Garan Carter-Woodgate

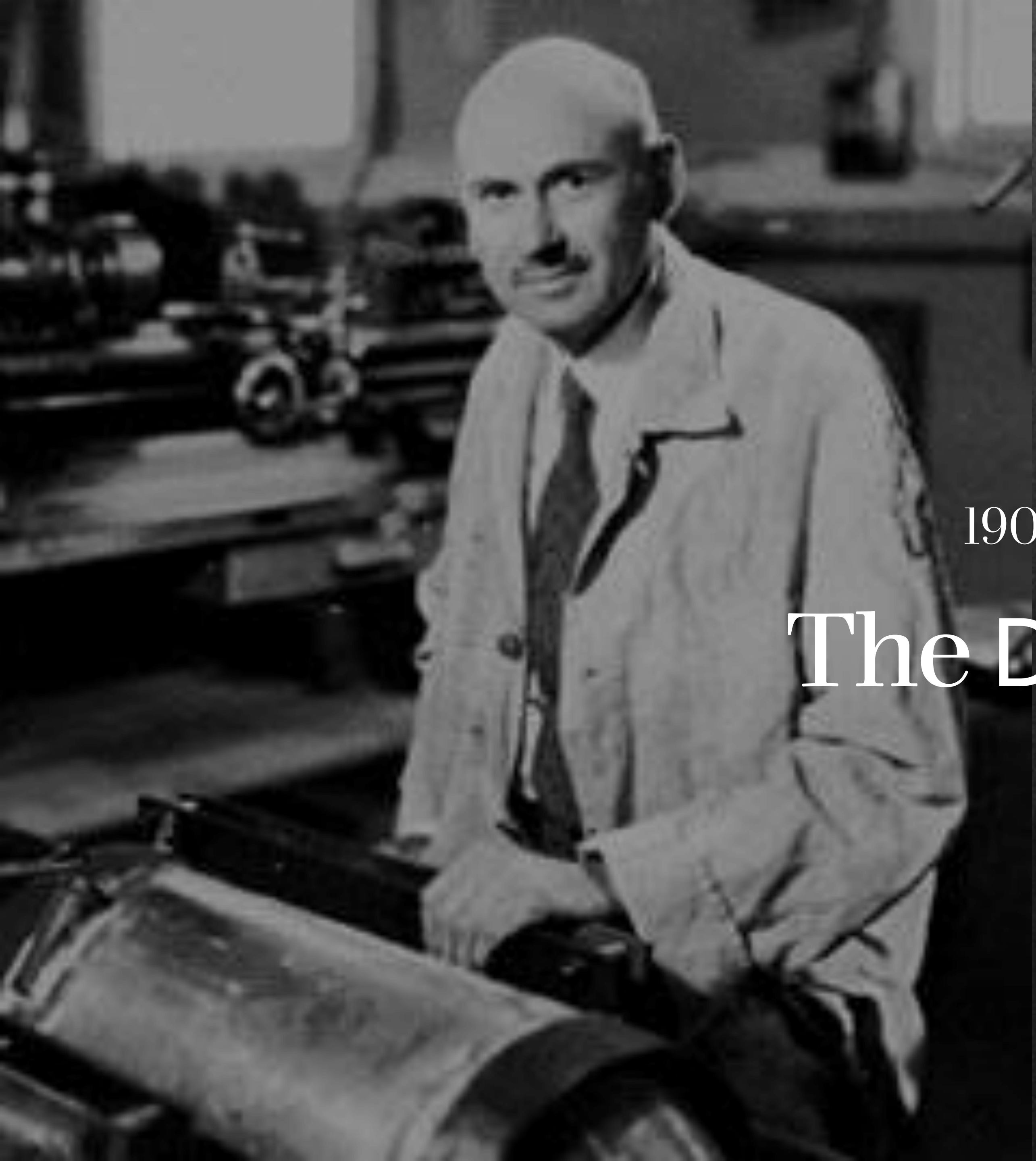
Adi Soundalgekar

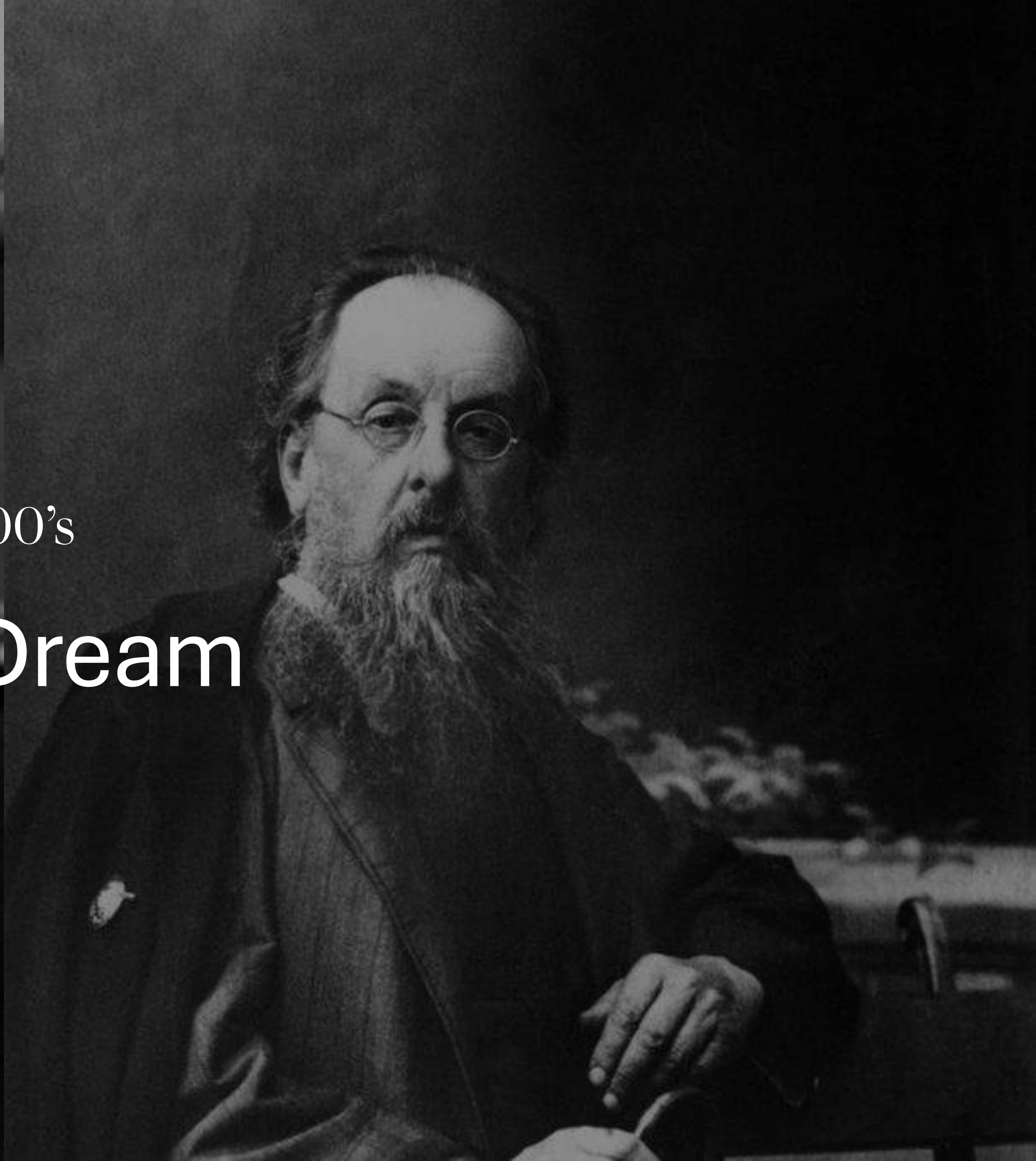
25/26 Team

SUEP 25-26

Motivation

Adi Soundalgekar





1900’s

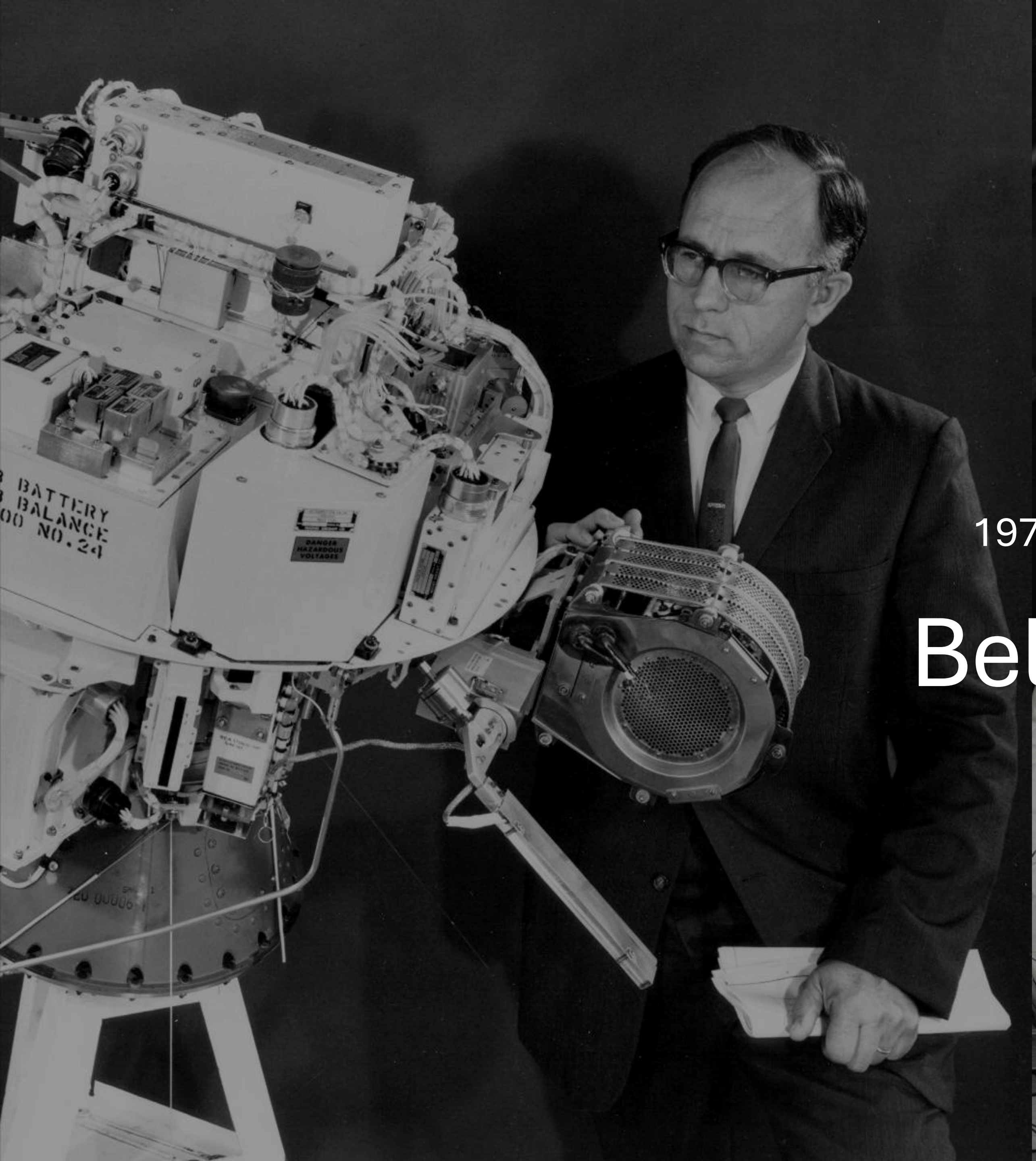
The Dream

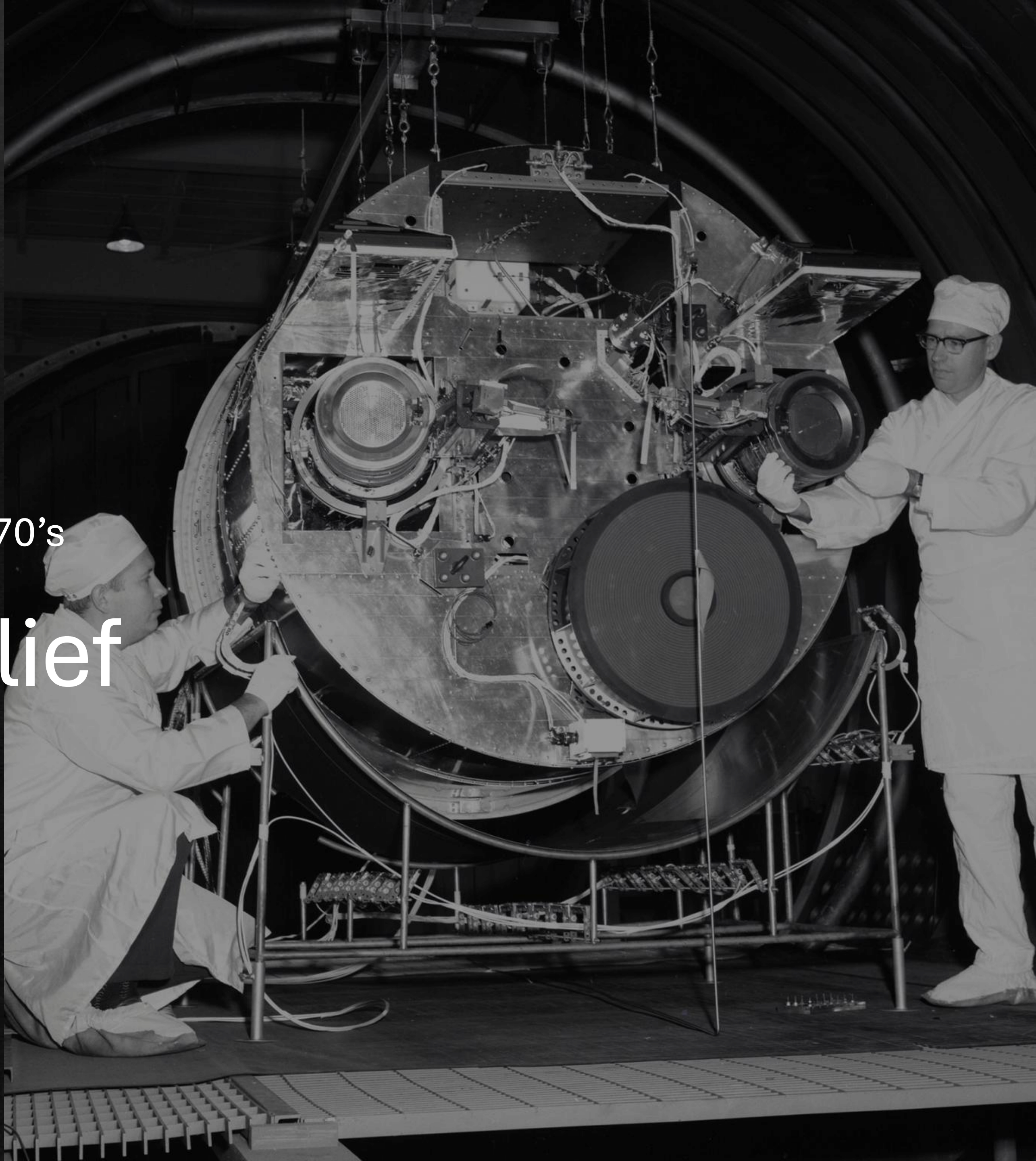
1900 — Tsiolkovsky, Goddard

1929 — Oberth

1950 — The USSR

1960 — NASA Lewis





1970’s

Belief

1960 — SERT I

1969 — SERT II

1970 — The USSR (again)

1973 — Daedalus

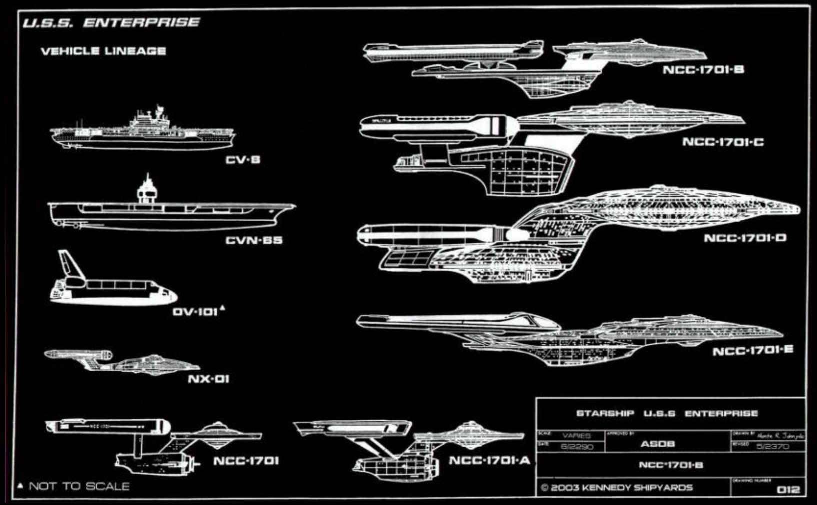
A new era

1980/90’s

OKB Fakel

The modern age

2000-2025

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ФАКЕЛ
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SITAEL

SITAEL

ALMASpace
"Space to your Business"

ALTA

MAGDRIVE

NASA

Jet Propulsion Laboratory
California Institute of Technology

PULSAR

Massachusetts Institute of Technology

UNIVERSITY OF MICHIGAN

Georgia Tech

Caltech

University of Southampton

cnrs

東京大学
THE UNIVERSITY OF TOKYO

Imperial College London

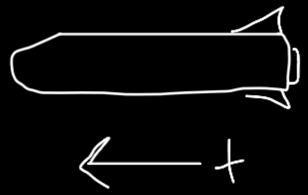
Université de Toulouse

EPFL

Our motivations

Fundamentals of spacecraft propulsion

Adi Soundalgekar



Tsiolkovsky rocket equation

Momentum conservation

$$F = T = M\,\frac{dv}{dt}$$

$$T = -\frac{d}{dt}(m_p v_{ex})$$

$$= -v_{ex}\,\frac{dm_p}{dt}$$

Rate of change of mass

$$M(t) = m_d + m_p$$

$$\frac{dM}{dt} = \frac{dm_p}{dt}$$

Substitution

$$M\,\frac{dv}{dt} = -v_{ex}\frac{dM}{dt}$$

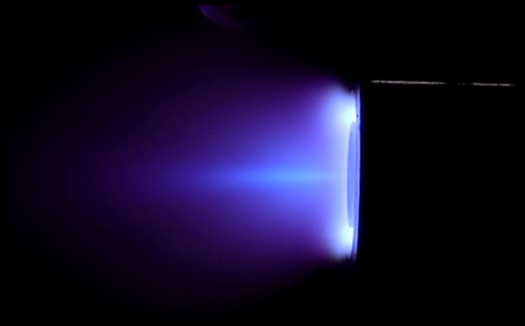
$$dv = -v_{ex}\frac{dM}{M}$$

$$\int_{v_i}^{v_f} dv = -v_{ex}\int_{m_d+m_p}^{m_d}\frac{dM}{M} \quad\Rightarrow\quad v_f - v_i = -v_{ex}\,(\ln(m_d) - \ln(m_d+m_p)) \quad\Rightarrow\quad \boxed{\Delta v = v_{ex}\ln(\frac{m_d+m_p}{m_d})}$$

Electric thruster types

Electric thrusters are generally described in terms of the acceleration mechanism used to provide the thrust. There are 3 main categories;

Electrostatic	Electromagnetic	Electrothermal
Ion thrusters $\boxed{\text{Hall thruster}}$ Electrospray / FEEP	Pulsed plasma thruster Magnetoplasmadynamic thruster	Resistojets Arcjets



Resistojet

Arcjet

HET

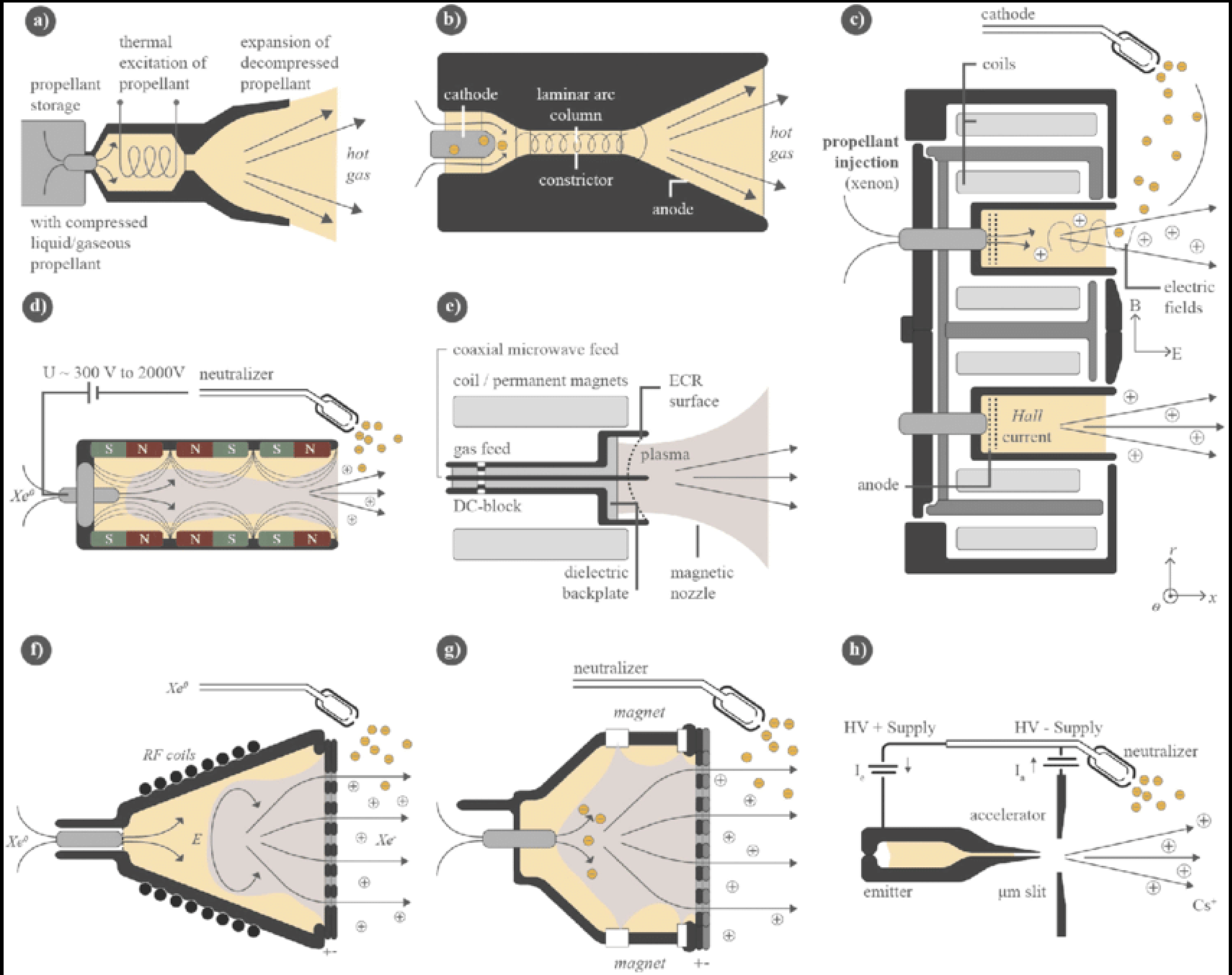
Ion thruster

Micro-electrohermal

RF-ion thruster

MPD

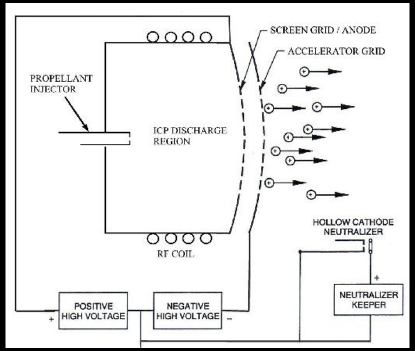
FEEP



Electrostatic thrusters

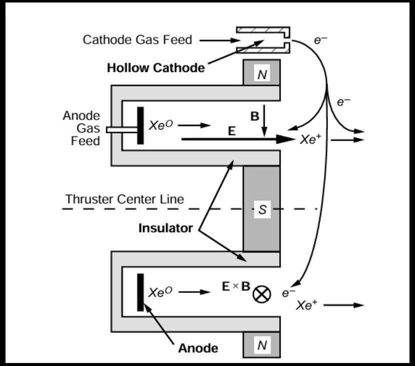
Ion thrusters

- Neutral gas atoms ionized by bombardment or RF excitation
- Positively charged ions extracted and accelerated through grids with a +ve bias
- Electrons are emitted from a neutralizer to maintain charge balance



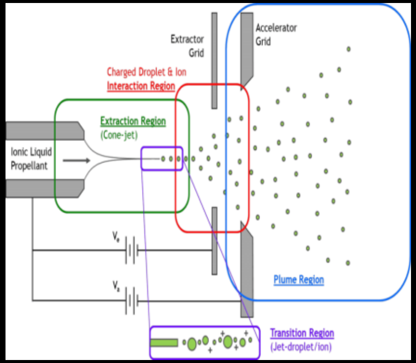
Hall thrusters

- Perpendicular axial electric and radial magnetic field
- Electrons from cathode trapped by magnetic field in azimuthal Hall motion
- Neutral gas atoms ionized, then accelerated out by electric field before electrons neutralise

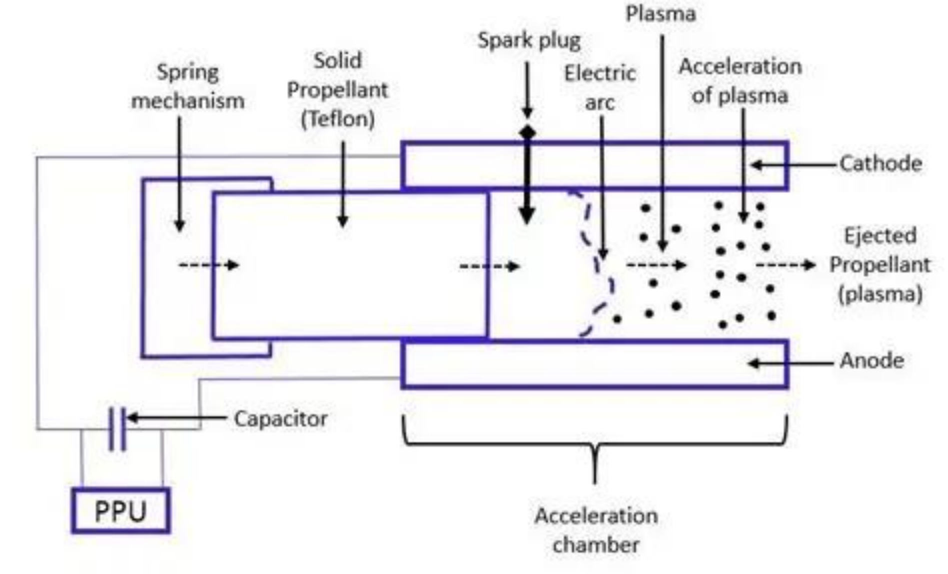


Electrospray thrusters

- Ionic liquids emitted through capillaries
- Strong electric field shapes the liquid surface into Taylor cone
- Ions extracted from cone tip and accelerated electrostatically through grid
- Alternate +ve –ve emission states to remain charge neutral
- FEEP use liquid metals instead



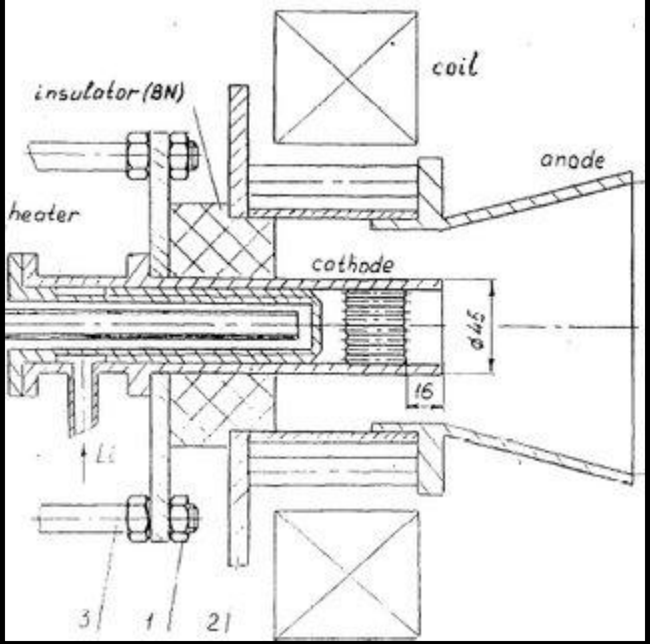
Electromagnetic thrusters



Pulsed plasma thrusters

- Rapidly discharge high-voltage Capacitor through electrodes => high current pulse
- Discharge vaporizes and ionizes solid propellant => plasma
- Plasma is accelerated by electromagnetic forces between electrodes

Magnetoplasmadynamic thrusters



- Neutral gas atoms ionized by bombardment or RF excitation
- Positively charged ions extracted and accelerated through grids with a +ve bias
- Electrons are emitted from a neutralizer to maintain charge balance

Thrust Ion/Hall

Kinetic Power

$\dot{m}_p = QM_p$: propellant mass flow rate

$$T = \dot{m}_p v_{ex}$$

We may define Kinetic Thrust Power as

$$P_{jet} = \frac{1}{2}\dot{m}_p v_{ex}^2$$

$$= \frac{T^2}{2\dot{m}_p}$$

Thrust

$$v_i \gg v_{ui}$$

$$\Rightarrow T \approx \dot{m}_i v_i$$

Conservation of Energy

Work done by electric field $= qV_B$

$$qV_B = \frac{1}{2} m_i v_i^2$$

$$\Rightarrow \quad v_i = \sqrt{\frac{2qV_v}{m_i}}$$

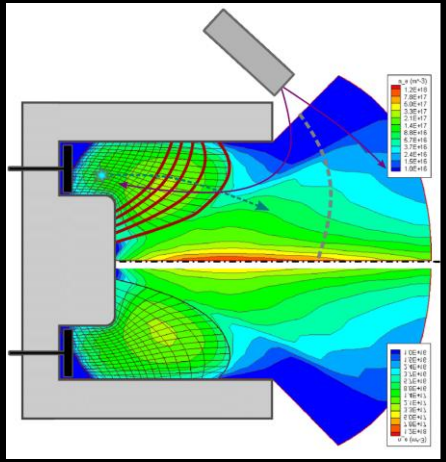
Explicit thrust

Remember $\dot{m}_i = \frac{mass_{ions}}{time}$

And $q = \frac{I_B t}{n}$, $I_B = \frac{qn}{t}$

$$\Rightarrow \dot{m}_i = \frac{m_i I_B}{q}$$

$$\Rightarrow \boxed{T = \sqrt{\frac{2m}{e}} * I_B * \sqrt{V_B}}$$



Specific Impulse

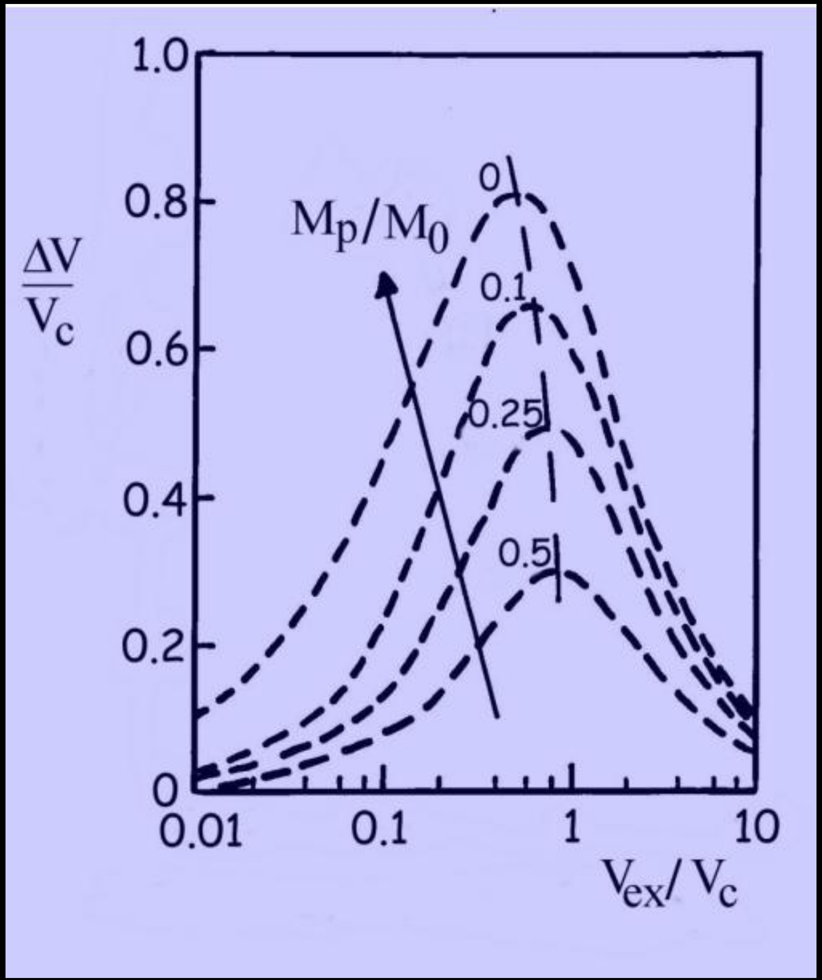
Definition

$$Isp = \frac{T}{\dot{m}_p g}$$

Hence we may generalize Isp for any thruster as :

$$Isp = \frac{v_{ex}}{g}$$

$$= \frac{T^2}{2\dot{m}_p}$$



Ion Thrust assumption (again)

$$v_i \gg v_{ui}$$

$$\Rightarrow T \approx \dot{m}_i v_i$$

$$\boxed{\Rightarrow Isp = \frac{v_i}{g}\frac{\dot{m}_i}{\dot{m}_p}}$$

Efficiency

$$\eta_t = \frac{P_{beam}}{P_{in}}$$

$$\eta_{m^*} = \alpha_m * \frac{I_B}{e} * \frac{m}{\dot{m}_p}$$

Parameter	NS-Station Keeping
Active grid diameter (cm)	12
Thruster input power (W)	541–611
Nominal Isp (s)	2402–2665
Thrust (mN)	20.9–23.2
Total efficiency (%)	45.6–49.7
Mass utilization efficiency (%)	66.2–73.5
Electrical efficiency (%)	78.2–79.5
Beam voltage (V)	996
Beam current (A)	0.43–0.48

Parameter	SPT-50	SPT-70	SPT-100	SPT-140
Slot diameter (cm)	5	7	10	14
Thruster input power (W)	350	700	1350	5000
Average Isp (s)	1100	1500	1600	1750
Thrust (mN)	20	40	80	300
Total efficiency (%)	35	45	50	>55
Status	Flight	Flight	Flight	Qualified

Ion Thruster