



SkyMapper Transient Program for Fast Radio Bursts

Seo-Won Chang

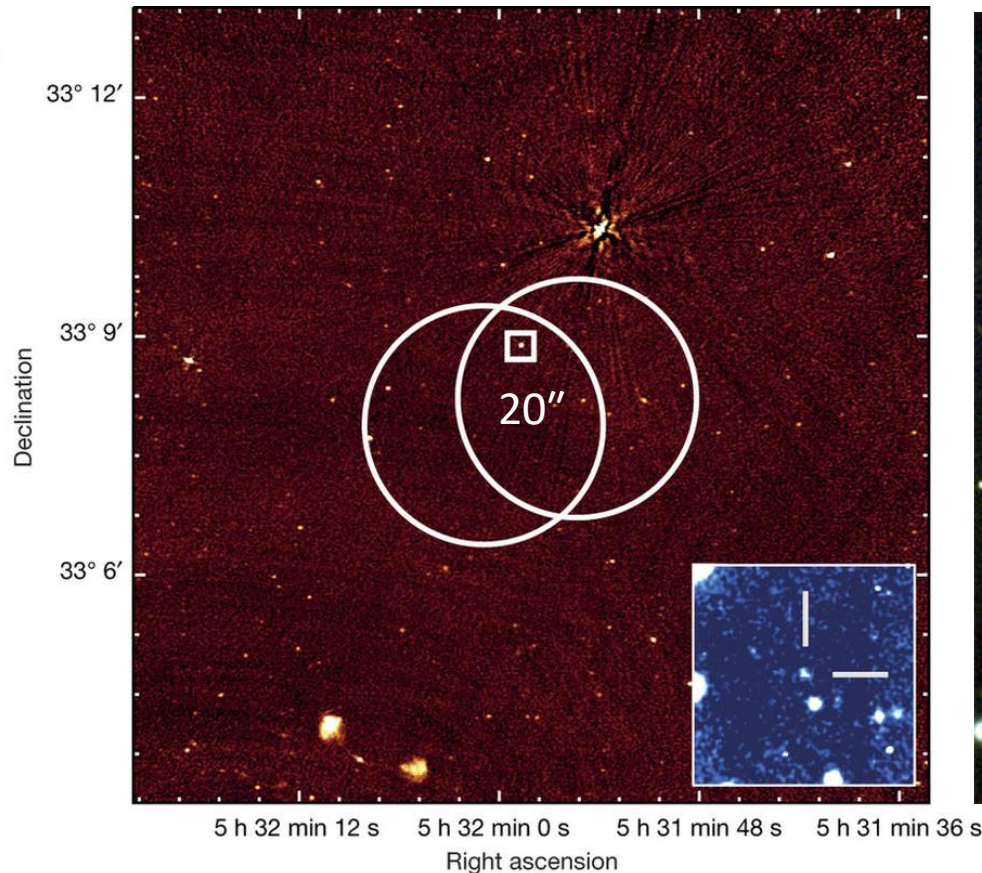
Christian Wolf, Anais Möller, Christopher A. Onken

Outline

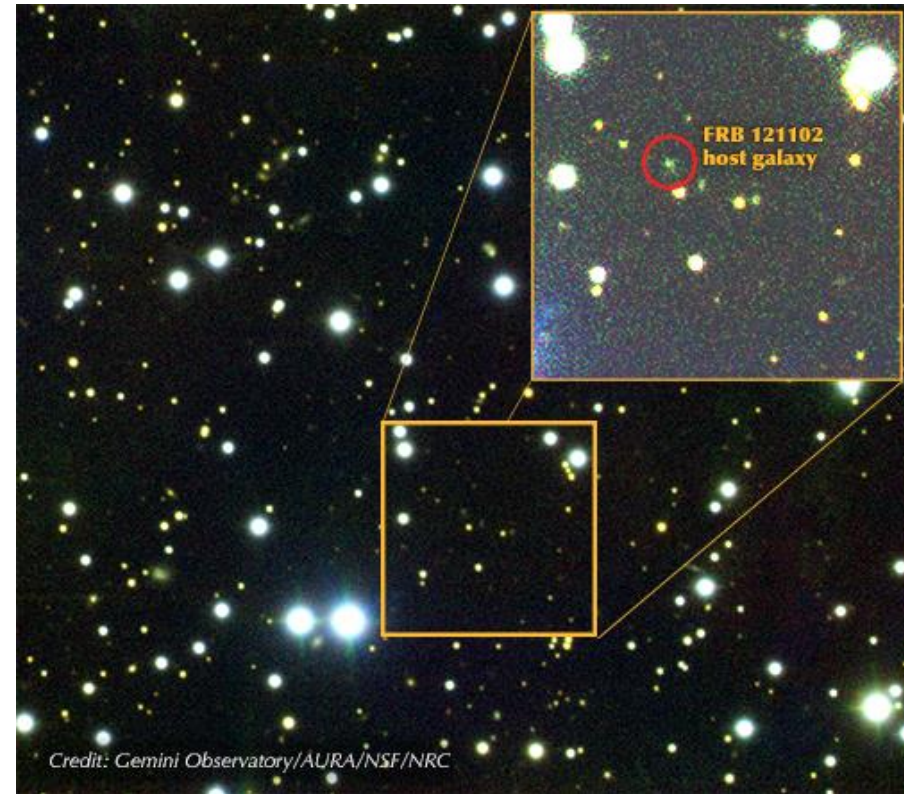
- ❑ SkyMapper Target-of-Opportunity (ToO) Program for FRBs:
 - Common sky with the Oz-based facilities, advantages of wide-field-of-view and multi-colour filters!
 - Email-based triggering mechanism since late 2016
 - Automated transient detection pipeline (planned to be upgraded)

- ❑ Search for associated optical emission of non-repeating FRBs in three ways: 2014 ~ 2017
 - Triggered follow-up observations - Parkes + Molonglo + DWF
 - Coordinated campaigns – Parkes + DWF
 - Potential shadowing observations with ASKAP?

Multi-wavelength campaigns delivered many key insights, thanks to *repeating* nature of FRB121102



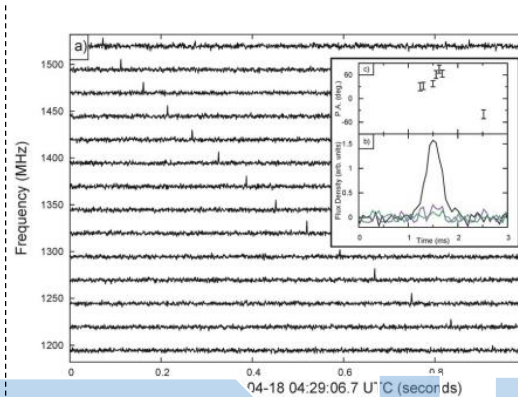
VLA radio counterpart
(Chatterjee+ 2017)



Gemini optical counterpart
(Irregular, low-metallicity
dwarf galaxy, $z = 0.192$)

When to look for EM counterparts – Two timelines

 Radio side



Frequency-dependent time delay

BOOM!
(FRB180216A)
- μs to ms

Repeating?

(FRB180216B)

 Optical side

$\Delta t \sim$ seconds to years earlier?

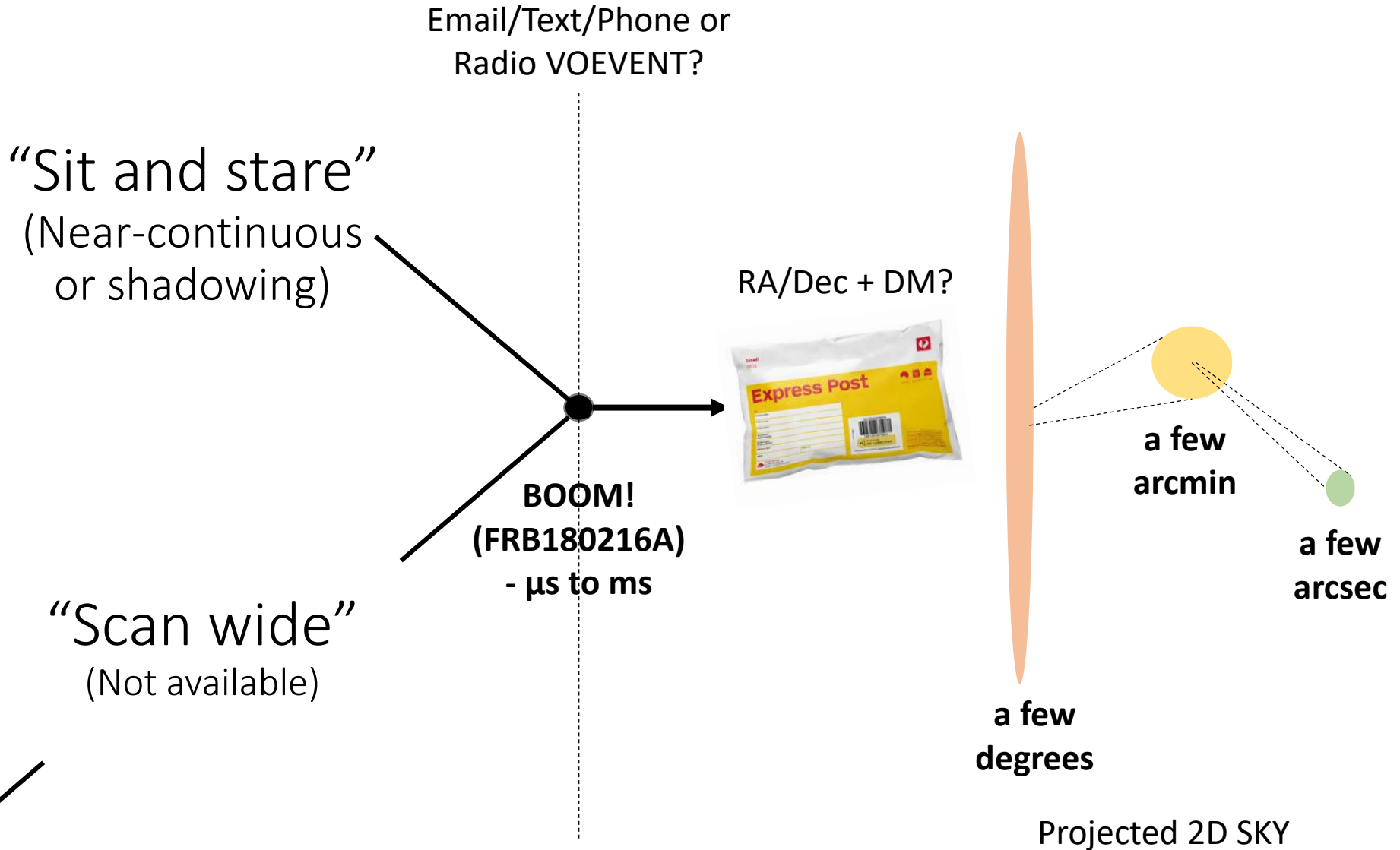
$\Delta t \sim$ minutes to hours later?

Precursor emission?
(preceding the FRB)

Prompt emission?
(generated concurrently)

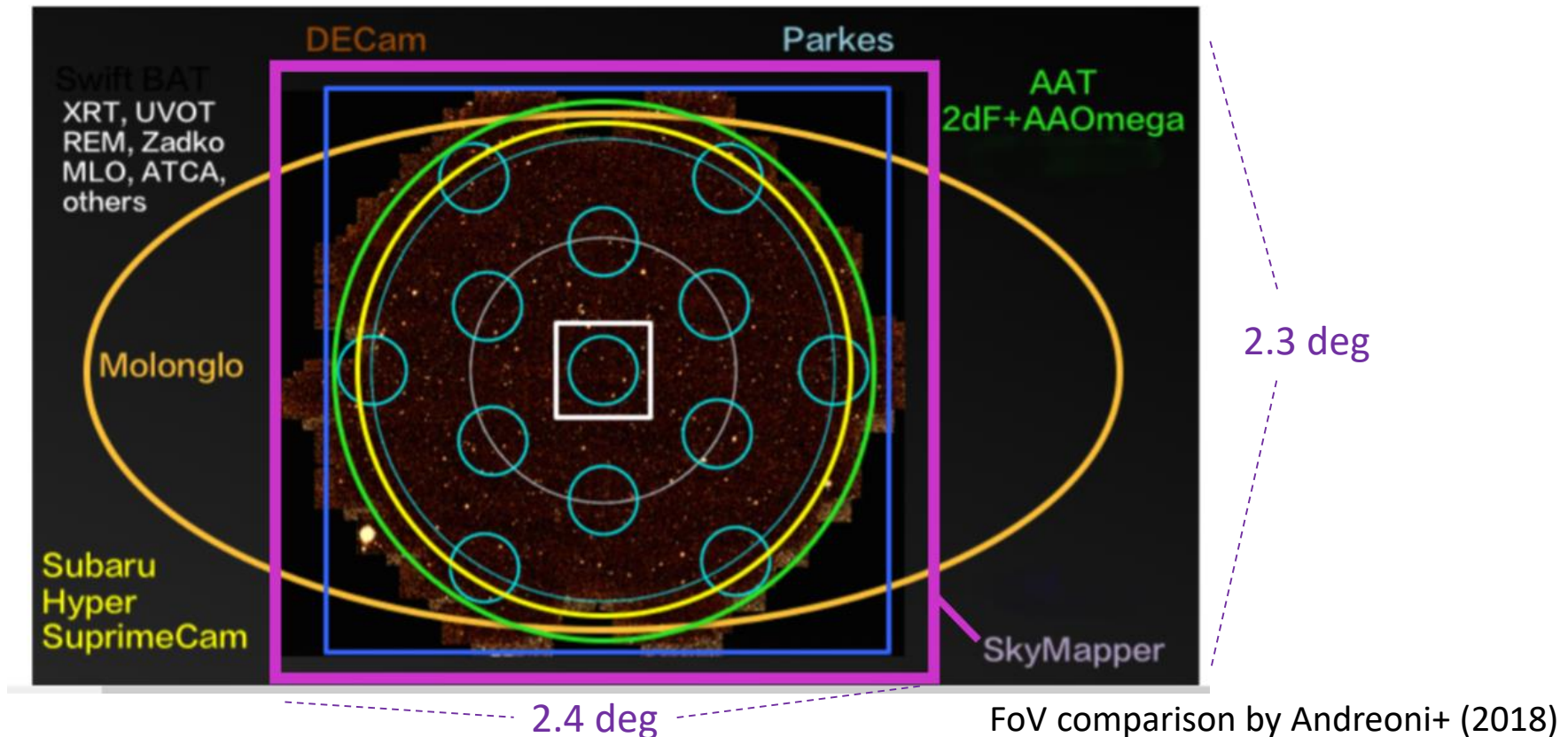
Afterglows?
(rising and fading later)

Where to look for EM counterparts? – Localisation



1.35m SkyMapper at Siding Spring (Wolf+ 2018)

- Common *night* sky with the Oz-based facilities such as Parkes, Molonglo.
- Limited depth of our single-epoch imaging (e.g., $r \sim 21$ with 100 sec exposure)
- Widest FoV (5.7 sq. degrees) compared to other facilities + taking six-filter images near simultaneously (20 sec overhead per exposure).



Email-based triggering system (by Dr Fang Yuan)

- Simplified version of VOEVENT notices, enabling a rapid response
 - New alert can be sent to SkyMapper directly with only minutes delay.
- Only need FRB event name (FRBYMMDD) and its sky position (RA, DEC).
- Find the best observation time for the trigger, and then schedule observing sequence with small random offsets.

Sending an FRB alert

Fastest way to trigger SkyMapper!

Email address: [REDACTED]

Subject: can be anything, but good to identify as "FRB alert". If "test" shows up in any case anywhere, the alert is considered a test-only event.

Content: should at least have a name (FRB event identifier) and coordinates, e.g.

name: FRB160505

J2000 RA: 13:20:43.0

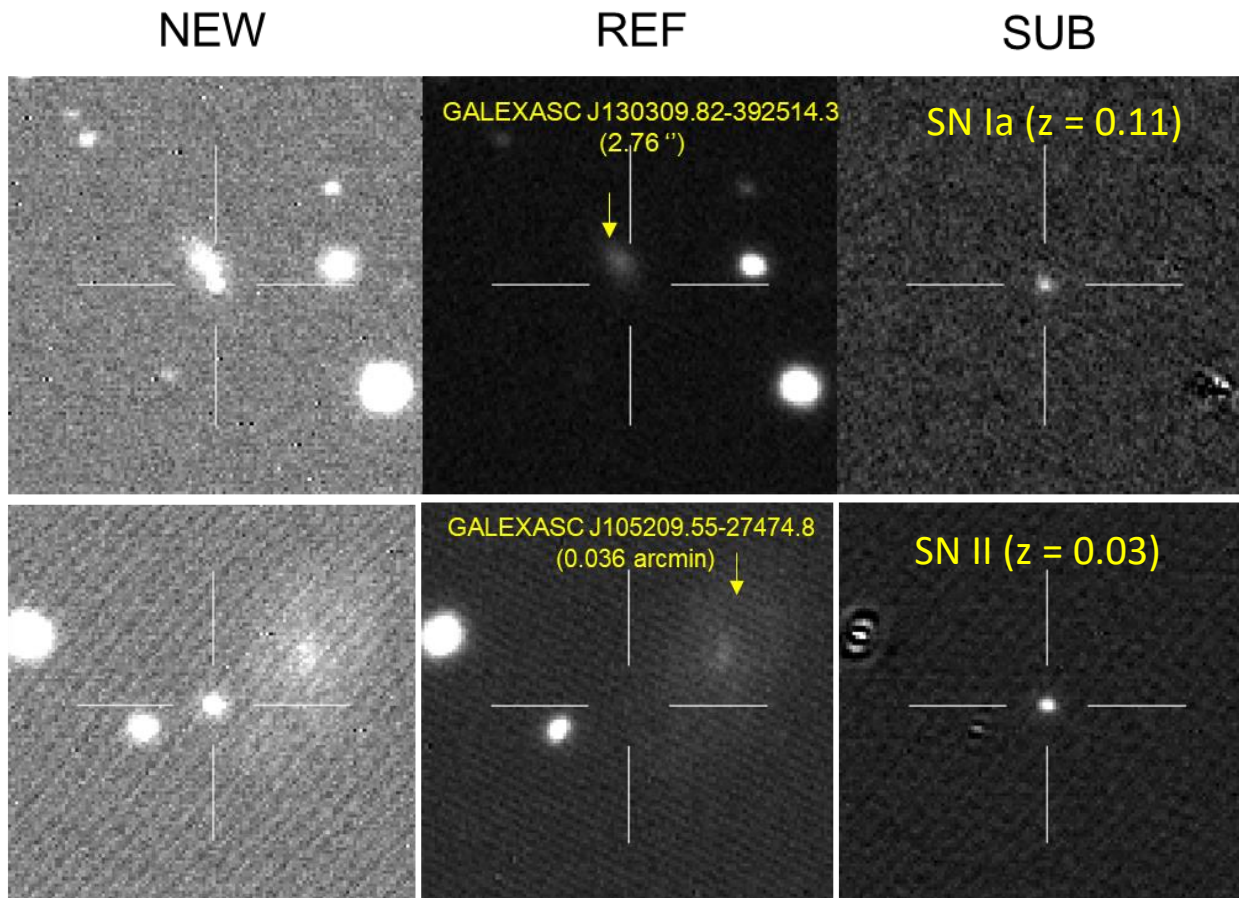
J2000 Dec: -15:22:30.0

Send an email to *SkyMapper* not to me if you ready!

"That is exciting! I've cc'd Seo-Won who is managing triggers of FRBs, GW-events, etc. Seo-Won see below, can we trigger SkyMapper? "

Current transient detection pipeline

- Mainly developed for discover Type Ia supernovae (Scalzo+ 2017)



Many discovery of SNs or other transients + host galaxies

Need a new transient detection pipeline

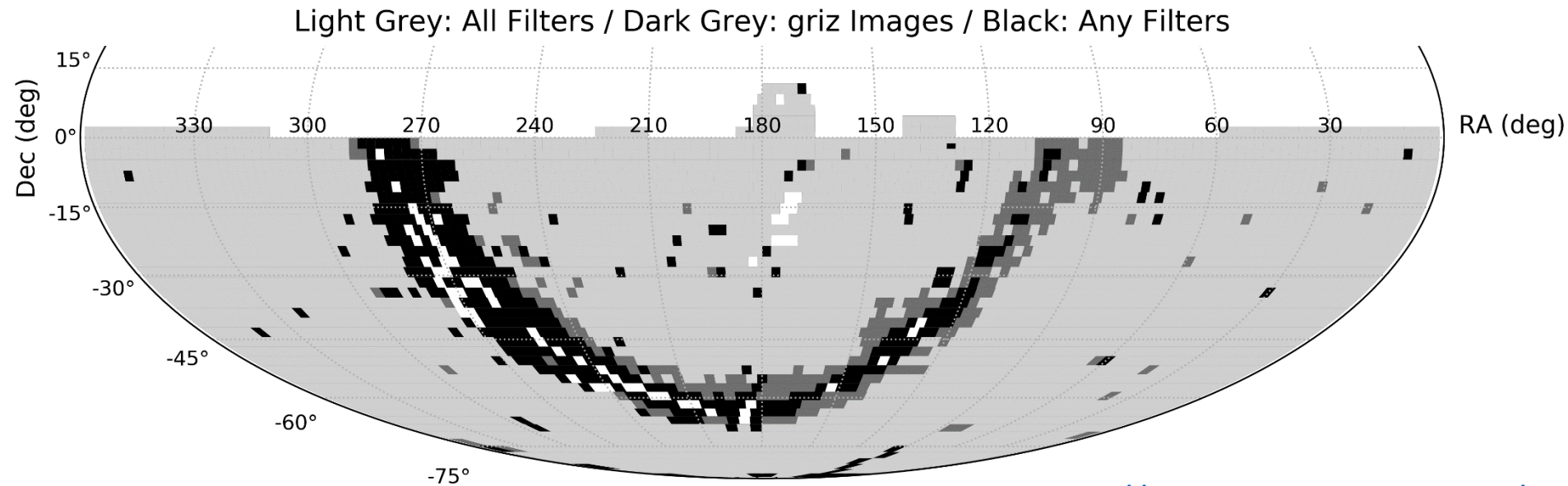
- Mainly developed for discover Type Ia supernovae (Scalzo+ 2017), limited by
 - a) Filter sets: prefer to use *gr* bands primarily,
 - b) Pre-defined survey fields: hard to get flexible pointing of the telescope,
 - c) Number of minimum epochs: at least two epochs per field due to lack of reference frames
 - d) Pre-processing issues: no de-fringing was applied to *iz* bands.

→ Planned to be implemented the Science Data Pipeline of the Main Survey (see Wolf+ 2018) to overcome these issues.

→ Soon to be get nearly full *ri* reference coverage (> 98%) of southern sky with the SkyMapper Data Release 2 (Mid-2018).

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Summary of SkyMapper ToO program (2014 ~ 2017)

Previous use of SkyMapper time (hours):

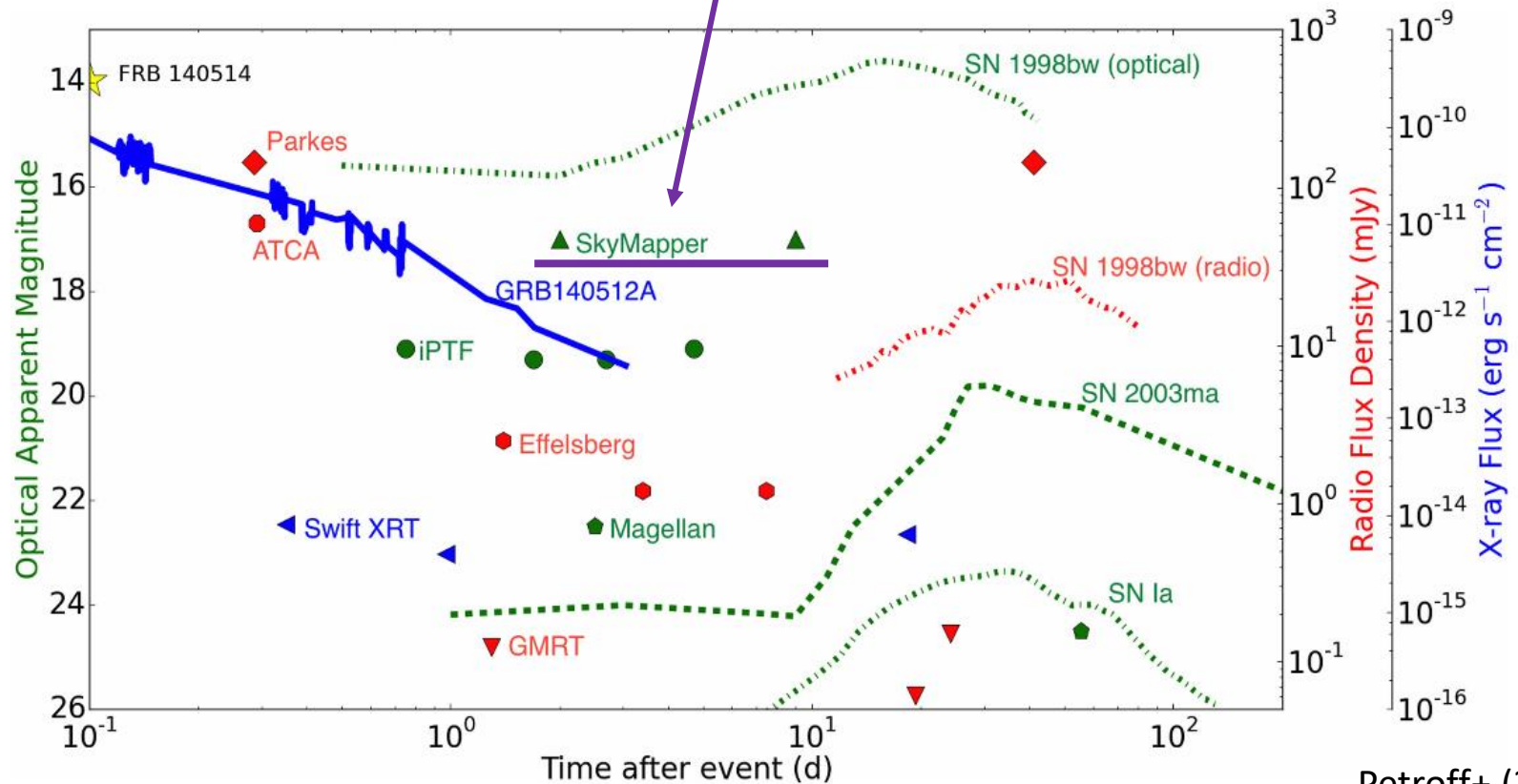
semester	GWs		FRBs		DWF		other
	hours	triggers	hours	triggers	hours	scheduled	hours
2014B	-	-	<0.1	FRB140514 [4]	-	-	-
2015A	-	-	0.3	1 event	-	-	-
2015B	1.9	GW150914 [1]	3.7	2 events	-	-	-
2016A	-	-	-	-	-	-	-
2016B	-	offline	-	offline	10	(u. analysis)*	0.3 Δ
2017A	2.7	2 events†	-	offline	1.1	(u. analysis)◦	0
2017B	5.1	GW170817 [2,3]	0.6	FRB170827‡	-	offline	0

→ 2018A: 17 hours for Molonglo FRB and DWF runs.

Case 1: Triggered follow-up observations (Parkes + Molonglo FRBs)

FRB140514 ($DM_{\text{FRB}} = 562.7 \text{ pc cm}^{-3}$, $z < 0.44$) - Parkes

- Triggered follow-up at other wavelengths (X-ray to radio) within hours of the event.
- $H\alpha$ observations 2 and 9 days after the event. No variable objects were seen across the two epochs of data.



2015A/B – Parkes SUPERB project

- Made an effort to get first-epoch images **within hours** of the FRB event
→ Yuan, Schmidt, Wolf (ANU) + Petroff, Keane, van Straten (Swinburne)

2015A

13-17 Jan
22-27 Jan
4-11 Feb

2015B

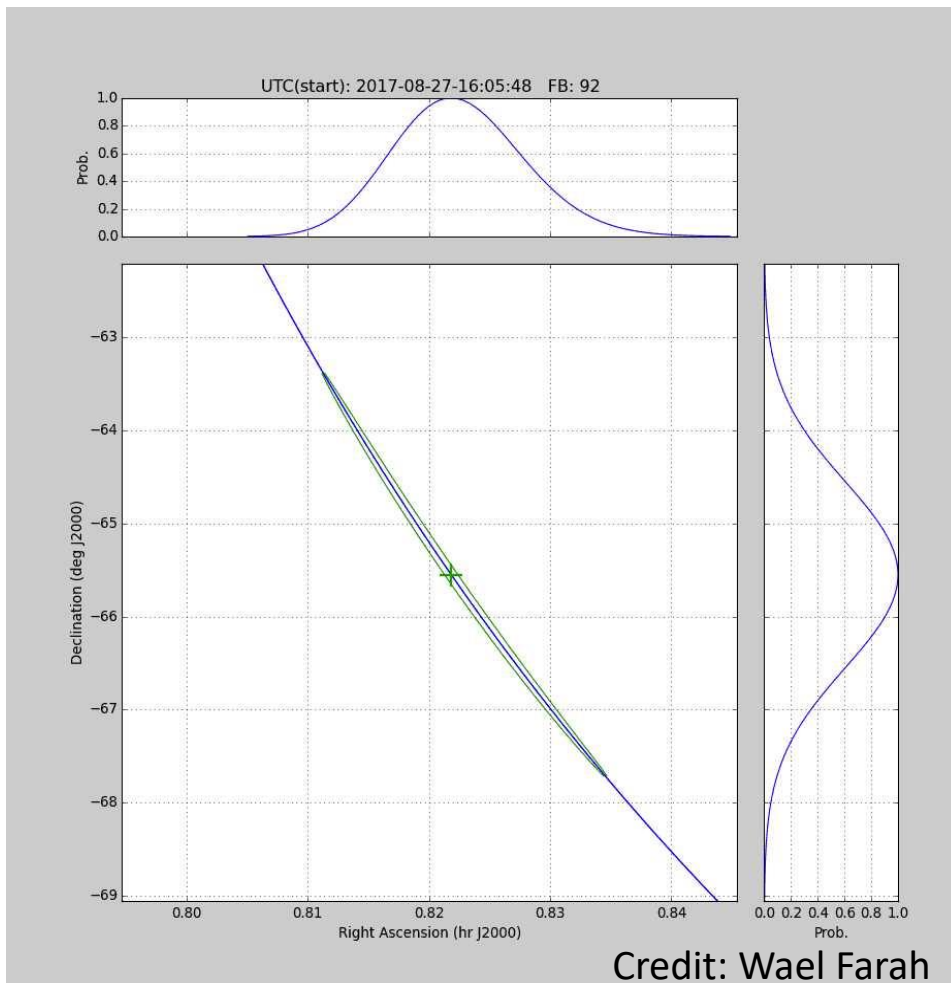
27 May – 2 June
4 – 12, 15-17 June
3 – 14 July
24 July – 5 Aug
10 - 11, 16 -24, 26 – 27 Aug
2 – 3, 10 - 20 Sep

One **delayed** FRB trigger from Parkes (not SUPERB), but location is too close to the Sun for SkyMapper follow-up.

Two **delayed** FRB triggers from Parkes. No optical detection of transient.

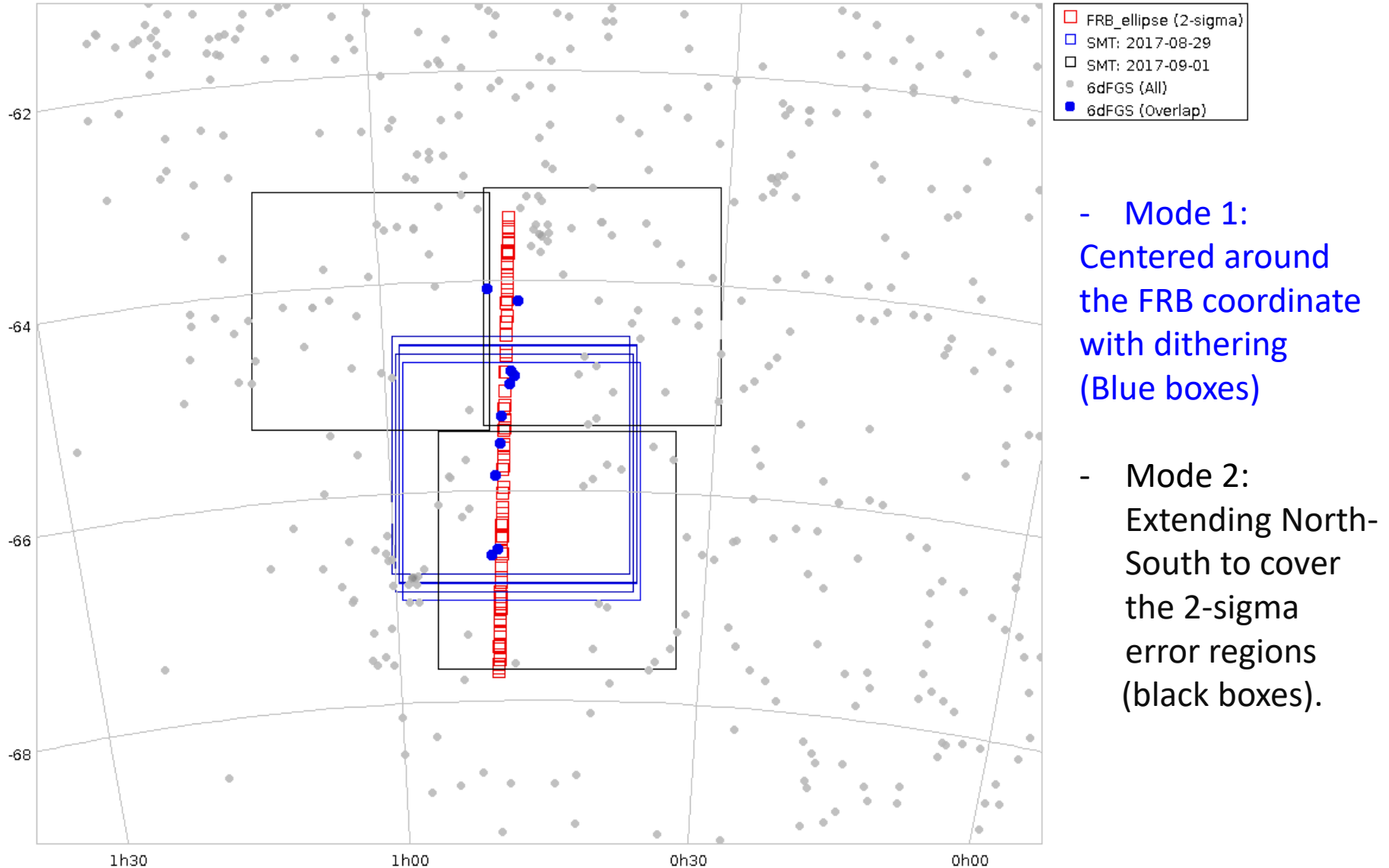
FRB170827 ($DM_{\text{FRB}} = 176.8 \text{ pc cm}^{-3}$, $z < 0.12$) - Molonglo

- Identified **three days after the event** which limited follow-up at other wavelengths.



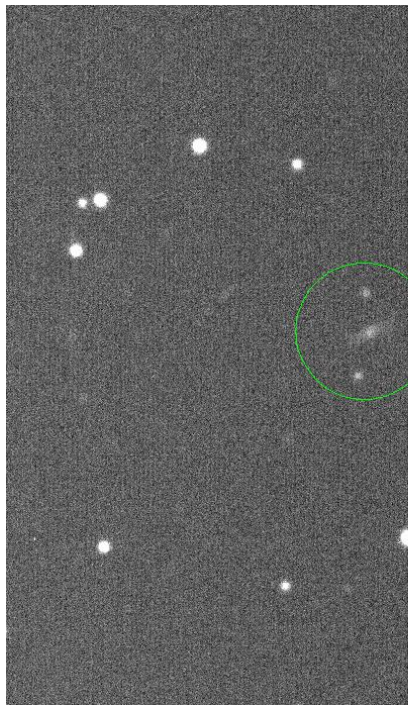
- Initial position that we had received:
00:49:18.66, -65:33(:03)
- It is extremely well localised in RA at any given Dec, but there is very poor localization in the Dec direction.
- No particular filter preference – colour of FRB afterglows is anyone's guess.

Follow-up modes and field coverage of SkyMapper

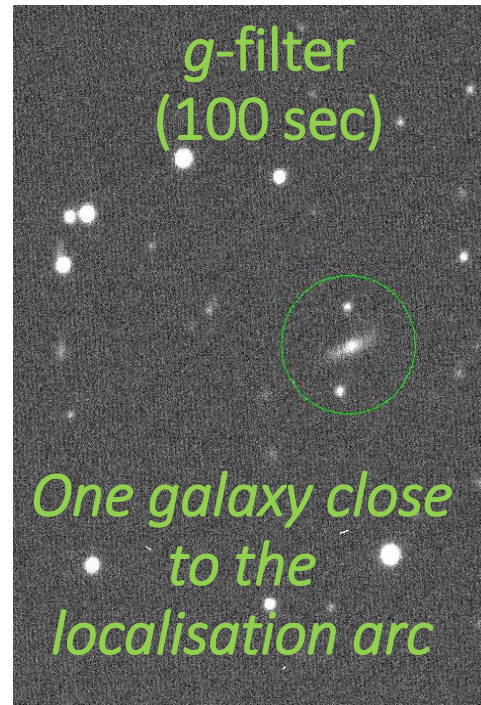


Photometric depths and image quality - 100 sec exposures

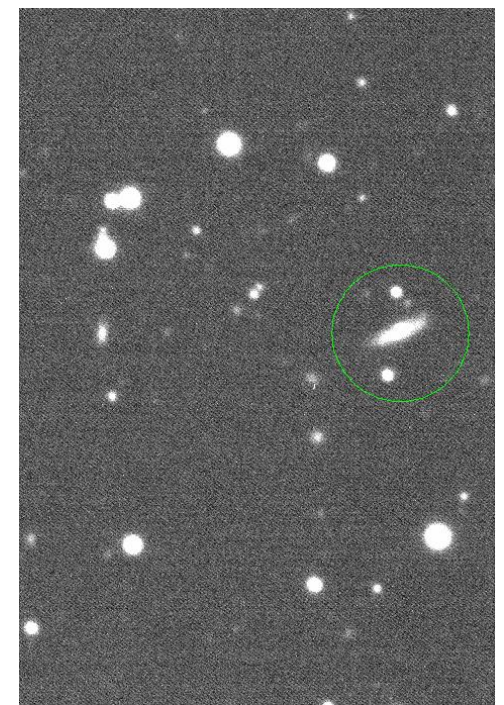
95% upper limit	<i>u</i>	<i>v</i>	<i>g</i>	<i>r</i>	<i>i</i>	<i>z</i>
SN pipeline	18.1	18.3	20.4	20.2	19.4	18.5
DR 2 (Mid-2018)	19.5	19.5	21.0	21.0	20.0	19.0



1st epoch



2nd epoch

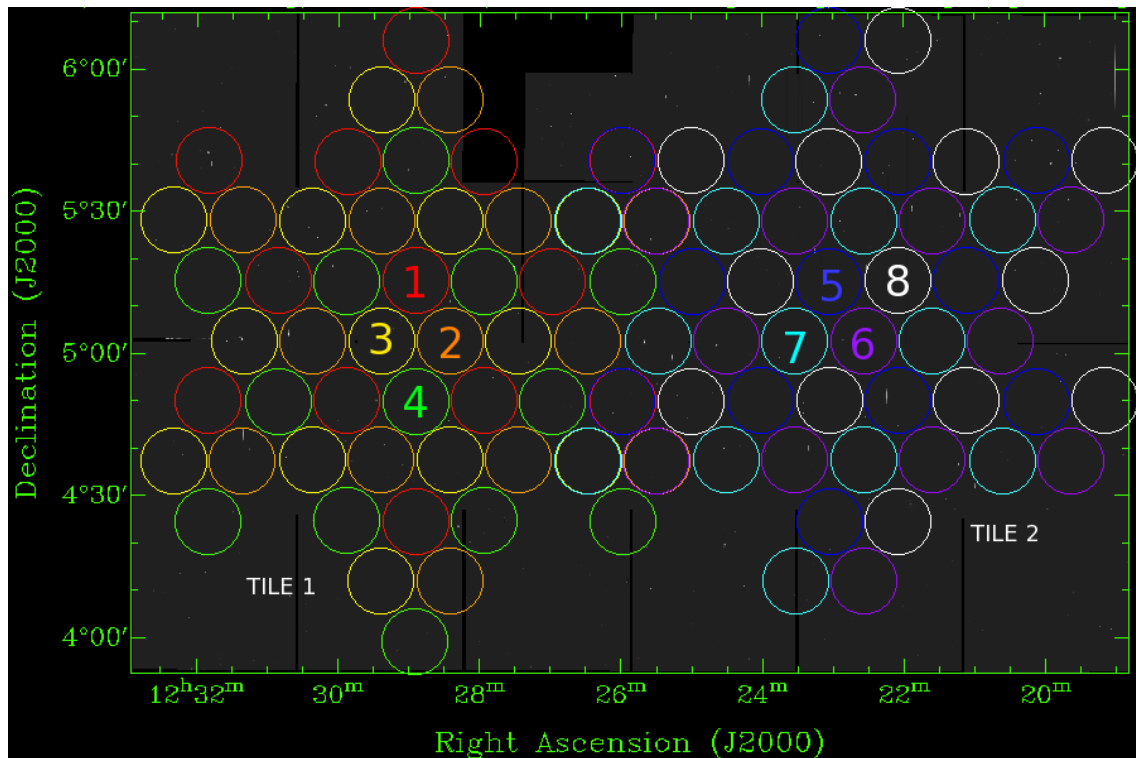


3rd epoch

Case 2: Coordinated campaigns (Parkes project P879)

2015 Feb/Mar – FRB live search (1)

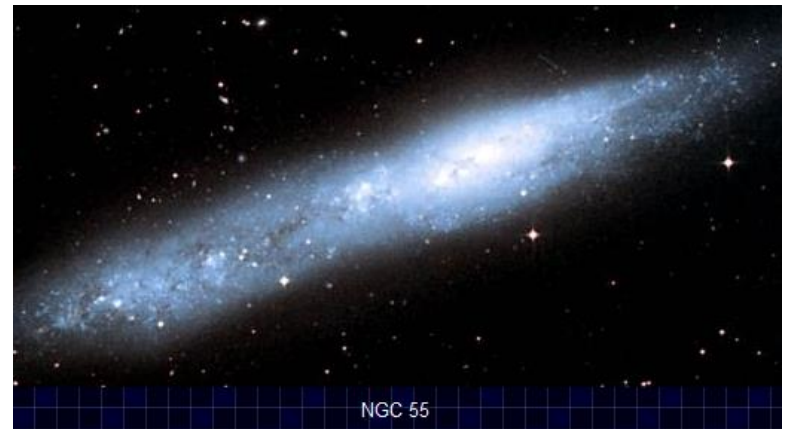
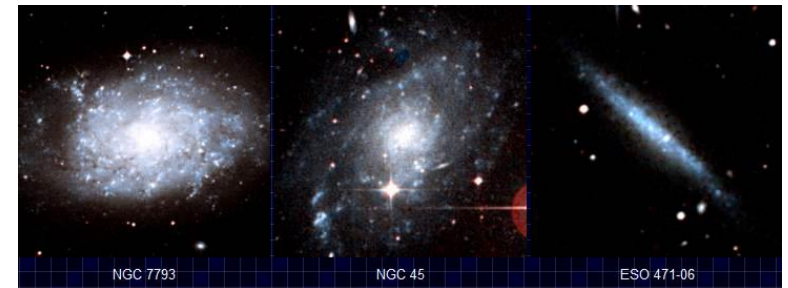
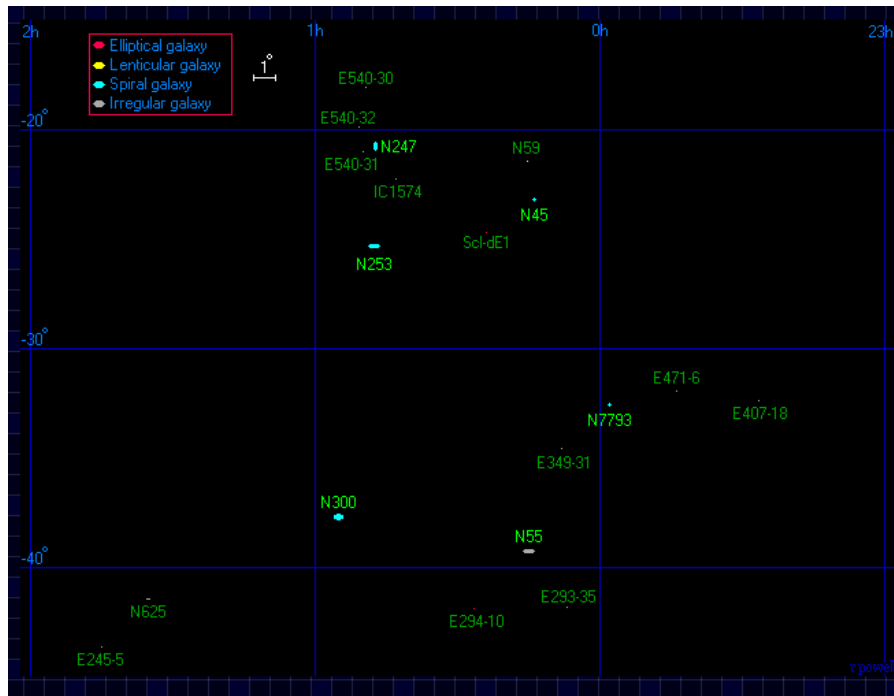
- Near-continuous monitoring of two selected fields by SkyMapper to observe concurrently to the Parkes FRB survey → taking snapshots at a cadence of ~20 minutes
- Many multi-messenger facilities were stand-by to receive our radio/optical trigger messages: Swift, Subaru, LCOGT, Liverpool telescope, Keck, Magellan, TNT/ULTRASPEC and PTF.



Expected 1-4 FRBs
→ None

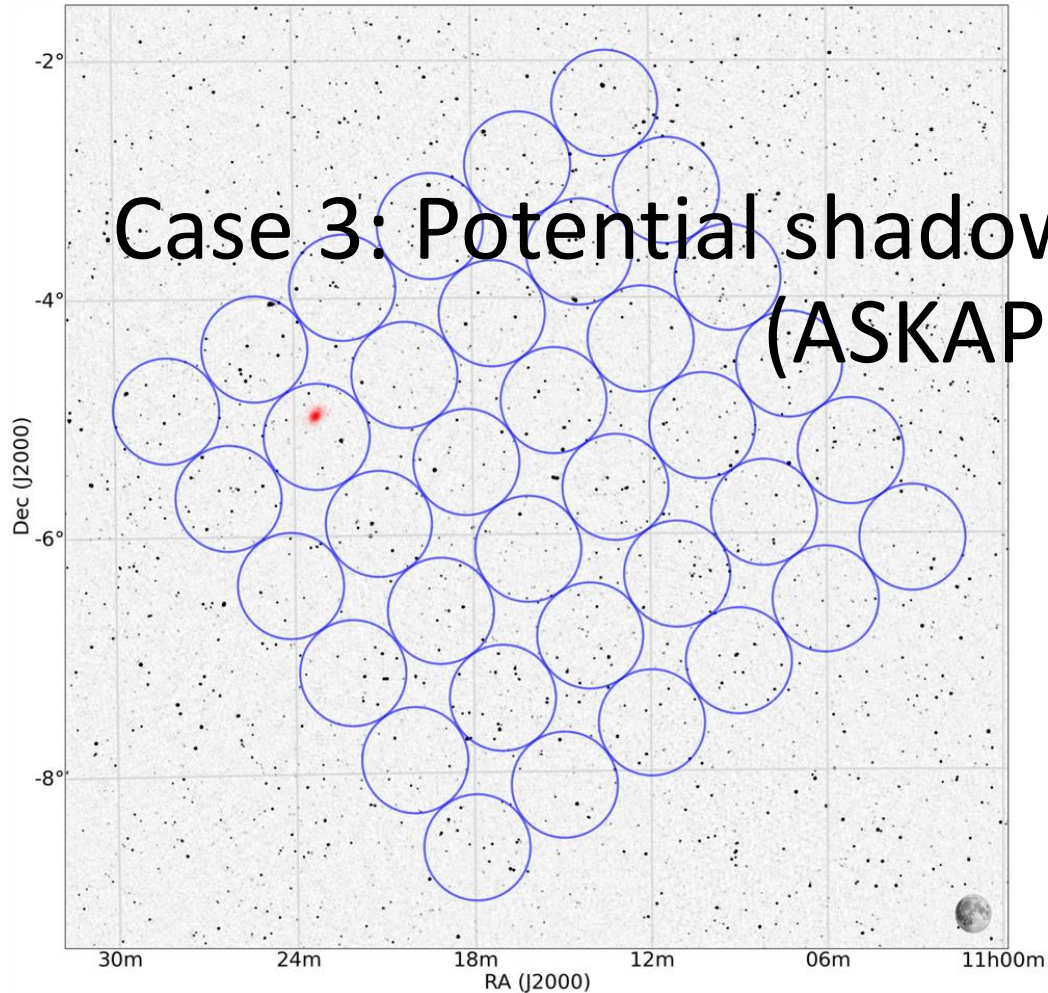
2015 Aug/Sep – FRB live search (2)

- Selected fields covering the local Sculptor Group of galaxies (~3.9 Mpc).
- Parkes observations (110 hours) were coordinated with continuous SkyMapper observation (cadence limited only by CCD read-out time).
- Test the “sit and stare” vs. blind-based “scan-wide” ideas.



Use 55 SkyMapper fields

[Centre coordinate: 00:30:00, -30:00:00]



Case 3: Potential shadowing observations (ASKAP)

- Many FRBs per day
- Rarer types of short-duration radio transients?
- FoV issue



Credit: Ian Heywood (CSIRO)

Outlook

SkyMapper ToO program for FRBs – We found no evidence of associated optical emissions of non-repeating FRBs so far. Still, significant lag between first radio detection and its related first optical images hampered a complete analysis.

- ❑ Still remained discoveries – Direct FRB counterpart emissions from other wavelengths on timescales immediately preceding and following the FRB detection.
- ❑ Continued follow-up observations for Molonglo FRBs in 2018, but our role will be limited after the full swing of UTMOST.
- ❑ Possibility of coordinated campaign with ASKAP (even though SkyMapper need many pointing) to catch precursor emissions or prompt emissions in the optical regime.