⅋ Measuring spectral reflectance and transmittance (350-2500 nm) of small and/or narrow leaves using the Spectra Vista Corporation (SVC) DC-R/T Integrating Sphere

Version 3

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Abstract

Here we describe the standardised protocol used by the Canadian Airborne Biodiversity Observatory (CABO) to measure leaf spectral reflectance and transmittance, using an integrating sphere fitted to a portable full-range field spectroradiometer, for the special case where an individual **leaf is too small and/or too narrow** to entirely cover the reflectance or transmission port of the integrating sphere. Briefly, six arrays of mature, healthy and sunlit leaves from a canopy plant are arranged on a custom sample mount, and are then used 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 is an adaptation of that of Noda et al. (2013) to the SVC DC-R/T sphere, and also builds from protocols by the Carnegie Airborne Observatory and the SVC integrating sphere user manual.

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 arrays during measurements (optional)

Consumables
- Nitrile gloves for handling leaves
- Whatman No. 2 filter paper (110 mm diameter)
- Acetate sheets (to make thin plastic sample mounts)
- Manila file folders (to make thin cardbboard sample platforms)
- Scotch™ Magic Tape

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.
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. **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).

Materials

Manila File Folders 116723 by **Staples**

Write-On Transparency Film 954144 by **Staples**

Whatman™ Qualitative Filter Paper: Grade 2 Circles (110 mm diameter) 09-810E by **Fisher Scientific**

Scotch™ Magic Tape 14172 by **Staples**

Protocol

Instrument Set-Up

Step 1.
Install the integrating sphere onto the spectroradiometer.

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

Step 2.

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.

Step 3.

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

Step 4.

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

Step 5.

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

➕ NOTES

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

Step 6.

Check lamp alignment.

➕ NOTES

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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.

Step 7.

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

➕ NOTES

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

<div style="background-color:#8BC98B; color:white; padding:4px;">Software Set-Up</div>

Step 8.

Launch SVC Scan.

<div style="background-color:#8BC98B; color:white; padding:4px;">Software Set-Up</div>

Step 9.

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

<div style="background-color:#8BC98B; color:white; padding:4px;">Software Set-Up</div>

Step 10.

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

➕ NOTES

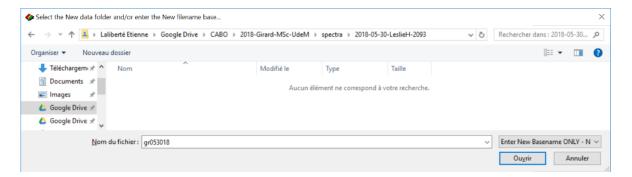**Etienne Laliberté** 04 Jun 2018

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).

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

<div style="background-color:#8BC98B; color:white; padding:4px;">Software Set-Up</div>

Step 11.

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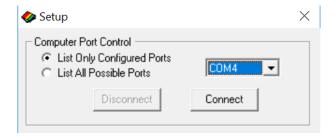

⊕ NOTES

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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 12.

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

⊕ NOTES

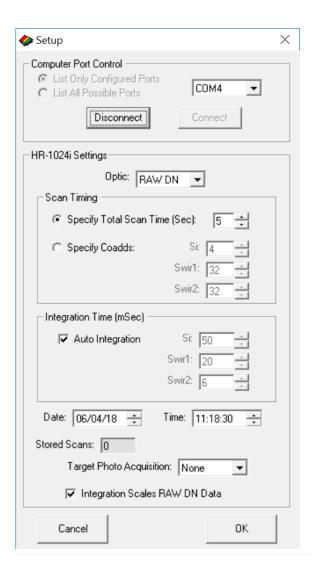**Etienne Laliberté** 04 Jun 2018

Different instruments may be configured under different virtual COM ports.

Software Set-Up

Step 13.

1. Choose the *RAW DN* optic
2. Select 5 sec scan time
3. Select *Auto Integration*
4. Ensure that the date and time are correct
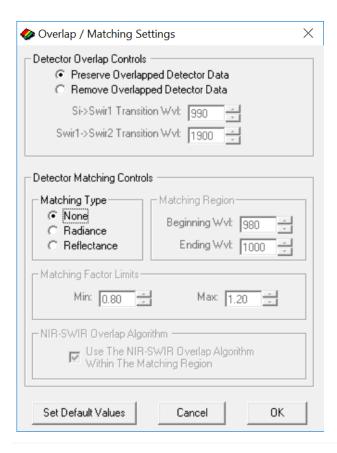5. Check *Integration Scales Raw DN Data*

Software Set-Up

Step 14.

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

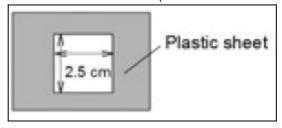1. Select *Preserve Overlapped Detector Data*

2. Select *Matching Type* > *None*

Step 15.

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

Prepare Sample Mounts and Holders

Step 16.

Build at least of six sample mounts from thin plastic (e.g. acetate sheets).

➕ NOTES

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The sample mount is made of a thin plastic sheet with a square window that is larger than the edge of the sample port lip (e.g. 2.5 cm × 2.5 cm).
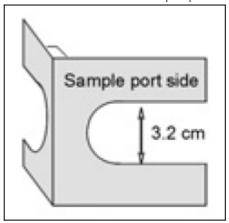
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Fig. 3a from Noda et al. (2013). https://doi.org/10.1111/pce.12100

Step 17.

Build at least six few sample platforms from thin cardboard (e.g. file folders).

➕ NOTES

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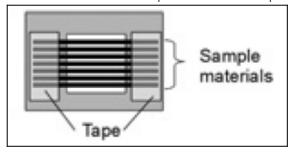The sample platform is made of cardboard and will eventually attach to the integrating sphere to create a flat surface.

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Fig. 3c from Noda et al. (2013). https://doi.org/10.1111/pce.12100

Prepare Leaf Arrays

Step 18.

Fix leaves onto the sample mount with tape to make leaf array #1.

➕ NOTES

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Fig. 3b from Noda et al. (2013). https://doi.org/10.1111/pce.12100

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Try to position as much leaf material as possible in the center of the port where the intensity of the light beam will be highest.

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <1.25 cm long), fix leaves by their petiole with tape in one (or two) rows.

Prepare Leaf Arrays

Step 19.

Fix leaves onto the sample mount with tape to make leaf array #2.

  ⊕ NOTES

Etienne Laliberté 20 Jun 2018

Try to position as much leaf material as possible in the center of the port where the intensity of the light beam will be highest.

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <1.25 cm long), fix leaves by their petiole with tape in one (or two) rows.

Prepare Leaf Arrays

Step 20.

Fix leaves onto the sample mount with tape to make leaf array #3.

  ⊕ NOTES

Etienne Laliberté 20 Jun 2018

Try to position as much leaf material as possible in the center of the port where the intensity of the light beam will be highest.

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <1.25 cm long), fix leaves by their petiole with tape in one (or two) rows.

Prepare Leaf Arrays

Step 21.

Fix leaves onto the sample mount with tape to make leaf array #4.

  ⊕ NOTES

Etienne Laliberté 20 Jun 2018

Try to position as much leaf material as possible in the center of the port where the intensity of the light beam will be highest.

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <1.25 cm long), fix leaves by their petiole with tape in one (or two) rows.

Prepare Leaf Arrays

Step 22.

Fix leaves onto the sample mount with tape to make leaf array #5.

  ⊕ NOTES

Etienne Laliberté 20 Jun 2018

Try to position as much leaf material as possible in the center of the port where the intensity of the light beam will be highest.

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <1.25 cm long), fix leaves by their petiole with tape in one (or two) rows.

Prepare Leaf Arrays

Step 23.

Fix leaves onto the sample mount with tape to make leaf array #6.

➕ NOTES

Etienne Laliberté 20 Jun 2018

Try to position as much leaf material as possible in the center of the port where the intensity of the light beam will be highest.

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <1.25 cm long), fix leaves by their petiole with tape in one (or two) rows.

Prepare Leaf Arrays

Step 24.

Fix sample mount holding leaf array #1 onto the sample platform with tape.

➕ NOTES

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The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

Prepare Leaf Arrays

Step 25.

Fix sample mount holding leaf array #2 onto the sample platform with tape.

➕ NOTES

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The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

Prepare Leaf Arrays

Step 26.

Fix sample mount holding leaf array #3 onto the sample platform with tape.

➕ NOTES

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The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

Prepare Leaf Arrays

Step 27.

Fix sample mount holding leaf array #4 onto the sample platform with tape.

NOTES

● NOTES

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The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

<div style="background:#e06b75;color:white;padding:4px 8px;">Prepare Leaf Arrays</div>

Step 28.

Fix sample mount holding leaf array #5 onto the sample platform with tape.

● NOTES

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The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

<div style="background:#e06b75;color:white;padding:4px 8px;">Prepare Leaf Arrays</div>

Step 29.

Fix sample mount holding leaf array #6 onto the sample platform with tape.

● NOTES

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The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

<div style="background:#e8a0f0;color:white;padding:4px 8px;">Configuration A: Reflectance Mode, Leaf Array, Reference</div>

Step 30.

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

● NOTES

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

<div style="background:#e8a0f0;color:white;padding:4px 8px;">Configuration A: Reflectance Mode, Leaf Array, Reference</div>

Step 31.

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

● NOTES

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Place the standard over the reflectance port so that the light beam shines directly on its reflective surface (= facing inside of the sphere).

<div style="background:#e8a0f0;color:white;padding:4px 8px;">Configuration A: Reflectance Mode, Leaf Array, Reference</div>

Step 32.

Position leaf array #1 over the **transmission port** so that the **adaxial** (upper) surfaces of the leaves face into the sphere.
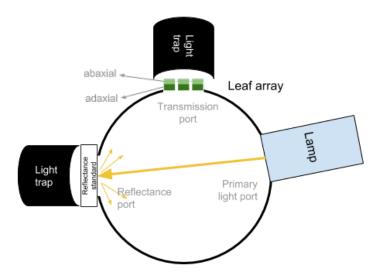

Step 33.

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

Reflectance mode
Leaf array
Reference radiance ($R_{ref,a}$)

➕ NOTES

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This corresponds to the **reference radiance** in reflectance mode for the **leaf arrays** 1-3 ($R_{ref,a}$). The reference data will be automatically saved in all successive target scan files until a new 'Reference Scan' is made.

Configuration A: Reflectance Mode, Leaf Array, Reference

Step 34.

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

Configuration B: Reflectance Mode, Leaf Array + Paper, Reference

Step 35.

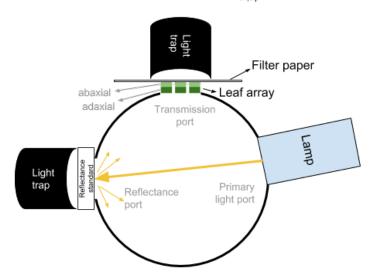Place a filter paper directly behind the sample platform holding leaf array #1.

➕ NOTES

Etienne Laliberté 25 Apr 2018

The leaf array #1 should remain in the same position.

Configuration B: Reflectance Mode, Leaf Array + Paper, Reference

Step 36.

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

Reflectance mode
Leaf array + paper
Reference radiance ($R_{ref,ap}$)

➕ NOTES

Etienne Laliberté 20 Jun 2018

This corresponds to the **reference radiance** in reflectance mode for the **leaf array + paper** ($R_{ref,ap}$) for leaf arrays 1-3.

Configuration C: Reflectance Mode, Paper, Reference

Step 37.

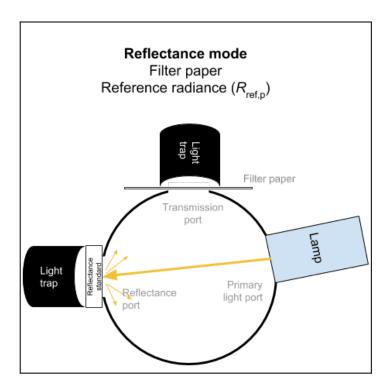Carefully remove the sample platform holding leaf array #1 from the transmission port.

➕ NOTES

Etienne Laliberté 25 Apr 2018

The filter paper should remain in the same position.

Configuration C: Reflectance Mode, Paper, Reference

Step 38.

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

Reflectance mode
Filter paper
Reference radiance ($R_{ref,p}$)

➕ NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **reference radiance** for the **filter paper** in reflectance mode ($R_{ref,p}$).

Configuration D: Reflectance Mode, Stray light

Step 39.

Remove the filter paper from the transmission port sample holder.

Configuration D: Reflectance Mode, Stray light

Step 40.

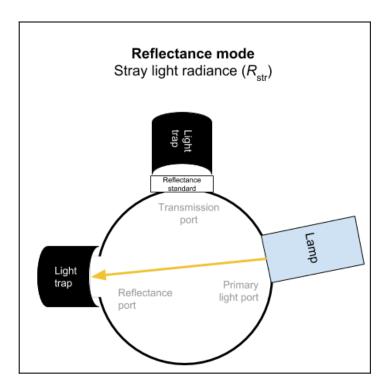Remove the tethered calibrated Spectralon® reflectance standard from the reflectance port.

Configuration D: Reflectance Mode, Stray light

Step 41.

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

Configuration D: Reflectance Mode, Stray light

Step 42.

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

Reflectance mode
Stray light radiance (R_{str})

➕ NOTES

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

Step 43.

Place the filter paper over the **reflectance port**.
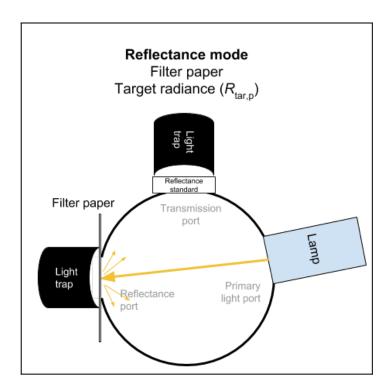
➕ NOTES

Etienne Laliberté 25 Apr 2018

Focus the measurements on the same area of the paper used in previous measurements.

Step 44.

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

Reflectance mode
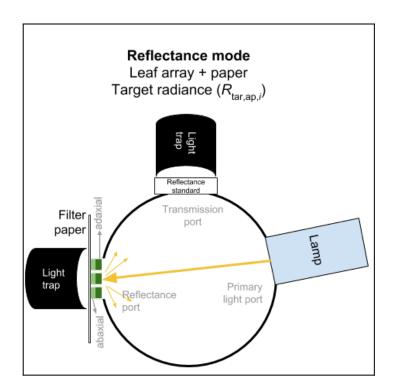Filter paper
Target radiance ($R_{tar,p}$)

Configuration F: Reflectance Mode, Leaf Array #1 + Paper, Target

Step 45.

Position the sample platform containing leaf array #1 in front the filter paper over the **reflectance port** with the **adaxial** (upper) surfaces of the leaves face into the sphere.

Configuration F: Reflectance Mode, Leaf Array #1 + Paper, Target

Step 46.

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

Reflectance mode
Leaf array + paper
Target radiance ($R_{tar,ap,i}$)

➕ NOTES

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This corresponds to the **target radiance** of **leaf array #1 + paper** in reflectance mode ($R_{tar,ap,1}$).

<div style="background:#e07a84; color:white; padding:4px;">Configuration G: Reflectance Mode, Leaf Array #1, Target</div>

Step 47.

Remove the filter paper from the reflectance port.

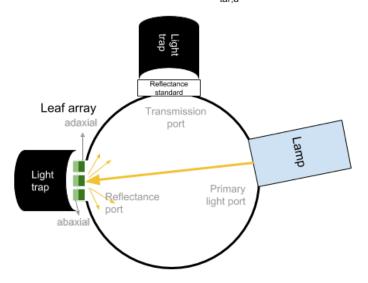➕ NOTES

Etienne Laliberté 04 Jun 2018

The sample platform holding leaf array #1 should remain in the same position.

<div style="background:#e07a84; color:white; padding:4px;">Configuration G: Reflectance Mode, Leaf Array #1, Target</div>

Step 48.

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

Reflectance mode
Leaf array
Target radiance ($R_{tar,a}$)

➕ NOTES

Etienne Laliberté 04 Jun 2018
This corresponds to the **target radiance** of **leaf array #1** in reflectance mode ($R_{tar,a,1}$).

Configuration F: Reflectance Mode, Leaf Array #2 + Paper, Target

Step 49.
Carefully replace leaf array #1 by leaf array #2.

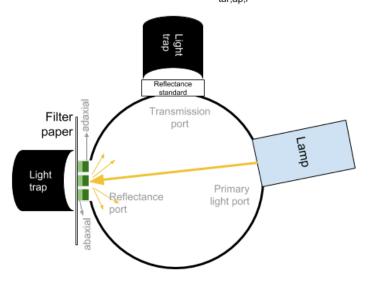Configuration F: Reflectance Mode, Leaf Array #2 + Paper, Target

Step 50.
Place the filter paper directly behind leaf array #2 over the **reflectance port**.

Configuration F: Reflectance Mode, Leaf Array #2 + Paper, Target

Step 51.
Collect a '**Target Scan**' in this configuration and **save the file**.

Reflectance mode
Leaf array + paper
Target radiance ($R_{tar,ap,i}$)

➕ NOTES

Etienne Laliberté 04 Jun 2018

This corresponds to the **target radiance** of **leaf array #2 + paper** in reflectance mode ($R_{tar,ap,2}$).

Configuration G: Reflectance Mode, Leaf Array #2, Target

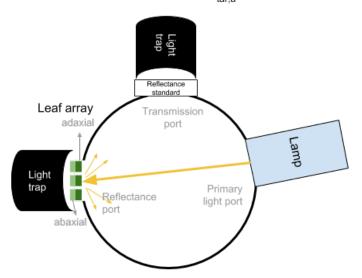**Step 52.**

Remove the filter paper from the reflectance port.

➕ NOTES

Etienne Laliberté 04 Jun 2018

The sample platform holding leaf array #2 should remain in the same position.

Configuration G: Reflectance Mode, Leaf Array #2, Target

Step 53.

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

Reflectance mode
Leaf array
Target radiance ($R_{tar,a}$)

🛨 NOTES

Etienne Laliberté 04 Jun 2018

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

Configuration F: Reflectance Mode, Leaf Array #3 + Paper, Target

Step 54.

Carefully replace leaf array #2 by leaf array #3.

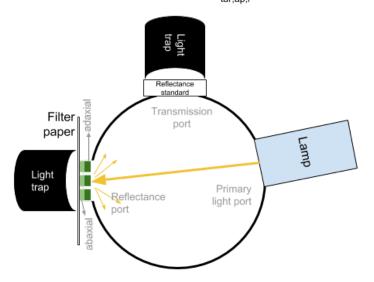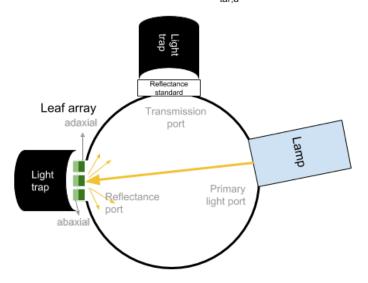Configuration F: Reflectance Mode, Leaf Array #3 + Paper, Target

Step 55.

Place the filter paper directly behind leaf array #3 over the **reflectance port**.

Configuration F: Reflectance Mode, Leaf Array #3 + Paper, Target

Step 56.

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

Reflectance mode
Leaf array + paper
Target radiance ($R_{\text{tar,ap},i}$)

Configuration G: Reflectance Mode, Leaf Array #3, Target

Step 57.

Remove the filter paper from the reflectance port.

Configuration G: Reflectance Mode, Leaf Array #3, Target

Step 58.

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

Reflectance mode
Leaf array
Target radiance ($R_{tar,a}$)

Configuration A: Reflectance Mode, Leaf Array, Reference

Step 59.

Remove leaf array #3 from the reflectance port.

Configuration A: Reflectance Mode, Leaf Array, Reference

Step 60.

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

Configuration A: Reflectance Mode, Leaf Array, Reference

Step 61.

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

Configuration A: Reflectance Mode, Leaf Array, Reference
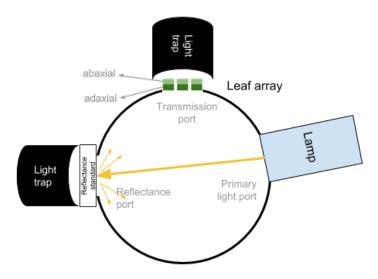
Step 62.

Position leaf array #1 over the **transmission port** so that the **adaxial** (upper) surfaces of the leaves face into the sphere.

Step 63.

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

Reflectance mode
Leaf array
Reference radiance ($R_{ref,a}$)

➕ NOTES

Etienne Laliberté 20 Jun 2018

This corresponds to the **reference radiance** for **leaf arrays** 4-6 in reflectance mode ($R_{ref,ap}$).

Step 64.

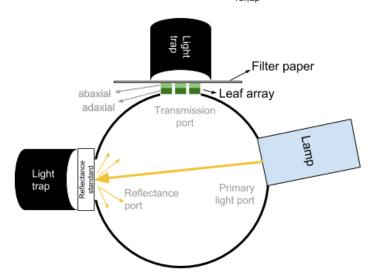Place a filter paper directly behind the sample platform holding leaf array #1.

➕ NOTES

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The leaf array #1 should remain in the same position.

Step 65.

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

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Reflectance mode
Leaf array + paper
Reference radiance ($R_{ref,ap}$)

➕ NOTES

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This corresponds to the **reference radiance** for the **leaf array + paper** in reflectance mode ($R_{ref,ap}$) for leaf arrays 4-6.

Configuration F: Reflectance Mode, Leaf Array #4 + Paper, Target

Step 66.

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

Configuration F: Reflectance Mode, Leaf Array #4 + Paper, Target

Step 67.

Remove leaf array #1 and filter paper from the **transmission port**.

Configuration F: Reflectance Mode, Leaf Array #4 + Paper, Target

Step 68.

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

Configuration F: Reflectance Mode, Leaf Array #4 + Paper, Target

Step 69.

Place the filter paper over the **reflectance port**.

➕ NOTES

Etienne Laliberté 20 Jun 2018

Focus the measurements on the same area of the paper used in previous measurements.
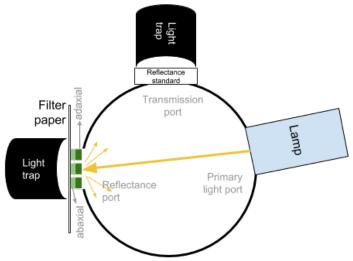

Step 70.

Position the sample platform containing leaf array #4 in front the filter paper over the **reflectance port** with the **adaxial** (upper) surfaces of the leaves face into the sphere.

Configuration F: Reflectance Mode, Leaf Array #4 + Paper, Target

Step 71.

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

Reflectance mode
Leaf array + paper
Target radiance ($R_{tar,ap,i}$)

➕ NOTES

Etienne Laliberté 20 Jun 2018

This corresponds to the **target radiance** of **leaf array #4 + paper** in reflectance mode ($R_{tar,ap,4}$).

Configuration G: Reflectance Mode, Leaf Array #4, Target

Step 72.

Remove the filter paper from the reflectance port.

➕ NOTES

Etienne Laliberté 20 Jun 2018

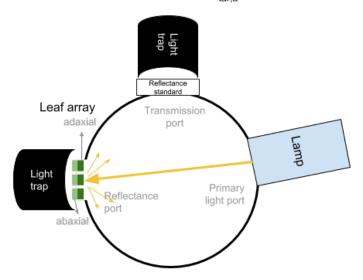The sample platform holding leaf array #4 should remain in the same position.

Step 73.

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

Reflectance mode
Leaf array
Target radiance ($R_{tar,a}$)

Configuration F: Reflectance Mode, Leaf Array #5 + Paper, Target

Step 74.
Carefully replace leaf array #4 by leaf array #5.

Configuration F: Reflectance Mode, Leaf Array #5 + Paper, Target

Step 75.
Place the filter paper directly behind leaf array #5 over the **reflectance port**.
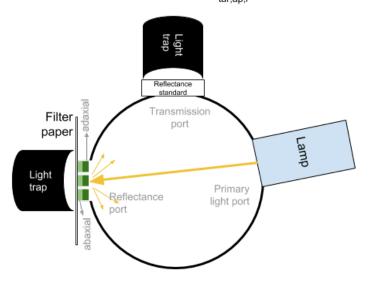
Configuration F: Reflectance Mode, Leaf Array #5 + Paper, Target

Step 76.
Collect a '**Target Scan**' in this configuration and **save the file**.

Reflectance mode
Leaf array + paper
Target radiance ($R_{tar,ap,i}$)

➕ NOTES

Etienne Laliberté 20 Jun 2018

This corresponds to the **target radiance** of **leaf array #5 + paper** in reflectance mode ($R_{tar,ap,5}$).

Configuration G: Reflectance Mode, Leaf Array #5, Target

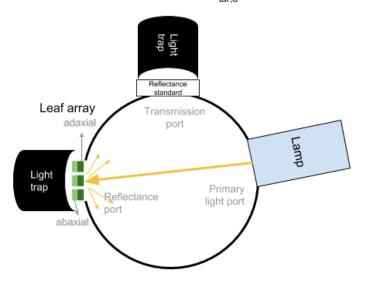**Step 77.**

Remove the filter paper from the reflectance port.

➕ NOTES

Etienne Laliberté 20 Jun 2018

The sample platform holding leaf array #5 should remain in the same position.

Configuration G: Reflectance Mode, Leaf Array #5, Target

Step 78.

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

Reflectance mode
Leaf array
Target radiance ($R_{tar,a}$)

➕ NOTES

Etienne Laliberté 20 Jun 2018

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

Configuration F: Reflectance Mode, Leaf Array #6 + Paper, Target

Step 79.

Carefully replace leaf array #5 by leaf array #6.

Configuration F: Reflectance Mode, Leaf Array #6 + Paper, Target

Step 80.

Place the filter paper directly behind leaf array #6 over the **reflectance port**.
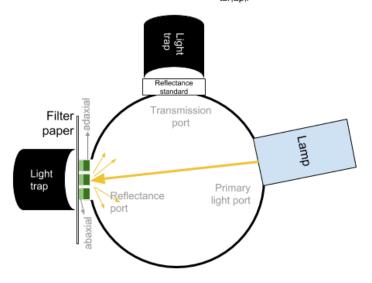
➕ NOTES

Etienne Laliberté 20 Jun 2018

Focus the measurements on the same area of the paper used in previous measurements.

Configuration F: Reflectance Mode, Leaf Array #6 + Paper, Target

Step 81.

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

Reflectance mode
Leaf array + paper
Target radiance ($R_{tar,ap,i}$)

⊕ NOTES

Etienne Laliberté 20 Jun 2018

This corresponds to the **target radiance** of **leaf array #6 + paper** in reflectance mode ($R_{tar,ap,6}$).

Configuration G: Reflectance Mode, Leaf Array #6, Target

Step 82.

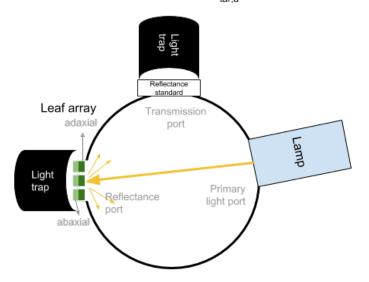Remove the filter paper from the reflectance port.

⊕ NOTES

Etienne Laliberté 20 Jun 2018

The sample platform holding leaf array #6 should remain in the same position.

Configuration G: Reflectance Mode, Leaf Array #6, Target

Step 83.

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

Reflectance mode
Leaf array
Target radiance ($R_{tar,a}$)

Etienne Laliberté 20 Jun 2018

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

Configuration A: Reflectance Mode, Leaf Array, Reference

Step 84.

Remove leaf array #6 from the reflectance port.

Configuration A: Reflectance Mode, Leaf Array, Reference

Step 85.

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

Configuration A: Reflectance Mode, Leaf Array, Reference

Step 86.

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

Etienne Laliberté 20 Jun 2018

Place the standard over the reflectance port so that the light beam shines directly on its reflective surface (= facing inside of the sphere).

Configuration A: Reflectance Mode, Leaf Array, Reference

Step 87.

Position leaf array #1 over the **transmission port** so that the **adaxial** (upper) surfaces of the leaves face into the sphere.
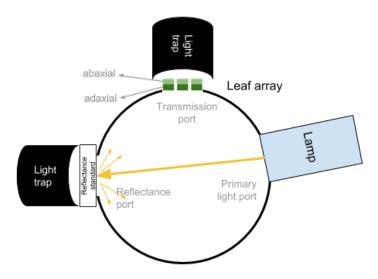
Step 88.

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

Reflectance mode
Leaf array
Reference radiance ($R_{ref,a}$)

➕ NOTES

Etienne Laliberté 20 Jun 2018

This third reference measurement is only used to assess system stability in reflectance mode for the leaf array reference.

Step 89.

Place a filter paper directly behind the sample platform holding leaf array #1.

➕ NOTES

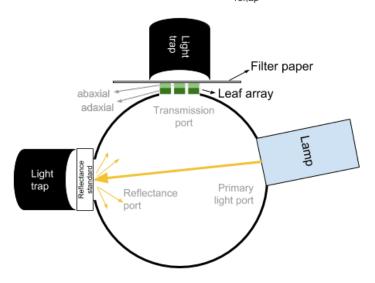**Etienne Laliberté** 20 Jun 2018

The leaf array #1 should remain in the same position.

Step 90.

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

Reflectance mode
Leaf array + paper
Reference radiance ($R_{ref,ap}$)

➕ NOTES

Etienne Laliberté 20 Jun 2018

This third reference measurement is only used to assess system stability in reflectance mode for the leaf array + paper reference.

Configuration H: Transmittance Mode, Reference

Step 91.

Remove leaf array #1 and filter paper from the **transmission port**.

Configuration H: Transmittance Mode, Reference

Step 92.

Position the sample platform containing leaf array #1 over the **reflectance port** with the **abaxial** (lower) surface of the leaves facing into the sphere.

Configuration H: Transmittance Mode, Reference

Step 93.

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

Configuration H: Transmittance Mode, Reference

Step 94.

Remove the light trap from the transmission port sample holder.

Configuration H: Transmittance Mode, Reference

Step 95.

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 H: Transmittance Mode, Reference

Step 96.

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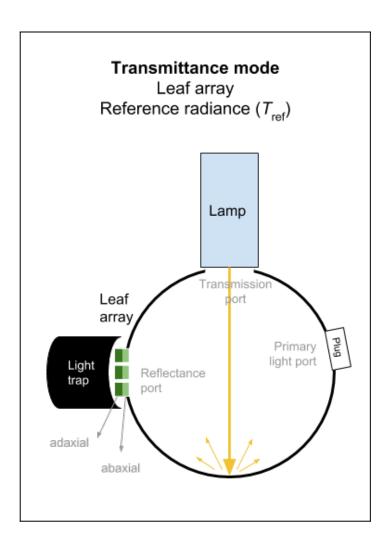
➕ NOTES

Etienne Laliberté 24 Apr 2018

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

Configuration H: Transmittance Mode, Reference

Step 97.

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

Transmittance mode
Leaf array
Reference radiance (T_{ref})

➕ NOTES

Etienne Laliberté 04 Jun 2018

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

<div style="background-color:#e89ff0">Configuration H: Transmittance Mode, Reference</div>

Step 98.

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

<div style="background-color:#a88df0">Configuration I: Transmittance Mode, Target</div>

Step 99.

Carefully remove leaf array #1 from the **reflectance port**.

<div style="background-color:#a88df0">Configuration I: Transmittance Mode, Target</div>

Step 100.

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

⚠ SAFETY INFORMATION

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

Step 101.

Place the sample platform holding leaf array #1 over the **transmission port** with the abaxial (lower) surfaces of the leaves facing into the sphere.
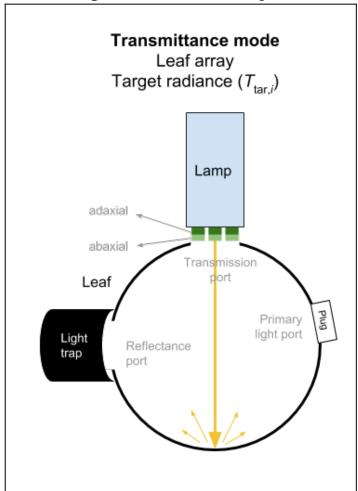
Step 102.

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

Step 103.

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

⊕ NOTES

Etienne Laliberté 04 Jun 2018

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

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Configuration I: Transmittance Mode, Target

Step 104.

Carefully replace leaf array #1 by leaf array #2.

Configuration I: Transmittance Mode, Target

Step 105.

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

➕ NOTES

Etienne Laliberté 04 Jun 2018

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

Configuration I: Transmittance Mode, Target

Step 106.

Carefully replace leaf array #2 by leaf array #3.

Configuration I: Transmittance Mode, Target

Step 107.

Collect a '**Target Scan**' for leaf array #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 array #3 ($T_{tar,3}$).

Configuration I: Transmittance Mode, Target

Step 108.

Carefully replace leaf array #3 by leaf array #4.

Configuration I: Transmittance Mode, Target

Step 109.

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

➕ NOTES

Etienne Laliberté 20 Jun 2018

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

Configuration I: Transmittance Mode, Target

Step 110.

Carefully replace leaf array #4 by leaf array #5.

Configuration I: Transmittance Mode, Target

Step 111.

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

> ➕ NOTES
>
> **Etienne Laliberté** 20 Jun 2018
>
> This corresponds to the **target radiance** in **transmittance** mode for leaf array #5 ($T_{tar,5}$).

Configuration I: Transmittance Mode, Target

Step 112.

Carefully replace leaf array #5 by leaf array #6.

Configuration I: Transmittance Mode, Target

Step 113.

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

> ➕ NOTES
>
> **Etienne Laliberté** 20 Jun 2018
>
> This corresponds to the **target radiance** in **transmittance** mode for leaf array #6 ($T_{tar,6}$).

Configuration H: Transmittance Mode, Reference

Step 114.

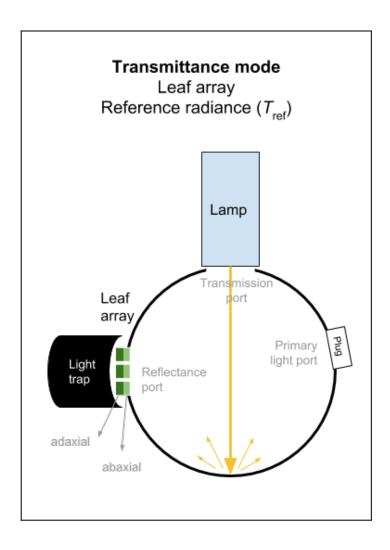Remove leaf array #6 from the transmission sample port holder.

Configuration H: Transmittance Mode, Reference

Step 115.

Position the sample platform containing leaf array #1 over the **reflectance port** with the **abaxial** (lower) surface of the leaves facing into the sphere.

Configuration H: Transmittance Mode, Reference

Step 116.

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

Transmittance mode
Leaf array
Reference radiance (T_{ref})

➕ NOTES

Etienne Laliberté 04 Jun 2018

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

Calculating Absolute Adaxial Reflectance of Leaf Array

Step 117.

The equation (Noda et al. 2013; eqn. 9) for **adaxial reflectance** of leaf array i, $\rho_{a,i}$ is

$$\rho_{a,i} = [(R_{tar,a,i} - R_{str}) \div (R_{ref,a} - R_{str})] \times \rho_{ref} \times [1 \div (1 - G_{r,i})]$$

where

$R_{tar,a,i}$ is the target radiance of leaf array i (adaxial side) in reflectance mode,

$R_{ref,a}$ is the reference radiance used for all leaf arrays in reflectance mode,

R_{str} is the stray light radiance in reflectance mode,

ρ_{ref} is the absolute reflectance of the calibrated Spectralon® reflectance standard, and

$G_{r,i}$ is the gap fraction in reflectance mode for leaf array i, which is calculated **at 400 nm** (Noda et al. 2013; eqn. 13) by

$$G_{r,i} = [\ (\ (R_{tar,ap,i} - R_{str}) \div (R_{ref,ap} - R_{str})\ ) - (\ (R_{tar,a,i} - R_{str}) \div (R_{ref,a} - R_{str})\ )\ ] \times (\ \rho_{ref} \div \rho_p)$$

where

$R_{tar,ap,i}$ is the target radiance of leaf array i + filter paper in reflectance mode,
$R_{ref,ap}$ is the reference radiance used for all leaf arrays + filter paper in reflectance mode, and
ρ_p is the absolute reflectance of the filter paper, which is calculated (Noda et al. 2013; eqn. 3) by

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

where

$R_{tar,p}$ is the target radiance of the filter paper in reflectance mode, and
$R_{ref,p}$ is the reference radiance of the filter paper in reflectance mode.

⊕ NOTES

Etienne Laliberté 20 Jun 2018

Leaf arrays 1-3 use the first $R_{ref,a}$ and $R_{ref,ap}$ measurements, whereas leaf arrays 4-6 use the second measurements.

Calculating Absolute Adaxial Transmittance of Leaf Array

Step 118.

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

(modified from eqn. 15 of Noda et al. 2013 for the SVC sphere)

$$\tau_{a,i} = [\ (T_{tar,i} \div T_{ref}) - G_{t,i}\ ] \times [\ 1 \div (1 - G_{t,i})\ ]$$

where

$T_{tar,i}$ is the target radiance of leaf array i in transmittance mode,
T_{ref} is the reference radiance used for all leaf arrays in transmittance mode,
$G_{t,i}$ is the gap fraction in transmittance mode for leaf array i, which is calculated <u>**at 400 nm**</u> (since $\tau_{a,i} = 0$ at that wavelength) by

$$G_{t,i} = T_{tar,i} \div T_{ref}$$

Warnings

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