

Experiences and Issues of The US PNT (Position Navigation and Time) Advisory Board (PNTAB)

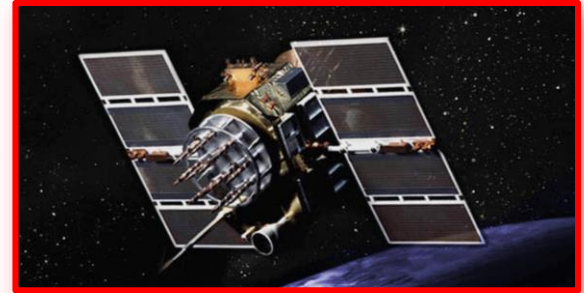
Analogies to UAG of the National Space
Council

Brad Parkinson Stanford

Including: Highlighting an ongoing threat regarding
Radio Frequency Allocations for Space-based systems

GPS - 24/7, worldwide

(Accuracies to fractions of an inch)



- Received signal weaker than a millionth of a billionth of a watt
- Over 3 Billion receivers in Use across planet
- Taken for granted world wide - literally 100s of applications
- Economic value greatly exceeds \$65B/year
- An essential part of US infrastructure (DHS)

Purpose of US PNTAB:

Assuring PNT for all

*FACA Representing 100s of millions of diverse users
and many scores of applications*

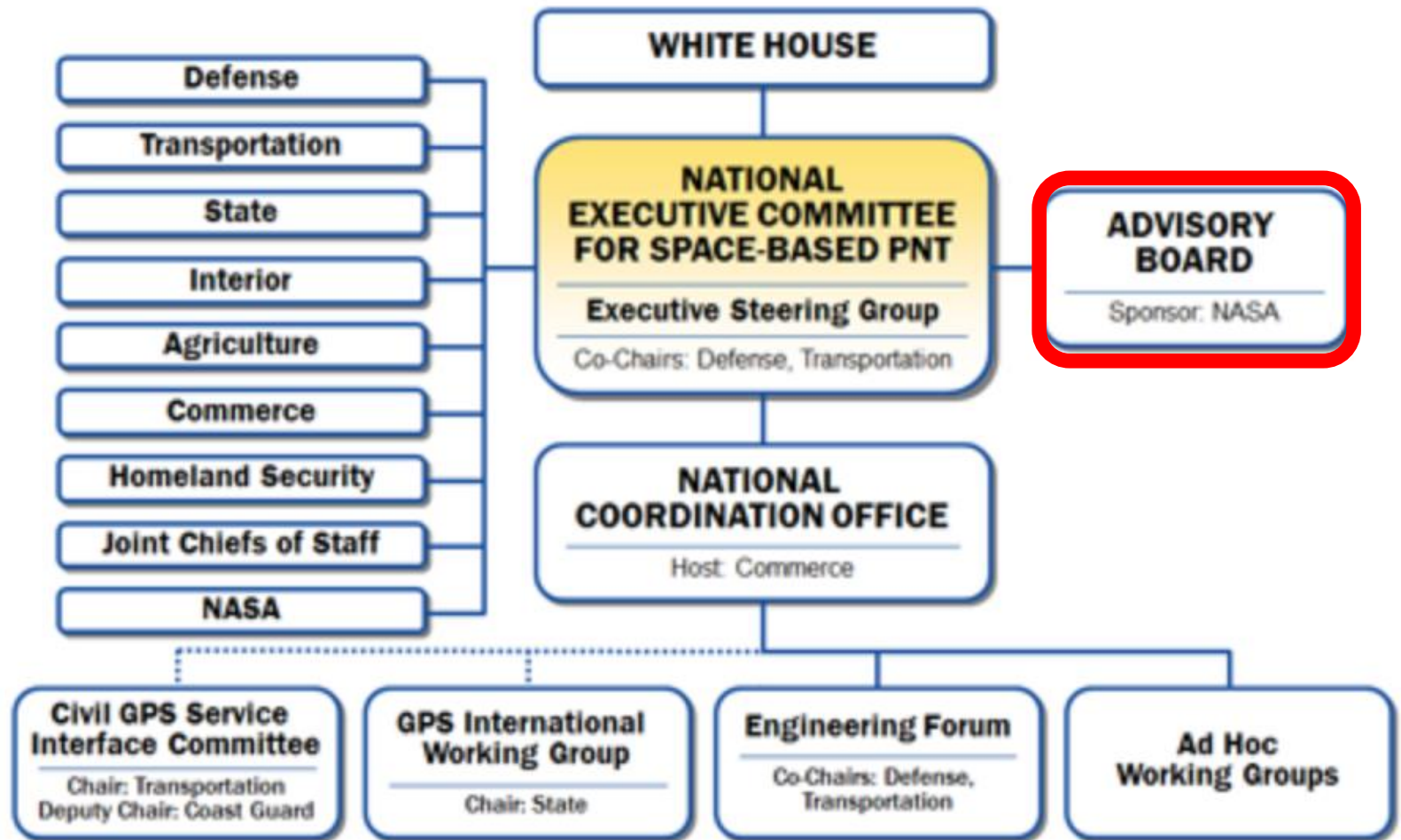
[Thad Allen](#) (Chairman), Booz Allen Hamilton

[John Stenbit](#) (Deputy Chairman), former Assistant Secretary of Defense

[Bradford Parkinson](#) (1st Vice Chair), Stanford University

[James E. Geringer](#) (2nd Vice Chair), Environmental Systems Research Institute (ESRI)

Organizational Structure



PNTAB

Membership

Over 450
Years of PNT experience -
Balanced US and International

- FACA since 2004
 - SGEs and Representatives
- The Advisory Board consists of GPS experts from outside the U.S. government.
- Currently, there are 25 members representing U.S. industry, academia, **including (5) international members.**
- The Chairman of the Advisory Board is Admiral (Ret.) Thad W. Allen. (former USCG Commandant)
- Administered by NASA under James Miller



An Example of PNTAB Activities -

Countering A Grave threat to GPS

for FAA, DOT, NASA, DOD
and
other High-Precision Users



- A certain company (Ligado) has License for transmitting Satellite to Ground for Communications in the very quiet MSS Band - very close to the Main GPS frequency
- ***But the received power was very low and did not support a large Data Rate***

But, in 2010, Ligado saw a great opportunity

- Convert the License to high power terrestrial transmissions (Asked for 15.8 Kw)
 - Tower Spacing at about $\frac{1}{4}$ mile
 - Would support broadband - sending movies etc. = 5G?
 - **Spectrum Value would jump: \$2B → \$12B+**
- Tried to get the FCC to slip this through just before Thanksgiving 2010 - while everyone was digesting turkey
- **PNT community found out and realized this would do grave harm to GPS civil receivers- We helped slow the process down. Over \$60B per year in productivity benefits were at risk...**
- **But*But** apparently a predecessor Lxxx company had already known there was a significant Clash with GPS...
 - Ligado claimed no knowledge
 - According to Harbinger lawsuit this was not true

Bottom Lines Up Front

- Ligado proposal was extensively tested by DOT
- Ligado now proposes **9.8 watt** transmitters. (Company could receive a windfall profit of over \$10B)
 - Unknown, but probably **very close tower spacing**
- Even at this reduced level, at 300m transmitter spacing, **over half the High Precision GPS receivers** would be degraded over more than 10% of the operating Region, with many degraded over 100% of the Region (Based on DOT extensive ABC Testing)
- Many other organizations have filed opposition
- The PNTAB strongly recommends **disapproval** of this proposal

At Stake: High-Precision = High-Productivity Applications

Partial List - Green particularly at risk

Aviation and Space

- Area and Enroute Navigation
- *Approach to Airport*
- *Landing to Cat III*
- *NextGen & ADS-B*
- *UAV Guidance (Drones)*
- *Space Launch Guidance*

Agriculture

- Auto Farming
- Crop Spraying
- Precision Cultivating
- Yield assessment

Robotics and Machine Control

- *Construction Vehicle Guidance*
- *Mining Vehicle Guidance*

Scientific

- International Time Standard
- Earth Crustal Movement
- Earth's Shape and Rotation Rate
- *Weather Probes*

Commercial Timing

- Power Grid Synchronization
- Cellular Network Synchronization
- Banking
- Stock Trading

Survey and Mapping

- Geodetic and Cadastral
- *Roads and Bridges*
- *Site Layout and Survey*
- *Geographic Information Systems (GIS)*

High Productivity: In harm's way ... Apt to be much less than 400 meters away from Transmitter

Construction/Infrastructure Scenarios



Photo courtesy of WSP Canada Inc

GPS HPR receiver used in construction/surveying



Photo courtesy ThinkStock

GPS HPR receiver used in construction guidance



Summary of Preliminary 2013 US GPS Benefit Estimates		
Application Category	Range of Benefits (\$ billions)	Mid-range Benefits (\$ billions)
Precision Agriculture – grain*	10.0-17.7	13.7
Earthmoving with machine guidance in construction*	2.2-7.7	5.0
Surveying	9.8-13.4	11.6
		0.145
		0.055
		0.185
		11.9
		0.038
		0.05
		5.5
		20.6
TOTAL (with alternative estimates for timing and consumer LBS averaged)	37.1-74.5	**68.7

Assured PNT for All 3

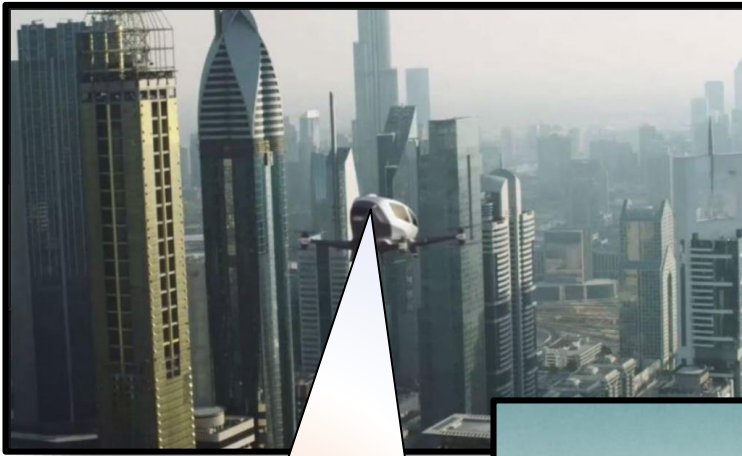
• Over \$65B In *Annual Benefits* in identified Commercial Areas

• Hi Productivity >\$33B - Heavy Reliance on High Precision GPS



Photo courtesy Medvedkov/ThinkStock
Construction/Surveying

Also In Harm's Way: Rapidly growing RPV/UAV applications



Both RPV Control and Air Traffic Monitoring depend on GPS – probable paths less than 400 Meters to Transmitter sites Apt to be Directly in Main Beam

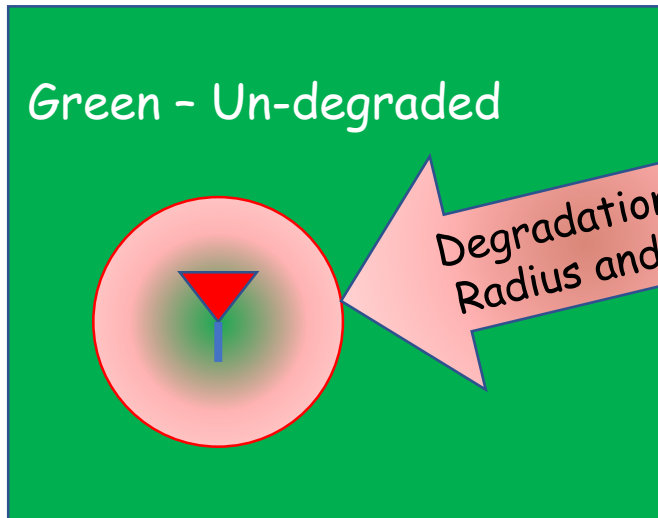
Adjacent band interference concern

“Upper” band is apparently off the table. Is this forever?



“Lower” band Power reduced to 9.8 Watts. Spacing not specified but original was ~400 meters. To meet 5G requirements it probably will be less. Perhaps about 100 to 200 meters.

Extensive DOT GPS testing helped define A "Degradation Radius"



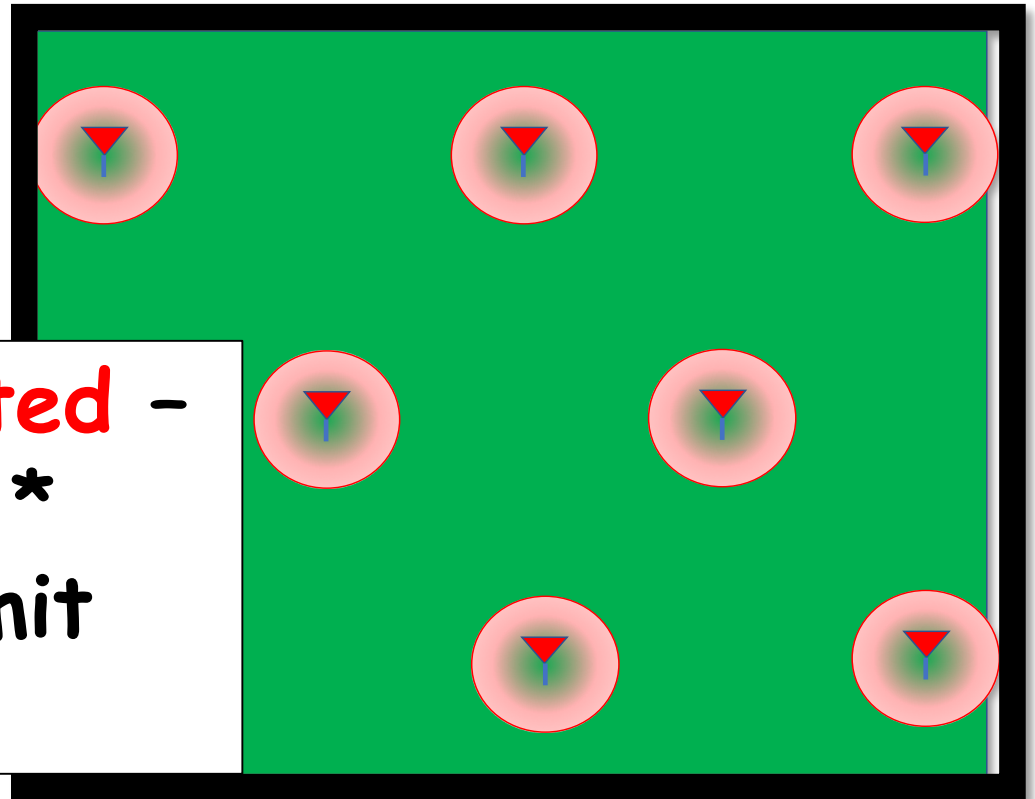
- Within that radius, GPS begins to experience degraded accuracy^{*}
- Reasonable to insist that Interfering transmitters blanket less than 10% of a region

Adjacent Band transmitters can achieve compatibility (acceptable-degradation) by either:

- Reducing Power
- Increasing Spacing between transmitters

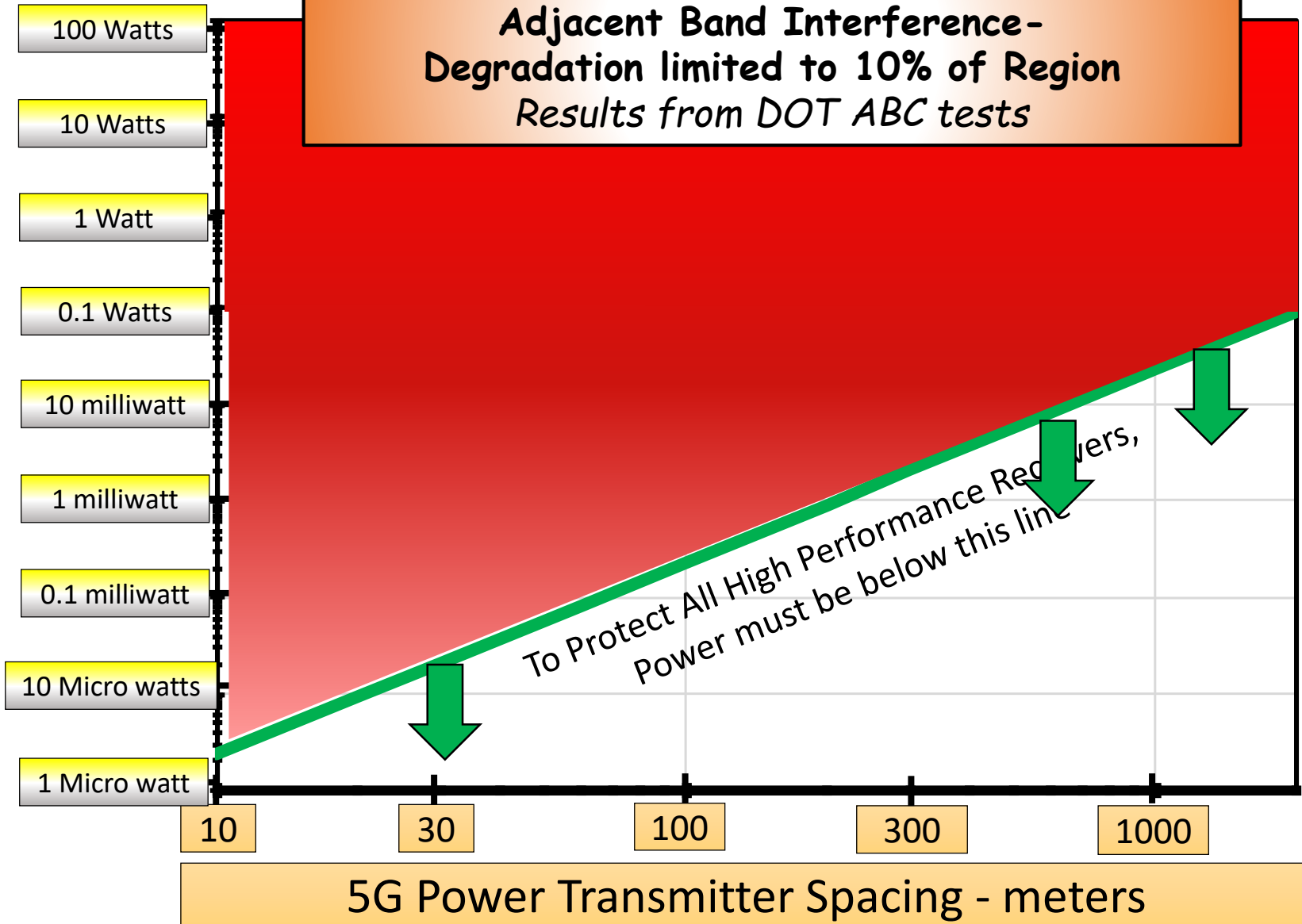
^{*} Degradation begins when interfering power exceeds 25% of the natural Background Radio Noise – (called the 1 dB interference power criterion)

So the Absolute
Minimum Spacing/Maximum Power
combination looks like:

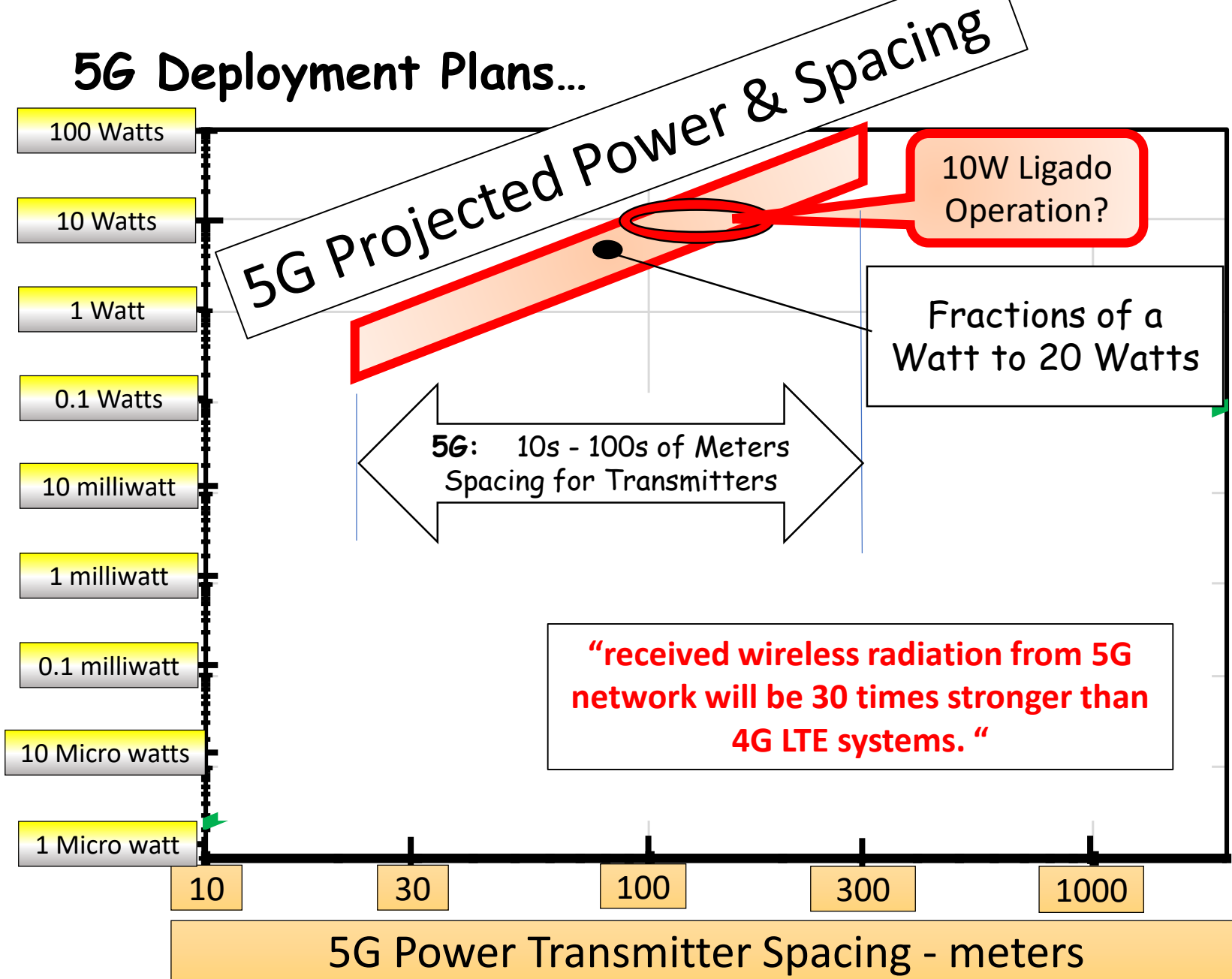


90% Area Protected -
Spacing = 6.0 *
Degradation Limit
Radius

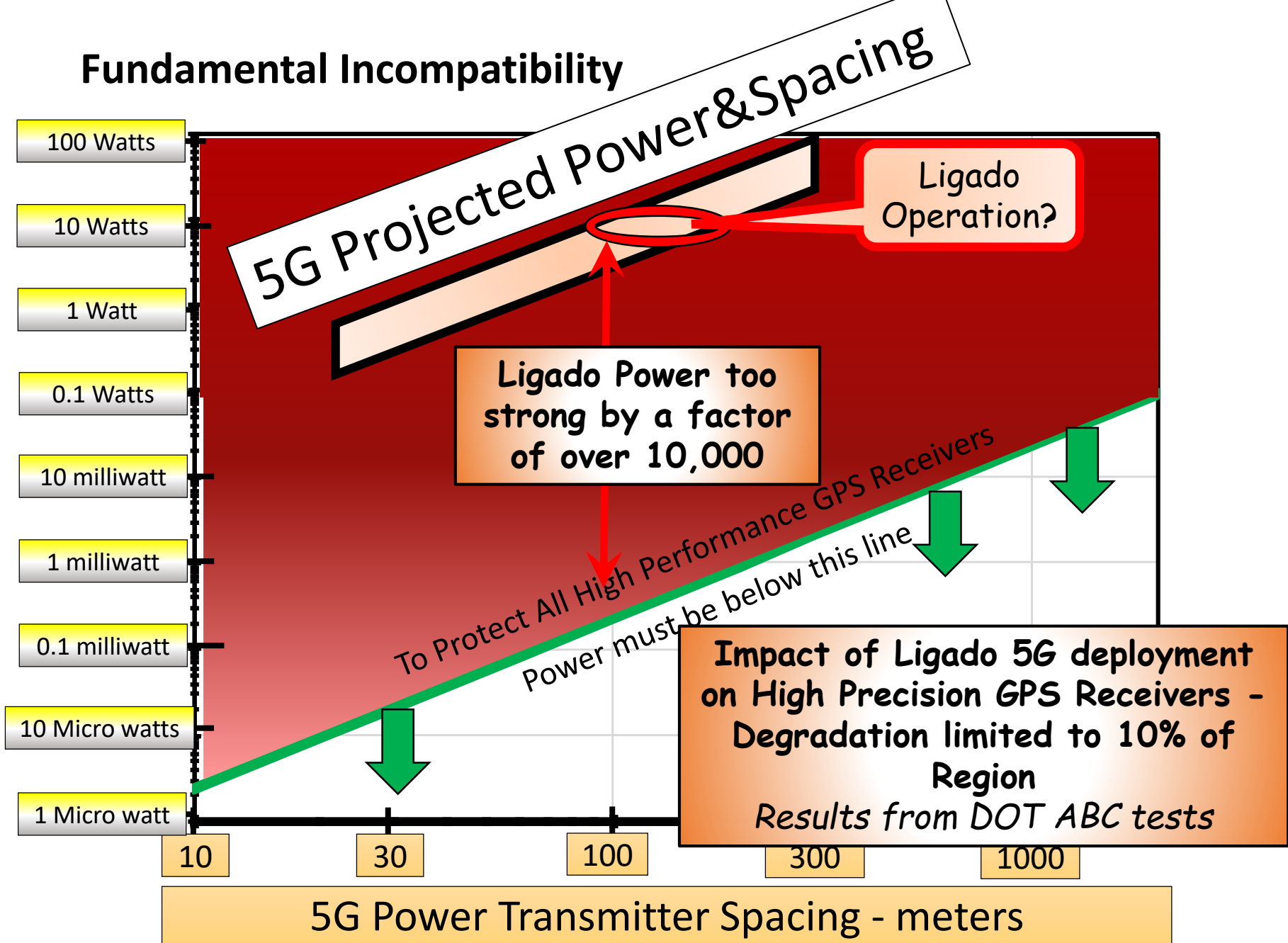
**Tolerance of High Precision GPS Receivers to
Adjacent Band Interference -
Degradation limited to 10% of Region
*Results from DOT ABC tests***



5G Deployment Plans...



Fundamental Incompatibility



To protect all High Performance
GPS receivers, at 9.8 Watts:
*tower spacing must exceed
20km -*

far greater (100 times) than the
~200 meters for 5G

What about the other
classes of GPS receivers?

Using the ABC Degradation Radii - Calculation of minimum Ligado 10W separation for various GPS Classes

Note: Ligado 5G spacing is probably 100 to 300 meters

Class of GPS Receiver	Bounding Degradation Radius for Receiver Class with 10W Transmitter (from ABC report – Appendix I)	Minimum Separation Between Ligado 10 Watt Transmitters
		<u>90 %</u> <i>Region Protected</i>
High Performance/ High Productivity (HPR)	3400 meters	20.5 km
Emergency Vehicles and General Navigation (GLN)	1045 meters	6.3 km
General Aviation and Helicopters (GAV)	1040 meters	6.2 km
Timing (TIM)	293 meters	1.7 km
Cell (CEL)	9.5 meters	57 m

90% is the minimum Area Protection Criterion (maximum 10% degradation)

It may be worse - not included in analysis...

- Multiple transmit towers contribute additive noise
- Reflections from ground and buildings can increase normal $1/R^2$ models by factors of over 10 (Factors of 15 measured in Las Vegas tests)
- The newer GNSS signals have wider RF bandwidths for greater accuracy and A/J, but the receivers also may have greater sensitivity to the adjacent band power. In ABC tests, the Galileo E1 signal was equally sensitive for HPRs.
- The new military signal deliberately pushes energy away from the center frequency, closer to Ligado power.

Agreement: Virtually all known Precision and Scientific user Groups of GPS oppose Ligado Filing because Validated Scientific and Technical Tests Consistently Confirm severe problems

- All Valid testing (AF/DOT - 2011 and 2016) has confirmed Ligado proposal will do severe harm - even at greatly reduced power levels
 - Company sponsored tests met none of the six essential criterion
- Opposition to Proposal to repurpose spectrum:
 - Virtually all involved in the Aircraft Industry including RTCA
 - Advanced applications such as RPVs and self-driving cars
 - Current and previous Generals commanding Air Force Space Command (GPS developers and operators)
 - An earlier PNT EXCOM, in spite of extreme administration pressure to approve
 - The USAF GPS Program office

Partial List: Groups filing opposition to the latest Ligado Filing

- AccuWeather
- Civil Aviation Aerospace Industries Association
- Operations and Safety Airlines for America
- ALERT Users Group
- American Geophysical Union
- American Meteorological Society
- American Weather and Climate Industry Association
- Aviation Spectrum Resources, Inc.
- DTN (formerly Schneider Electric)
- General Aviation Manufacturers Association
- Gogo Business Aviation
- International Air Transport Association
- Iridium Communications, Inc.
- Lockheed Martin
- Microcom Design, Inc.
- Narayan Strategy
- National Air Transportation Association
- National Emergency Number Association
- National Hydrologic Warning Council
- National Weather Association
- Resilient Navigation & Timing Foundation
- Rockwell Collins Inc.
- Satelles Inc.
- University of North Florida
- University of Wisconsin, Space Science and Engineering Center
- Idaho Geospatial Information Office
- Idaho Geospatial Council Executive Commit
- Boeing
- Air Line Pilots Association, International
- Airborne Public Safety Association
- Aircraft Owners and Pilots Association
- Airlines for America
- Association of Air Medical Services
- Helicopter Association International
- Helicopter Safety Advisory Conference
- National Business Aviation Association
- National EMS Pilots Association
- Professional Helicopter Pilots Association
- Users and Stakeholders of Hydrometeorological Information and Technology

So we requested USG support for PNTAB Recommendations:

- Reject latest Ligado 10 watt proposal
 - Does not meet PNT EXCOM January 2012 goal to protect "existing and evolving uses of space-based PNT services"
 - Not even close to acceptable
- Apply PNT EXCOM Adjacent Band Compatibility (ABC) methodology to any future proposals

Spectrum Issues: Application to UAG of National Space Council

- A Majority of Space-based systems rely on relatively weak radio signals from space
- Most are placed in radio bands of "like-use"
- Commercial pressure on many bands comes from desire for greater (*terrestrial*) data bandwidth - e.g. hi-def movies
 - Temptation is to reduce adjacent-band restrictions
- Vigilance is needed - once band use is allowed, it is not apt to be reversed

Some Good News: The FCC has finally approved the reception of Galileo signals in the US (Long Advocated by PNTAB)

FCC WAIVER FOR GALILEO

- Granted November 15, 2018
- First waiver of FCC licensing rules under foreign GNSS receiver waiver process established in 2011
- Permits non-federal U.S. receive-only earth stations to operate with specific signals of the Galileo GNSS without obtaining a license or grant of market access
- Based largely on cooperation under GPS-Galileo Agreement
- Request submitted to FCC by Commerce, on behalf of EC, with continual support from State and Commerce
- **Benefits all Galileo equipment makers selling in U.S., as well as their customers**

Example Achievements Caused or Catalyzed by PNTAB

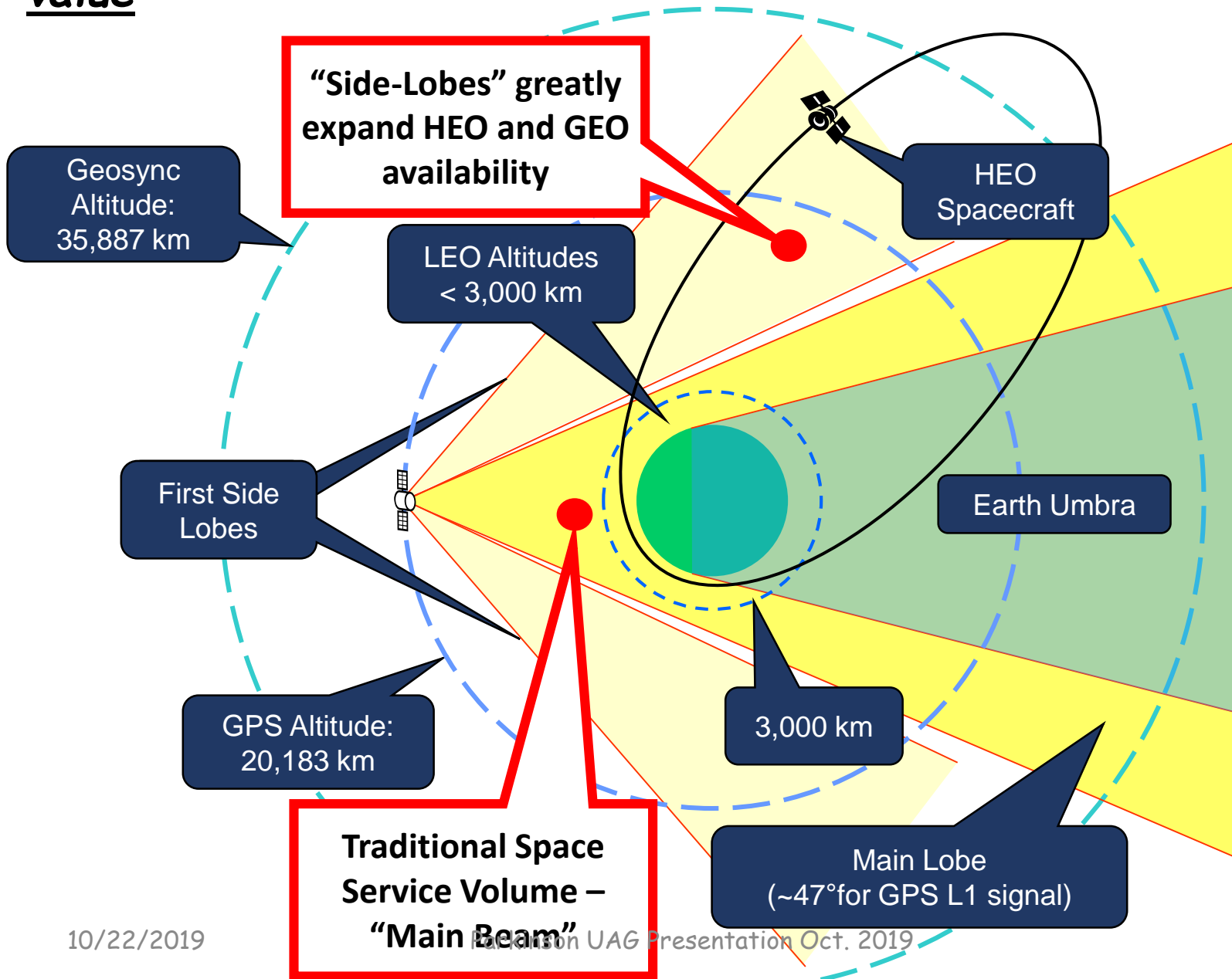
- Technical
 - **Space Service Volume Specification**
 - NASA International GPS Monitoring and Differential GPS Corrections
 - Laser Retroreflectors for precise ranging
- Policy
 - FCC:
 - Authorizing other GNSS (with verification)
 - **Postponing Adjacent band High Power Terrestrial transmitters**
 - Representing PNT interests for **Advanced Users**
 - **Example: UAVs, Robotic Trucks and Cars**

GPS for Space Applications

1. Booster Guidance
2. Mid-Course Launch Corrections
3. Satellite Station Keeping
4. Space Rendezvous
5. Trans-lunar flight capability under development at Goddard

#1 is susceptible to adjacent Band problems
#2 to #5 depend on using the the side-lobes of GPS satellite antennas - an unforeseen capability and application in 1978!

Space Service Volume: New techniques have greatly increased value



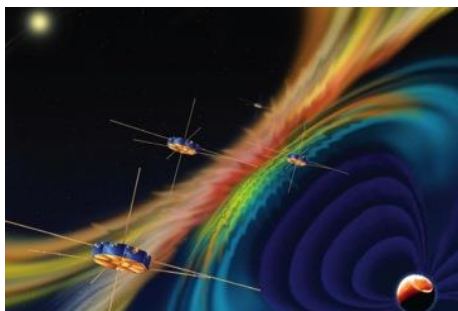
GPS for Real-Time Navigation in Space Service Volume

Benefits of GPS use in SSV:

- Significantly improves real-time navigation performance (from: km-class to: meter-class)
- Supports quick trajectory maneuver recovery (from: 5-10 hours to: minutes)
- GPS timing reduces need for expensive on-board clocks (from: \$100sK-1M to: \$15K-50K)
- Supports increased satellite autonomy, lowering mission operations costs (savings up to \$500-750K/year)
- Enables new/enhanced capabilities and better performance for **High Earth Orbit (HEO)** and **Geosynchronous Orbit (GEO)** missions, including:



Earth Weather Prediction using Advanced Weather Satellites



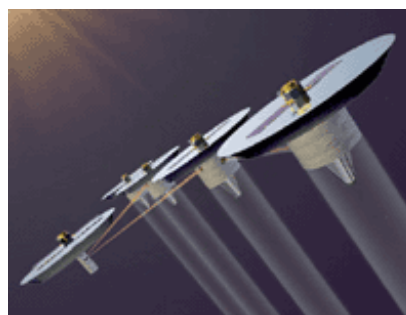
Space Weather Observations



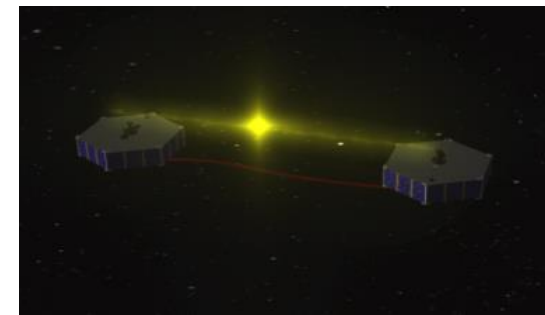
Precise Relative Positioning



Launch Vehicle Upper Stages & Beyond-GEO applications



Formation Flying, Space Situational Awareness (SSA), Proximity Operations



Precise Position Knowledge & Control at GEO

GPS Space Service Volume (SSV) History and Status

- GPS availability and signal strength *originally* specified for near-earth users of "Main Beam" - power levels specified at edge-of-Earth (14.3 degrees)
- Side-lobe signals not originally expected to improve availability for use above GPS altitude, but now proven to be essential to high altitude use
 - NASA et.al. developed weak signal HEO/GEO GPS receivers
 - Depend on unspecified side lobe power down to 1/100th of main beam
- Side Lobes now employed in numerous HEO/GEO missions with more in development
 - Greatly increases availability - especially at GEO/HEO
 - Side-lobe Capability is not protected with Requirements or Specifications

NASA and USAF have ongoing dialogue on assured SSV

PNTAB (a FACA committee) Operation

- Tone set by original Chairman:
Dr. James Schlesinger
- Meetings - twice a year (DC + elsewhere)
- One "Working day" and 1½ days of public meetings
 - Working subgroups
- Subjects both assigned by EXCOM and self assigned
 - "Assuring PNT for all"
- Periodic telephonic organizing and working meetings.
- Conclusions and recommendations all discussed in public sessions.

Selected PNTAB Issues/Opportunities

- Charter
 - Statement of Purpose should allow full-expertise to be brought to bear
- Independence
 - Tasks both assigned by conveners and self-assigned to meet purpose
- Conflicts of Interest: COI
 - Has been a challenge because of broad interpretation
- EXCOM - Educational Dimension
 - Members very bright, but frequently unknowledgeable - many not scientific/technical
- Decisions
 - Have been challenging - power is usually with the budget

Conclusions

- PNTAB Committee charter and operation share many characteristics with UAG
- Specific Foci of PNTAB has substantial synergies with UAG
 - Spectrum allocation is clearly a common problem
 - GPS applications span many of Space Operations Phases
 - Need to assure side lobes remain viable ranging enablers

Questions?