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DataCubes in Astrophysics

Lesson 4

Image convolution

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Or, more practically…:

Image convolution

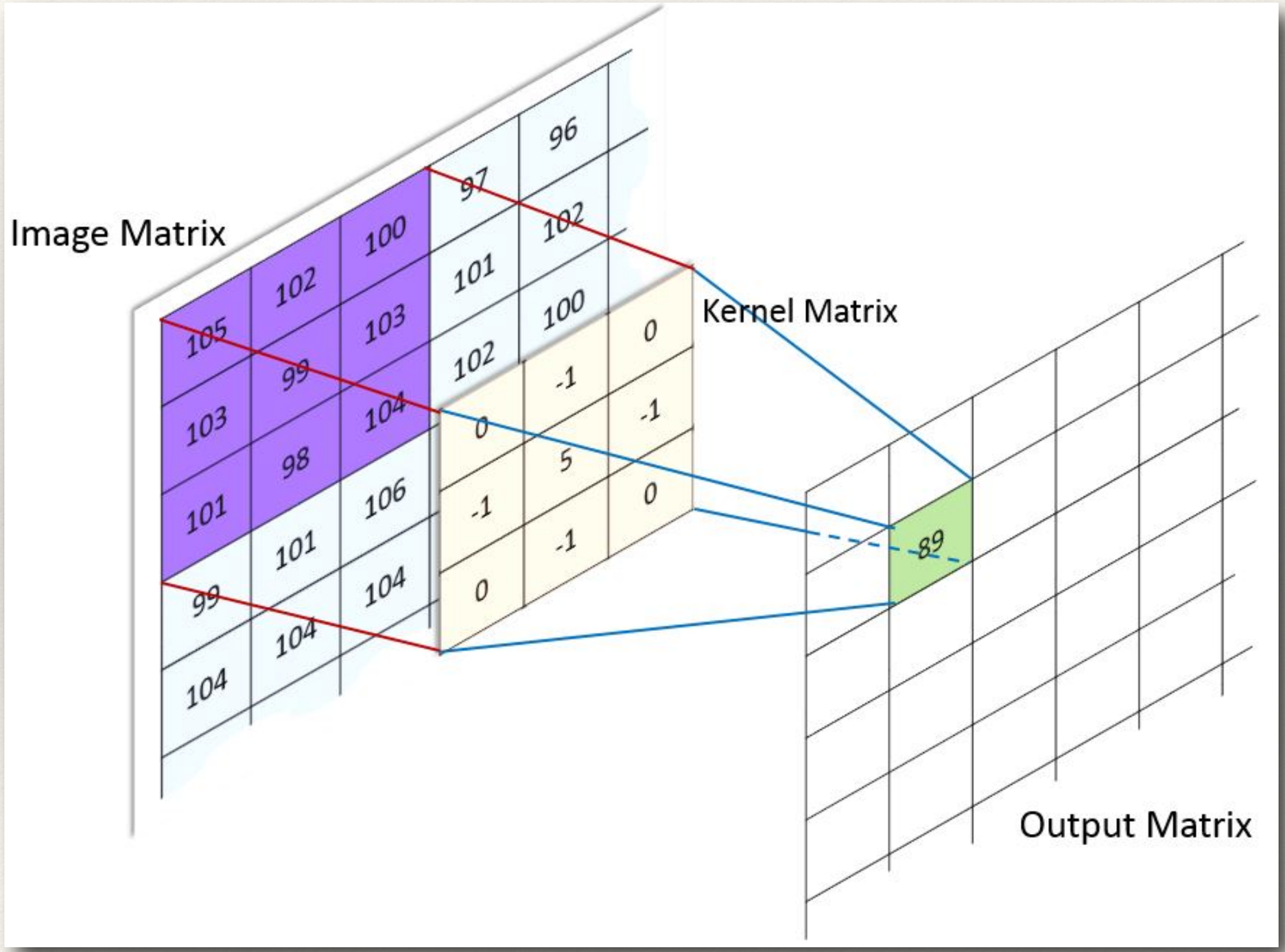

Image convolution

- With astronomic images, convolution is very often use to simulate observations with lower spatial resolution;
- when comparing 2 images, pixel by pixel, taken with different *instruments* or at different *wavelength*, the different characteristics of the PSF must be taken into account.

The Point Spread Function

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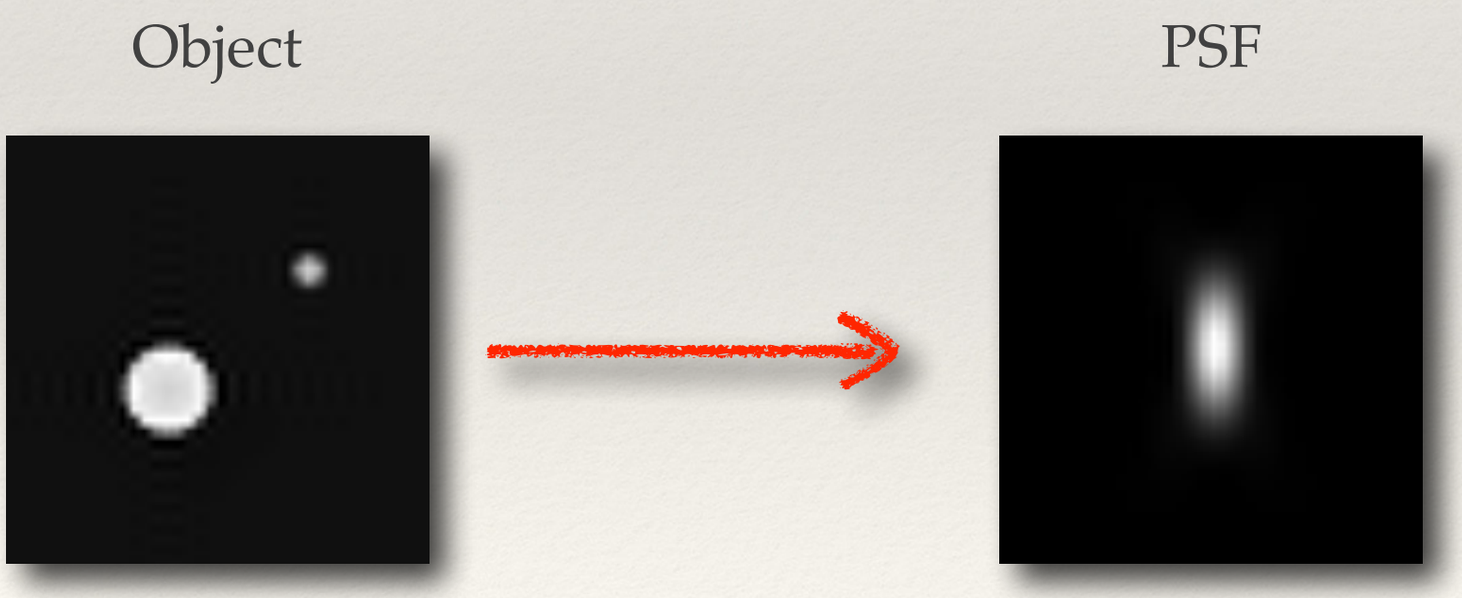

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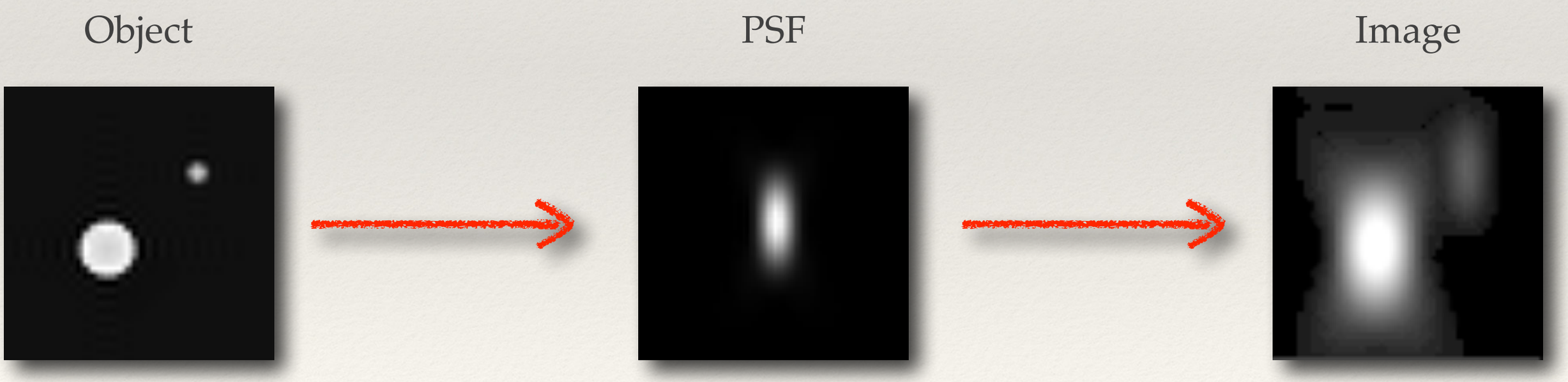
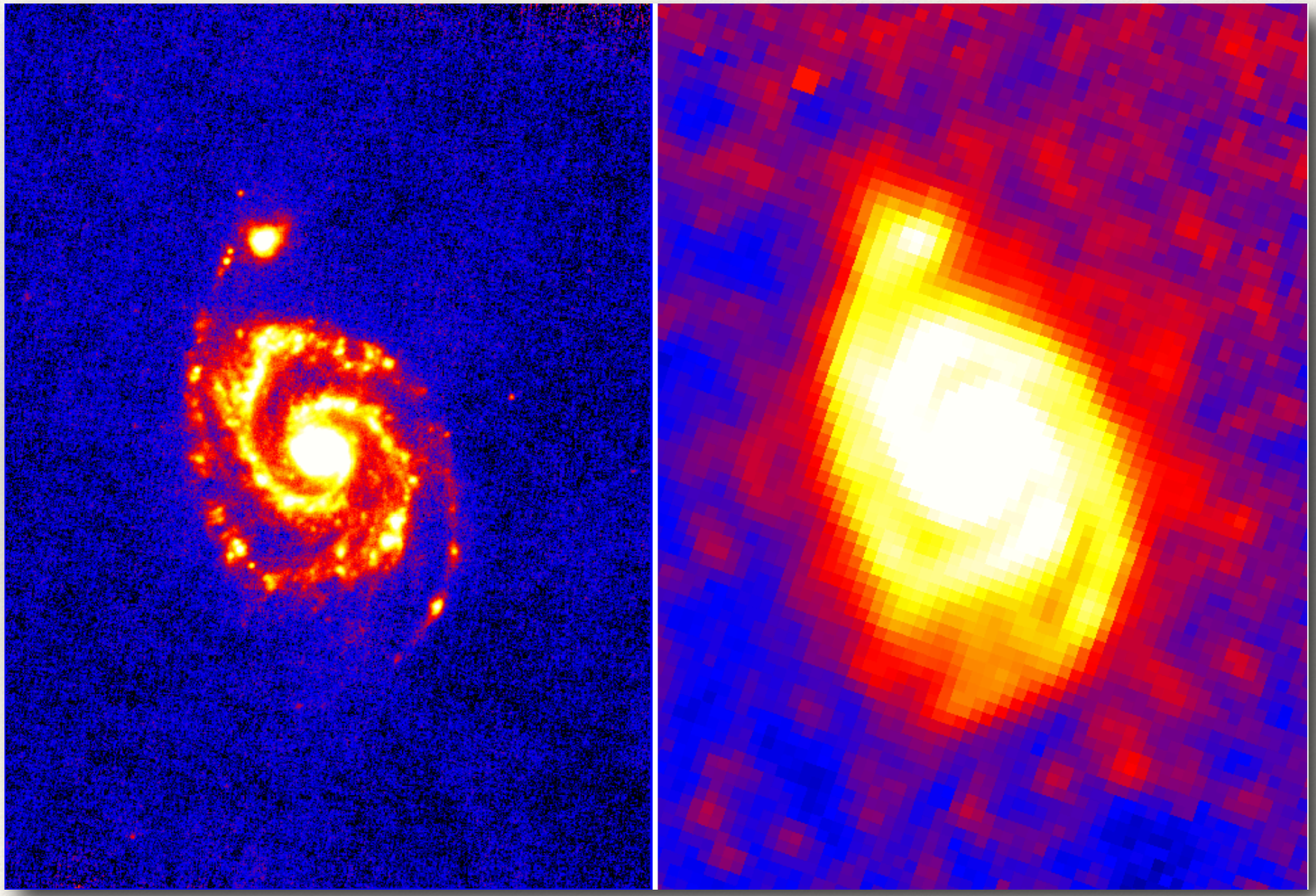


Image convolution

70 μm

500 μm

M51



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A list of Kernels can be found here:

https://www.astro.princeton.edu/~ganiano/Kernels.html

How to convolve?

- In the ideal case of an image with “infinite” resolution (a point source is a delta of Dirac function), we can use a 2D gaussian whose FWHM is the one of the low-resolution image;
- if the “high resolution image” is characterized by a PSF (as it always is), then we need to take this into account:

$$FWHM_{conv} = \sqrt{FWHM_L^2 - FWHM_H^2}$$

$$FWHM = 2 \cdot \sqrt{2 \ln 2}\sigma \simeq 2.35482 \cdot \sigma$$

How to convolve?

- Find the beam (linear) size of the two images;
- calculate the FWHM of the gaussian you need to convolve;
- convert to a value of sigma;
- create a kernel;
- convert the image to be convolved into surface brightness units;
- do the convolution;
- do the re-gridding.

Importing and reading

```
import numpy as np
from astropy.io import fits
from FITS_tools.hcongrid import hcongrid
from astropy.convolution import Gaussian2DKernel
from scipy.signal import convolve as sp_convolve
psf1 = # psf of the hi-res image in (for example) arcminute
psf2 = # psf of the low-res image in (for example) arcminute
kk = 2.*np.pi/(360.*3600.)          # one arcsec in rad units
img1 = 'image1'
img2 = 'image2'
hdulist1 = fits.open(img1)
hdulist2 = fits.open(img2)
header1 = hdulist1[0].header
header2 = hdulist2[0].header
cube = hdulist1[0].data      #data at the highest resolution
```

Convolution & re-gridding

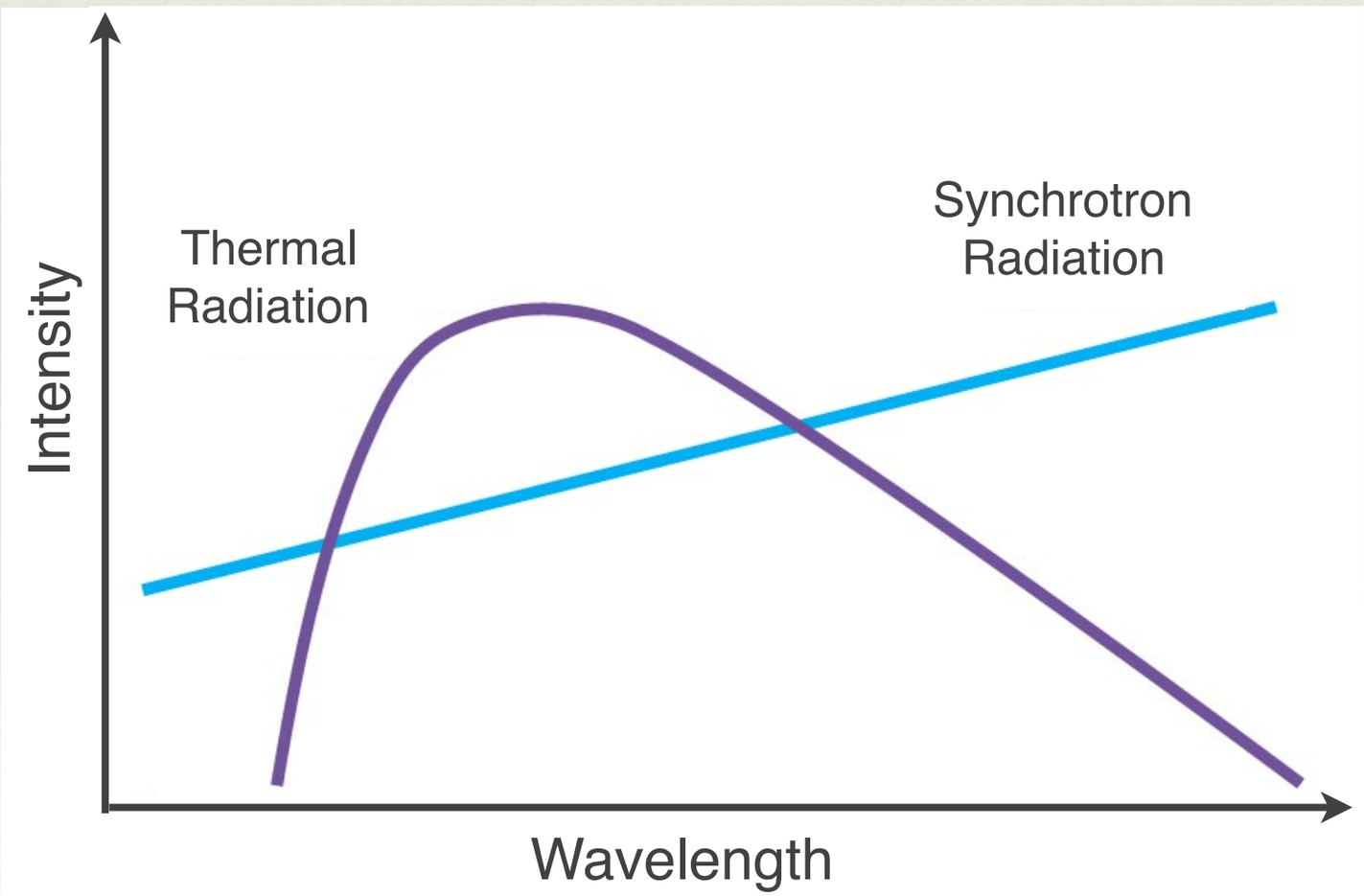
```
flx = cube[0,m,:,:]
pixsz1 = np.abs(header1['CDELT1'])*3600.
pixsz2 = np.abs(header2['CDELT1'])*3600.
flx_sb = map/(kk**2*pixsz1**2)
sigma = np.sqrt(psf2**2-psf1**2)/pixsz1
kernel = Gaussian2DKernel(stddev=sigma,x_size=40,y_size=40)
convolved = sp_convolve(flx_sb, kernel, mode='same')
flxmap = hcongrid(convolved,header1,header2)
flx_reg = flxmap*kk**2*pixsz2**2
outfile = 'convolved.fits'

hdu_s = fits.PrimaryHDU(flx_reg,header=header2)
hdu_s.writeto(outfile)
```

IR (Herschel) datacubes

IR emission: Where from?

- Thermal emission from dust;
- synchrotron emission from relativistic electrons.



IR emission: Where from?

- Thermal radiation is the electromagnetic radiation generated by the thermal motion of charged particles in matter;
- the thermal radiation spontaneously emitted by many ordinary objects can be approximated as black-body radiation;
- dust is very efficient in absorbing optical and UV light;
- Kirchoff's Law tells us that bodies that are good absorbers must also be equally good radiators.

IR emission: Where from?

- Equilibrium temperatures of grains exposed to the average interstellar radiation field are in the range of 20-50 K (or more);
- this means that they radiate predominantly in the far-IR (50-200 μm);
- NOTE that dust grains are DO NOT emit like blackbodies, but radiate as <u>modified blackbodies</u> with a strong <u>wavelength-dependent emissivity</u>.

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DUST

- Dust constitutes (ON AVERAGE!!!) about 1/100 —in mass— of the ISM;
- acts as a catalyst for molecular hydrogen formation;
- shields HII regions from UV photon preventing their dissociation;
- absorbs UV-optical light (30-50% on average but can be more), changing the way we observe astrophysical targets;
- creates the building blocks for planets.

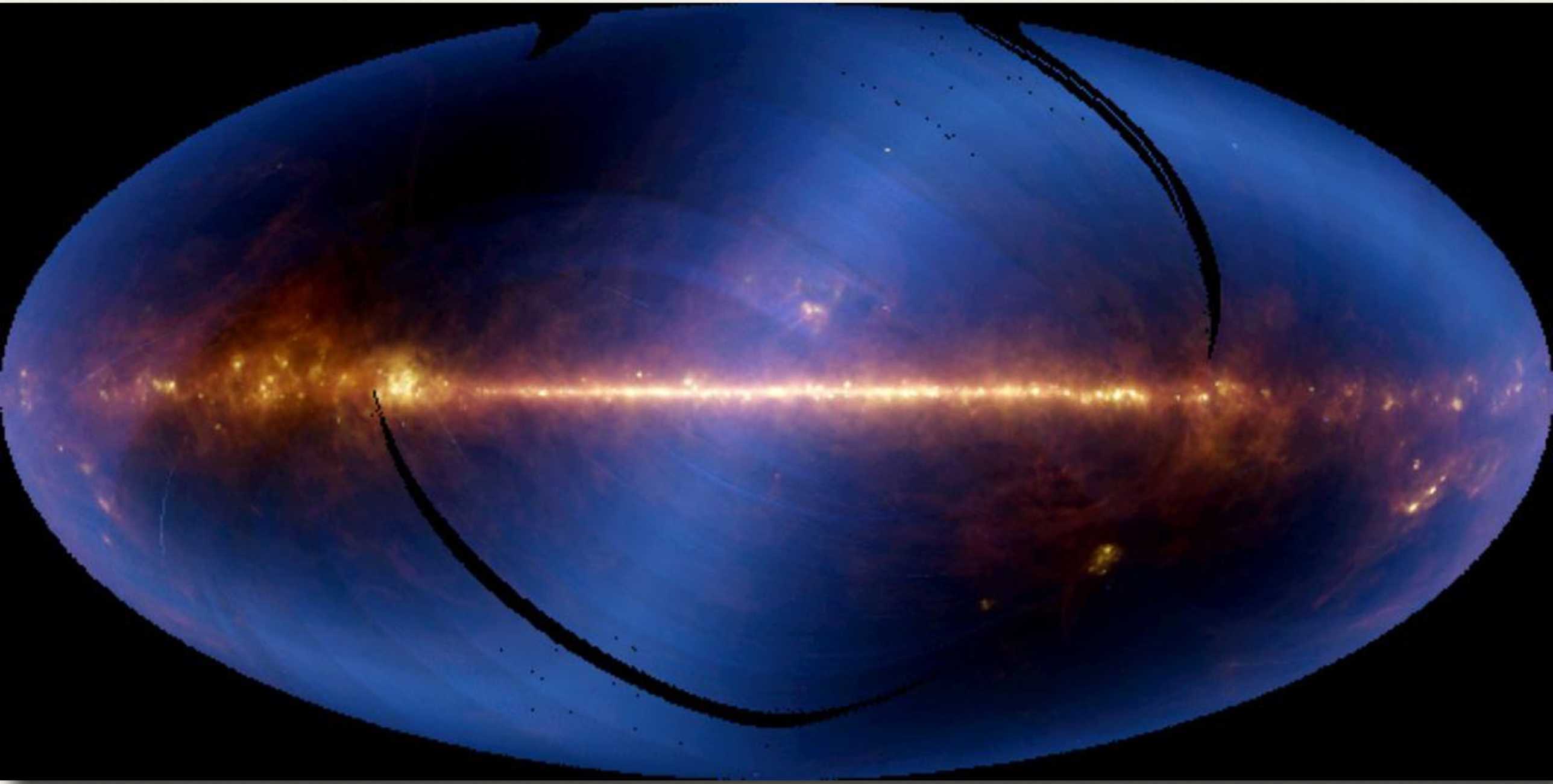
INFARED TELESCOPES

IRAS

- Launched in 1983;
- duration ~ 10 months.
- 57 cm cooled (4 K) mirror;
- 12, 25, 60, and 100 μm bands;
- 30′′ to 120′′ resolution;
- (decommissioned in 1983);
- performed the first FIR all-sky survey.

The IR Universe as seen by IRAS

Observed (among the other) about 250.000 IR sources



Opened a completely new view of the Universe

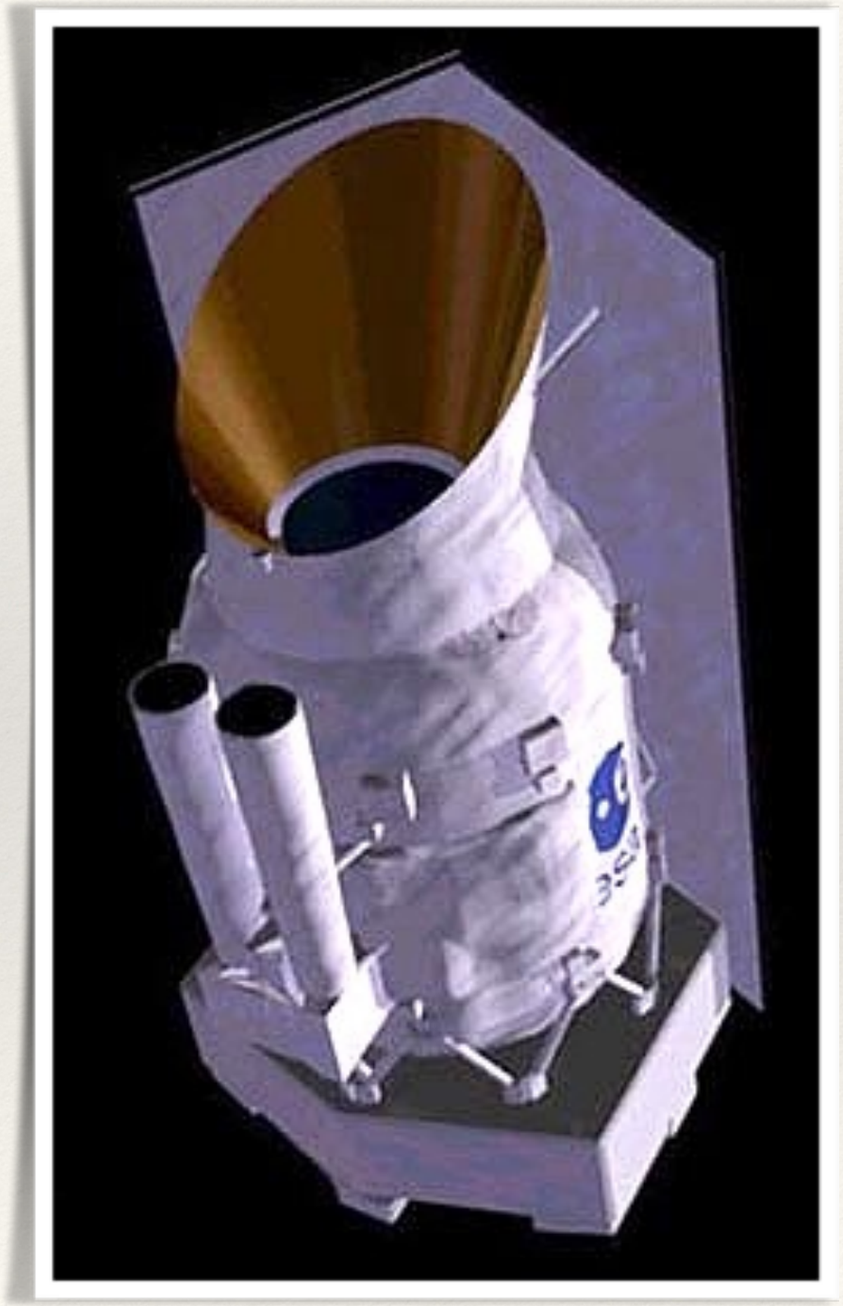
The IR Universe as seen by IRAS

- Covered 96 % of the IR sky in its 4 bands;
- created a catalogue of point and extended sources;
- more than 245.000 sources classified (many with formerly unknown counterparts).

Subsequent missions: ISO

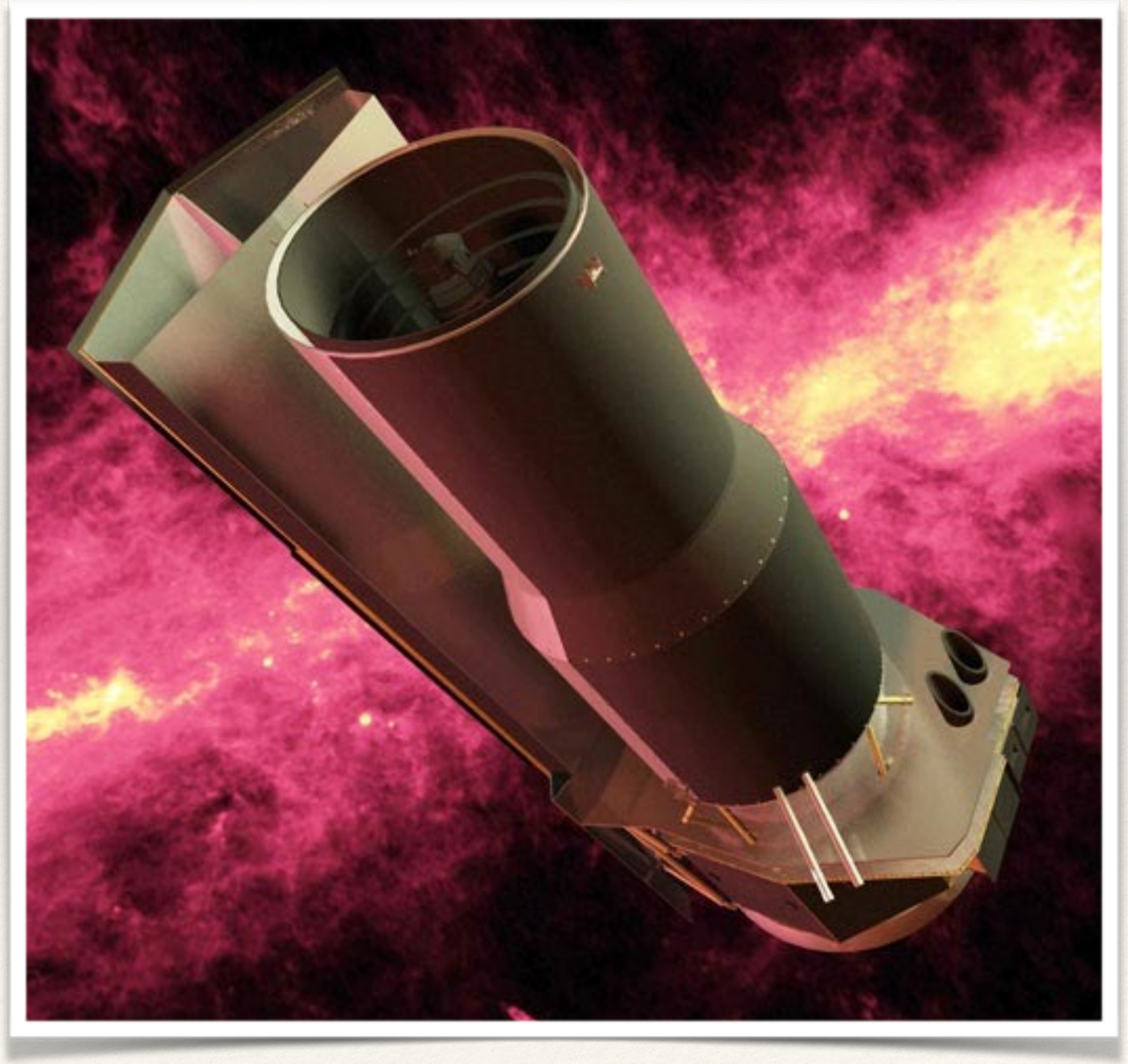
- Launched in 1995;
- duration ~ 29 months.

- 60 cm cooled (1.7 K) mirror;
- photometry (2.5 to 240 μm);
- spectroscopy (2.5 to 197μm);
- 30'' to 120'' resolution;



Subsequent missions: Spitzer

- Launched in 2003;
- duration ~ 5 year (currently in "warm phase").
- 85 cm cooled (~5.5 K) mirror;
- IRAC: photometer 3.6, 4.5, 5.6, 8 μm (1.44'', 1.80'', 1.49'', 1.71'');
- IRS: spectrometer (5.2 to 38 μm);
- MIPS: photometer 24, 70, 160 μm (6'', 18'', 40'').

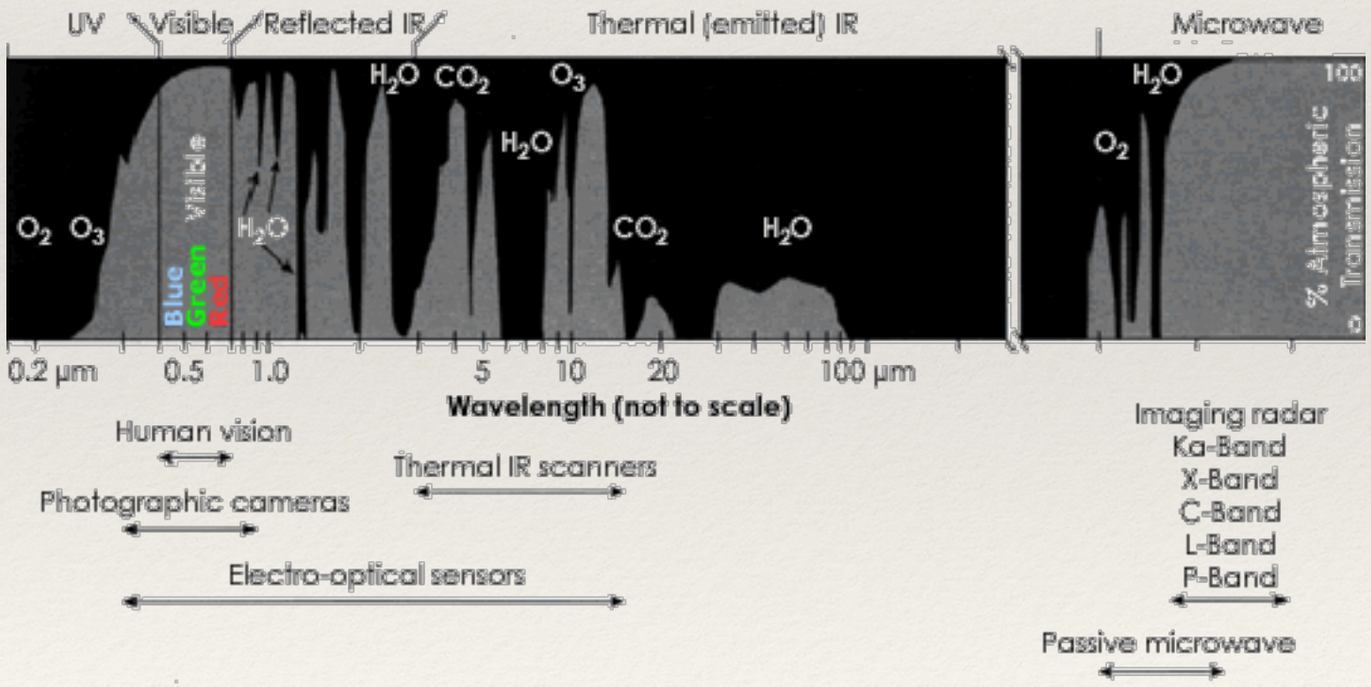


Subsequent missions: Herschel

- Launched in 2009;
- duration ~ 4 year (currently "dead").
- 3.5 m (~80 K) mirror;
- PACS: photometer 70/100, 160 μm (with spectral capabilities);
- SPIRE: photometer 250, 350, 500 μm (with spectral capabilities);
- HIFI: high-resolution spectrograph.

The enemy: atmosphere

- The (atmospherical) extinction coefficient in the IR is a strong function of the wavelength (caused by several different molecular species);



The enemy: atmosphere

- At $\lambda \lesssim 2$ μm, the night time sky background is dominated by (Rayleigh) scattered moon and star-light;
- at $\lambda > 2.3$ μm, the thermal (BB) radiation;
- depending on the observing site temperature, the telescope and the dome will also become an important source of IR emission;
- the detectors might be the dominant source of signal.

The space is not ideal either!

- Zodiacal light background: coming from dust in the solar system lying close to the ecliptic plane (see the works by Brian May);

- this is observed as scattered sun light, dominating the background up to about 3.5 μm;
- at longer wavelengths it is produced by the thermal emission from these particles.

The space is not ideal either!

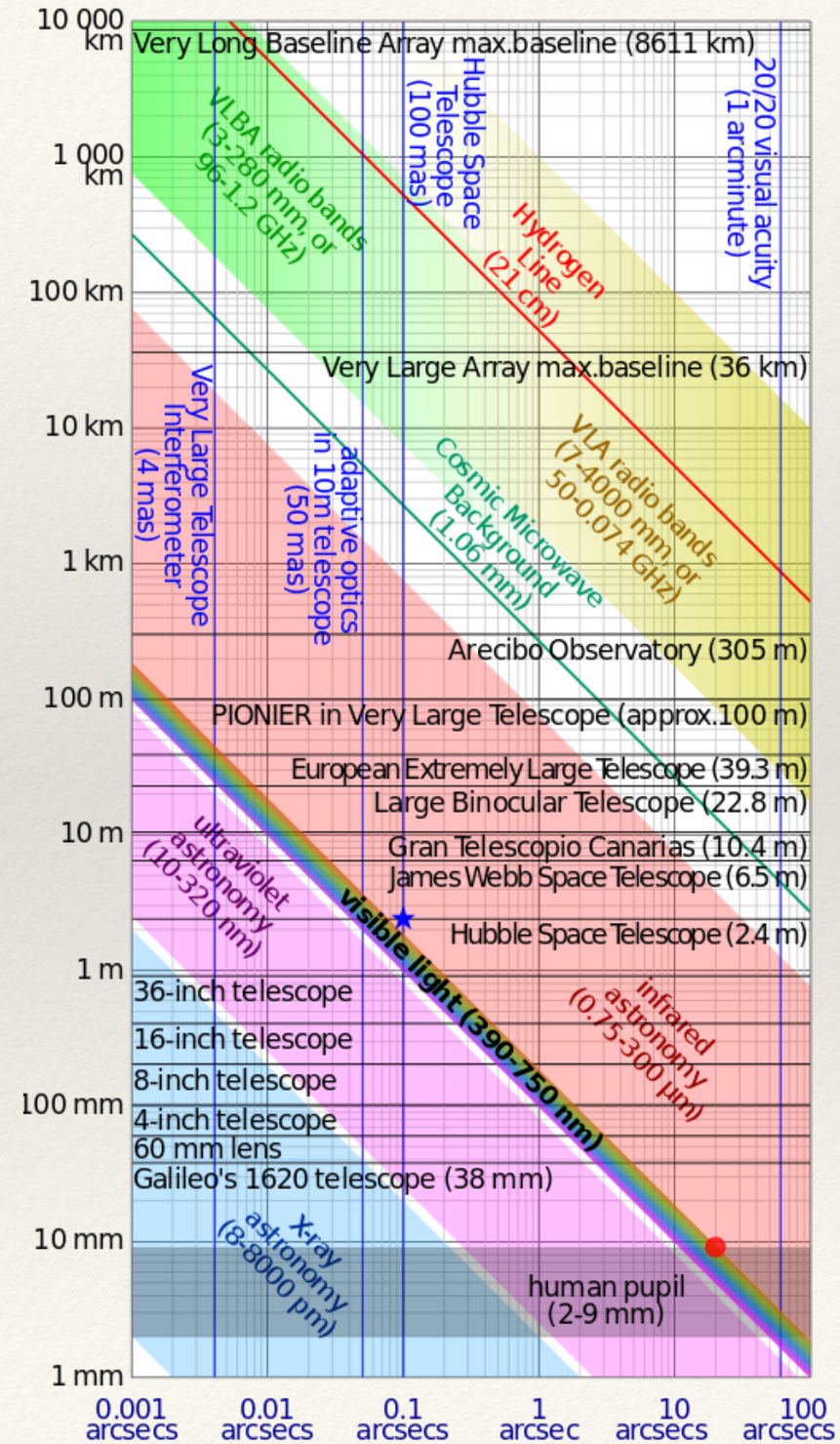
- Beyond 100 μm, the intergalactic dust (cirrus) is the main contributor to the background;
- the cosmic microwave background is the dominant source of background emission beyond 300 μm.

The Spatial Resolution

The angular resolution of a given dataset depends on:

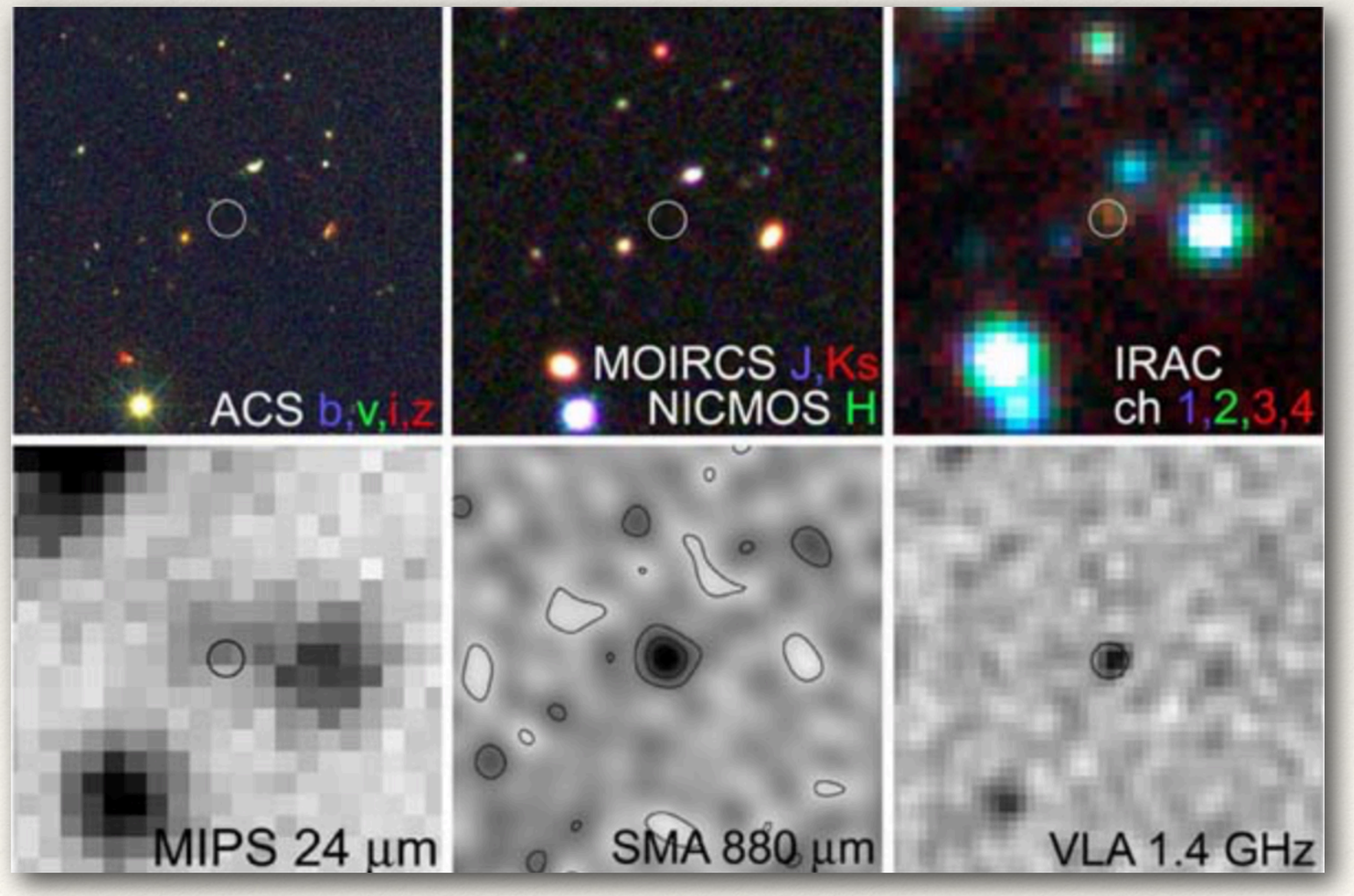
1. the wavelength of the data;
2. the diameter of the telescope.

$$\theta = 1.220 \frac{\lambda}{D}$$



Confusion

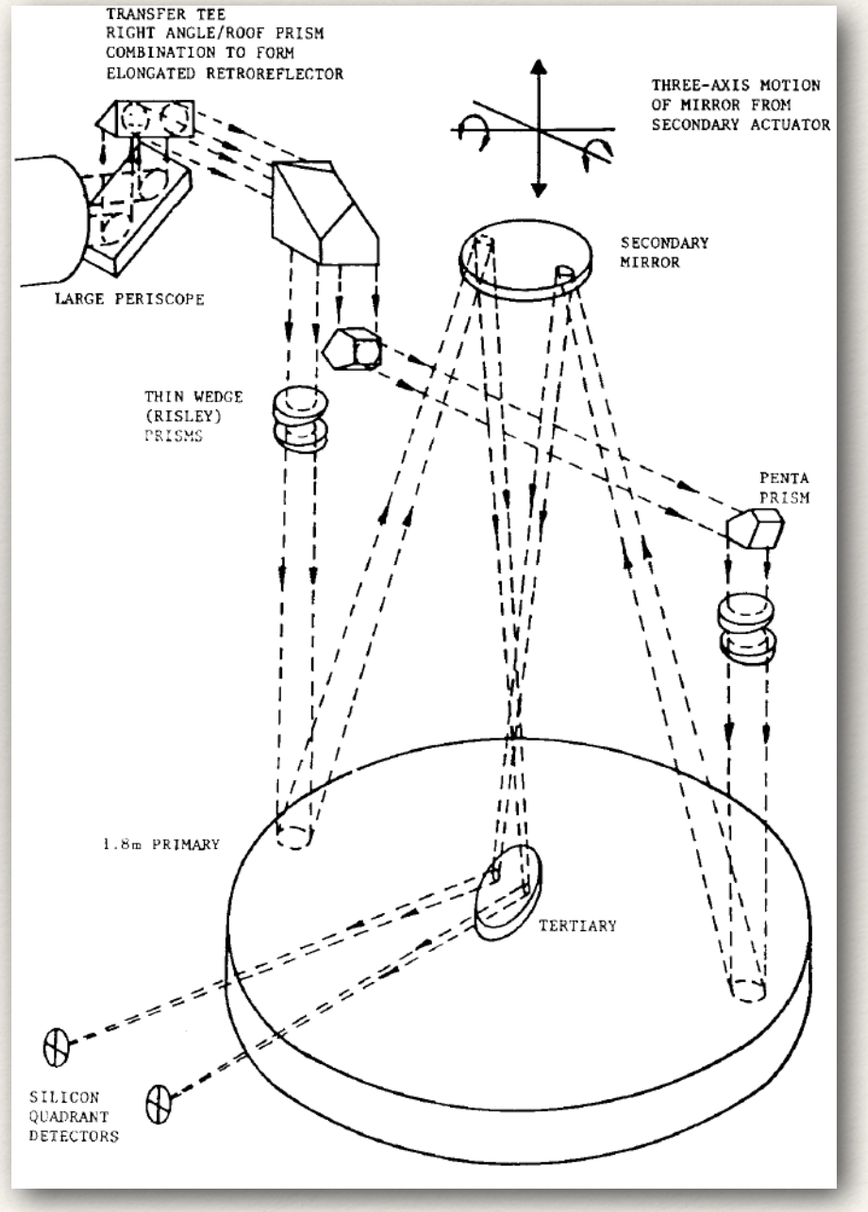
This is one of the reasons why the same field, when observed at different wavelengths and with different instruments, might appear very different



Observing technique(s)

CHOPPING

- A “chopper” is a mechanism which allows the secondary mirror to be rapidly tilted back and forth.



Observing technique(s)

CHOPPING

- Offers a way to overcome fluctuations in the background radiation;
- measure the signal from an “empty” portion of the sky, and subtracts it;
- done at a frequency of several time per second.

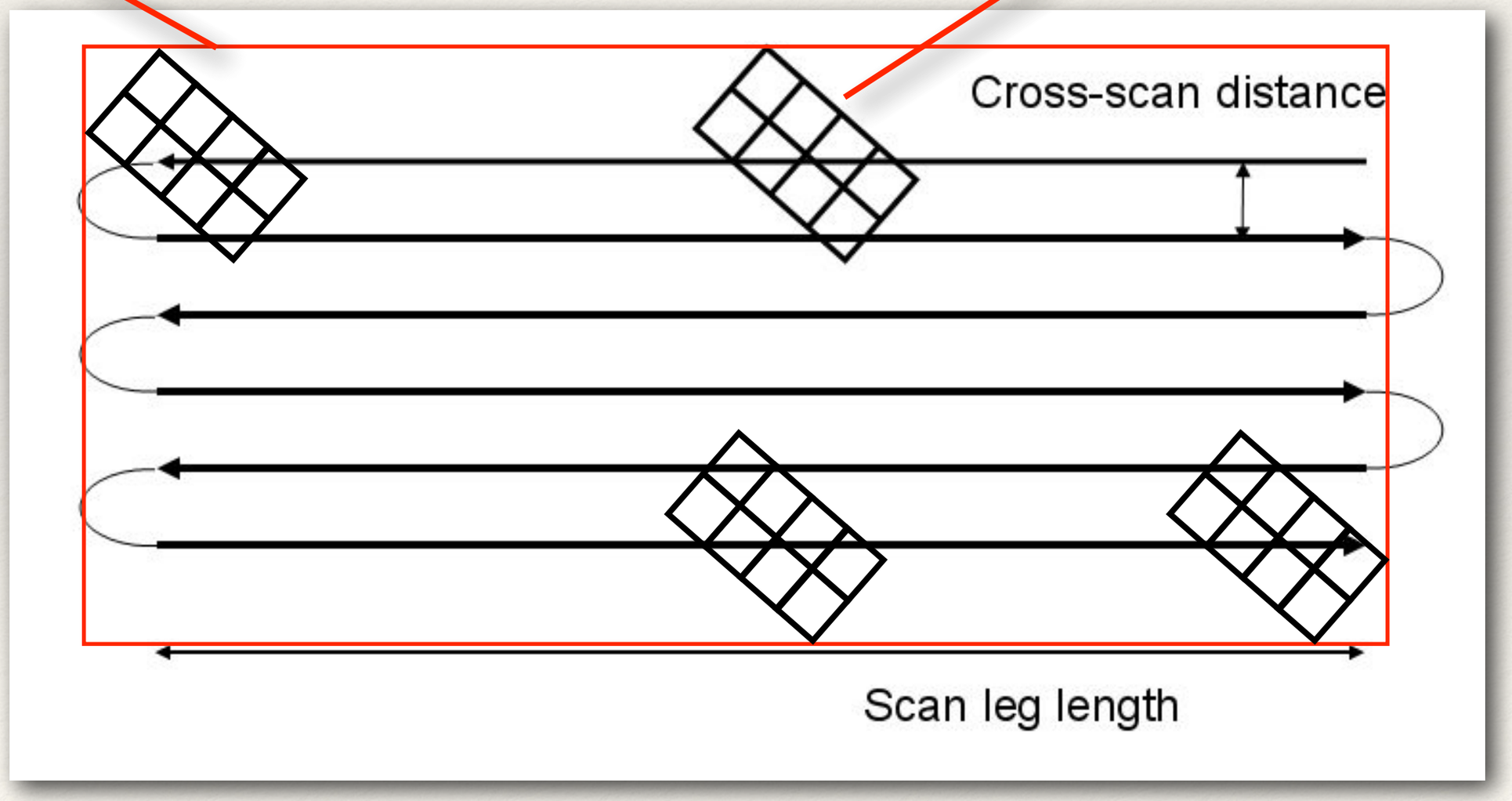
Observing technique(s)

SCANNING

- Scan maps are performed by slewing the spacecraft at a constant speed along parallel lines;
- this avoids technical problems of the “classical” readout techniques;
- several pixels “see” the source (at different times);
- the image is then reconstructed by projecting the pixels’ readings as a function of position.

Observing technique(s)

SCANNING



Task 3

- We will learn how to download Herschel data from the HSA;
- we will calculate fluxes in 5 bands for the galaxy M51;
- we will calculate errors to be associated to these fluxes;
- we will construct a modified black body model to reproduce these data;
- we will repeat the same but on a spatially-resolved base.

IR data: Herschel

- PACS observed 2 bands at the time: 70 or 100 μm and 160 μm;
- The FWHM is (but this depends on the kind of observations) ~5, arcsec;
- SPIRE observed 3 bands simultaneously: 250, 350, and 500 μm;
- FWHM of 18, 24 and 36 arcsec, respectively;
- The pixel size of the images can be set during the data reduction (so, check the header in the data!).

NOTE: higher resolution (SPIRE) data are also available, but…

PACS Point Spread Function

Band	Speed (''/s)	FWHM	PA (deg)
Blue (70 μm)	10	5.26 x 5.61	
	20	5.46 x 5.76	
	60	5.75 x 9.00	62.0
	60 parallel mode	5.86 x 12.16	63.0
Green (100 μm)	10	6.57 x 6.81	
	20	6.69 x 6.89	
	60	6.89 x 9.74	62.3
	60 parallel mode	6.98 x 12.70	63.0
Red (160 μm)	10	10.46 x 12.06	7.6
	20	10.65 x 12.13	9.3
	60	11.31 x 13.32	40.9
	60 parallel mode	11.64 x 15.65	53.4

IR data: Herschel

1. Go to: https://www.cosmos.esa.int/web/herschel/home ;
2. Select (left-tab): Data Products → Herschel Science Archive (HSA);
3. “Search”;
4. Instrument basic constraints (photometry only);
5. Select the data product (Level 2, 2.5 & 3);
6. Check availability;
7. Download.

IR data: Herschel

Observation ID	QCR	Target name	RA	Dec	Distance	Instrument	Observing Mode	#Publications	OD	Proposal ID	AOR Label	Access Status	QC Status	SPG
1342178069		m51	13h 30m 02.02s	+47d 10' 11.92"	131.590	PACS	PacsPhoto		27	Calibration_coppacs_2	Calibration_CPPhotBol_1-CPPhotBol_Trial_StdScan_grn_direct_M51_0001	Restricted	PASSED	SPG v14.2.0
1342178512		m51	13h 29m 57.54s	+47d 10' 19.21"	97.233	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_grn_direct_M51_0001	Restricted	PASSED	SPG v14.2.0
1342178513		m51	13h 29m 57.54s	+47d 10' 19.21"	97.233	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_grn_direct_M51X_0001	Restricted	PASSED	SPG v14.2.0
1342178516		m51	13h 29m 57.31s	+47d 10' 18.13"	96.990	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_grn_direct_M51_0002	Restricted	PASSED	SPG v14.2.0
1342178517		m51	13h 29m 57.31s	+47d 10' 18.13"	96.990	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_grn_direct_M51X_0002	Restricted	PASSED	SPG v14.2.0
1342178520		m51	13h 29m 57.60s	+47d 10' 20.07"	96.797	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_grn_direct_M51_0003	Restricted	PASSED	SPG v14.2.0
1342178521		m51	13h 29m 57.60s	+47d 10' 20.07"	96.797	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_grn_direct_M51X_0003	Restricted	PASSED	SPG v14.2.0
1342178524		m51	13h 29m 57.58s	+47d 10' 20.56"	96.263	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_grn_direct_M51_0004	Restricted	PASSED	SPG v14.2.0
1342178525		m51	13h 29m 57.58s	+47d 10' 20.56"	96.263	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_grn_direct_M51X_0004	Restricted	PASSED	SPG v14.2.0
1342178528		m51	13h 29m 57.65s	+47d 10' 20.28"	96.855	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_blu_direct_M51_0001	Restricted	PASSED	SPG v14.2.0
1342178529		m51	13h 29m 57.65s	+47d 10' 20.28"	96.855	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_blu_direct_M51X_0001	Restricted	PASSED	SPG v14.2.0
1342178532		m51	13h 29m 57.40s	+47d 10' 20.71"	95.179	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_blu_direct_M51_0002	Restricted	PASSED	SPG v14.2.0
1342178533		m51	13h 29m 57.40s	+47d 10' 20.71"	95.179	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_blu_direct_M51X_0002	Restricted	PASSED	SPG v14.2.0
1342178536		m51	13h 29m 57.47s	+47d 10' 19.65"	96.446	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_blu_direct_M51_0003	Restricted	PASSED	SPG v14.2.0
1342178537		m51	13h 29m 57.47s	+47d 10' 19.65"	96.446	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_blu_direct_M51X_0003	Restricted	PASSED	SPG v14.2.0
1342178540		m51	13h 29m 57.42s	+47d 10' 18.68"	97.065	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_blu_direct_M51_0004	Restricted	PASSED	SPG v14.2.0
1342178541		m51	13h 29m 57.42s	+47d 10' 18.68"	97.065	PACS	PacsPhoto	1	32	Calibration_coppacs_6	Calibration_CPPhotBol_1-CPPhotBol_Preview_StdScan_blu_direct_M51X_0004	Restricted	PASSED	SPG v14.2.0
1342178865		Messier 51	13h 29m 52.03s	+47d 11' 35.25"	10.191	PACS	PacsPhoto		38	Calibration_coppacs_9	Calibration_CPPhotFPG_1-CPPhotFPG_M51_SIAM_check_map	Restricted	PASSED	SPG v14.2.0
1342178866		Messier 51	13h 29m 52.03s	+47d 11' 35.25"	10.191	PACS	PacsPhoto		38	Calibration_coppacs_9	Calibration_CPPhotFPG_1-CPPhotFPG_M51_SIAM_check_map_xscan	Restricted	PASSED	SPG v14.2.0
1342188328		ngc5194	13h 29m 54.14s	+47d 11' 53.70"	18.308	PACS	PacsPhoto	20	221	KPGT_cwilso01_1	PPhoto-m51 - copy	Public	PASSED	SPG v14.2.0
1342188329		ngc5194	13h 29m 54.14s	+47d 11' 53.70"	18.308	PACS	PacsPhoto	20	221	KPGT_cwilso01_1	PPhoto-m51	Public	PASSED	SPG v14.2.0
1342188589		ngc5194	13h 29m 52.19s	+47d 11' 26.73"	16.993	SPIRE	SpirePhotoLargeScan	13	226	KPGT_cwilso01_1	SPhoto-m51	Public	PASSED	SPG v14.1.0
1342223510		SN2011dh	13h 30m 04.40s	+47d 10' 12.21"	149.882	PACS	PacsPhoto		770	TOO_herschel_2	PPhoto-M51-SN2011dh-70deg	Public	PASSED	SPG v14.2.0
1342223511		SN2011dh	13h 30m 04.40s	+47d 10' 12.21"	149.882	PACS	PacsPhoto		770	TOO_herschel_2	PPhoto-M51-SN2011dh-100deg	Public	PASSED	SPG v14.2.0
1342224023		SN2011dh	13h 30m 04.66s	+47d 10' 28.92"	142.649	SPIRE	SpirePhotoSmallScan		790	TOO_herschel_2	SPhoto-M51-SN2011dh	Public	PASSED	SPG v14.1.0
1342224632		SN2011dh	13h 30m 04.44s	+47d 10' 12.27"	150.241	PACS	PacsPhoto		798	TOO_herschel_2	PPhoto-M51-SN2011dh-70deg - 2	Public	PASSED	SPG v14.2.0
1342224633		SN2011dh	13h 30m 04.44s	+47d 10' 12.27"	150.241	PACS	PacsPhoto		798	TOO_herschel_2	PPhoto-M51-SN2011dh-100deg - 2	Public	PASSED	SPG v14.2.0
1342224973		SN2011dh	13h 30m 04.03s	+47d 10' 28.72"	137.314	SPIRE	SpirePhotoSmallScan		808	TOO_herschel_2	SPhoto-M51-SN2011dh - 2	Public	PASSED	SPG v14.1.0
1342231666		SN2011dh	13h 30m 05.30s	+47d 10' 10.77"	158.160	PACS	PacsPhoto		900	TOO_herschel_2	PPhoto-M51-SN2011dh-70deg - 3	Public	PASSED	SPG v14.2.0
1342231667		SN2011dh	13h 30m 05.30s	+47d 10' 10.77"	158.160	PACS	PacsPhoto		900	TOO_herschel_2	PPhoto-M51-SN2011dh-100deg - 3	Public	PASSED	SPG v14.2.0
1342232462		SN2011dh	13h 30m 05.40s	+47d 10' 13.92"	157.213	PACS	PacsPhoto		919	TOO_herschel_2	PPhoto-M51-SN2011dh-70deg -4	Public	PASSED	SPG v14.2.0
1342232463		SN2011dh	13h 30m 05.40s	+47d 10' 13.92"	157.213	PACS	PacsPhoto		919	TOO_herschel_2	PPhoto-M51-SN2011dh-100deg -4	Public	PASSED	SPG v14.2.0
1342234914		SN2011dh	13h 30m 04.71s	+47d 09' 53.96"	163.958	SPIRE	SpirePhotoSmallScan		948	TOO_herschel_2	SPhoto-M51-SN2011dh - 4	Public	PASSED	SPG v14.1.0

+ even more observations…

IR data: Herschel

PACS

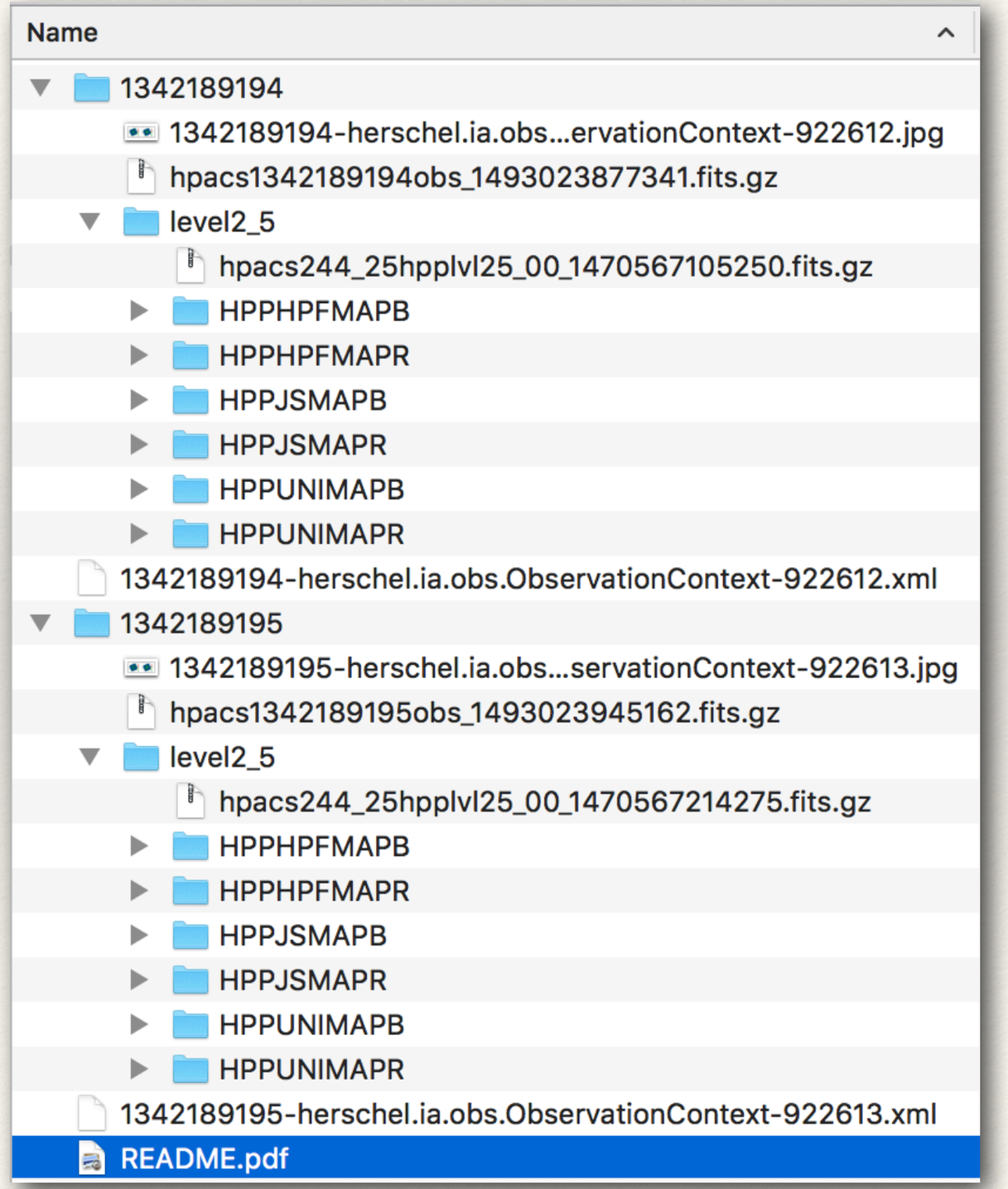
SPIRE

Observation ID	QCR	Target name	RA	De
1342211615		Carina Nebula Complex-1	10h 44m 04.19s	-59d 29' 4
1342211615		Carina Nebula Complex-1	10h 42m 56.00s	-59d 24' 3
1342211616		Carina Nebula Complex-1	10h 44m 04.19s	-59d 29' 4
1342211616		Carina Nebula Complex-1	10h 42m 56.00s	-59d 24' 3
1342255061		Field 288_0	10h 48m 49.54s	-60d 04' 4
1342255061		Field 288_0	10h 47m 29.82s	-60d 05' 5
1342255062		Field 288_0	10h 48m 49.55s	-60d 04' 4
1342255062		Field 288_0	10h 47m 29.82s	-60d 05' 5

- Chose either set of observation (the first is more centered)
- Remember L2.5 already combines different scans (nominal & orthogonal)
- PACS and SPIRE come in different archive files

Herschel data: PACS

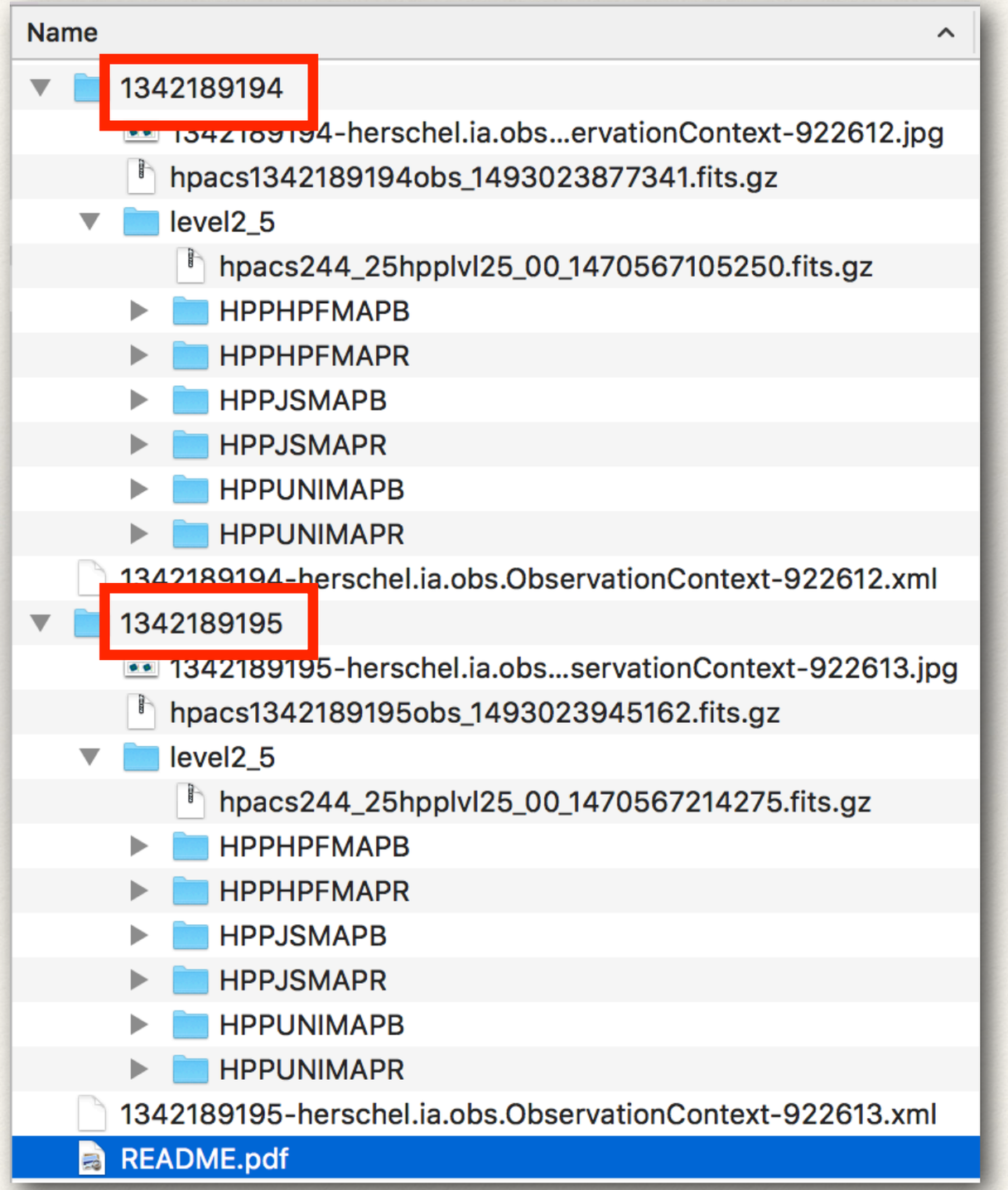
1. Change filename to ".tar";
2. Expand and check:



Herschel data: PACS

1. Change filename to ".tar";
2. Expand and check:

   a. OBSIDs;

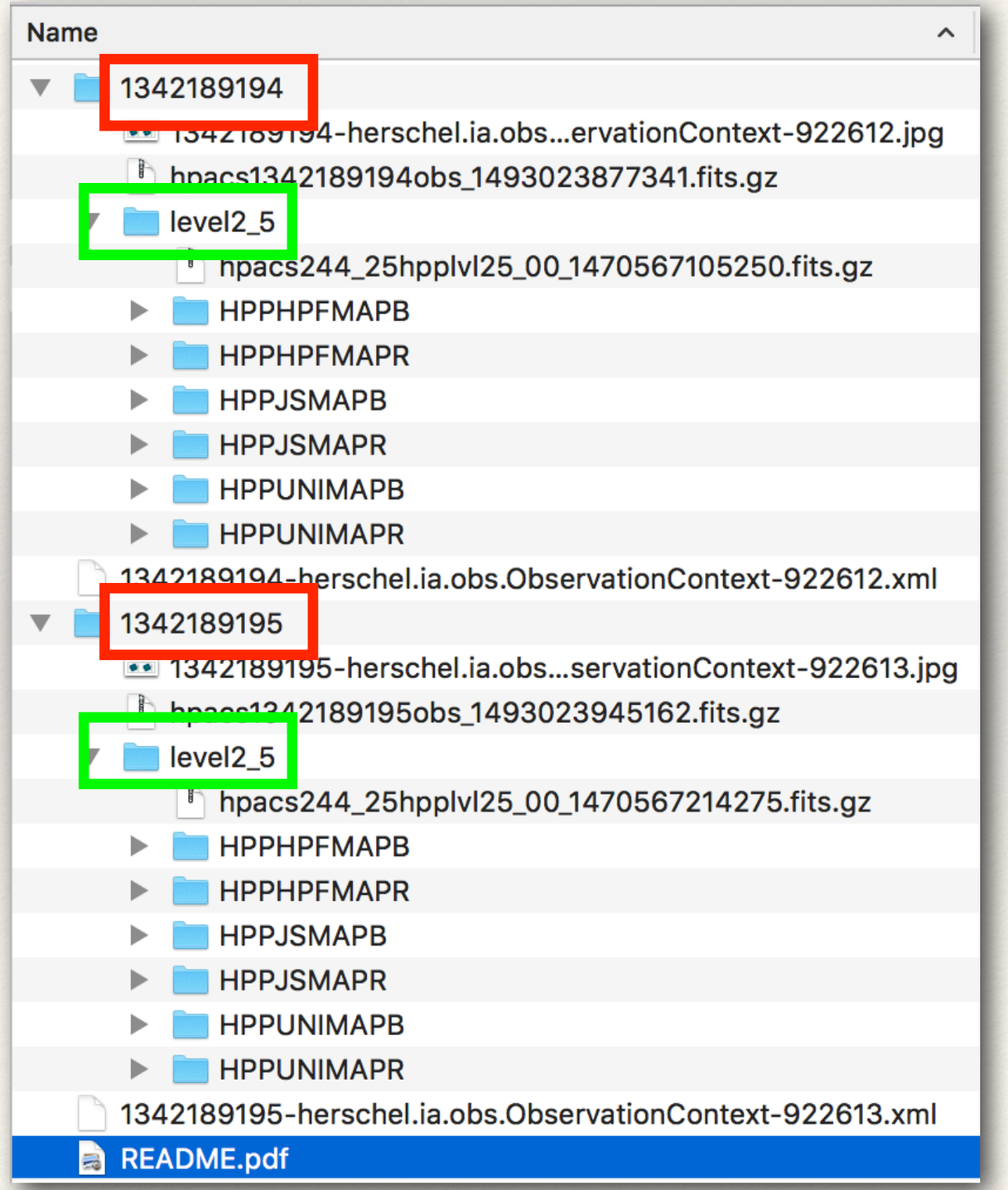


Herschel data: PACS

1. Change filename to ".tar";
2. Expand and check:

a. OBSIDs;

b. Data "manipulation" level;



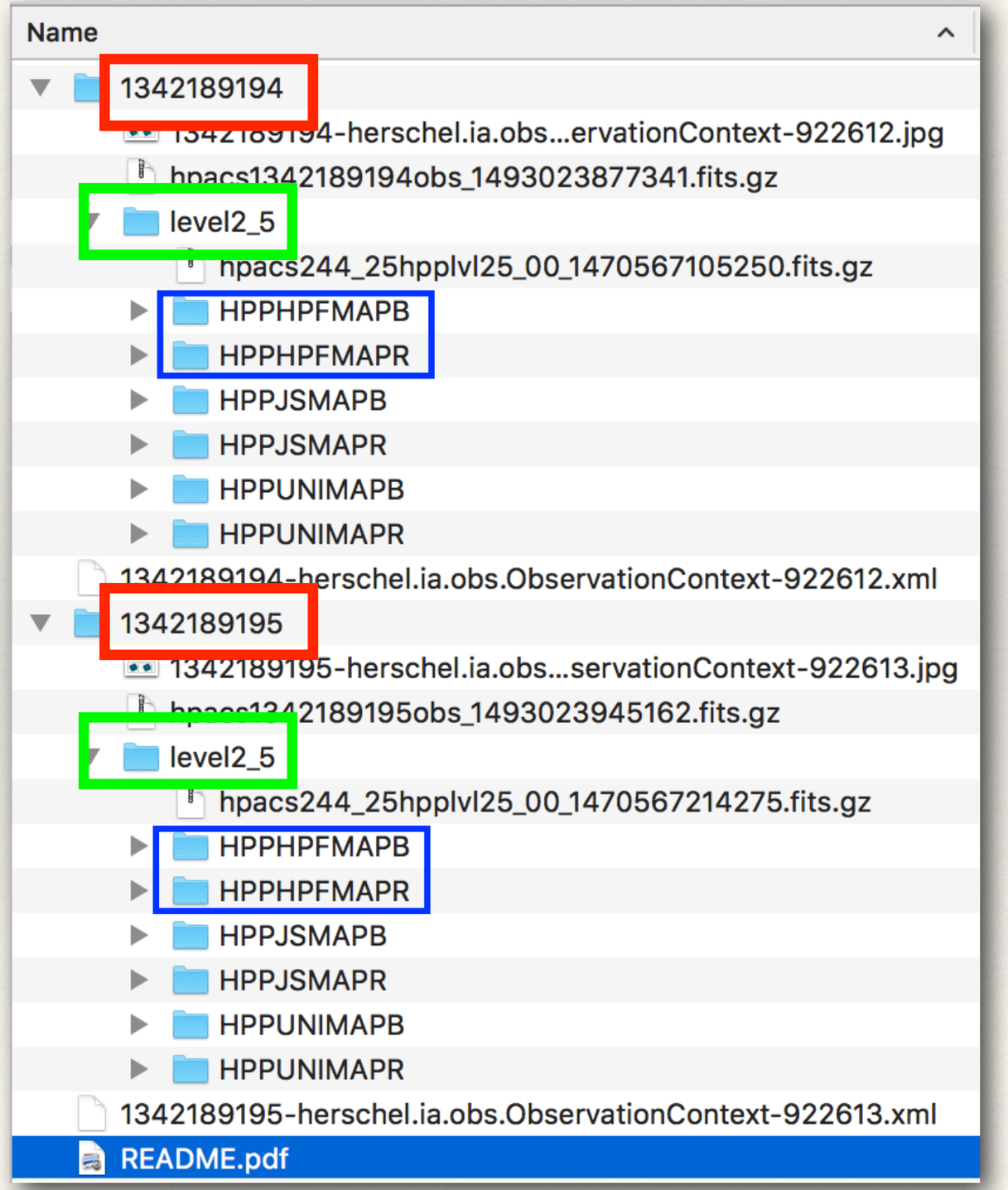
Herschel data: PACS

1. Change filename to ".tar";
2. Expand and check:

   a. OBSIDs;

   b. Data "manipulation" level;

   c. PhotProject maps;



Herschel data: PACS

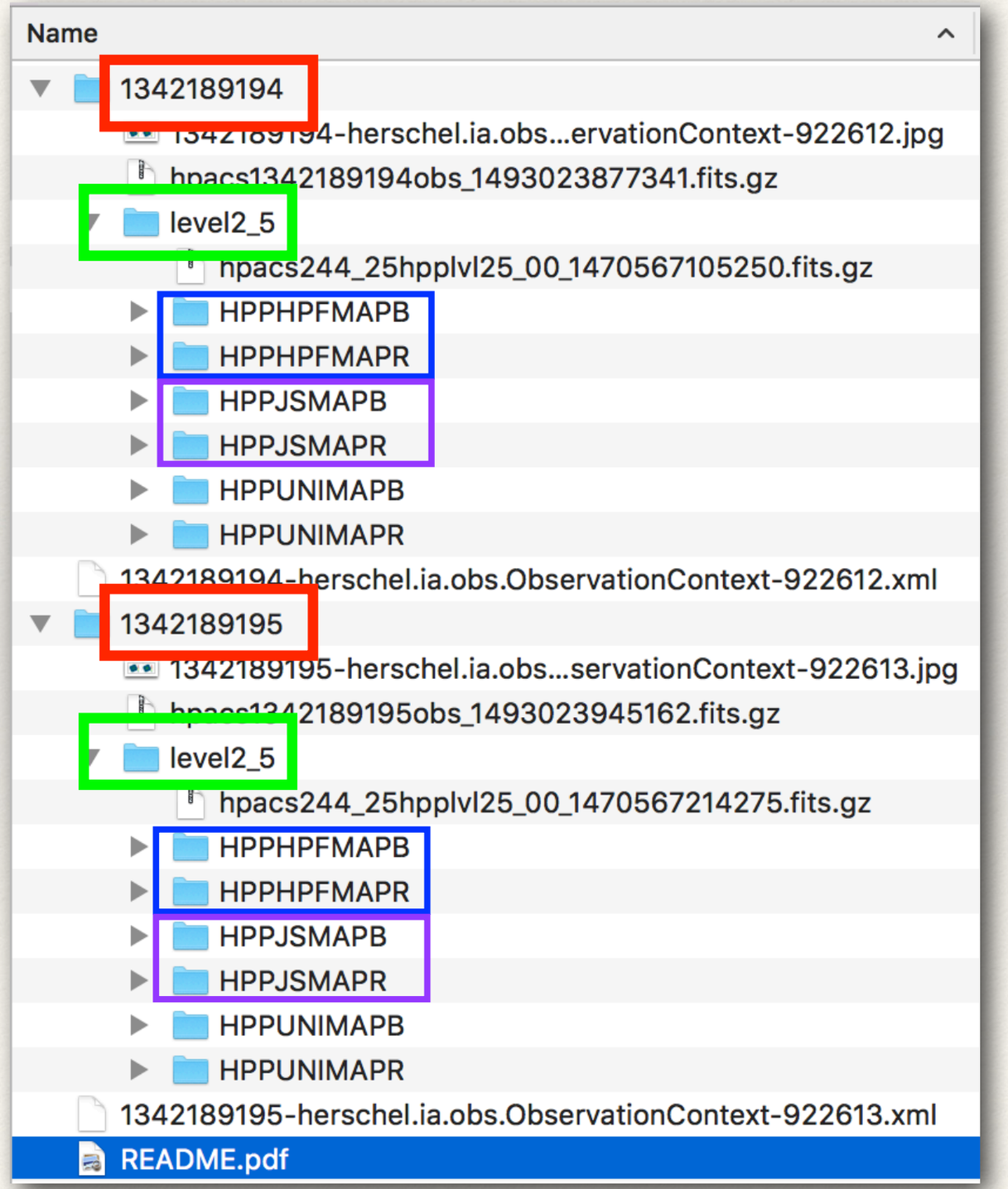
1. Change filename to ".tar";
2. Expand and check:

a. OBSIDs;

b. Data "manipulation" level;

c. PhotProject maps;

d. Jscan maps;



Herschel data: PACS

1. Change filename to ".tar";
2. Expand and check:

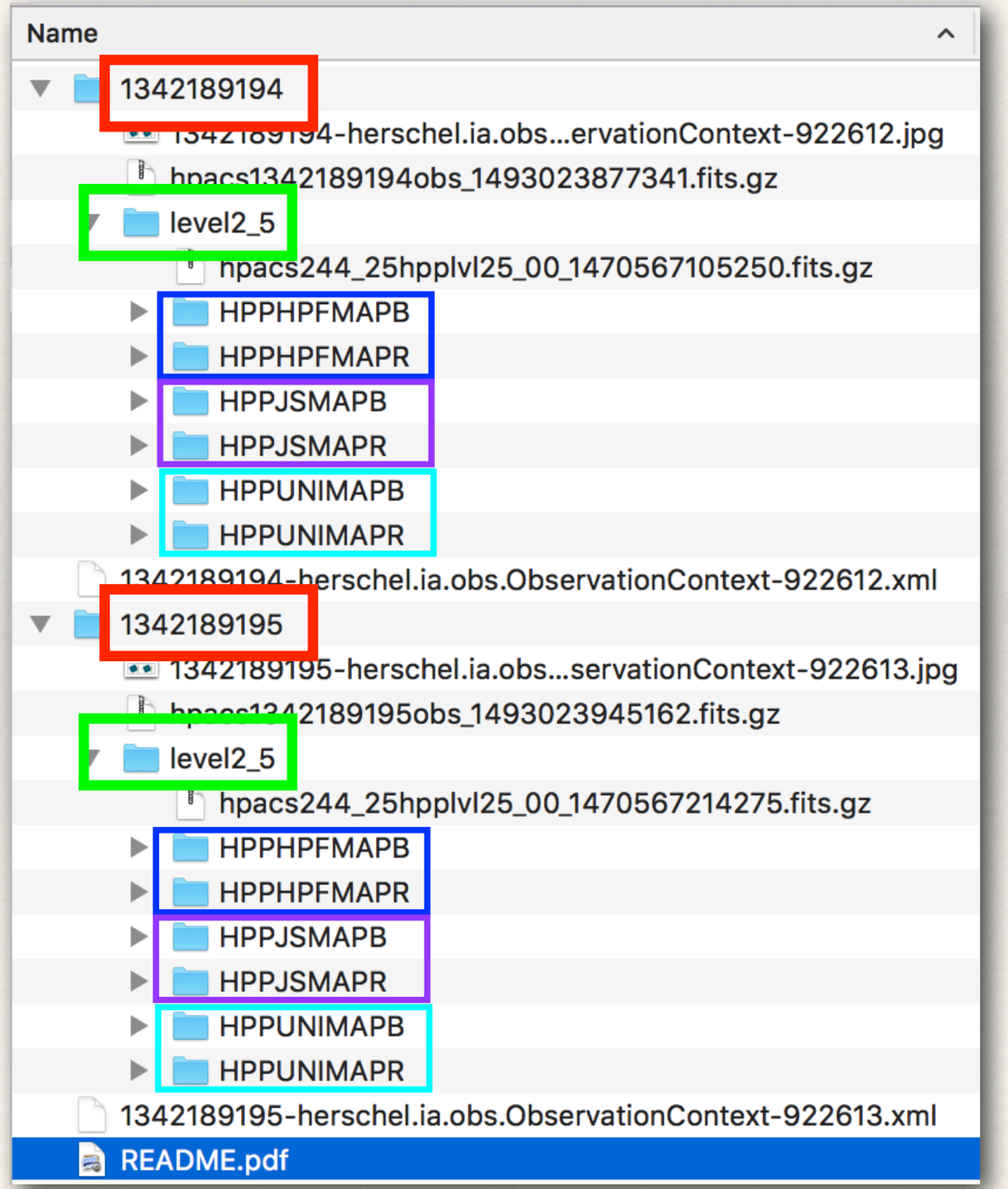
a. OBSIDs;

b. Data "manipulation" level;

c. PhotProject maps;

d. Jscan maps;

e. UNIMAP maps.



Herschel data: PACS

1. Change filename to ".tar";
2. Expand and check:

a. OBSIDs;

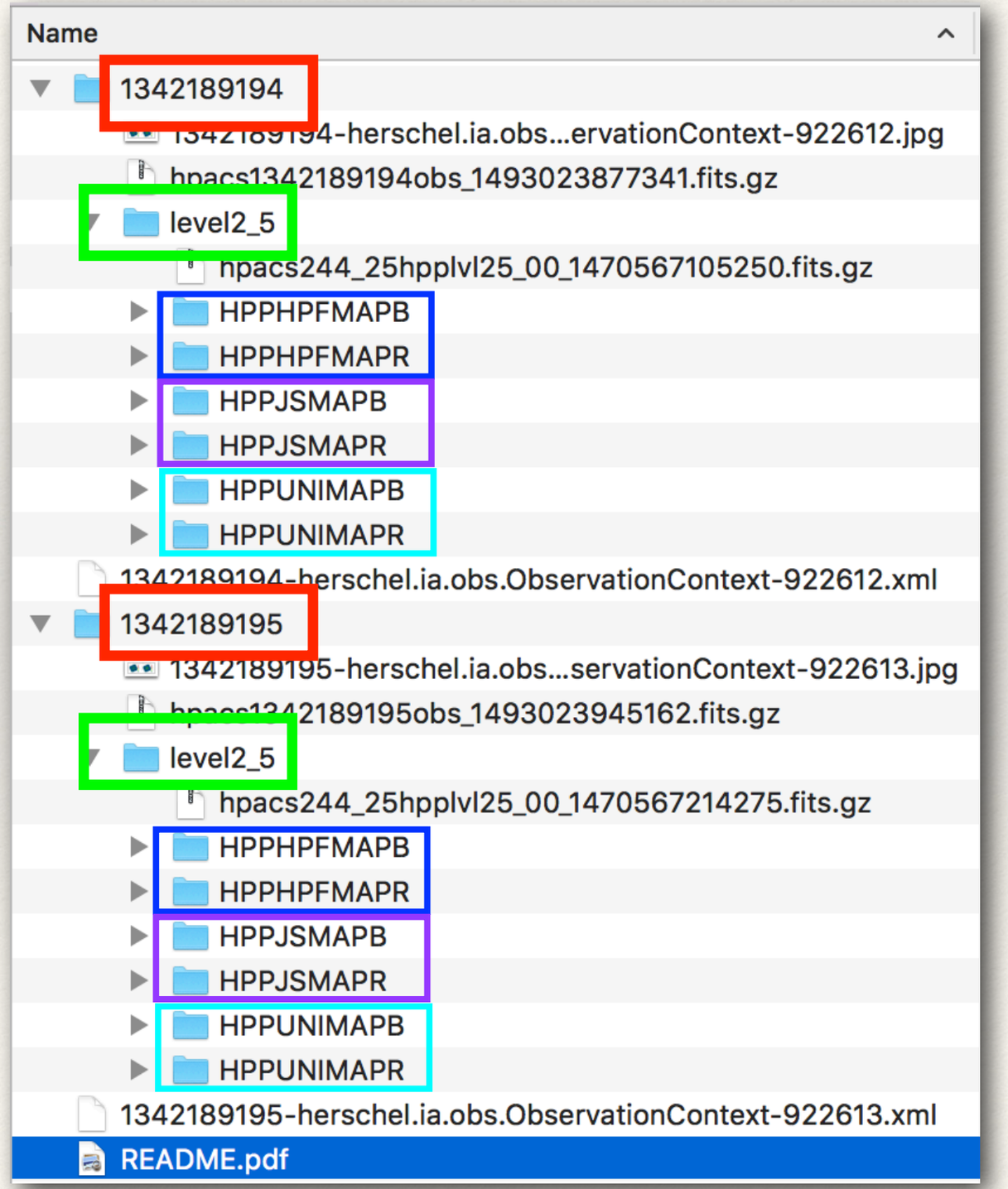
b. Data "manipulation" level;

c. PhotProject maps;

d. Jscan maps;

e. UNIMAP maps.

Each for 2 channels
(see header for more infos)



Herschel data: SPIRE

- Data for the SPIRE instrument, if any, are searchable in the same way as done for PACS;
- possible to choose between “normal” and “high res”;
- the three standard bands are available.

Modified Black-Body modeling

Dust emission model

Modified Black-Body emission:

$$F_\nu = k_\nu M_D \frac{B_\nu(\lambda, T)}{D^2}$$

Where: $$k_\nu = k_{\nu_0} \left(\frac{\nu}{\nu_0}\right)^{\boldsymbol{\beta}} \qquad B_\nu(\lambda, T) = \frac{2hc}{\lambda^3} \cdot \frac{1}{e^{hc/kT\lambda} - 1}$$

1. Check (and chose, when possible) the units of each variable;
2. find the values of the constants (in the appropriate units).

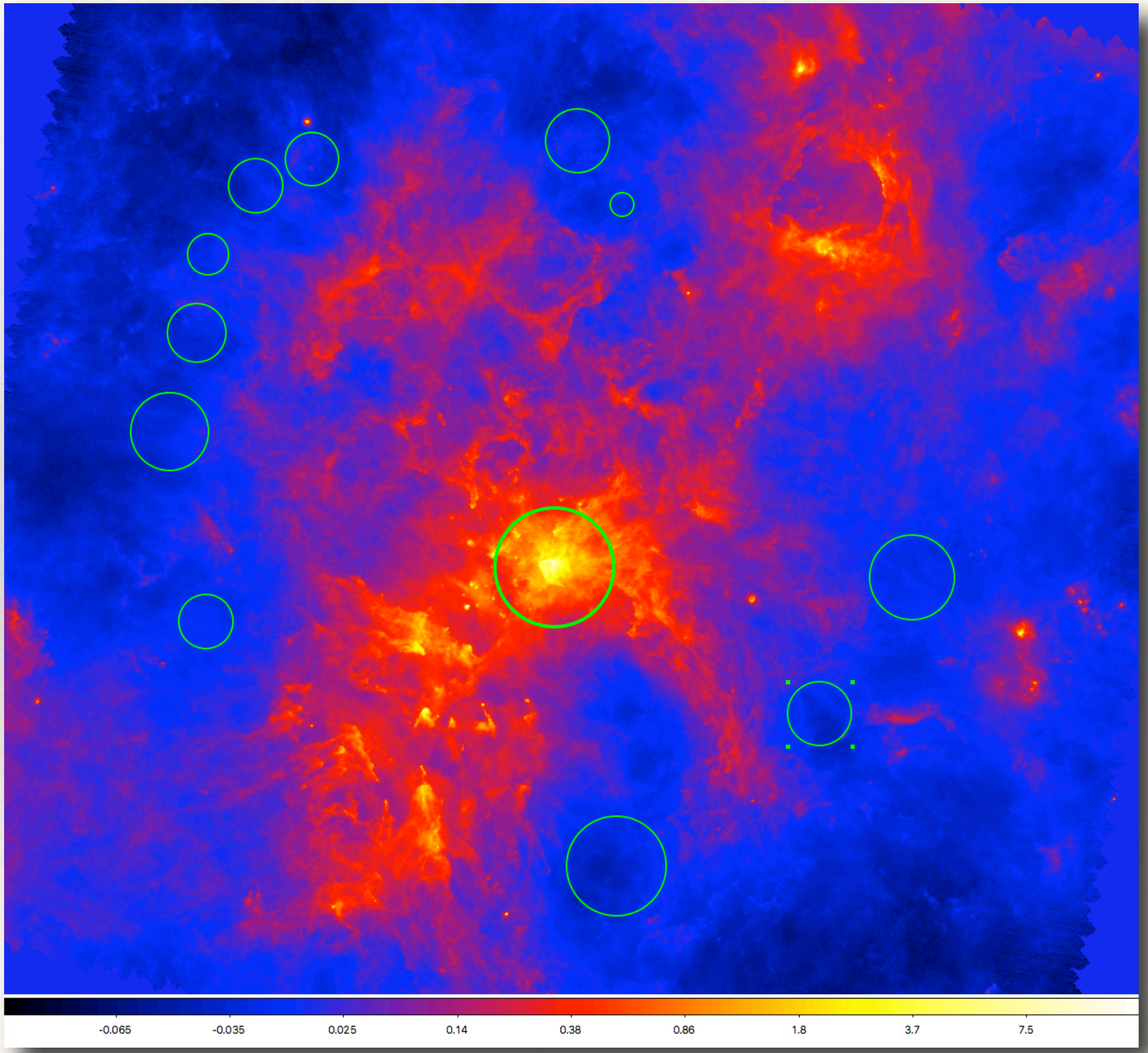
Total dust mass, T, and β

- We will calculate the total amount of dust, its average temperature, and the dust emissivity index, for the whole galaxy;
- to do so, we will fit the observed, integrated fluxes, with a mod-BB emission model;
- we first need to do source extraction and error calculations.

Source extraction

1. In DS9 define an aperture encompassing all the galaxy emission;
2. define several (>10) regions outside the galaxy devoid of sources: these will be used to calculated the average background emission;
3. save the regions in “image” coordinates;
4. this work for both PACS and SPIRE;
5. calculate observed errors on the fluxes.

An Example



Step-by-Step

```
import numpy
from astropy.io import fits
import pyregion
img = raw_input('Name of the PACS data: ')
reg_name = raw_input('Name of the regions: ')
hdulist = fits.open(img)
flxmap = hdulist[1].data
errmap = hdulist[3].data
header = hdulist[1].header
nx = header[‘NAXIS1']
ny = header[‘NAXIS2’]
size = (ny, nx)
source =  pyregion.open(reg_name)
nsky = len(source) - 1
del source[1:]
smask = source.get_mask(shape=size)
```

Step-by-Step

Source Flux calculation

```
flux = 0.0
err = 0.0
on_s_pix = 0
for i in range(nx):
    for n in range(ny):
        if smask[n,i] == True:
            flux = flux + flxmap[n,i]
            sqerr = err + errmap[n,i]**2
            on_s_pix = on_s_pix + 1
err = np.sqrt(sqerr)
sky_ap = numpy.zeros(nsky)
pix_ap = numpy.zeros(nsky)
```

Step-by-Step

```
sky_pix = []
for k in range(0,nsky):
    sky =  pyregion.open(reg_name)
    del sky[0:k+1]
    del sky[1:nsky]
    bmask = sky.get_mask(shape=size)
    sflx = 0.0
    pix = 0
    for i in range(nx):
        for n in range(ny):
            if bmask[n,i] == True:
                sflx = sflx + flxmap[n,i]
                pix = pix + 1
                sky_pix.append(flxmap[n,i])
    sky_ap[k] = sflx
    pix_ap[k] = pix
```

Step-by-Step

```
sk_p_pix = sum(sky_ap)/sum(pix_ap)
skyave = sky_ap/pix_ap
tflux = flux-on_s_pix*sk_p_pix
err1 = 0.05*tflux
for i in range(nx):
    for n in range(ny):
        if smask[n,i] == True:
            errsq = errsq + errmap[n,i]**2
err2 = numpy.sqrt(errsq)
```

Step-by-Step

```
sig_unc = (numpy.std(sky_pix))**2 * on_s_pix
sig_corr = (numpy.std(skyave) * on_s_pix)**2
err3 = numpy.sqrt(sig_unc+sig_corr)
tot_err = numpy.sqrt(err1**2 + err2**2 + err3**2)
rel_err = tot_err/tflux*100.
print 'err1=', err1
print 'err2=', err2
print 'err3=', err3
print ‘Sky-subtracted flux:', tflux,'±',tot_err,' Jy (',rel_err,' %)'
```

SPIRE flux calculations

- Flux calculation with SPIRE is in all similar to PACS;
- the only thing you have to take into account, is the different units of the pixels;
- these must be converted into Jy/pix before calculating both the flux and the errors.

Step-by-Step

```
beam = [465., 822., 1769.]          # beam area, in arcsec^2
cnoise = [0.0058, 0.0063, 0.0068]   # confusion noise, in Jy/beam
kk = 2.*np.pi/(360.*3600.)          # 1 arcsec in rad
img = raw_input('Name of the SPIRE data file: ')
reg_name = raw_input('File with the regions for flux and sky ')
hdulist = pyfits.open(img)
wavel = input('Wavelength of the image: ')
if wavel == 250:
    wind = 0
if wavel == 350:
    wind = 1
if wavel == 500:
    wind = 2
```

Step-by-Step

```
fluxmap = (hdulist[1].data[:,:])
errmap = (hdulist[???].data[:,:])
header = (hdulist[1].header)
nx = header["NAXIS1"]
ny = header["NAXIS2"]
size = (ny, nx)
pixsz = np.abs(header[“CDELT1"]) * 3600.
fluxmap = fluxmap * 1e6 * (kk * pixsz)**2
source =  pyregion.open(reg_name)
nsky = len(source) - 1
del source[1:]
smask = source.get_mask(shape=size)
```

Step-by-Step

```
flux = 0.0
err = 0.0
on_s_pix = 0
for i in range(nx):
    for n in range(ny):
        if smask[n,i] == True:
            flux = flux + fluxmat[n,i]
            err = err + errmat[n,i]**2
            on_s_pix = on_s_pix + 1
err2 = np.sqrt(errsq)
sky_ap = np.zeros(nsky)
pix_ap = np.zeros(nsky)
sky_pix = []
```

Step-by-Step

```
for k in range(0,nsky):
    sky = pyregion.open(reg_name)
    del sky[0:k+1]
    del sky[1:nsky]
    bmask = sky.get_mask(shape=size)
    sflx = 0.0
    pix = 0
    for i in range(nx):
        for n in range(nx):
            if bmask[n,i] == True:
                sflx = sflx + flux_mat[n,i]
                pix = pix + 1
                sky_pix.append(flux_mat[n,i])
    sky_ap[k] = sflx
    pix_ap[k] = pix
```

Step-by-Step

```
sk_p_pix = sum(sky_ap)/sum(pix_ap)
skyave = sky_ap/pix_ap
tflux = flux-on_s_pix*sk_p_pix
err1 = 0.07 * tflux
err2 = np.sqrt(errsq)
err3 = cnoise[wind] * np.sqrt(on_s_pix * pixsz**2/beam[wind])
eflx = 0.0
pix_b = 0
```

Step-by-Step

Instrumental uncertainty

```
eflx = 0.0
pix_b = 0
for k in range(nsky):
    sky = pyregion.open(reg_name)
    del sky[0:k+1]
    del sky[1:nsky]
    bmask = sky.get_mask(shape=size)
    for i in range(nx):
        for n in range(ny):
            if bmask[n,i] == True:
                eflx = eflx + errmap[n,i]**2
                pix_b = pix_b + 1
```

Step-by-Step

```
err4_1 = np.sqrt(eflx) * on_s_pix/pix_b
print "Instrumental background:",err4_1," Jy"
err4_2 = cnoise[wind]*np.sqrt(pixsz**2/beam[wind])*on_s_pix/
         np.sqrt(pix_b)
print "Confusion background:",err4_2," Jy"
err4_3 = np.std(sky_ap)/np.sqrt(nsky)
print "Large-scale background:",err4_3," Jy"
err4 = np.sqrt(err4_1**2+err4_2**2+err4_3**2)
```

Step-by-Step

```
print "Calibration error:", err1," Jy"
print "Instrumental error:", err2," Jy"
print "Confusion noise:", err3," Jy"
print "Background error:", err4," Jy"
tot_err = np.sqrt(err1**2 + err2**2 + err3**2 + err4**2)
rel_err = tot_err/tflux*100
print "Background-subtracted flux:", tflux,"±",tot_err,
      " Jy (“,rel_err," %)"
```