The Future of Imaging Spectroscopy – Prospective Technologies and Applications

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State of Science of Environmental Applications of Imaging Spectroscopy (in honor of Dr. Alexander F.H. Goetz)
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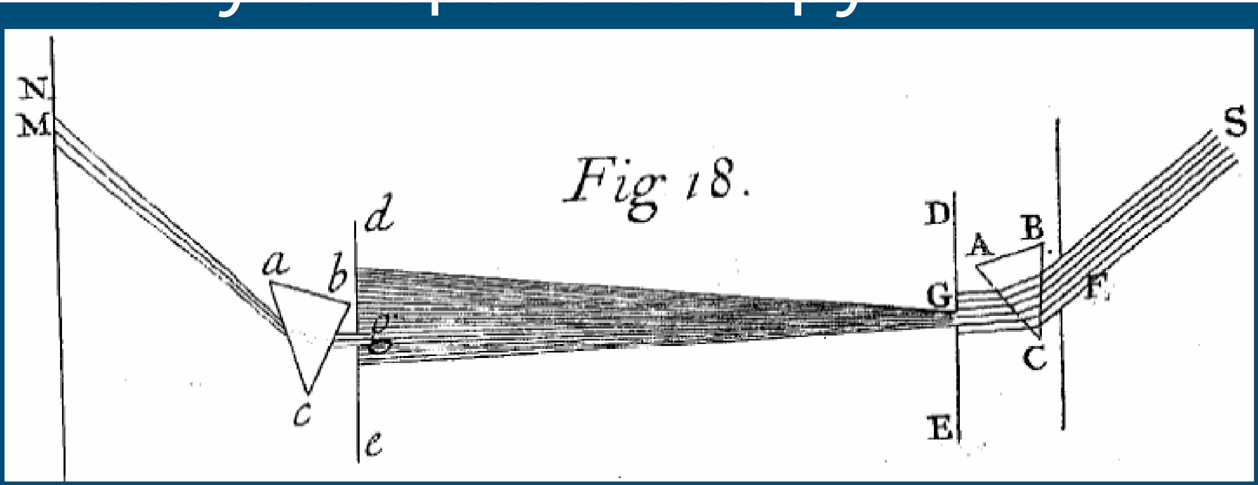
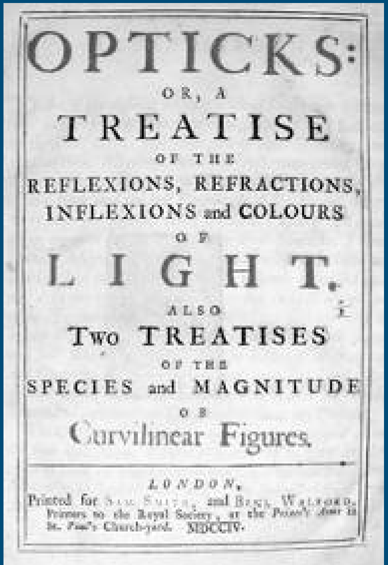
Outline

- Introduction
- Technology
- Applications
- Outlook

History of Spectroscopy




OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.

LONDON,

Sir Isaac Newton (1642-1727)

Joseph von Fraunhofer (1787-1826)

Gustav Robert Kirchhoff (1824-1887)

Robert Wilhelm Bunsen (1811-1899)

Sir William Huggins (1824-1910)

1990s Hyperion, CHRIS MERIS, (MOS, MODIS),

Spectral dispersion

Continuous spectrum, interrupted by dark lines

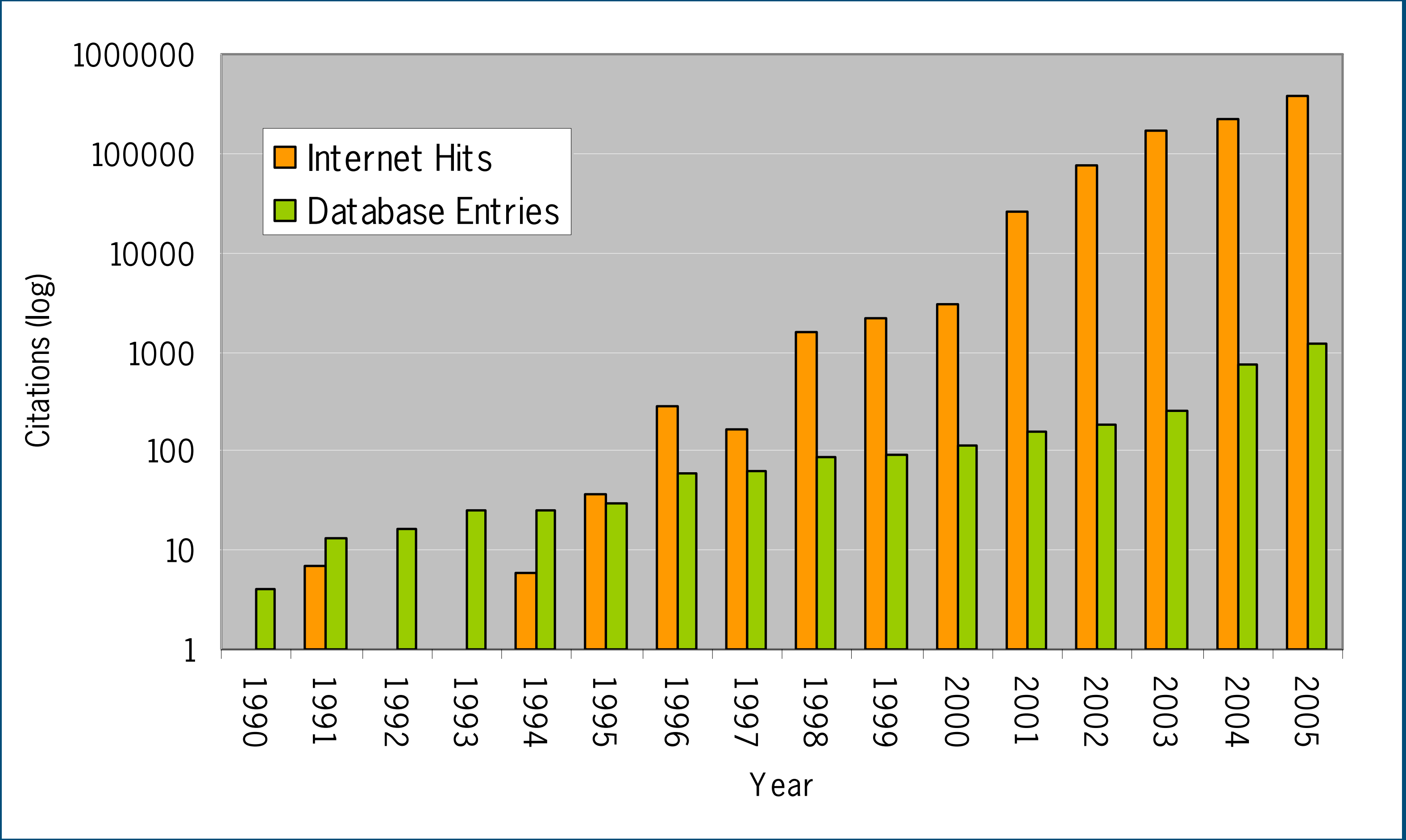
Explanation of Fraunhofer lines

Absorption in gas

Composition of astronomical objects

First imaging spectrometers in space

Continuous exponential growth of imaging spectroscopy



Planned Instruments – Which ones will be flying?

- Space Activities
  - HERO - Hyperspectral Environment and Resource Observer, Natural Resources Canada, Canadian Space Agency
  - EnMAP - Environmental Mapping and Analysis Program (GFZ, Germany)
  - Flora - NASA ESSP proposal
  - FLEX - ESA Earth Explorer proposal
  - SpectraSat - Full Spectral Landsat proposal
  - ZASat - South African proposal (University of Stellenbosch)
  - HIS - Chinese Space Agency
  - COIS - Coastal Optical Imaging Spectrometer (on NPOESS?)
- Airborne Activities
  - ARES (DLR, Germany)
  - APEX (RSL, VITO (CH, B))
  - HICO (NRL, USA)
  - SAMSON (NRL, NOAA, USA)
  - Continuation, upgrades from existing instruments (AVIRIS, CASI, AISA, Daedalus, etc.)

Technology Trends

- True spectroscopy focal plane arrays
- Advanced optical designs with enabling components (curved, high-efficiency dispersive elements and ultra-straight slits)
- Advanced calibration techniques, using onboard, in-situ and vicarious calibration efforts in combination with state space estimation algorithms
- Reprogrammable on-board logic and implementation of (lossless) data compression will help to overcome the downlink capacity problems.
- Non–traditional data reduction techniques such as cloud screening, band aggregation (when appropriate), and employing lossy compression over “stable” targets some of the time
- The simultaneously acquired spectral domain will be expanded into the UV and thermal range, plus adding multiangular capabilities

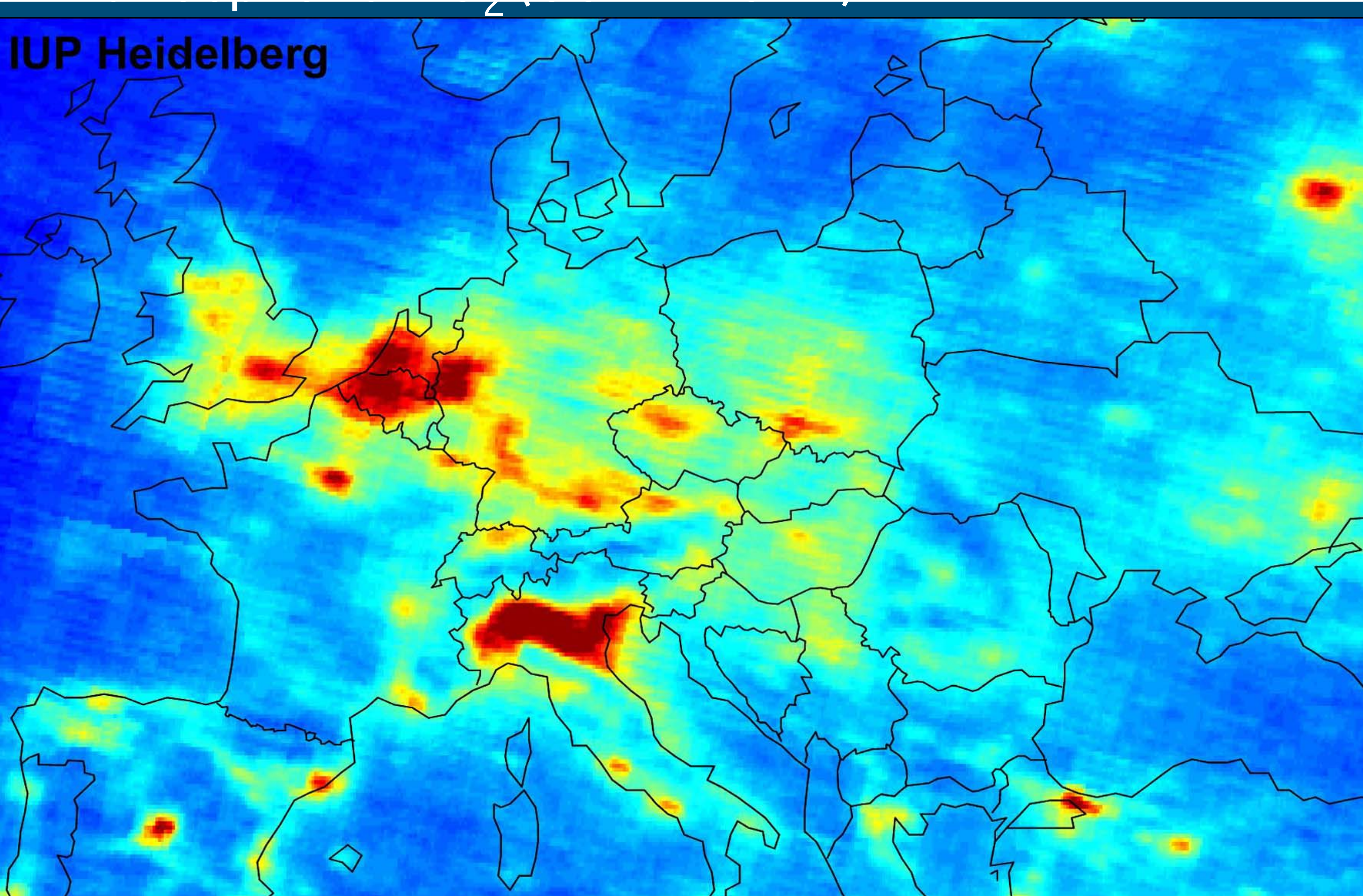
Pre-processing

- Improved computing environments, such as parallel and grid computing, as well as distributed computing approaches will profit from local (user) resources
- Approaches of soft classifiers based on expert systems, Support Vector Machines, Markov Random Fields (MRF) for sub-pixel mapping, and image change detection and fusion, to full expert system spectral analysis
- Data assimilation, applied optical estimation in combination with in-situ sensing

Application trends – Atmosphere

DHR, BHRiso *Black/White Sky Albedo*	Combined surface and atmospheric anisotropy	3D radiative transfer in partly clouded atmosphere	Combined atmospheric and ground chem. cycles
Albedo	Surface anisotropy	Clear sky radiative transfer	Columnar trace gases
Reflectance	BRDF	Non-clouded pixels	Atmospheric absorption

Atmospheric NO_2 (SCIAMACHY)



Application trends – Cryosphere (Snow)

Snow …

Snow dust content

Snow wetness

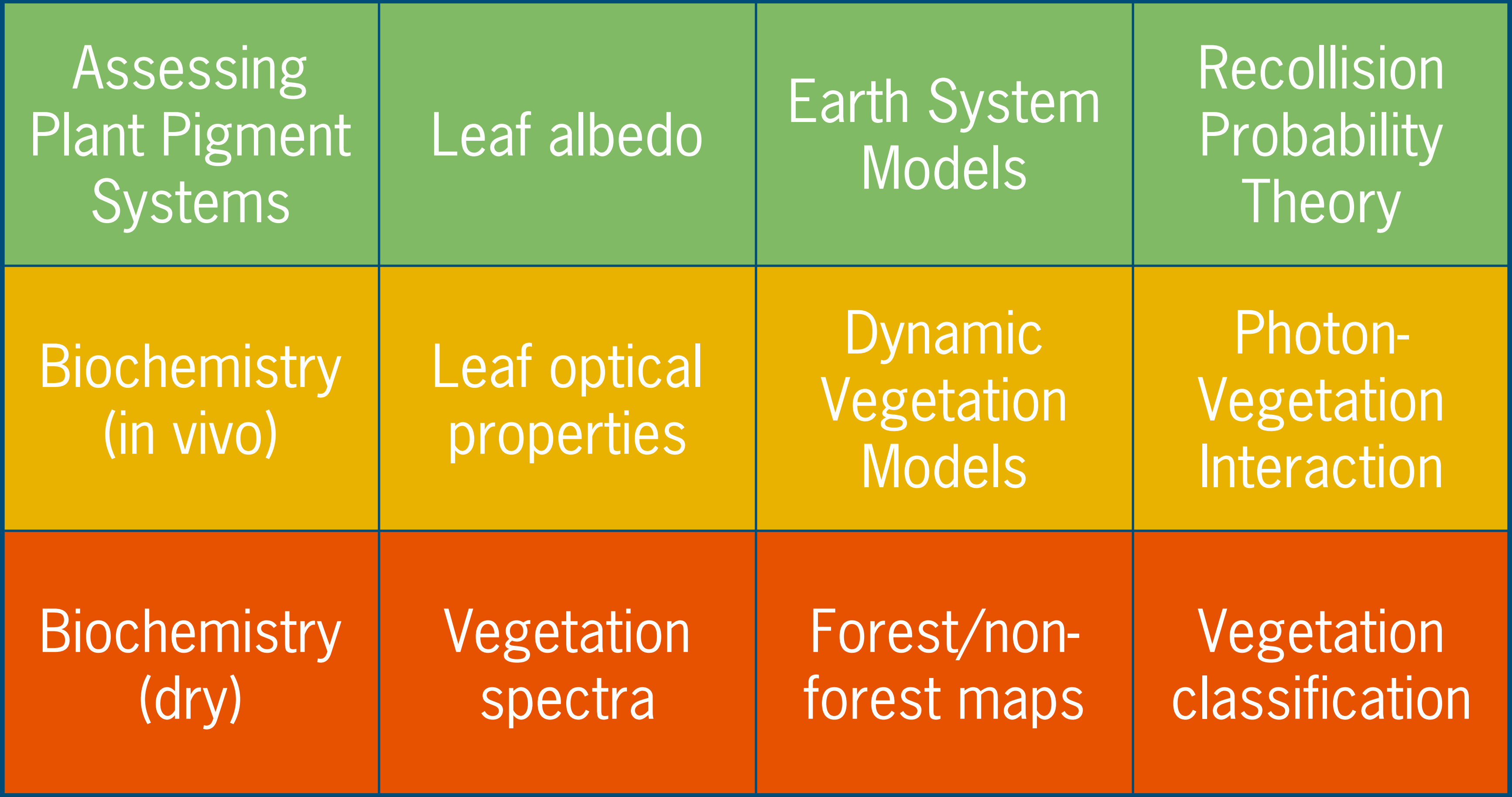
Snow algae

Snow albedo

Snow grain size

Snow covered area (fractional)

Application trends – Biosphere



Assessing Plant Pigment Systems	Leaf albedo	Earth System Models	Recollision Probability Theory
Biochemistry (in vivo)	Leaf optical properties	Dynamic Vegetation Models	Photon-Vegetation Interaction
Biochemistry (dry)	Vegetation spectra	Forest/non-forest maps	Vegetation classification

Applications trends – Limnology

Bathymetry, bottom types (albedo, sand, silt, macrophytes), and water column optical properties

Simultaneous retrieval (Phytoplankton, suspended sediments, DOM, fCover of bottom green macrophytes

RT for combining water apparent and inherent optical properties

Radiative transfer air-water interface

Water color

Application trends – Geosphere

Intrusive minerals (silicates)	Litter / woody biomass / lignin	Soil degradation, infiltration, biological crusts, dry carbon cover, moisture, formation, contamination
Individual minerals	Soil organic carbonates (SOC)	Soil mineralogy
Mineral groups	fCover (soil/vegetation)	Soil color

Conclusions

- Imaging spectroscopy enables biophysical and biochemical variables of the Earth's surface and atmospheric composition to be mapped with unprecedented accuracy.
- Imaging spectroscopy has significantly contributed to an improved physical understanding of interactions of photons with the atmosphere, cryosphere, land and water
- Imaging spectroscopy offers to bridge scaling gaps from previously non-accessible scale ranges (from molecules to ecosystems)
- Imaging spectroscopy is still an emerging market, but not yet sufficiently a commodity product

Conclusions

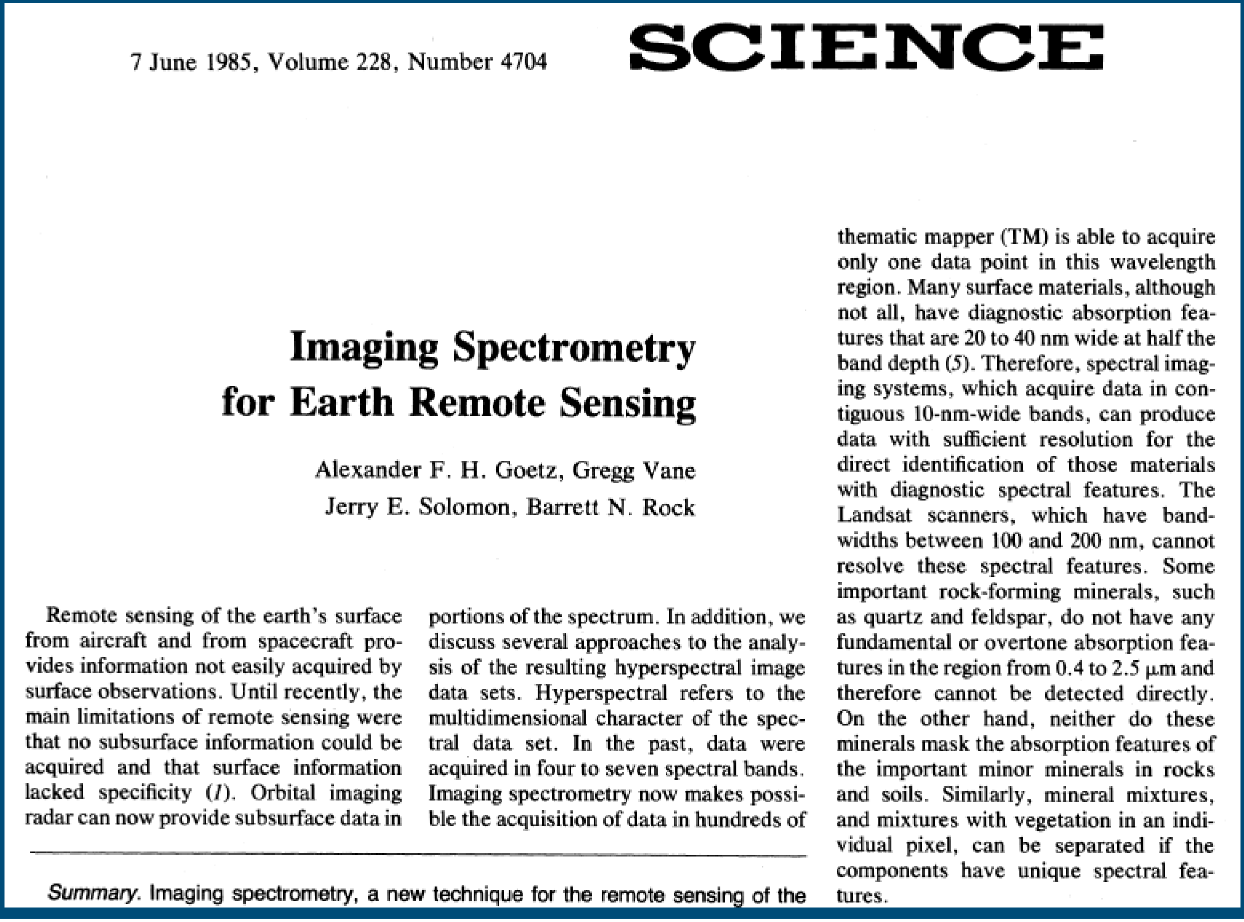
- Lessons (not) learned
  - ‘The advantage of the concept [of imaging spectrometry] is that no more committees need to be formed to develop a rationale for particular spectral bands and to compromise among disciplines when it comes time to build the sensor’ [Goetz, 1992]
- The spectroscopy community has significantly matured by gaining insight and competencies

Outlook

- To achieve new success, improved data quality and wider availability of consistent imaging spectrometer observations to the user community are required
- Combined instrumented approaches are not only with complementing measurement techniques (LIDAR, SAR, fluorescence, etc.), but also with multispectral sensors that have wider swaths and more frequent sampling intervals
- Broader availability of high-performance computing resources is needed to run quantitative, physically based models
- The imaging spectroscopy community has to increase its efforts to convince relevant stakeholders of the urgency to acquire for the Earth, continuous highest quality imaging spectrometer data for extended periods of time
- The observed trends indicate that this need is becoming better understood and seen as essential for the sustainable development of our resources and the protection of our environment.

A few personal remarks on Alex Goetz

- It all started with a risky decision …



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Imaging Spectrometry for Earth Remote Sensing

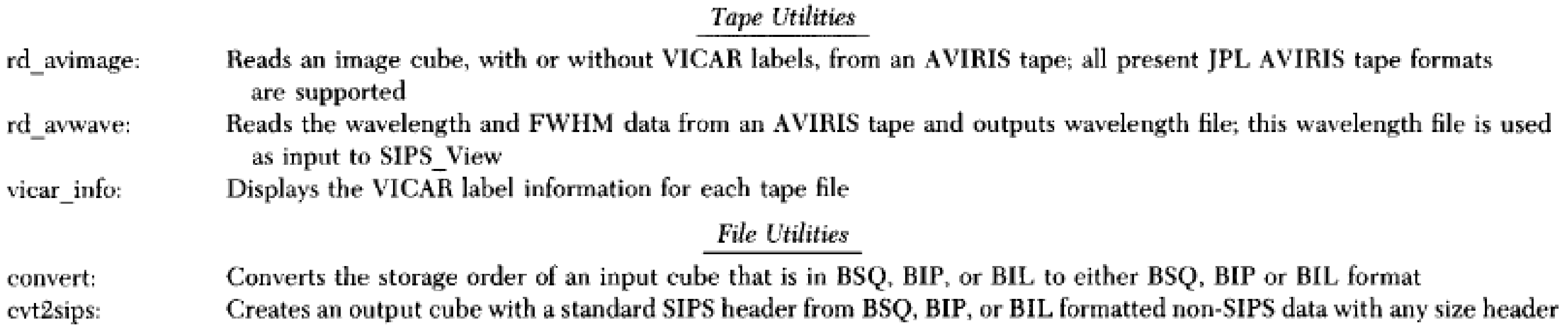
Alexander F. H. Goetz, Gregg Vane
Jerry E. Solomon, Barrett N. Rock

Remote sensing of the earth's surface from aircraft and from spacecraft provides information not easily acquired by surface observations. Until recently, the main limitations of remote sensing were that no subsurface information could be acquired and that surface information lacked specificity (*1*). Orbital imaging radar can now provide subsurface data in portions of the spectrum. In addition, we discuss several approaches to the analysis of the resulting hyperspectral image data sets. Hyperspectral refers to the multidimensional character of the spectral data set. In the past, data were acquired in four to seven spectral bands. Imaging spectrometry now makes possible the acquisition of data in hundreds of

thematic mapper (TM) is able to acquire only one data point in this wavelength region. Many surface materials, although not all, have diagnostic absorption features that are 20 to 40 nm wide at half the band depth (*5*). Therefore, spectral imaging systems, which acquire data in contiguous 10-nm-wide bands, can produce data with sufficient resolution for the direct identification of those materials with diagnostic spectral features. The Landsat scanners, which have bandwidths between 100 and 200 nm, cannot resolve these spectral features. Some important rock-forming minerals, such as quartz and feldspar, do not have any fundamental or overtone absorption features in the region from 0.4 to 2.5 μm and therefore cannot be detected directly. On the other hand, neither do these minerals mask the absorption features of the important minor minerals in rocks and soils. Similarly, mineral mixtures, and mixtures with vegetation in an individual pixel, can be separated if the components have unique spectral features.

Summary. Imaging spectrometry, a new technique for the remote sensing of the

Aller Anfang ist schwer ...

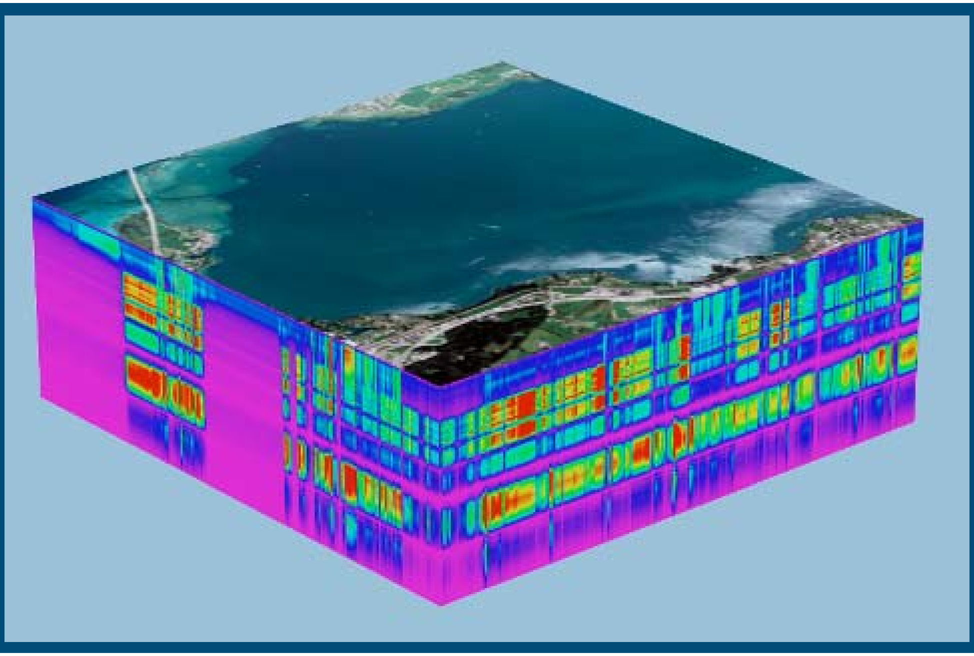


Tape Utilities

rd_avimage:	Reads an image cube, with or without VICAR labels, from an AVIRIS tape; all present JPL AVIRIS tape formats are supported
rd_avwave:	Reads the wavelength and FWHM data from an AVIRIS tape and outputs wavelength file; this wavelength file is used as input to SIPS_View
vicar_info:	Displays the VICAR label information for each tape file

File Utilities

convert:	Converts the storage order of an input cube that is in BSQ, BIP, or BIL to either BSQ, BIP or BIL format
cvt2sips:	Creates an output cube with a standard SIPS header from BSQ, BIP, or BIL formatted non-SIPS data with any size header



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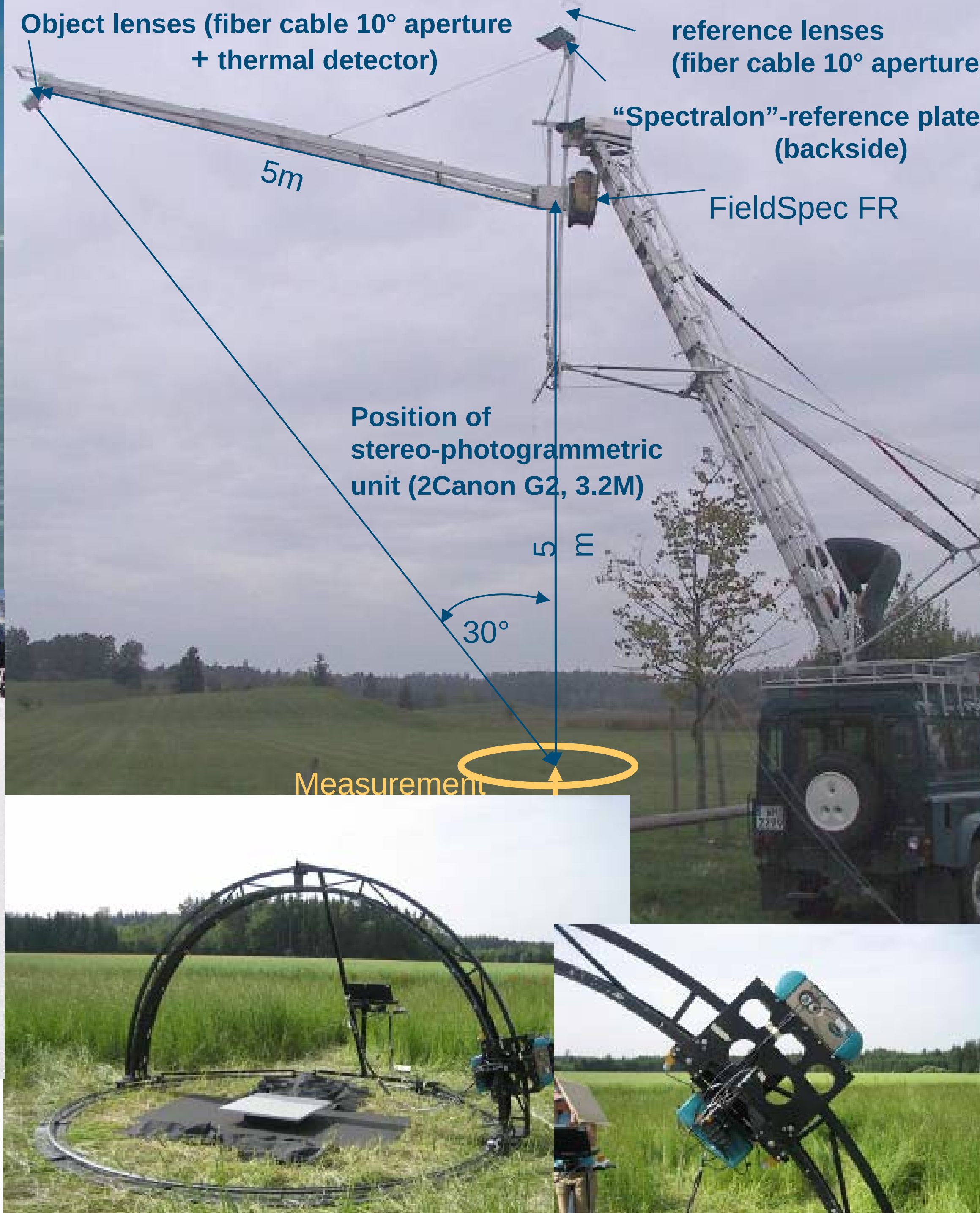

Object lenses (fiber cable 10° aperture
+ thermal detector)

reference lenses
(fiber cable 10° aperture

“Spectralon”-reference plate
(backside)

FieldSpec FR

Position of
stereo-photogrammetric
unit (2Canon G2, 3.2M)

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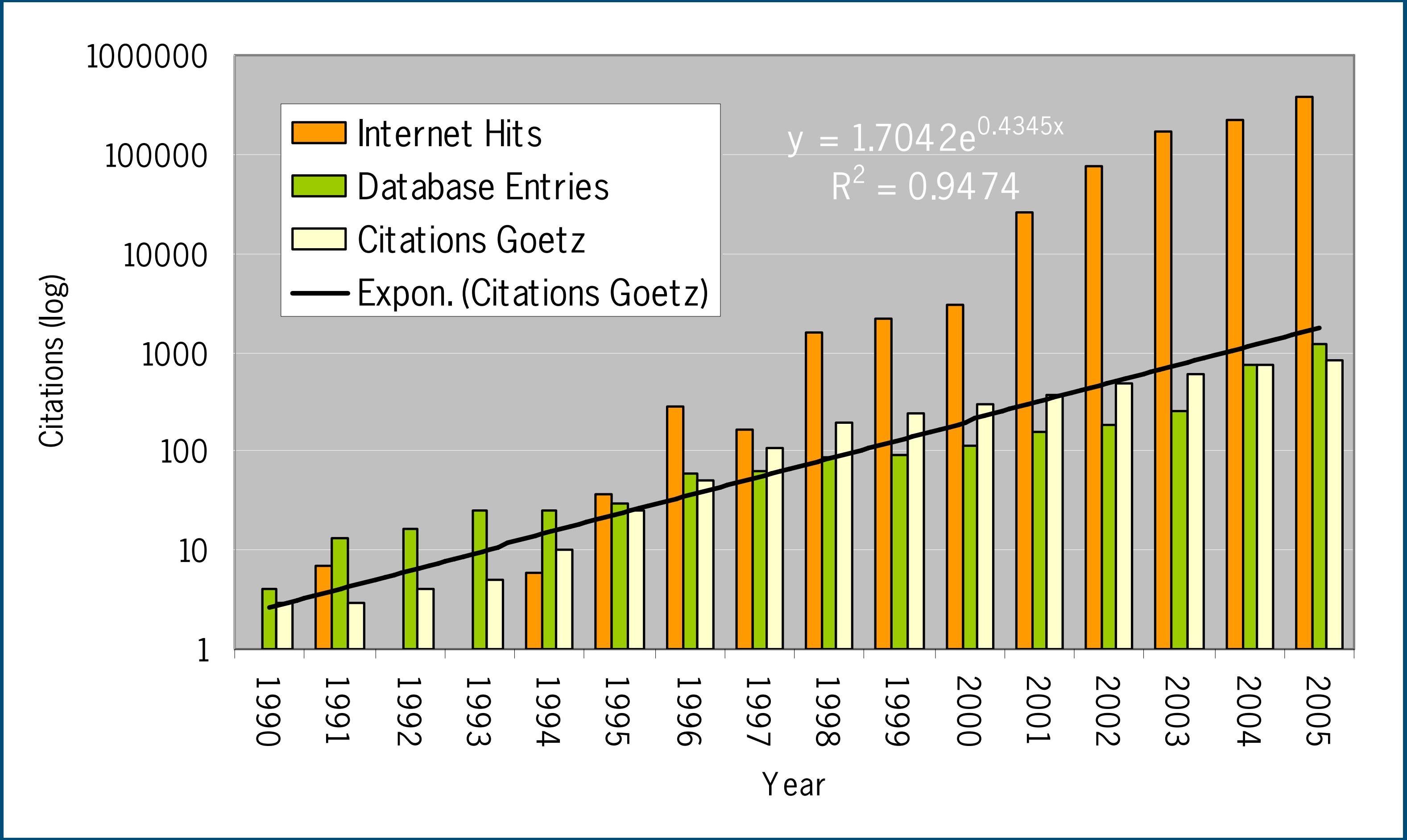
Continuous Impact



Closing Remark

- On behalf of all participants, co-authors, authors, and organizers of this event, we would like to thank Alex Goetz for his pioneering leadership in the field of imaging spectrometry!

Thank you for your attention!

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