Time Domain and Near-field Cosmology in the 2020’s

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• What is near-field cosmology? And why we need to go beyond the Local Group.

• Centaurus A as an example of what can be done with resolved stars and LSST. [Wish I could do diffuse dwarfs too]

• Time domain — There will be a flood, so focus on the tools and science you care about. Short cadence sister projects to augment LSST/ZTF & GW follow-up.
What is Near-Field Cosmology?
The Cold dark matter paradigm is extremely successful

Galaxy distribution from spectroscopic redshift surveys vs. mock catalogs from CDM simulations (see also CMB, Lyman alpha forest, etc).

But once you zoom in to the size of individual halos, there begin to be problems....
What is Near-Field Cosmology?

CDM halos have lots and lots of subhalos

- ELVIS simulations, meant to roughly correspond to the Local Group (Garrison-Kimmel et al.)
- Does each subhalo correspond to a dwarf galaxy?
What is Near-Field Cosmology?
The ‘Missing Satellites’ Problem

- Within the virial radius, the Milky Way should contain ~500 halos larger than Draco
- The galaxy cluster satellite function could reproduce numerical predictions, but not for a halo the size of the MW!

Moore et al. 1999; Clear lack of MW satellites, pre-SDSS
What is Near-Field Cosmology? Too Big to Fail

If you take the ten most massive subhalos in a CDM simulation, they are much denser than anything we see around the MW.

This is not a regime in which things can be explained away by baryons.

Relatively sensitive to the mass of the MW (which still has a factor of ~2 uncertainty).

Boylan-Kolchin et al. 2011, 2012
What is Near-Field Cosmology?  
Planes of Satellites?

• Also reported around the MW and M31. Not generally seen in simulations.

• Satellite distribution should be roughly spherical, but there is some observational evidence for planes and rotation. Difficult to reconcile with CDM, but could just be large scale structure.

Mueller et al. 2018

Boylan-Kolchin 2018
Realistic inclusion of baryons significantly reduces CDM’s ‘problems’

Theory + Observations converging in the Local Group.

Maybe not planes of satellites?

See recent review by Bullock & Boylan-Kolchin (2017)
Dozens of new satellites from Surveys in Southern Hemisphere

Bechtol et al. 2015; Koposov et al. 2015; Kim & Jerjen 2015; Martin et al. 2015; Drlica-Wagner et al. 2015 + others
~30 NEW SATELLITES FROM NEW SURVEYS IN SOUTHERN HEMISPHERE

Bechtol et al. 2015; Koposov et al. 2015; Kim & Jerjen 2015; Martin et al. 2015; Drlica-Wagner et al. 2015

Stolen from DES talk
Where do we go from here? The Local Group is nice, but....

• Are our baryonic solutions to the ‘Missing Satellites Problem’ and ‘Too Big to Fail’ just tuned to the Local Group?

• Halo to Halo scatter is expected. Can we observationally quantify this?

• Does parent galaxy morphology matter?

• Environment and formation history?

• Next step is to probe new systems -- our NEXT nearest neighbors, as well as isolated, nearby systems.
Where do we go from here? The Local Group is nice, but.... What we want:

Subhalo property can be dwarf luminosity function, stream richness, you name it.
WHERE DO WE GO FROM HERE? THE LOCAL GROUP IS NICE, BUT....

WHAT WE WANT:

Right now!
MW & M₃₁

Although lots of progress

Subhalo property can be dwarf luminosity function, stream richness, you name it.
Where do we go from here? The Local Group is nice, but....

Two Routes Forward

**Resolved Star Studies**

- Find dwarfs/streams: LSST & Subaru HSC (D~5 Mpc) and WFIRST (D~10-20 Mpc).
- Crude Kinematics: 8-10m (~3 Mpc) or TMT/GMT/ELT (D<10 Mpc). Intrinsically fainter systems.
- You actually know what you’re studying is at the appropriate distance (e.g. the TRGB).

**Diffuse Studies**

- Find dwarfs: Out to 100+ Mpc already with deep imaging surveys on large and small telescopes.
- Crude Kinematics: 8-10m (~100 Mpc), but very expensive. Low sky density, one at a time. Brighter systems.
- Need follow-up to confirm not background/foreground. Can be very expensive.

Do not forget HI kinematics.
Where do we go from here? The Local Group is nice, but....

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Ask me later
PAndAS survey of M31

McConnachie et al. 2009; Lewis et al. 2012, Martin et al. 2013 and MANY more

220 hrs of CFHT/Megacam; 400 deg$^2$
~2 mags below the Tip of the RGB
Beyond the Local Group

NGC 5128 -- ~3.8 Mpc, nearest large elliptical galaxy. Recent merger.

NGC 253 -- ~3.5 Mpc, with a mass and virial radius within a factor of two of the MW.

Last survey for satellites around NGC 253/NGC 5128 was done with photographic plates!
The Panoramic Imaging Survey of Centaurus and Sculptor (PISCes)

- Megacam on Magellan; ~24x24 arcmin
- Deep imaging (r~26) in g,r out to 150 kpc in two of our next nearest neighbors.
- ~1.5-2 mag below TRGB
- Directly comparable to PAndAS, MW and simulations.
A clearly disrupting dwarf galaxy -- detected not by low surface brightness measurements but in individual resolved stars!

There are clearly other streams emerging.

So exciting!
How well can we do?

This is an implanted Draco-sized ($M_V=-8$) dwarf galaxy at the distance of Centaurus A. With our algorithm, it is an 8-sigma detection.
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From B. Willman
A close pair of satellites

Crnojevic et al. 2014
A close pair of satellites

CenA-MM-Dw1 cluster?

CenA-MM-Dw1

Dec (degrees)

RA (degrees)

V-I

0

-1 0 1 2 3 4

I

0

22

22.5

23

23.5

24

24.5

25

25.5

26

26.5

27

27.5

28

28.5

29

29.5

30

30.5

31

31.5

32

32.5

33

33.5

34

34.5

35

35.5

36

36.5

37

37.5

38

38.5

39
A close pair of satellites

CenA-MM-Dw1 cluster?

Galaxy Center

1 kpc

1 2 3 4

(V-I)

0 1 2 3 4

0 1 2 3 4

22 22.5 23 23.5 24 24.5 25 25.5 26 26.5 27 27.5

CenA-MM-Dw1
The emerging field of Streams of CenA

Crnojevic et al. 2016

Upcoming VLT/VIMOS multislit spectroscopy to measure velocity gradient and metallicity via stacked spectra. ~3 nights.
The emerging field of Streams of Crnojevic et al. 2016

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Toloba, Sand et al. 2016
HST followup is revealing a rich variety of star clusters. Use star clusters to probe kinematics of halo substructures and DM profile of CenA.
WFIRST gets full coverage

M101: 7.4 Mpc

WINGS PI: B. Williams

~10 hours with WFIRST at 10 Mpc

PAndAS Survey of M31
Pause, and onto the Time Domain
• One of NSF’s ’10 Big Ideas’ for future investment, along with ‘Big Data’.

• This, along with investment in LSST+ZTF guarantee that the time domain will be vital through the next decade.

LSST - Large Synoptic survey telescope

- 8.4 m telescope; 10 sq deg camera with 3200 megapixels
- 30 TB of data per day
- Will observe the entire visible sky (from Chile) every few days
- 10 million alerts, but maybe \sim 1000 decent new transients per night (probably more), announced in real time.

What do we do with all this data? How do we prioritize follow-up? Build infrastructure now. 2022?
Many important recommendations relevant for transient science, including alert brokers.

Need telescopes/instruments at all aperture scales that can intelligently decide which transients are interesting, and then promptly observe them.

Full Report: https://www.noao.edu/meetings/lsst-oir-study/
Robotic Spectroscopy — LCO & FLOYDS

See also the SED Machine; see Blagorodnova et al. 2017
Seems overwhelming

• There will be a flood of data.
• Think about the science that matters to you.
• Try to control cadence to maximize the science you want to do.
• Become engaged in the transient brokers, telescopes and other infrastructure you might need now.
Don’t Forget Smaller Experiments
What I want to learn:

• What are the progenitors of the various SN types?

• How do they explode?
What I want to learn:

- To get clues about the progenitor, very early data is key (<days after explosion) before any hints are diluted away.

Progenitor -- SN map

(Gal-Yam et al. 2005)
Catching SN Ia early is another way to constrain their progenitor (but it has to be very early)

Kasen 2010

Non-degenerate companions and circumstellar material

Emergence of SN 2015F in NGC 2442

Piro & Morozova 2016
Supernova ejecta and/or the shock breakout can interact with or ionize material surrounding the progenitor star -- learn about its composition, velocity structure and extent from recombination spectrum and its evolution.
Where are we going to get very young SNe from?

- Even the best transient searches aren’t focused enough.
- A search of nearby galaxies could be done with ~0.5m telescopes. Looking at ~500 galaxies per night would find ~10 SNe per year, and could catch SNe within 1 day of explosion. Totally new capability if directly tied to FLOYDS.
DLT17u/SN2017cbv

D~17 Mpc; caught very young. The light curve is sick, thanks to Las Cumbres. That is a ~5 hr cadence over ~6 days.

Hosseinzadeh et al. 2017
DLT17u/SN2017cbv

Very blue early colors. Companion shock model works pretty well. Early carbon. Maybe a couple of other similar objects now (SN13dy, iPTF16abc)

Hosseinzadeh et al. 2017
How do I get a very fast (<1 day) Cadence in the LSST/ZTF era?

• Follow LSST/ZTF with DECam (or, e.g. 90Prime on Kitt Peak) to get the cadence & colors you want.

• Don’t worry about covering the whole area or finding everything! That’s for suckers. But do not forget that intense follow-up is needed.

• This should be done now, not later.

See also the High Cadence Transient Survey; Forster et al. 2016.
The Era of Multi-Messenger Astronomy Has Begun!
GW170817 — 2017 Aug 17; 12:41 UTC. LIGO+VIRGO.
- Short GRB detection, two seconds after GW.
- UV/Optical/NIR transient in NGC 4993 (D~40 Mpc). ~11 hours after GW, but was probably sooner.
- X-ray detection 9 days later; very unusual for a sGRB.
- Radio detection 16 days later.
- General picture is consistent with NS-NS coalescence and kilonova models.

DIFFERENT STRATEGIES — GALAXY-TARGETED & WIDE FIELD

Soares-Santos et al. 2017

Valenti, Sand et al. 2017
The Landscape

- Will be ~dozens of BNS and BH+NS events/yr.
- By ~2020’s, most GW events will have localizations <20 deg^2
- Will be necessary for some wide-field follow-up. DECam and/or LSST? Is there a ToO policy for LSST?
- Infrastructure for observation plan sharing would lead to less redundancy.
- See P. Cowperthwaite’s presentation at breakout session.

Abbott et al. 2016
Summary

• Near-field cosmology will flourish. Several dozen systems within D<5 Mpc will have halo+dwarf maps with LSST+Subaru/HSC data to compare with simulations. Spectroscopy will be a challenge met by the ELTs.

• The big time domain survey will provide a flood of new events, but still worth thinking about experiments that augment the cadence, filters, etc to do the science you want.

• Get ready for the era of MMA!