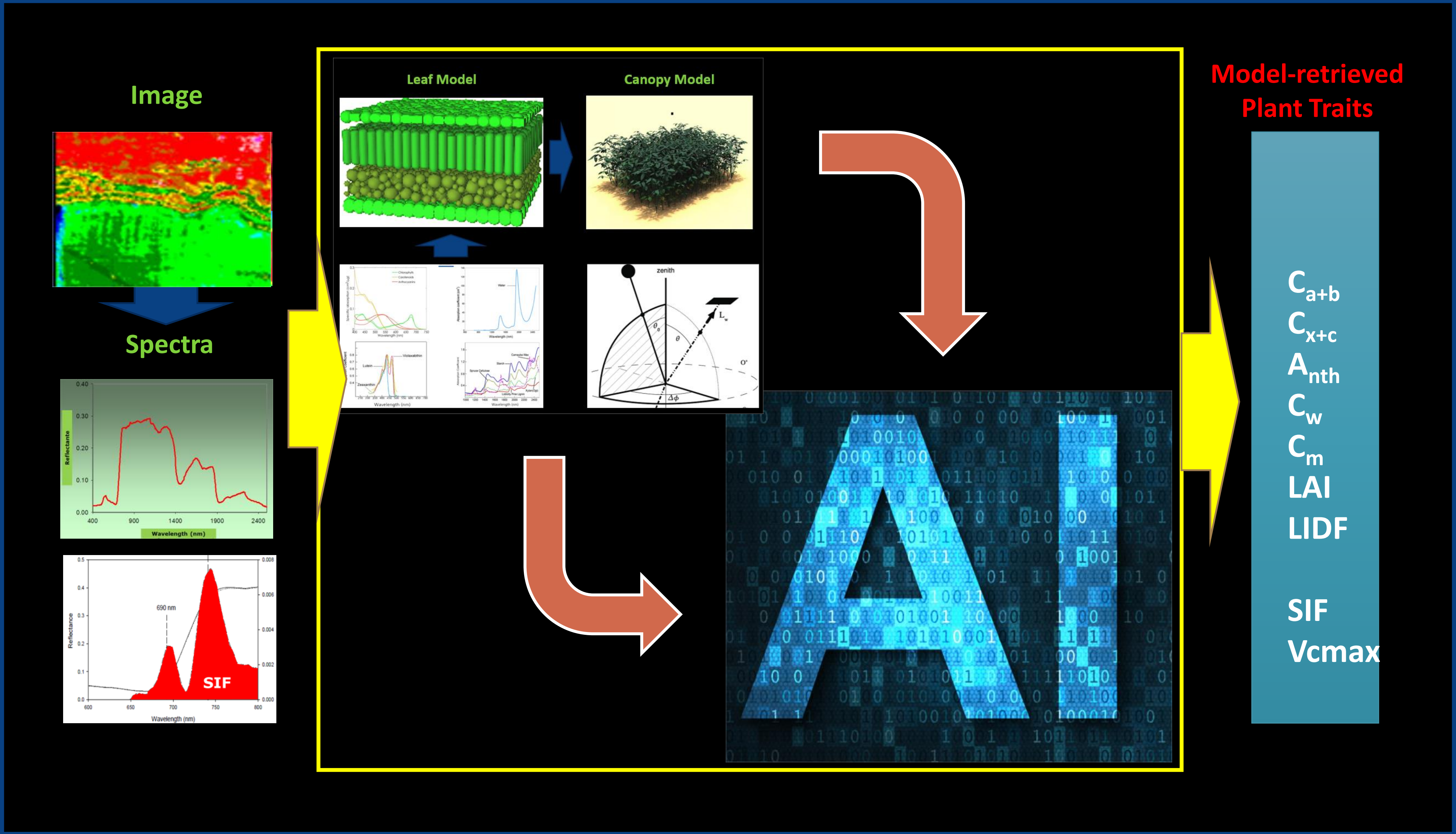


Revisited 1,762 trees out of 3,328 evaluated in June



FLIGHT & FIELD EVALUATION
REVISIT 1
REVISIT 2
REVISIT 3
REVISIT 4
Symptomatic (%)
100
80
60
40
20
0
June-16
October-16
February-17
June-17
July-17
FP
TN
Revisits

Linked leaf-canopy simulation models



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Some conclusions

1. Early detection of *Xf* and other harmful diseases at the pre-visual stage is posible using ***innovative*** remote sensing methods (VW / phytophtora / PWN …)

2. Critical to detect *Xf*-induced symptoms at ***early stage*** when infected areas are small

3. Adoption of new operational remote sensing methods is needed for ***surveillance*** purposes

4. ***Multidisciplinary*** collaboration has been critical for success in *Xf* detection

5. **Innnovation** is critical:
   - Standard RS methods would have failed
   - Technology currently provided by vendors / service providers would have failed
   - Innovation means *risk* → risk needs to be funded

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