Planetary Radio Interferometry and Doppler Experiment (PRIDE) for a Europa-Jupiter mission

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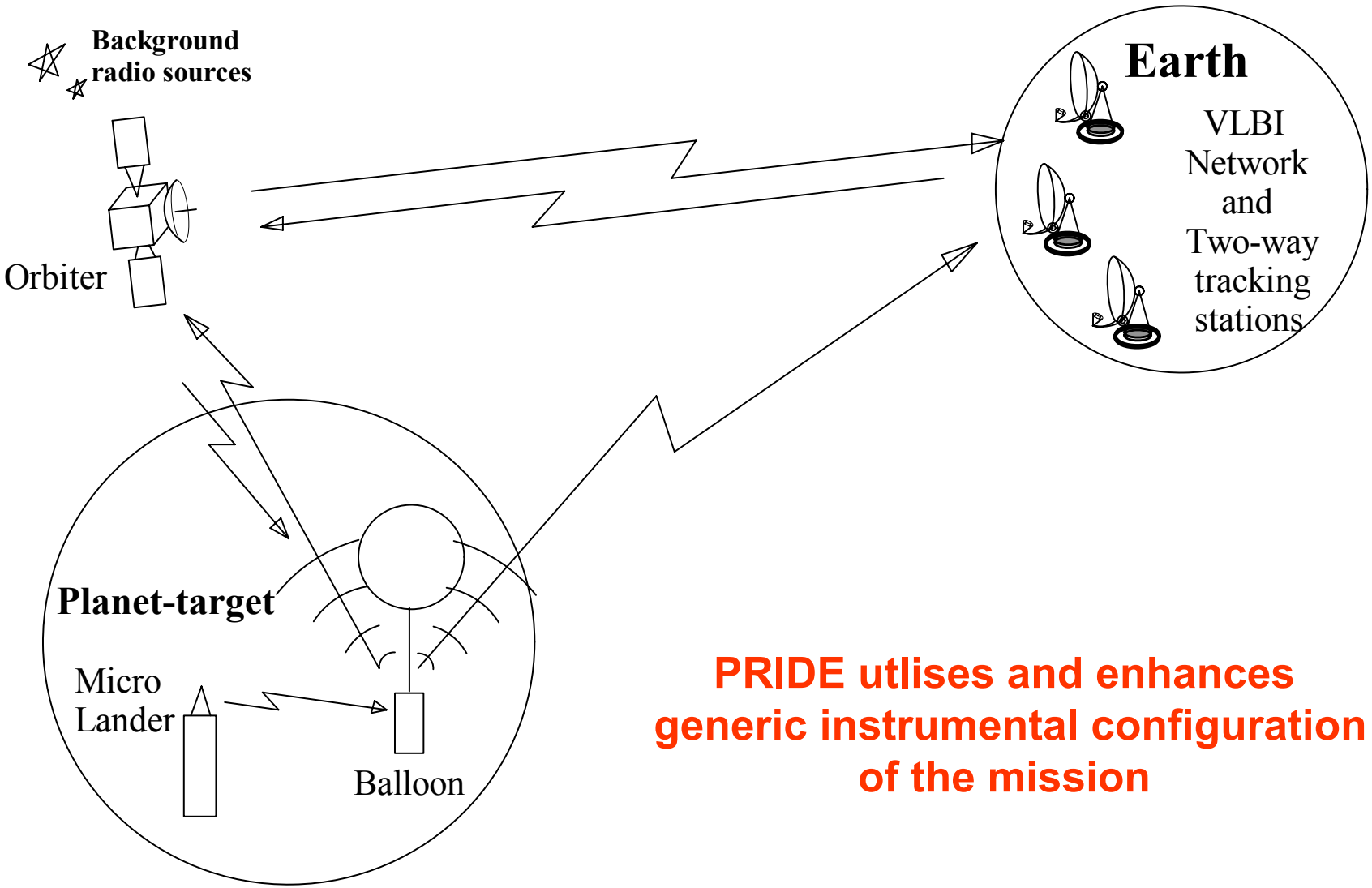
JIVE, Dwingeloo, The Netherlands

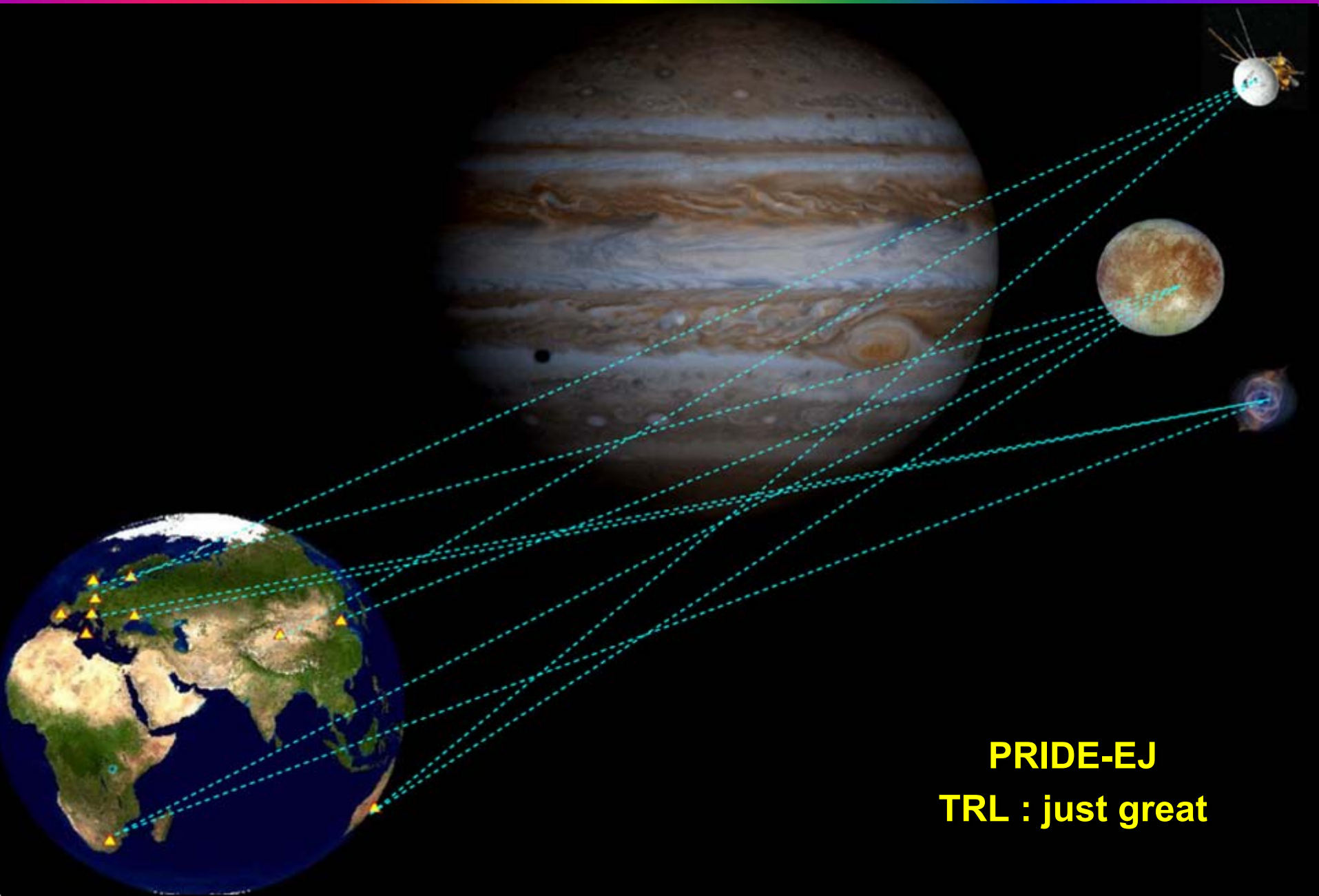
Europa Lander: Science Goals and Experiments
IKI, Moscow, Russia, 10-13 February 2009

Generic PRIDE configuration

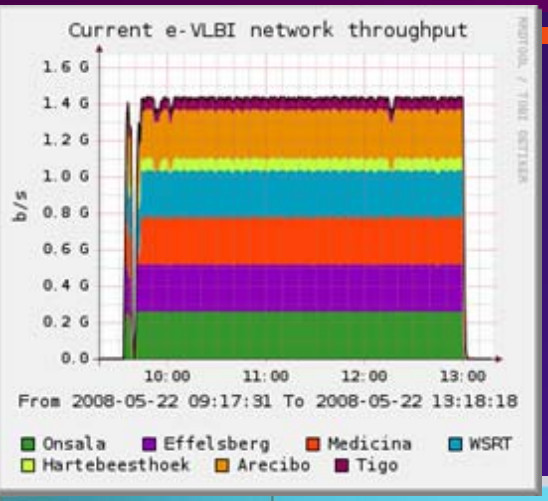


PRIDE utlises and enhances generic instrumental configuration of the mission

PRIDE-EJ: multi-target multi-purpose experiment

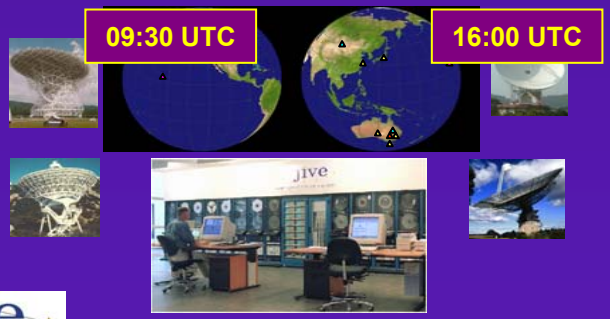


PRIDE: Earth-based segment



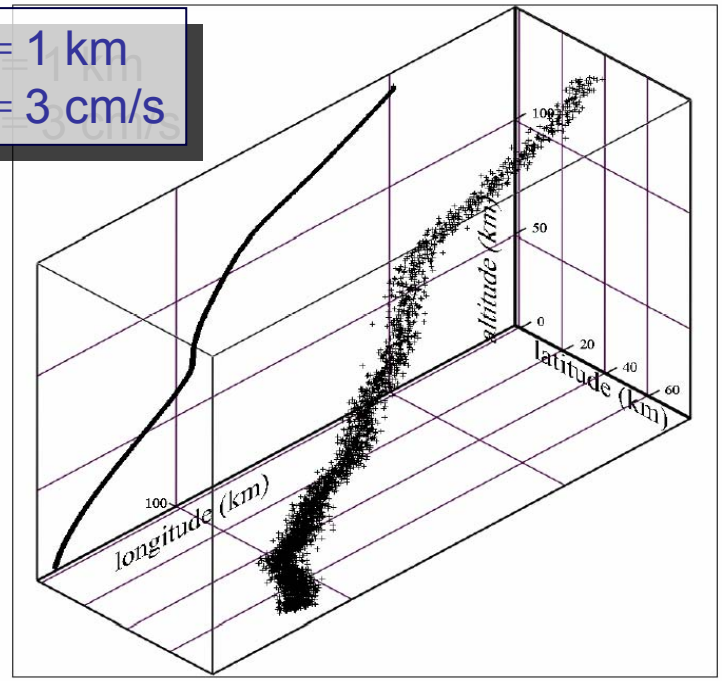
Huygens VLBI heritage, 2005

- Ad hoc use of the Huygens “uplink” carrier signal at 2040 MHz
- Utilised 17 Earth-based radio telescopes
- Non-optimal parameters of the experiment (not planned originally)
- Achieved 1 km accuracy of Probe’s descent trajectory determination



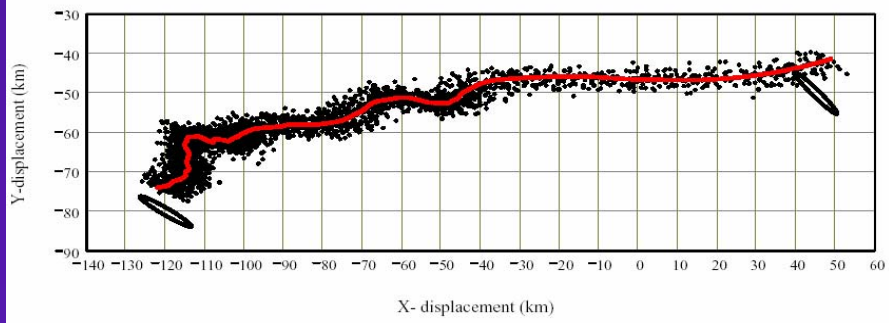
In 3D (altitude from DTWG trajectory)

$\sigma_x = 1$ km
$\sigma_v = 3$ cm/s



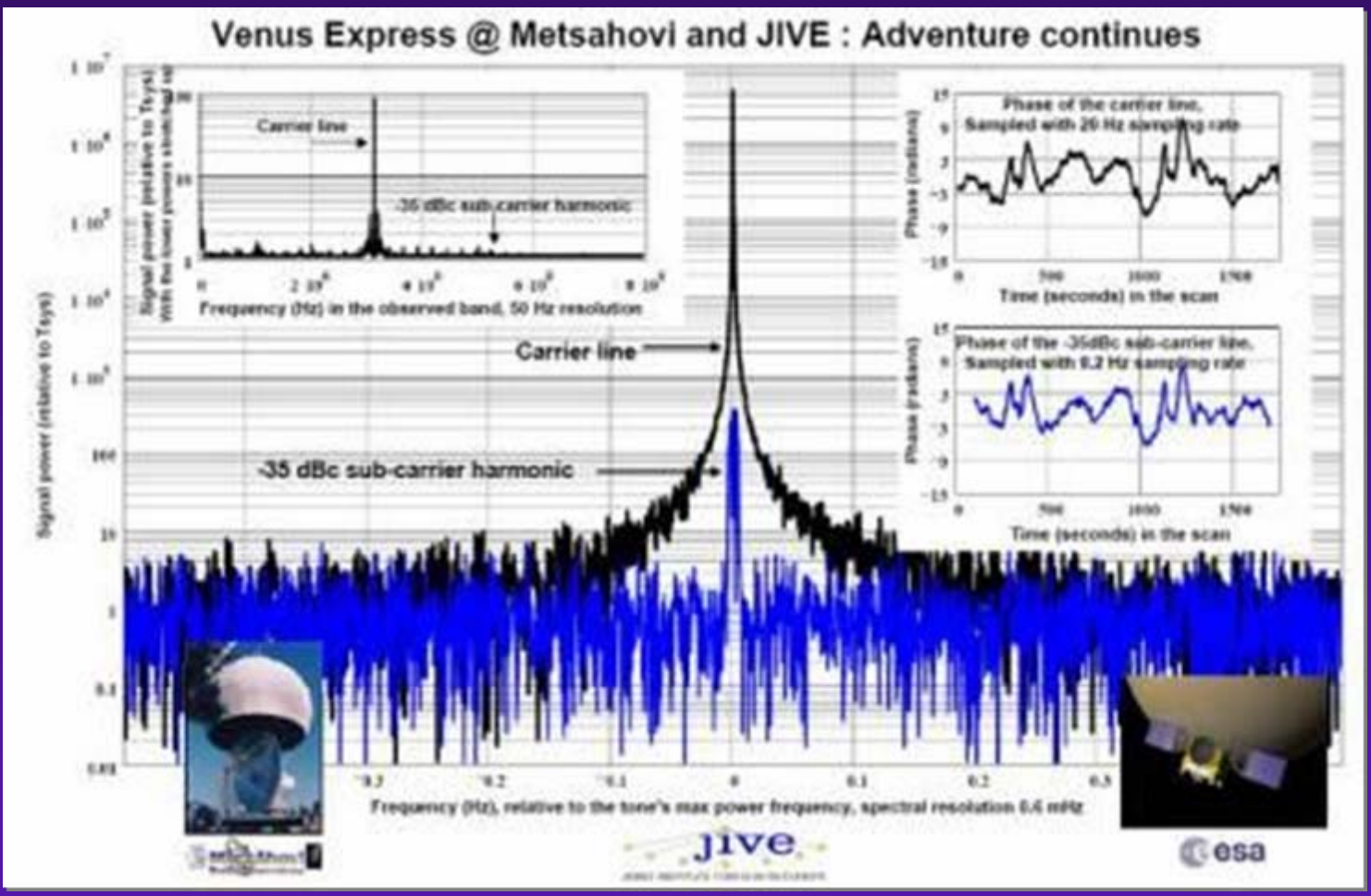
(Xp, Yp, Zp)

XY (Longitude/Latitude) Projection



+/- 3 σ error scatter ellipses are shown at the beginning and at the end of the trajectory

VEX Doppler tracking demo



- ESA's Venus Express carrier spectrum,
- Metsahovi observation,
- New S/W spectrometer
- 0.6 mHz spectral resolution

Science case for PRIDE-EJ

- Direct characterisation of the orbiter and probe(s) signal by means of "VLBI tracking" and radial Doppler measurements
- VLBI estimates of the probe(s) state vector (lateral coordinates)
  - *Tidal deformations/seismology of Europa (X- or Ka-band)*
  - *Gravimetry*
  - *Input to the fundamental physics package (see Odyssey ESA CV proposal)*
- Radio occultation observations (Jovian magneto-/iono-sphere)
- "Cruise" science plus mission diagnostics ("health check")
- High degree of synergy with in situ measurements
- Complementary to DeltaDOR measurements

plus

- Direct radio link with a small (Europa) probe (lander? penetrator?) as the case for SKA at S- or X-band(s)?

PRIDE-EJ versus Huygens VLBI tracking

	Huygens	PRIDE-EJ	Resolution gain
Radio link frequency	2 GHz	2/8/32 GHz	1/4/16
Distance	8 AU	~5 AU	1.5
VLBI "fringe" SNR	10 - 30	30 - 100	~3
Linear resolution (1σ)	1 km	240/50/13 m	~5/18/75

- Conservative estimate, today's technology (TRL>8)
- Minimal special requirements for the on-board instrumentation
- In-beam "Orbiter-Probe" calibration can improve SNR further

Instrumental requirements of PRIDE-EJ

- **Earth-based segment:**
  - *A global network of radio telescopes and tracking stations;*
  - *(Mission-adjusted) data processing centre*
  - *Logistical network*

- **Onboard segment (all probes/spacecraft of the mission):**
  - *Multi-frequency transmitters and related instrumentation (antennas etc.)*
  - *Stable Local Oscillator (LO)*

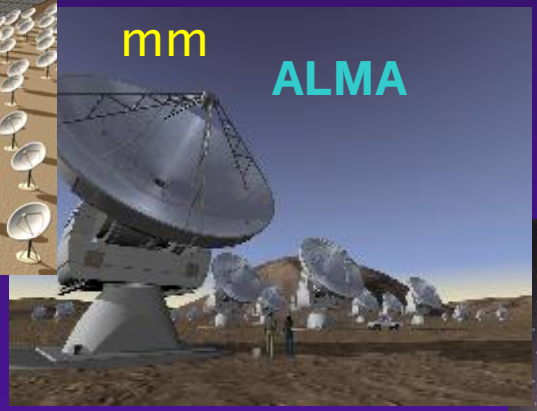
All required technologies are mature and verified!

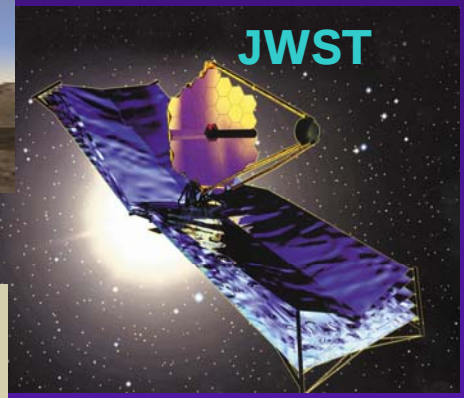
- **However:**
  - *Demo/preparatory experiments are desirable (and in fact being planned)*
  - *Multi-target multi-frequency mode can be verified using e.g. Mars probes/orbiters (helps to calibrate/mitigate propagation effects)*

Astronomy of the XXI century

radio

mm and sub-mm

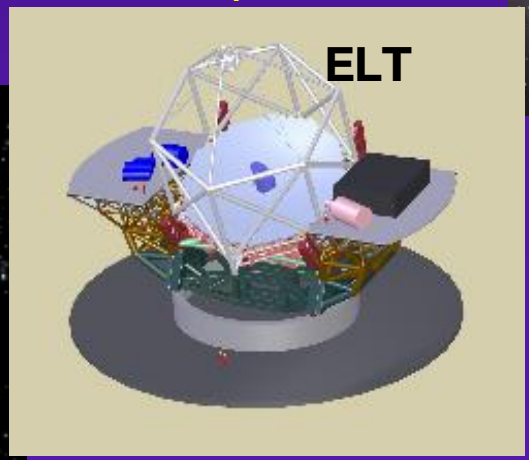




infra-red

λ

optical

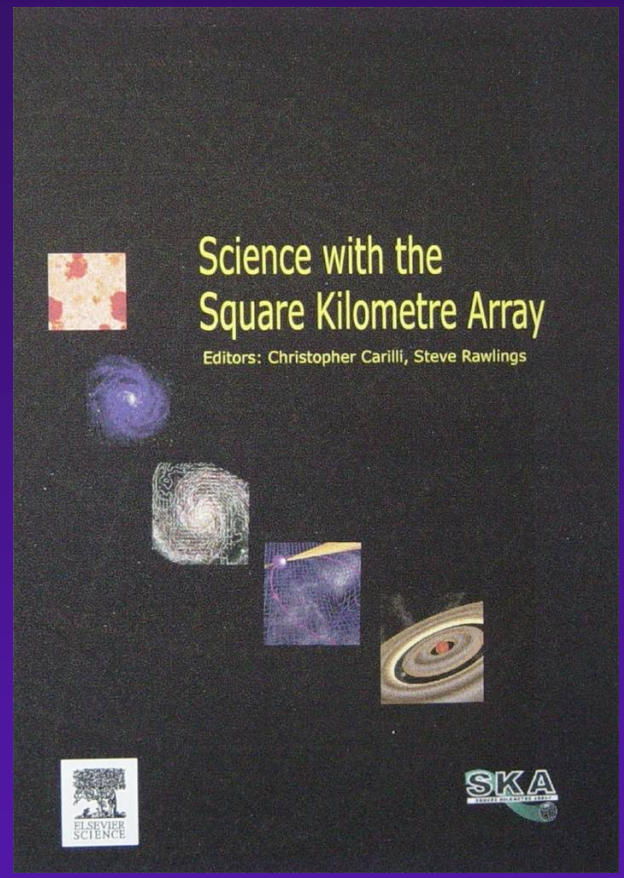


X-ray

SKA Science

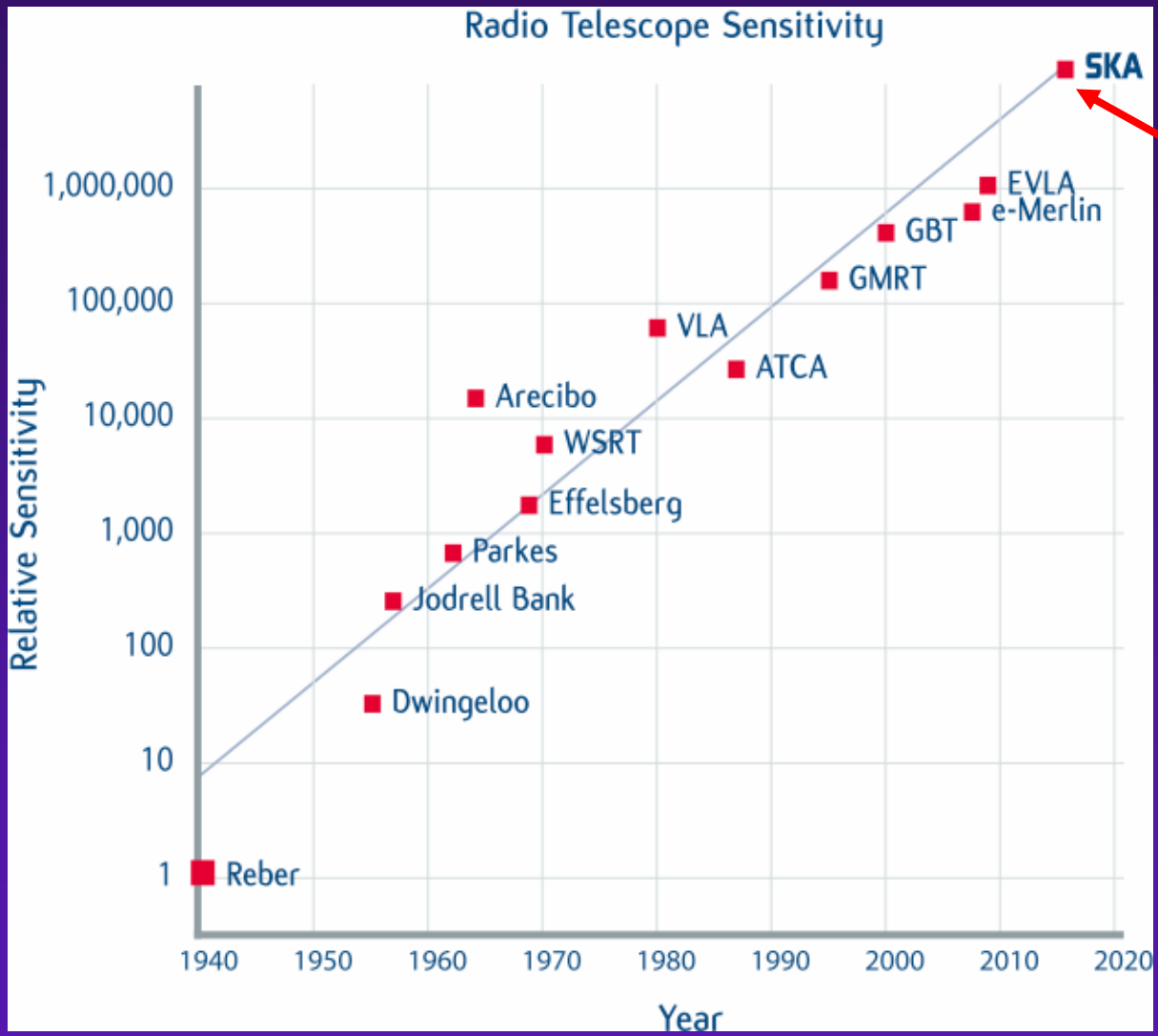
- Science case developed over ~10 yr by international group of astronomers and physicists
- Published as special issue of *New Astronomy Reviews*
- Five Key Science Projects (KSPs)
  1. **Probing the Dark Ages**
  2. **Galaxy Evolution, Cosmology, & Dark Energy**
  3. **The Origin & Evolution of Cosmic Magnetism**
  4. **Strong Field Tests of Gravity Using Pulsars and Black Holes**
  5. **The Cradle of Life/Astrobiology**

… plus **The Exploration of the Unknown** as an underlying philosophy for design and costing



eds. C.Carilli, S.Rawlings

90 years of radio astronomy



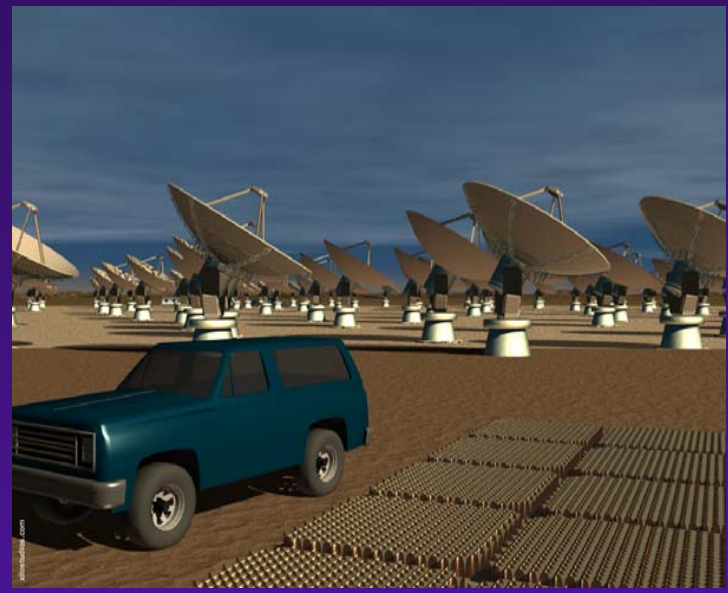
SKA and the Discovery exponent

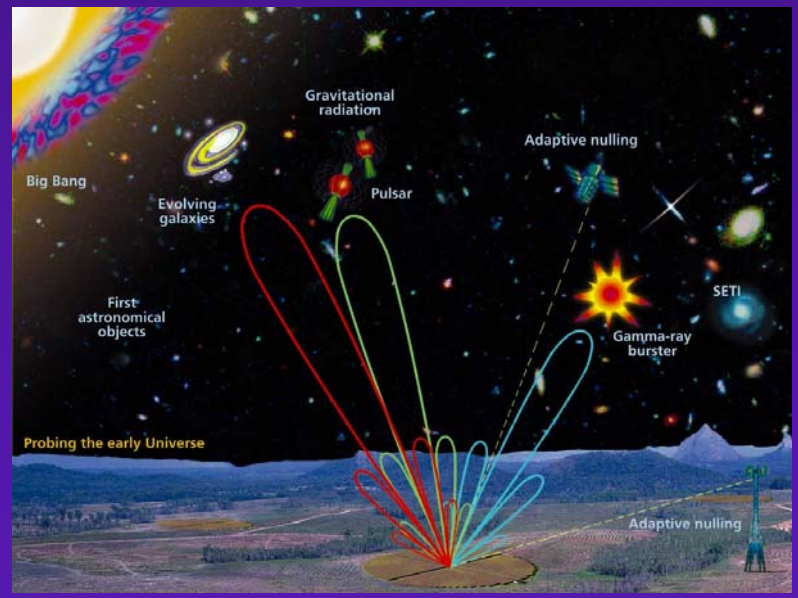
Global Radio Wavelength Observatory:

SKA-lo: λ > 0.5 metre
SKA-mid: 1 m < λ <~ 3 cm
SKA-hi: 6 cm < λ < 1 cm

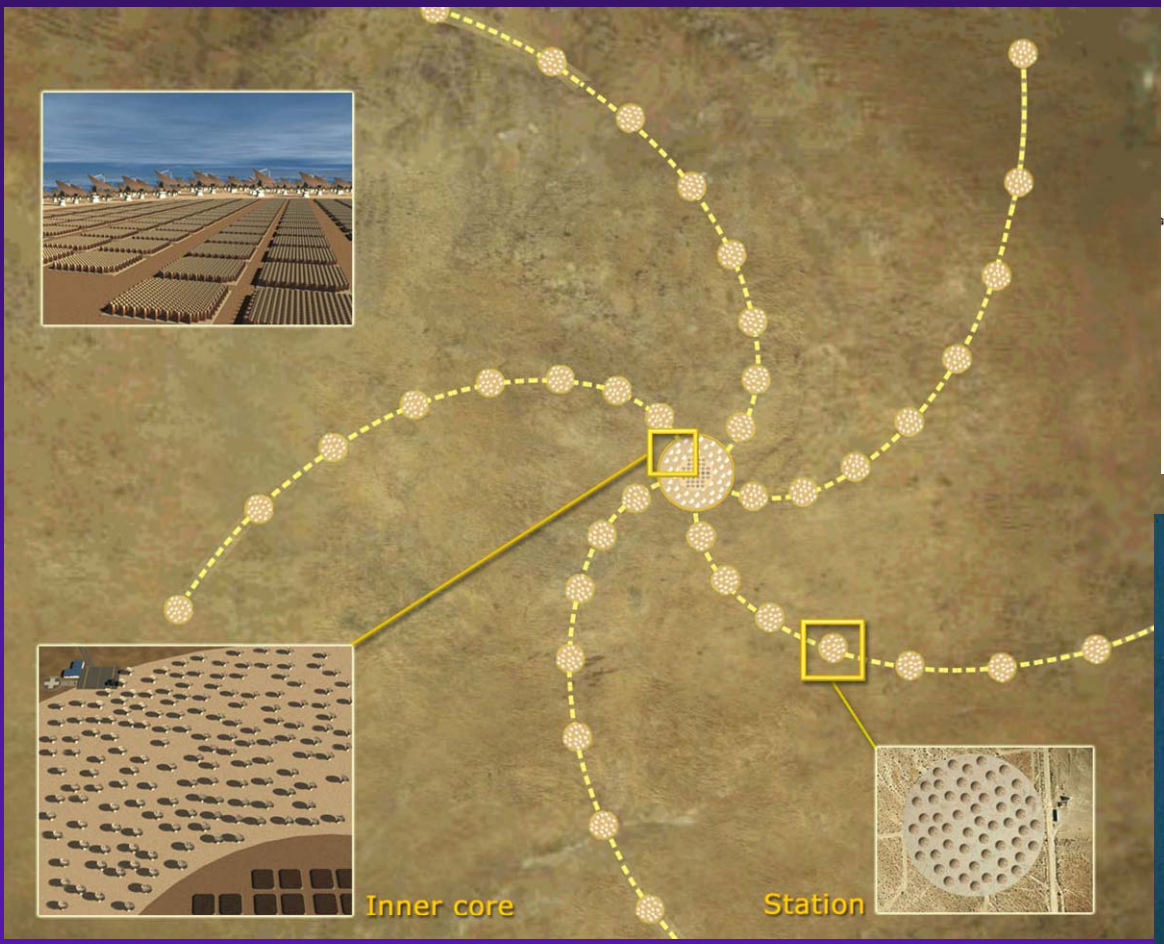
Square Kilometre Array (SKA) as a DtE facility

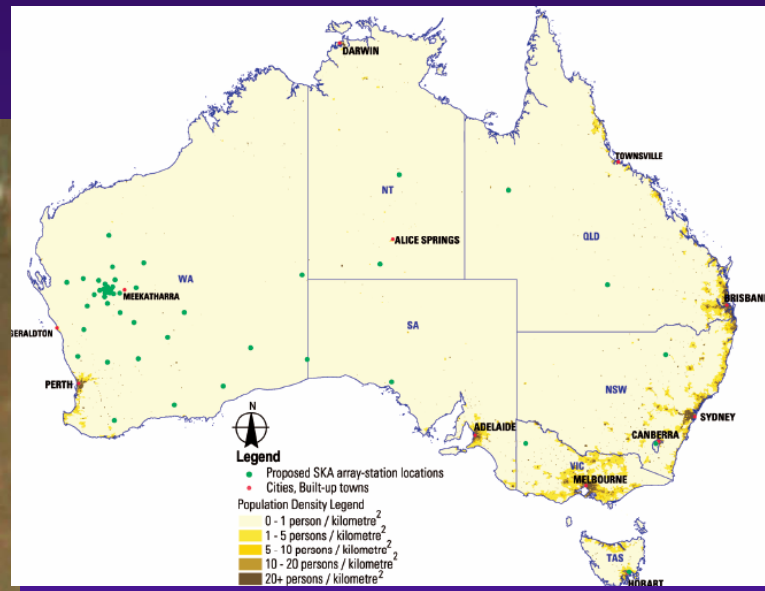
- Sensitivity gain over a large DSN-style antenna >100
- Frequency range: 0.3 – 20 GHz
- Prime goal: superior L-band sensitivity
- Fully operational in 2020; high operational readiness from 2018
- Multi-user (multi-field/multi-beam) functionality

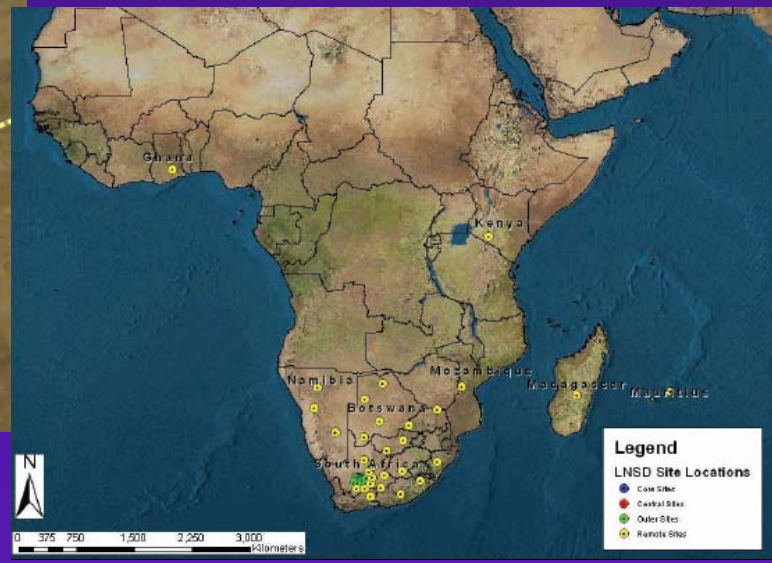




SKA Reference Design and possible locations

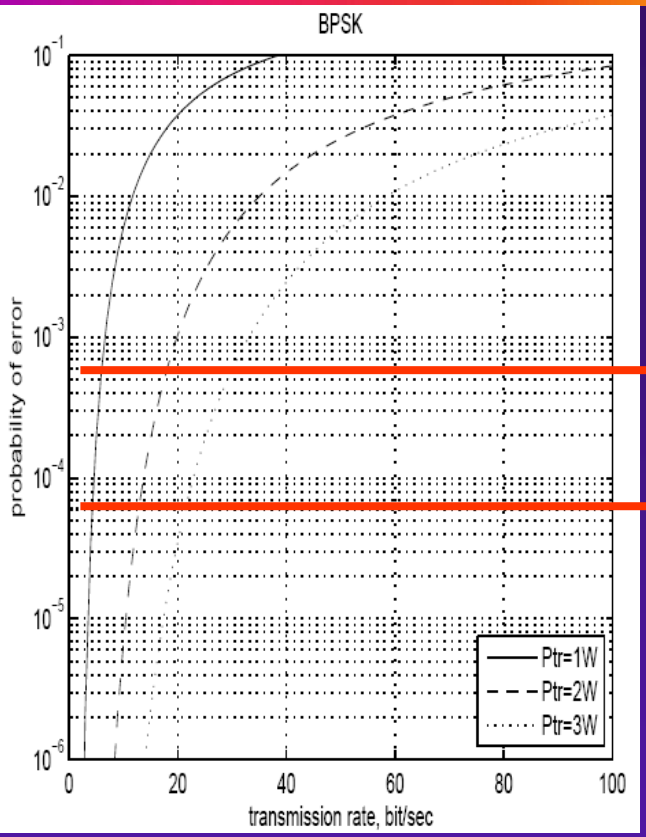


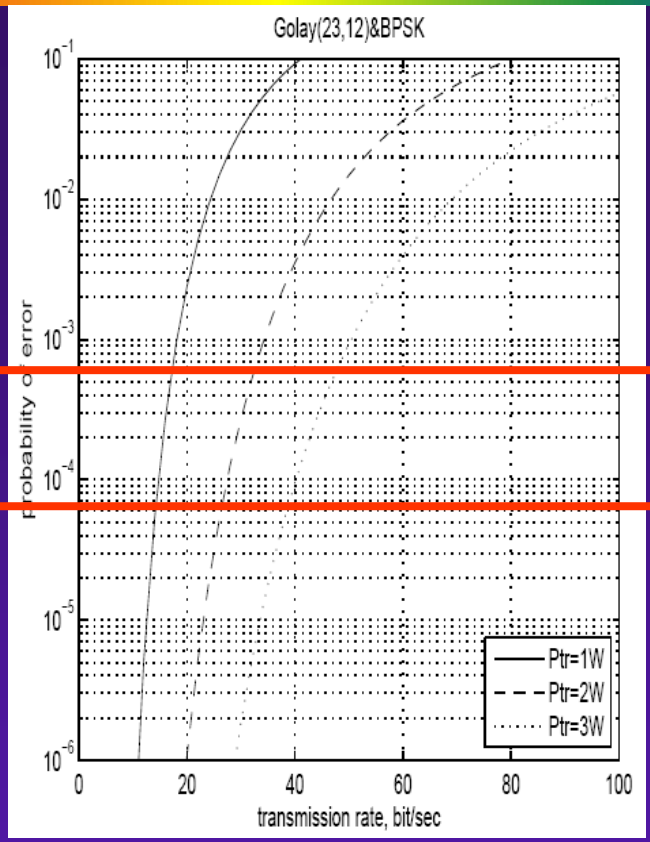


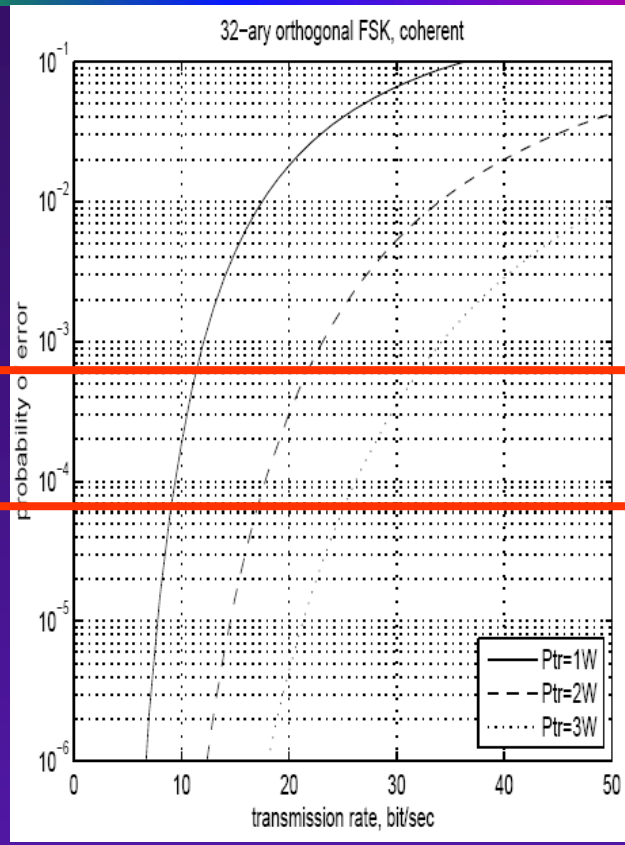


More info at: *www.skatelescope.org*

Bit-error rate for EJSM-SKA DtE







BPSK

BPSK + error control coding

32-ary orthogonal Coherent modulation

30–50 bps with ~10^{-4} – 10^{-3} BER achievable

Omnidirectional transmission, 1 – 3 W

Further details: Fridman et al., 2008, SKA Memo No. 104

PRIDE-JE summary and actions

- VLBI tracking of any EJSM S/C at 2 and/or 8 GHz is feasible; 2D lateral positional accuracy of >~100 m is achievable
- Trade-offs need to be addressed NOW (at least in preliminary terms)!
- VLBI tracking of the Jupiter orbiters at 8 and 32 GHz is feasible
- VLBI-based Radial Doppler measurements of the Europa lander at X-band would enable factor of 10-50 improvement over Huygens

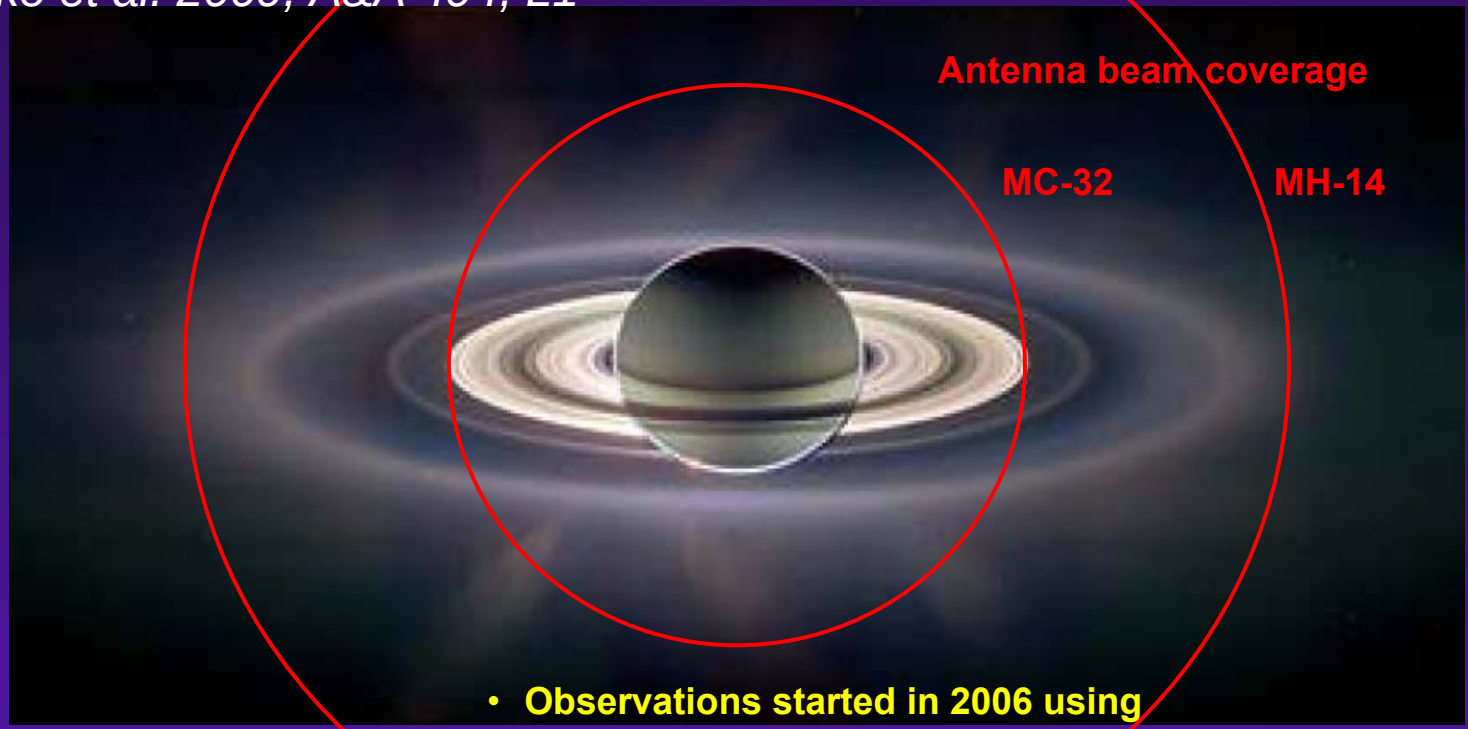
- Backup DtE of Europa lander signal with 30–100 bps at S- or X-band can be addressed – requires "injection" into the SKA design study

Questions:

- *Is there a need for a higher positional accuracy?*
- *How many targets PRIDE-JE deal with: orbiter, lander(s)?*

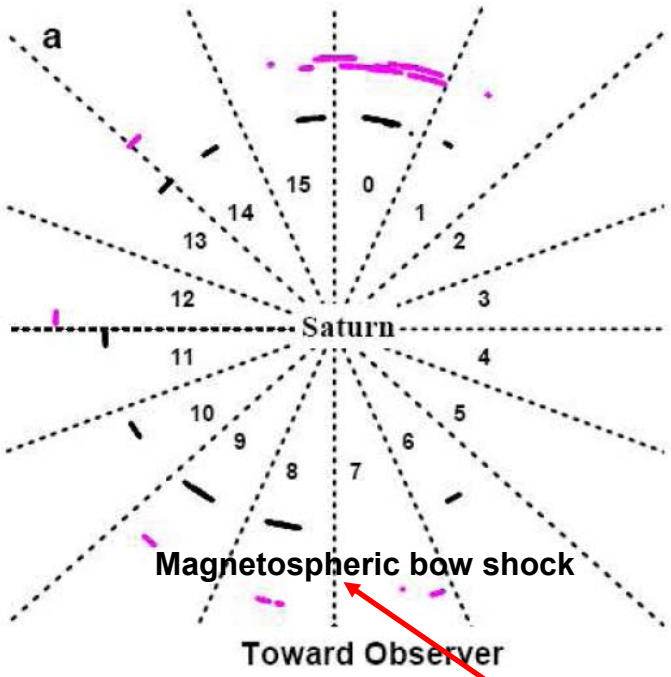
Hunting for water masers in Saturnian system

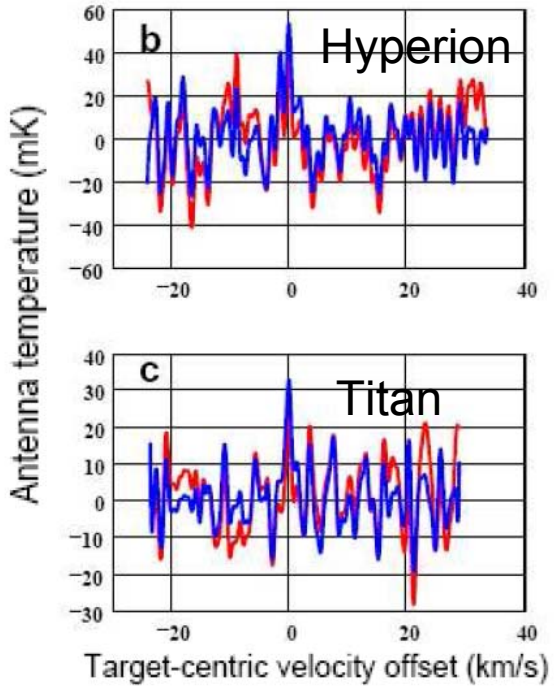
Pogrebenko et al. 2009, A&A 494, L1



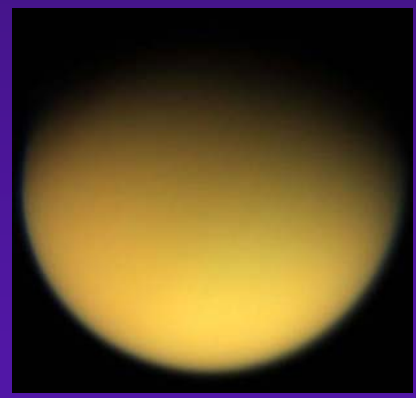
- **Observations started in 2006 using Huygens software correlator for Mk5A data processing.**
- **More than 300 hours of observation collected in 2006 – 2008 with MC and MH telescopes.**
- **HW spectrometer MSpec0 at Medicina.**
- **Software spectrometer was developed for Metsahovi.**
- **Data analysis @ JIVE.**

Orbital phases observed



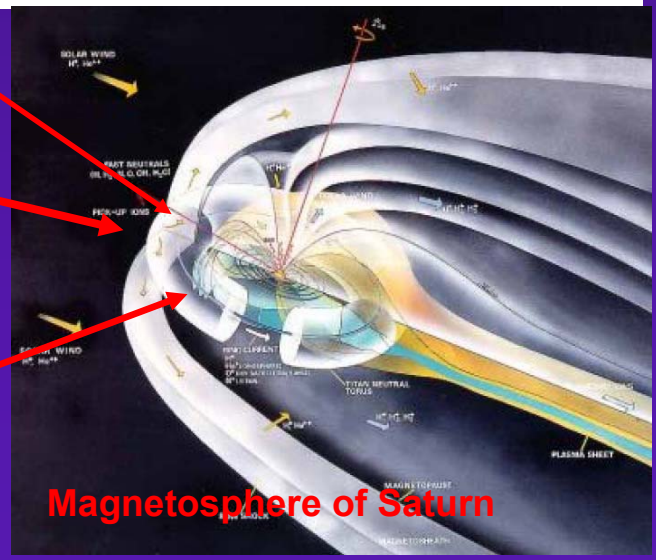


Sponge-like shape of Hyperion might be a result of a selective sublimation of ice, enhanced by interaction with Solar wind when the satellite is outside the Kronian magnetosphere.



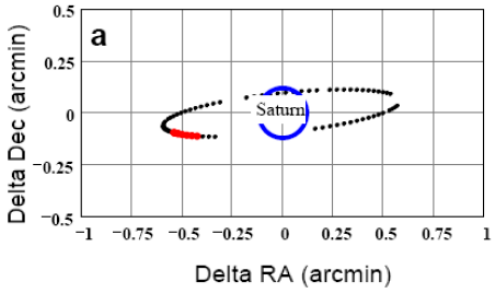
When outside thy magnetosphere, Hyperion is about there

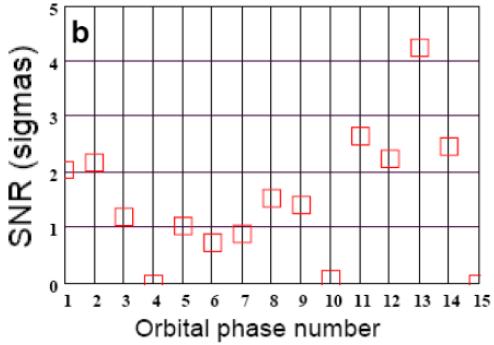
Titan's neutral torus

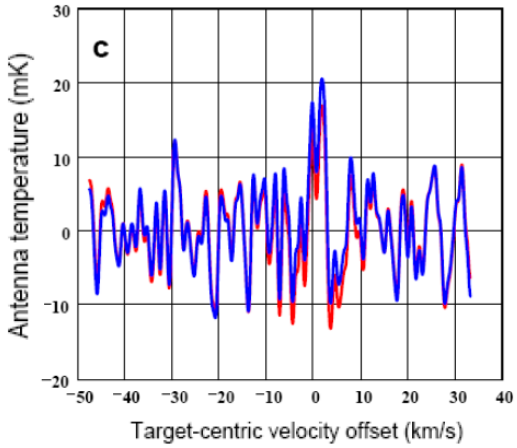


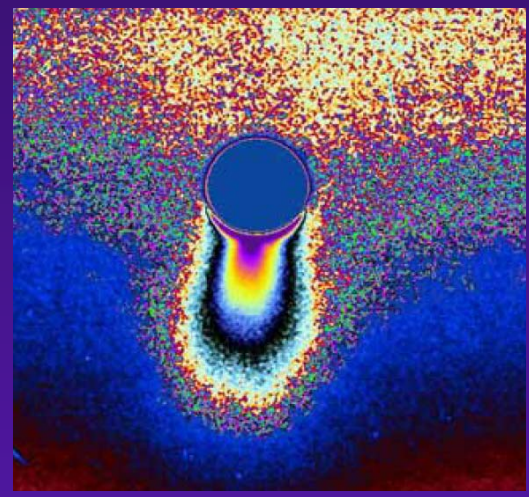
Titan has a lot of gases in its exosphere to provide collisional pumping for trapped water molecules.

Enceladus



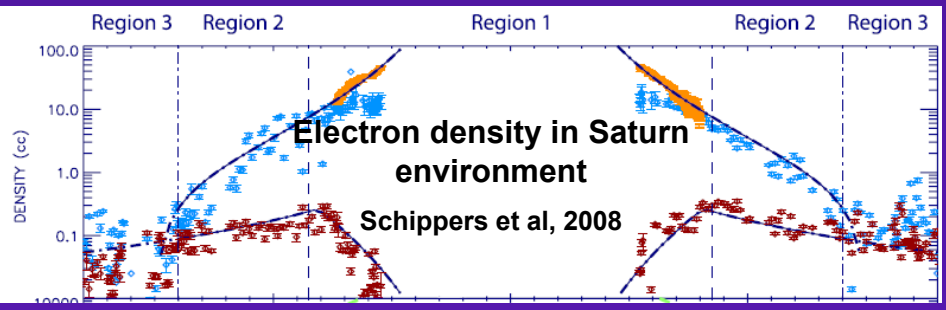


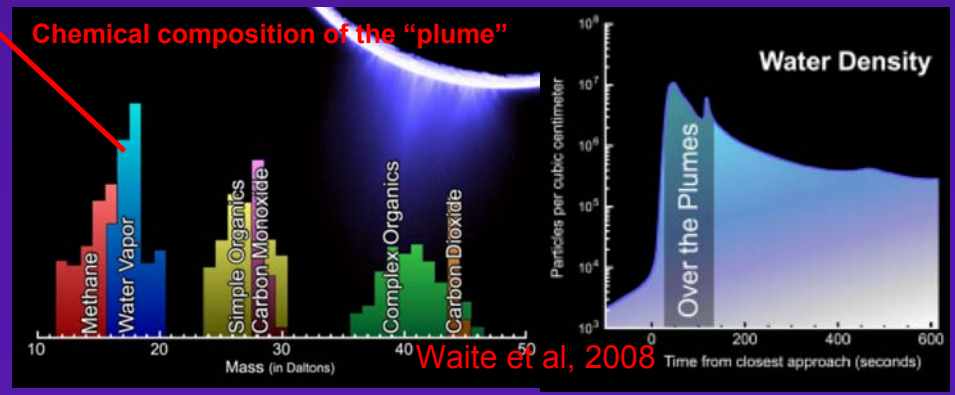




Water-water collisions dominated pumping ?

Presence of low energy electrons can also help (Elitzur & Fuqua 1989)

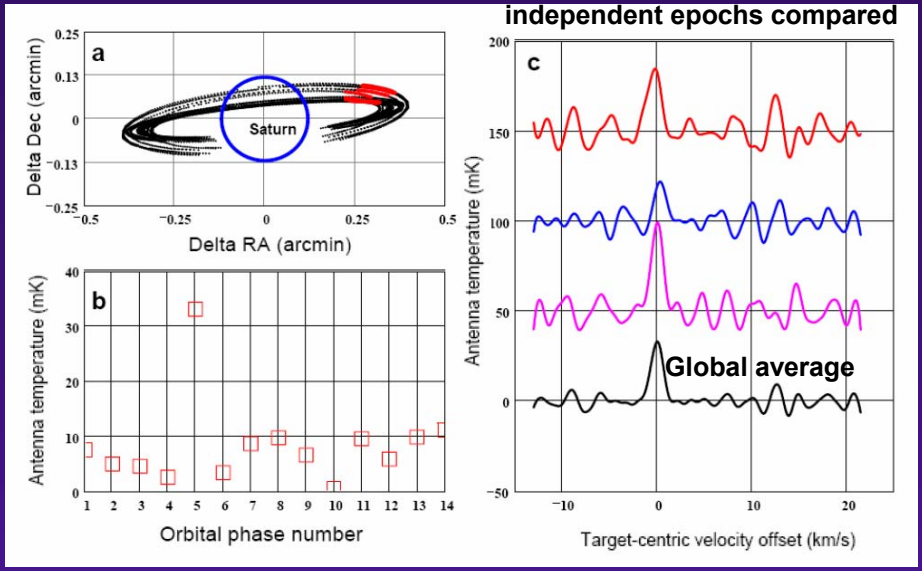


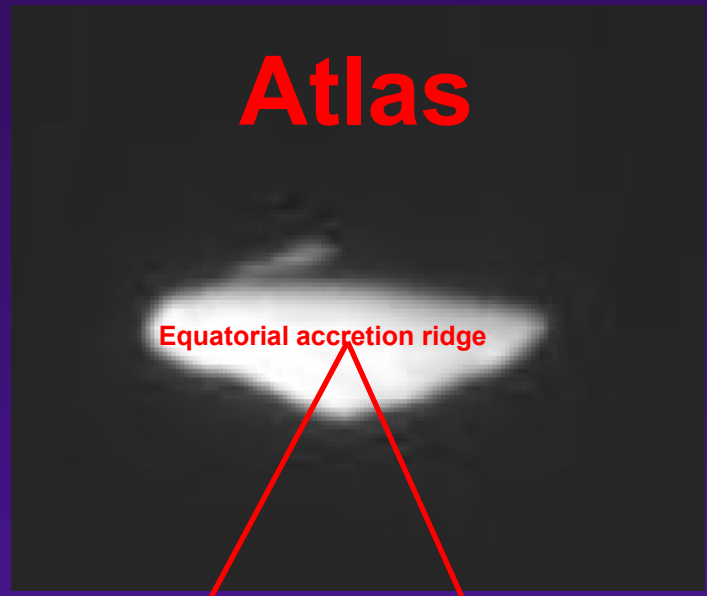


Possibility to compare astrophysical models with *in situ* measurements

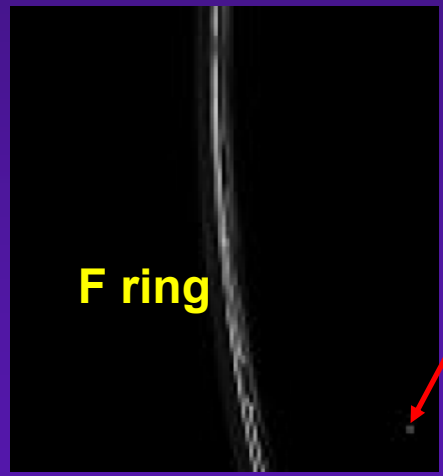
Orbital phase from which the emission was detected is indicated by red

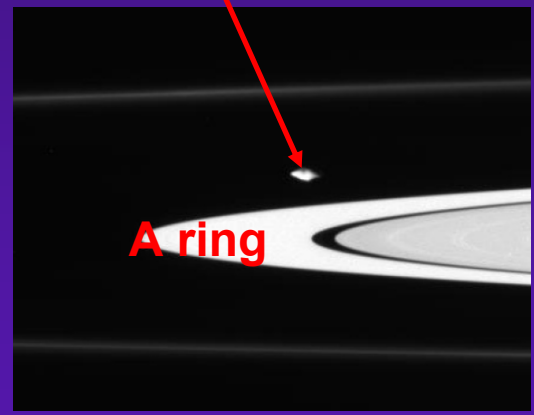
Persistence check: spectra for 3 independent epochs compared





Emission was detected not from Atlas itself, but associated with a spot lagging Atlas by few minutes along its orbit





F ring: quite an active