Mach Effects

For

In-Space Propulsion

Professor Heidi Fearn, PI • Team: Dr. José Rodal, Mr. Marshall Eubanks, Dr. Bruce Long, Mr. Paul March, Mr. Gary C Hudson & Emeritus Professor James F. Woodward, Consultant

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Proxima b Artist Concept Credits: European Southern Observatory – Spacecraft CAD and Mission Imagery Credit: Tom Brosz

Mach Effects for In-Space Propulsion

NIAC Study Approach – 3 Tasks

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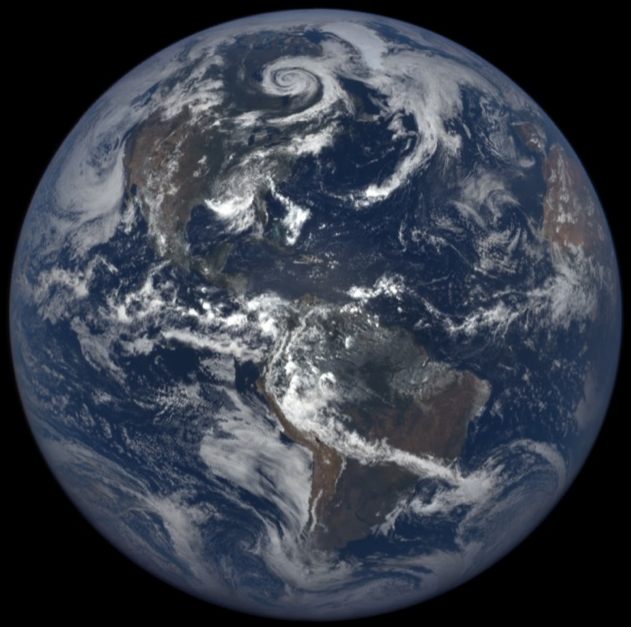
(2) Design and develop power supply & electrical systems to provide feedback and control of the input AC voltage and frequency, to improve efficiency of MEGA "Mach Effects" drive.

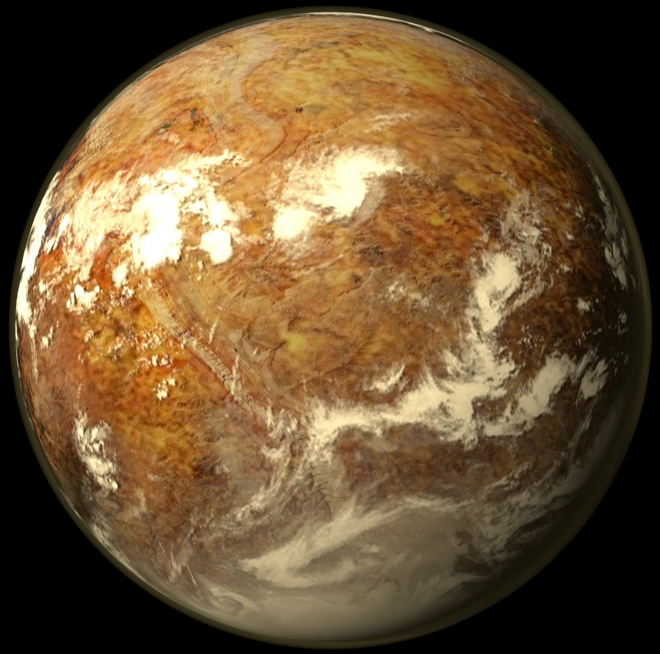
(3) Using the results from 1 & 2 above, design a probe to deliver ~400 kg payload to Proxima Centauri with a rendezvous with Proxima b in 20 years, one-way flight time. Data to be recorded and transmitted back over 5 additional years.

What is the Mission?

Our mission is to deliver a probe with ~400 kg of payload to Proxima Centauri, gather data and transmit it back within 25 years



Earth



Proxima b

(artist's concept)

Credit: PHL @ UPR Arecibo, NASA EPIC Team

What is the Challenge?

Traverse a hazardous expanse at relativistic velocity during more than two decades of flight time, then spend several years surveying the destination while ensuring the data is returned to Earth.

Credit: European Southern Observatory

What Propulsion Technology Can Enable this Mission?

Our Mach Effects Gravitational Assist "MEGA Drive" does not require ejecting propellant, avoiding the "tyranny of the rocket equation."

Benefits include needing only electrical energy for operation, potential all-axis thrust and attitude control and the ability to brake into the target system for multi-year exploration, which is not possible with flyby alternative approaches.

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Say what?

Standard Physics – Using Only General Relativity

Consider the Center of Mass (CoM) motion for a forced damped harmonic oscillator, with mass change m(t) terms, using sinusoidal forces of frequency ω and 2ω.

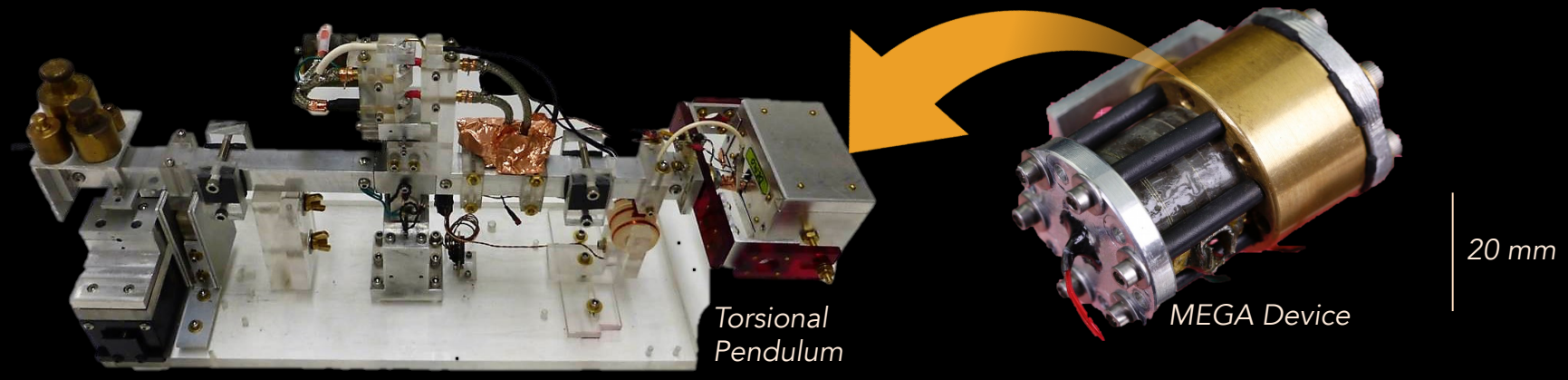
$$\dot{p}_{COM} = \frac{\dfrac{\dot{m}_1 \dot{x}_1}{\sqrt{1-\dot{x}_1^2/c^2}} + \dfrac{\dot{m}_2 \dot{x}_2}{\sqrt{1-\dot{x}_2^2/c^2}}}{\dfrac{m_1}{\sqrt{1-\dot{x}_1^2/c^2}} + \dfrac{m_2}{\sqrt{1-\dot{x}_2^2/c^2}}} + \text{higher order terms}$$

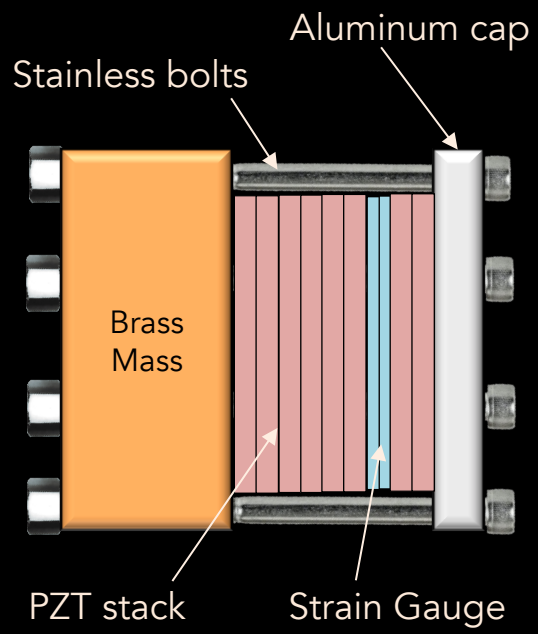
For details see poster/handout.

Replications already performed:

- Technical University Dresden, Germany (Prof. Tajmar) conducted at 4 μTorr
- University of Applied Sciences (Forschungs und Technologietransfer), Austria (N. Buldrini) conducted at 2 μTorr

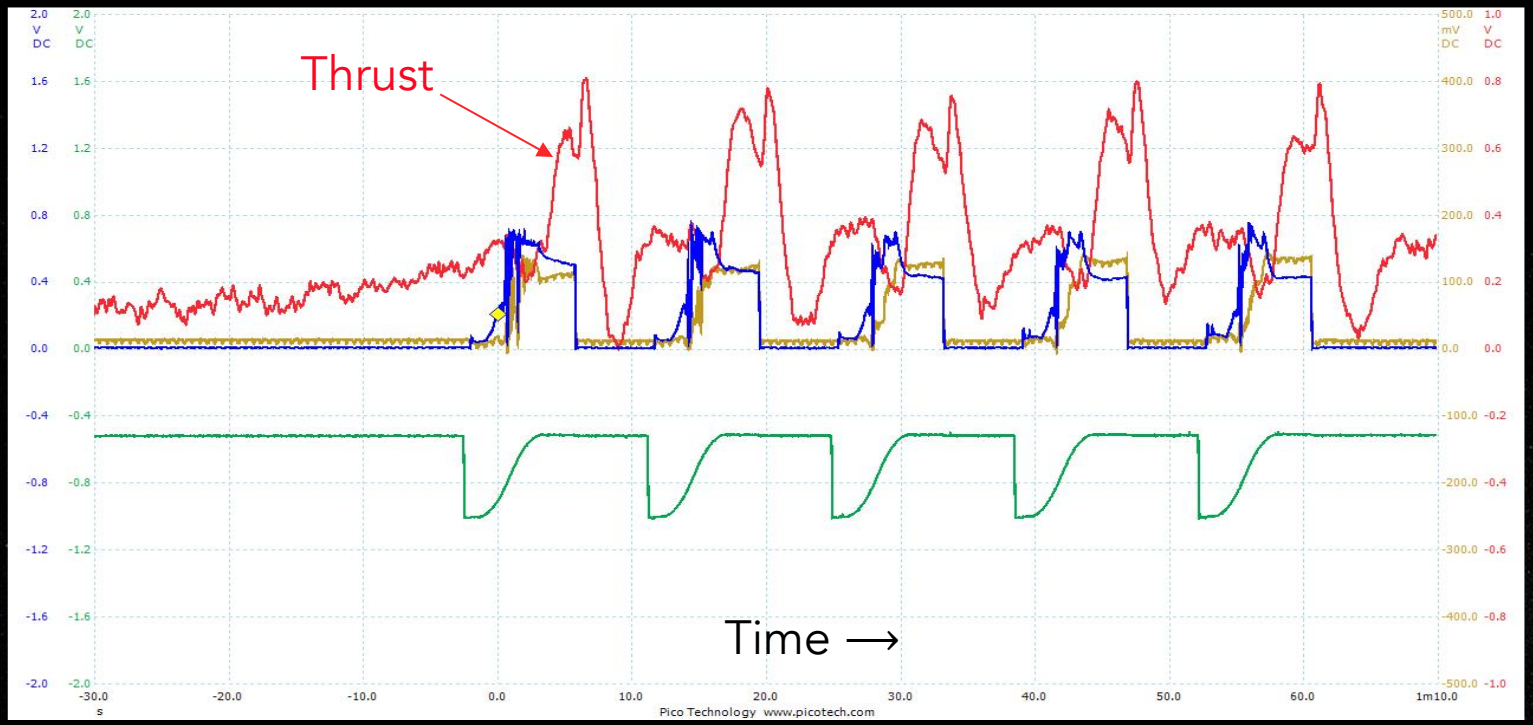
MEGA Device Description





On the left, a sectional diagram of a MEGA device. A stack of PZT (lead zirconate titanate) piezoelectric disks is compressed between a brass mass and a thin aluminum mass. The stack is excited with a voltage excitation resulting in two applied frequencies (f and 2f). The total energy, and therefore the mass of the stack, fluctuates with time on the order of a Planck mass ($\Delta m/m \sim 10^{-8}$). Due to conservation of momentum, the asymmetry of the variable mass through the length of the stack results in acceleration of the center of mass. This acceleration is magnified by orders of magnitude due to General Relativity's *Equivalence Principle* between gravitational and inertial mass.

Test Result From Chirped Runs



Frequency starts high then drops down to the resonant frequency of the device. Chirp is shown inverted in ***green****. The* ***blue*** *trace is the voltage pulse amplitude. The* ***red*** *trace is the thrust of the device. The* ***brown*** *trace is the voltage output from the strain gauge. Test conducted at 15 mTorr. See Ref [3] on poster.*

Recent Progress

- We've performed a number of new experiments, including statistical analysis, and are employing "chirped" power-shaping technology which is producing significant new results.

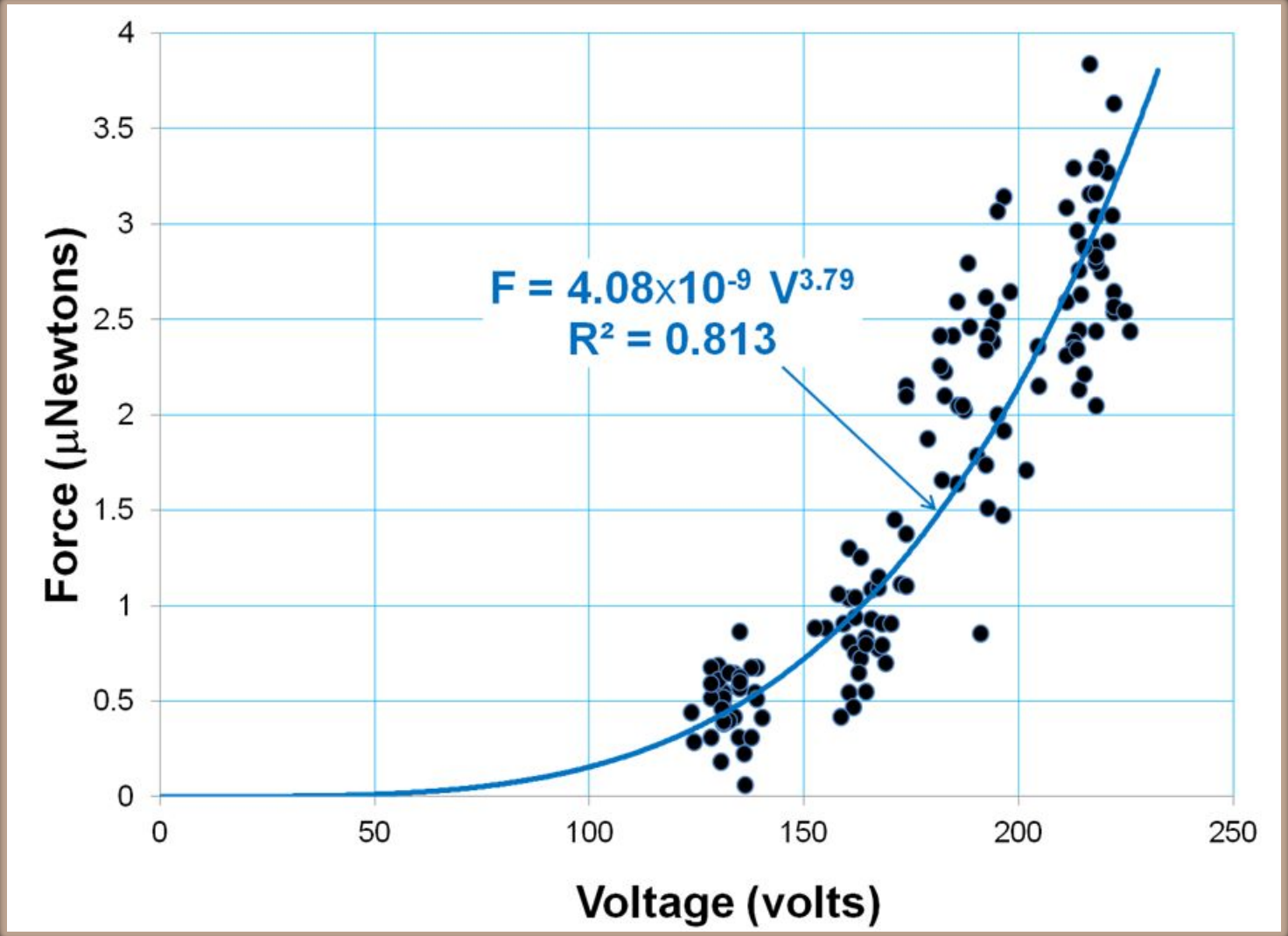
- Encouragingly, our experiments are matching independent theoretical analysis using *Mathematica* that illustrates the complicated force behavior *versus* the brass mass as well as Force *versus* Voltage.

- We have measured the internal stress distribution of the stack with pressure-measurement film and adjusted observed non-uniform stress distribution (measured from 800-7000 psi) to an optimally consistent 3000 psi by using numerically-machined domes designed based on theoretical analysis.

- We are ready to test state-of-the-art PIN-PMN-PT materials.

- We've demonstrated a Force *versus* Voltage scaling relationship that is consistent with the theory (following slide).

Force Scales With Voltage



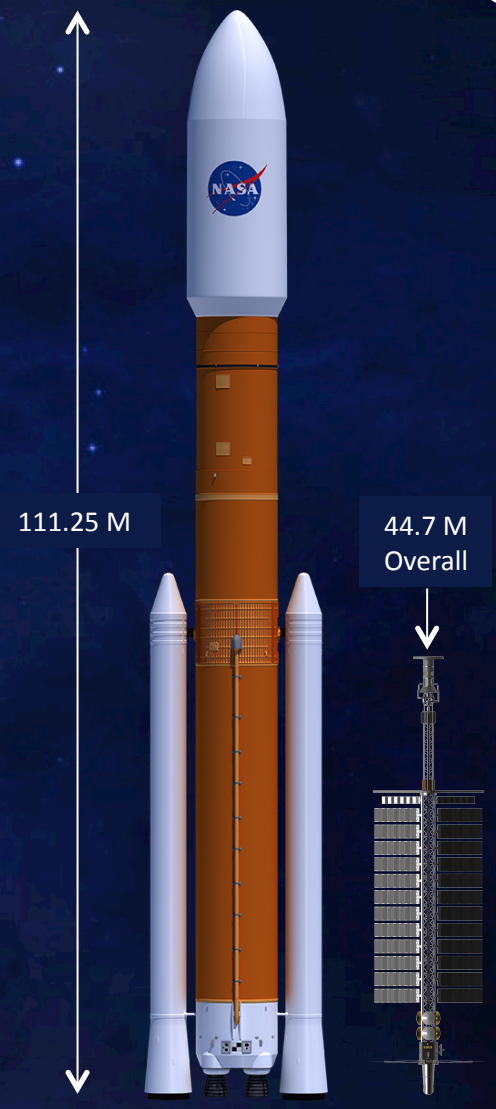
Interstellar Mach Effect Spacecraft (IMES) Requirements

- The spacecraft must survive a 25-30 year long mission, with full reactor power available to the drive for at least 20 years.
- Payload must be no less than 400 kg, with more desirable.
- The spacecraft must operate and navigate autonomously.
- The spacecraft must transmit data to Earth at a rate of 1GB/year or better over >4 LY distances.
- The spacecraft must survive at velocity up to 0.4 *c*.
- With the exception of the central structural boom and radiators, payload booms must not be deployed to protect them during interstellar cruise.
- The MEGA Drive Module must be located as close as possible to the spacecraft center of mass using a rigid attachment to the power-conditioning components of the reactor power plant.

IMES Subsystems and Scale

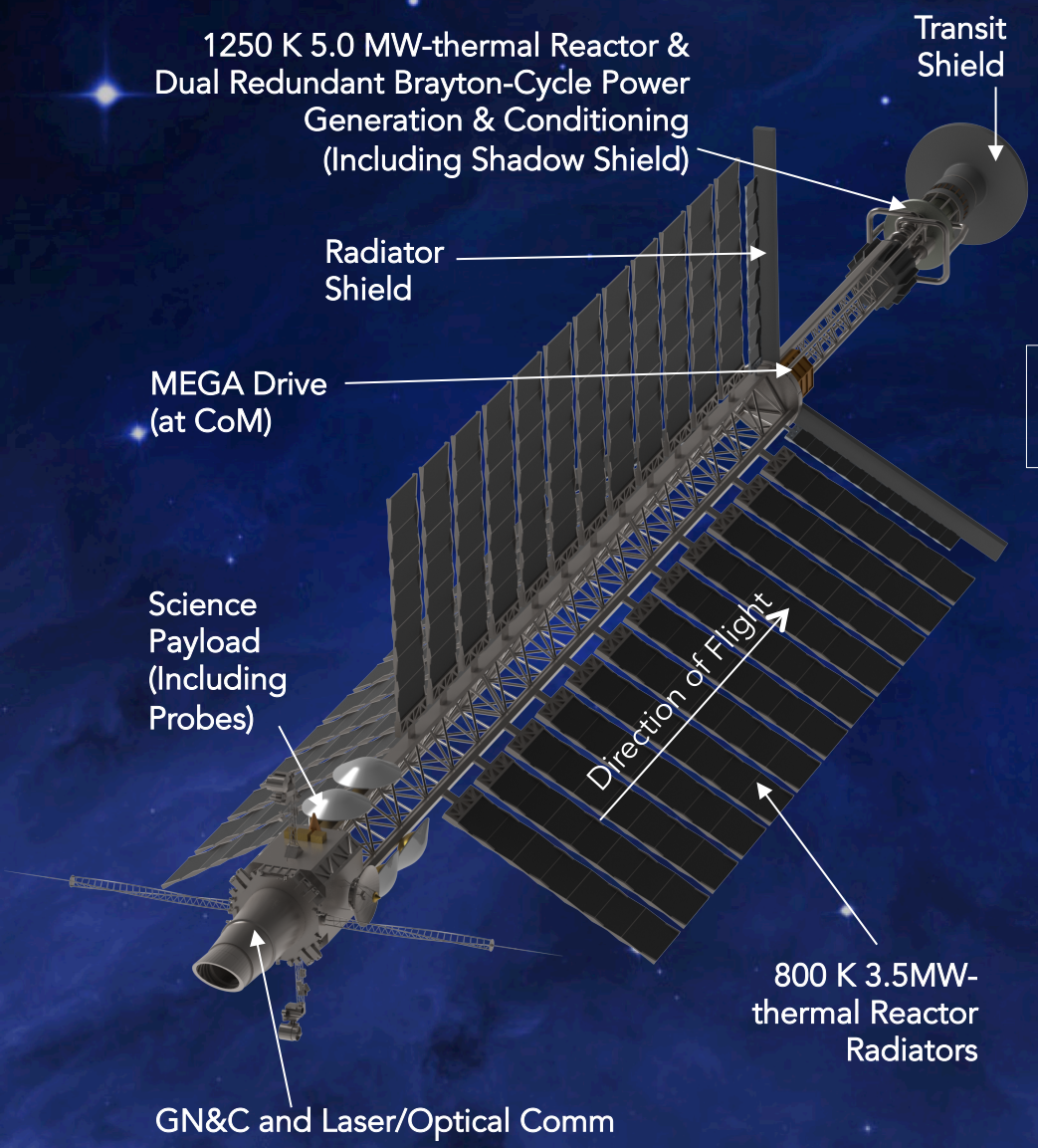
Principal Subsystems of 15,000 kg spacecraft:

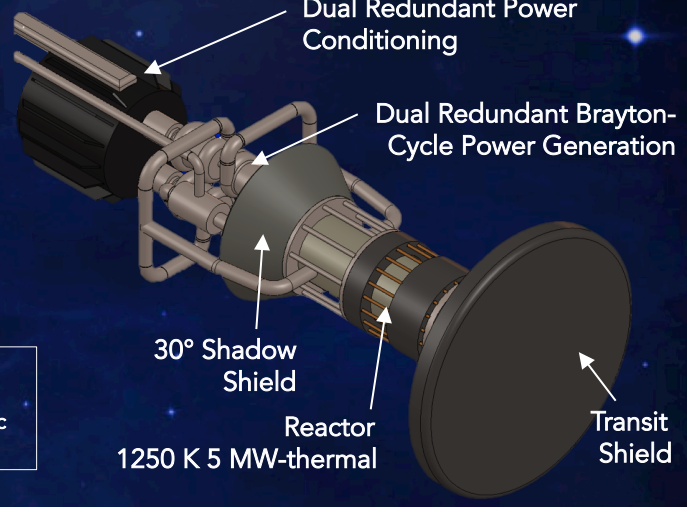
- Prime Power
  - Reactor (5MW-thermal, 1.5 MW-electric)
  - Power Generation
  - Power Conditioning
  - Power Thermal Control (radiators)
- Shields (Transit & Radiator)
- MEGA Drive Propulsion & Attitude Control
- Autonomous Guidance, Navigation & Control (GN&C)
- Comm Subsystem (1.06 μ 1kW Laser telescope)
- Science & Exploration Payload
  - Secondary Payload (Lander?)



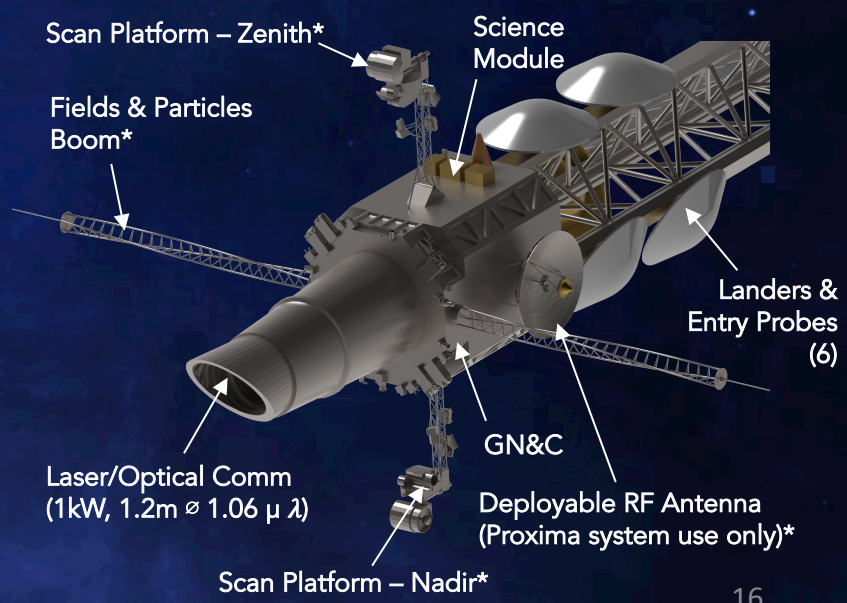
MEGA Drive Spacecraft Size Comparison to SLS Block II

IMES Configuration



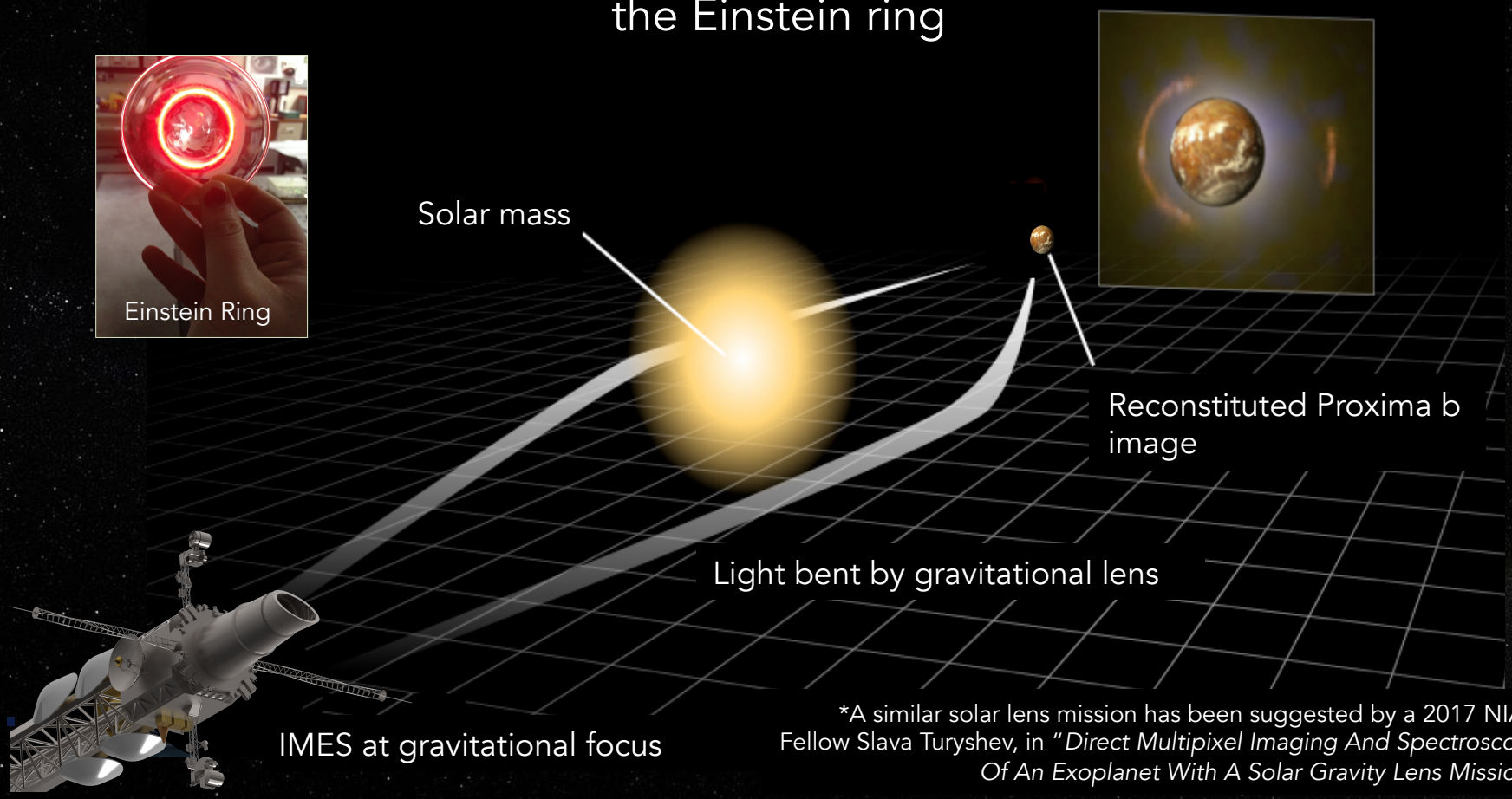


*Stowed during relativistic flight



Shakedown Cruise to the Solar Gravity Lens?

To the Sun's gravity lens focus...capture photons for spectroscopy and perhaps get an image of Proxima b from the Einstein ring

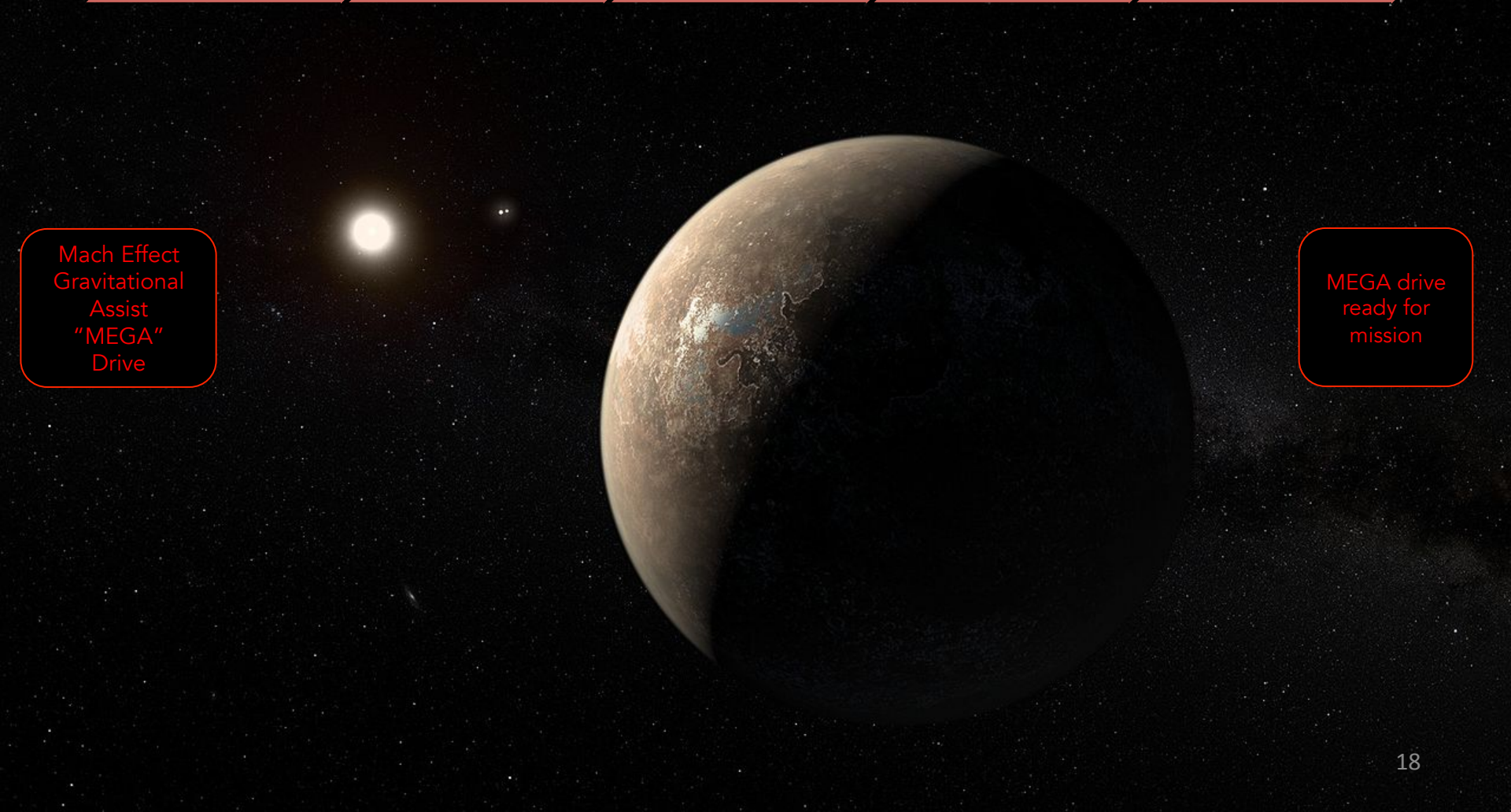


*A similar solar lens mission has been suggested by a 2017 NIAC Fellow Slava Turyshev, in "*Direct Multipixel Imaging And Spectroscopy Of An Exoplanet With A Solar Gravity Lens Mission*"

How Do We Get There From Here?

Now → 1 year → 5 year → 10 year → 20-25 year

Mach Effect Gravitational Assist "MEGA" Drive



MEGA drive ready for mission

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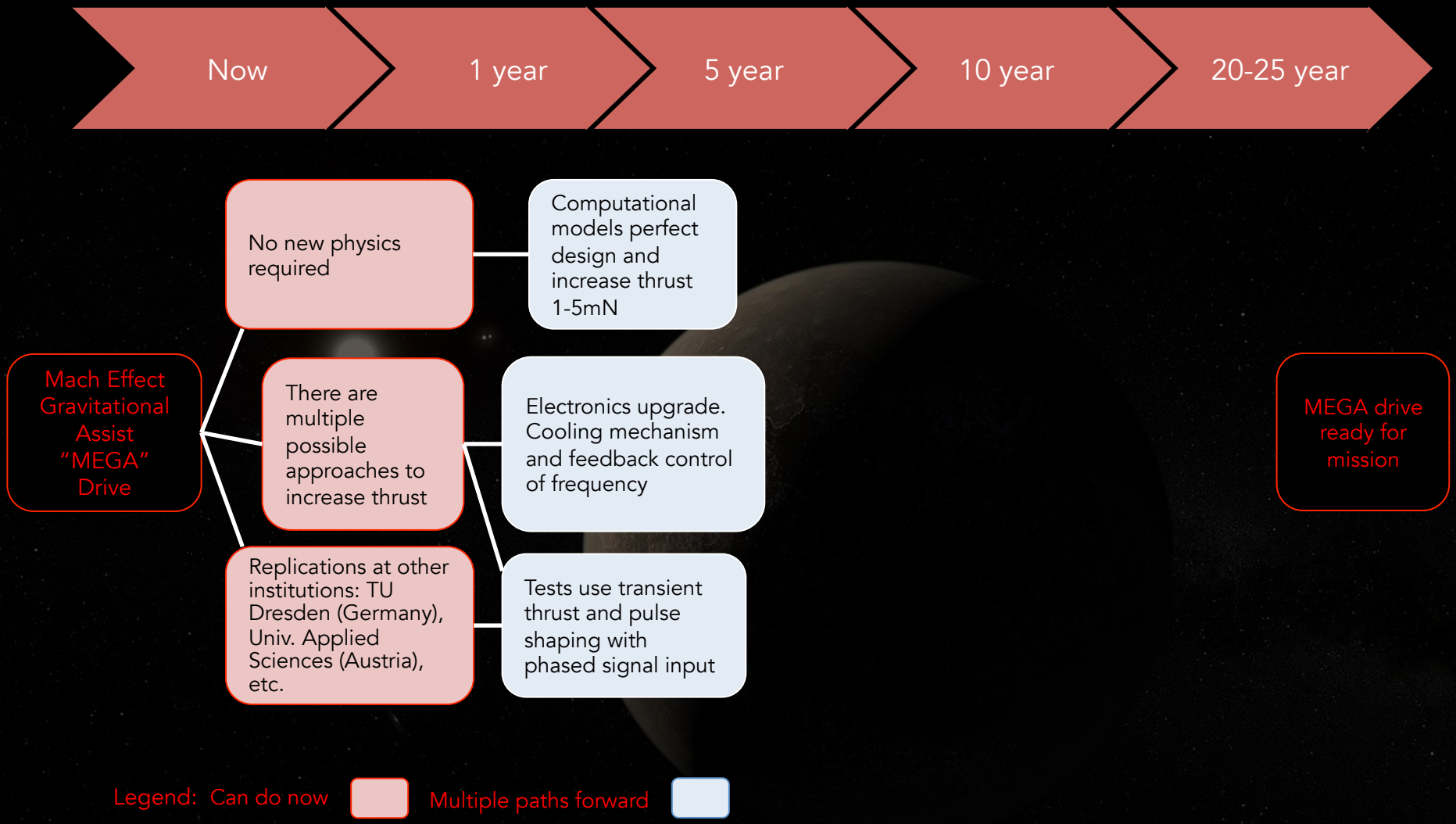
Mach Effect Gravitational Assist "MEGA" Drive

- No new physics required
- There are multiple possible approaches to increase thrust
- Replications at other institutions: TU Dresden (Germany), Univ. Applied Sciences (Austria), etc.

MEGA drive ready for mission

Legend: Can do now

How Do We Get There From Here?



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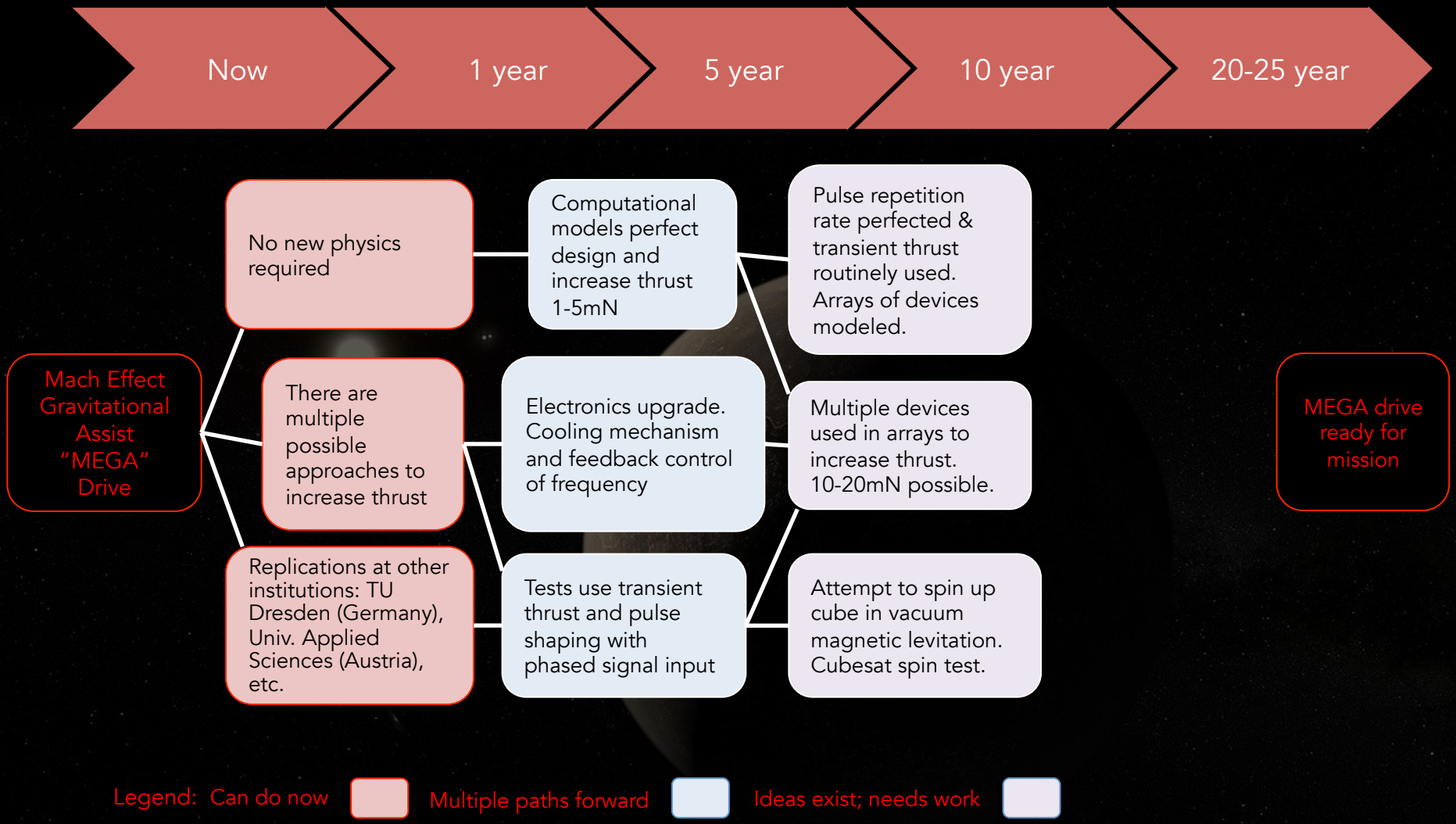

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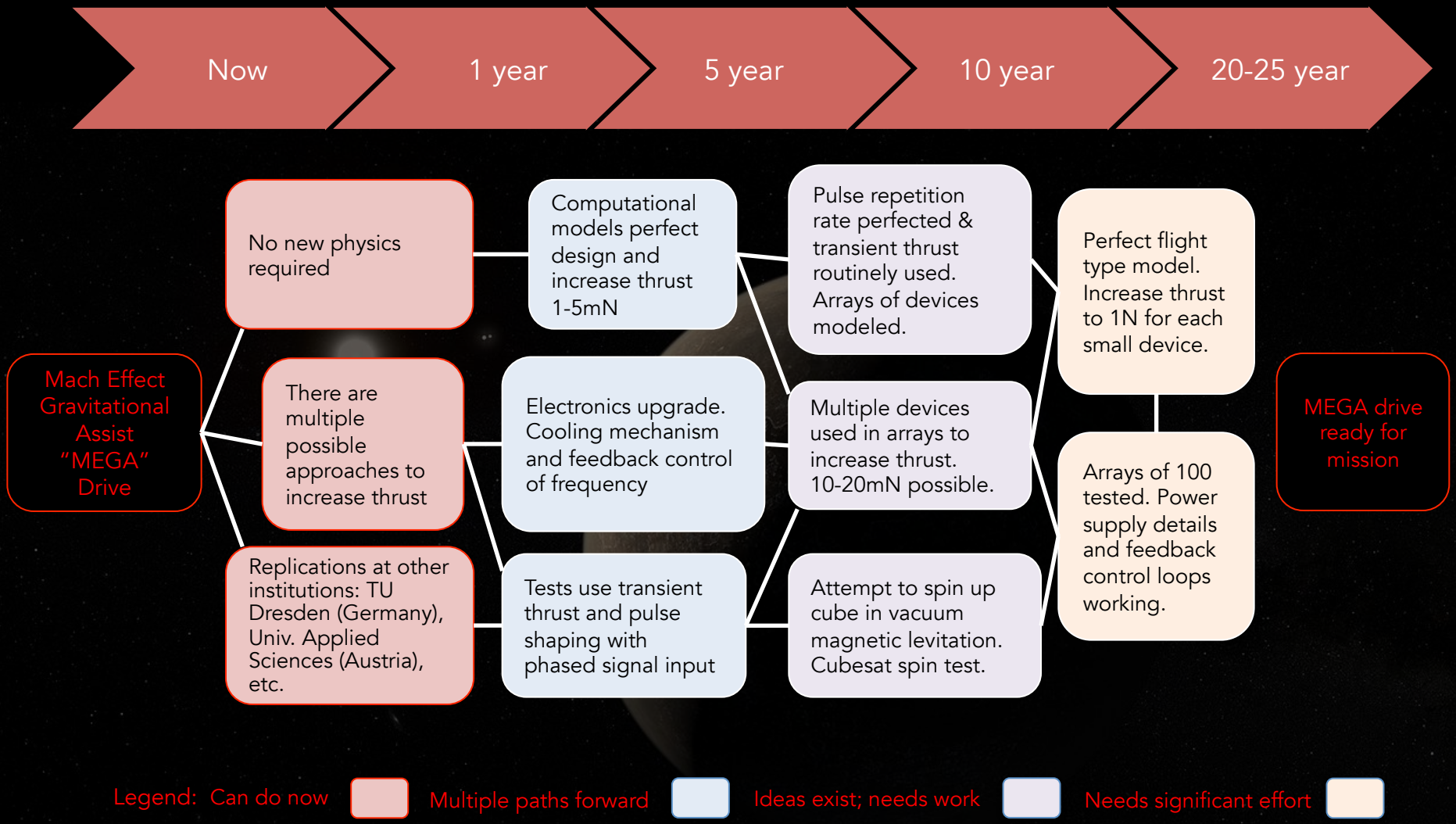

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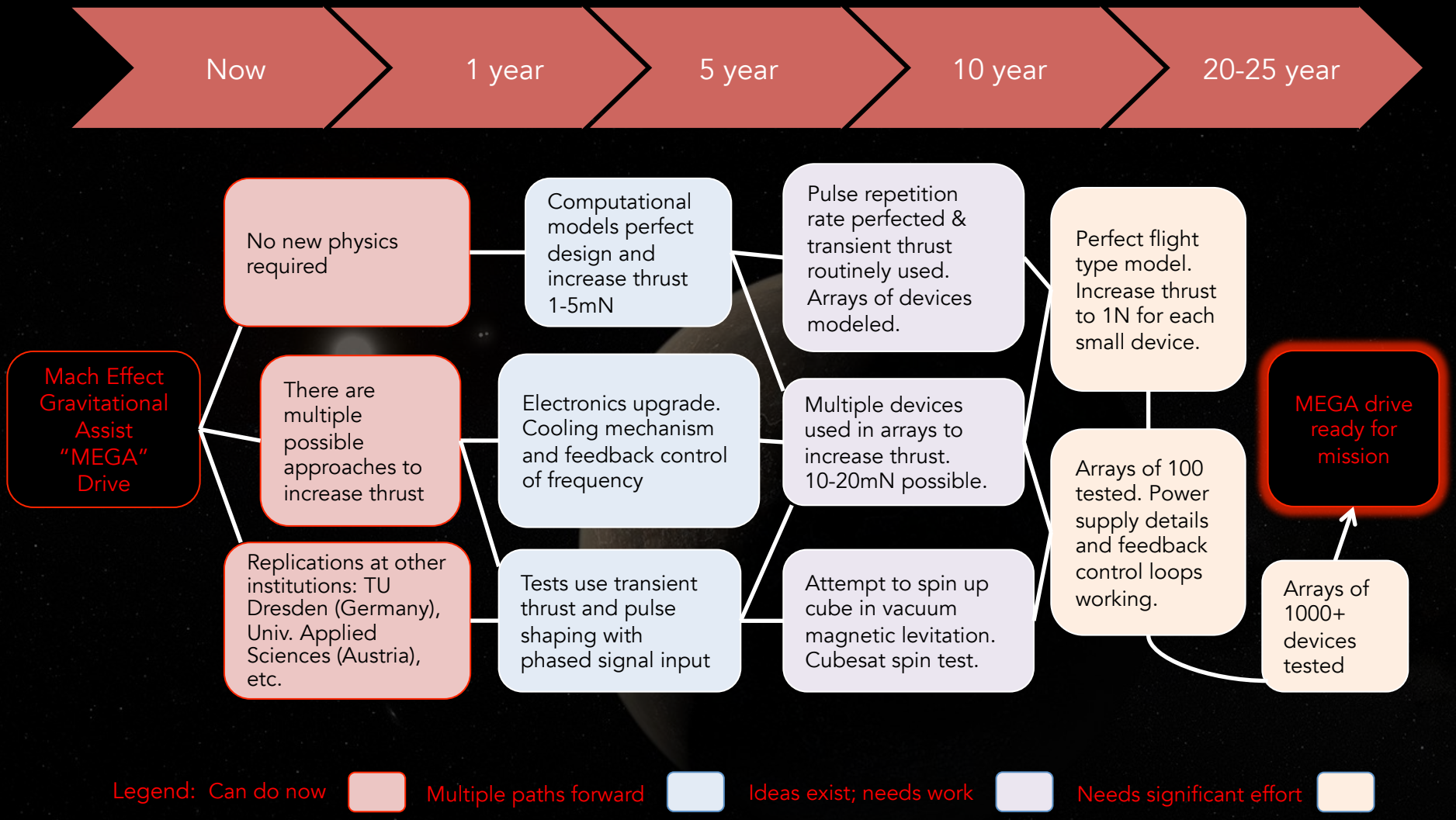

Next Steps

- Publish –
  - One or more papers on results of our current laboratory scale test program
  - Additional peer-reviewed papers on theory are in preparation
  - Paper on IMES-1 design and Concept of Operations (CONOPS)
- Upgrade test facilities and increase thrust –
  - Increase data rate and number of channels
  - Improve torsion balance
  - Increase thrust ~10x
- Design an on-orbit test of the MEGA drive –
  - Our planned on-orbit test using a microsatellite (or CubeSat) is presently at TRL ~ 2
  - We favor a rotational test, spinning a microsatellite up (and down) by opposing drives. This removes atmospheric drag as a major error source.

Thanks!

Professor Heidi Fearn, Principal Investigator

Team: Dr. José Rodal, Mr. Marshall Eubanks, Dr. Bruce Long, Mr. Paul March, Mr. Gary C Hudson

Consultant: Emeritus Professor James F. Woodward

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