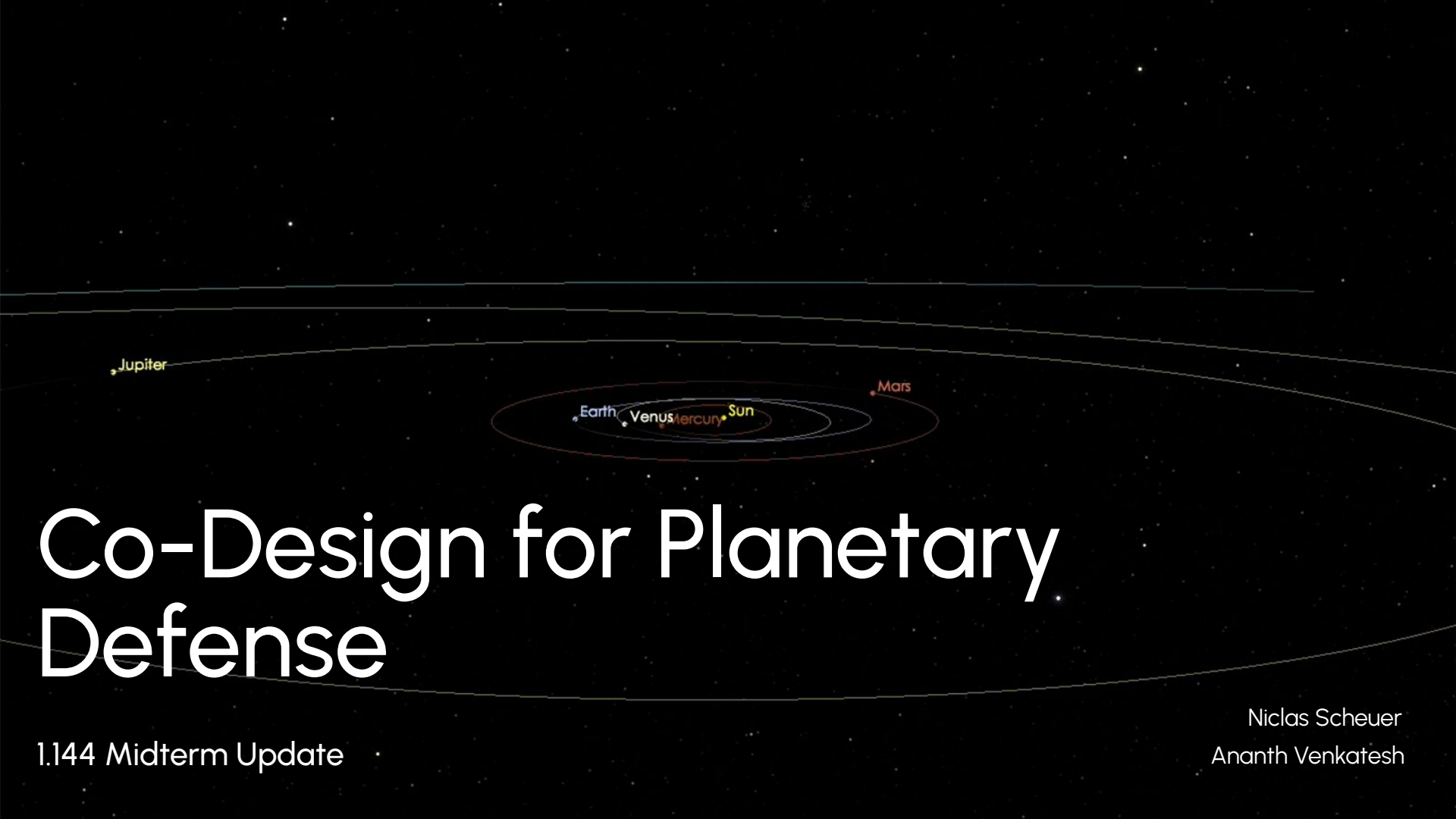


Co-Design for Planetary Defense

1.144 Midterm Update

Niclas Scheuer
Ananth Venkatesh

Mission Statement

Near-Earth Objects (NEO) of size (>50m) pose a significant risk to human life on Earth.

Mission Statement

Near-Earth Objects (NEO) of size (>50m) pose a significant risk to human life on Earth.

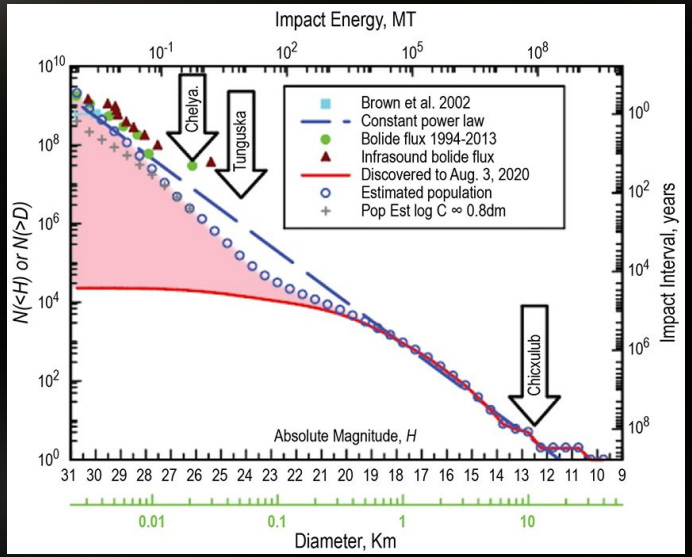
February 13, 2013

- 13-meter diameter meteor strikes Chelyabinsk, Russia
- > 1600 injured
- No prior warning

Mission Statement

Near-Earth Objects (NEO) of size (>50m) pose a significant risk to human life on Earth.

Majority of NEOs of size 50-140m remain **undiscovered**.



"The number of undiscovered NEOs larger than 140m is on the order of 10,000"

- NASA Decadal Planetary Defense Study [3]

Mission Statement

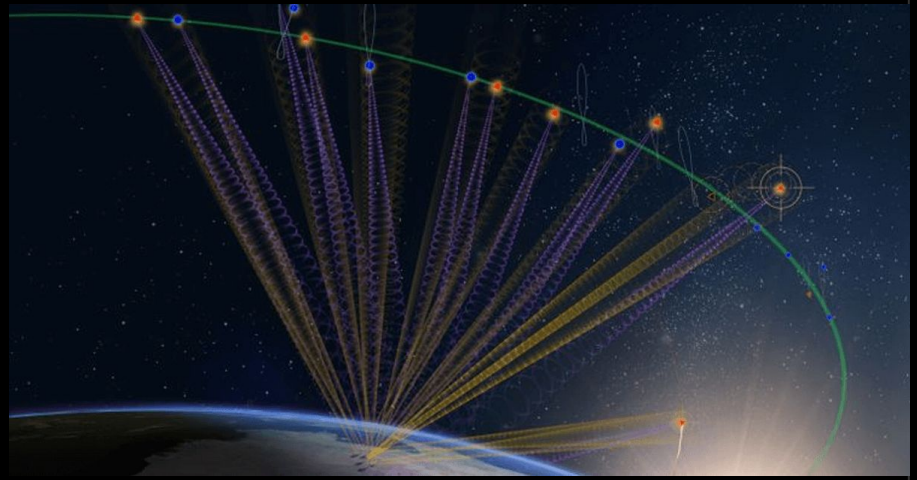
Near-Earth Objects (NEO) of size (>50m) pose a significant risk to human life on Earth.

Majority of NEOs of size 50-140m remain **undiscovered.**

Current NEO warning systems give us limited warning times.

Warning Times [3]:
- 20m NEO: 1 day
- 100m NEO: 21 days

Current Interception Times [4]:
- 54 months



The Case for Co-Design

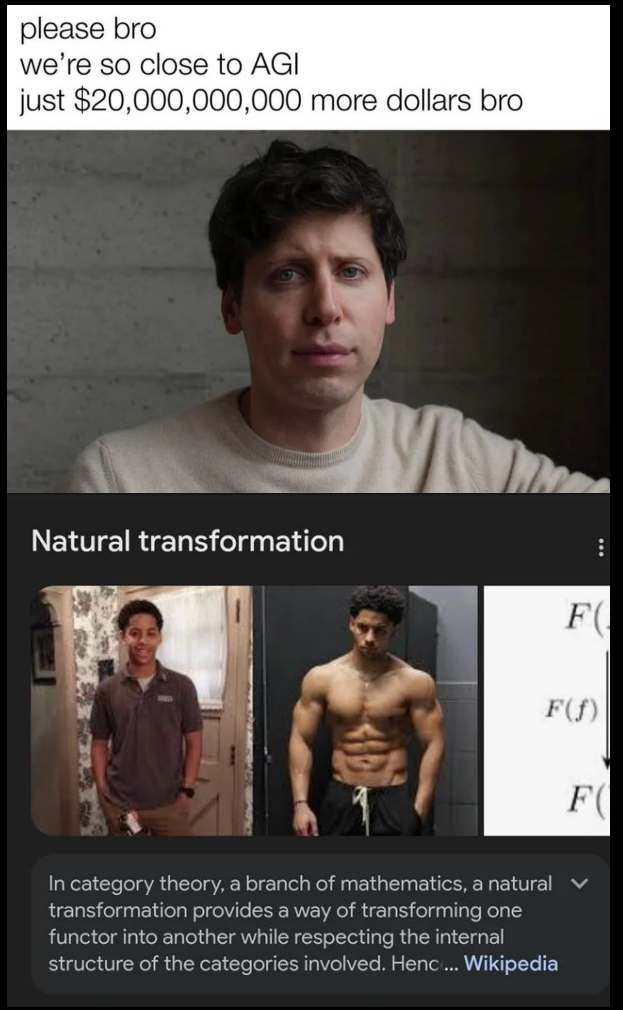
Many Stakeholders | Shared Responsibility
- Space agencies, observatories, defense organisations

Evolving and Interdependent Technologies
- Sensor and space-launch capabilities are rapidly evolving

Ethical and Planetary Equity
- Planetary defense is **free of geopolitics**

Holistic system design optimization
- Decisions are tractable and framework easily updated

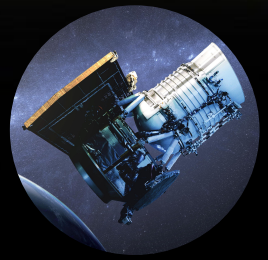
Most importantly, we need to use category theory to save the world.



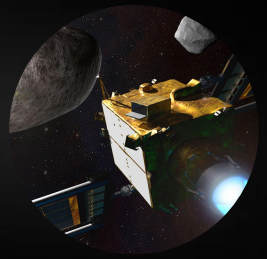
Design Problem

Given a distribution of **NEO sizes** and **velocities**, what combination of investments in **detection** and **redirection** yields the greatest value for planetary defense?

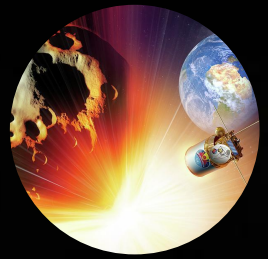
Ground-based Observatories



Space-based Observatories



Kinetic Impact (KI)



Nuclear Redirection

Modelling

Burritos for the Hungry Mathematician

Ed Morehouse

April 1, 2015

Abstract

The advent of fast-casual Mexican-style dining establishments, such as Chipotle and Qdoba, has greatly improved the productivity of research mathematicians and theoretical computer scientists in recent years. Still, many experience confusion upon encountering burritos for the first time.

Numerous burrito tutorials (of varying quality) are to be found on the Internet. Some describe a burrito as the image of a crêpe under the action of the new-world functor. But such characterizations merely serve to reindex the confusion contravariantly. Others insist that the only way to really understand burritos is to eat many different kinds of burrito, until the common underlying concept becomes apparent.

It has been recently remarked by Yorgey [9] that a burrito can be regarded as an instance of a universally-understood concept, namely, that of monad. It is this characterization that we intend to explicate here. To wit, *a burrito is just a strong monad in the symmetric monoidal category of food, what's the problem?*

1 The Category of Food

Modeling uncertainty has a natural monadic interpretation, and probability monads can be put in one-to-one correspondence with the different types of tortilla endofunctors. The proof is trivial given the generalization of the burrito presented by Morehouse (2015).

Modelling
Sensors

A sensor is characterized by its **angular resolution**, which relates range and diameter of target.

$$\text{Sensor} : \text{Range} \times \text{Diameter} \to [0, 1]$$
$$P_i(r, d)$$

We combine this with the angular cadence, i.e. percent of sky covered in 24 hours.

$$\text{DailySensor} : \text{Range} \times \text{Size} \times \text{St} \to [0, 1]$$
$$\bar{\alpha}_i \approx \frac{c_i}{4\pi} \qquad \bar{P}_i(r, s) = \bar{\alpha}_i P_i(r, d)$$

Finally, we define combined detection probability:

$$F(r, d) = 1 - \Pi_i(1 - \bar{P}_{ground,i}(r, d))\Pi_j(1 - \bar{P}_{space,j}(r, d))$$

Modelling
Sensors

NEO absolute magnitude:

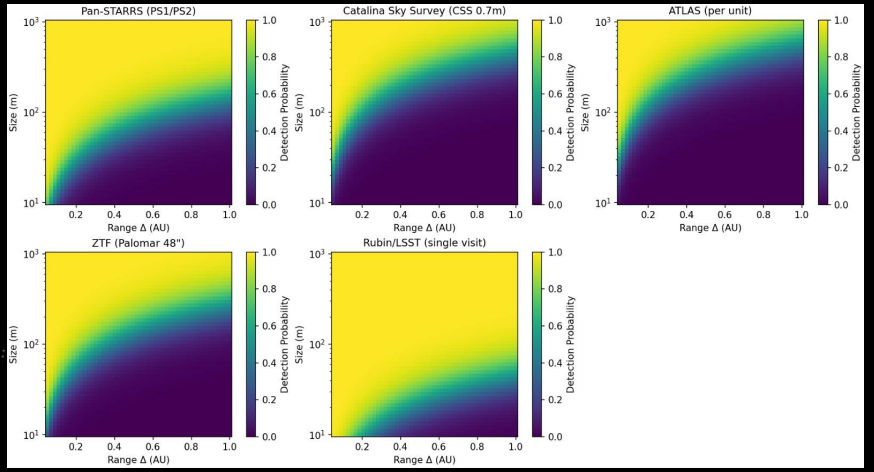
$$H = 5 \cdot \log_{10}\left(\frac{1329}{D_{\mathrm{km}}\sqrt{p_v}}\right)$$

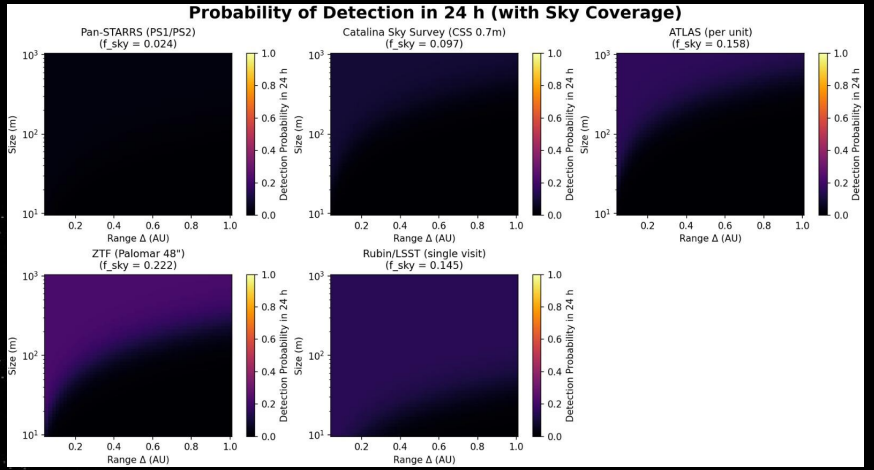
NEO apparent magnitude:

$$m \approx H + 5 \cdot \log_{10}(r_\odot \Delta)$$

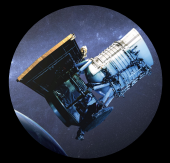
Single-Exposure Detection Probability

$$P_{det}(r,d) = \frac{1}{1 + exp\left(\frac{m(r,d) - m_{lim}}{k}\right)}$$





Modelling
Sensors



Equilibrium Temperature:

$$T(r) = 278\mathrm{K}\left(\frac{1-A}{\epsilon\mu}\right)^{\frac{1}{4}} r^{-\frac{1}{2}}$$

Planck Radiation

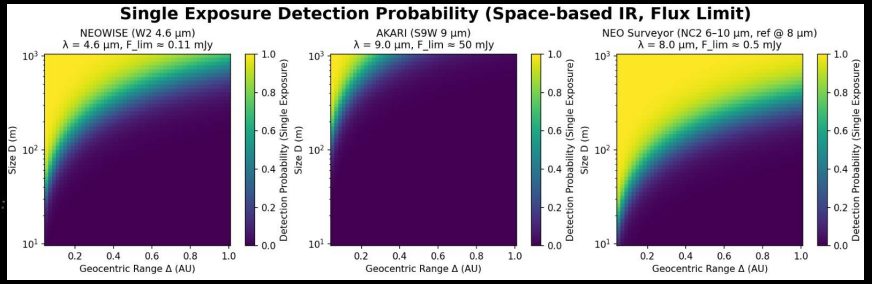
$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}}-1}$$

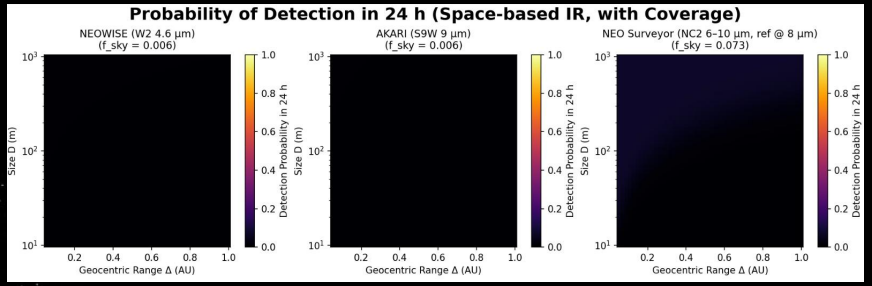
Flux at Earth

$$F_v(r,d) = \frac{\epsilon\pi B_\lambda(T) d^2}{4\Delta^2}\frac{\lambda^2}{c}$$

Single Exposure

$$P_{det}(r,d) = \frac{1}{1+exp\left(\frac{log_{10}(F_{v,lim})-log_{10}(F_v(r,d))}{k}\right)}$$





Modelling
Time to Impact

Provided the distributions:

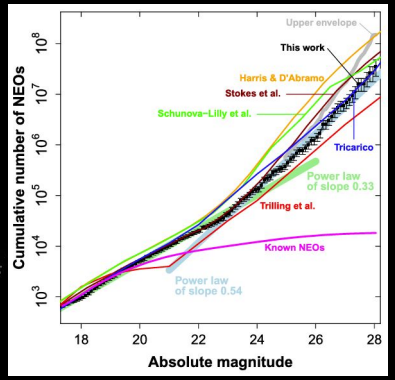
- Size: $p_D(d)$
- Velocity: $p_V(v)$
- Orbit Geometry: $p_\Phi(\phi)$

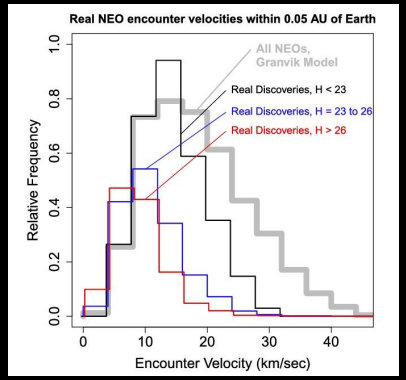
Hazard Function:

$$\lambda(\tau) = \int_d \int_v \int_0^{\frac{\pi}{2}} F(v\tau cos(\phi), d) p_D(d) p_V(v) p_\Phi(\phi) d\phi dv ds$$

Survival:

$$S(\tau) = exp\left(- \int_\tau^{\tau_{max}} \lambda(u) du \right)$$





Probability Distribution Function:

$$p_\tau(t) = \frac{\lambda(t) S(t)}{1 - S(0)}$$

Modelling
Delta V

Provided the distributions:

- Size: $p_D(d)$
- Velocity: $p_V(v)$
- Time to Impact: $p_T(t)$

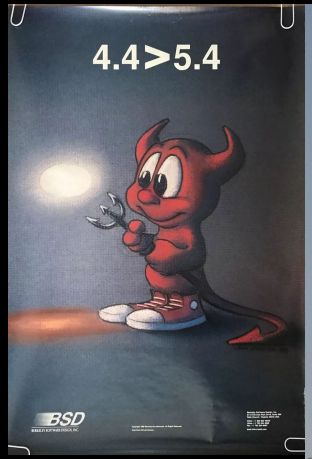
Tangential Delta-V that must be transferred for a 2-Earth Radii Miss [4][8]:

$$\Delta v = \frac{2R_\oplus}{t_{TTL}}$$

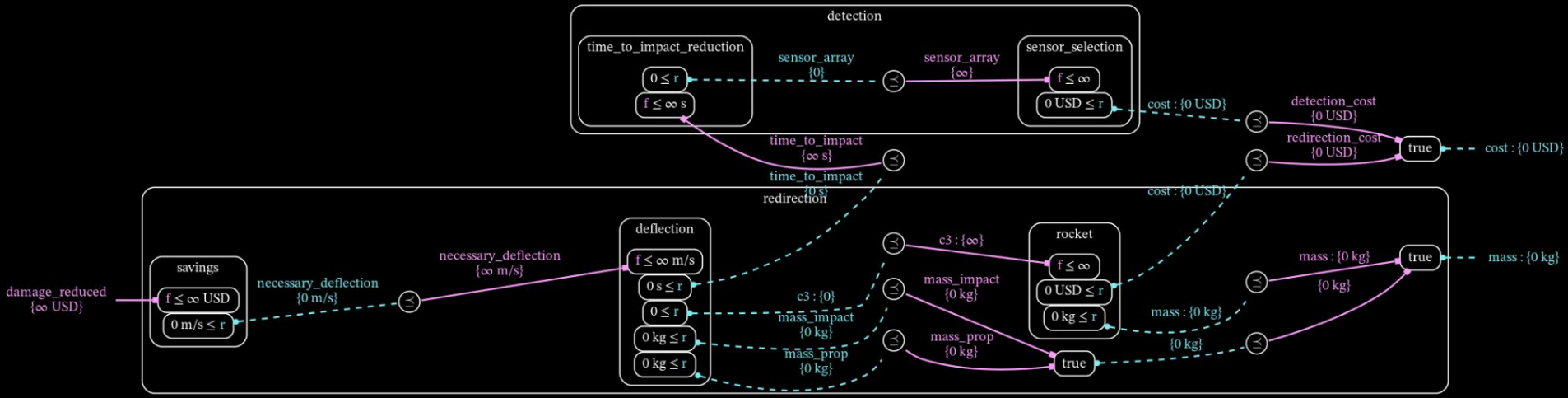
Interception angle plays an important role, difficult to model without simulation.

Modelling
Kinetic Interceptor

$$m_{\mathrm{NEO}} = \rho \frac{2000}{6} D^3$$



"The most important application of Toquos Theory is combating the devastating effects of Subgroup Psychosis stemming from several somnial attacks from the Number Devil, as he has the ability to invade dreams, especially those related to mathematics." —Emma O'Neil



Proprietary MCDPL-generated design schematics; for more information see:
https://code.functor.systems/q9i/blue-dome

Literature Review

[1] Researchers Propose Mission to Intercept the Next Interstellar Asteroid | Space

[2] Meteor Hits Russia Feb 15, 2013 - Event Archive

[3] Just Look Up: Expanded UH asteroid tracking system can monitor entire sky

[4] Planetary Defense Missions – Rapid Mission Architecture Study

[5] Wikimedia Commons image

[6] Scientific illustration

[7] Northrop Books $200M Space Force Contract for 2nd Deep Space Radar Tech Site – GovCon Wire

[8] Deflection Techniques: What Makes Sense | AIAA SPACE Forum

Luminary in the field of category theory, David Spivak, seen here introducing his mathematical theory of eating alongside prominent logician Gordon Plotkin

Bob Coecke, "independent researcher" and quantum physicist-turned-category theorist, whose insights have been crucial to the success of this project