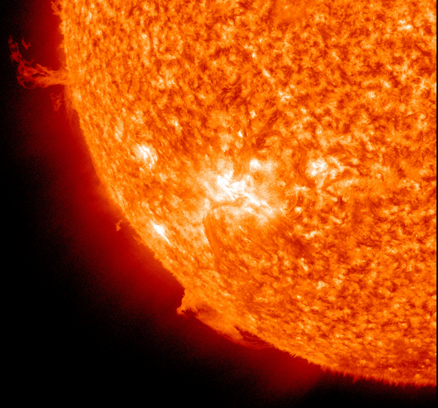
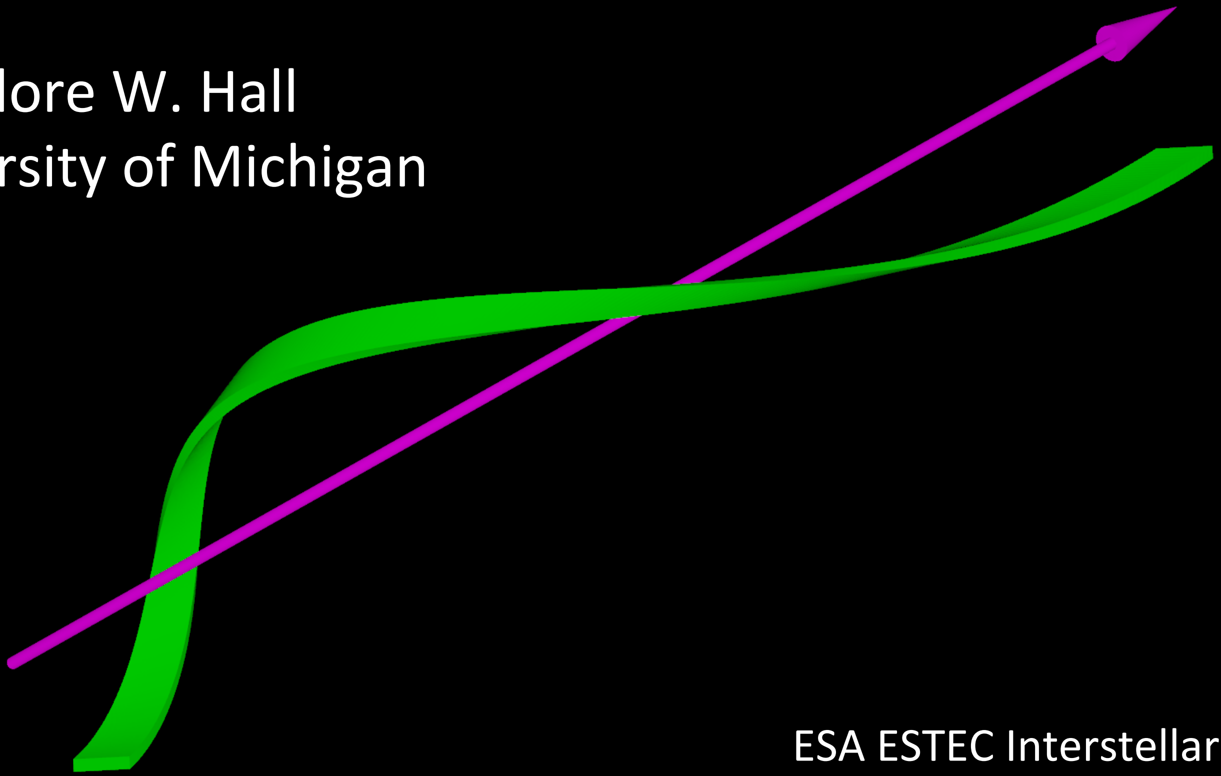
Artificial Gravity in Interstellar Travel



Theodore W. Hall
University of Michigan



ESA ESTEC Interstellar Workshop 2019-06-21

Effects of Chronic Weightlessness

- Fluid redistribution
- Fluid loss
- Electrolyte imbalances
- Cardiovascular changes
- Red blood cell loss
- Muscle damage
- Bone damage
- Eye damage
- Hypercalcemia
- Immune suppression.

… and others … ?

Alternatives to Weight for Preserving Health?

- Suspended animation
- J. D. Bernal,
  “three-dimensional, gravitationless way of living”

Weight & Gravity, in Theory …

Fundamental Forces (Interactions):

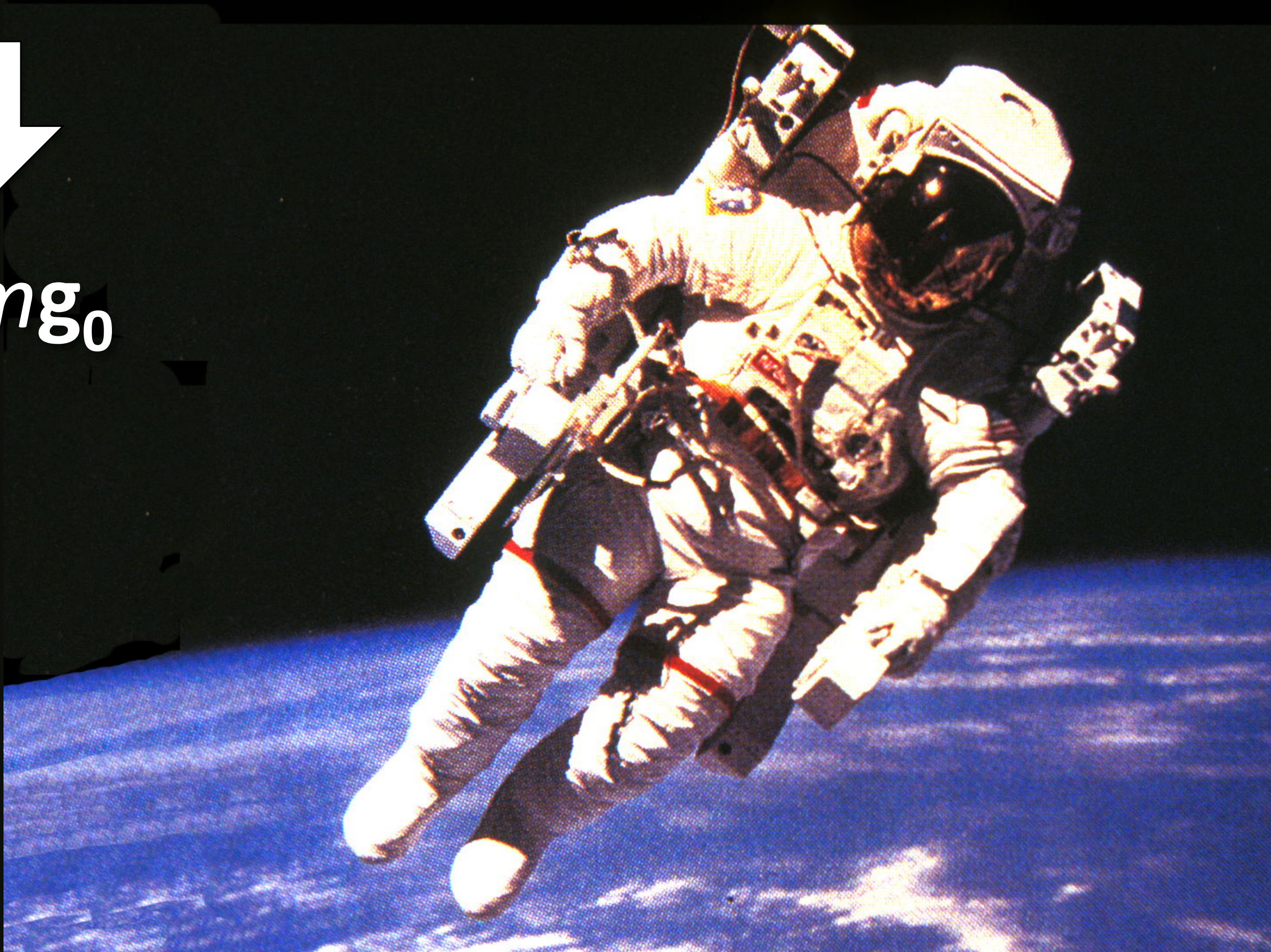
Standard Model of Particle Physics

1. Strong Nuclear (gluons)
2. Weak Nuclear (W & Z bosons)
3. Electromagnetic (photons)

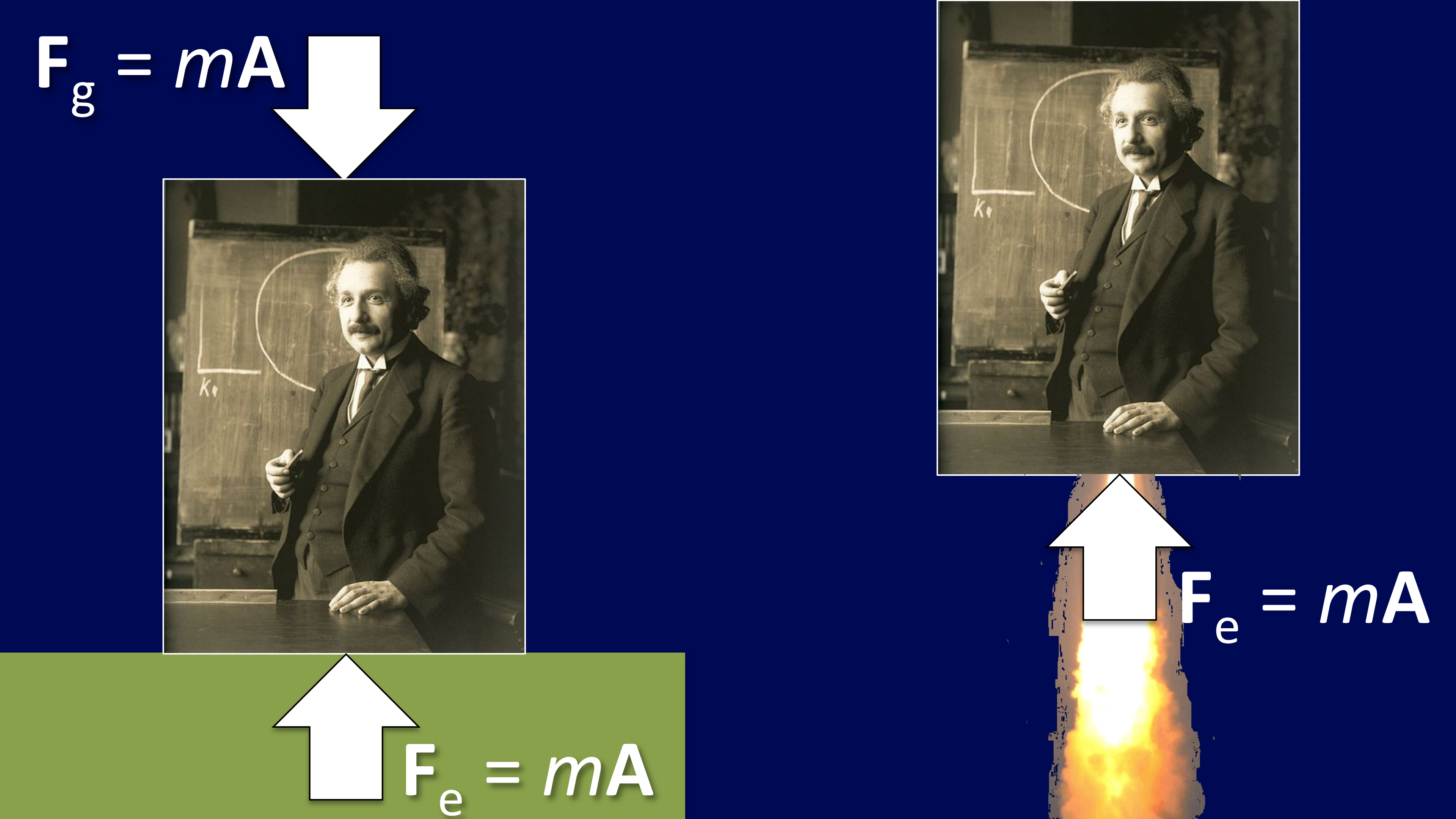
4. Gravitational (?)

$F_g = mA$

$F_g = 89\% \; mg_0$

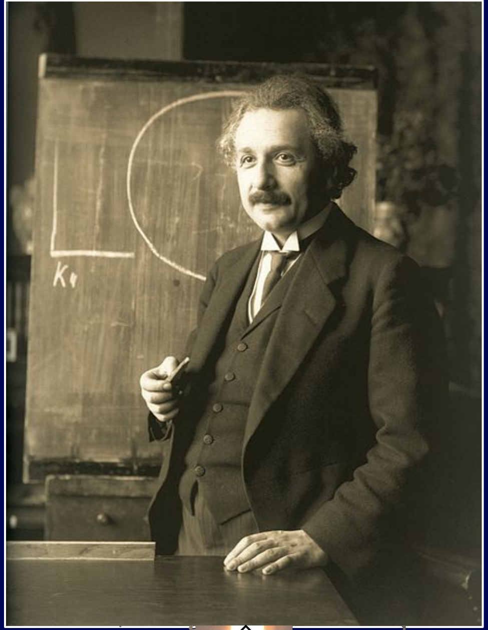


and yet he’s weightless.


$F_g = mA$
$F_e = mA$
$F_e = mA$

"a gravitational field exists for the man in the chest, despite the fact that there was no such field for the coordinate system first chosen"

– *Einstein*



$\mathbf{F}_e = m\mathbf{A}$

Gravity is Irrelevant:

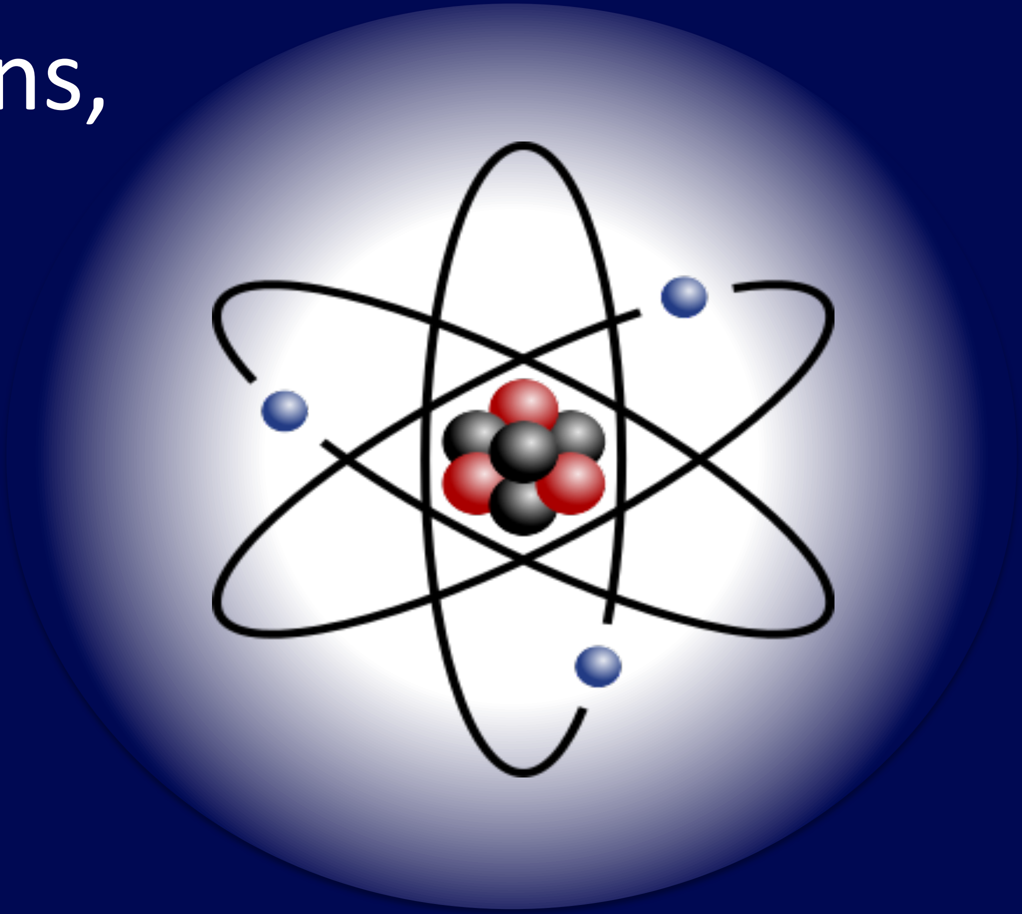
It’s neither necessary nor sufficient to preserve human health.

Planetary mostly

Gravity is Irrelevant:

It's neither necessary nor sufficient to preserve human health.

All mechanical and chemical interactions, including *bio*—, are <u>Electromagnetic</u>.



https://en.wikipedia.org/wiki/File:Stylised_atom_with_three_Bohr_model_orbits_and_stylised_nucleus.svg

If weightlessness
is the problem,

then mechanical acceleration
is the solution.

If weightlessness
is the problem,

maybe

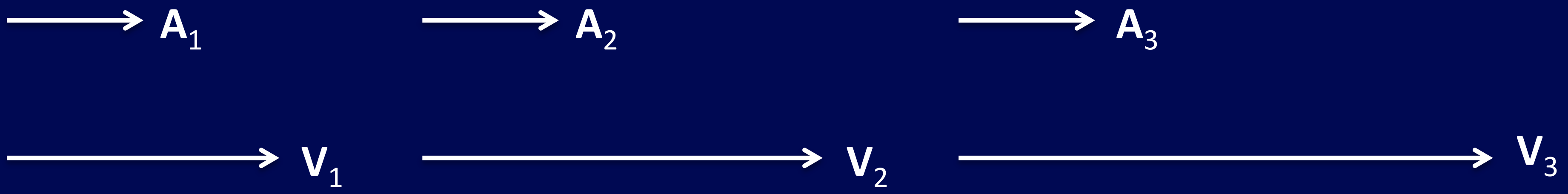
then mechanical acceleration
is the solution.

Linear Acceleration:
±1 g to Proxima Centauri (4.244 ly):

Naive, non-relativistic calculations:

t_{total} = 4.055 yr

V_{max} = 2.093 c



Space travel calculator [N. Geffen]

Distance	4.244	light-years	?+
Acceleration	9.80665	m/s^2	?+
Maximum velocity	0.9496121347735087	speed of light	?+
Observer time elapsed during journey	5.869961089378631	years	?+
Traveler time elapsed during journey	3.5412690887271987	years	?+
Payload (spacecraft mass without fuel)	25000	kilograms	?+
Fuel conversion rate	0.008	kg x m x m	?+
Fuel mass	117787801.00439891	kg	?+
Length of spacecraft at start of journey	1	meters	?+
Shortest length of spacecraft for observer	0.3134274931956345	meters	?+

Calculate Clear

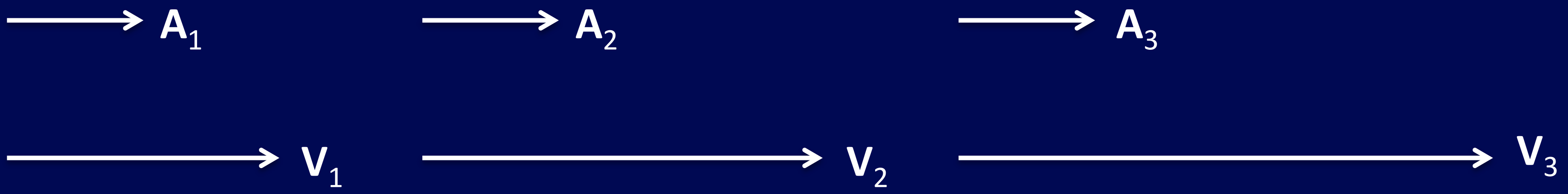
Linear Acceleration:
±1 g to Proxima Centauri (4.244 ly):

Relativistic calculations:

$t_{total\_craft} = 3.541$ yr

$t_{total\_earth} = 5.870$ yr

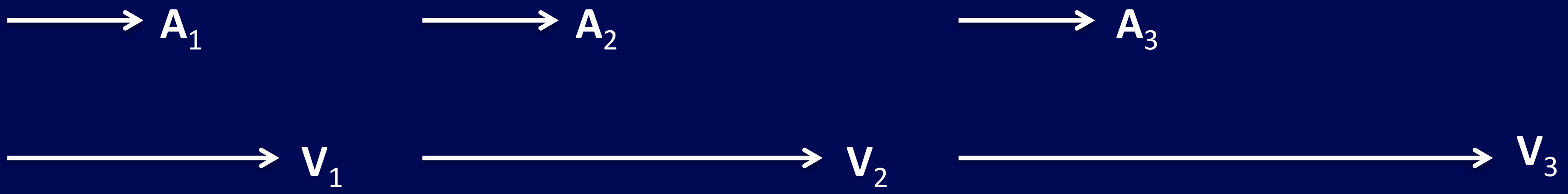
$V_{max\_earth} = 0.9496$ c



Linear Acceleration:

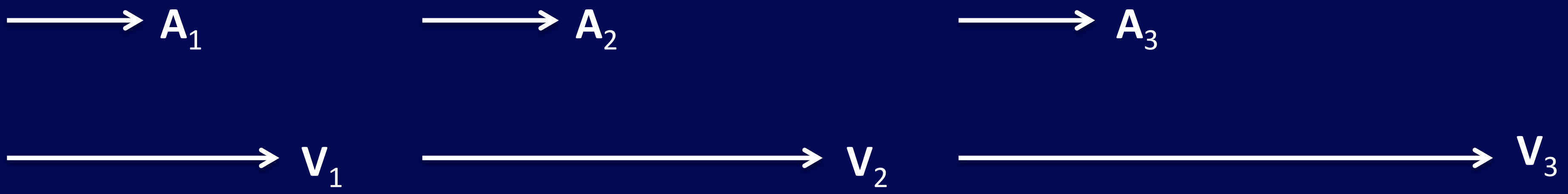
Not sustainable:

$$P = m\mathbf{A} \cdot \mathbf{V} \to \infty$$



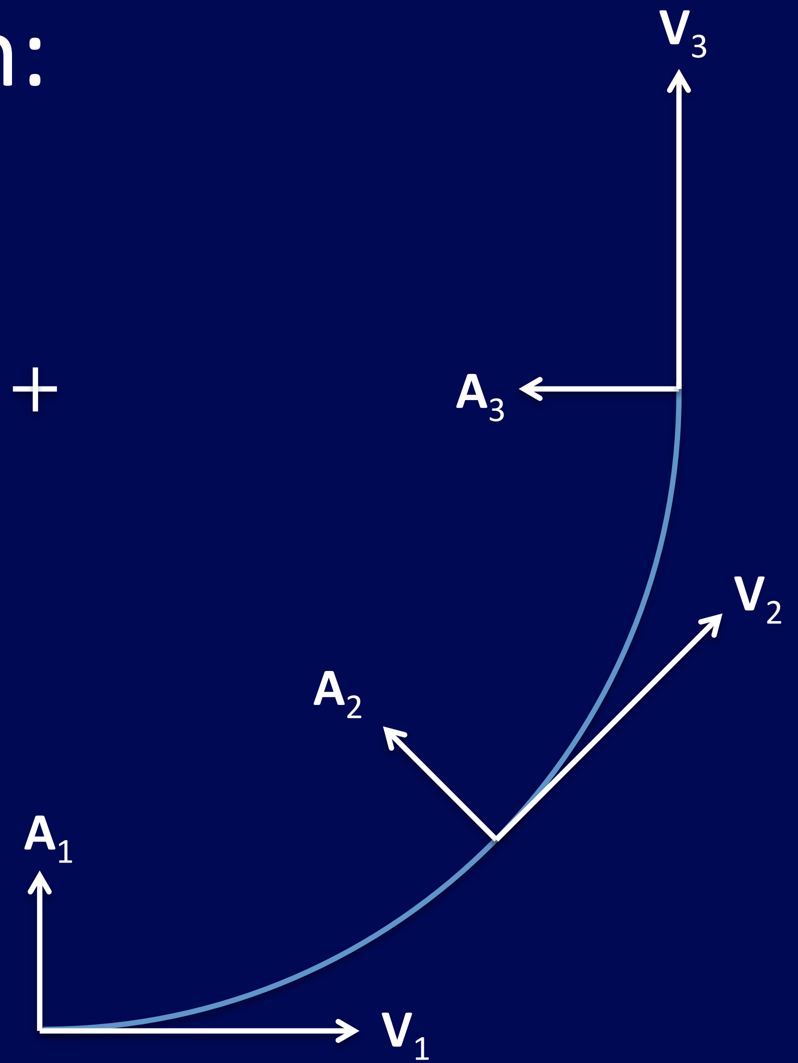
Linear Acceleration:
±a << 1 g to Proxima Centauri (4.244 ly):

A_{craft}	t_{total_craft}	V_{max_earth}
0.001000 g	128.2 yr	0.06608 c
0.001643 g	**100.0 yr**	0.08461 c
0.000572 g	169.6 yr	**0.05000 c**



Centripetal Acceleration: Sustainable

$$P = m\mathbf{A} \cdot \mathbf{V} = 0$$



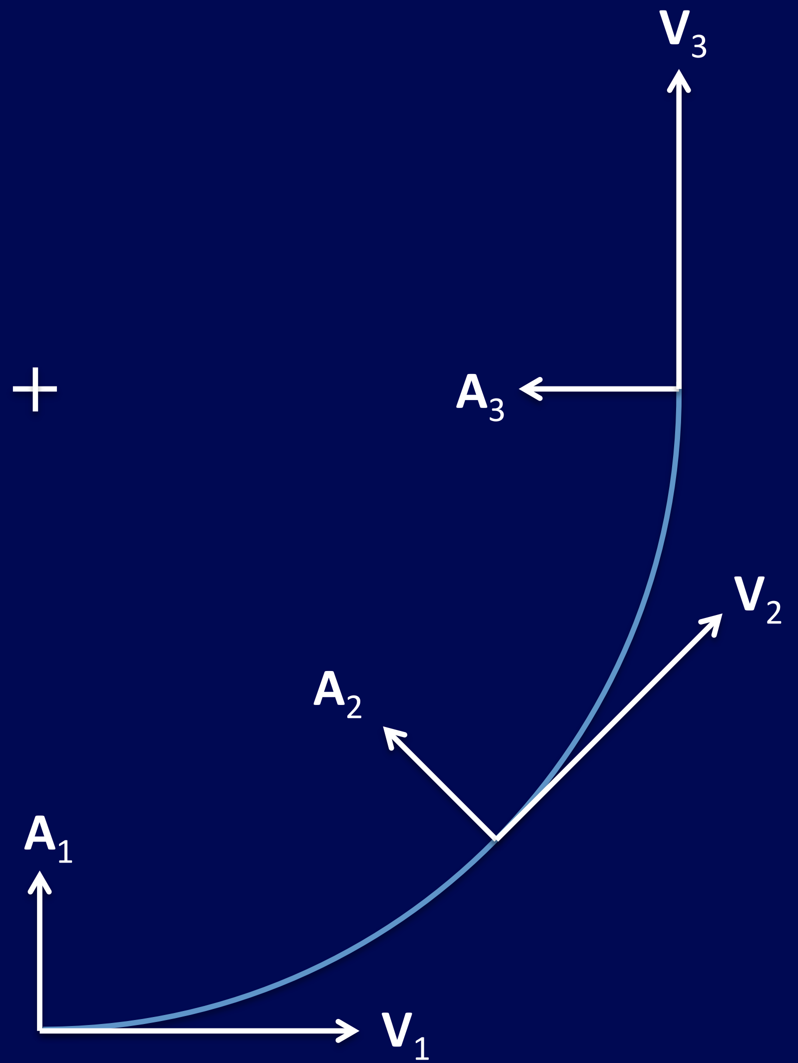
$$\mathbf{V}_{tan} = \mathbf{\Omega} \times \mathbf{R}$$

$$\mathbf{A}_{cent} = \mathbf{\Omega} \times \mathbf{V}$$

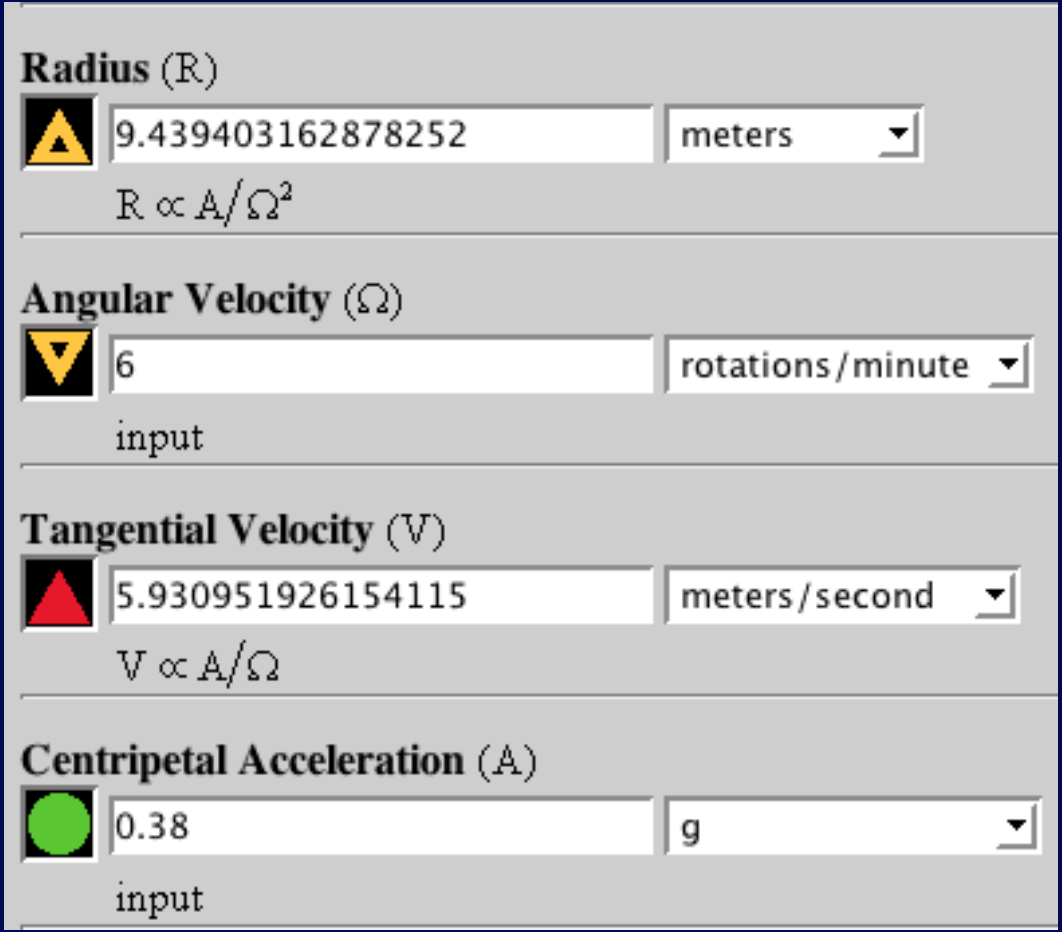
$$= \mathbf{\Omega} \times \left(\mathbf{\Omega} \times \mathbf{R} \right)$$

$$\mathbf{A}_{Cor} = 2\mathbf{\Omega} \times \mathbf{v}_{rel}$$

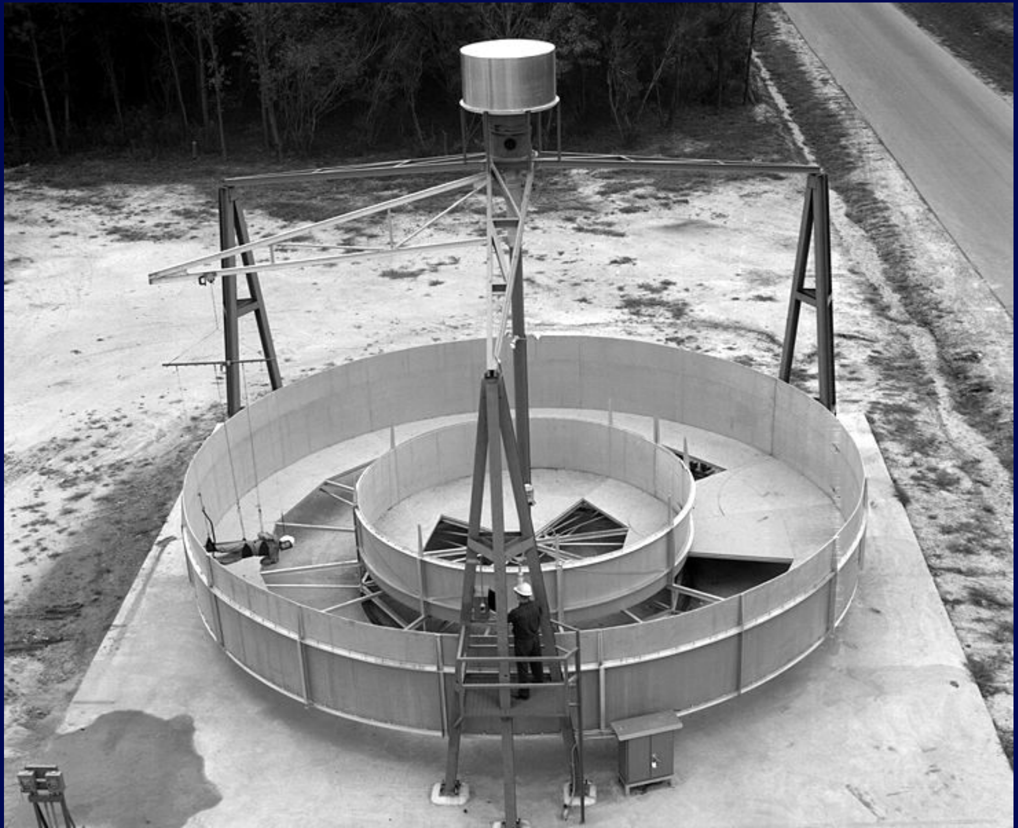
$$\frac{A_{Cor}}{A_{cent}} = 2\frac{V_{rel}}{V_{tan}}$$



SpinCalc artificial-gravity calculator

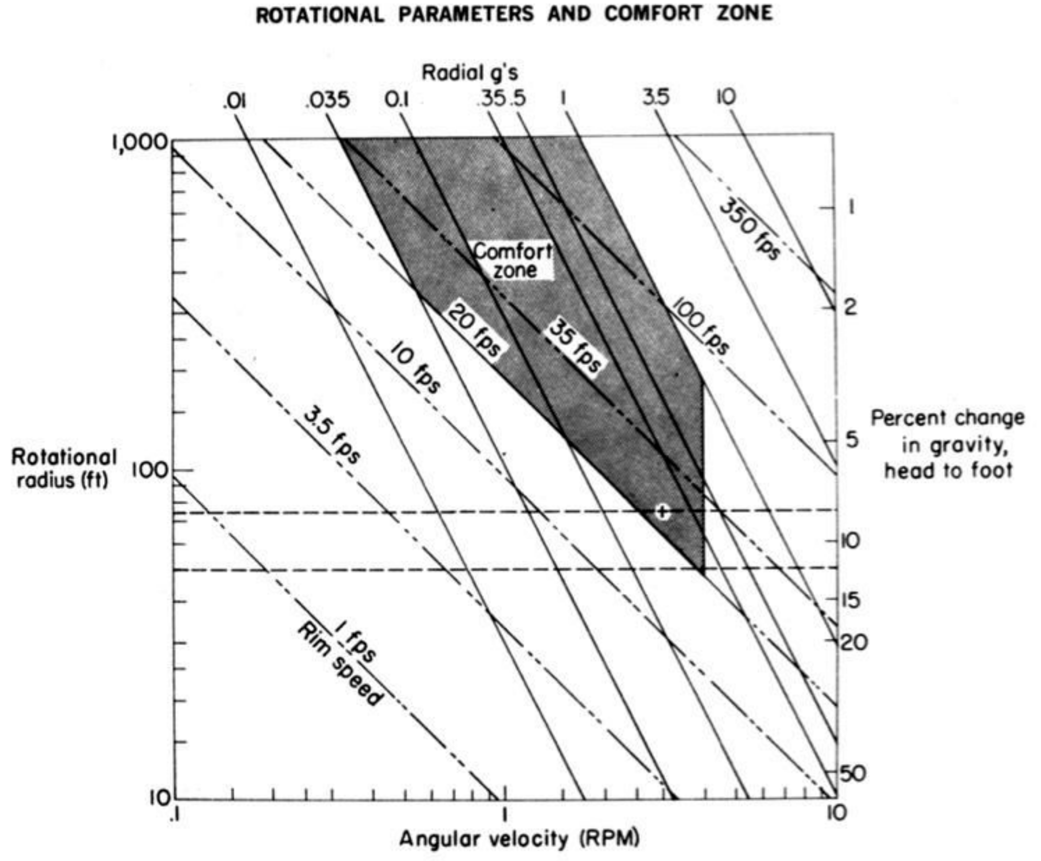


NASA Langley Research Center
Rotating Space Station Simulator, 1960s



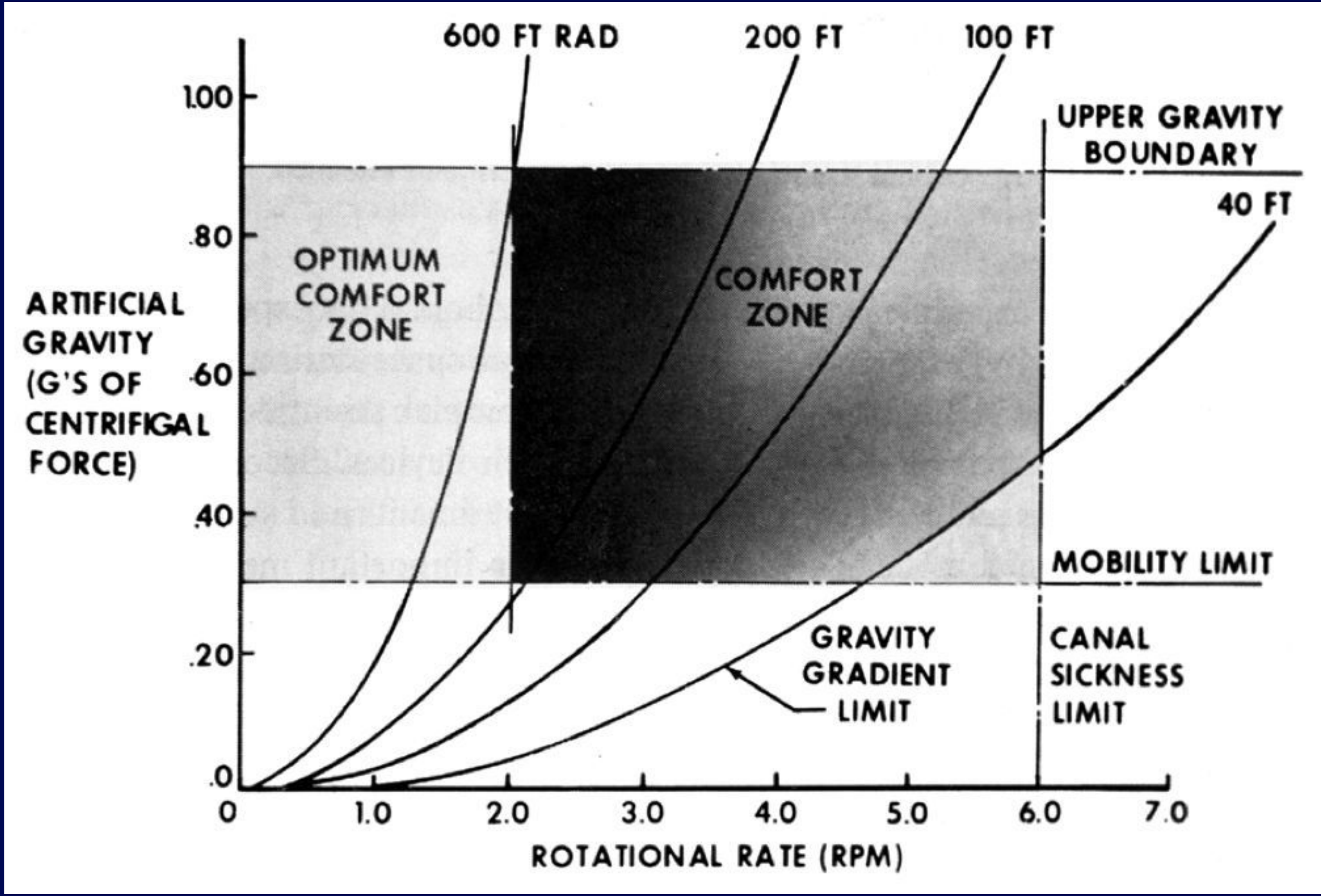
NASA Langley Research Center Rotating Space Station Simulator, 1960s

Comfort chart, Hill and Schnitzer, 1962

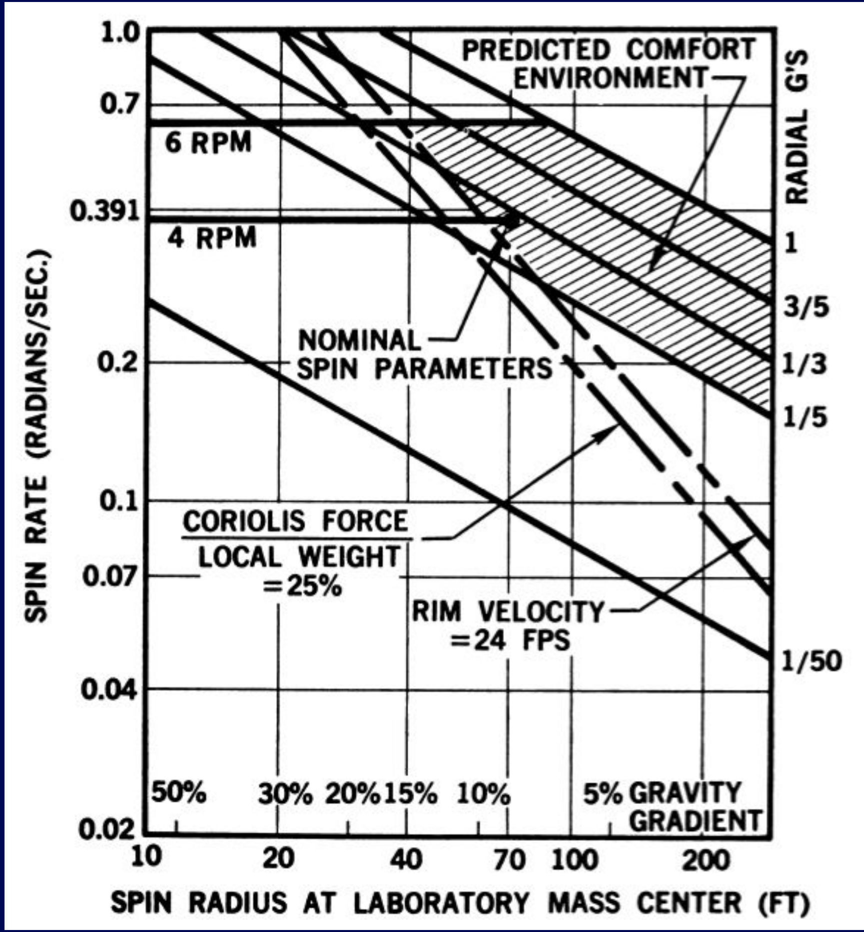


The graph defines the rotational characteristics that would be used in conjunction with interpretation of physiological response (comfort zone) to size a manned space station.

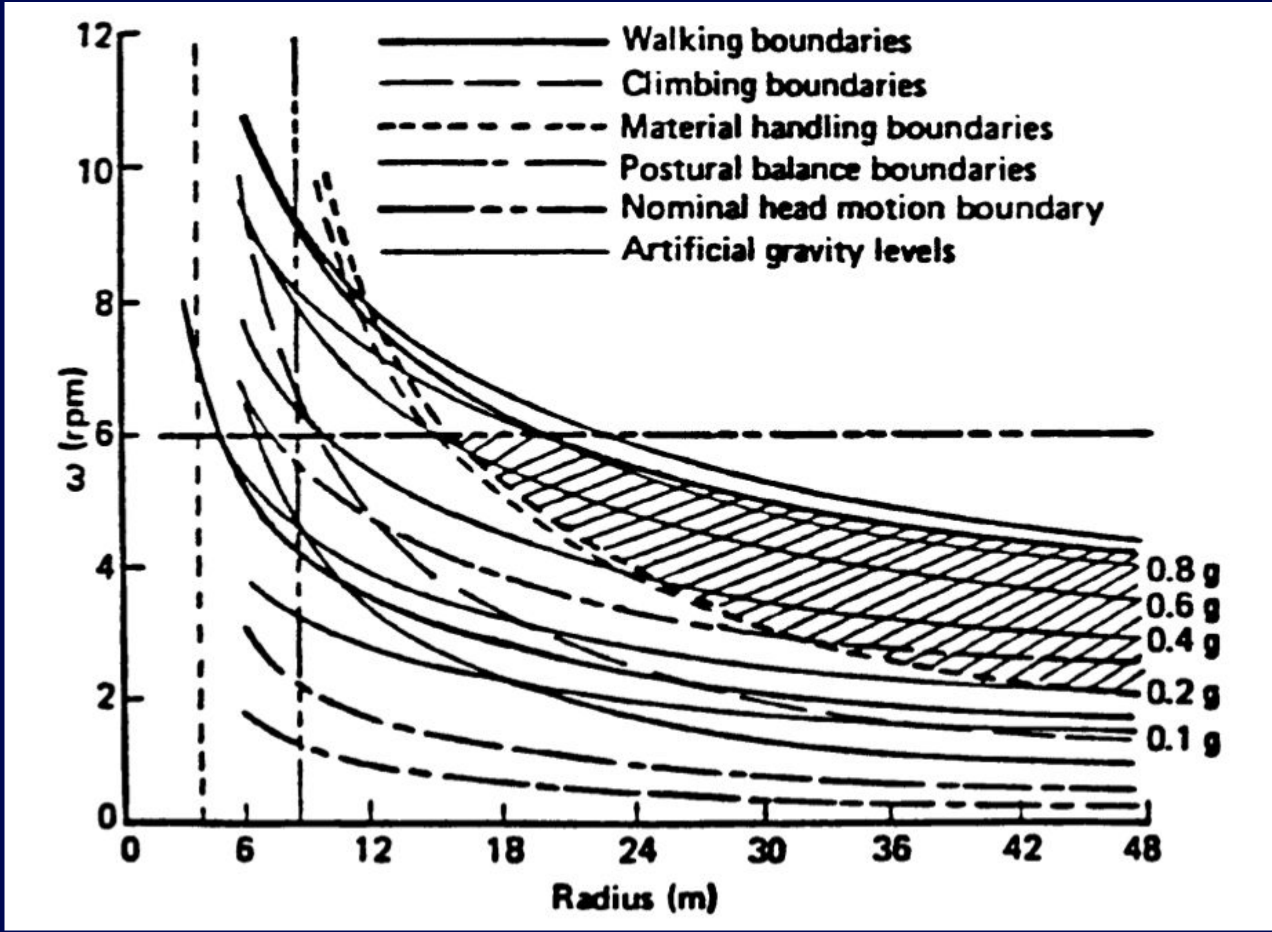
Comfort chart, Gilruth, 1969



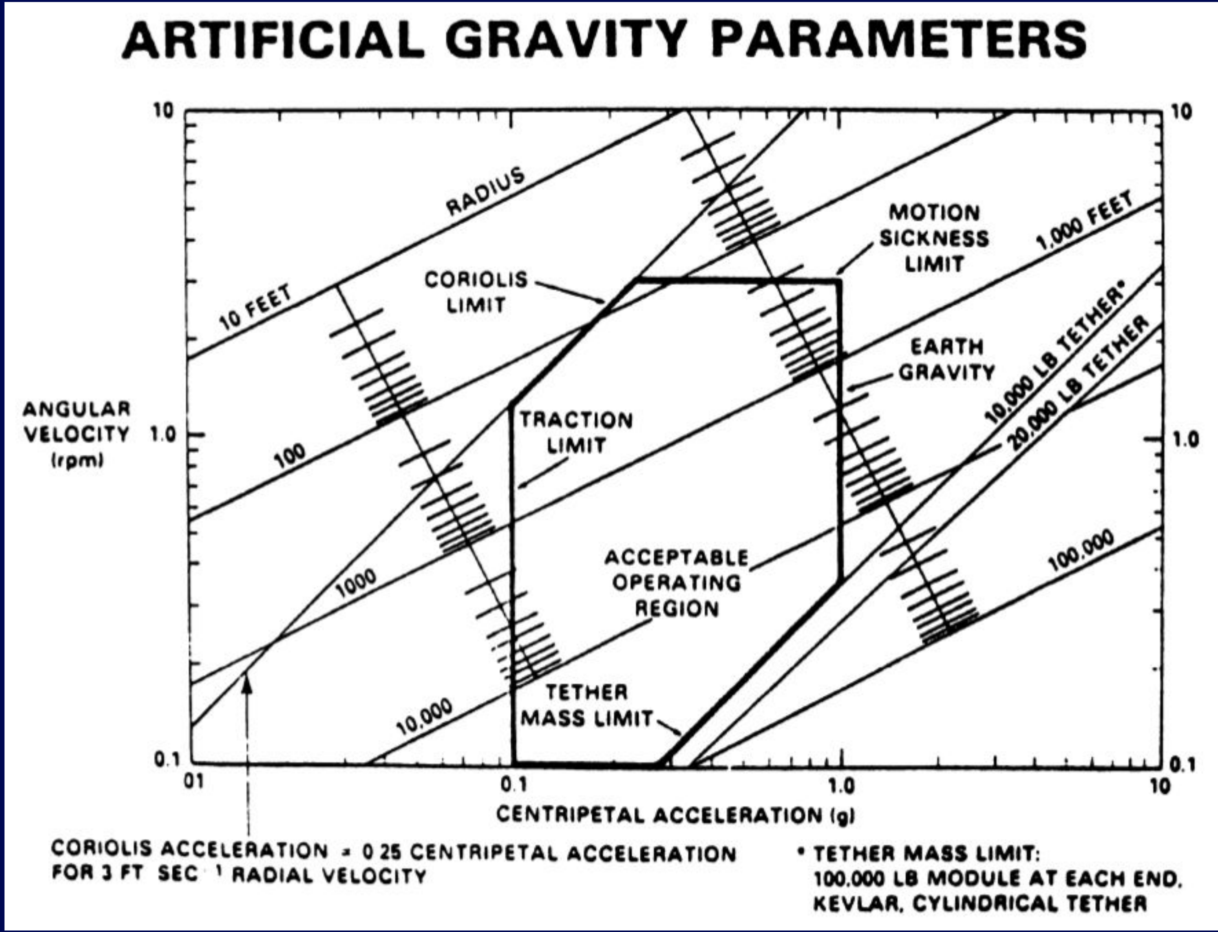
Comfort chart, Gordon and Gervais, 1969



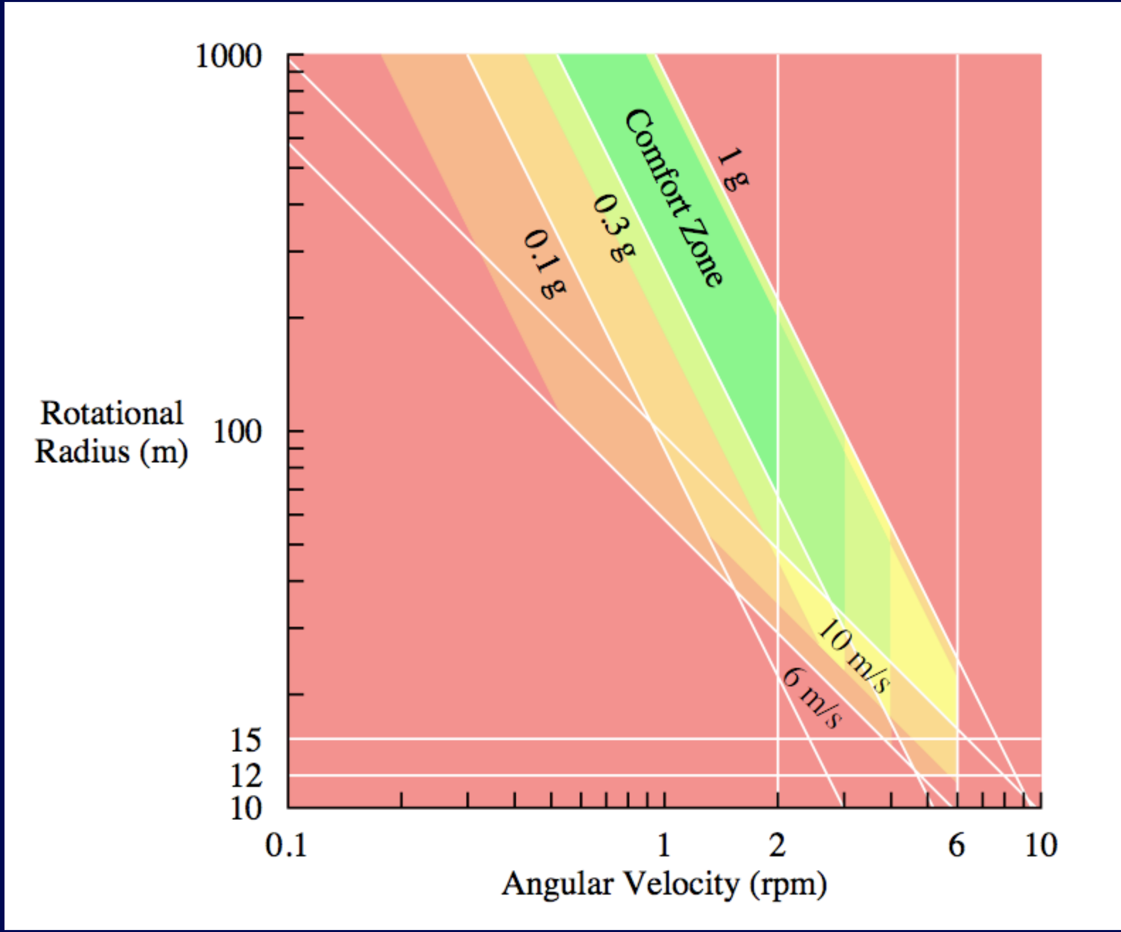
Comfort chart, Stone, 1973



Comfort chart, Cramer, 1985



Comfort chart – composite



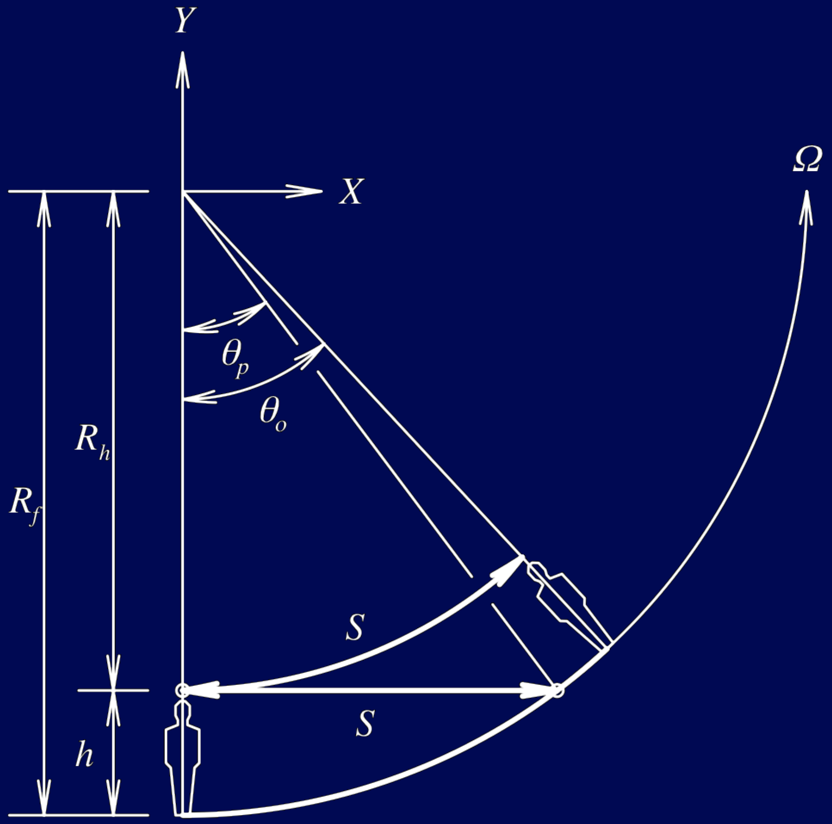
Starship population estimates:

Birdsell	10 – 100s	Marotta	1,000 – 8,000
Hodges	10/ss × #ss	& Globus	
Cohen & al.	100 - 500	Smith	40,000
Wachter	100s	Hein & al.	100,000

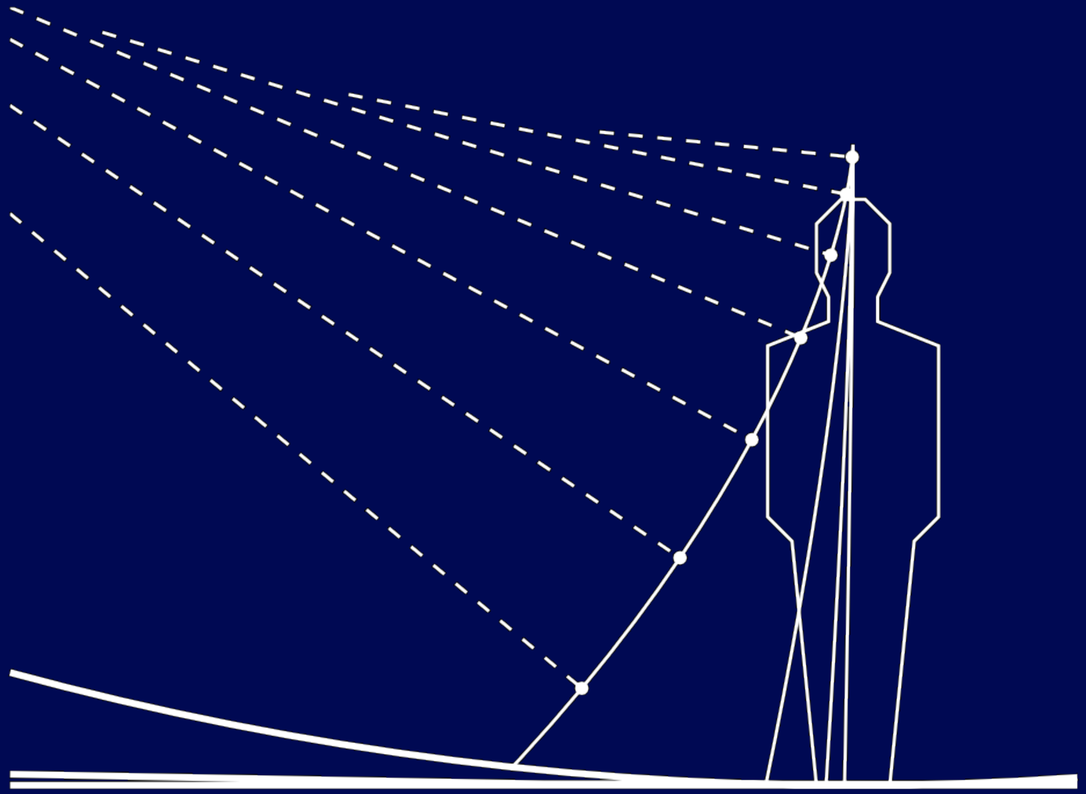
Starship size will be dictated by population size,

not by rotational tolerance.

Dropping particles, inertial view: h/R_f



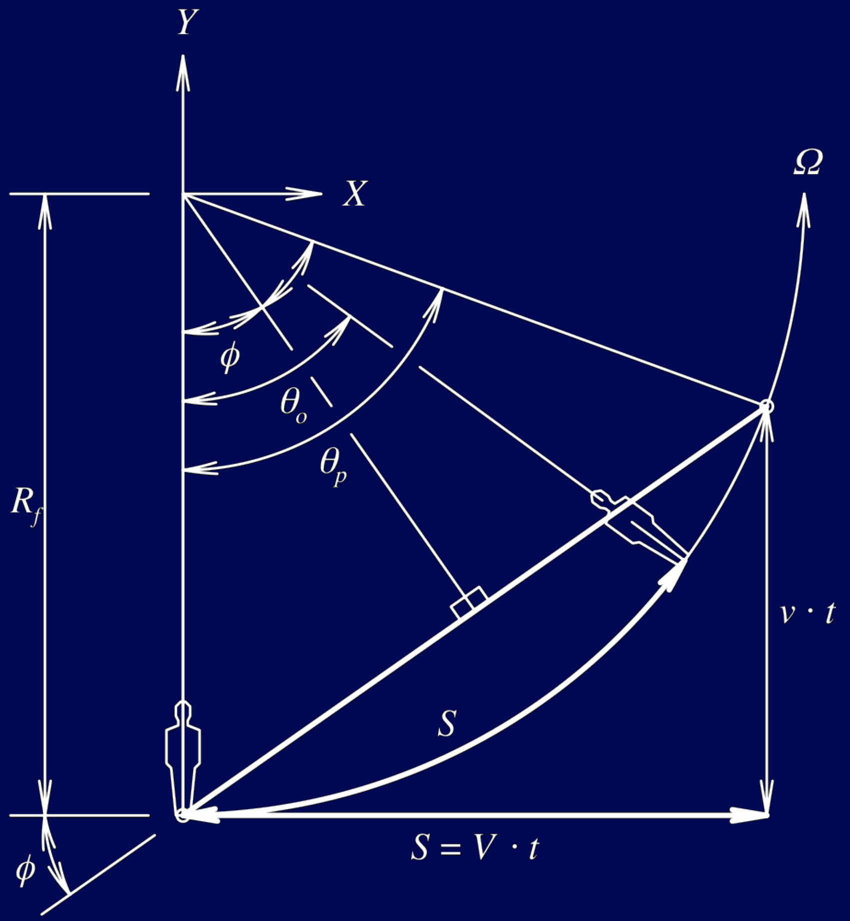
Dropping particles, rotating view: h/R_f



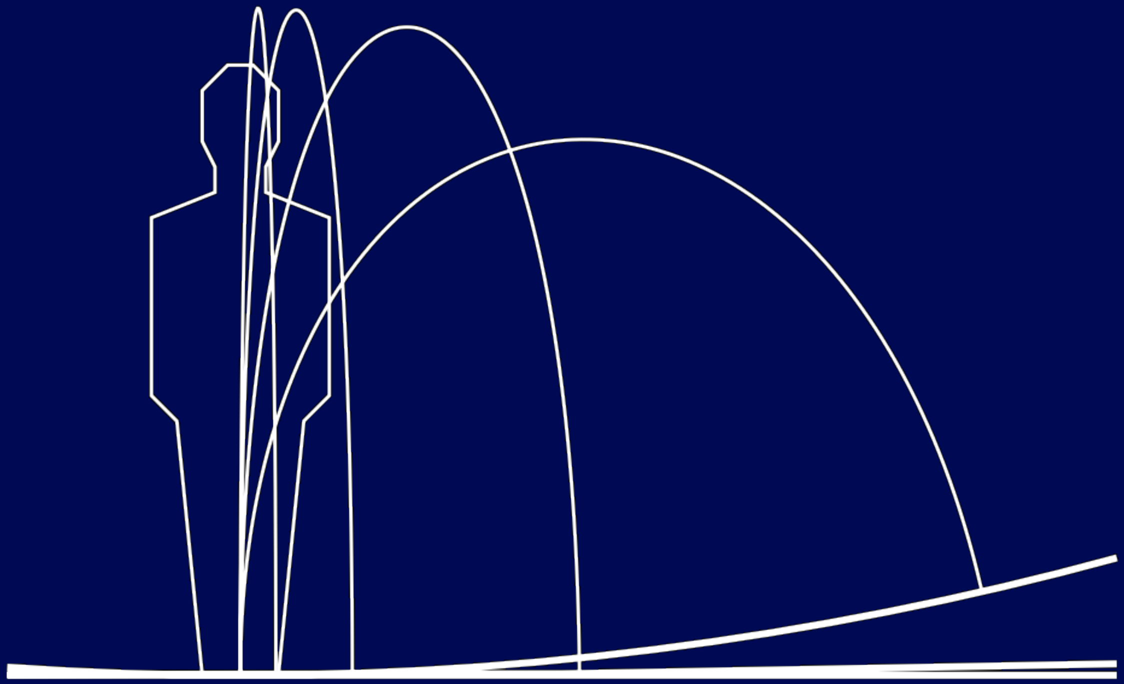
h = 2 m

R_f = 10 m 100 m 1000 m 10000 m

Hopping particles, inertial view: *v/V*

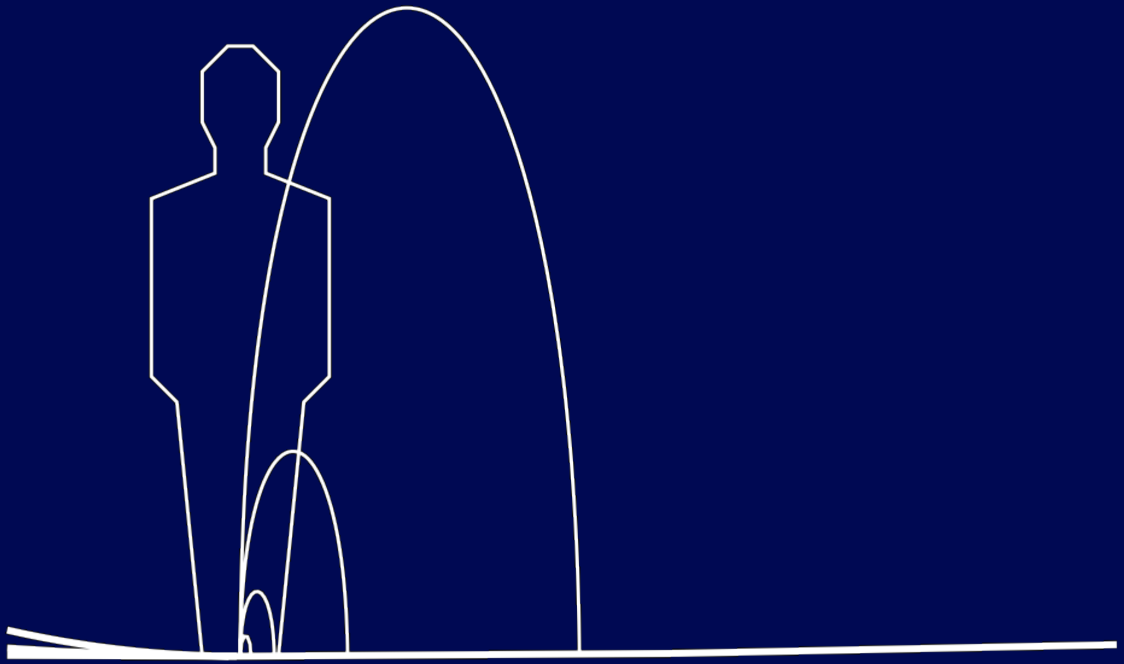


Hopping particles, rotating view: *v*/*V*



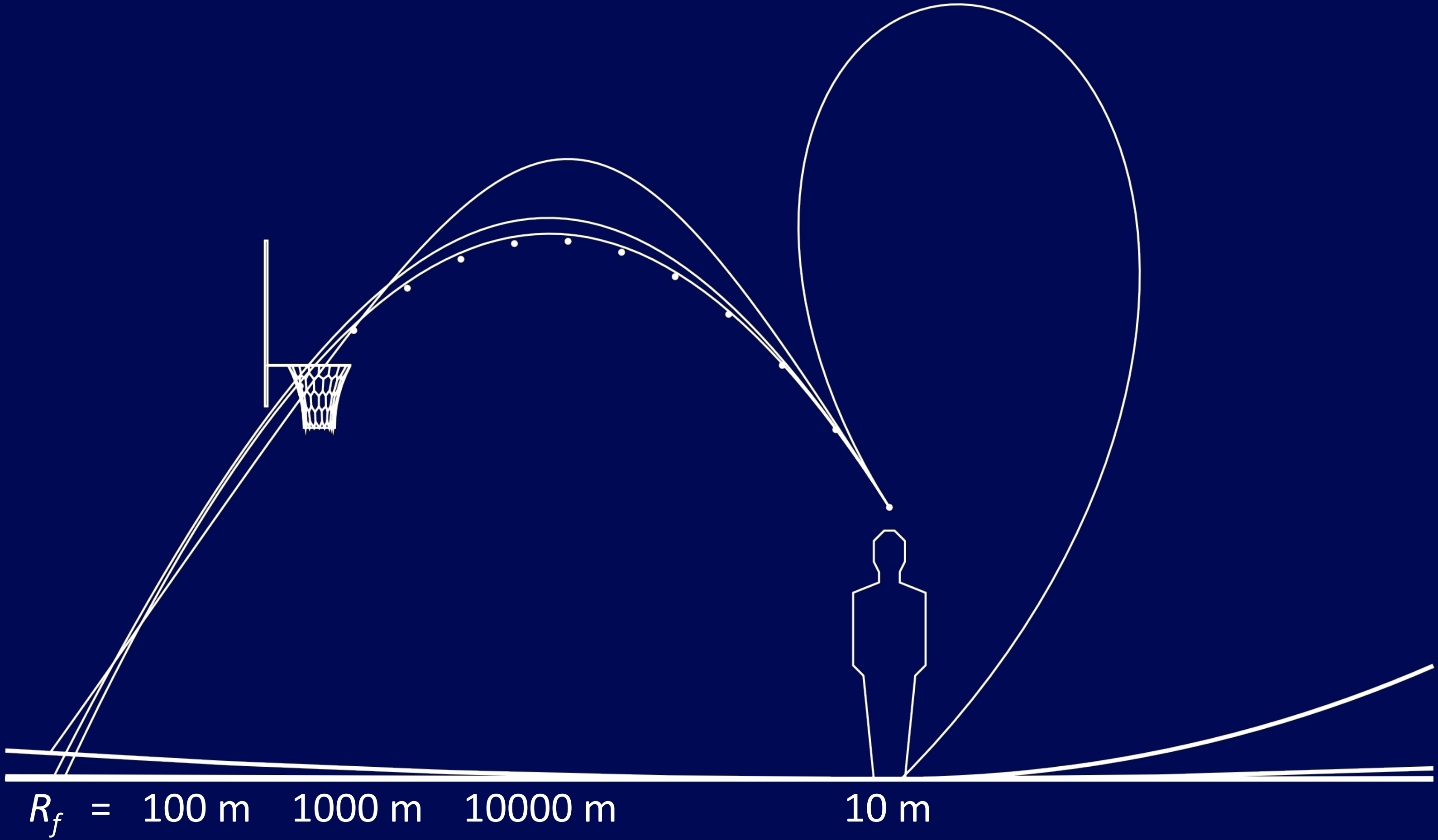
A_{cent}	=	1 m/s^2			
v	=	2 m/s			
V	=	100 m/s	32 m/s	10 m/s	3.2 m/s
R_f	=	10000 m	1000 m	100 m	10 m

Hopping particles, rotating view: *v*/*V*

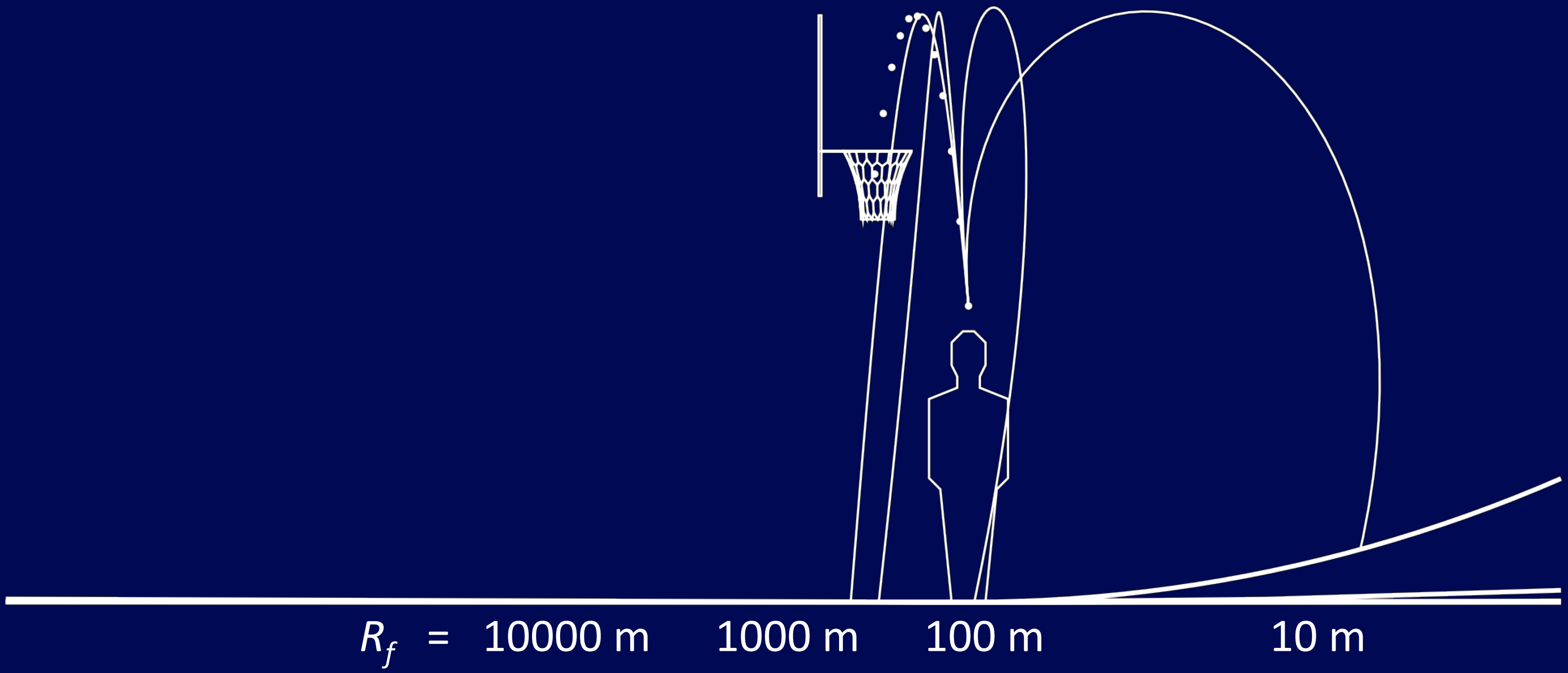


v	=	2 m/s			
V	=	10 m/s			
A_{cent}	=	32 m/s^2	10 m/s^2	3.2 m/s^2	1 m/s^2
R_f	=	3.2 m	10 m	32 m	100 m

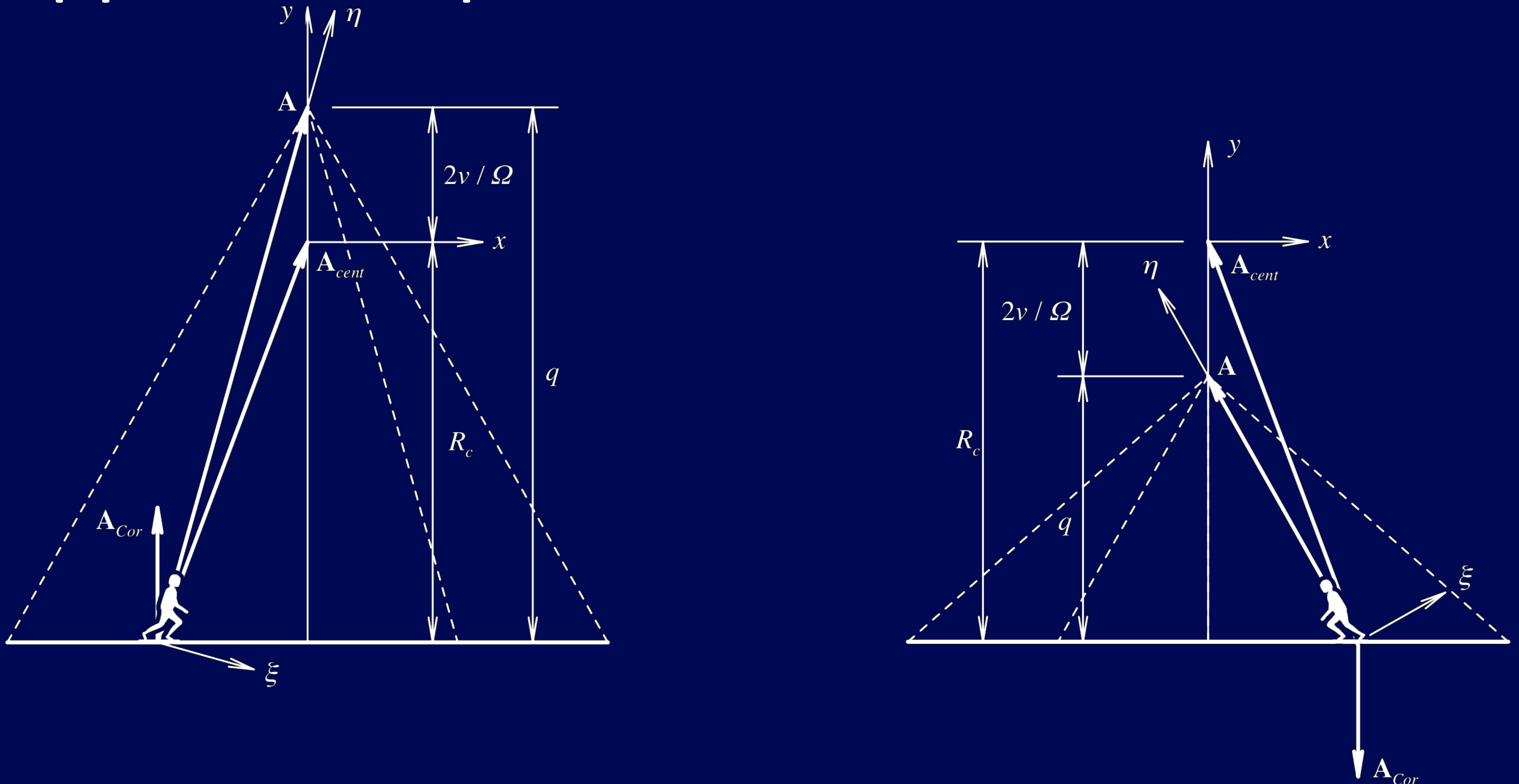
Basketball in 1-g AG: free throw



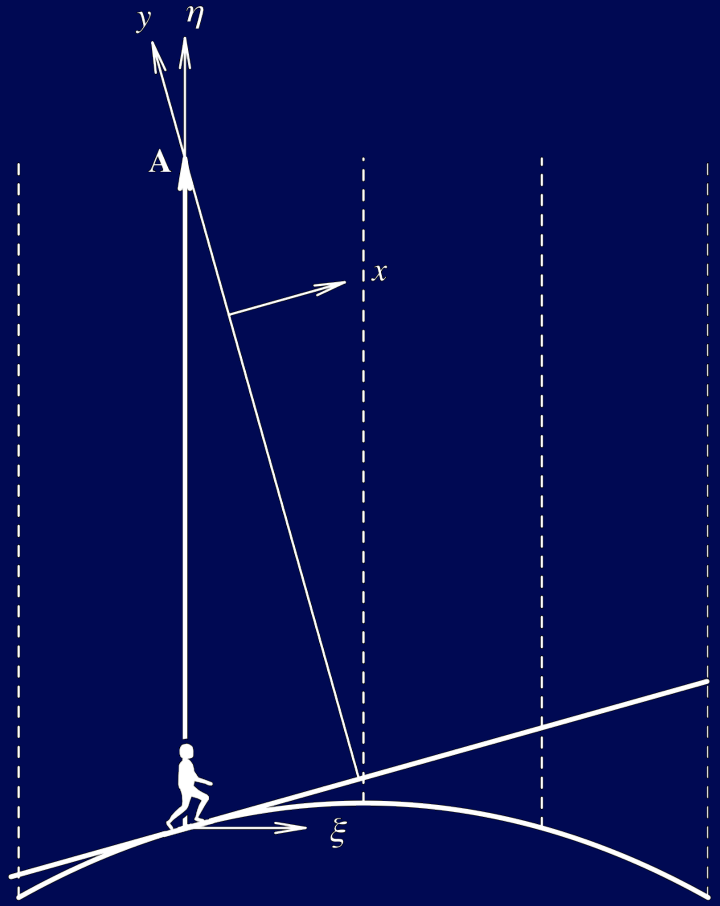
Basketball in 1-g AG: under the net



Apparent slope of flat floor

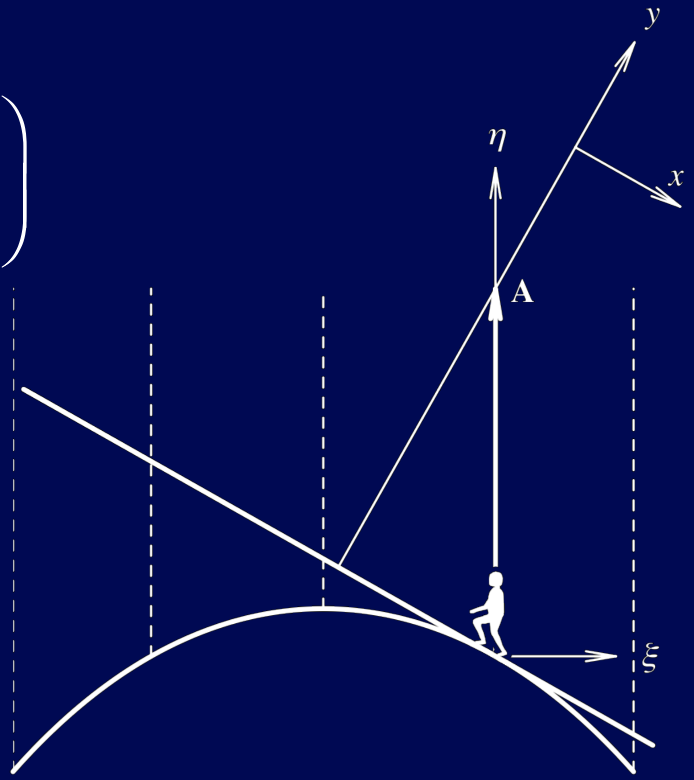


Apparent slope of flat floor: catenary arch

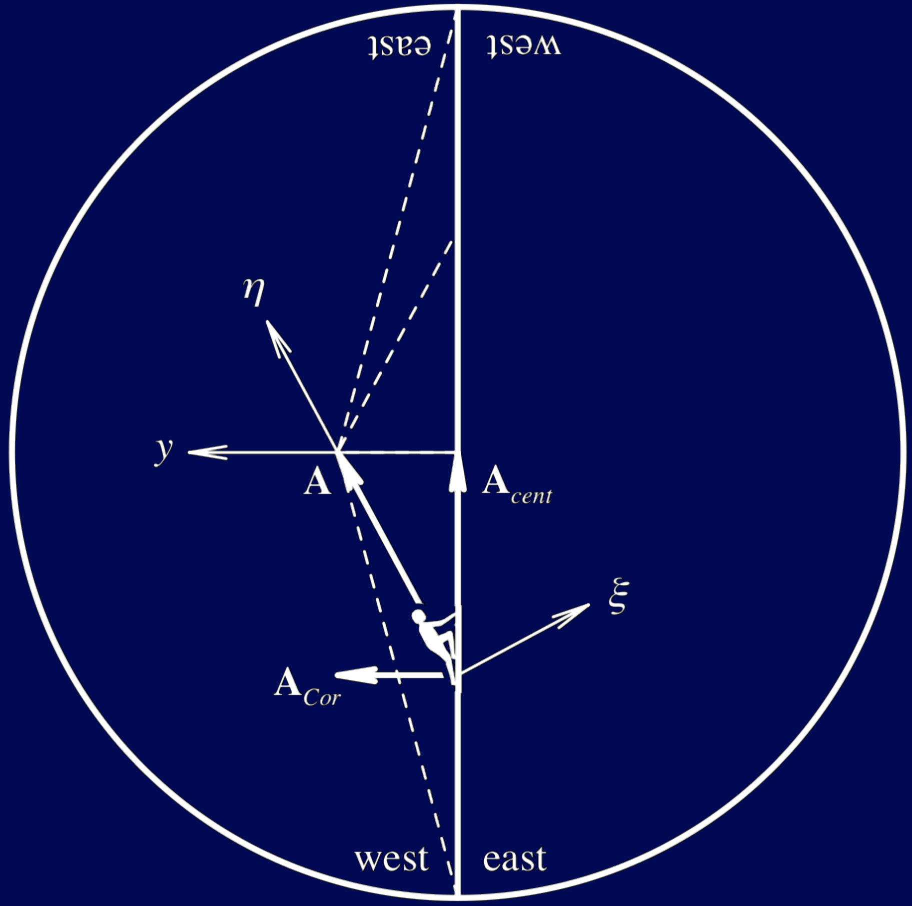


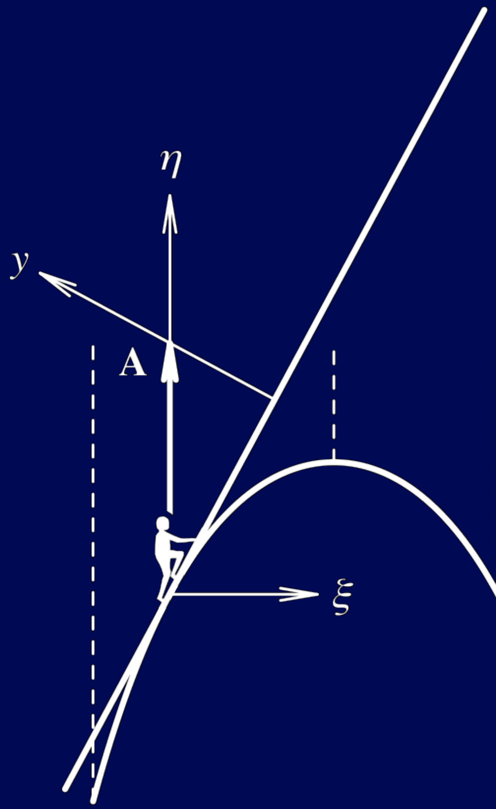
$$\frac{\eta}{q} = -\cosh\left(\frac{\xi}{q}\right)$$

$$\frac{A}{q} = \Omega^2 \cosh\left(\frac{\xi}{q}\right)$$

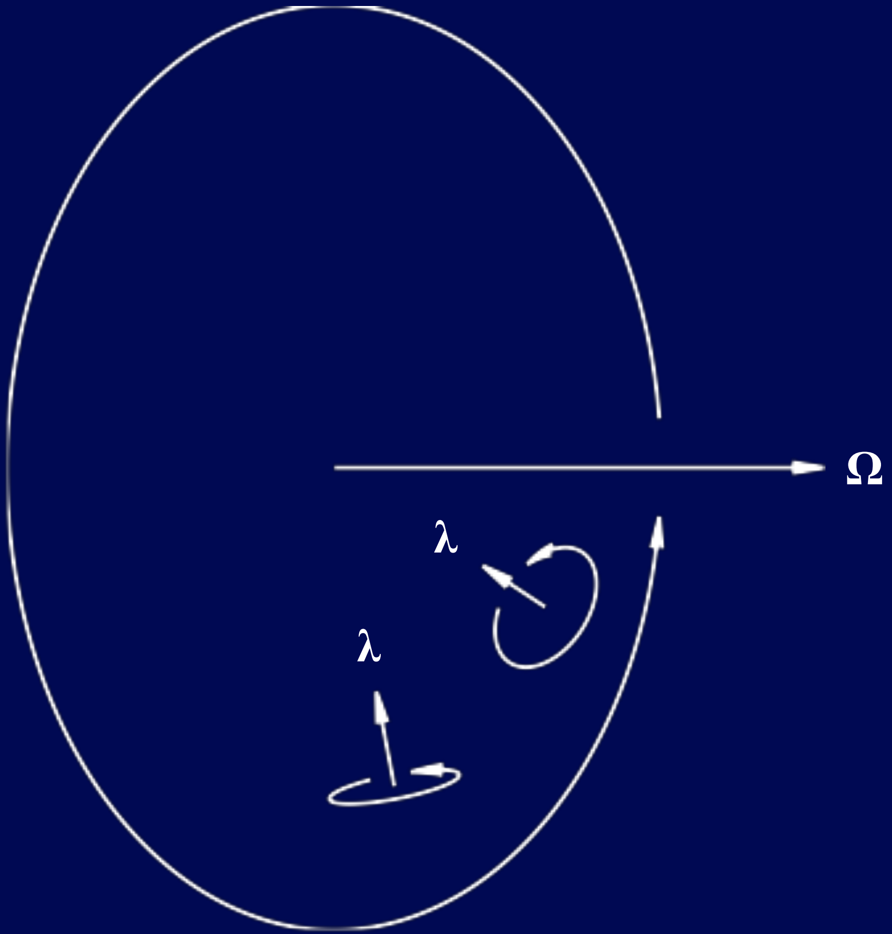


Apparent slope of ladder: catenary arch

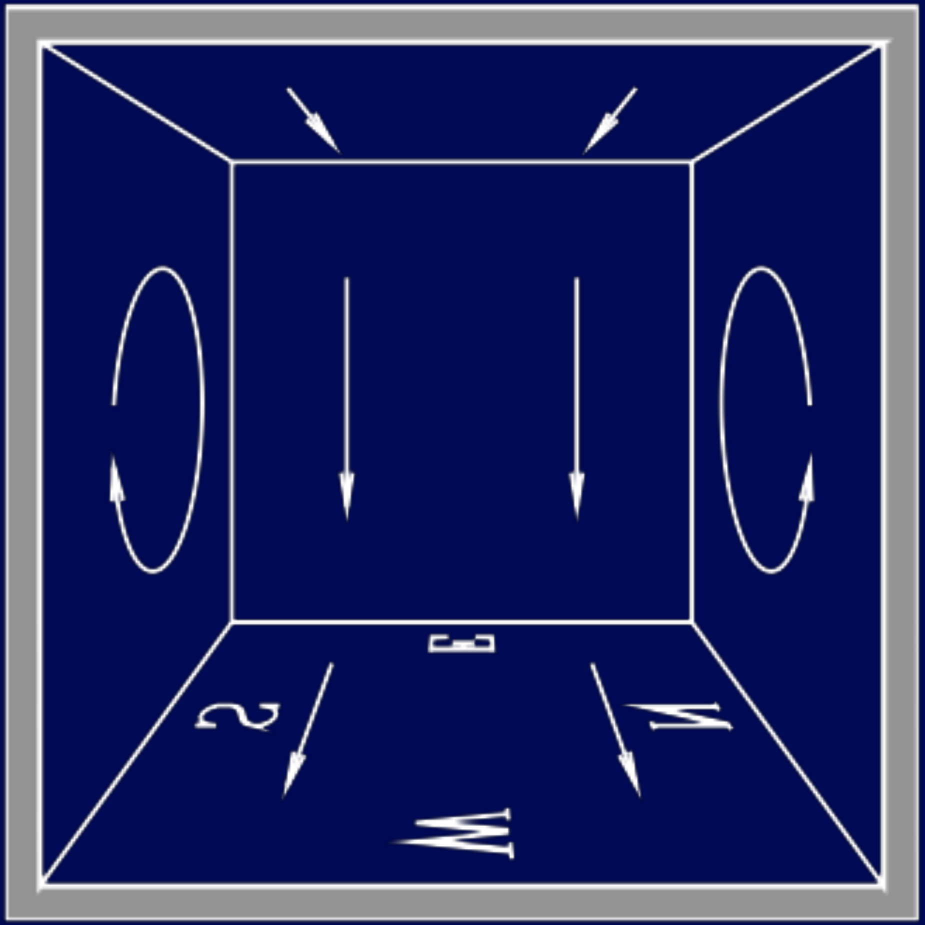




Cross-coupled rotations

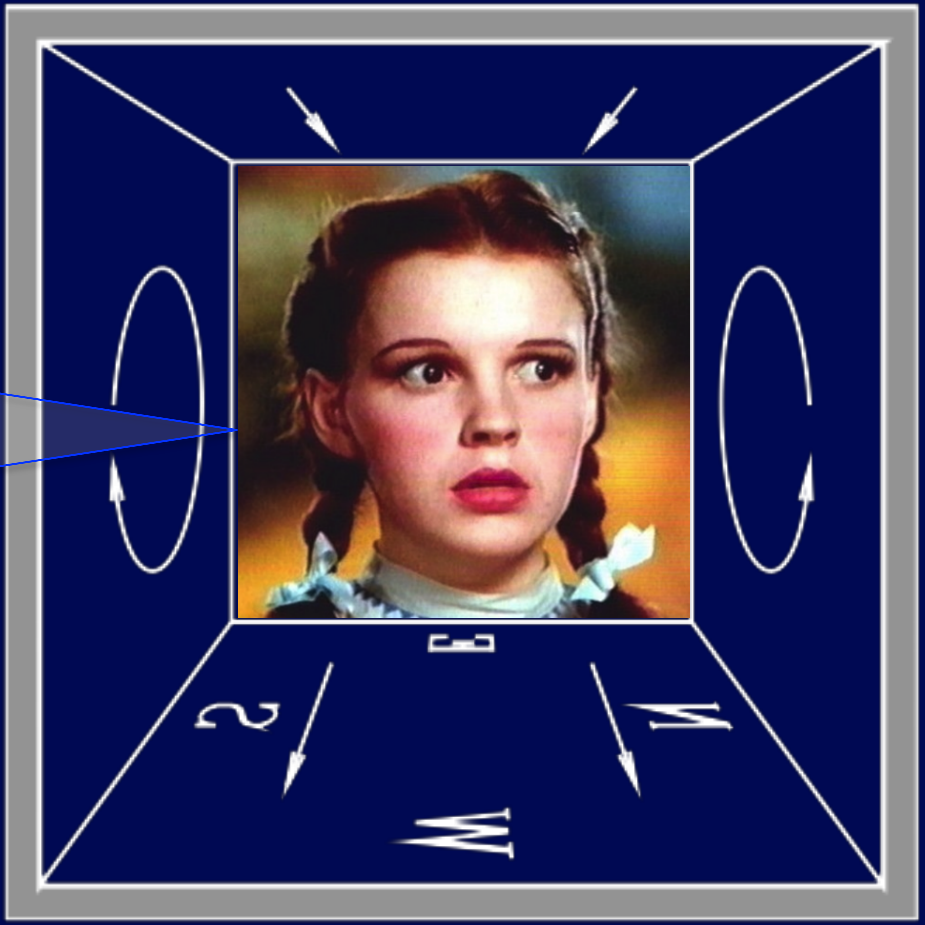


Principal directions: inside-out



The country and climate in which we build

We're not in Kansas anymore.
– *Gale*



Combined linear + centripetal acceleration