Digitizing the Harvard College Observatory Plate Collection

An Instrument for the "*Historic Sky*"

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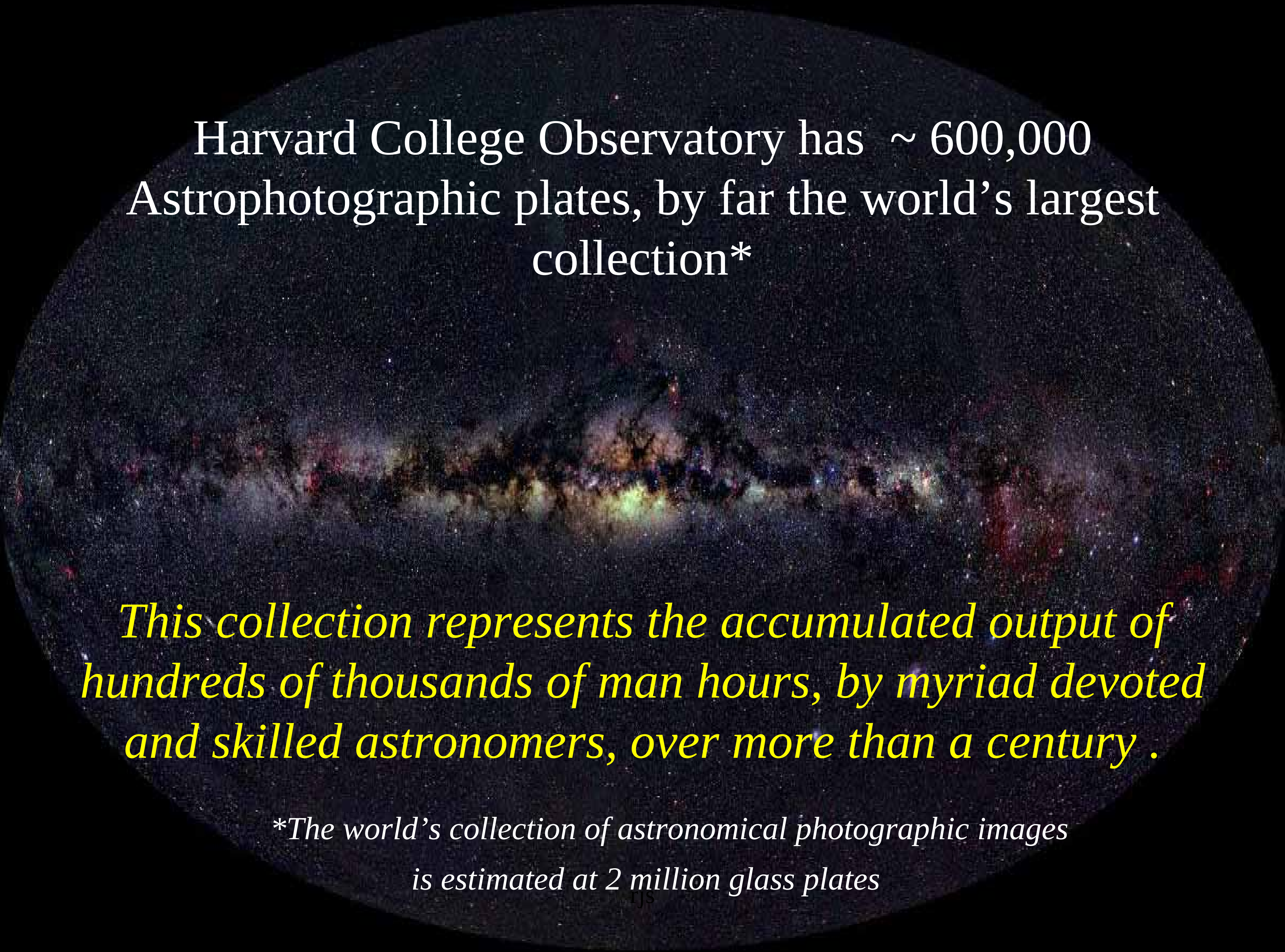


Harvard College Observatory has ~ 600,000 Astrophotographic plates, by far the world's largest collection*

This collection represents the accumulated output of hundreds of thousands of man hours, by myriad devoted and skilled astronomers, over more than a century .

**The world's collection of astronomical photographic images is estimated at 2 million glass plates*

The plates contain a 110+ years of “Sky History” that is an invaluable, irreplaceable database.

The data so painstakingly collected and reduced by hand from these plates laid the foundations of modern astronomical science!

Harvard’s plate collection contains the most complete sky coverage of both the northern and southern sky over the longest time period – 1872 to 1989

Harvard's collection, and other collections around the world, are already nominally in the public domain. But as a resource they are seriously under-exploited. The main reasons are:

a) Lack of catalog information in digital form about the plates

b) Lack of digitized data from the plates

The modern tools of astronomy require digital data!

Until now, despite the desire to convert the plates to a digital form, it was not technically or economically feasible to either digitize the plates or store the resulting data online.

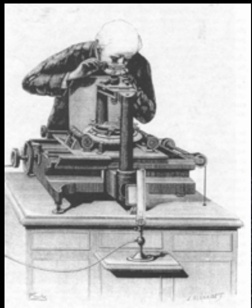
Now both are possible!

The "analog" storage of data on Harvard's photographic plates represents 200-500 Terabytes of digital data.

To scan Harvard's library of historic plates in a ~5 year timeframe, we need a machine that can digitize ~ 200 times faster than previous machines

To meet astrometric, photometric, and archival digitizing goals, the machine needs sub-micron positional accuracy, ~10um pixels-digitized to 12 bits, and an average plate digitizing speed of ~1minute (most plates are 8 x 10).

Automating the Measurements

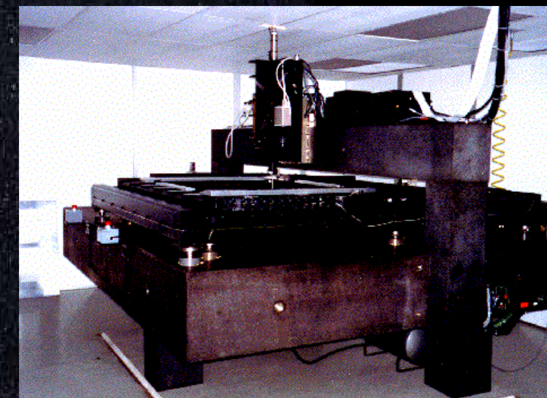


1886

*Gaertner single screw engine 1916

*The Grant 2 Measuring Engine-1967

**PMM (NRO ~1988)

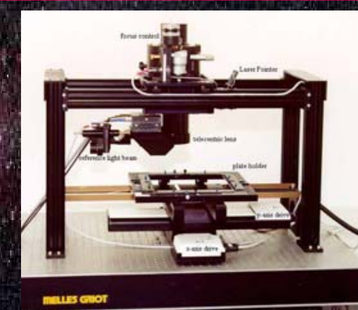


Astrometric

Photometric

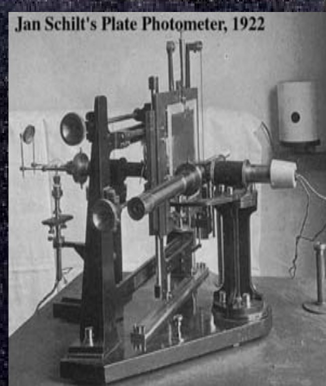
*Perkin-Elmer

PDS ~1980



Tautenburg~1995

*1916



Jan Schilt Photometer - 1922

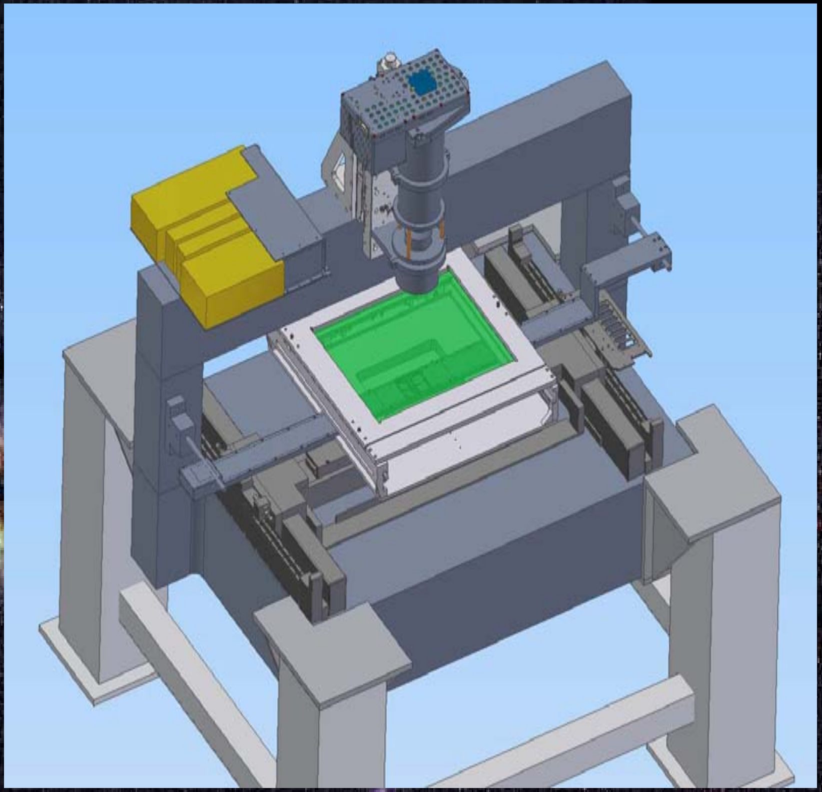
*http://www.astro.virginia.edu/~rjp0i/museum.html
**http://www.nofs.navy.mil/projects/pmm/pmm_caption.html

Using technology common to semiconductor wafer and flat panel display inspection stations, a machine can be built today that can do ultra-fast, ultra-precise digitizing.

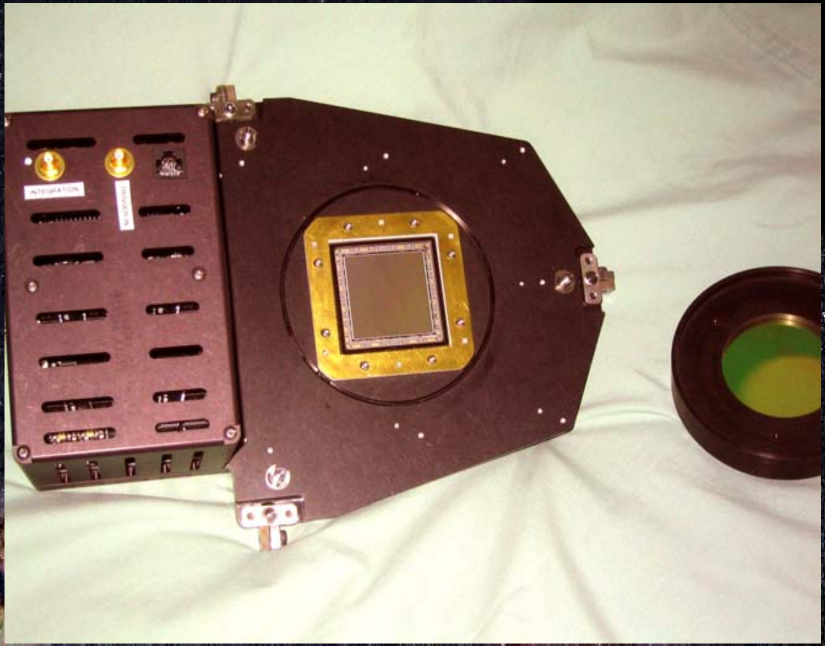
The goal is to digitize two 8 x 10 inch plates or a 14 x 17 inch plate in a little over a minute of machine time, generating enough data in that time to fill a DVD (5.8 Gigabytes-2 scans 14 x 17 plate).

Digitizer Subsystems

- CCD Camera
- Lens
- X-Y (Z) table
- Isolation stand
- Illumination
- Fixture to hold plates
- Computer/storage system



CCD - Issues

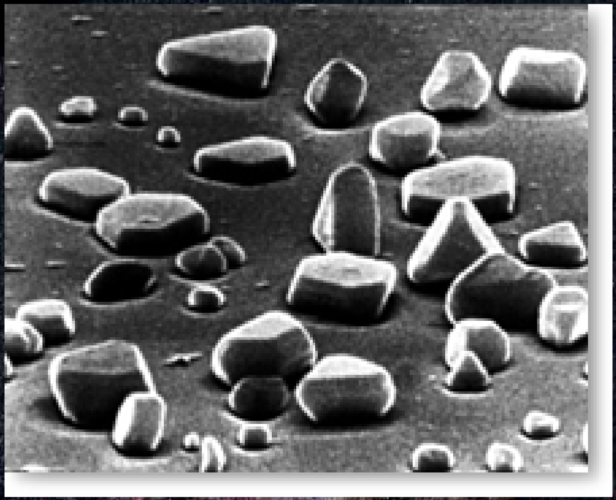


- What size pixels capture all of the information on the film?
- What speed readout?
- What sizes are available?
- How large is practical/affordable?
- Dealing with defects

-Solutions

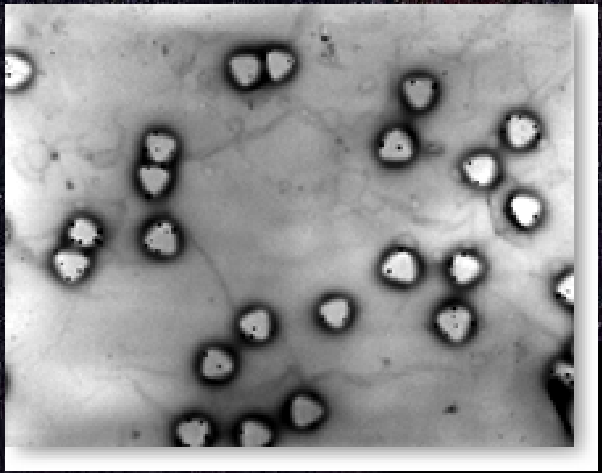
- Best candidate –ATMEL chip-**AT71201M** (old Thompson group)
- 4K x 4K, 11 um pixel, 7 frames/sec, 4 quadrant @40MHz
- No commercially available camera………but
- Generous Donor supplied a camera with a nearly perfect chip!!
- 12 bit Digitizing -32Megabytes/frame
- Scan pattern plan- ½ frame overlapping pictures in x direction, -64 pixel overlap in y direction

Capturing all of the data on the plates



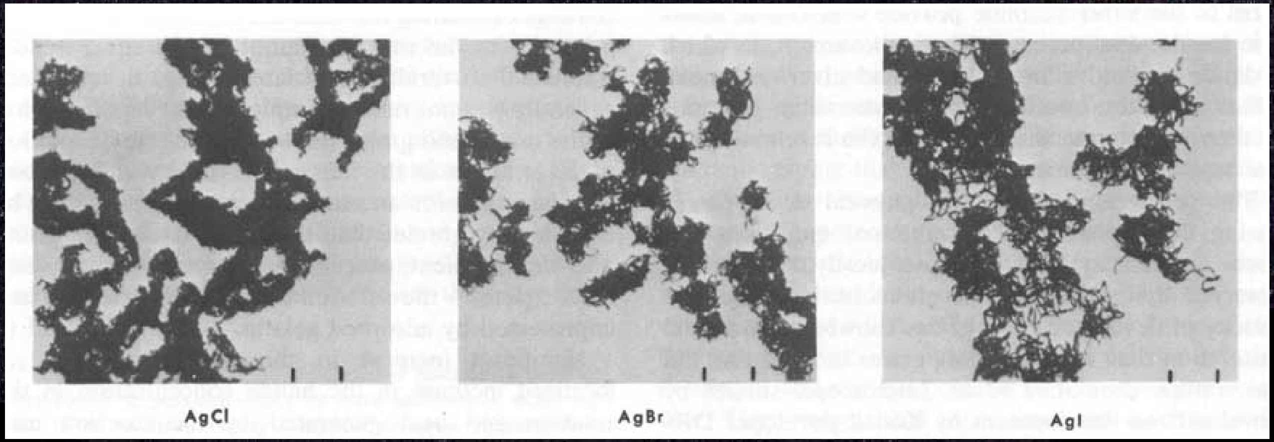
Unexposed crystal grains

Beginning to develop exposed grains

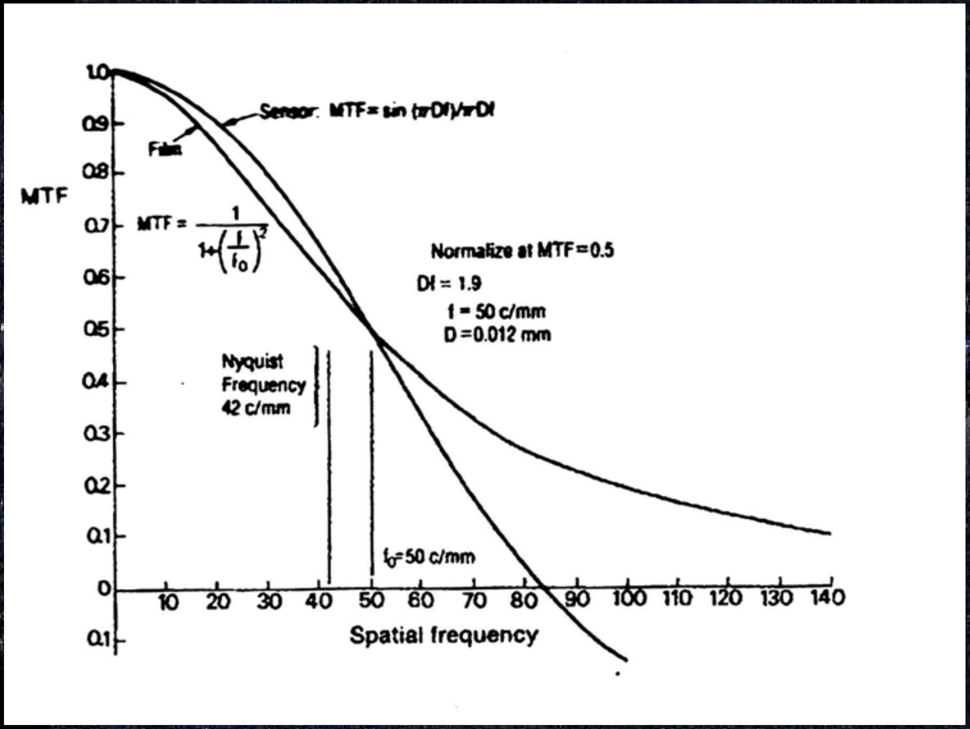


Grains develop into silver filaments

The developed grains turn into “silver wool” blobs



MTF analysis tells us the needed pixel size



11um pixel = 2309dpi

Smallest star image ~ 30um

A 8 x 10 plate at this resolution is 764 Mbytes

Film Equivalent Pixel Sizes

ISO Speed	Pixel Size
100	12um
200	14um
400	19um
1000	26um

rjs

Lens –

Issues

- Double telecentric desired
- Wide field

61mm diagonal on 45mm square CCD)

- 1:1 magnification
- large front lens
- No distortion
- Custom design?

Solution –lucky find, commercially available lens

- Sill Optics double telecentric lens
- 1:1 magnification
- 70mm max object size
- .01% distortion- still to be verified – this may be the largest error source
- 180mm working distance

X-Y Table -Issues

- Accuracy in not well controlled environment
- Speed of move and settling with fixture weight
- Size of the plates/size of the table
- Getting it into the building, access limited to a 4 foot by 4 foot window and interior limited by ~50 " steel support grid!
- Table configuration impact on illumination system

Solutions

- Chose Aerotech ABL-9000 380mm x 460mm customized table
  - Air bearing, linear motor – 75Kg load max (45-50 lb expected)
  - 22.5 mm move to +/-.1um final position in ~280 ms (light load)
  - Zerodur linear encoders, 4um multiplied to 10nm/encoder count.
  - 2D laser correction to .2u over table surface, our frame positions each laser mapped
- Table size ~4 x the largest plate size ~ min 28 in by 34 in (33.2 x 44.6{54.6})
- Table and stand must be modularized to go in through this window.
- H configuration chosen, ***No*** illumination through granite

Isolation stand

Issue

- The table is lightweight for the load and speed
- Testing showed a 5 Hz horizontal ~.5um ringing

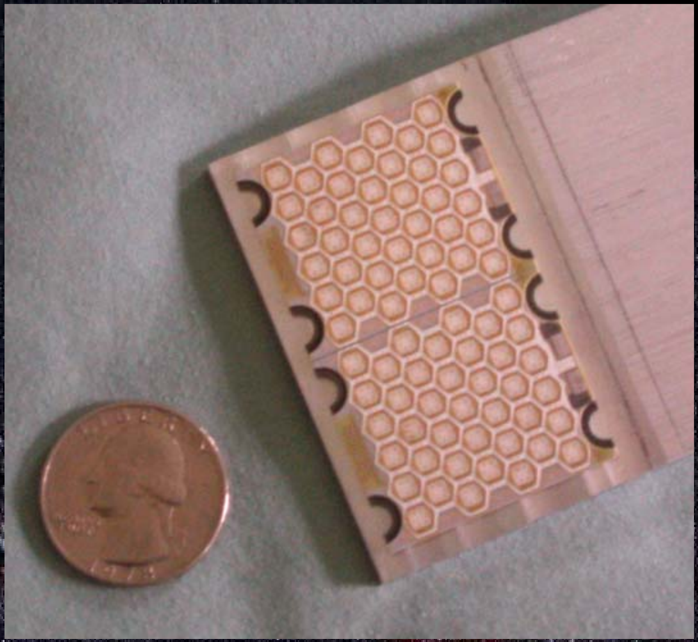
Solution

- Extension brackets for the 4 corners of the table
- Brackets allow lowering the center of gravity for the isolators and extends the effective table size.
- Added velocity control dampener devices to control x and y movement of the granite base.

Illumination System

Issues

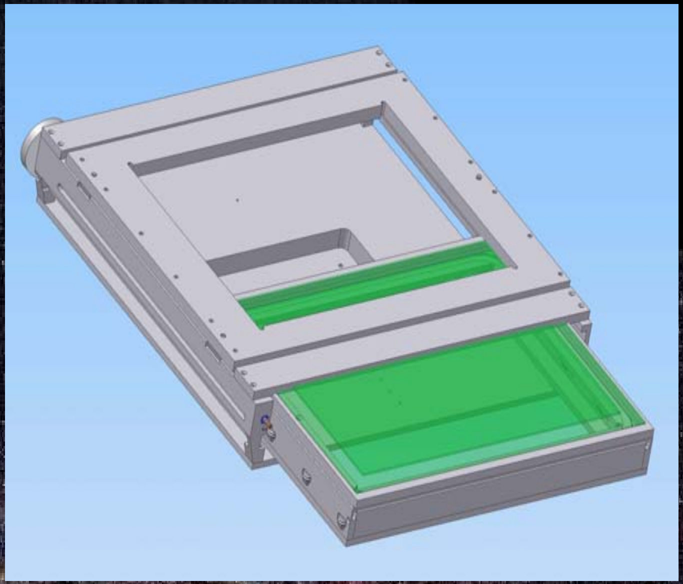
- Illuminate only CCD or whole plate
- How much light needed for 20-30ms exposure?
- Diffuse vs. collimated light
- Strobe light or shutter?
- Evenness of light, flat fielding issues



Solutions

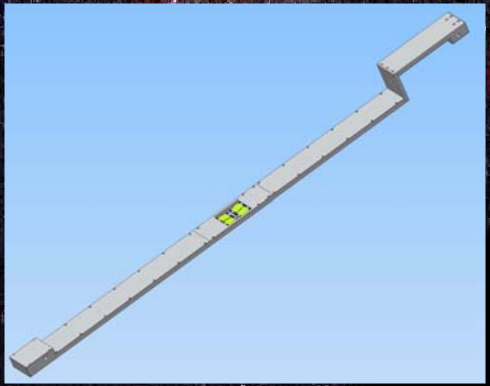
- Illuminate only the CCD –light system stationary while fixture moves
- Limited light source and support to ½ inch high 3 inch wide strip
- Strobe high power 525nm Green LED and have narrow BP filter in camera
- Diffuse the light with multiple layers of flash opal glass (also supports plates)
- After much experimentation, chose 4-Lamina 1inch LED arrays (234 LED’s per array, 936 total). LED arrays strobed with 225W constant current –20amp pulse!

Plate Holding Fixture



Issues:

- Holding the plates flat, emulsion side up
- Some old plates are not square
  and have considerable wedge
- Prevent Newton ring problems
- Support the plates above illumination system
- Make it easy to load and unload plates
- Allow modular changes for different size plates
- Fixture must move around light system



Solutions:

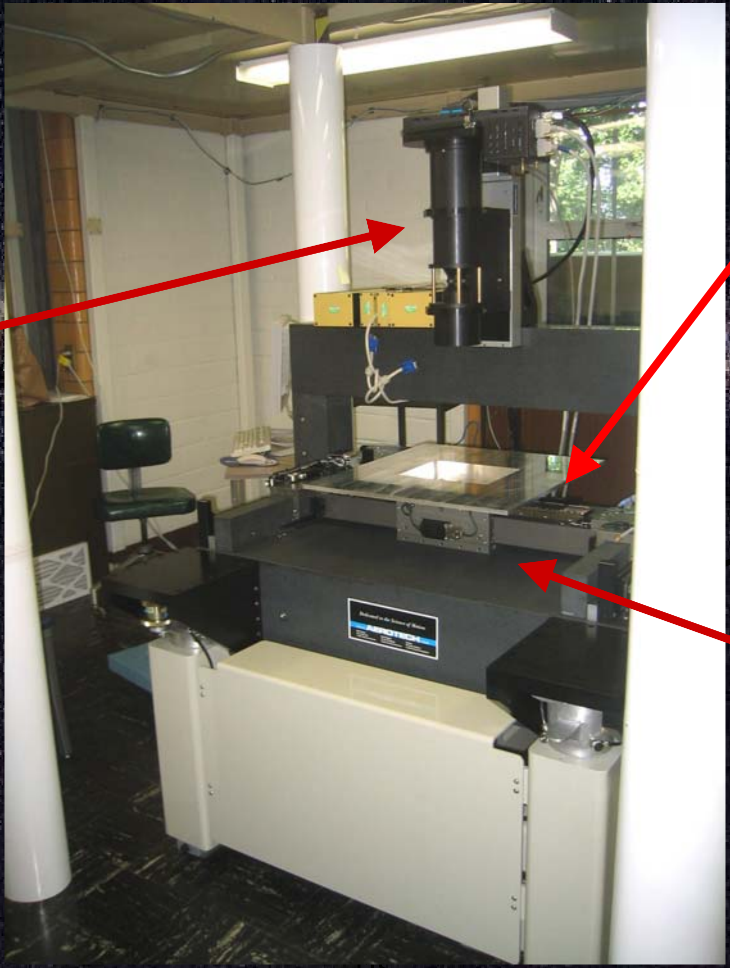
- Pneumatically hold plate against a kinematic
  mounted top plate
- Use glass support on moving platform to ease loading
- Support this above light system
- Use tubing under the support glass to equalize pressure for uneven plates

The digitizer provides astrometric and photometric accuracy while generating archival quality digital data.

Camera is capable of ~7 frames per second. We aim for 3 fps

Camera takes ~ 161 pictures in 60 seconds (2 exposures for each of ~80 sites).

11um pixels



A camera can scan two 8 x 10 inch plates or a single 14 x 17 inch plate

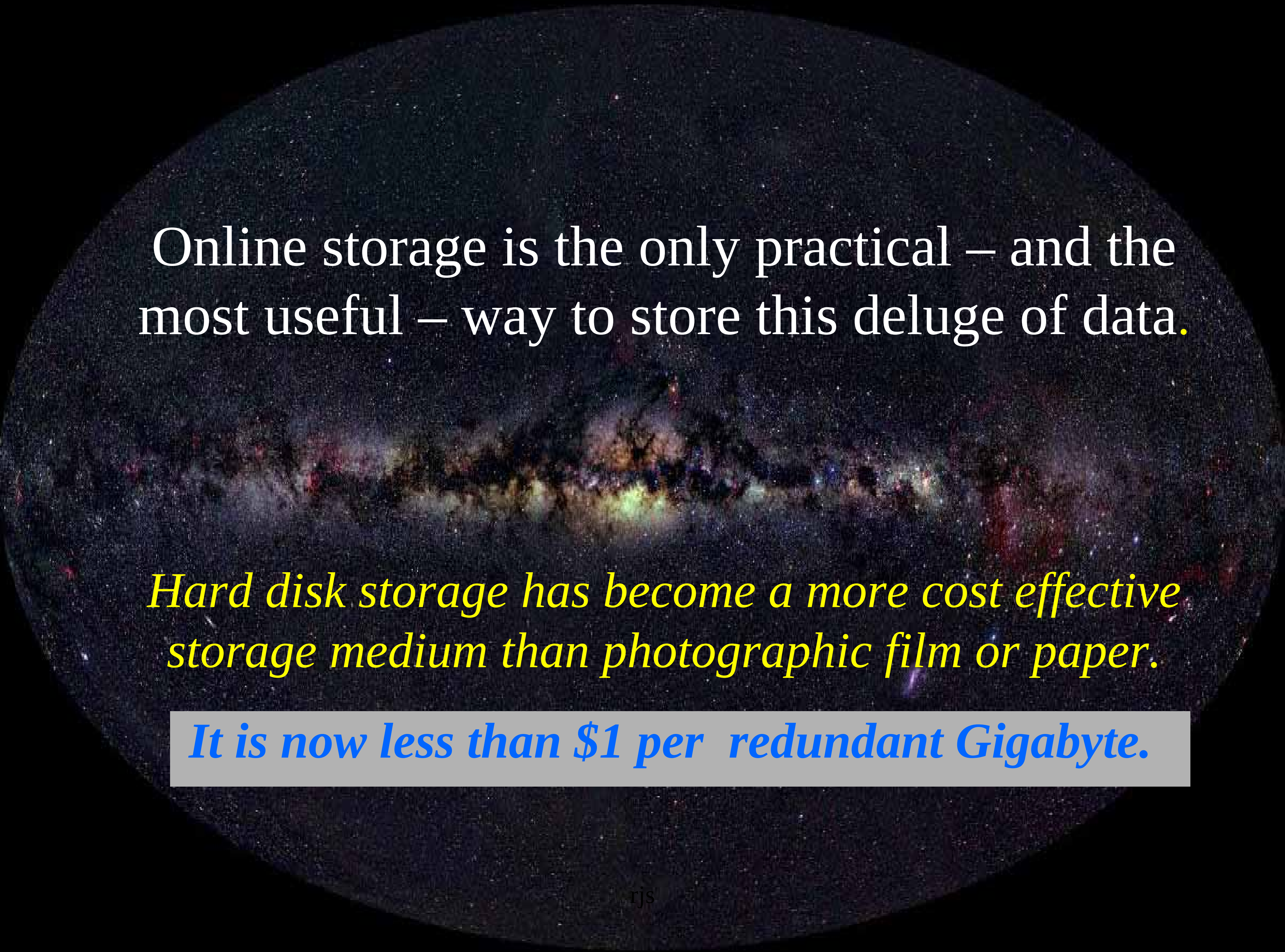
Special fixtures to hold 14 x 17, 14 x 14,10 x 10, 2(8 x 10), and smaller plates as needed

Table accurate to .2um over the working surface

Computer System

- Dual 3.2Ghz Xeon server motherboard
- 2Gbyte ECC memory
- Coreco (now Dalsa) Video capture X64-CL Dual card

  2 – 400 MHz Camera link base links (24 bits wide)
- Aerotech PCI 500-Ultra motion control card
- PCI-X 133/SATA Raid level 10 with 1Terabyte of fully redundant disk
- 3 frames/ sec generates need to write 96 Mbytes/sec to disks
- Data movement by physically changing disks! Even the local network with Gigabit Ethernet is too slow.



Online storage is the only practical – and the most useful – way to store this deluge of data.

Hard disk storage has become a more cost effective storage medium than photographic film or paper.

It is now less than $1 per redundant Gigabyte.

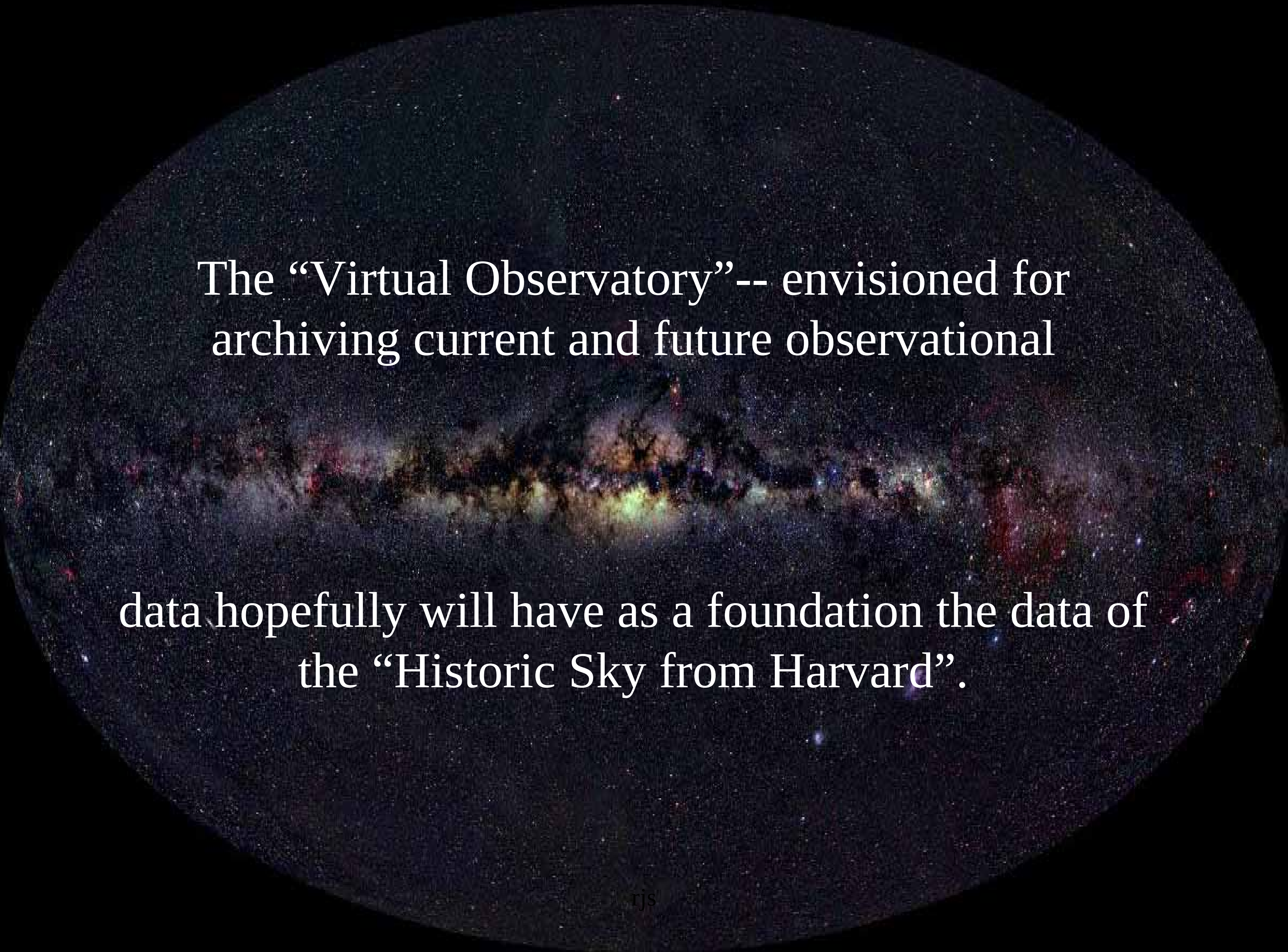
Status

- •The table and camera are functional
- •The lens system needs thorough testing.
- •The fixture is in construction.
- •Prototype light system functions – full light system and exposure time expected to be in the 30-50 ms region.
- •The original computer disk (single IDE drive) is too slow to collect data. We have upgraded the storage system to a raid 10 system (1Terabyte fully redundant). Time to write a frame ~380 ms.
- •It looks like we can achieve system throughput of a frame every 350ms by allowing write to disk to fall behind and then catch up when unloading and loading plates.
- •At this rate we should be able to digitize a 8 x 10 inch plate in ~ 20 seconds and a 14 x 17 inch in about a minute.

The worldwide astronomical community naturally looks to Harvard to lead the way in the effort to make 100+ years of collected "Historic Sky" available in digital format and online. This digitizer is the first step towards that goal.

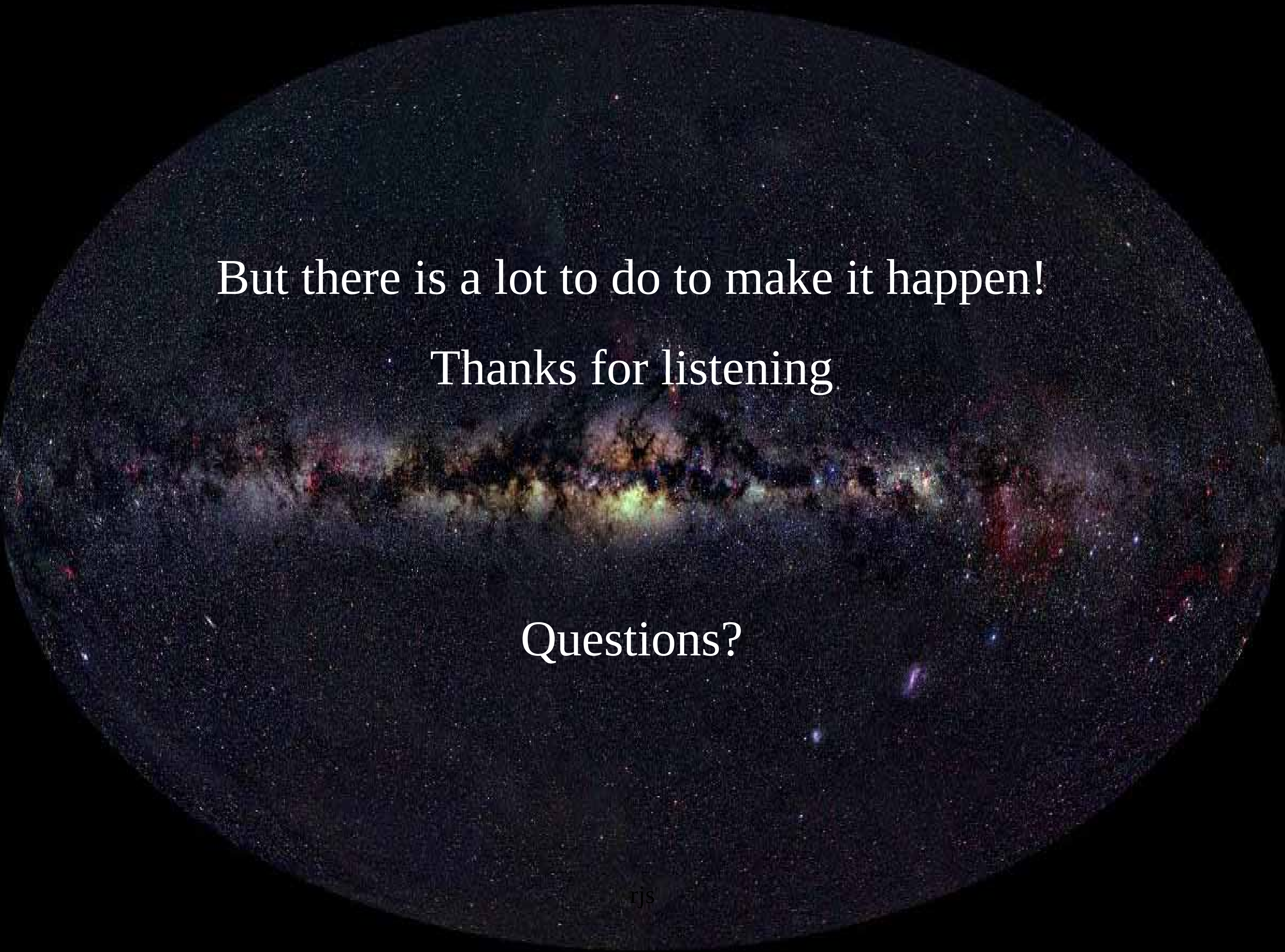
Much of what is on these plates has not been "mined", because previous data reduction was done by hand with simple measuring machines.

Perhaps 30% of the plates have not really even been examined !



The “Virtual Observatory”-- envisioned for archiving current and future observational

data hopefully will have as a foundation the data of the “Historic Sky from Harvard”.


But there is a lot to do to make it happen!
Thanks for listening
Questions?