Investigation traction system development for lunar mobility – Part 2 la suite…

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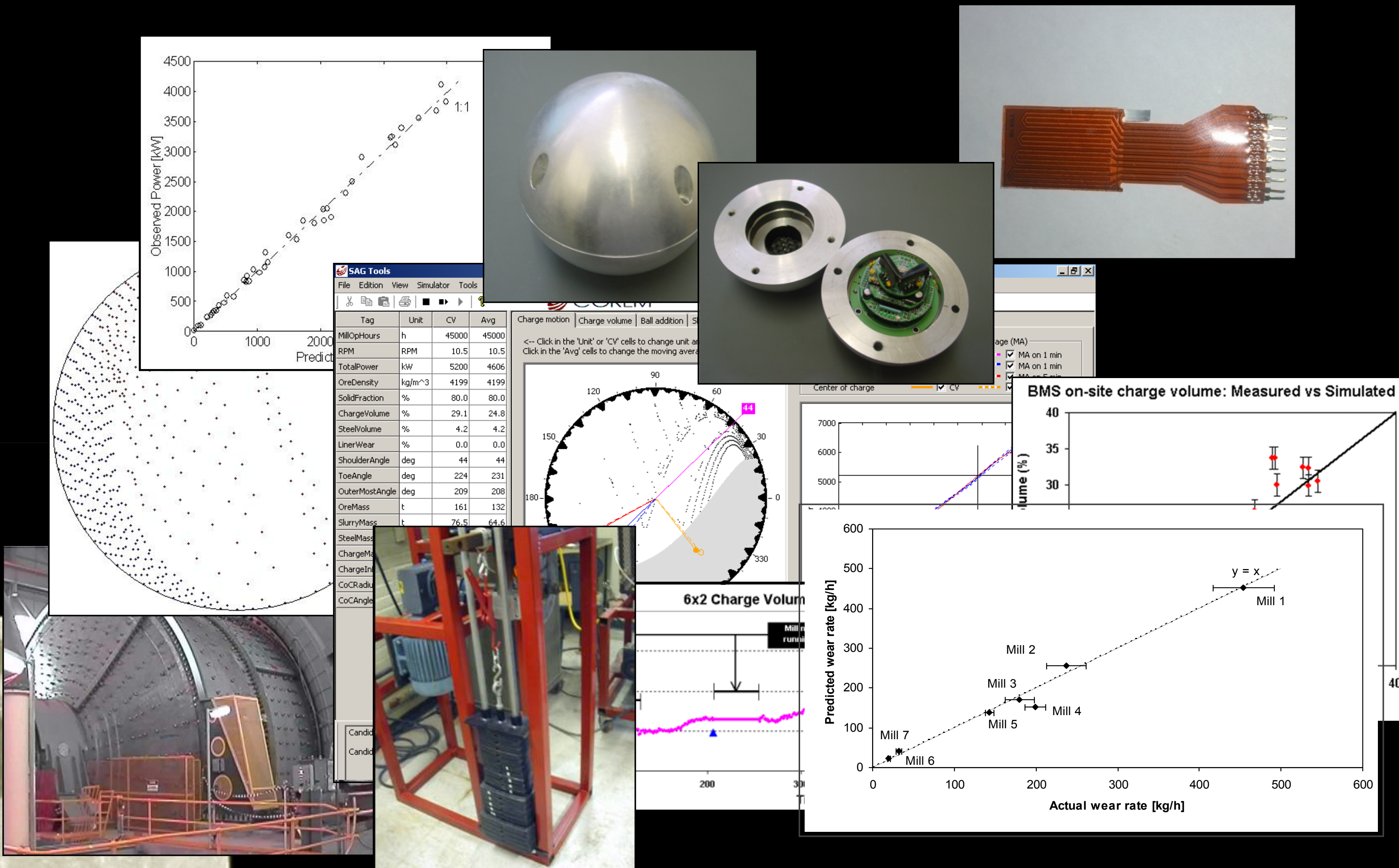
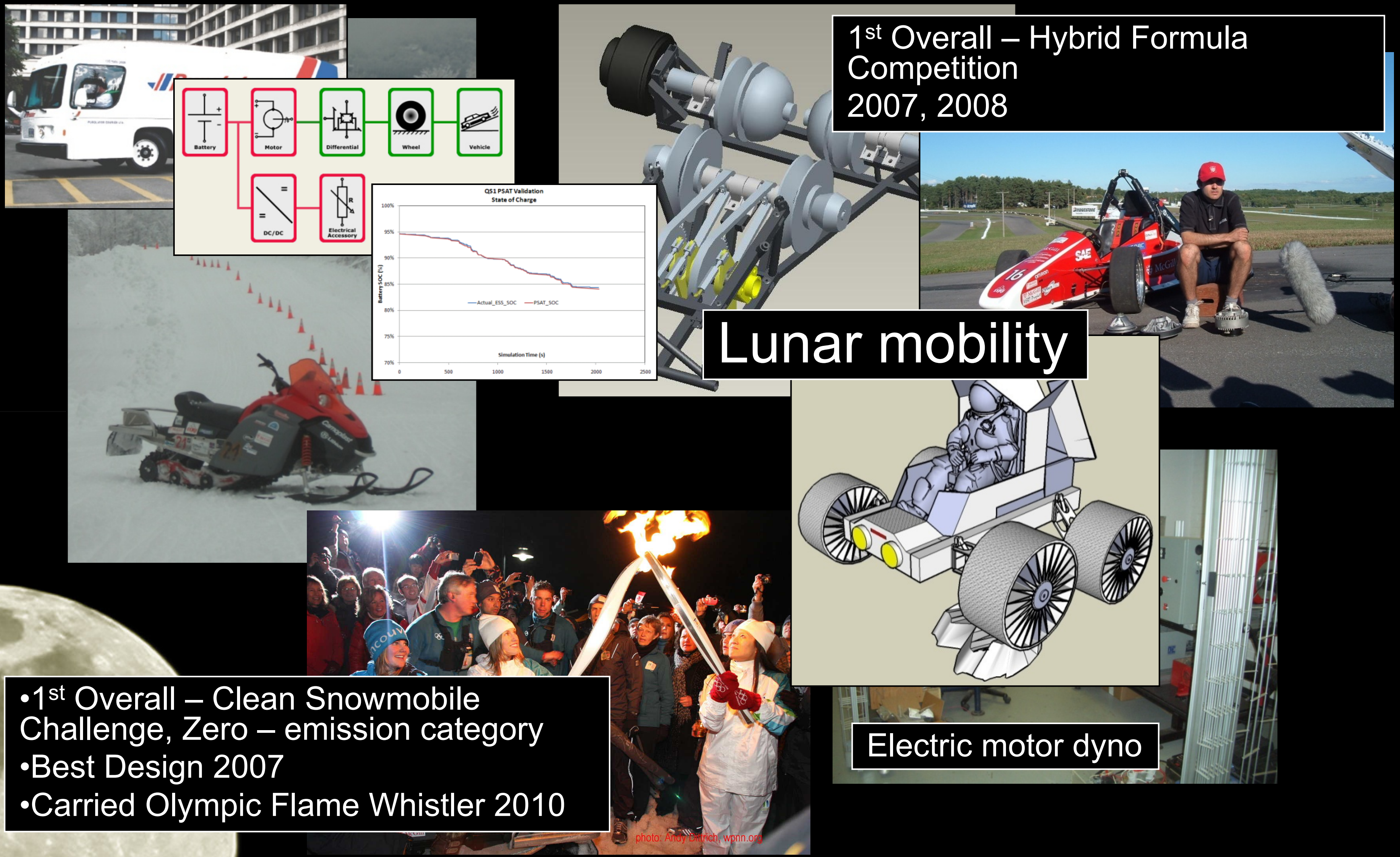
Rock


Observed Power [kW]
Predict
1:1
SAG Tools
File Edition View Simulator Tools
Tag Unit CV Avg
MillOpHours h 45000 45000
RPM RPM 10.5 10.5
TotalPower kW 5200 4606
OreDensity kg/m^3 4199 4199
SolidFraction % 80.0 80.0
ChargeVolume % 29.1 24.8
SteelVolume % 4.2 4.2
LinerWear % 0.0 0.0
ShoulderAngle deg 44 44
ToeAngle deg 224 231
OuterMostAngle deg 209 208
OreMass t 161 132
Charge motion
Charge volume
Ball addition
Center of charge
BMS on-site charge volume: Measured vs Simulated
6x2 Charge Volum
Predicted wear rate [kg/h]
Actual wear rate [kg/h]
y = x
Mill 1
Mill 2
Mill 3
Mill 4
Mill 5
Mill 6
Mill 7

Roll



1st Overall – Hybrid Formula Competition
2007, 2008

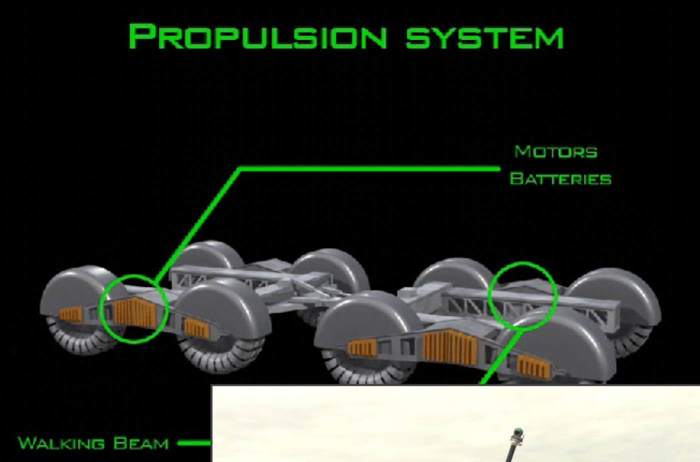
Lunar mobility

Electric motor dyno

- 1st Overall – Clean Snowmobile Challenge, Zero – emission category
- Best Design 2007
- Carried Olympic Flame Whistler 2010

Introduction

JUNO – from concept to multi-purpose work horse (Neptec Rover Team)



Introduction

PSP/CRD project

"INVESTIGATING TRACTION SYSTEMS FOR LUNAR ROVER MOBILITY"

Goal: Define, develop and validate a compliant wheel design methodology which will used to evaluate and compare the feasibility of different wheel configurations, steering and suspension strategies, and traction designs.

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Introduction

- Overview of wheel prototyping,
- Overview of iRings wheel prototyping,
- Avenues for further improvement,
- Summary

Overview of wheel prototyping

- **Based on the literature**
- Segmented type 1
- Segmented type 2
- Segmented type 3
- Brushed

Overview of wheel prototyping

- Based on the literature
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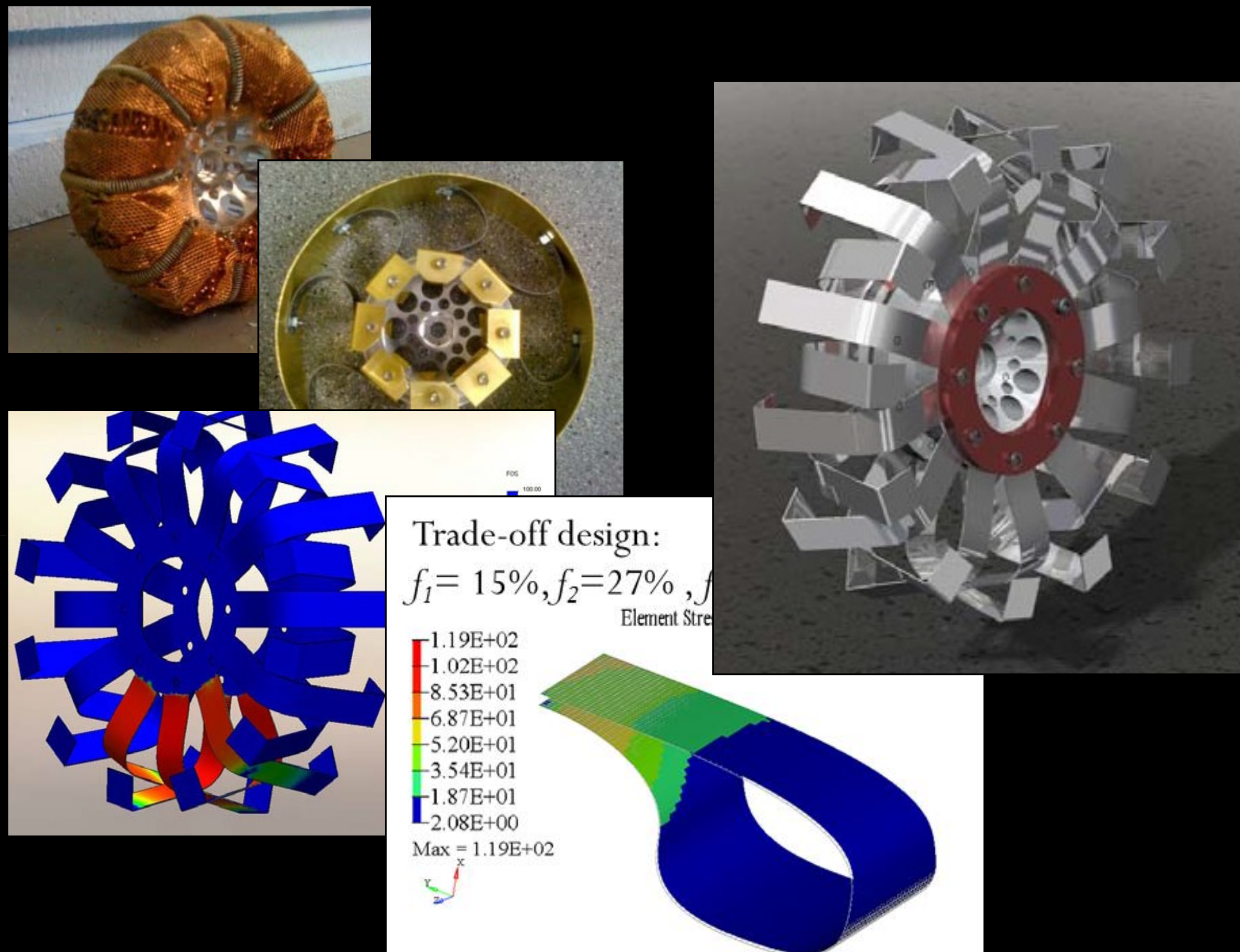
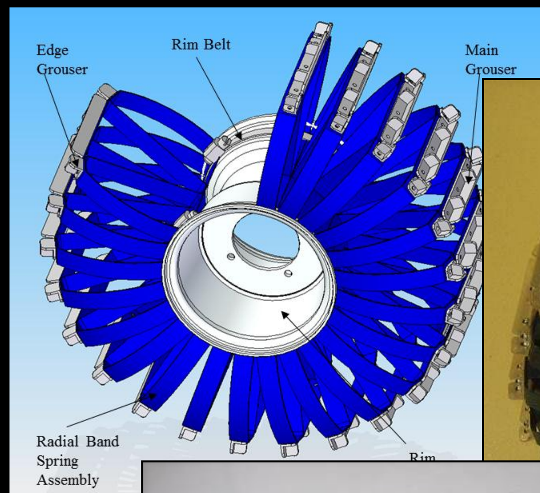
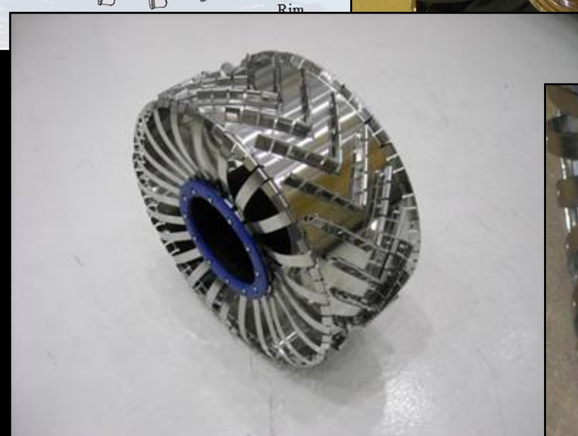


Overview of wheel prototyping

Canadian Space Agency wheel design (Mo Farhat)

- Based on the literature
- Segmented type 1
- **Segmented type 2**
- Segmented type 3
- Brushed

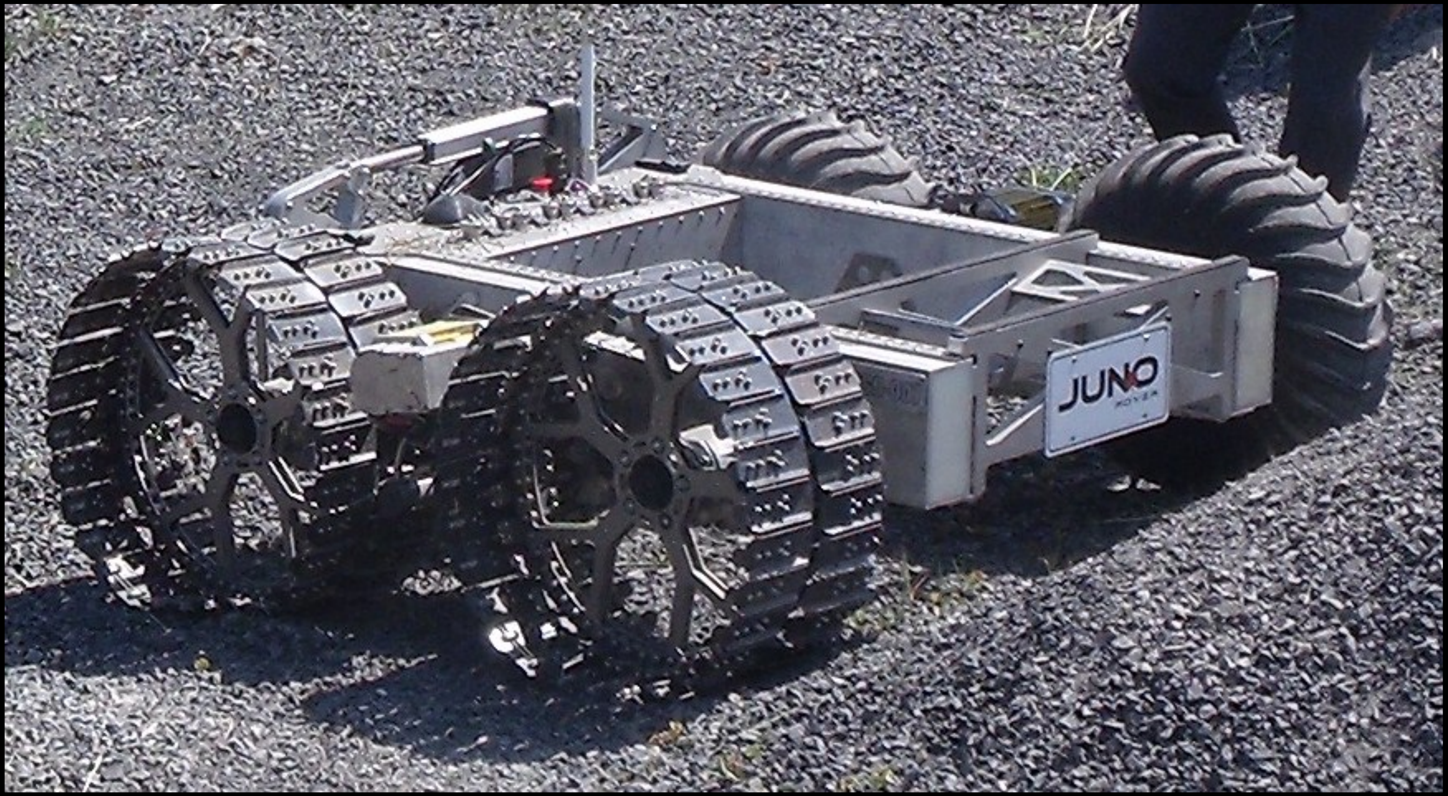




Overview of wheel prototyping

Ontario Drive and Gear wheel design (Peter Visscher)

- Based on the literature
- Segmented type 1
- Segmented type 2
- **Segmented type 3**
- Brushed



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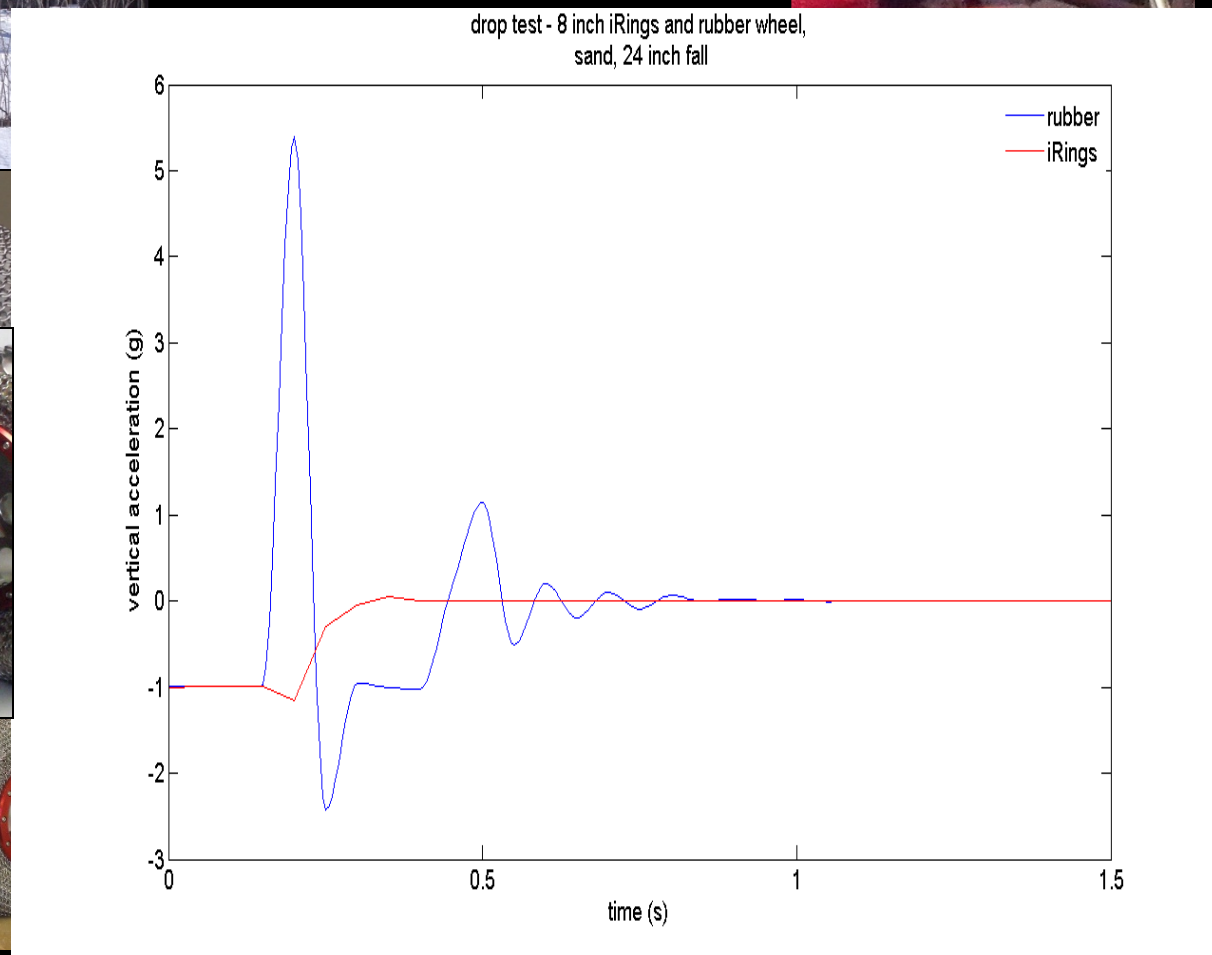
Overview of wheel prototyping

- Based on the literature
- Segmented type 1
- Segmented type 2
- Segmented type 3
- **Brushed**

Overview of iRings wheel prototyping



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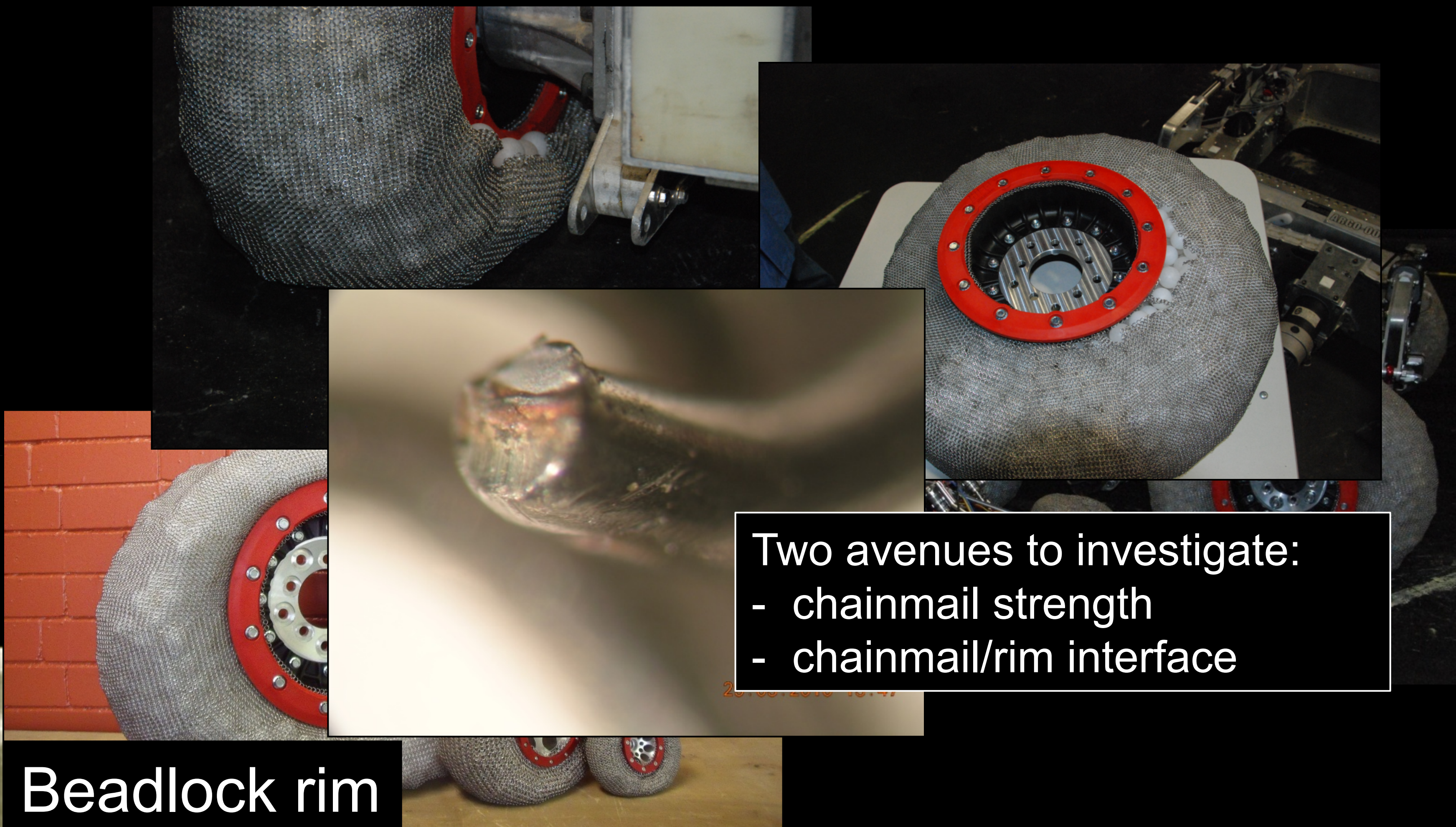
Overview of iRings wheel prototyping



Two avenues to investigate:
- chainmail strength
- chainmail/rim interface

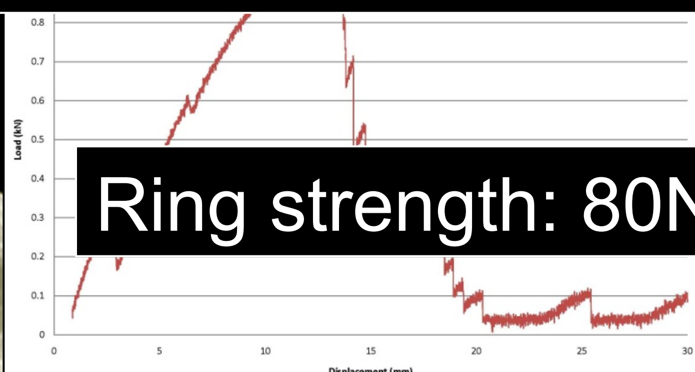
Beadlock rim

Overview of iRings wheel prototyping

Load limits	Load Limit	Applied Load	Comment
St		N bs o s)	
Tr		N	
La cri		N	
Fa ka kb kc		erna	
			yield: 0.5

Subsequent testing indicated a lot of variation (50%) in ring strength as low as 40N per ring.

→ Found a new chainmail supplier producing chainmail with ring strength (similar diameter) @ 400N.



Ring strength: 80N

Two avenues to investigae:

- **chainmail strength**
- chainmail/rim interface

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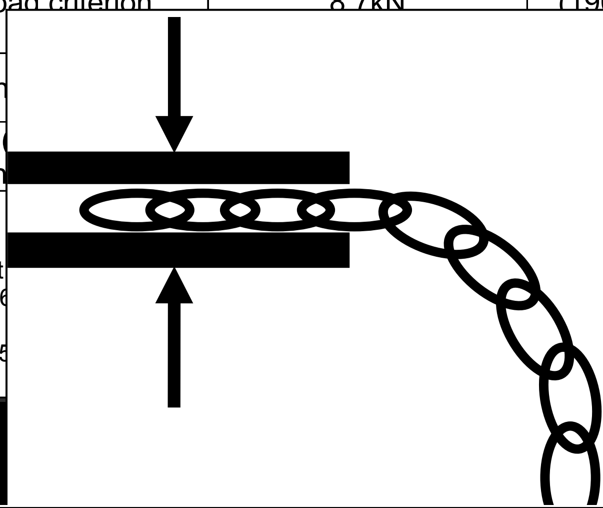
Overview of iRings wheel prototyping

Load limits	Load Limit	Applied Load	Comment
Static load criterion	8.7kN	0.47kN (190 kg/420lbs on 4 wheels)	No failure Safety factor: 18
Traction		0.35kN	No failure Safety factor: 12.3
Lateral criterion		0.59kN	No failure Safety factor: 7.3
Fatigue Sut k_a = 0.86 k_b = 1 k_c = 0.85		MPa alternating	No failure Safety factor: Mod. Goodman: 2.3 Gerber: 2.7 ASME Elliptic: 2.8 Langer 1st cycle yield: 6.3



Beadlock interface locks the chainmail in a vice limiting its movement in the first number of ring rows.

Two avenues to investigate:
- chainmail strength
- **chainmail/rim interface**

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Overview of iRings wheel prototyping

from beadlock interface
to spring interface.

Two avenues to investigate:
- chainmail strength
- **chainmail/rim interface**

Overview of iRings wheel prototyping

from prototype to production wheels
(JUNO Upgrade project)

Challenge:

design a wheel using the iRings concept that can provide failure free travel for a minimum of 10km.

→ maximize safety factors while maintaining general characteristics

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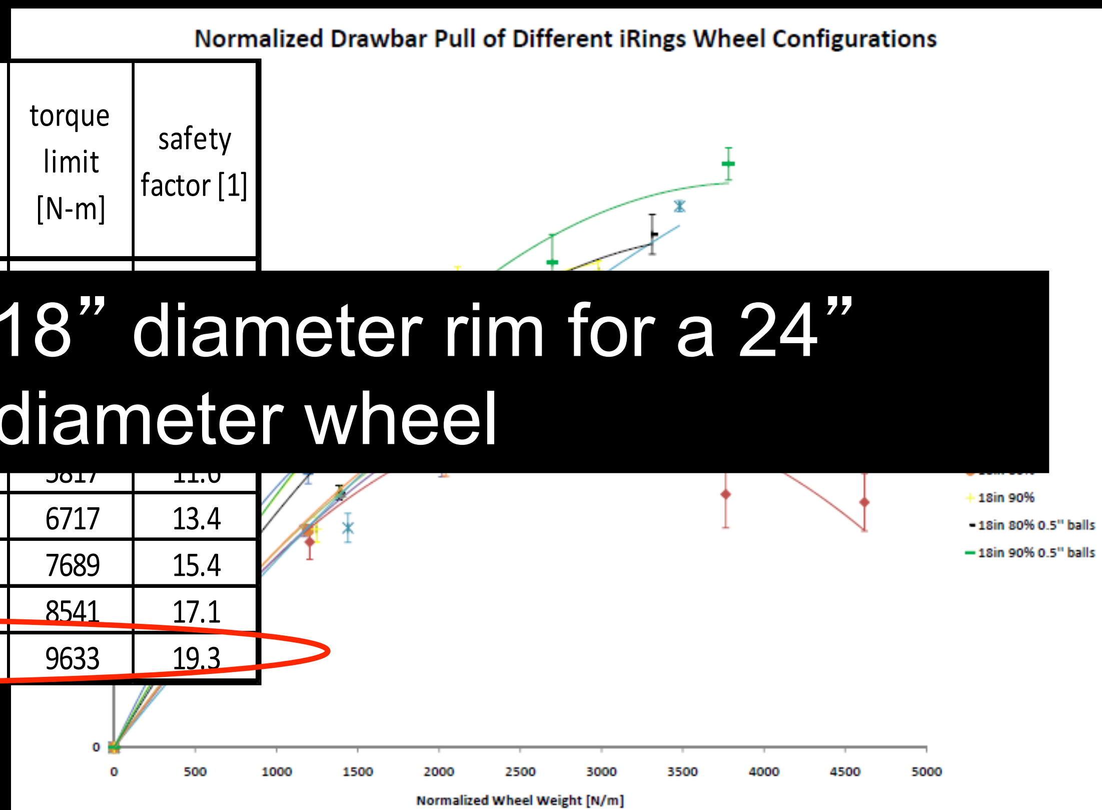
Overview of iRings wheel prototyping

from prototype to production wheels (JUNO Upgrade project)

rim radius r [m]	rim traction force F_r [N]	rim arc length [m]	n_{rings} [1]	rim resistance F_{resist} [N]	torque limit [N-m]	safety factor [1]
0.127	**2008**	**109.1492**	**27**	[illegible]	[illegible]	[illegible]
0.14	1821	120.3220	30	[illegible]	[illegible]	[illegible]
0.152	1678	130.6353	33	[illegible]	[illegible]	[illegible]
0.165	1545	141.8081	35	[illegible]	[illegible]	[illegible]
0.178	1433	152.9808	38	[illegible]	[illegible]	[illegible]
0.1905	1339	163.7239	41	35260	6717	13.4
0.2032	1255	174.6388	44	37840	7689	15.4
0.2159	1181	185.5537	46	39560	8541	17.1
0.2286	1115	196.4686	49	42140	9633	19.3

→ 18" diameter rim for a 24" diameter wheel



Overview of iRings wheel prototyping

from prototype to production wheels

Looked to see if 10km travel would break any thing…

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Overview of iRings wheel prototyping

from prototype to production wheels

After completing a first 10km of failure free travel we had some fun.

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Overview of iRings wheel prototyping

from prototype to production wheels

After having some (failure free) fun we continued on to achieve 100km to 200km failure free travel (with some heavy weight loads)!

- over 100,000 cycles

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Overview of iRings wheel prototyping

from prototype to production wheels

and then we delivered them…

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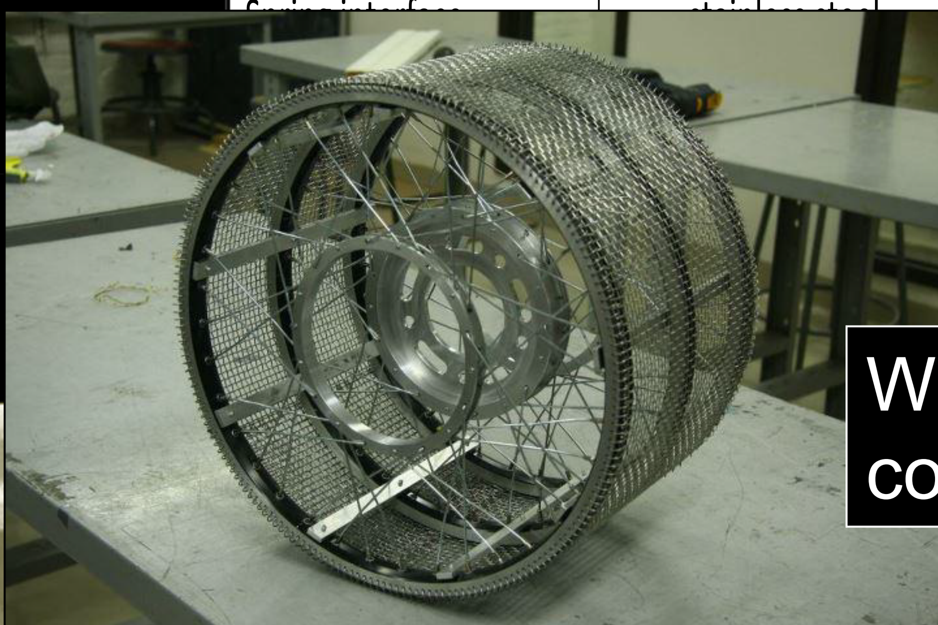
Avenues for further improvement

	Solid propylene balls
Mass of particulate [kg]	18.2
Rim design	current design
Rim mass [kg]	5



What about elastically compliant rims?

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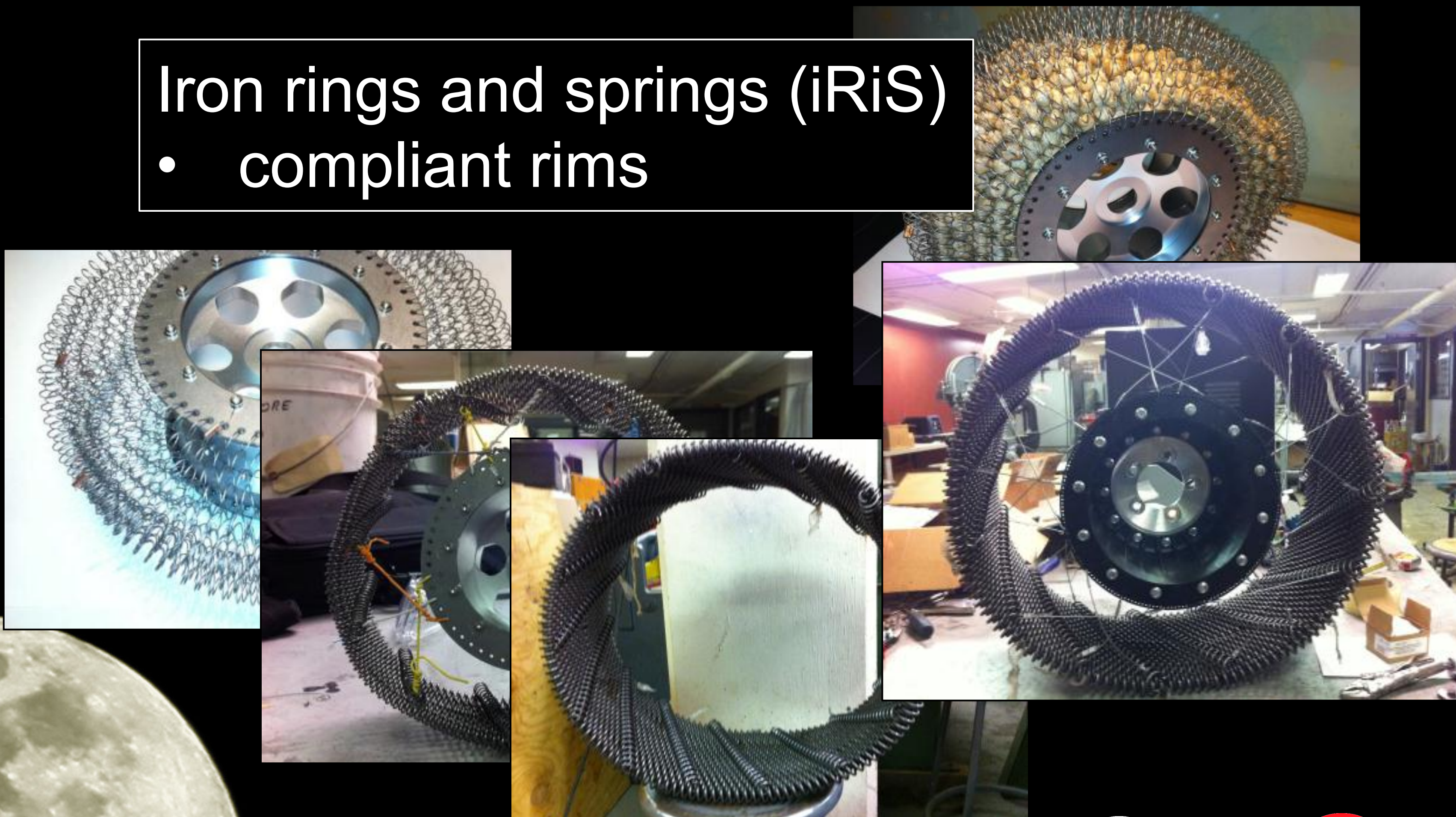
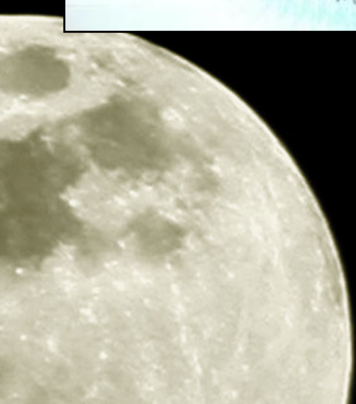
Avenues for further improvement

Iron rings and springs (iRiS)
- compliant rims





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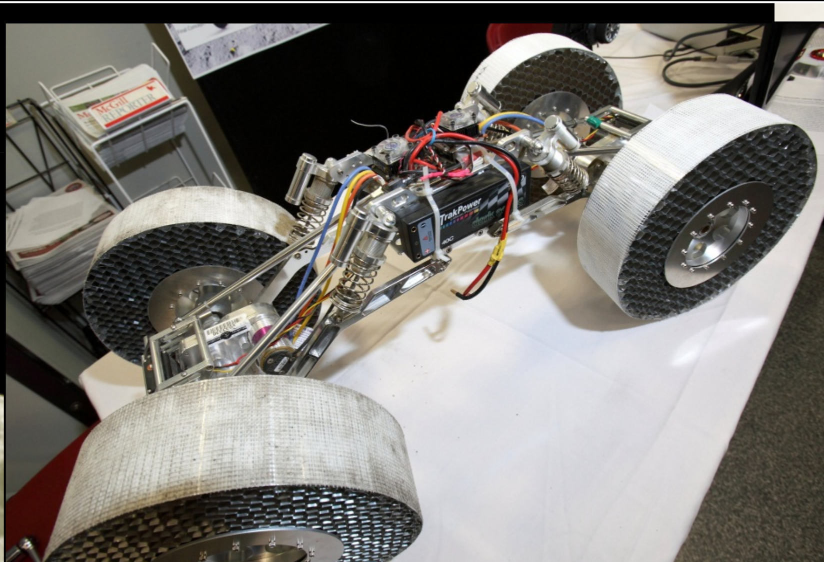
Avenues for further improvement

Elastically compliant rims/wheels

- Iron rings and springs (iRiS)
- Cellular structure rim/wheels



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Summary

PSP/CRD	Variations	Number of wheels
5" diameter	**9** (2 iRings, 5 segmented, 2 honey comb)	14
8" diameter	**5** (iRings, 1 scaled, 2 spring, 1 honeycomb)	20
22"/24" diameter	**9** (3 metal, 2 iRings, 1 spring, 1 brushed)	12
Spoked	**2**	2
JUNO Upgrade	**6** (3 exp., 2 eng., 1 production)	15
CSA	**2**	8
ODG	**1**	8
TOTAL	**33**	**79** (McGill 63)

- iRings is a wheel system that provides excellent traction, shock absorption, rock conforming characteristics;
- All iRings wheel components are candidates for in-situ replication:
  - particulates: centrifugal sieving, by-product of oxygen production or 3D printing
  - chainmail: 3D printing
  - rim: 3D printing
  - interface spring: 3D printing
- Compliant rim (& wheel) designs provide the possibility to engineer an iRing wheeled system with specific dampening and elastic characteristics.

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