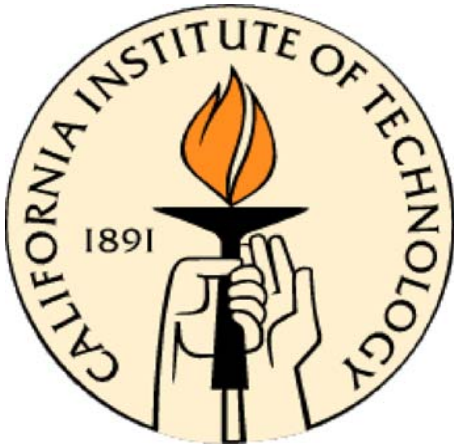
Motivation/Design of the Caltech Water-Ice Dusty Plasma Experiment



Paul M. Bellan and Kilbyoung Chai

Caltech

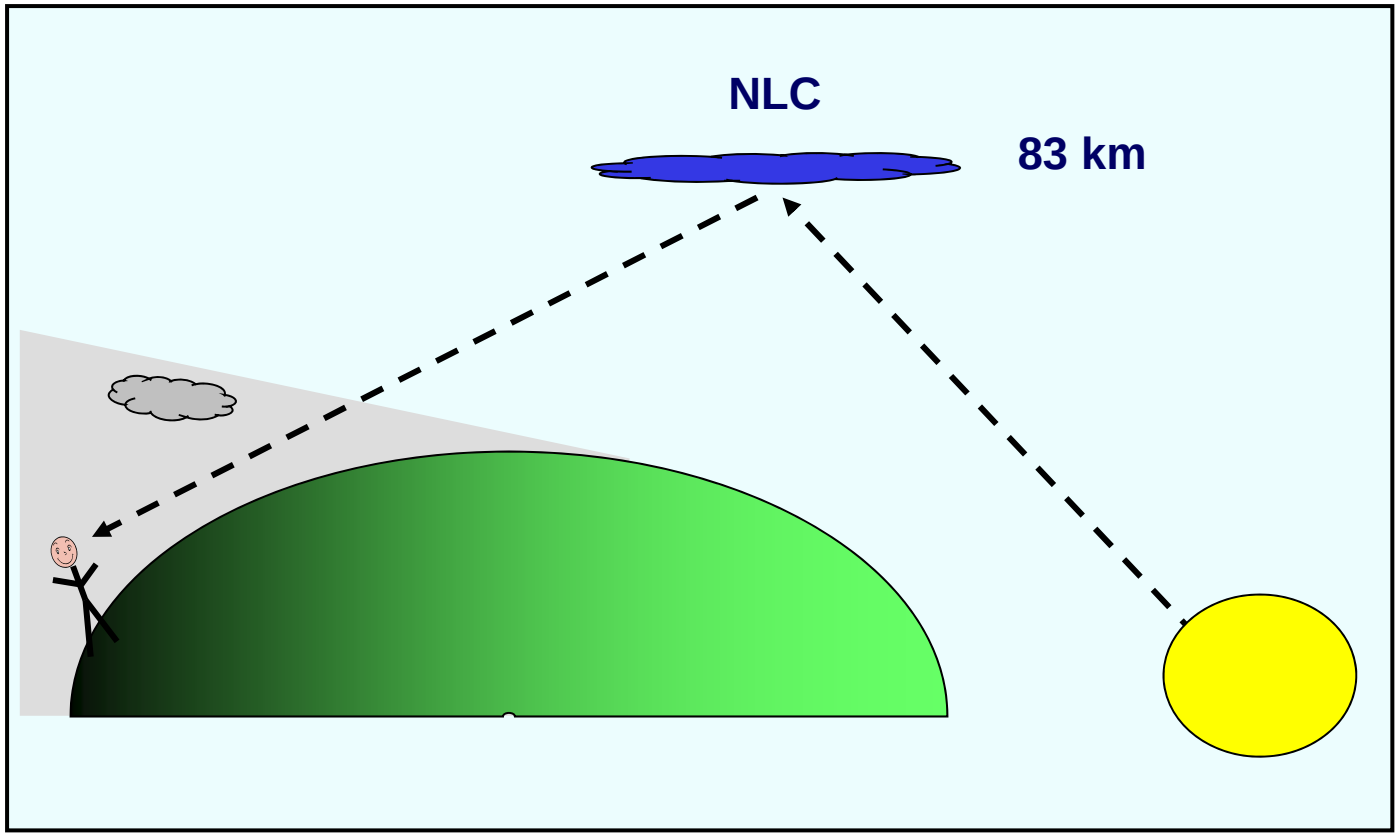
- Original motivation: metal coating of noctilucent clouds
  - still interested in this issue

- Current motivations
  - Study unexpected new phenomena that have been discovered
  - Understand growth, shape, constitution, motion
  - Relevance to noctilucent clouds, Saturn rings, astrophysics

Noctilucent clouds

- Observed in polar regions in summer
- Always at 85 km altitude
- Only seen in years after Krakatoa eruption?
- Seen at dawn or dusk
- Incidence seems to be increasing
  - Result of global warming?
- Strange radar properties

Why do noctilucent clouds shine at night?



Clouds occur 50 miles above the earth surface causing them to be illuminated after sunset

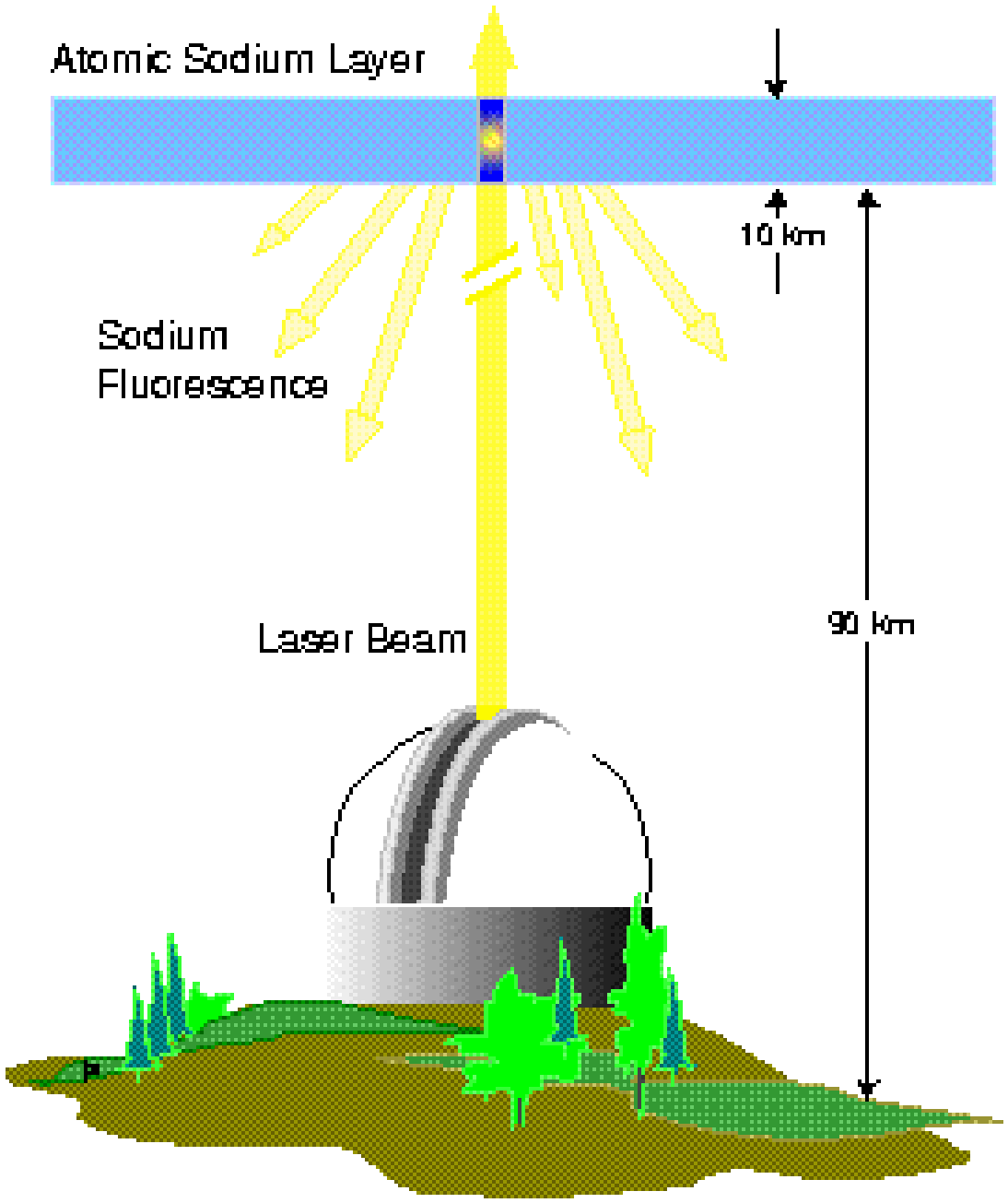
Credit for this slide: Scott Bailey

The sodium layer

Sketch of meteor shower from 19th century

Sodium Layer

- Result of sodium ablating from constant flux of micrometeoroids
- There are also potassium, iron, and calcium layers
- These layers are located immediately above noctilucent clouds


Atomic Sodium Layer
10 km
Sodium
Fluorescence
Laser Beam
90 km

Noctilucent clouds have strong interaction with metal layers (sodium, iron, etc.)

Removal of Meteoric Iron on Polar Mesospheric Clouds

John M. C. Plane,[1]* Benjamin J. Murray,[1] Xinzhao Chu,[2] Chester S. Gardner[2]

Polar mesospheric clouds are thin layers of nanometer-sized ice particles that occur at altitudes between 82 and 87 kilometers in the high-latitude summer mesosphere. These clouds overlap in altitude with the layer of iron (Fe) atoms that is produced by the ablation of meteoroids entering the atmosphere. Simultaneous observations of the Fe layer and the clouds, made by lidar during midsummer at the South Pole, demonstrate that essentially complete removal of Fe atoms can occur inside the clouds. Laboratory experiments and atmospheric modeling show that this phenomenon is explained by the efficient uptake of Fe on the ice particle surface.

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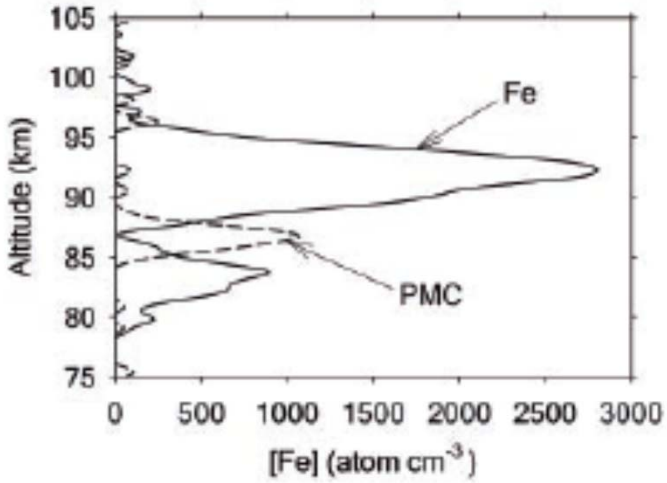
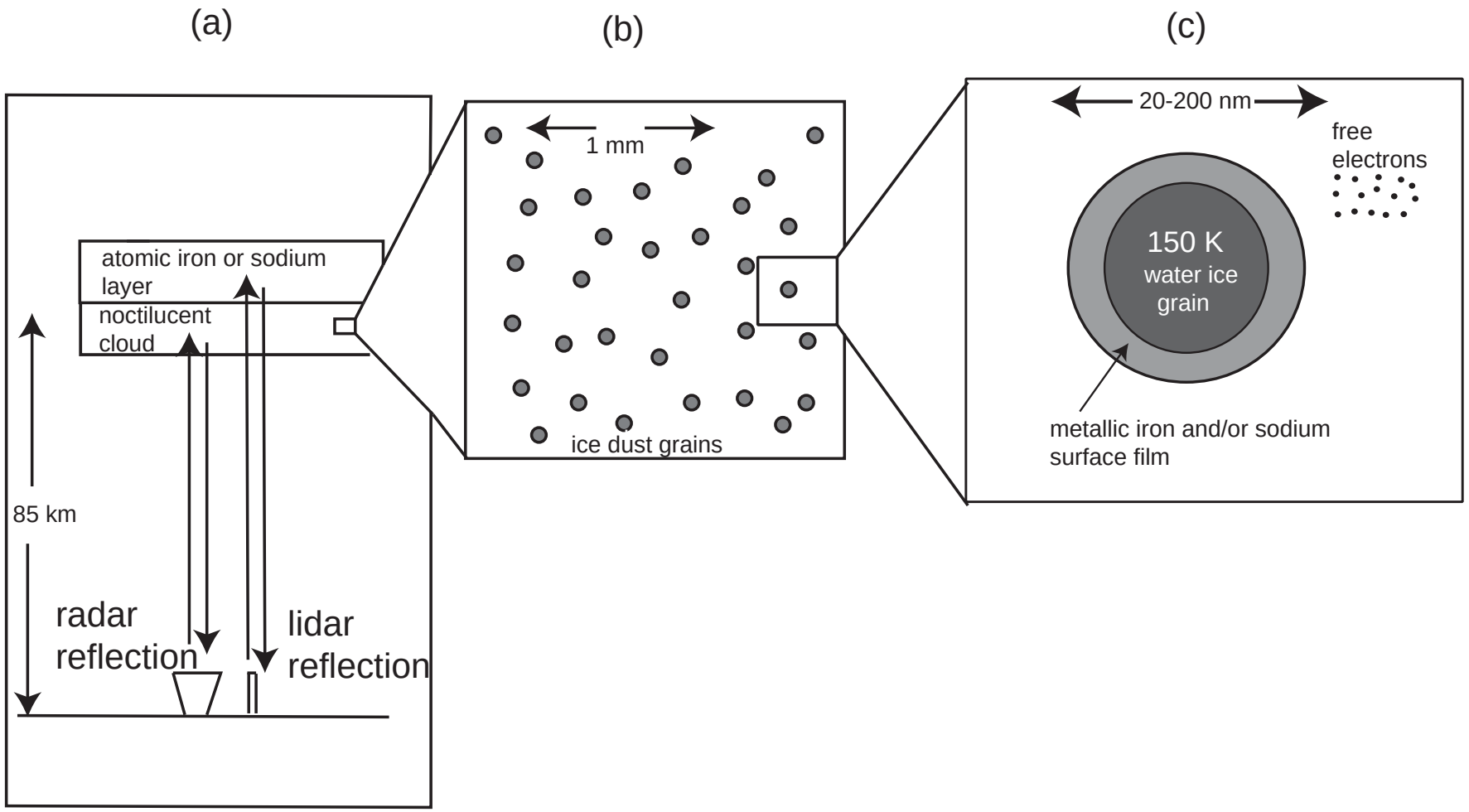


Fig. 1. Simultaneous observations of the atomic Fe density and PMC backscatter signal. The measurements were made with the University of Illinois Fe Boltzmann lidar, operating at 372 and 374 nm, respectively. The signals are averaged between 03:00 and 06:00 UT on 19 January 2000. The PMC backscatter signal is expressed as equivalent Fe atoms cm^{-3} for comparison with the atomic Fe resonance fluorescence signal.

Sodium also deposits on noctilucent clouds

Thayer, J. P., and W. L. Pan (2006), Lidar observations of sodium density depletions in the presence of polar mesospheric clouds, J. Atmos. Sol. Terr. Phys., 68(1), 85– 92.

Metal film on ice grains



Proposed in 2008 that metal coating
on ice grains would affect radar reflection

Now think metal coating affecting radar is unlikely,
but still feel that metal coating occurs and probably
has some interesting effects.

In course of analyzing radar problem, noted that
models typically assumed ice grains are spherical

All discussions were about how big radius is.

Considered why ice dust grains should be spherical and could not come up with a good answer

Considered why dust grains might be non-spherical and came up with some possibilities

Decided worth doing experiment to investigate whether ice grains are spherical or not

Shimizu had reported an ice grain experiment, but had not resolved grain size or shape

Decided to start with Shimizu-like experiment and investigate shape and size

New motivations

- See if ice is amorphous instead of crystalline
  - Transition occurs at temperature below about 100-125 K
  - Astrophysicists are very interested (Gudipathi, JPL)
  - Requires much more aggressive cooling

- Understand growth mechanism
  - According to noctilucent dogma, no ice unless non-ice nucleation agent
  - Many theories on how meteorite smoke (carbon dust) acts as nucleus
  - Caltech experiment forms ice grains fast and easy with no nucleation agent
    - Why?
  - Grain size saturates at certain size, why?
  - Grains sometimes spherical, sometimes not – why?

Shimizu et al (Garching) experiment:

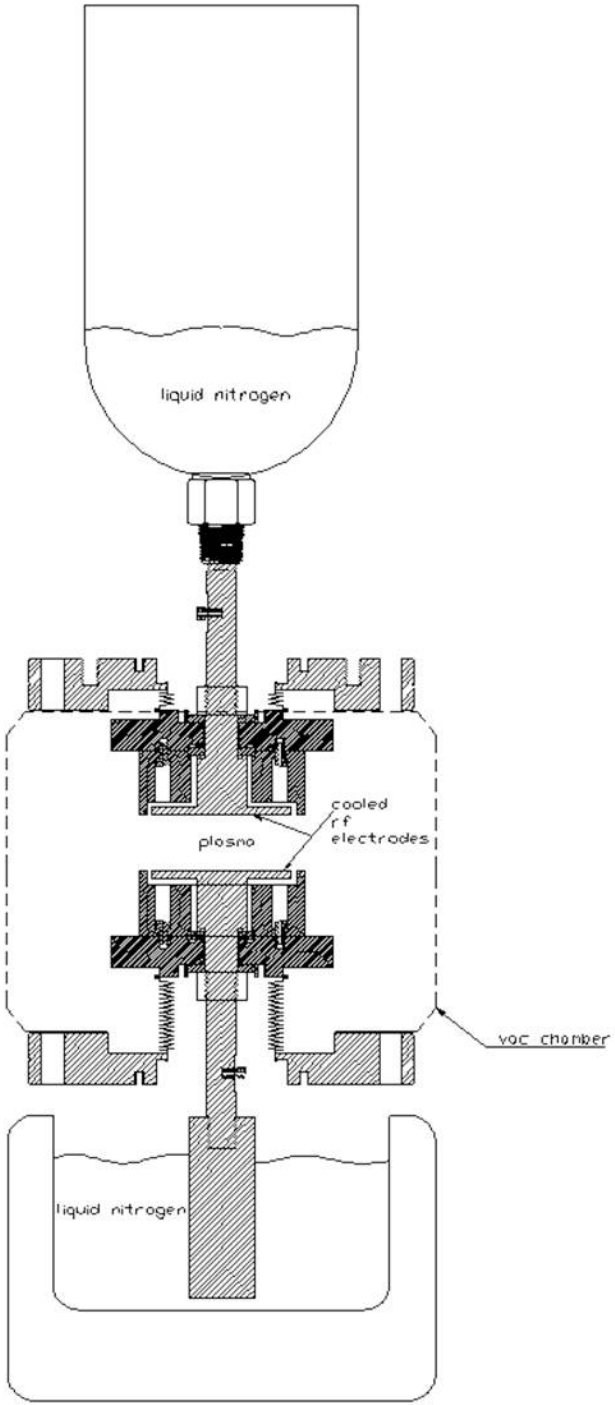
-cool both electrodes of RF discharge with LN2
-inject Deuterium and Oxygen to make a Deuterium-Oxygen plasma
-some Deuterium and Oxygen combine to make D_2O
-D_2O spontaneously formed ice grains
-no imaging of individual grains attempted

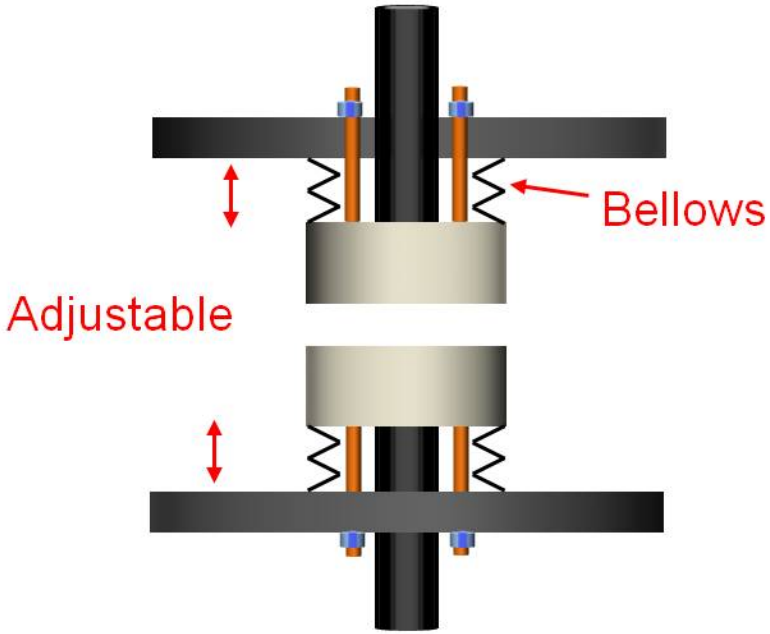
Caltech experiment

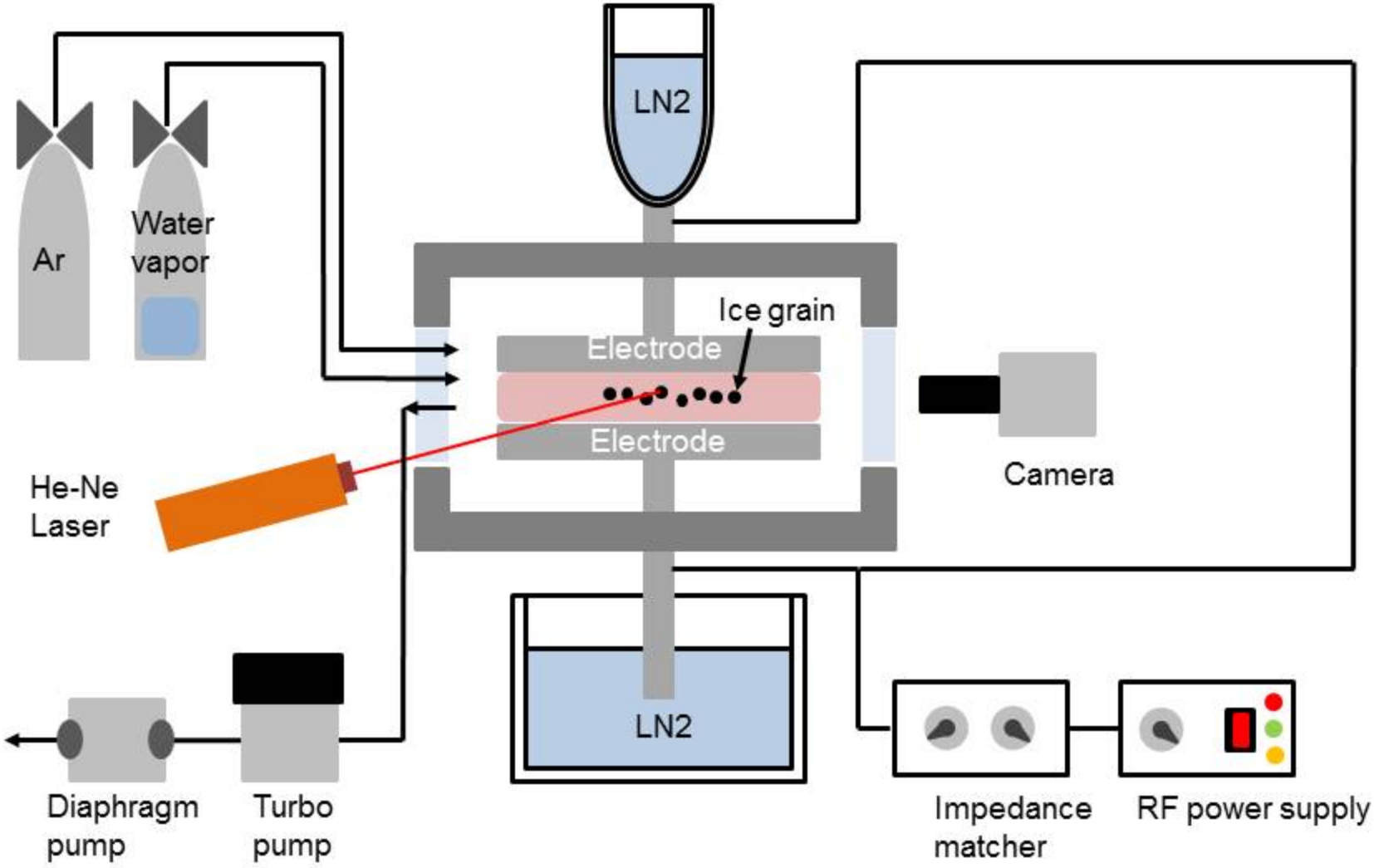
-also cool both electrodes of RF discharged with LN2
-make Argon discharge
-inject controlled amount of water vapor

Advantages:

-no explosion risk
-amount of water independently controlled
-can use different background gases
-can make non-water ice by injecting non-water vapor (e.g., acetone)


liquid nitrogen
cooled
rf
electrodes
plasma
VOC chamber
liquid nitrogen


Bellows
Adjustable


LN2
Ar
Water
vapor
Ice grain
Electrode
Electrode
He-Ne
Laser
Camera
LN2
Diaphragm
pump
Turbo
pump
Impedance
matcher
RF power supply

Design

- use commercially available vacuum chamber
- use turbo pump that can handle water vapor (killed one turbo that could not!)
- use indium seals (not o-rings) in cold areas
- use Vespel insulator (like Shimizu) to handle cold, vacuum, rf simultaneously
- use stainless bellows to have variable inter-electrode distance

Recent Upgrade

- better cryo design, better insulation, oxygen-free copper cold fingers, electrodes
- removable heat shield
- RTD's to measure temperature inside electrodes

Future upgrade (tentative)

- may have to go to cryocoolers, liquid helium to get lower temperatures
- YAG laser to vaporize metal (just starting to organize laser)

Diagnostic development

- Push imaging to the limit :
  - long distance microscope lens (thanks to J. Goree)
  - Different illumination schemes
- Temperature measurement- Eblana laser (in development)
  - Laser tuned to water vapor molecular line
  - Measure absorption, Doppler width
- FTIR spectroscopy of ice to tell if amorphous or crystalline
- Plus standard dusty plasma diagnostics

Develop theoretical models to explain what is seen

- Have tentative model for why grains are non-spherical
  - Some experimental evidence exists to back up model
- Model for why grains are vertically aligned (KB)
- Model for vortex motion (underway)
- Do not understand time scale for formation (quite fast)
- Do not understand growth saturation mechanism
- Do not understand fine structure (a bit dendritic)

Outreach

- Have spoken to noctilucent cloud (PMSE) community
- Have spoken to Saturn ring community (JPL)
- Have spoke to astrophysics community