PHM Society 2016
Denver, CO

Special Panel on “PHM for Human Assets”

PHM for Astronauts – A New Application

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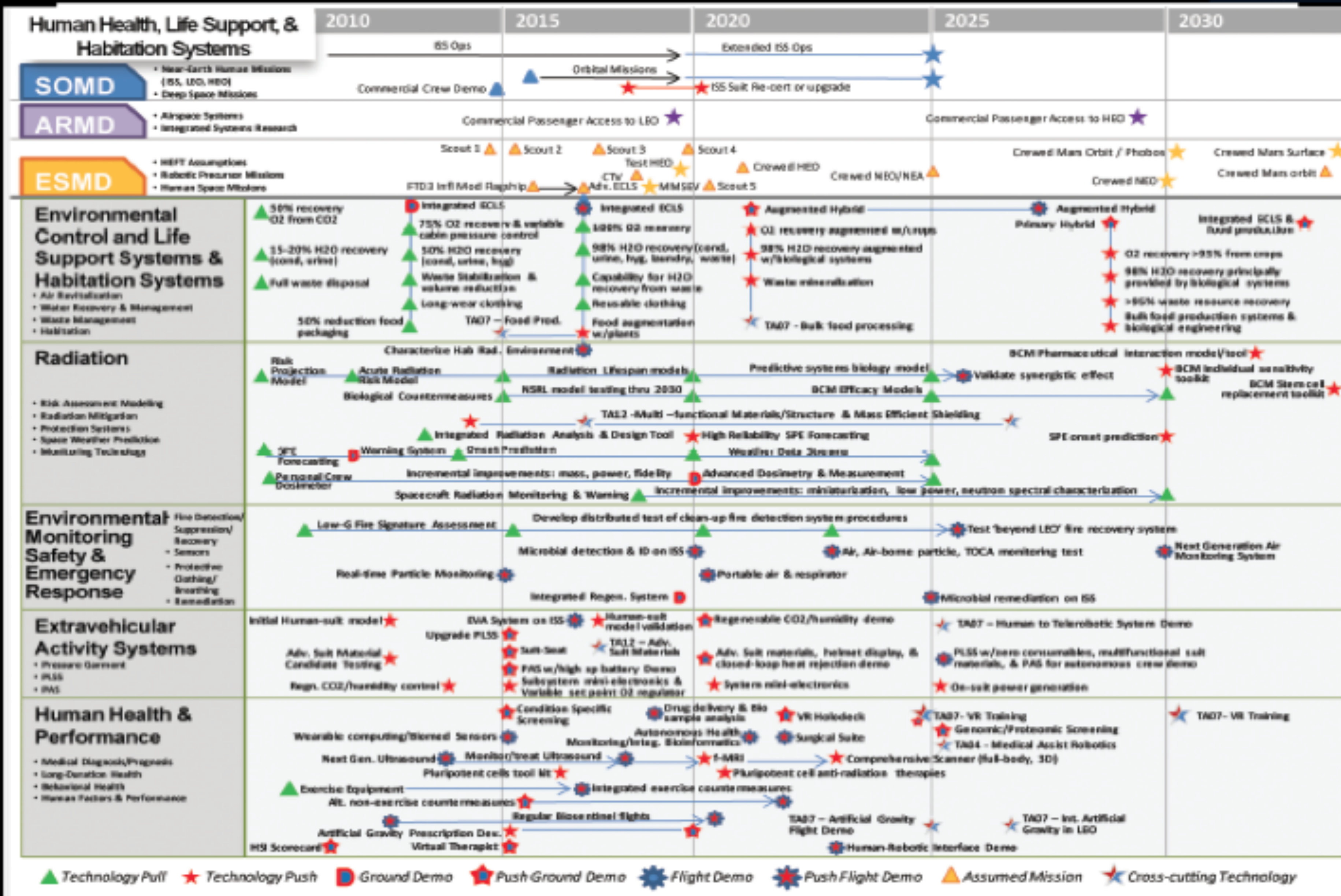
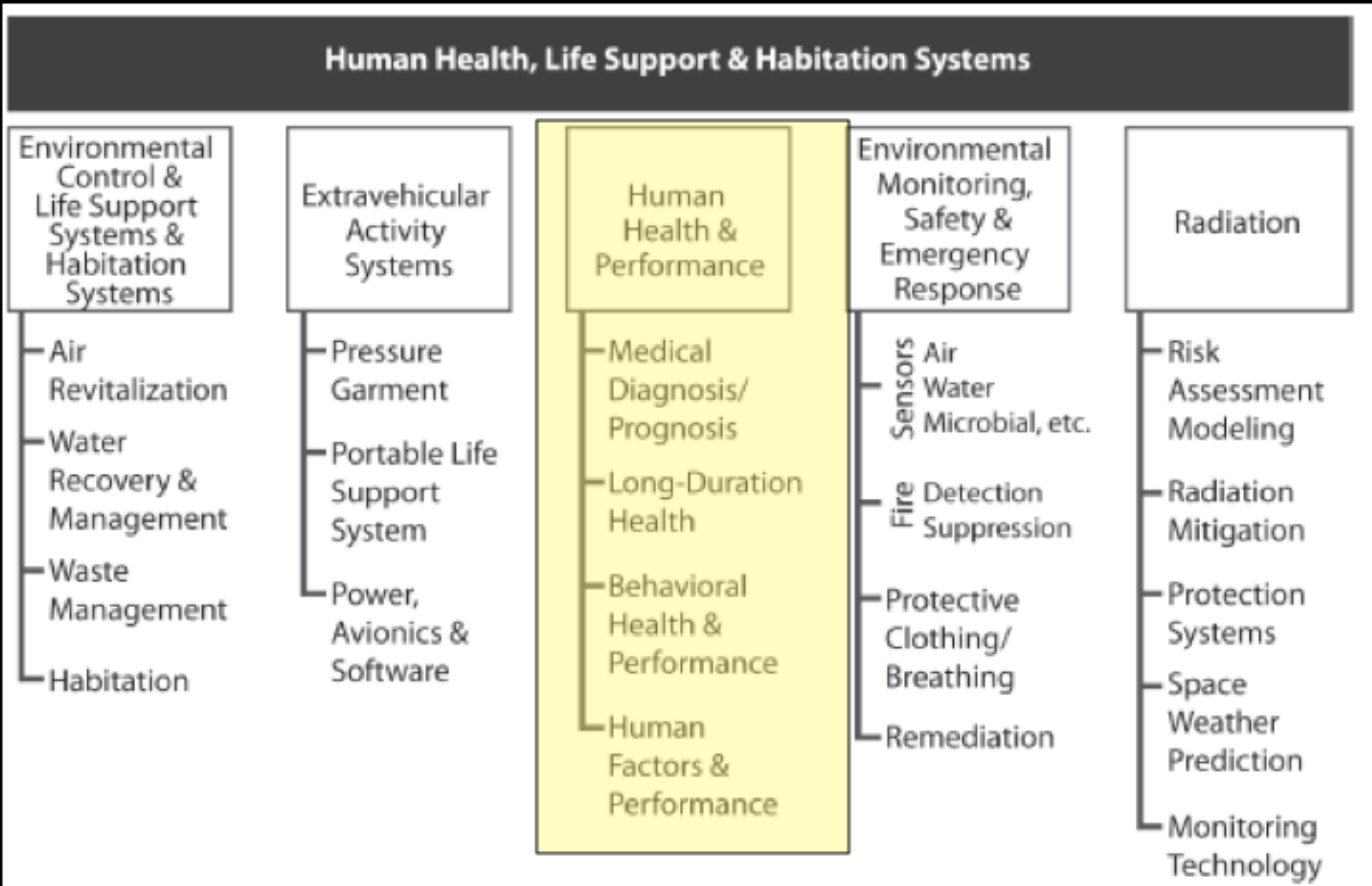
Space Technology Roadmap by NASA

Human Health, Life Support and Habitation Systems (Technology Area #6)



Human Health, Life Support and Habitation Systems

(Technology Area #6)



Human Health, Life Support and Habitation Systems
(Technology Area #6)

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Technology	Current SOA/Practice	Major Challenge(s)	Recommended Milestones/Activities to Advance to TRL-6 or beyond
Condition Specific Screening Technology	Astronauts are screened for physical and psychological conditions	Conditions exist that current medical technology cannot detect far enough in advance	2012-20: Early screening technologies for dental emergencies, subclinical medical conditions including malignancies, cataracts, individual susceptibility levels to radiation and carbon dioxide exposures, osteoporosis, oxidative stress and renal stone formation, sleep disorder, anxiety and depression. In a phased-fashion, the development in the identified areas will be implemented
Genetic/Phenotypic Screening	Not in practice for selections	Ethically acceptable screening technologies	2015-25: Screening technologies to personalize in-flight medical planning and care
Autonomous Medical Decision	Screen-shots of paper procedures	Lack of standards in data output from various medical instrumentation	2012-20: Handheld, smart device that integrates with vehicle, hardware, patient, care giver and Mission Control
Integrated Biomedical Informatics	Separate systems that do not seamlessly interface	Integrated standards	2012-20: Integrated electronic medical records, medical devices, inventory management system, procedures and utilizes a medical hardware communication standard

Background (continued)

PHM for Astronauts – A New Application. ***2013 Annual Conference of the Prognostics and Health Management Society*****, New Orleans, LO, October 2013**

- **Risk Mitigation Technologies to be developed:**
  - ✓ Autonomous medical decision*
  - ✓ Integrated biomedical informatics*

*NASA designation per "Human Health, Life Support and Habitation Systems: Technology Area 06" Roadmap, NASA, April 2012

Picture credit: NASA

Human Health and Performance Technical Area Details

(excerpt from the Roadmap, NASA, April 2012)

Technology	Current SOA/ practice	Recommended milestones/ activities to advance to TRL-6 or beyond
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Background

Medicine vs Engineering
Similarities

- Concepts of natural history, clinical course, and disease progression are similar to component aging, damage accumulation and fault progression
- Risk factors in medicine are similar to prognostic indicators used in PHM
- In medicine, prognostics is used to select optimal treatment/intervention policies
- In PHM, RUL estimation is used to determine optimal maintenance policies

parc
Palo Alto Research Center

Excerpt from "PHM: The second decade" by S. Uckun, M.D.,Ph.D, 2008 IEEE Aerospace conference

PHM-based Healthcare Concept vs Conventional Medicine

The PHM-based Healthcare Concept	Conventional Medicine
Focus on keeping astronaut healthy by predicting a deterioration or impairment in his/her health before a sign is detected or a symptom is manifested	Focus on detected signs and manifested symptoms in order to diagnose a medical condition, disease or disorder
Real-time 24/7 streaming, monitoring and processing	One-off, snapshots made in doctor's office
Astronaut generated data	Doctor ordered data
Individualized	Population-based
Panoramic	Data limited
Condition Based Maintenance (CBM)	Diagnosis-based treatment

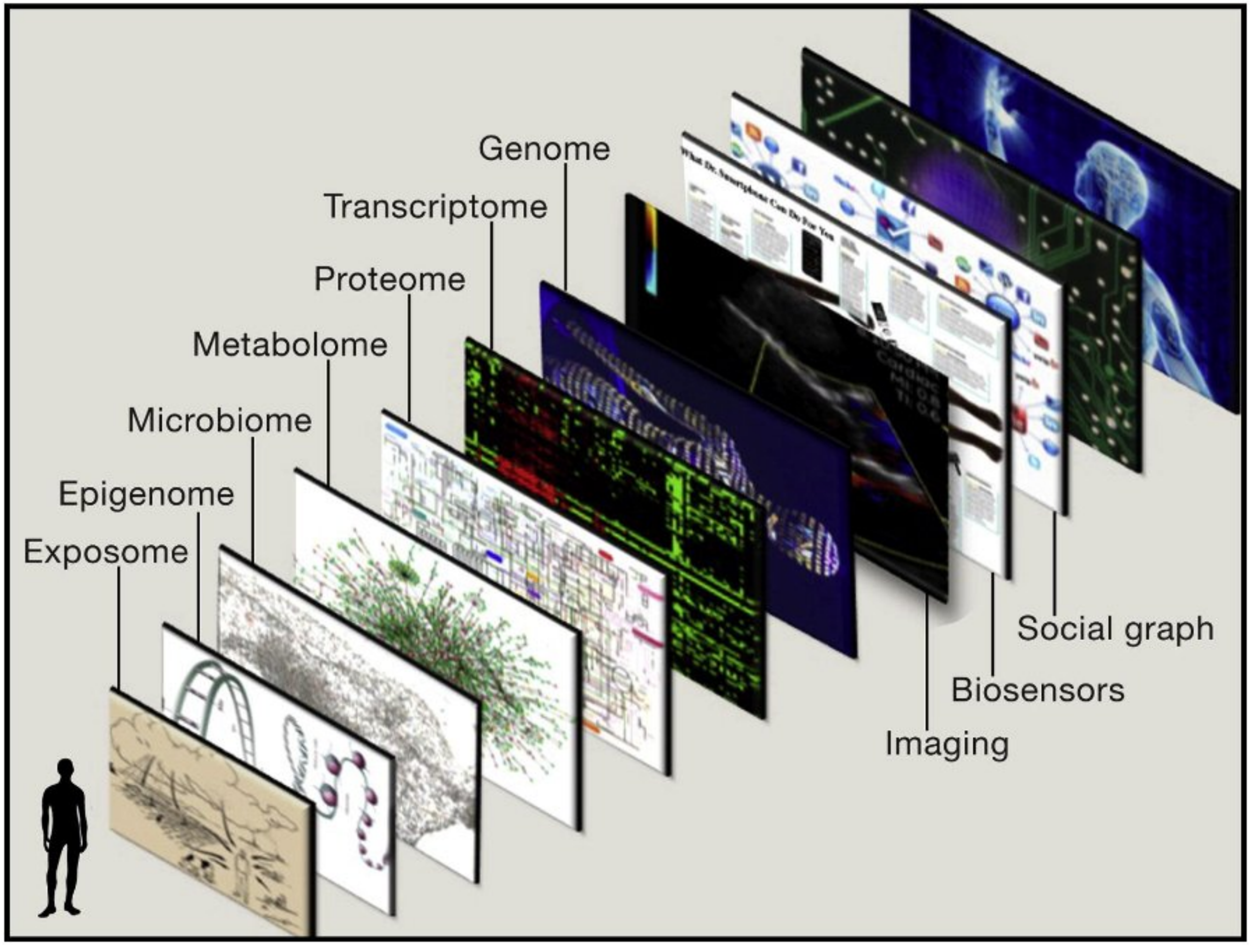
PHM-based Healthcare Concept vs Conventional Medicine (continued)

The PHM-based Healthcare Concept	Conventional Medicine
Evidence-based health maintenance	Diagnostics and treatment limited to experience and knowledge of healthcare provider
Used in conjunction with COTS wireless sensor network communicating with custom smartphone-based or tablet-based apps, reasonably priced	Expensive, Big-Ticket Technologies
Intuitive and customizable dashboard-based interface with user-friendly language designed for astronaut as the only end-user	Medical language and an interface designed for healthcare professional
Astronaut healthcare autonomy paradigm, rather than the one of tele-medicine	Medical Paternalism
Astronaut edited and owned his/her CEHR	Non-shared EHR that owned by healthcare provider
Astronaut engagement	Compliance with healthcare provider directives

The PHM-based Technology Key Components

- ✓ **Condition-Based Maintenance (CBM) with predictive diagnostics capability**
- ✓ **Non-attributed Electronic Health Records (EHR)**
- ✓ **Real-time health monitoring, measurement, and processing:**
  - ✓ Both natural and computationally generated bio-markers
  - ✓ Non-obtrusive and non-invasive sensors
- ✓ **Health management autonomy:**
  - ✓ Routine self-diagnostics
  - ✓ Decision making on which measurements, when, and with whom to share
- ✓ **Non-medical User Interface:**
  - ✓ The ultimate end-user of the portable system is crew member rather than healthcare professional
  - ✓ Intuitive and customizable

Health Monitoring and Data Fusion: Human Geographical Information System



Infografic credit: Topol, E.J. (2014).
Individualized Medicine from Prewomb to Tomb. Cell, vol. 157

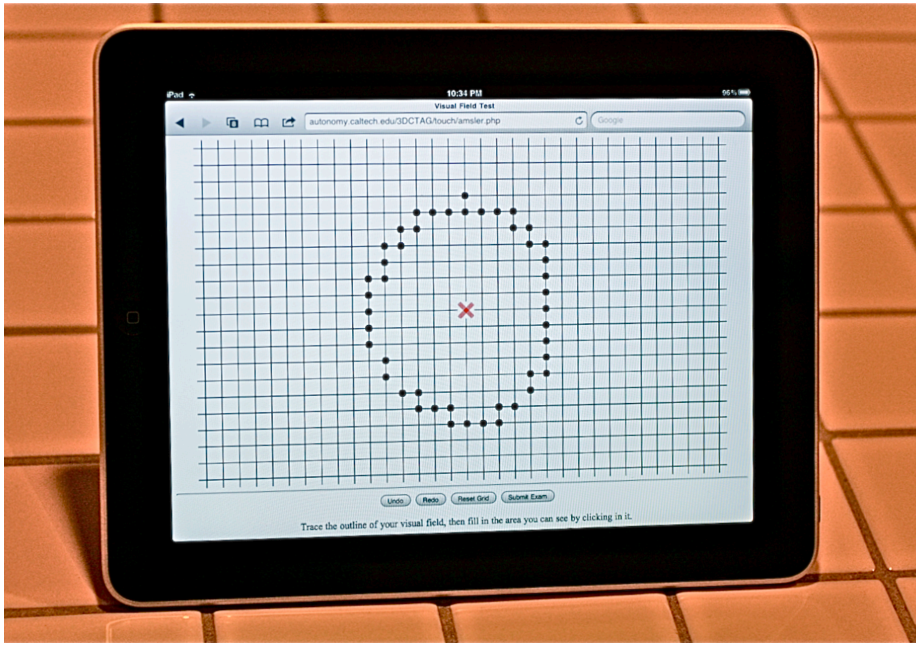
Natural Biomarkers vs Computationally Generated Biomarkers

- Biomarker is a health-related characteristic that is objectively measured and evaluated as an indicator of:
  - ✓ normal biological processes
  - ✓ pathogenic processes
  - ✓ pharmacologic responses to a therapeutic intervention
- Computationally generated biomarker is a biomarker that is generated indirectly by applying computation to health-related data in terms of the Human Geographical Information System (see slide 8). Examples are:
  - ✓ ECG morphological variability (a.k.a. heart rate variability)
  - ✓ Genetic diversity

mHealth Technologies vs the ones currently in use on ISS

Corventis Inc. https://www.youtube.com/watch?v=ILXNg1iSTT0

PHM-based technologies vs the ones currently on ISS (continued)



Picture credit:
[Visual and Autonomous Exploration Systems Research Laboratory at Caltech]

Picture credit: NASA

CEEABLE

Financial Disclosure: W. Fink is CTO and Co-Founder of Ceeable

Importance of Vision during Spaceflight

- Primary sense used by astronauts
- Essential during critical phases of spaceflight:
  - Launch
  - Entry and landing
  - Rendezvous and docking
  - Robotic operations
  - Spacewalks (EVA)

➔ **Vision is a key medical criterion for acceptance to the astronaut corps**

Note: 63% of pilot astronauts and 70% of mission specialists require vision correction

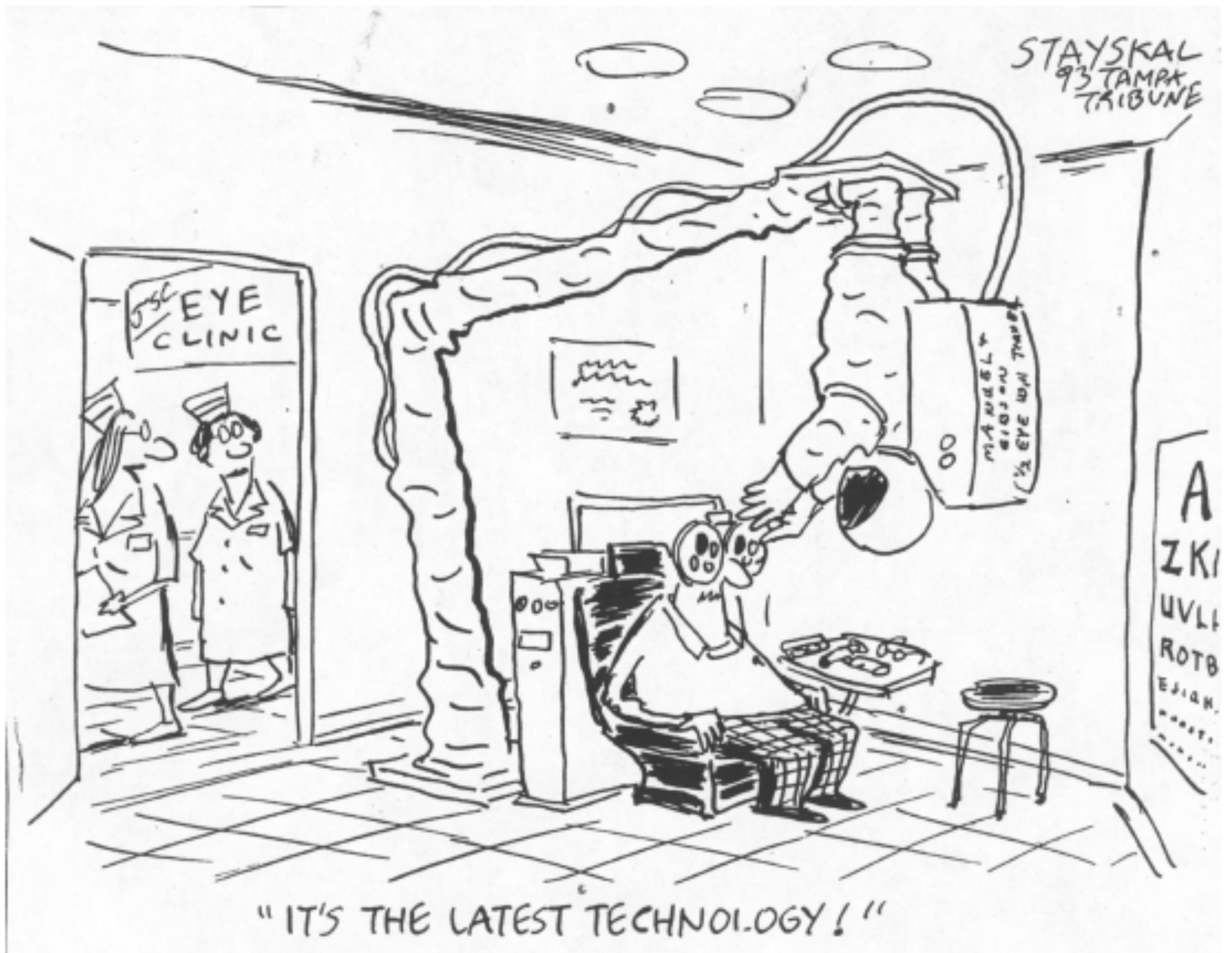
The spaceflight environment has significant influence on the visual and ocular system that can adversely affect astronaut performance, and may lead to long-term health consequences!

Vision Hazards of Human Spaceflight

- Intracranial hypertension from fluid shifts
- Intraocular hypertension and glaucoma from fluid shifts
- Cataracts
- Macular degeneration, Retinal migraine, Retinal detachment
- Blindness
- 34% of astronauts experienced vision changes during missions
- Half of long duration astronauts report primarily increasing farsightedness
- As of June 2012 15 US ISS long-duration spaceflight astronauts experienced some or all of the following: hyperopic shift, choroidal folds, cotton wool spots, globe flattening, and/or optic disc edema (papilledema) → Visual Impairment/Intracranial Pressure (VIIP) Syndrome (top spaceflight risk identified by NASA)
- Corneal, lens, and retinal damage from UV exposure
- Retinal thermal damage from excessive visible light, IR, and other types of radiation
- Hypoxia during depressurization prior to EVA
- Toxic environmental poisoning (several combustion events have occurred in space, and crews have been exposed to ethylene glycol, Freon, Halon, formaldehyde, lead, cadmium, and chloroform)

[NASA Patient Condition Database]

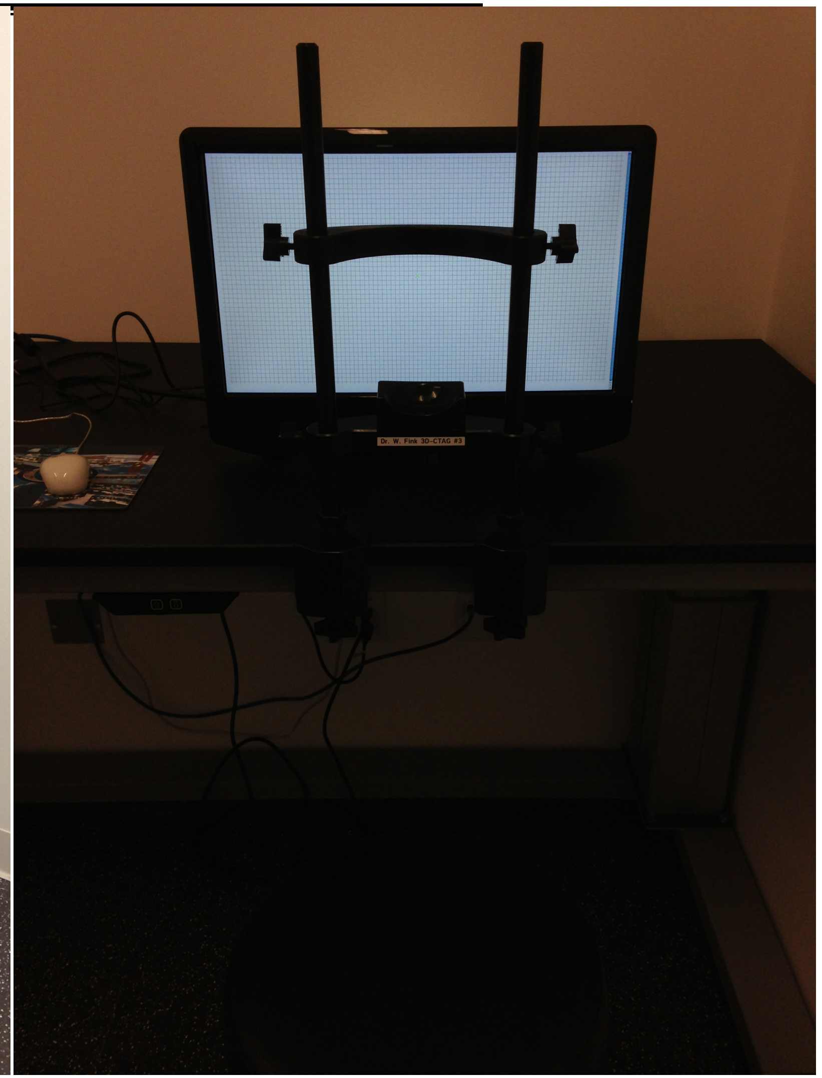
Future of "Vision Testing in Space" ???



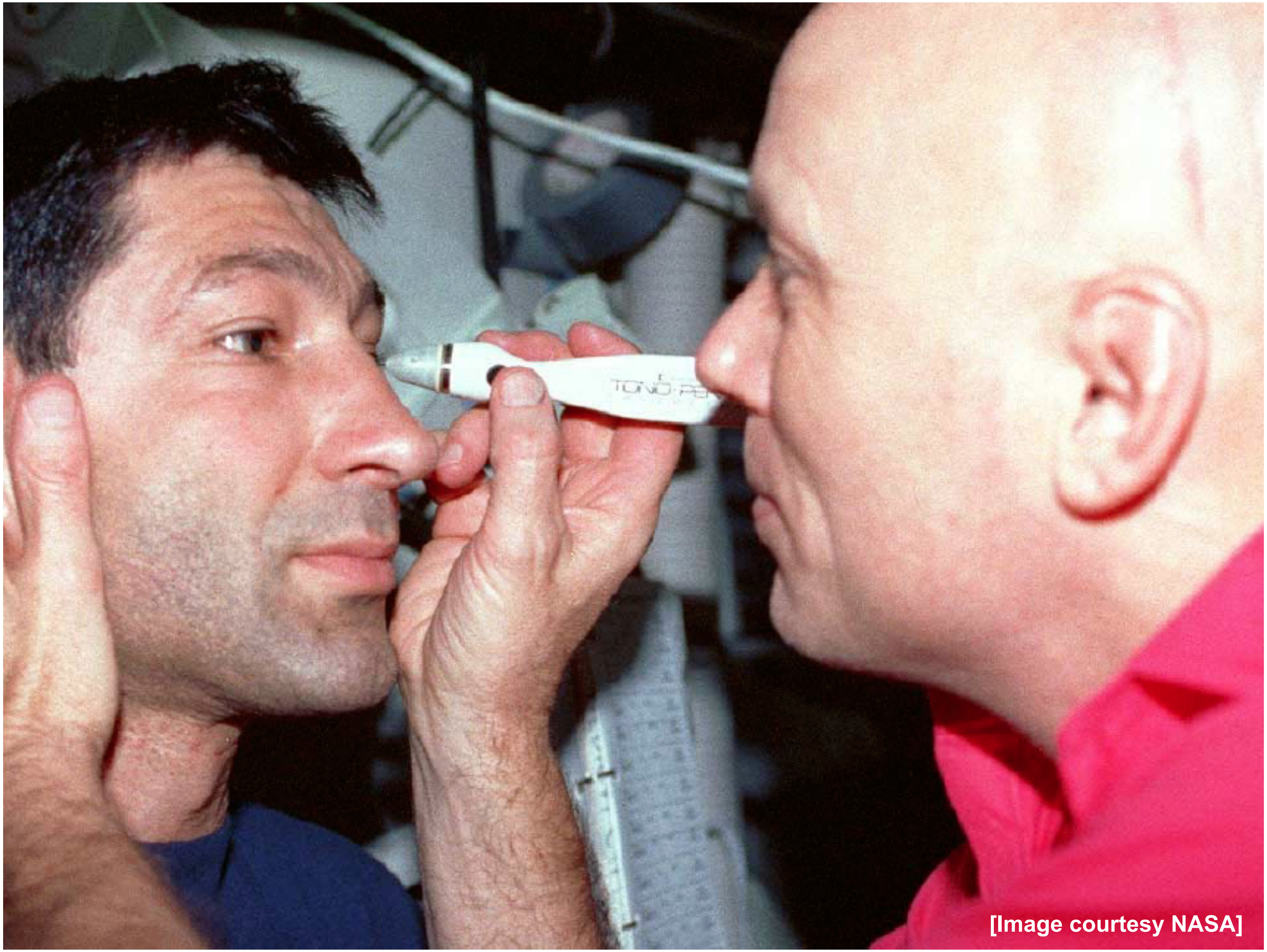
[Image courtesy Keith Manuel]

Comprehensive Visual Field Test & Diagnosis Systems

Clinical Setup to Examine VIIP Syndrome



Current Vision/Ocular Testing on Shuttle



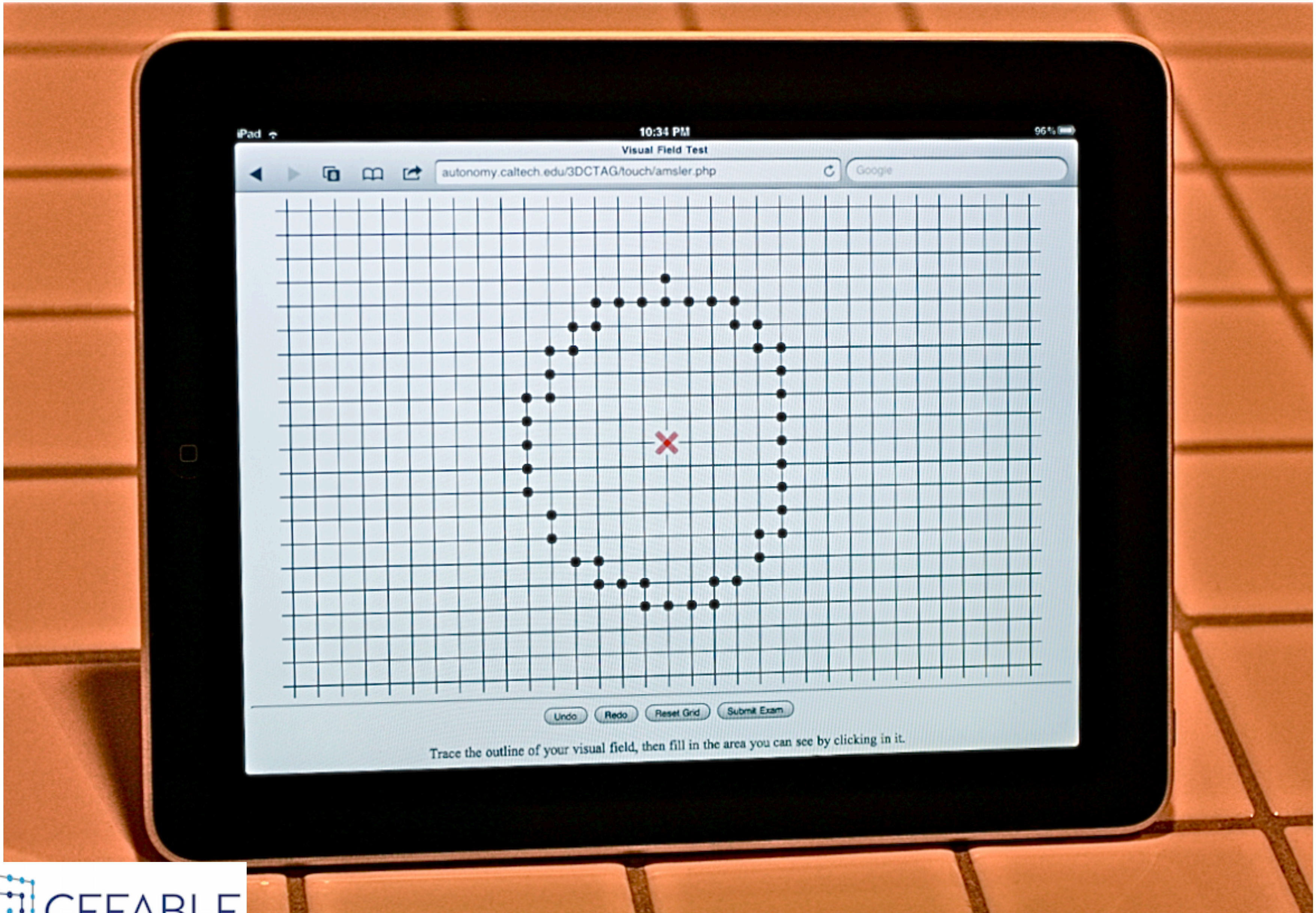
[Image courtesy NASA]

Current Vision/Ocular Testing on ISS

ISS027E013199

Comprehensive Visual Field Test & Diagnosis Systems

In-flight Testing via iOS Device (here: iPad)



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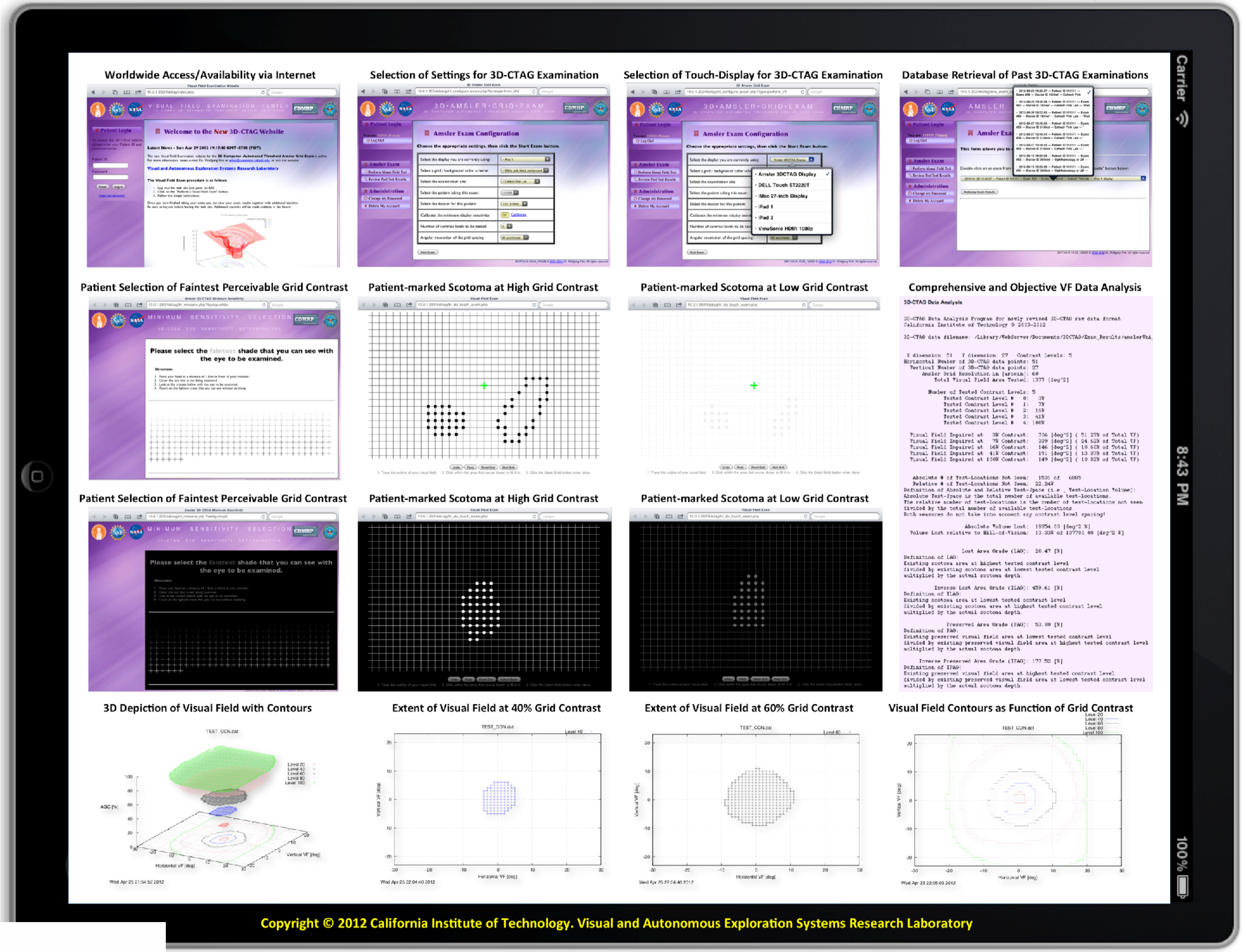
Comprehensive Visual Field Test & Diagnosis Systems

Visual Field Test Results, Analyses, and Interpretation

Fink et al., ARVO 2012; Fink & Sadun, J Biomed Opt 2004; Caltech US-Patents #6,578,966, #6,769,770, #7,101,044, EP #1276411



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Research Issues to Be Resolved

- ✓ Articulate mission-specific effects of stressors, alone and in combination
- ✓ Identify changes of pharmacokinetic characteristics of medications and respective side-effects during space mission
- ✓ Develop metrics to measure mission-relevant health performance
- ✓ Identify environmental, genetic, physiological, and psychological factors to understand their roles in resilience to stressors

Real-Time Monitoring for Astronaut Health: *Managing the Stressors*

- Exposure to solar and space radiation;
- Prolonged period of exposure to microgravity;
- Confinement in close, relatively austere quarters;
- Limited contact with family and friends;
- Isolation (small number of crew members);
- Chronically inadequate sleep;
- Work overload;
- Atmospheric composition (e.g., CO_2 concentration);
- Volatile organic compounds;
- Variation in light spectrum;
- Vibration;
- Noise;
- Monotony;
- Environment pollution.

Implementation Issues and Challenges

- ✓ Privacy
- ✓ Security
- ✓ ISS Crew Health Care System (CHeCS) out-of-date architecture
- ✓ Lack of actionable data
- ✓ Inconsistent data
- ✓ Stand-alone devices instead of being integrated into an interoperable ecosystem including big data applications in order to provide healthcare at the required level

Contributors to the Collaboration Project on Implementation of the Concept

✓AIAA Systems Engineering Committee (USA)

✓California Institute of Technology (USA)

✓Institute for Bio-Medical Problems of Russian Science Academy (Russia)

✓PHM Society (USA)

✓University of Arizona (USA)

✓University of Ontario Institute of Technology (Canada)

✓University of Technology (Russia)

The contributors are listed in the alphabetical order

Conclusion

- Rather than treat a diagnosed health disorder, the suggested PHM-based concept, in contrast, keeps the crew healthy by providing the crew with early and actionable real-time warnings of impending health issues that otherwise would have gone undetected.
- The PHM-based healthcare solutions enable long-duration, deep-space human exploration missions with inherent:
  - ✓ minimal resupply of consumables
  - ✓ limited support from the mission control center and ground personnel
- Spin-off examples:
  - ✓ Home and rural healthcare
  - ✓ Theatre
  - ✓ Healthcare in disaster-stricken areas

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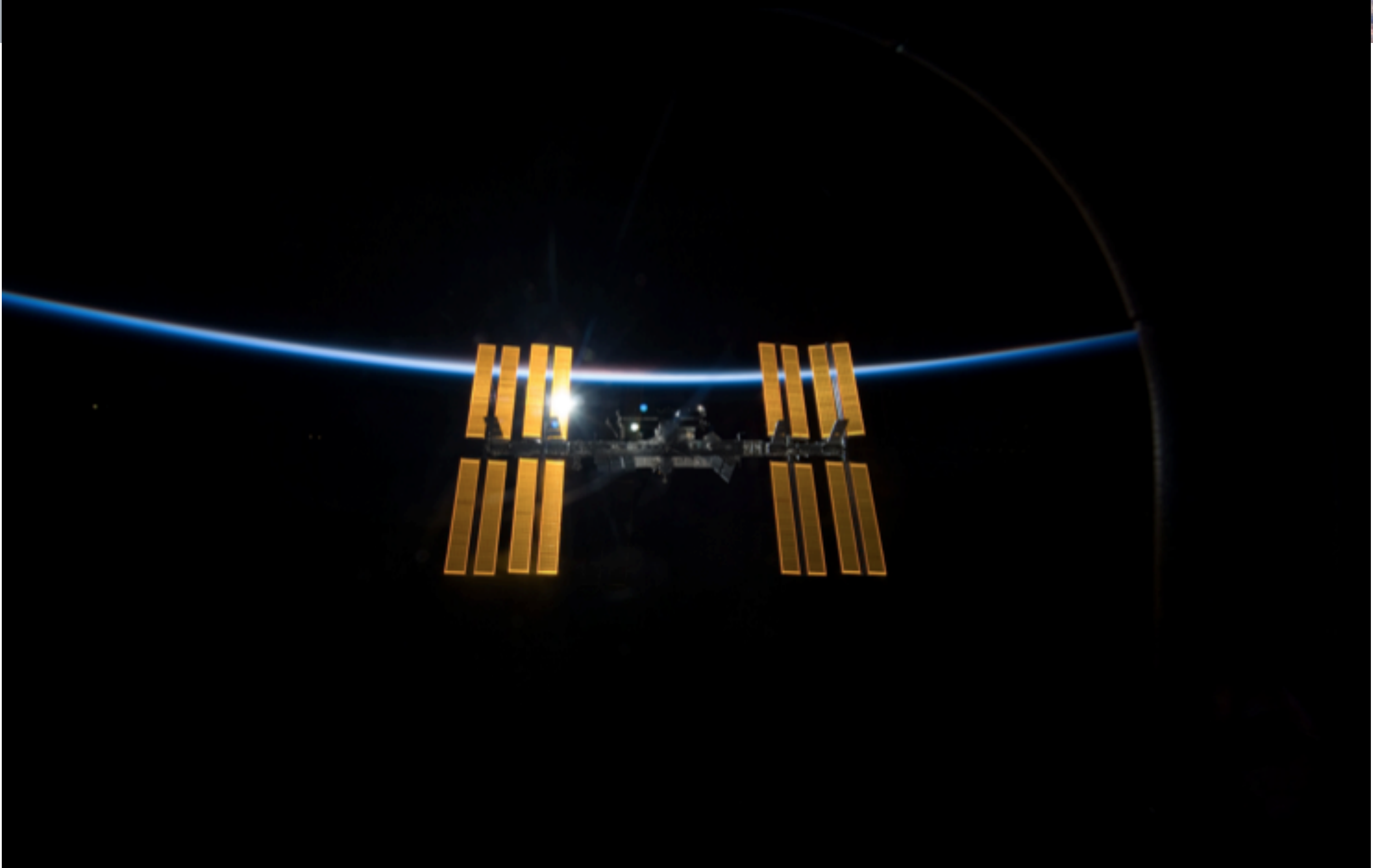

[Images courtesy NASA]

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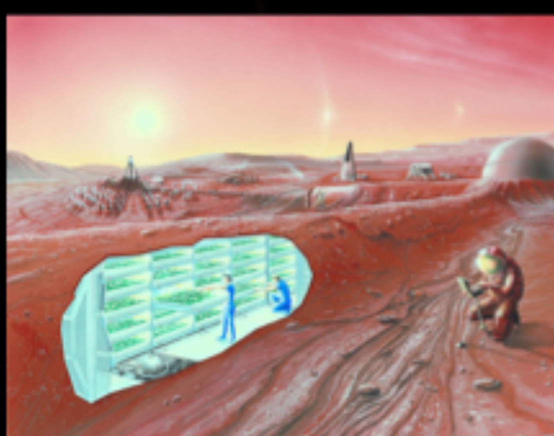
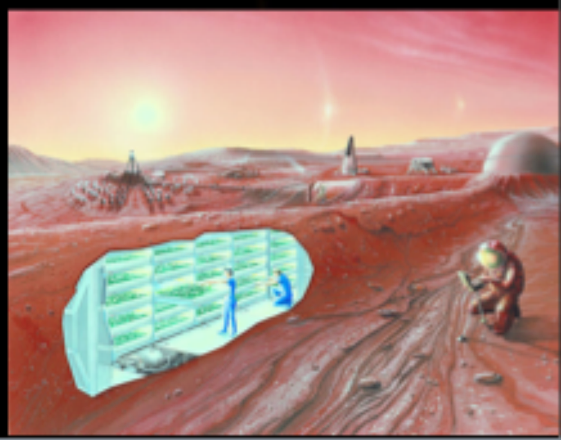


[Images courtesy NASA]

Thank you for your attention!



[Images courtesy NASA]

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