PACS Spectrometer Wavelength Calibration

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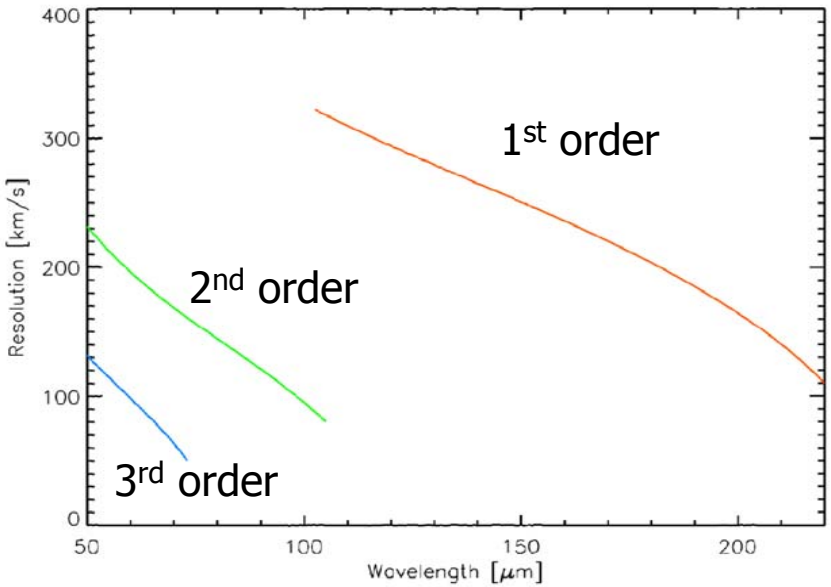
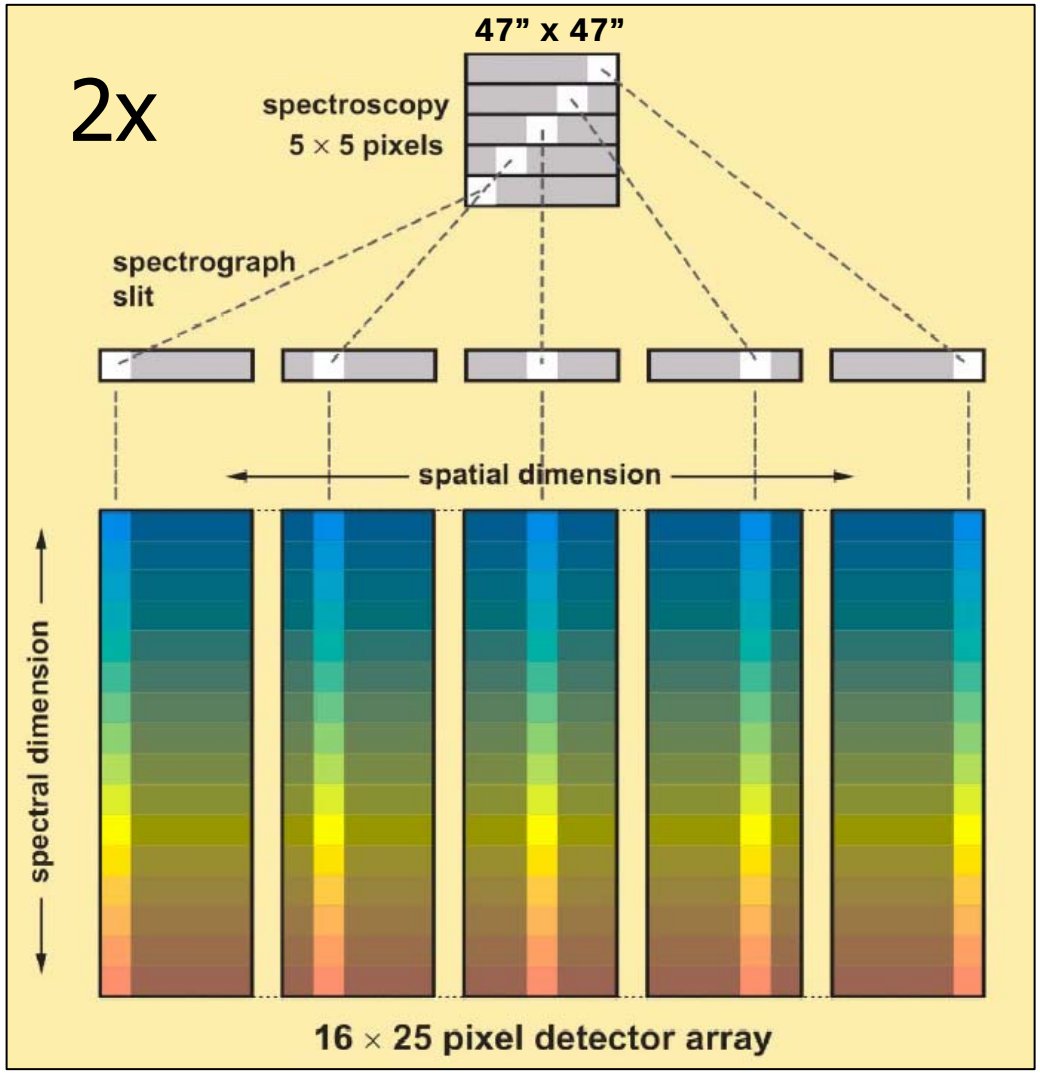
Description of the Calibration Problem

- Blue array: 400 pixels
- Red array: 400 pixels
- 2 different blue filters
- 3 grating orders
- Grating range:
  32000-1064000 positions
- Spectral resolution elements:
  ~3650 (x sampling x time)





Calibration Method (1)

The Littrow grating equation for PACS can be written as:

$$\lambda = \frac{g}{n}[sin(\alpha - \delta\alpha) + sin(\beta + \delta\beta + \delta pix \times (pix - 8))]$$

$\alpha=\beta$; $\delta\alpha=\delta\beta=0.6253°$; $g_{LHe}=117.175\mu m$; n=[1,2,3] ; pix=[1..16]

$$\alpha = \alpha_0 + (p_1\text{-}1)*(gratpos/dgrat) + p_2*(gratpos/dgrat)^2 + p_3*(gratpos/dgrat)^3$$

with dgrat = 23301 [steps/°]

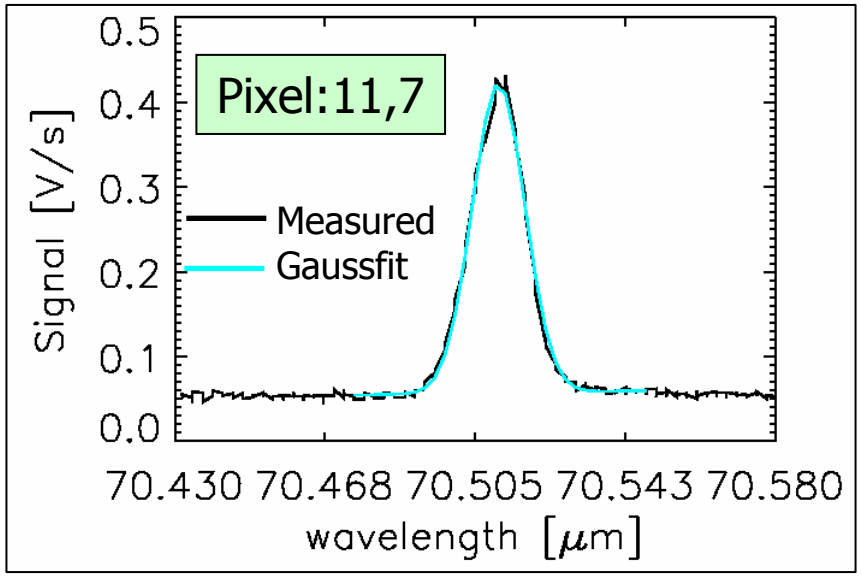
δpix_n = constant(n); n=[1,2,3,2']

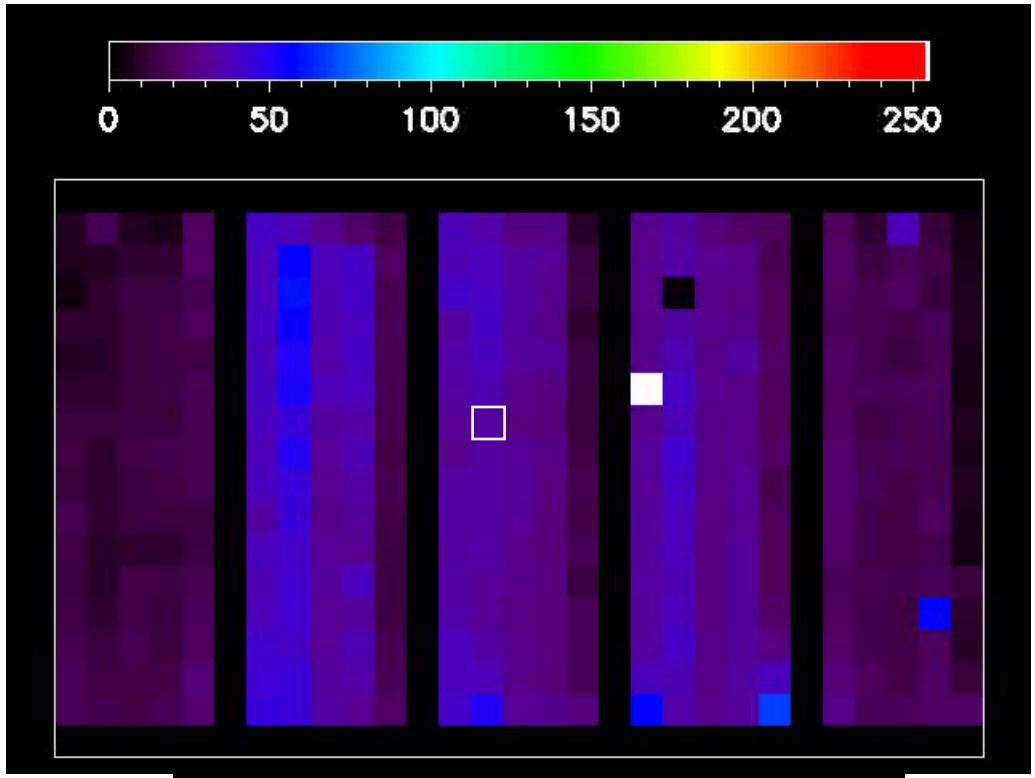
Calibration Method (2)

- Calculate model spectra (at expected PACS spectral resolution) for the wavelength range under investigation and define spectral intervals for correlation analysis or fitting
- Determine λ-calibration offsets for each interval
- Store 3rd order polynomial parameters fitted to offsets vs. (gratpos/dgrat) for each pixel
- $\alpha_{new} = \alpha_{old}$ + polynomial fit

"Frown" & "Smile"

Laser: 70.512 μm
Grating order = 3
Filter A





Signals beyond cut level in white

Status

- Initial uplink calibration available (from ILT)
- Not all FM ILT data analyzed
- FM ILT3 data only for chopper position zero
- Accuracies mostly in spec, single pixel outliers to be corrected
- Initial PV target and line lists available

- Preparation of detailed observations started

Accuracies

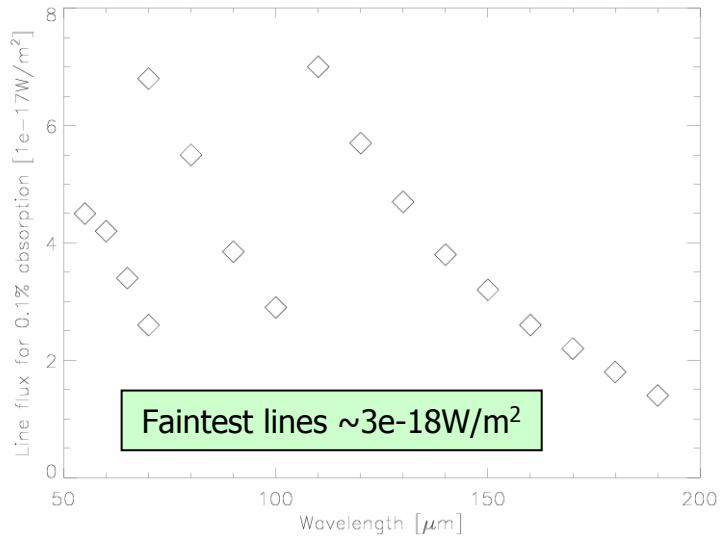
- PCD V8.0 (sec. 4.2.1):
  Required accuracy:
  "Peak position to within 10-20% of a spectral resolution element"

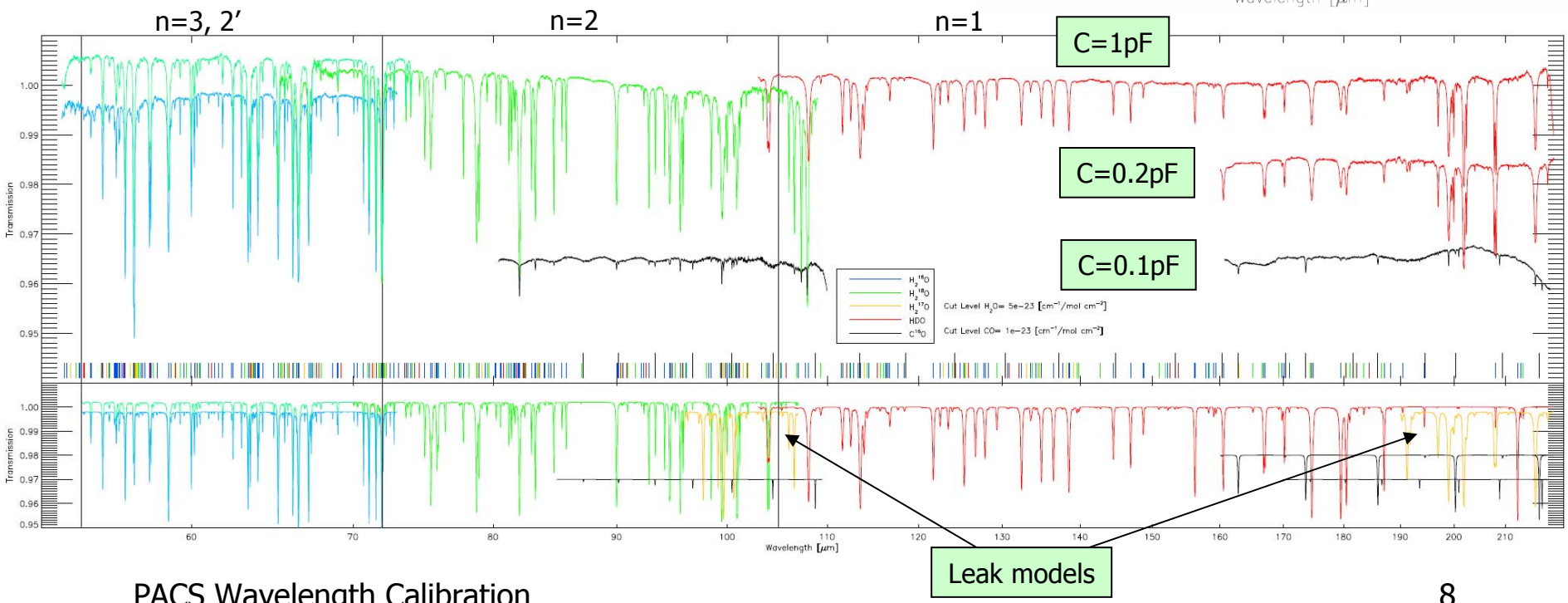
- In general the requirement is met throughout all bands however at band borders, due to leakage effects and lower S/N the calibration accuracy (in terms of σ over all pixels) is closer to 20% of a spectral resolution element, while in band centers, σ values even better than 10% are obtained.
  σ=stdev(all_pixels residual λ-shift vs. model)

- Absolute verification against Laser and CO lines
- Relative verification by combining all pixels
- Be aware: relative position of point sources within slit can have significant effect

PACS FM ILT Results

- Combination of all pixels into single spectrum (4.5h+4.5h scans on gas and vacuum)





Open Work

- Investigate/recalibrate few outlying pixels found during verification against Laser lines. The reason is essentially the poor S/N in the measurements during FM ILT 2.
- Calibrate –L/+L chopper throws, spot checks indicate that there is no significant change in calibration…
- Provide Report and Calfiles (version as of this presentation provided for PACS spectrometer pipeline)
- Calibration using FMILT 3 measurements in progress

- Code WaveCal into PacsCal_WaveCal observation → done !
- Code an equivalent to WaveCal with chopping into PacsCal_xxx

Wavelength Calibration in Flight (1)

- Observing modes for calibration measurements:
  - Use standard SpecRangeScan AOT
  - Use WaveCal mode with pointing request
  - Use chopped WaveCal with pointing request
  - Do we need/want chopping on the very high flux regime ?

improved sampling density

- Suitable target list containing strong molecular lines:

  - PICC-ME-TN-013, "Use of late type stars for PACS wavelength calibration", (D. Lutz)
  - "Photometric and Spectroscopic Calibration of Herschel Instruments with Planets and Satellites", (Th. Encrenaz, R. Moreno, A. Coustenis)

  - Uranus(H_2O), Neptune(H_2O, CO), Saturn(H_2O, NH_3, PH_3)
  - Jupiter (H_2O, NH_3, PH_3 ; fills entire 5x5 field of view !)

Wavelength Calibration in Flight (2)

- Further targets containing strong molecular lines:

Justtanont et al., A&A, 360, 1117-1125 (2000), "ISO-LWS observations of rotational CO lines from C-rich objects"

transition	λ (μm)	Line flux ($\times 10^{-19}$ W cm^{-2}) AFGL 2688	AFGL 618	NGC 7027
J=14-13	186.00	4.8±0.2	3.1±0.9	2.0±0.1
J=15-14	173.63	4.7±0.2	3.3±0.6	1.7±0.1
J=16-15	162.81	4.5±0.3	4.2±0.7	1.6±0.1
J=17-16	153.27	4.0±0.3	3.6±0.4	1.1±0.1
J=18-17	144.78	5.0±0.7	3.8±1.2	1.1±0.2
J=19-18	137.20	5.8±0.5	3.8±0.7	1.2±0.1
J=20-19	130.37	5.0±0.8	4.0±0.9	1.0±0.1
J=21-20	124.19	4.8±0.9	3.5±1.0	0.7±0.1
J=22-21	118.58	3.6±0.6	3.6±0.7	0.3±0.1
J=23-22	113.46	2.9±0.5	2.9±0.5	0.5±0.1
J=24-23	108.76	3.1±0.5	3.6±0.5	0.7±0.1
J=25-24	104.44	2.6±0.6	4.6±0.4	0.5±0.1
J=26-25	100.46	2.3±0.7	3.2±0.4	0.7±0.1
J=27-26	96.77	1.8±0.8	4.1±1.0	0.5±0.1
J=28-27	93.35	-	2.8±1.0	-
J=29-28	90.16	-	3.8±2.0	-
J=30-29	87.19	-	2.4±1.4	-
J=31-30	84.41	-	1.1±1.3	-
J=32-31	81.81	-	6.6±2.6	-
J=33-32	79.36	-	1.9±1.3	-
J=34-33	77.06	-	2.6±1.4	-
J=35-34	74.89	-	2.3±1.3	-
J=36-35	72.84	-	3.2±1.3	-
J=37-36	70.91	-	3.1±2.8	-

Wavelength Calibration in Flight (3)

- Suitable target list containing strong atomic fine-structure lines:
  - 19 selected Planetary Nebulae:

    IC418, IC2501, NGC5315, He2-131, NGC6210, NGC6543, NGC 6572, SwSt1, BD +30 3639, NGC6826, IC4997, NGC7027, NGC7662, NGC40, NGC3242, NGC3918, NGC5882, NGC6302, NGC6905
  - Atomic fine-structure lines within the PACS wavelength range:

    [OIII]=51.8145μm; [NIII]=57.317μm; [OI]=63.184μm; [OIII]=88.356μm; [NII]=121.898μm; [OI]=145.525μm; [CII]=157.741μm; [NII]=205.178μm;
  - References:

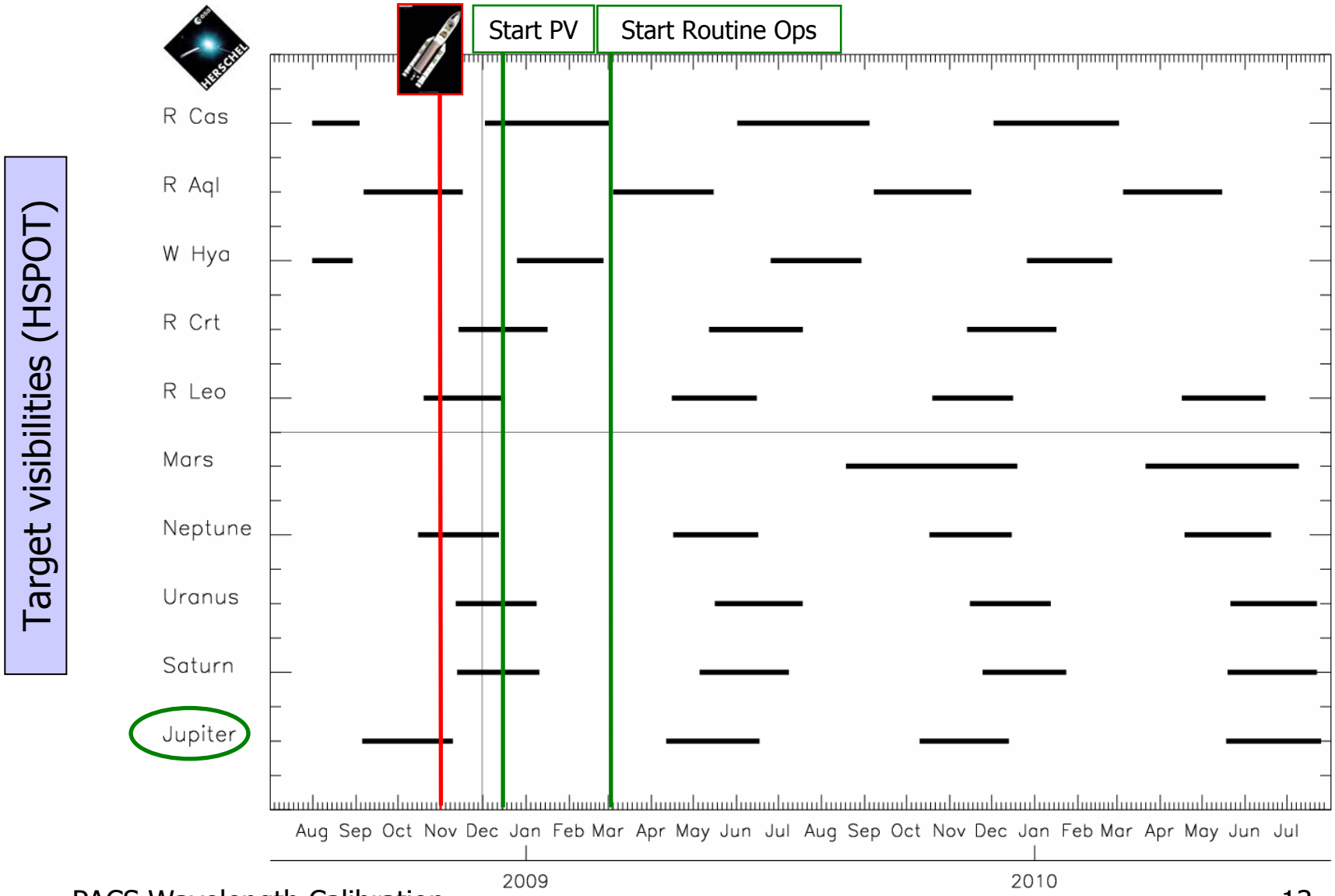
    1) ISO 95-015, Planetary nebulae to be used as ISO-SWS Astronomical Calibration Sources, H.W.W. Spoon, K.A. van der Hucht, D. Lutz

    2) An Infrared Spectral Line List of Astrophysical Interest (2.4-200μm) and its use in the SWS and LWS ISO Central Program

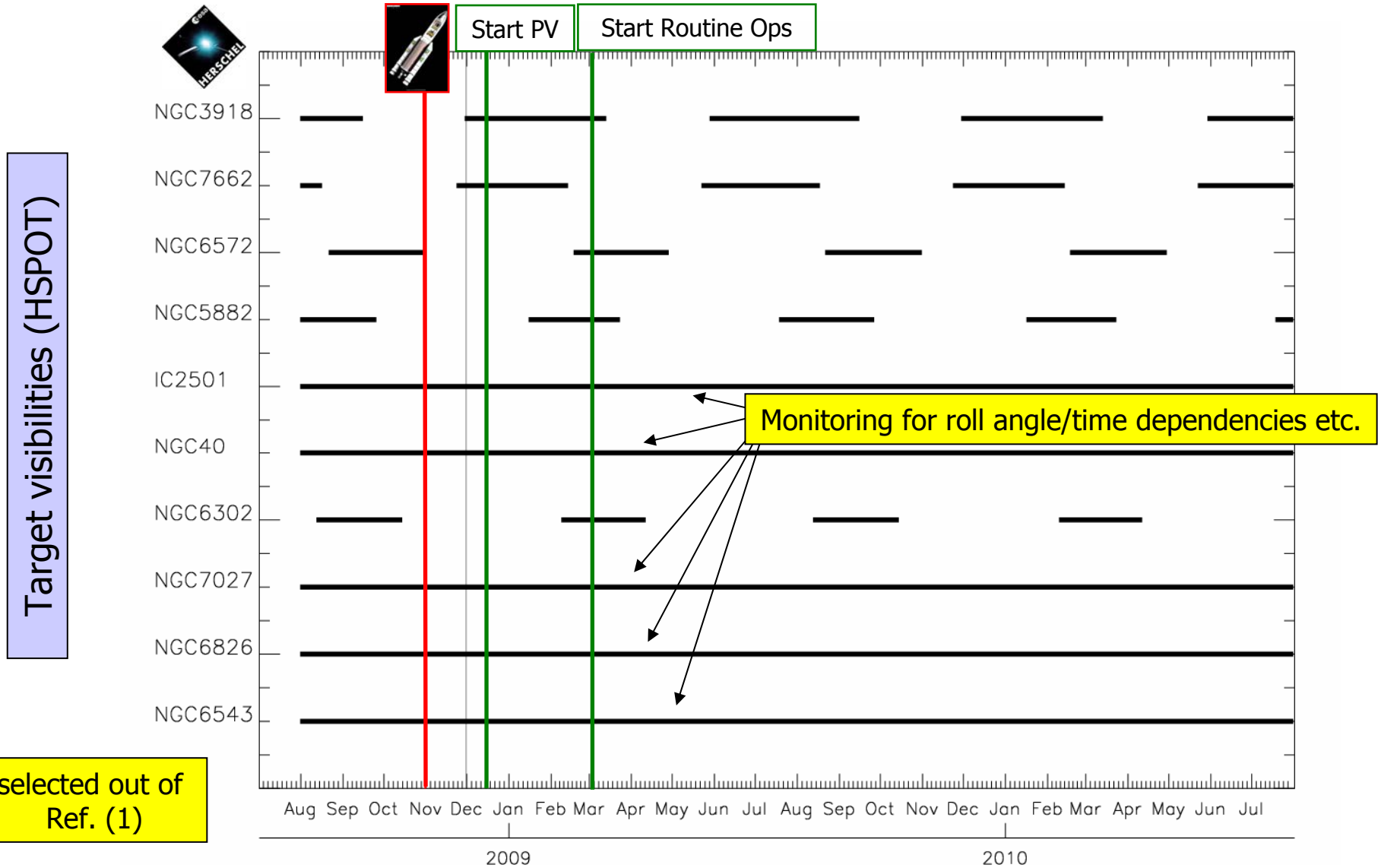
    3) www.mpe.mpg.de/ir/ISO/linelists/FSlines.html

    4) Liu et al., MNRAS, 323, 343, (2001), "ISO LWS observations of planetary nebula fine-structure lines" [provides also observed line fluxes]

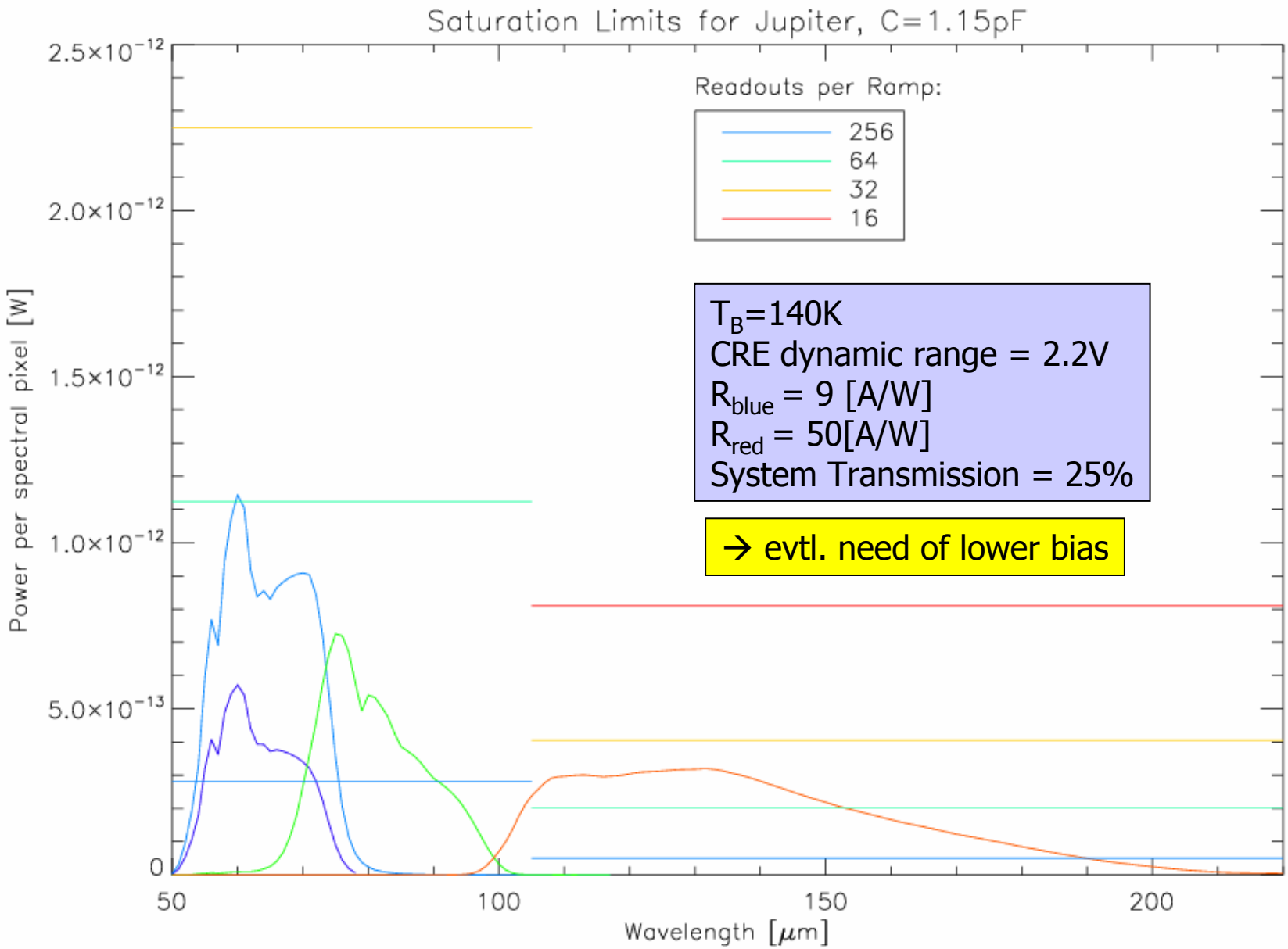
Calibration Targets for Molecular Lines

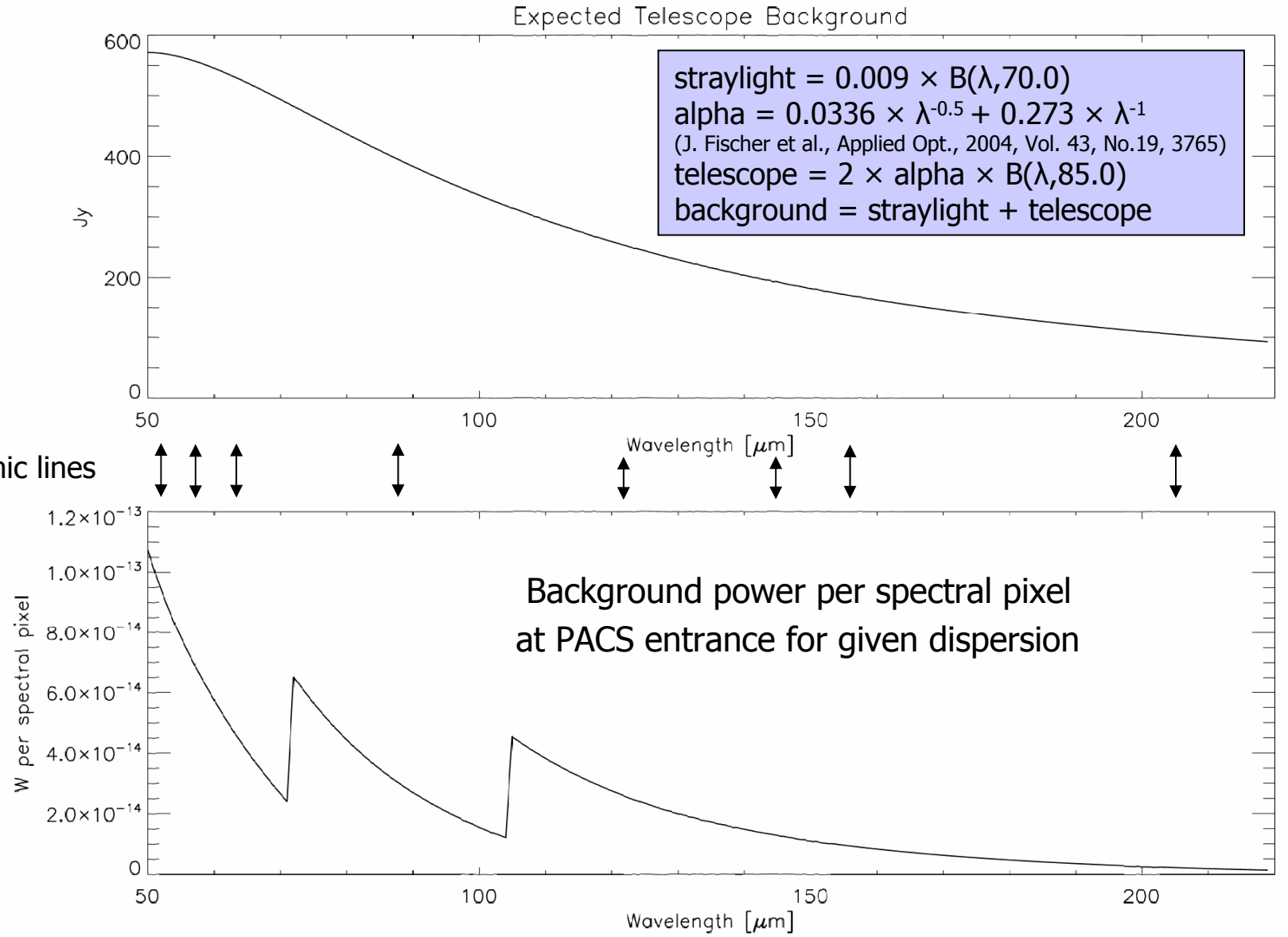


Calibration on bright PNs



selected out of Ref. (1)


Saturation Limits for Jupiter, C=1.15pF
Readouts per Ramp:
256
64
32
16
T_B=140K
CRE dynamic range = 2.2V
R_{blue} = 9 [A/W]
R_{red} = 50[A/W]
System Transmission = 25%
→ evtl. need of lower bias
Power per spectral pixel [W]
2.5×10⁻¹²
2.0×10⁻¹²
1.5×10⁻¹²
1.0×10⁻¹²
5.0×10⁻¹³
0
50
100
150
200
Wavelength [μm]


Expected Telescope Background
600
400
200
0
Jy
50
100
150
200
Wavelength [μm]
straylight = 0.009 × B(λ,70.0)
alpha = 0.0336 × λ^-0.5 + 0.273 × λ^-1
(J. Fischer et al., Applied Opt., 2004, Vol. 43, No.19, 3765)
telescope = 2 × alpha × B(λ,85.0)
background = straylight + telescope
Atomic lines
1.2×10^-13
1.0×10^-13
8.0×10^-14
6.0×10^-14
4.0×10^-14
2.0×10^-14
0
W per spectral pixel
Background power per spectral pixel
at PACS entrance for given dispersion
50
100
150
200
Wavelength [μm]