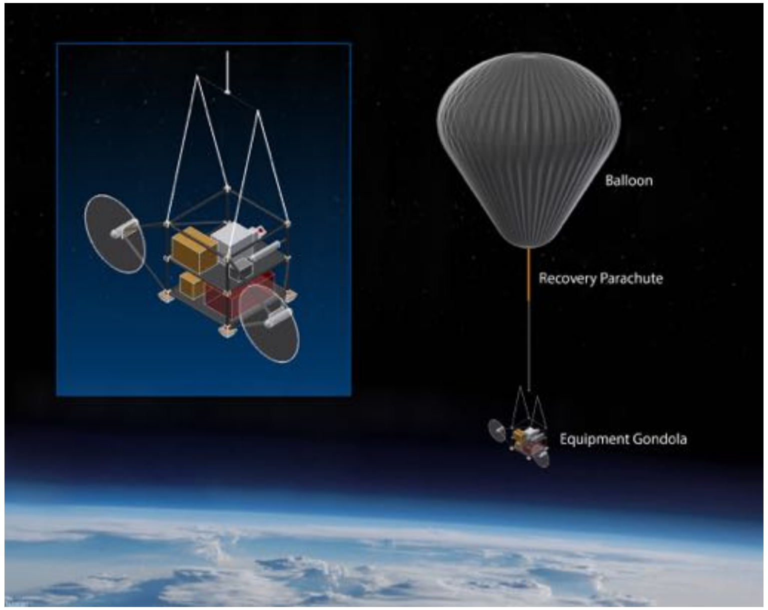
Stratospheric Controlled Perturbation Experiment (SCoPEx) Goals

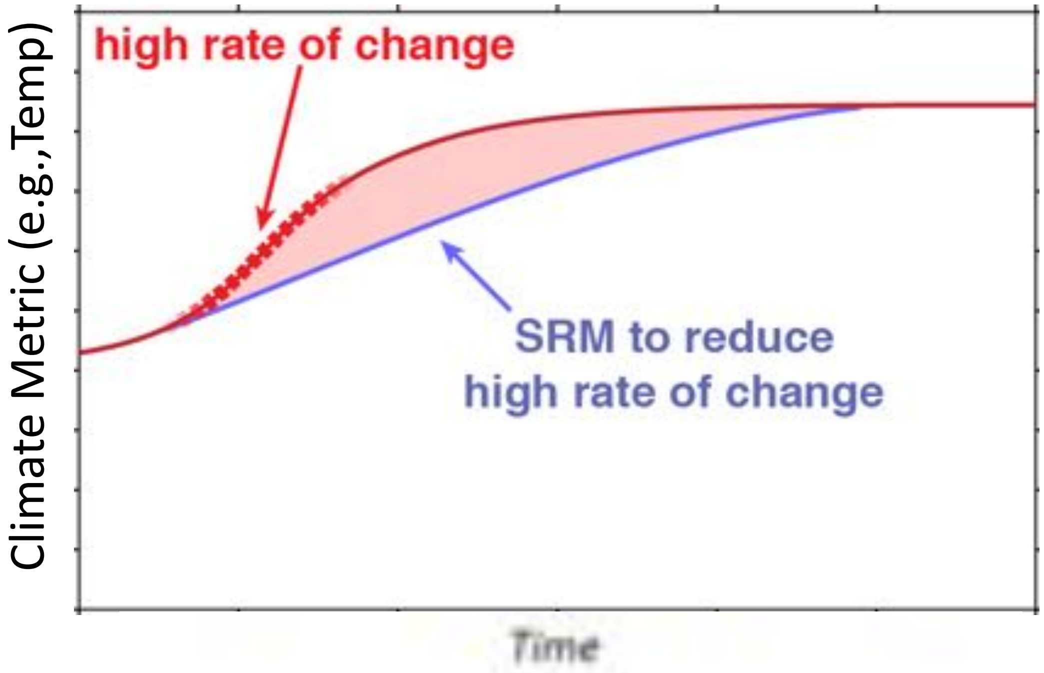
Experiments to improve understanding of stratospheric solar geoengineering's efficacy and some of its risks.

Perform experiments in a manner that exemplifies good governance, developing and implementing norms, mechanisms, and practices that can serve as useful templates for future solar geoengineering field experiments.



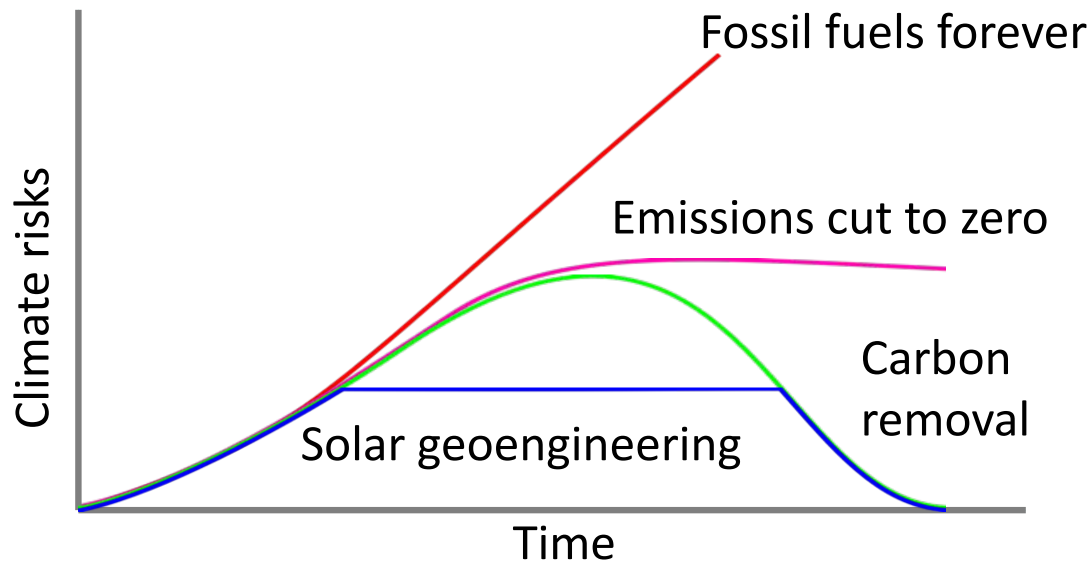
SRM as Supplement to Reduce Risk of Change

Risk: related to *rate of change* and *tipping points*



Mitigation efforts unable to reduce risk of change in the short term

SRM to reduce high rate of change and “peak shaving”



SRM at best supplement to mitigation, never solution

SCoPEx Science Goals

Overall goal: quantitative measurements of aerosol microphysics and atmospheric chemistry to improve large-scale models used to assess the risks and benefits of solar geoengineering

Scientific hypotheses and goals:

- Develop and test a propelled balloon that creates and monitors region of perturbed chemistry in the stratosphere.
- Test ability to generate and observe small air parcels with perturbed aerosols and chemical constituents.
- Investigate small scale stratospheric mixing.
- Study chemical and physical ageing of $CaCO_3$ (limestone) aerosol.
- Investigate role of aerosols in ozone destruction, under mid-latitude conditions.

SCoPEx: Basic design and concept of operations

Perturbative experiment requires:

(a) means to create small, perturbed volume in stratosphere.

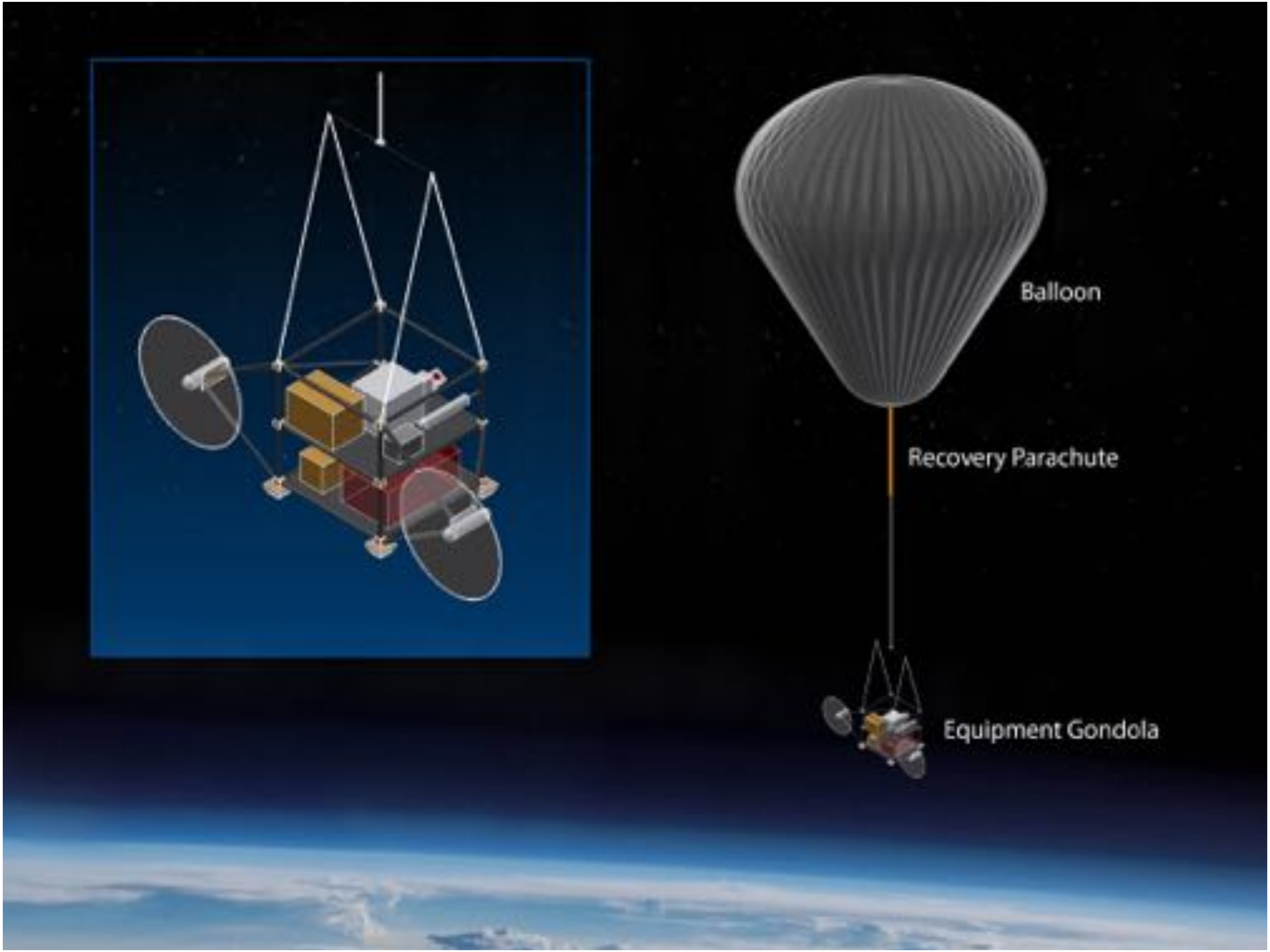
(b) observation of evolution of chemistry and aerosols in the volume.

(c) at 20km altitude disperse 0.1-1 kg material in plume 1km long, 100m in diameter.

Propelled balloon gondola containing instruments and drive system.

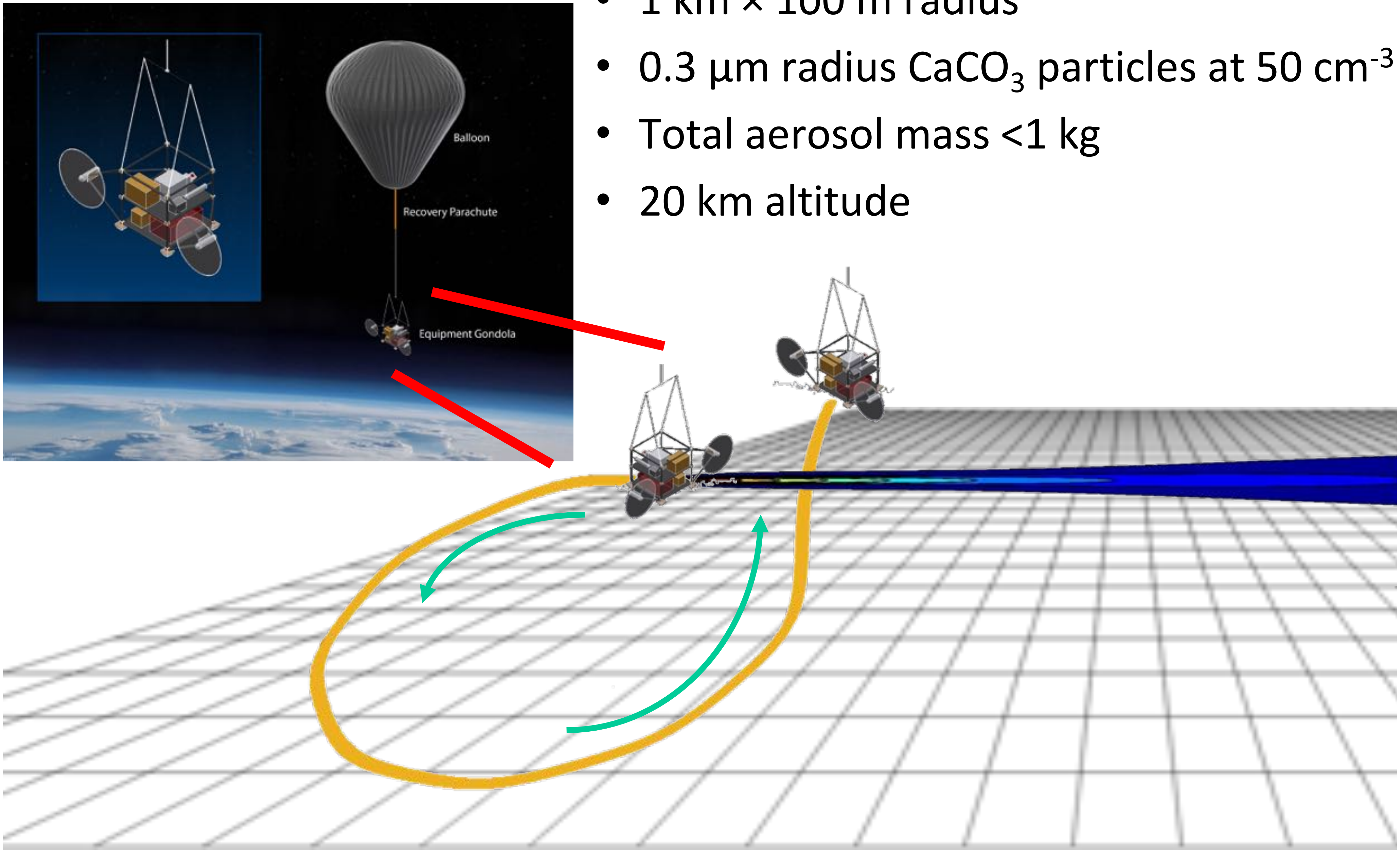
Aircraft usual platform for studying atmosphere where experiments exploit natural variability over a long flight track, but aircraft move too fast and may have insufficient loiter time, thus ***not allowing small*** perturbed volume to be created and observed.

A balloon naturally follows perturbed air mass, with little disturbance to surrounding air ***allowing small*** perturbation.


Balloon
Recovery Parachute
Equipment Gondola

Representative plume:

- 1 km × 100 m radius
- 0.3 µm radius $CaCO_3$ particles at 50 cm^{-3}
- Total aerosol mass <1 kg
- 20 km altitude



737 flight: 1-2 kg S or 3-6 kg sulfuric acid / 1000km flight

Why not stay in the laboratory?

Very hard to faithfully reproduce stratospheric conditions in the lab

- Walls and surfaces of reactor can affect experimental results.
- Hard to duplicate radiative environment
- Stratospheric trace chemicals or other parameters may not be considered/overlooked (unknown or deemed not to be important) that impact results

Field measurements are central to all forms of environmental research as they represent the critical "reality test"

Governance/Regulatory Requirements

Environmental health and safety. Independent processes to assess direct physical risks posed by experiment, including flight safety risks and risks associated with release of any materials into the environment.

Scientific peer review. Effective peer review is the core of the scientific process.

Scientific Integration. Instrumentation and scientists from other countries as part of SCoPeX

Transparency. Access to preliminary results, funding sources, treatment of innovations

Developing governance for field experiments. The requirements for national and international governance of solar geoengineering field experiments are contentious. SCoPEx should contribute to the development of effective governance through a bootstrap process in which we (a) invite a diverse set of stakeholders into a process which provides effective oversight for our experiment, and (b) facilitate learning that can be applied to the governance of future experiments.

Environmental health and safety

Management of EH&S requires independent governance processes with strong power. Two organizations have the primary responsibility for managing EH&S for our experiment.

First, Harvard’s EH&S and emergency management staff. Harvard’s program has authority which extends to all potentially risky activities led by Harvard personnel, on campus or around the world.

Second, World View, the company that will conduct our balloon launches, is responsible for flight safety. World View, in turn, works with FAA and other relevant government agencies

SCoPEx and CBD

Ensure, in line and consistent with decision IX/16 C, on ocean fertilization and biodiversity and climate change, in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities** **that may affect biodiversity** take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, **with the exception of small scale scientific research studies** that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment

Developing governance for field experiments: Advisory Committee

Composition and operating rules will be developed in collaboration with its chair. The following framework is a starting point:

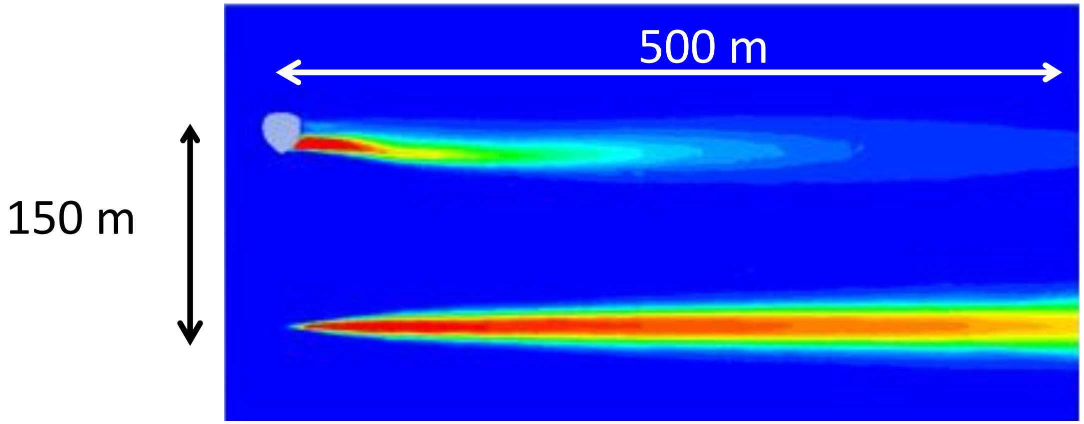
- To provide oversight and advice to principal investigators and the broader experiment team on issues related to SCoPEx
- To provide periodic public written evaluation of the evolving experiment plan, which will address subjects including (a) management of environmental health & safety, (b) regulatory compliance, (c) scientific peer review, (d) transparency, and (e) stakeholder engagement
- To conduct activities that the Advisory Committee deems necessary to implement good governance over the experiment
- To share governance lessons learned from SCoPEx with other geoengineering field experiments

BACKUP

Scientific Objectives: Stratospheric Mixing Processes

Stratospheric mixing processes between plume and GCM scale poorly understood:

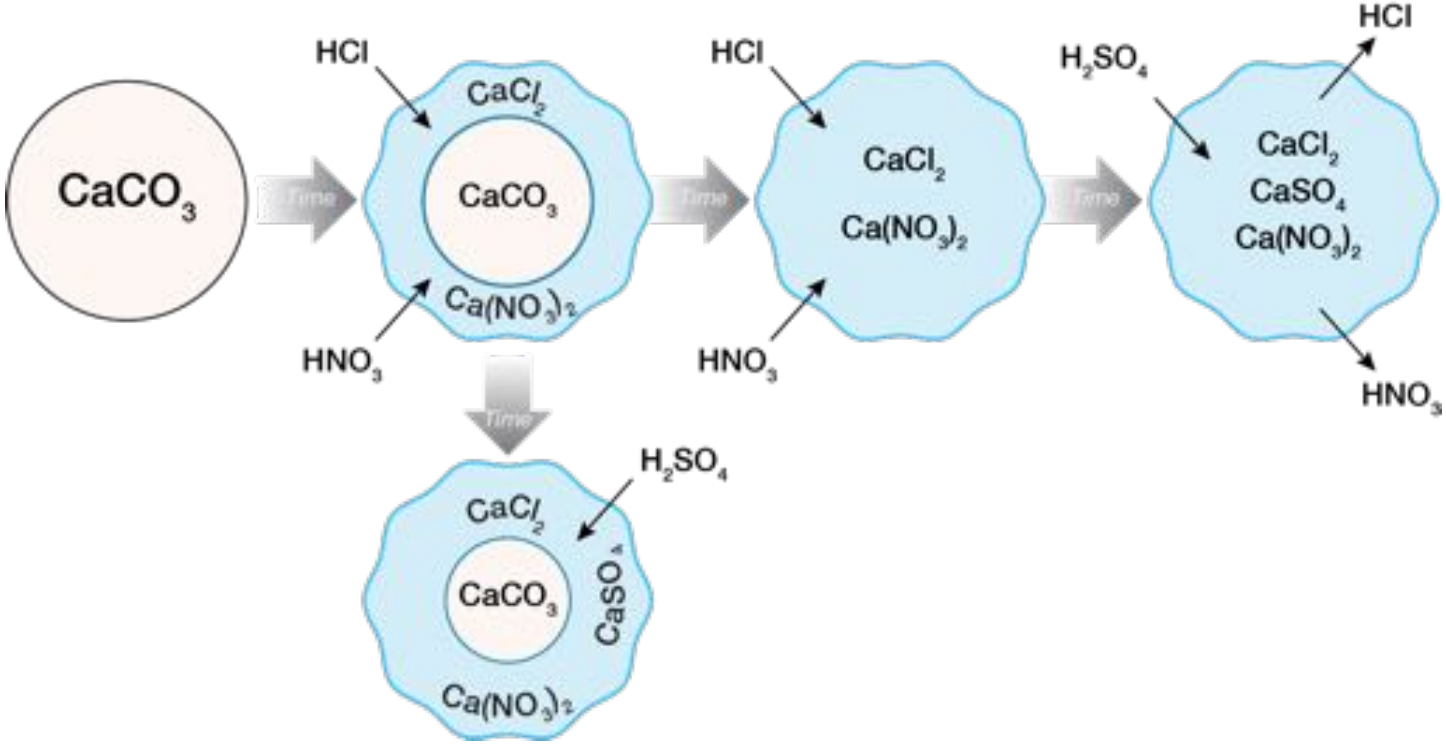
1. Good studies of near-field chemistry and microphysics in aircraft wakes in the troposphere exist, but only a few studies in the stratosphere
2. Knowledge gap between the aircraft wake/plume and GCM scale, relevant to the fate of injected aerosols and predictions of solar geoengineering
3. Theory says turbulence instabilities occur at a Richardson number threshold, but some observations (Haack et al. *GRL* 2014) suggest stratospheric turbulence is not well correlated with Richardson number
4. Large scale mixing constrained by observations of chemical tracers and dynamics --- but substantial uncertainties remain



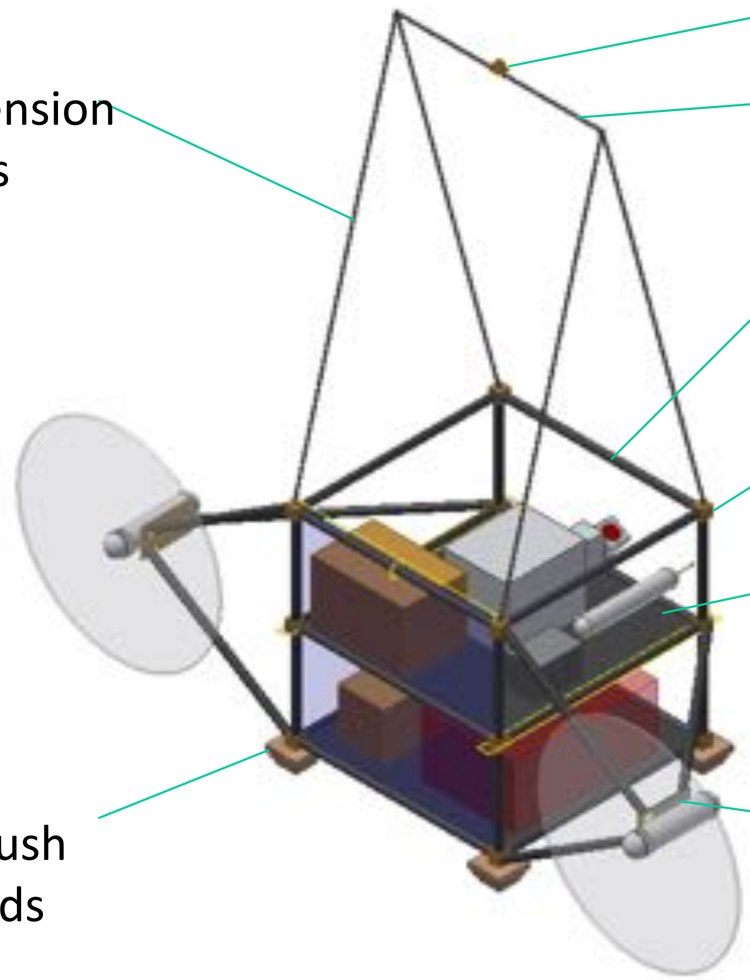
Scientific Objectives: Chemistry

Chemical composition and physical properties of injected aerosols critical for heterogeneous chemistry, determine optical properties of aerosols, and influence microphysical properties:

1. Fate of aerosol with respect to chemical composition and morphology?
2. Are heterogeneous reaction rates in the real stratospheric system in agreement with laboratory studies?



SCoPEx payload structure concept



- Leverage demonstrated Structural Designs and Concepts
  - SPIDER Balloon-borne Telescope
  - ASCENA Proposal
- Modular structural components
  - Multiple payload configurations
  - Scalable platform sizes

Engineering validation flights: plume created, imaged on Lidar, and gondola maneuvered to re-enter plume

Science phase 1: measure aerosol size distribution and plume mixing dynamics with sufficient accuracy to allow strong inferences about aerosol micro-physics

Science phase 2: make sufficient measurements of gas-phase and aerosol chemistry to allow strong inferences about relevant reaction rates and analyze changes in aerosol composition

Test models derived from laboratory experiments to allow inclusion in larger scale models used for risk assessment

Instruments for engineering and science phase 1 flights

Instrument	Notes	Institution	Mass (kg)	Peak Power (W)
Aerosol generator	Produces water ice particles, sulfate aerosol	Harvard	35	30
Aerosol counter	POPS: 0.14 – 3 µm size range, max rate 10,000 particles s^{-1}	Handix/ NOAA	<1kg	7
LIDAR	micropulse LIDAR; range resolution 30 m, integration time 1 sec	Sigma Space	28	120
O_3	Accuracy <2%, precision 2% 10 sec	2B Tech.	<5	<10
Meteorology	T, 3-axis anemometer	TBD	<5	<10
Aerosol optical depth	COBALD: backscatter 250 mW LEDs @ 450/870 nm, 300 Hz modulation	ETH	<1	2
Aerosol sampler	Bin centered at (in µm): 3.5, 1.7, 0.93, 0.65, 0.44, 0.30, 0.15	DrumAIR	<20	300
Solid aerosol injector	Disperses $CaCO_3$ particles (Nd = 10 - 100 cm^{-3}) with high-pressure nozzle	Harvard	<15	<10

Science phase 2 flights

Instrument	Notes	Institution	Mass (kg)	Peak Power (W)
NO_2	TBD, possibly cavity based absorption; 5% SNR ~100 pptv in 10 sec	TBD	TBD	TBD
HCl	TBD, possibly open path; SNR ~40 in 1 sec at 1 ppbv	TBD	TBD	TBD

Propellers serve two linked functions

- Propeller wake forms well mixed volume (~1 km long, 200 m diameter); serves as experimental 'beaker'.
- Propellers allow gondola to fly back and forth through the volume to measure evolution of properties of perturbed air mass.

Representative dense plume

- 2 km × 100 m radius
- 0.3 µm radius $CaCO_3$ particles at 50 cm^{-3}
- Total aerosol mass <1 kg