# Thermal Backgrounds
# Noise Budget
# &
# Instrument Temperature

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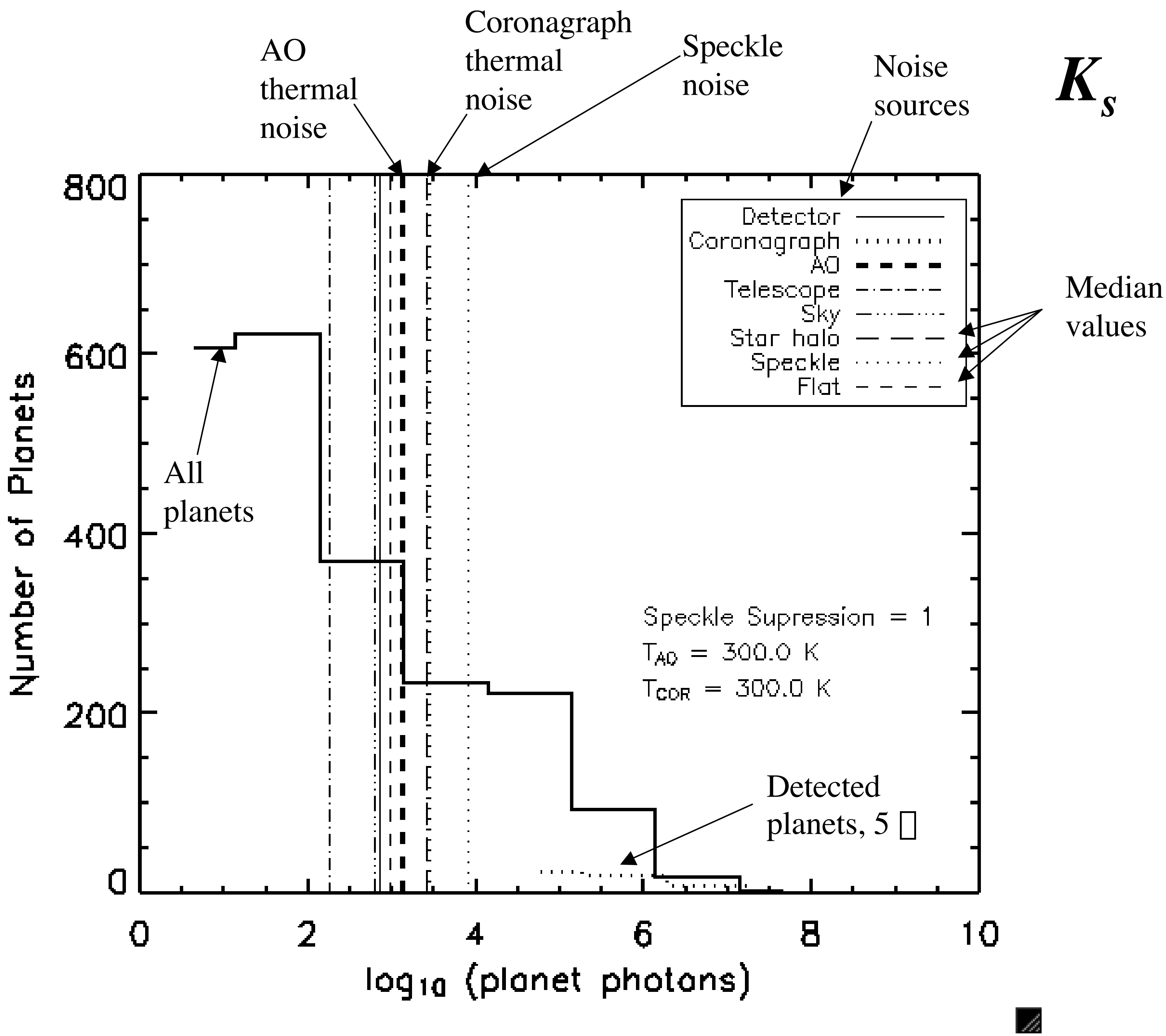
# Noise Budget @ *H*

- Noise associated with the thermal background from telescope, AO and coronagraph can be ignored at ***H*** (1.65 $\mu$m)
- Not true at $\boldsymbol{K_S}$ and $\boldsymbol{L_P}$
  - These wavelengths are important because
    - Predicted planet fluxes are less model dependent at longer wavelengths
    - Colors are diagnostic both for planets and debris disks

# Noise Budget @ $\boldsymbol{K_s}$

- AO performance
  - $I = 7$ mag. guide star, 51 nm WFE
- No speckle suppression
- Telescope at 273 K
- Coronagraph & AO at 300 K
  - Binary pupil mask coronagraph, $\square_{mask} = 0.5$
- Flat field accuracy = 0.1% per pixel
- Exposure time is 3600 seconds
  - 2164 stars observed
  - 51 planets detected
  - 2.4% success rate



AO thermal noise
Coronagraph thermal noise
Speckle noise
Noise sources
Ks
Median values
All planets
Detected planets, 5 
Detector
Coronagraph
AO
Telescope
Sky
Star halo
Speckle
Flat
Speckle Supression = 1
TAO = 300.0 K
TCOR = 300.0 K
Number of Planets
log10 (planet photons)
0
2
4
6
8
10
200
400
600
800

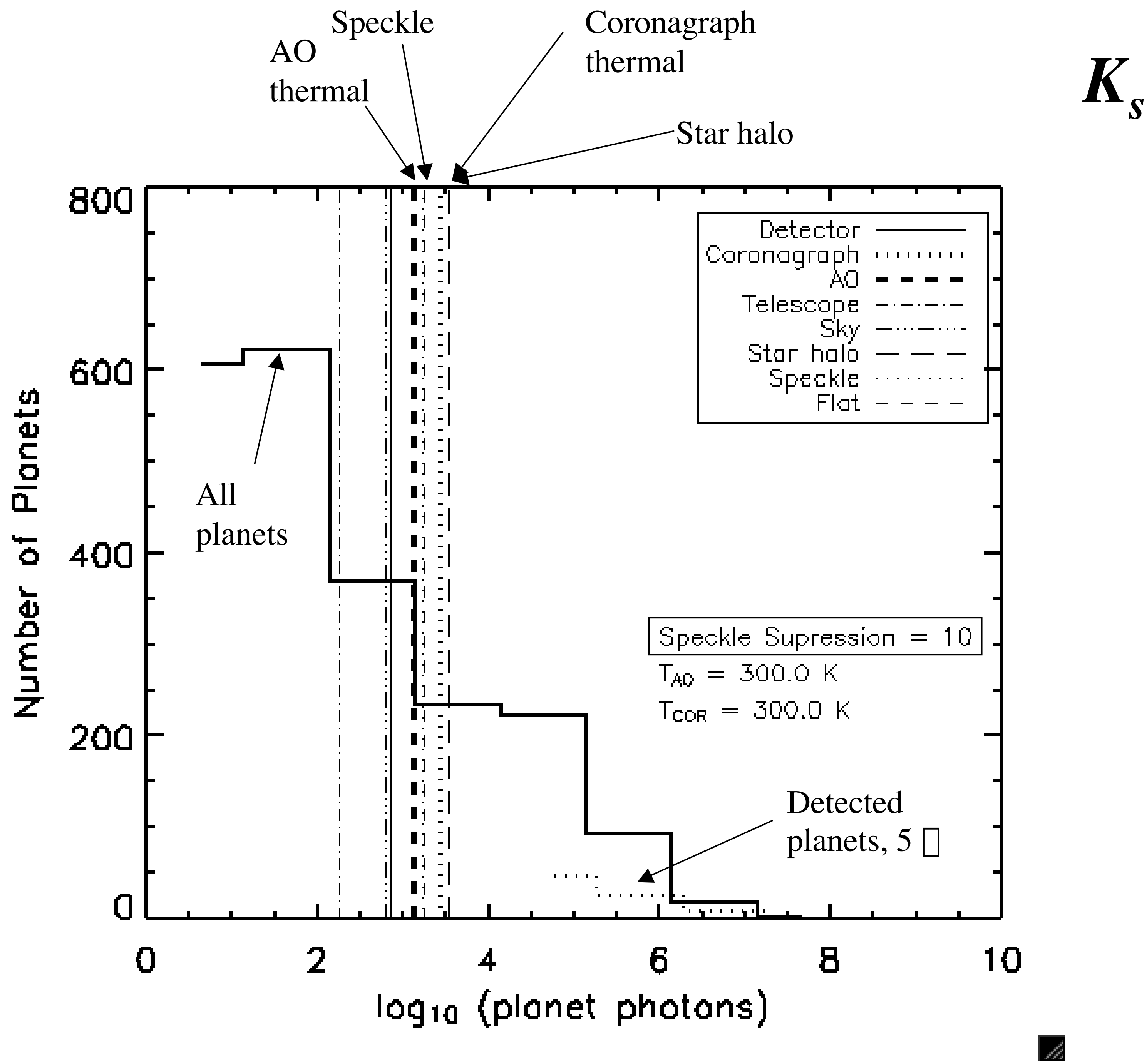
# Noise Budget @ $K_s$

- When there is no speckle suppression
  - Speckle noise dominates

***No advantage in $K_s$ from cooling the AO or the Coronagraph if there is no speckle suppression***

# Noise Budget @ $\boldsymbol{K_s}$

- x 10 speckle suppression
- Coronagraph & AO at 300 *K*
- Exposure time is 3600 seconds
  - 2164 stars observed
  - 82 planets detected
  - 3.8% success rate
- 61 % improved planet detection rate compared to no speckle suppression

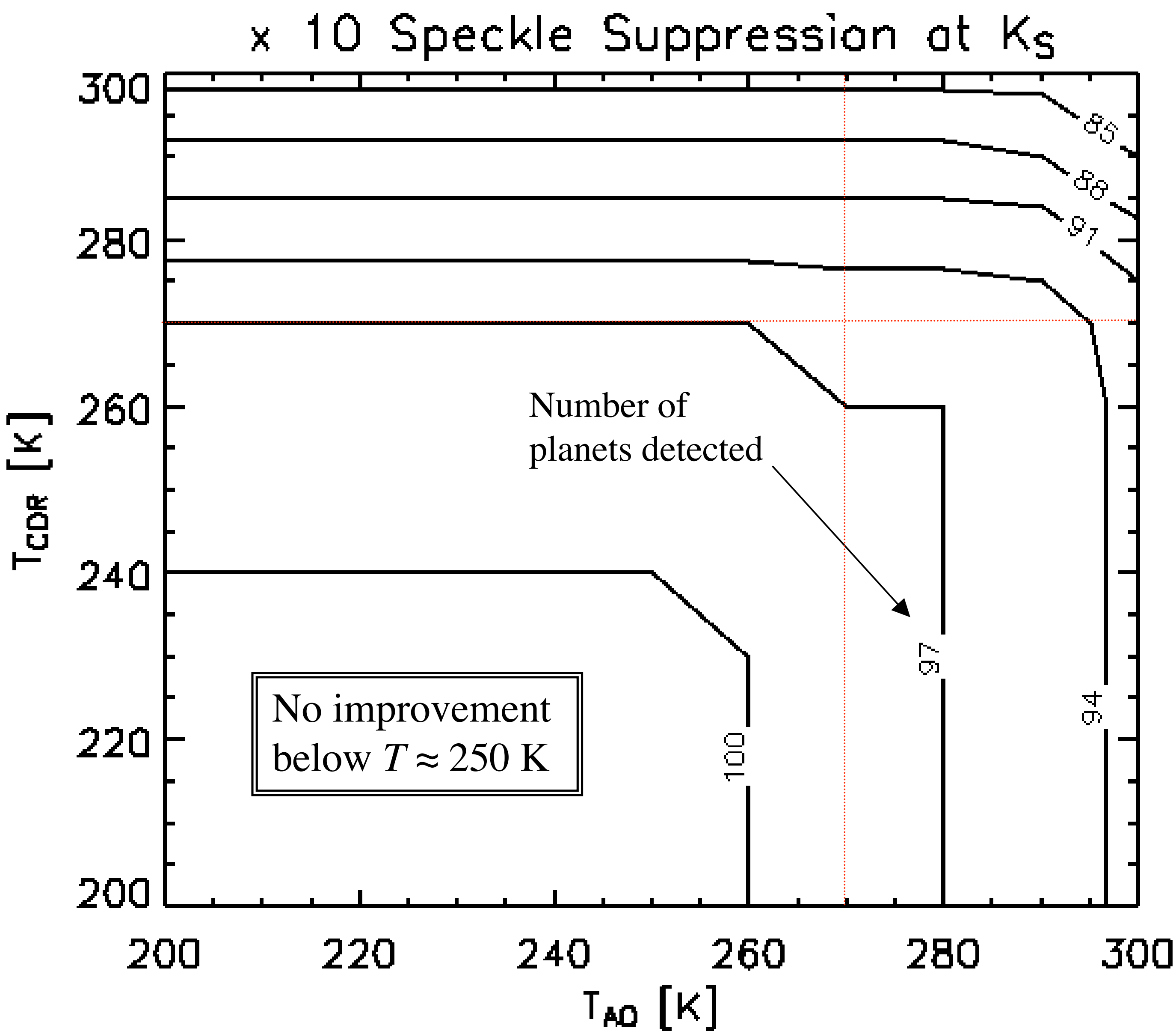


Speckle
AO thermal
Coronagraph thermal
Star halo
Ks
800
600
400
200
0
Number of Planets
0
2
4
6
8
10
log10 (planet photons)
Detector
Coronagraph
AO
Telescope
Sky
Star halo
Speckle
Flat
All planets
Speckle Supression = 10
TAO = 300.0 K
TCOR = 300.0 K
Detected planets, 5

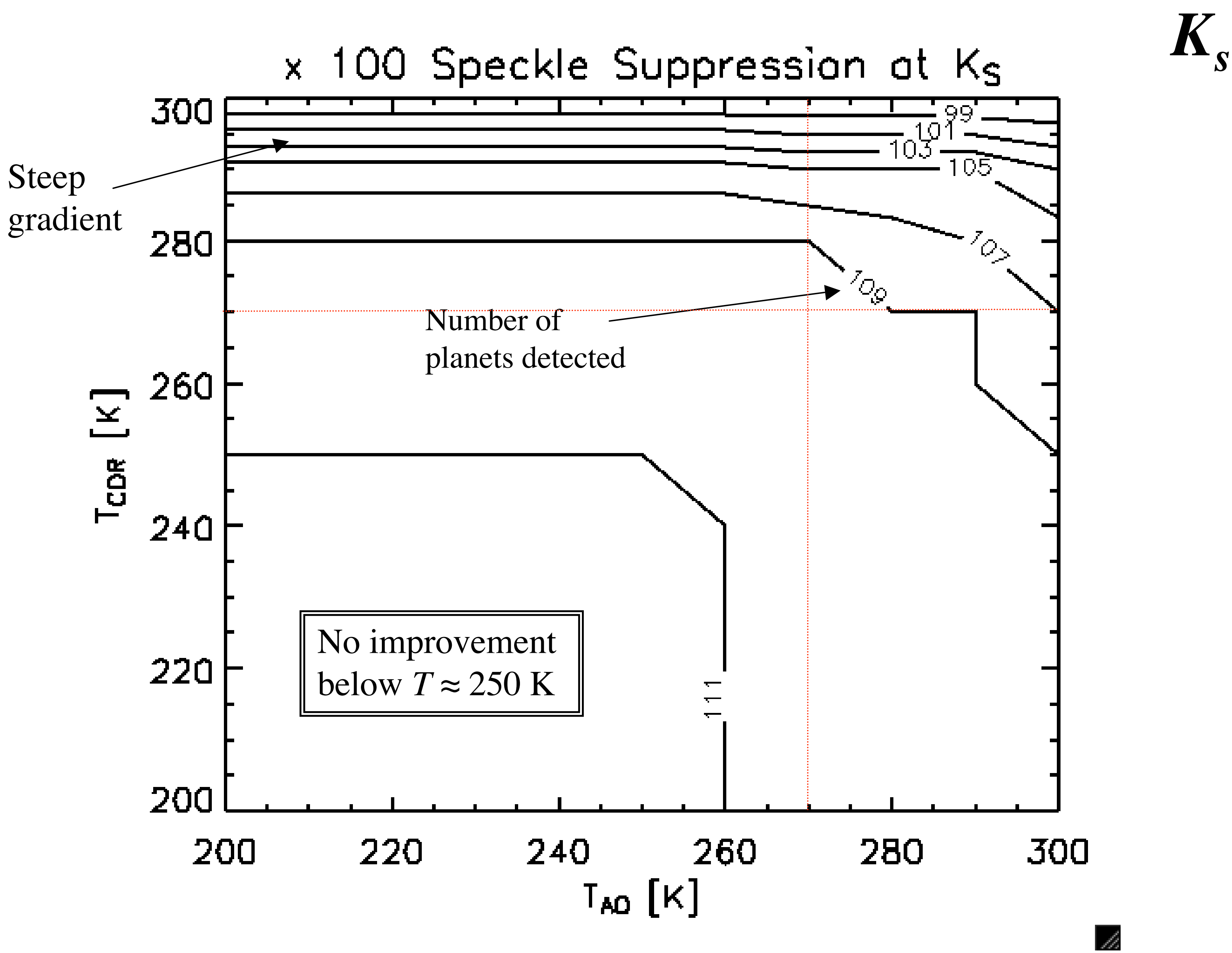
# Noise Budget @ $\boldsymbol{K_s}$ with x10 Speckle Suppression

- Star halo photon noise dominates
  - Coronagraph thermal noise is second
- Cooling the instrument can increase the planet detection rate
  - $T_{COR} \approx 240$ K and $T_{AO} \approx 260$ K yields 100 planets (4.6% detection rate
  - No gain from cooling below ~ 250 K at $\boldsymbol{K_S}$ with x 10 speckle suppression
  - Approximately equal gains from cooling coronagraph and AO

## $K_s$



x 10 Speckle Suppression at Ks
300
280
260
240
220
200
T_CDR [K]
200
220
240
260
280
300
T_AO [K]
85
88
91
94
97
100
Number of planets detected
No improvement below T ≈ 250 K



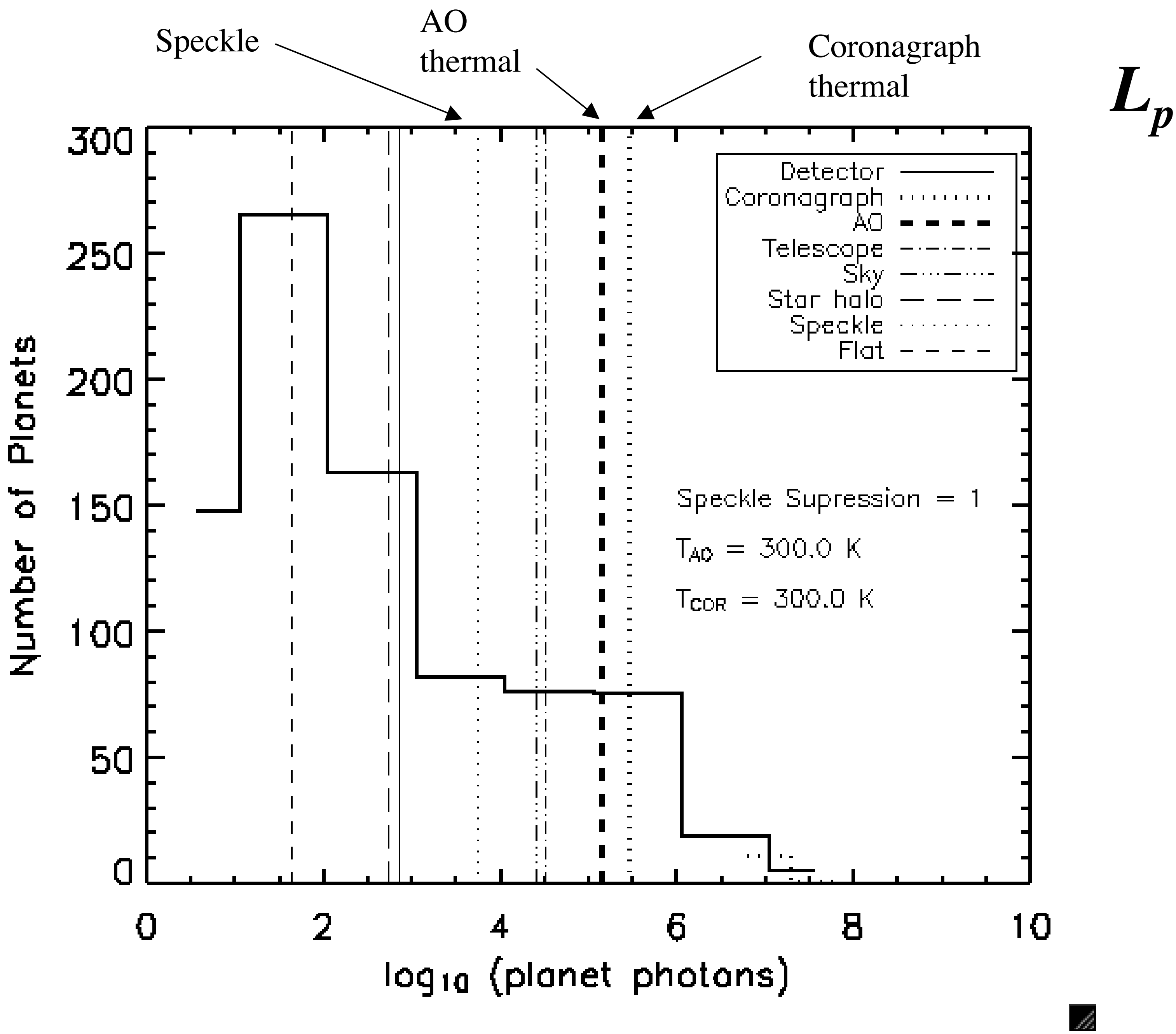
Ks
x 100 Speckle Suppression at Ks
Steep gradient
Number of planets detected
No improvement below T ≈ 250 K
99
101
103
105
107
109
111
300
280
260
240
220
200
TCDR [K]
TAO [K]

# Noise Budget @ $\boldsymbol{K_s}$ with Speckle Suppression

- Speckle suppression alone yields 100 planets if the AO & coronagraph are at ≈ 273 *K*
  - ***AO & coronagraph must not operate at "room temperature" (293 K)***
  - ***Cooling from 270 K to ≈ 250 K yields just a few more planets***
  - More critical to cool the coronagraph than the AO if using a binary pupil mask

# Noise Budget @ $L_P$

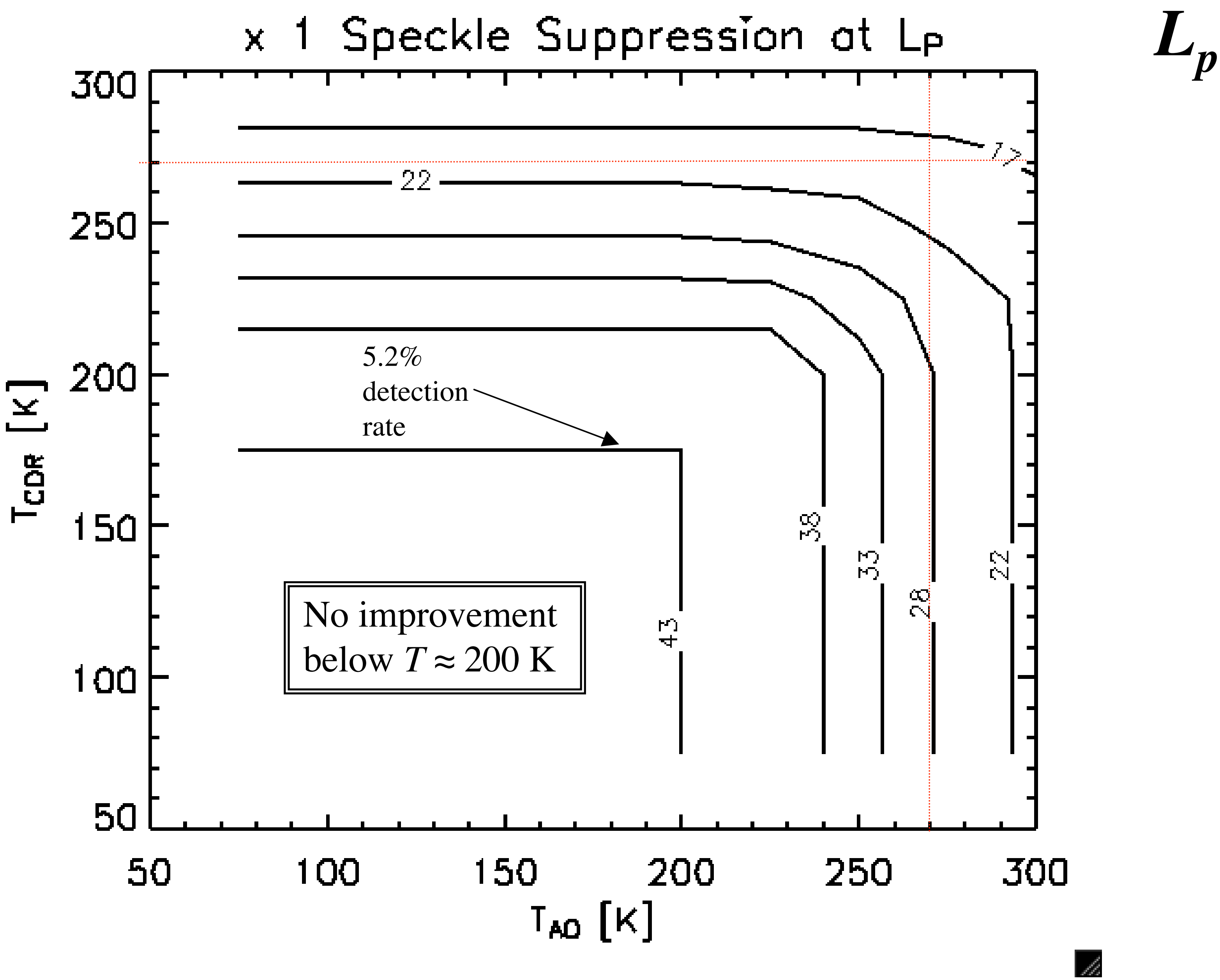
- AO has $I$ = 6 mag. guide star, 12 nm WFE
  - *Different simulation set—sorry*
- No speckle suppression
- Telescope at 273 K
- Coronagraph & AO at 300 K
  - Binary pupil mask coronagraph, $\square_{mask} = 0.5$
- Flat field accuracy = 0.1% per pixel
- Exposure time is 3600 seconds
  - 882 stars observed
  - 12 planets detected
  - 1.4% success rate



Speckle
AO thermal
Coronagraph thermal
$L_p$
Detector
Coronagraph
AO
Telescope
Sky
Star halo
Speckle
Flat
Speckle Supression = 1
$T_{AO}$ = 300.0 K
$T_{COR}$ = 300.0 K
Number of Planets
300
250
200
150
100
50
0
0
2
4
6
8
10
$\log_{10}$ (planet photons)

# Noise Budget @ $\boldsymbol{L_P}$

- Thermal background dominates (in decreasing order)
  - Coronagraph
  - AO
  - Telescope
  - Sky
- Cooling is necessary
  - Speckle suppression is irrelevant
  - Warm ExAOC will be outperformed at $\boldsymbol{L_P}$ by a regular AO system optimized for long wavelength operation, e.g., one that uses a deformable secondary



x 1 Speckle Suppression at Lp
$L_p$
5.2% detection rate
No improvement below $T \approx 200$ K
22
17
38
33
28
22
43
$T_{CDR}$ [K]
$T_{AO}$ [K]
300
250
200
150
100
50
50
100
150
200
250
300

# Noise Budget @ $\boldsymbol{L_P}$

- Warm AO/coronagraph is probably useless at $\boldsymbol{L_P}$
- Cooling the AO and coronagraph yields up to a twofold discovery rate
  - $T_{COR} < 180$ K
  - $T_{AO} < 200$ K
  - Need to cool both
- Speckle suppression does not improve the detection rate for a cooled system
  - Once the AO and coronagraphs are cooled the telescope and atmosphere dominate speckle noise

# Conclusions

- Broadly there are two choices for ExAOC
- Cool (< 280 K)
  - $\boldsymbol{H}$ & $\boldsymbol{K_s}$
  - Substantial speckle suppression (≈ 100)
  - Detector
    - NICMOS recipe $Hg_{1-X}Cd_XTe$
- Cold (< 180 K)
  - $\boldsymbol{L_p}$
  - No speckle suppression
  - Detector
    - InSb or JWST style long-wave $Hg_{1-X}Cd_XTe$

# Caveats/Future Work

- Calculations assume that there is no stray light
  - Only in-beam elements contribute to the background
- Need a consistent set of $\boldsymbol{H}$, $\boldsymbol{K_s}$ and $\boldsymbol{L_p}$ sensitivity curves