SPIRE Observing Strategies

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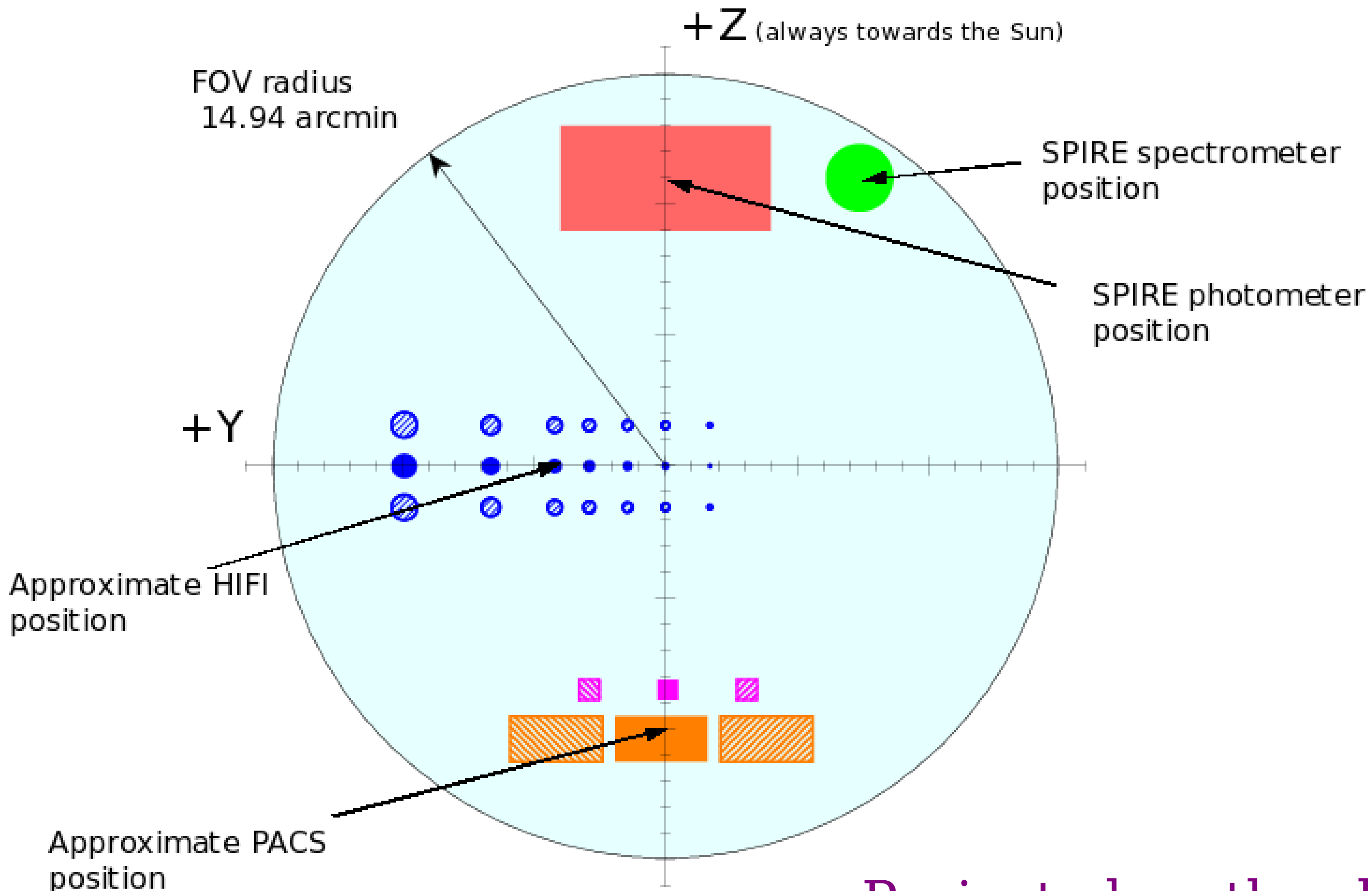
Outline

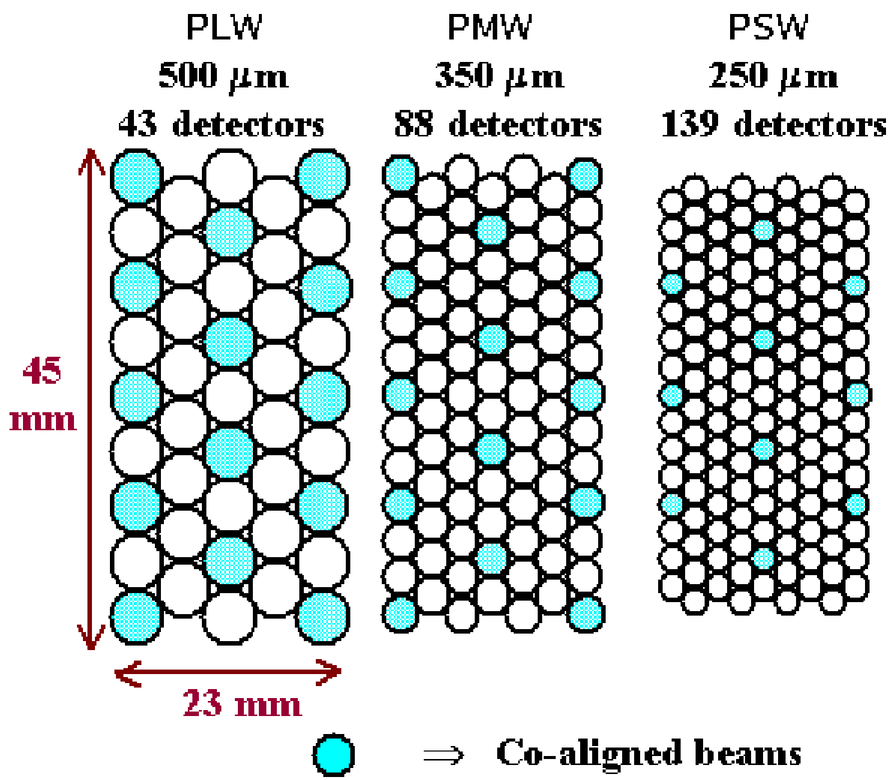
- **SPIRE quick overview**
- **Observing with SPIRE**
  - **A**stronomical **O**bservation **T**emplates (AOT)
    - Photometry: point source, small map, large map
    - Spectroscopy with Fourier-Transform Spectrometer (FTS)
  - Observing strategies

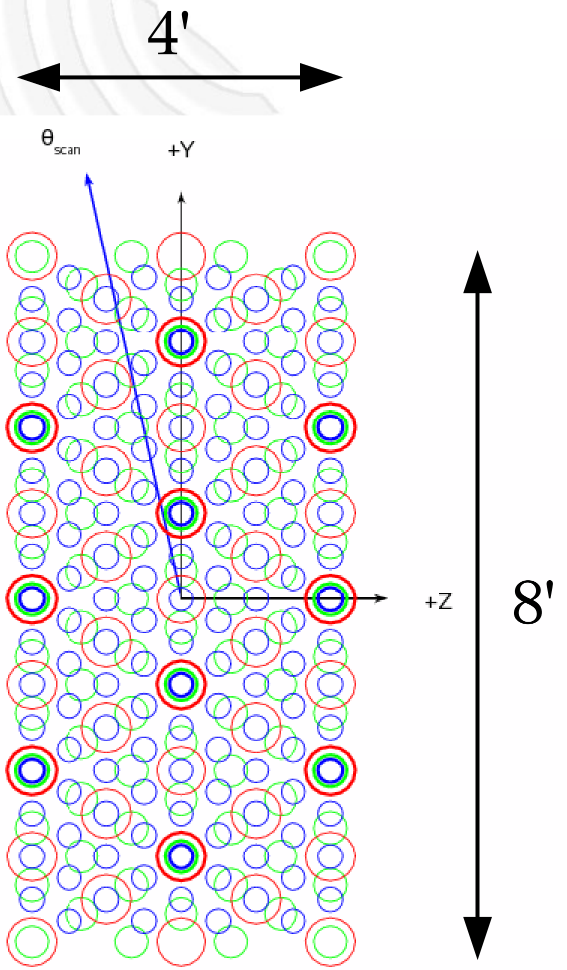
Herschel Focal Plane



Projected on the sky

SPIRE Photometer Overview

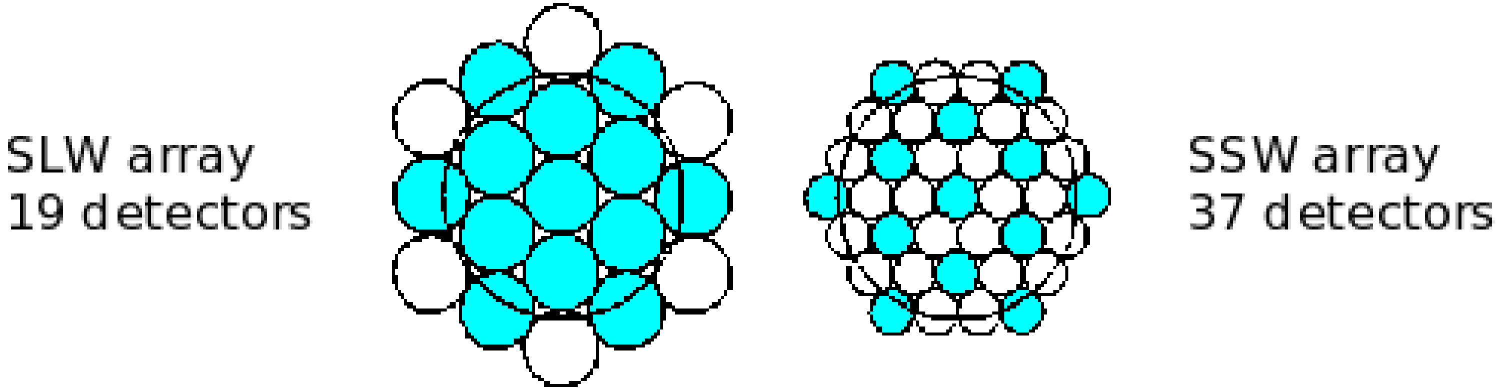




Beam: 18” 25” 36”

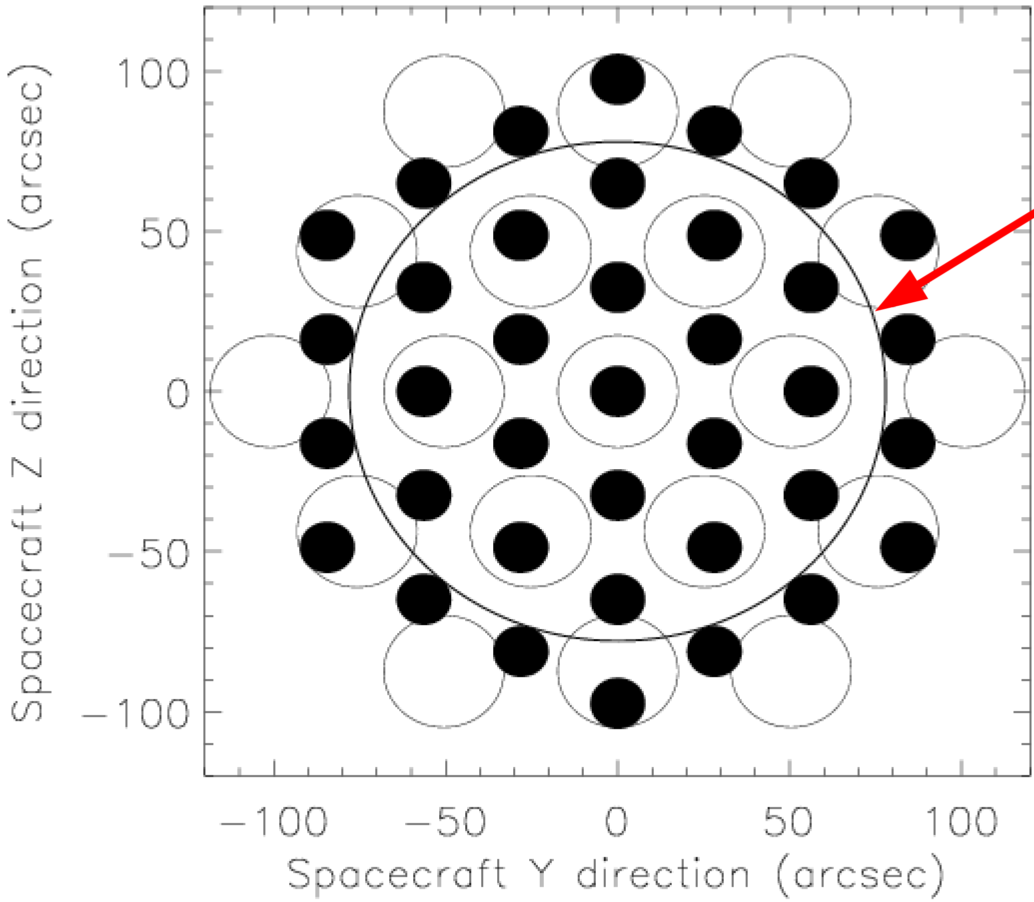
SPIRE Spectrometer

SLW: 316-672 μm SSW: 194-324 μm



Beam (FWHM): 34” 18”

SPIRE Spectrometer



Unvignetted field:
2.6' diameter

SPIRE Spectrometer Overview

- Fourier-Transform Spectrometer
  - Interferometer in Mach-Zehnder configuration
    - Signal vs Optical Path Difference (OPD)
    - Inverse Fourier transform => spectrum vs wavenumber (1/λ)
      The entire spectral coverage is observed in one go
  - Two bands:
    - Short (SSW): 194-324 μm (1545 – 925 GHz)
    - Long (SLW): 316-672 μm (949 – 446 GHz)
  - Spectral resolution:
    - Low: $\Delta\sigma = 1$ cm^{-1}
    - Medium: $\Delta\sigma = 0.25$ cm^{-1}
    - High: $\Delta\sigma = 0.04$ cm^{-1}
  - Field of view: 2.6' diameter

HERSCHEL SPACE OBSERVATORY

Things to Remember

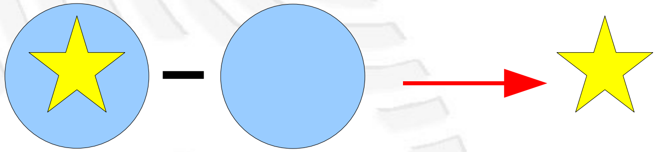
- Photometer and FTS in mid-IR/submm range:
  - 200-700 µm
- The two sub-instruments cannot operate simultaneously
- Five detector arrays (detector=bolometer)
  - PLW, PMW, PSW
  - SLW, SSW
- Operate at 300 mK with ^{3}He sorption cooler, 48 hours hold time

  => recycling necessary
- Photometer field of view: 4x8 arcmin
- Spectrometer field of view: 2.6 arcmin diameter
- Field of view not filled by the detectors

SPIRE Observing Templates

Photometric observations

- Introducing *chopping*:

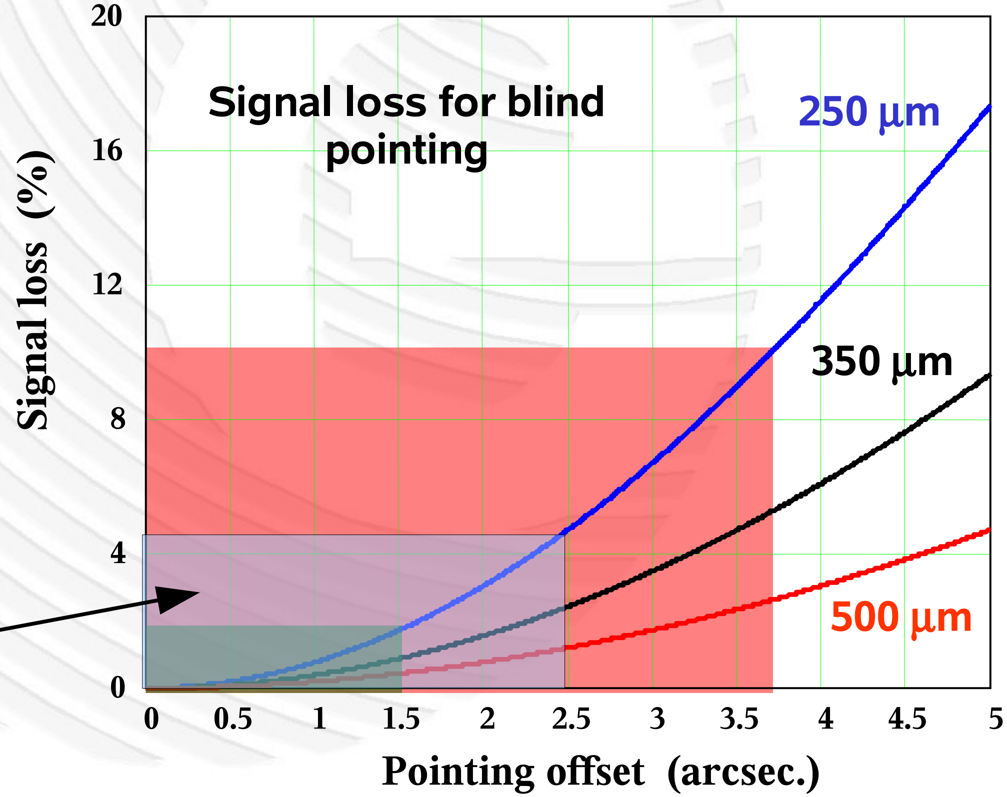


  - (source+background) – background
  - Done with the Beam Steering Mirror (BSM) on ± Y axis
  - Chop frequency (2Hz)
  - Chop throw depending on the observing mode
- Introducing *jiggling*
  - Moving the BSM to re-position the target in the instrument (Y,Z) plane
- Introducing *nodding*
  - Done with the Herschel spacecraft.

SPIRE Photometer
Point Source Photometry

Pointing Error

Introducing the Absolute Pointing Error (APE) of the telescope.

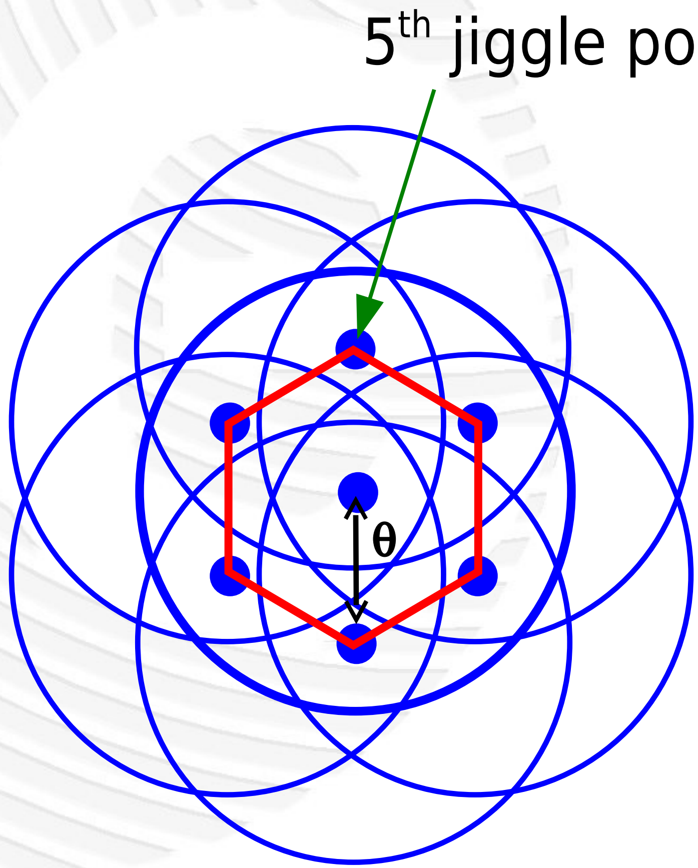


On-ground measured APE is 2.45” (68%)

Point Source Observations

- 7-point map (+ repeat the central point)
- Angular step θ ~ 6”
  - 1/3 of the beam at 250 μm
  - > twice the APE
- Total flux and position fitted
- Compared to single accurately pointed observation, S/N for same total integration time is only degraded by

  ~ 20% at 250 μm
  ~ 13% at 350 μm
  ~ 6% at 500 μm

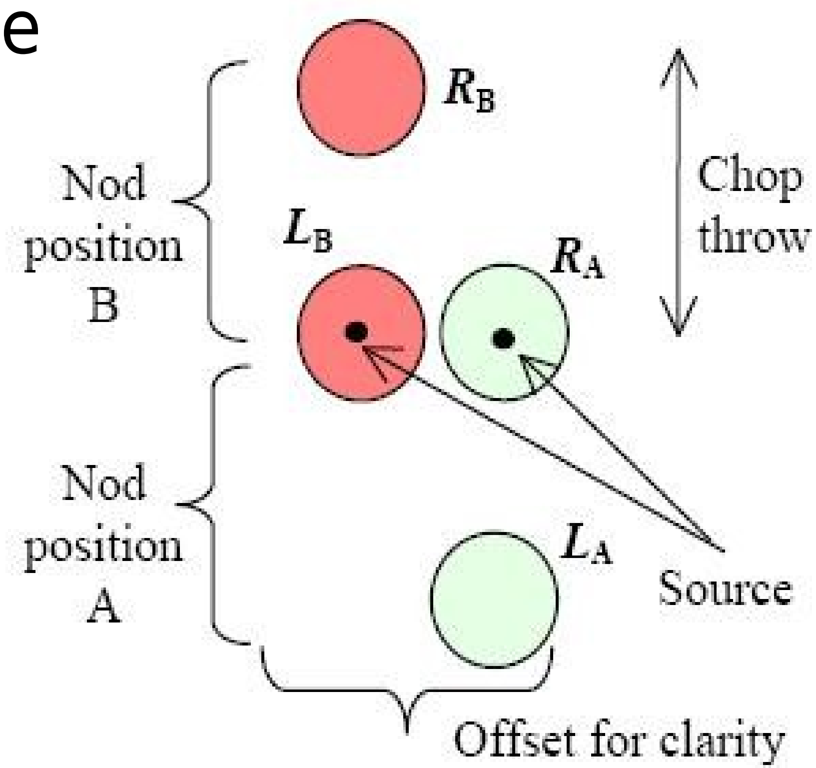


Point Source Observations

How is it working?

Introducing the **ABBA** cycle

- First nod position (Nod A)
  - At each 8 jiggle positions:
    - 16 chop cycles at 2 Hz
- Nod to second position (Nod B) and repeat
  - At each 8 jiggle positions:
    - 16 chop cycles at 2 Hz
- Stay in Nod B and repeat
- Nod to Nod A and repeat



Chop throw = Nod distance = 126” (± 63”)

Point Source Observations

Overall timing and performance

Number of repeats: 1 (number of ABBA cycles)
On-source integration time: 256 s
Instrument and observing overheads: 143 s
Observatory overhead: 180 s
Total observation time: 579 s

1-σ noise (250, 350, 500): (1.4, 1.6, 1.3) mJy

Note:
already lower than the extragalactic confusion noise limits.

Point Source Observations
Some Points to Note

- The calculated sensitivity assumes the ideal case in which the source is on-axis
- A sparse (undersampled) map of a roughly 2 x 4 arcmin region around the source will also be generated by seven-point observations
- Data will be fitted to find the flux density and position of the source (pipeline)

Point Source Photometry Résumé

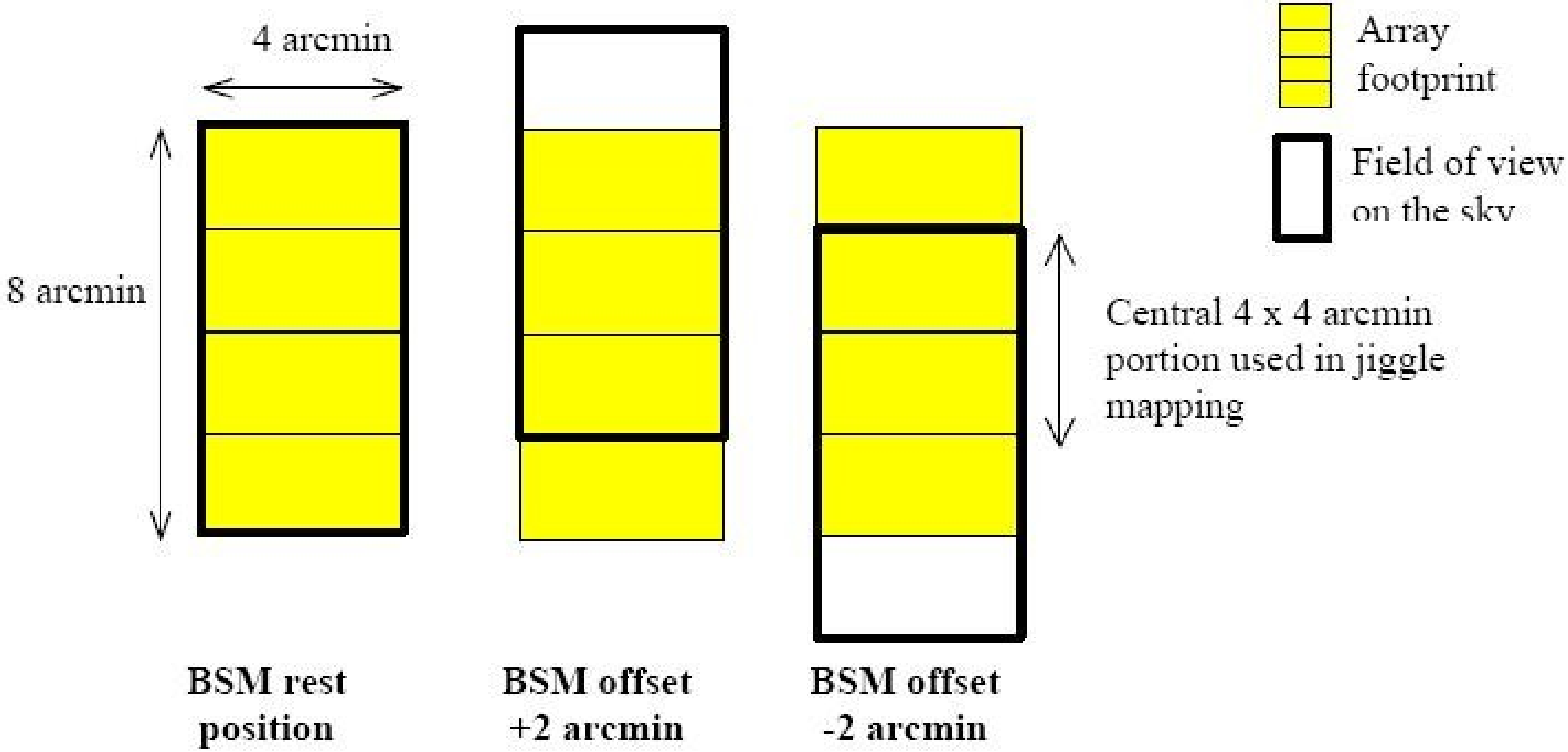
- For sources with intrinsic size less than the beam size
- 7-point jiggle and ABBA nod pattern with chopping
- Total duration ~10 min (including overheads)
- Sparse map around the source

SPIRE Photometer Small Map

Small Map Observations

- No full spatial sampling with SPIRE arrays
  - => fully filled jiggle pattern is necessary: 64 point jiggle
  - Only AB cycle:
    - 16 points per AB cycle, 4 chop cycles at 2 Hz
      1-16: AB, 17-32: BA, 33-48: AB, 49-64: BA.
    - Chop throw = Nod distance = 4' (±2')
  - Fully sampled field of view: 4'x4'
  - Guaranteed area is a circle with 4' diameter

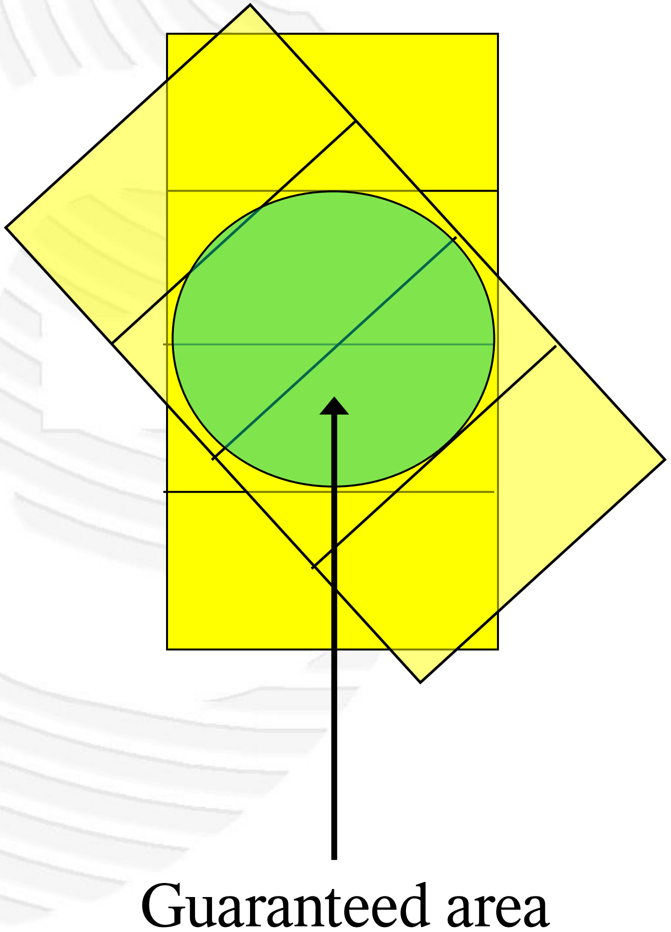
Small Map Observations



Small Map Observations

Array orientation on sky depends on date of observation

- Guaranteed area of 4 arcmin diameter circle
- Note:
  for sources near the ecliptic the array orientation on the sky is fixed



Small Map Observations

Overall timing and performance

Number of repeats: **1** (number of AB cycles)
On-source integration time: 256 s
Instrument and observing overheads: 251 s
Observatory overhead: 180 s
Total observation time: 687 s

1-σ noise (250, 350, 500): (4.7, 6.3, 5.3) mJy

Small Map Observations

Overall timing and performance

Number of repeats: **2** (number of AB cycles)
On-source integration time: 512 s
Instrument and observing overheads: 443 s
Observatory overhead: 180 s
Total observation time: 1135 s

1-σ noise (250, 350, 500): (3.3, 4.5, 3.8) mJy
already close to the confusion limits.

Small Map Observations Résumé

- Region of interest is of size ≤ 4 arcmin diameter
- 64-point jiggle with AB nod pattern, +chopping
- 4x4 arcmin fully sampled map at the observation day
- Total duration for one repeat: 11.5 minutes

Chop avoidance

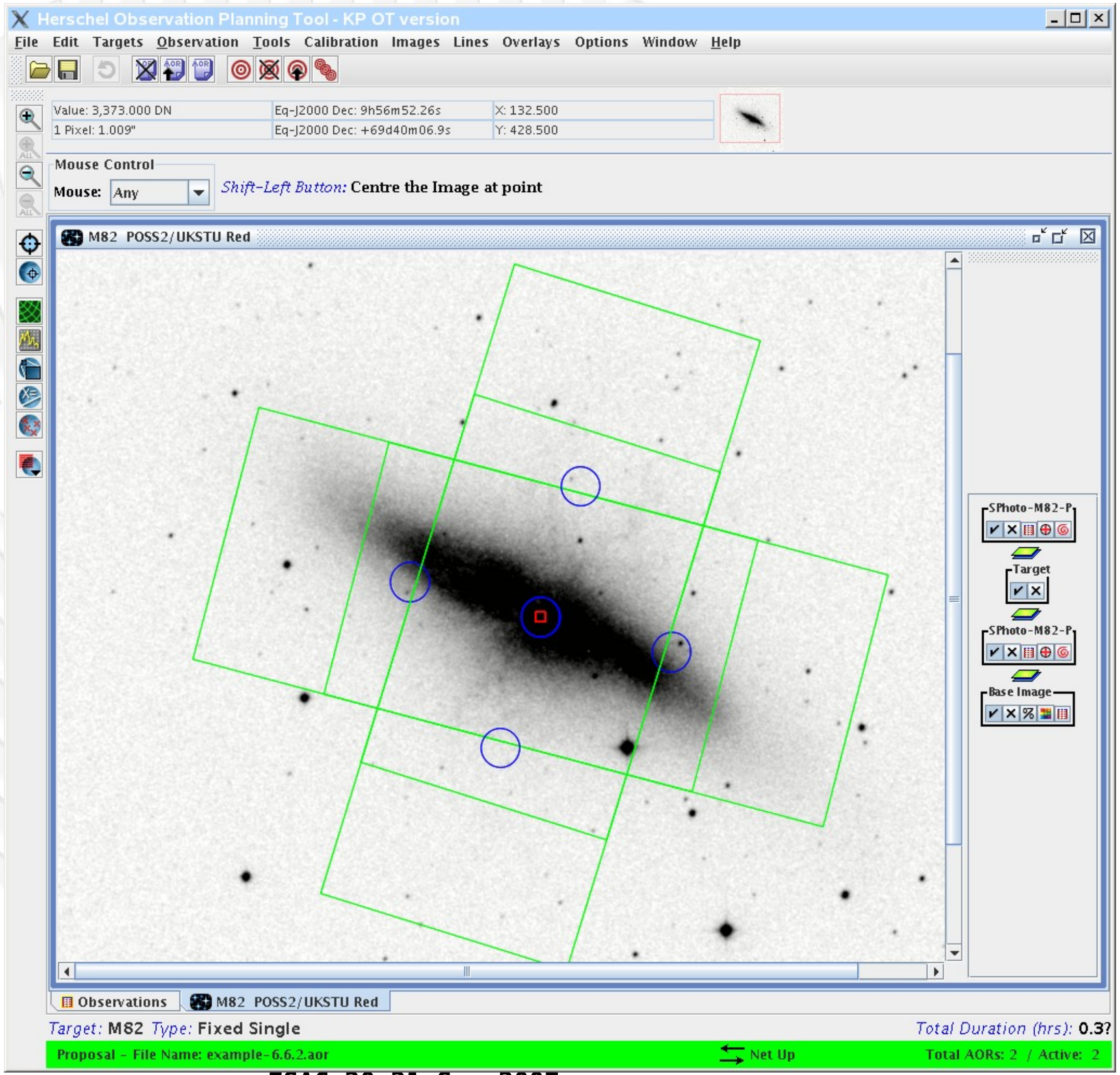
- For both Point Source Photometry or Small Map modes
  - three pairs of chop avoidance angles can be set:

    when the chopping falls on “bad” region” and may hamper the subtraction

    Note: chopping direction (+/- Y axis) depends on the observational day.
  - **Penalized by 10 min overhead: complicates the mission planning.**

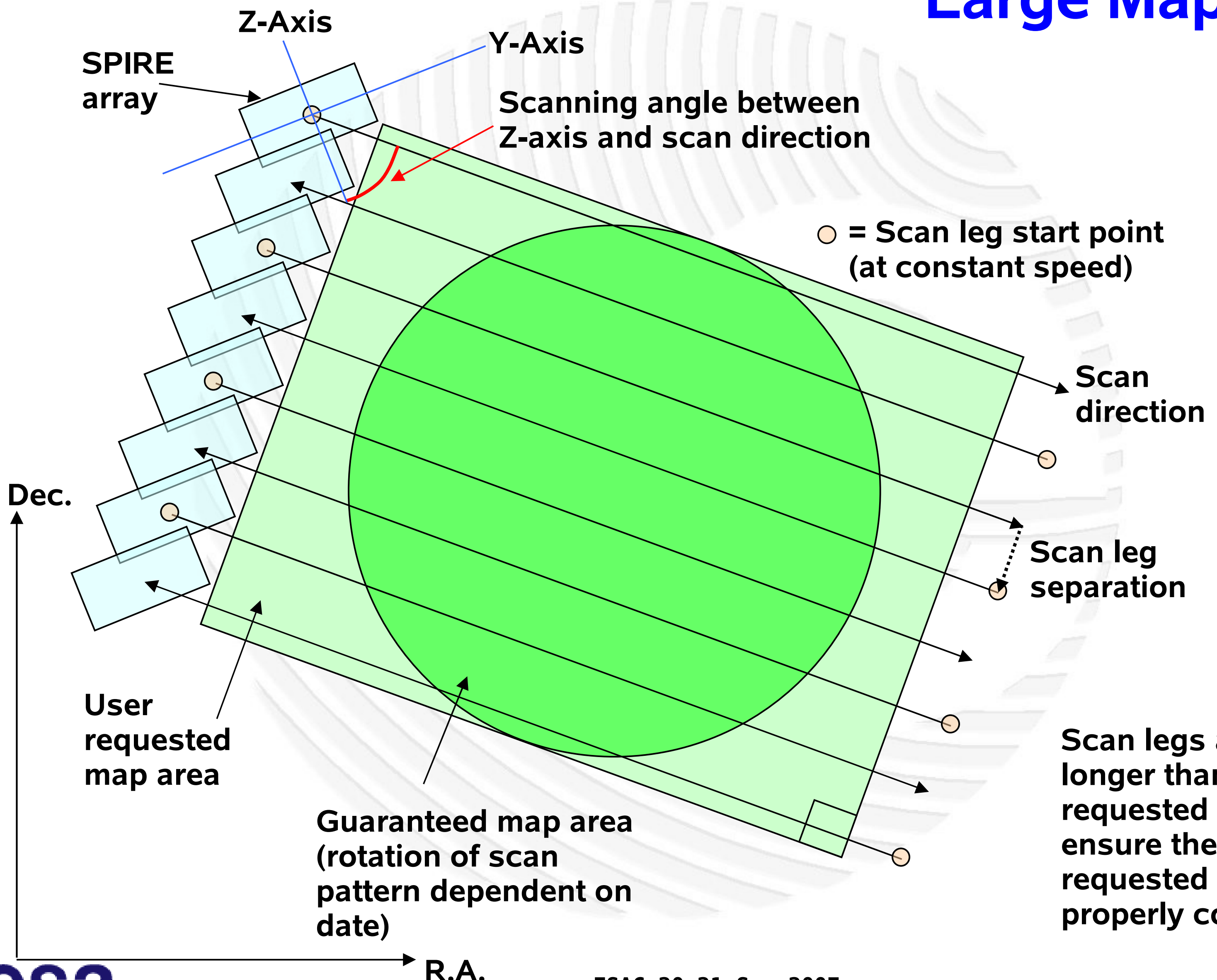
Chop avoidance

M82 example



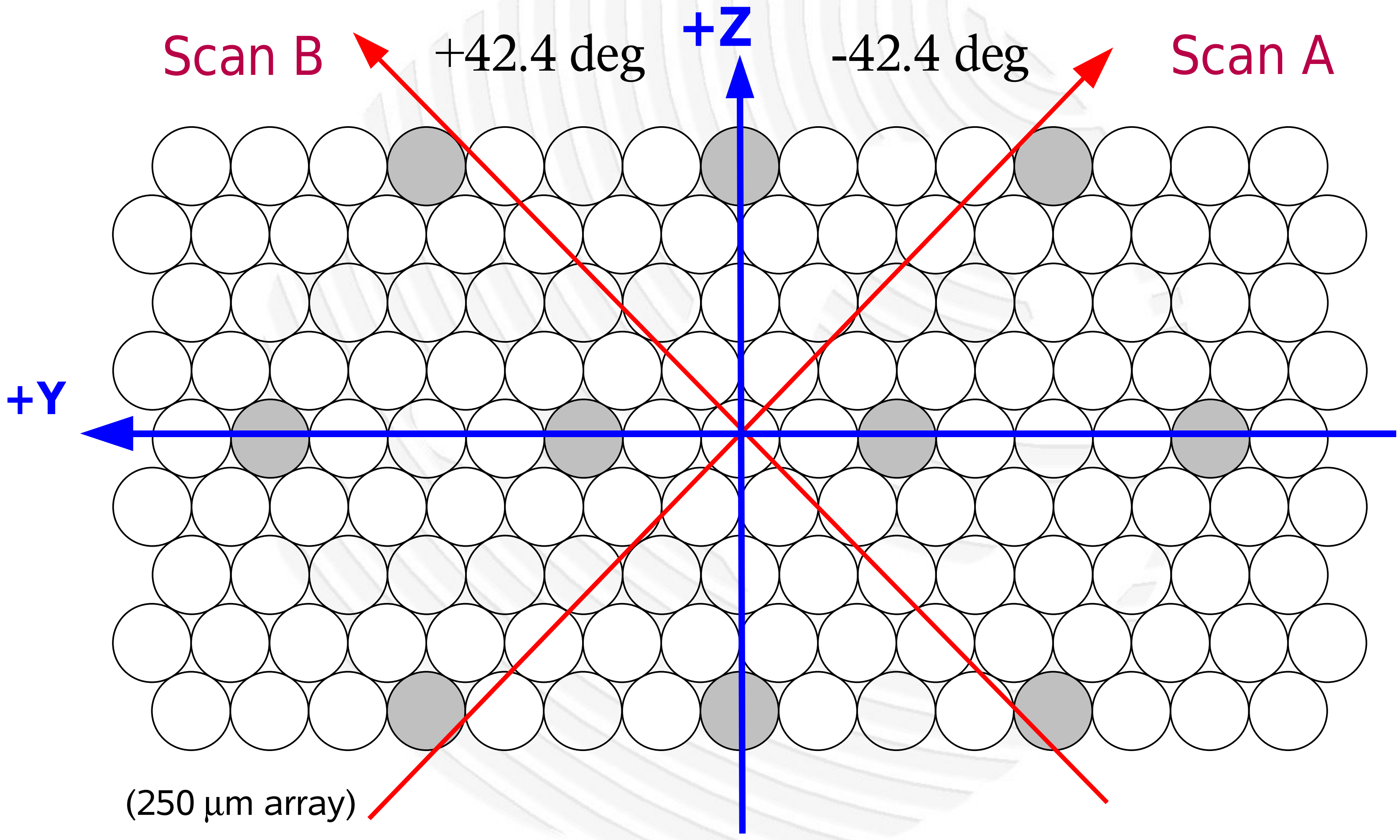
SPIRE Photometer Large Map

Large Map

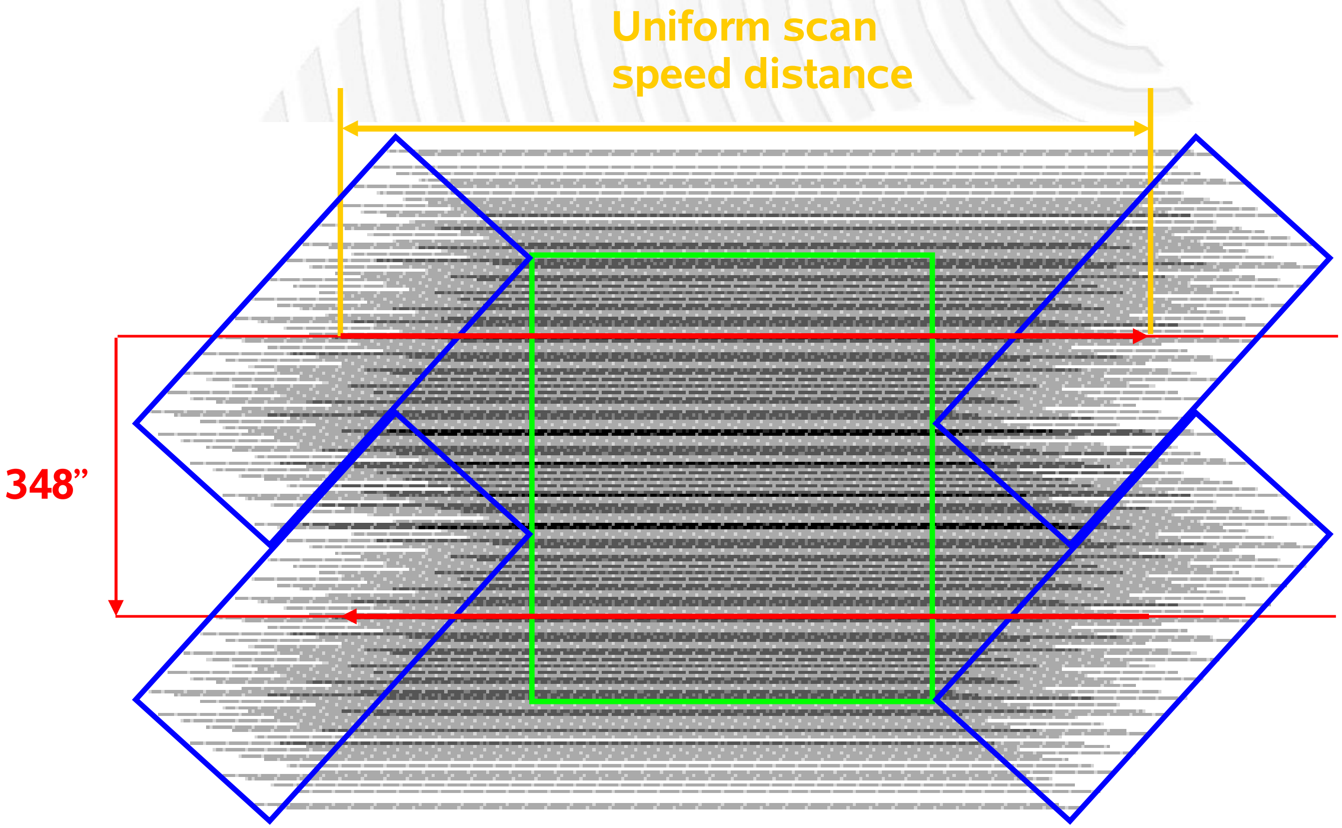


Scan legs are slightly longer than the user requested length, to ensure the user requested area is properly covered

Large Map scan directions



Scan coverage

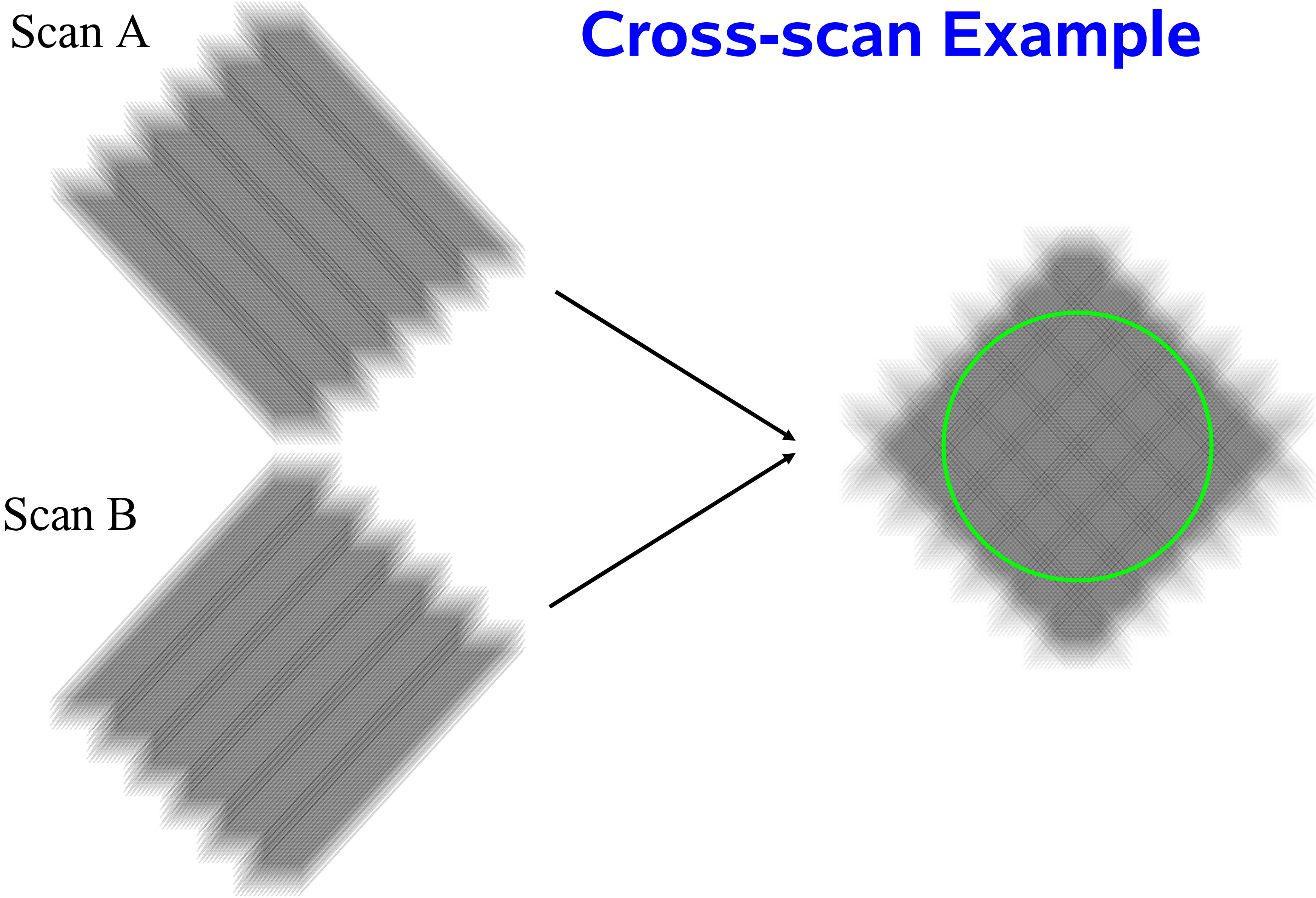


- Scan leg
- Map area covered to uniform sensitivity (user required area)
- SPIRE 250 μm array size

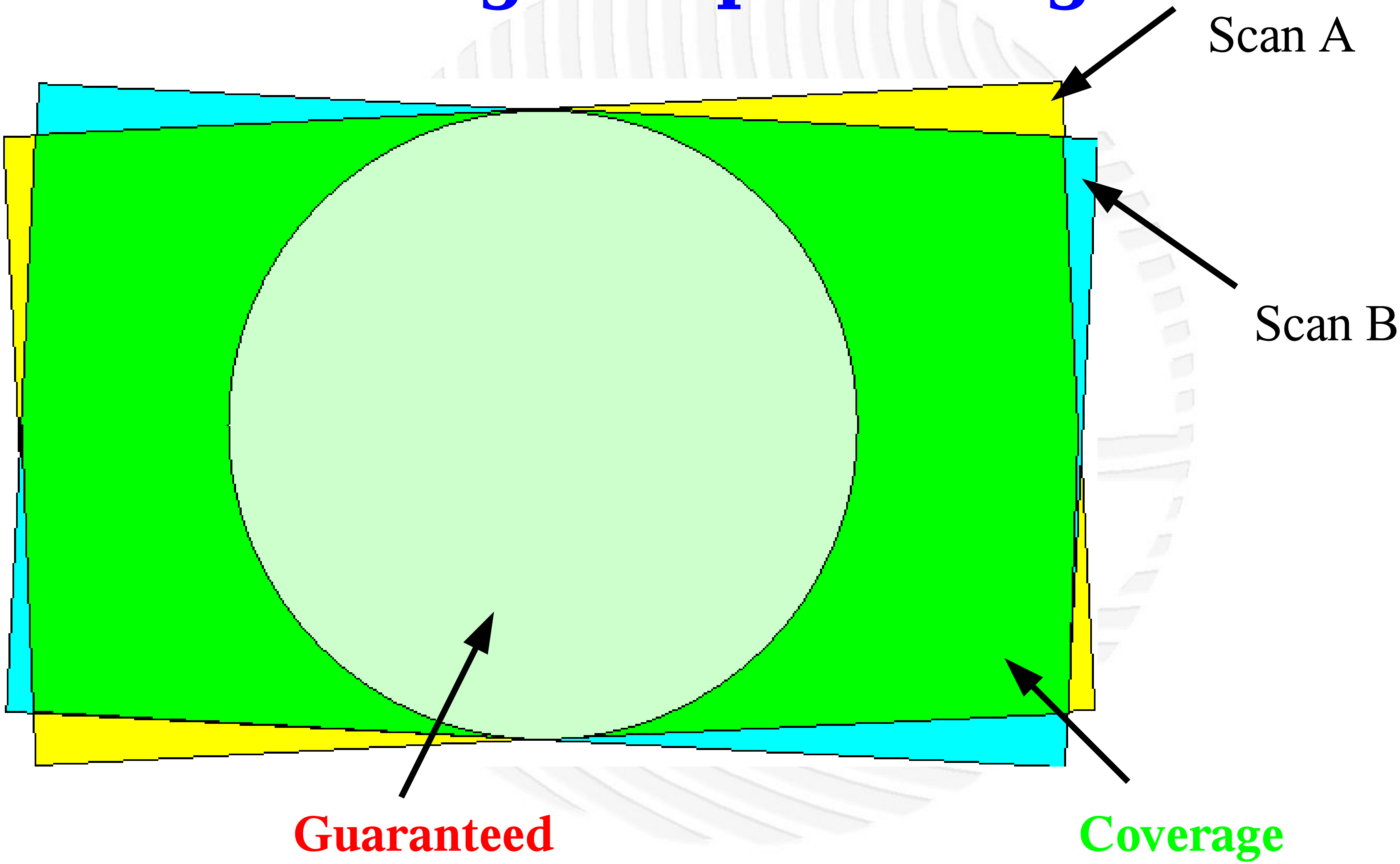
Large Map
1/f noise

- **Only in scan map mode**
  - Correlated and uncorrelated 1/f noise.
  - The correlated 1/f noise will be removed by the SPIRE pipeline.
  - Appears like large scale structure in the map and will affect the point source detection.
  - Uncorrelated 1/f noise can be dealt with by performing cross-linked observations.

Cross-scan Example



Large Map coverage



Large Map Observations

- **Scan speed:**
  Nominal (30”/s) and *Fast* (60”/s)
  - when to go for *Fast* scanning?
    - large-scale features (PSF smearing)
    - 1/f is less significant
- **Single scan direction:**
  either Scan A or Scan B direction
- **Cross-linked scans (default):**
  Scan A + Scan B

Large Map Observations

- Default scan speed: 30”/s
- Maximum scan length and height (single scan only): 19.82 x 4 deg
- Maximum cross-scan area: 226'x226' (~4x4 deg)
- Scan legs follow great circles on the sky
- Scanning angle is fixed at optimum observing
- Cross-linked observations for reducing 1/f noise
- Sensitive to all spatial scales, up to the size of the map itself

Large Map
some points to note

- '*On-source integration time*'
  refers to the total time it takes to observe the map area (excluding overheads)
  - This quantity does not determine the sensitivity
  - Sensitivity is governed by the number of map repeats
  - Maps of any size have the same sensitivity
  - This leads to discrete sensitivity levels: $\Delta S \sim 1/N^{1/2}$

- For single scan rectangular maps:
  - more efficient if scan length is greater than the scan height. It does not matter for cross-linked scans.

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Large Map overheads

- Telescope/spacecraft turn around and stabilisation of the pointing accuracy
  - acceleration/deceleration
- Regular (at least every 45 min) PCAL flashes
- The larger the map the more efficient the observation:
  - Effective integration time vs overheads

Large Map performance*

Array	250 μm	350 μm	500 μm
Effective integration time per map repeat (s)	11	11.4	12.3
ΔS (5 σ) for one map repeat (mJy)	68	93	79
Time to map 1 deg^2 to 3 mJy rms (hrs, excluding overheads)	8.5	16	12
Number of map repeats needed to reach 3 mJy rms	20	38	27

*HSpot sensitivities for version 3.0.7, Sep 2007

Large Map orientation

- Map orientation can be set:
  pair of angles East of North
- Currently no indication in HSpot:
  but see the SPIRE Observers' Manual
- Penalized by 10 min overhead

Large Map Résumé

- For areas greater than 4 arcmin diameter
- Scanning at constant speed over great circles at a specific angle
- Cross-linked scans to fight uncorrelated 1/f noise (max 4x4 deg)
- Sensitivity by map repeats

SPIRE Spectrometer

Spectrometer observing modes

Source size

Single point
(1 FOV with diameter of 2')

Raster
(many FOVs)

Spatial sampling

Sparse
2 beam spacing

Intermediate
1 beam spacing

Full
½ beam spacing (Nyquist)

Spectral resolution

(unapodised)

High 0.04 cm^{-1} (1.2 GHz)
Medium 0.25 cm^{-1} (7.5 GHz)
Low 1.0 cm^{-1} (30 GHz)
Low+High

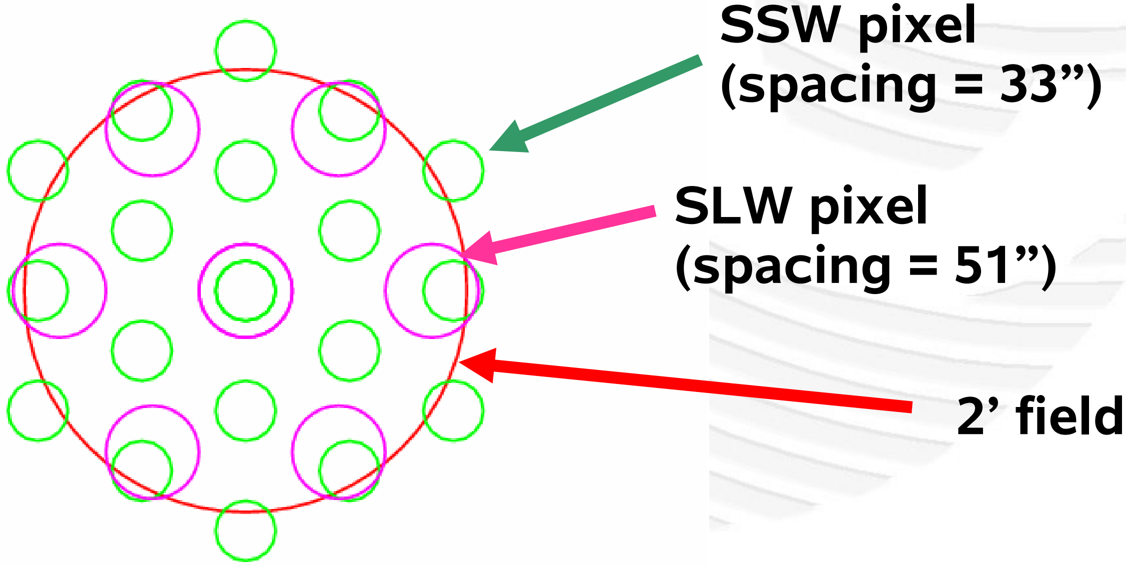
(constant in frequency)

24 possibilities

Spectrometer

→ SINGLE POINT: SPARSE

- Always get data from whole array



Spectrometer

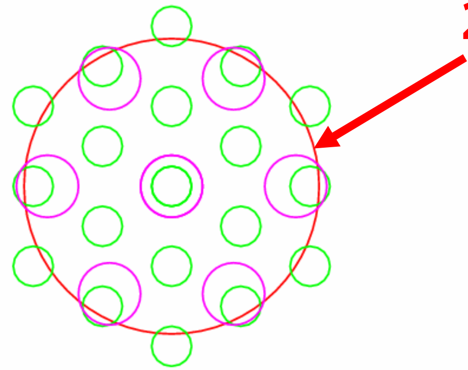
→ SINGLE POINT: SPARSE, INTERMEDIATE or FULL

SPARSE

2 beam spacing

SSW: 33”

SLW: 51”



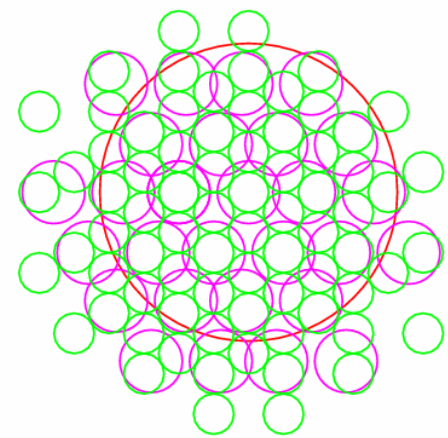
2’ field

INTERMEDIATE (4pt)

1 beam spacing

SSW: 16”

SLW: 25”

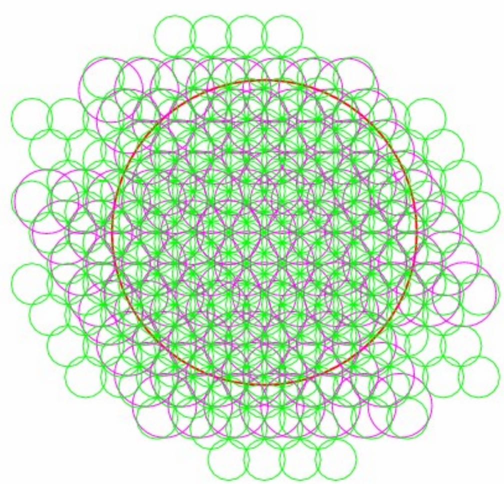


FULL (16pt)

½ beam spacing

SSW: 8”

SLW: 12”



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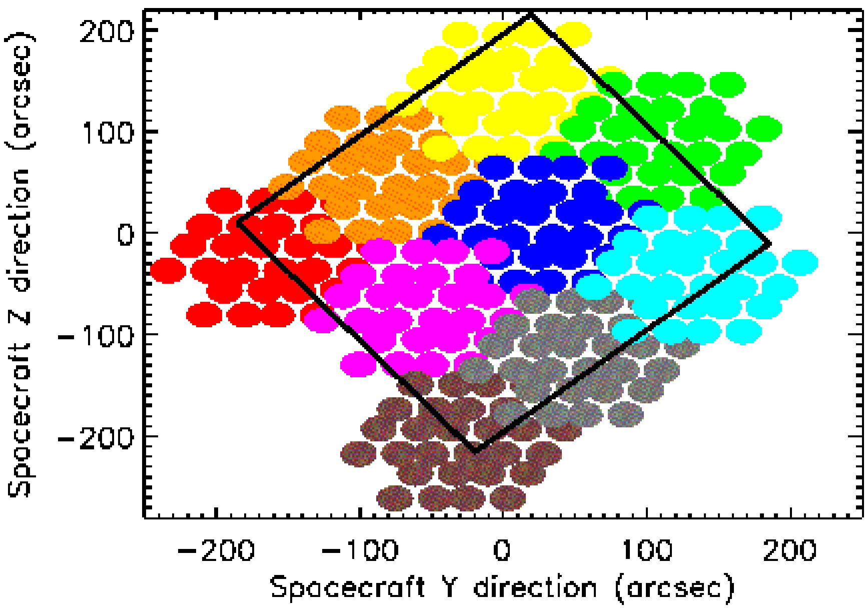
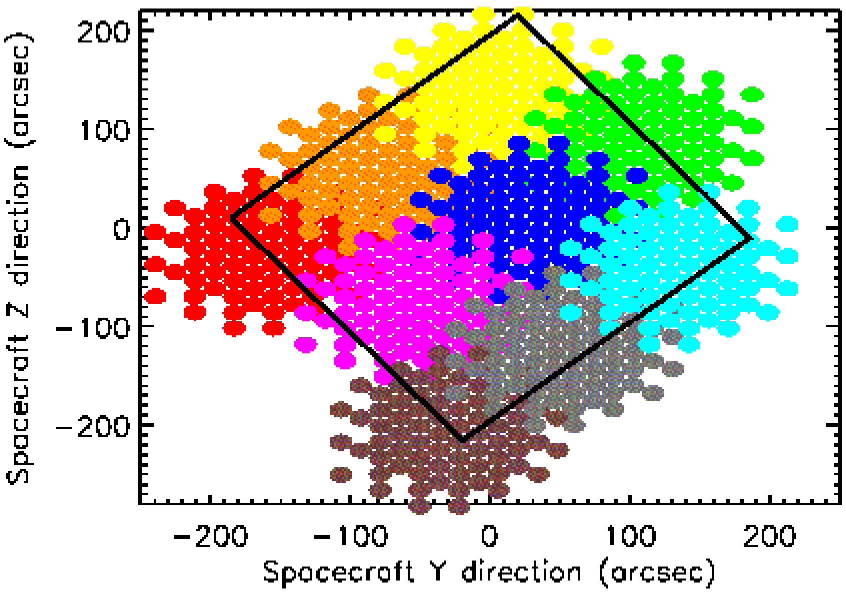
Spectrometer

→ RASTER: INTERMEDIATE



3x3 deg SLW



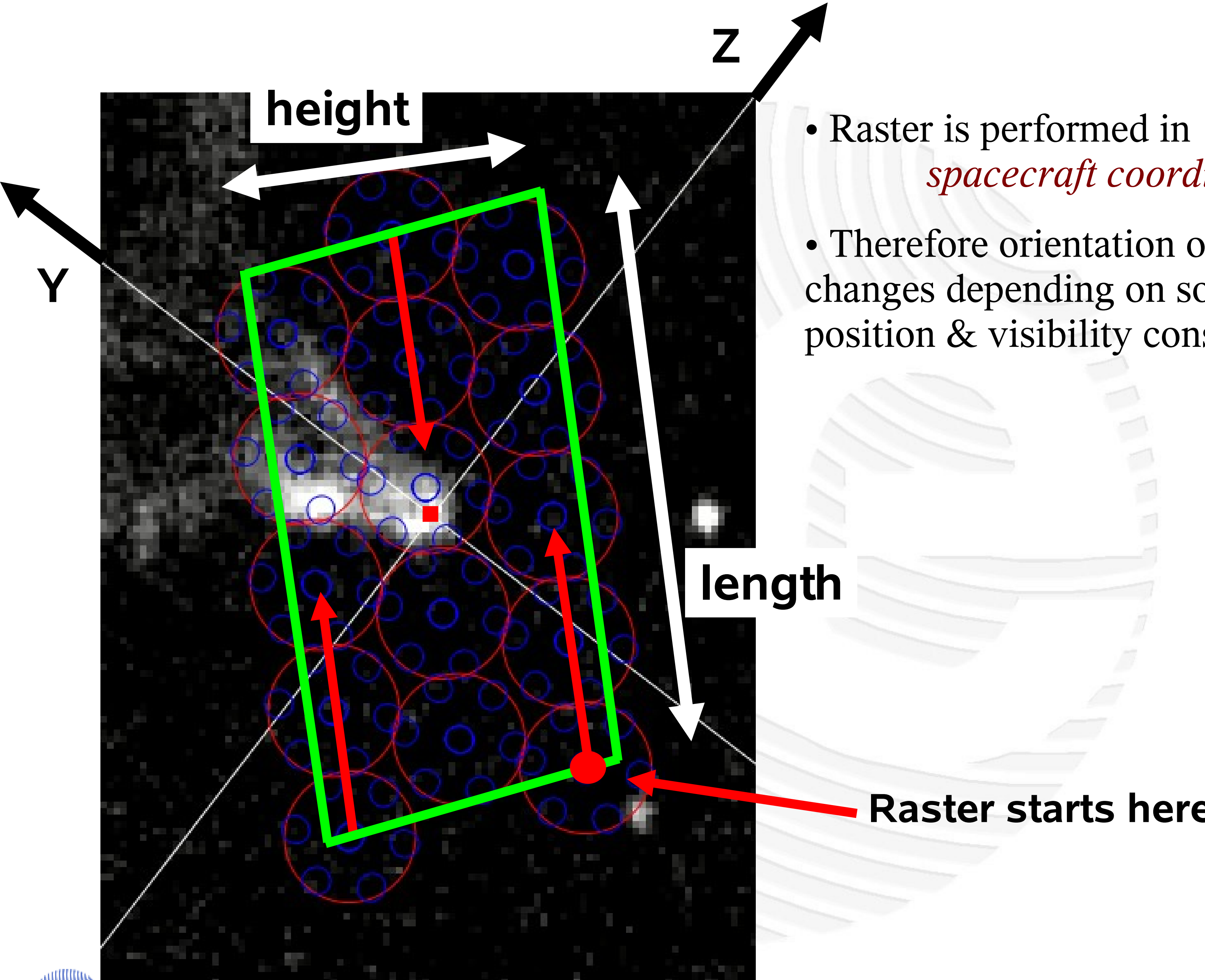
3x3 deg SSW

4pt jiggle at each raster

Spectrometer

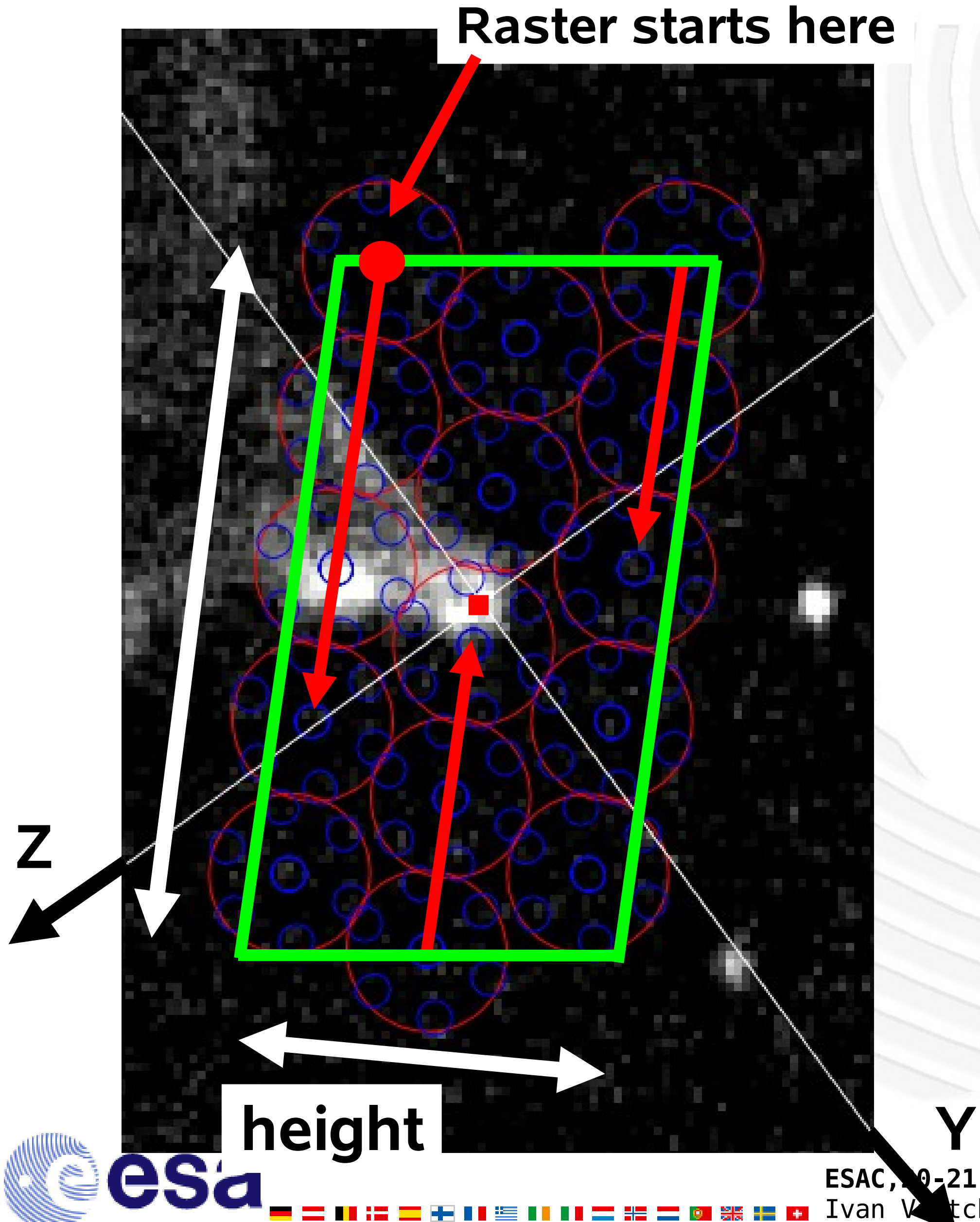
→ RASTER:

- The raster map is made up from a combination of individual fields of view
- Raster direction is fixed to spacecraft axes not to sky coordinates → check visualisation on different days!
- Coverage is a *parallelogram* on the sky
- Split into separate observations to make more complicated shapes



- Raster is performed in *spacecraft coordinates*
- Therefore orientation on the sky changes depending on source position & visibility constraints

HERSCHEL SPACE OBSERVATORY



- Raster is performed in *spacecraft coordinates*
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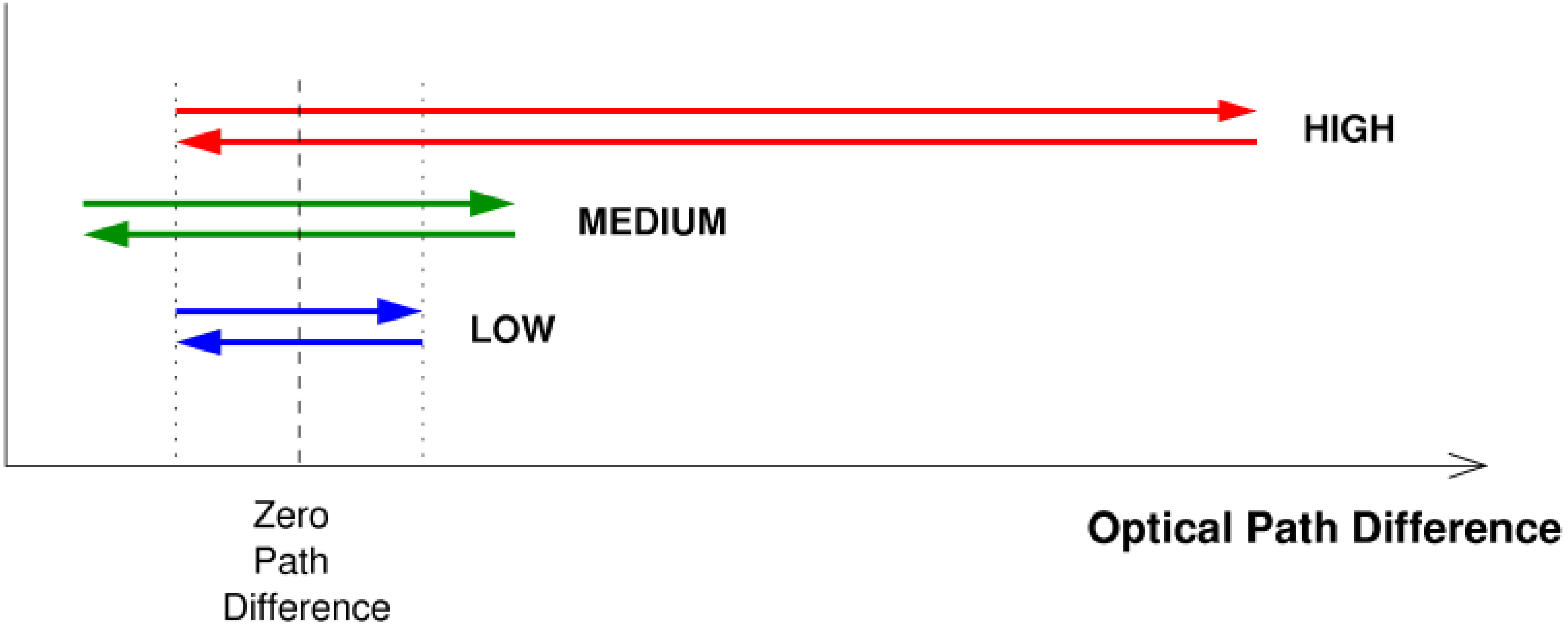
Spectrometer
Spectral resolution

SMEC movement

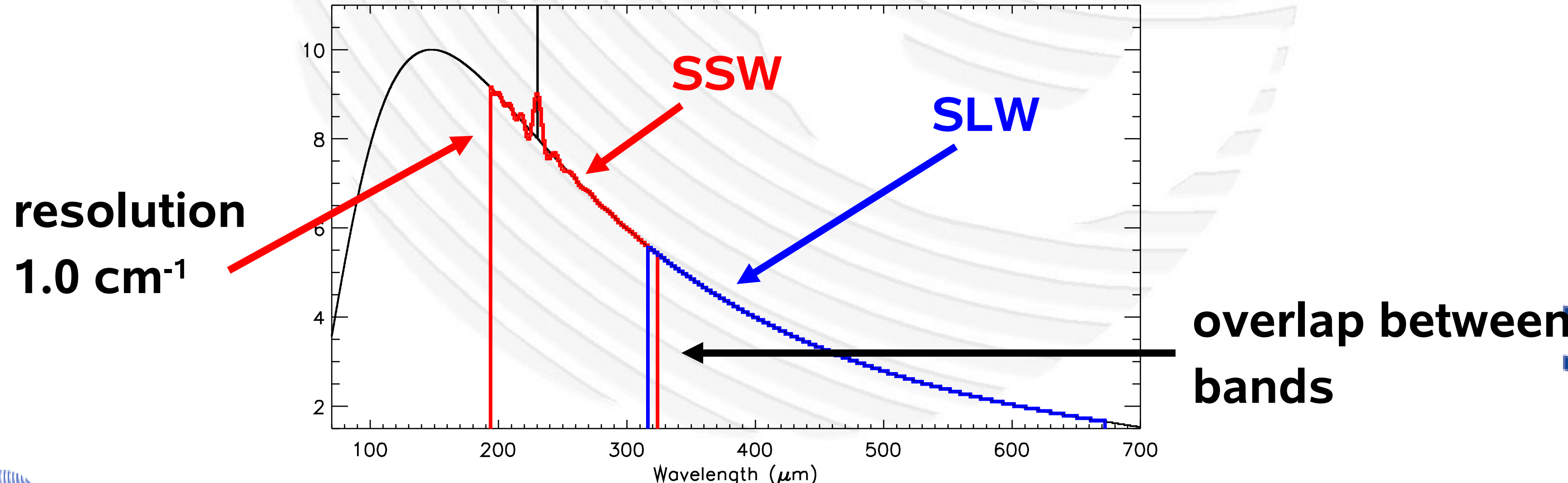


Spectrometer point source spectrum

LOW $\Delta\sigma$ = 1.0 cm^{-1} (30 GHz); R = 52 – 15

- Continuum measurements

36 (20+16) resolution elements across the whole range



Spectrometer
point source spectrum

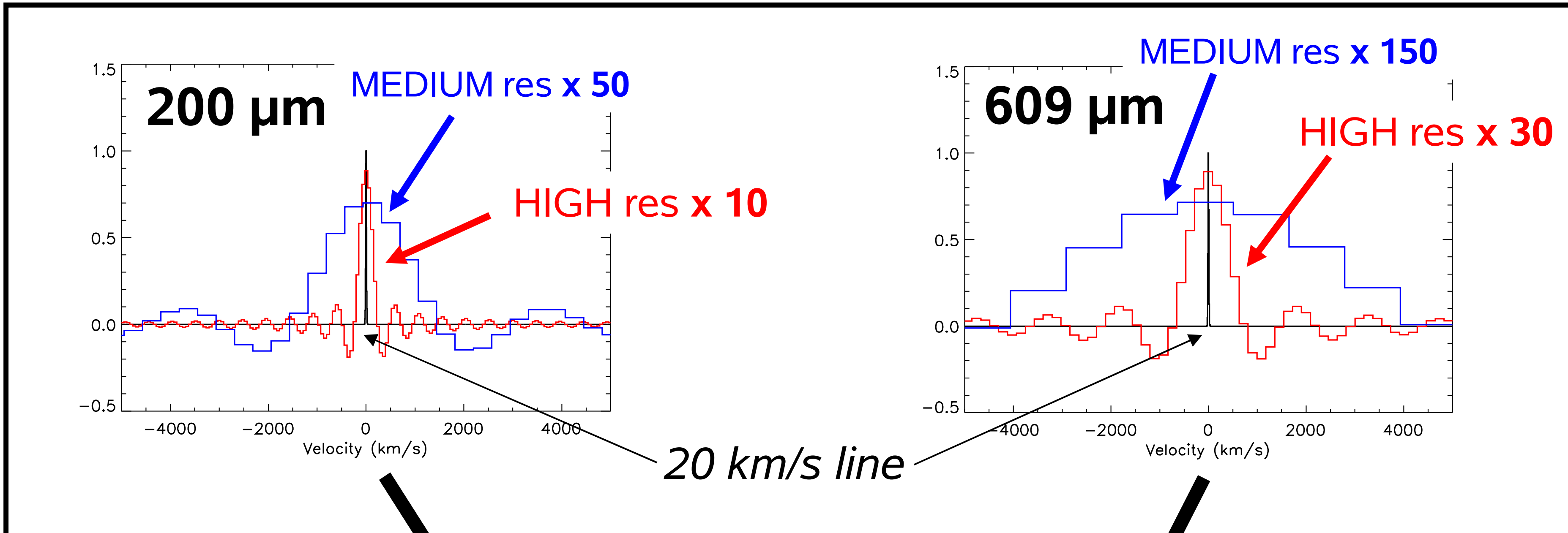
MEDIUM $\Delta\sigma = 0.25$ cm^{-1} (7.5 GHz); *R=200 – 60*

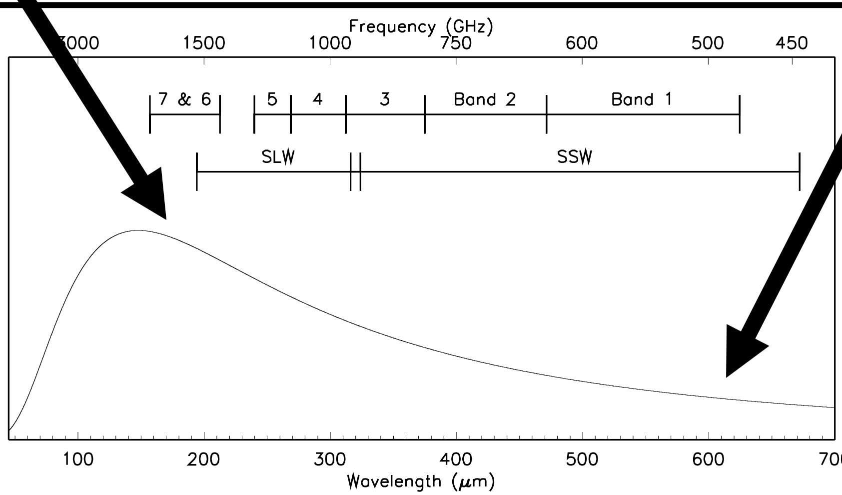
HIGH $\Delta\sigma = 0.04$ cm^{-1} (1.2 GHz); *R=1290 – 370*

- Line spectroscopy
- Measurement of total integrated line fluxes

(line widths 280 – 840 km/s in HIGH resolution mode)

High and Medium example





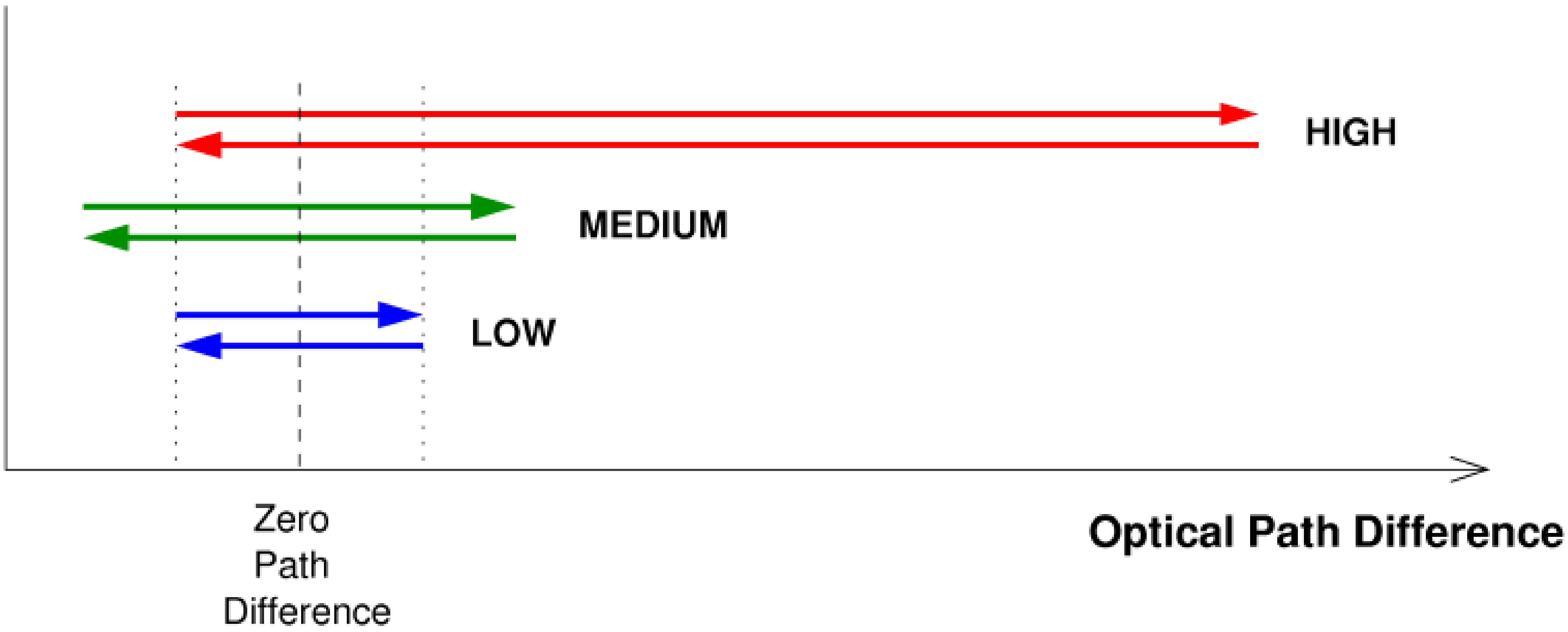
200 µm
(1499 GHz)

280 km/s (HIGH)
1810 km/s (INT)

609 µm
(492 GHz)

850 km/s (HIGH)
5510 km/s (INT)

High+Low resolution



Low resolution spectra are extracted from High resolution ones.

Spectrometer sensitivity

Note that all sensitivities are quoted for a point source on axis at 200 µm

Minimum times for each spectral resolution are (repetition=2)

LOW (30 GHz)	**26 sec** →	**0.27 Jy RMS**
MEDIUM (7.5 GHz)	**98 sec** →	0.55 Jy RMS → **4.1 x 10^{-17} W/m^2**
HIGH (1.2 GHz)	**266 sec** →	**0.27*** Jy RMS → **2.5 x 10^{-17} W/m^2**
HIGH+LOW	**292 sec** →	**0.19*** Jy RMS → **2.5 x 10^{-17} W/m^2**

Using the low resolution part in High res observations.

Why use FTS?

- The line sensitivity is good for broad lines (200 km/s) at low wavelengths (~200 μm).
- The full spectral range from 194 to 672 μm in one go.
- Always get a sparse map around the source.
- No wavelength calibration necessary.

Concluding remarks

- Offsets:
  - for each bolometer at the beginning of an observation
  - cannot be changed during an observation
  - can lead to “saturation” for bright sources or strongly varying background
- The photometer is the primary instrument
- Be careful when setting constrained observation
  - check visibility
  - check observing efficiency
- Use concatenation/grouping whenever appropriate

Where to go from here

Herschel Science Centre Web Pages:

– http://herschel.esac.esa.int

– Herschel Manuals + many other useful information and links.

Register to Herschel and use the help-desk

The End