Clustered Reversible-KLT for Progressive Lossy-to-Lossless 3d Image Coding

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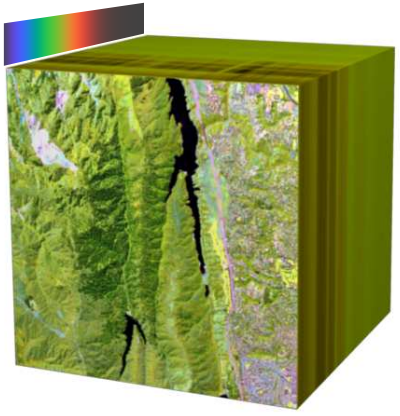
March 17th 2009

GICi
UAB
Universitat Autònoma de Barcelona

Context

Lossless compression

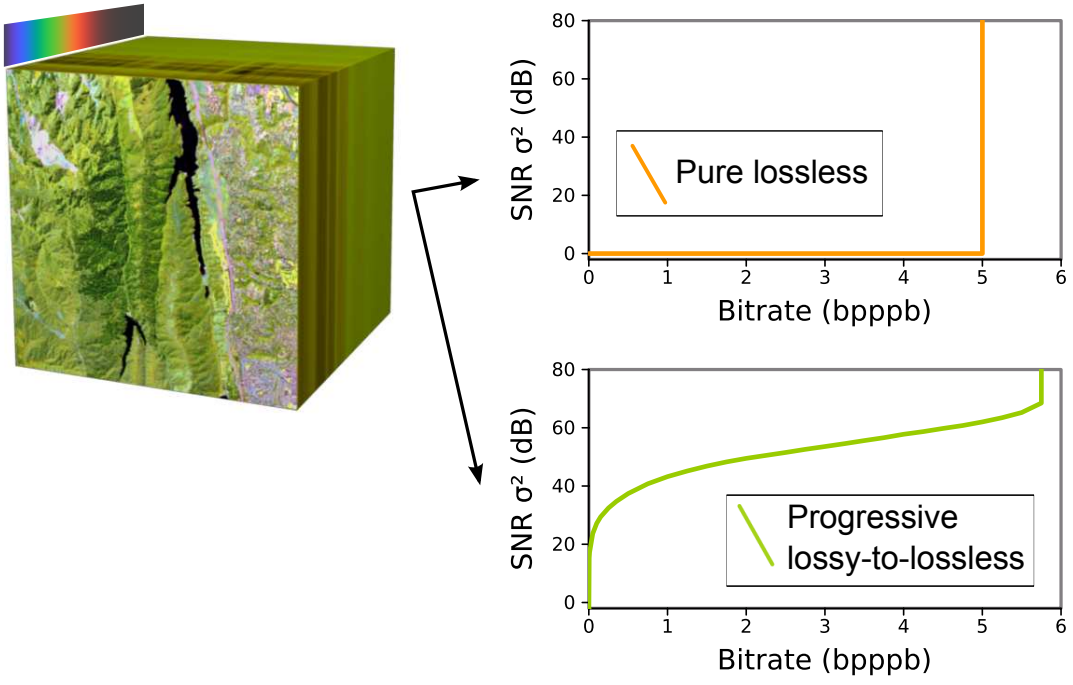


Motivation:

- High acquisition costs
- Legal issues
- Usage requirements

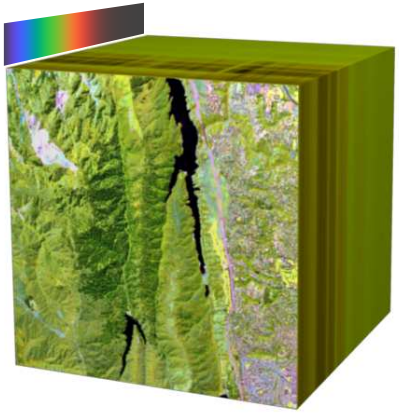
Context

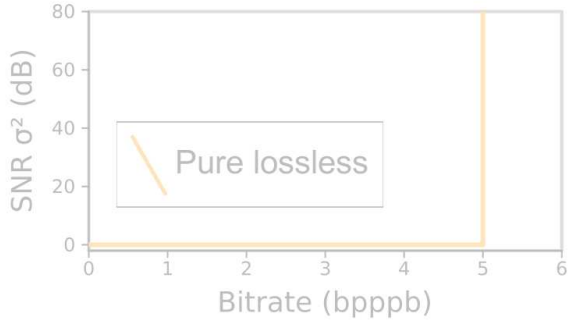
Lossless compression

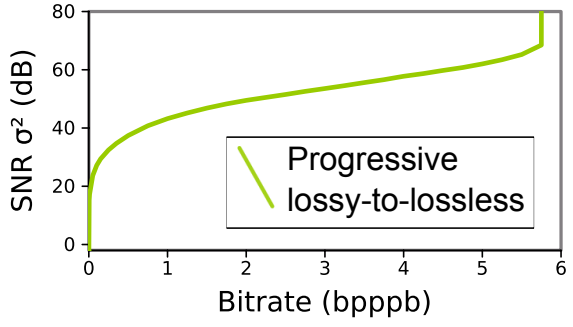


Context

Lossless compression





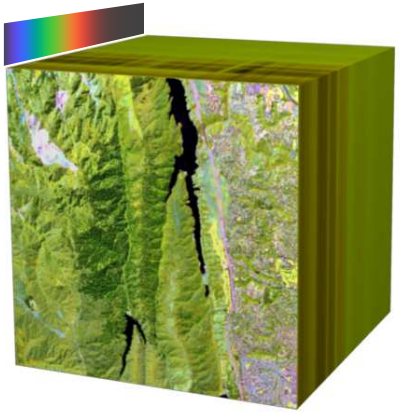


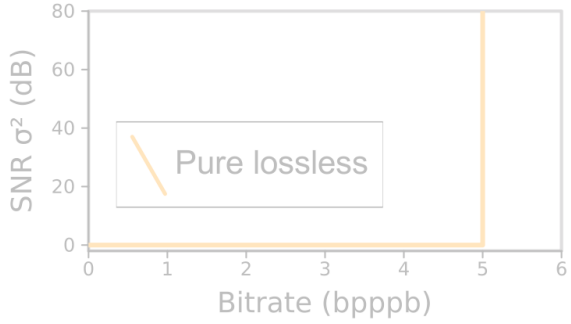
Motivation:

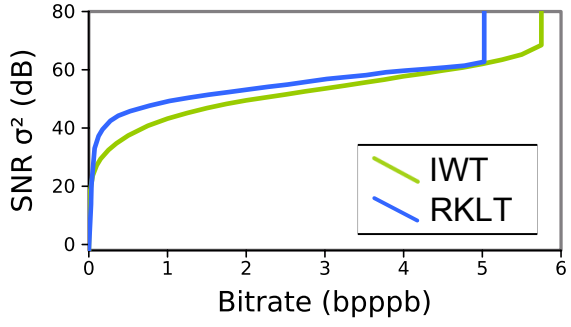
- Similar CRs
- Quality progressive

Context

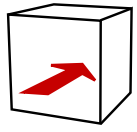
Lossless compression







Spectral Transform



IWT

- Moderate decorrelation
- Low cost

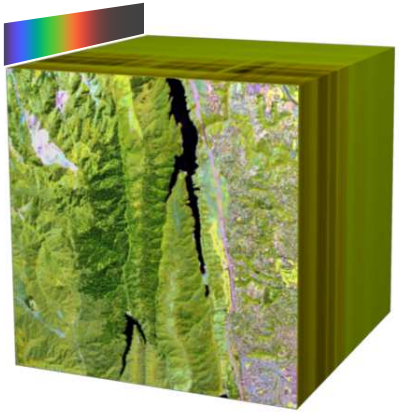
RKLT

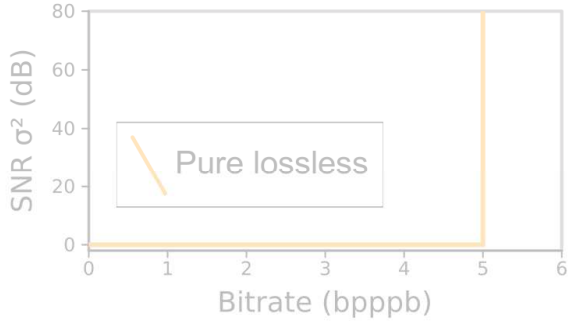
$\Phi_X = Q\Lambda Q^{-1}$

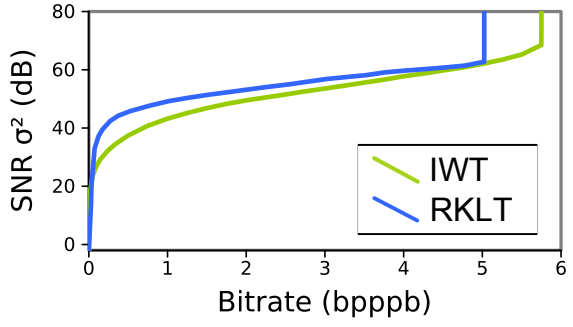
- Very high decorrelation
- High cost

Context

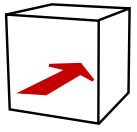
Lossless compression







Spectral Transform



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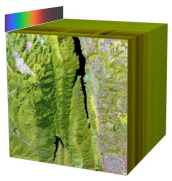
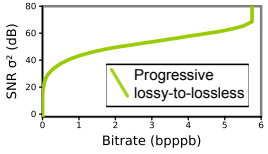




RKLT $\Phi_X = Q\Lambda Q^{-1}$

- Very high decorrelation
- High cost

Objective:
Encode hyperspectral images with progressive lossy-to-lossless, with focus on the RKLT.

Previous approaches:

- Lossy to lossless SPIHT-based volumetric image compression [G. Ginesu, D. Giusto, and W. Pearlman, 2004]
- Lossy-to-Lossless Compression of Hyperspectral Imagery Using Three-Dimensional TCE and an Integer KLT [J. Zhang, J. Fowler, and G. Liu, 2008]

Outline

RKLT

$\Rightarrow$ A lossless approximation of the KLT.

The KLT

$$KLT_{\Phi_X}(X) = Q^T X$$

It is based on the Singular Value Decomposition of the covariance matrix.

$$\Phi_X = Q \Lambda Q^{-1}$$

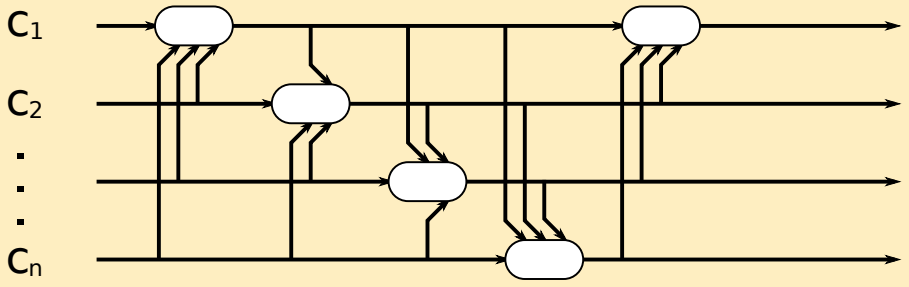
The RKLT

Using a Lifting scheme, Q^T is decomposed into elementary reversible steps (Hao & Shi, 2001).

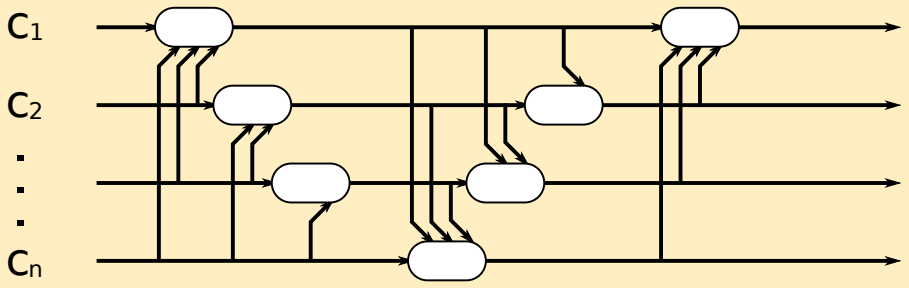
RKLT Application

“animation”

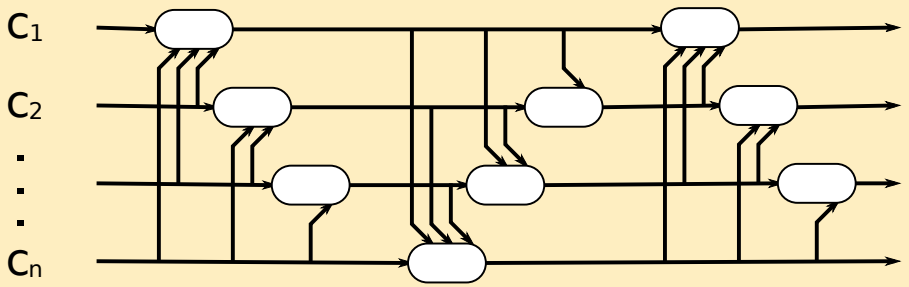
RKLT Lifting Structures



SERM (Hao & Shi, 2001)
- Standard in JPEG2000 part 2 (2001)



TERM (Hao & Shi, 2001)
- Less numerical problems



3TERM (Galli & Salzo, 2004)
- Better transform approximation

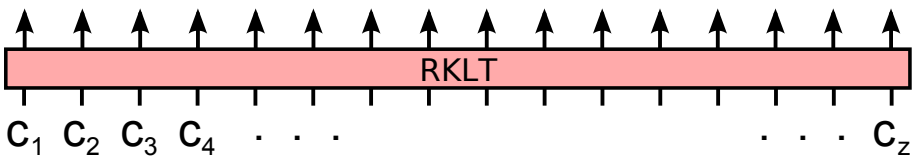
Issues

1. High computational cost.
2. The standardized lifting scheme produces very large coefficients.
3. Quality penalty at very high bitrates.

Outline

Clustering

Idea: Transform cost is $\sim O(n^2)$. Therefore, smaller transforms have a substantially lower cost.



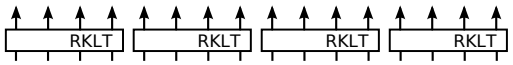
16 components

$\Rightarrow$ Both can be used within JPEG2000 part 2.

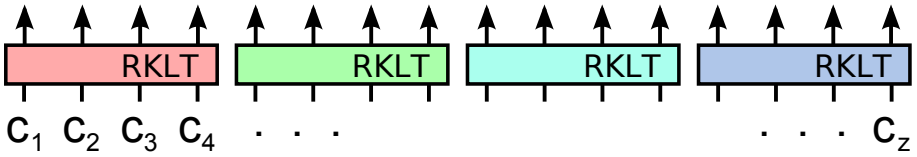
Clustering

Idea: Transform cost is $\sim O(n^2)$. Therefore, smaller transforms have a substantially lower cost.

a) Clustering



- Very fast
- Local decorrelation



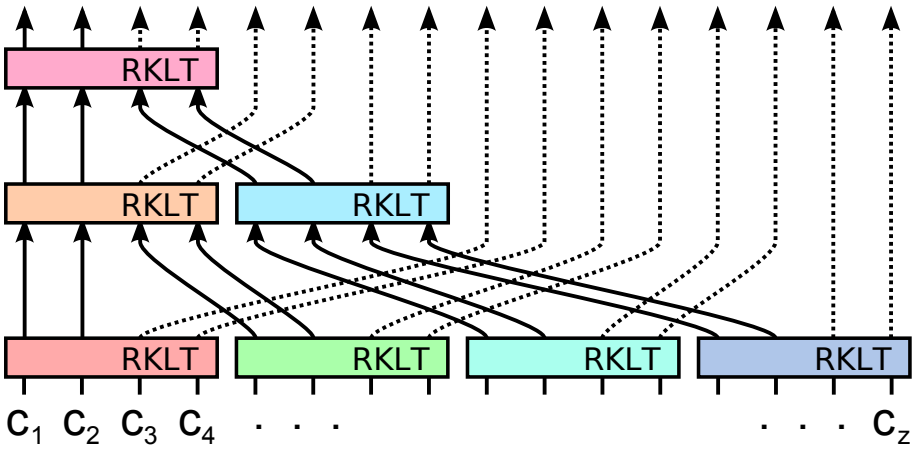
16 components, 4 clusters

26% of the original cost

$\Rightarrow$ Both can be used within JPEG2000 part 2.

Clustering

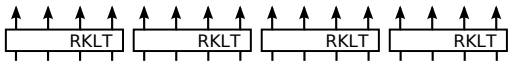
Idea: Transform cost is $\sim O(n^2)$. Therefore, smaller transforms have a substantially lower cost.



16 components, 4 multi-level clusters

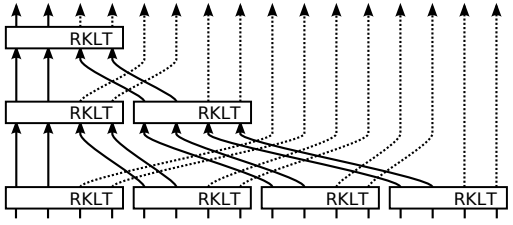
44% of the original cost

a) Clustering



- Very fast
- Local decorrelation

b) Multi-level Clustering



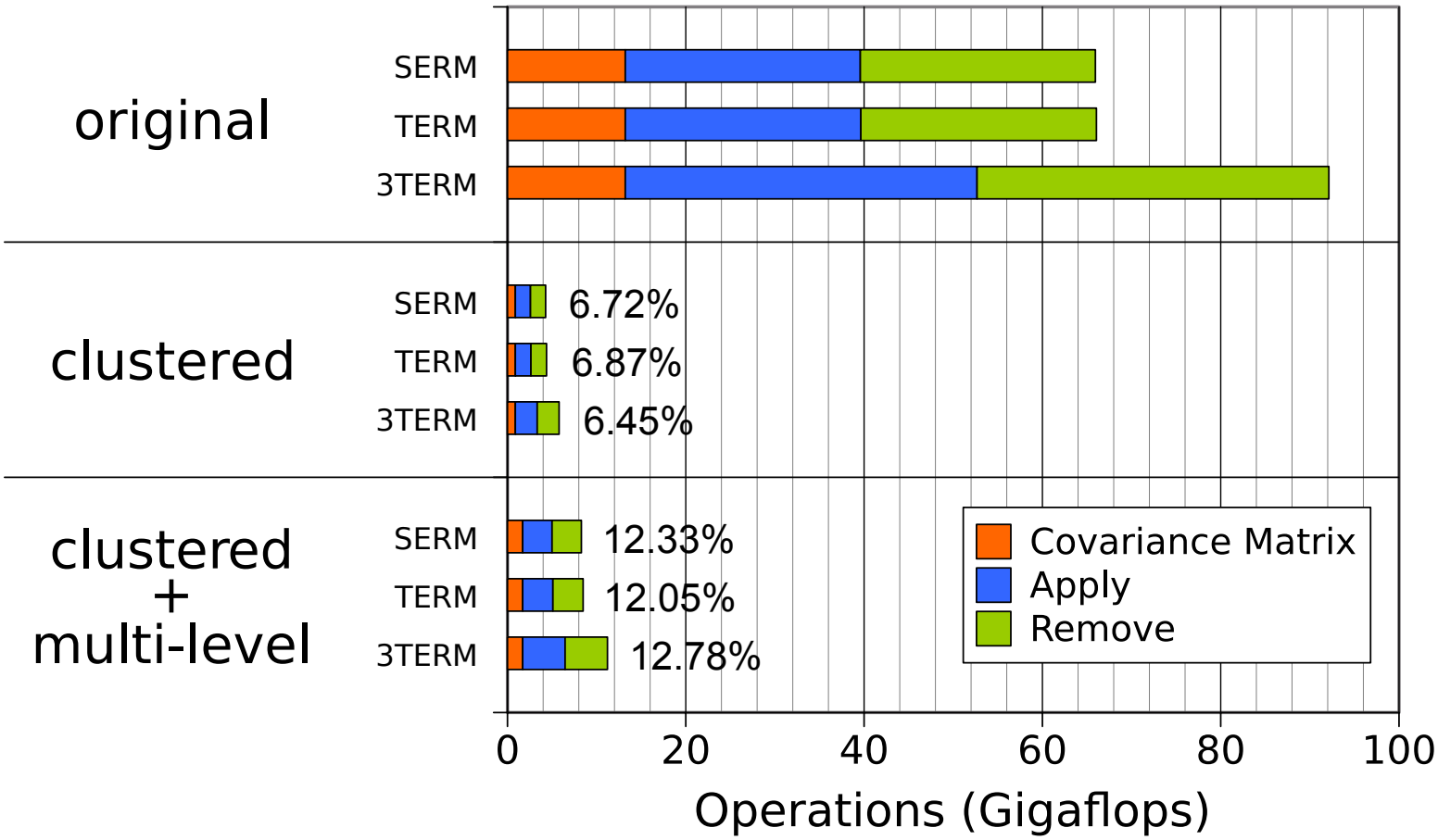
- Half as fast
- Global decorrelation

$\Rightarrow$ Both can be used within JPEG2000 part 2.

Computational Cost (1st problem)

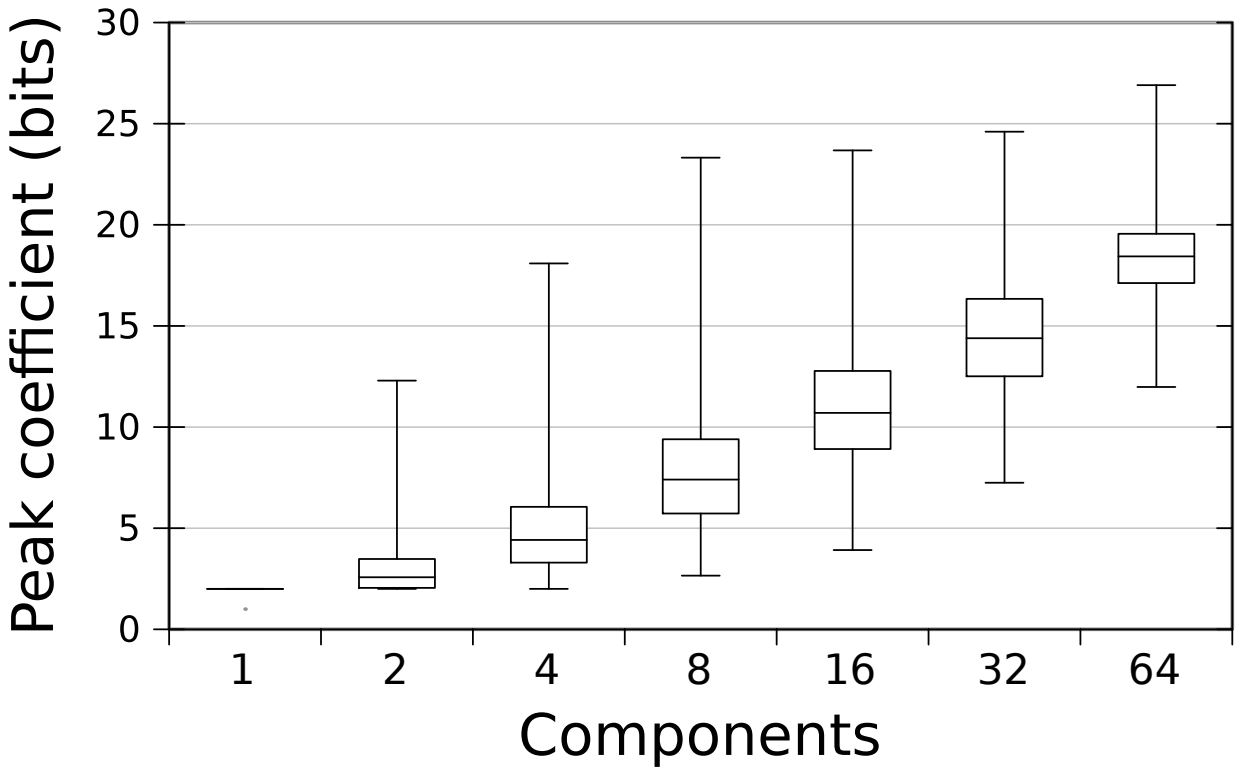
$\Rightarrow$ Greater savings as components increase.

Typical AVIRIS image (224 components $\times$ 512 $\times$ 512) with 16 clusters:



SERM Overflow (2nd problem)

$\Rightarrow$ Transforms with a large number of components (~ 256) may potentially have coefficients that do not fit in a 32 bit integer.



$\Rightarrow$ Clusters of less than 32 components are recommended.

Outline

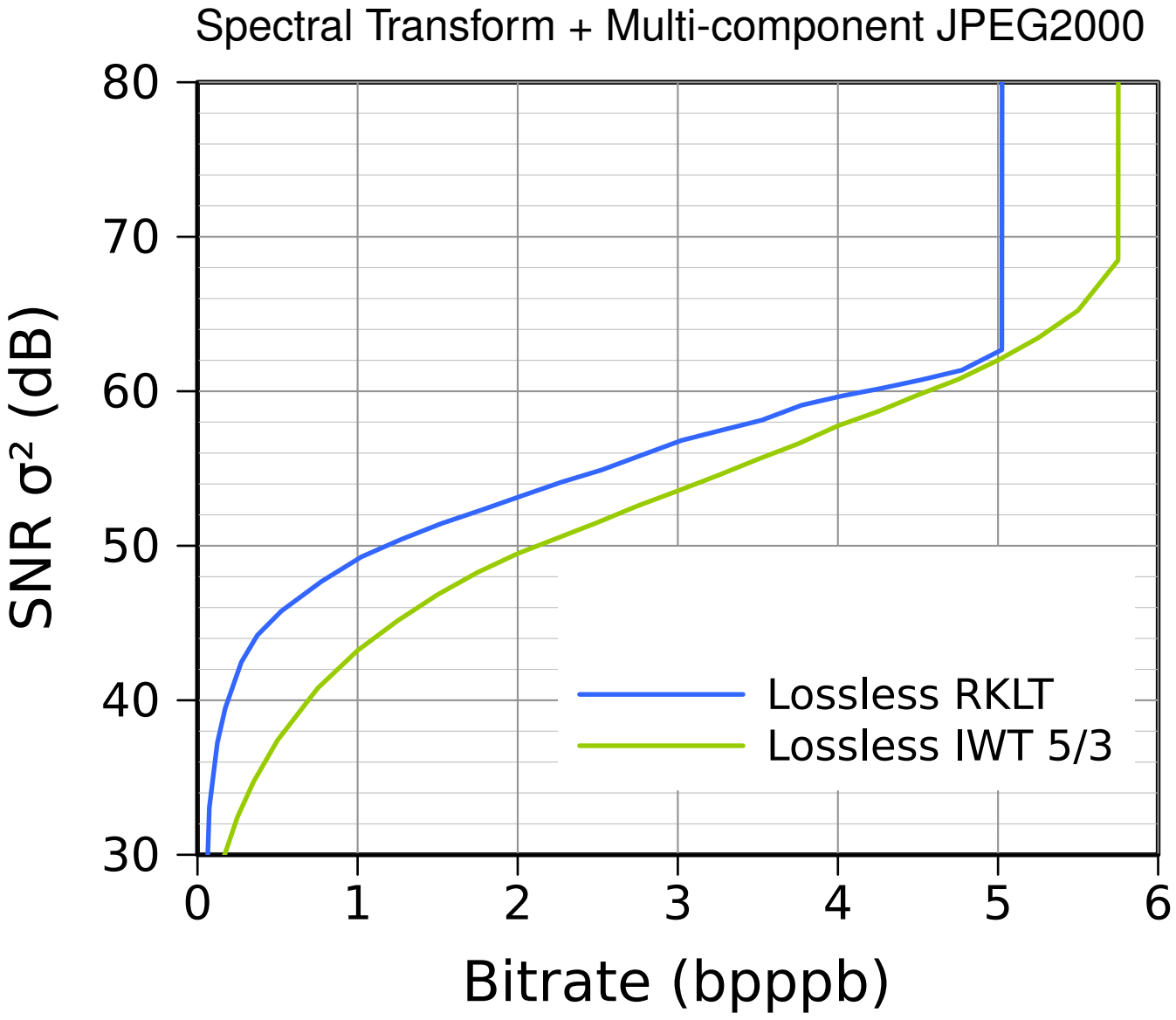
The RKLT versus other transforms

AVIRIS

Low Altitude

$512 \times 512 \times 224$

16bit signed



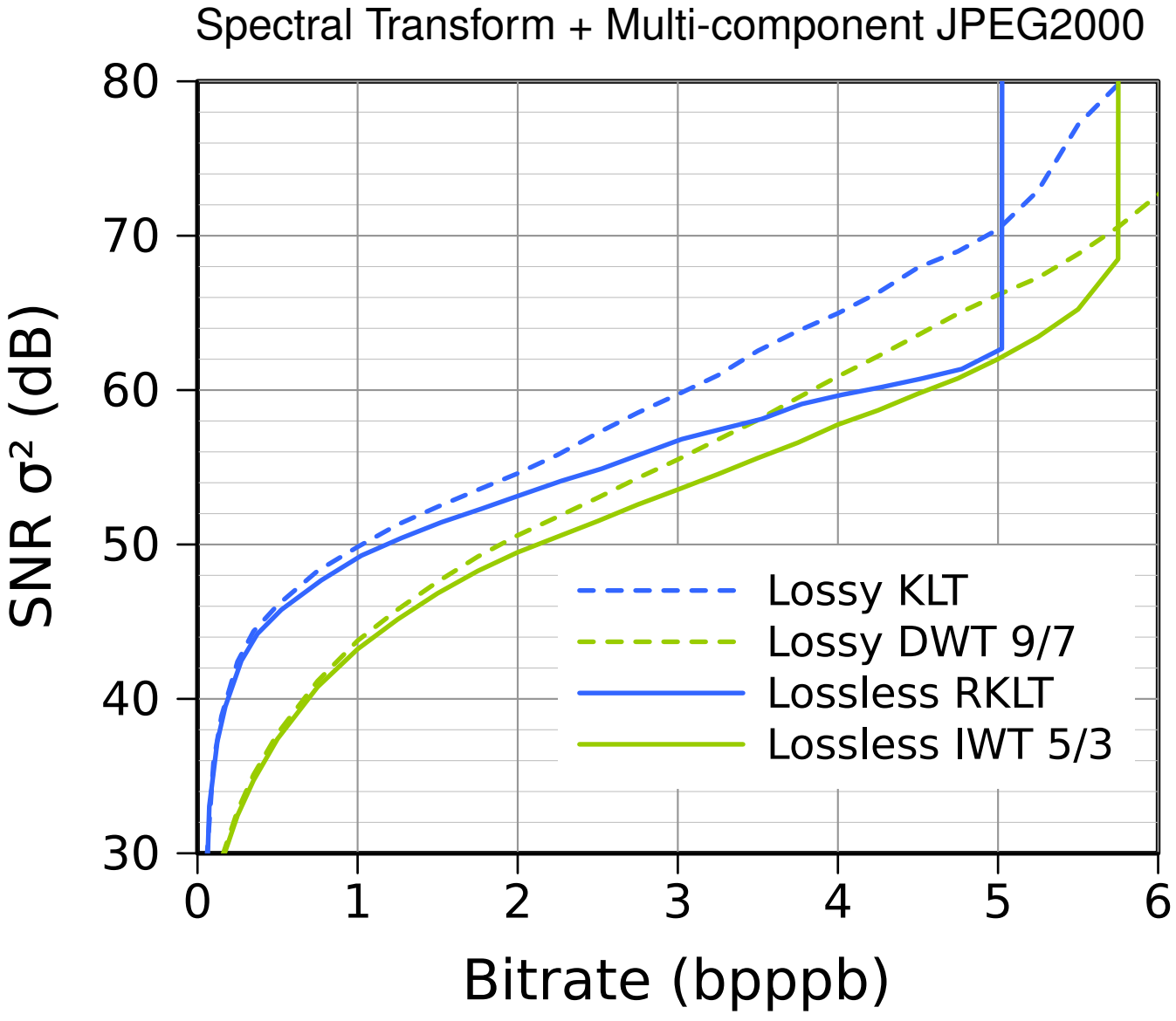
The RKLT versus other transforms

AVIRIS

Low Altitude

$512 \times 512 \times 224$

16bit signed



The RKLT versus other transforms

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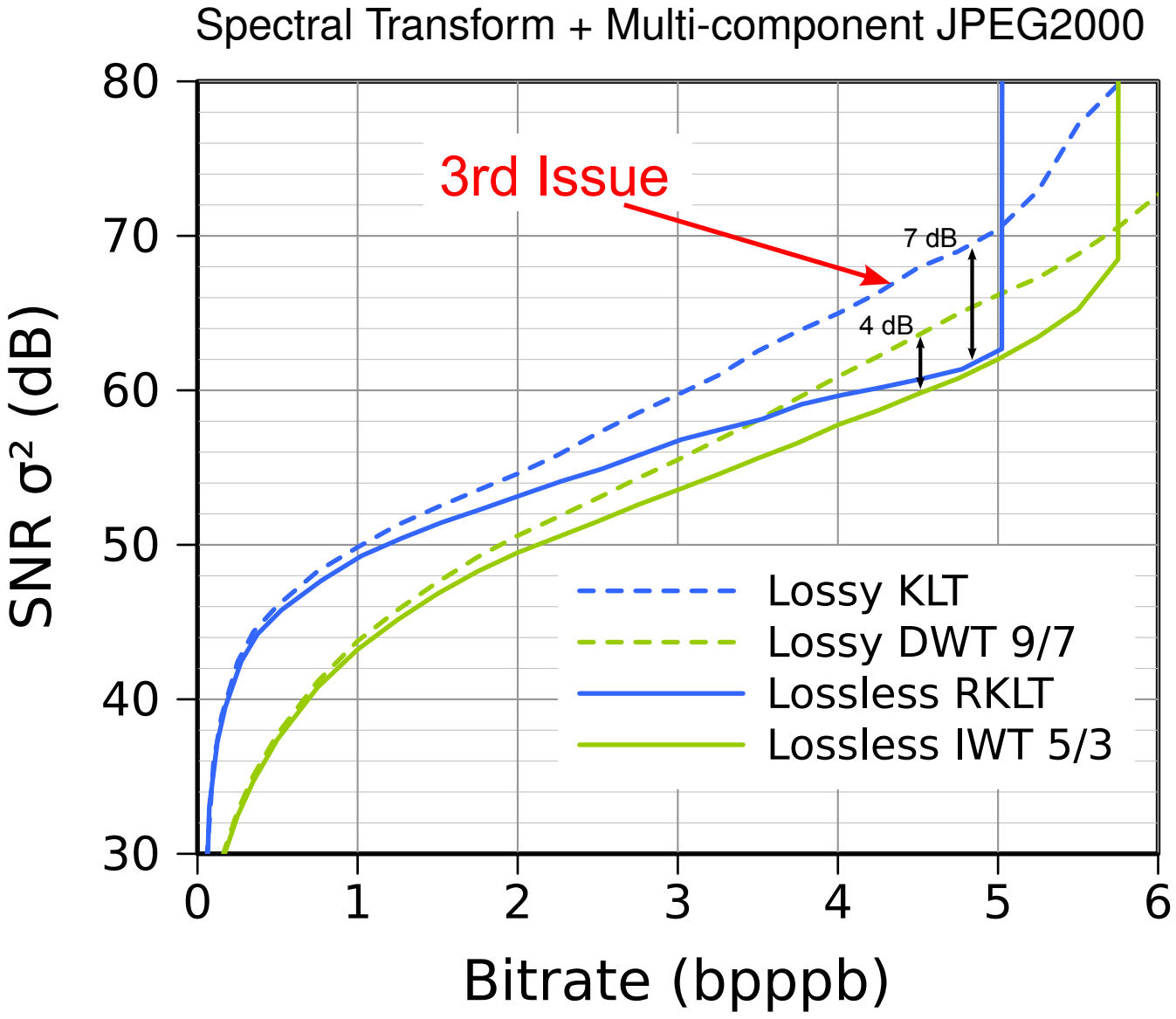
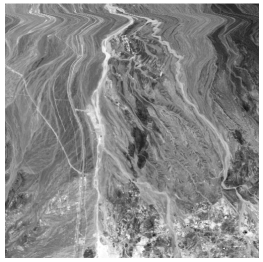


The clustered versions (Lossy Regime)

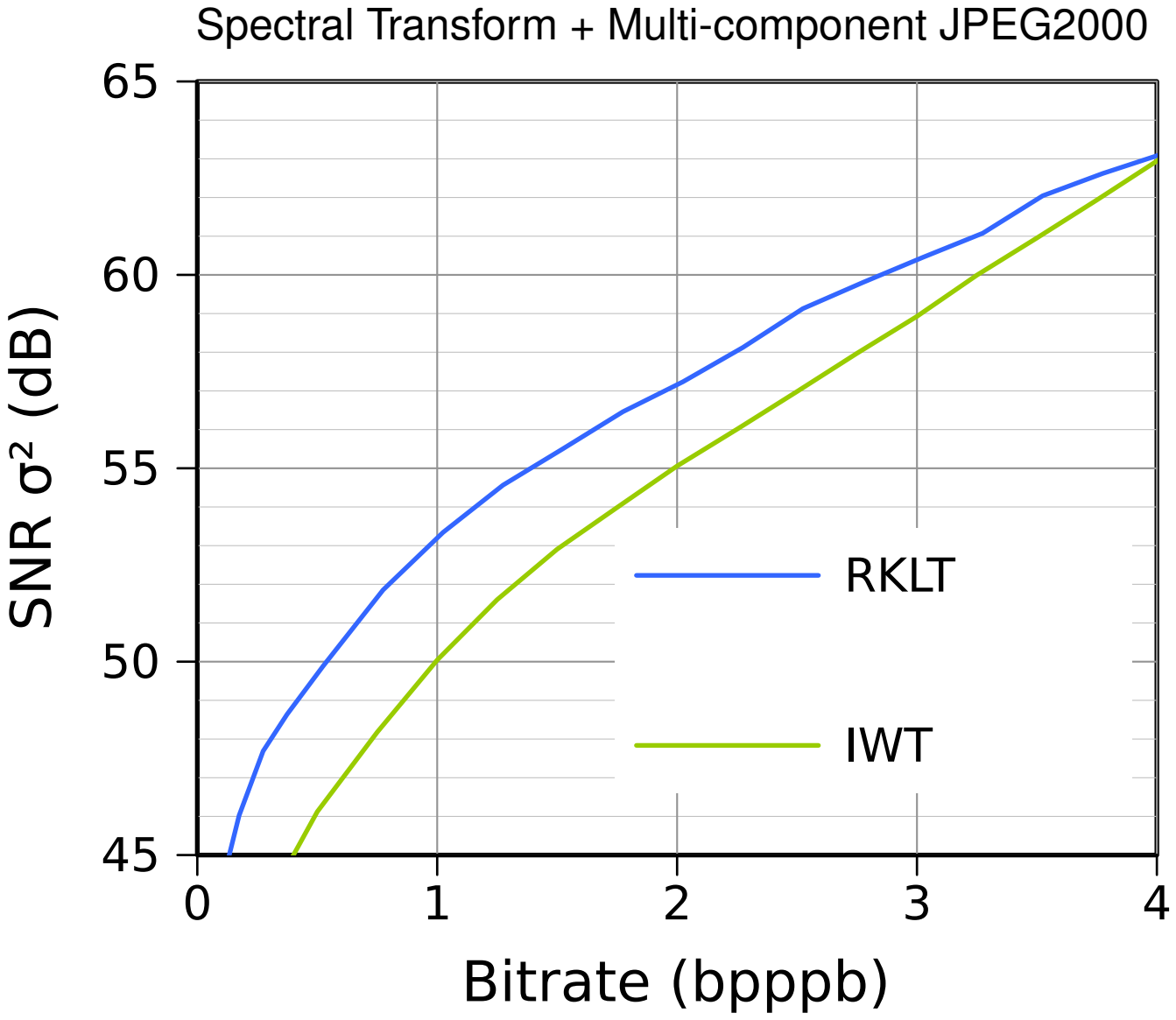


AVIRIS

Cuprite

$512 \times 512 \times 224$

16bit signed



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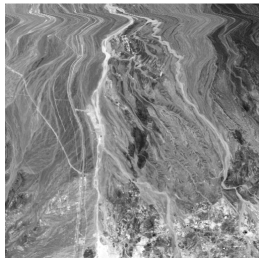

AVIRIS

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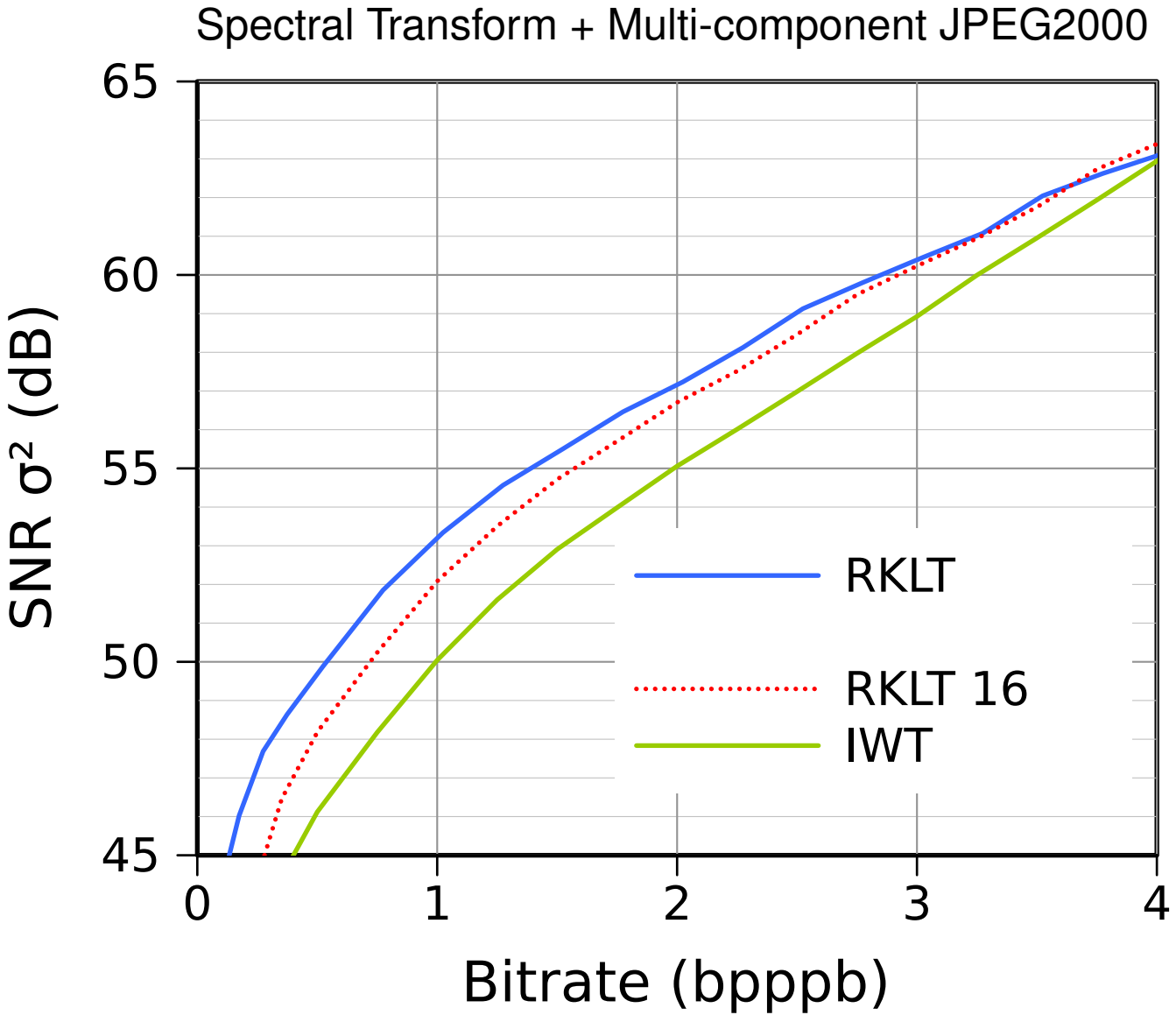
16bit signed



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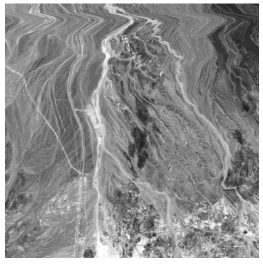

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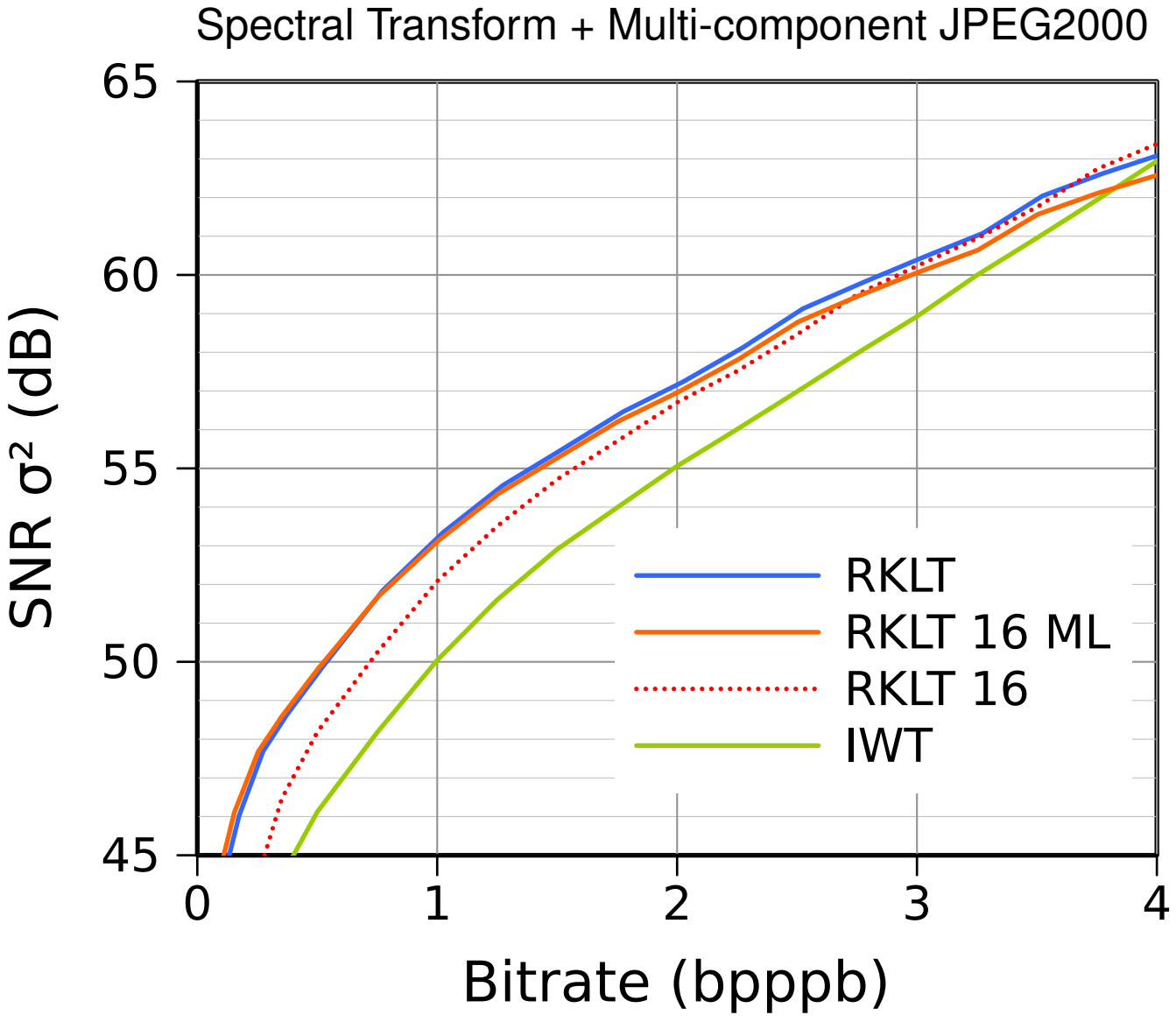

Lossless Compression

		Cuprite	Jasper Ridge	Moffett Field	Lunar Lake	Average
lossy-to-lossless[1]	none	7.01	7.66	7.79	6.91	7.34
	3d IWT	5.28	5.54	5.65	5.30	5.44
	RKLT	4.85	**4.84**	**4.94**	4.96	4.90
	RKLT 4	4.87	4.89	4.99	4.96	4.93
	RKLT 16	5.04	5.12	5.24	5.11	5.13
	RKLT 4 ML	4.85	**4.84**	**4.94**	4.95	4.90
	RKLT 16 ML	4.86	4.87	4.98	4.96	4.92
lossless	M-CALIC	4.86	4.96	5.05	4.96	4.96
	LUT	**4.61**	4.92	5.13	**4.77**	**4.86**

Required bitrate for lossless compression (bpppb).

[1] Encodings with JPEG2000

Lossless Compression

		Cuprite	Jasper Ridge	Moffett Field	Lunar Lake	Average
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lossless	M-CALIC	4.86	4.96	5.05	4.96	4.96
	LUT	**4.61**	4.92	5.13	**4.77**	**4.86**
	Difference	0.25	-0.05	-0.15	0.19	0.06

Required bitrate for lossless compression (bpppb).

[1] Encodings with JPEG2000

Goal:
Use progressive lossy-to-lossless on Remote Sensing, with focus on the RKLT.

Conclusions:

- The RKLT is very good but has very high cost.
- Two clustering strategies proposed

	Original	Clustered	Multi-level clustered
Computational Cost	Very High	Low (6%)	Low (12%)
Quality	Very high	High	Very high

- Using clusters, transforms coefficients do not overflow
- The RKLT has a problem on very high bitrates.

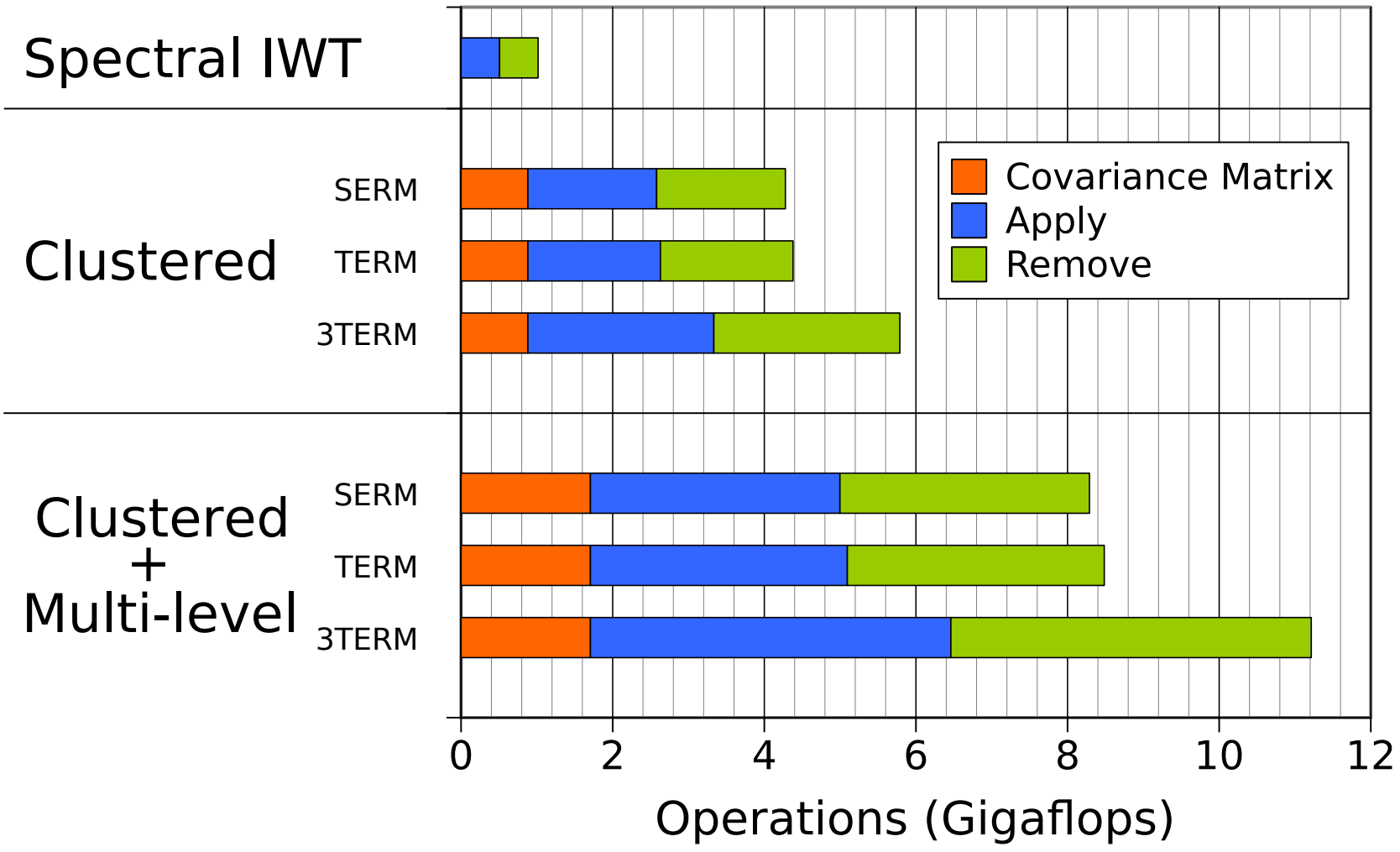
$\Rightarrow$ An open-source implementation is available at `http://gici.uab.es`.

Other slides

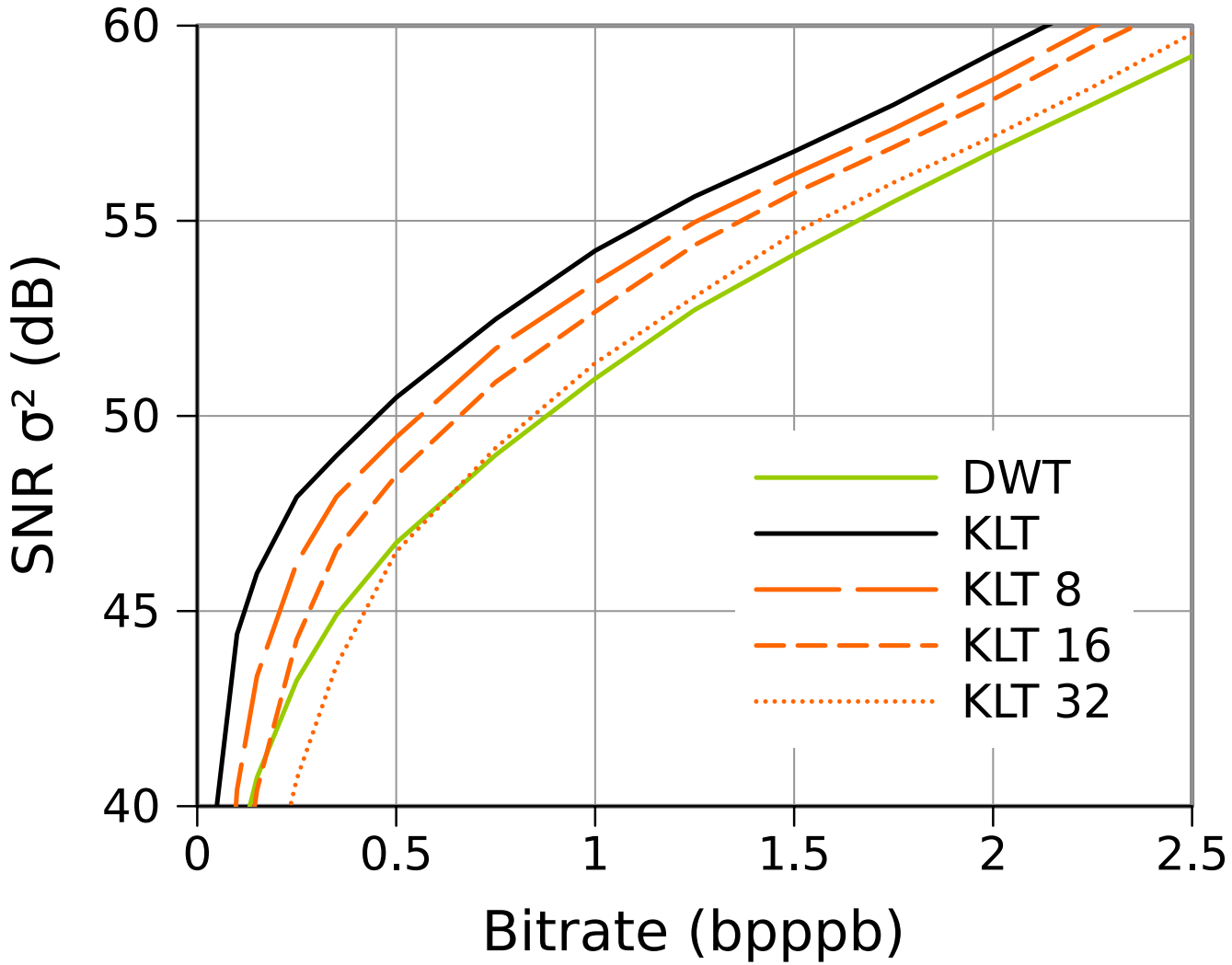
References

- J. Zhang, J. Fowler, and G. Liu, “Lossy-to-lossless compression of hyperspectral imagery using three-dimensional TCE and an integer KLT,” IEEE GRSL, October 2008.
- F. Bruekers and A. van den Enden, “New networks for perfect inversion and perfect reconstruction,” IEEE JSAC, 1992.
- P. Hao and Q. Shi, “Matrix factorizations for reversible integer mapping,” IEEE TSP, 2001.
- Y. Wongsawat, “Lossless compression for 3-d MRI data using reversible KLT,” ICALIP, July 2008.
- L. Galli and S. Salzo, “Lossless hyperspectral compression using KLT,” IGARSS 2004: IEEE IGARSS, 2004.

IWT Costs

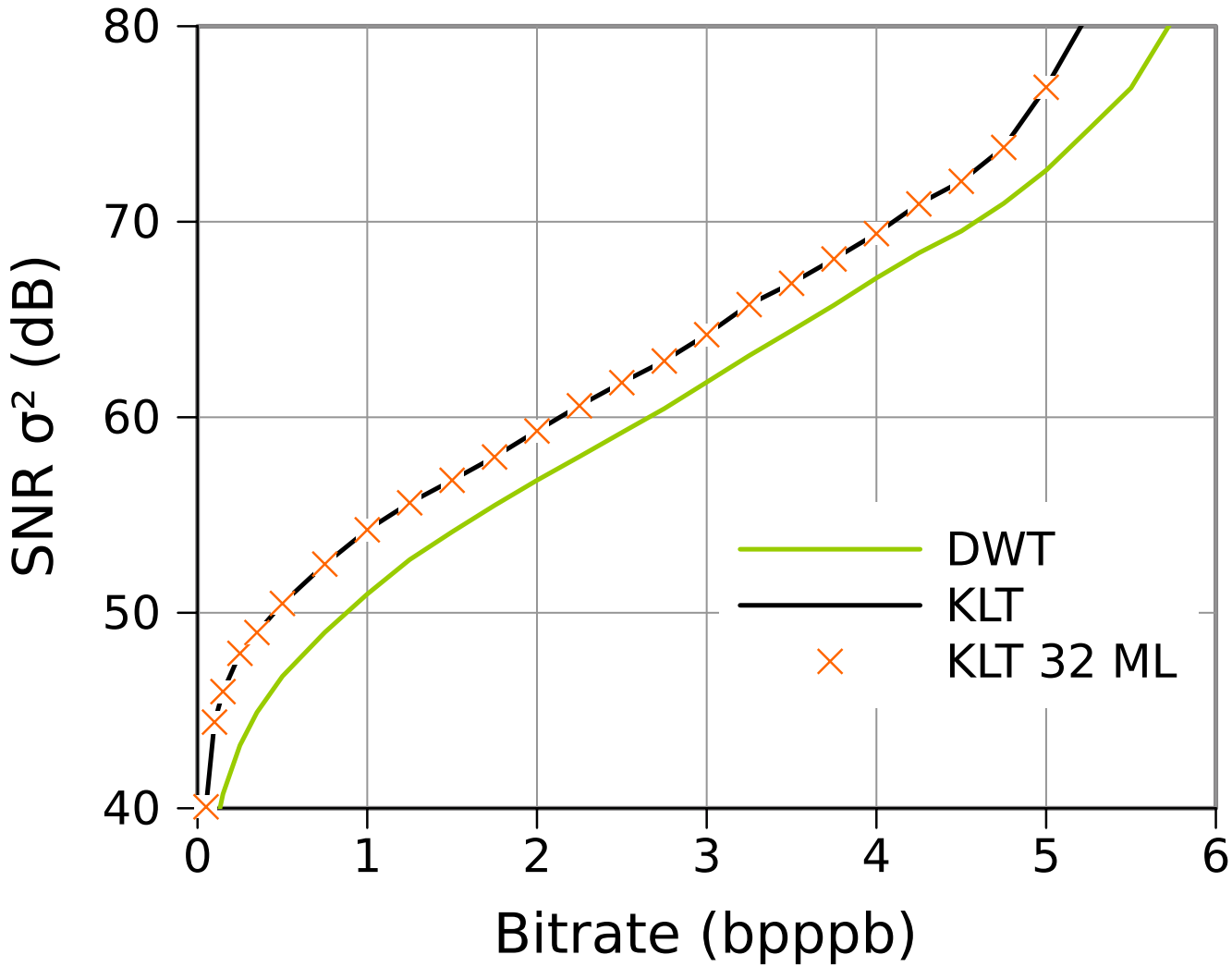

Spectral IWT
Clustered
SERM
TERM
3TERM
Clustered
+
Multi-level
SERM
TERM
3TERM
Covariance Matrix
Apply
Remove
0
2
4
6
8
10
12
Operations (Gigaflops)

Lossy Clustering



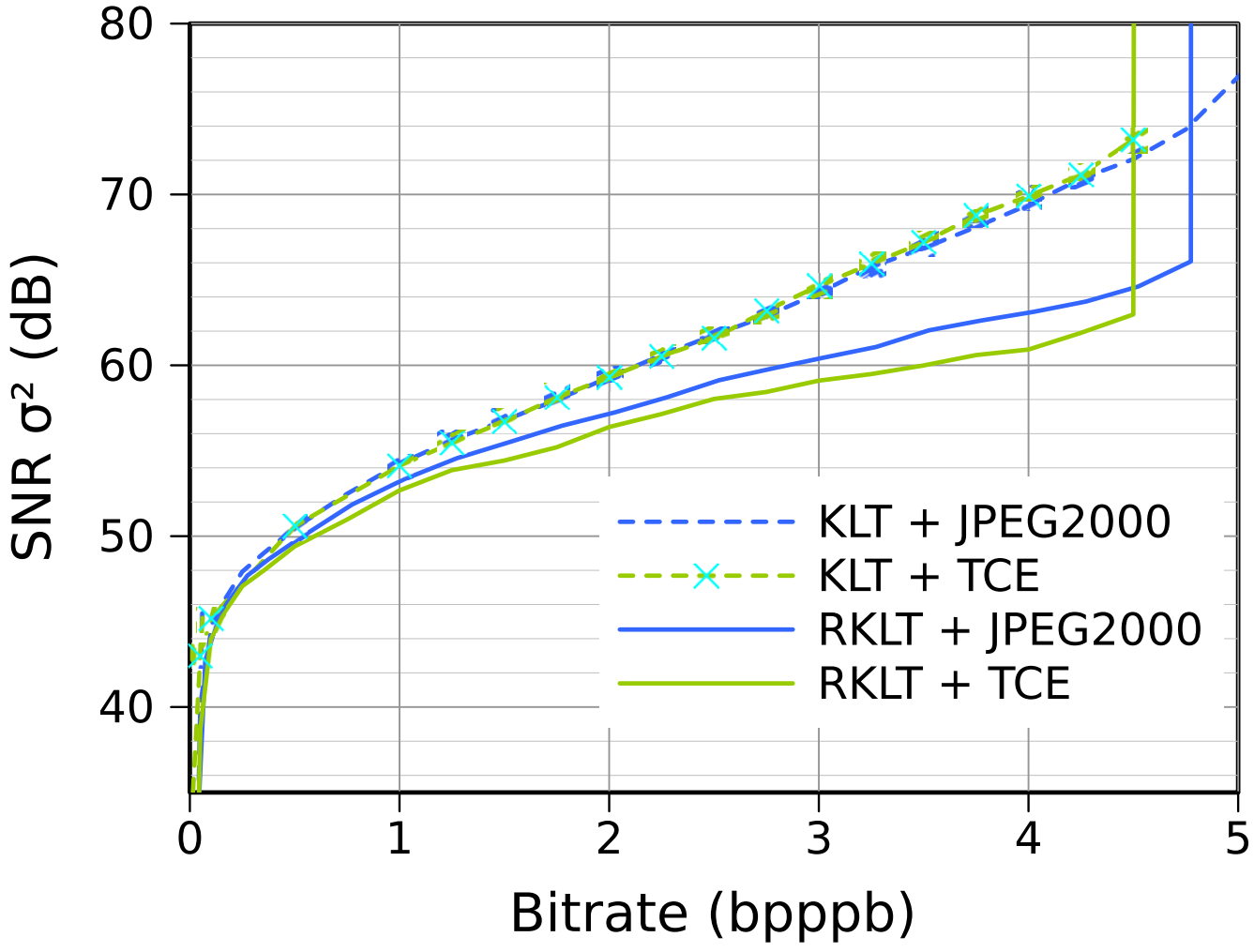
AVIRIS Cuprite + JPEG2000

Lossy ML Clustering



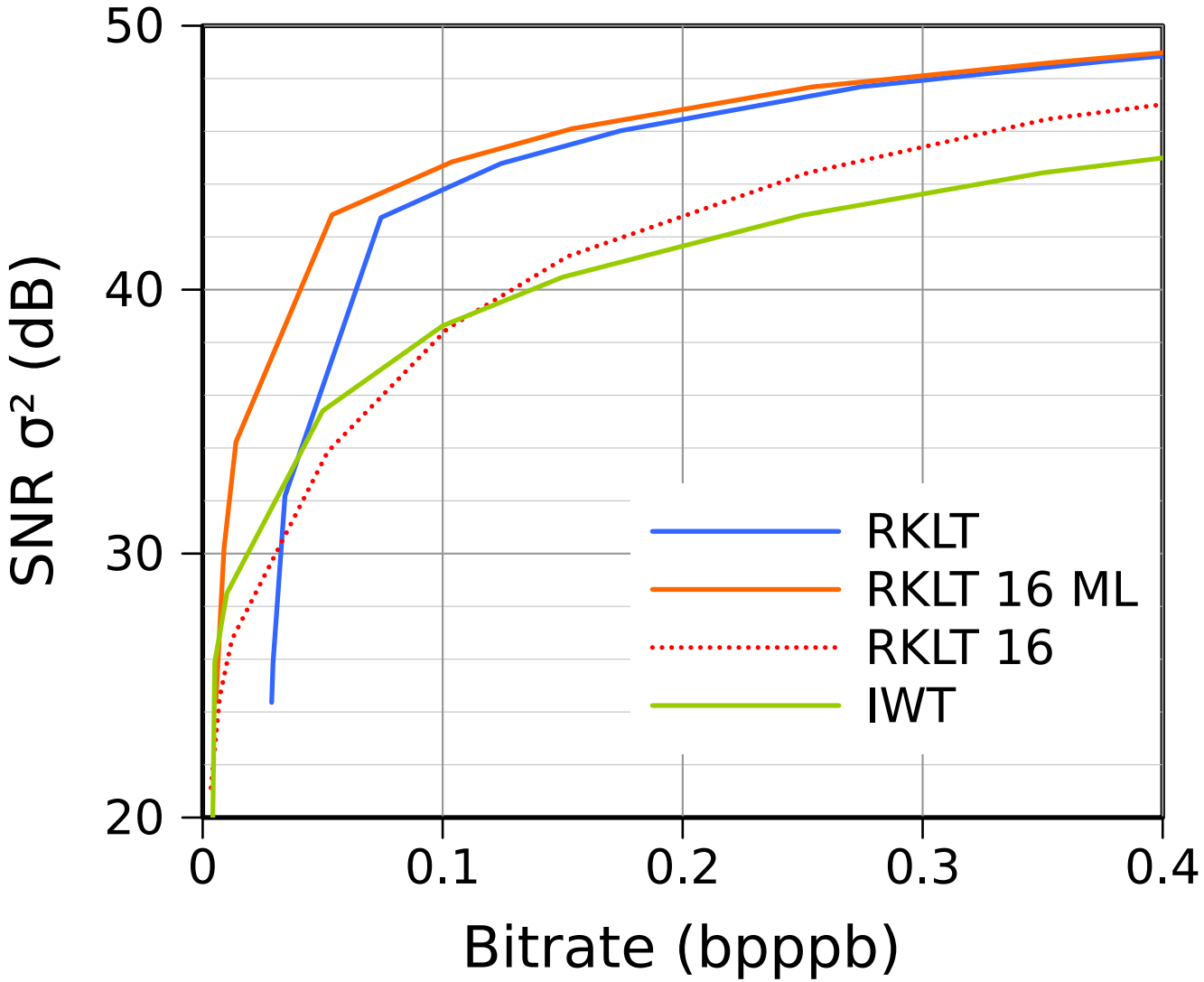
AVIRIS Cuprite + JPEG2000

TCE vs JPEG2000



AVIRIS Cuprite

The clustered versions - The other half of the plot



AVIRIS Cuprite

Cost vs Clusters