Narrow band filters for CFHT

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Why narrow band filters?

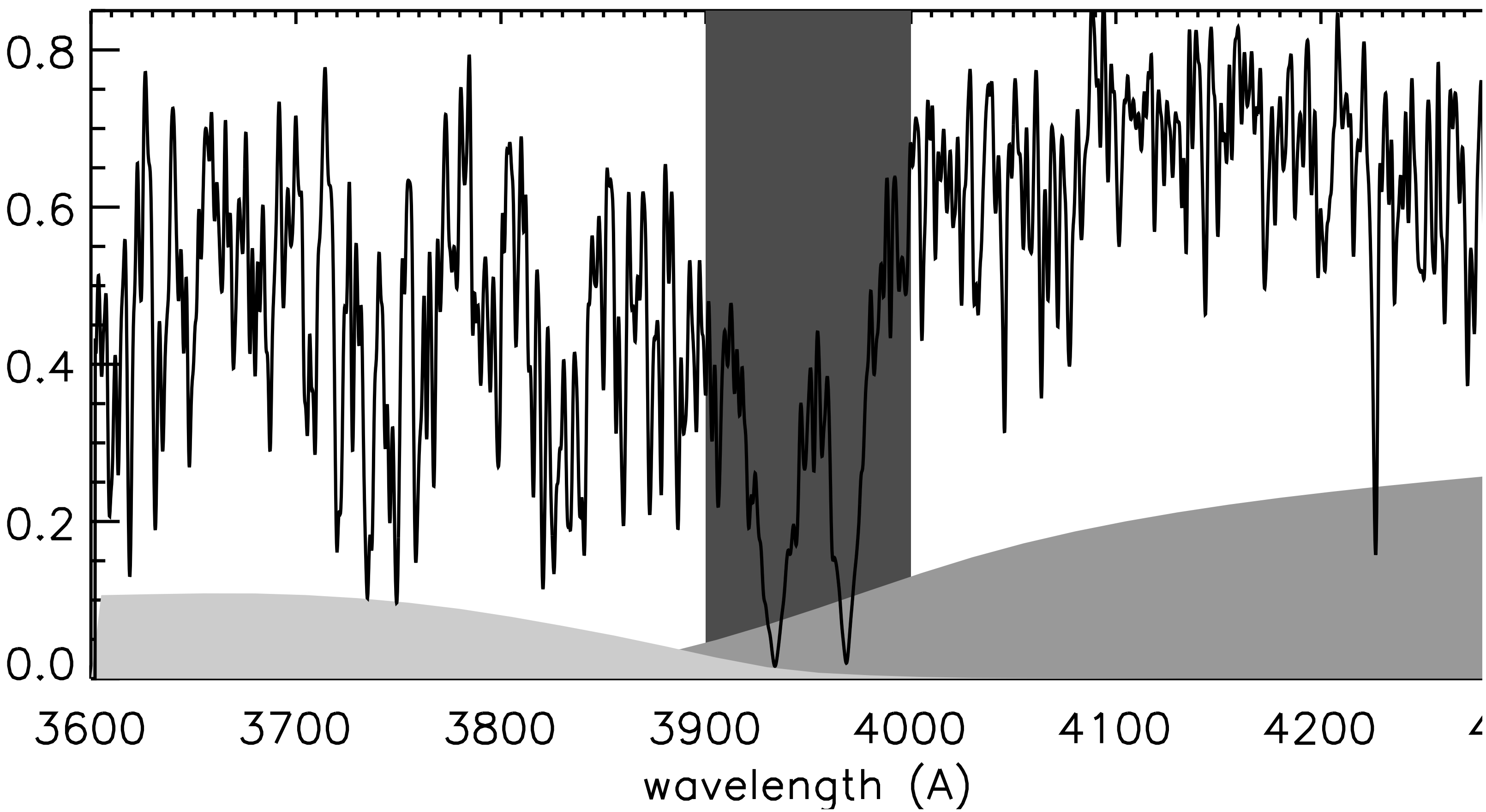
- Currently everything is done in ugriz
  - A large part of the Northern Hemisphere is covered (SDSS, CFHTLS, PanStarrs)
  - But many more science cases could benefit from more specific information
- Extra science cases by adding narrow band filters leveraging the current coverage
  - Cheap - filters cost 30-50K
  - Fast - large areas could be covered, broad band colors already available
    - No need to dedicate the telescope uniquely to these projects

Narrow band filters

- A suite of narrow-band filters for MegaCam*
  - Ca H&K filter (metallicity)
  - MgH (dwarf-giant discrimination for cooler stars)
  - G-band (Carbon)
  - H-alpha (star formation)
  - OIII (star formation and PNe)

*Note that already a suite of narrow-band filters was available for CFHT12K

One specific case: A narrow band filter centered on Ca II H&K



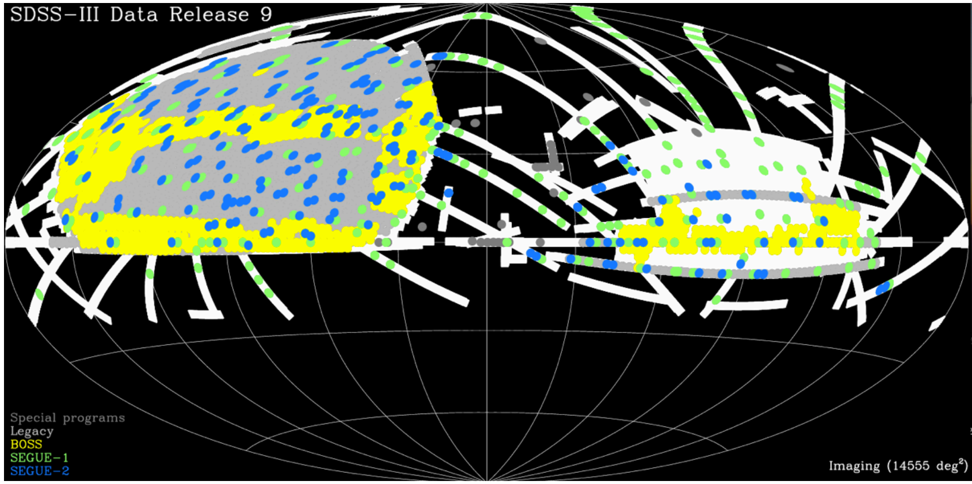
Spectrum: Giant with [Fe/H]=-1
Dark grey: Proposed band for narrow-band filter
Grey: g-band Sloan filter
Light grey: u-band Sloan filter

Motivation

- New narrow-band filter + existing broad-band colors:
  - Machine to find extremely metal-poor targets in the Milky Way
    - Past metal-poor star surveys as the HK survey and Hamburg-ESO survey were all designed around these spectral features – but grism, which has disadvantages
- Materion (formerly Barr Associates): "CaH&K filter will cost ~45-50K"
    - Quote is being prepared.
    - Note that this is one of the more expensive filters as so much red light has to be suppressed

Motivation: Why on CFHT?

- Novel approach in the Northern Hemisphere
- The overlap with the Sloan footprint
  - Broadband ugriz colors are available already
  - SEGUE stars can be used for calibration
- CFHT's excellent site
- Megacam's large field of view

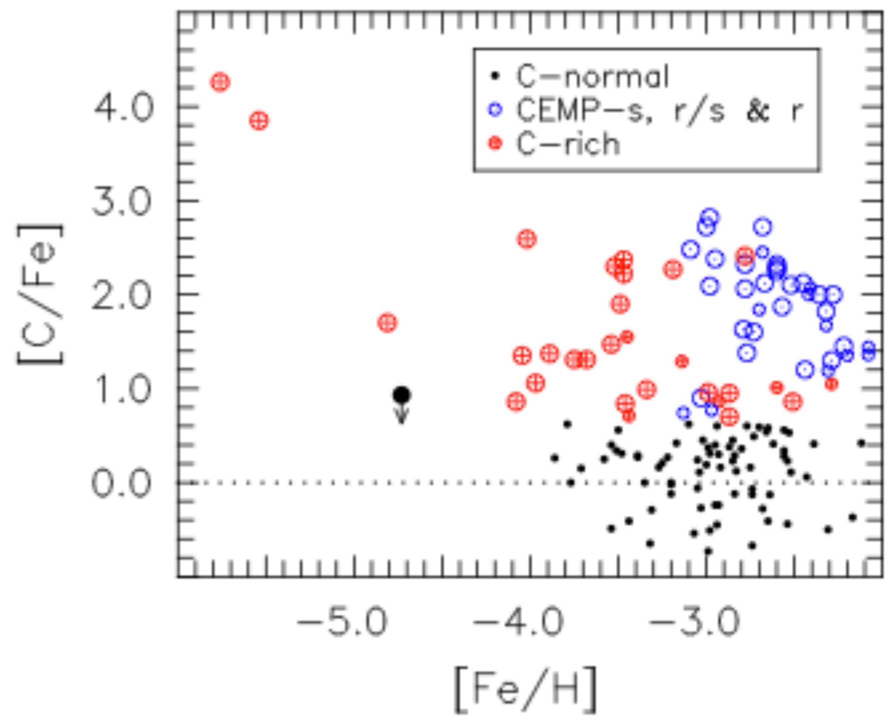


Sloan's footprint and the SEGUE pointings.

Reach required depth efficiently

Motivation: Why metal-poor stars?

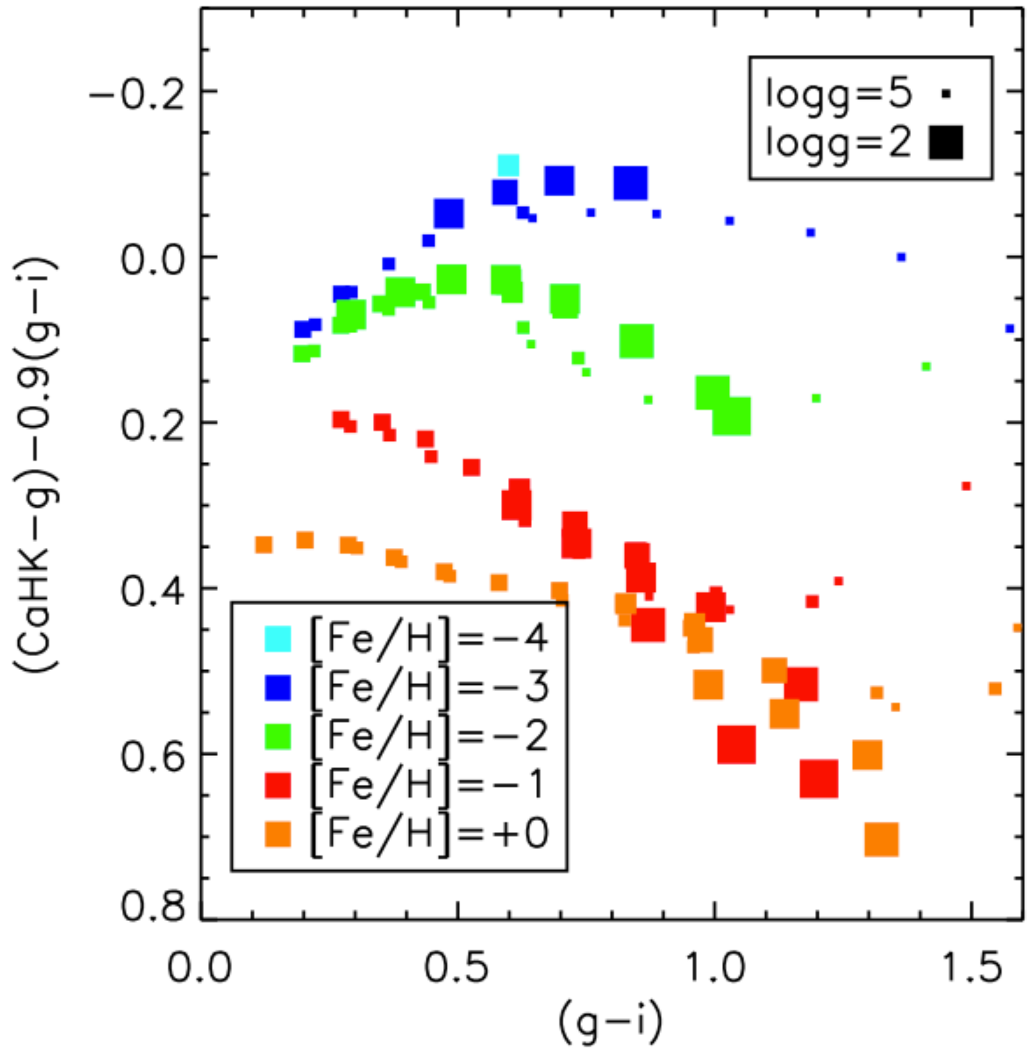
- Our closest observational approach to the First Stars, they teach us about:
  - What were the properties of the First Stars?
  - What are their chemical signatures?
  - Is there a metallicity floor?
  - Probing the early Universe – Epoch of re-ionization
- **Galactic archeaology:** Oldest stars tell the story of the past



From Norris et al., 2013. [Fe/H] and [C/Fe] compilation for metal-poor stars in the literature

Test case

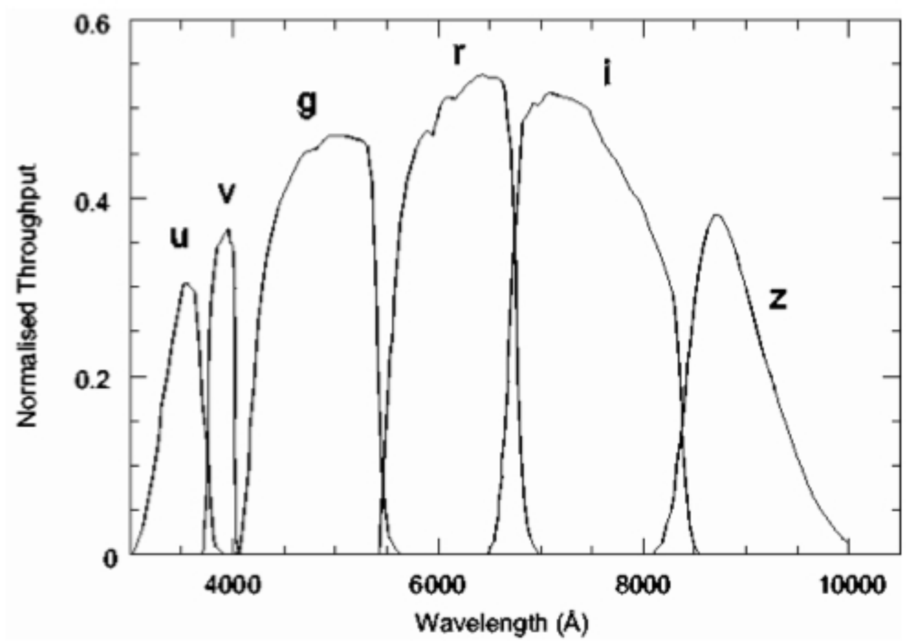
- Input: 10 sq degree TRILEGAL Milky Way model
  - l=200, b=59
  - 14 < g < 22 consistent with Sloan saturation/ depth
- Match each star to the nearest spectrum in a big model grid
  - -4.0 < [Fe/H] < 0.0
- Use filter efficiencies to calculate colors



Excellent parameter space to select metal-poor targets!

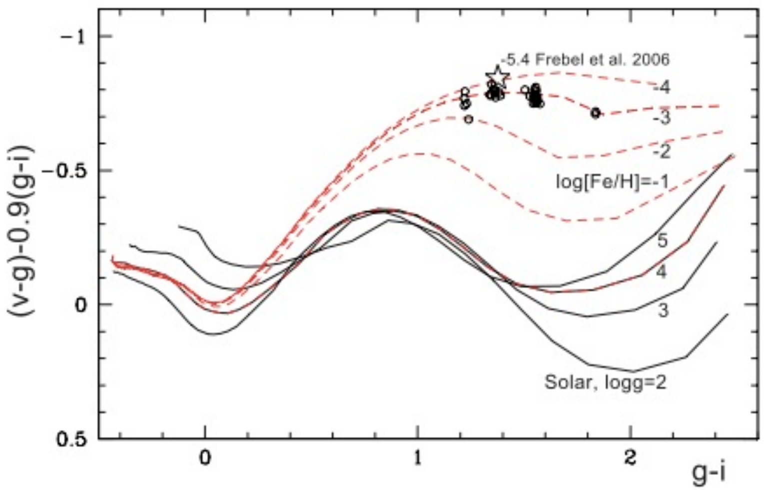
A proven science case: Skymapper

- Skymapper: Multi-colour, multi-epoch of all 20000 sq. degrees south of equator
  - ugriz filters + Stromgren-like v-filter (= Ca H&K)

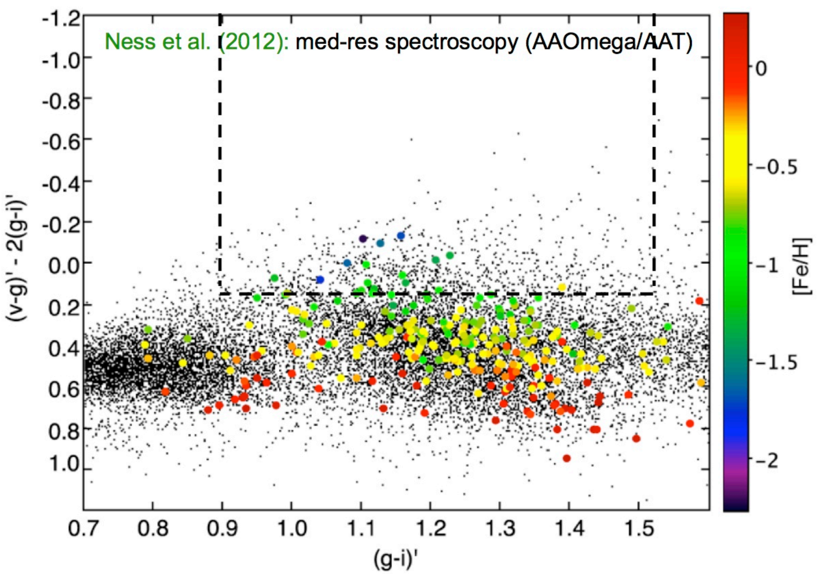


The Skymapper filter set. From: Keller et al., 2007

A proven science case: Skymapper



Predictions: From Keller et al., 2007. Predictions for various metallicities and gravities. Overplotted real EMP stars (Frebel et al., 2005, Cayrel et al., 2004)



Measurements: From Keller et al., 2012. A bulge field with overlapping medium resolution spectroscopy by Ness et al., 2012.

Science output: What to expect?

- SDSS/SEGUE confirmed 70 stars with [Fe/H]<-3 (Aoki et al., 2013), bringing the total at ~150

- Besancon/TRILEGAL: ~4 stars with [Fe/H]<-3 in 1 deg^2 within $14 < g < 22$
  - Number consistent with HES results (Schorck et al., 2009)
  - (= 1 Megacam pointing)
  - In the same field 40 stars with [Fe/H]<-2.5

- Sloan footprint: 14555 deg^2

Science output: What to expect?

- To equal Sloan depth (u=22.3) and get S/N=5 we need 89 sec per field
  - Assuming average conditions: grey time, airmass 1.2, seeing 1.0
  - In the following we include 40 sec overheads
- Just in **24 hrs=4.5 nights** double current sample
- Just **210 hrs=40 nights** would improve by an order of magnitude known [M/H] < -3 stars **at apparent magnitude V<18.5**
  - Bright so they are suitable for follow-up with classical high-resolution instruments
  - Naturally, more candidates will be found that can be followed up with medium-resolution spectra
  - (Using a very realistic 5.2 hrs per night)

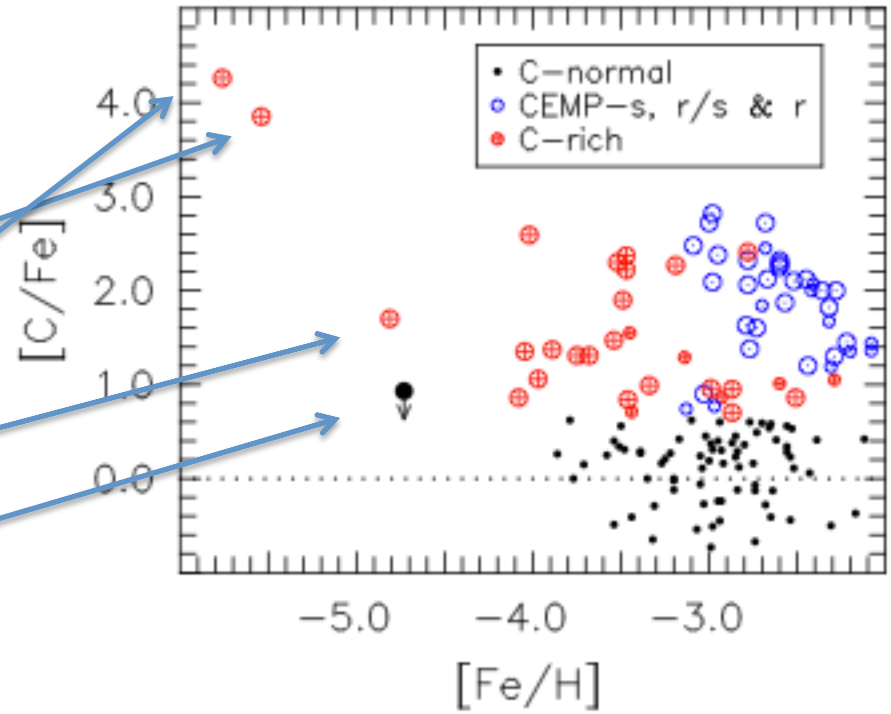
Science output: What to expect?

- Full Sloan area could be covered in **520 hours** assuming average conditions
  - ~100 nights
  - for instance 17 nights per semester for 3 years
- Potentially **~4000 bright** stars ($V<18.5$) with [Fe/H]<-3 to be uncovered

- Will produce catalogue of metal-poor stars for the Northern Hemisphere
- Without **any** follow-up (SEGUE calibration) we can produce the most unbiased metallicity distribution function for the low-metallicity tail

Science output: What to expect?

- The occasional extreme outlier!
  - Christlieb et al., 2002
  - Frebel et al., 2005
  - Norris et al., 2007
  - Caffau et al., 2011
    - Re-defined the metallicity floor
  - Skymapper reports a star that shows no Fe lines in its med-res spectrum!



See presentation by M. Asplund at the ngCFHT workshop: http://ngcfht.cfht.hawaii.edu/presentations/Session3-MAsplund.pdf

Science output: Follow-up

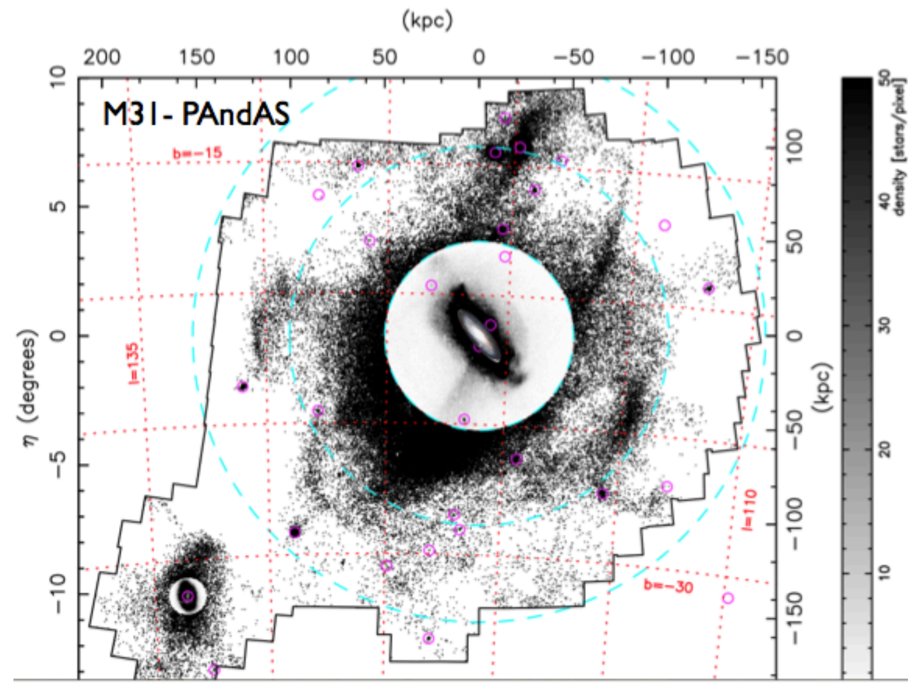
Instruments suitable (and available) for follow up in high- or medium-resolution:

- ESPaDOnS: brightest targets. Superb resolution & high efficiency
- VLT: UVES, FLAMES, X-shooter
  - There is a 40-50% overlap in sky coverage
- GMOS on Gemini North
- Time-exchange programs and/or collaborators to use the high-res spectrographs on Keck/Subaru
- PEPSI spectrograph on LBT
- UES on GranTeCan

} Available in next year

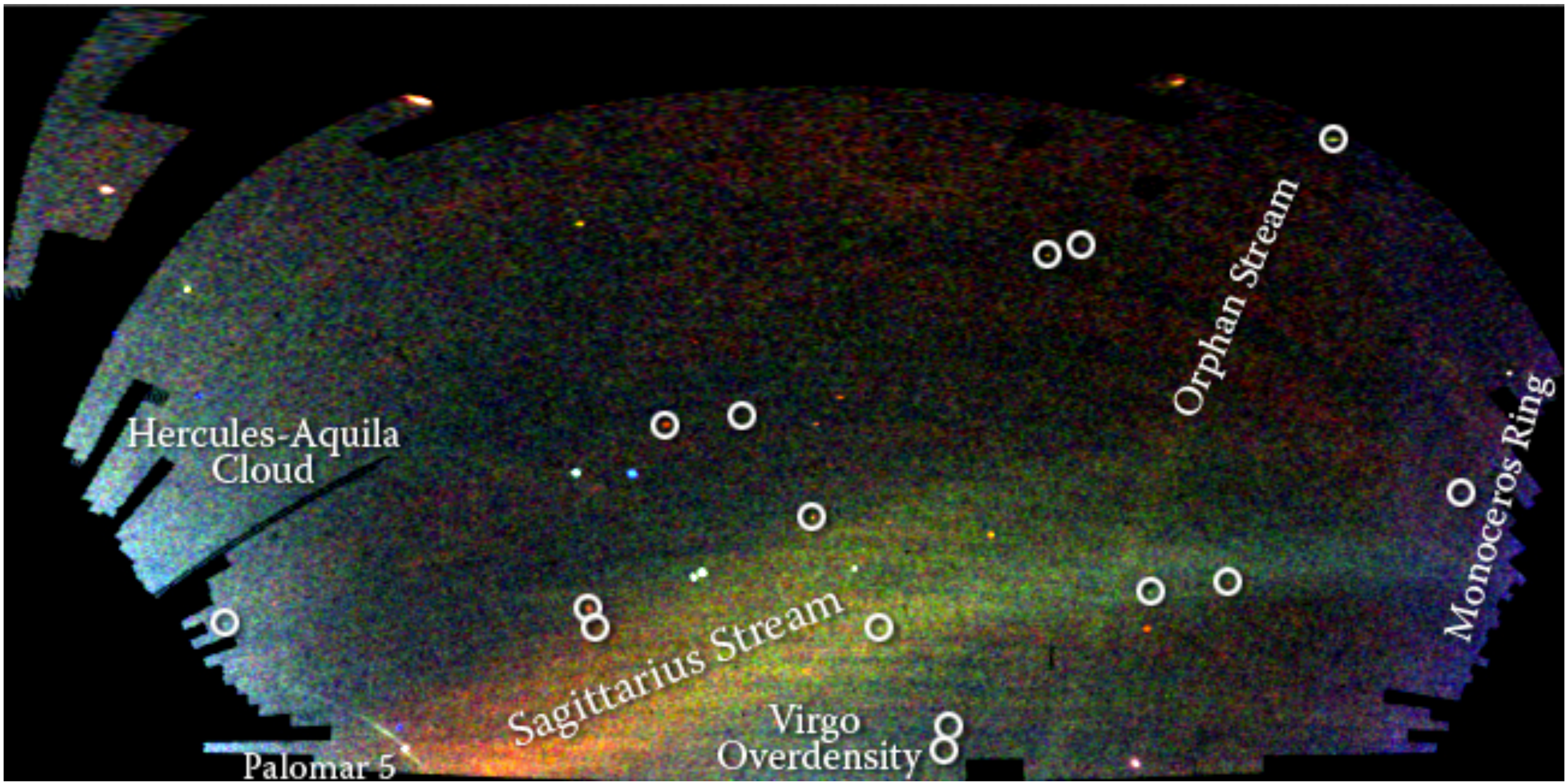
Additional science cases

- **Andromeda galaxy**
- Uniquely visible in the Northern Hemisphere
- Very deep broad band photometry exists within the PAndAS survey
- Mapping out metal-poor structures
- Follow-up targets for TMT



Density of stars in the PAndAS survey.
Courtesy: R. Ibata

- There are several other features and (dwarf) galaxies which are only accessible from the Northern Hemisphere



The field of streams from SDSS. Credit: V. Belokurov

Additional science cases

- **Ly-alpha emitters and QSOs @ z=2.2**
- Very unbiased sample
- Demonstrated science case on the MPG/ESO telescope with a similar filter

- **Chromospherically active FGK and T-Tauri stars**
- Without further follow-up discoveries could be verified by X-ray and IR surveys

Any further ideas are very welcome!

Conclusions

- New narrow-band Ca H&K filter will make CFHT into a machine to find extremely metal-poor targets
  - Cheap (expected cost for new filter ~ $45.000)
  - Fast, a huge area could be surveyed in Sloan depth
- Just **40 nights** would improve by an order of magnitude [M/H] < -3 stars bright enough for **full** high-res follow-up

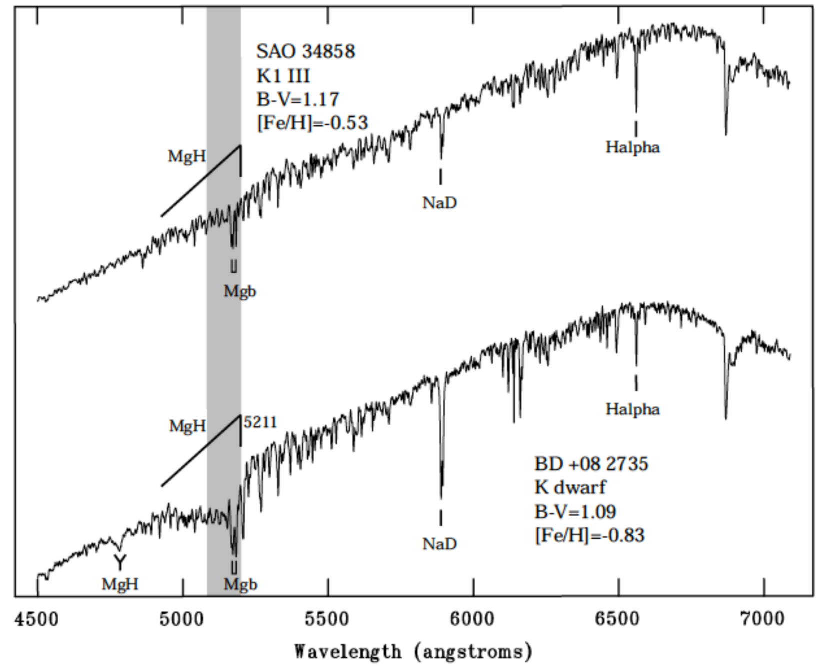
- Several additional interesting science cases could be carried out with such a filter

A suite of filters for CFHT

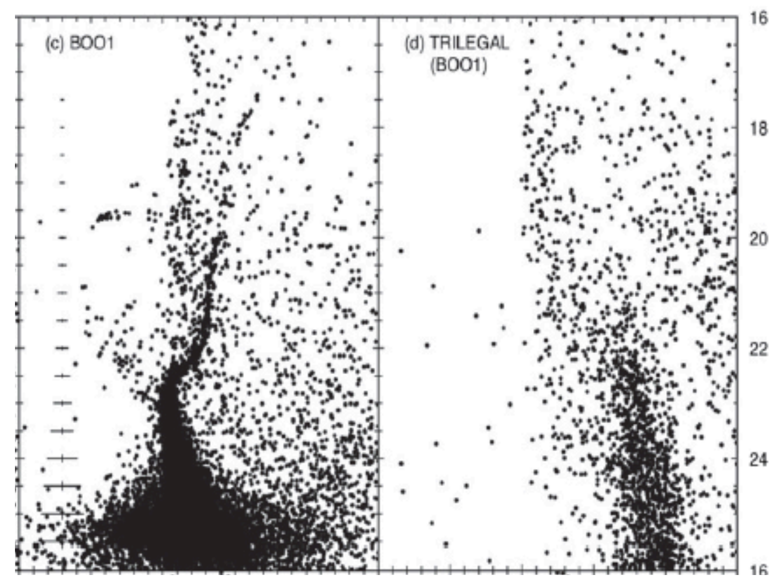
- Next to the Ca H&K science case just presented, one could think of more filters with excellent science cases

Stellar science

- Gravity sensitive filters (e.g. MgH ~5150A)
- Map out the stellar halo in cool giants
- Select members & contaminants in the dwarfs



Credit: Majewski et al. 2001

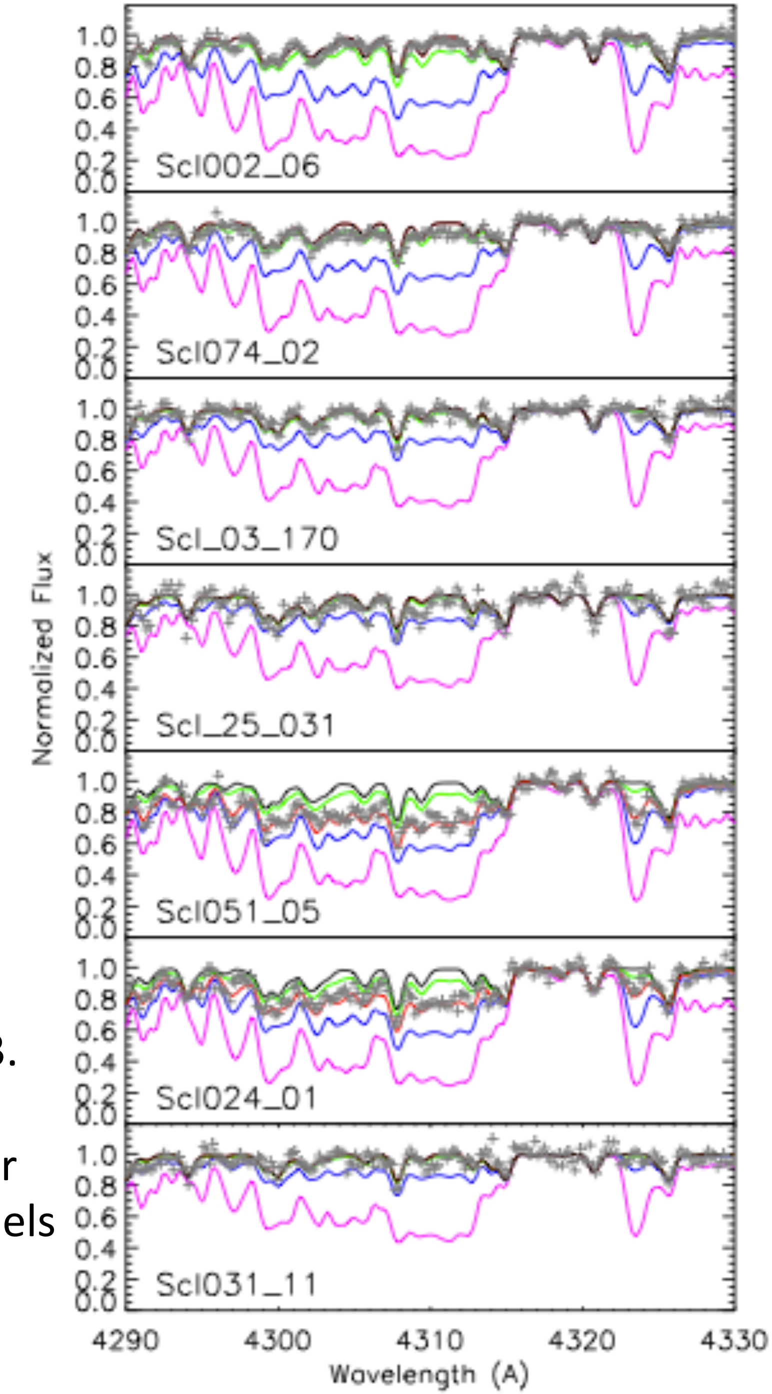


Credit: Okamoto et al. 2012

Stellar science

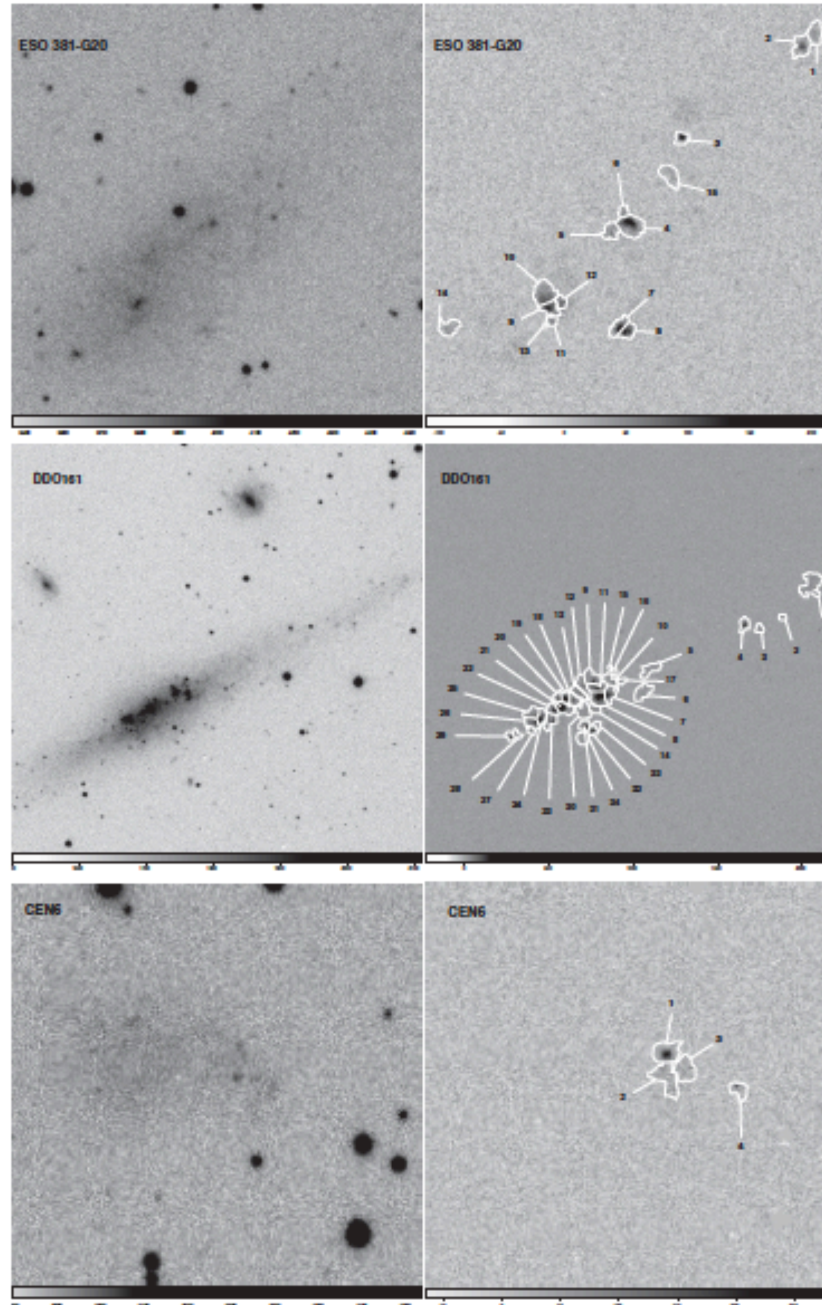
- Carbon sensitive filters (e.g. G-band ~4300A)
- Select Carbon stars and those metal-poor stars with lots of Carbon

Credit: Starkenburg et al., 2013. Spectra for several extremely metal-poor stars in the Sculptor dwarf galaxy. Overplotted models for [C/Fe]=+1.0 (pink)



Extragalactic science

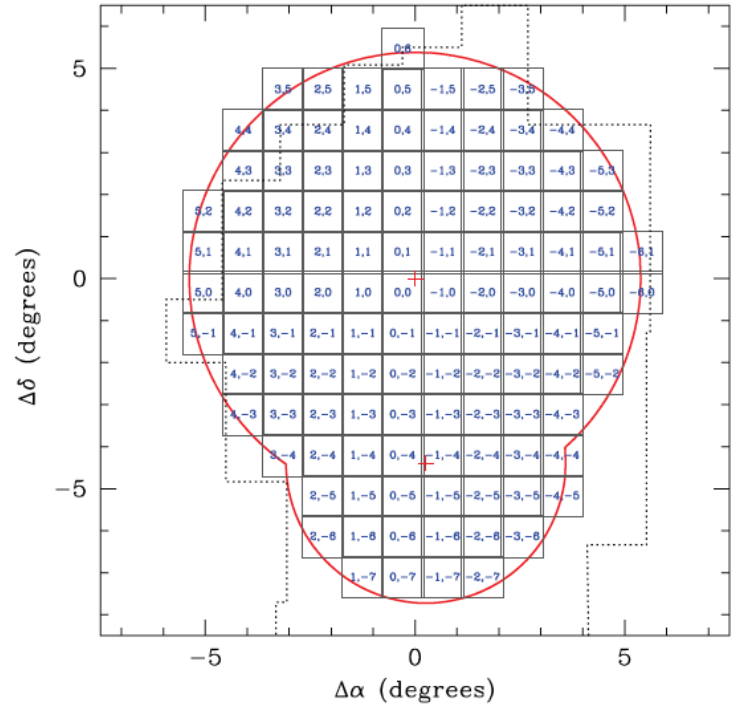
- Imaging of galaxies
- H-alpha
  - Tracing star formation
- OIII
  - Tracing star formation and search for extragalactic Planetary Nebulae

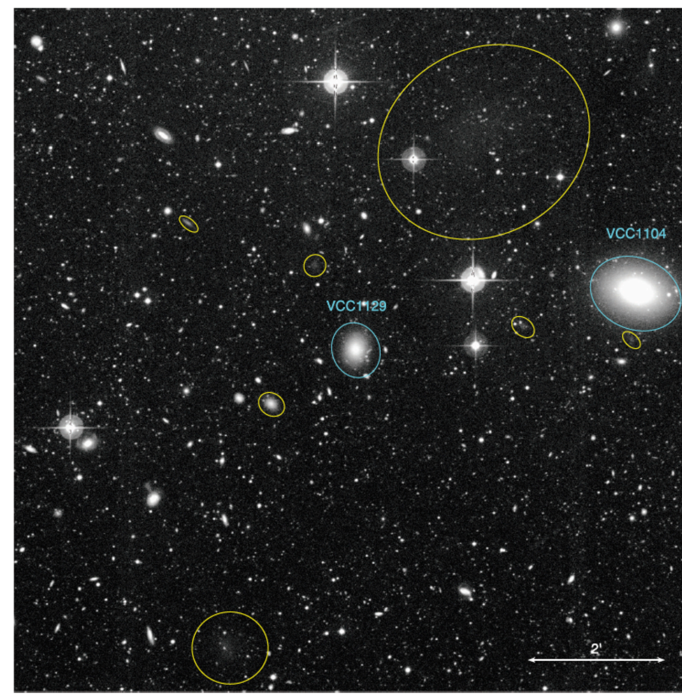


Credit: S. Cote et al., 2009. H-alpha iextragalactic Planetarmaging of galaxies in the CenA for a 150’’ by 150’’ field of view (MegaCam has a 500 times bigger field of view)

Extragalactic science

- Follow-up on well studied large fields
  - For instance using the field of the Next Generation Virgo Cluster Survey
  - Finding PNe in the halo of the Andromeda galaxy





Credit: NGVS Team. Field of view bottom panel is just 10’ by 10’

Conclusions

- We recommend the purchase of a suite of narrow-band filters for MegaCam
- Can highly leverage existing (CFHT, SDSS, Subaru, PS1) wide field broad band filters
- A relatively cheap way to improve science capabilities with CFHT
    - Ca H&K filter (metallicity)
    - MgH (dwarf-giant discrimination for cooler stars)
    - G-band (Carbon)
    - H-alpha (star formation)
    - OIII (star formation and PNe)

- Please contact us if you are interested!