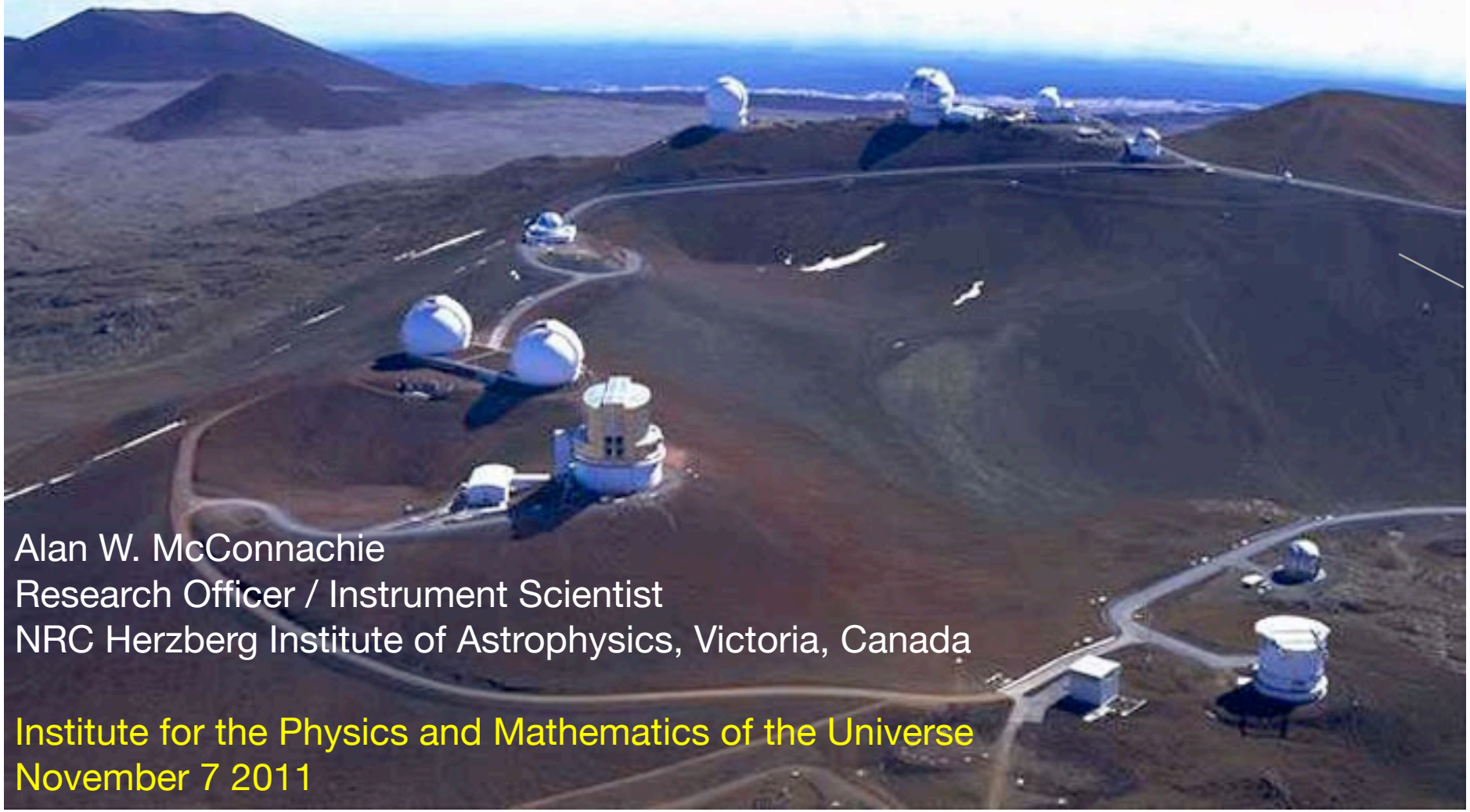
# The next generation of the CFHT:

## A 10m, Wide-Field, Spectroscopic Facility for the Coming Decade



Alan W. McConnachie
Research Officer / Instrument Scientist
NRC Herzberg Institute of Astrophysics, Victoria, Canada

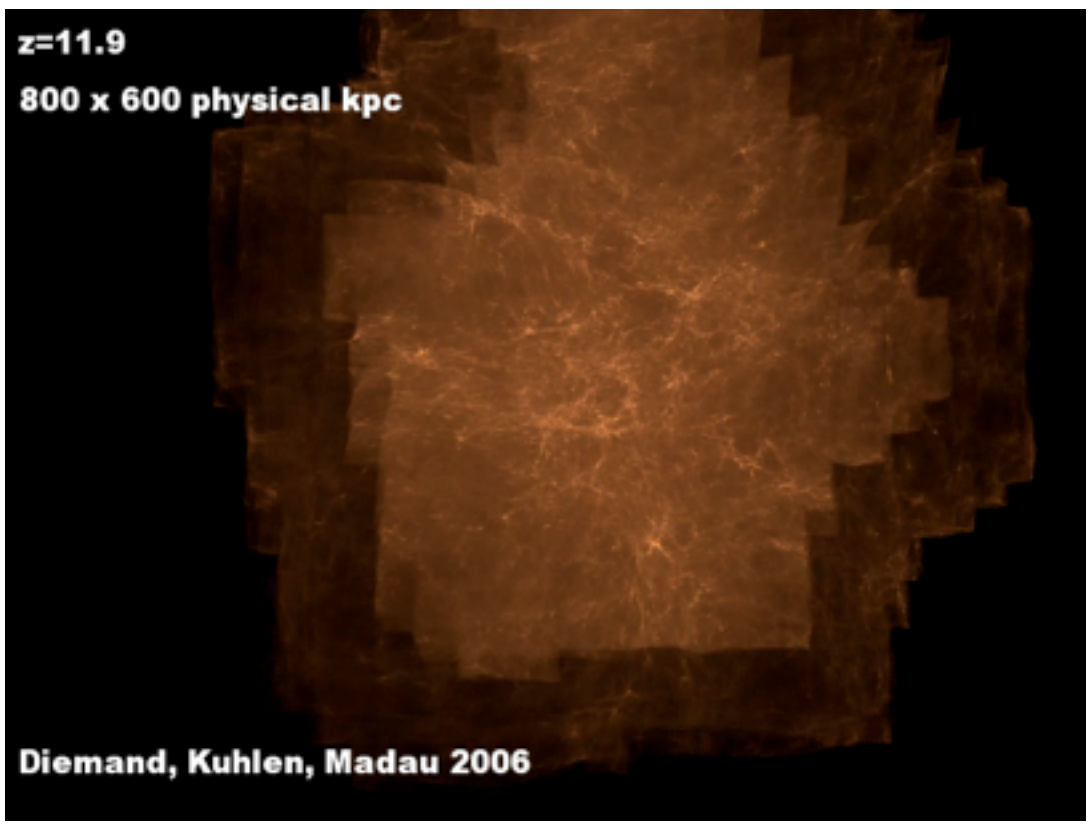
Institute for the Physics and Mathematics of the Universe
November 7 2011

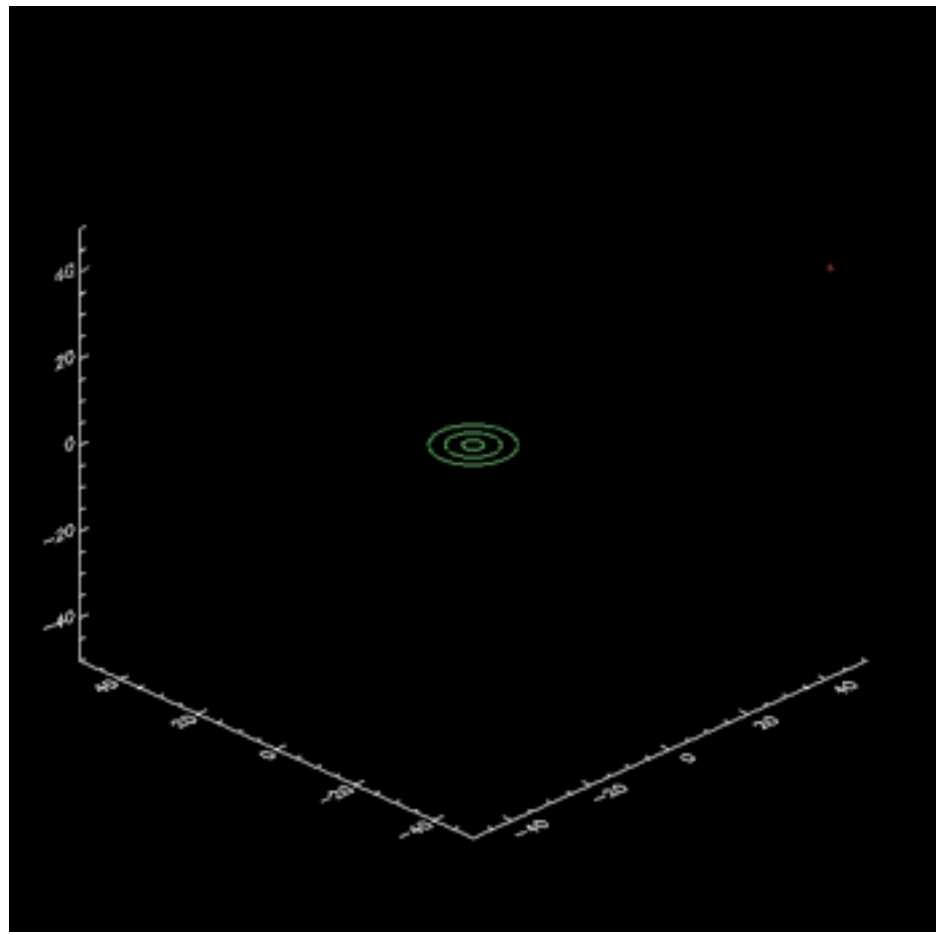
This talk:

- **Introduction: Who am I / what do I do?**
- **What is the CFHT?**
- **What is the missing but essential capability for astronomy in the next decade?**
- **What should we do about it?**

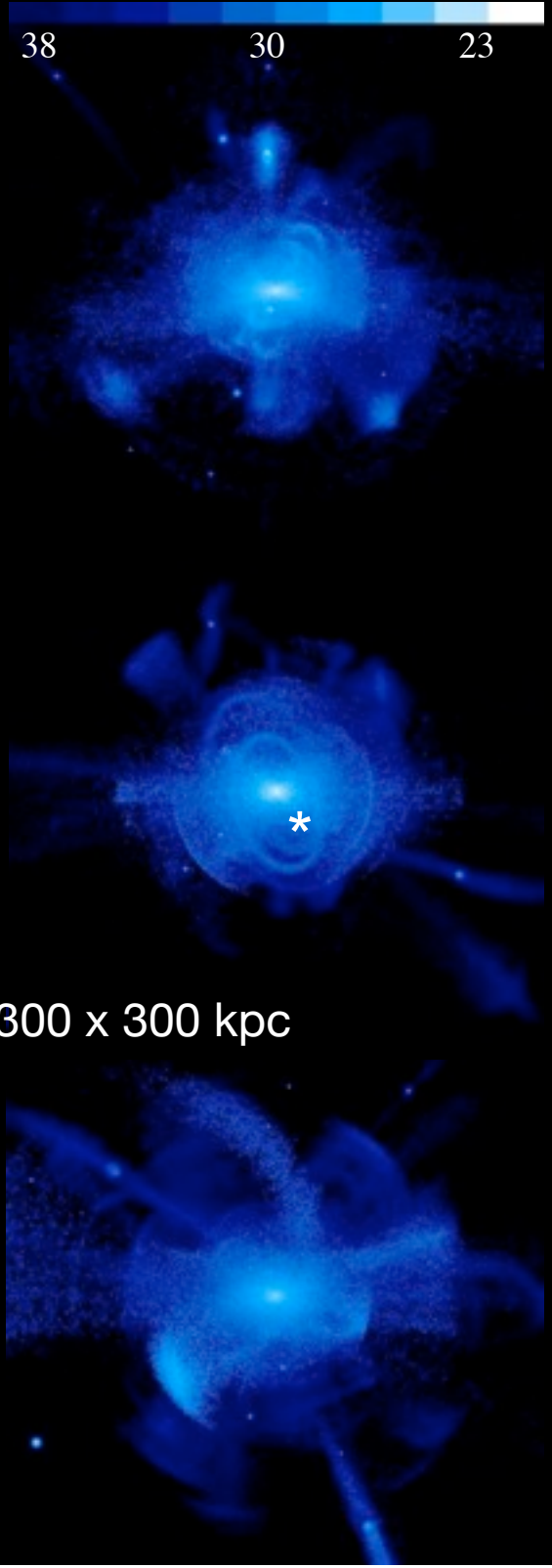
# Structure formation and the formation of the MW

- Gravitational collapse of dark matter: small structures form first and merge to form larger systems (hierarchical)
- No baryons



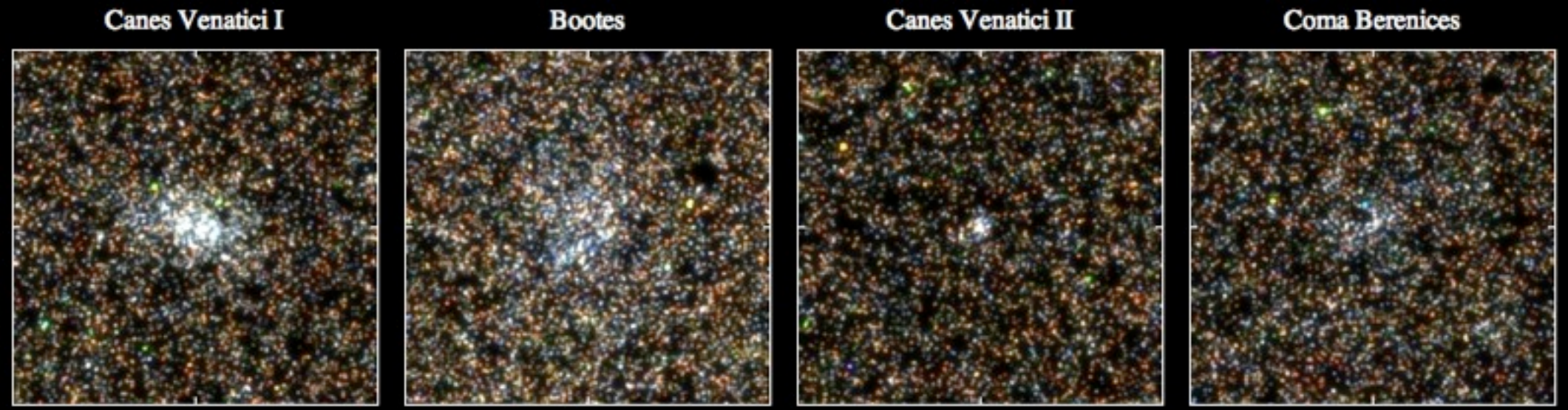



- MW-type haloes expected to accrete many dwarf-mass haloes, some of which will contain baryons (stars)
- Fossil remnants remain at z=0. *Very* faint.



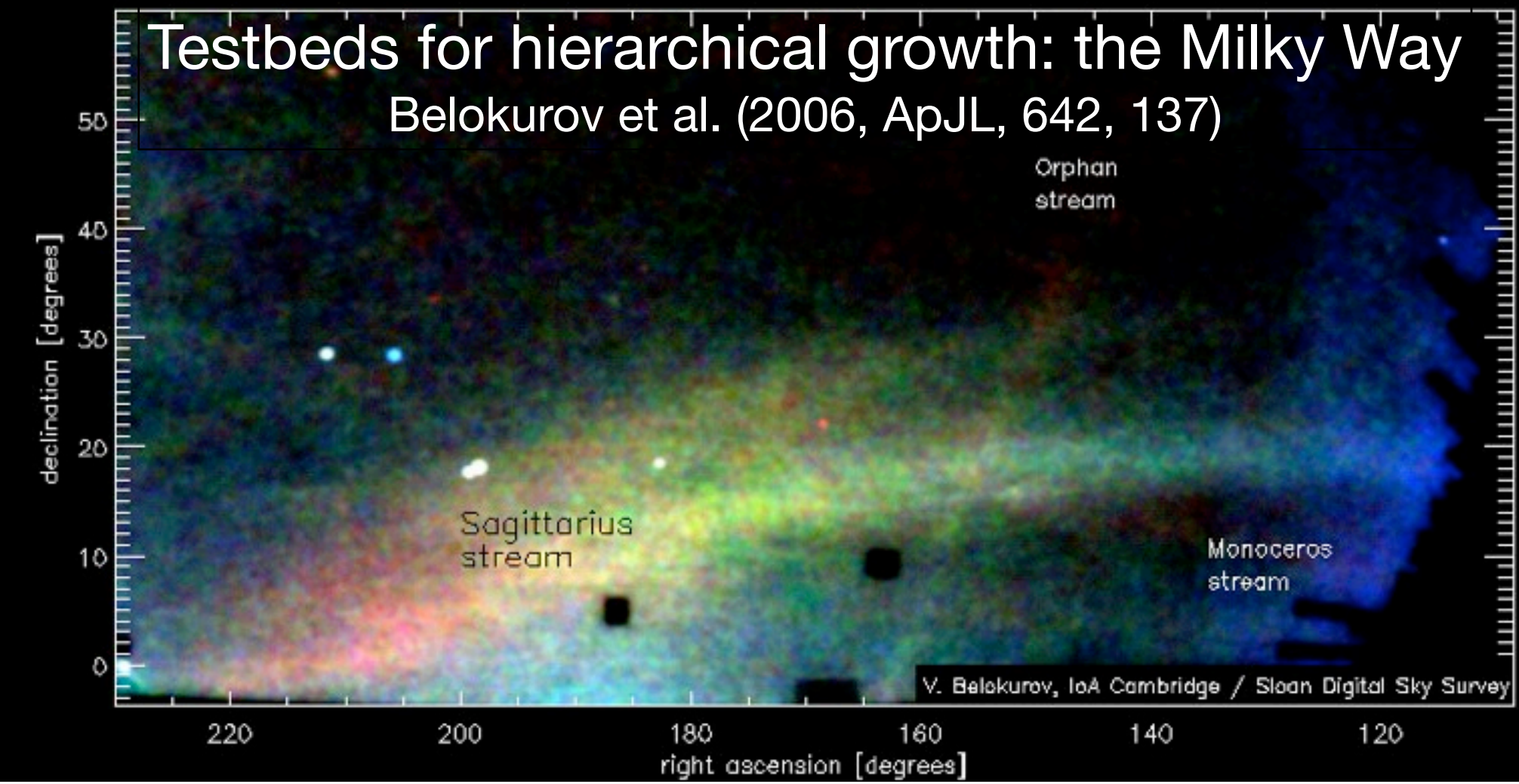

- Predictions now exist for dark and luminous matter on small scales:
  - over half of stellar halo in place 8 Gyrs ago; effectively all in place 4Gyrs ago;
  - stellar halo beyond 50kpc dominated by late accretions;
  - late, massive accretions rare;
  - stellar halo has power law index 3, 4 (steeper than the dark matter);
  - mildly triaxial

- Questions:
  - How much substructure? Too much? Too little?
  - Missing satellite problem - what is the LF of satellite galaxies?
  - What is the morphology of substructure? (Early versus late accretions)
  - What is the global shape of the stellar haloes?
  - Follow-up imaging + spectroscopy: what is the recent accretion history of M31 and M33?
  - SFH + chemical evolution of proto-galactic building blocks.




# Testbeds for hierarchical growth: the Milky Way

Belokurov et al. (2006, ApJL, 642, 137)

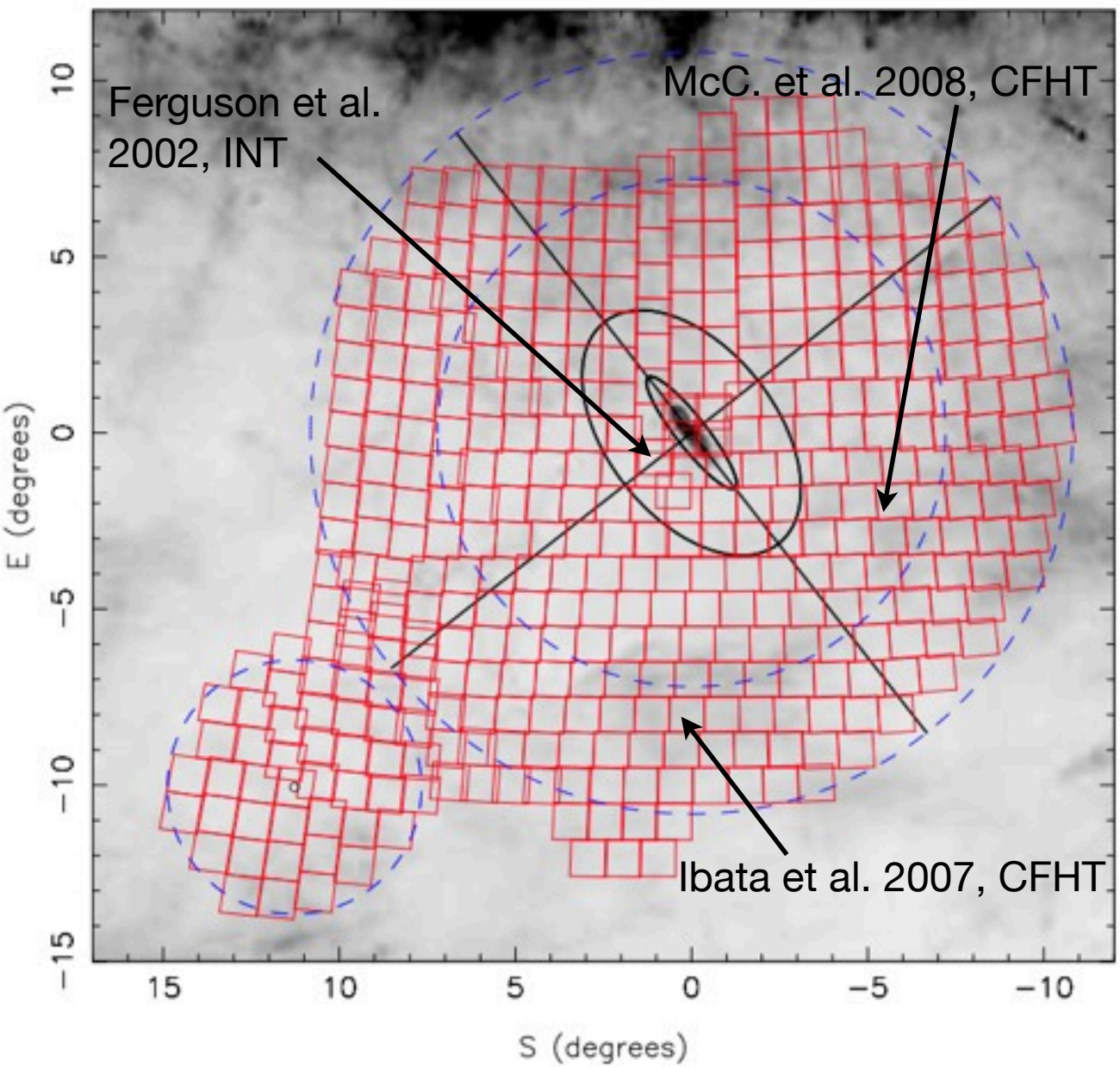


# The Pan-Andromeda Archaeological Survey (PAndAS)

P.I. Alan McConnachie

Arif Babul, Mike Barker, Pauline Barmby, Edouard Bernard, Scott Chapman, Robert Cockcroft, Michelle Collins, Anthony Conn, Pat Cote, Tim Davidge, Anjali Doney, Aaron Dotter, John Dubinski, Greg Fahlman, Mark Fardal, Annette Ferguson, Jurgen Fliri, Bill Harris, Avon Huxor, Rodrigo Ibata, Mike Irwin, Geraint Lewis, Dougal Mackay, Nicolas Martin, Mustapha Moucine, Julio Navarro, Jorge Penarrubia, Thomas Puzia, Mike Rich, Jenny Richardson, Harvey Richer, Arnaud Siebert, Nial Tanvir, David Valls-Gabaud, Kim Venn, Larry Widrow, Kristin Woodley...

# PAndAS: The Pan-Andromeda Archaeological Survey
# The Survey (S08B, S09B, S10B)

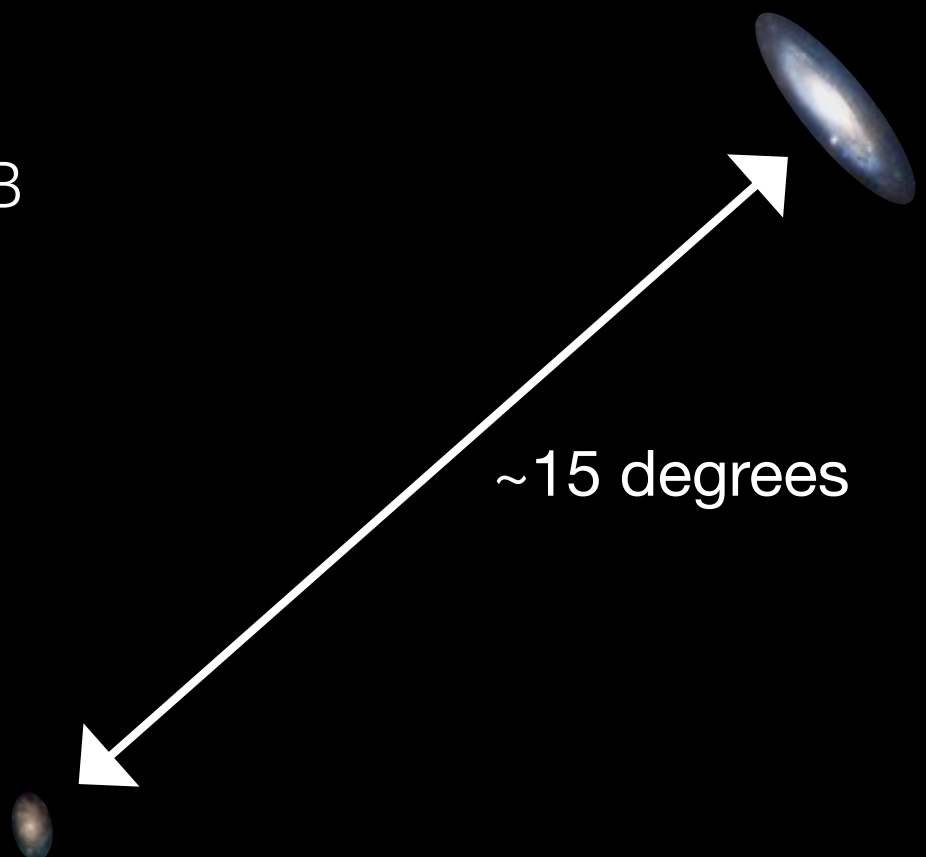



- CFHT/MegaCam (3.6m, 1degree field of view)
- S08B - S10B: 226 hours (41 nights) (B semesters only) on MegaCam in g and i bands
- Builds upon earlier P.I. programs by Ibata (S02B - S06B) and McConnachie (S06B - S07B)
- Total area of ~400 square degrees (>15 million cupic kpc of halo of M31/M33)

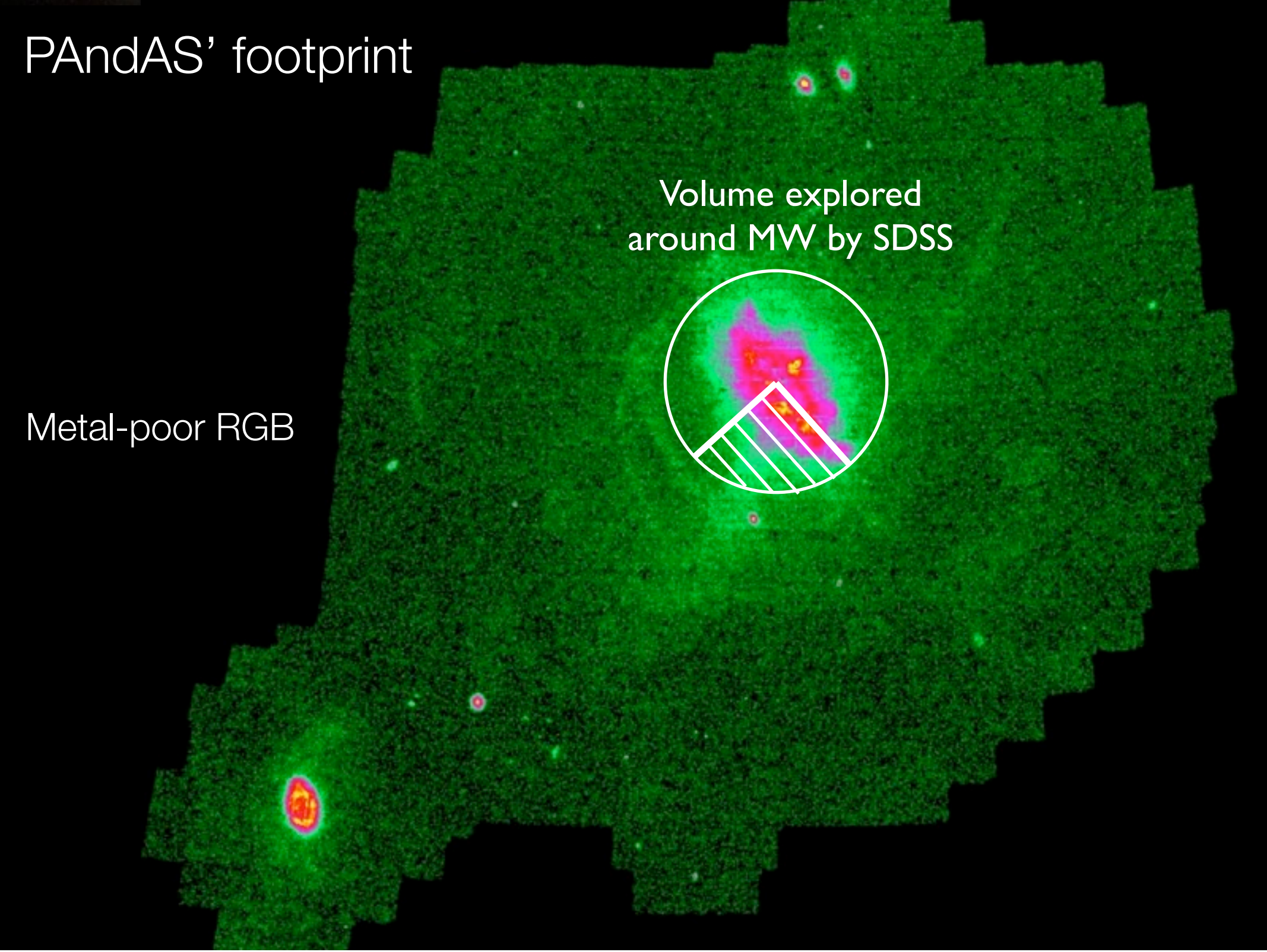
**Completed observations in January 2011**

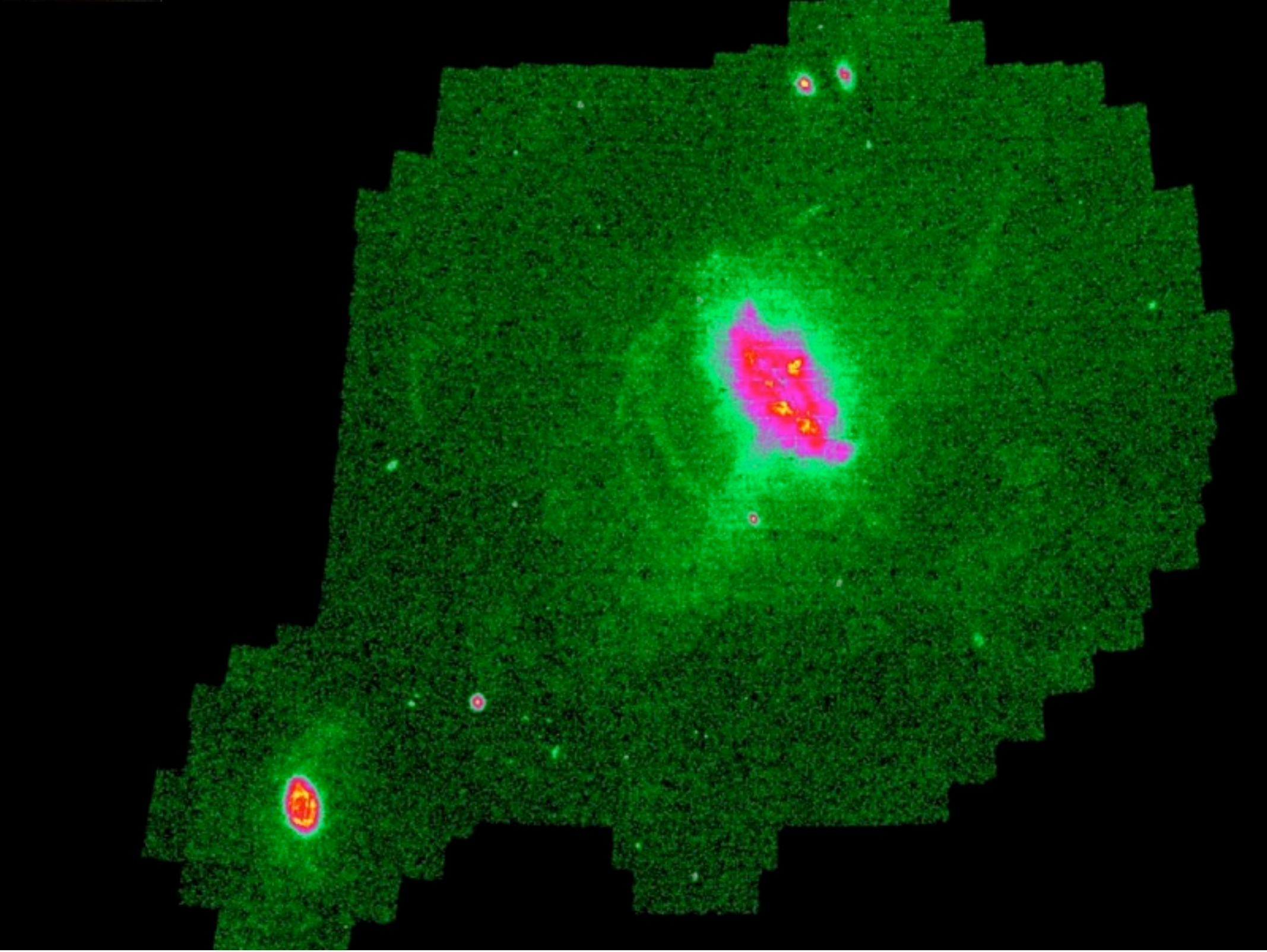
# PAndAS' footprint

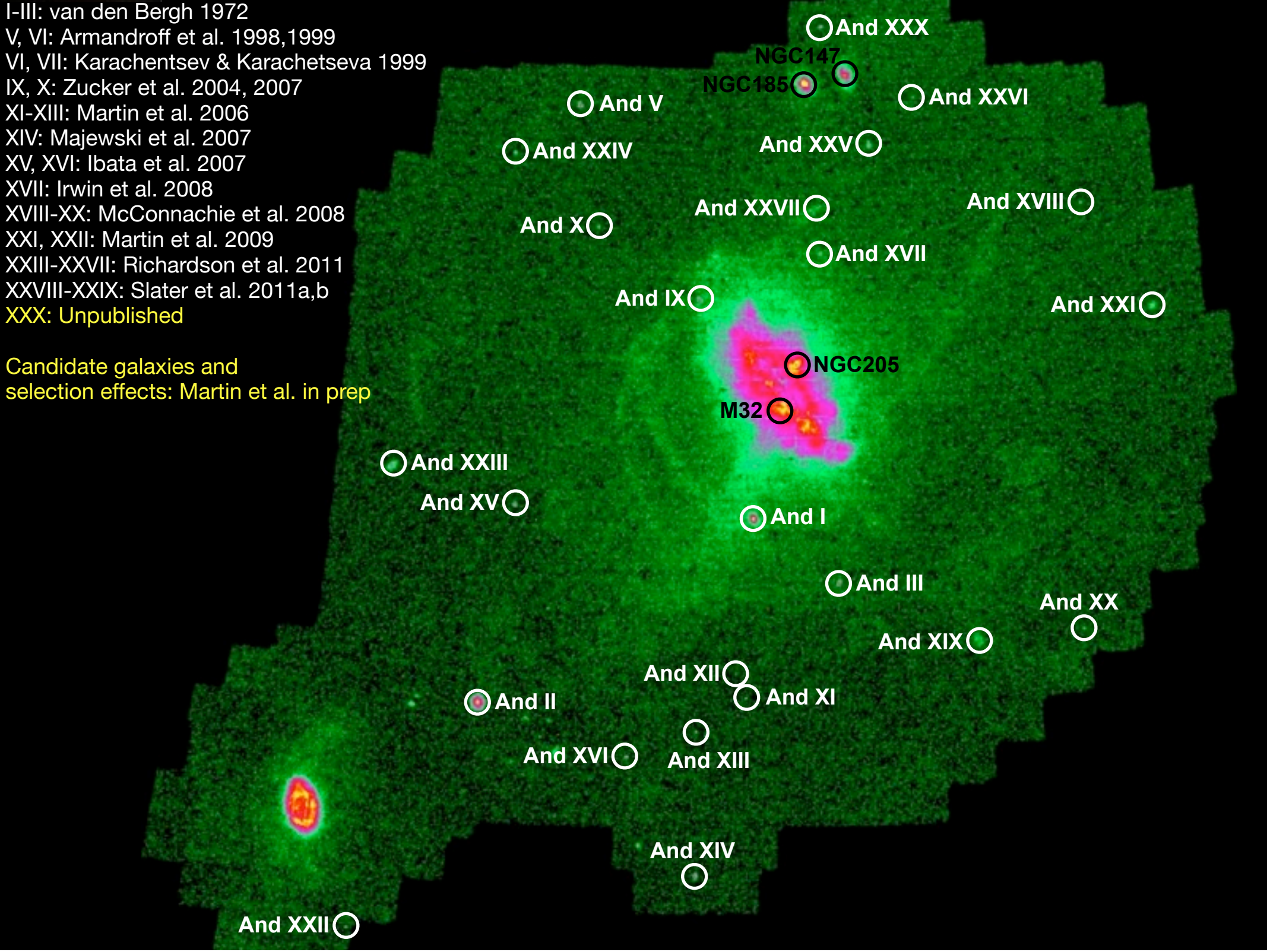
Metal-poor RGB



# PAndAS' footprint





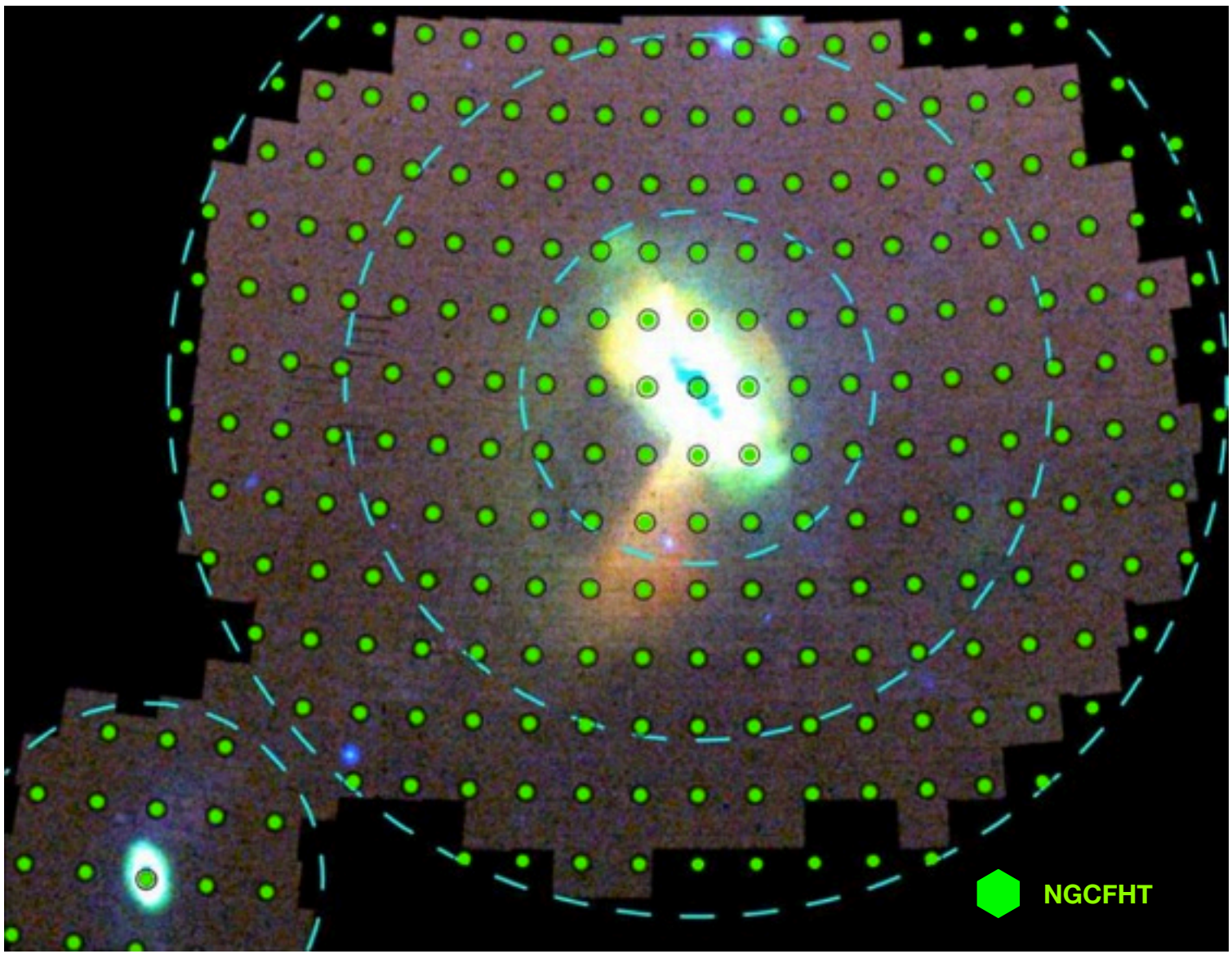

I-III: van den Bergh 1972
V, VI: Armandroff et al. 1998,1999
VI, VII: Karachentsev & Karachetseva 1999
IX, X: Zucker et al. 2004, 2007
XI-XIII: Martin et al. 2006
XIV: Majewski et al. 2007
XV, XVI: Ibata et al. 2007
XVII: Irwin et al. 2008
XVIII-XX: McConnachie et al. 2008
XXI, XXII: Martin et al. 2009
XXIII-XXVII: Richardson et al. 2011
XXVIII-XXIX: Slater et al. 2011a,b
XXX: Unpublished
Candidate galaxies and
selection effects: Martin et al. in prep
And XXX
NGC147
NGC185
And V
And XXVI
And XXIV
And XXV
And XXVII
And XVIII
And X
And XVII
And IX
And XXI
NGC205
M32
And XXIII
And XV
And I
And III
And XX
And XIX
And XII
And XI
And II
And XVI
And XIII
And XIV
And XXII

# Near field cosmology

- Instead of looking at galaxy formation in situ, we can use study the fossil remnants of the galaxy formation process in the nearest galaxies
- Here, ages of stars correspond to the redshifts at which they were formed
- Dynamical and structural studies of nearby galaxies connect to the structure formation process
- Star formation and chemical abundance studies give important information on the baryonic processes governing galaxy growth, and allow us to associate these processes with timescales
- The most detailed information will always be possible for the Milky Way, although external galaxies give us vital panoramic information and allow us to explore other morphological types

# Looking forward...

# Looking forward...from star counts to a velocity field?



# The Canada-France-Hawaii Telescope


- The Canada-France-Hawaii Telescope (CFHT) is a 3.6m optical and infrared telescope located on the summit of Mauna Kea, Hawaii (4204 m).

- First light in 1979
- 1979-1993:“best in the world”
  - various CCD and IR imagers; HRCam; HIFI; Herzberg, coudé and UV Prime spectrographs; CIGALE; etc.
- 1993-2010:“best in class”
  - Gecko, MOS/OSIS, Fabry-Pérot, OASIS, FTS, KIR, Redeye, CHFT-IR, PUEO, FOCAM, MOCAM, UH8K, CFH12K, etc
  - MegaCam (2003),WIRCam (2005), ESPaDOns (2005)
- 2010-2020:
  - short-term: `IMAKA, SITELLE, SPIRou, ~~or Gyes~~: available between 2013 to 2016?
  - long-term: upgrade to a Next Generation CFHT (ngCFHT)?
- Located at one of the world’s premier astronomical sites:
  - median seeing (free atmosphere) of 0.4˝
  - median precipitable water vapour=0.9mm
  - useable nights: 80% spectroscopic, 55% photometric.

# 2020+ : Telescopes in perspective

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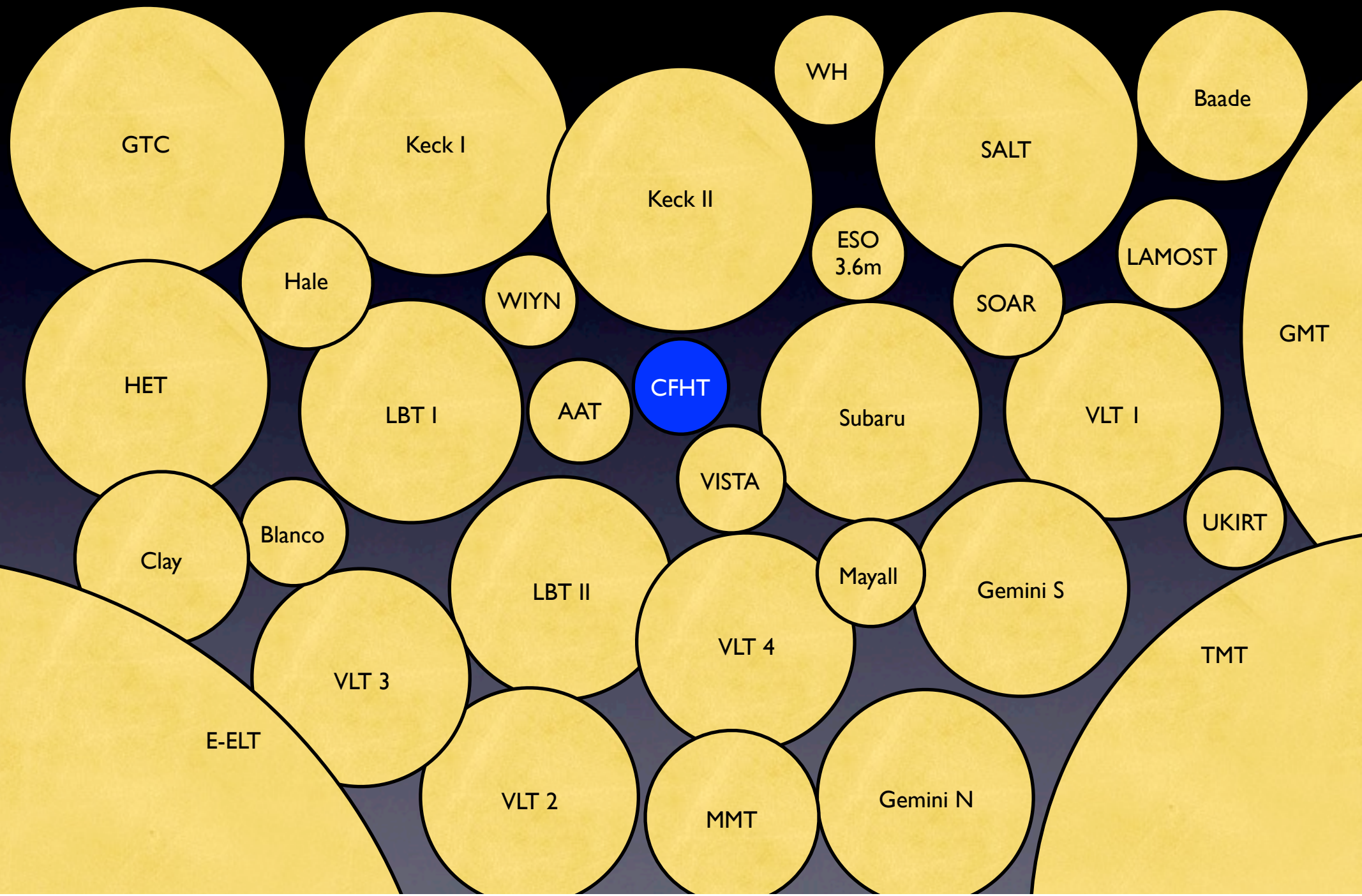
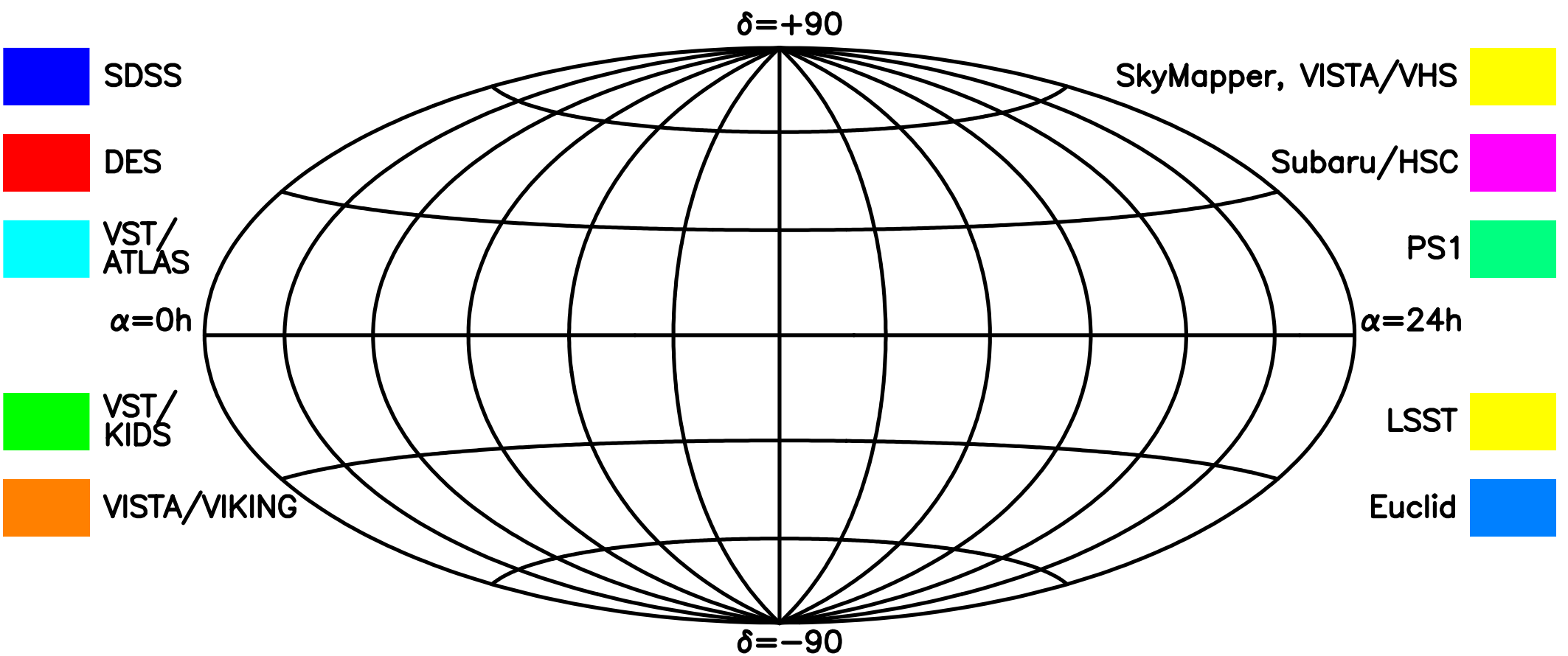


# Wide Field Imaging Facilities: 2010 - 2020+

| Instrument | Telescope | $D_{M1}$ (m) | Status | λ | Available | FOV ($deg^2$) | AΩ ($m^2$ $deg^2$) |
|---|---|---|---|---|---|---|---|
| MegaCam | CFHT | 3.6 | Existing | Optical | 2003 | 1 | 10.2 |
| WIRCAM | CFHT | 3.6 | Existing | IR | 2005 | 0.11 | 1.2 |
| PS1 | PS1 | 1.8 | Existing | Optical | 2009 | 7.3 | 18.6 |
| VISTA | VISTA | 4.0 | Existing | IR | 2010 | 0.6 | 7.5 |
| Skymapper | Skymapper | 1.35 | Existing | Optical | 2011 | 5.7 | 8.2 |
| **HSC** | **Subaru** | **8.2** | **Pending** | **Optical** | **2012** | **1.7** | **90** |
| ODI | WIYN | 3.5 | Pending | Optical | 2012 | 1 | 9.6 |
| DEC | Blanco | 4.0 | Pending | Optical | 2012 | 3 | 38 |
| PS2 | PS2 | 2x1.8 | Pending | Optical | 2012 | 7.3 | 37 |
| IMAKA | CFHT | 3.6 | Proposed | Optical | 2016 | 0.5 | 5.1 |
| LSST | LSST | 8.4 | Proposed | Optical | 2019 | 6.7 | 370 |
| Euclid | Euclid | 1.2 | Proposed | IR/Optical | 2018: | 0.5 | 0.6 |
| WFIRST | WFIRST | 1.5 | Proposed | IR/Optical | >2020 | 0.5 | 0.9 |

# Wide Field Imaging Facilities: 2010 - 2020+



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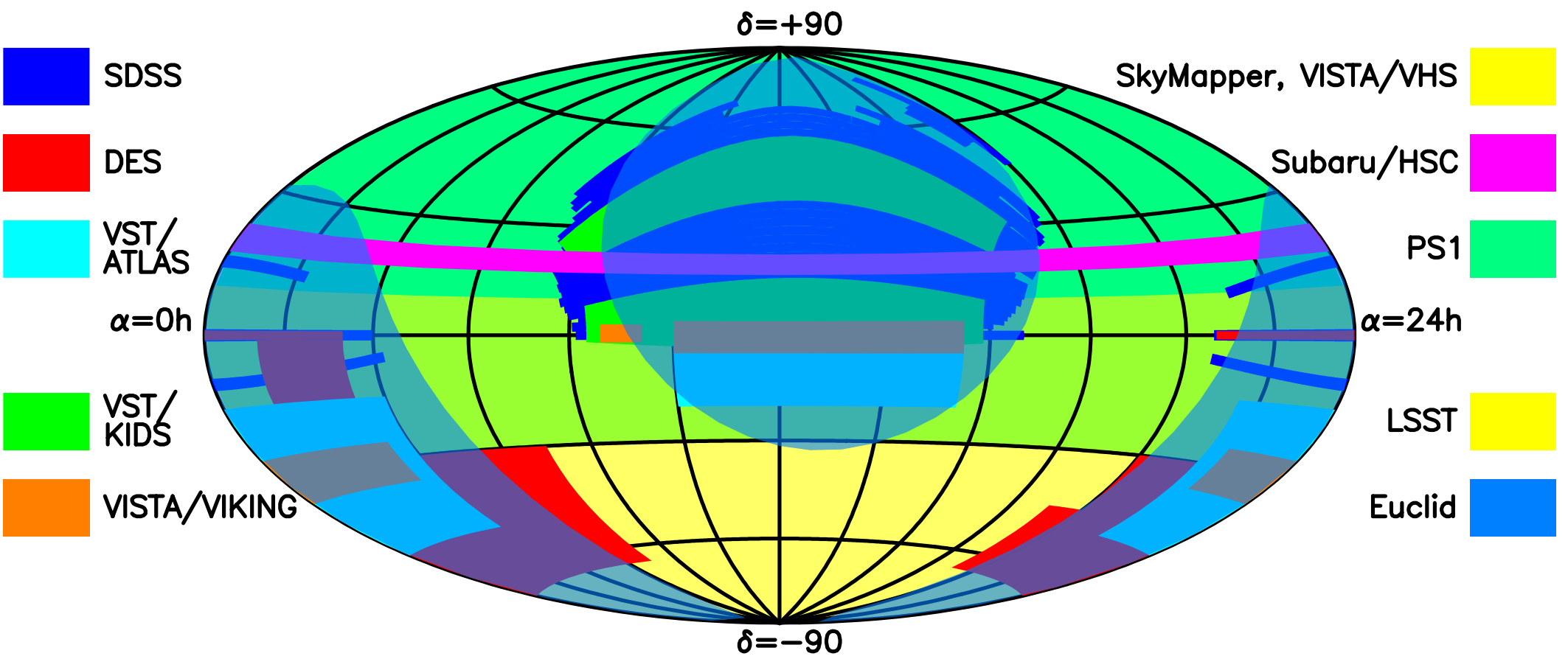


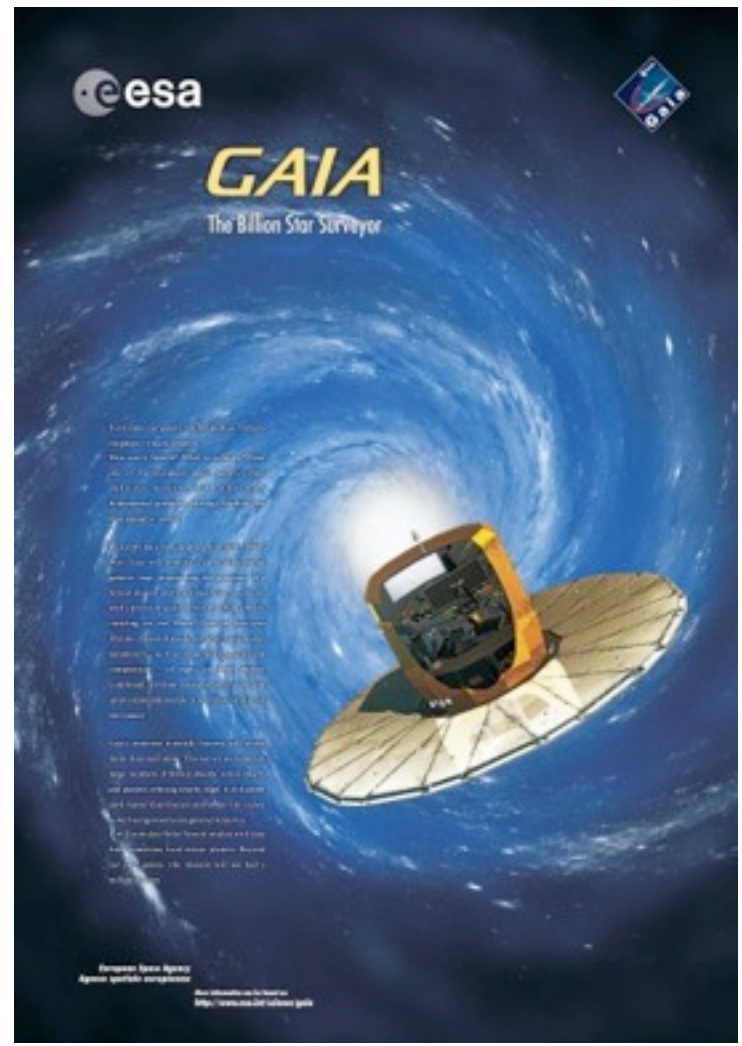
# Forthcoming astrometric missions

- **GAIA** - Near Field Cosmology in the Milky Way

- Launches in 2012. Nominal 5 year lifetime. All sky survey

- Astrometric catalogue complete to V ~ 20 (~1 billion stars)
- Parallaxes: median parallaxes of
  - 4 μas at V=10 mag
  - 11 μas at V=15 mag
  - 160 μas at V=20 mag
- Spectroscopy:
  - Radial velocities: <15 km $s^{-1}$ to V=16-17 mag
  - Astrophysical information (interstellar reddening, atmospheric parameters, rotational velocities) for V < 13 mag
  - Element abundances for V <12

- AAT/HERMES expected to follow-up on GAIA for southern sky, obtaining hi- res spectra (R~28000) for ~1 million stars to V~14 @S/N>100



# The Next Generation CFHT Proposal

- There is an extraordinary opportunity to capitalize on the need for extensive, wide field, highly multiplexed, optical/infrared spectroscopy in the coming decades

- The Next Generation CFHT concept: create a new and expanded partnership to:

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- The Next Generation CFHT concept: create a new and expanded partnership to:

1. replace the present 3.6m primary mirror with a 10m-class (segmented) mirror, mounted on the existing pier.

2. install a **dedicated** wide-field (1.5 deg$^2$) multi-object spectrograph that can simultaneously collect spectra for >3000 sources.

3. do this by 2020 and immediately begin spectroscopic surveys.
   - ngCFHT will provide an **essential spectroscopic compliment** to MegaCam, PS1, HyperSuprimeCam, Skymapper, WIYN-ODI, GAIA, LSST, EUCLID and WFIRST
   - ngCFHT will enable **focussed scienc**e on key targets

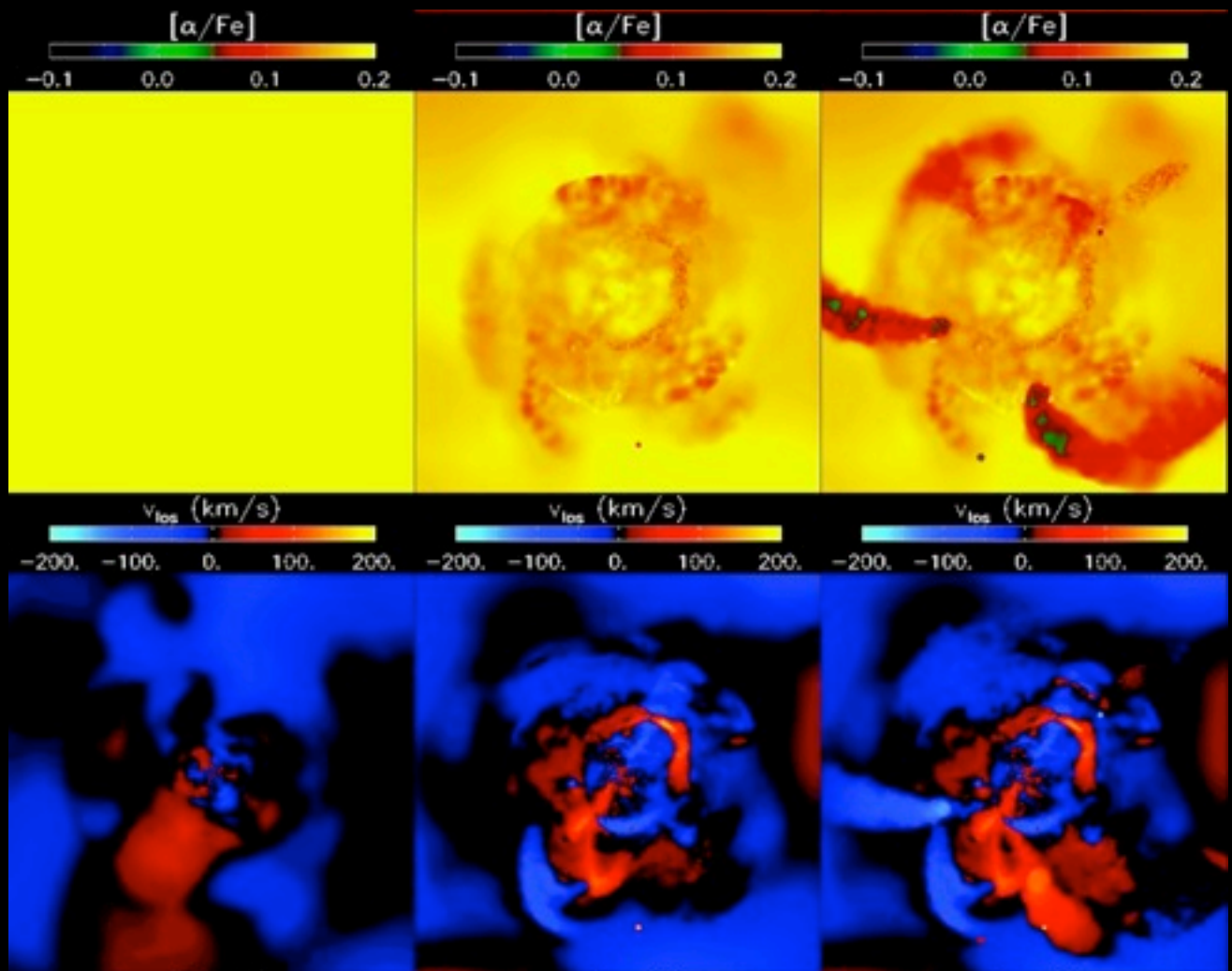
# The next generation of the CFHT:
# A dedicated 10-m, spectroscopic, wide-field telescope with extreme multiplexing

| | | | | |
|---|---|---|---|---|
| Primary Mirror | 10m (segmented) | | | |
| Field of View | 1.4 degree FOV (circular); Omega=1.5 sq. degree | | | |
| Vignetting | <15% | | | |
| Wavelength Range | 370 - 970nm | | | |
| IQ | FWHM < 0.55 arcsecs (free atm. ~0.40 +/- 0.05) | | | |
| Total system throughput* | 0.15-0.21 (low res) / 0.12-0.18 (hi-res) | | | |
| Spectral Resolution* | **1500**<br>420-650 | **3500**<br>630-970 | **5000**<br>480-550/815-885 | **20000**<br>480-680 |
| Fibre diameter * | 1.15 arcsecs (core) | | | |
| No. fibres | 3200 (low + hi-res) / 800 (hi-res with complete wavelength coverage) ] | | | |
| Positioner patrol region | 100 arcsec diameter (with some overlaps) | | | |
| Configuration time* | ~40 seconds | | | |
| $g_{lim}$ [$T_{exp}$=1hr] | 23.1 (R=5000, S/N=5 per A) / 19.7 (R=20000, S/N=20 per A) | | | |

* From Ellis et al.(2009)

# Key science: decoding the DNA of the Galaxy

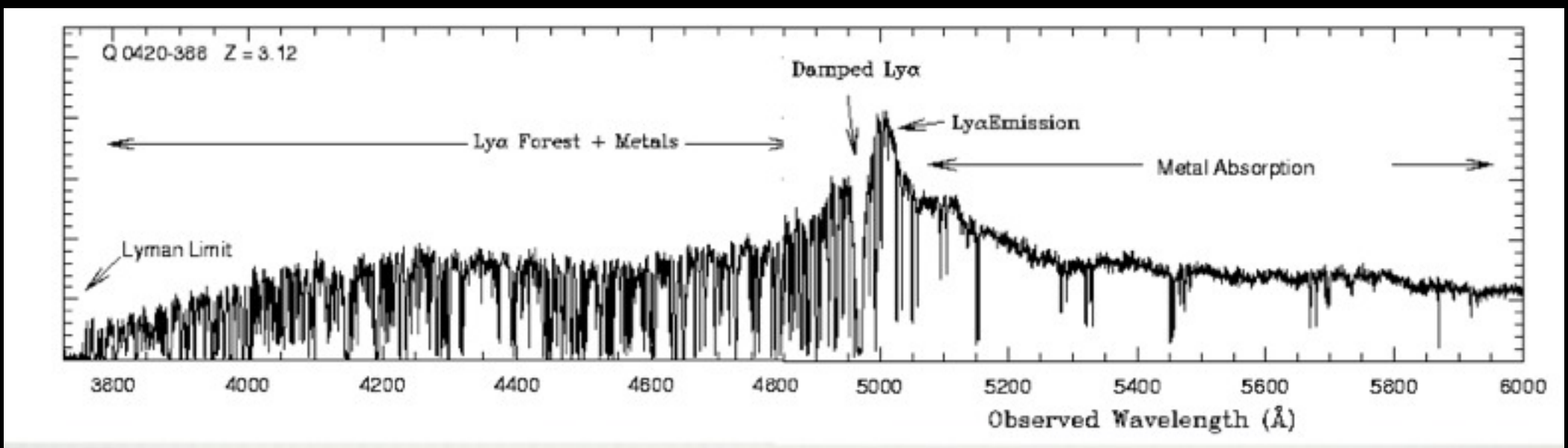
- Near-field cosmology in the Milky Way is a major growth area in astronomy that provides a unique perspective on galaxy formation and has a rich discovery-space
- GAIA (launch 2012/13) will be a truly transformational facility: in addition to precision astrometry, it will provide multi-element abundances for all stars to V~12
- ngCFHT will provide multi-element abundances (+velocities) for stars to V~20(23)
  - PopIII stars
  - Bulge/disks/halo chemo-dynamical decompositions
  - ...




•Bullock, Johnston, Font et al.
•Top: simulated alpha-element distribution for an L* galaxy (300x300kpc)
•Bottom: simulated line-of-sight velocity distribution for the simulated galaxy

# Key science: Cosmology and Dark Energy

- Large number of spectroscopic studies underway or proposed to constrain dark energy and the equation of state of the Universe (eg SDSS BOSS, BigBOSS...)
  - Typically smaller telescopes, poorer sites, survey lifetimes of a few years
  - cf. ngCFHT
- Also provide large scale test of General Relativity from structure growth and geometrical measurements
- Dark matter profiles from kinematic tracers of clusters
- Sight-lines probe the IGM density as a function of z. Can use this to study BAO at $2<z<3$ - evolution of w(z) ?



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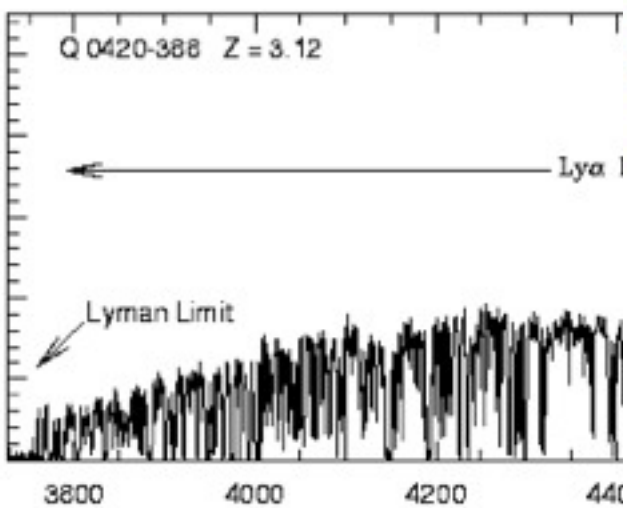
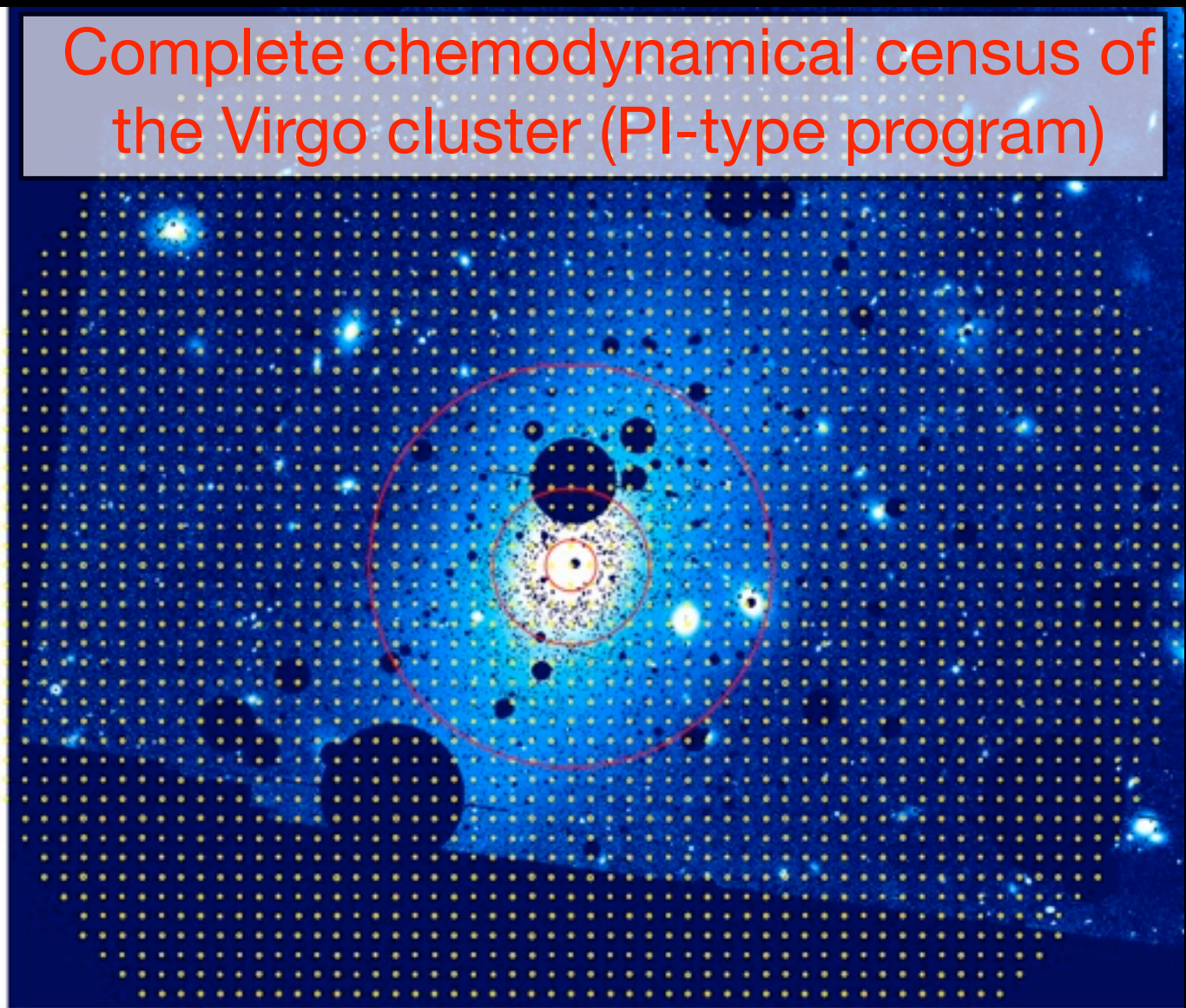



Complete chemodynamical census of the Virgo cluster (PI-type program)



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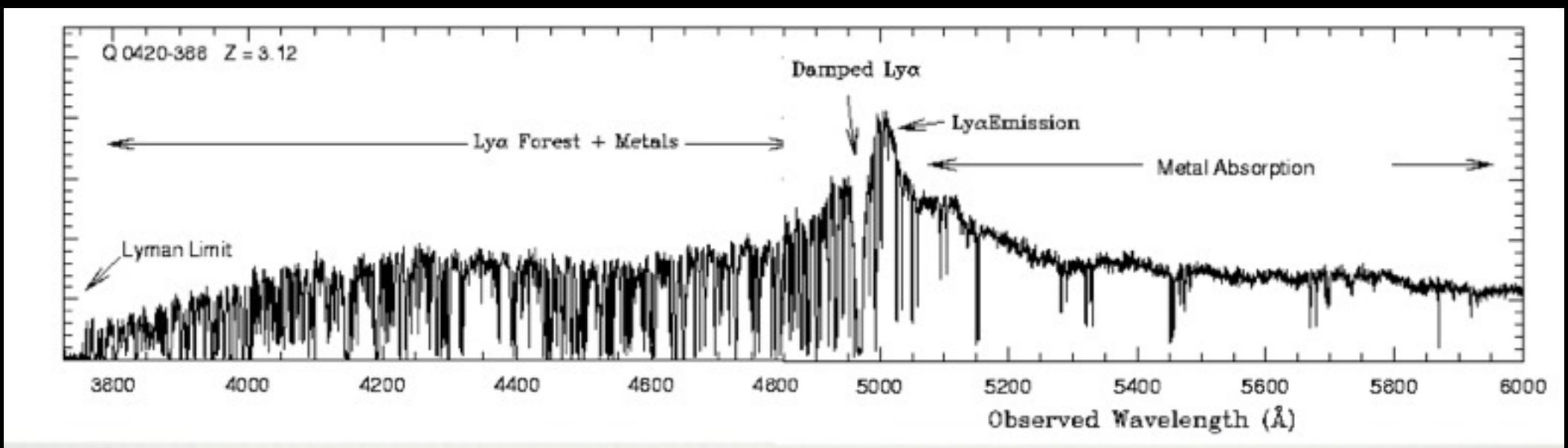

# ngCFHT: a versatile facility for astrophysical research

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- Essential to the scientific impact and versatility of ngCFHT is its operation as a dedicated spectroscopic facility

- Consider a baseline survey of 5 - 10yrs covering ~10000 square degrees of sky with a magnitude limit of g ~ 23.1 (R=5000, dark time) / g ~ 19.7 (R=20000, bright time)


- The only analogous facility in astronomy is the SDSS (similar area, limiting magnitude r ~17.7), with >100000 citations for >3000 papers (to date) in virtually every field of astrophysics

# Mauna Kea and CFHT redevelopment

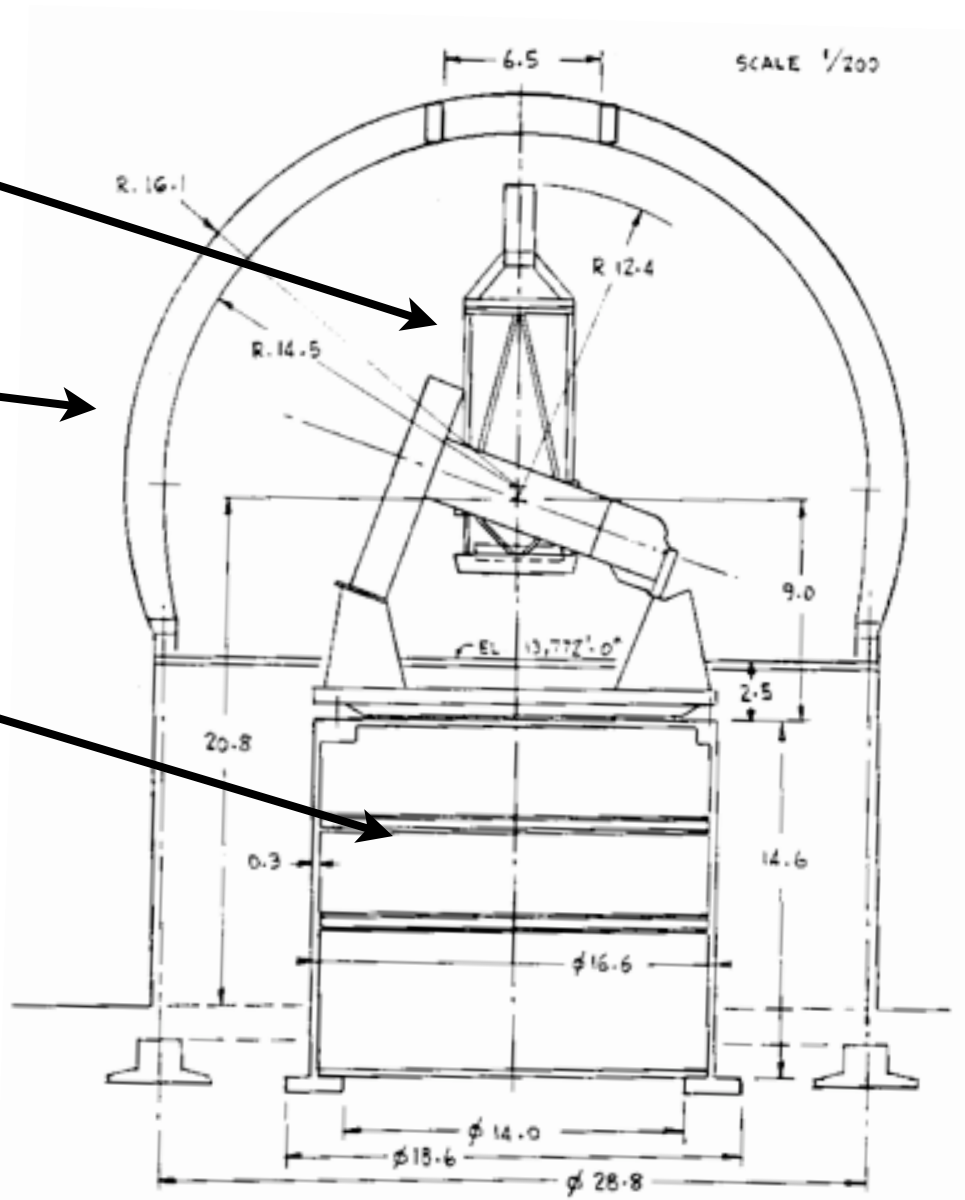
- At present, CFHT remains one of the most productive and high-impact telescopes in the world.
  - Excellent staff and infrastructure.
  - Effective governance model.
  - Considerable expertise with queue observing, implementation of large surveys, and automated data reduction thanks to shift toward wide-field imaging surveys in the 2000s.
- Site is available for redevelopment according to the Mauna Kea Master Plan.

# Mauna Kea and CFHT redevelopment

Telescope

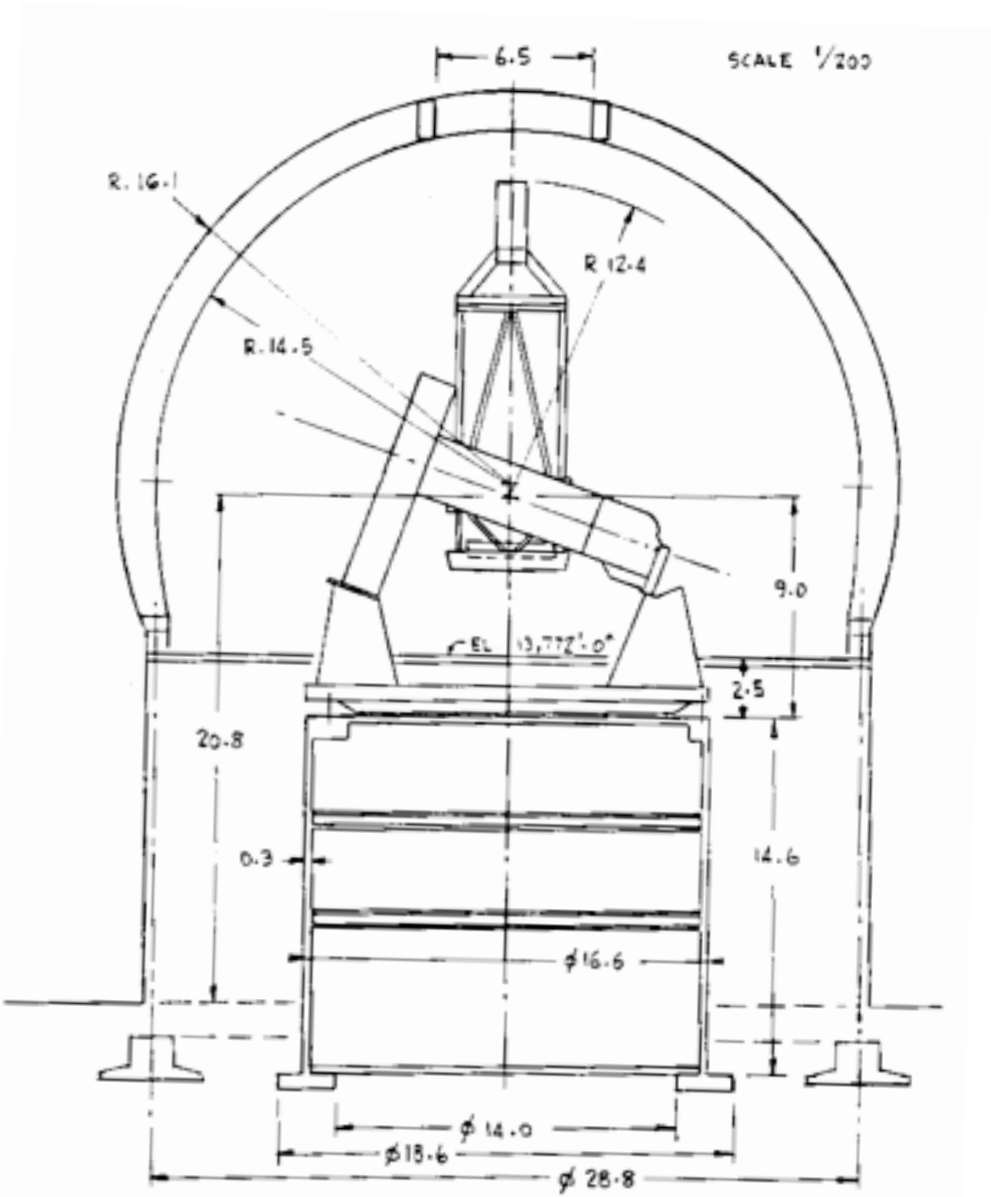
Existing dome with 6.5m shutter

Existing concrete pier




from Grundmann (1997)

# Mauna Kea and CFHT redevelopment



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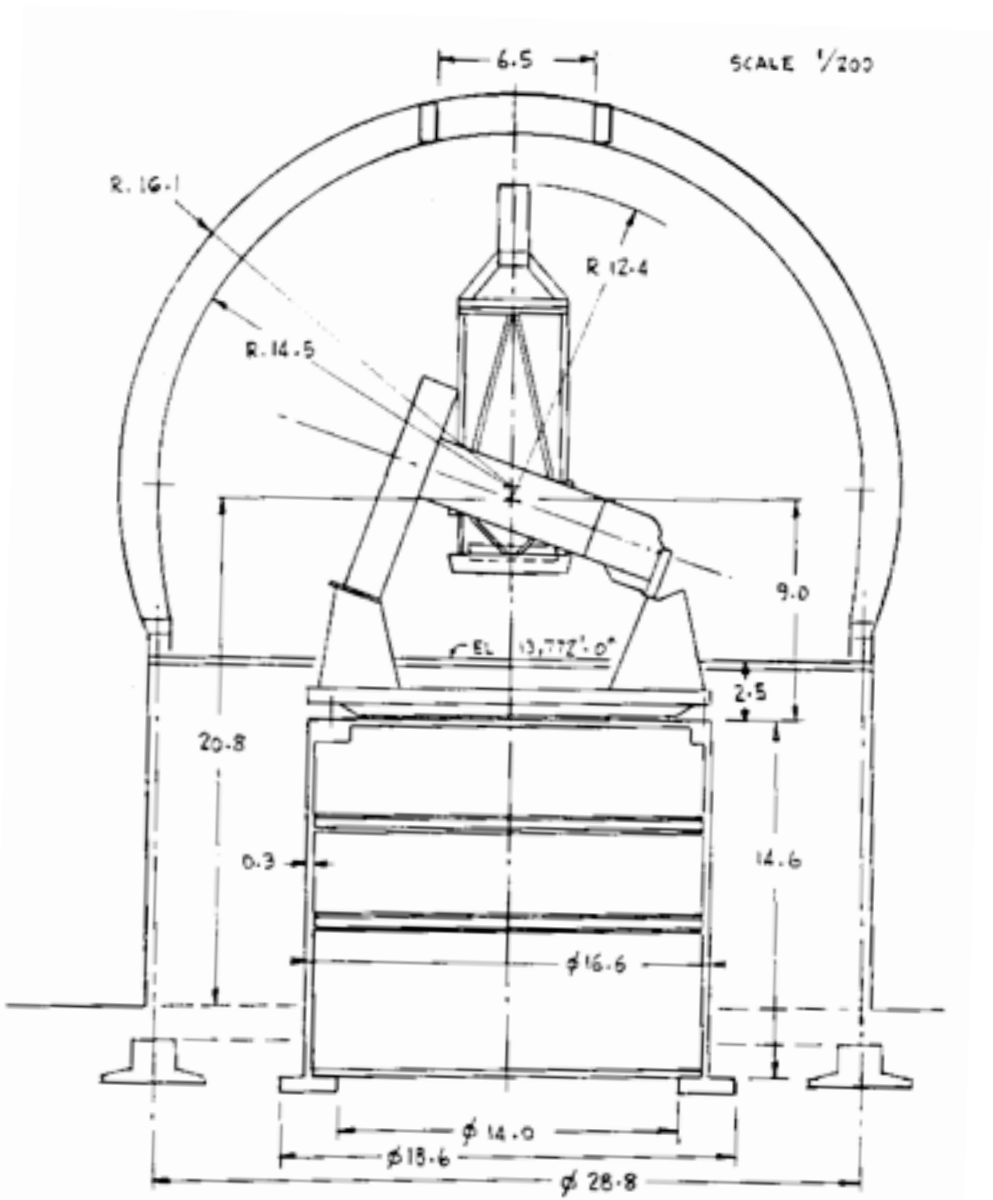
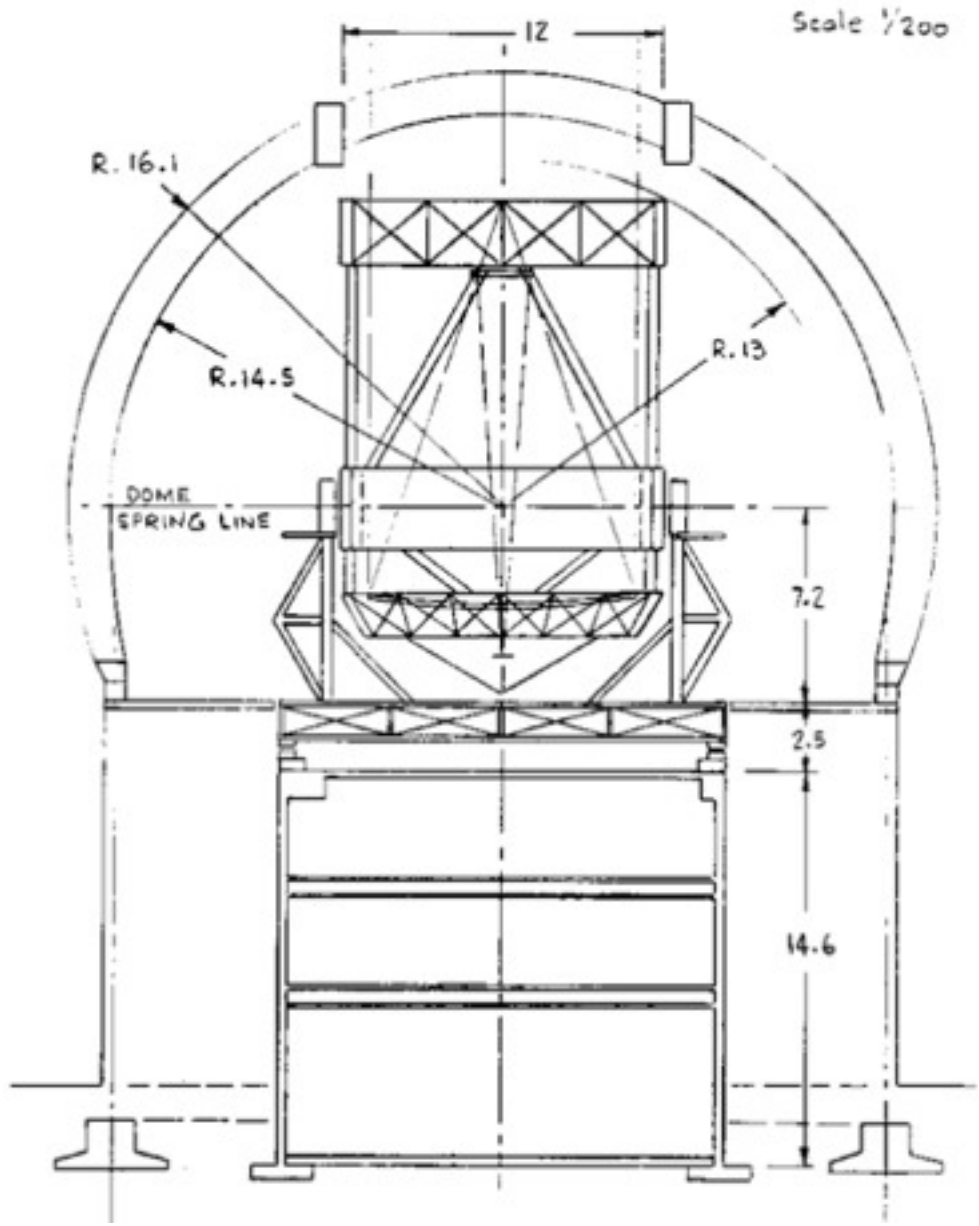


# Mauna Kea and CFHT redevelopment

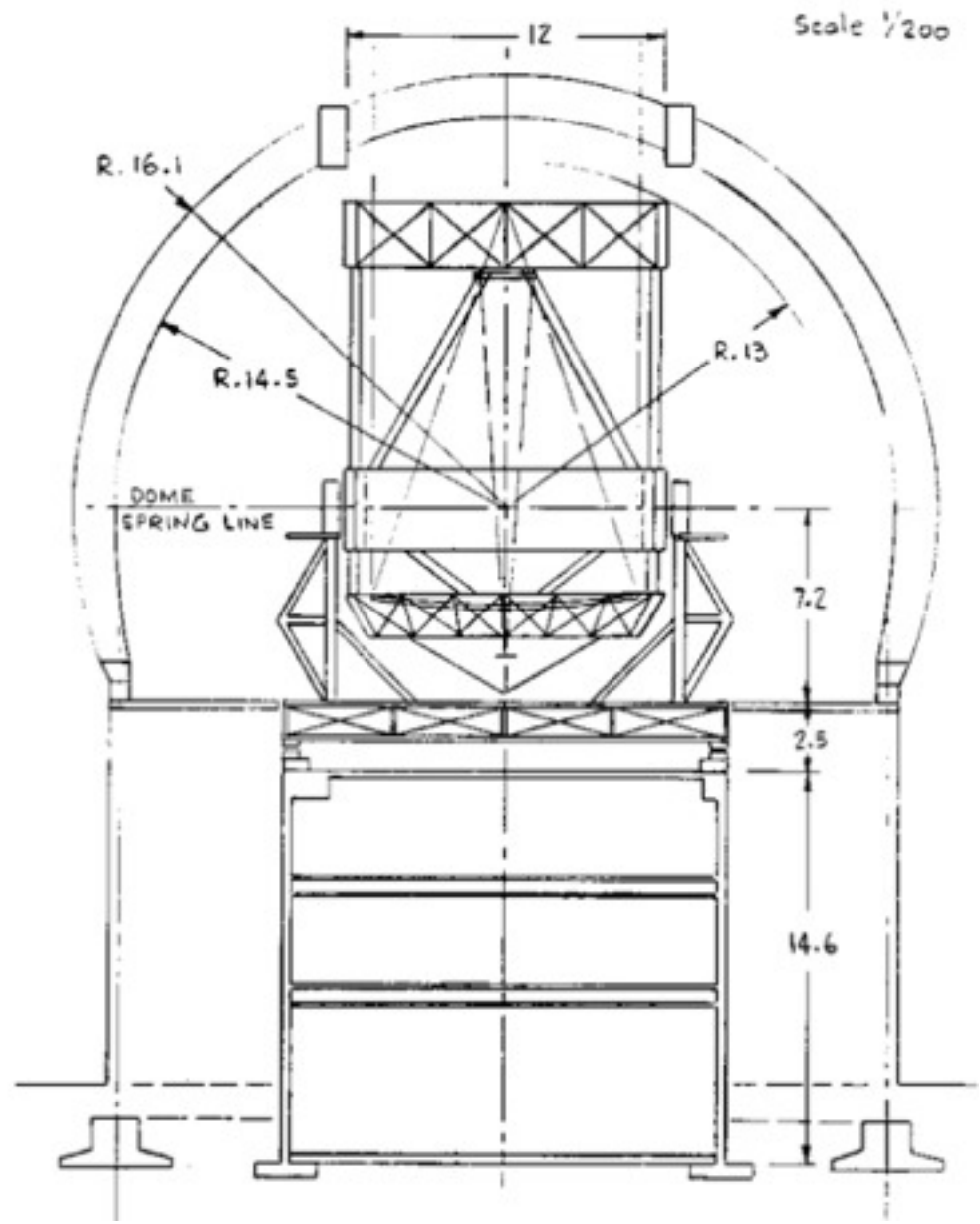
**Mauna Kea Master Plan**

- Allowed to redevelop the CFHT site
- Keep within the same 3-D footprint
- must not harm the ground beyond what has already been done
- the next generation of the CFHT will stay within the same envelope
- the less work done at the summit, the better (e.g., keep the building and pier if possible)

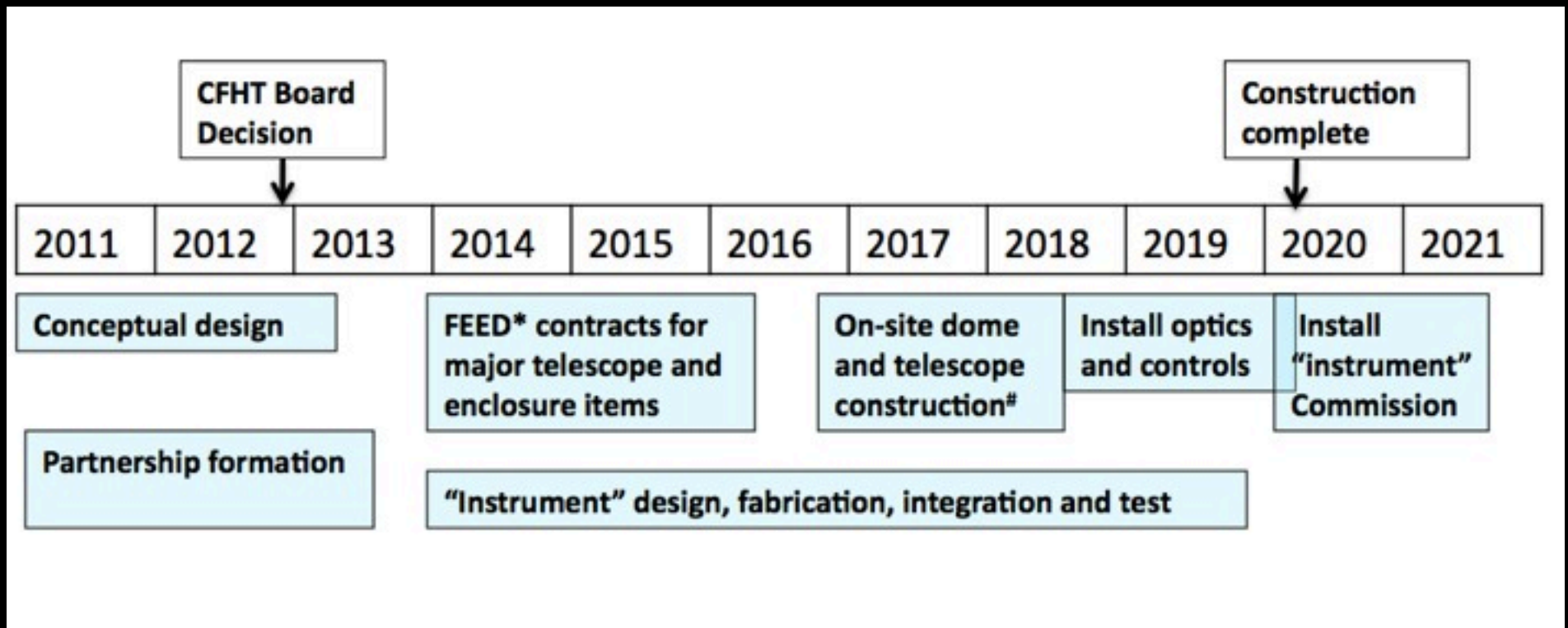
**Redevelopment of CFHT is not a new idea**

- e.g. SAC Working Group on the Future of CFHT (1996)
- Resulted in “CFH 12 - 16m Telescope Study”, Grundmann (1997) [right]

- CFHT 3.6m weighs 266 tonnes
- Keck is 270 tonnes



# Realistic schedule

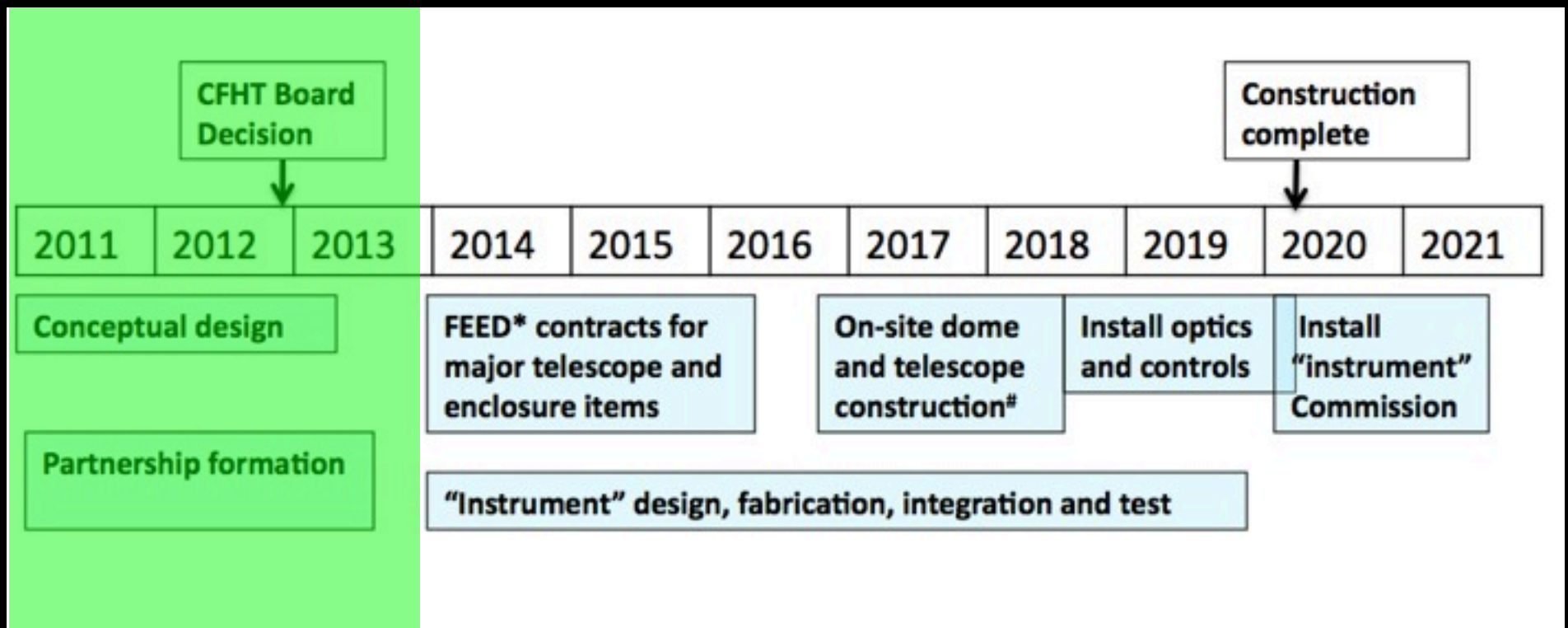



*FEED = "Front-End Engineering Design". Two competing industrial contracts for design and production of each major subsystem, resulting in fixed price offers (compete design rather than requirements)

# On-site construction includes 6 months to remove existing dome and telescope and prepare pier

• "instrument" includes corrector, positioner, fibres, spectrographs, SW, etc.

# Realistic schedule

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# Science Working Groups

- Do the baseline specifications enable transformational science? How do the specifications need to be modified in to maximise the scientific impact in the field?
- Lead scientist of Concept Development Team : Patrick Cote (HIA)

| Science Working Group | Lead Scientist |
|---|---|
| I. Exoplanets | Magali Deleuil |
| II. The Inter-stellar Medium | Rosine Lallement |
| III. Stars and stellar astrophysics | Kim Venn |
| IV. The formation of the Milky Way | Piercarlo Bonifacio |
| V. The Local Group | Alan McConnachie |
| VI. Nearby Galaxies and Clusters | Michael Hudson |
| VII. Galaxy Evolution | Michael Balogh |
| VIII. The Inter-Galactic Medium | Celine Peroux |
| IX. AGN and QSOs | Patrick Hall |
| X. Cosmology and Dark Energy | Pierre Astier |

- All partners and potential partners to participate in SWGS to define the science requirements. Opportunities for collaborations, student placements, etc

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- ngCFHT concept included in Canadian LRP2010 (February 2011). Science case described as “unassailable”

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- Detailed concept study, with reliable estimates of cost, risk and schedule to be submitted to the CFHT Board (November 2012).

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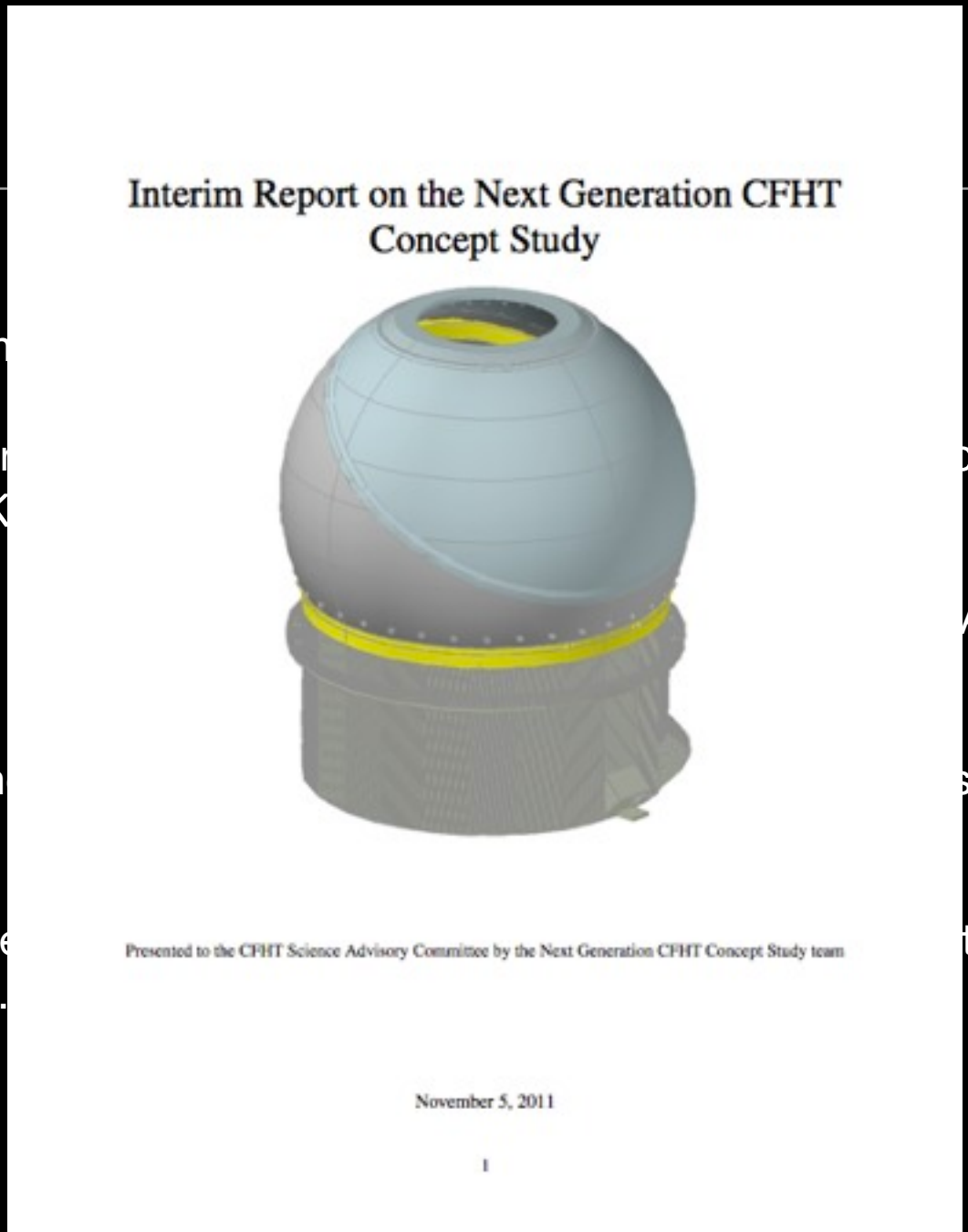


Interim Report on the Next Generation CFHT Concept Study

Presented to the CFHT Science Advisory Committee by the Next Generation CFHT Concept Study team

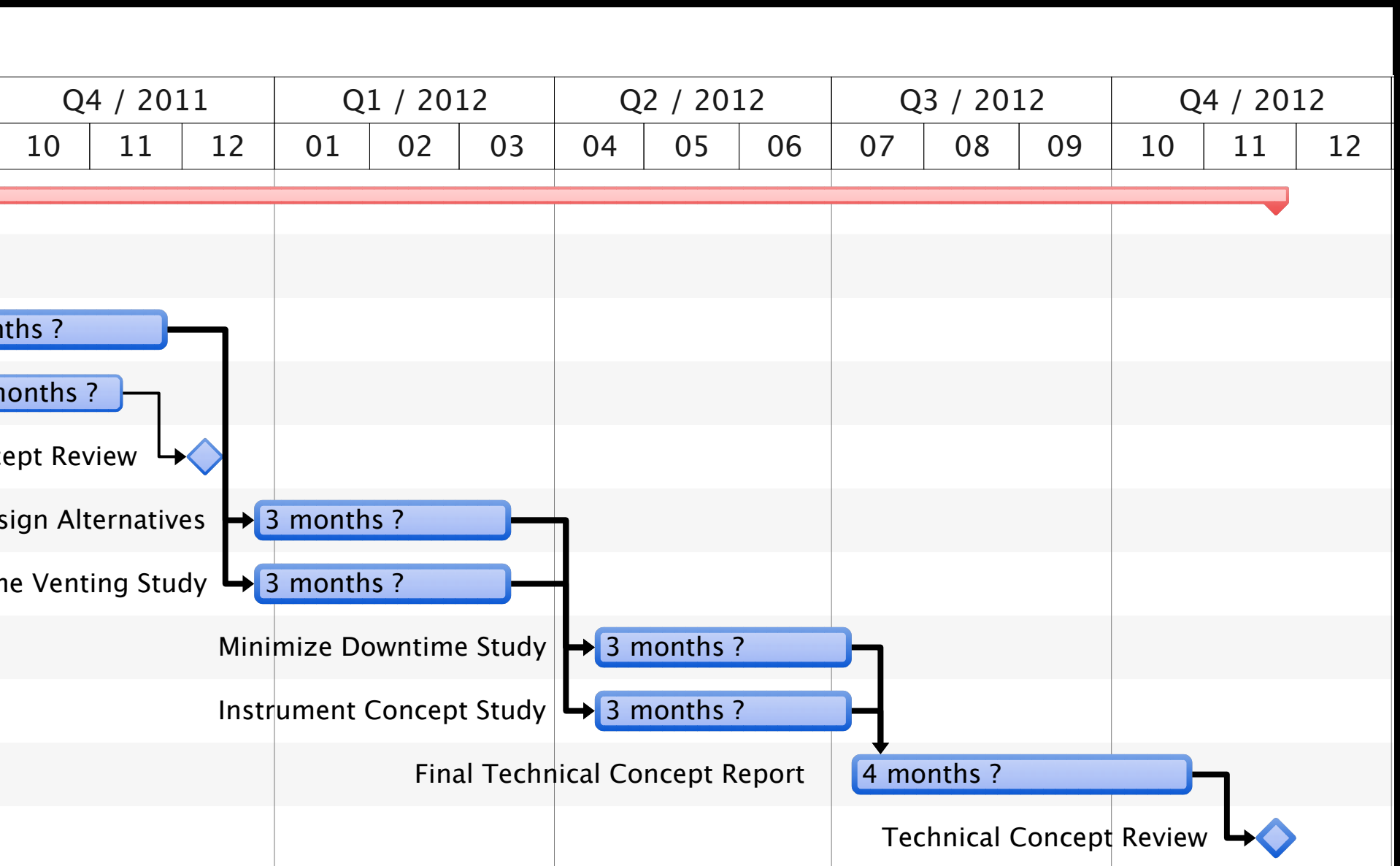
November 5, 2011

1

# Technical development

| # | Title | Q4 / 12 | Q1 / 2011 01 | 02 | 03 | Q2 / 201 04 | 05 |
|---|---|---|---|---|---|---|---|
| 0 | **ngCFHT Technical Concept** | | ngCFHT Technical Concept | | | | |
| 1 | Telescope Pier Study – UBC | | Telescope Pier Study – UBC | | | | 3 mo |
| 2 | Enclosure & Fixed Base Study | | | | | Enclosure & | |
| 3 | Draft Technical Concept Report | | | | | Draft Tech | |
| 4 | Interim Technical Concept Review | | | | | | |
| 5 | Telescope Optical Design Alternatives | | | | | | |
| 6 | Dome Venting Study | | | | | | |
| 7 | Minimize Downtime Study | | | | | | |
| 8 | Instrument Concept Study | | | | | | |
| 9 | Final Technical Concept Report | | | | | | |
| 10 | Technical Concept Review | | | | | | |

# Technical development



# Current cost estimates (revisit as part of Concept study)

| Item | Cost estimate ($M) | Comment |
|---|---|---|
| Design and Management | 10* | Several partners involved |
| Remove 3.6m and dome | 3 | Grundmann $1.6M |
| M1 optics | 10 | ELT heritage |
| M1 support system | 5 | ELT heritage |
| Telescope structure | 20 | DSL, Keck, ELT heritage |
| Wide Field Corrector | 5 | Pazder |
| Enclosure | 20 | DSL, ELT heritage |
| Controls | 10 | CFHT, ELT heritage |
| 30% contigency | 25 | |
| **Sub-total** | **108** | |
| **Instrument** | **65** | WFMOS: includes 20% contingency |
| **Total** | **173** | |

*Assumes involvement of current CFHT staff in addition to above “project” cost

# Current cost estimates (revisit as part of Concept study)

Is $108M credible for telescope and dome?

- Leverage all the ELT activity on segmented telescopes, controls, enclosures
- Leverage CFHT site, building, HQ, infra-structure, experience
- For comparison:
  - Grundmann (1997) estimate $58M (=2010 $75M Bank of Canada inflation)
  - (1992) $63.5M: Keck I dome and telescope cost
  - (2005) $20M SALT cost (~10m aperture, 91 segments, includes 25m dome - but spherical primary and restricted motion)

| | | |
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# ngCFHT in context

1. Kilo-Aperture Optical Spectrograph - KAOS (2002 - 2003) - Defunct
   - prime focus wide-field (1.8 $deg^2$) MOS for Gemini
   - 4000-5000 fibers; $1000 \leq R \leq 40000$
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| | Telescope | Eff. Aperture | Resolution | N | Comments |
|---|---|---|---|---|---|
| BOSS | SDSS | 2.5m | 1600-2600 | 1000 | 10000 sq.deg |
| LAMOST | Guoshoujing Telescope | 4m | 1000-10000 | 4000 | |
| HERMES | AAT | 3.9 | 28000 | 400 | $10^6$ stars, V=15 [GAIA follow-up] |

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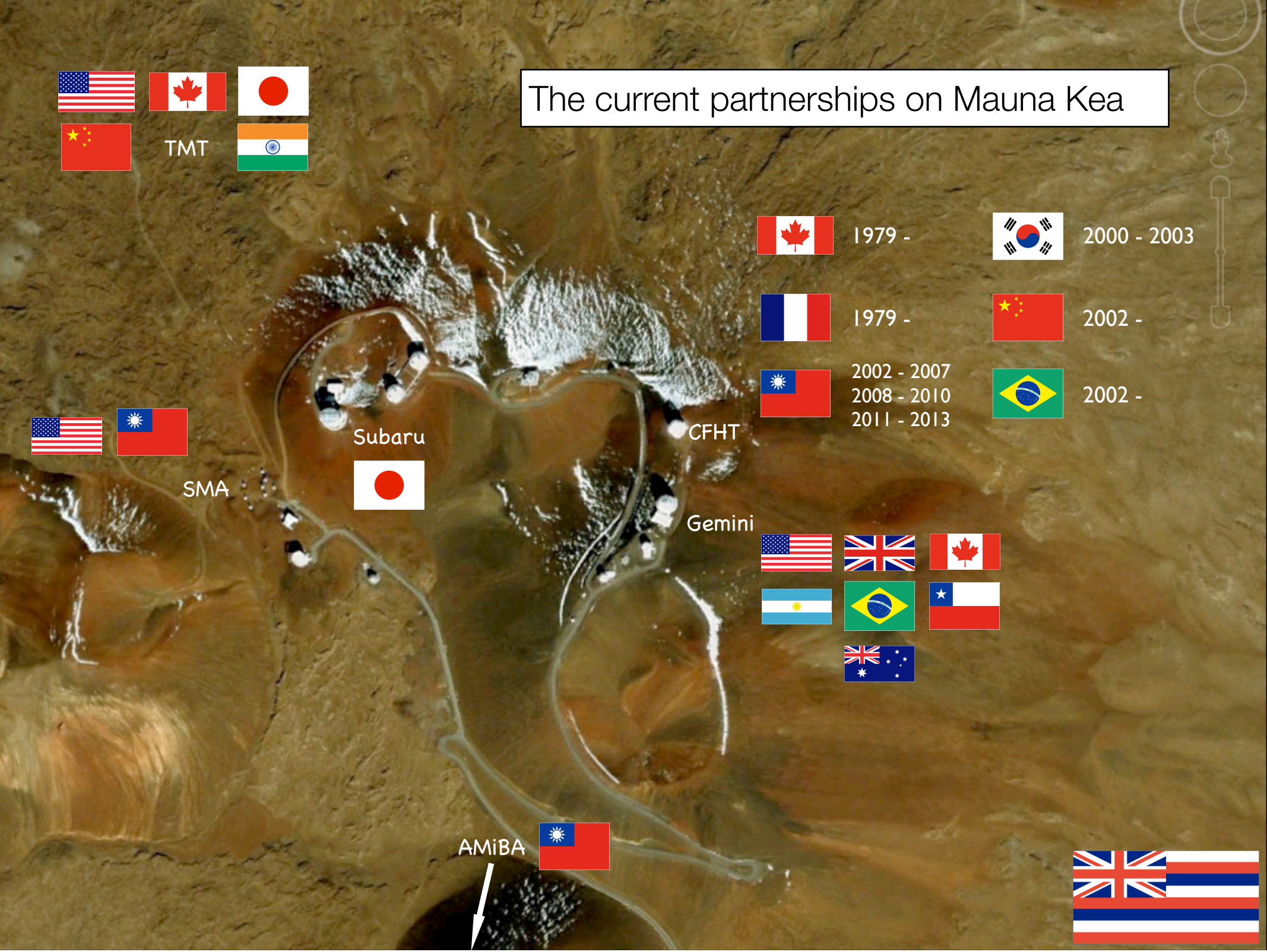
Proposed:

| | | | | | |
|---|---|---|---|---|---|
| BigBOSS | KPNO4m | 4m | 3000-4800 | 5000 | 14000 sq.deg (LRG+OII) |
| PFS | Subaru | 8.2 | ~3000? | 2400 | 2000sq.deg? |
| ngCFHT | ngCFHT | 10m | 1500-20000 | 3200 (800) | |

# Synergies with PFS?

- Japan and the Subaru community is clearly interested in much of the same science as ngCFHT would allow

- How best can we work together to ensure the maximum scientific impact and best results? Much scientific and technical overlap will exist


The current partnerships on Mauna Kea
TMT
1979 -
2000 - 2003
1979 -
2002 -
2002 - 2007
2008 - 2010
2011 - 2013
2002 -
Subaru
CFHT
SMA
Gemini
AMiBA

# Summary

- Exceptionally strong science case to redevelop the CFHT site to provide a dedicated 10m class, wide field, spectroscopic facility with extreme multiplexing working at a range of resolutions from R=1500 to ~20000

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- Participation of prospective new partners in the development of the project is strongly desired so that they can have a defining role in determining its capabilities

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# Fin

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http://orca.phys.uvic.ca/~pcote/ngcfht/Site/The_Next_Generation_CFHT.html