Astronomical Image Processing with Hadoop

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YAHOO! PRESENTS

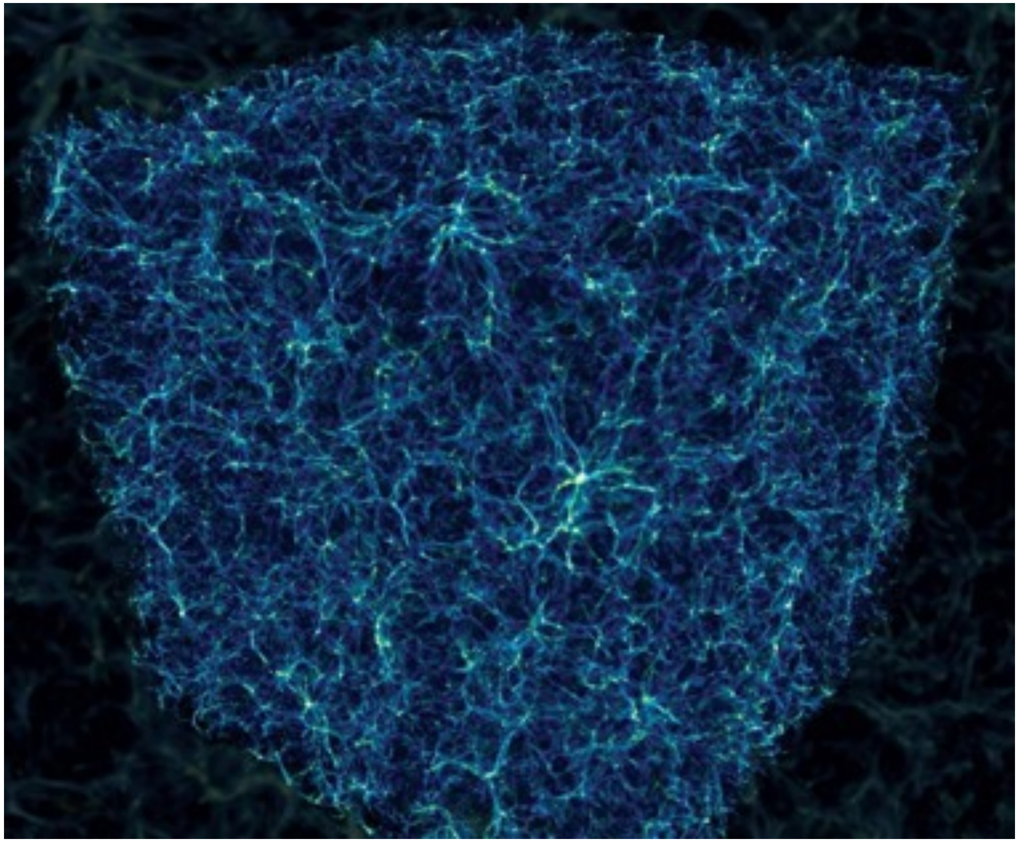
hadoop SUMMIT 2010

Session Agenda

- Astronomical Survey Science
- Image Coaddition
- Implementing Coaddition within MapReduce
- Optimizing the Coaddition Process
- Conclusions
- Future Work

Astronomical Topics of Study

- Dark energy
- Large scale structure of universe
- Gravitational lensing
- Asteroid detection/tracking



What is Astronomical Survey Science?

- Dedicated sky surveys,
  usually from a single calibrated telescope/camera pair.
- Run for years at a time.
- Gather millions of images and TBs of storage*.
- Require high-throughput data reduction pipelines.
- Require sophisticated off-line data analysis tools.

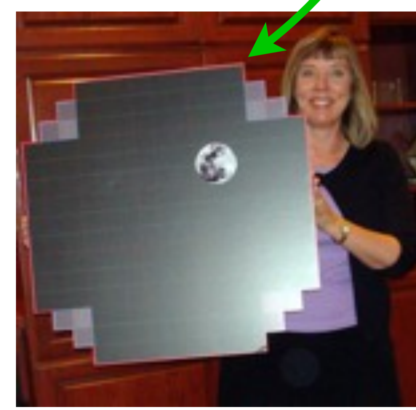
* Next generation surveys will gather PBs of image data.

Sky Surveys: Today and Tomorrow

- ***SDSS****** (1999-2005)
- Founded in part by UW
- 1/4 of the sky
- 80TBs total data

- ***LSST***† (2015-2025)
- 8.4m mirror, 3.2 gigapixel camera
- Half sky every three nights
- 30TB per night...
  ...one *SDSS* every three nights
- 60PBs total (nonstop ten years)
- 1000s of exposures of each location

That's a person!

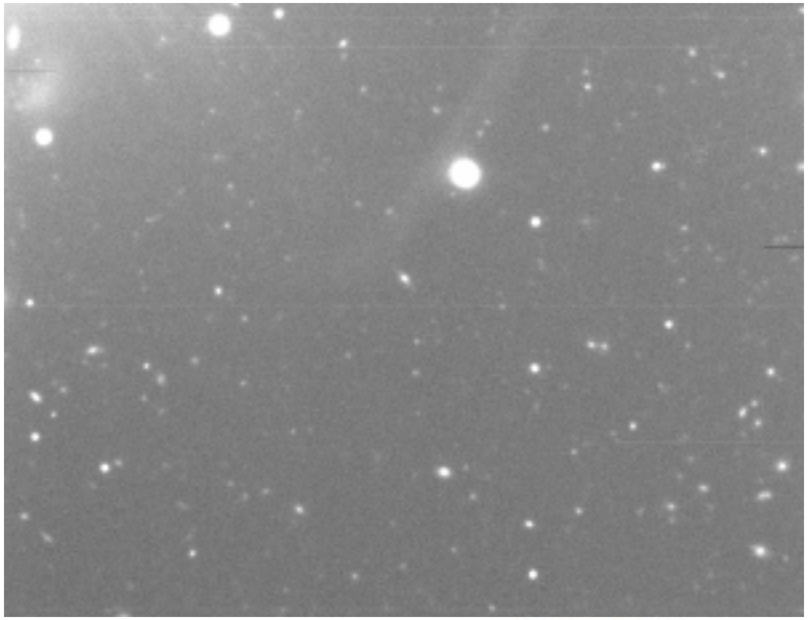


* Sloan Digital Sky Survey
† Large Synoptic Survey Telescope

FITS (Flexible Image Transport System)

- Common astronomical image representation file format
- Metadata tags (like *EXIF*):
  - **Most importantly:** Precise astrometry*
  - Other:
    - Geolocation (telescope location)
    - Sky conditions, image quality, etc.

- ***Bottom line***:
  - **An image format that knows where it is looking.**



* Position on sky

Image Coaddition

- Give multiple partially overlapping images and a ***query*** (color and sky bounds):
  - Find images' intersections with the query bounds.
  - **Project** bitmaps to the bounds.
  - **Stack** and **mosaic** into a final product.

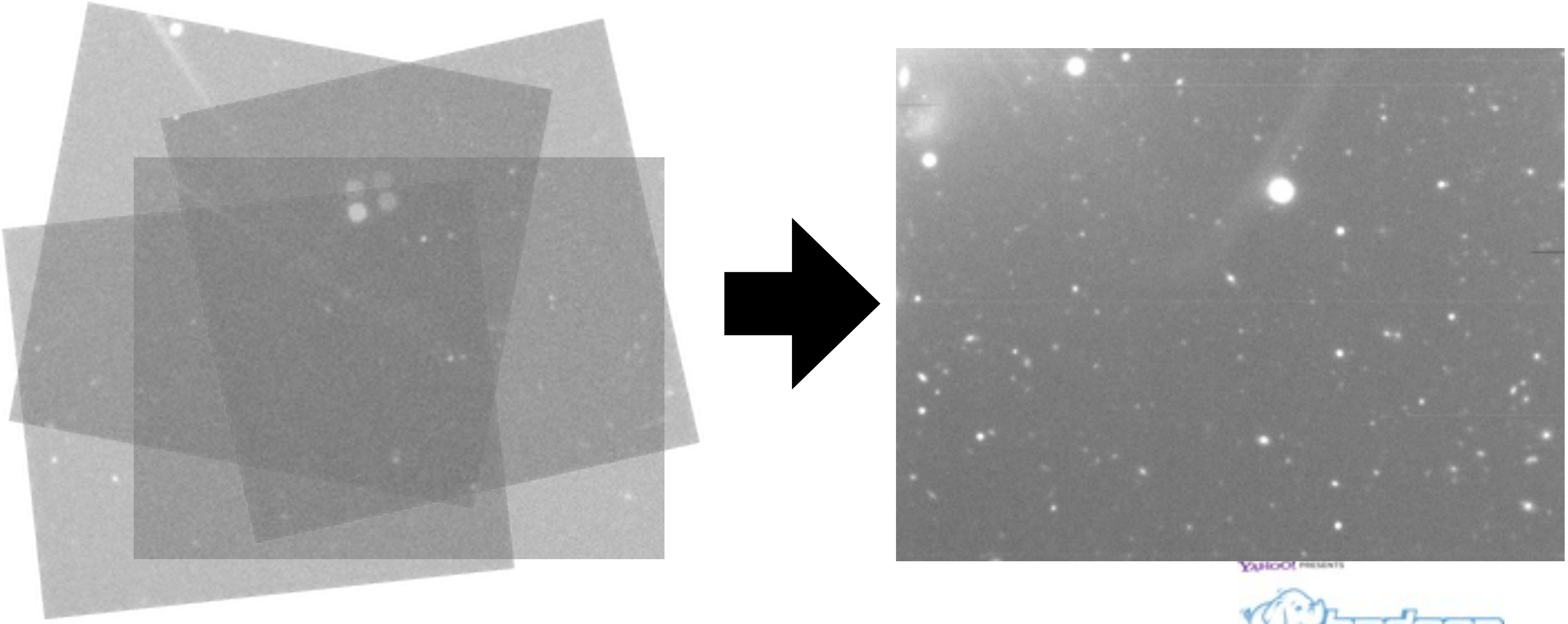
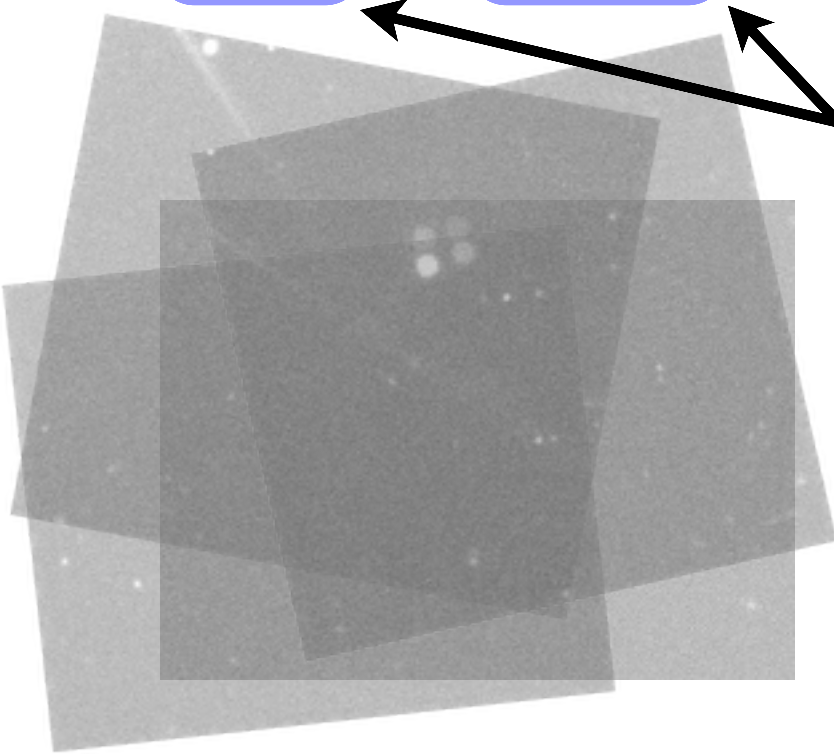


Image Coaddition

Expensive

- Give multiple partially overlapping images and a ***query*** (color and sky bounds):
  - › Find images' intersections with the query bounds.
  - › **Project** bitmaps to the bounds.
  - › **Stack** and **mosaic** into a final product.

Cheap



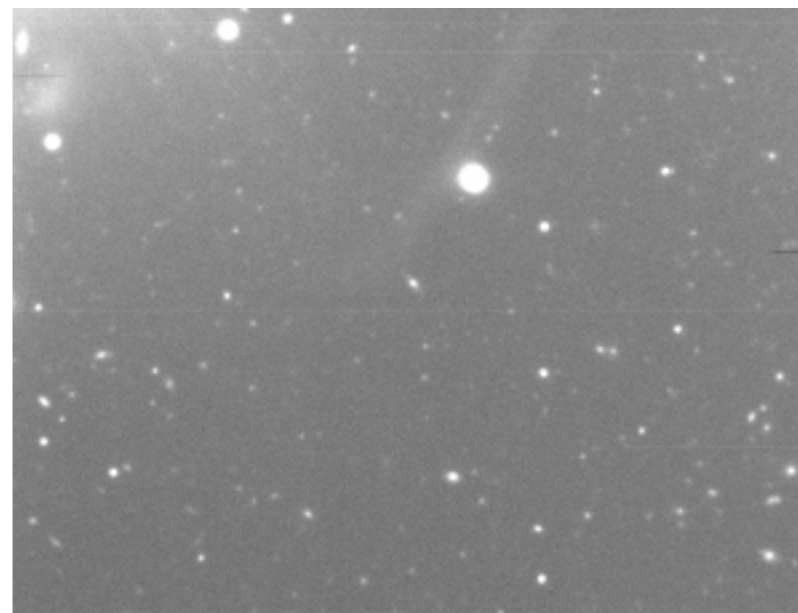
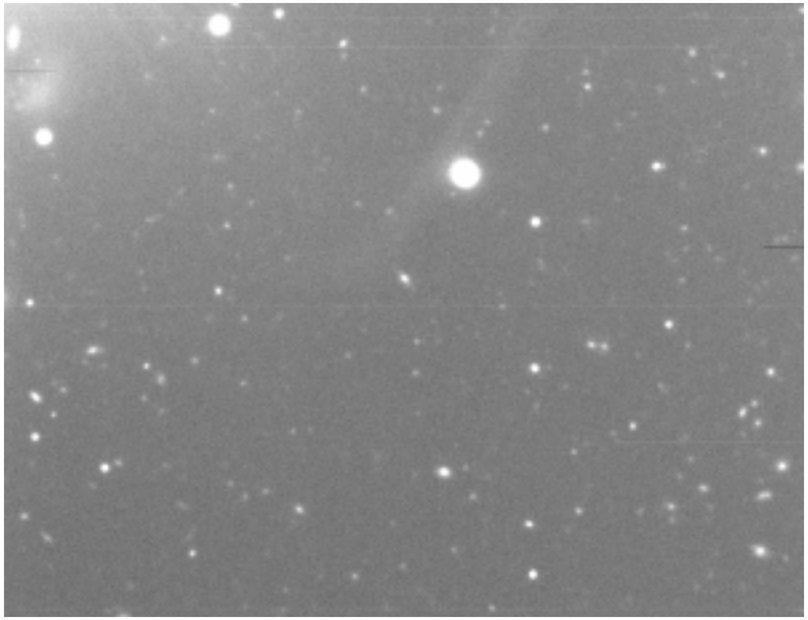
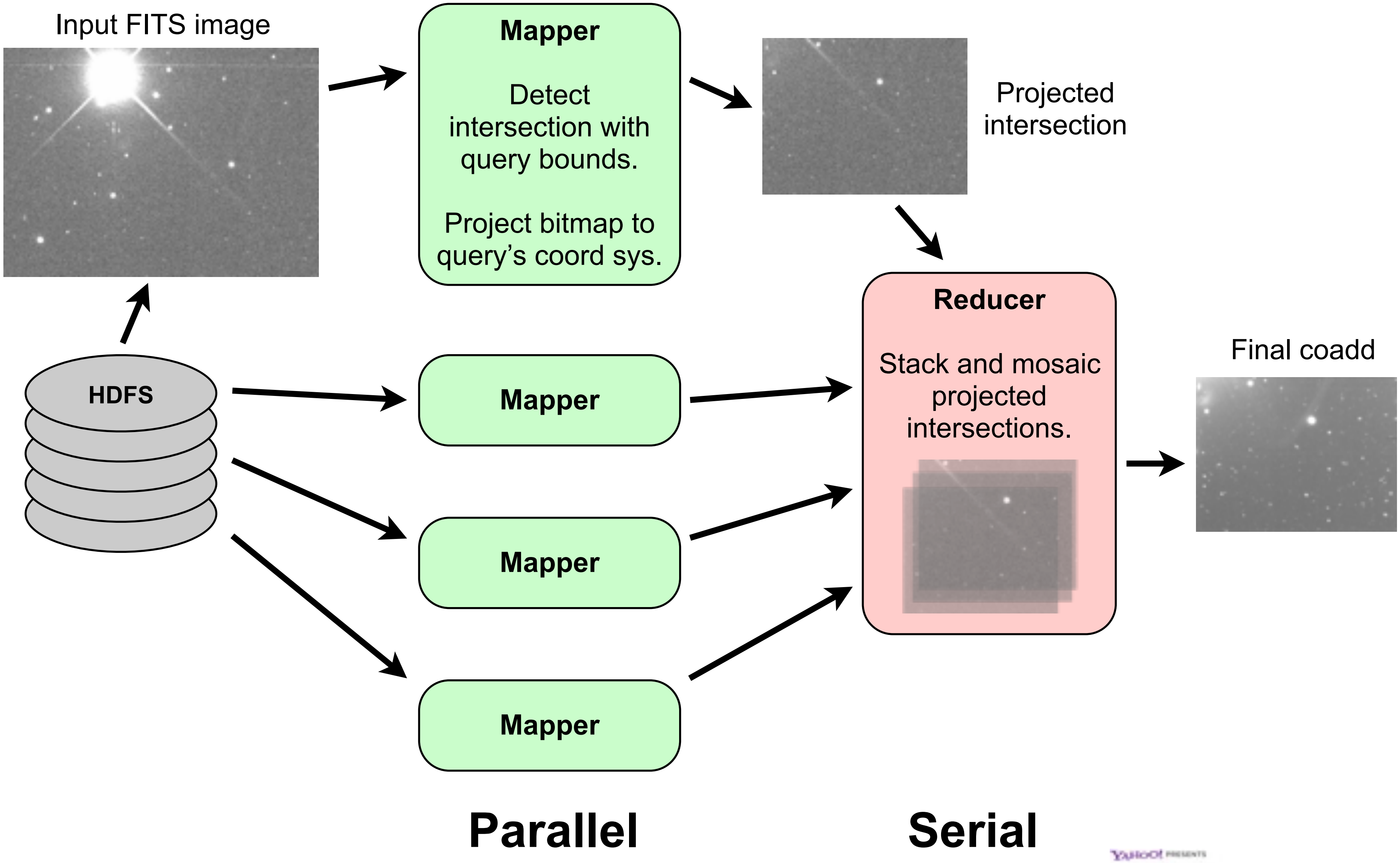


Image Stacking (Signal Averaging)



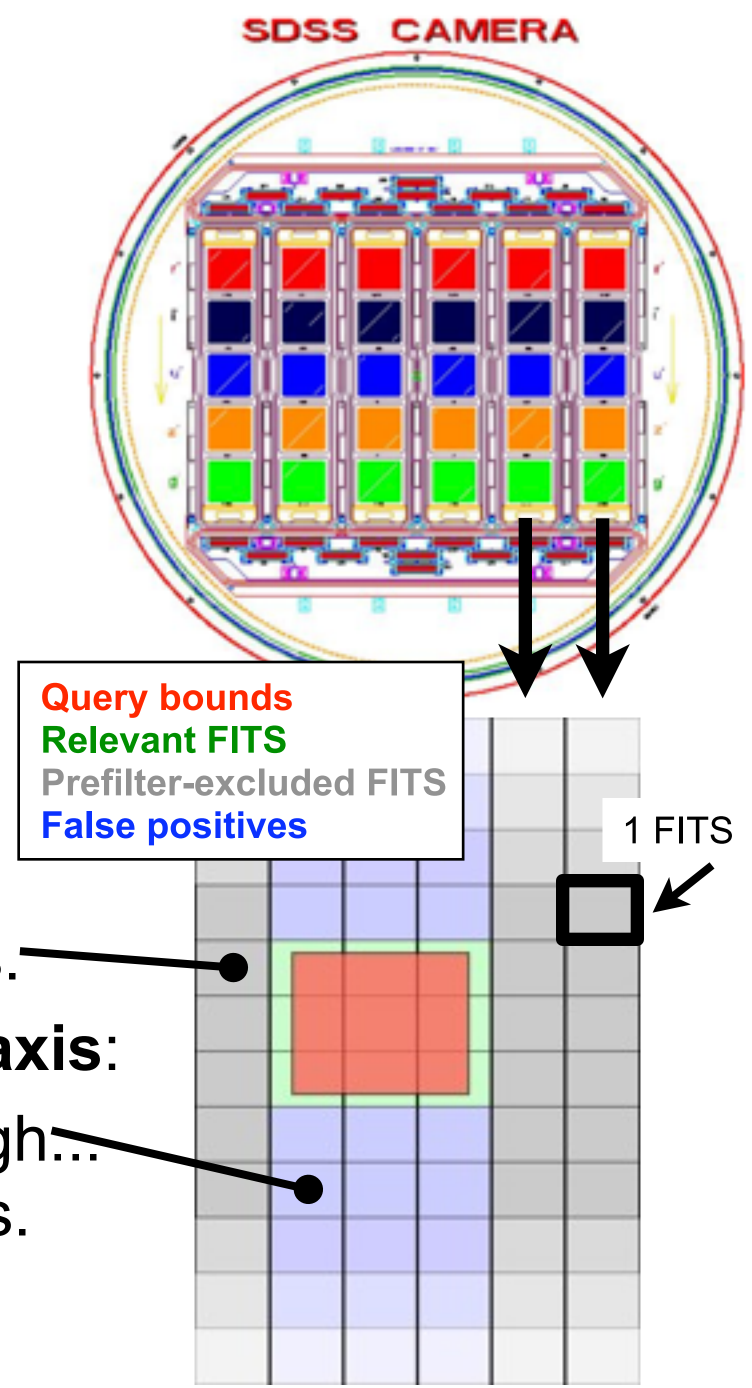
- **Stacking** improves SNR:
  - Makes **fainter objects visible.**
- Example (*SDSS*, Stripe 82):
  - **Top**: Single image, R-band
  - **Bottom**: 79-deep stack
    - (~9x SNR improvement)
    - Numerous additional detections
- Variable conditions (*e.g.*, atmosphere, PSF, haze) mean stacking algorithm complexity can exceed a mere sum.

Coaddition in Hadoop

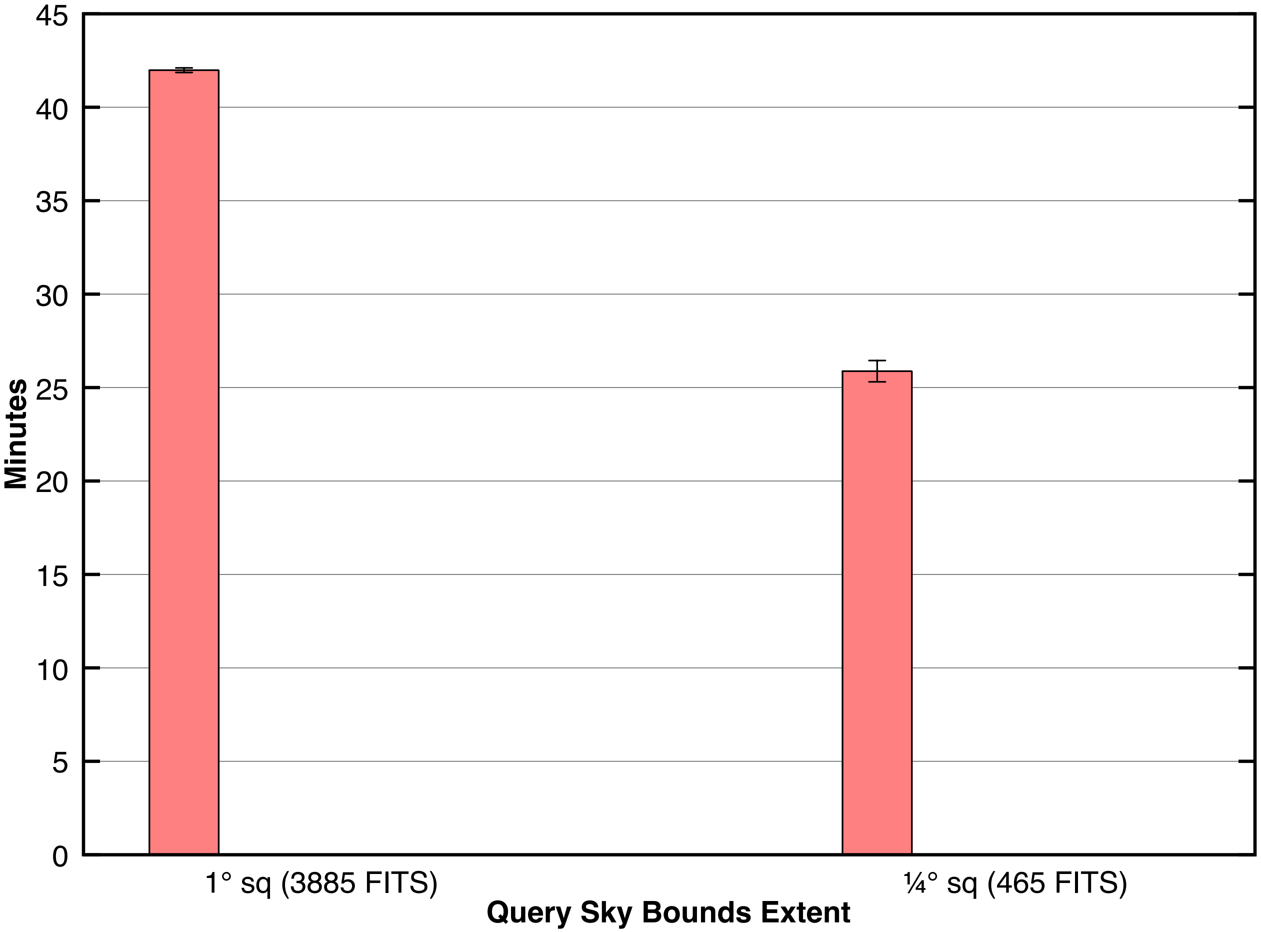


Driver Prefiltering

- To assist the process we prefilter the FITS files in the driver.
- *SDSS* camera has 30 CCDs:
  - 5 colors
  - 6 abutting strips of sky
- **Prefilter (path glob) by color and sky coverage** (single axis):
  - Exclude many irrelevant FITS files.
  - Sky coverage filter is only **single axis**:
    - Thus, **false positives** slip through...
      ...to be discarded in the mappers.



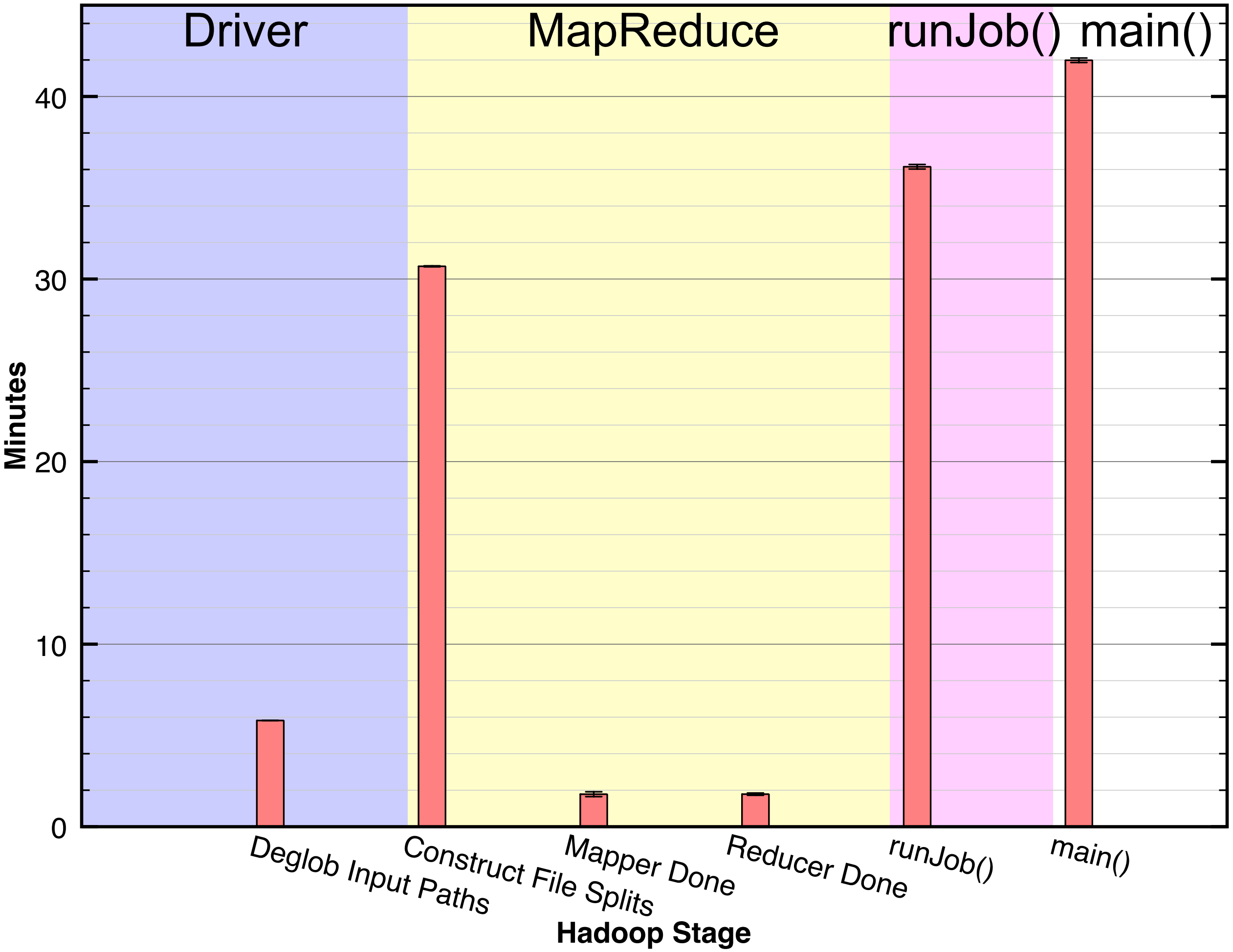
Performance Analysis



Error bars show 95% confidence intervals — Outliers removed via Chauvenet

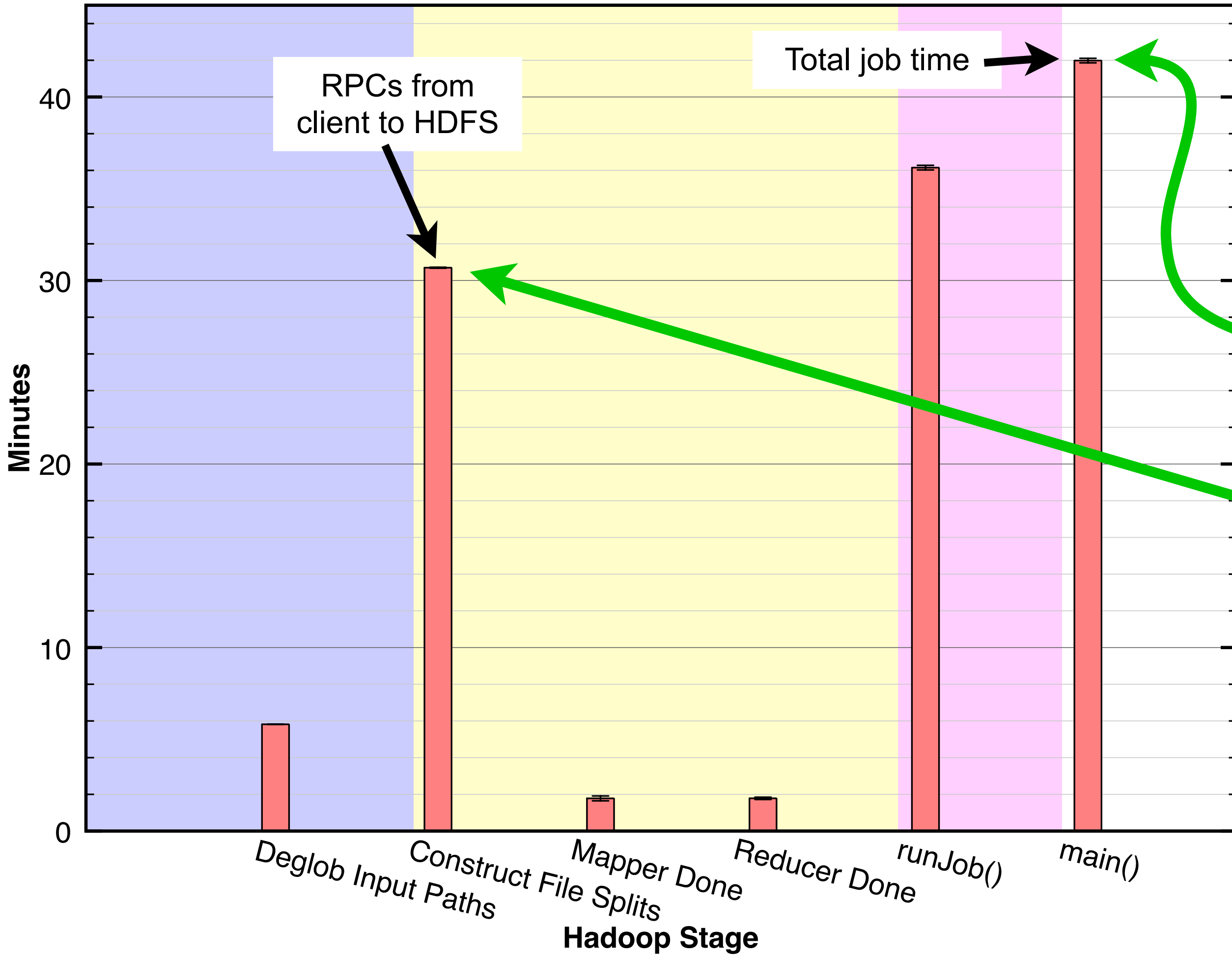
- Running time:
  - 2 query sizes
  - Run against 1/10th of *SDSS* (100,058 FITS)
- **Conclusion:**
  - Considering the small dataset, this is too slow!
  - Remember 42 minutes for the next slide.

Performance Analysis



- Breakdown of large query running time
- **main()** is sum of:
  - **Driver**
  - **runJob()**
- **runJob()** is sum of **MapReduce** parts.

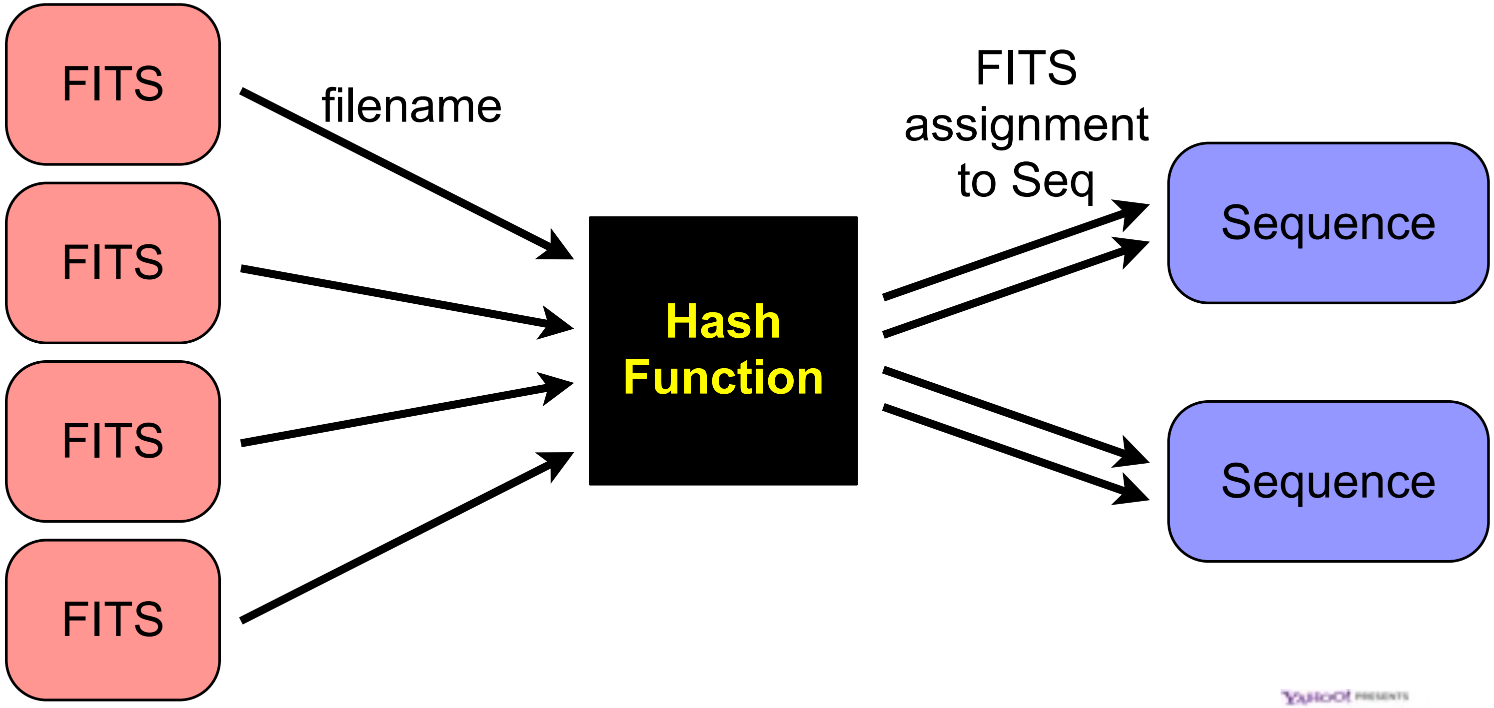
Performance Analysis



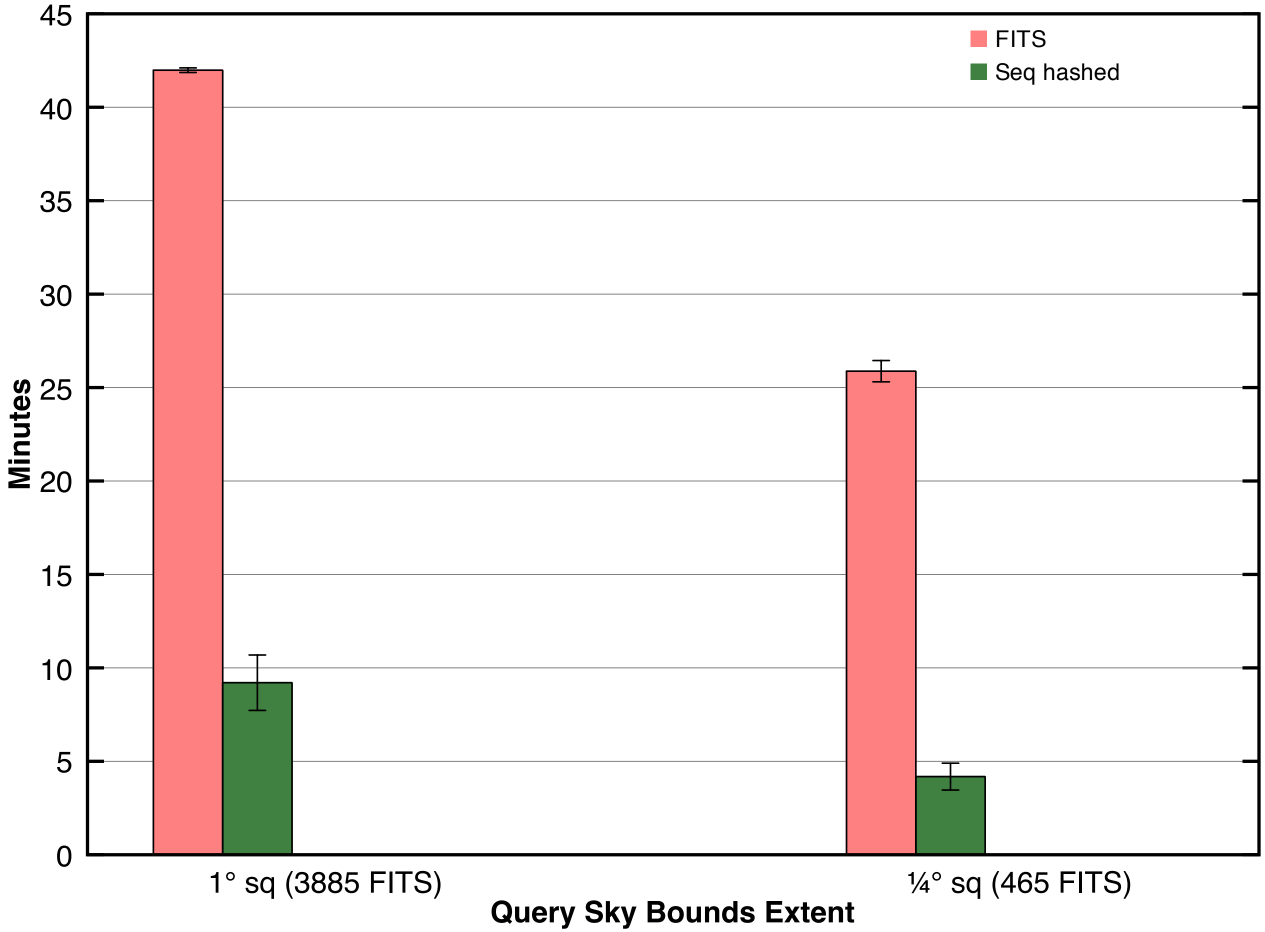
- Breakdown of large query running time
- **Observation:**
  - **Running time** dominated by **RPCs** from client to HDFS to process 1000s of FITS file paths.
- **Conclusion:**
  - **Need to reduce number of files.**

Sequence Files

- Sequence files group many small files into a few large files.
- ***Just what we need!***
- Real-time images may not be amenable to logical grouping.
  - Therefore, sequence files filled in an arbitrary manner:



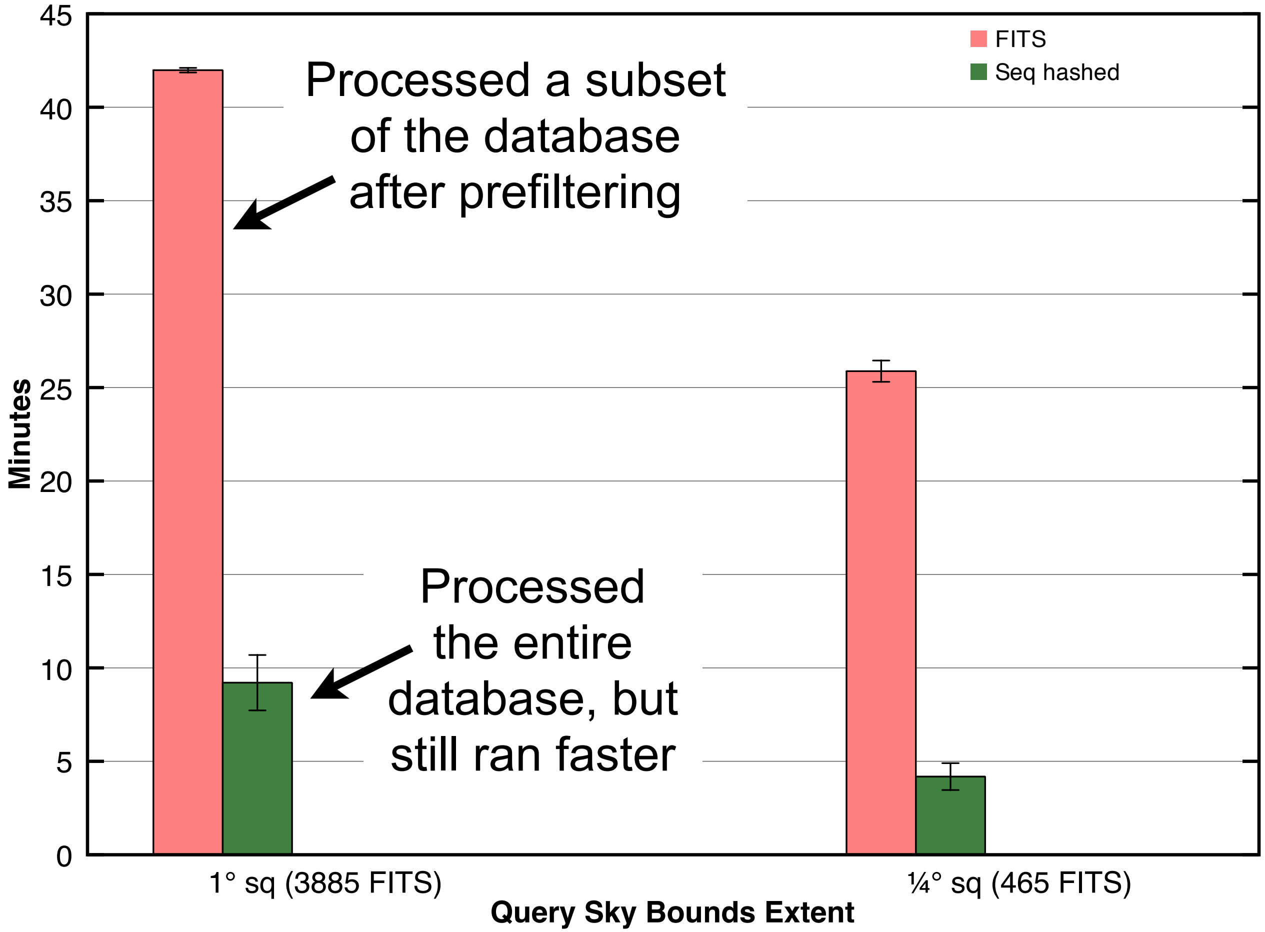
Performance Analysis



- **Comparison:**
  - FITS input vs. unstructured sequence file input*
- **Conclusion:**
  - *5x speedup!*
- Hmmm...
  Can we do better?

* 360 seq files in hashed seq DB.

Performance Analysis



- **Comparison:**
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- **Conclusion:**
  - *5x speedup!*
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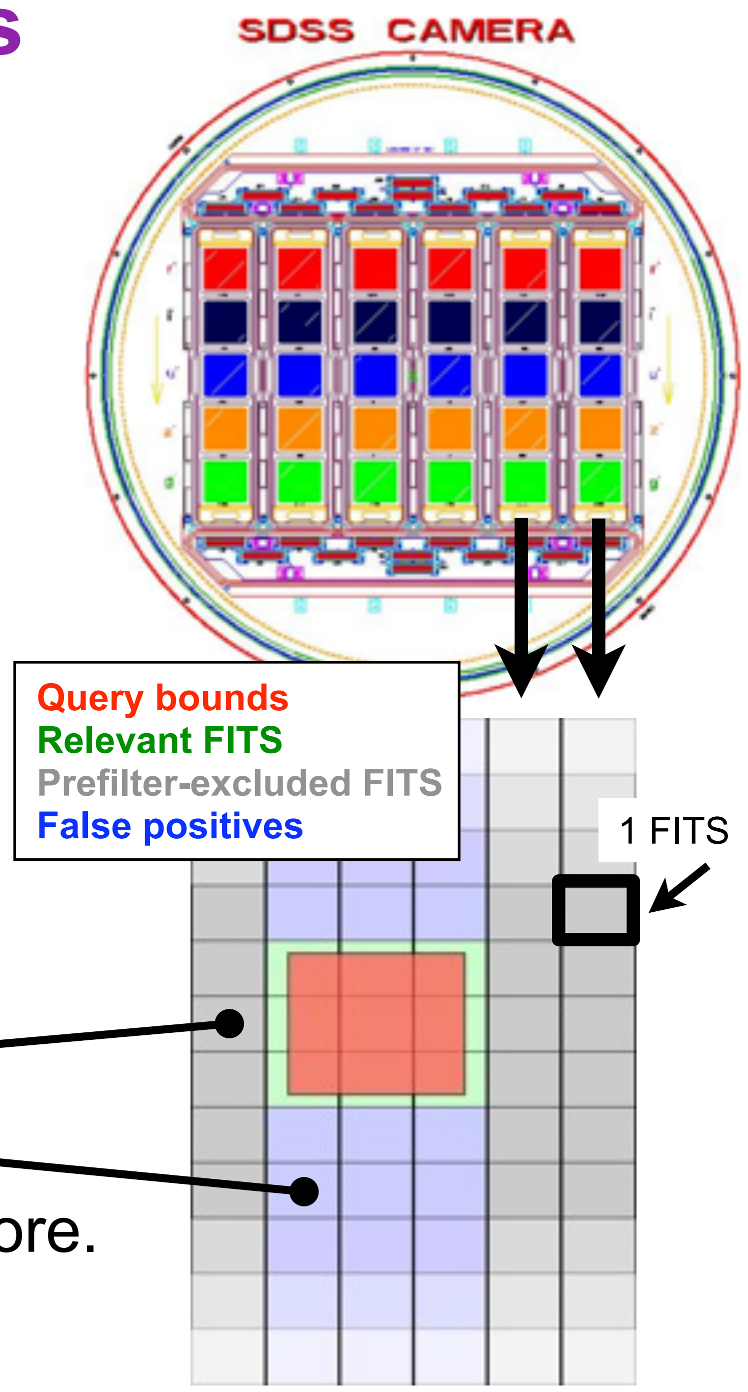
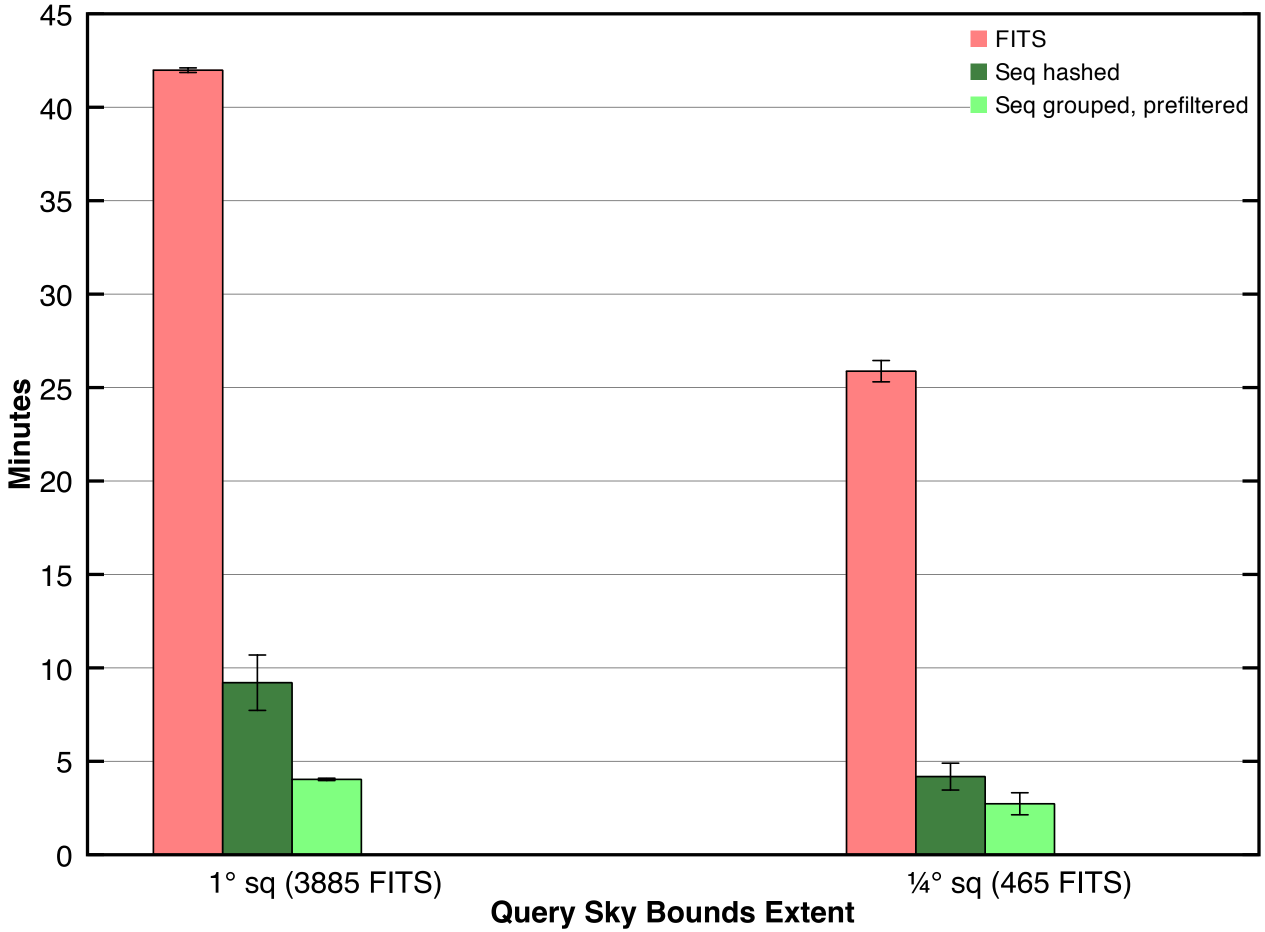
* 360 seq files in hashed seq DB.

Structured Sequence Files

- Similar to the way we prefiltered FITS files...
- *SDSS* camera has 30 CCDs:
  - 5 colors
  - 6 abutting strips of sky
  - **Thus, 30 sequence file types**
- Prefilter by color and sky coverage (single axis):
  - Exclude irrelevant sequence files.
  - Still have **false positives**.
  - Catch them in the mappers as before.



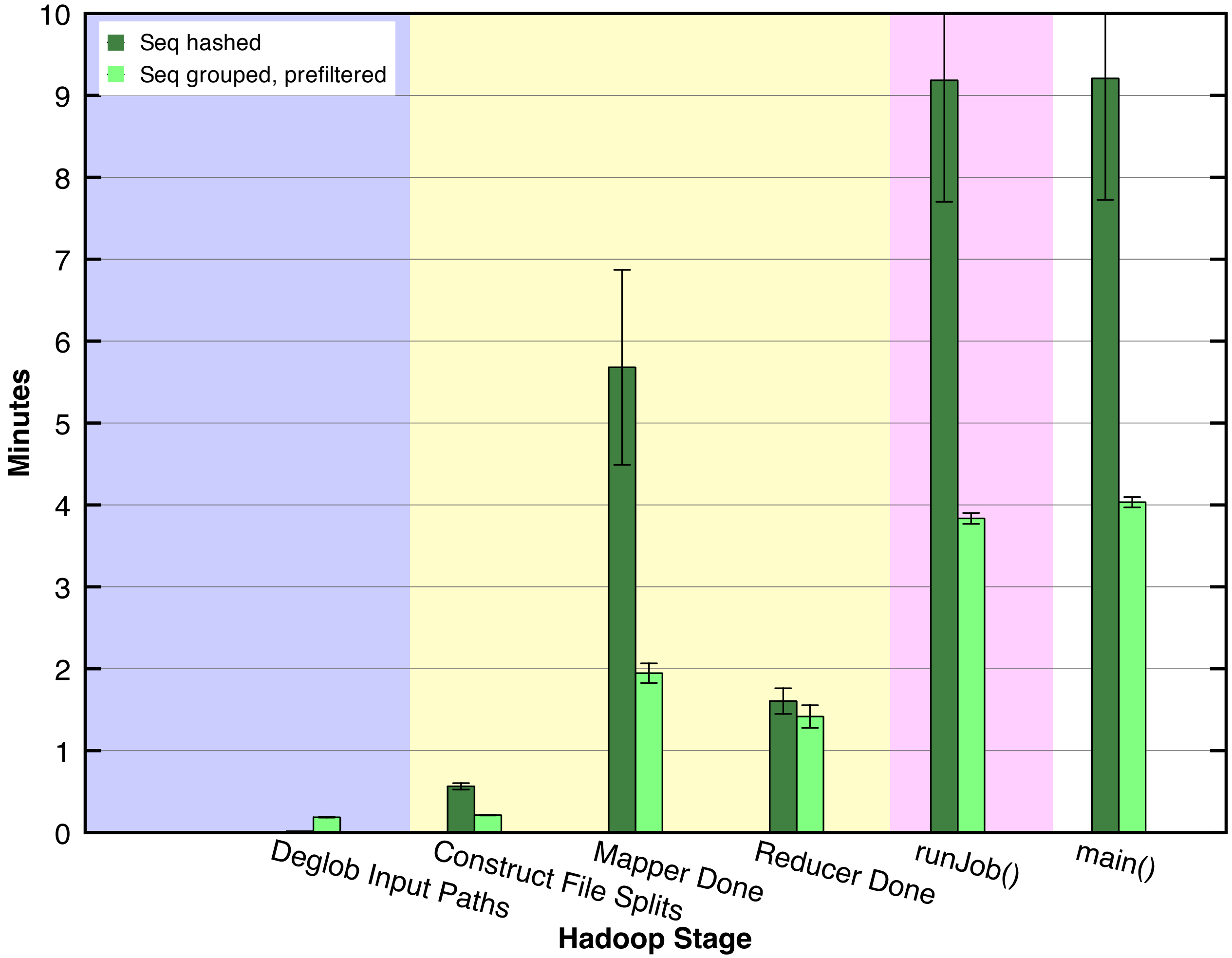
Performance Analysis



- **Comparison:**
  - FITS vs. unstructured sequence* vs. structured sequence files†
- **Conclusion:**
  - Another 2x speedup for the large query, 1.5x speedup for the small query.

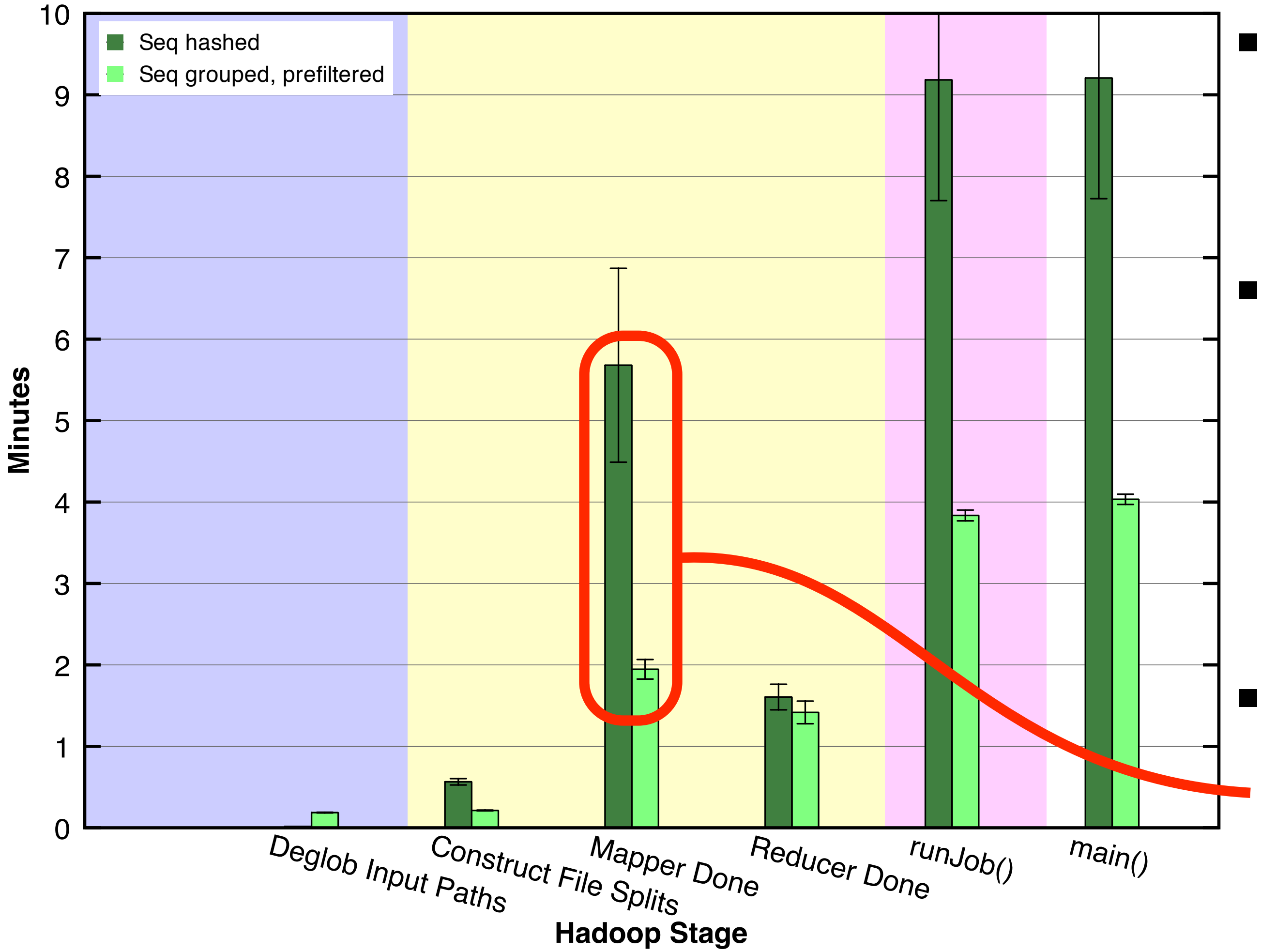
* 360 seq files in hashed seq DB.
† 1080 seq files in structured DB.

Performance Analysis



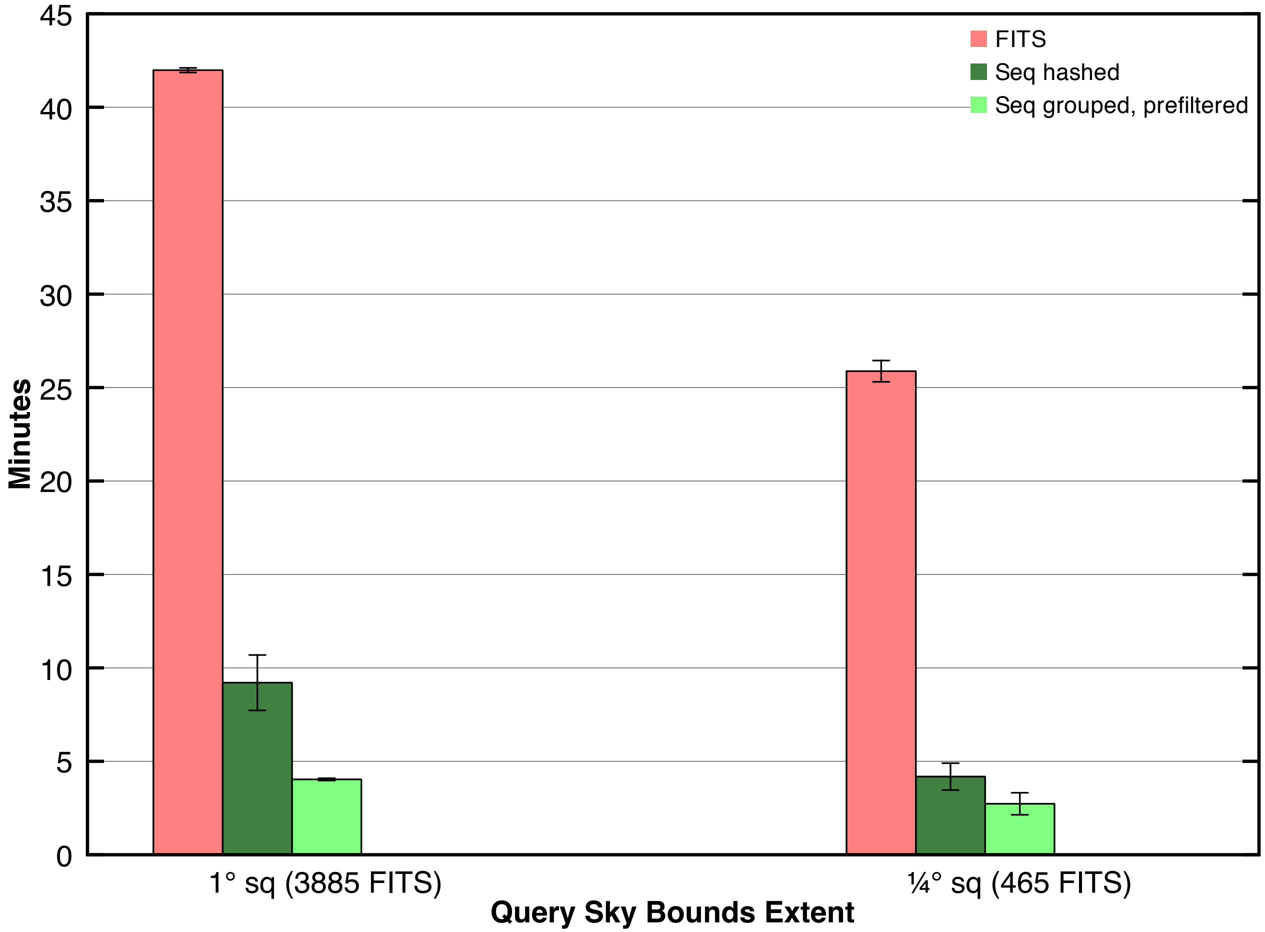
- Breakdown of large query running time
- **Prediction:**
  - Prefiltering should gain performance in the mapper.
- Does it?

Performance Analysis



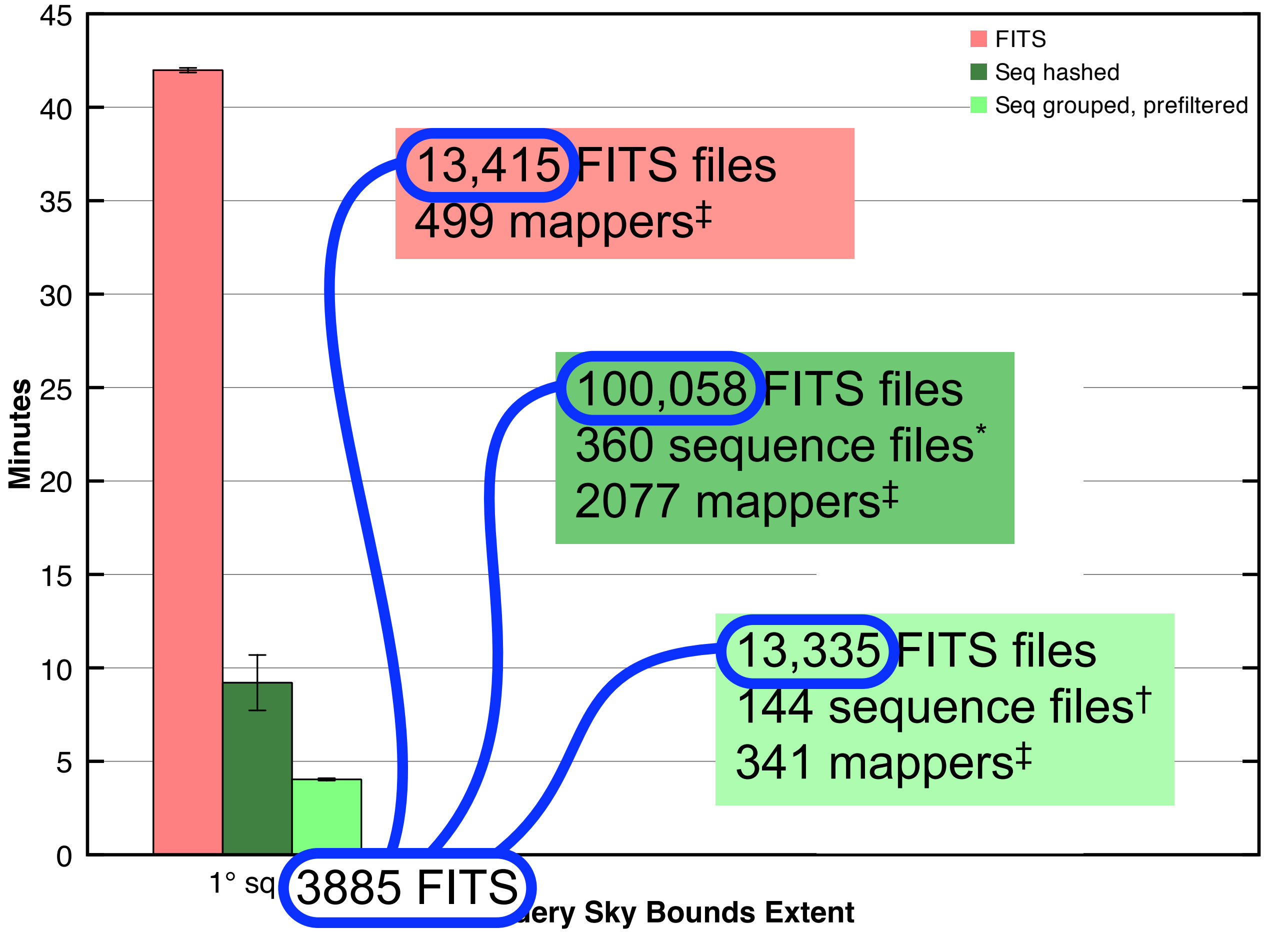
- Breakdown of large query running time
- **Prediction:**
  - Prefiltering should gain performance in the mapper.
- **Conclusion:**
  - Yep, just as expected.

Performance Analysis



- Experiments were performed on a 100,058 FITS database (1/10th *SDSS*).
- How much of this database is Hadoop churning through?

Performance Analysis

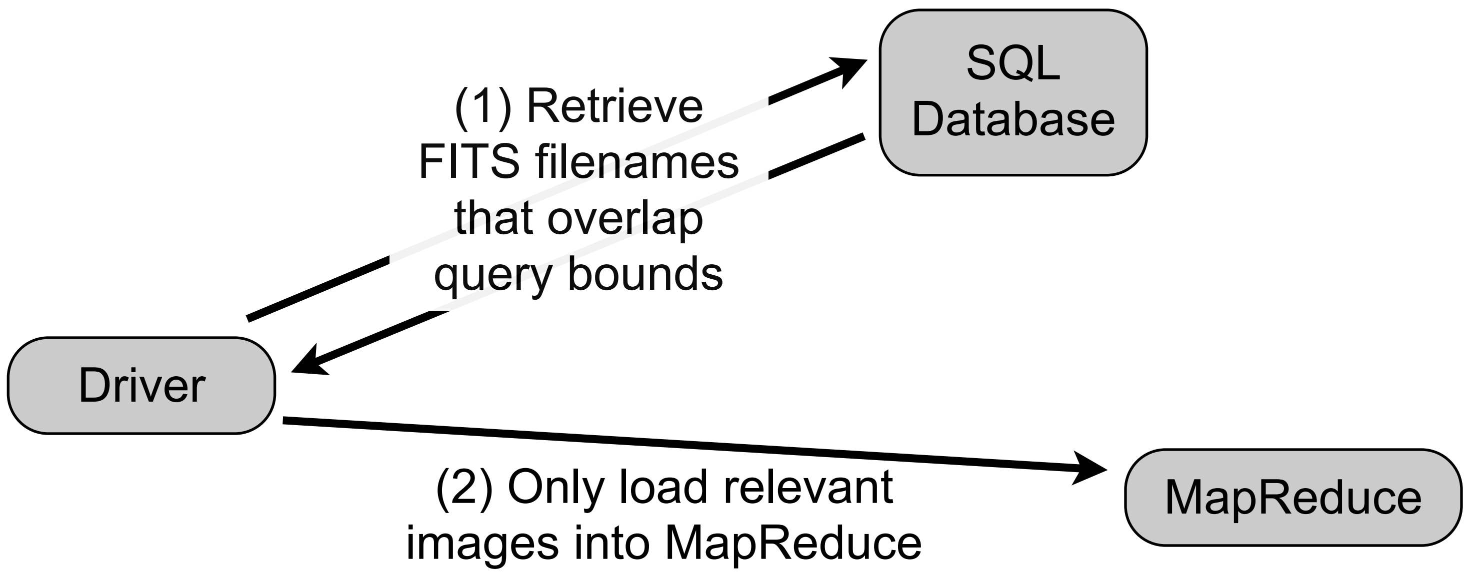


- **Comparison:**
  - Number of FITS considered in mappers vs. number contributing to coadd
- **Conclusion:**
  - Mappers must discard many FITS files due to nonoverlap of query bounds.

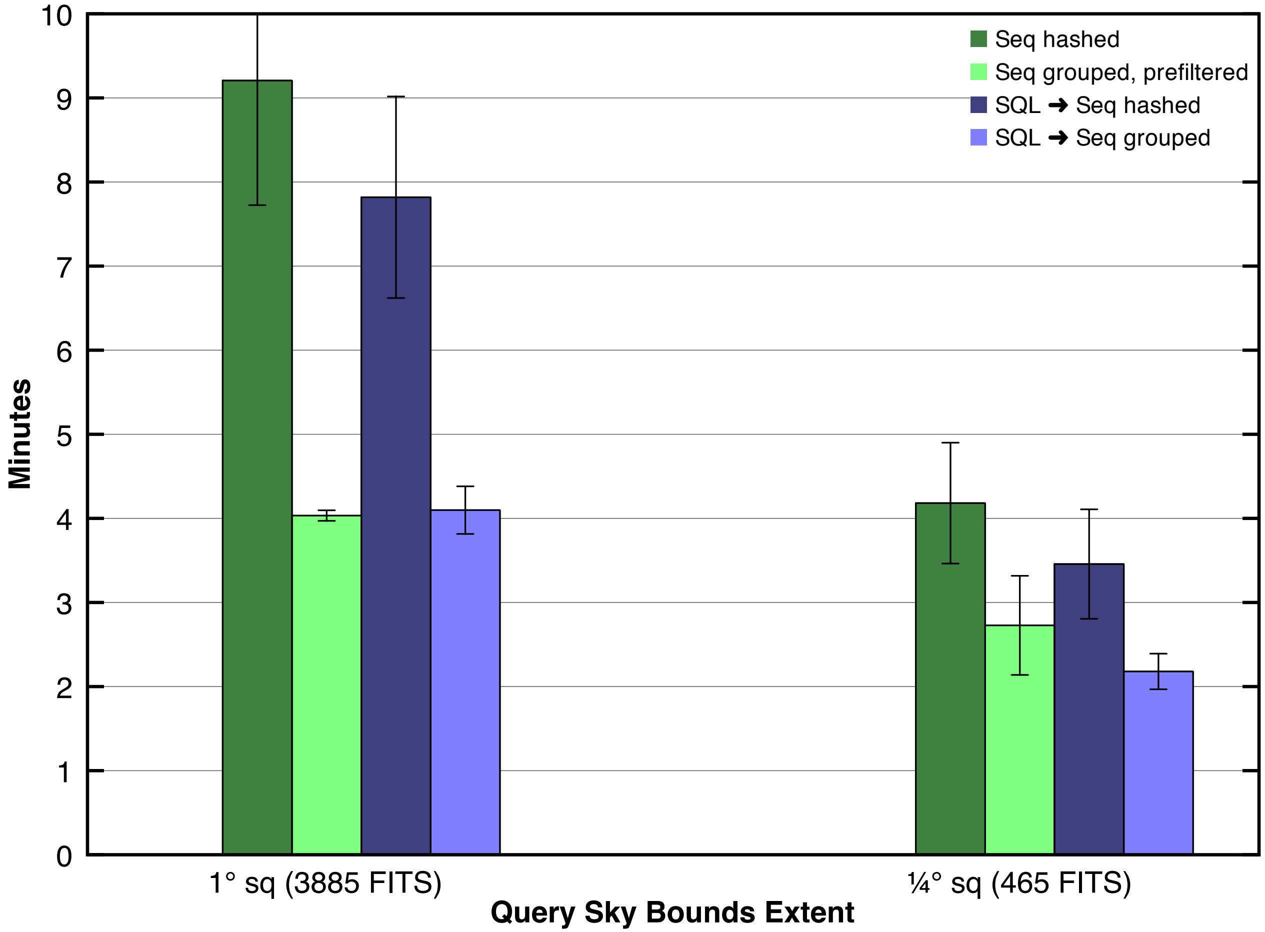
* 360 seq files in hashed seq DB.
† 1080 seq files in structured DB.
‡ 800 mapper slots on cluster.

Using SQL to Find Intersections

- Store all image colors and sky bounds in a database:
  - **First**, query color and intersections via SQL.
  - **Second**, send only ***relevant*** images to MapReduce.
- ***Consequence***:
  All images processed by mappers contribute to coadd.
  No time wasted considering irrelevant images.

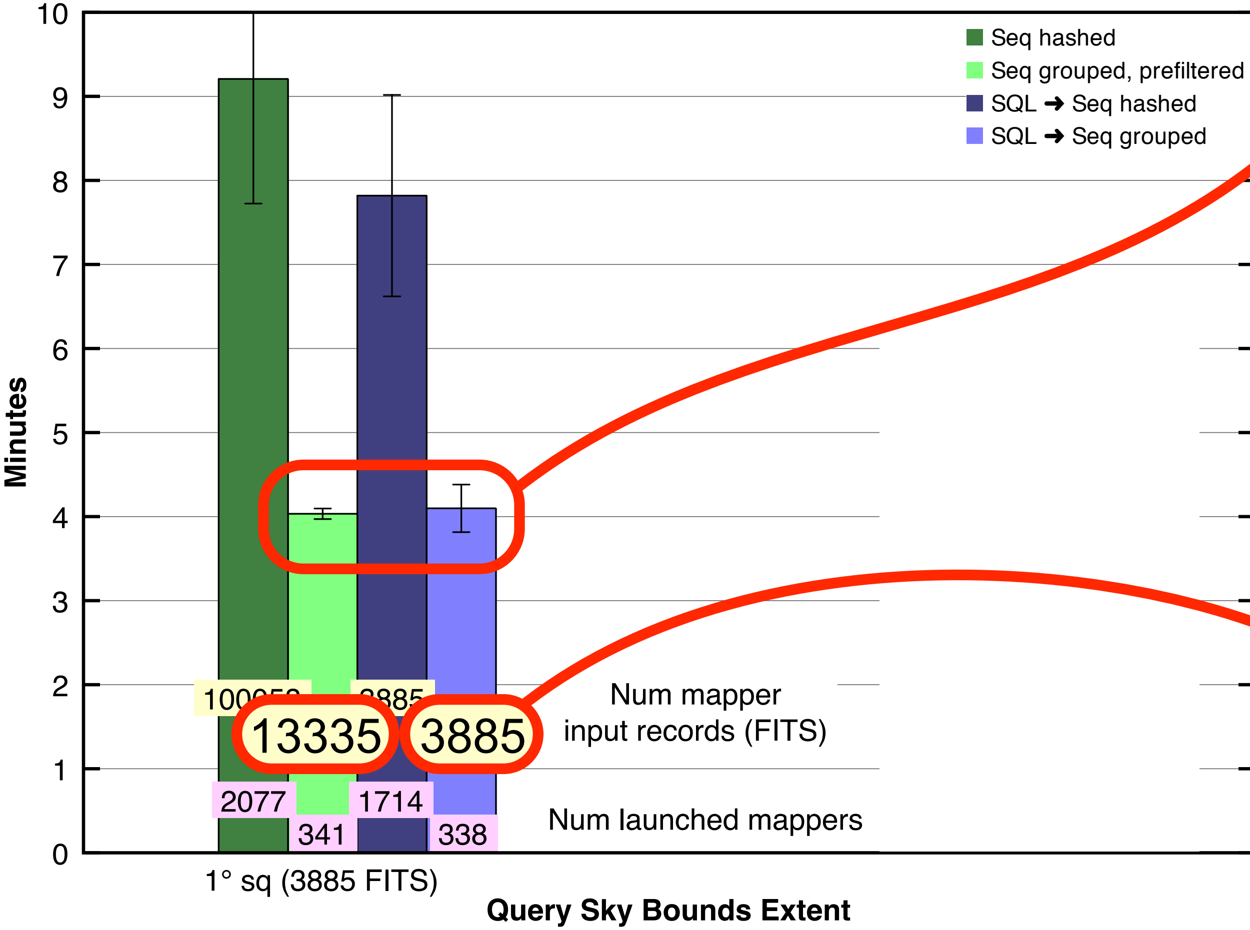


Performance Analysis



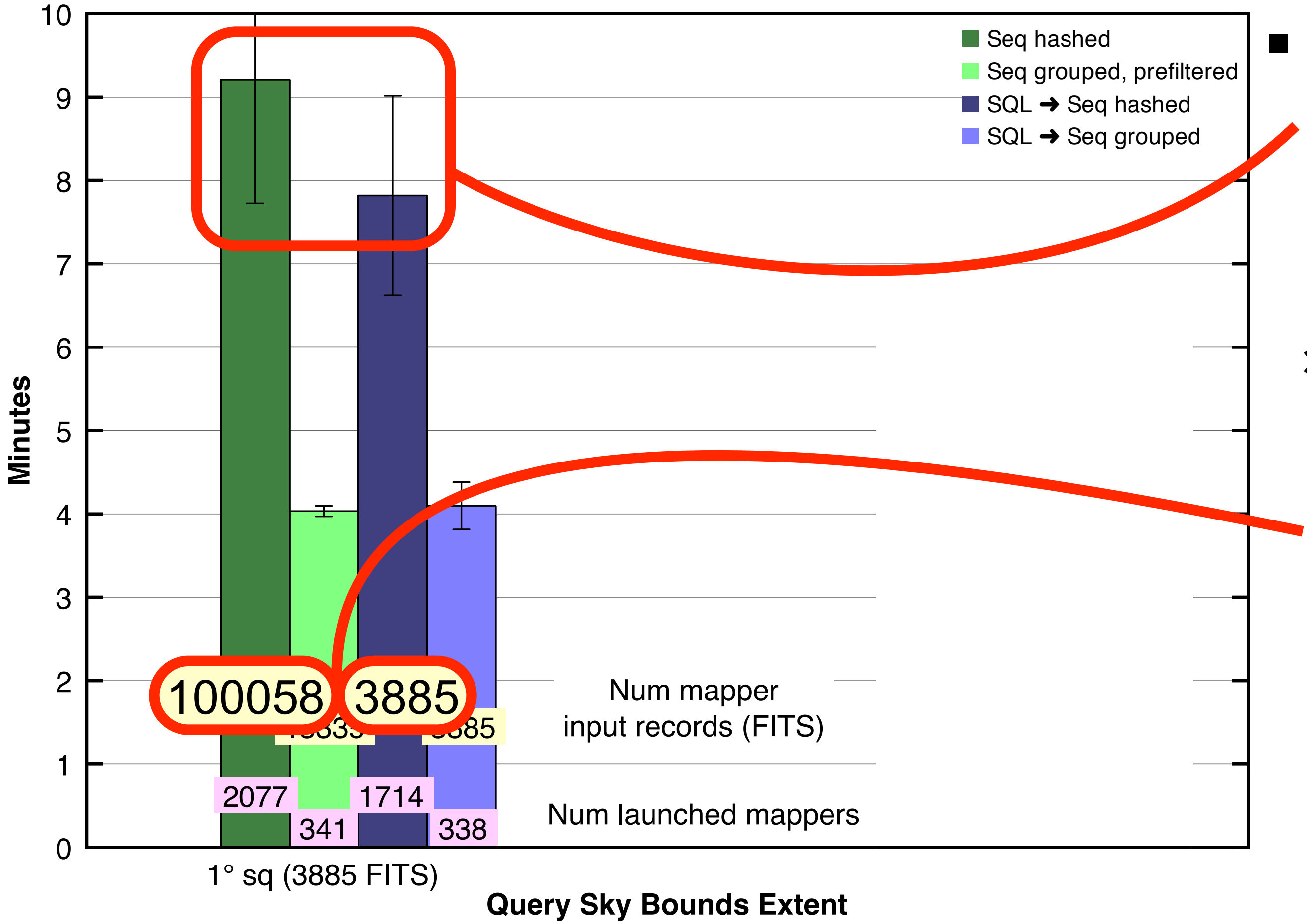
- **Comparison:**
  - **nonSQL** vs. **SQL**
- **Conclusion:**
  - *Sigh*, no major improvement (**SQL** is not remarkably superior to **nonSQL** for given pairs of bars).

Performance Analysis



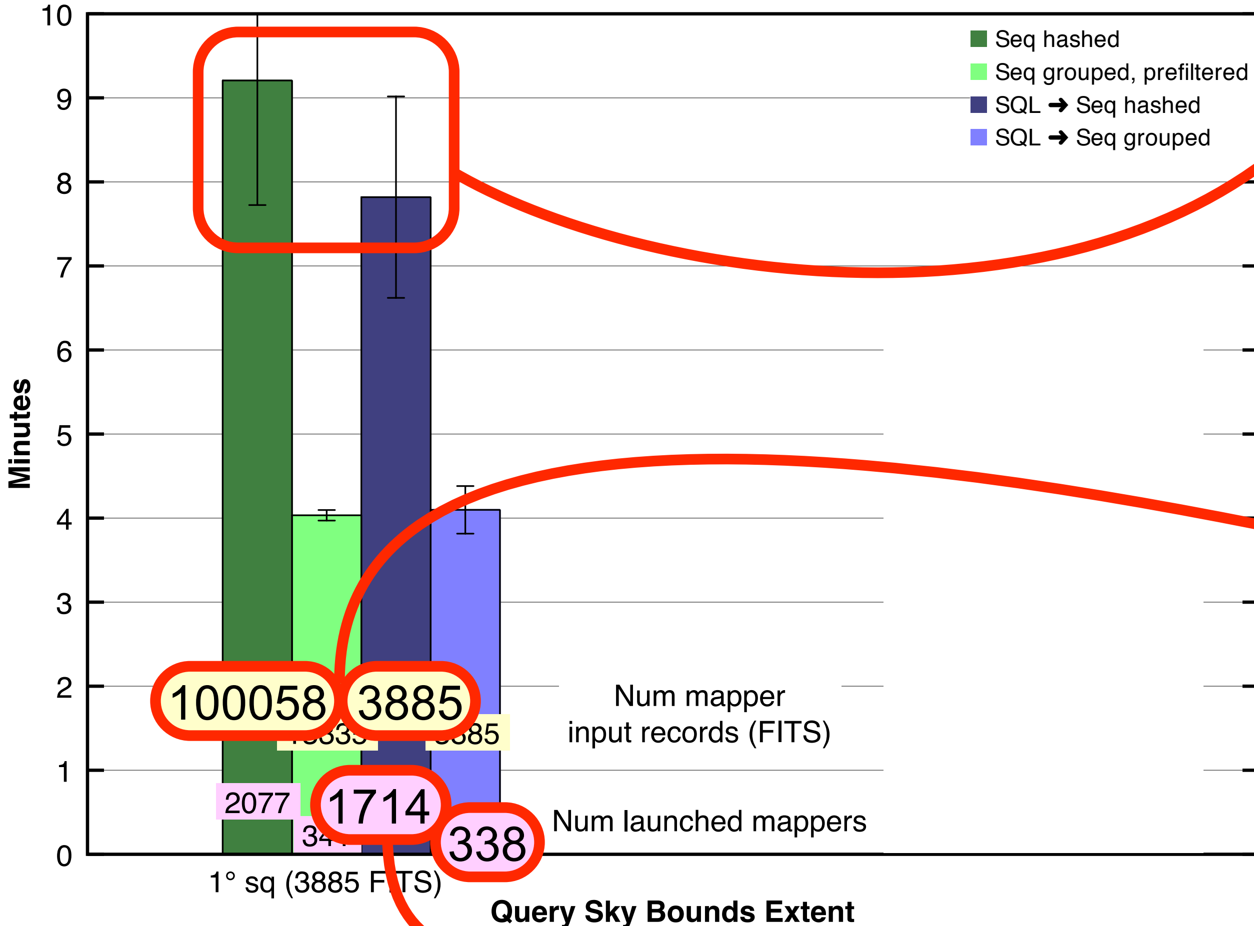
- Comparable performance here makes sense:
  - In essence, **prefiltering** and **SQL** performed similar tasks, albeit with 3.5x different mapper inputs (FITS).
- **Conclusion:**
  - Cost of discarding many images in the nonSQL case was negligible.

Performance Analysis



- Low improvement for SQL in the hashed case is surprising at first
  - ...especially considering 26x different mapper inputs (FITS).

Performance Analysis



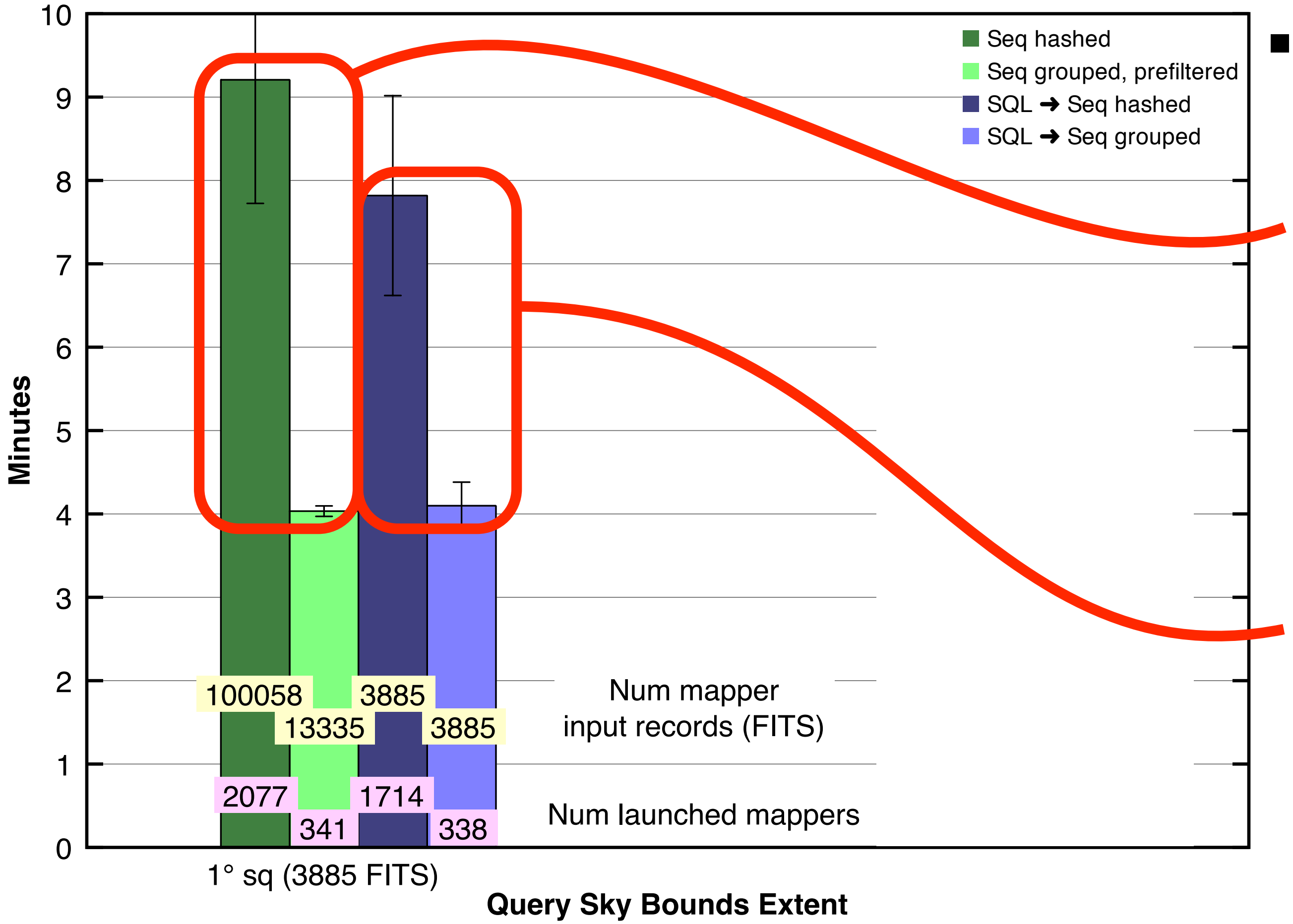
- Low improvement for SQL in the hashed case is surprising at first
  - ...especially considering 26x different mapper inputs (FITS).

- **Theory:**
  - Scattered distribution of relevant FITS prevented efficient mapper reuse.

Consequently

Mapper requirements exceeded cluster capacity(~800). We lost parallelism (mappers were queued)!

Results



- **Just to be clear:**
  - **Prefiltering** improved due to reduction of mapper load.
  - **SQL** improved due to data locality and more efficient mapper allocation – ***the required work was unaffected (3885 FITS)***.

Utility of SQL Method

- Despite our results
  (which show SQL to be equivalent to prefiltering)...

- ...we predict that SQL should outperform prefiltering on larger databases.

- Why?
  - Prefiltering would contend with an increasing number of false positives in the mappers*.
  - SQL would incur little additional overhead.

- No experiments on this yet.

* A spacing-filling curve for grouping the data might help.

Conclusions

- Packing many small files into a few large files is essential.
- Structured packing and associated prefiltering offers significant gains (reduces mapper load).
- SQL prefiltering of ***unstructured*** sequence files yields little improvement (failure to combine scattered HDFS file-splits leads to mapper bloat).
- SQL prefiltering of structured sequence files performs comparably to driver prefiltering, but we anticipate superior performance on larger databases.

- On a shared cluster (*e.g.* the cloud), performance variance is high – doesn't bode well for online applications. Also makes precise performance profiling difficult.

Future Work

- Parallelize the reducer.
- Less conservative CombineFileSplit builder.
- Conversion to C++, usage of existing C++ libraries.
- Query by time-range.
- Increase complexity of projection/interpolation:
  - PSF matching
- Increase complexity of stacking algorithm:
  - Convert straight sum to weighted sum by image quality.
- Work toward the larger science goals:
  - Study the evolution of galaxies.
  - Look for moving objects (asteroids, comets).
  - Implement fast parallel machine learning algorithms for detection/classification of anomalies.

Questions?

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YAHOO! PRESENTS

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