# Measuring spectral reflectance and transmittance (350-2500 nm) of large leaves using the Spectra Vista Corporation (SVC) DC-R/T Integrating Sphere Version 5

**Etienne Laliberté,Raymond Soffer**

## Abstract

Here we describe the standardised protocol used by the Canadian Airborne Biodiversity Observatory (CABO) to measure leaf spectral reflectance and transmittance, using the Spectra Vista Corporation (SVC) DC-R/T Integrating Sphere fitted to a portable full-range SVC HR-1024i field spectroradiometer. This standard version of our protocol describes the common case where an individual leaf is large enough to entirely cover the reflectance or transmission port of the integrating sphere. Briefly, six mature, healthy-looking and sunlit leaves from a canopy plant are selected for measurements of adaxial reflectance and transmittance. Reflectance measurements are referenced to a calibrated Spectralon® disk and corrected for stray light. Our leaf spectroscopy protocol builds from that of the Carnegie Airborne Observatory.

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## Guidelines

### Handling Spectralon®

- **Do not touch Spectralon®** (e.g. sphere interior, reference disks, plugs) with your fingers.
- **Do not use canned air** to remove dust on the Spectralon® disk; canned air contains chemicals that can alter Spectralon®'s optical properties.
- **Do not attempt to clean Spectralon®** in the field, other than **blowing surface dust only on the Spectralon® reference disk or sphere plugs** using the Canless Air Duster System; cleaning Spectralon® requires a special procedure that should only done in the lab.

### Equipment

- Spectra Vista Corporation HR-1024i full-range (350-2500 nm) field spectroradiometer
- Spectra Vista Corporation 3-inch Spectralon® DC-R/T Sphere
- Semi-rugged laptop or PDA running the SVC Scan software

- Canless Air Duster System $O_2$ Hurricane (**never use canned air**) to remove dust from the surface of the Spectralon® reference disk

- Plastic containers with lids to temporarily store leaf samples during measurements (optional)

### Consumables

- Nitrile gloves for handling leaves

## Before start

1. Consult the user manual of the spectroradiometer and the integrating sphere to set up the instrument.
2. The instrument should be set up in the shade, sheltered as much as possible from the elements (definitely not exposed to rain).
3. All canopy plants selected for measurements should have already been tagged, identified, and georeferenced before spectroscopy measurements start.
4. The spectroscopist should be positionned as close as possible to the sampled plants to minimise time from collection to measurement.
5. The spectroscopist should be in a confortable position and have enough room around the instrument to spread leaf samples around without the risk of mixing up individual leaves during handling.
6. **Six mature, fully-developped, healthy-looking leaves from the sunlit (>3 h per day of direct sunlight) portion of the canopy are selected** for spectral measurements from the bulk leaf sample (often one of a few branches). Leaves should be collected from the uppermost surface of the branch (i.e. receiving the most direct sunlight),
7. Leaves should be stored in a sealed, clear plastic bag (breathe into the bag before sealing it) and **brought immediately to the spectroscopist for measurements**.

## Protocol

Instrument Set-Up

**Step 1.**

Install the integrating sphere onto the spectroradiometer.

NOTES

**Etienne Laliberté** 30 May 2018

Follow the SVC integrating sphere manual p. 6-16.

Instrument Set-Up

**Step 2.**

Power the spectroradiometer and **warm up for >15 min**.

NOTES

**Etienne Laliberté** 26 Apr 2018

Record the **time of day** when the spectroradiometer was started.

Instrument Set-Up

**Step 3.**

Power the integrating sphere lamp and **warm up for >5 min**.

Software Set-Up

**Step 4.**

Ensure that the spectroradiometer is connected to the computer via Bluetooth.

NOTES

**Etienne Laliberté** 30 May 2018

The default Bluetooth password for SVC HR-1024i spectroradiometers is **hr1024i**.

Software Set-Up

**Step 5.**

Launch SVC Scan.


Software Set-Up

**Step 6.**

Select **auto-save mode** using *File* > *Data Options* > *Auto Save.*

Software Set-Up

**Step 7.**

Select *File* > *New* to create a new working folder in your shared '**spectra**' Google Drive CABO folder.

NOTES

**Etienne Laliberté** 30 May 2018

If you do not yet have a shared Google Drive folder for your project, contact the CABO data manager to create one (etienne.laliberte@umontreal.ca or jeremy.goimard@umontreal.ca).

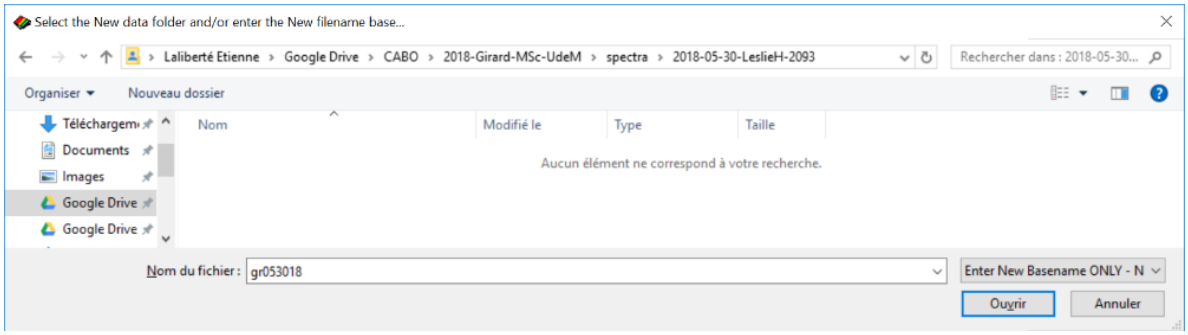
**Etienne Laliberté** 30 May 2018

Your shared CABO Google Drive folder should be named *YYYYstarted-YourLastName-Degree-University*, e.g. 2018-Girard-MSc-UdeM.

## Software Set-Up

**Step 8.**

Create a new folder named *YYYY-MM-DD-SiteID-SpectroradiometerSerialNumber* (without spaces) within that '**spectra**' folder, and keep the default file base name (= *grMMDDYY*).




NOTES

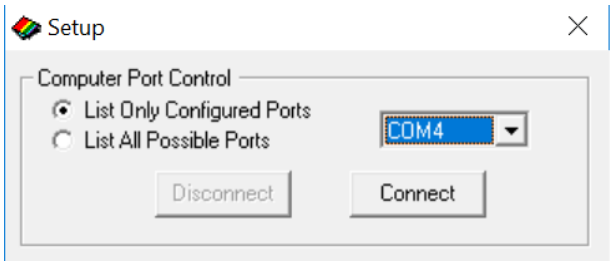
**Etienne Laliberté** 30 May 2018

The base file name is the prefix for all files that will be saved within that folder. In auto-save mode, each file will be added an incremental step, e.g., *gr053018_0000.sig*, *gr053018_0001.sig*, etc.

## Software Set-Up

**Step 9.**

Go to *Control* > *Setup Instrument...* to connect the spectroradiometer.




NOTES

**Etienne Laliberté** 30 May 2018

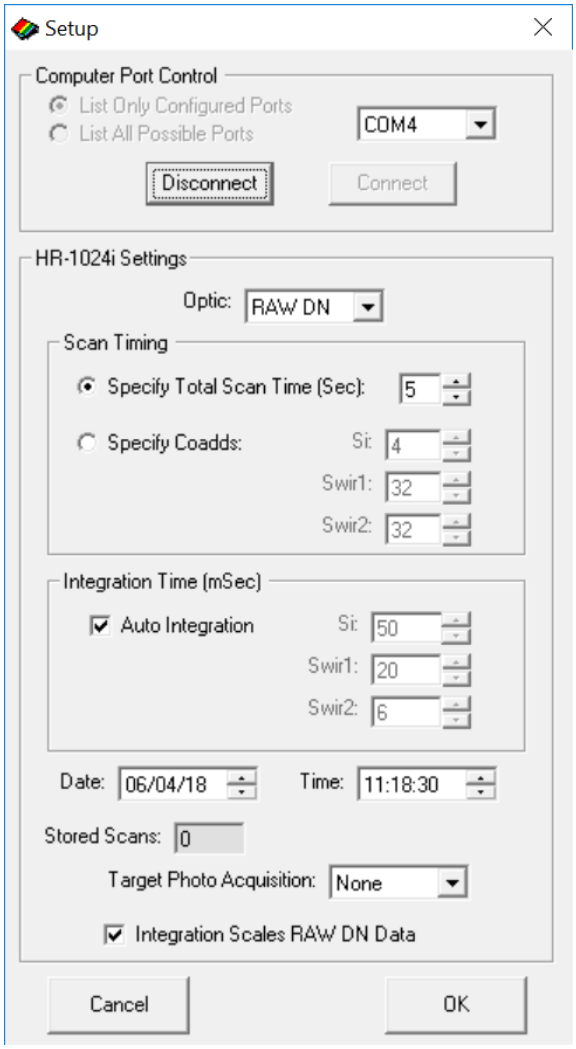
Different instruments may be configured under different virtual COM ports.

## Software Set-Up

**Step 10.**

1. Choose the *RAW DN* optic
2. Select 5 sec scan time

3. Select *Auto Integration*
4. Ensure the date and time are correct
5. Check *Integration Scales Raw DN Data*

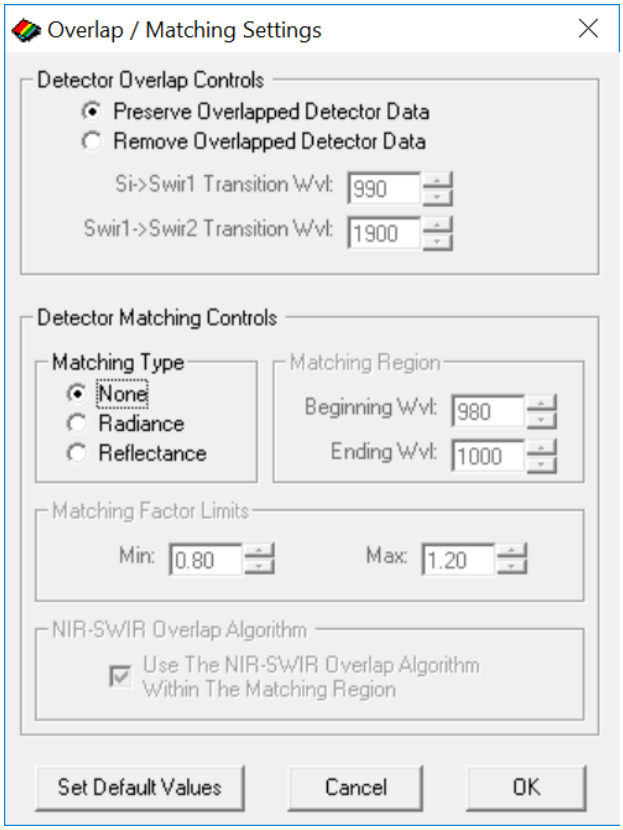



## Software Set-Up

**Step 11.**

In *Control* > Overlap / *Matching Settings:*

1. Select *Preserve Overlapped Detector Data*
2. Select *Matching Type* > *None*




## Review Protocol Summary Diagram

**Step 12.**

Review the document summarising the different sphere configurations (A–E), and the scans that need to be recorded in each configuration.

## Configuration A: Reflectance Mode, Reference

**Step 13.**

Position the lamp over the sphere **primary light entrance port**.

SAFETY INFORMATION

**The lamp can get very hot. Grab it by the slotted heat shield.**

NOTES

**Etienne Laliberté** 24 Apr 2018

Make sure lamp is secured in locked position.

## Configuration A: Reflectance Mode, Reference

**Step 14.**

Check lamp alignment.

NOTES

**Etienne Laliberté** 04 Jun 2018

Use a thin piece of paper at the exit of the reflectance sample port (empty port) the to ensure the light beam under-fills and is centered in the reflectance port. **If it is not, then proceed to lamp alignment** as described in the SVC integrating sphere user manual, p. 29-32.

ANNOTATIONS
**Etienne Laliberté** 07 Jun 2018

enlever 'the' avant 'to'

Configuration A: Reflectance Mode, Reference
**Step 15.**

Screw the tethered light trap on the **reflectance port** sample holder.

NOTES
**Etienne Laliberté** 24 Apr 2018

The light trap can stay on the sample holder for the entire measurement session.

Configuration A: Reflectance Mode, Reference
**Step 16.**

Screw the untethered light trap on the **transmission port** sample holder.

NOTES
**Etienne Laliberté** 26 Apr 2018

The light trap can stay on the sample holder for all measurements made in reflectance mode (configurations A−C).

Configuration A: Reflectance Mode, Reference
**Step 17.**

Place the tethered calibrated Spectralon® reflectance standard over the **reflectance port**.

NOTES
**Etienne Laliberté** 26 Apr 2018

Place the standard over the reflectance port so that the light beam shines directly on its reflective surface (i.e facing into the sphere).

## Configuration A: Reflectance Mode, Reference

**Step 18.**

Position leaf #1 over the **transmission port** with its adaxial (upper) surface facing into the sphere.

NOTES

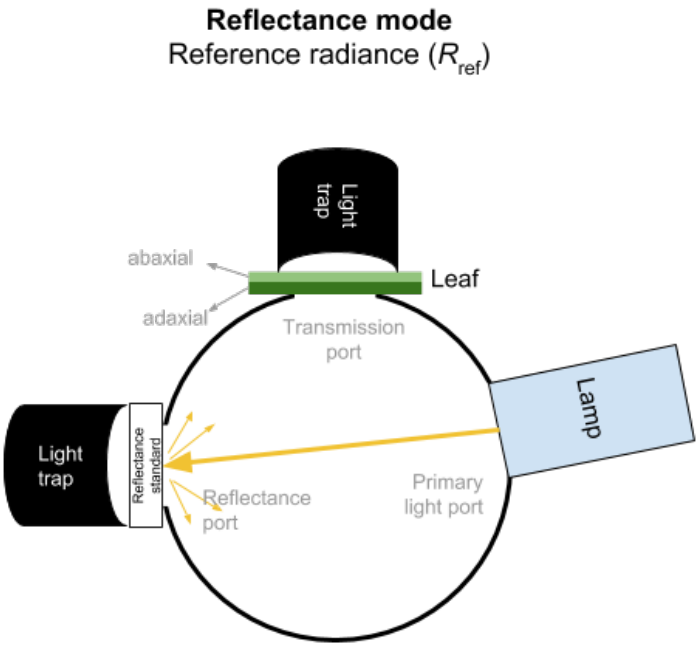
**Etienne Laliberté** 26 Apr 2018

Position the leaf so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

## Configuration A: Reflectance Mode, Reference

**Step 19.**

Collect a '**Reference Scan**' in this configuration.




NOTES

**Etienne Laliberté** 25 Apr 2018

This corresponds to the **reference radiance** in reflectance mode ($R_{ref}$). The reference data will be automatically saved in all successive target scan files until a new 'Reference Scan' is made.

## Configuration A: Reflectance Mode, Reference

**Step 20.**

Collect a '**Target Scan**' in this configuration and **save the file**.

NOTES

**Etienne Laliberté** 04 Jun 2018

This reference 'target' scan, immediately collected after the reference, should give relative reflectance around 1 (+ noise) for all wavelengths. It is saved in a separate file to facilitate post-processing of spectra.

Configuration B: Reflectance Mode, Stray light

**Step 21.**

Carefully remove leaf #1 from the transmission port sample holder.

Configuration B: Reflectance Mode, Stray light

**Step 22.**

Remove the tethered calibrated Spectralon® reflectance standard from the reflectance port.

Configuration B: Reflectance Mode, Stray light

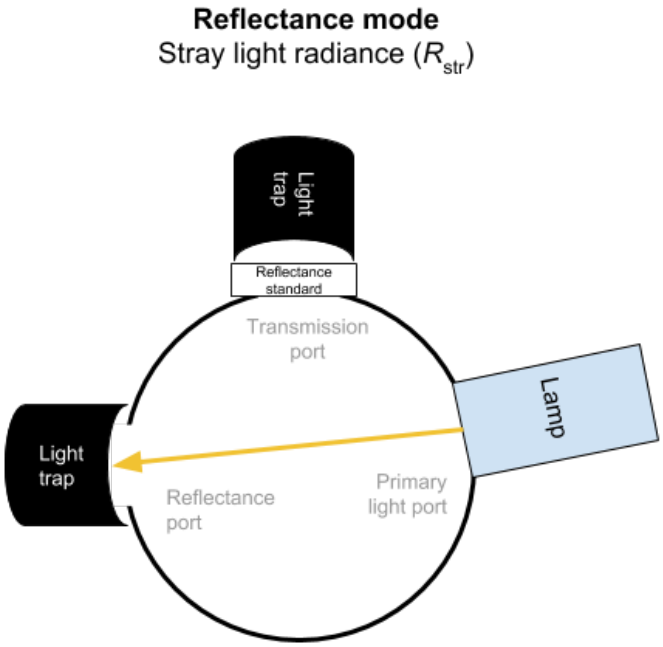
**Step 23.**

Place the tethered calibrated Spectralon® reflectance standard over the **transmission port** sample holder.

Configuration B: Reflectance Mode, Stray light

**Step 24.**

Collect a '**Target Scan**' in this configuration and **save the file**.




NOTES

**Etienne Laliberté** 25 Apr 2018

This corresponds to the **stray light radiance** in reflectance mode ($R_{str}$).

Configuration C: Reflectance Mode, Target

**Step 25.**

Position leaf #1 over the **reflectance port** with its adaxial (upper) surface facing into the sphere.

NOTES

**Etienne Laliberté** 24 Apr 2018

Position the leaf to target the same area measured for the reference radiance. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

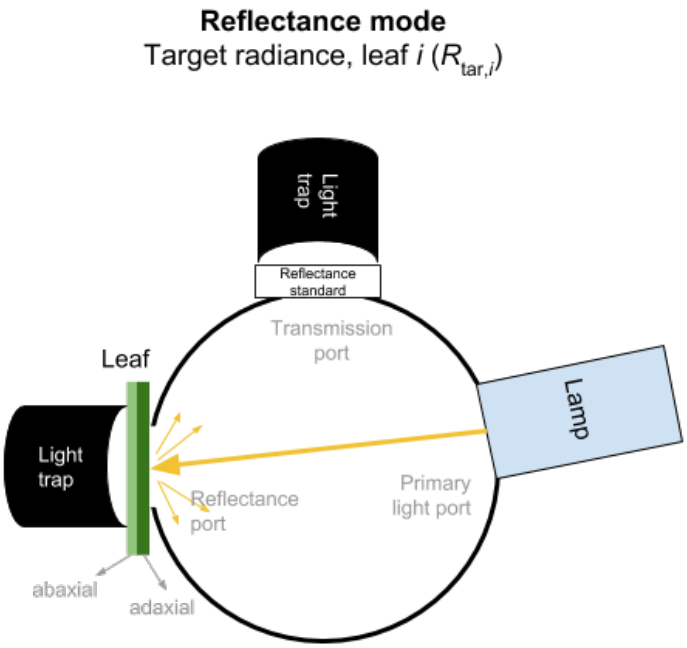
**Etienne Laliberté** 24 Apr 2018

The light trap should remain on the reflectance port sample holder.

Configuration C: Reflectance Mode, Target

**Step 26.**

Collect a '**Target Scan**' for leaf #1 in this configuration and **save the file**.




NOTES

**Etienne Laliberté** 25 Apr 2018

This corresponds to the **target radiance** in reflectance mode for leaf #1 ($R_{tar,1}$).

Configuration C: Reflectance Mode, Target
**Step 27.**

Carefully replace leaf #1 by leaf #2.

NOTES
**Etienne Laliberté** 24 Apr 2018

Position the leaf to target the same area measured for the reference radiance. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration C: Reflectance Mode, Target
**Step 28.**

Collect a '**Target Scan**' for leaf #2 in this configuration and **save the file**.

NOTES
**Etienne Laliberté** 24 Apr 2018

This corresponds to the **target radiance** in reflectance mode for leaf #2 ($R_{tar,2}$).

Configuration C: Reflectance Mode, Target
**Step 29.**

Carefully replace leaf #2 by leaf #3.

NOTES
**Etienne Laliberté** 24 Apr 2018

Position the leaf to target the same area measured for the reference radiance. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration C: Reflectance Mode, Target
**Step 30.**

Collect a '**Target Scan**' for leaf #3 in this configuration and **save the file**.

NOTES
**Etienne Laliberté** 24 Apr 2018

This corresponds to the **target radiance** in reflectance mode for leaf #3 ($R_{tar,3}$).

Configuration C: Reflectance Mode, Target
**Step 31.**

Carefully replace leaf #3 by leaf #4.

NOTES
**Etienne Laliberté** 24 Apr 2018

Position the leaf to target the same area measured for the reference radiance. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration C: Reflectance Mode, Target
**Step 32.**

Collect a '**Target Scan**' for leaf #4 in this configuration and **save the file**.

NOTES
**Etienne Laliberté** 24 Apr 2018

This corresponds to the **target radiance** in reflectance mode for leaf #4 ($R_{tar,4}$).

Configuration C: Reflectance Mode, Target
**Step 33.**

Carefully replace leaf #4 by leaf #5.

NOTES
**Etienne Laliberté** 24 Apr 2018

Position the leaf to target the same area measured for the reference radiance. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration C: Reflectance Mode, Target
**Step 34.**

Collect a '**Target Scan**' for leaf #5 in this configuration and **save the file**.

NOTES
**Etienne Laliberté** 24 Apr 2018

This corresponds to the **target radiance** in reflectance mode for leaf #5 ($R_{tar,5}$).

Configuration C: Reflectance Mode, Target

**Step 35.**

Carefully replace leaf #5 by leaf #6.

NOTES

**Etienne Laliberté** 24 Apr 2018

Position the leaf to target the same area measured for the reference radiance. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration C: Reflectance Mode, Target

**Step 36.**

Collect a '**Target Scan**' for leaf #6 in this configuration and **save the file**.

NOTES

**Etienne Laliberté** 24 Apr 2018

This corresponds to the **target radiance** in reflectance mode for leaf #6 ($R_{tar,6}$).

Configuration A: Reflectance Mode, Reference

**Step 37.**

Remove leaf #6 from the reflectance sample port holder.

Configuration A: Reflectance Mode, Reference

**Step 38.**

Place the tethered calibrated Spectralon® reflectance standard over the **reflectance port**.

NOTES

**Etienne Laliberté** 26 Apr 2018

Place the standard over the reflectance port so that the light beam shines directly on its reflective surface (i.e facing into the sphere).

Configuration A: Reflectance Mode, Reference

**Step 39.**

Position leaf #1 over the **transmission port** with its adaxial (upper) surface facing into the sphere.

NOTES

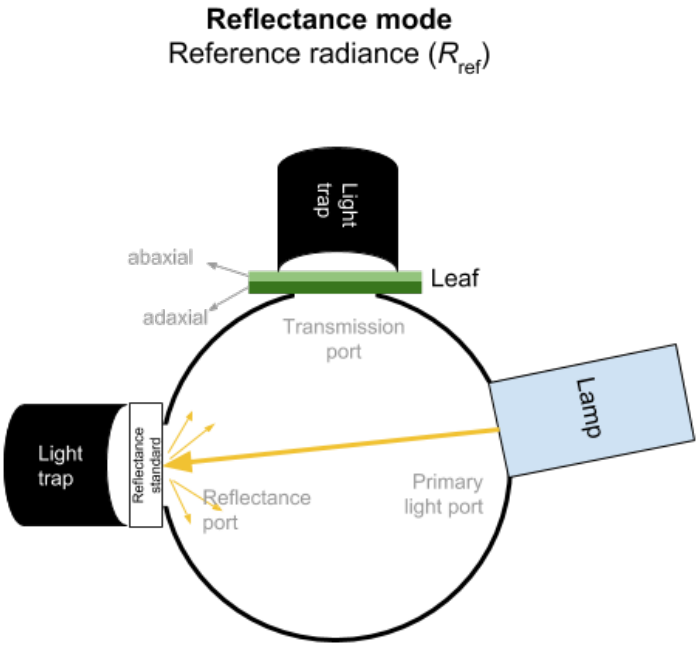
**Etienne Laliberté** 26 Apr 2018

Position the leaf so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

## Configuration A: Reflectance Mode, Reference

**Step 40.**

Collect a '**Target Scan**' in this configuration and **save the file**.




NOTES

**Etienne Laliberté** 08 May 2018

This second reference radiance scan is only used to assess the stability of the system in reflectance mode.

## Configuration D: Transmittance Mode, Reference

**Step 41.**

Remove the tethered calibrated Spectralon® reflectance standard from the sphere reflectance port.

## Configuration D: Transmittance Mode, Reference

**Step 42.**

Remove leaf #1 from the transmission port sample holder.

Configuration D: Transmittance Mode, Reference

**Step 43.**

Position leaf #1 over the **reflectance port** so that its **abaxial** (lower) side is now facing the inside of the sphere.

NOTES

**Etienne Laliberté** 24 Apr 2018

Position the leaf to target the same area measured for the reflectance radiance, with the exception that its abaxial surface now faces the inside of the sphere. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration D: Transmittance Mode, Reference

**Step 44.**

Remove the light trap from the transmission port sample holder.

Configuration D: Transmittance Mode, Reference

**Step 45.**

Position the lamp over the sphere **transmission port**.

SAFETY INFORMATION

**The lamp can get very hot. Grab it by the slotted heat shield.**

NOTES

**Etienne Laliberté** 24 Apr 2018

Make sure lamp is secured in locked position.

Configuration D: Transmittance Mode, Reference

**Step 46.**

Install the Spectralon® plug over the **primary light port**.

NOTES

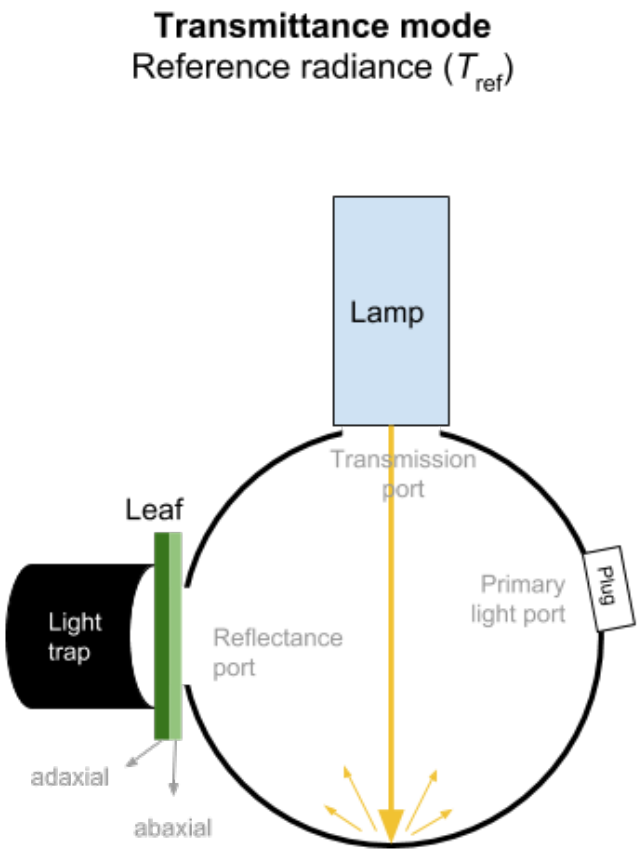
**Etienne Laliberté** 24 Apr 2018

Ensure that the curved plug is placed the correct way to match the curvature of the sphere.

Configuration D: Transmittance Mode, Reference

**Step 47.**

Collect a '**Reference Scan**' in this configuration.




NOTES

**Etienne Laliberté** 04 Jun 2018

This corresponds to the **reference radiance** in **transmittance** mode ($T_{ref}$).

## Configuration D: Transmittance Mode, Reference

**Step 48.**

Collect a '**Target Scan**' in this configuration and **save the file**.

NOTES

**Etienne Laliberté** 04 Jun 2018

This reference 'target' scan, immediately collected after the reference, should give relative reflectance around 1 (+ noise) for all wavelengths. It is saved in a separate file to facilitate post-processing of spectra.

## Configuration E: Transmittance Mode, Target

**Step 49.**

Carefully remove leaf #1 from the reflectance port sample holder.

NOTES

**Etienne Laliberté** 24 Apr 2018

The reflectance port should now be **empty** (but with **light trap on**).

Configuration E: Transmittance Mode, Target

**Step 50.**

Gently pull lamp and transmission sample holder away from the sphere.

SAFETY INFORMATION

**The lamp can get very hot. Grab it by the slotted heat shield.**

Configuration E: Transmittance Mode, Target

**Step 51.**

Place leaf #1 over the **transmission port** with its **abaxial** (lower) surface facing into the sphere.

NOTES

**Etienne Laliberté** 26 Apr 2018

Position the leaf to target the same area measured for the reflectance radiance, with the exception that its abaxial surface now faces into the sphere. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration E: Transmittance Mode, Target

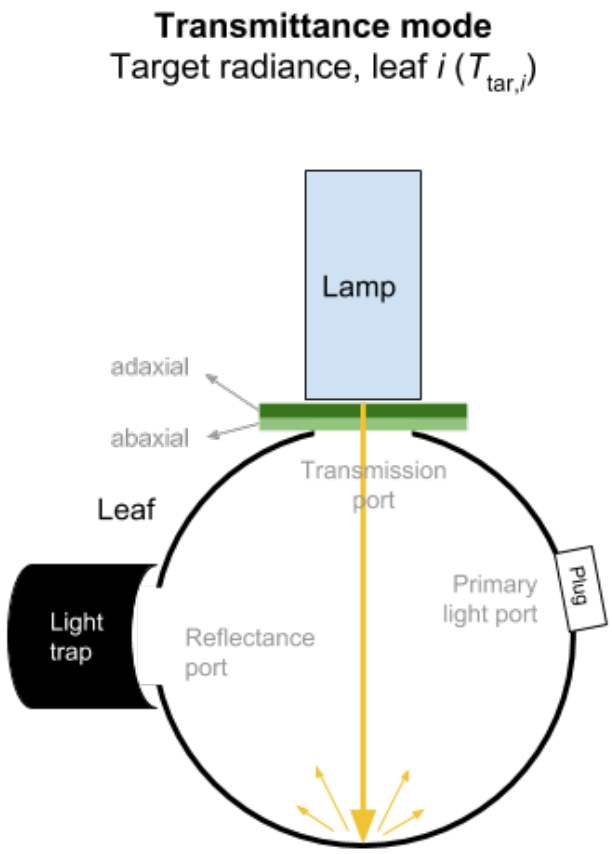
**Step 52.**

Release the transmission sample holder and move lamp back to its locked position.

Configuration E: Transmittance Mode, Target

**Step 53.**

Collect a '**Target Scan**' for leaf #1 in this configuration and **save the file**.




NOTES

**Etienne Laliberté** 04 Jun 2018

This corresponds to the **target radiance** in **transmittance** mode for leaf #1 ($T_{tar,1}$).

Configuration E: Transmittance Mode, Target

**Step 54.**

Carefully replace leaf #1 by leaf #2.

NOTES

**Etienne Laliberté** 26 Apr 2018

Position the leaf to target the same area measured for the reflectance radiance, with the exception that its abaxial surface now faces into the sphere. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration E: Transmittance Mode, Target

**Step 55.**

Collect a '**Target Scan**' for leaf #2 in this configuration and **save the file**.

NOTES
**Etienne Laliberté** 04 Jun 2018

This corresponds to the **target radiance** in **transmittance** mode for leaf #2 ($T_{tar,2}$).

Configuration E: Transmittance Mode, Target
**Step 56.**

Carefully replace leaf #2 by leaf #3.

NOTES
**Etienne Laliberté** 25 Apr 2018

Position the leaf to target the same area measured for the reflectance radiance, with the exception that its abaxial surface now faces the inside of the sphere. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration E: Transmittance Mode, Target
**Step 57.**

Collect a '**Target Scan**' for leaf #3 in this configuration and **save the file**.

NOTES
**Etienne Laliberté** 04 Jun 2018

This corresponds to the **target radiance** in **transmittance** mode for leaf #3 ($T_{tar,3}$).

Configuration E: Transmittance Mode, Target
**Step 58.**

Carefully replace leaf #3 by leaf #4.

NOTES
**Etienne Laliberté** 25 Apr 2018

Position the leaf to target the same area measured for the reflectance radiance, with the exception that its abaxial surface now faces the inside of the sphere. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration E: Transmittance Mode, Target

**Step 59.**

Collect a '**Target Scan**' for leaf #4 in this configuration and **save the file**.

NOTES
**Etienne Laliberté** 04 Jun 2018

This corresponds to the **target radiance** in **transmittance** mode for leaf #4 ($T_{tar,4}$).

Configuration E: Transmittance Mode, Target
**Step 60.**

Carefully replace leaf #4 by leaf #5.

NOTES
**Etienne Laliberté** 25 Apr 2018

Position the leaf to target the same area measured for the reflectance radiance, with the exception that its abaxial surface now faces the inside of the sphere. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration E: Transmittance Mode, Target
**Step 61.**

Collect a '**Target Scan**' for leaf #5 in this configuration and **save the file.**

NOTES
**Etienne Laliberté** 04 Jun 2018

This corresponds to the **target radiance** in **transmittance** mode for leaf #5 ($T_{tar,5}$).

Configuration E: Transmittance Mode, Target
**Step 62.**

Carefully replace leaf #5 by leaf #6.

NOTES
**Etienne Laliberté** 25 Apr 2018

Position the leaf to target the same area measured for the reflectance radiance, with the exception that its abaxial surface now faces the inside of the sphere. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration E: Transmittance Mode, Target

**Step 63.**

Collect a '**Target Scan**' for leaf #6 in this configuration and **save the file**.

NOTES

**Etienne Laliberté** 04 Jun 2018

This corresponds to the **target radiance** in **transmittance** mode for leaf #6 ($T_{tar,6}$).

Configuration D: Transmittance Mode, Reference

**Step 64.**

Remove leaf #6 from the transmission sample port holder.

Configuration D: Transmittance Mode, Reference

**Step 65.**

Position leaf #1 over the **reflectance port** so that its **abaxial** (lower) side is now facing the inside of the sphere.

NOTES

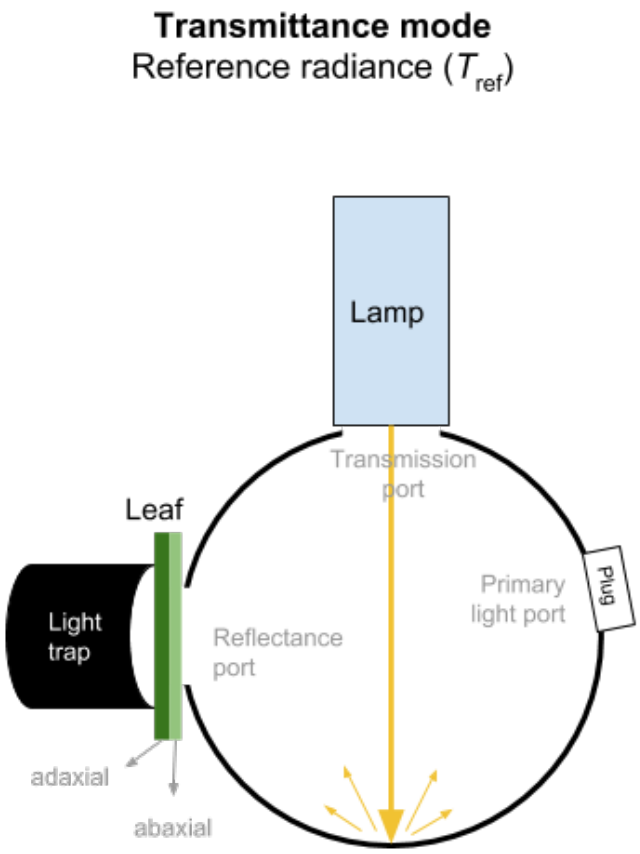
**Etienne Laliberté** 24 Apr 2018

Position the leaf to target the same area measured for the reflectance radiance, with the exception that its abaxial surface now faces the inside of the sphere. Position it so that the amount of leaf and vein material over the port is roughly proportional to the area of leaf and vein found throughout the leaf, while avoiding the large midrib vein. Position the leaf so that it is approximately halfway between the mid-rib vein and the leaf margin, and halfway between the tip and the base of the leaf lamina.

Configuration D: Transmittance Mode, Reference

**Step 66.**

Collect a '**Target Scan**' in this configuration and **save the file**.




NOTES

**Etienne Laliberté** 04 Jun 2018

This second reference radiance scan is only used to assess the stability of the system in transmittance mode.

## Calculating Leaf Reflectance (Adaxial Surface)

**Step 67.**

The equation for **adaxial reflectance** of leaf $i$, $\rho_{leaf,i}$ is

$$\rho_{leaf,i} = [\ (R_{tar,i} - R_{str}) \div (R_{ref} - R_{str})\ ] \times \rho_{ref}$$

where

$\rho_{ref}$ is the absolute reflectance of the calibrated Spectralon® reflectance standard.

## Calculating Leaf Transmittance (Adaxial Surface)

**Step 68.**

The equation for **adaxial transmittance** of leaf *i*, $\tau_{leaf,i}$ is

$$\tau_{leaf,i} = (T_{tar,i} \div T_{ref})$$

## Warnings

The lamp of the integrating sphere can get **very hot** and should handled from its slotted base to avoid burns.