GLITTER BELT:
High Altitude Reflectors To Counter Climate Change

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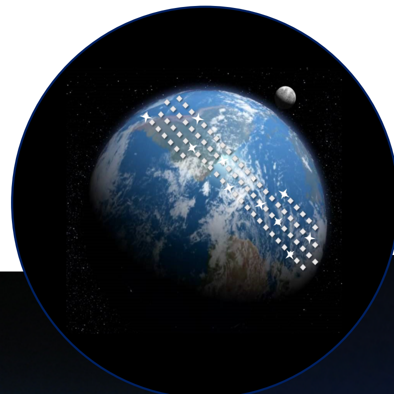
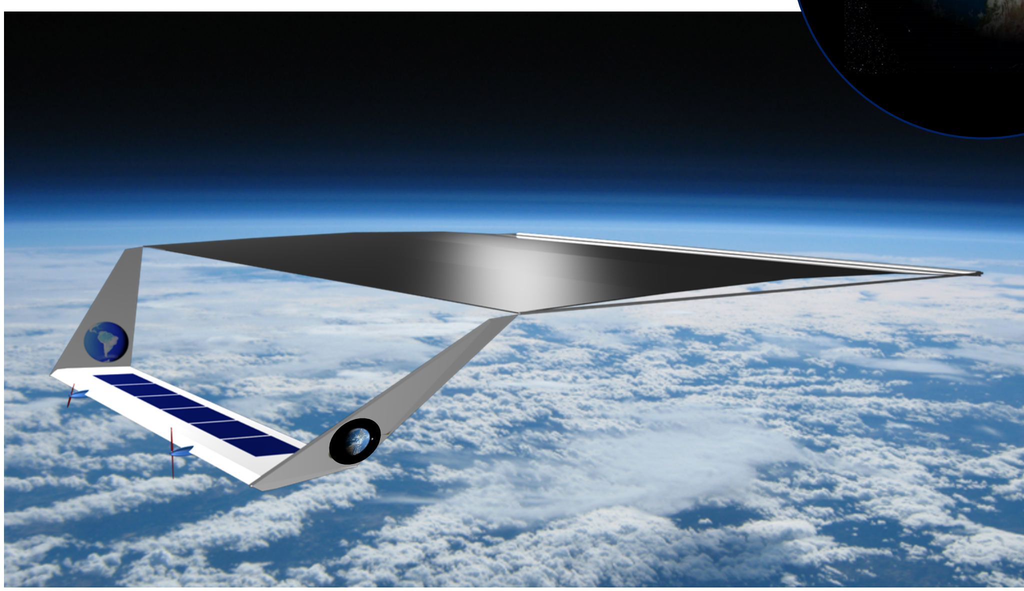
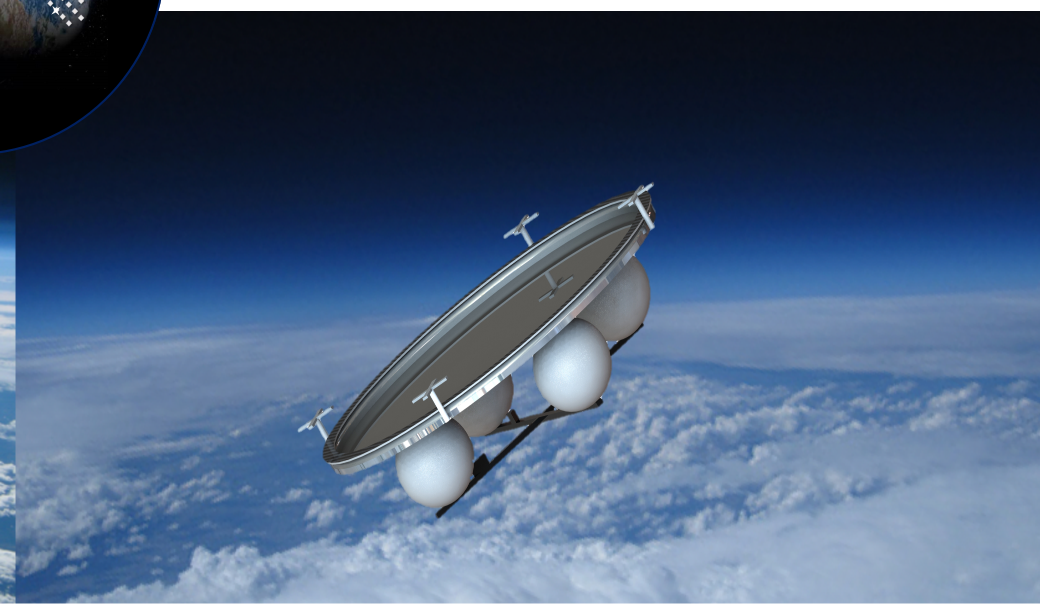
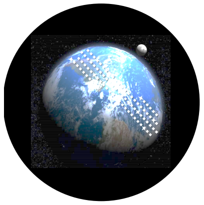








GLITTER BELT AIMS

AIM1: Cut Atmospheric Heat Retention Rate (AHRR) down from 2.92 to 1.5 W/m^2 by 2035.
AIM2: With other efforts, reduce AHRR to 0 by 2050.
AIM3: As knowledge improves, perform specific interventions (polar ice/ glaciers..)

GLITTER BELT IS NOT A PERMANENT FEATURE

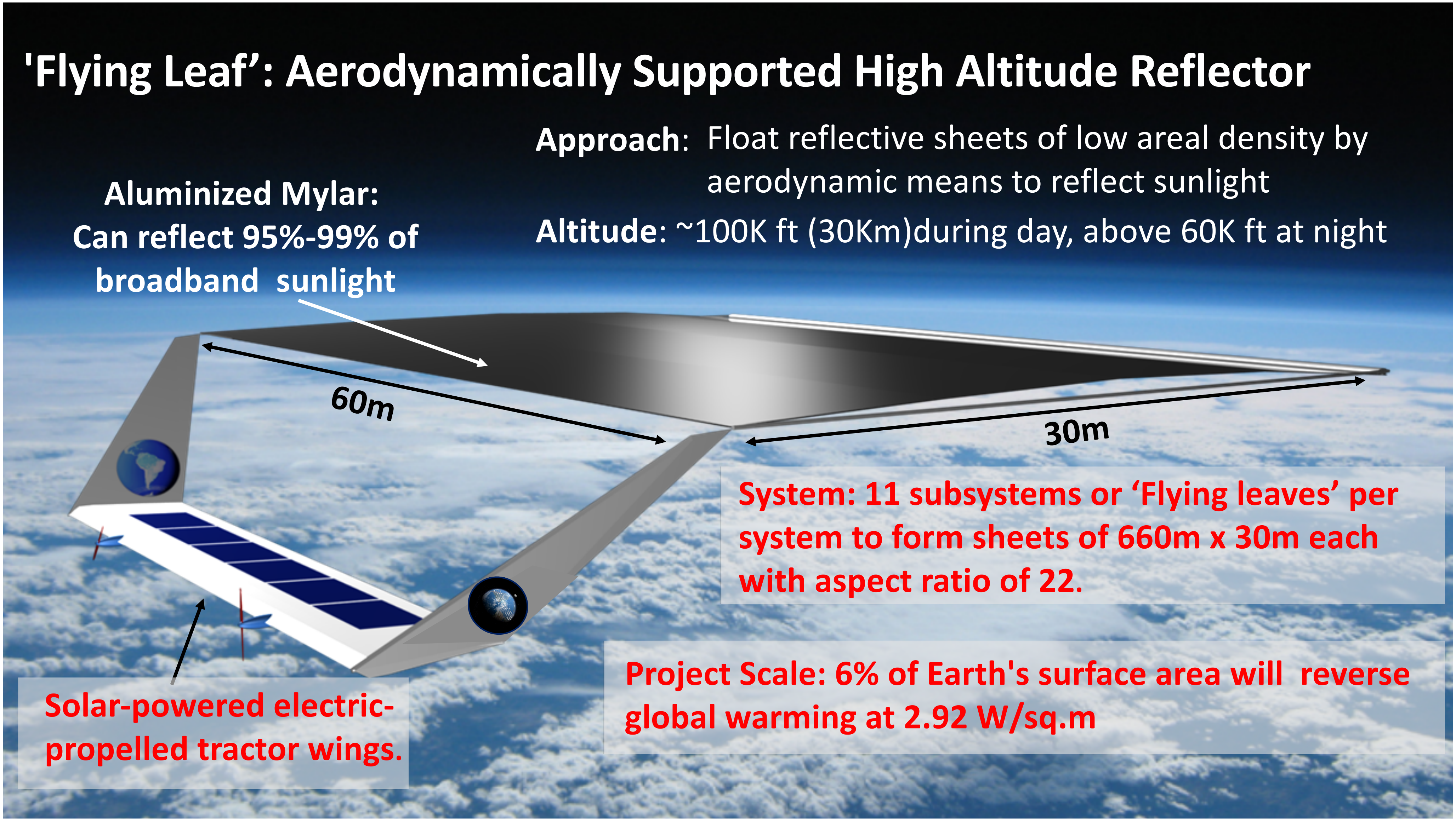
As reforestation and other environmental measures catch up, Glitter Belt can be completely removed.

MONITORED, CONTROLLED, REMOVABLE, RESTORABLE

- Each reflector is an autonomous UAV with Headless GPS-based Home Return.
- Swarm guidance and Health Monitoring; swarm monitoring at all times.
- Damage-tolerant collision avoidance control including during descent.
- All components recovered: All re-usable except recycling wrinkled reflector sheets.

INTEGRATED DATA ACQUISITION CAPABILITIES

UAV swarms integrate data acquisition and telemetry on solar flux, cloud cover, atmospheric properties, ozone, GHG all over the planet, continuously for long periods.


'Flying Leaf': Aerodynamically Supported High Altitude Reflector
Approach: Float reflective sheets of low areal density by aerodynamic means to reflect sunlight
Altitude: ~100K ft (30Km)during day, above 60K ft at night
Aluminized Mylar: Can reflect 95%-99% of broadband sunlight
60m
30m
System: 11 subsystems or 'Flying leaves' per system to form sheets of 660m x 30m each with aspect ratio of 22.
Project Scale: 6% of Earth's surface area will reverse global warming at 2.92 W/sq.m
Solar-powered electric-propelled tractor wings.

Prior Work on Direct Reversal

1. Reflectors in Space

2. Wind Turbines pumping Antarctic sea-water onto ice cap

3. Chimneys to ingest and “scrub” air

Energy requirements 10^6 times that of Glitter Belt (1)

Entropy, cost & heat of construction and human activity (2, 3)

4. Reflective particles in industrial exhaust

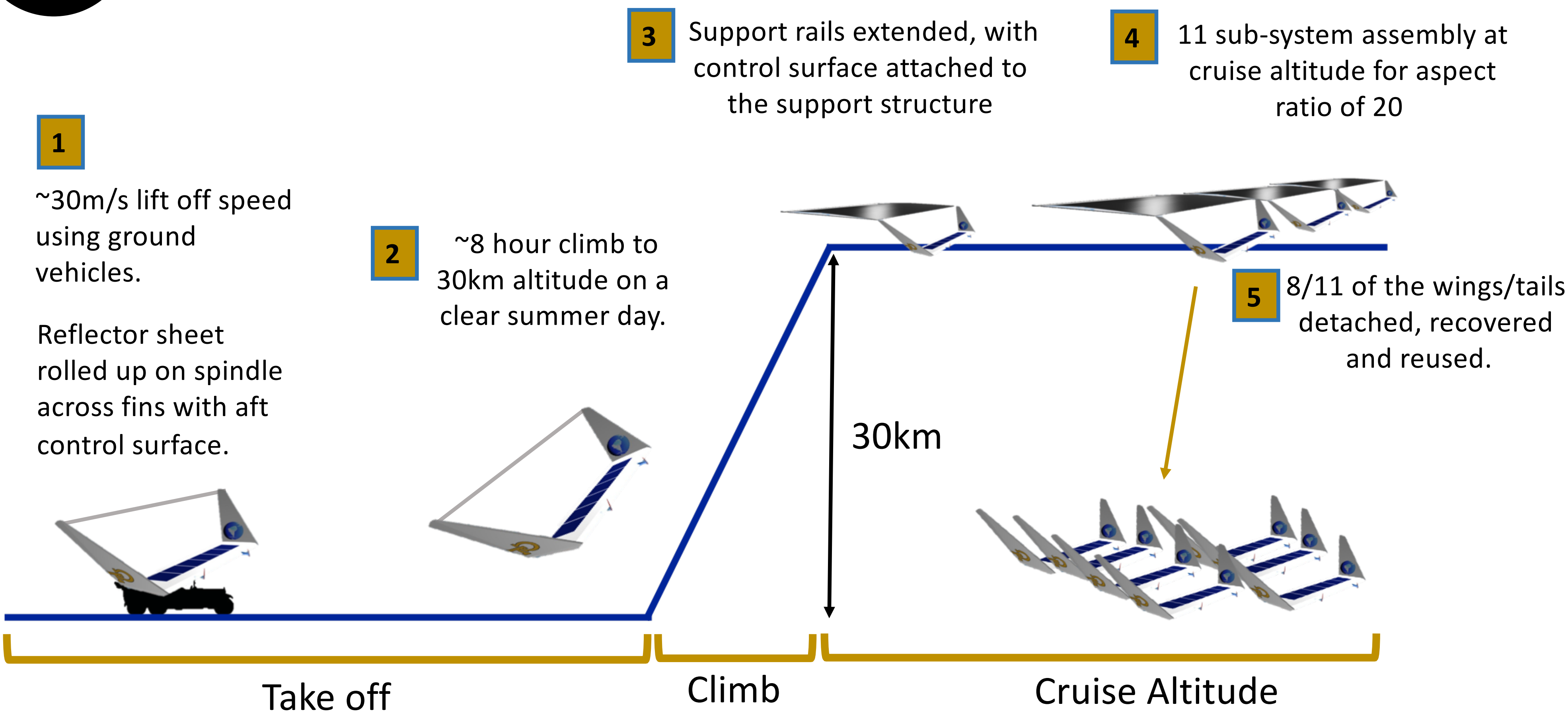
5. Aerosol clouds over Antarctica

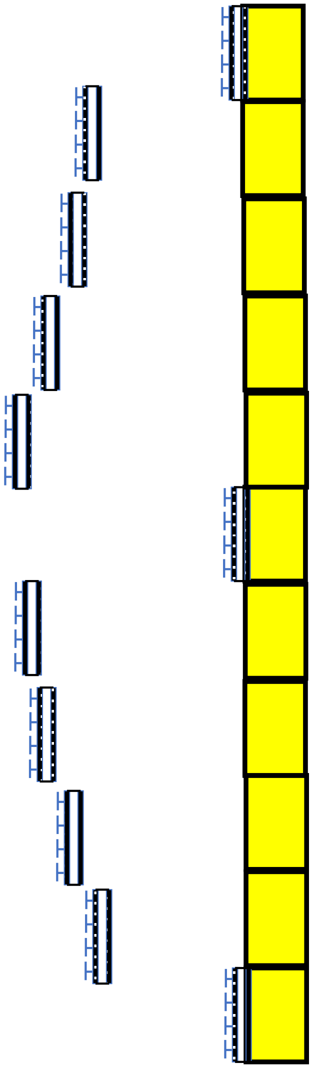
6. Reflective balloons released into the sky

7. Hollow glass beads over polar sea ice

Uncontrollable and irreversible once released. (4–6)

Deployment Process





FLYING LEAVES IN FORMATION

- 11 Flying Leaflets are attached at tips to form a Leaf with Aspect Ratio 22.
- 8 out of 11 propulsion wings shown returning to base to repeat launch operation. 3 units support and propel 11 sheets.

Reflector area of a Leaf = 60x 30 x 11 = 19,800 sq.m

Solar Power reflected = 27 MW.

Speed for Minimum Drag < 10 m/s
Night altitude loss < 5000m in 12 hrs.
N-S drift speed ~ 1m/s to follow Sun

A Flock of Leaves for efficiency, swarm control and health monitoring.

501 Leaves ~ 10 sq.km
Power reflected = 13.6 GW

Balloon Beanie Concept of the Glitter Belt

Suitable to position over given regions with tiltable surface (e.g. polar summer with shallow Sun)

1 Micron Reflective Mylar Sheet

Nominal design:
200m dia. ~ 31416 sq.m

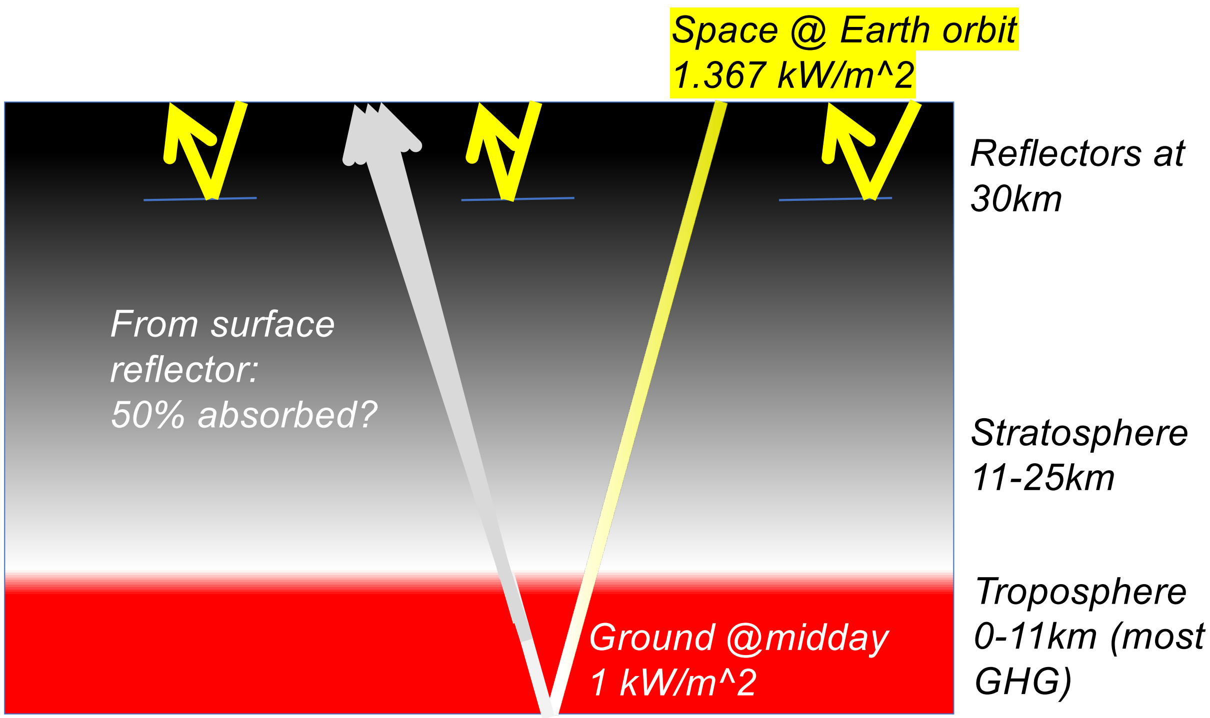
32 units for 1 sq.km of reflector

Hydrogen Filled High Altitude Balloons (Balloon size not scaled)

System Features

WHAT

- Reflectors at the top of the atmosphere: 99+% reflected.
- Supported by aerodynamic lift, centrifugal lift or aerostatic lift.
- Able to stay aloft 24 hours a day for several years.
- Twice as effective per unit area as ground-based reflectors.



WHY REFLECTORS IN THE UPPER ATMOSPHERE?

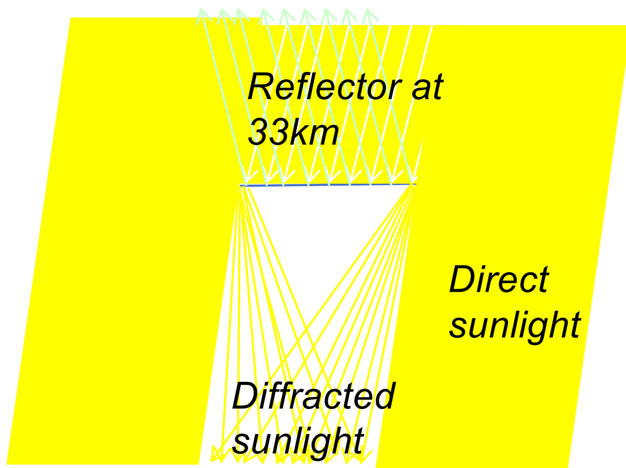
- Twice as effective per unit area as ground-based reflectors.
- Payload Fraction: 10% reaches Space; 100% reaches upper atmos (solar-powered).
- Kinetic energy/kg mass: 50-100 Million m^2/s^2 for Space. 100 m^2/s^2 for upper atmos.
- Modular. Small units. Evolving design.
- Completely “recallable” and reconfigurable on demand.
- Can start deploying inside a year from project start. vs. 1 month for landowning surface-reflectors on small scale, or 10 years for Space-based.

WHY DO FLYING LEAF SYSTEMS STAY UP 24 HOURS INDEFINITELY?

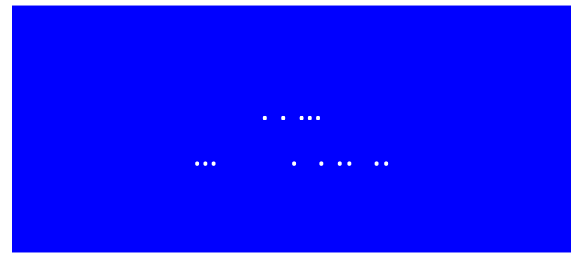
Vehicles such as NASA’s Solar Pathfinder and the European Space Agency’s more recent version have shown endurance through the night for limited periods. Absent sunlight, they use stored energy to run propellers as to reduce the sink rate and stay above the 60,000 foot (FL600) limit of controlled airspace. In time, they run out of stored fuel if they use a fuel cell. Battery storage implies more weight. Their flying wing designs trade off aspect ratio, span, stiffness and weight. In other words, all lift is from the wing whose chord must be small to keep aspect ratio high and reduce lift-induced drag. Fuel/ fuel cell, or batteries, are large “point loads” hanging from the wing in addition to solar panels, motors, propellers, control surfaces, servo actuators and other equipment. It’s a tough balancing act. And strength becomes marginal, with a high risk of aeroelastic flutter and failure.

Flying Leaf derives much of its lift ***from the large ultralight sheets themselves!*** So lift coefficient is small; Wing Loading is miniscule, flight speed is low and so is the sink rate at night. No auxiliary energy storage needed. We stay above 85000 feet in a 12-hour night, so we could last through a much longer night, except there is no need: We drift with the Summer Sun, so that the longest night is during Equator Crossing: 12 hours! Q.E.D.

OPTICS



Reflectors would not be visible from the ground 100,00 feet below, day or night. Underside is black, like outer Space, to absorb radiant heat from the surface at night and radiate out into Space.



Reflectors may be visible from Space in daytime as glittering points of bright light (hence the name Glitter Belt).

At night, reflectors would reflect moonlight and starlight. At 277K static temperature, they may be warmer than the general 192K Earth background.

Concerns About Geoengineering

Concern	Glitter Belt Response
• May negatively impact regional environments either through reduced rainfall or through direct pollution (HeSO4, solid particles) and energy use. Numerous unknowns still exist and certain concepts are not removable once put into implementation.	Continuous measurement & input to simulation are parts of GB deployment. Every swarm will have sensors. GB will greatly improve climate knowledge base on climate, all over the globe, with continuous data of high temporal and spatial resolution. Boost prediction accuracy.
• Uncontrolled after deployment.	GB is completely monitored, controlled and removable so the concern does not apply to GB.
• If stopped after started (without using time to grow trees and reduce GHG), global warming may jump up.	Can deploy and remove gradually or quickly, and re-use. Yes GB buys critical time for islanders and coastal communities.
• Geoengineering can lead to a false sense of security to politicians and the common man. This will cause society to once again temporarily ignore climate change's issues.	Maximum possible deployment rate is not high enough to merit this concern.
• Microcredits for reflecting sunlight will reduce funding for GHG reduction	Microcredits will slash huge upfront costs of Carbon Credit bureaucracy (now ~$100K per project!) and hence accelerate investment in GHG reduction.
Ice thickening schemes are intrusive and add heat& entropy.	Polar Necklace is non-intrusive: No ground components.

Architecture Development Planning

1. System development & performance/ longevity demonstrations
2. Data acquisition planning
3. Summer Follower Sweep 1: South India to Antarctic Circle and Back: Eastern Swarm
4. Summer Follower Sweep 2: Hawaii north to Arctic Circle, south to Antarctic Circle and Back: Western Swarm
5. Polar Circle 1: Stationary balloon-held sheets and Leaf Swarms over edge of Antarctic Ice Cap
6. Polar Circle 2: Stationary/ slow-moving balloon-held sheets and Leaf Swarms over Artic Ice Cap/ tundra

Risk Analysis: Climate Responses to Forcing

Concerns:

1. Displacement of Monsoons
2. Displacements of Warm Ocean Currents Near IceCaps
3. Displacements of Warm or Cold Currents Near Landmass

Prior Results

Chen & Ramaswamy (2006):
Effect of 37% increase in cloud cover ➔ -3.7 W/sq.m forcing.
Doubling of CO_2 ➔ +3.7 W/sq.m forcing.

- *Time / Space –Resolved Forcings?*
- *Amplification of Response?*
- *Maximum tolerable level compared to existing "normal" perturbations?*

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Marine Cloud Brightening

Pros

1. A simple process (spraying saltwater particles into air to make more reflective marine clouds)
2. Shipping industry is thought to be unintentionally performing this experiment with emissions from ships. If true, we can analyze and understand the data and effects from what has happened so far (it is estimated that Earth's temperature has already cooled 0.25 degrees Celsius)
3. Relatively safe and natural method that does not utilize toxic chemicals

Cons

1. Technology is not fully developed. High-end particle generation and delivery systems need to be developed to effectively distribute 100 nanometer particles
2. Negative impacts on regional weather patterns and ocean currents could occur due to increased cloud cover and reflectiveness. This could increase drying of rainforests
3. No concrete evidence exists proving that this method will work through long-term. Unknown negative side effects could exist

Cost

An upper-bound cost of $9 billion dollars would include unmanned vessels fitted with particle generation and delivery systems

Ocean Iron Fertilization

Pros

1. Effective since phytoplankton are responsible for half of current carbon fixation
2. Solution is simple in nature and does not require any new technology
3. Increase in phytoplankton biomass will lead to population booms throughout food chains (increase in fish populations)

Cost

$100 million annually

Cons

1. Could increase levels of nitrous oxide and methane (both are GHG)
2. Phytoplankton blooms can produce chemicals known as methyl halides which are known to erode ozone layer
3. Iron must be in the purest form or else potentially toxic metals could be introduced into ocean environments
4. Most of the CO_2 taken in by phytoplankton ends up recycled in the ocean food chain rather than sinking into ocean depths
5. Entire ocean food chains and ecosystems can be disrupted if unintended results occur
6. Will favor fast-growing diatom and phytoplankton species. These often release domoic acid which is a neurotoxin
7. No accurate method to track the phytoplankton growth on a global scale

Carbon Dioxide Scrubbing

Pros

1. Can pay for itself as the captured carbon dioxide can be sold for carbonated beverages, rejuvenating wells, and plant growth stimulators. Typically sells for $100 per ton
2. Addresses the root cause of global warming by directly removing the major greenhouse gas that contributes to the process

Cons

1. Requires massive amounts of energy as systems are inefficient due to carbon dioxide only represent 1 in 2,500 molecules in the air. This requires thousands of machines continuously operating
2. Difficulty of scalability as vast network of scrubbers and storage systems need t be developed
3. Removed carbon needs to be stored deep underground with complex systems to ensure permanent storage
4. Astronomical costs compared to other solutions

Cost

$3-$5 trillion to remove all the CO2 from the air

Stratospheric Aerosol Radiation Management

Pros

1. Technology needed to implement already exists and only needs simple modifications
2. Process mimics a naturally occurring one (volcanic eruptions) and thus we can study how this will affect Earth by watching natural experiments take place

Cost

$5-$8 billion annually
$360 - $576 billion for this century to hold temperatures constant

Cons

1. Affects regional and global hydrological processes with effects such as reduced precipitation, soil moisture loss, and decreased river flow. This will bring droughts and increase deforestation in the Southern hemisphere, while increasing frequency and intensity of hurricanes in the Northern hemisphere
2. Ozone layer depletion rate increase since aerosols serve as surfaces for chemical reactions that break apart ozone layer. This will increase incoming UV light, which can kill phytoplankton
3. Acid deposition through sulfate mixing
4. Unaccounted negatives could exist and there is no way to remove aerosols once added

Space-Based Reflector at L1 Lagrange Point

Pros

1. Non-invasive method that does not directly impact ecosystems in any way
2. Low resource needs. It is estimated that a Fresnel lens that is 1000 kilometers across with few millimeter thickness is enough to reduce incoming solar radiation by 1%
3. Potentially can pay for itself if solar power can be produced through reflector and beamed to Earth

Cons

1. Maintenance costs are high since solar radiation can damage reflector. Without maintenance, the reflector is expected to last five decades
2. Technology is far from ready as advancements in materials engineering are needed. Additionally, special thrusters to keep the reflector in space need to be developed (since L1 point is quasi-stable, but not fully stable)
3. Uneven temperature reduction would take place. Equator and lower latitudes would have higher temperature reductions while the poles would only have small temperature reductions

Cost

$1-$4 trillion with current space launch costs (Current launch costs are around $10,000 per kilogram, but if new rocket technologies such as SpaceX Starship are used in future, the costs could be reduced to around $60 billion)