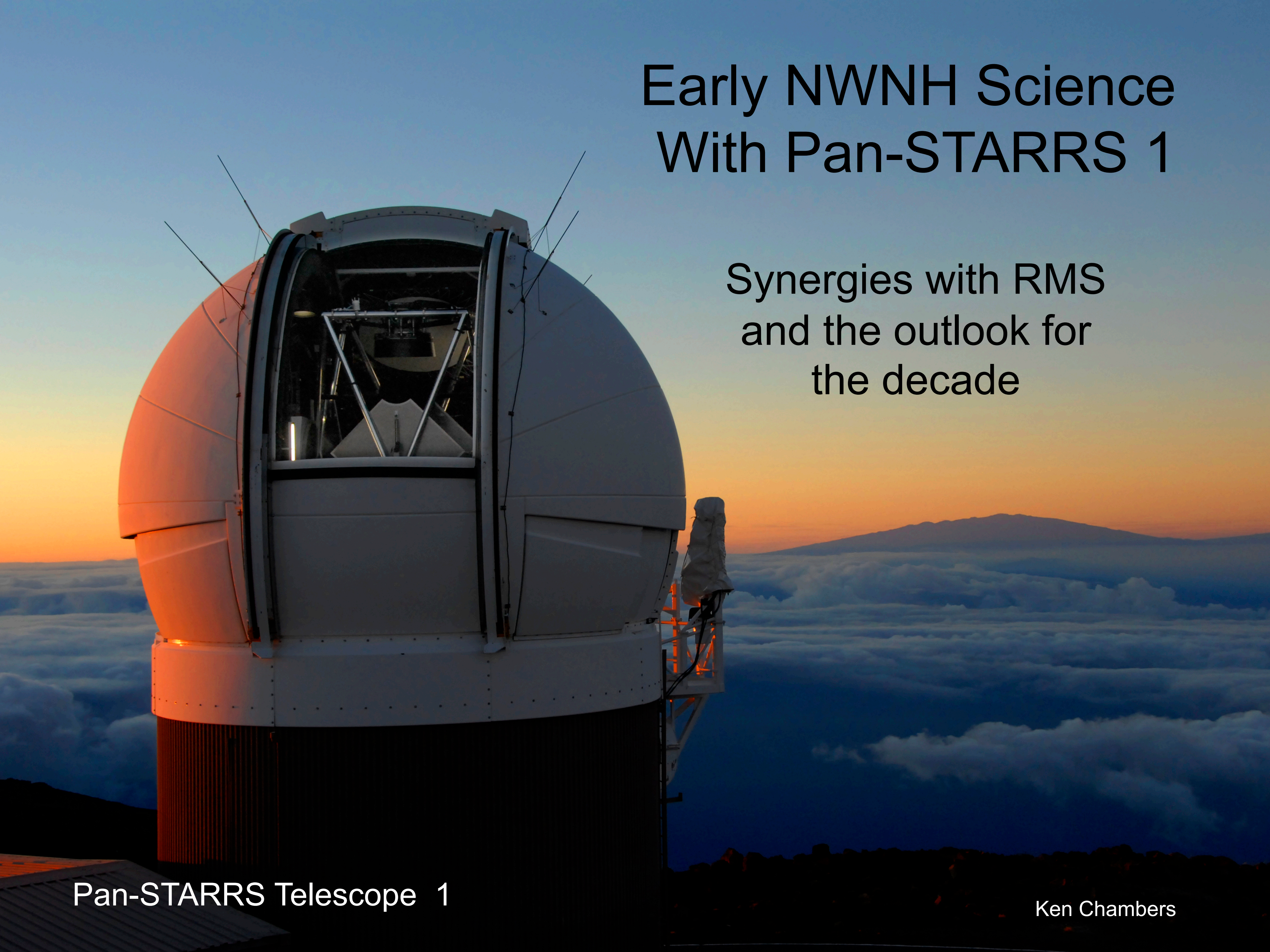
Early NWNH Science With Pan-STARRS 1

Synergies with RMS and the outlook for the decade



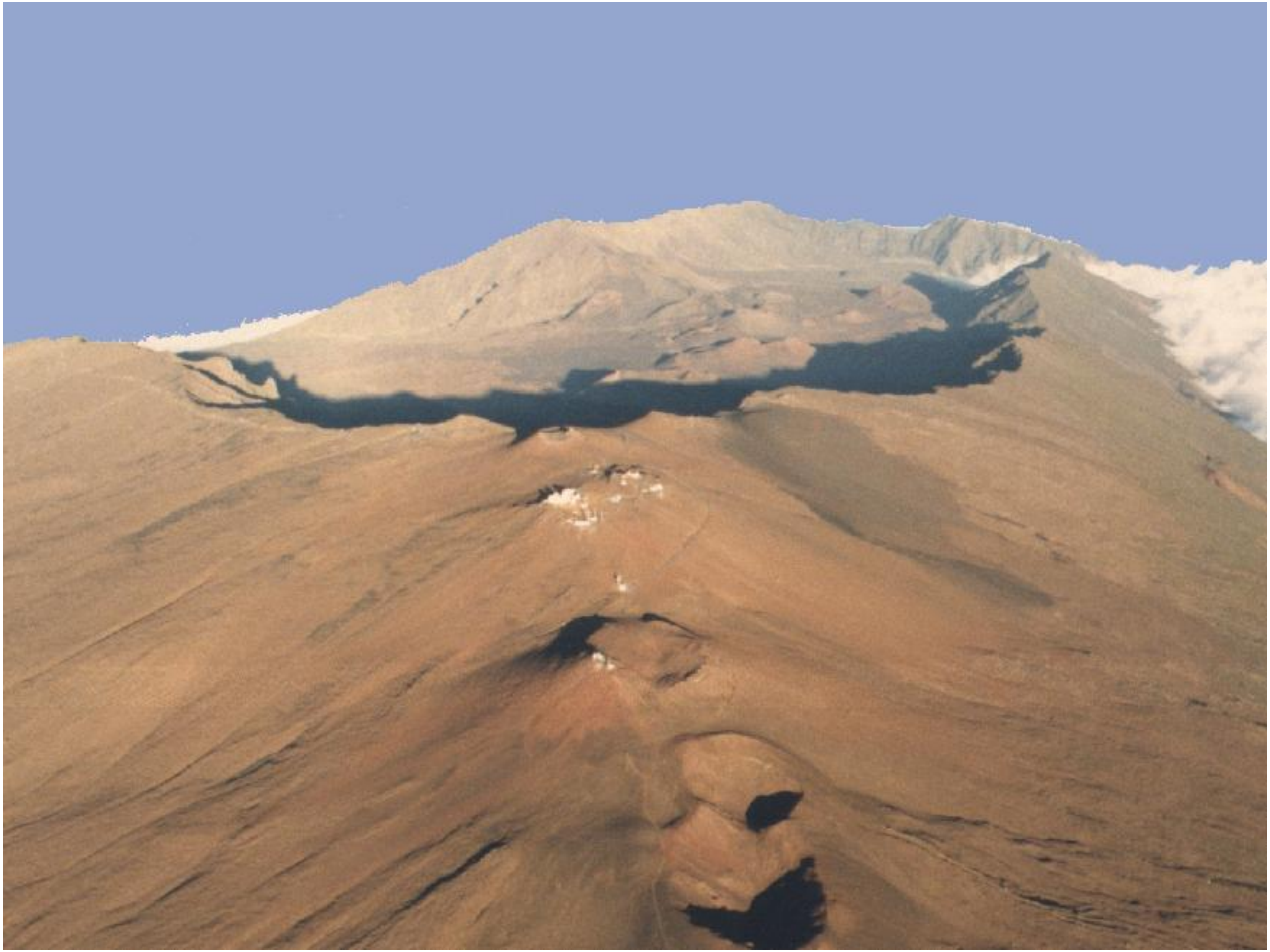
Pan-STARRS Telescope 1

Ken Chambers

The PS1 System -
a fully functioning pathfinder for LSST

- Prototype for Pan-STARRS project
- Construction funded by AFRL to develop technology to survey the sky
- 1.8 meter Telescope at f/4.4, 3.2 deg FOV
- 1.4 Gigapixel Camera with 0.256'' pixels
- Six bands: *g, r, I, z, y,* and *w*
- Functioning real time Image processing pipeline and alert system
- Hierarchical relational database in beta testing
- Science quality data since Jan 2010
- PS1 Science Mission started May, 13, 2010
- Completing first year coverage of the sky – 30,000 deg^2
- Operations funded by PS1 Science Consortium

Haleakala Observatories, Maui, HI

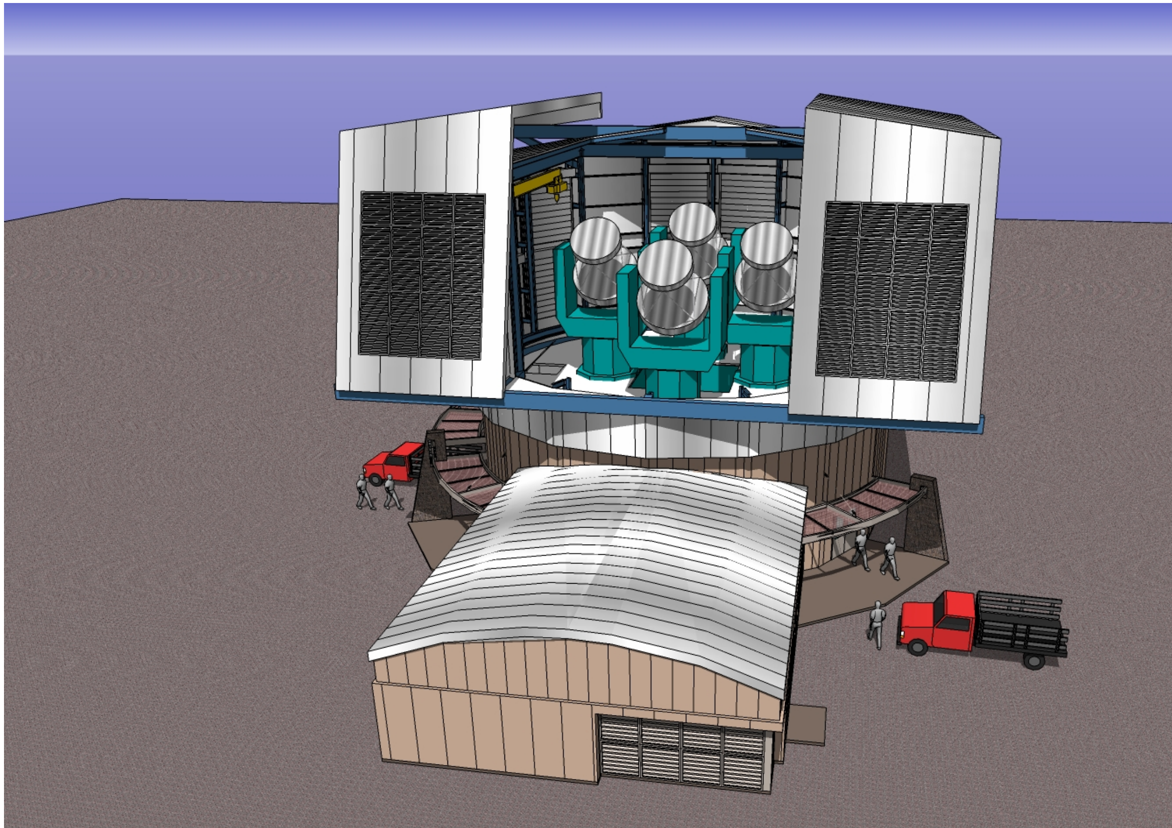


PS2 is under construction and will go in North Dome scheduled for completion by end of 2013

Pan-STARRS -> PS1 + PS2 + PS-4 = PS6?

- Pan-STARRS-4 observatory specifications
  - –Four 1.8m R-C + corrector
  - –7 square degree FOV - 1.4Gpixel cameras
  - –Sited in Hawaii
  - –A Ω = 50
  - –R ~ 24 in 30 s integration (meets NAS decadal review “LSST” spec)
    - –-> 7000 square deg/night
  - –All sky + deep field surveys in g,r,I,z,y and w filters

- Time domain astronomy
  - Transient objects
  - Moving objects
  - Variable objects
- Static sky science
  - Enabled by stacking repeated scans to form a collection of ultra-deep static sky images



Ken Chambers

Pan-STARRS

Panoramic Survey Telescope and Rapid Response System

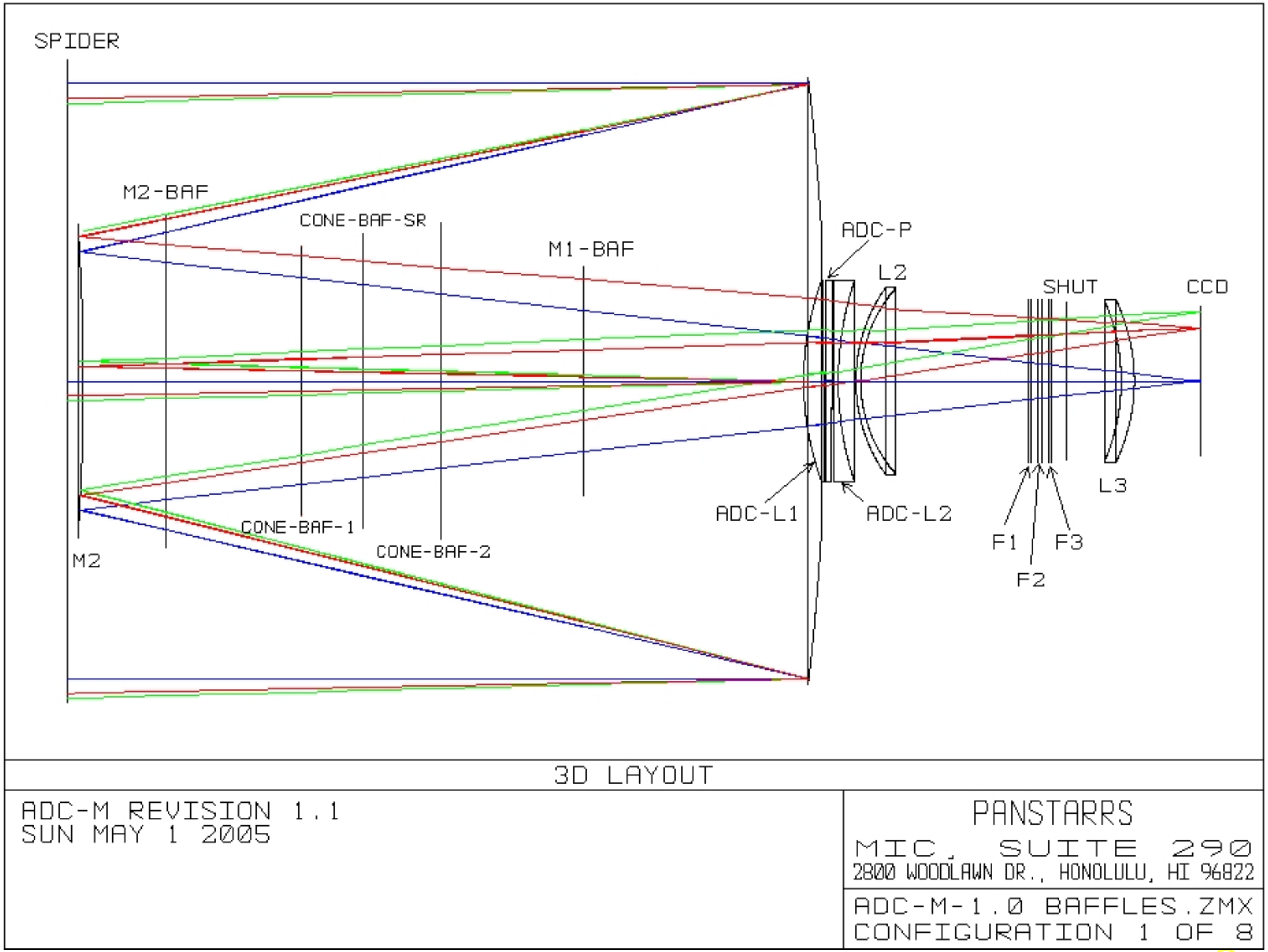
The construction of Pan-STARRS has so far been a demonstration R&D project by the University of Hawaii Institute for Astronomy for the AFRL to develop the technology to survey the sky

Operations and ongoing development is being funded by PS1SC

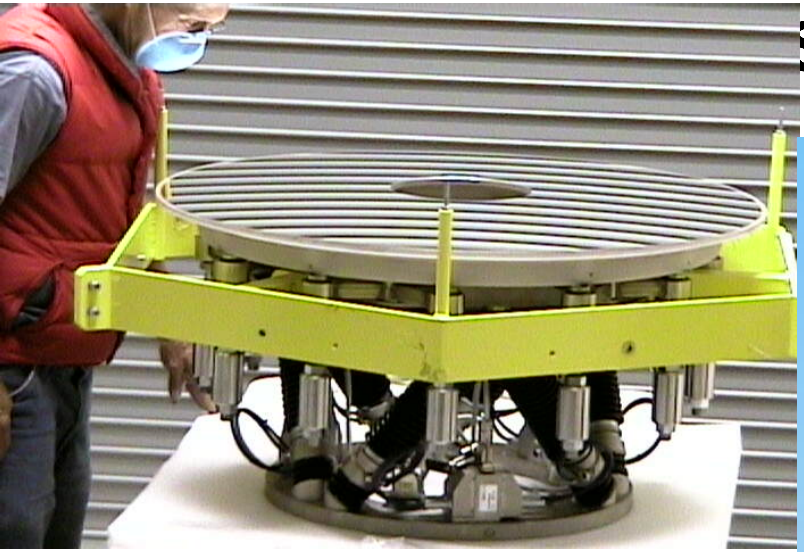
Pan-STARRS

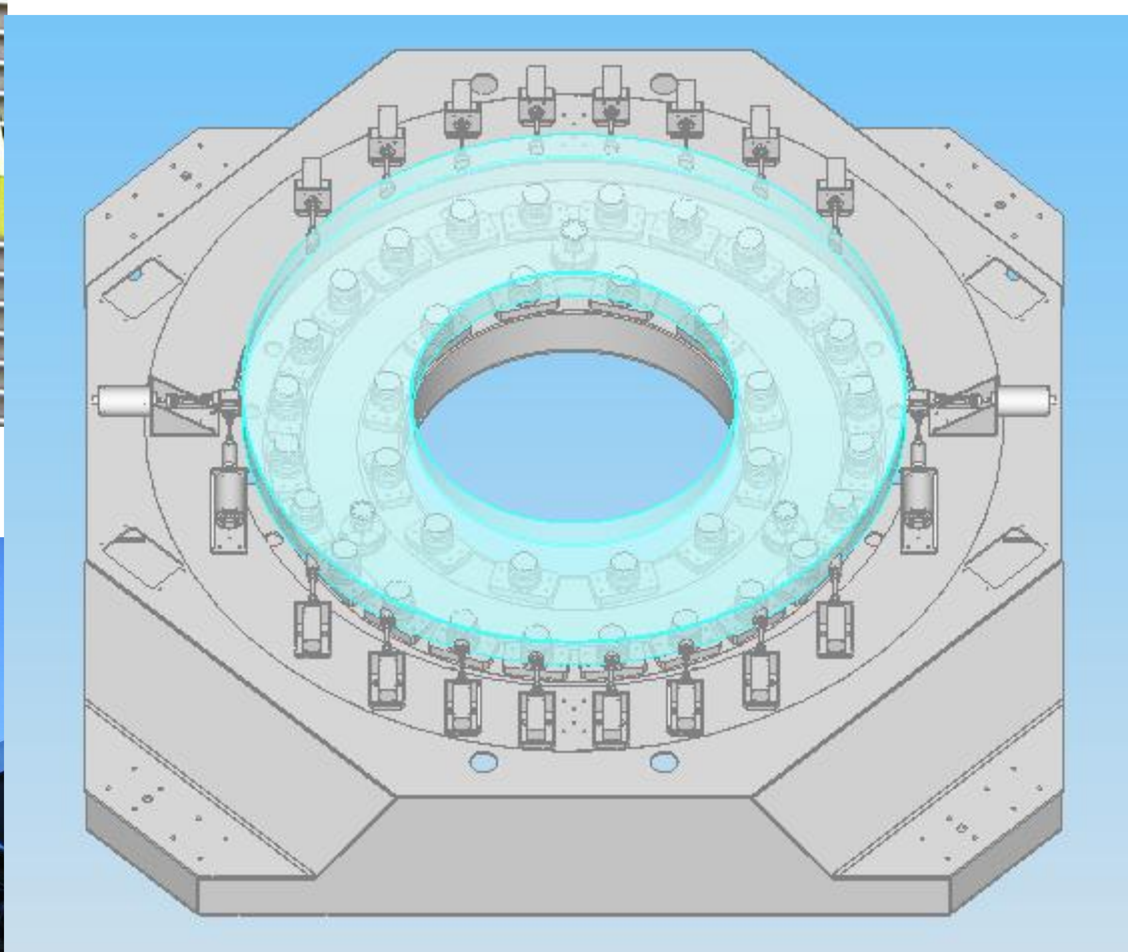
PS1 Science Consortium

PS-1 Optical Design - RC + 3-element wide-field corrector

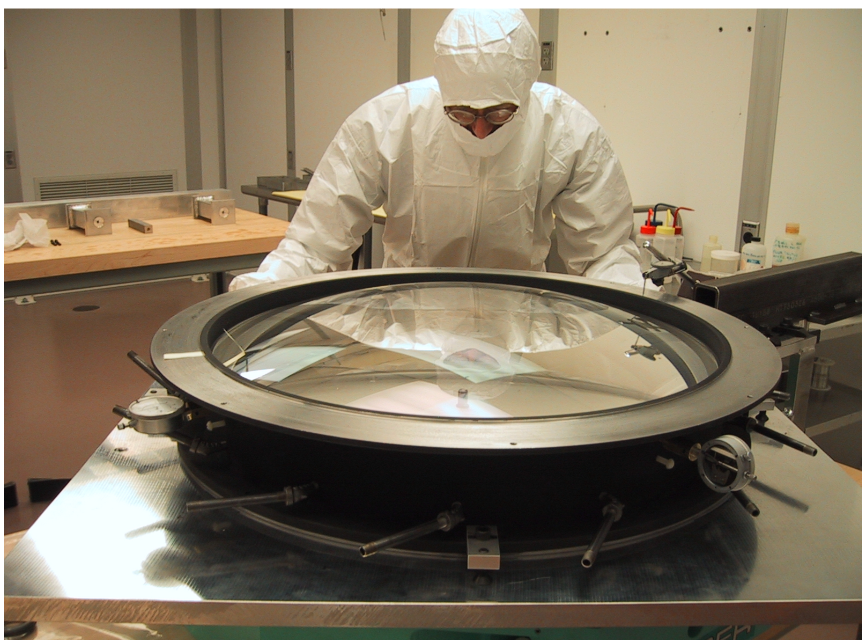


Support Systems

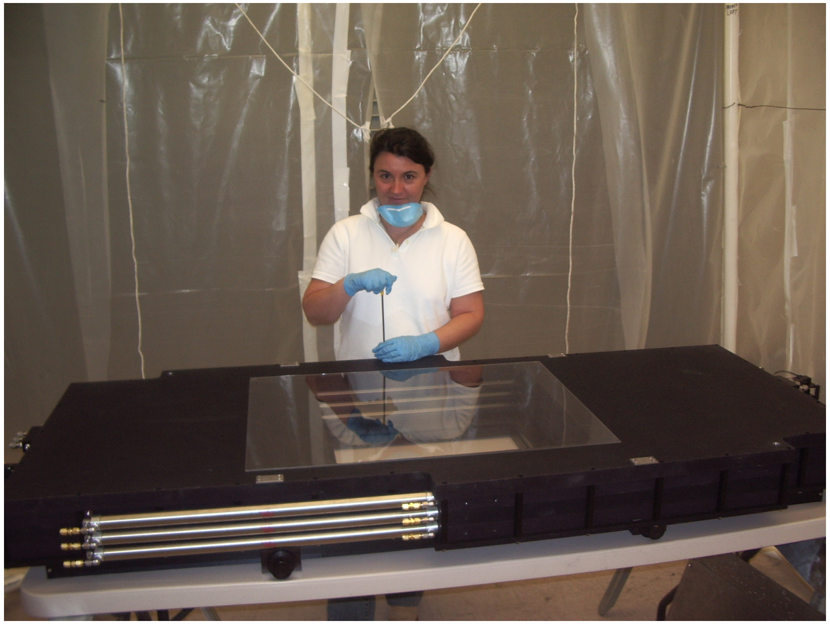


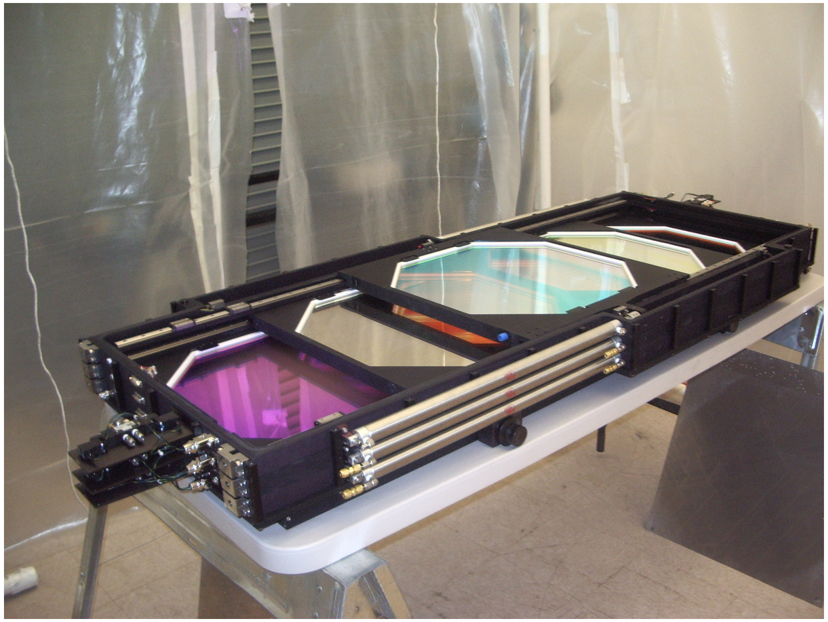


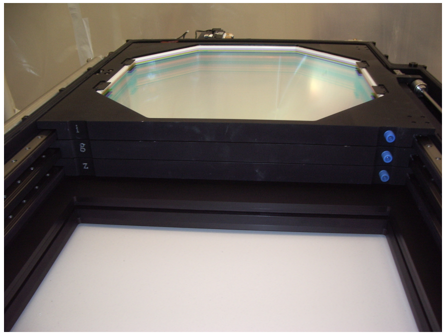
Corrector Optics Installation

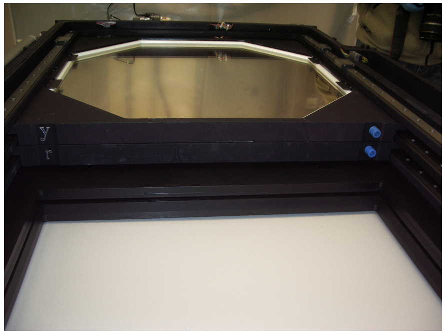


Filter Mechanism Installation









The PS1 Pineapple Slicer

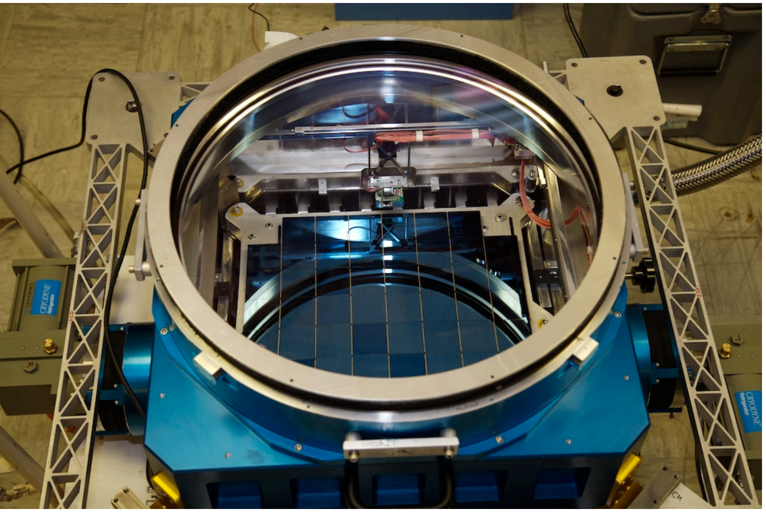
University of Bonn

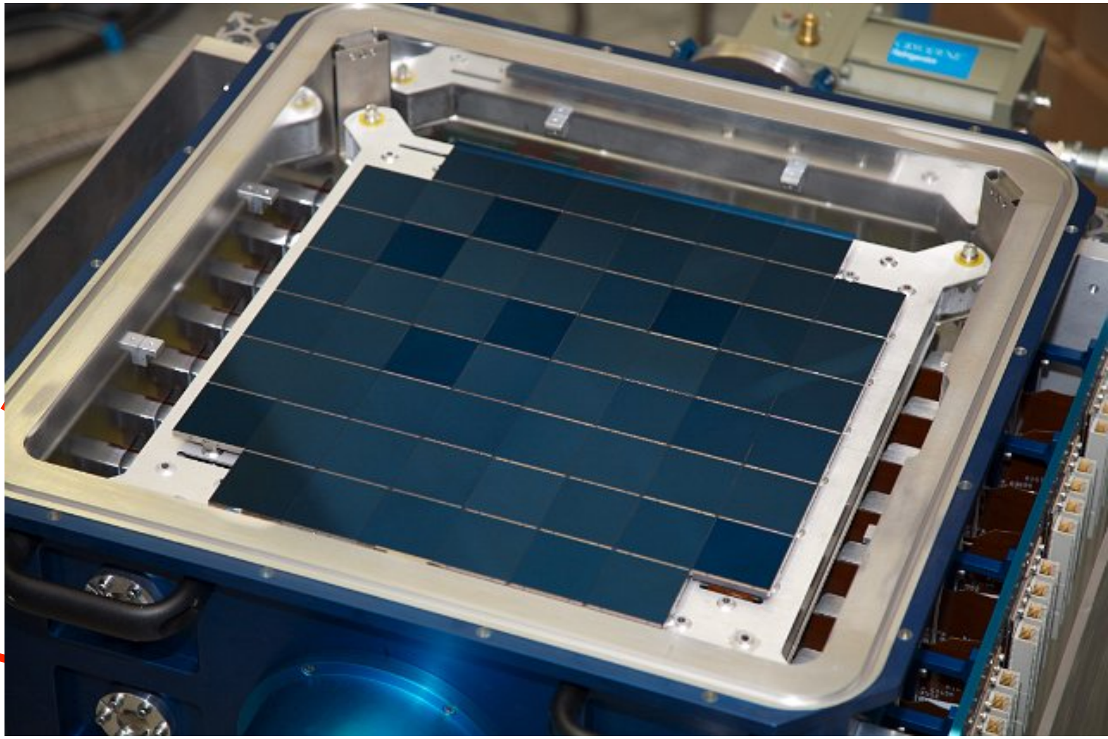
40 cm aperture

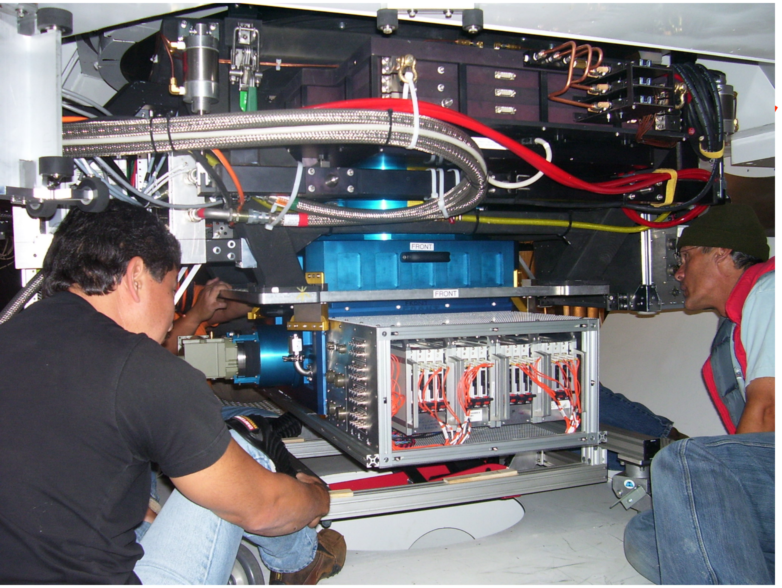
twin blade Shutter

Trajectory repeatable to10 millisec!

GPC1

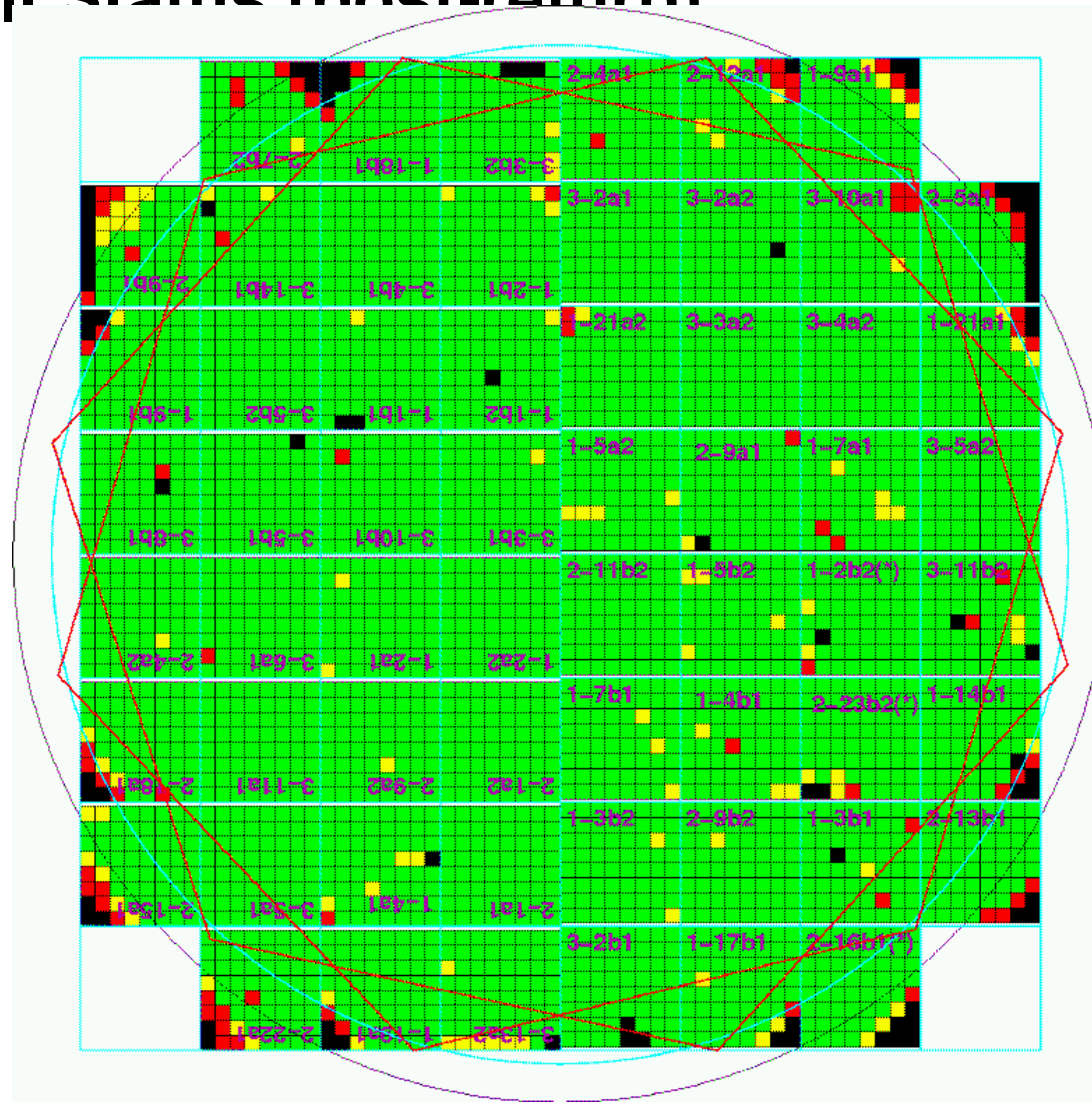






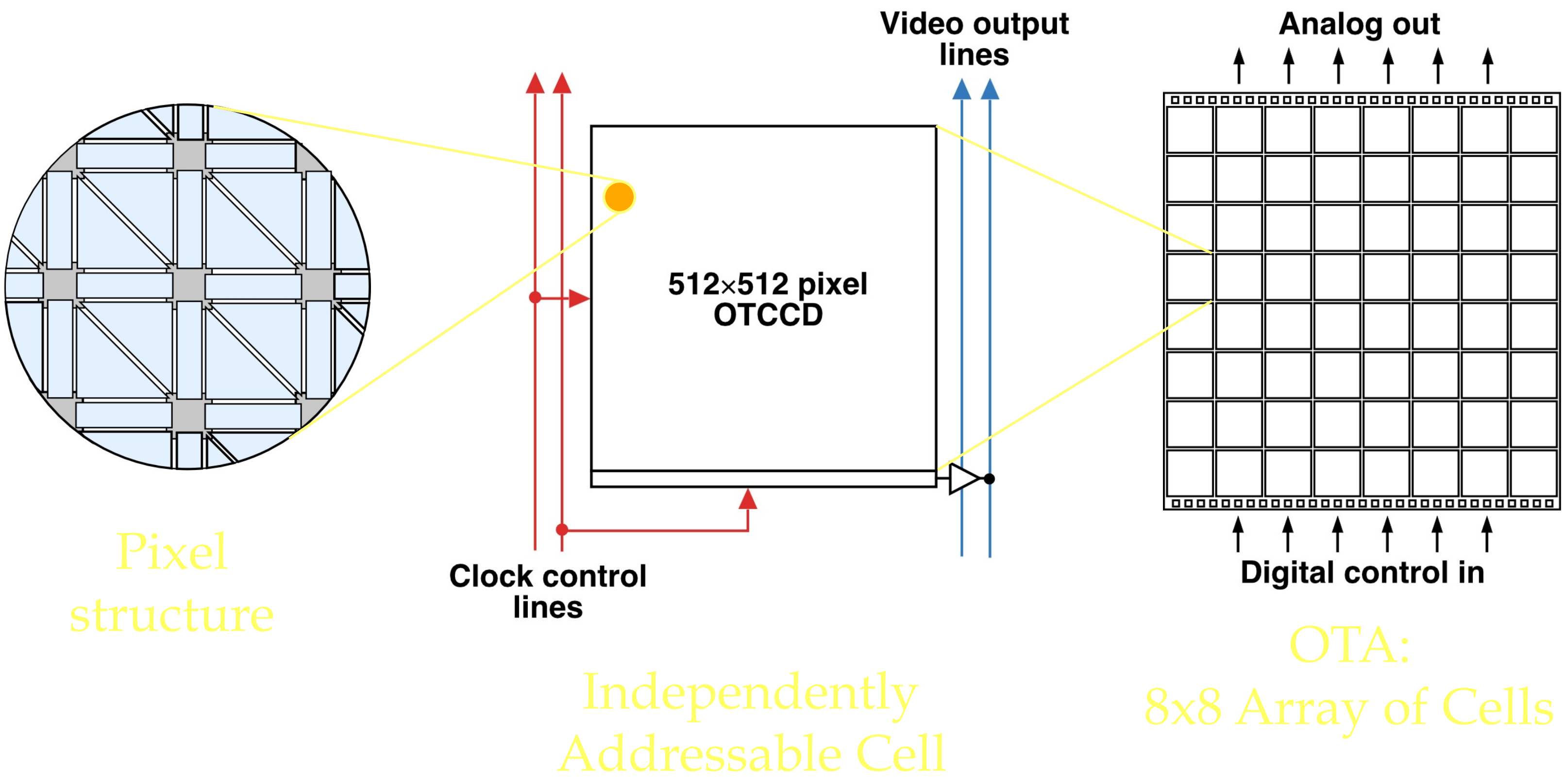
GPC1 Cell Status (post-refurb)

- Cell colors
  - Black = useless
  - Red = probably useless
  - Yellow = probably useful
  - Green = OK
- Cyan circle = 3º
  - 1.7% loss
- Black circle = 3.3º
  - 3.4% loss
- Red = hexagonal sky tesselations



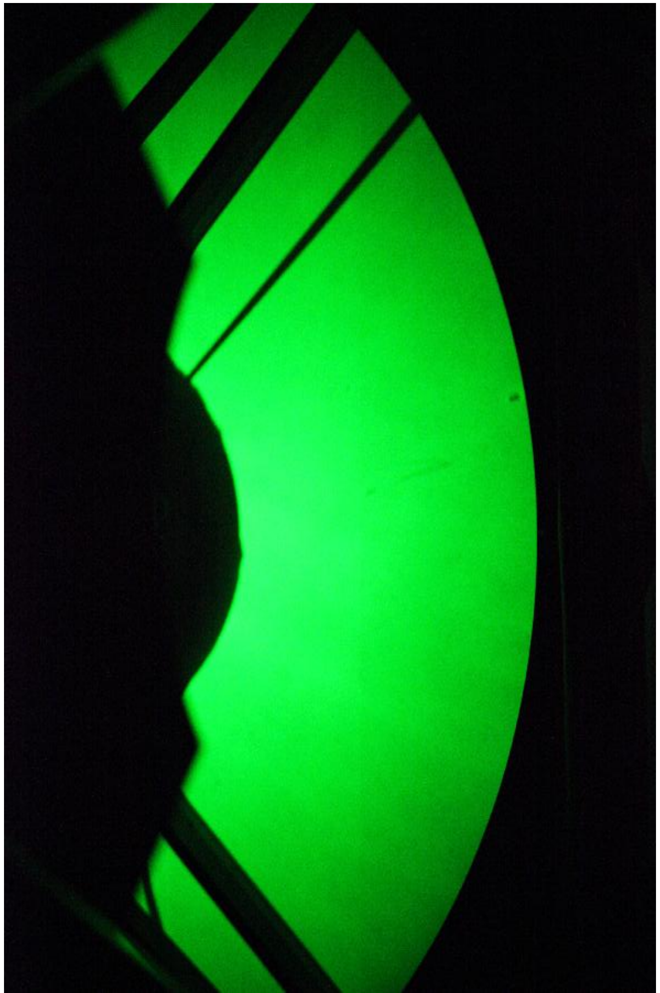
Orthogonal Transfer Array

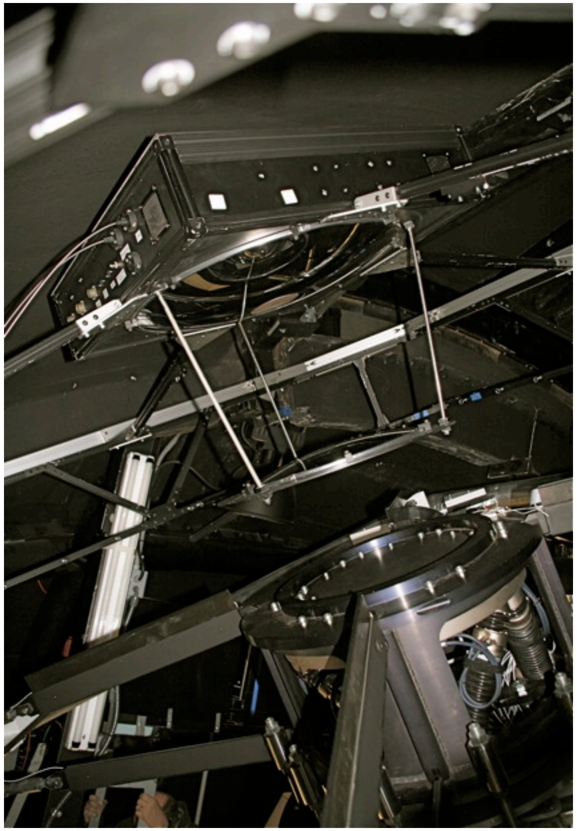
- A new paradigm in large imagers.
- Partition a conventional large-area CCD imager into an array of independently addressable CCDs (cells).
- Massively parallel design allows rapid read-out -> rapid sky coverage

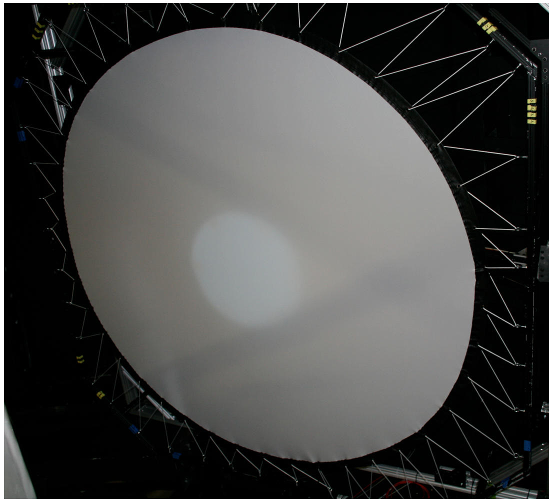


Precision Calibration System at PS1

Operational with both white light source and NIST tunable laser
One NIST photodiode looks at screen, and one is mounted inside the dewar at the focal plane. The ratio gives the the throughput including mirror reflectivity, filter transmission, optics coatings and transmission.







PS1 Operations

The PS1 System consists of:

PS1 Telescope and GIgapixel camera, at Summit of Haleakala

The observatory is operated from the PS1SC Remote Control Center at the ATRC, IfA in Pukalani, Maui

Reduced images and object catalogs, and data products are produced by the Image Processing Pipeline at the Maui High Performance Computing Center in Kihei,Maui.

Data Reduction and Processing overseen from IfA Manoa on Oahu.

Data products sent by internet to Scientists of PS1SC

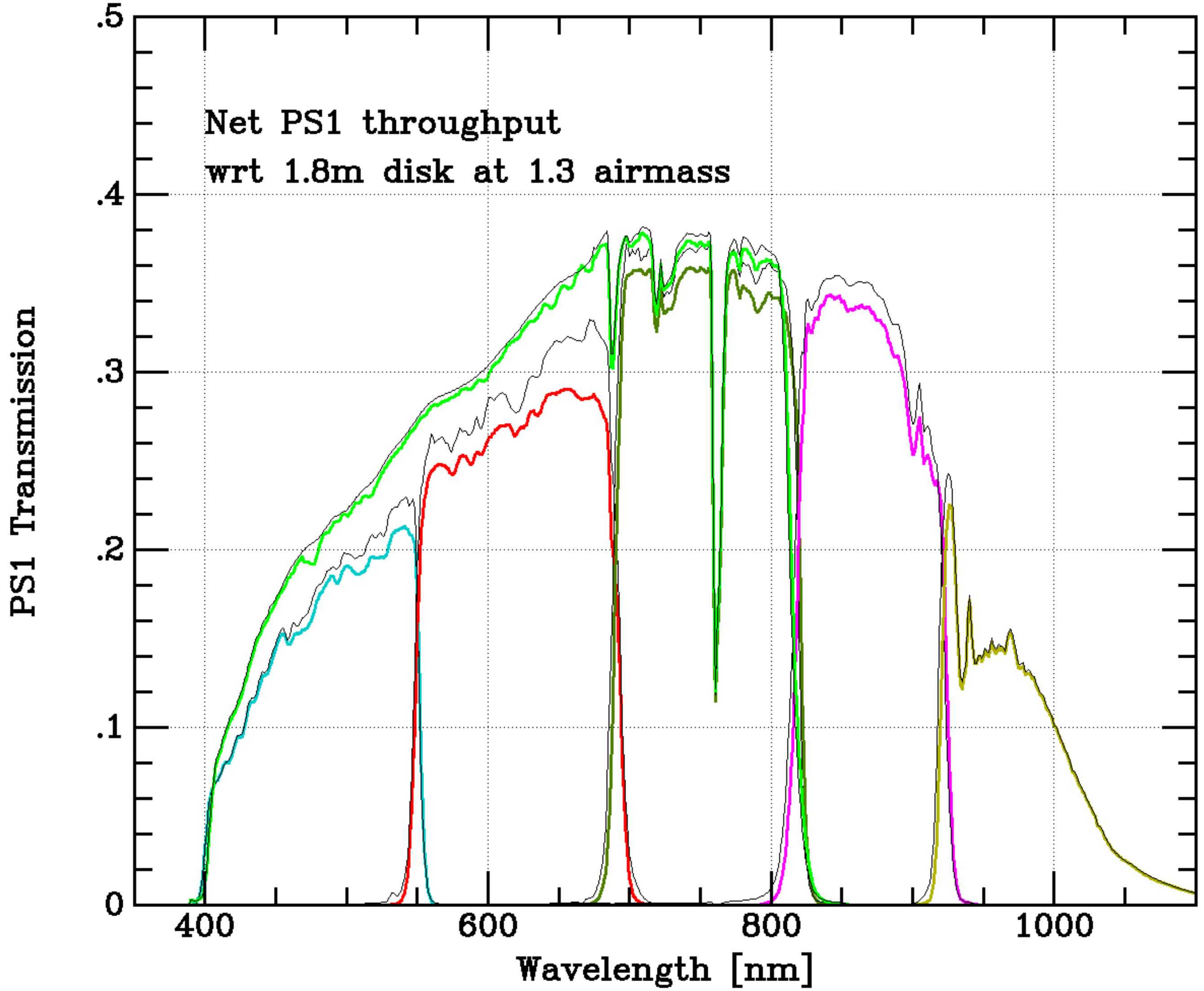
Pan-STARRS
PS1 Science Consortium

Data products eventually released to the world community.

PS1 Remote Operations Center, ATRC, Maui

PS1 Remote Operations Center, IF A ATRC, Pukalani, Maui

PS1 throughput measured with Harvard Calibration screen, NIST tunable laser, and NIST photodiodes. With atmospheric characterization the goal is 1% precision photometry.



PS1 Surveys

- **3π Steradian Survey**
  - grizy, 56% of the time, 4 visits x 5 filters per year, 60 epochs in 3 years. Changing cadence Jan 18, 2011.
- **Medium Deep**
  - grizy, 25% of the time, 8 images nightly over 50 sq deg,
  - 70 sq deg total
- **Deep survey of M31**
  - grizy, 4% of the time, 4 images separated by 3 hrs nightly
- **Stellar transit survey**
  - r, 5% of the time, 64 images nightly
- **Solar System survey: sweet spot and opposition in w**
  - 5% of the time
- **Calibration fields, including Celestial North Pole**
  - grizy, 2% of the time

PS1 Key Science Areas

- Populations of objects in the Inner Solar System
- Populations of objects in the Outer Solar System
- Low-Mass Stars, Brown Dwarfs, and Young Stellar Objects
- Search for Exo-Planets by dedicated Stellar Transit Surveys
- Structure of the Milky Way and the Local Group
- A Dedicated Deep Survey of M31
- Massive Stars and Supernovae Progenitors
- Cosmology Investigations with Variables and Explosive Transients
- Galaxy Properties
- Active Galactic Nuclei and High Redshift Quasars
- Cosmological Lensing
- Large Scale Structure

PS1 New Science – everything else, new ideas,

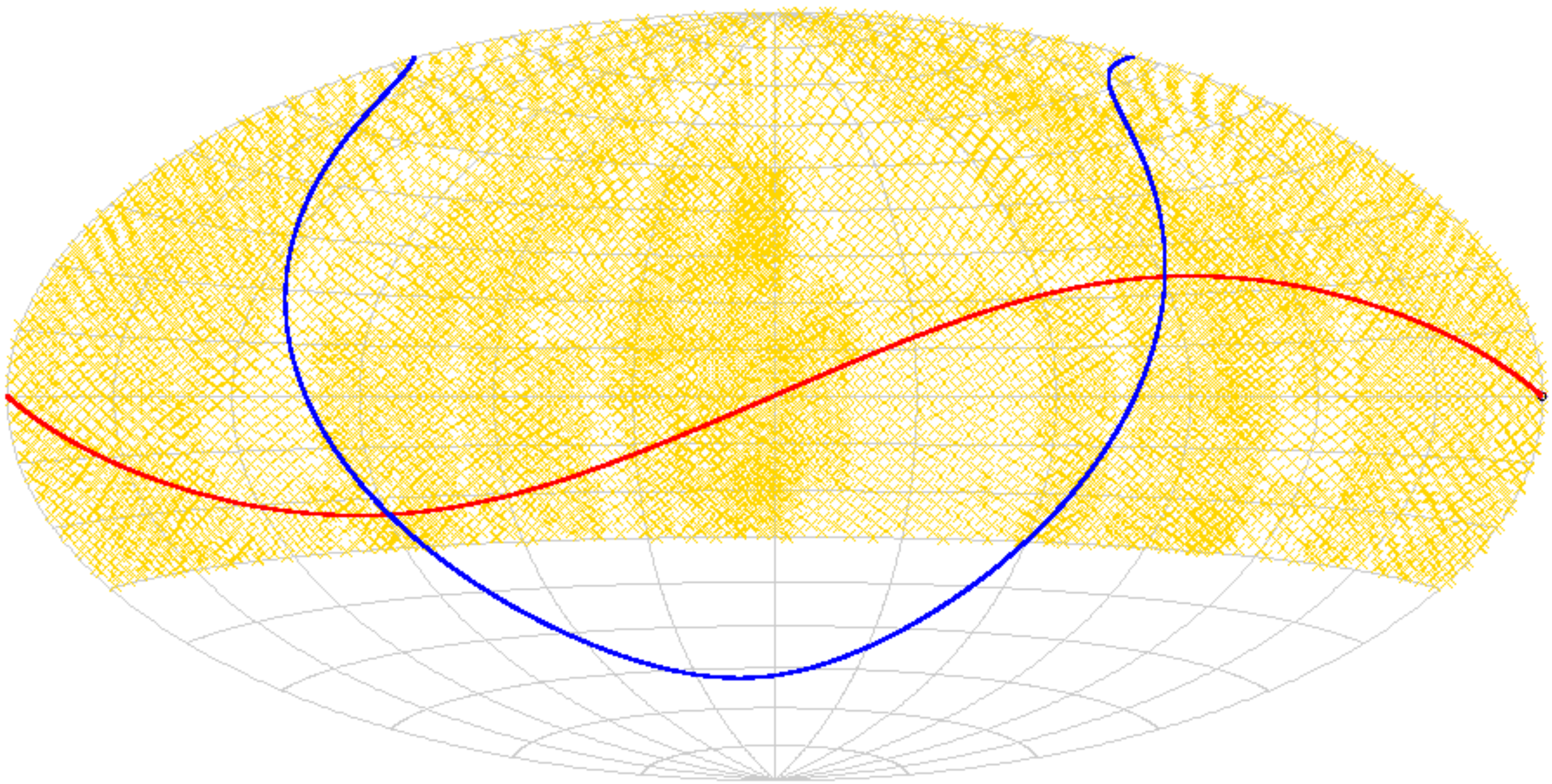
serendipitous discoveries

PS1 Surveys

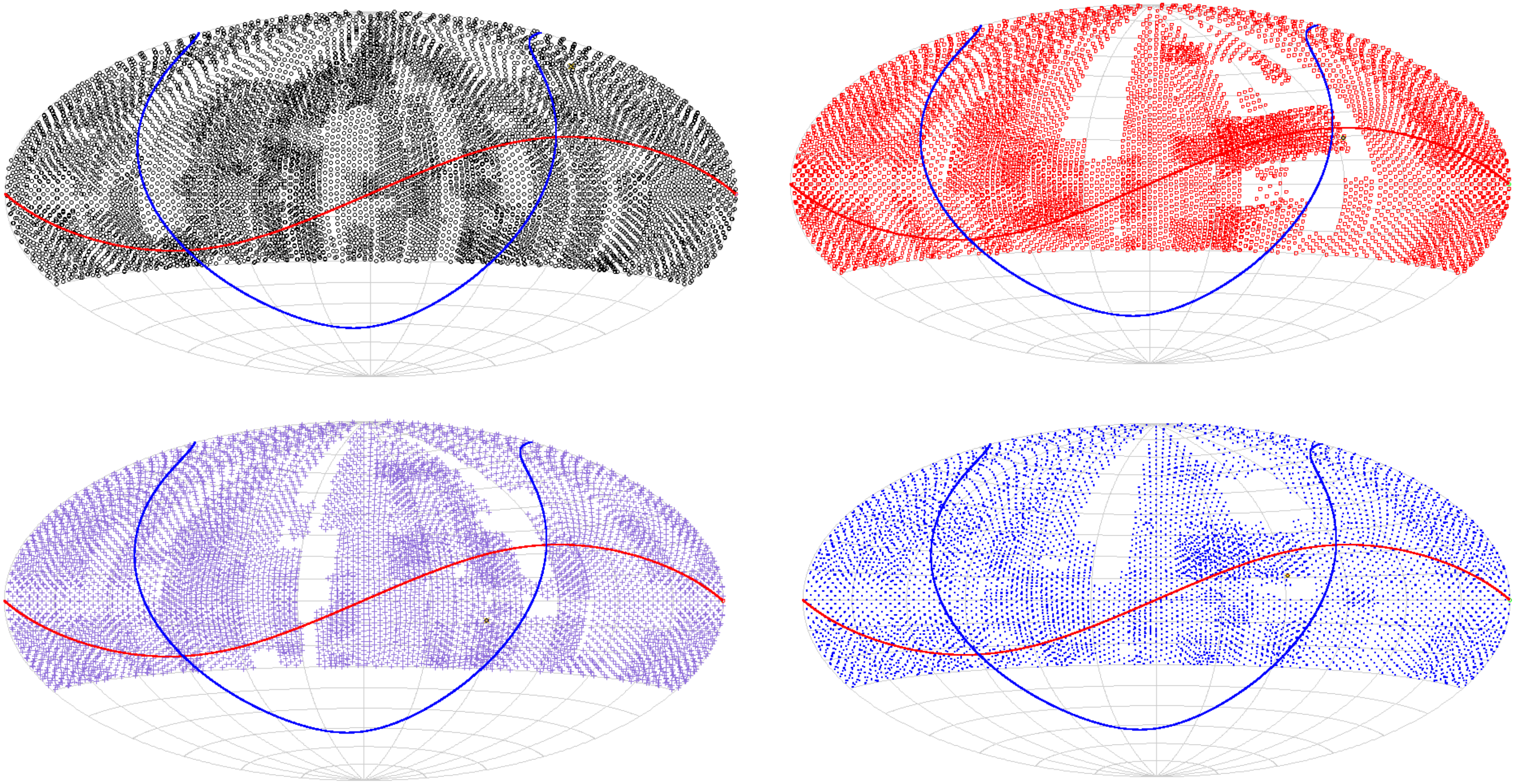
Table 2: *The PS1 Mission Concept Surveys and time distribution.*

PS1 Surveys	Filters	Percent time
3 π Steradian Survey	g, r, i, z, y	56
Calibration Fields	g, r, i, z, y	2
Medium Deep Survey	g, r, i, z, y	25
Solar System "Sweet Spot" Survey	r	5
Stellar Transit Survey -"PanPlanets"	i	4
Microlensing in M31 "Pandromeda" Survey	g, r, i, z, y	2
Principal Investigator Discretionary Time		6

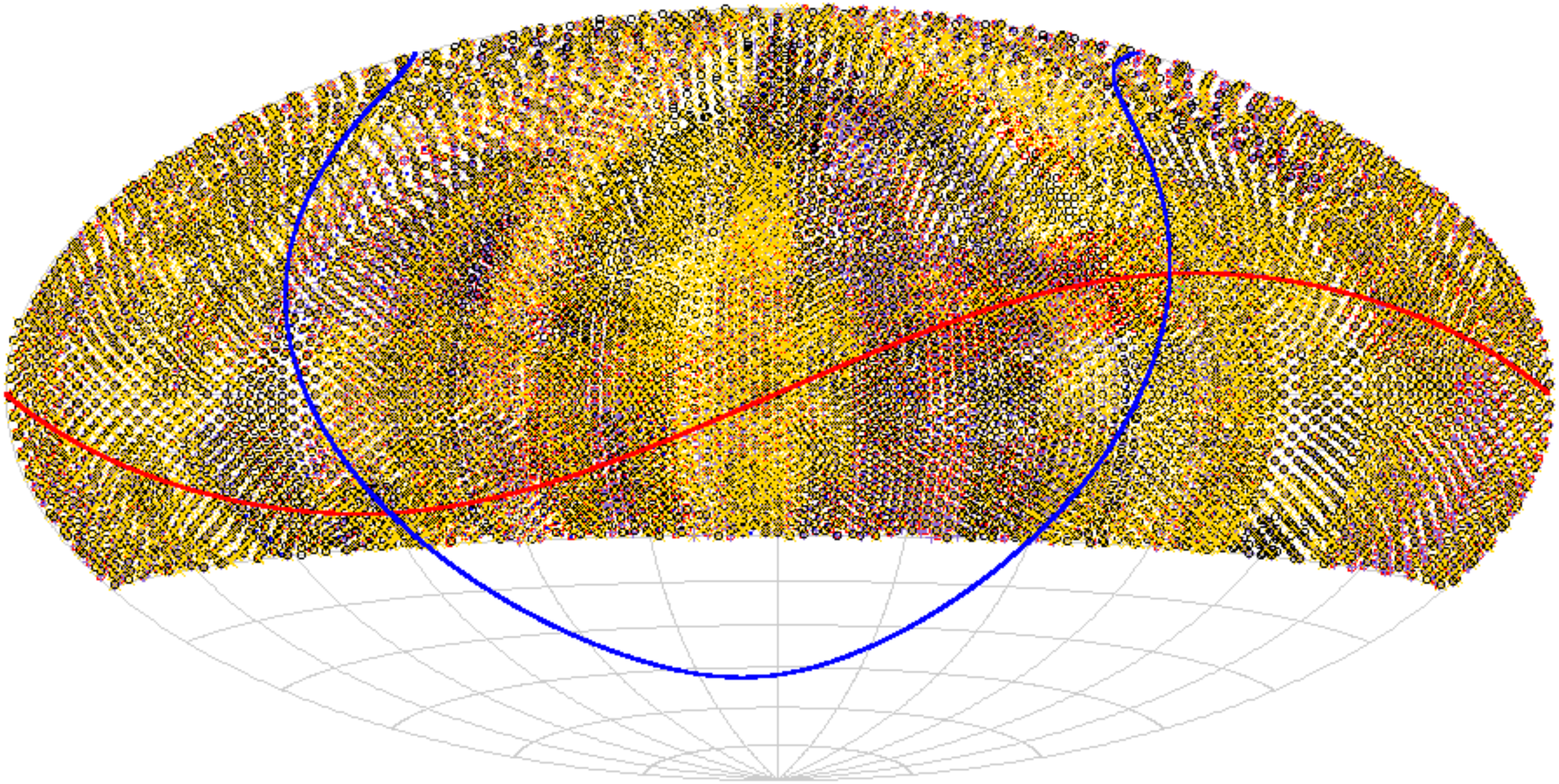
PS1 y-band – first 1 micron image of the sky



PS1 z, i, r, g band coverage 2011-02-14



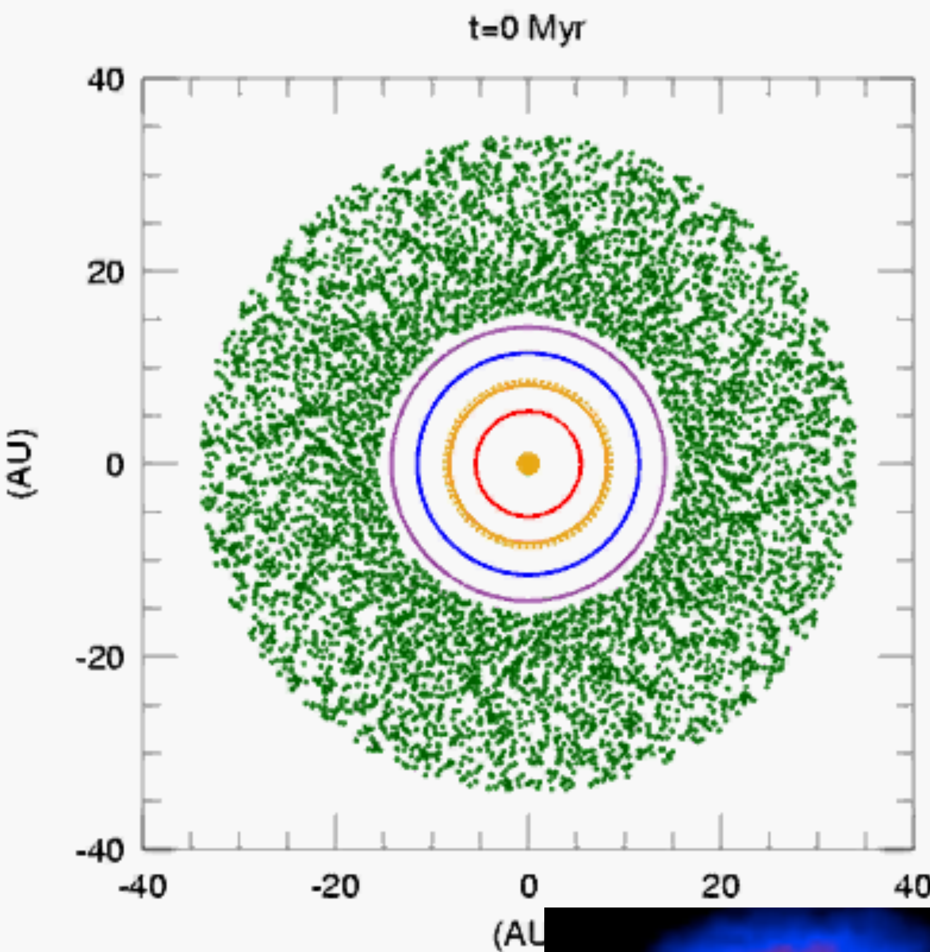
PS1 3pi survey – 15 to 20 images in five bands, building astrometric catalog for re-processing

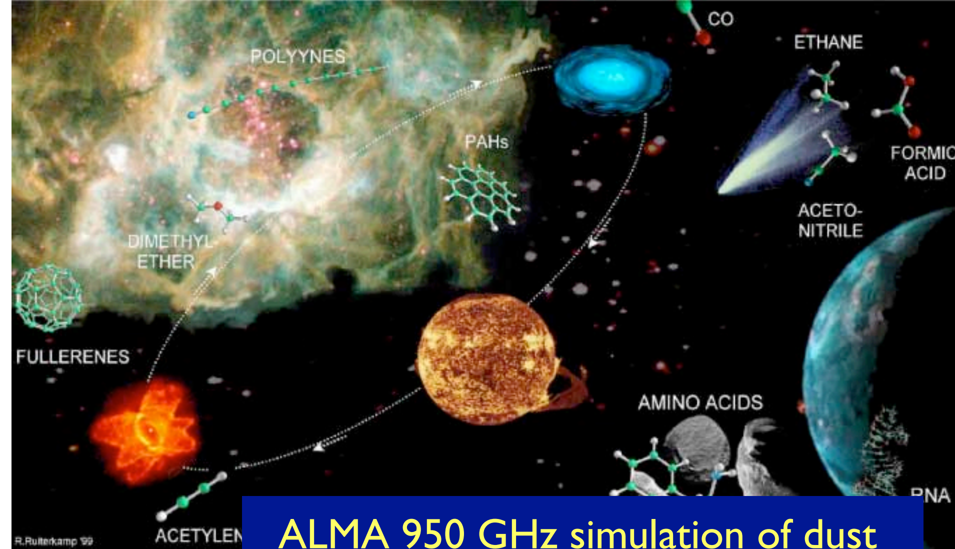


PS1 Early Science: Census of the Solar System

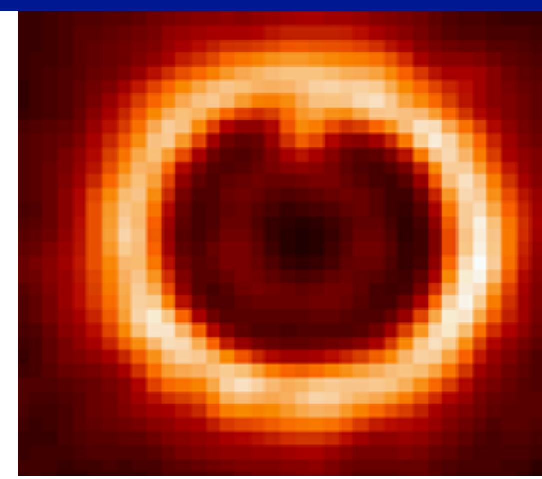
- Inner Solar System (Jedike, Denneau, Wainscoat)
  - 40 new Near Earth Objects discovered
  - 9 Potentially Hazardous Object
  - 2 Comets
  - 1000 Main Belt Asteroids
  - > 500,000 detections submitted to MPC of numbered and unnumbered asteroids
- Outer Solar System (Holman et. al)
  - 10 Kuiper Belt Objects (300- 500 km in size)

- Current discovery rates with modified survey strategy
- ~ 300 to 500 NEO per year (depends on followup vs self-recovery)
- ~350 KBO's per year
- ~1 interstellar comet in 10 years – pristine material from another solar system.

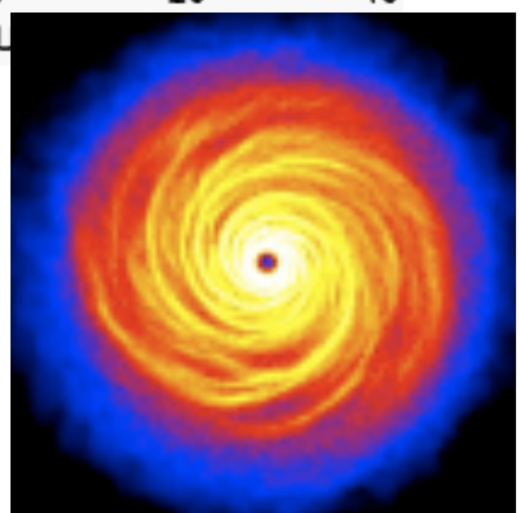




ALMA 950 GHz simulation of dust from forming protoplanet at 100 pc (Wolf & D'Angelo)



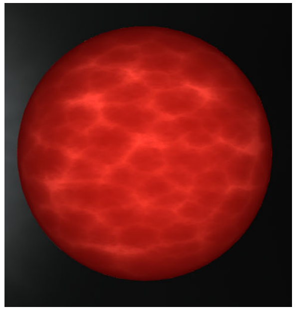
Synergy with RMS



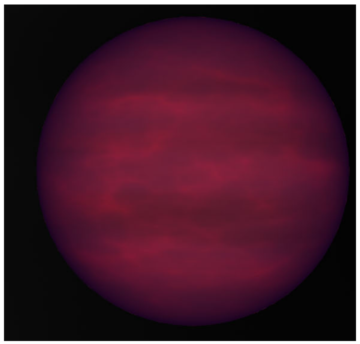
ALMA 345 GHz simulation of dust opacity in a face-on circumstellar disk at 50 pc (Cossins et al. 2010)

Ultracold brown dwarfs
the link to giant planets

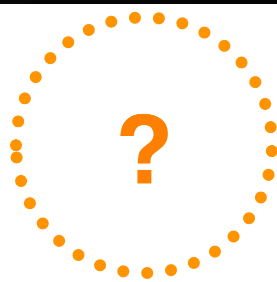
L dwarf
~1700 K



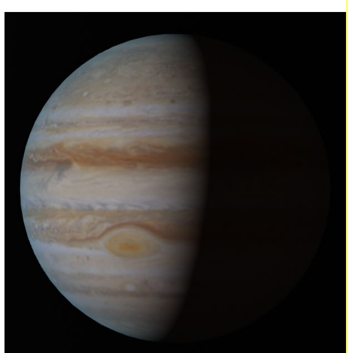
T dwarf
~800 K



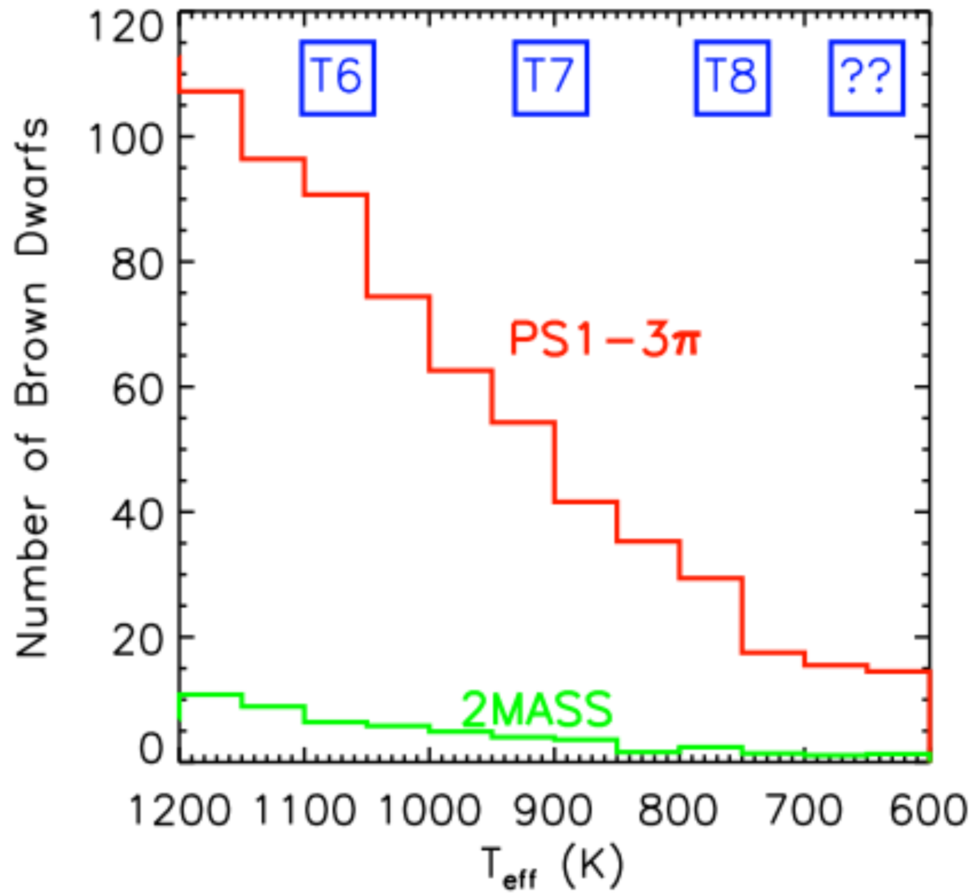
Y dwarf
~600 K?



Jupiter
~150 K

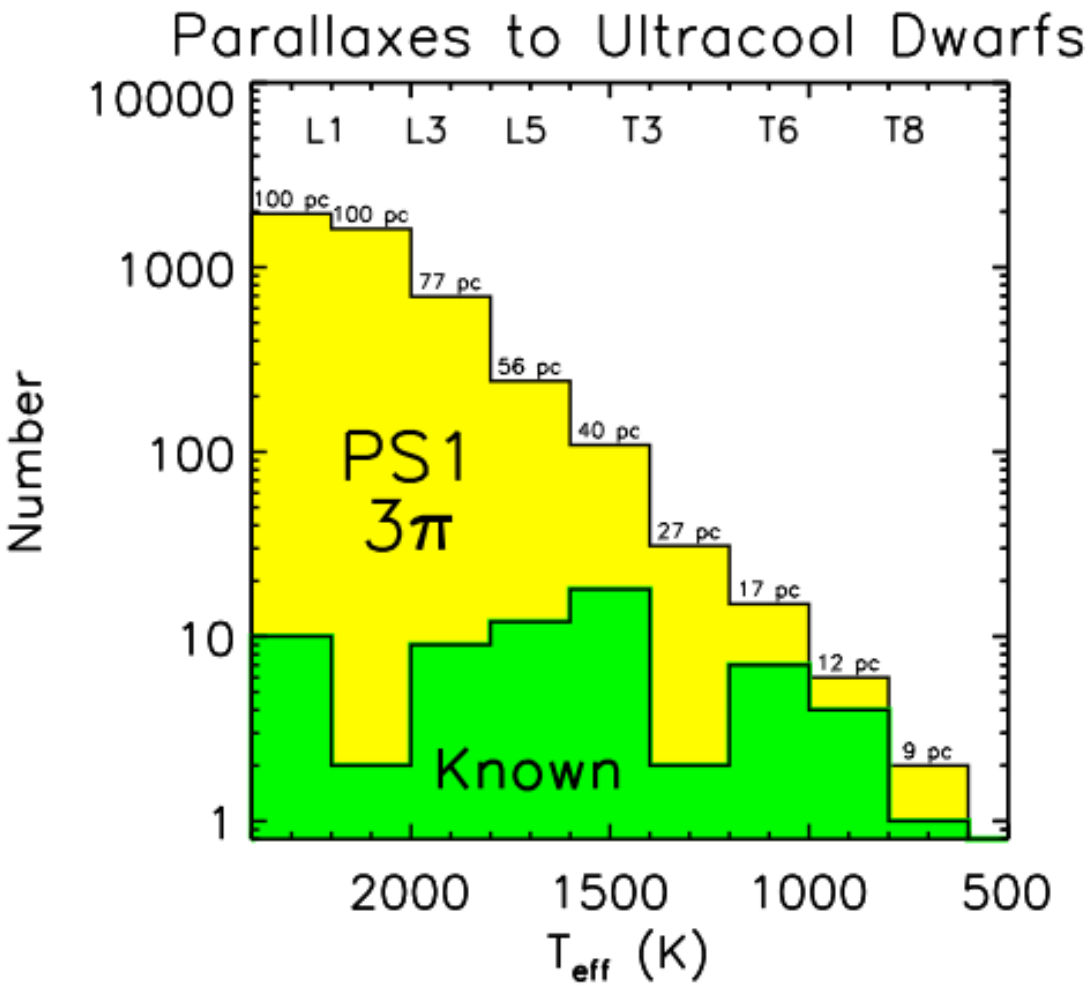


- PS1 covers **~10x greater volume** than 2MASS for finding T/Y dwarfs.



Towards a Complete Low-Mass Census

All-sky parallaxes will be a fundamental leap forward.

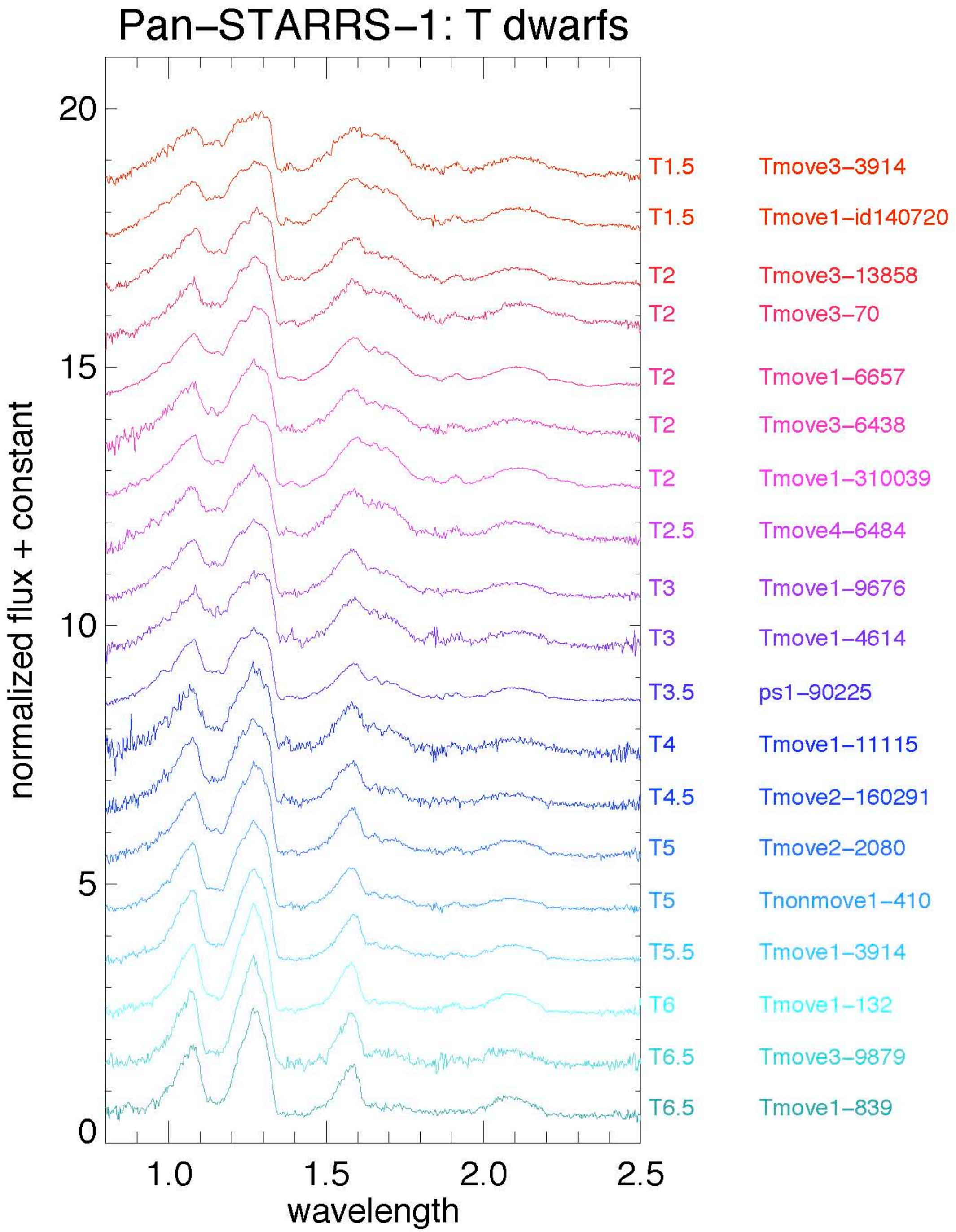


- PS1 will provide **first all-sky parallax catalog of faint objects.**
- ~60x gain over present, and could discover unanticipated low-luminosity objects.
- M2 – L0
  - >100,000 objects to ~100pc
- L0 – L3
  - ~3,000 objects to ~90pc
- L3 – L5
  - ~400 objects to ~75pc
- L5 – T3
  - ~250 objects to ~40pc

PS1 Early Scienc
Brown Dwarfs

- 2 sub L dwarfs
- 2 late M/early L dwarfs
- 2 L dwarfs
- 20 T dwarfs
  up to T6.5

(Liu, Magnier, Goldman, et al).



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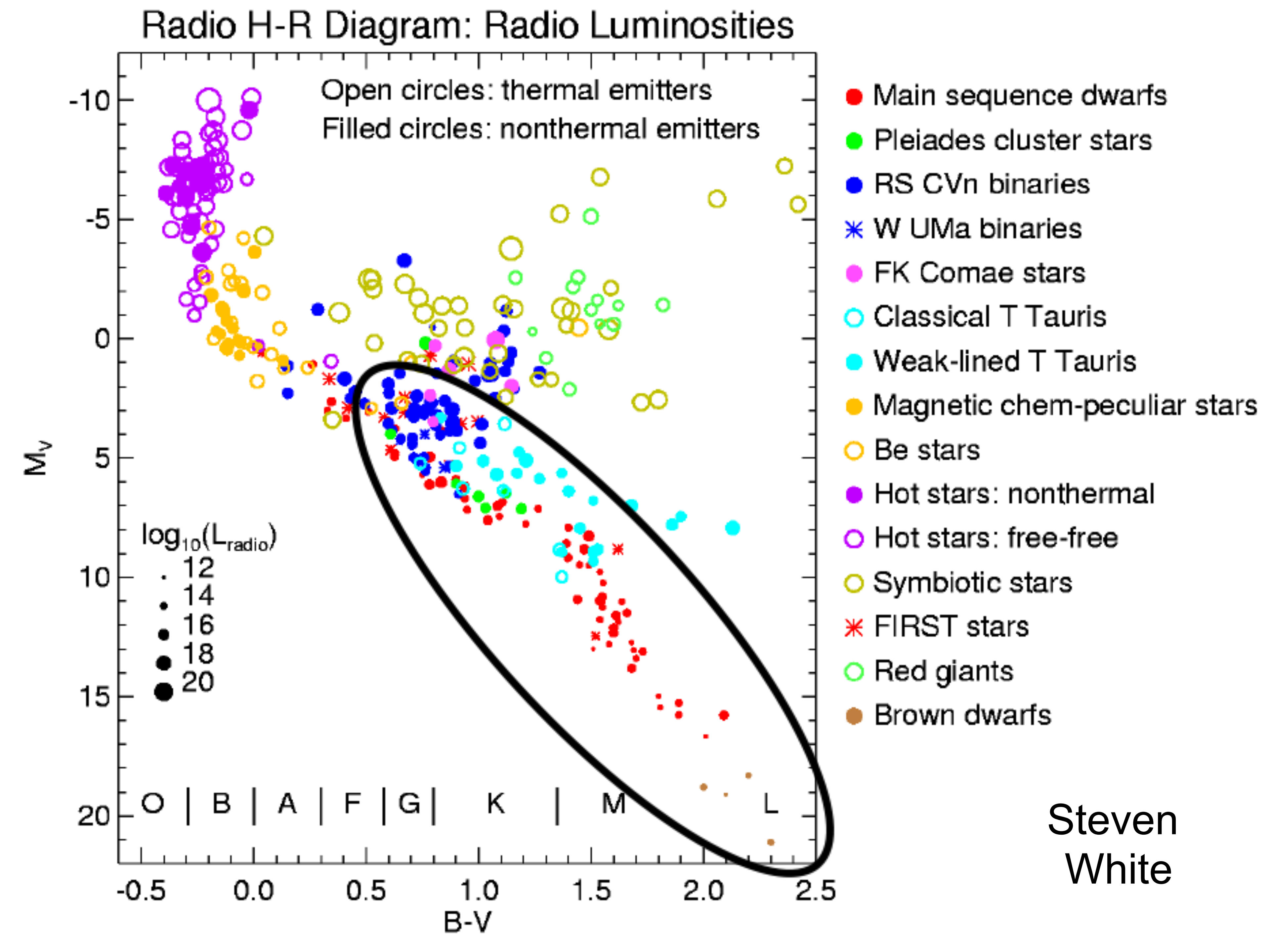
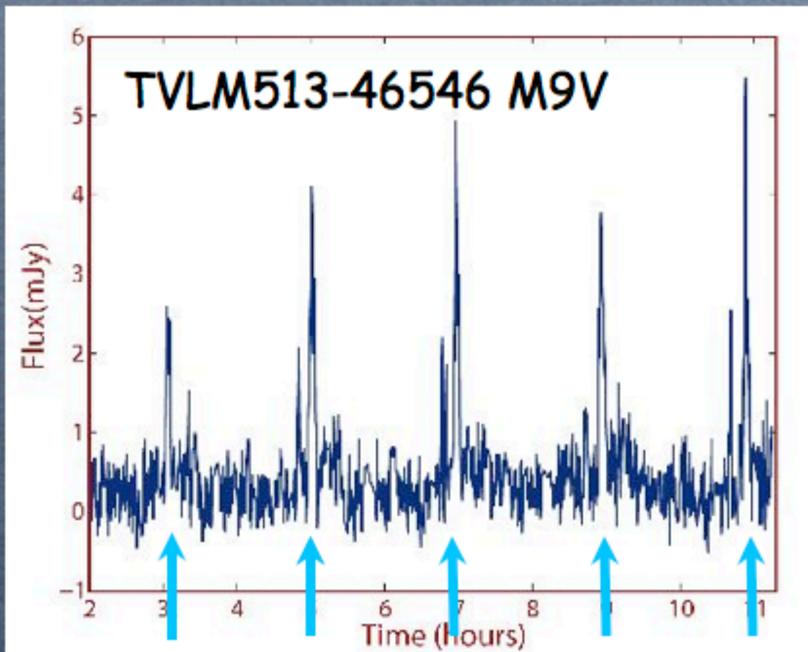


Steven White

Magnetic structures are seen on substellar objects -- ultracool dwarfs (UCDs)

Slide From Rachel Osten



0.1 M_{sun}, 0.1 R_{sun} star with P_{rot} ~ 2 hours, showing pulsating radio bursts

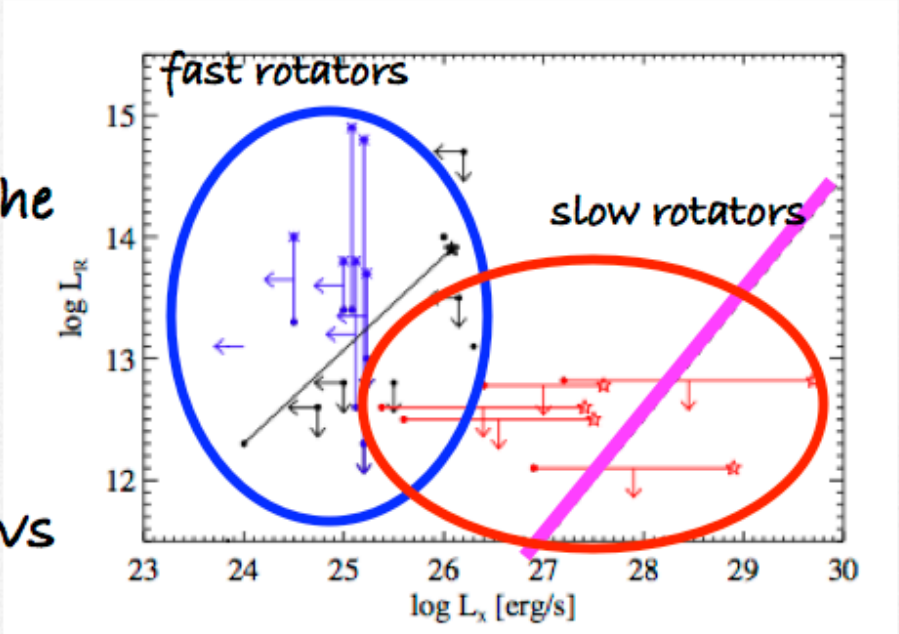
magnetic field of strength 3 kG produces maser emission at 8.4 GHz = 3.6 cm

Hallinan et al. 2007

brown dwarf is behaving more like a planet than a star

multi-wavelength behavior of UCDs

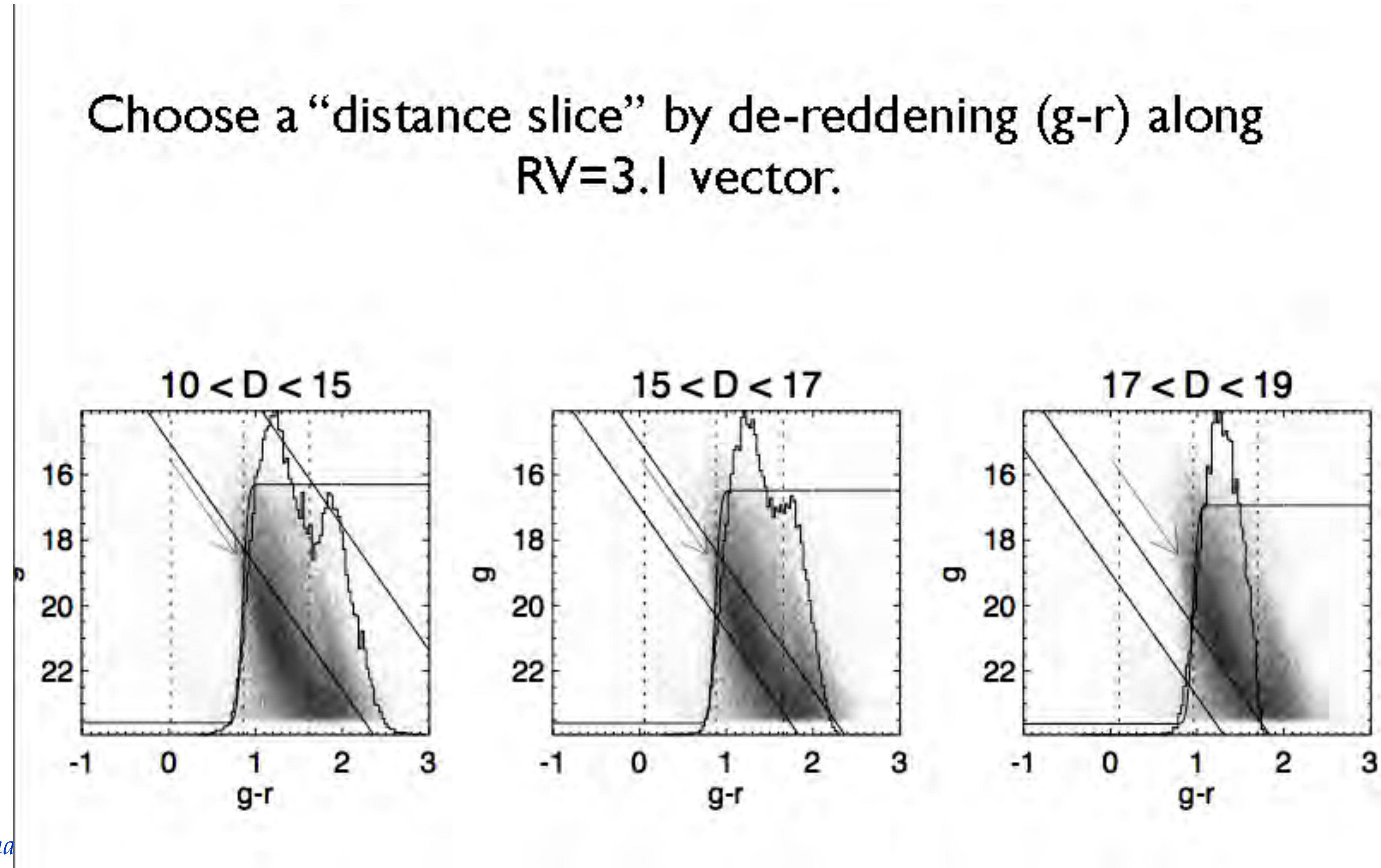
- UCDs display a "violation" of the Güdel-Benz relation held by most active stars & solar flares
- dichotomy of radio- and X-ray emitting UCDs: ``radio-loud" vs ``X-ray-loud"
- why do only ~10% show radio emission?
- possible importance of beaming, field geometries



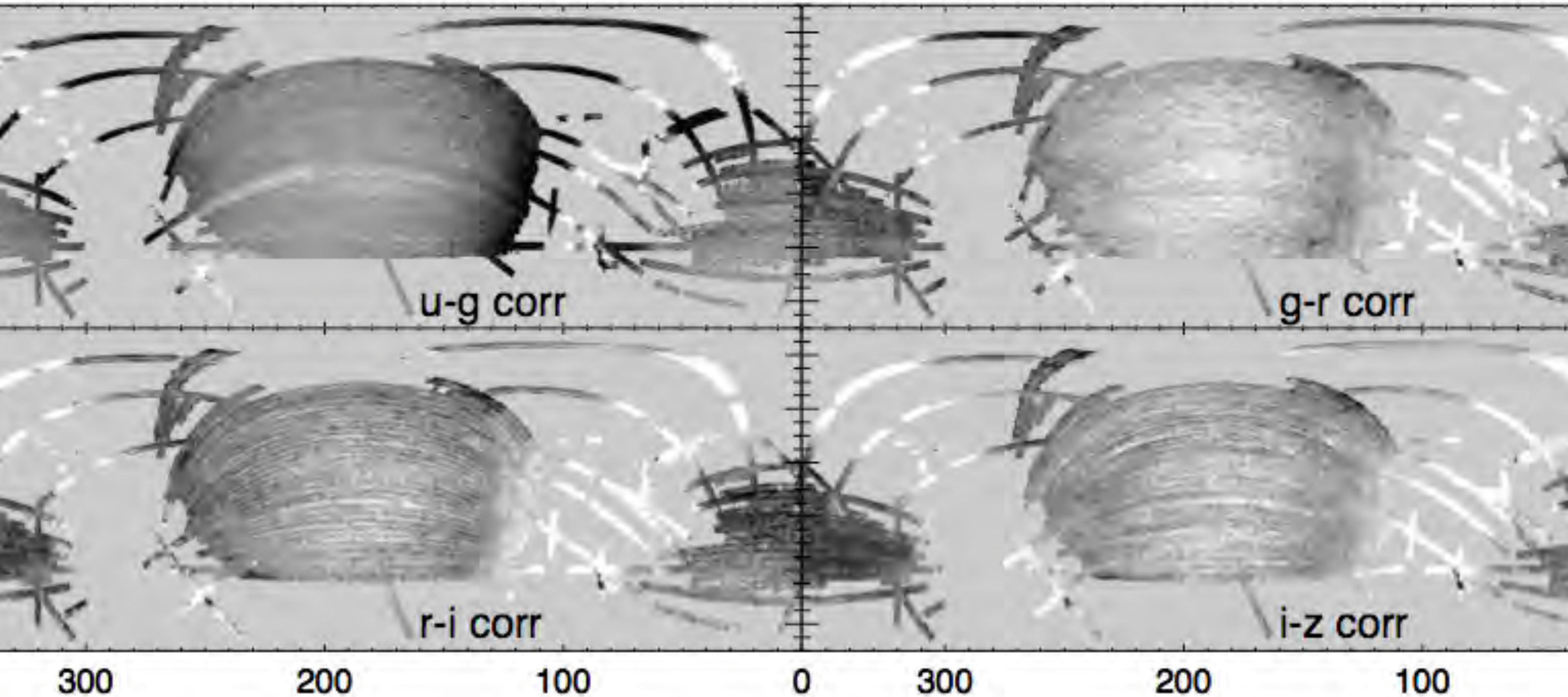
radio and X-ray variability common feature; small number have quiescent detections at both bands

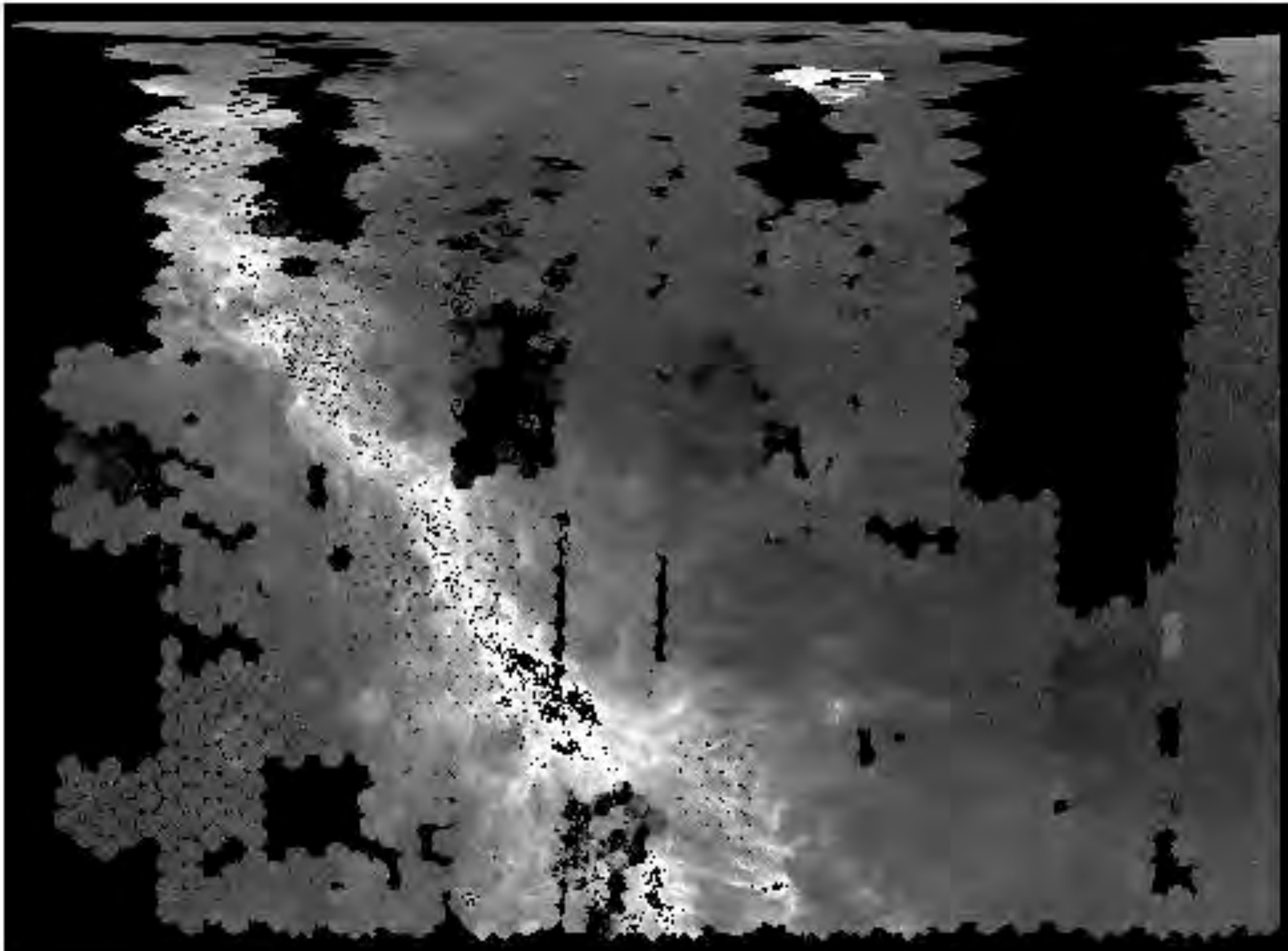
PS1 Early Science:

- Mapping the Dust in the Galaxy and eventual 3-D dust map (Finkbeiner & Schafly et al.) Use procedure of SFD:

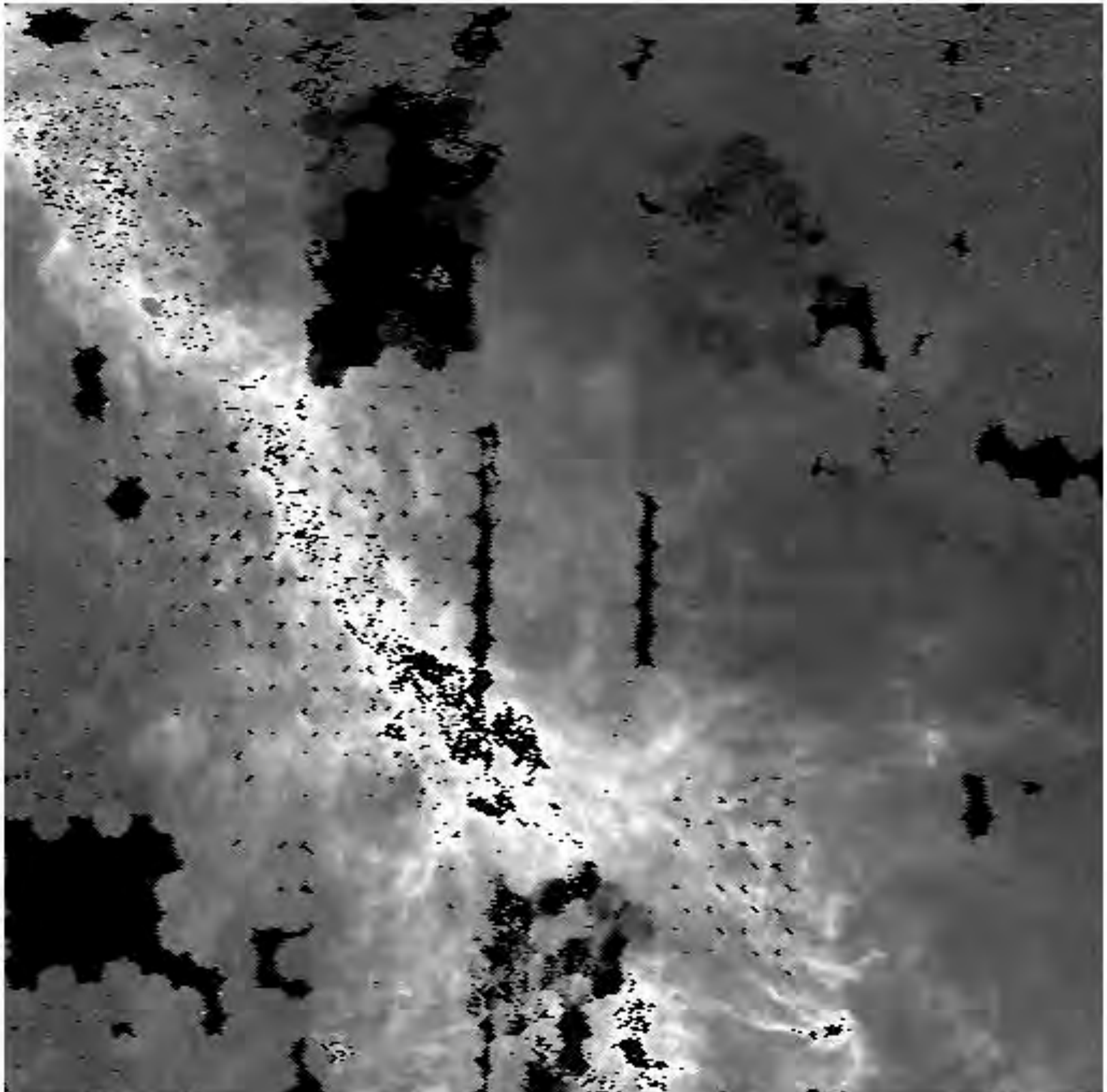


Thick disk is redder in (u-g), bluer otherwise.
Can see calibration systematics!!!





PS1 bluetip (g-r) *preliminary – no calibration*

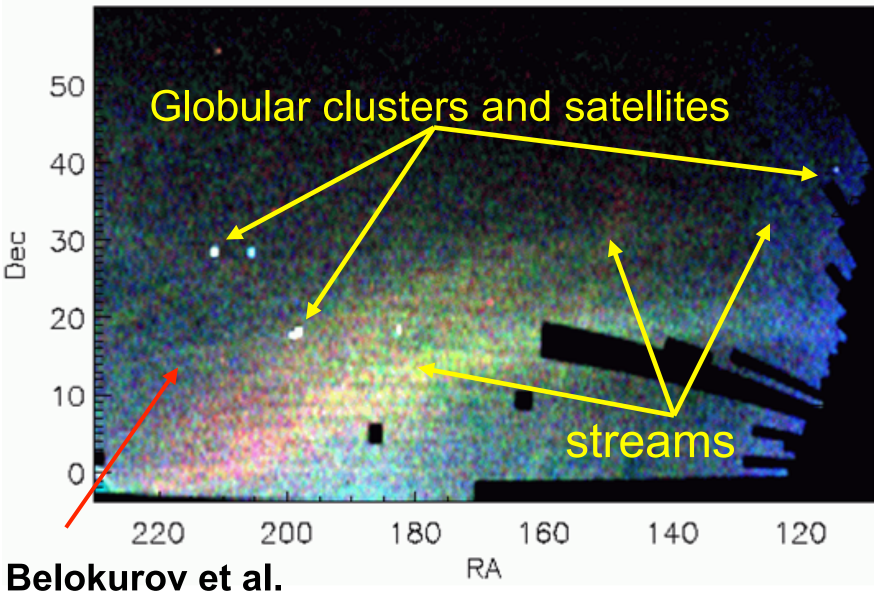


Structure of the Milky Way and Local Group

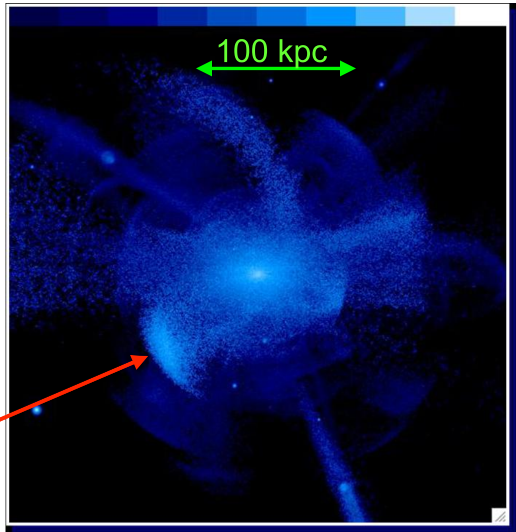
- Goal: 3-dimensional/5-dimensional structural/ kinematic map of the Milky Way and the Local group
  - Complete census of satellites and streams within 1Mpc
  - Quantify the traditional smooth components (thin and thick disks; halo)
  - Make a kinematic map of the 1kpc around the Sun

- Compare these maps with cosmological predictions

- Require primarily 3pi survey catalogues and proper motions



Belokurov et al. 2006 with the SDSS
Color – distance of main sequence turn-off stars
Brightness – density on sky

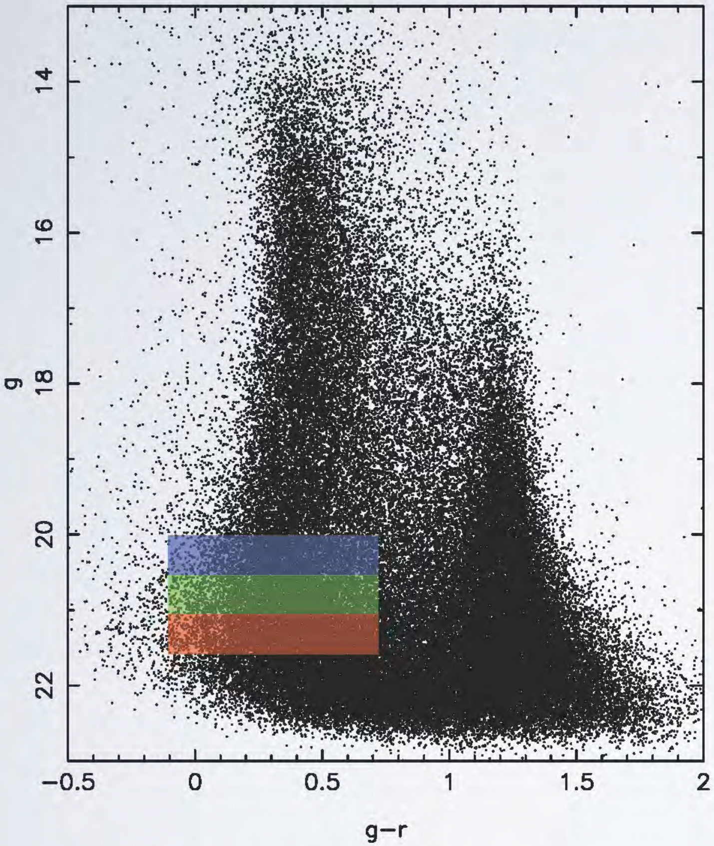


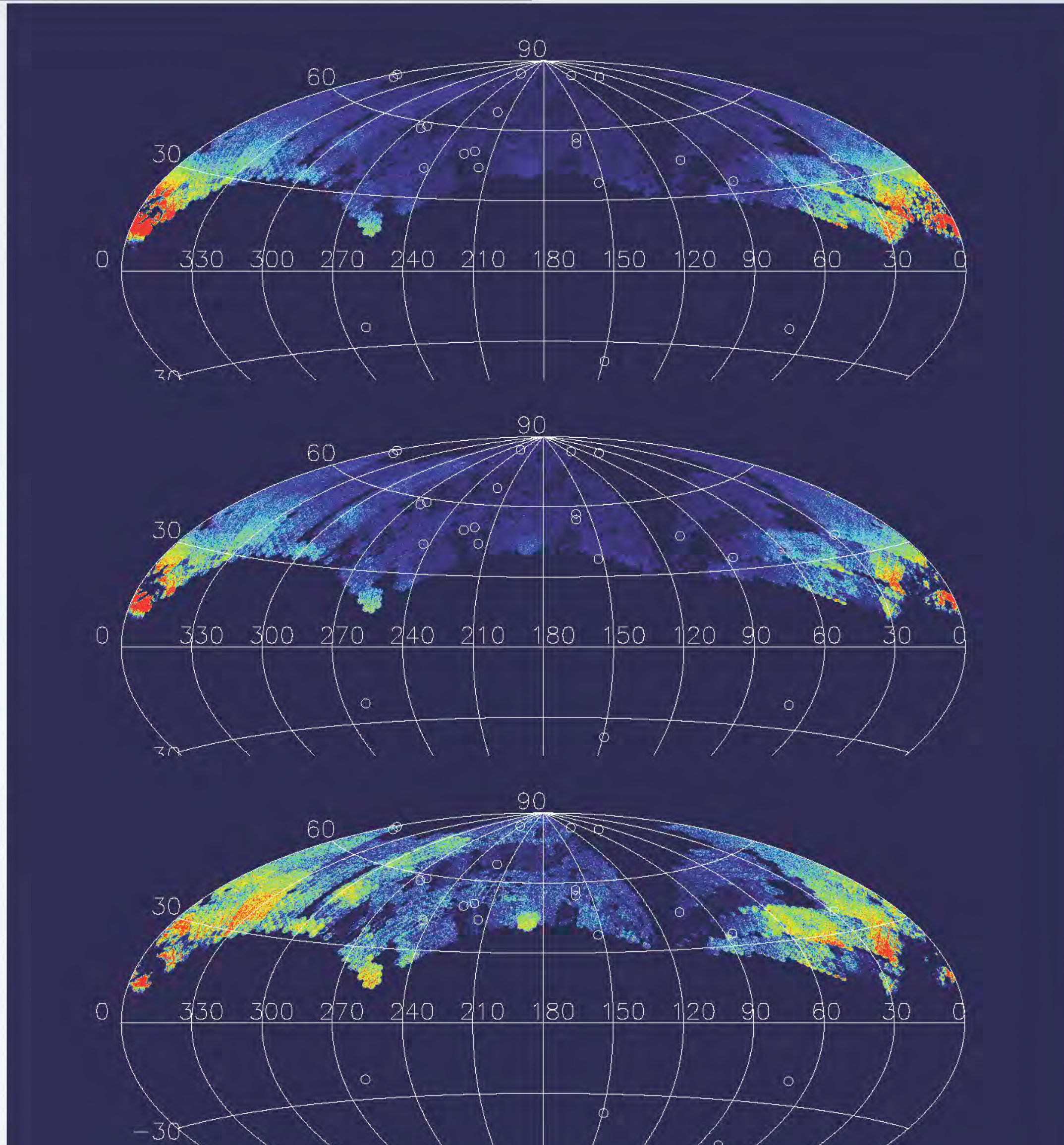
Bullock & Johnston 2005 cosmological predictions of a Milky Way stellar halo

Early PS1 Science

- Structure in the Milk Way, Martin et al.

The PS1 view



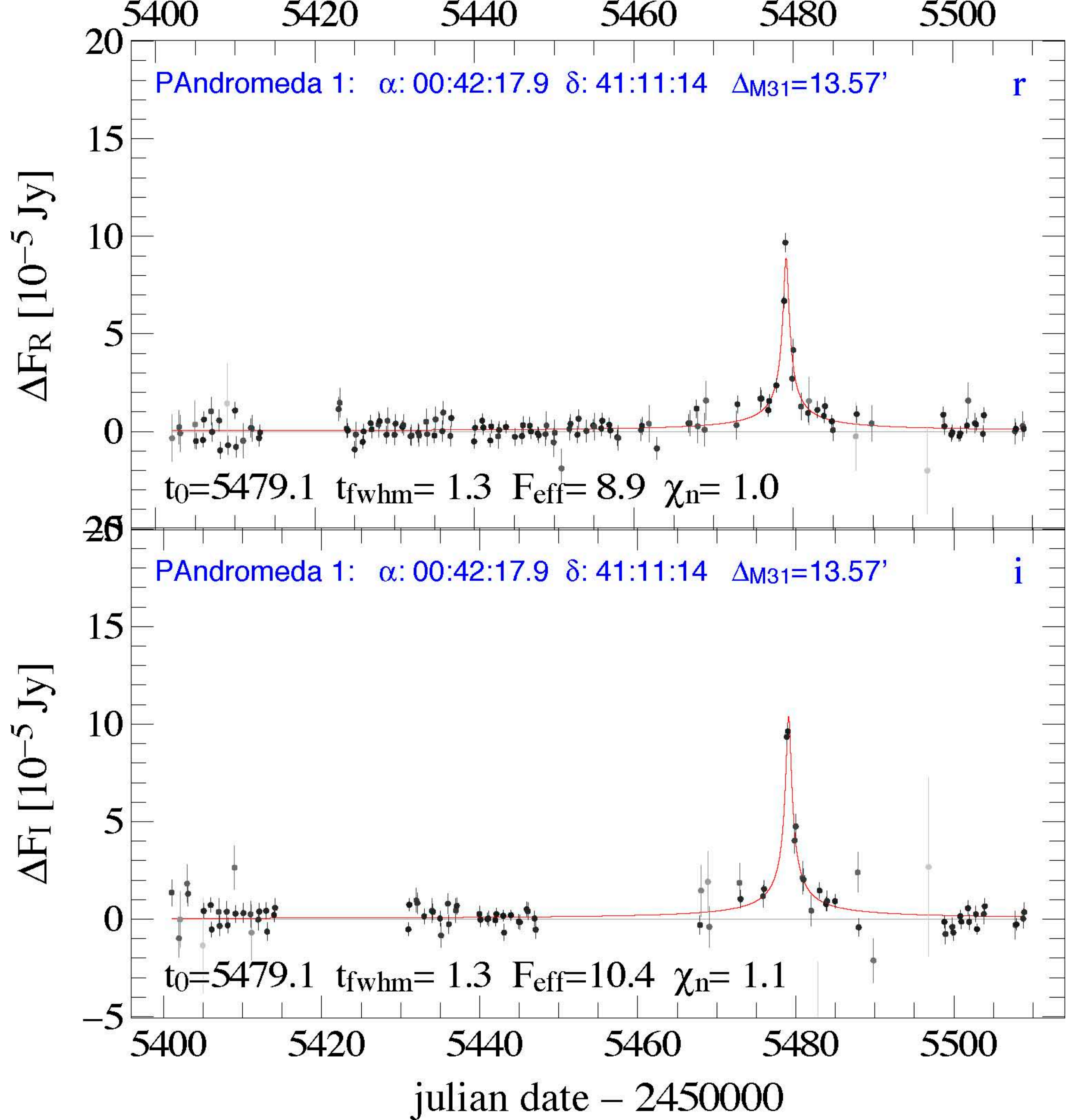


- zero point issue?
- data quality issue?

Early PS1 Science: M31

- Microlensing events in M31

(Bender et al.)



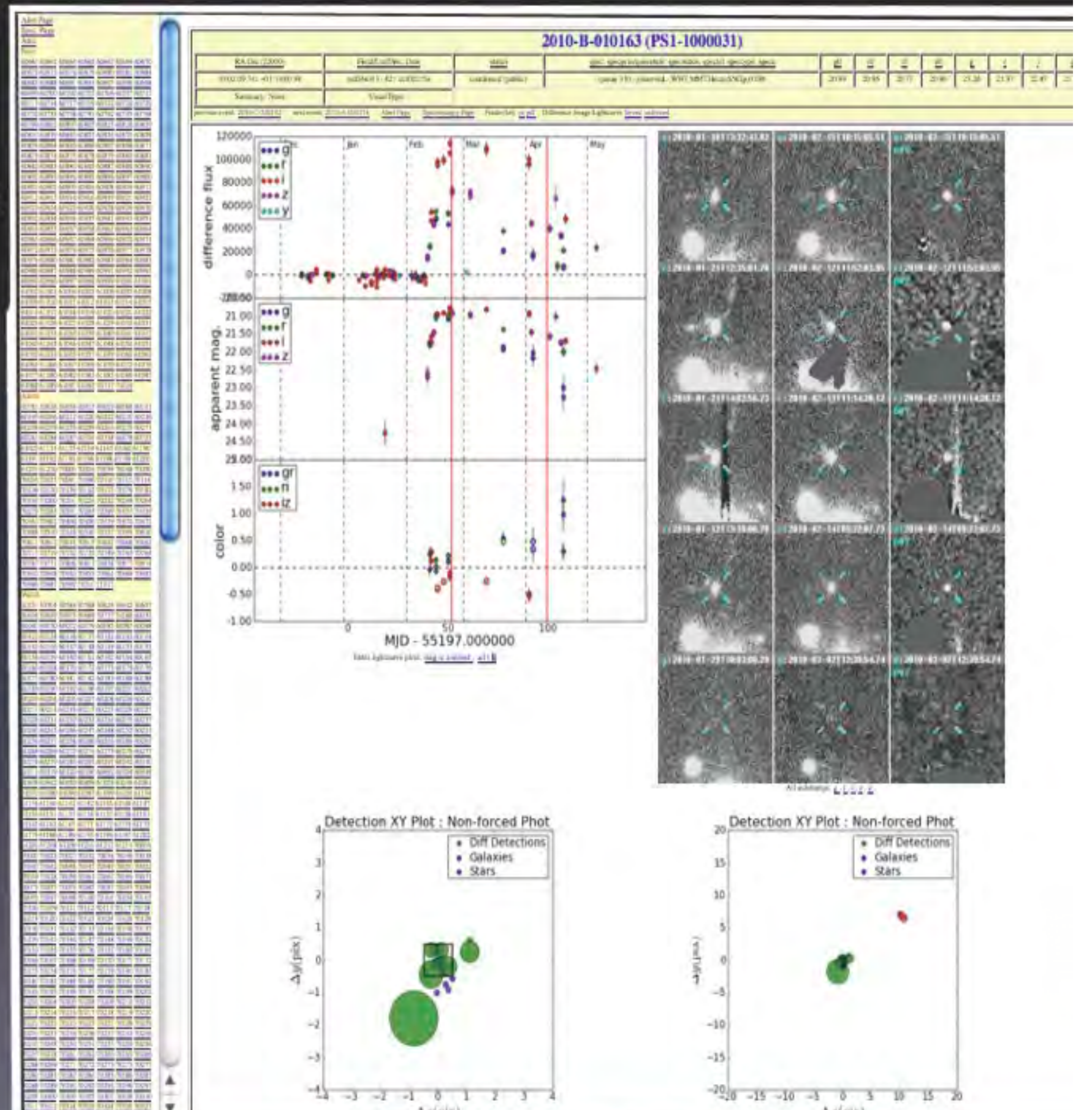
Ken Chambers

PS1 Early Science: Transients

• Rest, Huber, Smartt et al

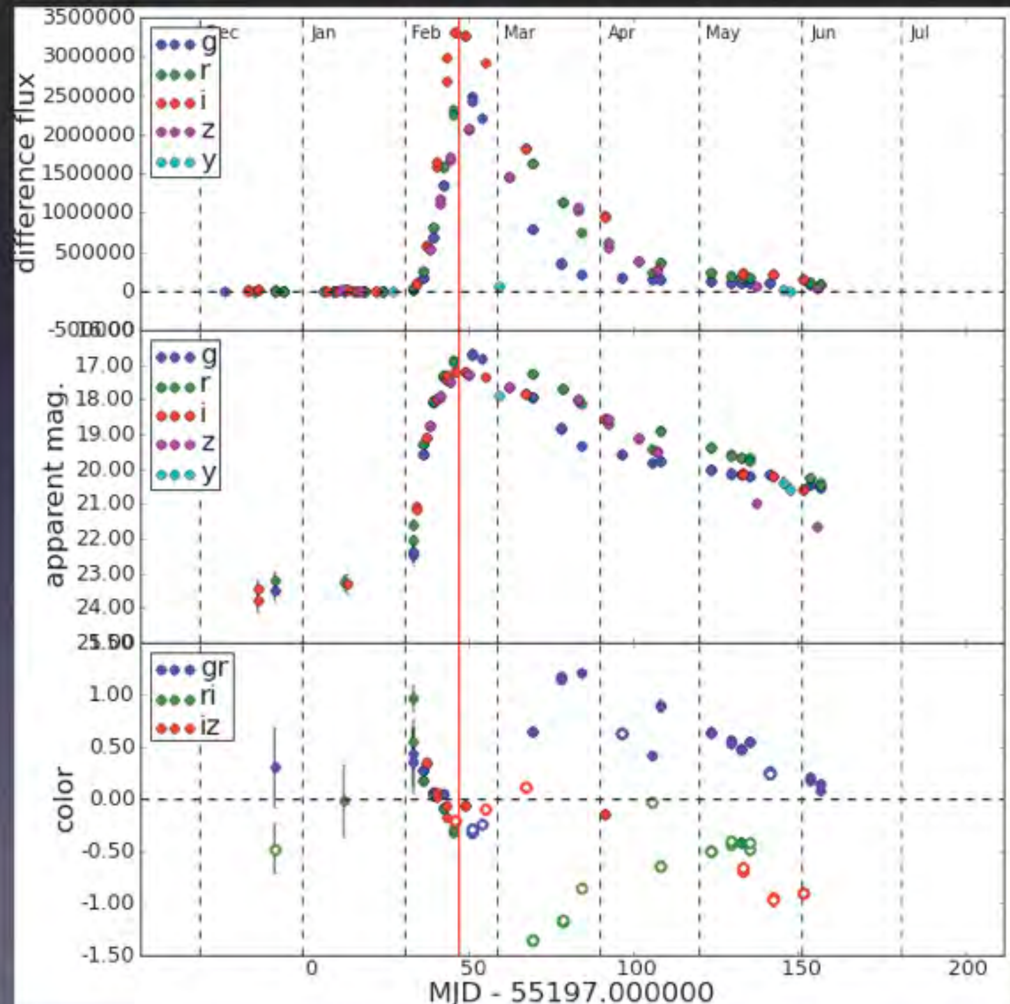
Event Page

- Full Difflm stamps gallery
- Full table and light curve files directly available (flatfiles) via web
- Follow-up queue, finders, and archive



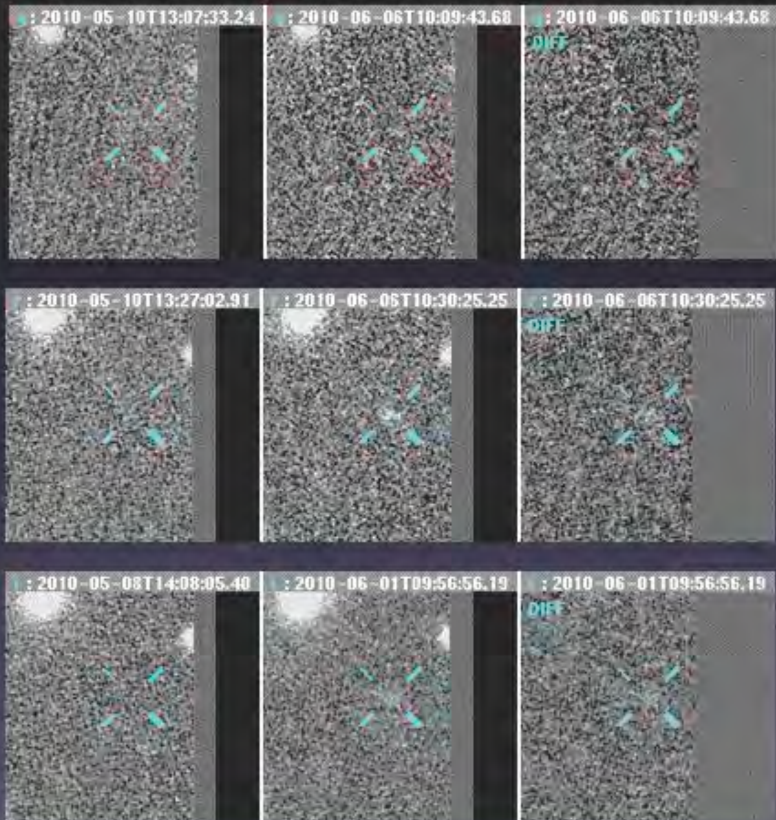
http://telescopes.rc.fas.harvard.edu/ps1/alerts2010/2010-B-010163/2010-B-010163.html

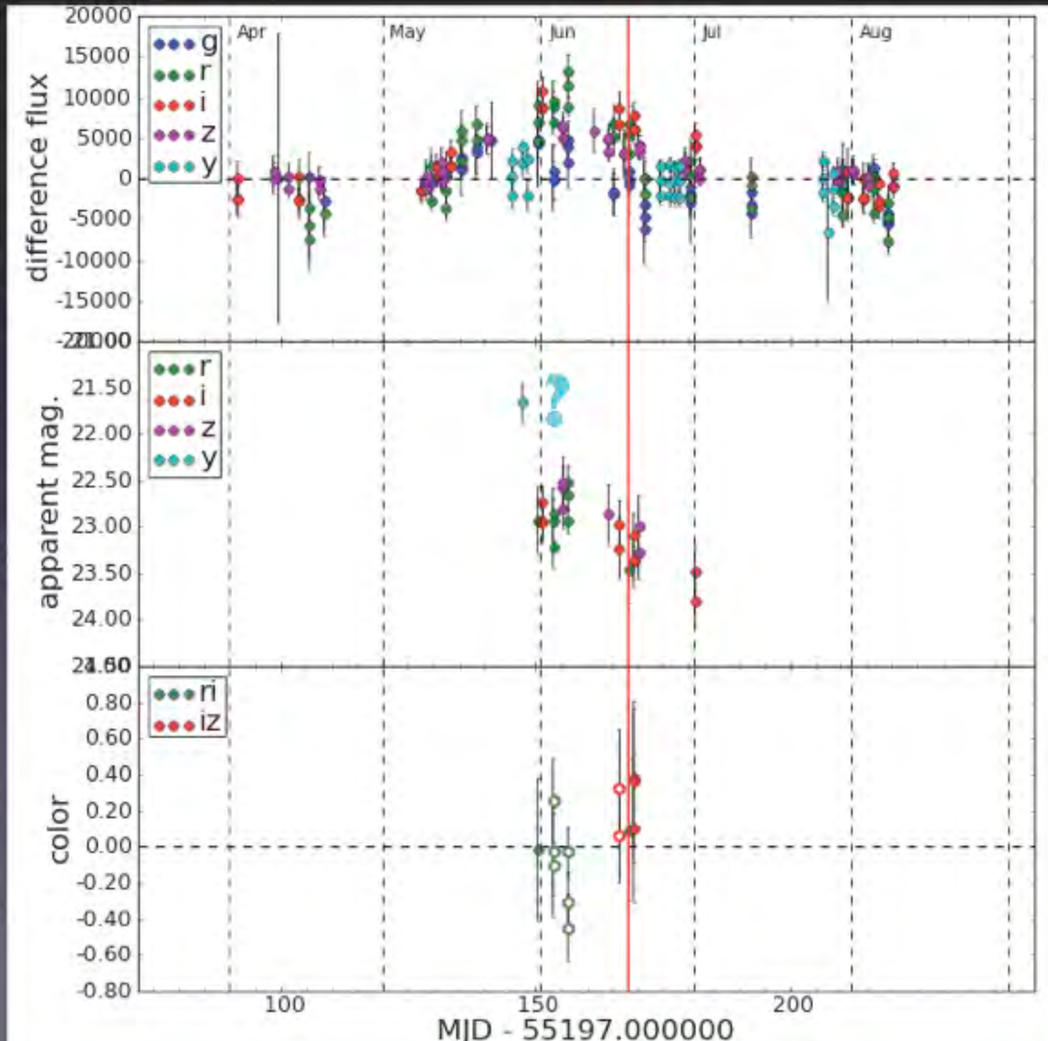
PS1-1000023 SNIa @ z~0.031



- 2010-B-010026, on 20100213 in MD05

PS1-1000287 SNIa @ z~0.576

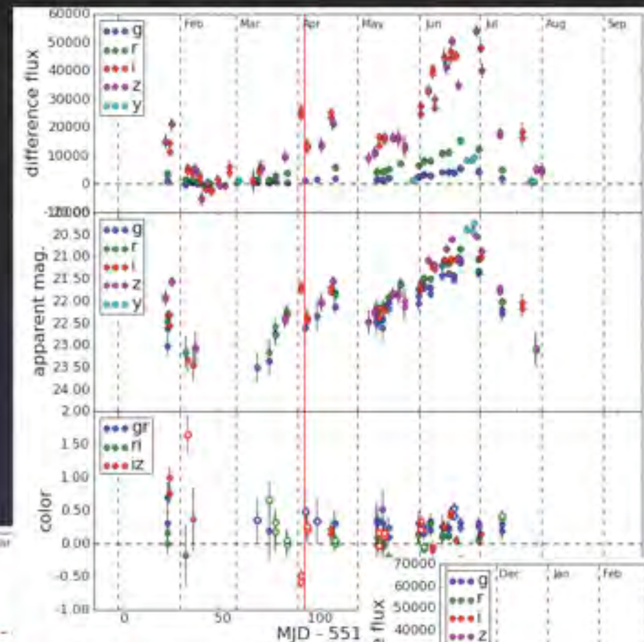


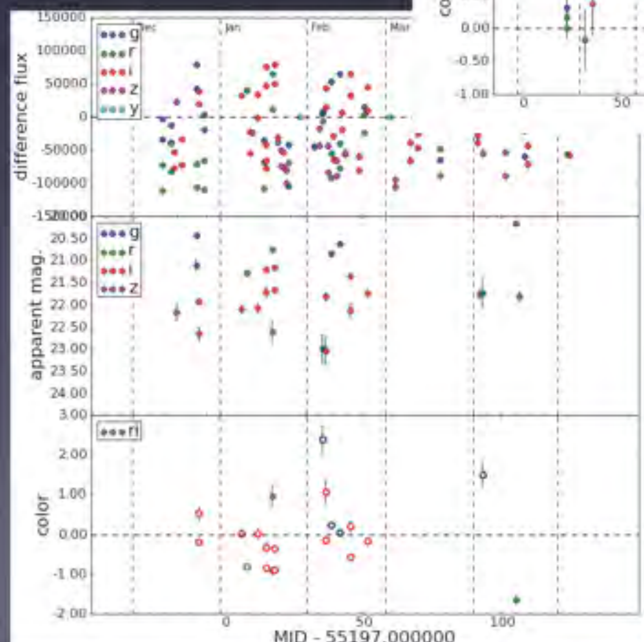


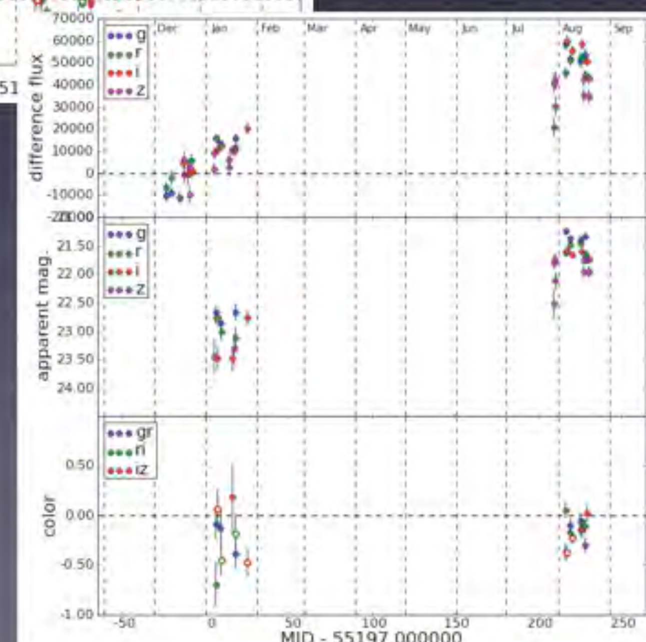
- 2010-F-050203, on 20100116 in MD04

Sample of Events - Others

- AGN/QSO?
- RR Lyr?
- faint variables?
- movers?

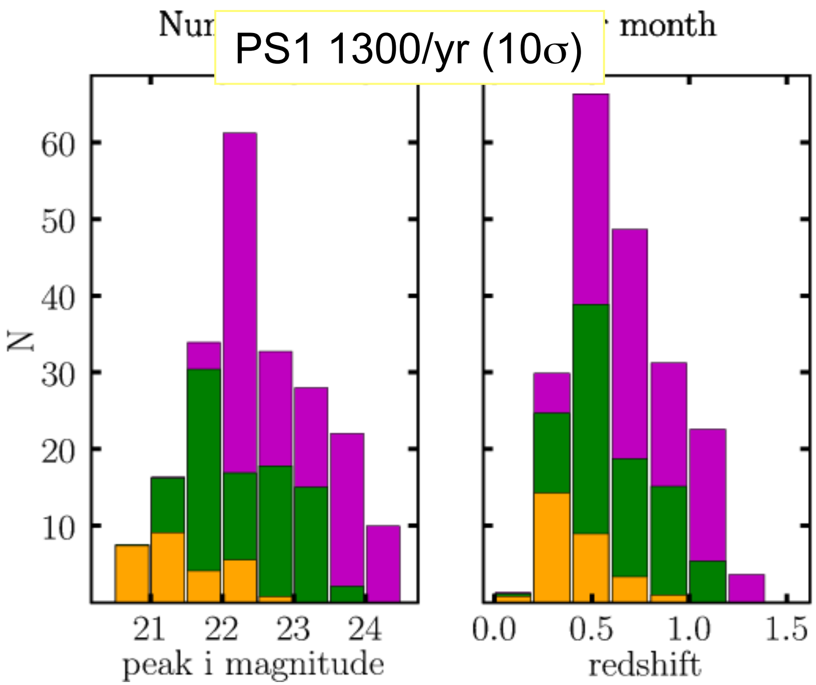


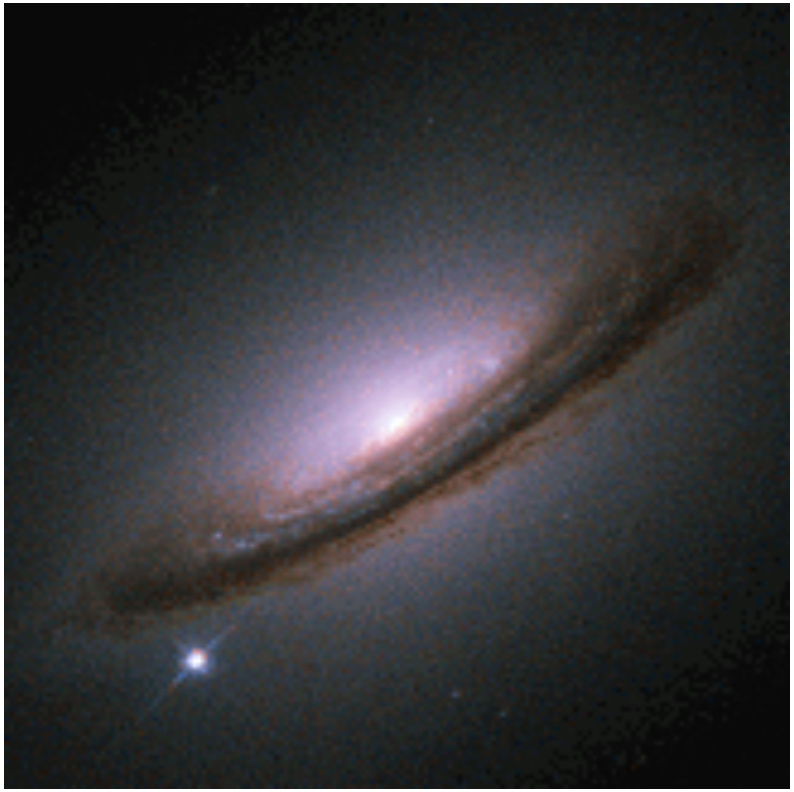


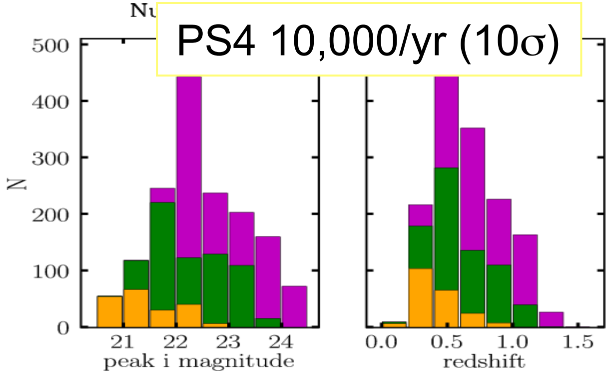


Cosmology – Supernovae

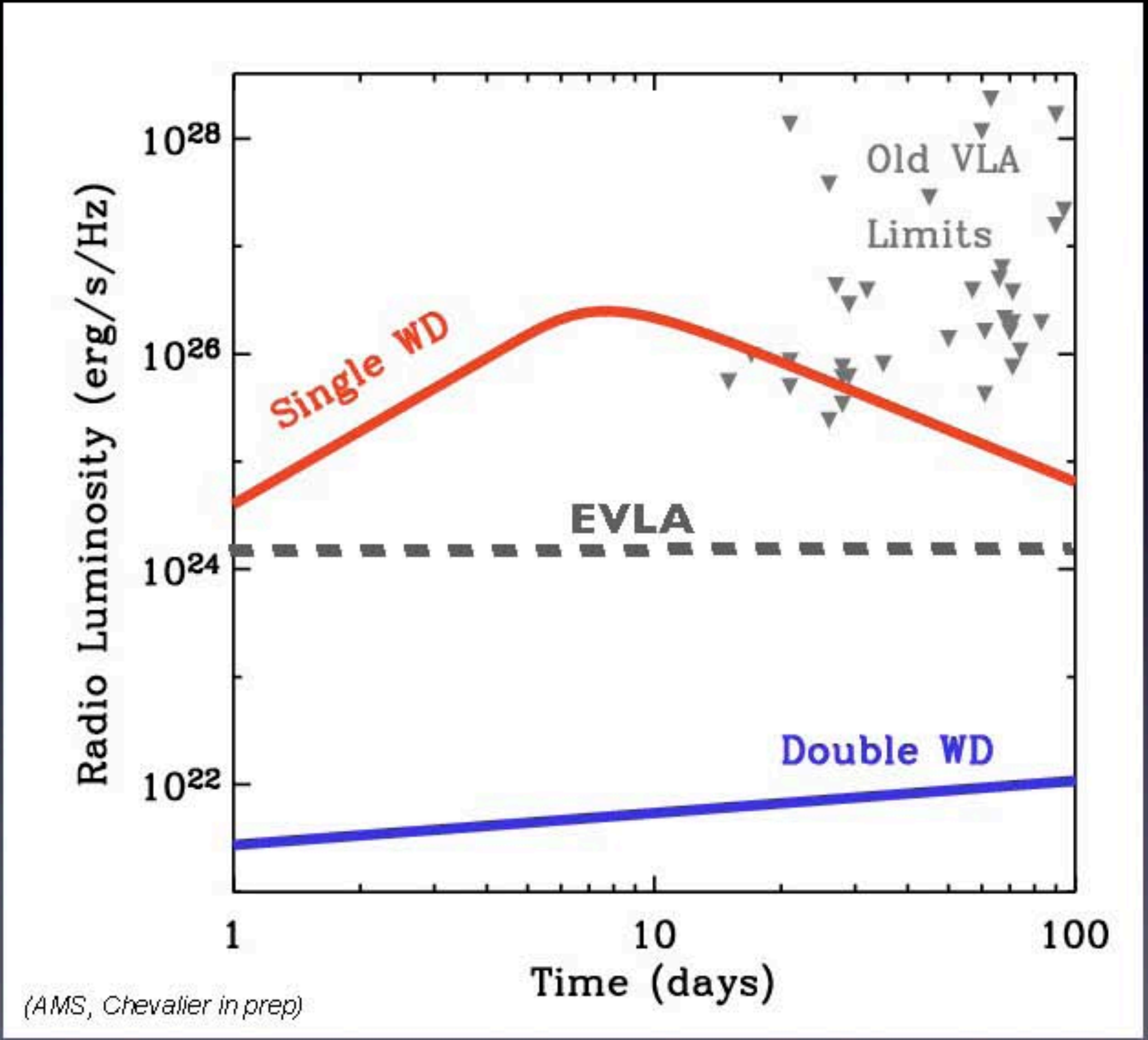
- Hubble diagram
  - Dark energy equation of state w(z)
  - Cosmological parameters
- Supernova physics
- Star formation history

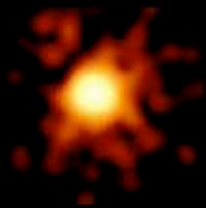






Models for SN Ia Radio Emission



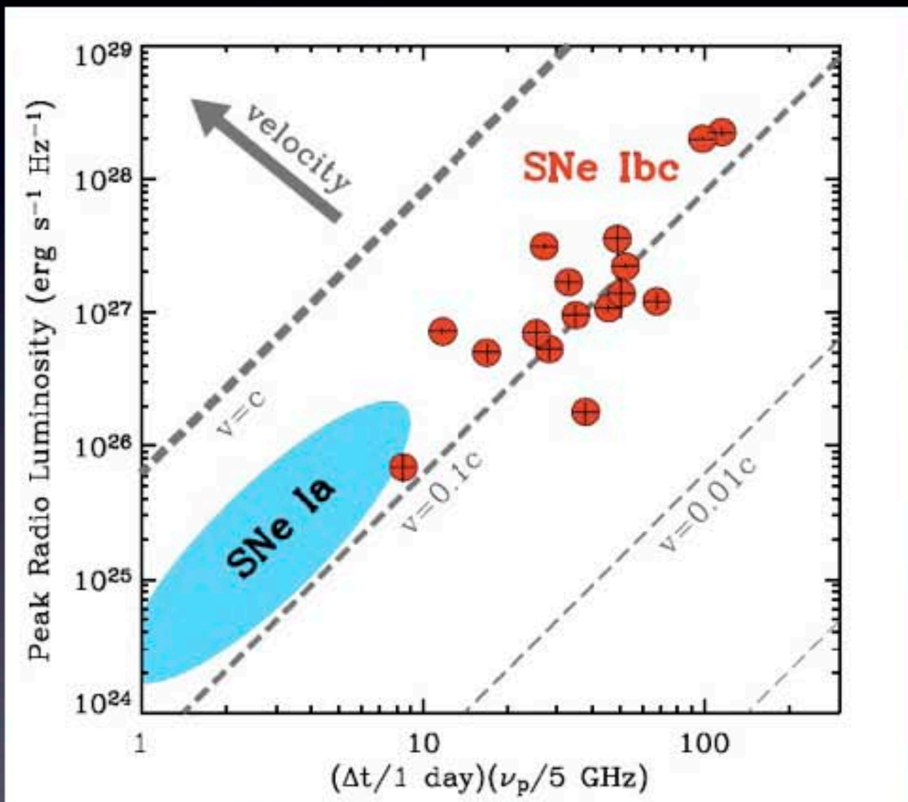


EVLA: The progenitors of SNe Ia

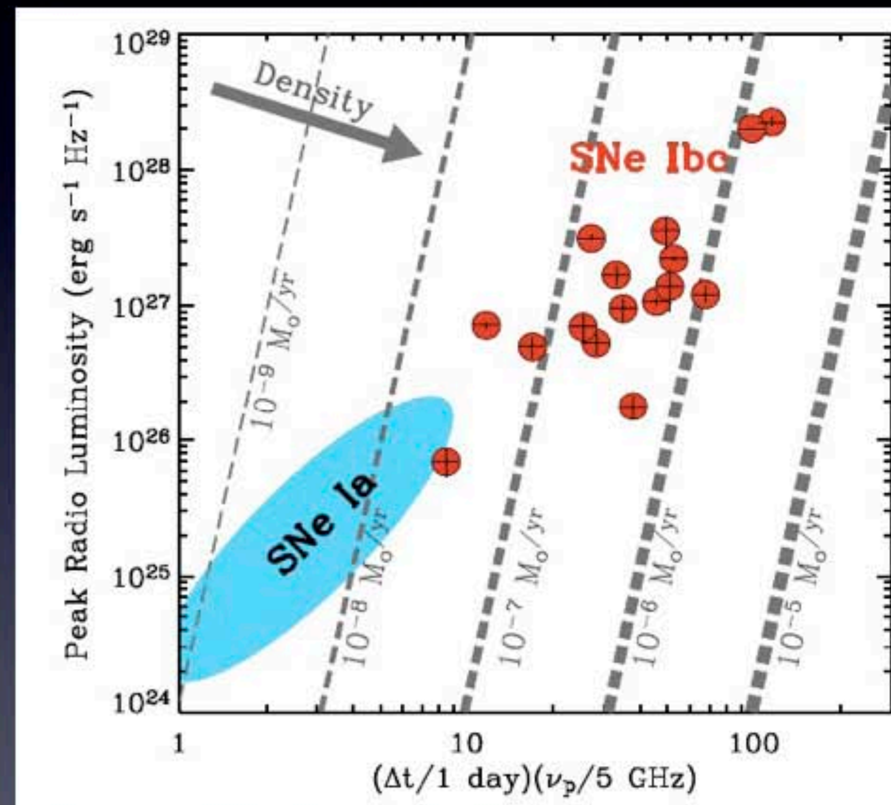
(One of ten RSRO programs; PI Soderberg)

co-I's: Chevalier, Fransson, Badenes, Chomiuk

Velocity



Mass Loss Rates



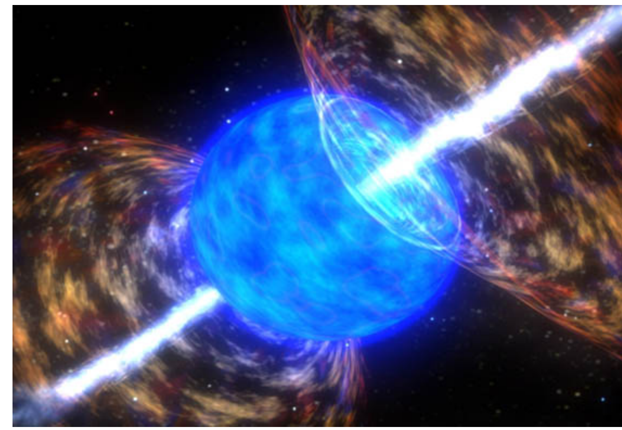
EVLA sensitivity = 10 x VLA

ALMA detection of Gamma Ray Bursts and First Stars

Long duration GRBs - death of massive stars - bright, long-lived afterglow emission - observable to great distances

- Probe formation of first stars through to reionization

- GRB 090423 (z~8.3)possibly detected at PdBI in mm (Stanway et al 2011), and GMT at 3mm 0.2my, Castro-Tirado et al 2009 detectable with ALMA to 5σ in 2 min



ALMA should be able to monitor subsequent creation

- O ([O I], [O III], OH, H_2O)
- C ([C I], [C II], CO, CH, CH^+, ^{13}C)
- N ([N II], NH, N_2H^+)

Courtesy Carol Londsdale

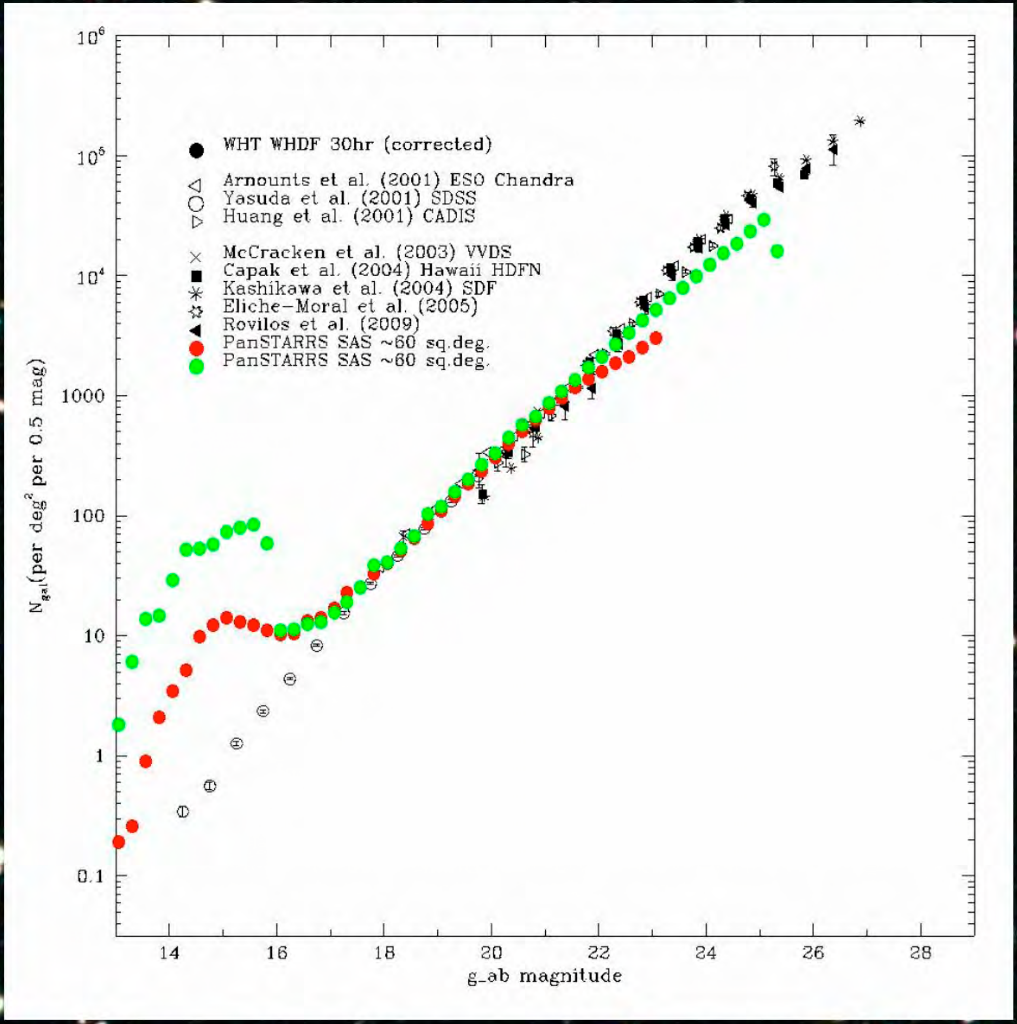
PS1 Early Science: Galaxy counts • Metcalf et al.

g-band counts

MD08:
78 warps
12500 sec
Sky 1.1/sec
DRM 25.3

DRM sky 0.8/sec

SAS:
26 warps
1300 sec
Sky 2.9/sec
DRM 24.1



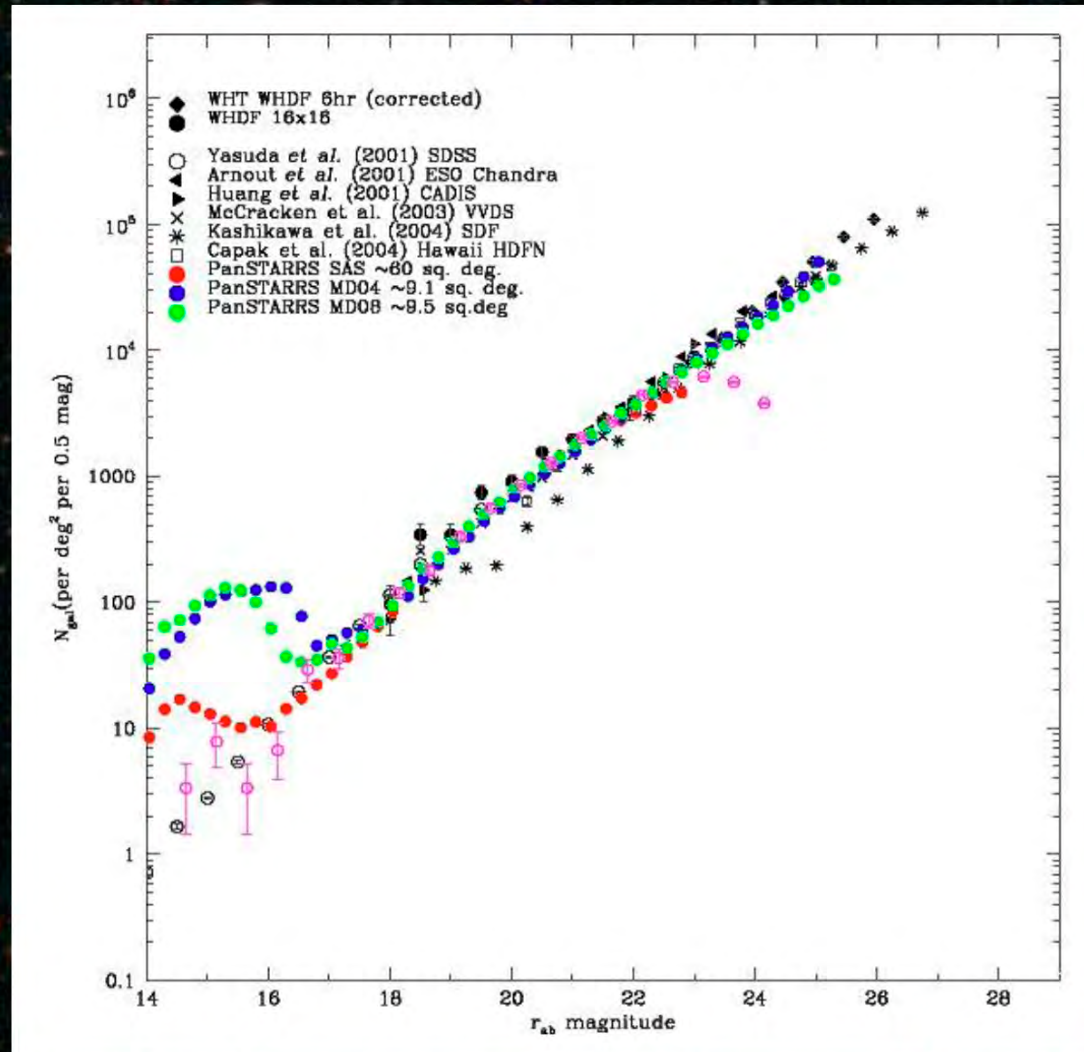
r-band counts

MD08:
89 warps
14000 sec
Sky 2.1/sec
DRM 25.2

MD04:
90 warps
15000 sec
Sky 1.7/sec
DRM 25.2

DRM sky 2.5/sec

SAS:
32 warps
1100 sec
Sky 3.8/sec
DRM 23.7

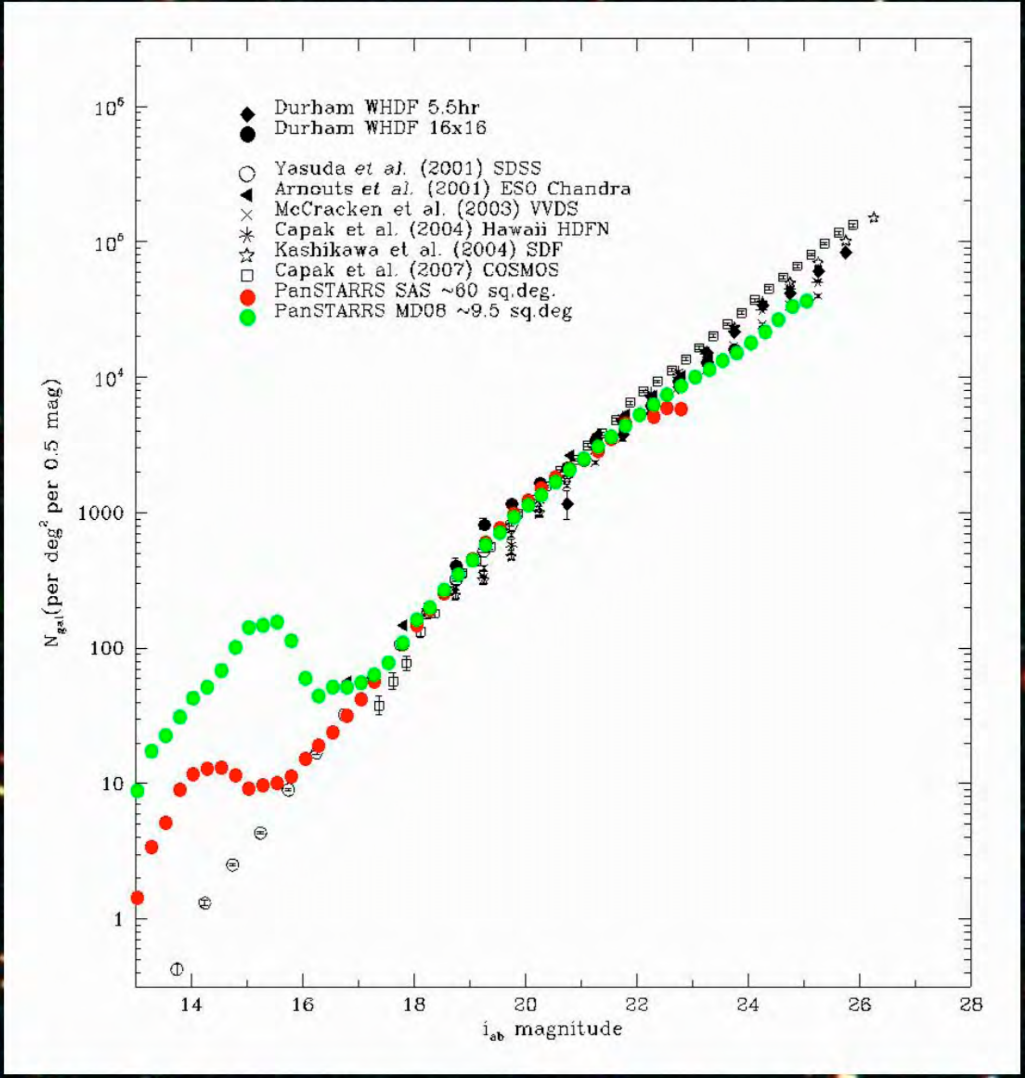


i-band counts

MD08:
81 warps
19000 sec
Sky 4.9/sec
DRM 24.9

DRM sky 4.5/sec

SAS:
30 warps
960 sec
Sky 15.2/sec
DRM 23.2

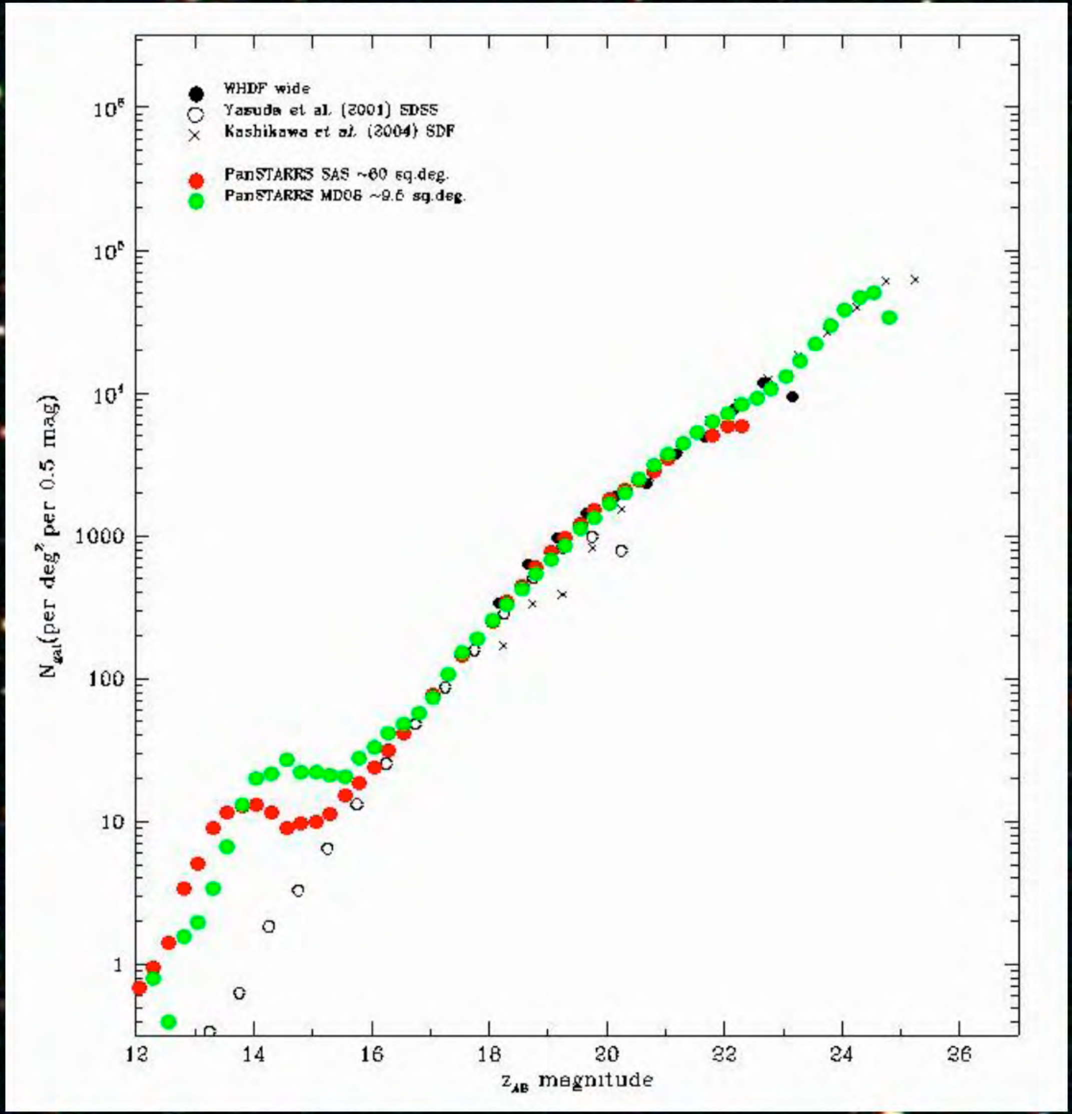


z-band counts

MD08:
115 warps
27500 sec
Sky 5.5/sec
DRM 24.5

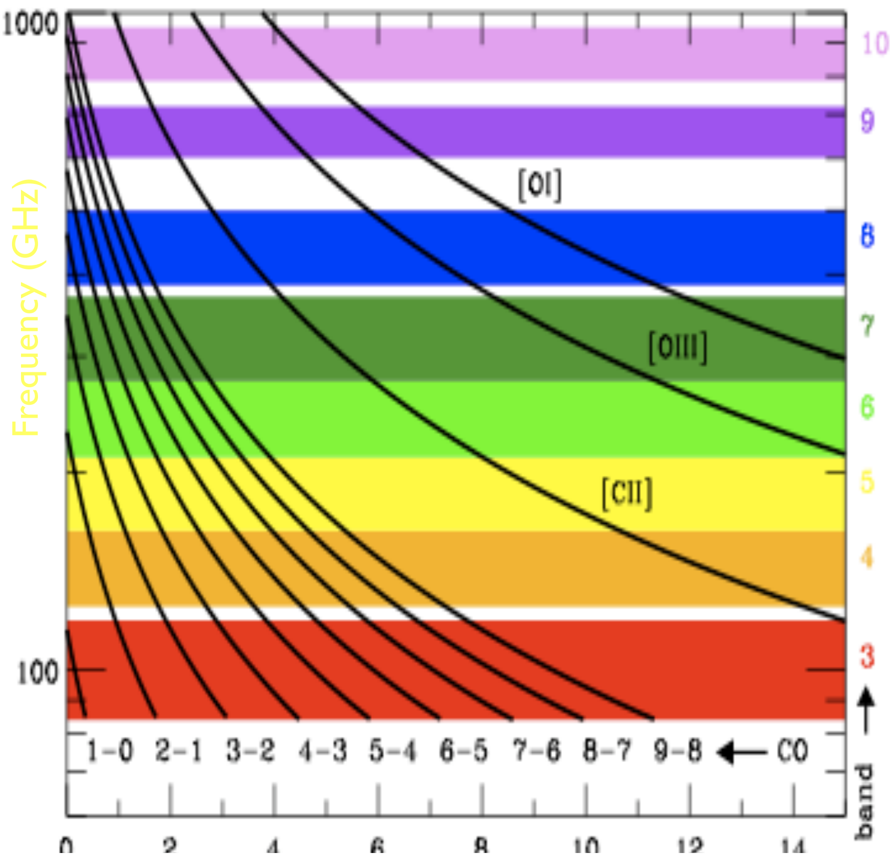
DRM sky 7.2/sec

SAS:
15 warps
900 sec
Sky 26.0/sec
DRM 22.5

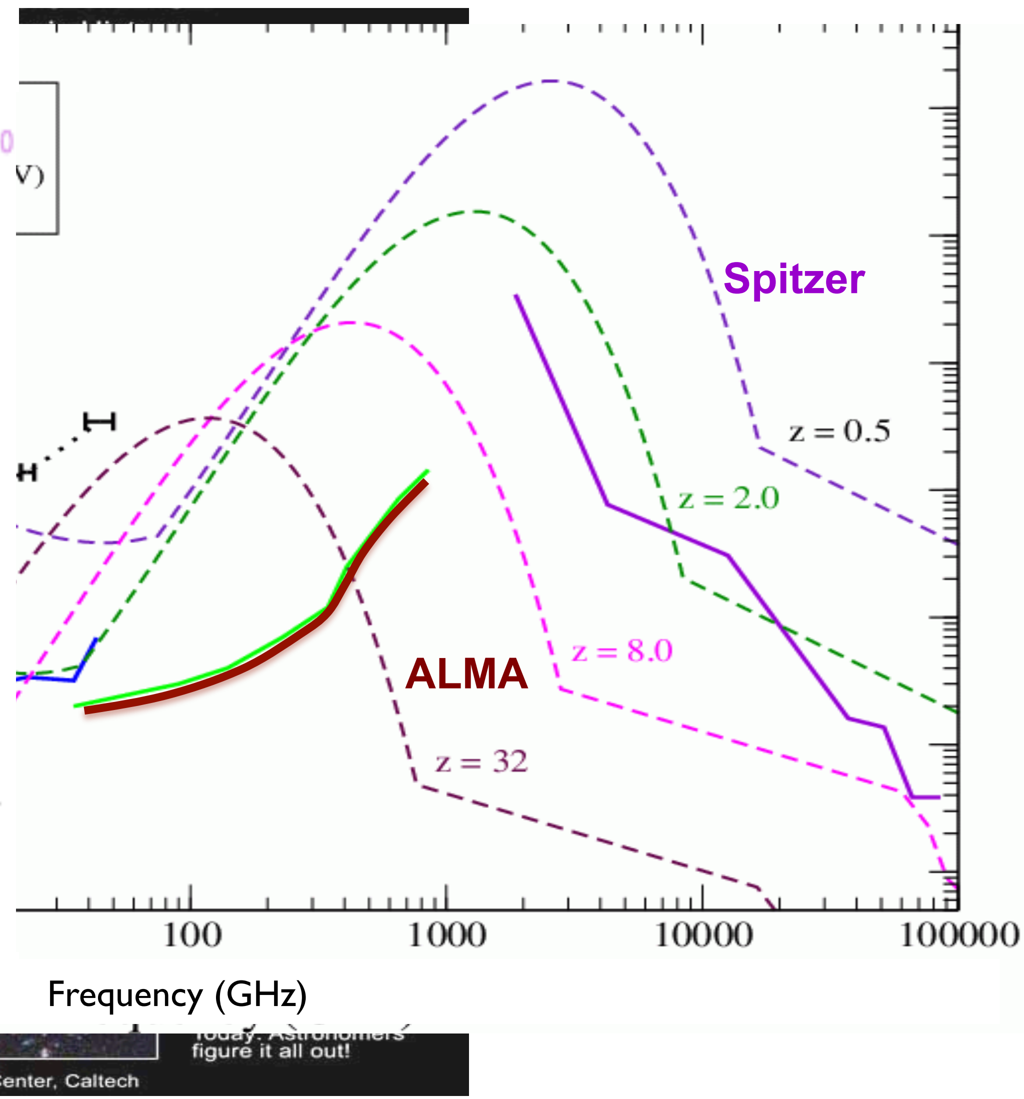


Cosmic Dawn and Galaxy Formation

Nearly continuous coverage of important lines as a function of redshift (Maiolino 2008)



Redshift (z)

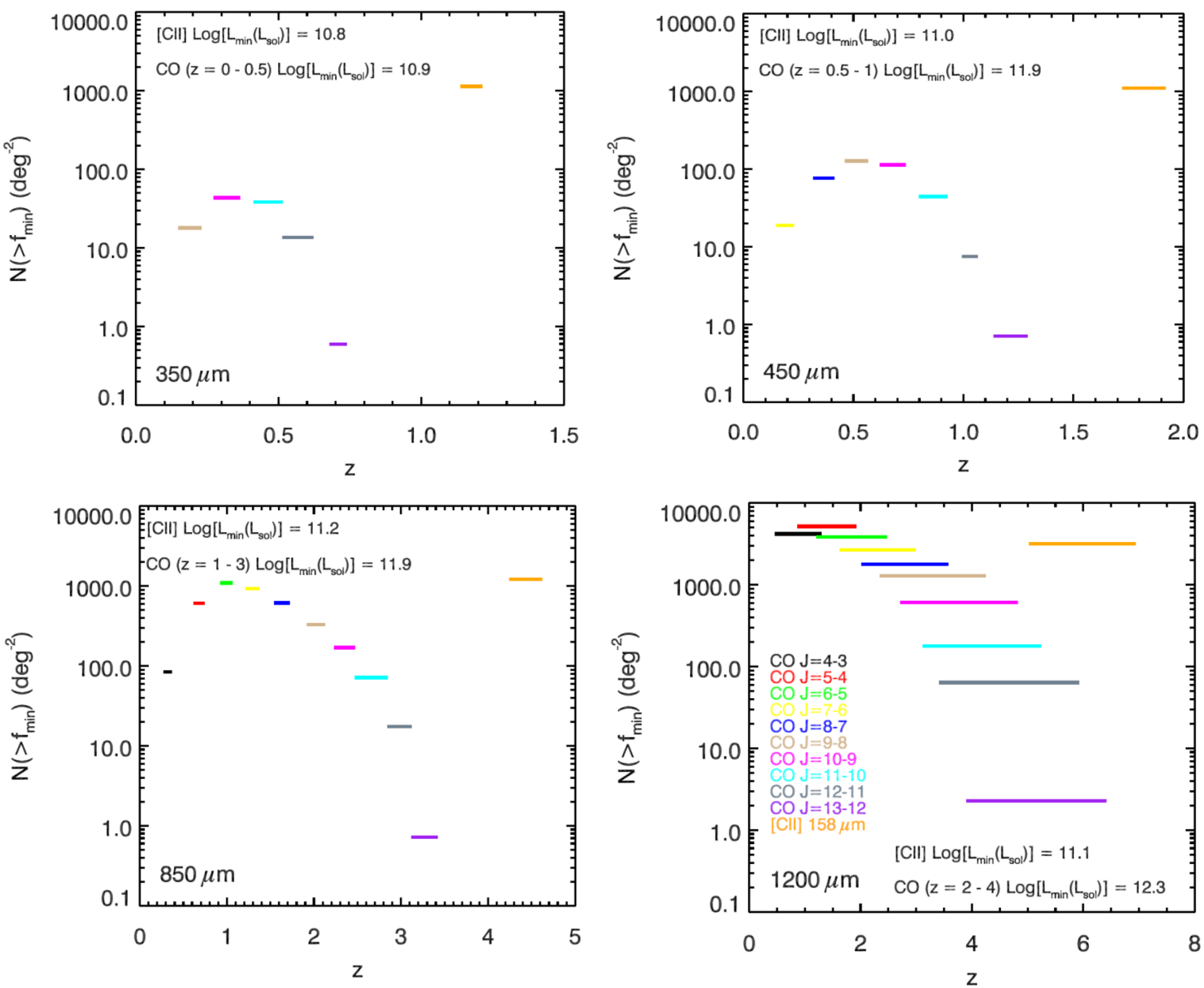


Frequency (GHz)

How Many High-z Galaxies Can CCAT Detect Spectroscopically?

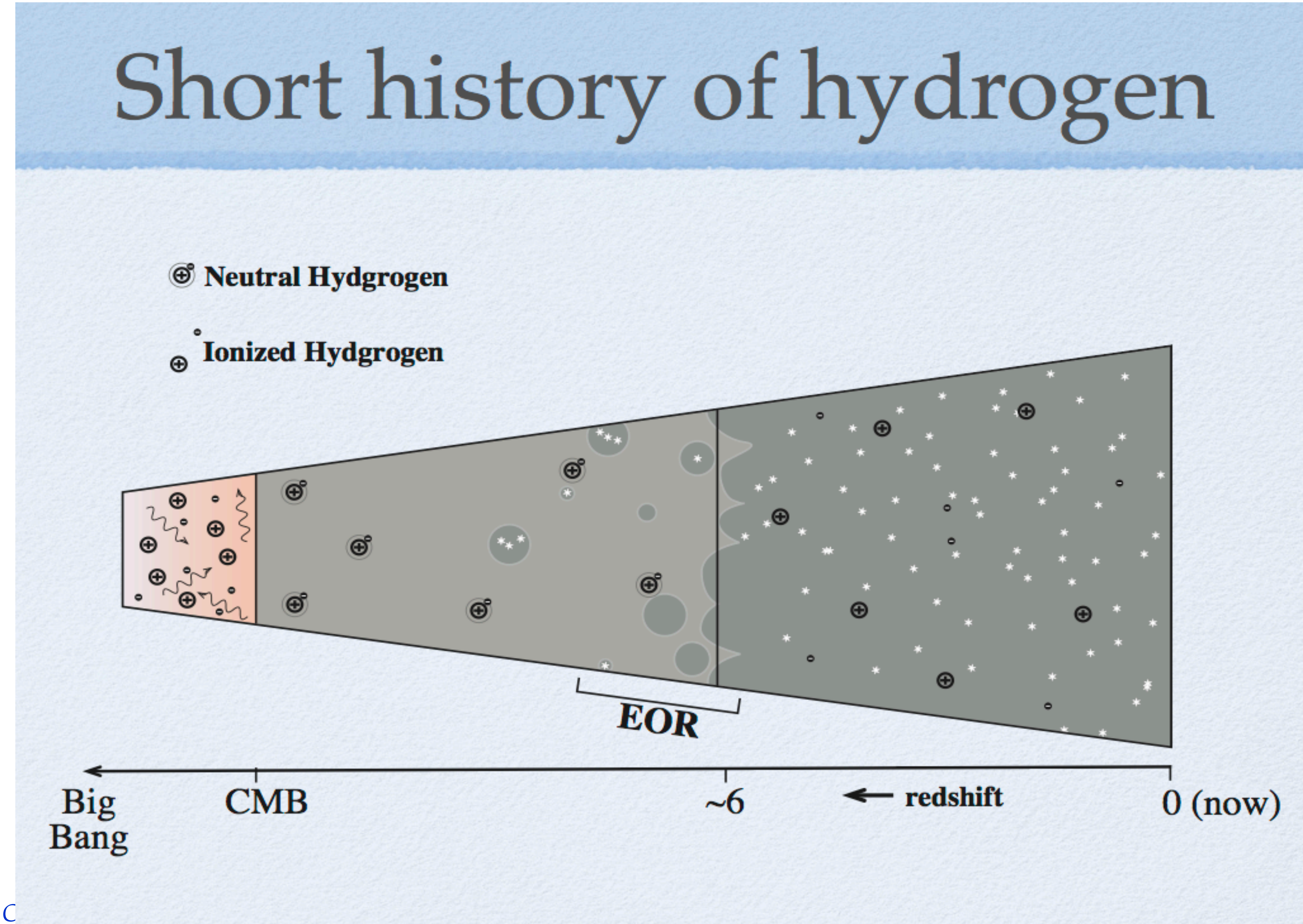
And, what kind of spectrometer does CCAT need?

Other fine-structure lines will be detectable at high z: [OI] 63 & 146 μm, [NII] 122 & 205 μm

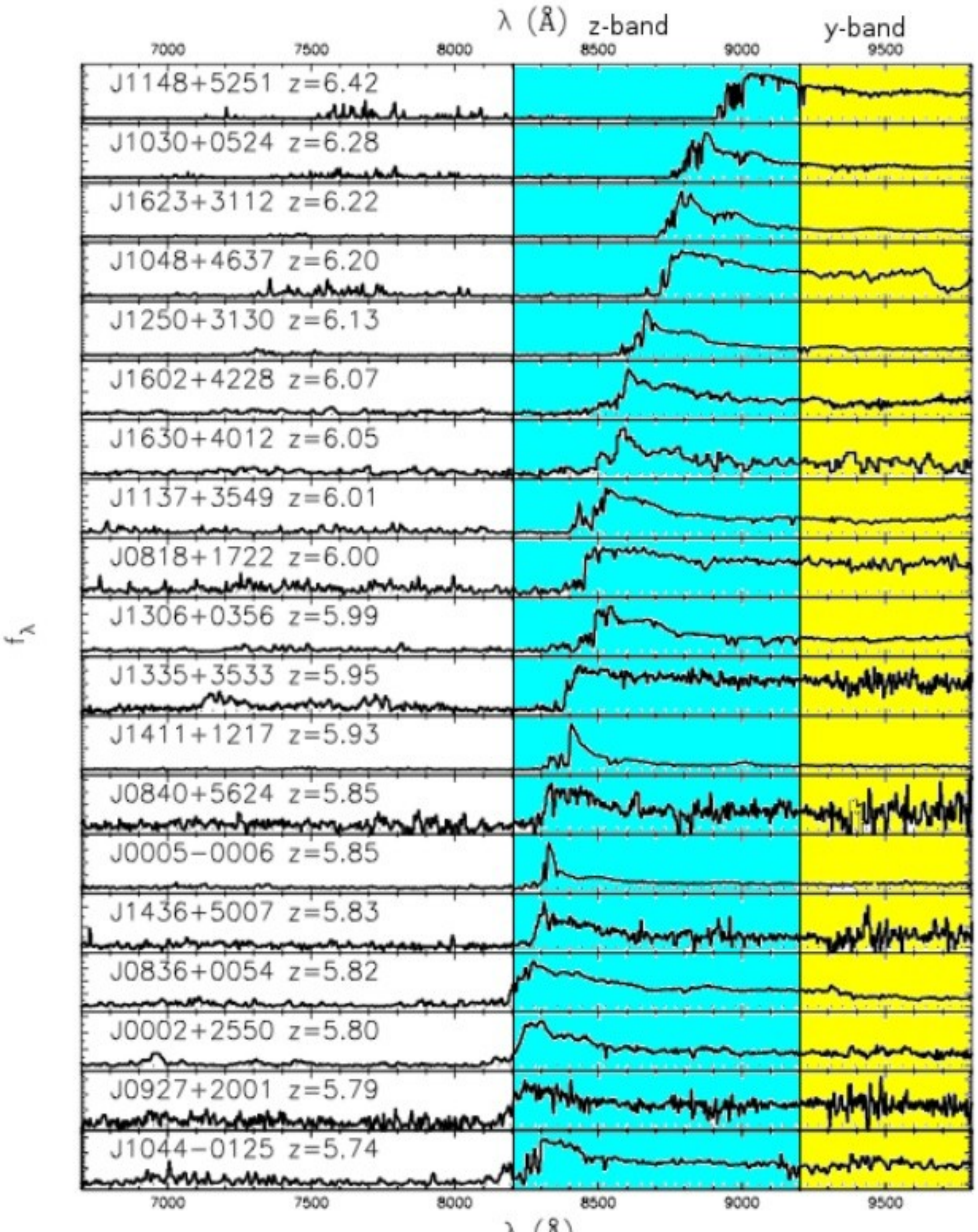


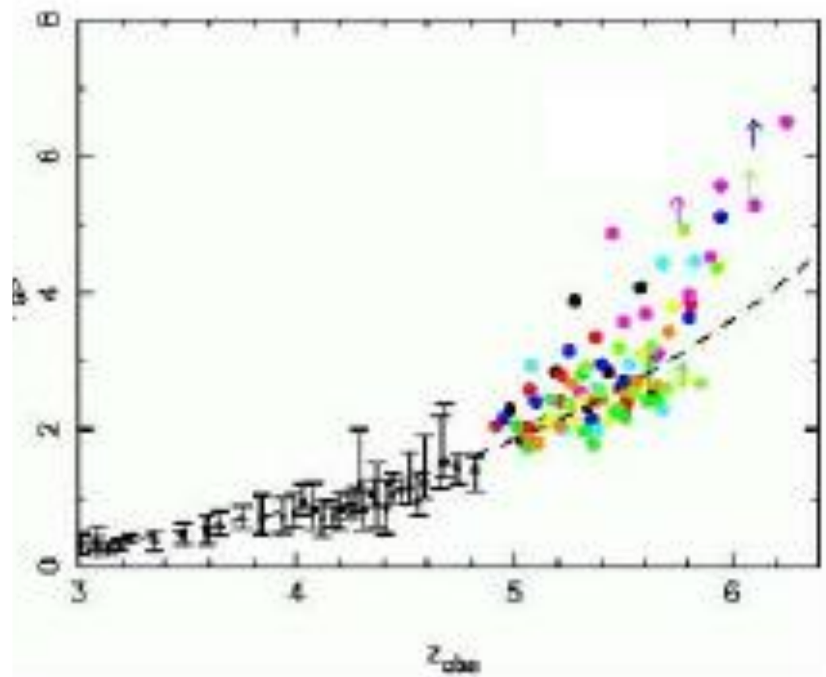
Ken Chambers

Epoch of Reionization

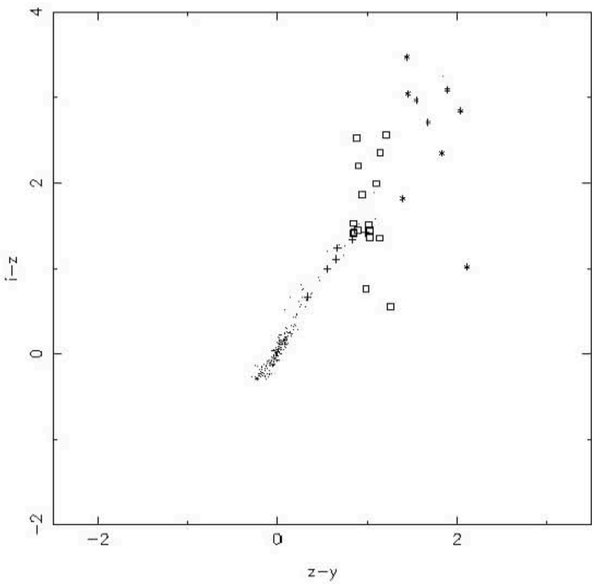


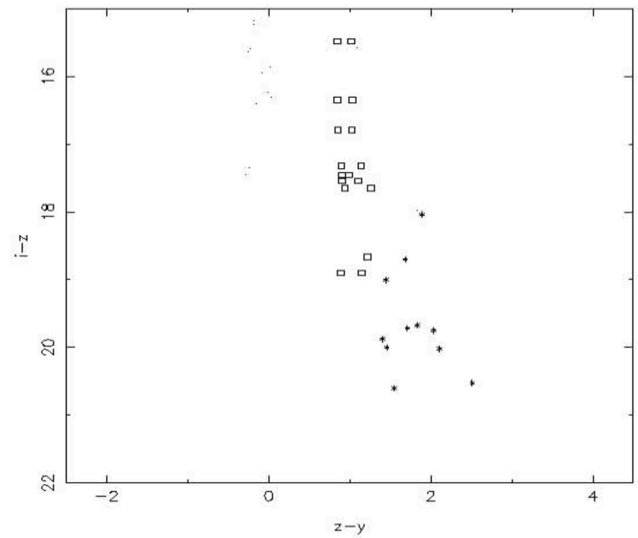
High redshift quasars

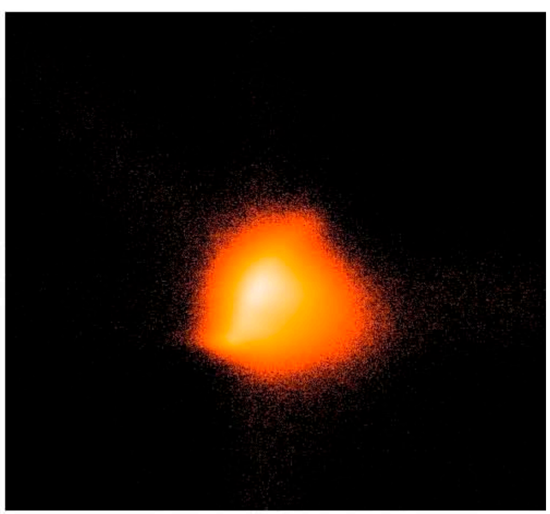


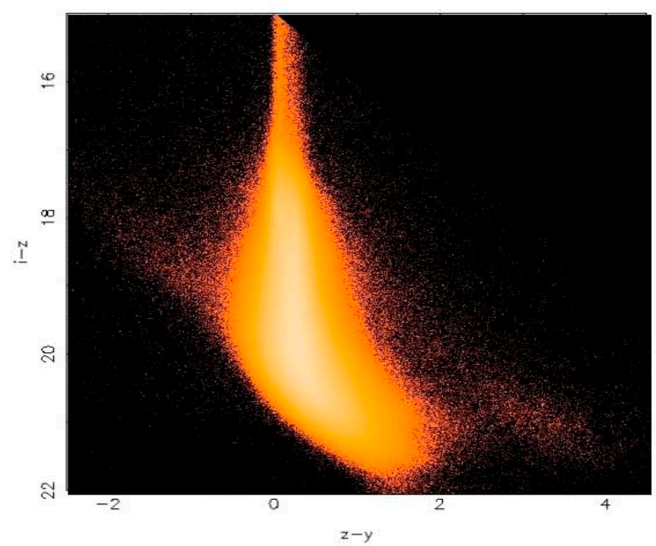


Finding redshift ~ 7 quasars in PS1 3pi Survey

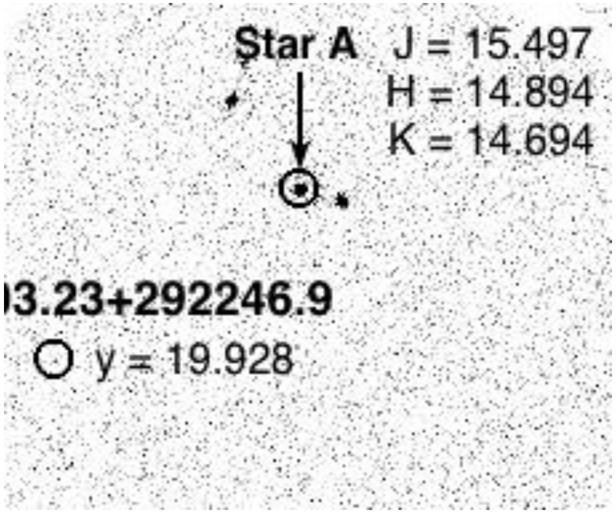


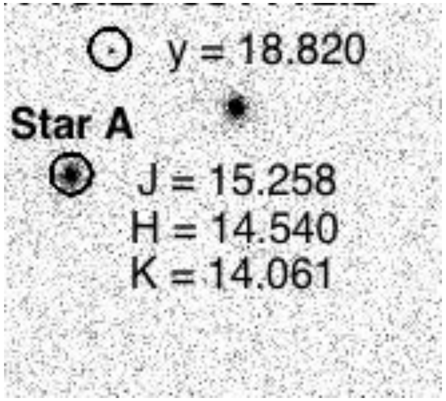


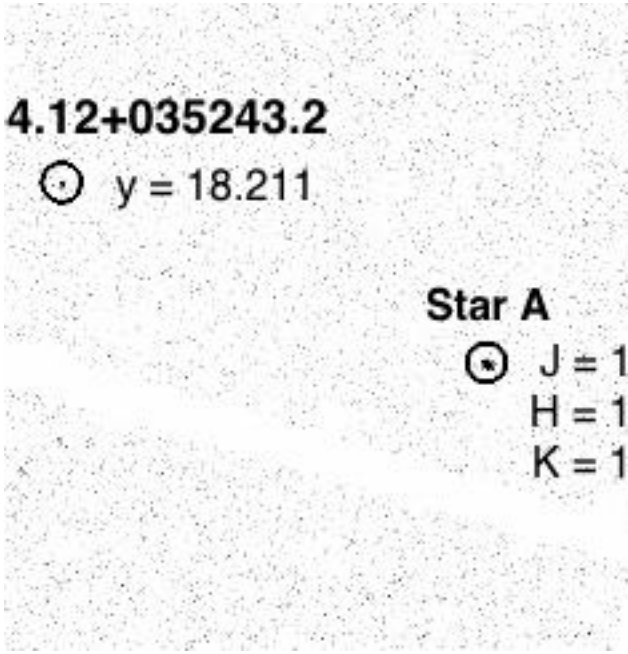




z-band dropouts, candidates for high z sources

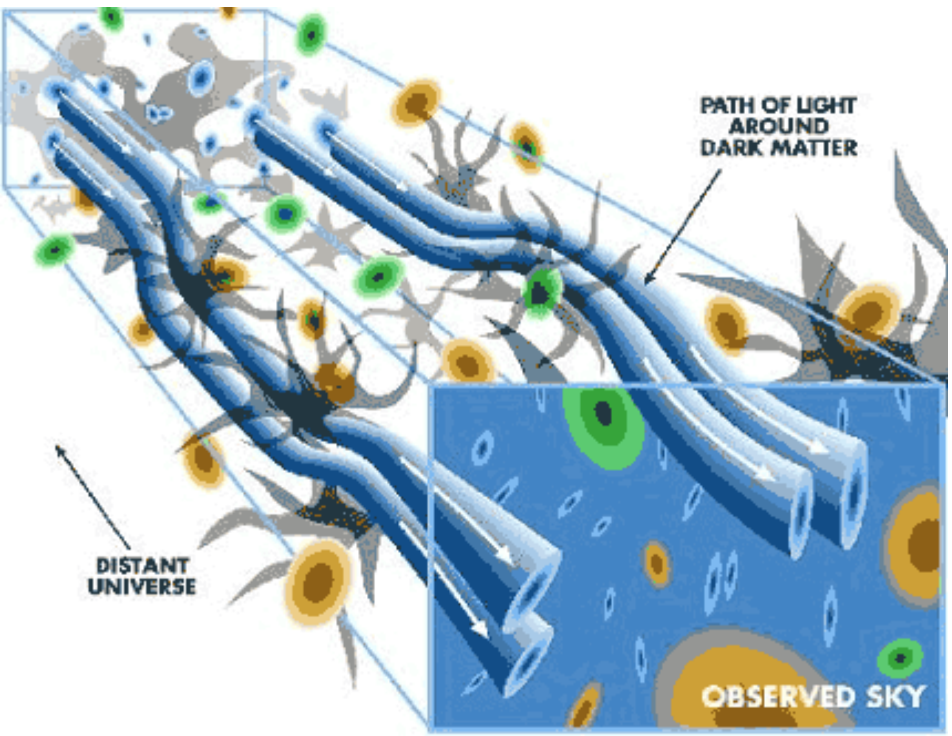


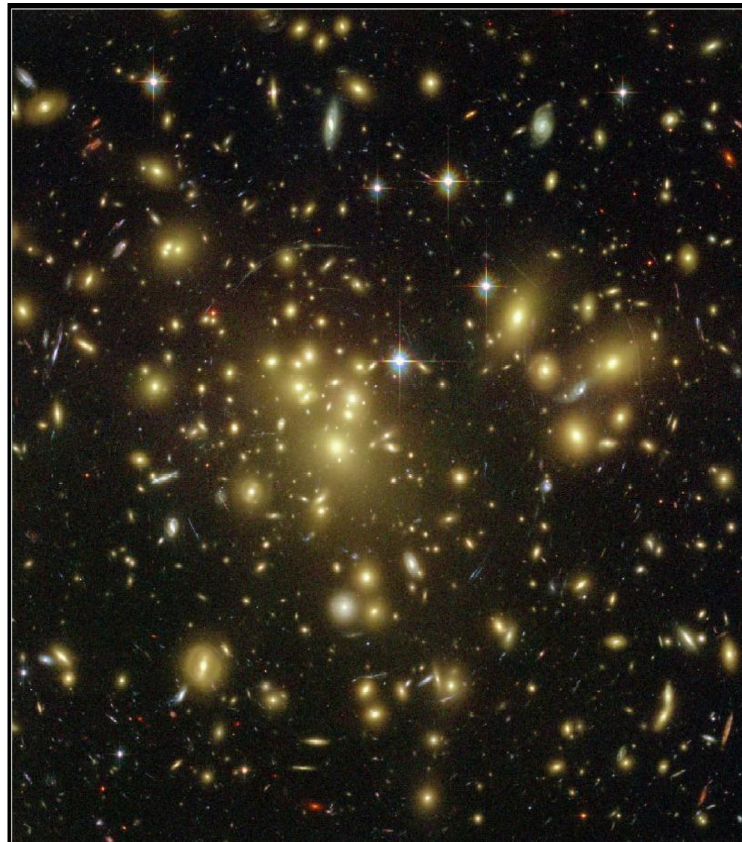




Cosmological Lensing

- Mass power spectrum P(k) to large scales
  - Test of inflation theory
  - Evolution of P(k)
  - Dark Energy eq. of state
- Cluster mass function
- Cosmology

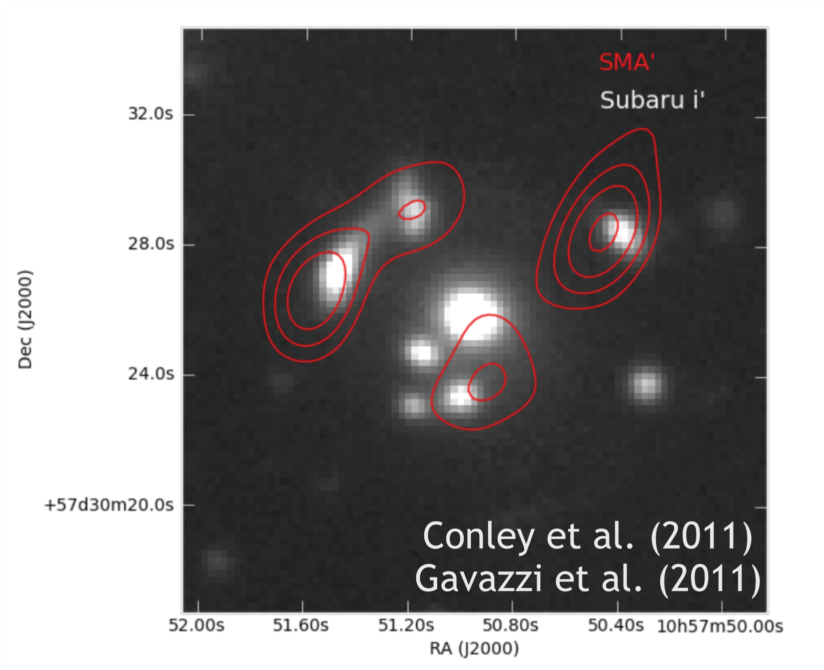


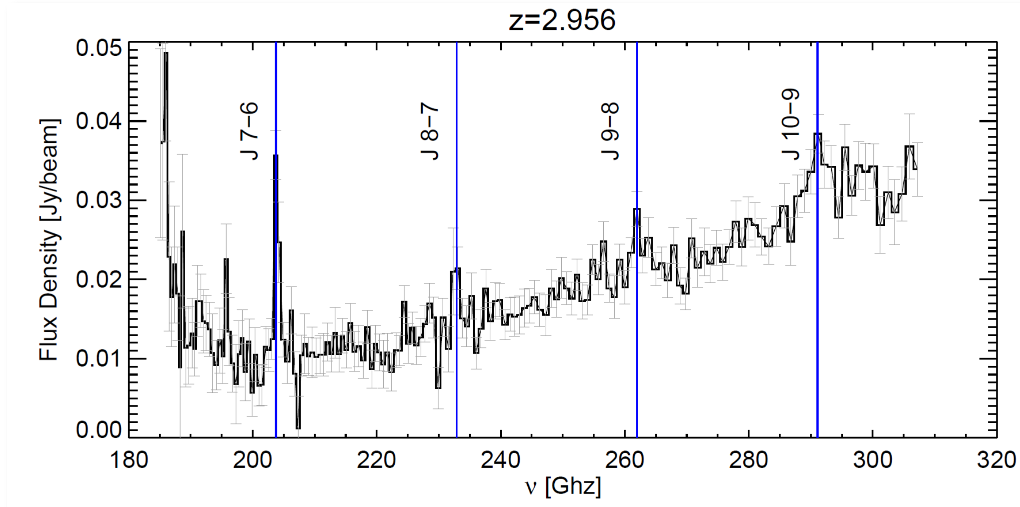


Galaxy Cluster Abell 1689
Hubble Space Telescope • Advanced Camera for Surveys

Lensing Studies of High-z Galaxies

Lensing allows intrinsically faint (L_{IR} ~ 10^{11} L_{sun}) galaxies to be studied





Z-Spec spectrum: dust continuum
+ CO line(confirmed with PdBI)

Scott et al. 2011

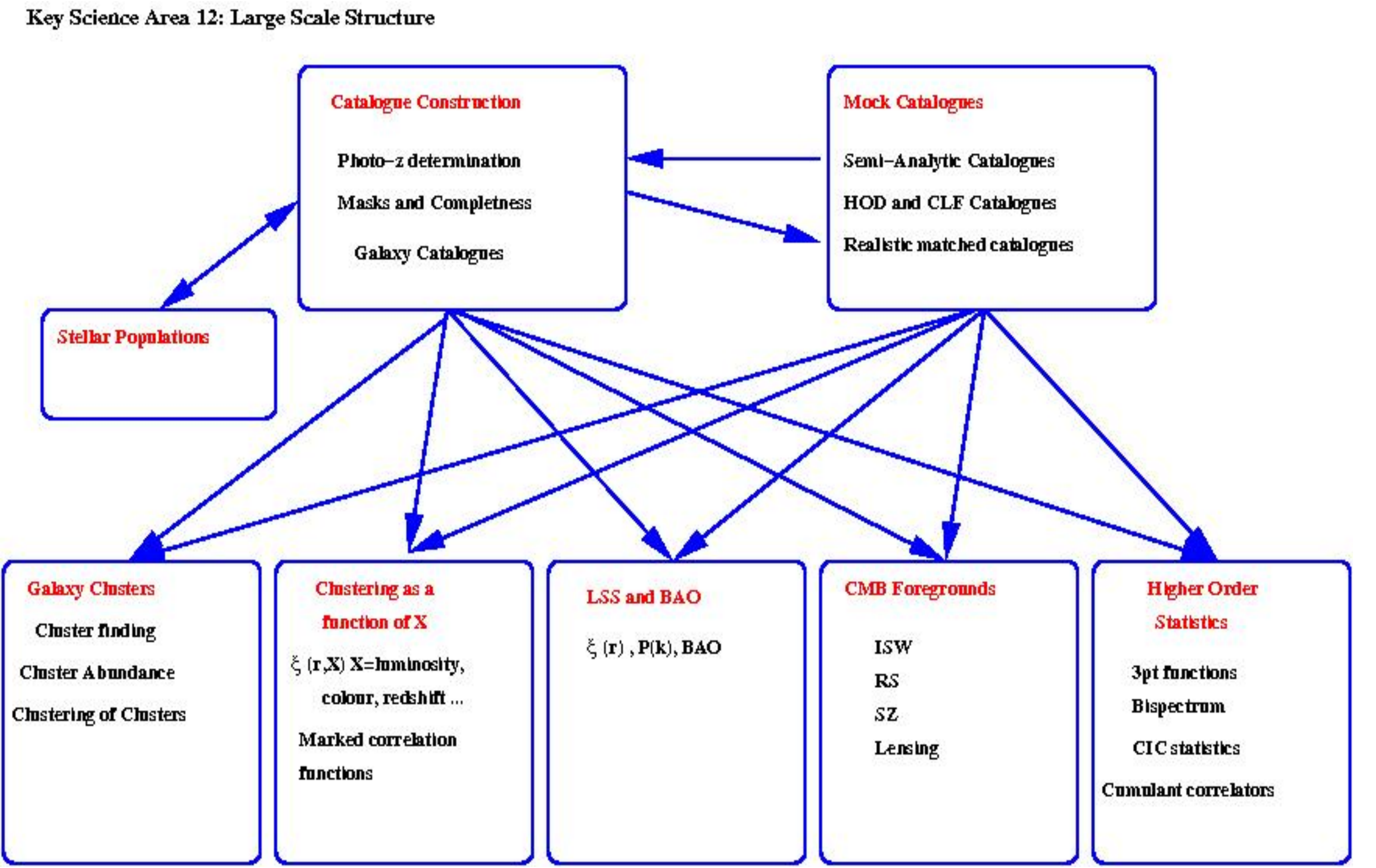
9″ separation of components

Lens mass ~ 5 x 10^{12} M_{solar}; T_{dust} = 90 K + AGN

Jason GLenn

- CCAT will resolve lenses and identify them by correlated colors and by cross-correlating with Pan-STARRS, DES, or LSST foreground galaxies
- Lensed galaxies will be targeted with ALMA for morphologies & dynamics

Large Scale Structure and Baryon Acoustic Oscillations at z~0.8 with red sequence galaxies



Conclusions, talking points….

- PS1 is a functioning pathfinder for LSST !

- Emphasis is on doing precision astronomy -> Very careful attention to
- systematic errors !!!

- In the time domain this is even more important, because you can’ beat down
- the systematic errors by doing itat a different time. Best way is by coincident
- timing measurements – means redundant detectors.

- Adding PS2 to PS6, would give a full sky synoptic survey,
- 8.4 Gigapixels, and enable excellent control of systematics.

- Need serious attention to new techniques to track not only the error bars,
- but the covariances and tools for determining the detection efficiency,
- this is important for every field

- Example of innovative mid-scale program that will enable a large
- number of astronomers to do a lot of astronomy

- Emphasisze that need balance of experiments and survey instruments.